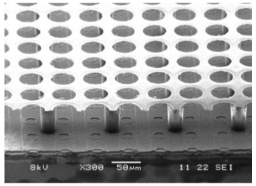
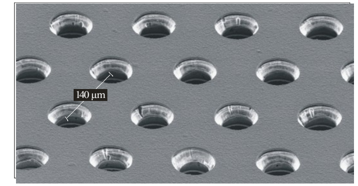


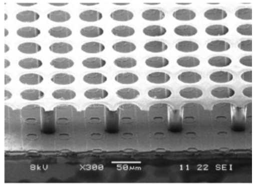


Time Projection Chambers with Micropattern Gaseous Detectors

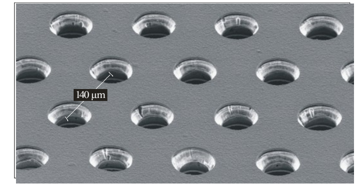
Jochen Kaminski

University of Bonn

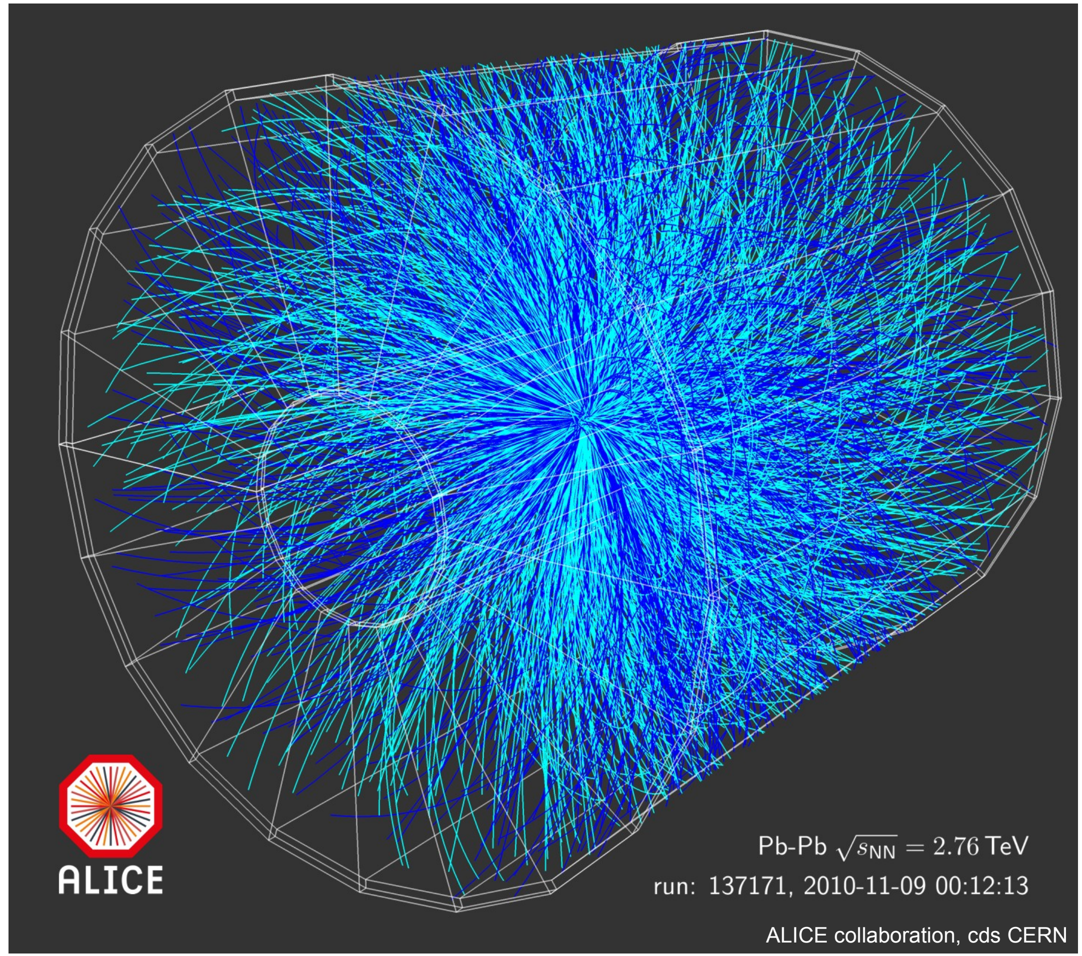
Cygnus-TPC kick-off meeting
Frascati, 7th April 2016

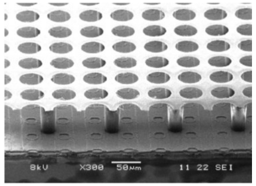


Content

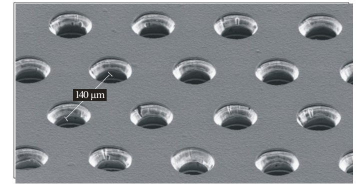


- Historic Overview
- Working principle of TPCs
- MPGDs
    - Micromegas
    - GEMs
    - GridPix
- TPCs with MPGDs
    - Rare events (T2K)
    - Heavy ion physics (ALICE)
    - High energy physics (ILD-TPC)
- Summary



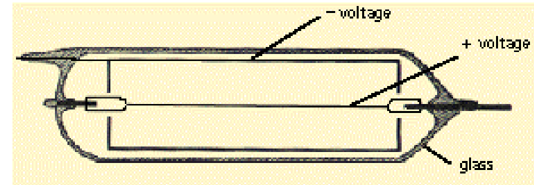


History of Gaseous Detectors



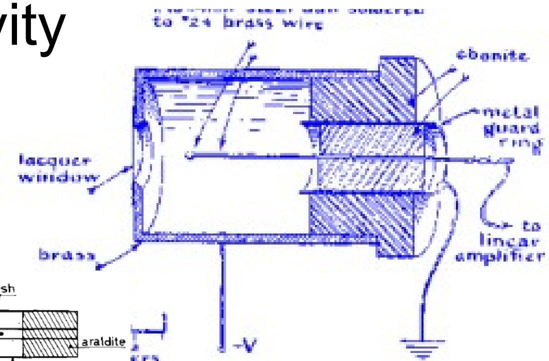
1908: First wire counter used by Rutherford

E. Rutherford and H. Geiger, Proc. Royal Soc. A81 (1908) 141



1928: Geiger-Müller Counter - single Electron sensitivity

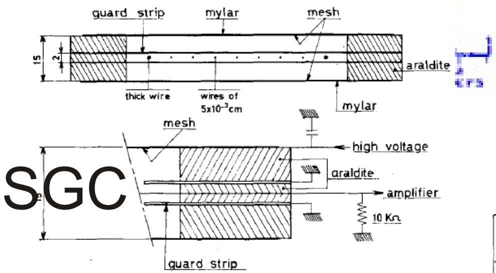
H. Geiger and W. Müller, Phys. Zeits. 29 (1928) 839



1945: Proportional tubes

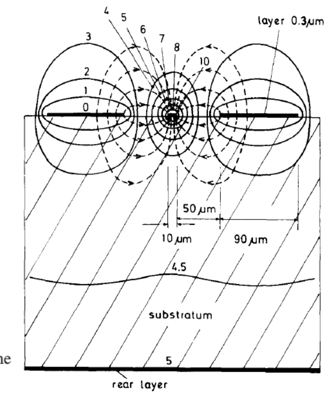
1967: Multi-wire Proportional chambers

G. Charpak, NIM 62 (1968) 262.



1988: First MPGD invented by A. Oed: MSGC

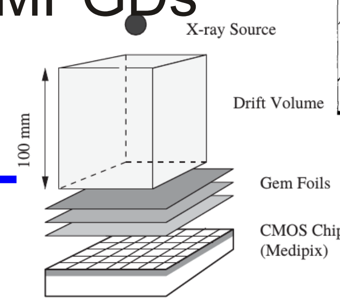
A. Oed, NIM A263 (1988) 351.

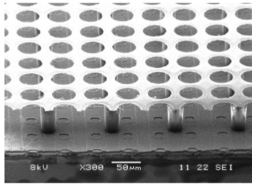


2004: ASIC-based highly pixelized Readout of MPGDs

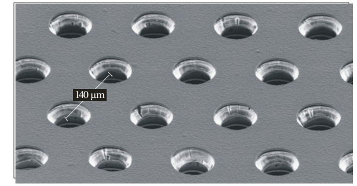
R. Bellazzini, NIM A535 (2004) 477.

H. van der Graaf, NIM A535 (2004) 506.



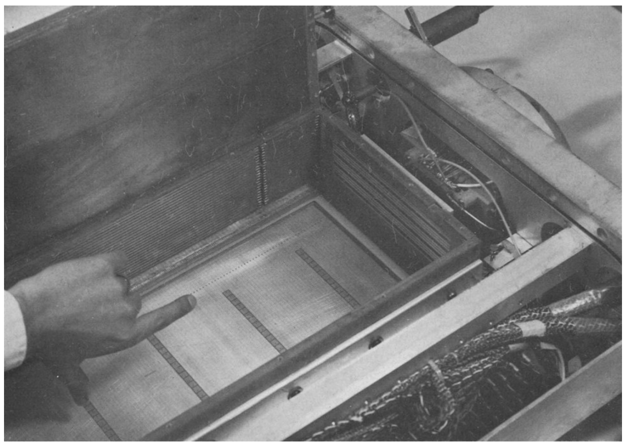


Time Projection Chamber

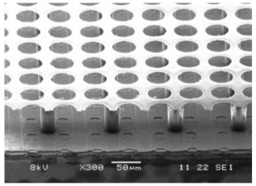


1974 Time Projection Chambers (TPCs) are invented by D. R. Nygren.

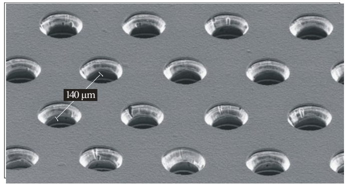
It is said that they went straight from a 90×13 cm² demonstrator with 10 cm drift to a large scale detector with 2 m diameter and 2 m overall length.

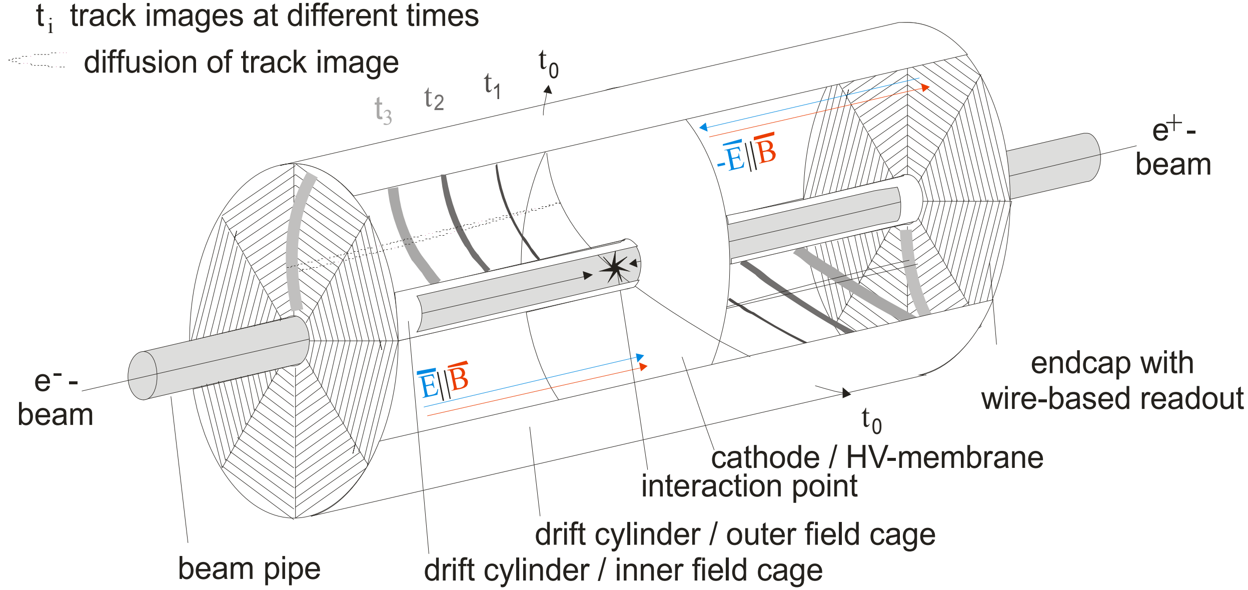


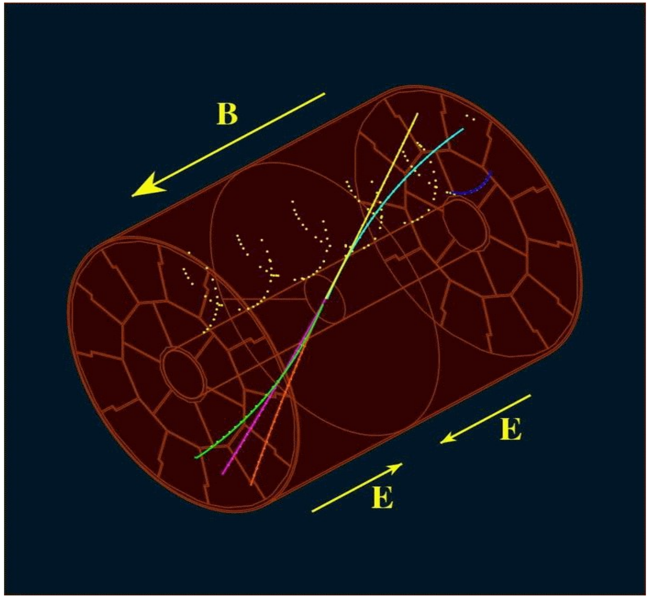
NIM A161 (1978) 383



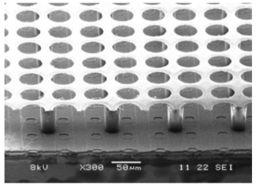
Operation Principle of a TPC



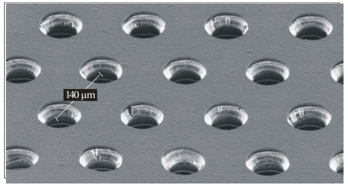




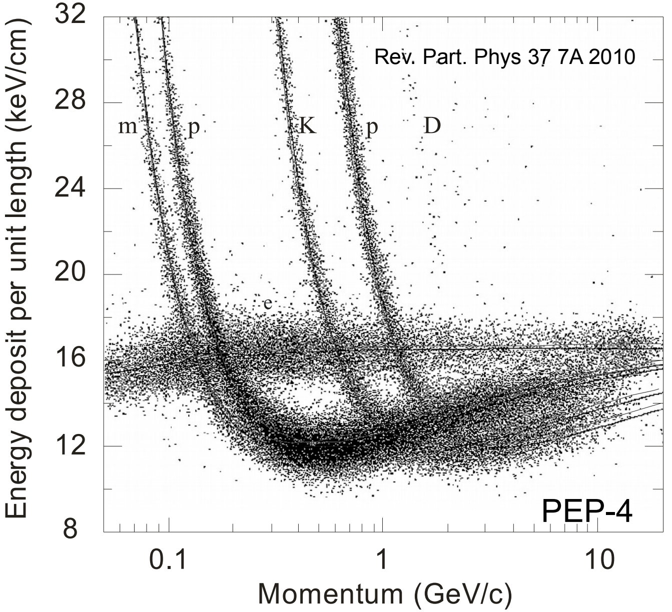
- Large gas filled volume
- Particles traversing the volume ionize the gas
- Electrons drift towards the endcaps
- Signal is amplified and generates a 2D picture
- Measuring drift time allows the reconstruction of 3rd dimension

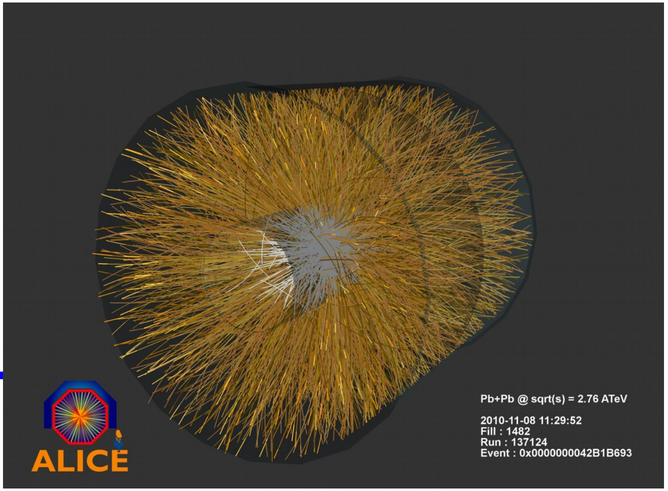


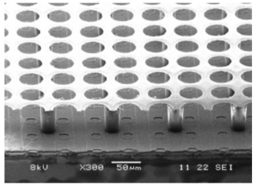
Advantages of a TPC



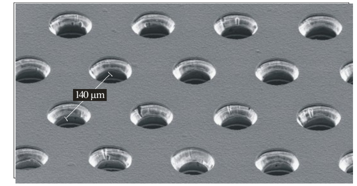
- Good spatial resolution (O(100µm))
- Good energy resolution with dE/dx
- Large number of measurements
- Truly 3-dimensional detector
  (no ambiguities)
- High granularity
- Robust tracking in high multiplicity
  environment
- Low material budget (O(1-10% X_0))
- Very homogeneous (only gas)
- Low number of el. readout channels
  compared to volume
- Comparably cheap



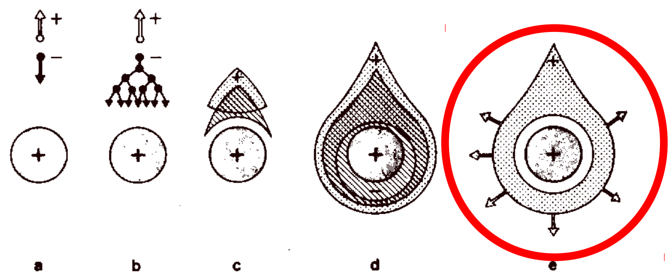




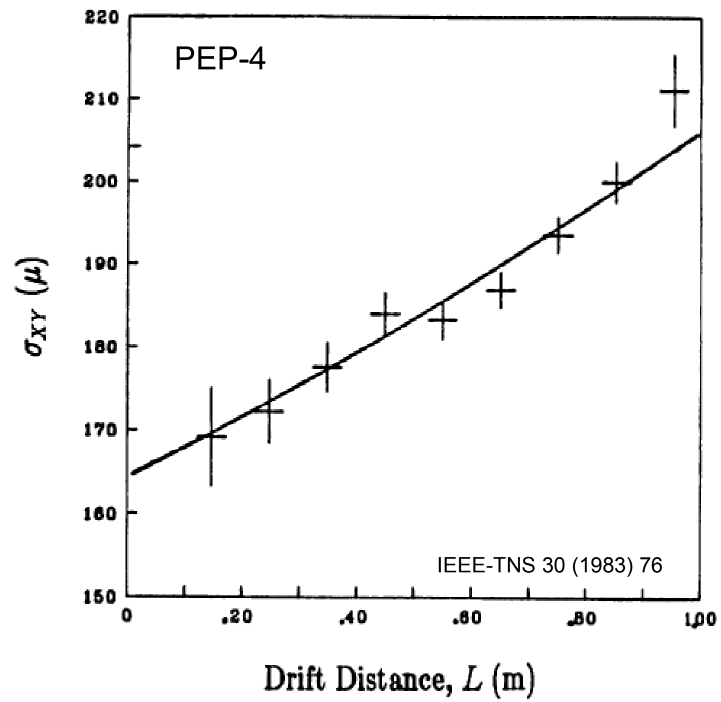
Challenges of a TPC design

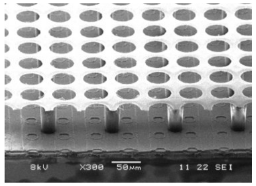


- Long drift times (40 µs)
- Ions have to be neutralized after gas amplification
- Diffusion and pad size limit spatial resolution

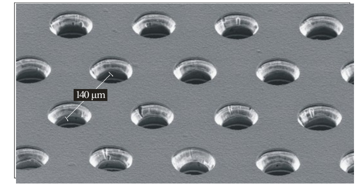


Sauli, CERN-77-09





Application of TPCs

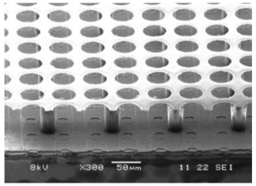


Three major fields of application:

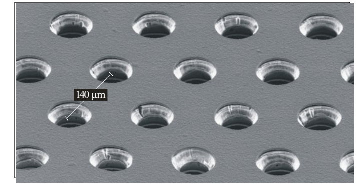
1.) TPCs in rare event searches (T2K, XENON, NEXT)

2.) TPCs in Heavy Ion Physics (STAR, ALICE)

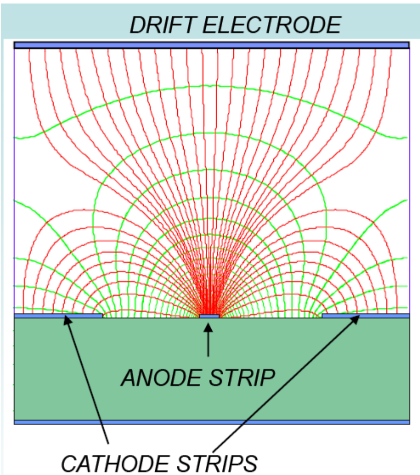
3.) TPCs in High Energy Physics (PEP-4, ALEPH, Delphi, ILD)

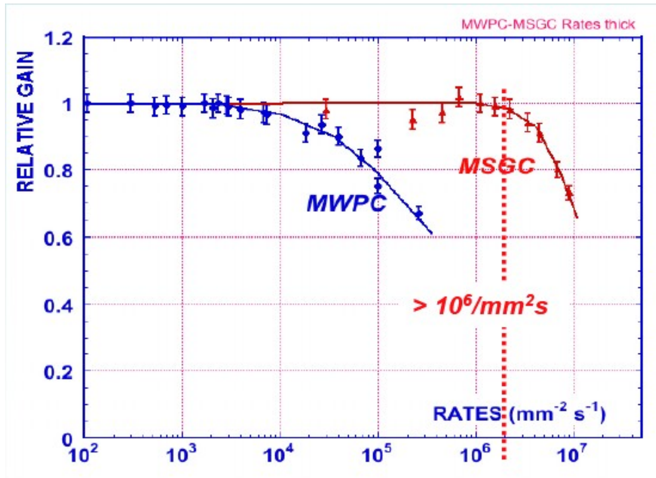


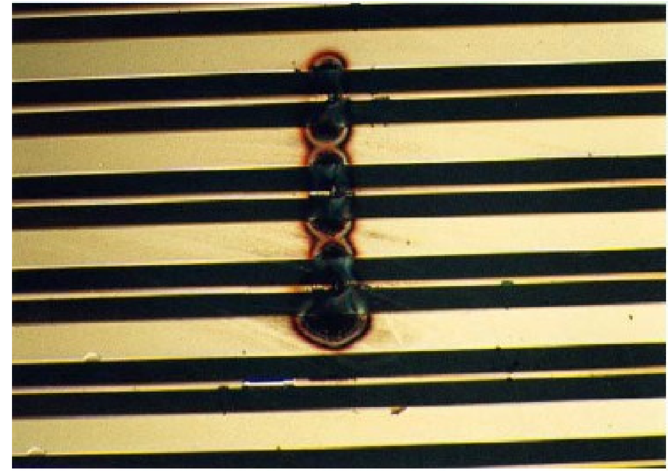
MPGD



In 1988 A. Oed introduced the age of micro pattern gas detectors.

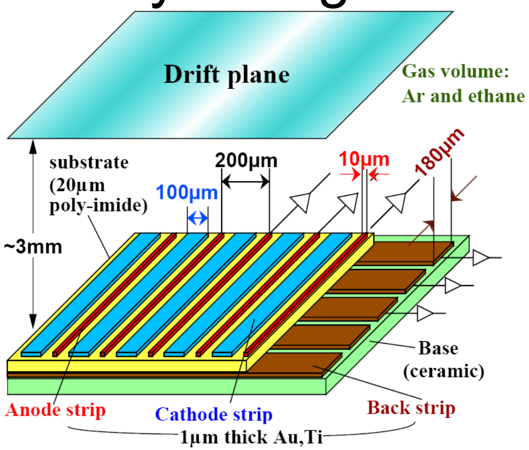




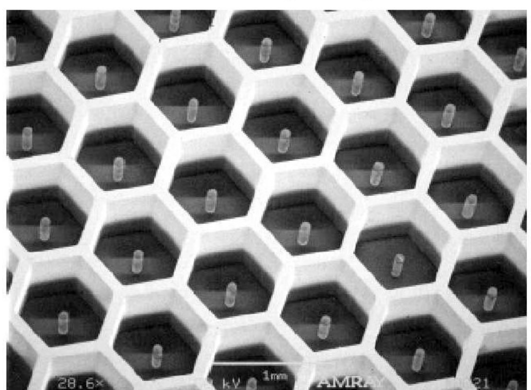


AnnRevNuclPart 49 (1999) 341

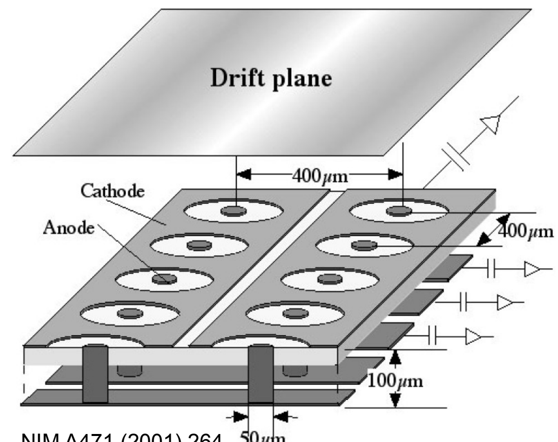
Many new geometries were tested, …



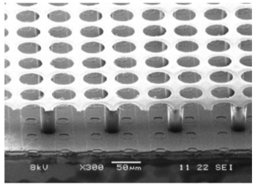
MICRO-PIN ARRAY (MIPA)



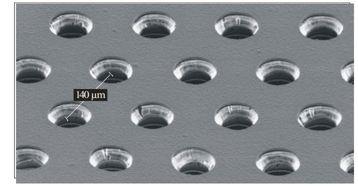
but only 2 prevailed

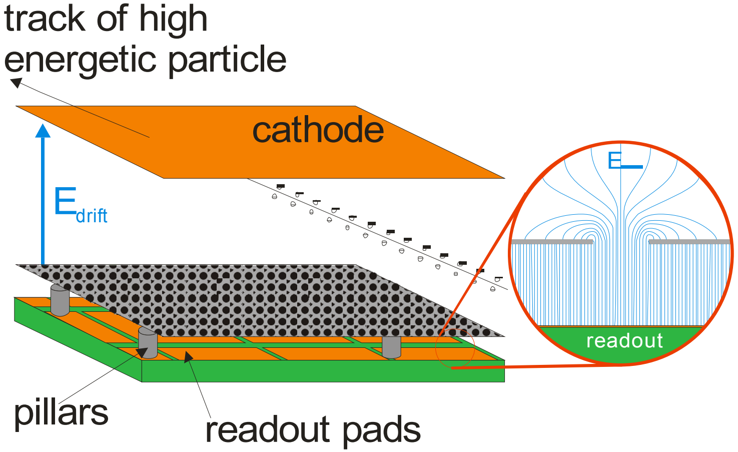


NIM A471 (2001) 264

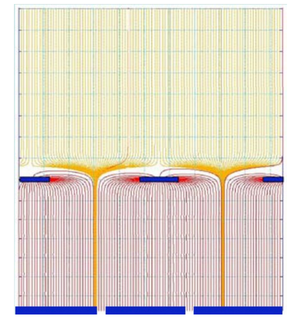


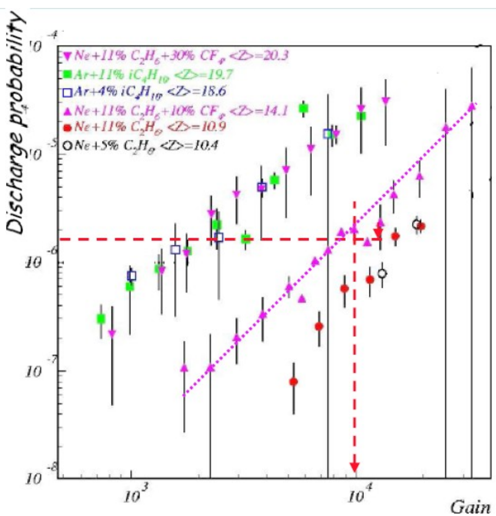
Micromegas



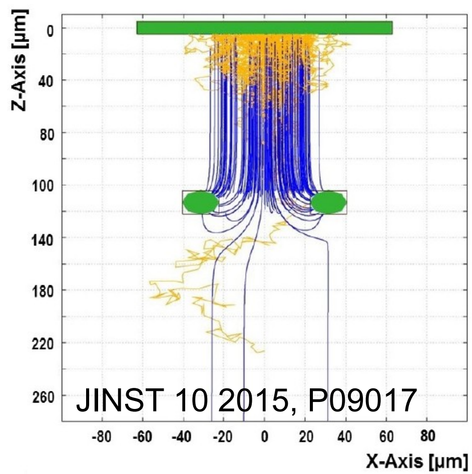


Micromegas consist of a mesh placed 50-150 µm above the readout pads. Gas amplification takes place in the gap between the grid and the pads.

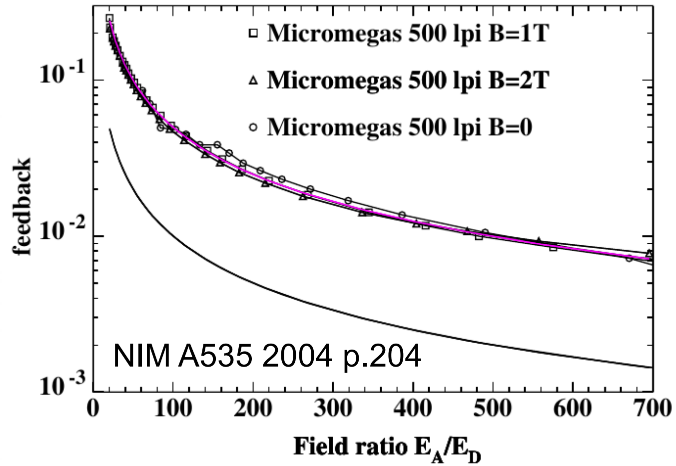


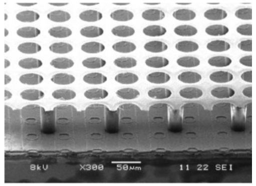


discharge probability of the tracker of COMPASS: $\sim 10^{-6}$

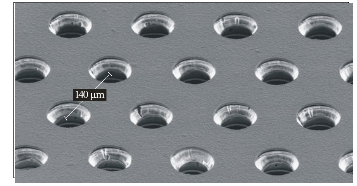


Low ion backflow





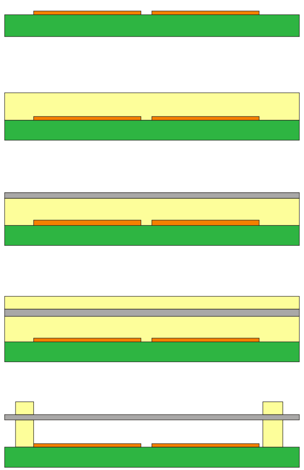
Production of Micromegas



First Micromegas had quartz spacers between mesh and readout
many test followed: e.g. with fishing lines

IMPORTANT: optimize for high gains and good energy resolution
=> keep gap between grid and anode as precise as possible

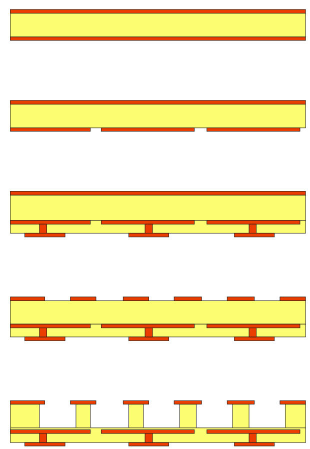
1. Bulk-Micromegas



- copper pads on FR4
- photosensitive film
- positioning of mesh
- encapsulating of mesh
- development of spacers

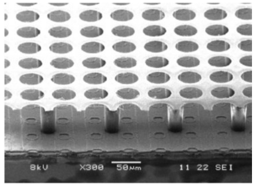
Bulk Micromegas produced by lami-nation of a woven grid on an anode

2. Microbulk-Micromegas

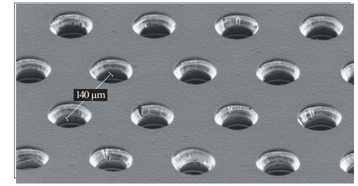


- 50 µm Kapton, with 5 µm Cu on both sides
- patterning of readout pads
- attaching Kapton/Cu-layers, via construction, readout patterning
- mesh patterning
- Kapton etching (pillars)

Microbulk Micromegas produced by etching from kapton/copper sandwich

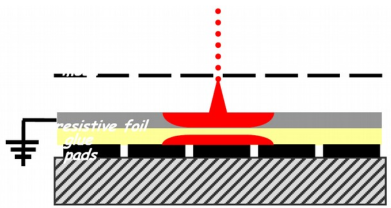


MPGDs with Resistive Electrodes



The latest area of interest is the application of resistive material for electrodes, analog to RPCs, to avoid and/or stop discharges:
If a streamer develops, the current in the electrode towards the point of discharge is limited, therefore, the el. potential drops locally and the streamer breaks down.

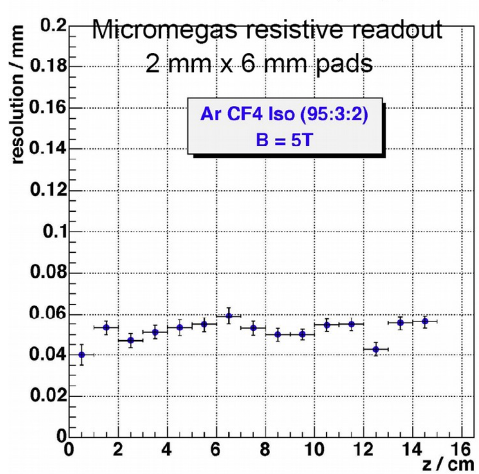
1. Spreading of the charge after gas amplification to broaden the signal shape: the readout pads are covered with a resistive foil.



NIM A581(2007) 254

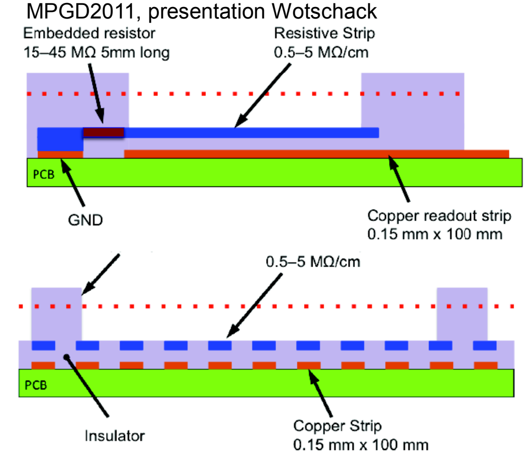
B= 5 T D_T= 19 µm/√cm

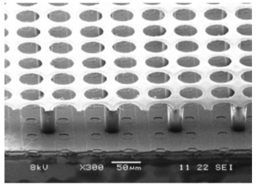
M. Dixit et al., NIM581(2007)254-257



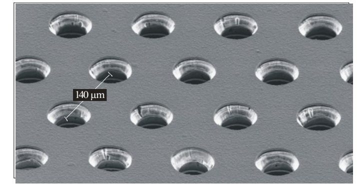
2. Collecting the signal on resistive strips and coupling the signal capacitivly to the readout strips.
=> no charge spreading

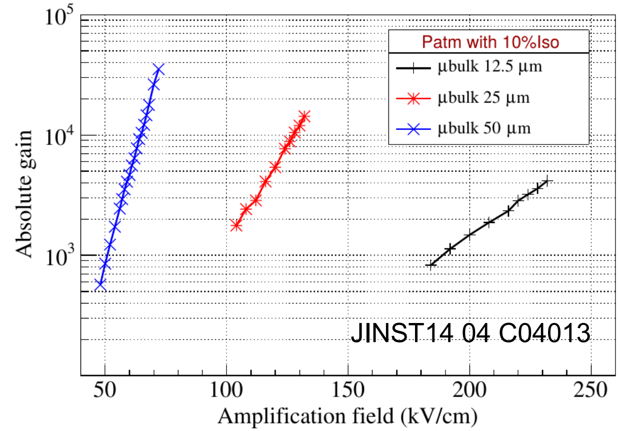
MPGD2011, presentation Wotschack





Further Studies with MMs





Small gap Micromegas:

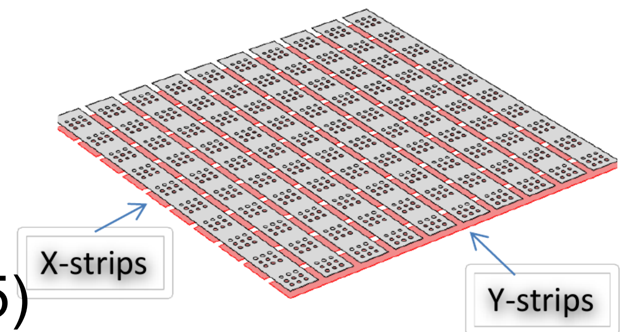
Various gap sizes between grid and readout have been studied.
Standard gap sizes (NIM A732 2013 p.208) and small gap sizes (JINST14 04 C04013)

Genetic Multiplexing:

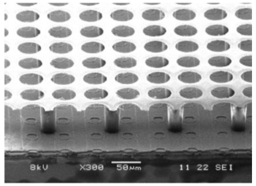
To reduce the number of electronic readout channels necessary to cover a certain area, strips can be smartly combined to one readout channel and position determined by finding adjacent strips with signal at the same time.(NIM A729 2013 p.888)

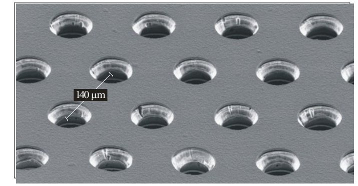
X-y readout of Micromegas:

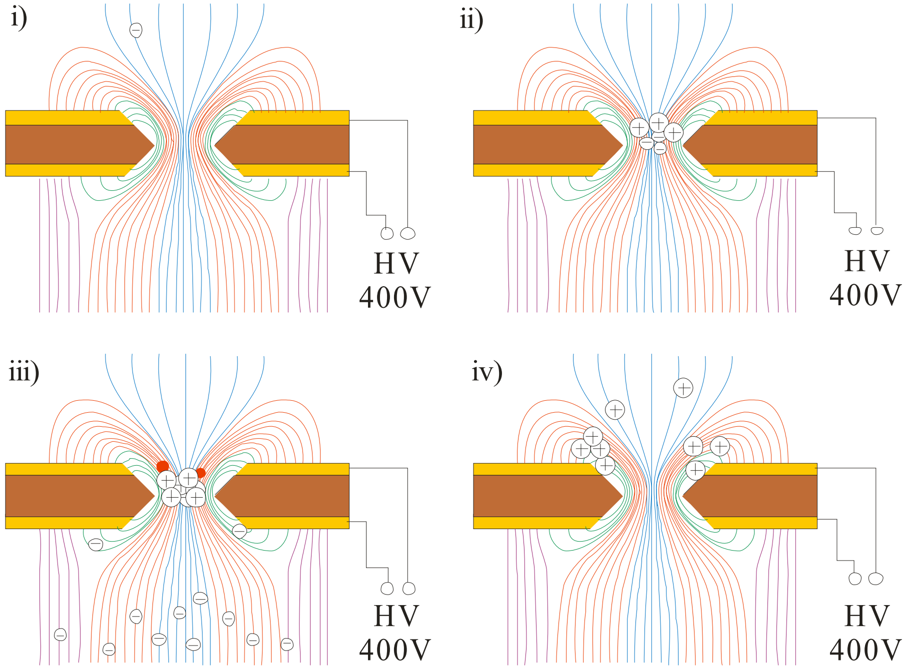
To obtain the 2D position information of a hit, both the readout and the grid are patterned with strips perpendicular to each other. (PoS (TIPP2014) 055)

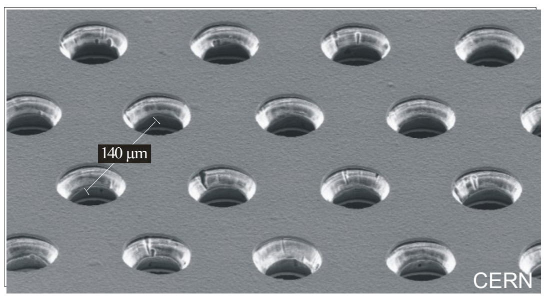


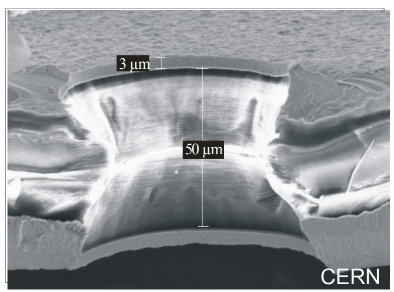
GEMs



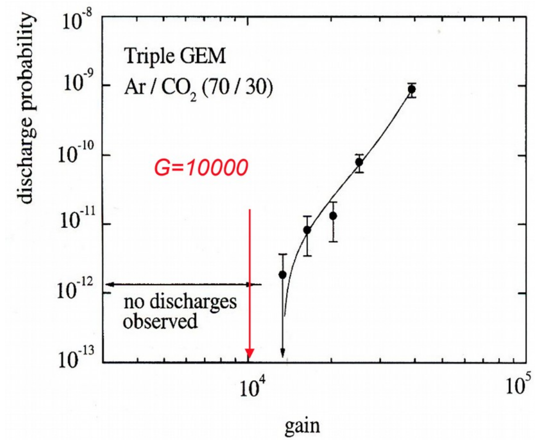




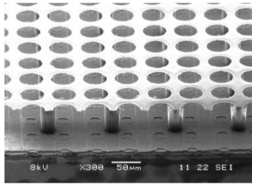




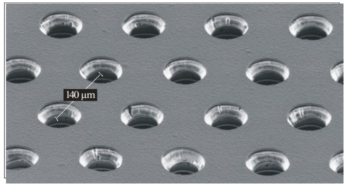
GEMs are made of a copper-kapton-copper sandwich, with holes etched into it. 'Standard CERN-GEMs' have a hexagonal pattern with:
Hole pitch 140 µm
Hole diameter 50-70 µm
Often GEMs are stacked to reduce the discharge probability



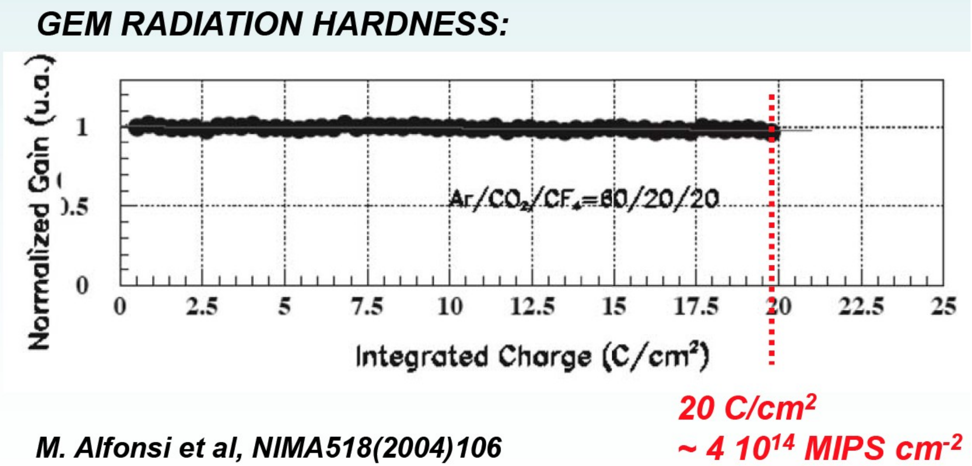
discharge probability of the tracker of COMPASS: $<10^{-12}$



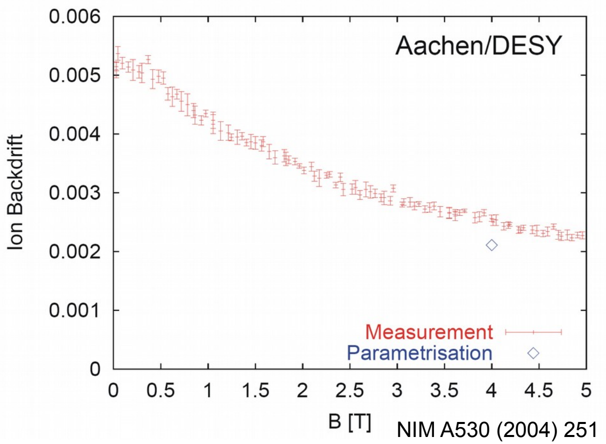
GEMs

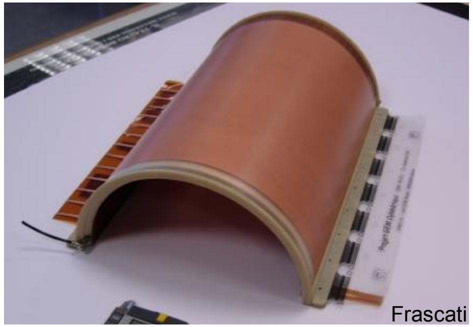


A large number of experiments have lead to a fair understanding of the enormous parameter space in GEM-detectors.

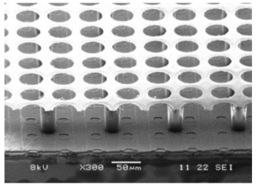


low ion backflow

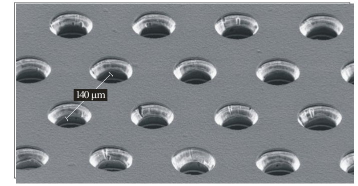




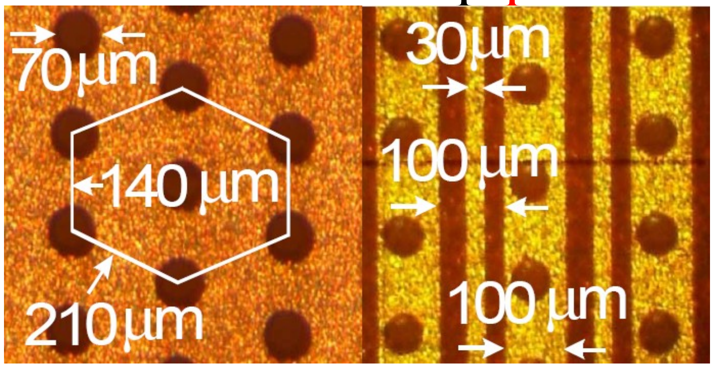
GEMs are very flexible and various shapes can be formed.
GEM sizes are limited by the 60 cm wide base material. But length can be up to 2 m.

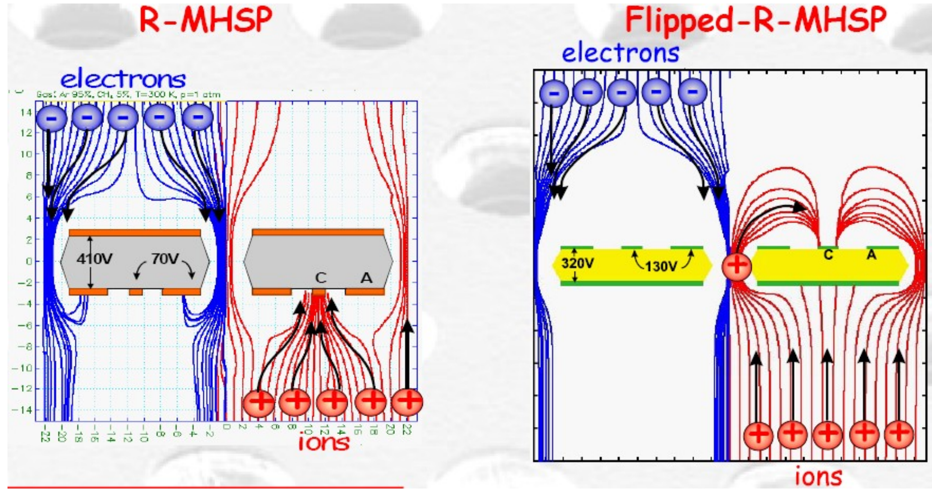


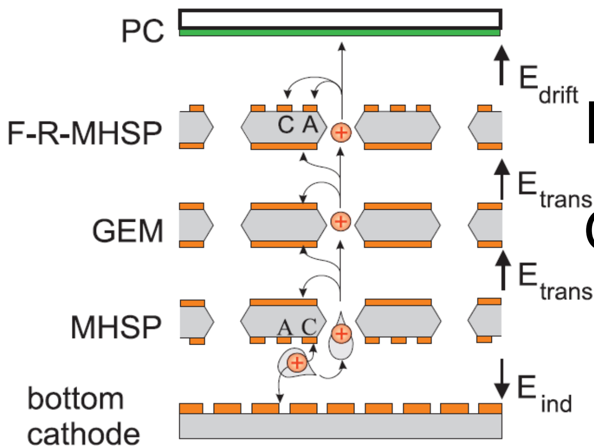
Further Reduction of IBF



Microhole & Strip plate





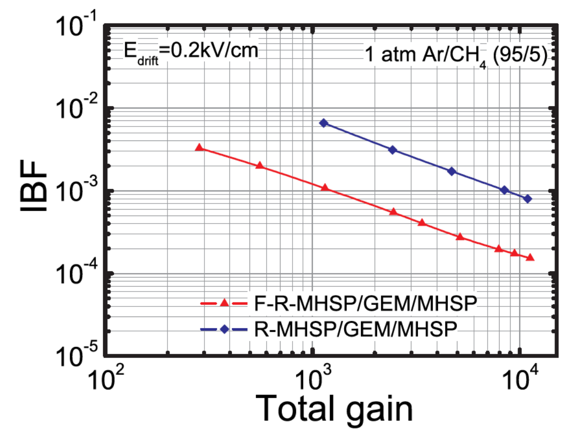


Ion collection

Gas amplification

Gas amplification

Jinst 2006 10 P10004
Jinst 2007 08 P08004



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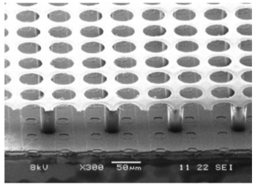
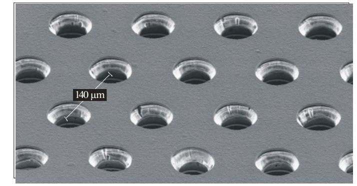
Even better with COBRA GEMs (JINST 9 2014 C03014).

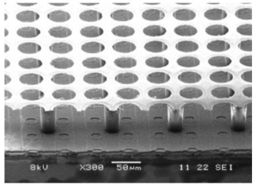


Derivates of GEMs

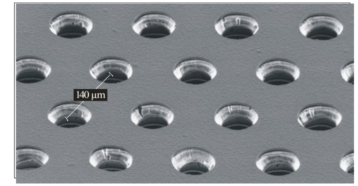


Thick GEMS (THGEM): made of PCB material:
FR4 as insulator, holes are drilled
=> holes pitch/diameters are larger
Performance somewhat degraded compared
to 'Standard CERN GEMs' (e.g. spatial resolution)

Changing the insulator:
Glass GEM (NIM A724 2013 p.1),
Ceramic THGEMs (Chinese Physics C 39(6), 2015),
Teflon GEMs (JINST 9 2014 C03016),
LCP GEMs (see LCTPC)

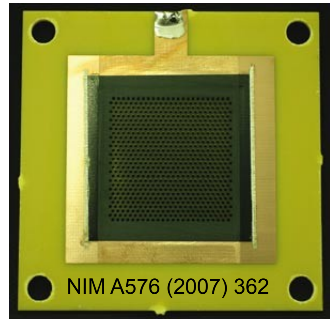


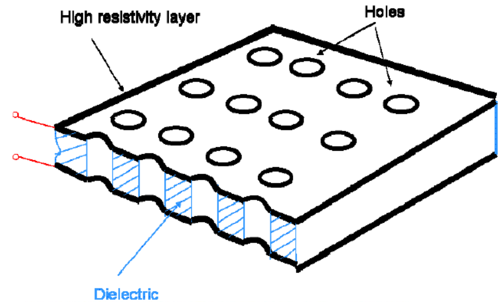
Resistive Electrodes



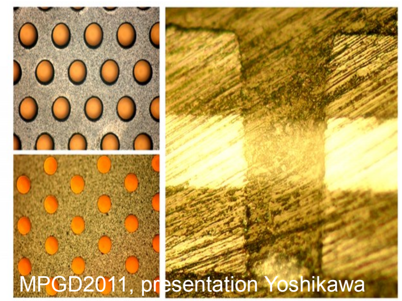
To further reduce the discharge probability of GEMs. various methods to make electrodes resistive are tested. Examples are:

<u>1.) RETGEM</u> (NIM A576 (2007) 362):
0.3-0.8 mm, pitch 0.7- 1.2 mm,
thickness 0.5-2 mm.
Electrodes with resistivity: 200-800kΩ/cm
made of kapton 100XC10E / PVC

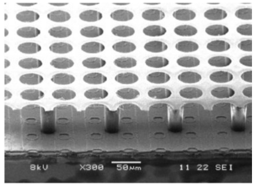




<u>2.) RE-GEM</u> (JINST 7 2013 C06006)
Sandwich of resistive kapton and bonding sheets,
possibly also a liquid crystal polymer.
Holes are laser drilled



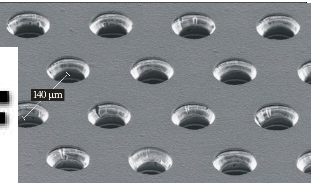
<u>3.) Carbon coated GEMs</u> (NIM A423 1999 p.297)
Covering the Cu electrodes with a resistive
material, so sparks can not develop.

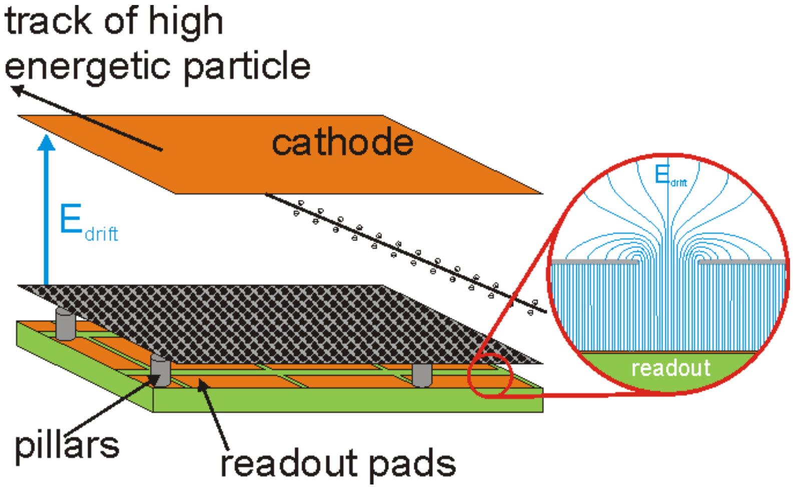


MESA+ Institute for Nanotechnology

GridPix

NIKHEF





Could the spatial resolution of single electrons be improved?

Ar:CH_4 90:10 → σ = 24 µm

Ar:iButane 95:5 → σ = 24 µm

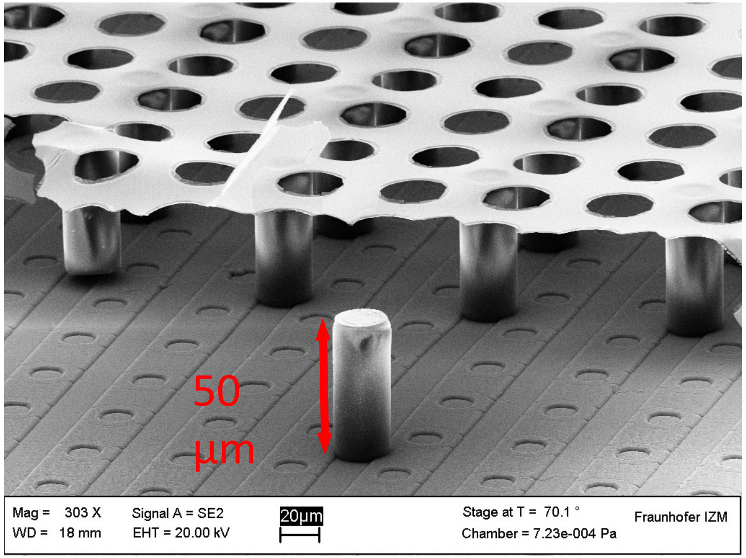
Smaller pads/pixels could result in better resolution!

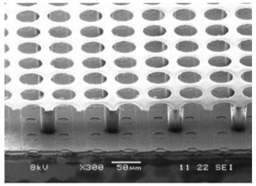
The GridPix was invented at Nikhef.

Standard charge collection:

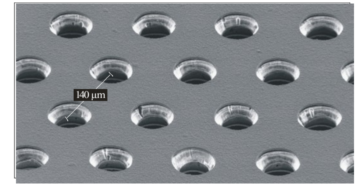
- Pads of several mm²
- Long strips (l~10 cm, pitch ~200 µm)

Instead: Bump bond pads are used as charge collection pads.





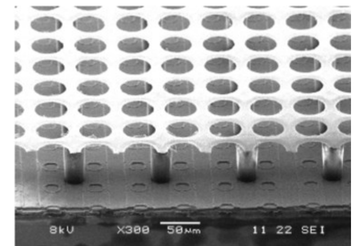
History/Nomenclature



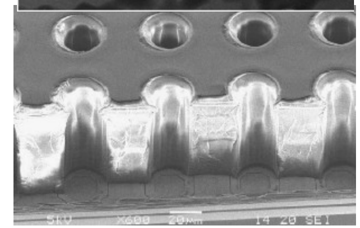
MPGDs with Pixel readout: 200 µm pad realized in PCB-technology (NIMA 513, pp. 231, 2003)

Gas Pixel Detector (GPD): single GEMand dedicated CMOS ASIC (NIMA, 566, pp. 552,2006)

Timepix / Medipix2: CMOS-ASIC designed by the Medipix collaboration, originally planned as an imaging chip for medical applications (NIMA 581, pp. 485, 2006)



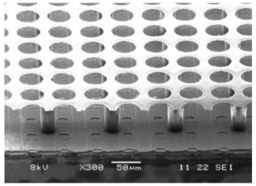
InGrid: Integrated Grid: Micromegas structure built on top of pixel chip with industrial postprocessing techniques (NIMA 556, pp. 490, 2006)



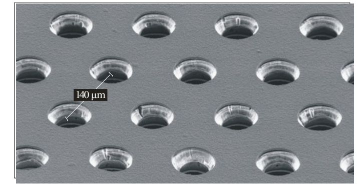
GridPix/GasPix: complete detector based on InGrids + Pixel chip including cathode, gas volume etc.

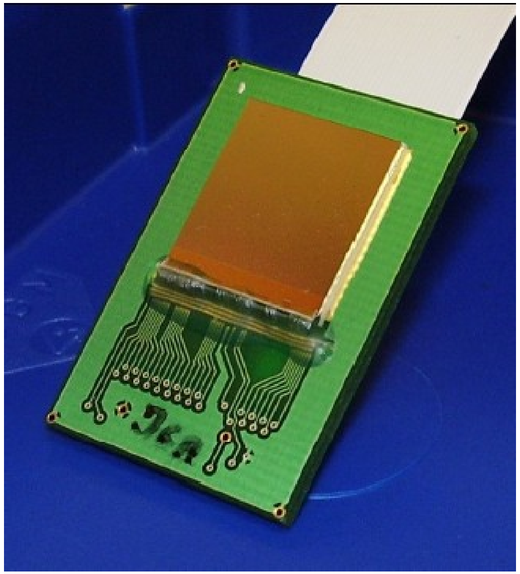
GEMGrid: Same as InGrid, but grid rests on solid layer with holes, instead of pillars (NIMA 608, pp. 96, 2009)

Gossip: Gas On Slimmed Silicon Pixels, a very thin GridPix detector with minimal material budget, e.g. 1 mm of gas gap, thinned ASIC



Timepix ASIC

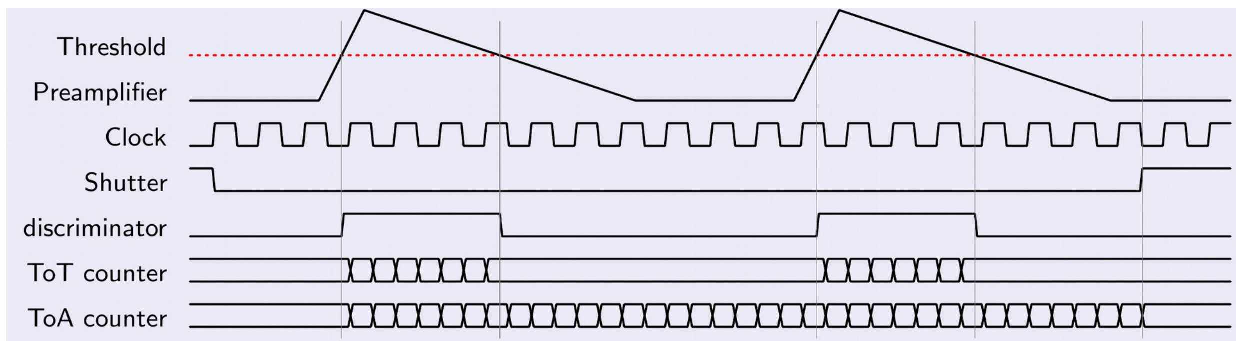


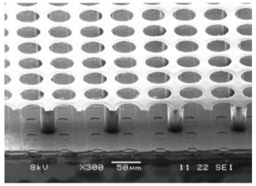


Number of pixels: 256 × 256
Pixel pitch: 55 × 55 µm²
Chip dimensions: 1.4 × 1.4 cm²
ENC: ~ 90 e⁻

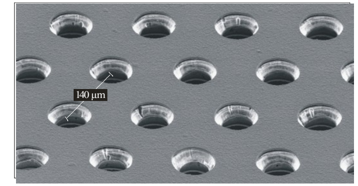
Limitations: no multi-hit capability, charge and time measurement not possible for one pixel. Each pixel can be set to one of these modes: TOT = time over threshold (charge)
Time between hit and shutter end.

Successor ASIC:
Timepix-3 is available.
→ Addresses limitations of Timepix, in particular much faster readout.

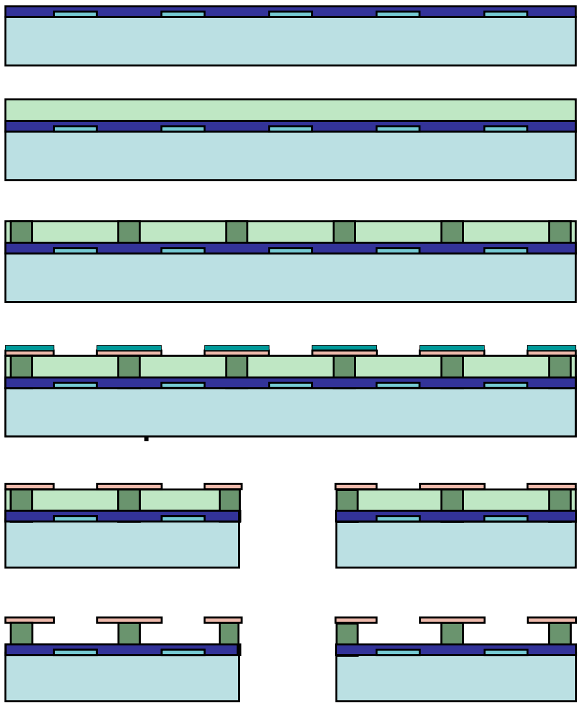




Wafer-based GridPix Production

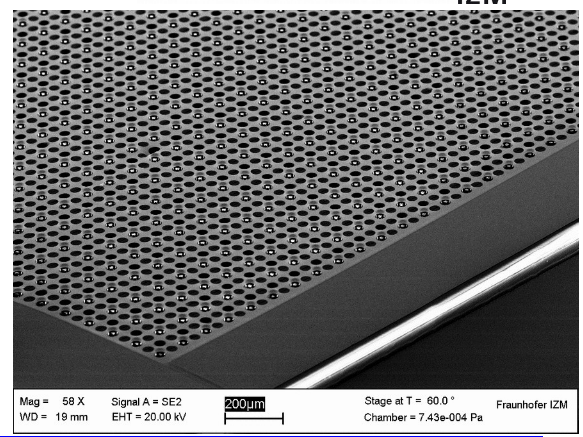


Production at Twente was based on 1 - 9 chips process.
→ Could not satisfy the increasing demands of R&D projects.
A new production was set up at the Fraunhofer Institut IZM at Berlin.
This process is wafer-based → batches of several wafers (107 chips each)

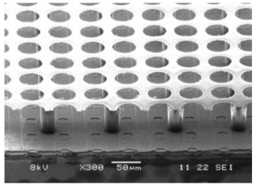


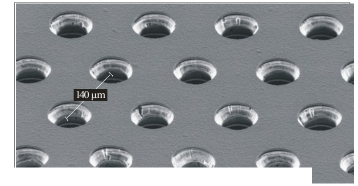
1. Formation of Si_xN_y protection layer
2. Deposition of SU-8
3. Pillar structure formation
4. Formation of Al grid
5. Dicing of wafer
6. Development of SU-8

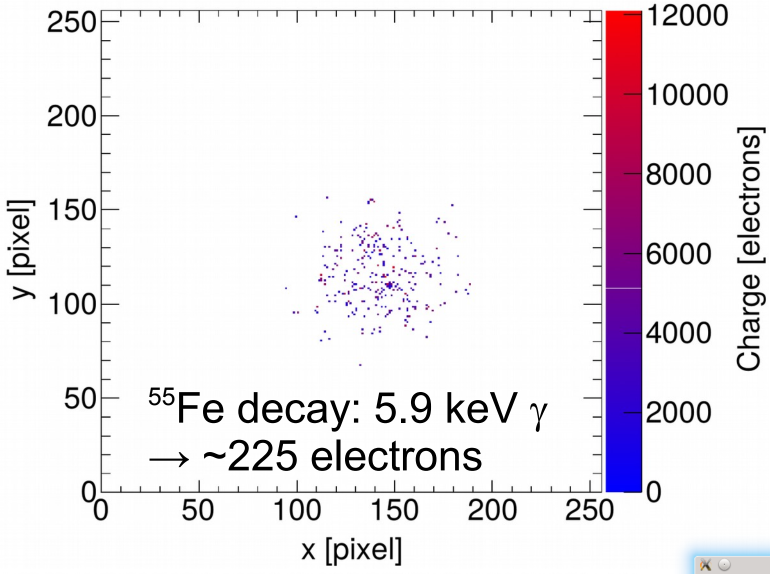
Fraunhofer IZM

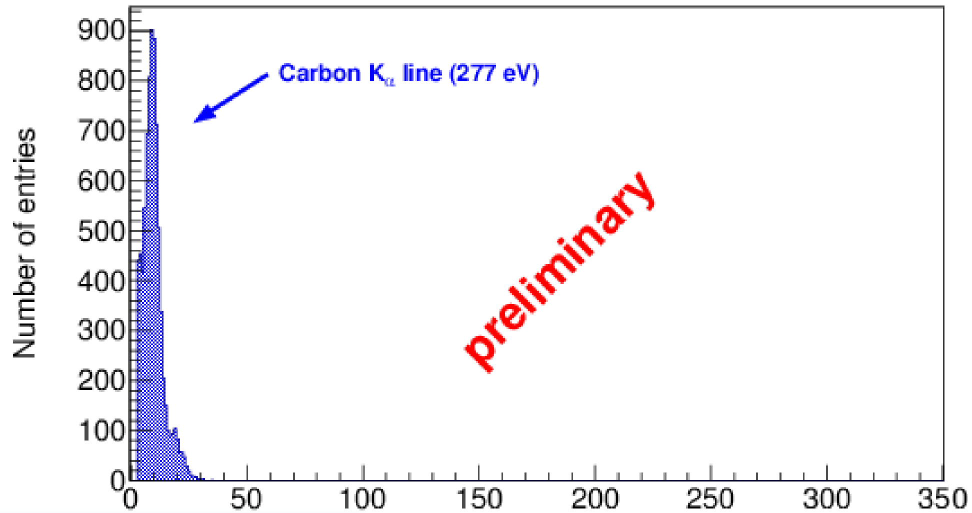


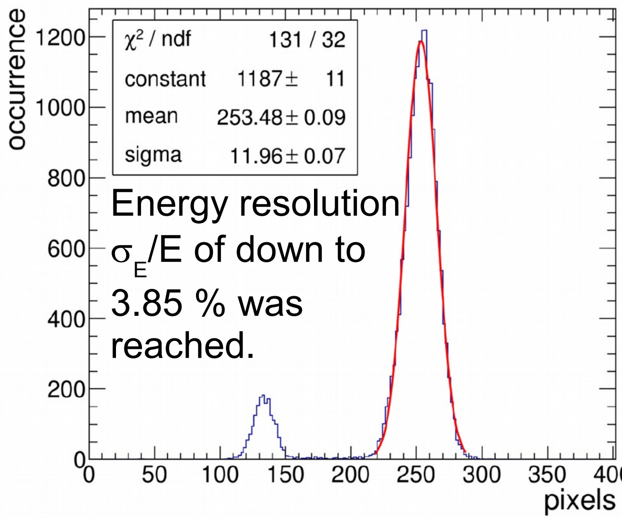
GridPix Performance

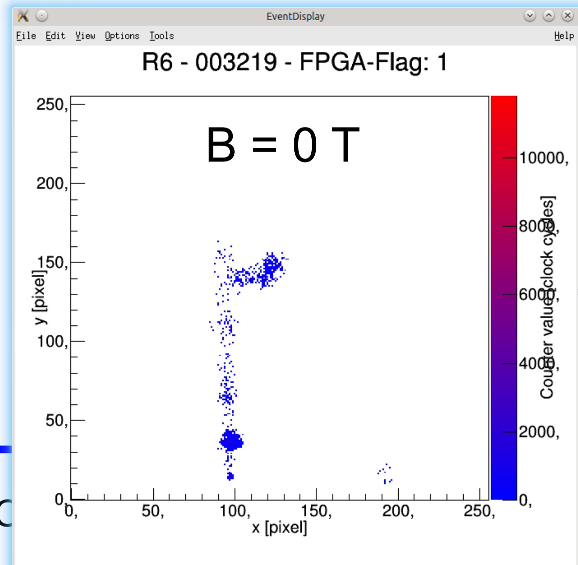


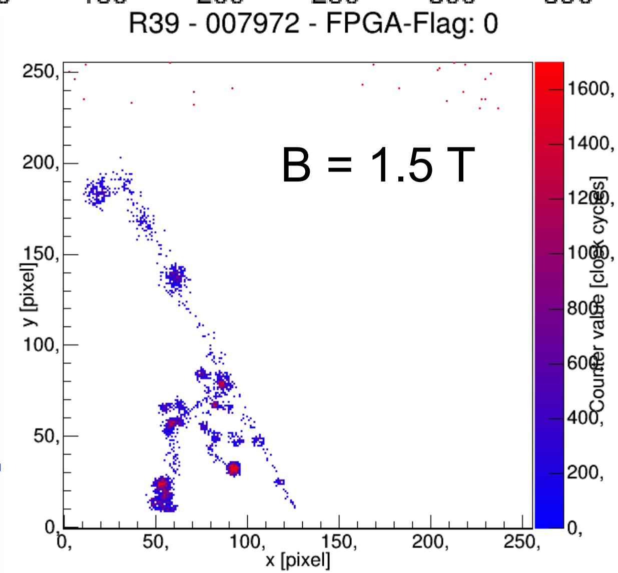


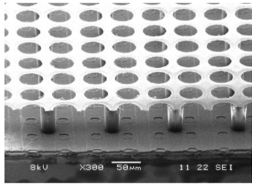




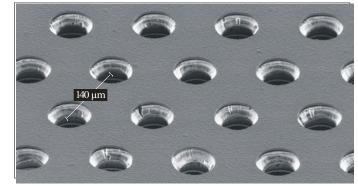




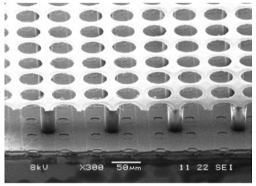


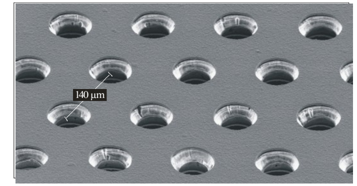


Advantages of MPGDs

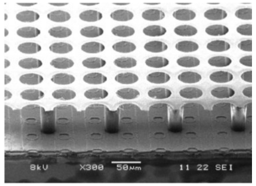


- ion backflow can be reduced significantly
  => continuous readout might be possible
- small pitch of gas amplification regions (i.e. holes)
  => strong reduction of E×B-effects
- no preference in direction (as with wires)
  => all 2 dim. readout geometries can be used
- no ion tail => very fast signal (O(10 ns))
  => good timing and double track resolution
- no induced signal, but direct e^--collection
  => small transverse width
  => good double track resolution

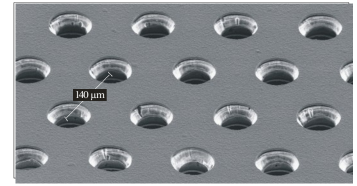




TPCs in Rare Event Searches



T2K

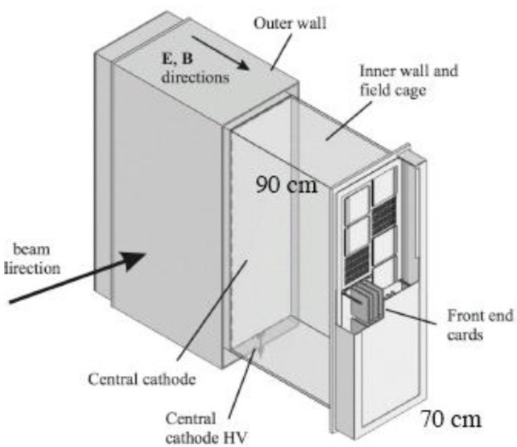


T2K experiment measures $\nu_\mu \rightarrow \nu_e$ oscillations.

Near detector (ND280) characterizes the ν_μ-beam and measures the ν_e contamination 280 m after the target with in a magnetic field (B=0.2T)

Each TPC has the dimension of 2× 70 cm × 90 cm × 200 cm

700 MeV neutrinos undergo CCQE and charged leptons are created.



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Requirements:

$\partial p_t/p_t < 10\ \%$ @ 1 GeV

to measure E-spectrum

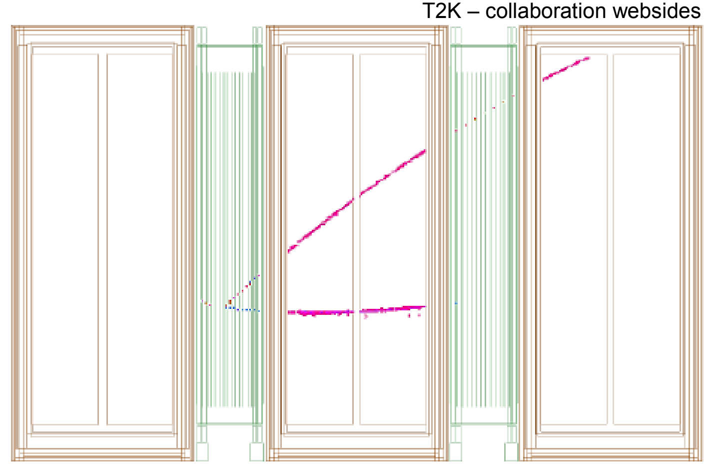
Absolut $\partial p_t < 2\ \%$

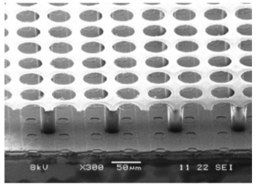
to measure Δm^2_{32}

dE/dx < 10 %

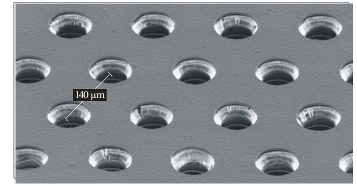
to separate μ and e

T2K – collaboration websides

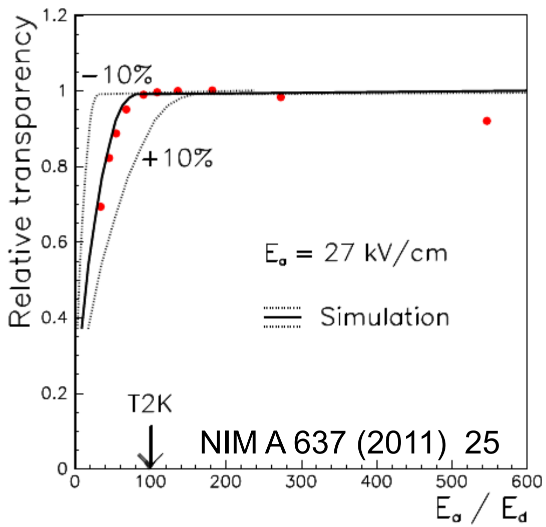


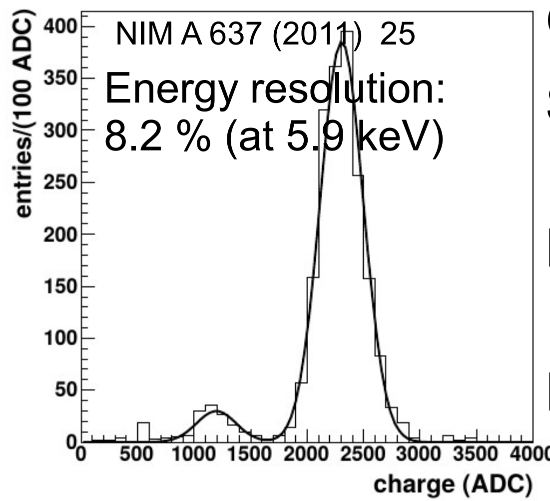


T2K Setup



Both GEMs and Bulk-Micromegas were tested and performed equally well.
Bulk-Micromegas were chosen first large scale application of MPGDs: 9 m².
Each side is covered with 12 modules.
Gas: $Ar:CF_4:iC_4H_{10}$ 95:3:2 (low diffusion in B and fast e^- drifting)
Mesh: 400 LPI steel mesh / gap size: 128 µm
E-Field configuration: E_{drift} = 275 V/cm, E_{ampl} = 27.4 kV/cm



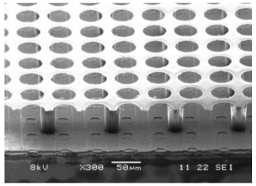


Gas gain ~ 1500

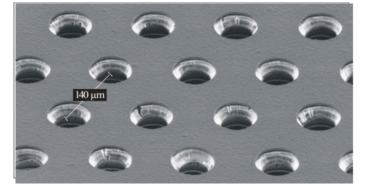
Spark rate
< 0.1 sparks / h

No aging observed
for 0.17 C/cm²

Pad pitch:
9.8×7.0 mm²



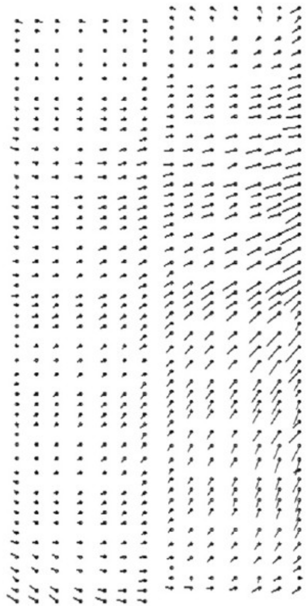
T2K-TPC Performance



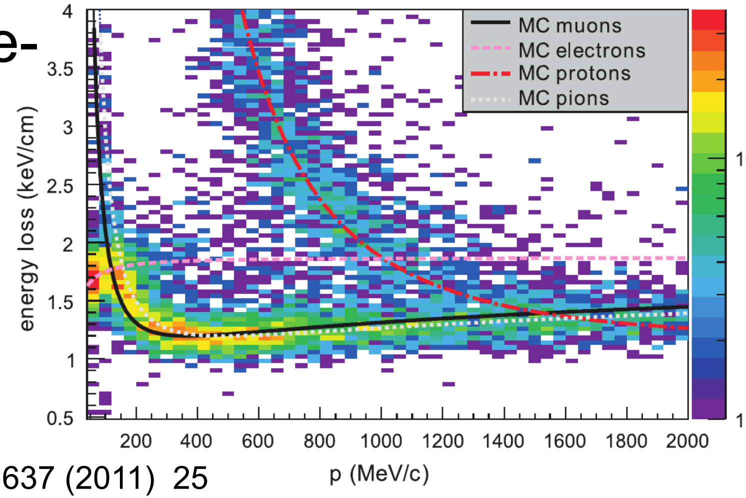
<u>Calibration system:</u>

- Al targets on Cu cathode
- Flashing 266 nm light on cathode

→ Photoelectrons are used to understand field distortions and drift velocity.



All require-ments could be fulfilled.



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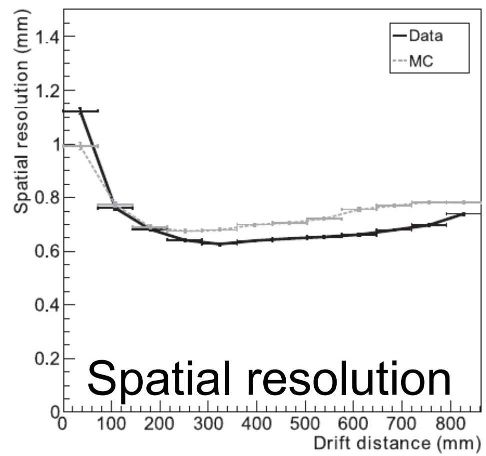
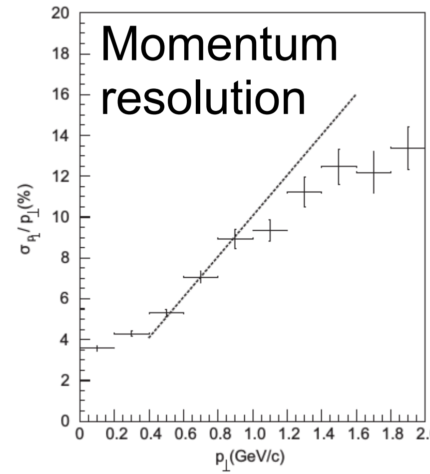
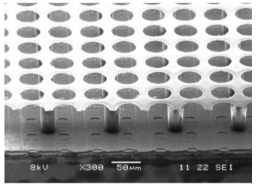
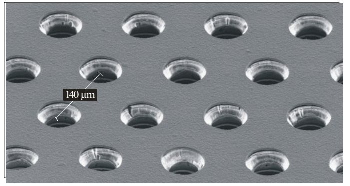


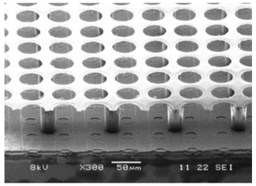


universitätbonn

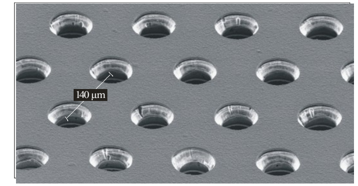




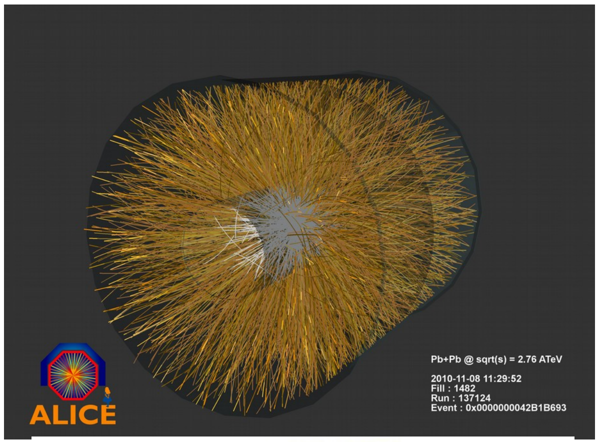
TPC in Heavy Ion Physics

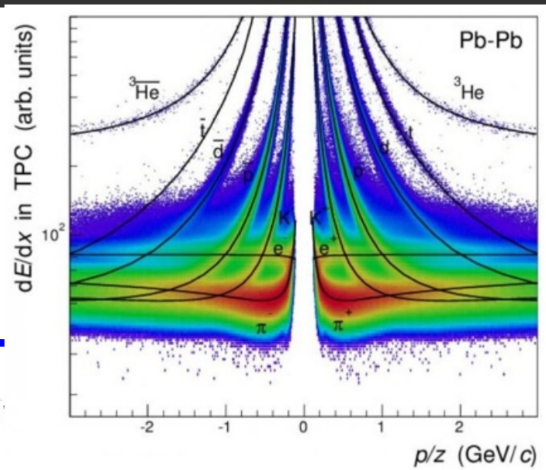


ALICE - TPC



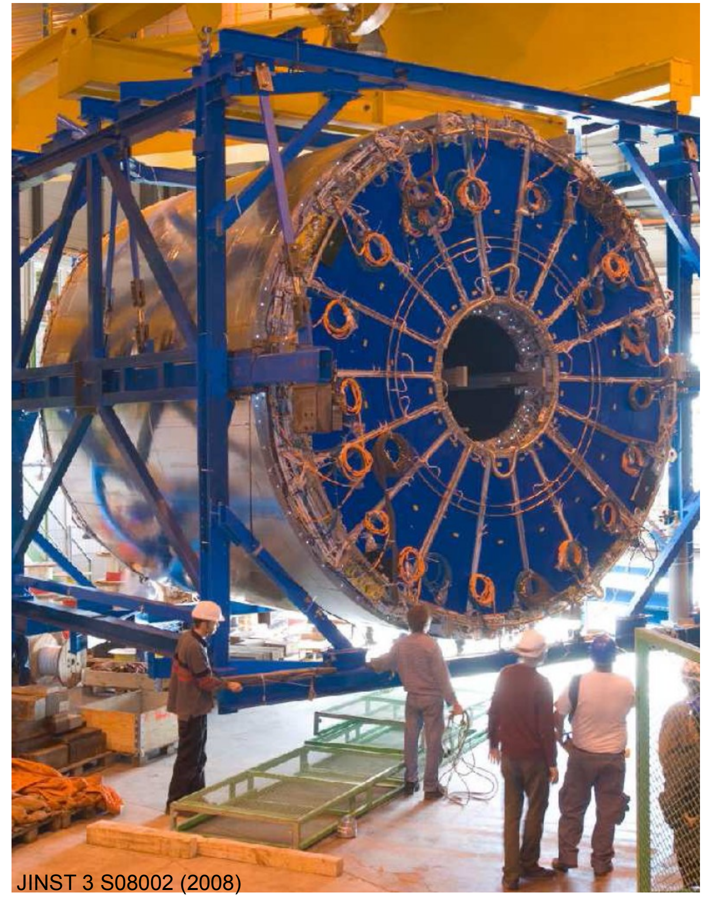
The chamber was designed to study the heavy ion collisions at the LHC (Pb with 2.7 TeV/nucleon → $\sqrt{s}$ = 574 TeV).

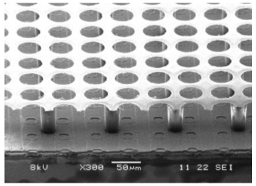




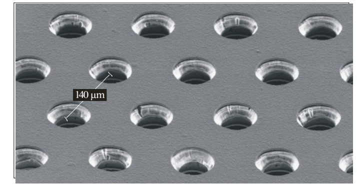
Design choices were made to meet the high expected multiplicity of 8000 tracks per event on average and up to a maximum of 20000 tracks per event and still excellent PID

Length: 5 m
Diameter: 5 m
=> Volume: 88 m³


JINST 3 S08002 (2008)



Requirements of Upgrade



<u>Limitation because of gating in Run 1:</u>

- Ion Backflow suppression of a MWPC with a gating grid ~ 10^{-5}
- 100 µs electron drift time + 200 µs to neutralise all ions
- Total cycle time ~ 300 µs limits the maximal readout rate to ~ 3 kHz (in p-p)
- Trigger Rate ~ 600 Hz for Pb-Pb (300 Hz in Run 1)

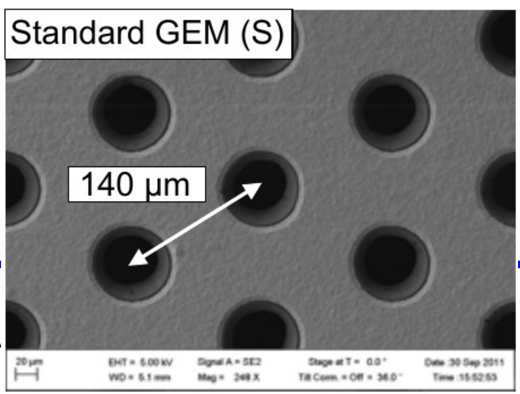
<u>Requirements for Run 3:</u> Operation at 50 kHz (Pb-Pb)

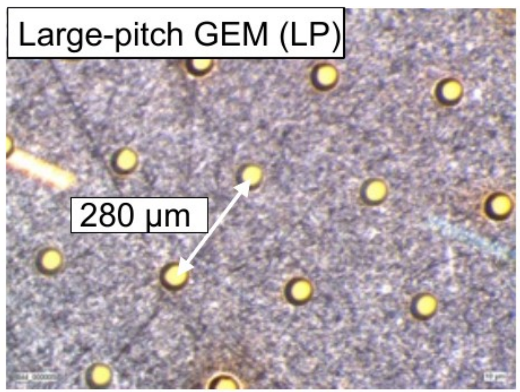
=> Gating not possible anymore, need 'permanent' ion reduction =>MPGDs

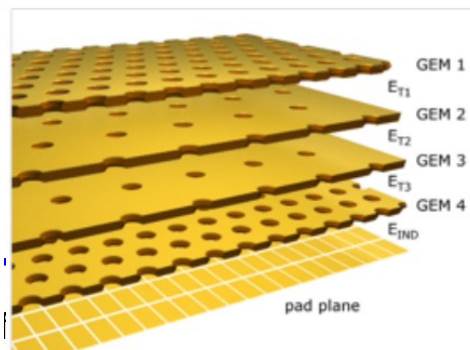
- Effective gas gain: 2000
- IB: < 1 %

Along with similar performance as in Run 1, e.g. σ/E (5.9 keV): < 12 %

Requirements could not be fulfilled with standard GEMs – use LP GEMs







M. Ball, DPG presentation 2016

Hugh effort to optimize the HV setting of the GEM stack for ion reduction.

Ion trapping with GEMs

ALICE universitätbonn

Presentation by M. Ball, Bonn

Electron transport properties for IB optimised HV settings

ε_{coll} = collection efficiency

ε_{extr} = extraction efficiency

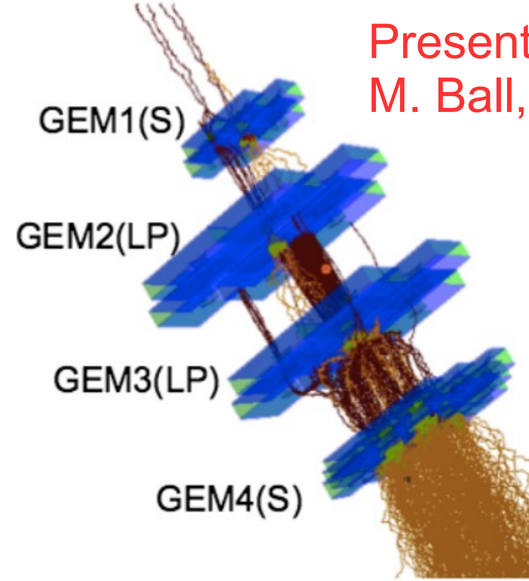
M = gas multiplication factor

$G_{eff} = \varepsilon_{coll} \times M \times \varepsilon_{extr}$ = effective gain

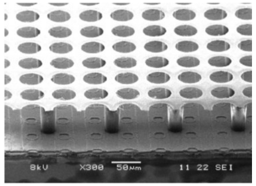
$n_{e\text{-}ion}$ = number of produced e-ions pairs

$n_{ion,back}$ = number of ions drifting back into the drift volume (ε)

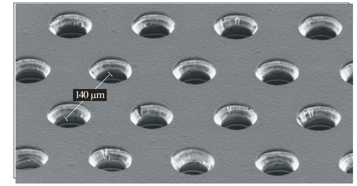
fraction of total IB: simulation vs. experiment

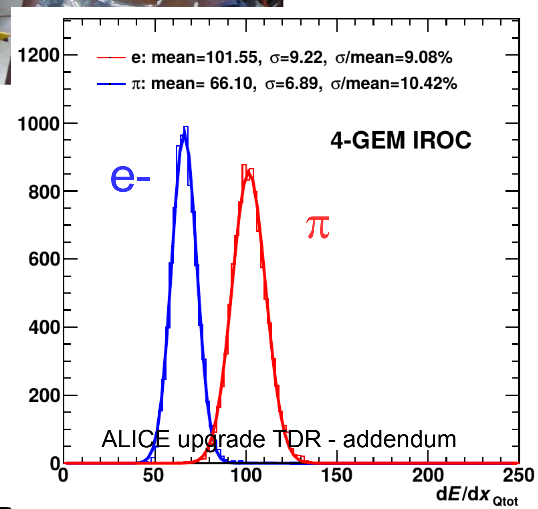


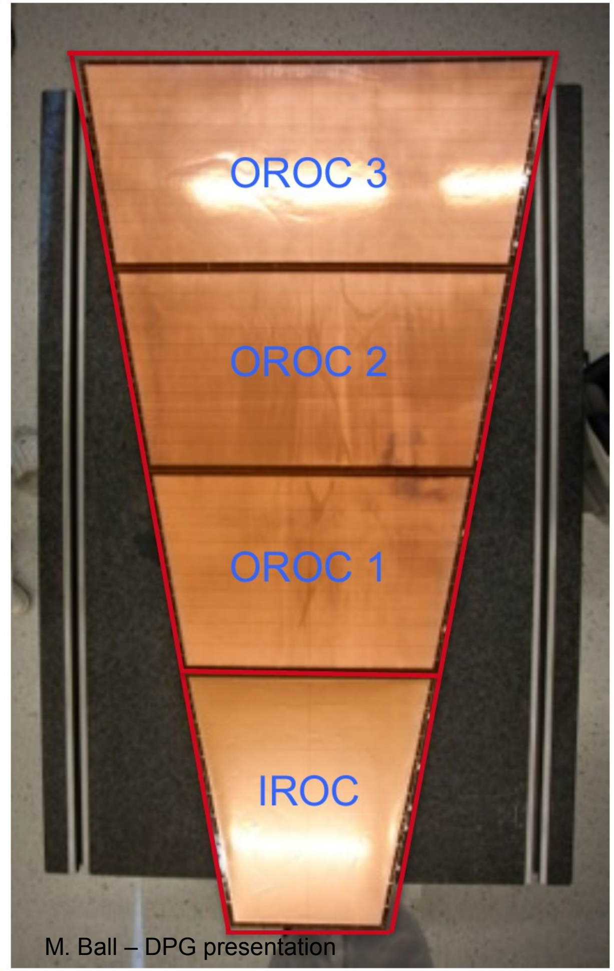
	ε_{coll}	$n_{e,in}$	M	n_{e-ion}	ε_{extr}	$n_{e,out}$	G	$n_{ion,back}$	fraction of total IBF (sim.)	fraction of total IBF (meas.)
GEM1 (S)	1	1	14	13	0.65	9.1	9.1	3.6 (28%)	40%	31%
GEM2 (LP)	0.2	1.8	8	12.7	0.55	8	0.88	3.3 (26%)	37%	34%
GEM3 (LP)	0.25	2	53	104	0.12	12.7	1.6	1.3 (1.3%)	14%	11%
GEM4 (S)	1	12.7	240	3053	0.6	1830	144	0.84 (0.03%)	9%	24%
Total				3183		1830	1830	9 (0.28%)		



Test Measurements at CERN







Energy resolution:

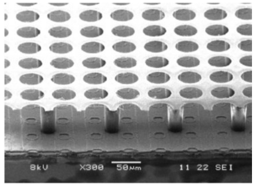
The required σ/E (5.9 keV) ≈ 12 % was reached

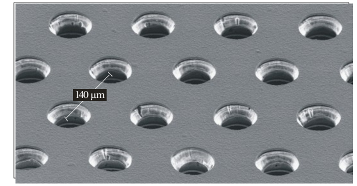
Resulting in a e/π (1 GeV) separation of approx. 4.5.

Discharges:

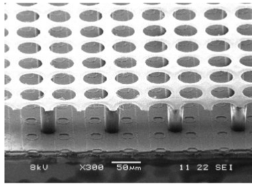
Observed during test beam at SPS:

- 3 discharges observed → $(6\pm4)10^{-12}$ discharge probability / incoming hadron
- 5 discharges expected per year and GEM stack in Run 3

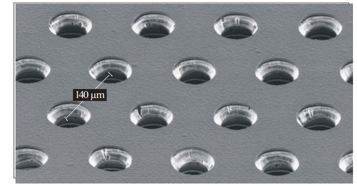




TPCs in HEP



TESLA-D. / LDC / ILD / CLIC-D.

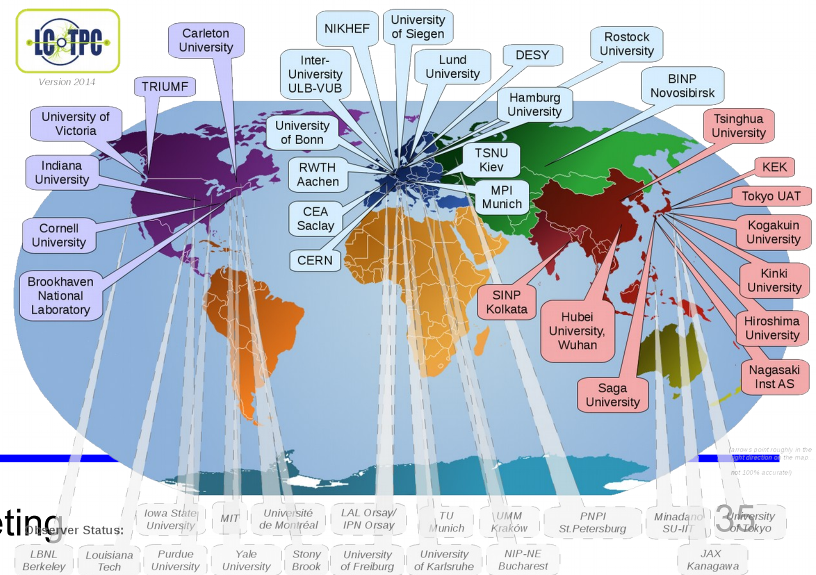


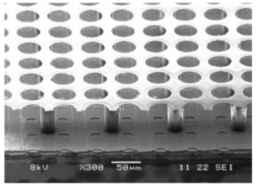
International Linear Collider (ILC) / Compact Linear Collider (CLIC):
e^+e^- colliders @ $\sqrt{s}$ = 500 GeV – 1TeV / 3TeV

Both accelerators require very precise multi-purpose detectors.
Concept of particle flow is considered optimal reconstruction scheme.
=> need low material budget tracking detectors with high precision, high efficiency and robust particle identification.

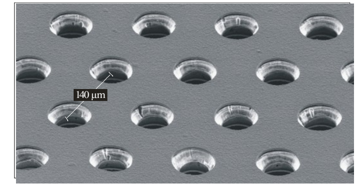
TPC is chosen as tracking detector for some detector concepts.

LCTPC collaboration:
30 Institutes from 12 countries
+ 18 institutes have an observer status

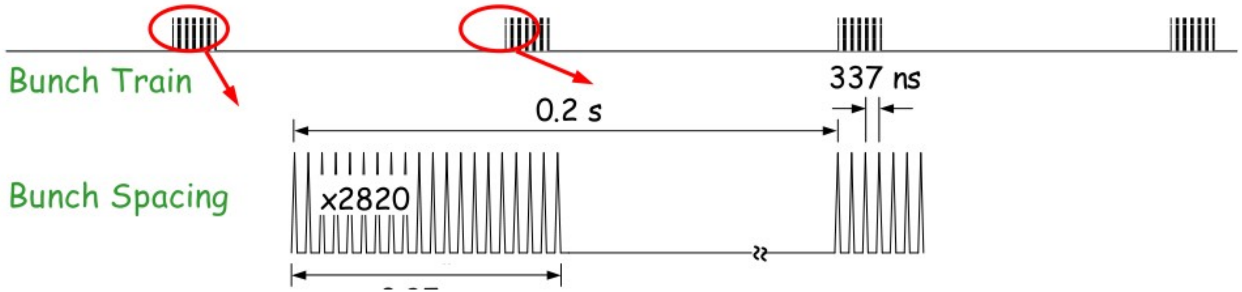




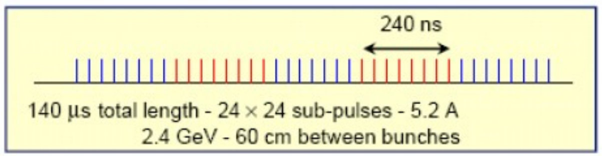
The Bunch Train Structure

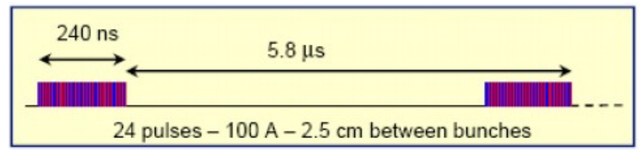


ILC



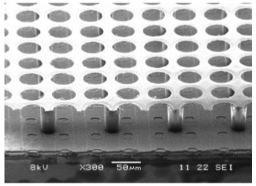
CLIC



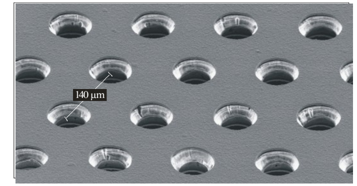


Events from a major fraction of a bunch train are integrated, but can be disentangled.

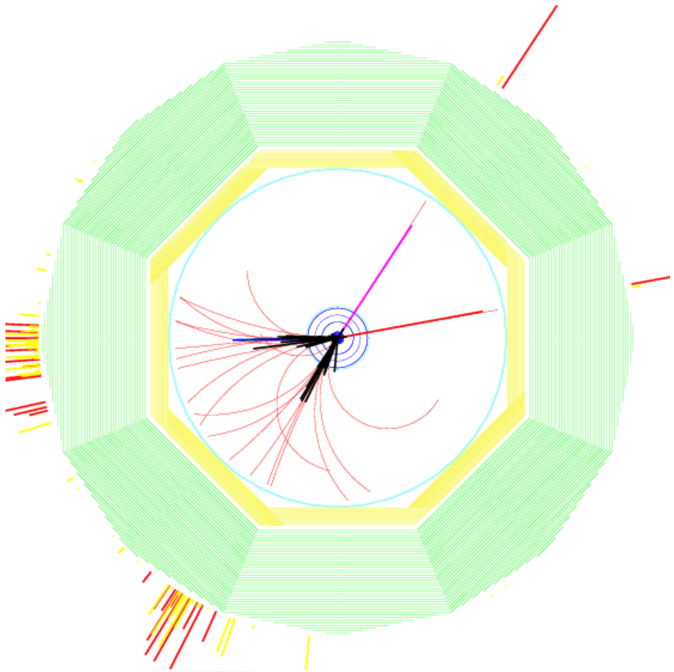
If necessary, TPC can be gated between the bunch trains.



Requirements on LCTPC

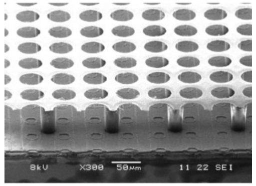


Requirements are driven by benchmark processes, in the case of ILD – TPC the most stringent measurement is the Higgs-recoil measurement:

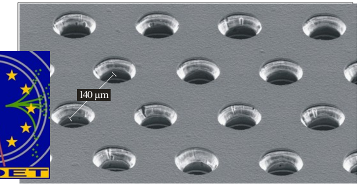


Requirements of TPC from ILD LOI

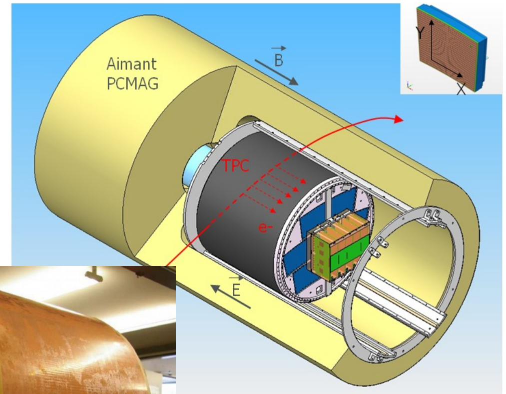
Size	$\phi = 3.6$m, L $= 4.3$m outside dimensions
Momentum resolution (3.5T)	$\delta(1/p_t) \sim 9 \times 10^{-5}$/GeV/c TPC only ($\times$ 0.4 if IP incl.)
Momentum resolution (3.5T)	$\delta(1/p_t) \sim 2 \times 10^{-5}$/GeV/c (SET+TPC+SIT+VTX)
Solid angle coverage	Up to $\cos\theta \simeq 0.98$ (10 pad rows)
TPC material budget	$\sim 0.04X_0$ to outer fieldcage in r
	$\sim 0.15X_0$ for readout endcaps in z
Number of pads/timebuckets	$\sim 1{\times}10^6/1000$ per endcap
Pad size/no.padrows	$\sim$ 1mm$\times$4–6mm/$\sim$200 (standard readout)
σ_{point} in $r\phi$	$< 100\mu$m (average over $L_{sensitive}$, modulo track ϕ angle)
σ_{point} in rz	$\sim$ 0.5 mm (modulo track θ angle)
2-hit resolution in $r\phi$	$\sim$ 2 mm (modulo track angles)
2-hit resolution in rz	$\sim$ 6 mm (modulo track angles)
dE/dx resolution	$\sim$ 5 %
Performance	$>$ 97% efficiency for TPC only ($p_t > 1$GeV/c), and
	$>$ 99% all tracking ($p_t > 1$GeV/c) [87]
Background robustness	Full efficiency with 1% occupancy,
	simulated for example in Fig. 4.3-4(right)
Background safety factor	Chamber will be prepared for 10 $\times$ worse backgrounds
	at the linear collider start-up

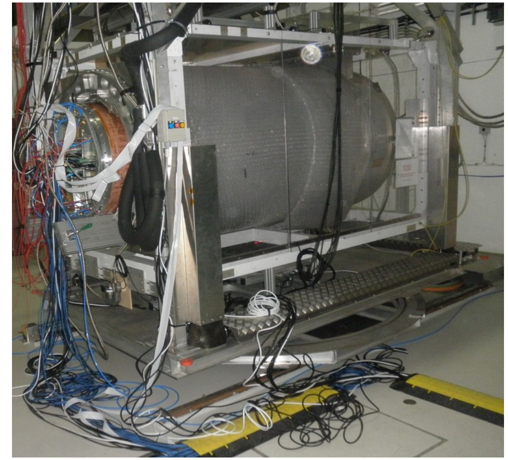


EUDET-Facility at DESY



Large Prototype has been built to compare different detector readouts under identical conditions and to address integration issues.





Setup consists of:

PCMAG: B < 1.2 T,

e^- test beam: E = 1- 6 GeV

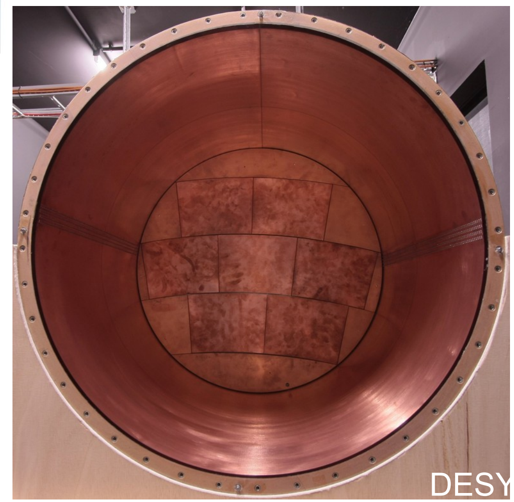
Movable support structure

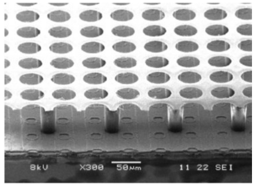
LP Field Cage Parameter:

- length = 61 cm
- inner diameter = 72 cm
- drift field: E ≈ 350 V/cm
- made of composite materials: 1.24 % X_0

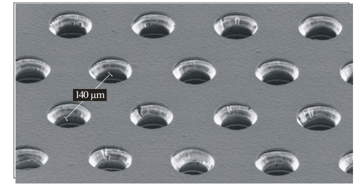
Modular End Plate

- 7 module windows, size ≈ 22 × 17 cm^2





Standard GEM Module



Design goals:

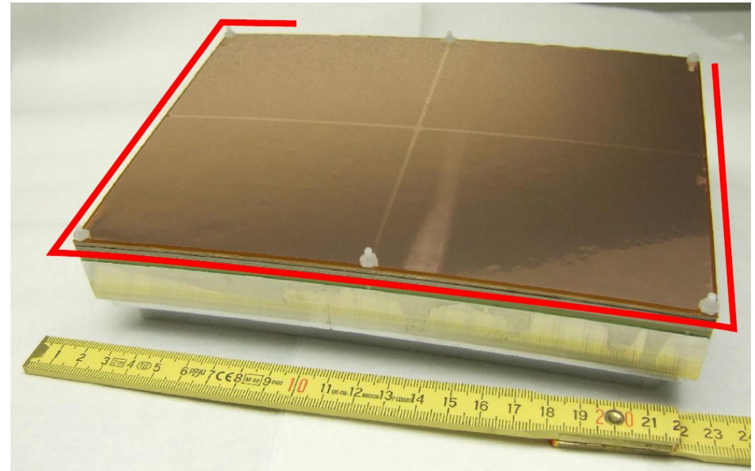
- Minimal dead space
- Stable operation
- Even GEM surface
- Min. material budget

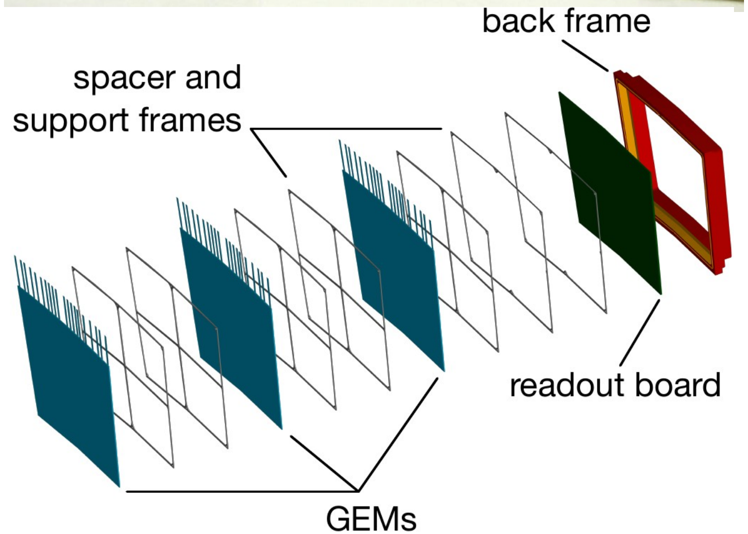
Solution:

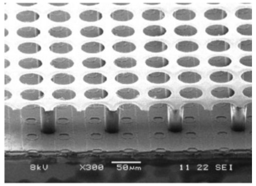
- Triple GEM stack
- Thin ceramic mounting grid
- Anode divided into 4 sectors
- No division on cathode side
- 4829 pads (1.26×5.85 mm²)
- Field shaping wire

Test beam setup

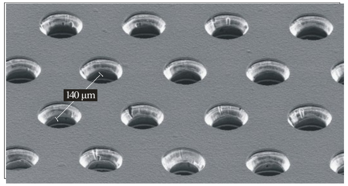
- 3 partially equipped modules
- 7212 channels of ALTRO electronics
- Standard environment (E= 240 V/cm $Ar:CF_4:iC_4H_{10}$ 95:3:2



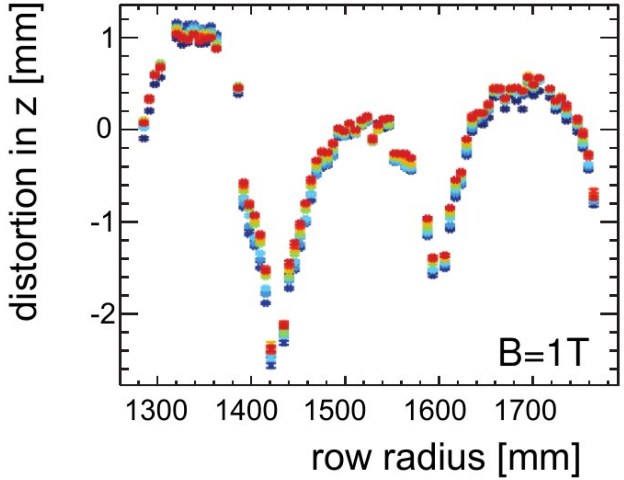


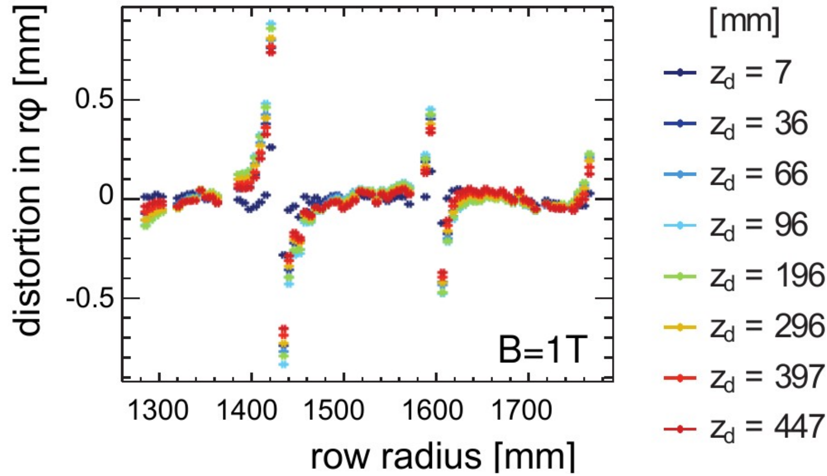


Local Field Distortions

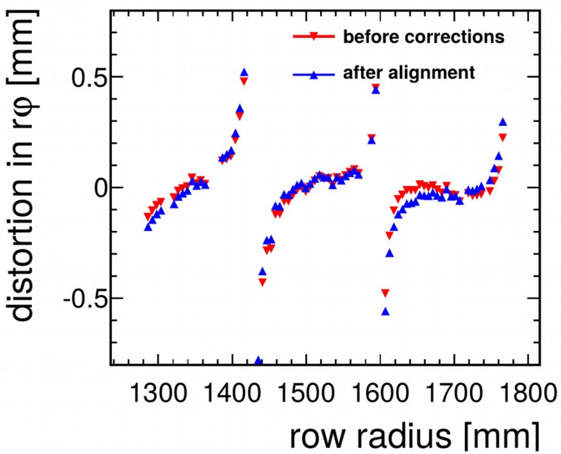


Field distortions from E and B inhomogeneities, e.g. non-perfect E-field at gap between modules



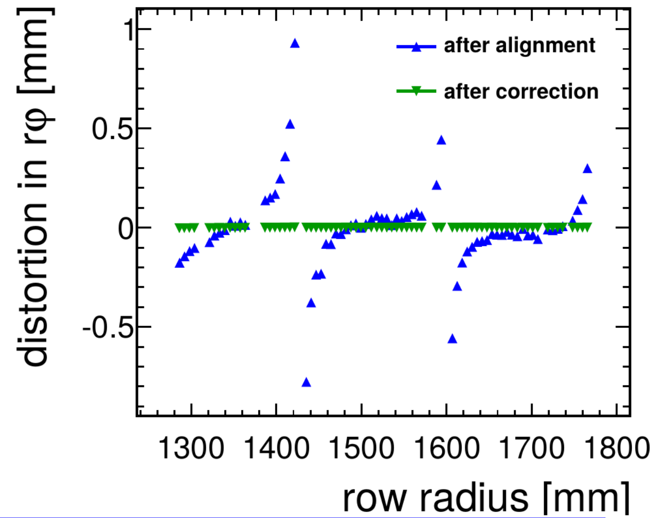


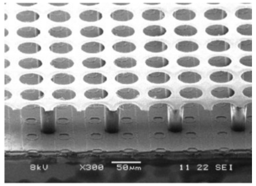
Correction methods:



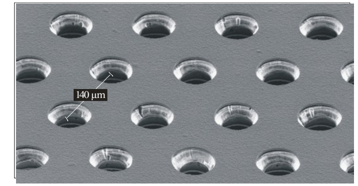
<u>Alignment correction:</u>
Fitting tracks with Millipede
Optimizing rotation and alignment of modules at B = 0 T

<u>Distortion correction:</u>
Systematic shift of residuals derived from 10 % of data, applied to all

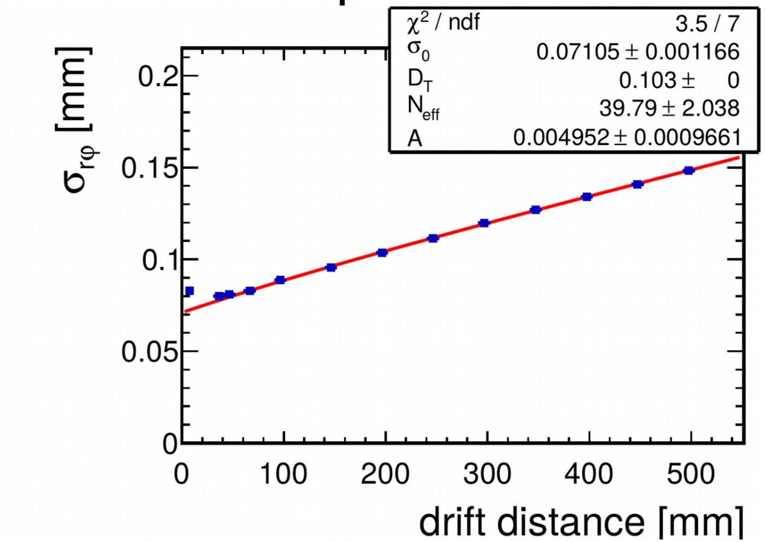




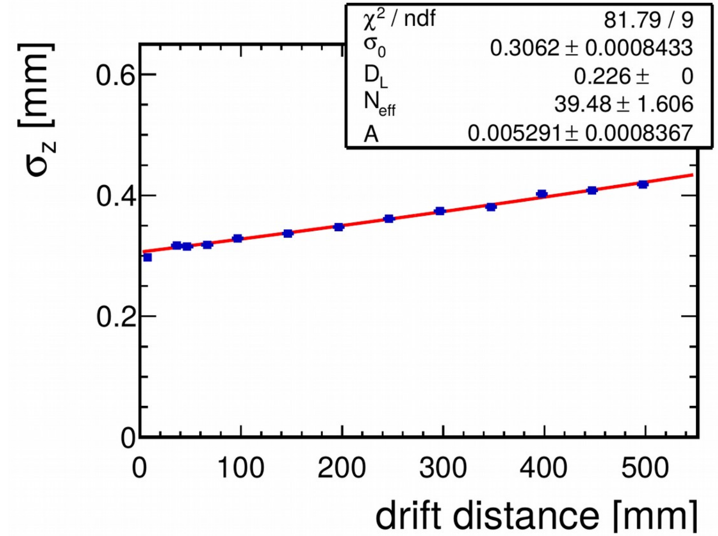
Spatial Resolution



Transverse spatial resolution



Longitudinal spatial resolution

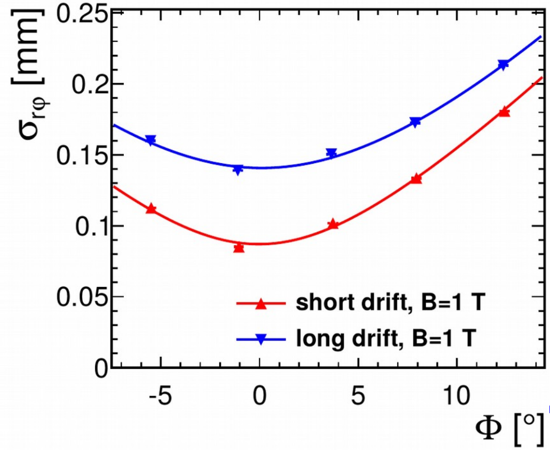


For fitting the drift dependence

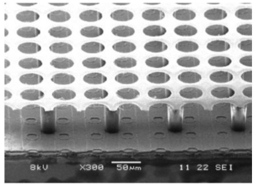
$$\sigma_{r\varphi/z}(z) = \sqrt{\sigma_0^2 + \frac{D_{t/l}^2}{N_{\mathrm{eff}} \cdot e^{-Az}} z}$$ was used.

For azimuthal dependence:

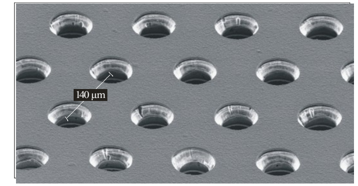
$$\sigma_{r\varphi}(\Phi) = \sqrt{\sigma_0^2(z) + \frac{L^2}{12\hat{N}_{\mathrm{eff}}} \tan^2(\Phi - \Phi_0)}$$



universitätbonn

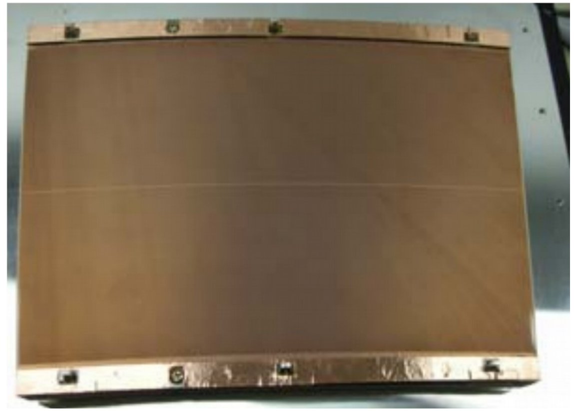


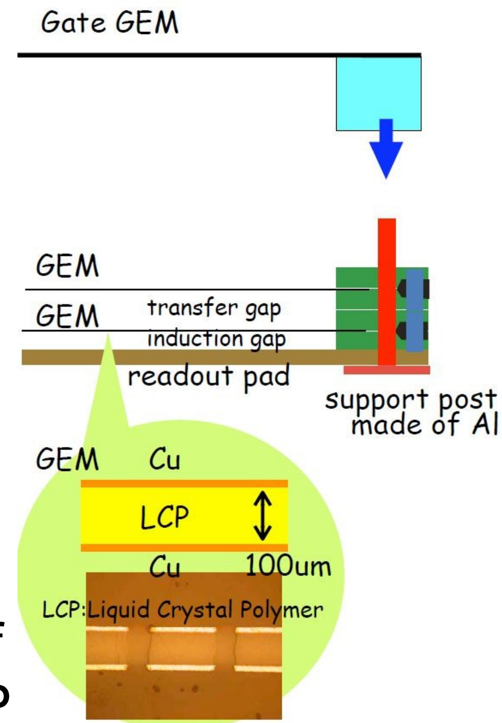
LCP-GEM Module

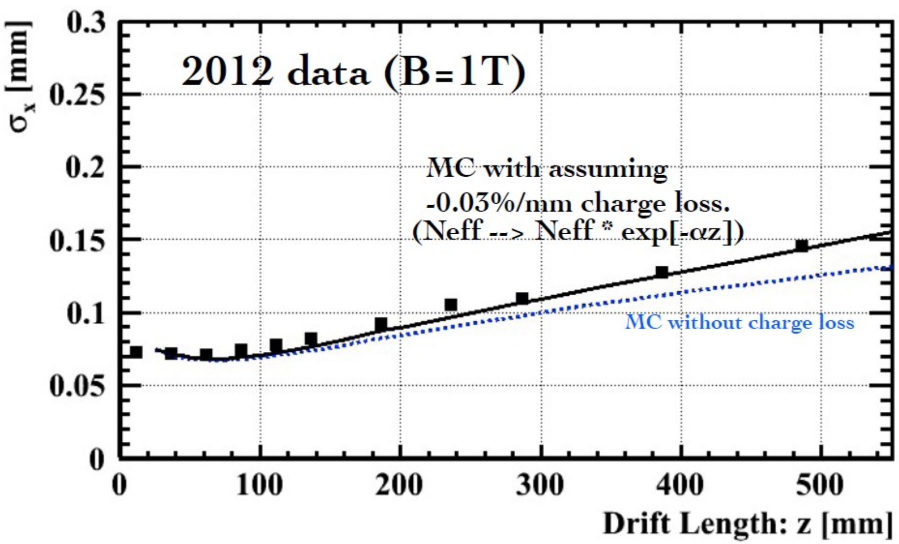


Design idea:

- Minimize insensitive area pointing towards the IP
=> no frame at modules sides
- Use thicker GEMs to give more stability (100 µm LCP)
- Broader arcs at top and bottom

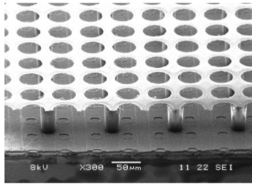




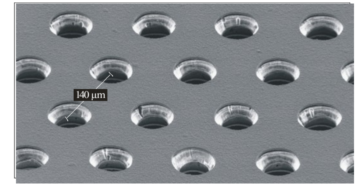


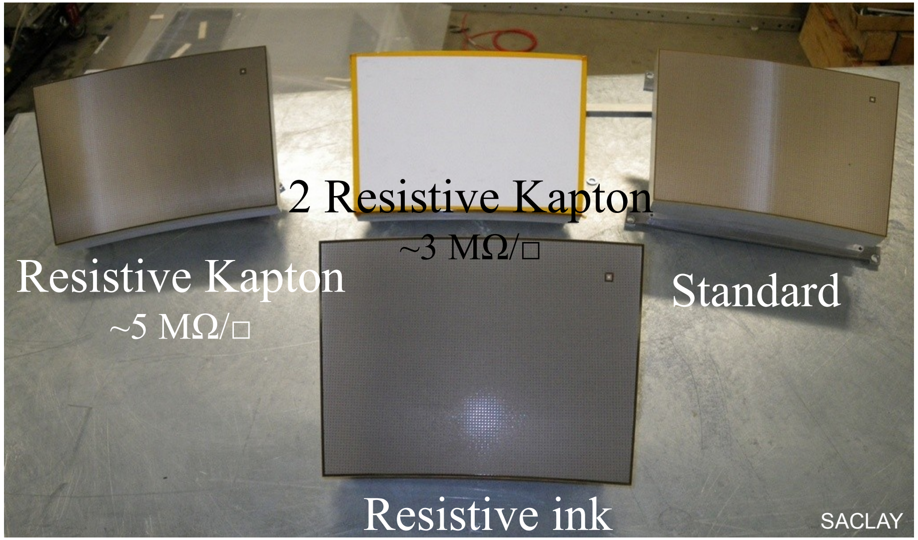
GEM Modules:

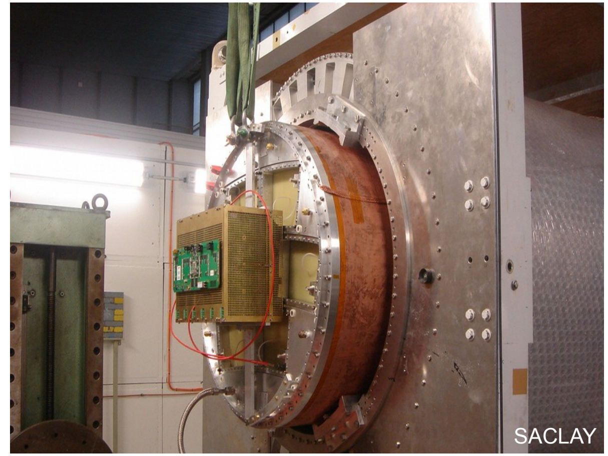
- 2 GEMs made of 100 µm thick LCP
- $1.2\times5.4mm^2$ pads - staggered
- 28 pad rows (176-192 pads/row)
=> 5152 channels per module



Micromegas

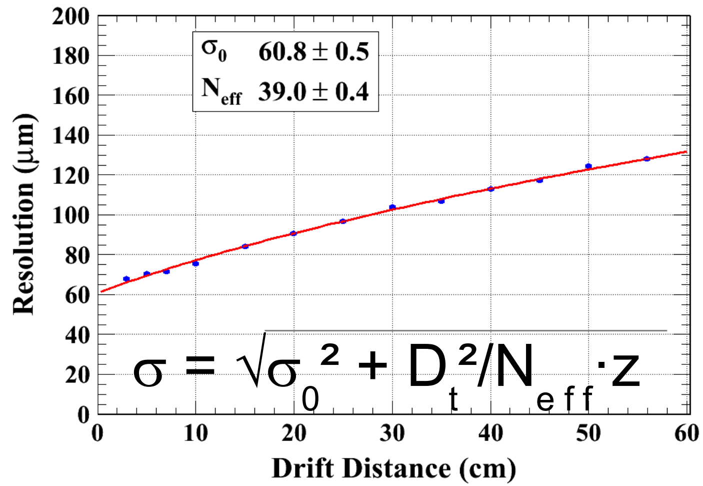


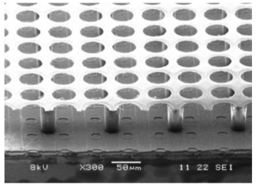




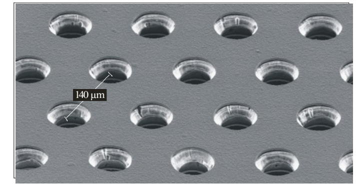
Micromegas Module

- 3×7 mm^2 large pads
- 24 row with 72 pads
  → 1728 pads per module
- Testing resistive foil / carbon loaded kapton (O(1MΩ/□))
- AFTER electronics (T2K)



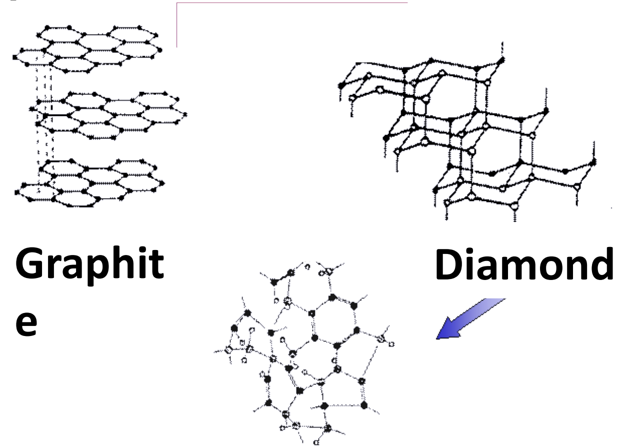


New Resistive Coating

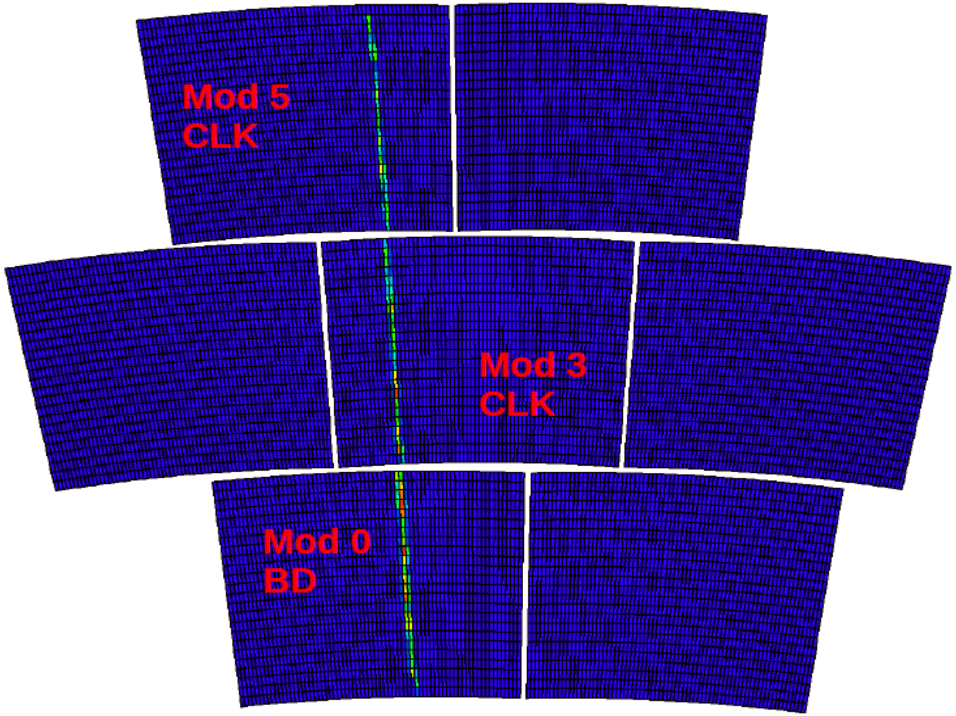


<u>Black Diamond (BD)/ Diamond like Carbon (DLC)</u>

often used as a layer on tools to harden surface and as lubricant

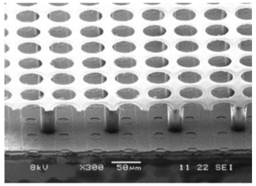


Black diamond' and Carbon-loaded kapton

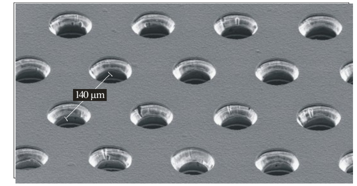


BD layer was produced in Japan by A. Ochi: 100 nm on a kapton foil

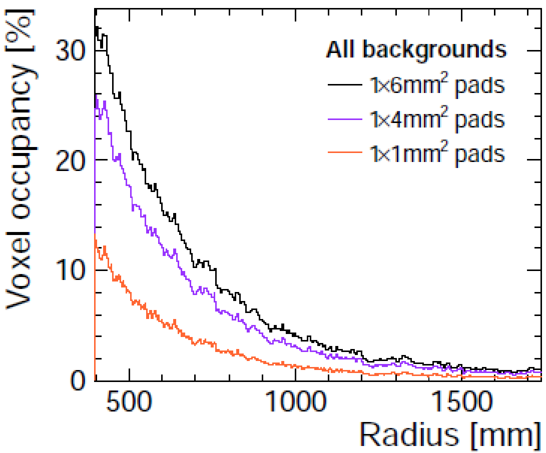
Two modules with BD were tested this year with 5 CLK ones (carbon loaded kapton).

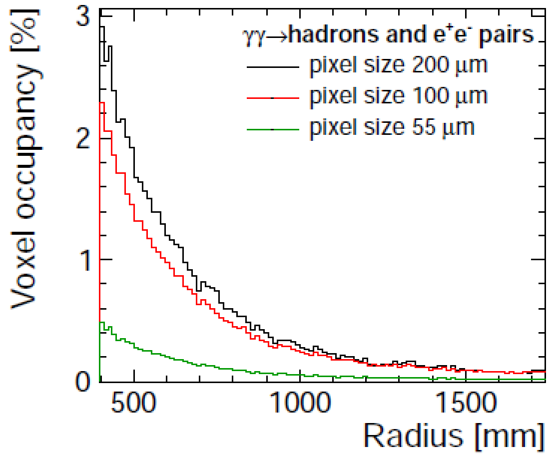


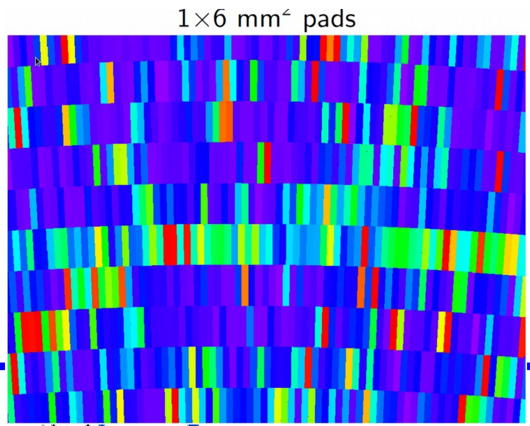
GridPix Benefits - Challenges

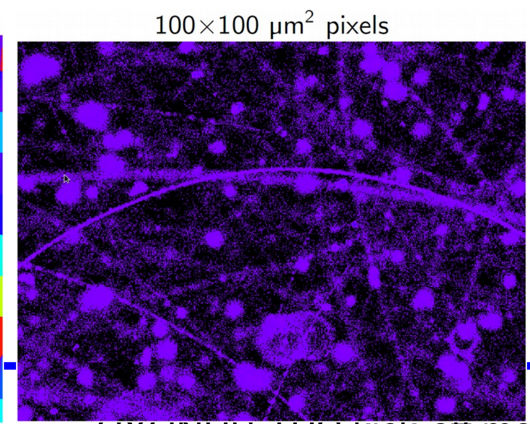


The background (γγ → hadrons, e^+e^- → pairs/beam halo μ) is accumulated in the TPC creating a significant occupancy (Simulation for the CLIC detector, M. Killenberg, LCD-Note-2013-005)



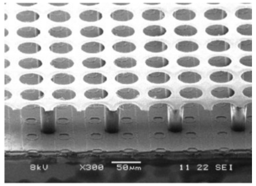




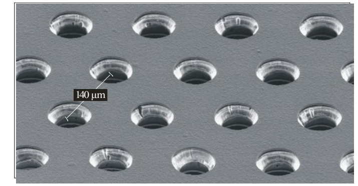


- Lower occupancy → better track finding
- Identification and removal of δ-rays and kinks
- Improved dE/dx, because of primary e^- counting
- Pad plane and readout electronics fully integrated

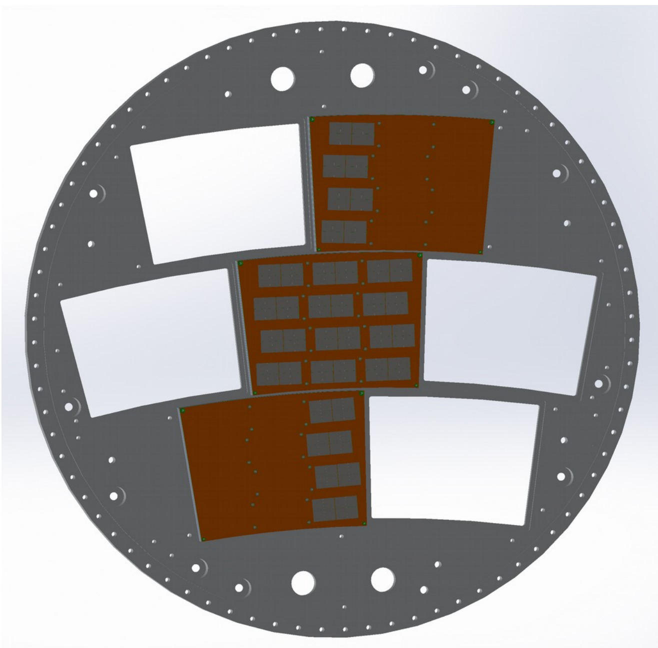
Complete TPC with GridPixes:
~100-120 chips/module
240 module/endcap (10 m²)
→50000-60000 GridPixes



Envisioned Test beam Setup

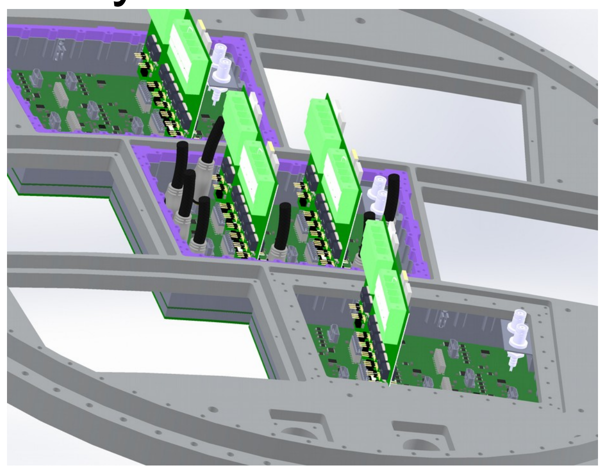


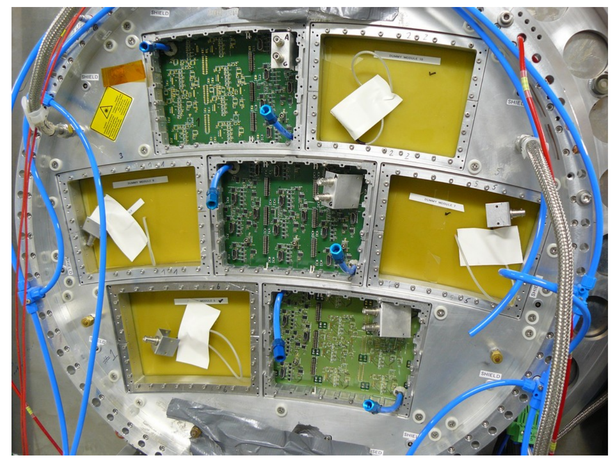
The goal foresaw an LP-module covered completely with GridPixes (~100). This goal could even be surpassed by adding two partially covered modules. 160 GridPixes covered an active area of 320 cm²: - central module with 96 chips (coverage 50 %)
- 2 outer modules with 32 chips each

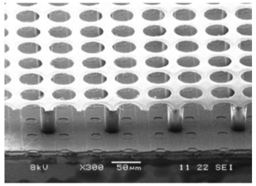


Some challenges:

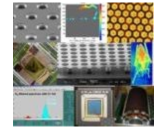
- InGrid production
- Synchronized readout
- LV distribution
- Cooling

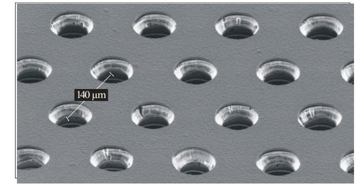






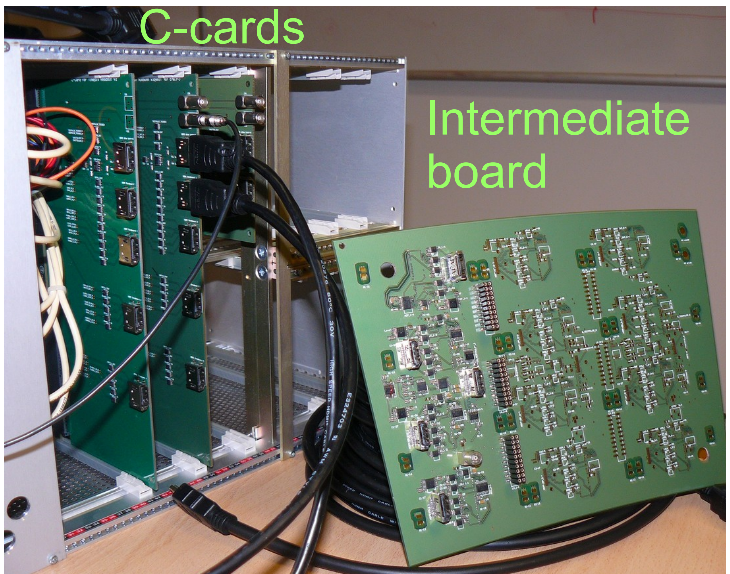
Readout System

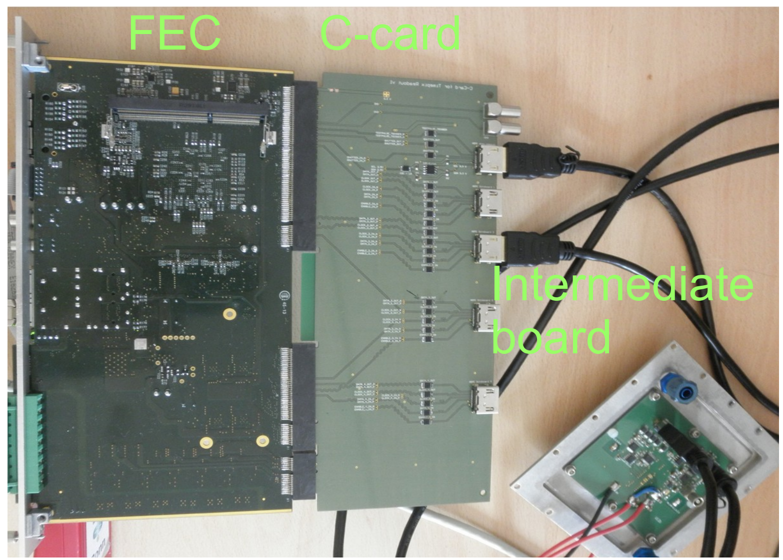




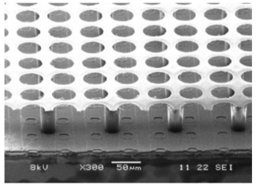
We have built one based on the Scalable Readout System of RD51, because it is easy to scale, cheap and optimized for R&D.

Idea of SRS: produce flexible readout electronics, which can handle different chips (new FPGA code, chip carrier), which many groups can use.
New C-Card, intermediate board, and chip carriers were designed for Timepix.
Now up to 32 Timepix ASICs can be used per FEC/C-card.

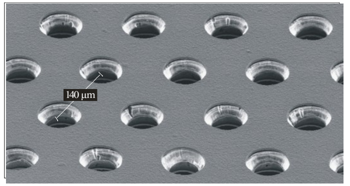


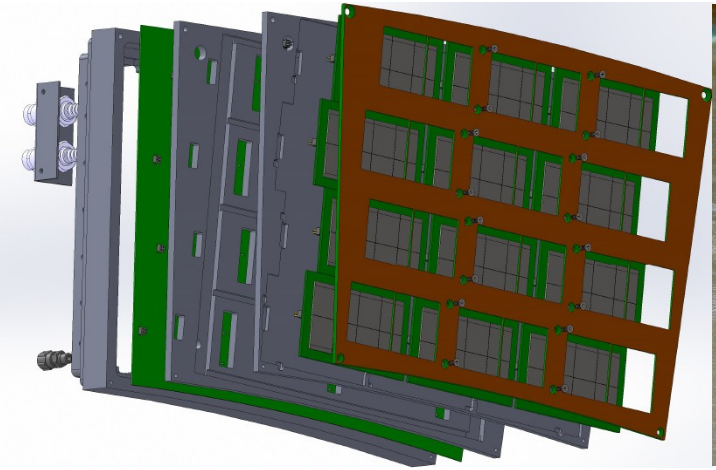


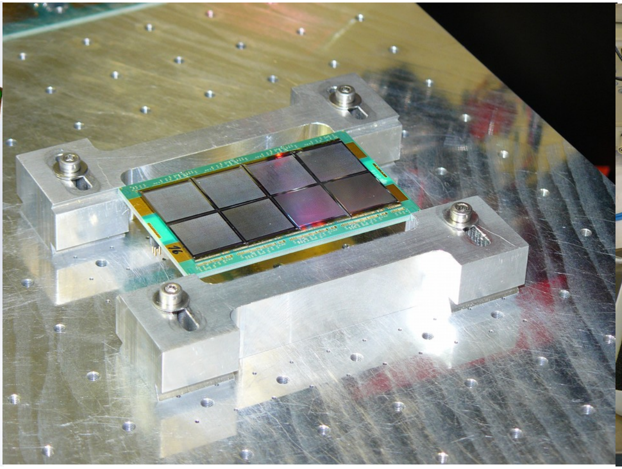
A small-size system using the same FPGA code and most of the hardware can be based on a Virtex6 evaluation board. This is used in CAST.

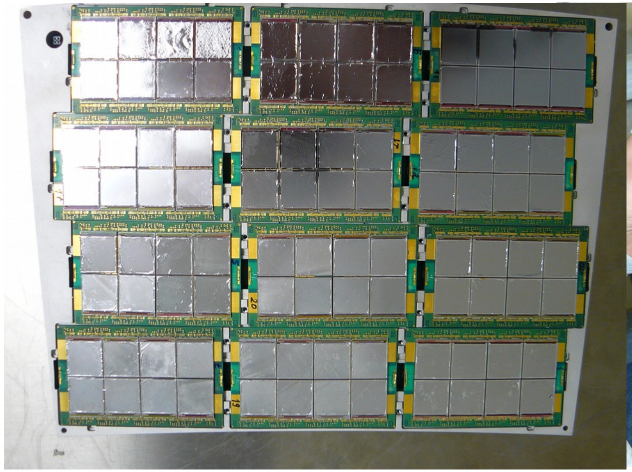


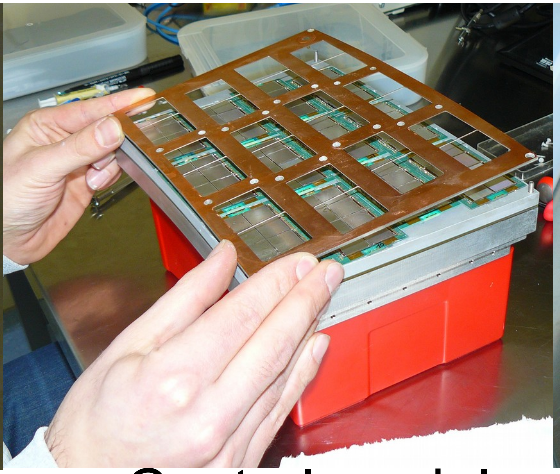
Module Production

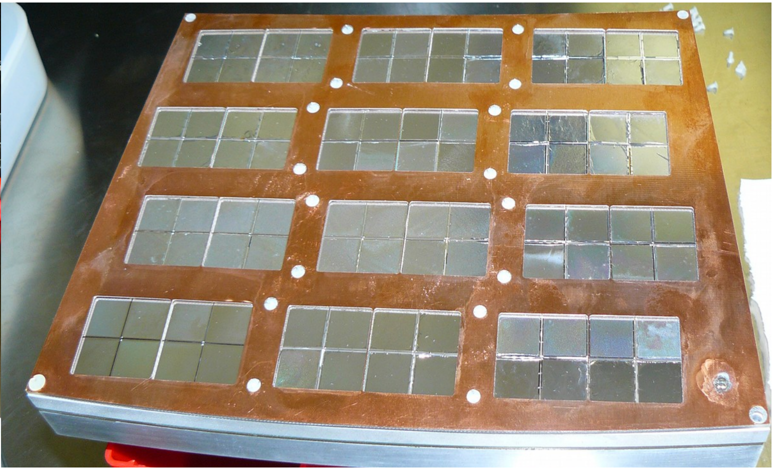






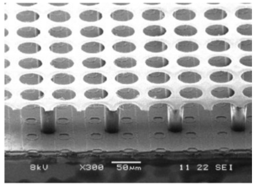




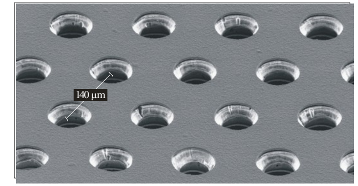


Central module

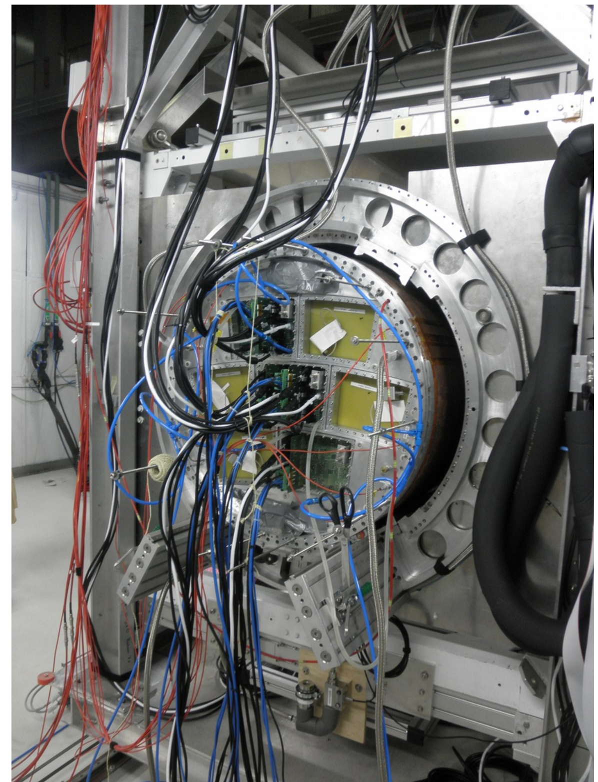
J. Kaminski
CYGNUS-TPC kick-off meeting
7th April 2016



Test Beam



The test beam was a huge success. A lot of people now think, that a pixel TPC is not a crazy idea anymore, but it is realistic.
During the test beam we collected ~10^6 frames at a rate of 4.3-5.1 Hz.

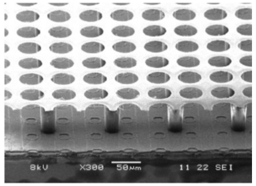


Test beam program included:
– Voltage scans (gas gain)
– Different angles
– With and without magnetic field (B=1T)
– Two different electrical drift fields

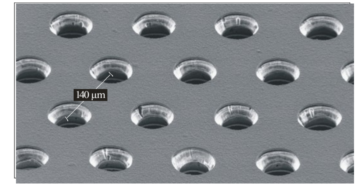
The analysis has started.

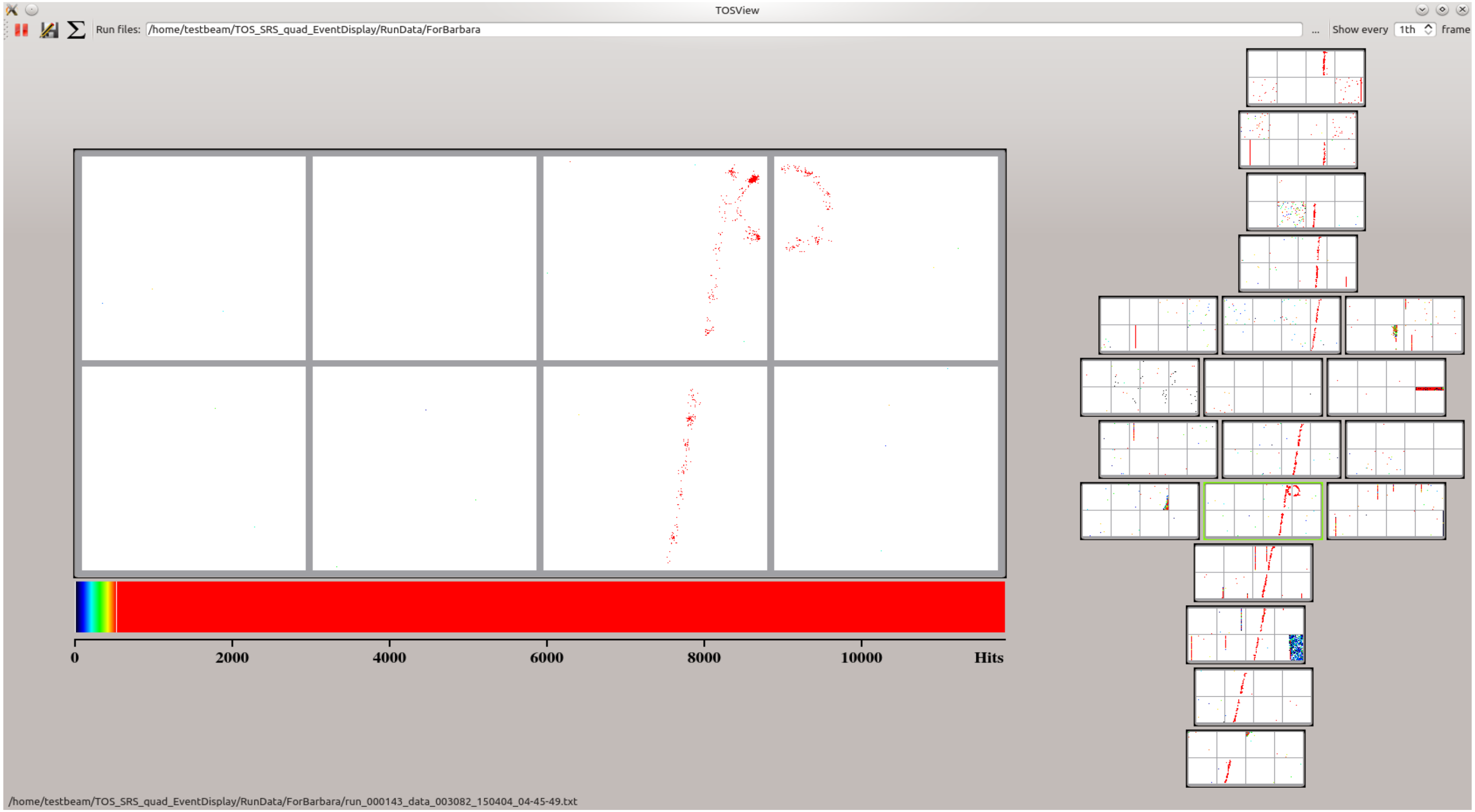
Material budget of 96 chip module (not optimized!)
- metallic frame 4.1 % X_0, cooling plate 5.9 % X_0
- 2 LV boards 2.5 % X_0, 12 Octoboards 2.9 % X_0

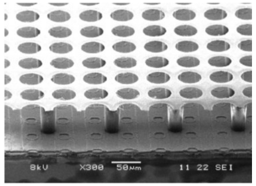
In total: 18.5 % X_0



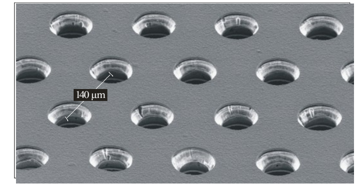
Online Event Display(I)

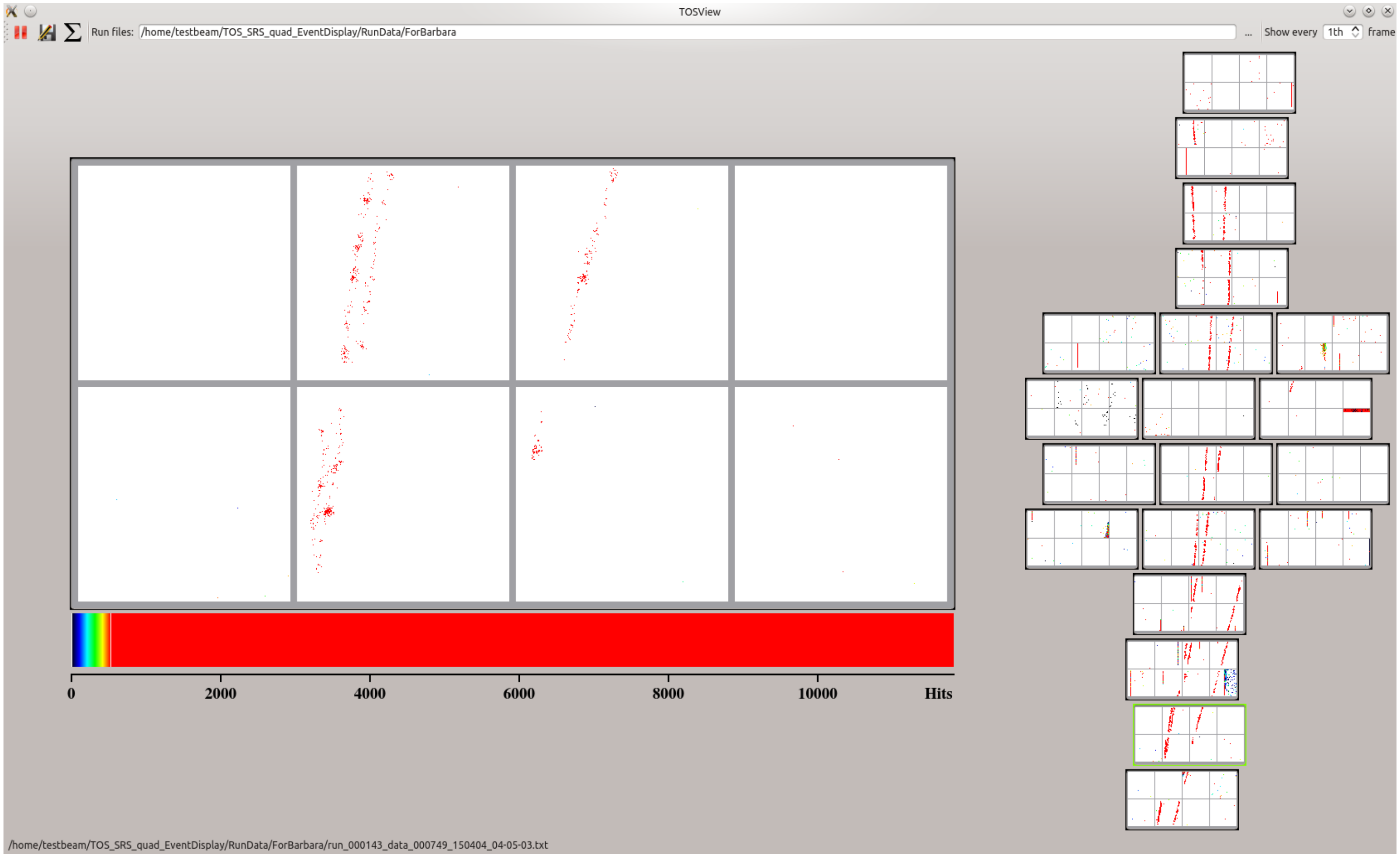






Online Event Display (II)





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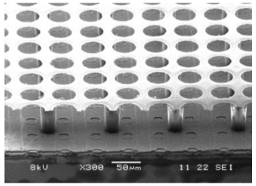
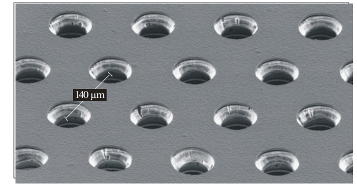
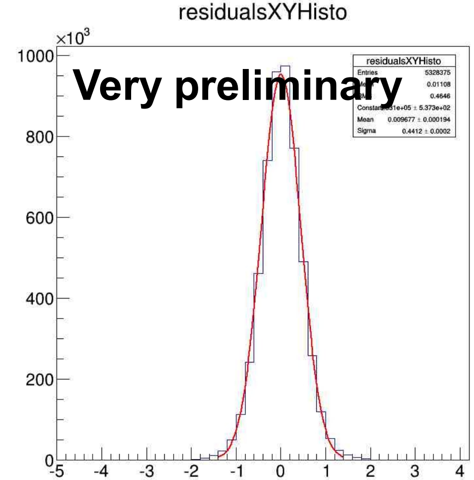


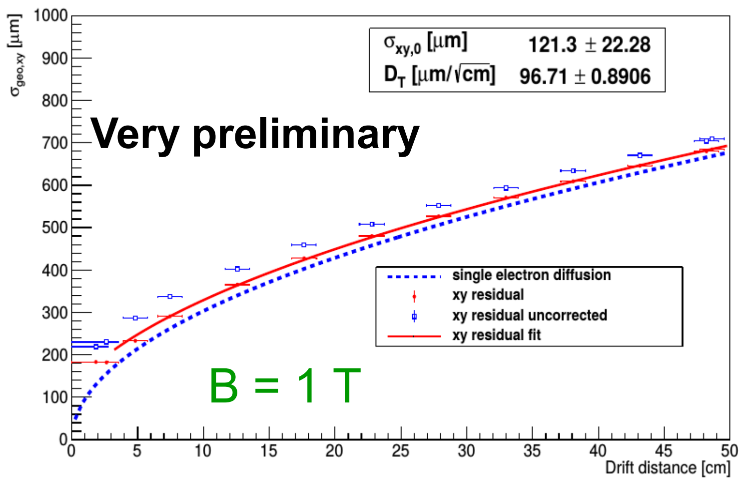
Spatial Resolution

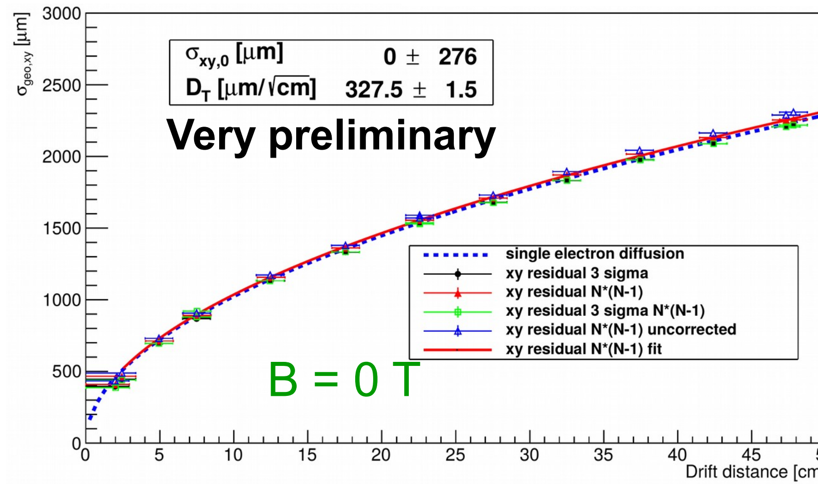


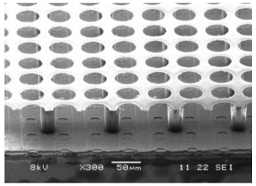
- The spatial resolution is determined by calculating the residuals of single hits to fitted track.
- Spatial resolution follows the diffusion of single electrons.

Condition	Measurement	Simulation
E = 230 V/cm, B= 0T	327.5 ± 1.5 µm/√cm	324 ± 12 µm/√cm
E= 230 V/cm, B= 1 T	96.7 ± 0.9 µm/√cm	96 ± 5 µm/√cm

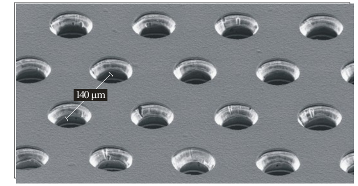






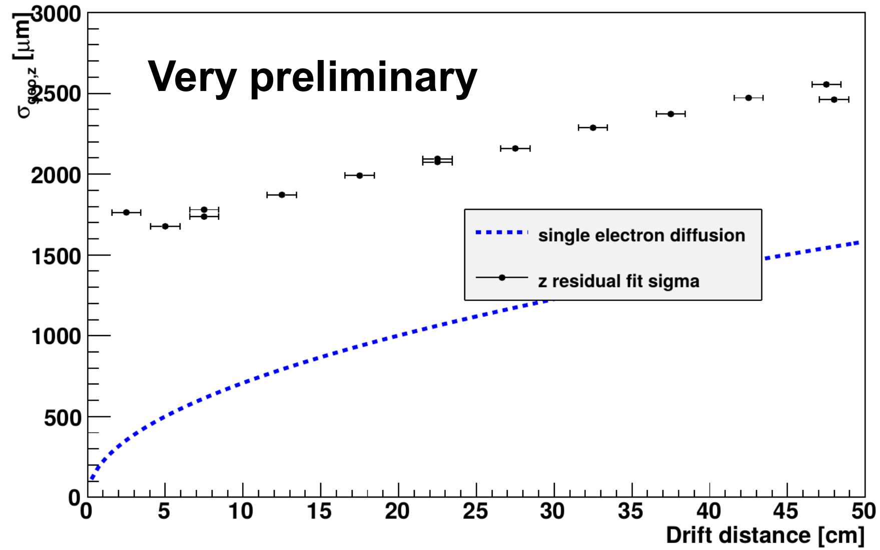


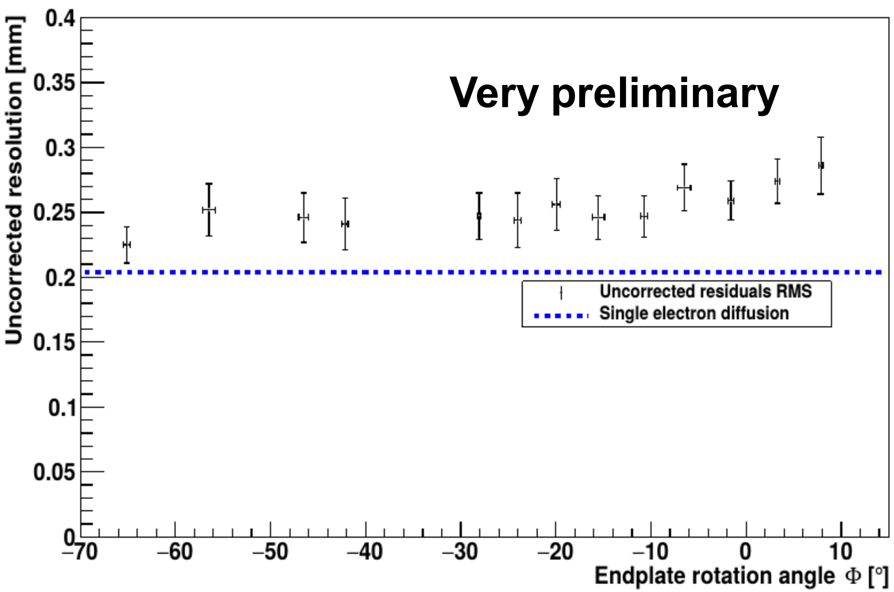
More Spatial Resolutions



Longitudinal spatial resolution is much worse, because of many effects:

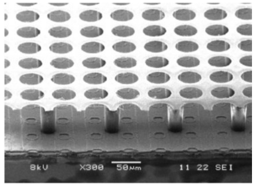
- Time walk effect (partially compensated by fitting only the unaffected side of the residual distribution)
- Electrical field distortions at the border of the GridPixes
- 40 MHz clock for digitization



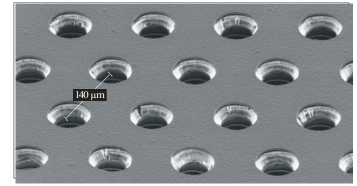


No dependence of transverse spatial resolution on track inclination in the pad plane (turning the TPC)

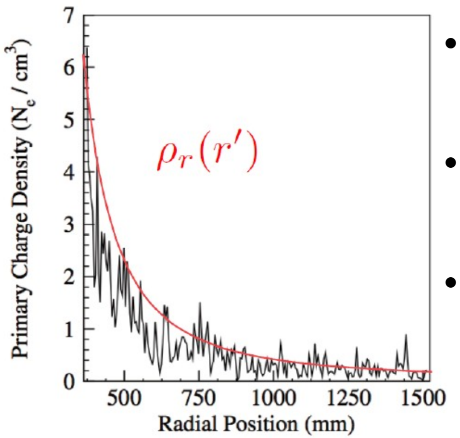
Error bars represent fluctuations of residuals for tracks



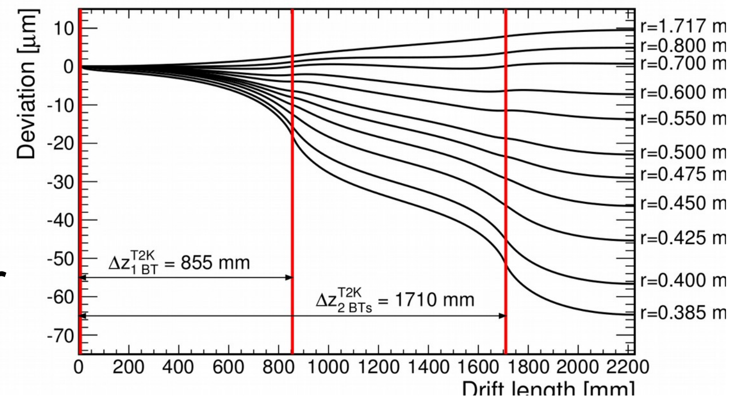
Ion Feedback and Gating



Primary ions create distortions in the electric field which result in O(<1µm) track distortions including a safety margin of estimated BG.

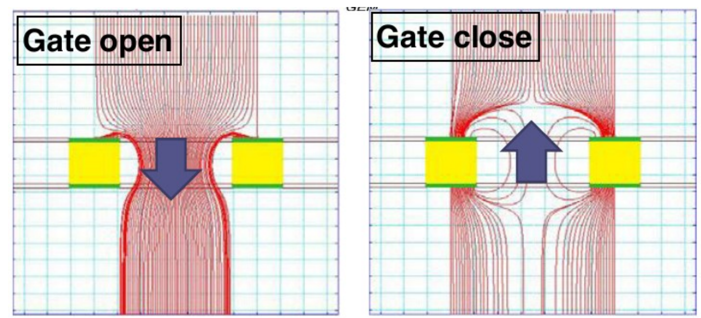


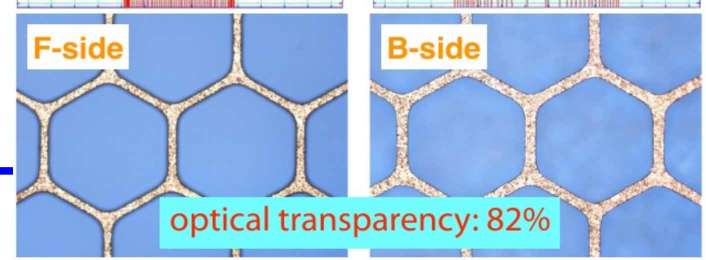
- Machine induced background has 1/r shape
- Ions from gas amplification stage build up discs
- Track distortions are 20 µm per disc without gating device, if IBF is 1/gain →Gating needed

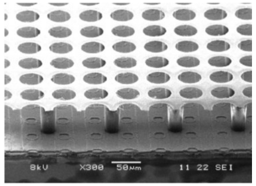


- Wire gate is an option
- Alternatively: GEM-gate
- Simulation show: Max. electron
- transparency close to optical transparency
- Fujikura Gate-GEM Type 3

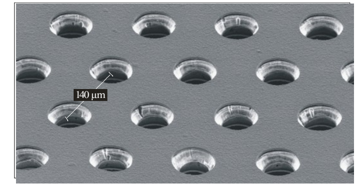
Hexagonal holes: 335 µm pitch, 27/31 µm rim
Insulator thickness 12.5 µm







Summary



Time Projections Chambers have been invented 27 years ago.
A first golden age was during the LEP era, when wire-based were fully understood and optimized.

MPGDs give a new boost to the TPC R&D: Improved spatial resolutions, intrinsic ion back flow suppression are only two of many advantages.

Today, many experiments in different areas of particle physics use/prepare/consider TPCs with MPGDs.
Only few could be mentioned because of time constraints.

GridPix detectors are novel developments promising optimal spatial and energy resolution.