Gaseous Detectors
History and New Developments

100 years ago
Hans Geiger operated first gaseous detector in Manchester, UK, 1908

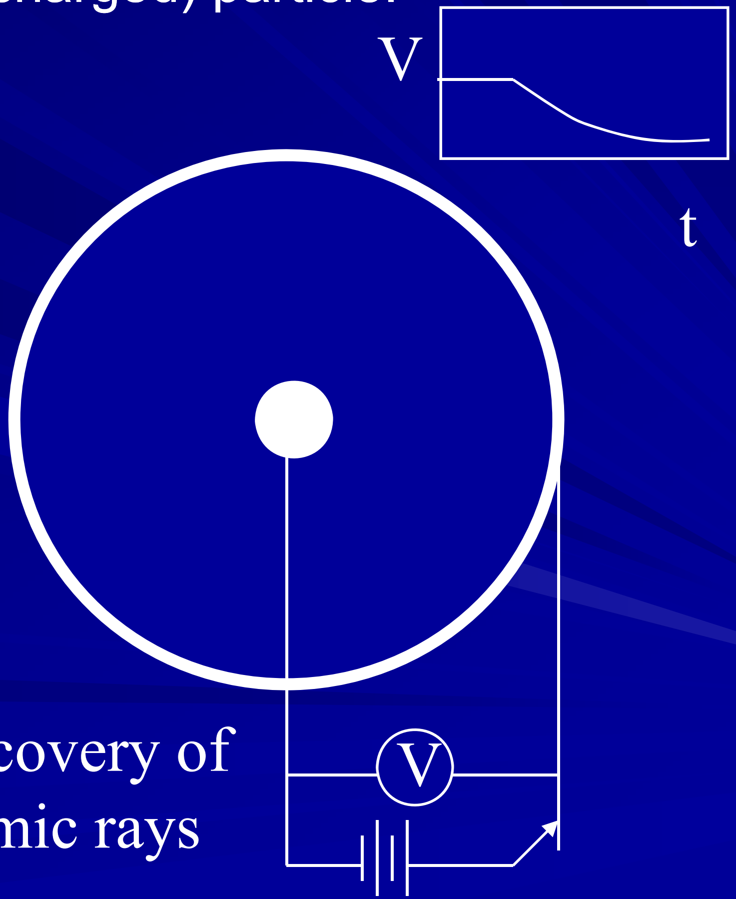
Harry van der Graaf, Nikhef, Amsterdam

CERN Student Seminar, March 13, 2008

First Gaseous Detectors

- Ionisation chamber

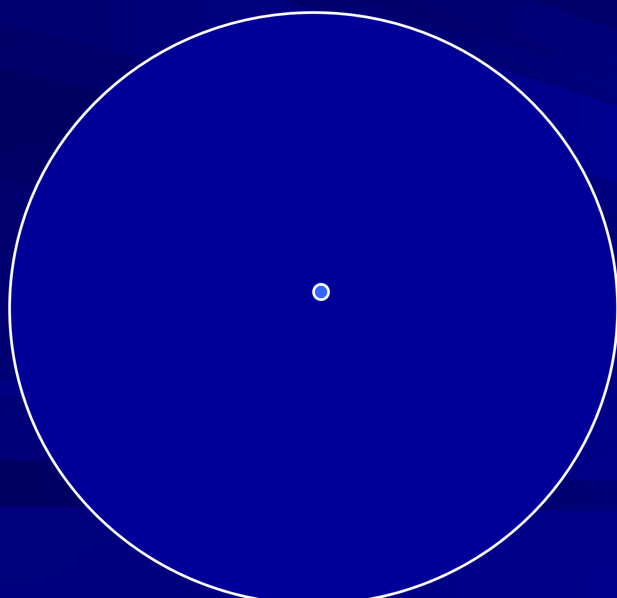
  Gas filled space with anode and cathode. A current flows after the passage or the absorption of a (possibly charged) particle.

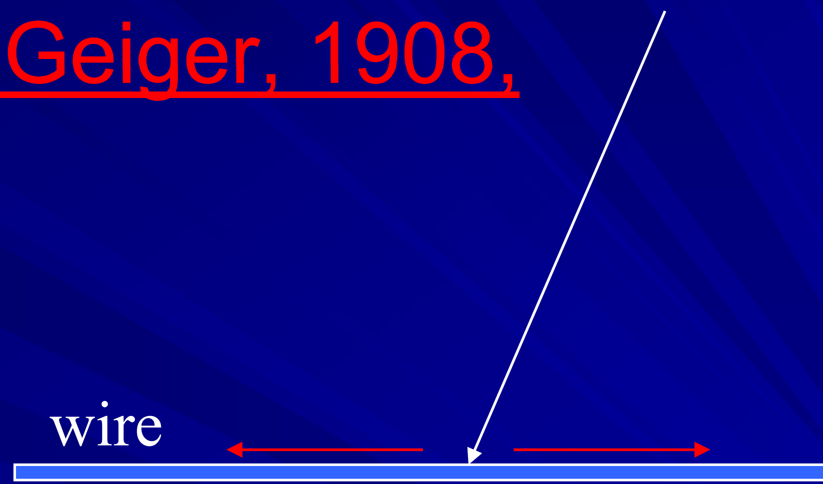


Discovery of cosmic rays

First Gaseous Detectors

- Geiger Counter: Hans Geiger, 1908, Manchester





- Gas ionisation
- electron drift
- electron avalanche
- discharge propagation
- (self) quenching

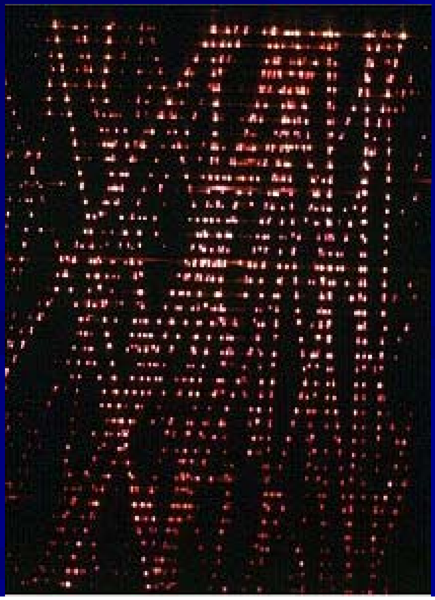
Early Gaseous Detectors

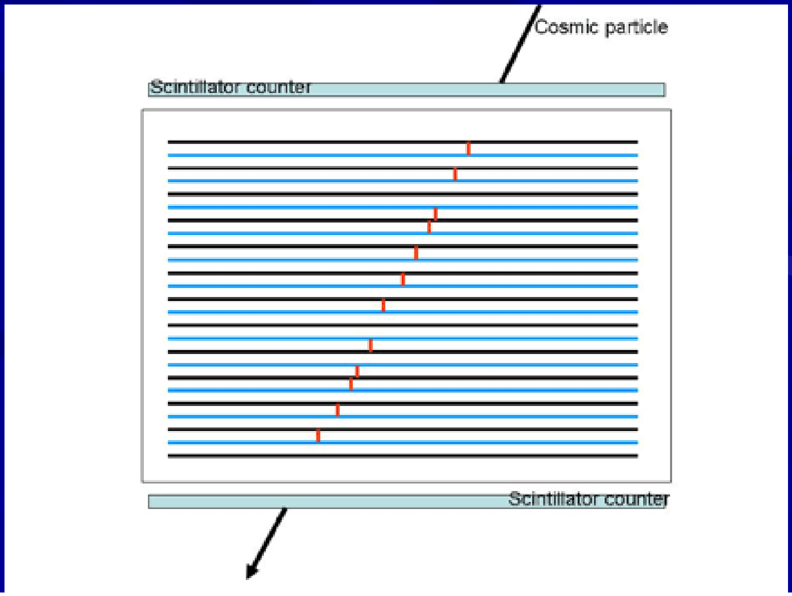
- Spark chamber

  Parallel conducting plates connected alternating to high-voltage supply (pulsed after external trigger) and ground. Filled with noble gas. High voltage causes avalanche formation leading to production of UV light seen as sparks

- Streamer chamber

  Large gap spark chamber, with high voltage (typically about 500 kV) applied during short time after external trigger. Avalanches develop only in the vicinity of the initial ionization, resulting in short segments, "streamers",producing UV light.





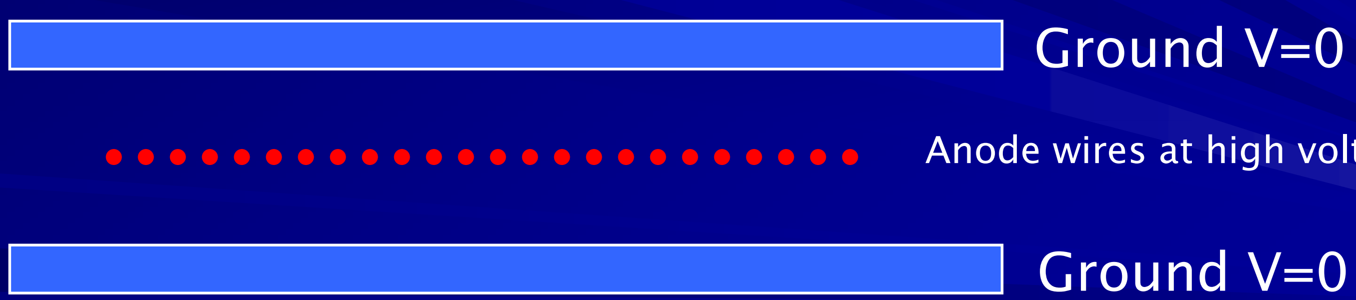
- Gaseous detectors are mainly used to measure the trajectory of a charged particle

- When a magnetic field is applied the momentum can be determined by measuring the curvature of a particle track

- If the momentum is determined than the energy loss of the particle can be related to its mass → particle identification

Principle

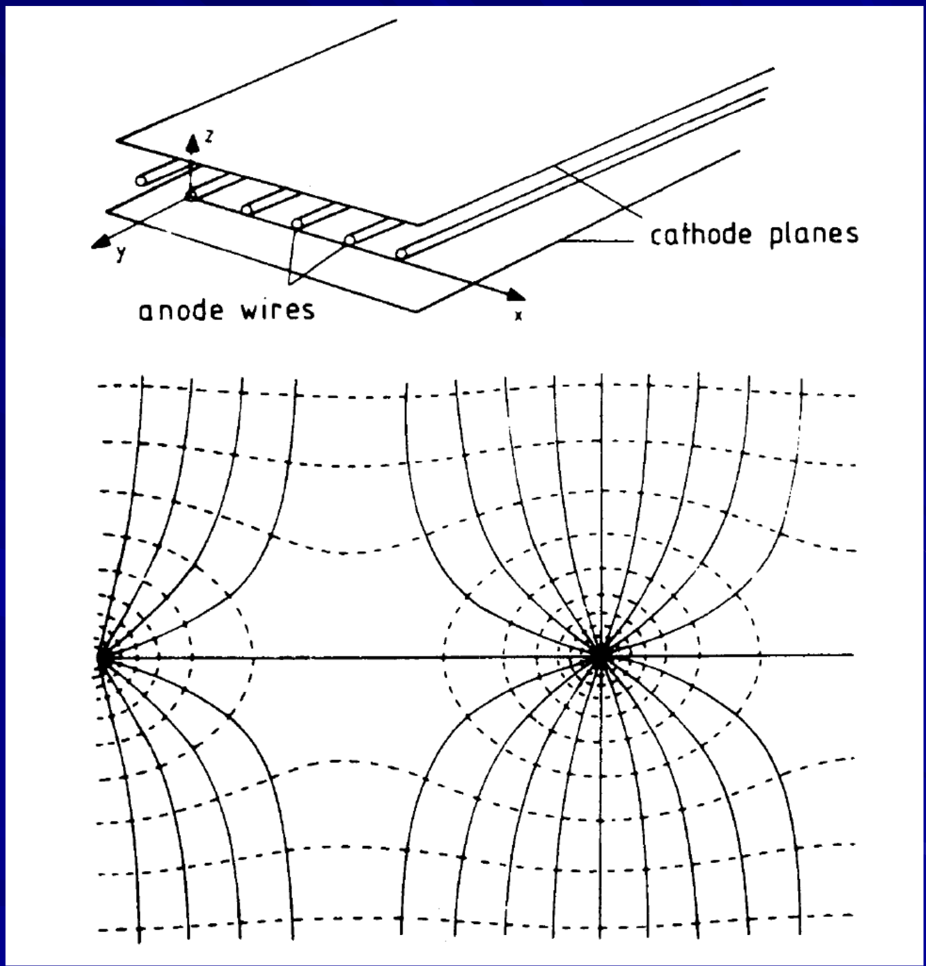
- Passing fast charged particle creates electron-ion pairs along track
- Electrons drift towards positive anode
- Close to the anode the field is strong the electrons are accelerated such that they produces secundary electrons, accelerated such that they produces secundary electrons, accelerated such that they produces secundary electrons, accelerated such that they produces secundary electrons.....................an avalanche!
- The measured signal is caused by the slow ions moving away from the anode



Fernow, page 218-219

Multi Wire Proportional Chamber
Charpak & Sauli, 1968

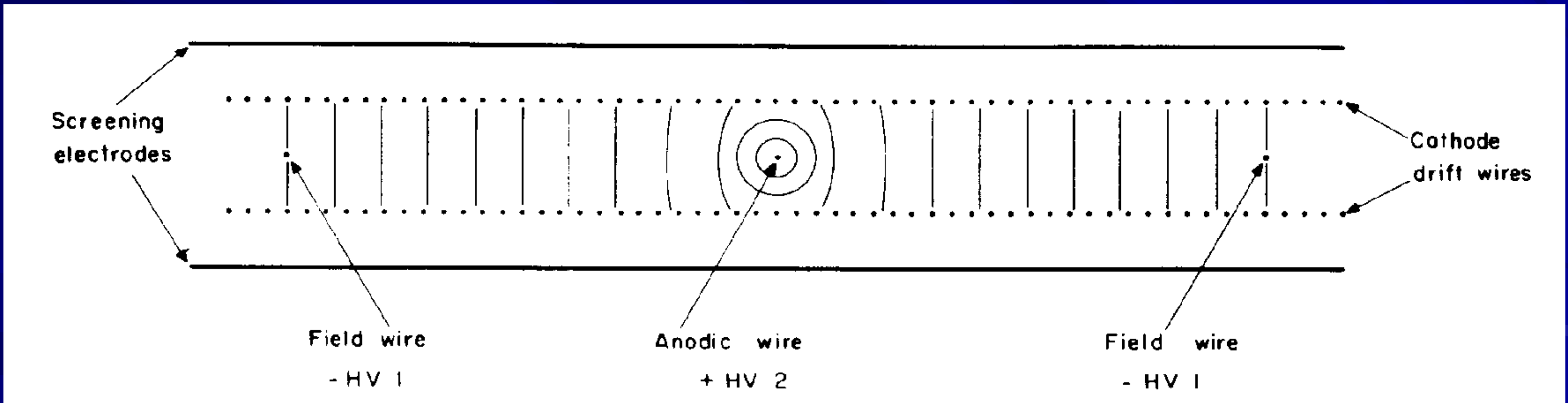
- The signal on the wire provides the coordinate in 1-dimension
- The resolution is determined by the wire pitch P. <u>No drift time: σ = P /√12</u>
- Typical dimension
  - Thickness 10 mm
  - Pitch 2 mm
  - Surface 1000 x 1000 mm
- Mind the electrostatic force between the two wires



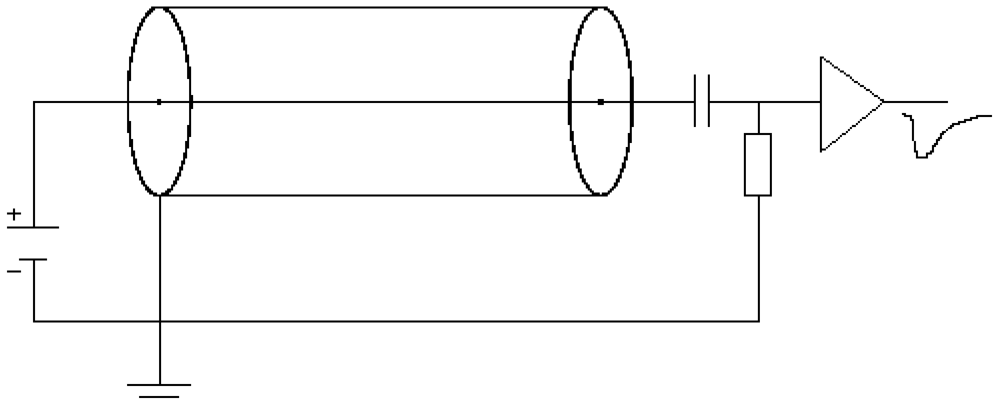
Fast detector, not expensive, fast all-electronic readout

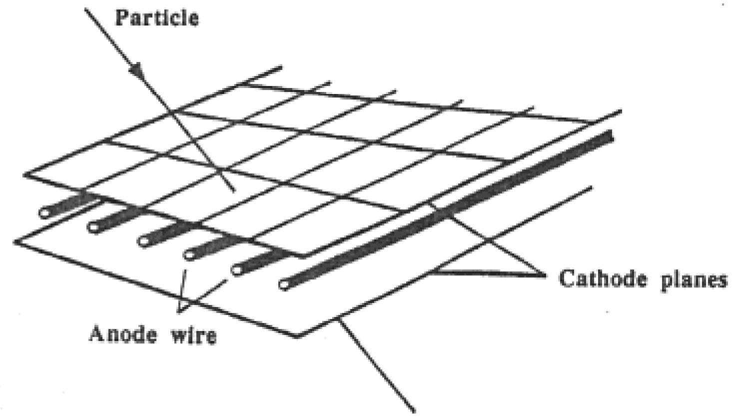
Drift Chamber

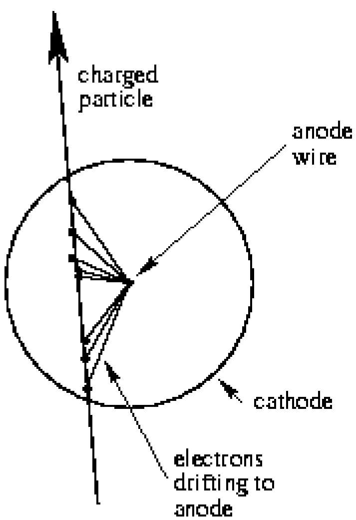
- After the MWPC: introduction of the drift time measurement
- To improve the elctric field configuration field wires are used

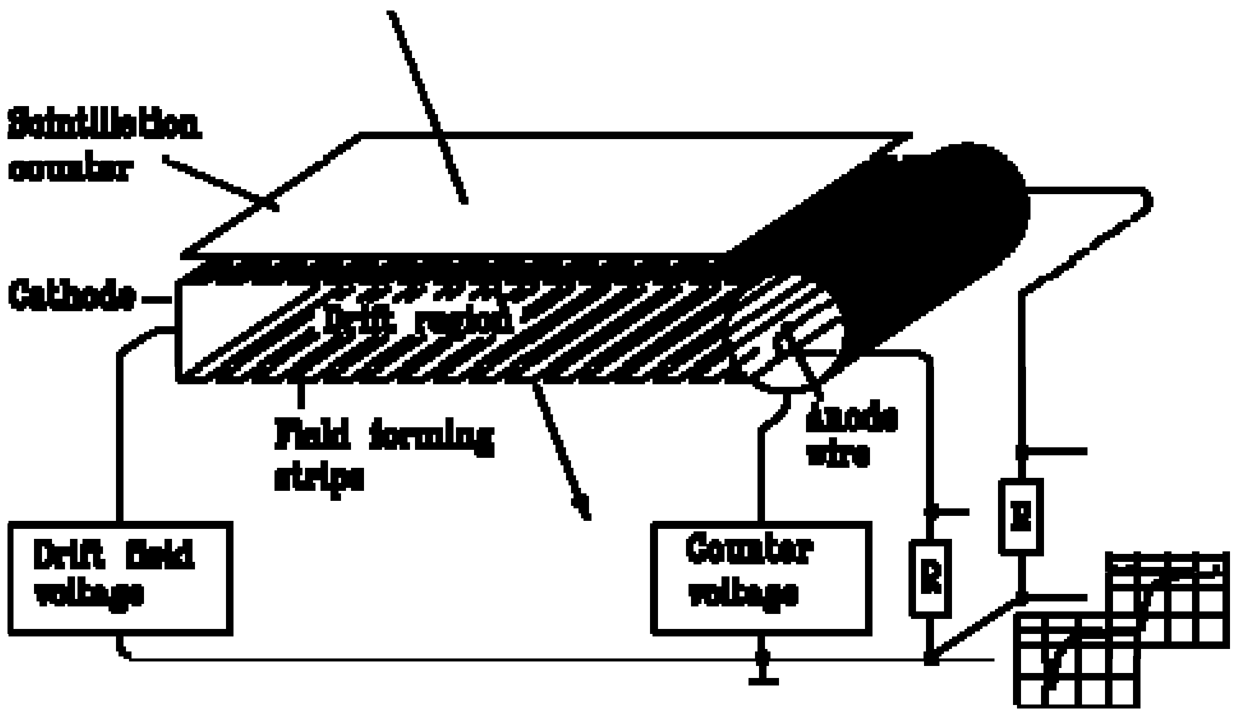


Very good position resolution, low cost (but not so fast)


+
−


Particle
Cathode planes
Anode wire


charged particle
anode wire
cathode
electrons drifting to anode


Scintillation counter
Cathode
Drift region
Field forming strips
Anode wire
Drift field voltage
Counter voltage
R
R

Avalanche close to wire

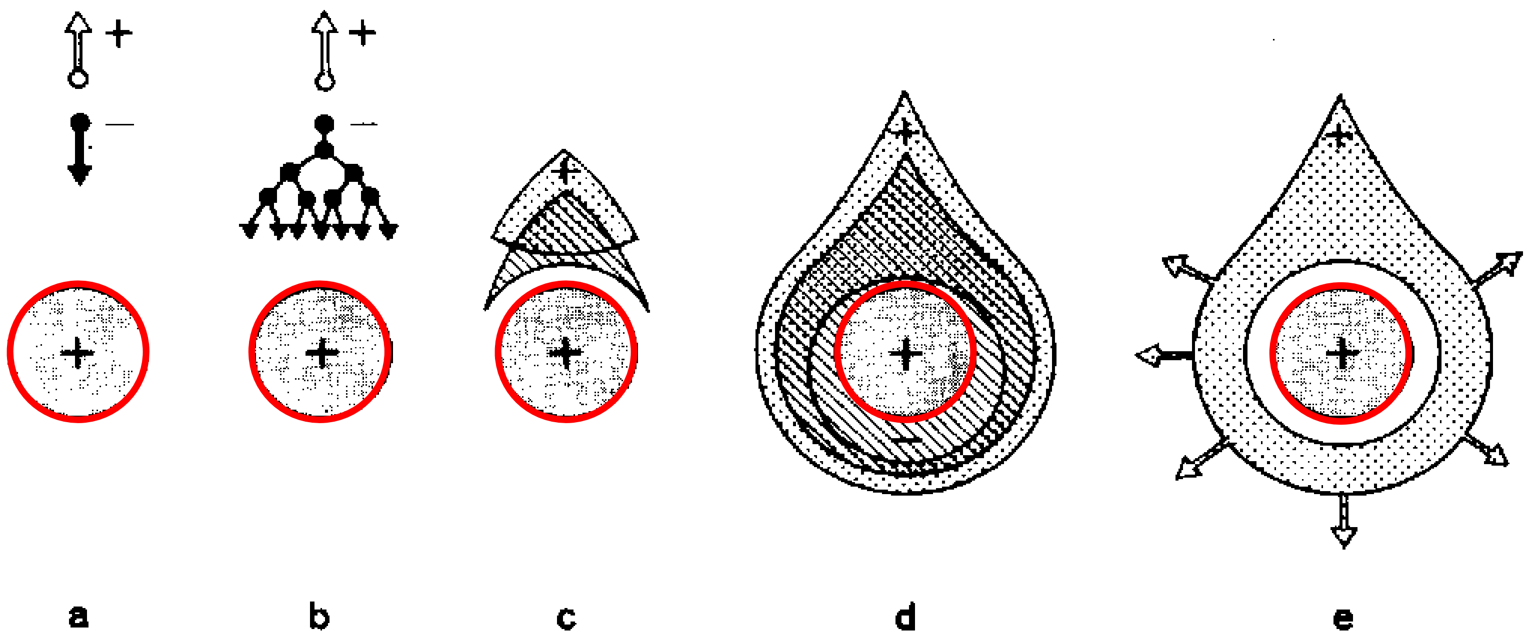


Fig. 49 Time development of an avalanche in a proportional counter[30]. A single primary electron proceeds towards the anode, in regions of increasingly high fields, experiencing ionizing collisions; due to the lateral diffusion, a drop-like avalanche, surrounding the wire, develops. Electrons are collected in a very short time (1 nsec or so) and a cloud of positive ions is left, slowly migrating towards the cathode.

F.Sauli, CERN-77-09

Time development

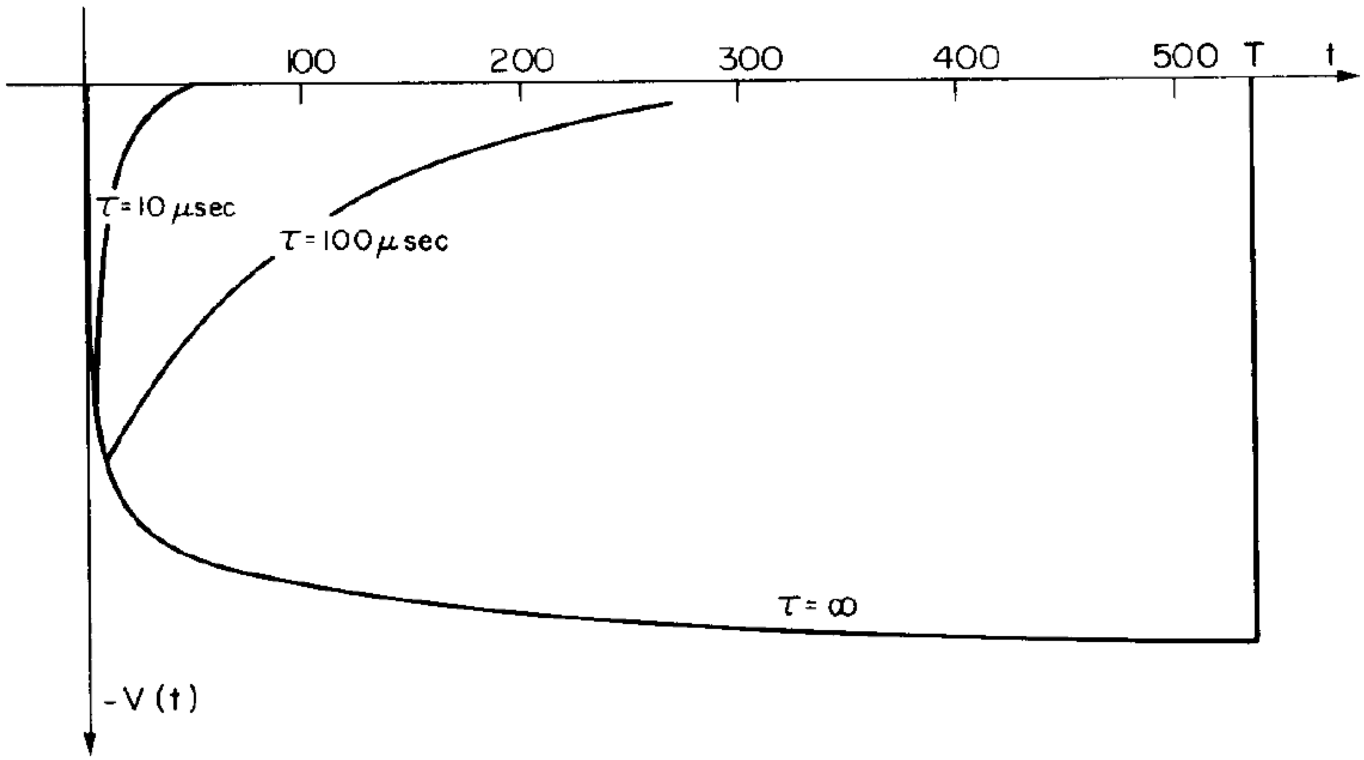


Fig. 52 Time development of the pulse in a proportional counter; T is the total drift time of positive ions from anode to cathode. The pulse shape obtained with several differentiation time constants is also shown.

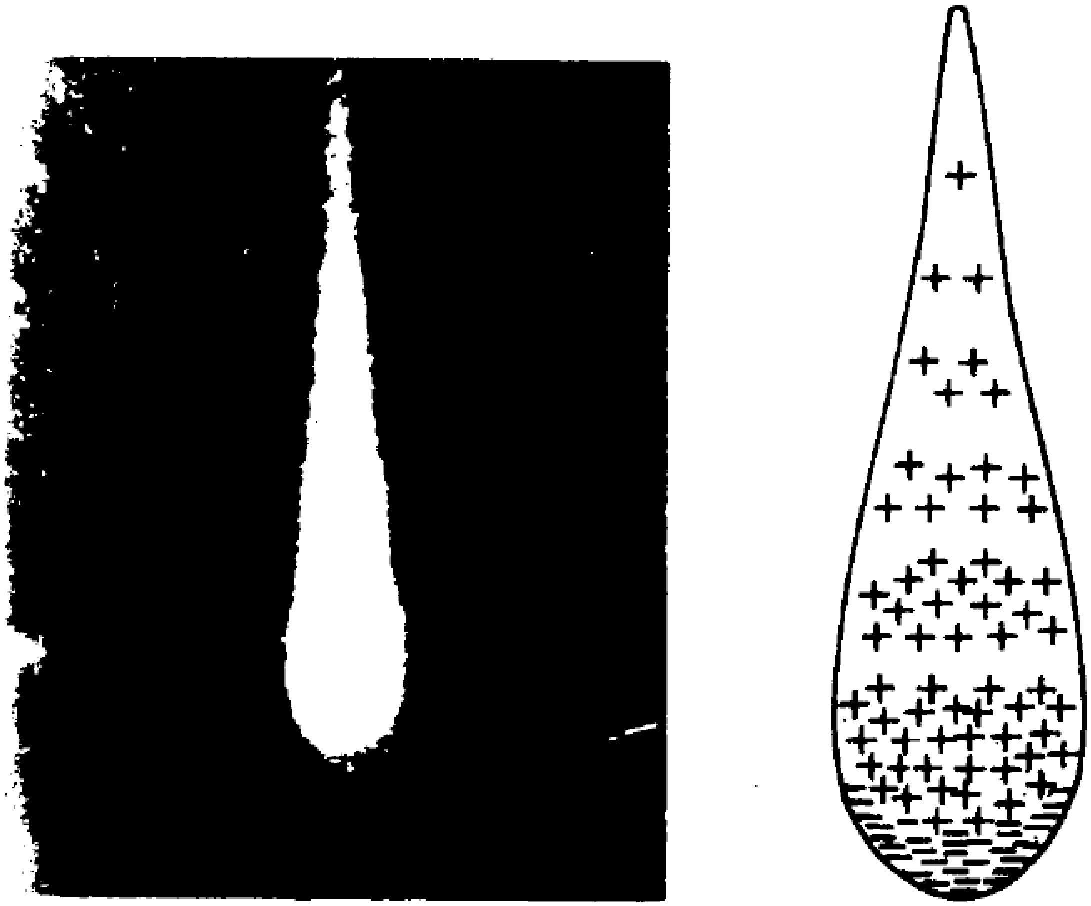
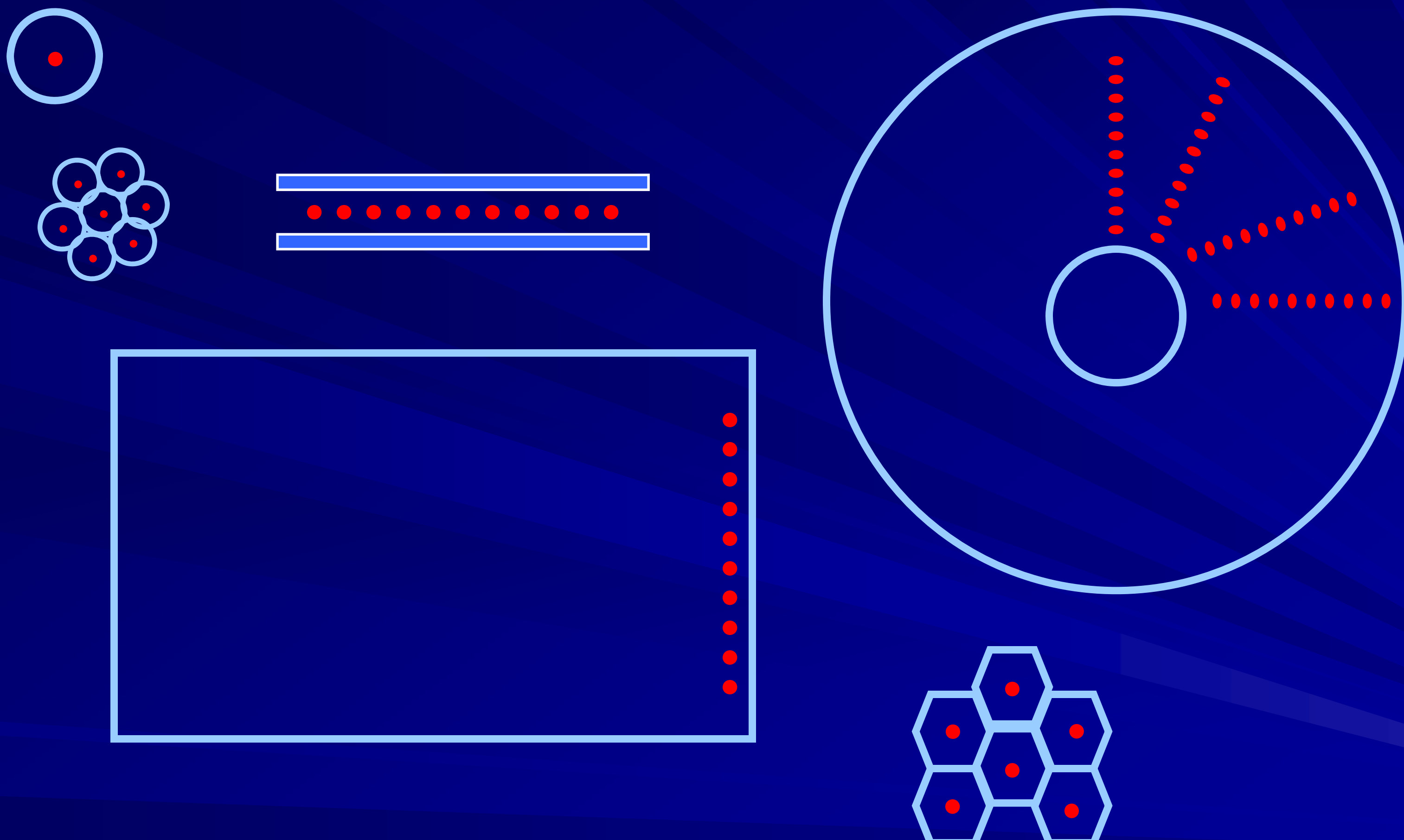
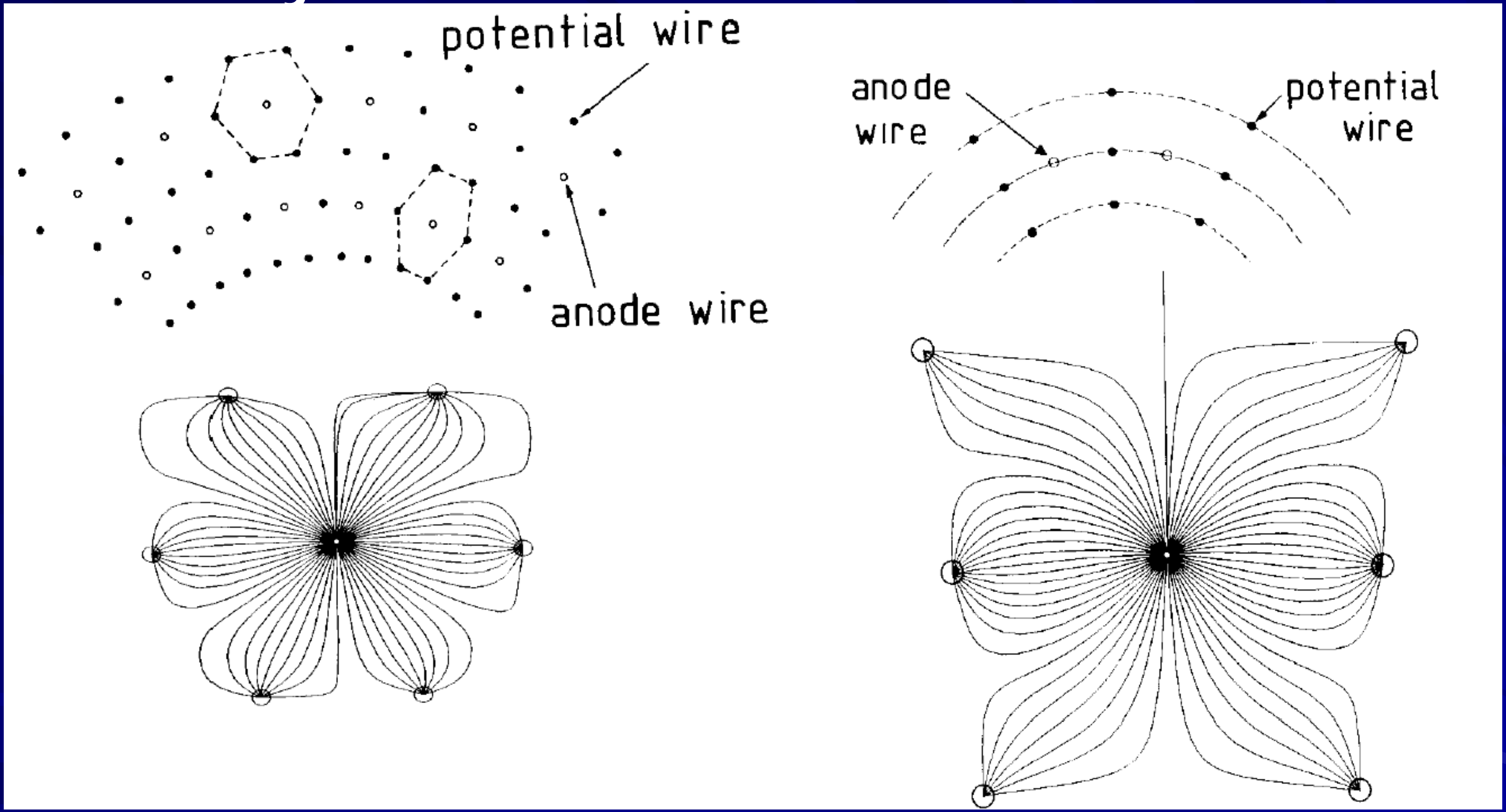


Fig. 46 Drop-like shape of an avalanche, showing the positive ions left behind the fast electron front. The photograph shows the actual avalanche shape, as made visible in a cloud chamber by droplets condensing around ions[18].

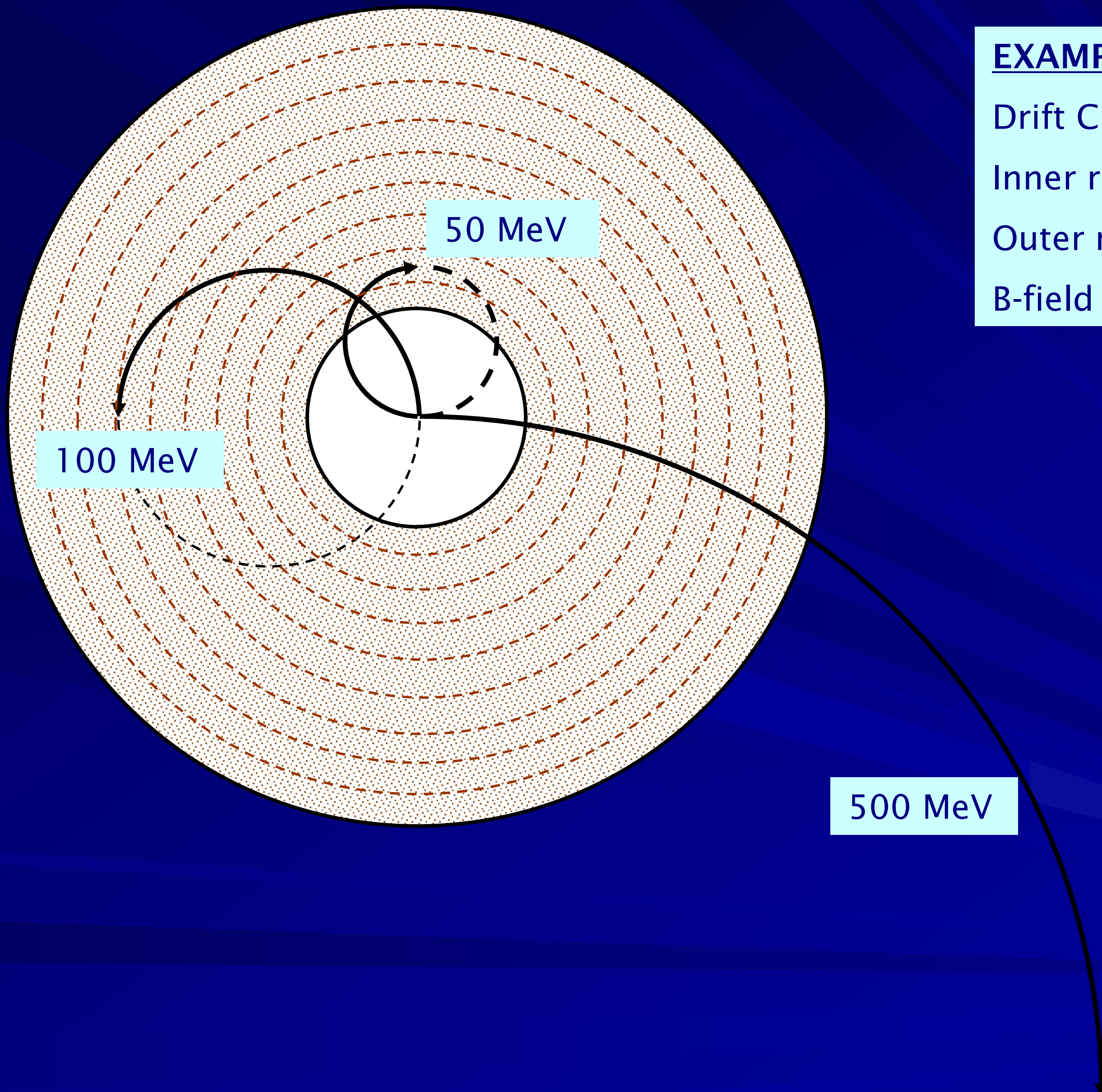
Many configurations....



Cylindrical Drift Chamber



C.Joram. CERN Academic Training 1997-1998



EXAMPLE: ZEUS

Drift Chamber

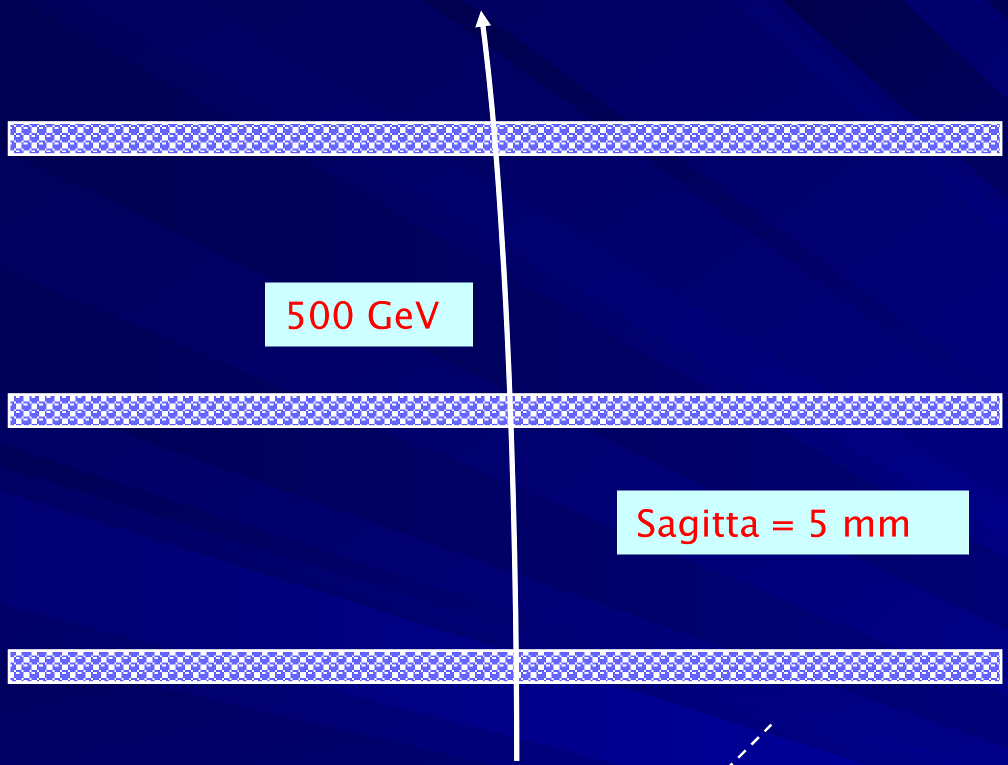
Inner radius 16 cm

Outer radius 85 cm

B-field = 1.5 Tesla

$$\text{radius} = \frac{1}{\rho}$$

$$\rho = \frac{0.3\,B}{p \cdot \sin\theta}$$



EXAMPLE: ATLAS

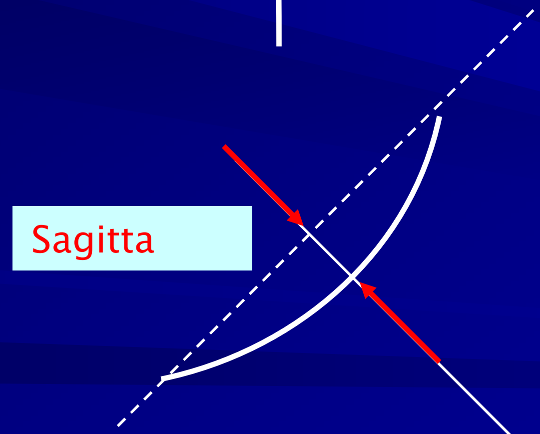
Drift tubes

Inner radius 5 m

Middle radius 10 m

Outer radius 15 m

B-field = 0.6 Tesla

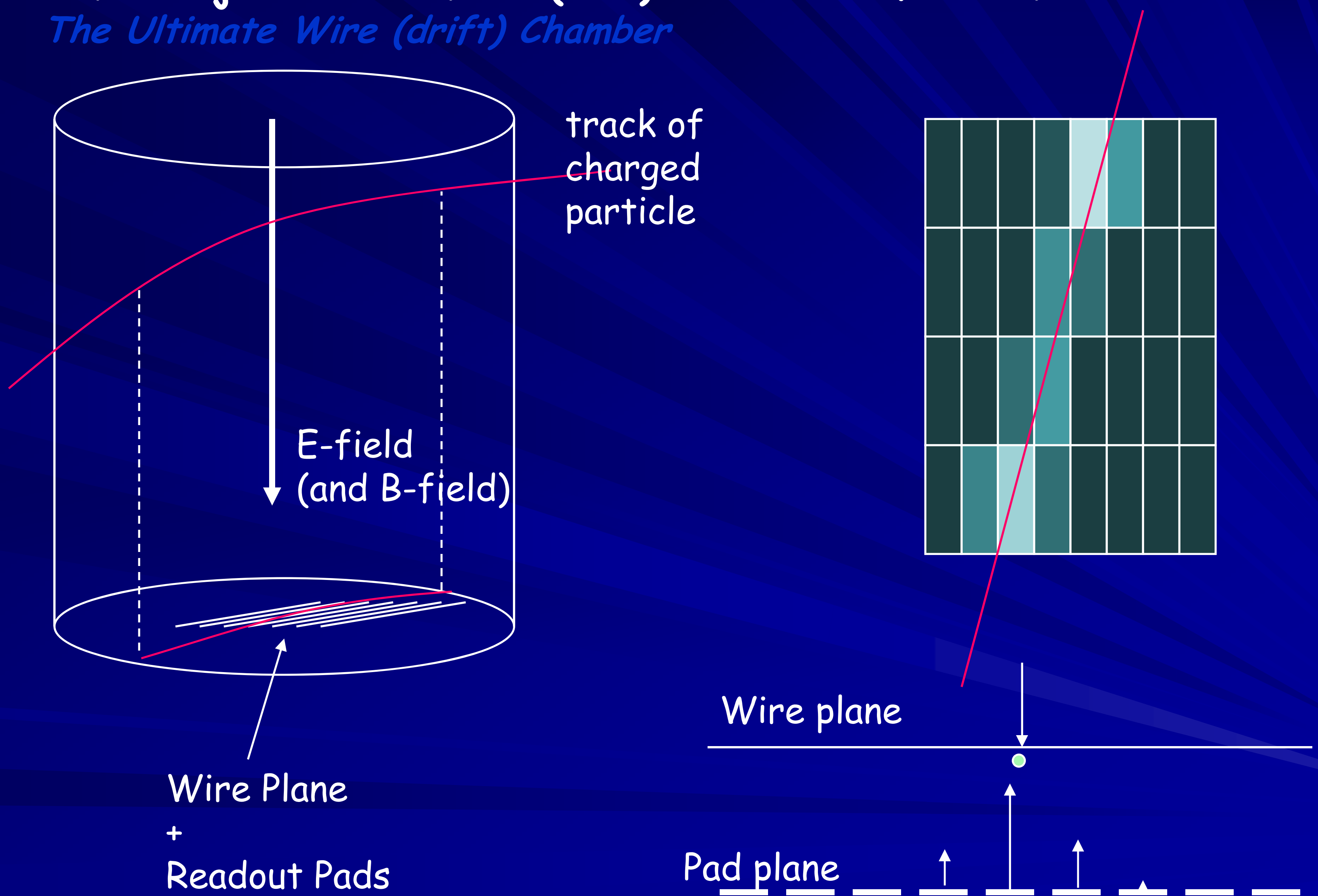


radius = R

Sagitta = $L^2/8R$

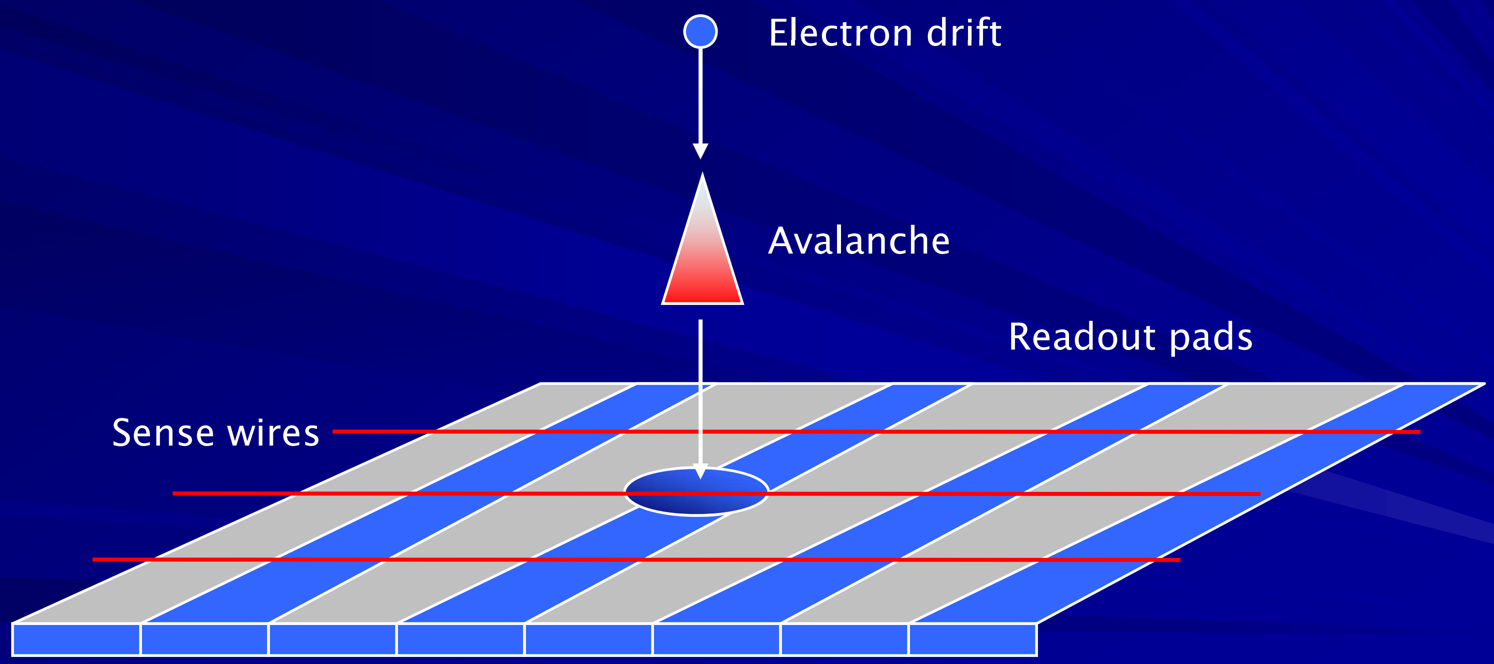
Time Projection Chamber (TPC): 2D/3D Drift Chamber

The Ultimate Wire (drift) Chamber



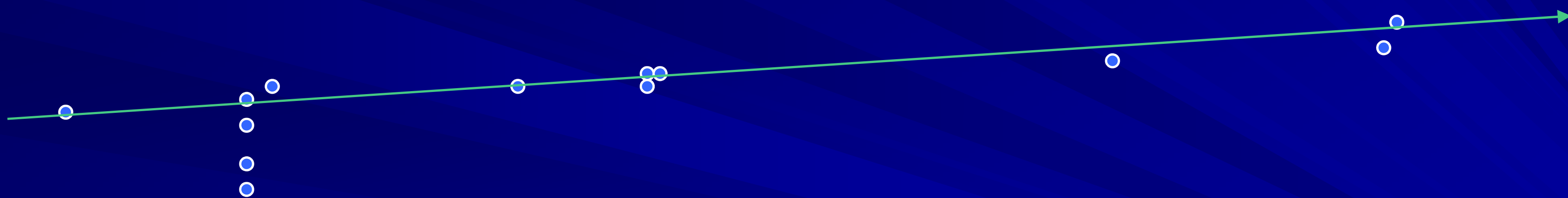
Time Projection Chamber

- Large drift volume of several meters to measure accurate drift time.
- Electron drifts parallel to B-field
- Avalanche induces signal on sense wires & readout pads



Essential: - number of clusters per mm tracklength
- number of electrons per cluster

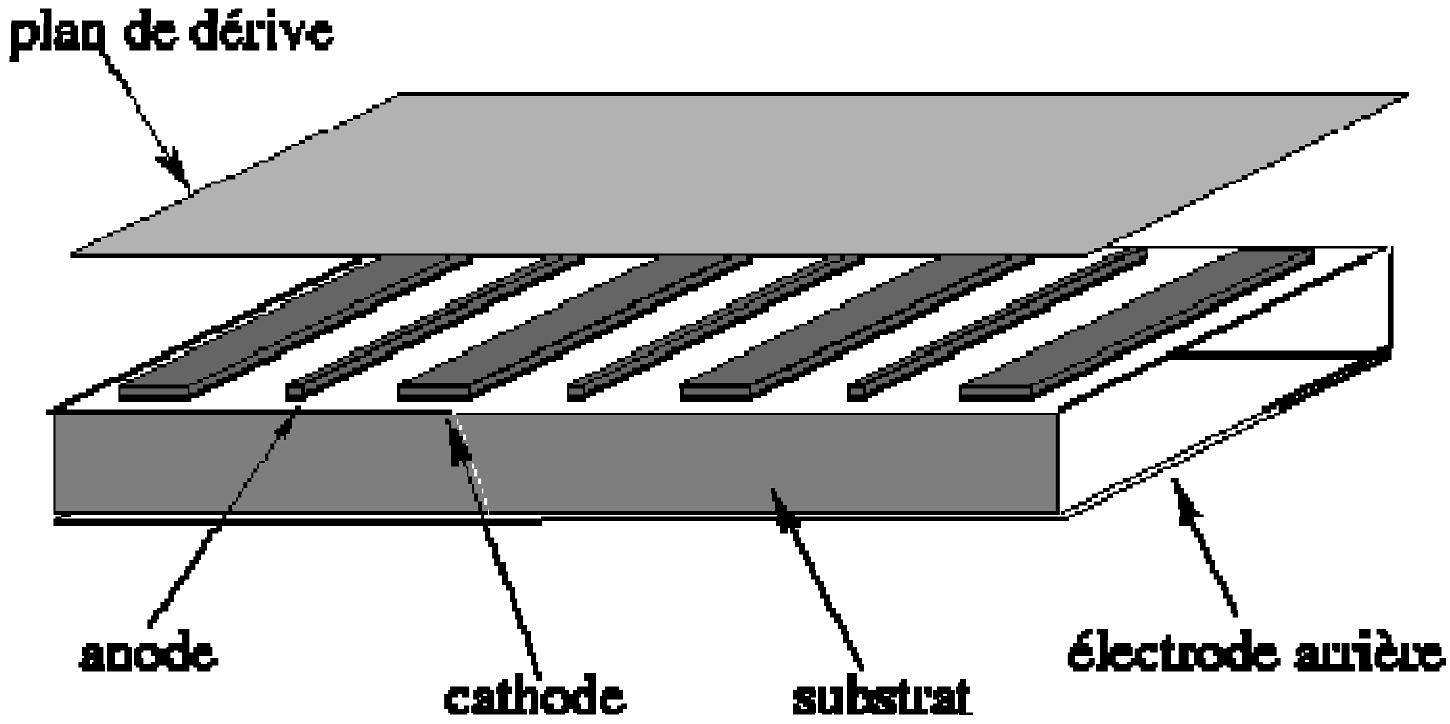
specific for gas (and density ρ, thus T, P!)



Micro Pattern Gas Chambers (MPGCs)

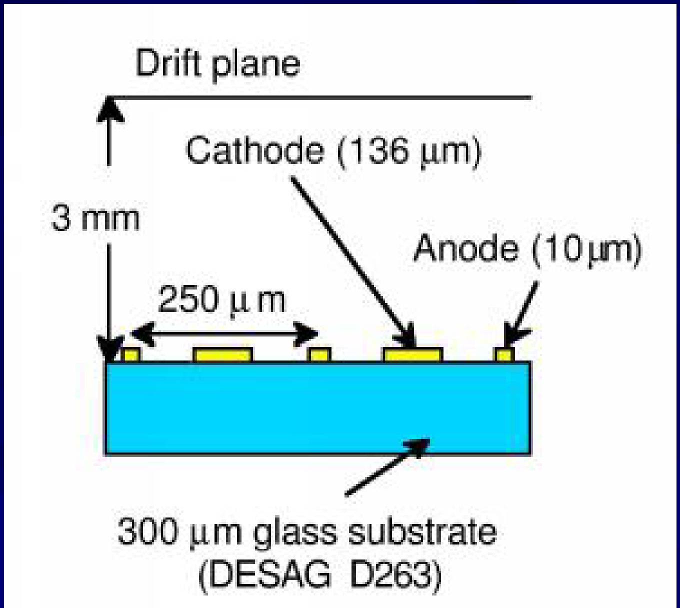
- MSGC
- Micromegas
- GEM
- GridPix chambers

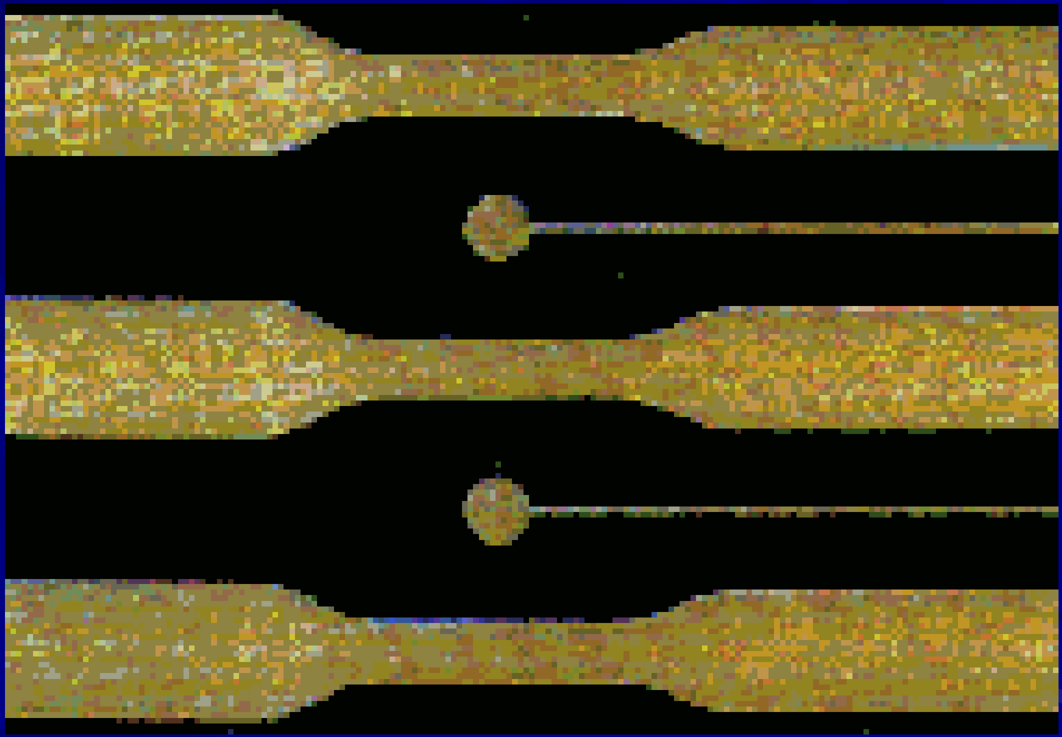
Micro Strip Gas Counter



Wire chambers: granularity ~ 1 mm
MSGCs: granularity 200 µm

Invented by A. Oed, 1988

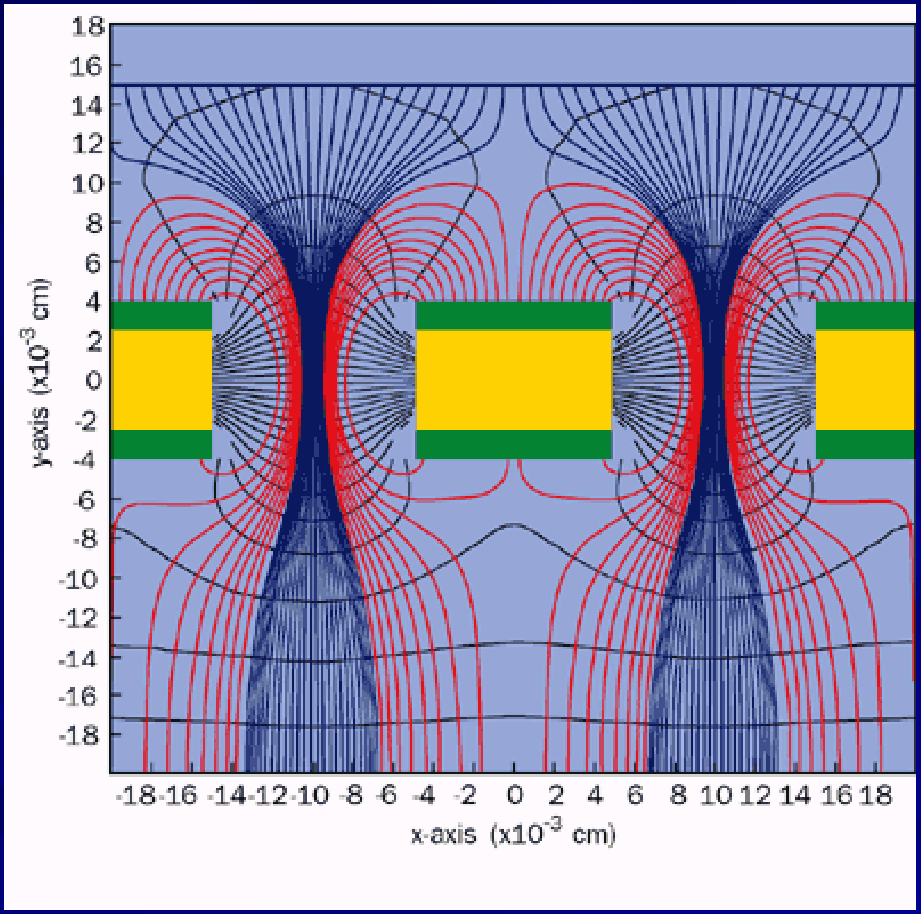




Not often applied:

…sparks……!

1996: F. Sauli: Gas Electron Multiplier (GEM)



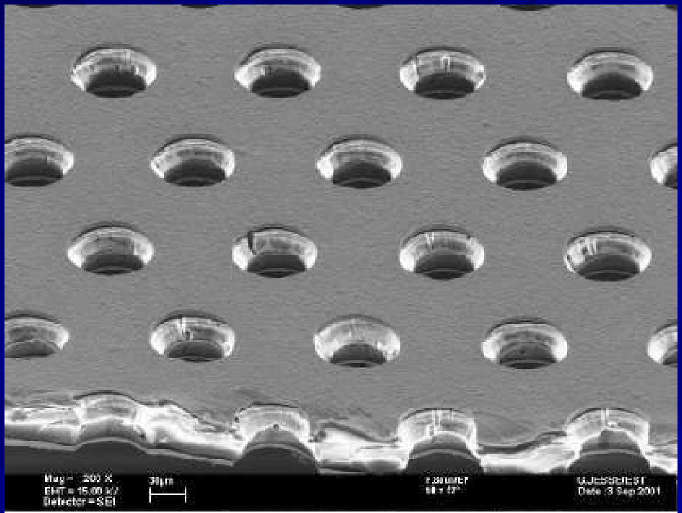


Fig. 7

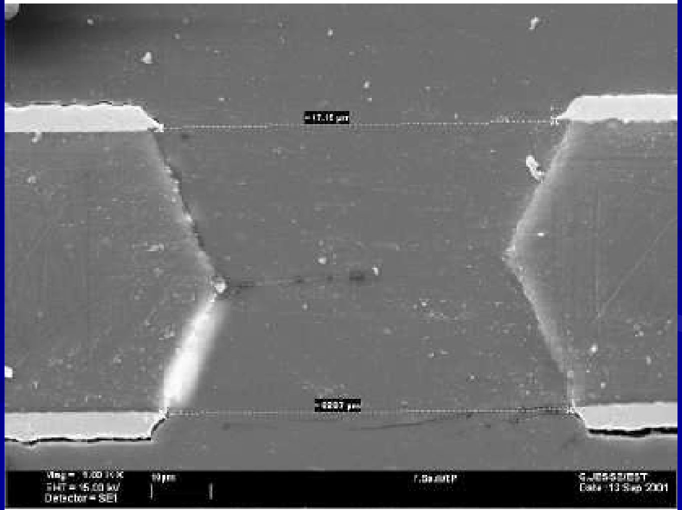
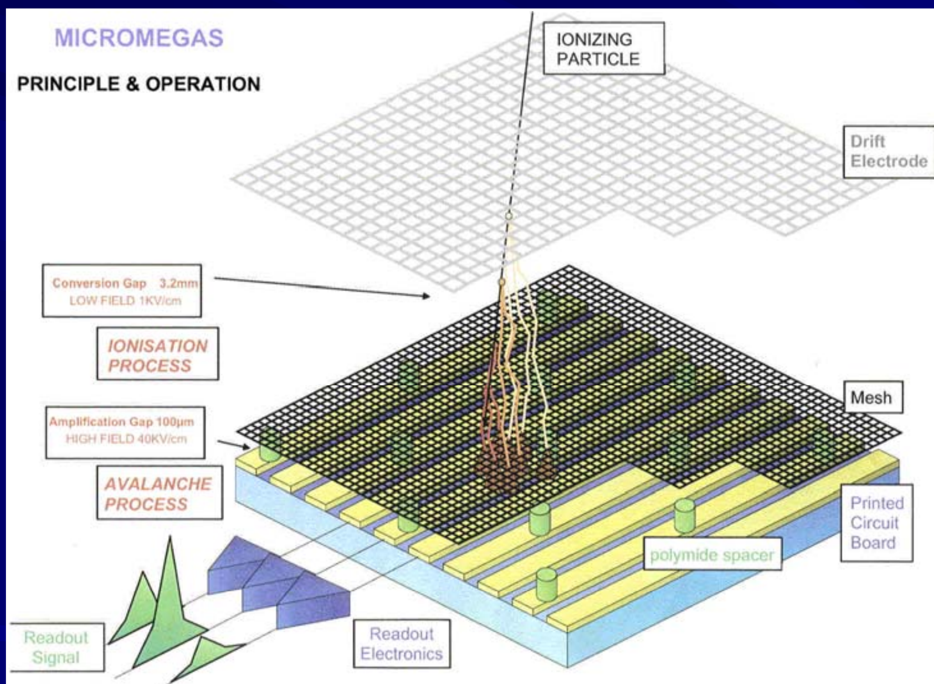
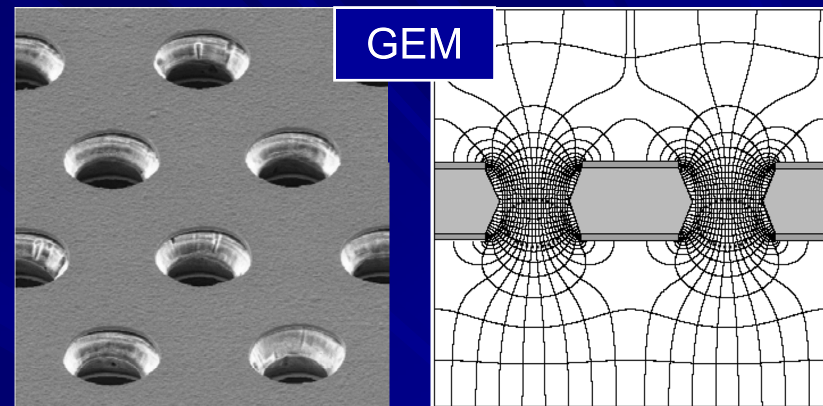


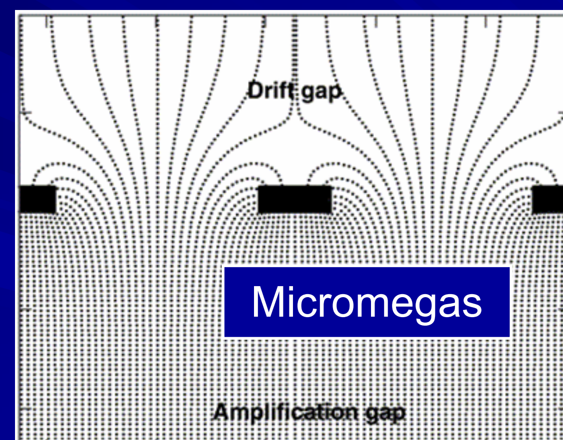
Fig. 8

Micro Patterned Gaseous Detectors

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



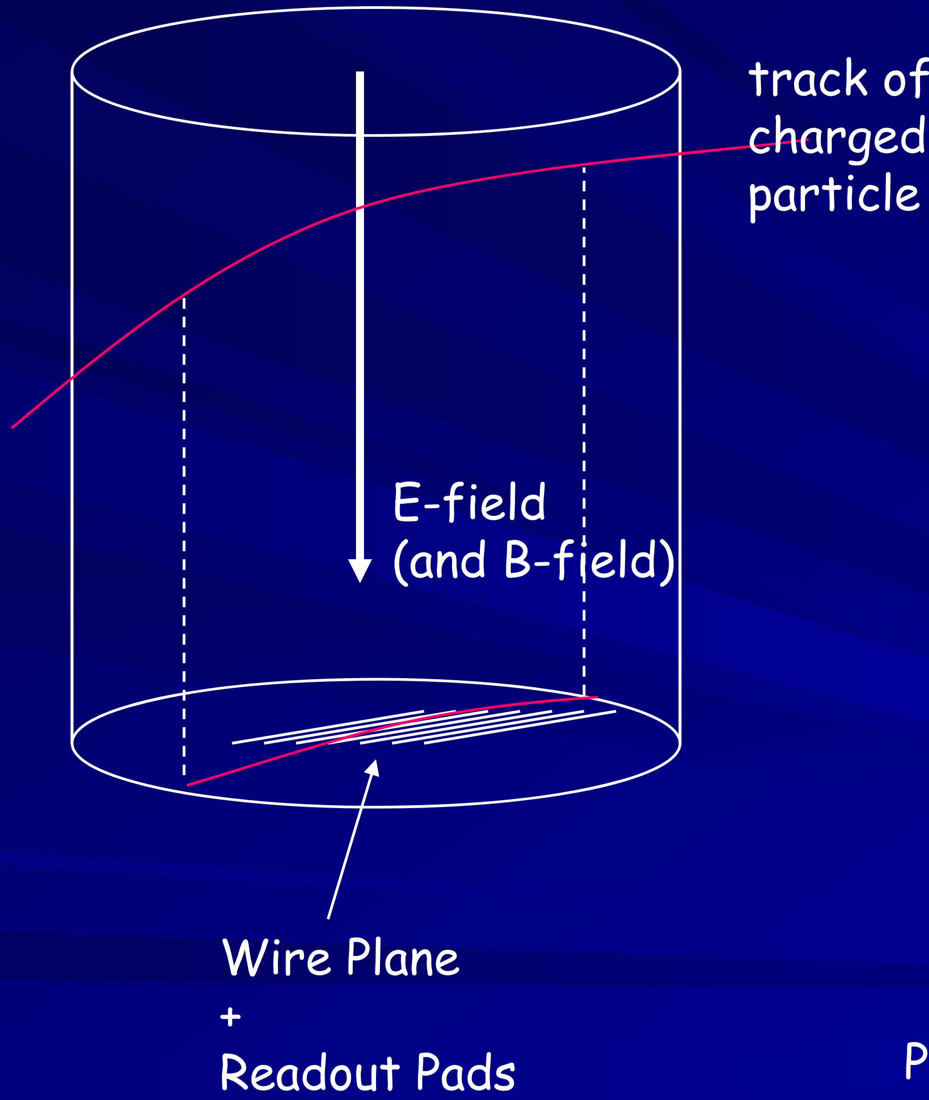


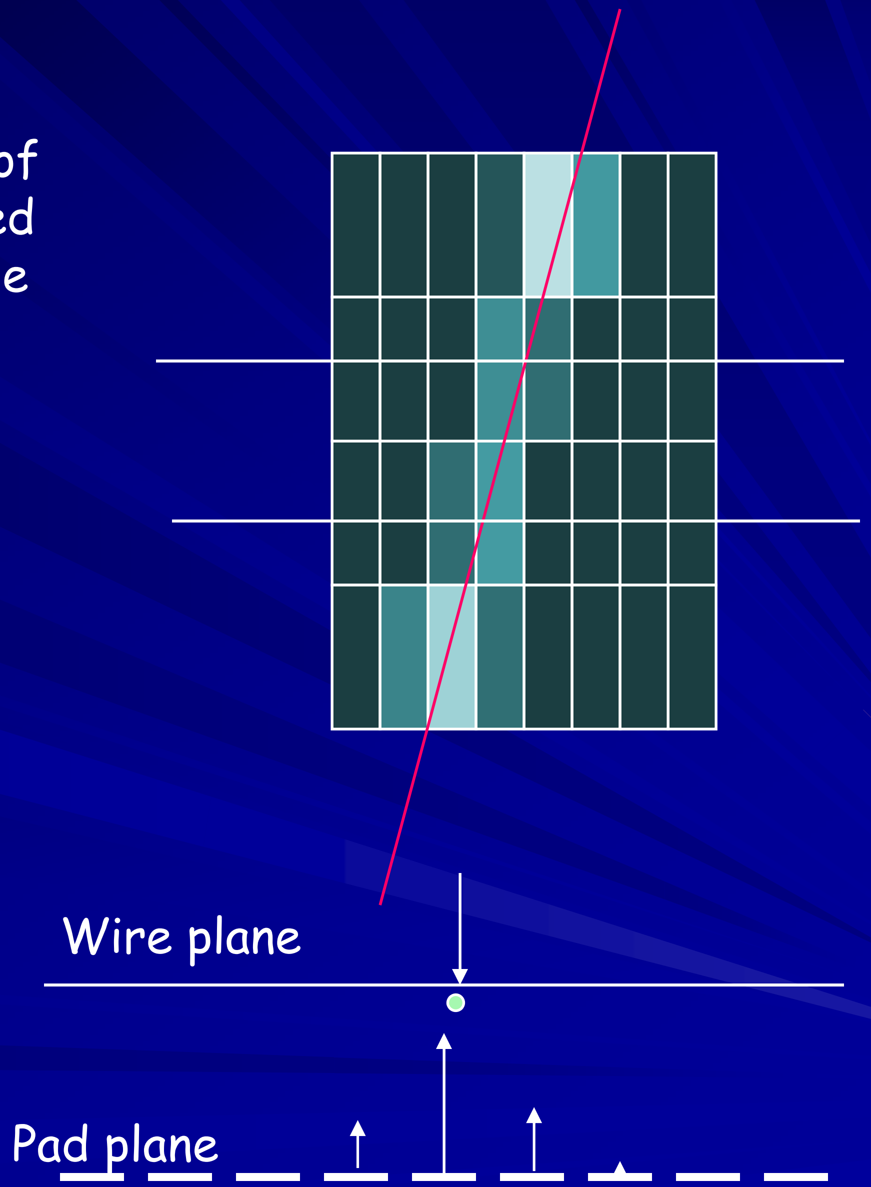


improved granularity : wire chambers react on COG of many electron clouds/clusters

Time Projection Chamber (TPC): 2D/3D Drift Chamber

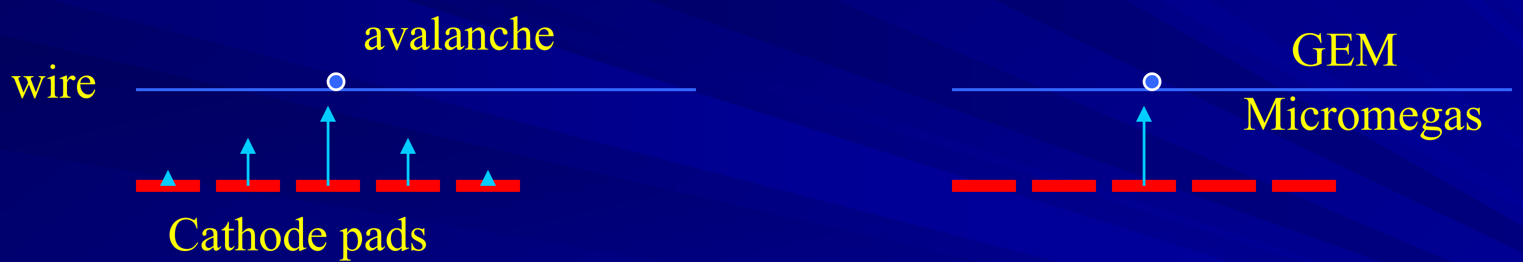
The Ultimate Wire (drift) Chamber





Problem

With wires: measure charge distribution over cathode pads:
c.o.g. is a good measure for track position;
With GEMs or Micromegas: narrow charge distribution
(only electron movement)



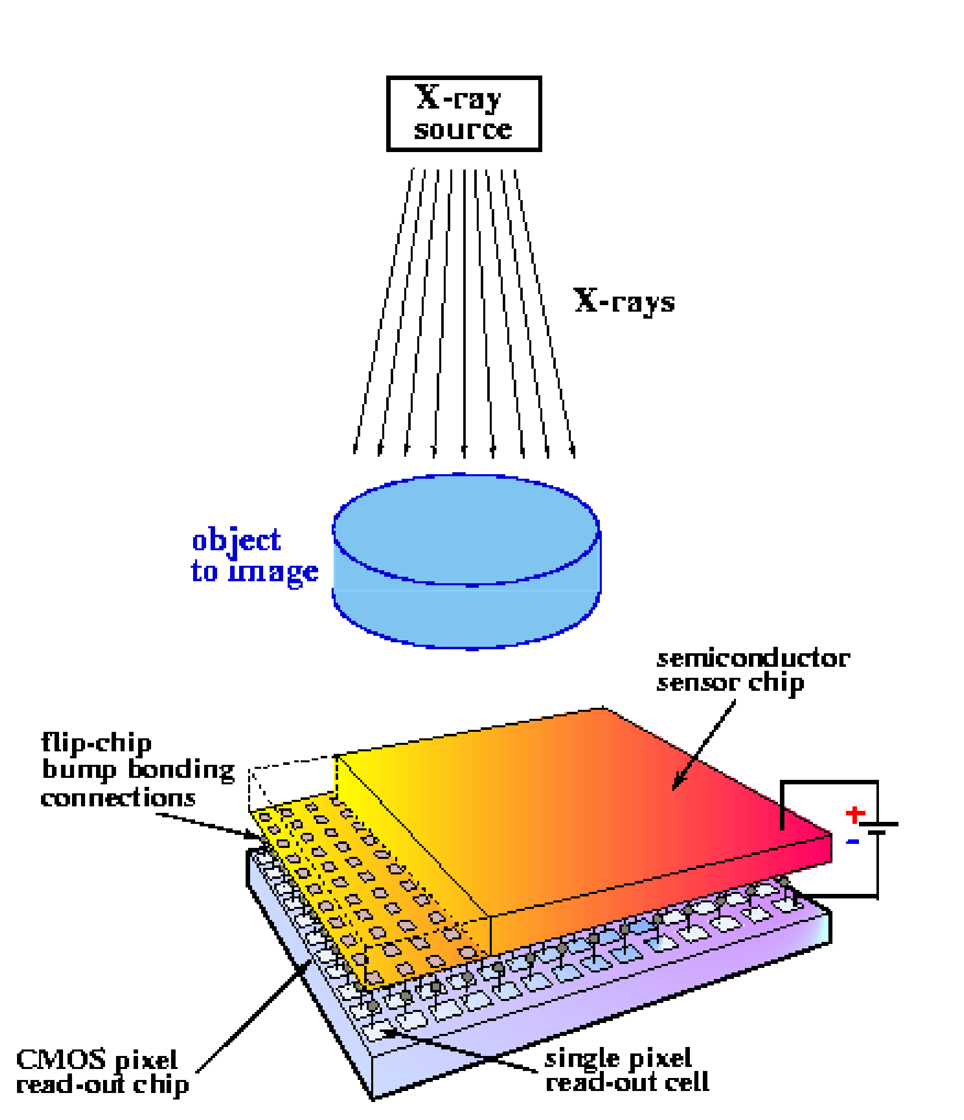
Solutions:

- cover pads with resisitive layer
- 'Chevron' pads
- many small pads: pixels!

The MediPix2 pixel CMOS chip

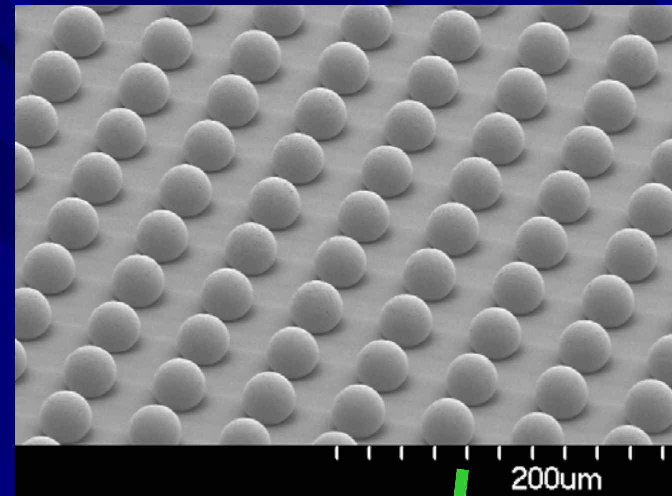
256 x 256 pixels
pixel: 55 x 55 μm^2
per pixel: - preamp
- shaper
- 2 discr.
- Thresh. DAQ
- 14 bit counter

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

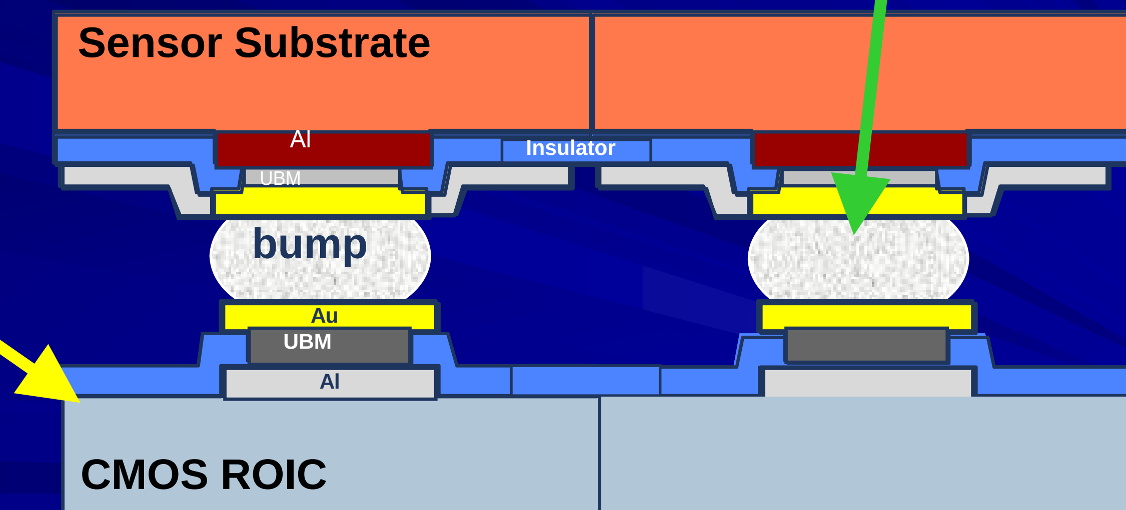


We apply the 'naked' MediPix2 chip without X-ray convertor!

Medipix2: Hybrid Pixels

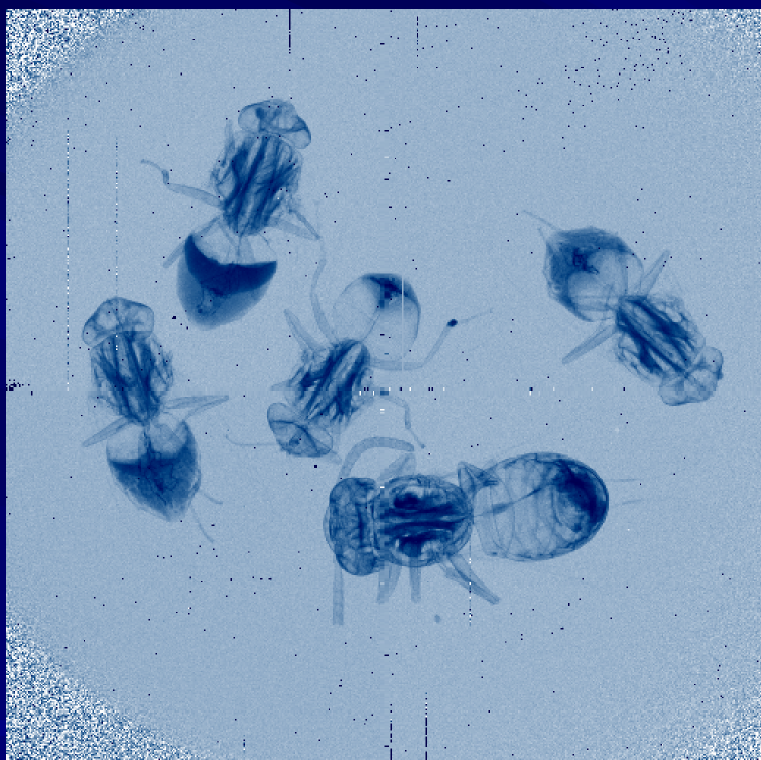


Schematic of a hybrid pixel detector



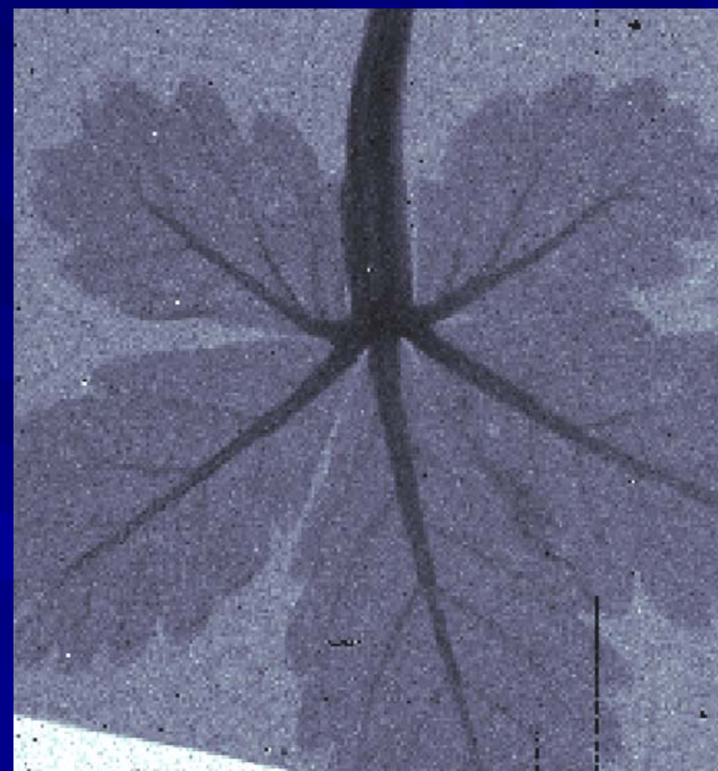
Some Images

28 mm



Flies @ 10 keV
Tungsten source

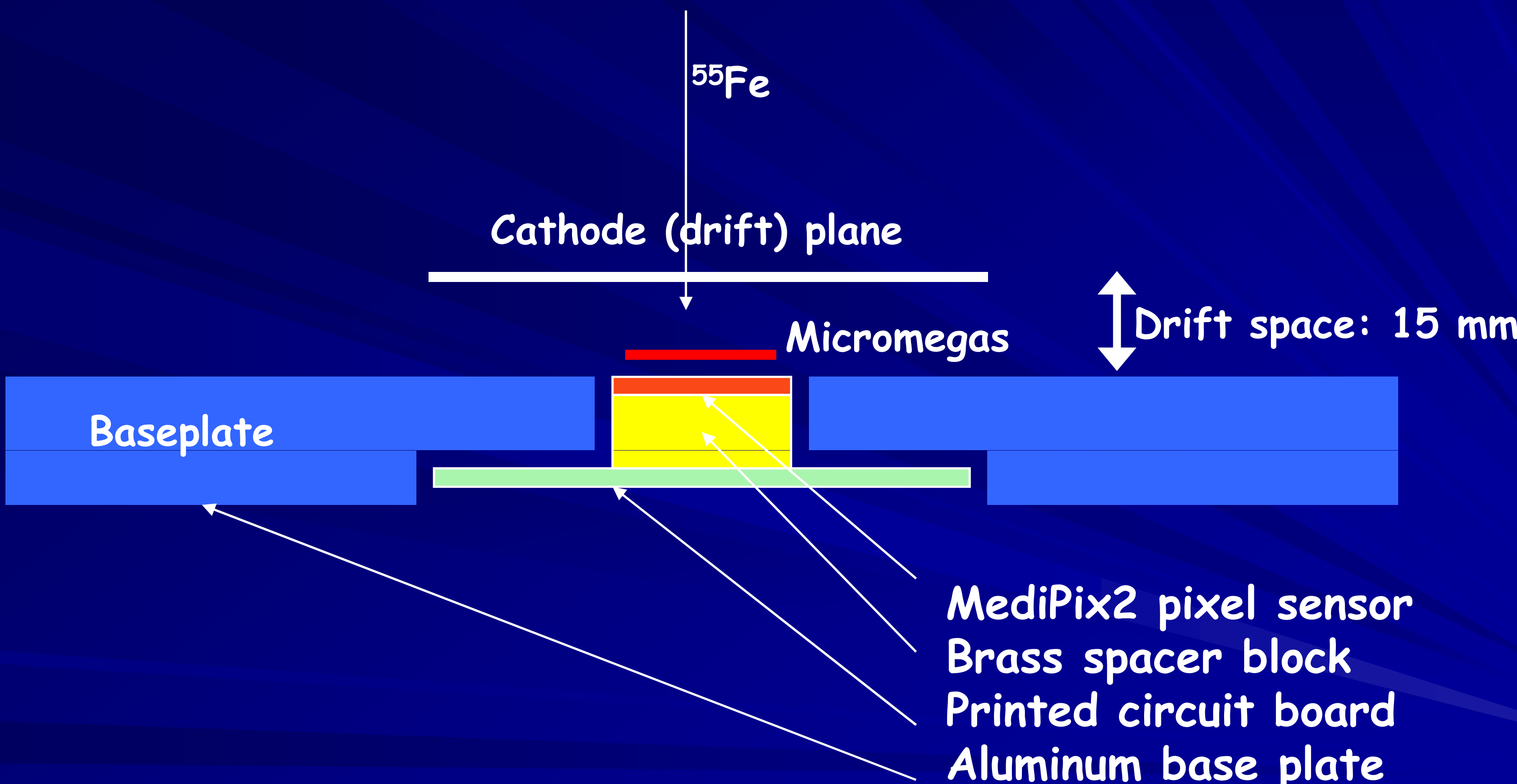
14 mm



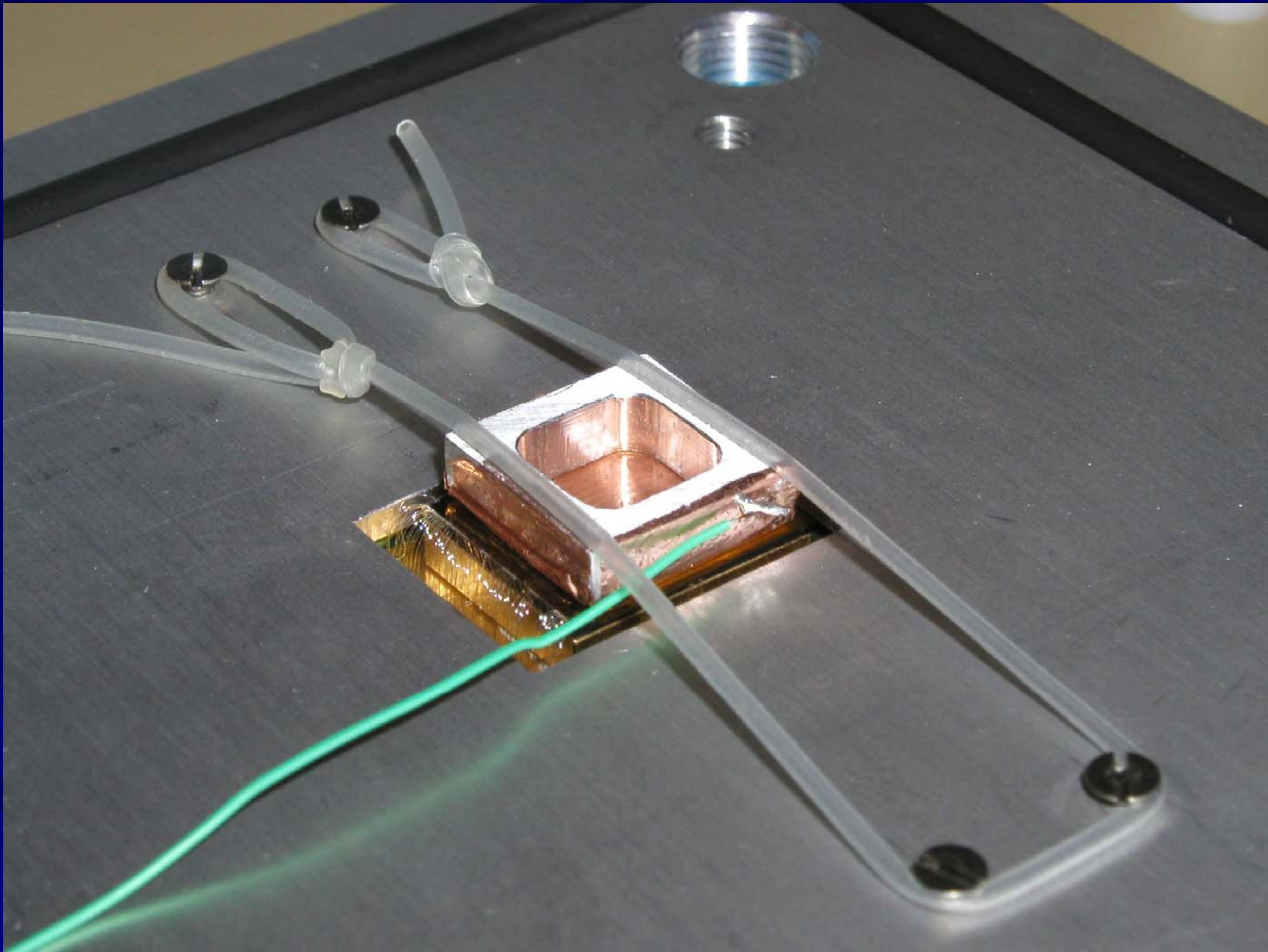
Leaf @ 5.9 keV
^{55}Fe source

MediPix2 & Micromegas:

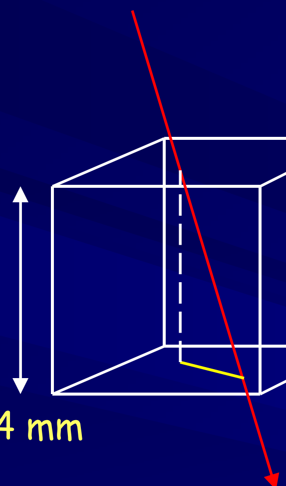
apply the 'naked' MediPix2 chip without X-ray convertor!



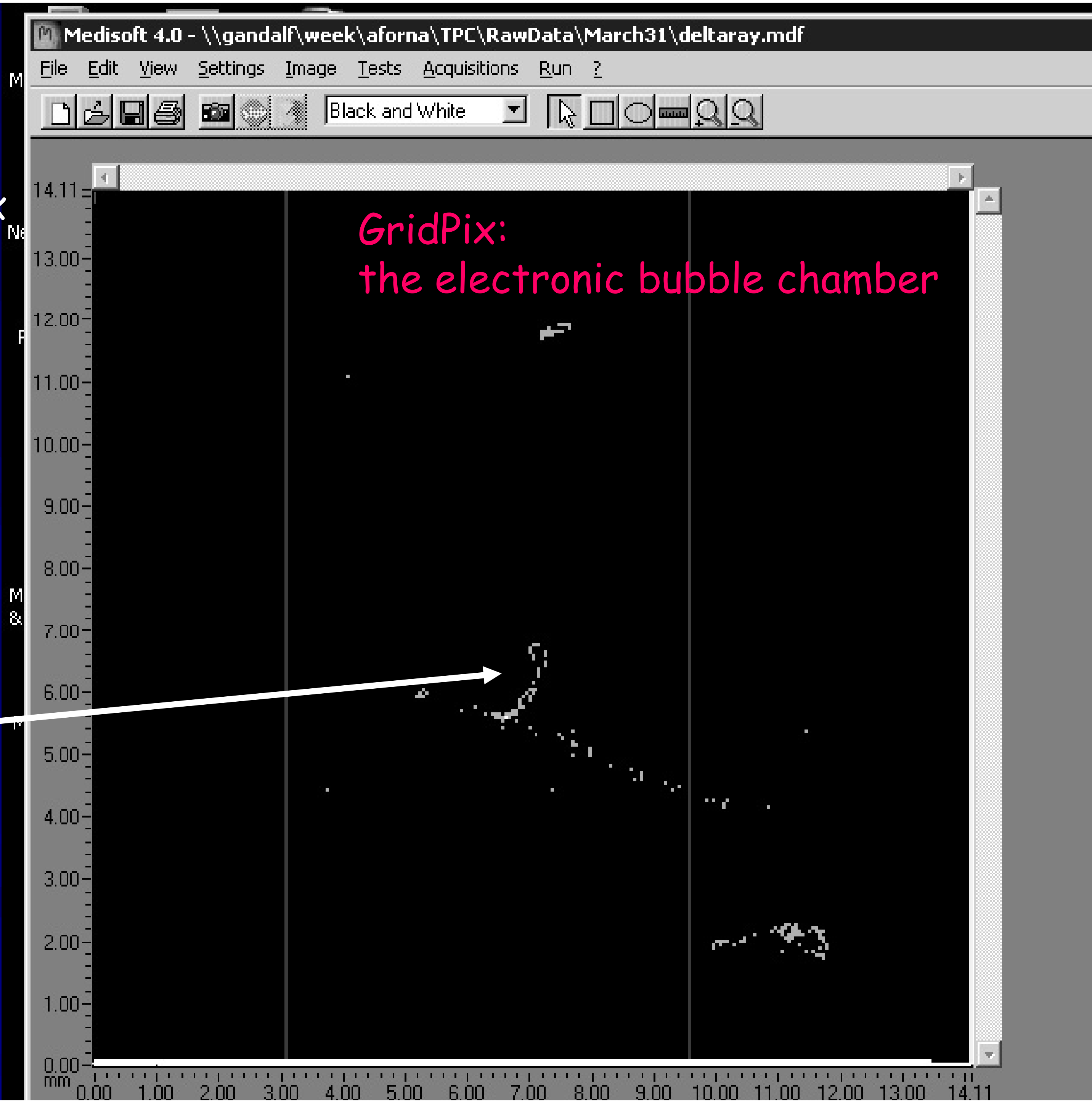
Very strong E-field above (CMOS) MediPix!



He/Isobutane
80/20
Modified MediPix



δ-ray!



Efficiency for detecting single electrons:
< 95 %

Integrate GEM/Micromegas and pixel sensor:

InGrid

‘GEM’ ‘Micromegas’

‘wafer post processing’

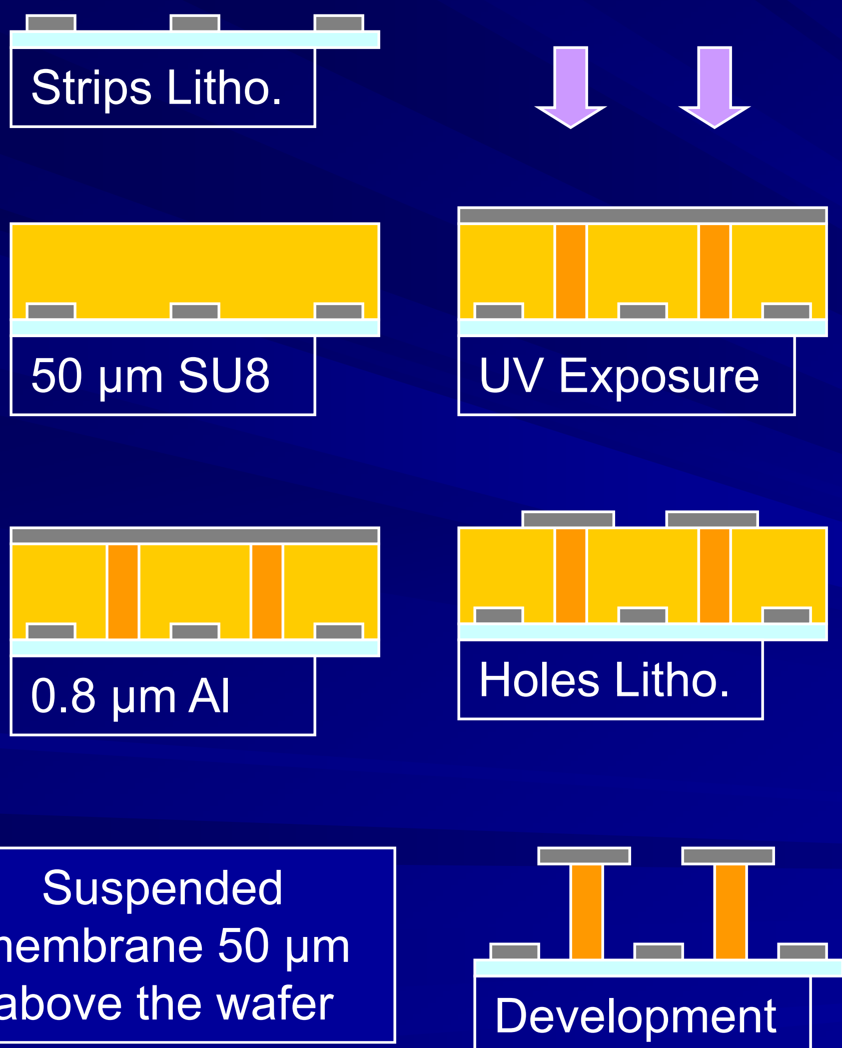
by

Univ. of Twente, MESA+

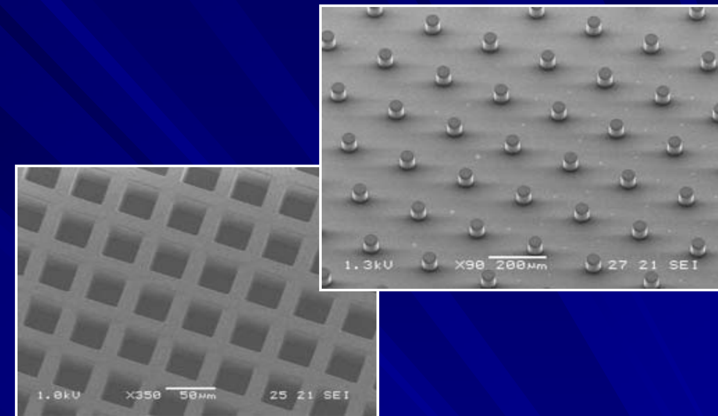
approved VICI proposal

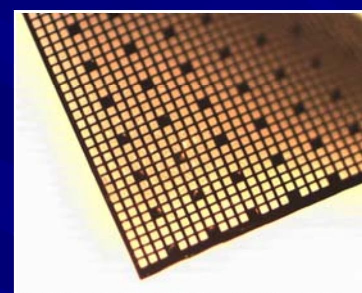
‘there is plenty of room at the top’

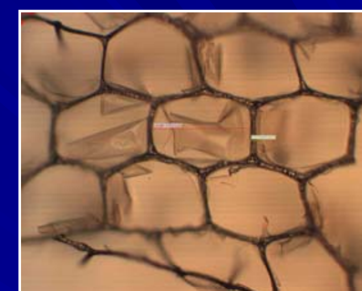
Processing InGrids

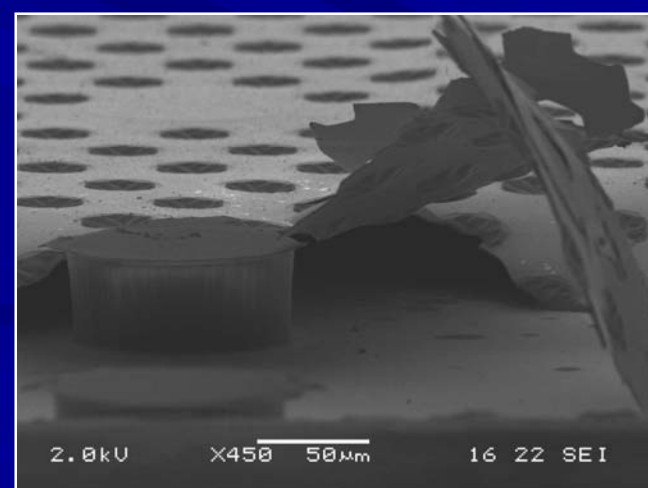


Suspended membrane 50 µm above the wafer

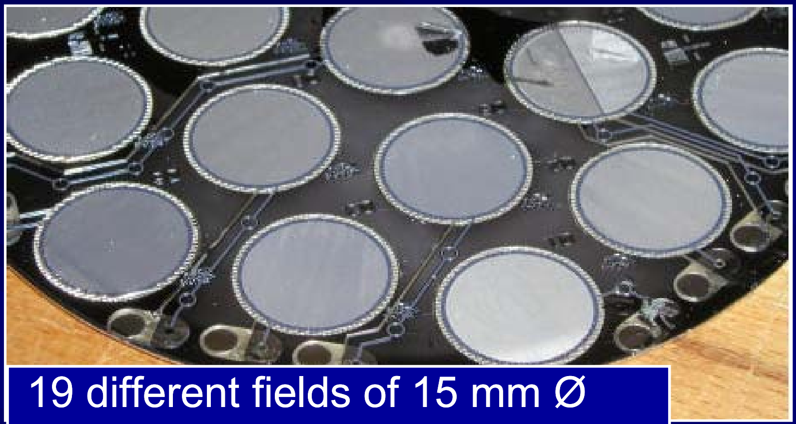






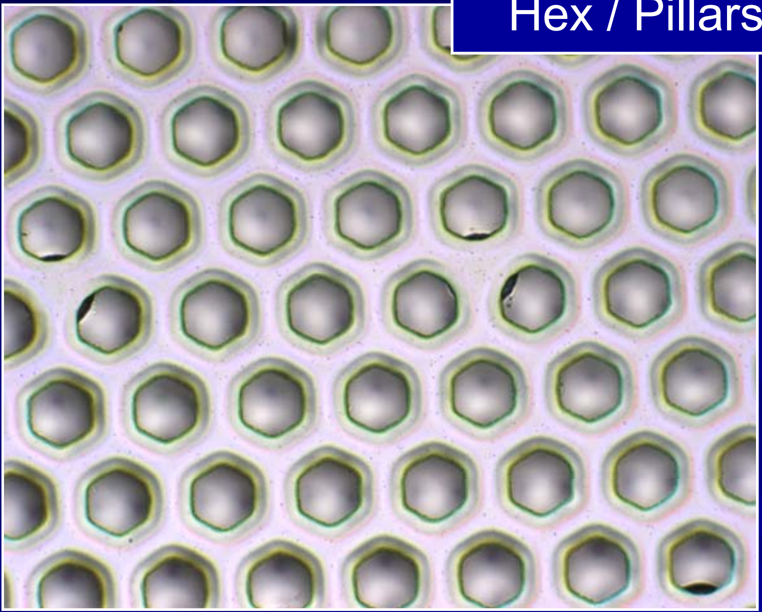


Prototypes

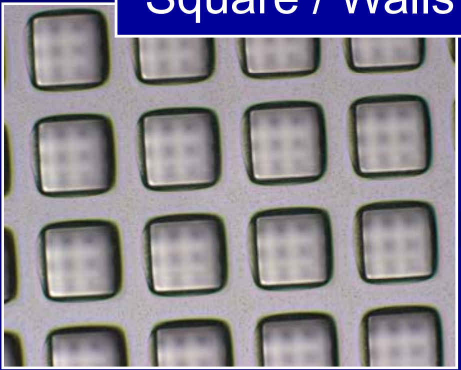


19 different fields of 15 mm Ø
2 bonding pads / fields

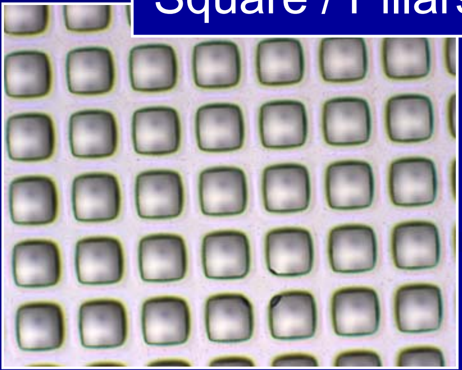
Hex / Pillars



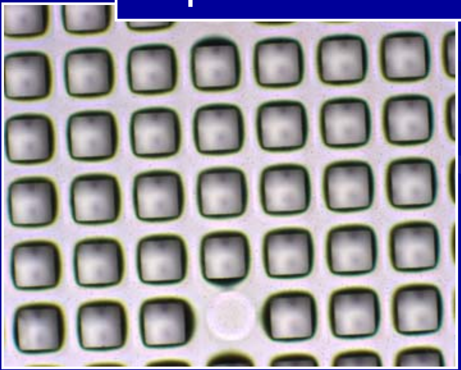
Square / Walls



Square / Pillars

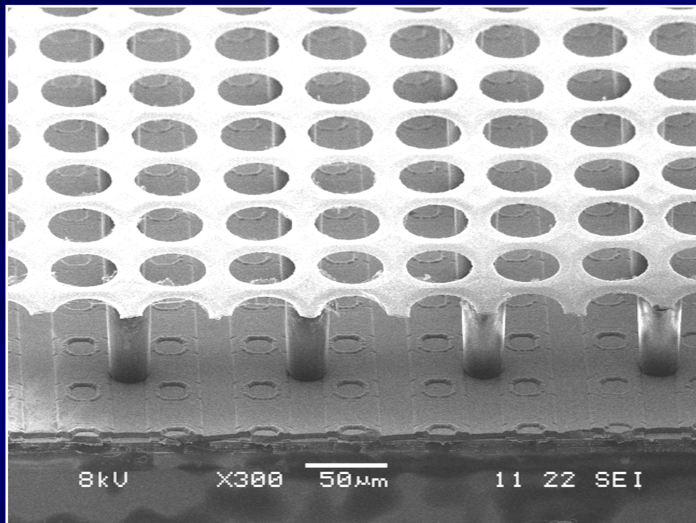


Square / Pillars

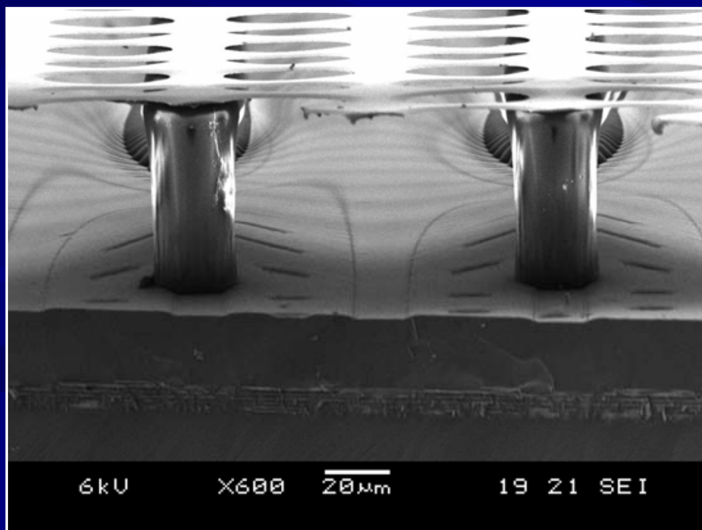


Full post-processing of a TimePix

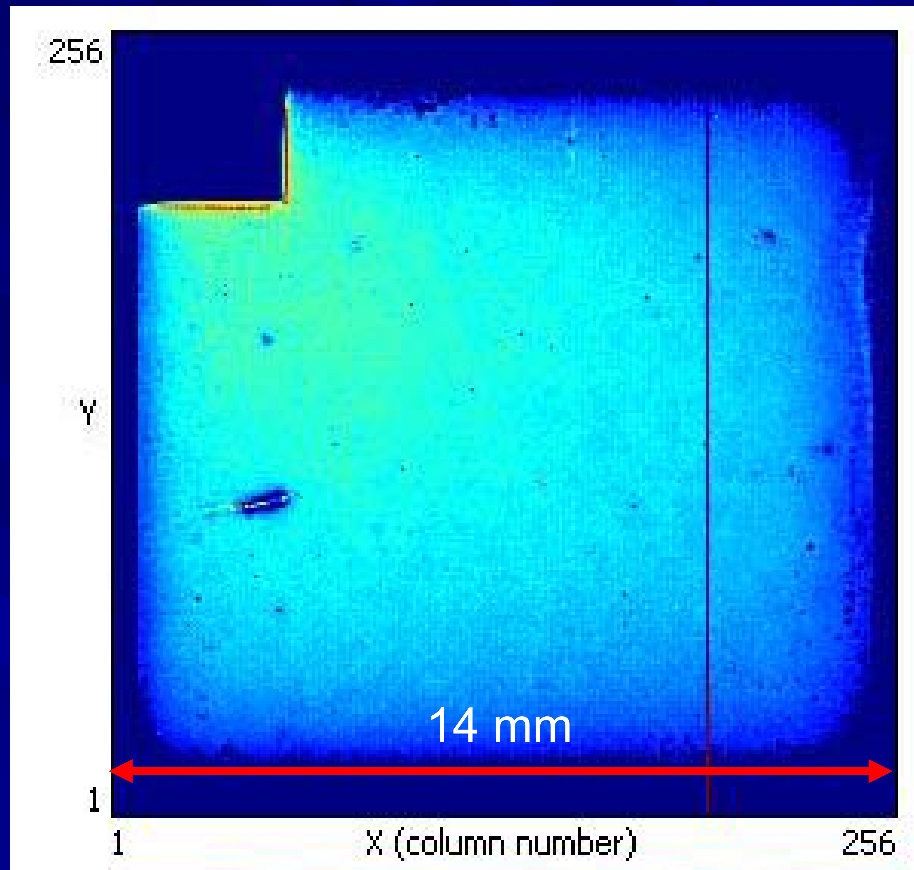
- Timepix chip + SiProt + Ingrid:



MESA+

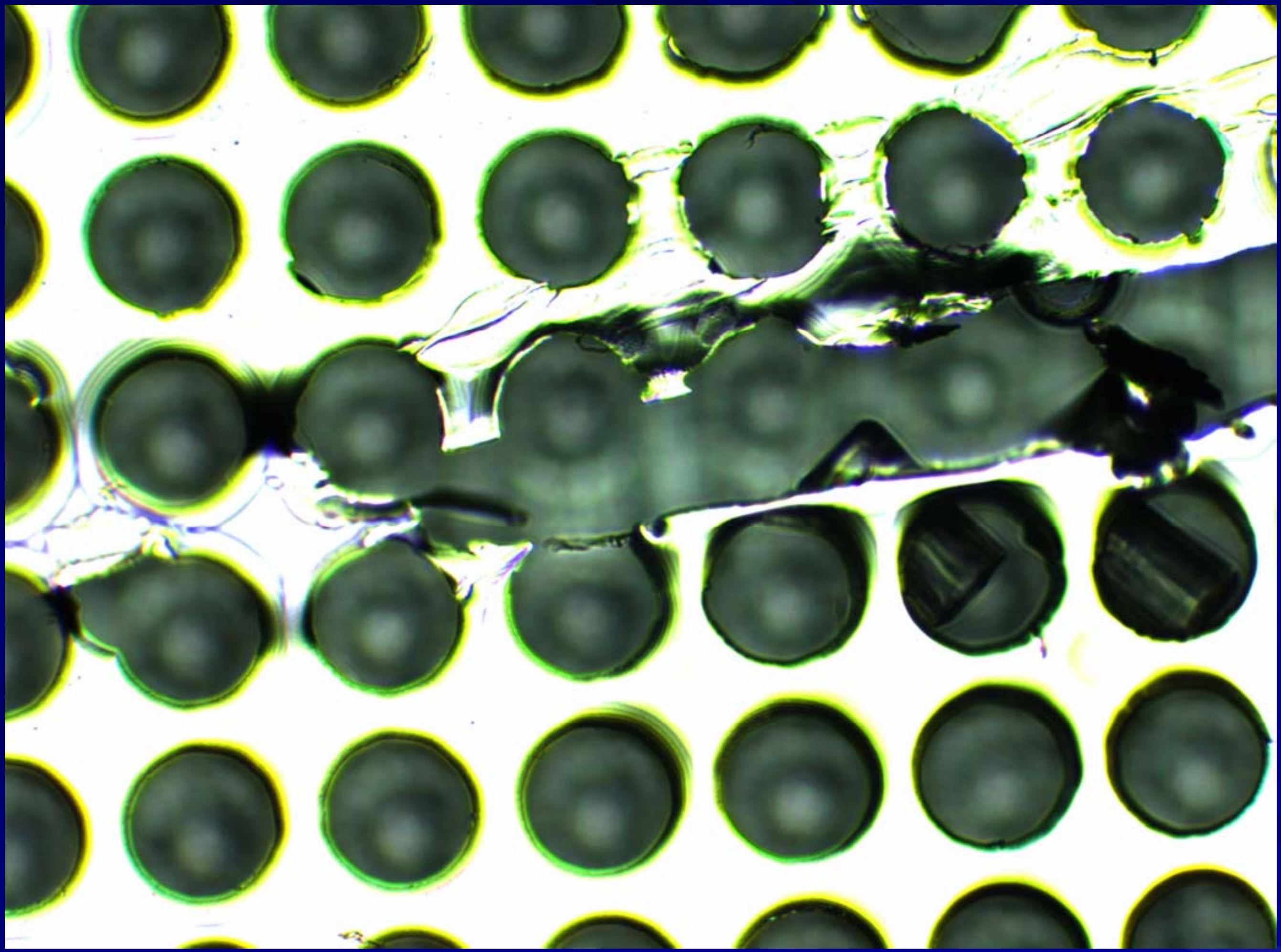


IMT
Neuchatel



"Uniform"

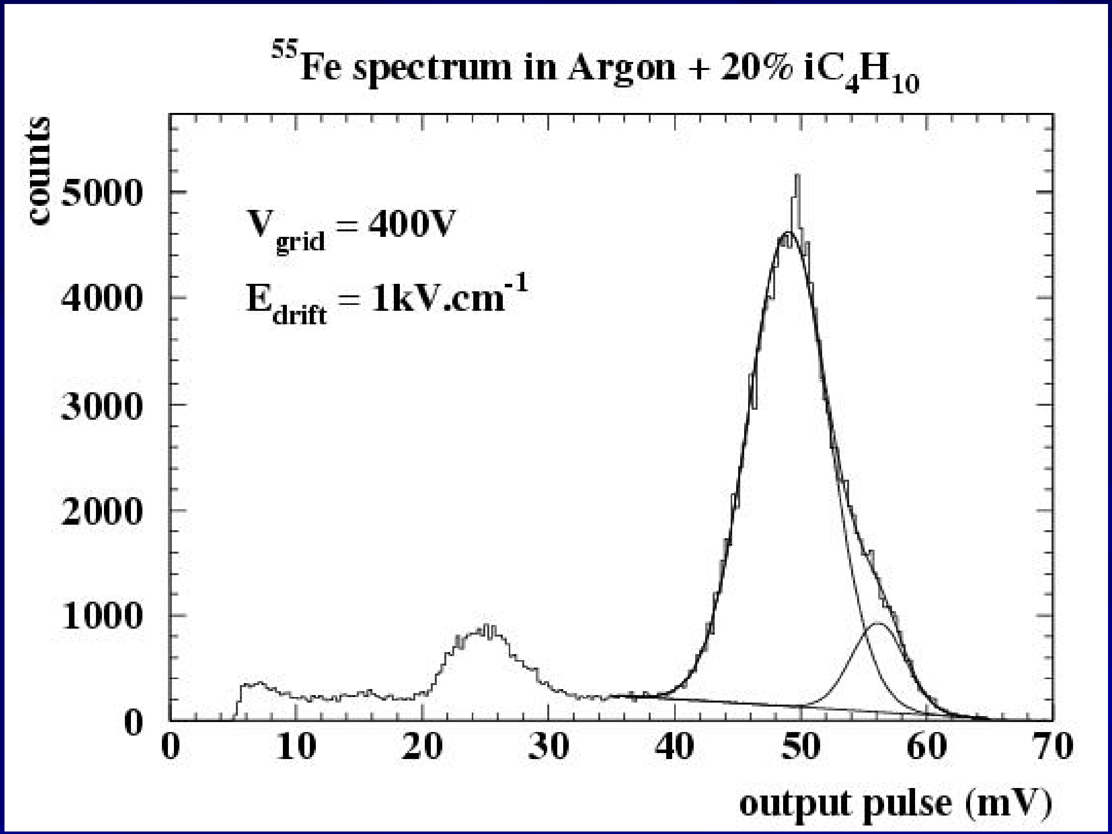
Charge mode



A “scratch” occurred during the construction of Ingrid;

Loose parts removed. Ingrid working!

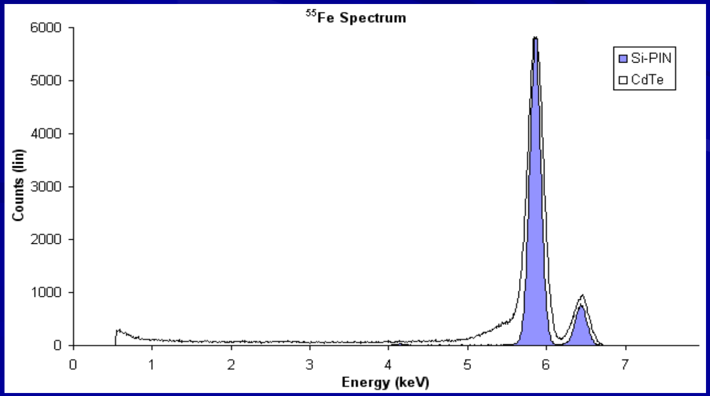
Energy resolution in Argon IsoC_4H_{10} 80/20



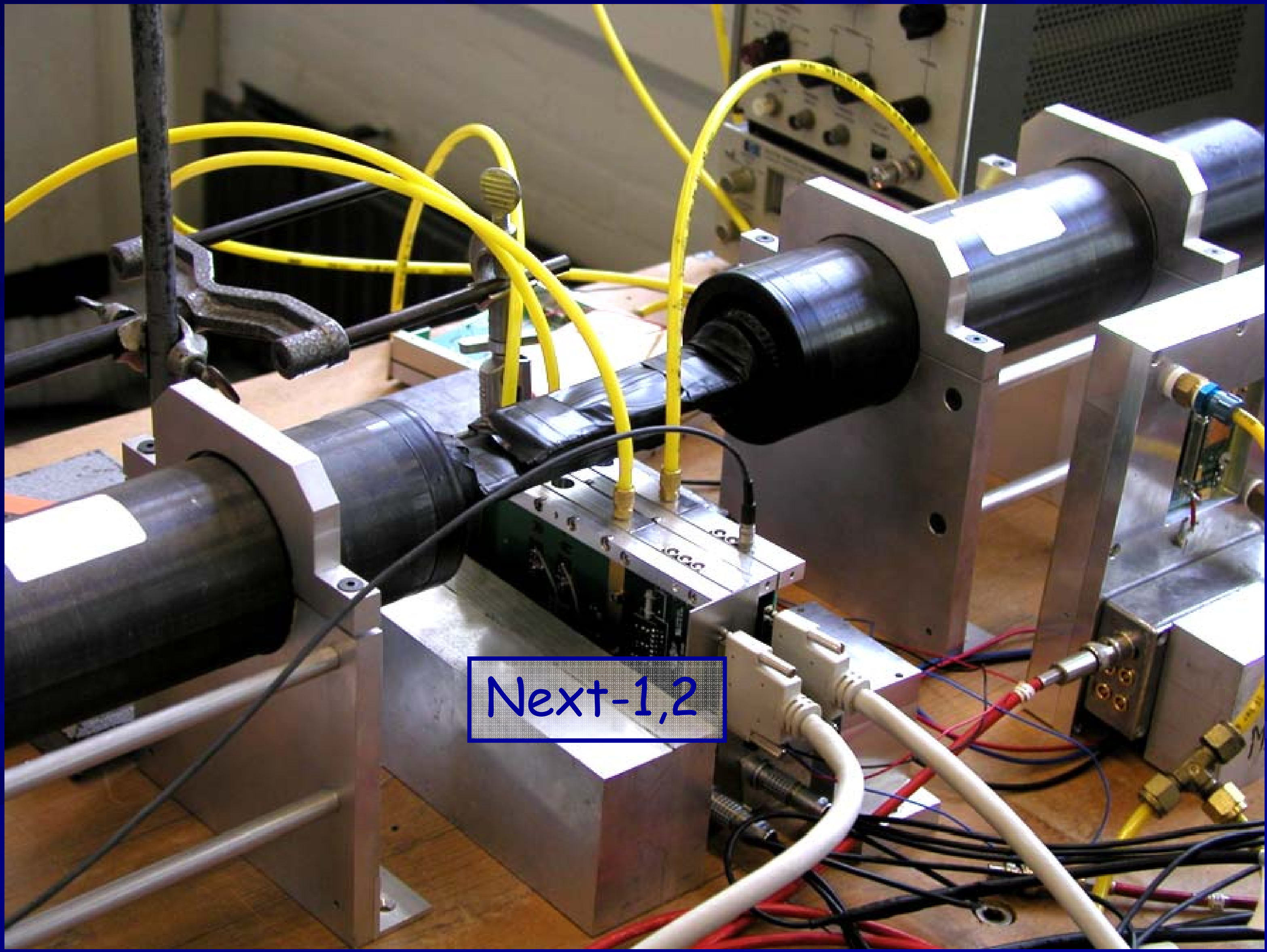
- Observation of two lines:
  - K_α @ 5.9 keV
  - K_β @ 6.4 keV
- FWHM of the K_α distribution
  - 16.7 %
- Gain fluctuations
  - < 5%

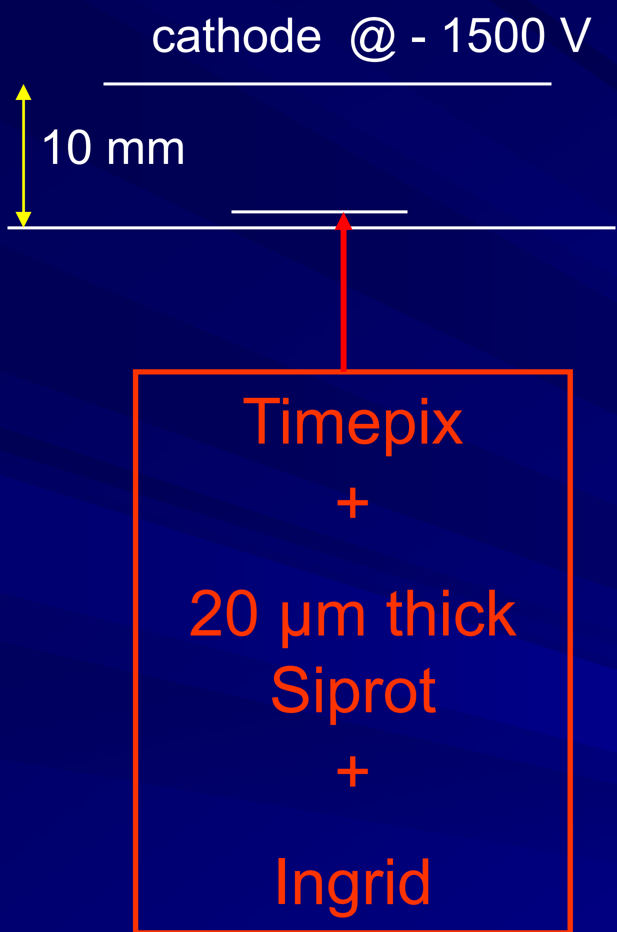
Very good energy resolution:

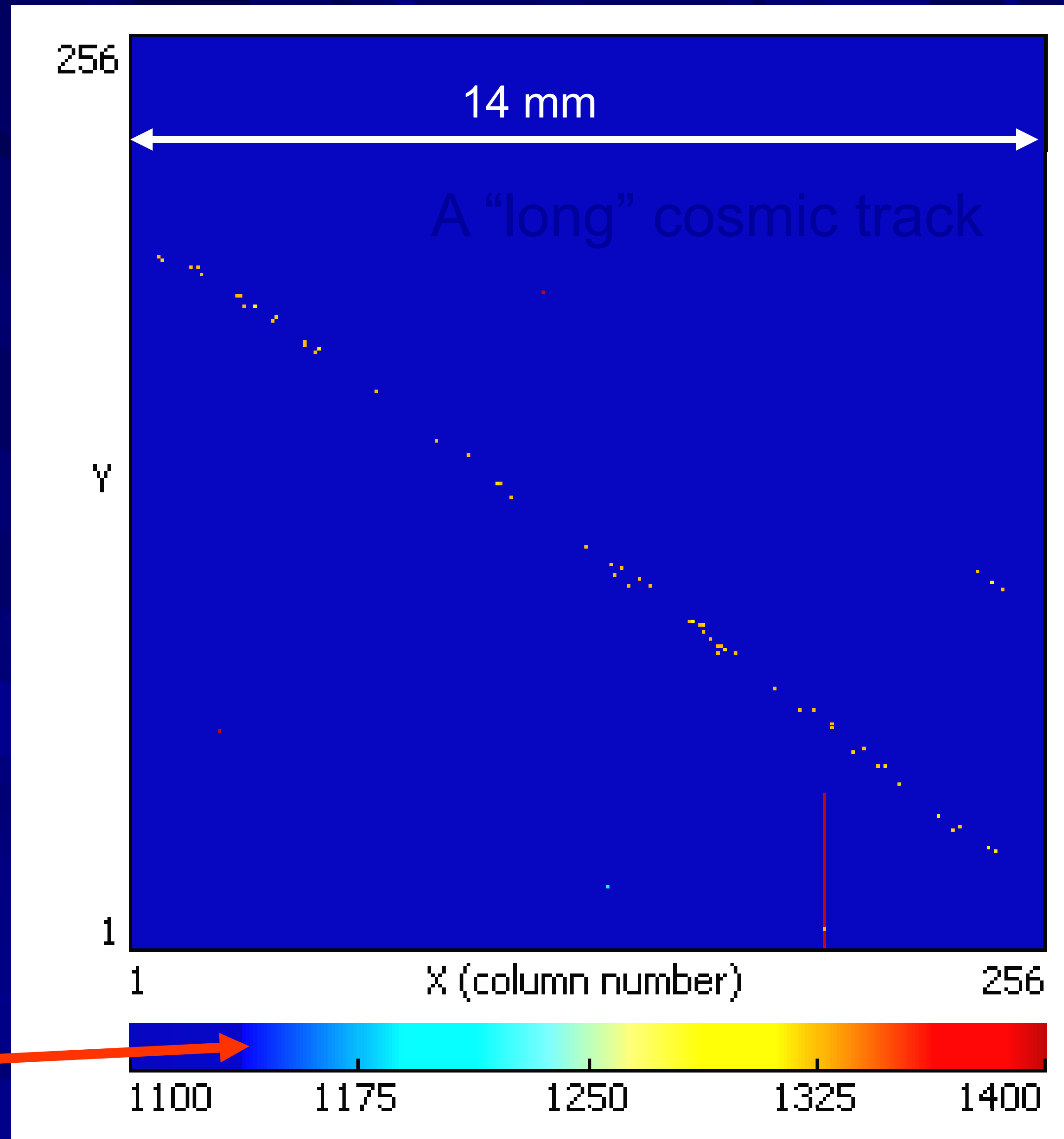
Very precise dimensions d < 0.1 µm



setup





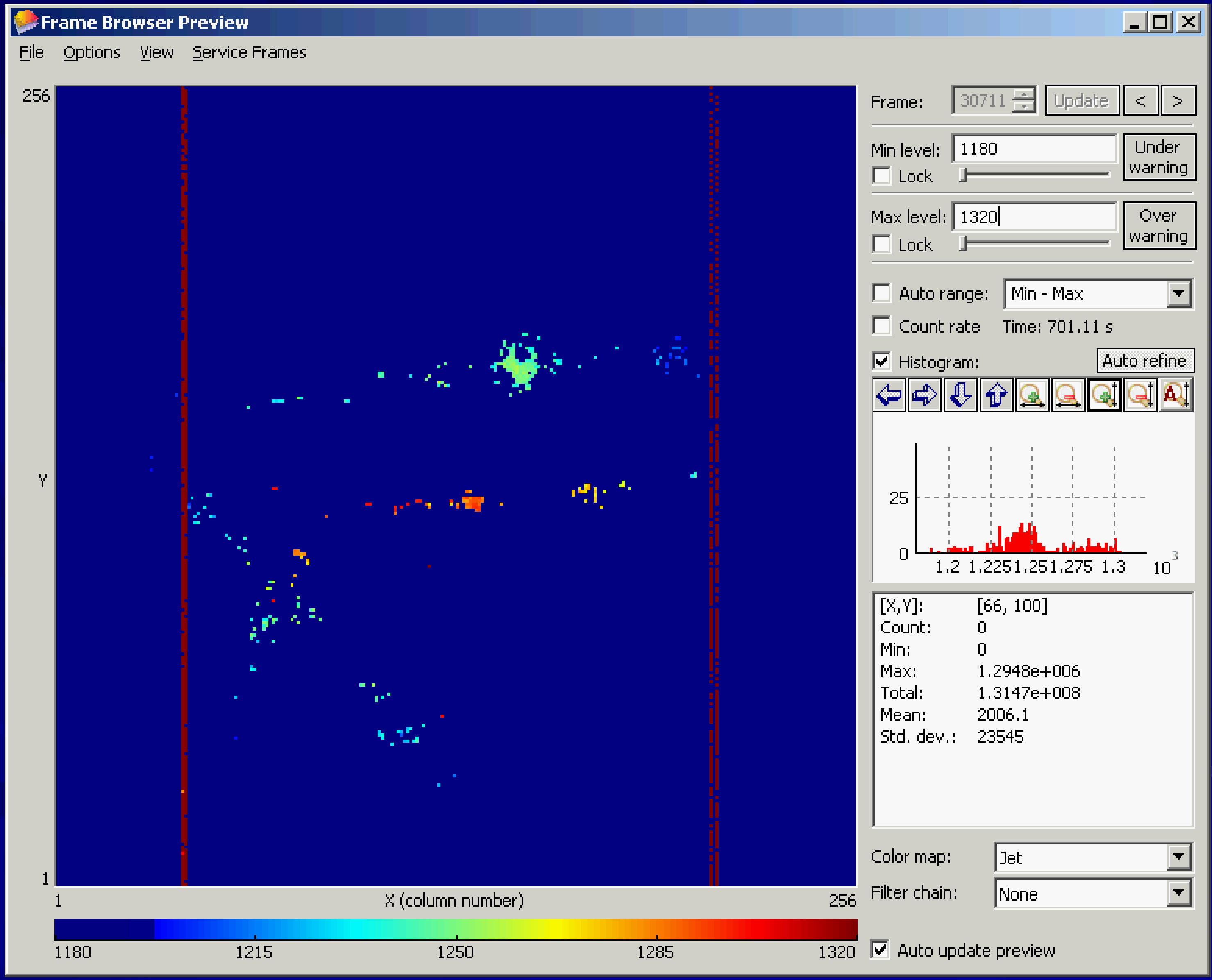


Drifttime (bin = 10 ns)

Stable operation in He iC4H10

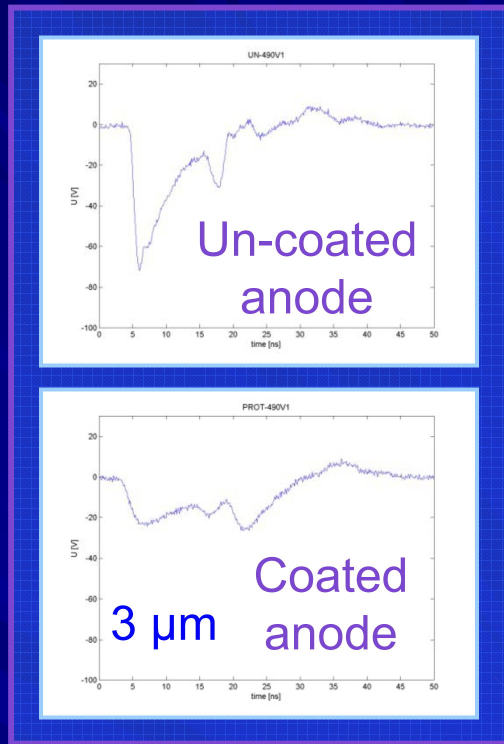
Cosmic rays in Argon

Time mode



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'



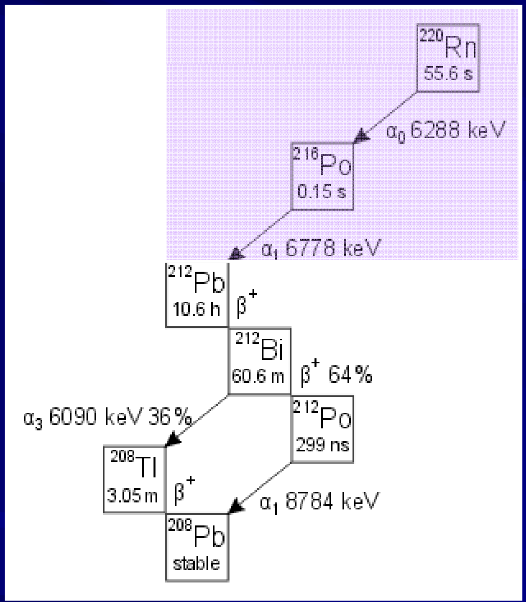
SiProt: a low T deposited hydrogenated amorphous silicon (aSi:H) layer

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

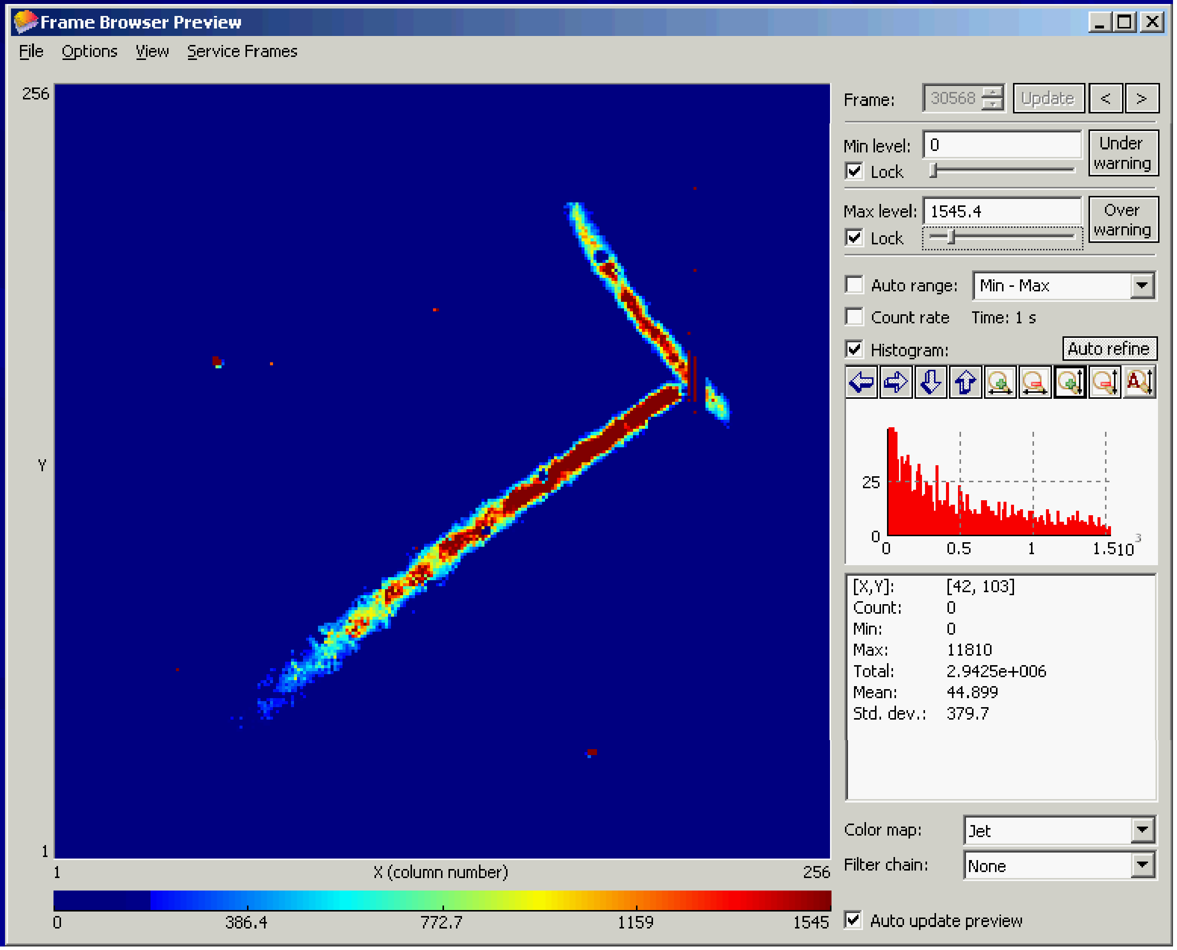
Final assessment: spark-proofness

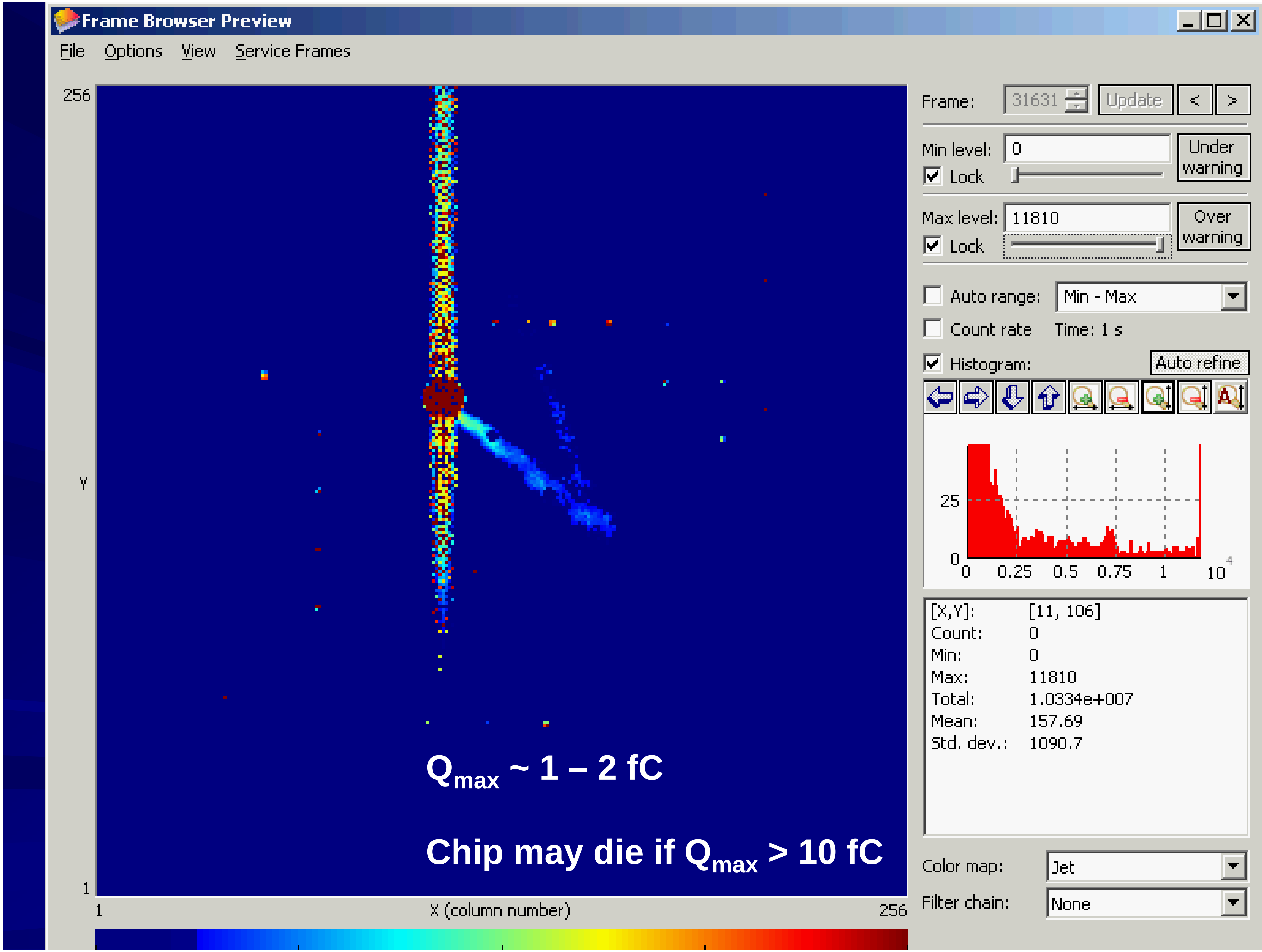
- Provoke discharges by introducing small amount of Thorium in the Ar gas
  - Thorium decays to Radon 222 which emits 2 alphas of 6.3 & 6.8 MeV
  - Depose on average 2.5.10^5 & 2.7.10^5 e- in Ar/iC_4H_{10} 80/20 at -420 V on the grid, likely to trigger discharges

Charge mode



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





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

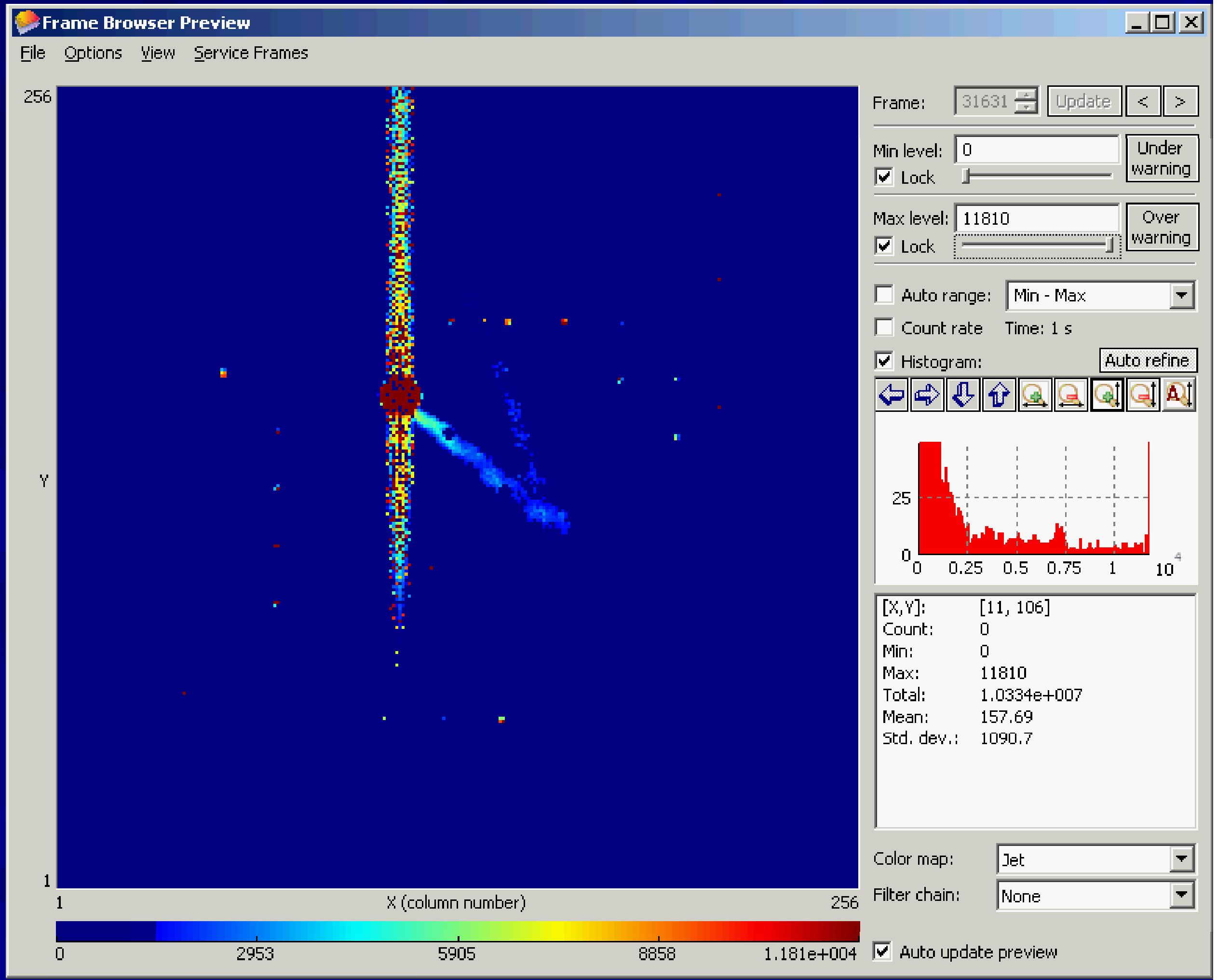
… discharges are observed !

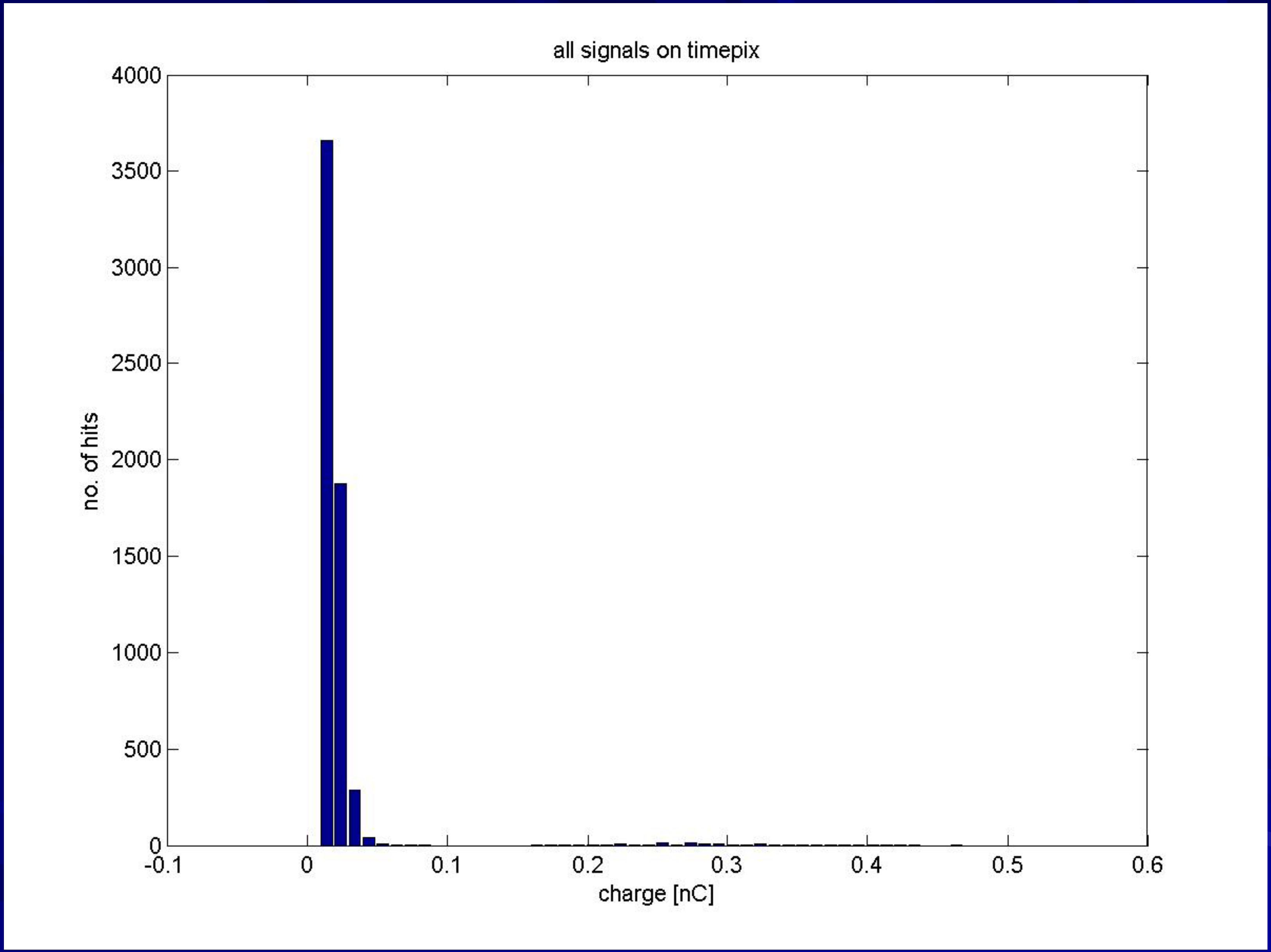
For the 1st time: image of discharges are being recorded

Round-shaped pattern of some 100 overflow pixels

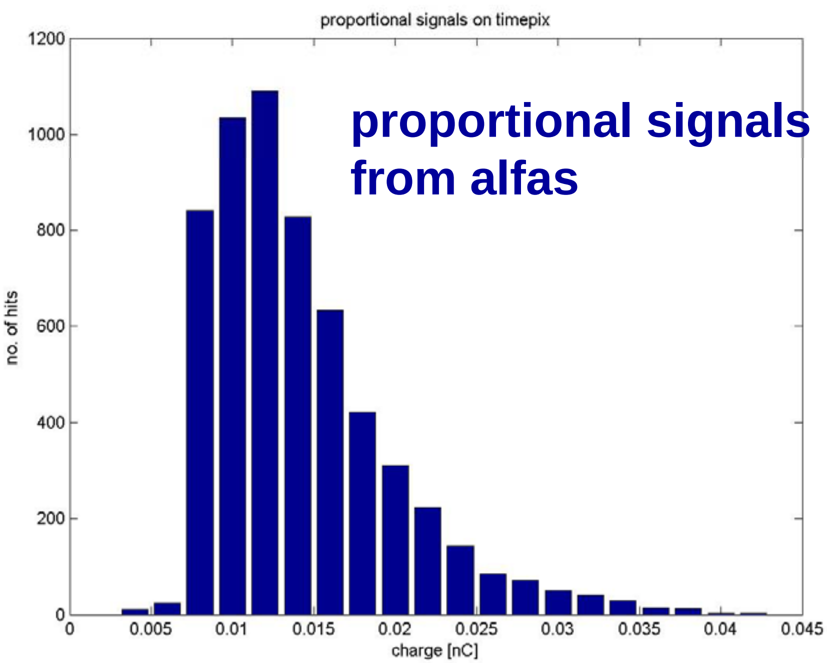
Perturbations in the concerned column pixels
- Threshold
- Power

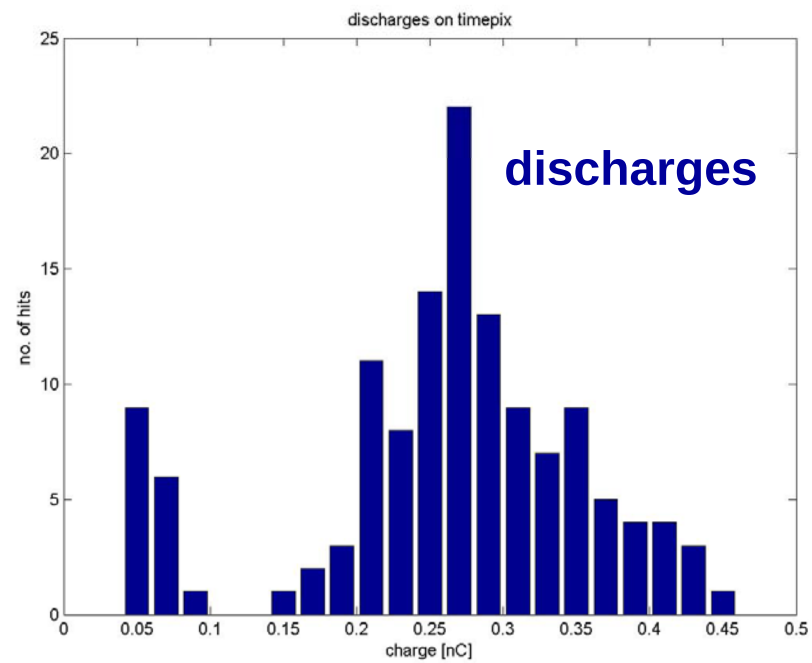
Chip keeps working





Discharge signals on grid directly measured on scope



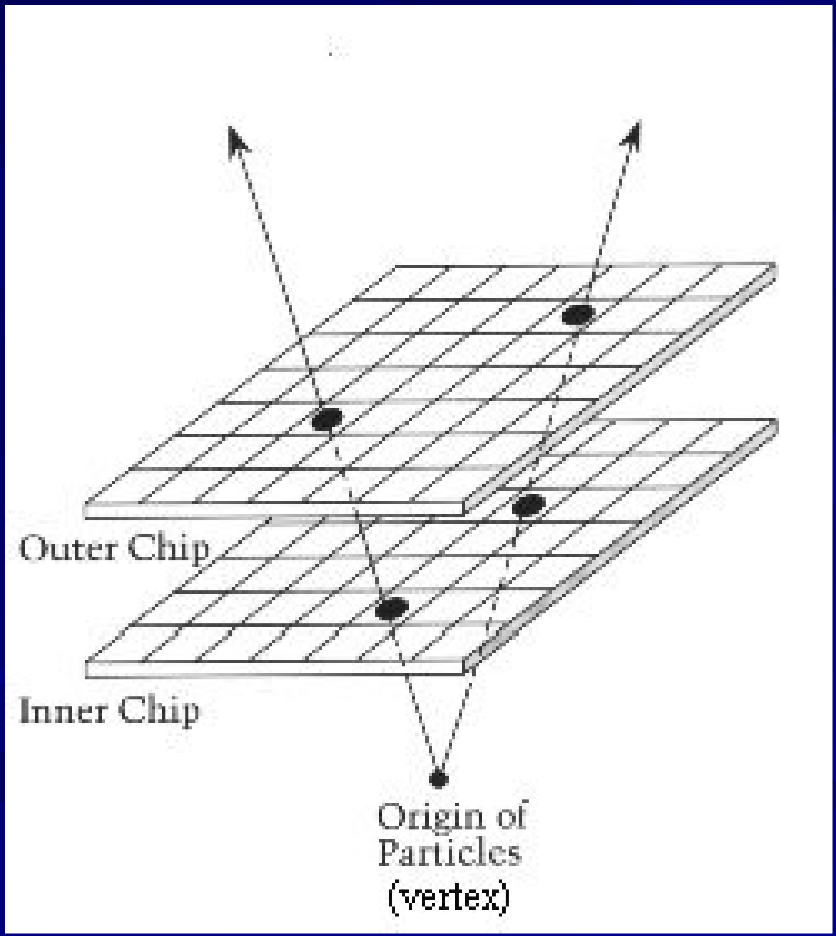


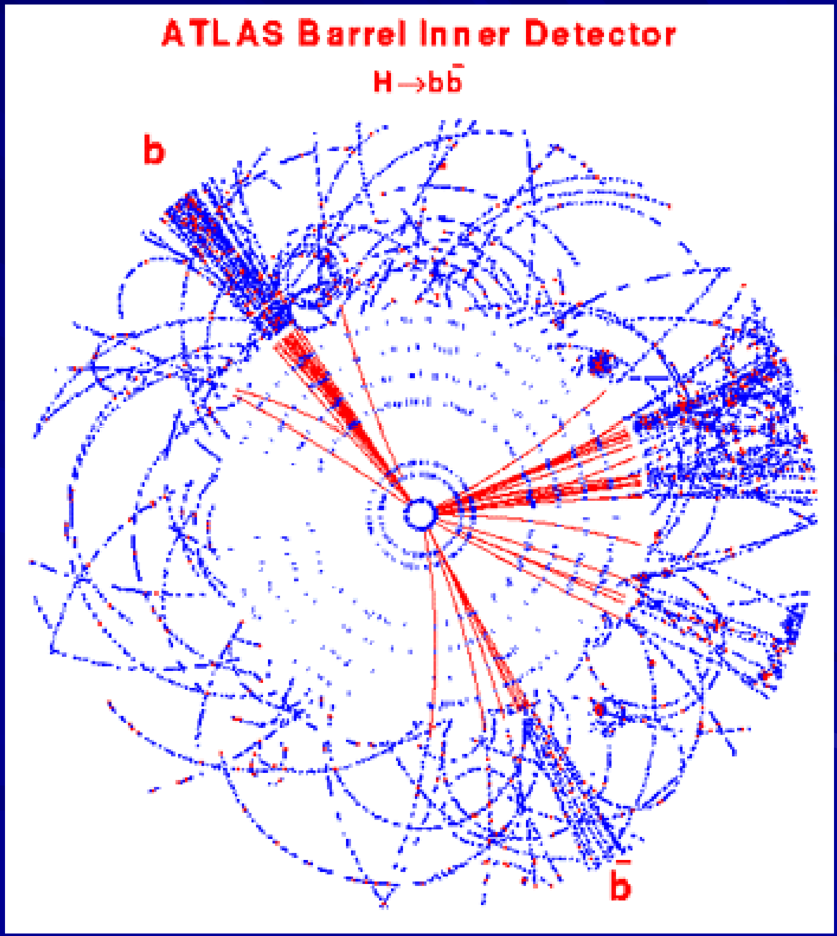
- CMOS chips are no longer destroyed

- discharges in gas proportional chambers are hard to exclude

- SiProt makes chips spark proof

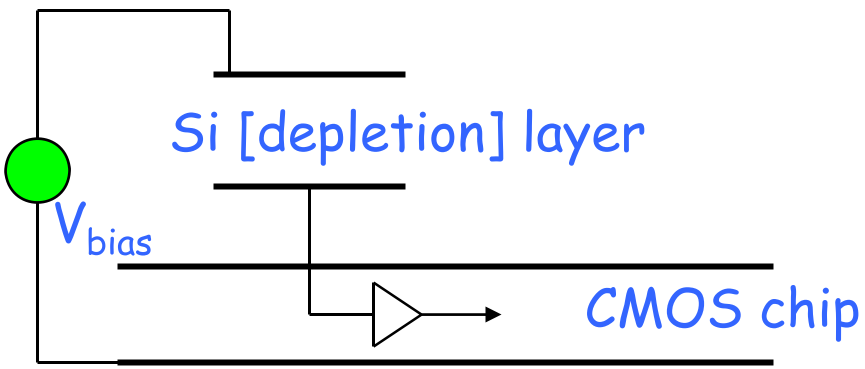
Vertex detectie: alternatief voor Si

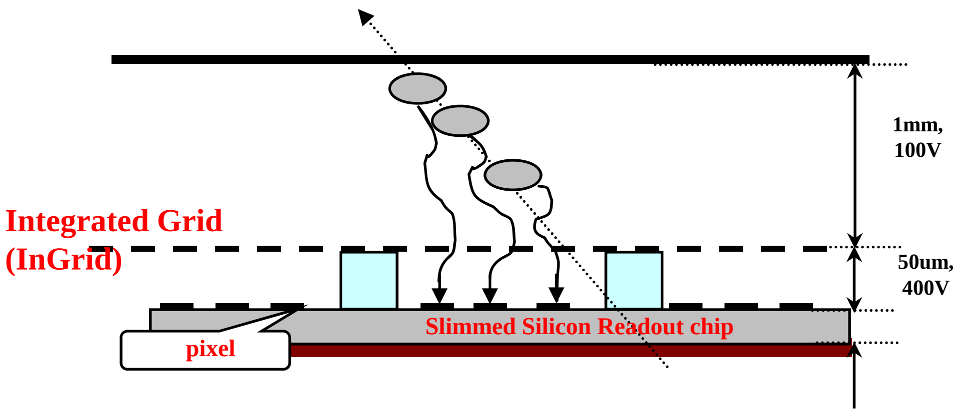




Si (vertex) track detector

GOSSIP





- Si strip detectors
- Si pixel detectors
- MAPs
- CCDs

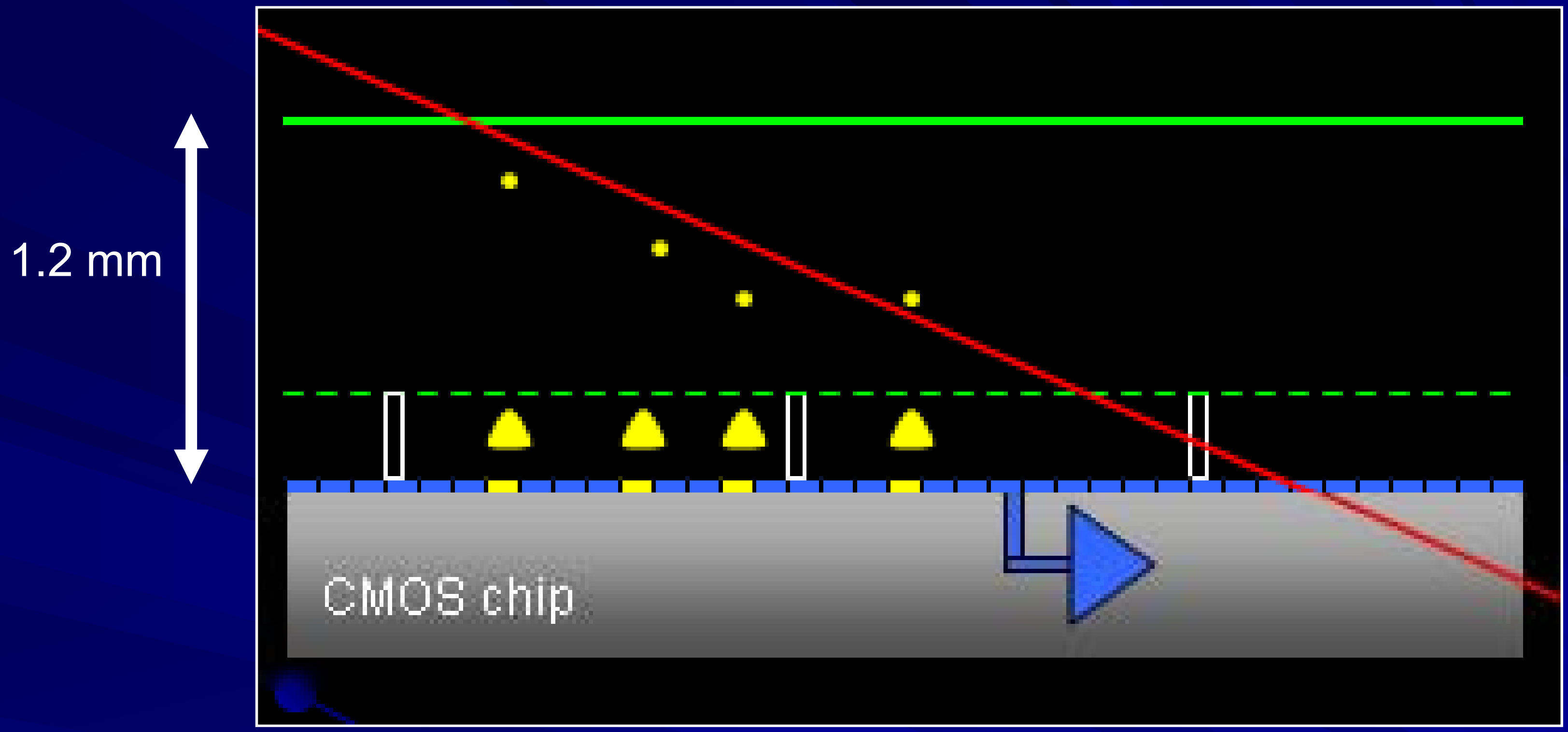
Gas: 1 mm as detection medium

99 % chance to have at least 1 e-

Gas amplification ~ 1000:

Single electron sensitive

All signals arrive within 20 ns



Gossip: replacement of Si tracker

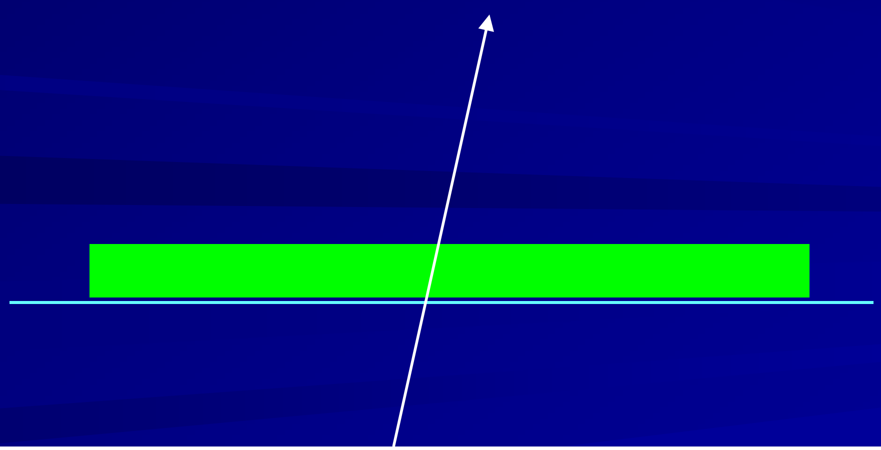
Essential: thin gas layer (1.2 mm)

Essentials of GOSSIP:

- Generate charge signal in gas instead of Si (e-/ions versus e-/holes)
- Amplify # electrons in gas (electron avalanche versus FET preamps)

Then:

- No radiation damage in depletion layer or pixel preamp FETs
- No power dissipation of preamps
- No detector bias current
- Ultralight detection layer (Si foil)



Tracking sensor material: gas versus Si

- it is light

- primary electrons can simply be multiplied: gas amplification: low power

- no bias current: low power & simple FE circuits

- gas can be exchanged: no radiation damage of sensor

- gas has a low ε_r: with small voxels the source capacity can be small (10 fF) allowing fast, low-noise, and low-power preamps

- gas is usually cheap

- low sensitive for neutron and X-ray background

- δ-rays can be recognized

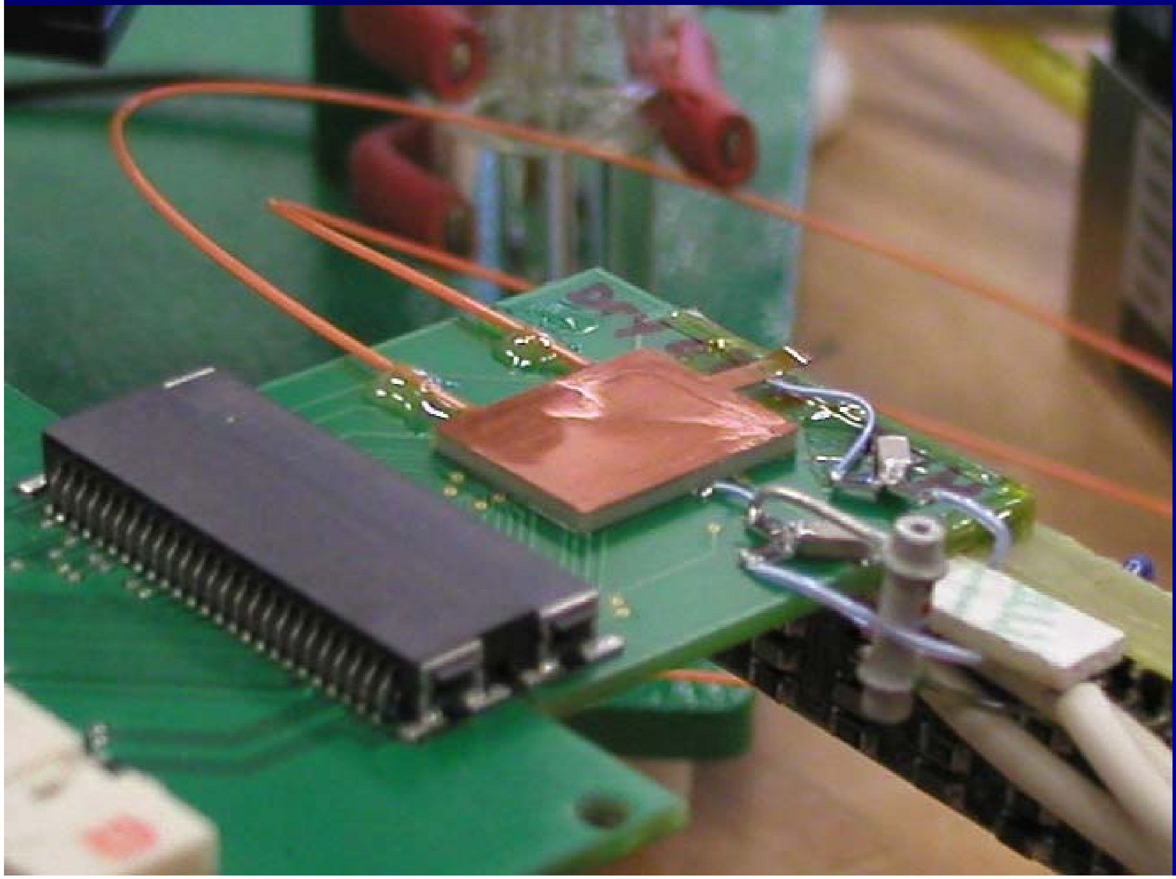
- [high ion & electron mobility: fast signals, high count rates are possible]

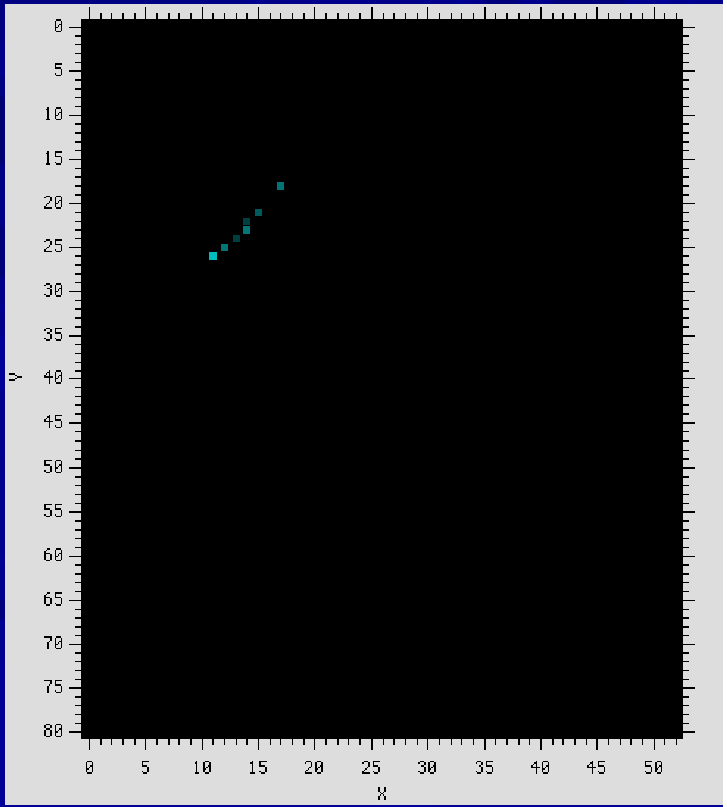
- discharges/sparks: readout system should be spark proof
- ageing: must be solved and must be understood / under control
- diffusion: limits max. drift length

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

First prototype of GOSSIP on a PSI46 is working:

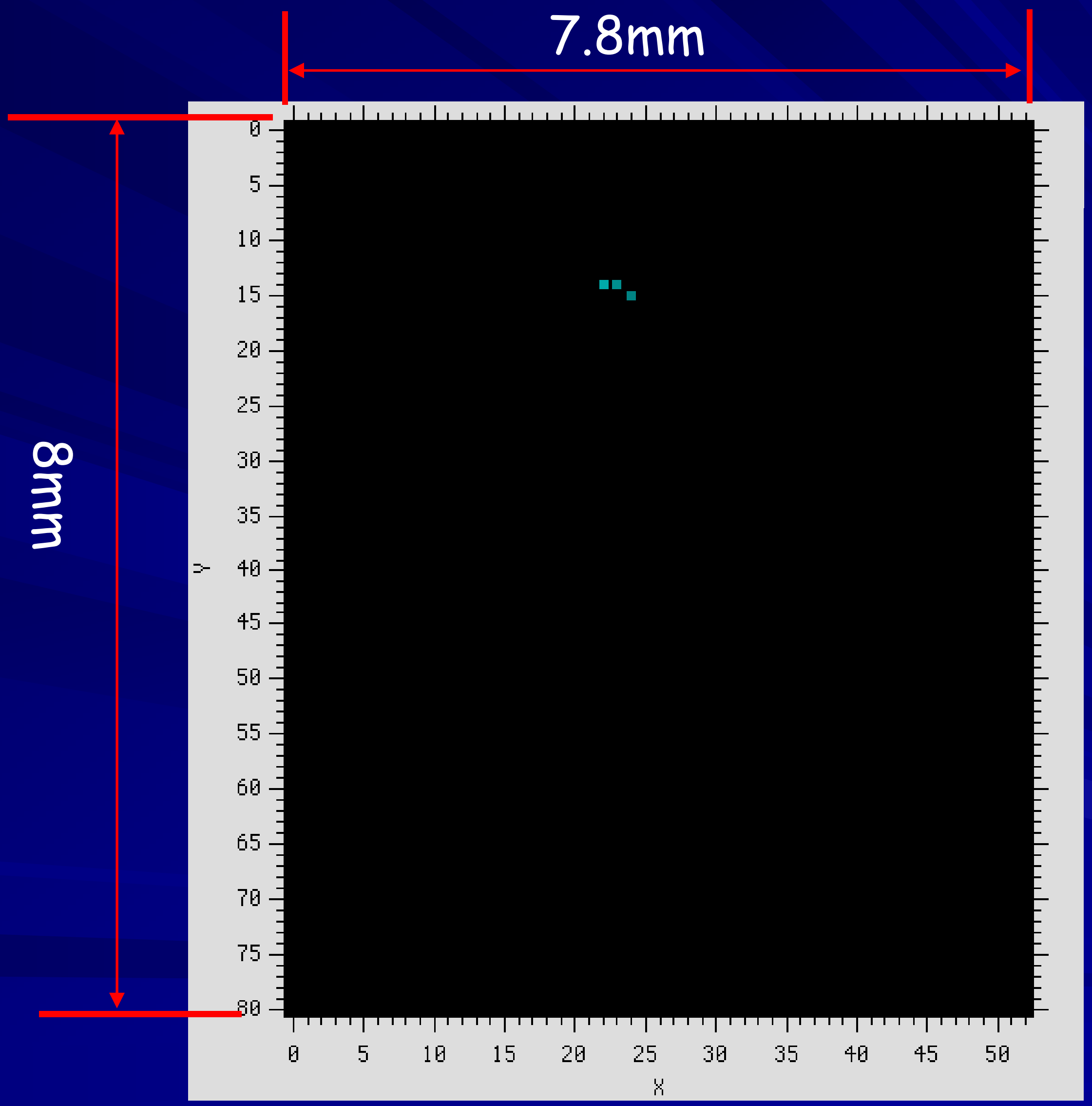
- 1.2 mm drift gap
- Grid signal used as trigger
- 30 μm layer of SiProt





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)

Ageing

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

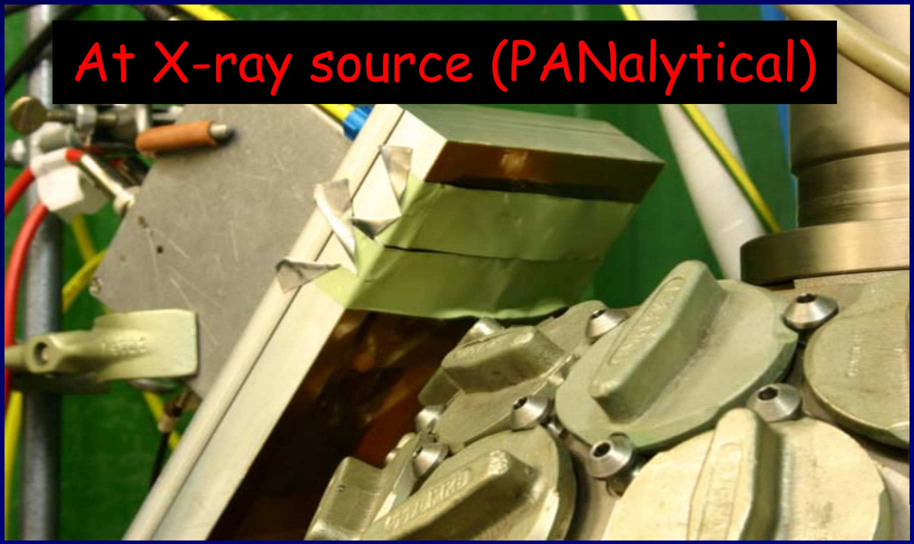
Radiation damage of sensor:
not relevant for Gossip sensor since this is gas being exchanged

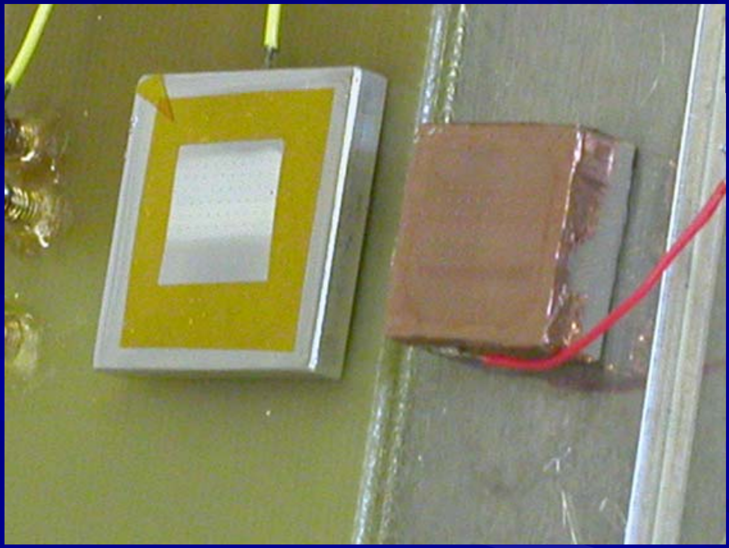
Typical for gaseous detectors: the deposit of an (insulating) polymer on the electrodes of a detector. Decrease of signal amplitude

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

Aging test

- ratio of anode surface: thin wire surface versus anode plane (~20x)
- low gas gain due to fast signal and low source capacity (~20x)

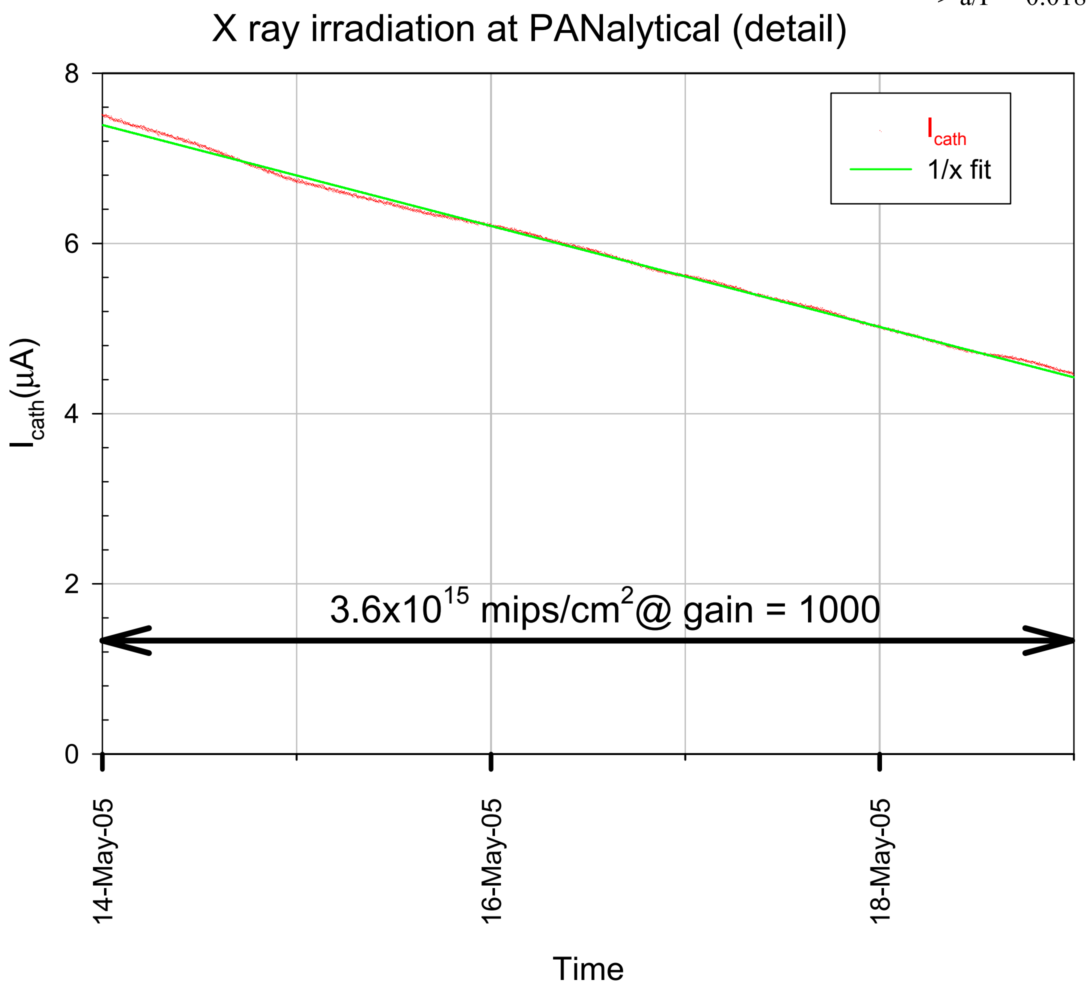




With standard Ar/Methane 90/10 mixture:

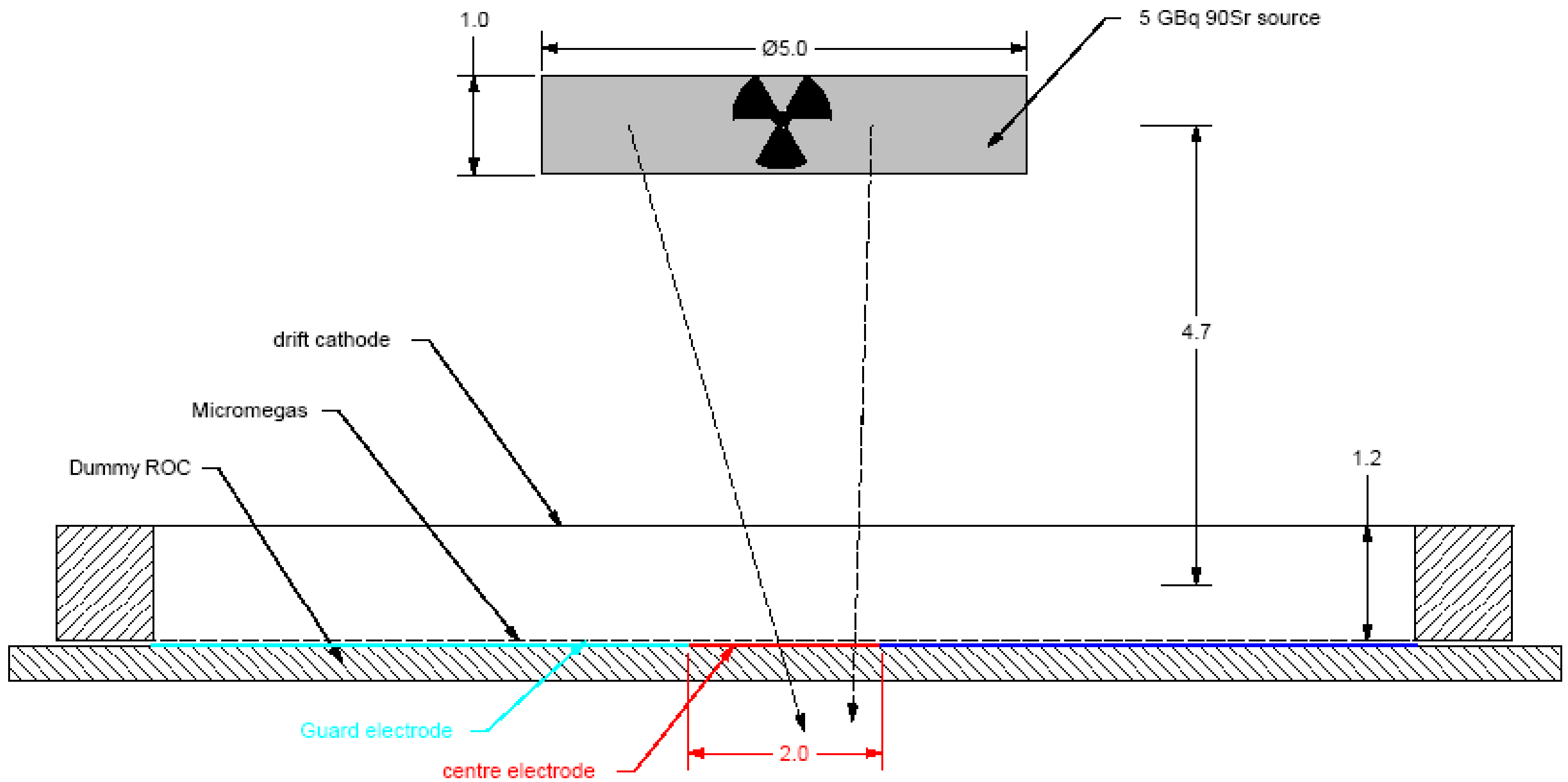
Equivalent of 3 years Super LHC @ 2 cm from beam pipe

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

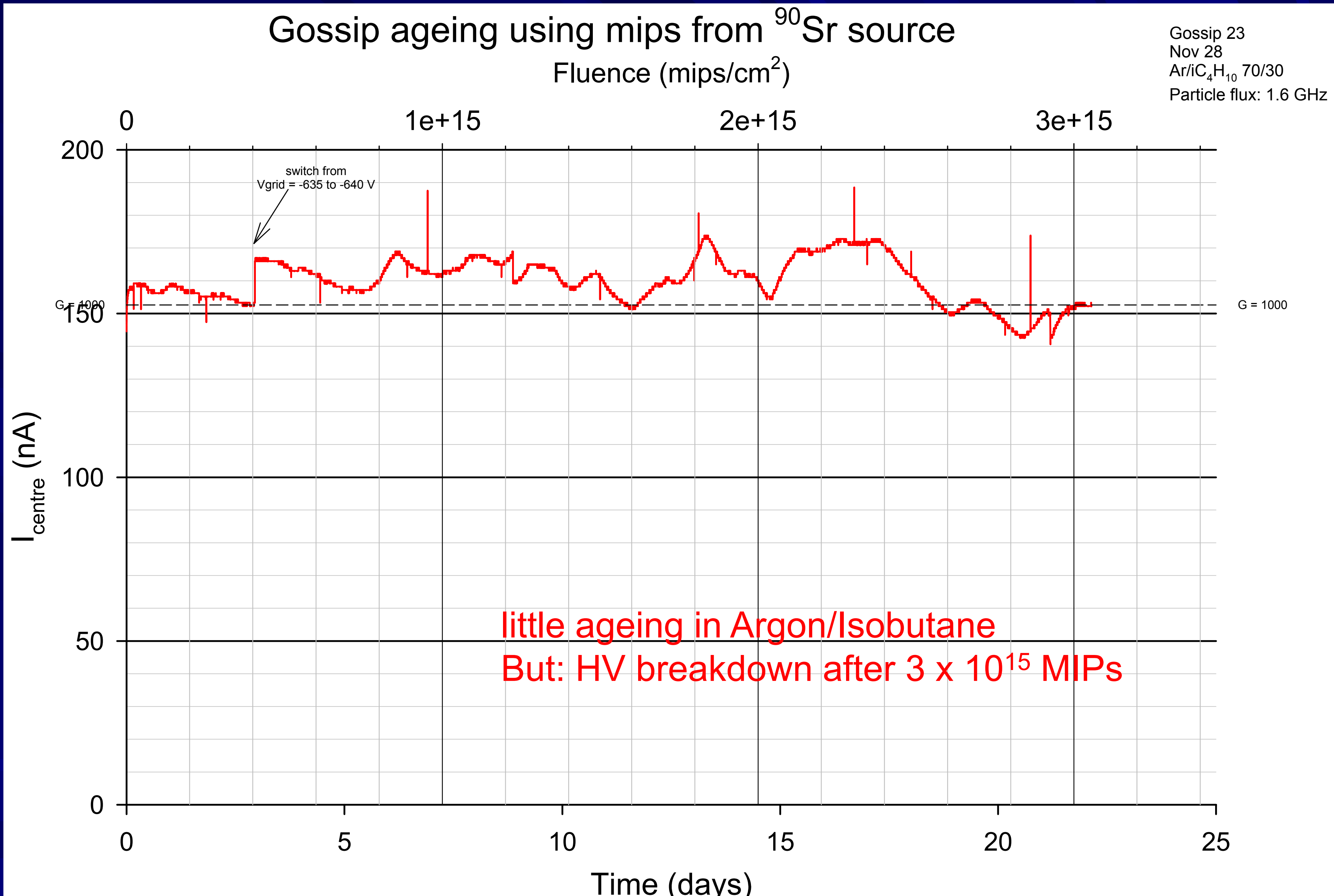


av current = 5.9 μA
=> total charge deposited
= 5.9*3600*24*4
= 2.55 C
surface 0.49 cm^2
=> 5.2 C/cm^2
assume: drift distance 1 mm
Ar/CH4 having $9e^-/mm$
=> 1 mip = $9*1000*1.6*10^{-19}$
= $1.44\ 10^{-15}$C
deposited charge corresponds to
$3.6\ 10^{15}$ mips/cm^2

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

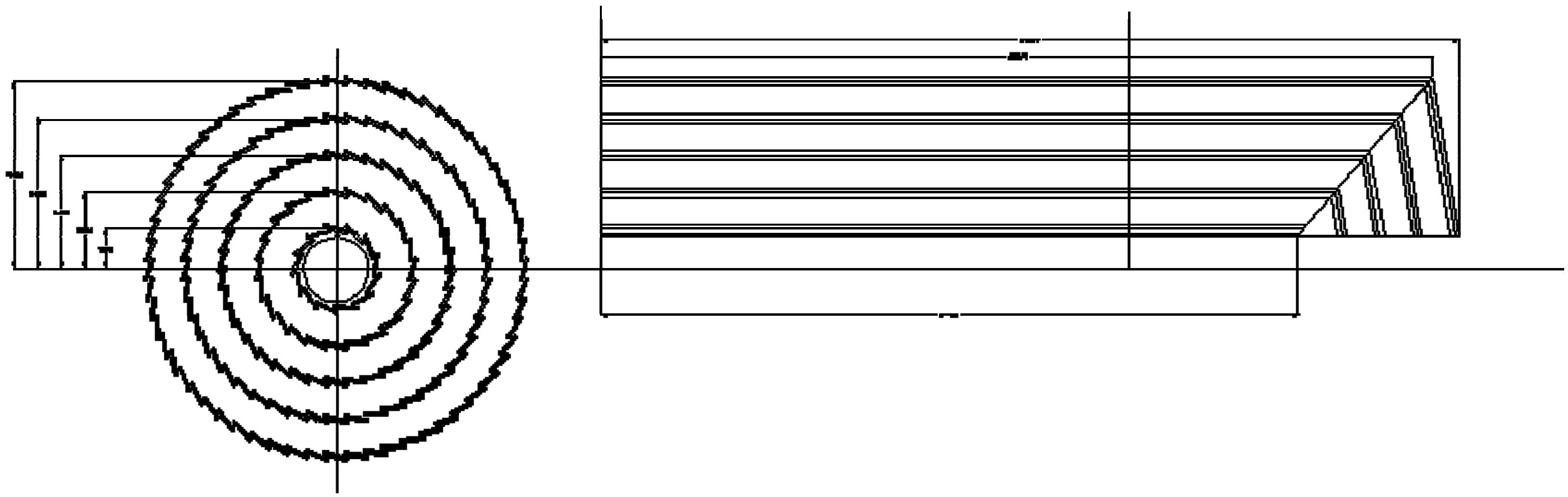


set up ageing test



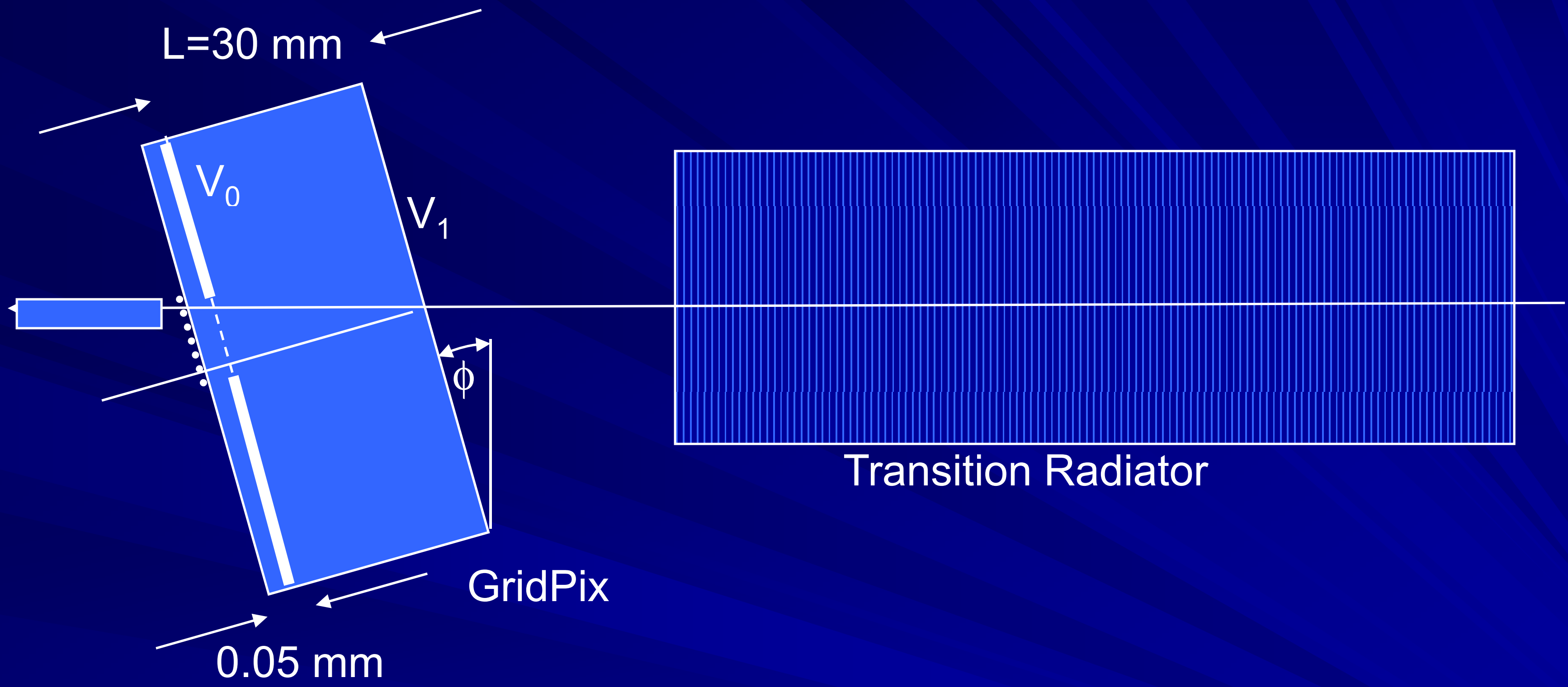
Gossip ageing using mips from 90Sr source
Fluence (mips/cm2)
Gossip 23
Nov 28
Ar/iC4H10 70/30
Particle flux: 1.6 GHz
0
1e+15
2e+15
3e+15
switch from
Vgrid = -635 to -640 V
G = 1000
G = 1000
200
150
100
50
0
Icentre (nA)
little ageing in Argon/Isobutane
But: HV breakdown after 3 x 1015 MIPs
0
5
10
15
20
25
Time (days)

Application of Gossip in ATLAS Upgraded detectors



- Ladder strings fixed to end cones
- Integration of beam pipe, end cones & pixel vertex detector
- 5 double layers seems feasible

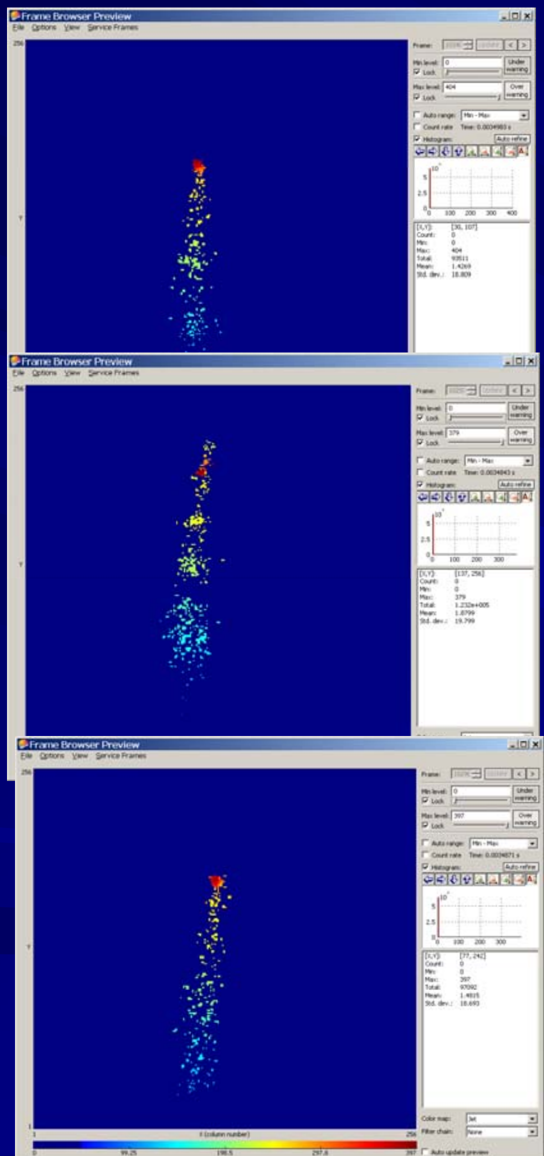
Testbeam Nov 5 – 12, 2007
PS/T9: electrons and pions, 1 – 15 GeV/c



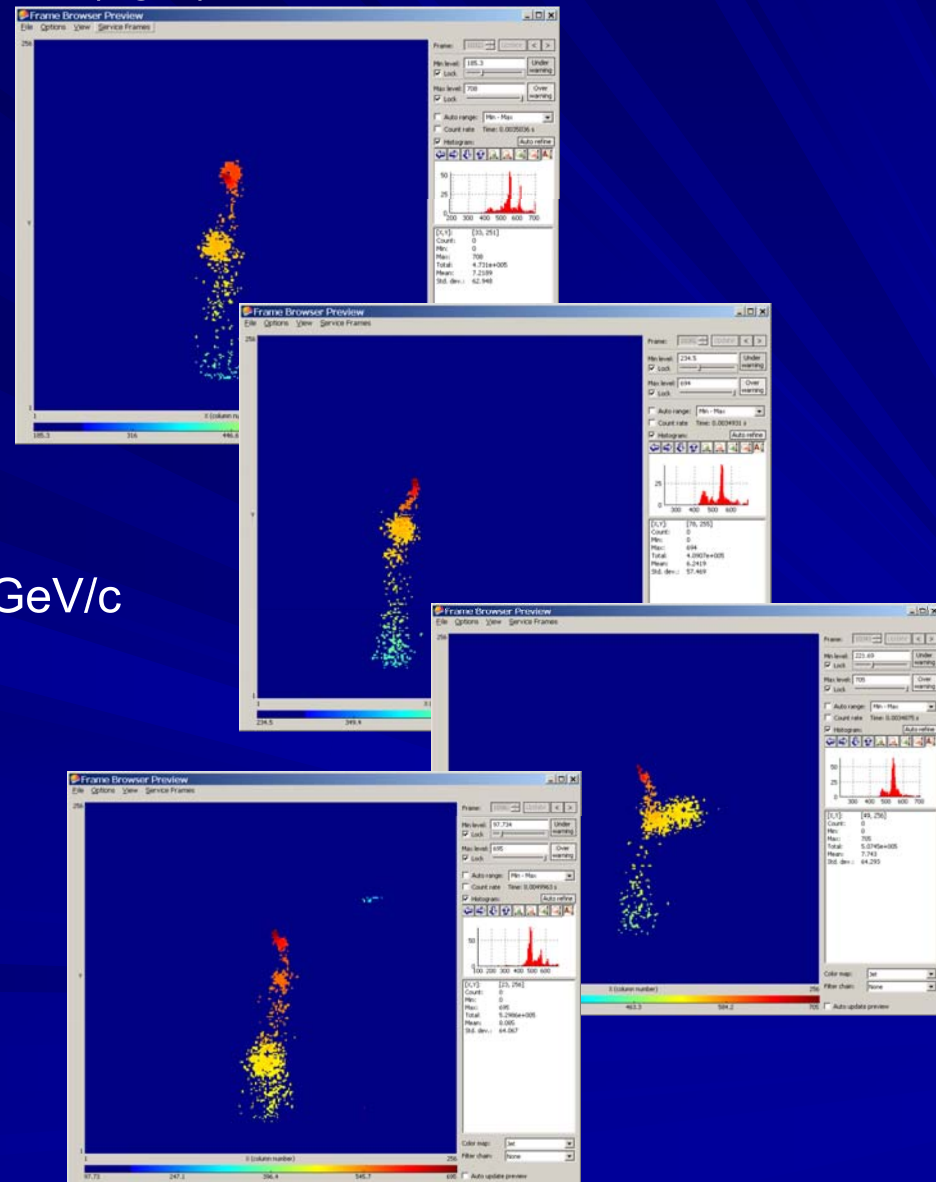
Anatoli Romaniouk, Serguei Morozov, Serguei Konovalov
Martin Fransen, Fred Hartjes, Max Chefdeville, Victor Blanco Carballo

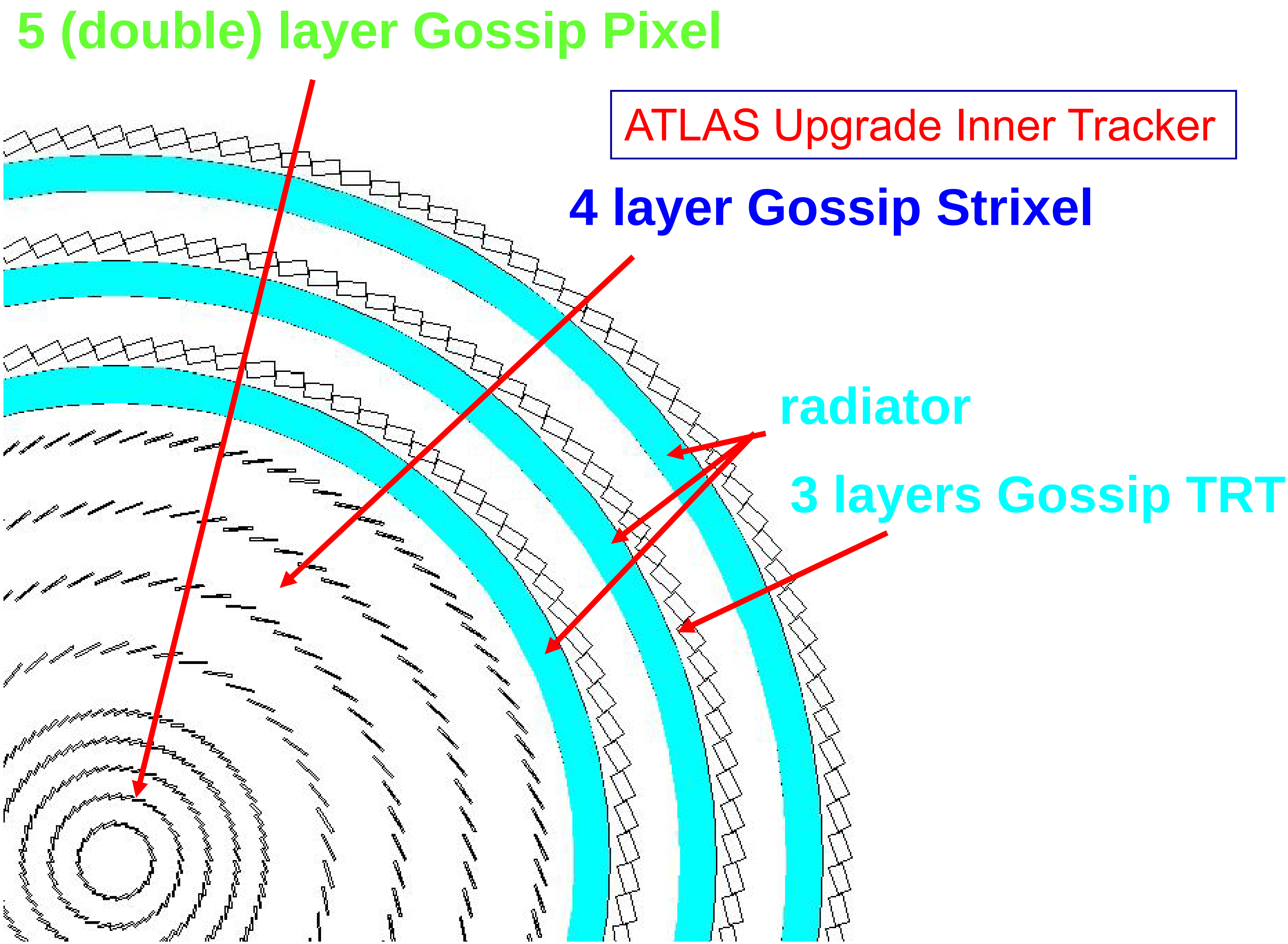
Particle Identification

Samples pions (left) and electrons (right)

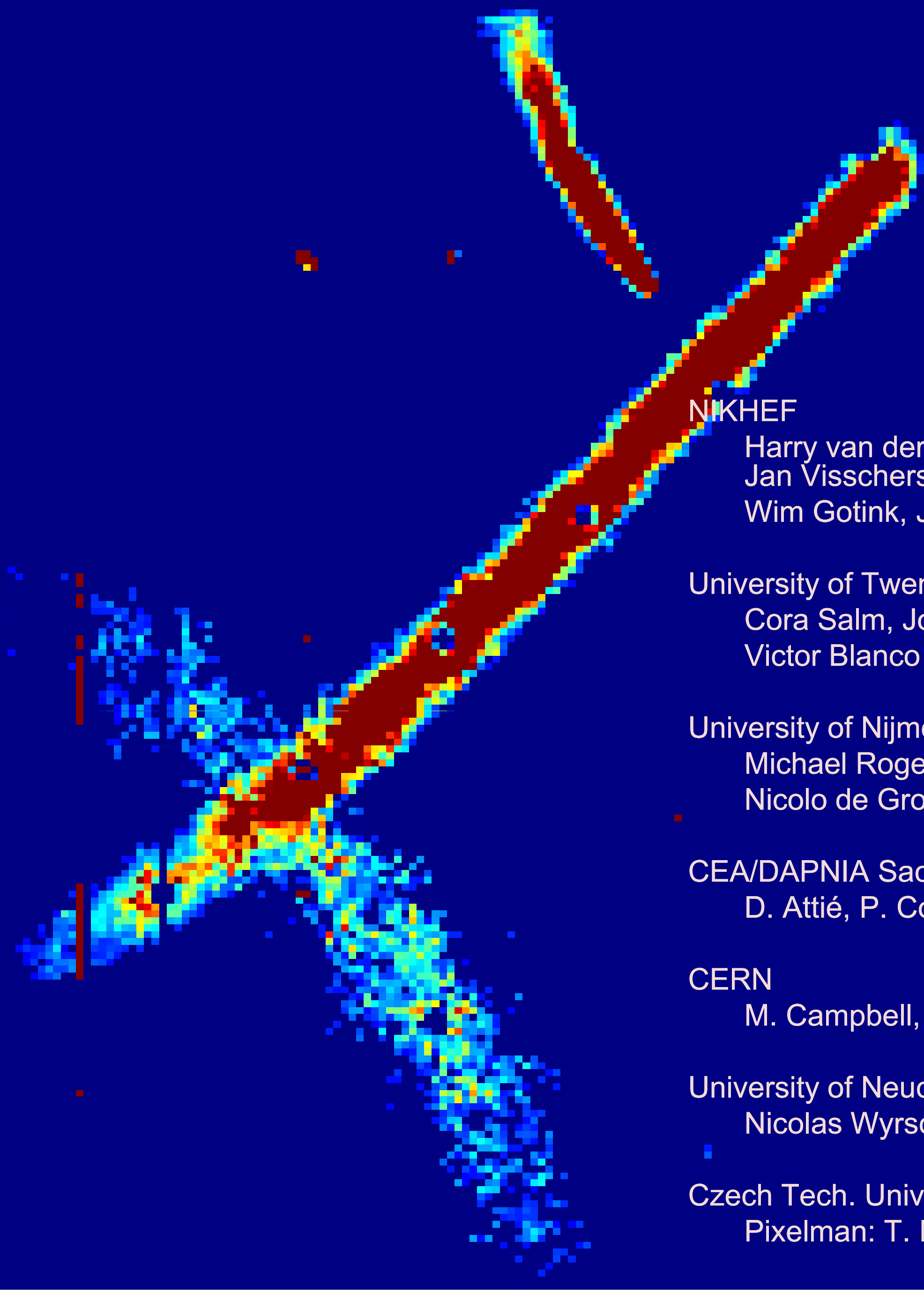


6 GeV/c





5 (double) layer Gossip Pixel
ATLAS Upgrade Inner Tracker
4 layer Gossip Strixel
radiator
3 layers Gossip TRT



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