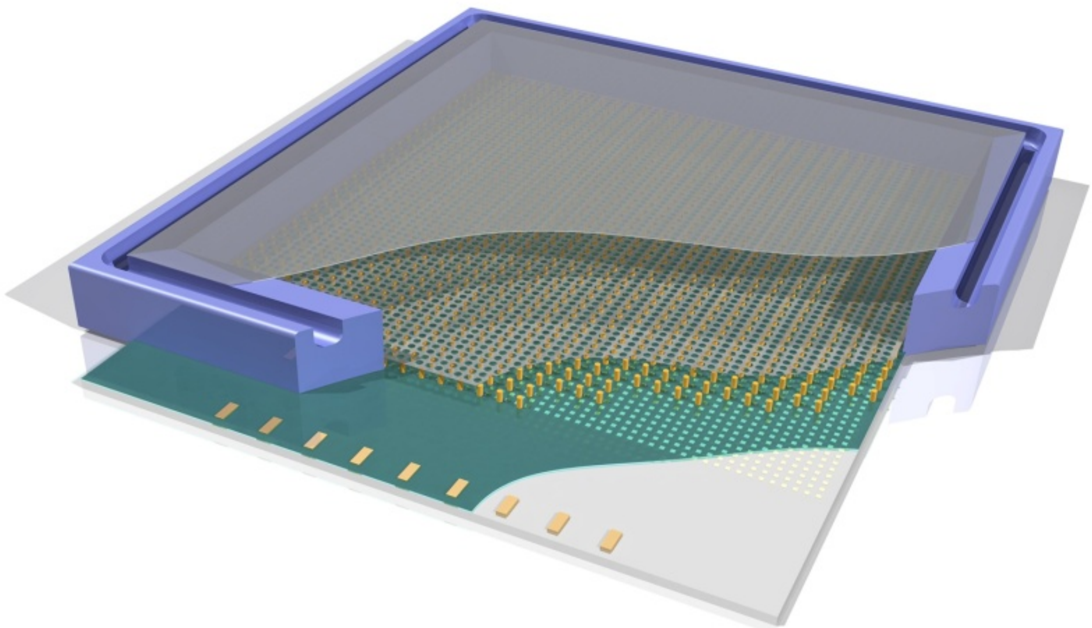
The gaseous pixel detector GOSSIP for the Atlas Inner Detector



Victor Blanco Carballo,Yevgen Bilevych, Martin Fransen, Harry van der Graaf, Fred Hartjes, Wilco Koppert, Michael Rogers, Sander Smits, Rob Veenhof

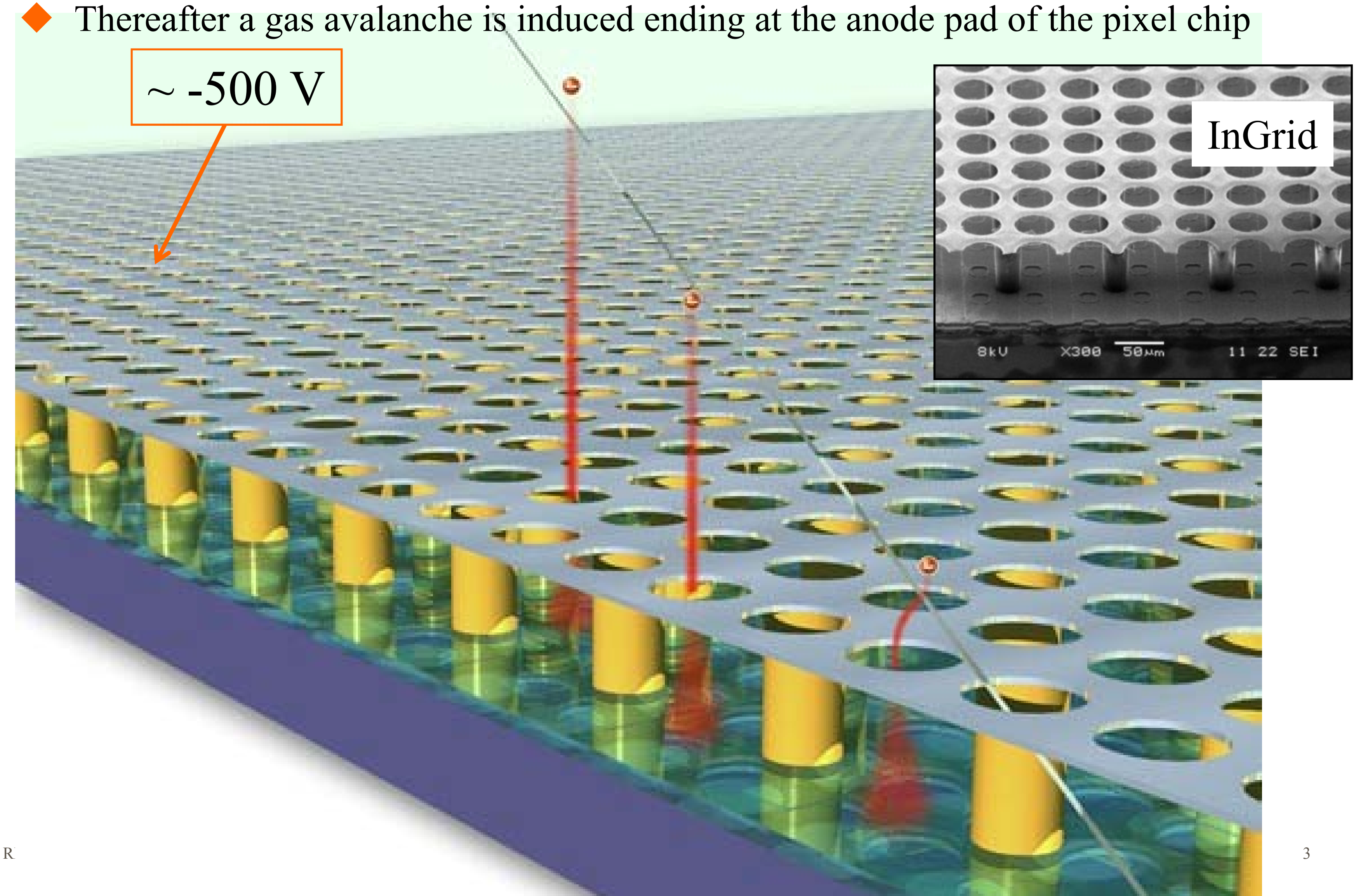
RD51 Collaboration Meeting
Kolympari, Crete, June 16, 2009

Overview

- Introduction of the gaseous detector GridPix/Gossip
  - Functioning of GridPix/Gossip
  - Pros and cons of Gossip
- Aspects on putting Gossip into Atlas Inner Detector for sLHC
- Position resolution simulation
- Electronics
  - Time structure of the charge signal
  - Frontend electronics
  - Prototype tracker
- Mechanical layout Atlas pixel tracker
- Gossip R&D programme
- Summary

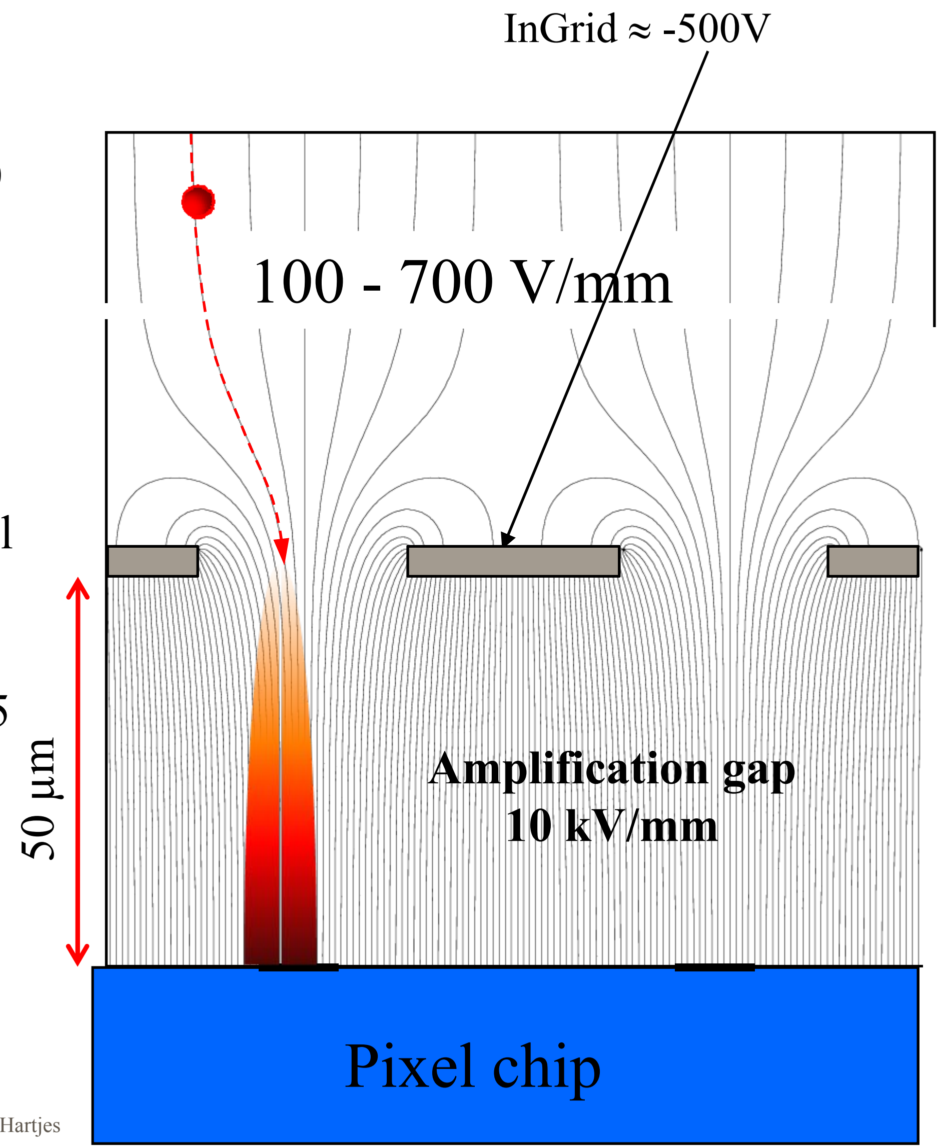
Functioning GridPix/Gossip

- Electron from traversing particle drifts towards Micromegas grid and is focused into one of the holes
- Thereafter a gas avalanche is induced ending at the anode pad of the pixel chip



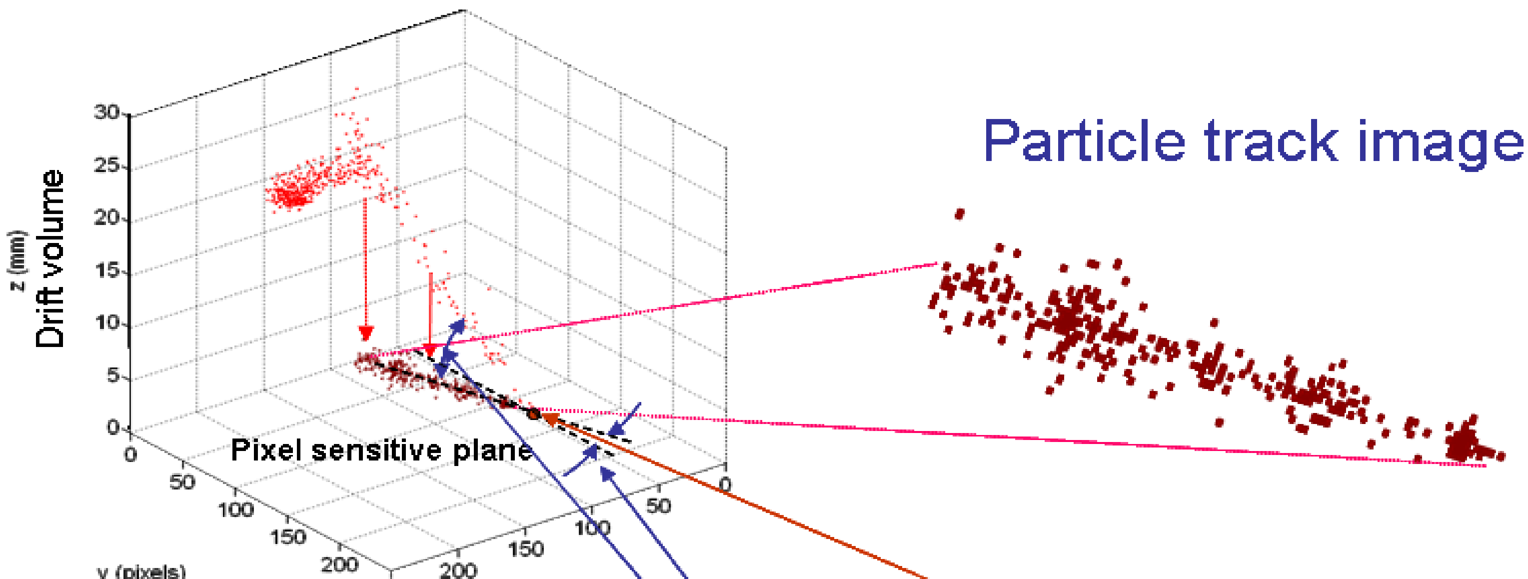
Field configuration of GridPix/Gossip

- Comparatively low drift field (100 -700 V/mm)
- High amplification field (~ 10 kV/mm) to induce gas avalanche
- Micromegas holes centred on pads pixel chip
- Avalanche broadened by diffusion to 15 – 20 μm



Operation of Gossip/GridPix

- Track reconstructed from projected ionisation on the pixel plane



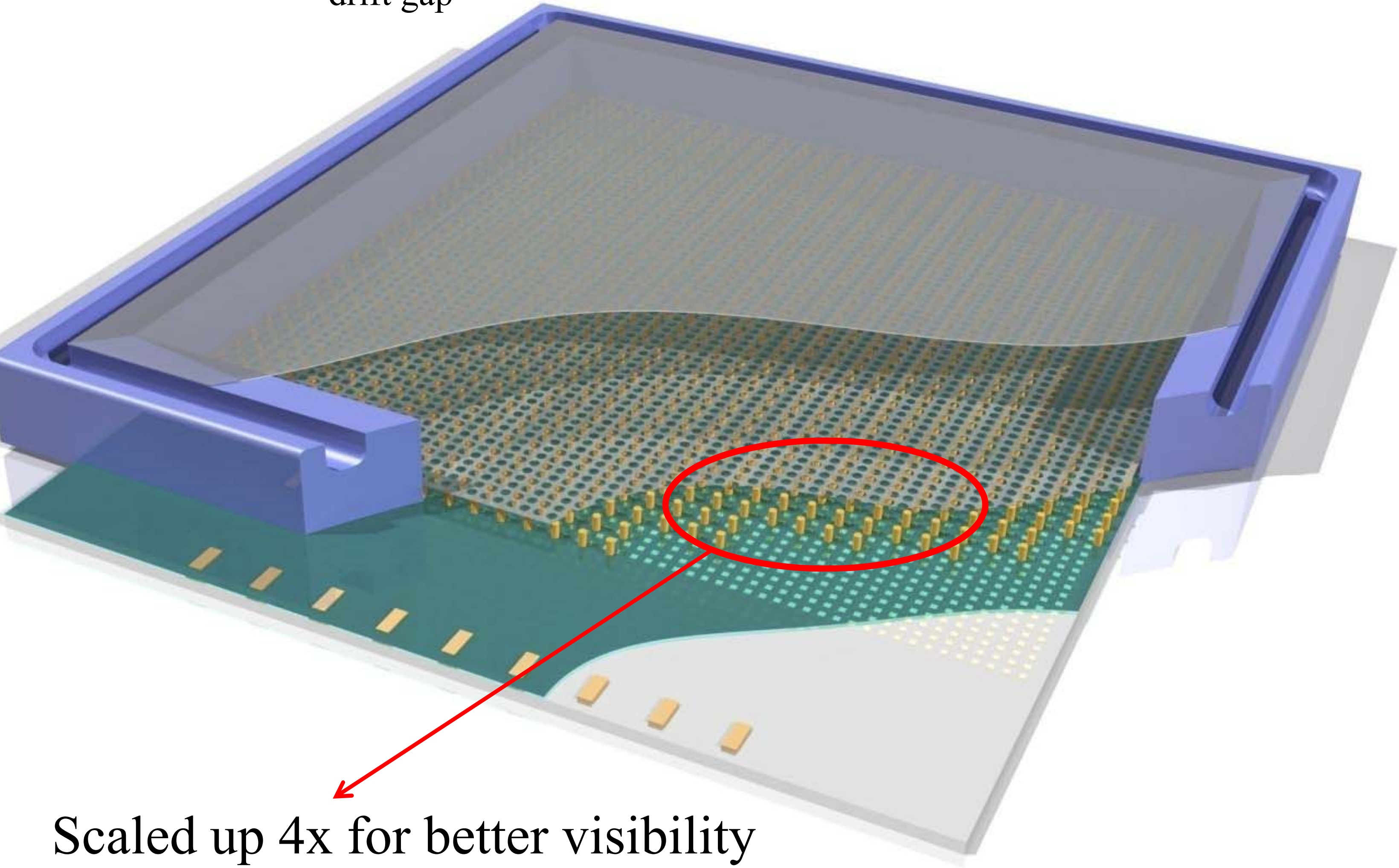
Space point and two angles are measured:

θ = angle **in** pixel plane

φ = angle **to** pixel plane

Gossip vs GridPix

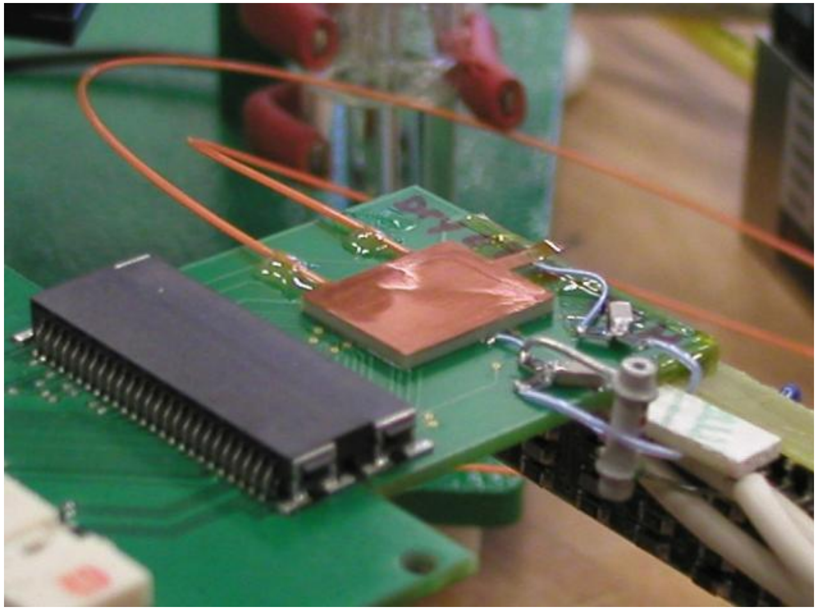
- GOSSIP is a speciality of GridPix
  - Minimal drift gap (1.0 - 1.2 mm) for short collection time
  - Actual value determined by cluster density and efficiency demand
  - 1 mm gap and DME/CO_2 => 98.9% chance on having at least **one** cluster in the drift gap



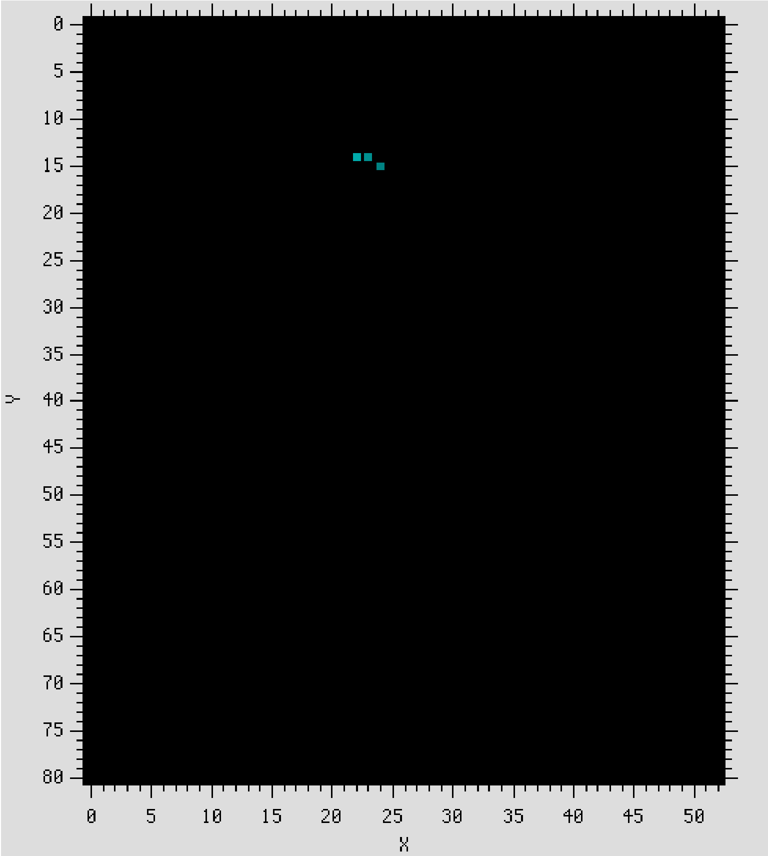
Scaled up 4x for better visibility

Demonstration functional Gossip

- Using PSI 46
  - CMS pixel FE chip
  - 50 x 150 μm pixels
- Gas gap 1.2 mm
- Gas: Ar/iC_4H_{10} 85/15
- Protected by 30 μm aSi



Hits from ^{90}Sr electron tracks
Scintillator triggered



7.8 x 8.0 mm

Replacing silicon technology in Atlas ID with Gossip detectors brings a number of crucial benefits

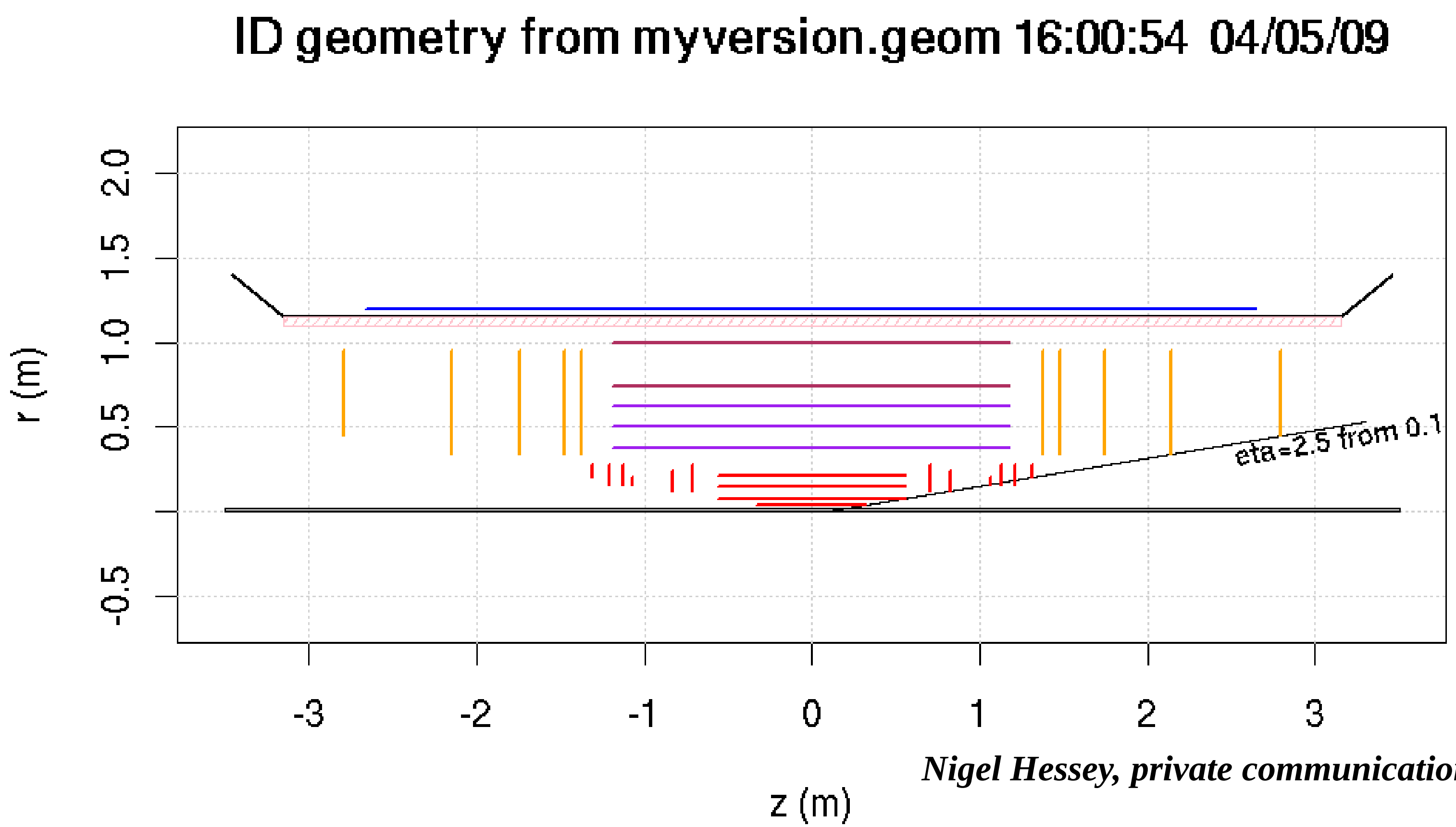
- Outlook for extremely high radiation tolerance (>> 10^{16} MIPS/cm^2)
  - By far exceeding the range of any solid state detector
- Almost insensitive for neutrons and hard X-rays
- No bias current, only signal current
  - BL @ sLHC: 3.5 μA/cm^2 @ 0.9 GHz/cm^2 (~30 pA/pixel of 55 x 55 μm)
  - → low power dissipation (2 μW/pixel)
- Operation at wide temperature range, relaxed cooling requirements
- → reduced material budget: 1.25 % estimated (services and support **included**)
- No bump bonding → major cost reduction
- No additional input capacity → very low threshold possible (350 e^-)

But everything has its drawbacks

- Additional services required
  - Gas pipes (may be thin: 0.8 mm or even 0.4 mm)
  - 2nd high voltage line for drift field (no critical regulation)
- Lower position resolution than is possible with solid state detectors
  - Limited ionization statistics (about 5 to 10 e^- , could be less)
  - Diffusion in the drift gap
  - → resolution does not quite meet the B-layer requirements (< 10 μm)
  - more layers needed, more data channels needed
- Critical regulation of grid voltage
  - Variation 30 V → factor 2 in gain
  - Many HV channels needed → local low power HV PS needed
- Tendency to sparking
  - Rate induced sparking, under investigation
  - FE chip should be made spark proof → problem basically solved
- Long charge collection time (30 – 70 ns, to be investigated)
- Risk on accelerated ageing (can be minimized)

Inner detector layout in phase II of sLHC upgrade (10^{35} $cm^{-2}s^{-1}$)

- Baseline layout
  - 2 long strip layers
  - 3 short strip layers
  - 3 pixel layers
  - 1 B-layer (pixel layer 0)



Nigel Hessey, private communication, June 3, 2009

Fluences for subdetectors after 3000 fb^{-1} (1 MeV n_{eq} cm^{-2})

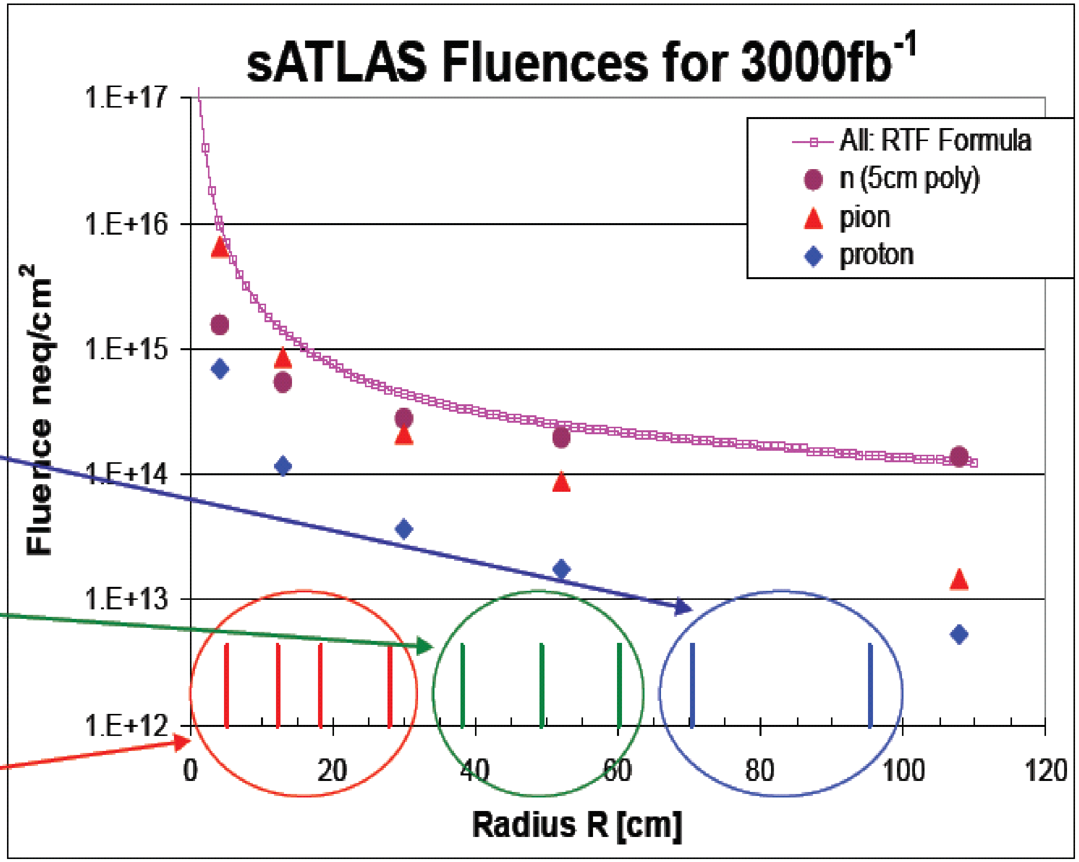
- Long strips: ~ 1.5 $*10^{14}$
- Short strips: 2 – 3 $*10^{14}$
- Pixels: 0.6 – 8 $*10^{15}$ **(omitting B-layer)**

Strip length and segmentation determined by occupancy< 2%

Long Strips

Short Strips

Pixels



Mix of neutrons, protons, pions depending on radius R

Long and short strips damage largely due to neutrons

Pixels damage due to neutrons and pions

ATLAS Radiation Taskforce http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/RADIATION/RadiationTF_document.html

Fluence for the B-layer at sLHC in phase II

- R = 37 mm

- Dose
  - At b-layer radiative dose is dominated by direct tracks
  - Assume 3000 fb^{-1} data * safety factor 2 * 79 mb pp Xsec * 6.3 tracks/η /interaction
  - → **$3*10^{17}$ tracks/η** (mostly pions)#
  - At R = 37 mm, 1 cm is 0.269 units of η and 0.268 units of ϕ out of 2π
  - → at R = 37 mm we get **$3.4*10^{16}$ charged particles/cm^2**
    - (Damage factor ~0.6 for pions → **$2.0*10^{16}$ n_{eq}/cm^2** relevant for Si)#

Corresponds to 9.5 * 10^6 Gy (950 Mrad)

- Rate
  - **0.9 GHz/cm^2 for 25ns sLHC**

Data from Atlas experts (Craig Buttar, Ian Dawson and Nigel Hessey)

Radiation tolerance of Gossip

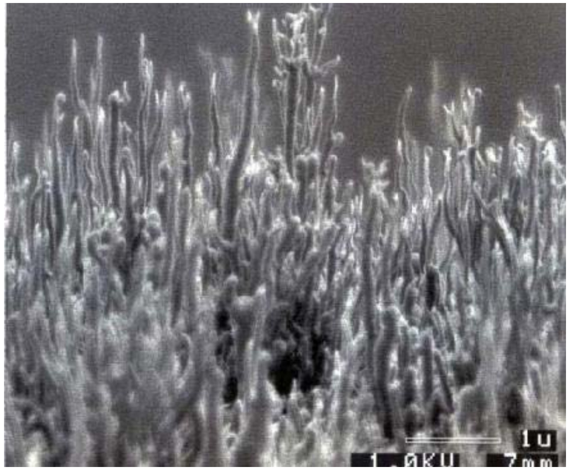
- No ageing of detecting medium (gas)

but

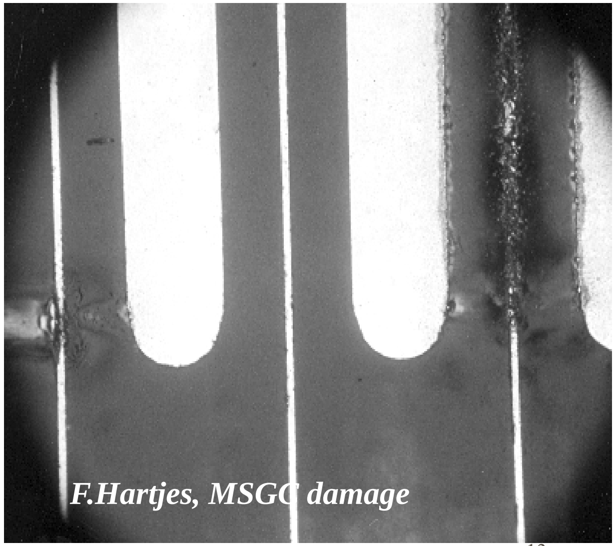
- Most important: **deposit** on anode surface caused by the avalanche
  - May be thin insulating layer (polymer)
  - Loss of gain due to voltage drop across the deposited layer (rate dependent)
  - Effect in first order proportional to collected charge
  - → figure of merit of gaseous detector ageing is **collected charge per unit of anode surface**

- Other ageing effects
  - Electrode damage from sparking
    - Can be prevented using resistive materials
  - Ageing of construction materials
    - Addressed in generic studies by RD51 using X-rays

SILICON FILAMENTS ON AGED ANODE WIRES:



M. Binkley et al, Nucl. Instr. and Meth.A515(2003)53



Working point for present studies

- **Chamber gas**: DME/CO_2 50/50
  - Low, constant mobility, even at high drift fields
  - → low Lorenz angle (~9° at B = 2 T)
  - High primary ionization (45 clusters/cm)
  - Excellent quencher (UV absorption, preventing sparks)
  - Low diffusion (σ = 100 μm/√cm)
- **Gas gain** 5000 - 10000
  - → good Z resolution (slew rate)
  - Optimal hit efficiency
  - Gain of 5000 challenging at B-layer!!!
- **Drift gap** 1 mm
  - → theoretical hit efficiency 98.9%
  - → minimal ballistic deficit
- **Drift field** 7 kV/cm
  - → good drift velocity, short drift time even for this low mobility gas

Target dose values for Gossip

- Expressing dose as **charge per cm^2** (rather than **n_{eq}/cm^2**)
  - Assume
    - Gas gain = 5000
    - 12.6 e^- average ionization across 1.0 mm (DME/CO_2 50/50)
  - → 1 MIP => 10 fC
  - → sLHC BL dose of 3.4×10^{16} MIPs/cm^2 translates into **342 C/cm^2**
- Comparison to numbers for wire chambers
  - Assume sense wire Ø 20 µm
- **342 C/cm^2 ↔ 2.1 C/cm**

Fair number for wire chambers

Well possible if **outgassing** elements are avoided

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]*

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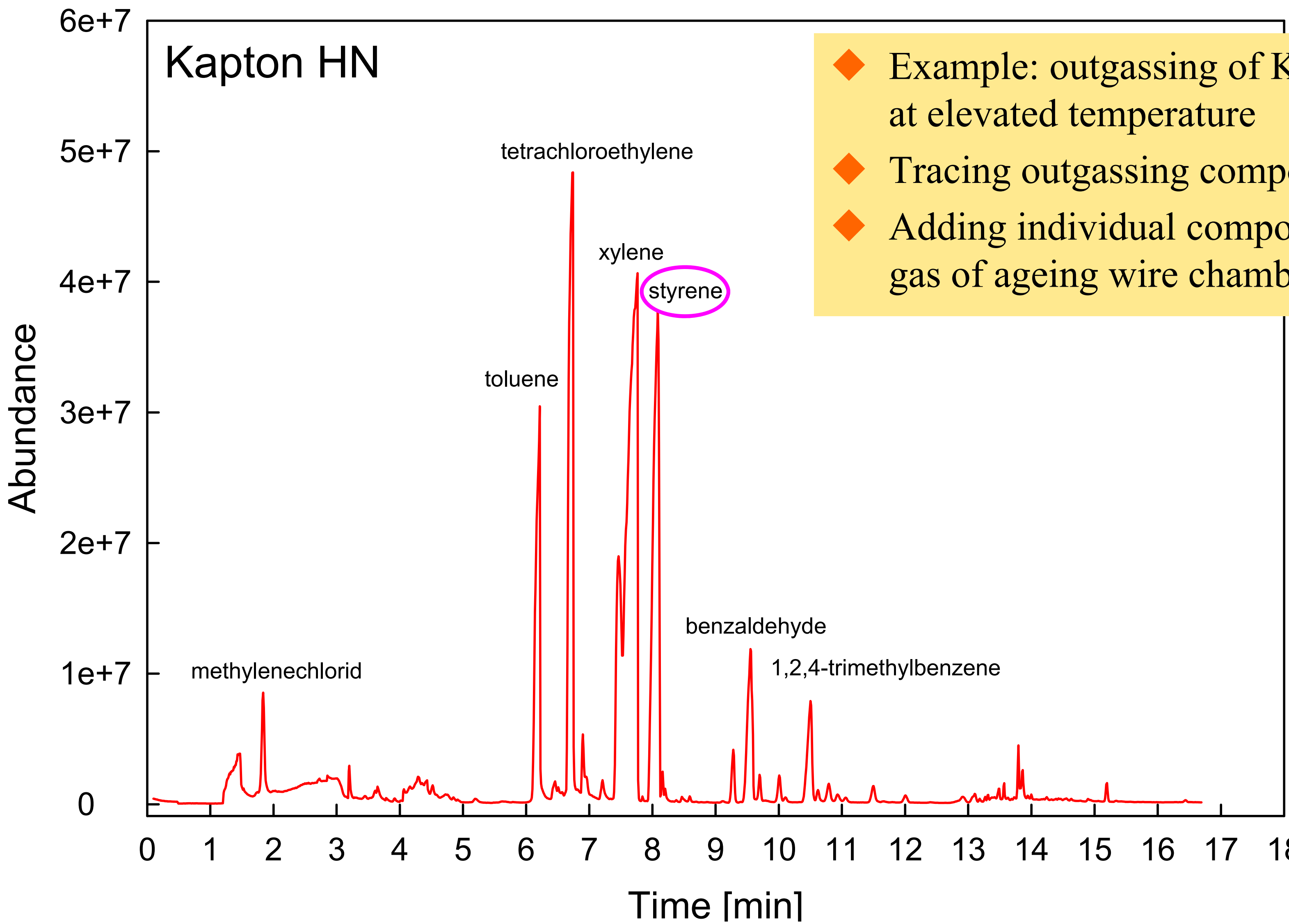
[d]Metorex International Oy, P.O.Box 85, FIN-02631 Espoo, Finland

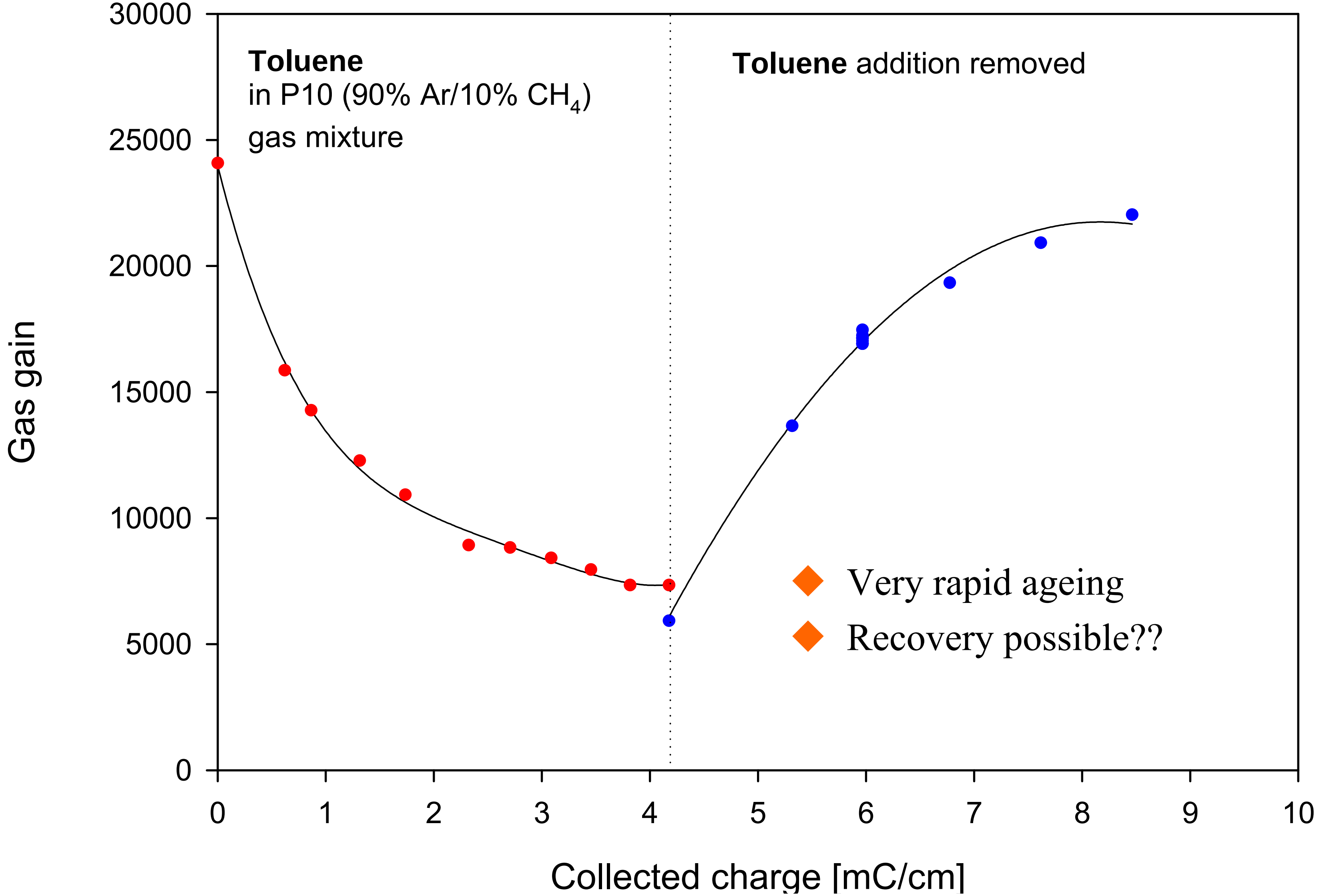
based on talks given in NSS 2003 and NSS2004 symposium
(see conf.CDs and IEEE Trans. on Nucl. Sci 51 No.5, 2004)

Ageing by impurities from outgassing



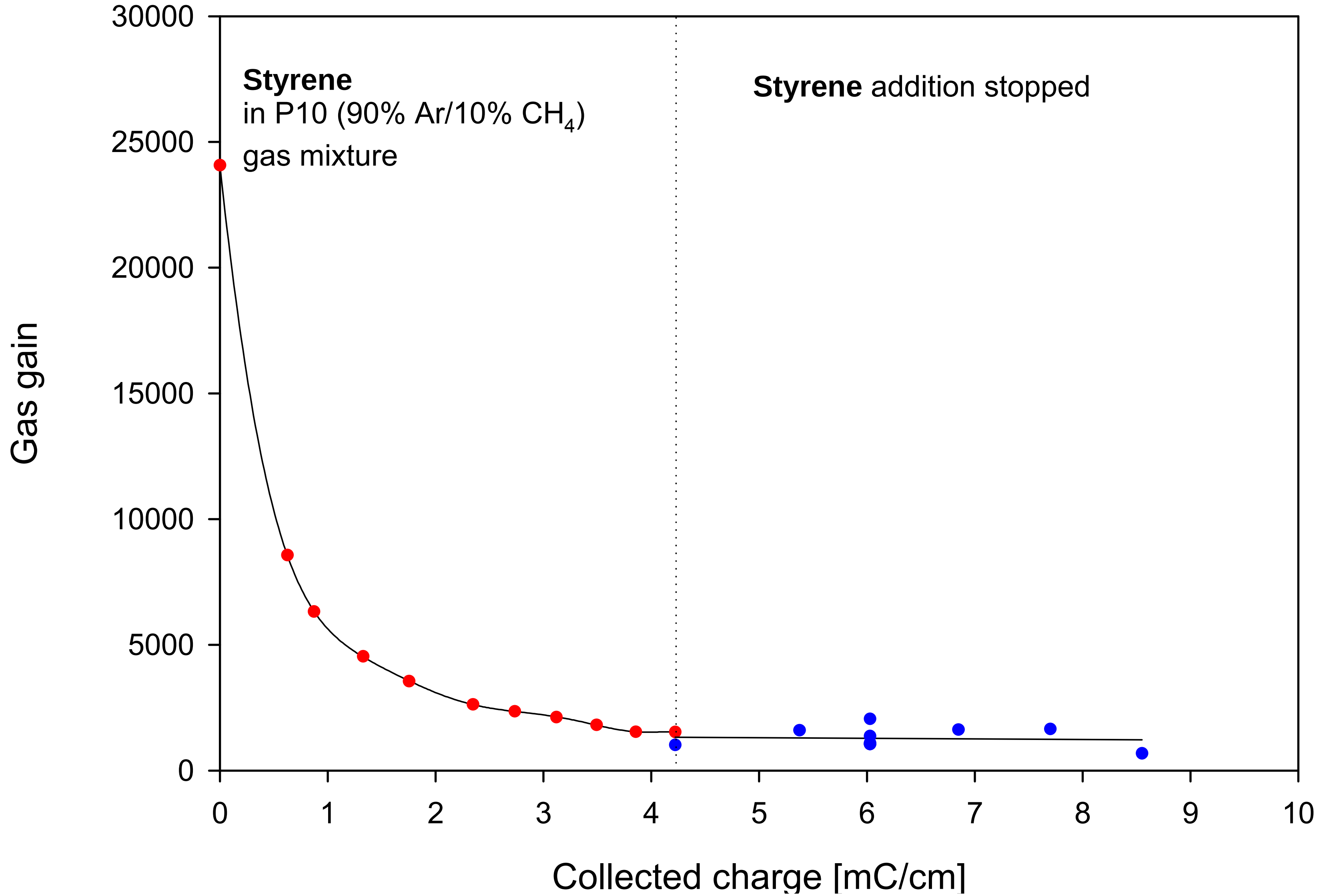
- Example: outgassing of Kapton at elevated temperature
- Tracing outgassing compounds
- Adding individual compounds to gas of ageing wire chamber

Ageing test using wire chamber



- Very rapid ageing
- Recovery possible??

Recovery for most agents, but not for styrene!



Outlook outgassing studies

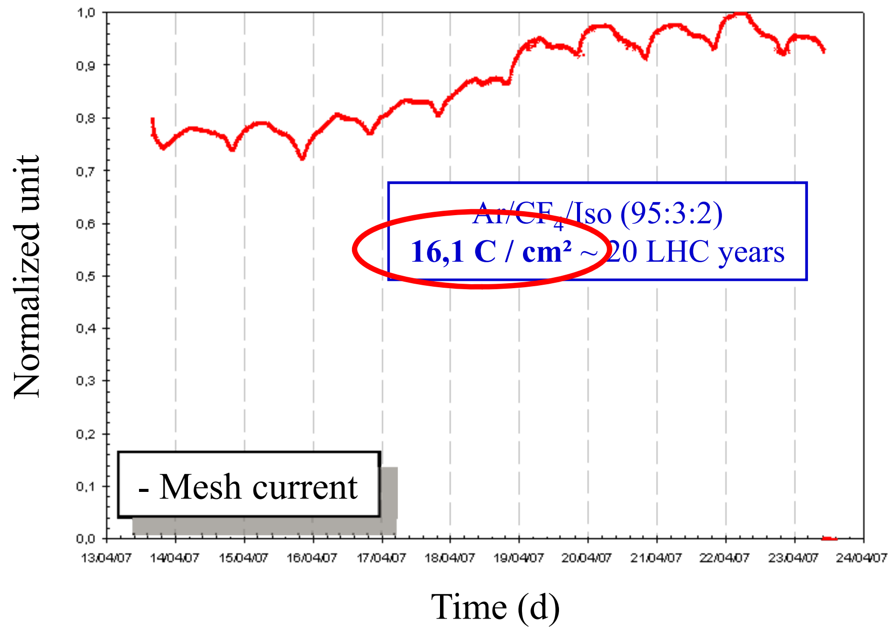
- Still many possible rapid ageing compounds to be investigated
  - But investigation in Helsinki stopped

- Study doesn’t answer the slow ageing from inorganic deposits (carbon whiskers, silicon)

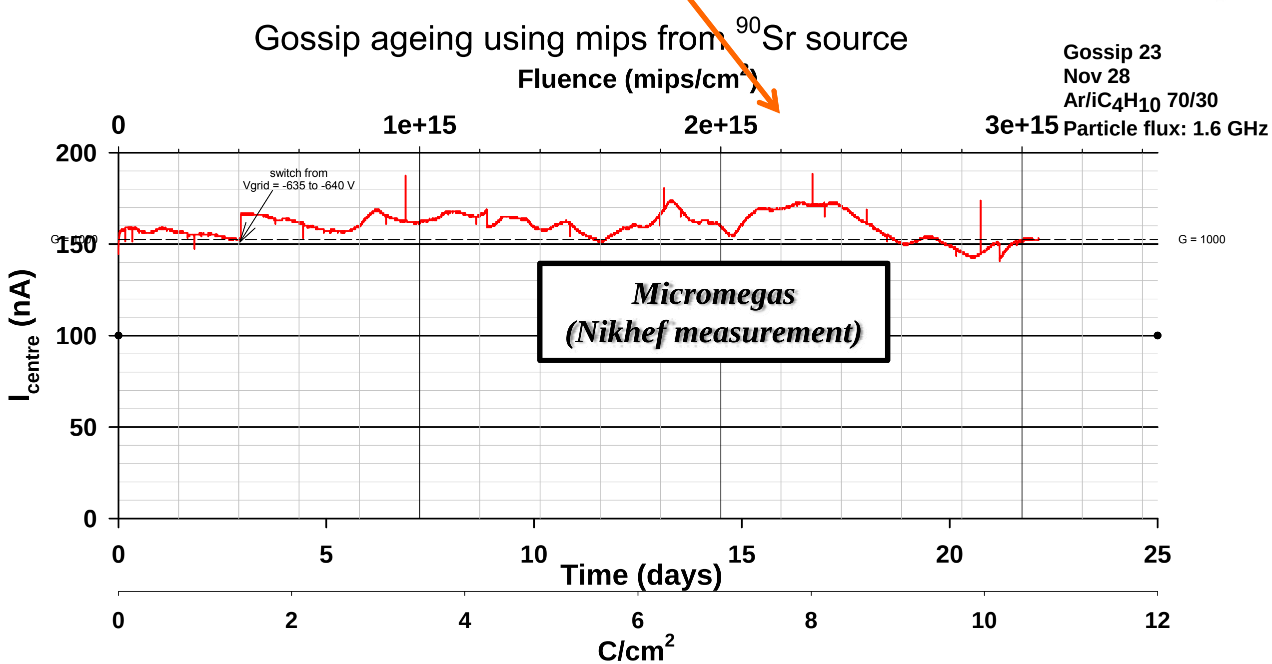
- To cope with ageing best approach is doing many ageing studies in advance
    - Different setups
    - Different sites
  - Use as clean as possible materials for the detector and the gas system
    - Avoid ~~epoxies~~

Experimental results using Micromegas based detectors

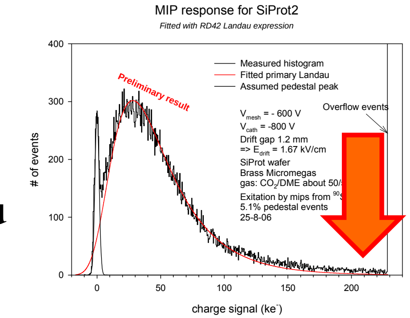
- 16.1 C/cm^2 obtained so far
  - Non-clean gas system
  - Epoxies used (Araldite)
  - measurement terminated because of sparking
- **Goal: 342 C/cm^2**



David Attié, MPGD workshop CERN Sept. 2007



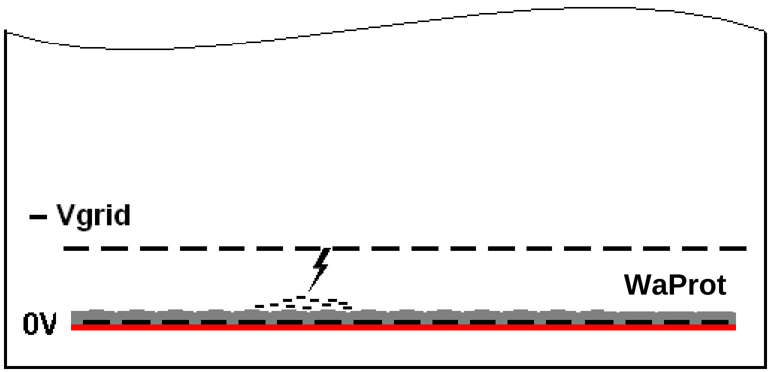
Spark protection

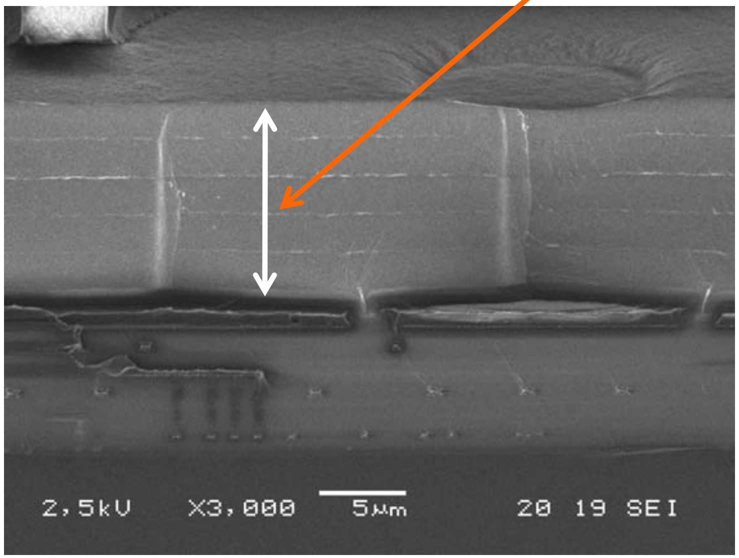


- Always needed for gaseous detectors
  - Spark induced by dense ionisation cluster from the tail of the Landau
  - Unprotected pixel chip rapidly killed by discharges

5 layers of 1.4 µm Si_3N_4

- WaProt: 7µm thick layer of **Si_3N_4** on anode pads of pixel chip
  - Normal operation: avalanche charge capacitively coupled to input pad
  - At spark: discharge rapidly arrested because of rising voltage drop across the WaProt layer

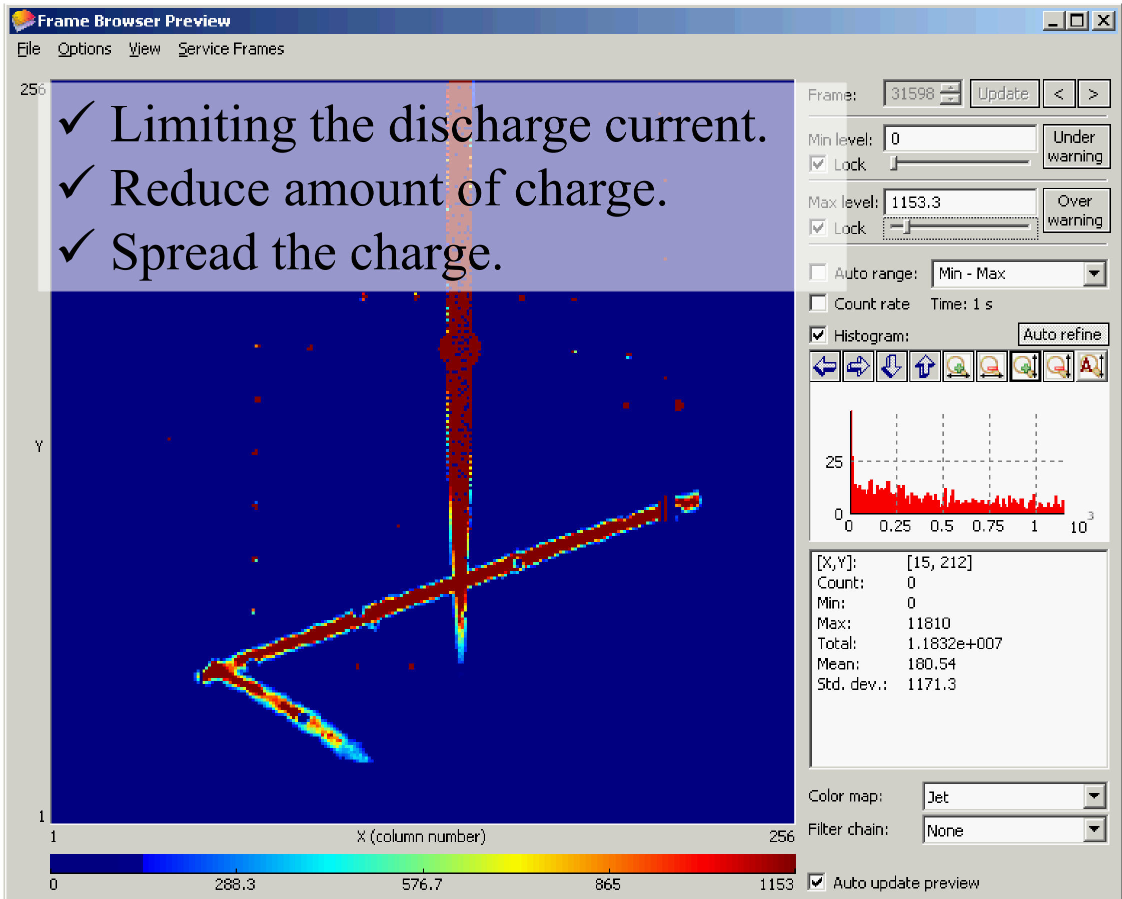




  - Conductivity of WaProt tuned by Si doping
  - For sLHC BL we should not exceed $1.6*10^9$ Ωcm (10 V voltage drop)
  - Has proven to give excellent protection against discharges

Testing WaProt using alphas

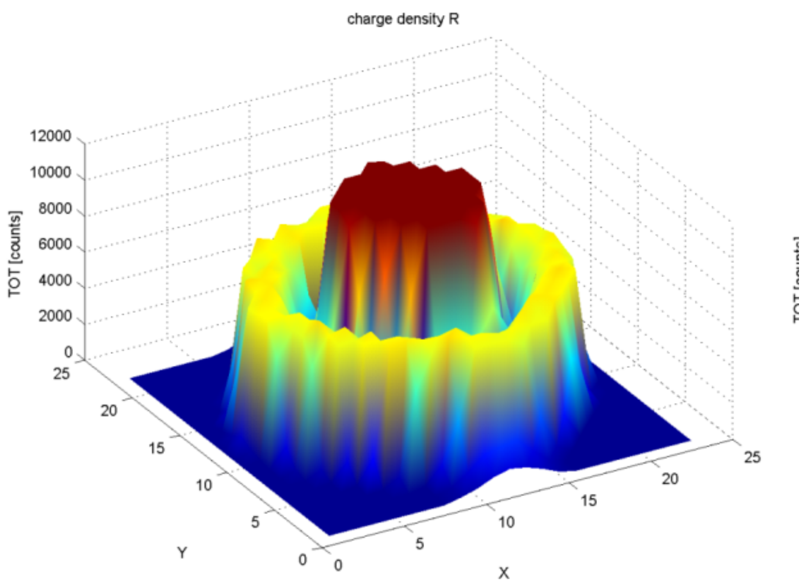
- α tracks having high primary ionisation → exceeding Raether limit of 10^8 e^- in the avalanche



Pixelman software: IEAP, Prague

Details of the current distribution on a discharge

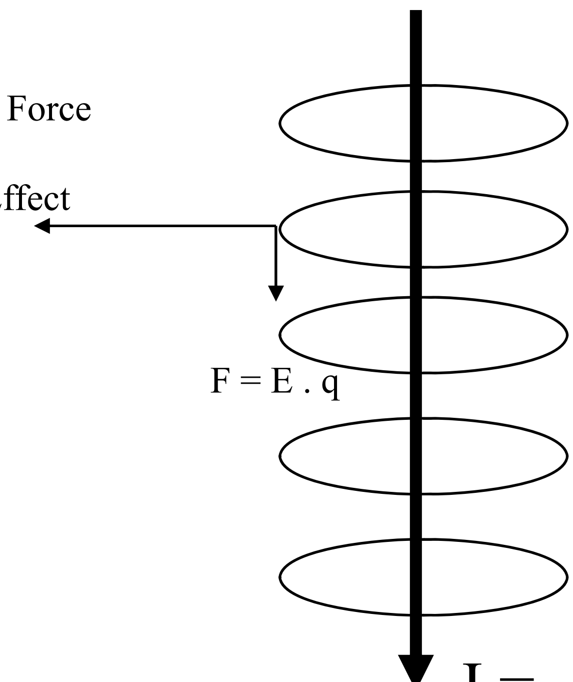
- Study possible by the fine granularity of the pixel chip (Timepix)
- NOT the Gaussian profile one would naively expect
- But a circular ditch caused by the centrifugal Lorenz force



Study by Martin Fransen, Nikhef

Lorentz Force

Skin Effect

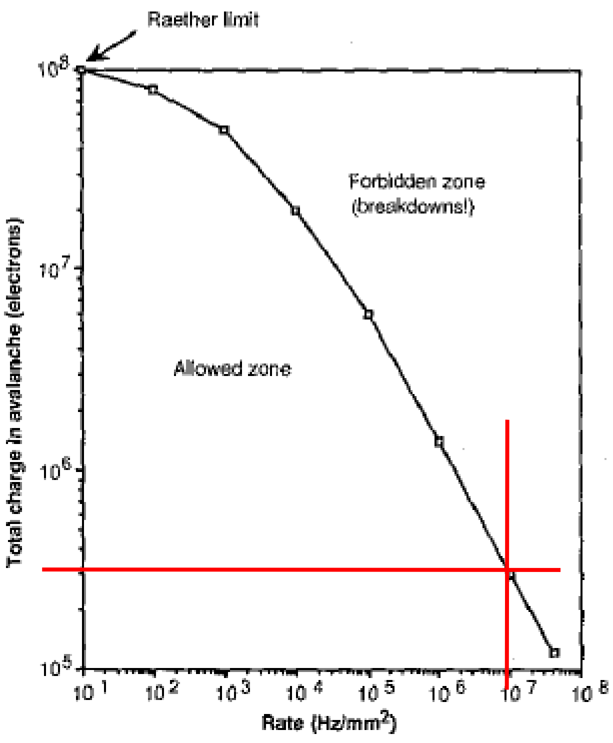


F = E . q

I = ~ 3A !

Maximum rate of Gossip possibly limited sparking

- → sLHC BL rate of 0.9 GHz/cm² sparking at total avalanche charge of 3*10⁵ e⁻
- → **sparking** at **60 primary electrons would occur** at a gain of 5000
- Average MIP ionization 10 – 15 e⁻
- > 60 e⁻ → happens frequently in the Landau tail of the primary ionization
- → we need a good protection against sparking
- **→ Gossip at B-layer sLHC would be close to sparking**
- But Gossip prototype sustained **60 µA/cm²** induced by UV light (Nikhef test)
  - → 9 µA/cm² (present working point) would be OK?
- Systematic research using MIPS needed
  - ^{90}Sr source
  - SPS muon test beam



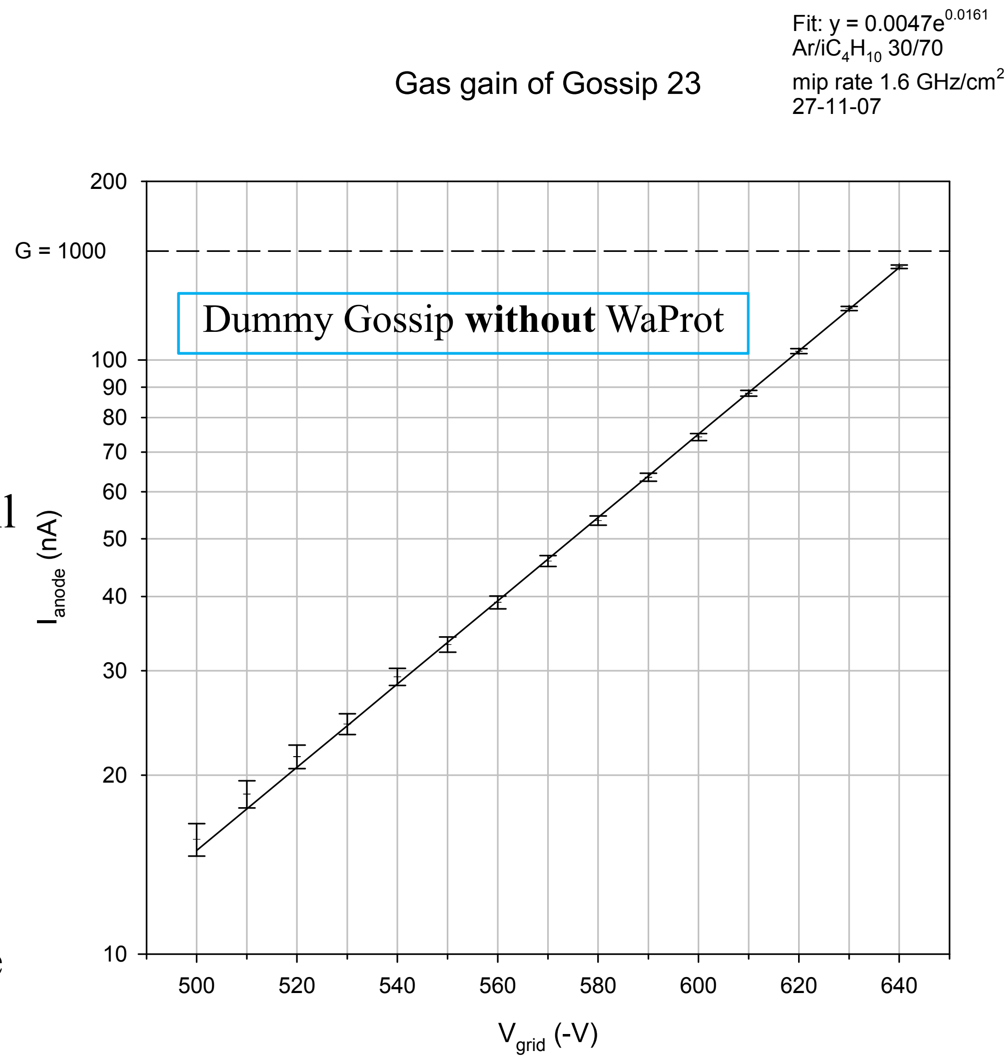
P.Fonte, V. Peskov, B. Ramsey, The fundamental limitations of high-rate gaseous detectors, Nuclear Science Symposium, 1998, 1998 IEEE, vol.1, p 91.

Experimental result on rate tolerance

- MIP rate 1.6 GHz/cm^2
- Gas: Ar/iC_4H_{10} 70/30
- Exponential raise of gain vs V_{grid}

$$G = a \cdot e^{bV_{grid}}$$

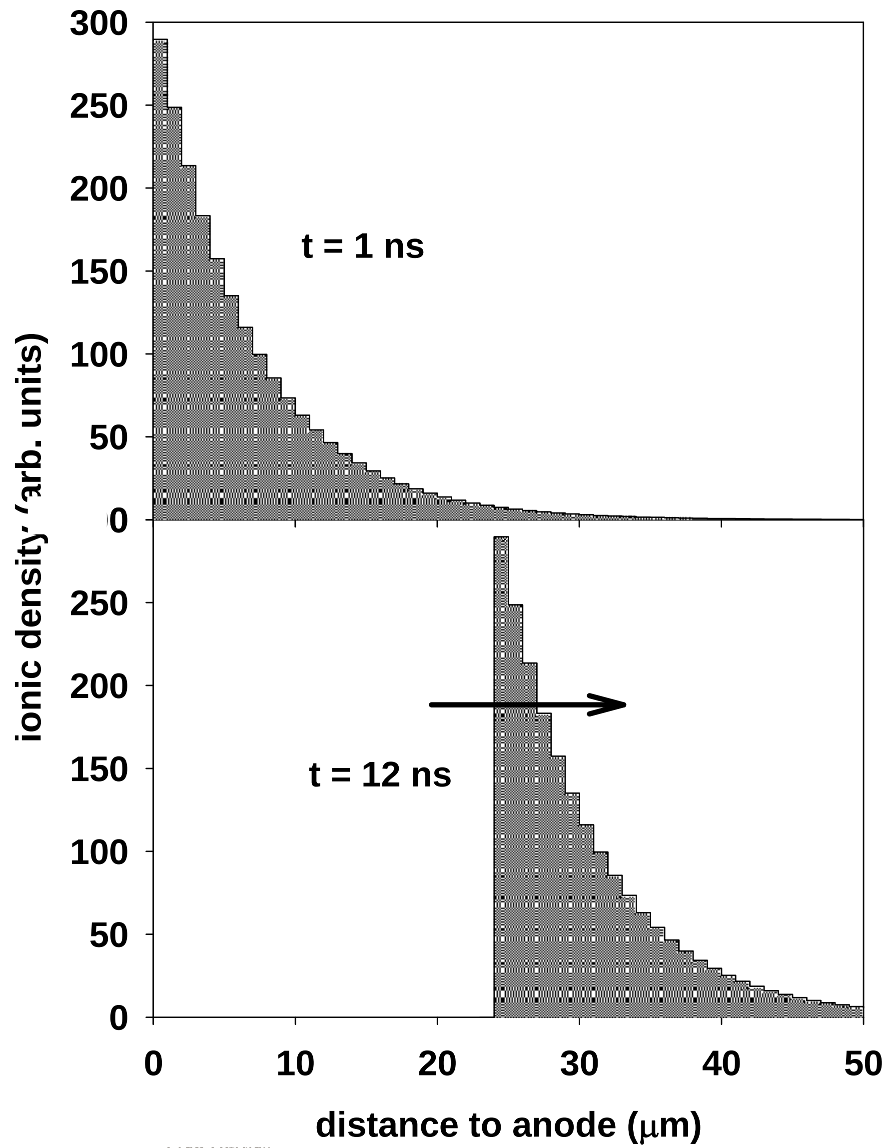
- No sign of saturation until $G \cong 1000$
- To be repeated with WaProt layer
- Dependence of signal time structure on this rate still to be investigated



Charge signal development
Ion cloud drifting in 50 μm wide avalanche gap

- Avalanche proceeds in ~ 1 ns

- Anode signal develops during drifting of the ion cloud towards the grid

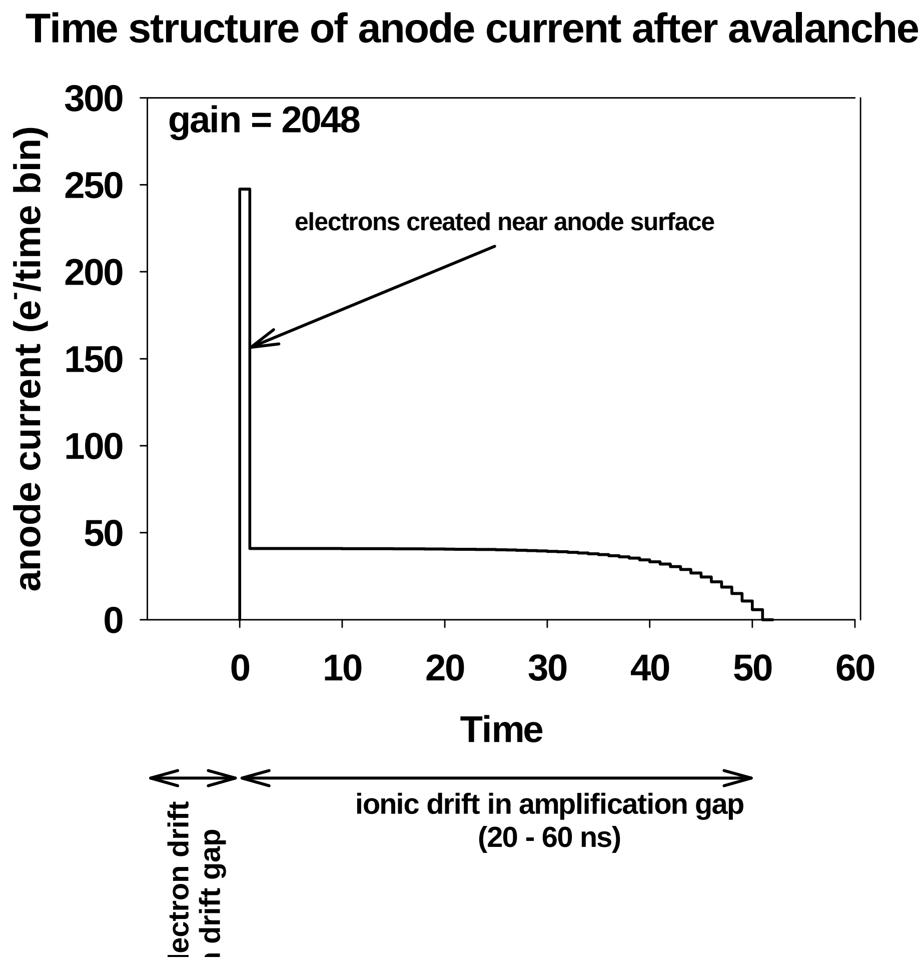


Simplified time structure of charge signal for a single electron

1) No signal for 0 – 20 ns (electron drift)

2) Delta pulse (~10%) from electrons created on the anode surface

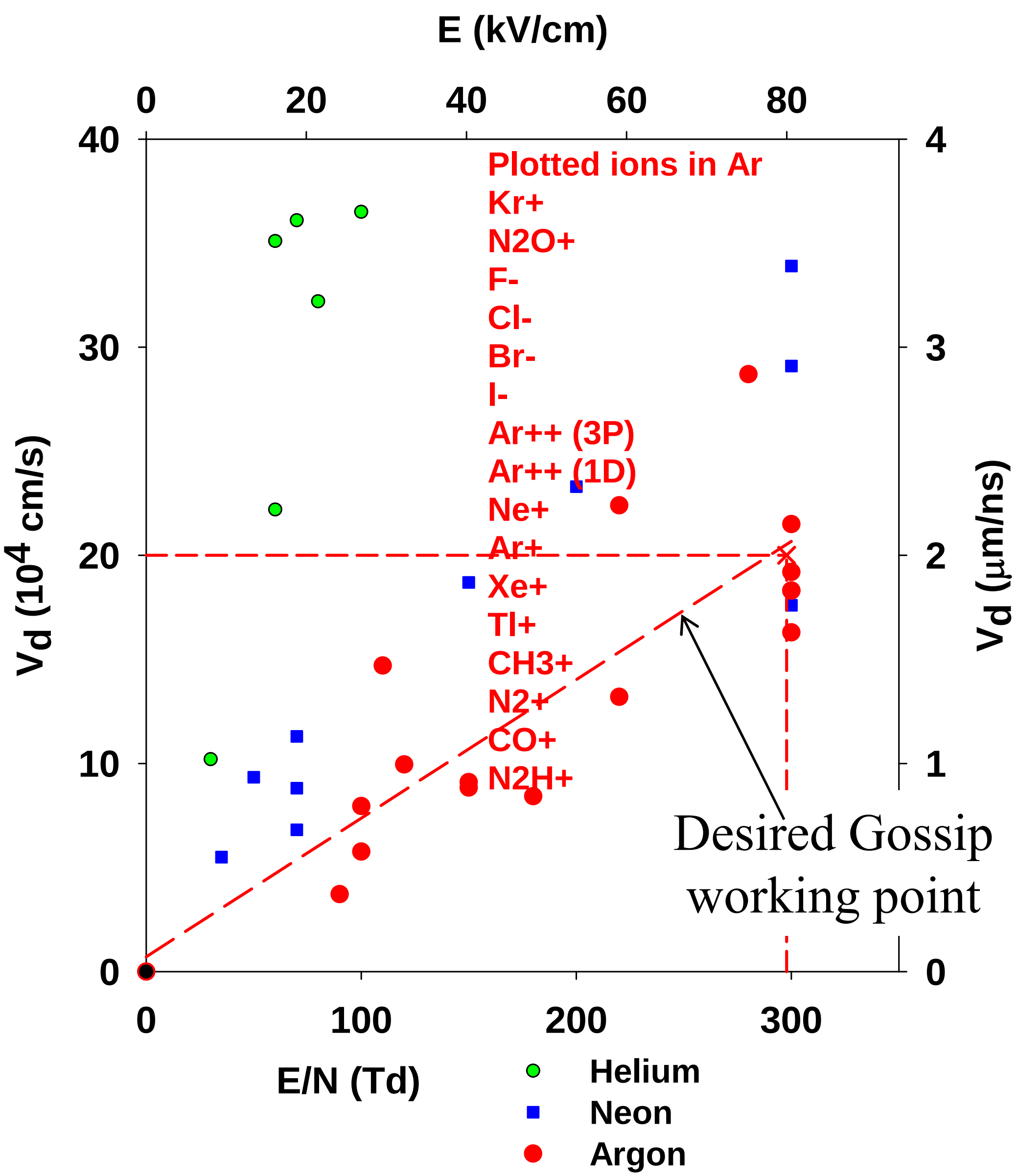
3) Steady current for 20 - 60 ns from ionic drift
   - ~ 60 ns (Ar^+ in Ar)
   - ~ 20 ns (CO_2^+ in Ar)
   - To be investigated for DME/CO2



Signal duration given by ionic drift

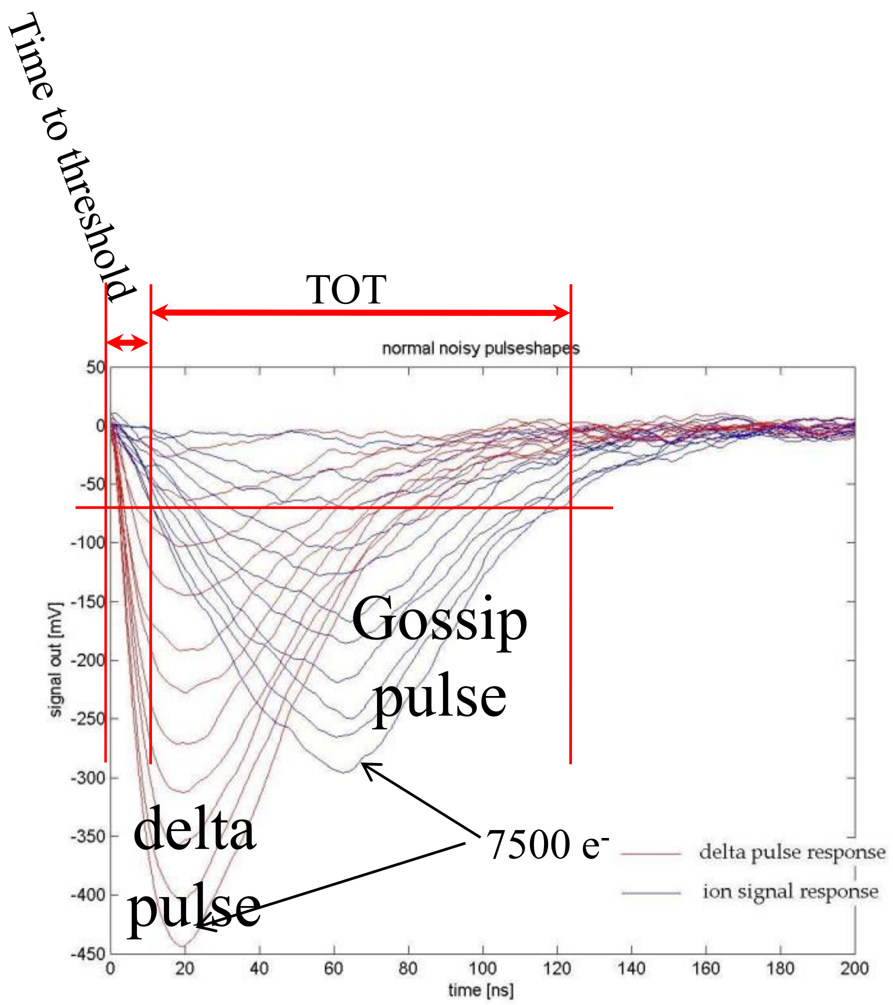
- Not much experimental data in literature on ionic drift at high fields (> 100 kV/cm)
- No good model on ionic drift
- → we have to measure charge collection time
  - using laser induced ionisation

Ionic drift velocities from literature in He, Ne and Ar



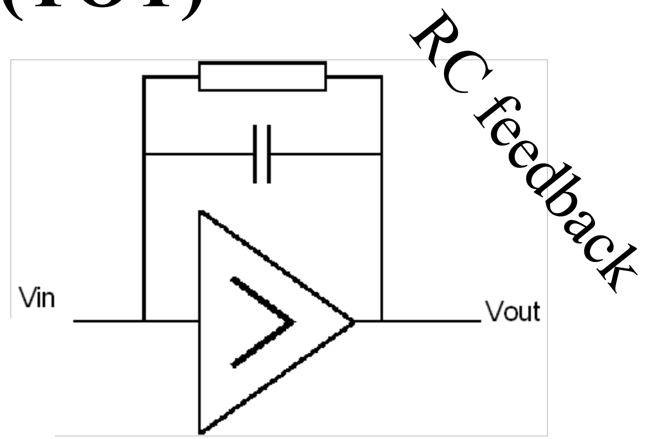
Handling time slewing

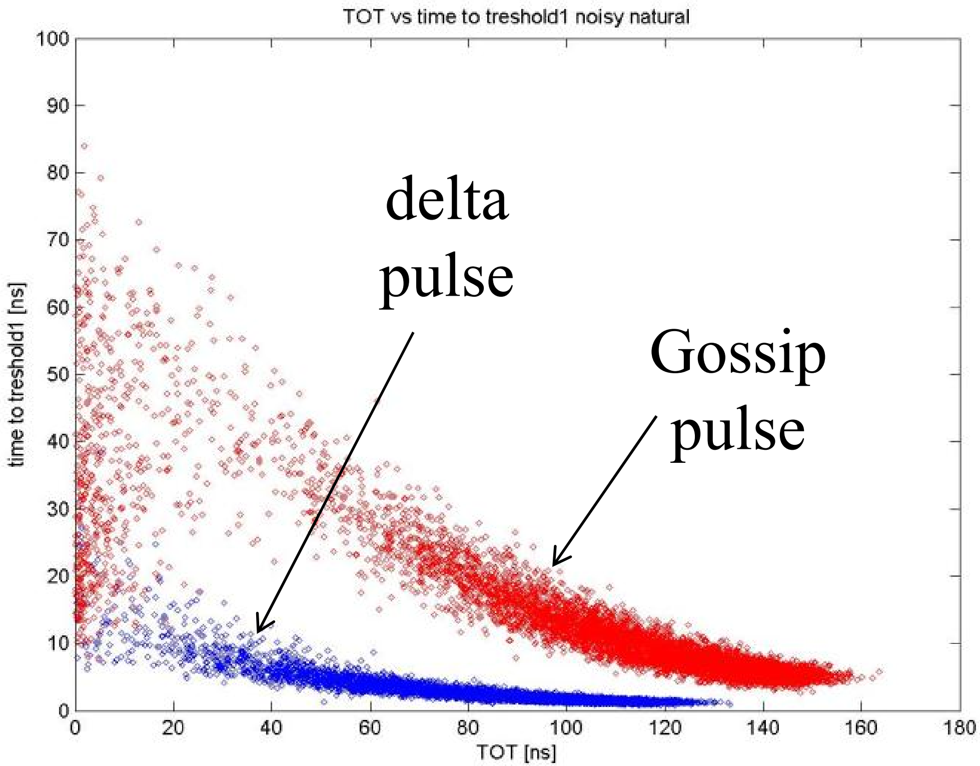
- Simulation for Gossipo preamp
- State of the art frontend
  - 130 nm technology
  - 2 μW power
- Without any compensation, time slewing destroys Z resolution
  - 15 – 50 ns delay, exceeding range of drift time measurement (25 ns)
  - => Z errors ~300 μm rms
  - => compensation really required
- Possible compensation by
  - Time-over-threshold (TOT) measurement
  - => use this value to correct the measured arrival time
- Constant fraction discriminator



Correction of measured drift time using measured Time Over Threshold (TOT)

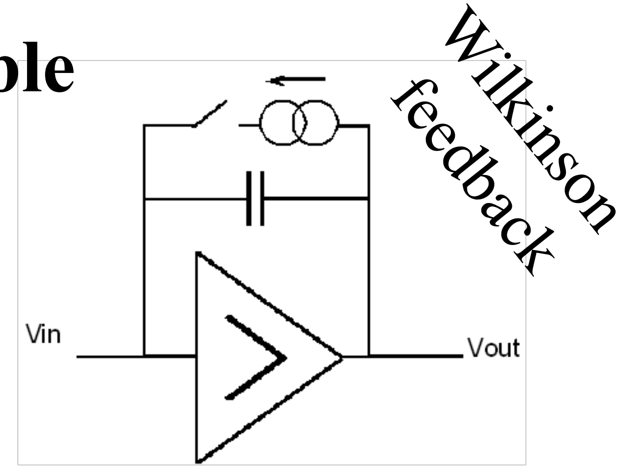
- Works in principle
- For small charge signals (<1000 e- → TOT ~ 60 ns) the correspondence is poor

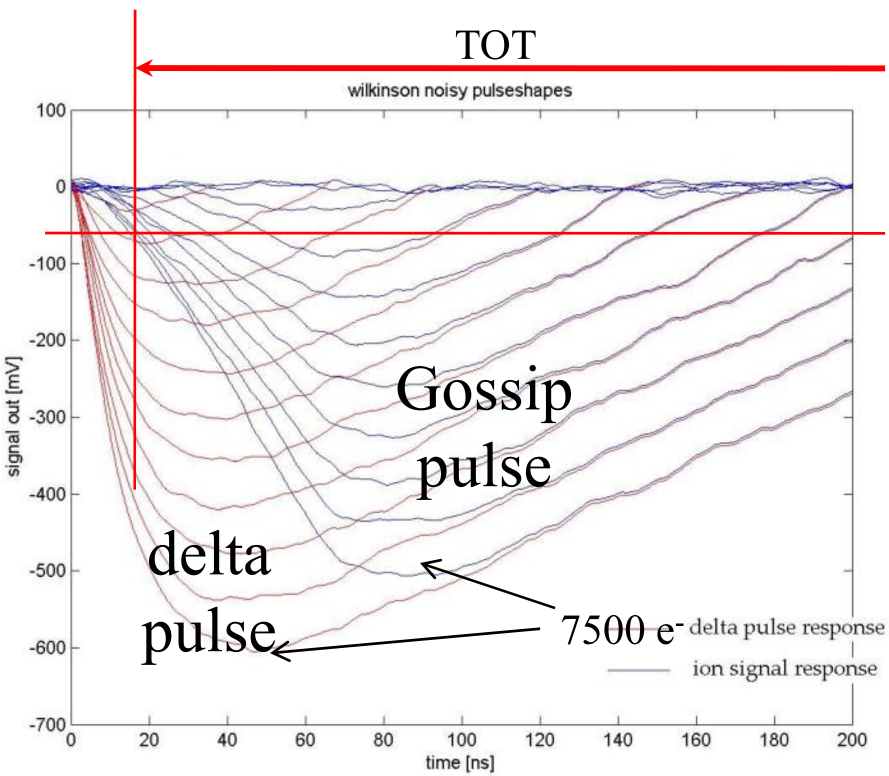


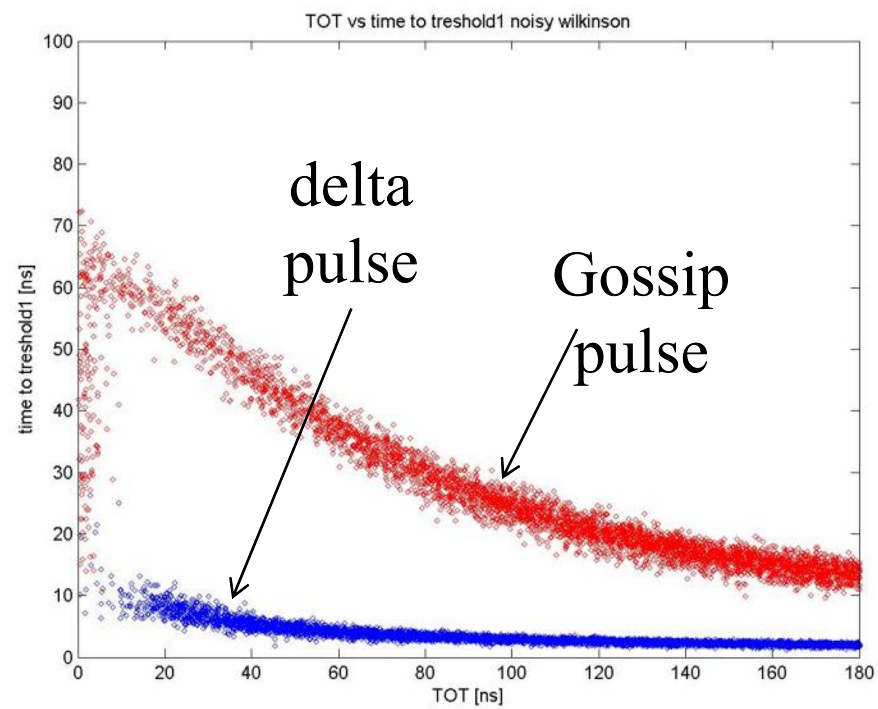


Making time slewing more predictable

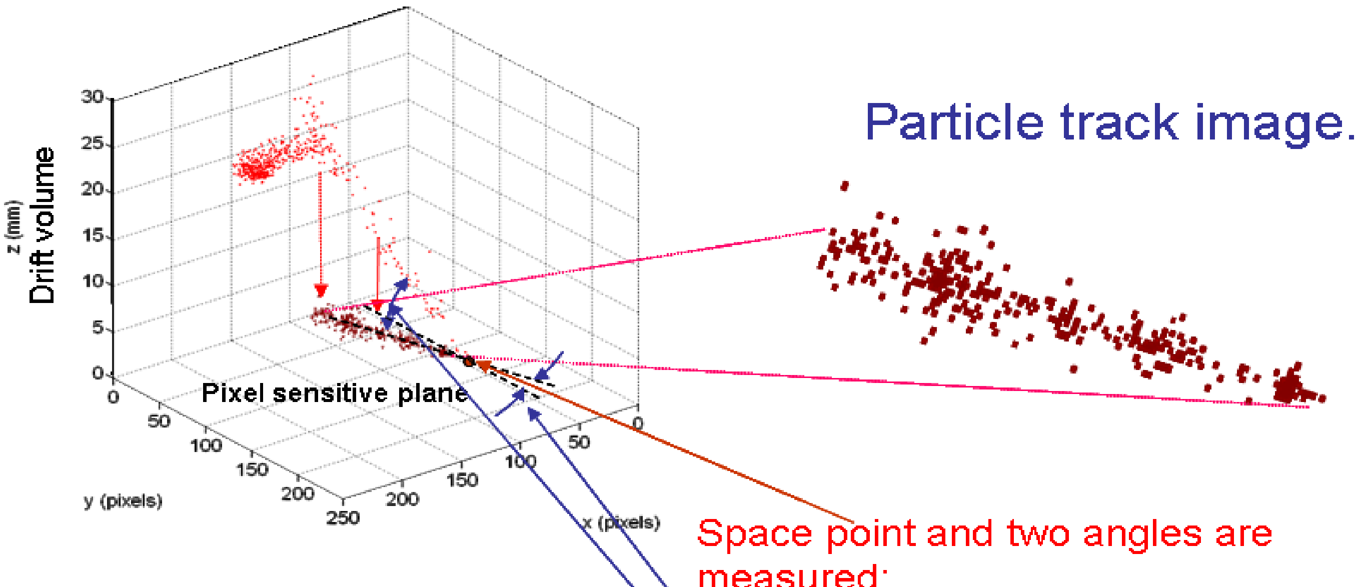
- Using Wilkinson feedback (switching current source)
- Accurate drift time correction possible using the correlation of TOT to time-to-threshold
- => remaining time jitter ~ 2ns (50 µm) rms
- But more pile-up







Simulating position resolution
Reconstructing space track in GridPix



θ = angle **in** the pixel plane

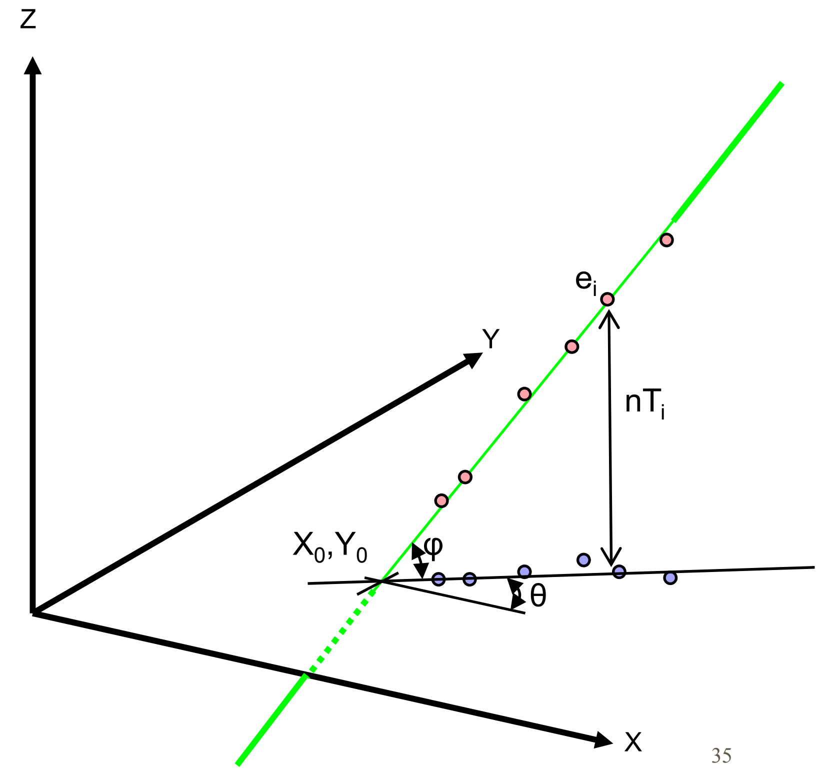
φ = angle **to** the pixel plane

MC calculations

- Done by Wilco Koppert
- Generate track with crossing point with grid characterised by X, Y, φ, θ
- Assuming Poisson probability to produce an ionisation cluster along track
  - Most clusters consist of only one electron/ion pair
  - δs included
  - No fluorescence or Auger yet
- Just handling pure gas transport in drift gap
  - => no electronics contribution included
  - ~~Noise~~
  - ~~Time slewing~~
  - ~~Avalanche statistics~~

Track reconstruction

- Actual position of electron (e_i) in space is given by (X_i, Y_i, T_i)
- Measured position of electron e_i in space given by integers nX_i, nY_i, nT_i
  - (nX_i and nY_i are the quantisation of the pixel address, nT_i of the drift time in TDC counts)
  - Calculate from weighted straight line fit through all nX_i, nY_i, nT_i the trajectory of the track
  - Weight has square root dependence on nT_i
- Resulting track given by crossing point with the grid as X_0, Y_0, φ_0, θ_0
- Residuals => $X - X_0$; $Y - Y_0$; $\varphi - \varphi_0$; $\theta - \theta_0$
- Discard single electron events (5%) in this stage
  - To be used for tracker fit only



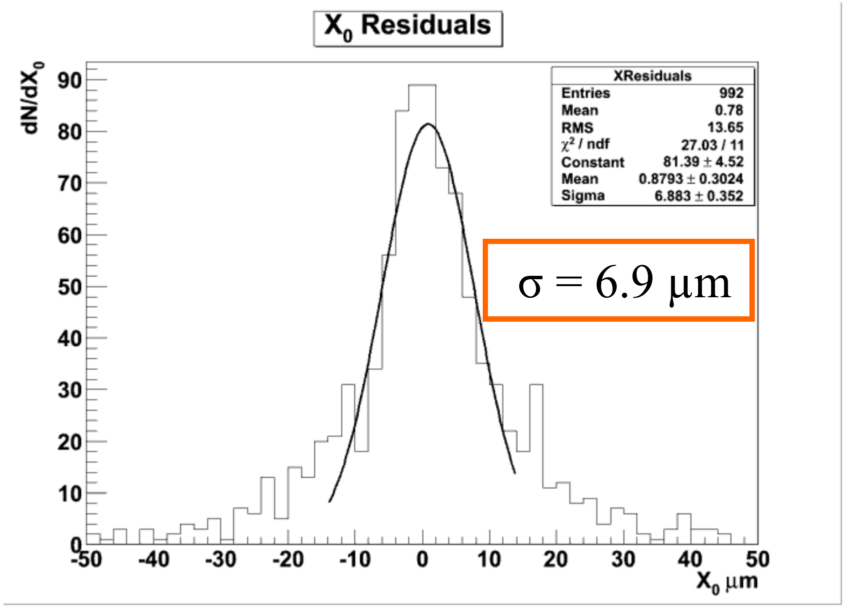
Gossip working point for the simulations

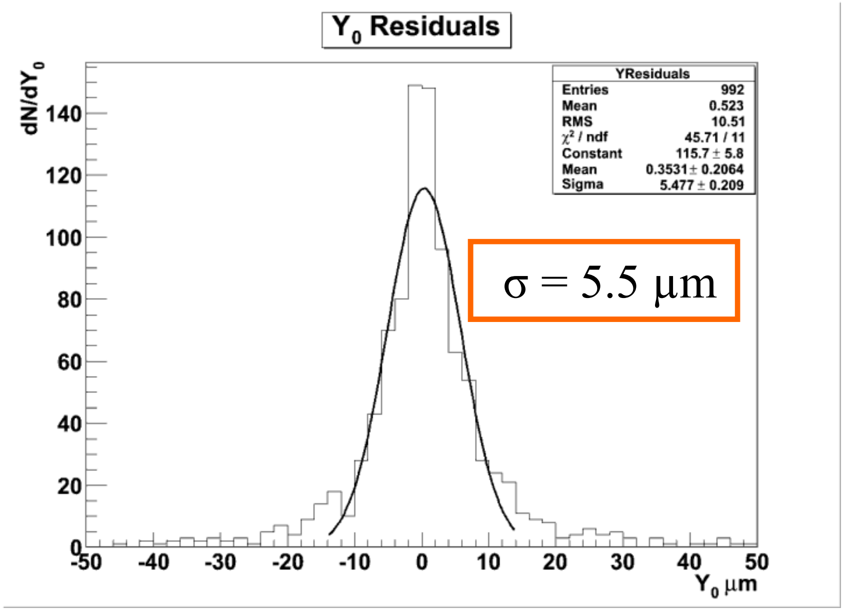
- Gain = 10000
- Gas: DME/CO_2 50/50
  - σ_{DL} = 98.5 µm/√cm (HEED)
  - σ_{DT} = 114.5 µm/√cm (HEED)
- Drift gap 1 mm
- Drift field 7 kV/cm

Example from MC for 1 μm pixel pitch

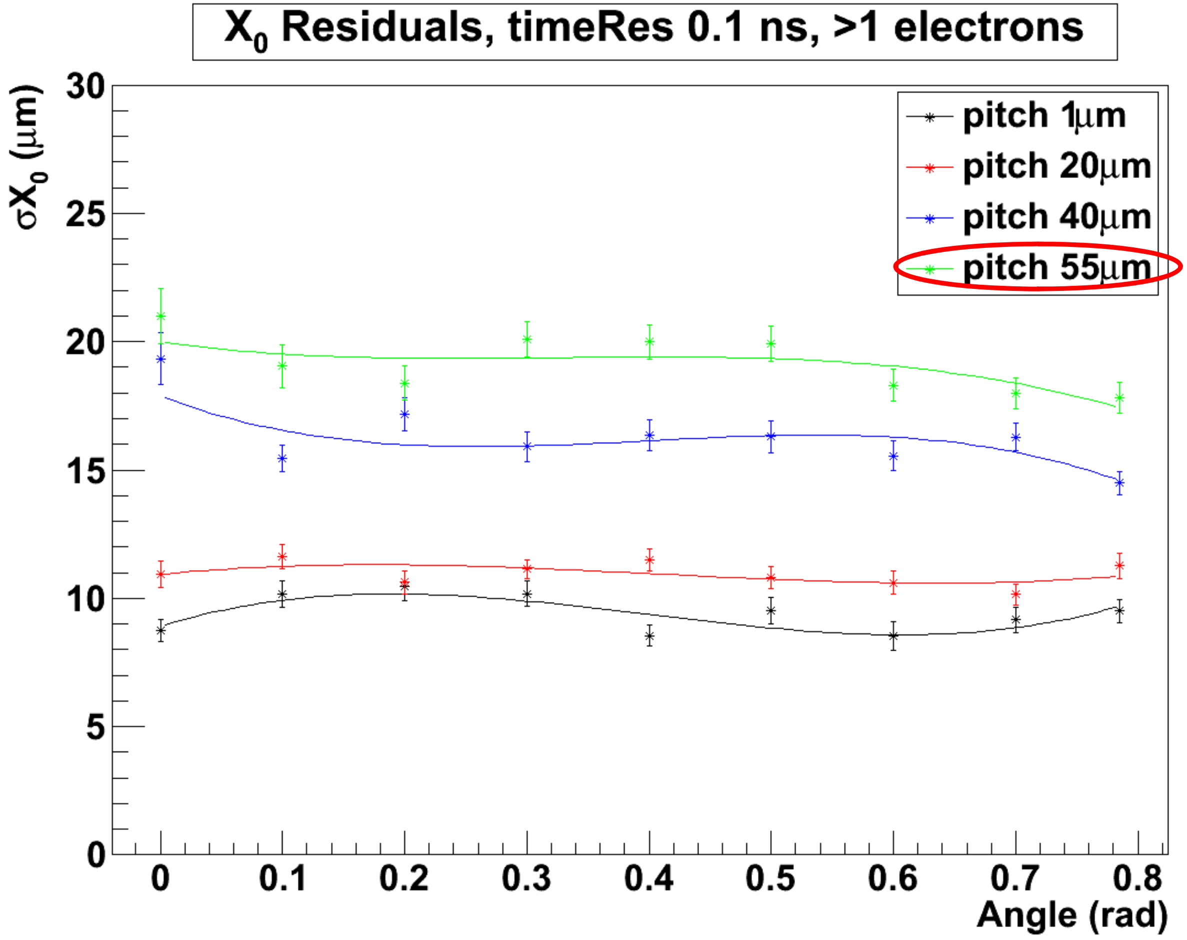
- Residuals from MC generated tracks for tracks under 45°
  - $\varphi = 45^{o}$
  - $\theta = 0^{o}$

  Projection in X direction
  - Drift gap 1 mm
  - Gas: DME/CO_2 50/50
  - **Using drift time info**



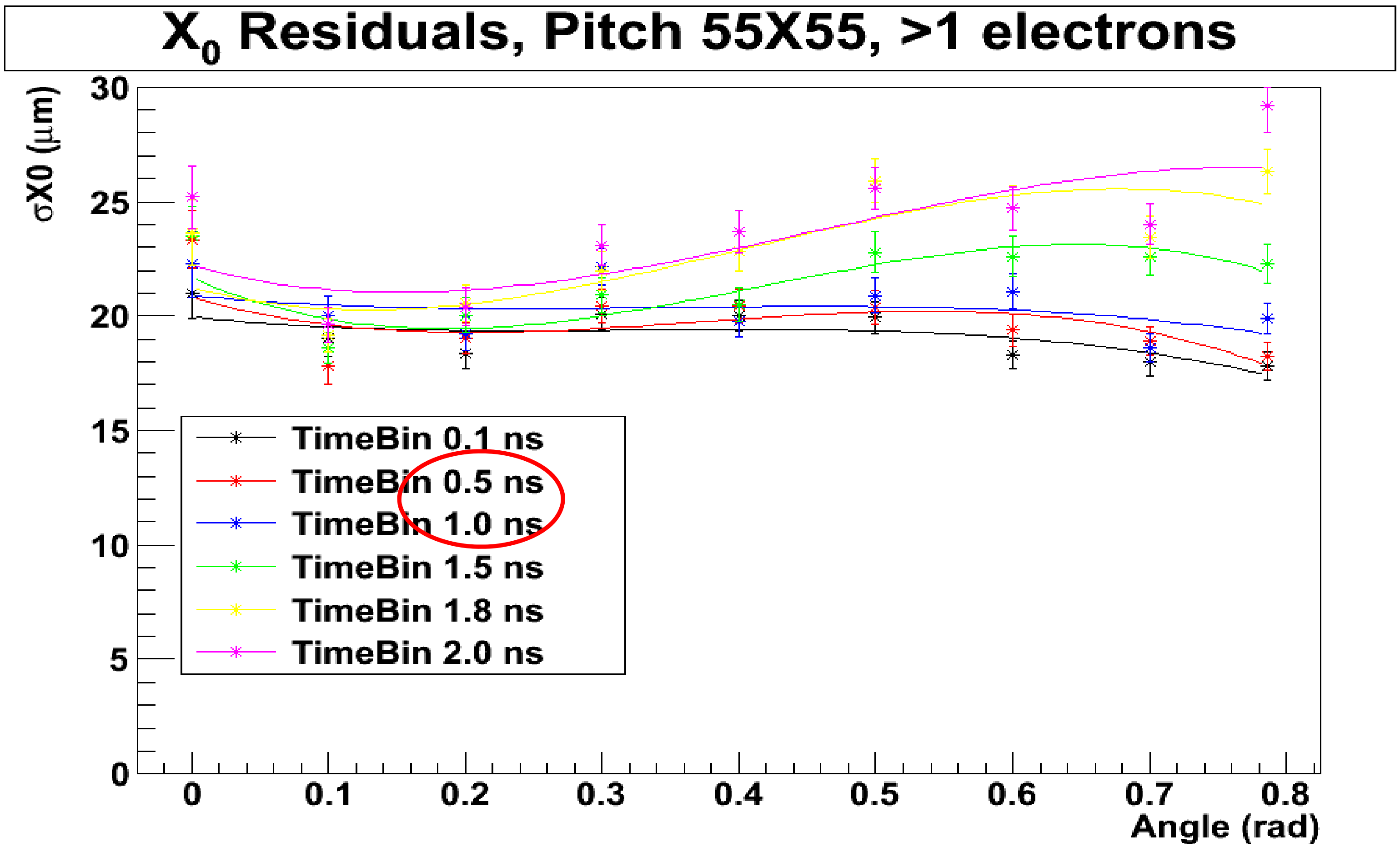


Angular dependence of $X - X_0$ residuals for other pixel pitches



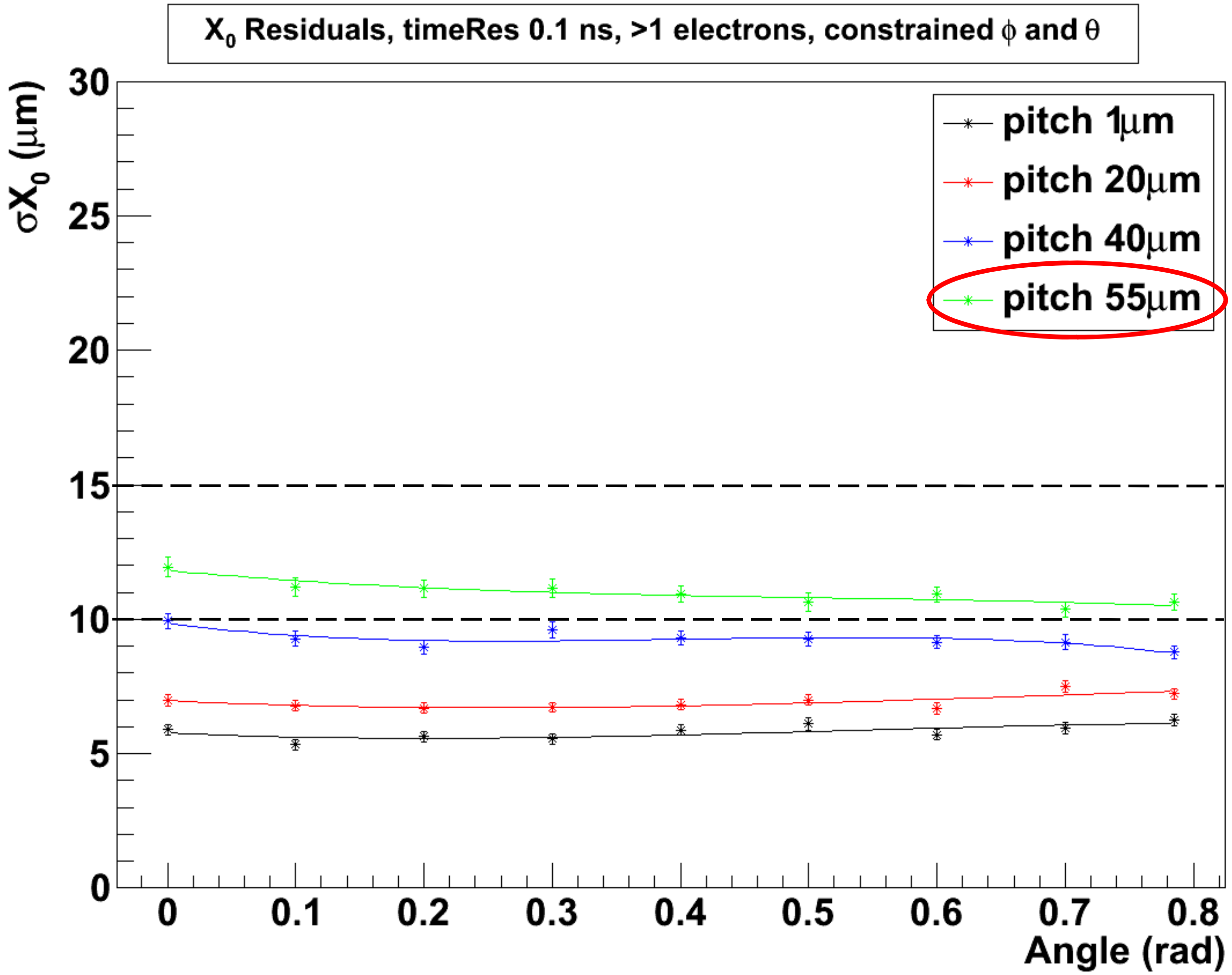
Effect of time least count on resolution

- 1 μm pixel pitch
- Presently used: 0.7 ns



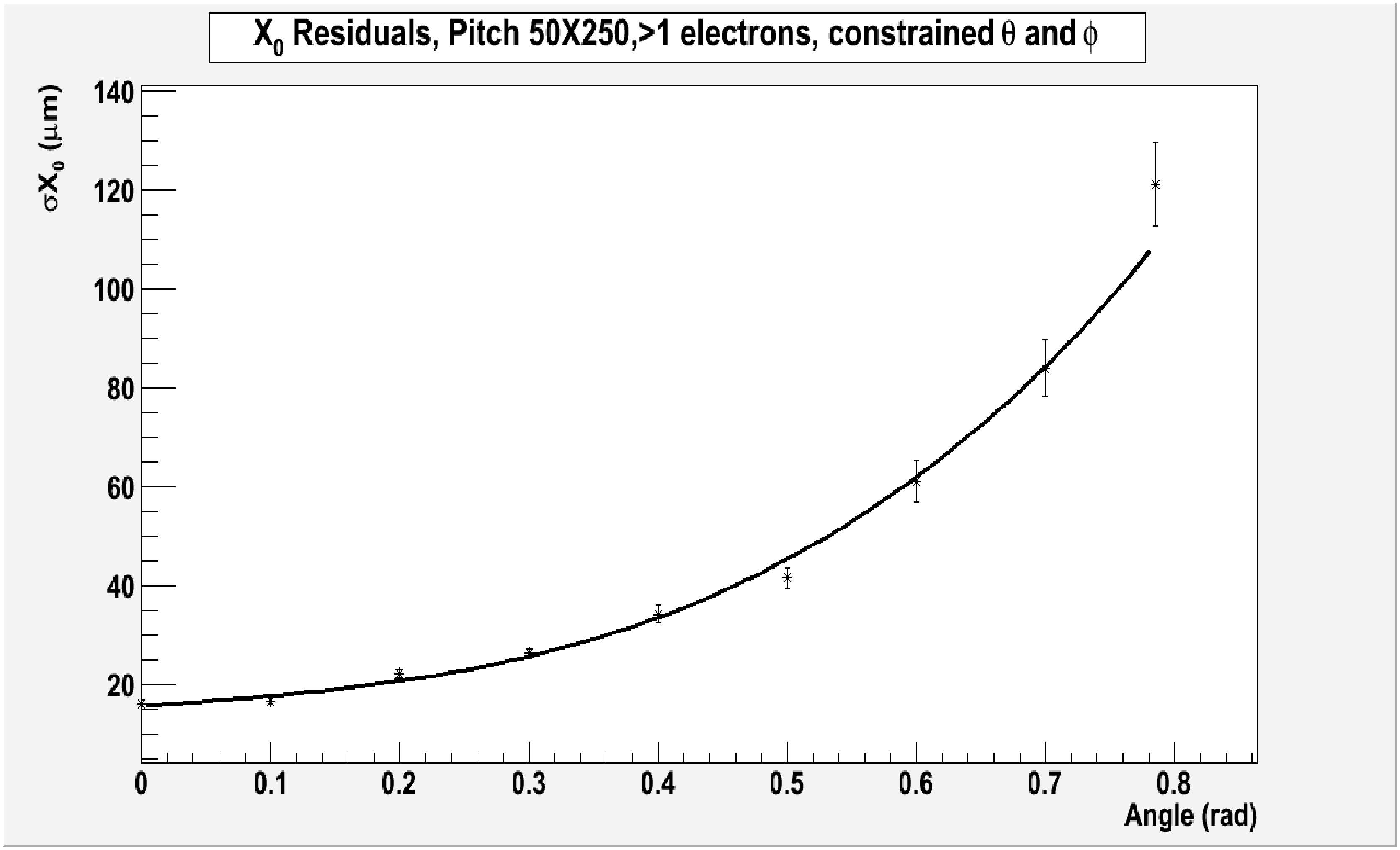
Strong resolution improvement for constrained φ and θ

- After fitting in tracker
- σX_0 = 11 – 12 μm for 55 μm pitch



Worst case: omitting time info

- Pitch 50 (X) x 250 (Y) µm (Atlas FE-I4 chip, in development)
- Angle constrained in φ and θ

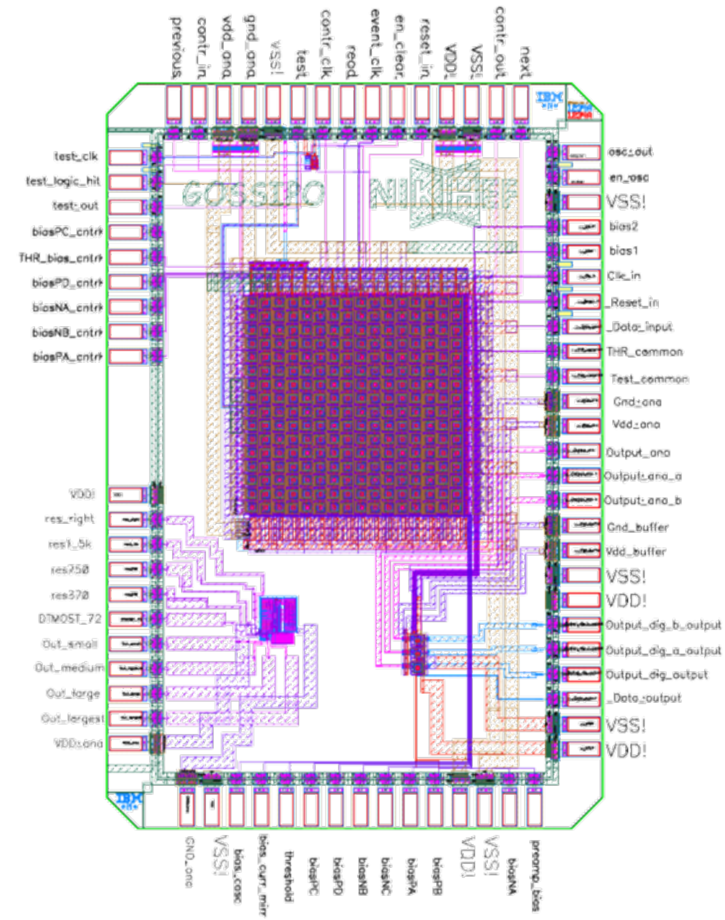


Summary position resolution simulations

- Atlas requires ~ 10 μm resolution for B-layer
- Outcome simulation near this value possible for constrained fit (using tracker fit info)
  - 11- 12 μm resolution
- But electronic effects (noise, time slewing not yet included)
- Also deterioration by single electron events

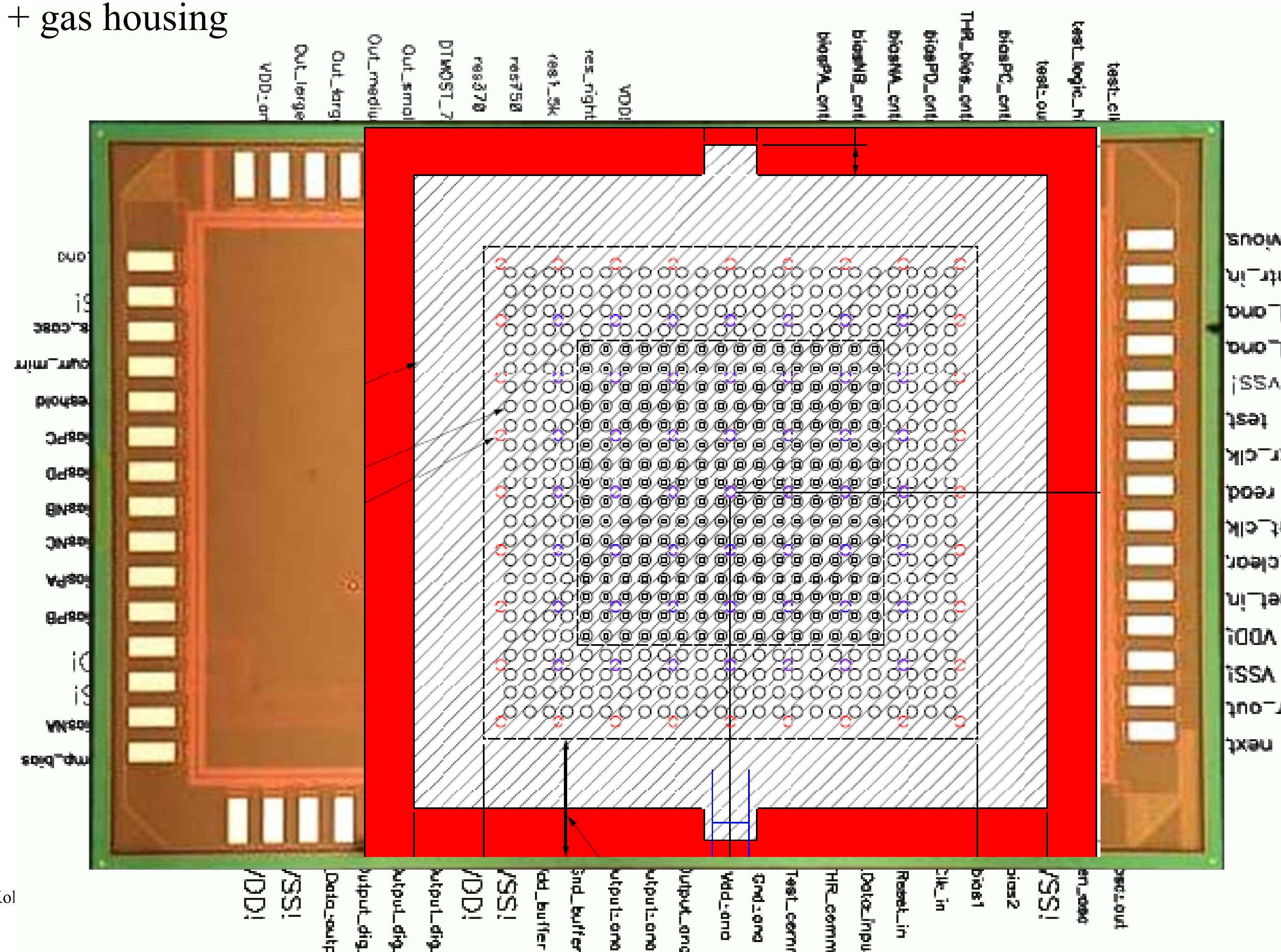
Prototype studies for future pixel chip

- **Gossipo-2** (V. Gromov, R. Kluit, Nikhef)
  - 16 x 16 matrix, 55 x 55 µm pitch
  - ENC=70 e$^-$
  - **Threshold 350 e$^-$**
  - **Power 2 µW per channel**
  - Using 40MHz external time reference
  - Z-measurement: drift time using TDC + 600 MHz clock



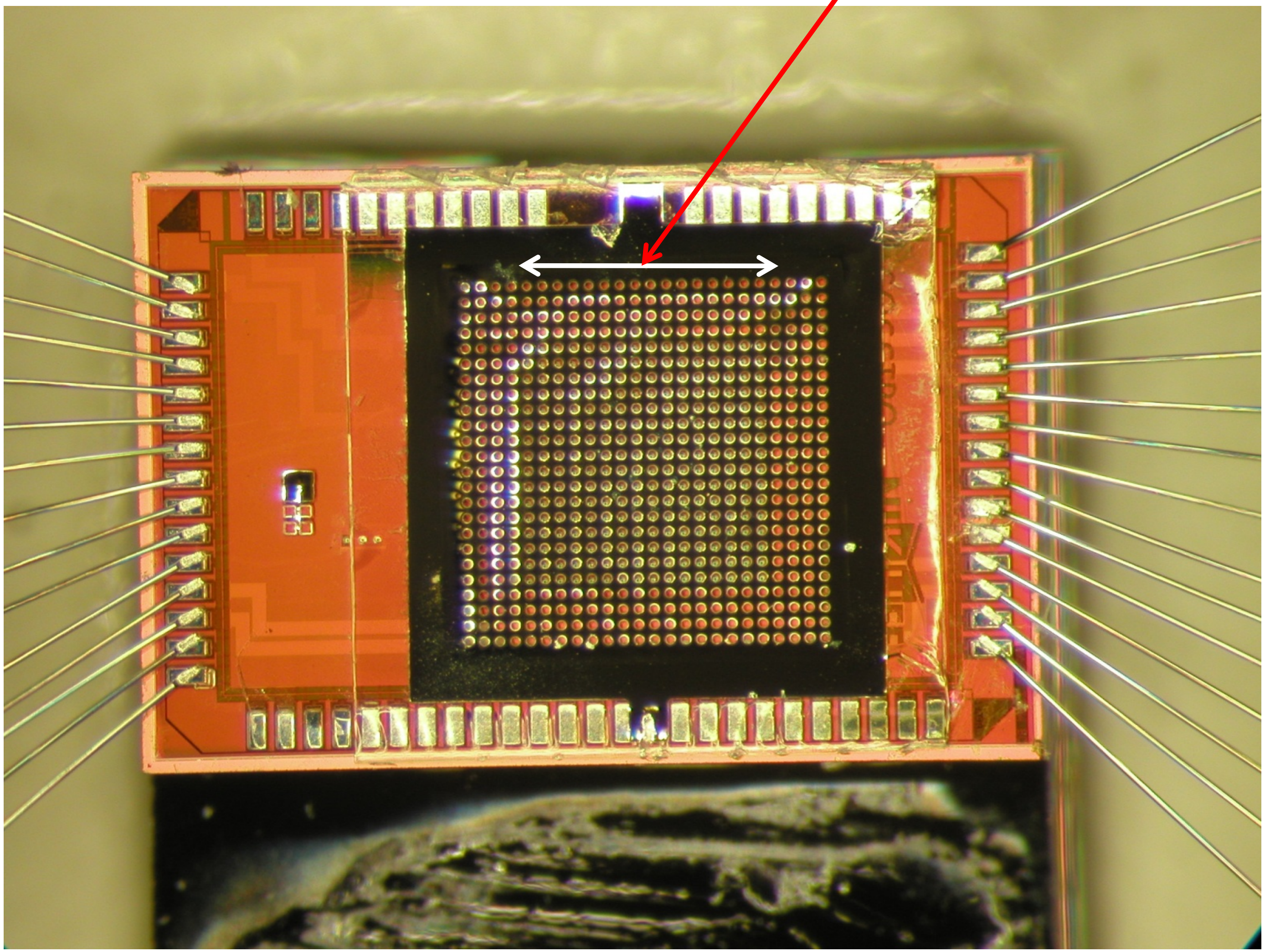
How to make a real particle detector from Gossipo2 chip

- Si_3N_4 layer (spark protection)
- InGrid (for gas amplification)
- Field foil + gas housing



Realized

Sensitive area 0.88 mm square

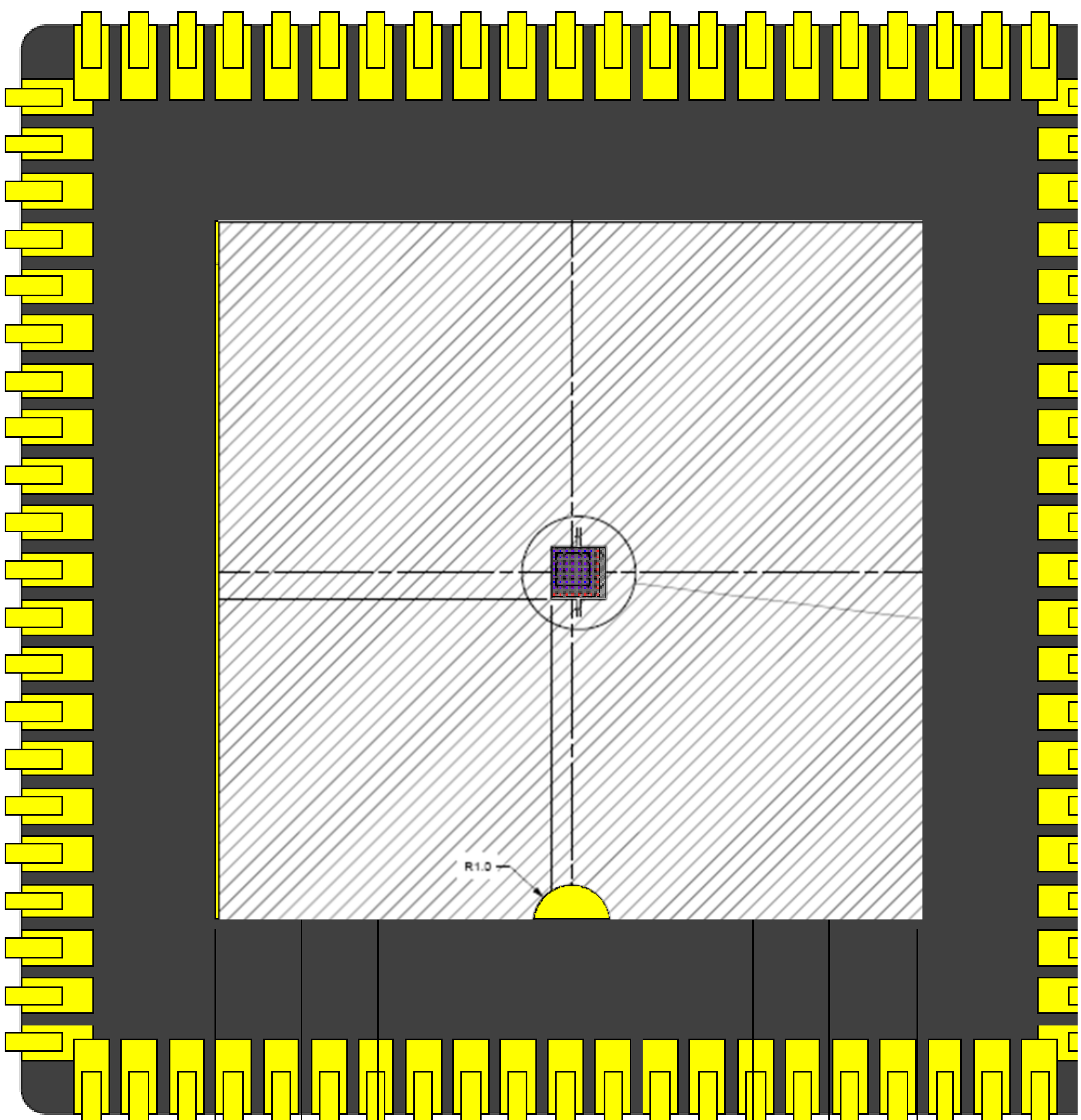


Gossipo-2 with InGrid

Detector from Gossipo2 chip

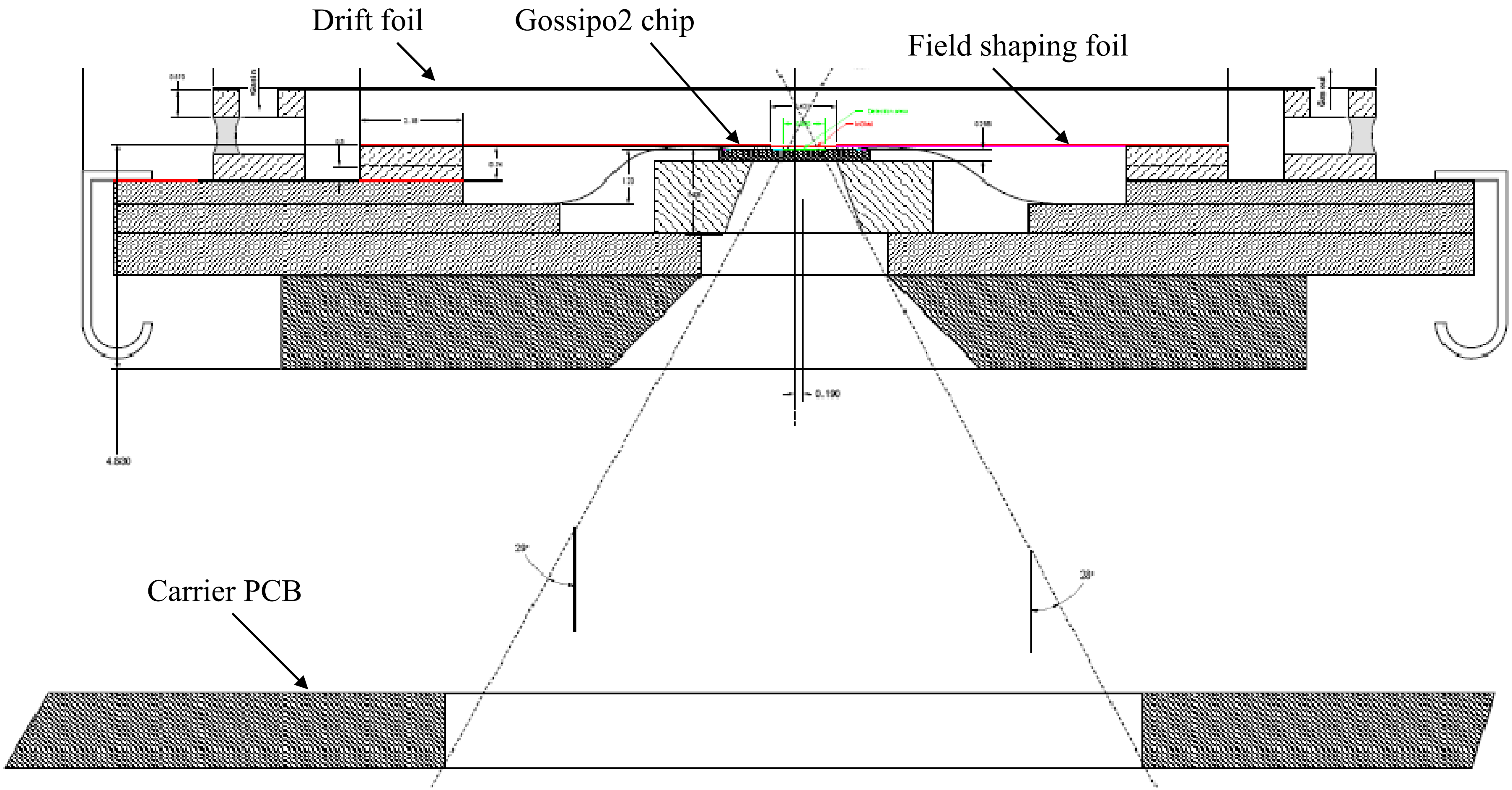
- Using standard chip package as base
- InGrid operating at ~ -400 V
- => adding field shaping foil at ~ -300V for homogeneous drift field

  (50 μm Kapton + 1 μm Cu)



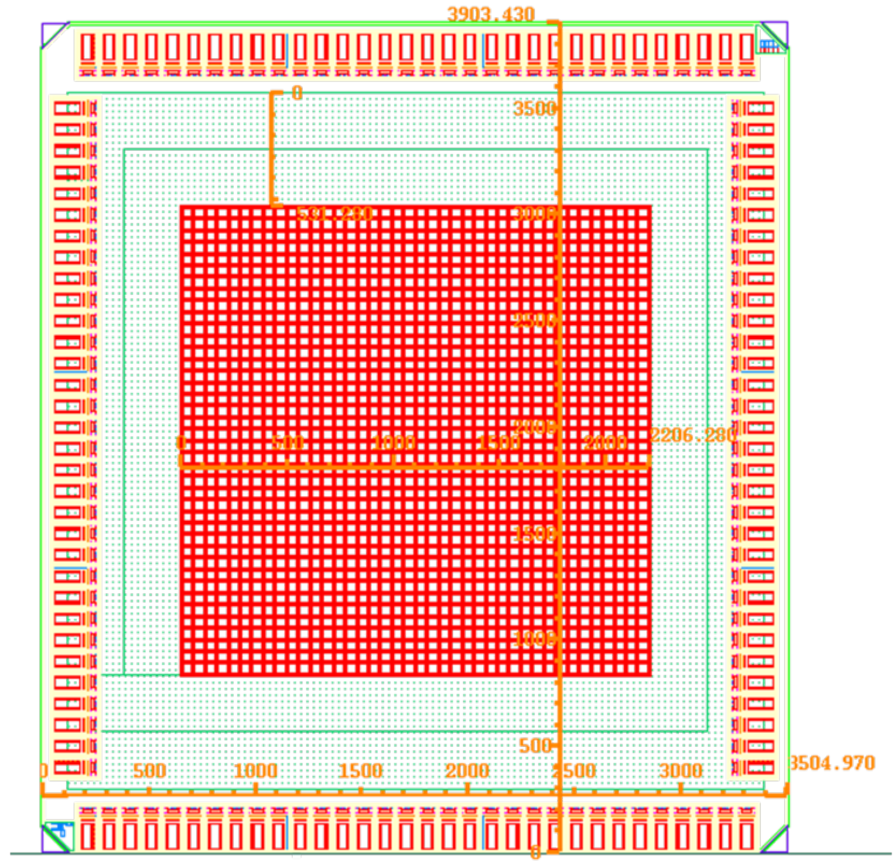
Cross section Gossipo2 detector

- Material under Gossipo removed to avoid multiple scattering
- Limiting angle about +/- 30º



Asic development

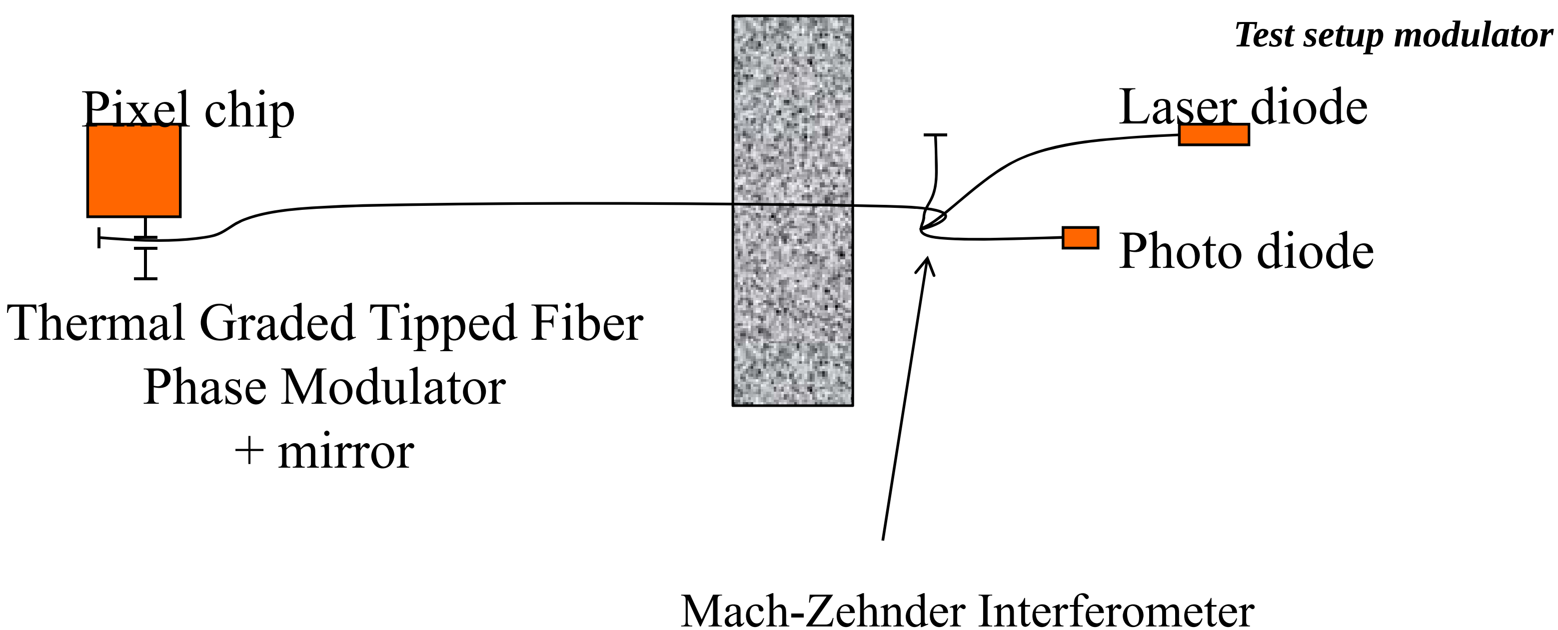
- Gossipo 3 and 4
  - Improved frontend
  - 32 x 32 pixel array 55 x 55 µm
  - → better suited for position resolution measurements
  - Advanced r.o structure
  - Joint Nikhef/Bonn project
  - Submit expected 2010
- FE-I4
  - New ATLAS pixel chip
  - FP420: time resolution added
- TimePix-2
  - Medipix Consortium
  - CERN TT: commercial interest (Panalytical)



Layout Gossipo-4 (draft)

New optical link technology => Iflink

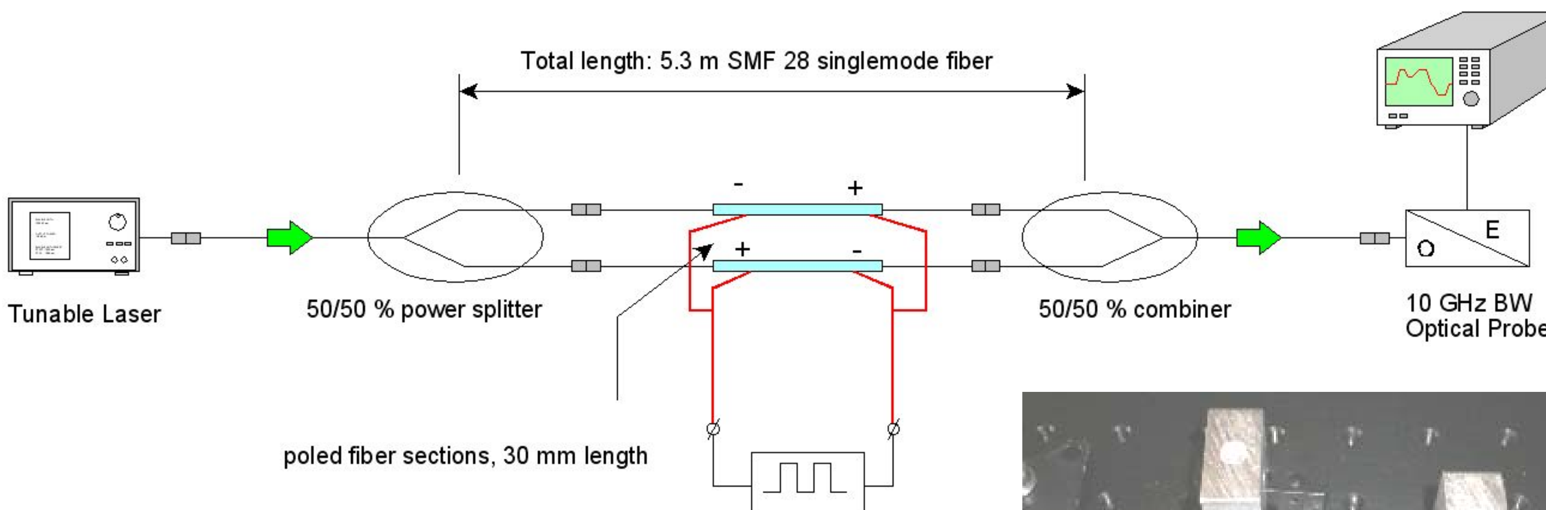
- Present VCSEL technology not sufficient rad hard (1.5 10^{15} cm^{-2} n_{eq}) for B-layer
- Alternative => **Iflink**
  - Using Pockels effect: change of ε_r by transverse E field
  - Thermally poled electro-optic active fibre (quartz)
  - => possibly sufficiently rad-hard for B-layer
    - Low modulator mass
  - TU-Delft (Neth.), ACREO (Sweden) and Van der Hoek Optics involved

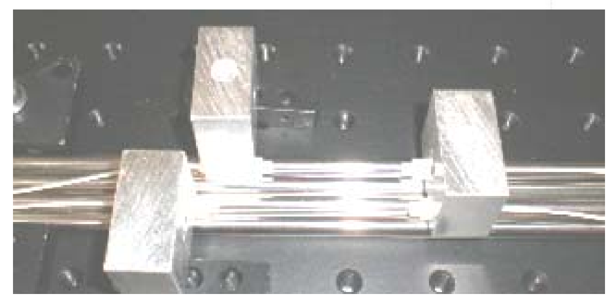


Testing just started

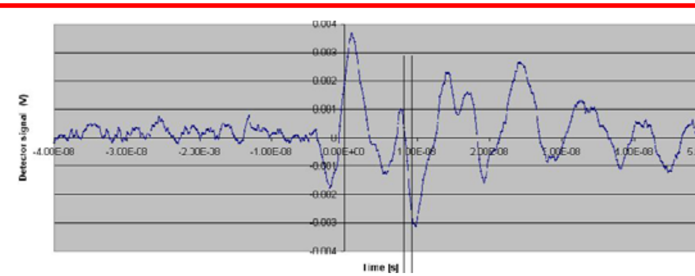
- Differential fibre to compensate for wavelength instability

Interferometer with poled fibre sections in each branch





Response from a step function
=> 1 ns risetime



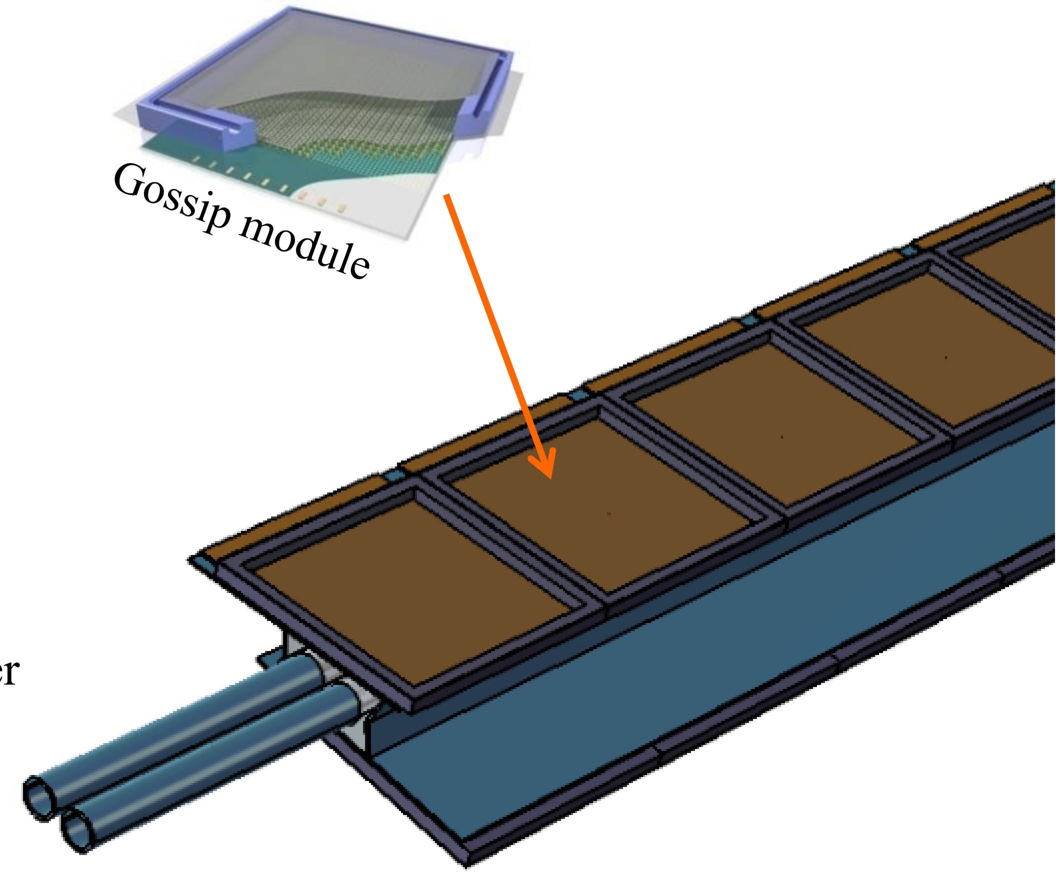
To investigate/ improve on Iflink

- Theoretical aspects of the new data transmission systems
  - fiber optics
  - laser optics
  - MZ interferometer
  - Polarization
  - Kerr & Pockels Effect

- Radiation hardness of the modulator
- Lowering modulator voltage
  - 300 V to few volts level

Mechanical layout: stave

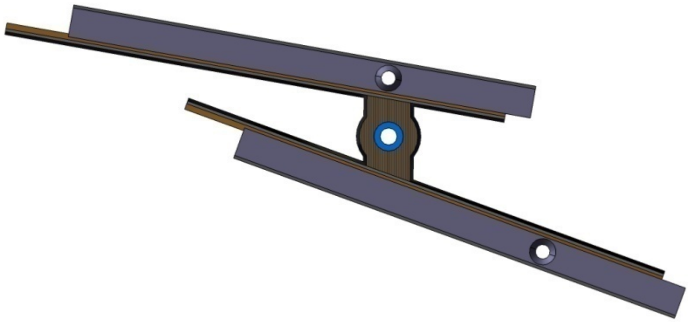
- 2 x 3 cm chips assembled as modules having individual gas envelope
  - Advantage
    - manufacturing small self contained units
    - No sensitivity for dust
  - Drawback
    - Significant dead area
- Gas envelope by ceramic frame and cathode foil
- Stave is reworkable by interchanging the individual modules
- Supported by TPG heat spreader
- Thermally coupled by glass cooling pipes
- CO_2 cooling



Radiation length stave (X_0)

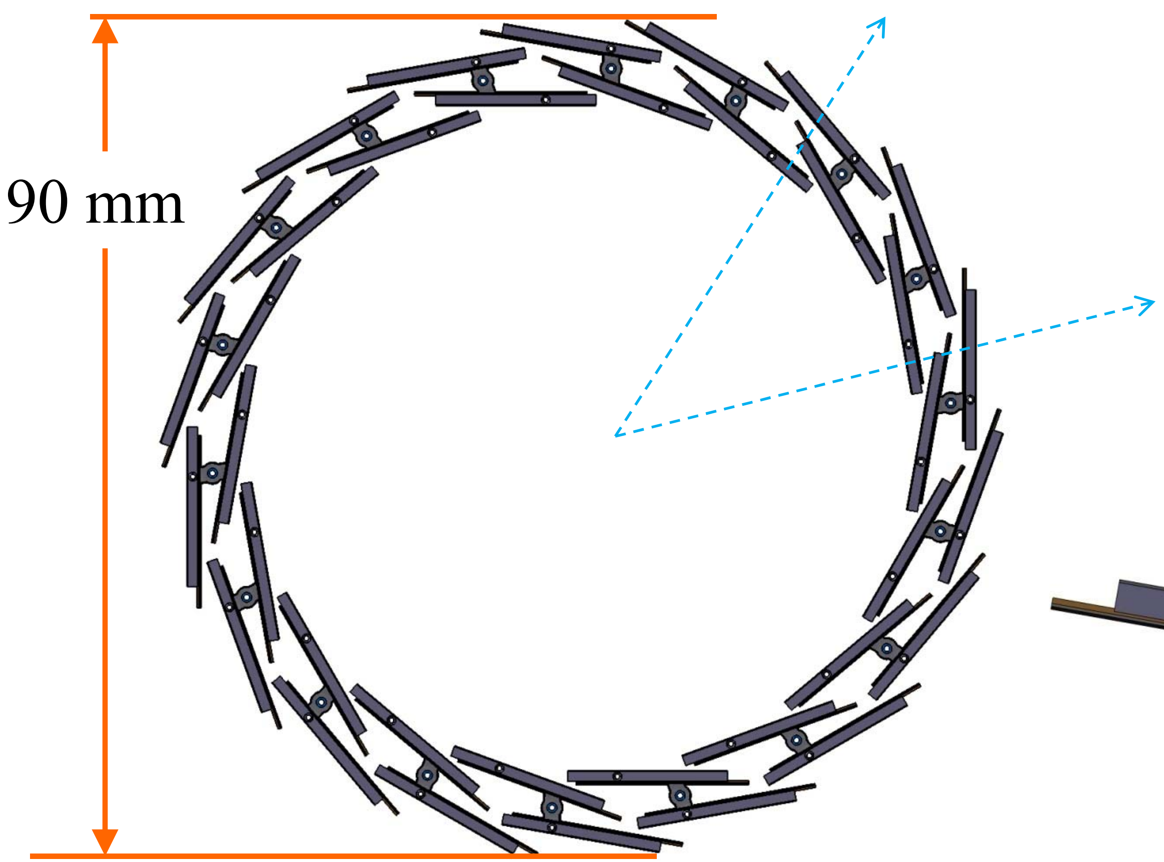
Radiation length (X_0)	
Thinned (50 μm) pixel chips	2 x 0.053%
Cathode frame	2 x 0.083%
TPG layer 100 μm	2 x 0.048%
PG body 20 mm2	1 x 0.5%
Cooling tube (glass)	1 x 0.083%
Carbon fibre composite	3 x 0.1%
Total for stave	**1.25%**

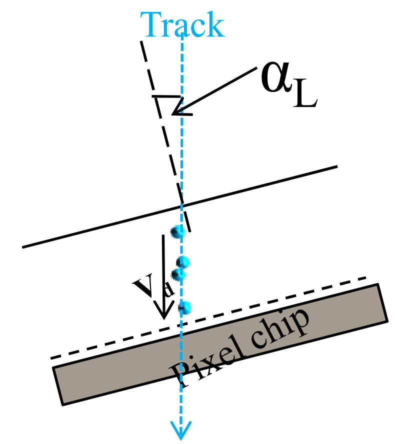
- Dominated by support and services (78%)



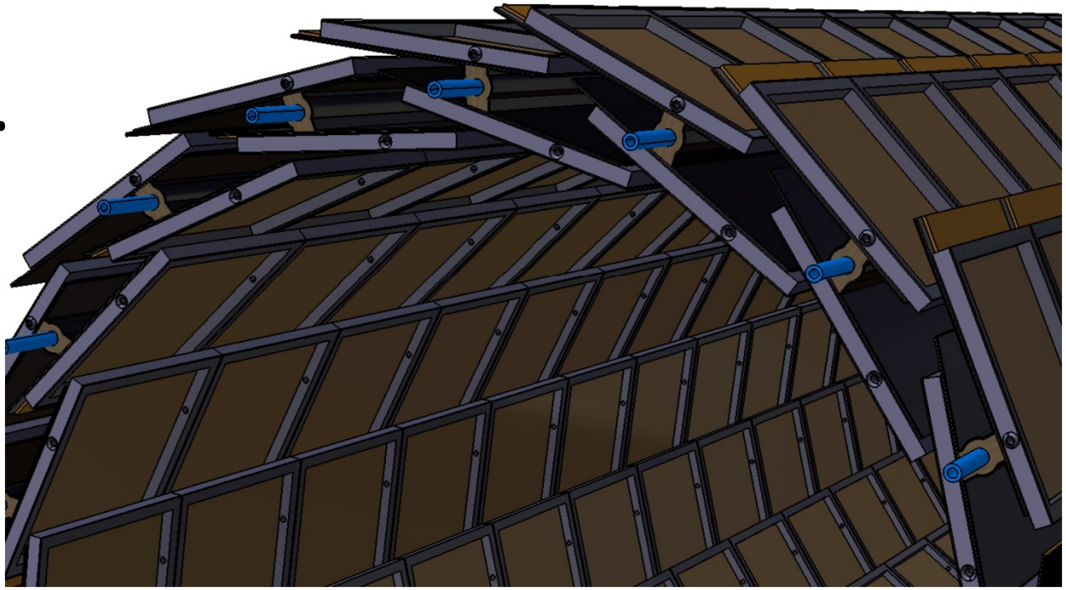
Dimensioning B-layer

- Modules oriented at Lorenz angle (~ 9º) for high momentum tracks
- Always 2 – 3 layers hit





Full Gossip B-layer



- By combining detector layers placed at different radii, wider staves can be made, increasing the momentum of inertia

Research programme at this working point

- **Position resolution**
  - Simulation
  - Experimental
    - Gossipo-2 tracker, Timepix/PSI46 tracker
- **Rate capability**
  - Operation possible for G = 5000 @ 0.9 GHz/cm^2?
- **Ageing**
  - Clean gas system
  - Can we permit certain amount of epoxies?
  - How critical are we for pollution?
- **Charge collection time**
  - Ionic drift time

Research programme cntd

- **Frontend design and ASIC development**
  - Slewing correction in frontend
- Developing **production technology** (thin /thick film photolithography)
- Design **mechanical layout**
- **Simulations**
  - **Including time slewing**
- **Powering**
  - Serial/parallel?
  - Optical powering? (study Martin Fransen)
- **DAQ managing**
  - Iflink

Summary

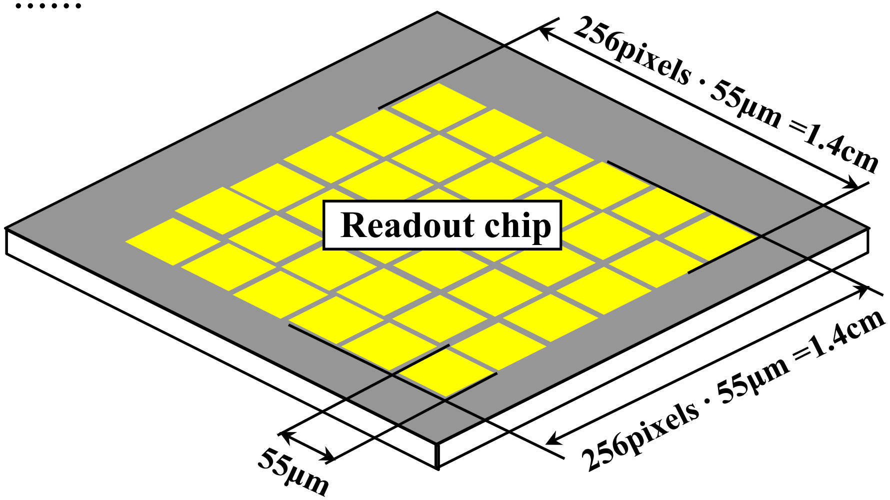
- Applying the Gossip technology in the pixel layers brings great benefits
  - Very relaxed cooling requirements
  - High radiation tolerance
    - 3.4×10^{16} MIPS/cm^2 possible
  - Low costs (no bumpbonding)
  - Low material budget (1.25%)

- But we don't get it for free
  - We might have to face ageing phenomena, but they are probably solvable
    - Many ageing tests to be done, more time consuming than for solid state detectors
  - New technology without running experience
  - Less good position resolution
    - Limited statistics in primary ionization
  - Additional services (HV, gas)
  - Possibly more dead area
    - => more layers required

SPARE

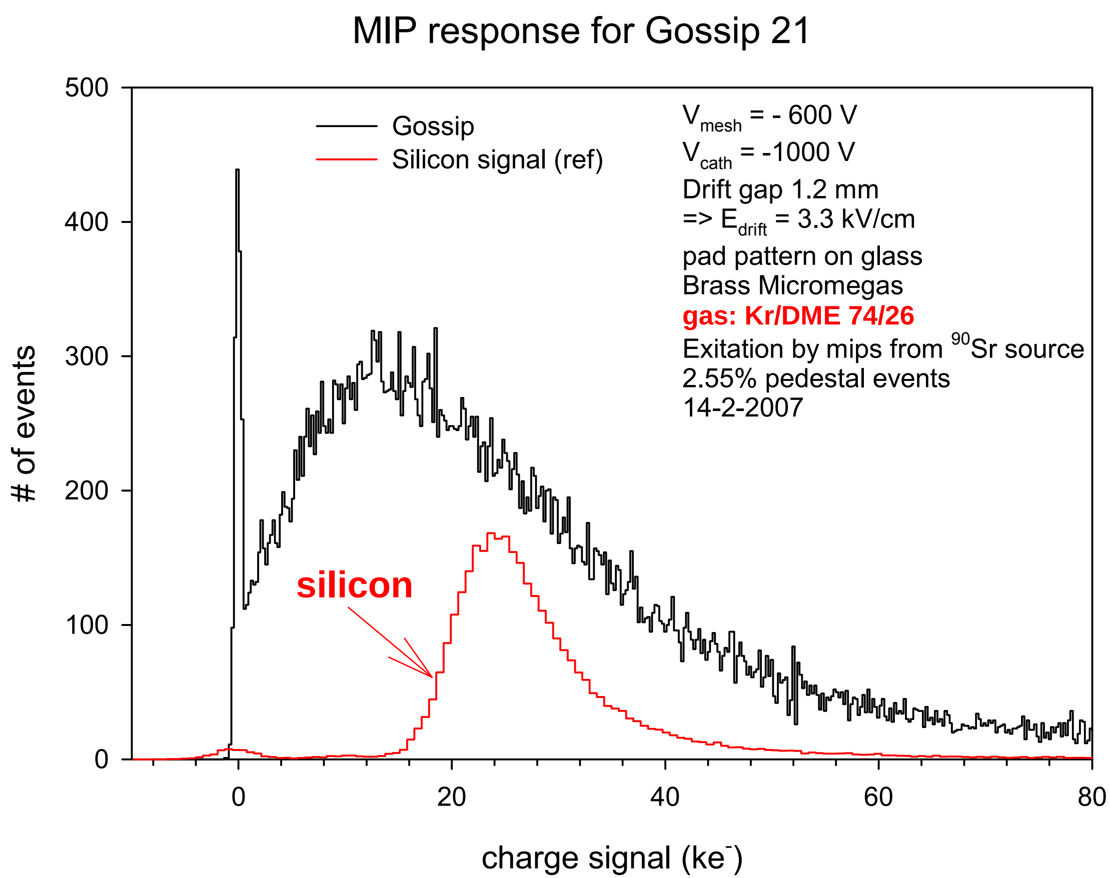
Planned to incorporate into Timepix-2 chip

- **Designers**: CERN, NIKHEF, Bonn, Saclay ......
- **Technology**: IBM 0.13 um CMOS
- **Power:** ~ 0.5W/cm^2
- **Functionality**
  - single pixel operation only
  - noise ~ 70e$^-$ RMS
  - threshold < 400e$^-$ (spread ~ 40e$^-$)
  - TDC-per-pixel
  - hit timestamp < 2ns (for signals > 4000e$^-$)
  - TDC dynamic range (under discussion)
  - analog information ToT / Dual Threshold (under discussion)
  - local (on-pixel) memory (multiple hits)
- **Readout**
  - external 40MHz clock
  - data taking and data readout are independent and run in parallel
  - fast serial link (≥1Gb/s)



Example of charge signal distribution

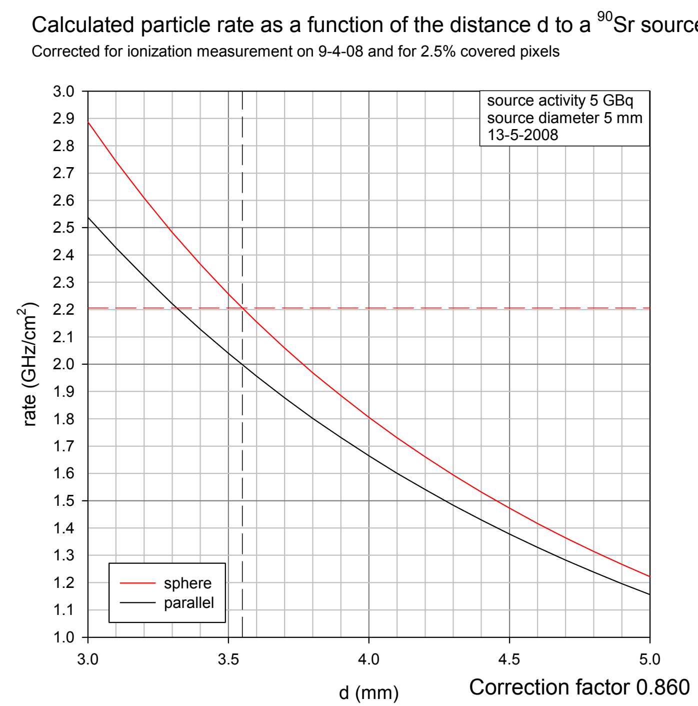
- MIPs traversing a 1.2 mm wide drift gap
- Kr/DME 74/26
- Gain ~1000
- pdf ~ 1.2
- Pedestal peak 2.55%
- Background triggers 1.74% from characterisation station
- → **inefficiency** from empty hits (no primary ionization): 0.81 %



Method for Gossip ageing studies

Nikhef irradiation facility
5 GBq ^{90}Sr source

- Gammas like used in GIF++ (622 keV) do NOT give representative results for MIP ageing (if ever a micro pattern gas detector can be operated at all in this environment)
- Very intense MIP irradiation (direct PS beam) has a too high rate → continuous sparking
- Best is a steady MIP source like ^{90}Sr
  - Test beams do not operate for months with 100% duty cycle



- Example: Nikhef irradiation facility
- ~ 2 GHz/ cm^2 max on small surface
- **→ 200 days to achieve 3.4*10^{16} MIPS/cm^2**
- We probably cannot do this much faster

Variation of the gas gain

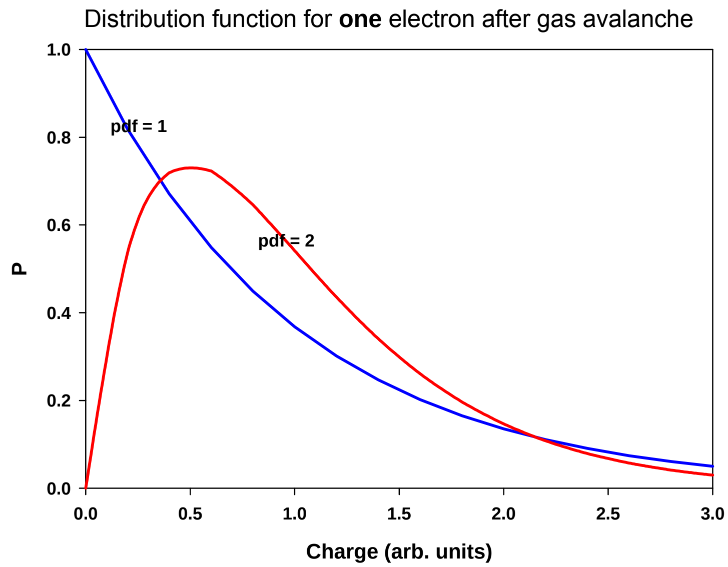
- Dominated by Poisson statistics
- Basically exponential distribution for single electron
- But in practice a bit less variation
  - Curve can be described by the (empirical) Pólya function
  - pdf = 1 → pure statistical avalanche growth

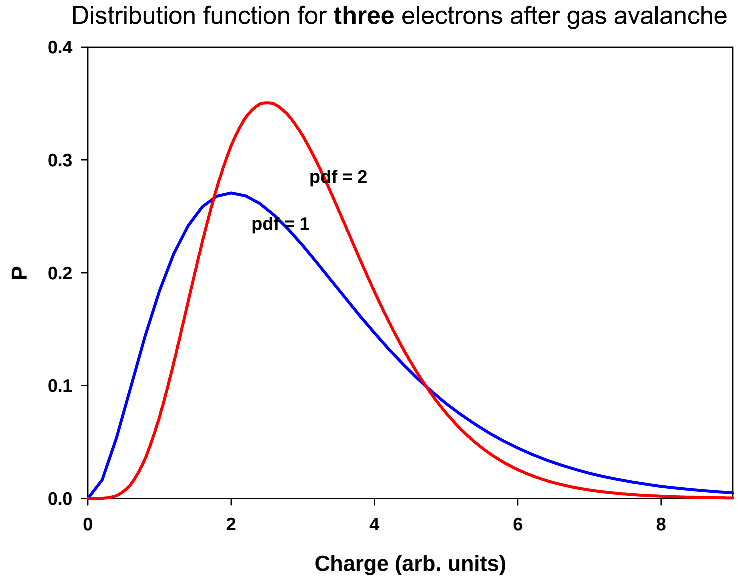
$$P\left(x, n_e = N\right) = \frac{x^{N-1}}{\left(N-1\right)!} \cdot e^{-x}$$

  - pdf = 2 → avalanche growth depending on its size

$$P\left(x, n_e = N\right) = \frac{2^{2N}}{\left(2N-1\right)!} \cdot x^{2N-1} e^{-2x}$$

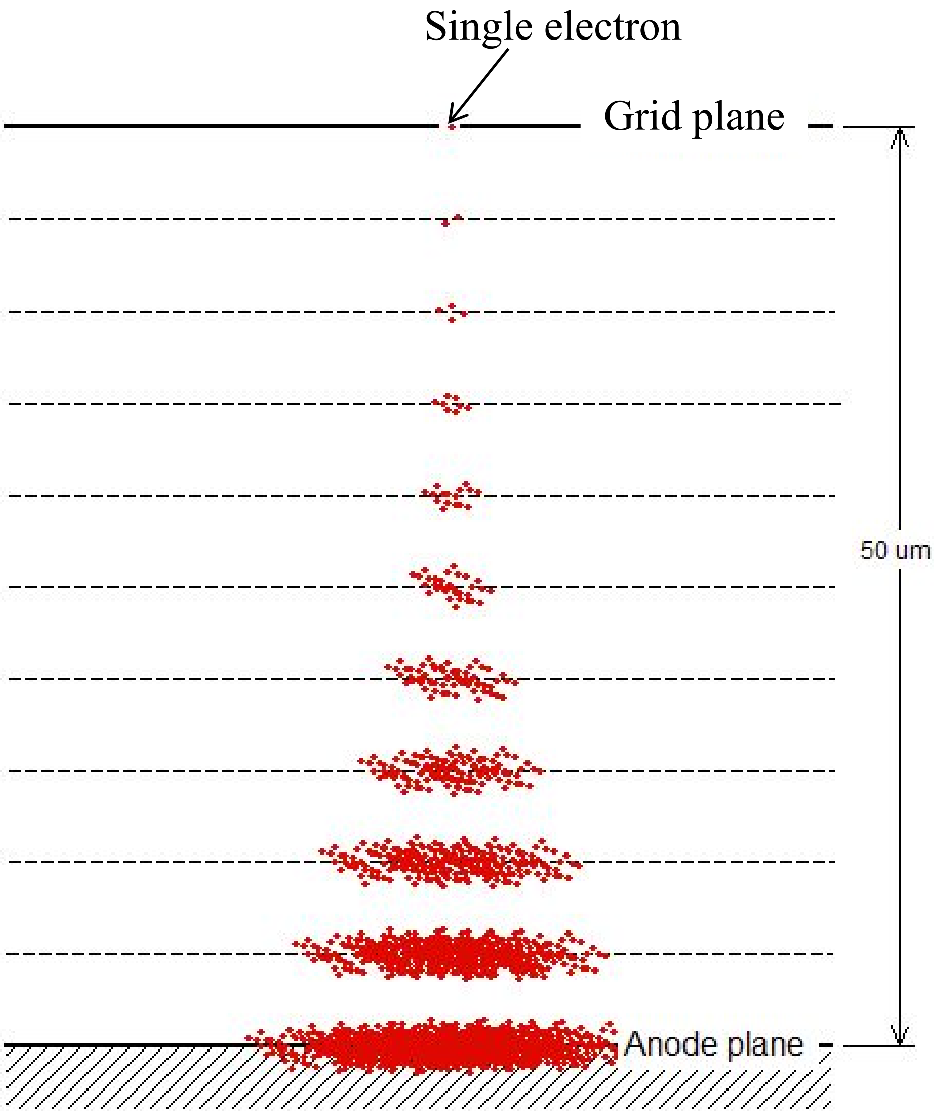
- Experimental results: pdf ≅ 1.0 – 2.5





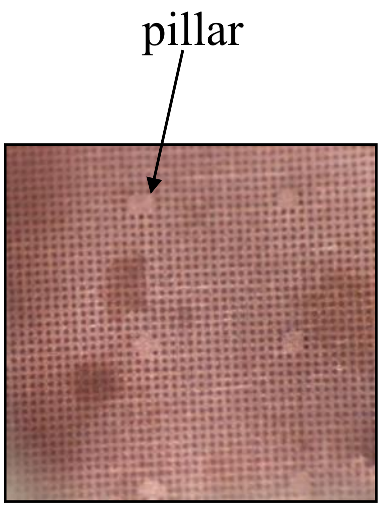
Gas amplification in Gossip

- Gas amplification occurs by the ionization at collisions between a free electron and the molecules of the chamber gas (avalanche process)
- For this example (Gossip geometry) we have a homogenous electrical field
- We subdivide the amplification area into 10 zones
  - For a gas gain of 1000 each zone creates 2x charge amplification
- **=> most charge is created within a few µm from the anode plane**

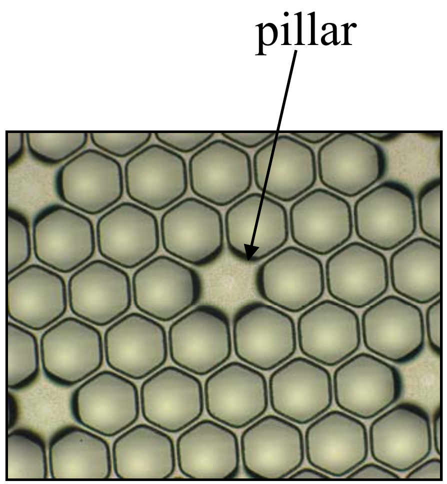


INGRID

- New development where the mesh is deposited onto pixel chip by wafer post processing
- Insulating pillars from photoresist
- Advantages
  - => much better control of mesh-to-chip distance and alignment
  - Less risk on dust in the amplification gap
  - No dead pixels in pillar region



Micromegas
130 µm wide pillars



One of the
INGRID structures
30 µm wide pillars