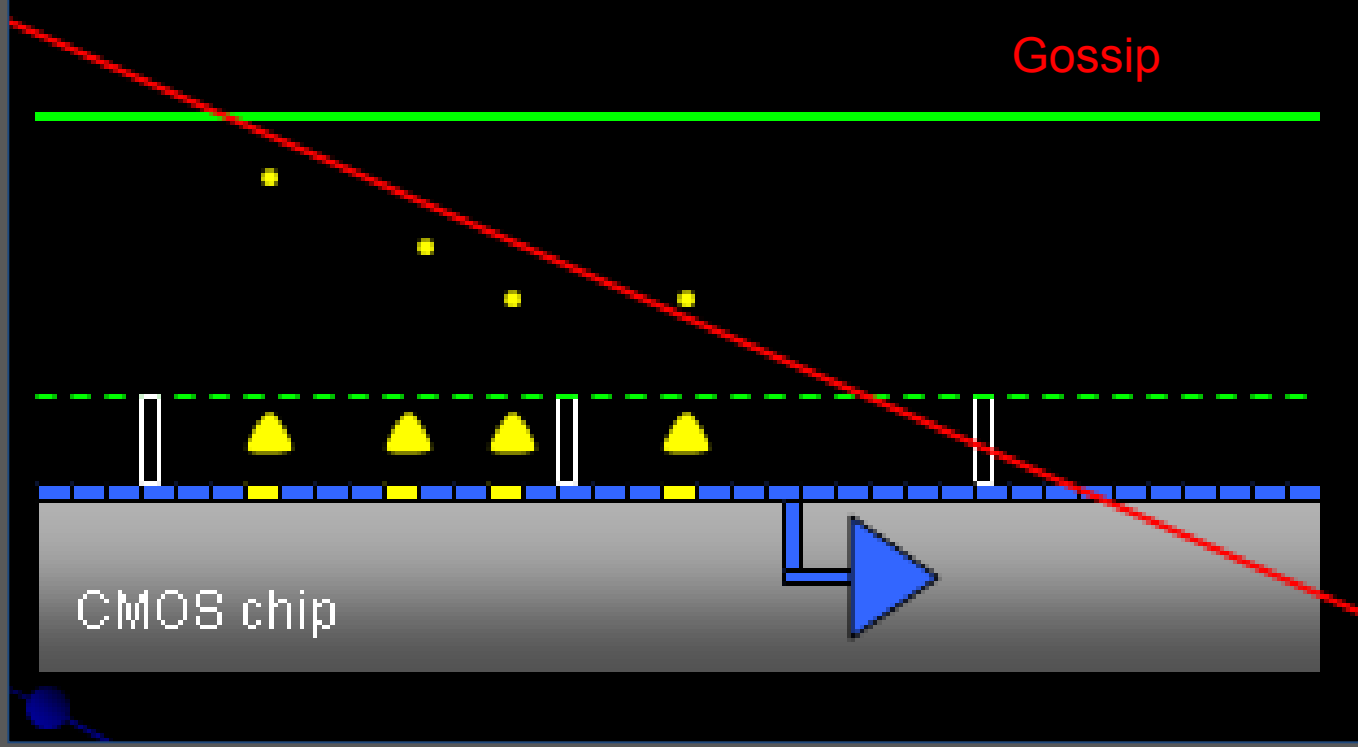
Future of pixels in non HEP experiments [TIPP 2011 work title]

The GridPix Gaseous Pixel detector: status, plans & applications

Harry van der Graaf, Nikhef, Amsterdam

Thursday June 9, 17:10 h
TIPP 2011, Chicago, Ill, USA
[528]

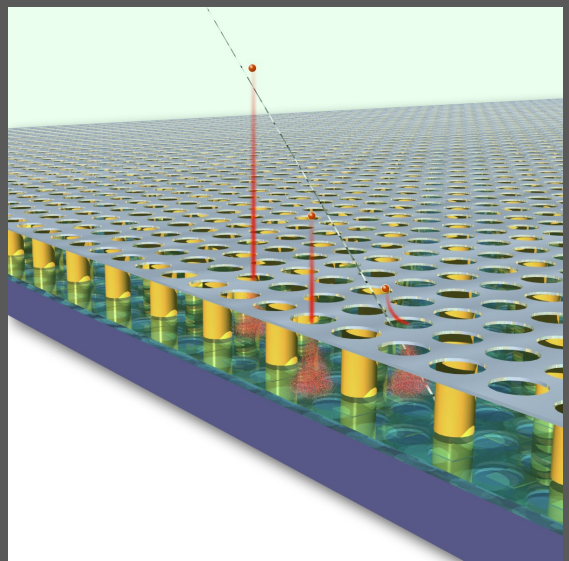


GridPix: readout of TPC ionisation charge

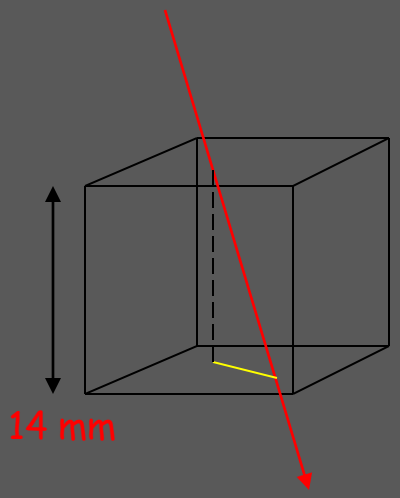
Gossip: Gas On Slimmed SIlicon Pixels

Essential: thin gas layer (1 mm)

Gossip: replacement of Si tracker



He/Isobutane
80/20
Modified MediPix



δ-ray!

Efficiency for
detecting single
electrons:
< 95 %

Medisoft 4.0 - \\gandalf\week\aforna\TPC\RawData\March31\deltaray.mdf

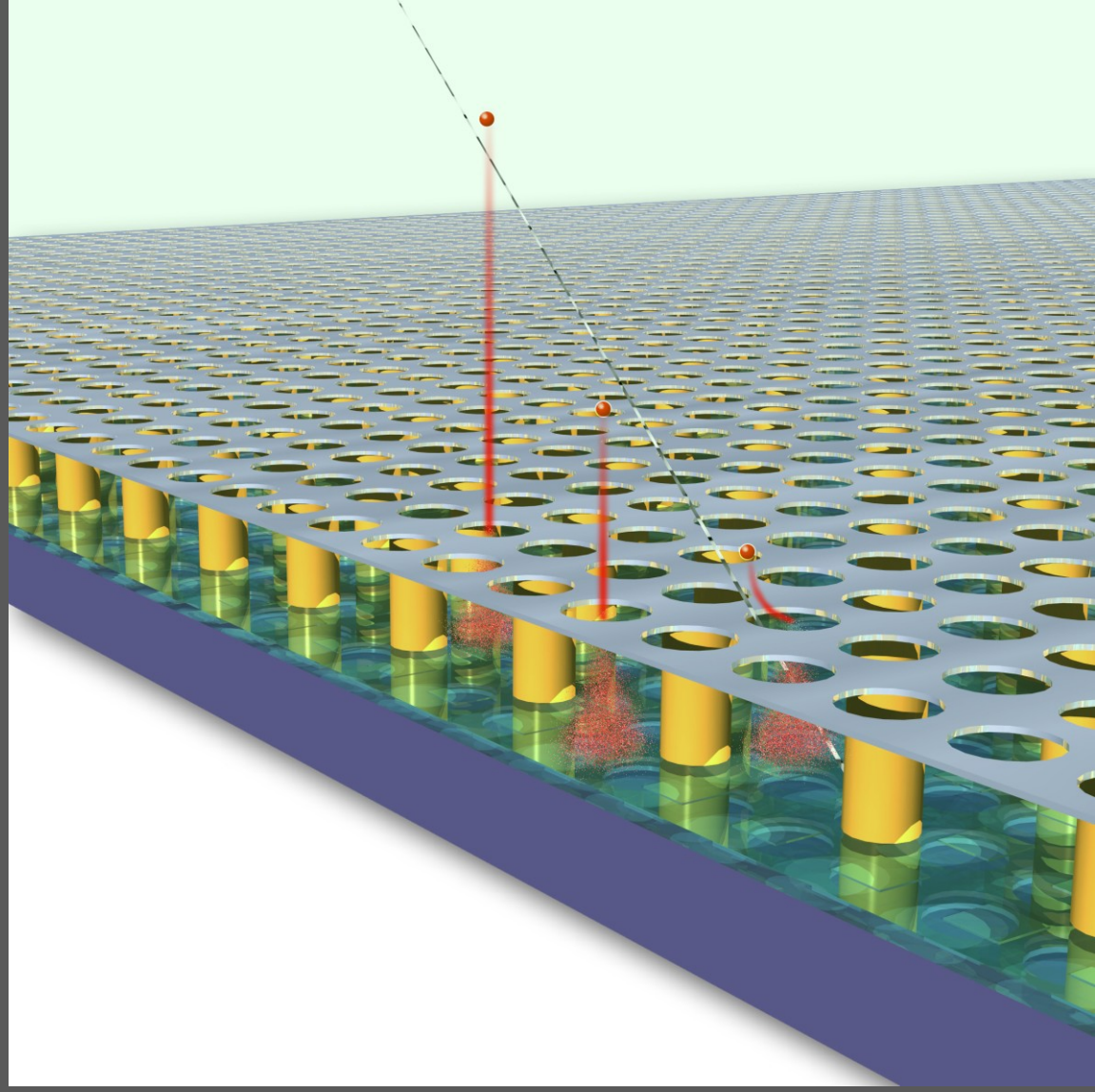
File Edit View Settings Image Tests Acquisitions Run ?

Black and White

GridPix:
the electronic bubble chamber
April 2004

14.11 13.00 12.00 11.00 10.00 9.00 8.00 7.00 6.00 5.00 4.00 3.00 2.00 1.00 0.00 mm

0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00 8.00 9.00 10.00 11.00 12.00 13.00 14.11



Application of Micromegas

New:
- pixel chip as active anode readout
- MEMS made Micromegas: Integrated Grid InGrid

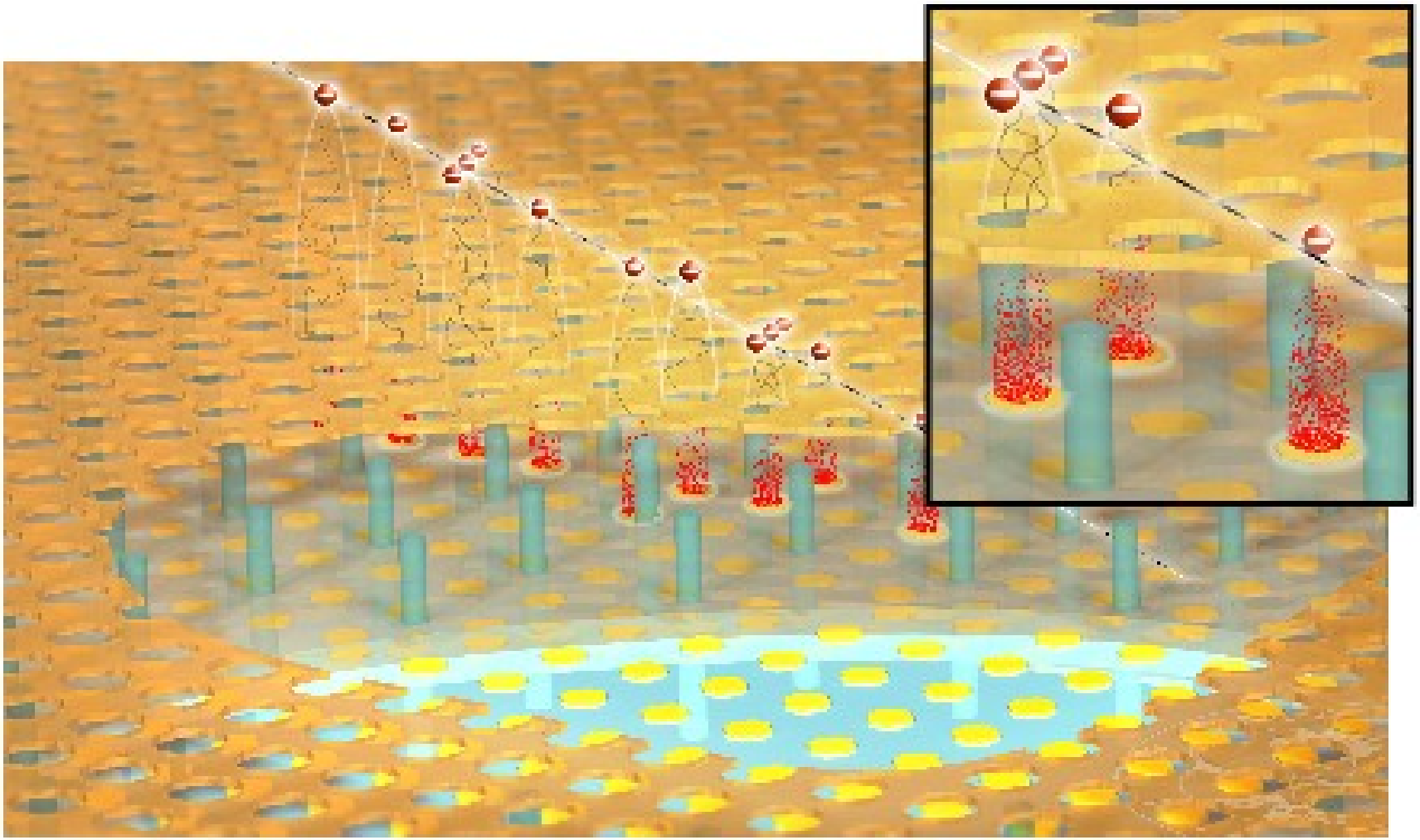


Fig.3: The GridPix detector: a passing fast charge leaves a track of ion-electron pairs in the gas volume above the readout chip. The liberated electrons drift towards the chip and cause an avalanche in the high-field region between the perforated electrode (green dashed line) and the microchip. The inset highlights the gas avalanche part of the detector.

The MediPix2 pixel CMOS chip

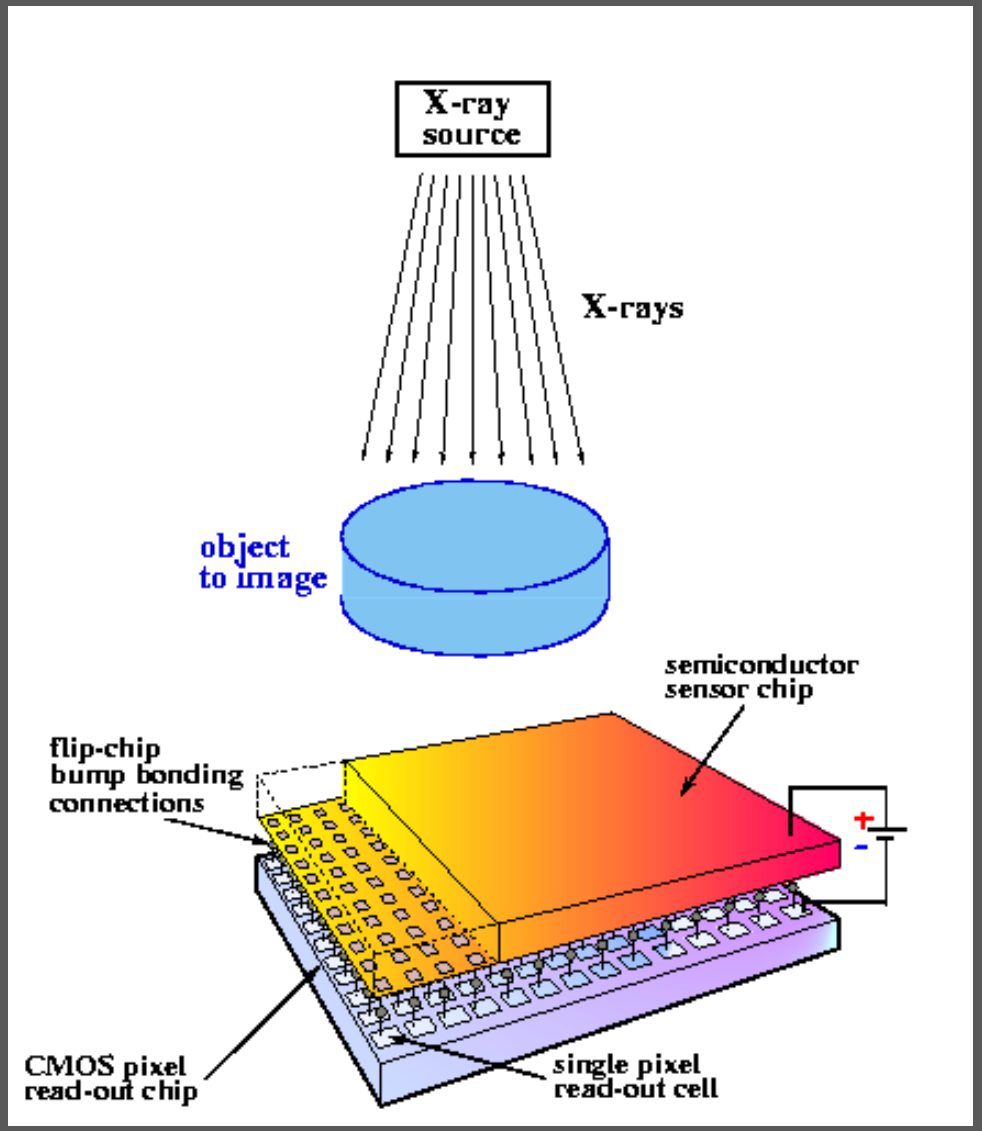
256 x 256 pixels
pixel: 55 x 55 μm^2
per pixel:
- preamp
- shaper
- 2 discr.
- Thresh. DAQ
- 14 bit counter

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

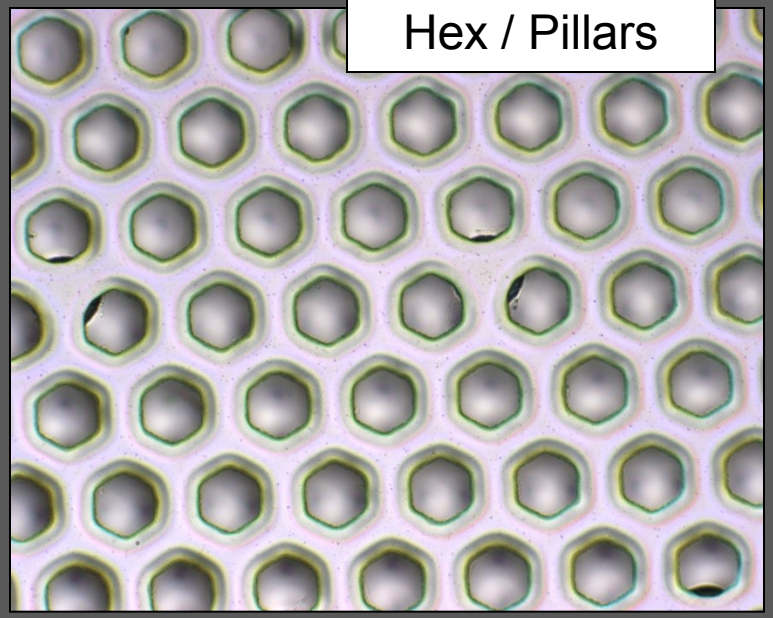
We apply the 'naked' MediPix2 chip without X-ray convertor!

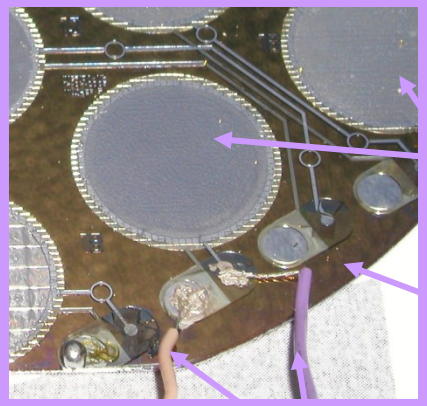
Applied chips:

Medipix-2
TimePix
PSI-46
FE-I4
TimePix-3: underway: submission Dec 2011



Wafer post-processing:InGrid



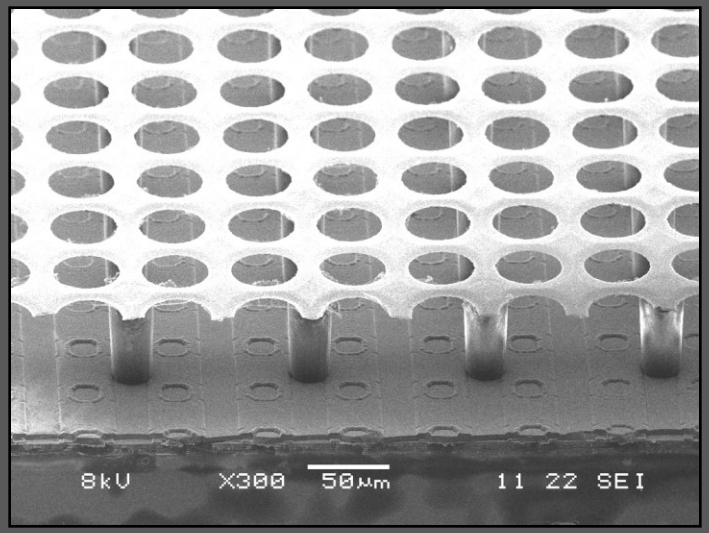


InGrid: an Integrated Grid on Si (wafers or chips)

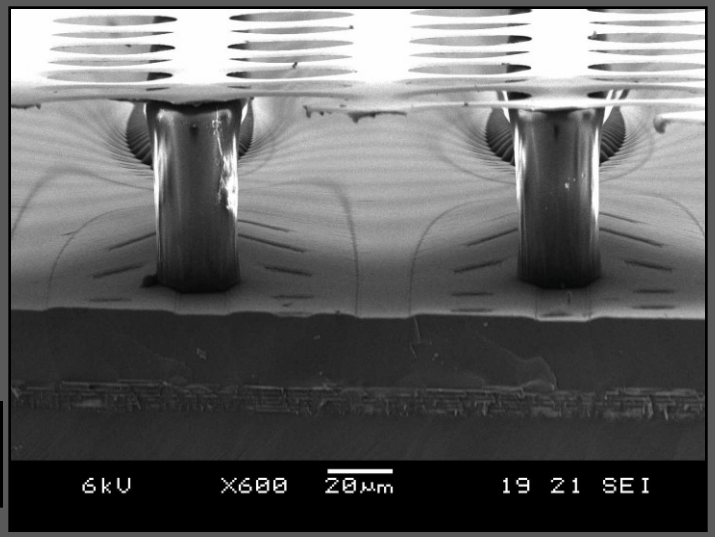
- perfect alignment of grid holes and pixel pads
- small pillars Ø, hidden pillars, full pixel area coverage
- Sub-micron precision: homogeneity
- Monolithic readout device: integrated electron amplifier

Full post-processing of a TimePix

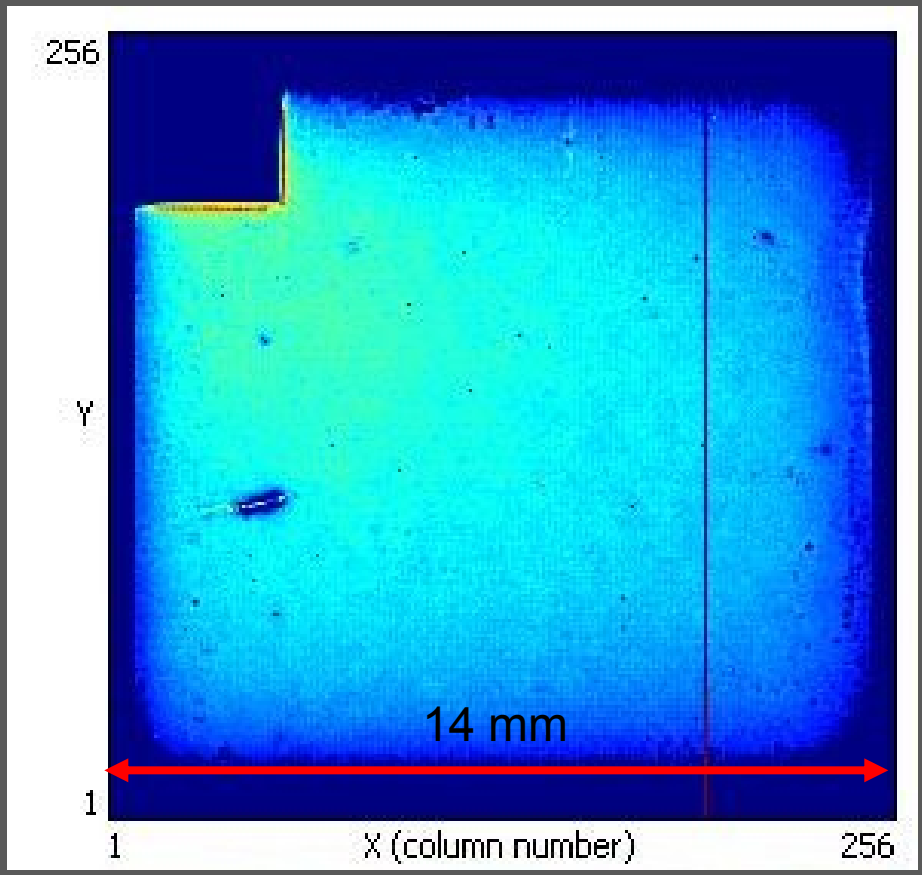
- Timepix chip + SiProt + Ingrid:



MESA+

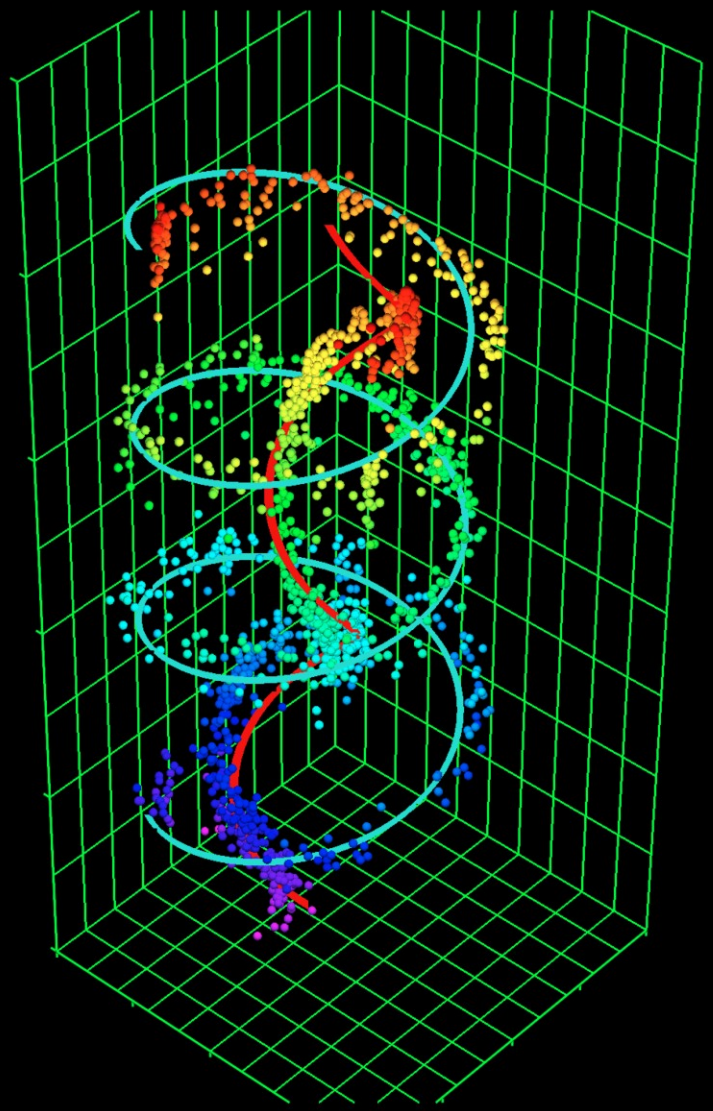


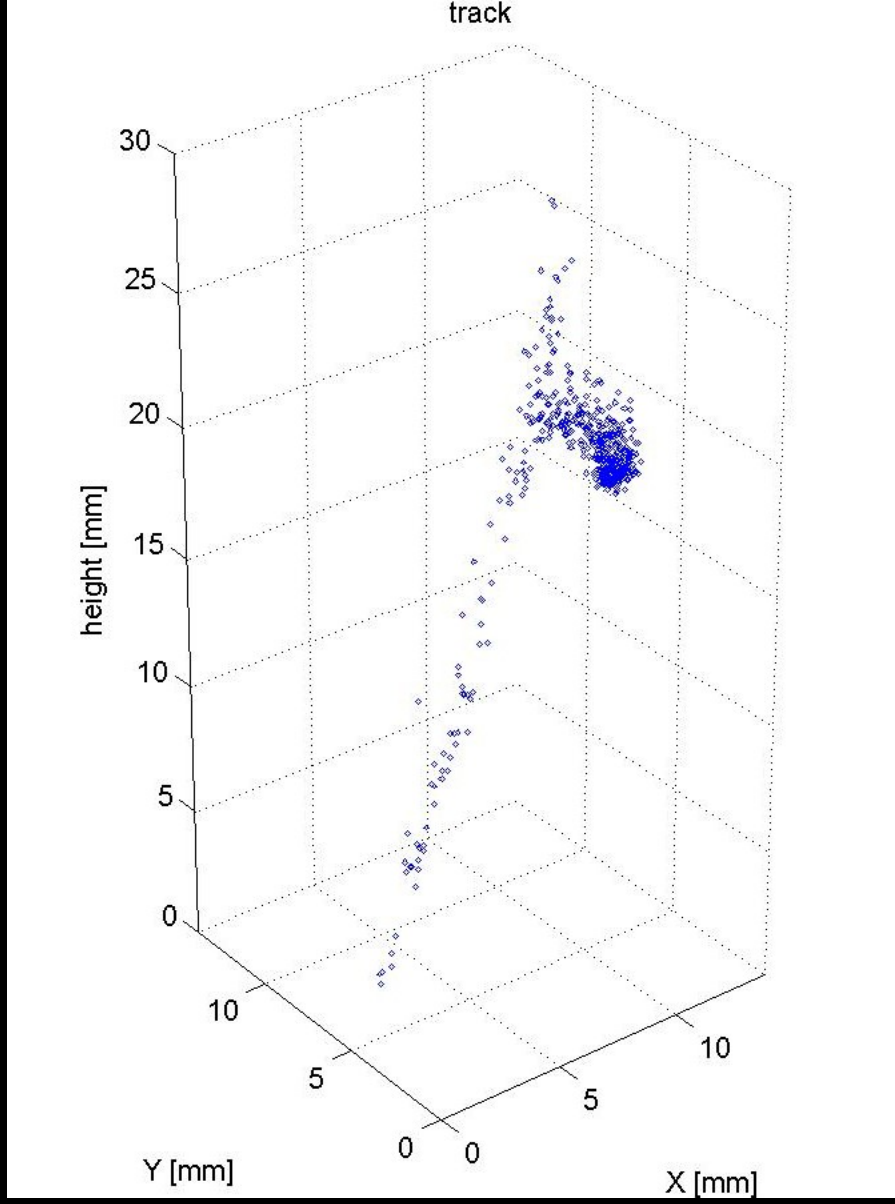
IMT Neuchatel



"Uniform"

Charge mode



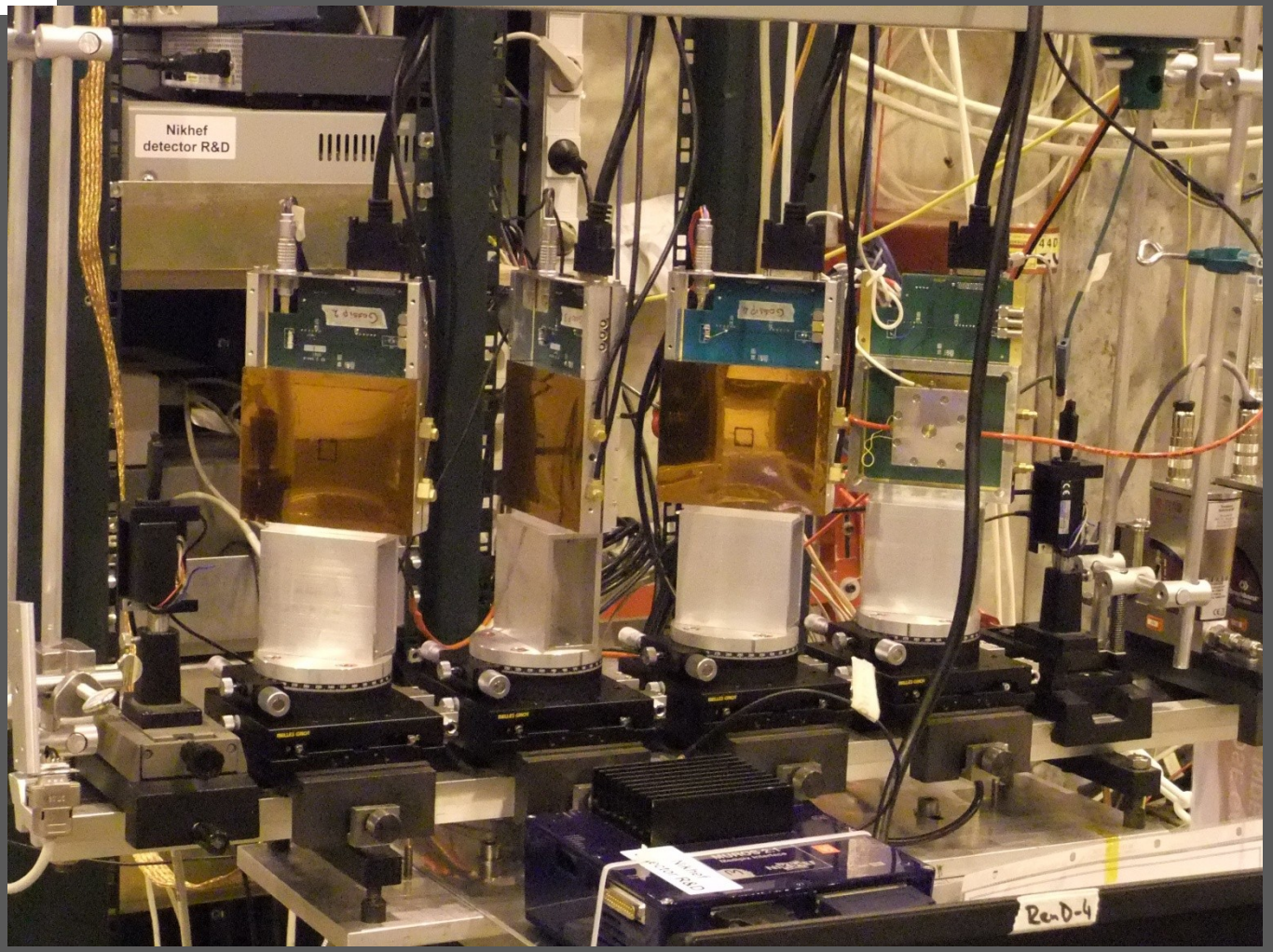


two beta's from 90Sr in a 0.2 T B-field

100 GeV Muon in testbeam 2010 @ CERN

Gossip testbeam August 12 – 22 , 2010

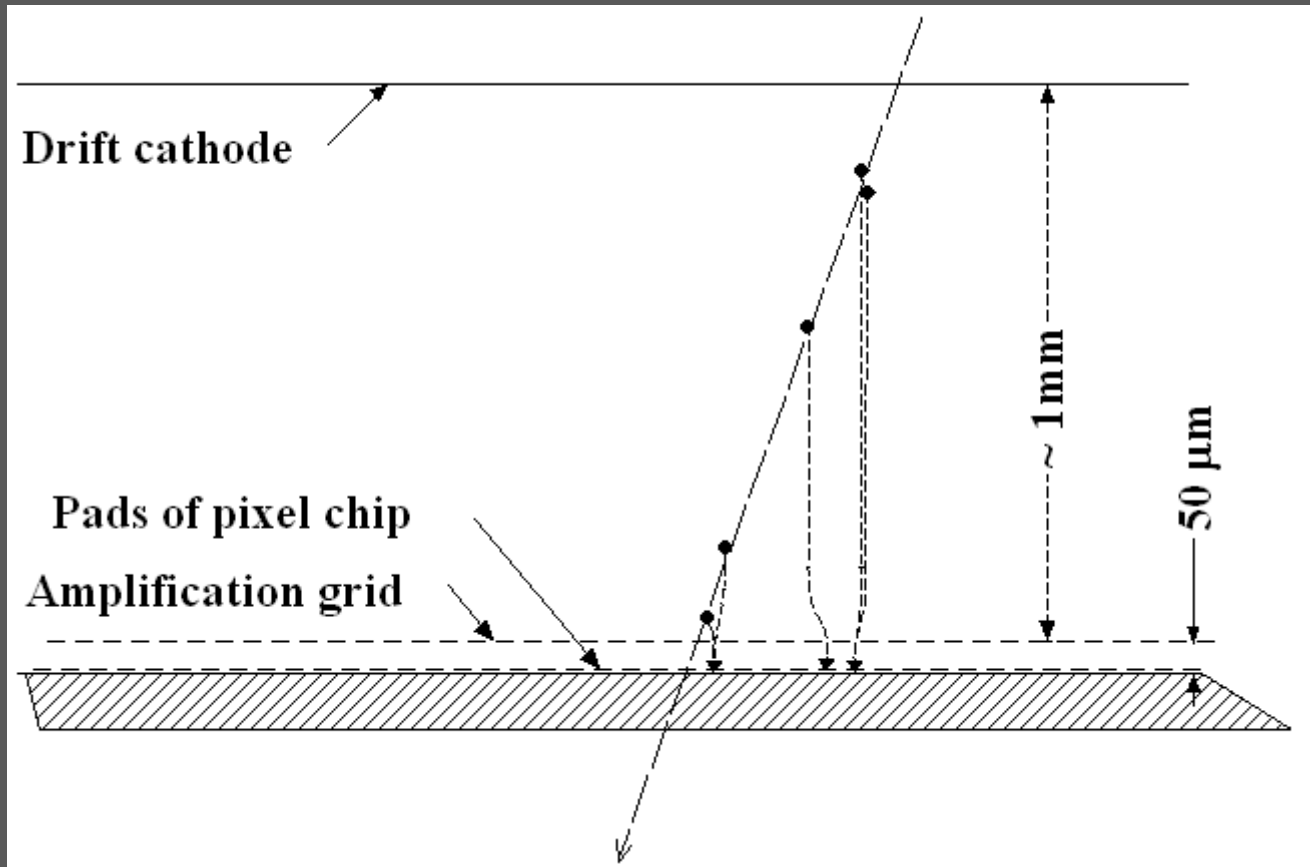
Maarten van Dijk
Martin Fransen
Harry van der Graaf
Fred Hartjes
Wilco Koppert
Sjoerd Nauta
Rolf Schön



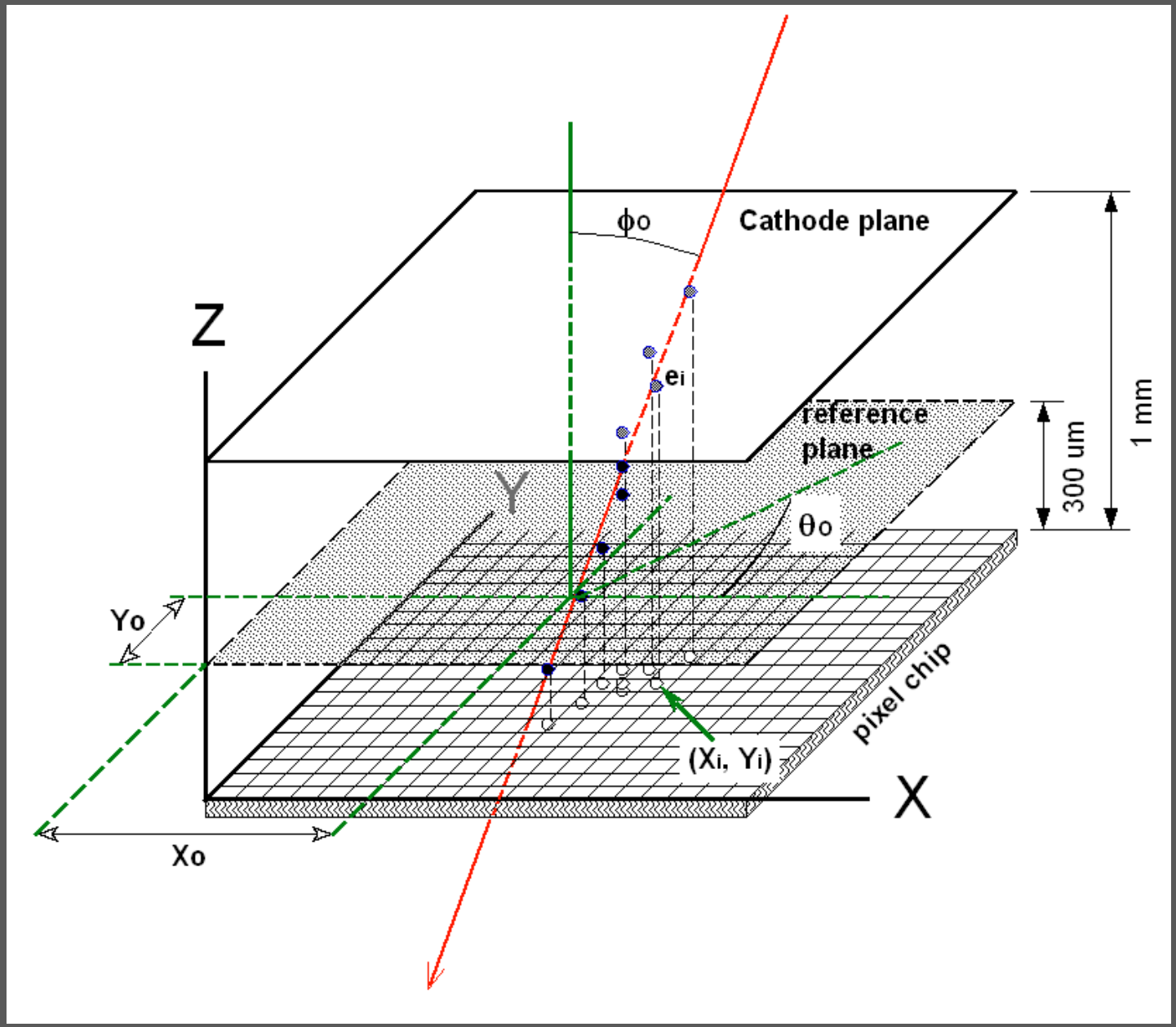
Testbeam Aug 2010, RD51/H4, SPS, CERN

Gossip functioning

- Pixel chip with integrated Micromegas (InGrid)
- Drift gap height 1 mm
  - Getting > 95% track detection efficiency
- Often detecting individual electrons
- Reconstructing track segment
  - **Crossing point**
  - **Direction**

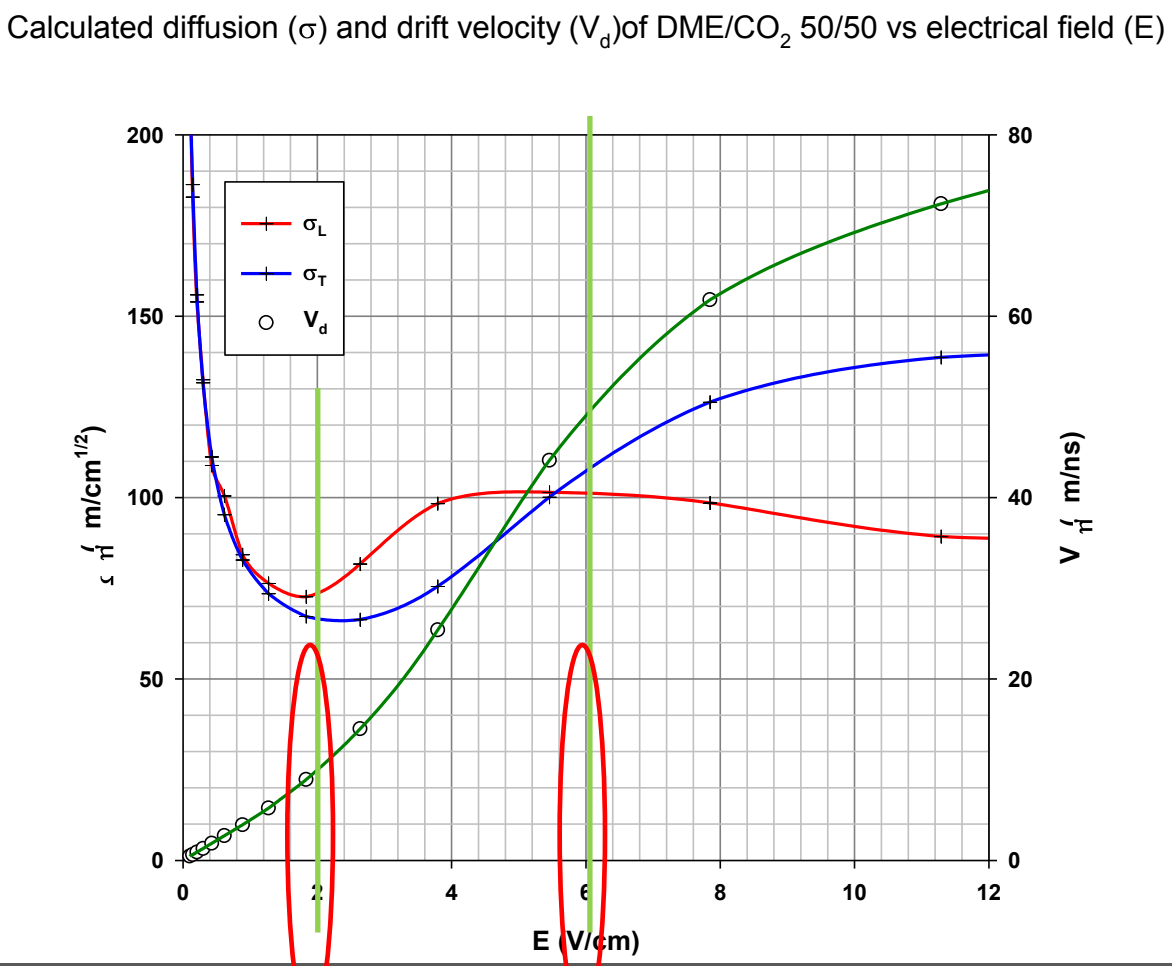


Reconstructing track segment



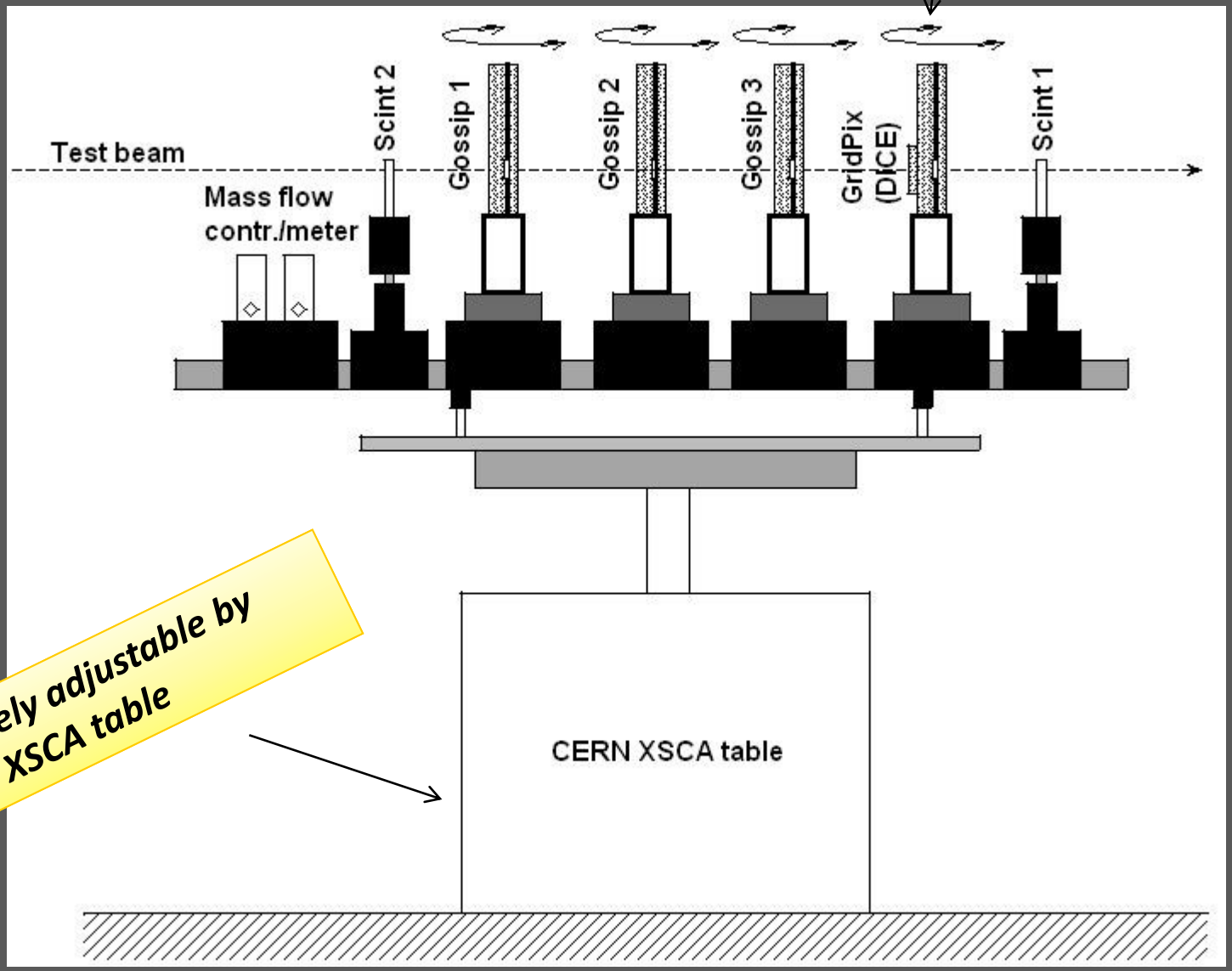
Chamber gas: DME/CO_2 50/50

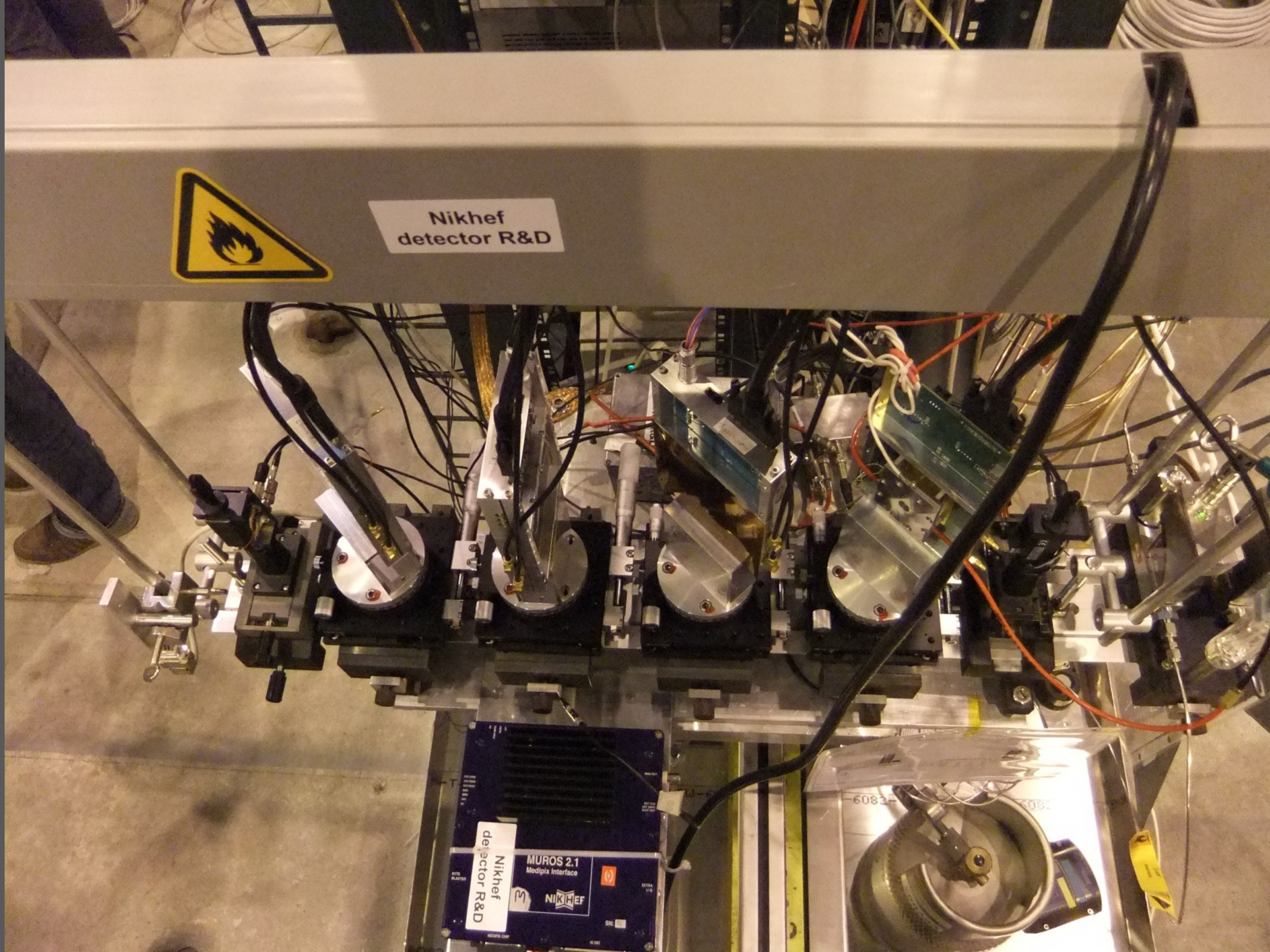
- DME/CO_2 50/50
  - Very slow and “cool” gas
  - High drift field required
  - Very low diffusion
- Drift fields used in Gossips
  - **2 kV/cm** (lowest diffusion)
  - **6 kV/cm** (Vd = 50 µm/ns)

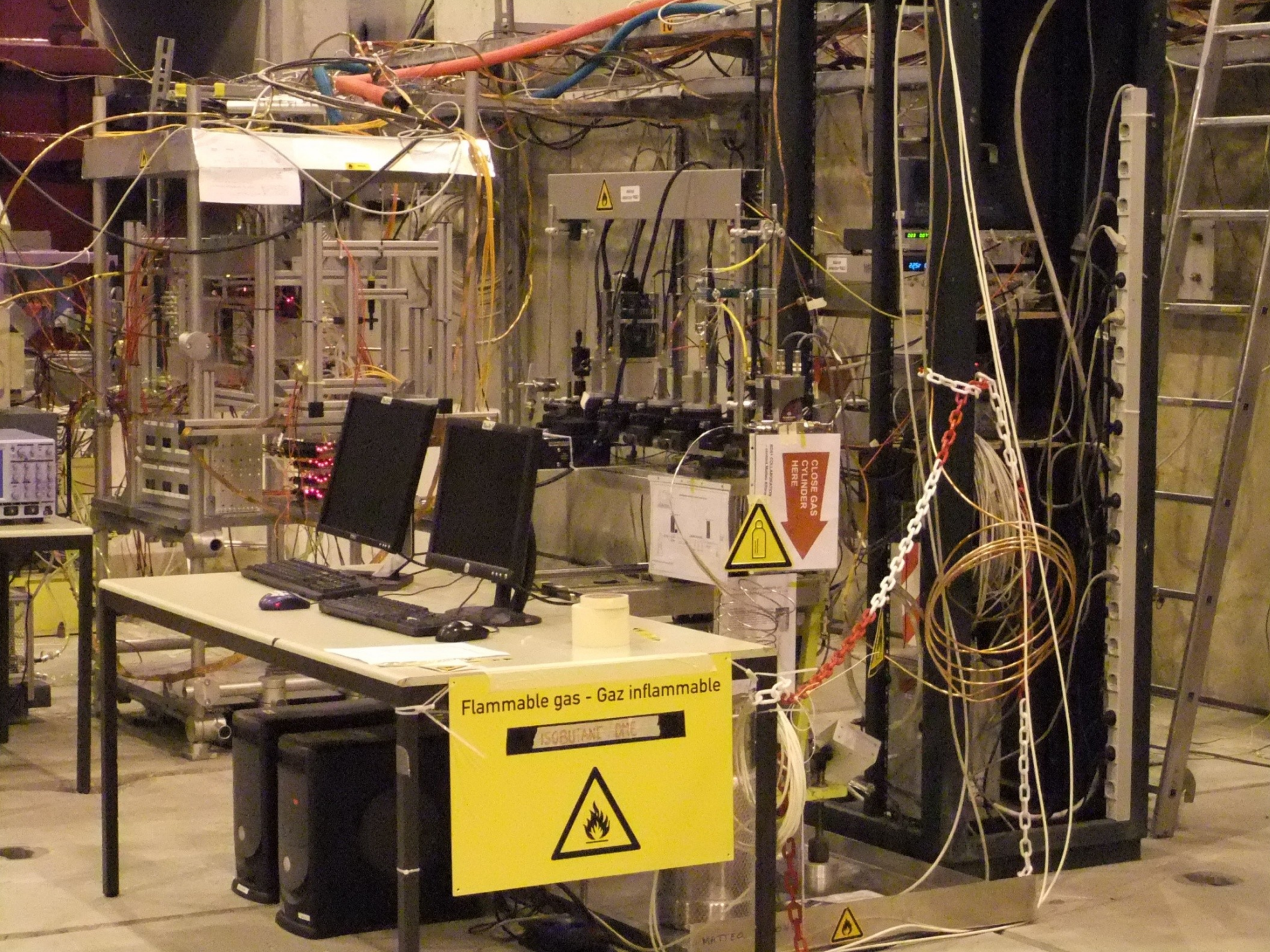


Mechanical set-up in testbeam

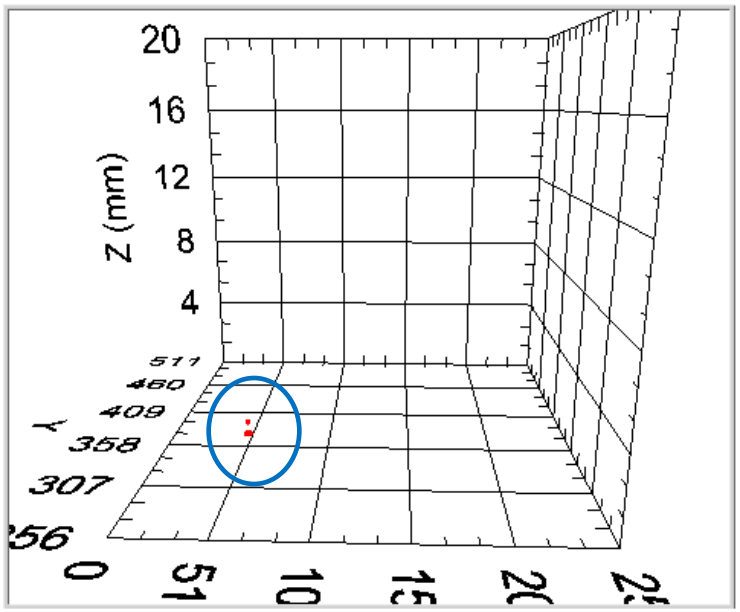
- Optical bench
- 4 Gridpix detectors
  - 3 x Gossip
  - GridPix)
- 2 Scintillators 15 x 15 mm
- Mass flow controller/meter

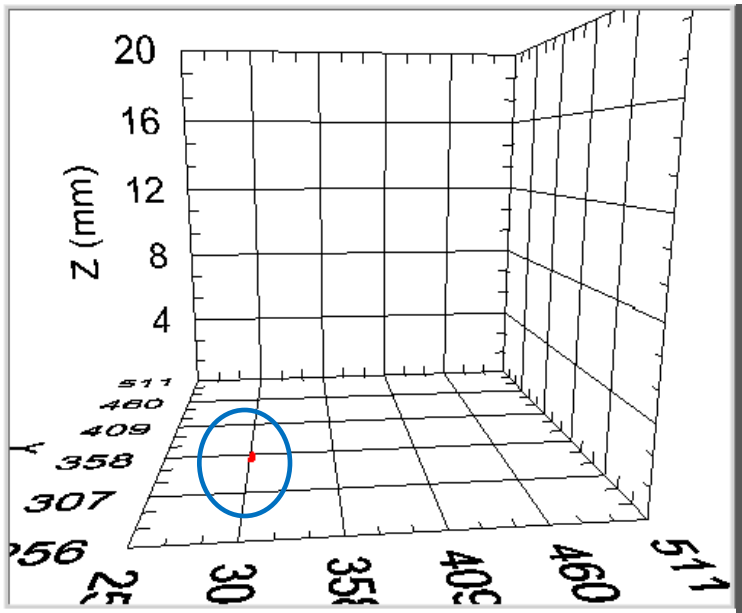



Nikhef
detector R&D
MUROS 2.1
Medipix Interface
NIKHEF
Nikhef
detector R&D

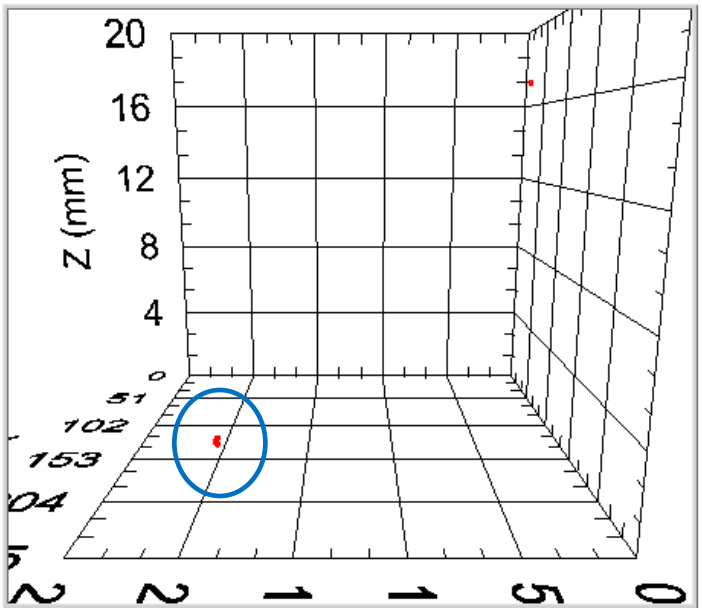

CLOSE GAS CYLINDER HERE
Flammable gas - Gaz inflammable
ISOBUTANE GAS

Typical event in all 4 detectors (angle 10°)

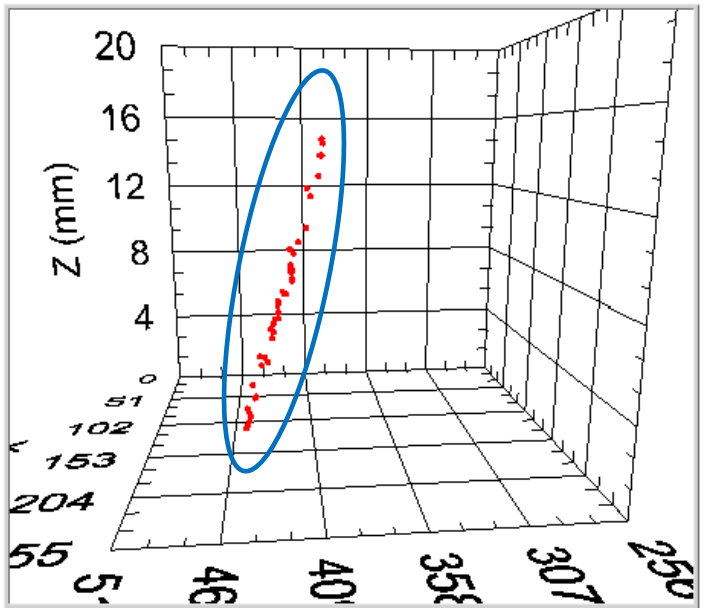




Position 3



DICE



Summary of Performance of Gossip

- track position resolution:15 μm: simulation 15 μm;
- single electron efficiency: > 90 %
- track detection efficiency: 99.6 %; simulation 99.4 %

Three new infrastructural issues:

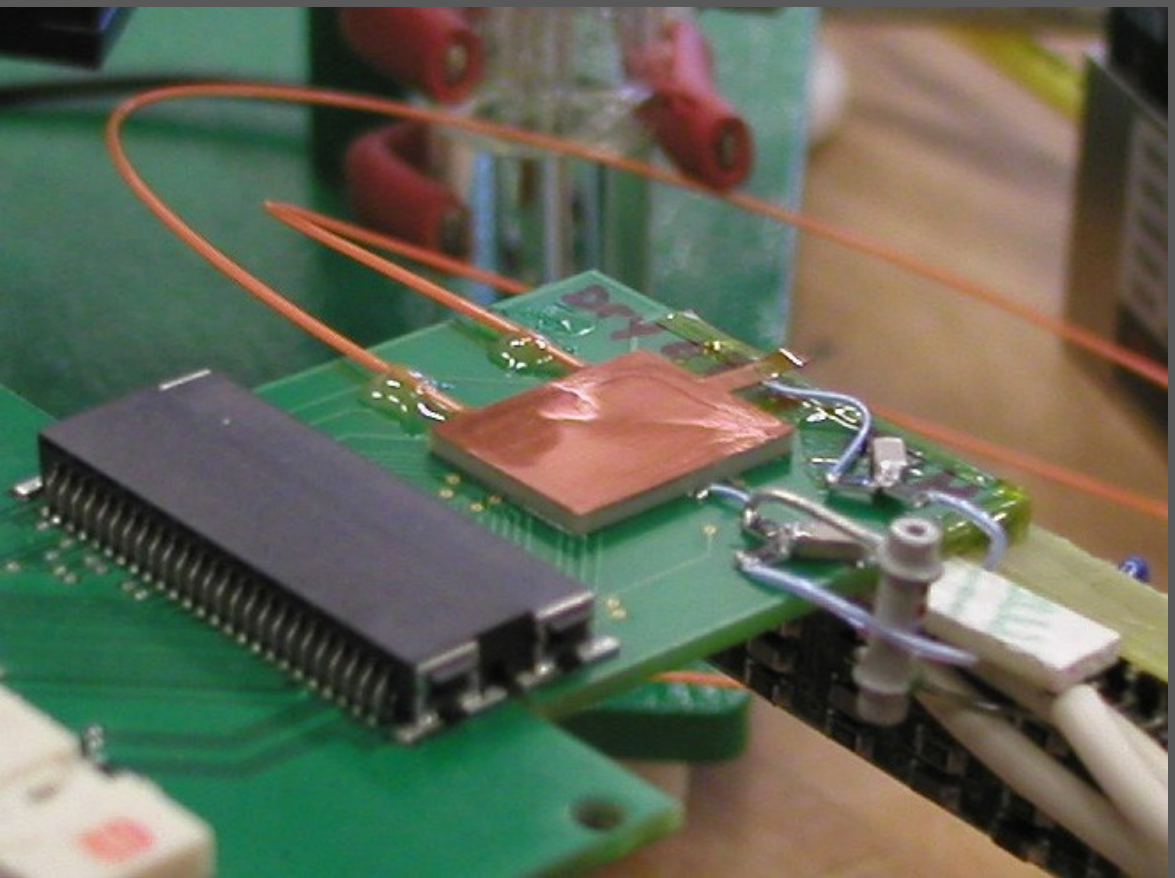
- New gas
- miniHV
- ReLaXd readout interface for TimePix-Medipix

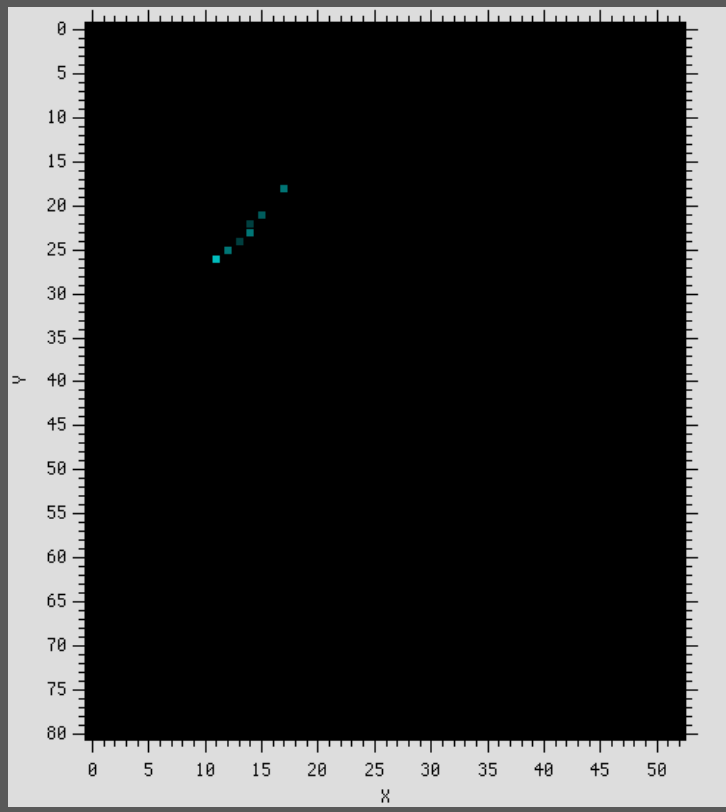
GOSSIP-Brico: PSI-46 (CMS Pixel FE chip)

First prototype of GOSSIP on a PSI46 is working:

- 1.2 mm drift gap
- Grid signal used as trigger
- 30 µm layer of SiProt

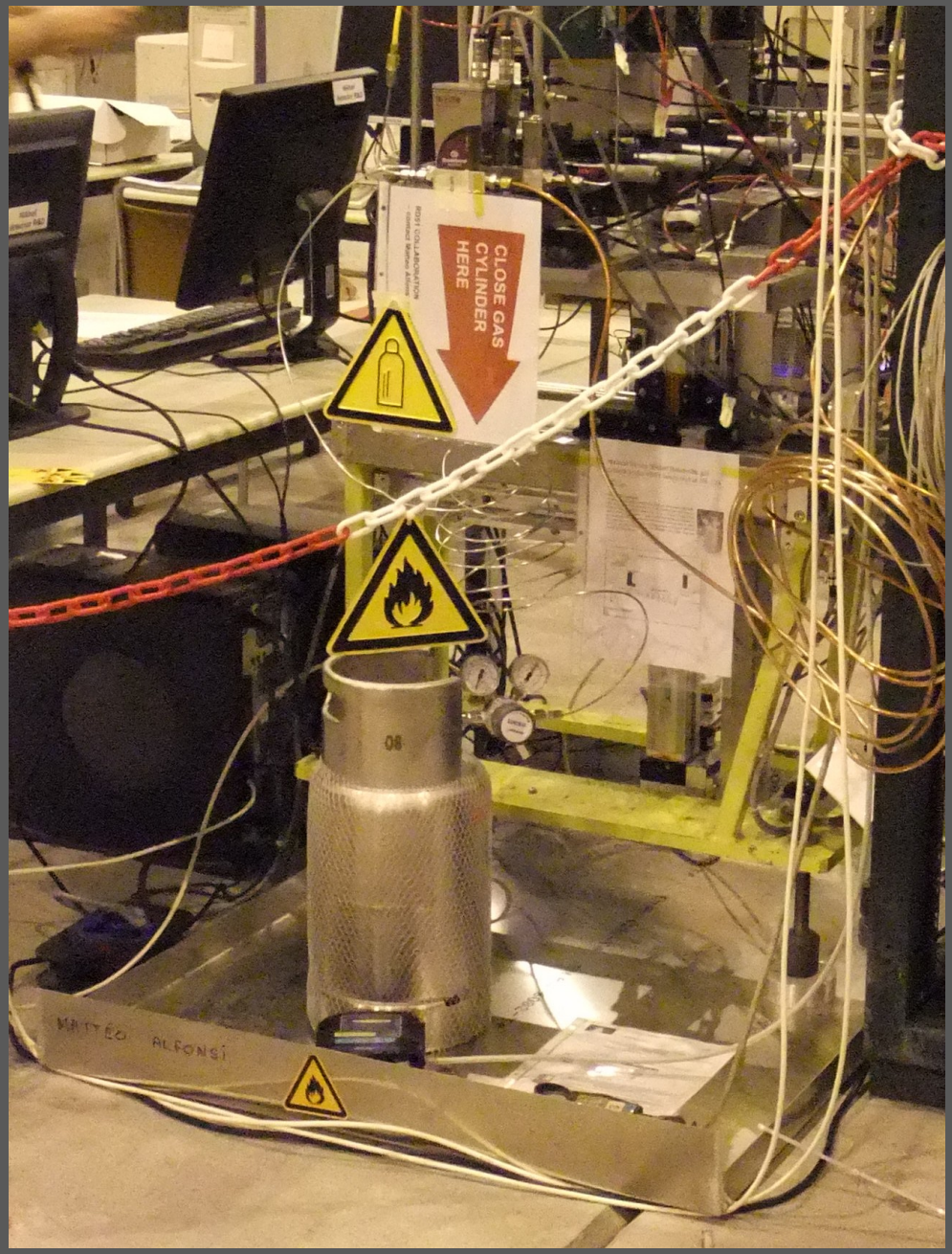
NewGas





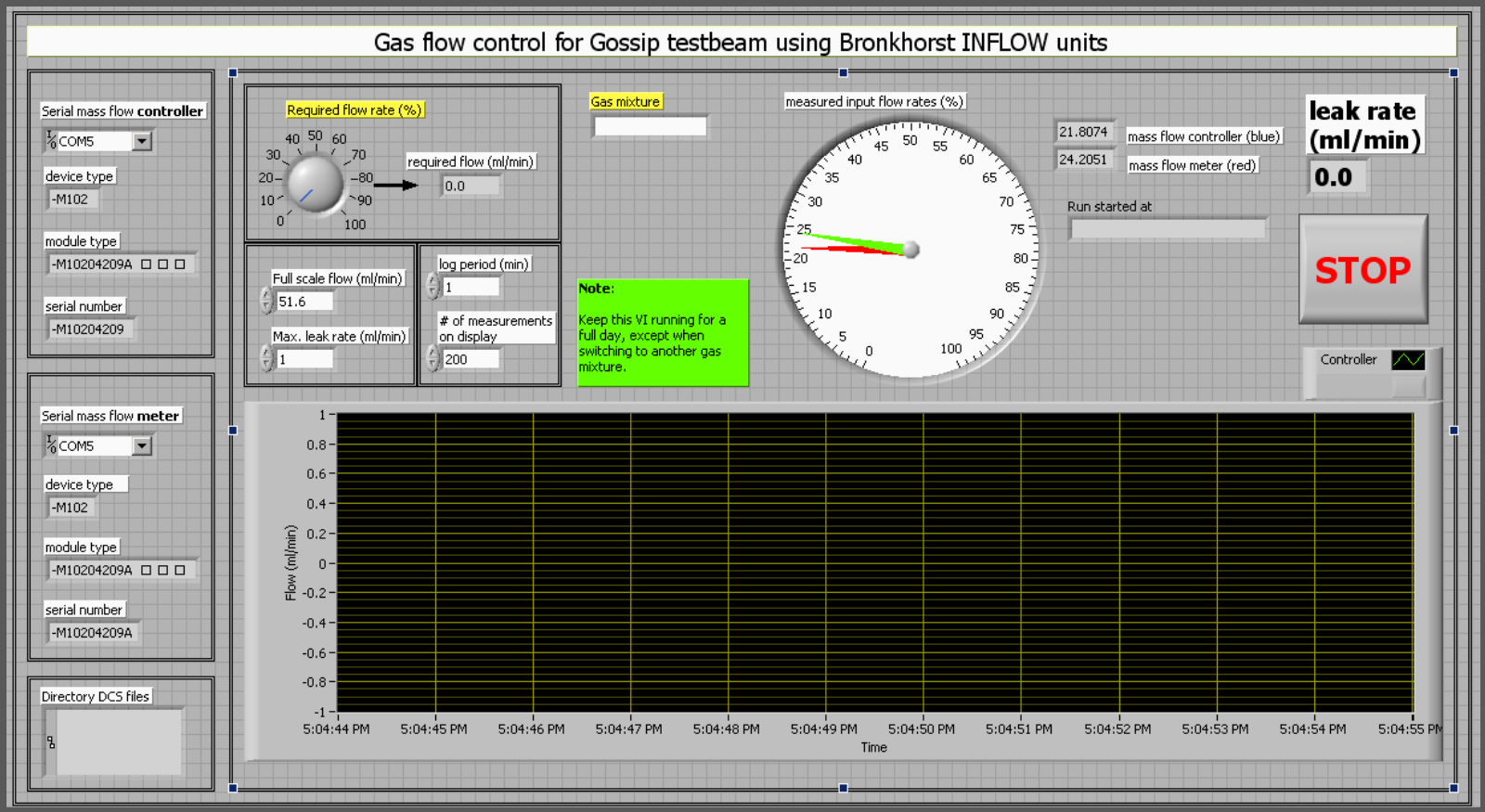
Special requirements for flammable gas

- Gas mixture from 120 l JSP gas bottle
- Whole gas system including bottle contained in leak tray
- Checking gas leaks by measuring deficit between input flow and exhaust flow
- Connected to flammable gas exhaust line



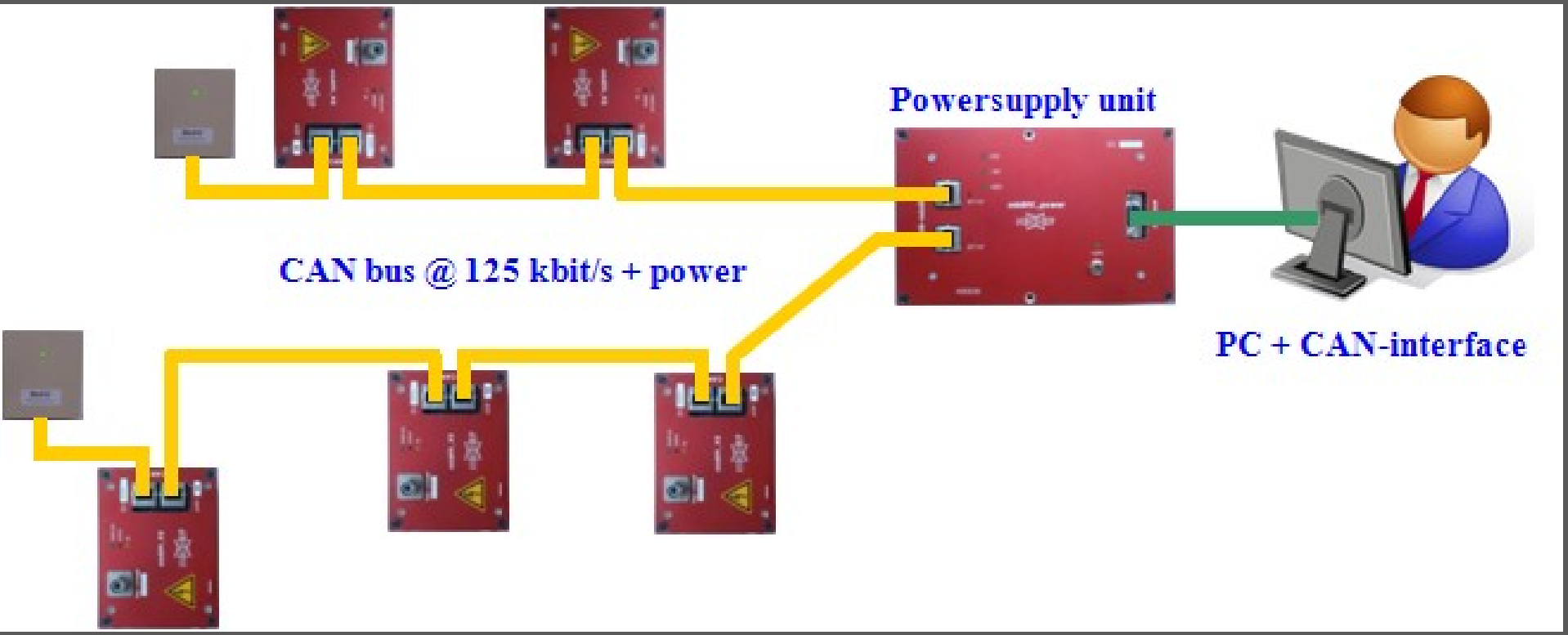
LabView controlled gas system

- Operation
  - Flow logged each minute
  - Alarm at leak rate > 3 ml/min
  - Shut off at integrated leak volume of 30 ml
- Gas flow set between 5 and 50 ml/min
  - Possible calibration error by factory (flow too low)



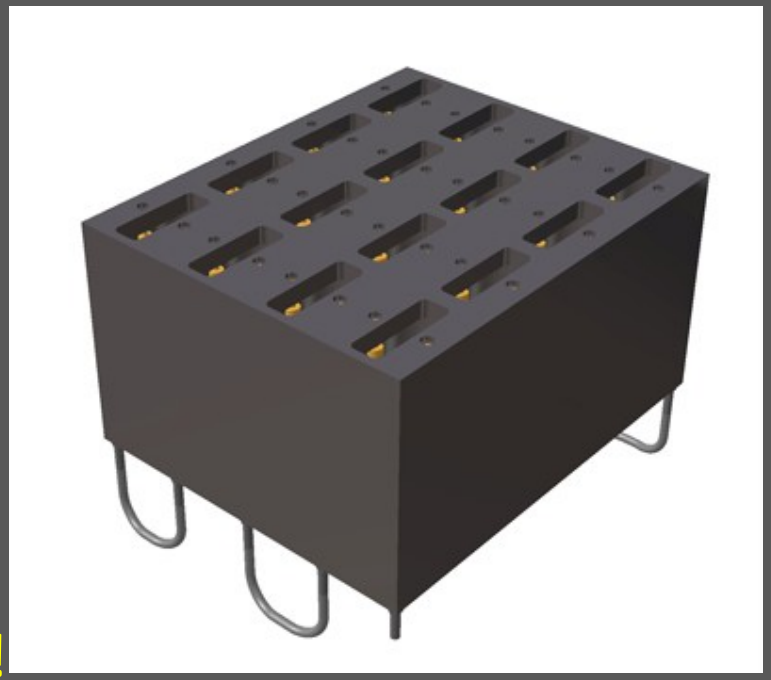
miniHV HighVoltage (low current) system

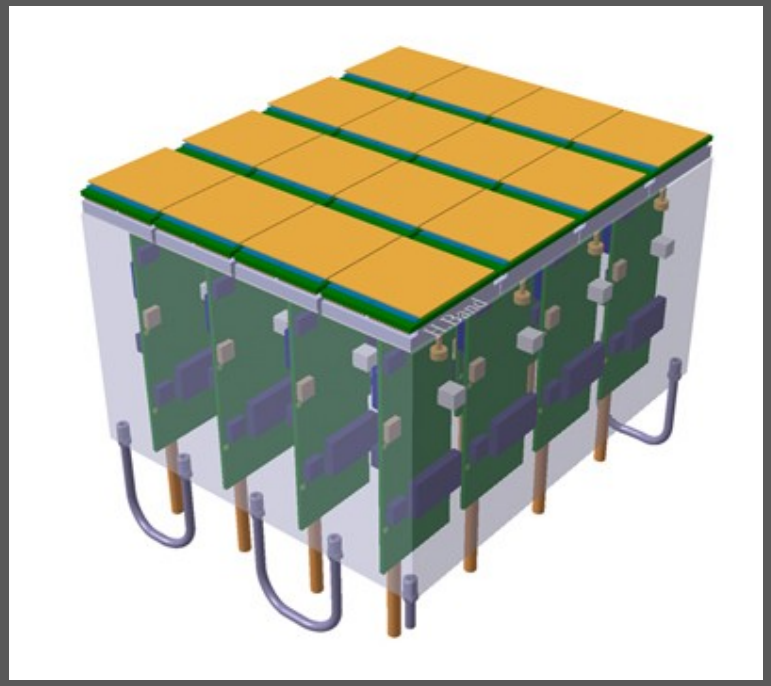
- HV: - 1000 V or – 2000 V
- Current: up to 5 µA
- current measurement: 20 pA resolution
- CAN bus (pc) controlled
- discharges are monitored & counted



ReLaXd Readout

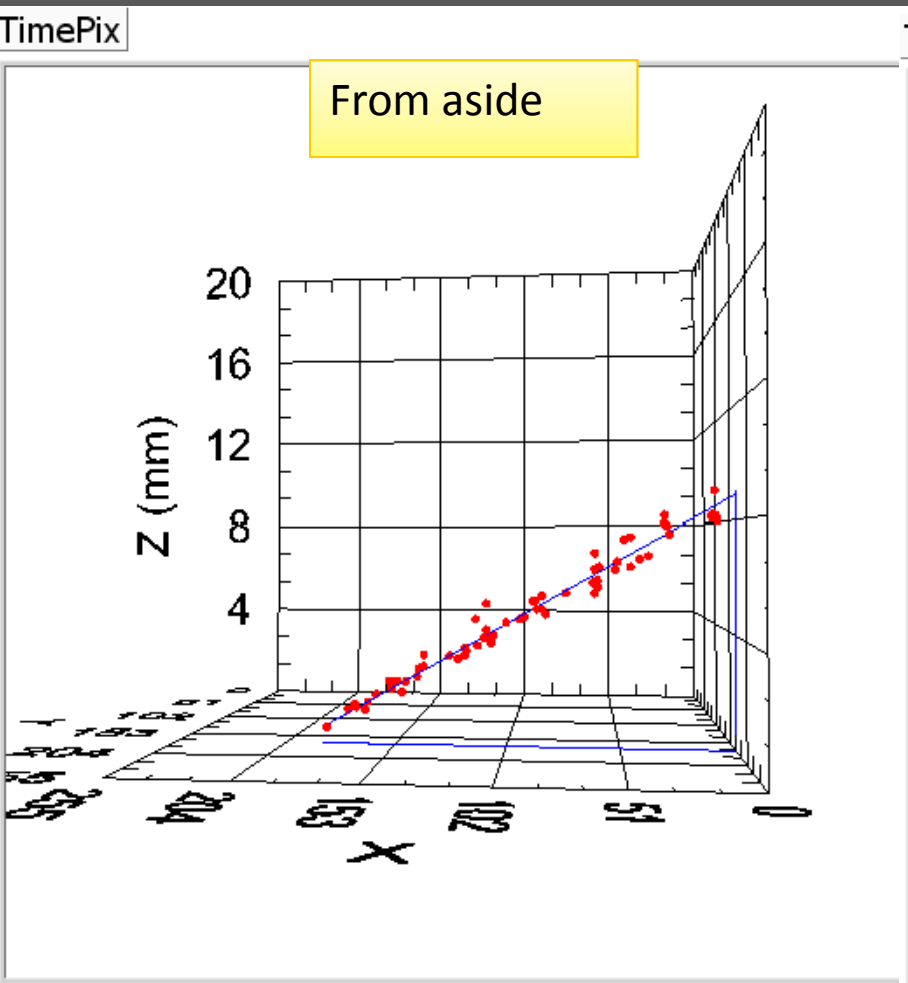
Support & CO_2 cooling!

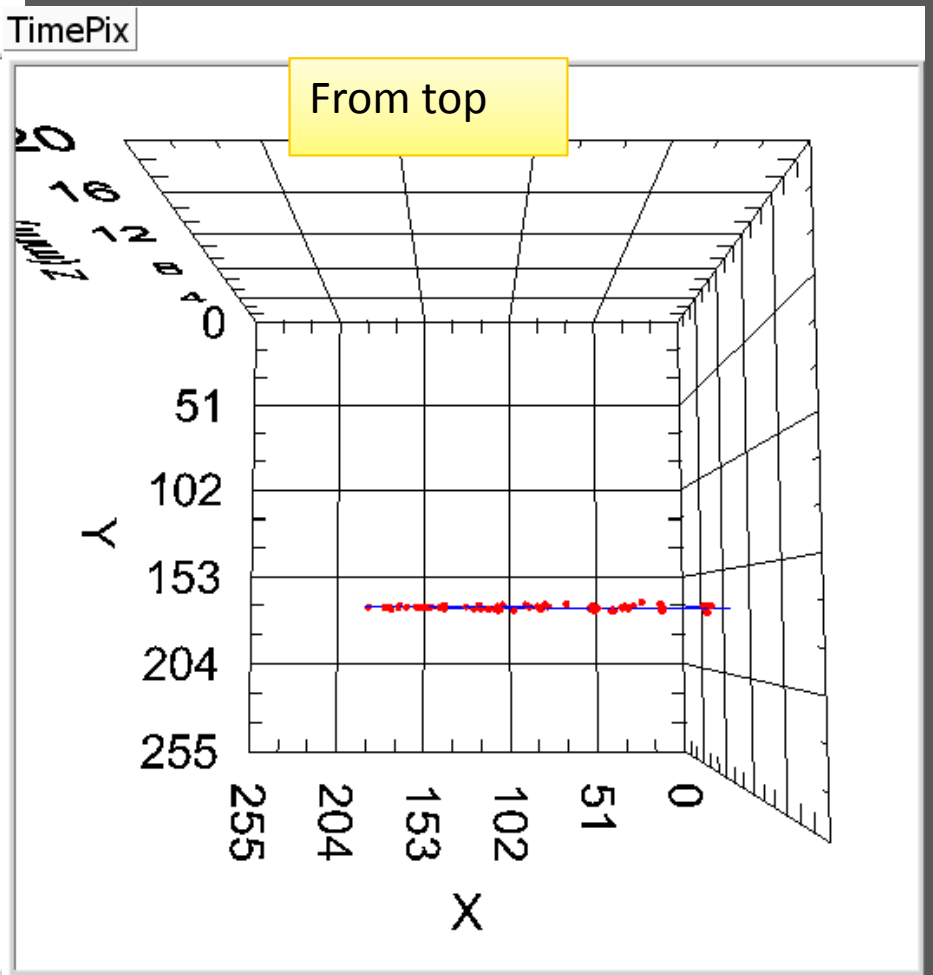




Typical event in GridPix under 45°

- Very small diffusion but big time slewing





Gas versus Si (or Gossip versus Si detectors)

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
- single (free drifting) electron sensitive

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 limits spatial resolution

There is a broad interest in GridPix chips

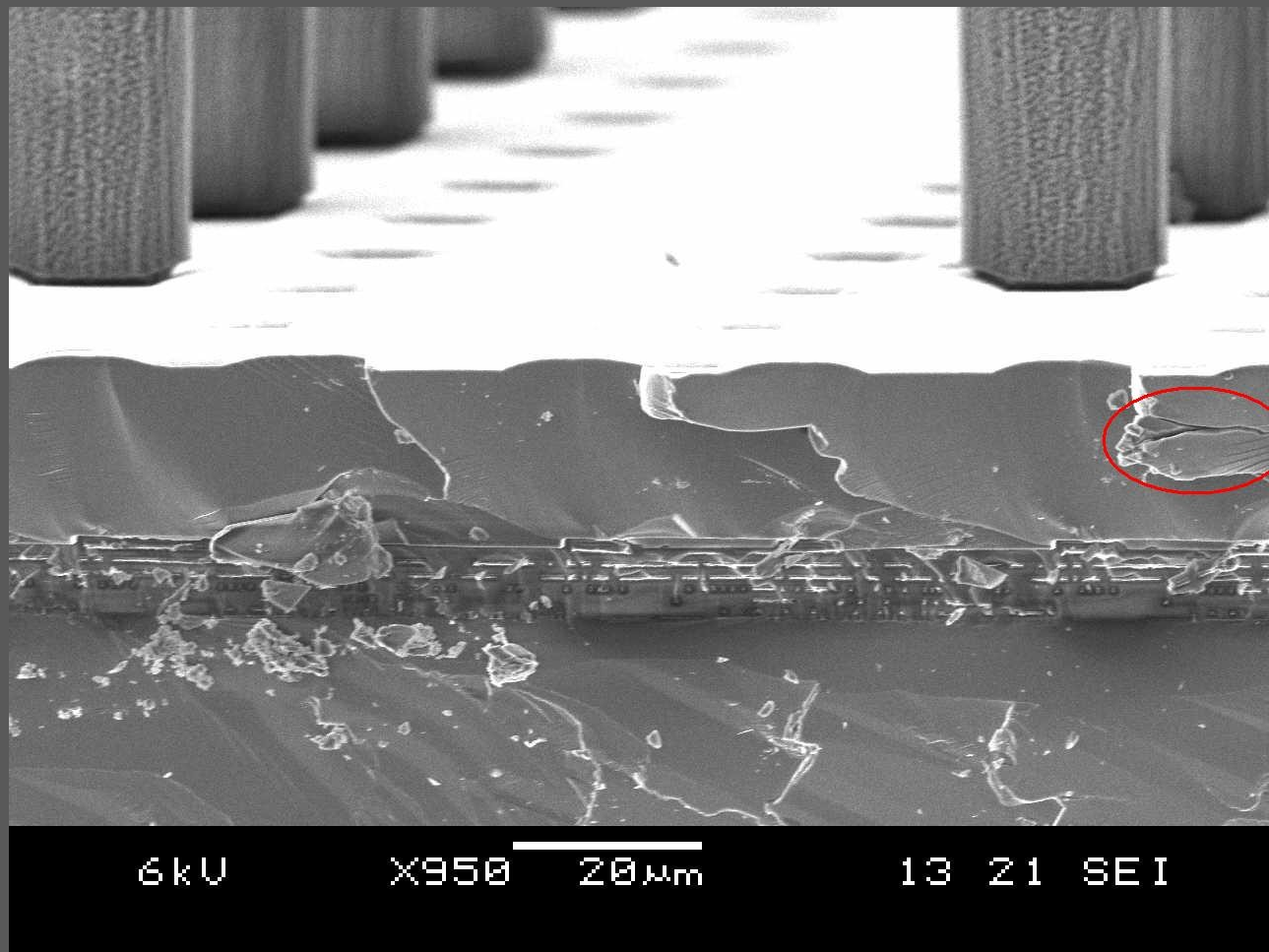
Commercial production is under development at IZM-Fraunhofer, Berlin.

Goal:
to make robust InGrids on 8” wafers,
for a low price, in large numbers

IZM-Berlin
MESA+/Univ of Twente
Nikhef
Univ. of Bonn
Saclay

MEMS Technology

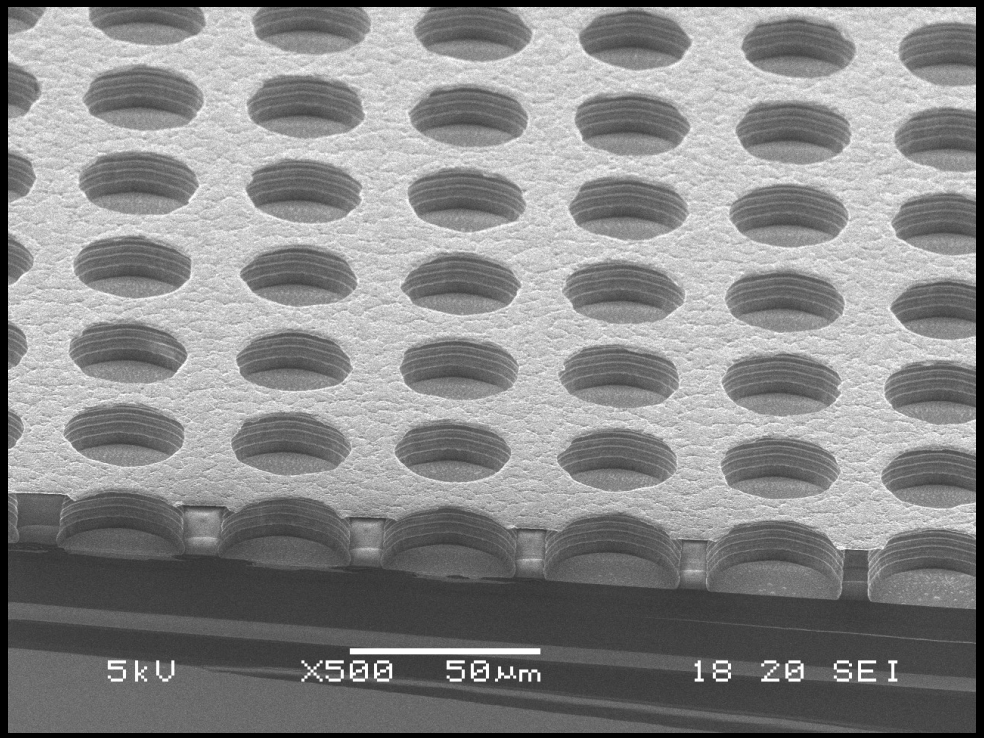
- May 2010: 18 pcs GridPix (= TimePix + SiNProt + InGrid) made
  - quite good sparkproof!
- weak spots in protection layer found: future: all ceramic InGrid



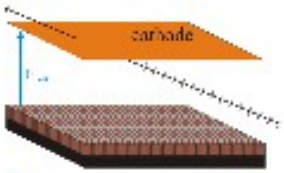
New R&D: the all-ceramic GridPix:

- Si TimePix chip
- SiNitride protection layer
- SiNitride InGrid

➔common thermal expansion coefficient: 6 x 10^{-6} K^{-1}

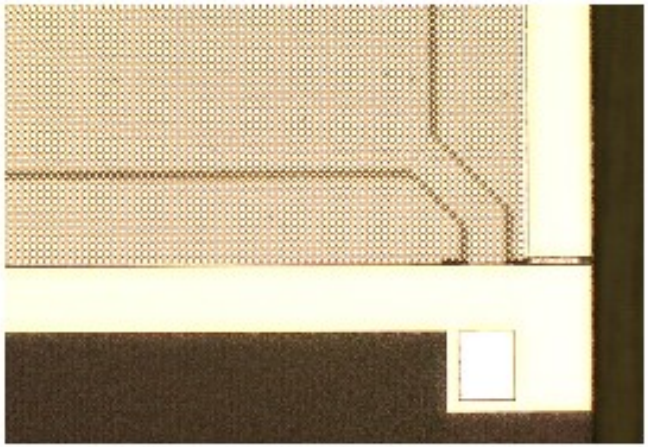


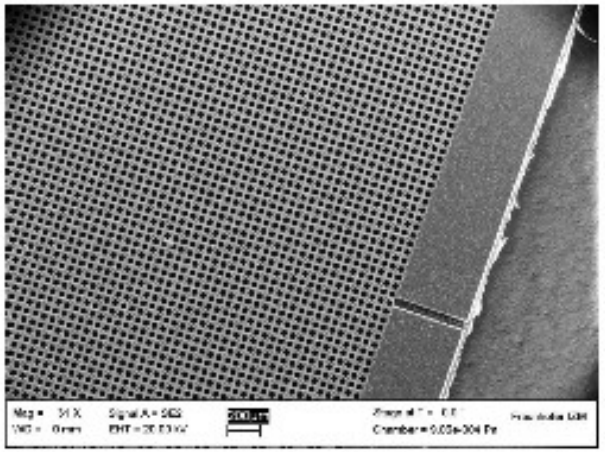
First GEMGrid with SiO2 as insulating spacer between grid and substrate
Victor Blanco Carballo, MESA+/Nikhef

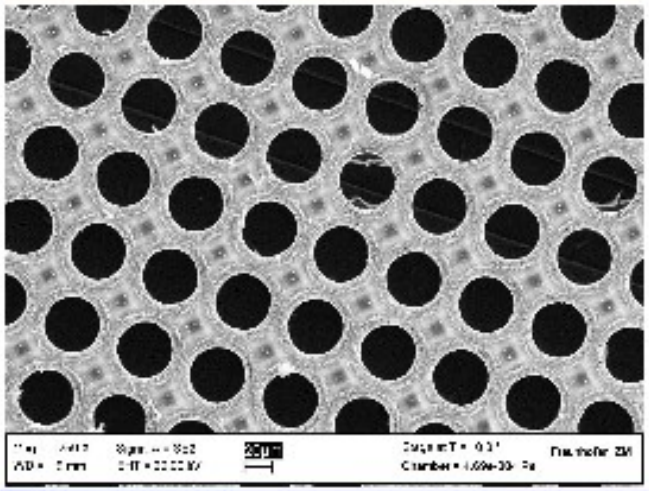


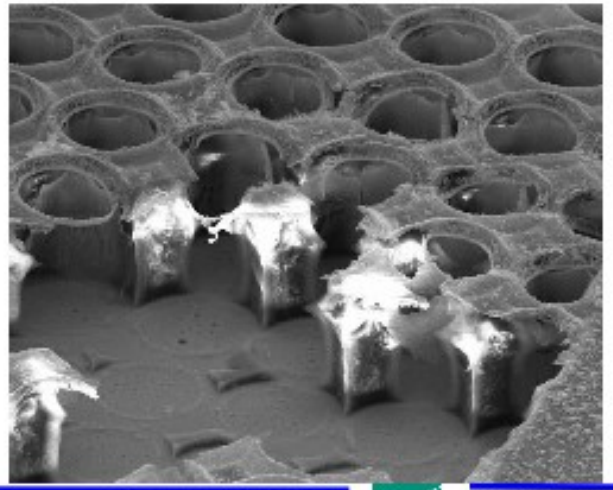
Processing of GEMGrid Test Chip (II)

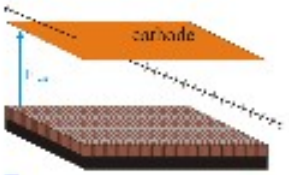
GEMGrid Test Chip after BCB Dry Etch



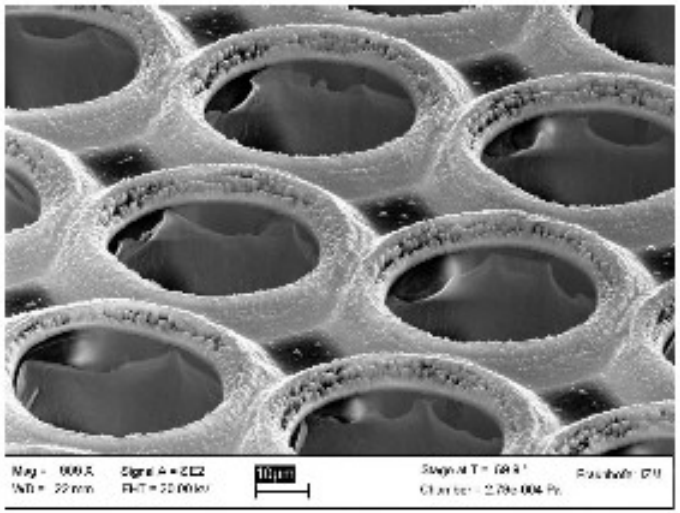






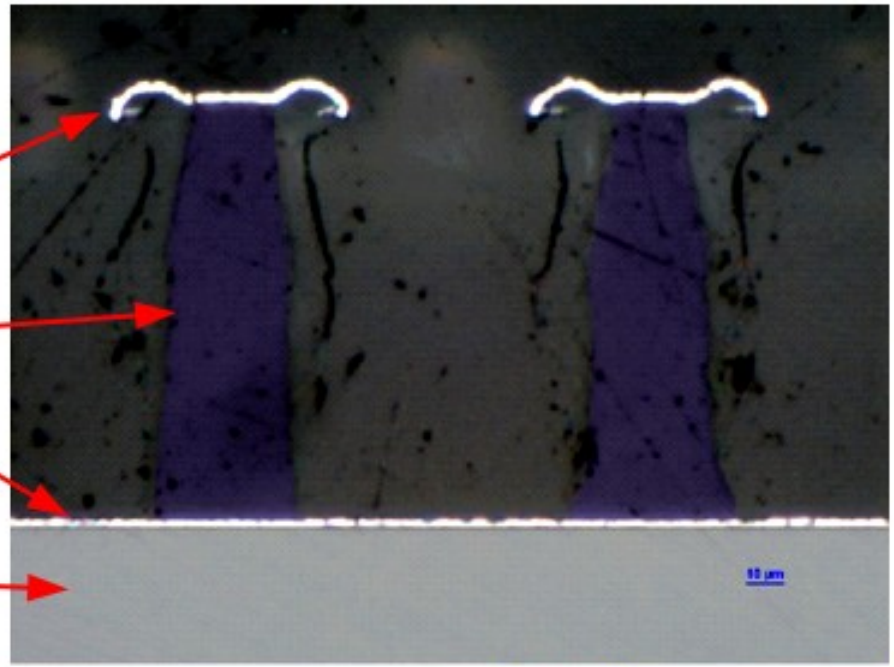


Processing of GEMGrid Test Chip (III)



Cross section of GEMGrid test chip embedded in a transparent Epoxy

BCB pillars blue coloured



Top electrode – aluminum

Dielectric layer- BCB

Bottom electrode – aluminum

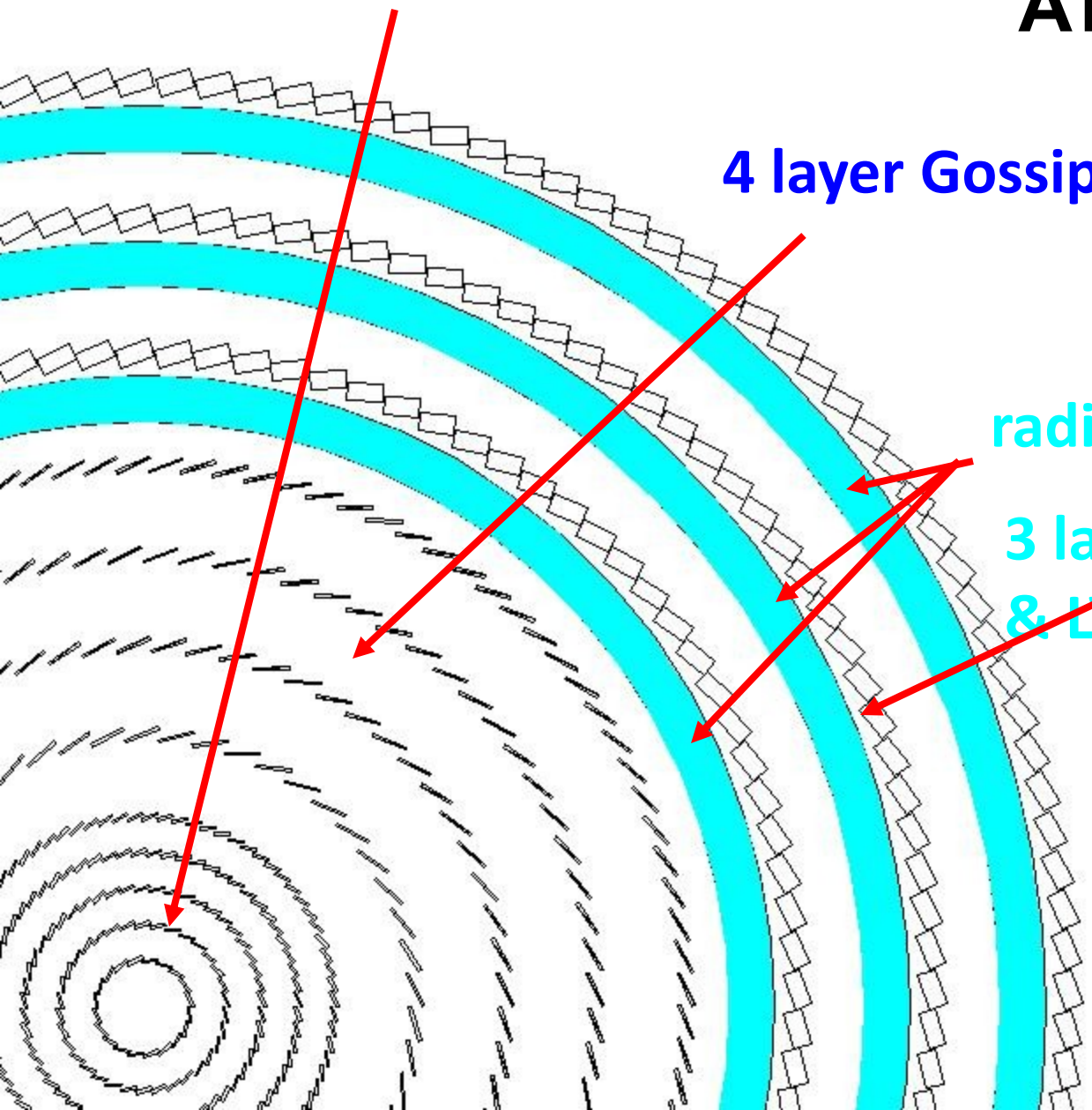
Silicon wafer

Applications of GridPix and Gossip

ATLAS:

"The baseline ATLAS inner tracker upgrade is an all- silicon detector. New technologies such as GridPix and the Gossip version of it could become an alternative sensor technology to pursue for part of the detector. They would only be adopted in case of major performance or cost advantages over silicon technology, or if technical issues are found in the silicon projects in the next 2--3 years. The EB has considered the Gossip R&D proposal, and supports this R&D for a limited duration of 3 years to demonstrate and quantify performance, cost and reliability. In 2013, ATLAS will review the results and consider if there are sufficient elements for further pursuance of this technology for ATLAS"

ATLAS Upgrade

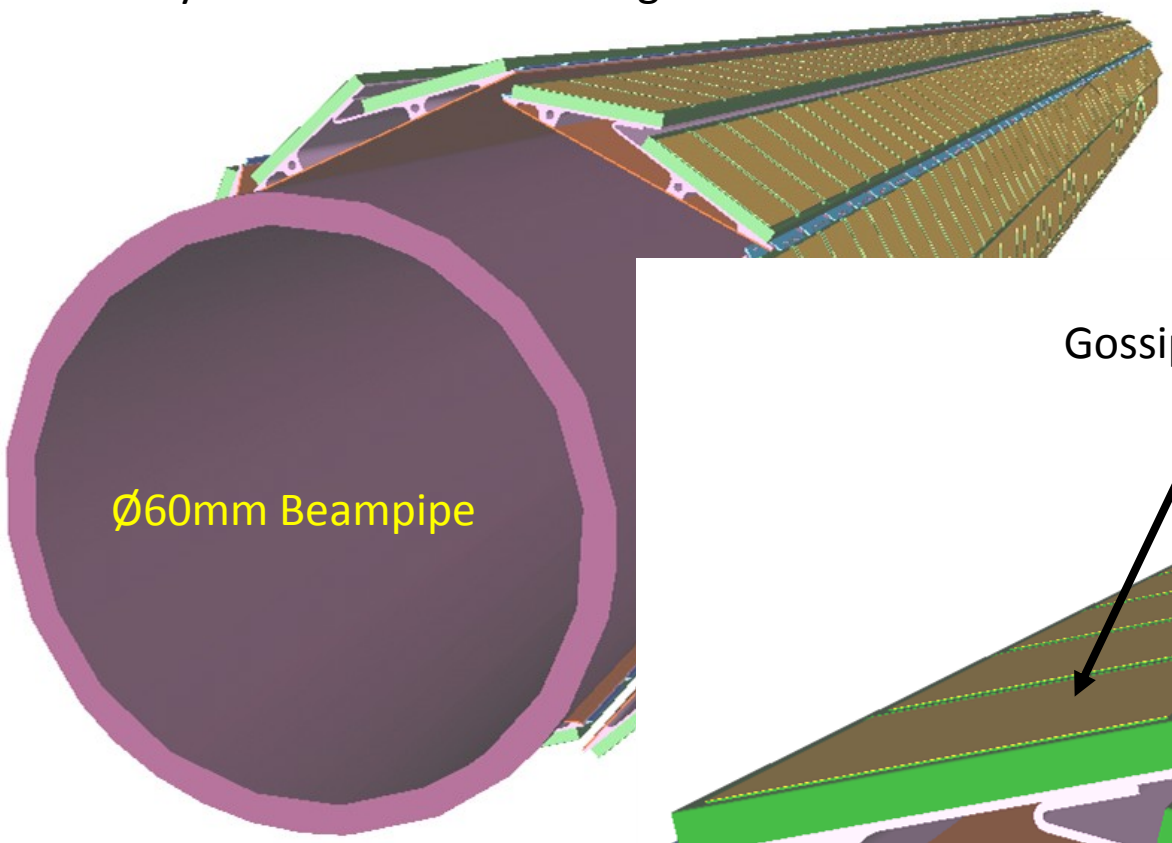


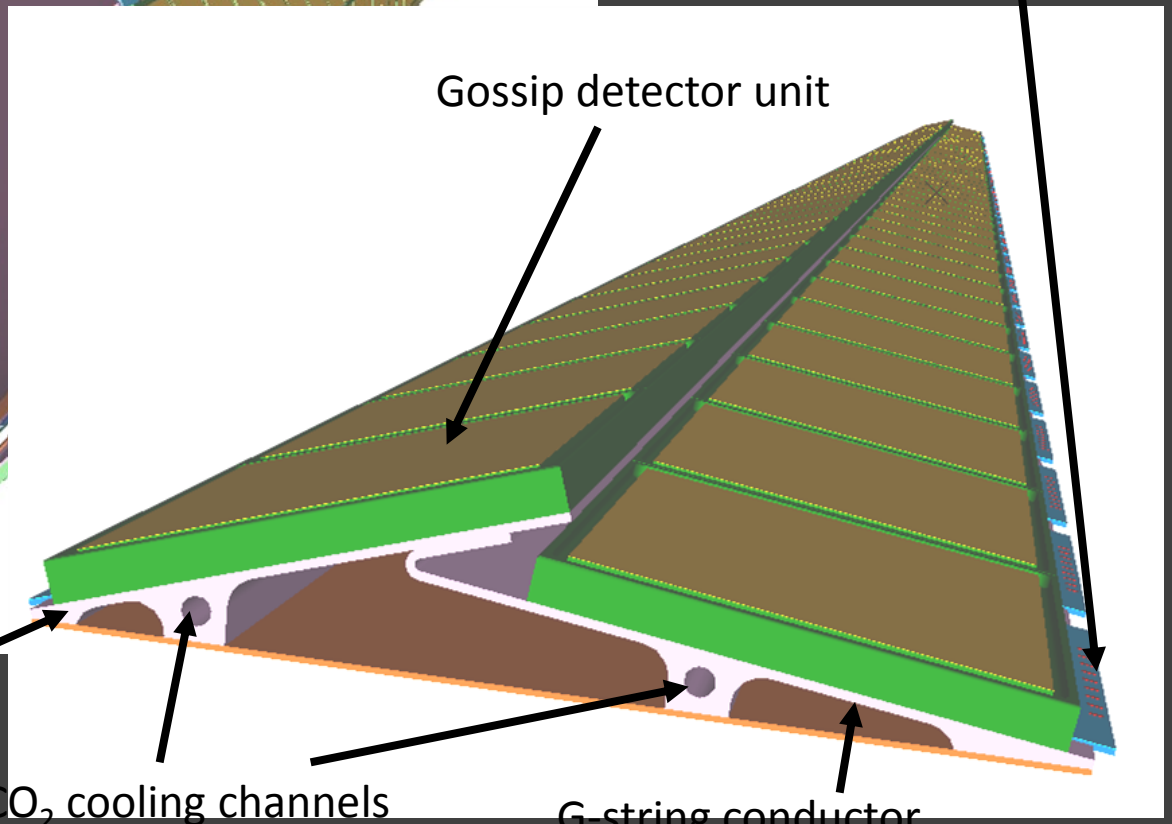
GOssip in ATlas

Alternative for TimePix:

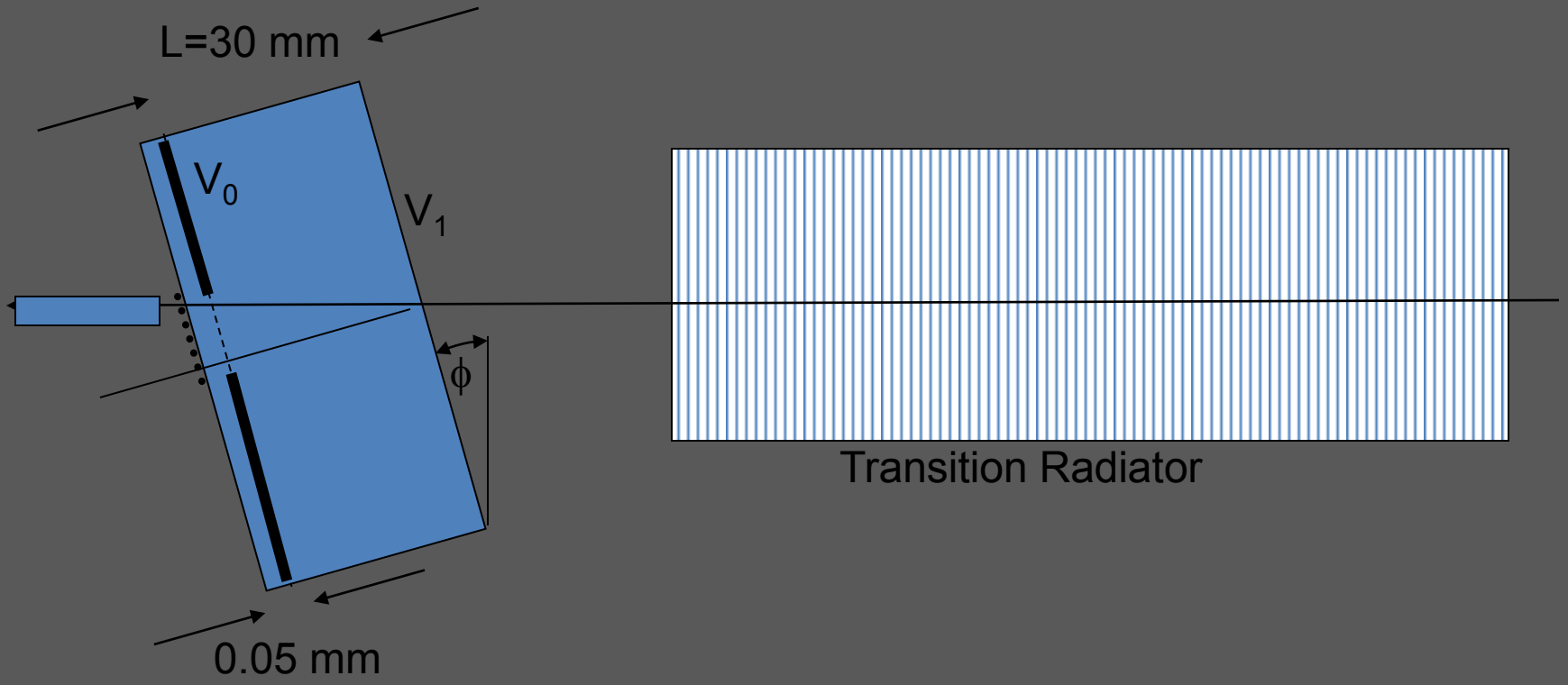
Gossip made with FE-I4 pixel chip:
rate effect studies (in testbeam)

Inner Layer: 7 double Goat strings





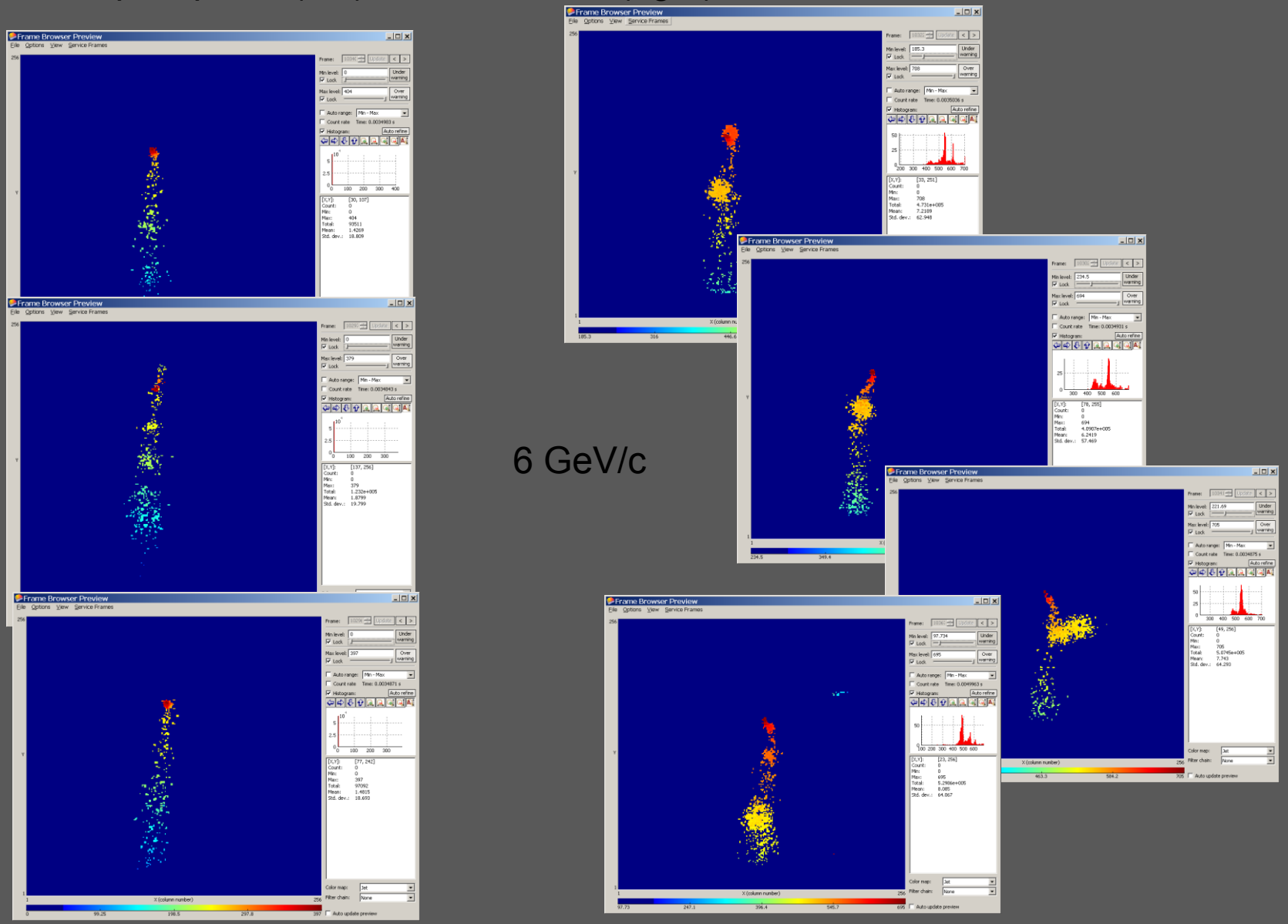
Testbeam Nov 5 – 12, 2007
PS/T9: electrons and pions, 1 – 15 GeV/c



Anatoli Romaniouk, Serguei Morozov, Serguei Konovalov
Martin Fransen, Fred Hartjes, Max Chefdeville, Victor Blanco Carballo

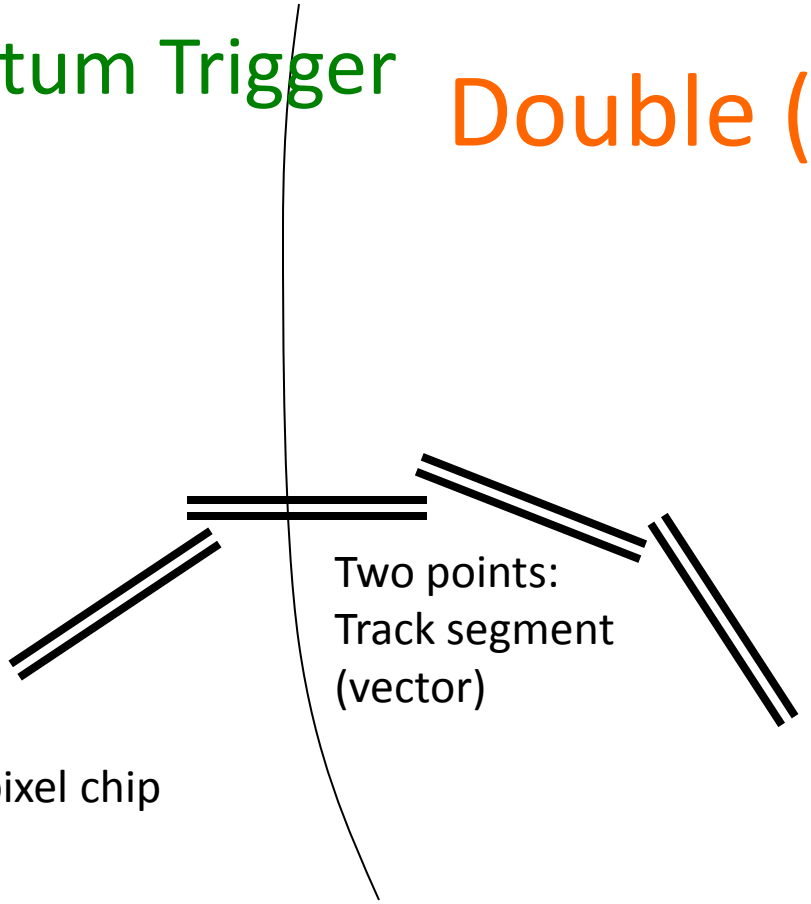
Particle Identification

Samples pions (left) and electrons (right)



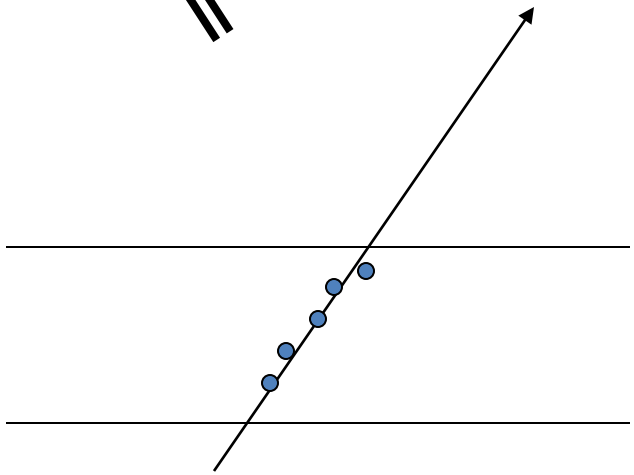
LVL1 Momentum Trigger

Double (Si) layers

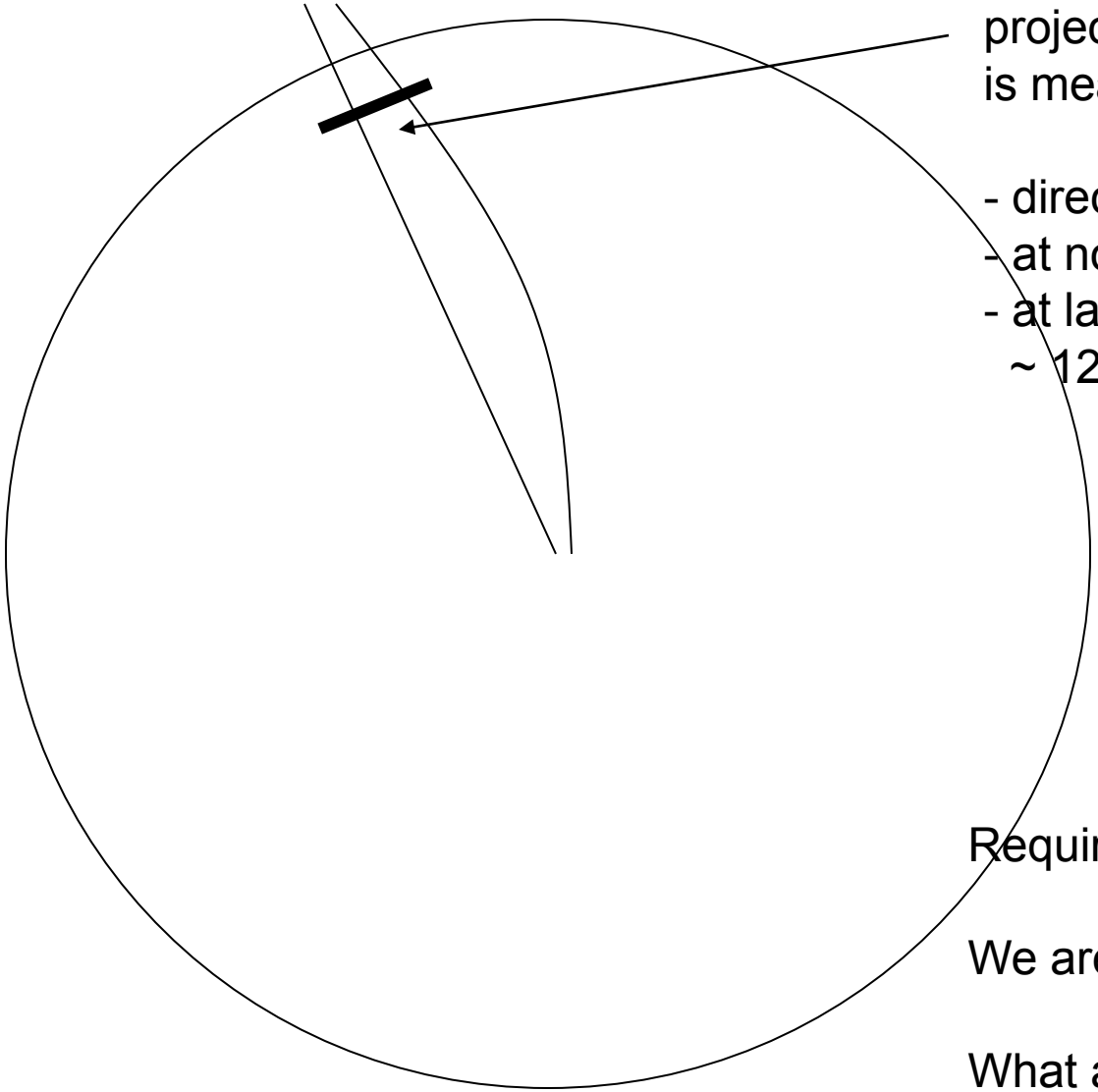


Two points:
Track segment
(vector)

Requires inter-pixel chip communication



Gossip measures track segment in single layer



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

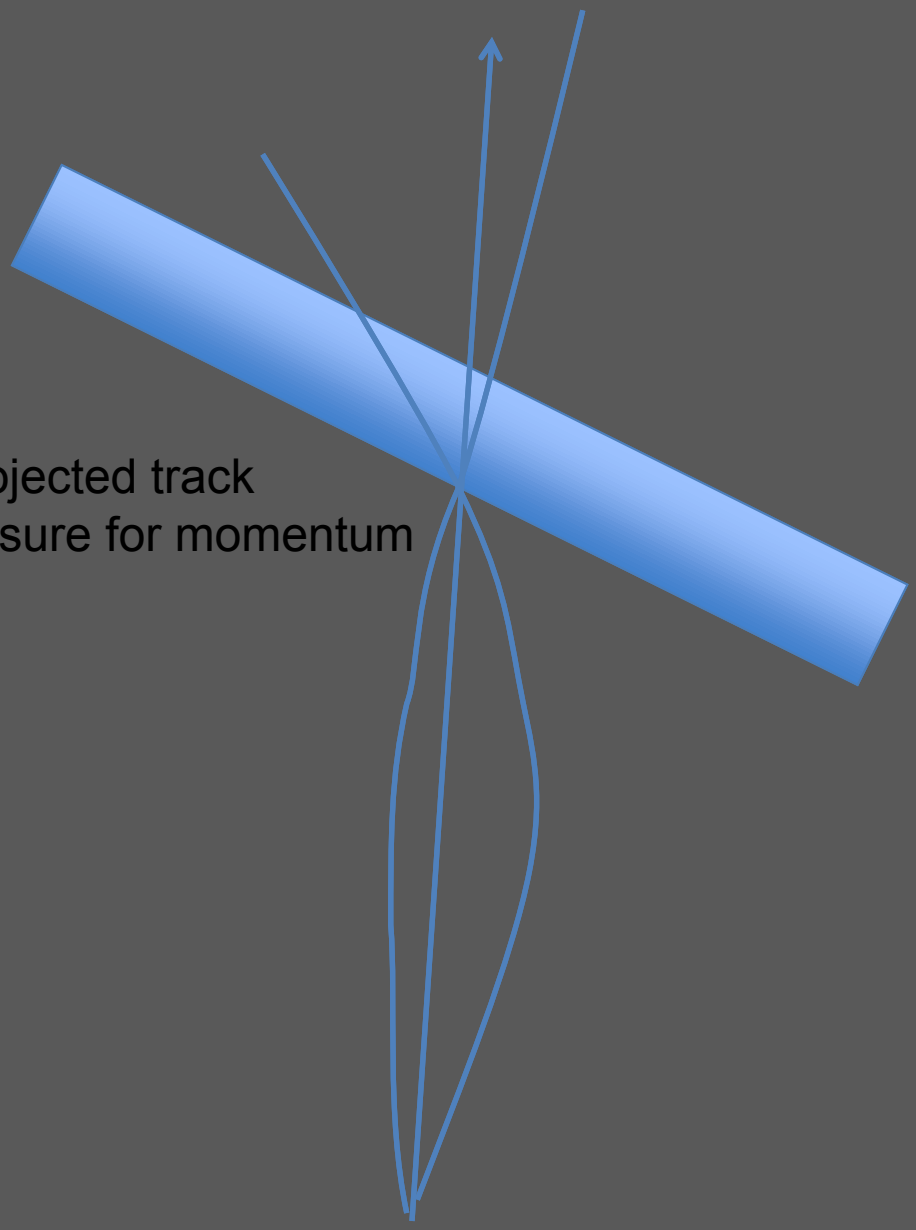
Requires fast on-pixel chip processing

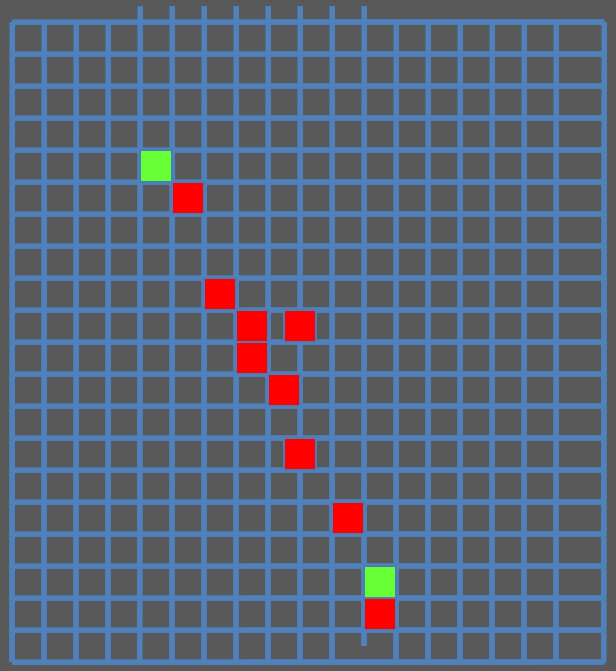
We are using 130 nm tech.

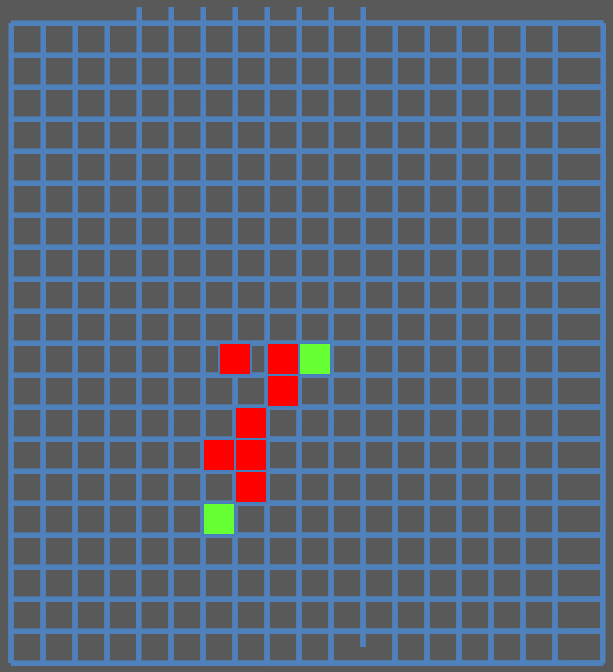
What about 45 nm tech?

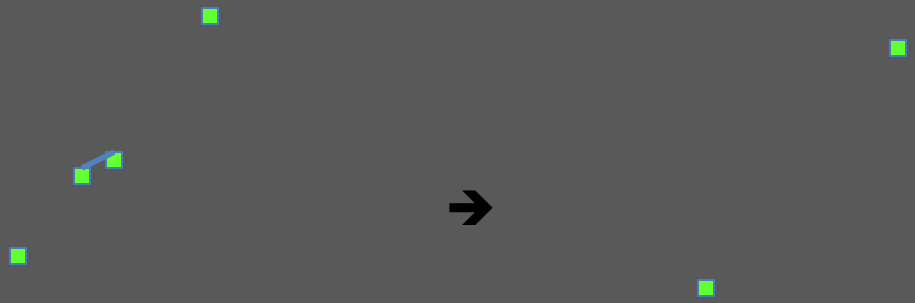
LVL1 trigger from inner tracker

Length of projected track
is direct measure for momentum

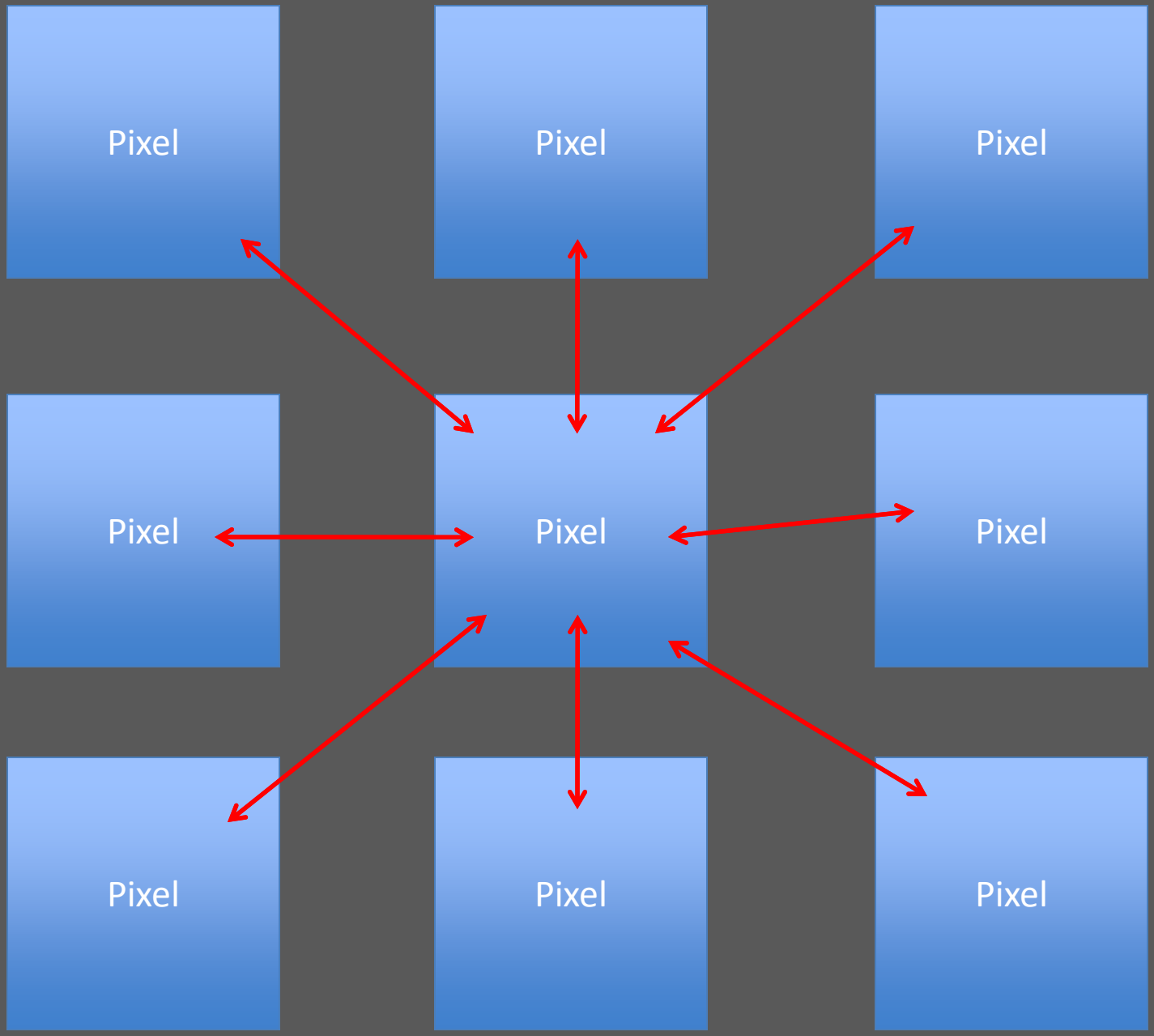








Endpoint Annihilation


Pixel
Pixel
Pixel
Pixel
Pixel
Pixel
Pixel
Pixel
Pixel

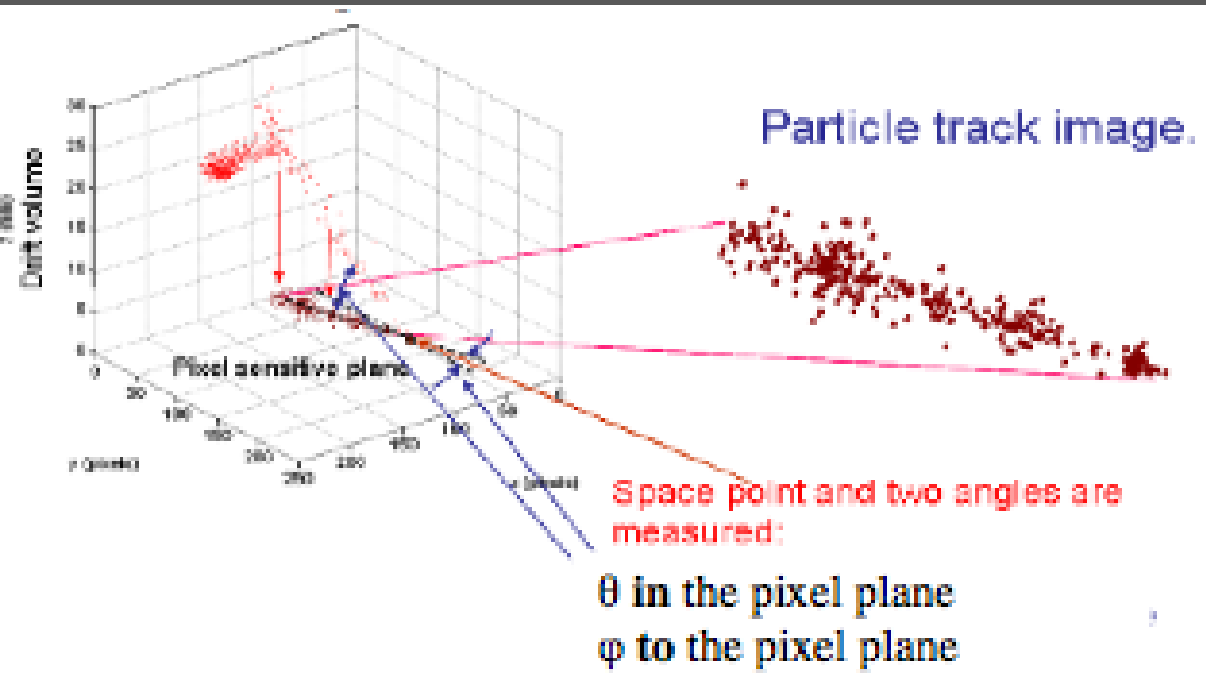
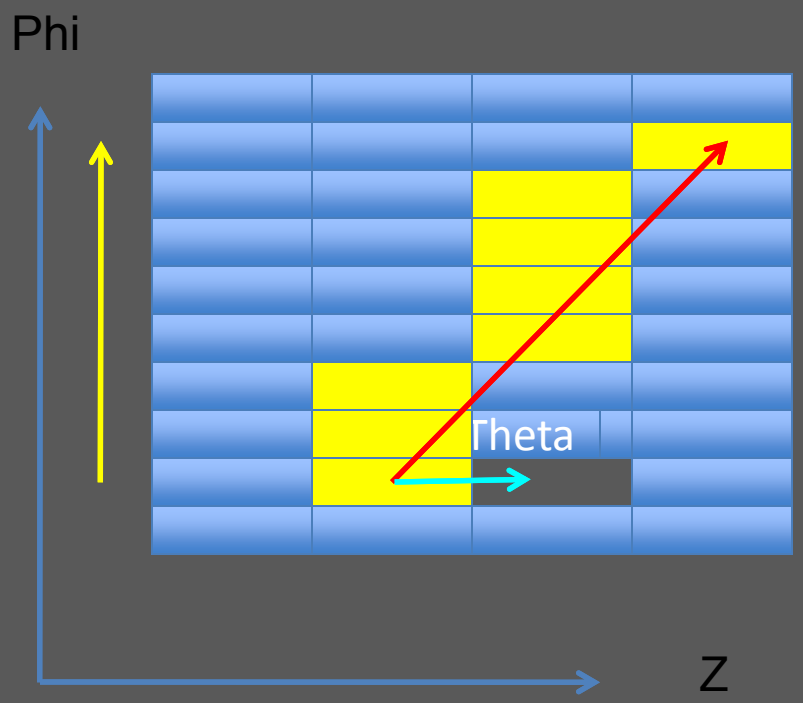


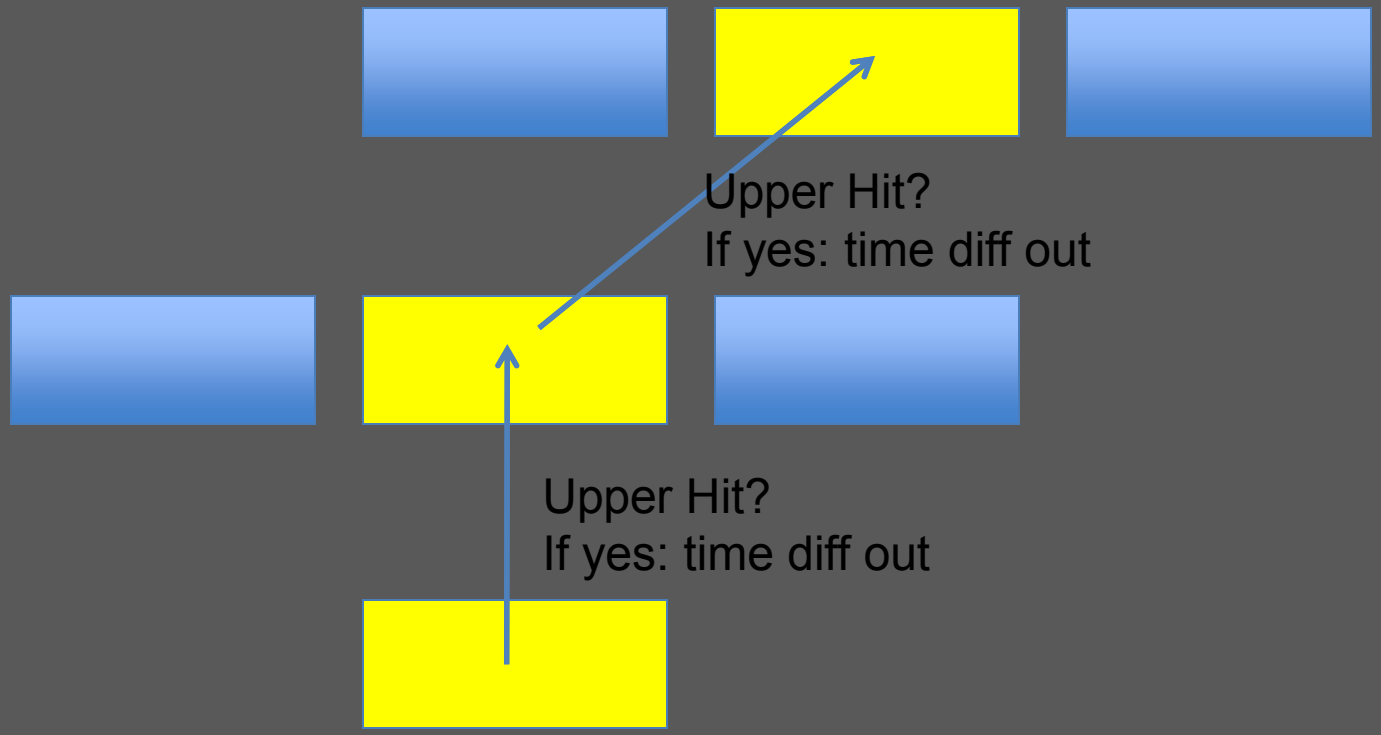
Fig. 41. Principle of the Grid-Pix tracker

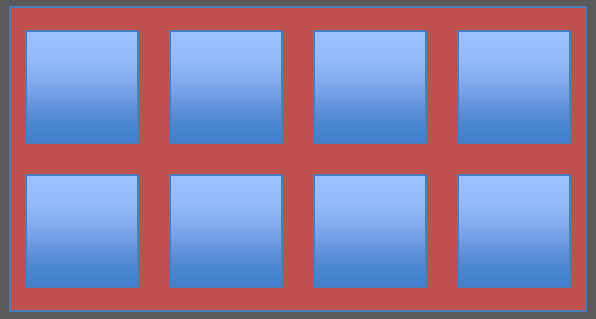
First simulation results on momentum resolution
by Anatoli Romaniouk

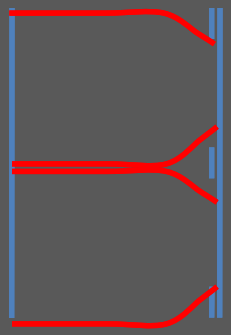


-Theta is fixed by geometry
- With proper tilt: fixed later/earlier orientation
- momentum info sits directly in (Ored) column

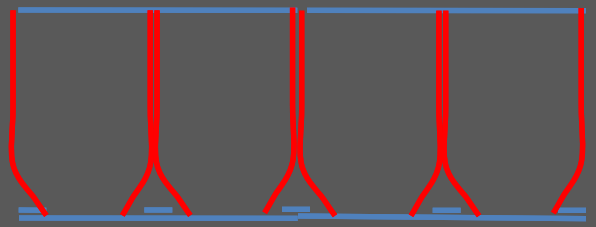
Autonomous process:
column propagation







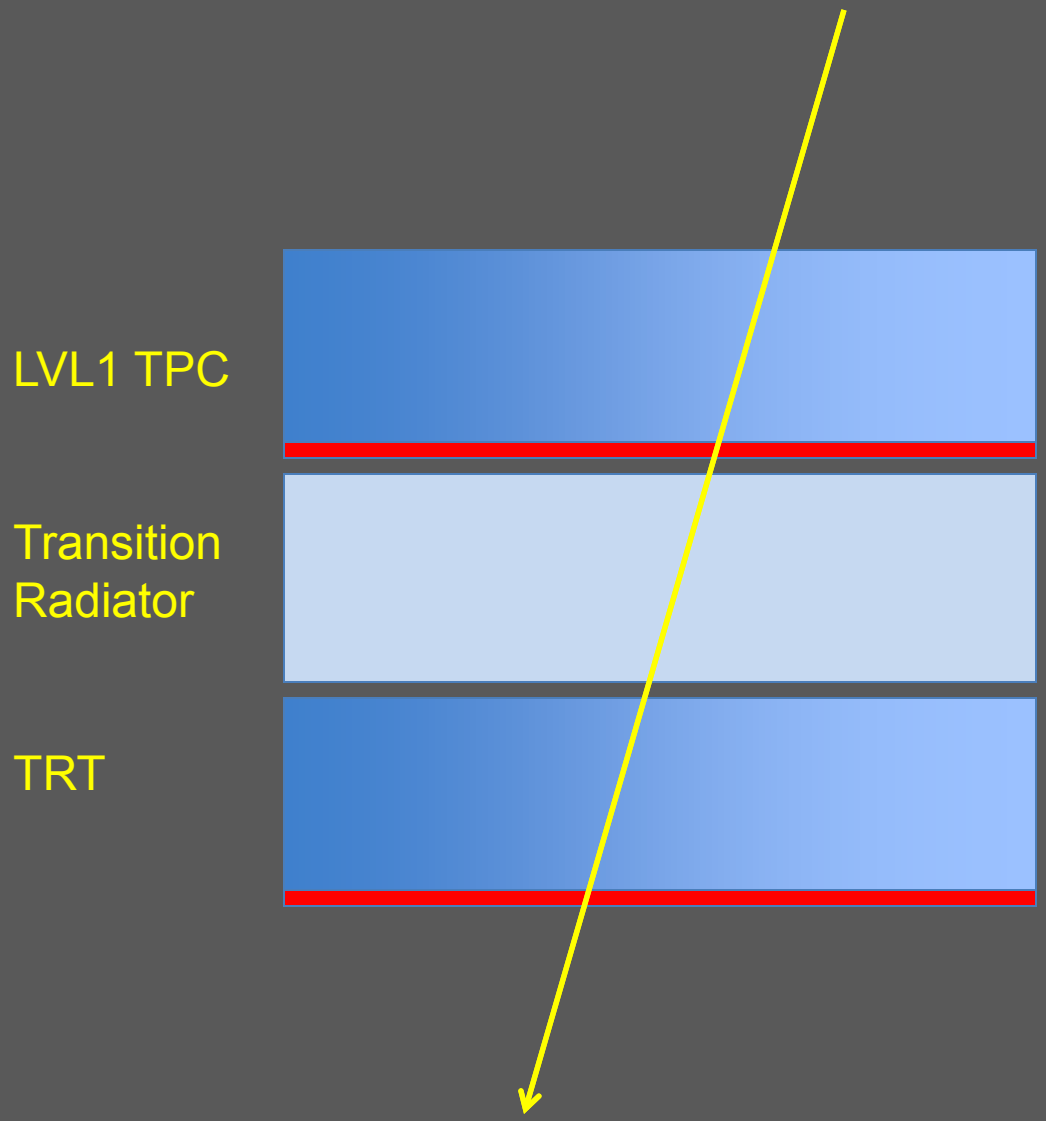
TPC readout:
Fiducial surface
Inter Chip Dead regions



With ‘guard’ electrode

Electrostatic focussing: elimination of dead regions.

Electrostatic lensing: the magnifying TPC! Explored by Martin Fransen



LVL1 trigger for threshold momentum
Particle Identification: electron-pion discrimination

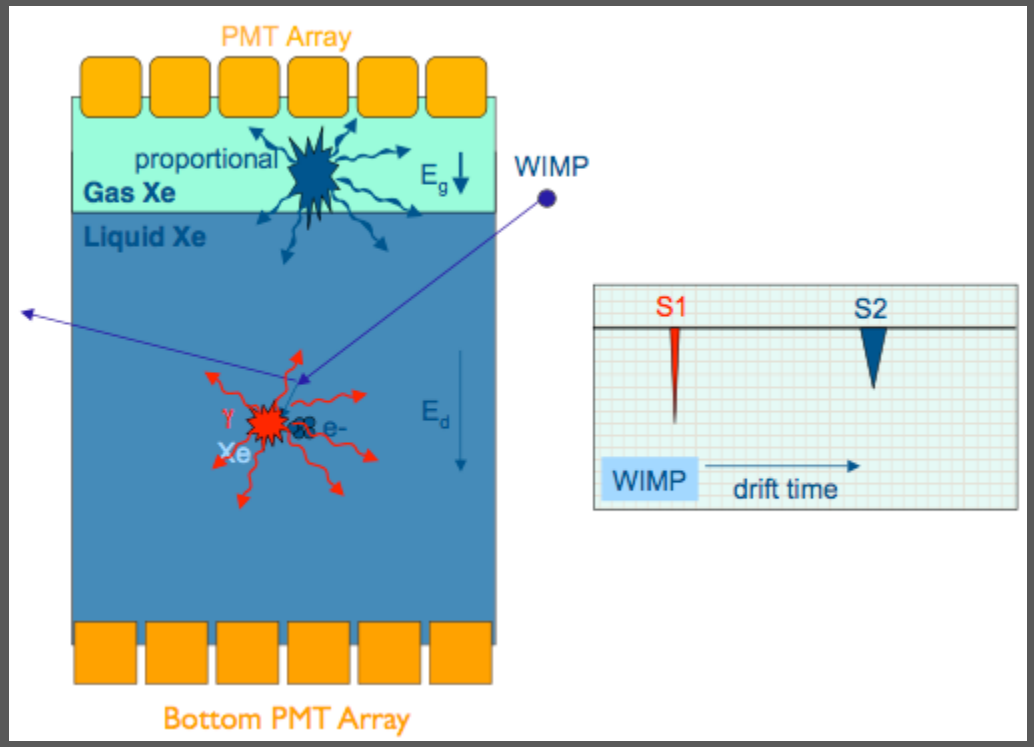
WIMP search, bi-phase Xenon

- GridPix TPC

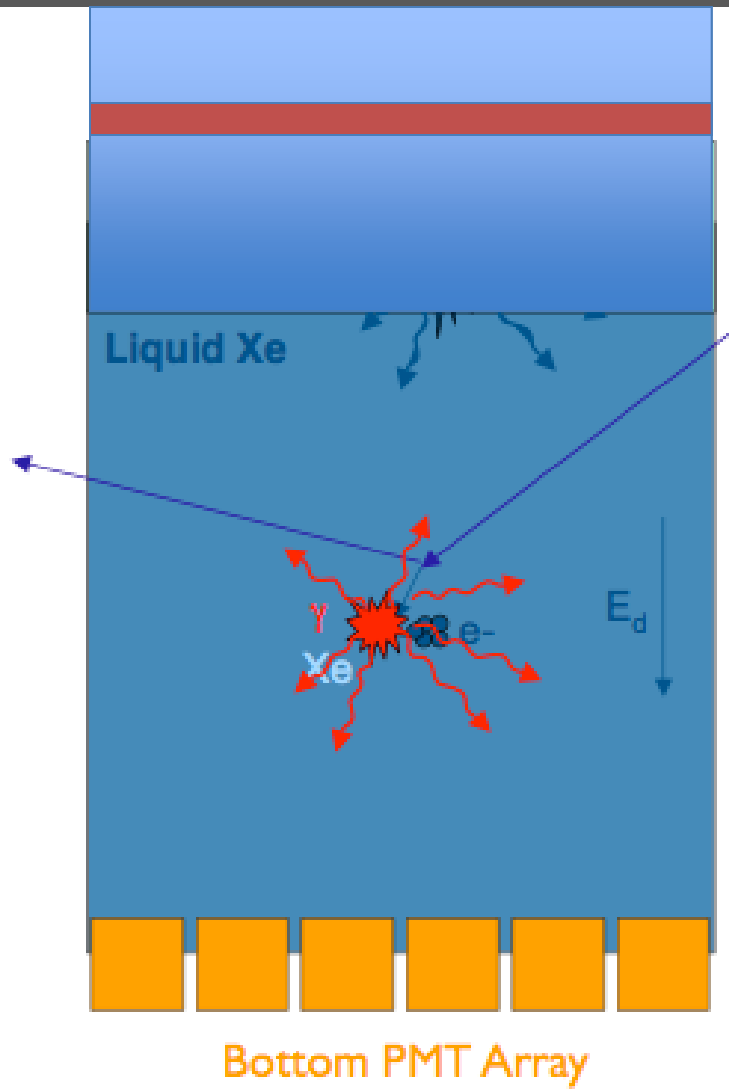
as

WIMP / DBD

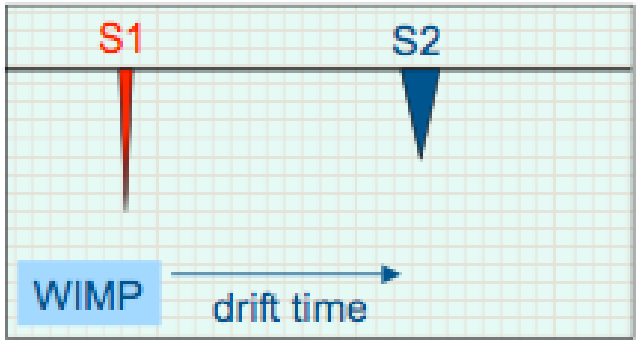
detector



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



In gas phase:
GridPix (=TimePix + InGrid)
with grid facing down!

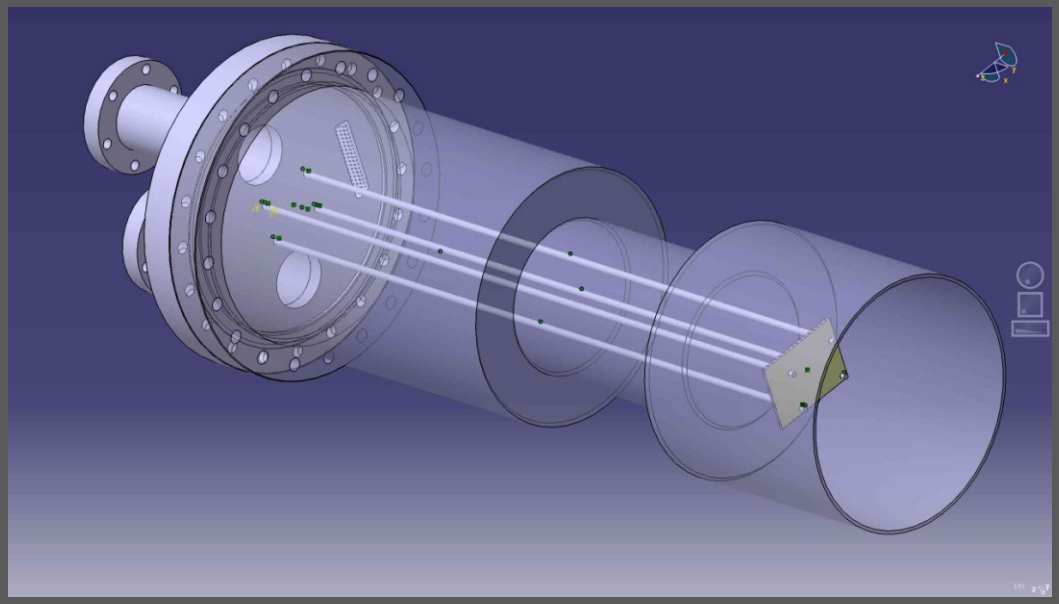


Detects single electron events with 99% efficiency!

[Essentially due to small pixel input pad capacity]

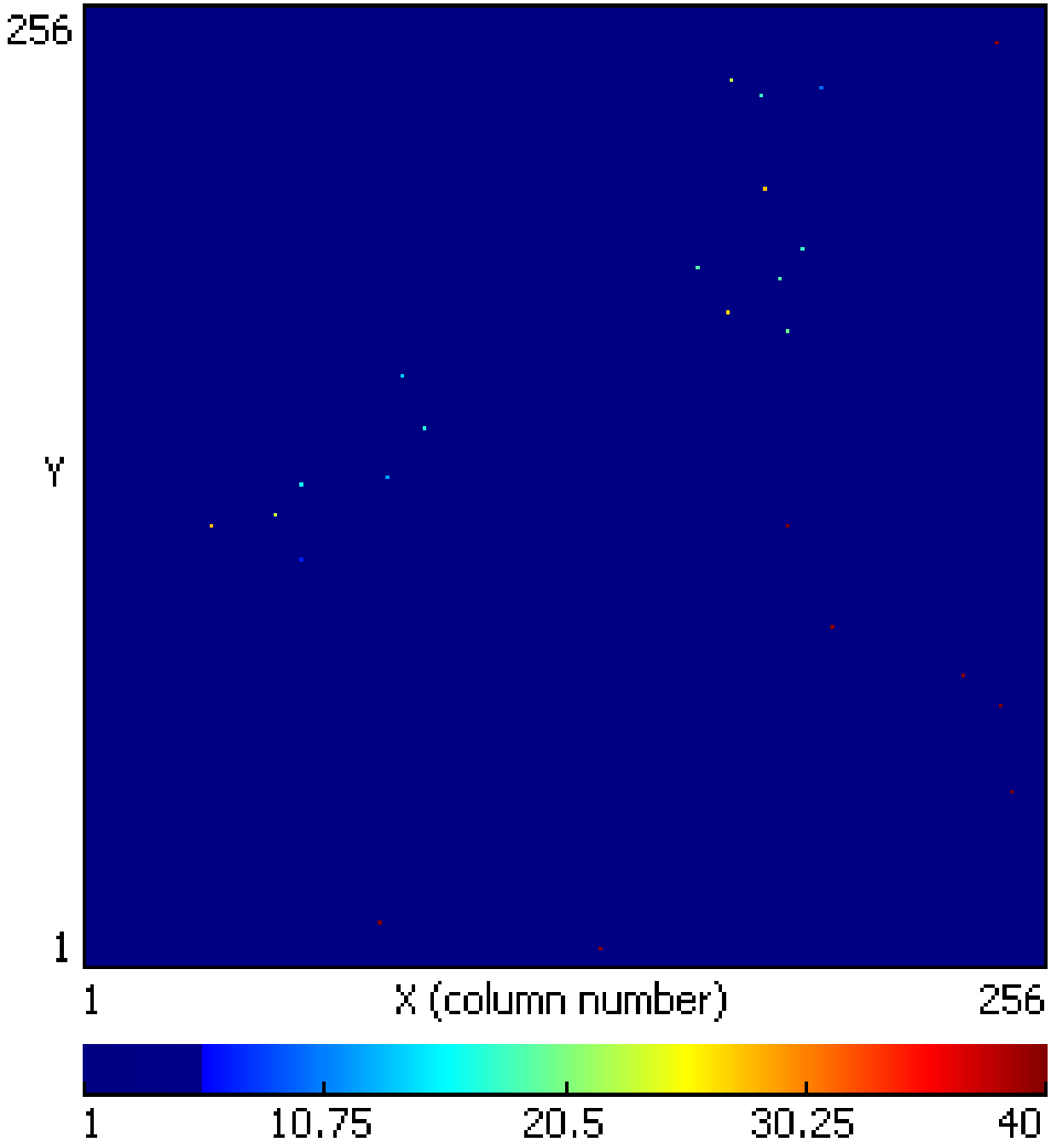
Gridpix in Xenon: Test setup

- Collaboration DARWIN/XENON



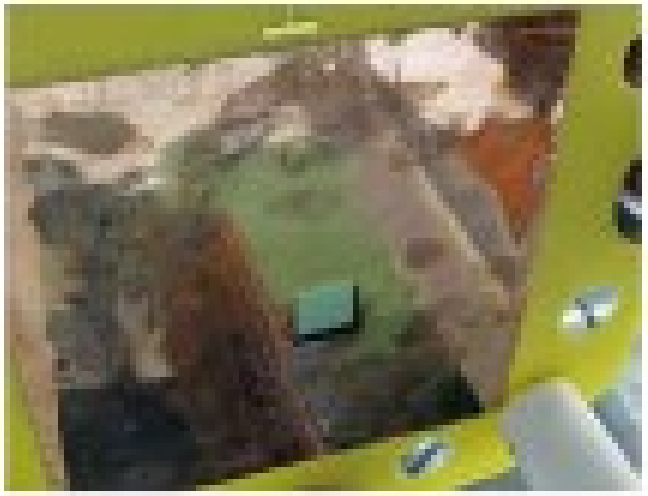
55Fe in pure argon,
HVgrid = 340 V
P = 1 bar
T = -70 C
at NLR cryostat

gain: ~ 200 !

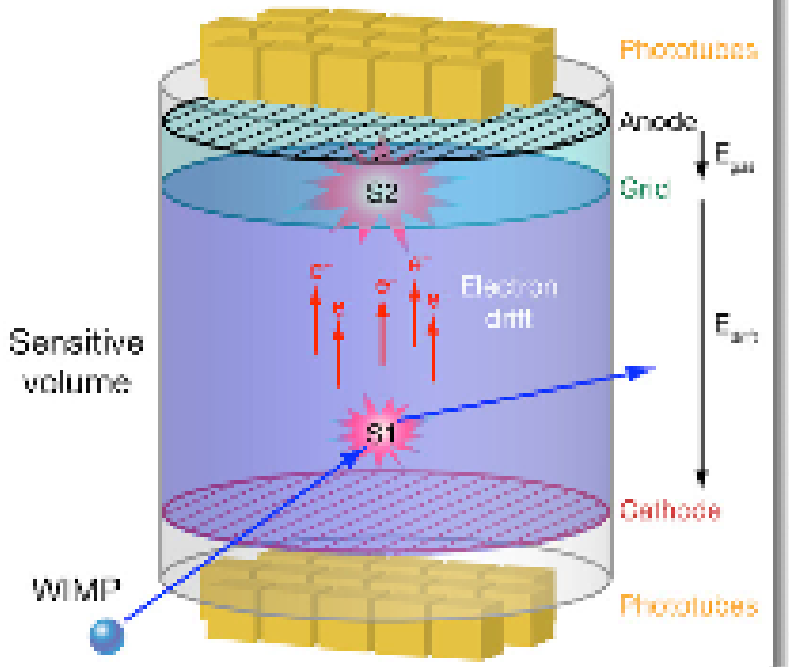


In Andre Rubbia's cryostate @ CERN

Setup



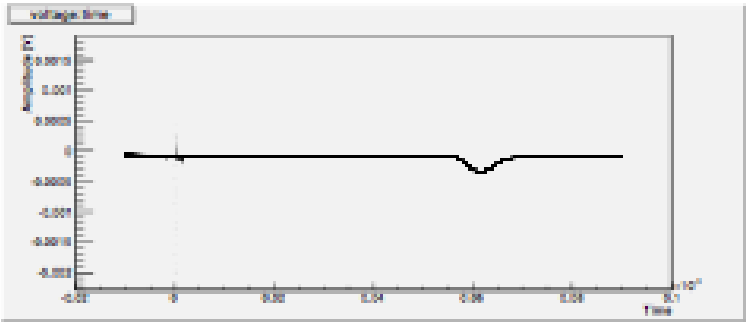
Xenon 100 experiment



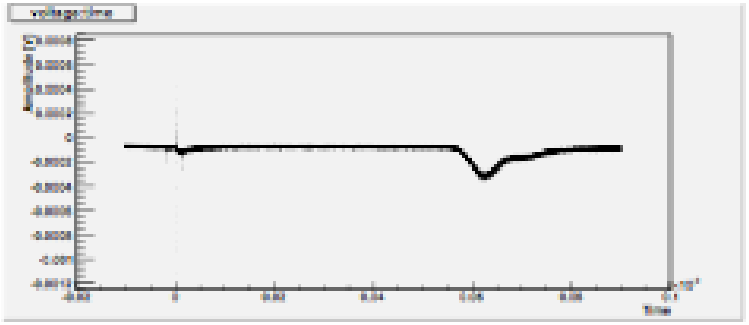
Measurements

NIKHEF

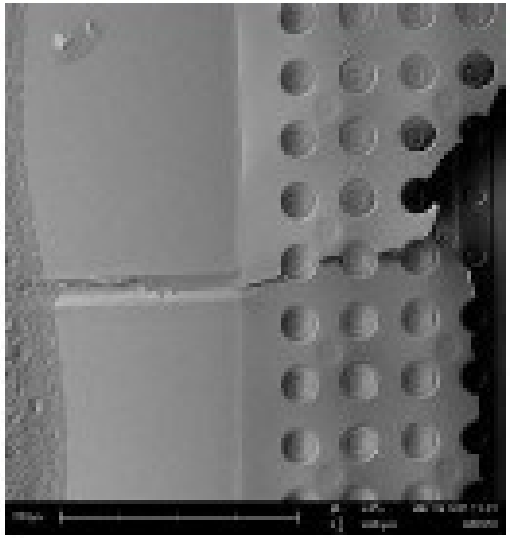
Cold GAr 150V



Cold GAr 600V



Visual and SEM view

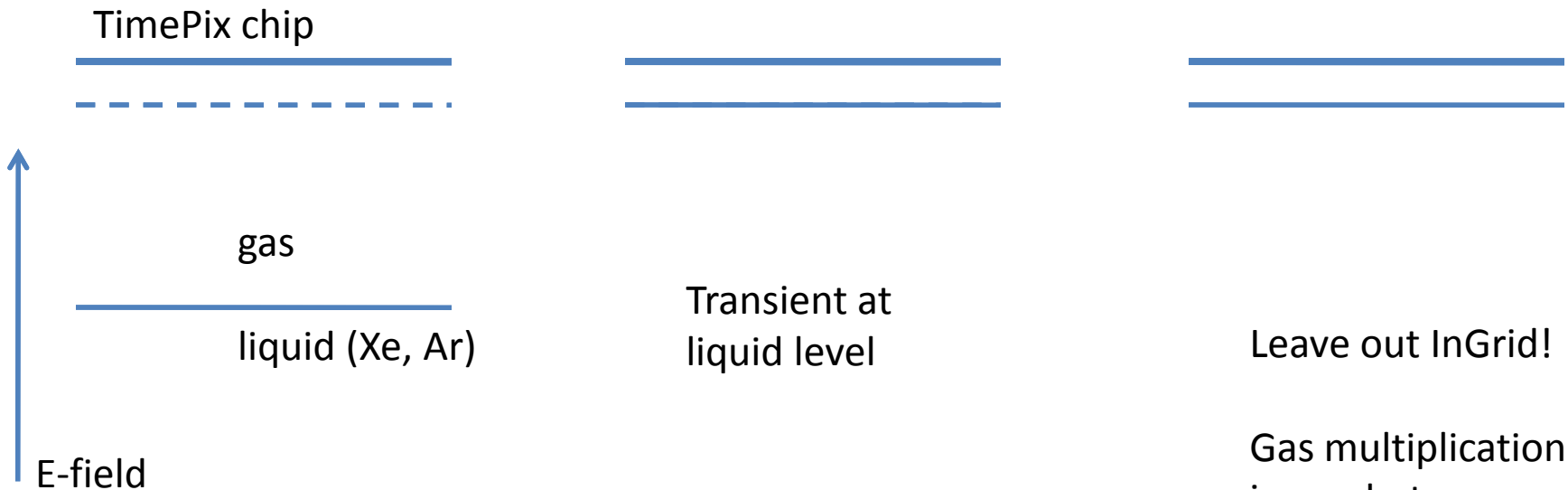


Results:

- TimePix functions well in LAr temperature (-180 C)

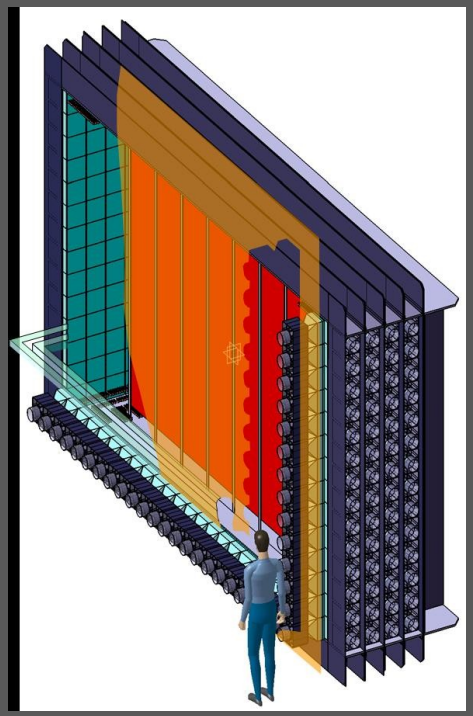
- In pure Argon, gas gain is limited to ~ 10. Confirmed by other (GEM & TGEM tests)
  UV light avalancje propagation?
  Needs to be understood: simulations. A gain of 300 would be sufficient.
  GEMGrid?

- InGrid collapses at low temperature, due to differences in thermal expansion
  of InGrid materials (epoxy, aluminium, Si).
  Requires all-ceramic GridPix: also good for outgassing.


TimePix chip
gas
liquid (Xe, Ar)
E-field
Transient at
liquid level
Leave out InGrid!
Gas multiplication
in gap between
chip and liquid surface!
Gap ~ 50 microns,
needs active feedback
control.

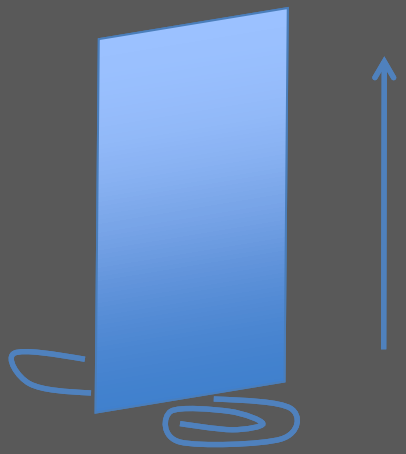
Gaseous 0-v Double Beta Decay Experiments

superNEMO:
Geiger tracker+
scintillators



hyperNEMO

TPC with GridPix readout



B-field:
- Beta tracks contained in gas volume
- momentum measurement from init curvature
- total absorption: energy measurement

good energy resolution!

GridPix as photon detector

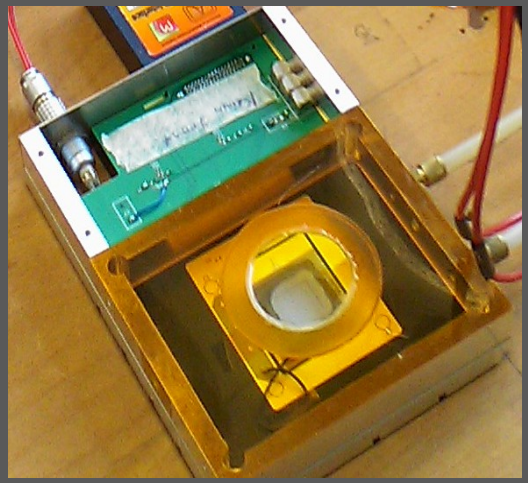
- Photon conversion on InGrid, possibly covered with CsI

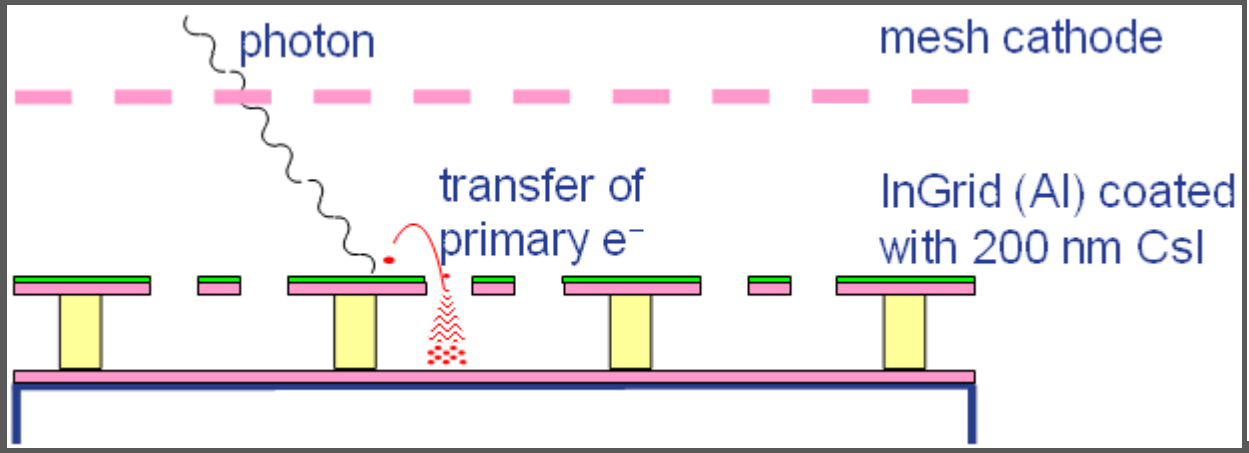
- Photon conversion in gas (100 eV – 1 MeV)

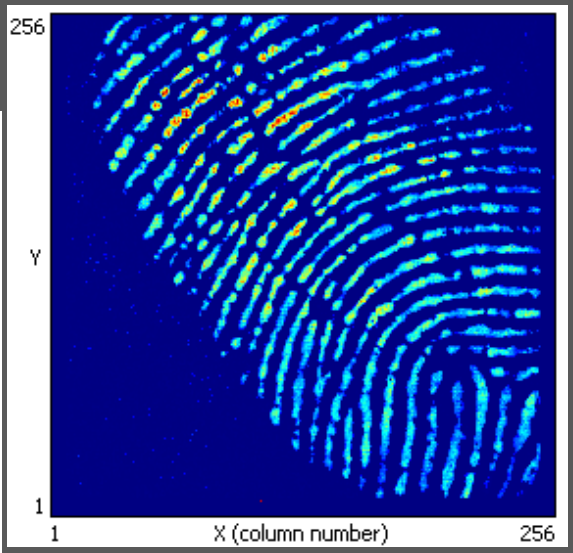
Gaseous Photomultiplier

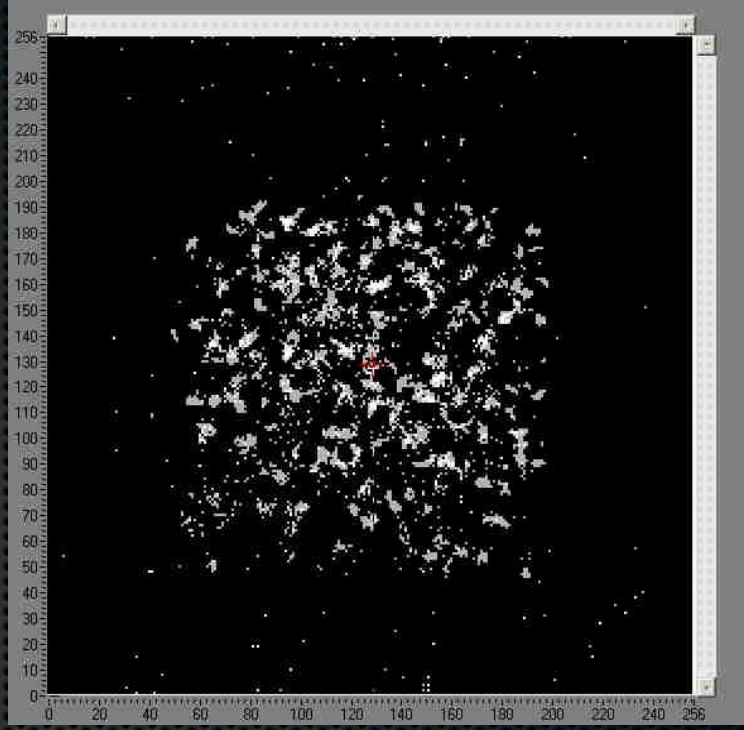
- Photoelectric effect
- Future possibility:

  CsI layer on grid





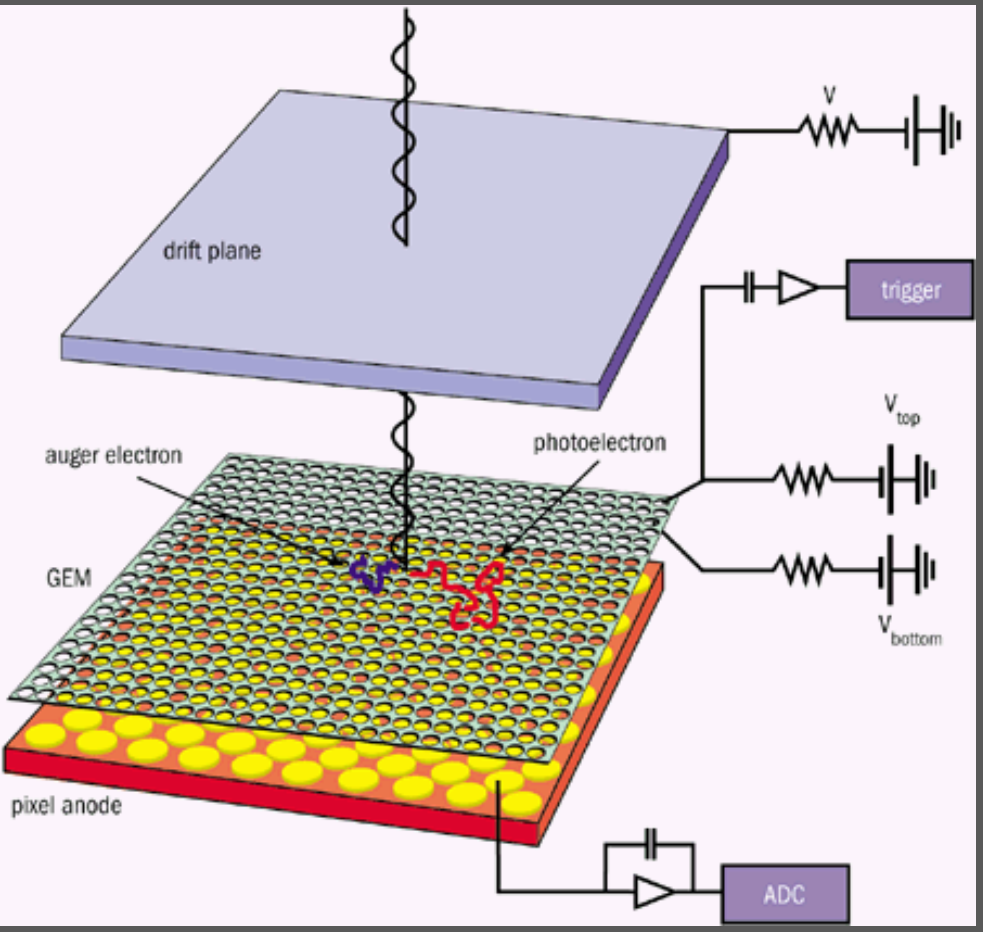


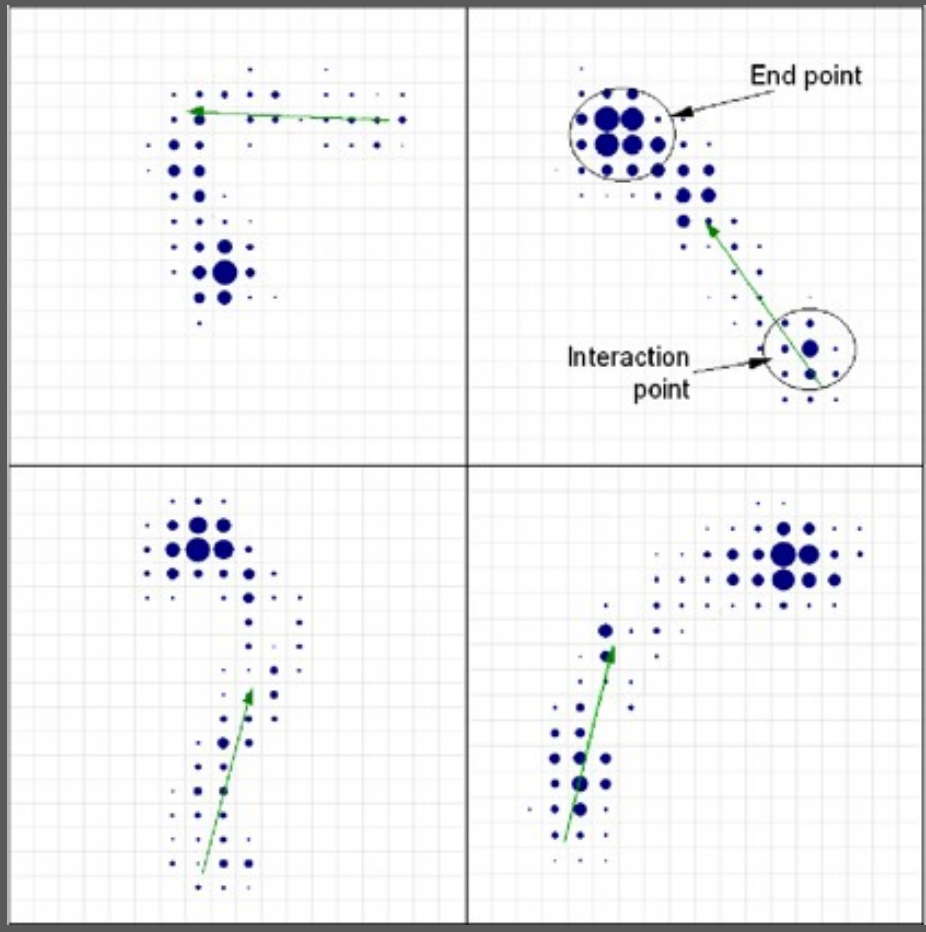


PolaPix

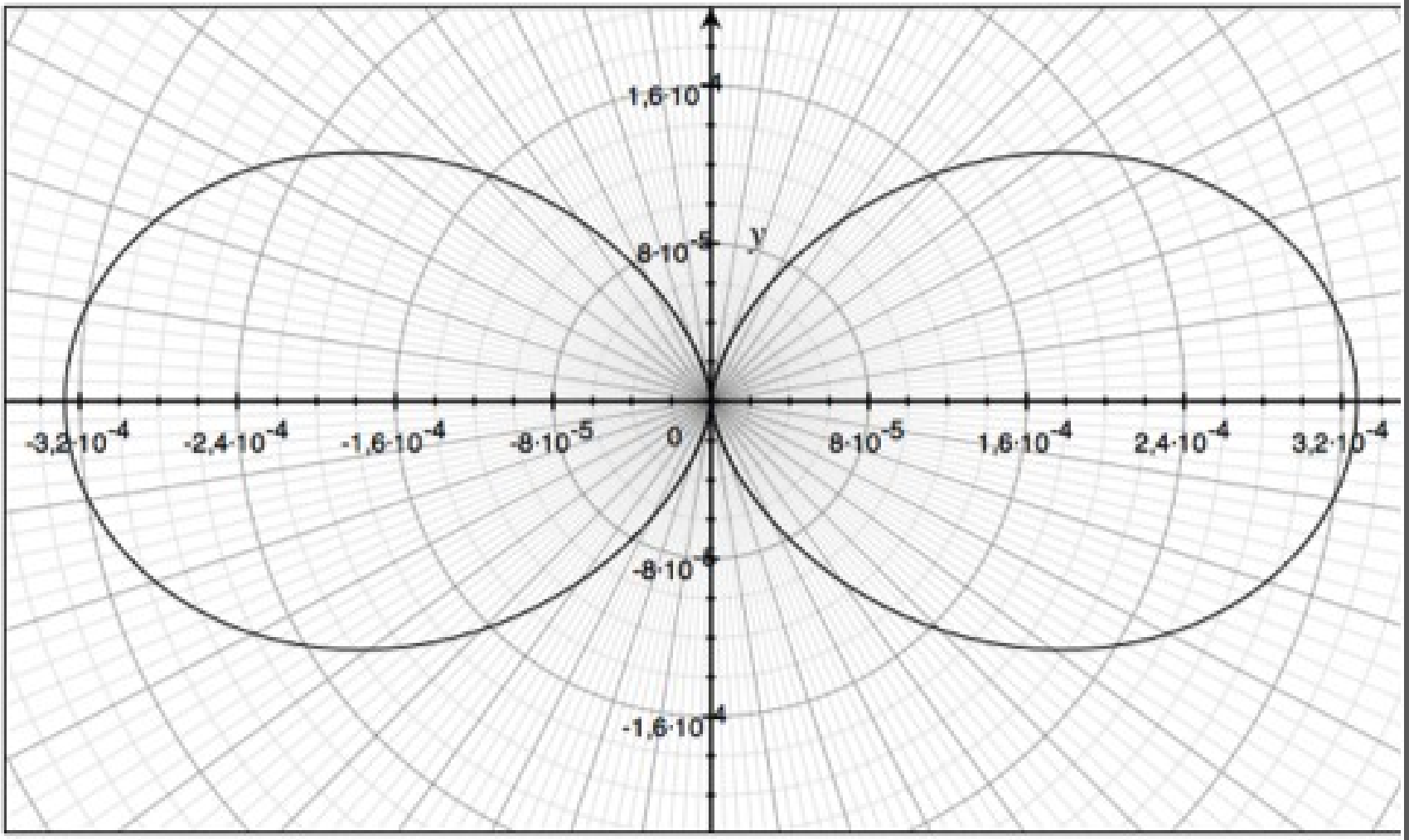
Using a GridPix detector for the 3D detection of polarized X-ray photons

Sjoerd Nauta - Nikhef





X-ray Polarimeter proposed by R. Bellazzini



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

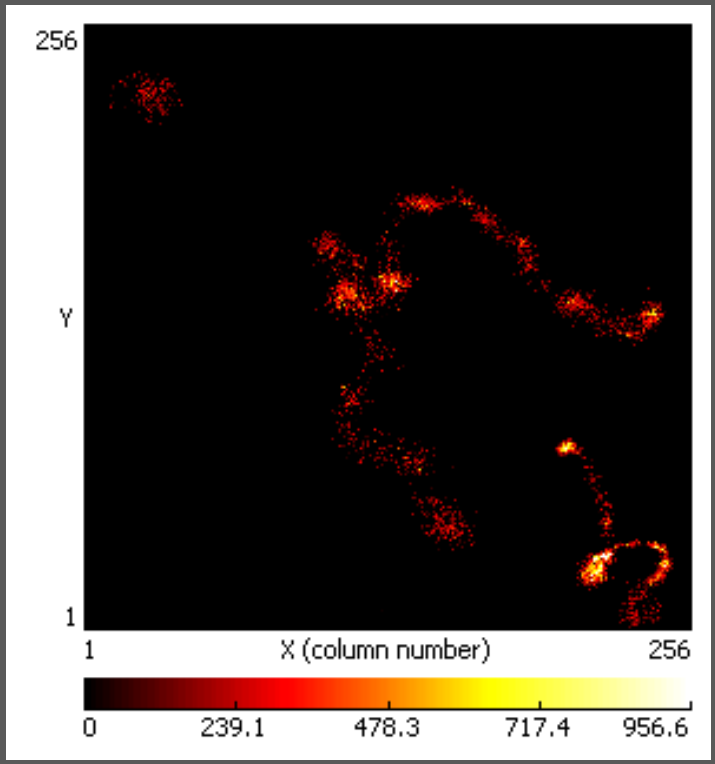
With ECAP/University of Erlangen

PolaPix

GridPix as (gas-filled) photon detector for applications in space observatories via tracking photo-electron or Compton-electron. Measurement of

- photon energy
- photon direction
- polarisation

in the range of 1 – 511 keV photons



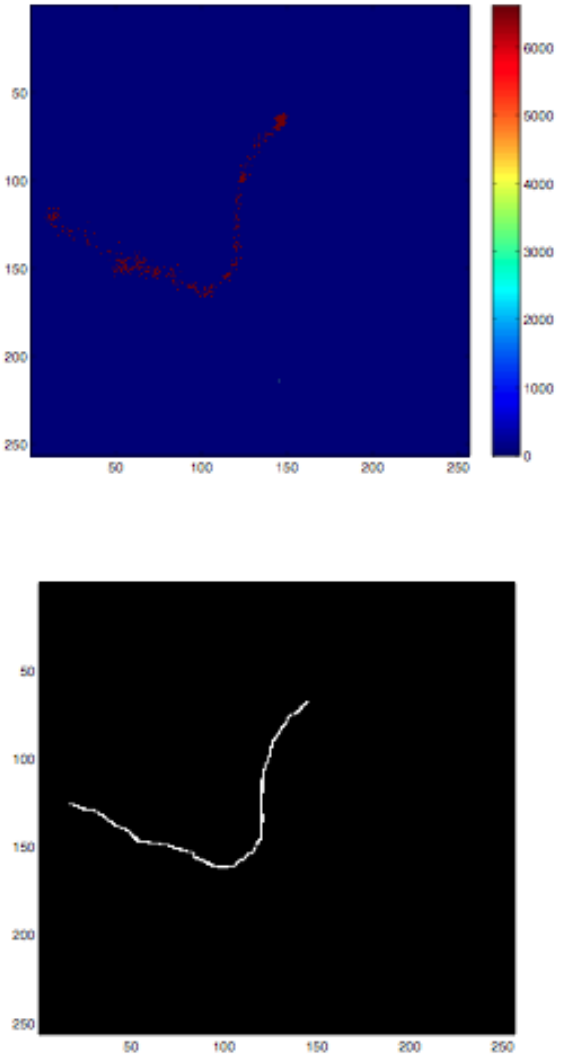
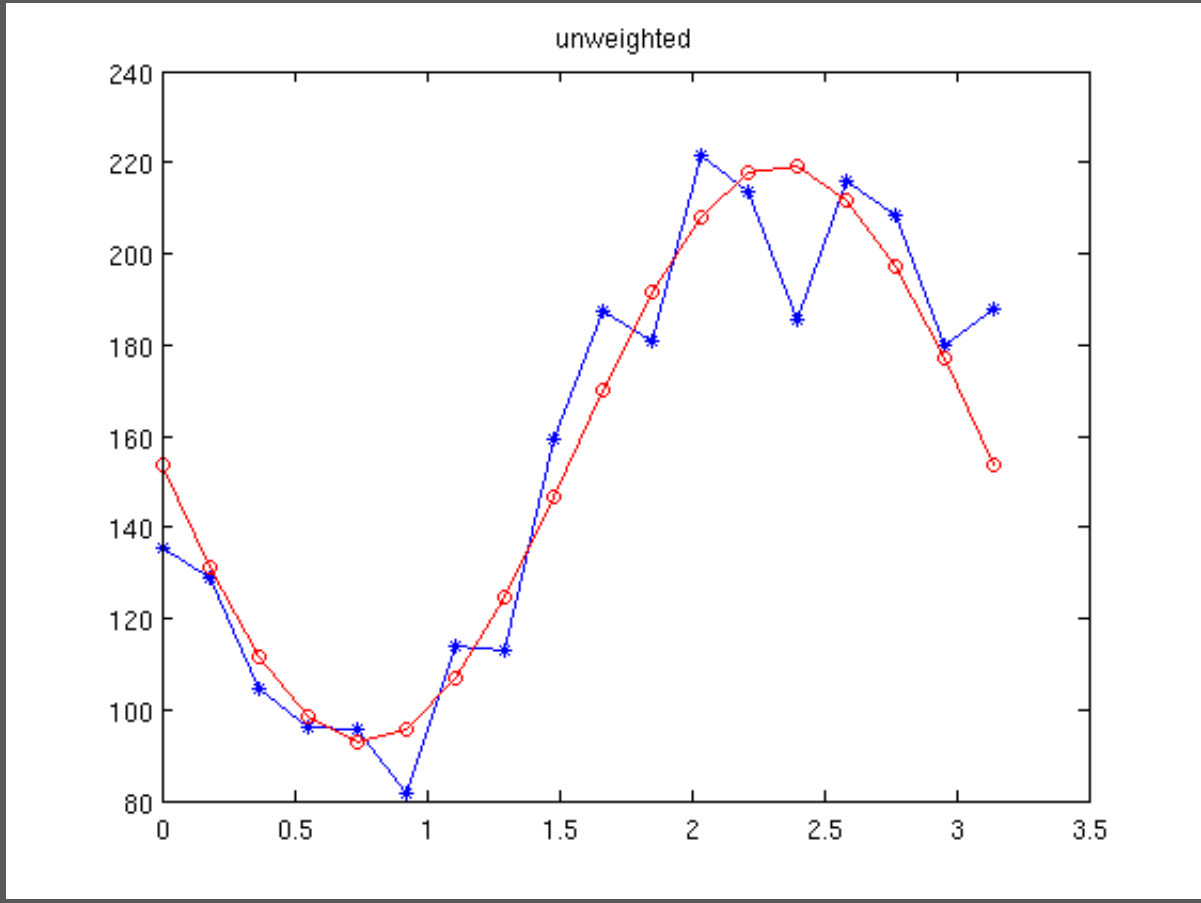


Figure 4.11: An example of a skeletonized track. On the left, the original measurement is shown, on the right the skeletonized version of the same track is shown. This picture has been made by the group at the university of Erlangen.

photo-electron
after photon interaction

X-ray source

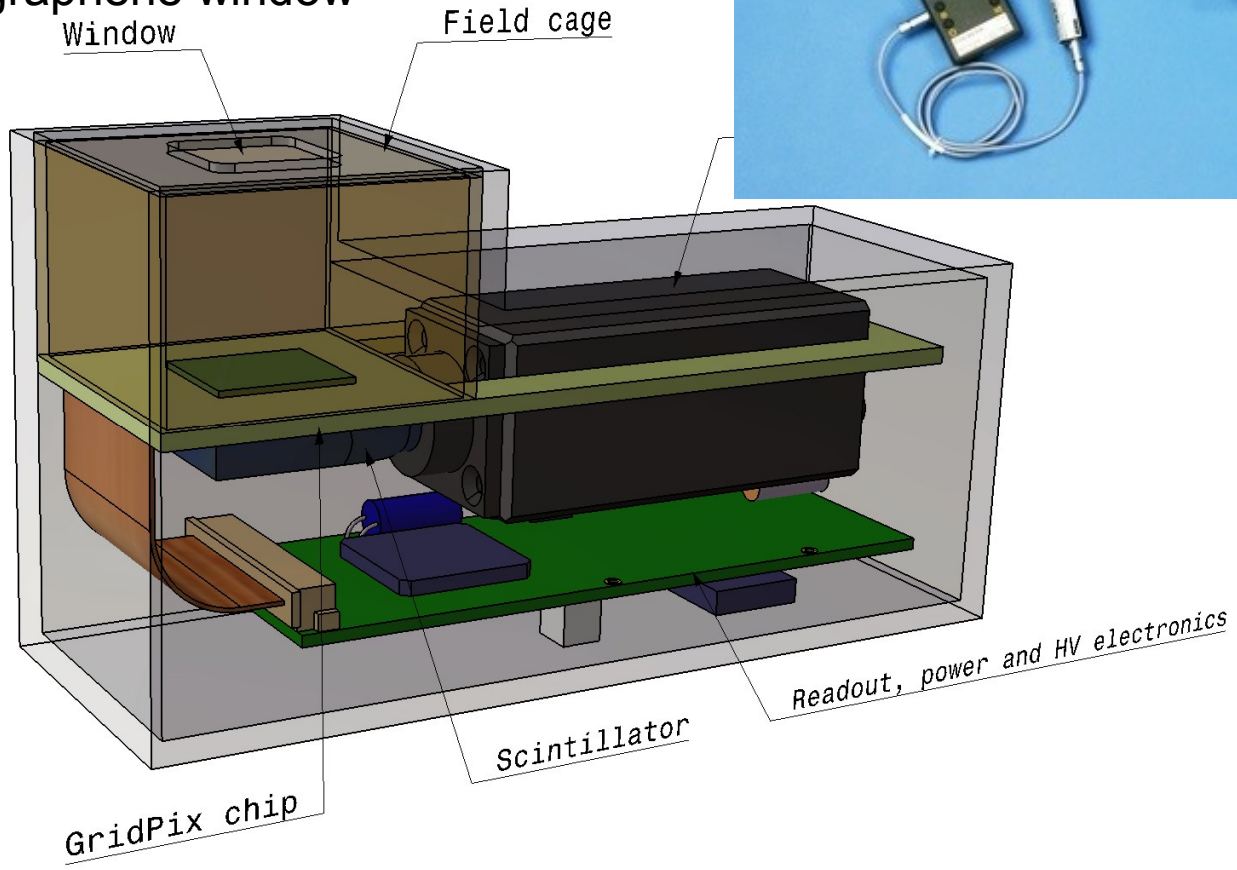
Compton Scattered
(polarised) photons



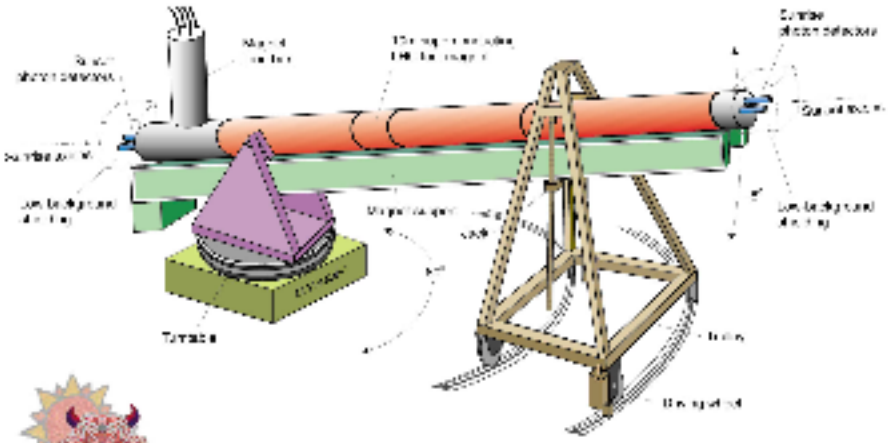
Thilo Michel (Univ. of Erlangen/ECAP)

The TinyTPC

graphene window



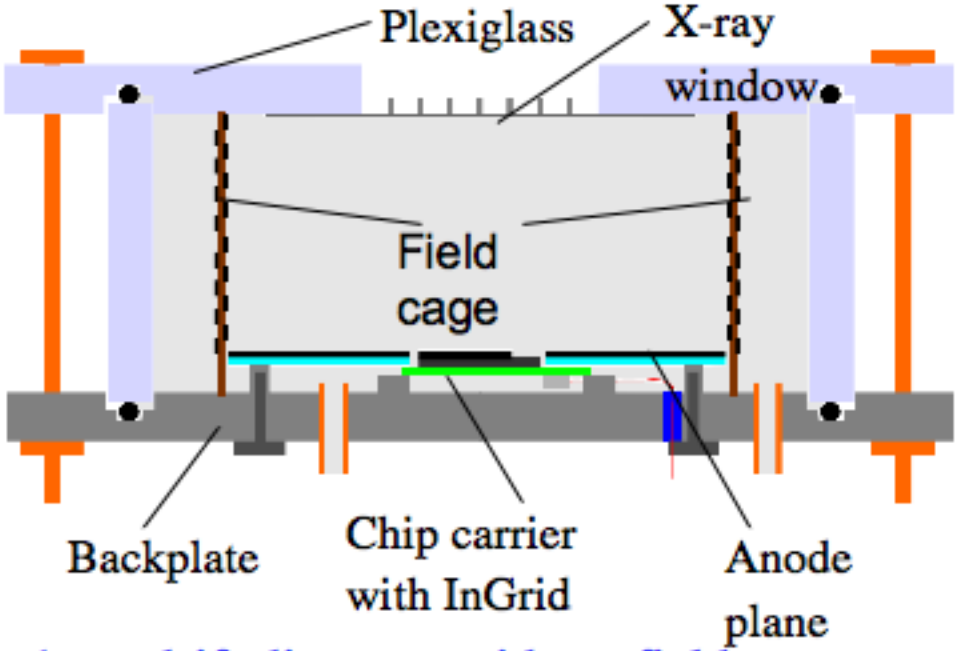
Ingrid for CAST



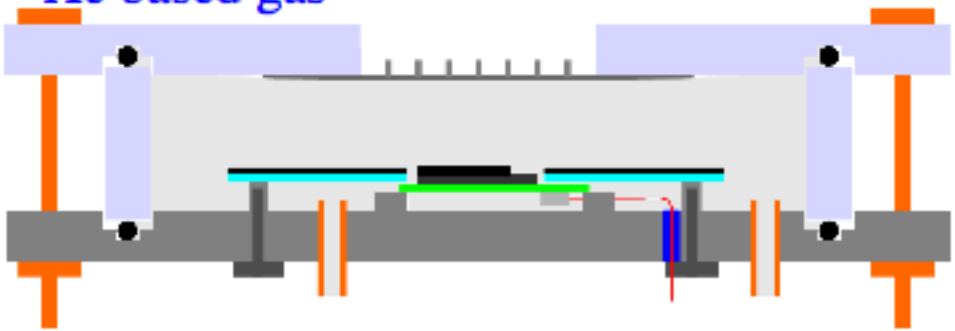
Cern Axion Solar Telescope

Two detectors under discussion:

- 3 cm drift distance, field cage, Ar based gas



- 1 cm drift distance, without field cage, Xe based gas



Special attention on:

- As little copper as possible
- Radiopurity of materials

When construction is finished:

- Background rates
- X-ray spectra
- Study n background

University of Technology Twente & MESA+
IZM-Fraunhofer, Berlin
Univ. of Bonn
Saclay
ECAP Univ. of Erlangen
CERN Medipix Consortium
Nikhef, Amsterdam