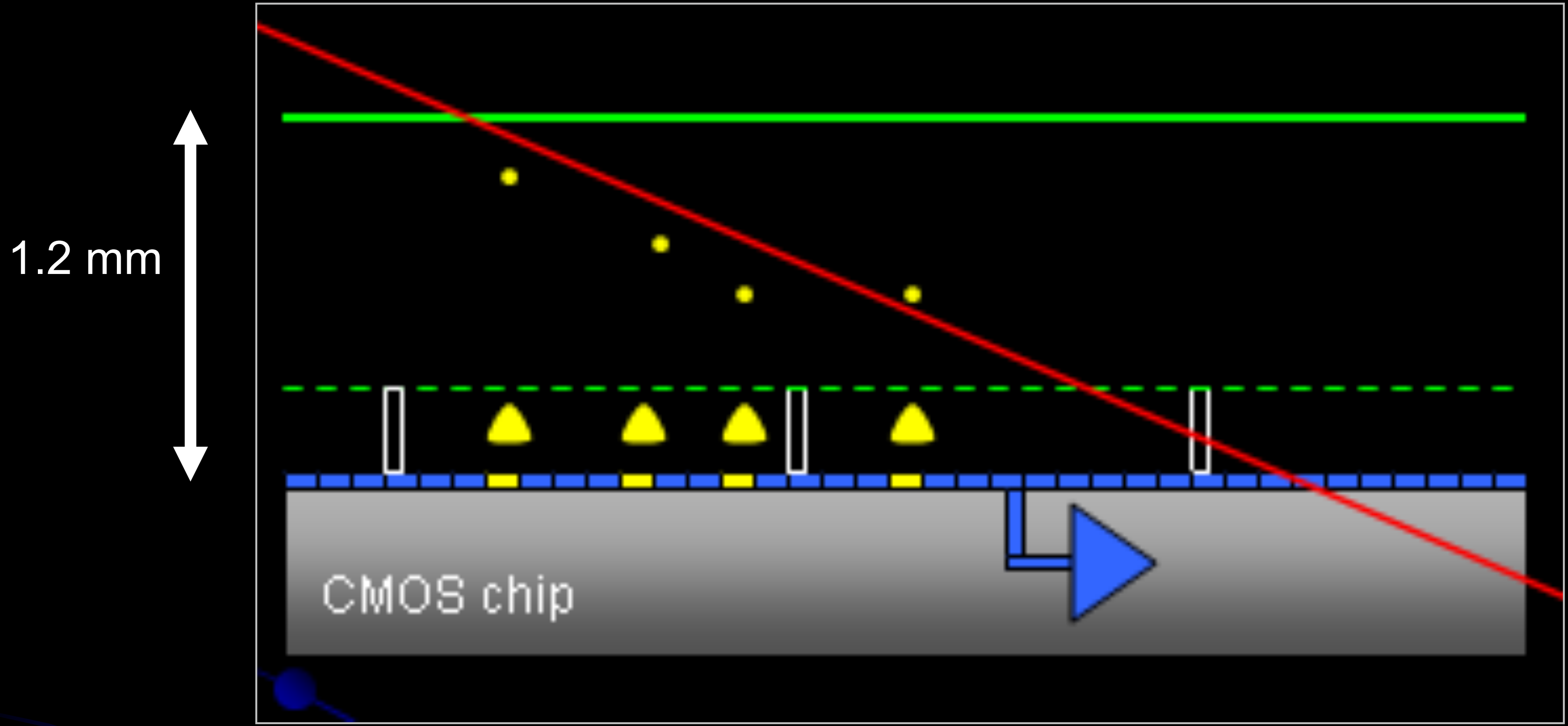
gasless gaseous detectors

Harry van der Graaf
Nikhef, Amsterdam

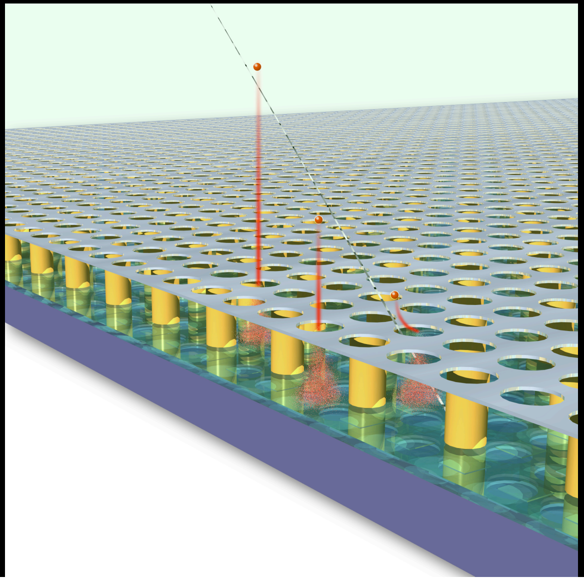
Instrumentation Seminar
DESY, Aug 13, 2010

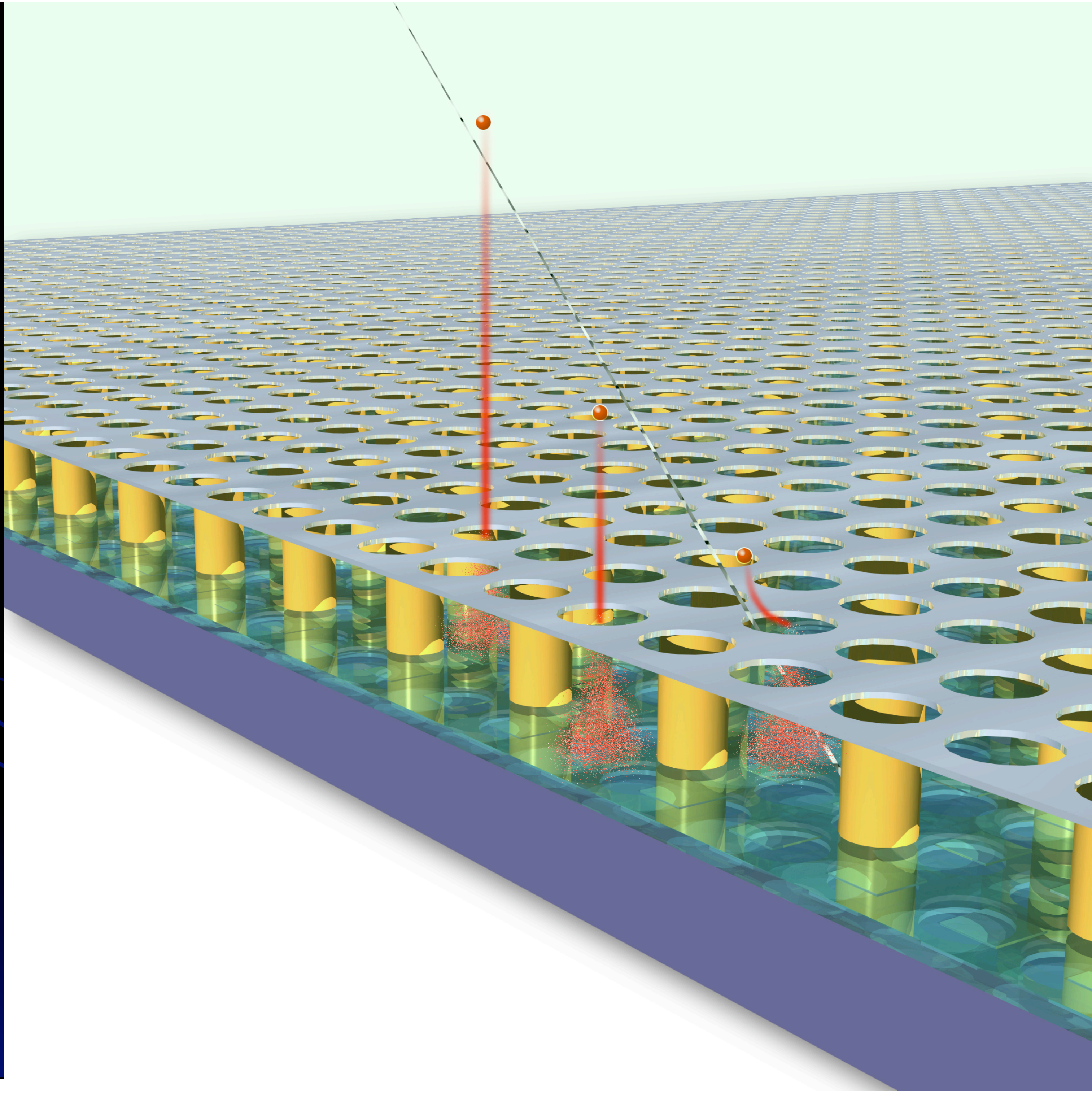


GridPix and
Gas On Slimmed SIlicon Pixels

Gossip: replacement of Si tracker

Essential: thin gas layer (1.2 mm)

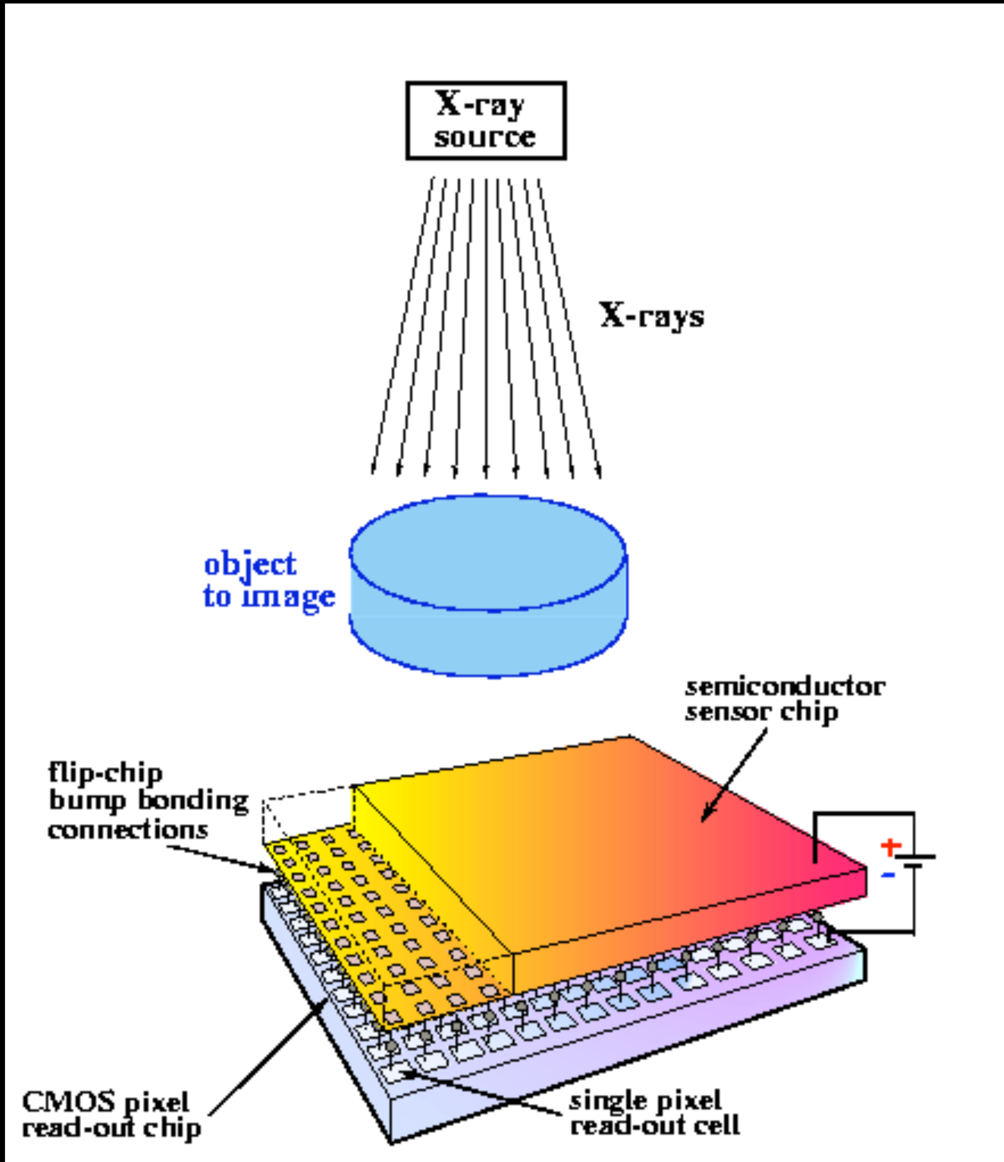




The MediPix2 pixel CMOS chip

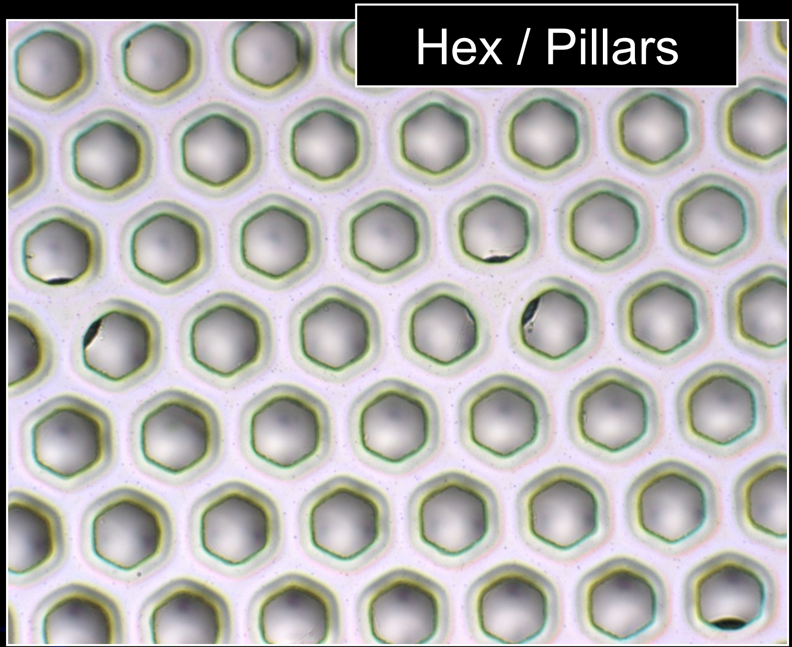
256 x 256 pixels
pixel: 55 x 55 μm^2
per pixel: - preamp
- shaper
- 2 discr.
- Thresh. DAQ
- 14 bit counter

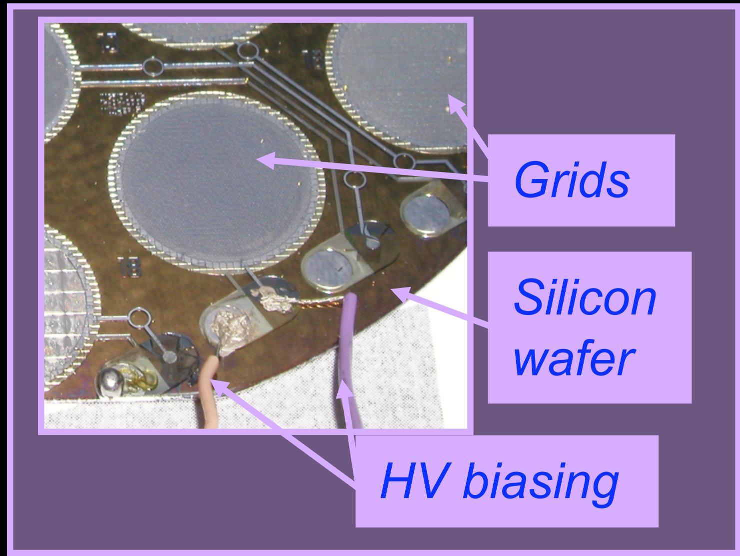
- enable counting
- stop counting
- readout image frame
- reset



We apply the 'naked' MediPix2 chip without X-ray convertor!

Wafer post-processing:InGrid



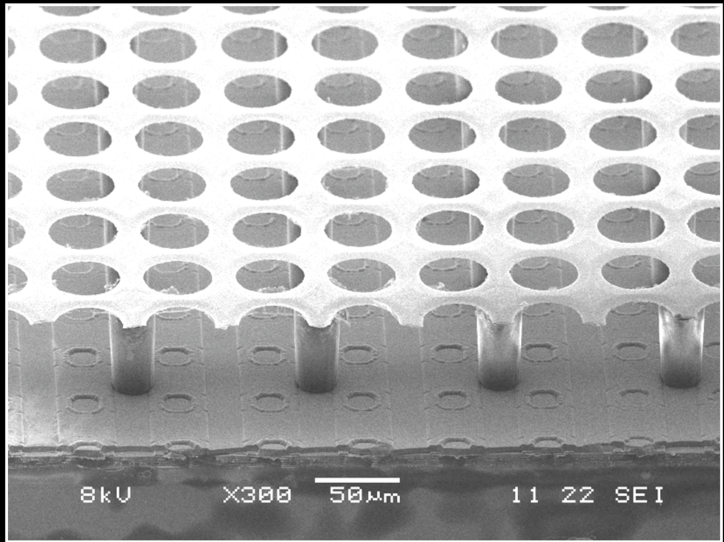


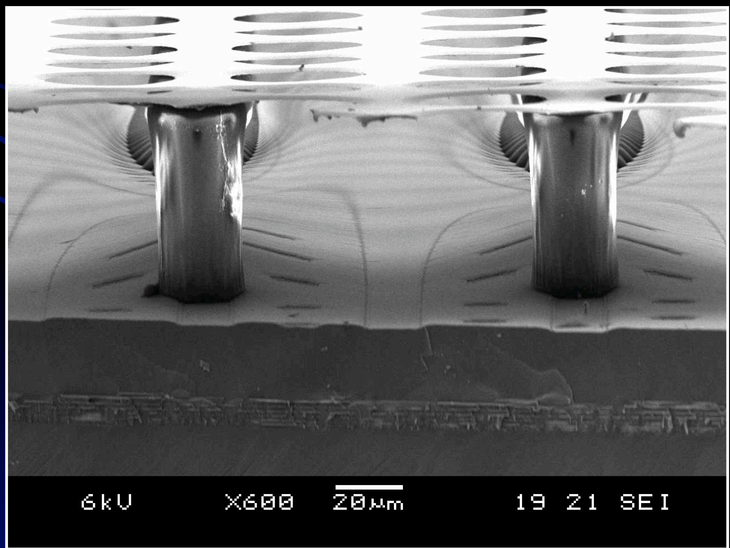
InGrid: an Integrated Grid on Si (wafers or chips)

- perfect alignment of grid holes and pixel pads
- small pillars Ø, hidden pillars, full pixel area coverage
- Sub-micron precision: homogeneity
- Monolithic readout device: integrated electron amplifier

Full post-processing of a TimePix

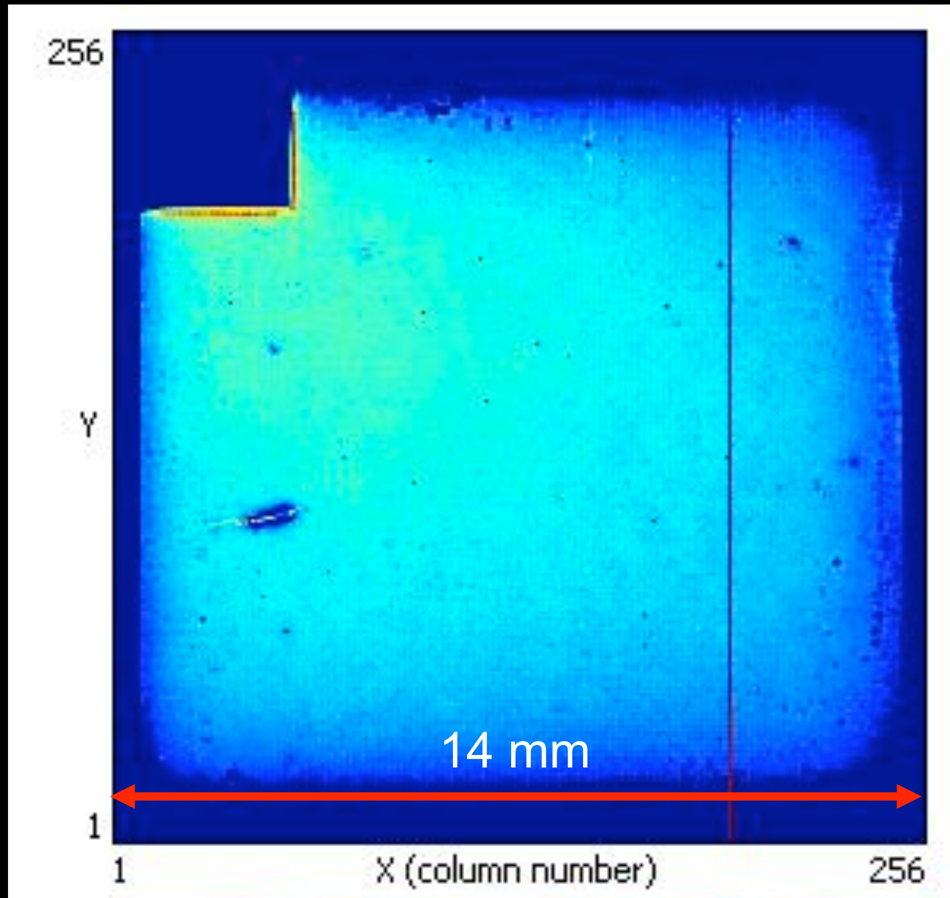
- Timepix chip + SiProt + Ingrid:





MESA+

IMT Neuchatel



"Uniform"

Charge mode

Gas instead of Si

Pro:

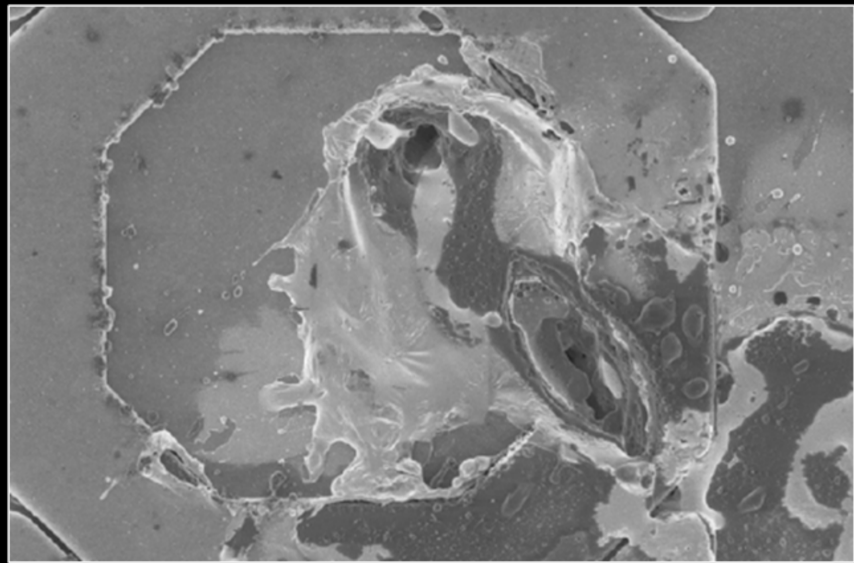
- no radiation damage in sensor: *gas is exchanged*
- modest pixel (analog) input circuitry: low power, little space
- no bias current: simple input circuit
- low detector material budget: 0.06 % radiation length/layer
  typical: Si foil. New mechanical concepts
- low power dissipation : little FE power (2 μW/pixel); no bias dissipation
- operates at room temperature (but other temperatures are OK)
- less sensitive for neutron and X-ray background
- 3D track info *per layer* if drift time is measured
- gas is cheap (and *very* cheap wrt. Si sensors!), and light

Con:

- Gaseous chamber: discharges (sparks): destroy CMOS chip
- gas-filled proportional chamber: 'chamber ageing'
- limit in spatial resolution due to low primary gas-particle
  interaction statistics
- Needs gas flow
- Parallax error: 1 ns drift time measurement may be required
- diffusion of (drifting) electrons in gas limit spatial resolution

But, are these good enough?

2006-2007 dead chips everywhere
2007-2008 spark protection and Ingrid
2008-2009 characterizing performance of GridPix

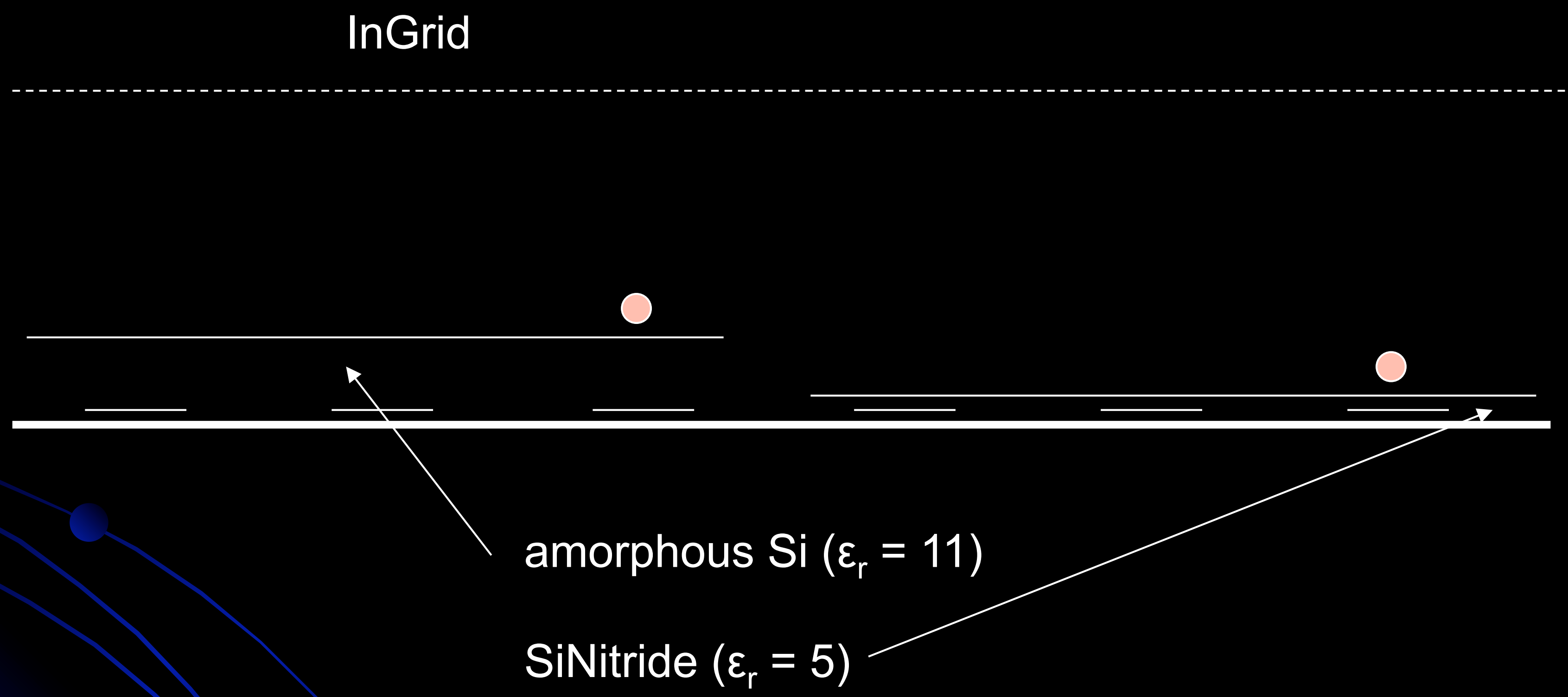


Cathode
- Drift volume (~0.1-few kV/cm)

Grid
- Gain region (~50-150 kV/cm)

Pixel readout chip

Now with Si_3N_4: lower dielectric constant



7 µm SiNitride:
Factor ~2 more charge on input pad for normal (proportional) signals

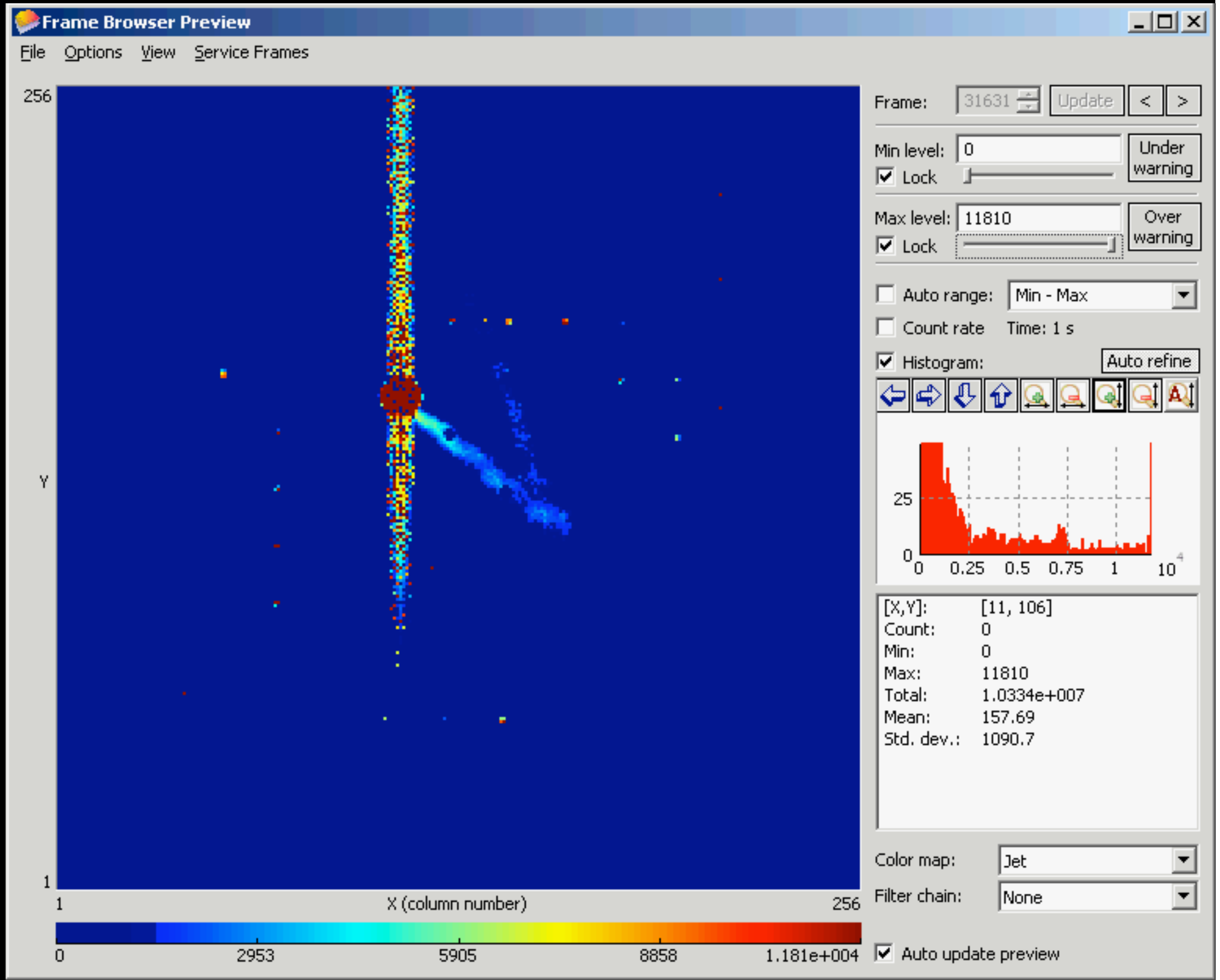
… discharges are observed !

For the 1st time: image of discharges are being recorded

Round-shaped pattern of some 100 overflow pixels

Perturbations in the concerned column pixels
- Threshold
- Power

Chip keeps working



Protection layer of amorphous silicon: 2007

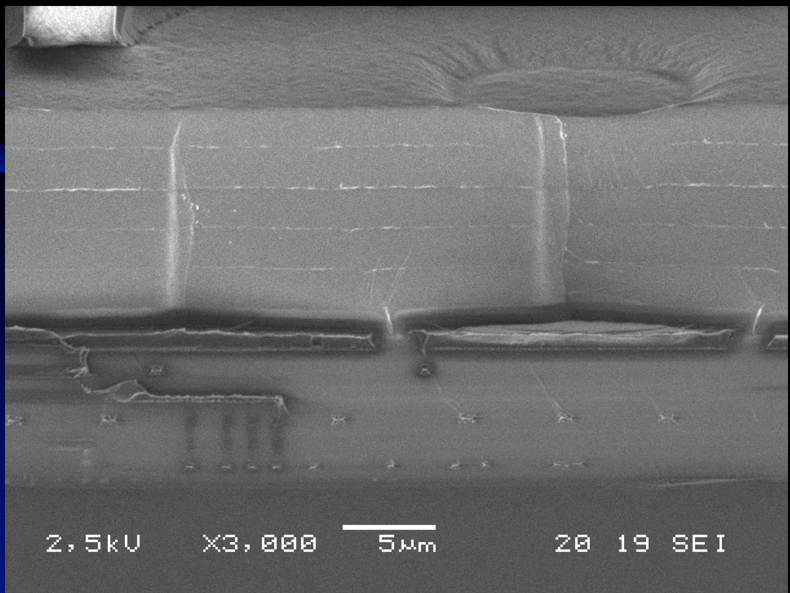
July 2008: protection layer made of Si_3N_4 (Silicon Nitride), only 7 µm thick

$$3\,SiH_4 + 4\,NH_3 \rightarrow Si_3N_4 + 12\,H_2$$

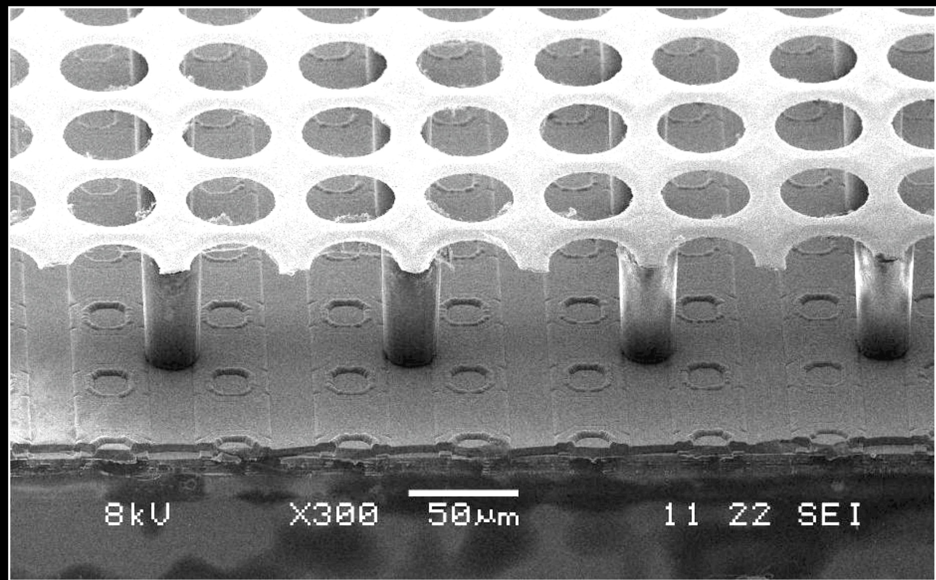
- Silicon Nitride is often applied as passivation layer: top finish of chips.

- With overdose of SiH_4:conductivity: high resistivity bulk material

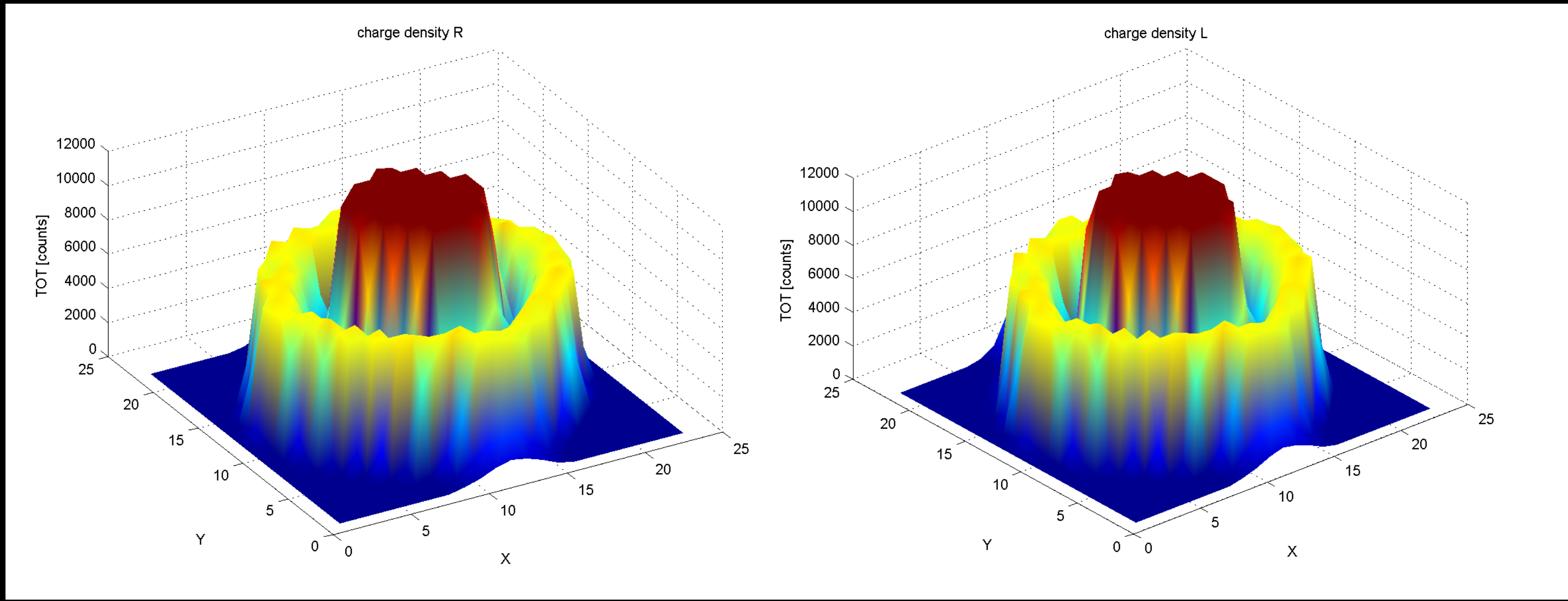
- Favored material for bearings in turbo chargers, jet engines

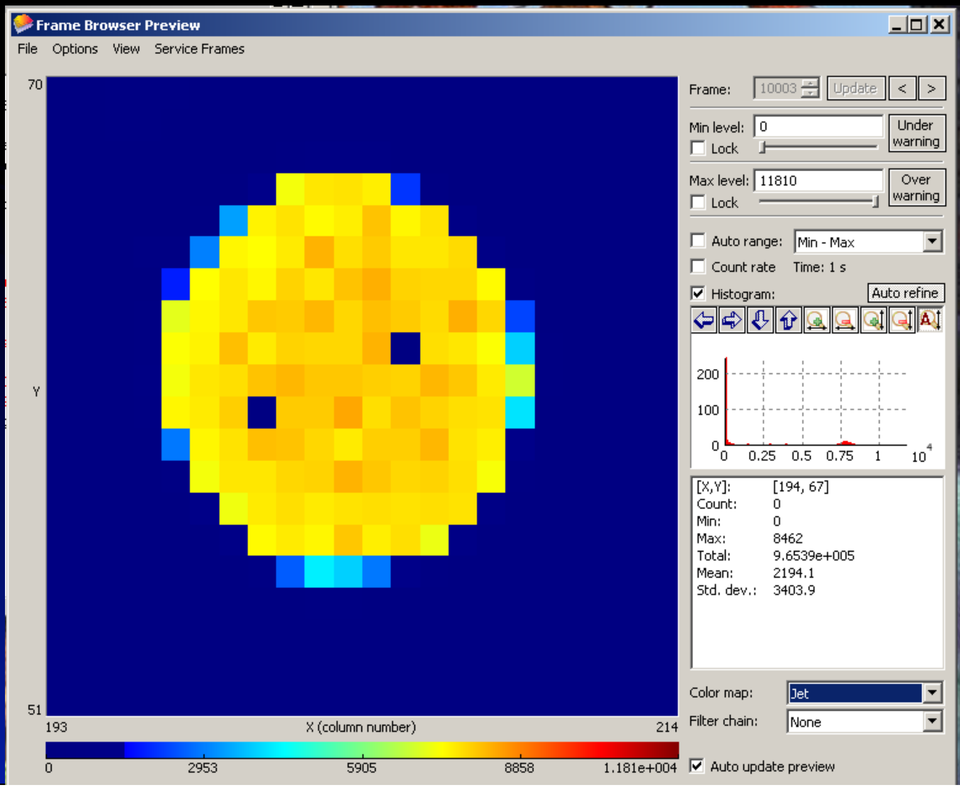


5 layers of Si_3N_4

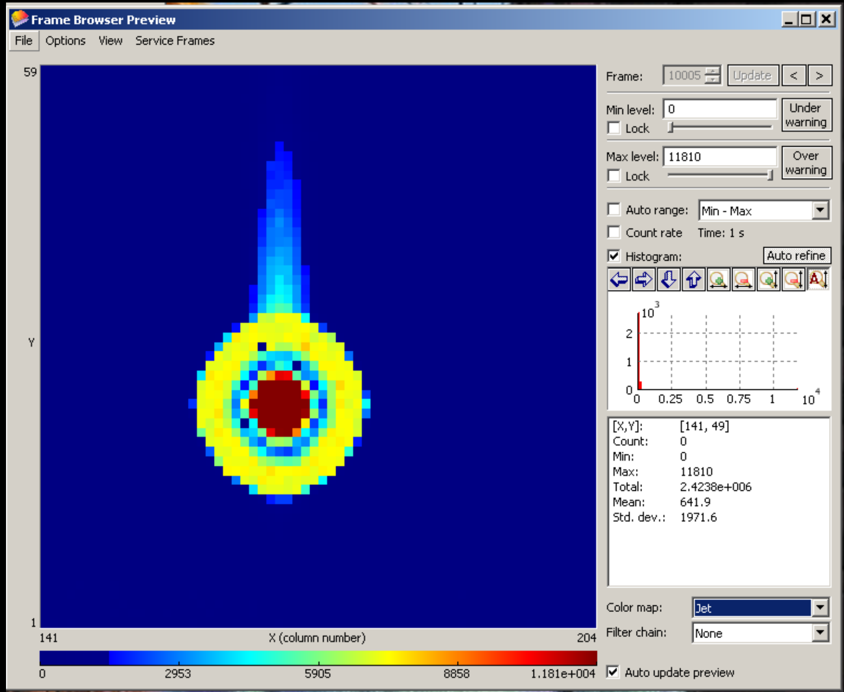


InGrid + a-Si:H



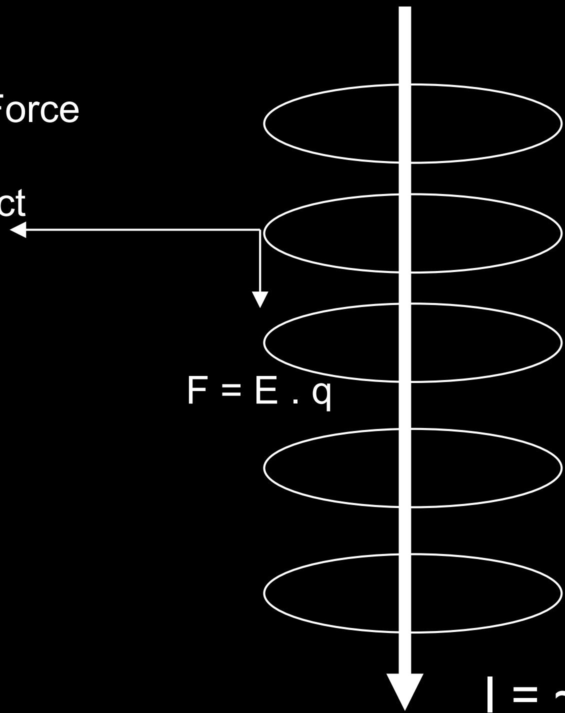


Discharge (protection) studies:
Martin Fransen



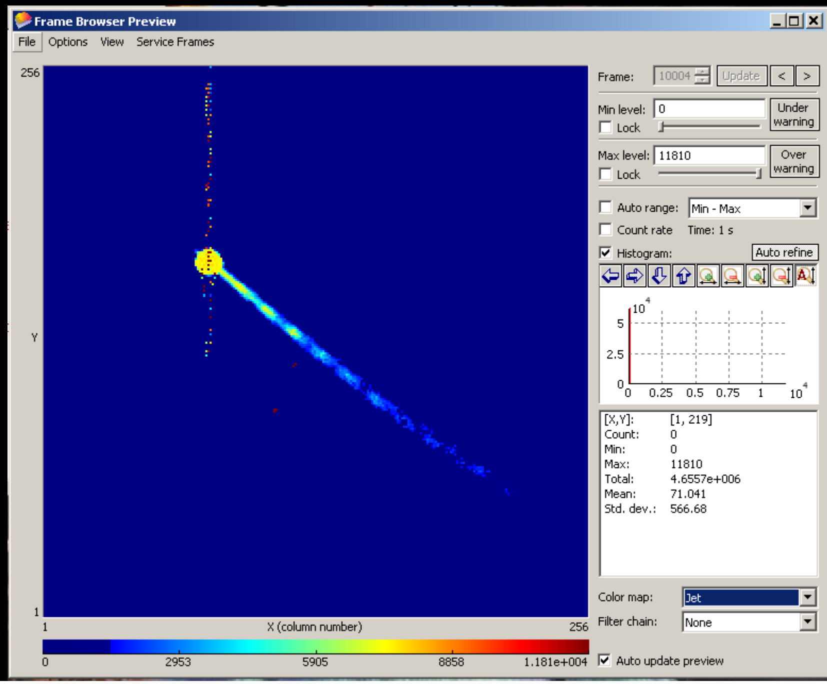
Lorentz Force

Skin Effect

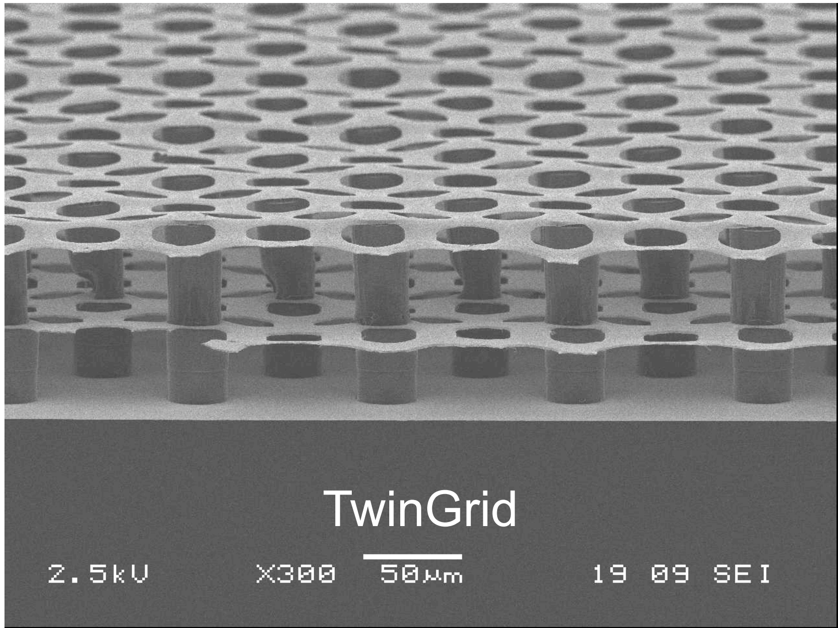


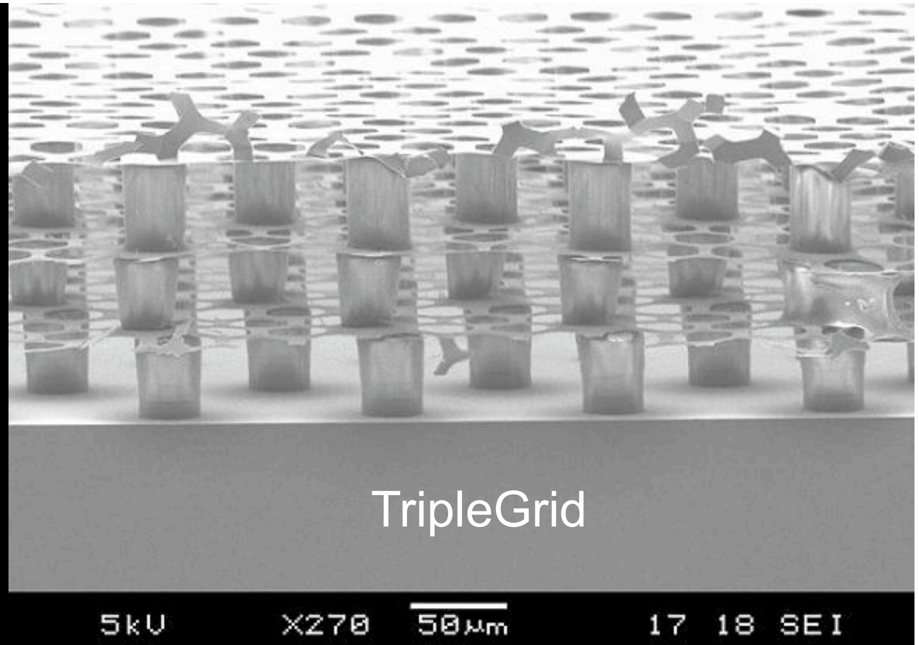
$F = E \cdot q$

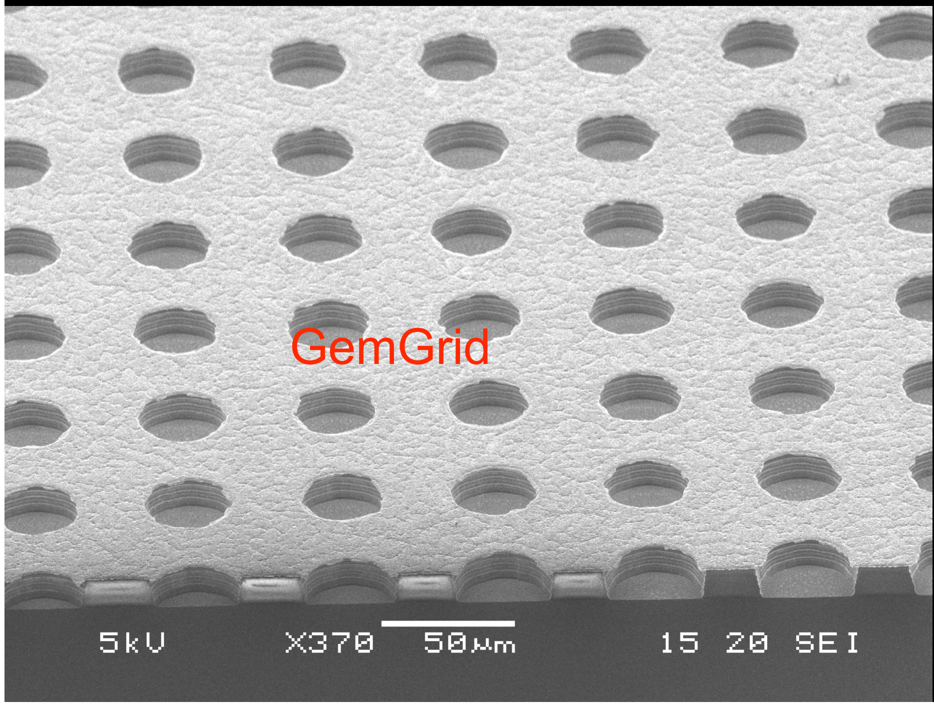
$I = \sim 3A$!

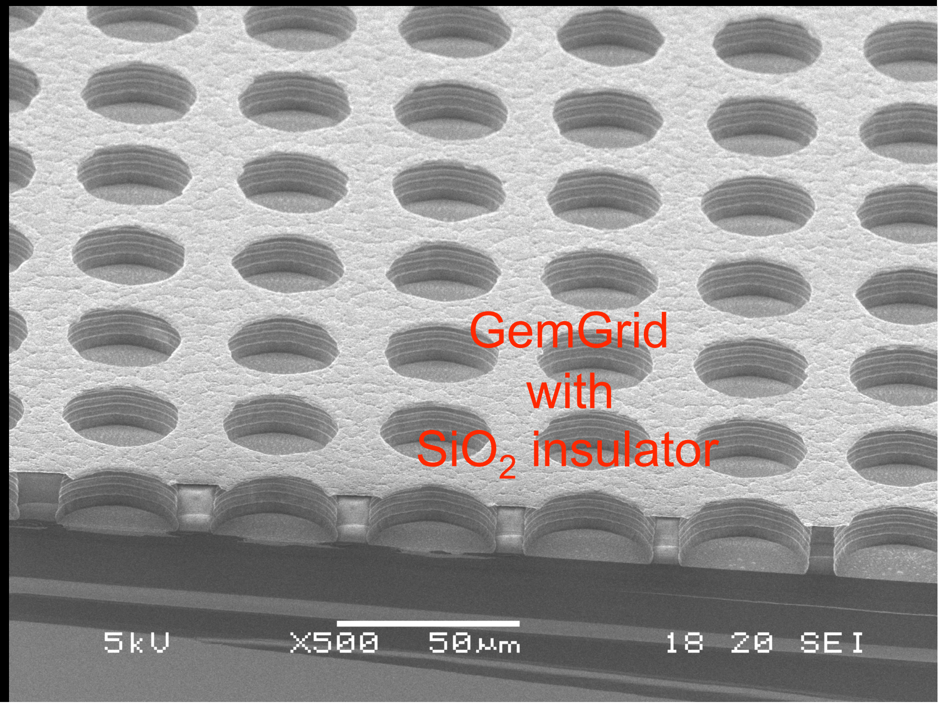


Improvement with Si Nitride


TwinGrid
2.5kV X300 50μm 19 09 SEI

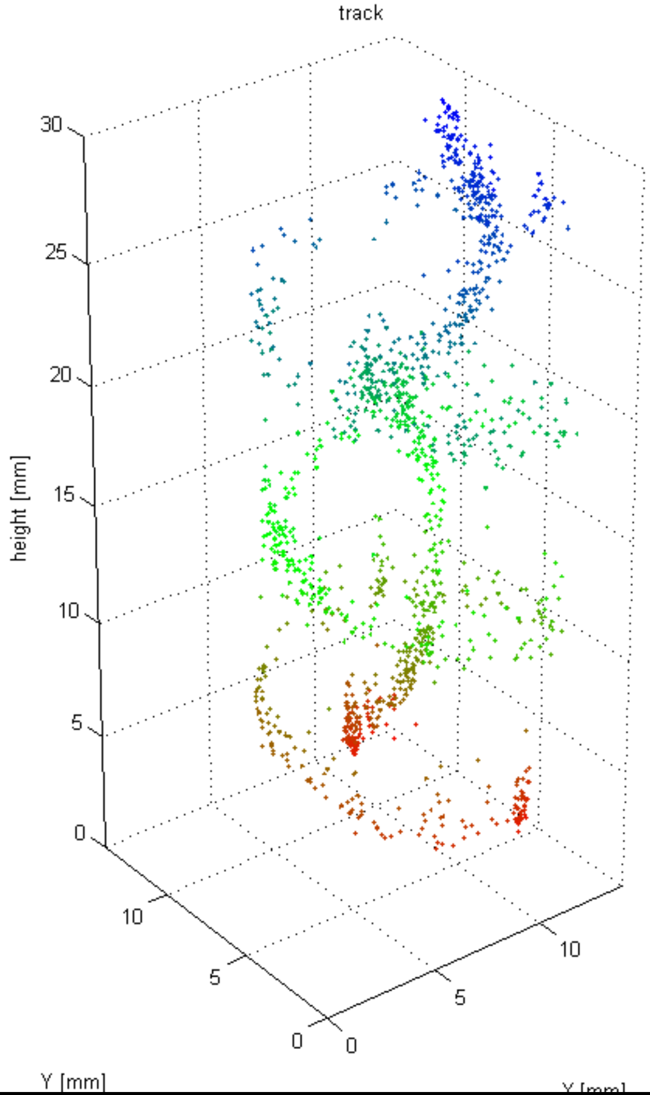

TripleGrid
5kV X270 50μm 17 18 SEI


GemGrid
5kV X370 50μm 15 20 SEI


GemGrid
with
SiO_2 insulator
5kV X500 50μm 18 20 SEI

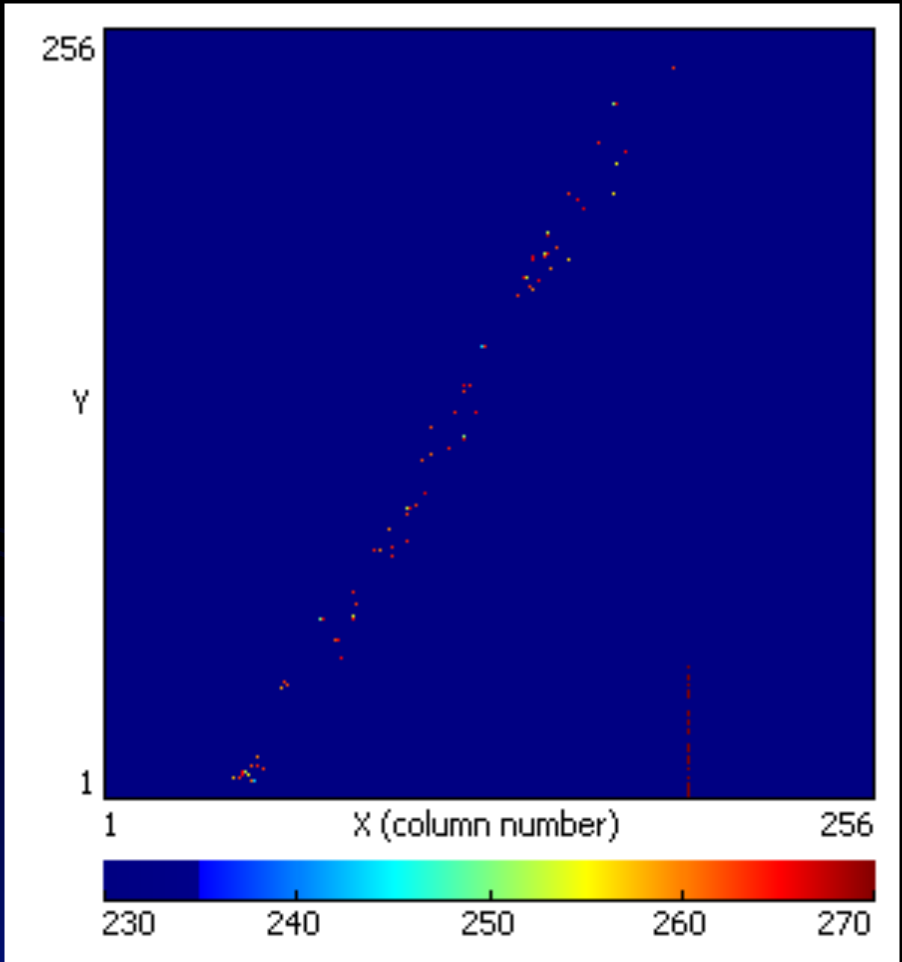
^{90}Sr β events

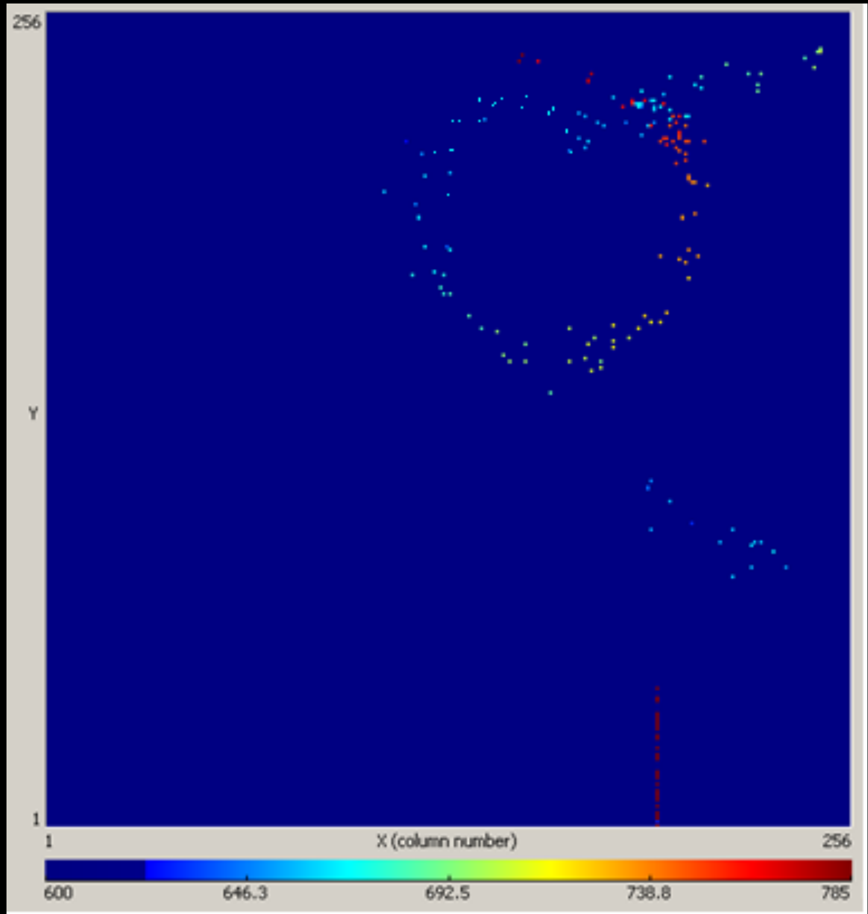
Gas: Ar/i-butane 80/20



B = 0.2 T

Analysis of test beam data and cosmic muon data with GridPix

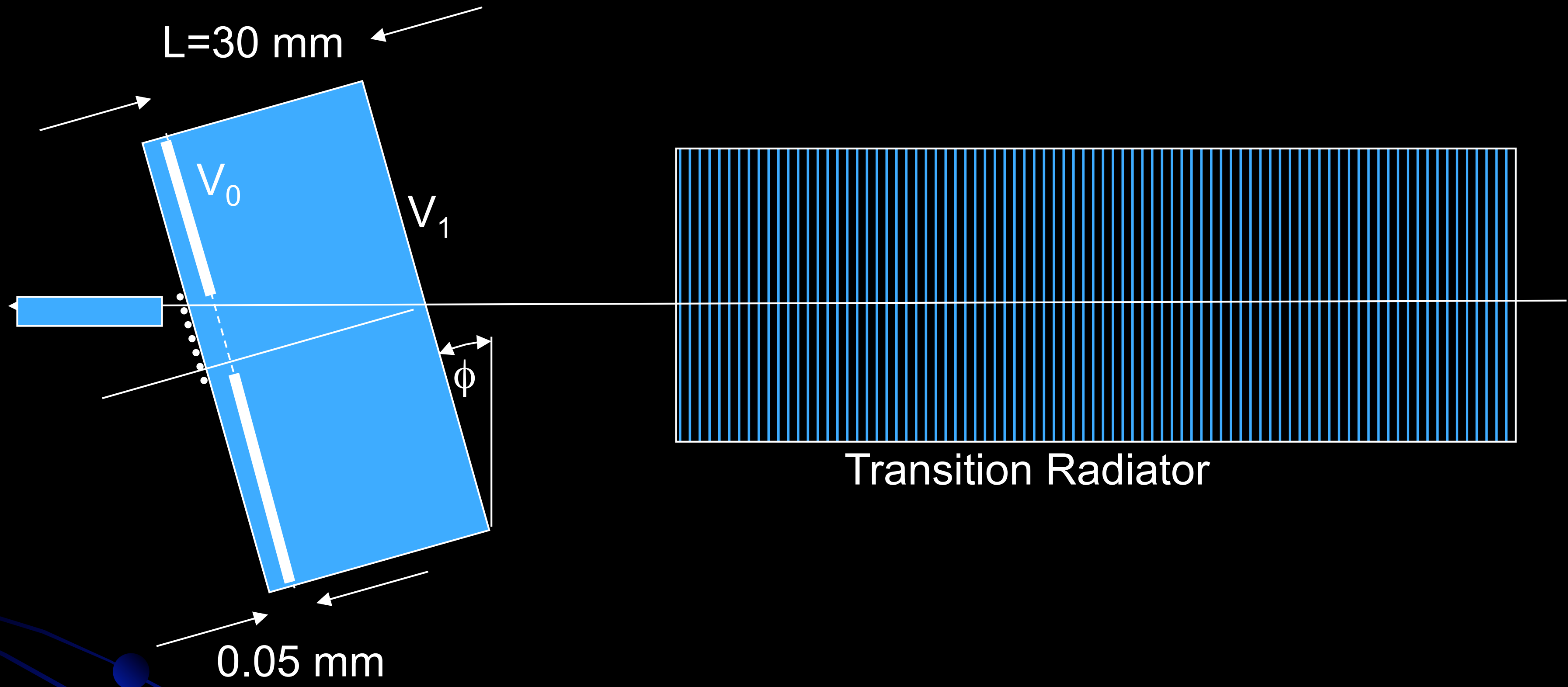




Colloquium Lucie de Nooij, Tuesday 13 January, 15h, H331

Testbeam April 2008

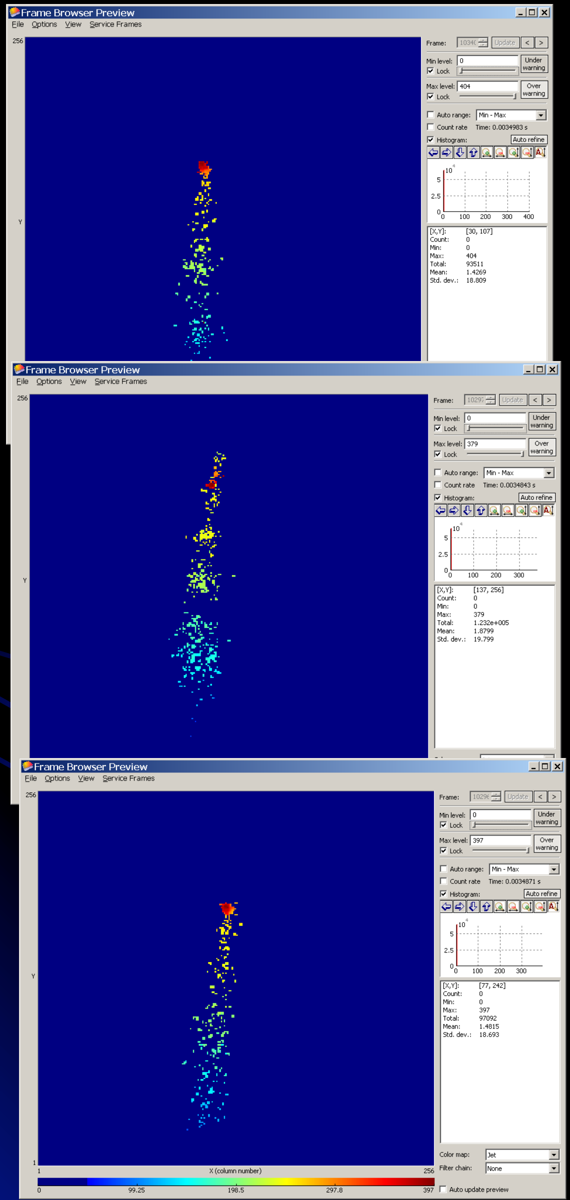
PS/T9: electrons and pions, 1 – 15 GeV/c

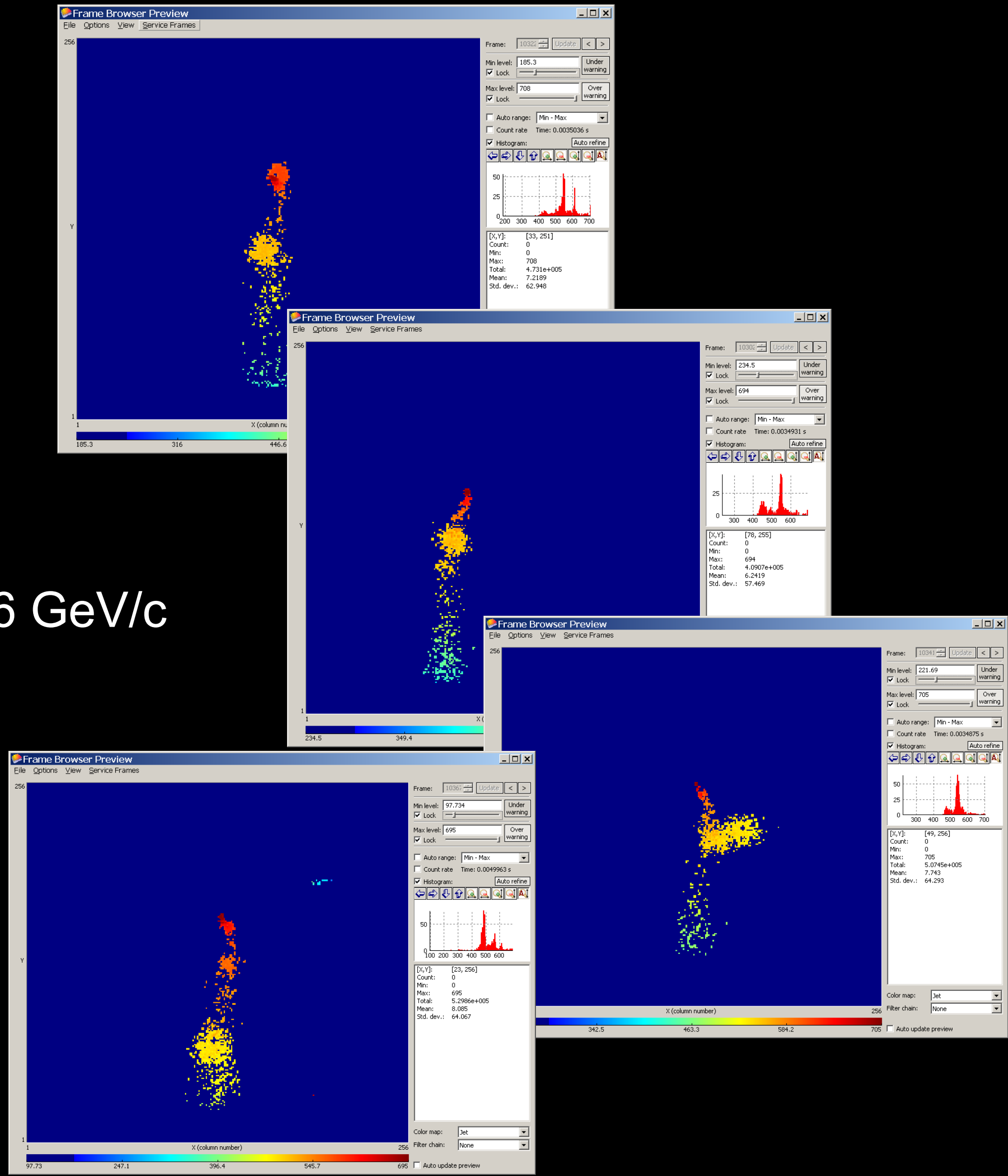


! detection of Transition Radiation photons !

Particle Identification

Samples pions (left) and electrons (right)

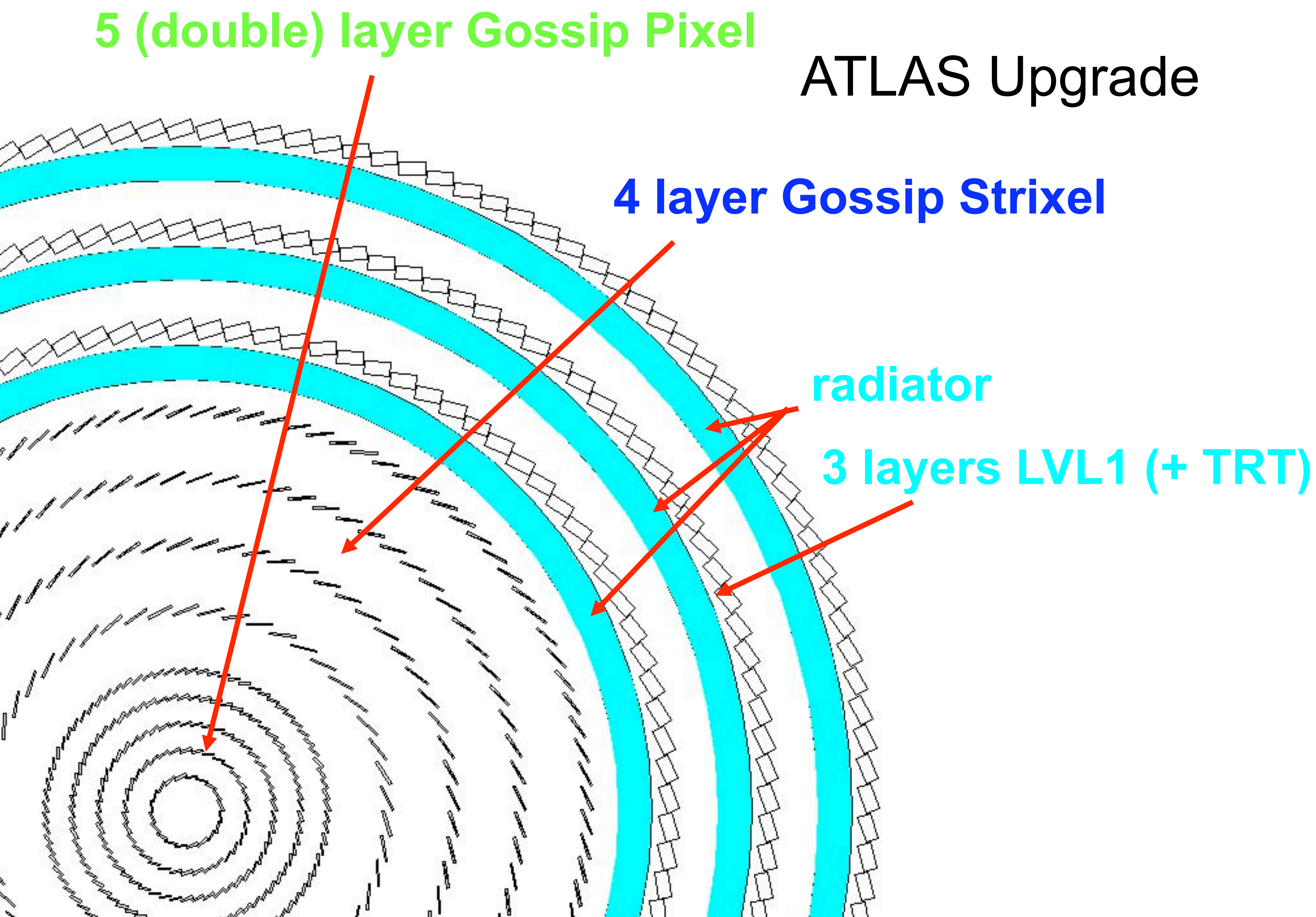


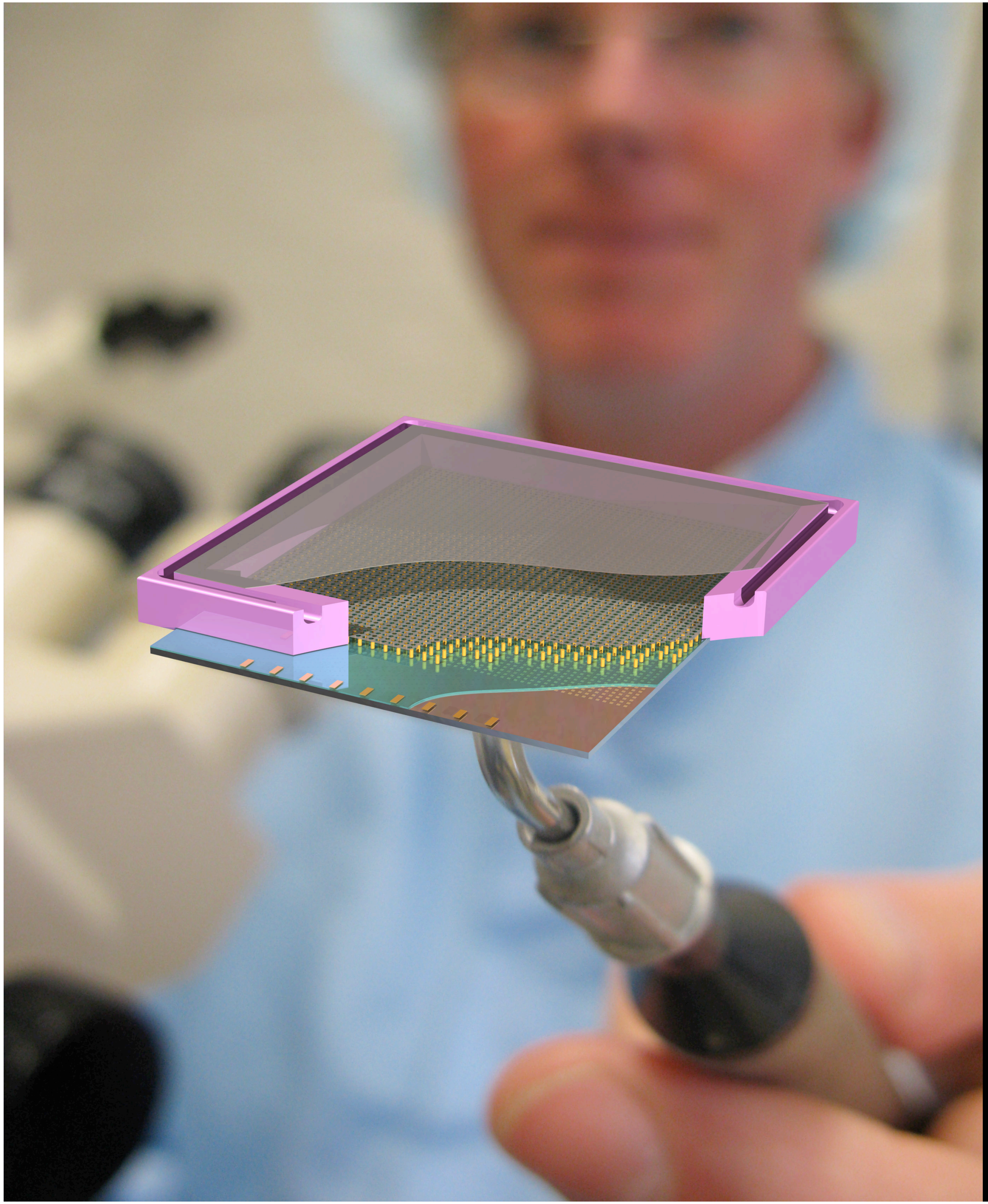


6 GeV/c

…broke TimePix chip in Xe: 490 V on grid…

ATLAS Upgrade



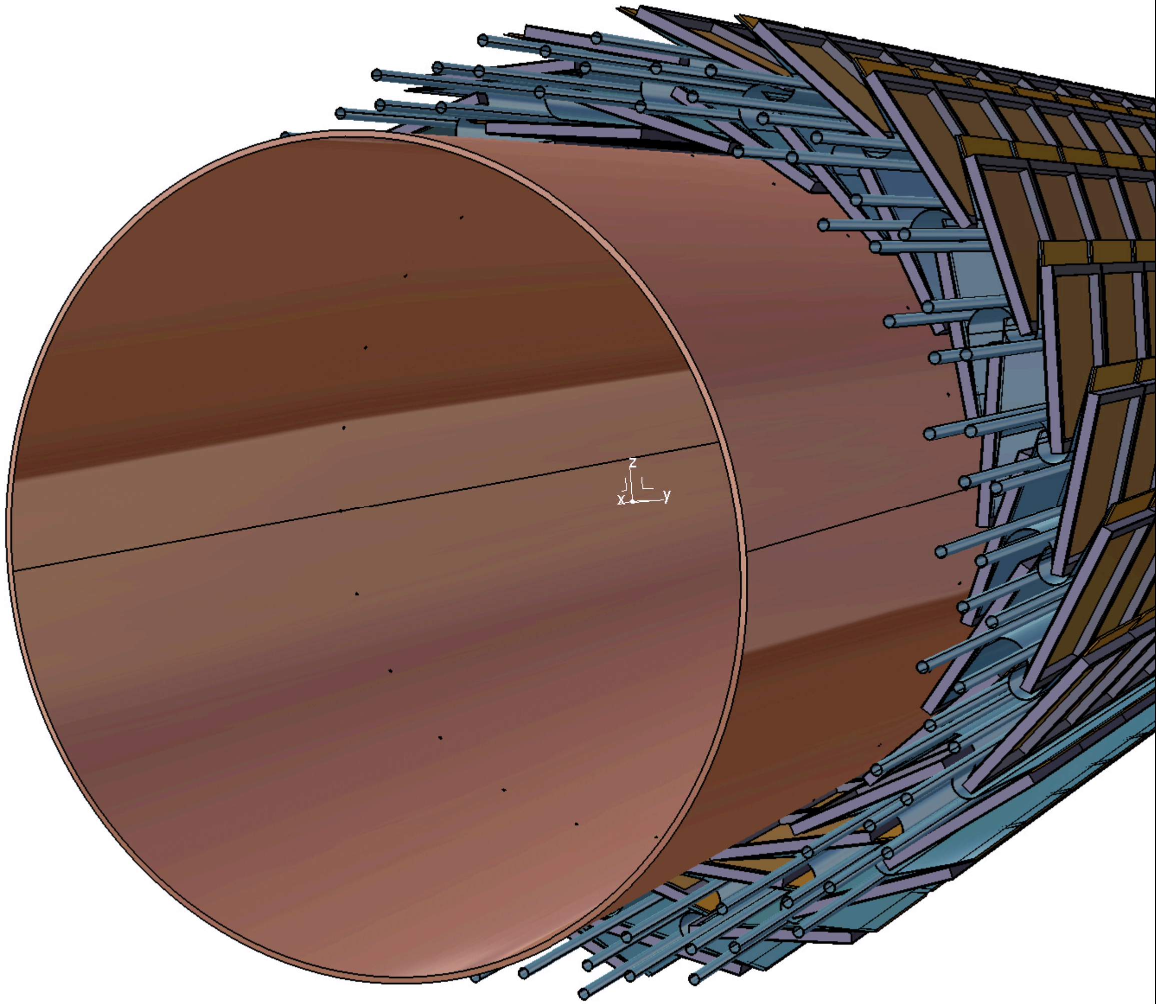


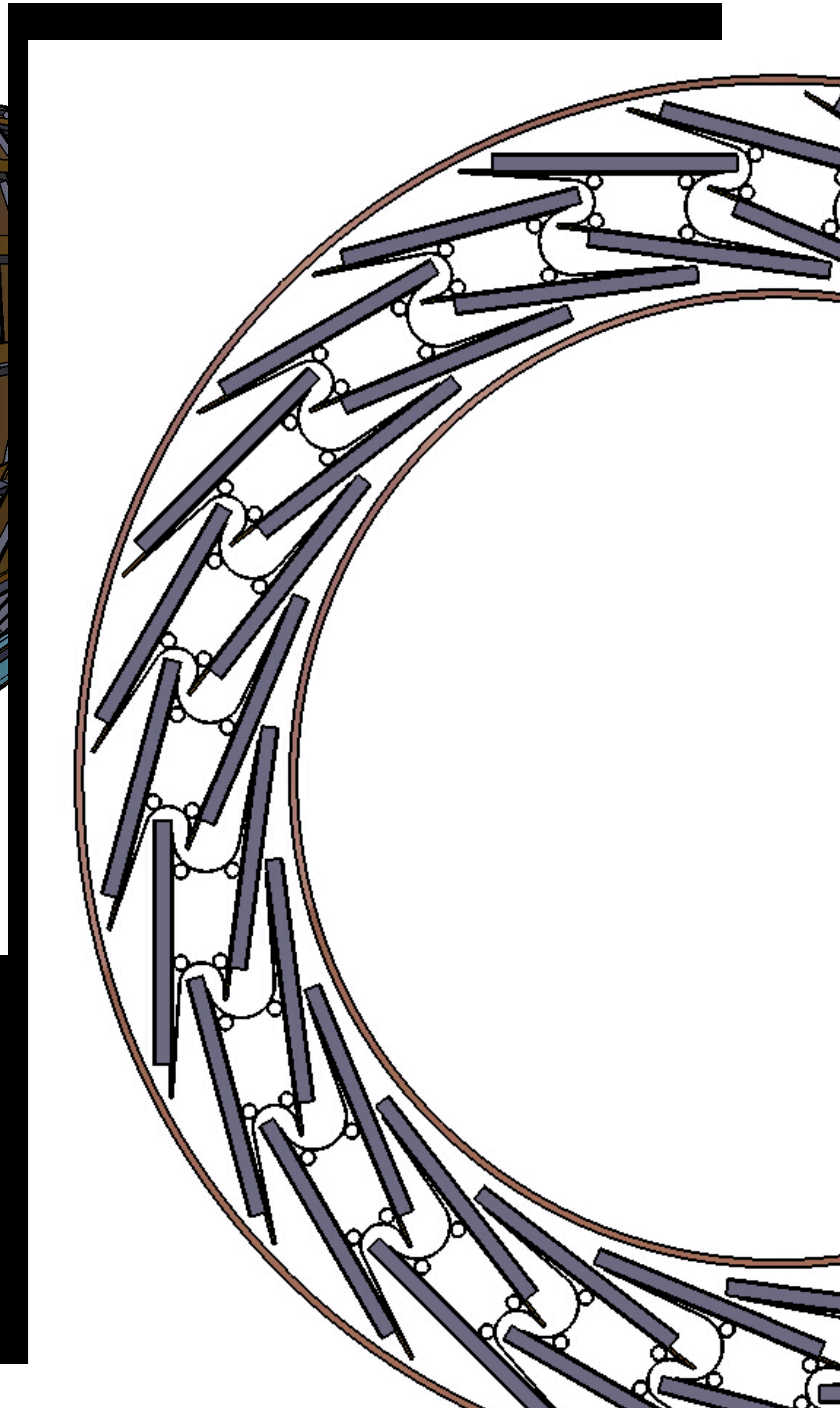
Vertex Pixel detector

Strixel detector

LVL1 trigger

TRT



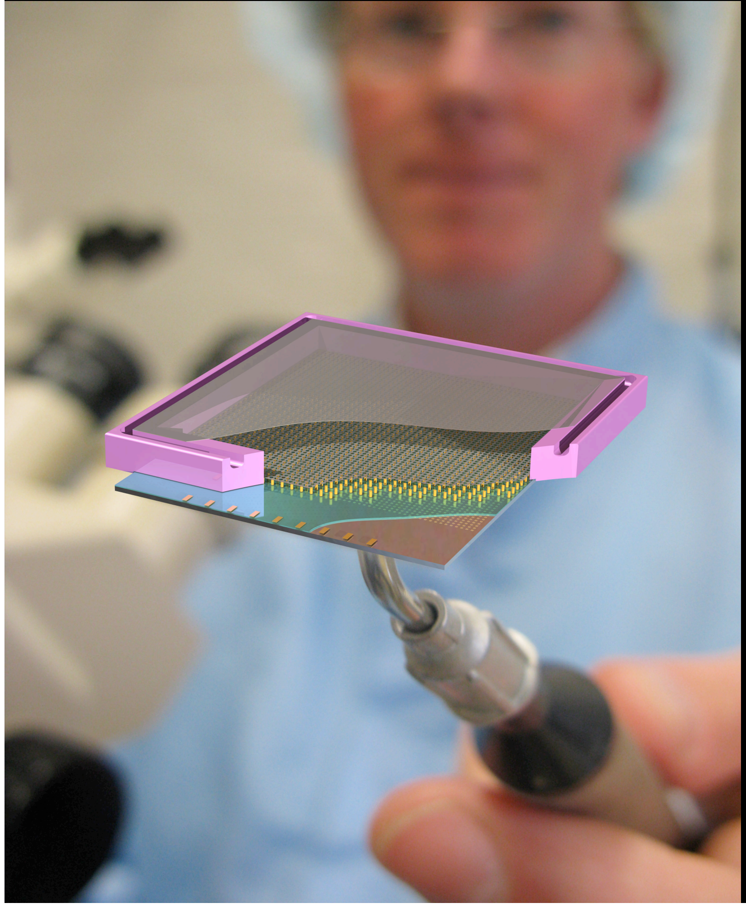


ATLAS:
Gossip as vertex detector

GridPix replacing the Si Strip Tracker:

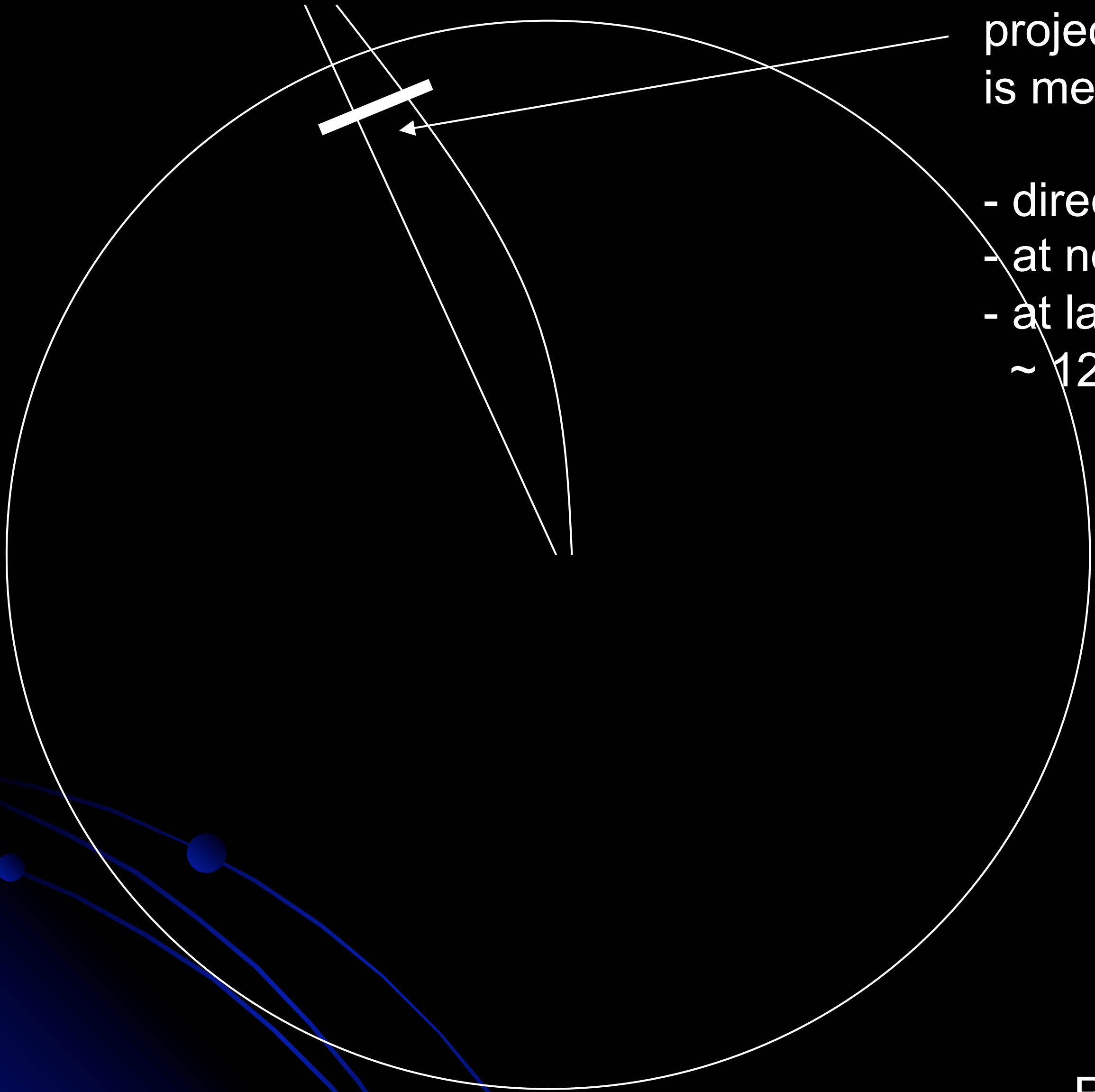
- huge surface: up to 200 m^2
- replace strip sensor+ CMOS FE chips with strixel CMOS chips
- lower occupancy: thicker gas layer. more track info

➔



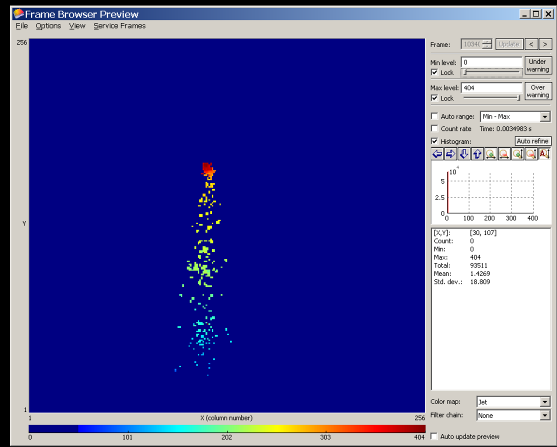
- Cost: 10 + 10 \$ cm^{-1} for Gossip
- ultralight: 0.2 % X_0/layer
- Track segment info
- Many layers (> 10) feasable

LVL1 trigger from inner tracker



projected track length
is measure for momentum:

- directly available (LVL1)
- at no (extra) cost (mass, power)
- at larger R: gas drift gap ~20 mm
  ~ 12 BXs



Requires fast on-board processing

We are using 130 nm tech.

What about 45 nm tech?

Test Beam (H4 at SPS, CERN) Aug 12, 2010

Martin, Victor, Fred, Harry
Wilco, Sjoerd

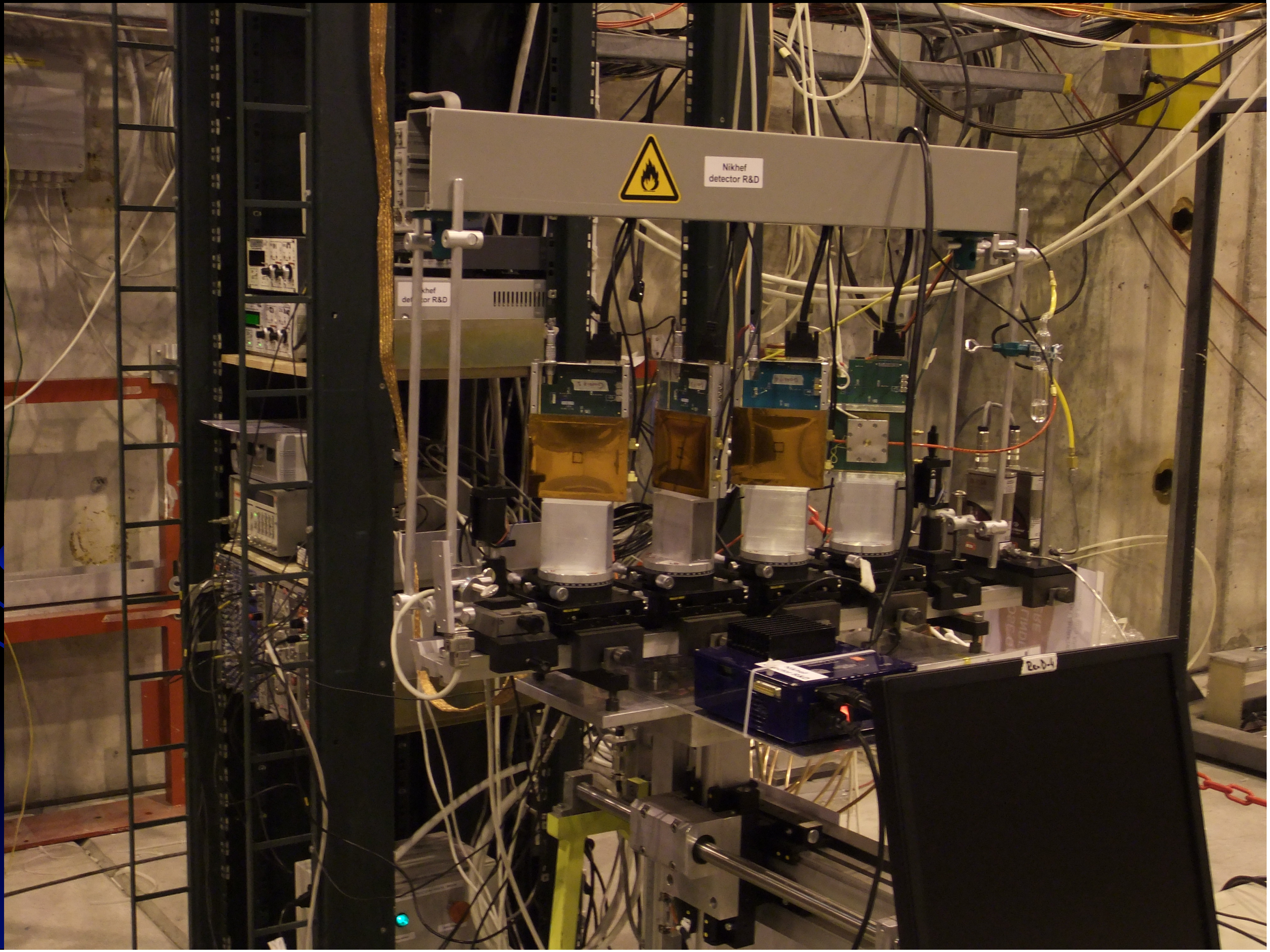


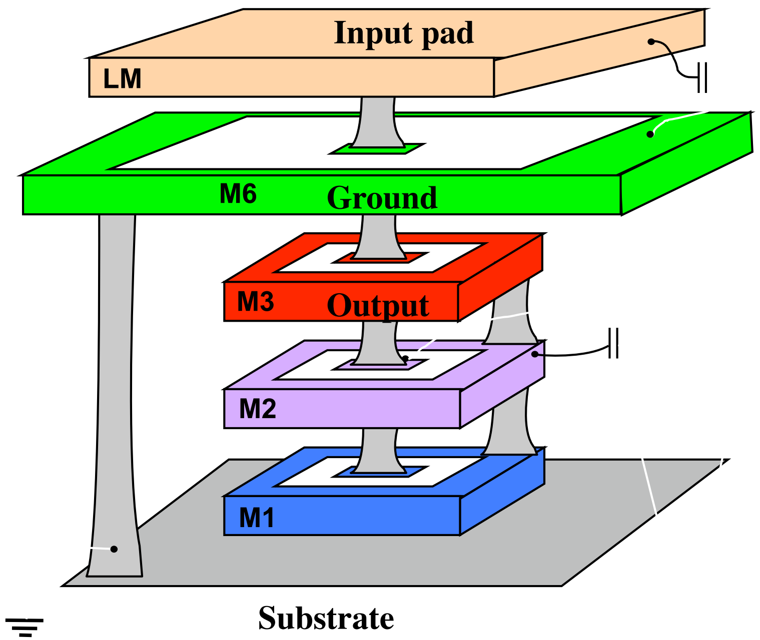
*Fig. 10. Drift time plots of a typical event from a 15 GeV π^- traversing three Gossip prototypes and a GridPix detector with 20 mm drift height. The drift times are indicated by colours. For better visibility only a rectangle of 80*80 pixels is displayed of each detector.*

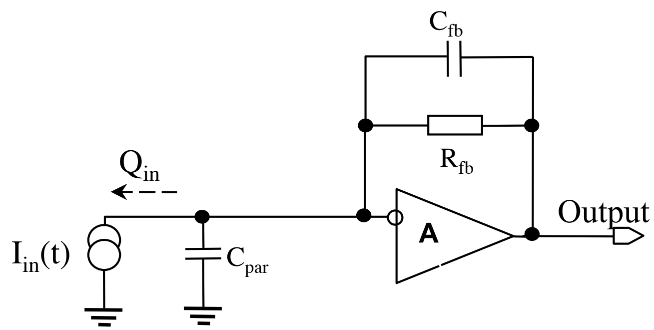
Electronics

GOSSIPO-1:

test of preamp-shaper-discriminator for GOSSIP

'MultiProjectWafer' in 0.13 μm technology



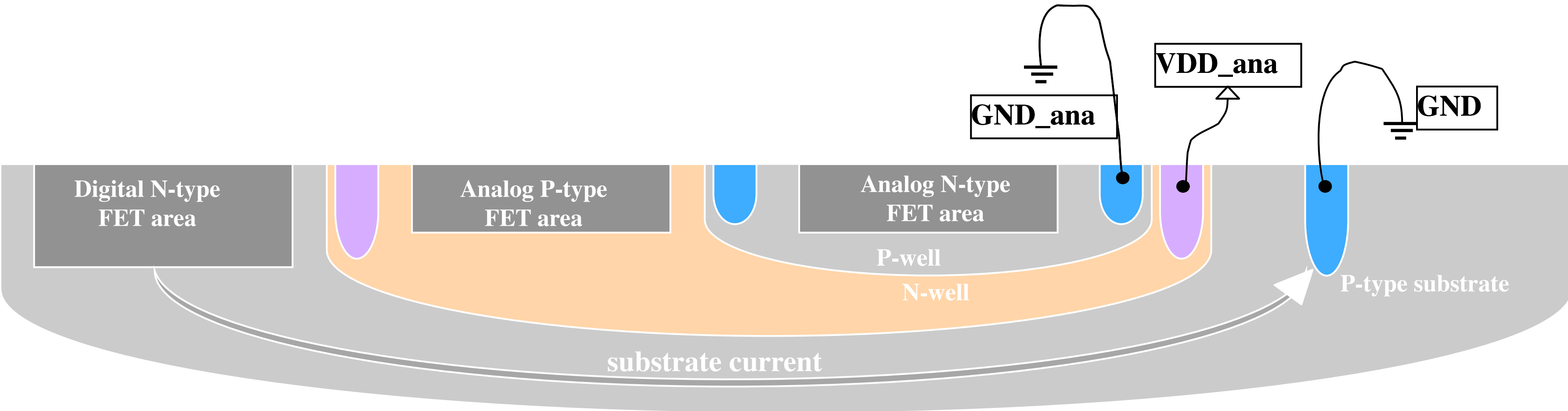


Very low (parasitic) capacitance at the input ($C_{par} \rightarrow$ 10fF) .

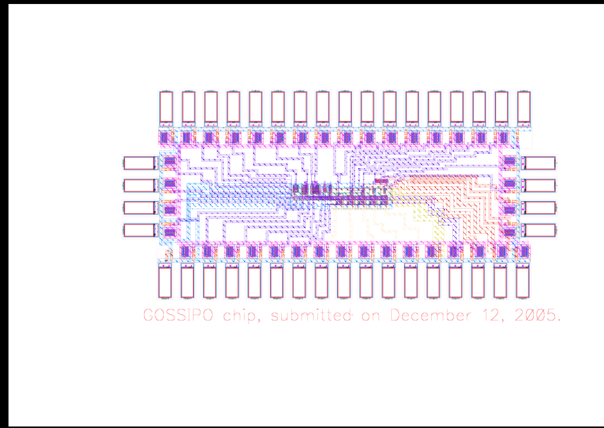
Coaxial-like layout of the input interconnection.

Triple well layout in 130 nm (IBM) technology:

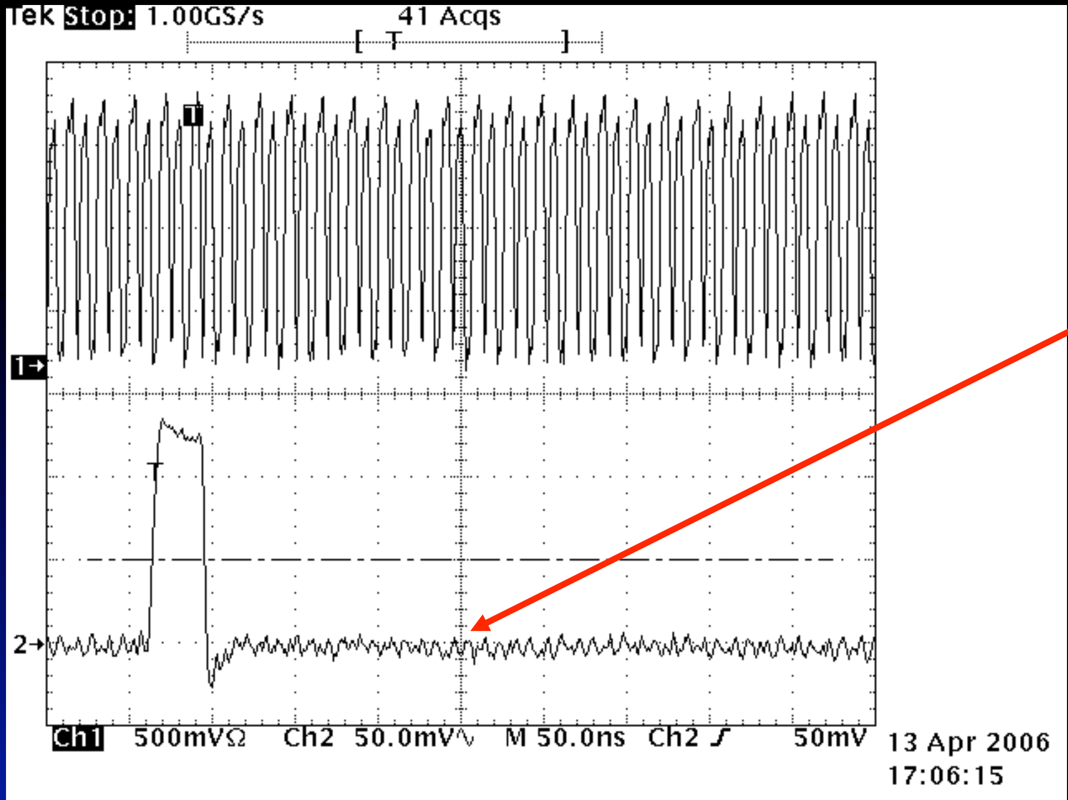
isolation of digital
and
analog sections



- match extreme small source capacity: 15 fF
- peaking time: 40 ns
- noise (expected: 60 e- input eq.)
- power: 2 μW/pixel (!)



GOSSIPO chip
Submitted December 2005.



- Input noise eq. reached
- No effect of digital switching within pixel

MultiProject Wafer:

Vladimir Gromov/NIKHEF
CERN Micro-electronics group

GOSSIPO-2

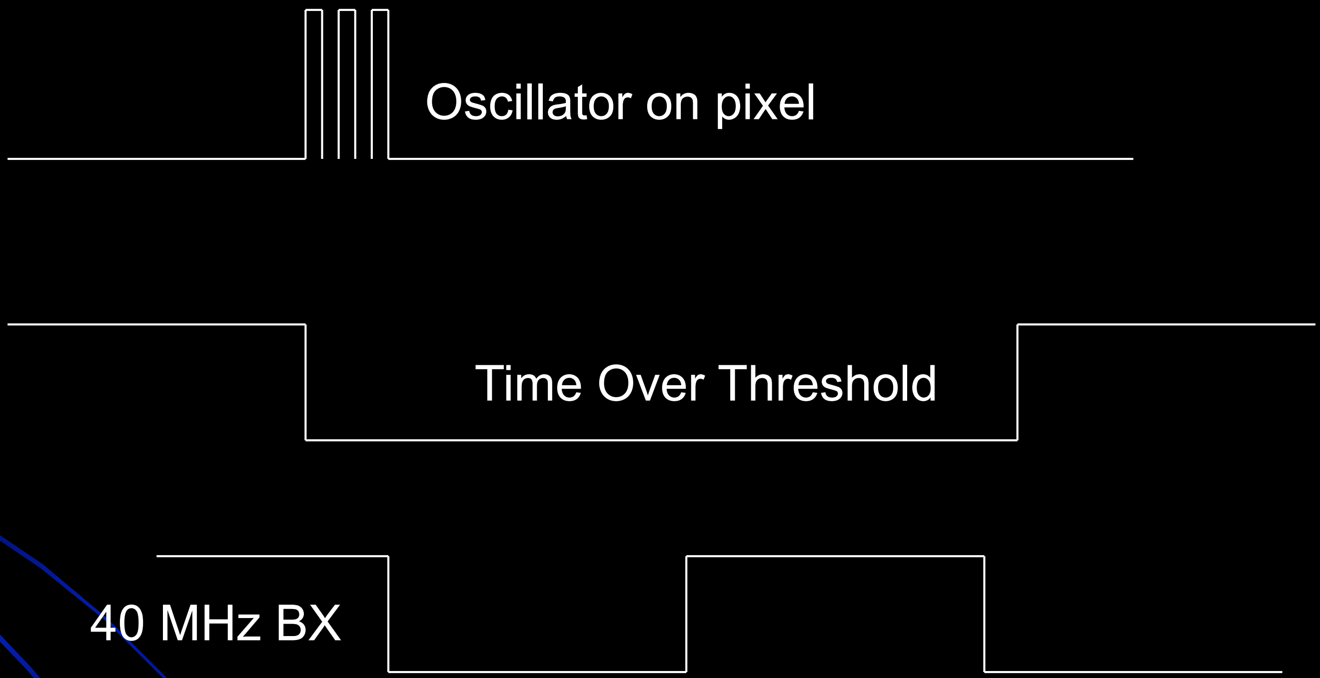
test of preamp-shaper-discriminator

+

700 MHz TDC per pixel

- 0.13 μm technology
- containing 16 x 16 pixels
- Submission Nov 2006
- Can be used for GOSSIP demo!

1 ns TDC per pixel



Gossipo-3

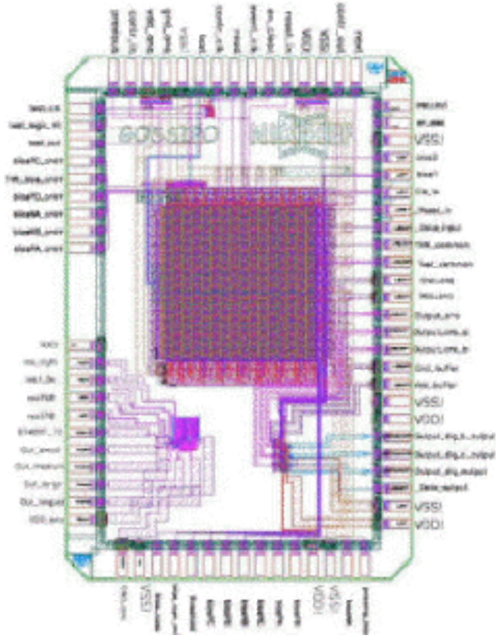
In collaboration with Bonn   [FE-I4]
Preparation of TimePix-2 (TPX-2)

TimePix-2

Gossipo-2 MPW

600 MHz osc
in each pixel

Low-noise,
low power analog
input



Medipix-1

Medipix-2

250 nm technology

TimePix

Medipix-3

130 nm technology

TimePix-2

TimePix-2:

- TDC per pixel: σ = 1 ns
- 'ADC' per pixel: TimeOverThreshold
- noise: 80 e- eq.
- discharge protection circuit
- fast (trigger enabled) readout

Essentially ALL info on primary electrons in gas is extracted!

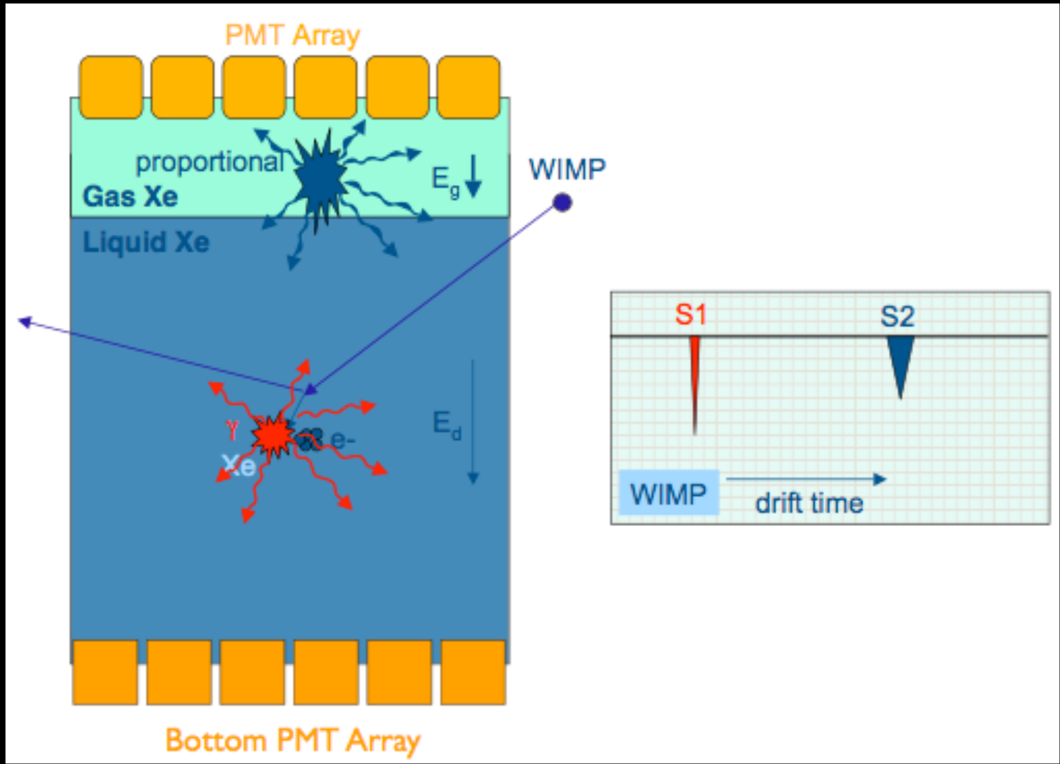
WIMP search, bi-phase Xenon

- GridPix TPC

as

WIMP / DBD

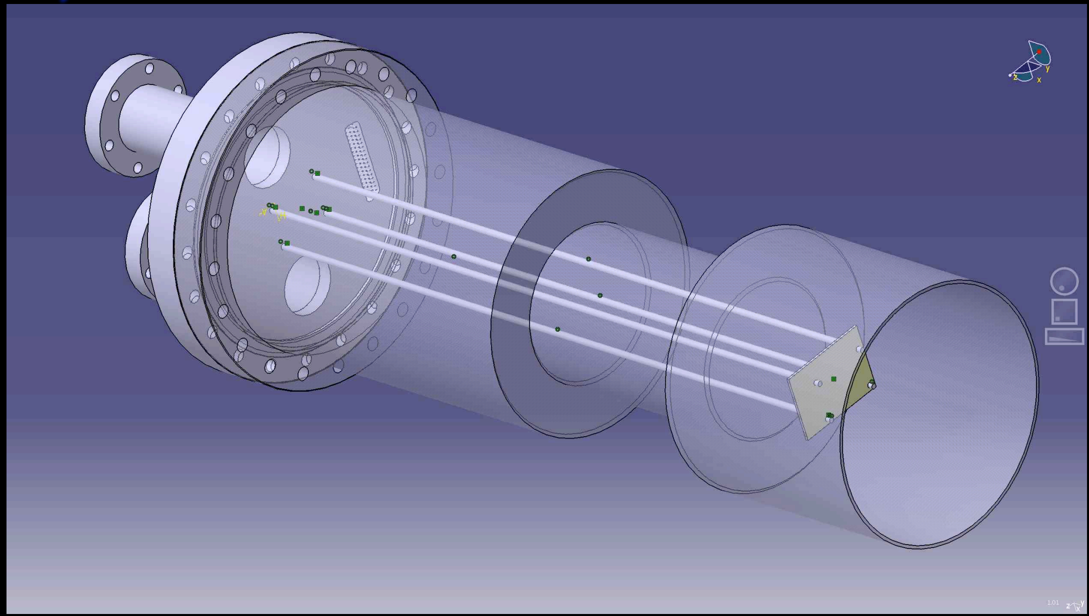
detector



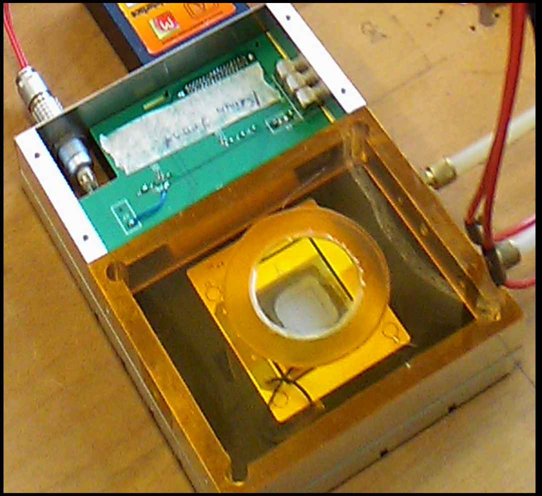
Source: Direct Searches for Dark Matter, Elena Aprile, EPS - HEP, July 21 2009, Krakow, Poland

Gridpix in Xenon: Test setup

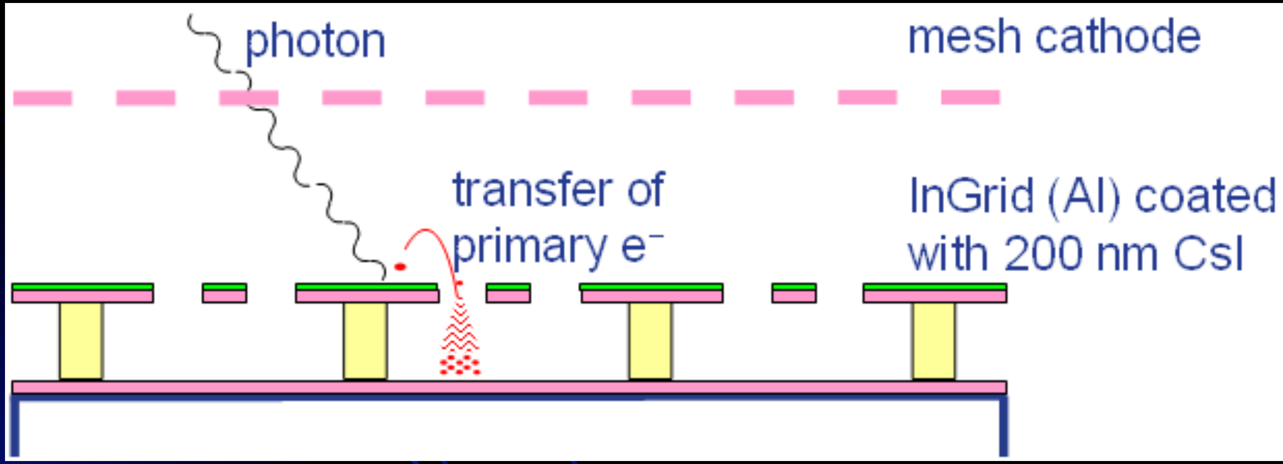
- Collaboration DARWIN/XENON
  Columbia Univ., N.Y.

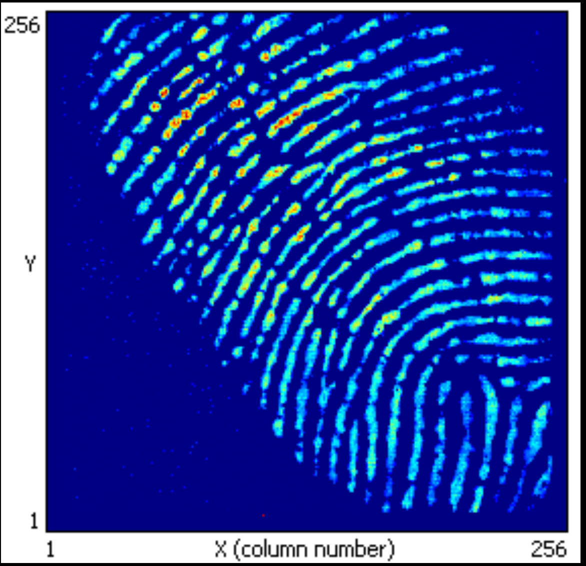


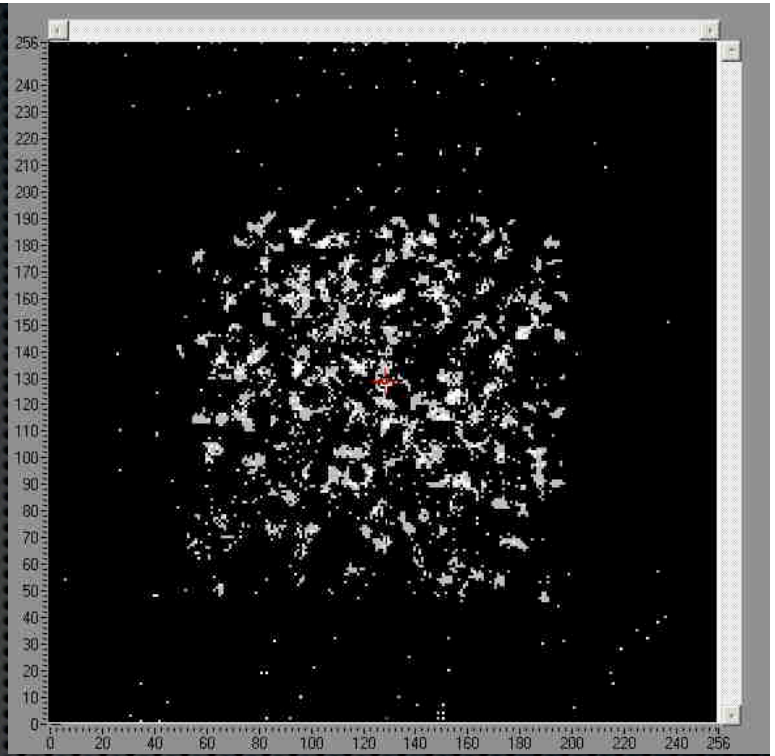
GridPix as photon detector



- Photoelectric effect
- Future possibility:
  CsI layer on grid





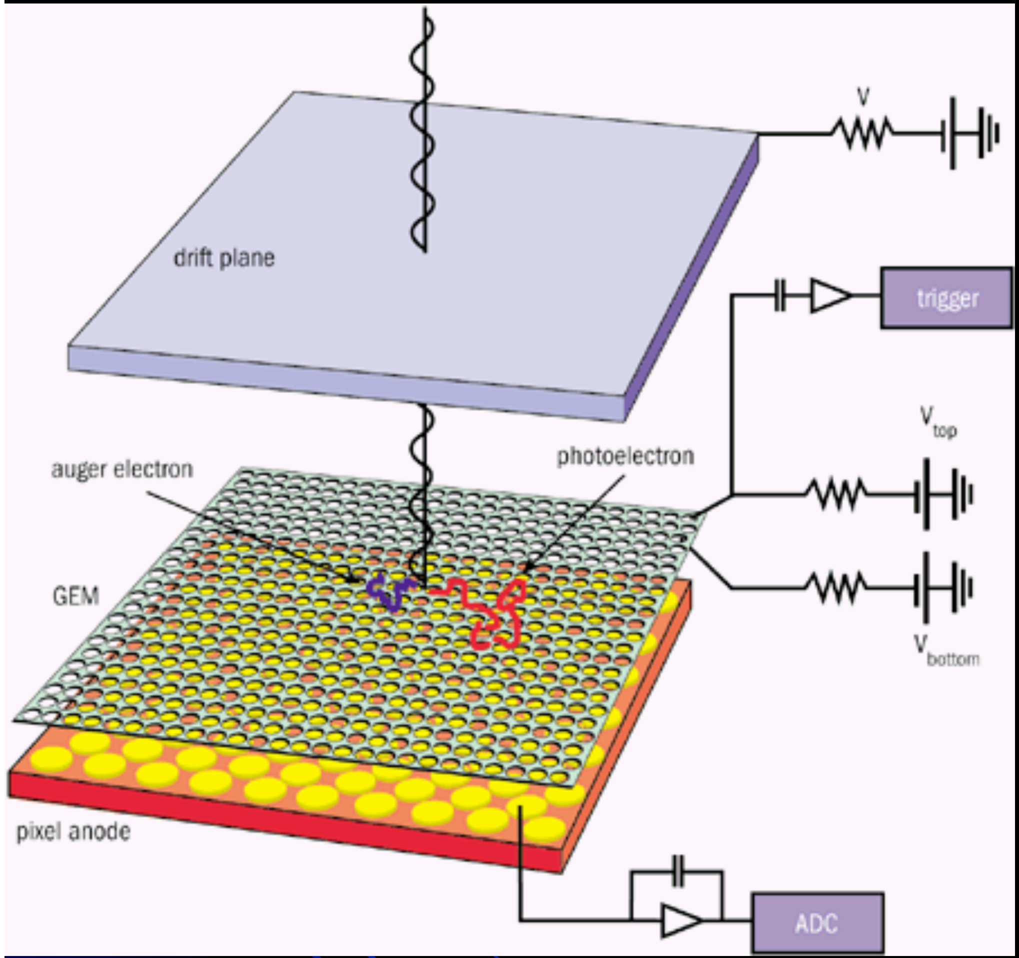


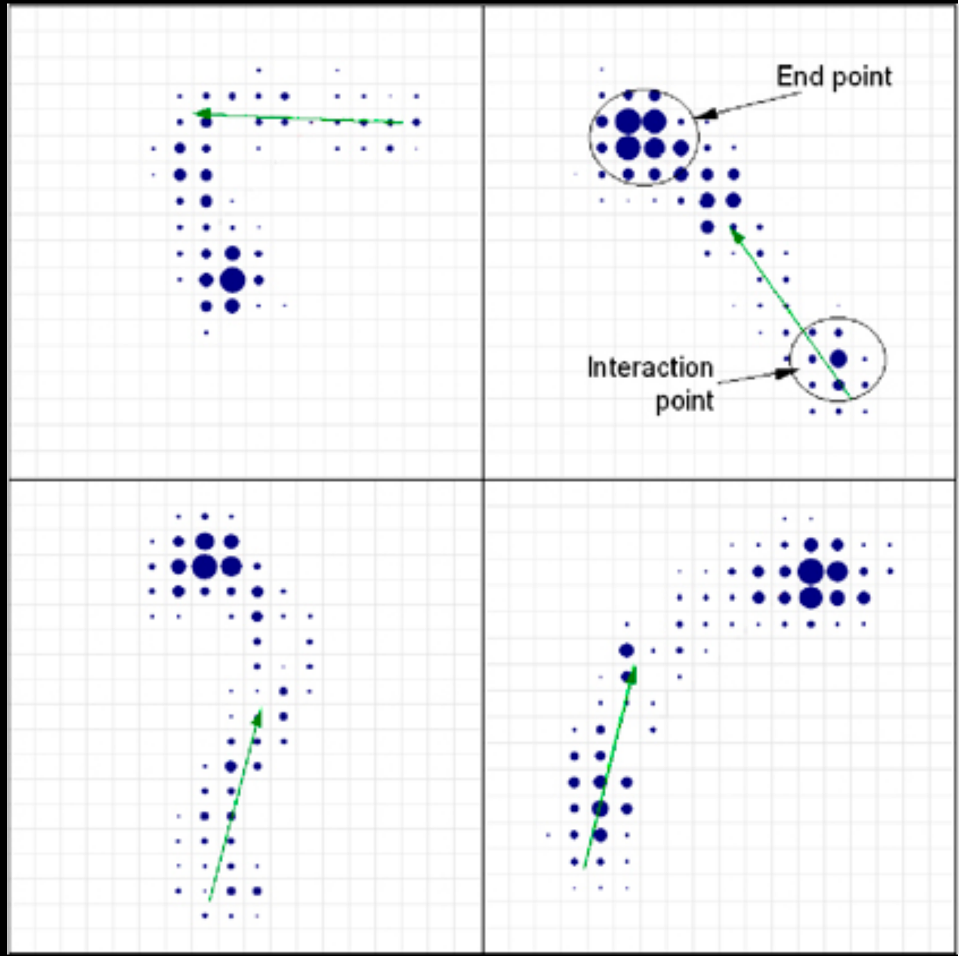
PolaPix

Using a GridPix detector for the 3D detection of polarized X-ray photons

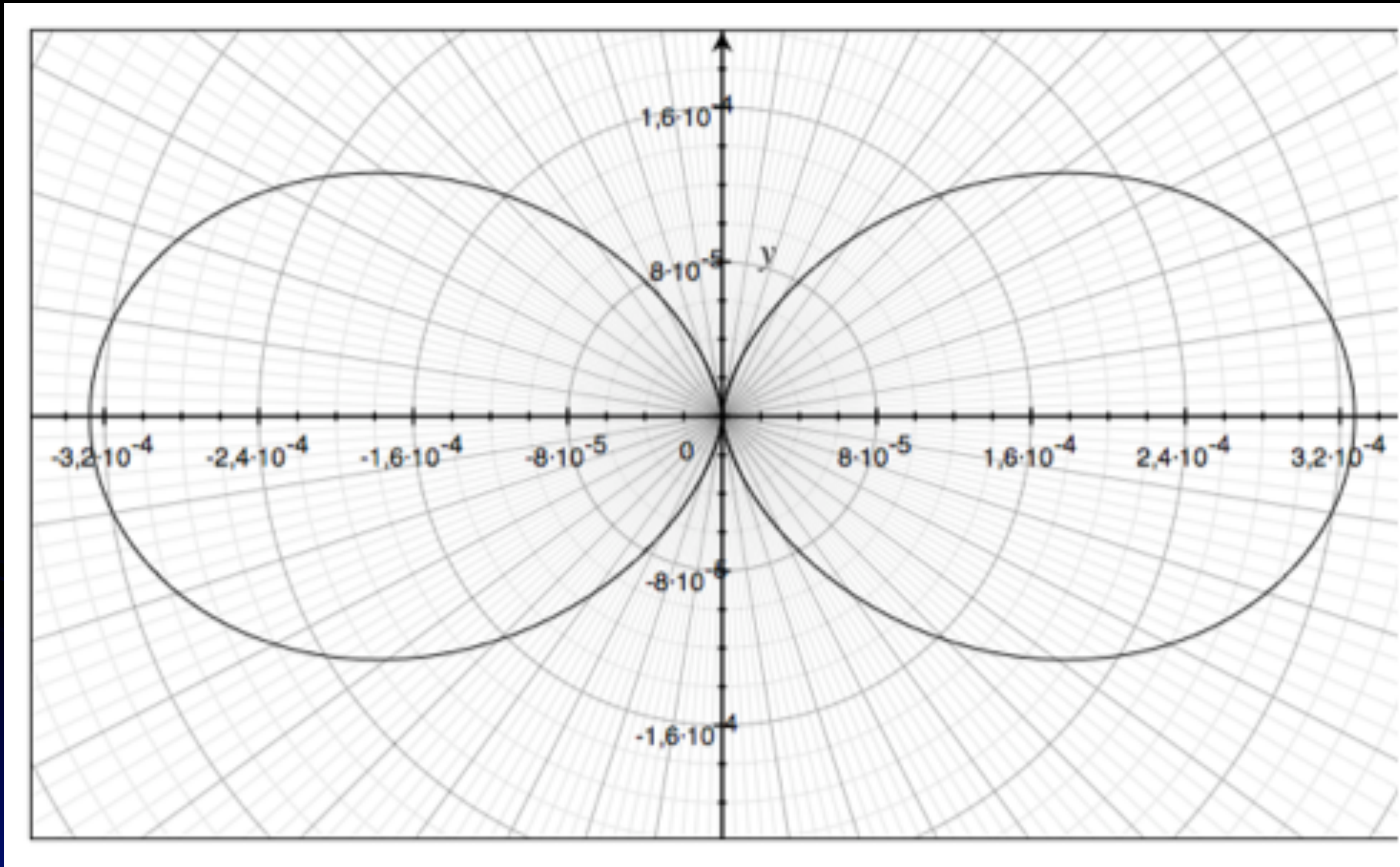
Sjoerd Nauta - Nikhef

NIKHEF TUDelft



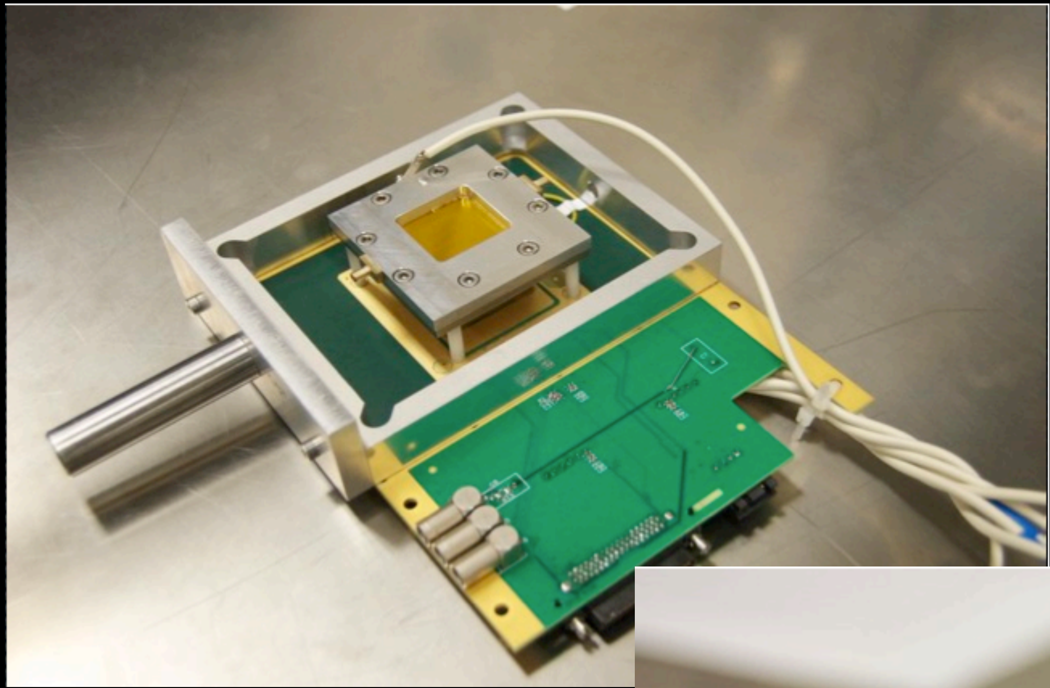


X-ray Polarimeter proposed by R. Bellazzini



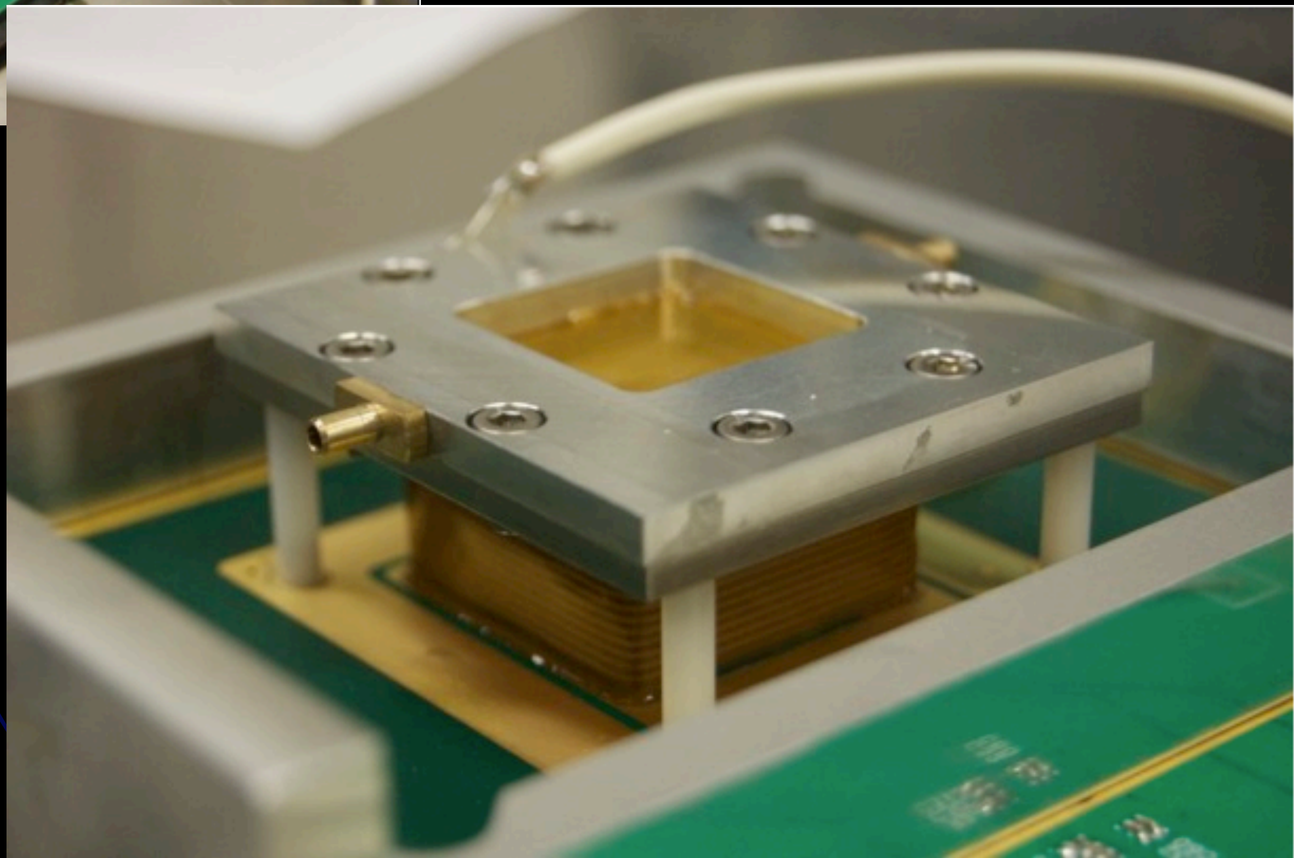
Distribution of direction of photo-electron of (fully) polarised X-rays

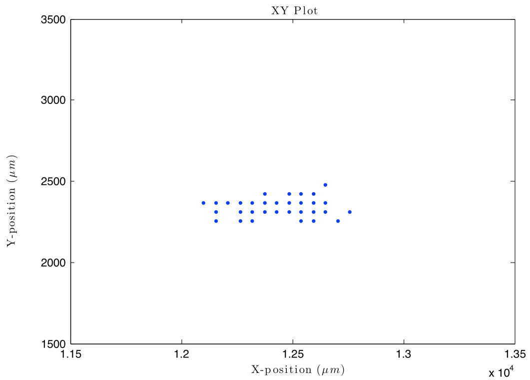
PolaPix

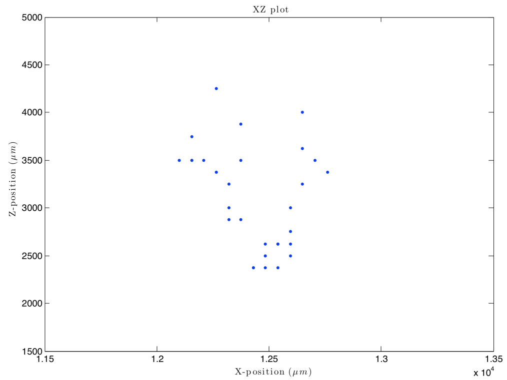


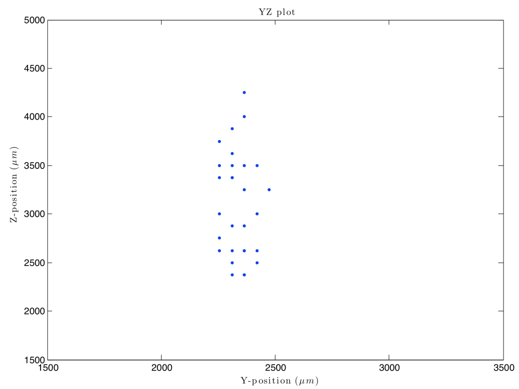
collaboration with

Erlangen Astroparticle Physics Group









XY

XZ

YZ

^{55}Fe photoelectron in DME/CO2 50/50

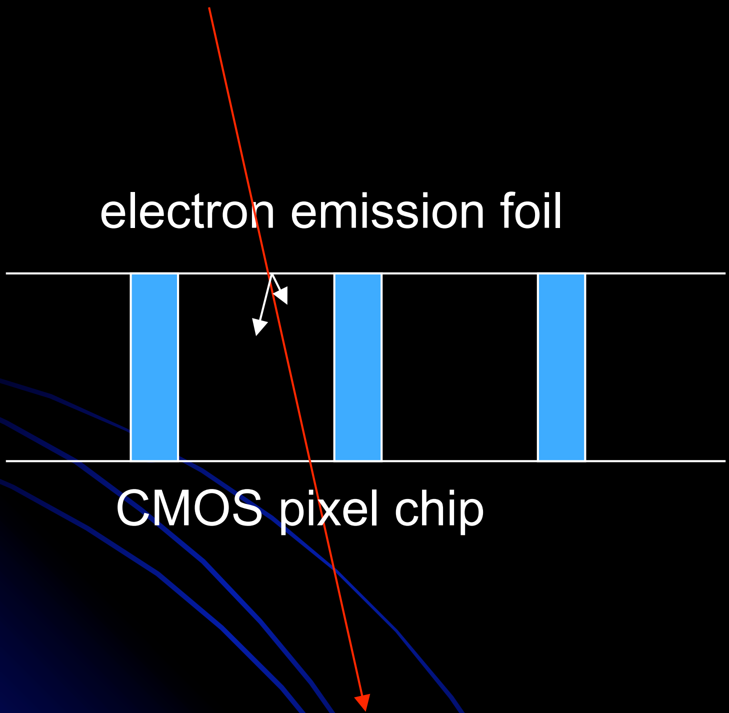
Risky project:

- electron emission & multiplication detectors
- eliminate gas as detection matter

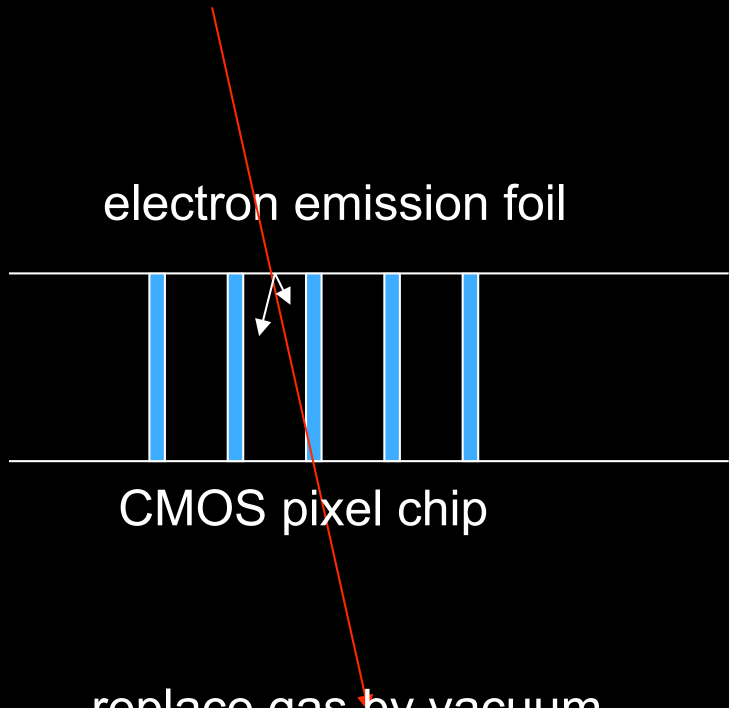
The future:

Electron Emission Foil

MEMS made MicroChannelPlates: 200 ps time resolution: CLIC

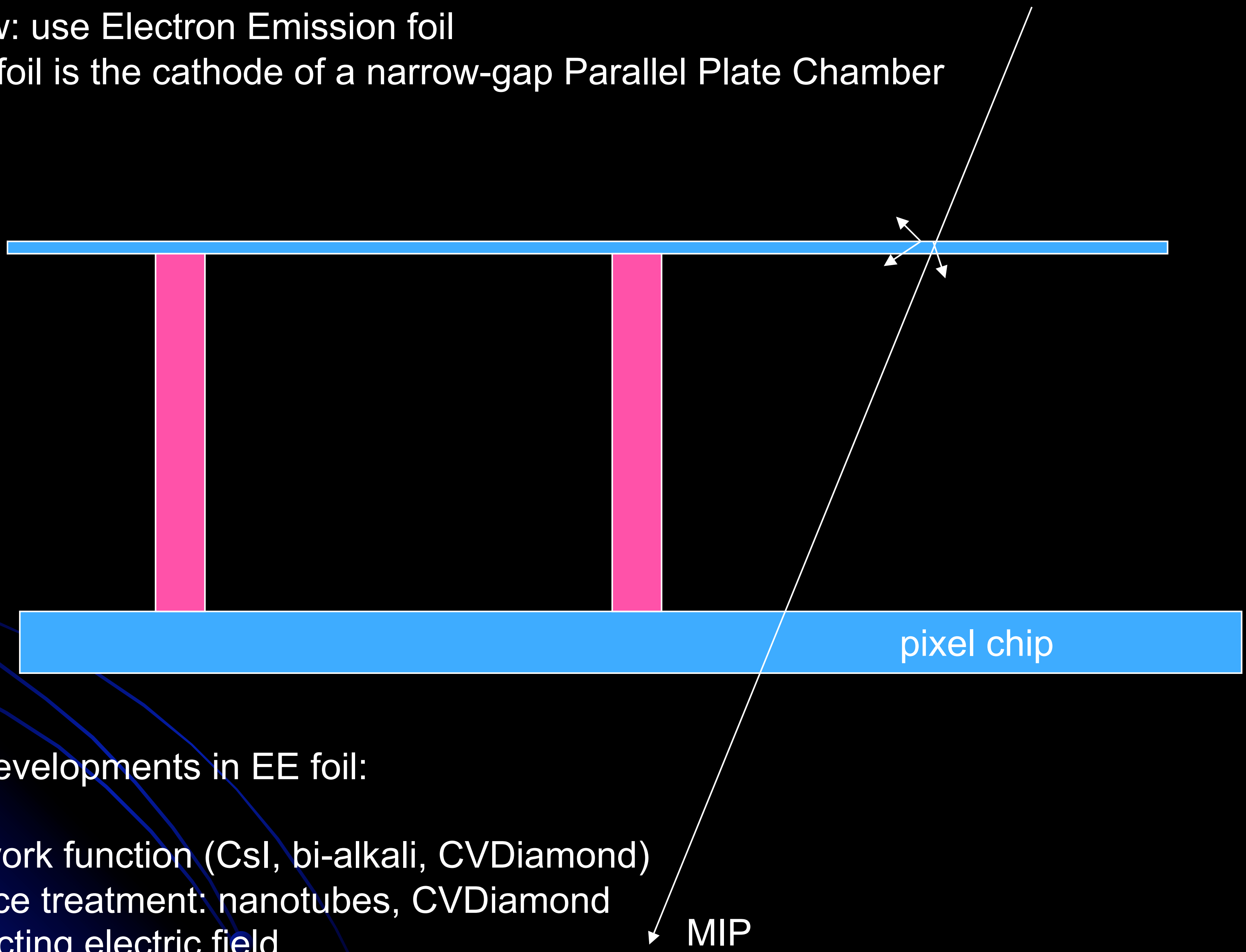


electron avalanche in gas
EE-Foil replaces InGrid
Parallel Plate Chamber



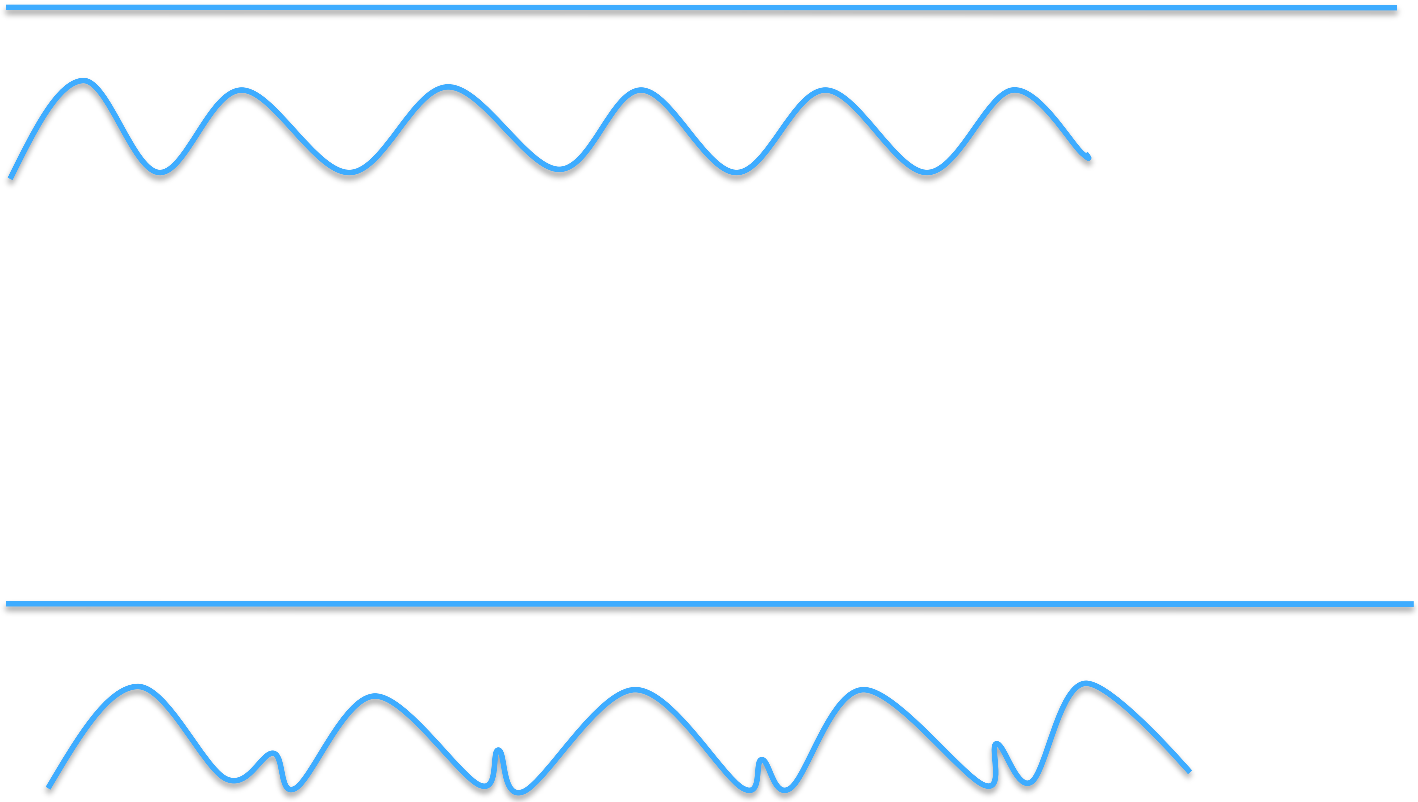
replace gas by vacuum
Micro Channel Plate
sub-ns time resolution
Note CLIC experiments

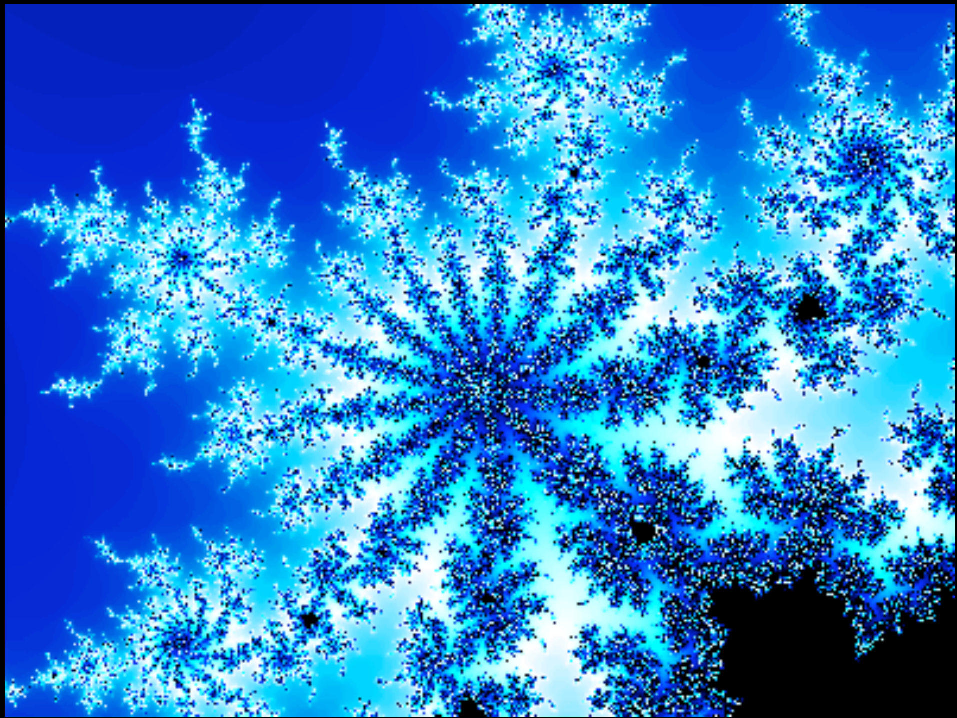
New: use Electron Emission foil
EE foil is the cathode of a narrow-gap Parallel Plate Chamber



New developments in EE foil:

- low work function (CsI, bi-alkali, CVDiamond)
- surface treatment: nanotubes, CVDiamond
- Extracting electric field





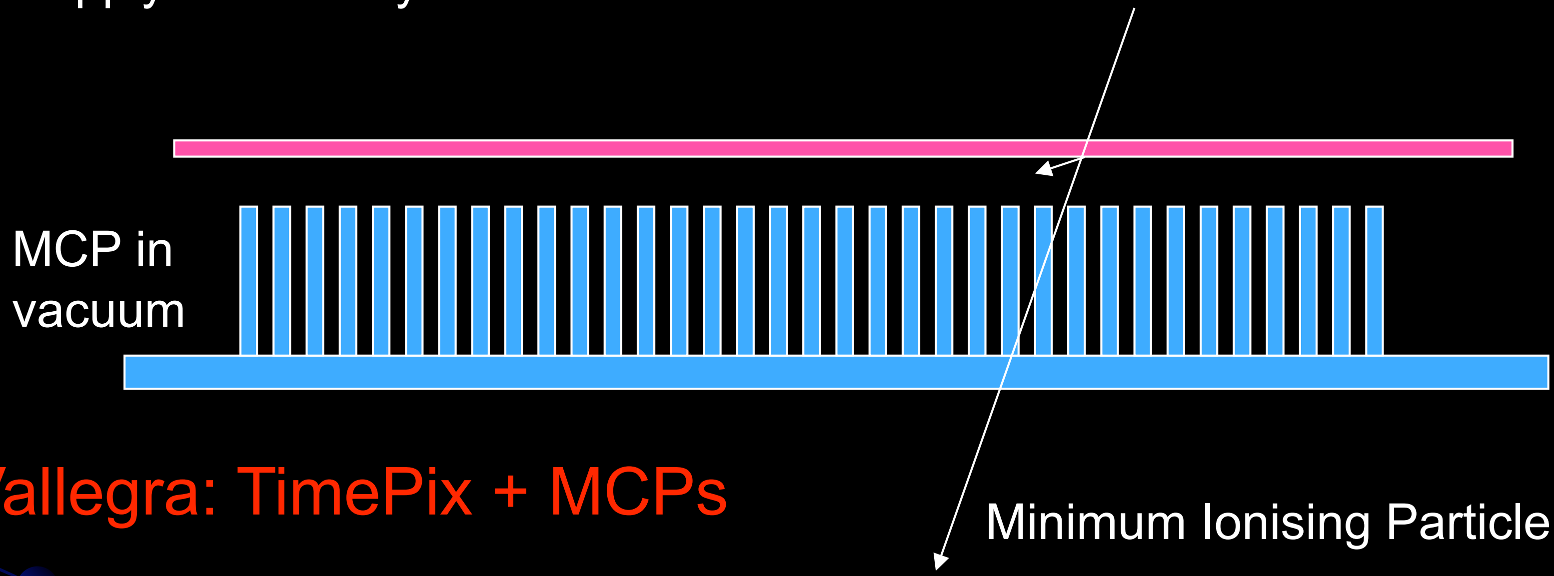
Fractals!

- Eff Alu, Cu: ~ 4 %
- Eff ceramics (Diamond, CsI, Si_3N_4): 20 %?
- Surface increase: factor 5
- essential: constant field strength at surface
- essential: impedance matching of material-vacuum boundary

Now wires are eliminated from gaseous detectors (‘wire chambers’)

Replace InGrid by Micro Channel Plate (wafer post processing tech.)

Apply ‘secondary electron emission’ foil



Vallegra: TimePix + MCPs

Time resolution < 200 ps

CLIC: BXs separated by 0.5 ns!

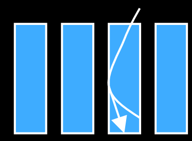
Gasless track detector

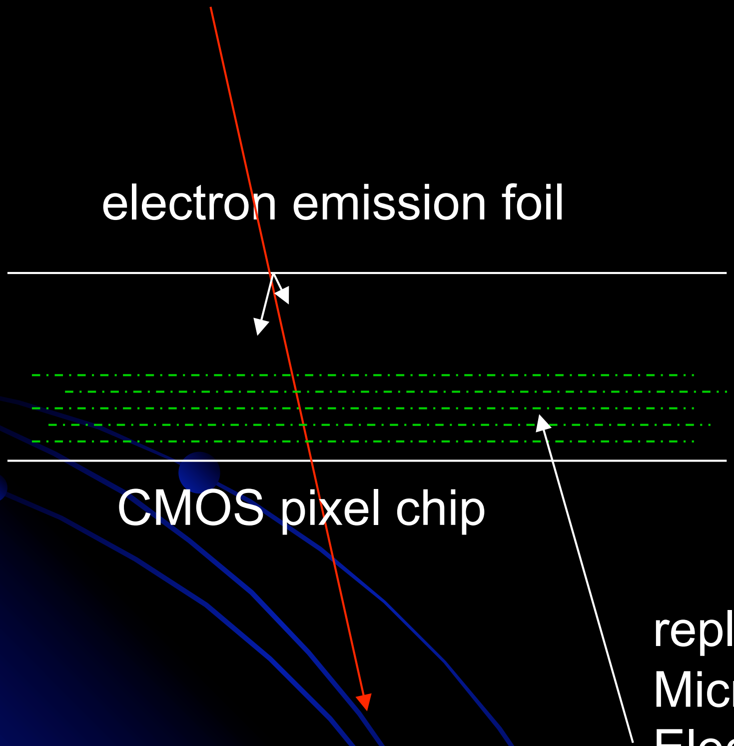
The future:

electron emission & avalanche detectors

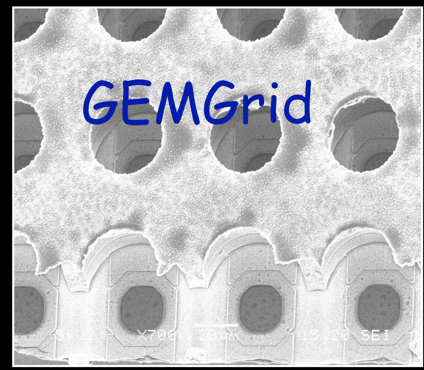
Electron Emission Foil

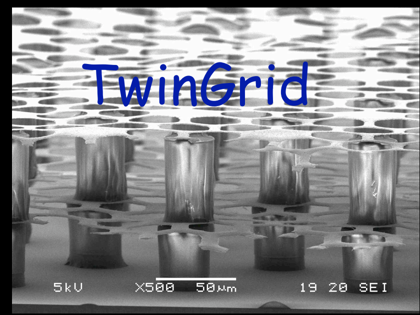
MEMS made MicroChannelPlates: 200 ps time resolution: CLIC

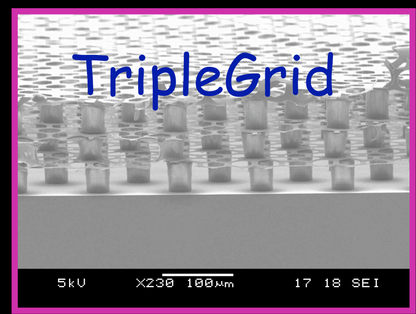




replace gas by vacuum
Micro Channel Plate (MCP)
ElectronMultiplyingGrid (EmGrid)
sub-ns time resolution
Note CLIC experiments, FP420
Works in magnetic field!



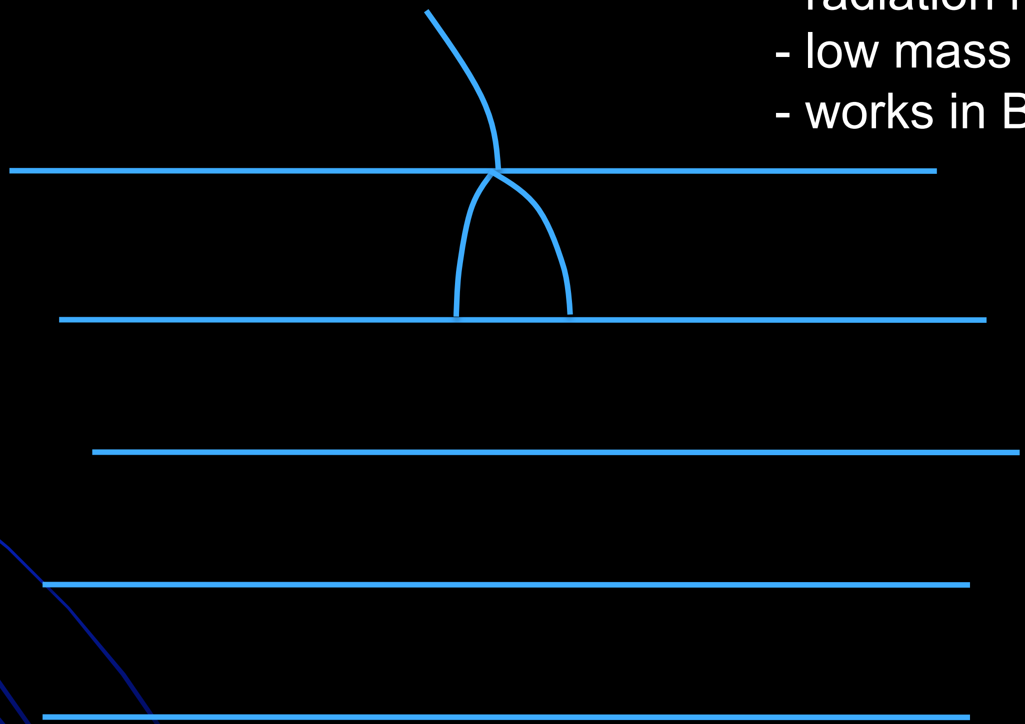




The ultimate electron multiplier: ultra thin (100 nm) dynode layers

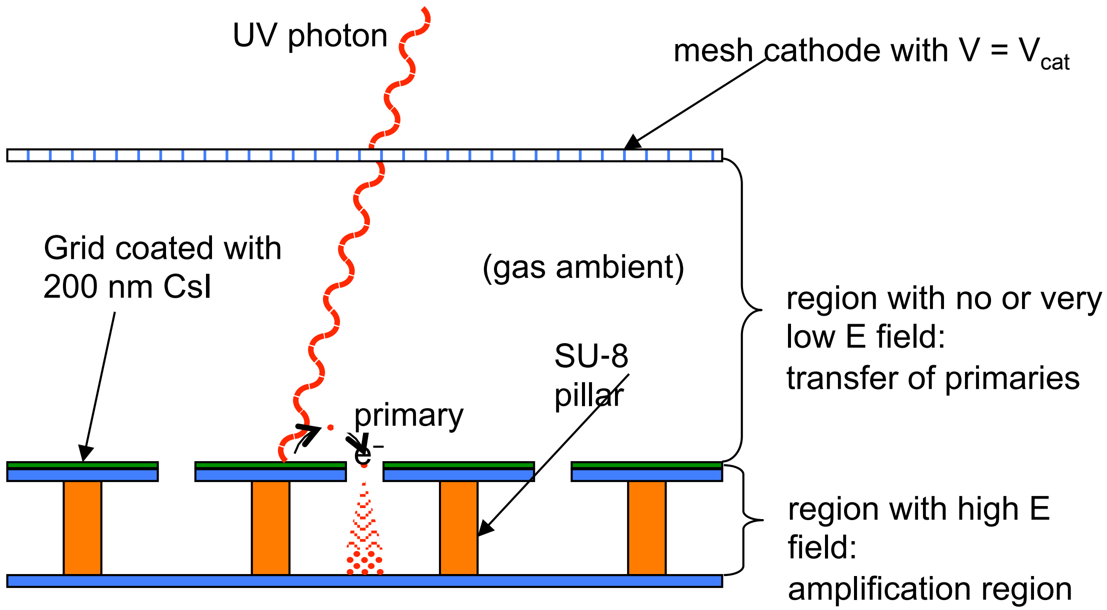
diamond

- ultra fast detector (0.1 ns)
- radiation hard
- low mass
- works in B-field!



In vacuum: no gaseous detector………..

Now operational:



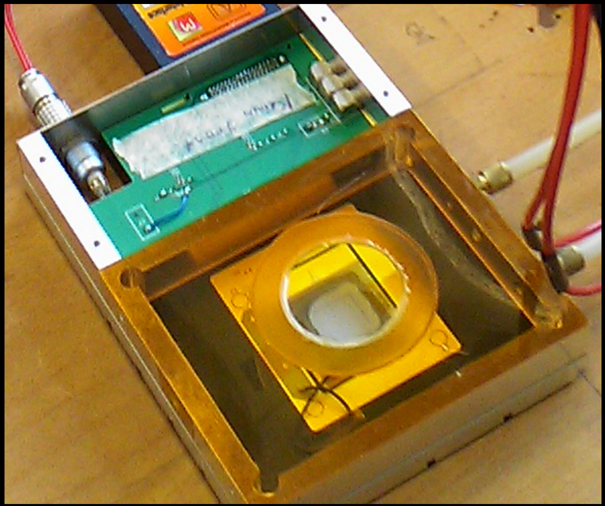
Joost Melay, Univ. Twente, MESA+
Jurriaan Schmitz’ STW project ‘There is plenty of room at the top’

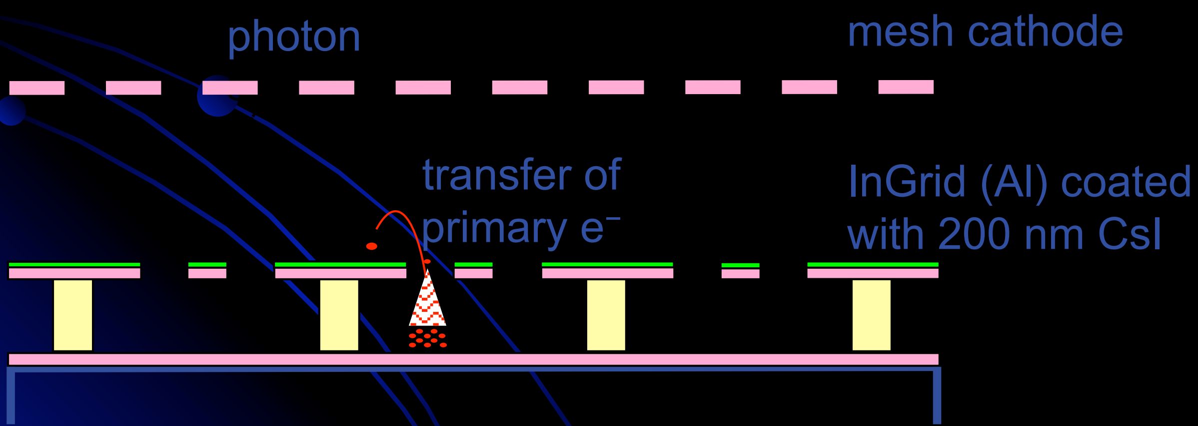
With Amos Breskin, Weizmann Institute of Science in Rehovot, Israel ,

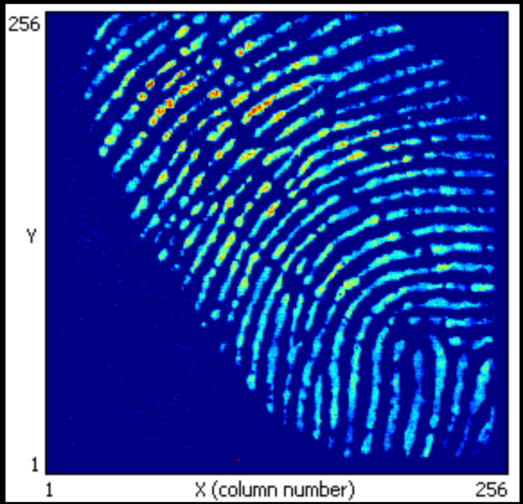
Photosensitive GridPix

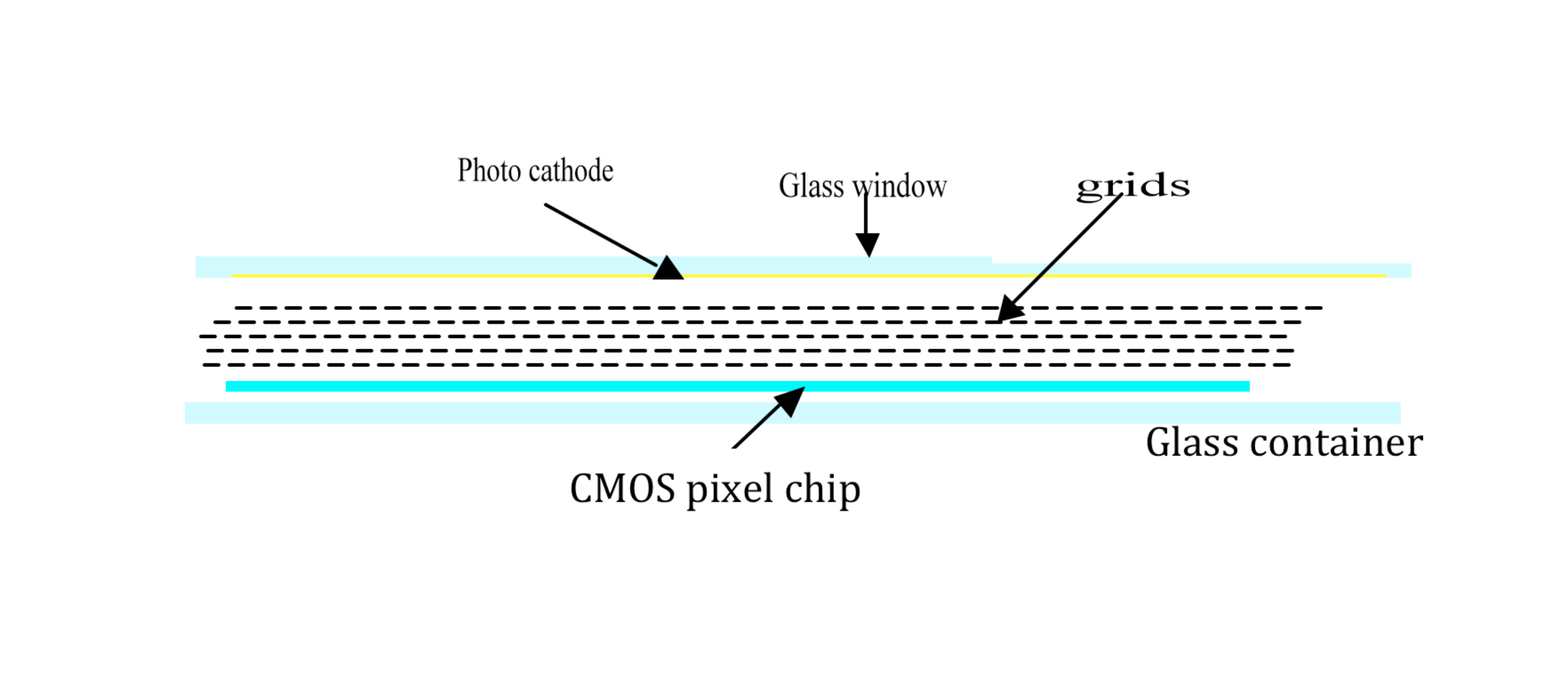
Univ. Twente and Weizmann institute
InGrid with CsI on alu. anode
Detect by means of gasgain
Better anode readout → TimePix

UV light 200-400 nm
First test, InGrid without CsI
UV well absorbed by my fingerprint





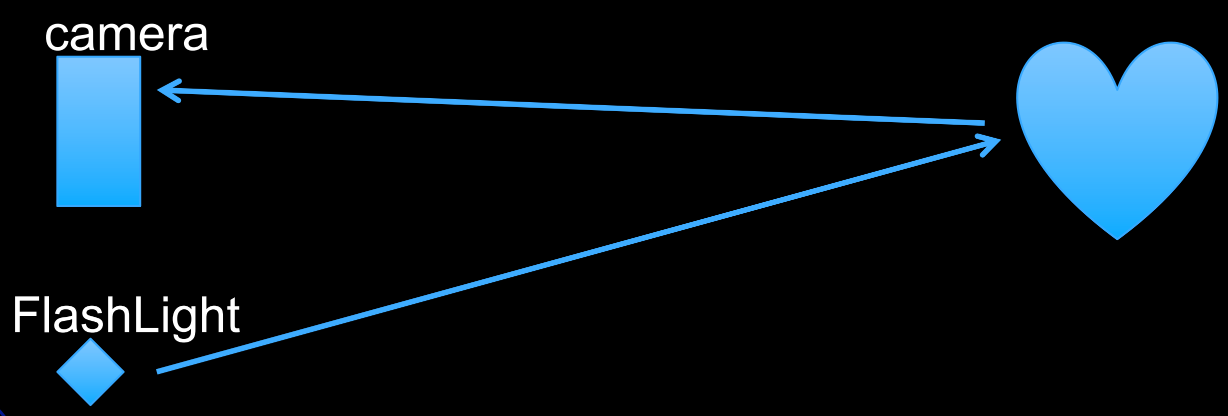




Timed Photon Counter ‘TiPC’
- spatial resolution: 30 um
- time reolution: 10 ps
- operated in B field
- rad hard
- light

Feasible if MEMS technology enables

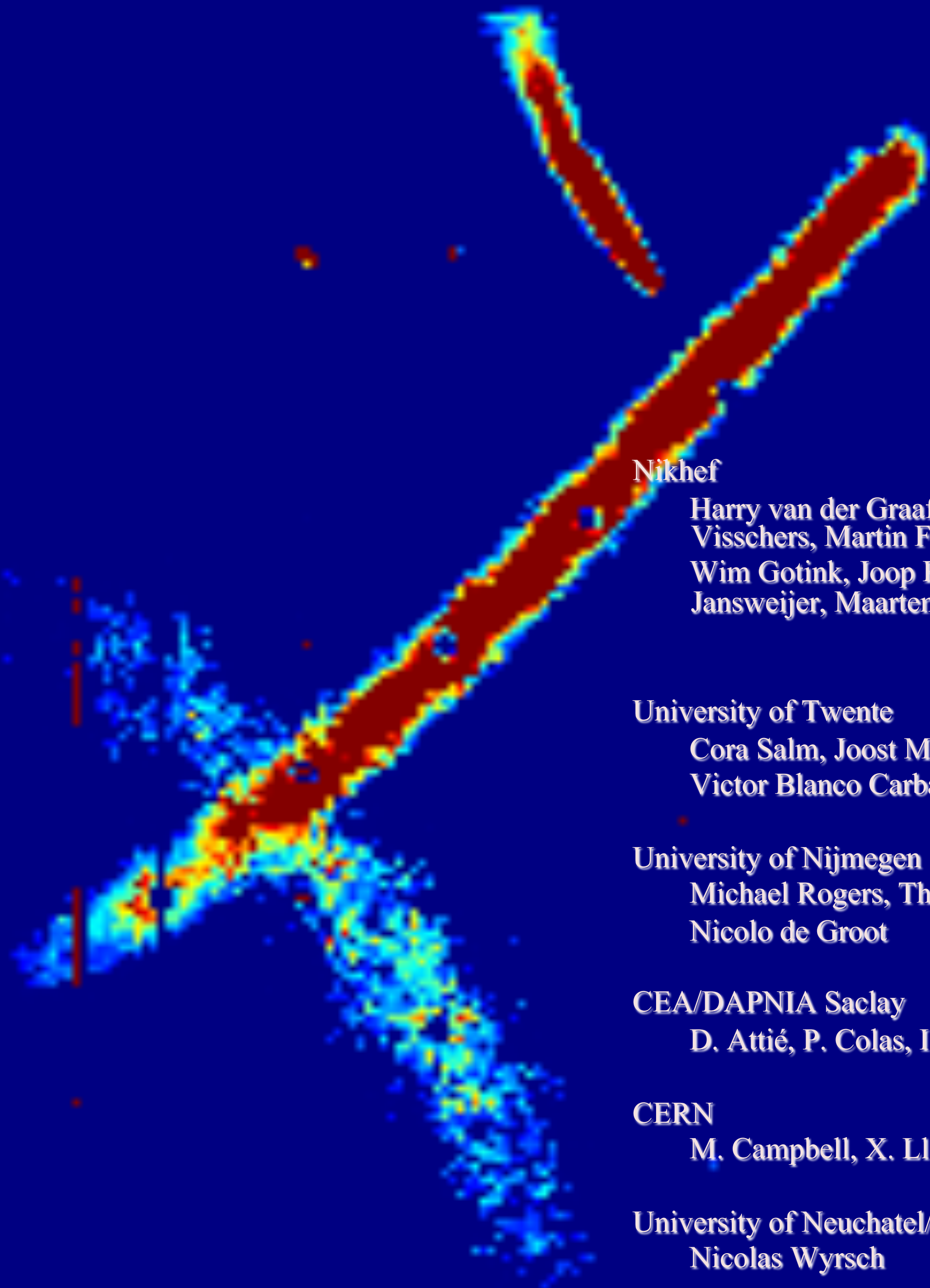
Commercial application: 3D flash TOF camera



Summary

- Gas-filled GridPix/Gossip detectors seem applicable as
    - tracker in HEP experiments
    - photon detectors
    - Dark Matter [DBD] experiments
    - [digital calorimeters]

- Development of Electron Emission foil
- Development of MEMS made electron multiplier
        - New PM tube: TiPC 'Tipsy'



Nikhef

Harry van der Graaf, Max Chefdeville, Fred Hartjes, Jan Timmermans, Jan Visschers, Martin Fransen, Yevgen Bilevych, Wilco Koppert

Wim Gotink, Joop Rovekamp, Lucie de Nooij, Wout Kremers, Peter Jansweijer, Maarten van Dijk, Sjoerd Nauta, Jan Visser.

University of Twente

Cora Salm, Joost Melai, Jurriaan Schmitz, Sander Smits, Victor Blanco Carballo

University of Nijmegen

Michael Rogers, Thei Wijnen, Adriaan Konig, Jan Dijkema, Nicolo de Groot

CEA/DAPNIA Saclay

D. Attié, P. Colas, I. Giomataris

CERN

M. Campbell, X. Llopart, Anatoli Romaniouk

University of Neuchatel/MTI

Nicolas Wyrsch

Czech Tech. Univ. Prague, Praha

Pixelman: T. Holy et al.