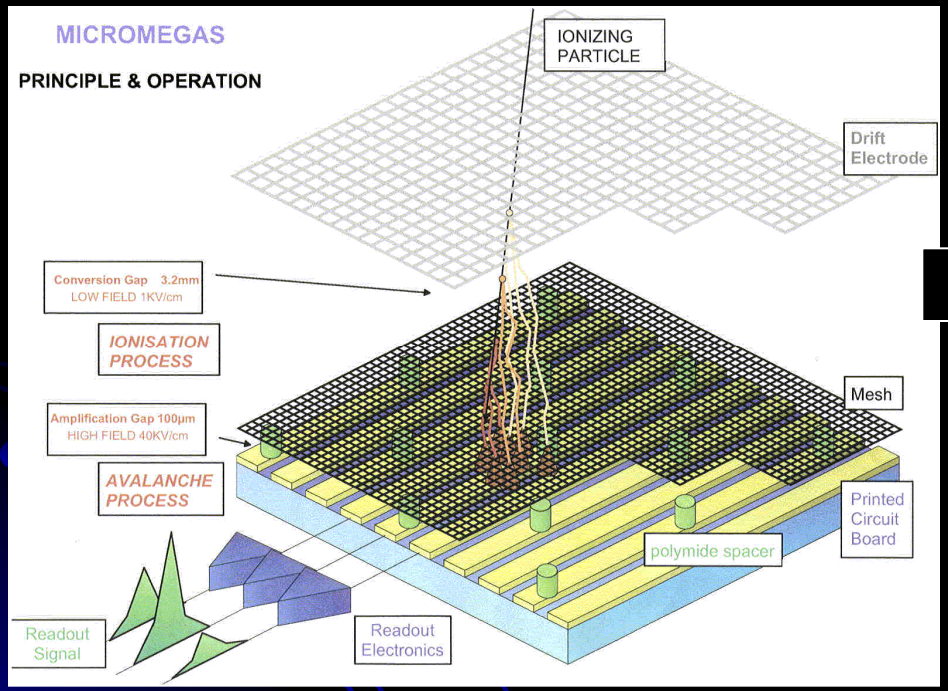
gaseous detectors

Harry van der Graaf
Nikhef, Amsterdam

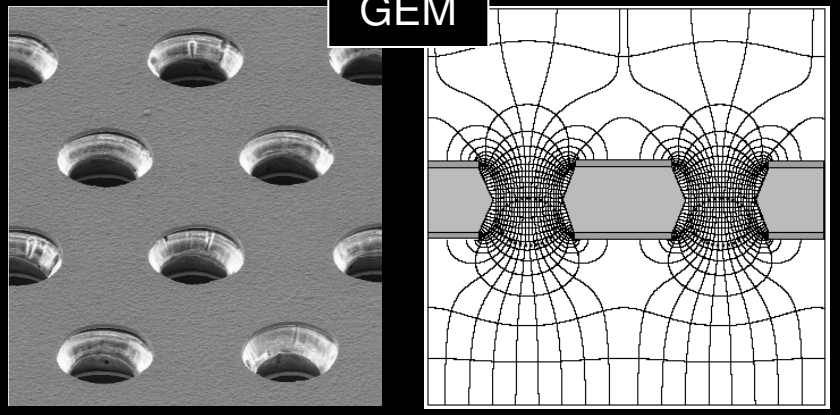
VCI 2010
Vienna, Feb 16, 2010

Micro Patterned Gaseous Detectors

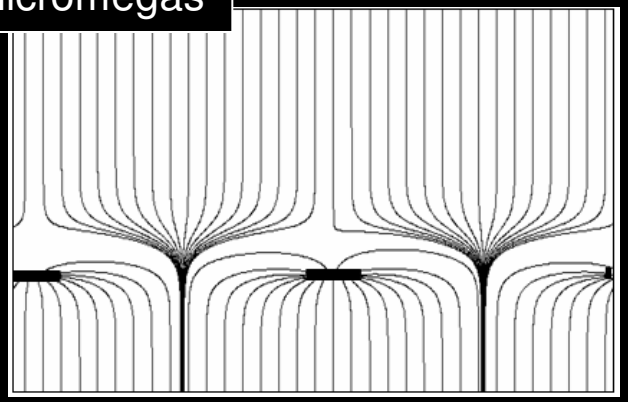
- High field created by Gas Gain Grids
- Most popular: GEM & Micromegas



GEM



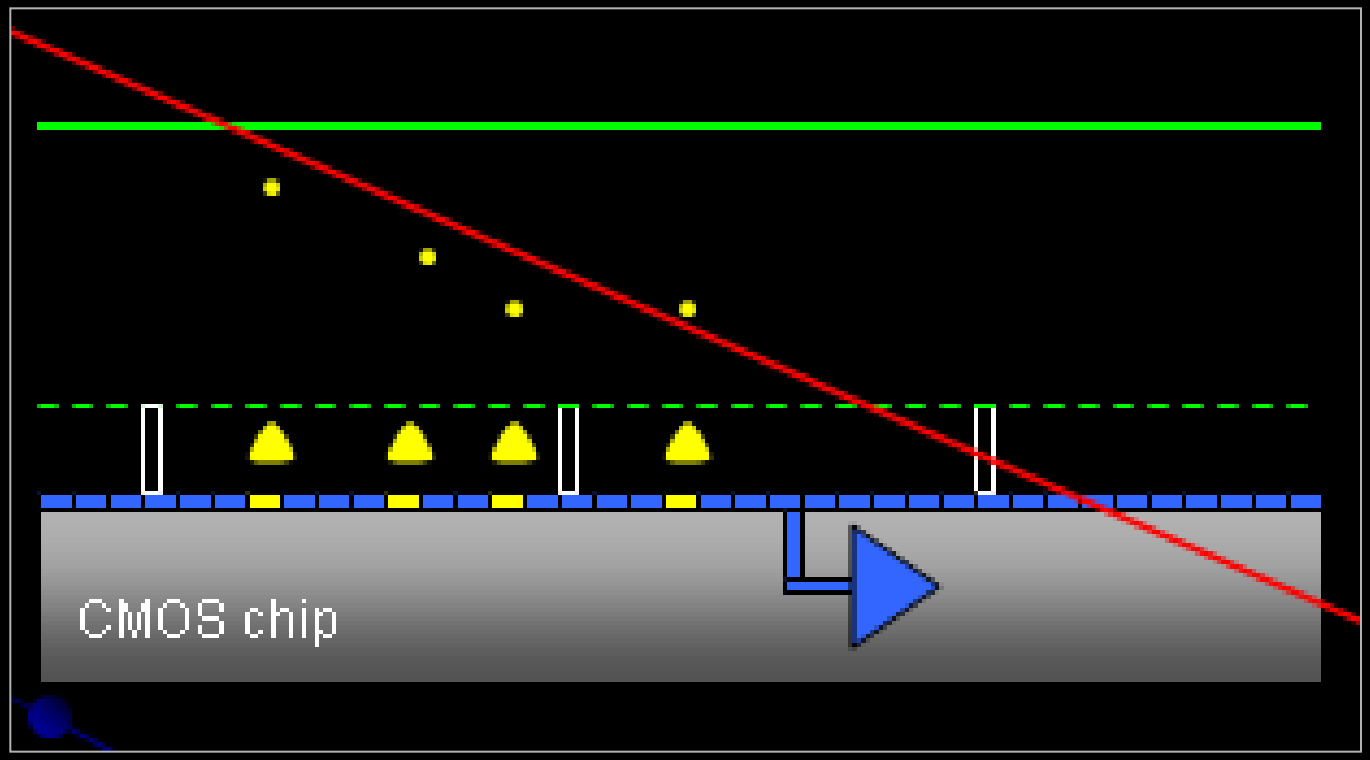
Micromegas



Ideally: each grid hole red out by a pad

Pad size ~ hole pitch !

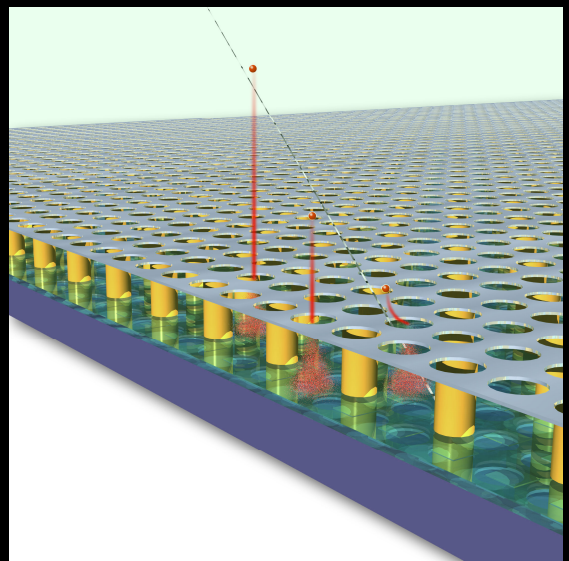
→ VLSI pixel readout chip

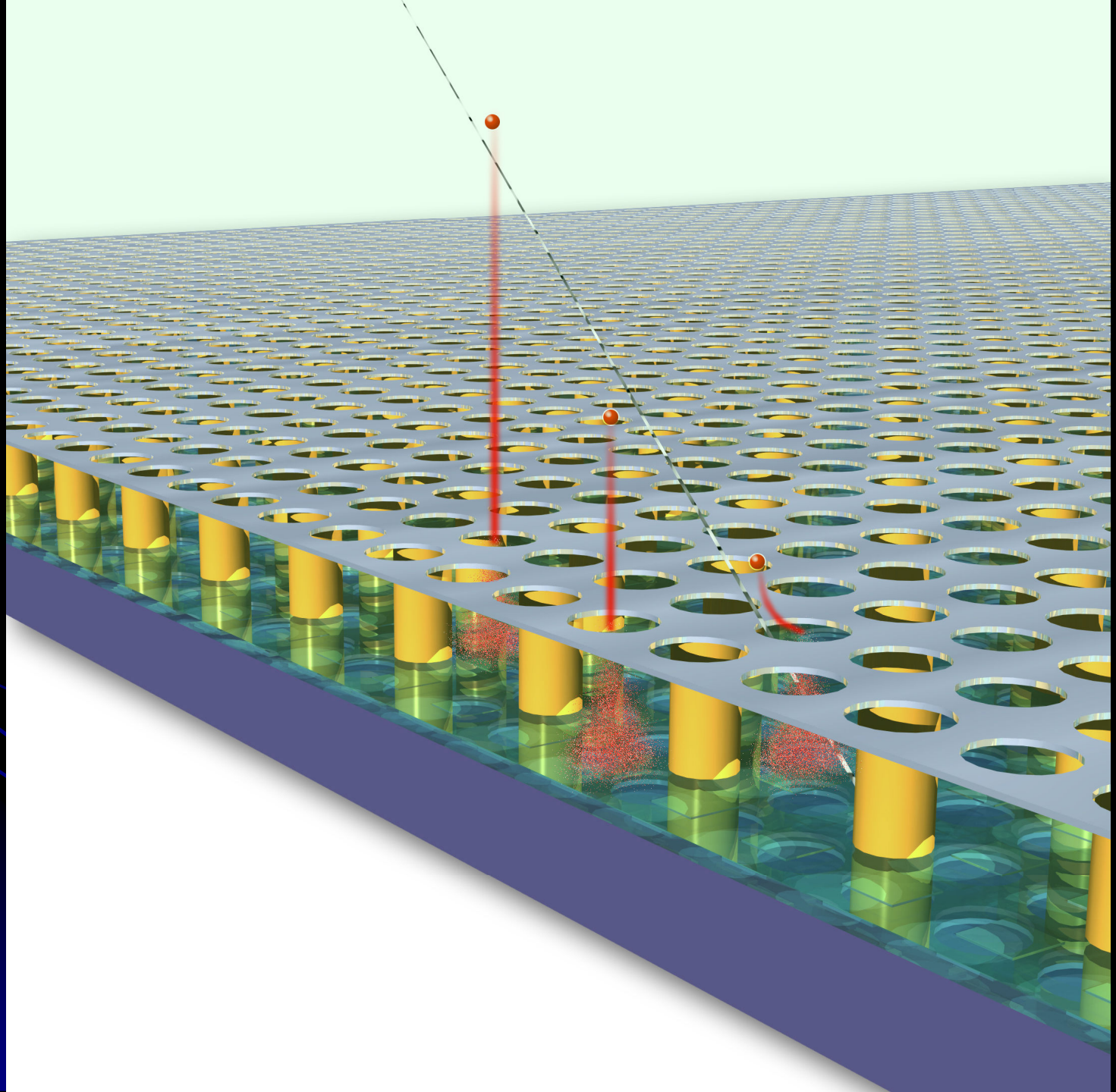


GridPix and
Gas On Slimmed SIlicon Pixels

Gossip: replacement of Si tracker

Essential: thin gas layer (1.2 mm)

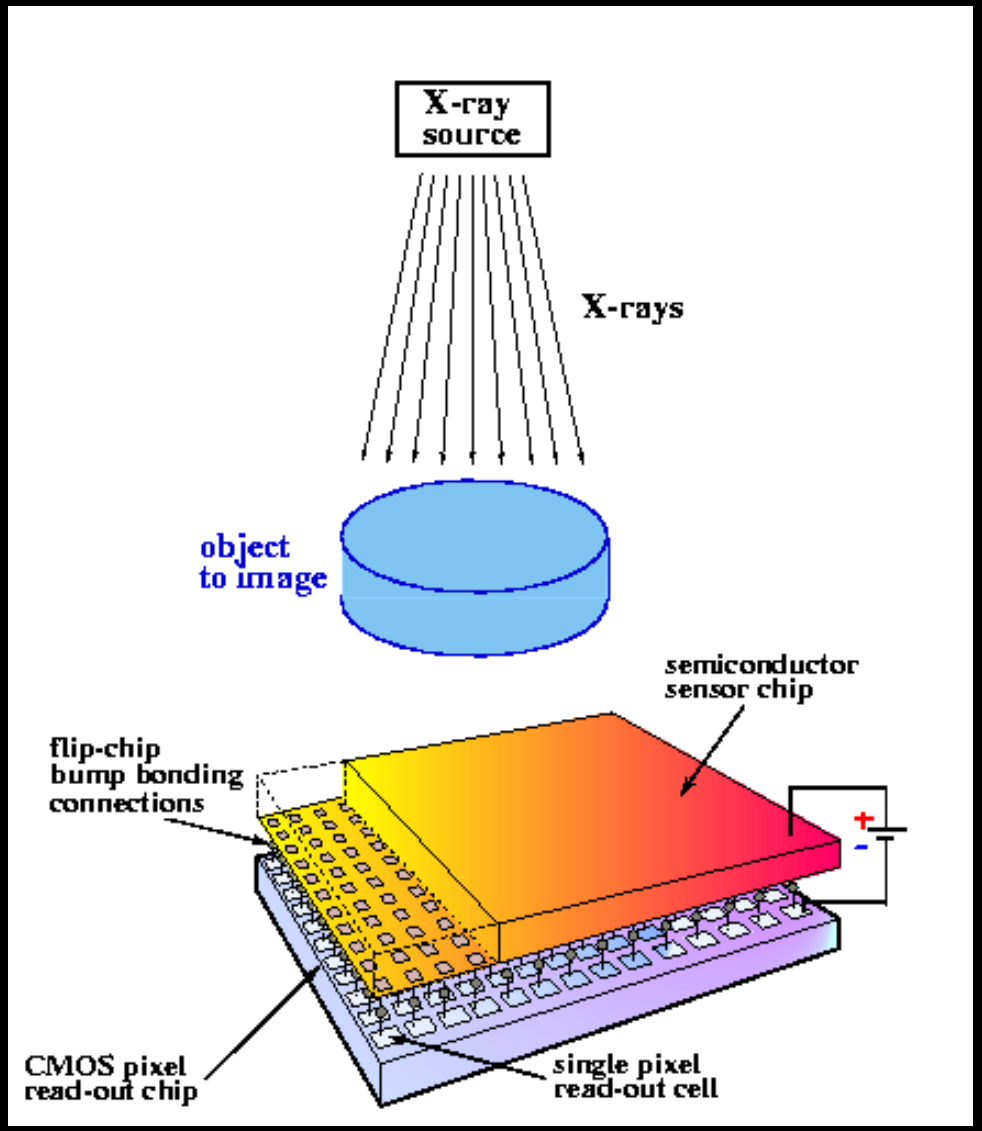




The MediPix2 pixel CMOS chip

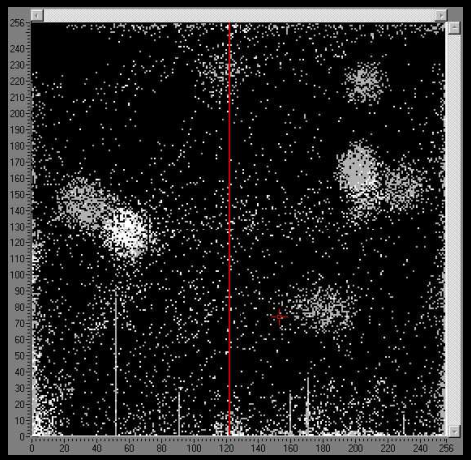
256 x 256 pixels
pixel: 55 x 55 μm^2
per pixel:
- preamp
- shaper
- 2 discr.
- Thresh. DAQ
- 14 bit counter

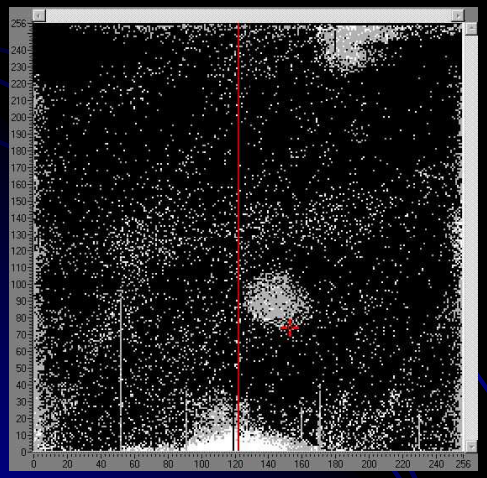
- enable counting
- stop counting
- readout image frame
- reset

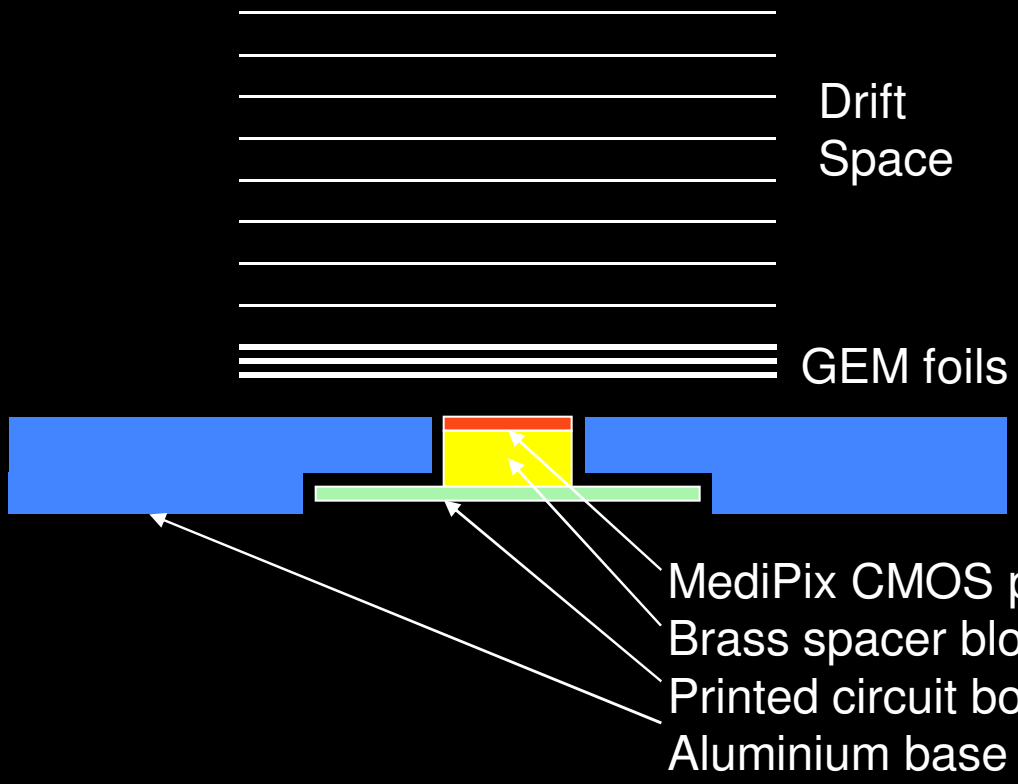


We apply the 'naked' MediPix2 chip without X-ray convertor!

March 29, 2003

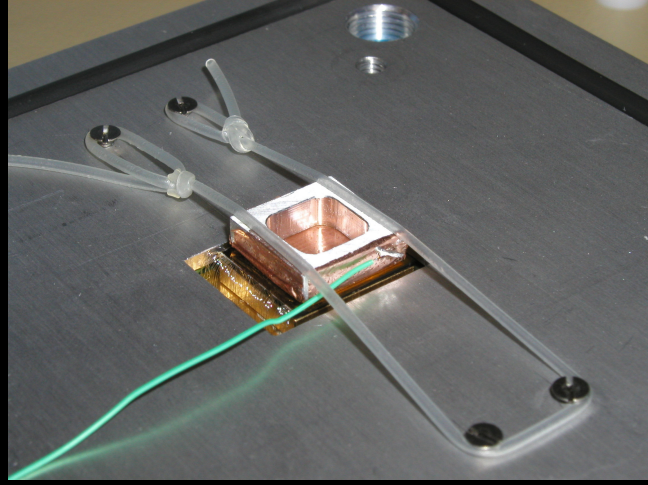


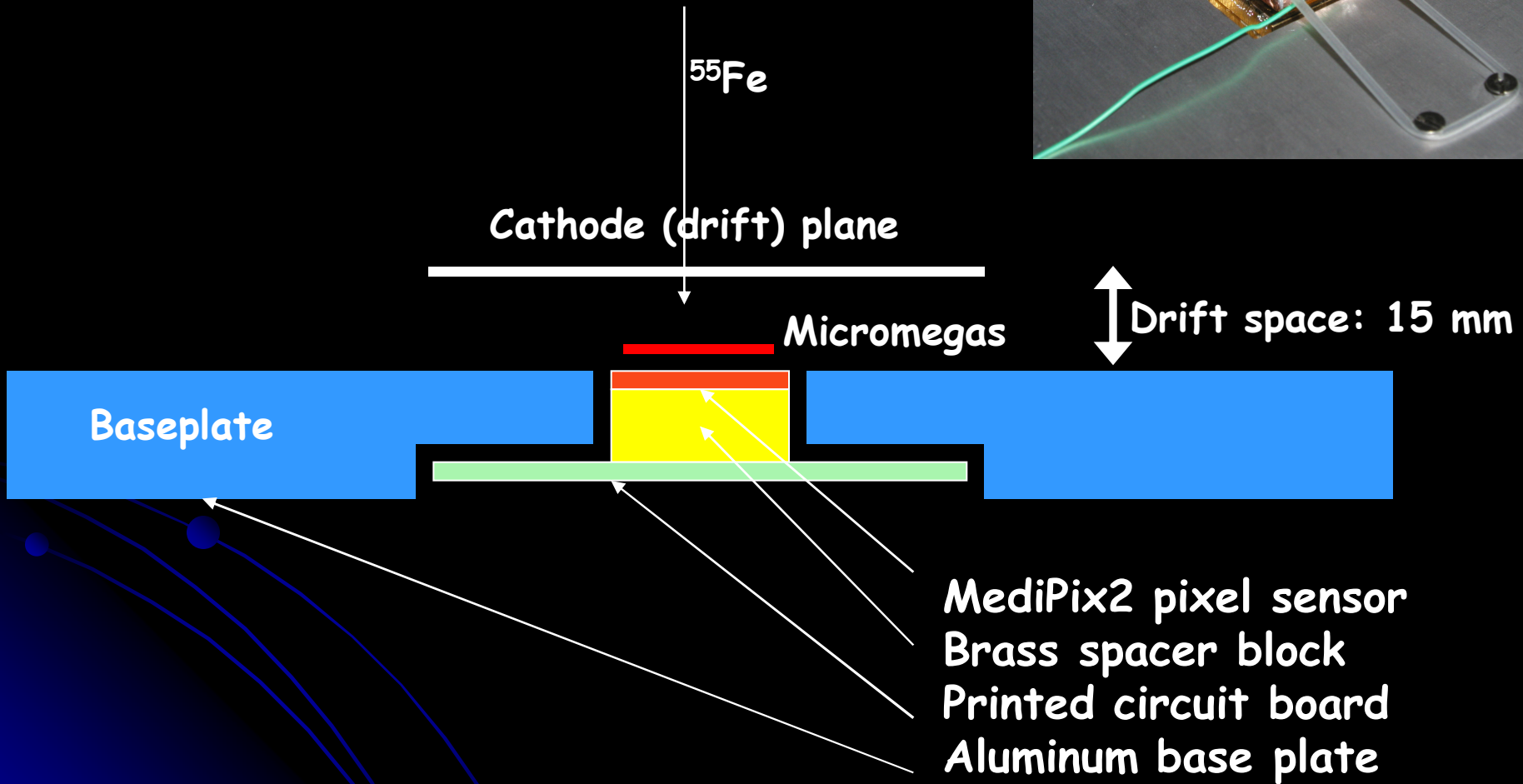




First events, recorded on March 29, 2003.
Drift space irradiated with ^{55}Fe quanta
Gas: Ar/Methane 90/10

MediPix2 & Micromegas:
apply the 'naked' MediPix2 chip
without X-ray convertor!

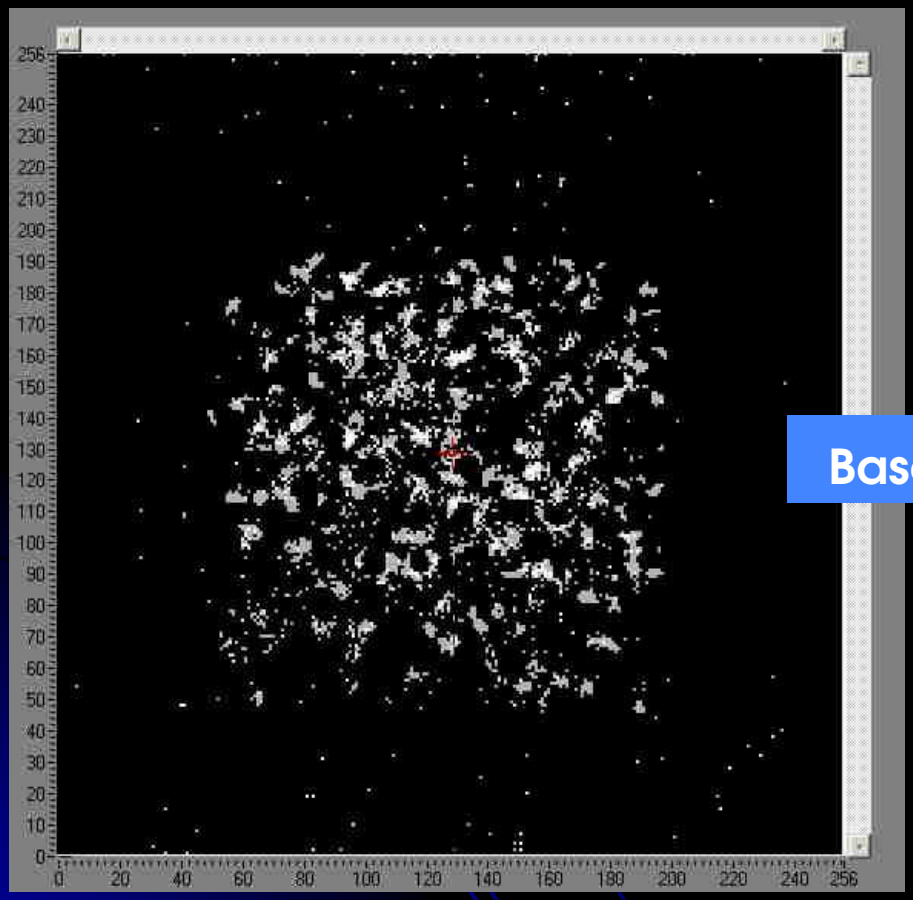




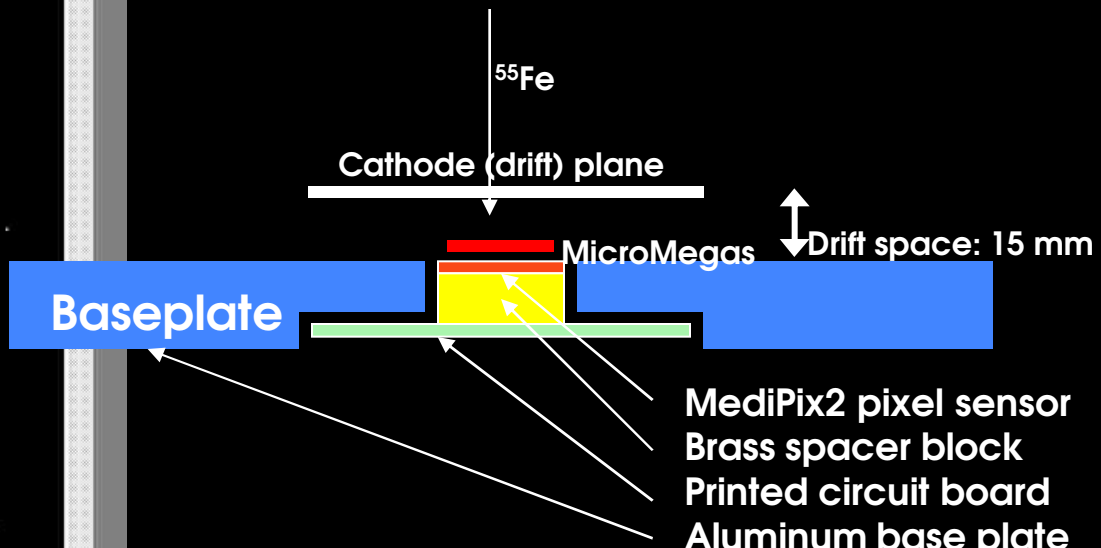
Very strong E-field above (CMOS) MediPix!

February 2004

Very strong E-field above (CMOS) MediPix!

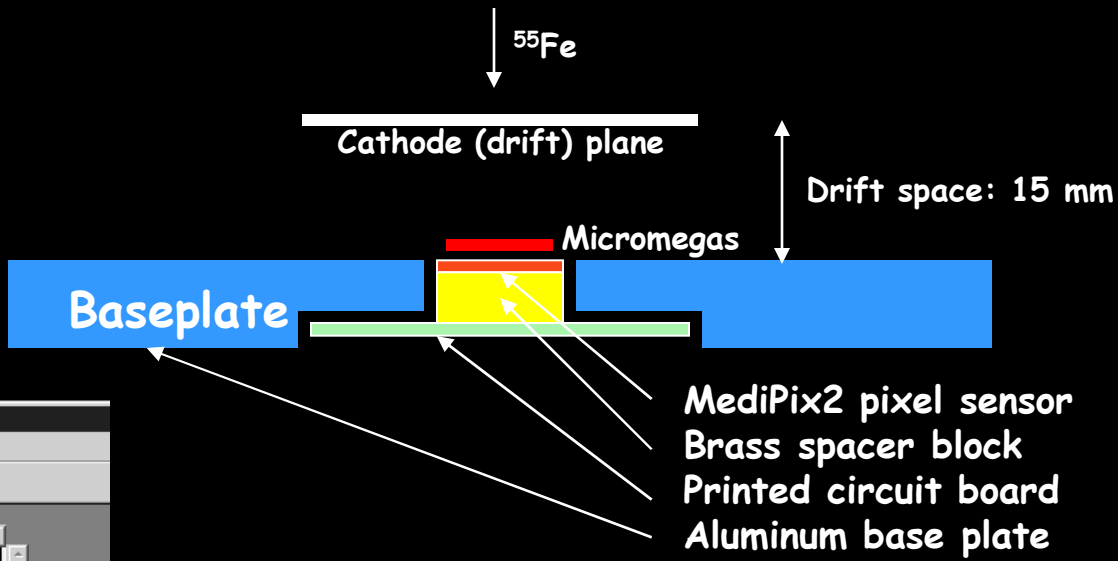


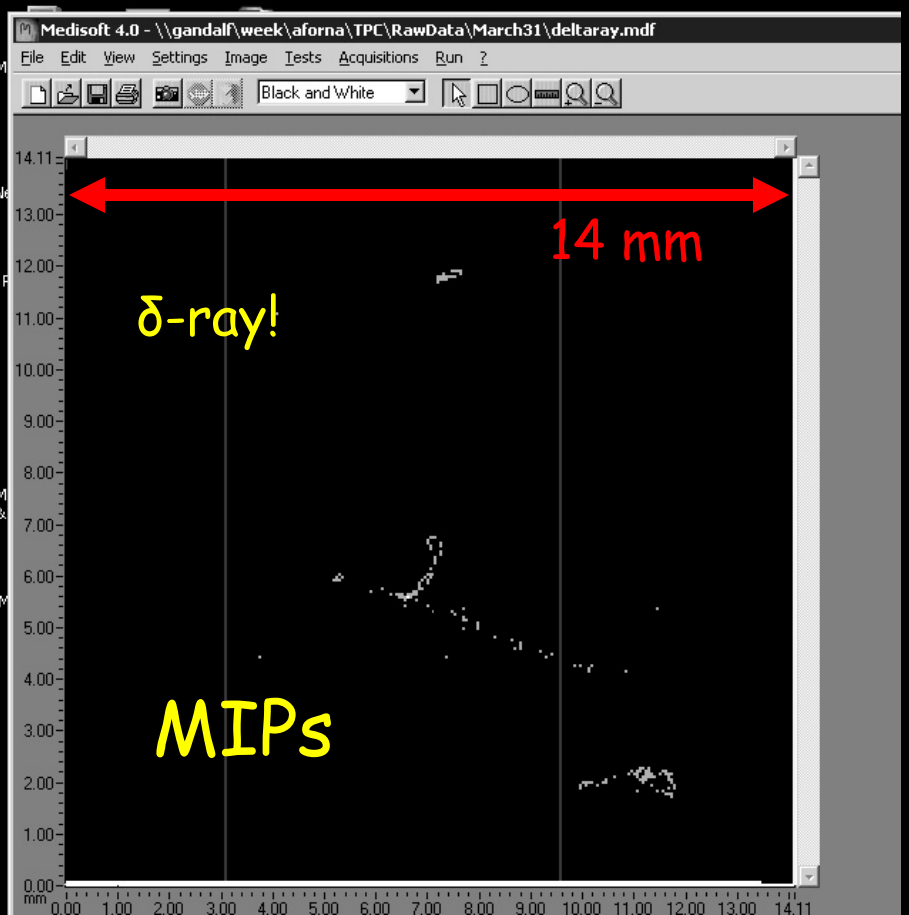
^{55}Fe

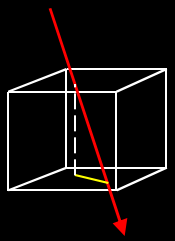


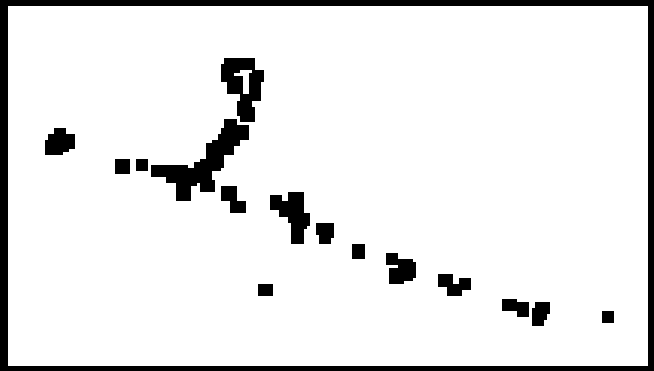
…just in time for VCI 2004……

April 2004 Micromegas + MediPix 2 NIKHEF/Saclay/Univ. Twente:

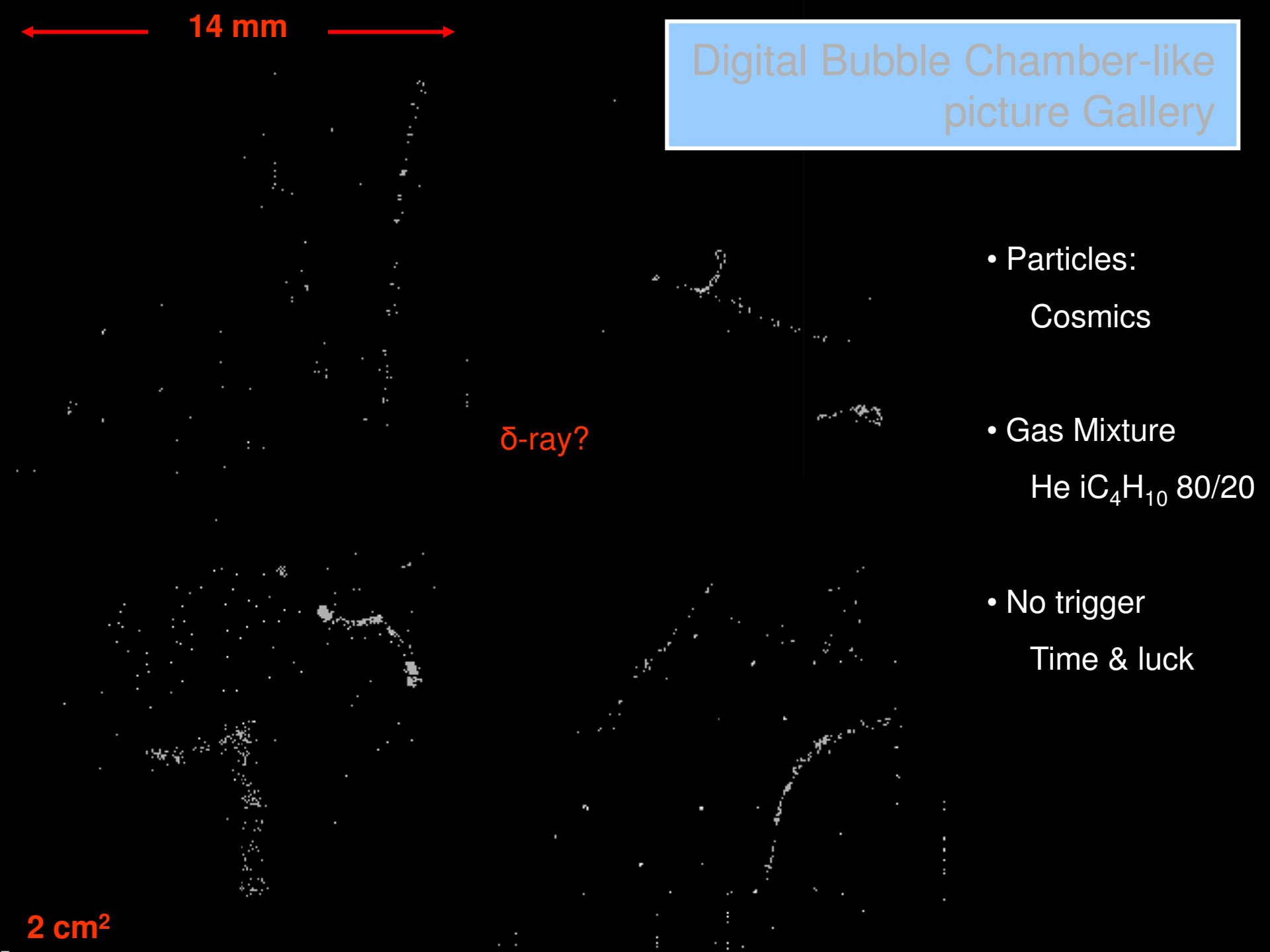








He/Isobutane
80/20
Modified MediPix



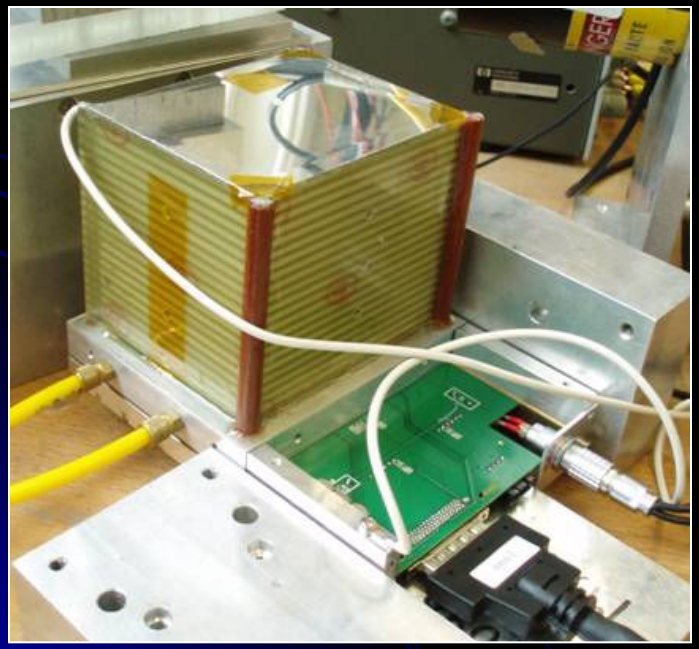
Digital Bubble Chamber-like picture Gallery

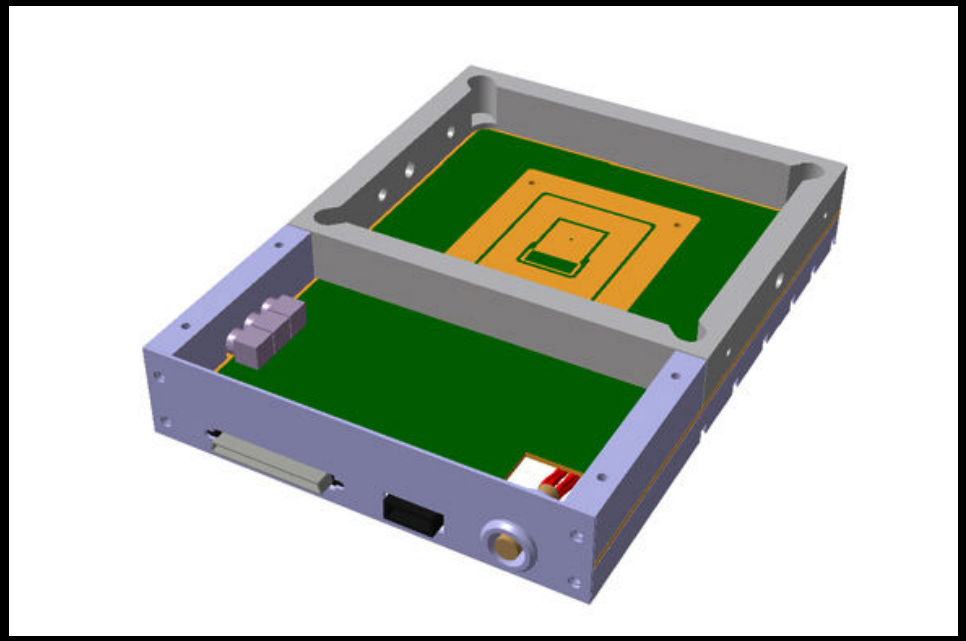
- Particles:
  Cosmics
- Gas Mixture
  He iC_4H_{10} 80/20
- No trigger
  Time & luck

Construction of test chambers

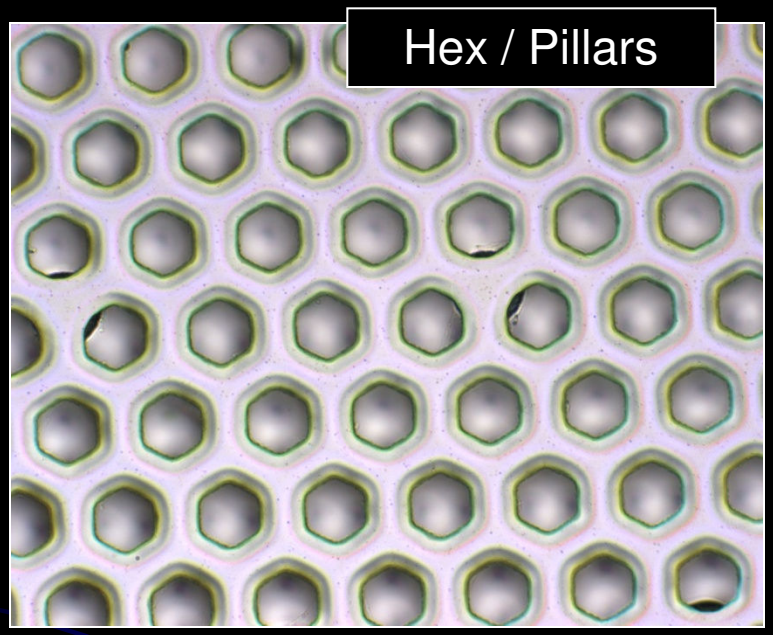
prototypes Next-1,2,3,4,5
Next Quad (EUDET deliverable)
Next-64 (ReNexd, ReLaXd) (EUDET deliverable)

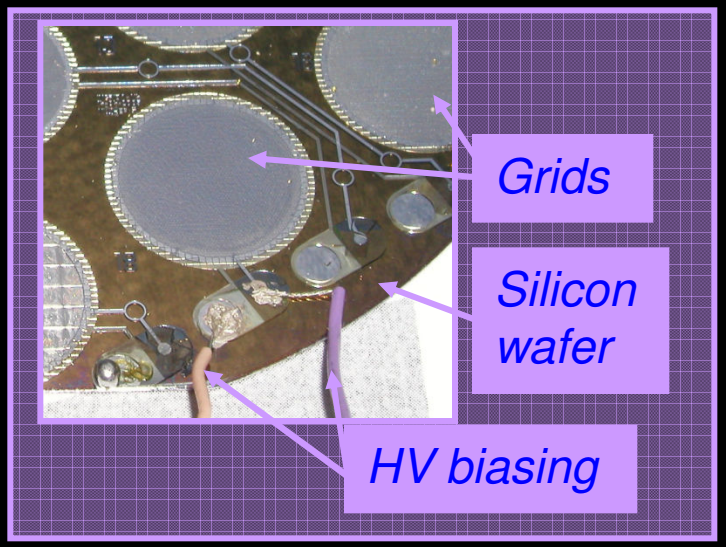
DICE
Ageing Chambers





Wafer post-processing:InGrid



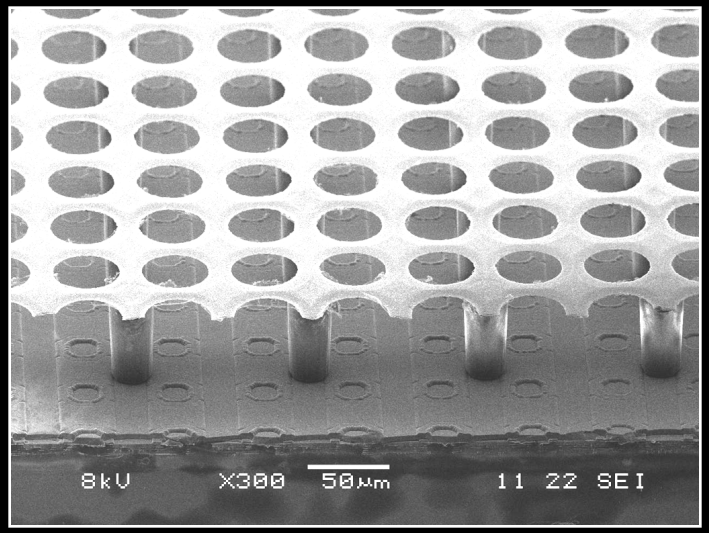


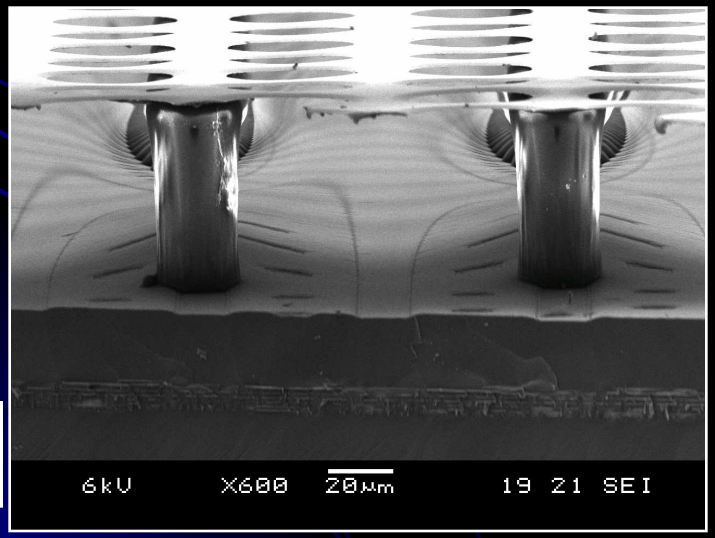
InGrid: an Integrated Grid on Si (wafers or chips)

- 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

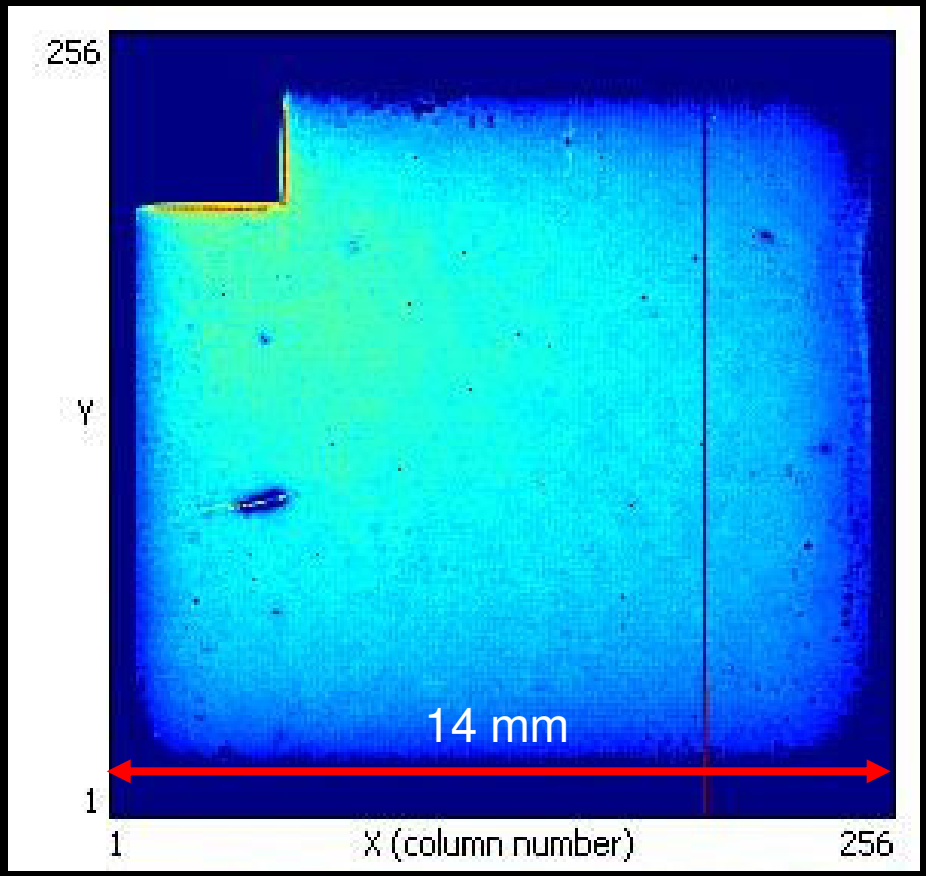
- Timepix chip + SiProt + Ingrid:





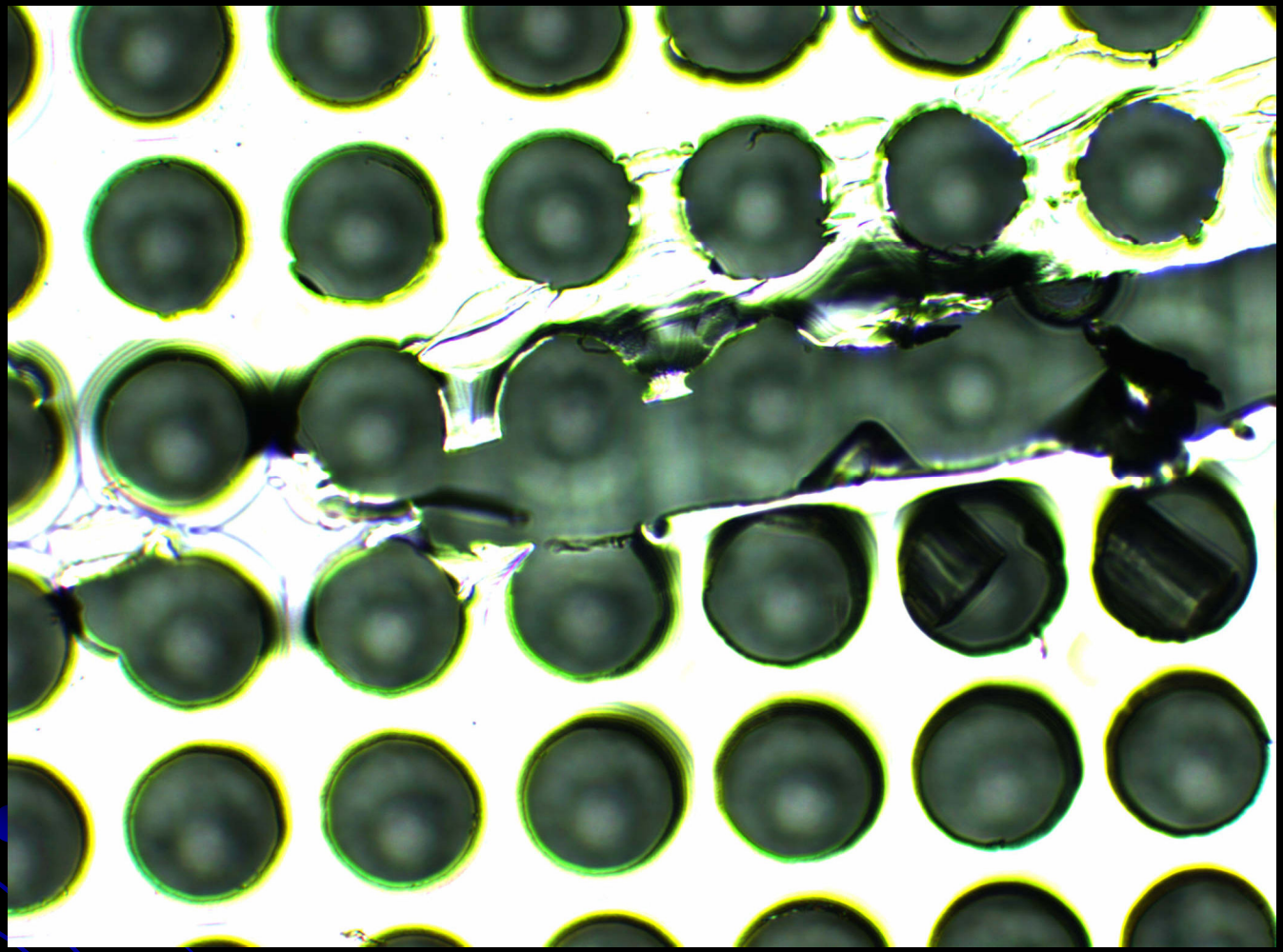
MESA+

IMT Neuchatel



"Uniform"

Charge mode

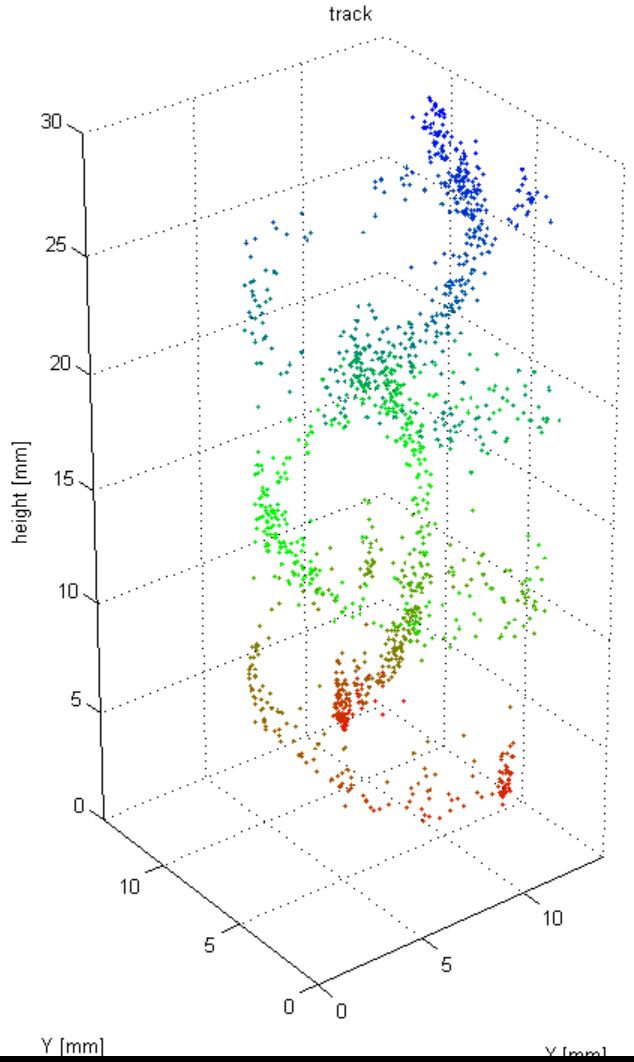


A “scratch” occurred during the construction of Ingrid;

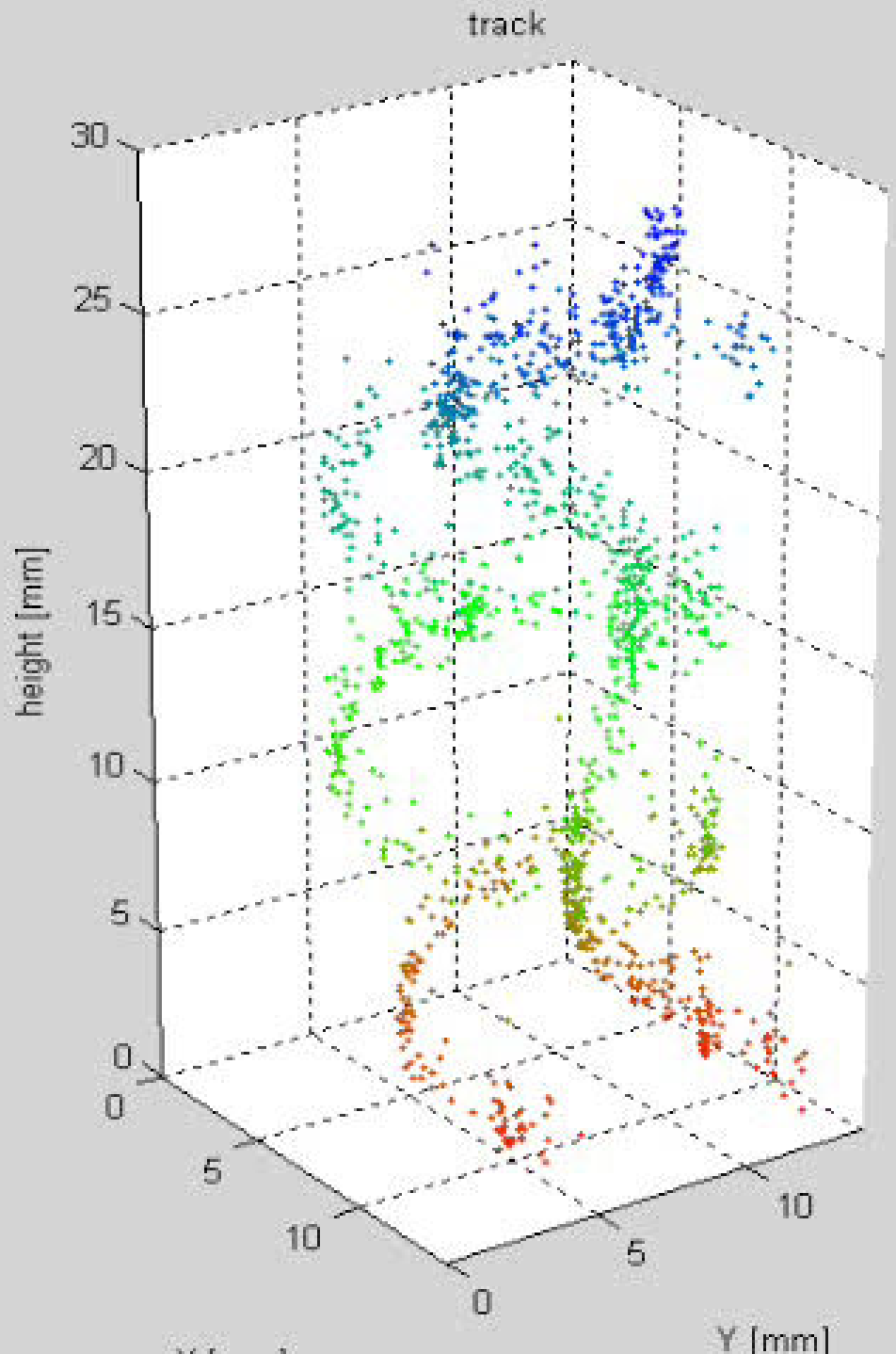
Loose parts removed. Ingrid working!

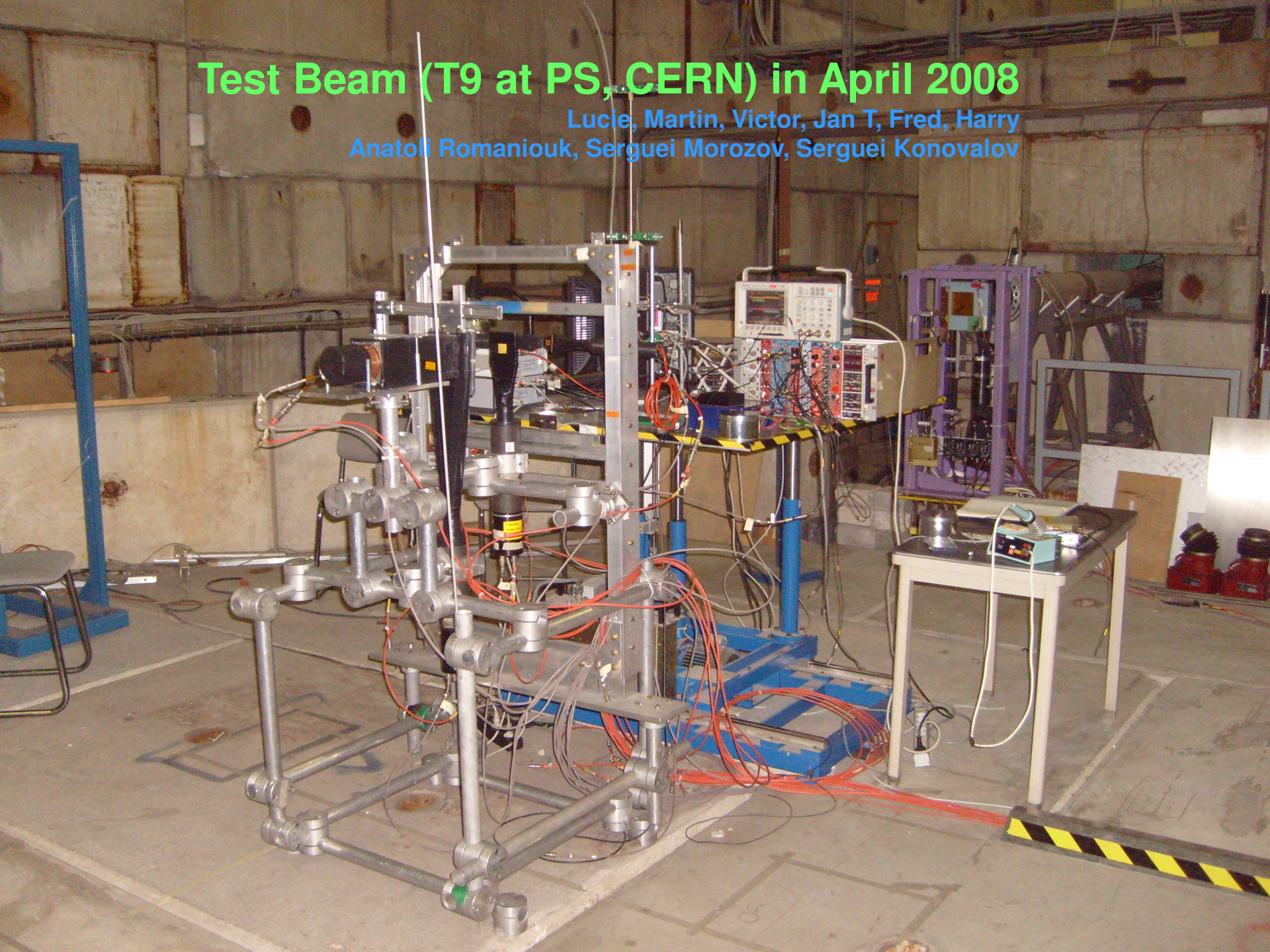
^{90}Sr β events

Gas: Ar/i-butane 80/20

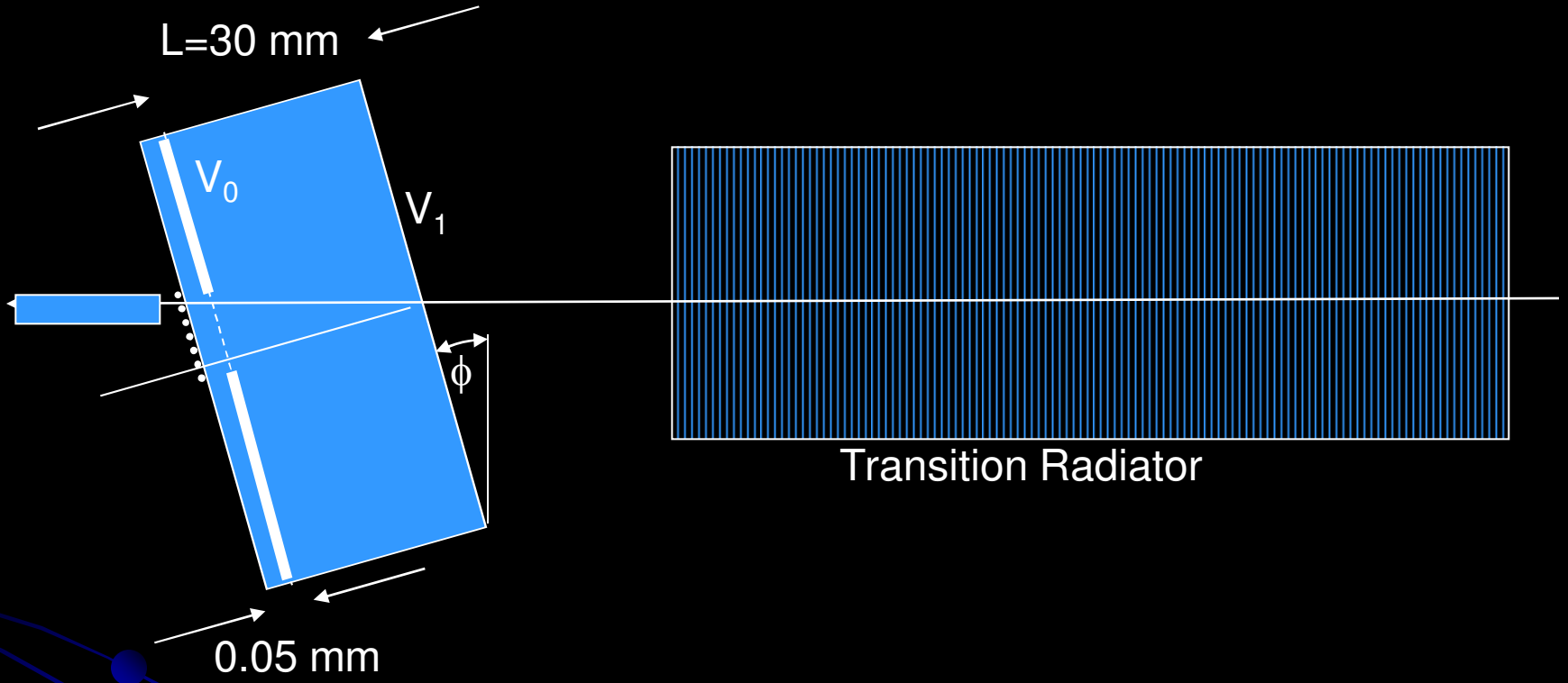


B = 0.2 T


track
height [mm]
30
25
20
15
10
5
0
0
5
10
0
5
10
Y [mm]

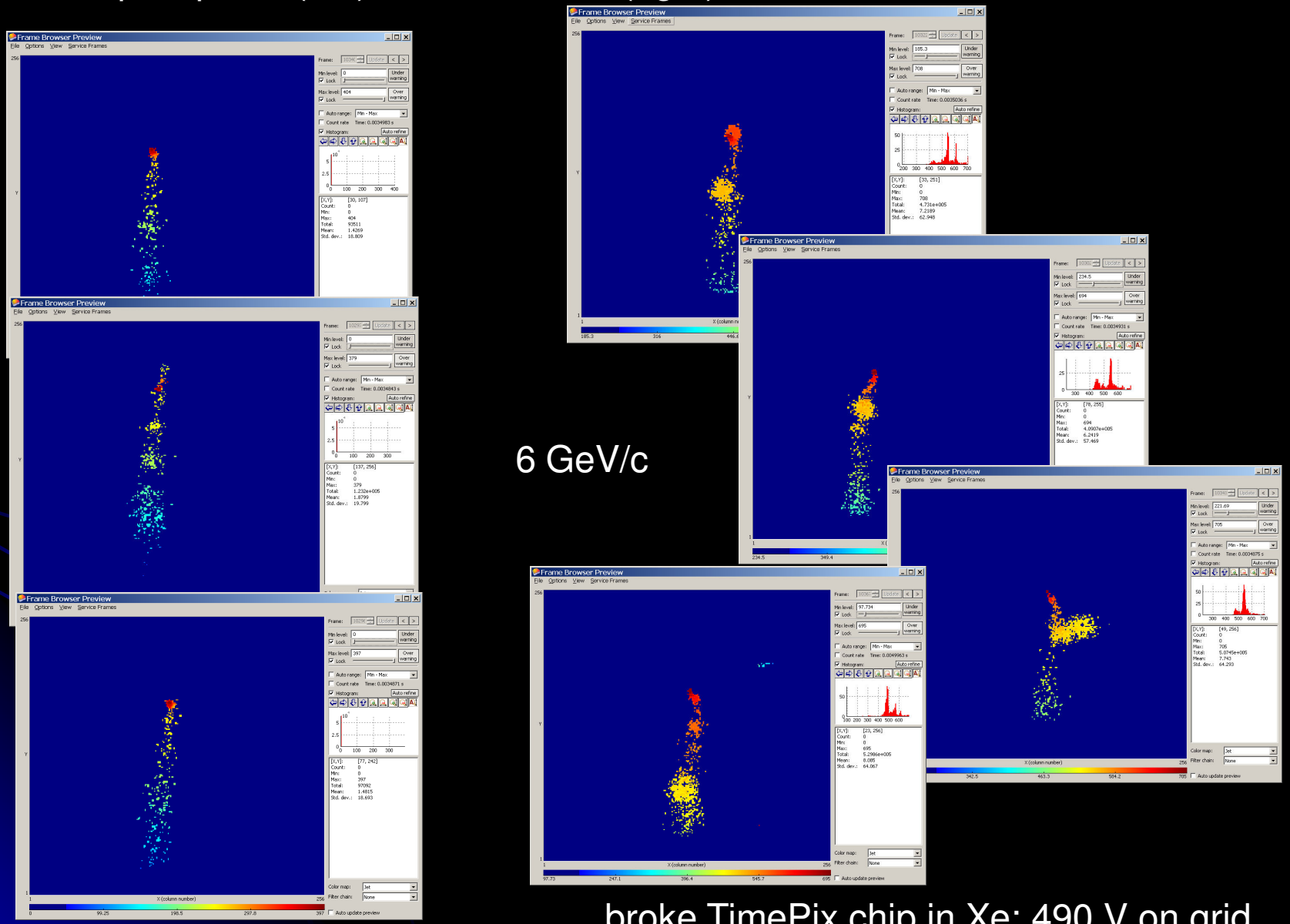

Test Beam (T9 at PS, CERN) in April 2008
Lucie, Martin, Victor, Jan T, Fred, Harry
Anatoli Romaniouk, Serguei Morozov, Serguei Konovalov

Testbeam April 2008
PS/T9: electrons and pions, 1 – 15 GeV/c



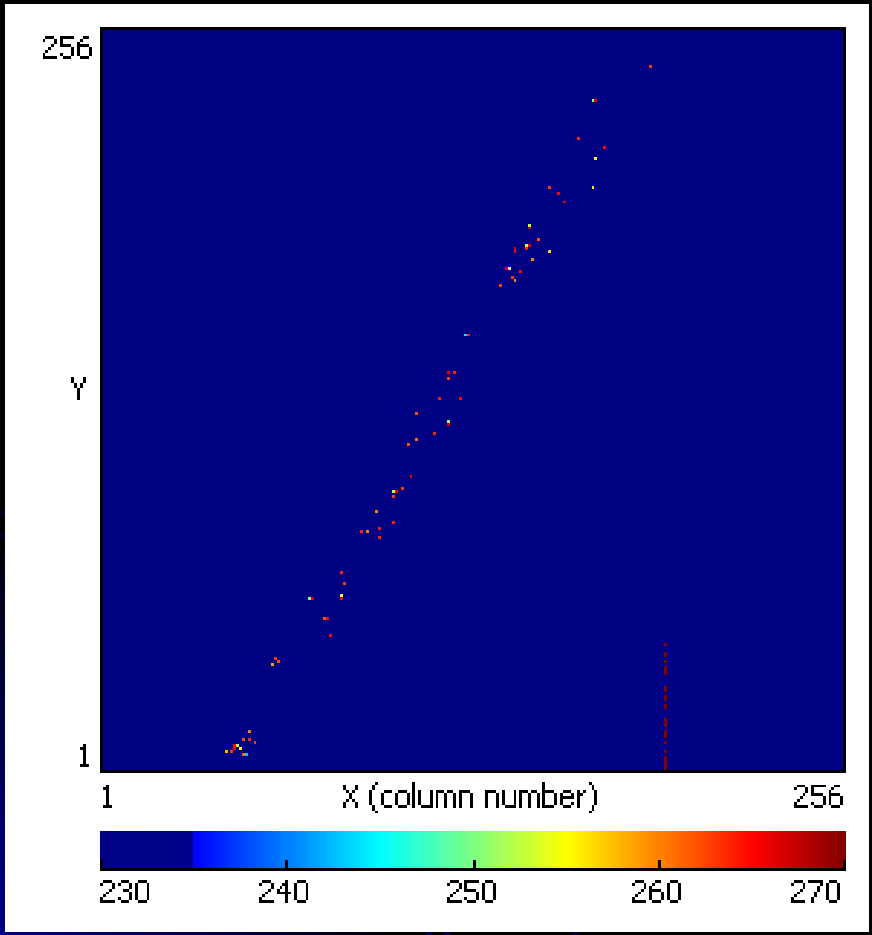
Particle Identification

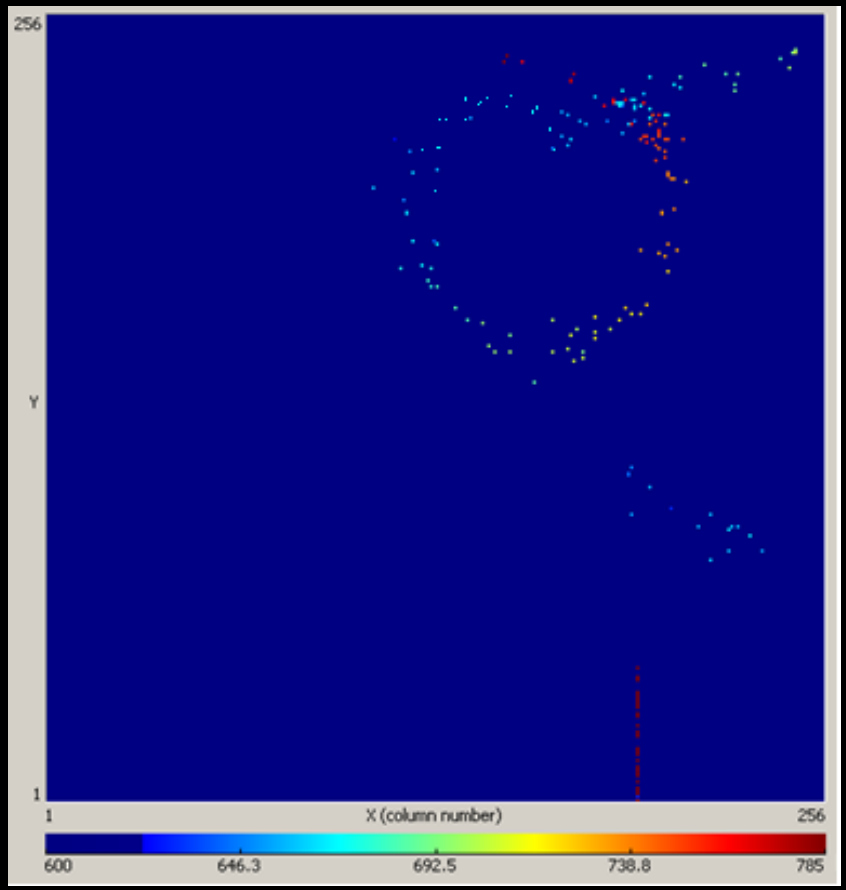
Samples pions (left) and electrons (right)



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

Analysis of test beam data and cosmic muon data with GridPix



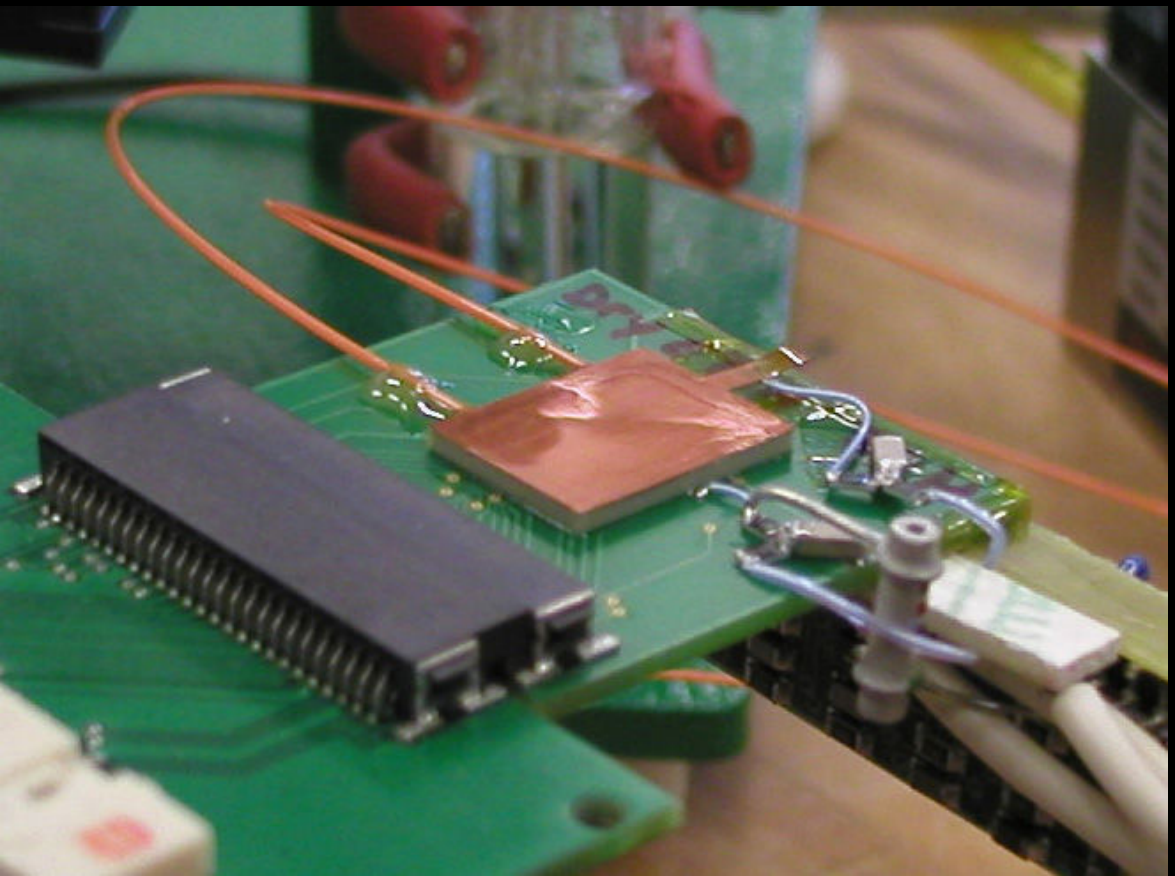


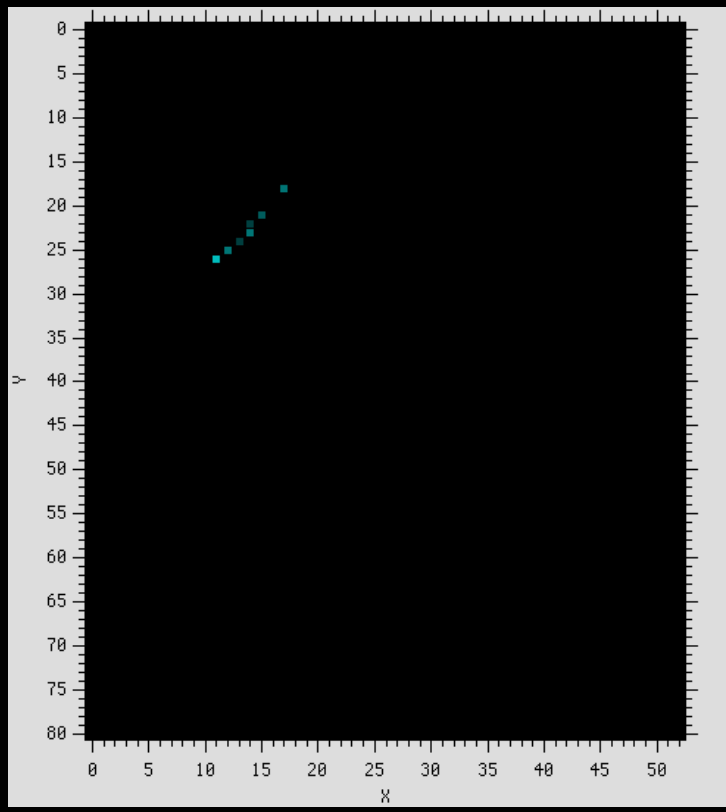
Colloquium Lucie de Nooij, Tuesday 13 January, 15h, H331

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

First prototype of *GOSSIP* on a PSI46 is working:

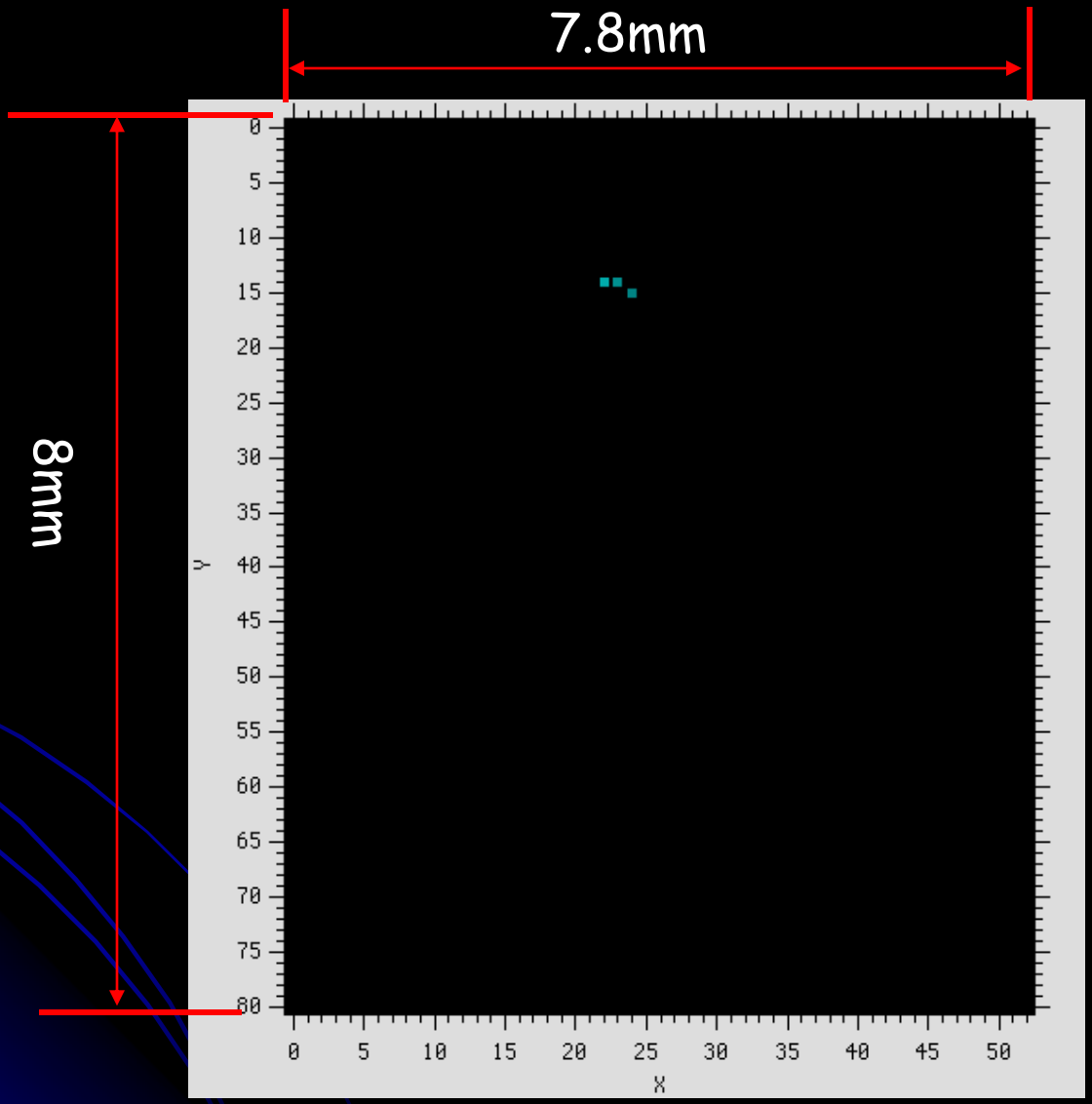
- 1.2 mm drift gap
- Grid signal used as trigger
- 30 µm layer of SiProt





We can see tracks!

(Frame # 17 is really great)



Animated GIF of 100 hits on the PSI46 brico, 30μm SiProt.
(if this does not animate, drop the picture into a web browser)

Gas instead of Si

Pro:

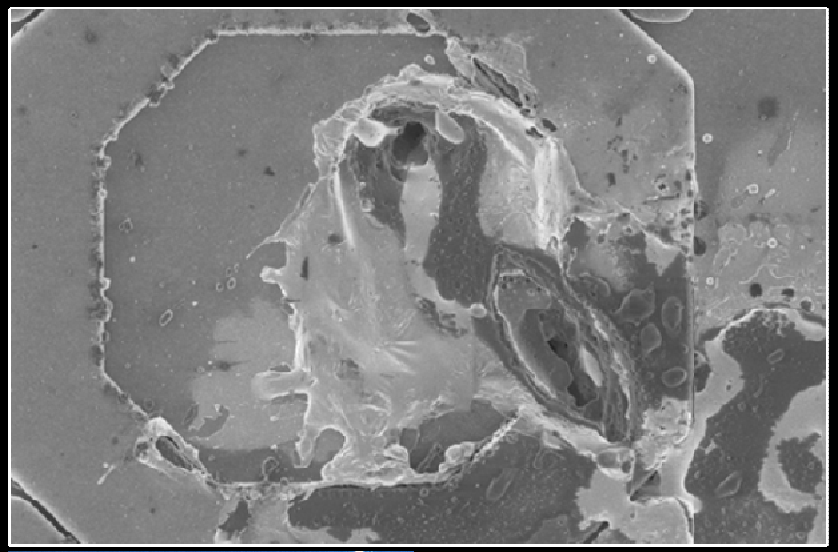
- no radiation damage in sensor: gas is exchanged
- modest pixel (analog) input circuitry: low power, little space
- no bias current: simple input circuit
- low detector material budget: 0.06 % radiation length/layer
  typical: Si foil. New mechanical concepts
- low power dissipation : little FE power (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

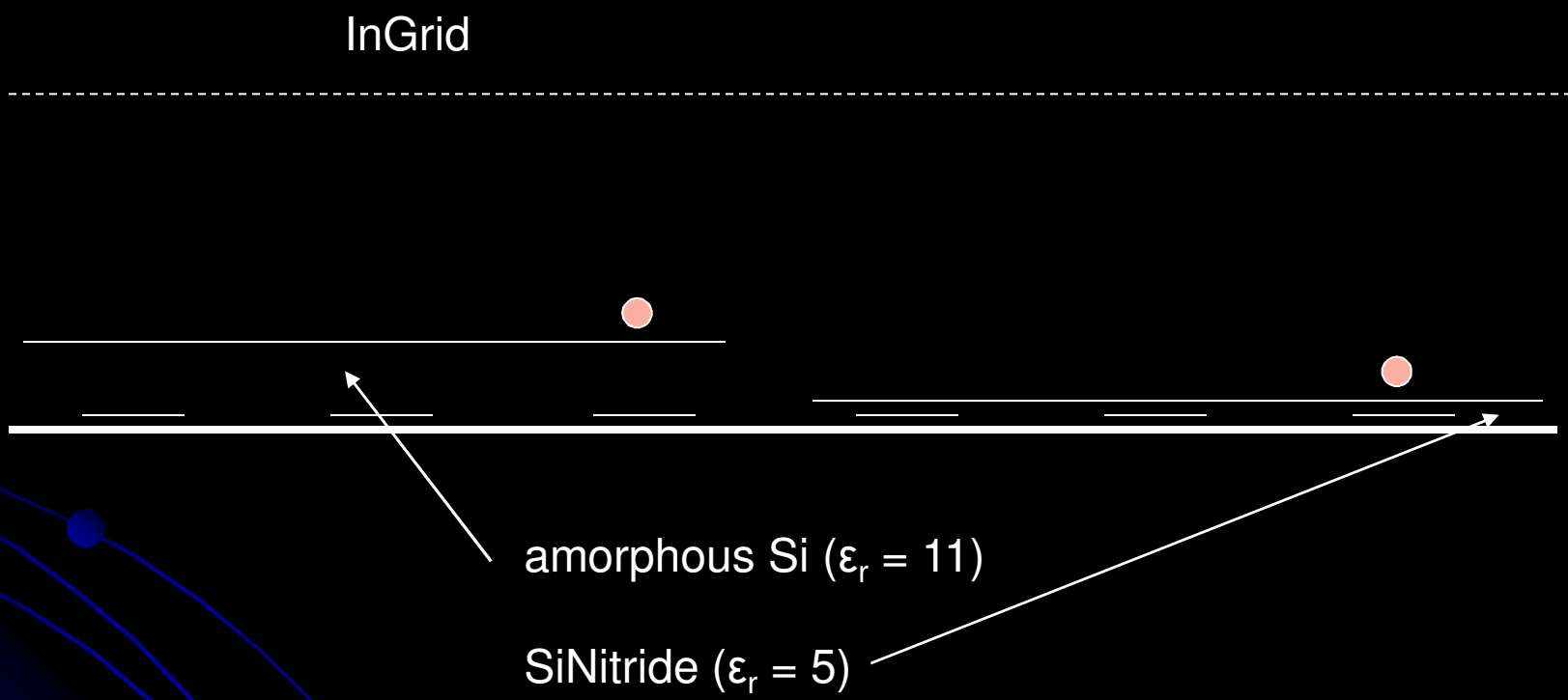
But, are these good enough?

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

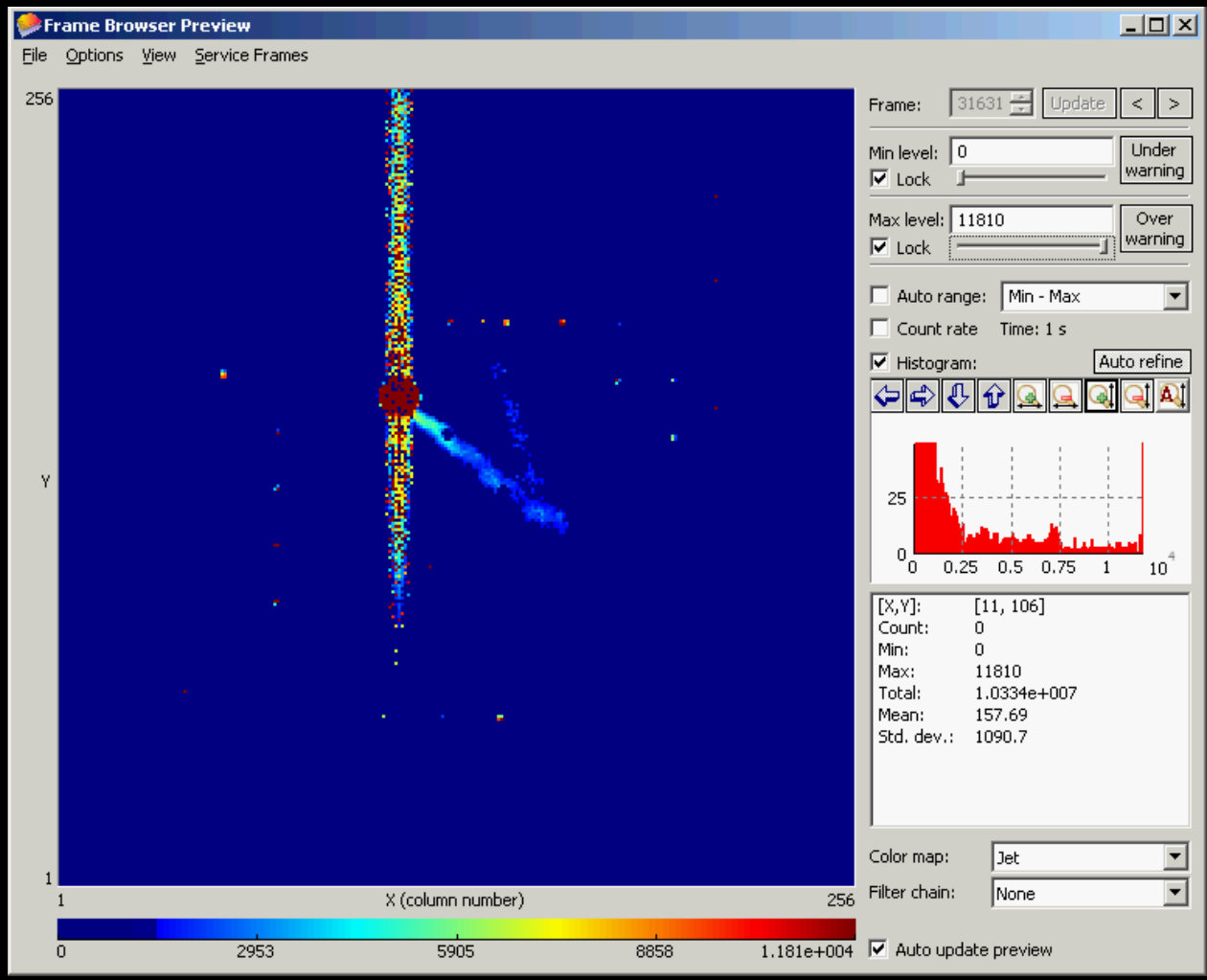
… discharges are observed !

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

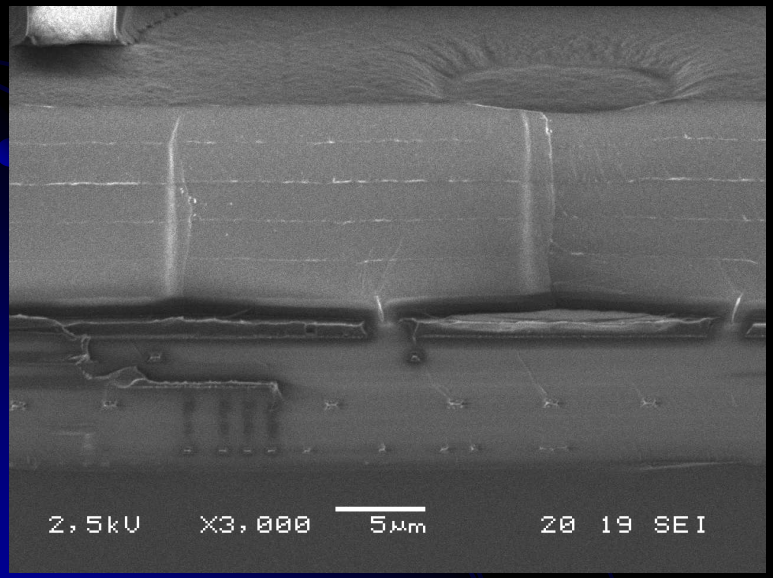
July 2008: protection layer made of Si_3N_4 (Silicon Nitride), only 7 µm thick

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

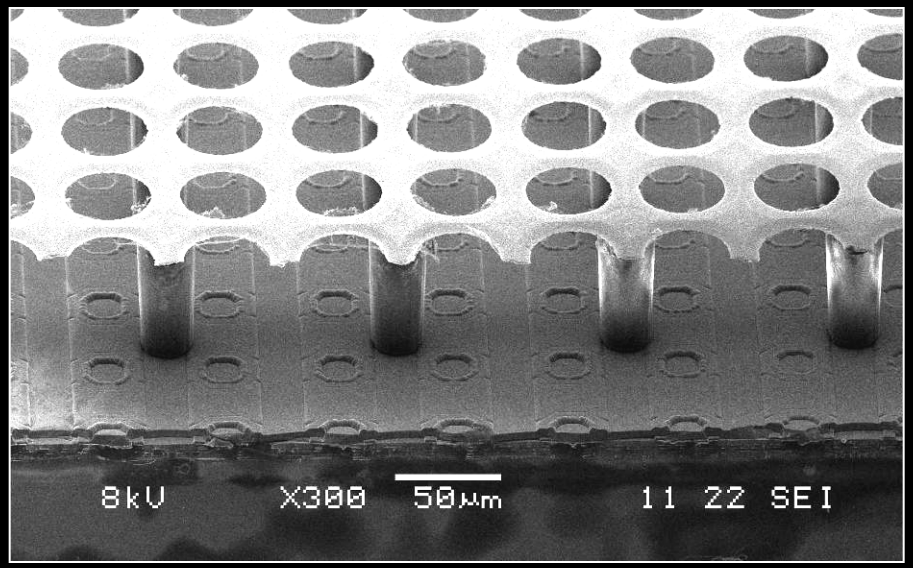
- Silicon Nitride is often applied as passivation layer:
  top finish of chips.

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

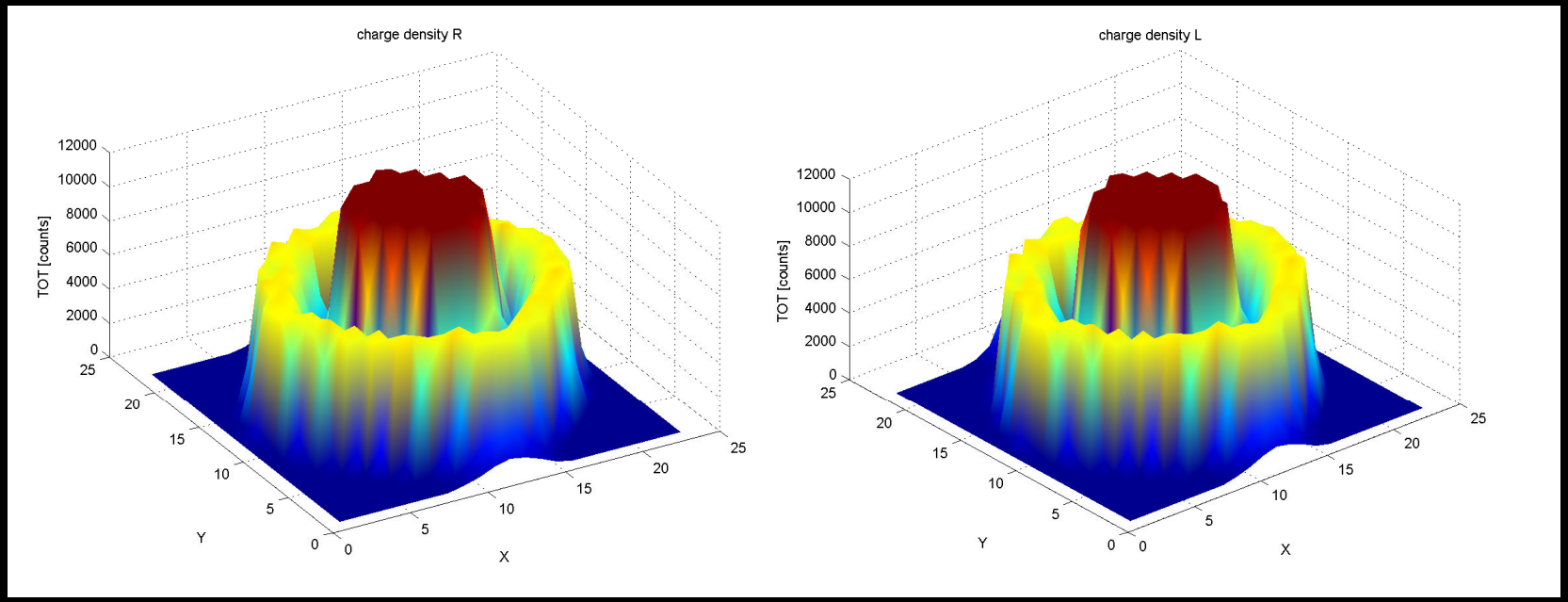
- Favored material for bearings in turbo chargers, jet engines

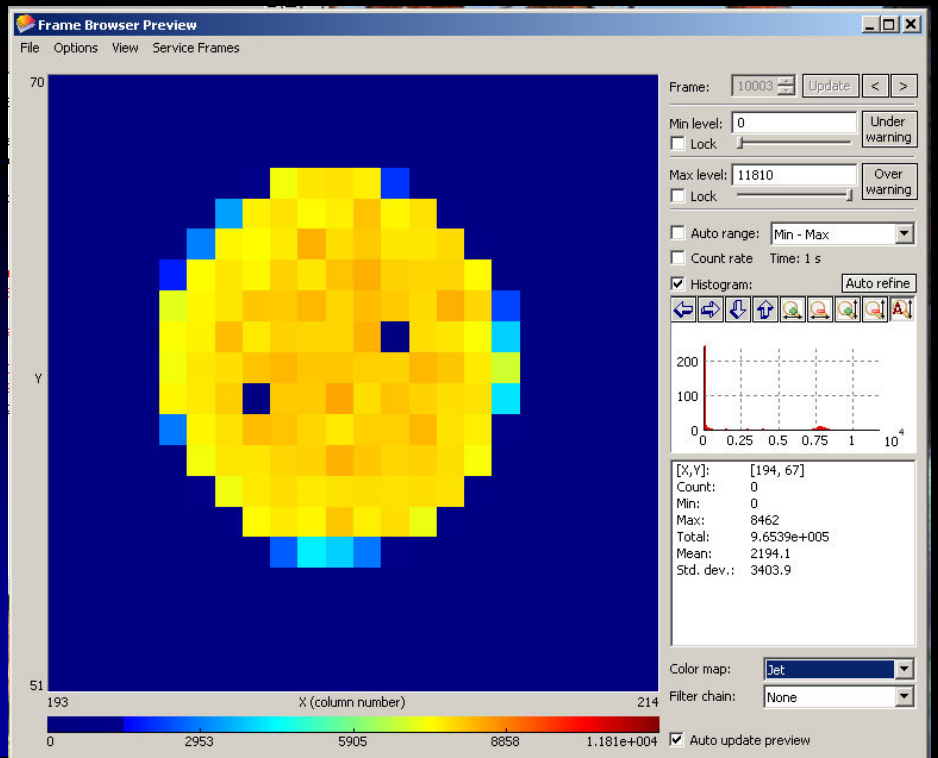


5 layers of Si_3N_4

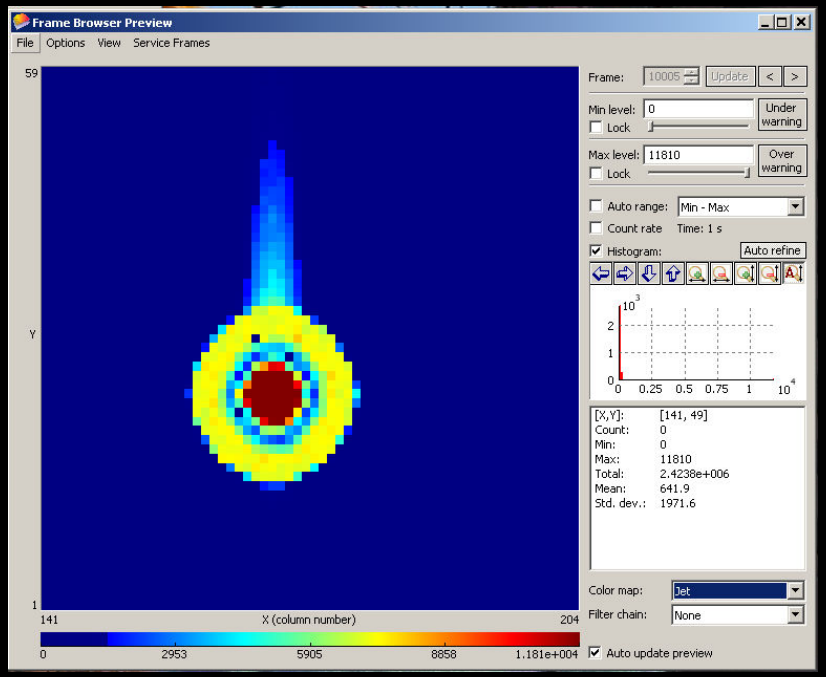


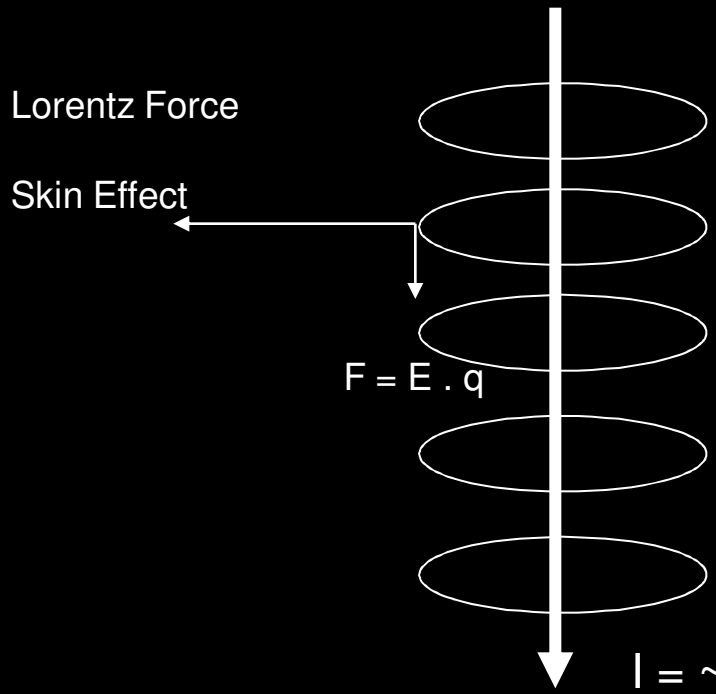
InGrid + a-Si:H



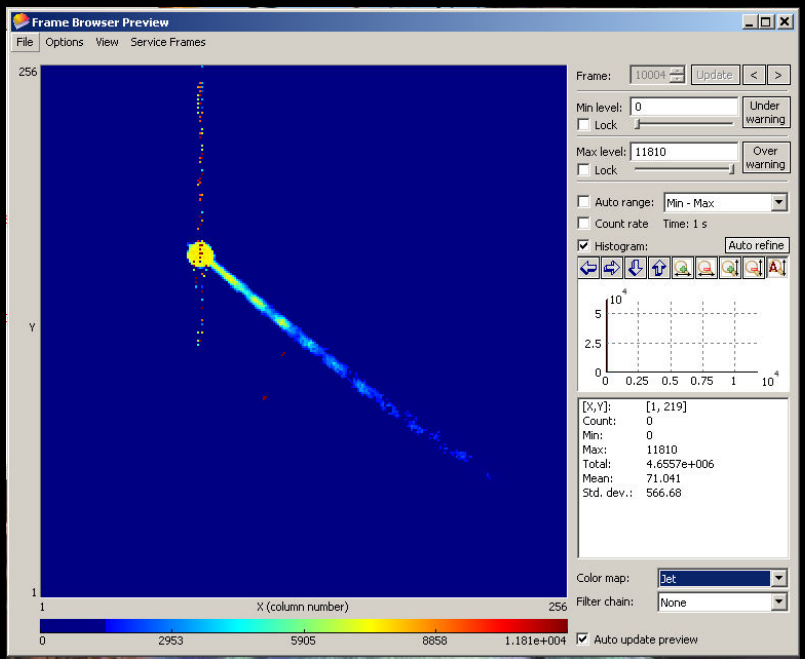


Discharge (protection) studies:
Martin Fransen





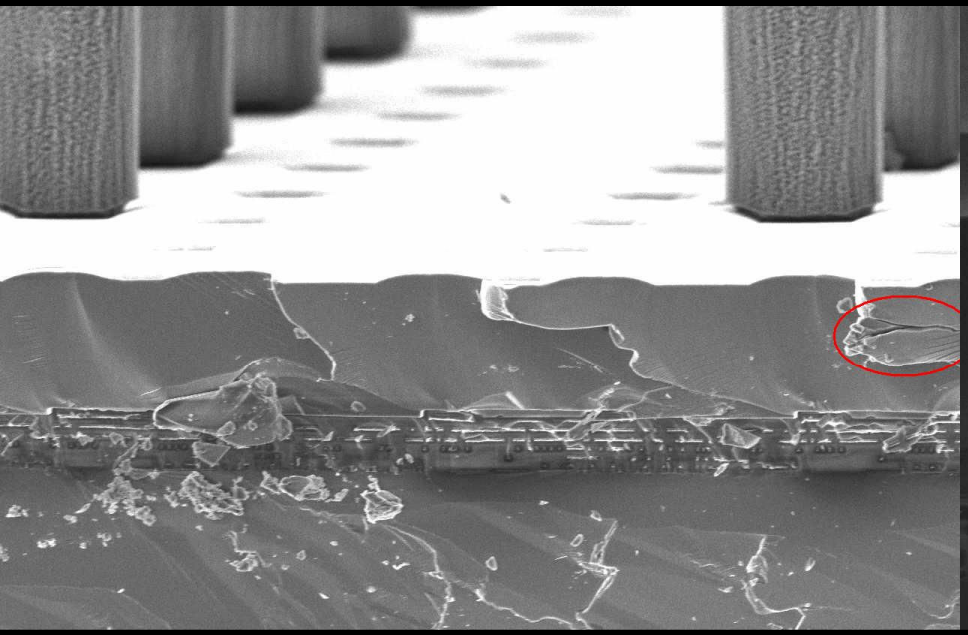
Improvement with Si Nitride

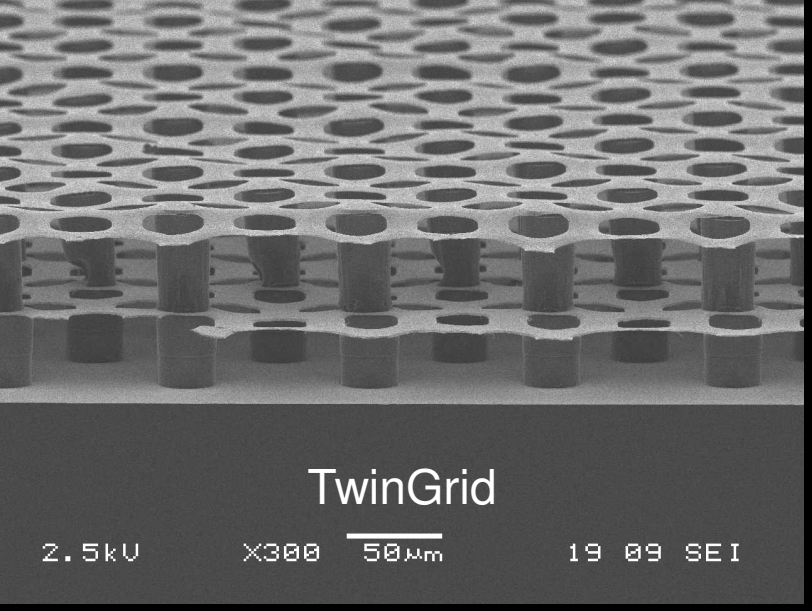


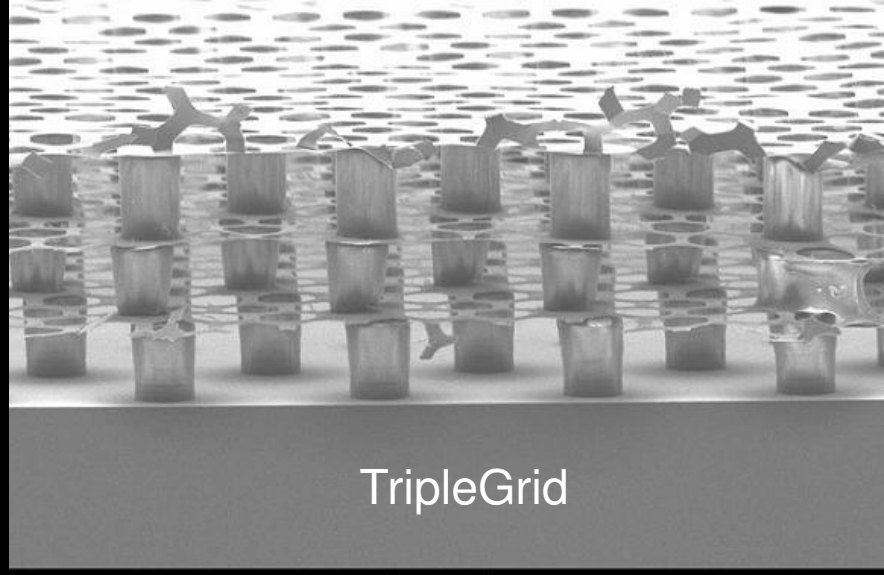
Chips still die after month of full-scale exposure
(Thorium induced) discharges

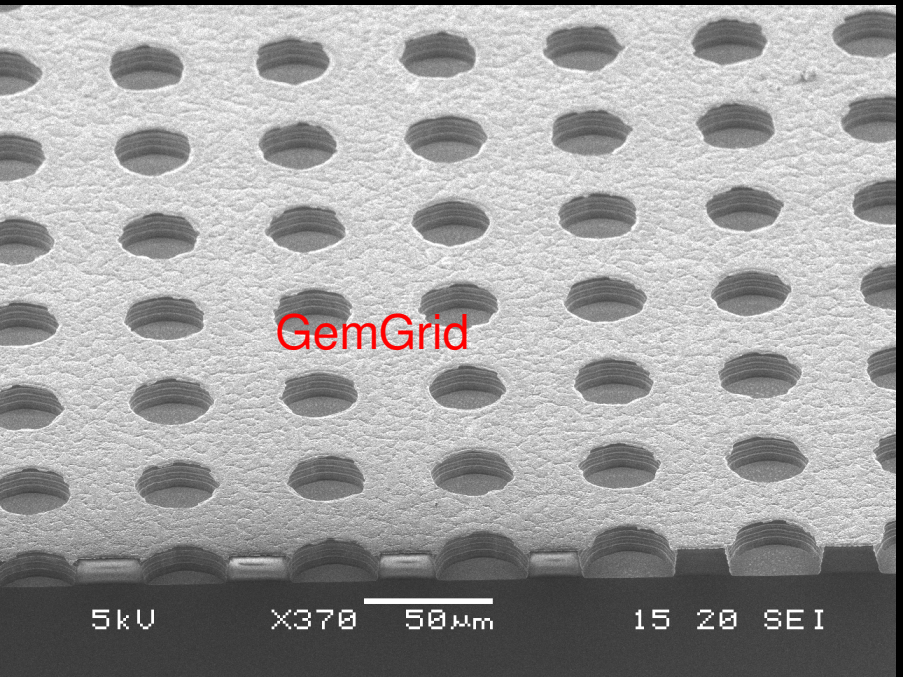
-discharges along non-protected paths (edges, peripherals)
- Pinholes in Si_3N_4 layer

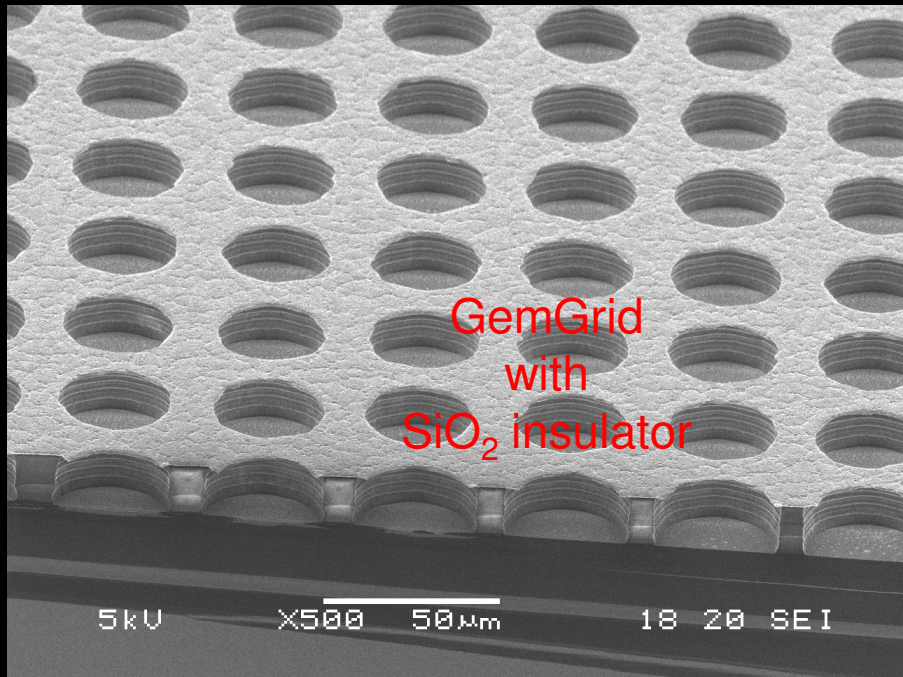
Highest priority to solve:
!!!! InGrid made of Si_3N_4 !!!!




TwinGrid
2.5kV X300 50µm 19 09 SEI


TripleGrid
5kV X270 50µm 17 18 SEI


GemGrid
5kV X370 50µm 15 20 SEI


GemGrid
with
SiO2 insulator
5kV X500 50µm 18 20 SEI

Goal R & D 2010:

- TT to industry: commercial InGrid technology

- InGrid supported by SiO_2 pillars: stronger, more adhesive, no outgassing

- InGrid: made of Si_3N_4 instead of (sputtered) aluminium

Simulations

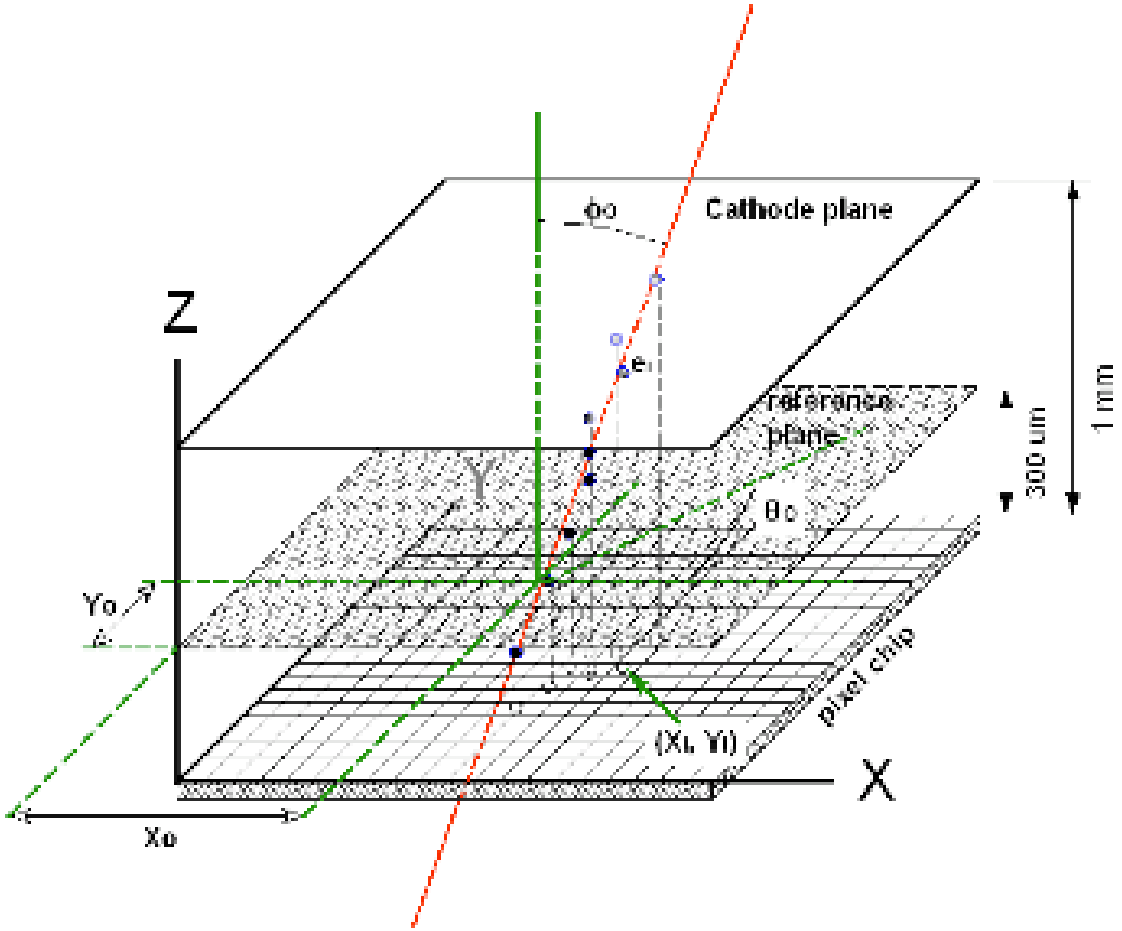


Fig. 13. Coordinate system and nomenclature of track parameters. The X-Y coordinate (X_0, Y_0) is given by the crossing point of the fitted track with the reference plane.

3D position of individual primary electron is registered:
- electron clusters
- diffusion

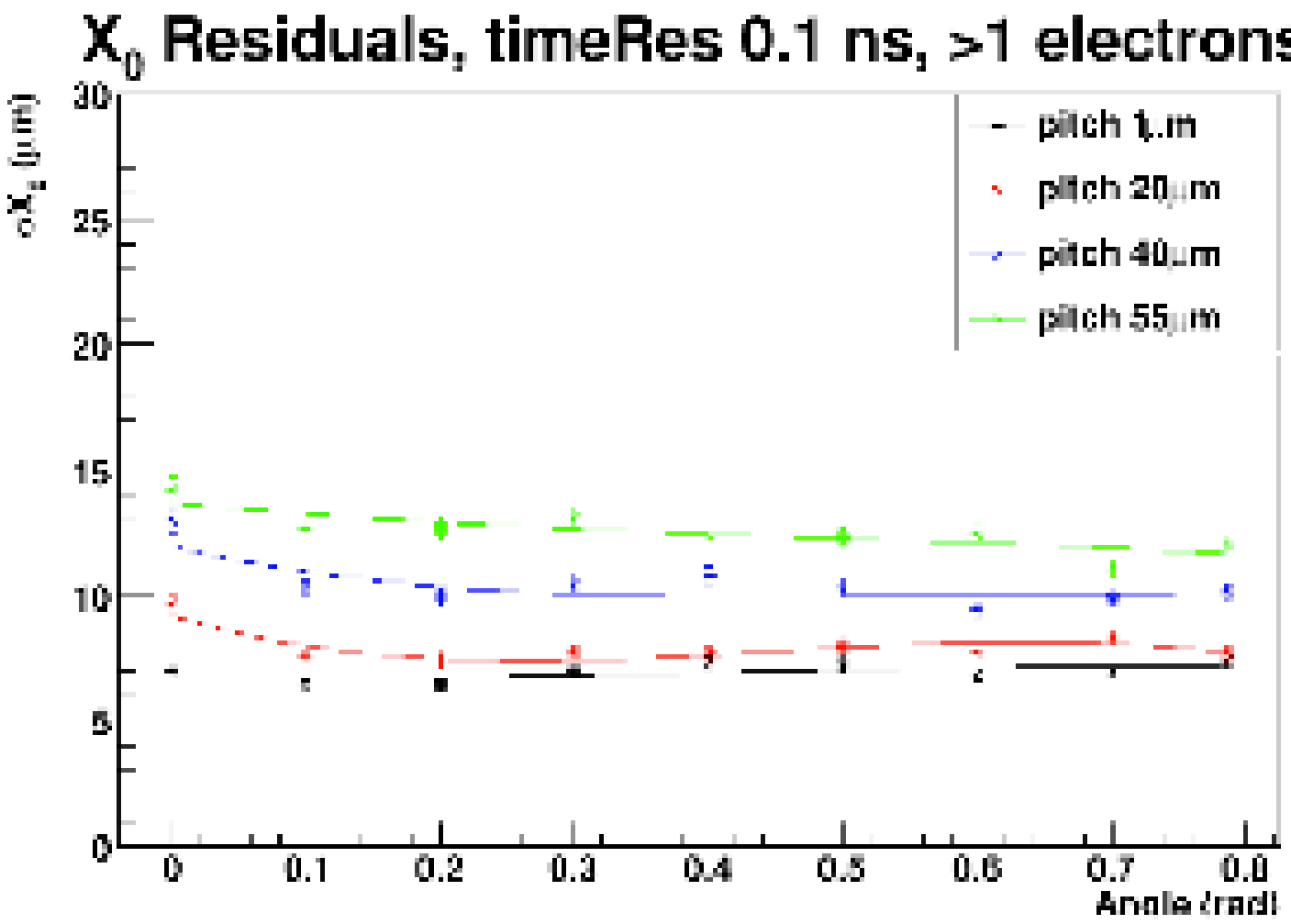


Fig. 16. The spatial resolution $X - X_0$ vs agle of incidence φ for different (square) pixel pitches, assuming a perfect time measurement.

Gossip (1 mm gas layer)

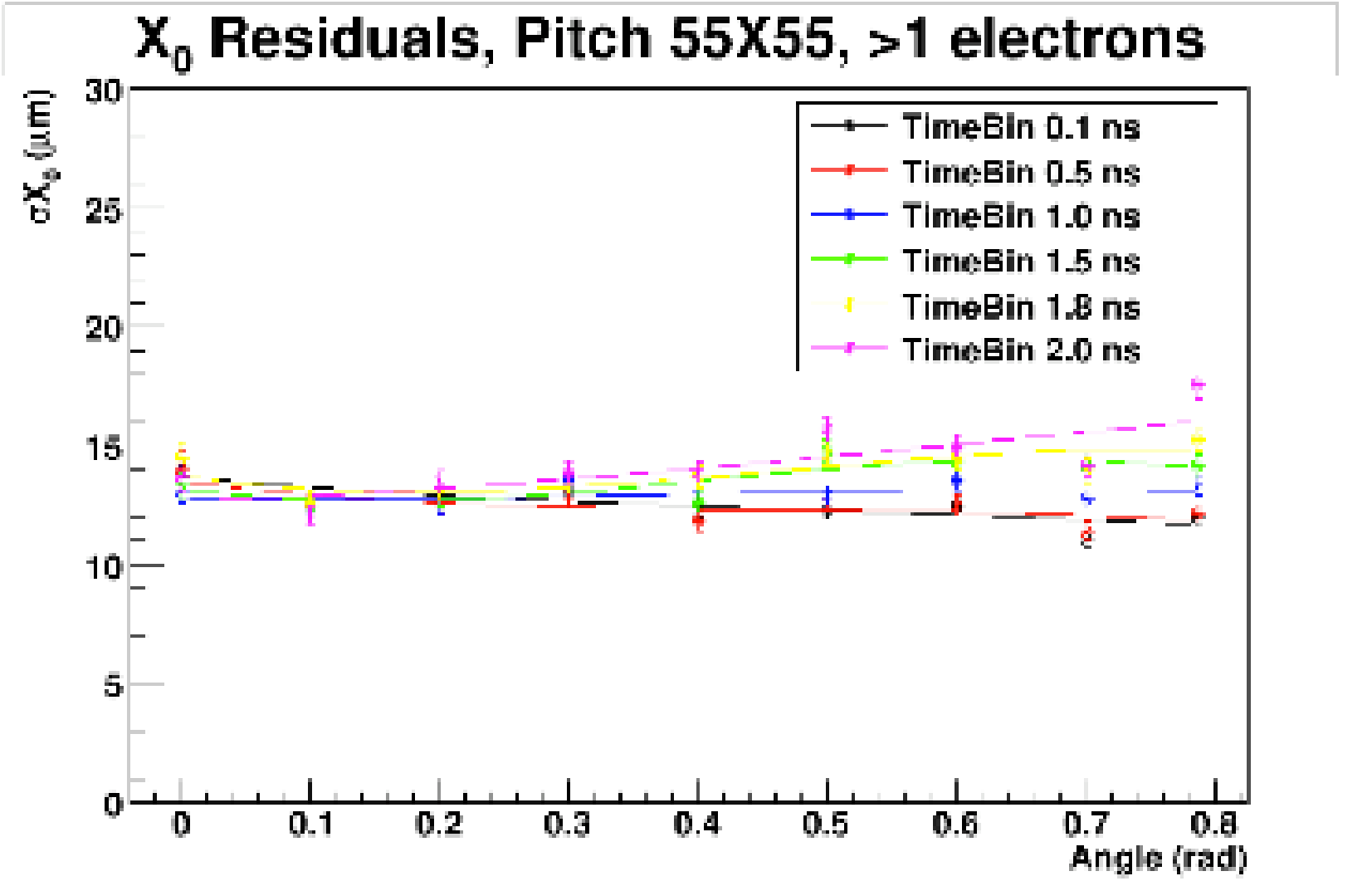
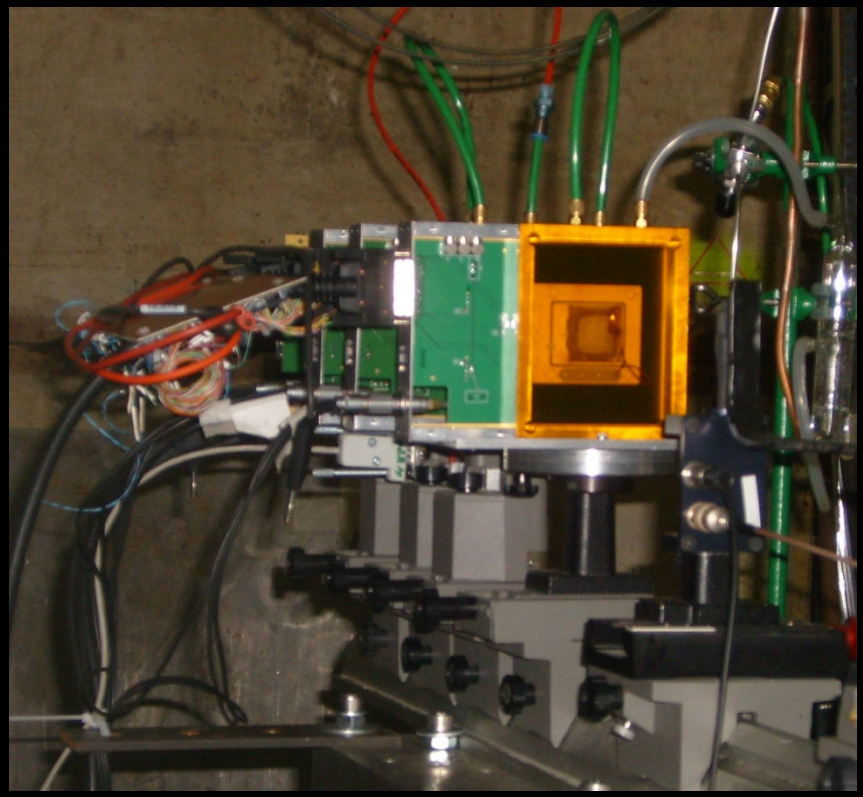


Fig. 18. Position resolution vs angle of incidence φ for different time measuring least counts.

Gossip (1 mm gas layer)

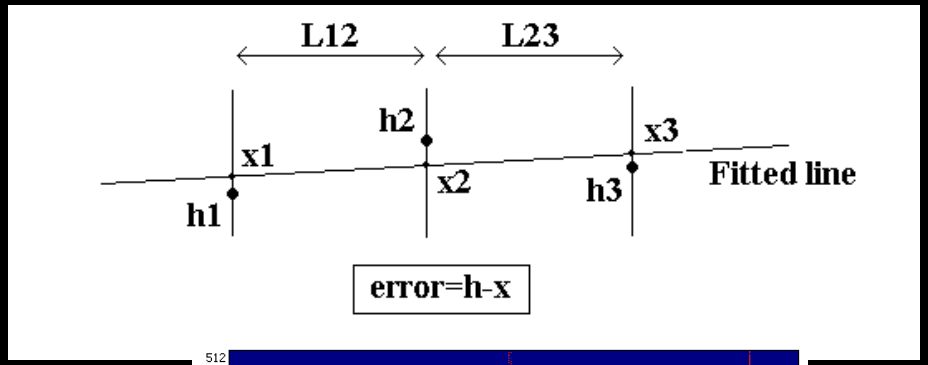
GridPix at Test Beam @ CERN

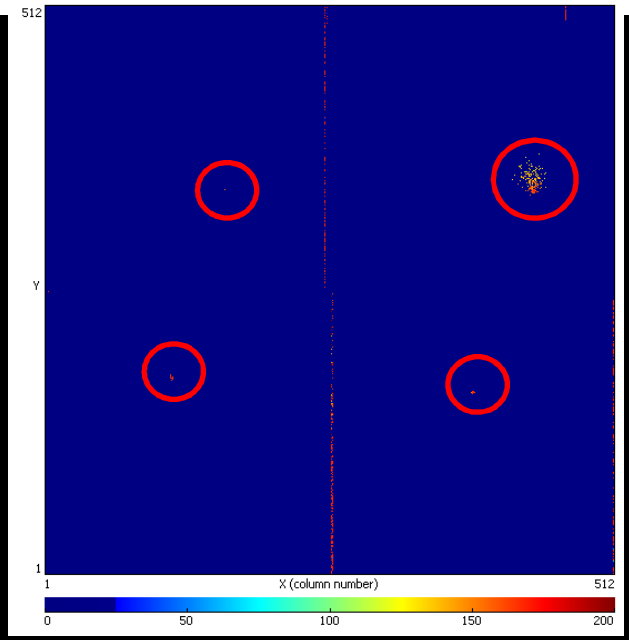
Test of Gossip detector
Low mass rad hard vertex detector.
use ~1mm gas instead of silicon
TimePix chips
3 X Gossip and DICE in series
DICE 19.5 mm drift gap
Gossips: 1 and 1.5 mm drift



Beamtests at CERN

DICE is reference detector
Determine center of gravities h1,h2 and h3
No time information used (too much timewalk)
Determine relative positions of chips
L12, L23; distance between detectors
X1,2,3; best fit





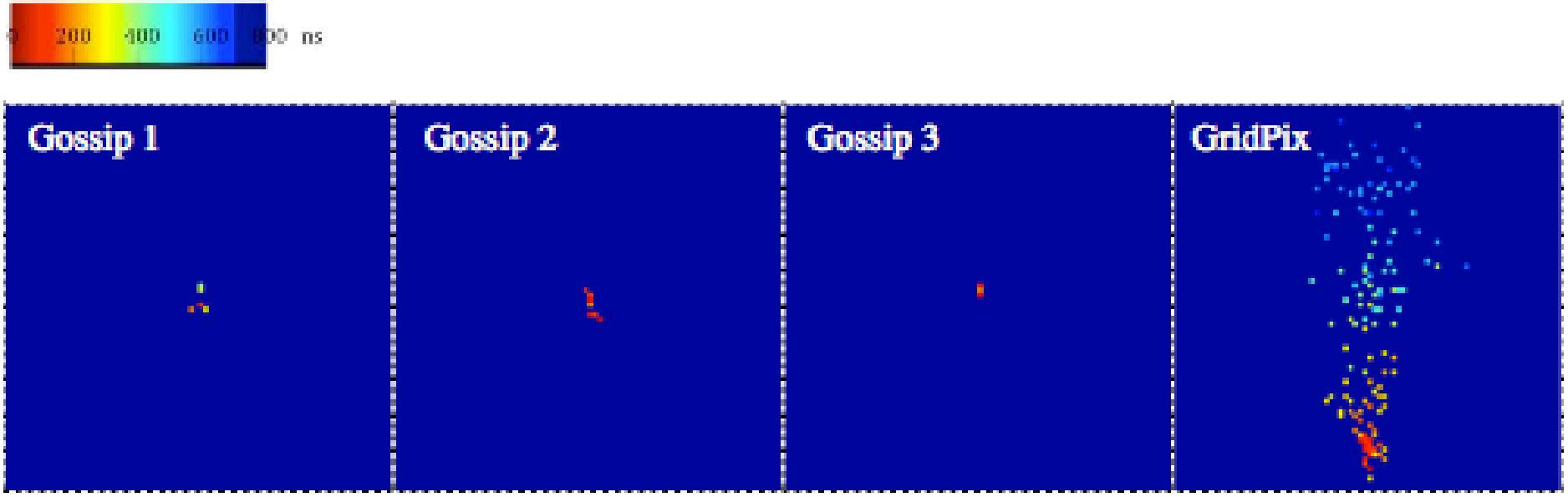
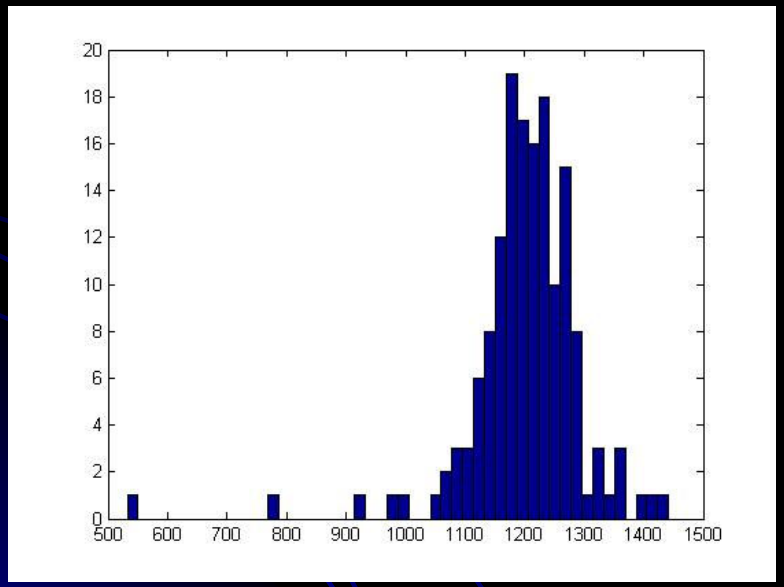
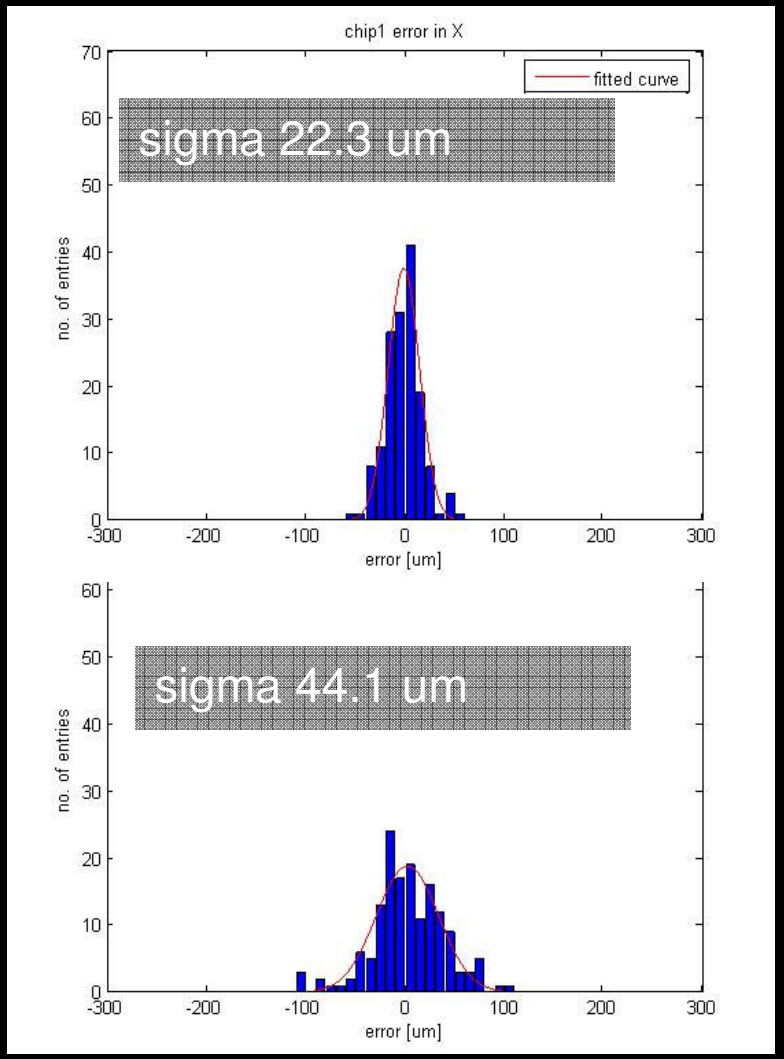


*Fig. 10. Drift time plots of a typical event from a 15 GeV π^- traversing three Gossip prototypes and a GridPix detector with 20 mm drift height. The drift times are indicated by colours. For better visibility only a rectangle of 80*80 pixels is displayed of each detector.*

Beamtests at CERN

150 GeV “stuff” from SPS
Ar/ISO 80:20

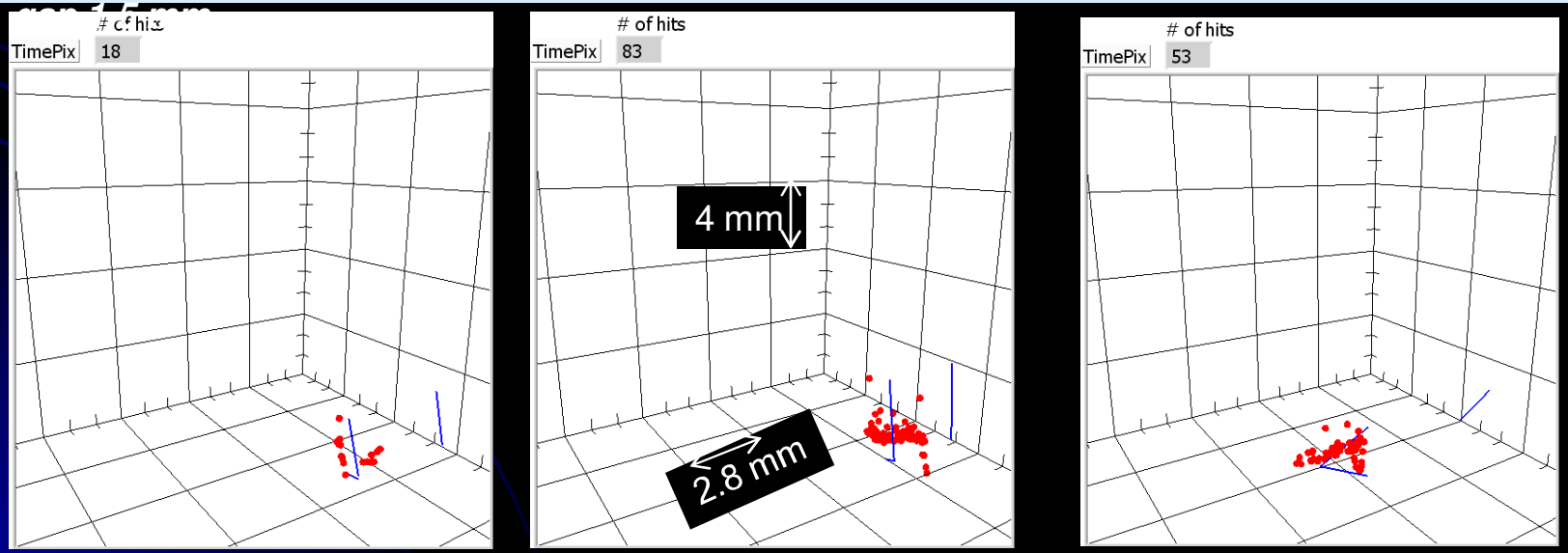




3. Performance
delta rays

- Typical artefact of gaseous detectors
  - Do not exist in solid state detectors because of their short range
- Affecting ~ 1 - 2% of the events
- Deteriorate resolution for most gaseous detectors since they are averaged with the rest of the track
- In Gossip most of them can be rejected in the track fitting using its high granularity
  - Using track info from other detectors

Examples of data rays in test beam data of run Sept 2009 using DME/CO_2 50/50. Gossip gas

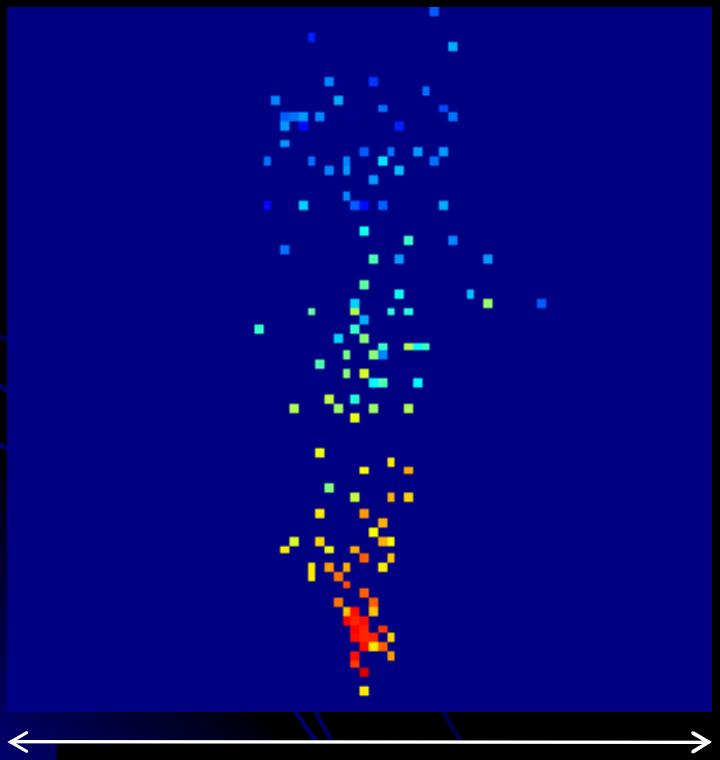


1. Working point (cntd)

gas mixture

Not Gossip but GridPix with 19.3 mm drift gap

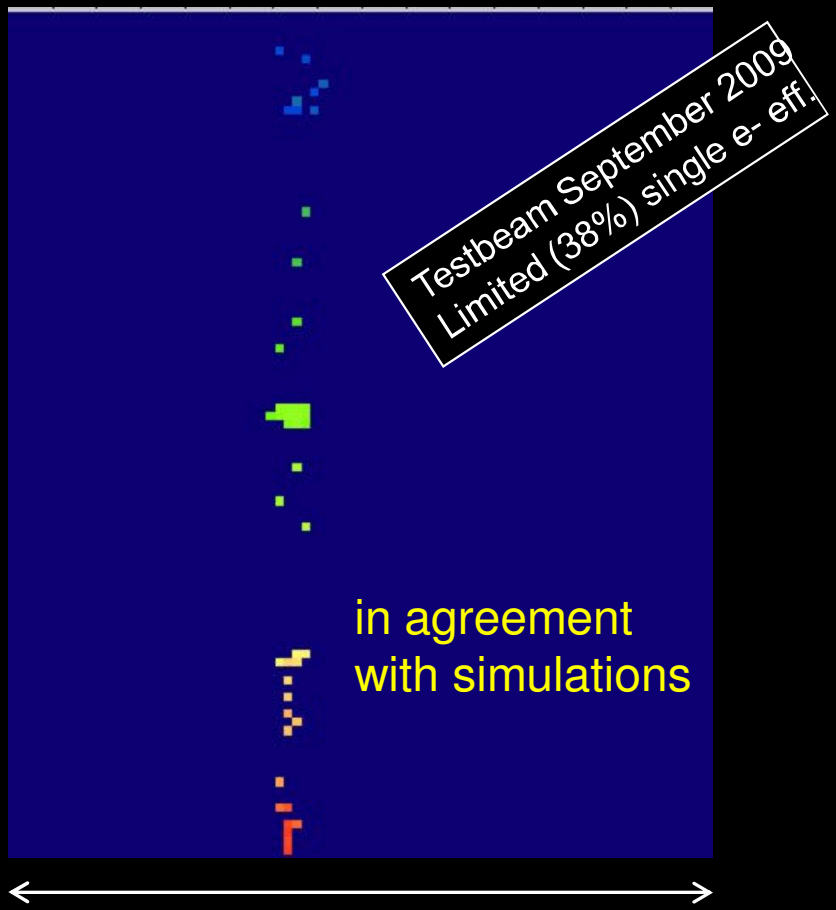
Ar/iC_4H_{10} 80/20
(June 2009 testbeam)



80 pixels (4.4 mm)

- Our favourite is presently DME/CO2 50/50
  - Low diffusion (70 – 100 µm/√cm)
  - Low Lorentz angle (9º @ 2T)
  - Good cluster density (**~~45 cl/cm~~**)
    - 125 electrons/cm

CO_2/DME 50/50



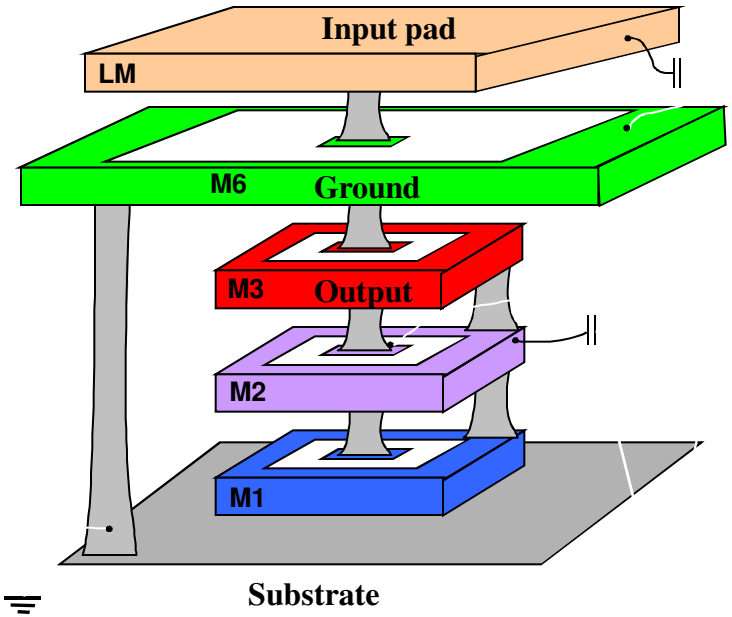
80 pixels (4.4 mm)

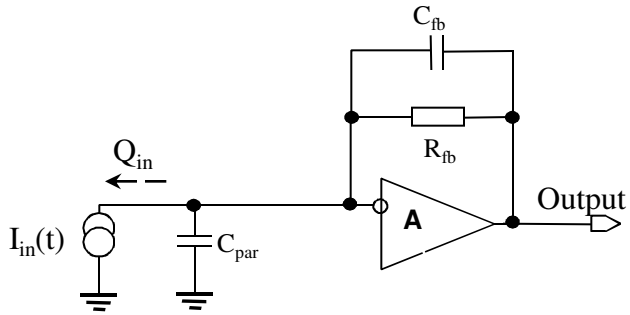
Electronics

GOSSIPO-1:

test of preamp-shaper-discriminator for GOSSIP

'MultiProjectWafer' in 0.13 μm technology



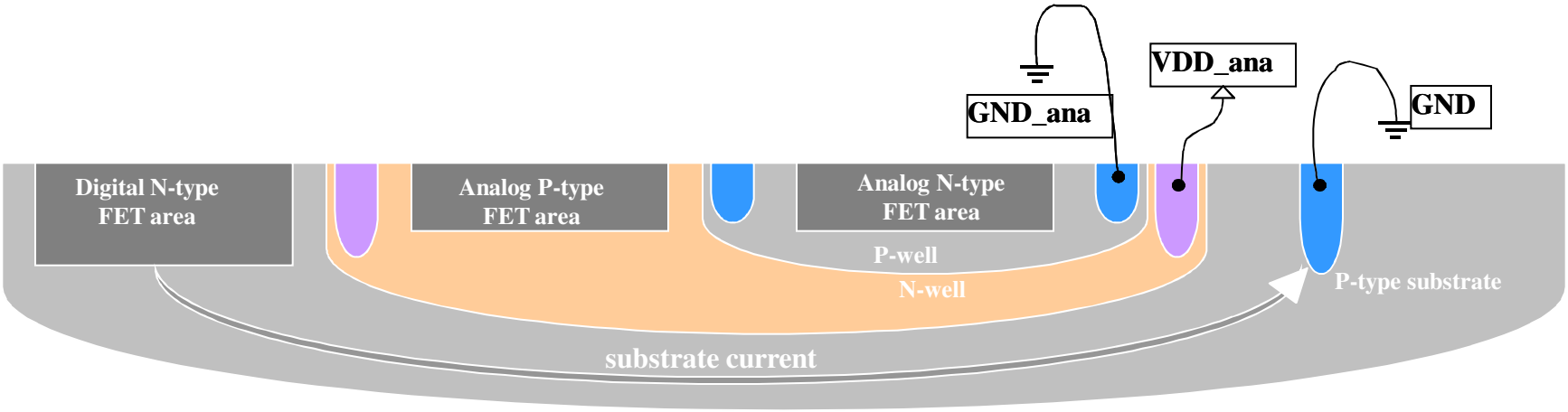


Very low (parasitic) capacitance at the input (C_{par} → 10fF) .

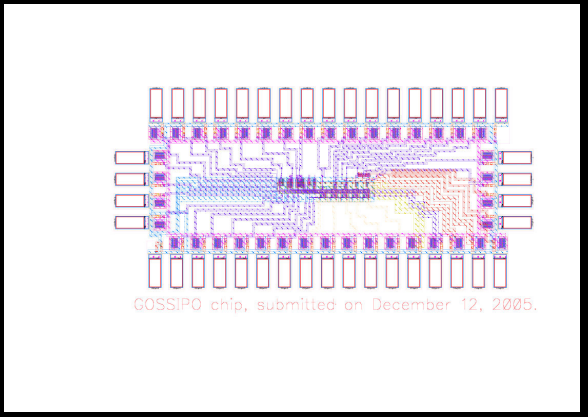
Coaxial-like layout of the input interconnection.

Triple well layout in 130 nm (IBM) technology:

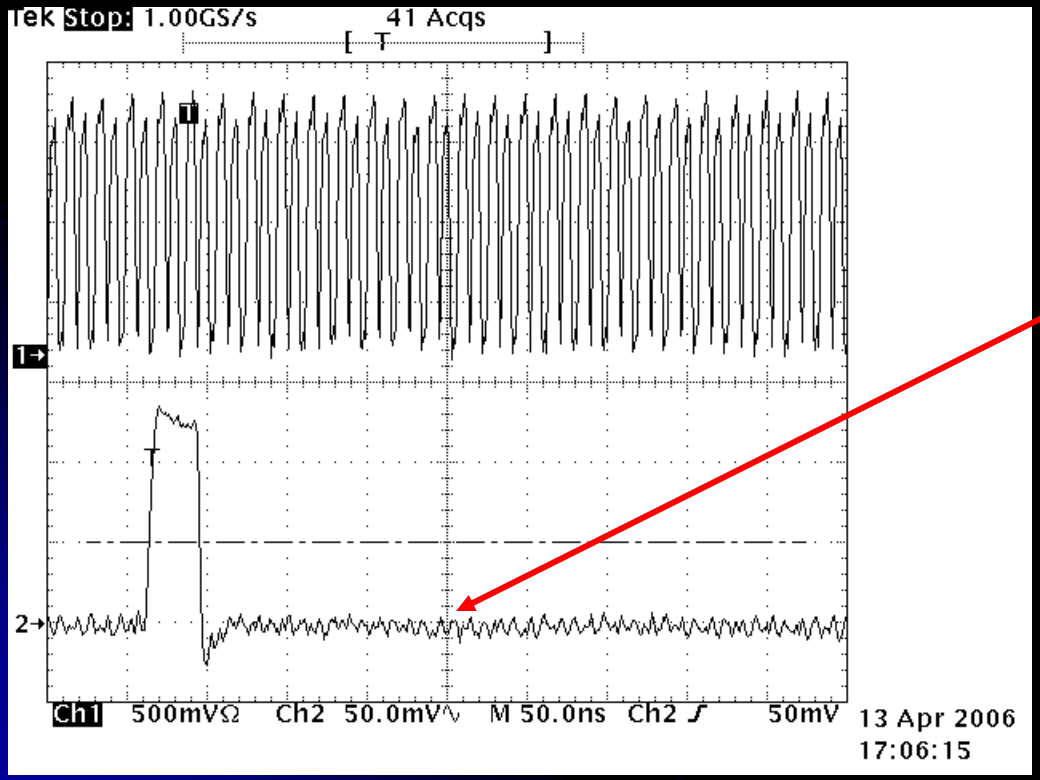
isolation of digital
and
analog sections



- 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

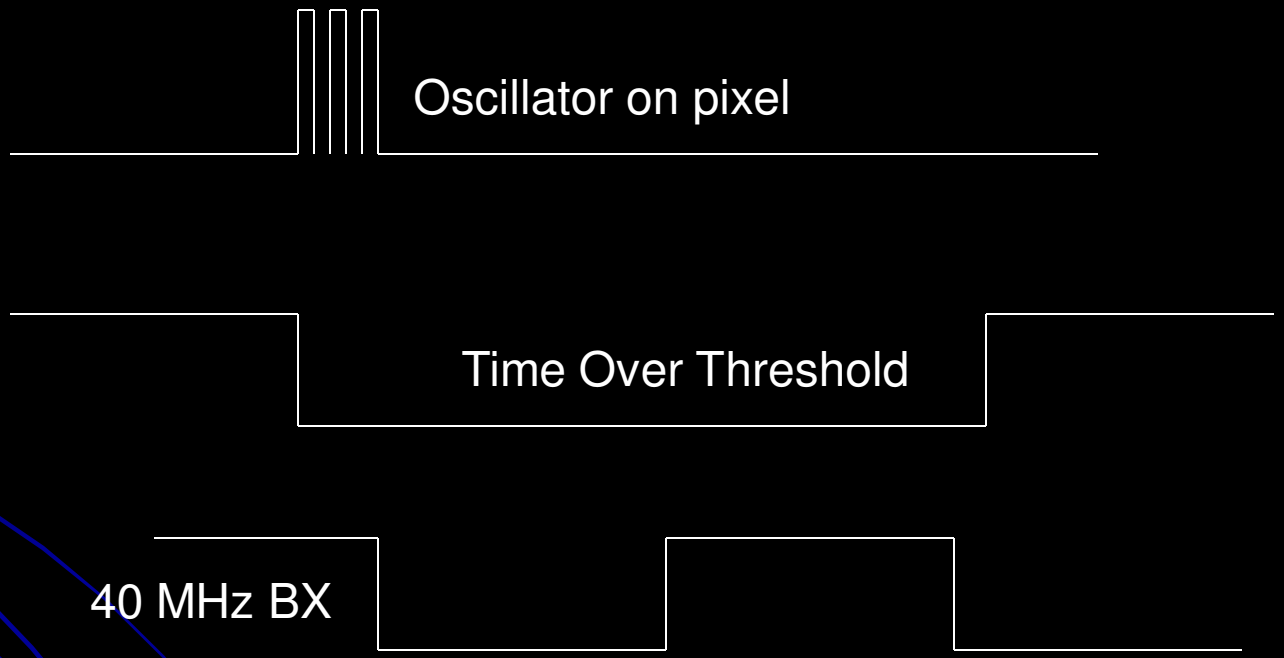
test of preamp-shaper-discriminator

+

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

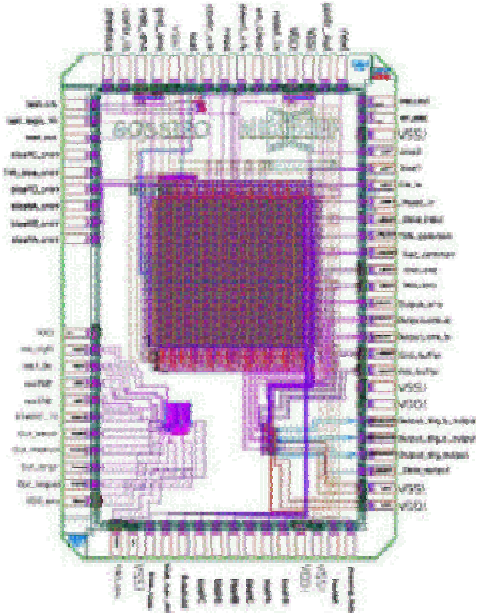


TimePix-2

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!

Ageing effects

New, essential discoveries by Finnish groups

HELSINKI INSTITUTE OF PHYSICS

RD-51 WG2 meeting 10th Dec. 2008

Ageing tests and analysis of organic compounds released from various detector materials

Kari Kurvinen on behalf of

H.Andersson[d], T.Andersson[d], J.Heino[a], J.Huovelin[c], K.Kurvinen[a,], R.Lauhakangas[a], S.Nenonen[d], A.Numminen[a], J.Ojala[a], R.Orava[a,b], J.Schultz[c], H.Sipilä[d], O.Vilhu[c]*

[a]*Helsinki Institute of Physics, P.O.Box 64, FIN-00014 University of Helsinki, Finland*

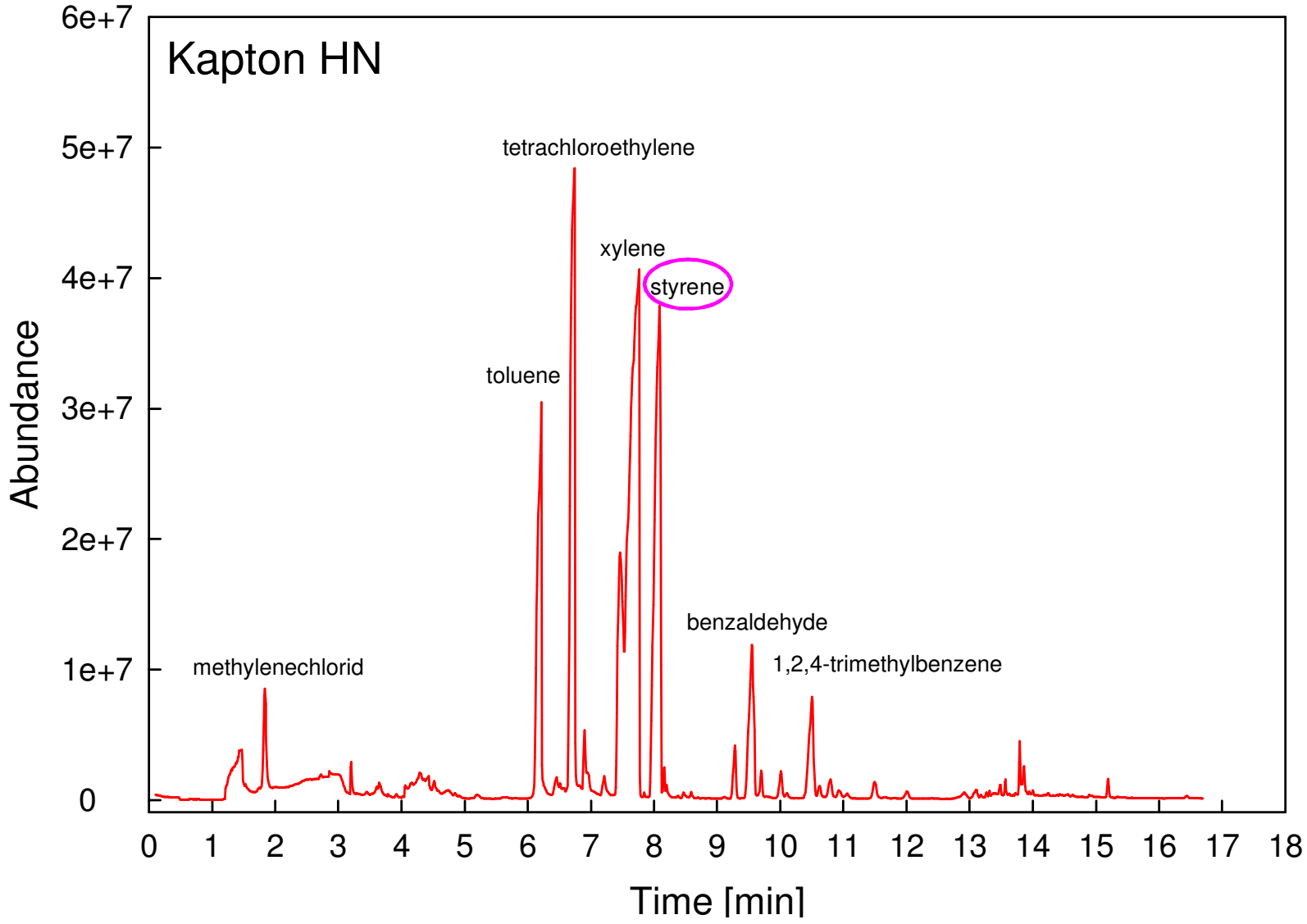
[b]*Department of Physical Sciences / Division of High Energy Physics, P.O.Box 64, FIN-00014 University of Helsinki, Finland*

[c]*Observatory, P.O.Box 14, FIN-00014 University of Helsinki, Finland*

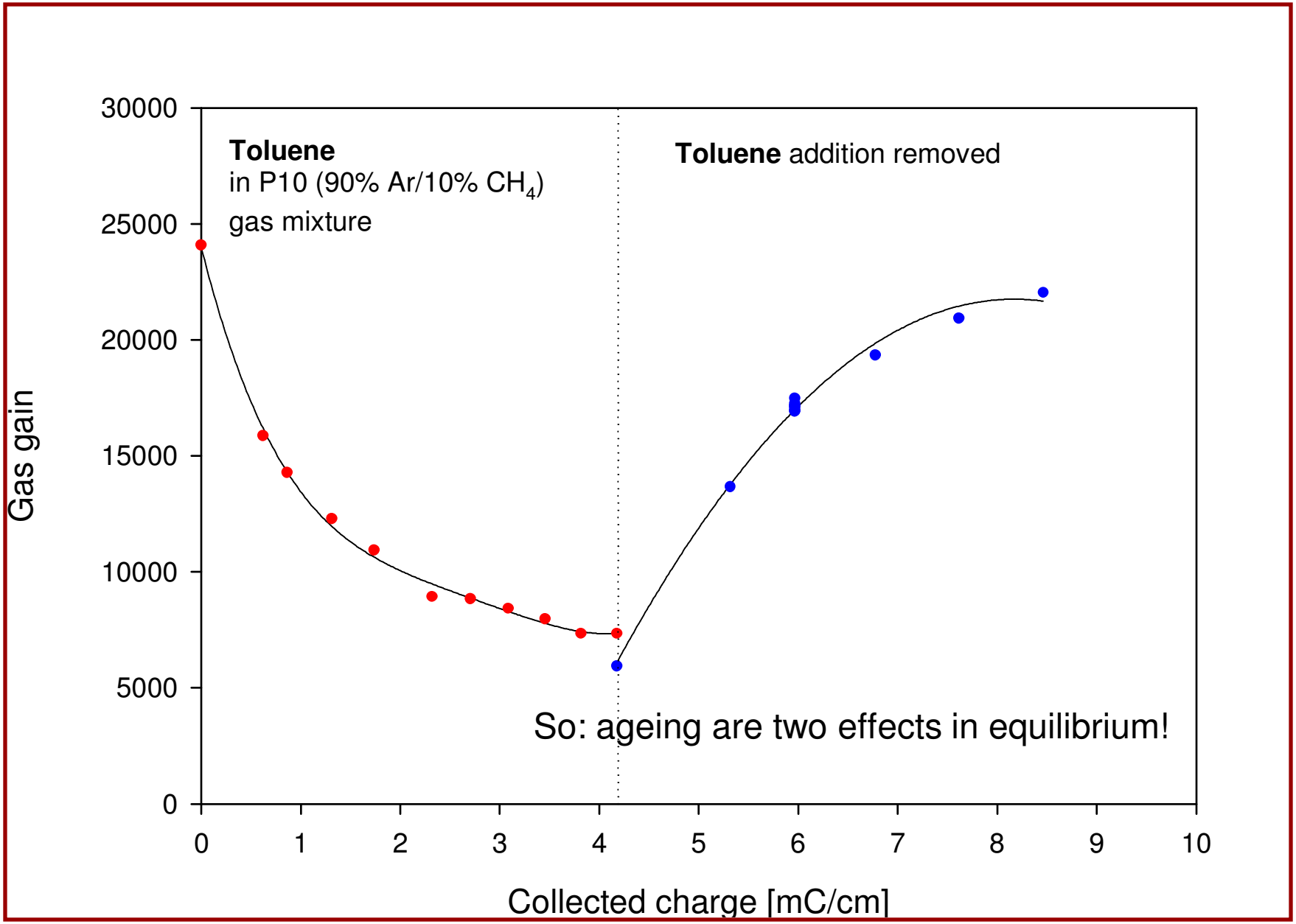
[d]*Metorex International Oy, P.O.Box 85, FIN-02631 Espoo, Finland*

based on talks given in NSS 2003 and NSS2004 symposium
(see conf.CDs and IEEE Trans. on Nucl. Sci 51 No.5, 2004)

Results - Outgassing Analysis



Results - Accelerated Aging Test



As a result:
- ageing is a process in equilibrium
- compounds causing ageing identified: i.e. Toluane, Styrene

- Serious consequences:

- Inventarisation of ALL outgassing compounds of materials in system
- Knowledge of ALL found outgassed compounds on ageing properties

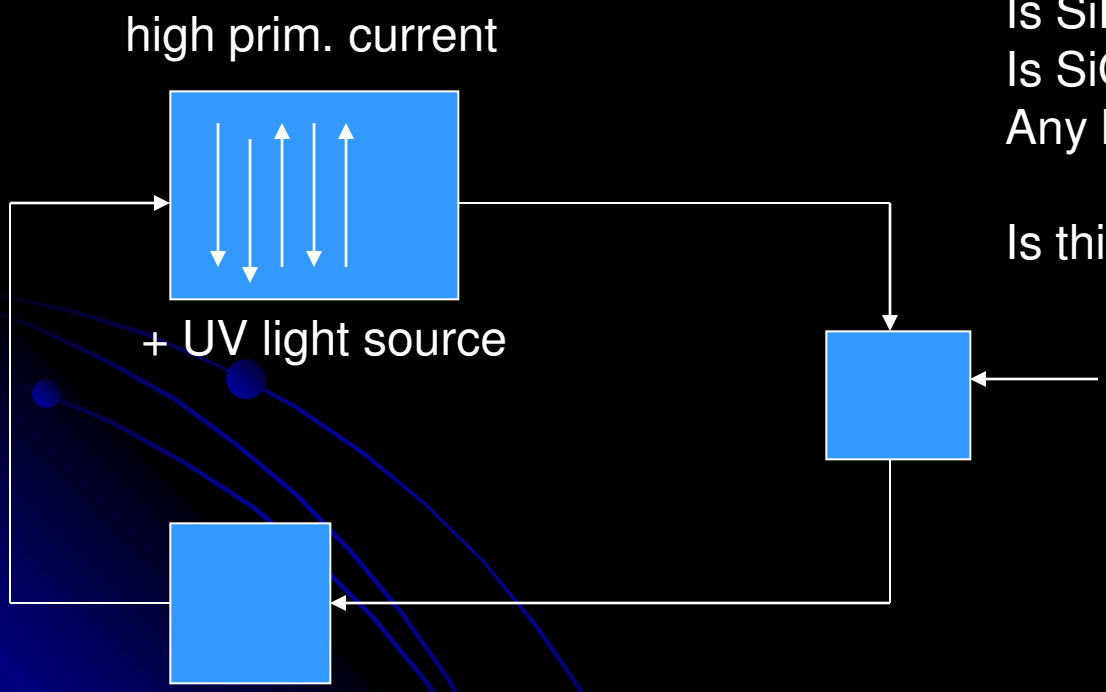
➔ elimination of ageing risks

+ final tests in beams and irradiation facilities

RD-51: task

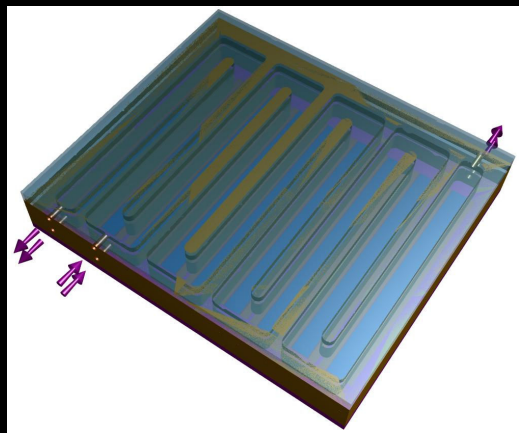
Up to now not a single compound is known to cause ageing

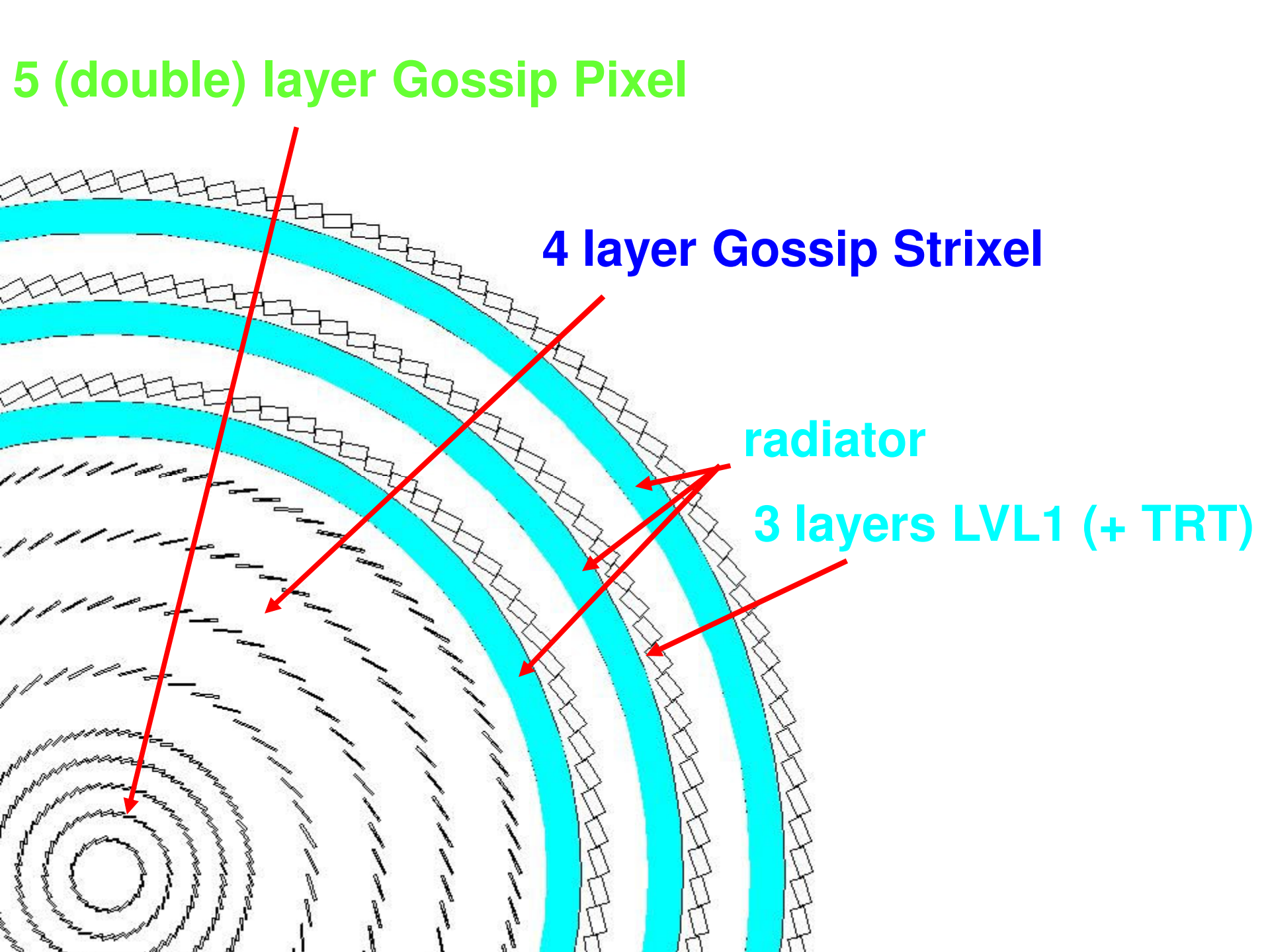
New approach: a non-ageing, but ageing-sensitive set up:

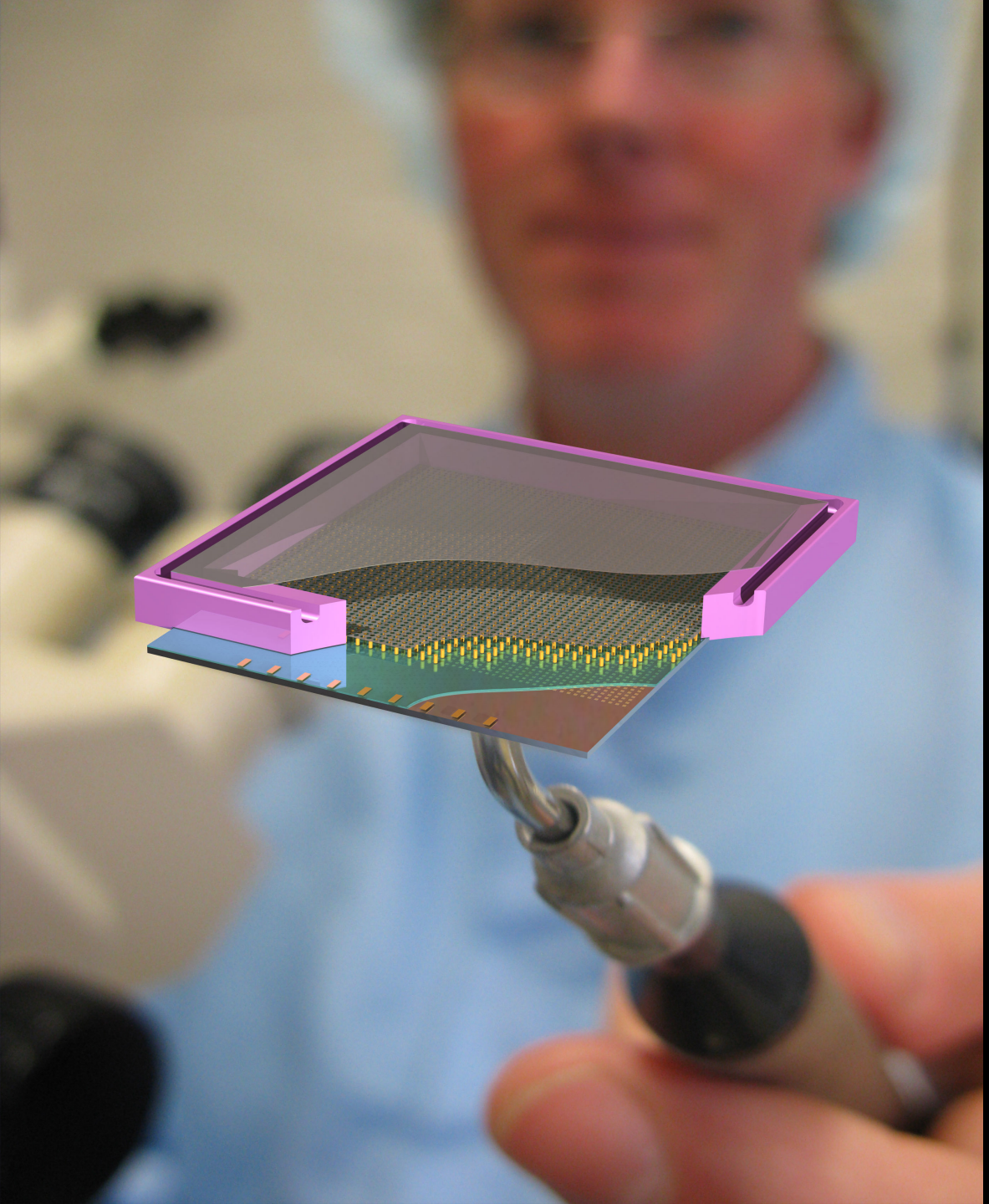


Is radiation creating radicals?
Is SiH_4 an ageing causing compound?
Is SiO_2 causing ageing?
Any hydro-carbon with Si replacing C?

Is this magic or science?




5 (double) layer Gossip Pixel
4 layer Gossip Strixel
radiator
3 layers LVL1 (+ TRT)

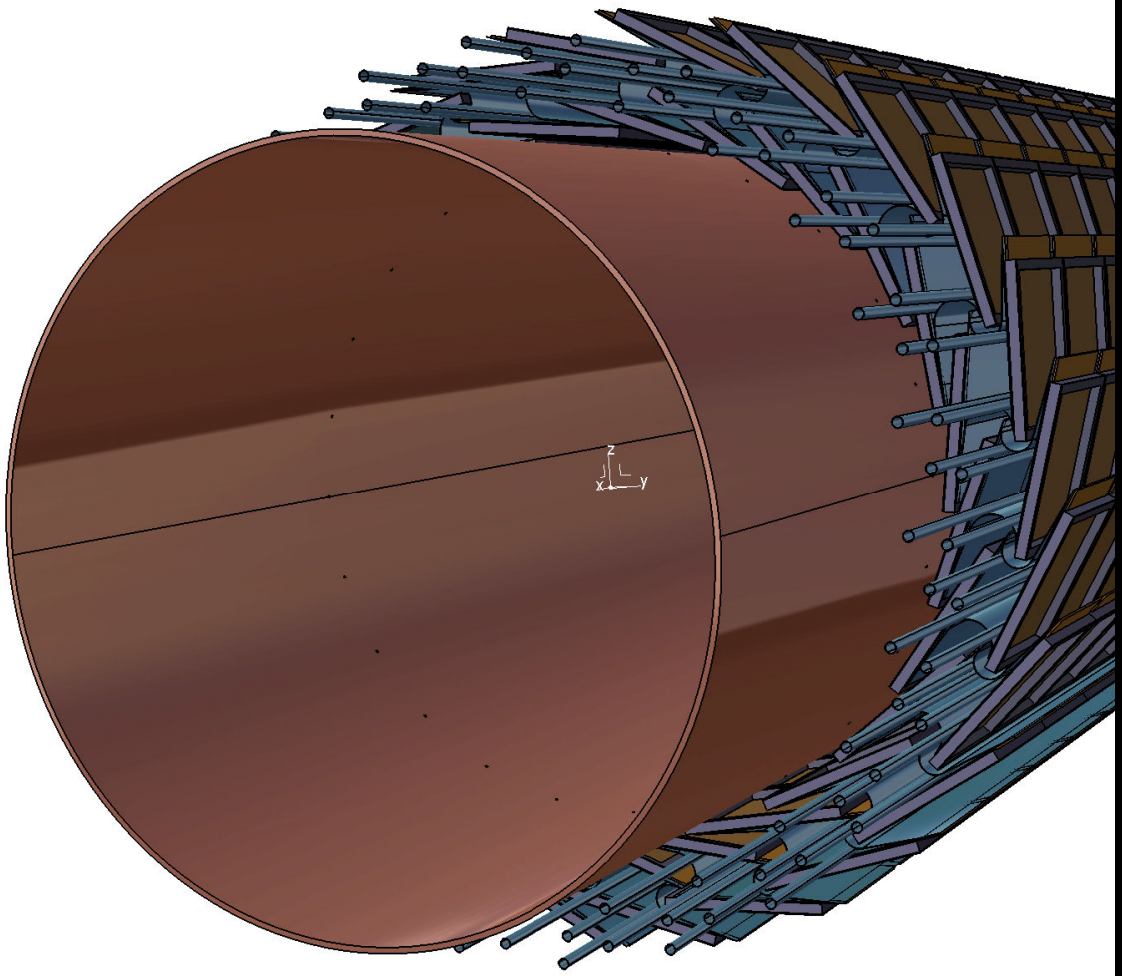


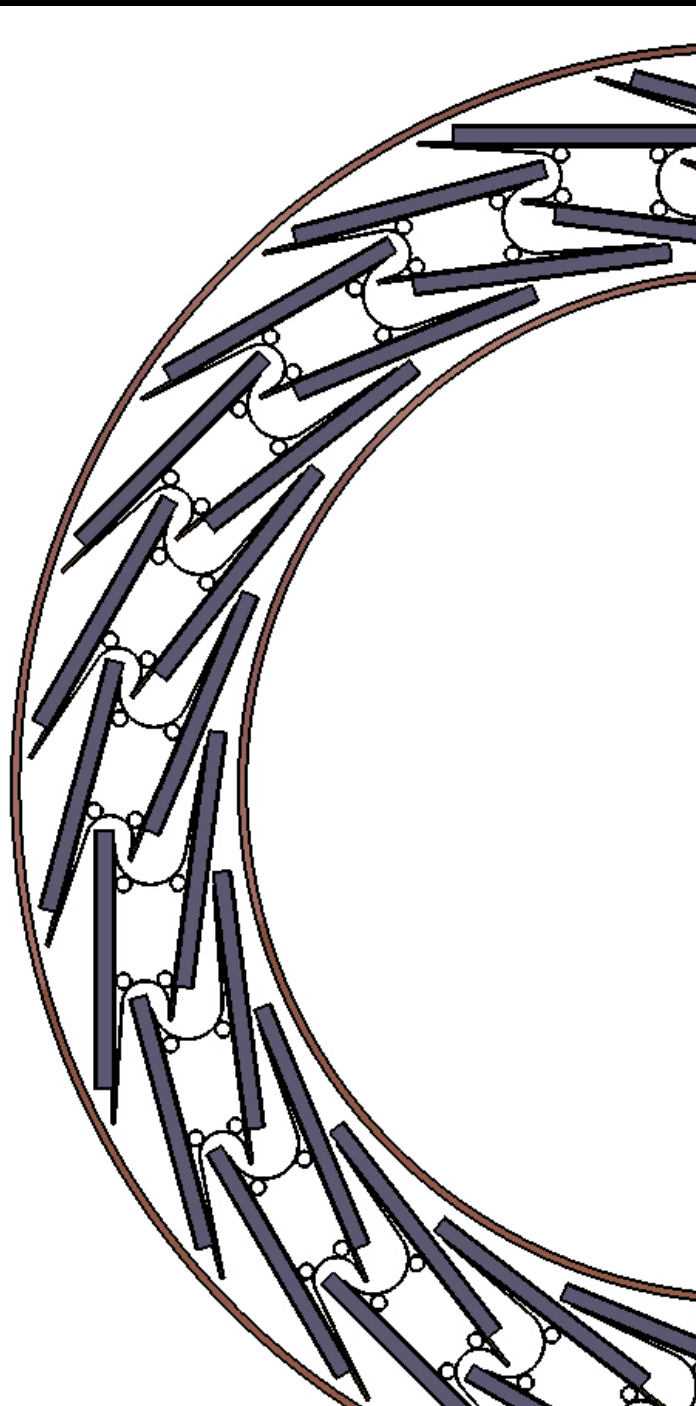
Vertex Pixel detector

Strixel detector

LVL1 trigger

TRT

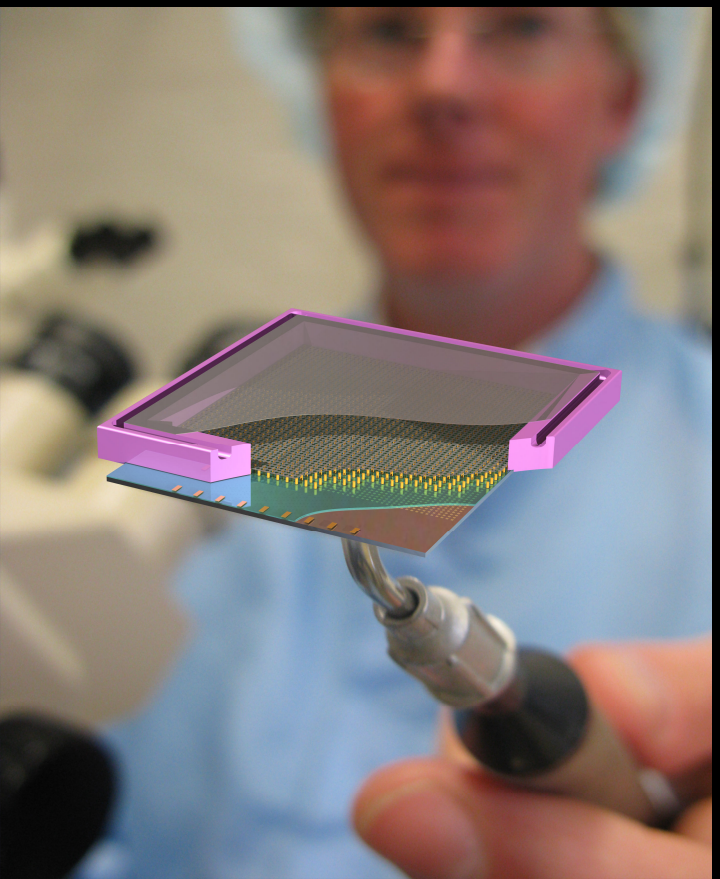




ATLAS:
Gossip as vertex detector

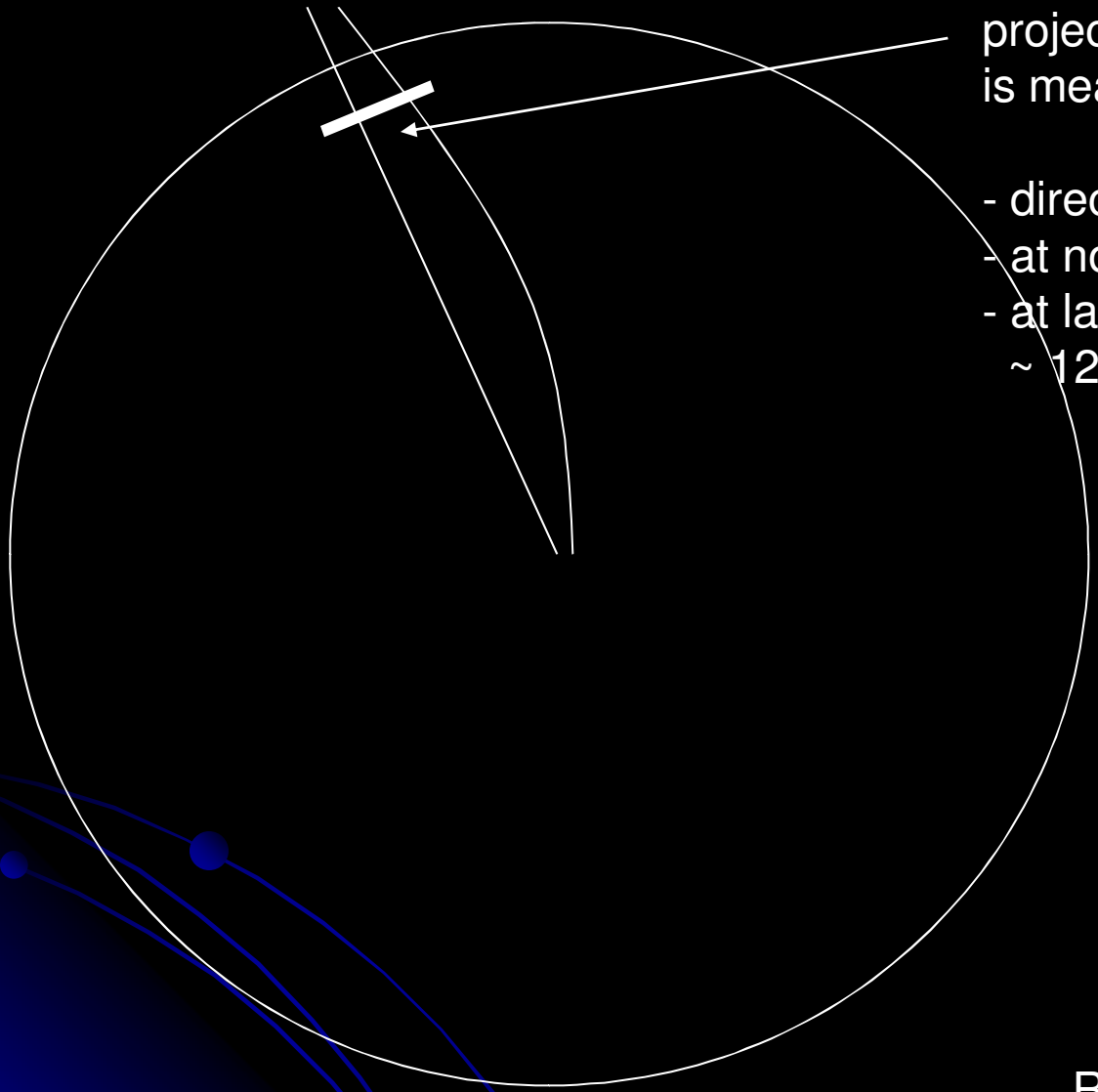
GridPix replacing the Si Strip Tracker:

- 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



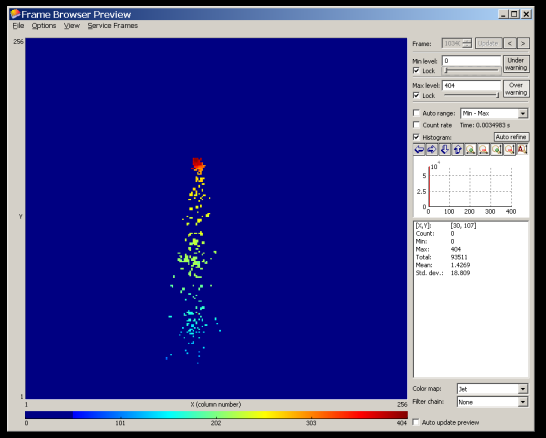
➔

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



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



LVL1 trigger from inner tracker

Requires fast on-board processing

We are using 130 nm tech.

What about 45 nm tech?

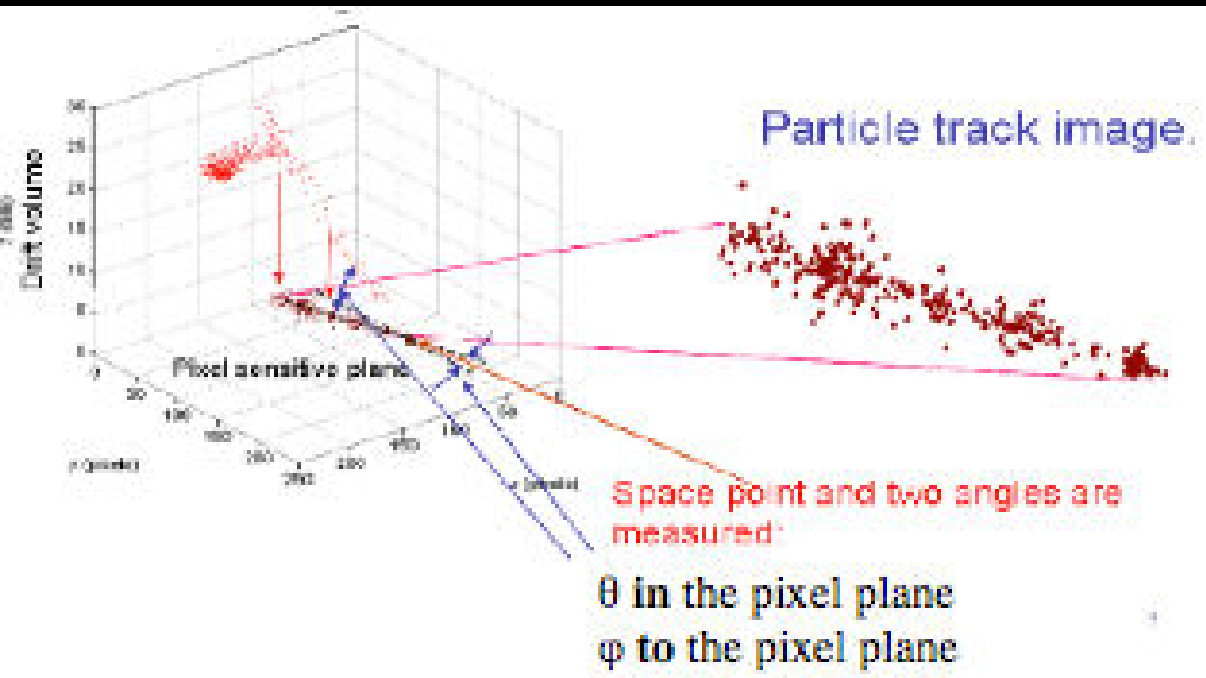
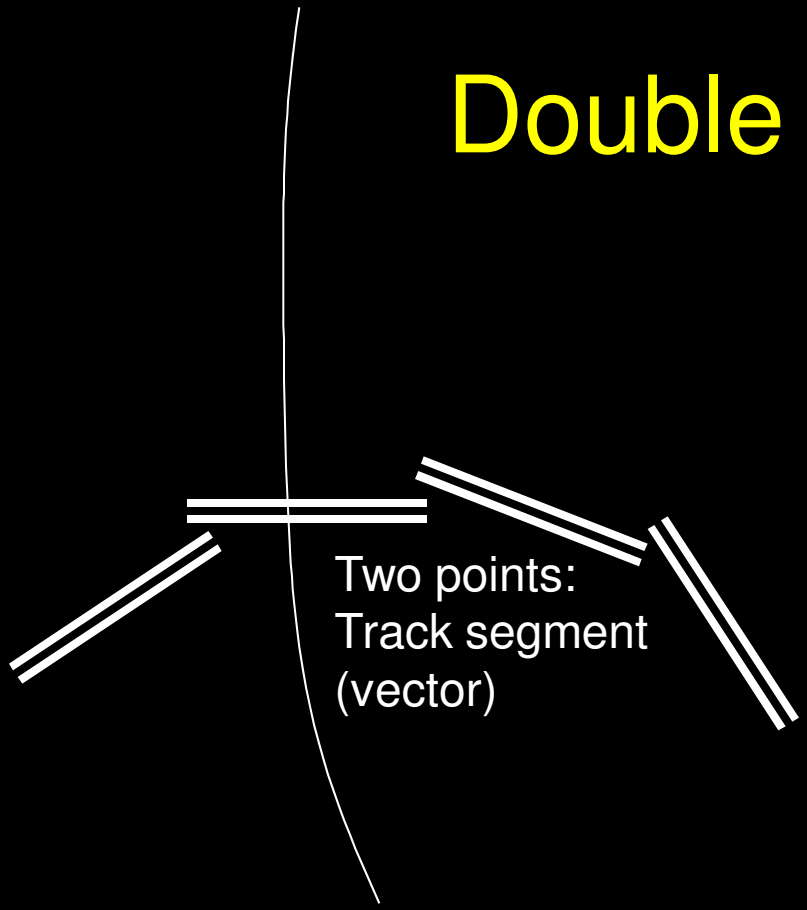


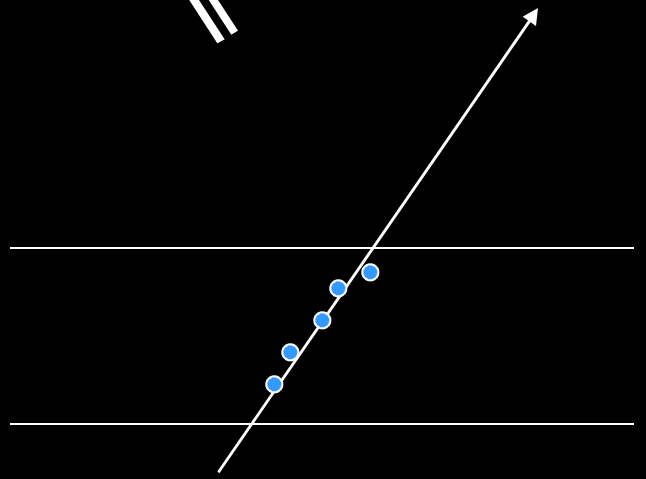
Fig. 41. Principle of the Grid-Pix tracker

First simulation results on momentum resolution
by Anatoli Romaniouk

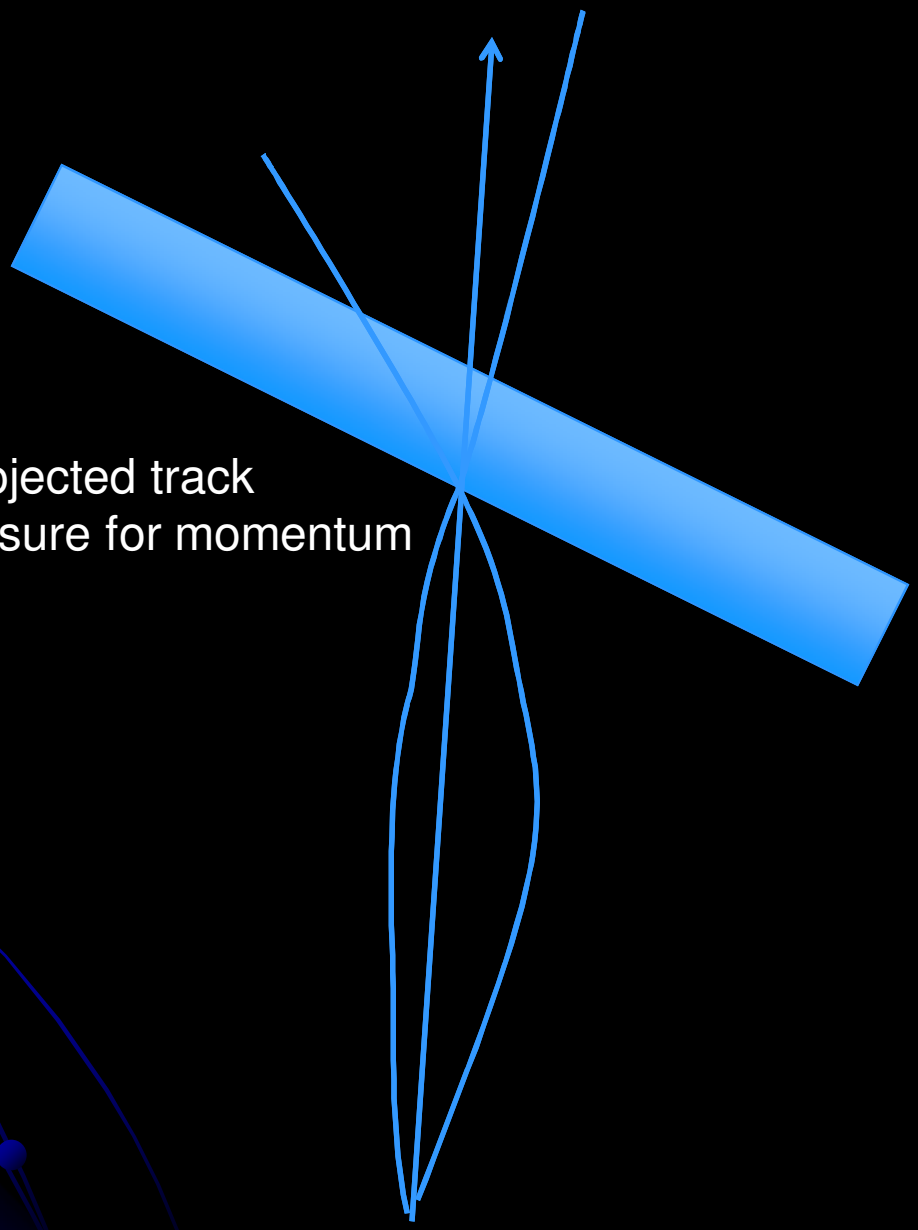
Double (Si) layers



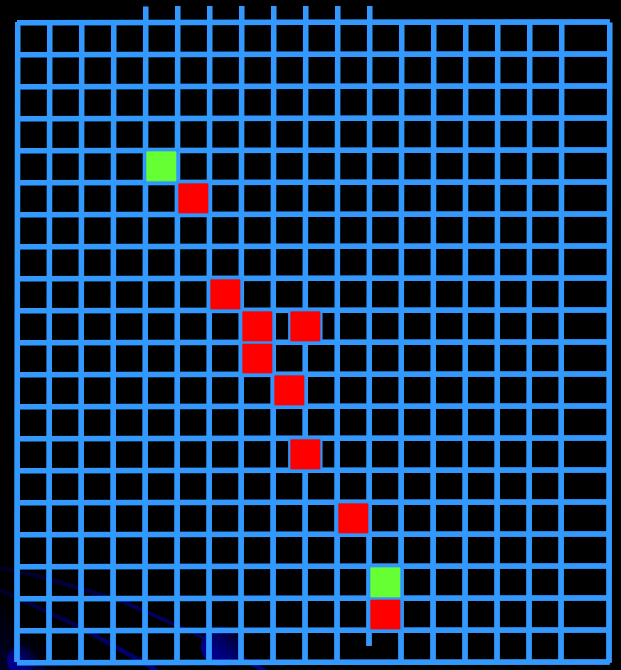
Requires inter-pixel chip communication,
or data transport to common correlation processor

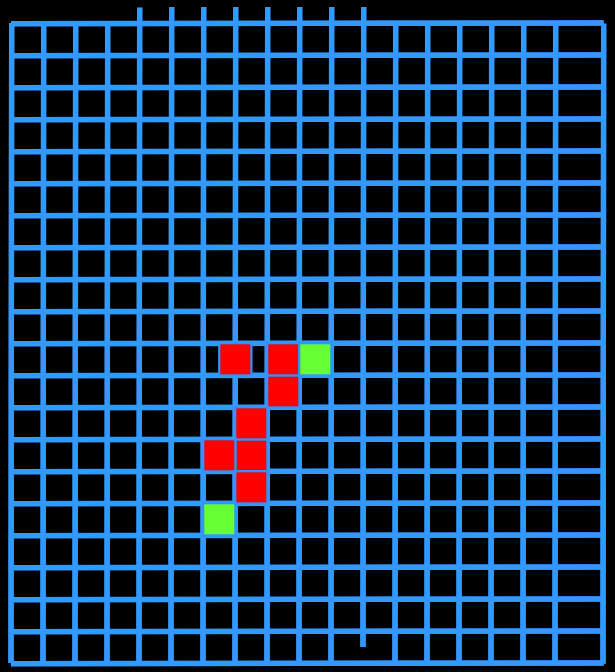


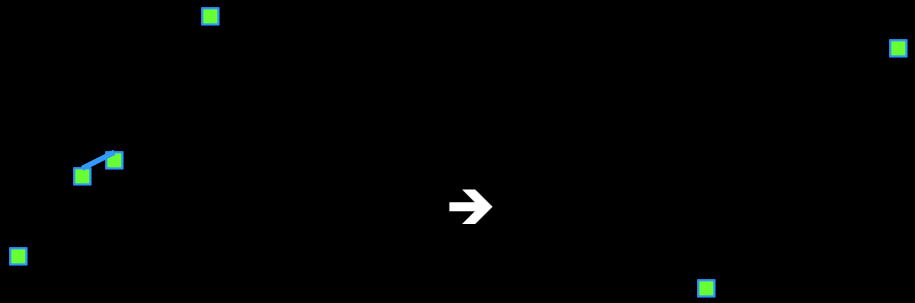
Gossip measures track segment vector in single layer



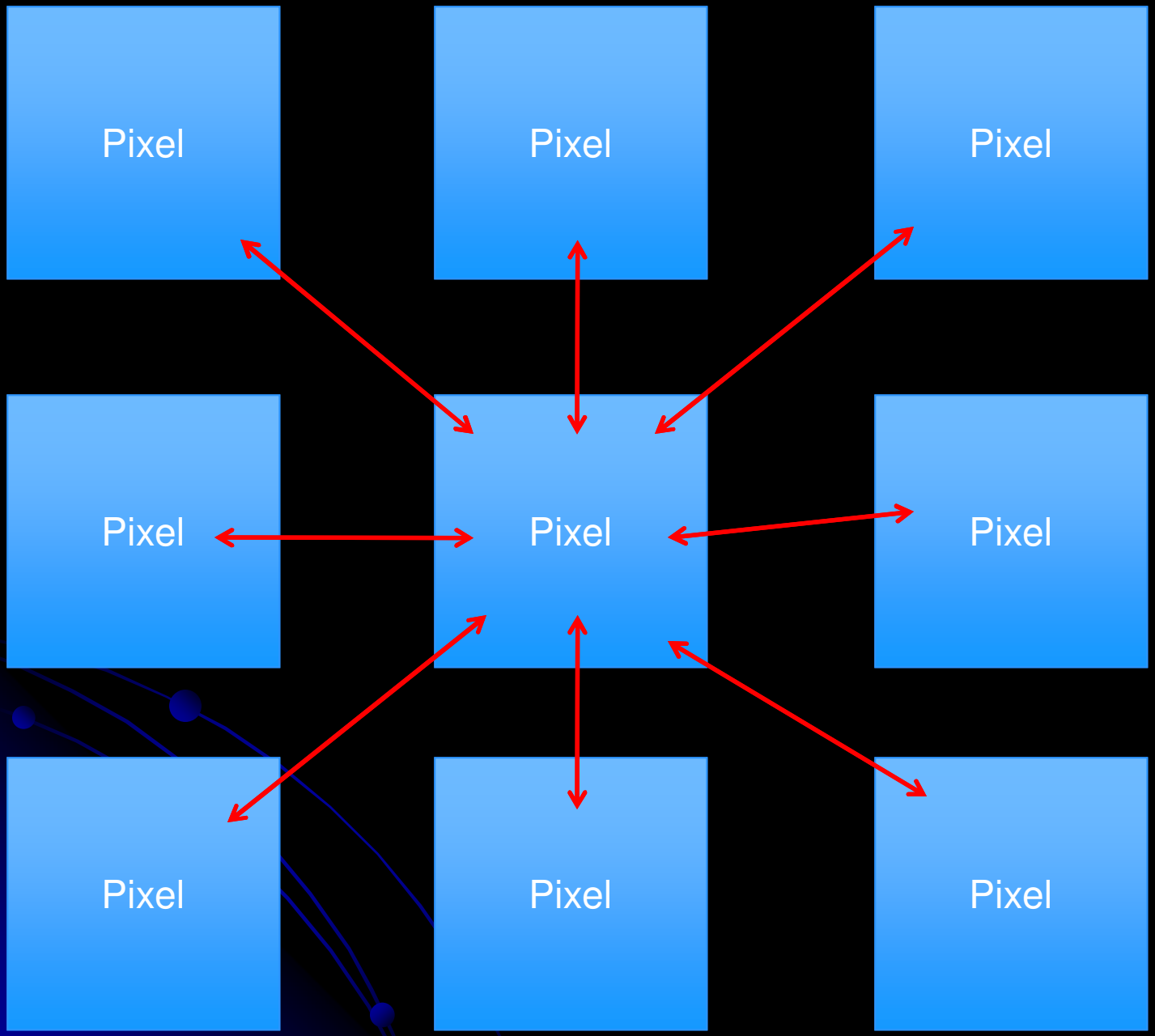
Length of projected track
is direct measure for momentum

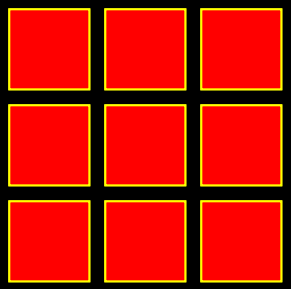






Endpoint Annihilation


Pixel
Pixel
Pixel
Pixel
Pixel
Pixel
Pixel
Pixel
Pixel



Workshop on Intelligent Trackers WIT 2010
Berkeley, Ca, USA. Feb 3 – 5, 2010

Goals of algoritm: find projected track length well within 1 μs, possible within ~ 10 ns.

- pixel: am I hit?
  -I may be part of a track
- is my neighbour hit?
- if two neighbours are hit I am probably not an endpoint
- if only one neighbourt is hit I may be an endpoint
- if there is another endpoint near me we should probably merge and annihilate
- Very unlikely to have two min. bias events on one chip

Large problem: projected tracks not contained in one chip
- at least two trigger LVL1 layers (maybe many more!)
- can be solved if ‘endpoint’ data can be processed externally

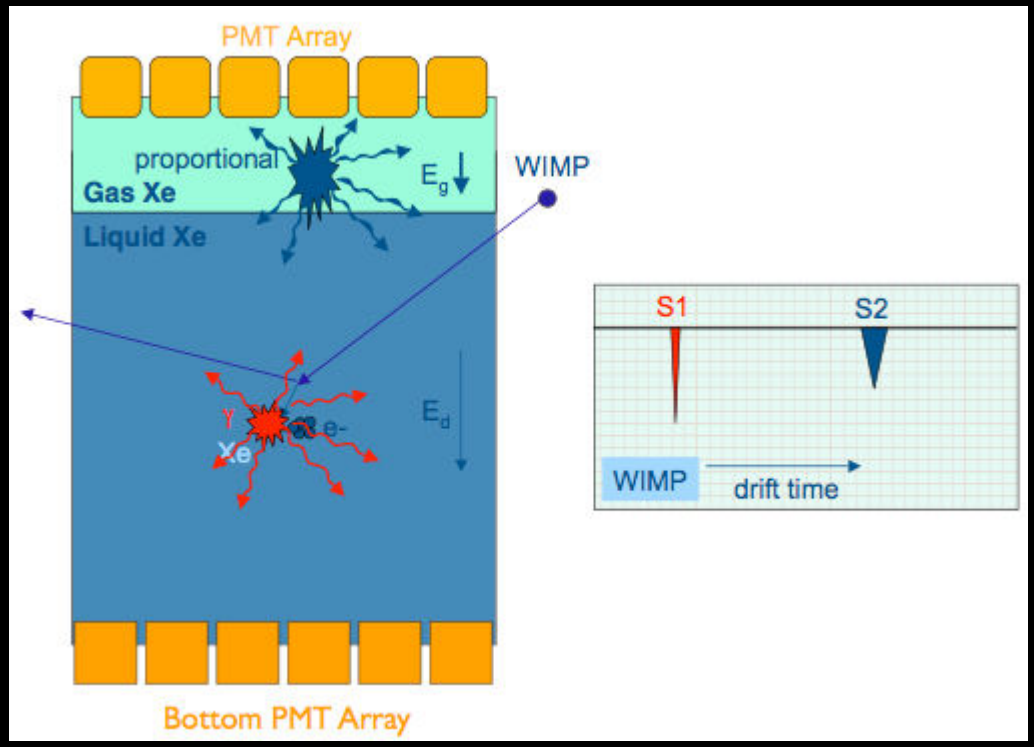
WIMP search, bi-phase Xenon

- GridPix TPC

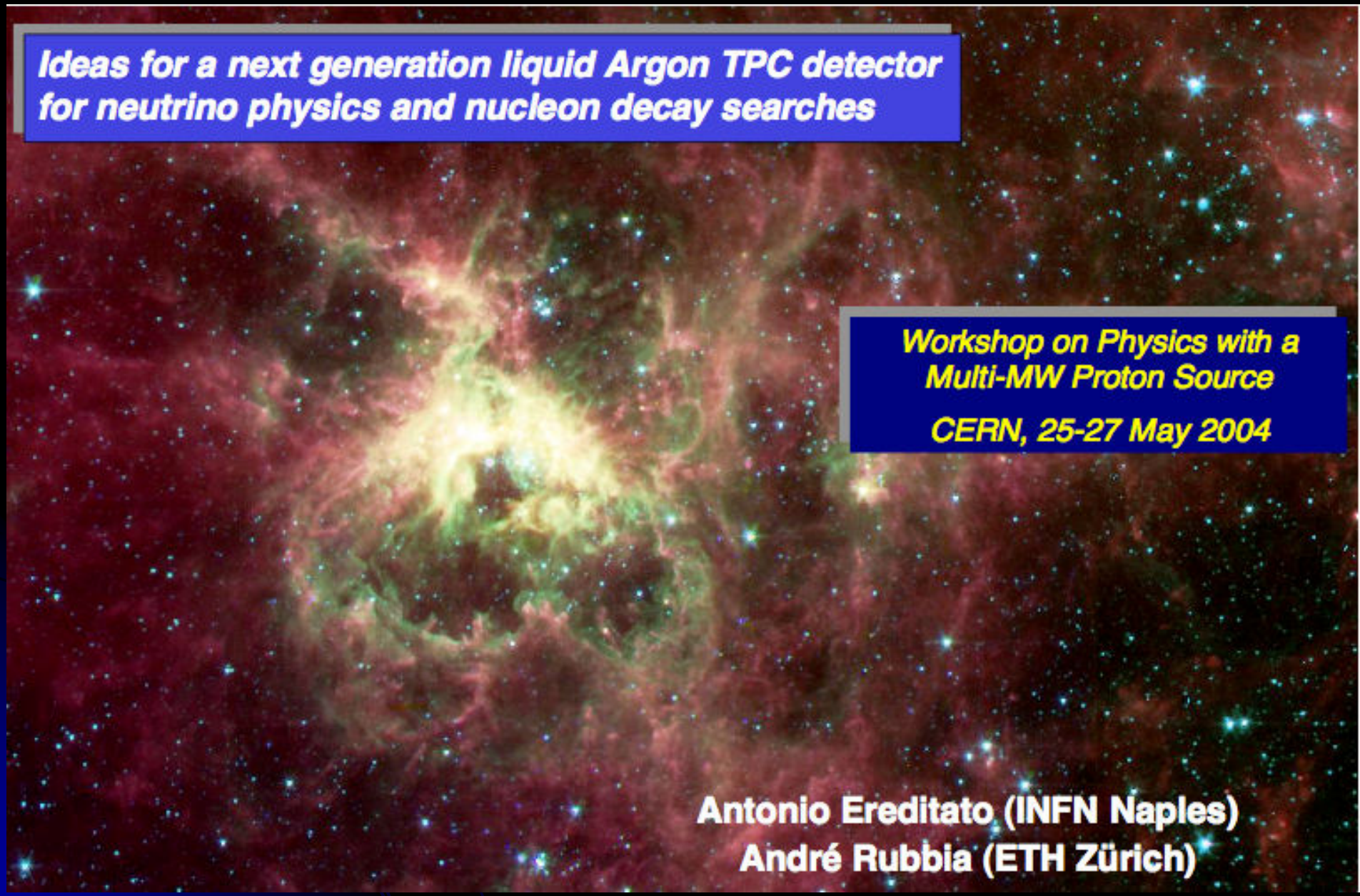
as

WIMP / DBD

detector



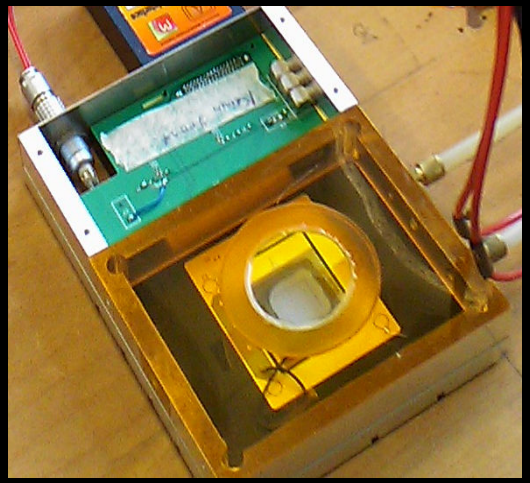
Source: Direct Searches for Dark Matter, Elena Aprile, EPS - HEP, July 21 2009, Krakow, Poland

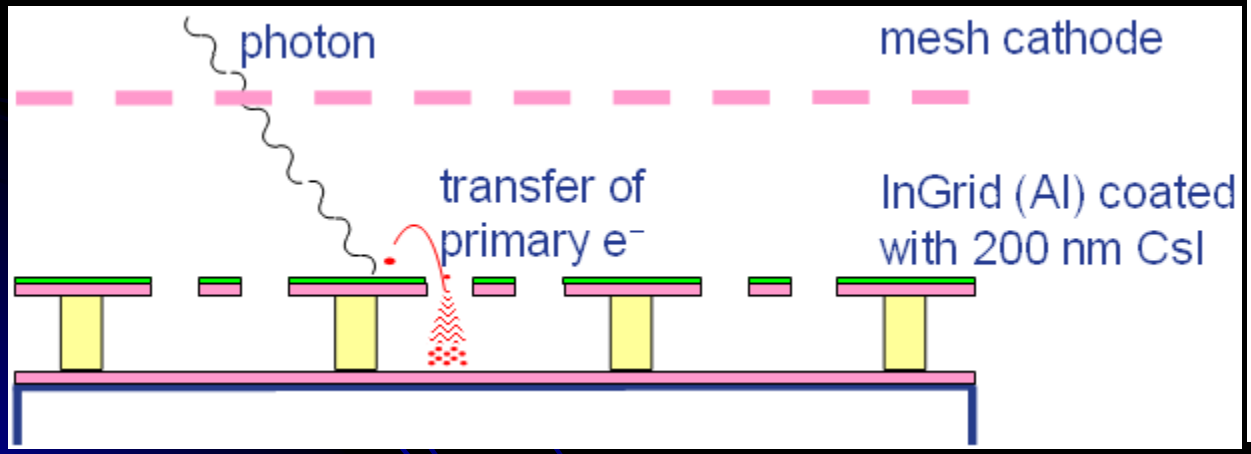

Ideas for a next generation liquid Argon TPC detector for neutrino physics and nucleon decay searches
Workshop on Physics with a Multi-MW Proton Source
CERN, 25-27 May 2004
Antonio Ereditato (INFN Naples)
André Rubbia (ETH Zürich)

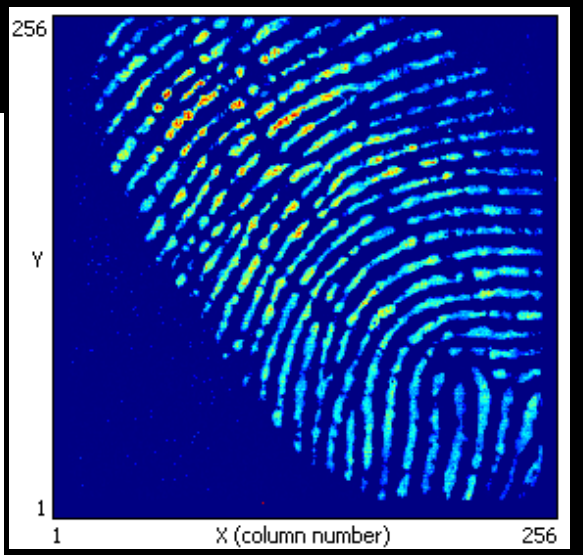
Expanding GridPix?

- Photoelectric effect
- Future possibility:

  CsI layer on grid

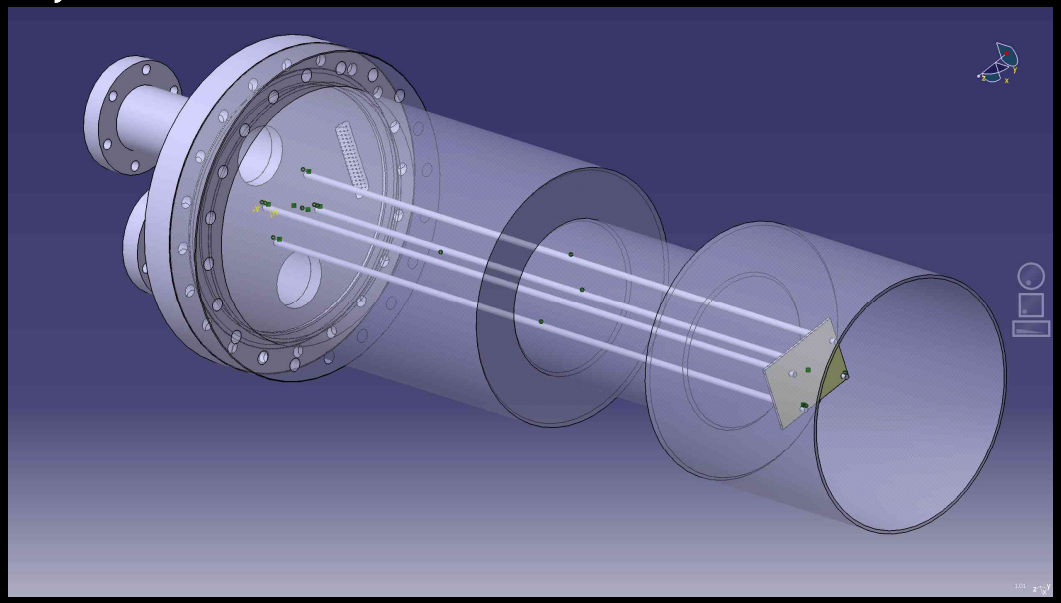


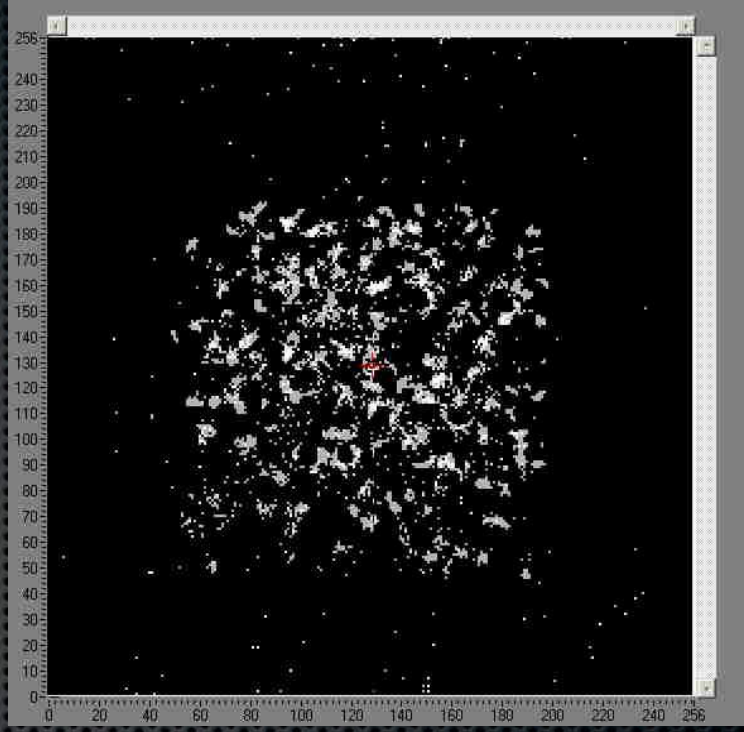




Gridpix in Xenon: Test setup

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

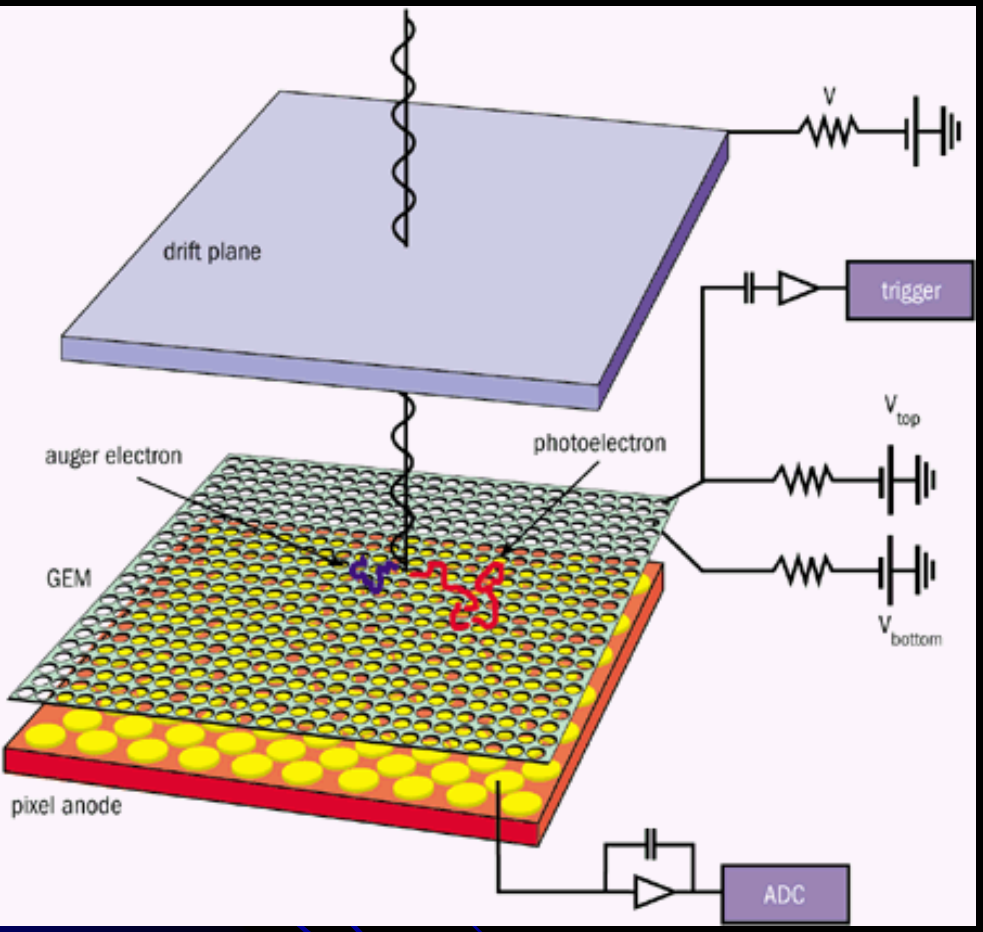


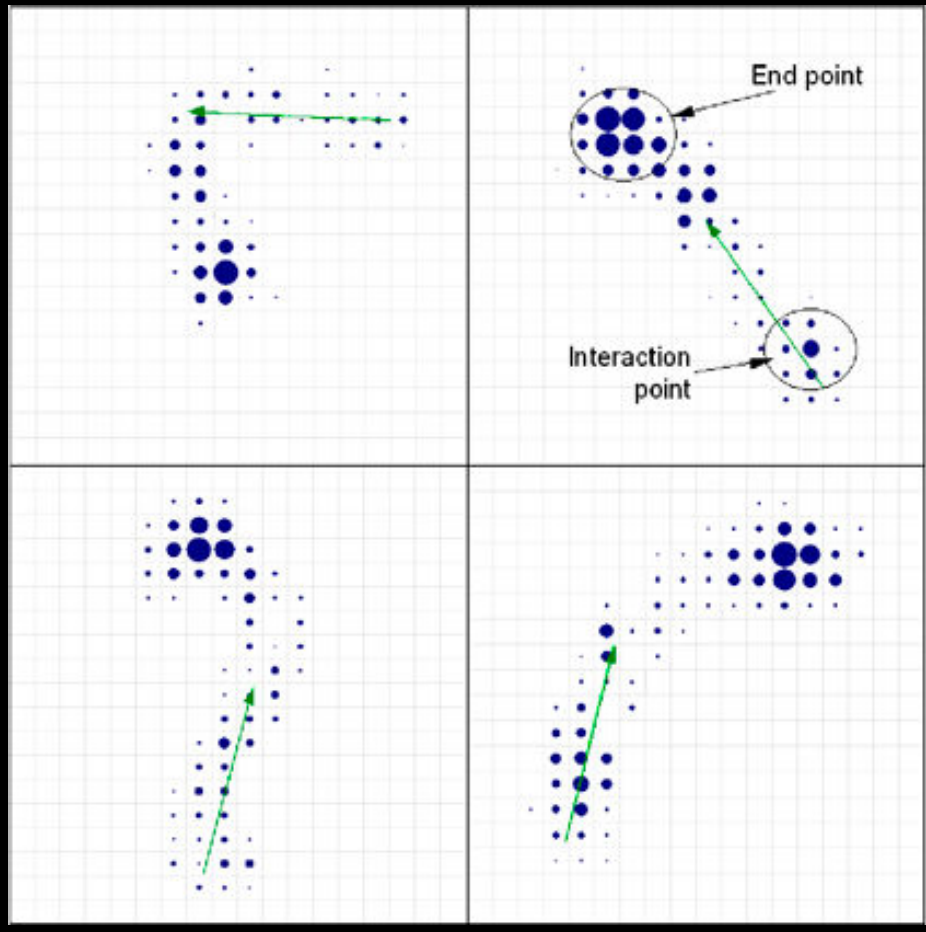


PolaPix

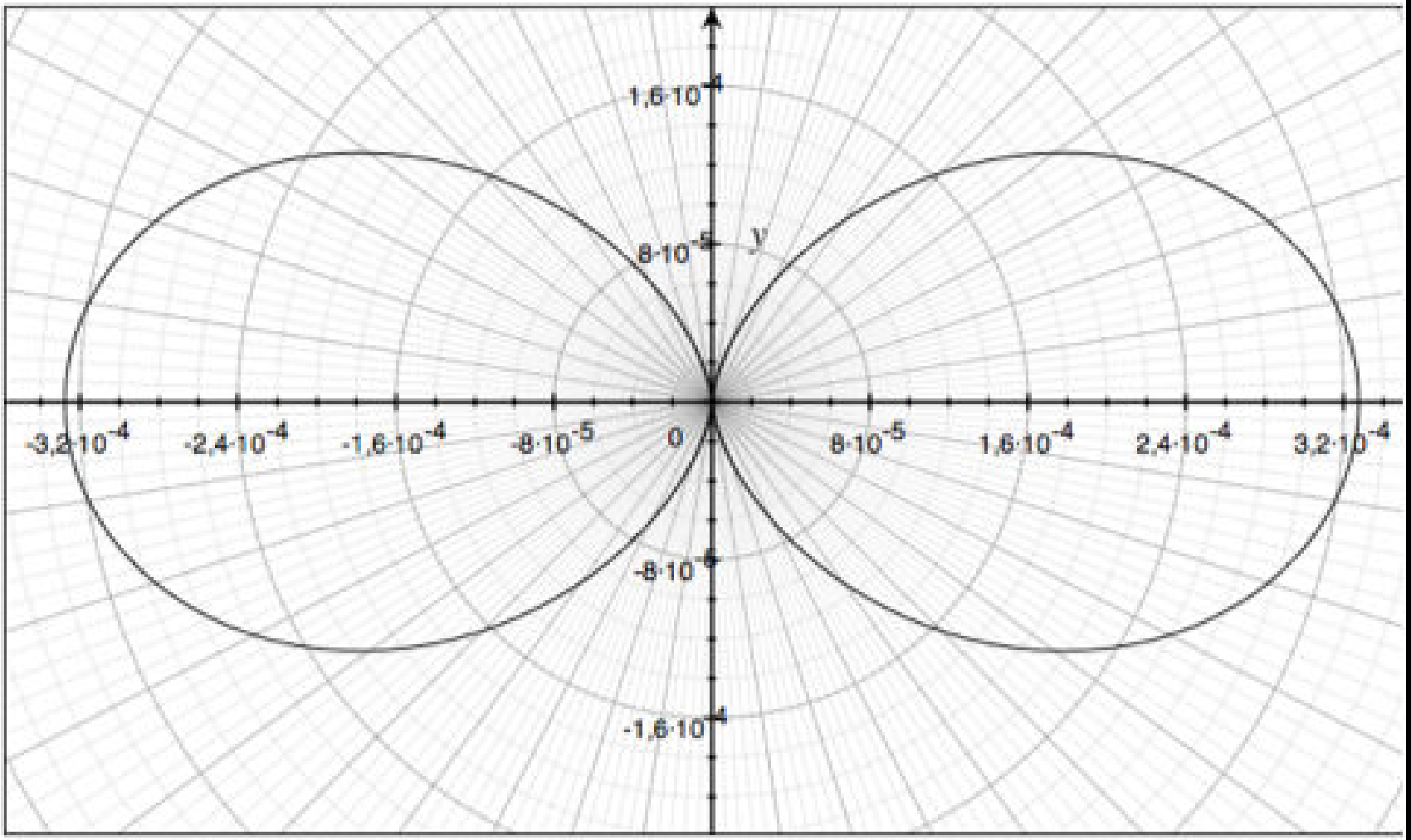
Using a GridPix detector for the 3D detection of polarized X-ray photons

Sjoerd Nauta - Nikhef

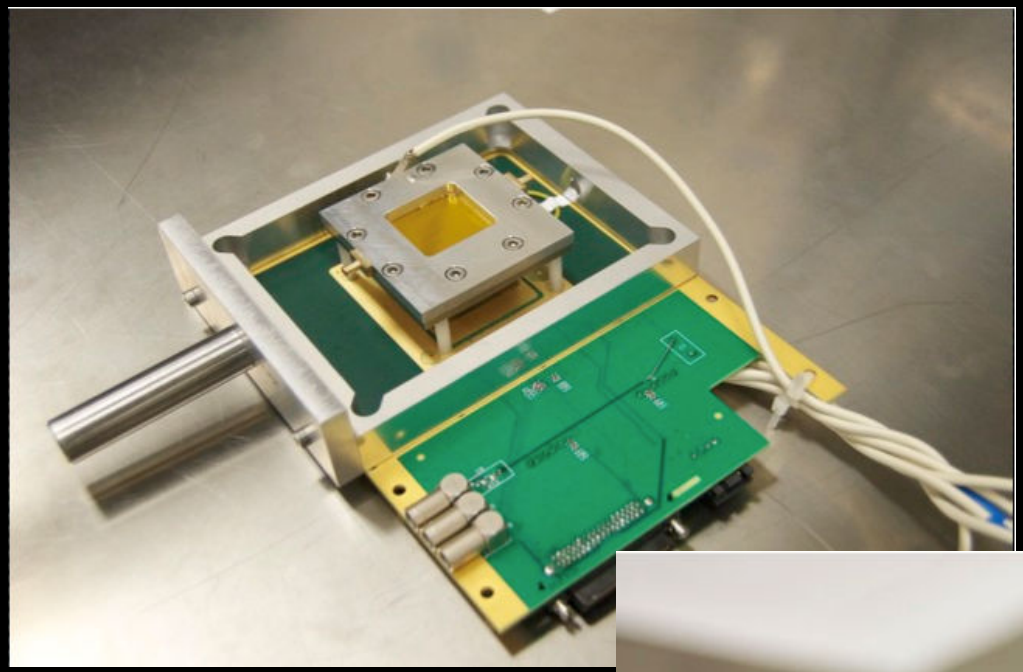




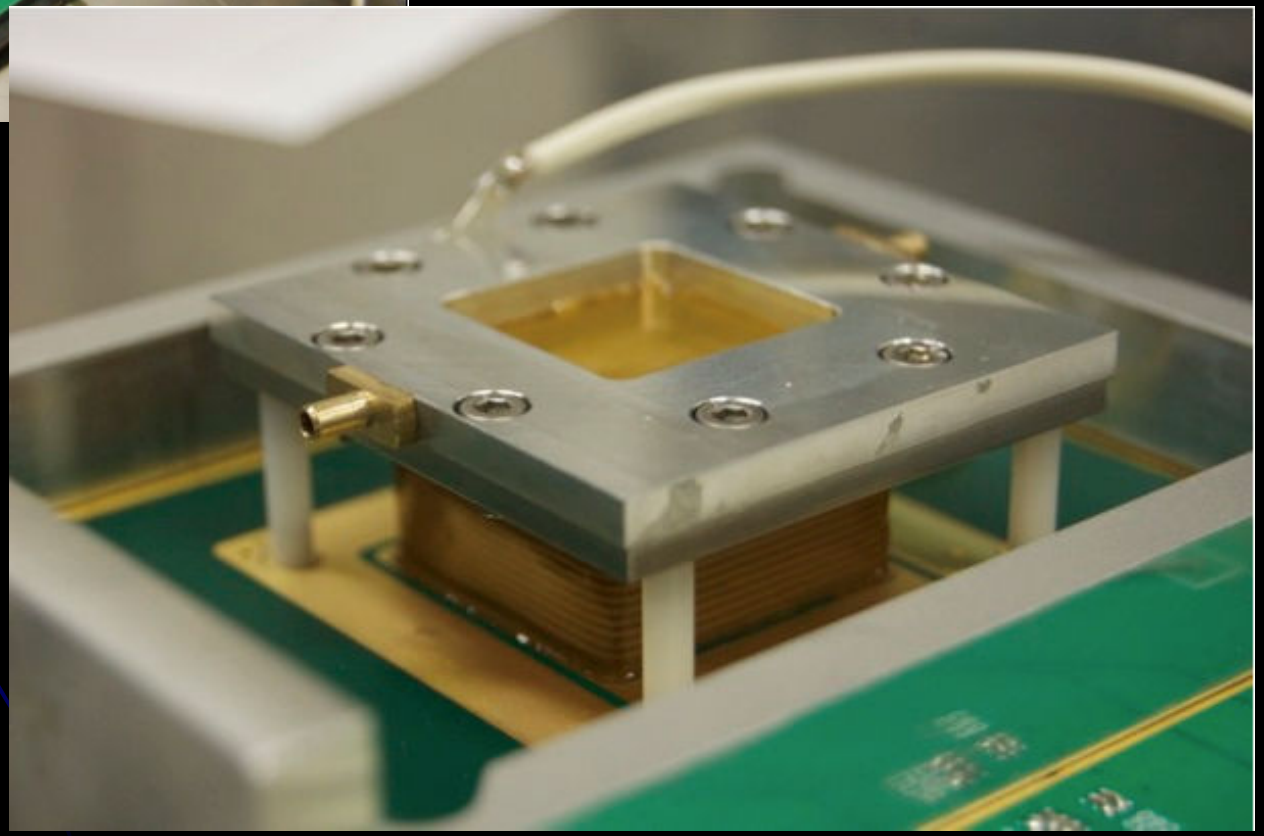
X-ray Polarimeter proposed by R. Bellazzini



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

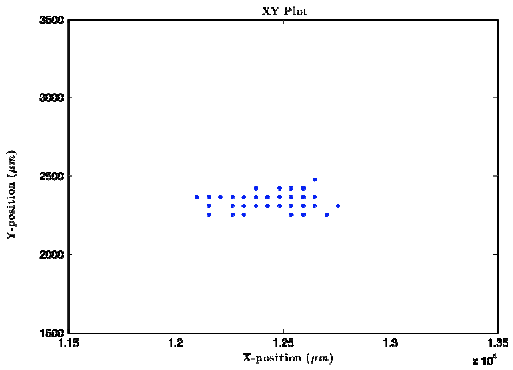


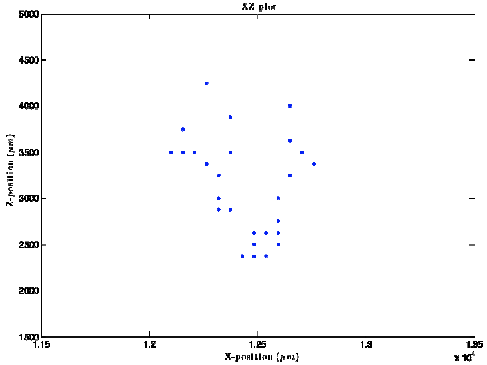
PolaPix

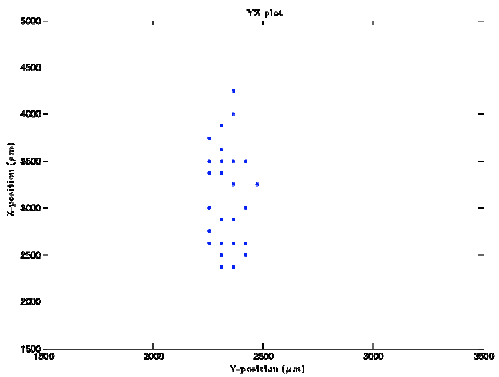


collaboration with

Erlangen Astroparticle Physics Group







XY XZ YZ

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

Two new (risky) projects:

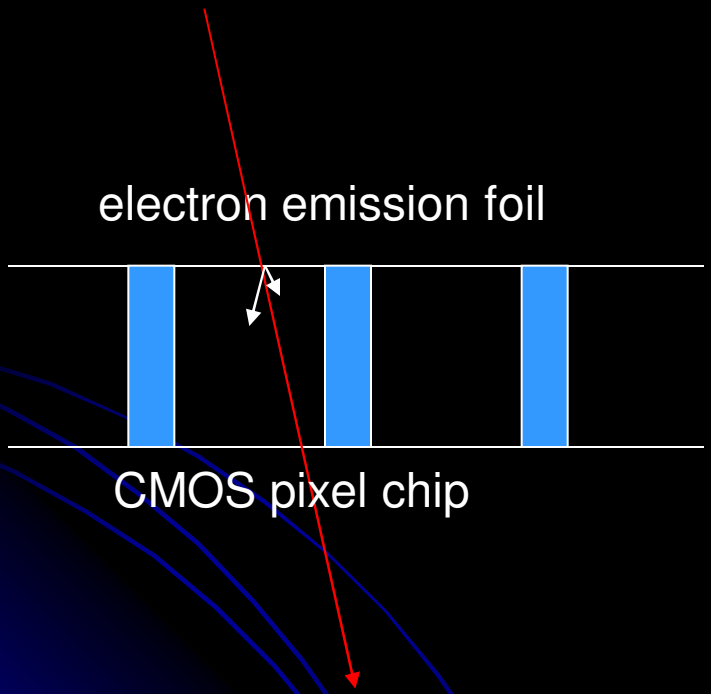
- electron emission & multiplication detectors

- light & light digital communication system

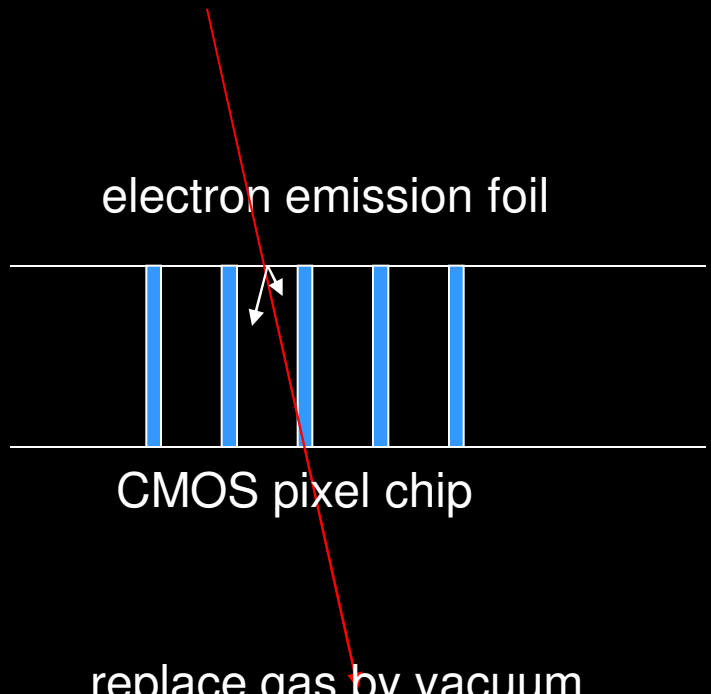
The future:

Electron Emission Foil

MEMS made MicroChannelPlates: 200 ps time resolution: CLIC

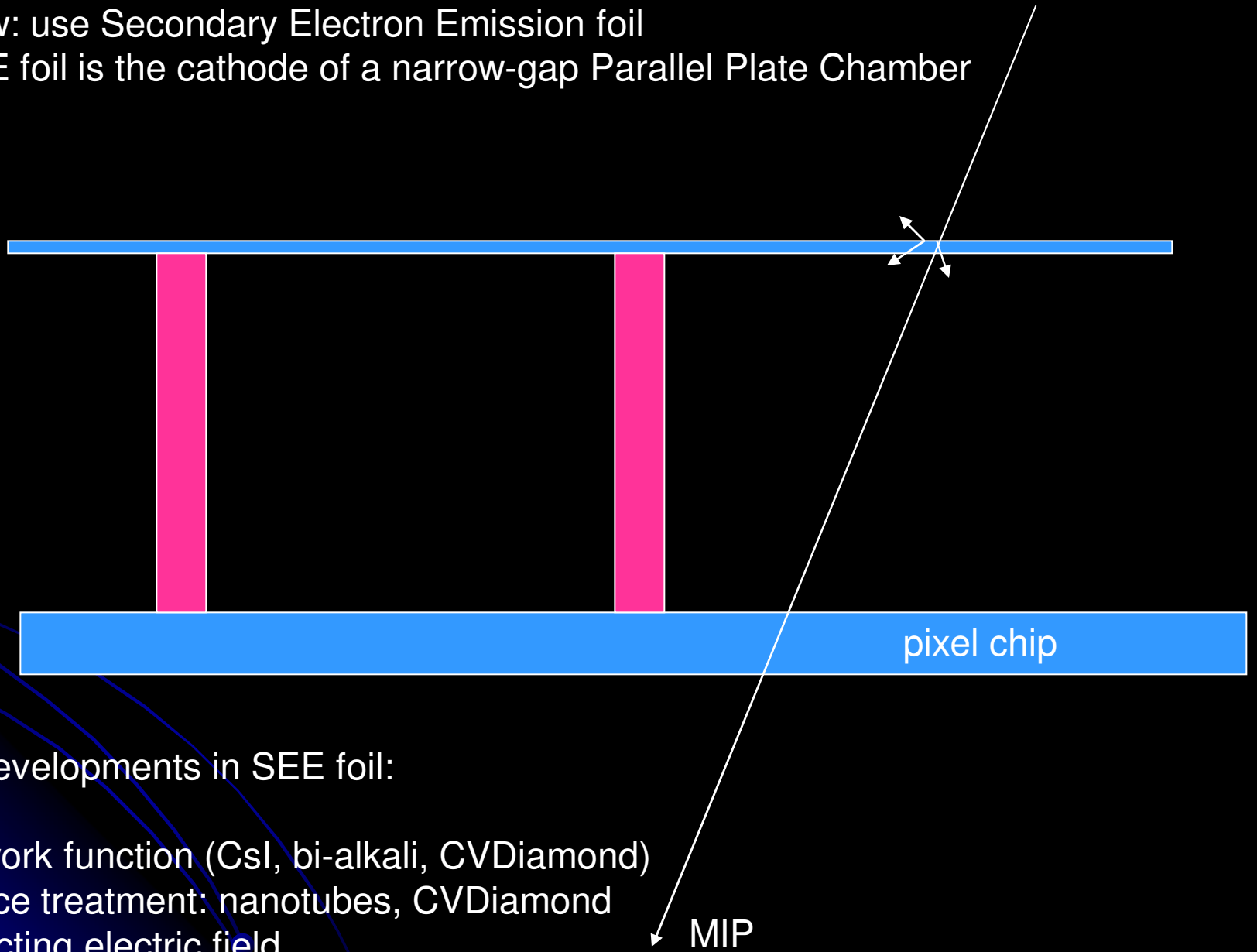


electron avalanche in gas
EE-Foil replaces InGrid
Parallel Plate Chamber



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

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



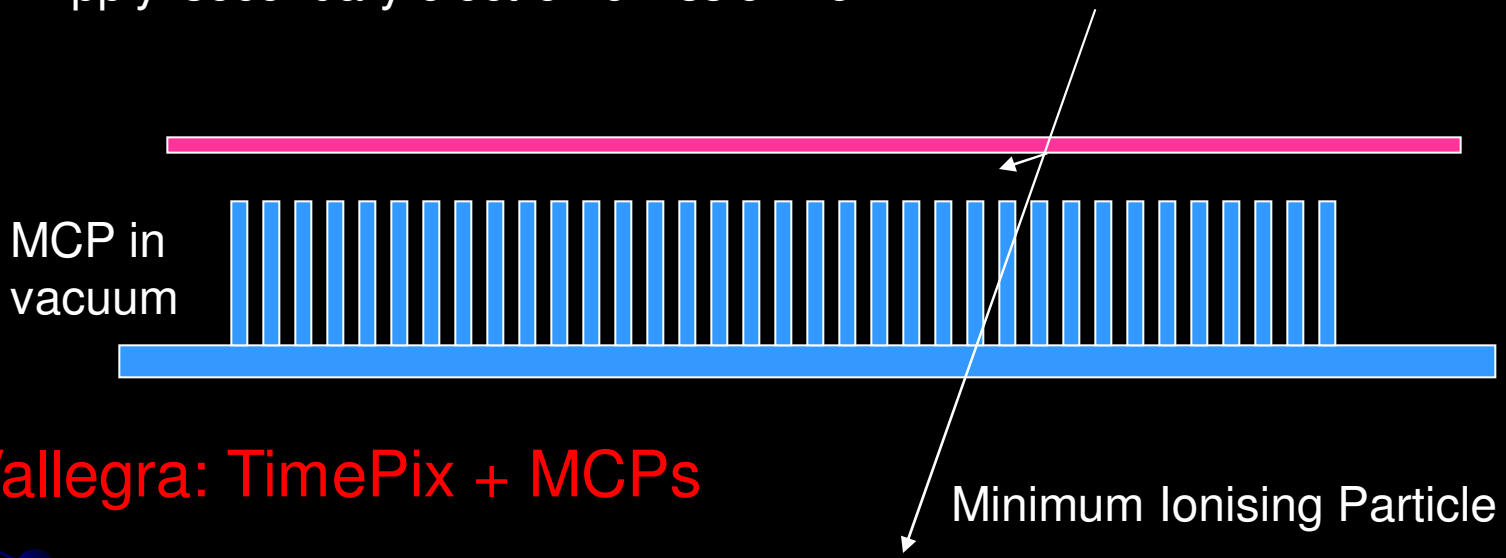
New developments in SEE foil:

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

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

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

Apply ‘secondary electron emission’ foil

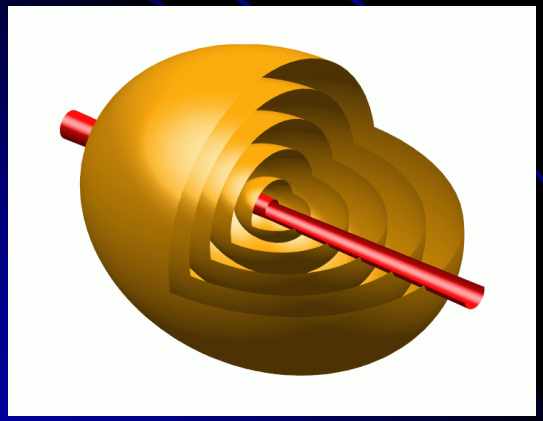


Vallegra: TimePix + MCPs

Time resolution < 200 ps

CLIC: BXs separated by 0.5 ns!

Gasless track detector

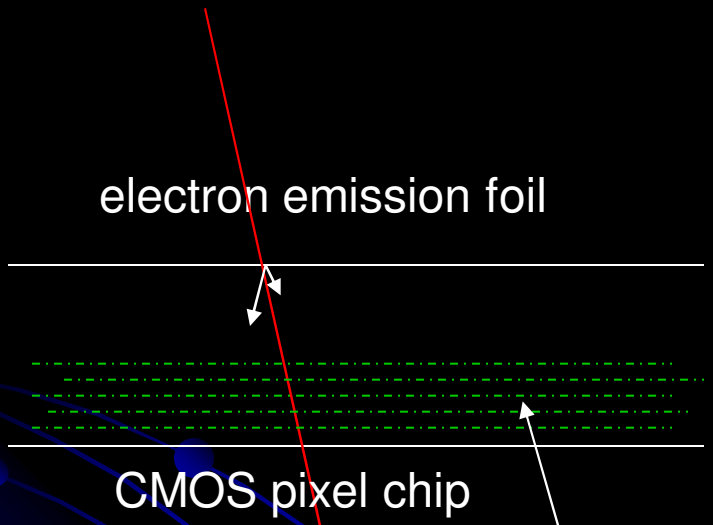


The future:

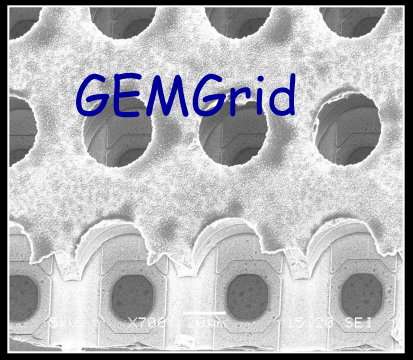
electron emission & avalanche detectors

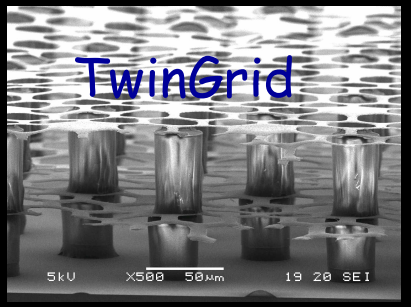
Electron Emission Foil

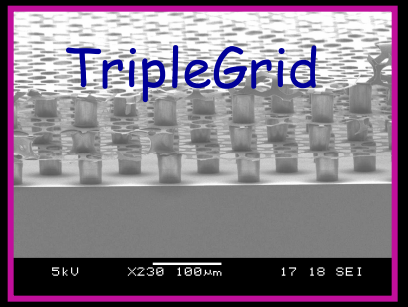
MEMS made MicroChannelPlates: 200 ps time resolution: CLIC



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



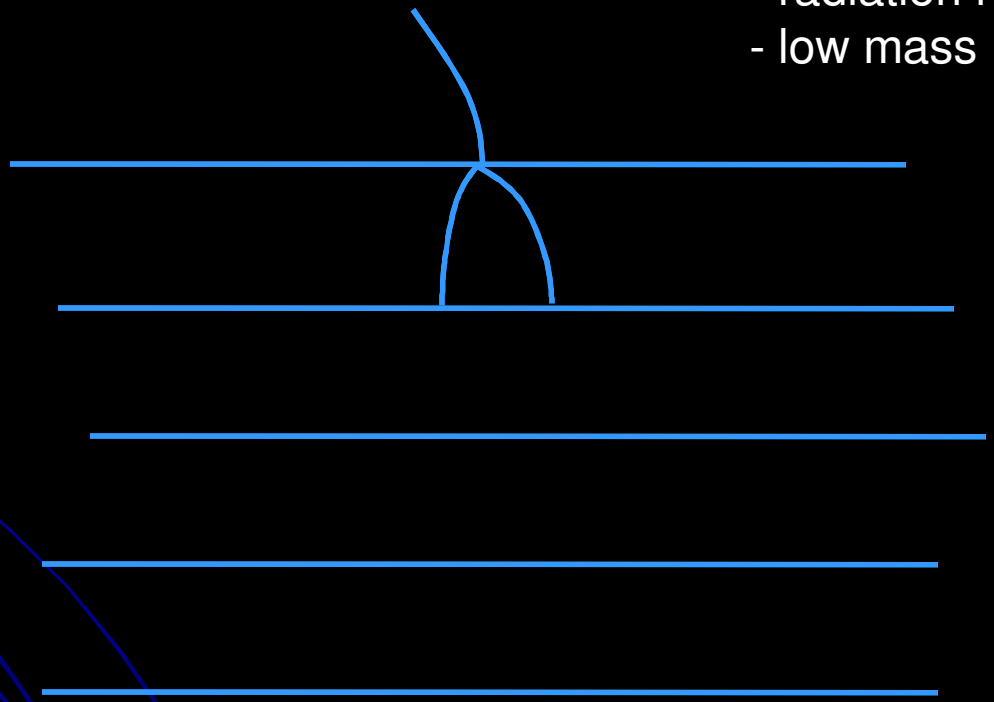




The ultimate electron multiplier: ultra thin (100 nm) layers

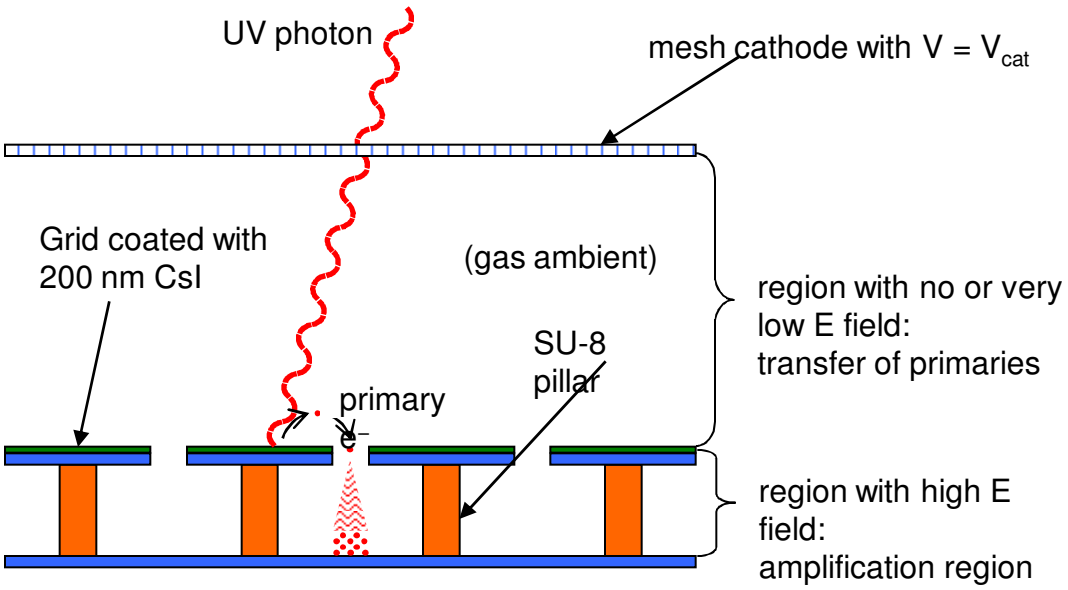
diamond

- ultra fast detector (0.1 ns)
- radiation hard
- low mass



In vacuum: no gaseous detector……..

Now operational:



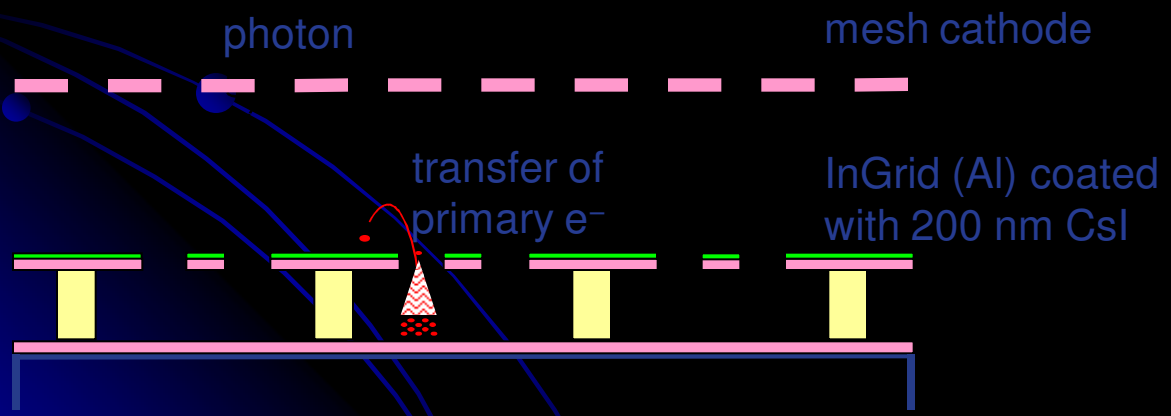
Joost Melay, Univ. Twente, MESA+
Jurriaan Schmitz' STW project 'There is plenty of room at the top'

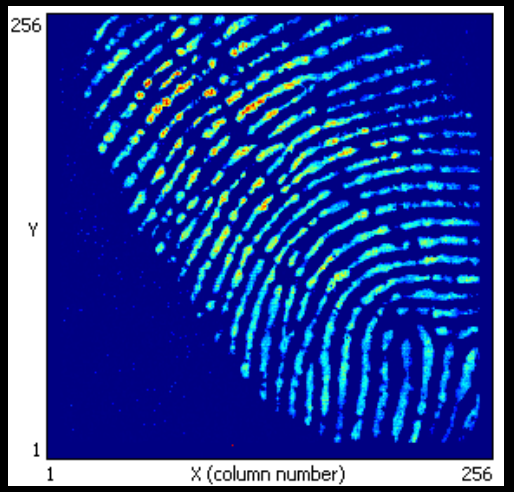
With Amos Breskin, Weizmann Institute of Science in Rehovot, Israel ,

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





Phase Modulator

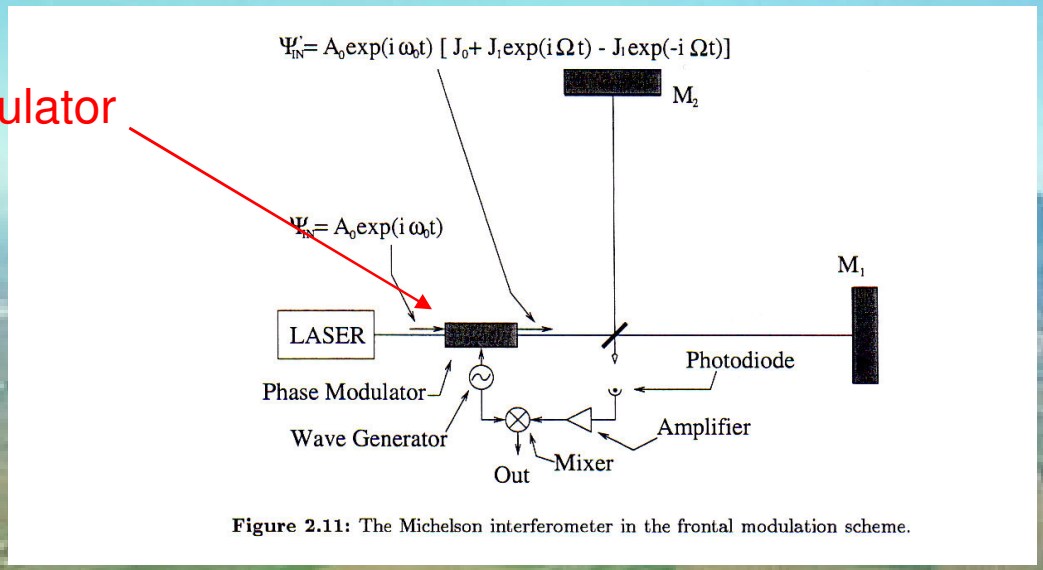


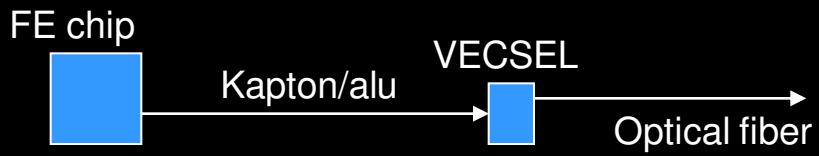
Figure 2.11: The Michelson interferometer in the frontal modulation scheme.

VIRGO

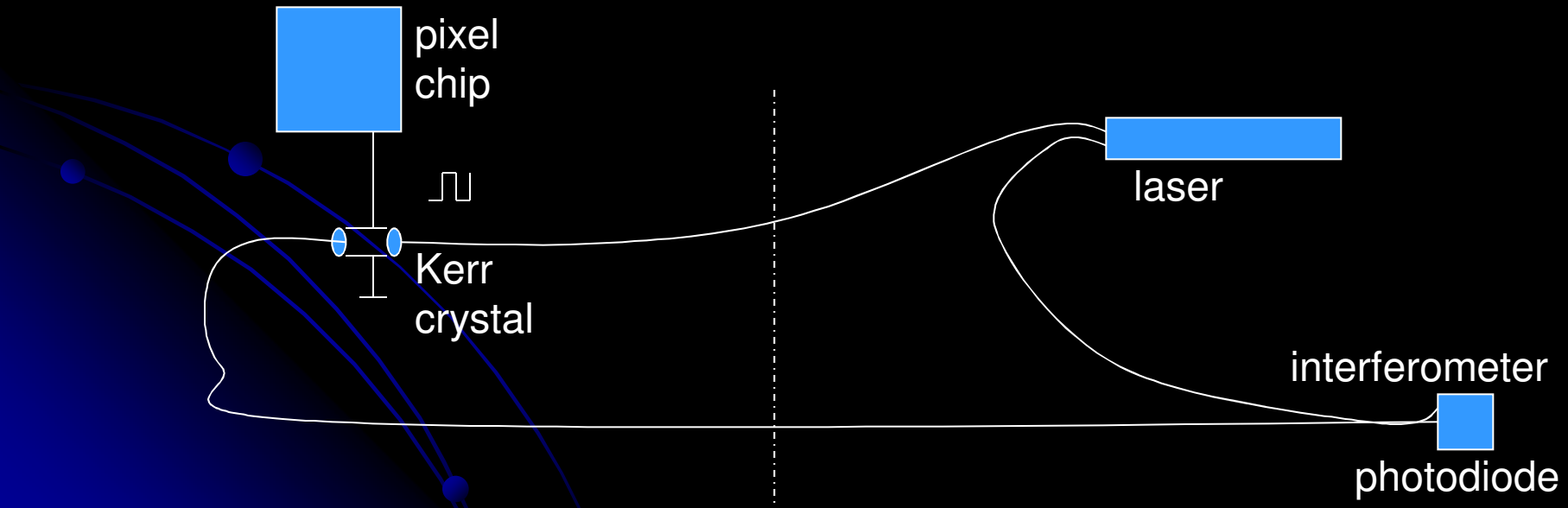
Data Transport

New bottleneck:
Data bus Kapton/Cu/Al

- data to outside world
- inter (pixel) chip communication
- Level 1 trigger



status: kapton/aluminium: dominant material for pixel detectors @ sLHC!
VECSELs + optical fiber: not rad hard, much material, much power required



IfLink

A new optical fiber data connection based on interference

- one-way communication
- modulation directly on fiber with LVDS levels

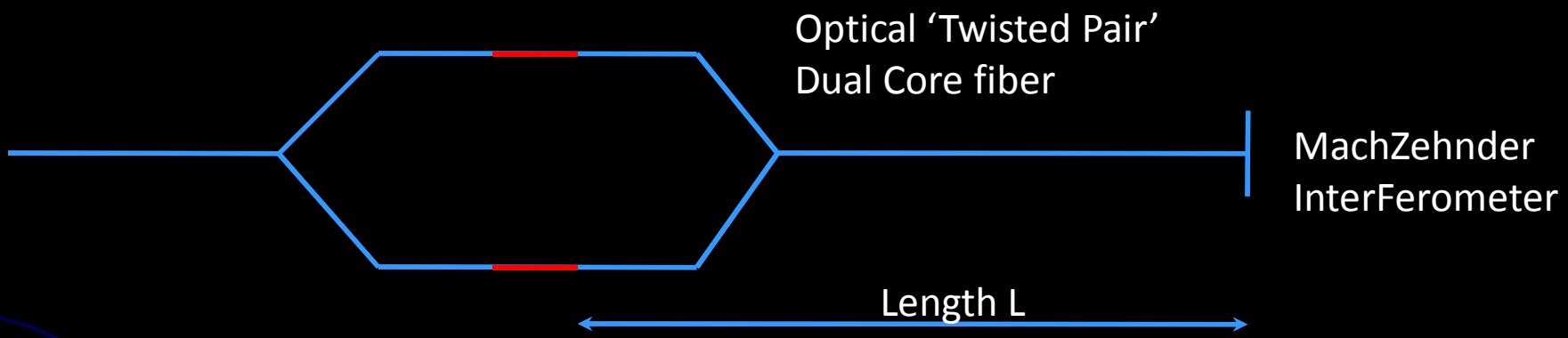
- radiation hard

- low (essentially non) modulation power dissipation at sensor

- no modulator volume & mass

Essential: phase shift modulation in ‘thermally poled’ (quartz) fibers, or rad-hard LithiumNiobate Xtals (RD24 (1993)).

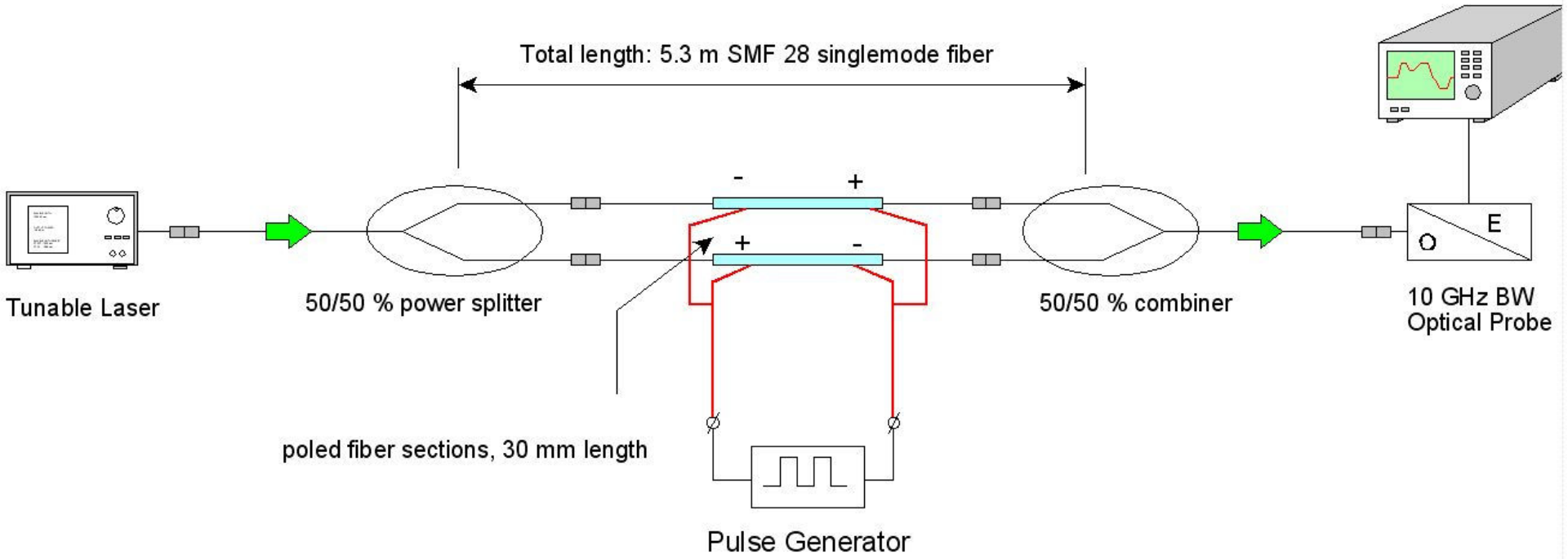
Final try: optical ‘twisted pairs

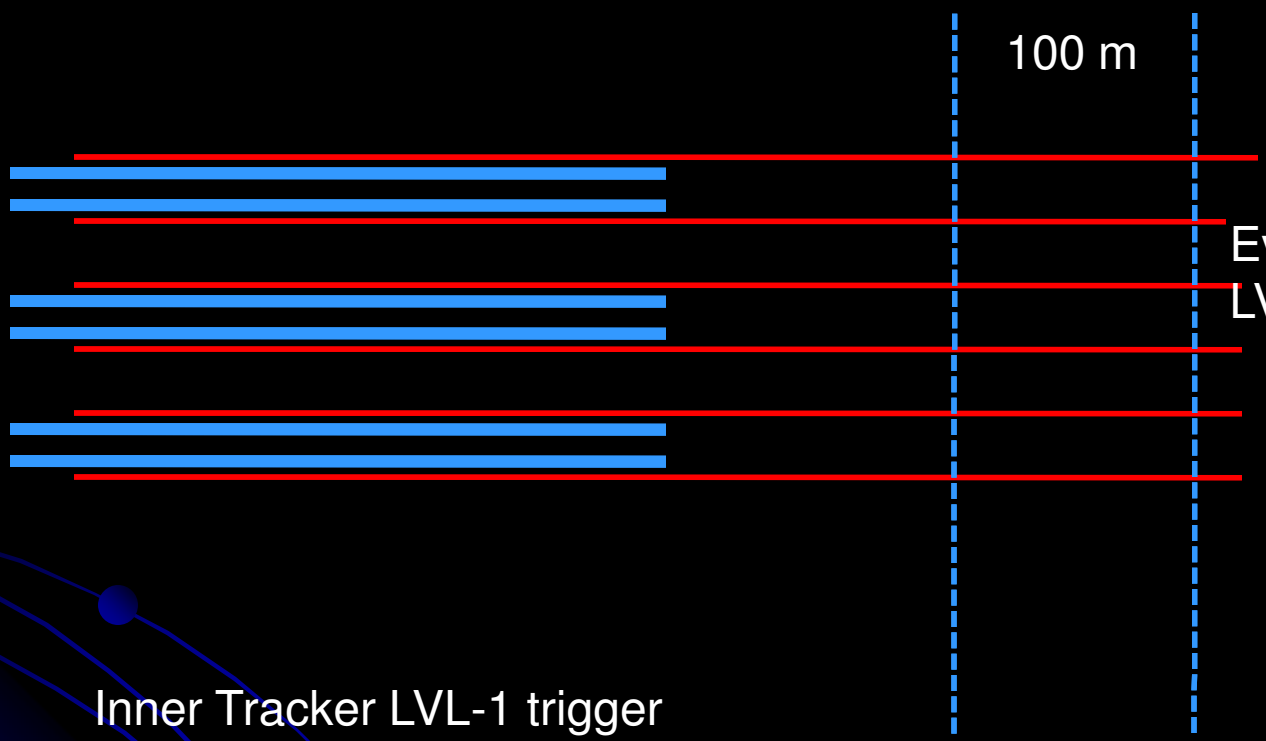


- Phase noise as a function of length L?
- ICFO (Barcelona) proposes small MZM
- 40 Gb/s seems feasible

Interferometer with poled fibre sections in each branch

VANDERHOEKPHOTONICS





Inner Tracker LVL-1 trigger
readout with fiber-per-(pixel) chip

How ‘light’ can we make a detector?

Lots of upgrade and new detector plans

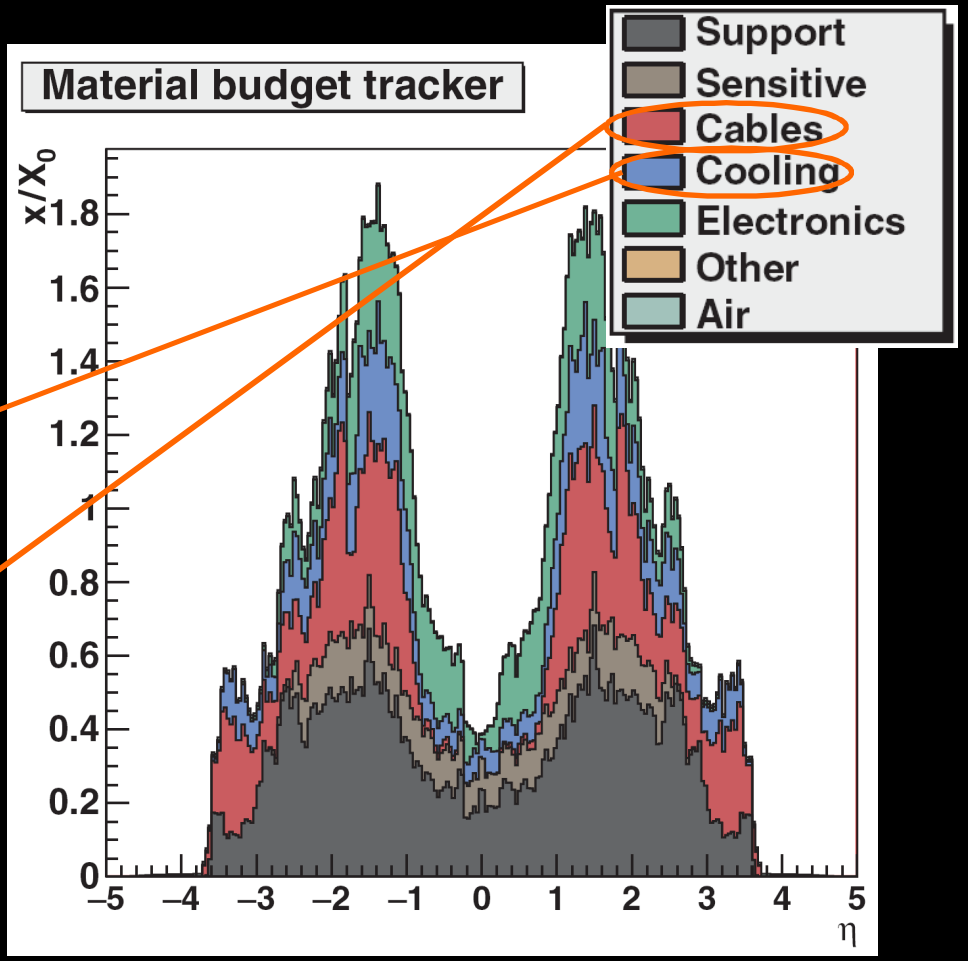
All should become less massive than present detectors

A lot to gain in cooling and cabling

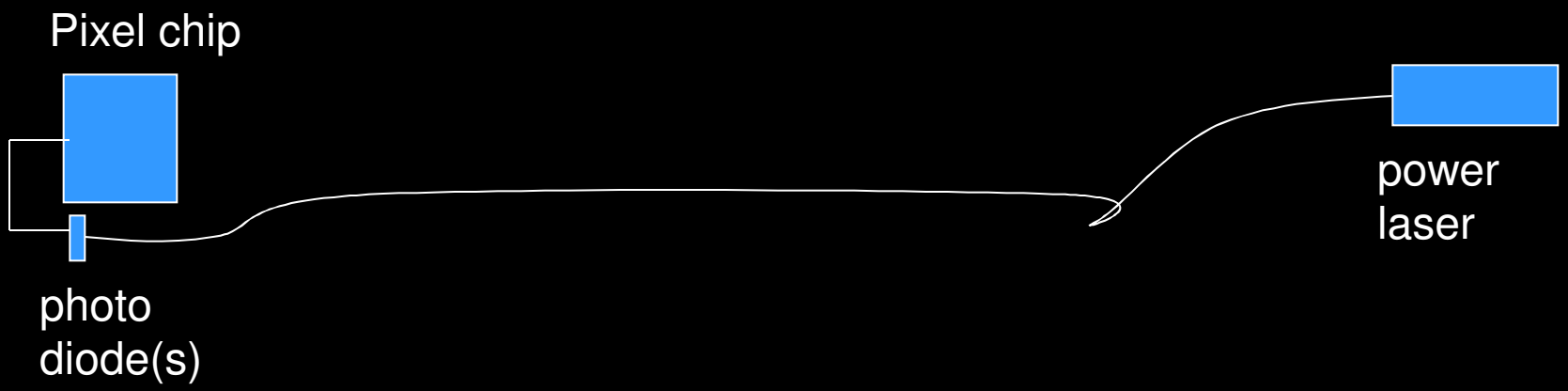
Cooling → CO_2 (Bart Verlaat, Nikhef)

Cables → Data AND Power through glass fiber

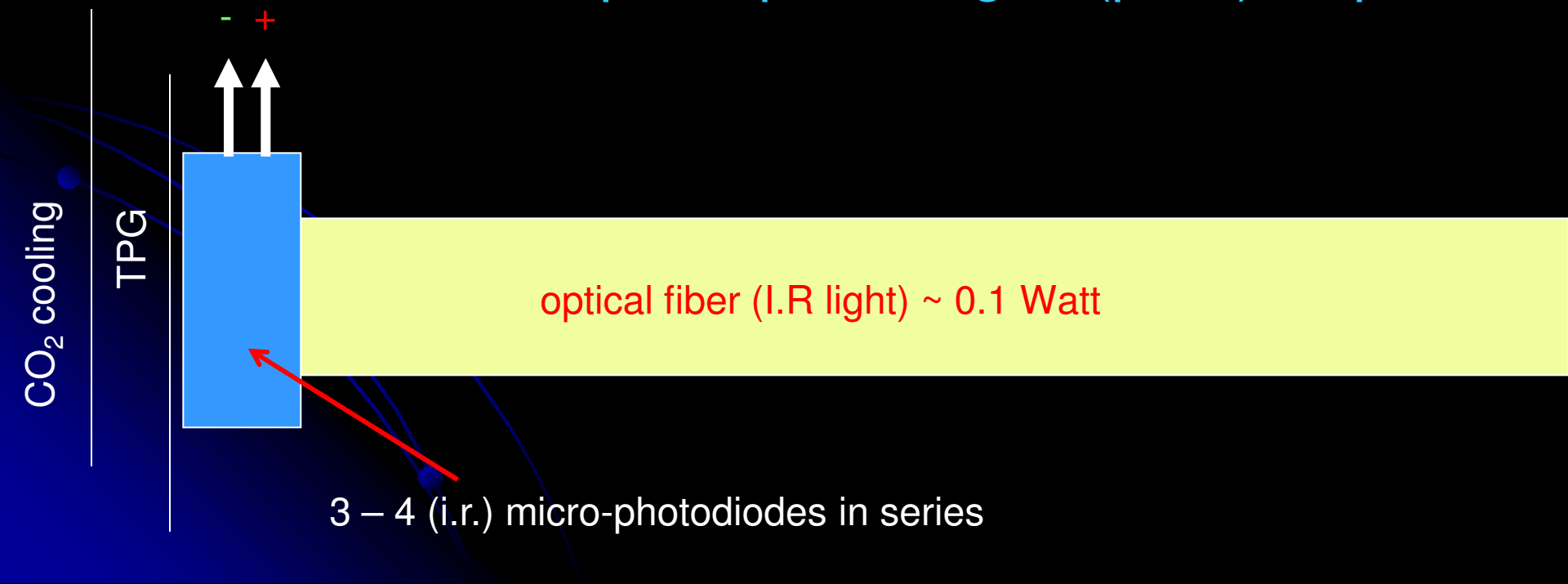
Cu out, SiO_2 in

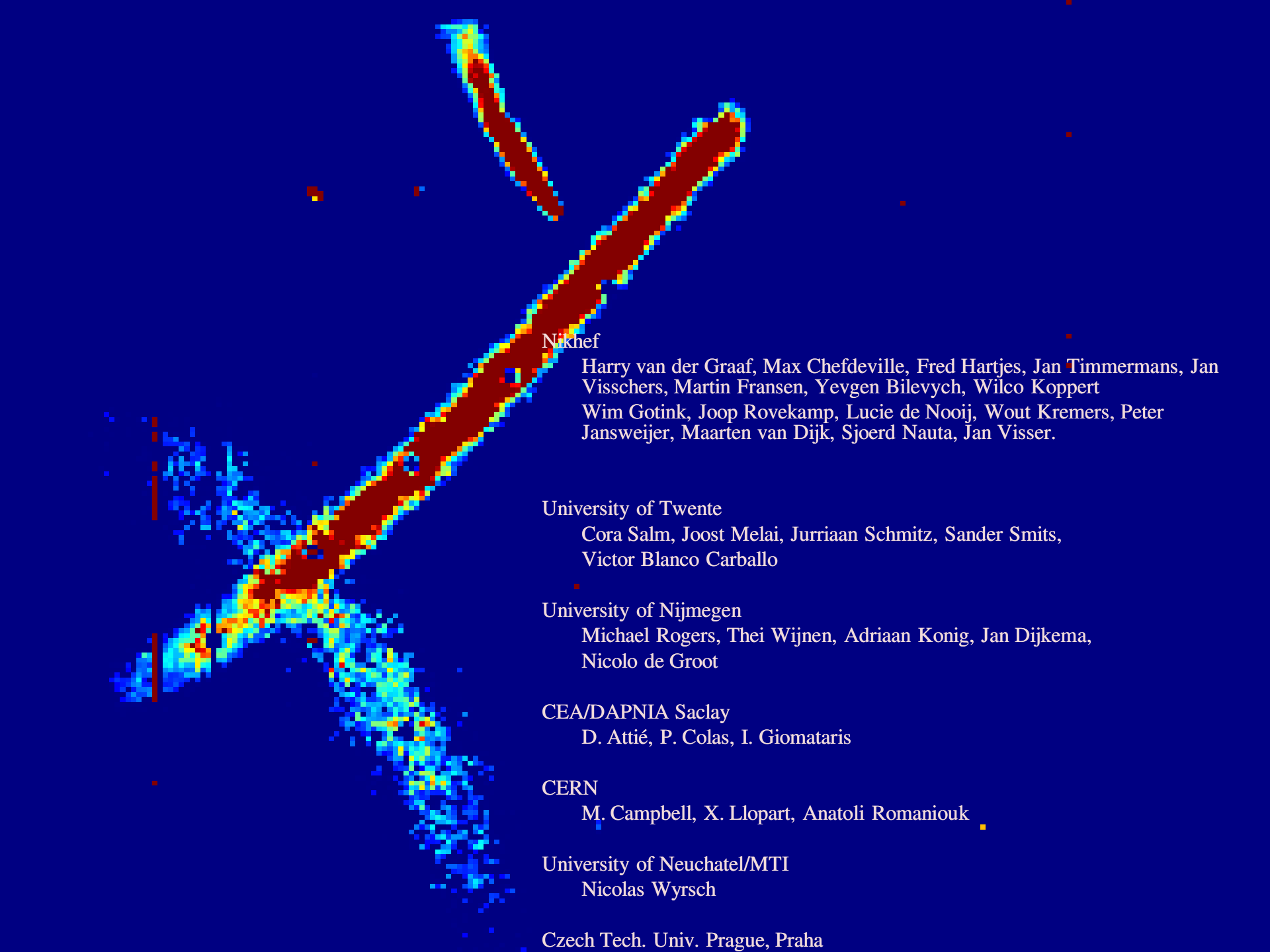


Ch.Genta, Performances of the CMS tracker



Optical powering of (pixel) chips





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