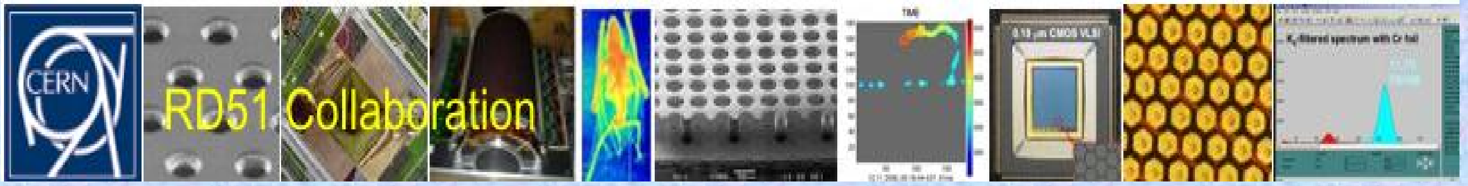
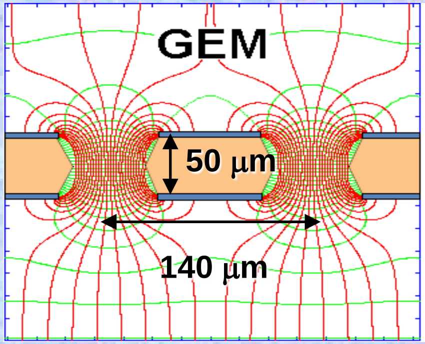
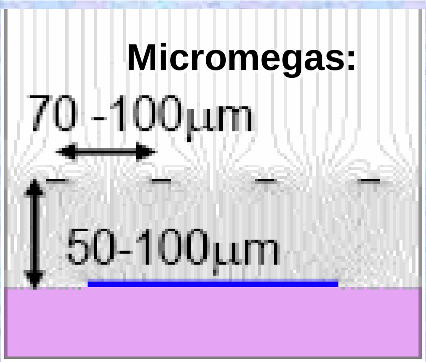
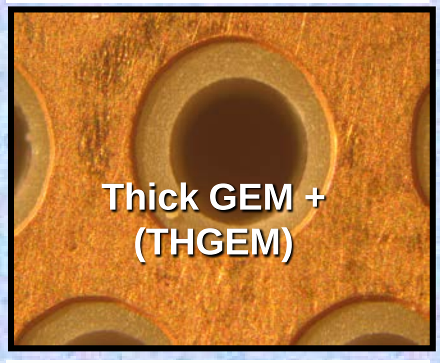


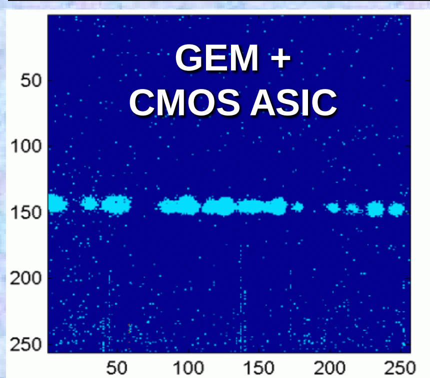
The RD51 Collaboration, Development of Micro-Pattern Gas Detector Technologies

Maxim Titov, CEA Saclay, France









SEMINAR OUTLINE:

- RD51 Motivation and Main Objectives
- Micro-Pattern Gas Detectors (GEM, Micromegas, Thick GEM)
- RD51 Collaboration Activities and Results
- Summary and Outlook

Joint HEP / XFEL Instrumetation Seminar, DESY, July 16, 2010

RD51 Collaboration: Motivation and Main Objectives

World-wide coordination of the research in the field to advance technological development of Micropattern Gas Detectors

- Foster collaboration between different R&D groups; optimize communication and sharing of knowledge/experience/results concerning MPGD technology within and beyond the particle physics community

- Investigate world-wide needs of different scientific communities in the MPGD technology

- Optimize finances by creation of common projects (e.g. technology and electronics development) and common infrastructure (e.g. test beam and radiation hardness facilities, detectors and electronics production facilities)

- The RD51 collaboration will steer ongoing R&D activities but will not direct the effort and direction of individual R&D projects

- Applications area will benefit from the technological developments developed by the collaborative effort; however the responsibility for the completion of the application projects lies with the institutes themselves.

RD51 Collaboration Milestones

- **CERN MPGD workshop (10-11 September 2007)**

  Micro Pattern Gas Detectors. Towards an R&D Collaboration. (10-11 September 2007)

- **1st draft of the proposal presentation during Nikhef meeting (17 April 2008)**

  Micro-Pattern Gas Detectors (RD-51) Workshop, Nikhef, April 16-18, 2008

  Gas detectors advance into a second century - CERN Courier

- **Proposal presentation in CERN/LHCC open session (2 July 2008)**

  94th LHCC Meeting Agenda (02-03 July 2008);

  CERN-LHCC-2008-011 (LHCC-P-011)

- **CERN/LHCC committee close session (24 September 2008)**

  Meeting with LHCC referees (23 September 2008); LHCC-095 minutes

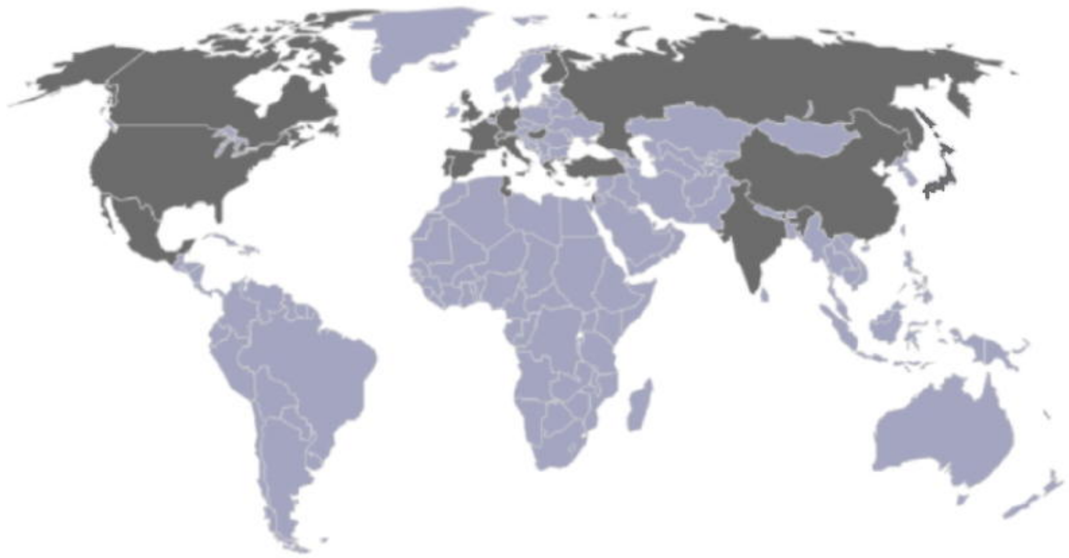
- **2nd RD51 Collaboration meeting (Paris 13-15 October 2008)**

  2nd RD51 Collaboration Meeting (13-15 October 2008)

- **CERN Research Board approval(5 December 2008)**

  186th Research Board meeting minutes

RD 51 : Development of Micro-Pattern Gas Detector Technologies



Collaboration of ~75 institutes worldwide, ~ 430 authors

"RD51 aims at facilitating the <u>development of advanced gas-avalanche detector technologies and associated electronic-readout systems,</u> for applications in basic and applied research."

Co-Spokespersons: L. Ropelewski, M. Titov
CB Chair and Deputy: S.Dalla Torre, A. White
Management Board members: A.Breskin, I.Giomataris, F.Sauli, H. Taureg, H. van der Graaf, A.White

Collaboration Meetings:
1st - Amsterdam April 16-18, 2008 : http://indico.cern.ch/conferenceDisplay.py?confId=25069
2nd - Paris, October 13-15, 2008 : http://indico.cern.ch/conferenceDisplay.py?confId=35172
3rd - Crete (Greece), June 12-16, 2009 : http://candia.inp.demokritos.gr/mpgd2009/
4th – CERN, November 23-25, 2009 : http://indicobeta.cern.ch/conferenceDisplay.py?confId=72610
5th – Freiburg, Germany, May 24-27, 2010 : http://indico.cern.ch/conferenceDisplay.py?confId=89325
6th – Bari (Italy), October 7-10, 2010

MPGD 2009

1st International Conference on Micro-Pattern Gaseous Detectors

12-15* June 2009, at the Orthodox Academy of Crete
Kolympari, Crete, Greece

- Technologies, performance, new developments
- Readout electronics
- Simulation and Software
- Applications in:
  - Particle and Astroparticle Physics
  - Nuclear Physics
  - Industry, Medicine and other Applied Sciences

International Organizing Committee

Ioannis Giomataris (CEA, Saclay)
Alessandro Cardini (INFN, Cagliari)
Klaus Desch (U. Bonn)
Manolis Dris (NTU, Athens)
Tatsuo Kawamoto (ICEPP, Tokyo)
Venetis Polychronakos (Brookhaven)
Jörg Wotschack (CERN)

Local Organizing Committee

George Fanourakis (INP, Demokritos)
Theo Geralis (INP, Demokritos)
Pavlos Ioannou (U. Athens)
Dimos Sampsonidis (U. Thessaloniki)
Yorgos Tsipolitis (NTUA, Athens)

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Amos Breskin (Weizmann Institute)
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John Jaros (SLAC)
Takeshi Matsuda (KEK)
Werner Riegler (CERN)
Leszek Ropelewski (CERN)
Fabio Sauli (TERA Foundation)
Maxim Titov (CEA, Saclay)
Andy White (University of Texas)

Web address: http://candia.inp.demokritos.gr/mpgd2009
email: mpgd2009@inp.demokritos.gr

*The conference will be followed by an RD51 collaboration meeting on 16-17 June at the same venue.

Scientific Secretary: Rachel Avramidou

2nd MPGD Conference is planned for end of August 2011 in Japan

RD51 Public Collaboration Webpage

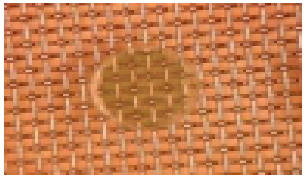
http://rd51-public.web.cern.ch/RD51-Public

RD51 Collaboration
Development of Micro-Pattern Gas Detectors Technologies

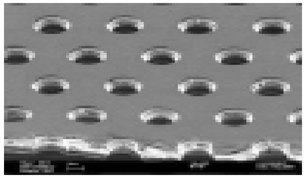
The proposed R&D collaboration, RD51, aims at facilitating the development of advanced gas-avalanche detector technologies and associated electronic-readout systems, for applications in basic and applied research. **The main objective of the R&D programme is to advance technological development and application of Micropattern Gas Detectors.**

The invention of Micro-Pattern Gas Detectors (MPGD), in particular the Gas Electron Multiplier (GEM), the Micro-Mesh Gaseous Structure (Micromegas), and more recently other micro pattern detector schemes, offers the potential to develop new gaseous detectors with unprecedented spatial resolution, high rate capability, large sensitive area, operational stability and radiation hardness. In some applications, requiring very large-area coverage with moderate spatial resolutions, more coarse Macro-patterned detectors, e.g. Thick-GEMs (THGEM) or patterned resistive-plate devices could offer an interesting and economic solution. The design of the new micro-pattern devices appears suitable for industrial production. In addition, the availability of highly integrated amplification and readout electronics allows for the design of gas-detector systems with channel densities comparable to that of modern silicon detectors. Modern wafer post-processing allows for the integration of gas-amplification structures directly on top of a pixelized readout chip. Thanks to these recent developments, particle detection through the *ionization of gas* has large fields of application in future particle, nuclear and astro-particle physics experiments with and without accelerators.

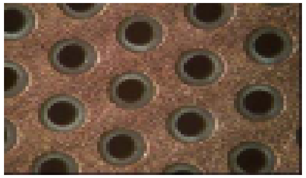
The RD51 collaboration involves ~ 350 authors, 59 Universities and Research Laboratories from 20 countries in Europe, America, Asia and Africa. All partners are already actively pursuing either basic- or application-oriented R&D involving a variety of MPGD concepts. The collaboration established common goals, like experimental and simulation tools, characterization concepts and methods, common infrastructures at test beams and irradiation facilities, and methods and infrastructures for MPGD production.



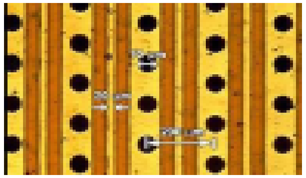
Micromegas



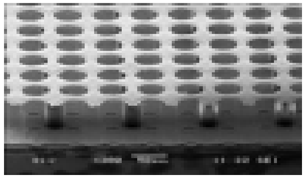
GEM



THGEM



MHSP



Ingrid

WG Activities, internal notes, talks, training, popularization and education …

RD 51 Collaboration - Working Groups

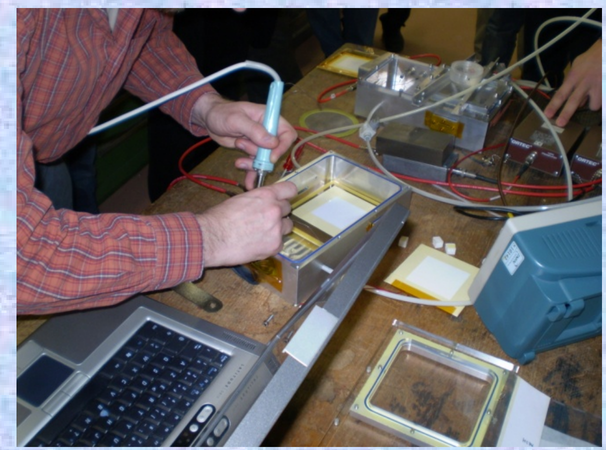
"Transverse organization" of MPGD activities in 7 Working Groups

RD51 – Micropattern Gas Detectors

	WG1 MPGD Technology & New Structures	WG2 Characterization	WG3 Applications	WG4 Software & Simulation	WG5 Electronics	WG6 Production	WG7 Common Test Facilities
Objectives	Design optimization Development of new geometries and techniques	Common test standards Characterization and understanding of physical phenomena in MPGD	Evaluation and optimization for specific applications	Development of common software and documentation for MPGD simulations	Readout electronics optimization and integration with MPGD detectors	Development of cost-effective technologies and industrialization	Sharing of common infrastructure for detector characterization
Tasks	Large Area MPGDs Design Optimization New Geometries Fabrication Development of Rad-Hard Detectors Development of Portable Detectors	Common Test Standards Discharge Protection Ageing & Radiation Hardness Charging up and Rate Capability Study of Avalanche Statistics	Tracking and Triggering Photon Detection Calorimetry Cryogenic Detectors X-Ray and Neutron Imaging Astroparticle Physics Appl. Medical Applications Synchrotron Rad. Plasma Diagn. Homeland Sec.	Algorithms Simulation Improvements Common Platform (Root, Geant4) Electronics Modeling	FE electronics requirements definition General Purpose Pixel Chip Large Area Systems with Pixel Readout Portable Multi-Channel System Discharge Protection Strategies	Common Production Facility Industrialization Collaboration with Industrial Partners	Testbeam Facility Irradiation Facility

RD51 / MPGD Training Session

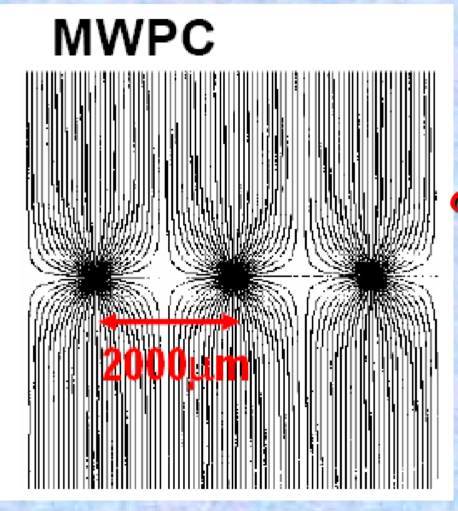
February 16-20, 2009 @ CERN: GEM and Micromegas detector design and assembly training - lecture session



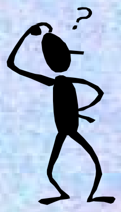
http://rd51-public.web.cern.ch/RD51-Public/Meetings/TrainingSessions.html

Software for gaseous detectors training session → January/February 2011

Closing the Gap between Wire Chambers and Silicon Detectors

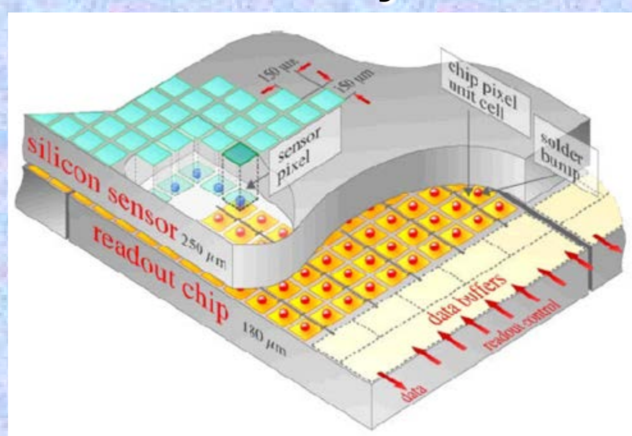


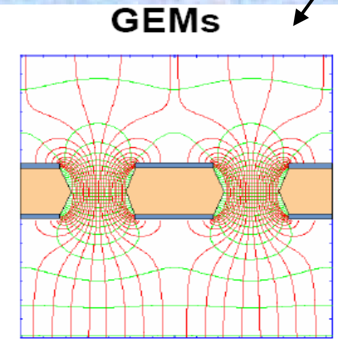
$\sigma \sim 100\ \mu m$

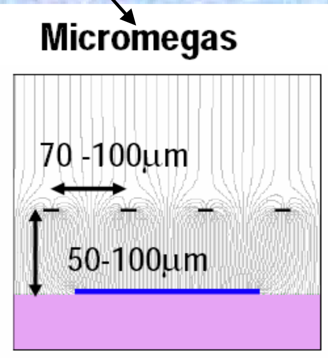


$\sigma < 10\ \mu m$

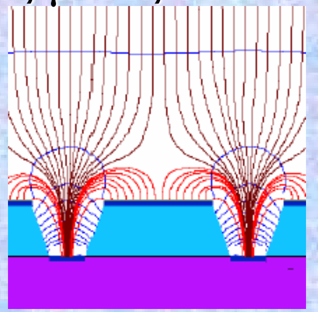
Novel Pixel System:







CAT, μCAT, mGROOVE, …



Evolution is always driven by the physics requirements and experimental conditions

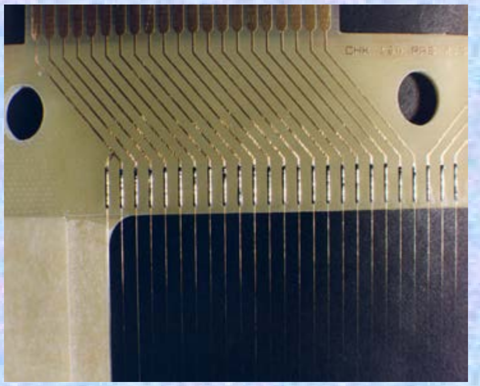
→ Trade-offs between read-out, S/N, power, and segmentation
(Often defined by state-of-the-art in microelectronics or etching technology):

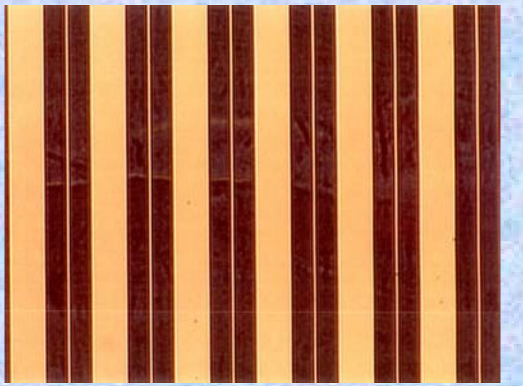
- **Microelectronics – eg. Silicon pixels**
- **Bump bonding technology – low capacitance connections**
- **Modern etching technology – eg. Micro pattern Gaseous Detectors**

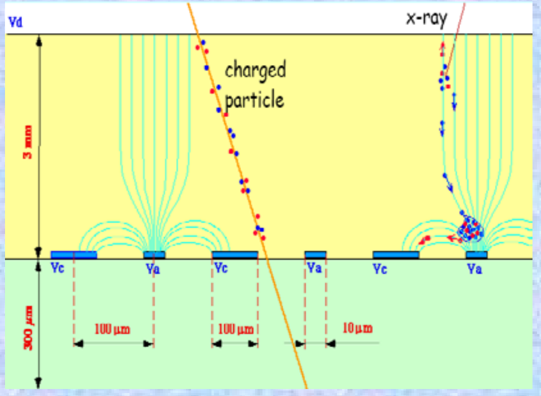
Micro-Strip Gas Chamber (MSGC)

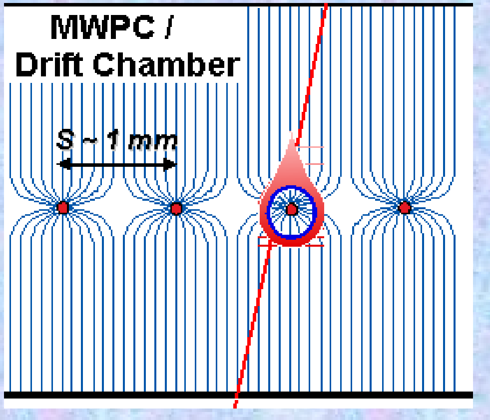
MWPC

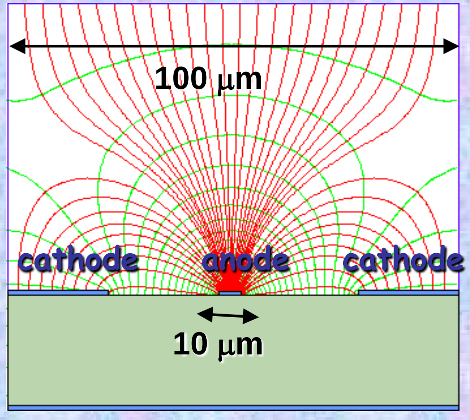
MSGC



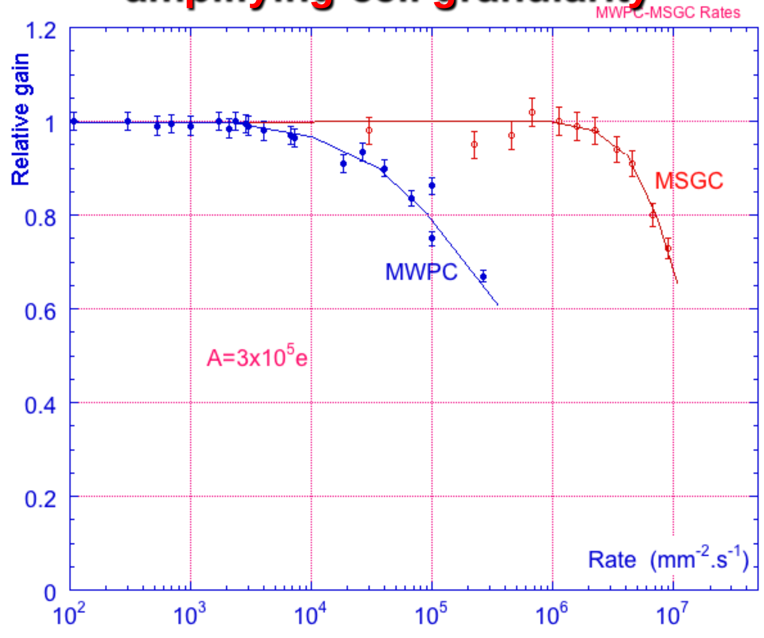








Rate capability limit due to space charge overcome by increased amplifying cell granularity



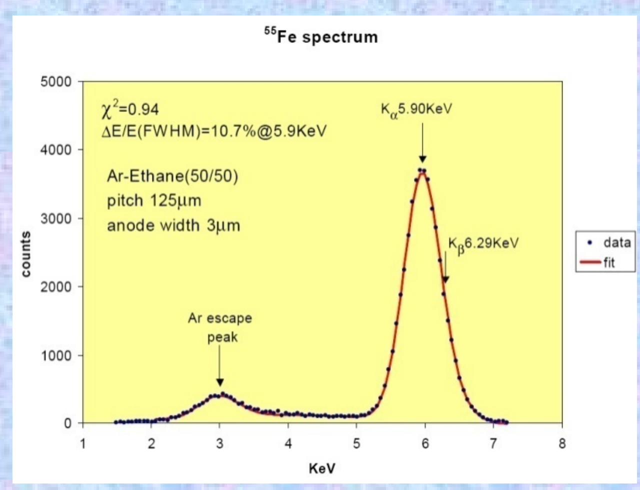
Typical distance between wires limited to 1 mm due to mechanical and electrostatic forces

Typical distance between anodes 200 µm thanks to semiconductor etching technology

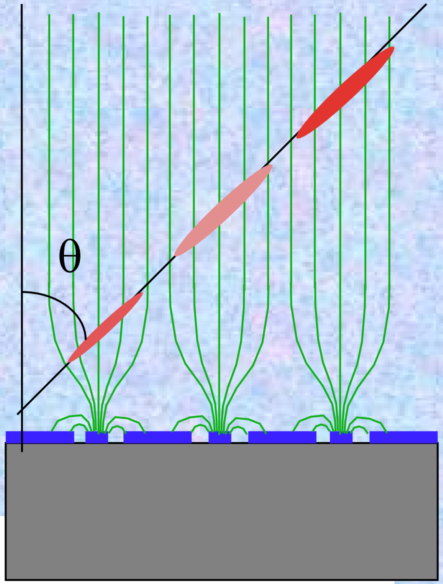
A. Oed, Nucl. Instr. and Meth. A263 (1988) 351.

MSGC Performance

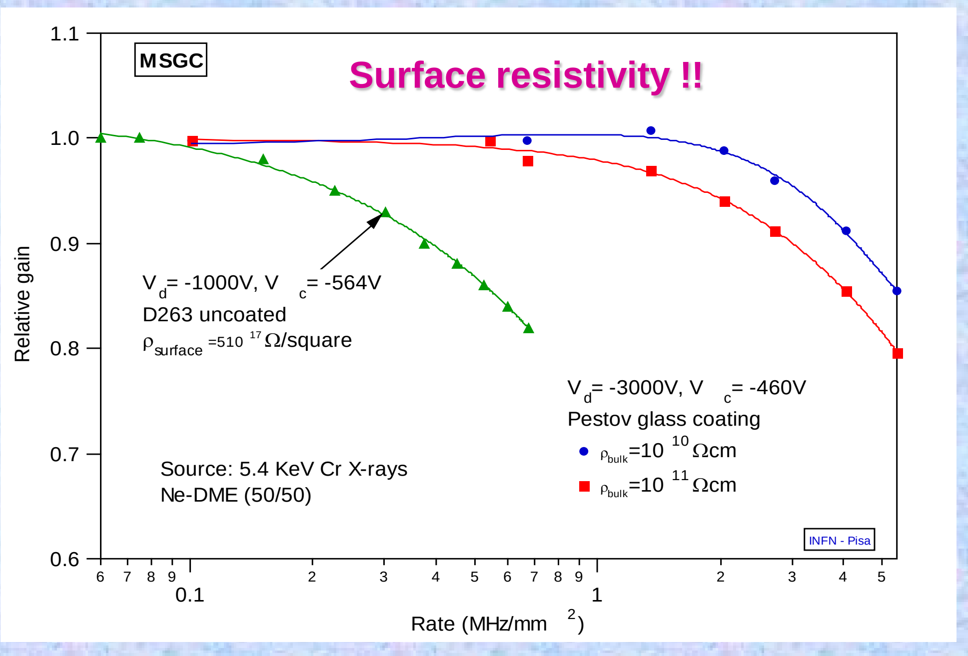
EXCELLENT RATE CAPABILITY, SPATIAL AND MULTI-TRACK RESOLUTION

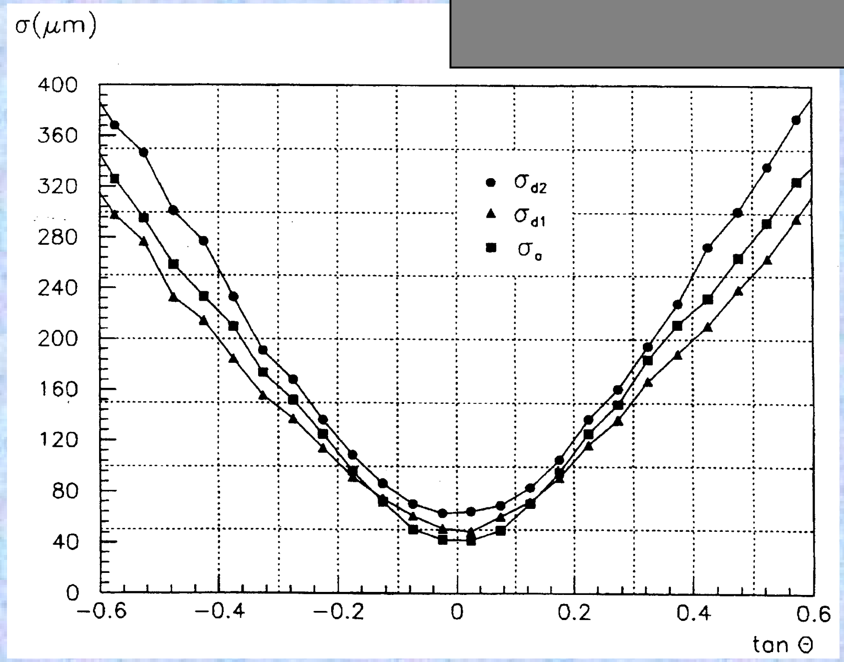


RATE CAPABILITY > 10^6/mm^2 s
SPACE ACCURACY ~ 40 μm rms
2-TRACK RESOLUTION ~ 400 μm



ENERGY RESOLUTION ~11% for 5.9 keV

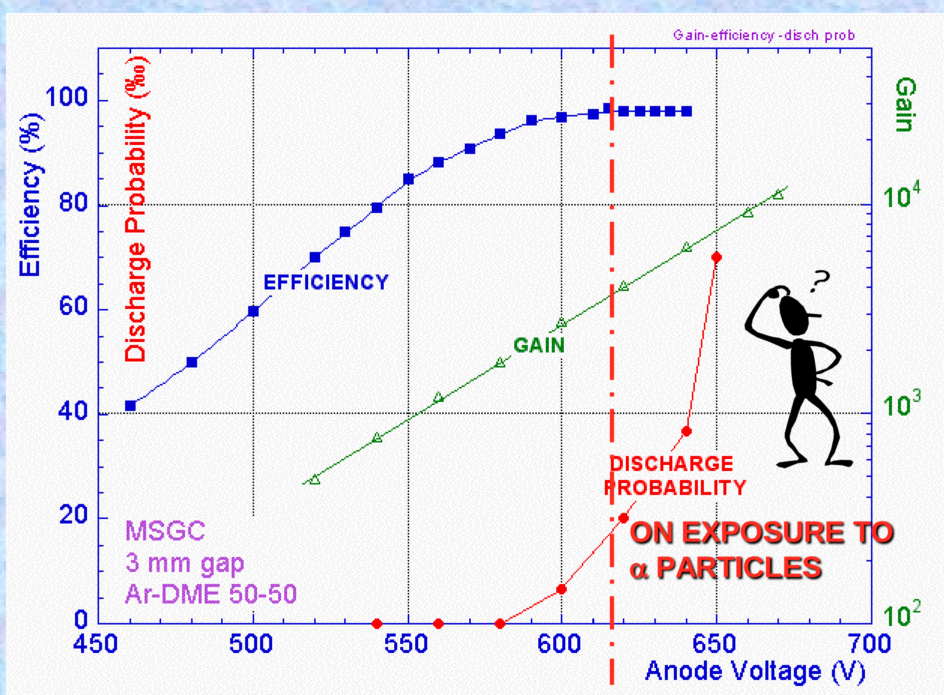




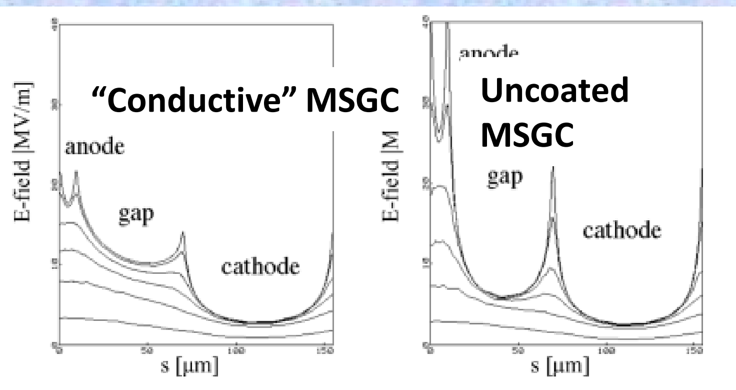
F. Van den Berg et al, NIMA A349 (1994) 438

Micro-Strip Gas Chambers: Discharge Problems

Major processes leading at high rates to MSGC operating instabilities:



- **Substrate charging-up and time-dependent modification of the E field**
  → slightly conductive support



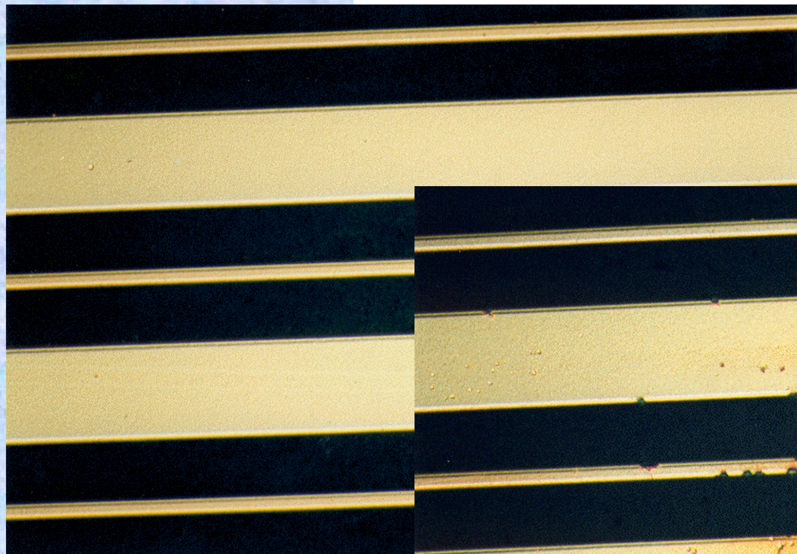
- **Deposition of polymers (aging)**
  → validation of gases, materials, gas systems

- **Discharges under exposure to highly ionizing particles**
  → multistage amplification, resistive anodes

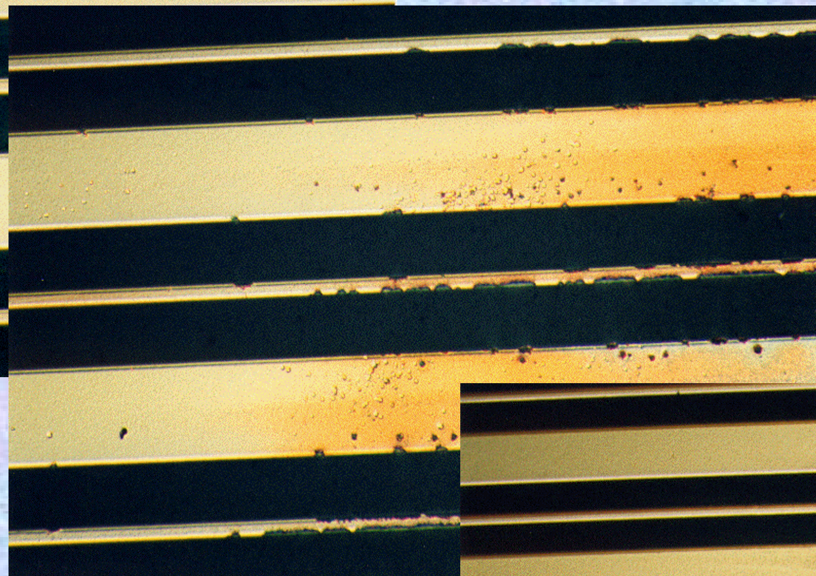
Induced discharges are intrinsic property of all single stage micropattern detectors in hadronic beams (MSGC turned out to be prone to irreversible damages)

A. Bressan et al, NIMA A424 (1999) 321.

MSGC Discharge Problems



Discharge is very fast (~ns)
Difficult to predict or prevent



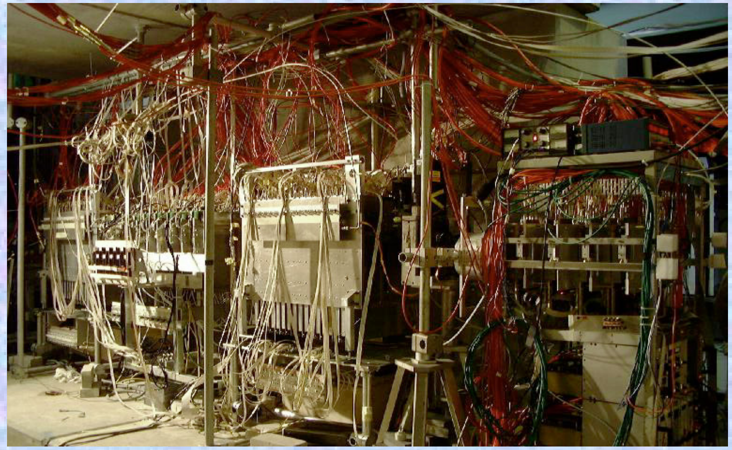
MICRODISCHARGES

FULL BREAKDOWN

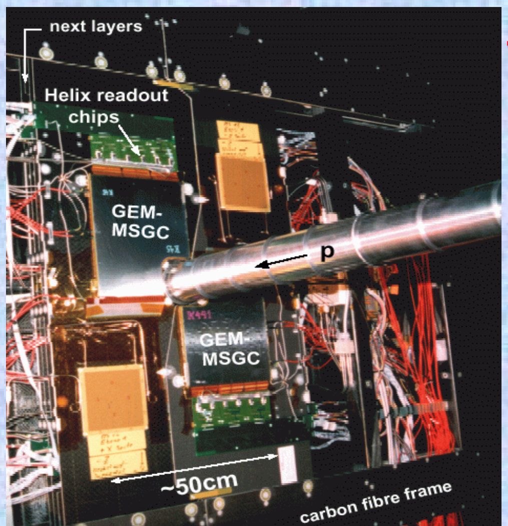
Owing to very small distance between anode and cathode the transition from proportional mode to streamer can be followed by spark, discharge, if the avalanche size exceeds
RAETHER'S LIMIT
Q ~ $10^7 – 10^8$ electrons

F. Sauli, http://www.cern.ch/GDD

Micro-Strip Gas Chamber (MSGC)

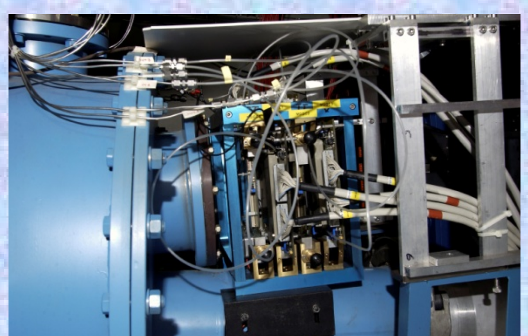


Telescope of **32 MSGCs**
tested at PSI in Nov99
(CMS Milestone)



HERA-B Inner Tracker @ DESY

MSGC-GEM detectors
R_{min} ~ 6 cm
⇒ 10^6 particles/cm^2•sec
300 mm pitch
184 chambers: max 25x25 cm^2
~ 10 m^2; 140.000 channels



DIRAC

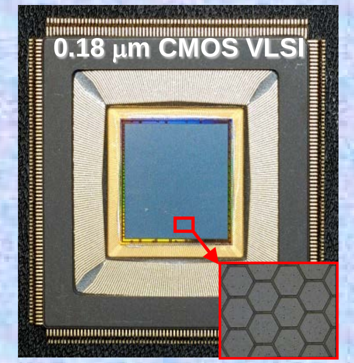
4 planes MSGC-GEM
Planes 10x10 cm^2

The D20 diffractometer MSGC is working since Sept 2000

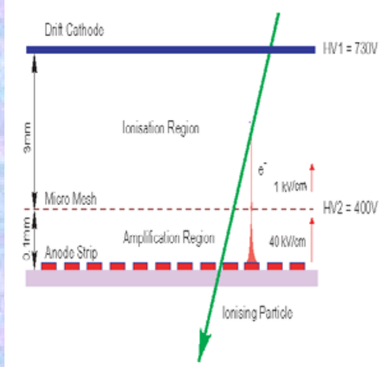
1D localisation
48 MSGC plates (8 cm x 15 cm)
Substrate: Schott S8900
Angular coverage : 160° x 5,8°
Position resolution : 2.57 mm (0,1°)
5 cm gap; 1.2 bar CF4 + 2.8 bars 3He

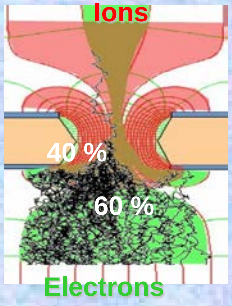
Current Trends in Micro-Pattern Gas Detectors (Technologies)

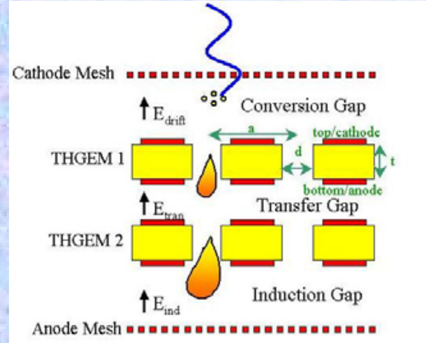
- Micromegas
- GEM
- Thick-GEM, Hole-Type Detectors and RETGEM
- MPDG with CMOS pixel ASICs
- Ingrid Technology

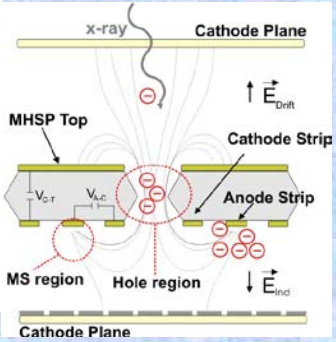


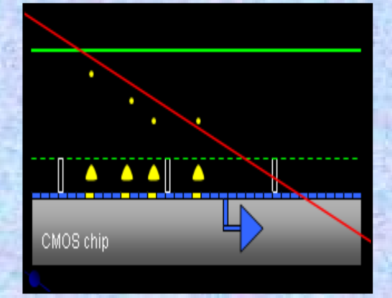
CMOS high density readout electronics

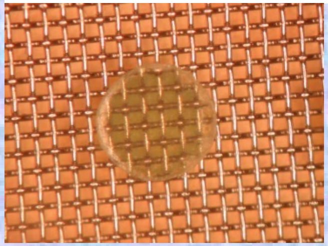




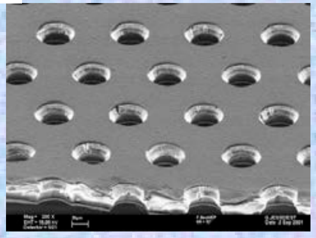




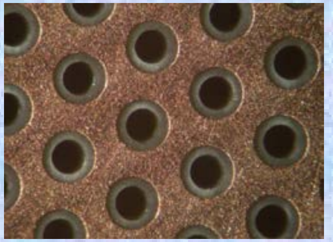




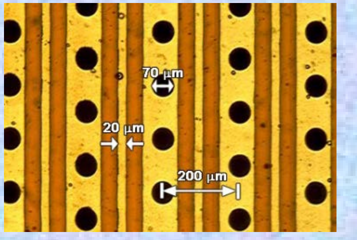
Micromegas



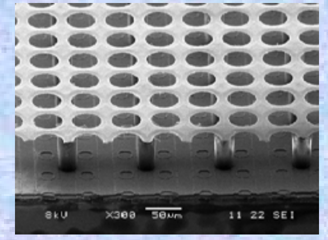
GEM



THGEM



MHSP

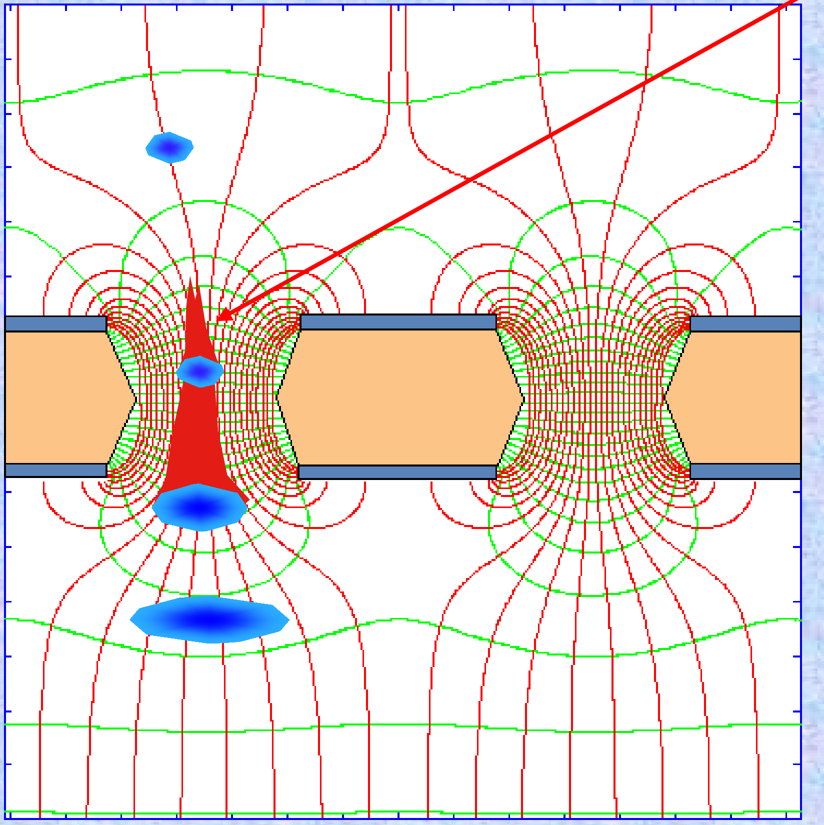


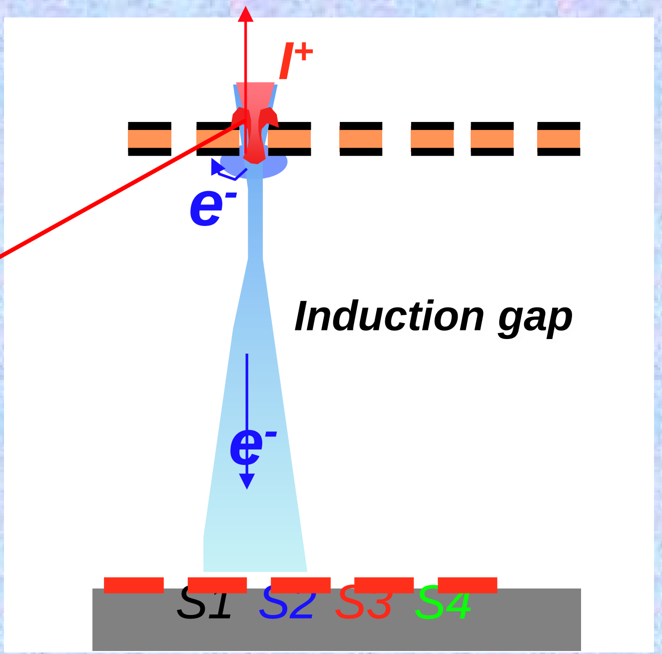
Ingrid

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.

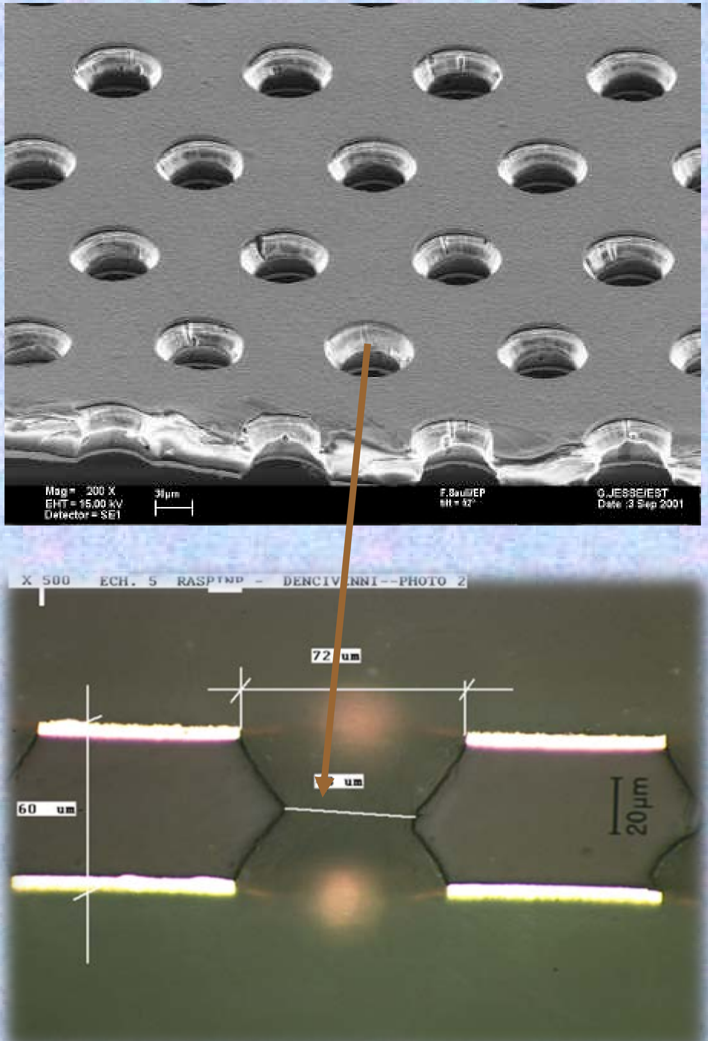
A fast signal can be detected on the lower GEM electrode for triggering or energy discrimination.

All readout electrodes are at ground potential.

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

GEM Manufacturing

Typical geometry:
5 µm Cu on 50 µm Kapton
70 µm holes at 140 mm pitch



50 µm Kapton
5 µm Cu both sides

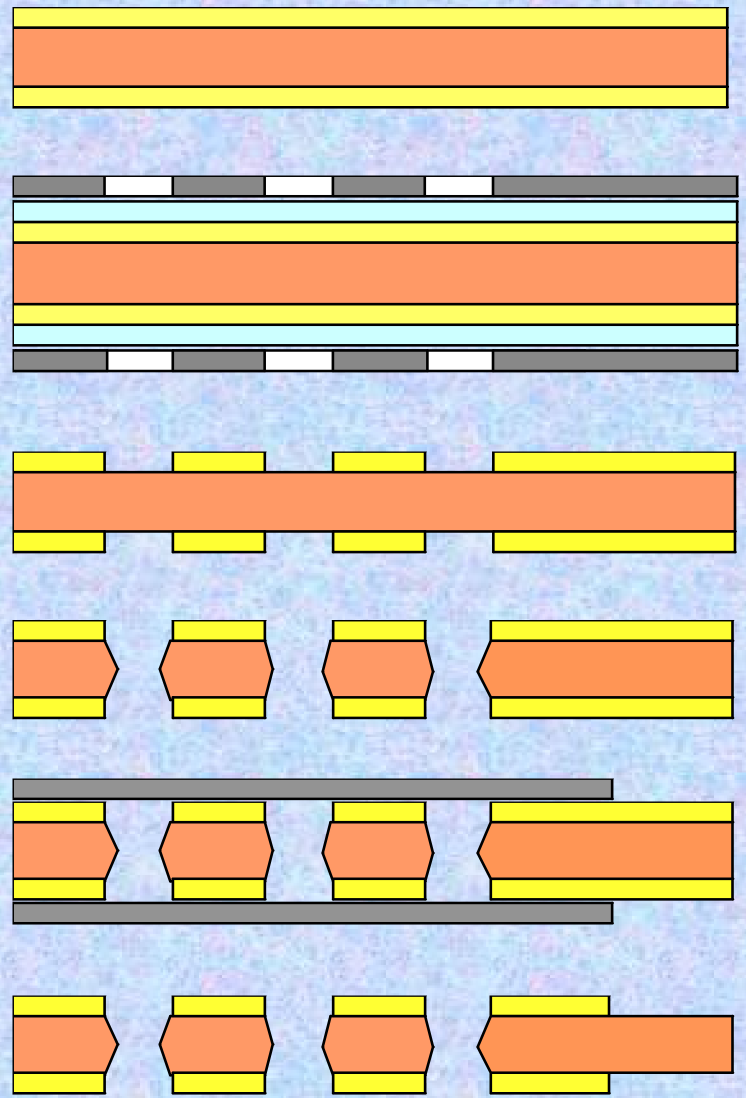
Photoresist coating, masking and exposure to UV light

Metal chemical etching

Kapton chemical etching

Second masking

Metal etching and cleaning

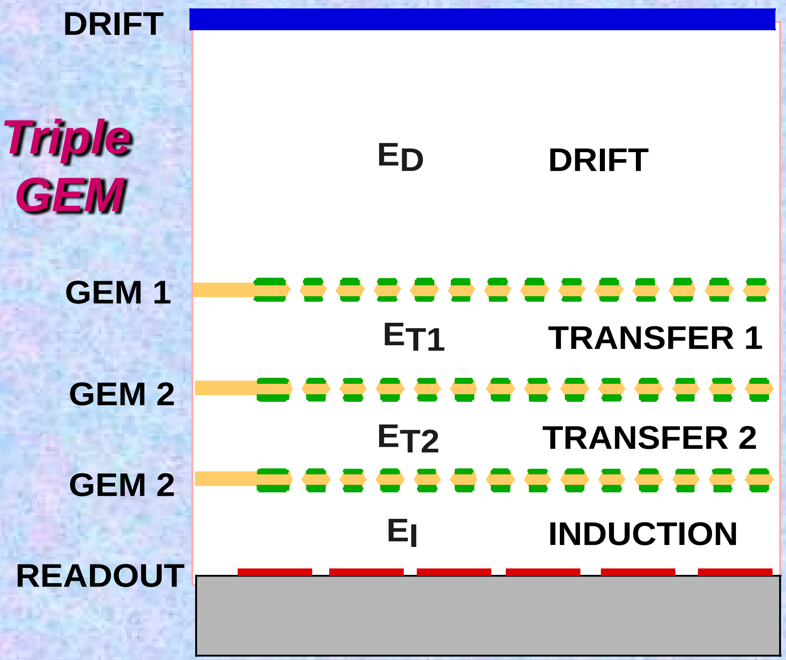


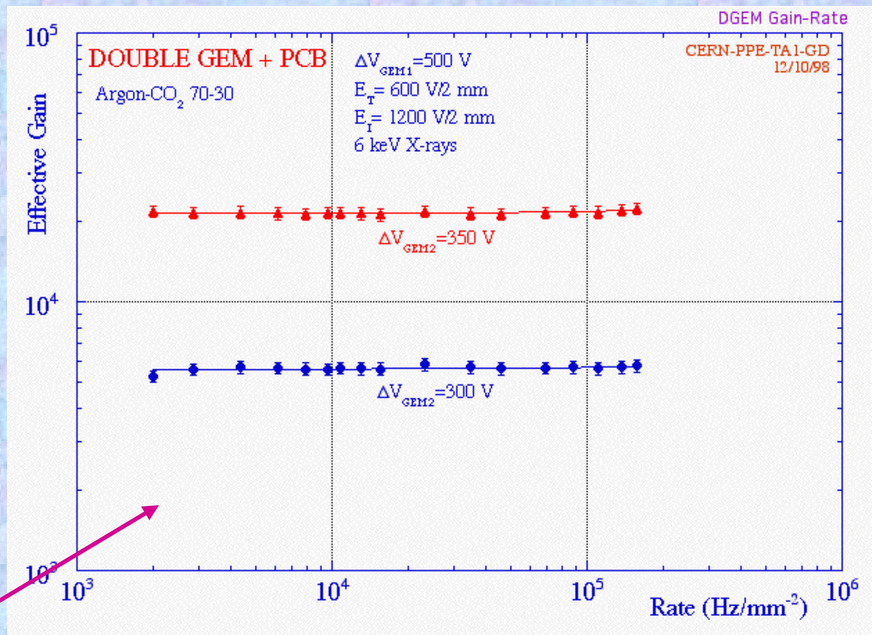
4/5/09

Multiple GEM Structures

Cascaded GEMs achieve larger gains and safer operation in harsh environments

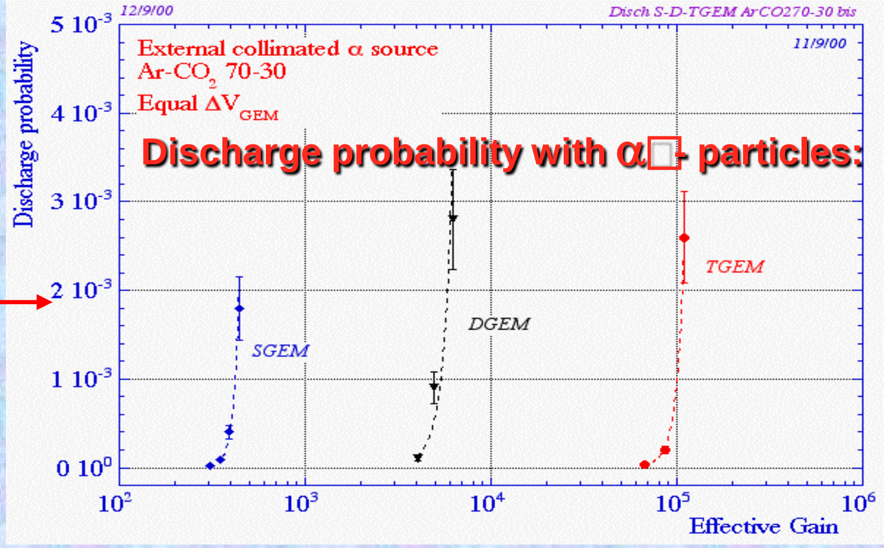
Triple GEM





High-rate capability > 10^5 Hz/mm^2;
No space-charge phenomena

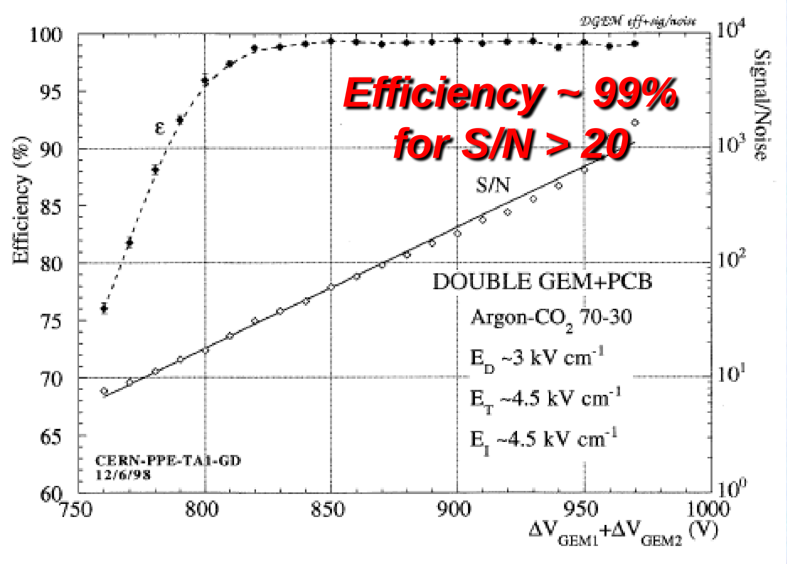
Discharge probability with α- particles:

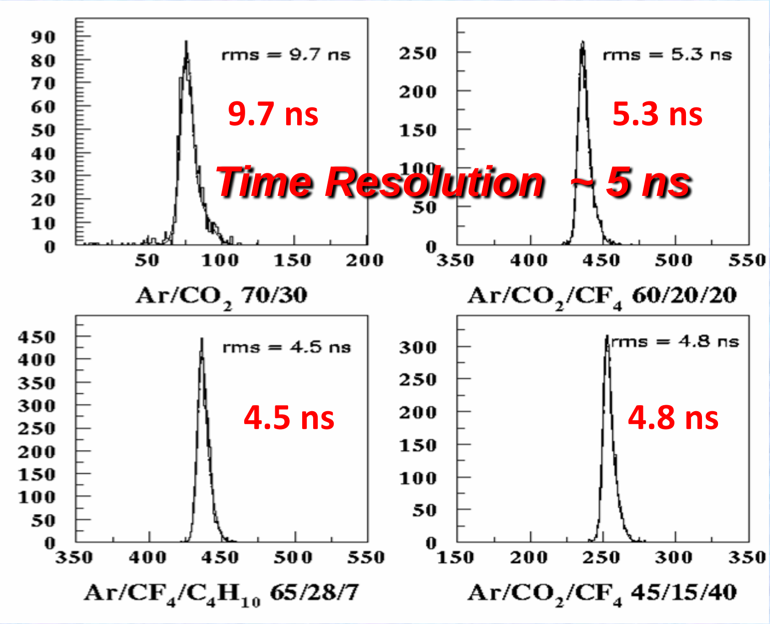


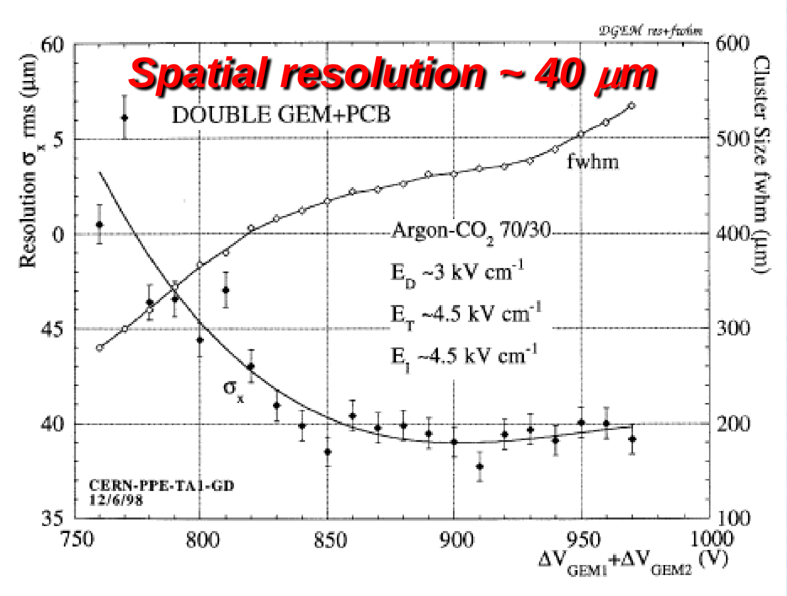
Multiple GEM structure strongly reduces probability of discharges

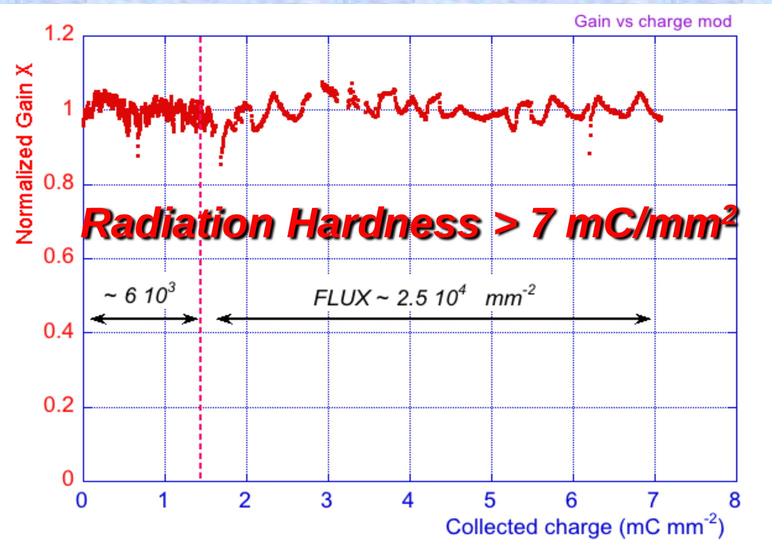
S. Bachmann et al, NIM A 479(2002)294

Multiple GEM Performance







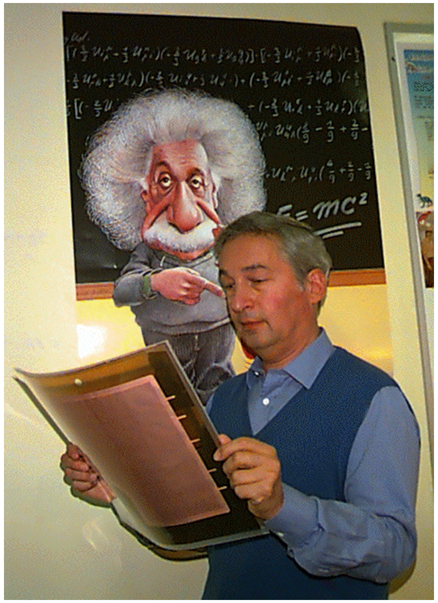


A. Bressan et al, Nucl. Instr. and Meth. A425 (1999) 262

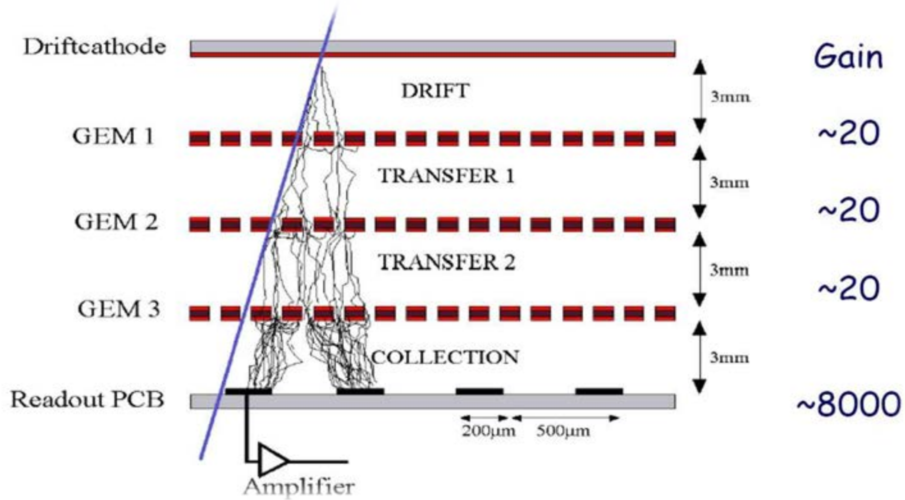
J. Benlloch et al, IEEE TNS 45(1998)234; C. Altunbas et al, Nucl. Instr. and Meth. A515 (2003) 358

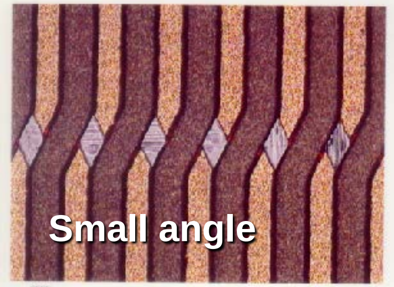
Gas Electron Multiplier (GEM)

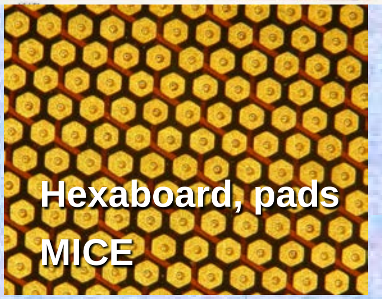
F. Sauli, NIM A386(1997) 531;
F. Sauli, http://www.cern.ch/GDD

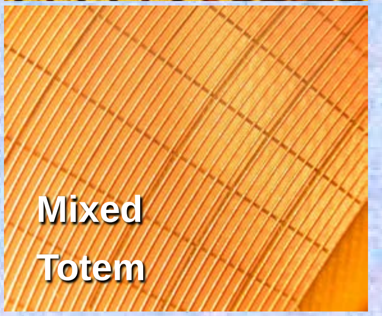


Full decoupling of amplification stage (GEM) and readout stage (PCB, anode)

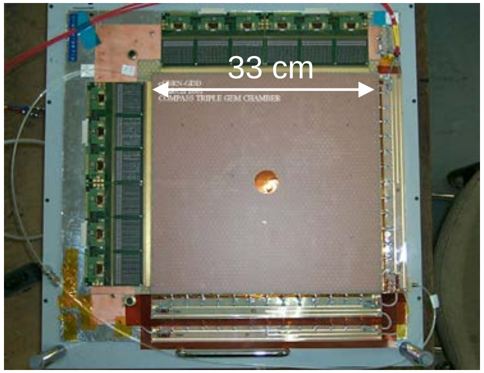






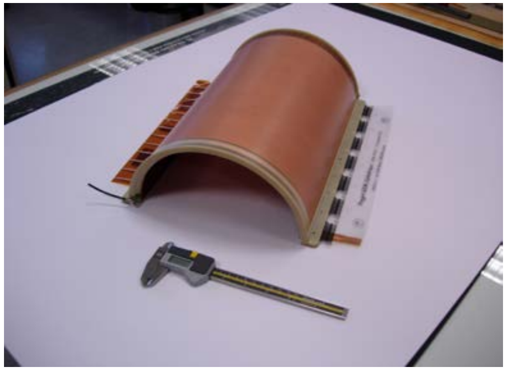


Amplification and readout structures can be optimized independently !



Compass

Totem



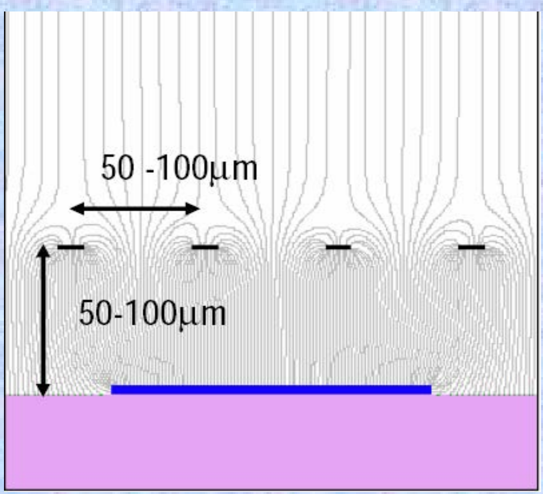
NA49-future

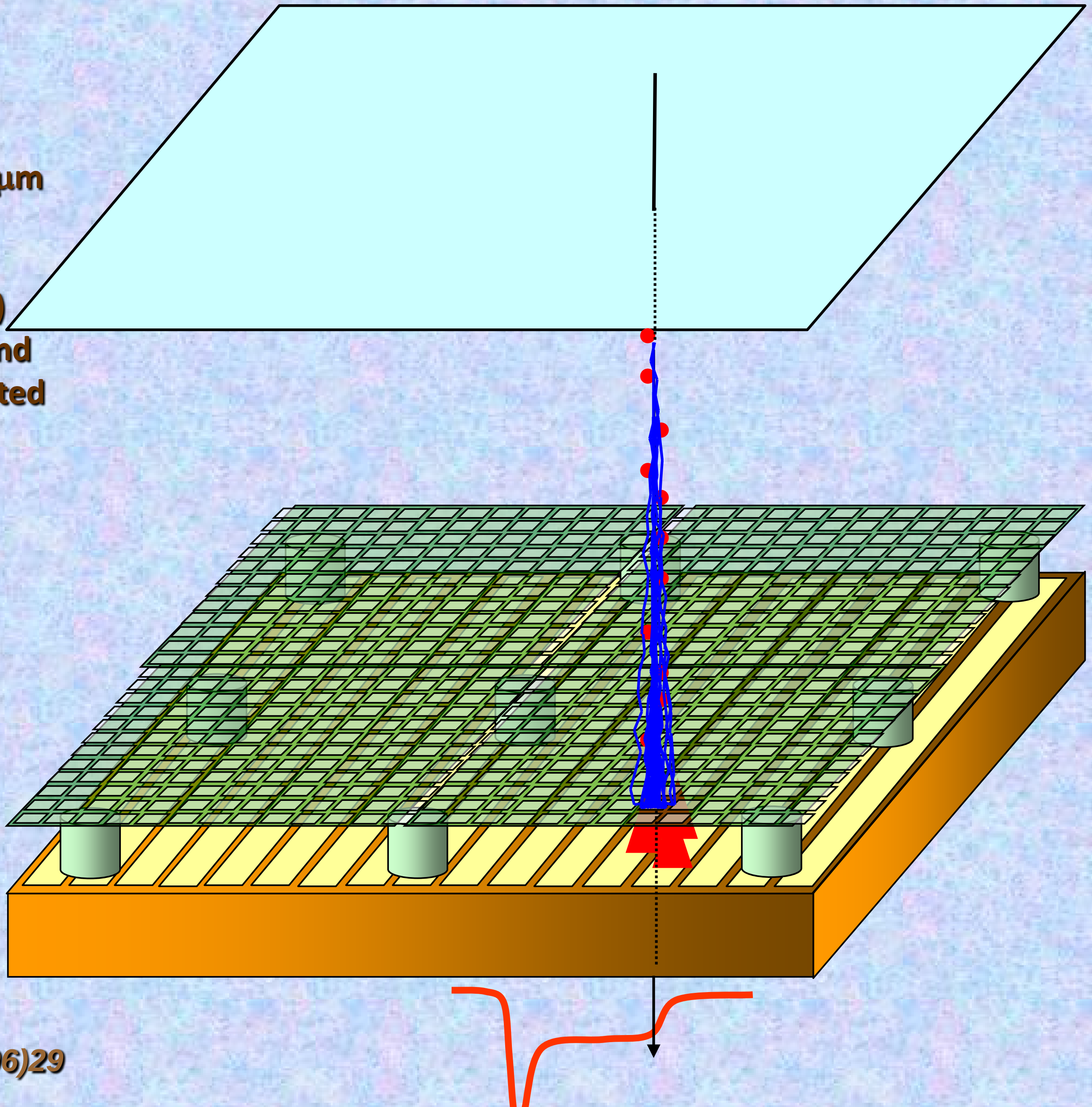
MICro MEsh GAseous Structure (MICROMEGAS)

Micromesh Gaseous Chamber: a 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

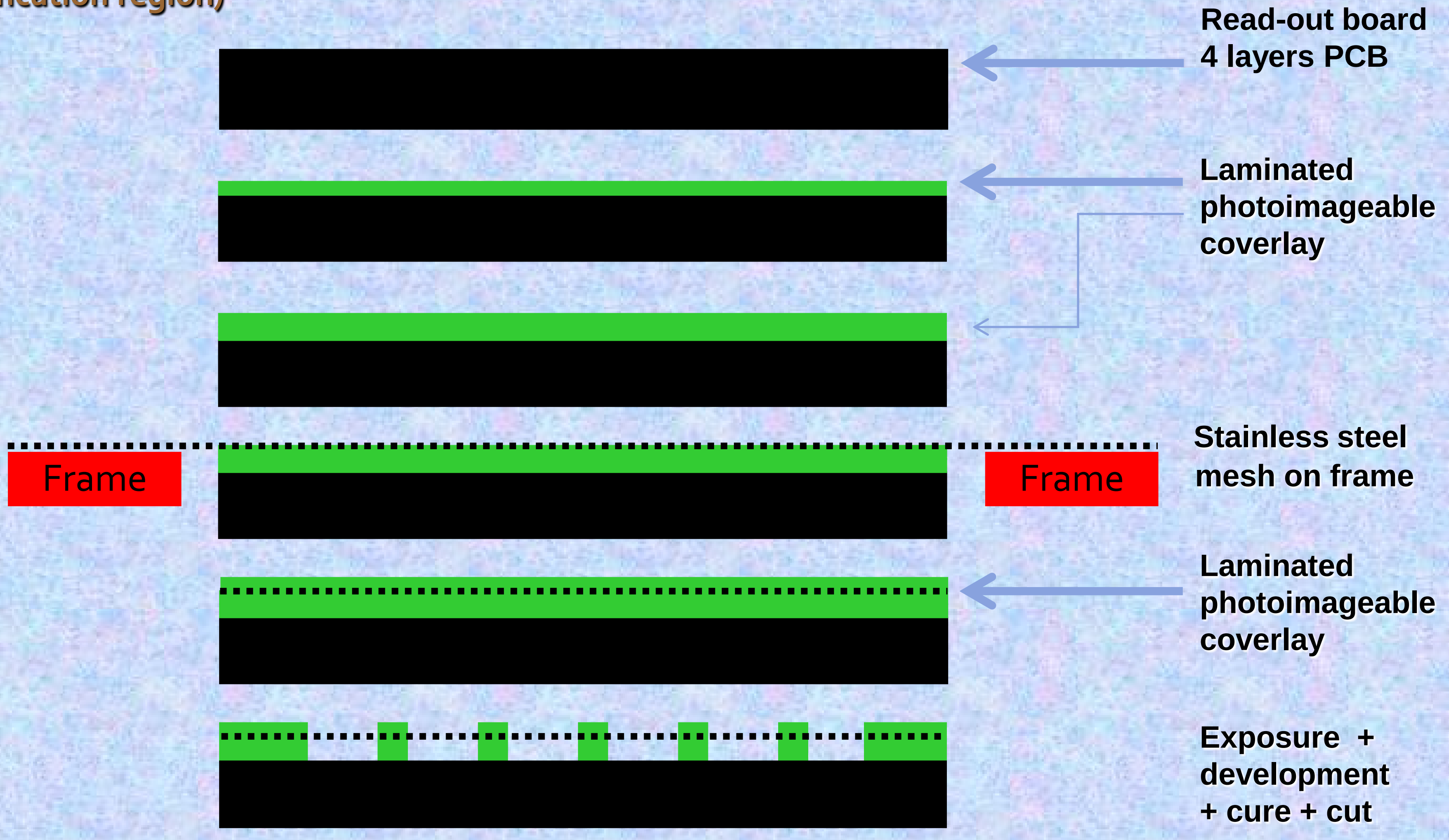




Y. Giomataris et al, NIM A376(1996)29

Manufacturing Bulk Micromegas

The micro mesh consist of 18um µm thick stainless steel 400 Lpi woven microstrings. This micro mesh is embedded between two photoimageable coverlay layers with a micron precision (to define the amplification region)

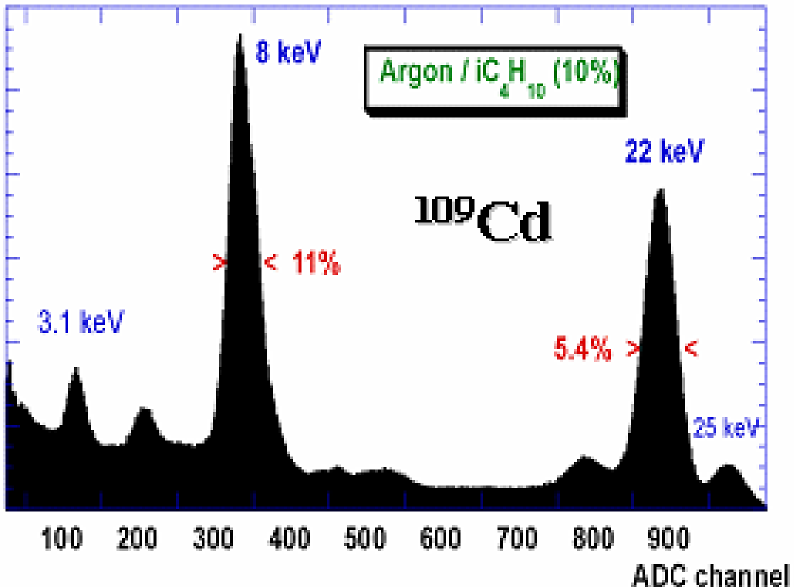


Easy manufacturing - Large size compatible - Low cost
Robust and electrically testable at the production time

I. Giomataris et al, NIM A560 (2006) 405

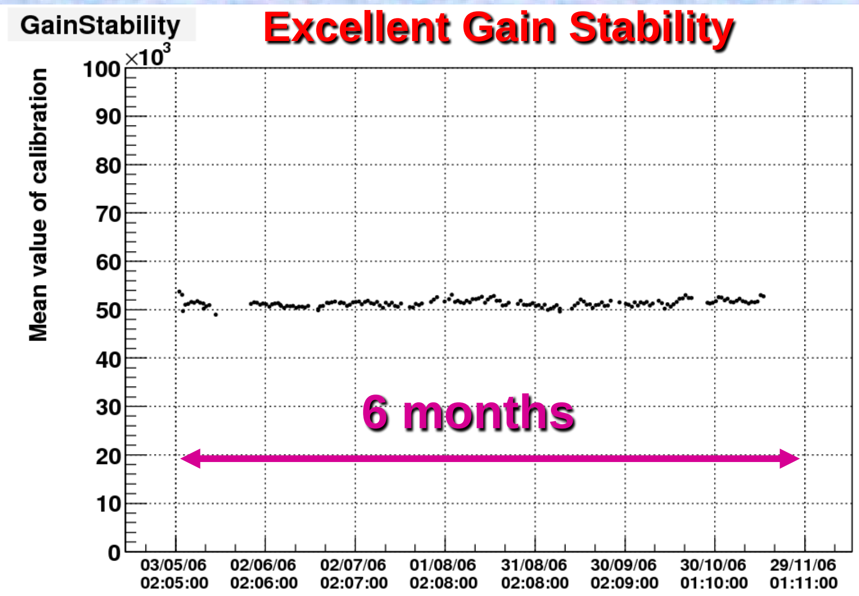
Micromegas Performance

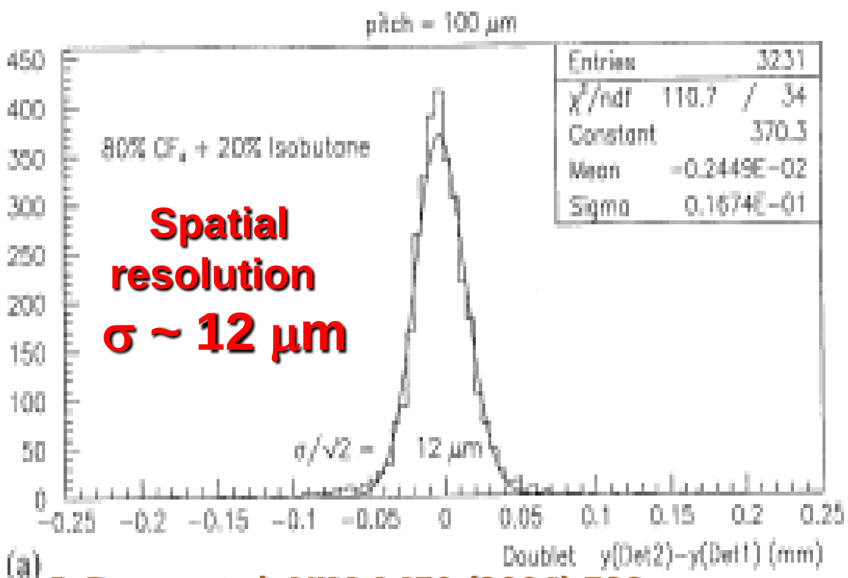
Small gap→ good energy resolution



G. Charpak et al., NIMA478 (2002) 26

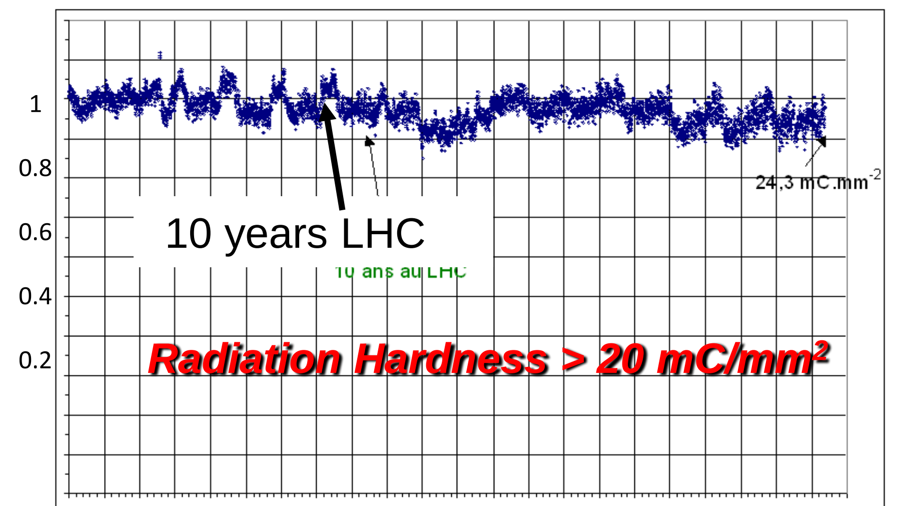
Excellent Gain Stability





J. Derre et al, NIM A459 (2001) 523

ageing:Ar-iC_4H_{10} 94-6% up to 24.3mC/mm²

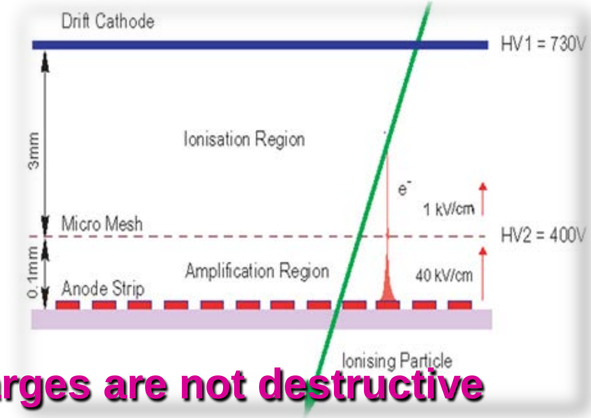


G. Puill et al., IEEE Trans. Nucl. Sci. V.46(6), 1894 (1999)
J. Derre et al., NIM A449 (2000) 314

MICROMEGAS

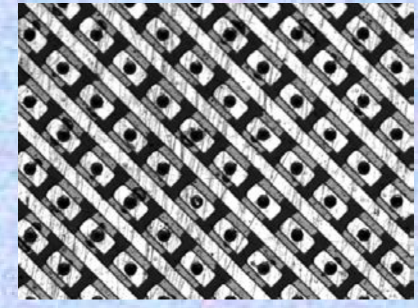
Y. Giomataris et al, NIM A376(1996)29

Parallel plate multiplication in thin gaps between a fine mesh and anode plate

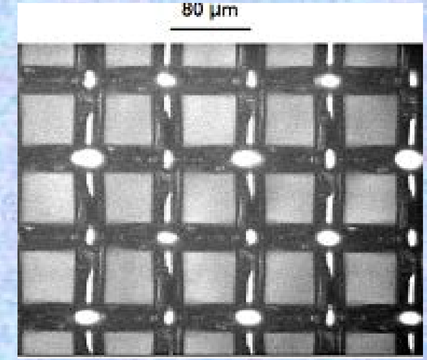


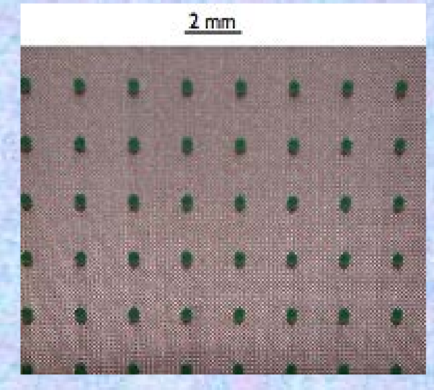
- **Discharges are not destructive**
- **Dead time during charge-up**
- **Different spark reduction options under study (resistive coating, double step amplification)**

CAST readout:



"Bulk" Micromegas:

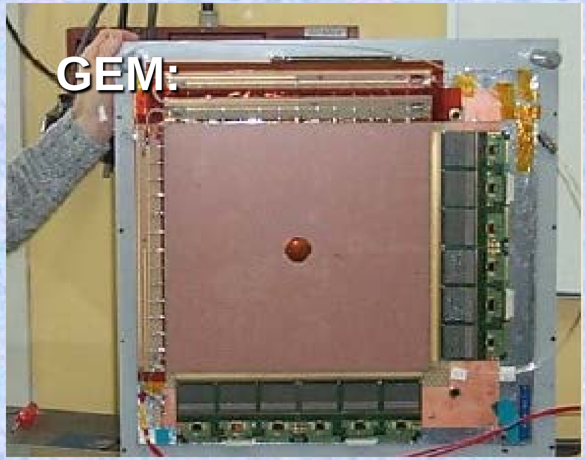




GEM / Micromegas in COMPASS - Textbook of Modern Detectors

High Rate Forward spectrometer:

COMPASS beam ~ 5* 10^7 muons/s on ^{6}LiD target

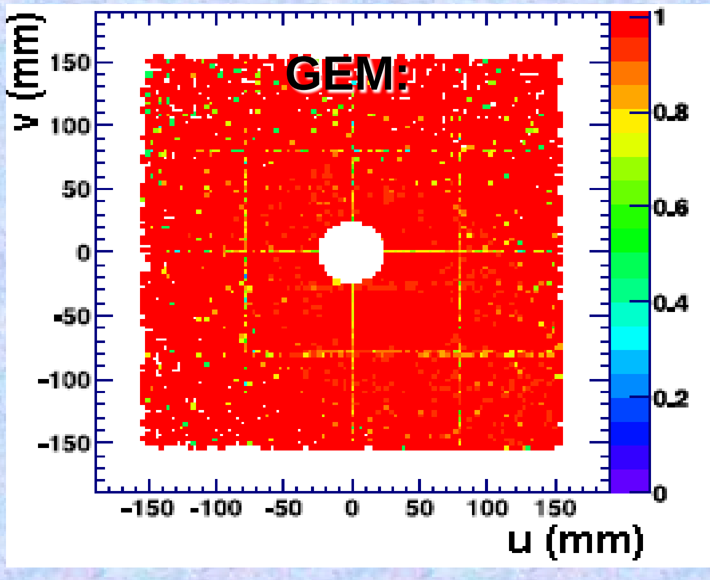


***22* TRIPLE GEM DETECTORS (31*31 cm^2)**

& 12 MICROMEGAS PLANES (40*40 cm^2)

High Rate / High Precision / Low Mass Detectors:

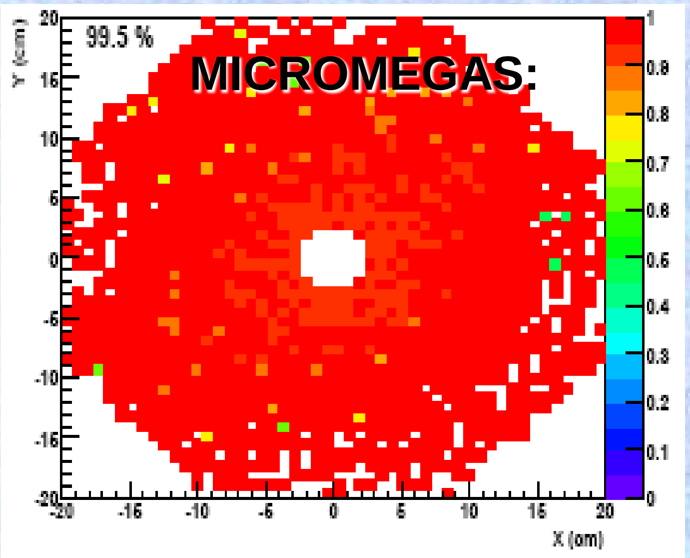
25 kHz/mm^2



UNIFORMITY OF TRACKING EFFICIENCY: (ε > 95 %)

RELIABLE OPERATION in 2002 – 2006

NO SIGN OF AGING



B. Ketzer et al, NIM A535 (2004) 314

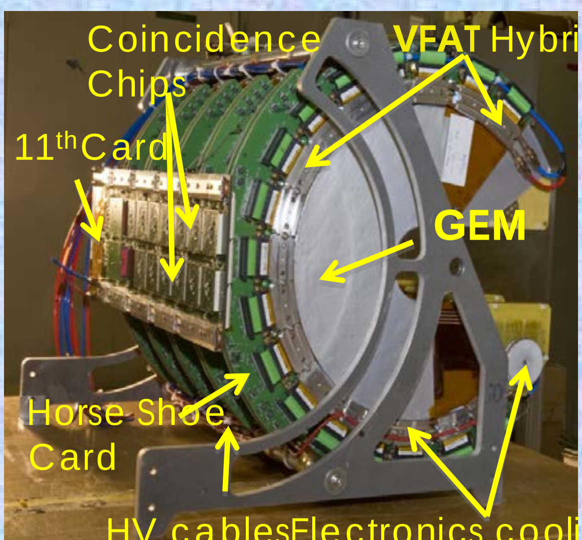
F. Kunne, 2006 IEEE NSS/MIC Conference Record

D. Neyret, arXiv: 0909.5402

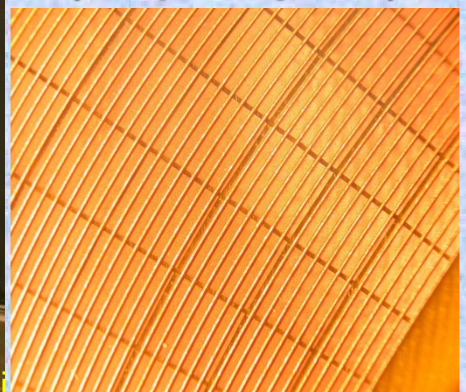
GEM in the LHC Experiments

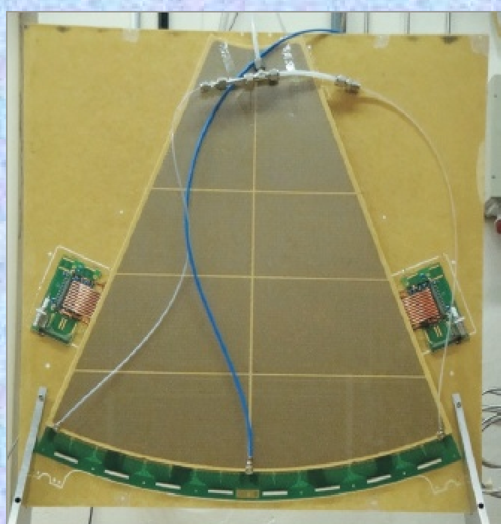
GEMs are used in the TOTEM (tracking and triggering) and LHCb Muon (triggering)

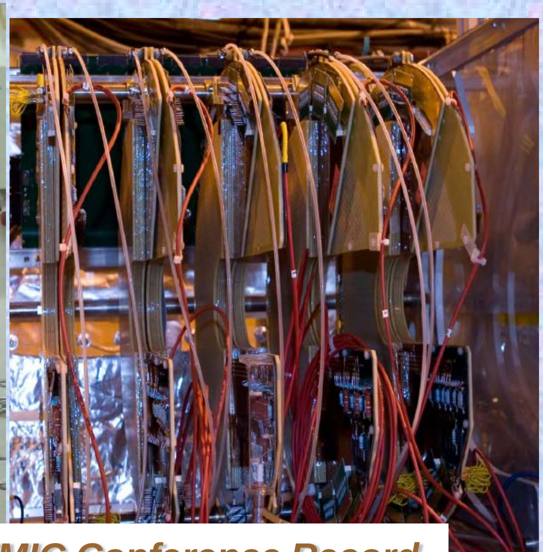
TOTEM GEMs:



2D readout (strips & pads)





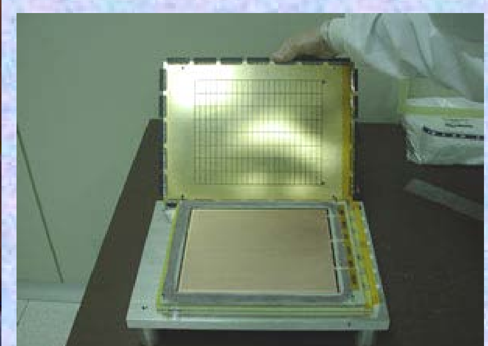


S. Lami, 2009 IEEE NSS/MIC Conference Record.

LHCb Muon Trigger:

(12 double TGEM detectors)

Rate - 5 kHz mm-2
Time resolution 4.5 ns rms
Radiation hard up to integrated charge of 20 mC mm-2 (15 LHCb years)



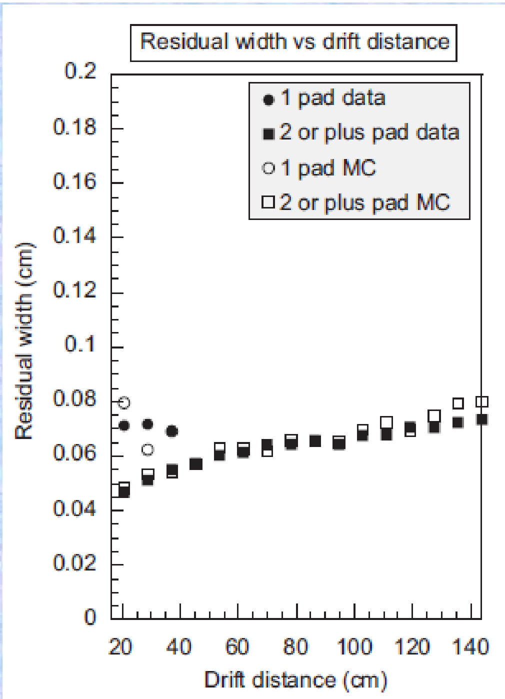
M. Alfonsi et al, NIM A535(2004)319

Micromegas in the Neutrino & Astrophysics Experiments

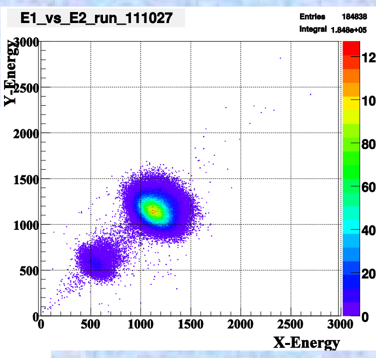
T2K TPC:

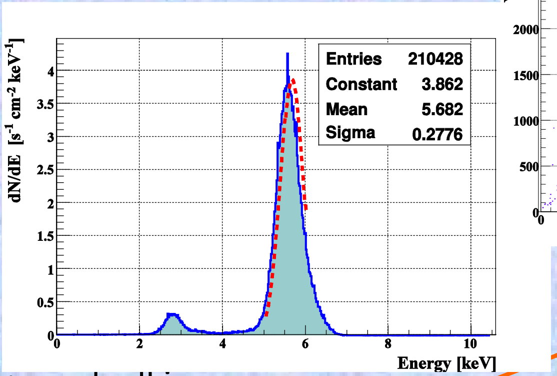
72 bulk-Micromegas (34 * 36 cm^2) for 3 TPCs

9 m^2 of bulk Micromegas
124272 FEE channels



CAST (Micro-Bulk Technology):

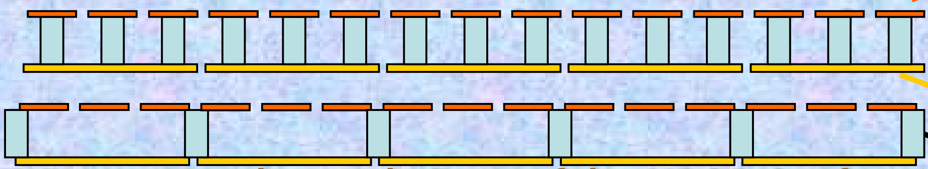




Micro-Bulk Technology:

^{55}Fe with Ar – 5%
iC4H10 @ 1 bar
FWHM @ 6 keV = 11.5 %

Readout plane + mesh all in one



T. Papaevangelou et al., Proc. of the MPGD Conference, Crete, June 2009

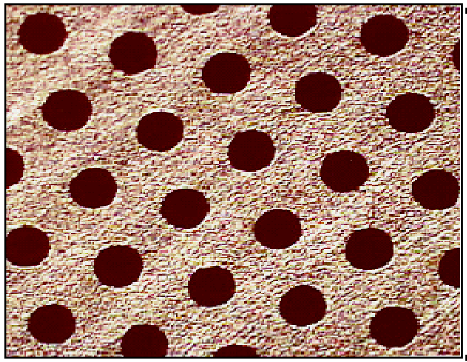
Lower capacitance
Under development

S. Anvar et al, NIM A602 (2009) 415
J. Beucher et al., Proc. of the MPGD Conference, Crete, June 2009

Thick-GEM Multipliers (THGEM)

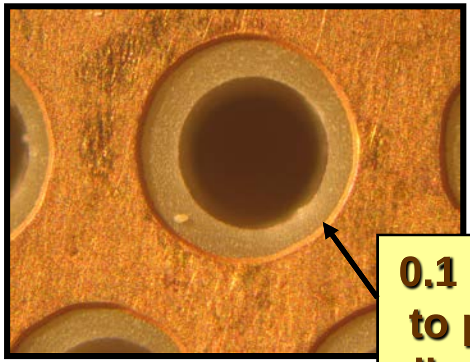
Simple & Robust → Manufactured by standard PCB techniques of precise drilling in G-10 (and other materials) and Cu etching

STANDARD GEM
10^3 GAIN IN SINGLE GEM



1 mm

THGEM
10^5 gain in single-THGEM



0.1 mm rim to prevent discharges

C. Shalem et al, NIMA558 (2006) 475;

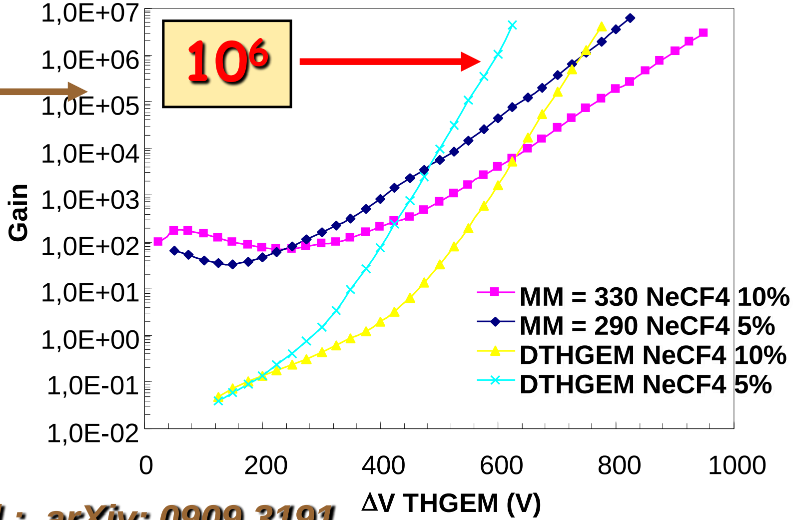
Other groups developed similar hole-multipliers:

- 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**

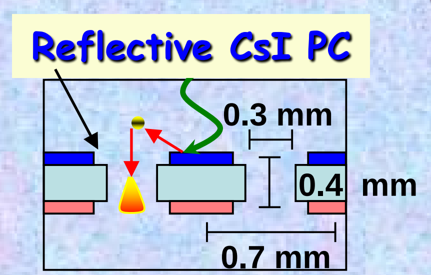
Double THGEM or THGEM/Micromegas



C. Azevedo et al.; arXiv: 0909.3191

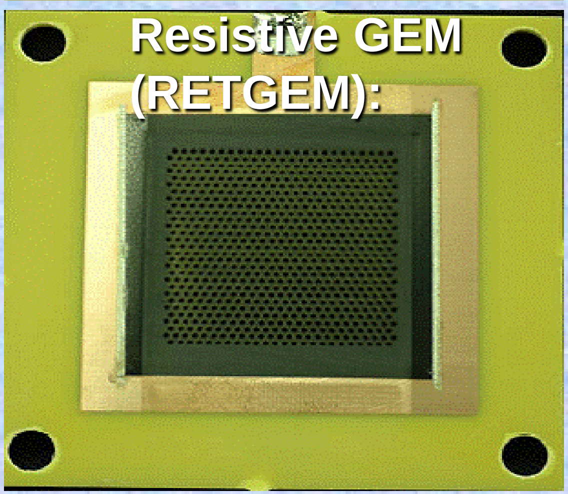
Photon Detectors based on THGEM/RETGEM

Several advantages of using THGEM / RETGEM for RICH Applications:



- **Very high and stable gains** ($>10^5$) can achieved with THGEMs in several gases (e.g. Ne-based mixtures)

- THGEM can operate in badly quenched gases as well as in gases in which are strong UV emitters → possibility of using **windowless detectors** for some RICH designs



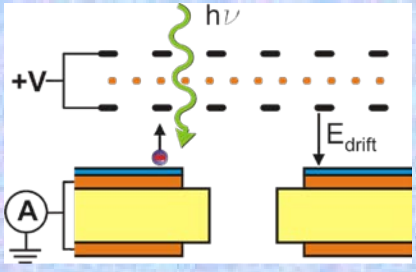
Project under discussion in RD51 → Development of gaseous photomultipliers for visible spectral range

(Wider bandwidth → figure of merit N_0, Smaller chromatic aberration, larger choice of radiators) –

A. Lyashenko at al., JINST 4:P07005,2009;
R. Chechik, A .Breskin, NIMA595 (2008)116;
V. Peskov, RD51 Collab. Meet., Nov.23-25, 2009, WG2 Meeting

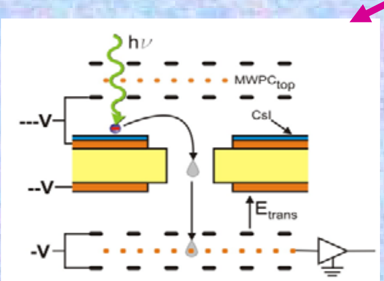
THGEM Photon Detectors for RICH: Efficiency Evaluation

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



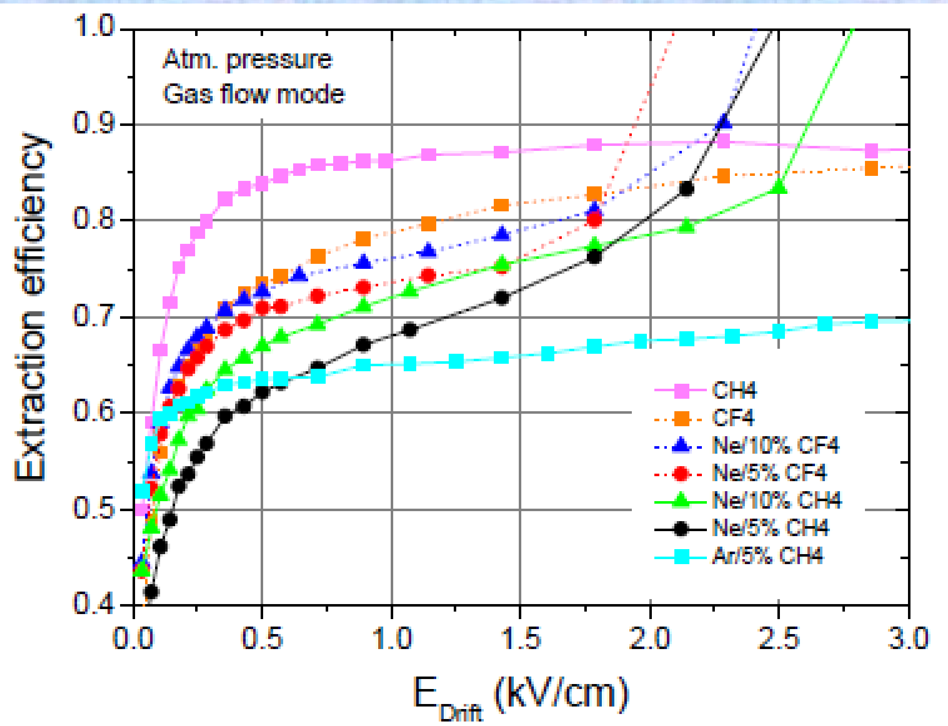
PE efficiency extraction into the gas vs vacuum:

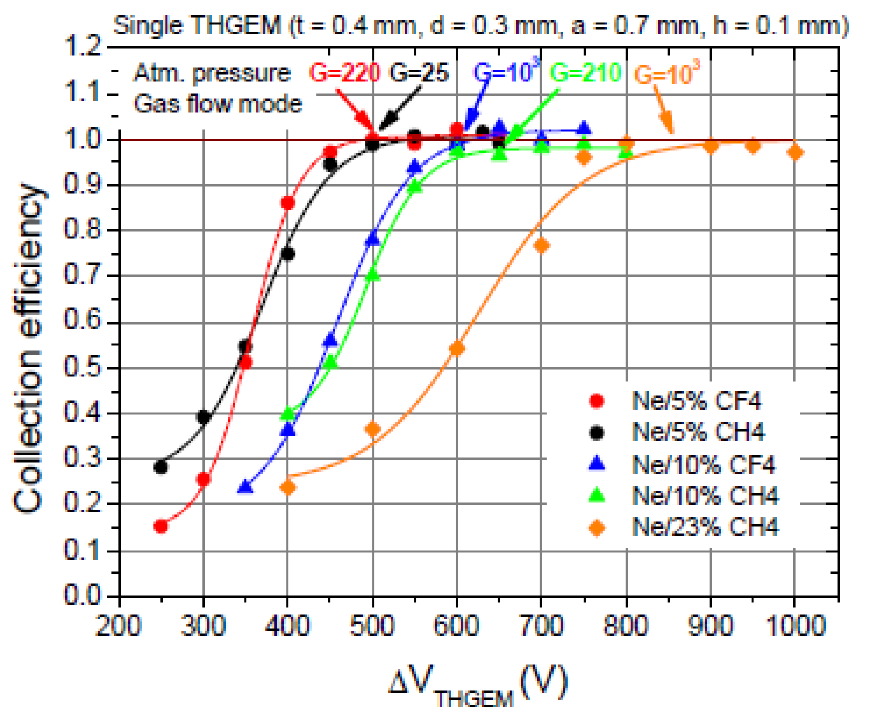
$$\varepsilon_{extr} = \frac{I_{gas}}{I_{vac}}$$



Single PE collection efficiency into THGEM holes:

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



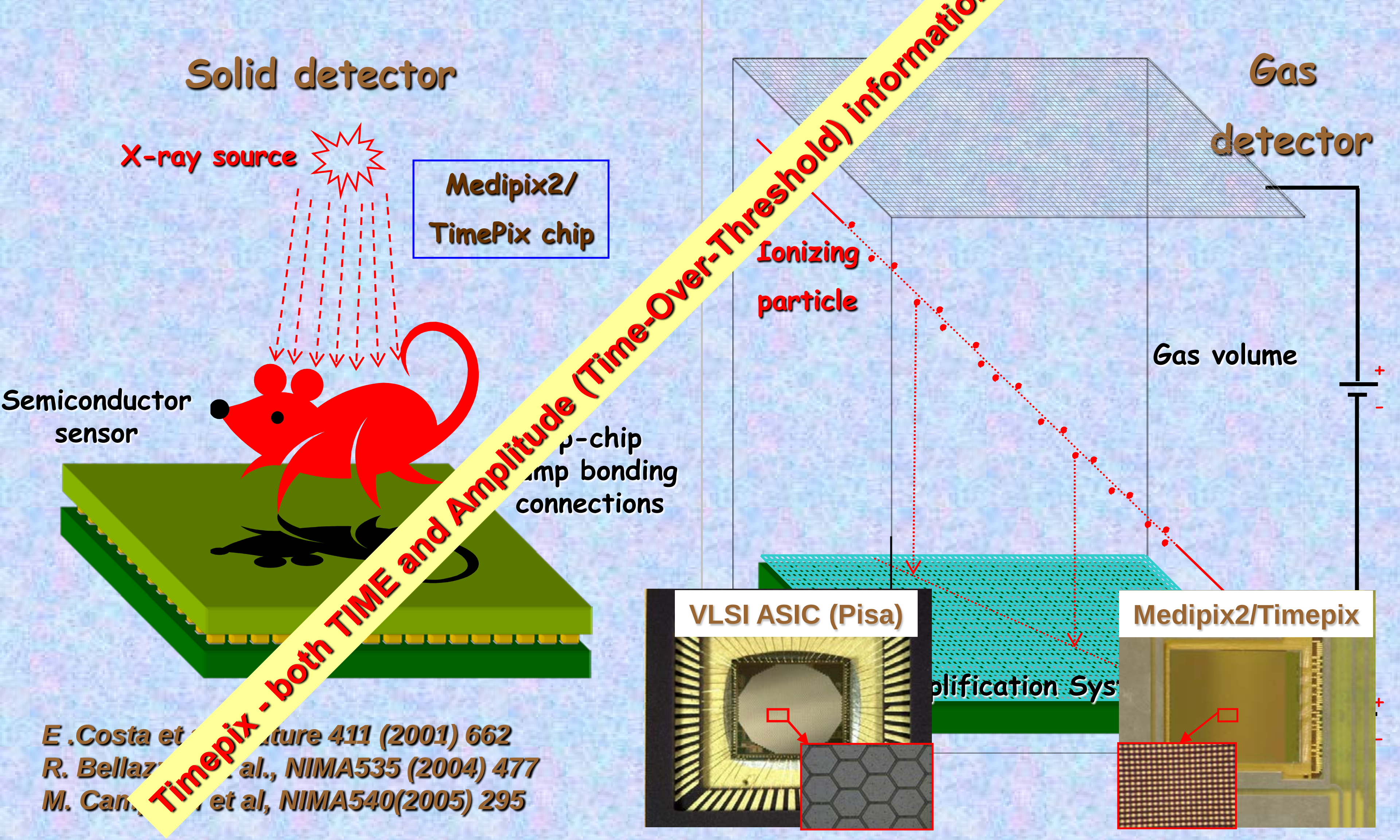


Azevedo et al., arXiv:0909.5357

Pixel Readout of Micro-Pattern Gas Detectors

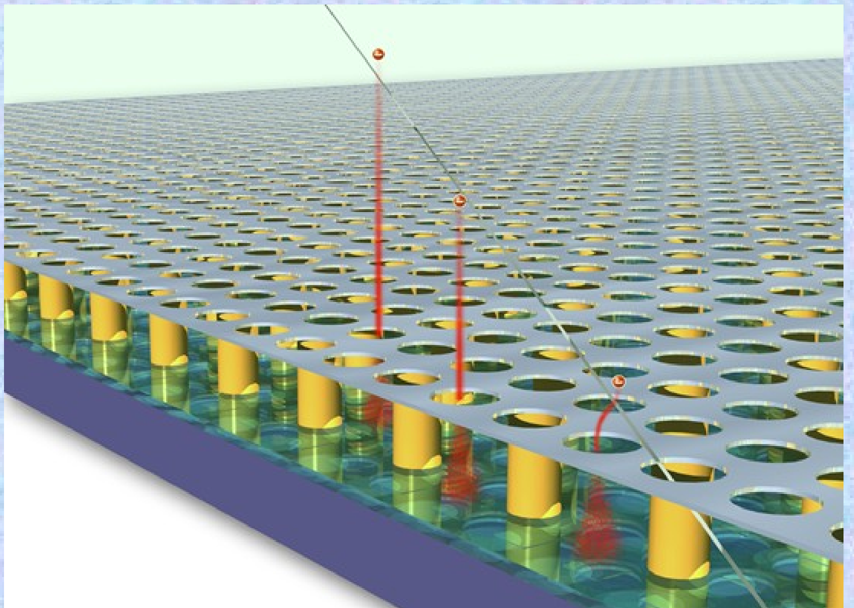
Gas Detector Readout by multi-pixel CMOS array (used as charge collecting anode)

CMOS readout concept → Analog VLSI ASIC (Pisa), MEDIPIX2 / TIMEPIX Chips



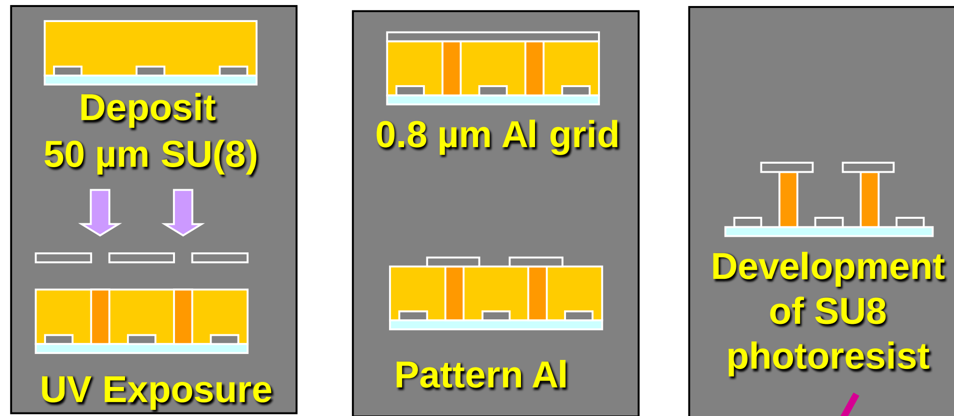
E. Costa et al., Nature 411 (2001) 662
R. Bellazzini et al., NIMA535 (2004) 477
M. Campbell et al, NIMA540(2005) 295

Micromegas/Ingrid + Timepix Detector



InGrid: integrate Micromegas & pixel chip by Si-wafer post-processing technology

- **Grid robustness & Gap/Hole accuracy**

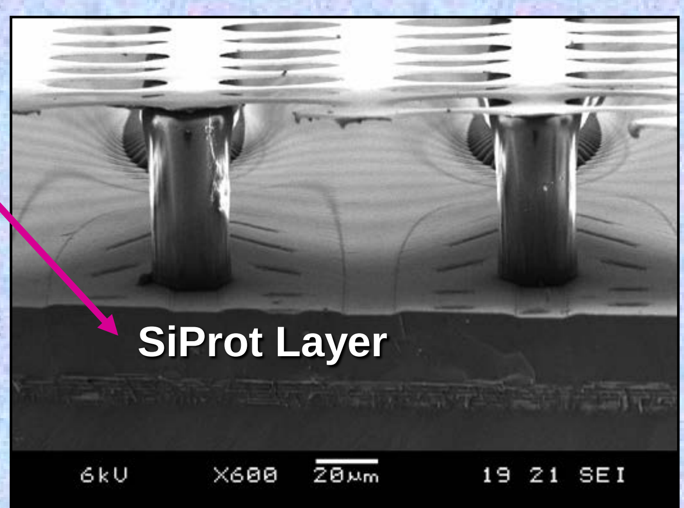


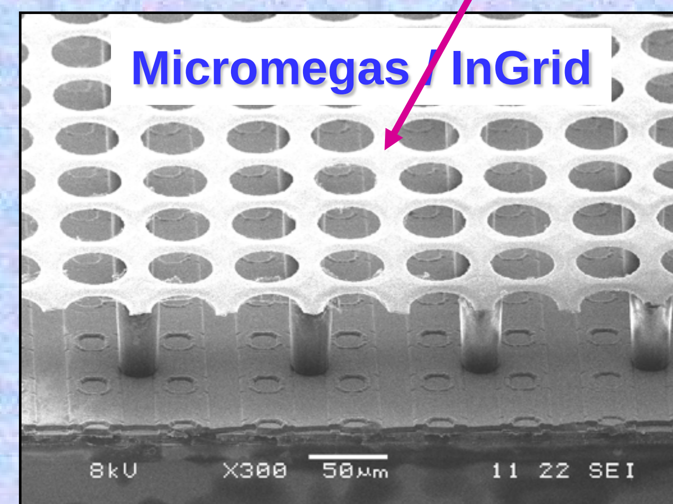
Micromegas/Ingrid + SiProt + Timepix Detector:

Apply Si3N4 (high resistivity layer 3-20 µm)

for discharge quench & SPARK PROTECTION

before InGrid production



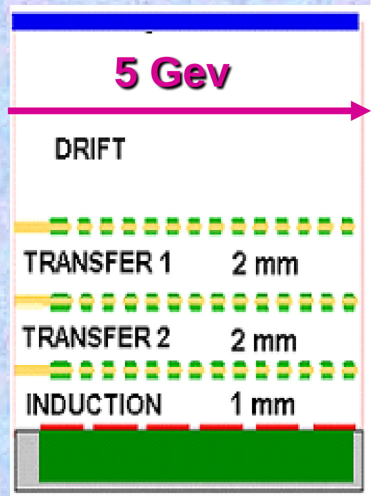


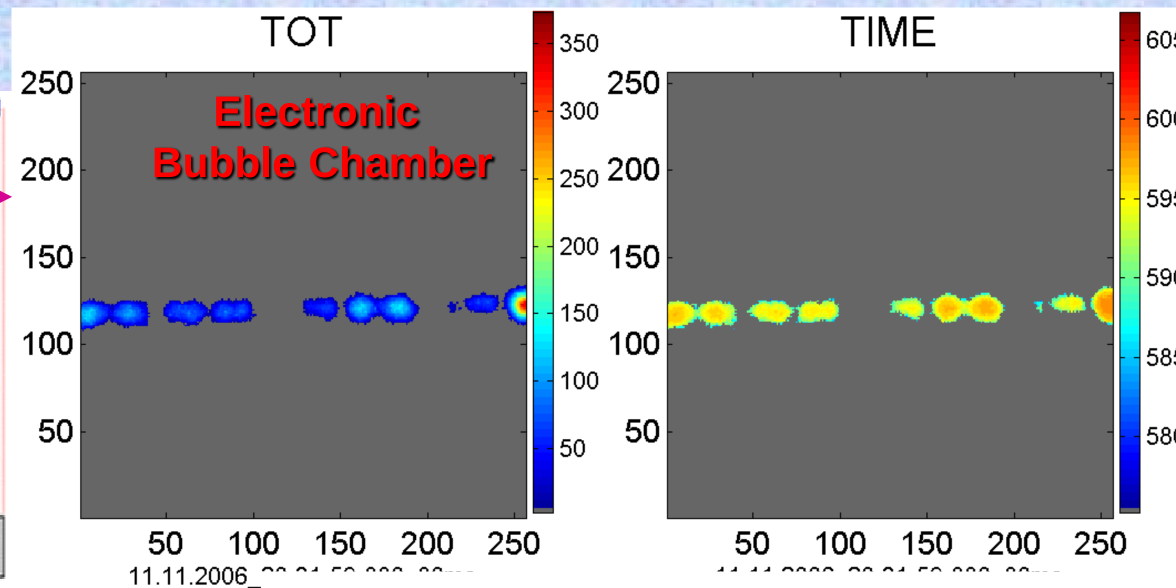
M. Chefdeville et al, NIMA556(2006) 490

GEM/Micromegas + Timepix Readout @ 5 GeV Electron Beam

Triple GEM + Timepix:

Operated in checker-board pattern of TOT (charge) and TIME (time)

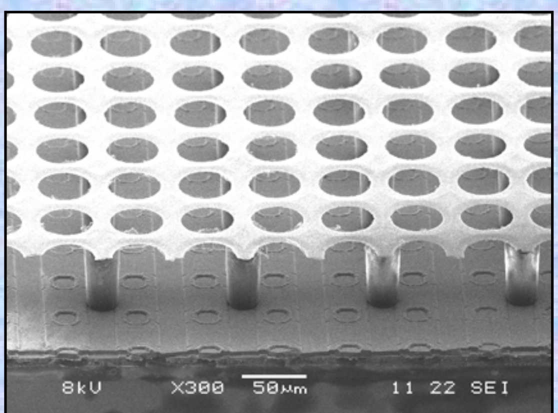


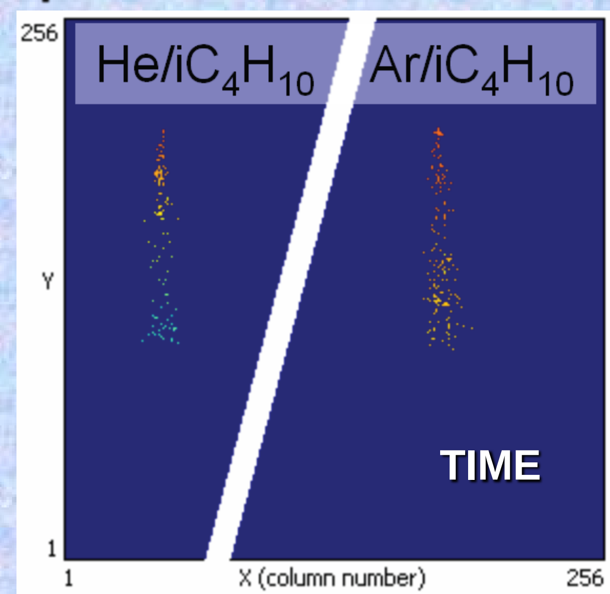


M. Titov, Nucl. Instr. and Meth. A581 (2007) 25.

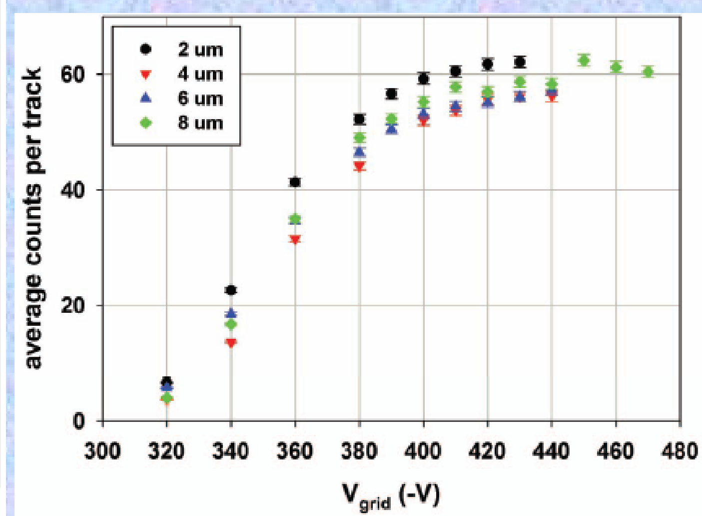
Micromegas/ Ingrid + Timepix:

Studies of SiProt layer thickness (efficiency & discharges):





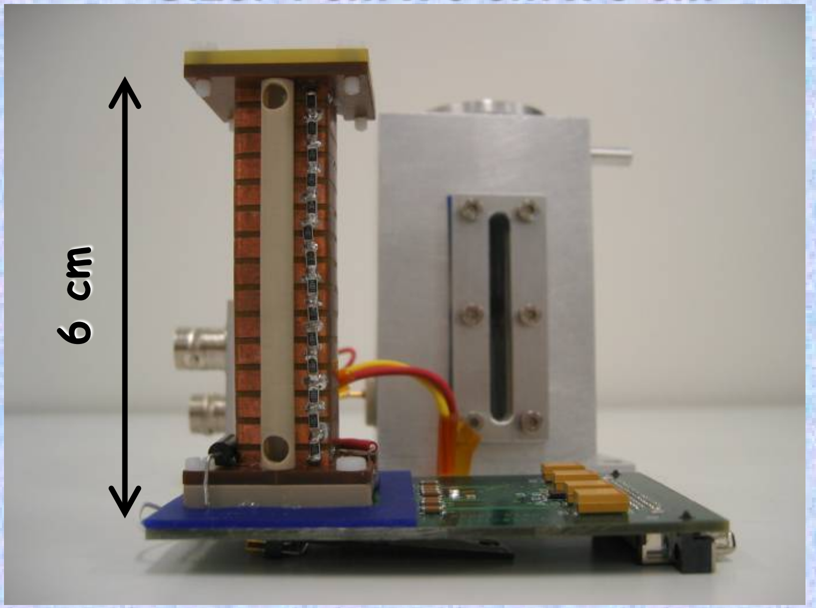
<Nhits> per track vs Si3N4 layer thickness:



Y. Bilevych et al., 2009 IEEE NSS/MIC Conference Record.

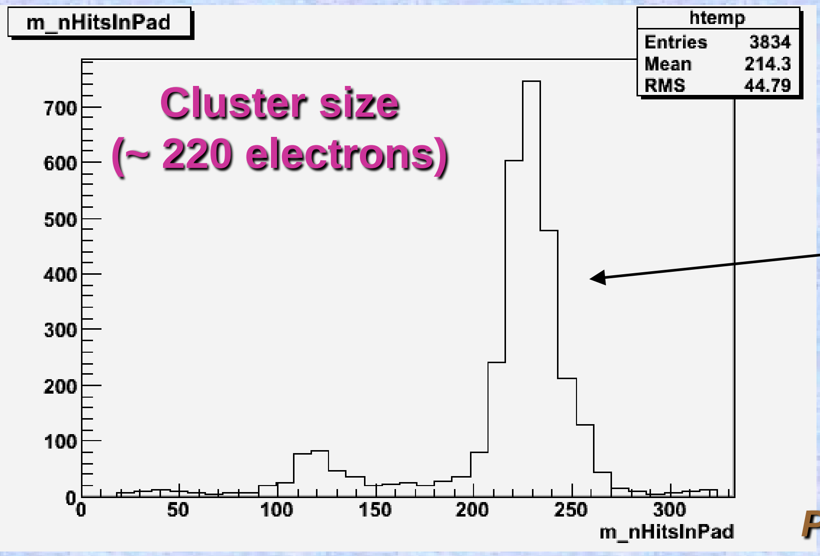
Micromegas/Ingrid + Timepix & microTPC

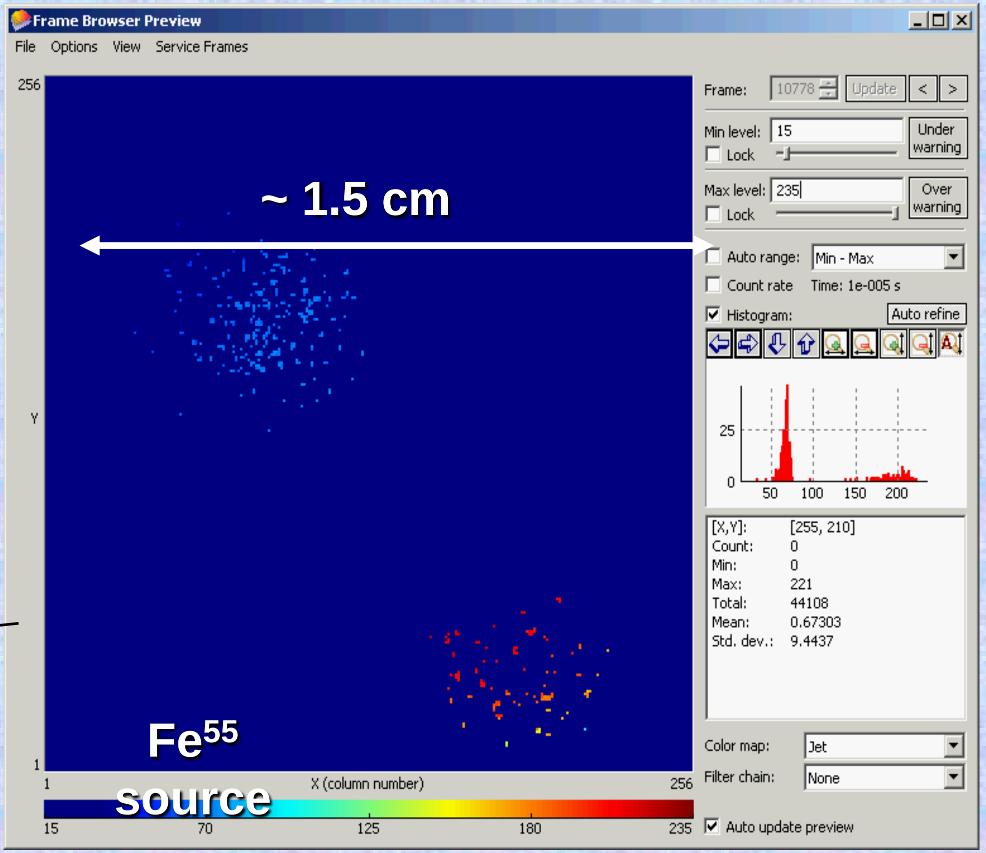
μTPC with a 6 cm height field cage
Size: 4 cm x 5 cm x 8 cm



Observe electrons (~220) from an X-ray (5.9 keV) conversion one by one and count them

→ Study single electron response





Micromegas/Ingrid + Timepix & Discharges

- **Strong electric field (70 – 100 kV/cm) over the Si-pixel chip**

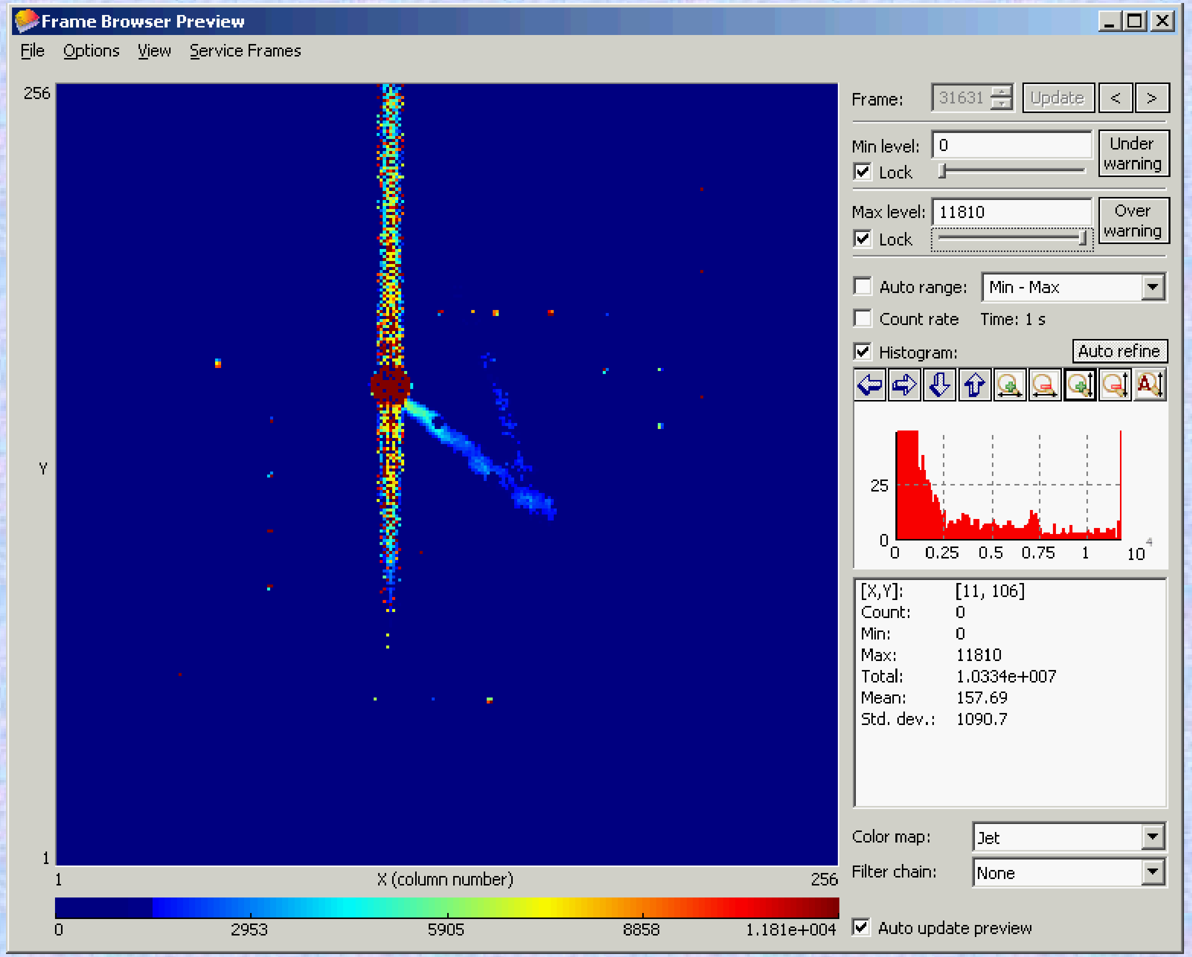
- **Provoke discharges by introducing small amount of Thorium in the Ar gas**
  - **- Thorium decays to Radon 222 which emits 2 alphas of 6.3 & 6.8 MeV (~ 10^5 e)**

- **Round-shape images of discharges are being recorded**

- **Perturbations in the concerned columns**

  - Threshold ?
  - Power ?

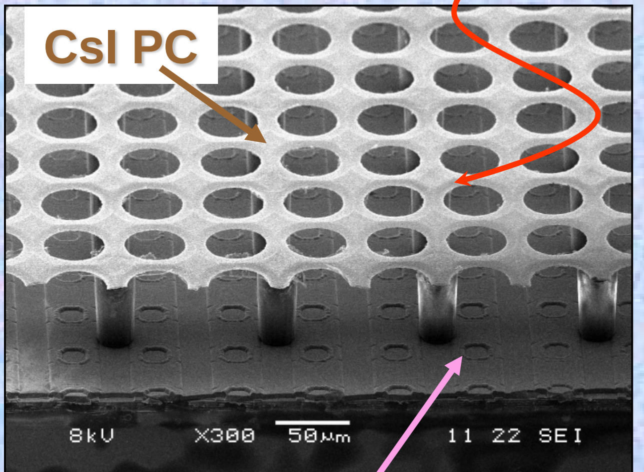
Chip keeps working !

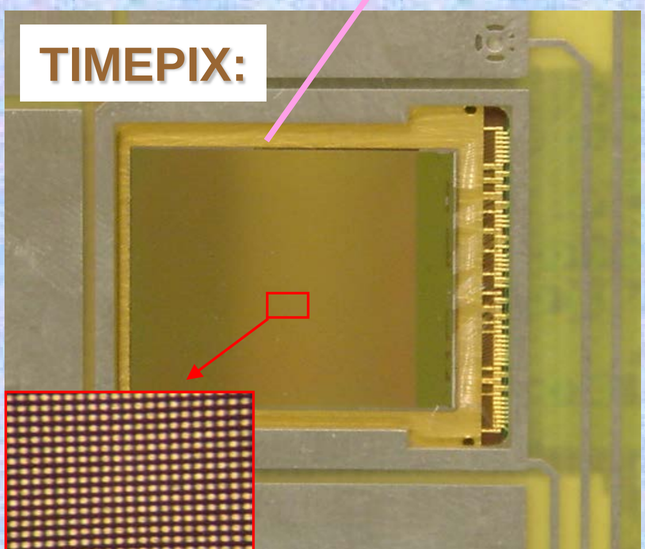


Photosensitive Detector: Integrating Ingrid and CMOS readout

MICROMEGAS (InGrid) covered with CsI

photon

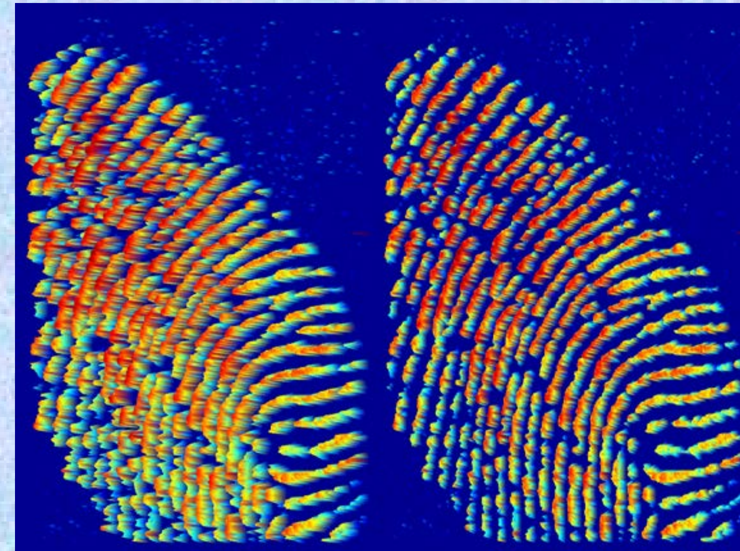




Chip area: 14x14mm².
(256×256 pixels of 55×55 µm²)

Ingrid without CsI

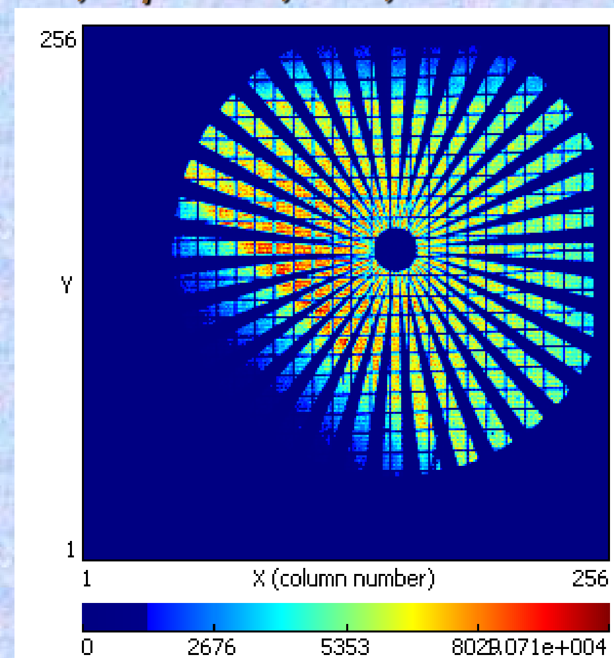
UV absorbed by the fingerprint on the window



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

Ingrid with CsI PC:

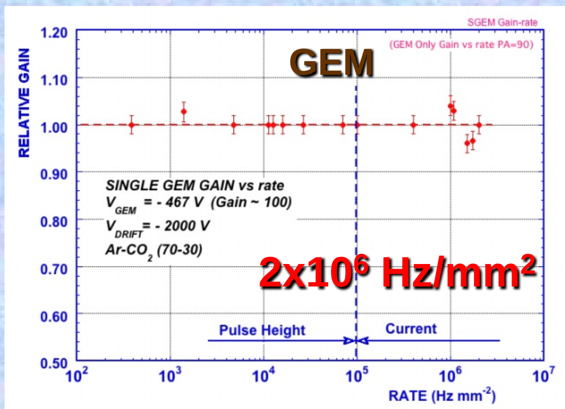
2D UV Image of a 10mm diameter mask

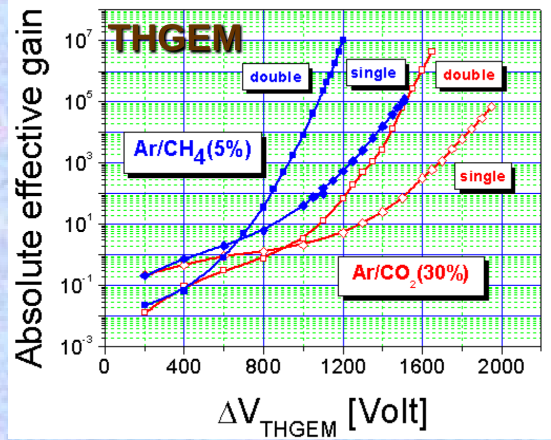


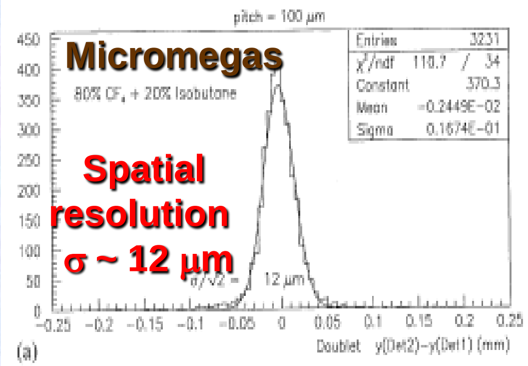
A. Breskin, RD51 Collab. Meet., Nov.25, 2009, RD51 Plenary

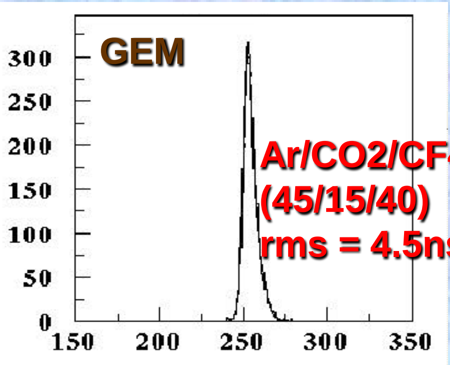
Micro-Pattern Gas Detectors Performance Summary

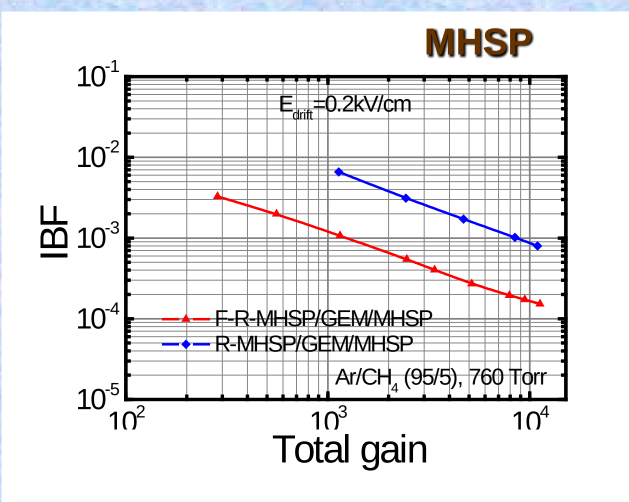
- **Rate Capability**
- **High Gain**
- **Space Resolution**
- **Time Resolution**
- **Energy Resolution**
- **Ageing Properties**
- **Ion Backflow Reduction**
- **Photon Feedback Reduction**

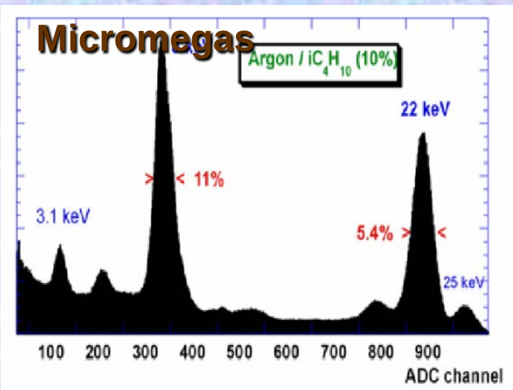


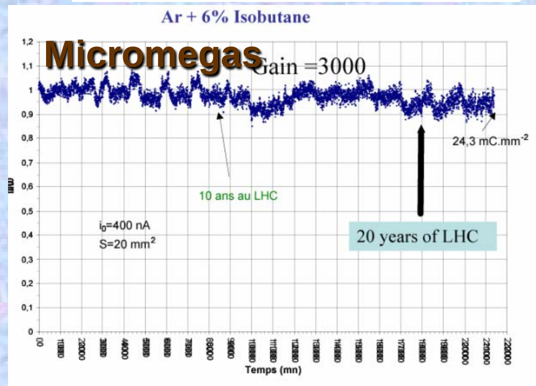












RD 51 Collaboration - Working Groups

Advance Technological Developments of Micro-Pattern Gas Detectors

RD51 – Micropattern Gas Detectors

	WG1 MPGD Technology & New Structures	WG2 Characterization	WG3 Applications	WG4 Software & Simulation	WG5 Electronics	WG6 Production	WG7 Common Test Facilities
Objectives	Design optimization Development of new geometries and techniques	Common test standards Characterization and understanding of physical phenomena in MPGD	Evaluation and optimization for specific applications	Development of common software and documentation for MPGD simulations	Readout electronics optimization and integration with MPGD detectors	Development of cost-effective technologies and industrialization	Sharing of common infrastructure for detector characterization
Tasks	Large Area MPGDs Design Optimization New Geometries Fabrication Development of Rad-Hard Detectors Development of Portable Detectors	Common Test Standards Discharge Protection Ageing & Radiation Hardness Charging up and Rate Capability Study of Avalanche Statistics	Tracking and Triggering Photon Detection Calorimetry Cryogenic Detectors X-Ray and Neutron Imaging Astroparticle Physics Appl. Medical Applications Synchrotron Rad. Plasma Diagn. Homeland Sec.	Algorithms Simulation Improvements Common Platform (Root, Geant4) Electronics Modeling	FE electronics requirements definition General Purpose Pixel Chip Large Area Systems with Pixel Readout Portable Multi-Channel System Discharge Protection Strategies	Common Production Facility Industrialization Collaboration with Industrial Partners	Testbeam Facility Irradiation Facility

RD 51 Collaboration Organization

Consolidation around common projects: large area MPGD R&D, CERN/MPGD Production Facility, electronics developments, software tools, beam tests

WG1: large area Micromegas, GEM; THGEM R&D; resistive anode readout; design optimization (discharge protection)

WG2: single-electron response, avalanche fluctuations, photo detection with THGEM, GOSSIP/Ingrid (radiation tolerance, discharge protection, rate effects)

WG3: applications beyond HEP, industrial applications (X-ray diffraction, homeland security)

WG4: microtracking; neBEM field solver, electroluminescence simulation tool, Penning transfers, GEM charging up; MM transparency and signal

WG5: scalable readout system; Timepix multi-chip MPGD readout

WG6: CERN MPGD Production Facility; TT Network

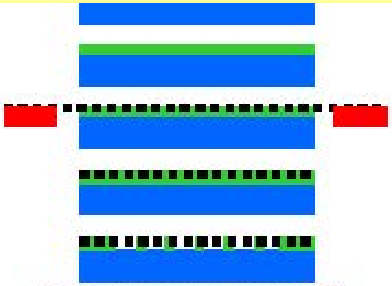
WG7: RD51 test beam facility (November 2009 - 8 groups/5 setups)

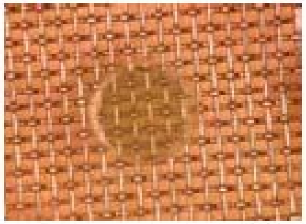
RD 51 WG1- MPGD Technology and New Structures

Objective: Detector design optimization, development of new multiplier geometries and techniques.

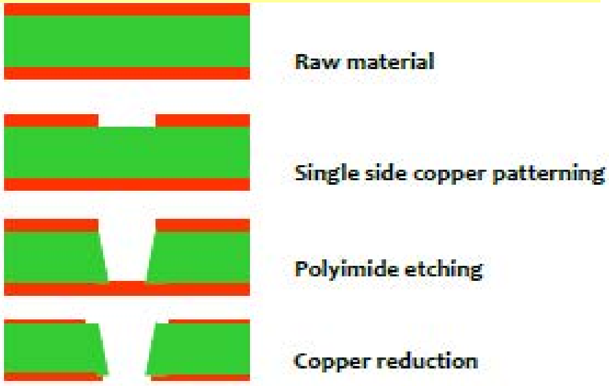
- **Development of Large Area MPGD (production of demonstrators)**

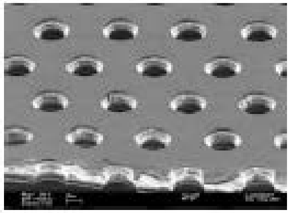
Bulk Micromegas



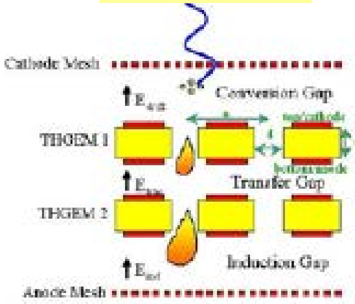


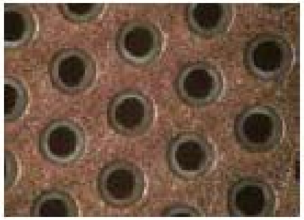
NEW - Single mask GEM





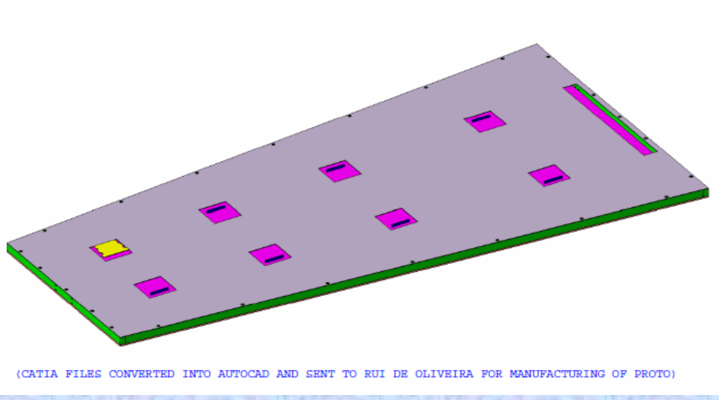
THGEM



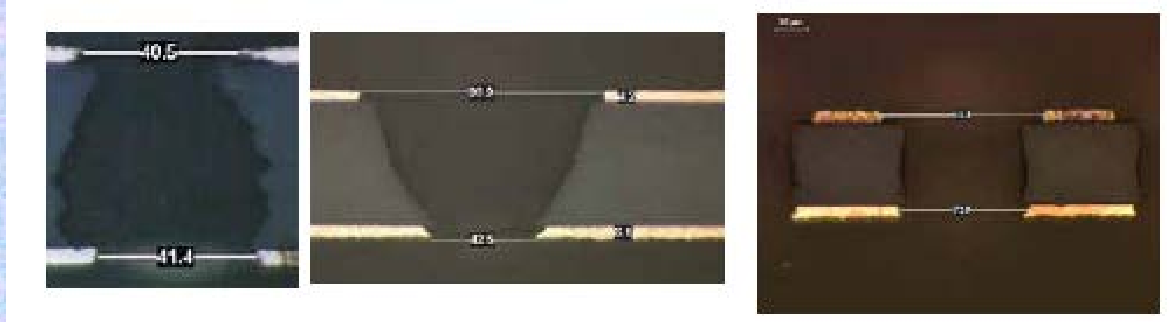


Large Area GEM Detector Development

GEM feasibility studies for CMS high-eta ($\eta > 1.6$) upgrade:



New single mask technology: Development and evaluation With small prototypes



TWO-SECTORS TRIPLE-GEM PROTOTYPE FOR TOTEM T1 UPGRADE ($60x60\ cm^2$)

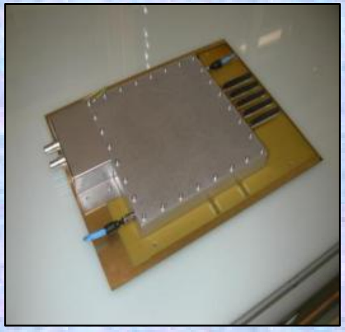
Large Area Micromegas Detector Development

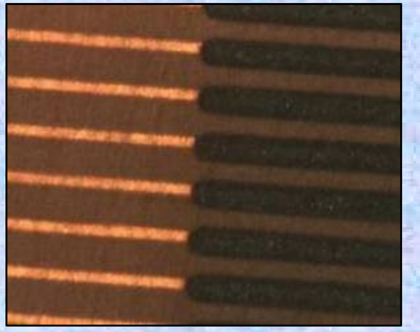
sLHC ATLAS Muon Upgrade (MAMMA Collaboration):

On the road to large area detectors: (1.5 * 0.5 m^2) – Half the final size

Segmented mesh, 250 and 500 μm strip pitches, Longer strips (350 & 850 μm)

Study of resistive coatings for spark protection (smaller prototypes)



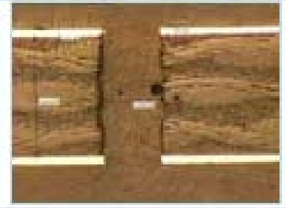


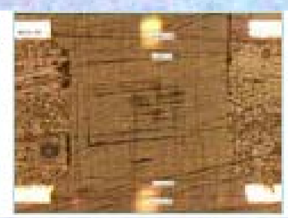
Uniformity, robustness, easy fabrication. small dead regions →

<u>"Full path of industrial production"</u>

Development of UV Large Photon Detectors based on THGEM

Technology Development & Prototype Construction





$300 \times 300 mm^2$ THGEM
90,000 0.5mm diameter holes
(Print Electronics, IL)

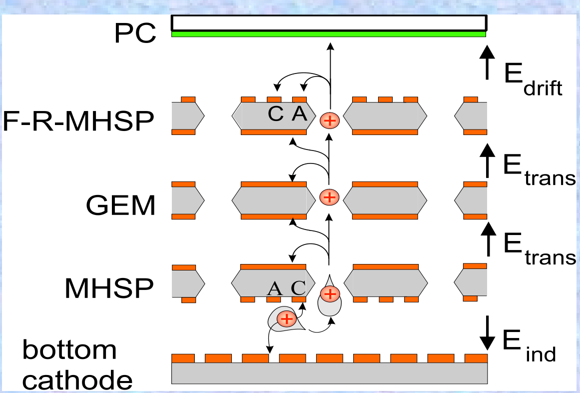
$600 \times 600 mm^2$ THGEM
600,000 0.4mm diameter holes
(Eltos, IT)

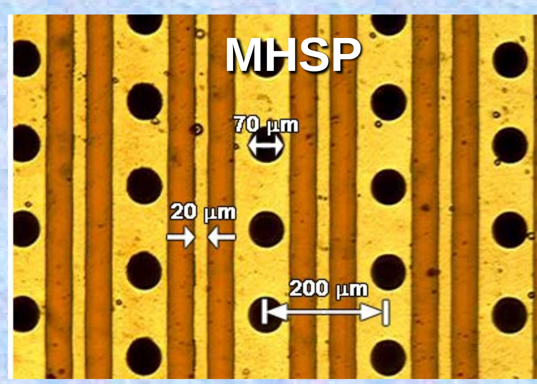
<u>Large-Area Detectors</u> possible (ns, sub-mm, MHz/mm^2)

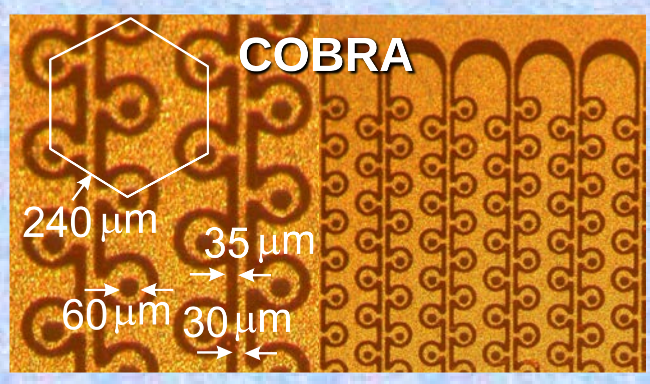
Status: so far only “mechanical” electrodes

RD 51 WG2 - Common Characterization and Physics Issues

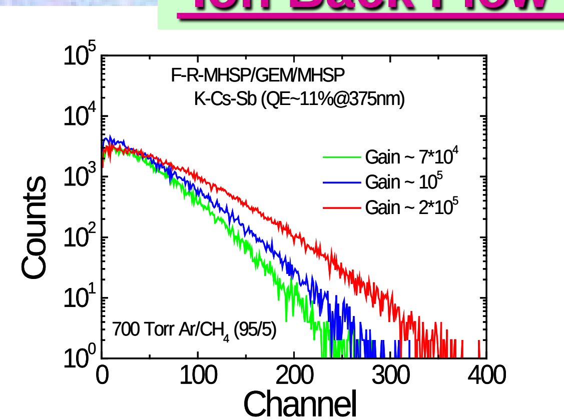
Objective: Development of common standards and comparison of different technologies, performance evaluation of different MPGD detectors.

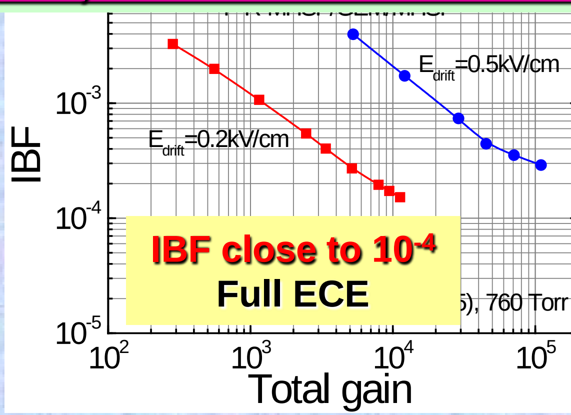


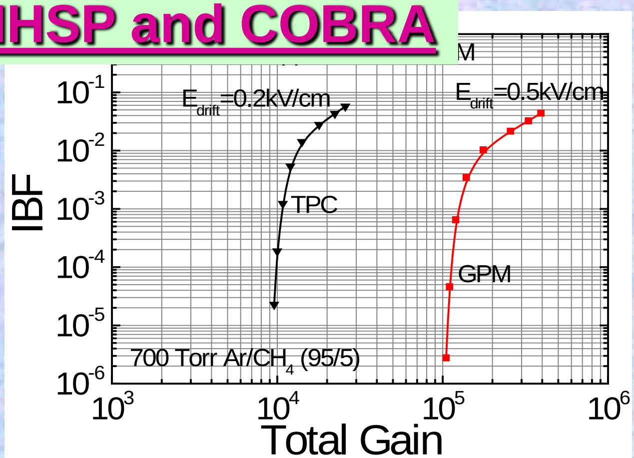




Ion Back Flow (IBF) Achievements with MHSP and COBRA







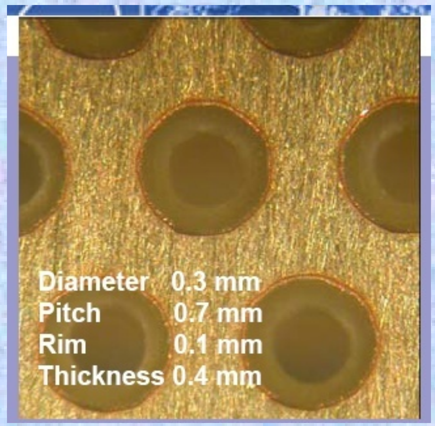
IBF 1000 x lower than with GEMs
At the expense of ECE (20%)

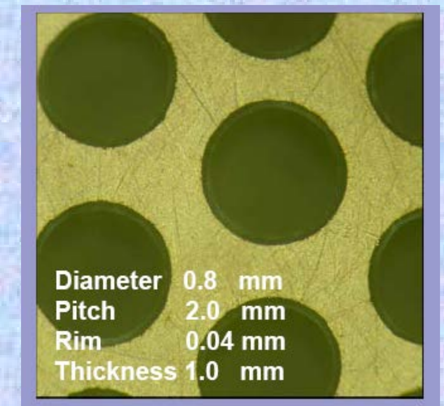
A. Lyashenko et al., NIMA 598(2008)116 and arXiv: 0706.3606
J. Veloso et al., Proc. of the MPGD Conference, Crete, June 2009
C. Azevedo et al. RD51 Collab. Meet., Nov.23-25, 2009, WG1 Meeting

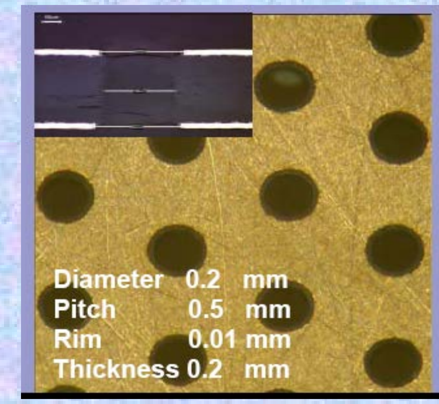
V. Peskov, P. Fonte, Research on Discharges in MPGD and what is important to study in the framework of RD51, *arXiv: 0911.0463, RD51 Note-2009-004*

Thick-GEM (THGEM) Desing Optimization

Choice of geometry (charging up, gain stability, maximum gain):





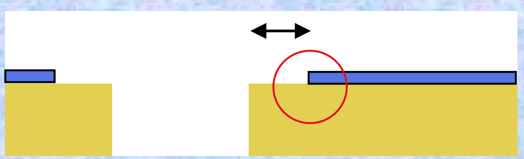


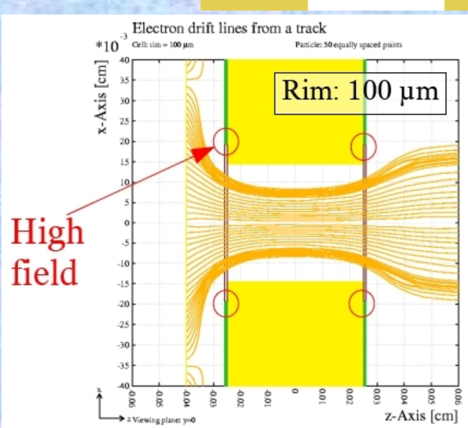
Mask etching + drilling; rim = 0.1mm

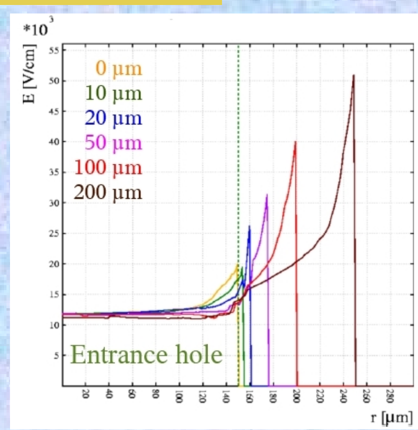
Drilling + chemical rim etching without mask

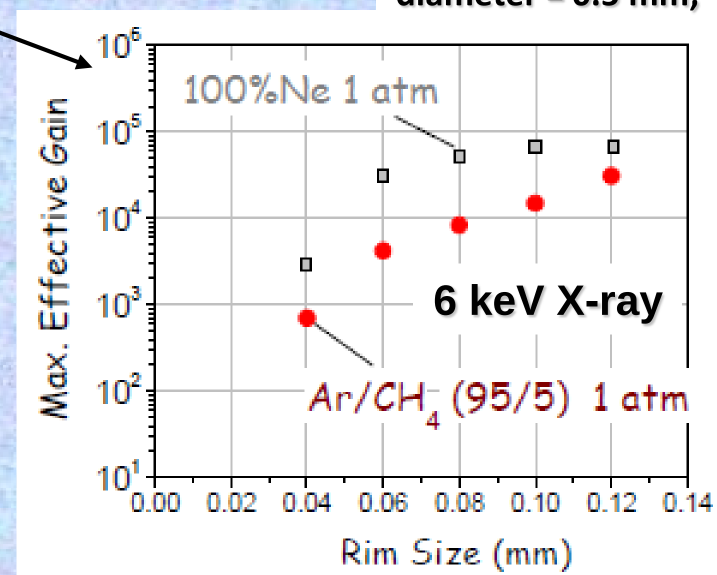
Holes with no rim: best stability (minimal charging up);
But: no-rim results in 10-100 times lower maximum gain

pitch = 1 mm;
diameter = 0.5 mm;





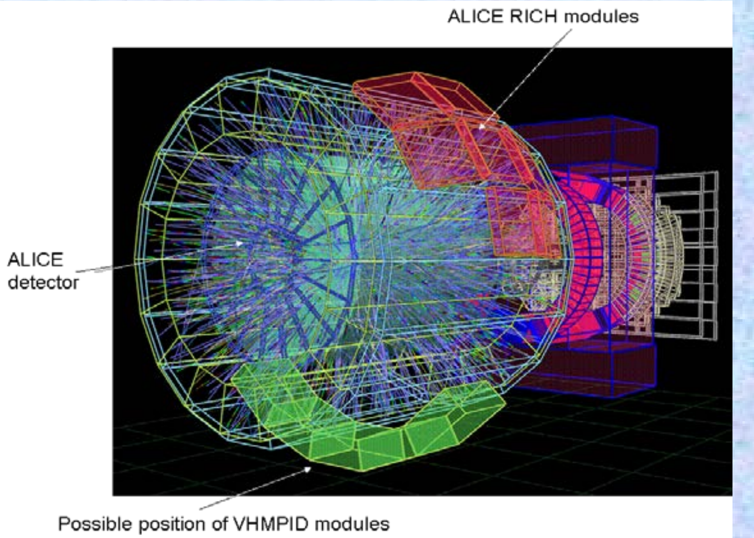


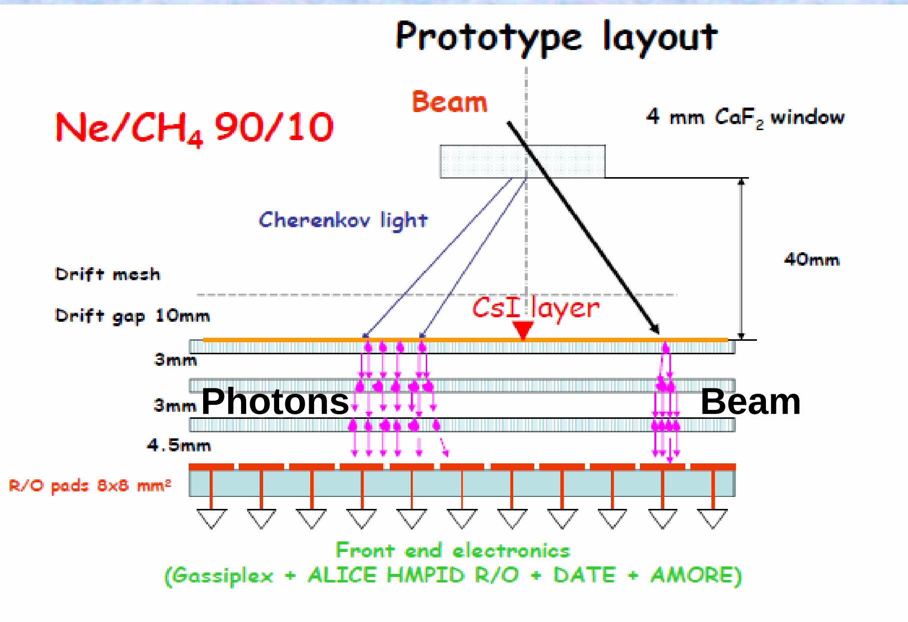


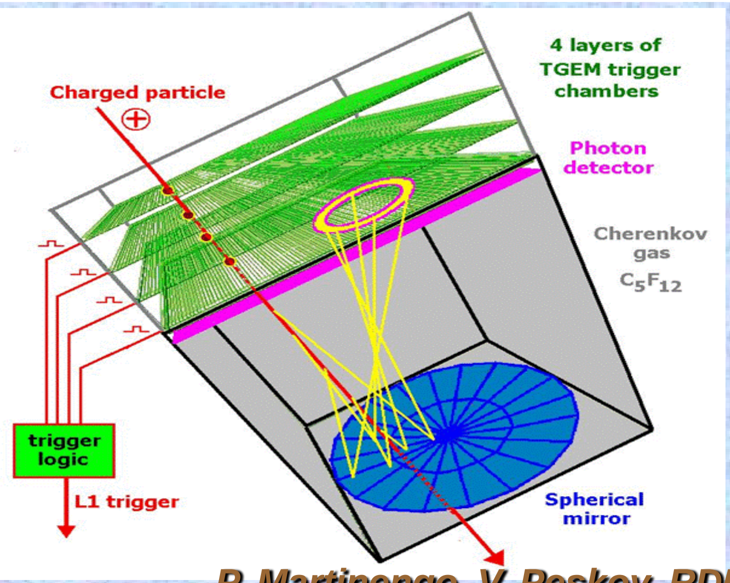
A. Breskin et al., NIMA 598 (2009) 107; F. Tessarotto et al., Proc. of the MPGD Conference, Crete, June 2009

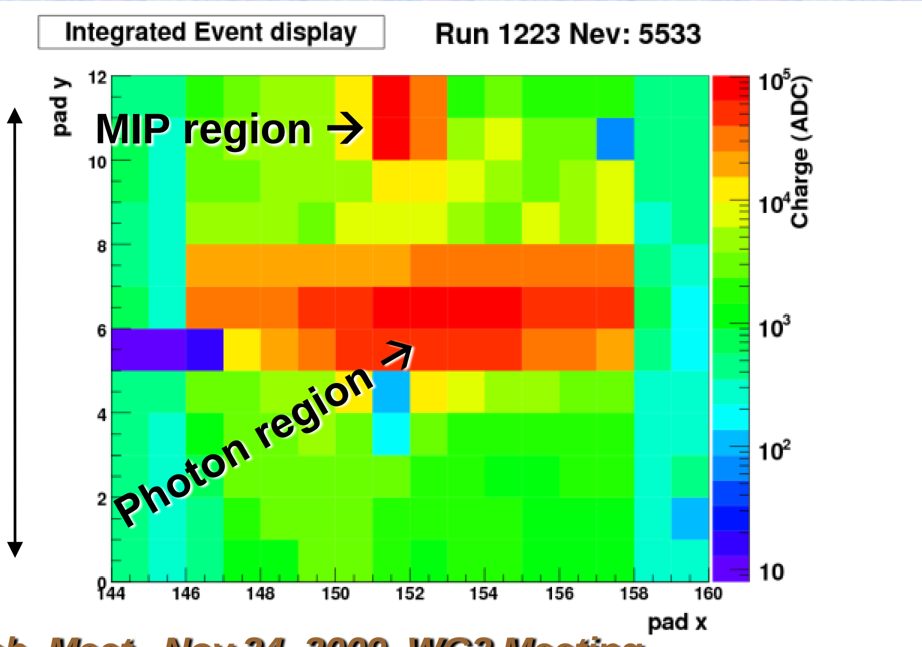
Detection of Cherenkov Light with CsI coated triple THGEM

3THGEM Detector is proposed for Very High Momentum Particle Identification Detector (VHMPID) for ALICE









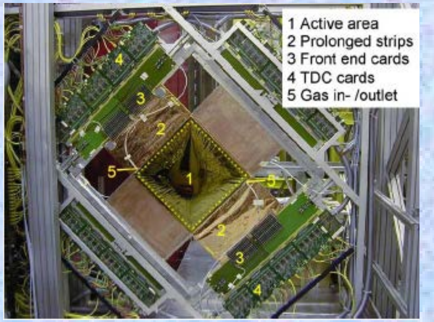
P. Martinengo, V. Peskov, RD51 Collab. Meet., Nov.24, 2009, WG2 Meeting

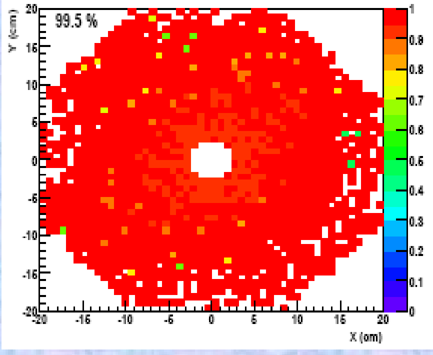
RD 51 WG3 - Applications

Objective: Evaluation and optimization of MPGD technologies for specific applications.

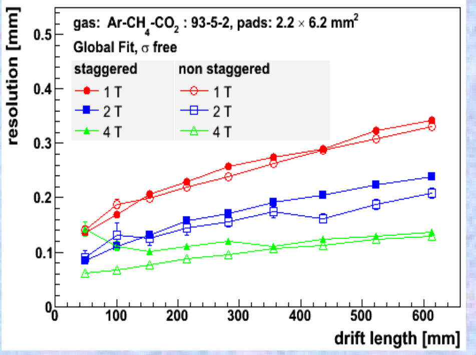
- MPGD based detectors for tracking and triggering (including Muon Systems).
- MPGD based Photon De
- Applications of MPGD ba
- Cryogenic Detectors for
- X-ray and neutron imagi
- Astroparticle physics ap
- Medical applications.
- Synchrotron Radiation and Homeland Security applications.

Applications area will benefit from the technological developments proposed by the Collaboration; however the responsibility for the completion of the application projects lies with the institutes themselves.

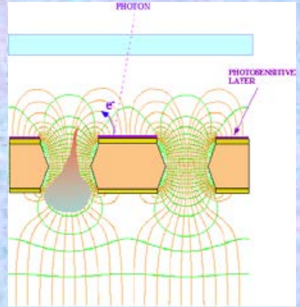


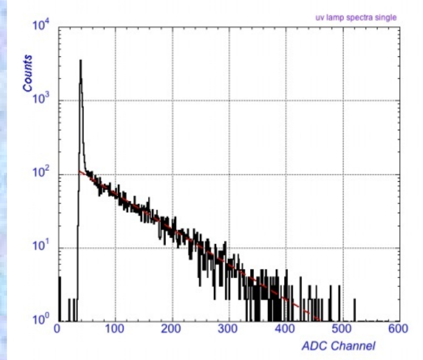


Tracking

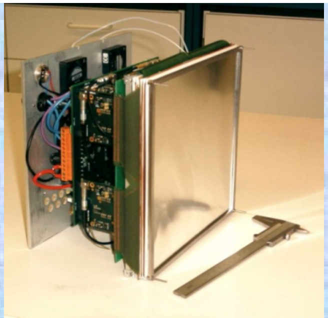


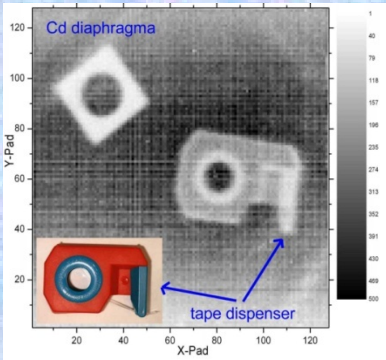
TPC readout





UV photon detection

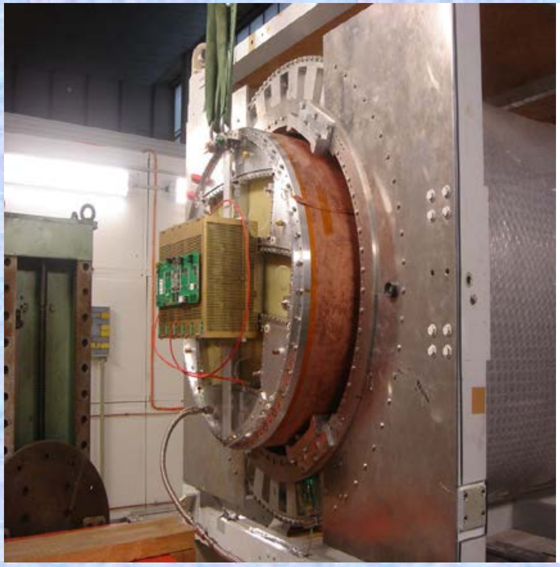


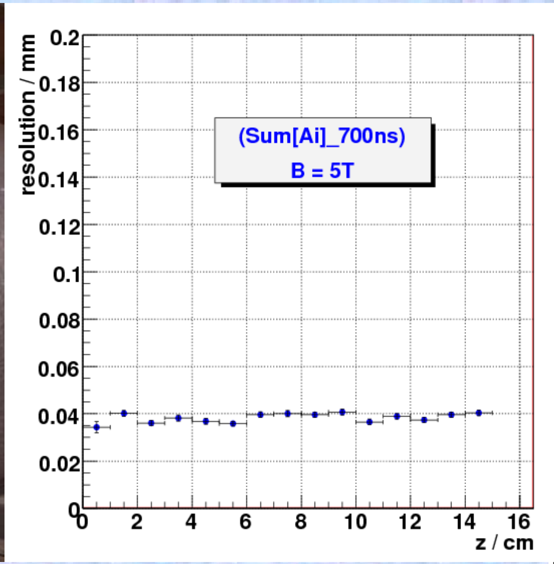


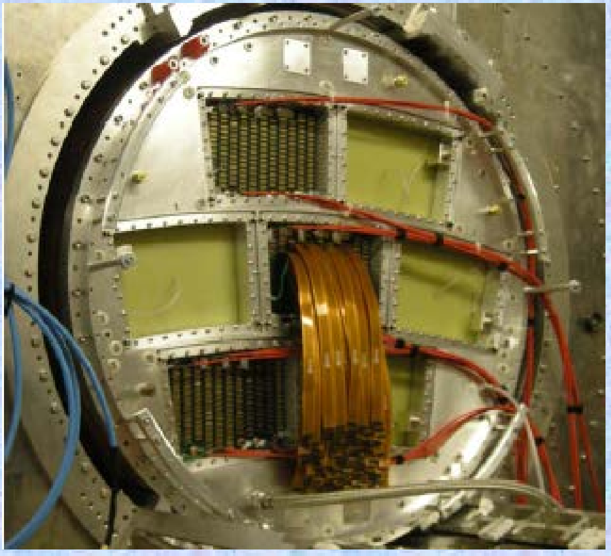
Neutron detection

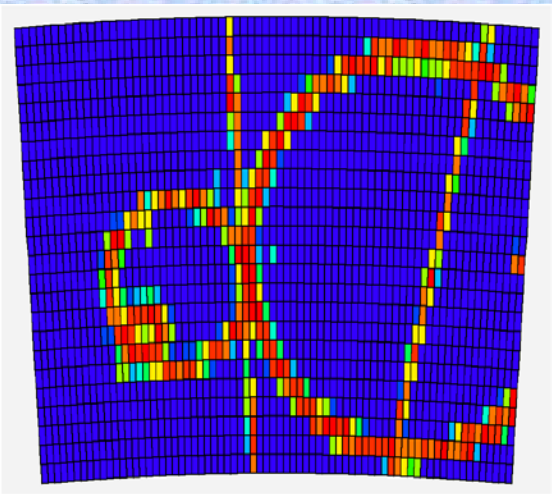
Micromegas/GEM for the ILC TPC

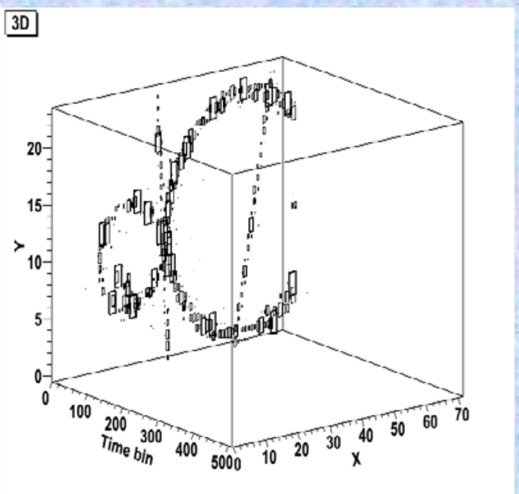
Micromegas TPC **(Large Prototype Tests at DESY in 2009)** **GEM TPC**

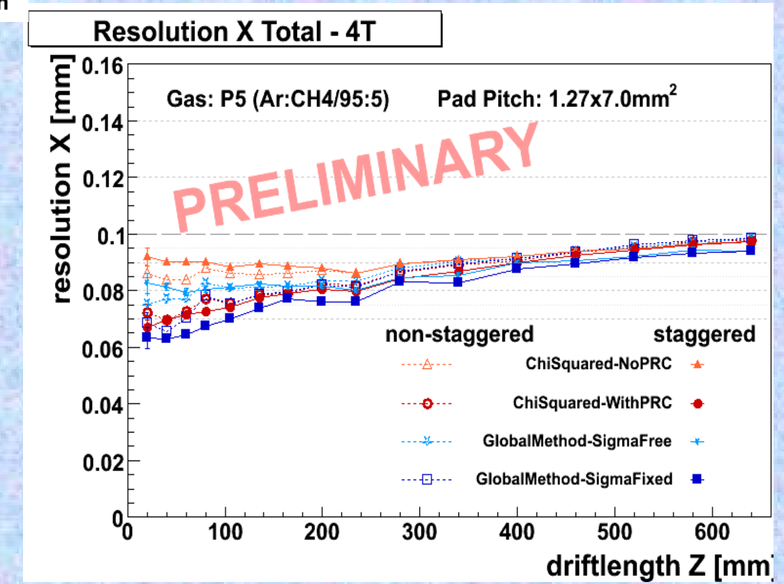










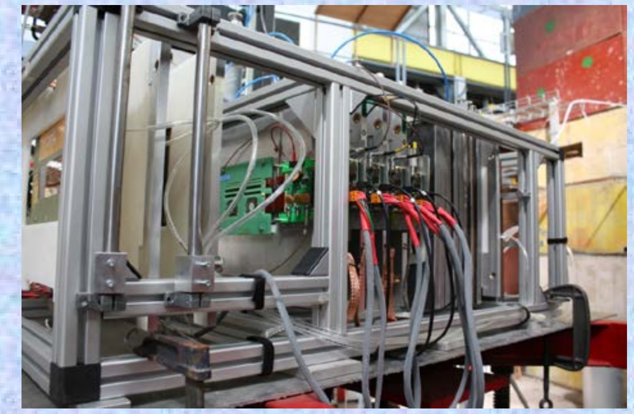


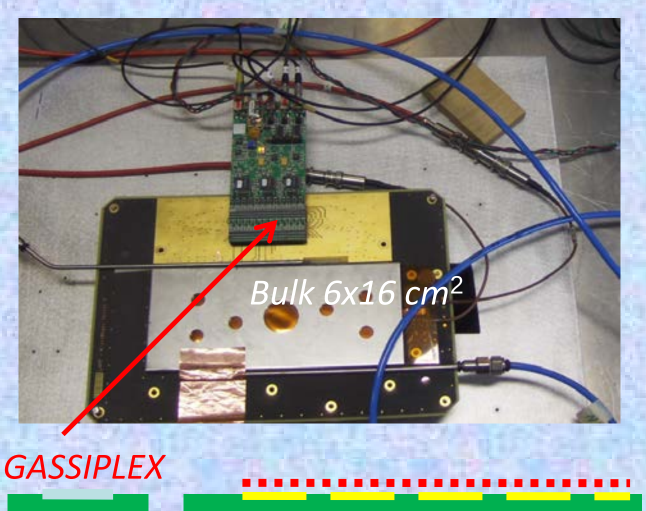
M. Dixit, Proc. of the MPGD Conf., Crete, June 2009
D. Attie, Proc. of the MPGD Conf., Crete, June 2009
T. Matsuda, Proc. of the MPGD Conf, Crete, June 2009
G. W. P. De Lentdecker, 2009 IEEE NSS/MIC Conf. Rec.

Micromegas/GEM for the ILC DHCAL

Micromegas DHCAL:

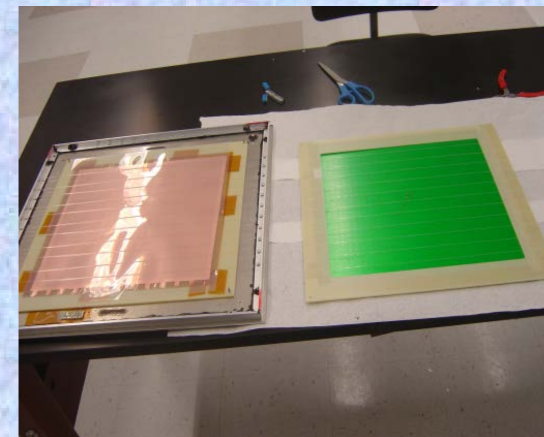
- **Analog readout prototypes for characterization (GASSIPLEX chips)**
- **Digital readout prototypes with embedded electronics (HARDROC/DIRAC)**

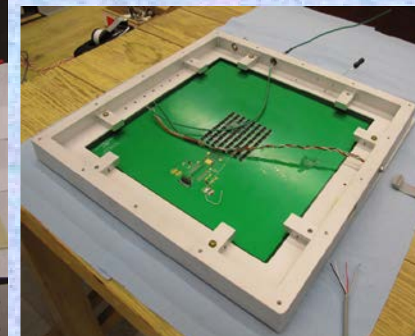




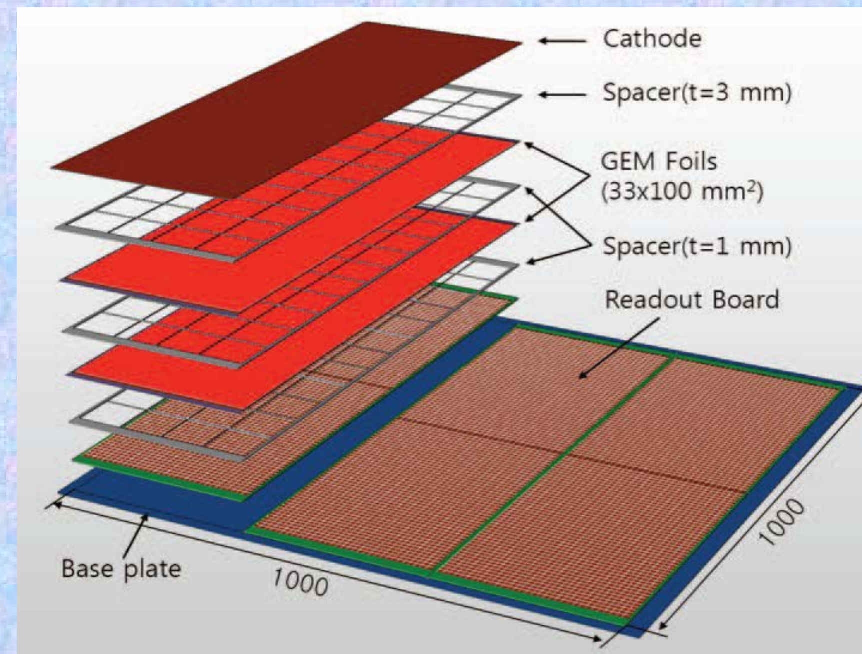
C. Adloff et al., Proc. of the MPGD Conf., Crete, June 2009

GEM-based Digital HCAL:





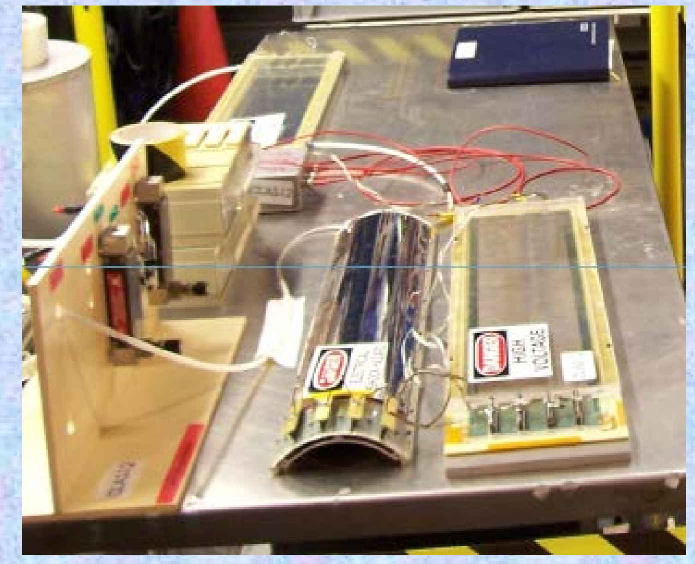
Construction of 1m * 1m unit detector:

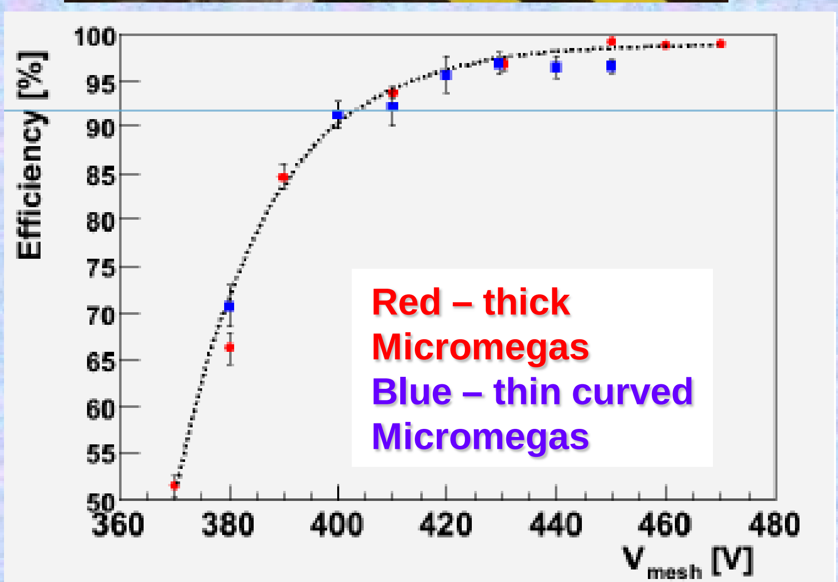


J. Yu, 2009 IEEE NSS/MIC Conference Record

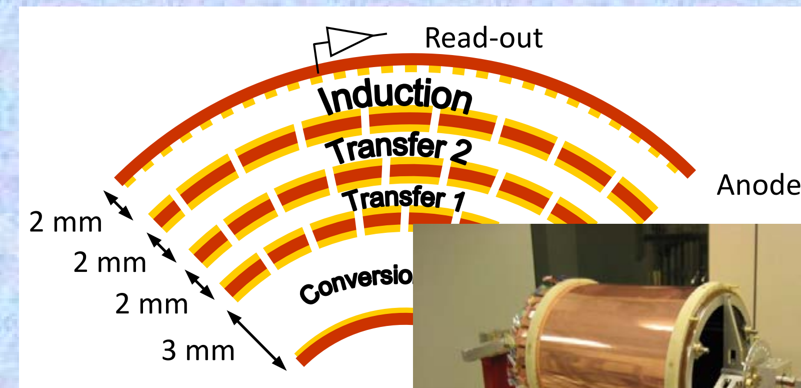
Curved Bulk Micromegas and Cylindrical GEMs

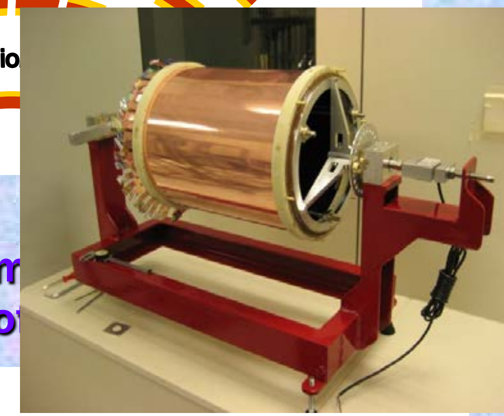
Thin Curved Micromegas for CLAS12



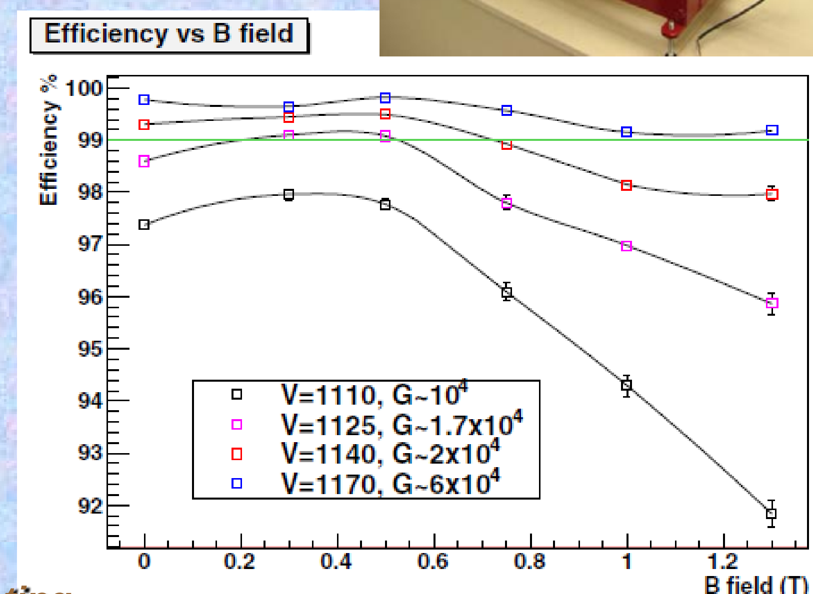


Cylindrical GEM for KLOE2 Inner Tracker:





Increase of m
larger spread o



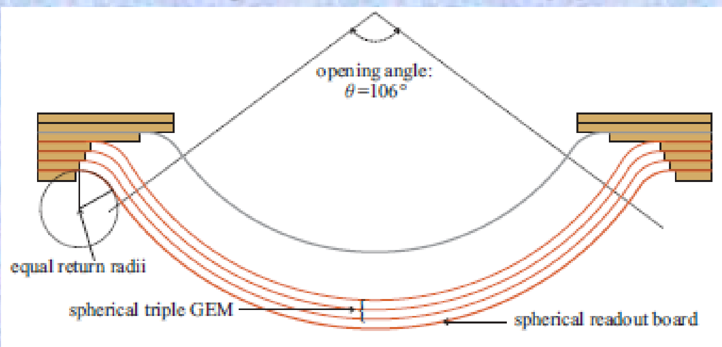
D. Nygret, RD51 Collab. Meet., Nov.23-25, 2009, WG7 Meeting

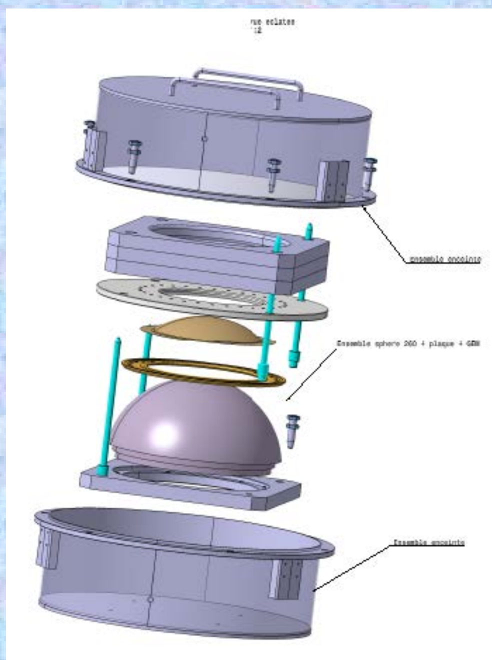
S. Aune, Proc. of the MPGD Conf., Crete, June 2009

A. Balla et al., 2009 IEEE NSS/MIC Conference Record.

GEM - Freedom of Shapes and Production Techniques

Spherical GEM for X-Ray diffraction application

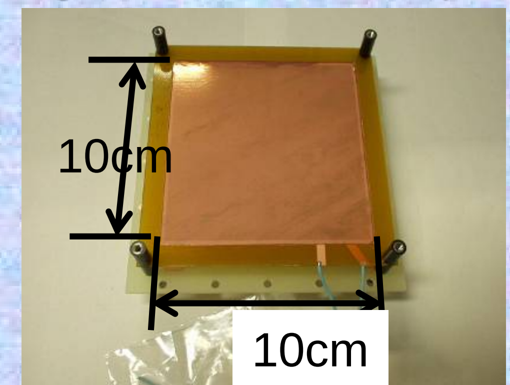


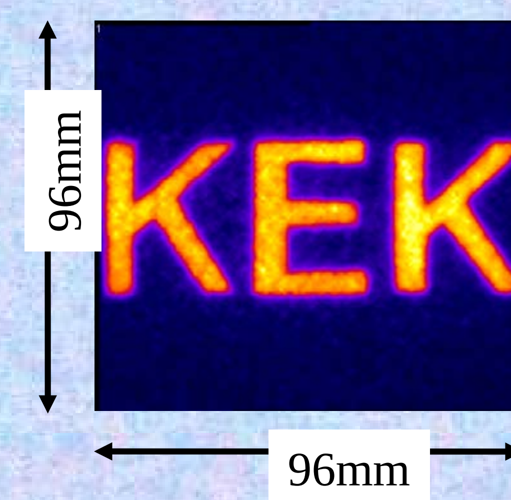


S. Duarte Pinto et al., 2009 IEEE NSS/MIC Conference Record.

New Methods of GEM Production (Scienergy Co., LtD):

- **Plasma etching**
  M. Inuzuka, et al., NIM A 525(2004) 529
- **Laser + Plasma etching:**
  T.Tamagawa, et al., NIM A560(2006) 418

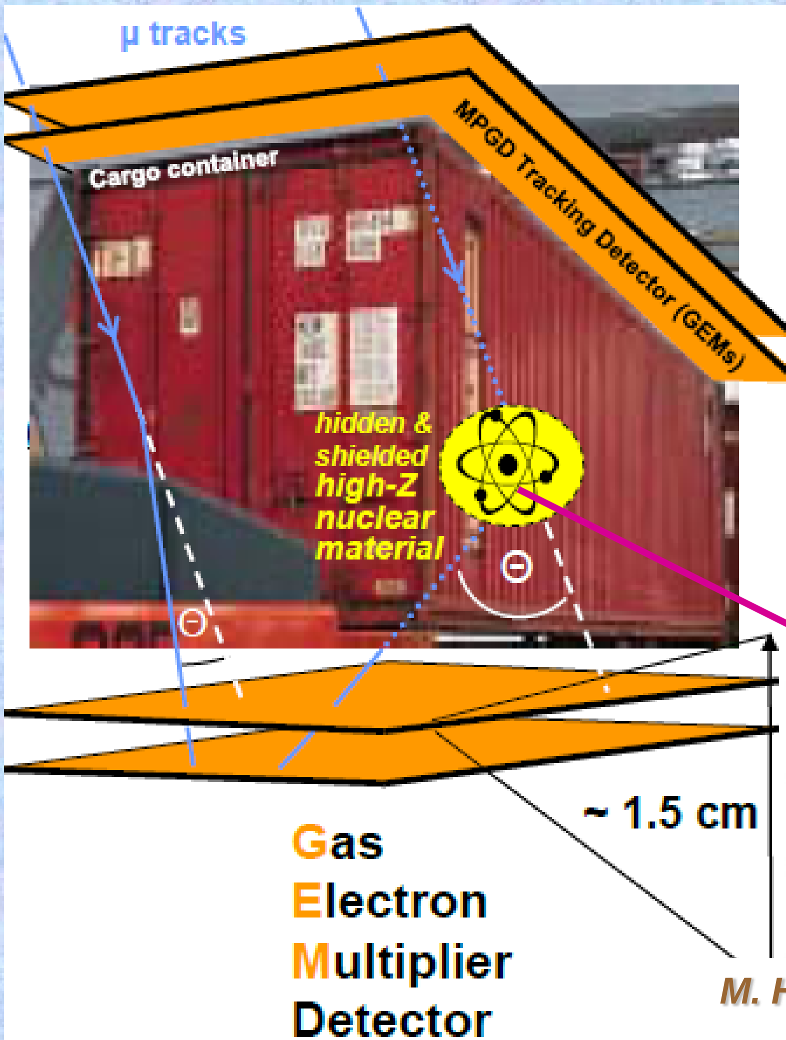


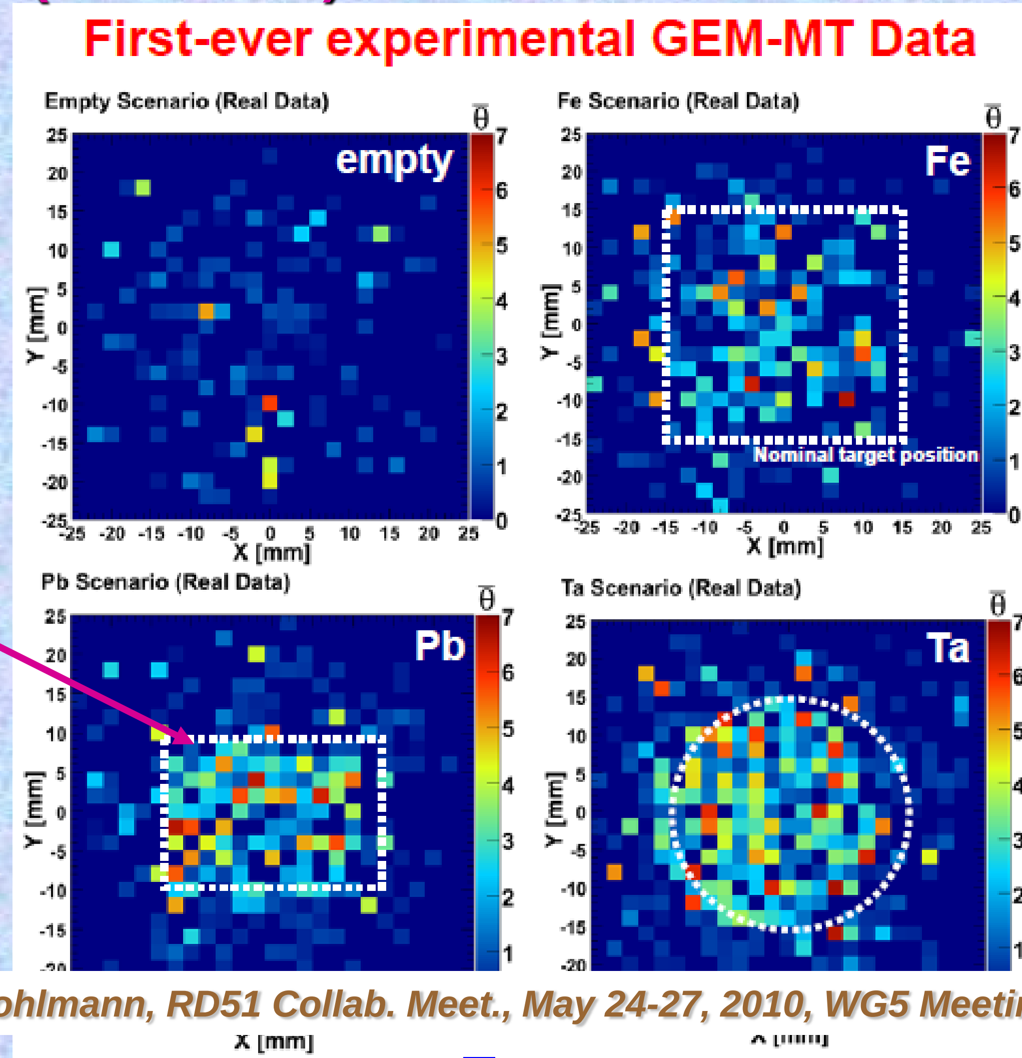


S. Uno, Proc. of the MPGD Conf., Crete, June 2009

Muon Tomography with GEM Detectors

First prototype using 10 GEMs (30*30 cm2) → build 1*1 m² station



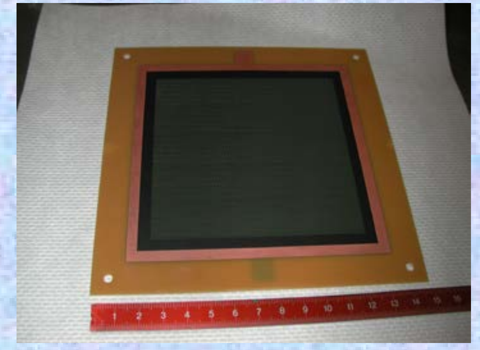


M. Hohlmann, RD51 Collab. Meet., May 24-27, 2010, WG5 Meeting

Article at www.wired.com - the online version of "WIRED", a US magazine on technology and popular science: http://www.wired.com/wiredscience/2010/07/muon-detector/

Micro-Pattern Detectors for Forest Fire Warning System

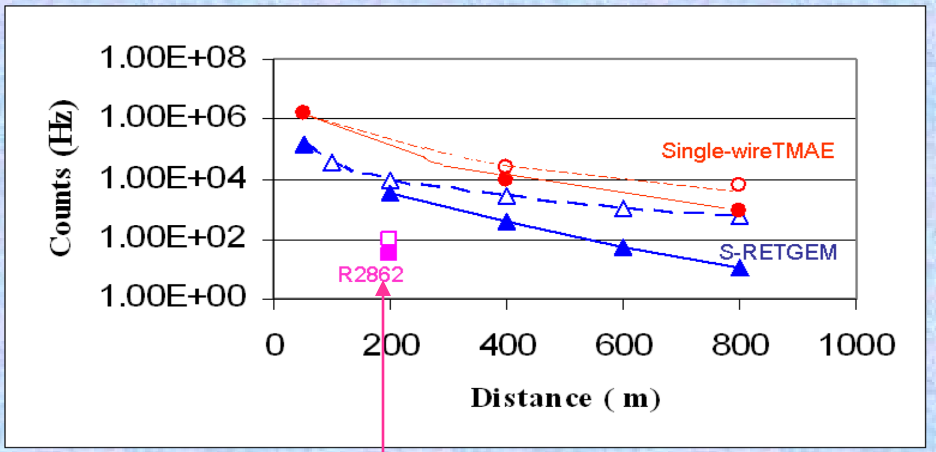
Long distance small flame detection under direct sun irradiation



Resistive GEM

Single-wire counter

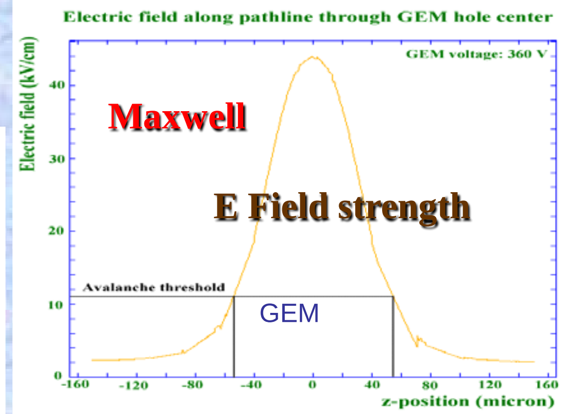
Results of long-distance tests:



The best existing commercial detector

Gaseous detectors could be 100-1000 times more sensitive than the best commercial detectors

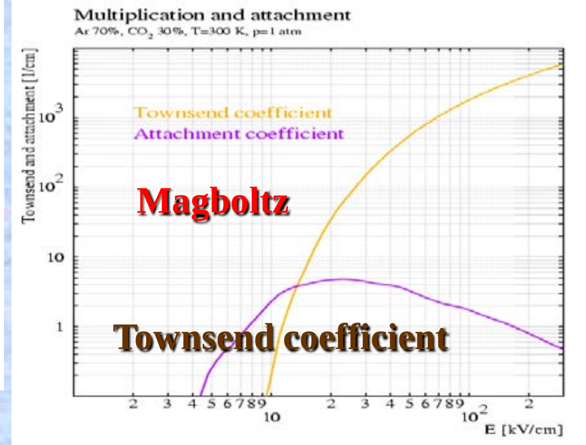
RD51 WG4 - Simulation and Software Tools

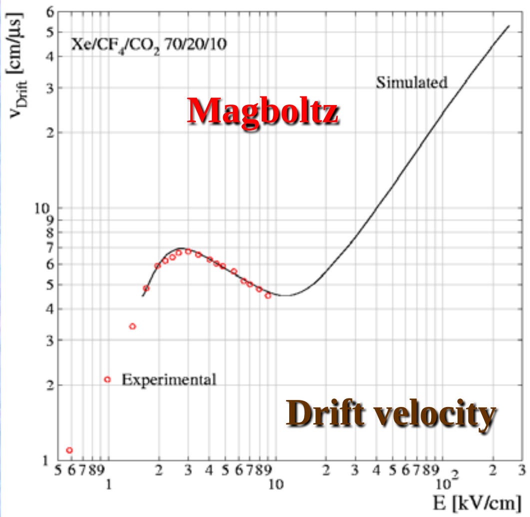


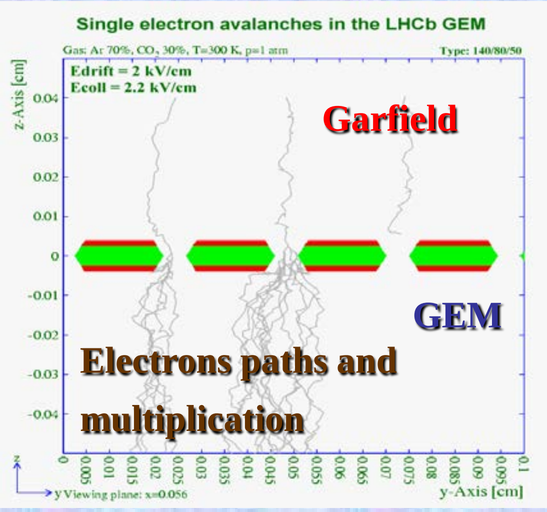
- **Development of common platform for detector simulations** (gas detector simulation in Geant4, interface to ROOT).

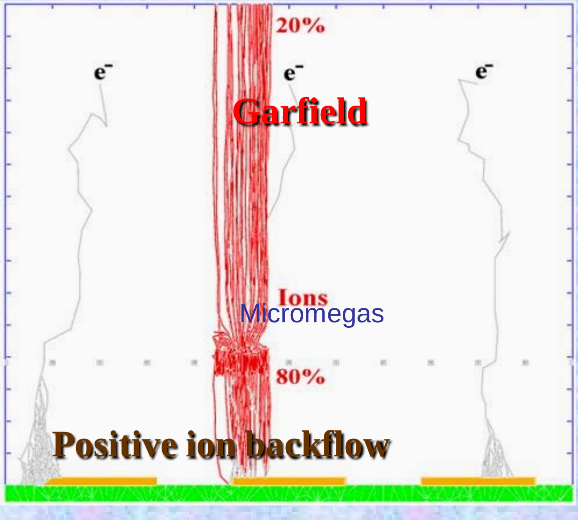
- **Development of algorithms** (in particular in the domain of very small scale structures - <u>implementation of nearly exact boundary element method interfaced to Garfield</u>).

- **Simulation improvements** (" Penning transfer in argon-based gas mixtures », 2010 *JINST* 5 P05002)



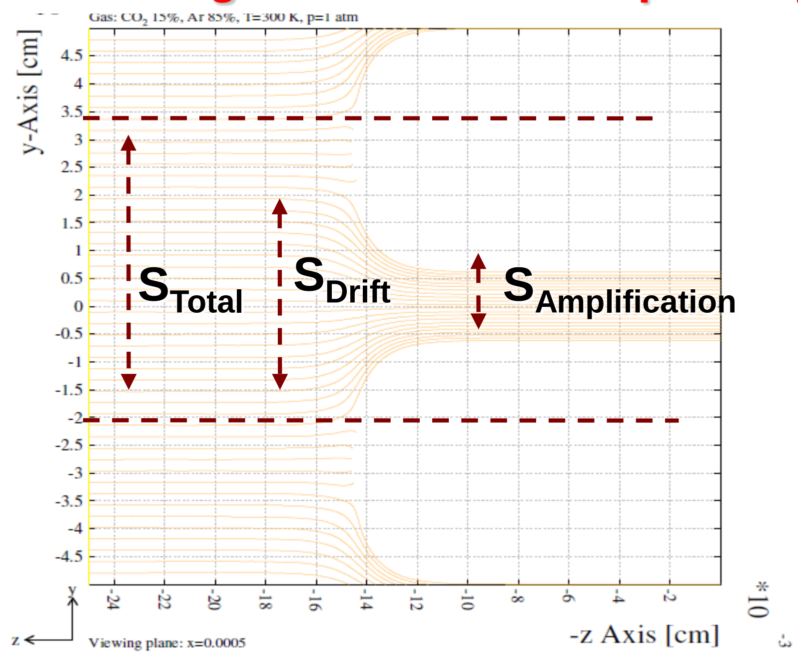


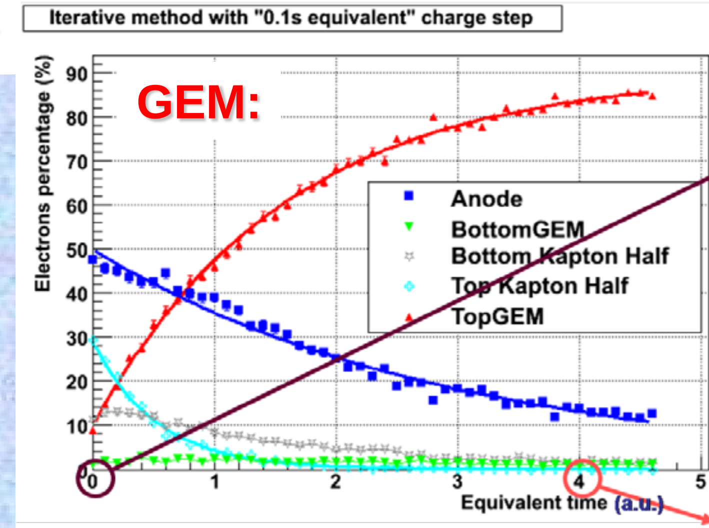


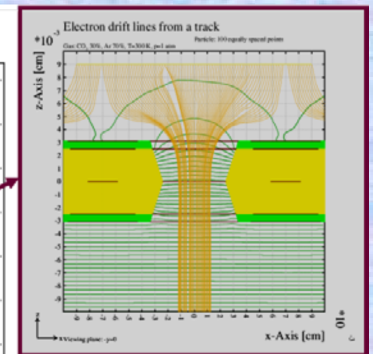


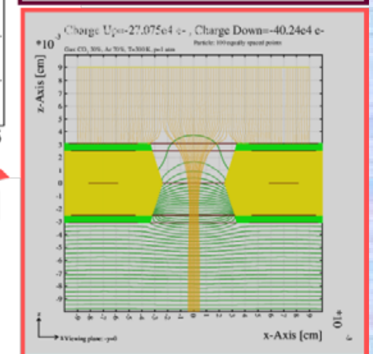
GEM and Micromegas: Charging-Up and Transparancy Simulation

Micromegas Electron Transparancy

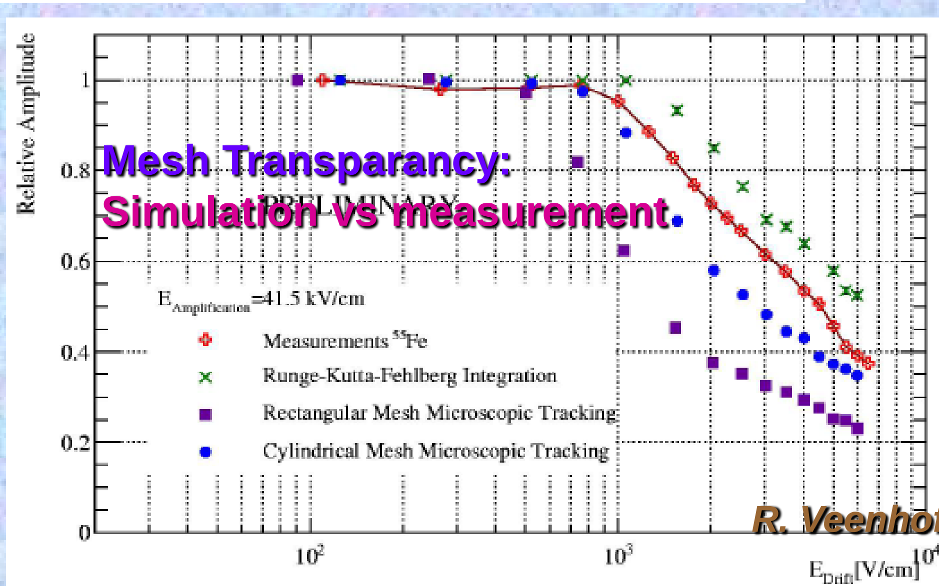








First "manual" iterative method GEM simulation with "0.1s equivalent charge step



Micromegas Electron Transparancy:

$$P(\text{e-collection}) = S_{Drift} / S_{Total}$$

$$= S_{Amplification} \times \text{Field-Ratio} / S_{Total}$$

~ (hole diameter)^2 ~ (wires pitch)^2

R. Veenhof, RD51 Collab. Meet., June 16-17, 2009, WG4 Summary

RD51 WG5: MPGD Electronics Developments

Objective: Readout electronics optimization and integration with detectors.

Survey of existing conventional readout systems:
GASSIPLEX, ASDQ, CARIOCA, ALTRO, SUPER ALTRO; APV, VFAT

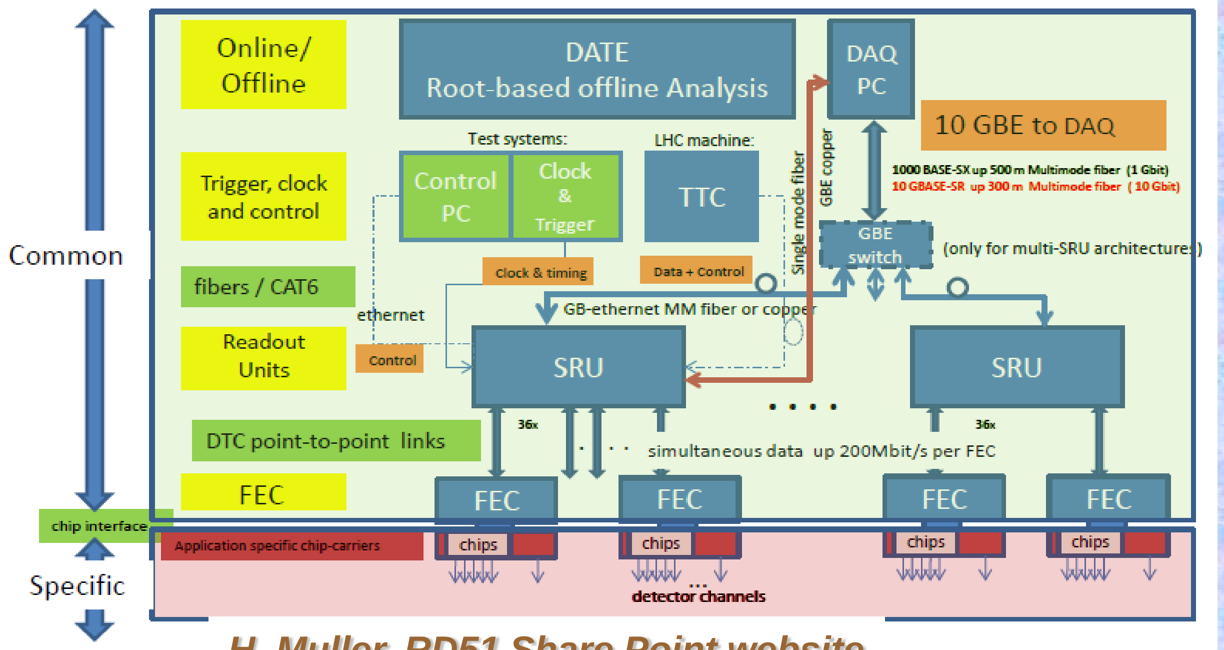
Name	Exp	Det	#ch	Shaper (ns)	Noise	Range (fC)	Pol.	ADC	f (MHz)	P/ch. (mW)	Feat.	Tech	Rad hard
APV25	CMS	Si strip	128	50	270+38e/pF	20	both	A	40	2.7	PD, PR	0.25 CMOS	10
AFTER	T2K	TPC	72	100-2000 s-gauss	(350-1800)+(22-1.8)e/pF	19	both	A	1-50 (100)	7.5	VG,VS	0.35 CMOS	no
MSGCROC	DETNI	Gas strip	32	T: 25 E: 85	2000e @ 40pF	800	both	A,1	2ns TDC		VG, ZS	0.35 CMOS	no
Beetle	LHCb		128	25	500+50e/pF	17.5	both	A/1	40	5.2	F-OR	0.25 CMOS	40
VFAT	TOTEM		128	22	650+50e/pF	18.5 (cal)	both	1	40	4.47	F-OR	0.25 CMOS	50
NINO	ALICE	TPC	8	1	1900+165/pF	2000 th<100	both	1	async	30	BR	0.25 CMOS	no
CARIOCA	LHCb	MWPC	8	<15 @ 220pF	2000+40e/pF	250	both	1	async	46	BR	0.25 CMOS	20
PASA+ ALTRO	ALICE TPC	TPC	16	190$_{fwhm}$ s-gauss	570e @20 pF	160	both	10	20	< 40	BC, TC, ZS	0.35,0.25 CMOS	
SVX4	CDF, D0	Si strip	128	100-360	410+45e/pF	60fC	neg	8	106 (212)	2	ZS	0.25 CMOS	20
SPIROC	ILC, T2K	SiPM	36	A:25-175 T: 10	A: 1/11pe; T:1/24pe	2000 pe	neg	8-12	100ps TDC	0.025 *pulse*	dual-gain	0.35 SiGe	no
Legend:	PD = peak detection, PR = pile-up rejection, VG = variable gain, VS = variable shaping, F-OR = fast-OR, BR = baseline restorer, BC = baseline correction, TC = tail correction, DC = data compression, ZS = zero suppression												

- shaping time: 5ns .. 1us
- dynamic range: <100fC
- power: < 10 mW/ch (?)
- ADC accuracy: 10 bits (?)
- TDC accuracy: 1ns

...

*We need an **APV25** chip with <u>variable gain and shaping time</u> like the **AFTER** chip, <u>dynamic range</u> like **MSGCROC**, integrated <u>fast-OR</u> like **Beetle**, <u>integrated ADC</u> like **SVX4**, <u>digital signal processor</u> like **ALTRO***

RD51 Scalable Readout System



H. Muller, RD51 Share Point website

Logical overview of the scalable readout system architecture

First prototypes are already under testing

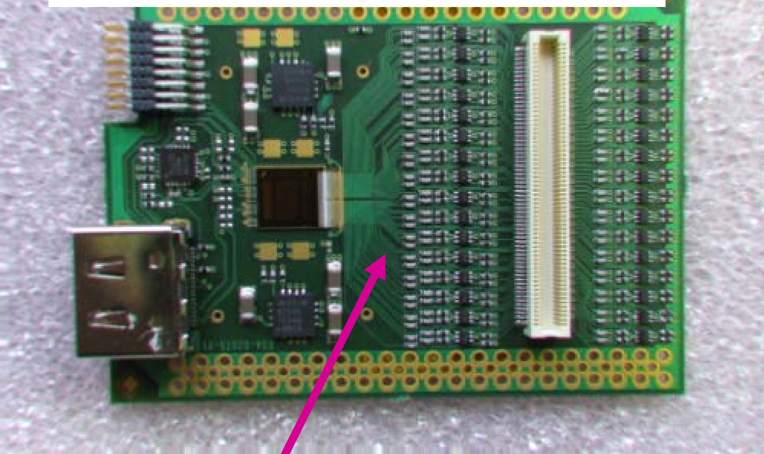
(potential applications EMcal/DCAL ALICE, ATLAS MM, CMS GEM Muon, muon tomography, ...)

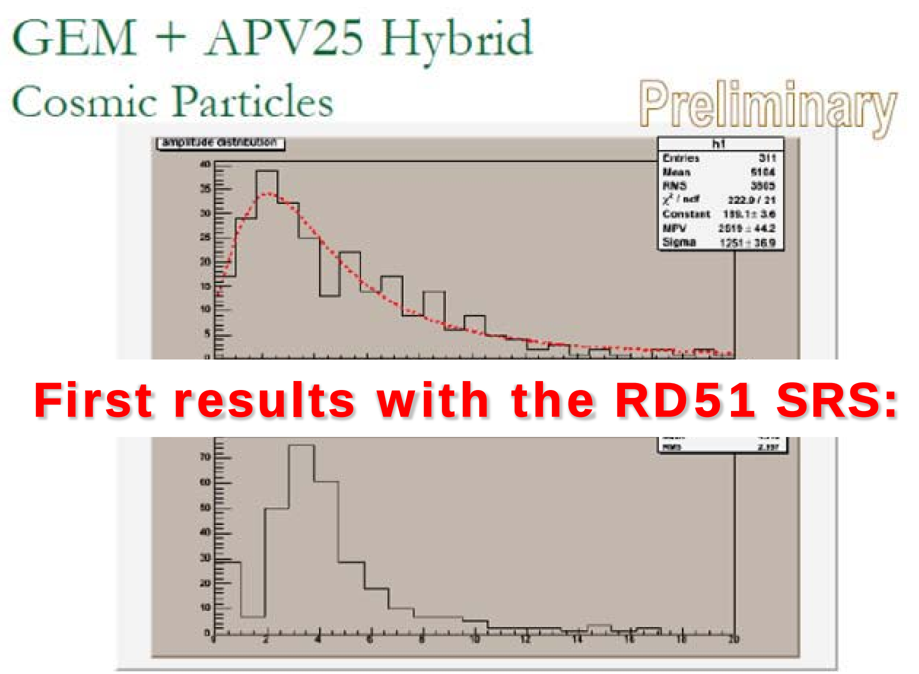
The large spread in readout requirements obviously does not allow for a simple common solution, unless one designs a system with the following general properties:

- **Common chip link interface** for a variety of different readout chip
- **Scalability from a small to a large system** based on the a single, common readout backend
- **Integration of commercial standards** for a minimum of custom hardware modules between the chip frontend and the online system
- **Default availability of a very robust and supported data acquisition package**
- **SRS allows to implement different readout architectures and trigger schemes**

Physical Overview of RD51 SRS

Front-end hybrid APV25

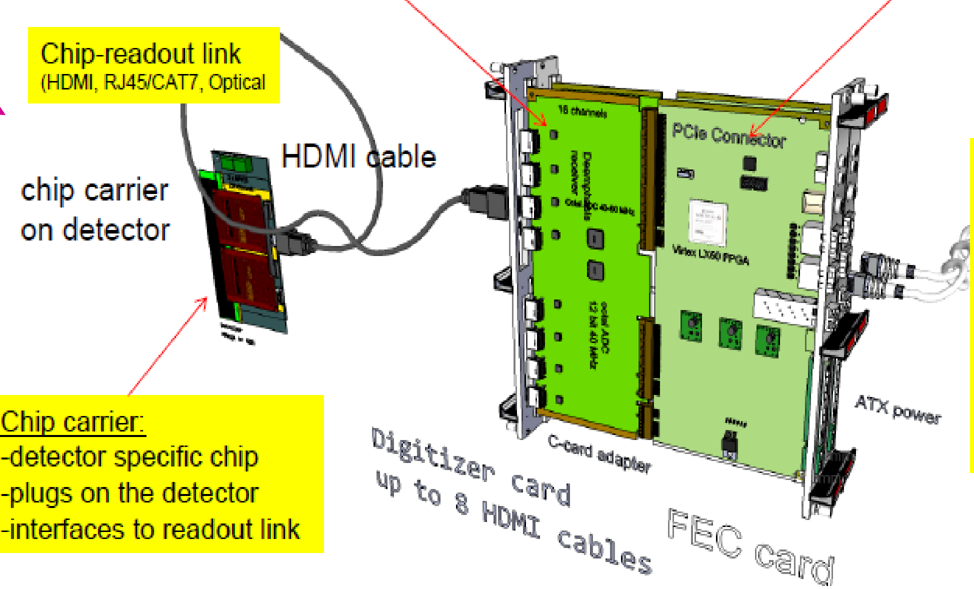




First results with the RD51 SRS:

Adapte
Matches
->analogu
->digital c
->photodetectors: amplifiers/shaper/ADC

Chip-readout link
(HDMI, RJ45/CAT7, Optical



Chip carrier:
-detector specific chip
-plugs on the detector
-interfaces to readout link

either
DTC link
- Data
-Trigger
-Control
-➔ SRU

or
ETHERNET
-➔ DAQ computer

H. Muller, RD51 Share Point website

RD 51 WG6 - MPGD Production

Objective: Development of cost-effective technologies and industrialization

<u>1) Current:</u> CERN-MPGD workshop is the UNIQUE MPGD production facility (generic R&D, detector components production, quality control)

Detector Technology	Currently produced	Future Requirements
	cm * cm	cm * cm
GEM	40 * 40	50 * 50
GEM, single mask	70 * 40	200 * 50
THGEM	70 * 50	200 * 100
RTHGEM, serial graphics	20 * 10	100 * 50
RTHGEM, Kapton	50 * 50	200 * 100
Micromegas, bulk	150 * 50	200 * 100
Micromegas, microbulk	10 * 10	30 * 30

RD51 Collaboration Survey:

<u>2) Future MPGD R&D and CERN TS-DEM MPGD workshop upgrade:</u>

Reinforcement of CERN-MPGD workshop infrastructure to produce 2x1m Bulk Micromegas and 2x0.5 m GEMs has been approved by CERN Management (Nov. 2009)

→ New infrastructure/machines to be installed in early 2011

Additional funds for the CERN-MPGD workshop requested in the FP7 AIDA proposal

RD51 WG6 - Technology Industrialization (potential partners)

THGEM Technology – ELTOS S.p.A. (Italy)

GEM Technology
- New Flex (Korea, Seoul)
- Tech-ETCH (USA, Boston)
- Scienergy (Japan, Tokyo)

Micromegas Technology
- TRIANGLE LABS (USA, Nevada)
- SOMACIS (Italy, Castelfidarco)
- CIREA (France, CHOLET)

Technology Transfer - Contract summary 12/9/2008

SUMMARY

CERN has developed, and owns all rights to a technology concerning Radiation Detectors of Very High Performance and Planispherical Parallax-Free X-Ray Imager using Gas Electron Multipliers (GEM foil technology). GEM technology is a proven concept of gas amplification that was introduced in 1996 by Fabio Sauli and GEM foils are currently being manufactured at a small workshop on CERN premises by the TS/DEM group. Furthermore, the use of GEM foils as gas detectors is also covered by a patent owned by CNRS (the CAT patent) to which CERN has a sub-licensable license.
SciEnergy is a Japanese company developing, manufacturing and selling X-Ray detectors systems. This company works closely with Hamagaki Laboratory (U. Tokyo) in Japan, and it is through the latter's involvement in the RD51 Collaboration that SciEnergy's interest in GEM foils grew. After initial contacts with participants to the RD51 Collaboration, SciEnergy approached CERN to request a license from CERN to manufacture and sell GEM foils and GEM based detector systems both to the R&D community and commercial end-users.

Scienergy, Japan signed license contract for GEMs

Partnership agreement signed (2009) between CERN and industrial company for the development and implementation of spherical GEMs for X-Ray diffraction detectors

Technology Transfer Network

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

INCREASING EFFICIENCY OF TECHNOLOGY TRANSFER ACTIVITIES IN MEMBER STATES

REPORT ON THE ACTIVITIES OF THE TECHNOLOGY TRANSFER NETWORK WITHIN THE FRAMEWORK OF THE EUROPEAN STRATEGY FOR PARTICLE PHYSICS

(Reported in CERN-Council-S/049, September 7, 2009)

- **"One-stop licensing for industry" (bridging the gap between institutes and industry)**
- **The IP coming from the HEP research community is better identified and more visible**

The RD-51 collaboration[2] on Micro Pattern Gaseous Detectors (MPGD) accounts for more than 50 institutes including non-PP institutes interested in developing detectors targeted to their research needs. Detector developments rely on PP technologies, such as Gaseous Electron Multipliers (GEM), MicroMEsh Gaseous Structure (MicroMEGAS), front-end readout and software. MPGD technologies are owned by organisations that are members of the TT Network and constitute therefore a very good case for technology pooling. Industry is willing to manufacture the technologies for the community's needs but has also shown interest in commercializing detectors provided a better understanding of the market potential is made available.

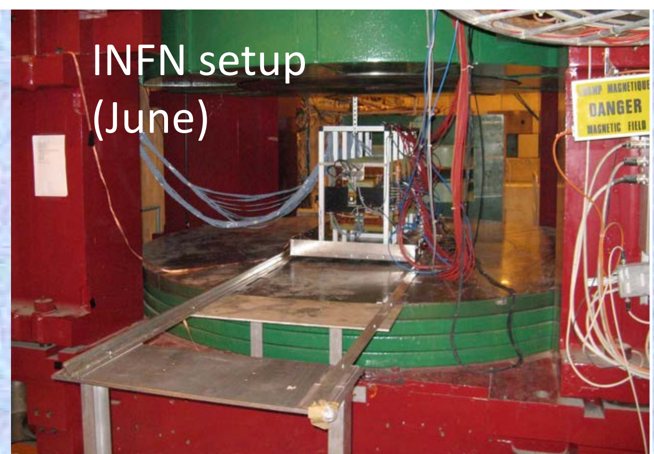
The TT Network considers MPGD as very illustrative of the PP community's assets and will therefore focus the first pilot on this case.

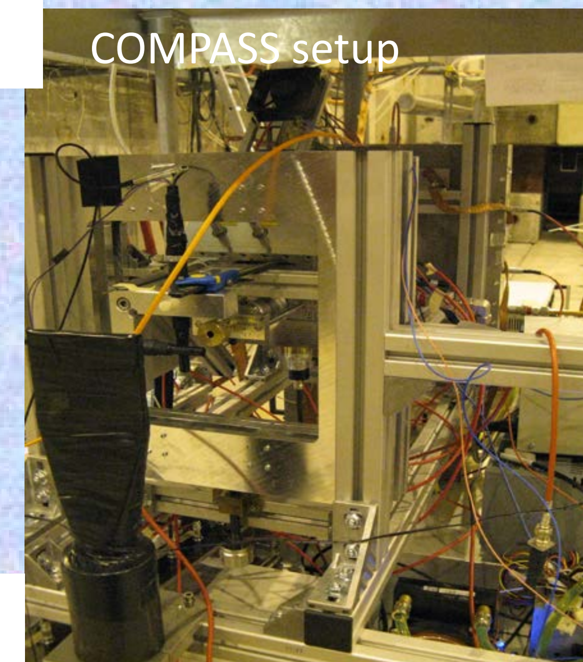
RD 51 WG7 - Common Test Facility

Objective: Design and maintenance of common infrastructure for detector characterization ("semi-permanent" test-beam infrastructure at CERN SPS@H4 beam)

RD51 test-beam periods in 2010:

- June 20-July 7
- August 12th - 23rd
- October 18th - November 1st





Development of common infrastructure:
services, trigger, tracking telescope, DAQ, slow control

8 RD51 groups have been taking data in parallel during the last test beam campaign (Oct. 22 – Nov. 2, 2009)

Summary and Outlook

• **RD51 aims at facilitating the <u>development of advanced gas-avalanche detector technologies and associated electronic-readout systems</u> → Many successful common projects were initiated during the first years of collaboration**

• **Industrial methods of MPGD production allows to extend technology to ~ m^2 areas → many potential MPGD applications within the HEP and beyond**

• ***Collaboration with industrial partners has been started***

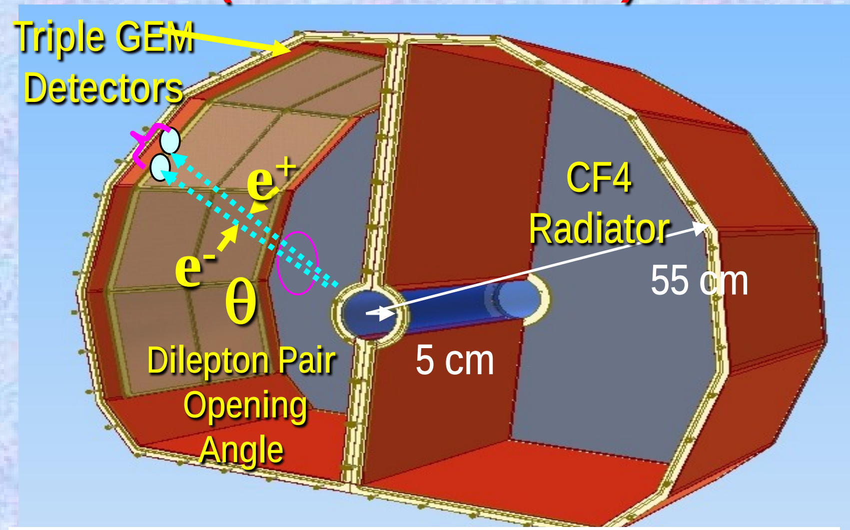
• ***Progress in micro-pattern detector developments promises to extent the applicability of gaseous detectors to the* precision tracking & triggering (<u>unit detectors of ~ m^2 size & spatial resolution *down to 30-50 μm*</u>)**

• ***Modern, sensitive & low noise electronics will enlarge the range of applications***

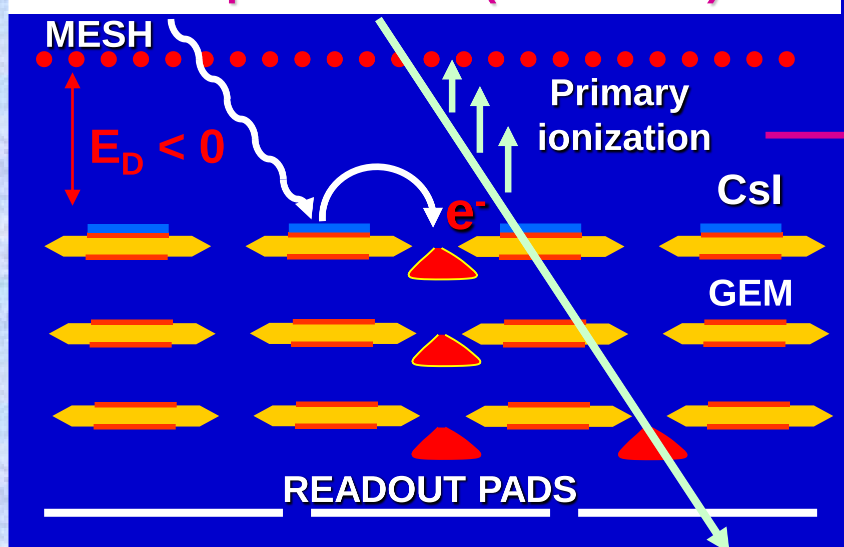
Backup Slides

Hadron Blind Detector for PHENIX at RHIC

HBD in the heart of the PHENIX (5 cm < R < 55 cm):



3-GEM + CsI reflective photocathode with pad readout (~ 2*2 cm2)



1^{st} Windowless Cherenkov Detector

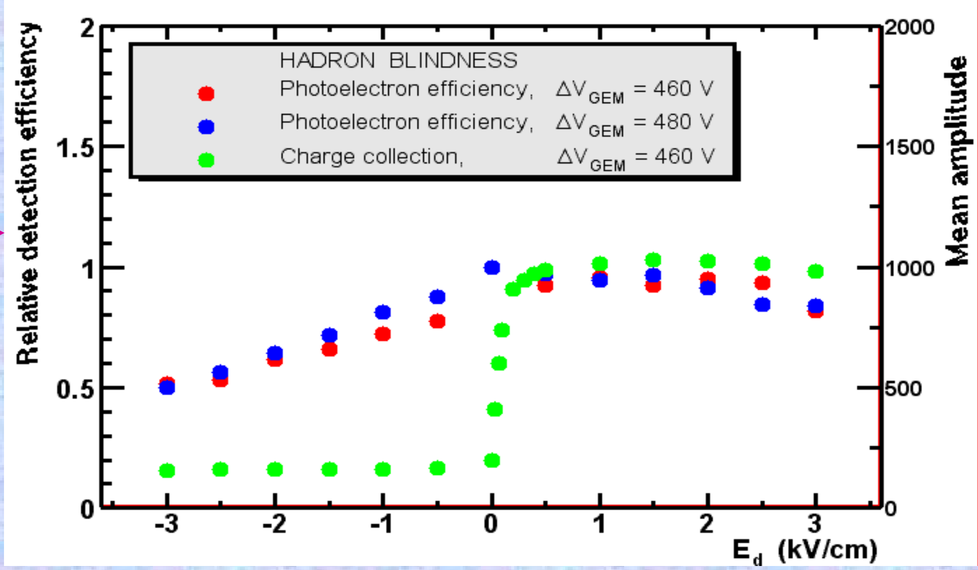
- **CF_4 as radiator and detector gas:** (n_{CF4} =1.000620, $L_{RADIATOR}$ = 50 cm)
- **Proximity focused configuration:**

Cherenkov photons form blobs:

$Q_{max} = \cos^{-1}(1/n)$ ~ 36 mrad;

R_{BLOB} ~ 1.8 cm

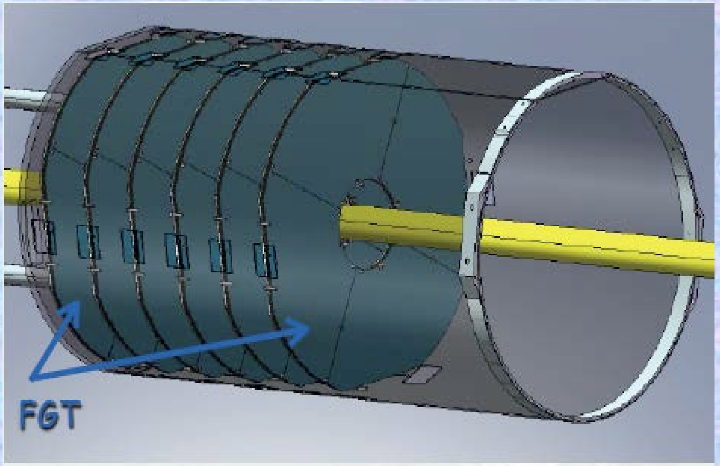
Primary ionization is suppressed at $E_D < 0$, photo-e⁻ collection efficiency is preserved



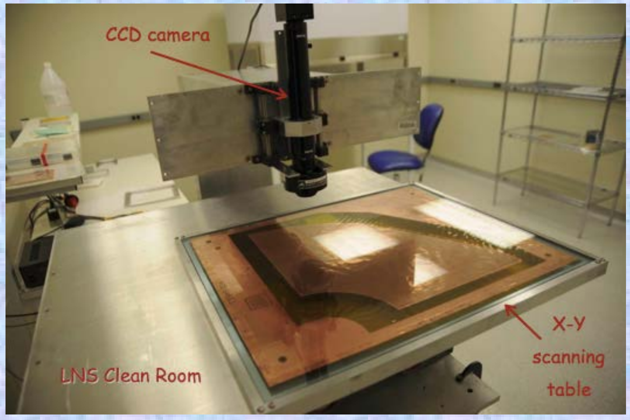
C. Woody et al., 2009 IEEE NSS/MIC Conference Record; R. Chechik, A .Breskin, NIMA595 (2008)116

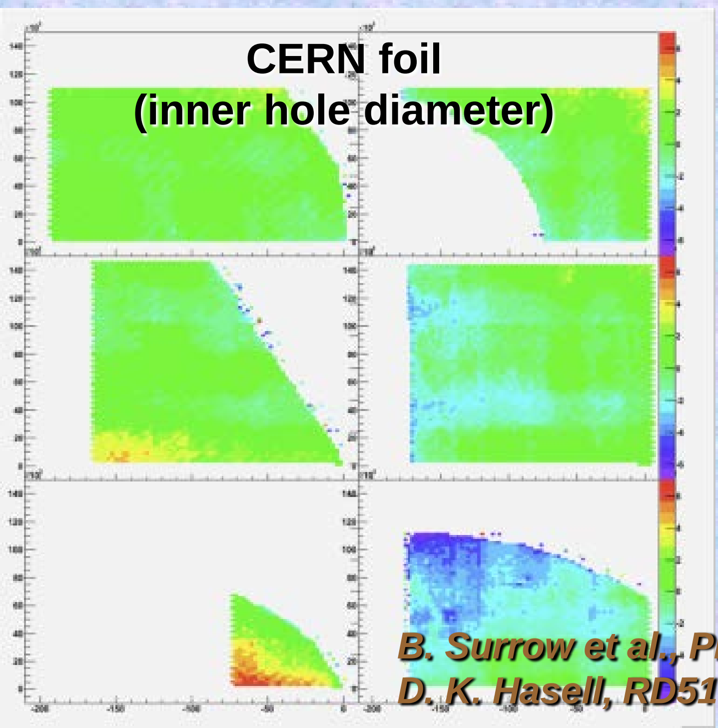
STAR Forward GEM Tracking Upgrade

Production of GEM foils – collaborative effort of Tech-Etch with BNL, MIT and Yale



CCD surface scanner to assess GEM foil quality

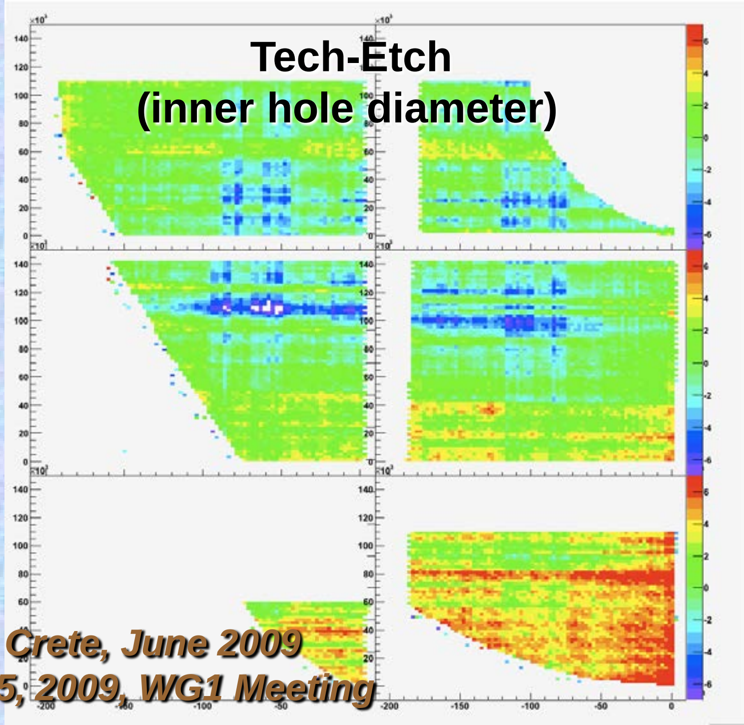




Systematic Tech-Etch and CERN GEM foil comparison:

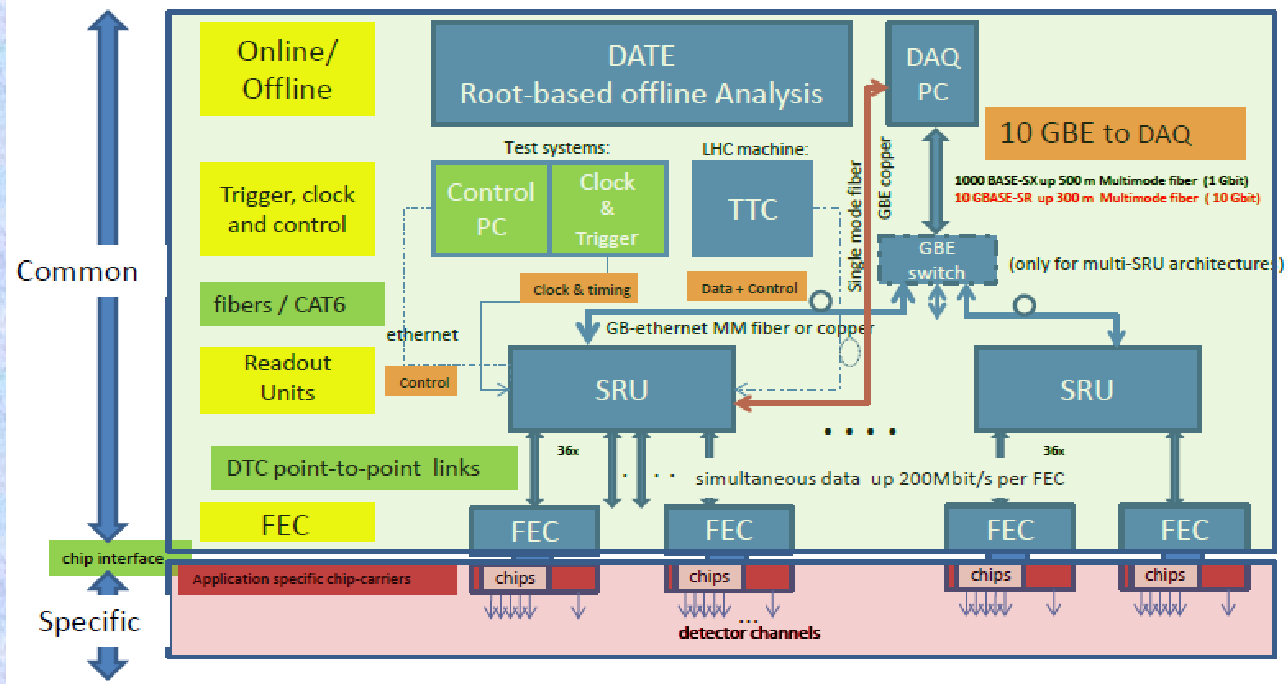
Blue – 6 μm below average

Red – 6 μm above average



B. Surrow et al., Proc. of the MPGD Conf., Crete, June 2009
D. K. Hasell, RD51 Collab. Meet., Nov.23-25, 2009, WG1 Meeting

Development of Portable Multi-Channel DAQ Systems for MPGD

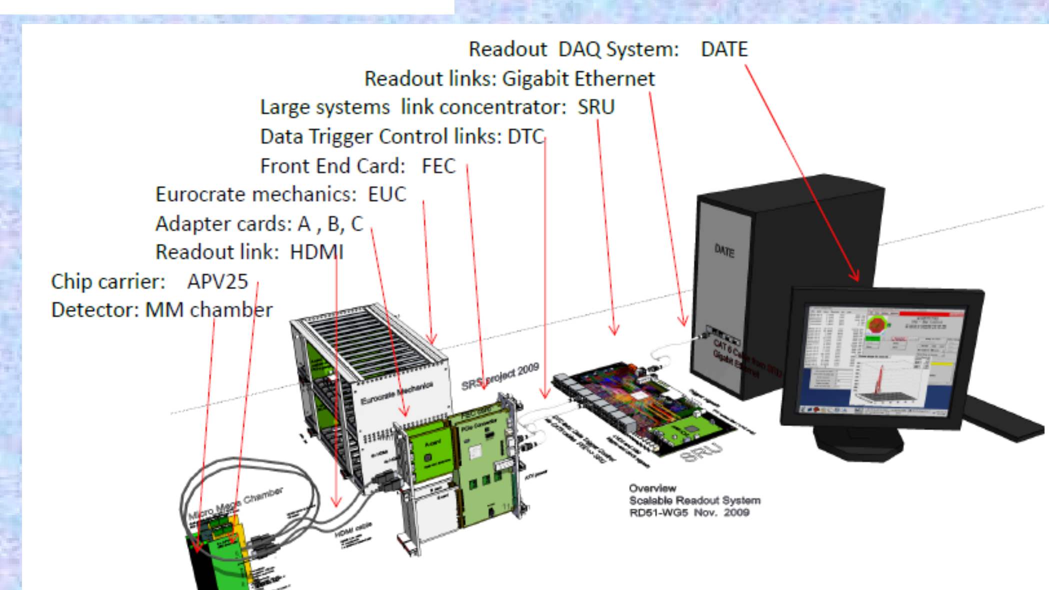


"RD51 Common Project" (financed by the RD51)→

First prototype system to be ready in June 2010

- **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 and supported DAQ software package.**

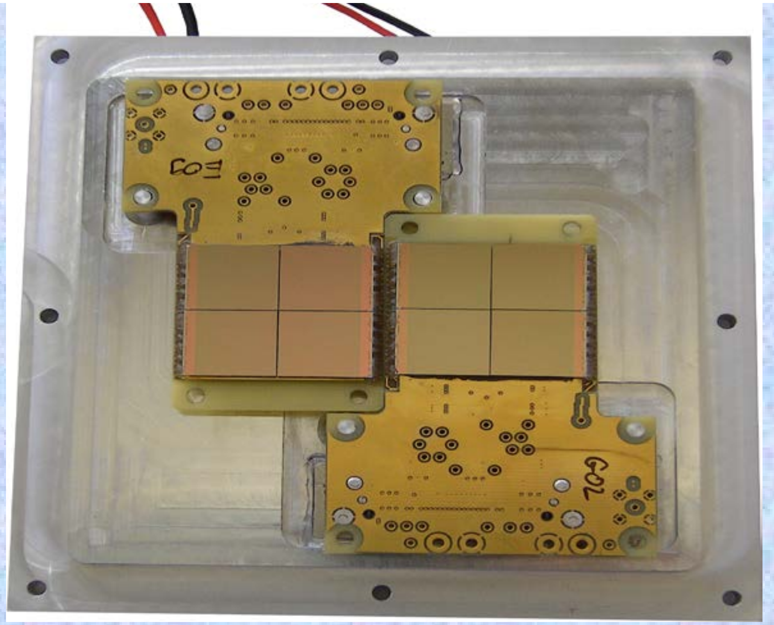
→ Scalable Readout System



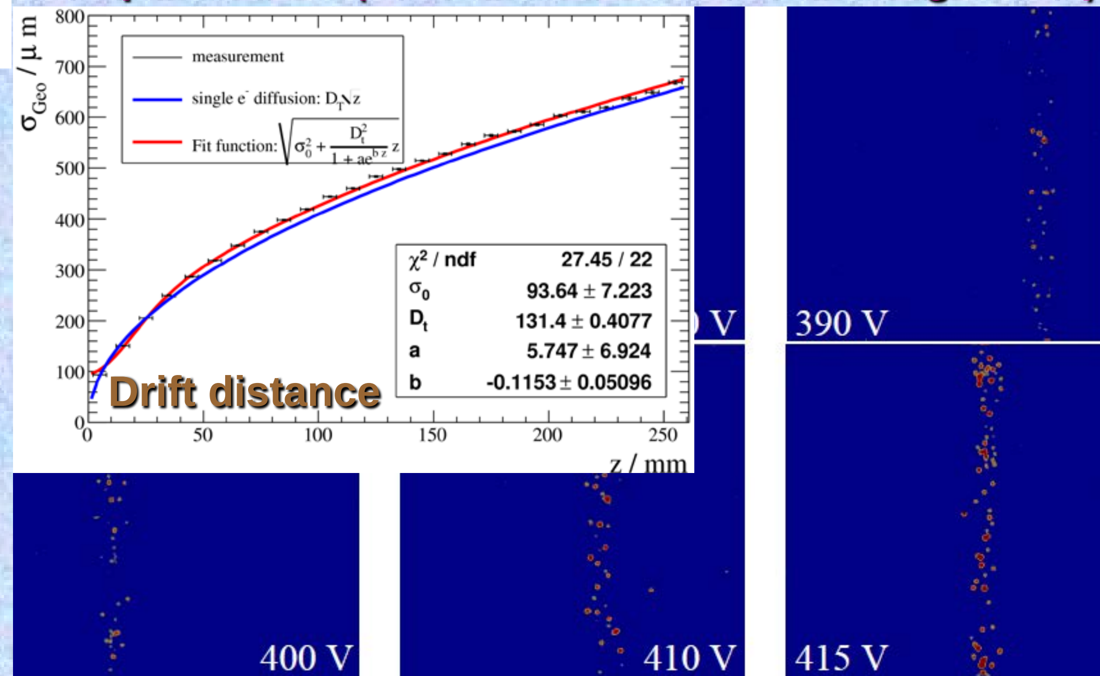
H. Muller, RD51 Collab. Meet., Nov.23-25, 2009, WG5 Meeting

Development of Large Area Detectors with Pixel Readout

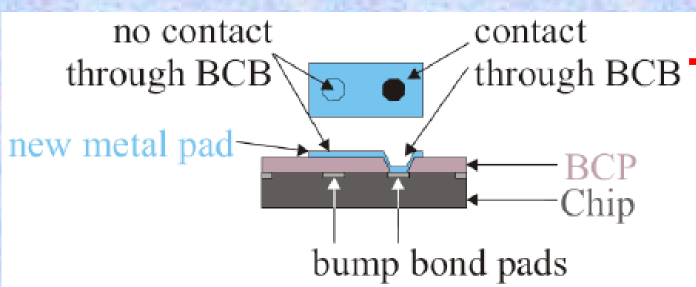
8 Timepix Readout Matrix (~ 3* 6 cm^2)
55*55 μm^2 pixel size

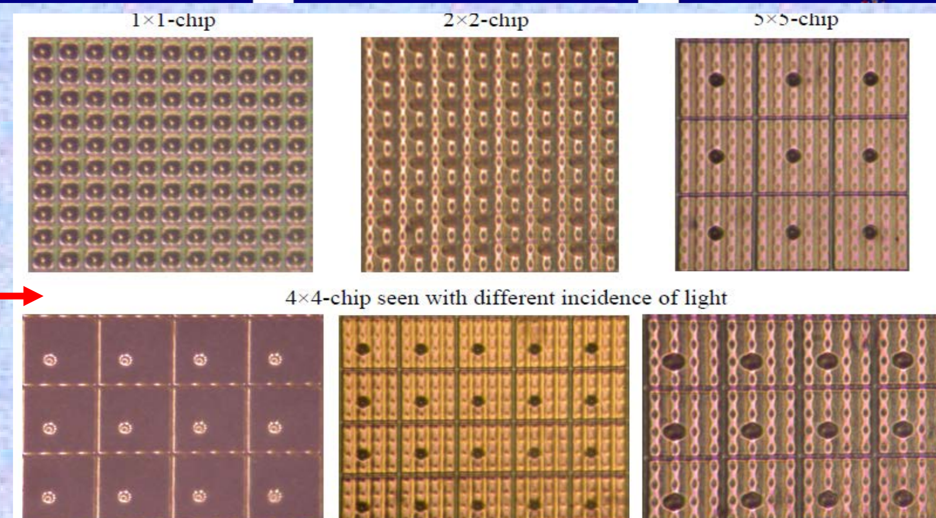


4 Chips + 3GEM (150 GeV muons after drifting 25 cm)



Test chips with larger pixels:
expensive to design new chips, easier to combine pixels by post-processing (55*55, 110*110, 220*220, 275*275 μm^2)





J. Kaminski et al, RD51 Collab. Meet., Nov.23-25, 2009, WG7 Meeting