Progress in the CMOS Pixel TPC concept

Jan Timmermans - NIKHEF

- Micro Pattern Gas Detector: pixelised anode + Micromegas or GEM
- Integration of grid and readout: InGrid
- 3D readout: TimePix
- Discharge protection
- Future developments

Groups involved: Bonn, CEA Saclay, CERN, Freiburg, NIKHEF

Goals

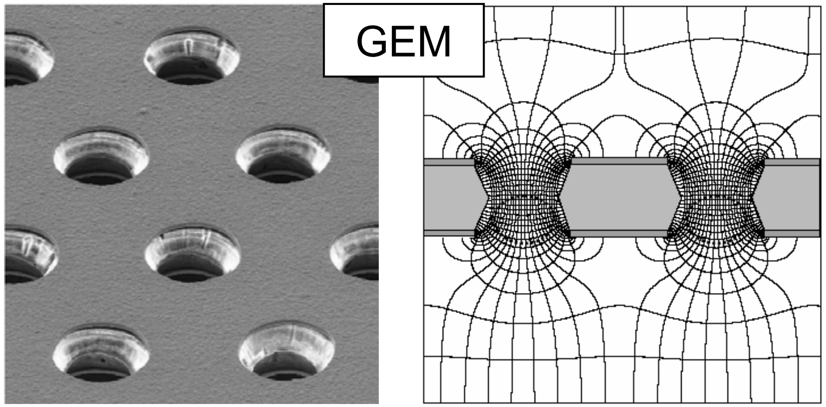
- Gas multiplication GEM or Micromegas foil(s)
- Charge collection with granularity matching primary ionisation cluster spread

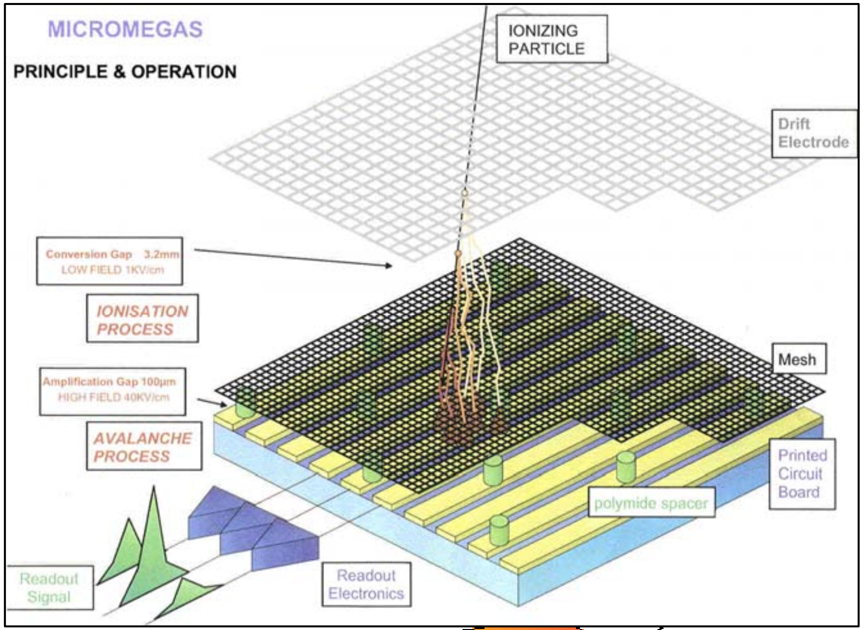
  (this needs sufficiently low diffusion gas)
- Investigate measurement dE/dx using cluster counting

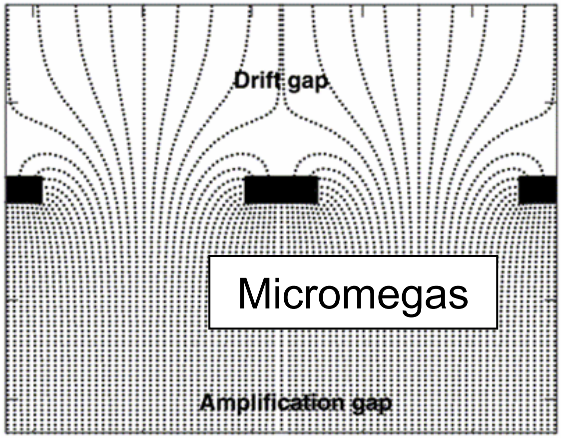
- 2D "proof of principle" based on existing Medipix2 readout chip: achieved
- Add 3rd coordinate: Medipix2 → TimePix: available; first results
- Integrate grid with pixel chip: InGrid: some results

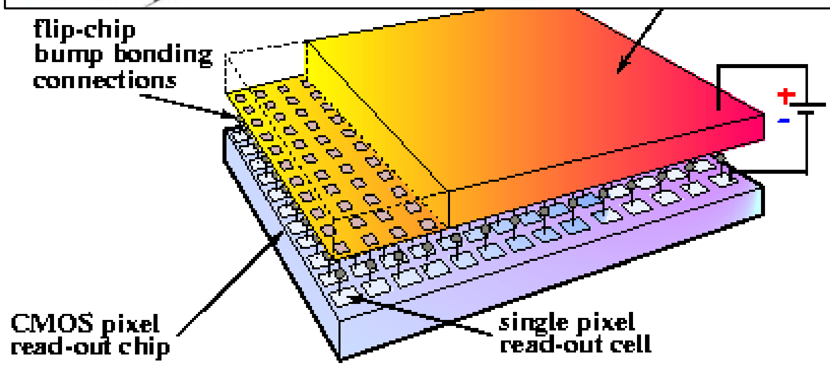
Micro Patterned Gaseous Detectors

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





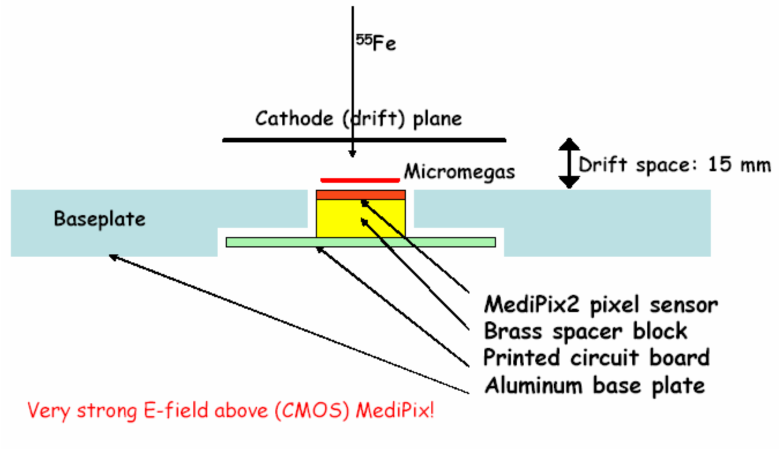




Use 'naked' CMOS pixel readout chip as anode

Results pixel readout gas detectors

NIKHEF-Saclay-CERN-Twente

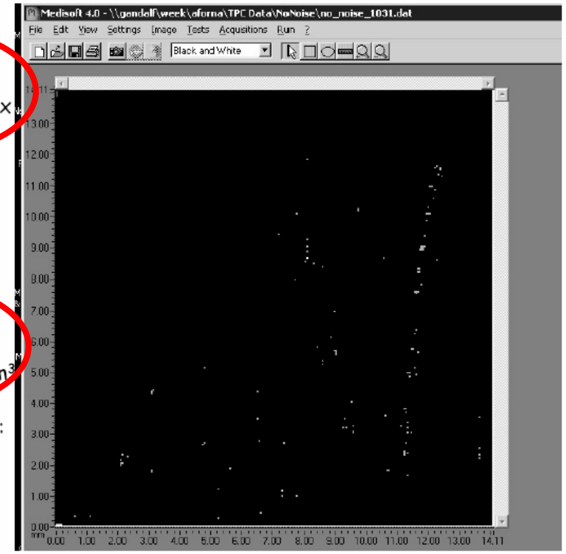


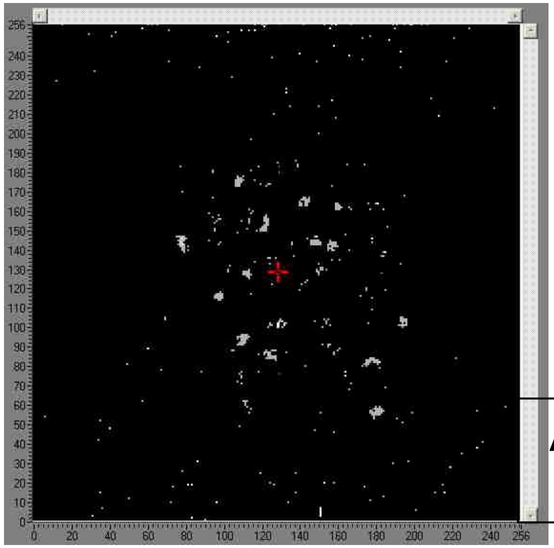
He/Isobutane 80/20 Modified MediPix

31 March 2004

Sensitive area: 14 x 14 x 15 mm^3

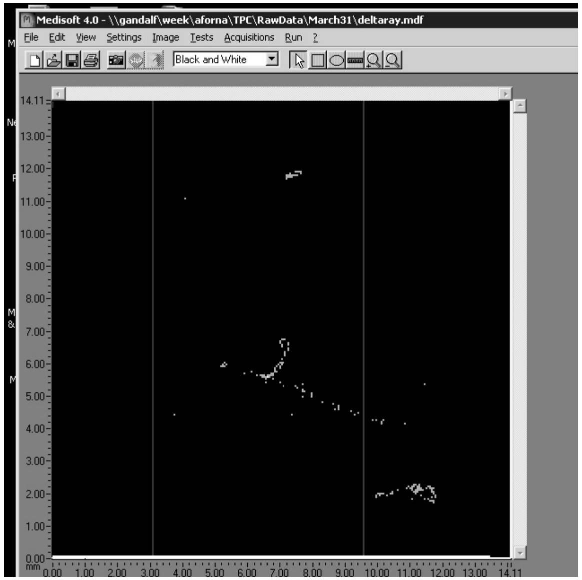
Drift direction: Vertical max = 15 mm





Ar/isobutane 95/5

55x55 μm^2 pixels



δ ray

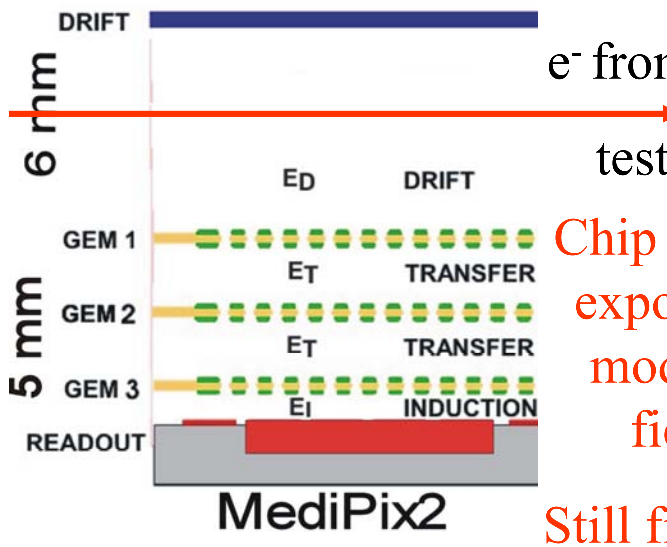
Observation of min. ionising cosmic muons: high spatial resolution + individual cluster counting !

NIM A540 (2005) 295 (physics/0409048)

GEM-TimePix Project

Institute of Physics, Albert-Ludwigs-Universität Freiburg

- Micro Pattern Gas Detectors (MPGD): high resolution readout and high rates
  - pixelated readout offers high resolution Digital Bubble Chamber
- a TPC at the ILC needs excellent momentum resolution =>GEM-TimePix for end plate readout
  - Cluster counting as a goal



e^- from source

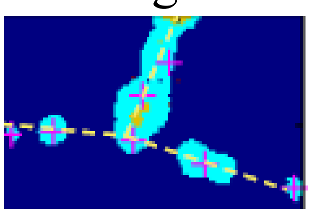
test beam

Chip surface exposed to moderate fields

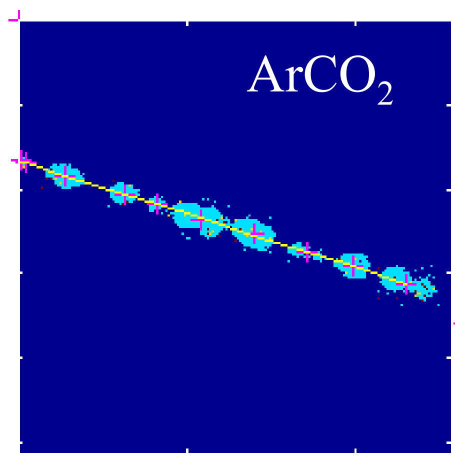
Still first chip since 1.5 y !

Results from MediPix Prototype setup:

For ArCO2 and HeCO2: point/cluster resolution determined with different algorithms between 50 - 60 μ m



δ-electron in HeCO2



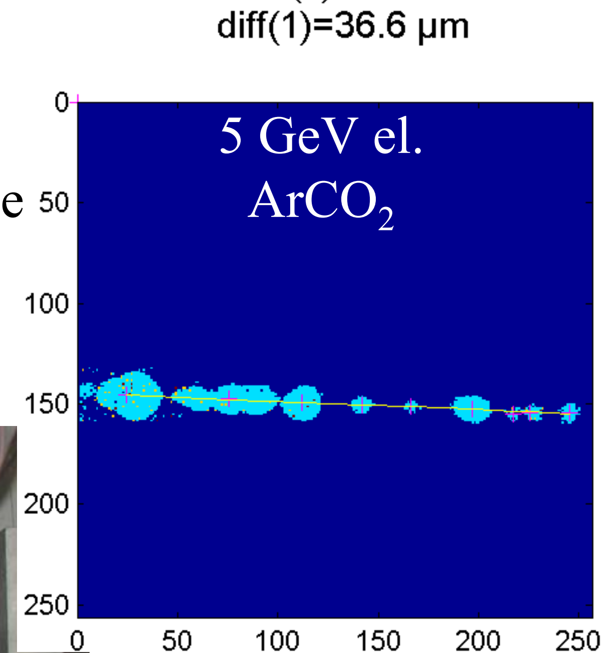
Charge depostion on the MediPix Chip electron track from ^{106}Ru source and straight line fit

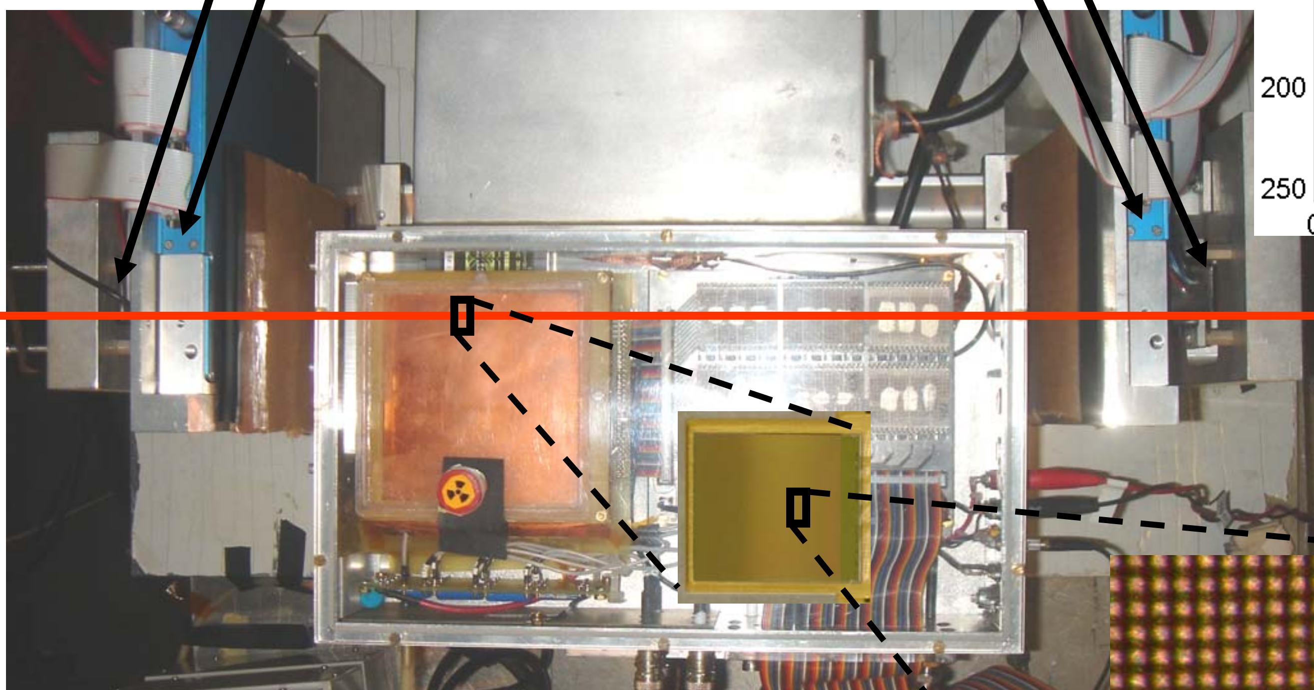
Test beam event

multiple scattering negligable on MediPix/TimePix scale

trigger counters ~8 mm wide

Si telescope (~20 μm precision)

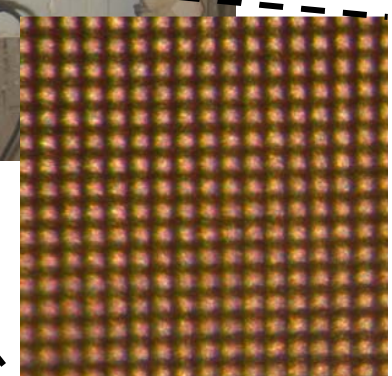




e^- from DESY II

GEM stack of 10x10 cm^2

MediPix2/TimePix chip 14x14 mm^2

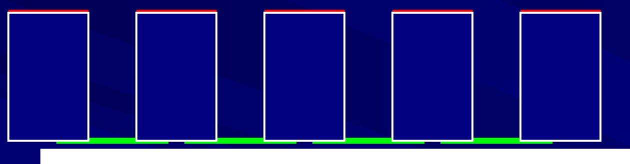


pitch of pixels 55 μm

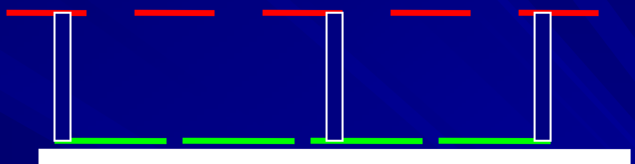
InGrid

Integrate GEM/Micromegas and pixel sensor

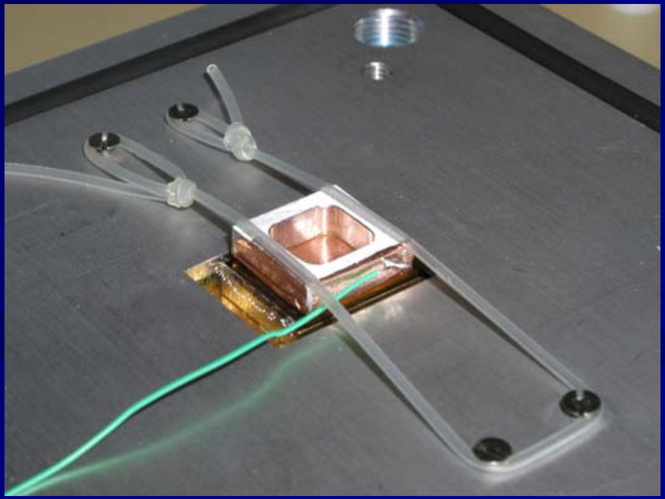
‘GEM’



‘Micromegas’



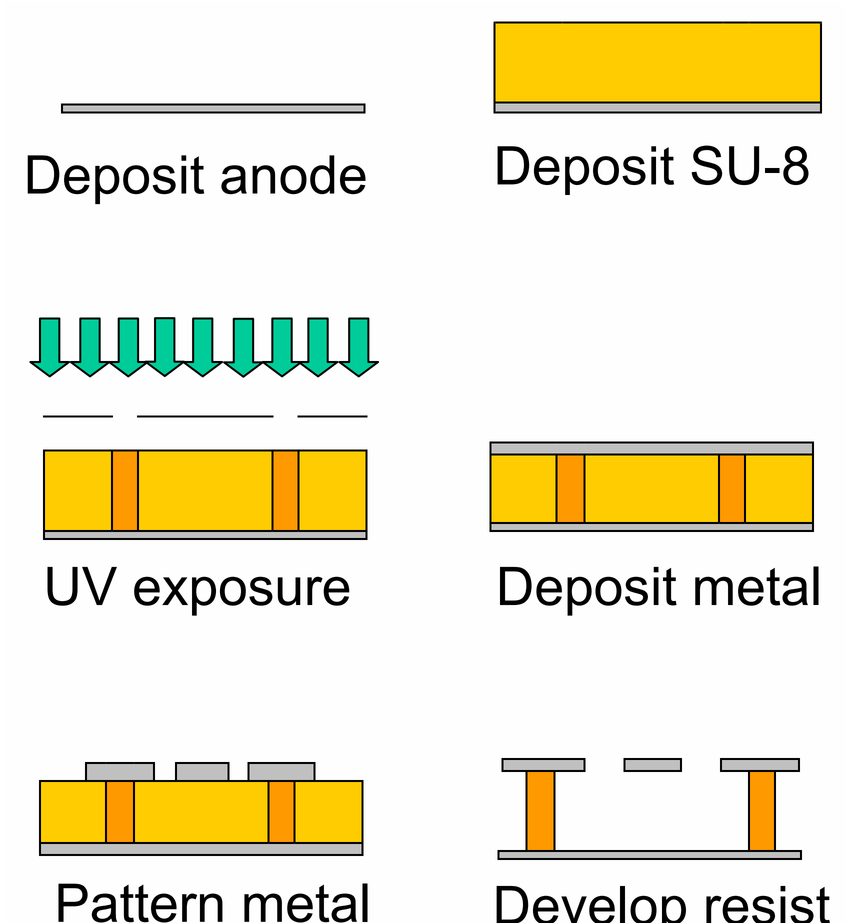
By ‘wafer post processing’

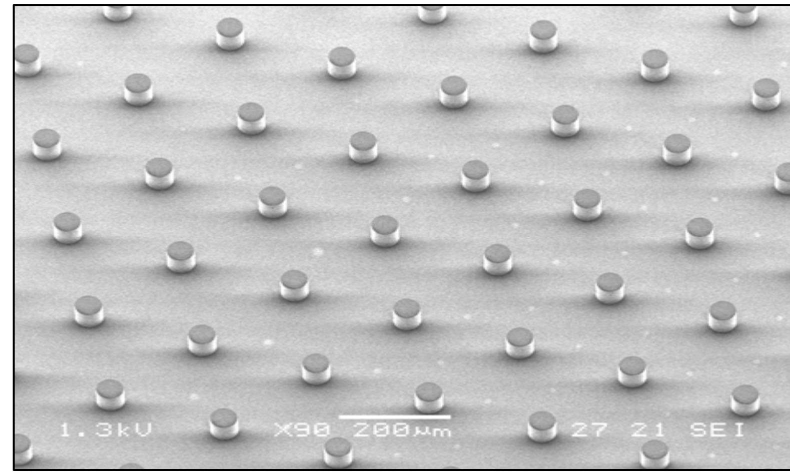


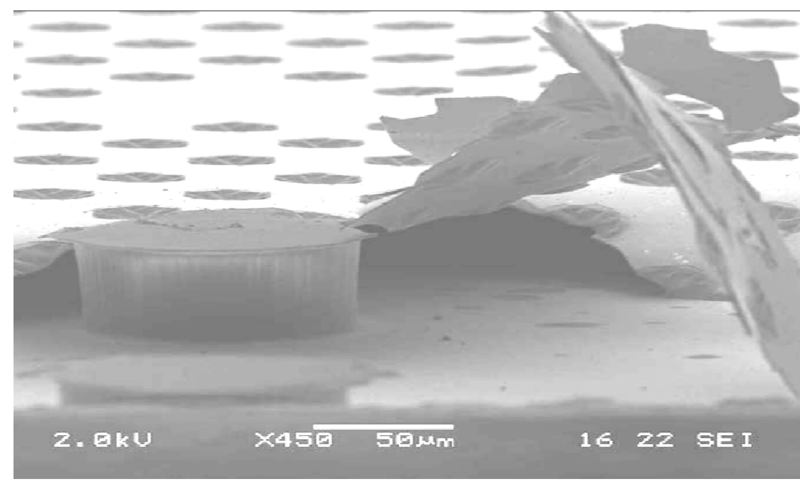
4” wafer

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

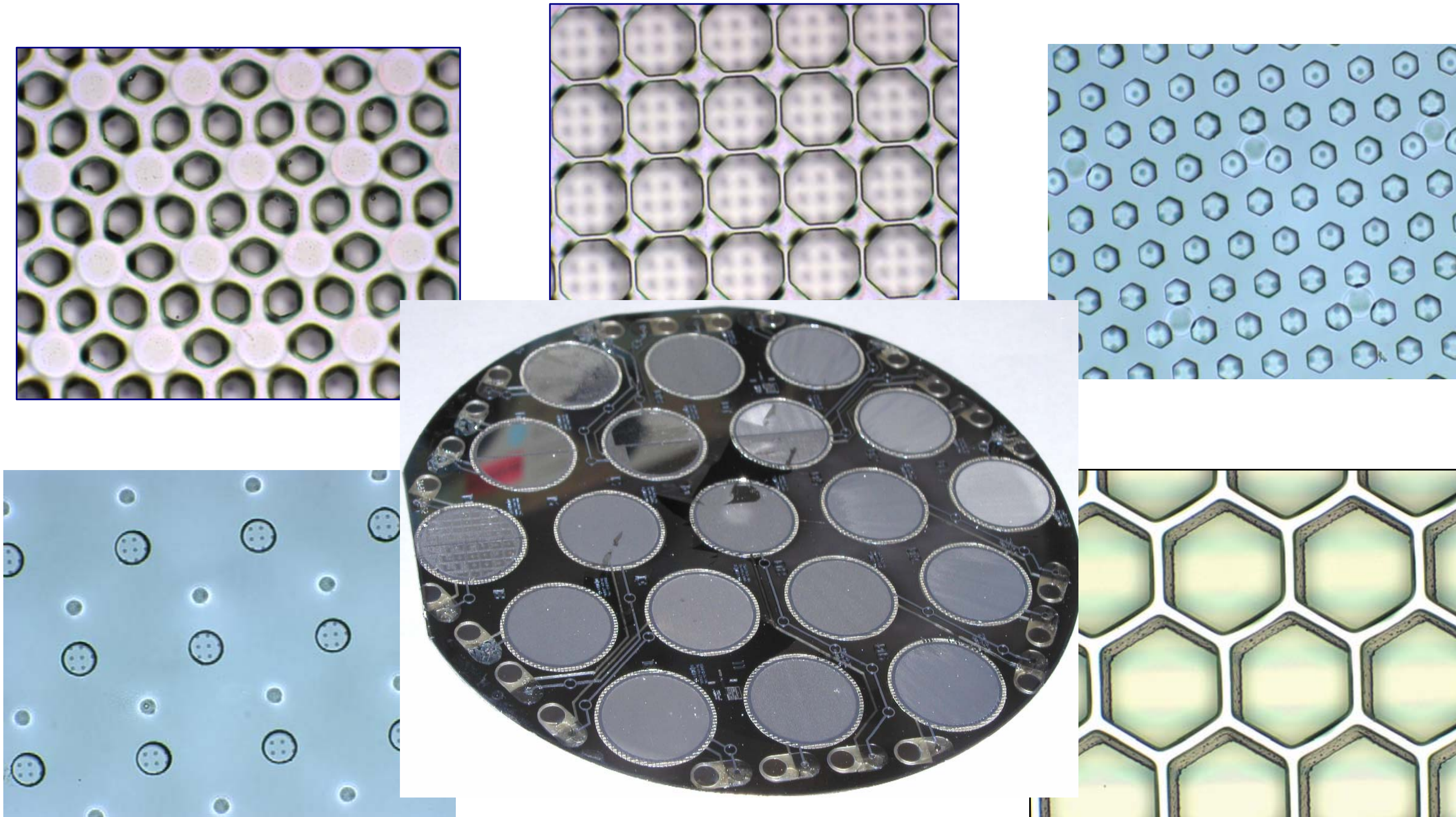
NIKHEF/Twente: InGrid (Integrated Grid)





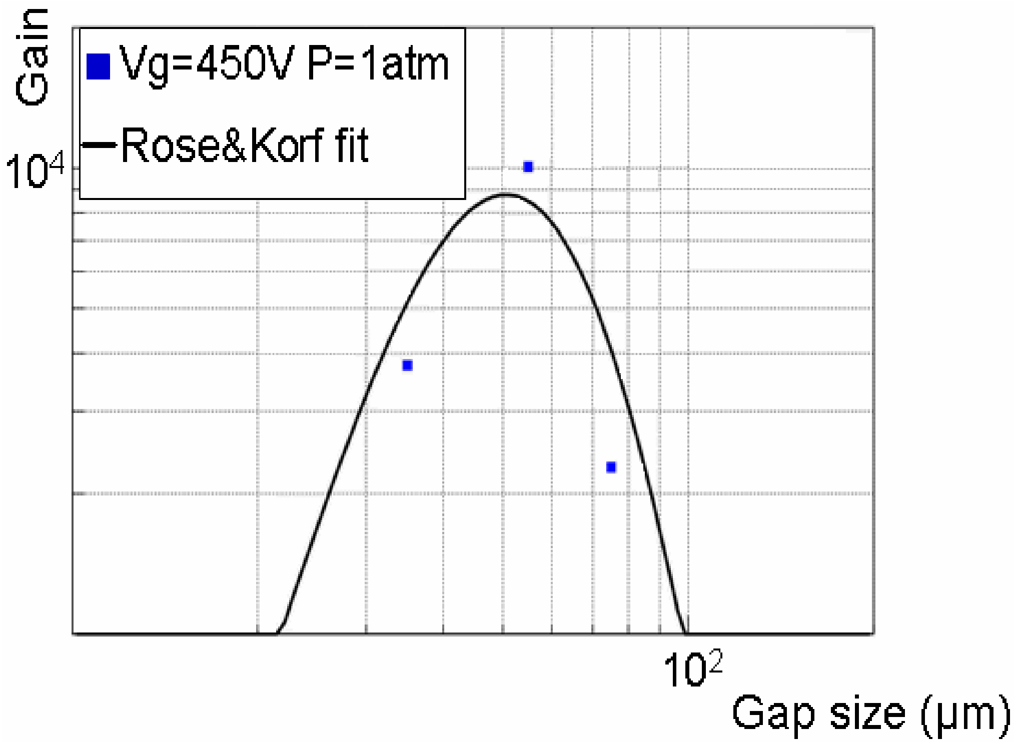


Any field structure feasible



Gain for different gap sizes (many other measurements in backup slides)

Maximum predicted in gain vs gap curve



$$M = e^{\alpha d}$$

d gap thickness

$$\alpha = pAe^{-Bp/E}$$

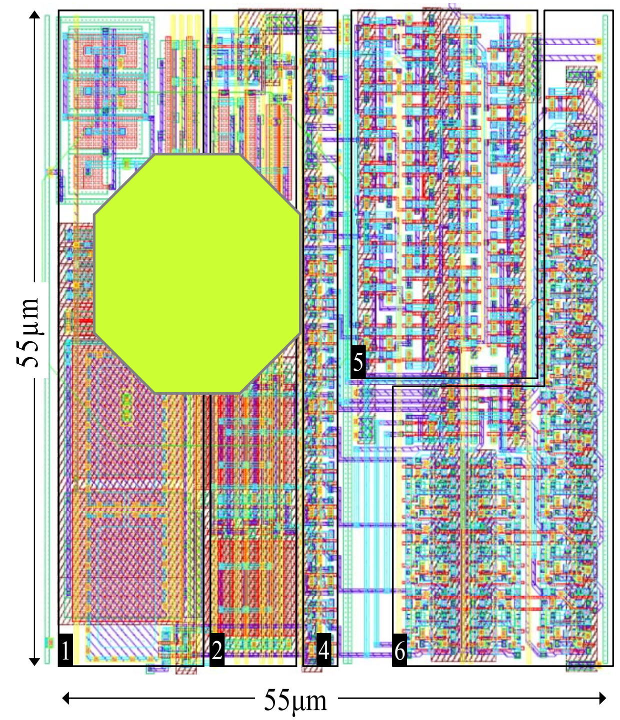
Rose & Korff

p pressure

A,*B* depend on gasmixture

TimePix (EUDET: Bonn,Freiburg, Saclay, CERN, NIKHEF)

- Distribute clock to full 256x256 pixel matrix (50-100-160MHz)
- Enable counting by first hit after ‘shutter’ opens, until ‘shutter’ closes (common stop); also time-over-threshold possible
- Dynamic range 2^{14} x 10 ns = 160 µs
- (for the time being) no zero-suppress
  to remain fully compatible with Medipix2
- Shaping time ~200 ns
- Keep same chip-size, pixel-size, readout protocol
- 1st full reticle submit done July 2006;
  IT WORKS! Now doing tests in gas detectors.



TimePix Test Beam Results (TimePix + GEM setup)

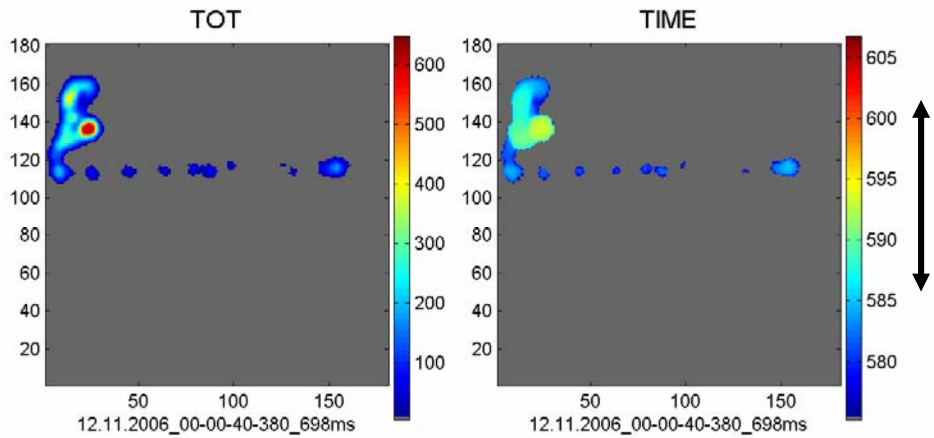
- Point resolution from a straight line fit averaged over all drift volume of 6mm: 39.3 ± 1.3 μm for Ar/CO_2
- Resolution near the first GEM (selected by Si- telescope and using the parametrisation of c $\sigma^2_{mean} = \sigma^2_0 + \frac{D^2_t \cdot y}{n^{el}_{cl}}$
  - 25.0 ± 2 μm for Ar/CO_2
  - 30.0 ± 2 μm for $HeCO_2$

Events taken with the mixed mode

- Gas mixture $HeCO_2$
- delta-electrons, example of a ~6 keV:

left side TOT (charge), left side: Time of arrival

max. charge at 600 cts
equivalent to 0.3 fC/pixel

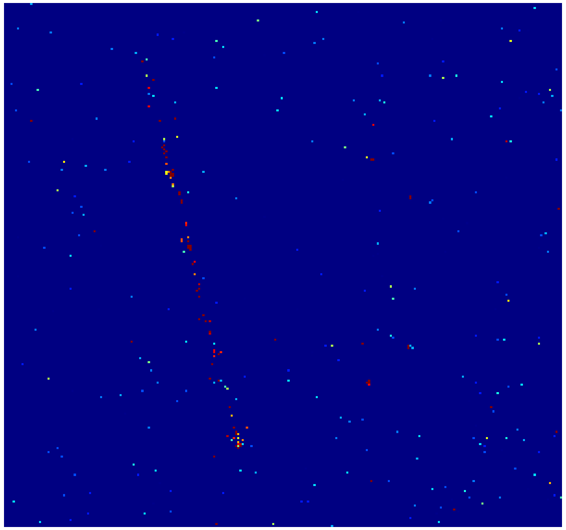


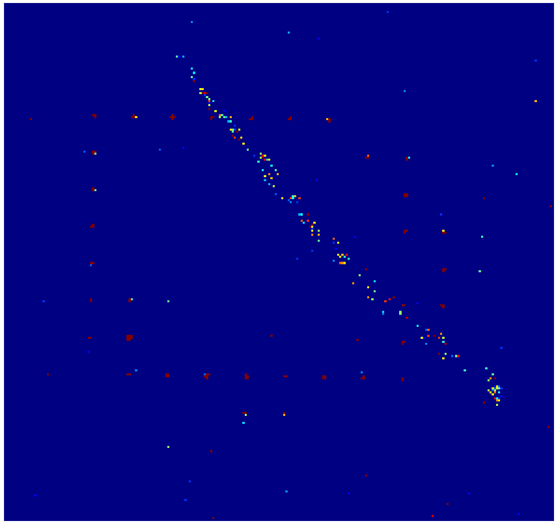
300 ns

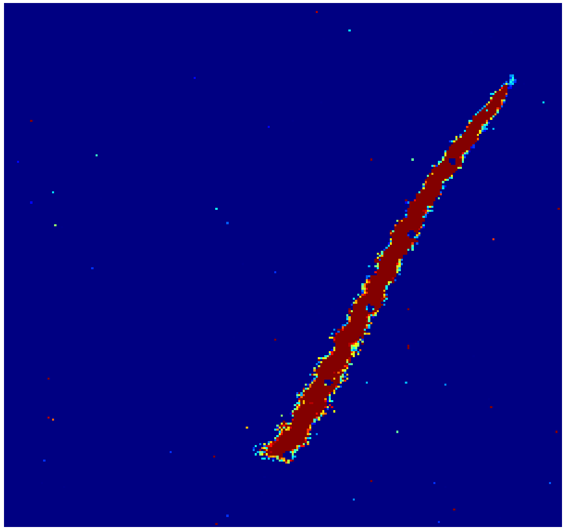
First tracks with TimePix+Micromegas: cosmics + α particle

V_grid= -400 V; gain ~6000

He/Isobutane 80/20



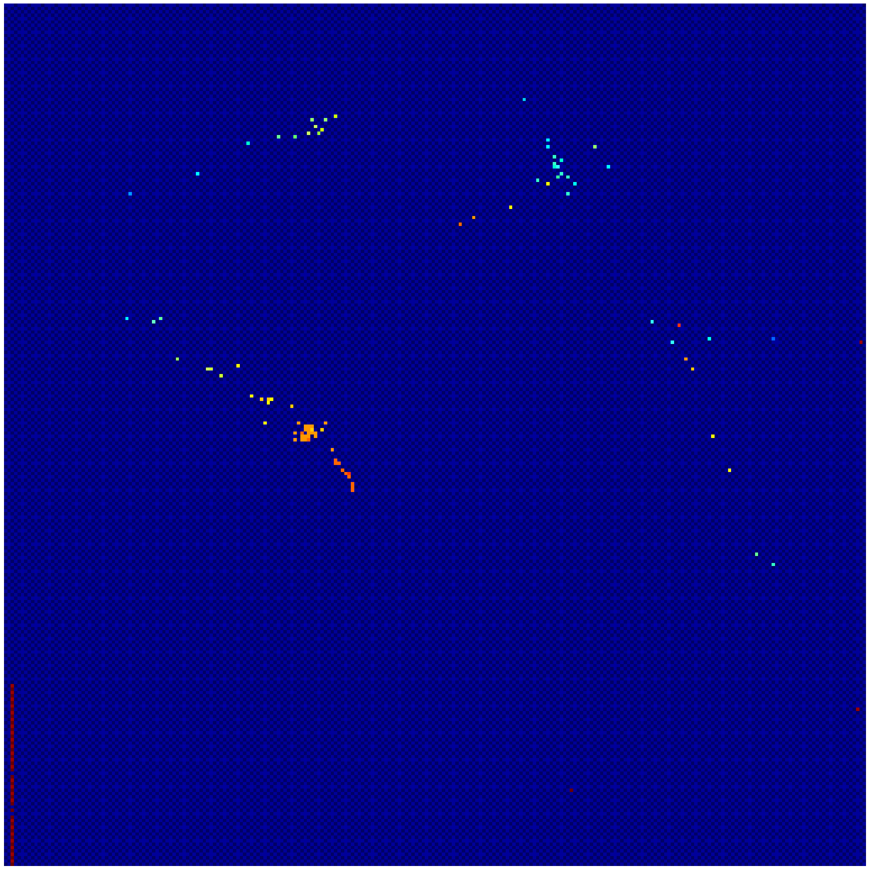


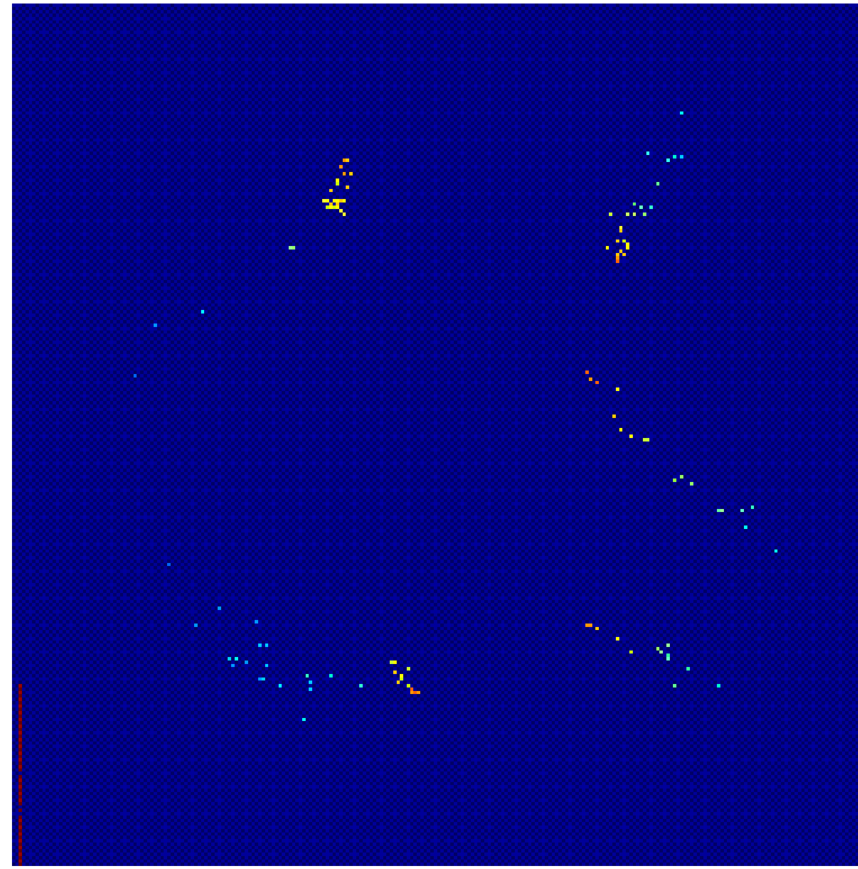


Acquisition (‘shutter’) time ~ 1sec

And triggered cosmics (sum of several triggers)

Shutter time = 15 μs



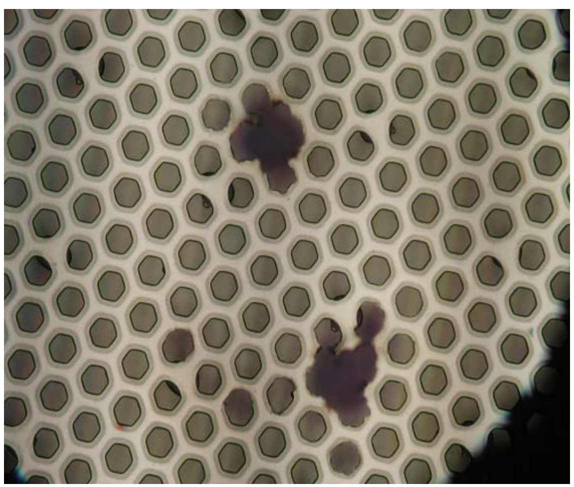


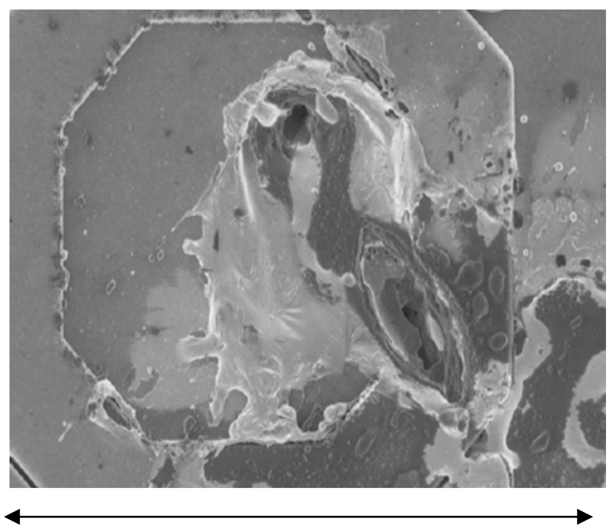
TimePix chip stayed alive for 40 days with He/isobutane

And 'died' after 1.5 day with Ar/isobutane 80/20

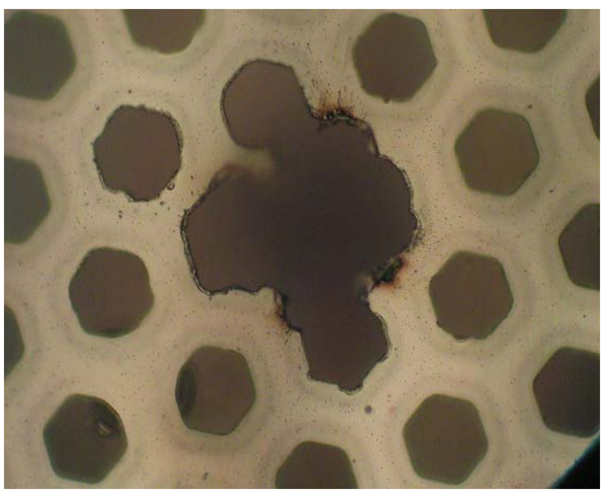
Sparking

- Chip faces 80kV/cm with no protection (unlike the GEM setup; 1.5 yr using same chip)
- Degradation of the field, or total destruction of grid but also CMOS chip





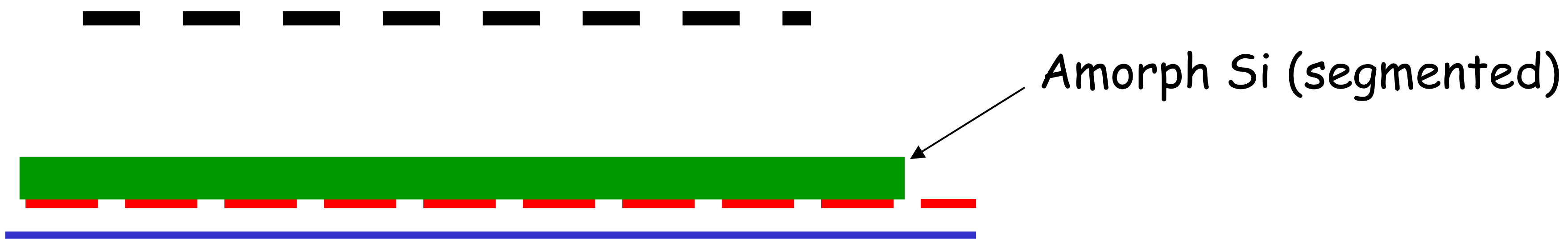
10μm



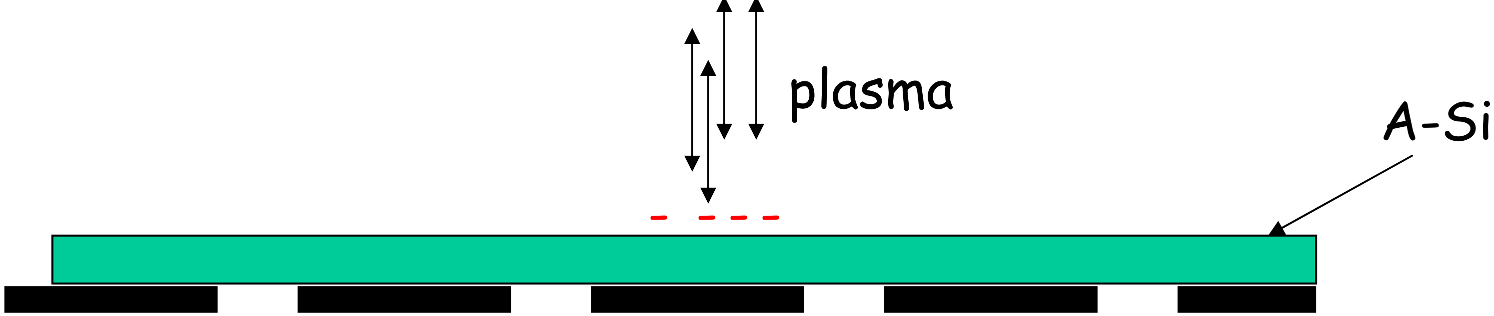
CMOS Chip protection against

- discharges
- sparks
- HV breakdowns
- too large signals

Silicon Protection: SiProt



Empirical method:
Try RPC technology



- RPC principle: reduction of local E-field
- Avalanche charge: electrostatic induction towards input pad
- Specific resistance:
  - high enough to 'block' avalanche charge
  - low enough to flow signal current
  - layer thickness 4 μm, R_{vol} = 0.2 GΩ/cm

Technology

A-Si deposit possible in general; avoid wafers get too hot

☺ Univ. of Neuchatel/IMT/P. Jarron (CERN) uses this for integrated X-ray sensor/convertor on MediPix 2

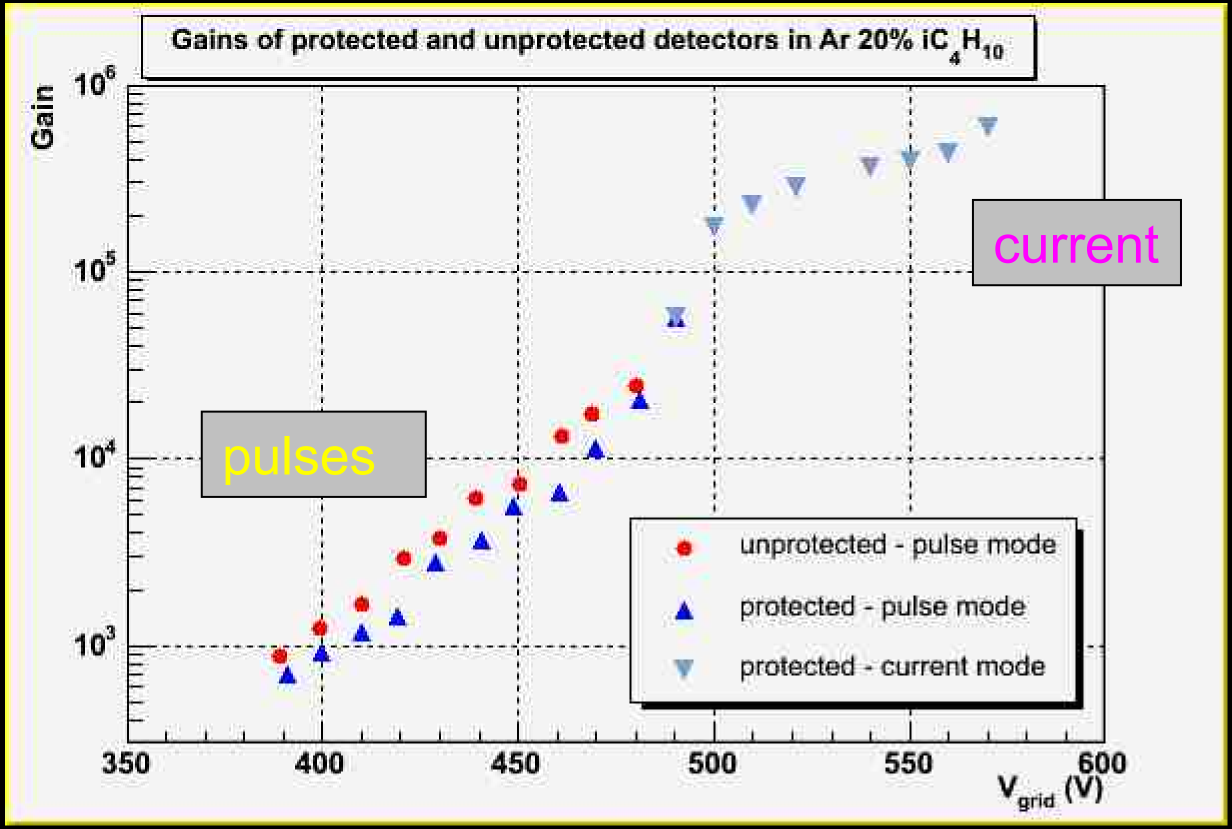
Test: put Thorium in gas: Radon α-decays:
- large (proportional) signals
- Discharges: like short circuits

Gain

Iron 55 source

Look at the pulses from a pre amplifier (low grid voltage)

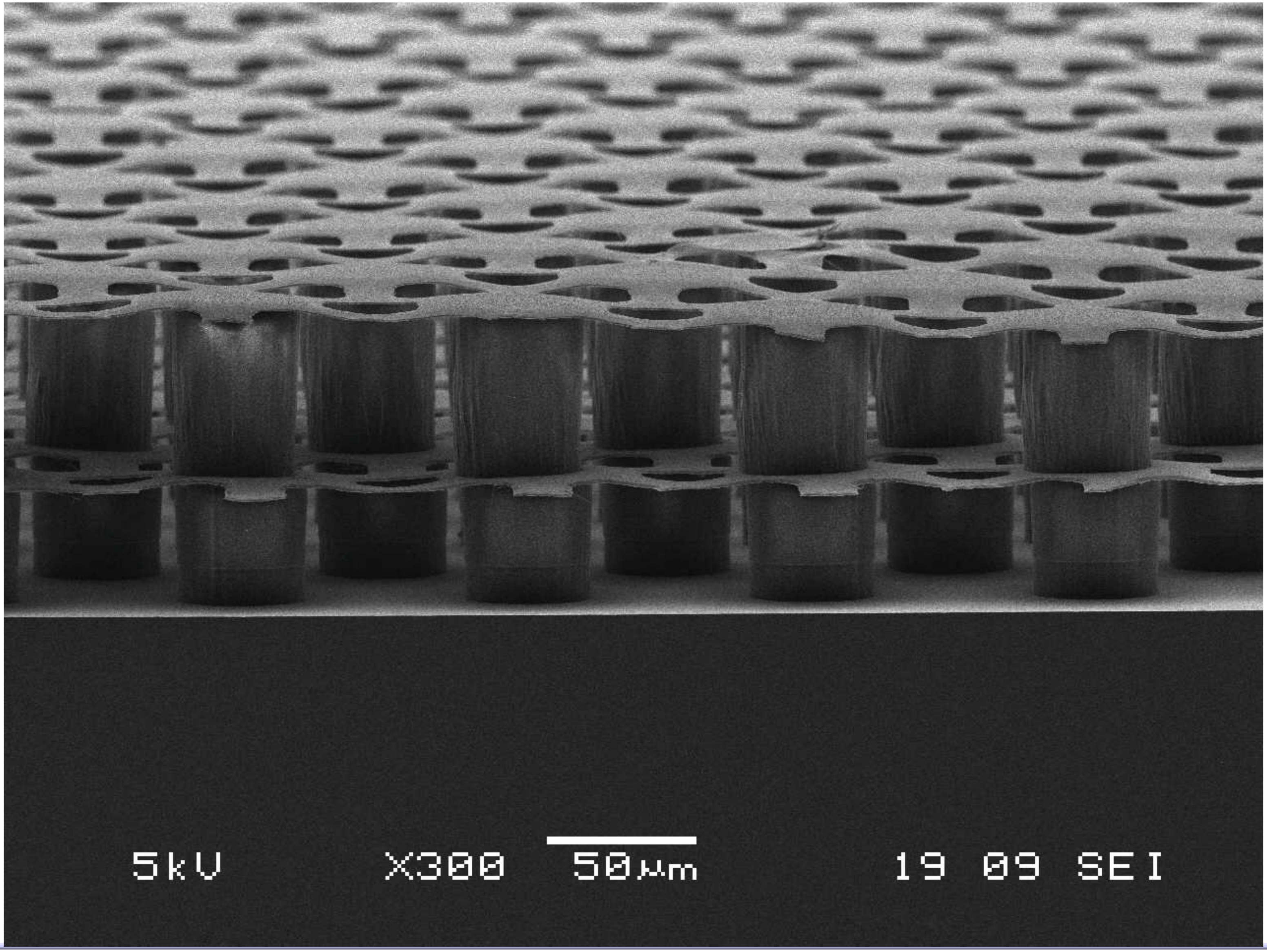
Look at the current flowing through the power supply (high grid voltage)



No sparks up to 570 V on the grid !

Burn the grid above 570...

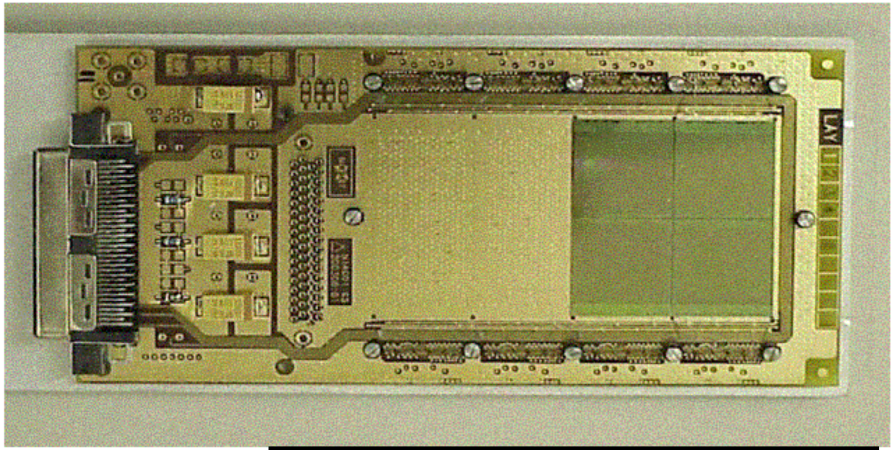
Alternative: TwinGrid



Further Developments

- Chip tiling: large(r) detector surfaces
  (2x2, 2x4 chips)
- Through Si connectivity: avoiding bonding wires
- Fast readout technology
  (~5 Gb/s)

- Intermediate size TPC
- Endplate module for LP

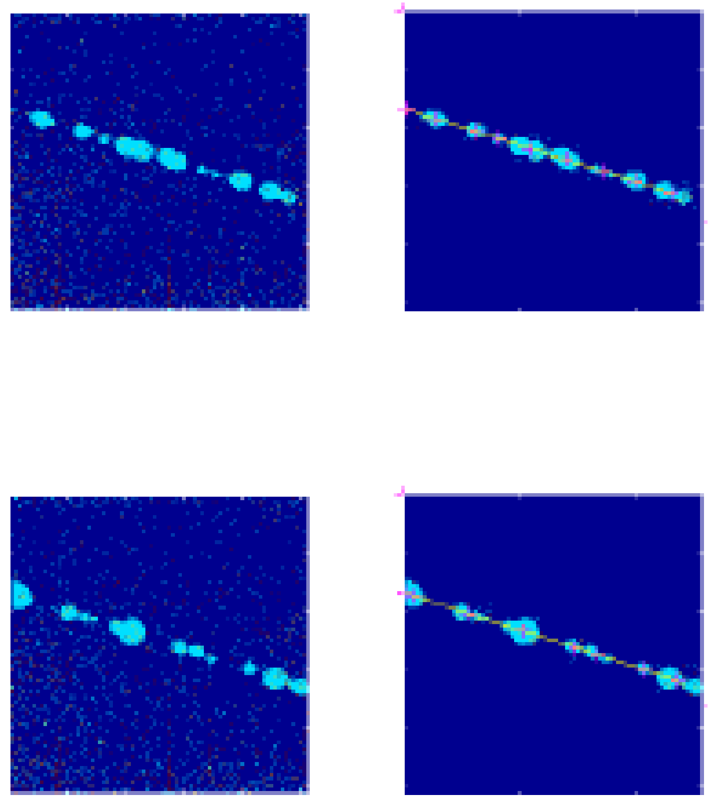


- Octal chip board:
  56 mm x 110 mm
  12-layer pcb

Backup slides

Some events with fits (β source)

(from Freiburg GEM+Medipix setup - Andreas Bamberger)



Triple GEM

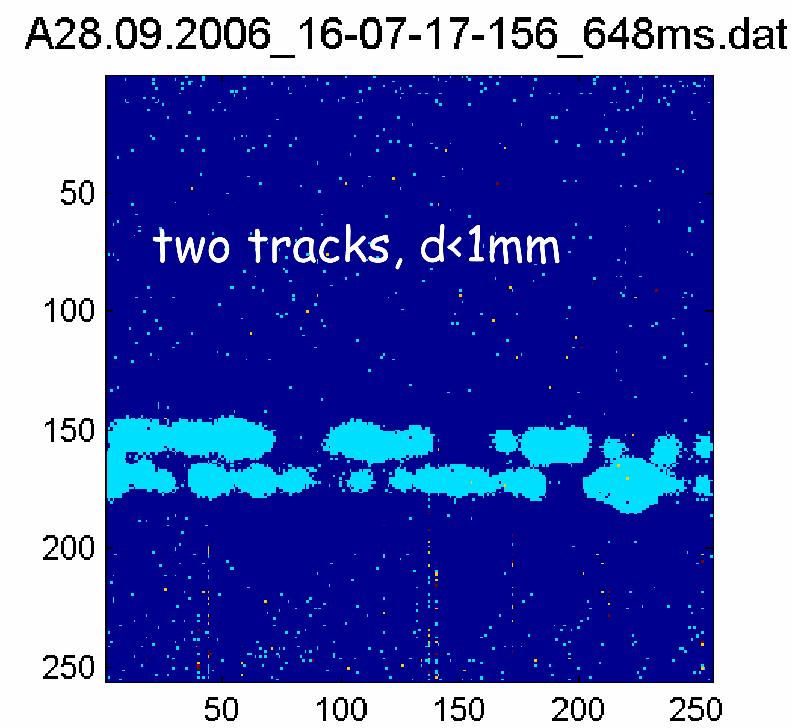
Total gain ~60k

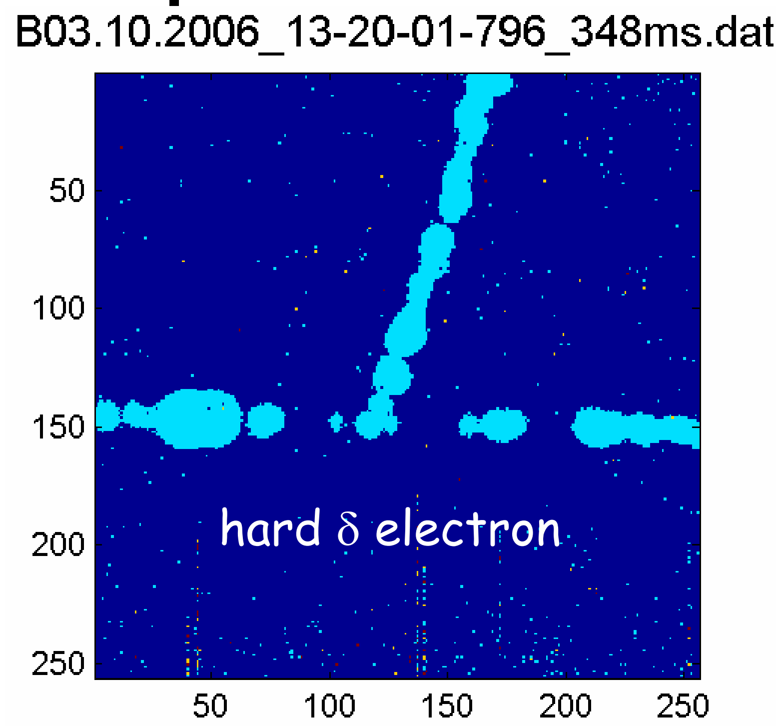
~ 50 μm resolution

Difference between Micromegas and GEM setup understood (simulation Michael Hauschild/CERN)

4. Testbeam at DESY: 3-GEM+Medipix

Freiburg
Bonn

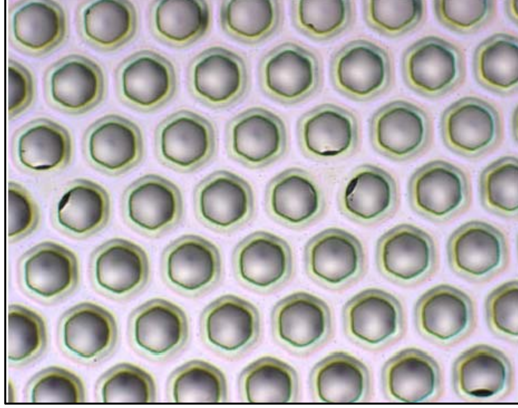




Lots of data to be analyzed
Still the same Medipix chip as 1.5 years ago
Prepare for Testbeam with Timepix in same setup a.s.a.p.

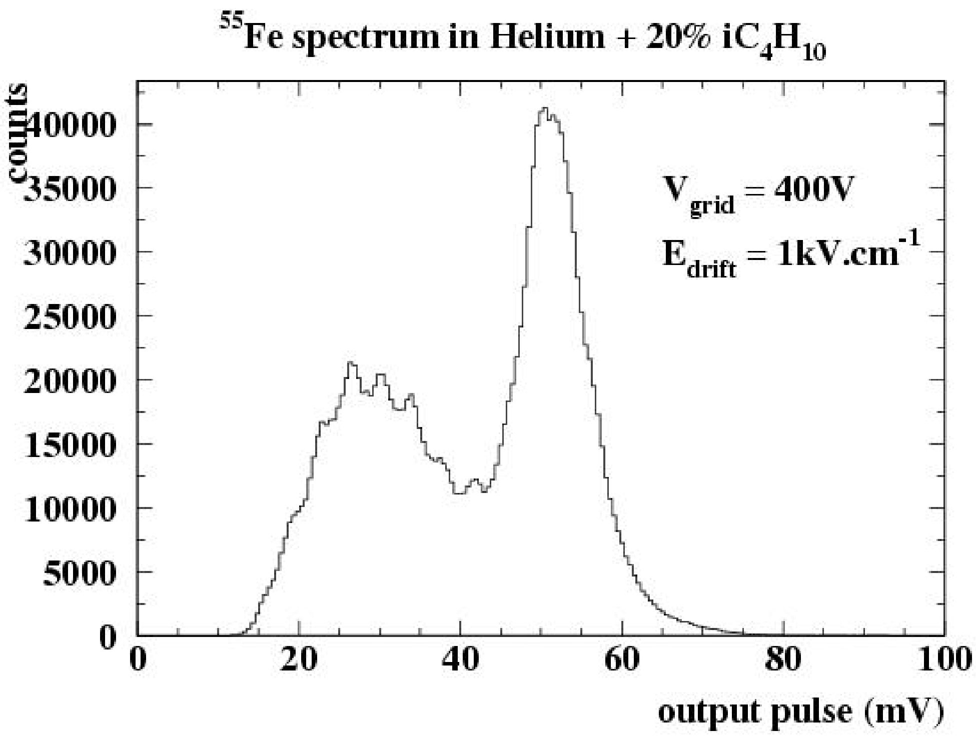
Measuring the InGrid signals

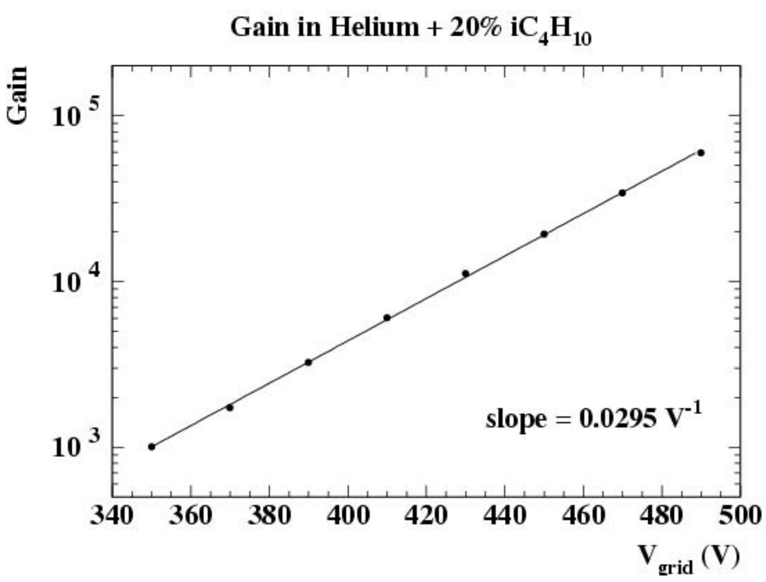
(NIM A556 (2006) 490)



(After 9 months of process tuning and unsuccessful trials)

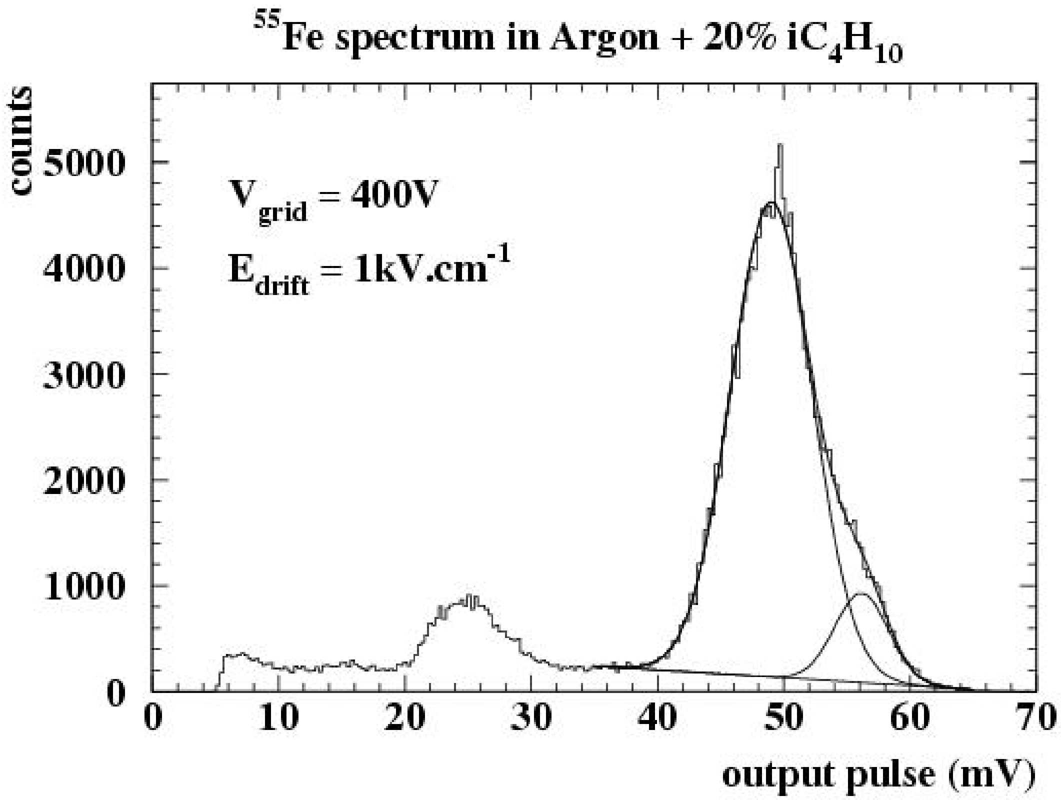
Pulseheight and gain: He + 20% iC_4H_{10}





- Gas gains 10^3 - $6{\cdot}10^4$

Energy resolution in Argon IsoC4H10 80/20

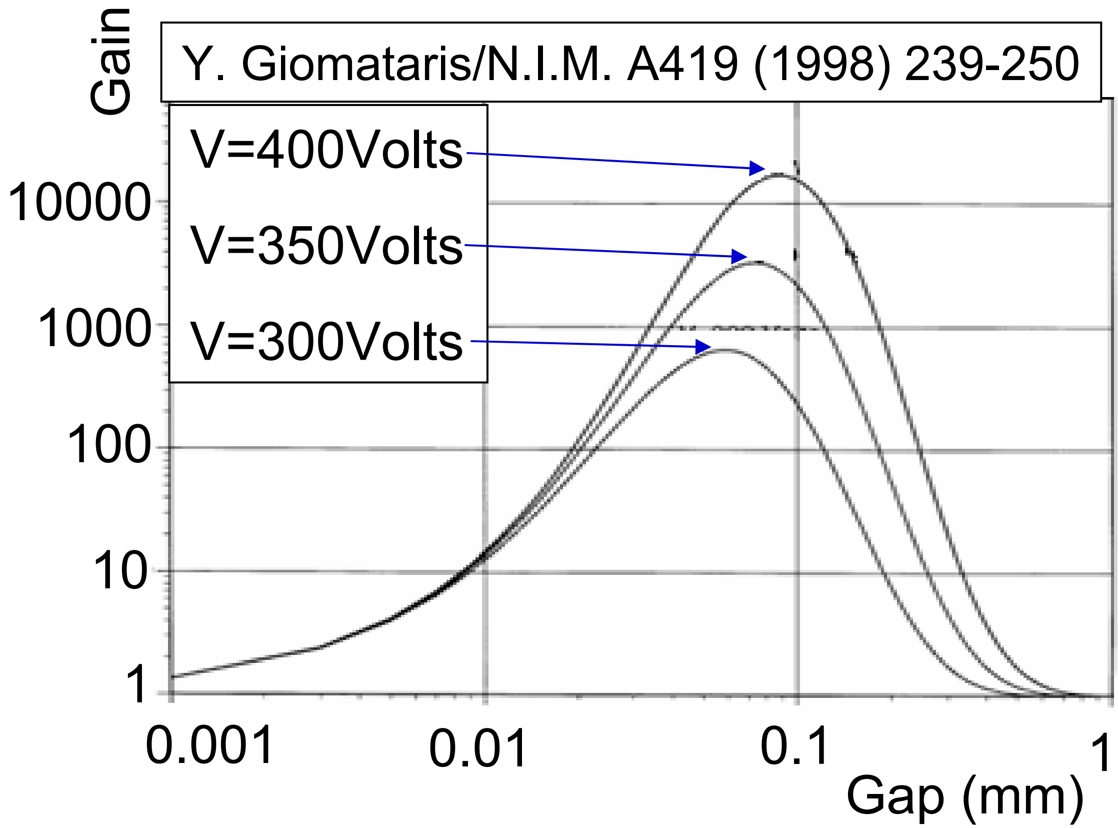


- Observation of two lines:
  - K_α at 5.9 keV
  - K_β at 6.4 keV
- Resolution $\sigma_E/E = 6.5\%$
  - (FWHM = 15.3%)
- Gain variations < ±5%

- Photo peak asymmetry seen
- Very good energy resolution

Gain for different gap sizes

Maximum predicted in gain vs gap curve



$$M = e^{\alpha d}$$

d gap thickness

$$\alpha = pAe^{-Bp/E}$$

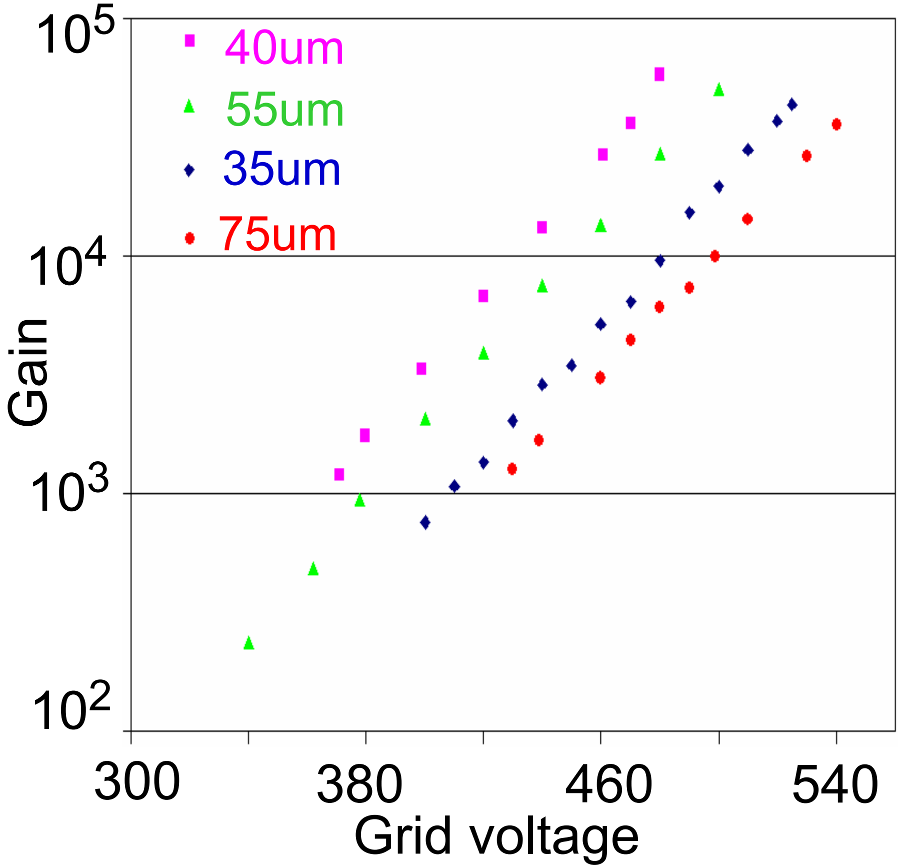
Rose & Korff

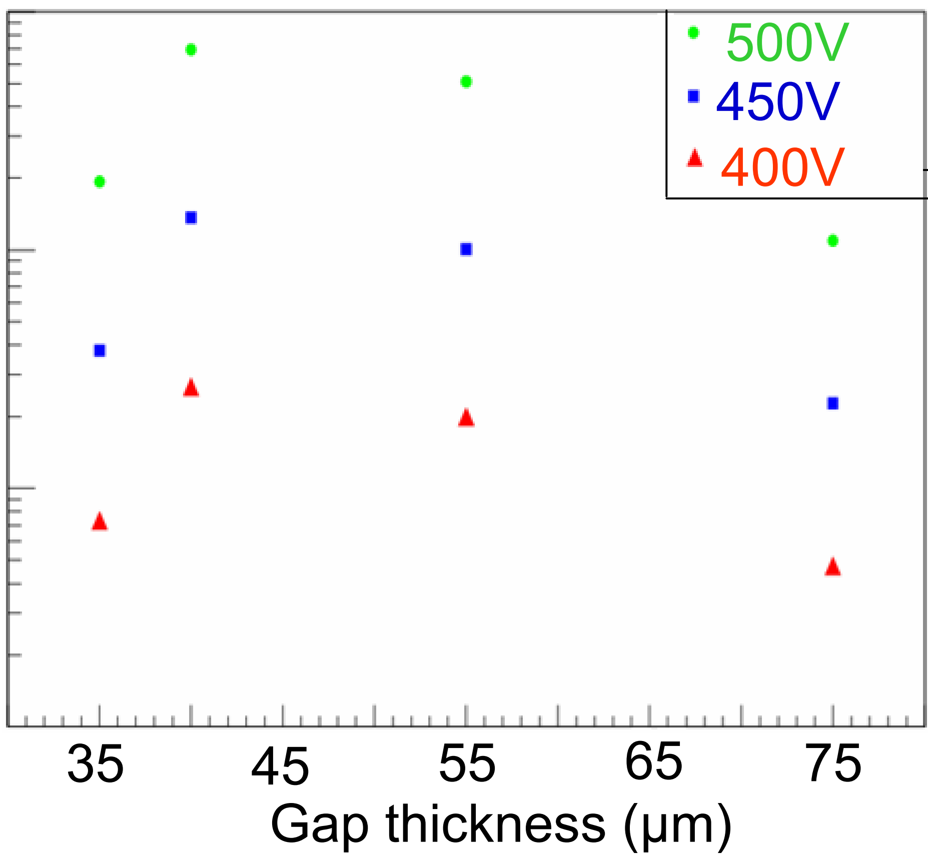
p pressure

A,B depend on gasmixture

Gain for different gap sizes

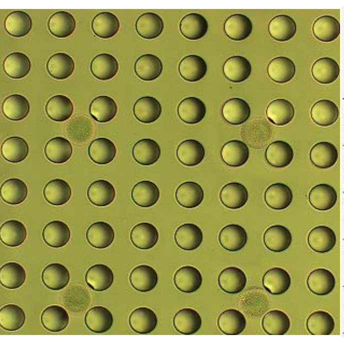
- But now we can make measurements

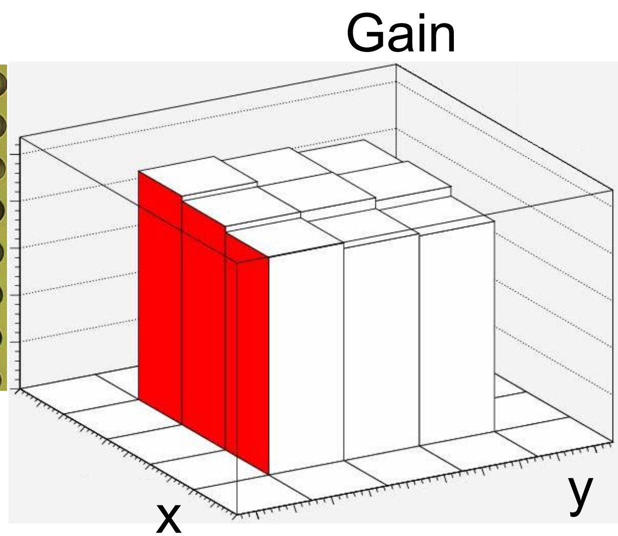




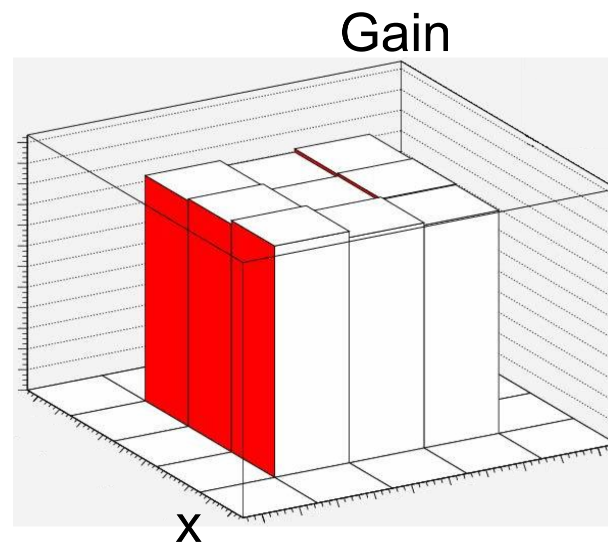
Homogeneity

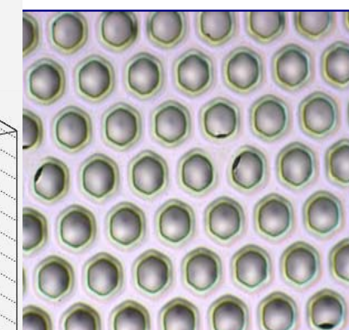
- Gain measurements scanning the surface of the detector
- Homogeneity given by grid quality





2.6 % RMS

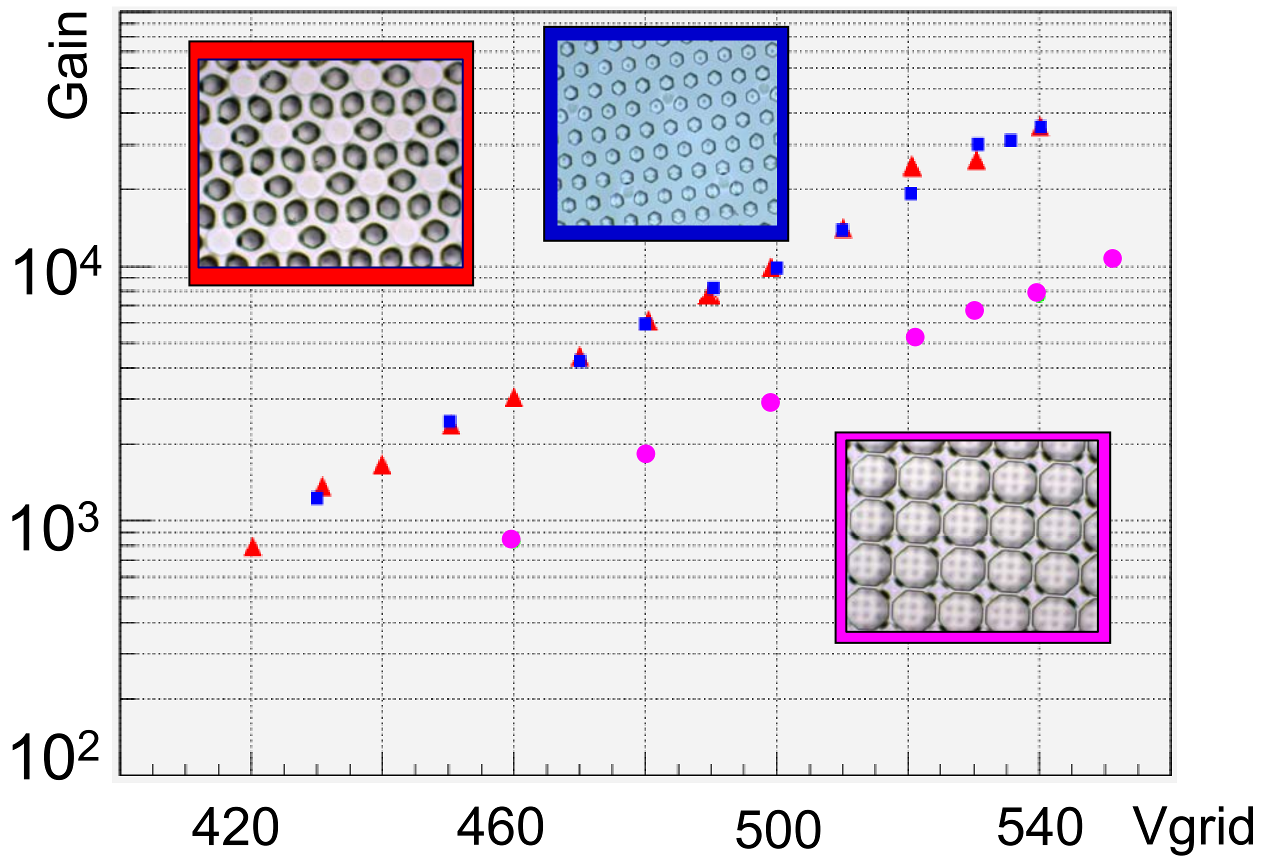




1.6 % RMS

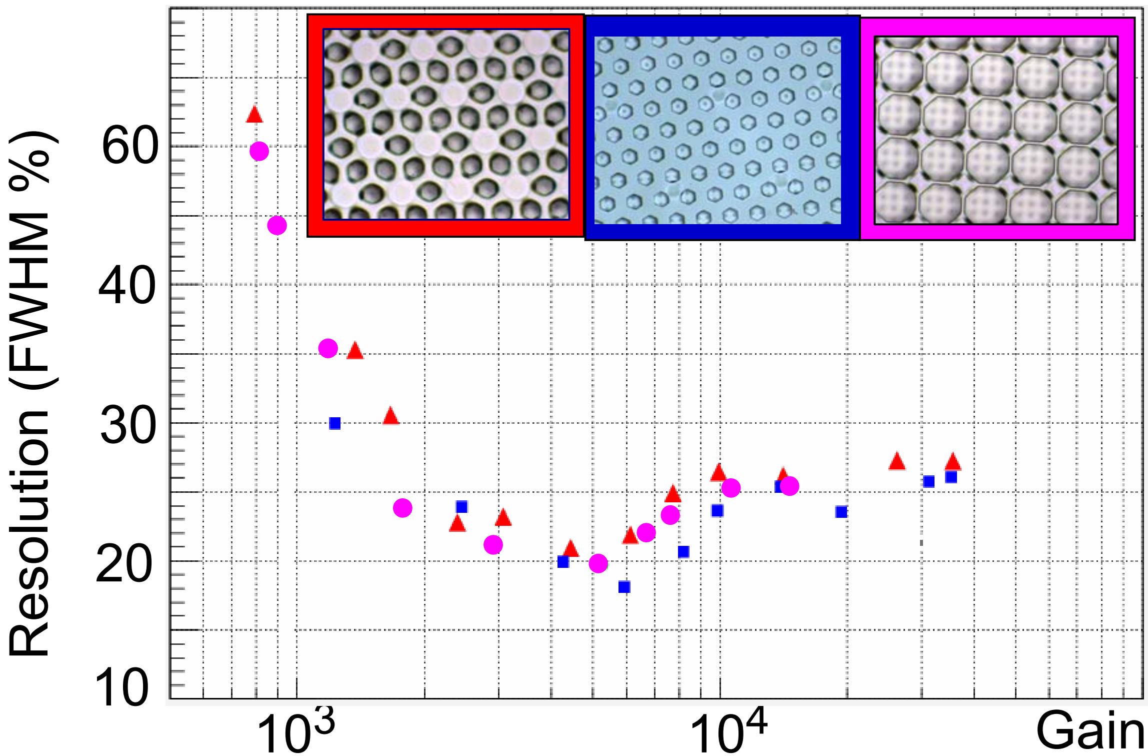
Measured gain for different hole size

And measurements confirm simulations



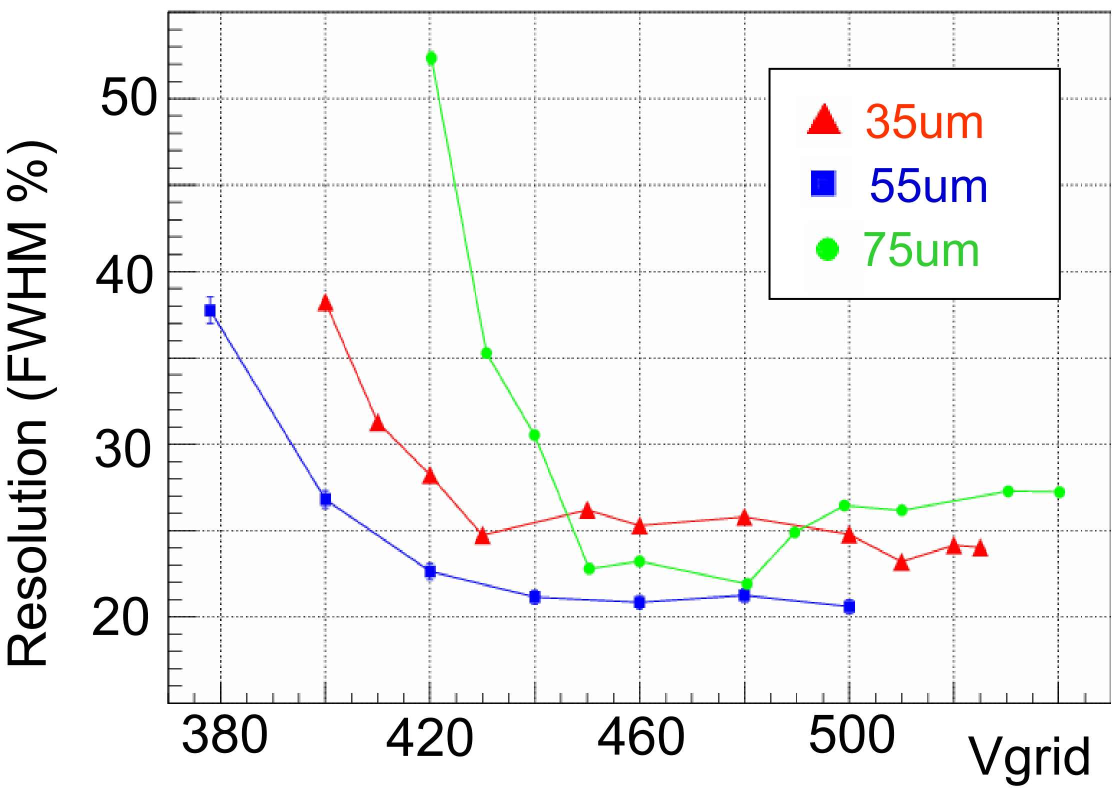
Energy resolution

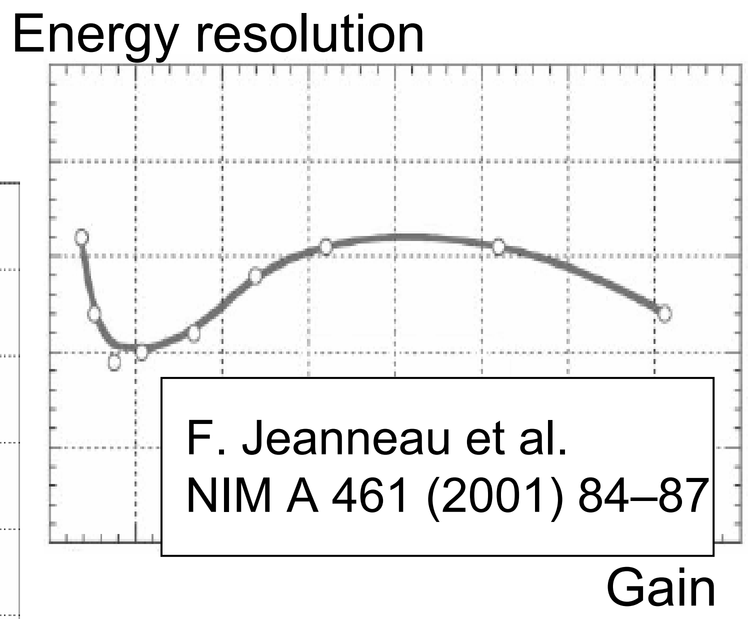
- Resolution depends on
  - Primary,attachment,T,P
  - Collection efficiency (field ratio)
  - Gain homogeneity & transverse diffusion

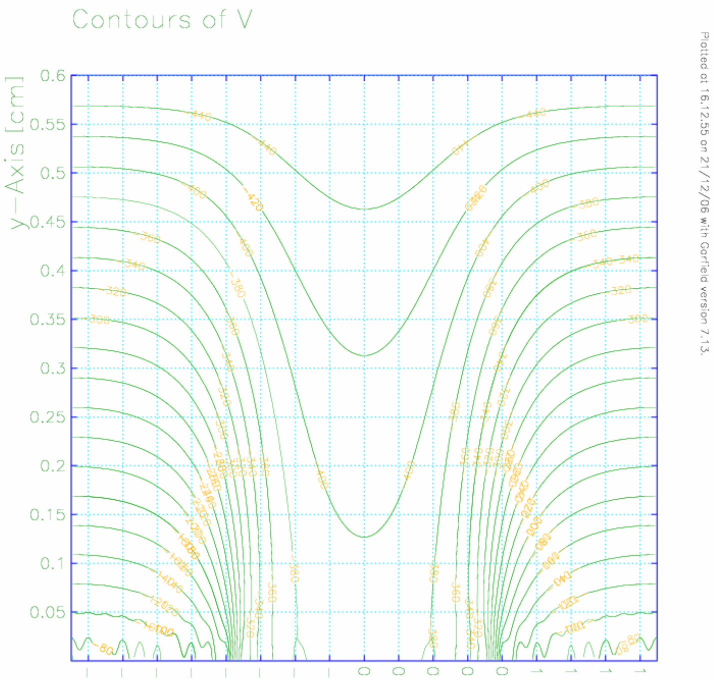


Resolution as function of gap

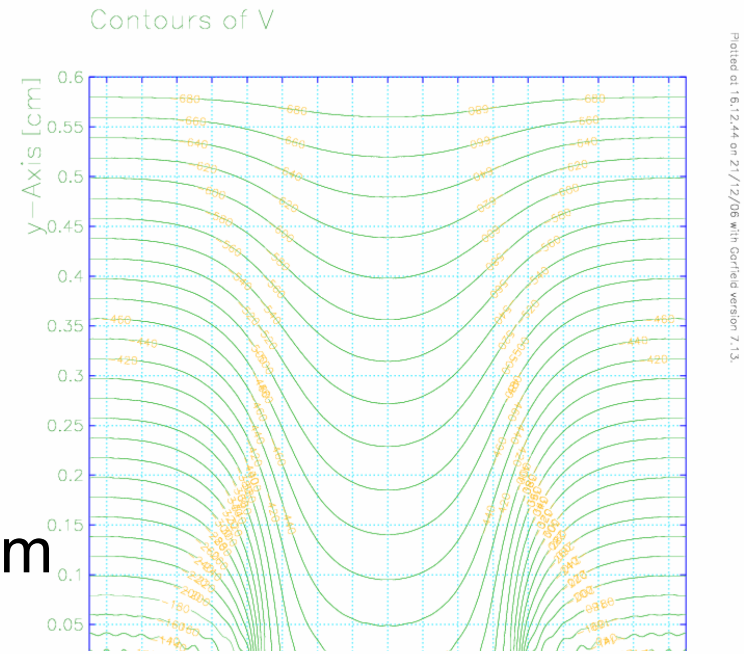
- Why a parabolic behavior ?



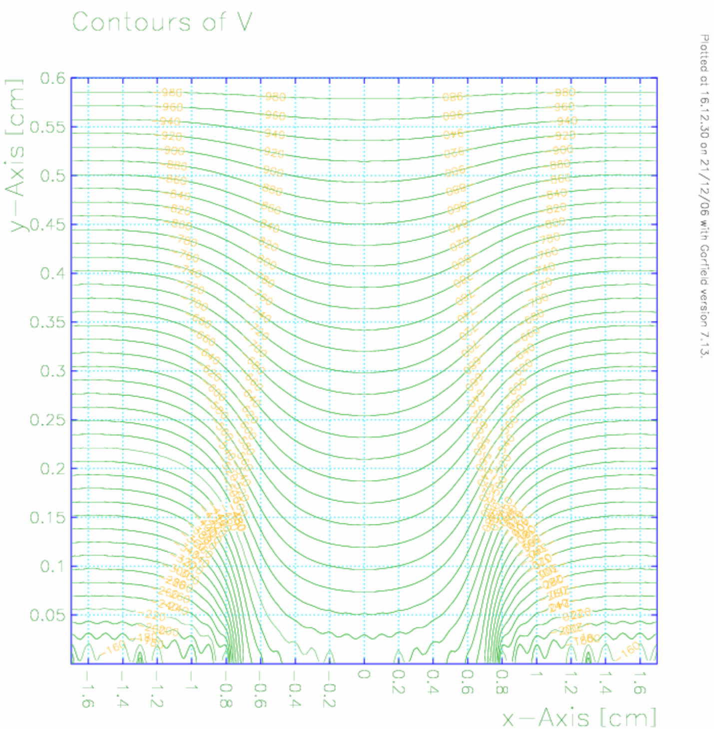




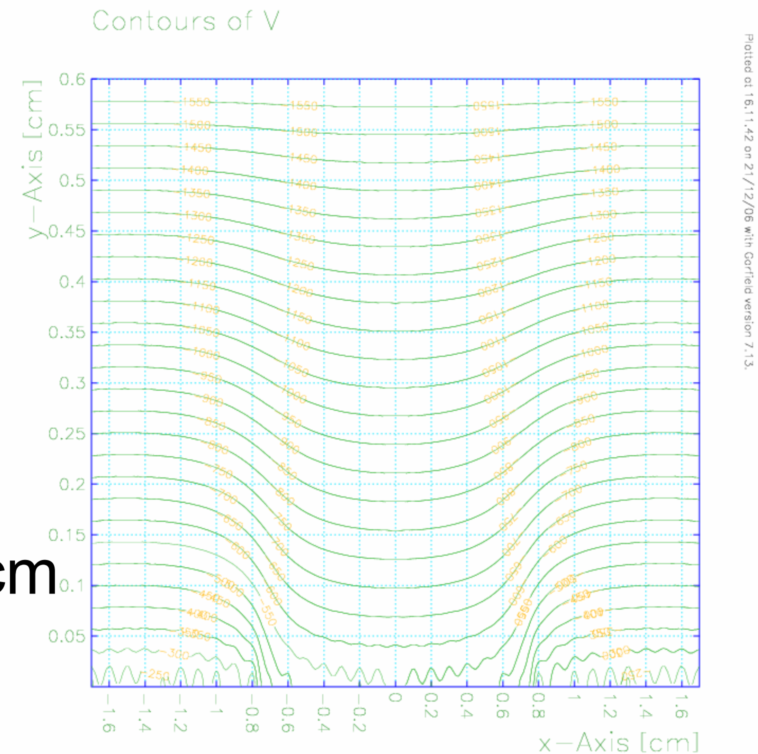
100 V/cm



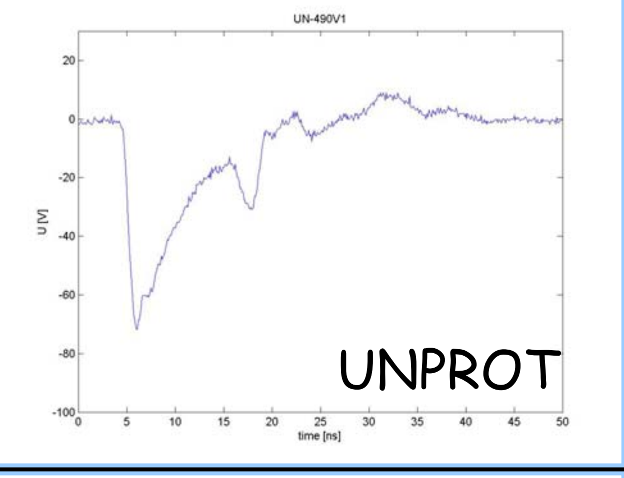
500 V/cm

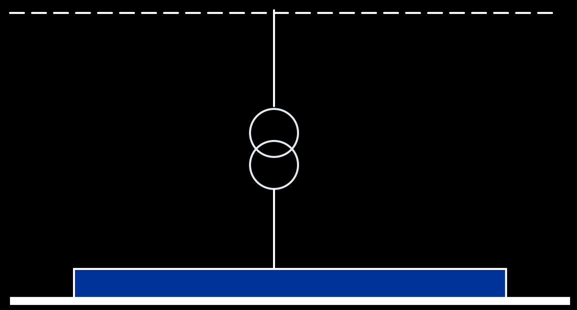


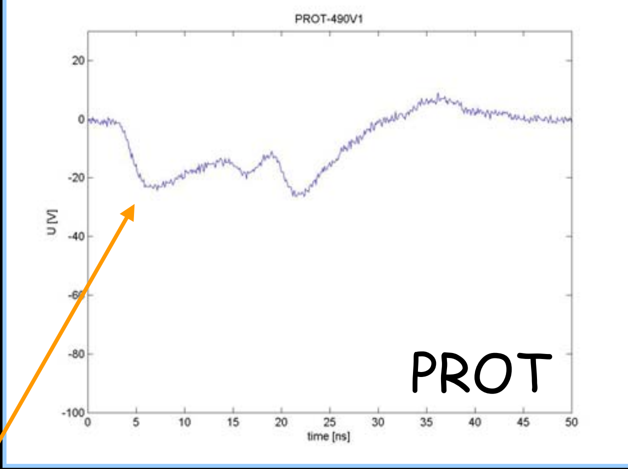
1 kV/cm

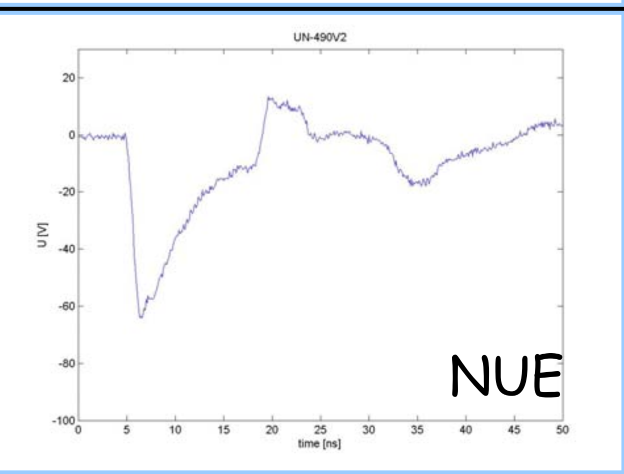


2 kV/cm

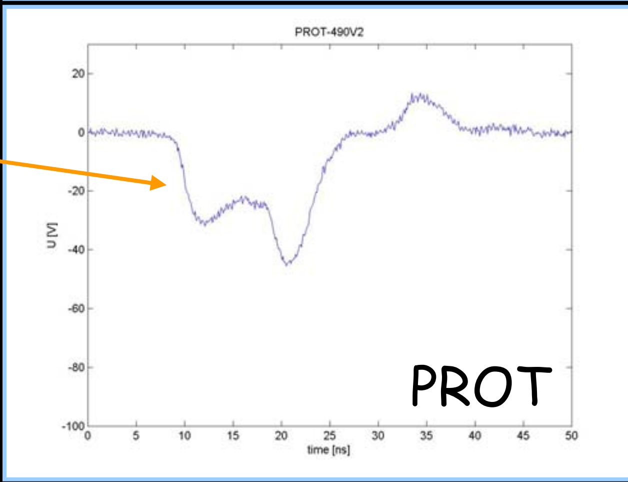




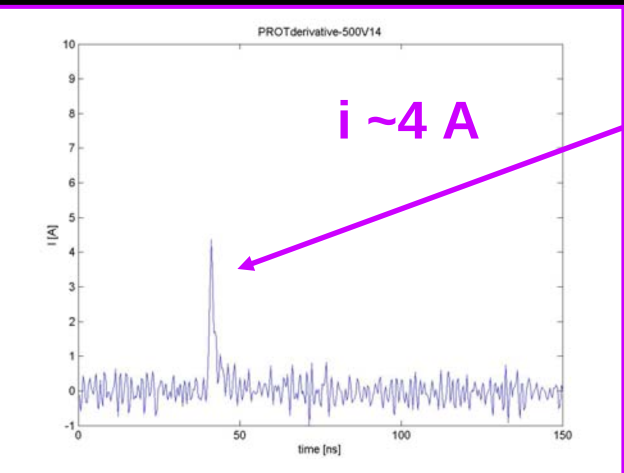


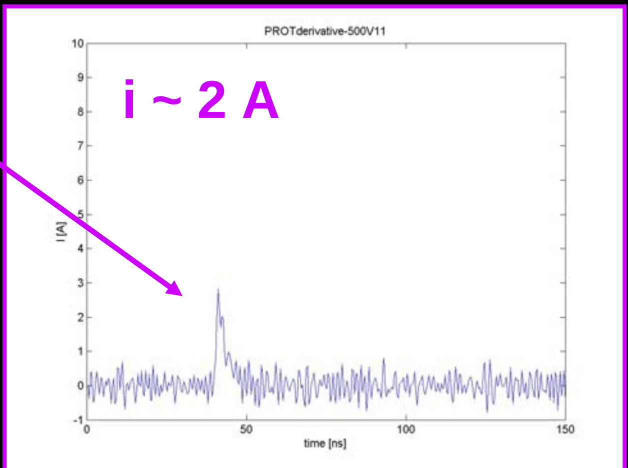


Slope less steep for protected anode



Current reduced





Enough to protect the chip?

TripleGrid