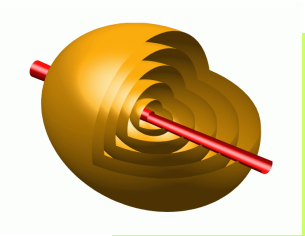


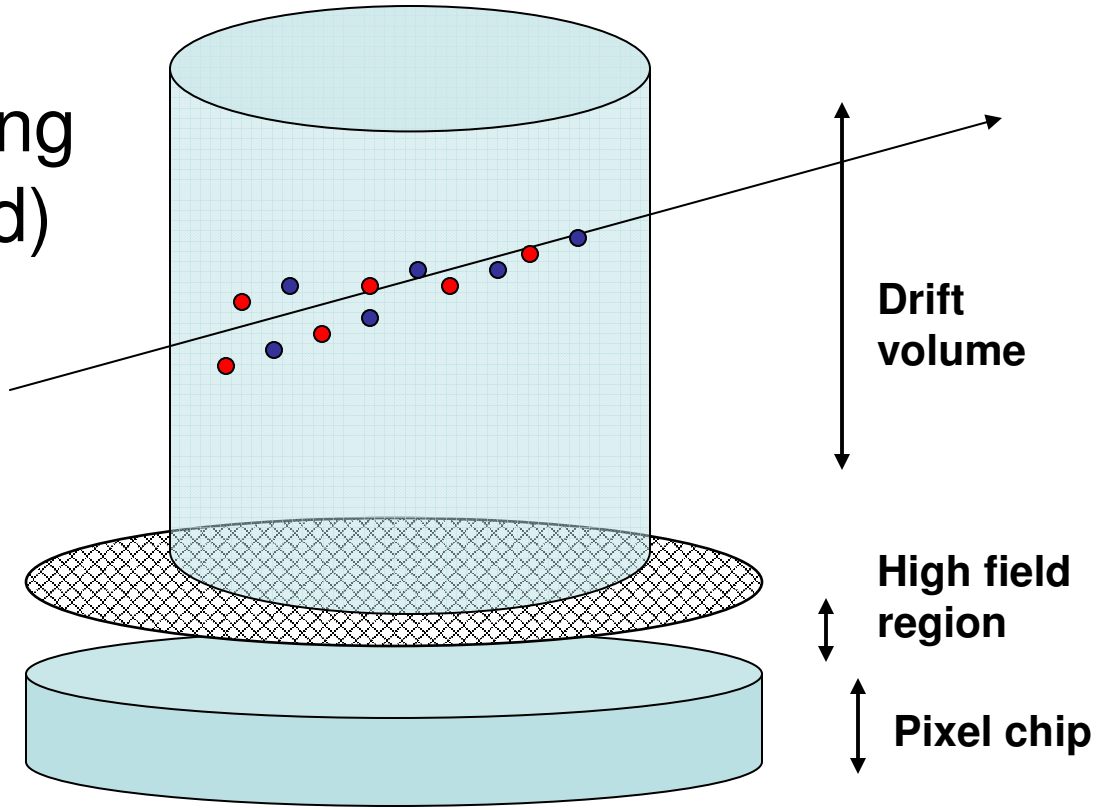
Gossip [gas on slimmed silicon pixels]

1. Existing pixels
2. Micro Pattern Gas detectors
3. Tracking with Gossip

Els Koffeman
Nikhef/UvA

What is in a name ?

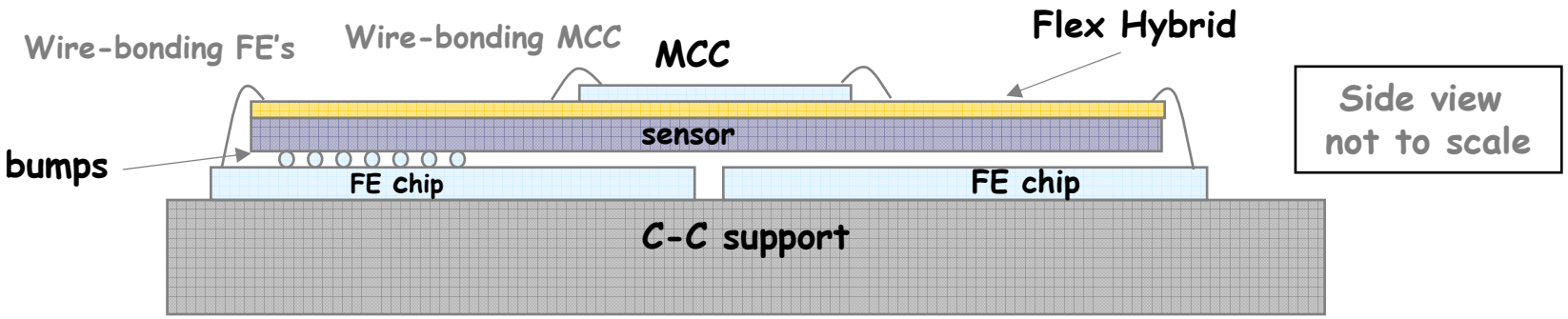
- Gridpix = match grid pattern with pixels on a chip
- Ingrid = wafer processing to make grid (integrated)
- Gossip = thin drifter (~mm) to make vertex layer

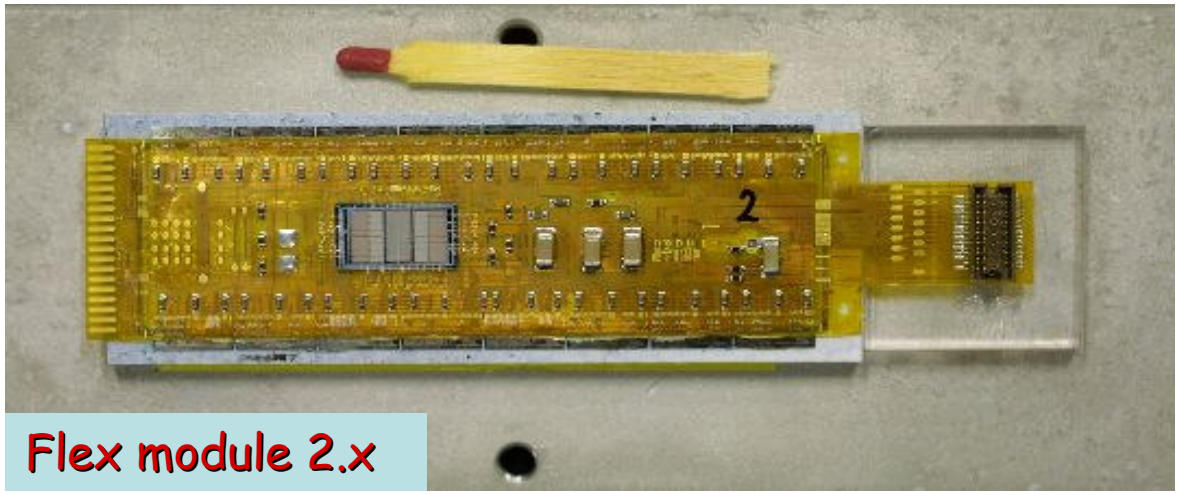


Existing pixel detectors

- Silicon pixels at ATLAS and CMS
  - Silicon sensor bump bonded to CMOS front end chips
  - Typical cell size of Atlas 50 x 400 um (CMS 100 x 150 um)
  - Readout clock 40 Mhz
  - Each cell connected to (analog) readout and pipeline on the chip
- State of the art performance
  - Position resolution (10 um)
  - Two track separation (200 um)
  - Occupancy and efficiency (10-6 and 99%)
  - Radiation hardness (10^15 Neq/cm2 and 50 Mrad)
  - Particle identification
  - Material budget
  - Cost & complexity

Example : ATLAS pixel detector





Pixel chips

- FEI-3 (Atlas)
  - Version 2003
  - Time over threshold – digital readout
  - 0.25 um CMOS
- PSI-46 (CMS)
  - Version 2005
  - Analog 6-8 bits
  - 0.25 um CMOS
- Medipix…..

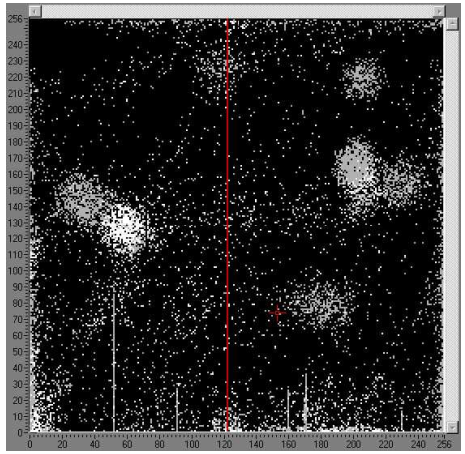
Medipix in a nutshell

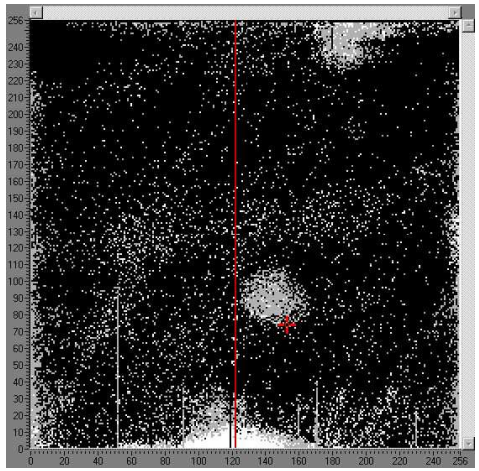
- Pixel chip developed for photon counting
- 55 x 55 um
- shutter time

- Medipix has been used to develop ‘gas on pixel principle’ because it was readily available

- Meanwhile the Timepix-I has a TDC per cel

- First events (Fe 55) march 2003)

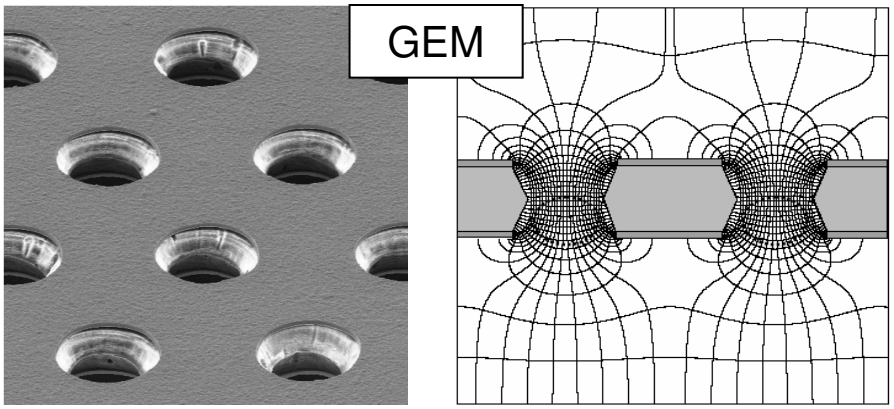


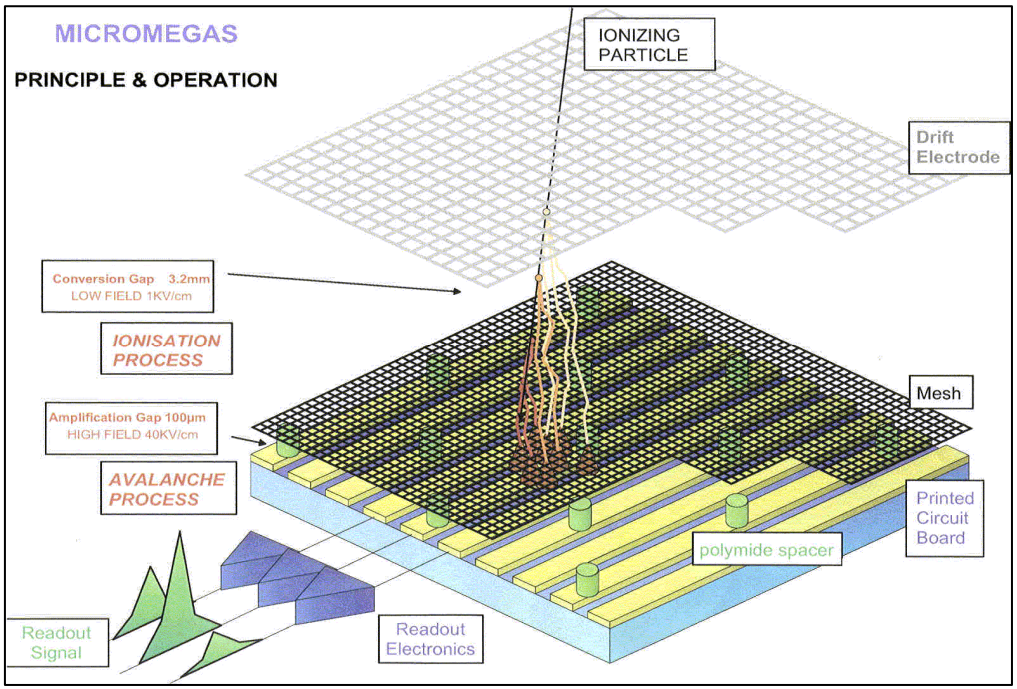


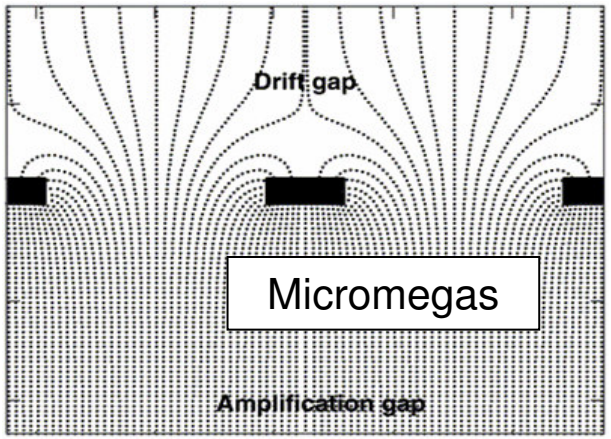
Existing developments:

Micro Patterned Gaseous Detectors

- TPC has long drift region
- High field created by Gas Gain Grids
- Most popular: GEM & Micromegas
- Readout with anode pads directed to FE

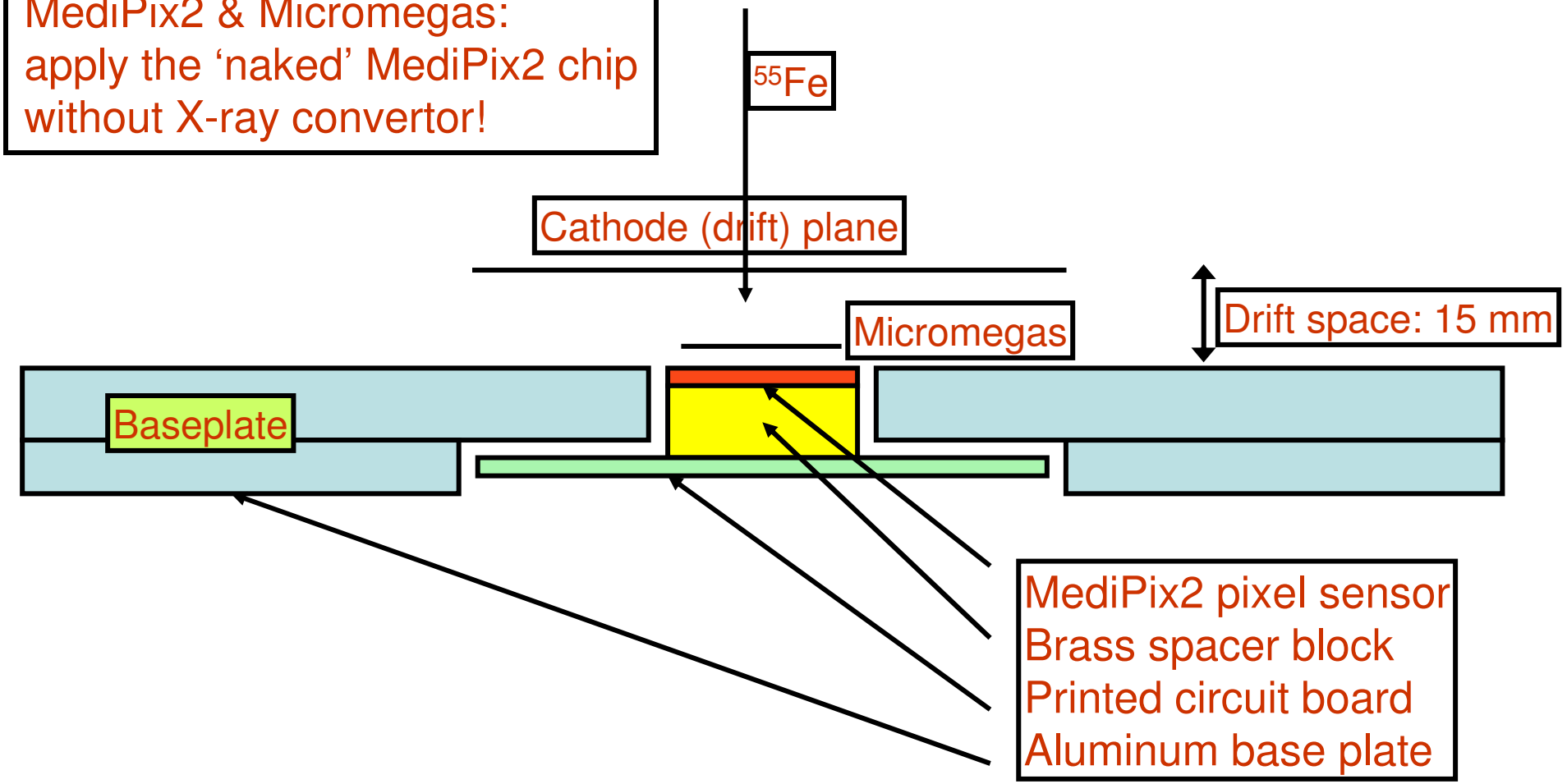






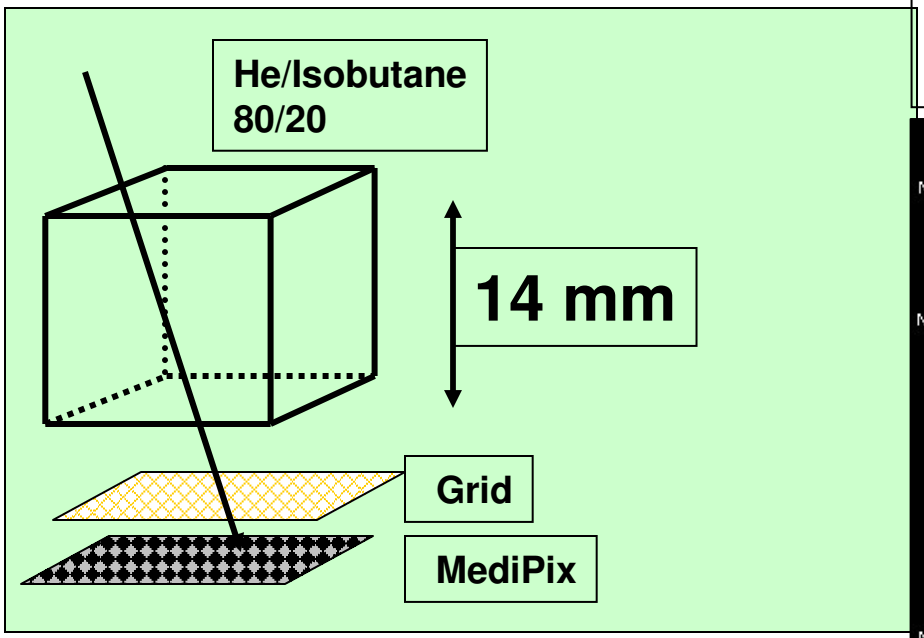
New TPC based on GridPix

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

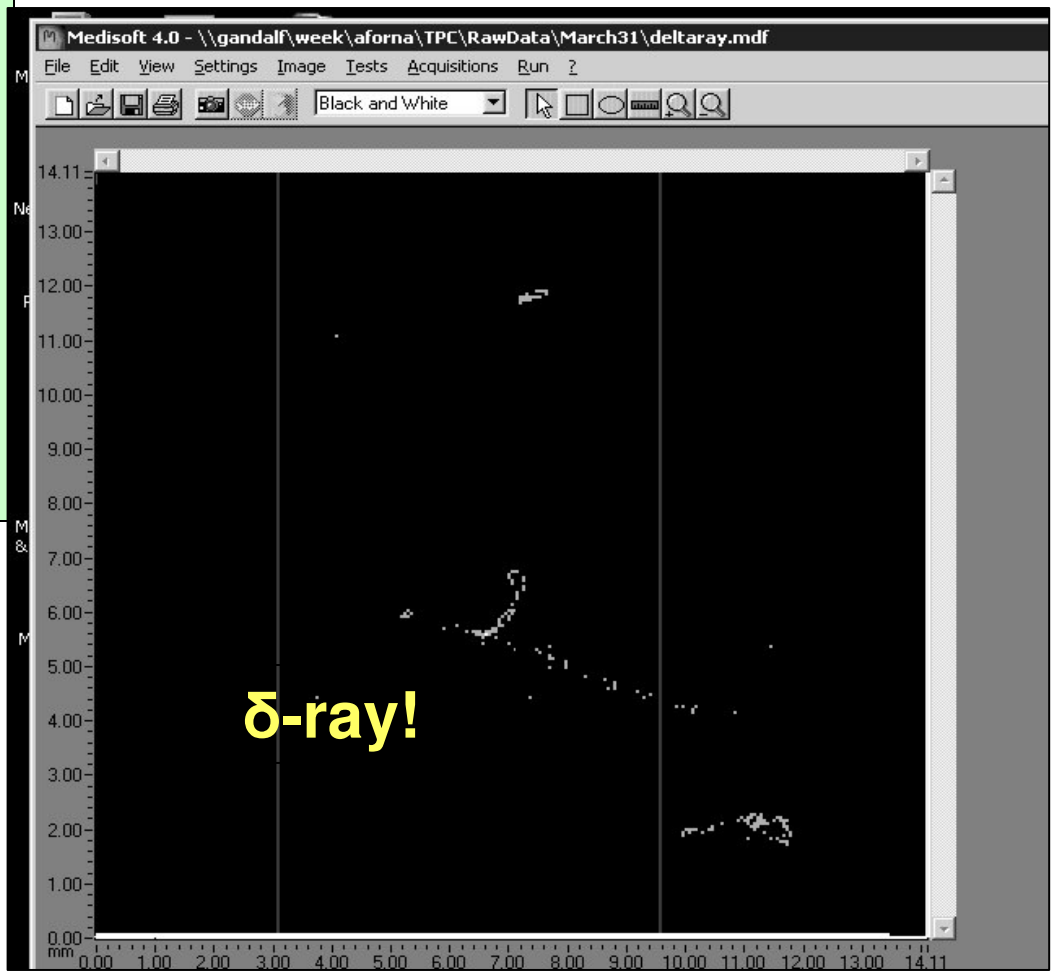


Very strong E-field above (CMOS) MediPix!

Gridpix: Time projection chamber

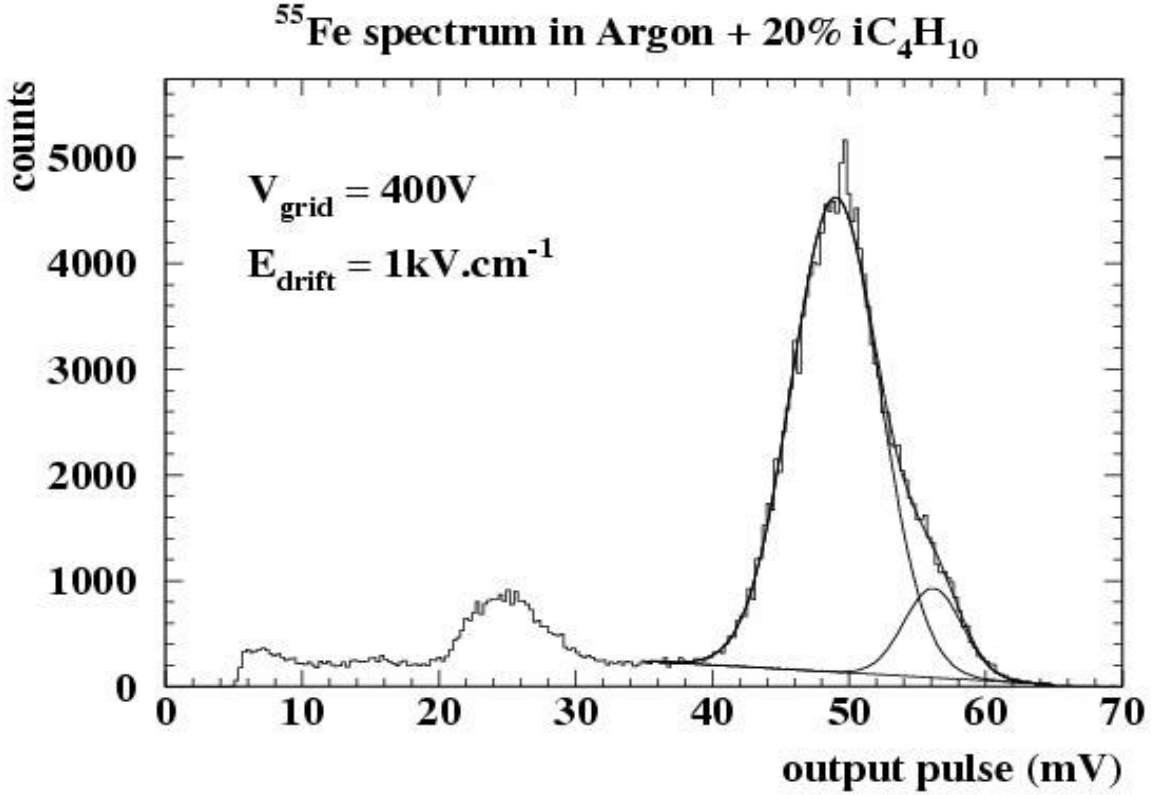


GridPix:
the electronic bubble chamber

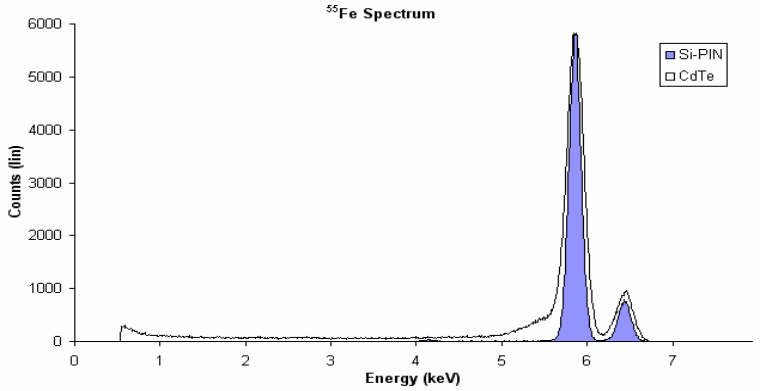


Efficiency for detecting single electrons:
~ 95 %

Energy resolution in Argon $IsoC_4H_{10}$ 80/20



- Observation of two lines:
  - K_α @ 5.9 keV
  - K_β @ 6.4 keV
- FWHM of the K_α distribution
  - 16.7 %
- Gain fluctuations
  - < 5%

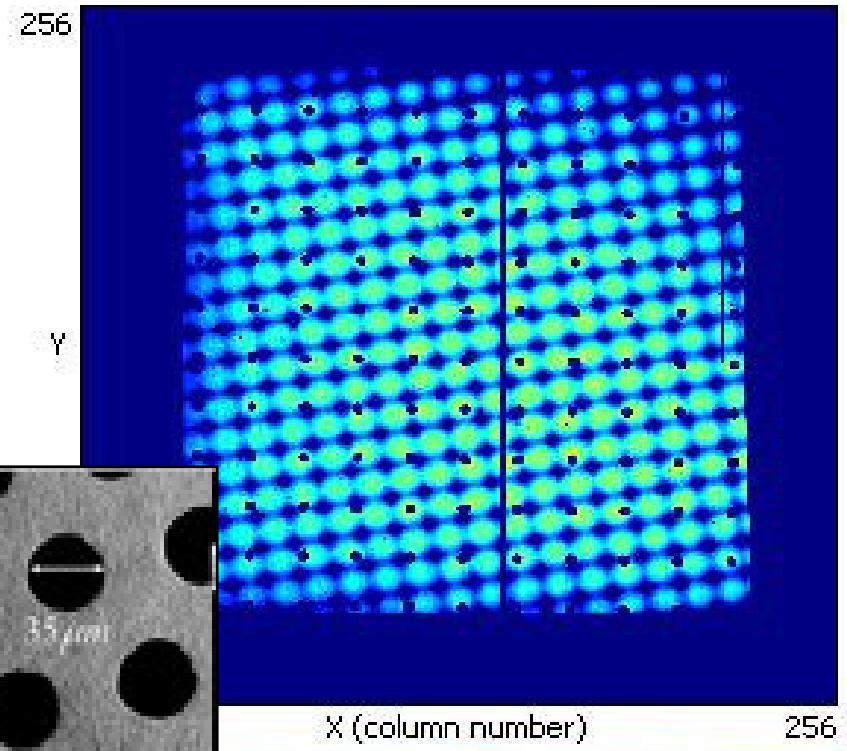


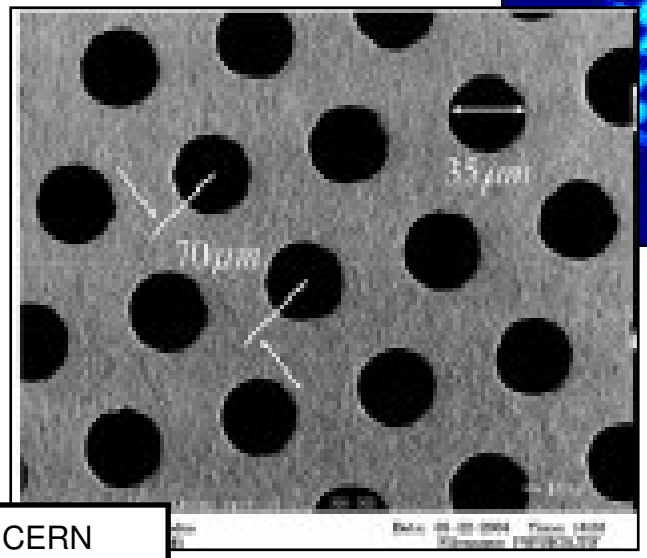
Very good energy resolution:

Very precise dimensions d < 0.1 µm

Micromegas foil

- Micromegas foil is mounted over the chip
- Pitch mismatch causes ‘moire effect’
- See pillars supporting the foil



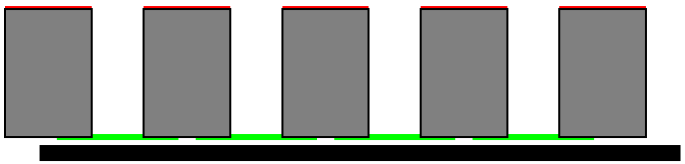


Charge mode

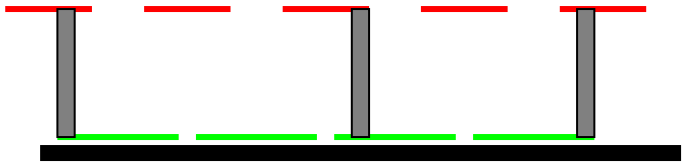
INGRID

- Integrate GEM/Micromegas directly on top of CMOS wafer.

‘GEM’



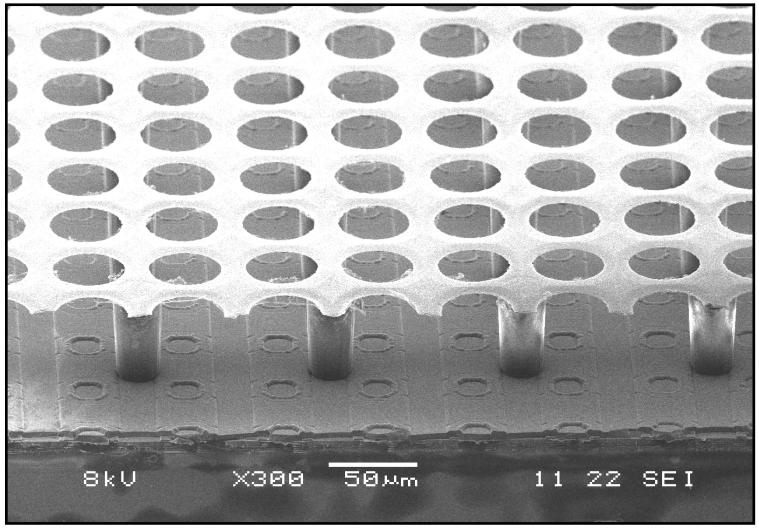
‘Micromegas’



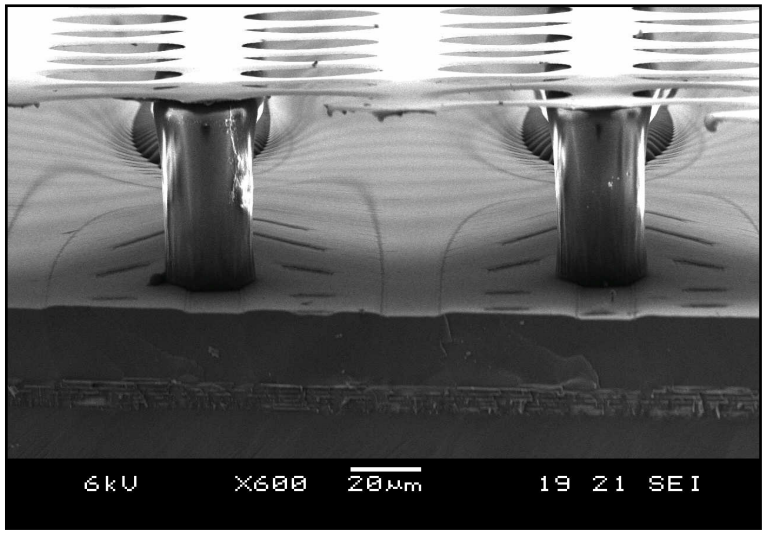
wafer post processing is performed at Technical University of Twente/MESA+

Post-processing of a TimePix

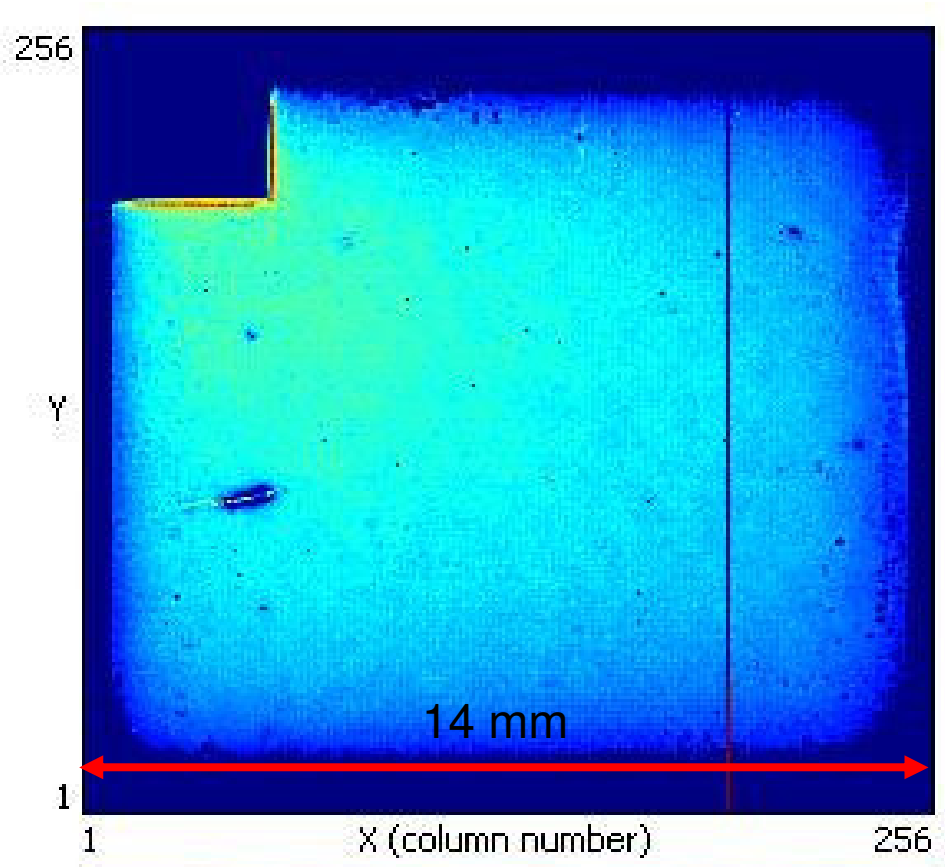
- Timepix chip + SiProt + Ingrid:



MESA+



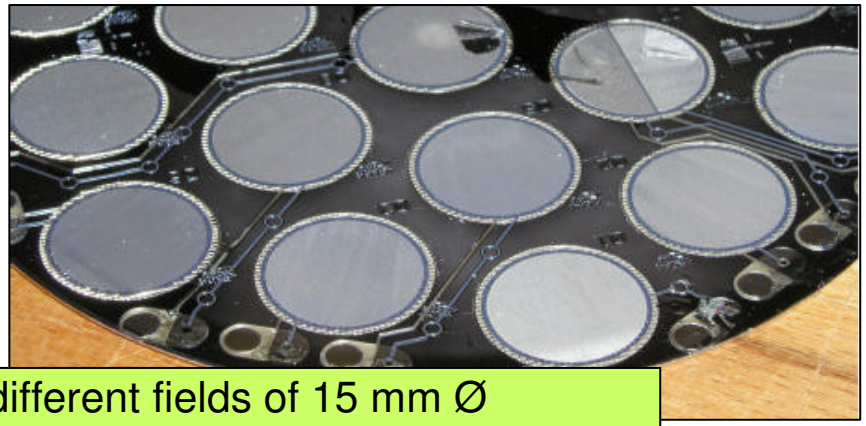
IMT Neuchatel



"Uniform"

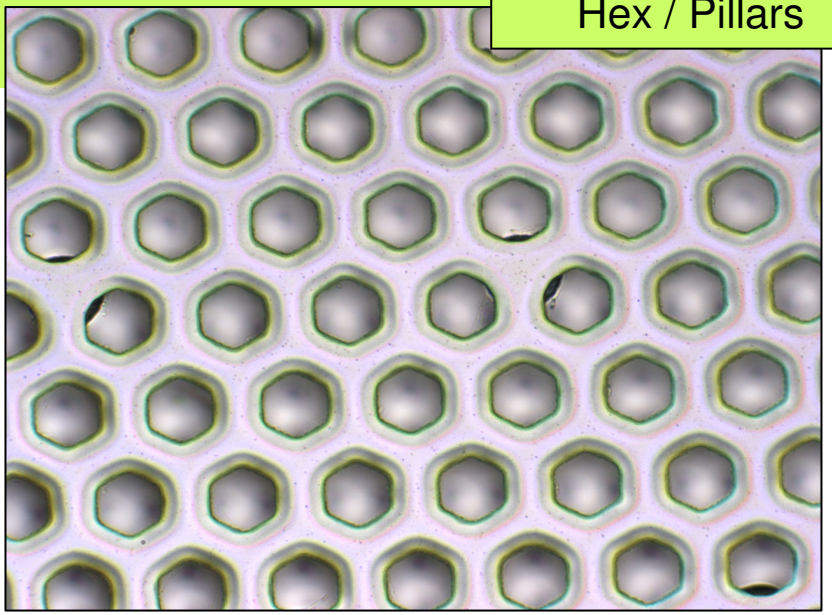
Charge mode

Prototypes

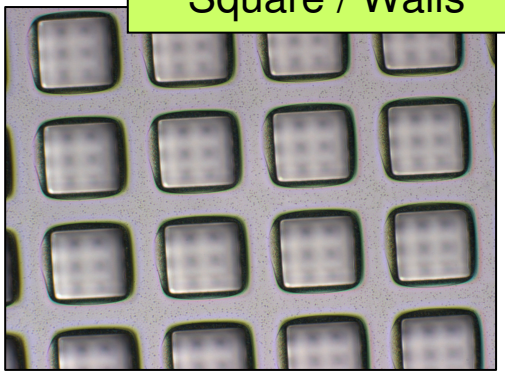


19 different fields of 15 mm Ø
2 bonding pads / fields

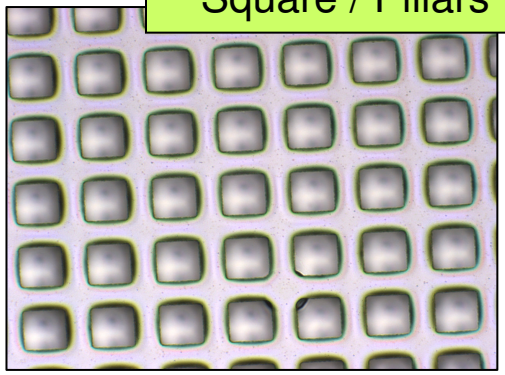
Hex / Pillars



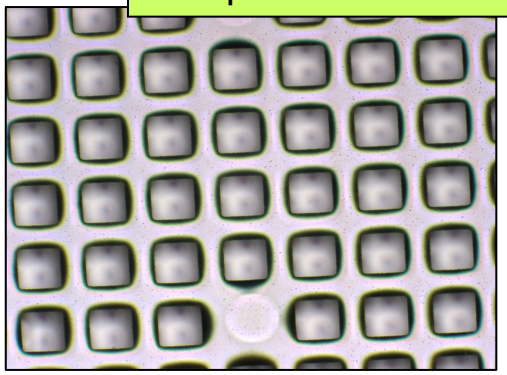
Square / Walls



Square / Pillars

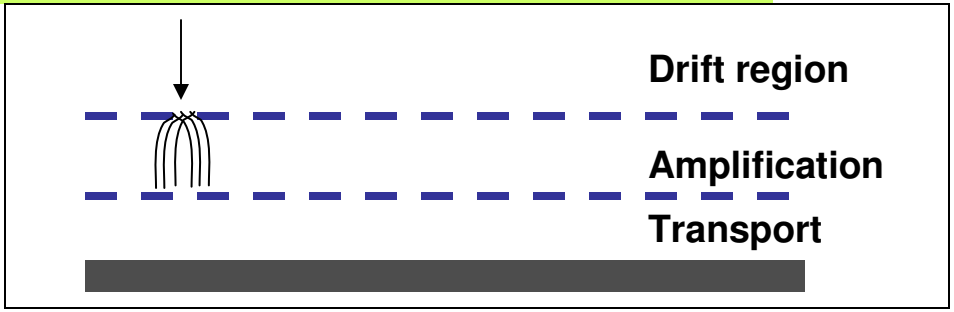


Square / Pillars

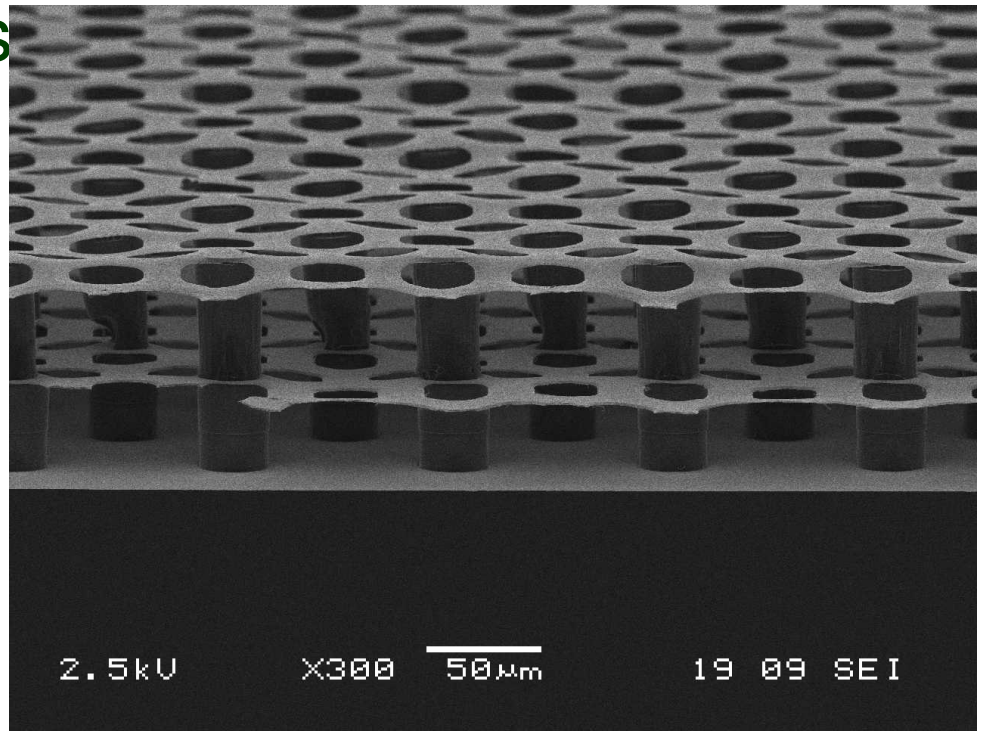


Twingrid

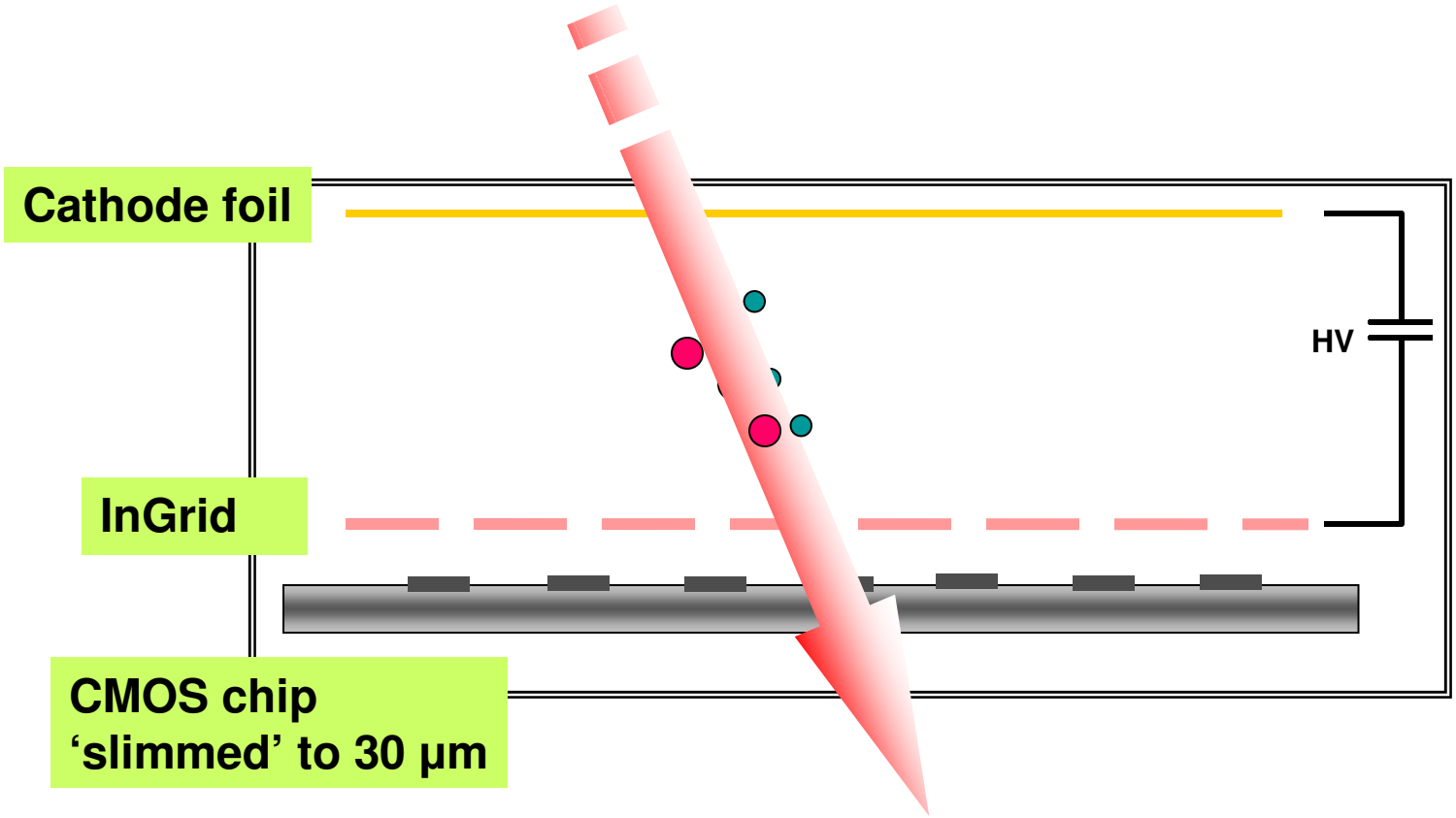
- First grid used for gas multiplication
- Second grid small gain and transport of electrons
- Solution against sparks
- Fast signal (ions are gated)



- TUT/MESA production of prototype =>

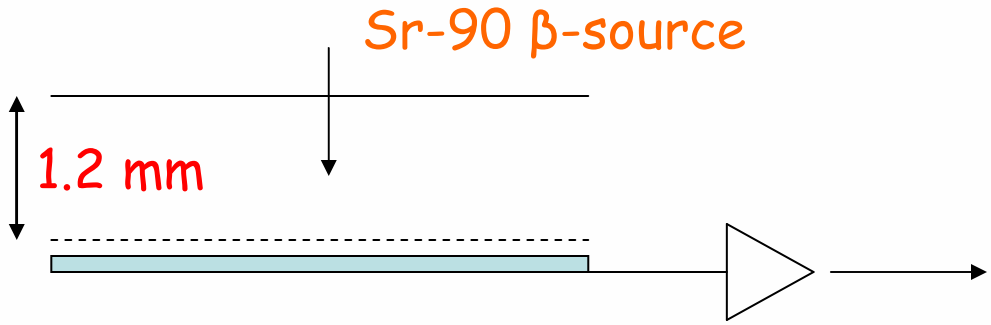


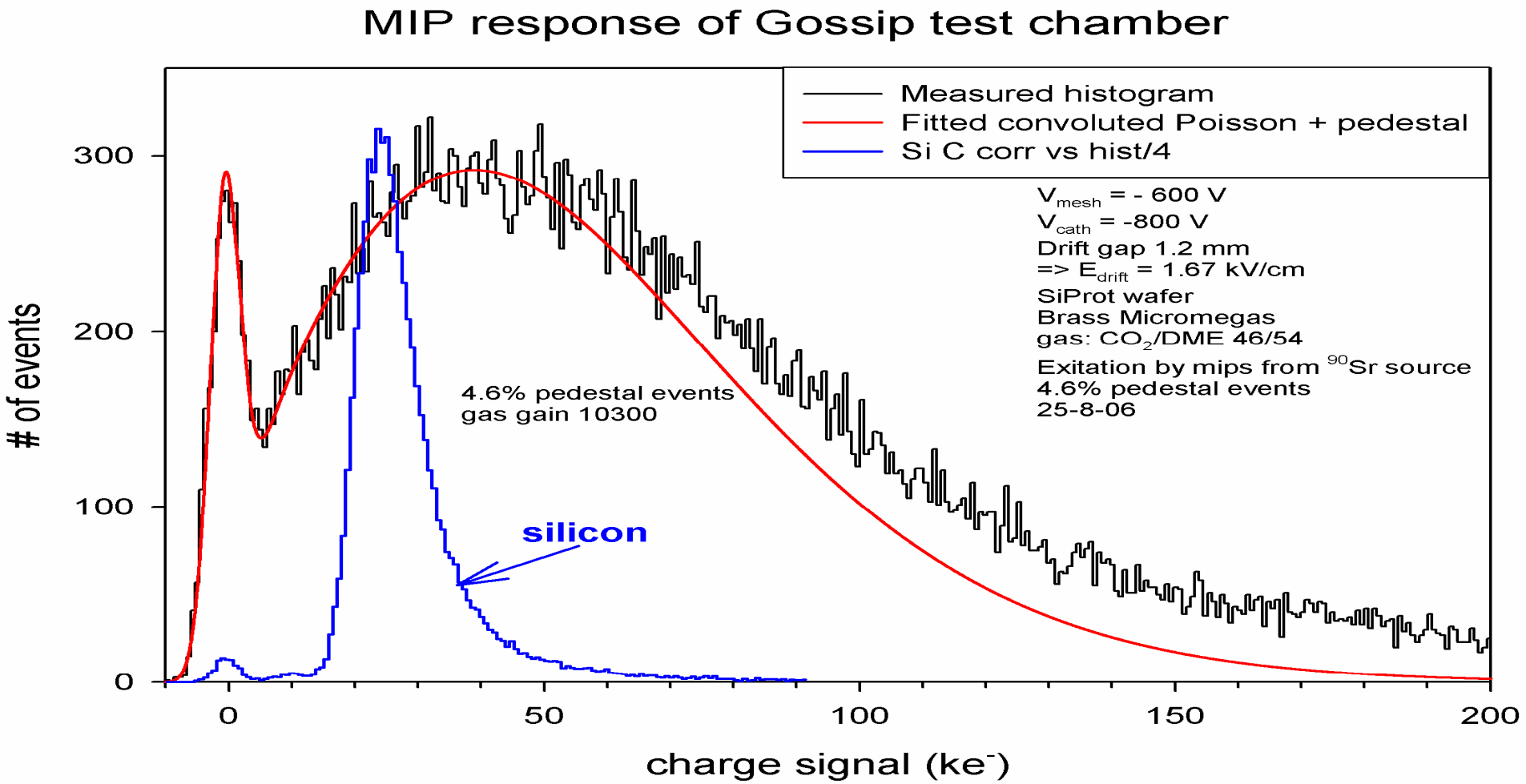
Gossip: Gas On Slimmed Silicon Pixels



Drift gap: 1 mm
Max drift time: 16 ns

Avalanche over 50 µm
Gain ~ 1000


Sr-90 β-source
1.2 mm


MIP response of Gossip test chamber
Measured histogram
Fitted convoluted Poisson + pedestal
Si C corr vs hist/4
V_{mesh} = - 600 V
V_{cath} = -800 V
Drift gap 1.2 mm
=> E_{drift} = 1.67 kV/cm
SiProt wafer
Brass Micromegas
gas: CO_2/DME 46/54
Exitation by mips from ^{90}Sr source
4.6% pedestal events
25-8-06
4.6% pedestal events
gas gain 10300
silicon
# of events
charge signal (ke$^-$)
0
100
200
300
0
50
100
150
200

History

- 2004: GEMs + MediPix2
  - Detection 'high resolution‘ 55Fe quanta: Auger+ photo-electronseparately visible
  - Propose InGrid (and possily TwinGrid)
  - Cosmic muons: single electron eff. better 95 %
  - (May) Propose Gossip.
- 2005: InGrid
  - best energy-resolution ever in proportional gas detector
  - Submit frontend in 0.13 CMOS
- 2006: Gossip
  - SiProt layer for spark protection with signals are as before and discharges are very small and not destructive (needs longterm test)
  - (June) First true GOSSIP tracks with track efficiency > 96 % , DME/CO2 laag van 1 mm.
  - (August) Propose TwinGrid:
  - (September)Twingrid available

Challenges ☺

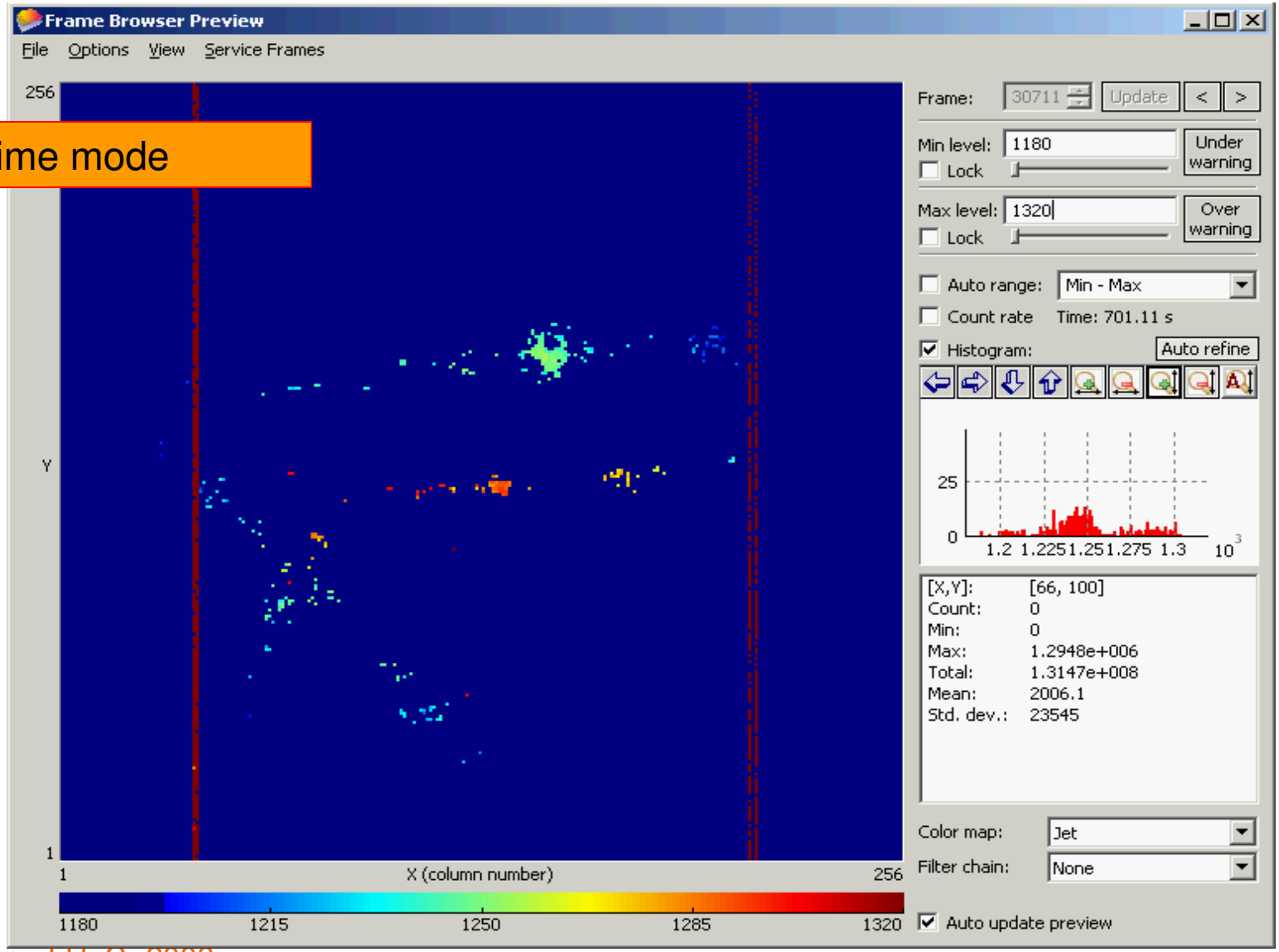
- Radiation hardness
  - CMOS process is unaltered so expected to be good
- Spark protection
  - Highly resistive layer (amorphous silicon and silicon nitride)
  - Twingrid
- Ageing
  - ^{60}Co irradiation encouraging
  - Low fields compared to wire chambers
  - Small gas flow
  - Process not fully understood
- Diffusion and drift velocity
  - Limits position measurement
  - Signal development needs more simulation
  - If occupancy allows it one can read more than one hit per track

Recent developments

- Sparking is under control with SiN layer
- Drift time measurements with Timepix chip
- Measurements with **thin drift layer** on a PSI-46 (CMS pixel) chip in a testbeam
- Radiator in testbeam seek transition radiation
- Tracks in a magnetic field

Cosmic rays in Argon

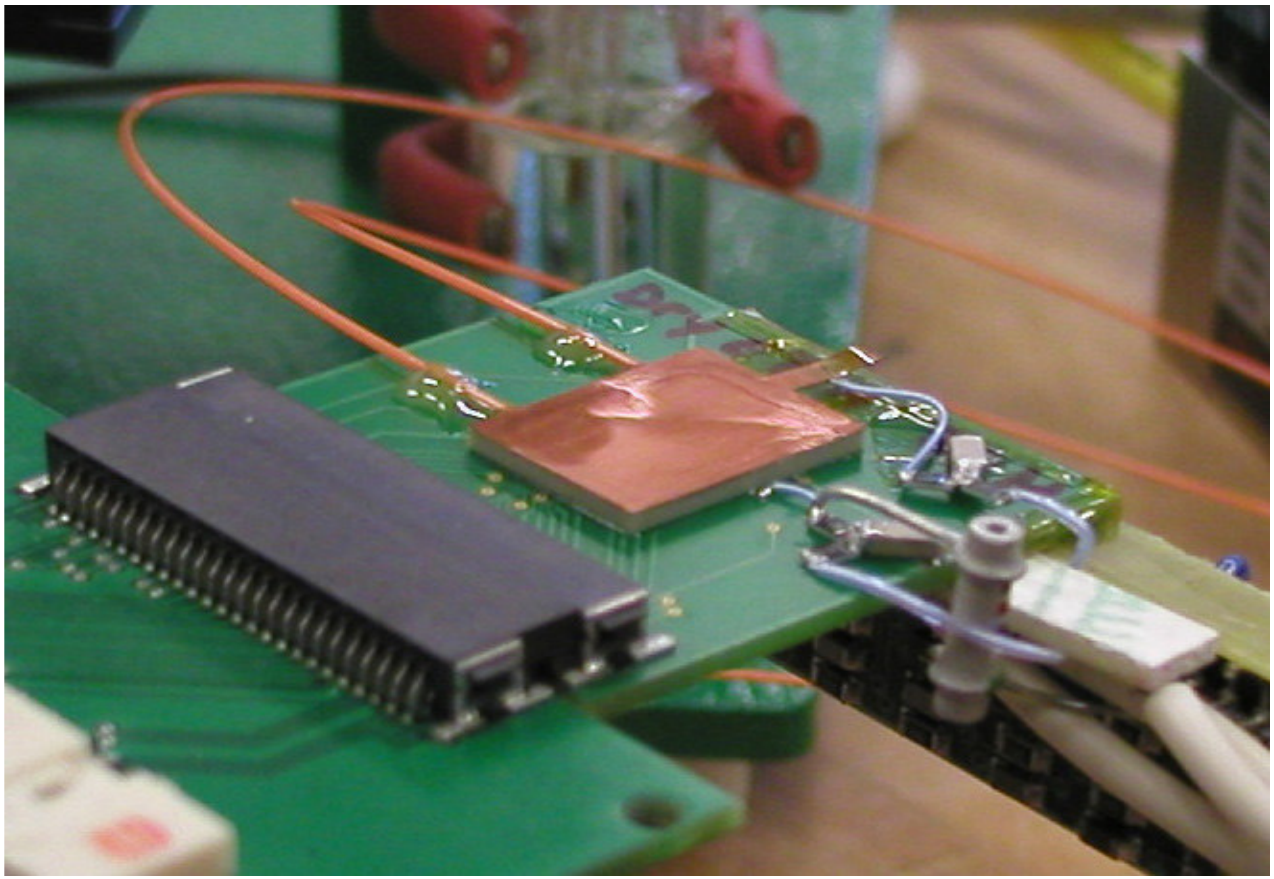
Time mode

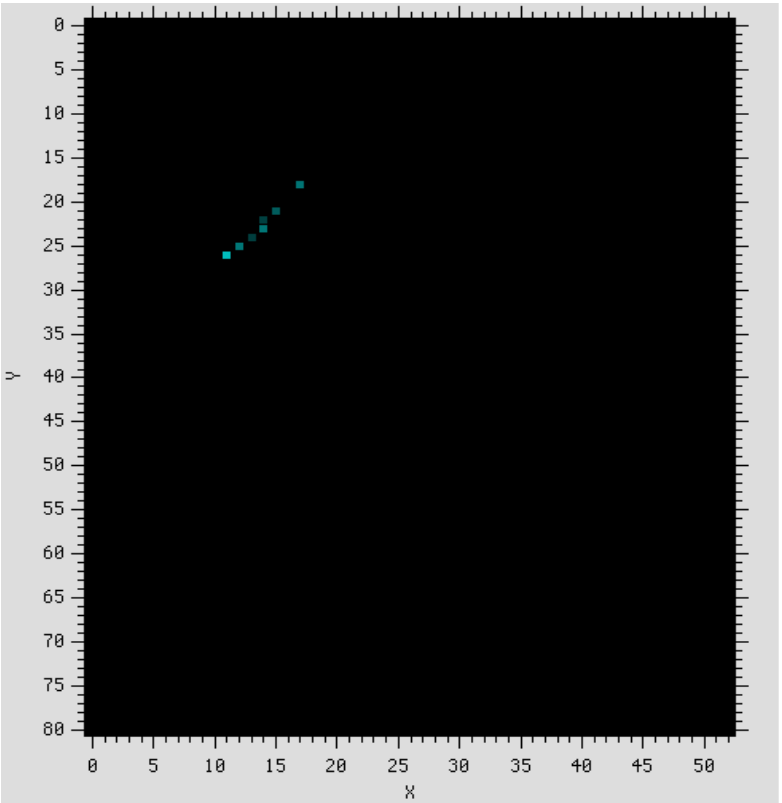


GOSSIP-Brico: PSI-46 (CMS Pixel FE chip)

First prototype of GOSSIP on a PSI-46 (CMS Pixel FE chip)is working:

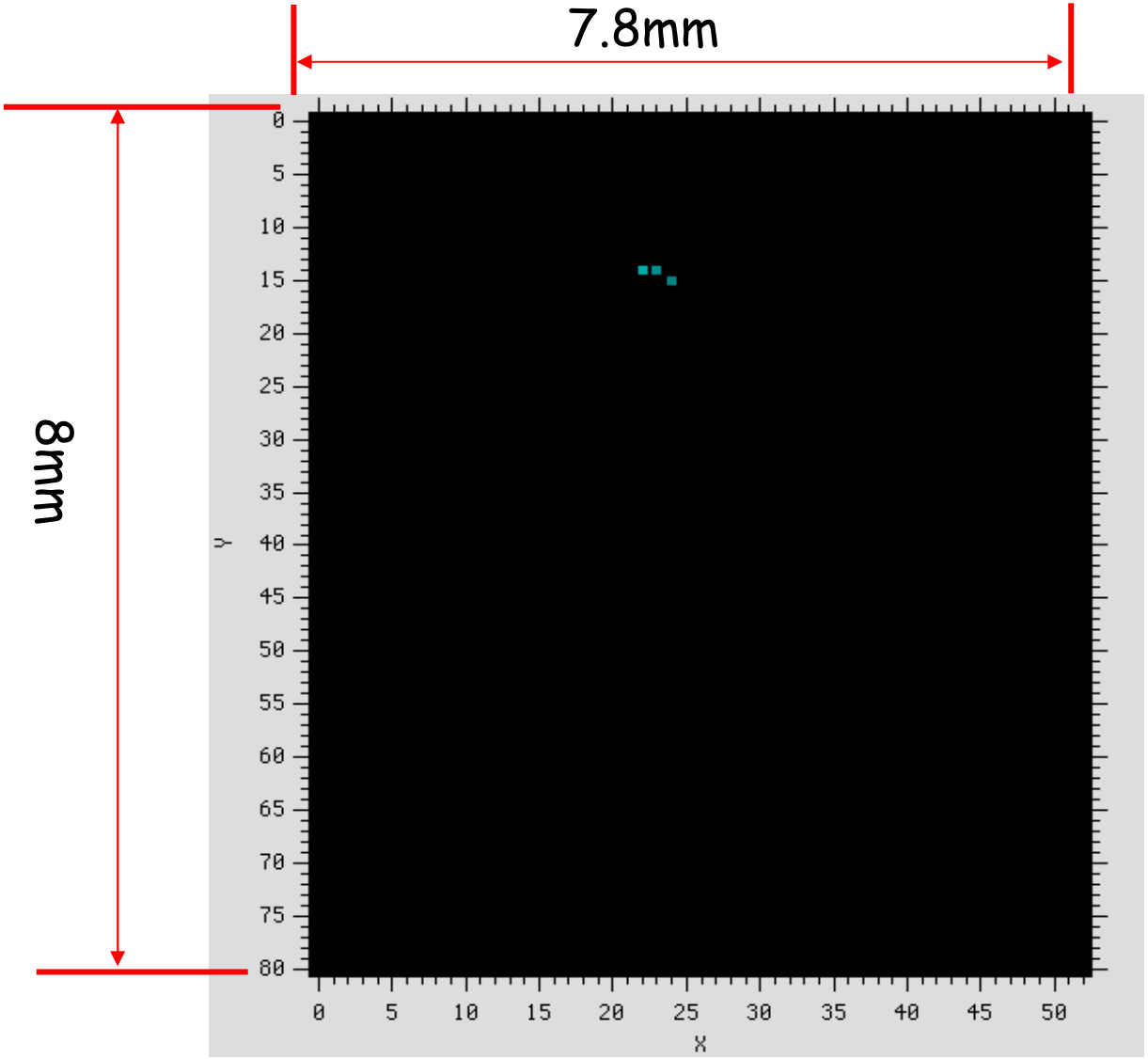
- 1.2 mm drift gap
- Grid signal used as trigger
- 30 µm layer of SiProt





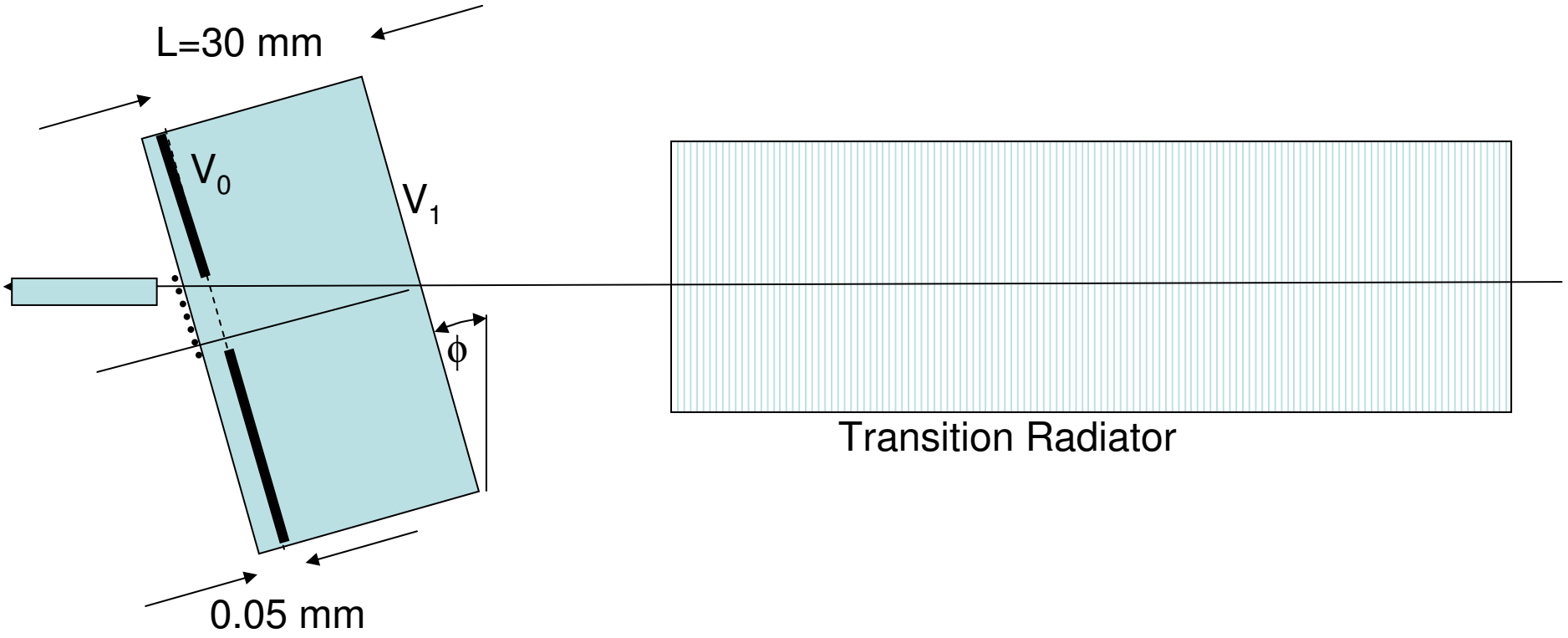
We can see tracks!

(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)

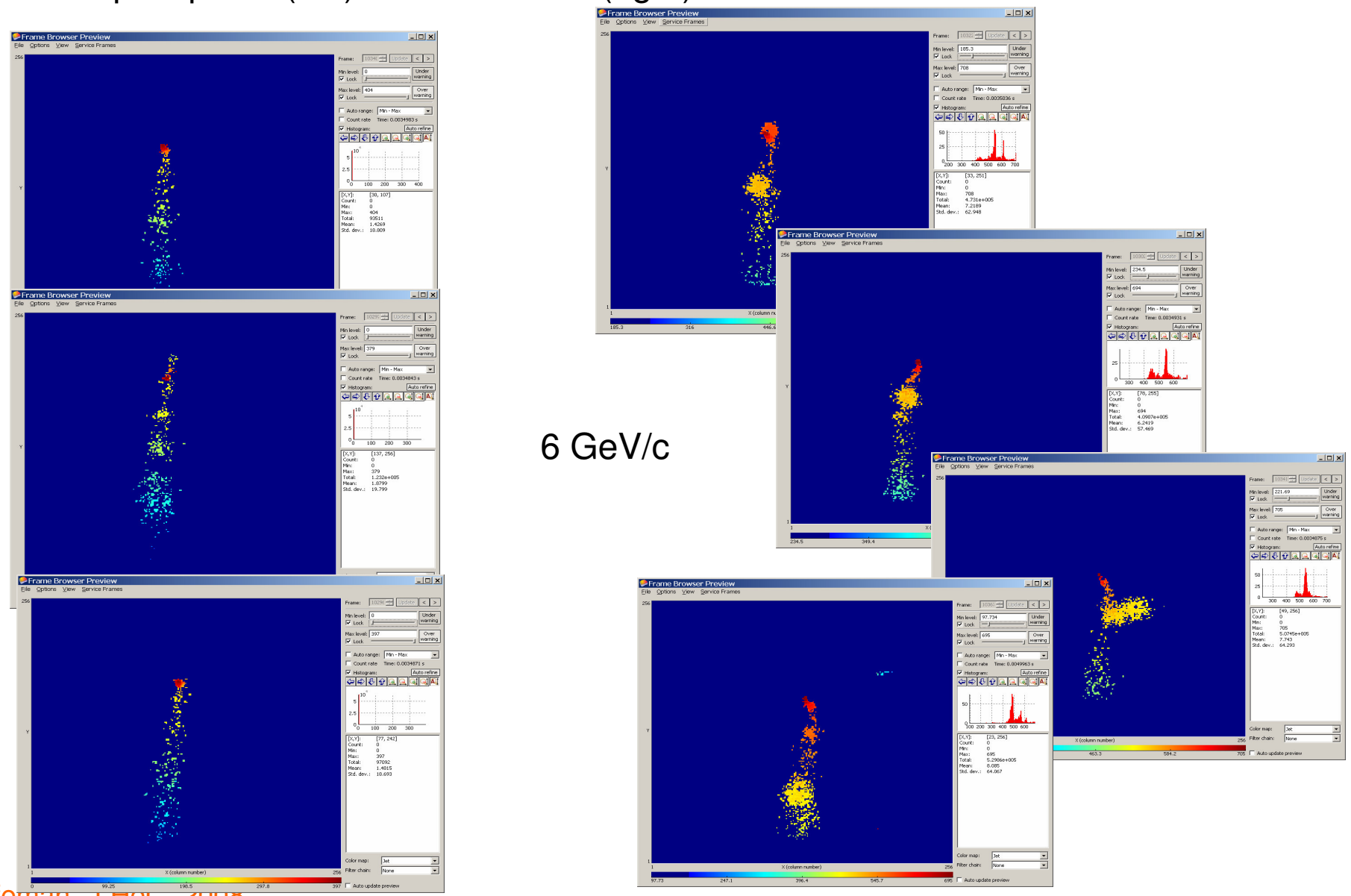
Testbeam Nov 5 – 12, 2007
PS/T9: electrons and pions, 1 – 15 GeV/c



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

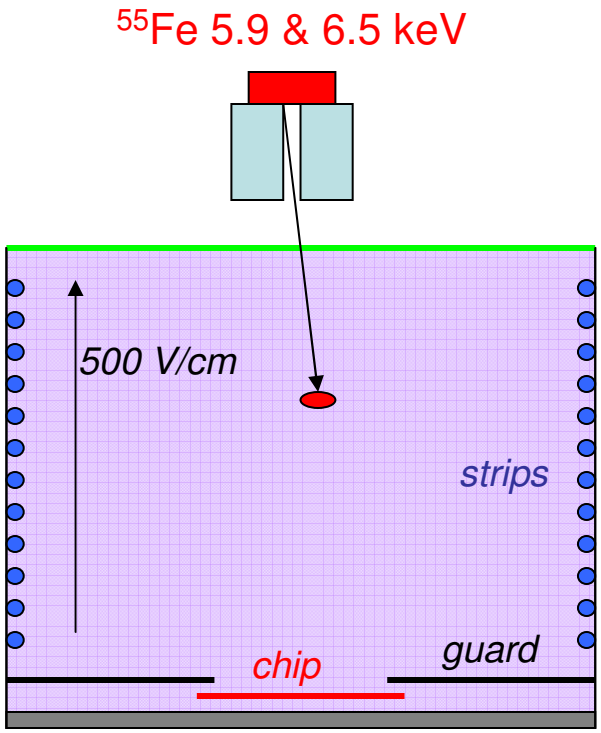
Transition radiation : Typical events ☺

Samples pions (left) and electrons (right)



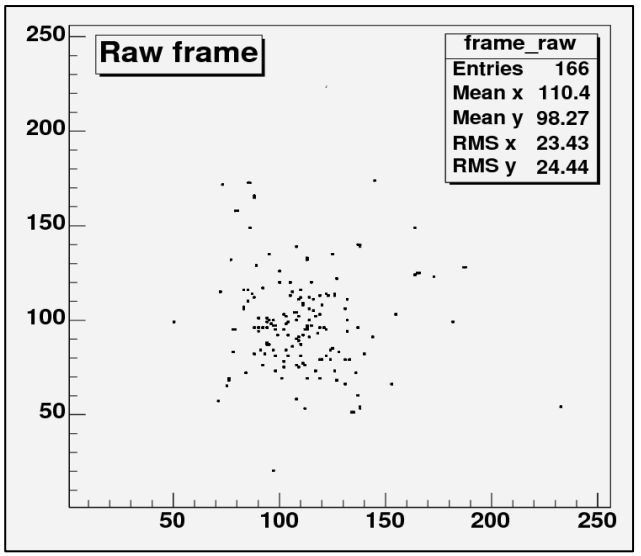
Demo: the digital TPC

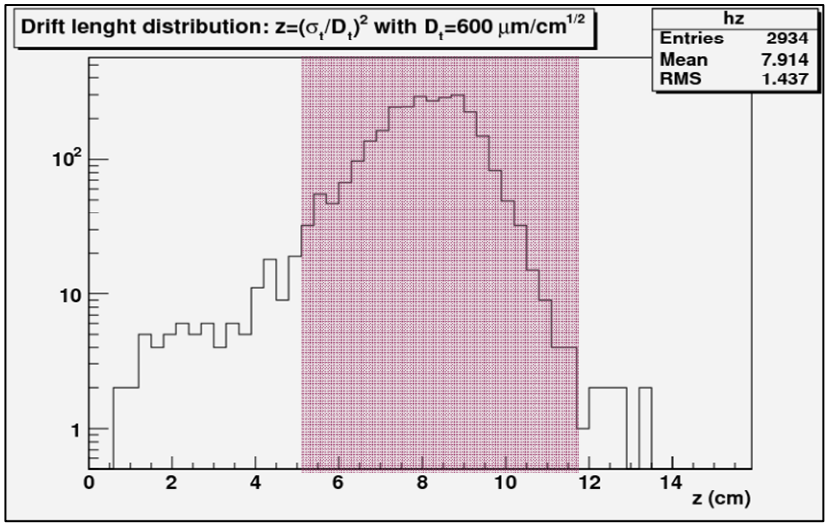
- Gas chamber
  - Timepix chip
    15 µm SiProt + 50 µm InGrid
  - 10 cm drift gap
  - Cathode strips and Guard electrode
  - Ar 5 % iC_4H_{10}
- 55Fe source placed on top
  - Collimated to 2 mm Ø beam
  - Difficult to align precisely
- Ideally, gain & threshold homogeneous
  - Pixel to pixel threshold variations
    Threshold equalization provides uniform response
  - Gain homogeneity should be OK thanks to:
    Amplification gap constant over the chip (InGrid)
    Amplification gap close to optimum
- Imperative: have enough diffusion to perform counting
  - Long drift length, look at escape peak
  - However: SiProt layer induces charge on neighboring pixels



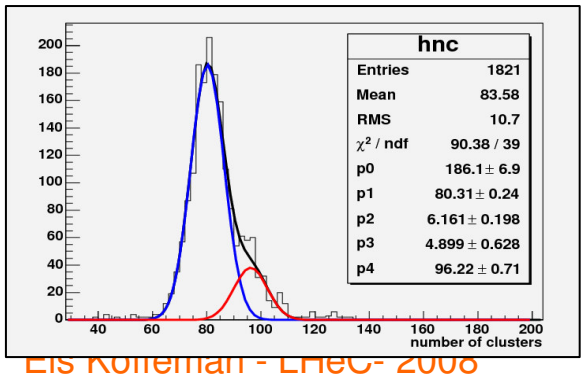
Event selection

- Suppress noise hits
  - Operate chip in TIME mode
    10 μs active time
    count clock pulses of 10 ns
  - Cut hits $4\sigma_t$ away from the mean time
  - Cut hits $4\sigma_{x,y}$ away from the mean x,y
- Select large diffusion events
  - Measure the number of clusters as a function of spread (σ_t^2) for increasing grid voltages
- Effective number of electron from double Gaussian fit

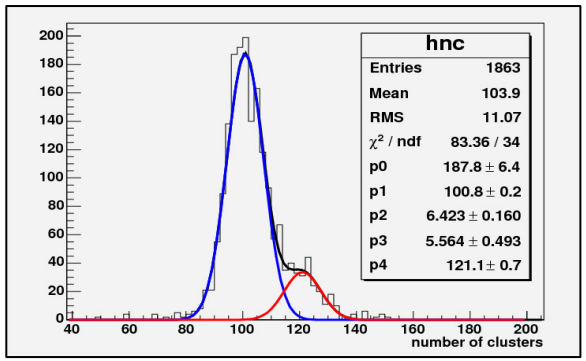




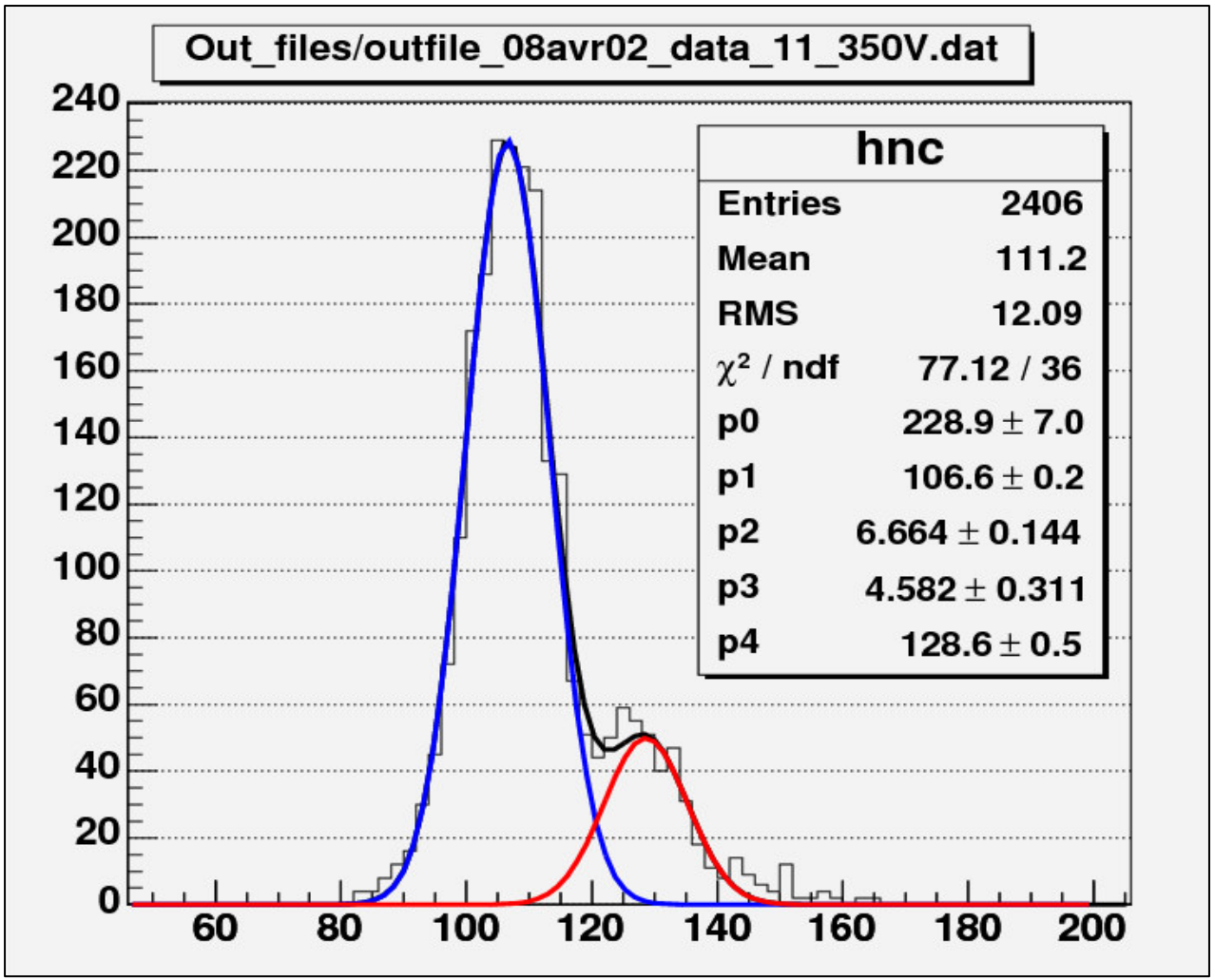
320 V



340 V



At 350V…^{55}Fe escape peak!!



RMS_t = 6.25 %

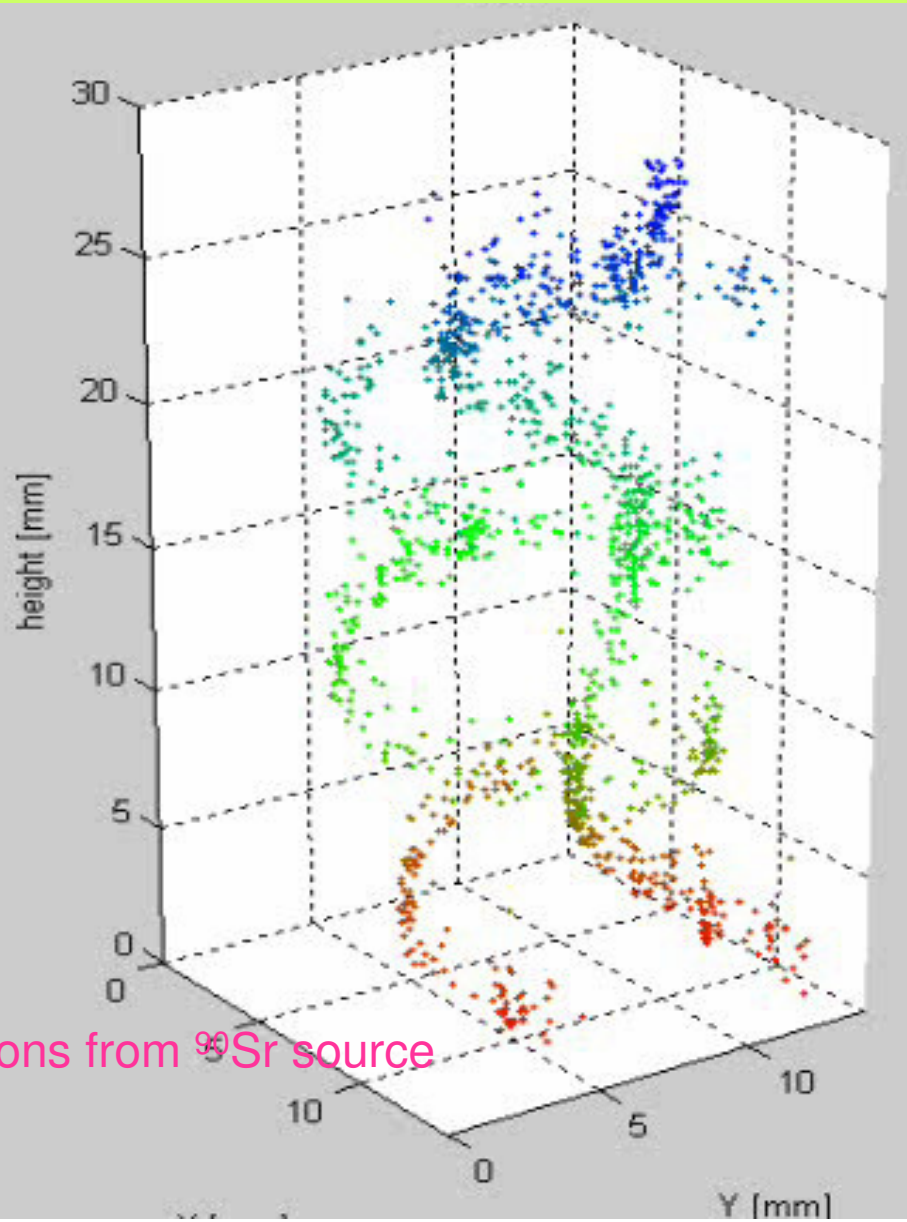
η = 0.93

RMS_η = 2.56 %

RMS_p = 5.70 %

F = 0.35

In a magnetic field



B = 0.2 T

Vertical field line

Electrons from ^{90}Sr source

Gas in a tracking detector

- Amplification of primary electrons in gas
  - No bias current
  - Low capacitance (10 fF) per pixel
- No radiation damage of sensor
  - Operation at room (or any other) temperature
- low sensitivity for neutron and X-ray background
- δ-rays can be recognized
- High ion & electron mobility: fast signals, high count rates are possible

- Discharges/sparks: readout system should be spark proof
- Ageing: must be solved and must be understood / under control
- Diffusion: limits max. drift length or position resolution

Gas in a tracking detector

- Amplification of primary electrons in gas
  - No bias current
  - Low capacitance (10 fF) per pixel
- No radiation damage of sensor
  - Operation at room (or any other) temperature
- low sensitivity for neutron and X-ray background
- δ-rays can be recognized
- High ion & electron mobility: fast signals, high count rates are possible

This may result in a design with:

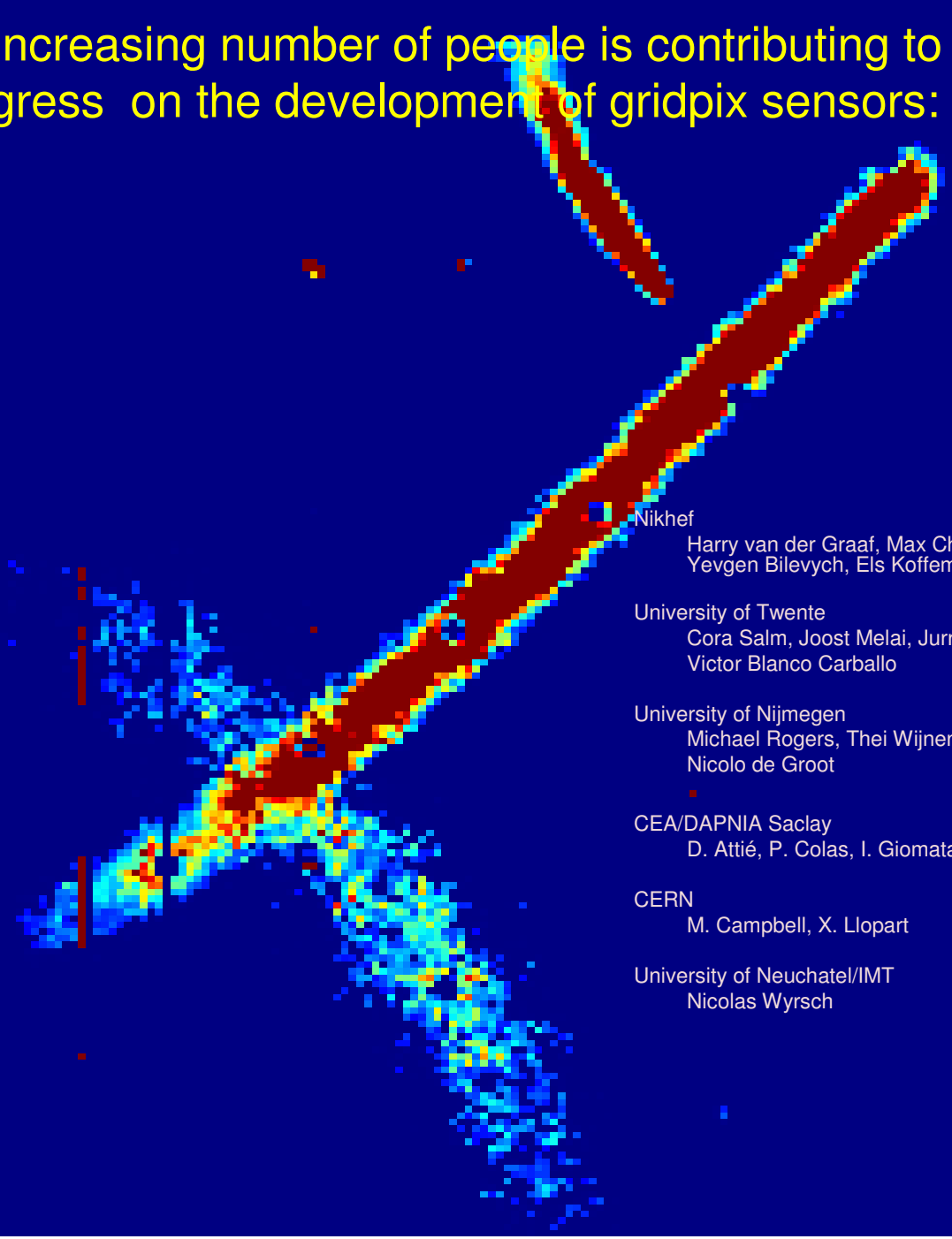
1. Less power consumption
2. Less cooling
3. Reduced complexity (wafer processing in stead of bumping)
4. Less material

Plans

- Large drift volume :TPC for a linear collider
- Micro TPC for nuclear physics
- Thin drift layer : B-layer for ATLAS
- Radiator : transition radiation tracker
- High field : micro channel plate

- LHeC ?

An increasing number of people is contributing to the progress on the development of gridpix sensors:



Nikhef
Harry van der Graaf, Max Chefdeville, Fred Hartjes, Jan Timmermans, Jan Visschers, Martin Fransen, Yevgen Bilevych, Els Koffeman, Nigel Hessey, Wim Gotink, Joop Rovekamp, Lucie de Nooij

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

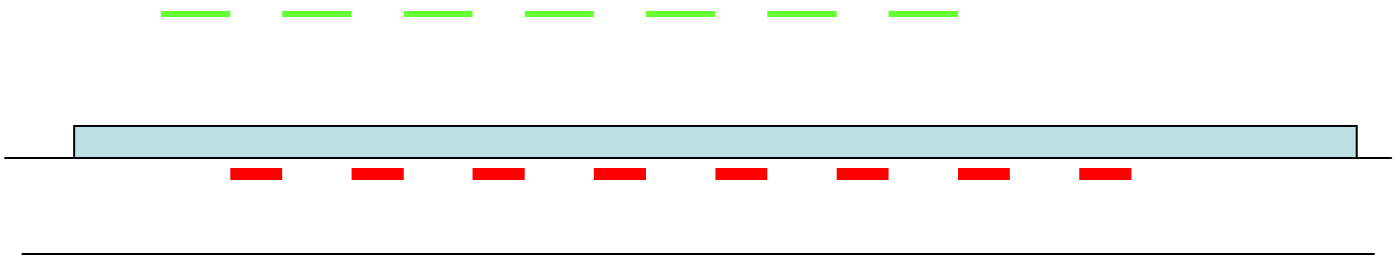
University of Nijmegen
Michael Rogers, Thei Wijnen, Adriaan Konig, Jan Dijkema, Nicolo de Groot

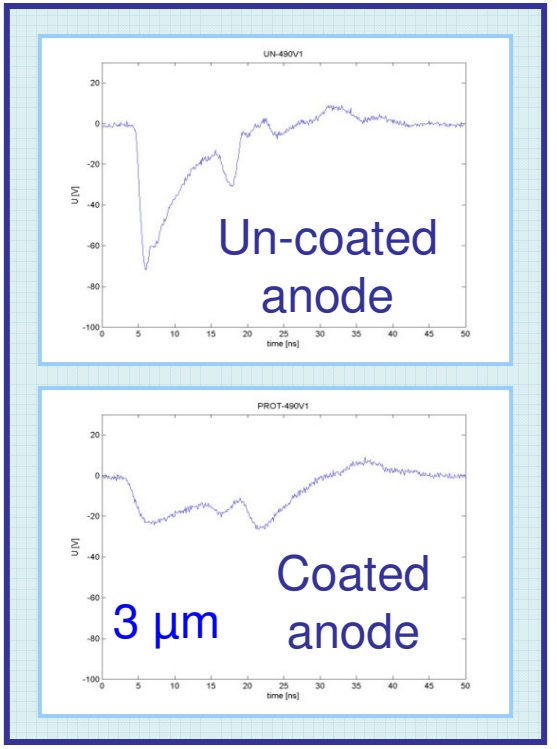
CEA/DAPNIA Saclay
D. Attié, P. Colas, I. Giomataris

CERN
M. Campbell, X. Llopart

University of Neuchatel/IMT
Nicolas Wyrsch

Backup slides





SiProt protection against:

- hot spark plasma
- Too large charge in pixel circuitry [principle of RPCs]
  - local reduction of E-field: quenching
  - widening discharge funnel: signal dilution
  - increased distance of 'influention'

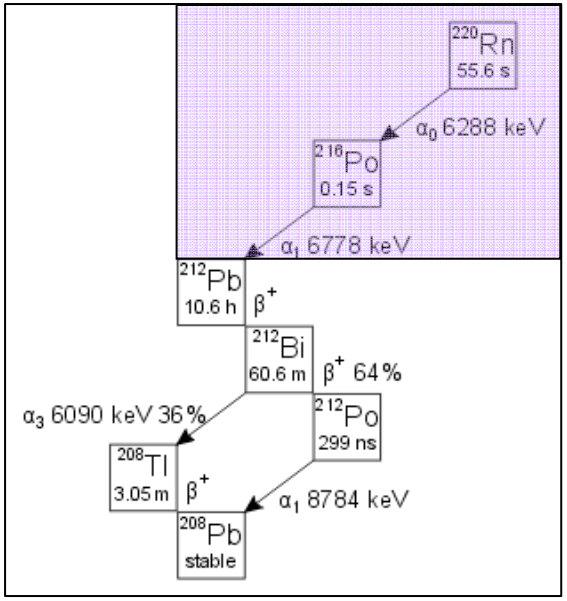
SiProt: a low T deposited hydrogenated amorphous silicon (aSi:H) layer

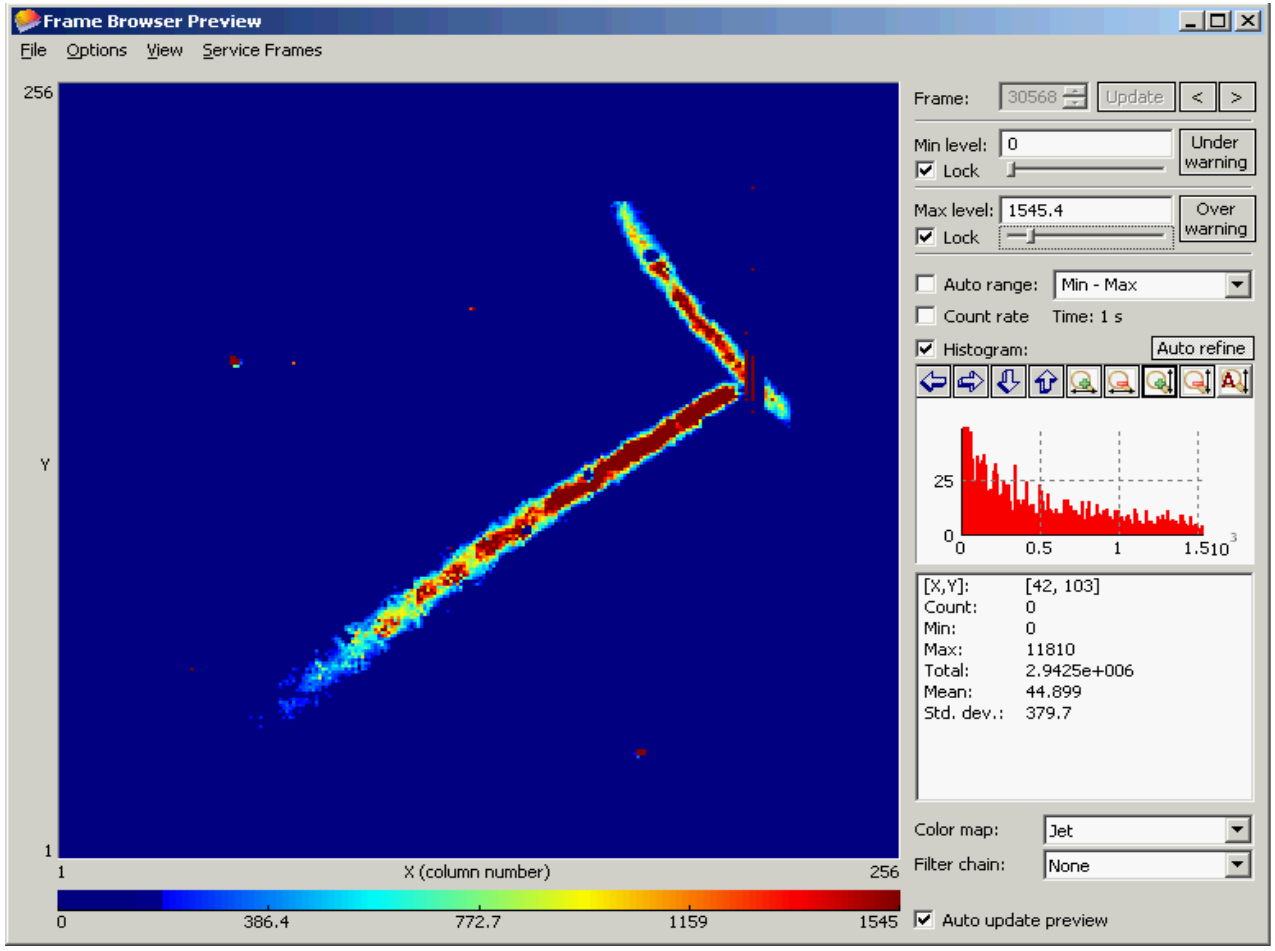
Up to 50 µm thick films, ~ 10^7 - 10^{11} Ω.cm

Final assessment: spark-proofness

- Provoke discharges by introducing small amount of Thorium in the Ar gas
  - Thorium decays to Radon 222 which emits 2 alphas of 6.3 & 6.8 MeV
  - Depose on average $2.5.10^5$ & $2.7.10^5$ e- in Ar/iC_4H_{10} 80/20 at -420 V on the grid, likely to trigger discharges

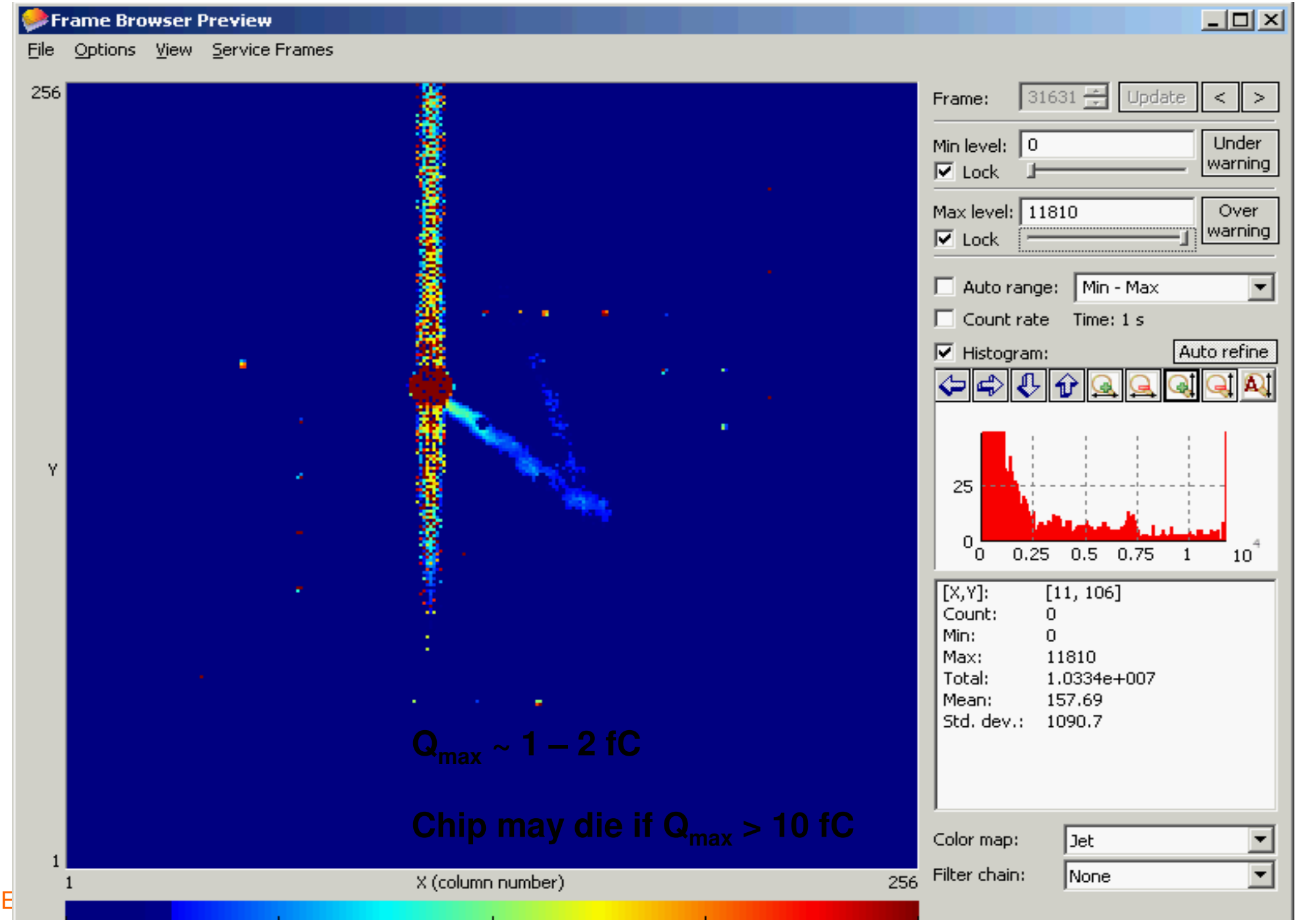
Charge mode





Since 1 week, some 5.10^4 alpha events recorded in 1% of which …

Els Koffeman - LHeC- 2008


Frame Browser Preview
File
Options
View
Service Frames
256
Y
1
1
X (column number)
256
Frame:
31631
Update
<
>
Min level:
0
Lock
Under warning
Max level:
11810
Lock
Over warning
Auto range:
Min - Max
Count rate
Time: 1 s
Histogram:
Auto refine
25
0
0
0.25
0.5
0.75
1
10
4
[X,Y]: [11, 106]
Count: 0
Min: 0
Max: 11810
Total: 1.0334e+007
Mean: 157.69
Std. dev.: 1090.7
Color map:
Jet
Filter chain:
None
Q_max ~ 1 – 2 fC
Chip may die if Q_max > 10 fC

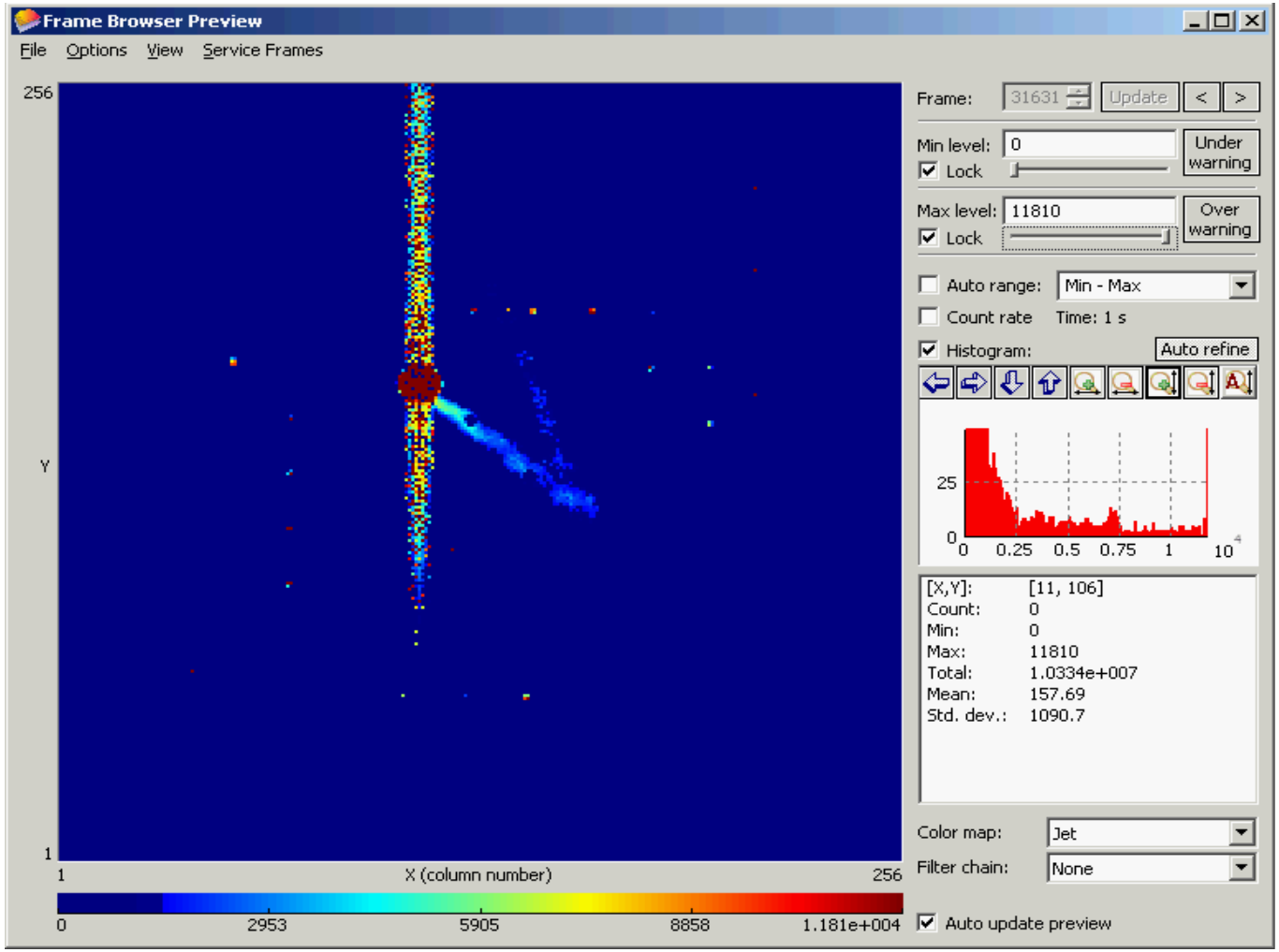
… discharges are observed !

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

Round-shaped pattern of some 100 overflow pixels

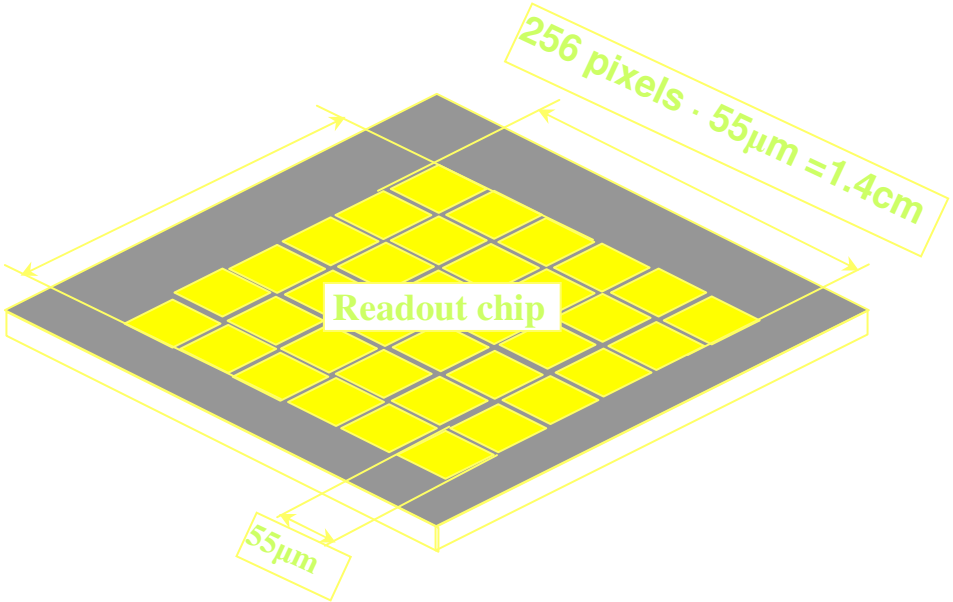
Perturbations in the concerned column pixels
- Threshold
- Power

Chip keeps working



Readout chip

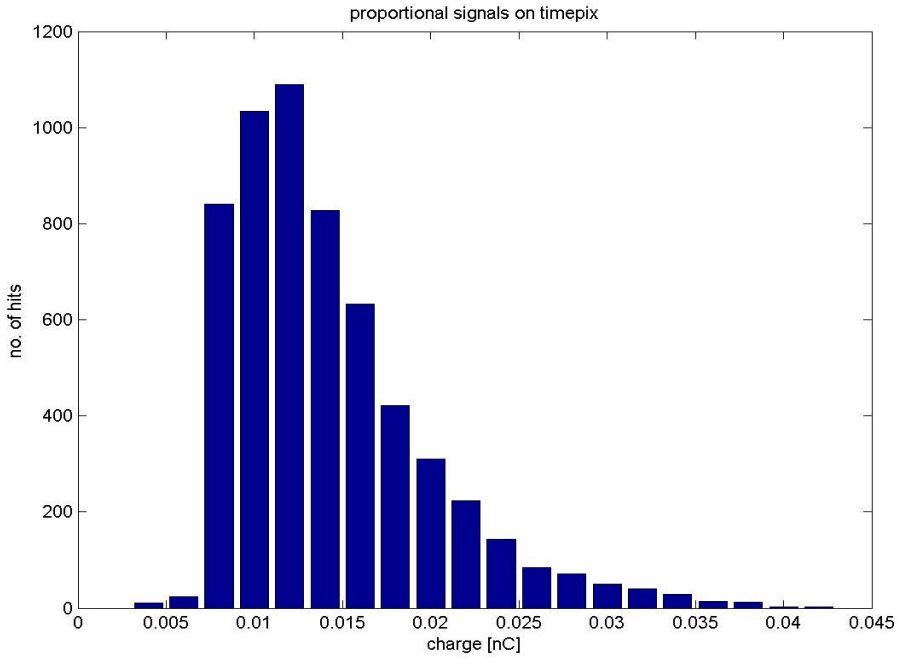
- Goal
  - pixel pitch 55µm x 55µm
  - sensitive area a matrix of 256 x 256 pixels (1.98 cm2.)

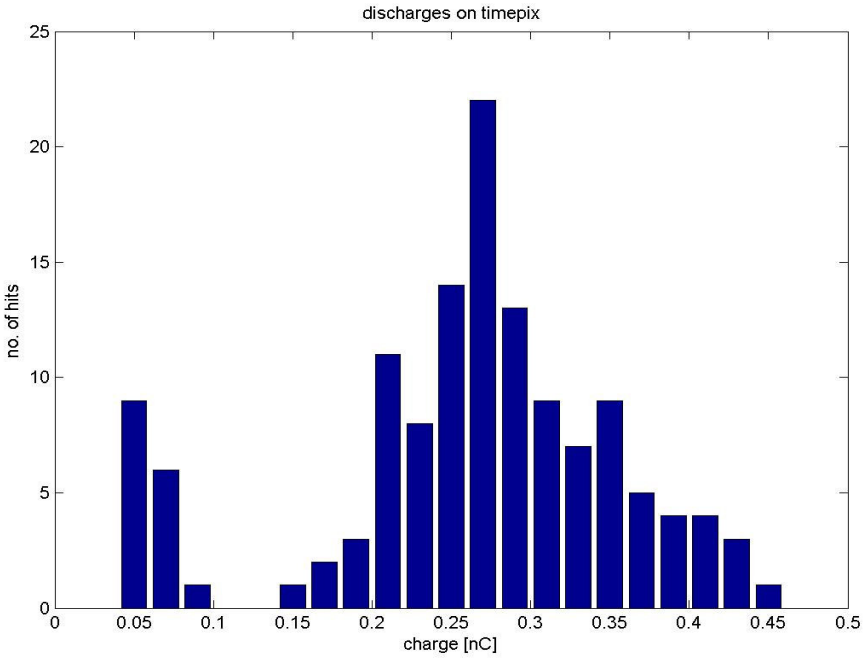


- December 2005:
  - The first prototype of the fast (40 ns peaking time), low-noise (ENC = 60 e- (RMS) and low-power (2 µW per channel) input circuit for the GOSSIP chip has been successfully implemented in 0.13µm CMOS technology.
- December 2006
  - First prototype tdc-per-pixel to be submitted (700 MHz)
  - 16 x 16 pixels
- Develop also prototypewith existing pixel chips

Current Front End Chip FEI-3

- Analog Front-end
- The FE uses a DC-feedback preamp design which provides excellent leakage current tolerance, close to constant-current return to baseline for TOT, and very stable operation with different shaping times.
- The control logic provides 7-bit threshold trim (TDAC) in each pixel, plus a 3-bit feedback current trim (FDAC) for tuning the TOT response.
- There are four control bits, including Kill (shut down preamp), Mask (block hit readout), HitBus (enable global FastOR) and Select (enable charge injection), for a total of 14 bits.
- Digital Readout (designed for VDD=2.0V operation):
- It uses an 8-bit Grey-coded 40 MHz differential “timestamp” bus as a timing reference throughout the active matrix. All pixels measure their leading and trailing edge timing by asynchronously latching this reference in RAMs.
- Hits (address plus LE/TE timing) are transferred from the pixels as soon as the trailing edge occurs, using a shared bus structure in the pixel column pair. This bus operates at transfer rates up to 20 MHz in order to meet our requirements.





- CMOS chips are no longer destroyed

- discharges in gas proportional chambers are hard to exclude

- SiProt makes chips spark proof

Ageing

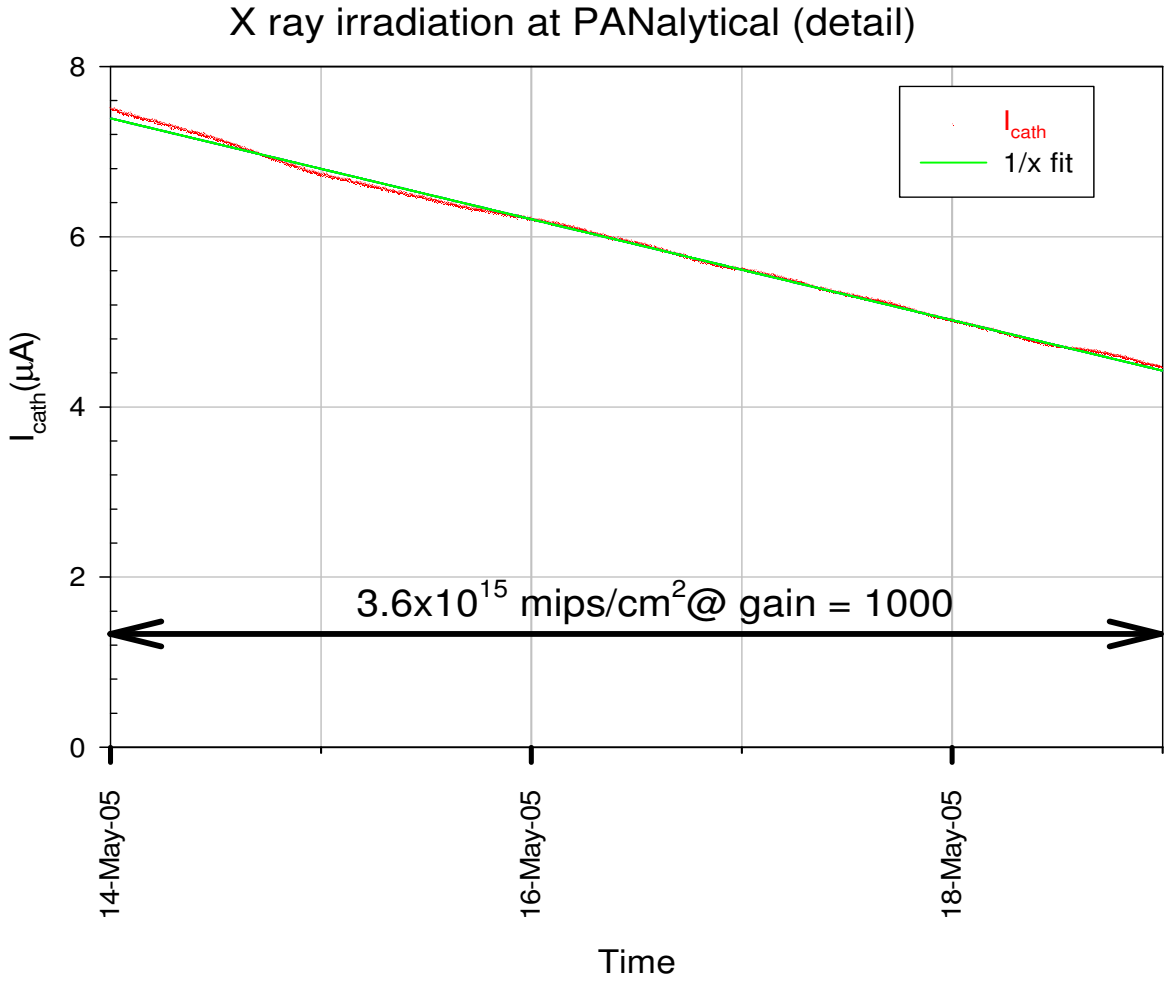
Radiation damage of CMOS pixel chip is relevant
- common for all tracking detectors
- believed to widthstand ATLAS Upgrade Dose in 90 nm technology

Radiation damage of sensor:
not relevant for Gossip sensor since this is gas being exchanged

Typical for gaseous detectors: the deposit of an (insulating) polymer
on the electrodes of a detector. Decrease of signal amplitude

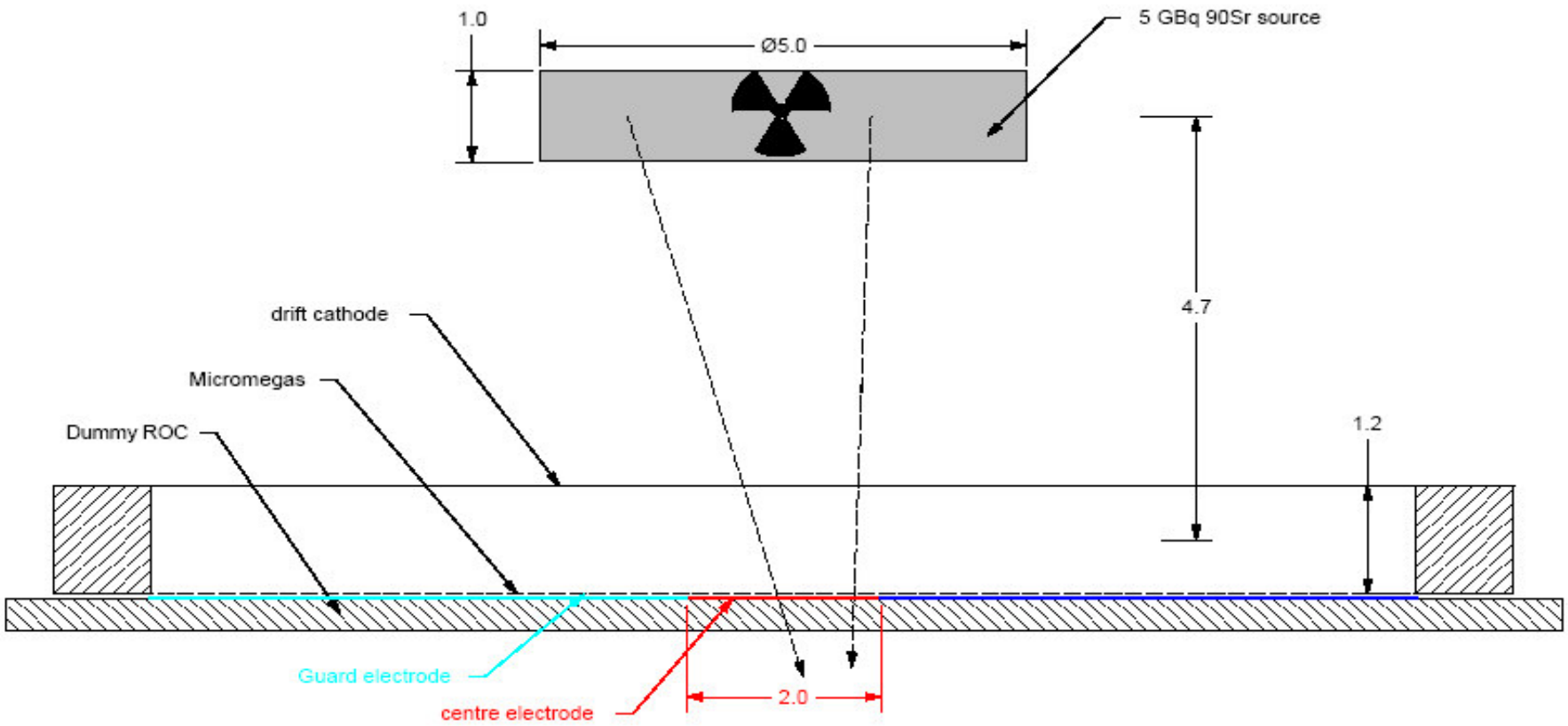
Little ageing expected:
- little primary ionisation (~ 10 e-/track)
- low gas gain (500 – 1000)
- large anode surface (compare pixel anode plane with surface of thin wire)
- E-field at flat anode ~3 lower than E-field at anode wire

Linear fit
$I = I^0 + a.t$
$a = -0.5932$
$\Rightarrow a/I^2 = 0.0183$

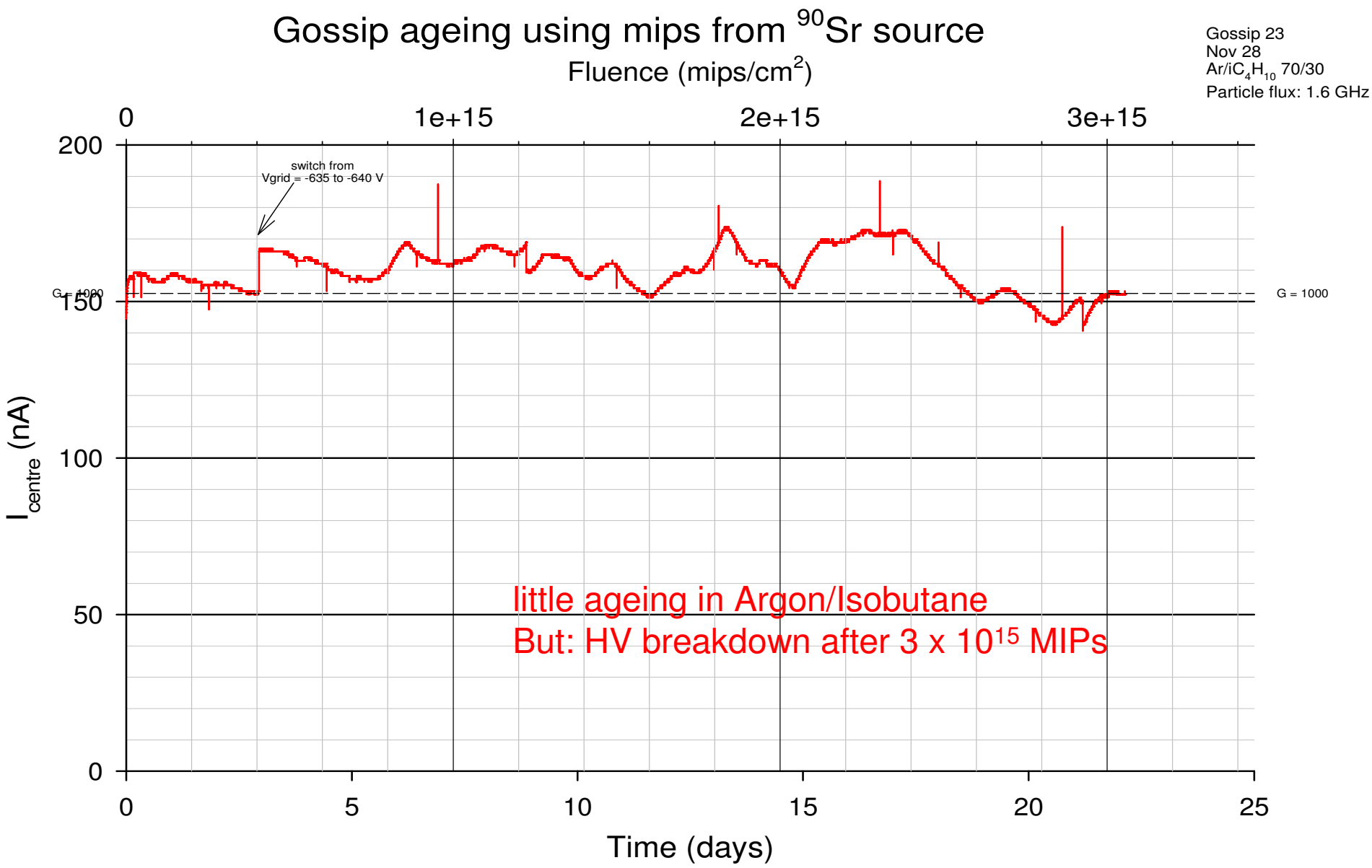


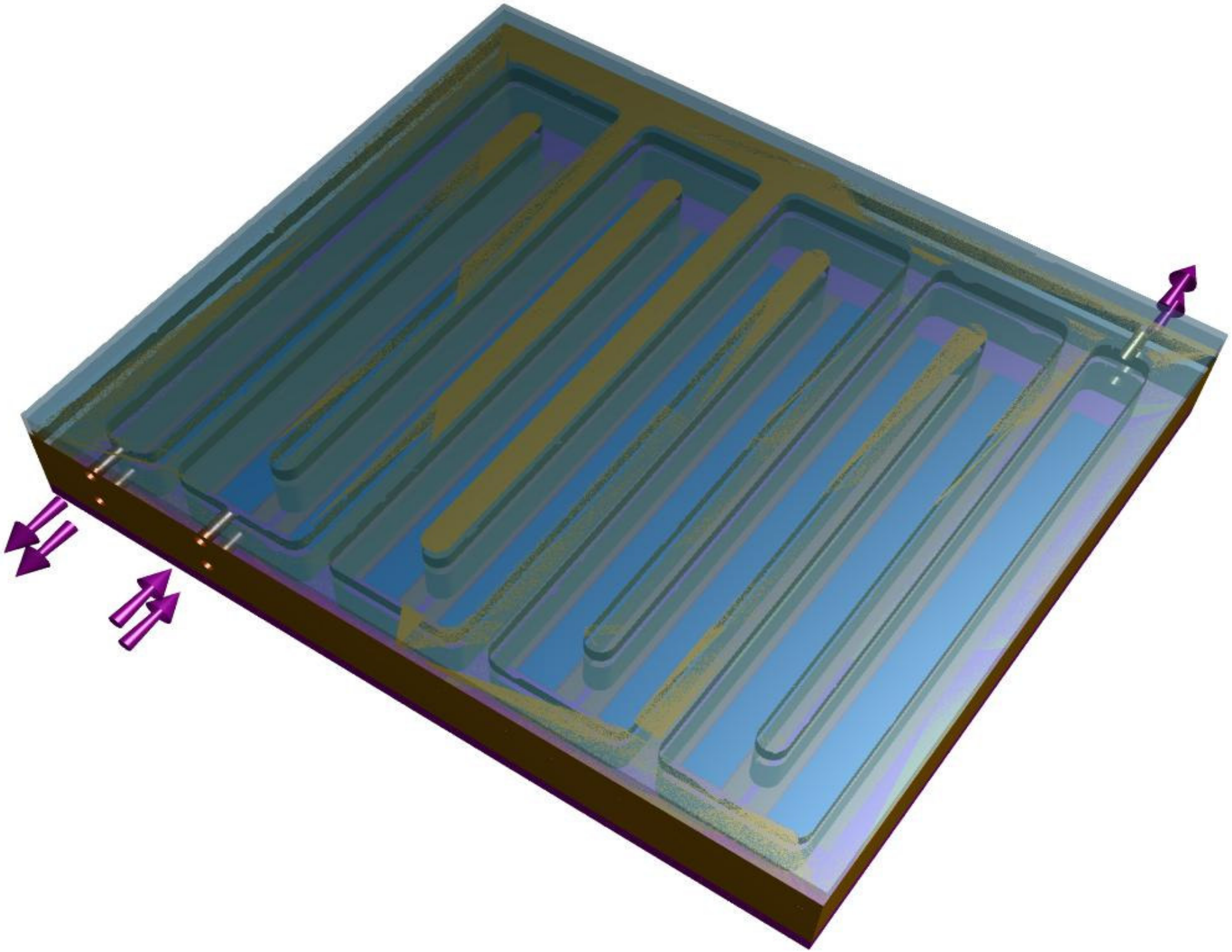
av current = 5.9 µA
=> total charge deposited
= 5.9*3600*24*4
= 2.55 C
surface 0.49 cm^2
=> 5.2 C/cm^2
assume: drift distance 1 mm
Ar/CH4 having $9e^-/mm$
=> 1 mip = $9*1000*1.6*10^{-19}$
= $1.44\ 10^{-15}$C
deposited charge corresponds to
$3.6\ 10^{15}$ mips/cm^2

gas: standard Ar/Methane 90/10. Deposit containing C found on anode

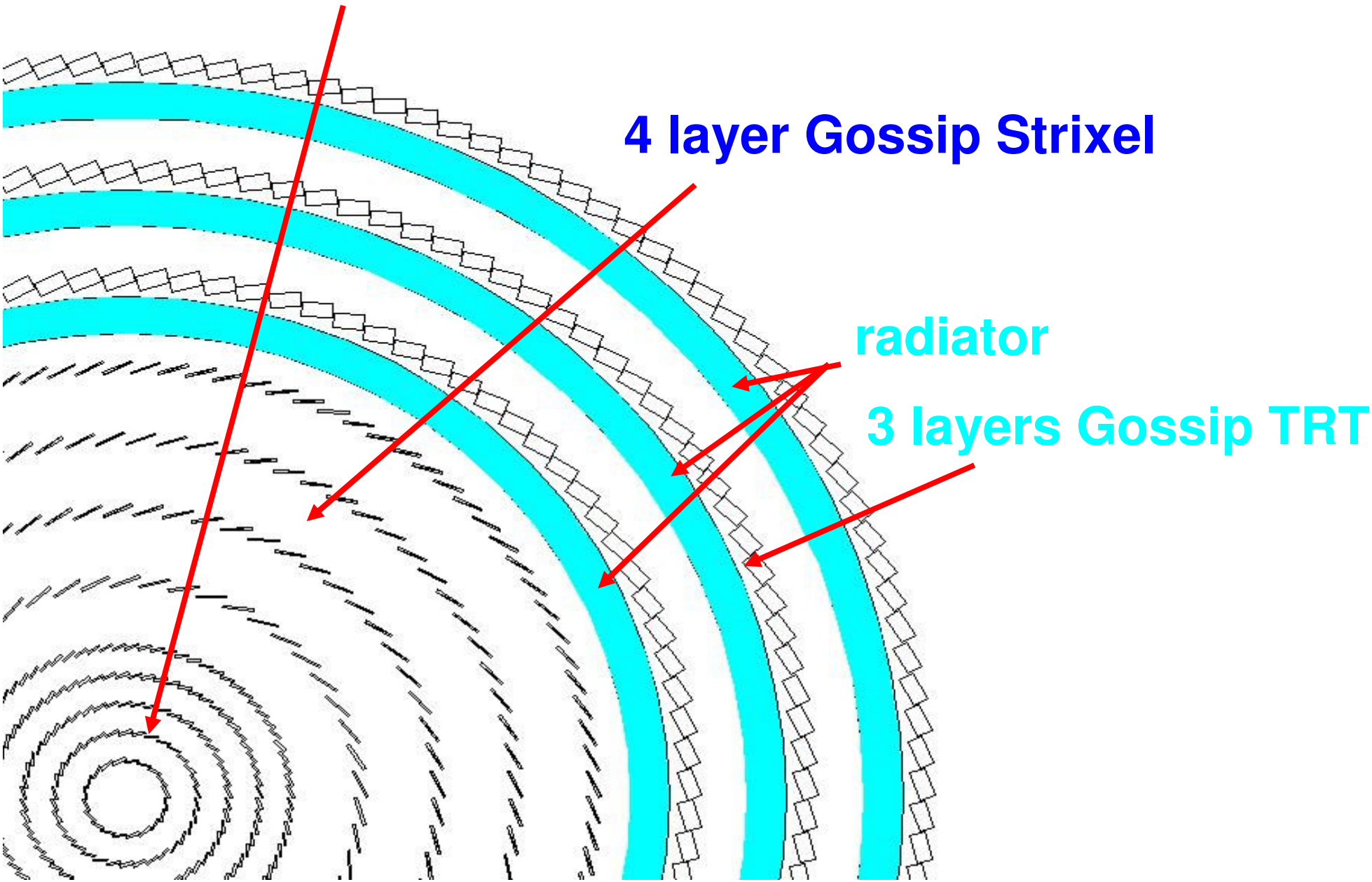


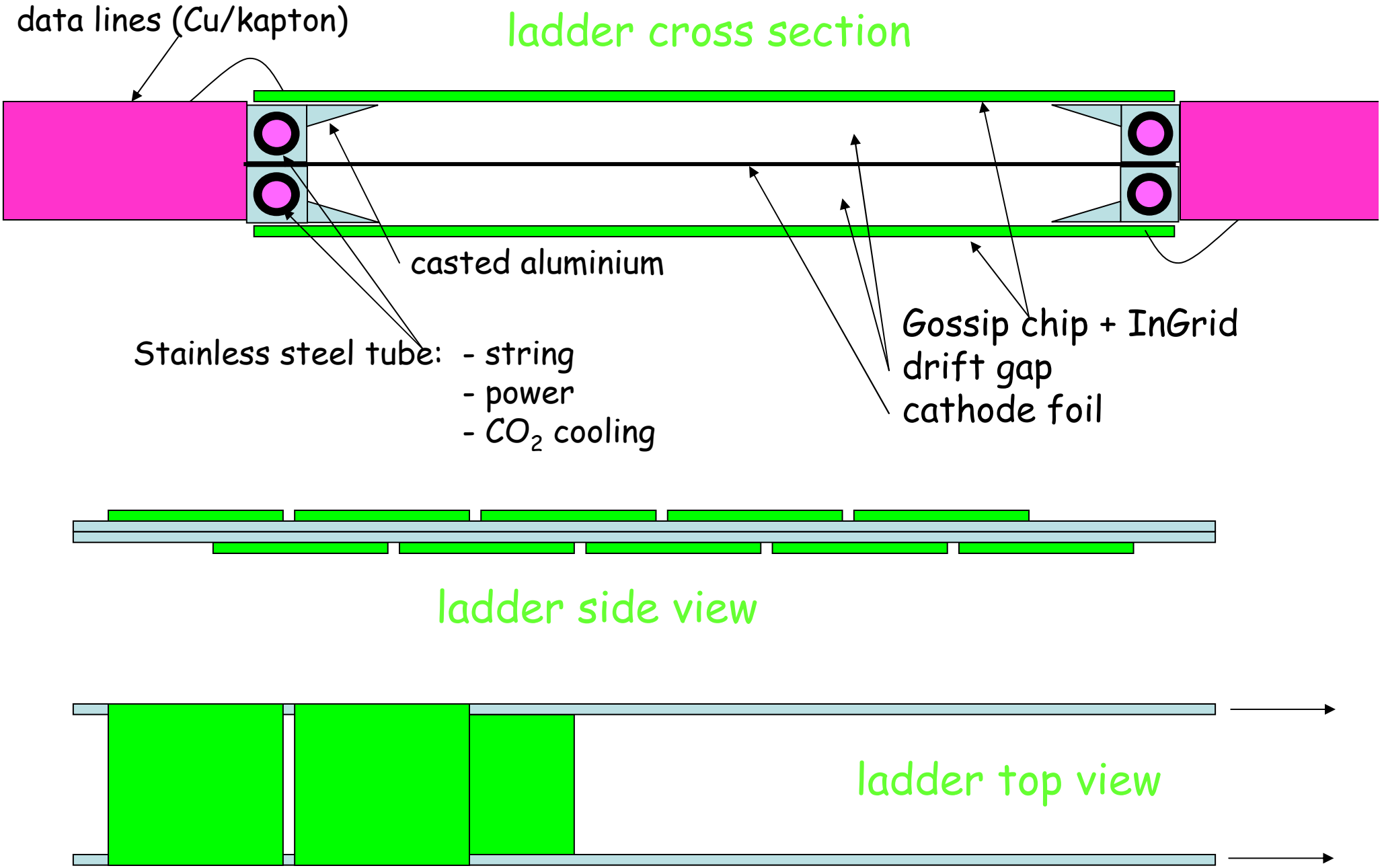
set up ageing test


Gossip ageing using mips from ^{90}Sr source
Fluence (mips/cm^2)
Gossip 23
Nov 28
Ar/iC$_4$H$_{10}$ 70/30
Particle flux: 1.6 GHz
0
1e+15
2e+15
3e+15
200
150
100
50
0
switch from
Vgrid = -635 to -640 V
G = 1000
G = 1000
I$_{centre}$ (nA)
little ageing in Argon/Isobutane
But: HV breakdown after 3 x 10^{15} MIPs
0
5
10
15
20
25
Time (days)



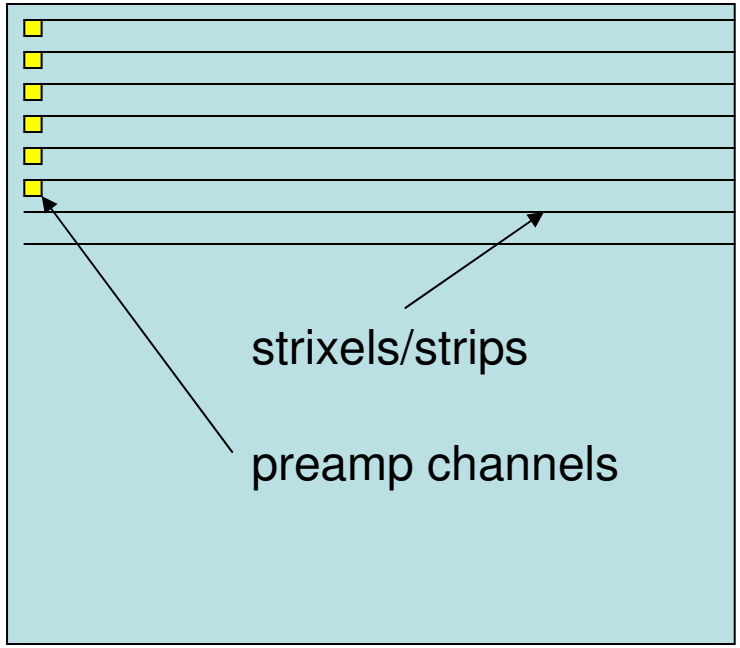
E


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


data lines (Cu/kapton)
ladder cross section
casted aluminium
Stainless steel tube:
- string
- power
- CO_2 cooling
Gossip chip + InGrid
drift gap
cathode foil
ladder side view
ladder top view

Upgraded SCT: Gossip/GridPix could replace:

- Pixel vertex detector: Gossip
- Si Strip detectors: replace by Gossip Strixel detectors
- TRT: use GridPix as tracker/TR X-ray detector



~ 20 mm

Essentials:

- power dissipation: 1/16 x 60 mW/cm^2 = 4 mW/cm^2
  now:25 mW/cm2
- intrinsic mass: 0.1 % radiation length
- low cost: 10 $ / cm^2