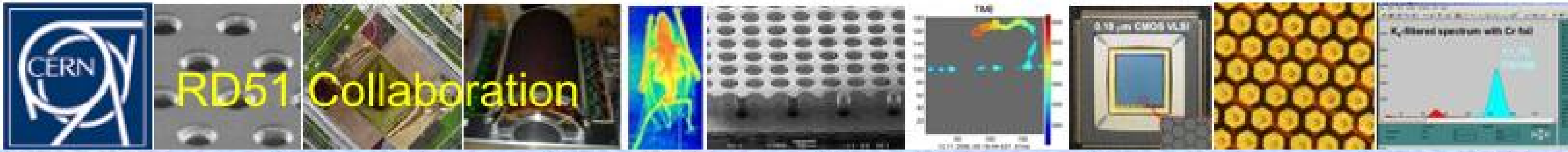
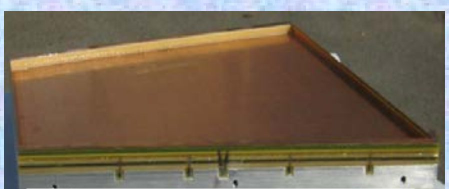
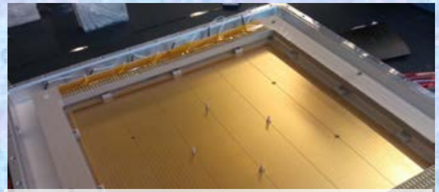



MM for ATLAS upgrade


GEM for CMS upgrade


GEM for ALICE TPC upgrade


THGEM for COMPASS upgrade

« Development of Micro-Pattern Gaseous Detector Technologies » and the RD51 Collaboration

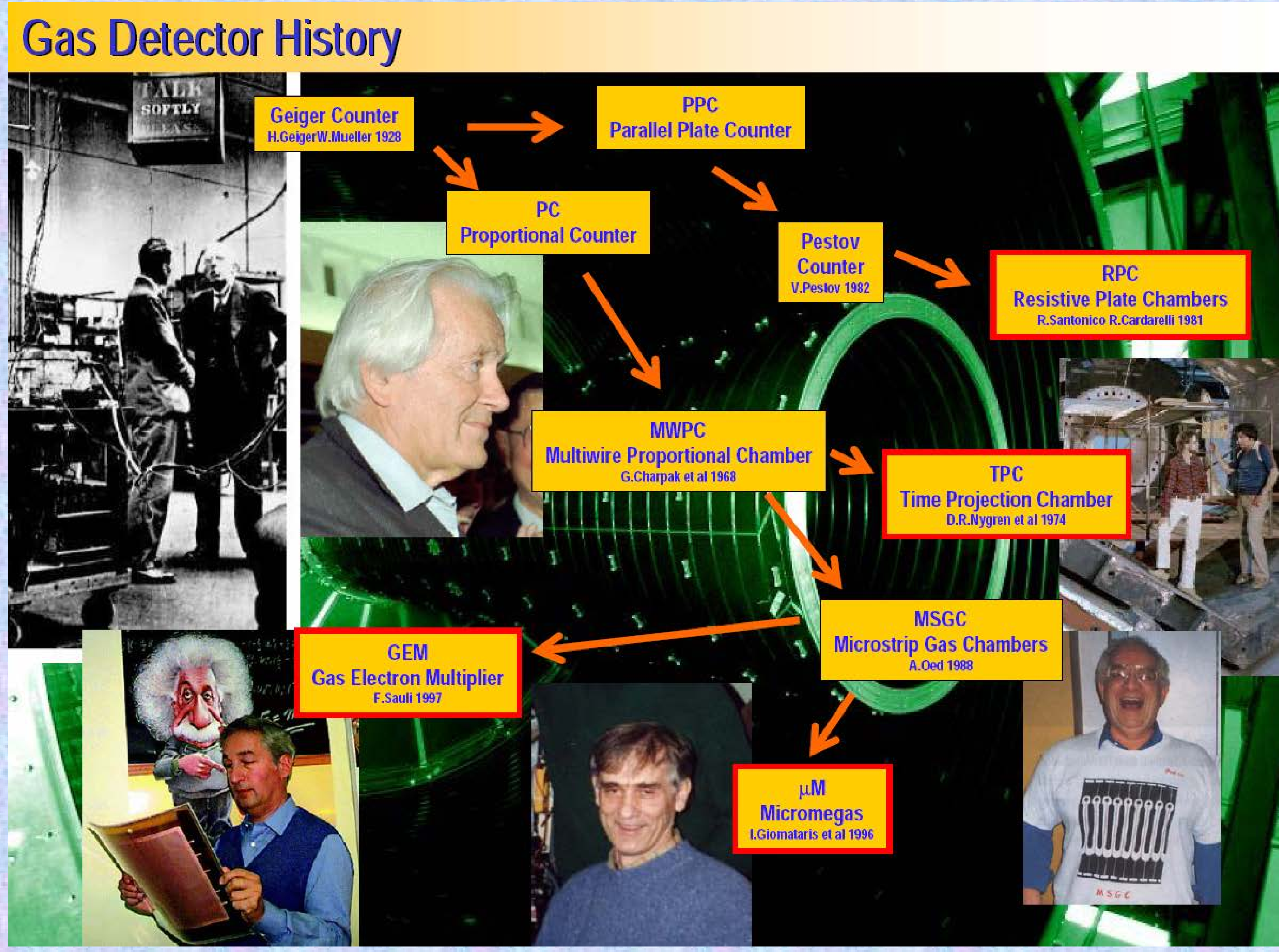
Maxim Titov, CEA Saclay, France

OUTLINE of the TALK:

- Introduction: Major Micro-Pattern gas Detector Technologies (GEM, Micromegas, Thick GEM, InGrid, mPIC)
- Summary of the RD51 – MPGD Technology Highlights
(Large area MPGDs - Support of HL- HLC Upgrades, R&D (quality control, long-term tests), Academia-Industry Matching Event, Software & Simulation, SRS Electronics, CERN MPGD Production Facility & Industrialization, RD51 Test Beam Facility, Training)

Joint Instrumentation Seminar, DESY/Hamburg, September 4, 2015

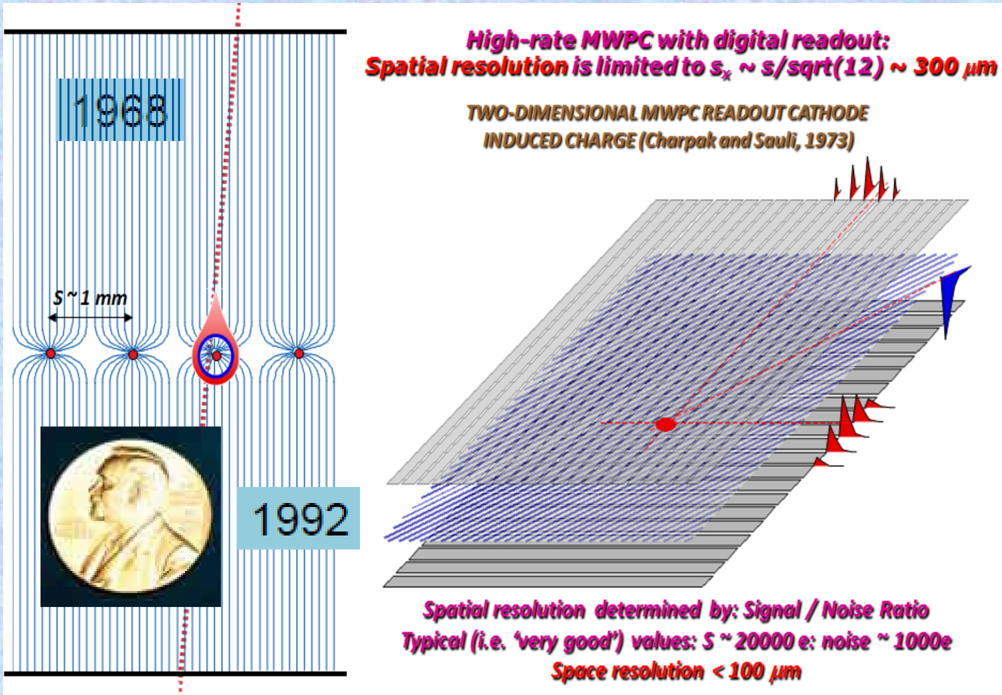
History of Gaseous Detector Developments



M. Hoch, 2004 *Wire Chamber Conference*

Multi-Wire Proportional Chamber (MWPC)

Gaseous proportional tracking detectors that revolutionized High Energy Physics



With Fabio Sauli et Jean Claude Santiard
The 1st "Large Wire Chamber"…

The invention revolutionized particle detection, which passed from the manual to the electronic era.

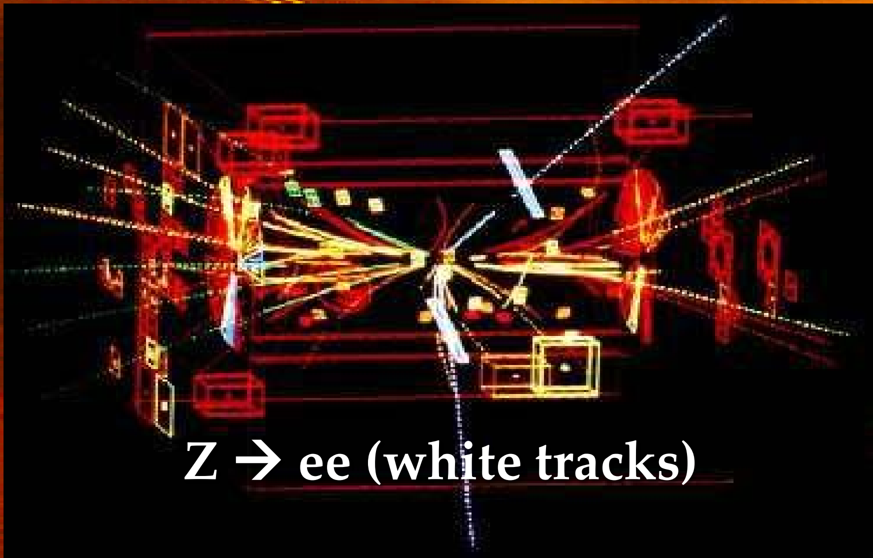
Georges Charpak
1924 – 2010

Nobel Prize: W, Z - Discovery at UA1/UA2 (1983)

UA1 used the largest imaging drift chamber of its day
(5.8 m long, 2.3 m in diameter)

It can now be seen in the CERN Microcosm Exhibition

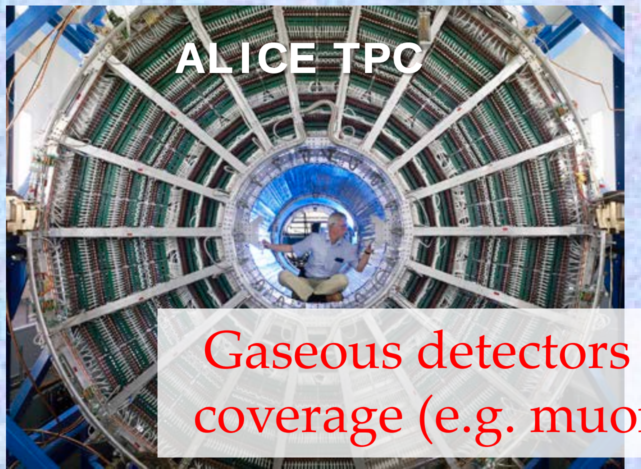
Particle trajectories in the CERN-UA1
3D Wire Chamber
Discovery of W and Z bosons
C. Rubbia & S. Van der Meer
Nobel Prize 1984

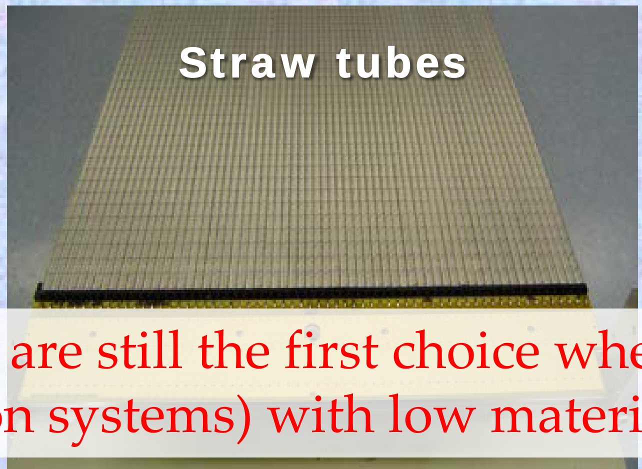


Z → ee (white tracks)

Gaseous Detectors in LHC Experiments

	Vertex	Inner Tracker	PID/ photo-det.	EM CALO	HAD CALO	MUON Track	MUON Trigger
ATLAS	-	TRD (straws)	-	-	-	MDT (drift tubes), CSC	RPC, TGC (thin gap chambers)
CMS TOTEM	-	-	-	-	-	Drift tubes, CSC, GEM	RPC, CSC GEM
LHCb	-	Straw Tubes	-	-	-	MWPC	MWPC, GEM
ALICE	-	TPC (MWPC)	TOF(MRPC), PMD, HPMID (RICH-pad chamber), TRD (MWPC)	-	-	Muon pad chambers	RPC





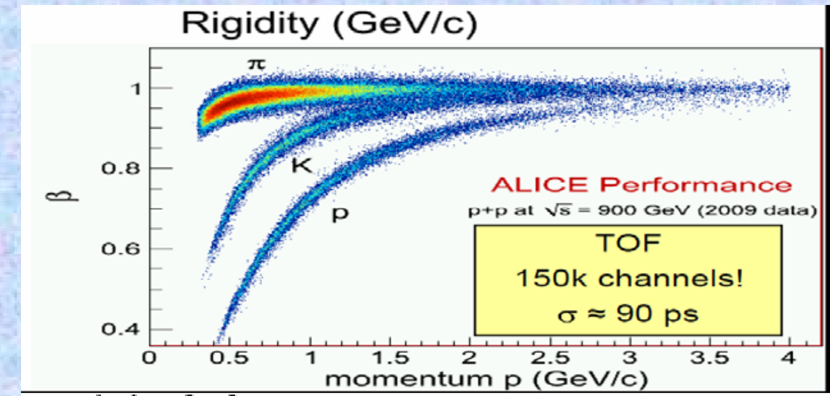
Gaseous detectors are still the first choice whenever the large-area coverage (e.g. muon systems) with low material budget is required

ALICE Multi-Gap RPC: Timing Resolution

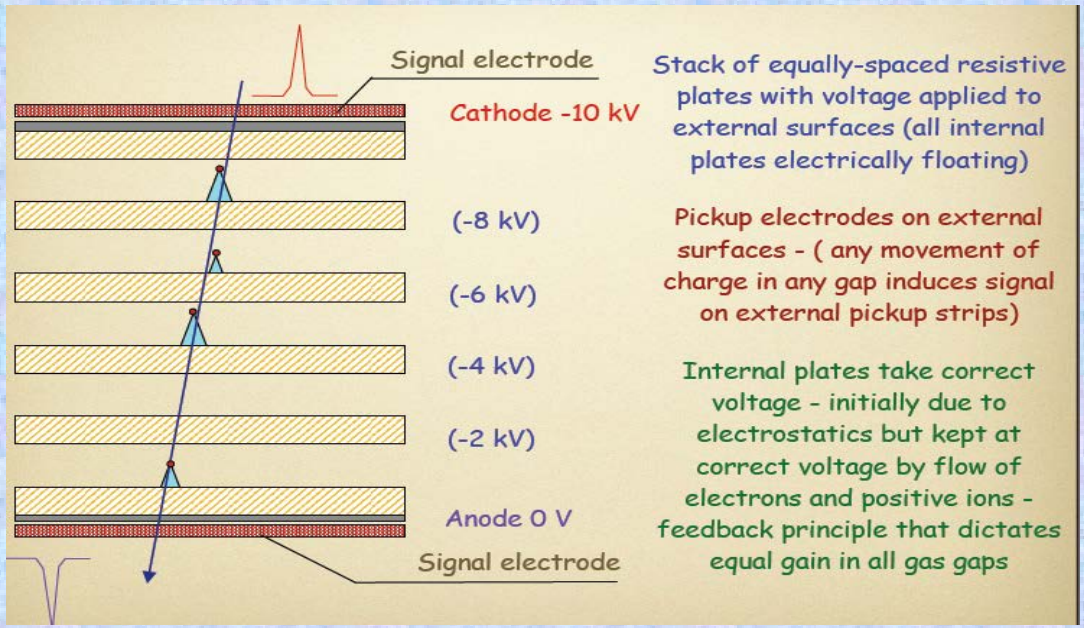
- Relevant scale in HEP: t ~ L(m)/c ~ o(ns)

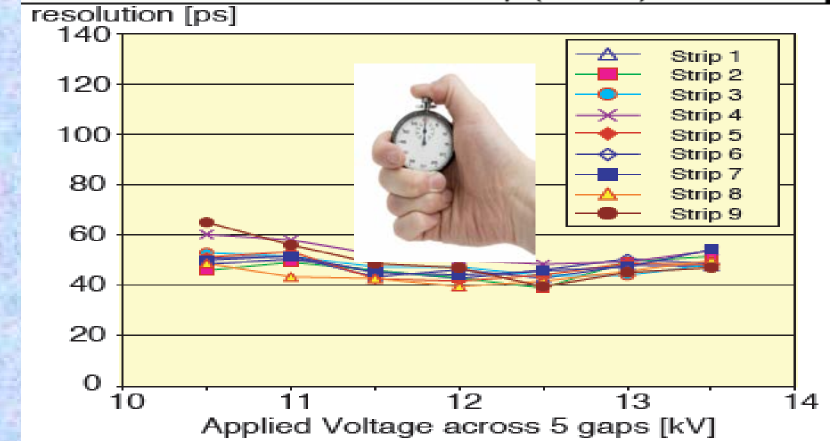
$$T_1 - T_2 = \frac{L}{c}\left(\frac{1}{\beta_1} - \frac{1}{\beta_2}\right) = \frac{L}{c}\left(\sqrt{1 + m_1^2/p^2} - \sqrt{1 + m_2^2/p^2}\right) \cong (m_1^2 - m_2^2)L/2cp^2$$

- Traditional technique:
  - Scintillator + PMT ~ *o* (100 *psec*)
- Breakthrough with a spark discharge in gas
  - Pestov counter → ALICE MRPC ~ 50*psec*



Multi-Gap Resistive Plate Chamber: Basic Principle





Technology	Time resolution
• Pestov Counter	30-50 ps
• RPC	~ 1-5 ns (MIP)
• MultiGap RPC	~ 50 ps (MIP)
• GEM	~ 1-2 ns (UV) ~ 5 ns (MIP)
• Micromegas	~ 700 ps (UV) ~ 2-5 ns (MIP)

C. Williams, CERN Detector Seminar "ALICE Time of Flight Detectors": http://indico.cern.ch/conferenceDisplay.py?confId=149006

ALICE Multi-Gap RPC: Timing Resolution

- Relevant scale in HEP: t ~ L(m)/c ~ o(ns)

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- Traditional technique:
  - Scintillator + PMT ~ *o* (100 *psec*)
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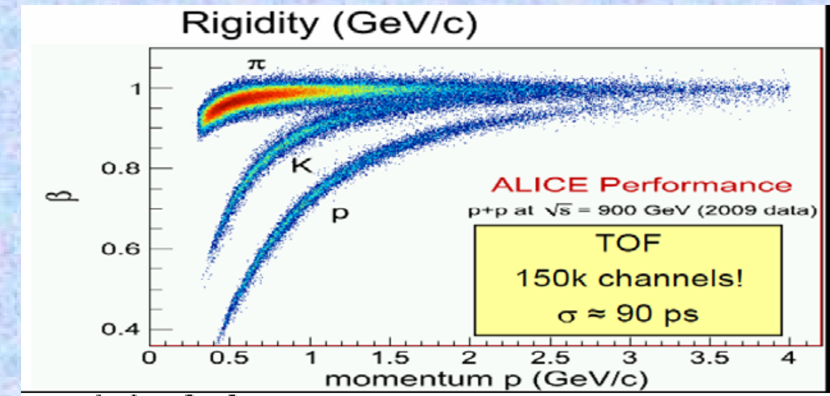
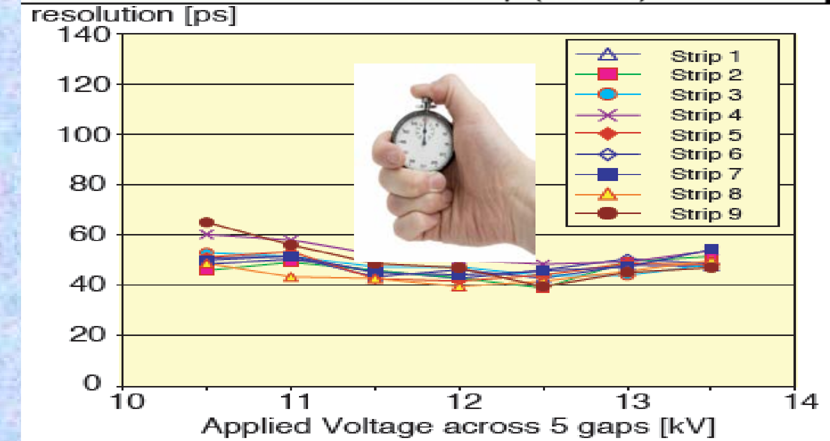
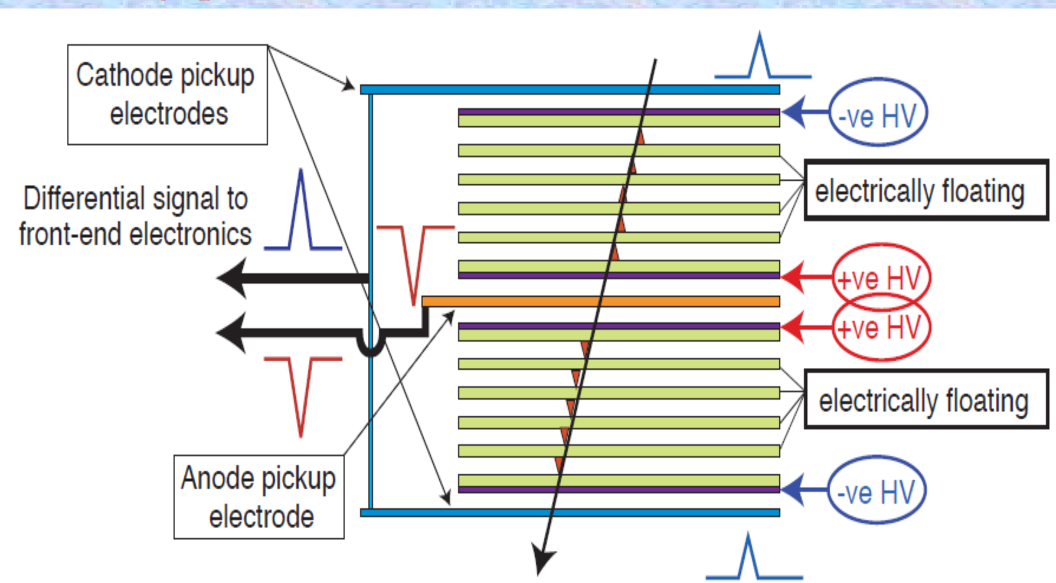




ALICE-TOF has 10 gaps (two stacks of 5 gas gaps); each gap is 250 micron wide



Technology	Time resolution
• Pestov Counter	30-50 ps
• RPC	~ 1-5 ns (MIP)
• MultiGap RPC	< 50 ps (MIP)
• GEM	< 1-2 ns (UV) ~ 5 ns (MIP)
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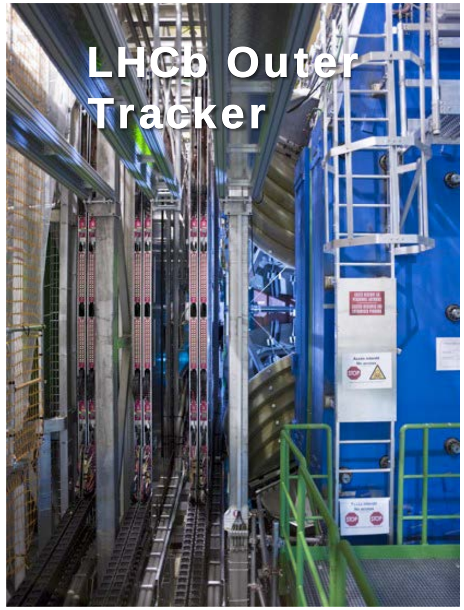
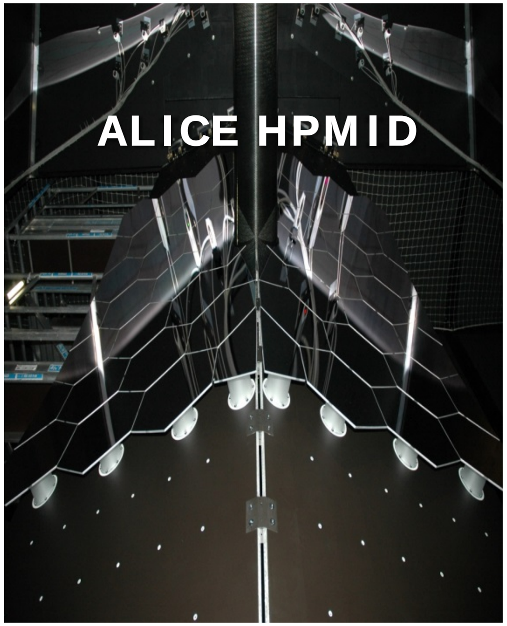
C. Williams, CERN Detector Seminar "ALICE Time of Flight Detectors": http://indico.cern.ch/conferenceDisplay.py?confId=149006

Gaseous Detector Systems for the High-Luminosity LHC



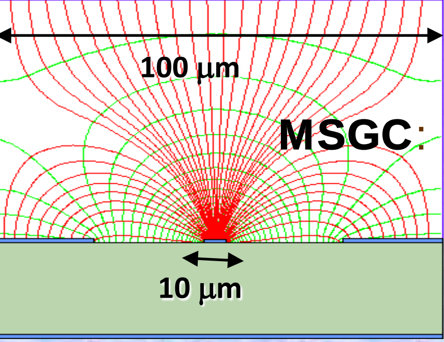


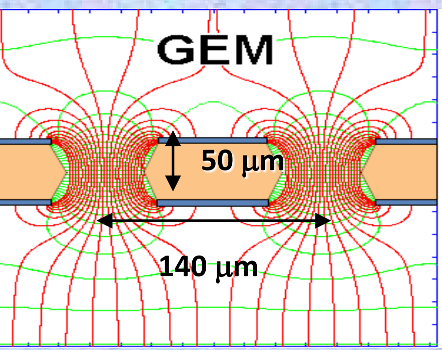
Upgrade Options for HL-LHC:

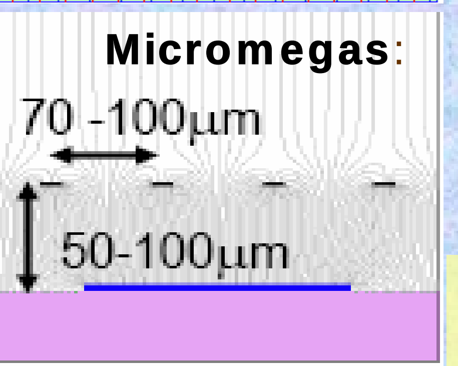
1. **Upgrade without changing detectors**
   - ATLAS, CMS and LHCB: Largest part of the Muon systems
   - ALICE: Replace only electronics for TRD and Muon system
   - CMS: New electronics with better trigger capabilities for DT chambers
   - R&D: Run RPCs at lower gas gain with new low noise electronics
2. **Upgrade by scaling standard geometries**
   - ATLAS: sMDT (small Muon Drift Tubes) for BME (in LS1) and BIS (in LS2) regions
   - ATLAS: sTGCs (small-strip Thin Gap Chambers) for New Small Wheel
   - R&D: RPCs with thinner or lower resistivity electrodes
3. **Upgrade by introducing novel gas detectors** (Micro-Pattern Gas Detectors)
   - ATLAS: MicroMegas for New Small Wheel
   - ALICE (TPC), CMS (Forward Muon system) and LHCb (Muon system): GEMs

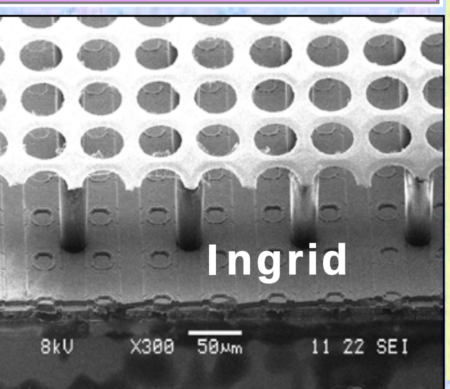
INSTRUMENTATION FRONTIER:

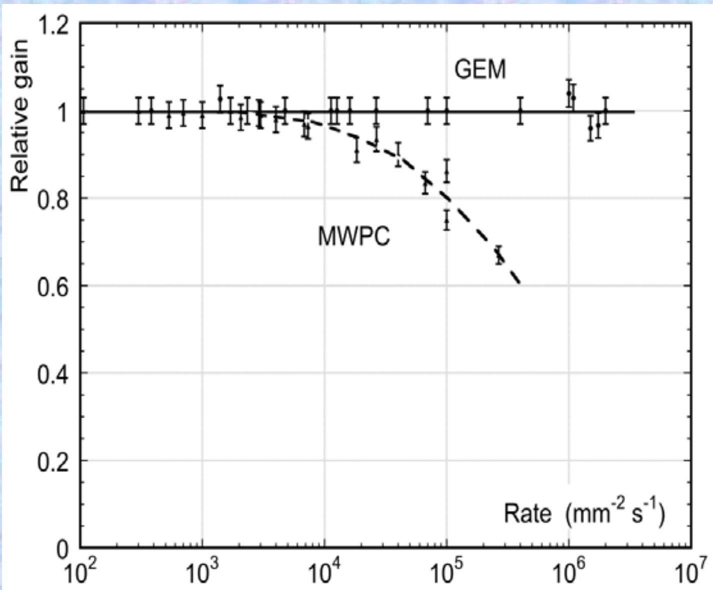
DEVELOPMENT OF MICRO-PATTERN GASEOUS DETECTOR TECHNOLOGIES











High Rates & enormous occupancy:

Silicon detectors:

Si-strips →Pixel (2D)→ 3D detectors & 3D TSV integration

Gaseous detectors:

Wire Chamber → Wireless MPGD (2D) → InGrid/Timepix (3D)

Detector –Electronics Integration → Enabled by Advanced Technologies

(better granularity / high precision / small amount of material)

- Modern photo-lithography technology → Micro-Pattern Gas Detectors
- Microelectronics – eg. Silicon pixels
- Bump bonding technology – low capacitance connections

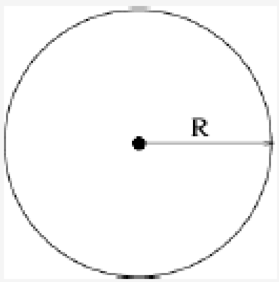
Trade-offs between high-speed, power, S/N, integration, segmentation, radiation tolerance → defined by the state-of-the-art in microelectronics

Summary & conclusion

Christian Lippmann, 2nd ECFA High Luminosity LHC Experiments Workshop, Aix-les-bains, France, October 21-23 (2014)

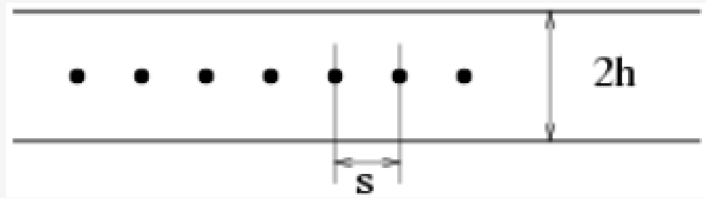
Geiger- Müller (1908), 1928
Drift Tube (1968)

1)



G. Charpak, 1968
Multi Wire Proportional Chamber

2)



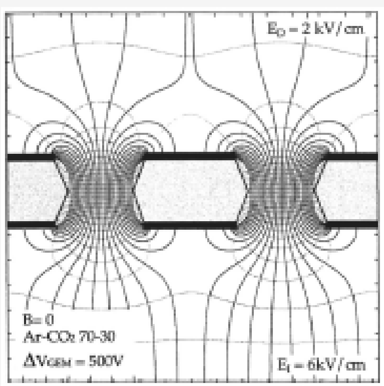
R. Santonico, 1980
Resistive Plate Chamber

3)

… will at HL-LHC be joined by:

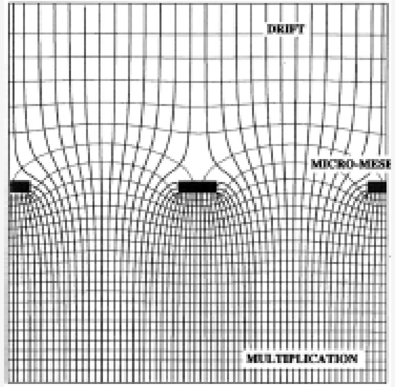
F. Sauli (1997)
Gas Electron Multiplier

4)



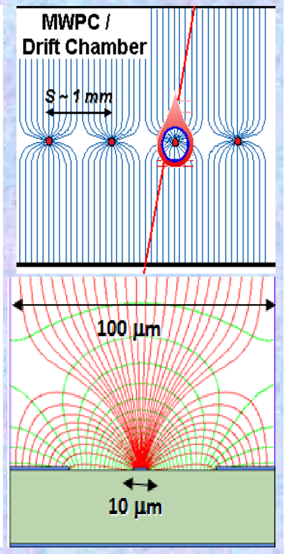
I. Giomataris et al. (1996)
Micro-mesh gaseous chamber (Micromegas)

5)

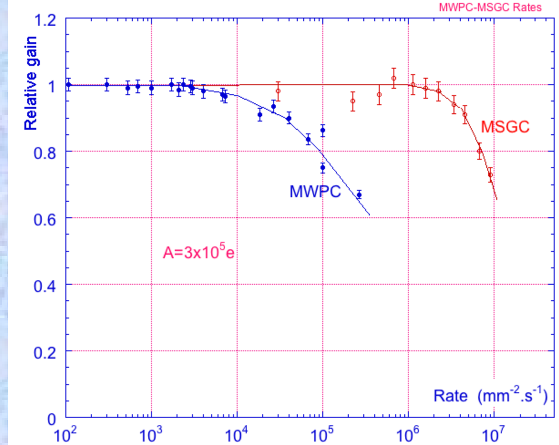


Micro-Pattern Gaseous Detector Technologies for Future Physics Projects

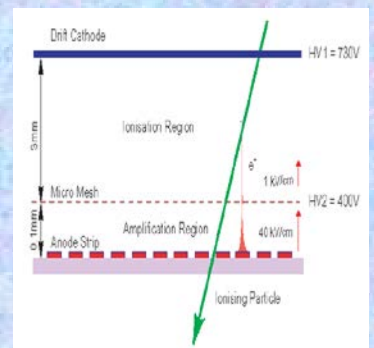
- Micromegas
- GEM
- Thick-GEM, Hole-Type and RETGEM
- MPDG with CMOS pixel ASICs ("InGrid")
- Micro-Pixel Chamber (µPIC)

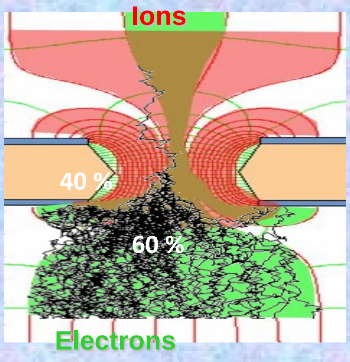


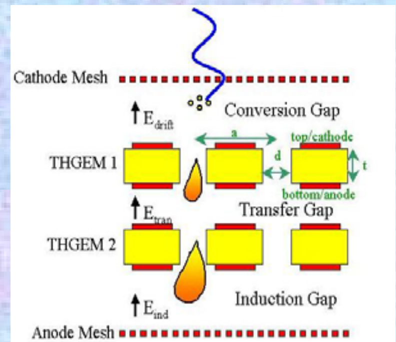
Rate Capability:
MWPC vs MSGC

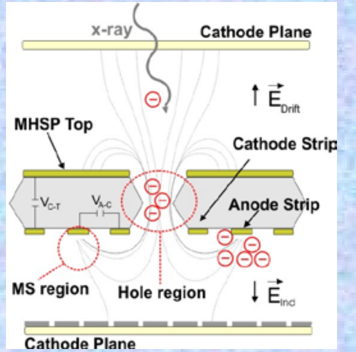


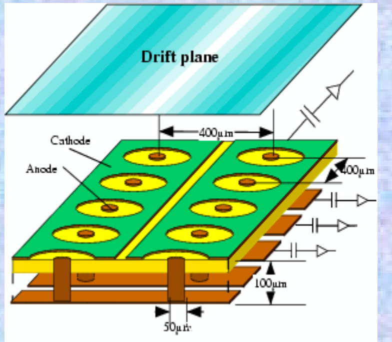
Micromegas GEM THGEM MHSP µPIC

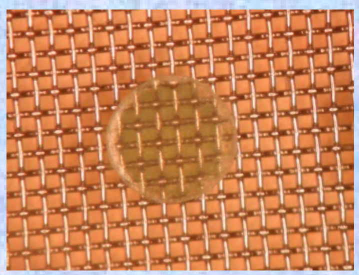


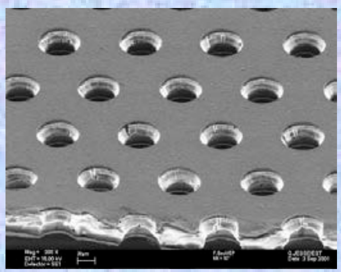


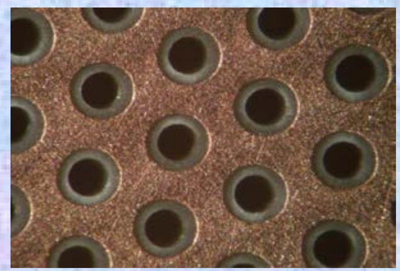


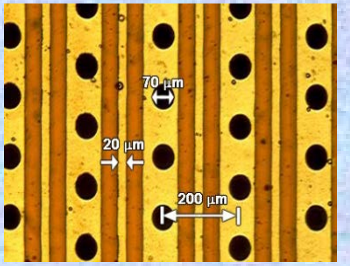


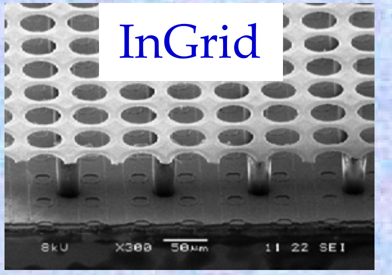










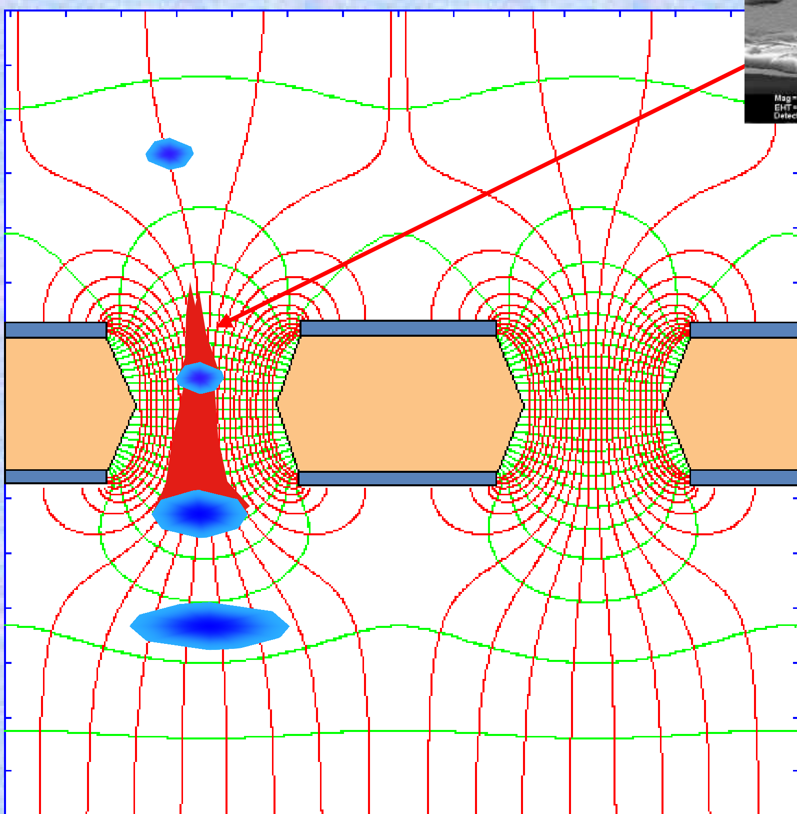


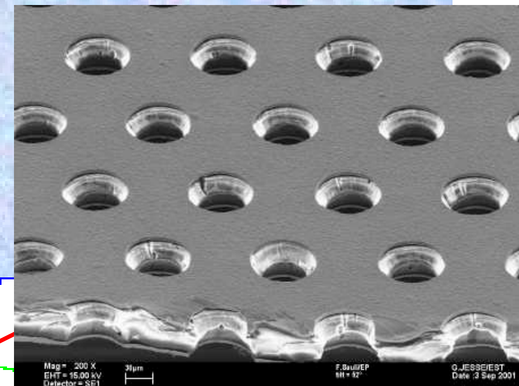
GEM (Gas Electron Multiplier)

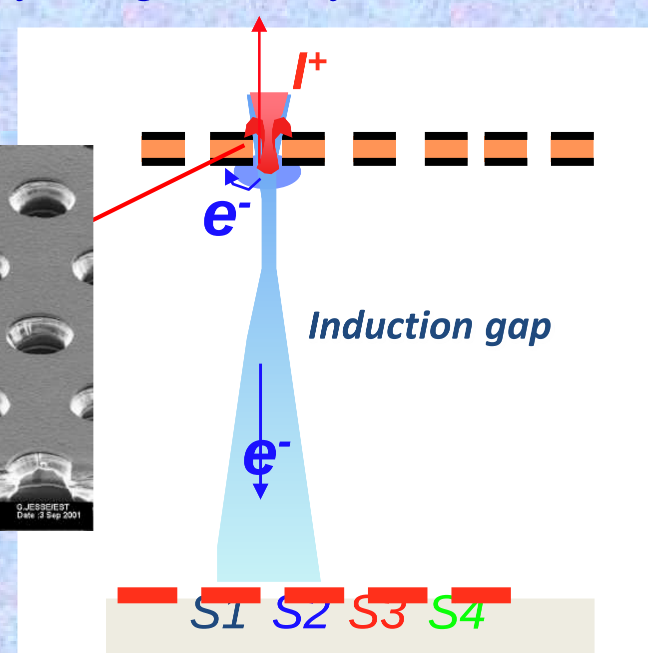
Thin metal-coated polymer foil chemically pierced by a high density of holes

A difference of potentials of ~ 500V is applied between the two GEM electrodes.

→the primary electrons released by the ionizing particle, drift towards the holes where the high electric field triggers the electron multiplication process.







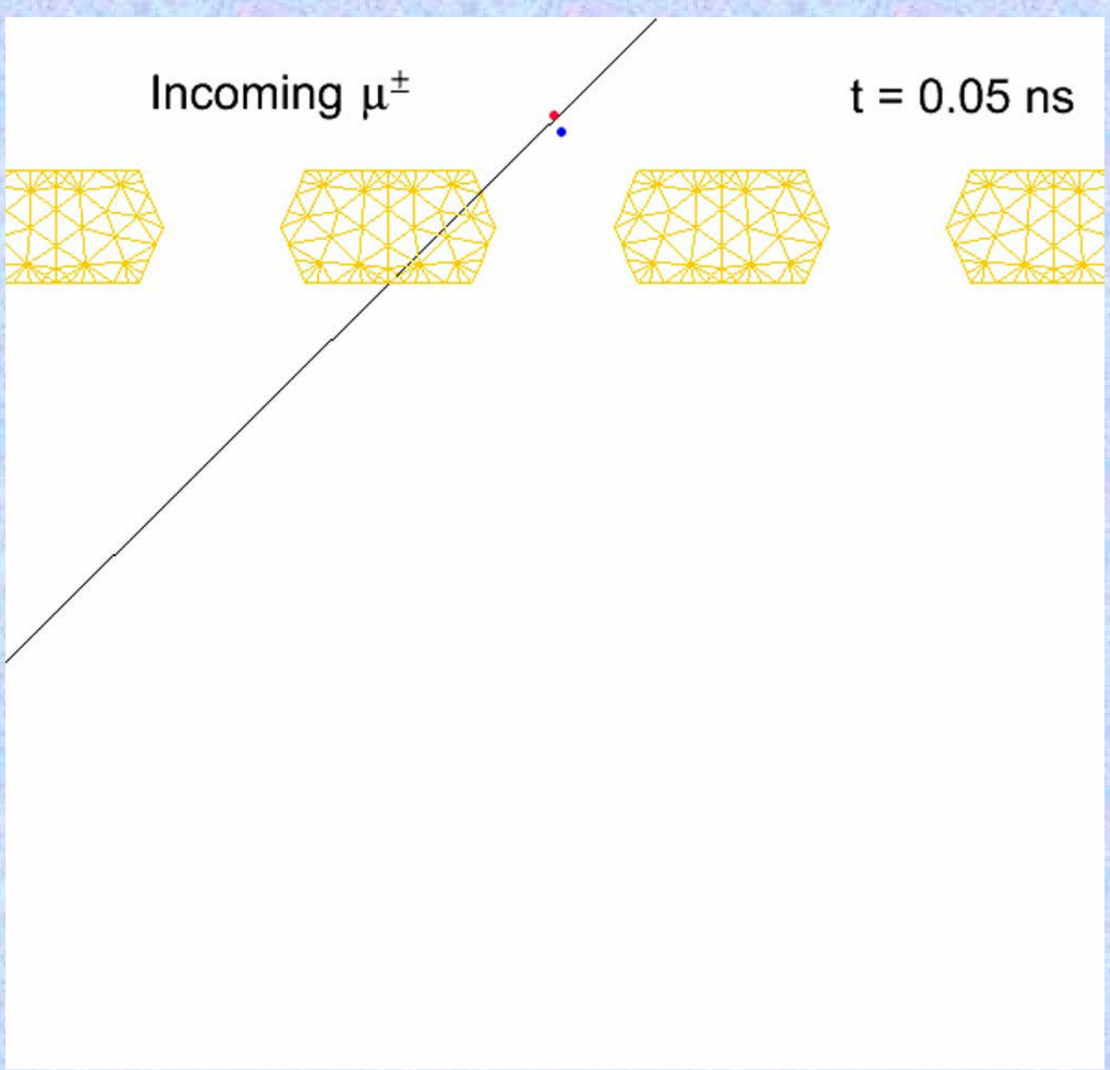
- Electrons are collected on patterned readout board.
- A fast signal can be detected on the lower GEM electrode for triggering or energy discrimination.
- All readout electrodes are at ground potential.

F. Sauli, Nucl. Instrum. Methods A386(1997)531
F. Sauli, http://www.cern.ch/GDD

MPGD Simulation Tools (Avalanche Simulation in GEM)

Animation of the avalanche process (monitor in ns-time electron/ion drifting and multiplication in GEM):

electrons are blue, ions are red, the GEM mesh is orange

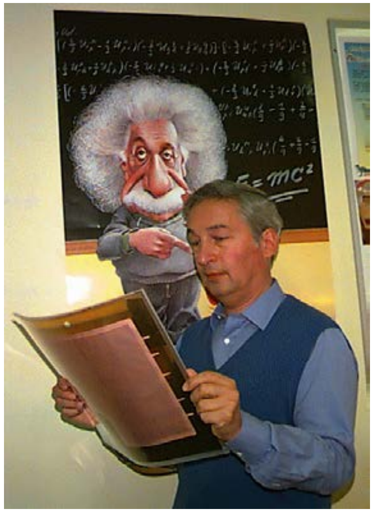


- ANSYS: field model
- Magboltz 8.9.6: relevant cross sections of electron-matter interactions
- Garfield++: simulate electron avalanches

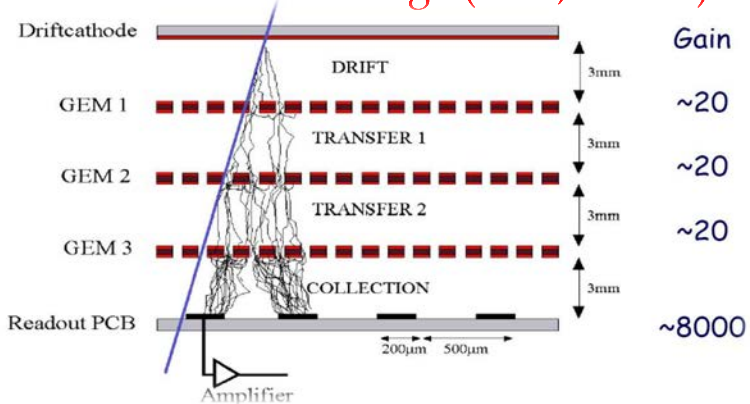
http://cern.ch/garfieldpp/examples/gemgain

Gas Electron Multiplier (GEM)

F. Sauli, NIM A386(1997) 531;
F. Sauli, http://www.cern.ch/GDD



Full decoupling of amplification stage (GEM) and readout stage (PCB, anode)

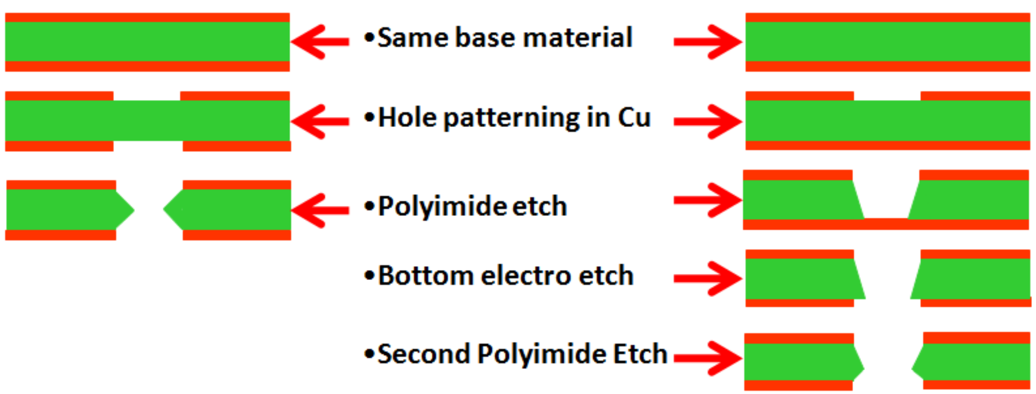


2009: NEW: Single mask GEM production technique → allow to extend GEM foils to ~ m^2 area

•Double mask

•Single mask

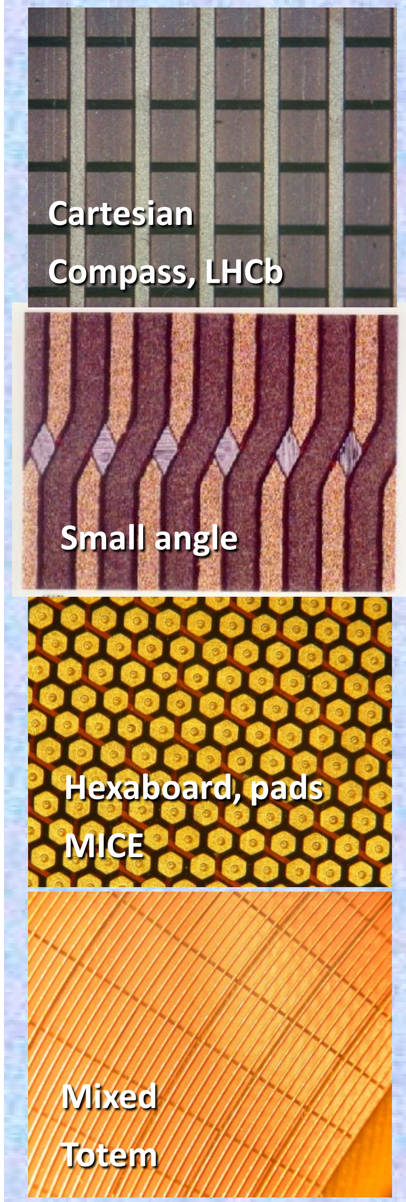
1996:



2009:

•Limited to 40cm x 40cm due to
- •Mask precision and alignment

•Limited to 2m x 60cm due to
- •Base material
- •Equipment

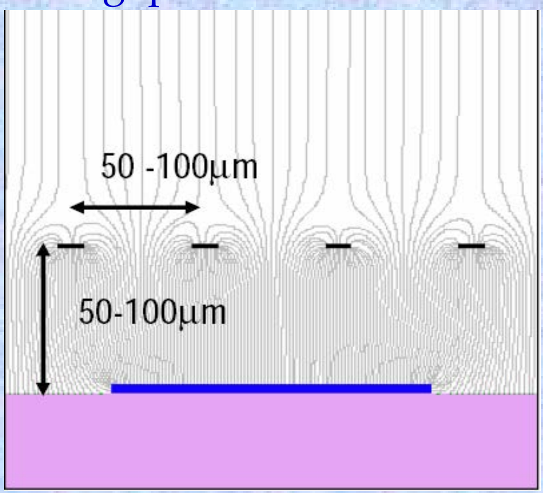


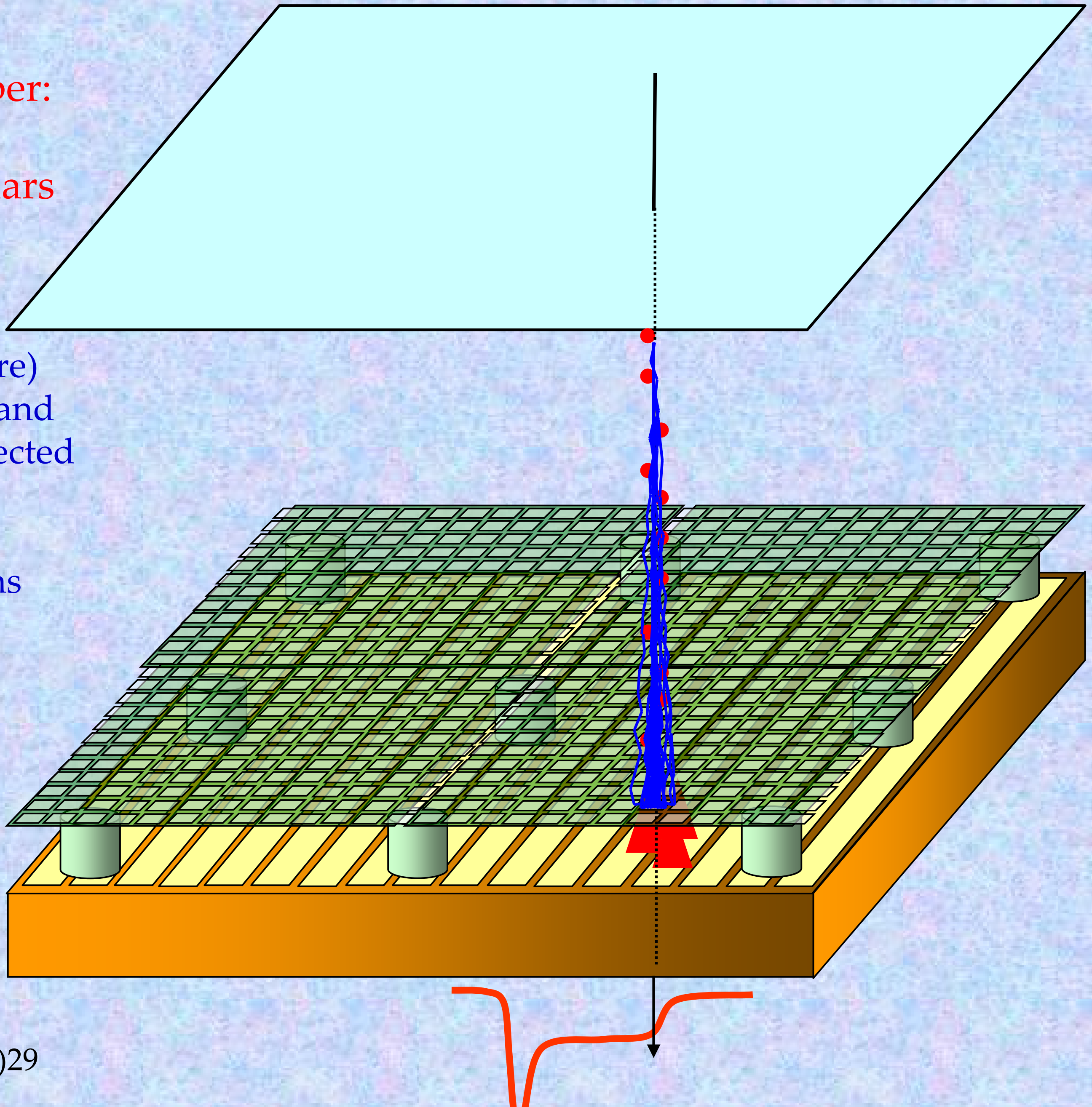
MICro MEsh GAseous Structure (MICROMEGAS)

Micromesh Gaseous Chamber:
micromesh supported
by 50-100 μm insulating pillars

Multiplication (up to 10^5 or more) takes place between the anode and the mesh and the charge is collected on the anode (one stage)

Small gap: fast collection of ions



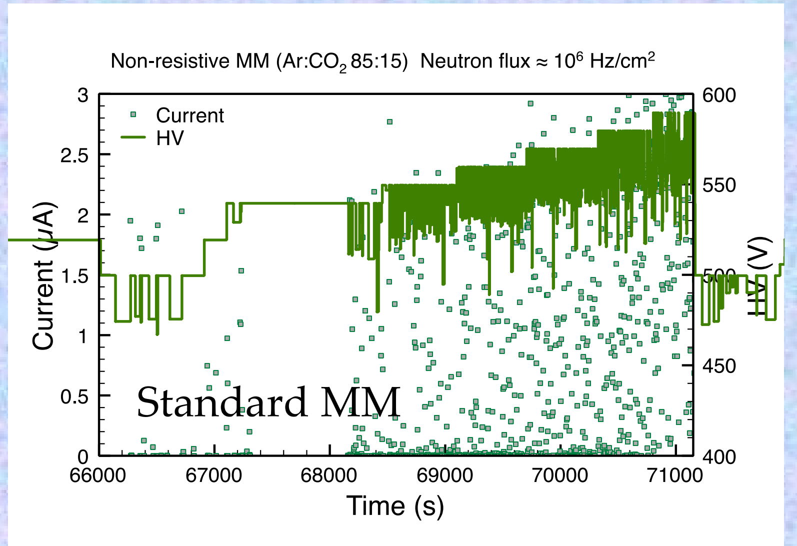


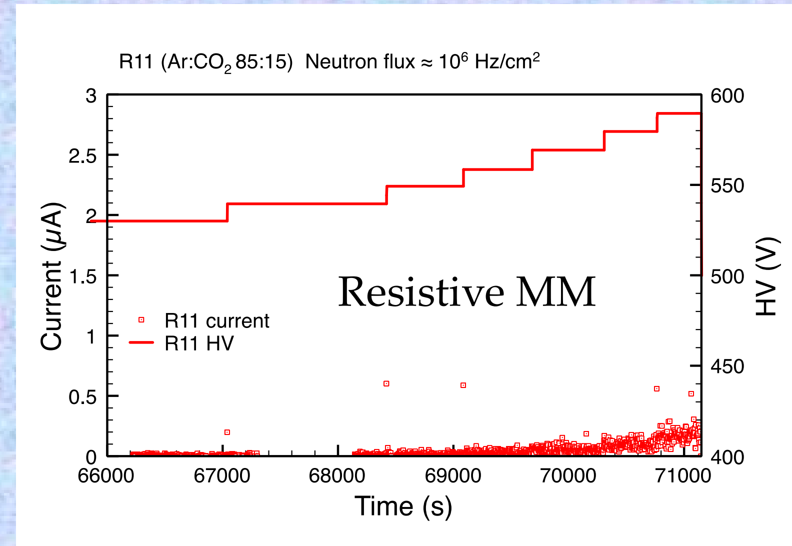
Y. Giomataris et al, NIM A376(1996)29

Standard vs Resistive Micromegas Sparking

- Standard MM could not be operated in neutron beam
- HV break-down and currents > several μA for gains ~ 1000–2000

- MM with resistive strips worked perfectly well
- No HV drops, small spark currents up to gains of 2 x 10^4



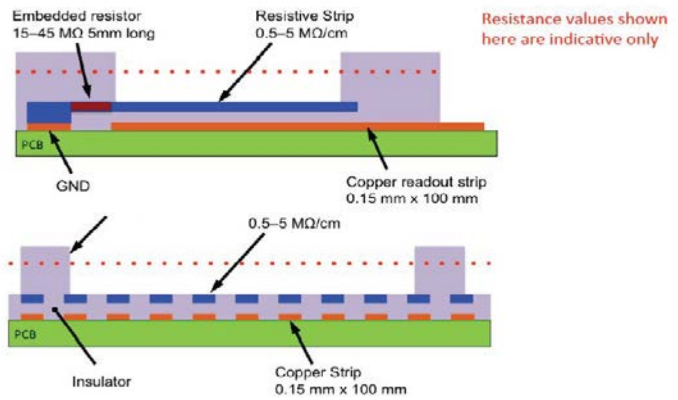


Since 2010: Resistive Micromeas technology

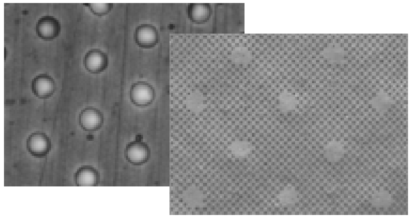
❖ Problem was solved by adding a layer of resistive strips above the readout strips

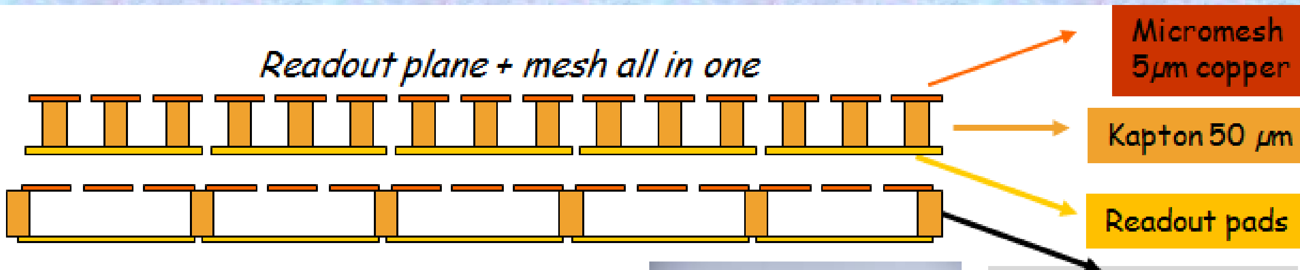
❖ Spark neutralization/suppression (sparks still occur but become inoffensive)

The resistive-strip protection concept



« MicroBulk » Micromegas





Microbulk Technology

An I. Giomataris and R. De

The pillars are constructed by chemical processing of a kapton foil, on which the mesh and the readout plane are attached. ***Mesh is a mask for the pillars!***

Typical mesh thickness 5 μm, gap 50/25 μm

A microbulk has all the advantages of a bulk micromegas but with enhanced performance.

In addition: uniformity, clean materials, stability

- ✓ **Energy resolution** (down to 10% FWHM @ 6 keV)
- ✓ **Low intrinsic background & better particle recognition**
- ✓ **Low mass detector**
- ✓ **Very flexible structure**

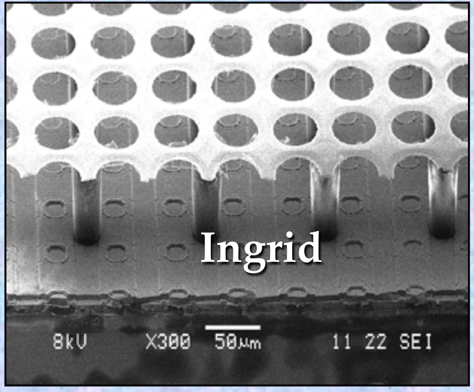
- × Higher capacity
- × Fabrication process complicated
- × Fragility / mesh can not be replaced

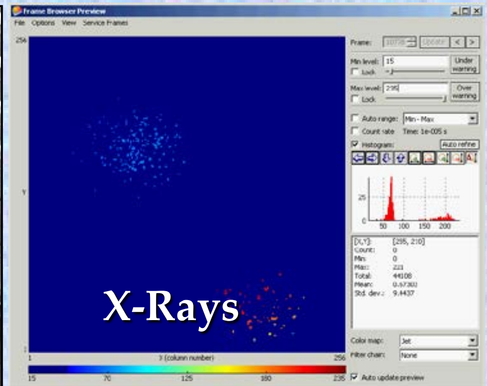
Microbulk radiopurity:
➔ mostly Cu & Kapton
Measured with HPGe at Canfranc:
- raw material (double clad kapton foil)
- samples from old CAST detectors

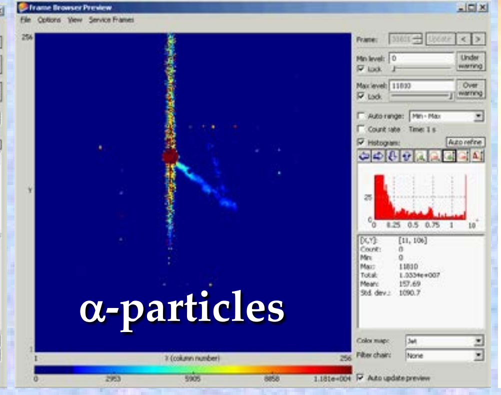
S. Cebrian et al., Astropart. Phys 34 (2011) 354-359

Results in μBq/cm²	^{232}Th	^{235}U	^{238}U	^{40}K	^{60}Co
Microbulk	<9.3	<13.9	26.3±13.9	57.3±24.8	<3.1*
Kapton-Cu foil	<4.6*	<3.1*	<10.8	<7.7*	<1.6*
Cu-Kapton-Cu foil	<4.6*	<3.1*	<10.8	<7.7*	<1.6*

*Level obtained from the Minimum Detectable Activity of the detector

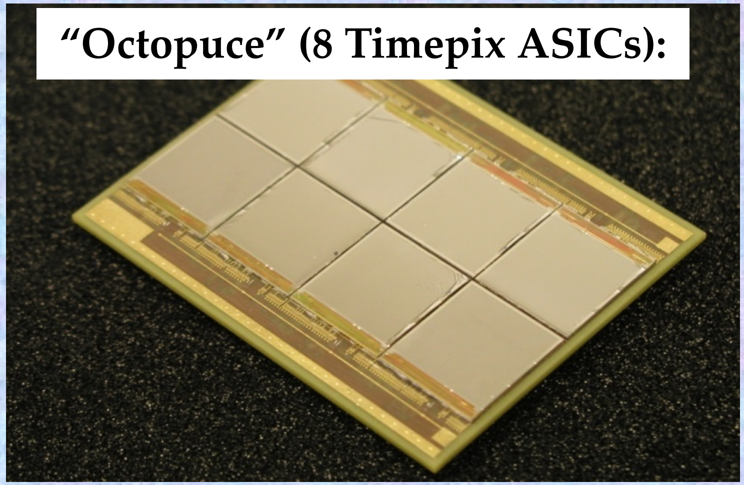


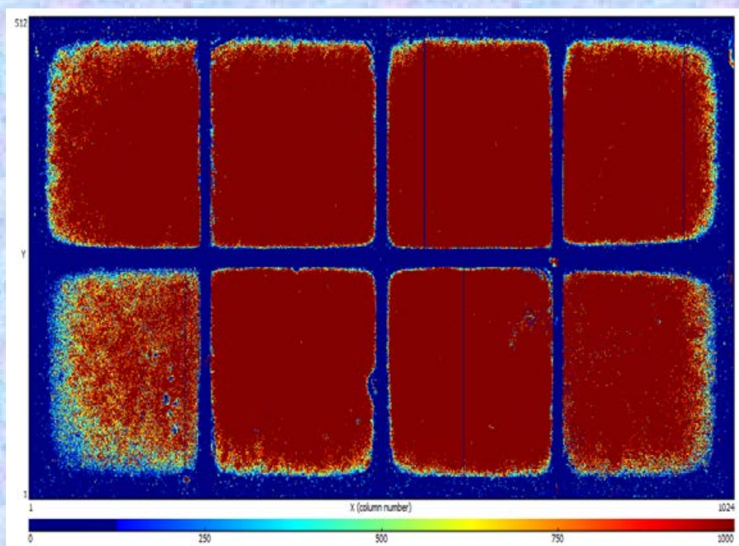


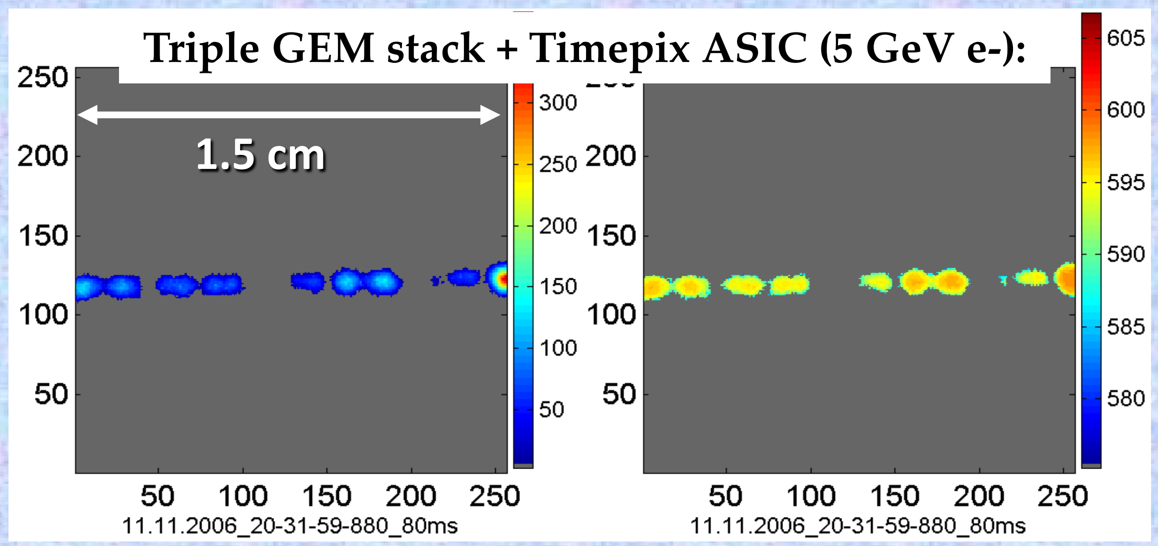


INSTRUMENTATION FRONTIER:

PIXEL READOUT OF MPGDs – Ultimate Gas-Silicon Detector Integration



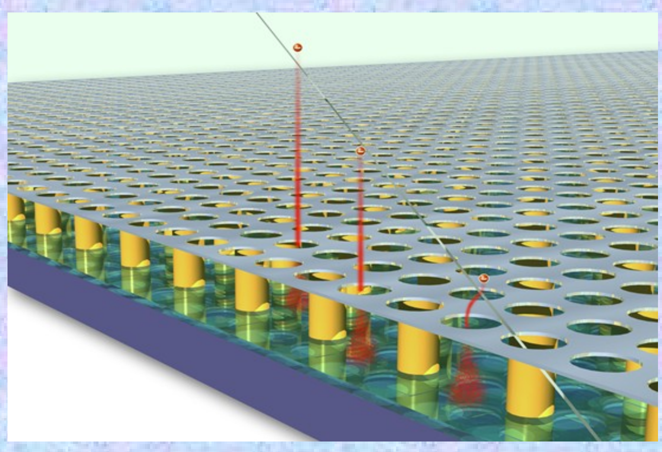


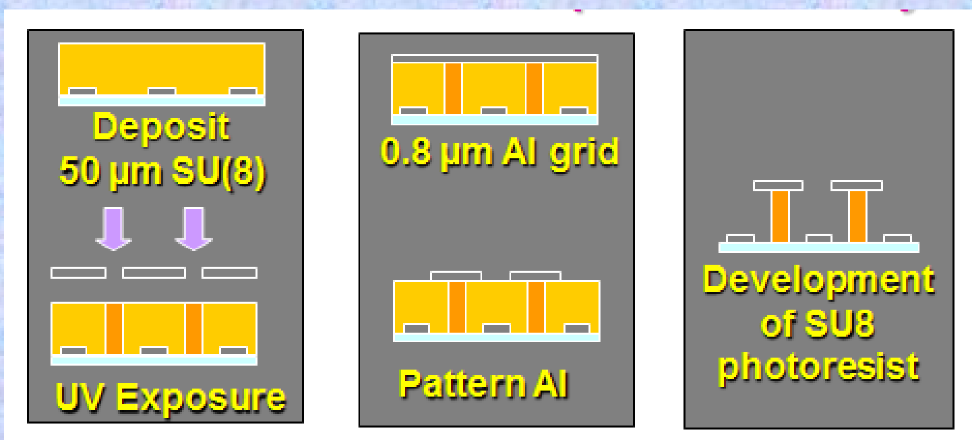


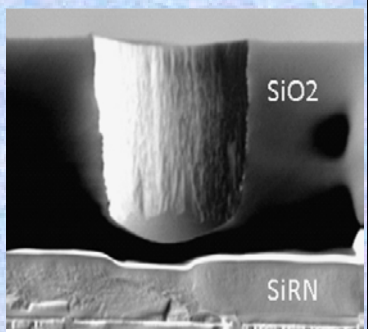
Pixel Readout of MPGDs: "InGrid" Concept

"InGrid" Concept: By means of advanced wafer processing-technology INTEGRATE MICROMEGAS amplification grid directly on top of CMOS ("Timepix") ASIC

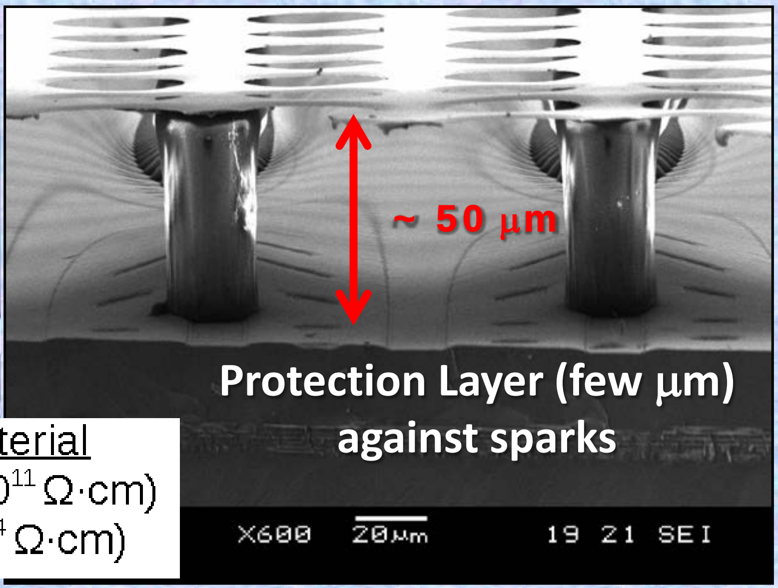
3D Gaseous Pixel Detector → 2D (pixel dimensions) x 1D (drift time)

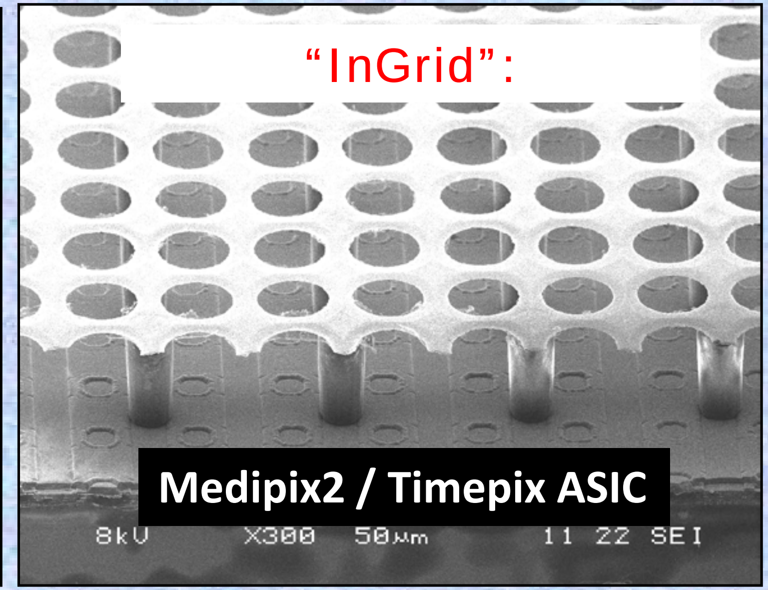






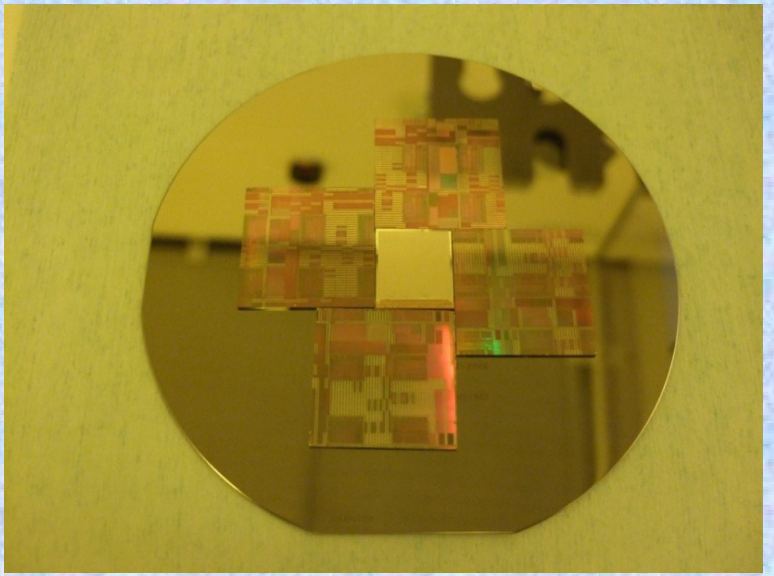
high resistive material
15 µm aSi:H (~10^{11} Ω·cm)
8 µm Si_XN_Y (~10^{14} Ω·cm)



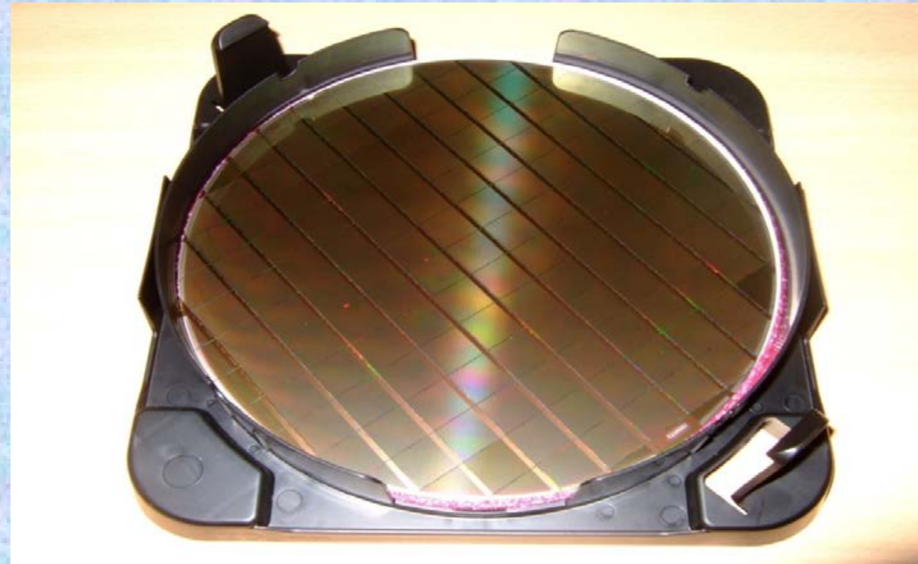


"InGrid' Technology and "Driving" Developments

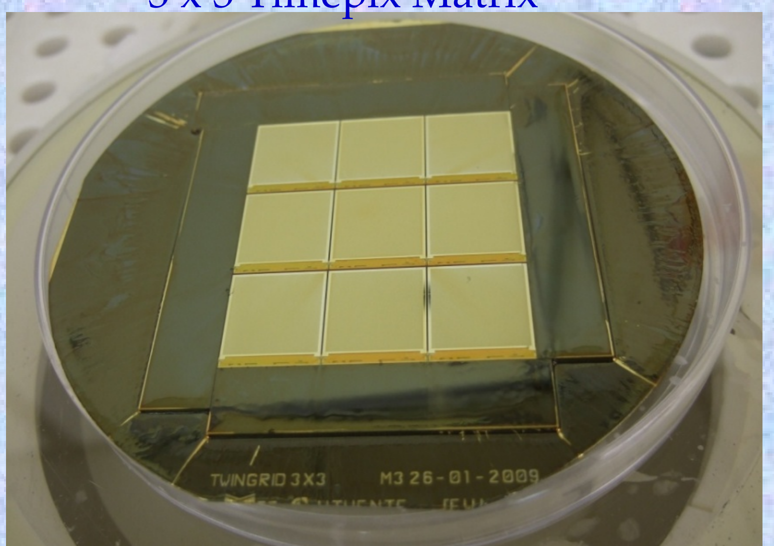
2005: Single "InGrid" Production

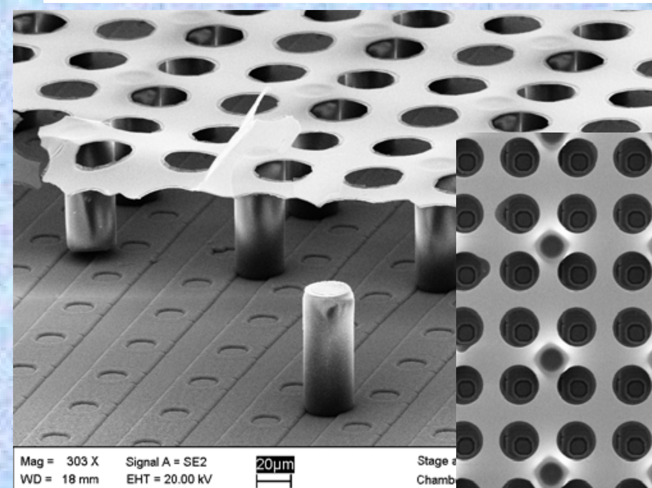


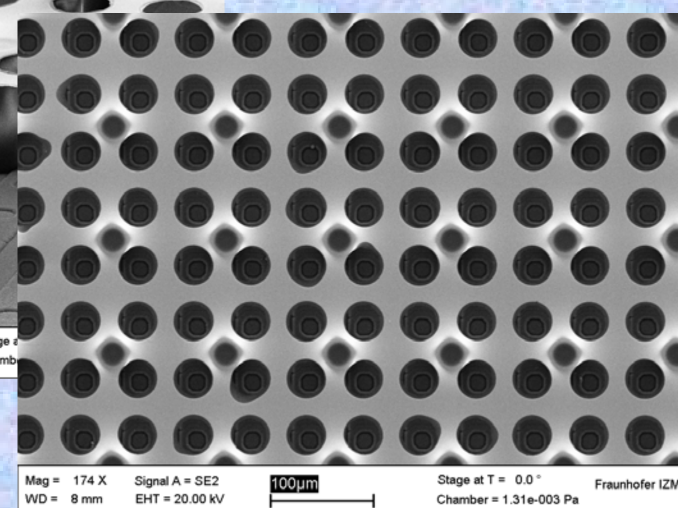
Since 2011: Major Step Forward →
InGrid Production on a wafer level (107 chips)



2009: "InGrid" Production on a
3 x 3 Timepix Matrix



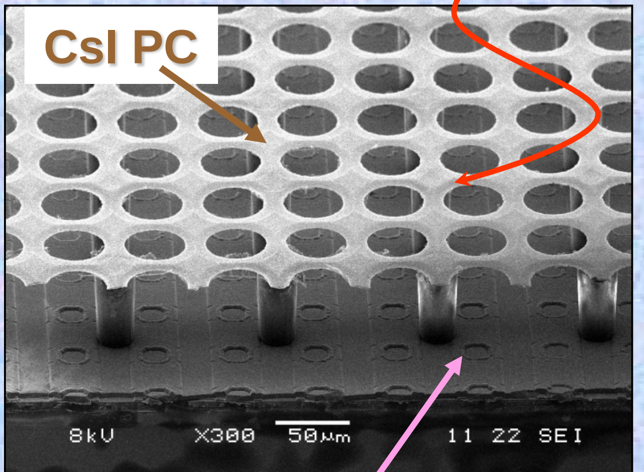


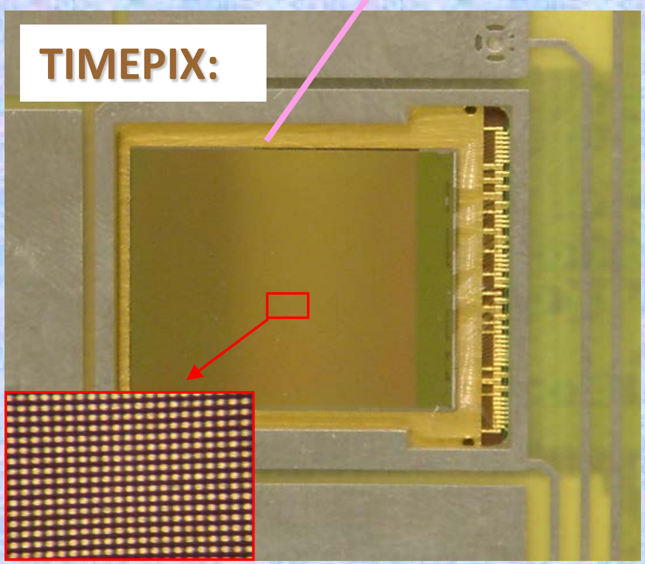


Photosensitive Detector: Integrating Ingrid and CMOS readout

MICROMEGAS (InGrid) covered with CsI

photon

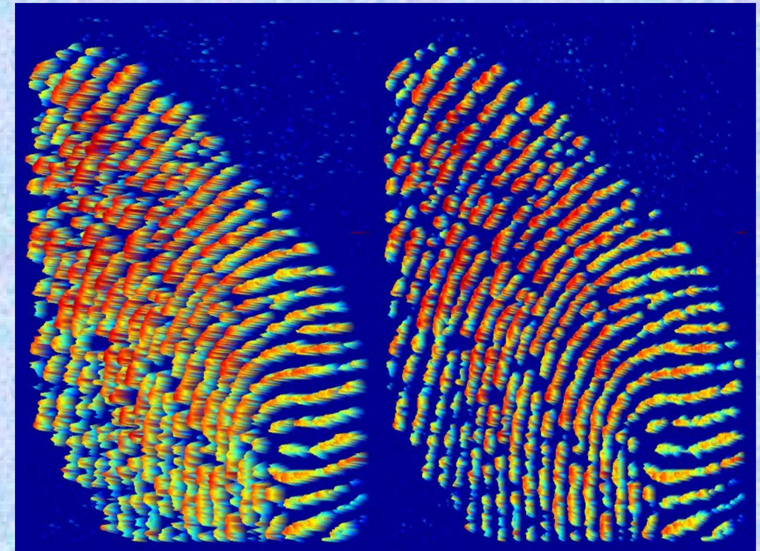




Chip area: 14x14mm^2.
(256×256 pixels of 55×55 μm^2)

Ingrid without CsI

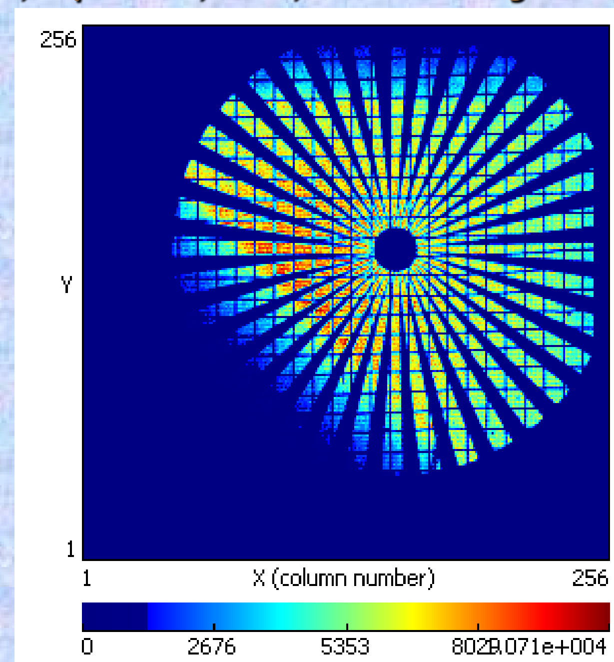
UV absorbed by the fingerprint on the window



M. Fransen, RD51 Mini-Week, Sep. 23-25, 2009, WG2 Meeting

Ingrid with CsI PC:

2D UV Image of a 10mm diameter mask



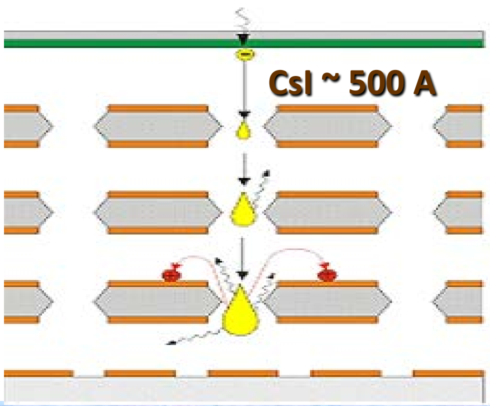
MPGD-Based Gaseous Photomultipliers (GPM)

GEM Gaseous Photomultipliers (GEM+CsI photocathode) to detect single photoelectrons

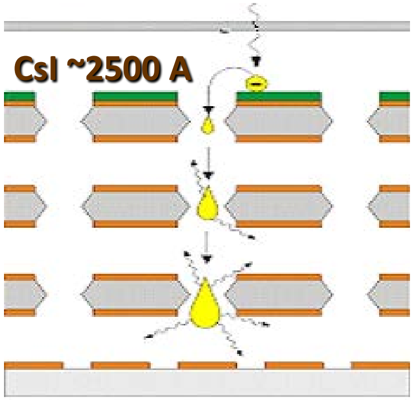
Multi-GEM Gaseous Photomultipliers:

- ❖ Largely reduced photon feedback (can operate in pure noble gas & CF_4)
- ❖ Fast signals [ns] → good timing
- ❖ Excellent localization response
- ❖ Able to operate at cryogenic T

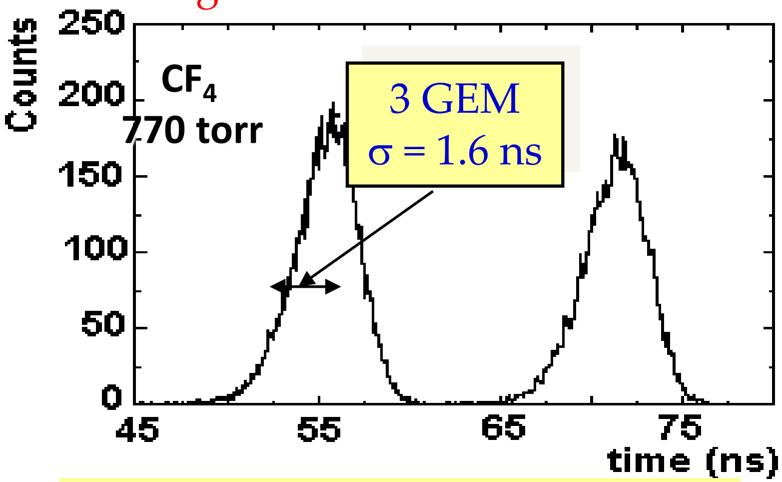
Semitransparent Photocathode (PC)



Reflective Photocathode (PC)

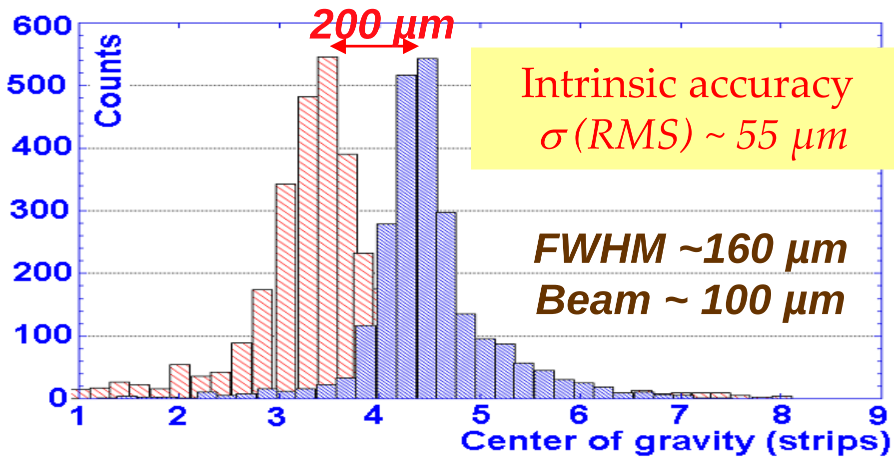


Single Photon Time Resolution:



Micromegas: σ ~ 0.7 ns with MIPs

Single Photon Position Accuracy:



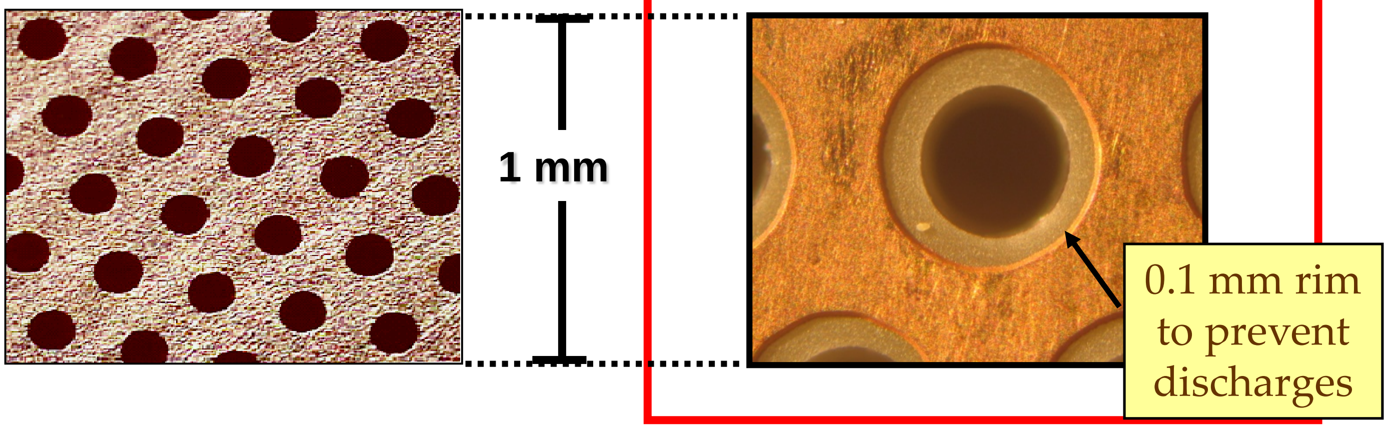
E.Nappi, NIMA471 (2001) 18; T. Meinschad et al, NIM A535 (2004) 324; D.Mormann et al., NIMA504 (2003) 93

Thick-GEM Multipliers (THGEM)

Simple & Robust → Manufactured by standard PCB techniques of precise drilling in G-10 (and other materials) and Cu etching

STANDARD GEM
10^3 GAIN IN SINGLE GEM

THGEM
10^5 gain in single-THGEM



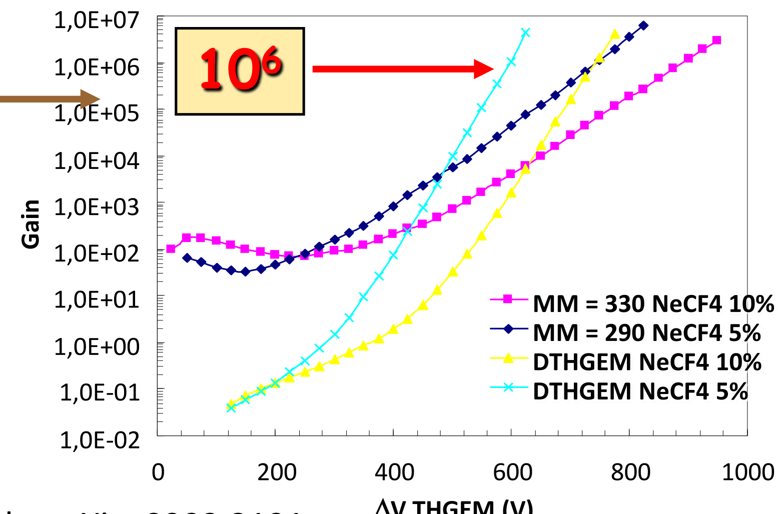
Other groups developed similar hole-multipliers:

- Optimized GEM: L. Periale et al., NIM A478 (2002) 377.

- LEM: P. Jeanneret, - PhD thesis, 2001.

- Effective **single-electron** detection (high gas gain ~10^5 (>10^6) @ single (double) THGEM)
- **Few-ns** RMS time resolution
- **Sub-mm** position resolution
- **MHz/mm²** rate capability
- **Cryogenic operation: OK**
- Gas: **molecular and noble gases**
- Pressure: **1mbar - few bar**

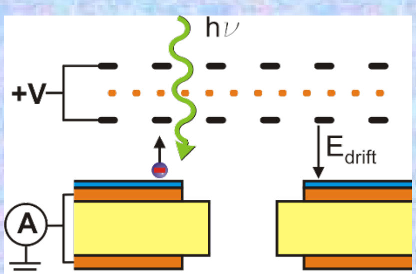
Double THGEM or THGEM/Micromegas



C. Azevedo et al.; arXiv: 0909.3191

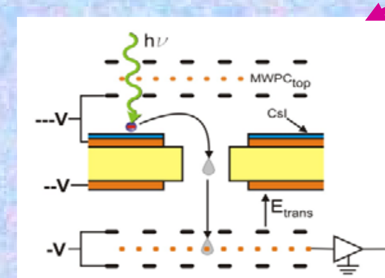
THGEM Photon Detectors for RICH: Efficiency Evaluation

Photon Detection Efficiency = QE (CsI) * Photo-current (Gas / Vacuum) * Electron Collection Efficiency



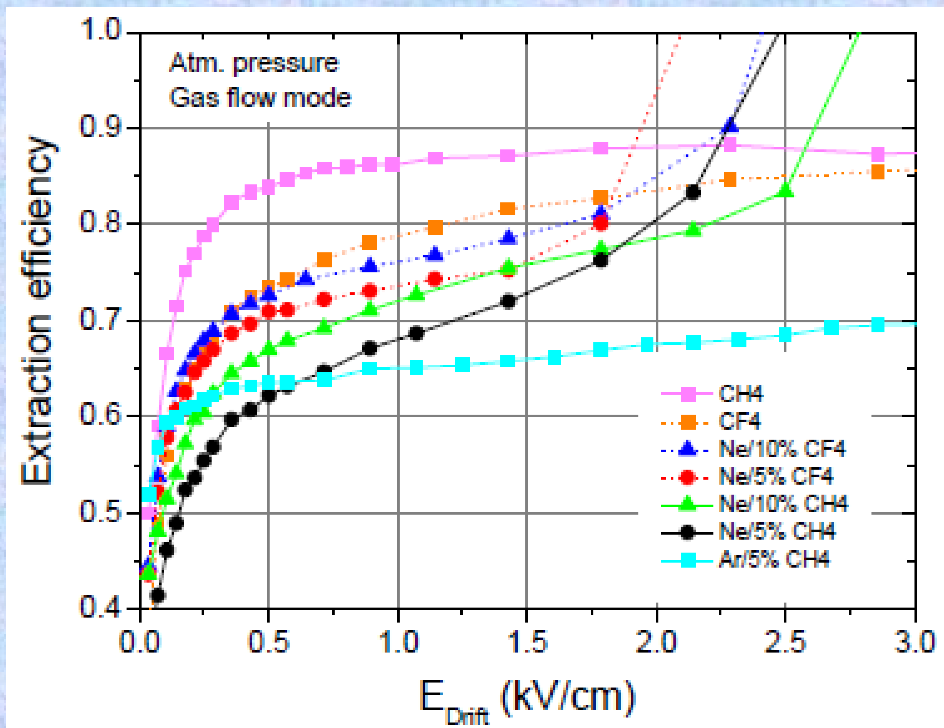
PE efficiency extraction into the gas vs vacuum:

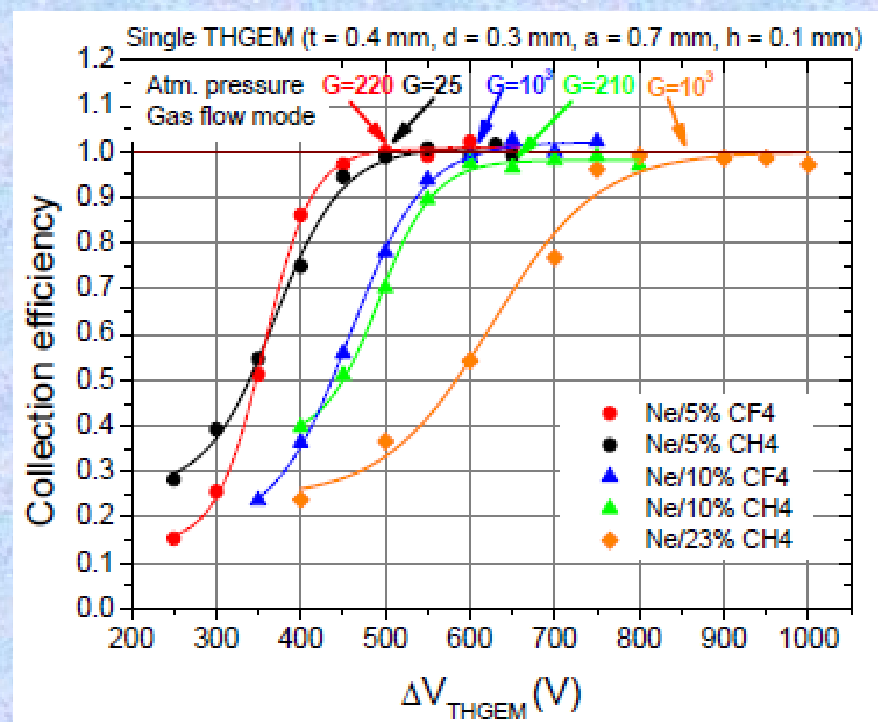
$$\varepsilon_{extr} = \frac{I_{gas}}{I_{vac}}$$



Single PE collection efficiency into THGEM holes:

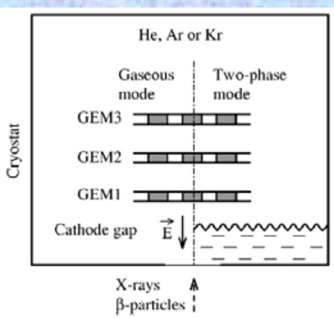
$$\varepsilon_{coll} = \frac{N_{THGEM}}{N_{ref}}$$

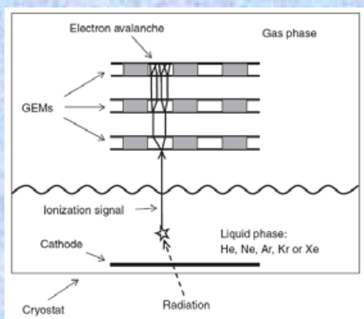




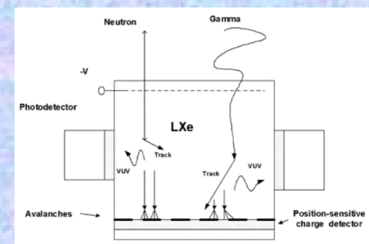
Azevedo et al., arXiv:0909.5357

MPGD-Based Cryogenic Avalanche Detectors: Concept Gallery

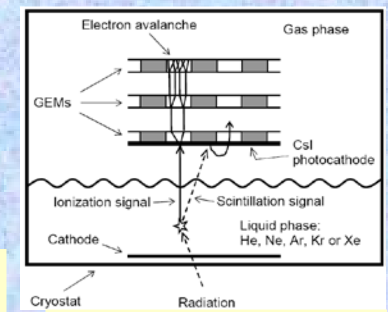




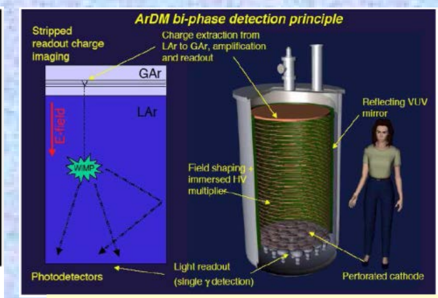
A.Buzulutskov et al, IEEE TNS 50 (2003) 2491;
A.Bondar et al, NIMA 524 (2004) 130



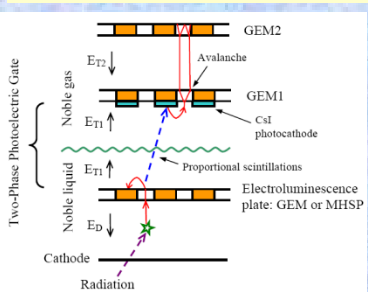
L.Periale et al, IEEE TNS 52 (2005) 927



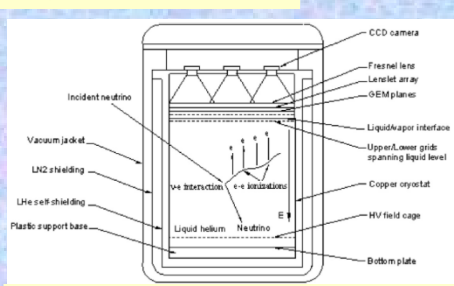
A.Bondar et al, NIMA 556 (2006) 273



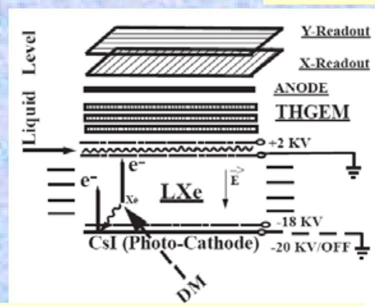
A.Rubbia, J. Phys. Conf. Ser. 39 (2006) 129



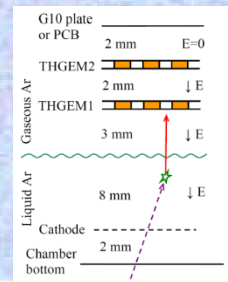
A.Buzulutskov, A.Bondar, JINST 1 (2006) P08006



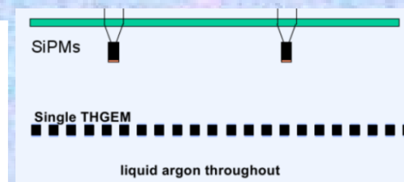
Y.L.Ju et al, Cryogenics 47 (2007) 81



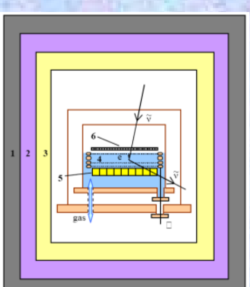
M.Gai et al, Eprint arxiv:0706.1106 (2007)



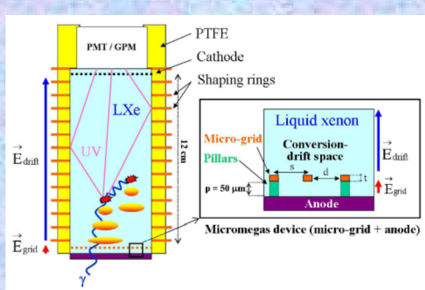
A.Bondar et al, JINST 3 (2008) P07001



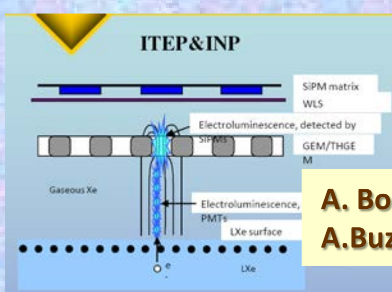
P.K.Lightfoot et al, JINST 4 (2009) P04002
N.McConkey et al, IPRD 2010, Siena, Italy; Nucl. Phys. B Proc. Suppl. 215 (2011) 255



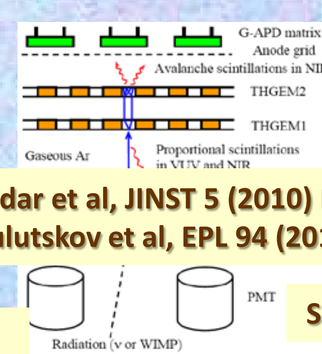
D.Akimov et al, JINST 4 (2009) P06010



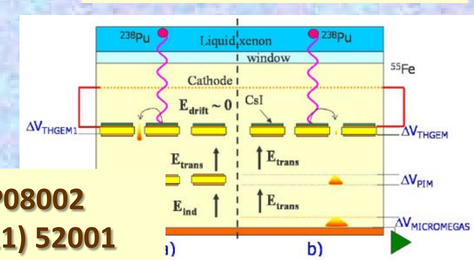
S. Duval et al, JINST 4 (2009) P12008



D.Akimov, NIMA 628 (2011) 50



A. Bondar et al, JINST 5 (2010) P08002
A.Buzulutskov et al, EPL 94 (2011) 52001

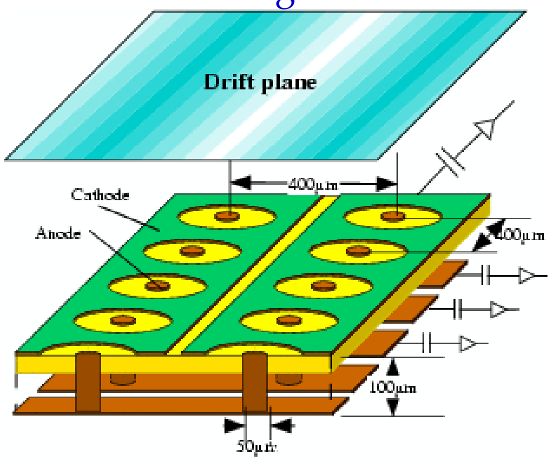


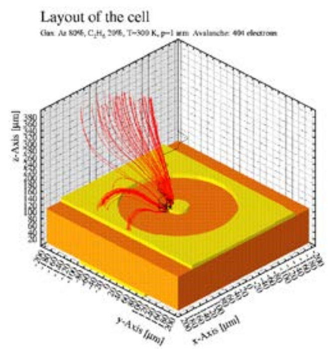
S. Duval et al, JINST 6 (2011) P04007

Micro-Pixel Chamber (μPIC) at Kobe University

μ-PIC : micro pixel gas chamber
- Area: 10x10cm – 30x30cm
- Readout pitch :400μm
- Production using PCB technology

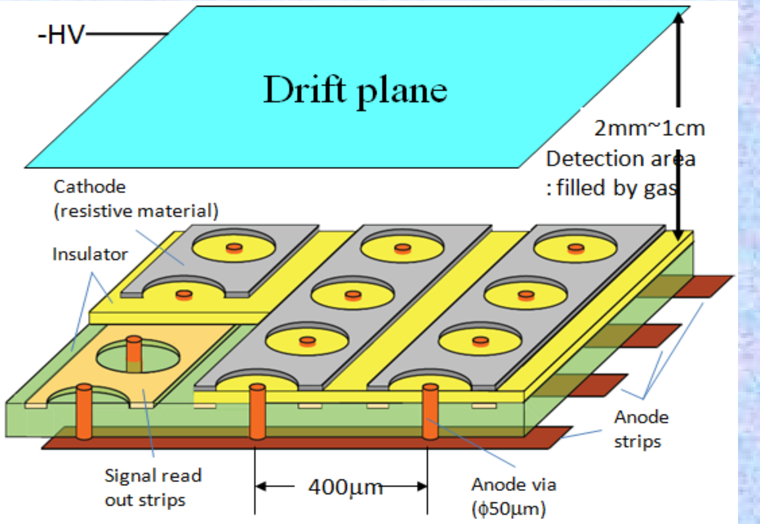
Invented by A.Ochi, T.Tanimori (NIMA471 (2001) 264)
Application: X-ray imaging, Gamma camera, Medical RI tracing

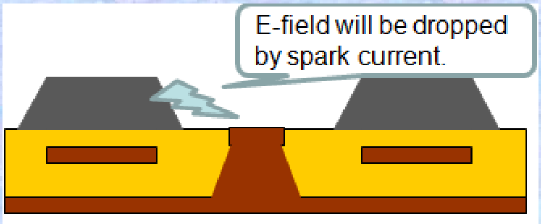




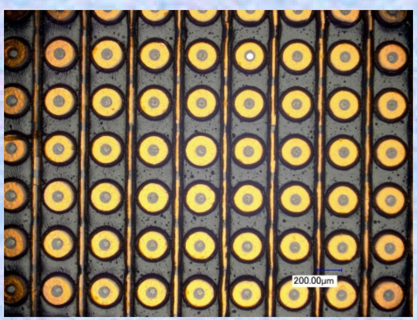
NEW: μ-PIC design with resistive cathode:

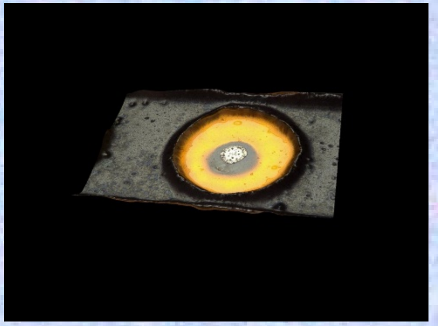
- Cathode patterns are formed by resistive material.
- Large current from spark reduce the e-field, and spark will be quenched.
- This design provide one promising possibility of MIP detector under hadronic background





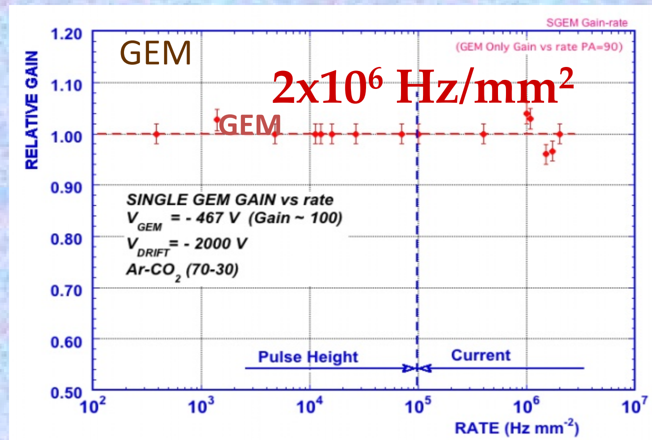
Surface pictures of resistive μPIC:

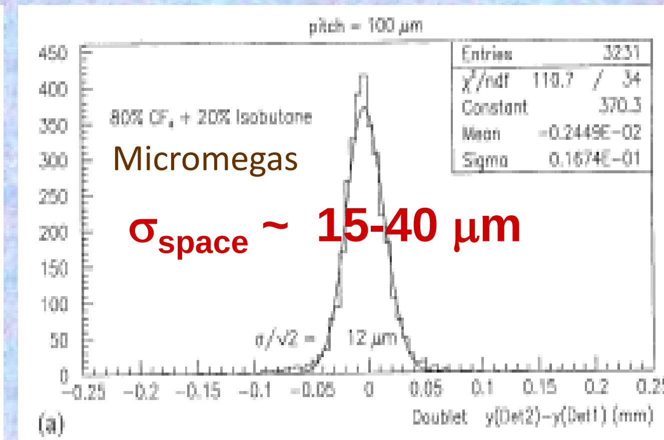


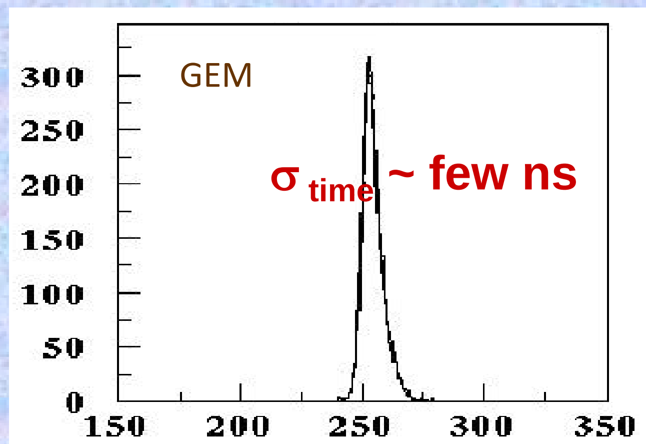


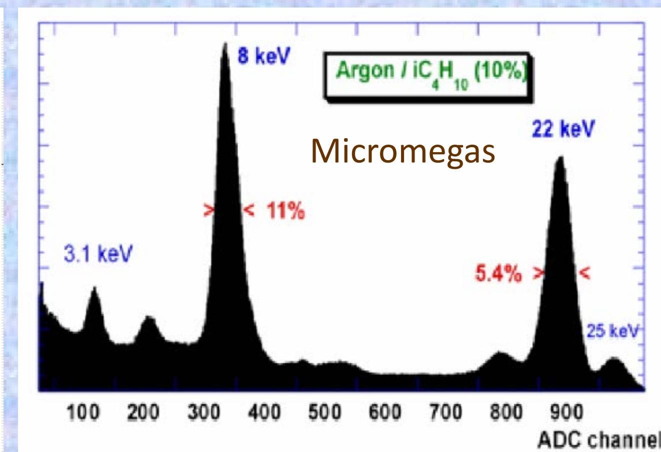
Why Micro-Pattern Gaseous Detectors are so attractive …

- High Rate Capability
- High Gain
- High Space Resolution
- Good Time Resolution
- Good Energy Resolution
- Excellent Radiation Hardness
- Ion Backflow Reduction
- Photon Feedback Reduction









One of the recent reviews describing the progress of the RD51 collaboration:

Modern Physics Letters A
Vol. 28, No. 13 (2013) 1340022 (25 pages)

DOI: 10.1142/S0217732313400221

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MICRO-PATTERN GASEOUS DETECTOR TECHNOLOGIES AND RD51 COLLABORATION

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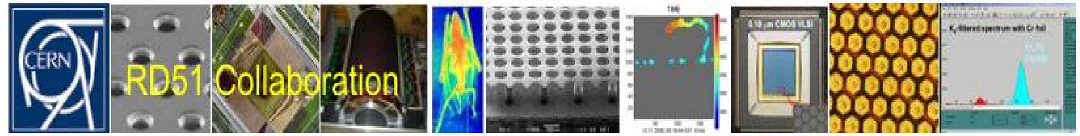
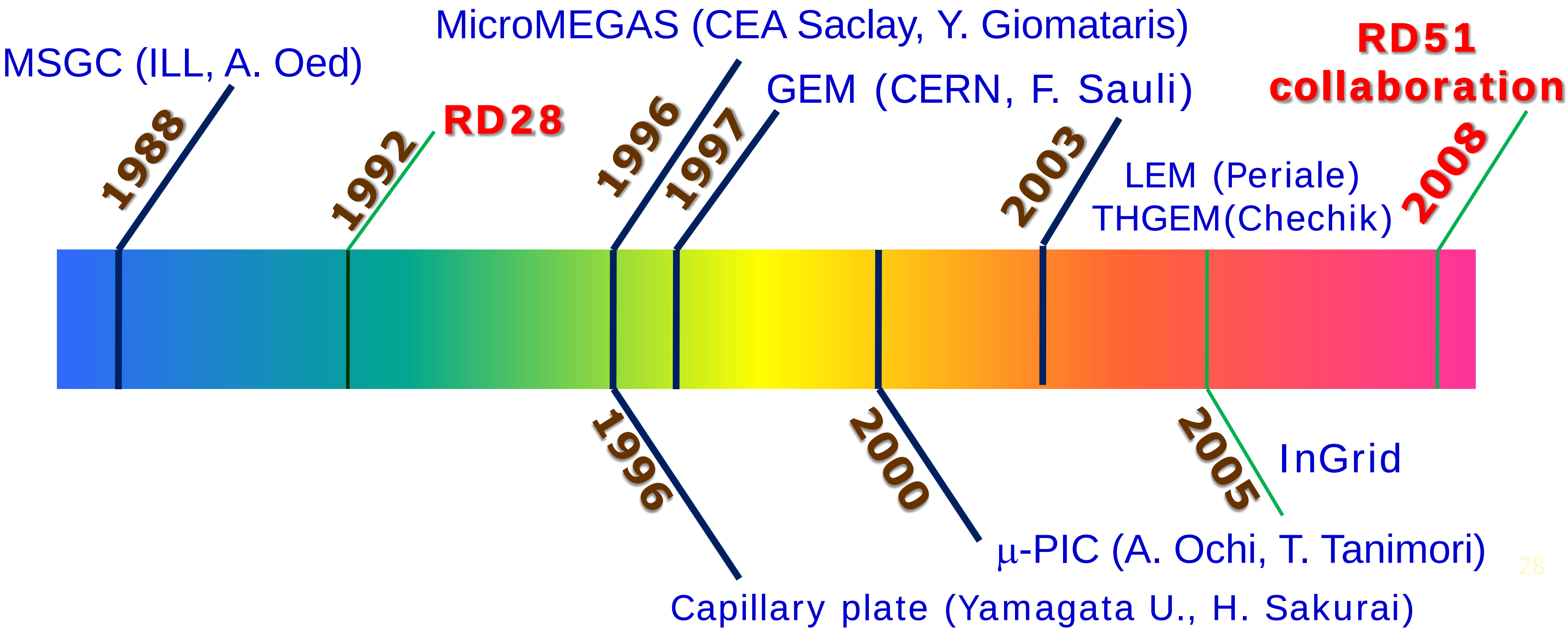
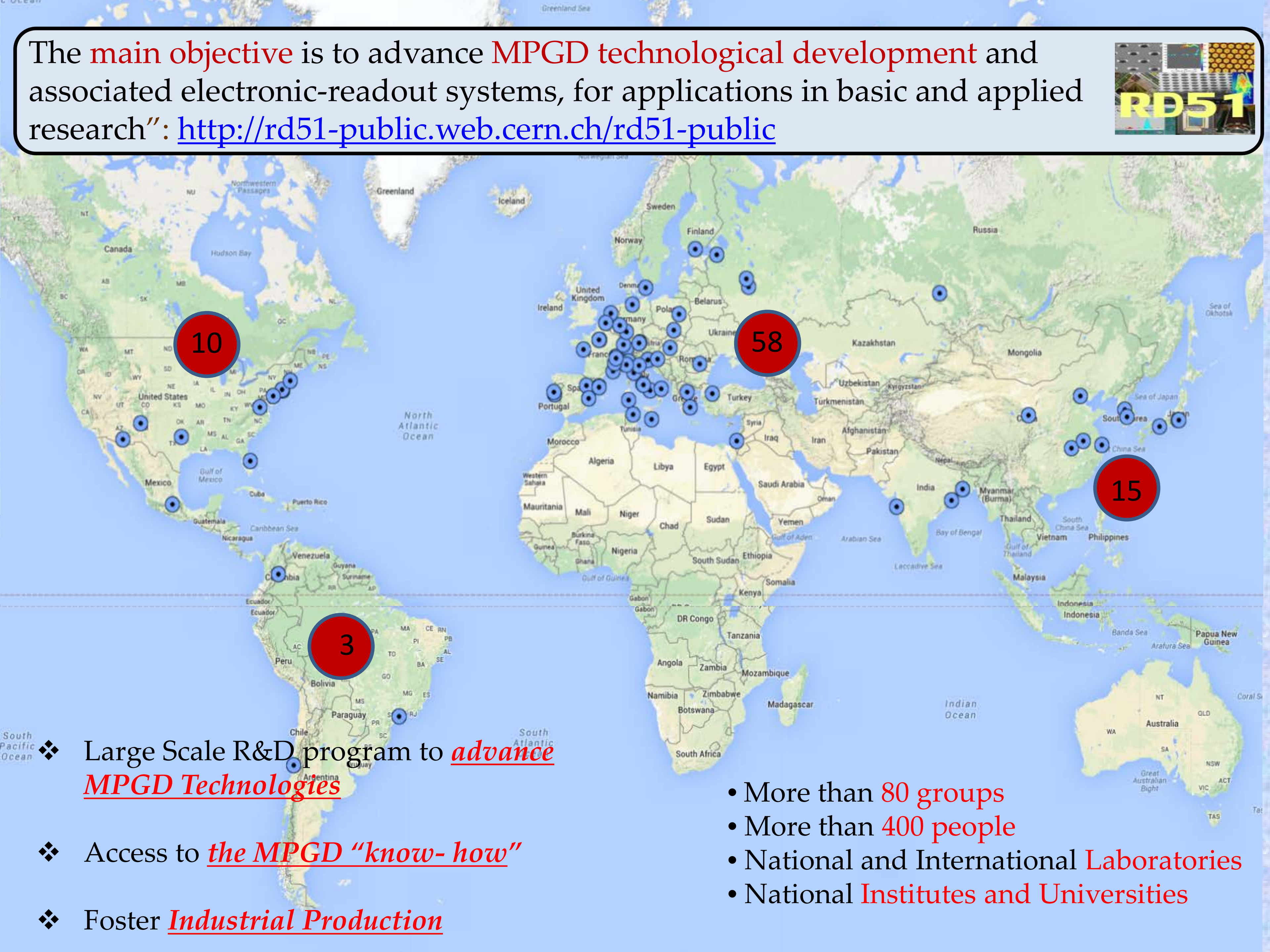
Historical Roadmap of the MPGD Technologies and RD51 Collaboration





- Many of the Micro-Pattern Gaseous Detector Technologies were introduced before the RD51 Collaboration was founded
- With more techniques becoming available (or affordable), new detection concepts are being introduced and the existing ones are substantially improved

The main objective is to advance MPGD technological development and associated electronic-readout systems, for applications in basic and applied research": http://rd51-public.web.cern.ch/rd51-public



- Large Scale R&D program to ***advance MPGD Technologies***
- Access to ***the MPGD "know- how"***
- Foster ***Industrial Production***

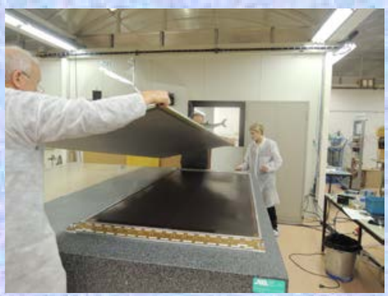
- More than 80 groups
- More than 400 people
- National and International Laboratories
- National Institutes and Universities

Summary of the RD51 Achievements (2008 – 2013)

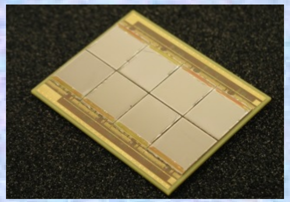
- Consolidation of the Collaboration and MPGD Community Integration (> 80 institutes, 450 members);
- Major progress in MPGD Technologies: Large area GEM (single mask), Micromegas (resistive) and THGEM; picked up by experiments, including LHC upgrades;
- Secured future of the MPGD Technologies development through the TE MPE workshop upgrade and FP7 AIDA contribution
- Contacts with industry for large volume production; MPGD industrialization and first industrial runs
- Major improvement to the MPGD simulation software framework for small-scale structures for applications;
- Development of common, scalable readout electronics (SRS); many developers and > 50 user groups; Production (PRISMA company and availability through CERN store); Industrialization (re-design of SRS in ATCA in EISYS)
- Infrastructure for common RD51 test beam and facilities (> 20 user groups);

Future RD51 Collaboration Activities (beyond 2013)

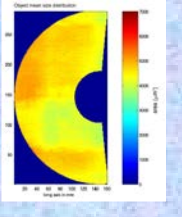
Large Area Detectors
Assembly Optimization



WG1:



RD51 Common Projects
Generic R&D, QA
Long Term Stability

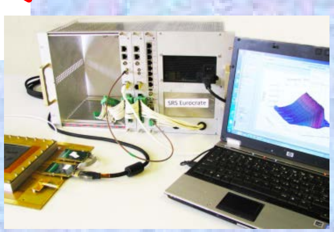
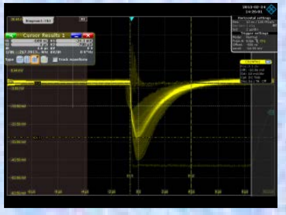




WG2:

RD51

WG5:

MPGD
Electronics

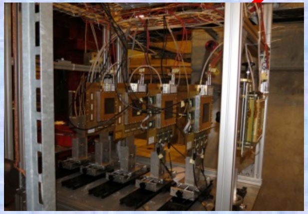
WG4:

Software Tools
and
Simulations

WG3/NEW WG:

- Conferences / Schools
- Academia-Industry
  Matching Events

WG7:

RD51 Common
Test Beam and Lab
Facilities

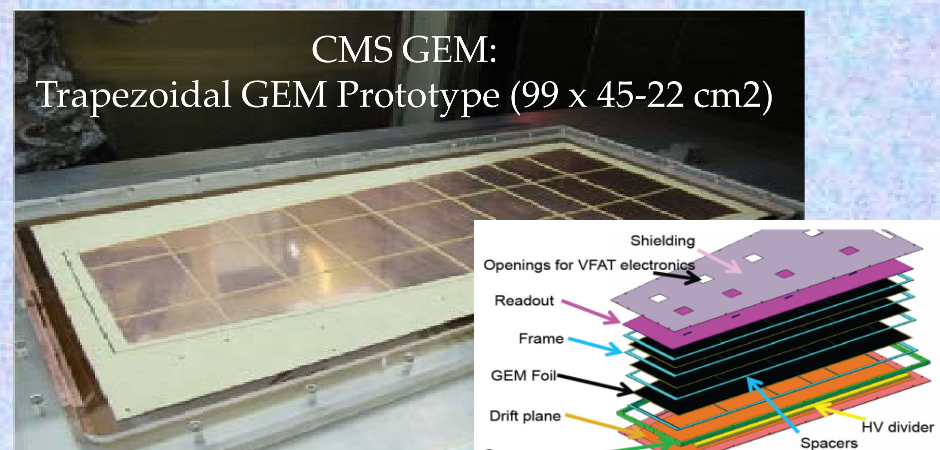
WG6:


CERN MPGD
Workshop,
Quality Control
and
Industrialization

MPGD Technologies for Energy Frontier (HL-LHC, LC)

	Vertex	Inner Tracker	PID/ photo-det.	EM CALO	HAD CALO	MUON Tracking	MUON Trigger
ATLAS						Micromegas	Micromegas
CMS					Backing-HE (GEM, MM)	GEM	GEM
TOTEM						GEM	GEM
LHCb							GEM
ALICE		TPC (GEM)					
Linear Collider		TPC(MM,GEM, InGrid)			DHCAL(MM, GEM,THGEM)		

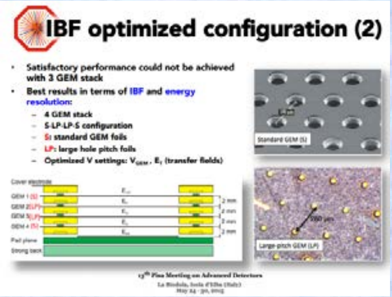

ATLAS Micromegas:
On a road to large-area detectors:
(1.2 * 0.6 m^2)

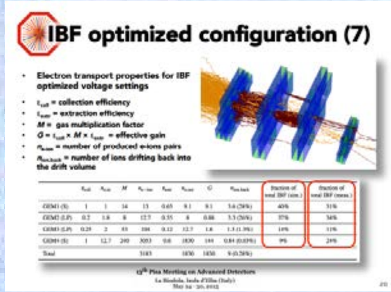


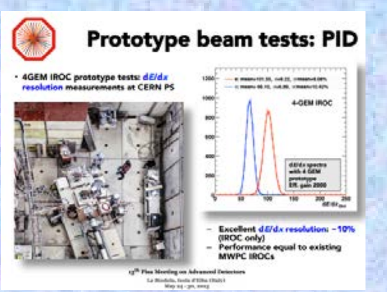
CMS GEM:
Trapezoidal GEM Prototype (99 x 45-22 cm2)

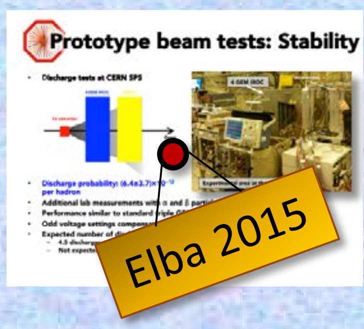
WG1: Examples of CERN/LHC Upgrades ("large achievement for MPGD community")

ALICE (GEM)

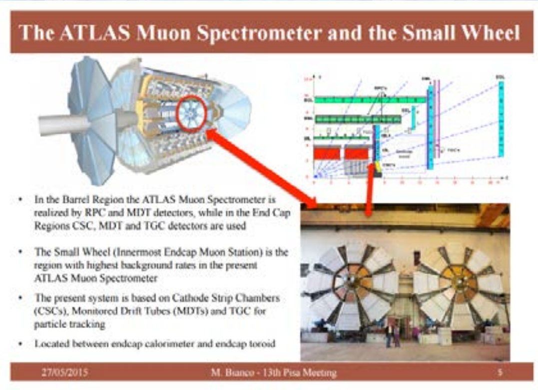


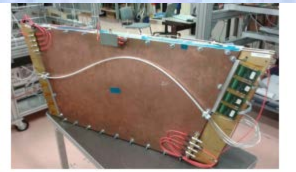


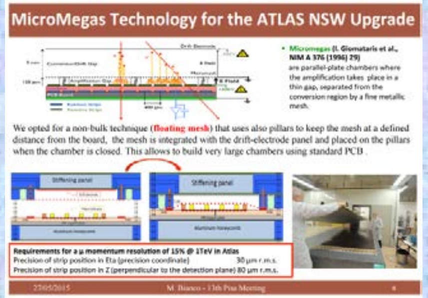


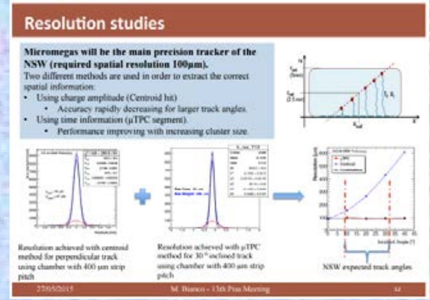


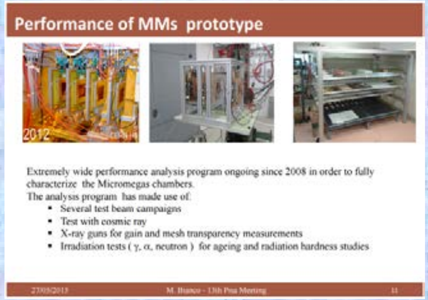
ATLAS NSW (Micromegas)

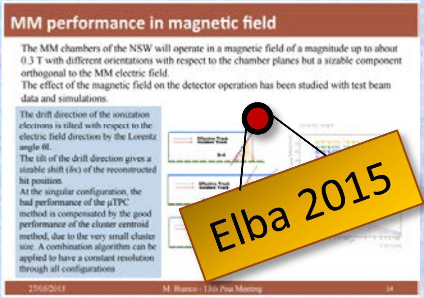










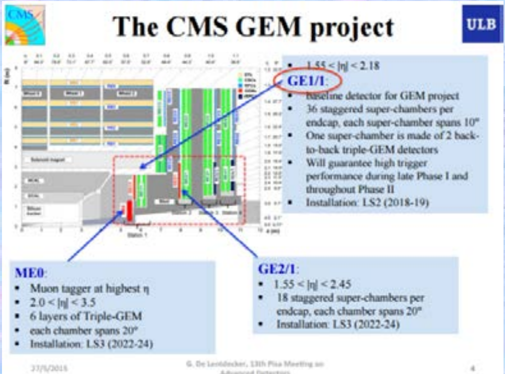


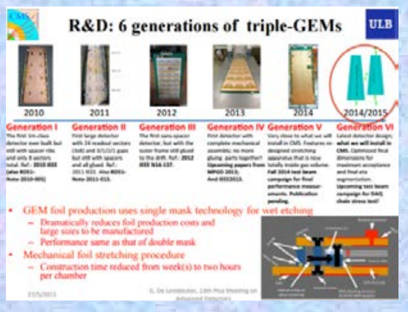
LHC Upgrades: Original R&D efforts emerged from RD51 activities.

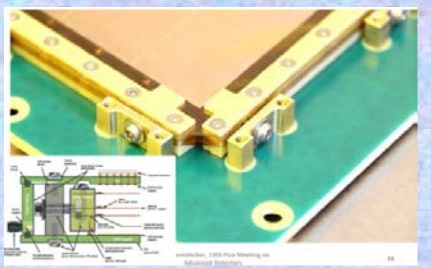
Today: production phase under the project effort , access to RD51 facilities (laboratory, test beam, workshops) and tools (simulation, electronics,…) to facilitate this particular phase

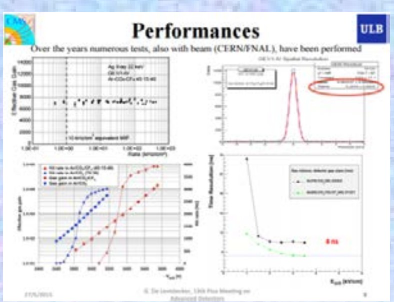
WG1: Examples of CERN/LHC Upgrades ("large achievement for MPGD community")

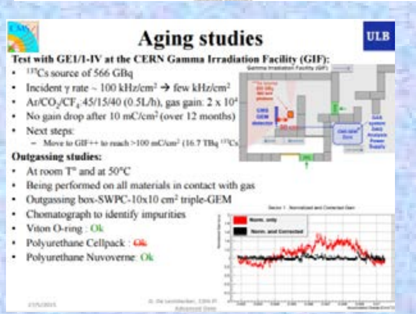
CMS (GEM)



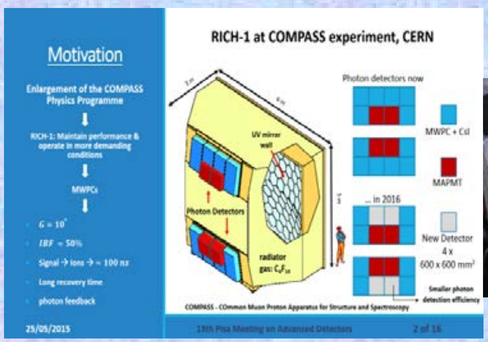


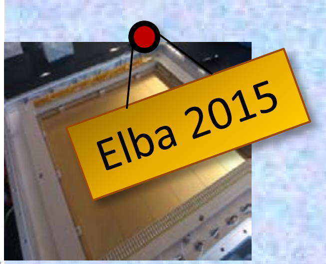


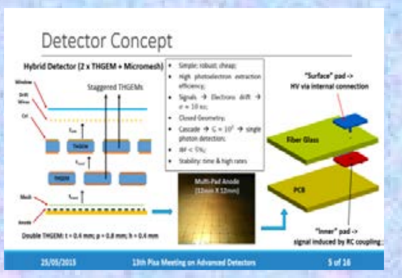


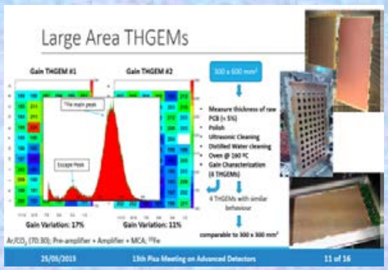


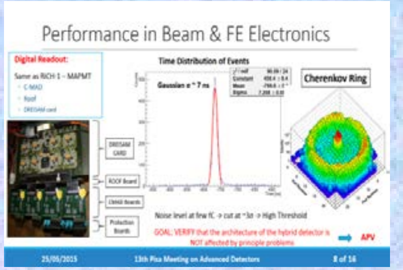
COMPASS RICH-1 (THGEM+MM)

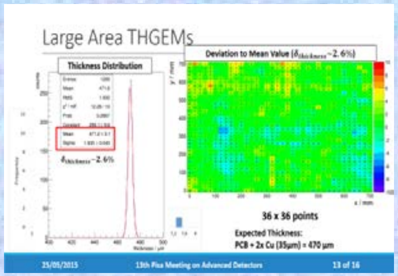












LHC Upgrades: Original R&D efforts emerged from RD51 activities.

Today: production phase under the project effort , access to RD51 facilities (laboratory, test beam, workshops) and tools (simulation, electronics,…) to facilitate this particular phase

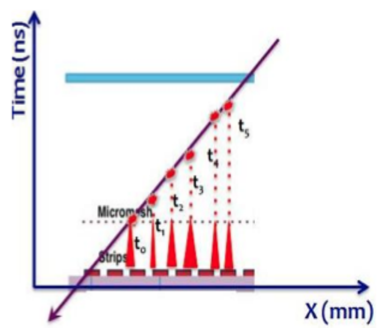
Resistive Micromegas Performace: Resolution vs Track Angle

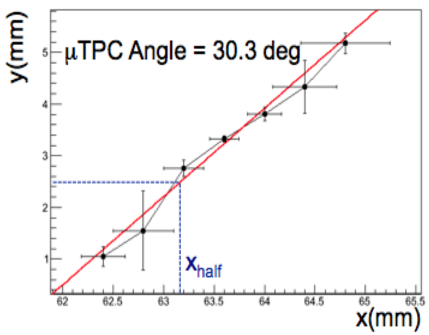
- Using charge amplitude (Centroid hit)

▪Spatial resolution rapidly decreases for inclined tracks if the cluster centroid (e.g., charge weighting) is used; small strip pitch does not help

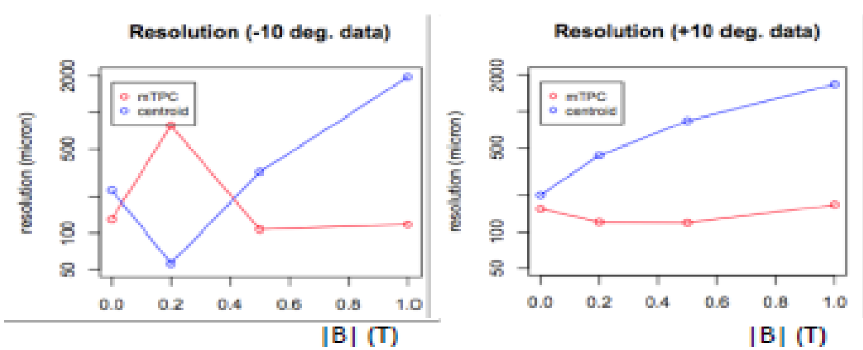
- Using time information (TPC segment)

Measuring the arrival time of the signals opens a new dimension; in this case the MM functions like a TPC => Track vectors/plane for inclined tracks



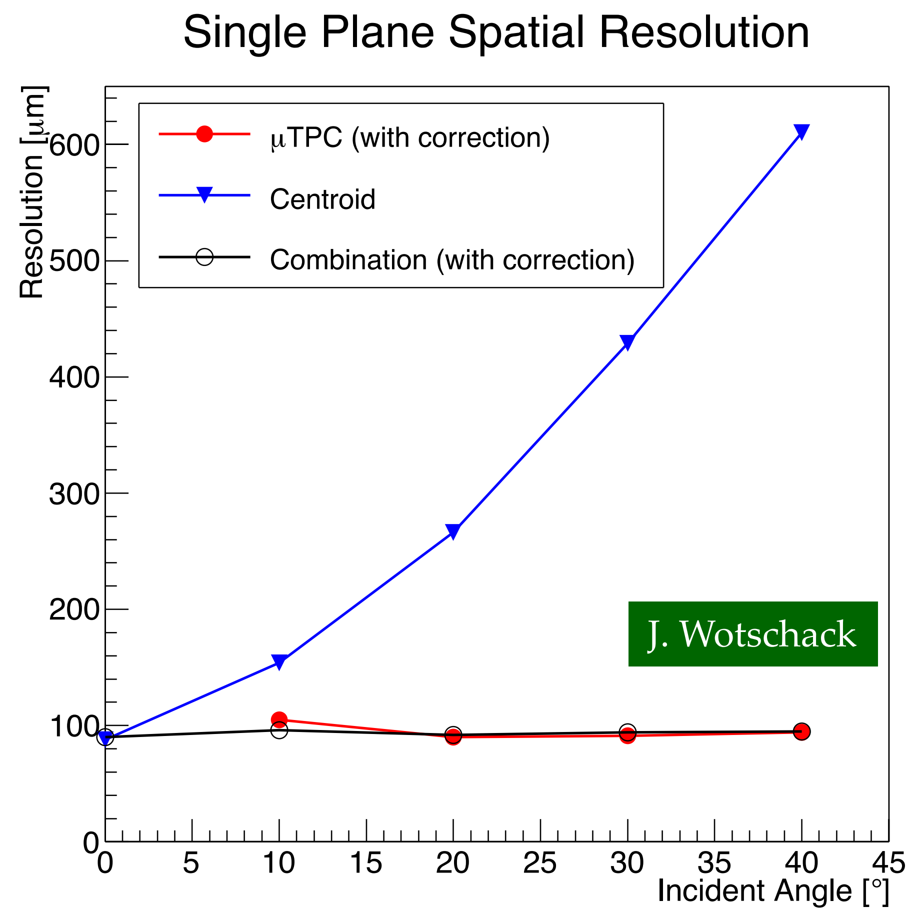


Spatial resolution vs magnetic field:



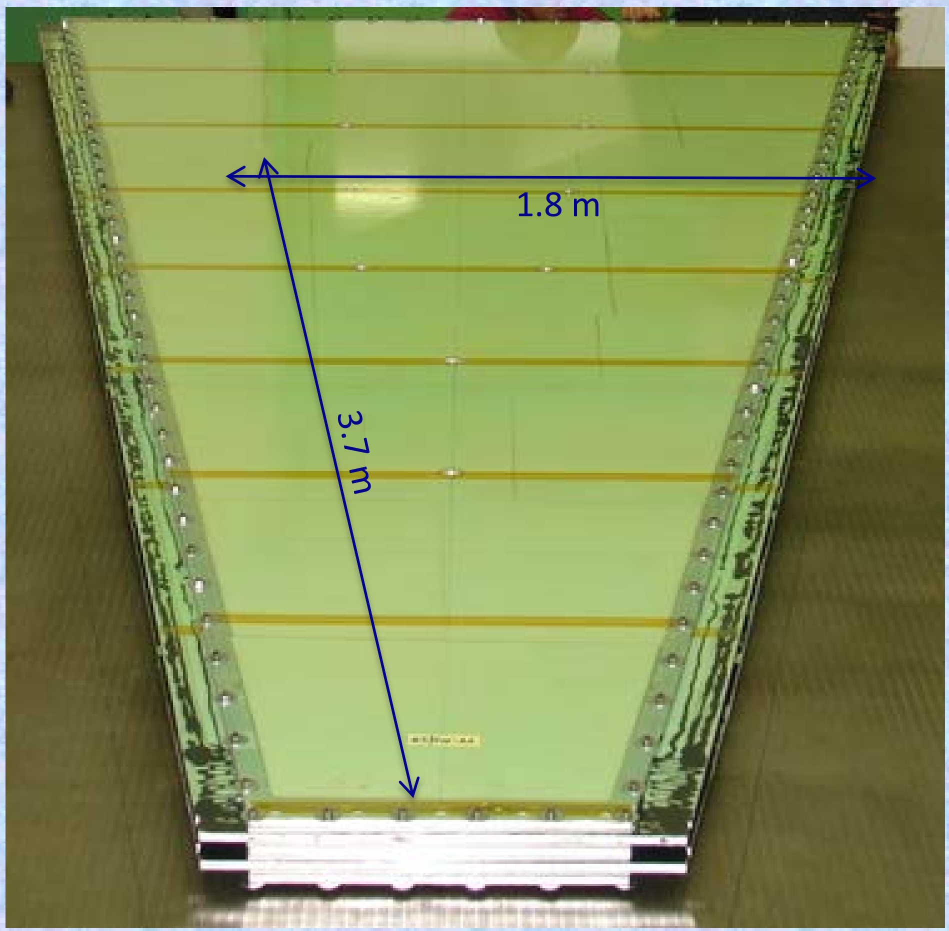
Combination of centroid & TPC →

spatial resolution < 100 μm independently of track incident angle !



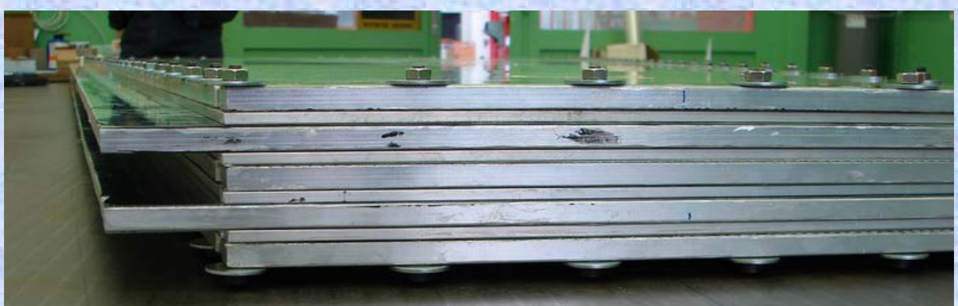
Range of track angles in NSW

Micromegas for ATLAS NSW: Full Sector Mechanical Prototype (CERN)



Test of segmented FR4 skin glueing with different stiffeners

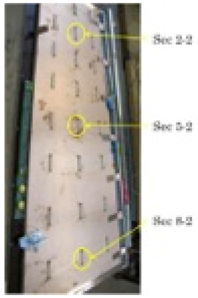
Will serve for deformation studies



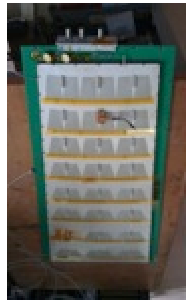
J. Wotschack

GEM Technology: From GE 1/1 to GE1/1-v6 Prototypes

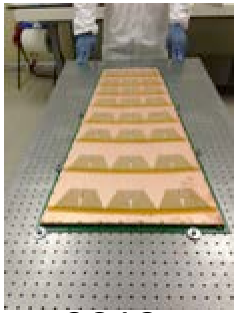
2010



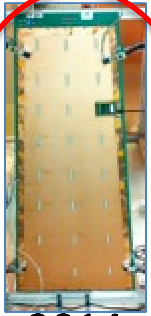
2011



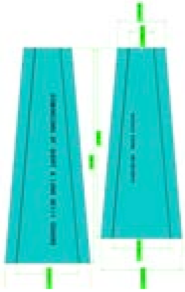
2012



2013



2014



2014/2015

Generation I

The first 1m-class detector ever built but still with spacer ribs and only 8 sectors total.
Ref.: 2010 IEEE (also RD51-Note-2010-005)

Generation II

First large detector with 24 readout sectors (3x8) and 3/1/2/1 gaps but still with spacers and all glued.
Ref.: 2011 IEEE. Also RD51-Note-2011-013.

Generation III

The first sans-spacer detector, but with the outer frame still glued to the drift.

Ref.: 2012 IEEE N14-137.

Generation IV

First detector with complete mechanical assembly; no more gluing parts together!

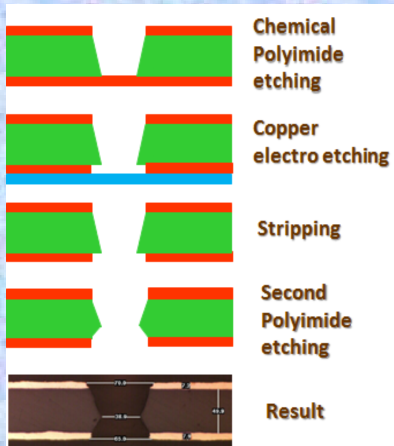
MPGD 2013; and IEEE2013.

Generation V

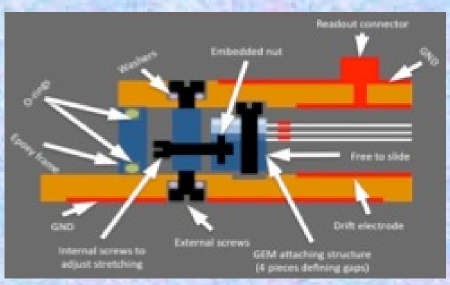
Nearly final CMS design: stretching apparatus that is now totally inside gas volume. **Ongoing test beam campaign for final performance measurements.**

Generation VI

Latest detector design; **to be installed in CMS.** Optimized final dimensions for max. acceptance and final eta segmentation. **Ongoing test beam campaign for DAQ**

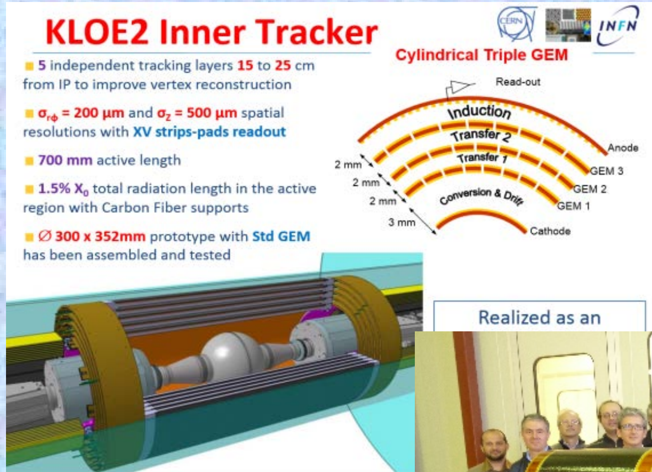


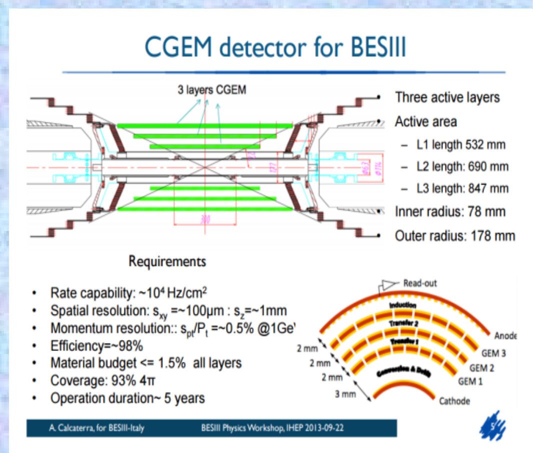
- GEM foil production uses single mask technology for wet etching
  - Dramatically reduces foil production costs and allows large sizes to be manufactured
- NS2 assembly technique developed
  - Construction time reduced from week(s) to two hours per chamber

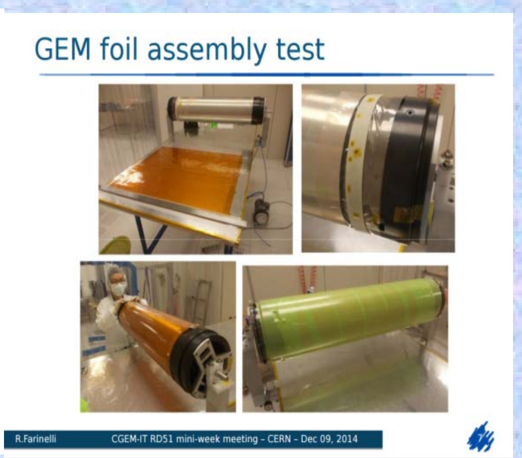


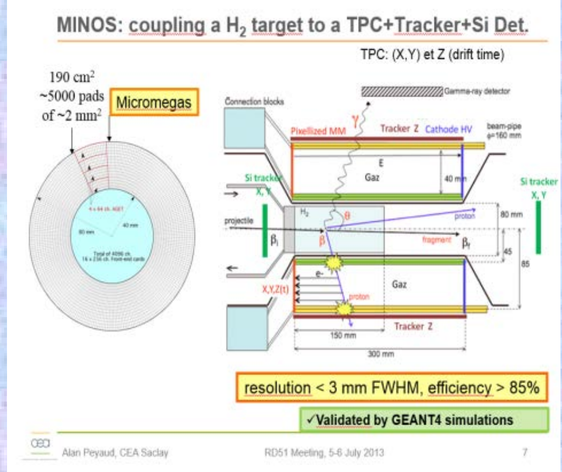
A. Sharma

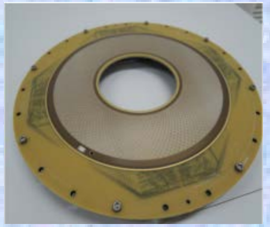
Consolidation of existing structures: Cylindrical MPGDs as an example

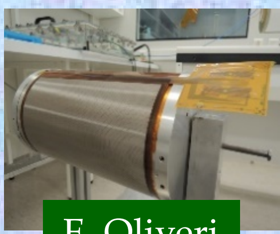






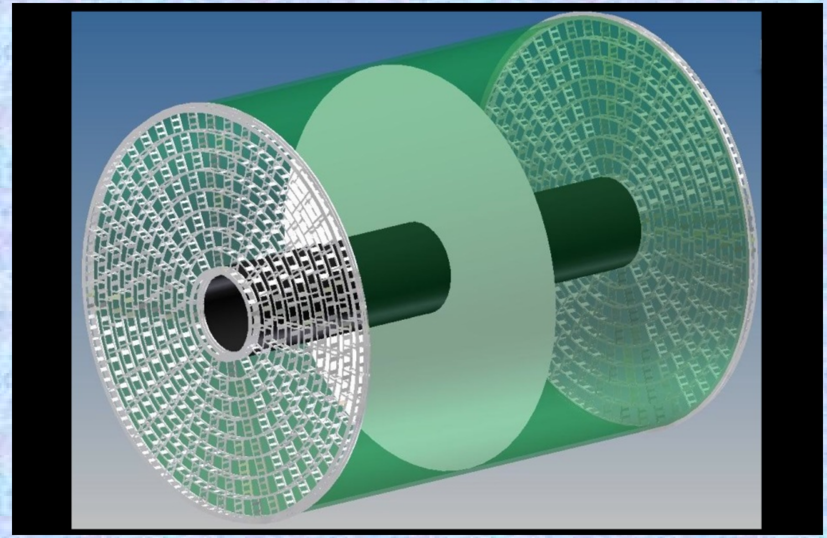






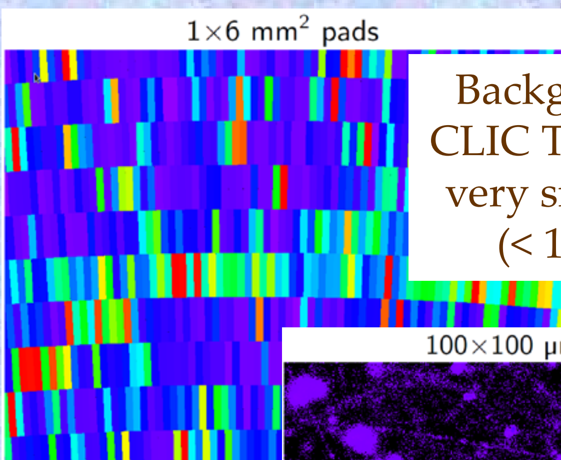
E. Oliveri

MPGD Readout for the Time Projection Chamber at the ILC/CLIC

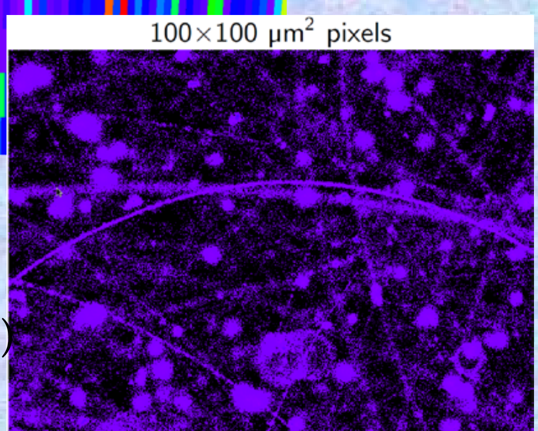


MPGDs are foreseen as TPC readout for ILC or CLIC (size of endcaps of ~ 10 m^2):

- Standard "pad readout" (1x 6 mm^2): 8 rows of det. modules (17×23 cm2); 240 modules per endcap
- "Pixel readout" (55x 55μm^2): ~100-120 chips per module → 25000-30000 per endcap



Backgrounds in CLIC TPC requires very small pixels (< 1x1 mm^2)



CLIC TPC Simulation (M. Killenberg)

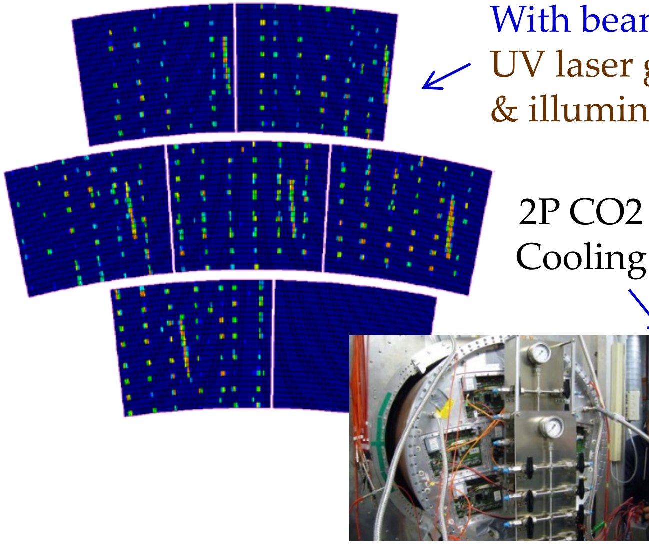
ILCTPC with MPGD-Readout:
(spatial resolution < 100 μm @ 5T)

- Laser-etched GEMs 100μm thick ('Asian GEMs')
- Wet-etched triple GEMs
- Resistive MM with dispersive anode
- GEM + pixel readout
- InGrid (integrated Micromegas grid with pixel readout)

MPGD-based "Pad Readout" for ILC TPC

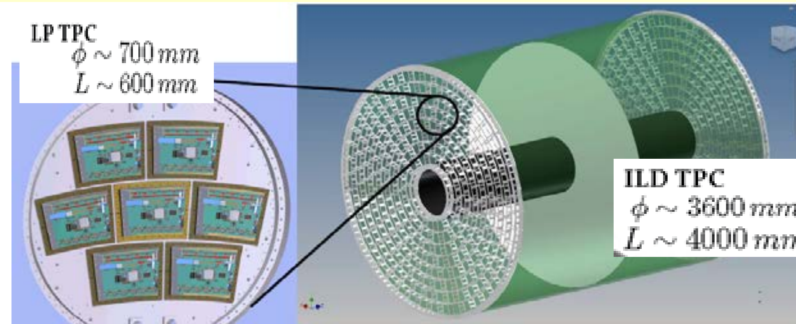
Efforts to improve the modules design for all technologies. Several test beams campaigns:

- 7 Micromegas modules with 2-phase C02 cooling

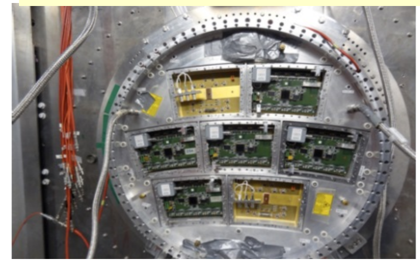


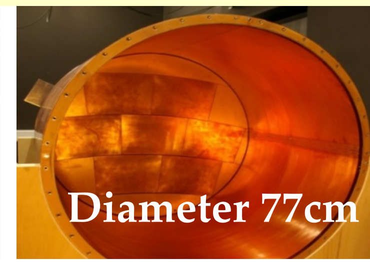
With beam and laser dots:
UV laser gererates MIP tracks
& illuminate calibration spots

2P CO2
Cooling

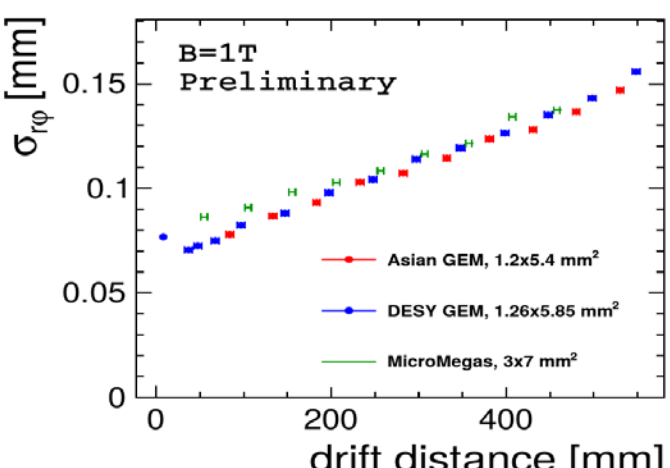


Large TPC Prototype with versatile endplate @ DESY

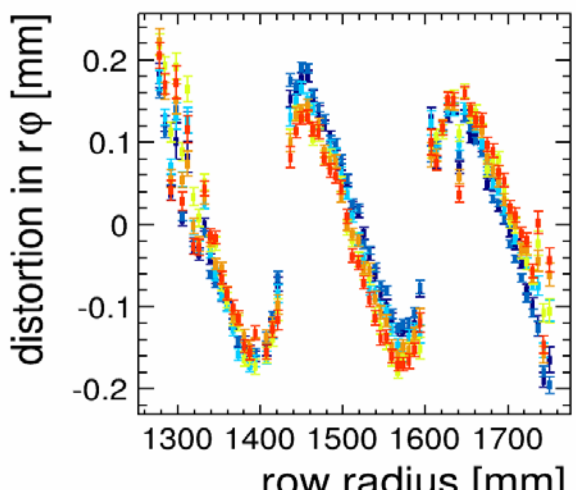




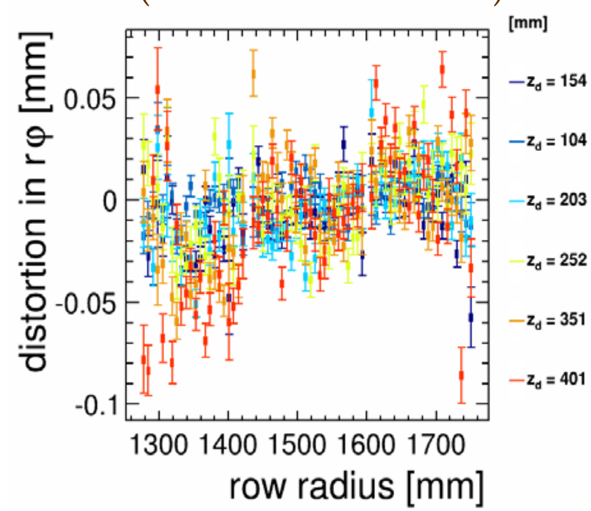
Goal for final TPC can be reached:
GEM / MM performance similar



MM (B=0): Before correction



MM (B=0): After correction
(note – different scale)



MPGD-based "Pixel Readout" for ILC TPC

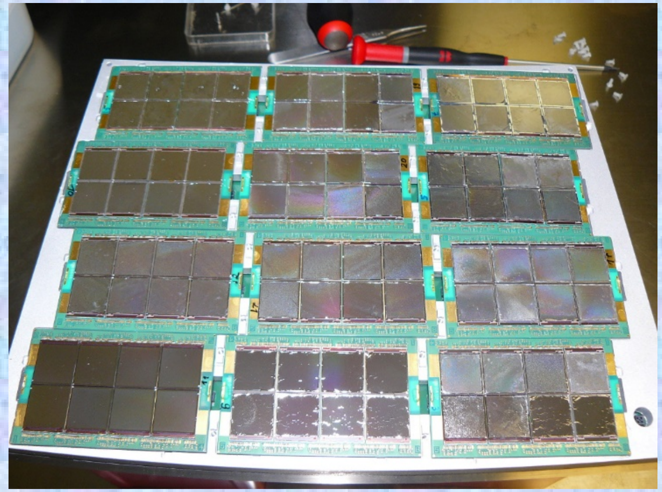
LARGE AREA: 160 InGrid detector setup

→ 3 modules: 1 x 96 InGrid, 2 x 24 InGrids

→ Readout 5 SRS FECs

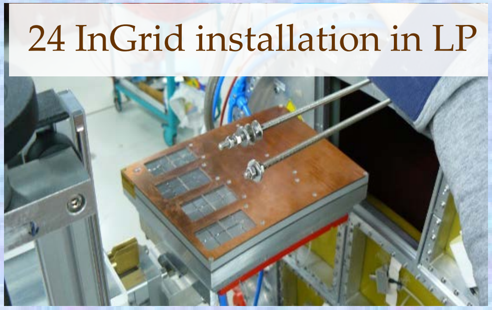
By design:

- Singe electron detection
- Time-of-arrival measurement
- High granularity; Uniform gas gain

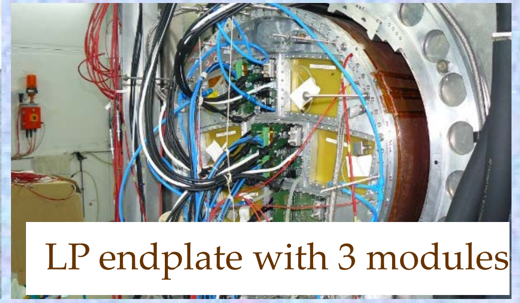


Module with
96 InGrids
on 12 „octoboards“

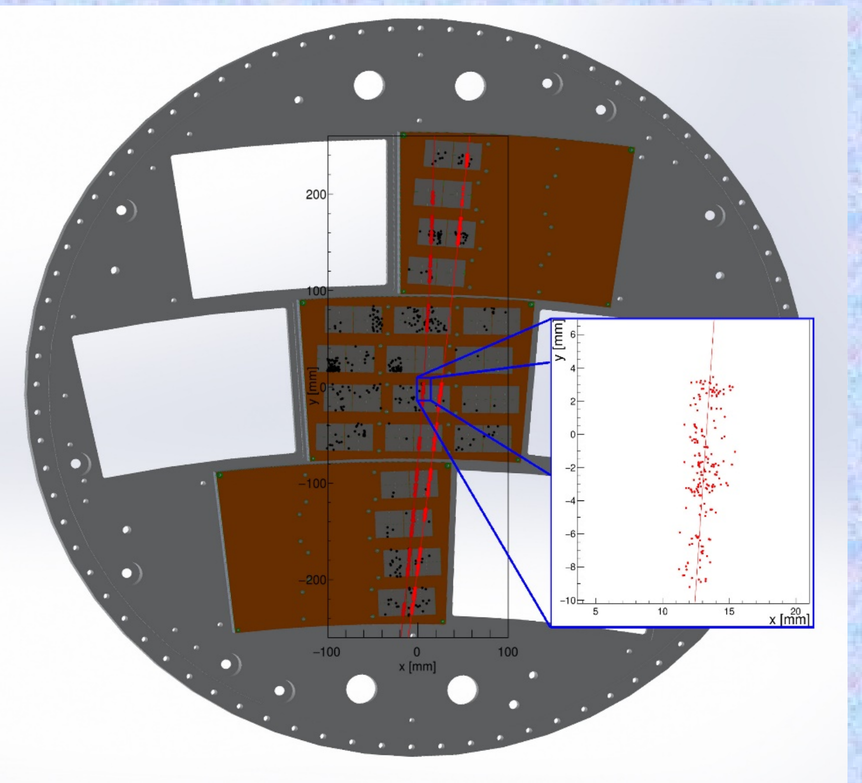
M. Lupberger



24 InGrid installation in LP



LP endplate with 3 modules



Preliminary data analysis:

- Track reconstruction

→ straight and curved tracks

→ ≈ 3000 hits per 50 cm track

- Physics properties of the TPC

→ field distortions; reliability

→ dE/dx resolution;delta identification

→ single point resolution

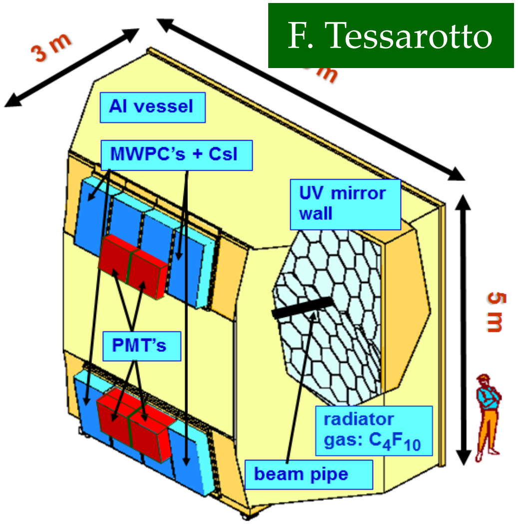
→ momentum measurement

COMPASS RICH I Upgrade: Long-Term Experience, Performance

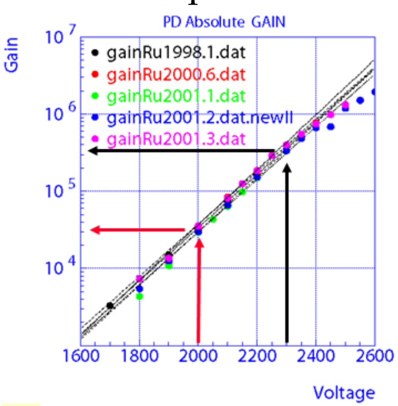
❖ COMPASS RICH I:

➢ 1999-2000: 8 MWPC with CsI (RD26 @ CERN)

F. Tessarotto



After a long-term fight for increasing electrical stability at high rates: robust operation is not possible at gain~10^5 because of photon feedback, space charge & sparks



❖ beam off: stable operation up to > 2300 V

❖ beam on: stable operation possible only up to ~2000 V

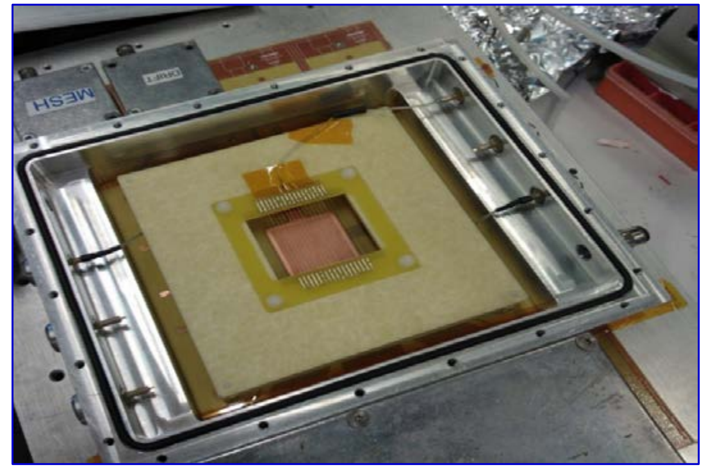
❖ 2006: 4 central CsI+cathodes: remove and insert frames with MAPMTs and lense telescopes

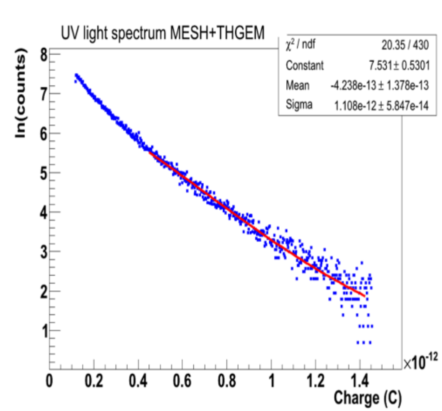
PMTs not adequate → only small demagnification factor allowed; 5 m² of PMTs not affordable.

❖ UPGRADE OF COMPASS RICH I:

➢ MPGD-Photon Detectors are the best option

→ Micromegas +THGEM, the hybrid architecture structure, is one of the most advanced scheme:





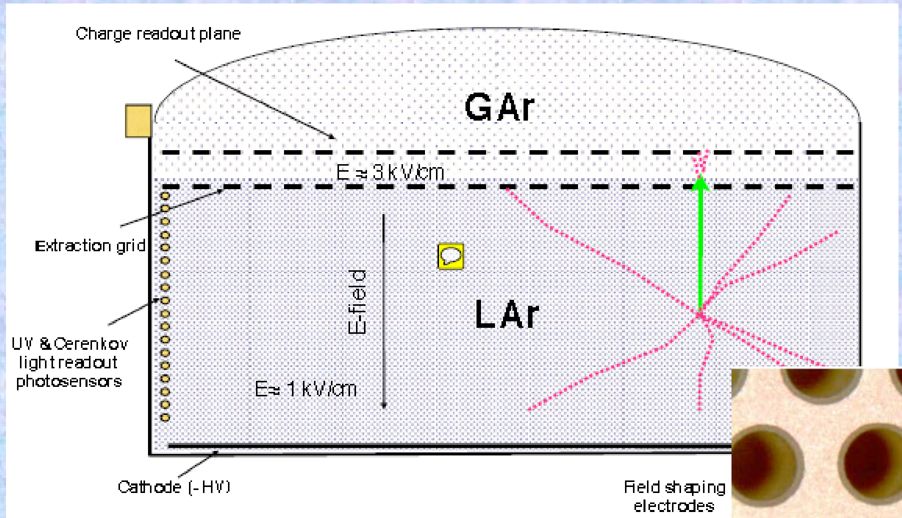
E_{mesh} ~ 30 kV/cm
E_{trans} = 1.2 kV/cm
ΔV = 1575 V
E_{drift} = 0 V/cm
Gain ~10^6
IBF ~ 4%

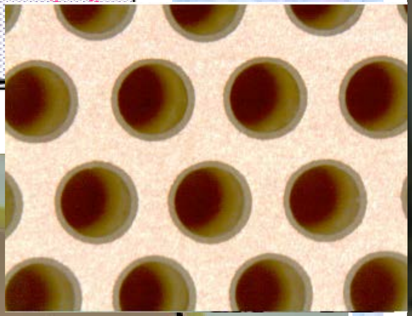
Higher performance reached with the MM + THGEM architecture (than multiple-THGEM structures)

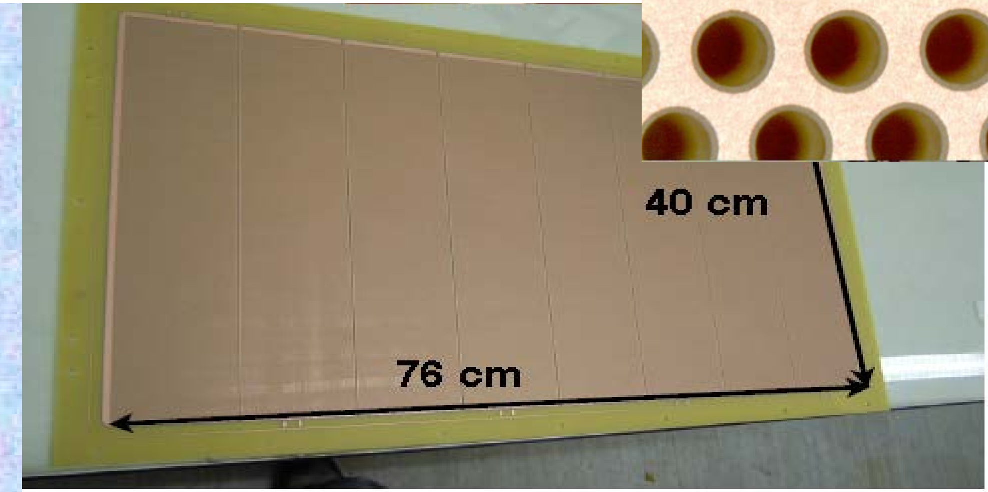
LEM (THGEM) Technology for Double Phase Ar-TPC

Giant Liquid Argon Charge Imaging ExpeRiment

GLACIER (hep-ph/0402110) is a proposed giant liquid argon multi-purpose next-generation underground neutrino observatory at the 100 kton scale.



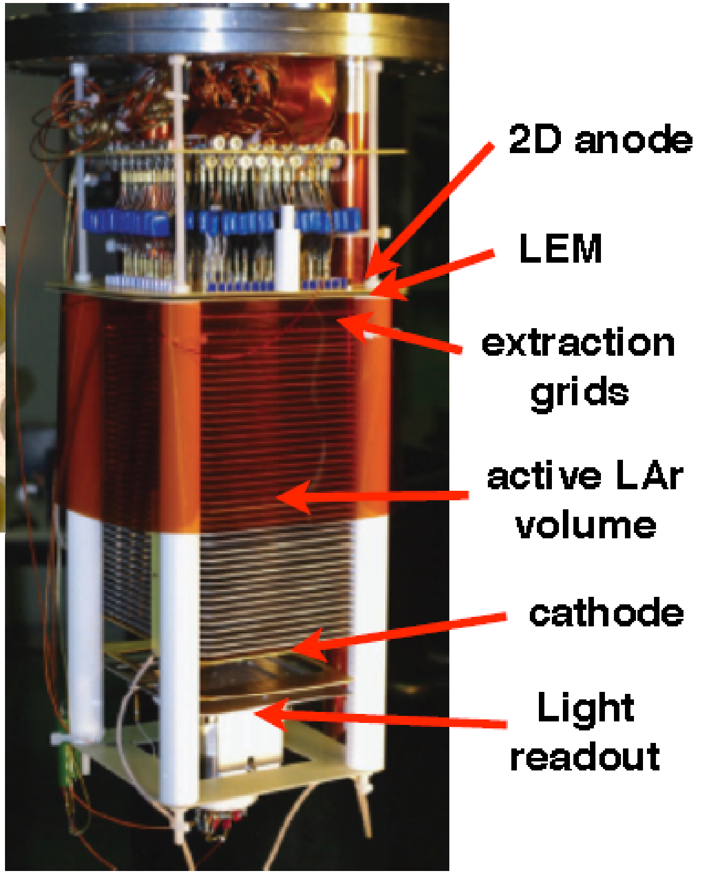




produced by CERN TS/DEM group & ELTOS company (I)

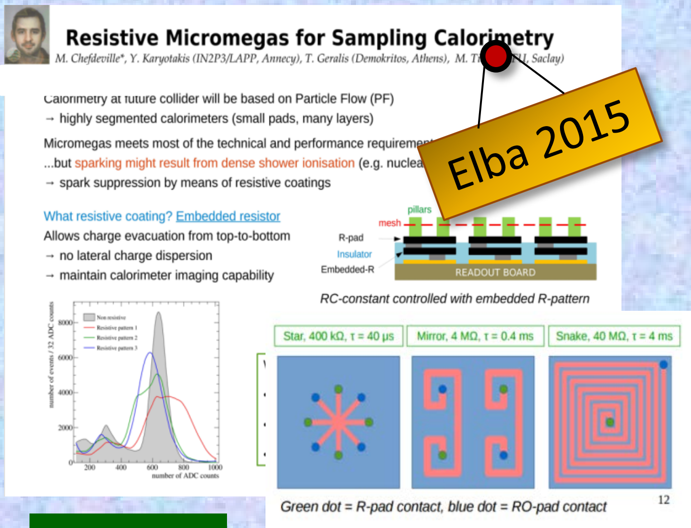
Double-phase Ar LEM TPC

the TPC



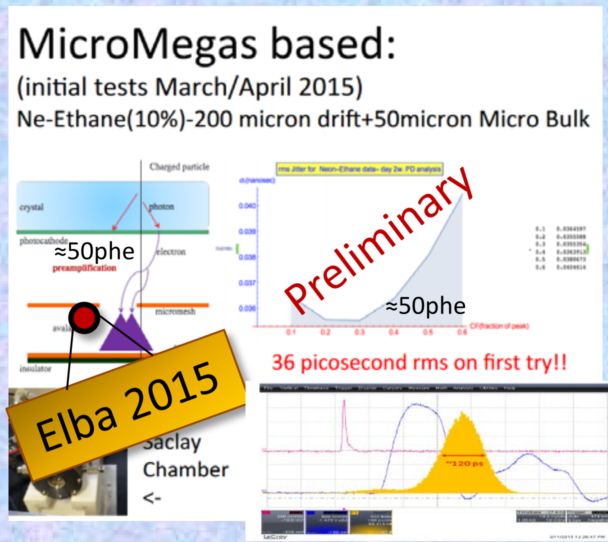
WG2: Generic R&D, Examples of New Ideas, Applications

Calorimetry with MPGD:

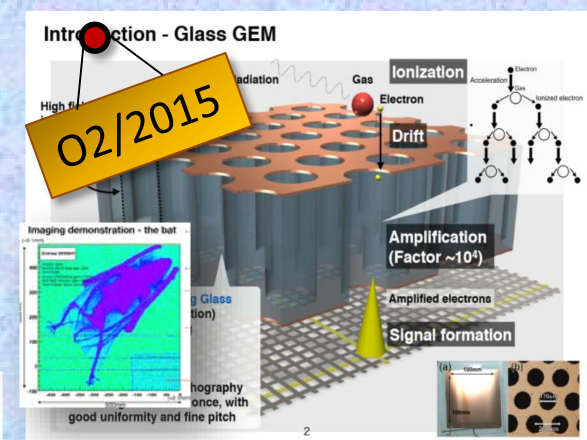


E. Oliveri

Fast Timing:

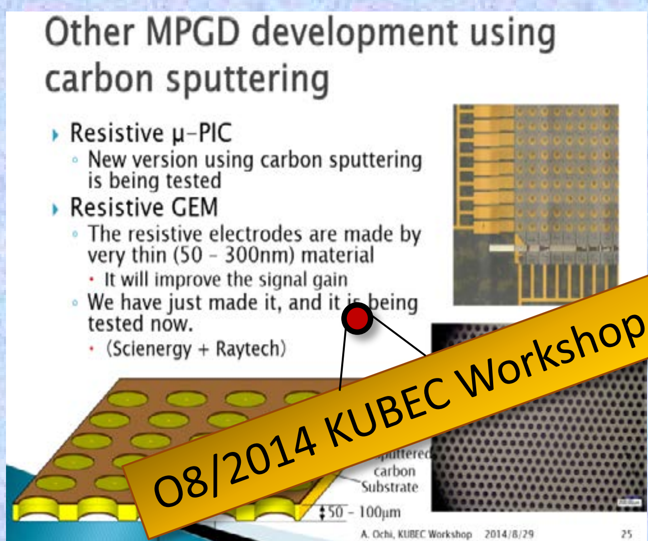


New Materials (Glass GEM):

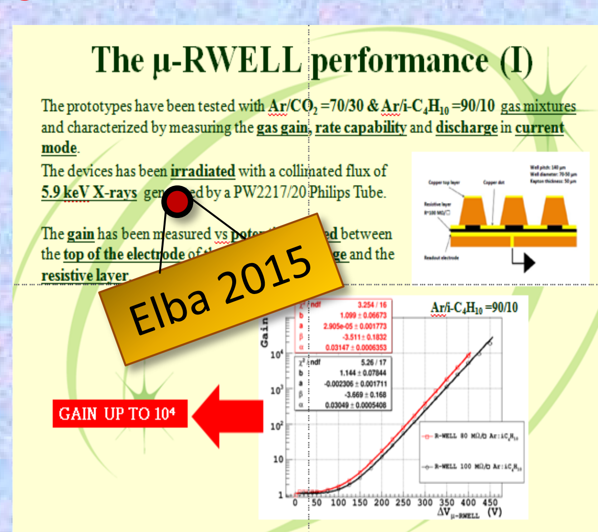


The Latest Results of Crystalized Glass GEM, Y. Mitsuia, RD51 miniweek (GDD/RD51 lab)

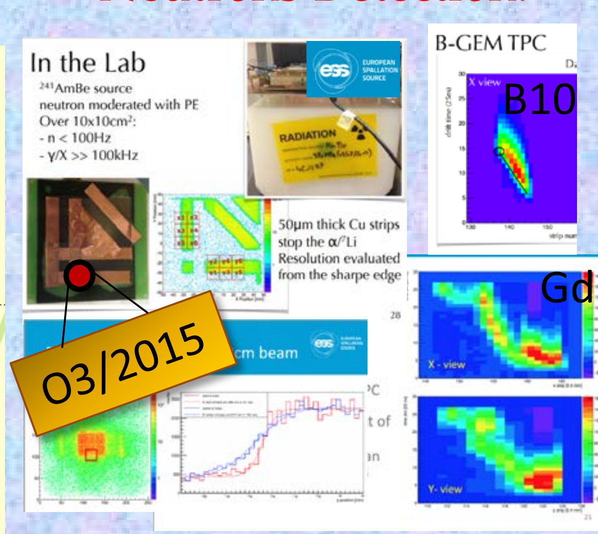
Resistive Material:



Large Area Thin Detectors:



Neutrons Detection:



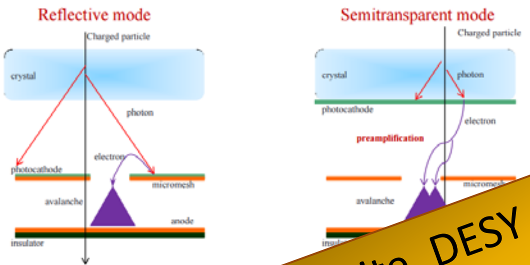
European Spallation Source (ESS)

WG2: Generic R&D, Examples of New Ideas

FAST-TIMING MPGDs on MM concept:

Primary ionization: photoelectrons

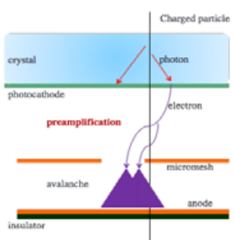
- Cherenkov light produced by charged particles crossing a MgF_2 crystal
- Photoelectrons extracted from a photocathode (CsI)
  - → Simultaneous & well localized ionization of the gas

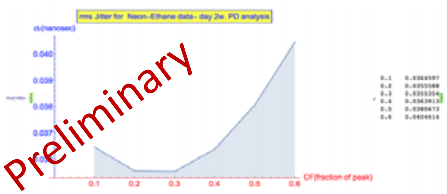


Irfu Thomas Papaevangelou 15th RD51 Co...

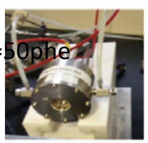
S. White, DESY Seminar, June 12, 2015

MicroMegas b...
(initial tests March/April ...15)
Ne-Ethane(10%)-200 micron drift+50micron Micro Bulk





36 picosecond rms on first try!!



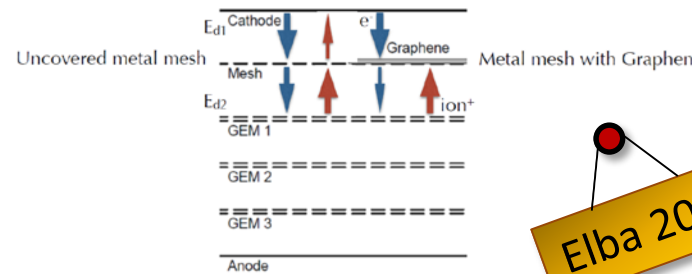
Saclay Chamber <-

Convert single-photoelectron time jitter of a few hundred picoseconds into an incident-particle timing response of the order of 50 ps

Study of charge-transfer properties through graphene for gas detector applications:

The idea

Build a suspended Graphene layer without defects transparent to the drifting electrons and opaque to ions eliminating the ion back-flow in gaseous detectors

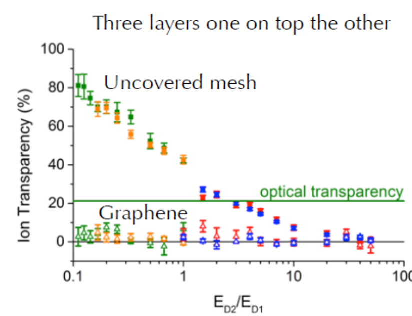


Elba 2015

It can also be used as protective layer (e.g. photocathodes) and to enhance secondary electron emission from materials

The measurements

F. Resnati



Single Graphene layer: dominated by defects
Triple Graphene layer: ion transparency drastically reduced, but also electrons do not tunnel easily

Solutions:
1) increase the energy of the electrons, i.e. different gases, larger fields (GEM holes)
2) improve the procedure to transfer the Graphene on the metal mesh to avoid ruptures of the layer

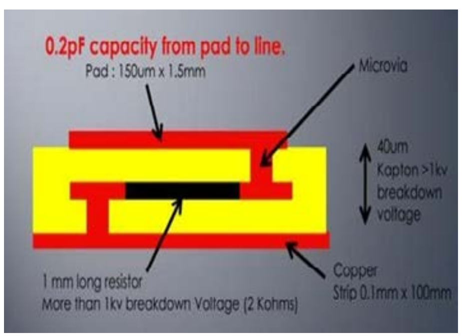
WG2: Generic R&D, Tracking/Calorimetry Applications

RESISTIVE MICROMEGAS: Resistive layers are known to quench sparks at early stage

- "Horizontal" evacuation of charge → might be too slow for large areas
- Segmented R-layer to limit physical crosstalk

Optimisation:
→ reduce resistivity and evacuation time but still suppress sparking

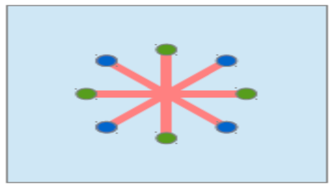
– "Vertical" evacuation of charge using buried resistors, proposed by Rui de Oliveira



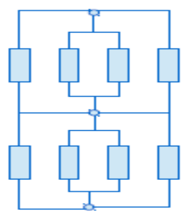
– Ongoing program: Vary the RC, measure the linearity (rate & dE/dx scans), check sparking

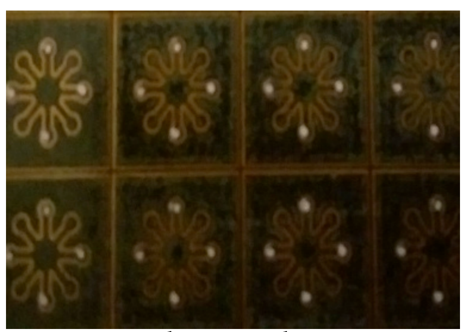
Work by LAPP Annecy, NCSR Demokritos , Univesrity of Athens, CEA IRFU

Star



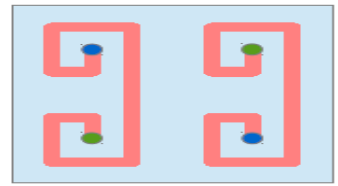
L_{eff} ~ 0.13 cm
R(100 k/sq) ~ 400 kOhm
R(1 k/sq) ~ 4 kOhm



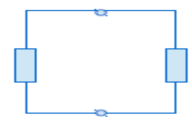


Real R1 values:
400 -750 KOhms with 100KΩ/Sq

Mirror

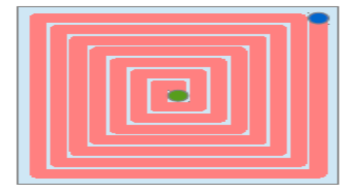


L_{eff} ~ 1.3 cm
R(100 k/sq) ~ 4 Mohm
R(1 k/sq) ~ 40 kOhm

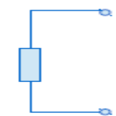


Real R1 values:
4 MOhms with 100KΩ/Sq

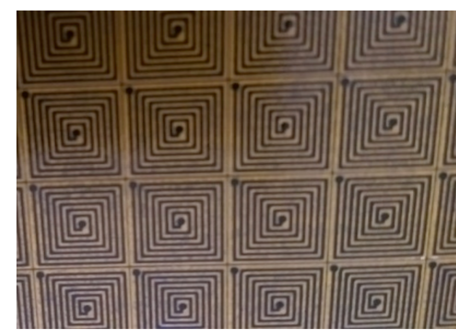
Snake



L ~ 13 cm
R (100 k/sq) ~ 40 MOhm
R (1 k/sq) ~ 400 kOhm



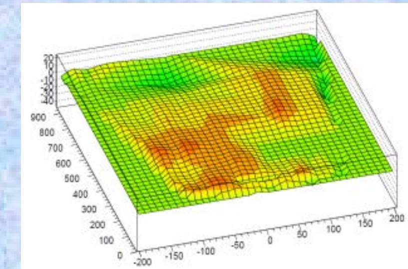
M. Chefdeville, T. Geralis

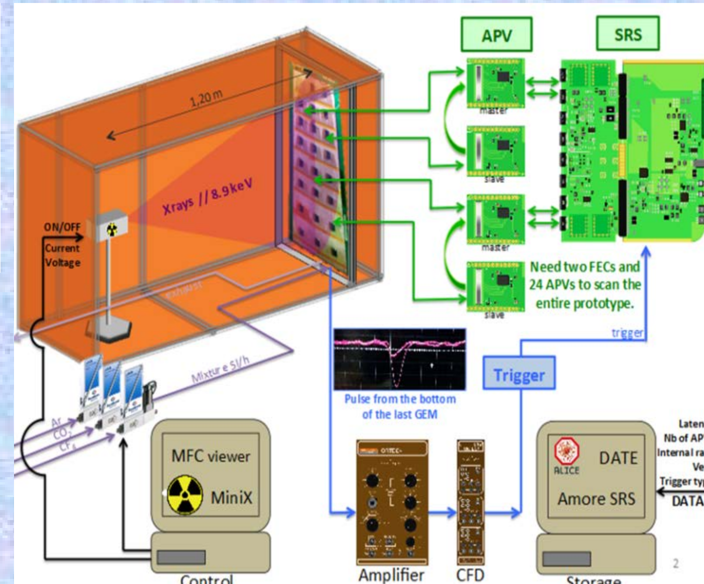


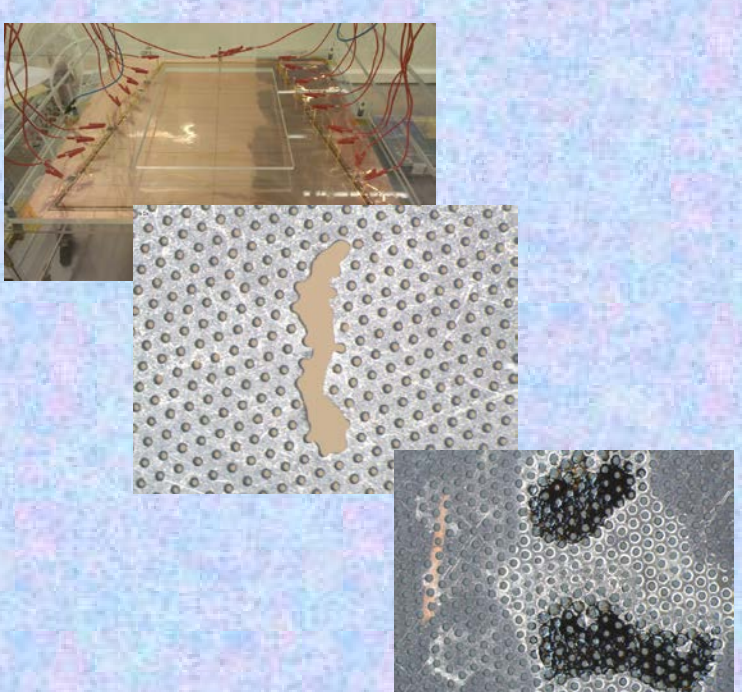
Real R1 values:
40 MOhms With 100KΩ/Sq

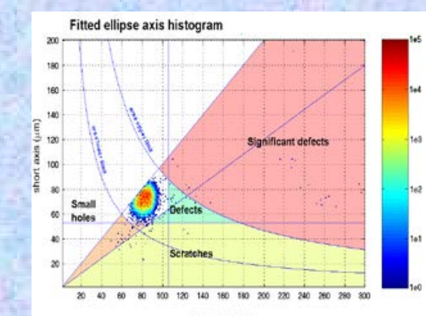
WG2: R&D Continuation - Quality Control

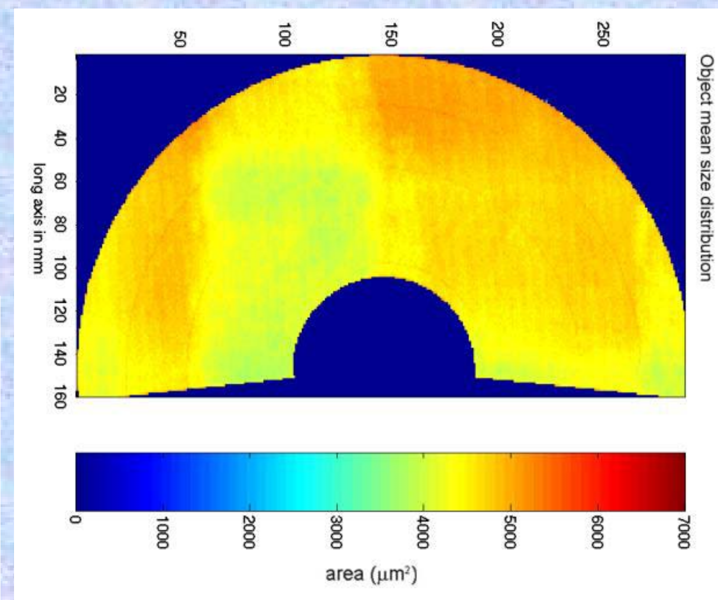
- Electrical rigidity
- Hole diameter uniformity in GEM
- Gap uniformity in MicroMegas
- THGEM thickness uniformity
- Final detector calibration and characterization protocols and infrastructure







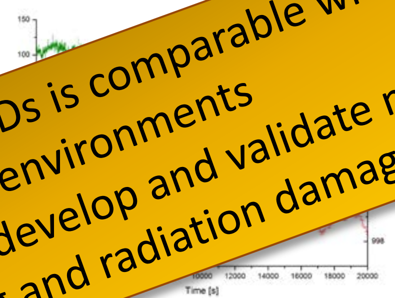


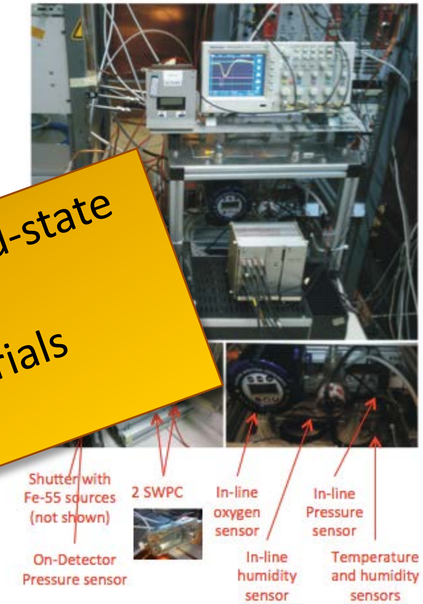


WG2: Radiation Hardness Studies - Long Term Stability

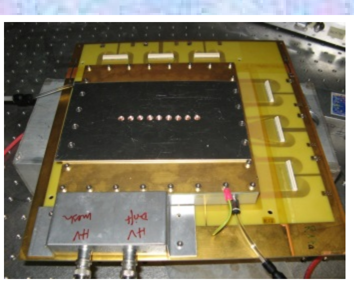
- Classical gas detectors ageing detector
- Radiation hardness and activation of detector components
- Sustainability to neutrons and heavily ionizing particles induced discharges
- Exposure to X-Ray, Gamma, Neutron and Alpha Sources
- Monitoring infrastructur

Portable gas monitoring system for detector stability studies
→ to be used by LHCb and CMS upgrade for the muon system

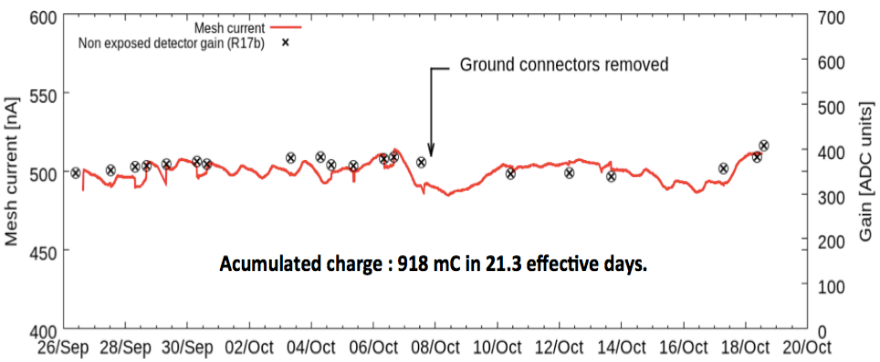




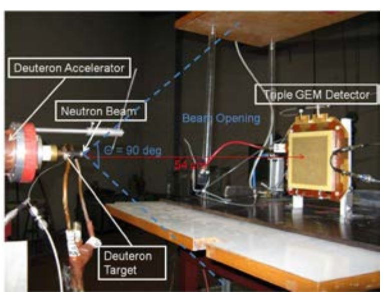
Radiation hardness of MPGDs is comparable with solid-state Sensors in harsh radiation environments
→ still, it is important to develop and validate materials with resistance to ageing and radiation damage.

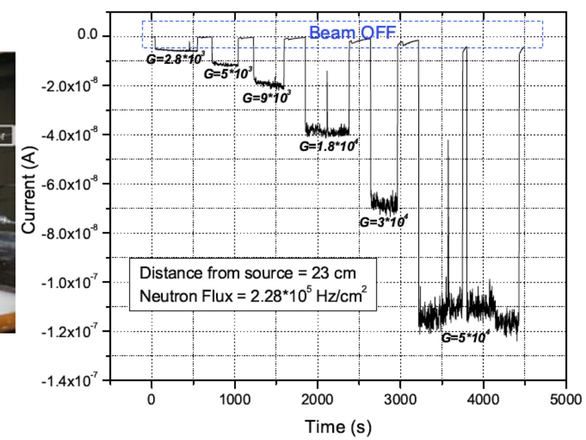


Re… gas stab… formance under X-Ray irradiation



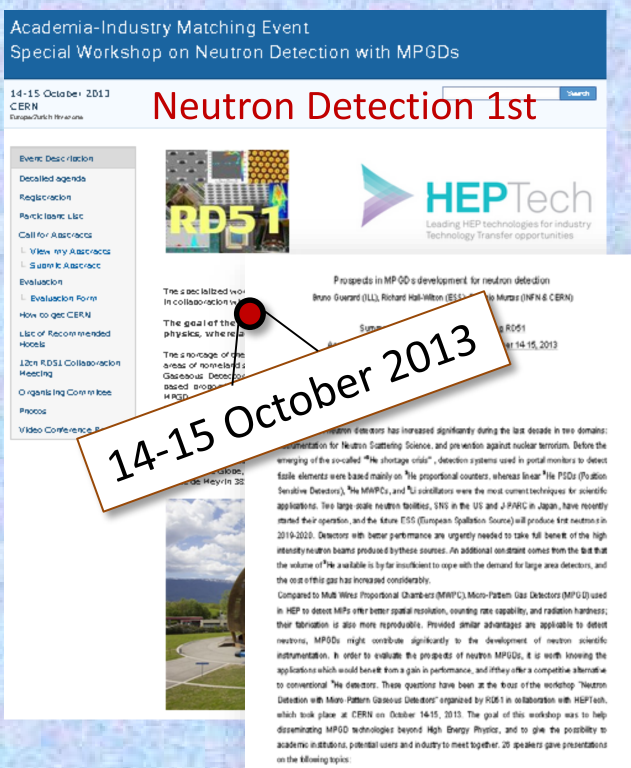
Discharge studies of the triple GEM detector exposed to the low energy neutron flux

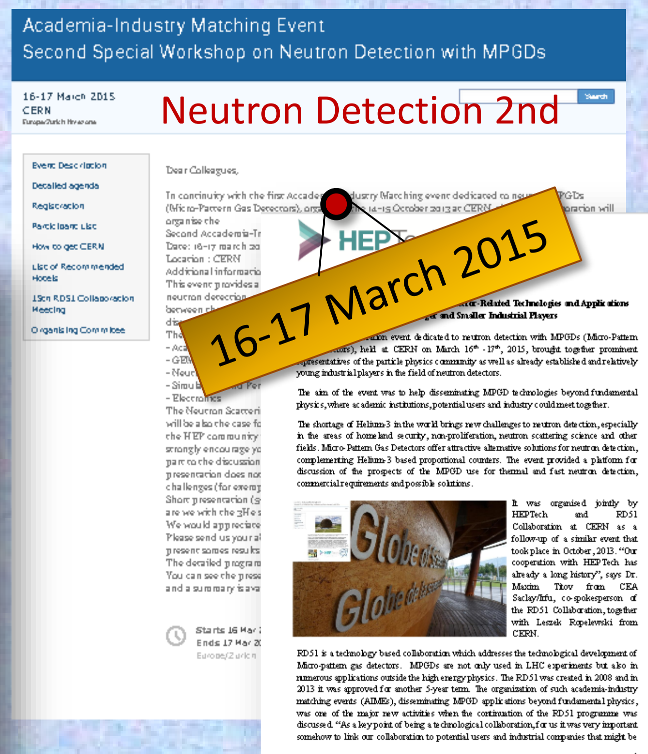


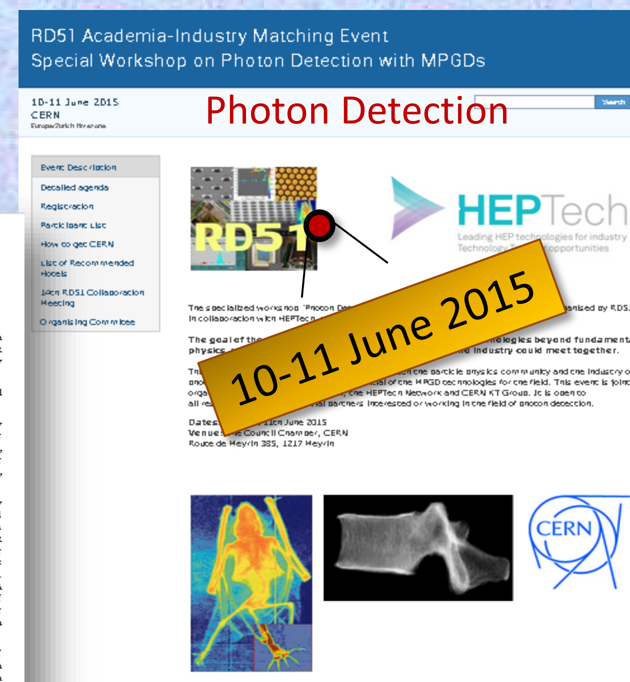


WG3: RD51 Academia – Industry Matching Events

Platform: Research + industry + potential users to foster collaboration on dedicated applications







https://indico.cern.ch/event/392833/

(understanding requirements, applications, approaching new communities and technologies)

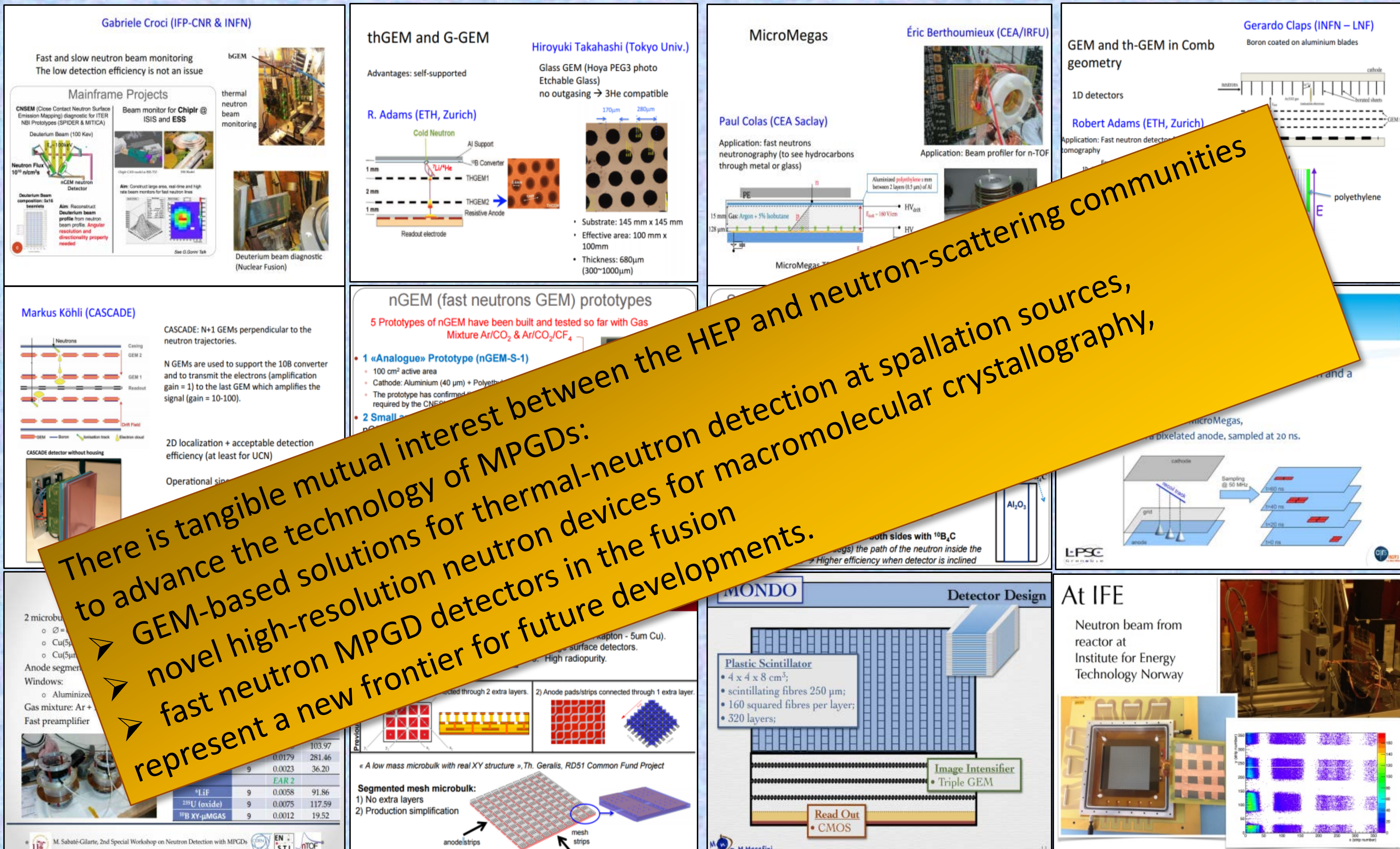
https://indico.cern.ch/event/265187/

Summary (arXiv 1410.1070)

https://indico.cern.ch/event/365840/

Press release

WG3: RD51 Academia – Industry Matching Events: Neutrons & MPGDs



There is tangible mutual interest between the HEP and neutron-scattering communities to advance the technology of MPGDs:

- GEM-based solutions for thermal-neutron detection at spallation sources,
- novel high-resolution neutron devices for macromolecular crystallography,
- fast neutron MPGD detectors in the fusion

represent a new frontier for future developments.

A large Community - Strong interaction with RD51

Use of MPGD Detector R&D, tools and electronics (RD51 SRS & ATLAS NSW VMM)

WG3: RD51 Collaboration & International Schools

RD51 Organized Events:

MPGD assembly

MPGD simulation

MPGD electronics

The vitality of the MPGD community resides in the relatively large number of young scientists
→ educational events constitute an important activity.

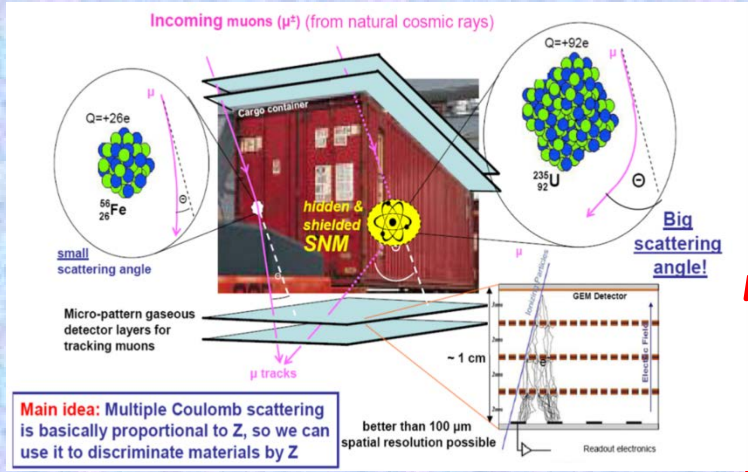
RD51 MPGD Lectures:
MPGD students lectures (1 week) at the International Workshop on Advance Detectors & RD51 CM in Kolkata

RD51 participated in XII ICFA School (Bogota, Colombia)

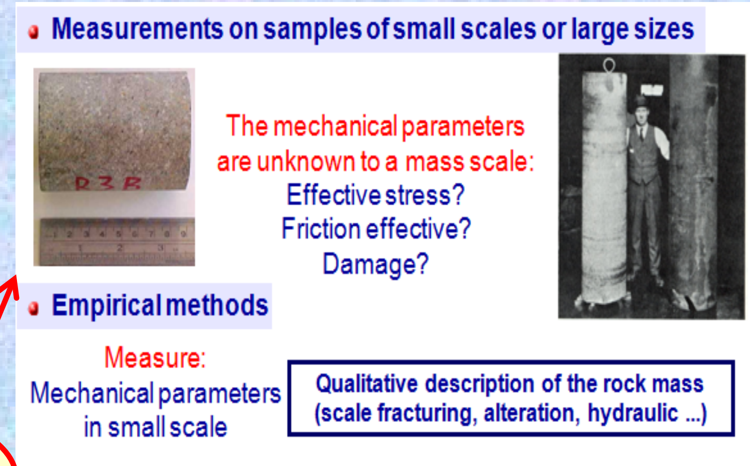
RD51 participated in Danube School on Instrumentation (Novi Sad Serbia)

Spin off is important key word for the HEP labs to survive …

Cosmic Ray Muon Tomography Using GEMs for Homeland security



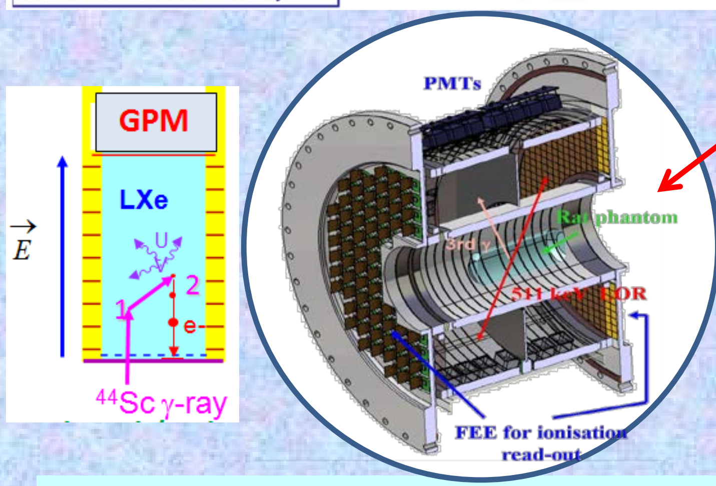
T2DM2: Temporal Tomography Densitometric by the Measure of Muons



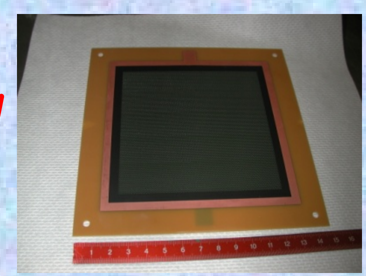
Technology

RD51

Technology



Liquid xenon detectors for functional medical imaging



CsI-RETGEM for UV flame detection

- Applications area will benefit from the technological developments developed by the RD51
- The responsibility for the completion of the application projects lies with the institutes themselves

WG4: MPGD Simulation Tools

- Focus on providing techniques for calculating electron transport in small-scale structures
- The main difference with traditional gas-based detectors is that the electrode scale (~ 10 μm) is comparable to the collision mean free path

Microscopic Tracking (Development and Maintenance of Garfield++):
Garfield++ is a collection of classes for the detailed simulation of small-scale detectors.

Garfield++ contains:
- electron and photon transport using cross sections provided by Magboltz
- ionisation processes in gases, provided by Heed and MIP
- ionisation and electron transport in semi-conductors
- field calculations from finite elements, boundary elements, analytic methods

Simulation Improvements:

→ Transport:
- ion mobility and diffusion, measurement and modelling
- Magboltz cross sections (Ar, Xe, He, Ne; GeH_4, SiH_4, $C_2H_2F_4$) are frequently updated in collaboration with LXCAT (http://www.lxcat.laplace.univ-tlse.fr)
- e-ion recombination process in Xe
- thermal motion

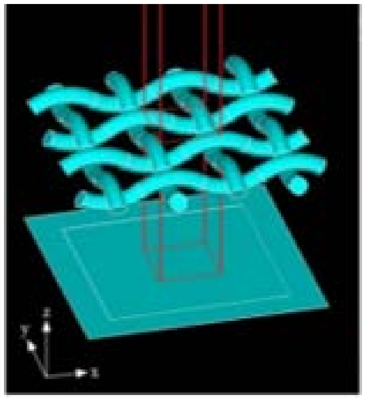
→ Photons:
- update in UV emission
- inclusion of IR production
- photon trapping and resulting excitation transport
- photon absorption in the gas (gas feedback)
- photon absorption in and electron emission from walls (feedback)
- photo cathodes

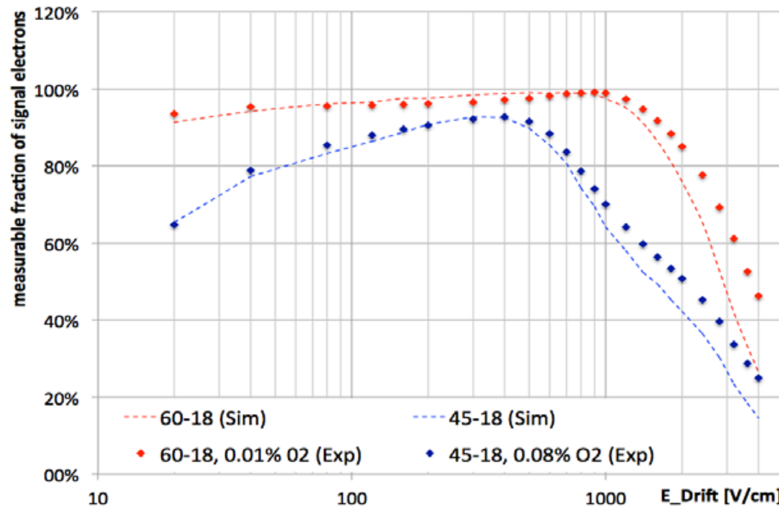
WG4: MPGD Strong Simulation Efforts in Very Specific Needs

Applications:

- **GEM:** multiplication process and polyimide properties; charging up effects
- **MicroMegas:** timing and effects of resistive layers;

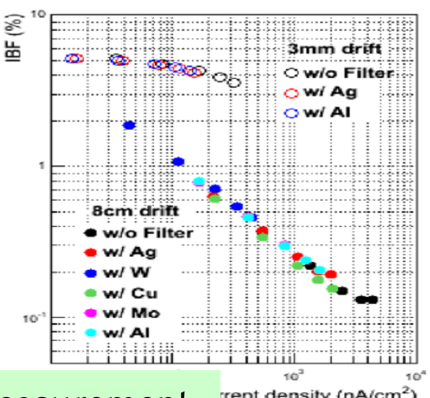
  → ATLAS NSW upgrade: study of electron losses in MM with different mesh specifications



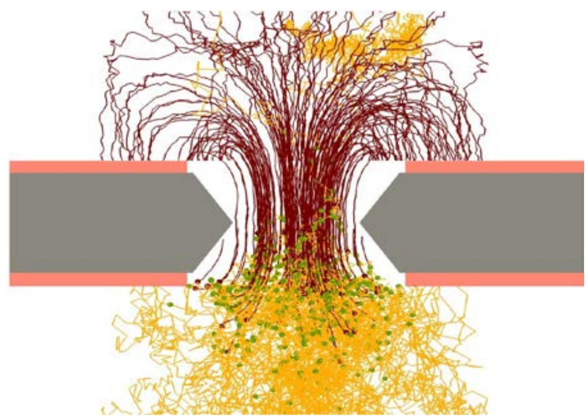


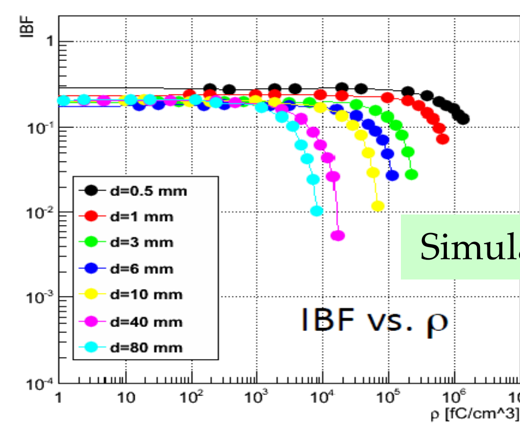
- **TPC GEM:** ion backflow

  → ALICE TPC upgrade: rate dependence of the Ion Back Flow in GEM



Measurement



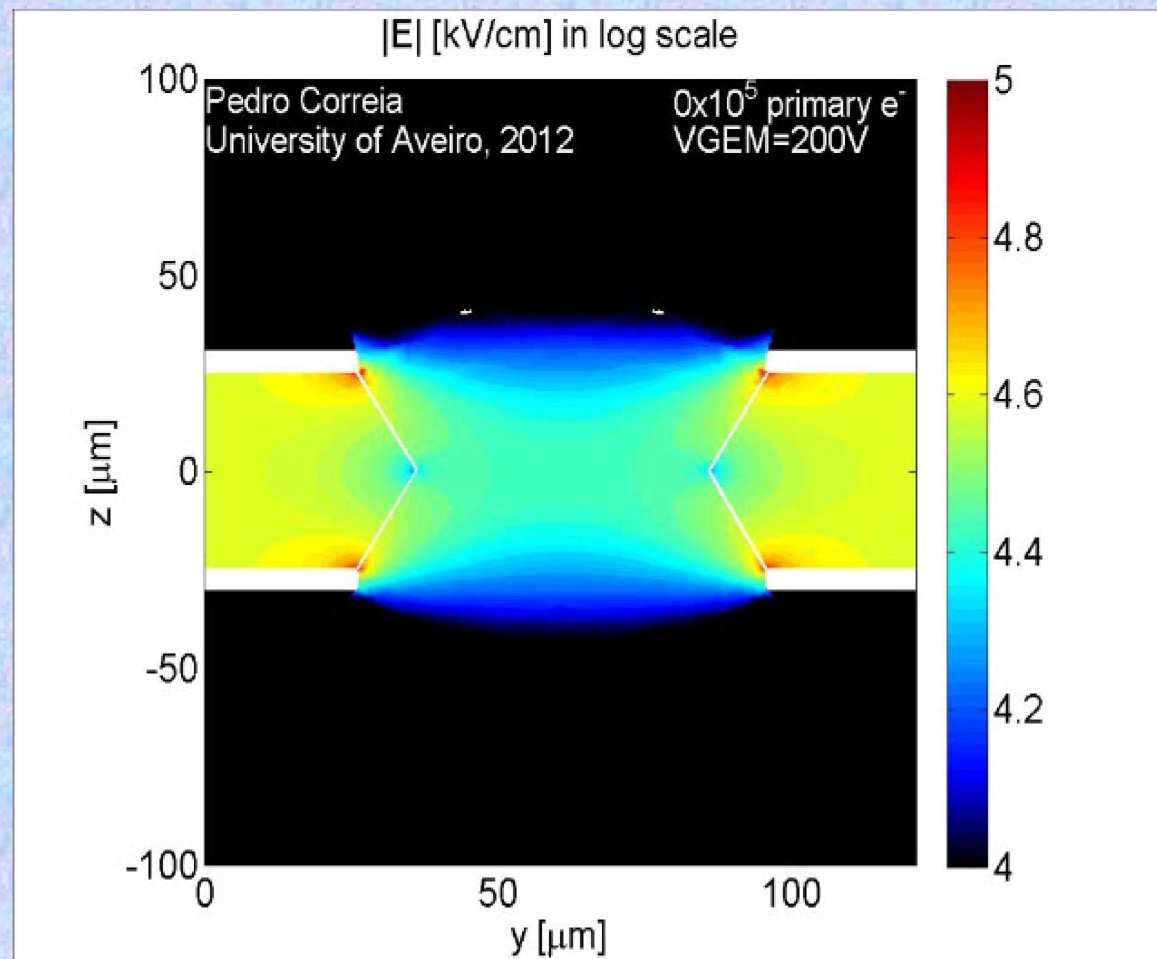


Simulation

WG4: GEM Charging-Up Effects Simulation

Electric Field Intensity during the charging-up process:

each iteration correspond to the number of primary electrons that already reached to the hole



- ANSYS: field model
- Magboltz 9.0.1: relevant cross sections of electron-matter interactions
- Garfield++: simulate electron avalanches

Charging effects are much smaller after (100 – 150) $*10^5$ avalanches
→ GEM gas gain stabilizes

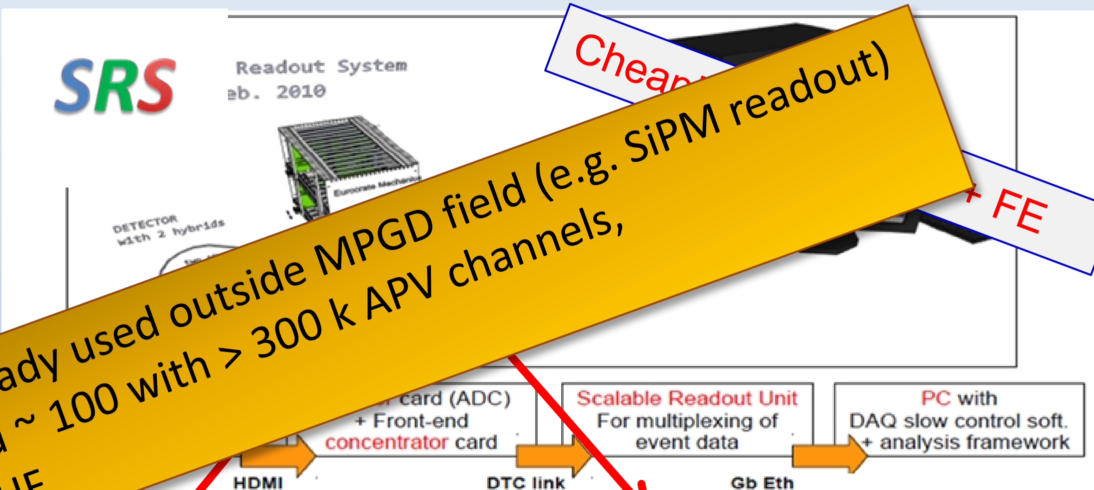
WG5: The RD51 Scalable Readout System (SRS) for MPGD

RD51 Development / Industrialization: portable multi-channel readout system (2009-2012)

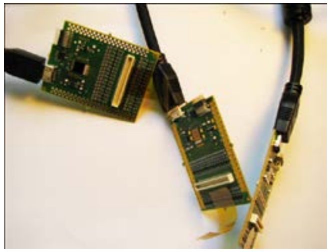
- Scalable readout architecture: from ~ 100 channels up to very large LHC systems (> 100 k ch.)
- Project specific part (ASIC) + common acquisition hardware and software

Physical Overview of SRS:

- Scalability from small to large system
- Common interface for replacing the chip frontend
- Integration of proven and commercial solutions for a minimum of development
- Default availability of a very robust a... supported DAQ software pack...



RD51 SRS is very successful → already used outside MPGD field (e.g. SiPM readout)
TODAY: # of SRS systems deployed ~ 100 with > 300 k APV channels,
total volume of SRS sales ~ 1 MCHF



Frontend hybrids: based on APV25, VFAT, Beetle, VMMx and Timepix chips

ADC frontend adapter for APV and Beetle chips

ADC plugs into FEC to make a 6U readout unit for up to 2048 channels

FEC cards (common): Virtex-5 FPGA, Gb-Ethernet, DDR buffer, NIM and LVDS pulse I/O, High speed Interface connectors to frontend adapter cards

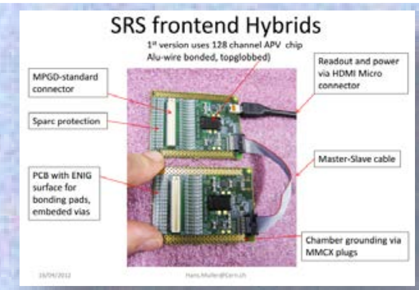
WG5: The RD51 Scalable Readout System (SRS) for MPGD

SRS & APV25 FE chip

Worldwide use in the RD51 community (>2000 hybrids)

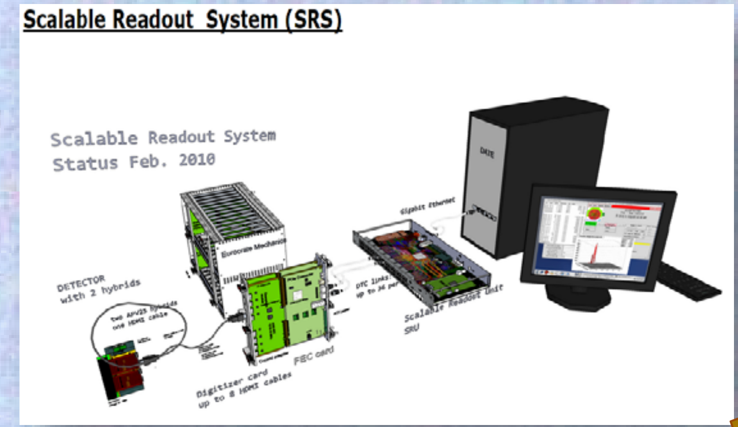
SRS+SiPM (NEXT TPC)

E. Oliveri



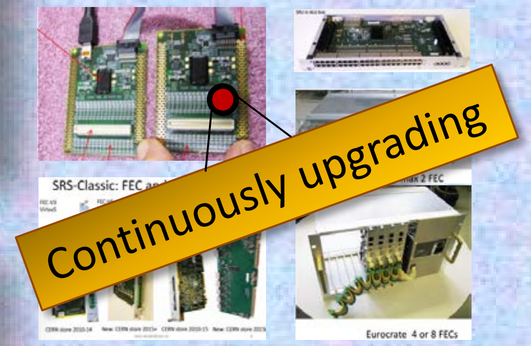
SRS-FEC+TOTEM DAQ

SRS+Timepix (LC-TPC) – Bonn/Desy

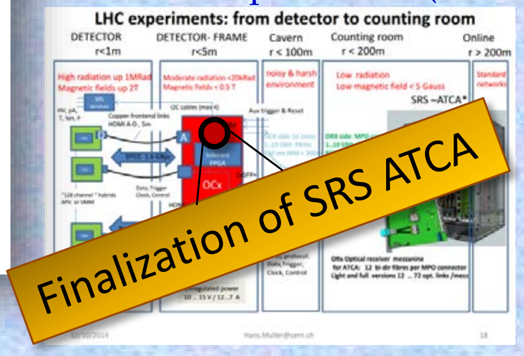


SRS: Different System

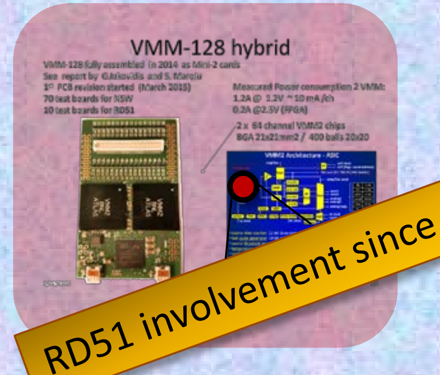
SRS for R&D on Detectors

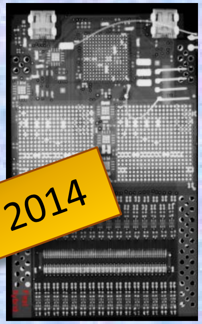


SRS for experiments (ATCA)



Very appealing for the future: VMM (NSW ATLAS FE chip)





Baseline solution for RD51 SRS community.

Interest and support from ESS (European Spallation Source) and ALICE FOCAL

SRS for spatially distributed system (optical SRS)

http://indico.cern.ch/event/356113/session/6/contribution/29/material/slides/1.pdf

WG6: MPGD Technology & Production @ CERN

Interesting Workshop Overview Capabilities

Antonio Teixeira

https://indico.cern.ch/event/352483/

•SBS tracker	GEM 600mm x 500mm
•ALICE TPC upgrade	GEM 600mm x 400mm
•CMS muon	GEM 1.2m x 450mm
•ATLAS NSW muon	Micromegas 2m x 1m
•COMPASS pixel Micromegas	GEM & Micromegas 500mm x 500mm
•BESIII	GEM 600mm x 400mm
•KLOE	GEM 700mm x 400mm
•SOLID	GEM 1.1m x 400mm
•CLAS 12	Micromegas 500mm x 500mm
•LSBB (geoscience)	Micromegas 1m x 500mm
•Prad	GEM 1.5m x 55cm
•CBM	GEM 1m x 450mm
•ASACUSA	Micromegas

MPGD Projects….

•Most of them are still at the R&D phase but some are already in production:

•ATLAS NSW	1300 m2
•SBS Tracker	100 GEMs
•ALICE TPC upgrade	350 GEMs
•COMPASS pixel Micromegas	20 GEM + Micromegas
•BESIII	15 GEM
•CLAS 12	30 Micromegas
•CMS	450 GEM

New Capabilities….

UV exposure unit limited to 2m x 0.6m → 2.2m x 1.4m — OK

Resist developer limited to 0.6m width → 1.2m
Resist stripper "
Copper etcher
Dryer — OK

GEM electro etch limited to 1m → 2m — OK

GEM polyimide etch limited to 1m → 2m — OK

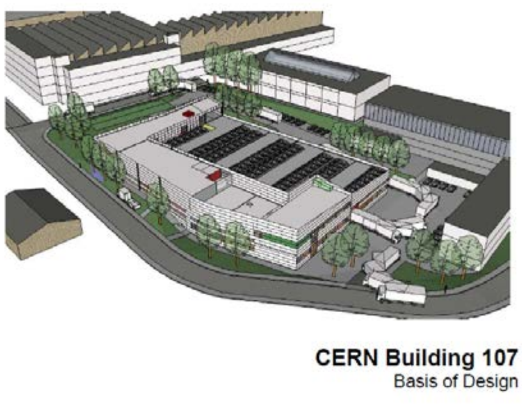
Ovens limited to 1.5m x 0.6m → 2.2m x 1.4m — OK

Laminator limited to 0.6m width → 1.2m — OK

installation of the new infrastructure (to fabricate 2x1m^2 Bulk MM & 2x0.5m^2 GEM) COMPLETED

Construction of the new workshop's building:

Start : beginning 2012
End: end 2017



WG6: MPGD Technology Industrialization

Technology Industrialization → transfer "know-how" from CERN workshop to industrial partners

GEM Technology (contacts):

- Mecharonix (Korea, Seoul)
- Tech-ETCH (USA, Boston)
- Scienergy (Japan, Tokyo)
- TECHTRA (Poland, Wroclaw

THGEM Technology (contacts):

- ELTOS S.p.A. (Italy),
- PRINT ELECTRONICS

GEM Licenses signed by:

- ✓ Mecharonics, 21/05/2013
- ✓ TECH-Etch, 06/03/2013
- ✓ China IAE, 10/01/2012
- ✓ SciEnergy, 06/04/2009
- ✓ Techtra, 09/02/2009
- ✓ CDT, 25/08/2008
- ✓ PGE, 09/07/2007

MicroMegas Technology(contacts):

- ELTOS S.p.A. (Italy)
- TRIANGLE LABS(USA, Nevada)
- SOMACIS (Italy, Castelfidarco)
- ELVIA (France, CHOLET)

GEM Industrialization Status (June 2015):

TECH-ETCH

• Single Mask process fully understood. Many 10cm x 10cm produced and characterized.
• 40cm x 40cm GEM successfully produced
• CMS GE1/1 size of 1m x 0.5m started

TECHTRA

• Production Line Operational
• Stable process for 10cm x 10cm
• Single Mask process completely understood – 10cm x 10cm produced
•30cm x30cm Single Mask Produced

MECHARONICS

• 10cm x 10cm double mask produced and tested
• 30cm x 30cm double mask under evaluation @ CERN
•CMS GE1/1 size of 1m x 0.5m started

Micromegas Industrialization Status (June 2015):

ELVIA

• Bulk Micromegas detectors are routinely produced with sizes up to 50cm x 50 cm.
• Contract for ATLAS NSW module-0 signed
•Tendering process for full production ongoing

ELTOS

• Many small size bulk Micromegas detectors have been produced.
• Contract for ATLAS NSW module-0 signed
•Tendering process for full production ongoing

ATLAS NSW upgrade → will first detector mass-produced in industry
using a large high-granularity Micromegas:
det. area ~1300 m2 divided into 2 m x 0.5 m2 units

WG7: PH-GDD Laboratory … Laboratory available for RD51 Collaboration

E. Oliveri

Permanent installations (Today): ALICE, ATLAS, ESS
CMS moved roughly two years ago to TIFF, access to the lab for specific measurements
More than 15/20 groups per year coming to perform measurements

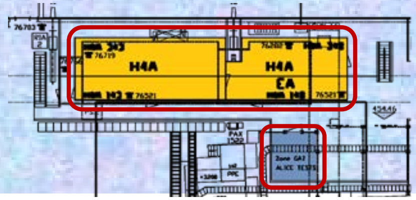
Clean Rooms

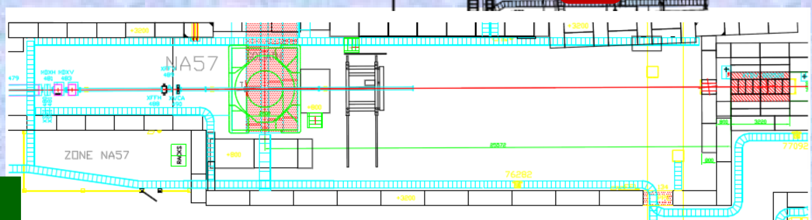
Mechanical and Electronic Workshop

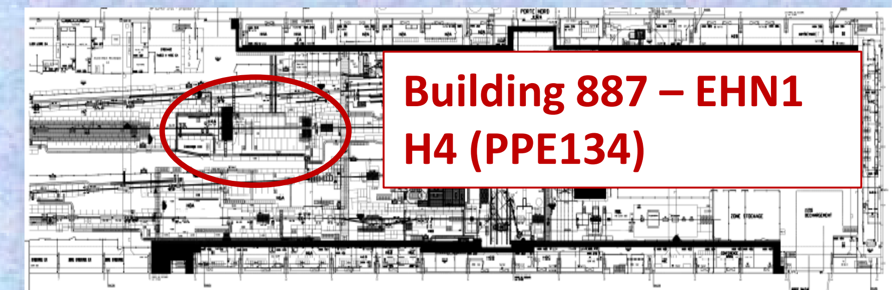
Technical support
MPGD Detectors
Gas system and services
Readout electronics (std and custom RD51 SRS&APV)
Radioactive Sources
Interface with CERN services (RP, gas, metrology, irradiation facilities,…)

WG7:Semi-Permanent Test Beam Infrastructure in the SPS line

Three periods of two weeks each per year
About fifteen-twenty users per year

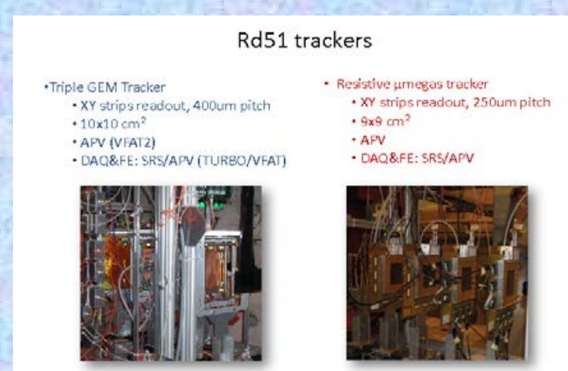


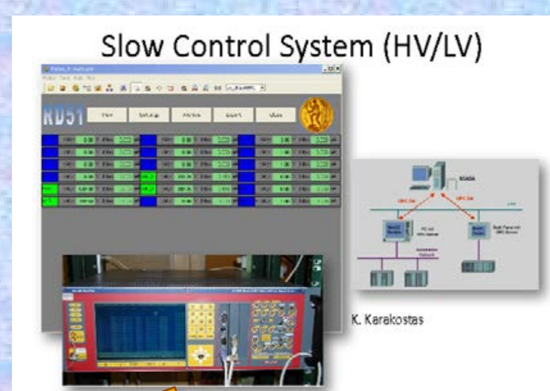


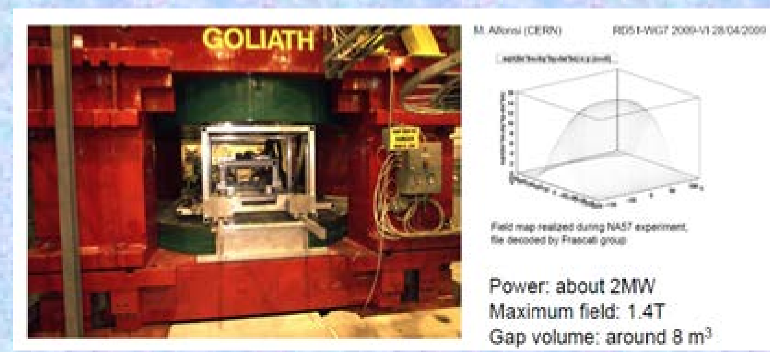


E. Oliveri

Goliath Magnet (1.4 T)
→ Ship Experiment?

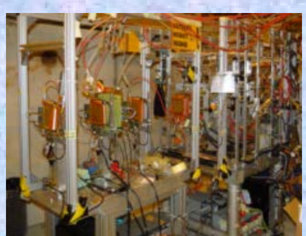






2014 test Beam

December 2014

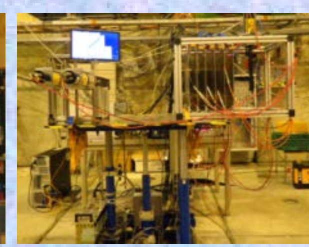


CMS (GEM)

WIS/A/C(WELL, THGEM)

ATLAS NSW (mm)

BESS III & SHIP (GEM)



LAPP/DEM/IRFU(mm)

ALICE TPC (GEM and mm)

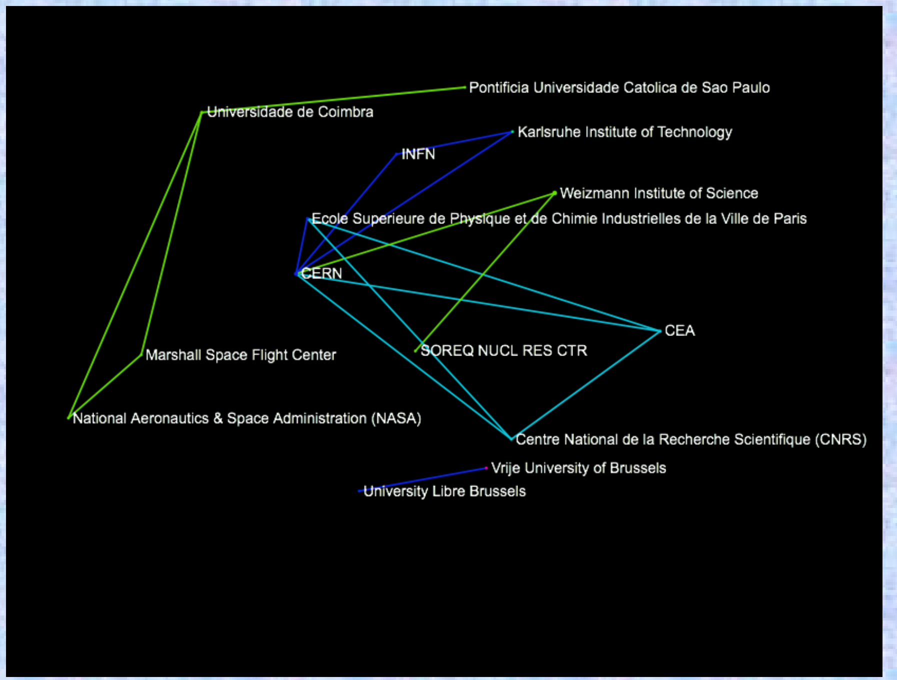
2008-2015: ~ 40 RD51 groups participated (2015 test Beam: May-June, July, October)

IWAD conference & RD51 Collaboration Meeting

MPGD conferences & RD51CM

RD51 and the Rise of Micro-Pattern Gas Detectors

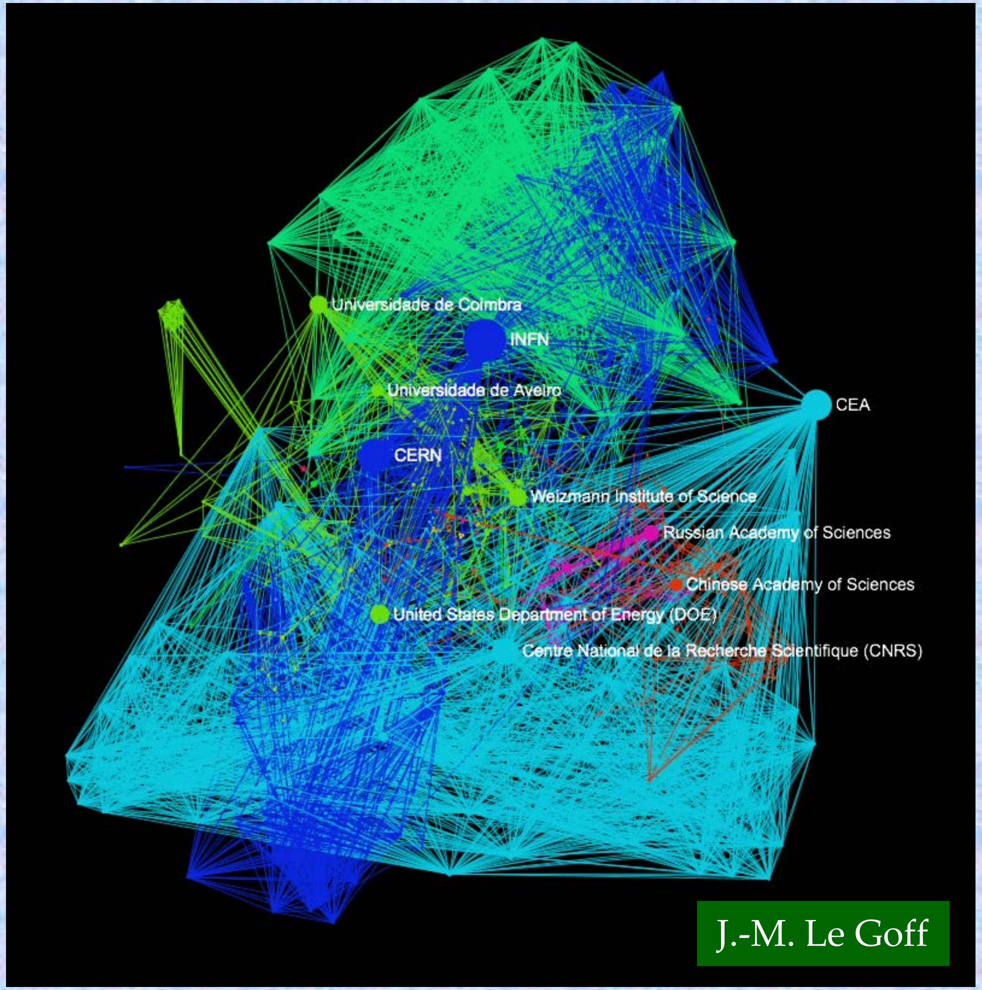
A fundamental boost is offered by RD51: from isolate MPGD developers to a world-wide net



A combined map of organizations working with MPGDs built with collaboration-spotting software developed at CERN

→ huge growth in interest in the MPGD technologies

Collaboration Spotting Software: http://collspotting.web.cern.ch/)



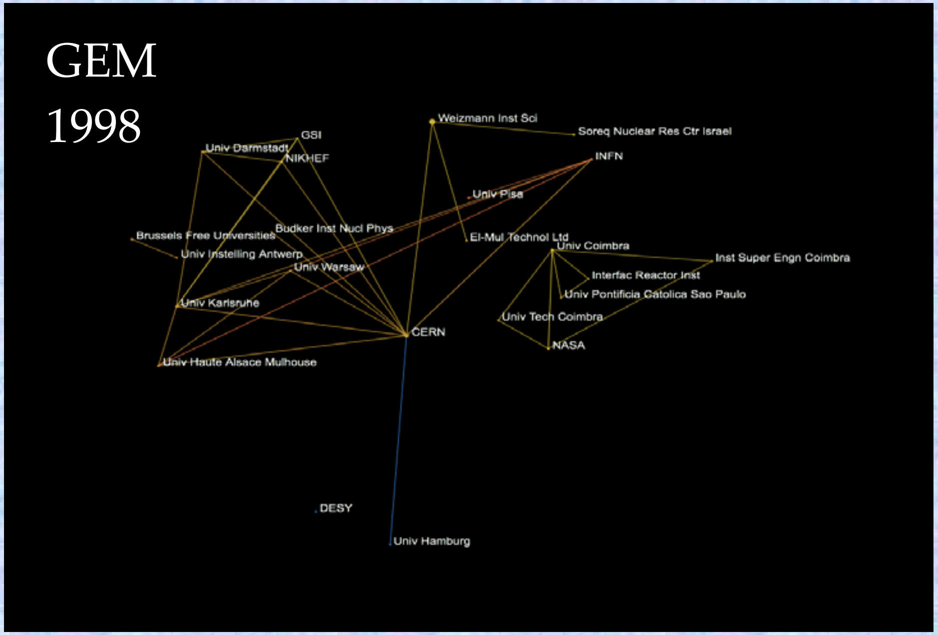
Map: RD51

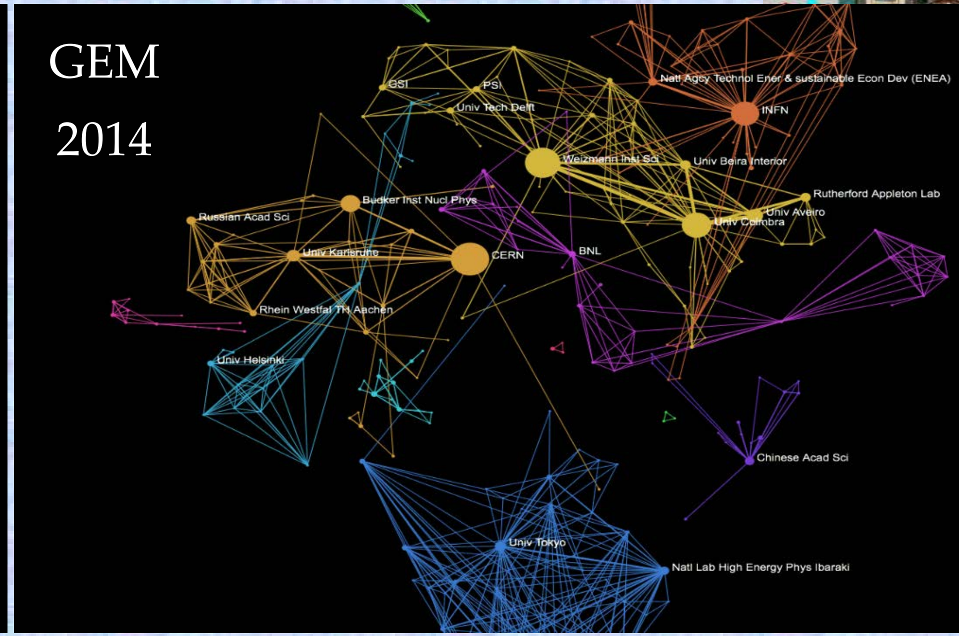
Current year:	1998
Organisations:	40/717
Clusters:	5
Publications:	35/1059

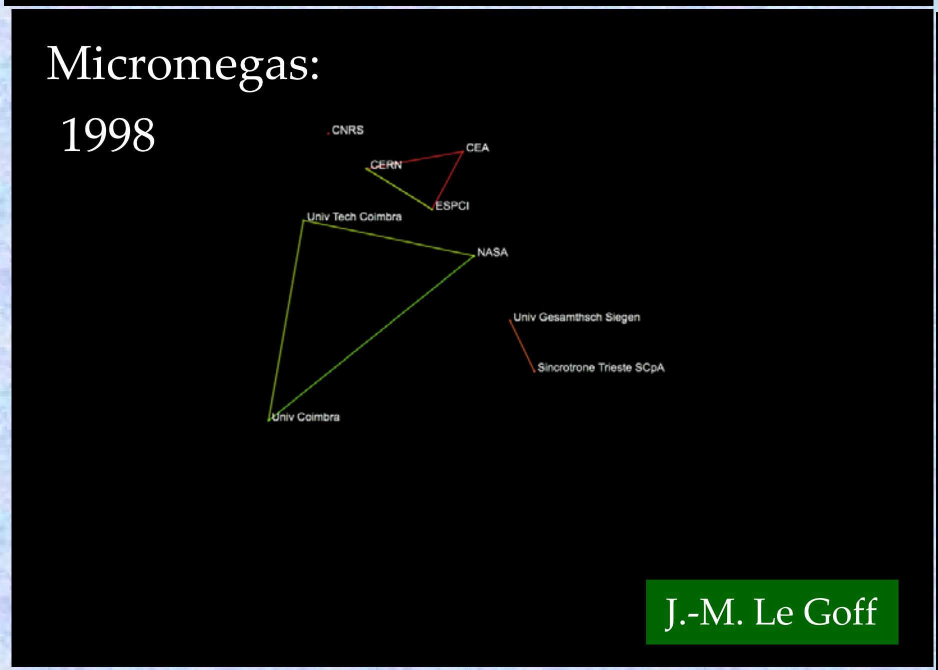
Map: RD51

Current year:	2015
Organisations:	717
Clusters:	12
Publications:	1059

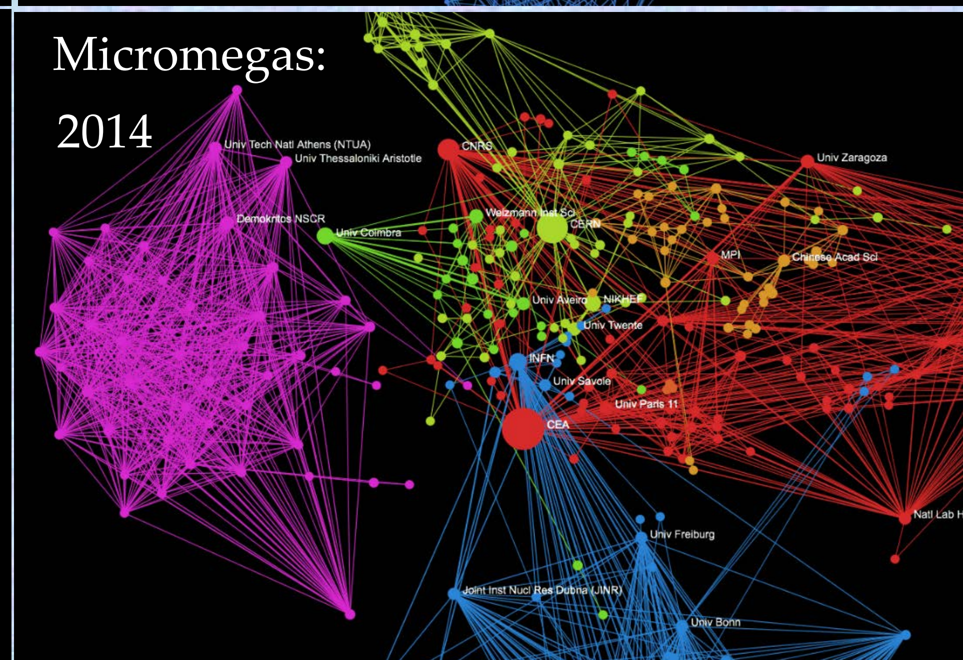
RD51 and the Rise of Micro-Pattern Gas Detectors







J.-M. Le Goff



CERN Courier, October 2015

CERN Courier October 2015

Detector R&D

RD51 and the rise of micro-pattern gas detectors

Since its foundation, the RD51 collaboration has provided important stimulus for the development of MPGDs.

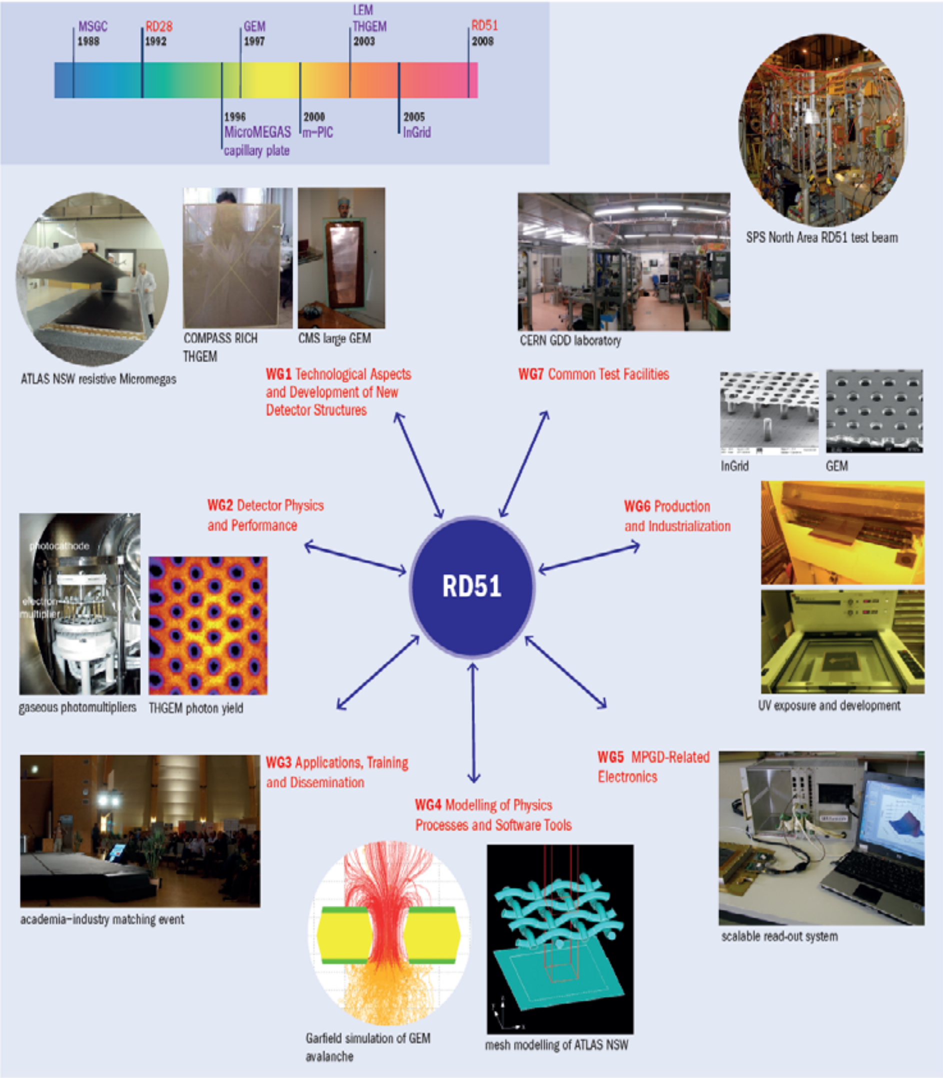


Fig. 1. The seven working groups of RD51, with illustrations of just a few examples of the different kinds of work involved. Top left: the 20-year pre-history of RD51. (Image credits: RD51 Collaboration.)

Improvements in detector technology often come from capitalizing on industrial progress. Over the past two decades, advances in photolithography, microelectronics and printed circuits have opened the way for the production of micro-structured gas-amplification devices. By 2008, interest in the development and use of the novel micro-pattern gaseous detector (MPGD) technologies led to the establishment at CERN of the RD51 collaboration. Originally created for a five-year term, RD51 was later prolonged for another five years beyond 2013. While many of the MPGD technologies were introduced before RD51 was founded (figure 1), with more techniques becoming available or affordable, new detection concepts are still being introduced, and existing ones are substantially improved.

In the late 1980s, the development of the micro-strip gas chamber (MSGC) created great interest because of its intrinsic rate-capability, which was orders of magnitude higher than in wire chambers, and its position resolution of a few tens of micrometres at particle fluxes exceeding about 1 MHz/mm^2. Developed for projects at high-luminosity colliders, MSGCs promised to fill a gap between the high-performance but expensive solid-state detectors, and cheap but rate-limited traditional wire chambers. However, detailed studies of their long-term behaviour at high rates and in hadron beams revealed two possible weaknesses of the MSGC technology: the formation of deposits on the electrodes, affecting gain and performance ("ageing effects"), and spark-induced damage to electrodes in the presence of highly ionizing particles.

These initial ideas have since led to more robust MPGD structures, in general using modern photolithographic processes on thin insulating supports. In particular, ease of manufacturing, operational stability and superior performances for charged-particle tracking, muon detection and triggering have given rise to two main designs: the gas electron-multiplier (GEM) and micro-mesh gaseous structure (Micromegas). By using a pitch size of a few hundred micrometres, both devices exhibit intrinsic high-rate capability (> 1 MHz/mm^2), excellent spatial and multi-track resolution (around 30 μm and 500 μm, respectively), and time resolution for single photoelectrons in the sub-nanosecond range.

Coupling the microelectronics industry and advanced PCB technology has been important for the development of gas detectors with increasingly smaller pitch size. An elegant example is the use of a CMOS pixel ASIC, assembled directly below the GEM or Micromegas amplification structure. Modern "wafer post-processing technology" allows for the integration of a Micromegas grid directly on top of a Medipix or Timepix chip, thus forming integrated read-out of a gaseous detector (InGrid). Using this approach, MPGD-based detectors can reach the level of integration, compactness and resolving power typical of solid-state pixel devices. For applications requiring imaging detectors with large-area coverage and moderate spatial resolution (e.g. ring-imaging Cherenkov (RICH) counters), coarser macro-patterned structures offer an interesting economic solution with relatively low mass and easy construction – thanks to the intrinsic robustness of the PCB electrodes. Such detectors are the thick GEM (THGEM), large electron multiplier (LEM), patterned resistive thick GEM (RETGEM) and the resistive-plate WELL (RPWELL).

RD51 and its working groups

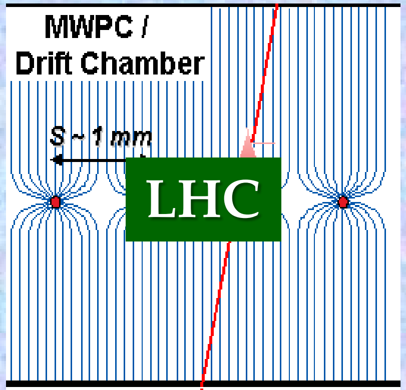
The main objective of RD51 is to advance the technological development and application of MPGDs. While a number of activities have emerged related to the LHC upgrade, most importantly, RD51 serves as an access point to MPGD "know-how" for the worldwide community – a platform for sharing information, results and experience – and optimizes the cost of R&D through the sharing of resources and the creation of common projects and infrastructure. All partners are already pursuing either basic- or application-oriented R&D involving MPGD concepts. Figure 1 shows the organization of seven Working Groups (WG) that cover all of the relevant aspects of MPGD-related R&D.

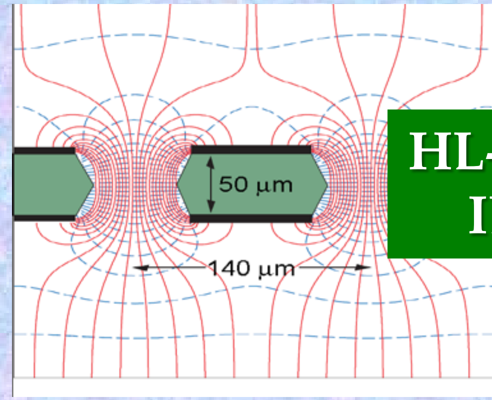
WG1 Technological Aspects and Development of New Detector Structures. The objectives of WG1 are to improve the performance of existing detector structures, optimize fabrication methods, and develop new multiplier geometries and techniques. One of the most prominent activities is the development of large-area GEM, Micromegas and THGEM detectors. Only one decade ago, the largest MPGDs were around 40 × 40 cm^2, limited by existing tools and materials. A big step towards the industrial manufacturing of MPGDs with a size around a square metre came with new fabrication methods – the single-mask GEM, "bulk" Micromegas and the novel Micromegas construction scheme with a "floating mesh". While in the "bulk" Micromegas, the metallic mesh is integrated into the PCB read-out. In the latter case, the mesh is integrated in the panel containing drift electrodes and placed on pillars when the chamber is closed. The single-mask GEM technique overcomes the cumbersome practice of alignment of two masks between top and bottom films, which limits the achievable lateral size to 50 cm. This technology, together with the novel "self-stretching technique" for assembling GEMs without glue and spacers, simplifies the fabrication process to such an extent that, especially for large-volume production, the cost per unit area drops by orders of magnitude. ▷

Gaseous Tracking: Detector-Electronics Integration Trends

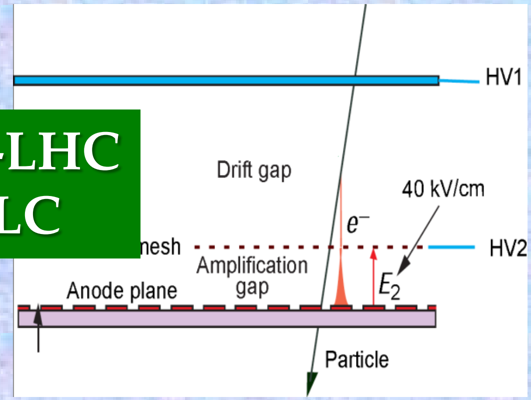
Wire Chambers, TPC, RPC → MPGD (GEM, Micromegas) → InGrid (3D)

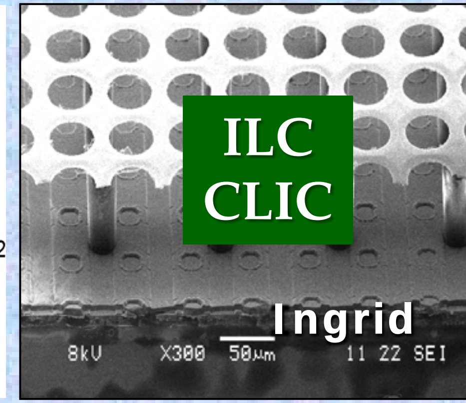
YESTERDAY: —INTEGRATION→ **TODAY:** —INTEGRATION→ **FUTURE:**



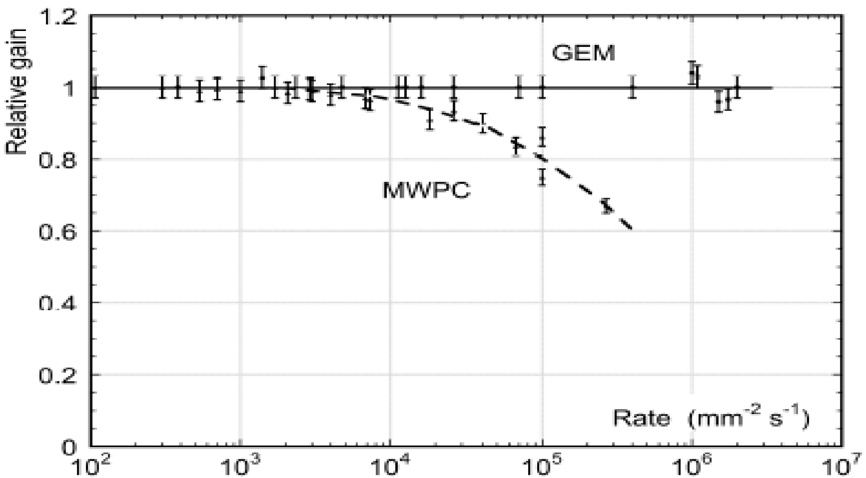


HL-LHC
ILC

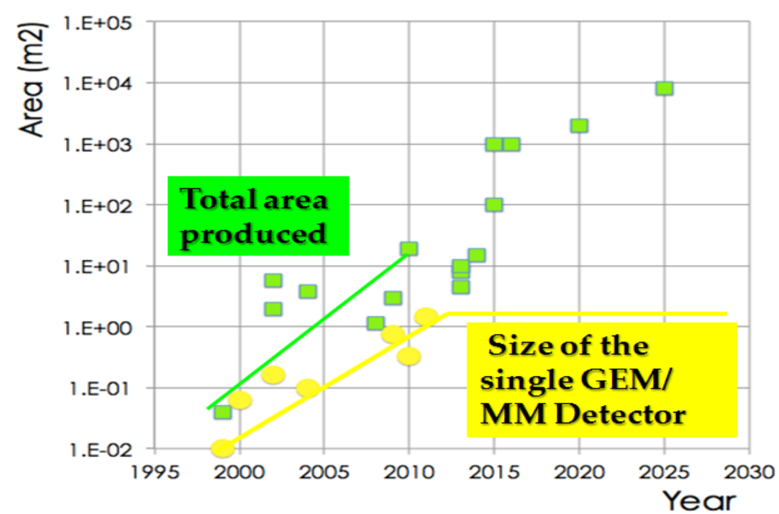




- High rate capability ~10^6 Hz/mm^2
- Spatial res. ~ 30-50 µm (TRACKING)
- Time res. ~ 3-5 ns (TRIGGER)



Advances in photolithography →
Large Area MPGDs (~ m^2 unit size)



Instead of Outlook … MPGD Performance Summary

MPGD Characteristics	Gas Electron Multipliers (GEM)	Micromegas/ Resistive MM
➢ Active areas (Size of single detector module) / Large Scale Industrial Production	~ 1 x 0.5 m² yes	~ 2 x 1 m² yes
➢ Radiation Hardness	> 10 HL-LHC years	> 10 HL-L[illegible] years
➢ High-Rate Capability	~ 50 MHz/cm²	[illegible](cm²): [illegible]ure)
➢ Spatial resolution	[illegible]	<~30 μm (single layer) ang. dep.: μTPC
➢ Track[illegible]	99%	98%
[illegible]ming	95-98%	95-98%
➢ [illegible]olution	~4-5 ns (MIP) & CF_4 how to improve (?)	3-5 ns (MIP) & CF_4 how to improve (?)

MPGDs have also found numerous applications → they are being used or considered:
X-ray and neutron imaging, neutrino–nucleus scattering experiments, dark- matter
and astrophysics experiments, plasma diagnostics, material sciences, radioactive-waste
monitoring and security applications, medical physics and hadron therapy.