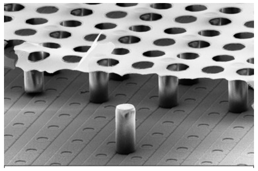

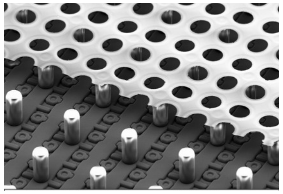

Gaseous Tracking for Linear Colliders

J. Kaminski
University of Bonn

12th Terascale Detector WS
Dresden,
13.3.2019

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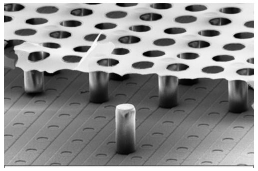
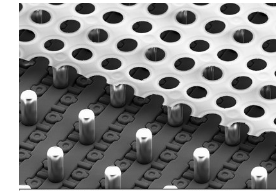
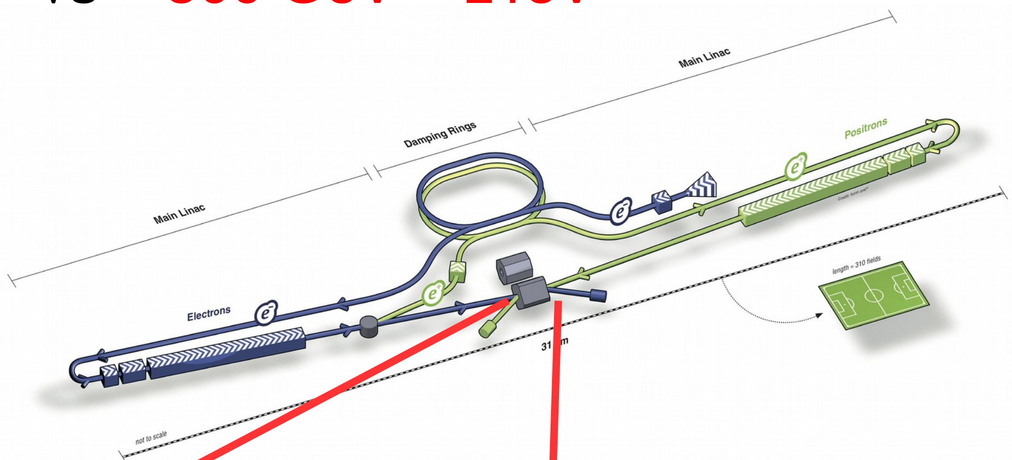
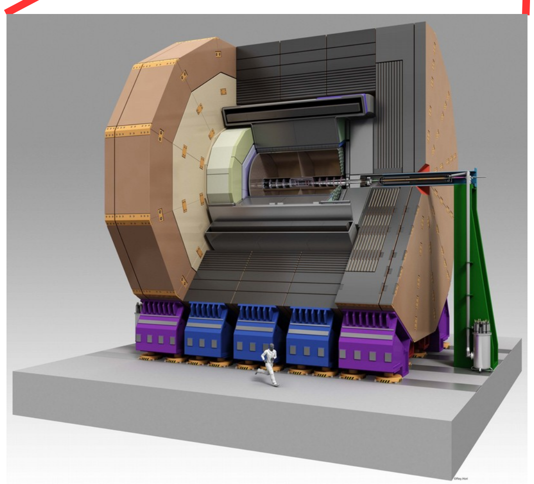


LCTPC



International Linear Collider (ILC)
is a linear e^+e^- colliders with
$\sqrt{s}$ = 500 GeV – 1TeV

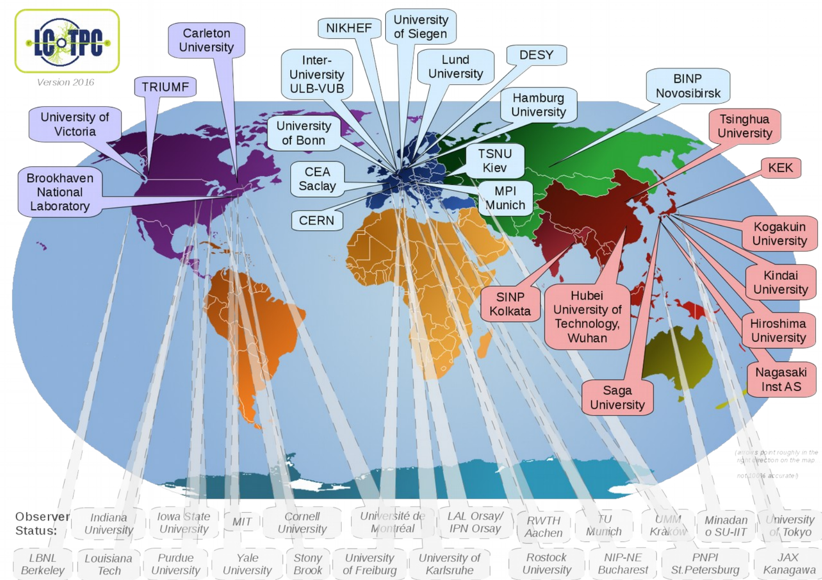




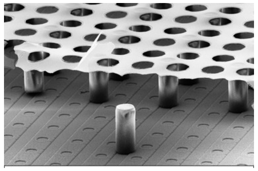
International Large Detector
- Standard HEP detector
- TPC as main tracker

MPGDs in TPCs

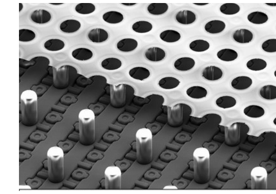
- Ion backflow can be strongly reduced
- Small pitch of gas amplification regions
  => strong reduction of E×B-effects
- No preference in direction
  => all 2 dim. readout geometries possible



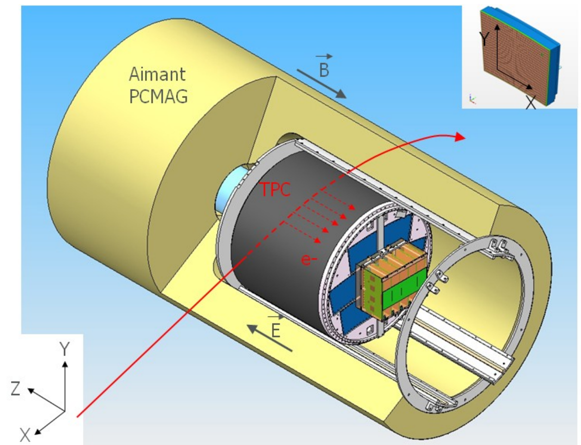
LCTPC-collaboration studies MPGD detectors for the ILD-TPC:
25 Institutes from 12 countries

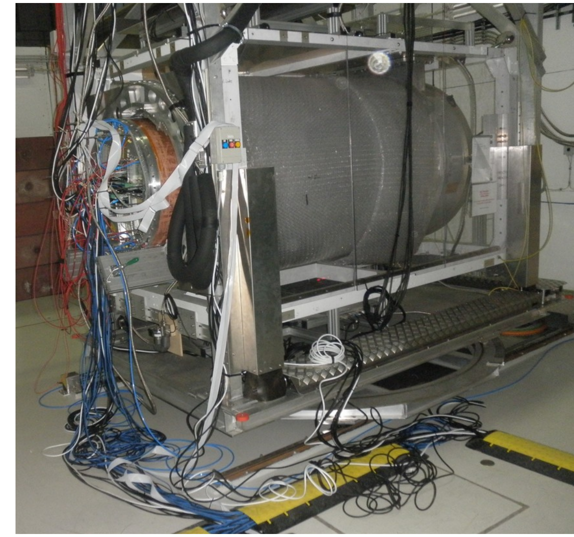


Infrastructure at DESY

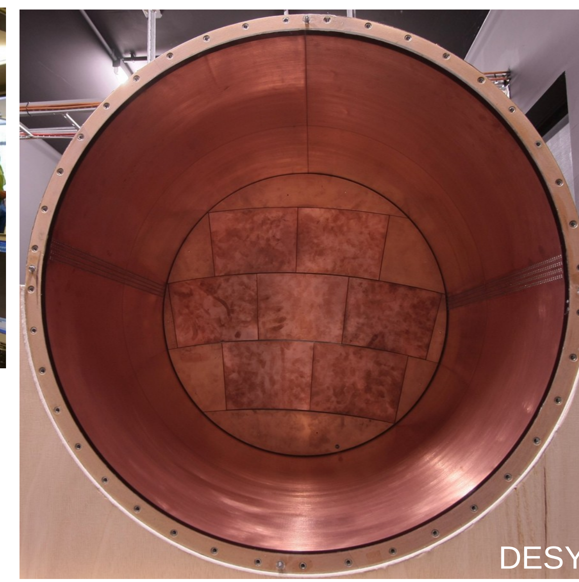


PCMAG: B < 1.2 T, bore diameter: 85 cm
Electron test beam: E = 1- 6 GeV
LP support structure
Beam and cosmic trigger
2pCO_2 cooling unit





<u>LP Field Cage Parameter:</u>
length = 61 cm
inner diameter = 72 cm
up to 25 kV at the cathode
=> drift field: E ≈ 350 V/cm
made of composite materials: 1.24 % X_0

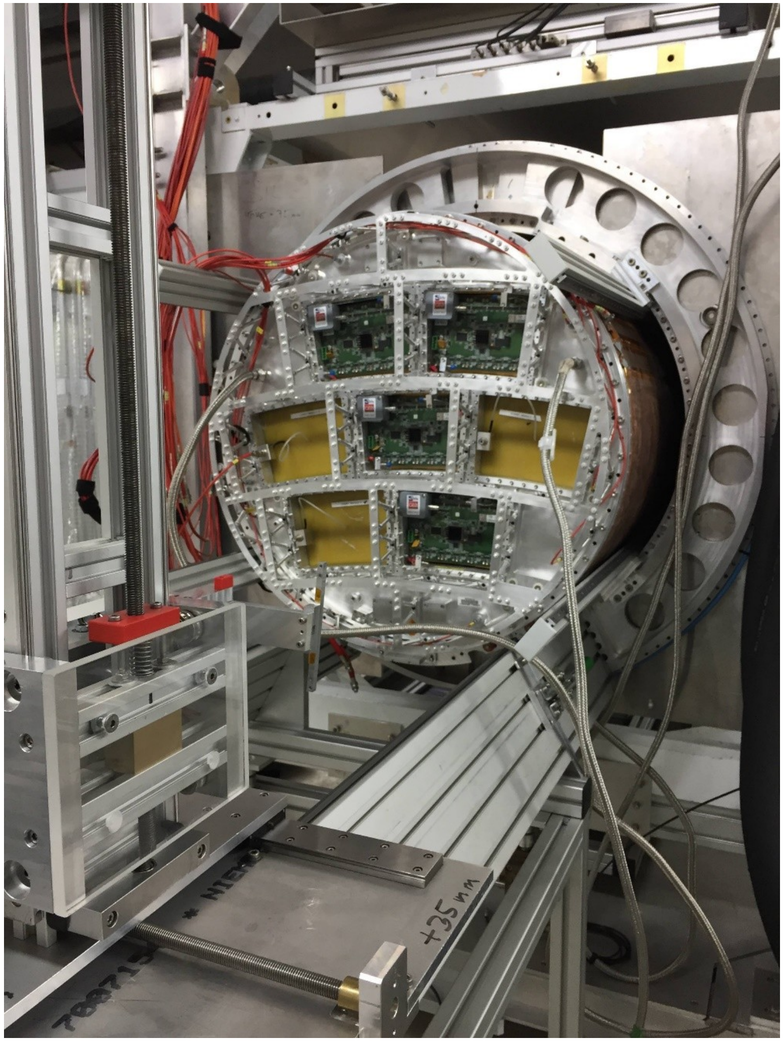


<u>Modular End Plate</u>
first end plate for the LP made from Al
7 module windows → size ≈ 22 × 17 cm^2

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

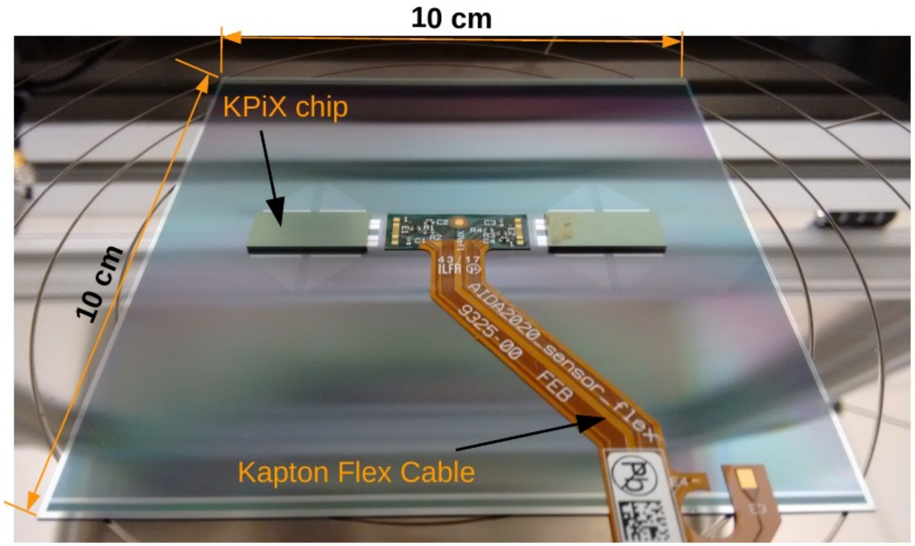
New Additions to TB Area

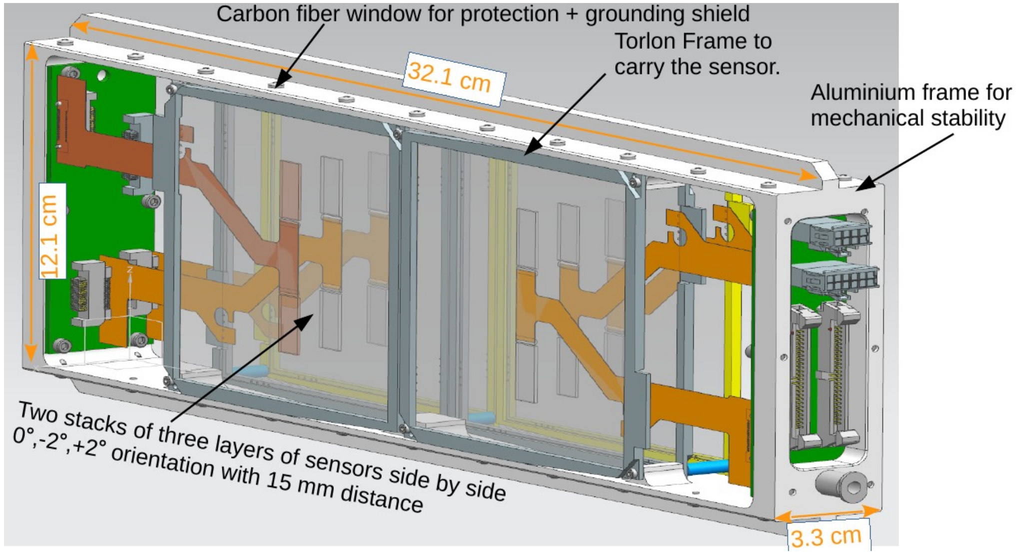
New space frame endplate: less material budget

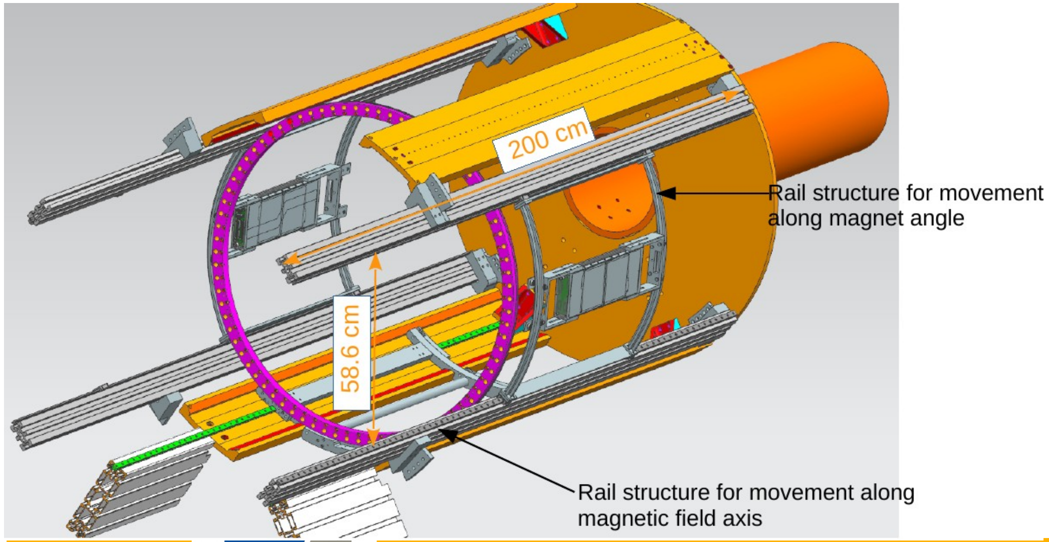


New Addition: LYCORIS

External tracking device: SiD Silicon Strip sensors with KPiX readout - mounted in front and behind the LP





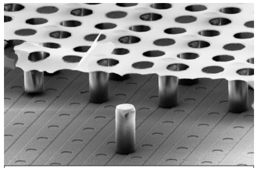


Sensors: 320 µm thick,
25 µm strip pitch

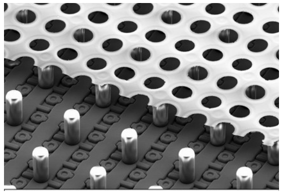
System will consist of 2 layers in front and 2 layers behind the TPC.

- → active area: 10x20 cm²
- → material budget: 0.3 X0
- → expected tracking resolution: 7 µm

Components are available, test system with 1 sensor and 1 KpiX has been tested in test beam.



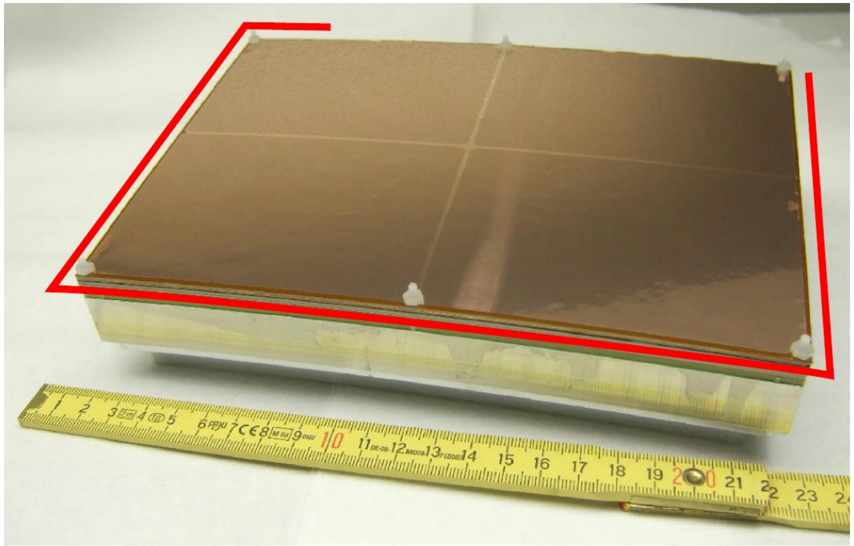
DESY GEMs - Design

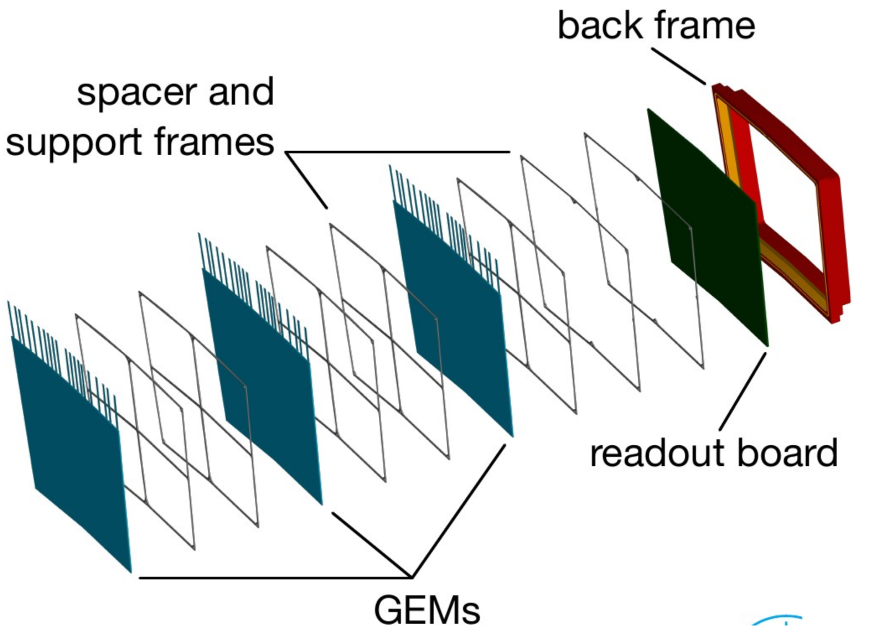


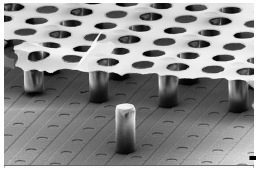
Design goals:
- Minimal dead space
- Minimal material budget
- Even surface of GEMs
- Stable operation

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

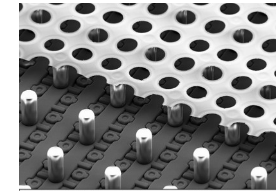
Test beam setup
- 3 partially equipped modules
- 7212 channels of ALTRO electronics
- Standard environment (E= 240 V/cm) $Ar:CF_4:iC_4H_{10}$ 95:3:2



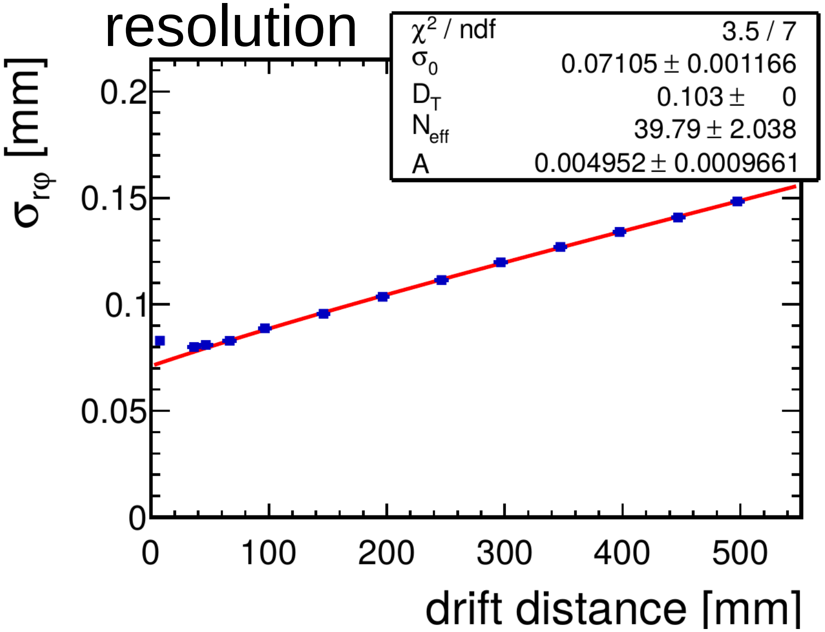




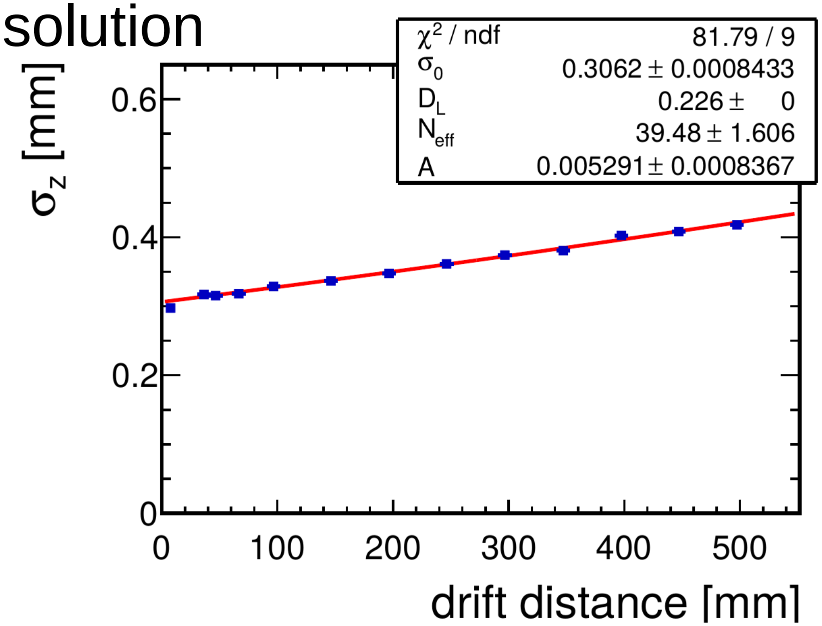
GEMs – Results Tracking



Transverse spatial resolution



Longitudinal spatial resolution



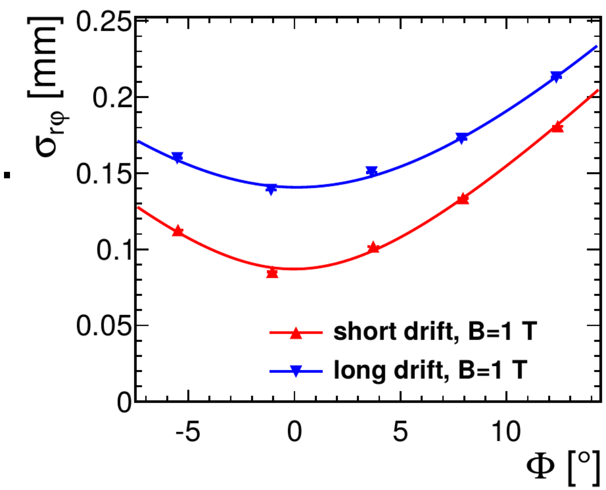
For fitting the drift dependence

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

was used.

For azimuthal dependence:

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



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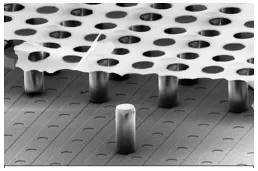
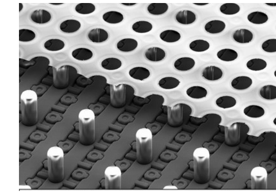
NIM A 856 (2017) 109-118



DESY GEMs - Improvements

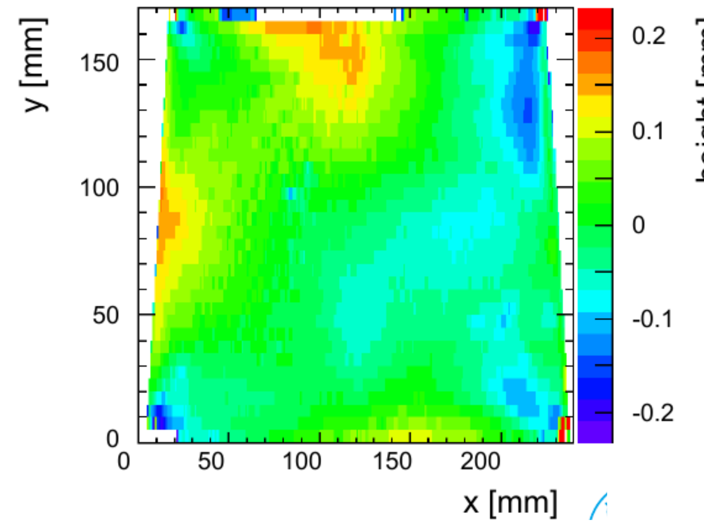


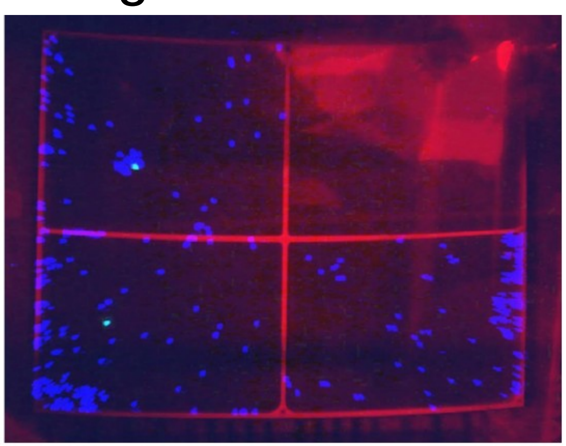
A second set of modules was produced with a higher degree of reproducible manufacturing steps (→ automatized production), in particular

- Improved method of gluing field forming wire/strip

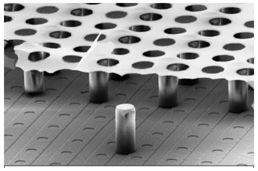
- Improve GEM stretching and gluing procedure.
  Sofar, sagging of up to 200 µm was observed.
  (Stretching was done by hand before.)

- Improve the HV-stability of the GEMs.
  One single destructive discharge was observed during measurements after first test beam.

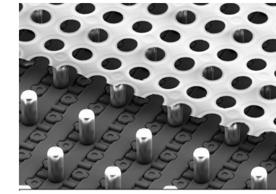




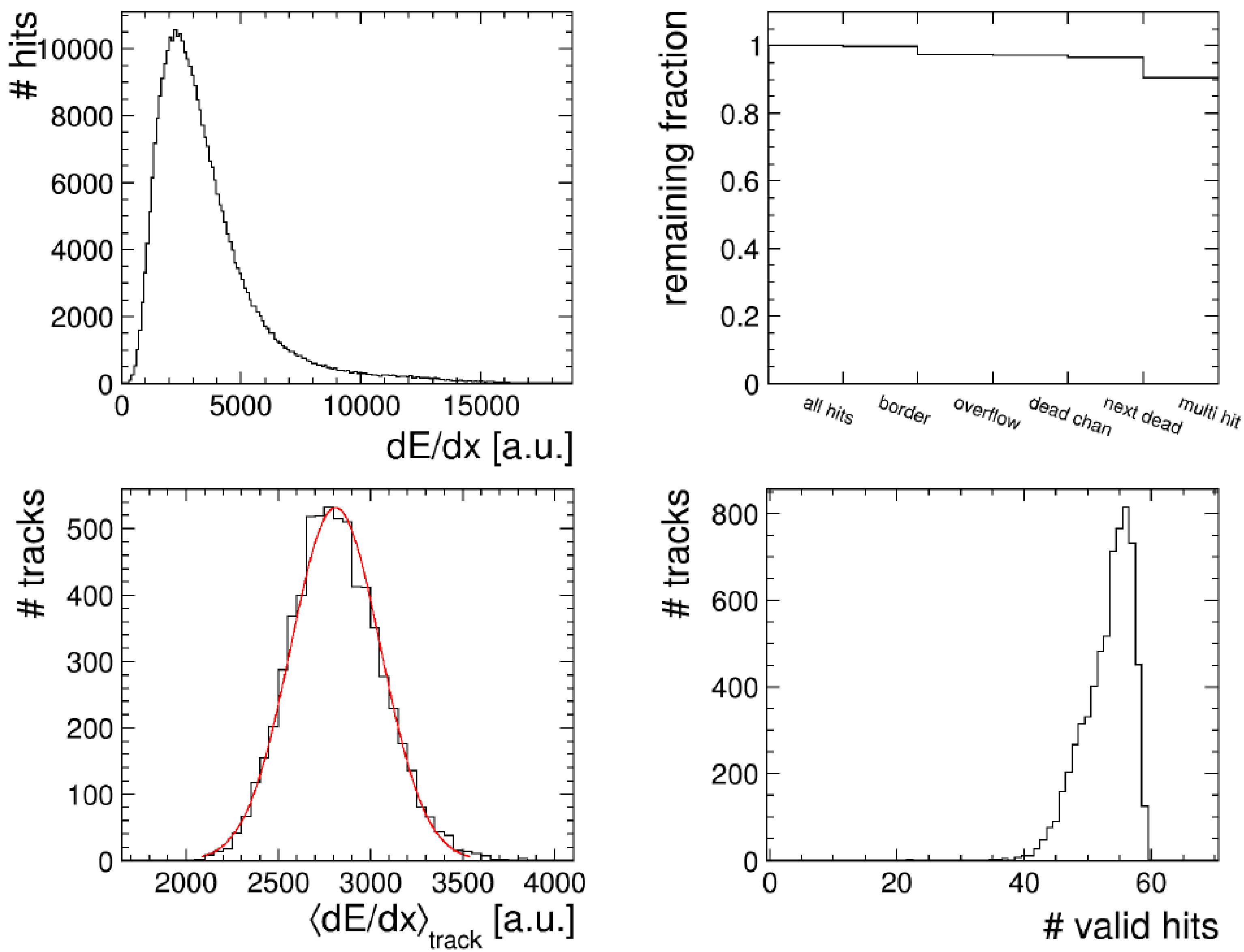
Discharges were provoked in lab and observed with camera => several double and triple discharges
CST-simulations show surface current oscillations
Solution: the oscillations are damped with RC-circuit
→ No more multiple discharges observed

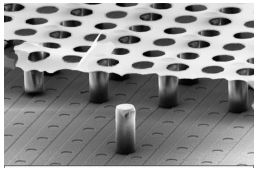


GEMs – Results dE/dx

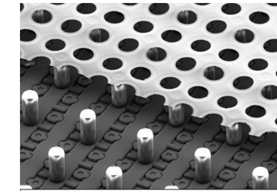


- Used 5 GeV electrons to determine dE/dx
- Up to 60 samples (pads) per track, 53 on average
- Studied various estimators.
- Best result: dE/dx = 8.7 %
- Extrapolating to full ILD-TPC: dE/dx=4.2 %

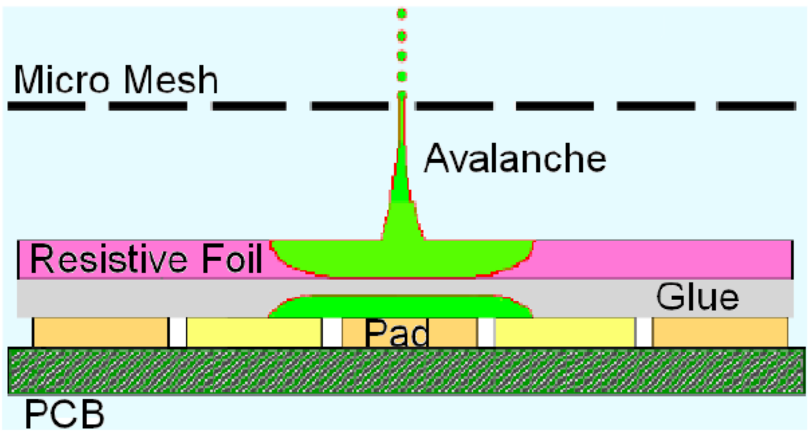


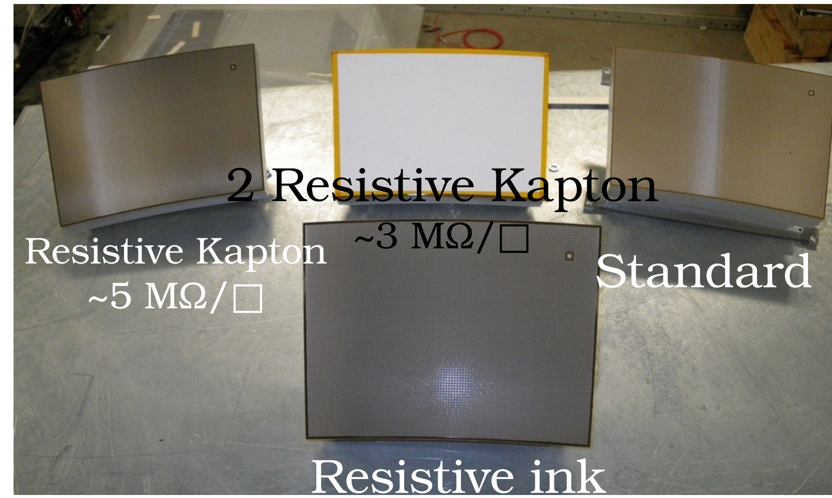


Micromegas

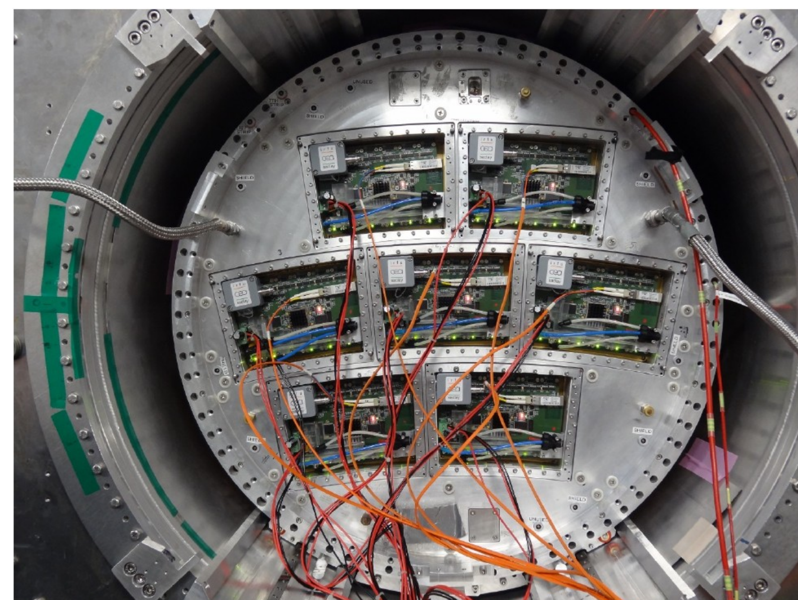


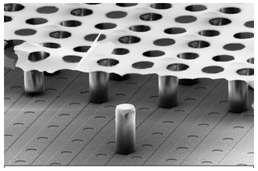
Micromegas give rather thin signals
→ hits are collected by one pad
→ degrades spatial resolution
=> use resistive layer to spread signal over several pads!



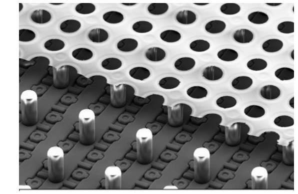


Modules have large pads (3×7 mm²)
1728 channels per module
connected to AFTER electronics.
Several resistive layers have been tested
9 modules built in a miniseries.

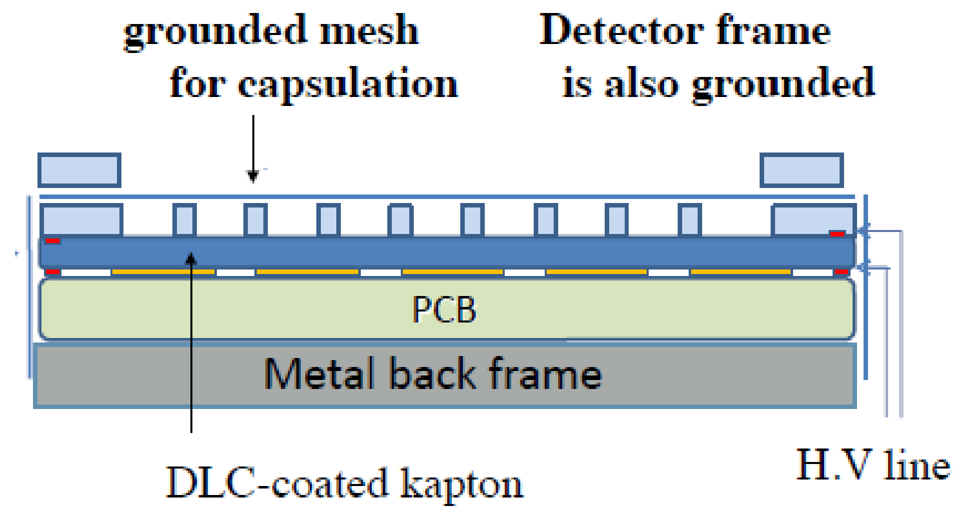


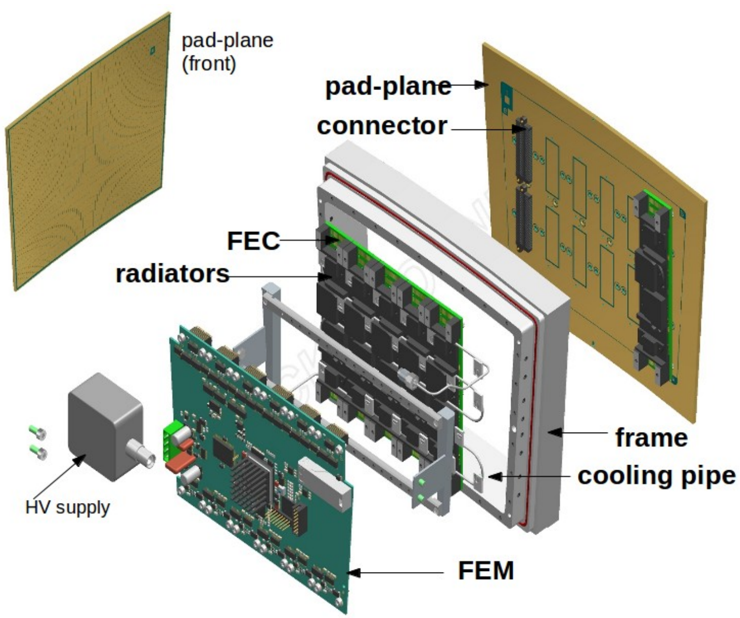


New Micromegs Modules

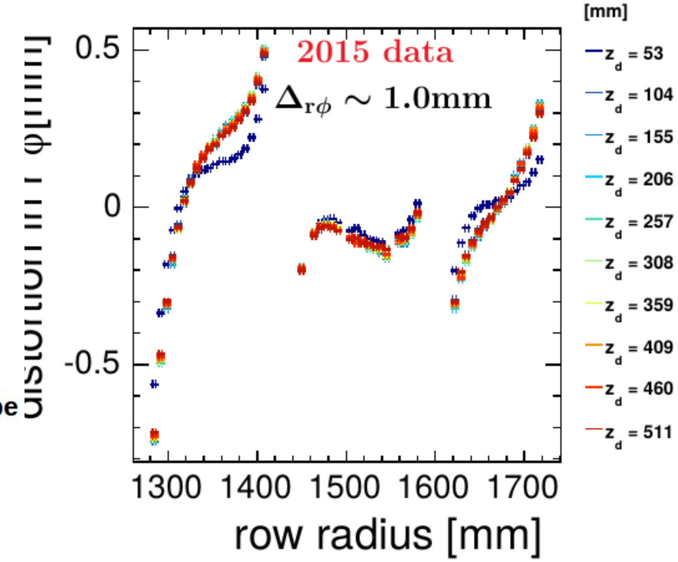


Encapsulated Resistive Anode MMs
mesh at the same potential as the frame, and resistive anode at +HV.
New scheme reduce distortions at the edges of the modules, and makes amplification field independent of drift field.

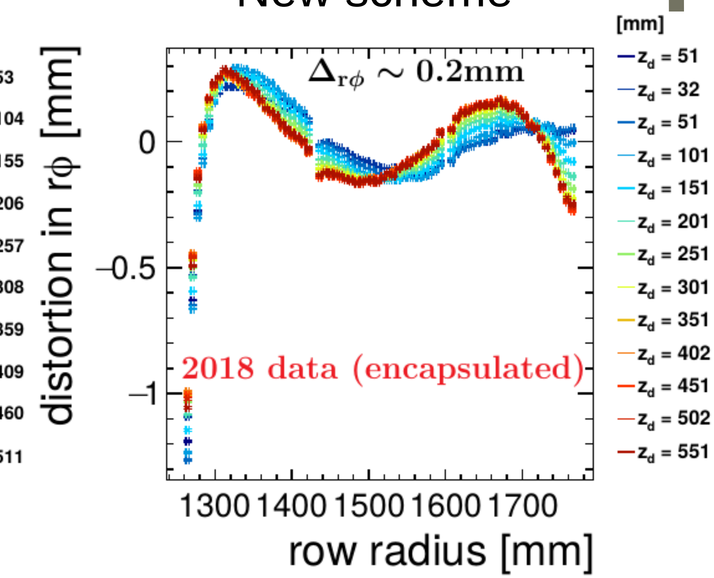


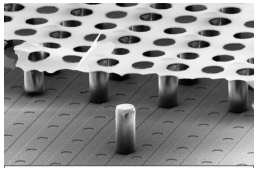


Old scheme

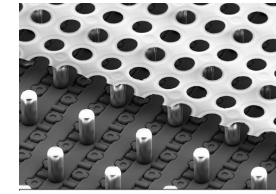


New scheme

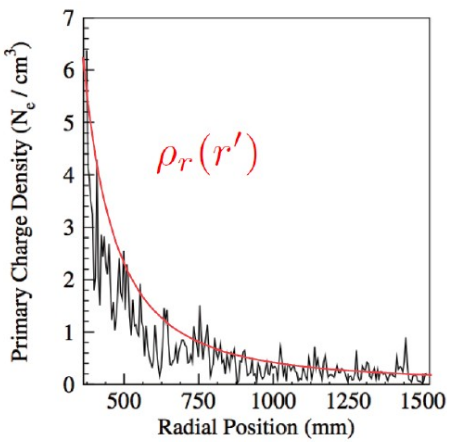




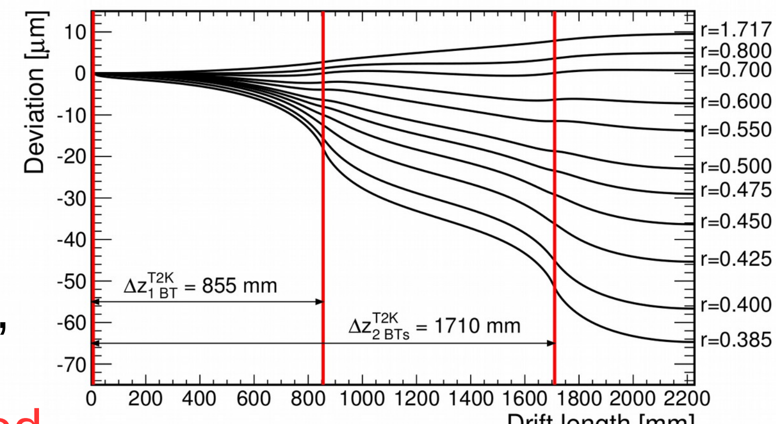
Gating Foil



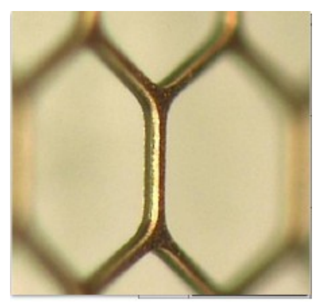
Primary ions create distortions in the electric field which result in O(<1µm) track distortions including a safety margin of estimated BG.

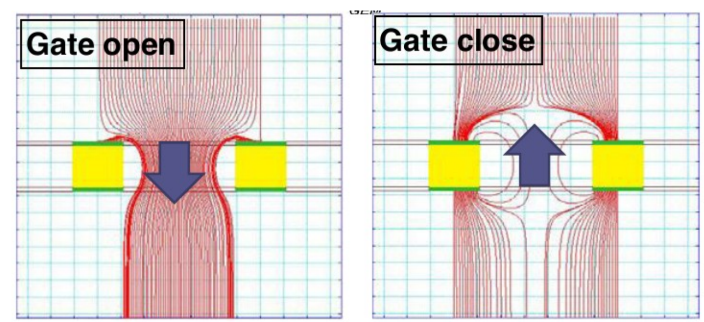


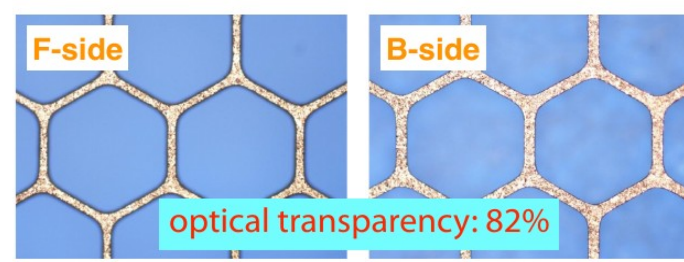
- Machine induced background has 1/r shape
- Ions from gas amplification stage build up discs
- Track distortions are 20 µm per disc without gating device, if IBF is 1/gain
- Total: 60 µm => Gating is needed

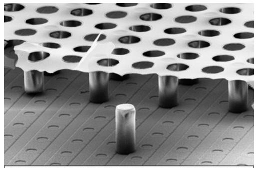


- Wire gate is an option
- Alternatively: GEM-gate
- Simulation show:
  Maximum electron transparency is close to optical transparency
- Fujikura Gate-GEM Type 3
  Hexagonal holes: 335 µm pitch, 27/31 µm rim
  Insulator thickness 12.5 µm

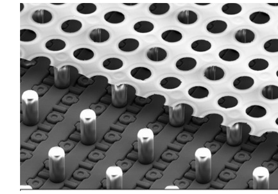




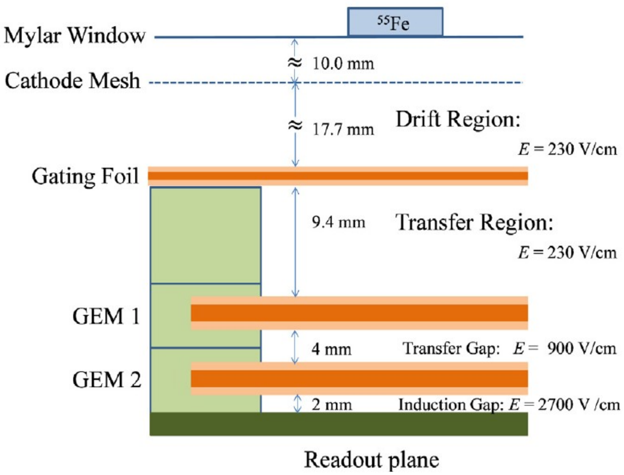




Gating Foil - Measurements

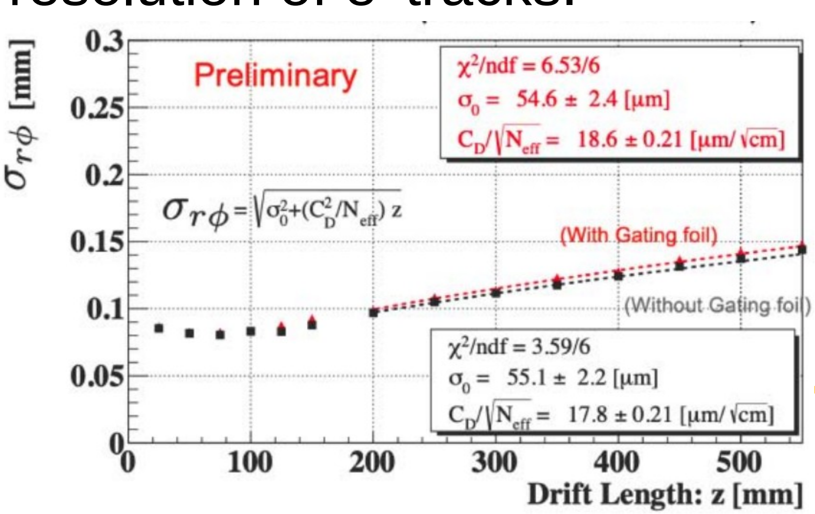


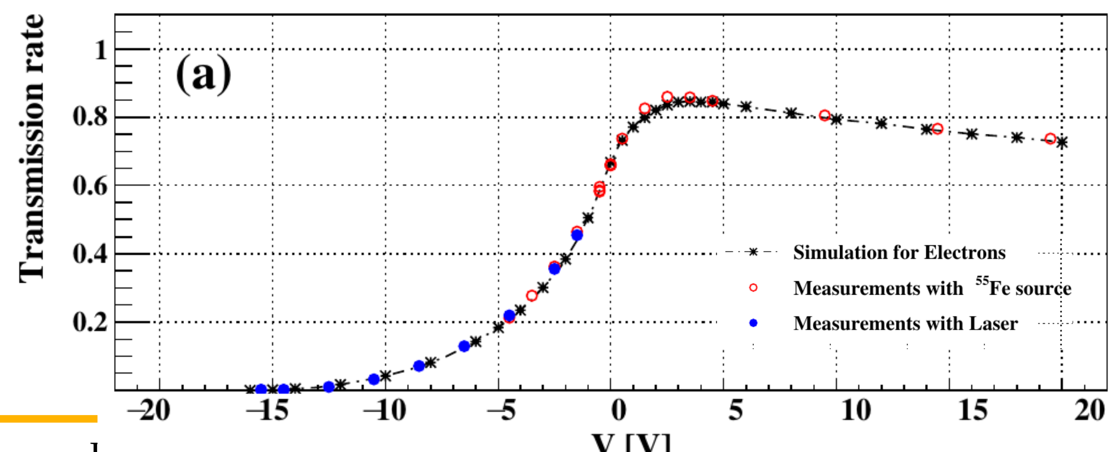
Electron transparency important to ensure the good spatial resolution:
→ measure electron transparency with ^{55}Fe source, laser and in test beam



- X-ray signals have been reconstructed
- Determined charge generated by each photon
- Shift in charge peak gives absorption of electron
- Measurement compared to Garfield++ simulation
- Measurement confirmed with charge generated by laser beam
- Electron transparency is equal to optical transparency (~82 %)

Results confirmed at DESY test beam by measuring degradation of spatial resolution of e^- tracks.

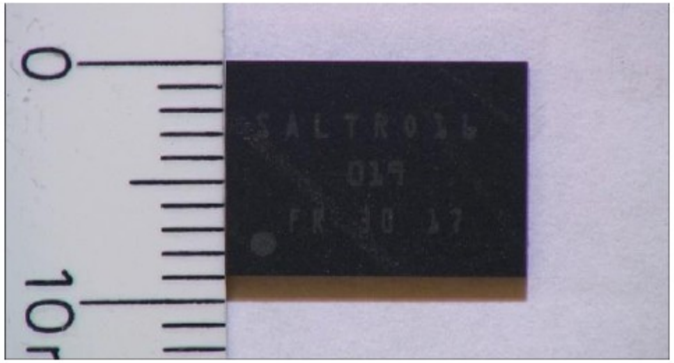


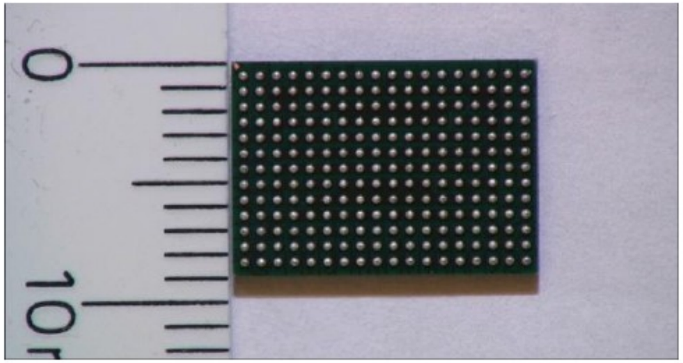


SALTRO

Measurements have been performed sofar with electronics based on the ALTRO or AFTER ASIC.

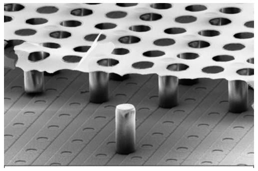
New electronics based on the SALTRO ASIC is being developed.
- ASICs have been packaged in sufficiently small packages.



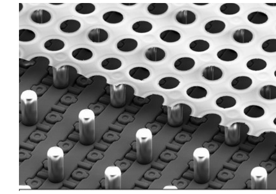


- Test boards are available to test the ASICs.
  First pre-series showed connection problems and a yiels of less then 60%
  Second pre-series had a much better yield of more than 80%.

Final boards are being designed, but a FPGA – programmer is needed to adapt the current code to the final functionality.



ROPPERI – The Concept

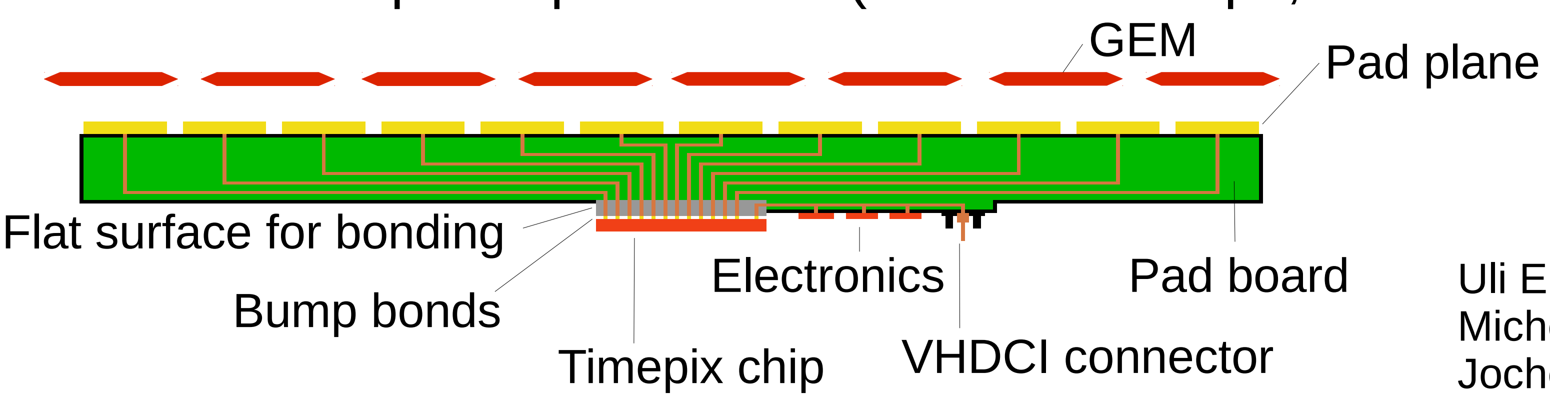


Readout Of a Pad Plane with Electronics designed for pixels

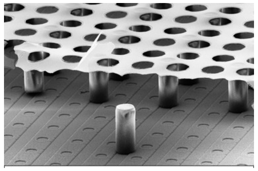
Standard Readout of Micropattern Gaseous detectors:
Gas amplification by GEMs or Micromegas,
Charge collection by pads (or strips) and
Digitization by readout electronics (~16-128 channels per ASIC).

New idea: Replace standard ASICs by ASICs designed for pixel detectors
- → Higher number/density of readout channels per ASIC
  (e.g. Timepix: 65,536 channels, each of size 55x55 µm²)
- → One ASIC enough for a complete pad plane
- → Smaller pads are possible making electron/cluster counting possible

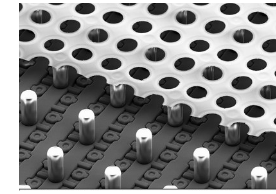
Challenges: Connect ASICs to readout plane (PCB),
Mismatch of input capacitances (TP: ~ 10-100 pF, detector: 2-5 nF)

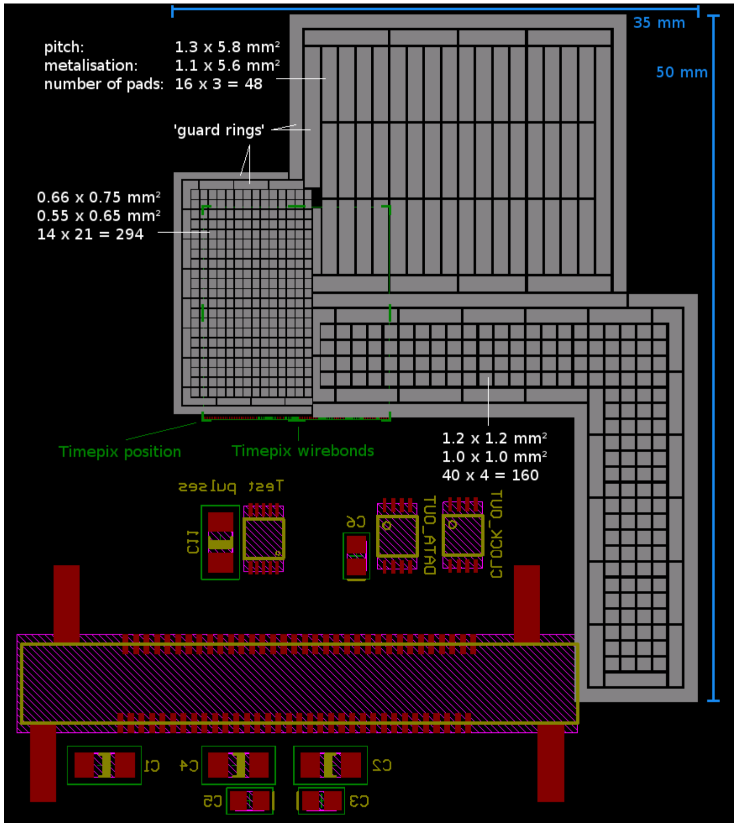


Uli Einhaus (DESY)
Michele Caselle (KIT)
Jochen Kaminski (UBonn)



ROPPERI - Tests



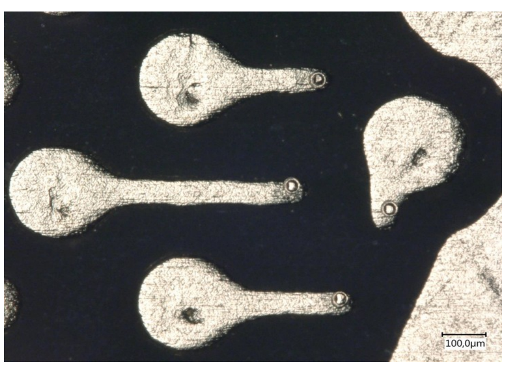


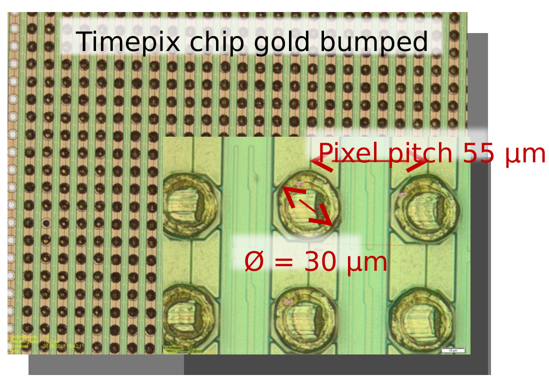
Prototype board:

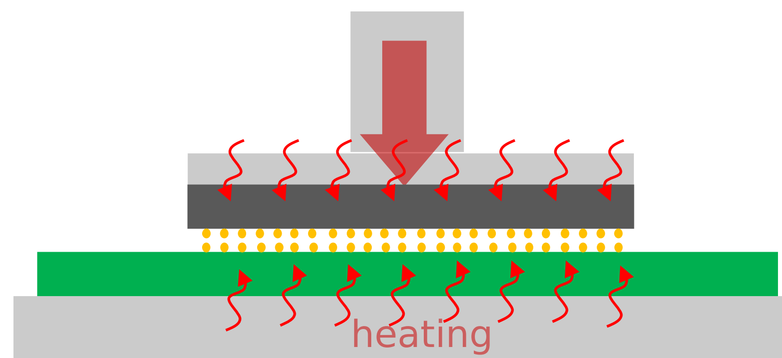
- PCB of 9 x 9 cm^2
- 3 pad sizes (1.3x5.8mm^2, 1.2x1.2mm^2, 0.65x0.75mm^2)
- Various connection lengths
- 500 channels connected in total
- To be used with 10 x 10 cm^2 GEMs

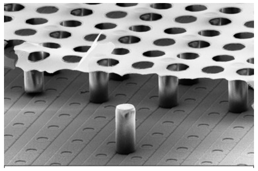
Stud Ball Bumping (SBB) process:

- Gold wire 12.5 µm → Bump diameter 23 µm
- Studs on PCB and on ASIC
- Flip-Chip Process - Bonding Machine
- Some boards with underfill for mech. stability
- Tests with readout electronics on machine

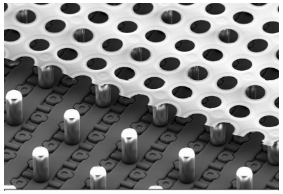




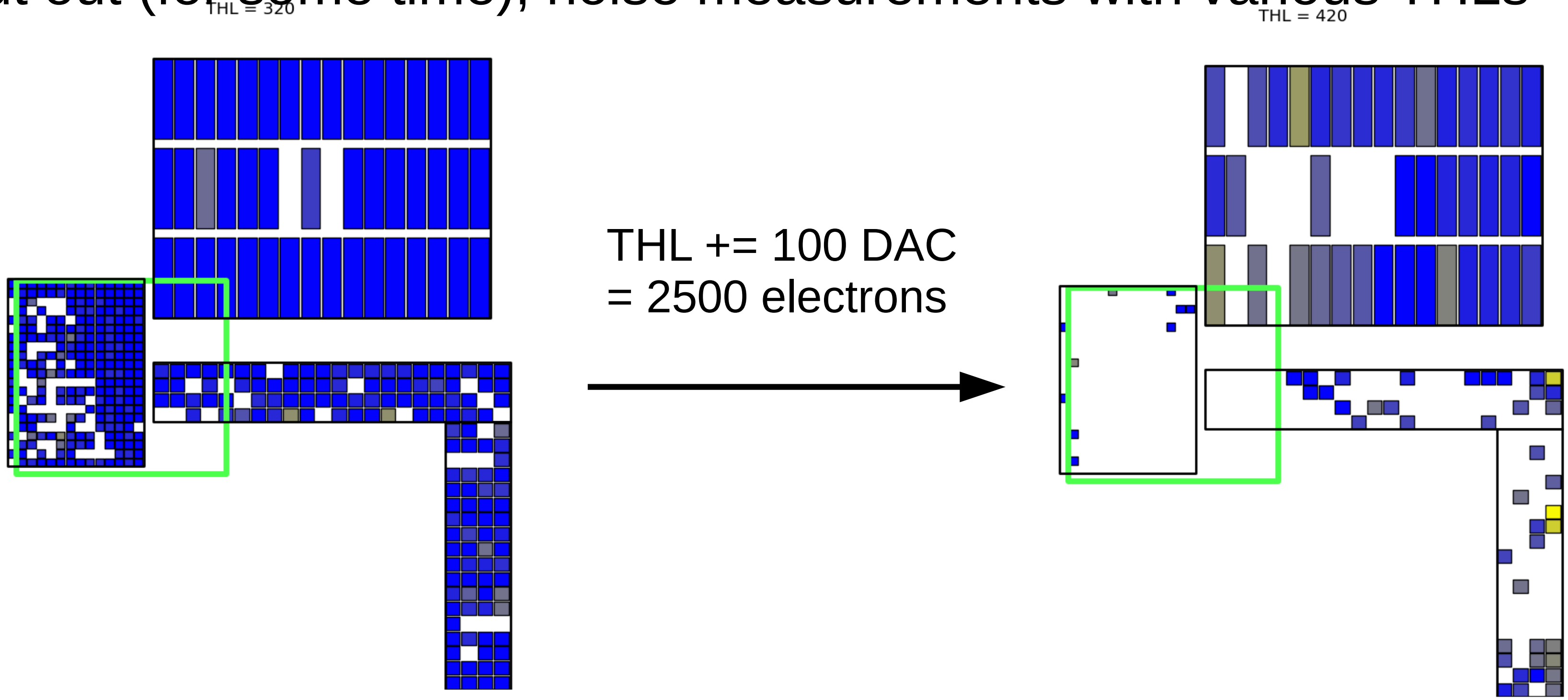




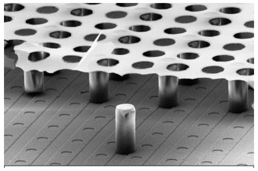
ROPPERI - Measurements



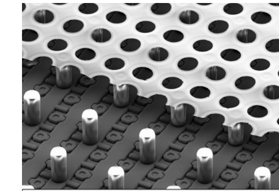
1. production: no connection of readout to chip
2. production: boards with lower temperature coefficient - 1 board could be readout out (for some time), noise measurements with various THLs



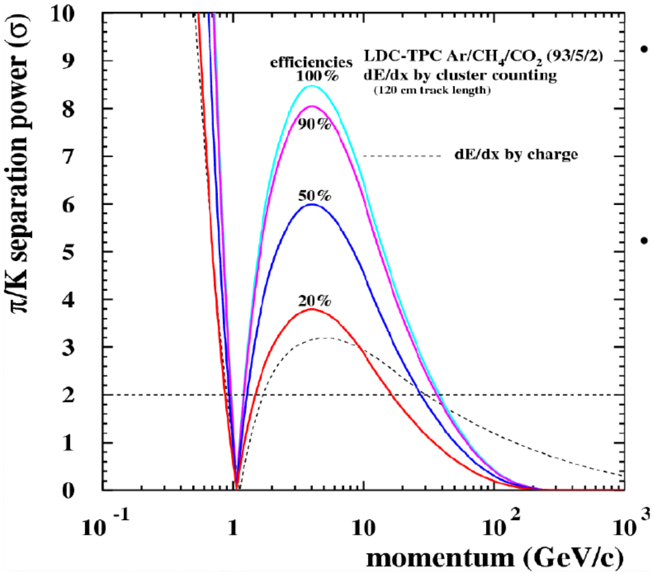
- ROPPERI board has about 3 times the noise as a bare Timepix (ENC~ 90 e^-)
  → ~ 300 e^- for ROPPERI and clear dependence on routing length
- A GEM-gain of 10k would allow the identification of a single electron with 3x3 300 µm pads each receiving 3 ENC.
- Combining 9 pads into one measurement → the S/N increases to 9.



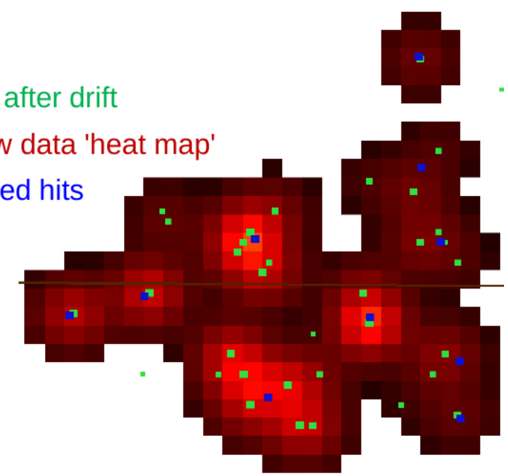
dE/dx -Measurement with Cluster Counting

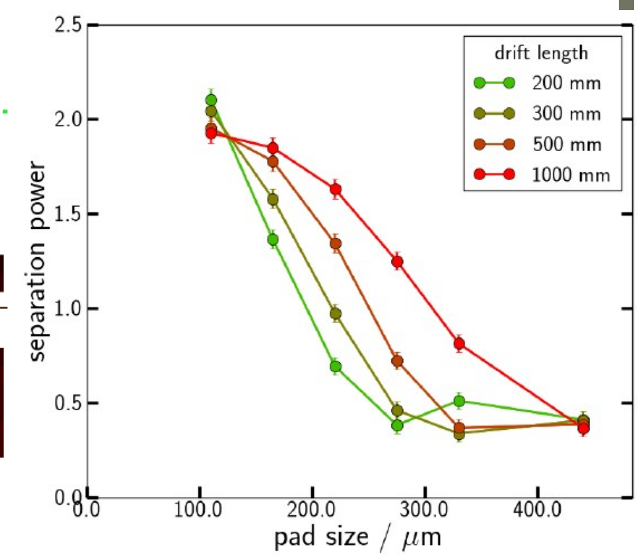


The benefit of cluster counting with respect to PID has been shown by M. Hauschild in 2006.
Because the ROPPERI development allows for sufficiently small pixel sizes, the interest is renewed and more detailed simulations have been done.

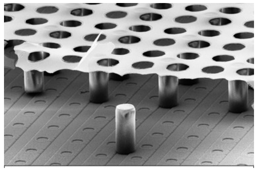


- Event display:
  - Green: electrons after drift
  - Red: digitised raw data 'heat map'
  - Blue: reconstructed hits
- Identify and count clusters / hits

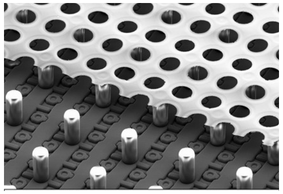




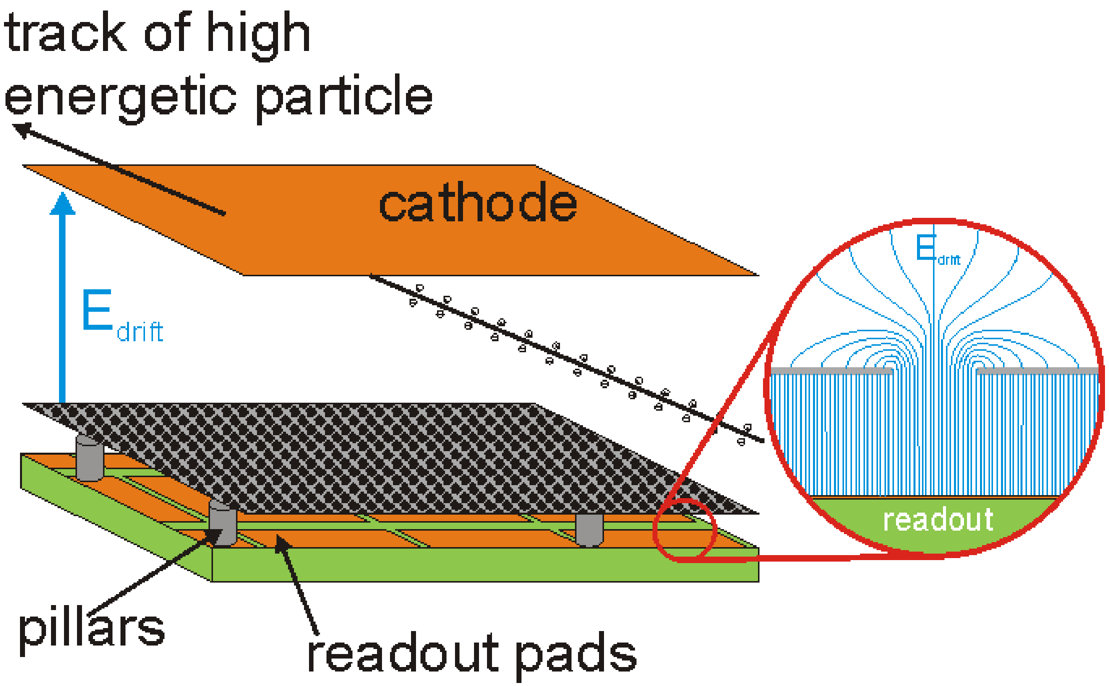
With pixel/pad sizes of 300x300 µm² the separation efficiency is above 20 % improving the pion Kaon separation power significantly above the charge measurement.



GridPix – The Concept



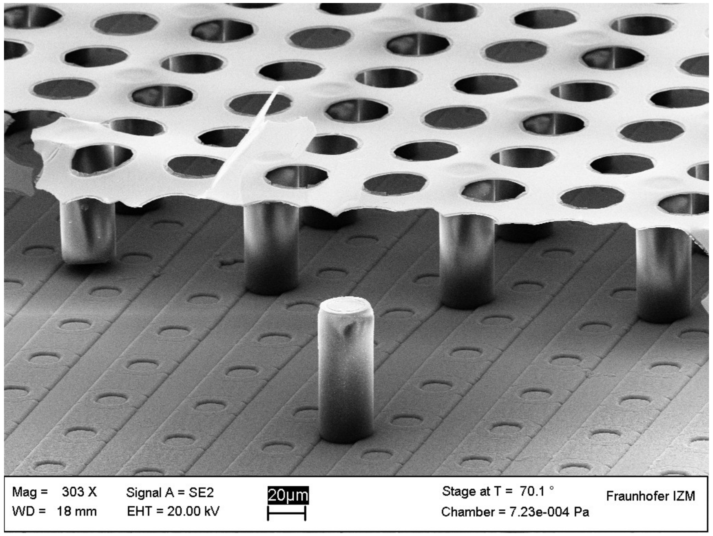
MM invented by Y. Giomataris, et al. (NIMA 376, p. 29-35, 1995)



Standard charge collection:

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

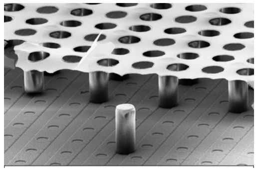
Instead: Bump bond pads are used as charge collection pads.



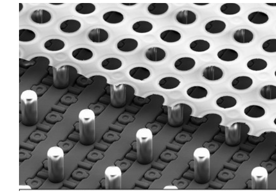
Could the spatial resolution of single electrons be improved?

Ar:CO_2 70:30 → D_t = 187 µm/√cm → σ = 21 µm

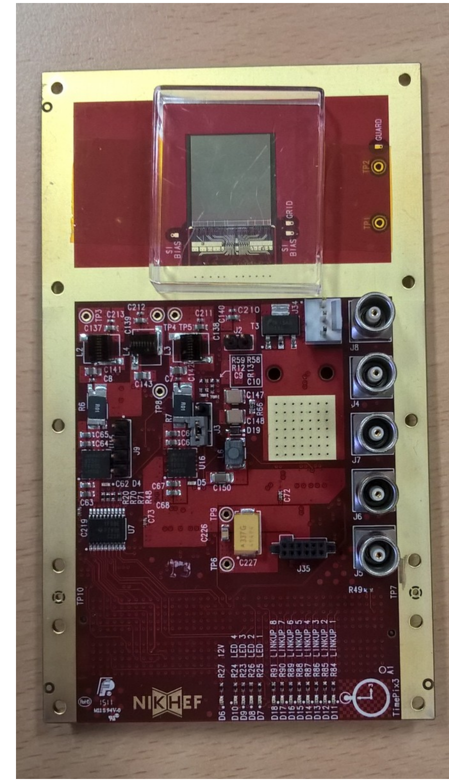
Smaller pads/pixels result in better resolution!
At NIKHEF the GridPix was invented.

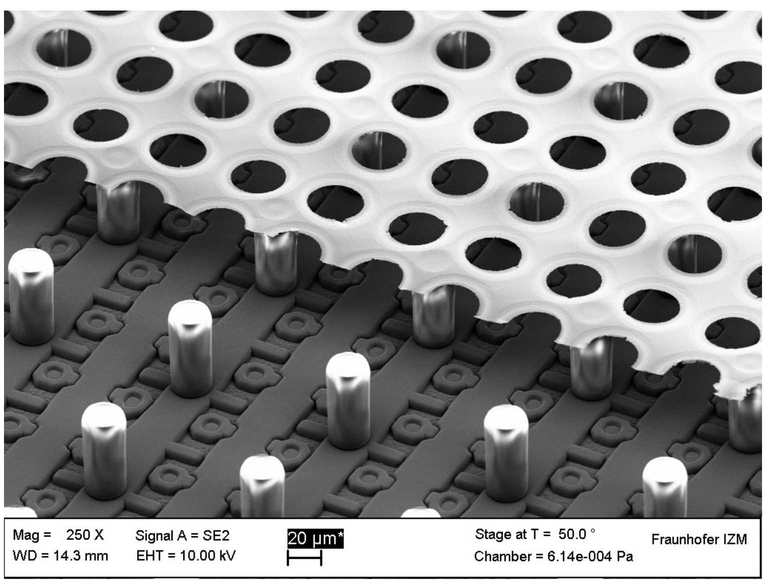


GridPix – based on Timepix3



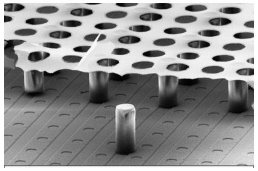
- Number of pixels: 256 × 256 pixels
- Pixel pitch: 55 × 55 µm²
- ENC: ~70 e^-
- Charge (ToT) and time (ToA) available for each hit
- Timing resolution: 1.56 ns for duration of ~410 µs
- Zero suppression on chip (sparse readout)
- Multi-hit capable (pixels sensitive after t_{ToT}+475 ns)
- Output rate up to 5.12 Gbps
- Power pulsing possible (800 ns for start up)

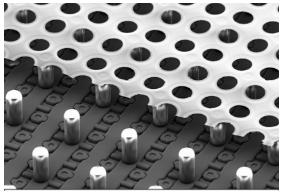




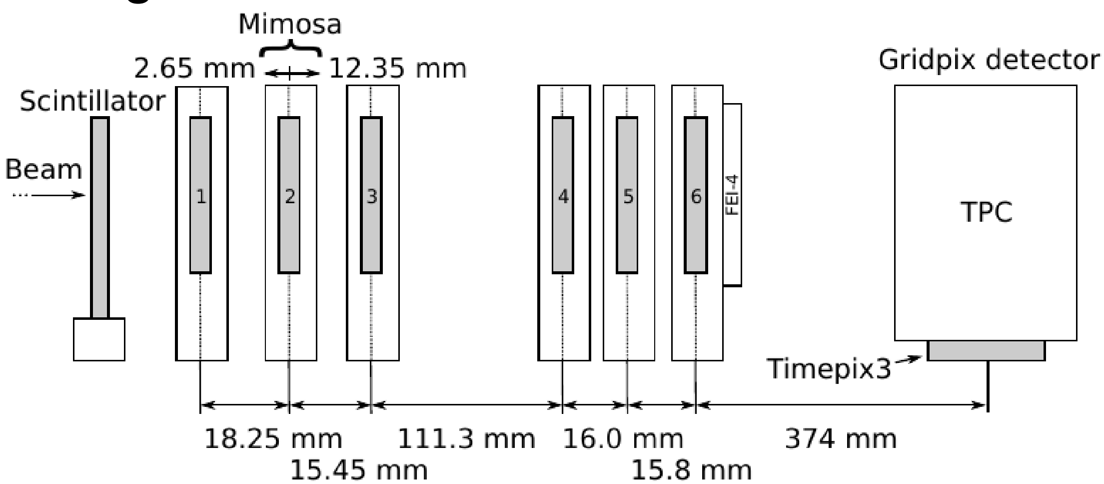
The grid has been redesigned reducing the fraction of pixels covered by SU8 from 8.7 % to 2.3 %.

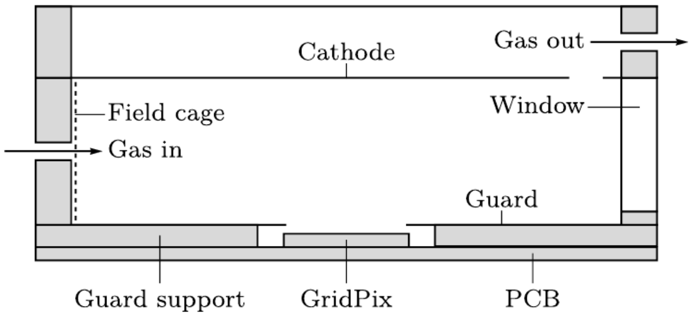
GridPix – First Measurements





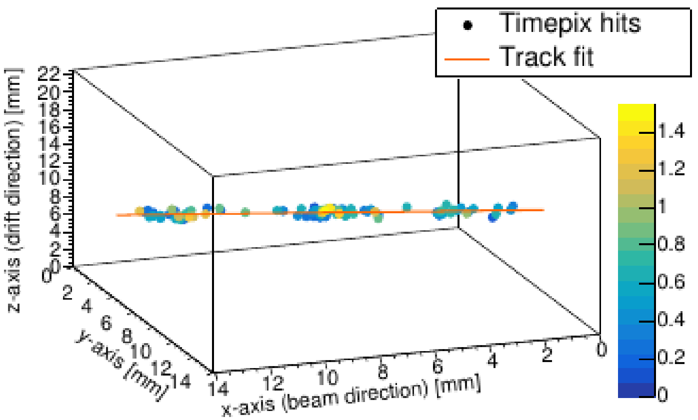
Using 2.5 GeV electrons at ELSA, Bonn with up to 10 kHz.

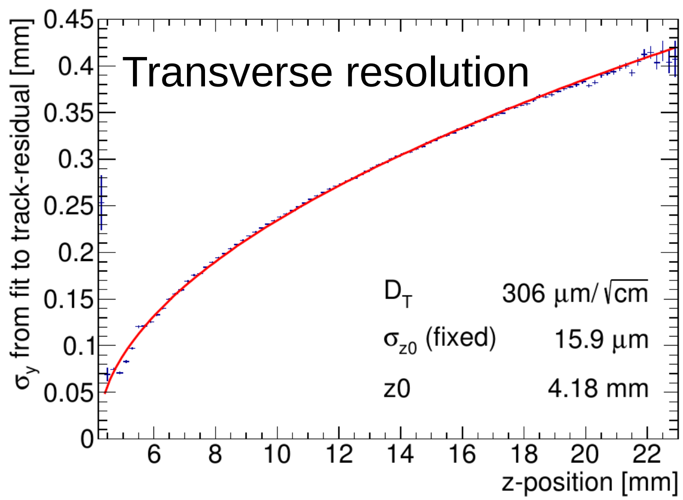


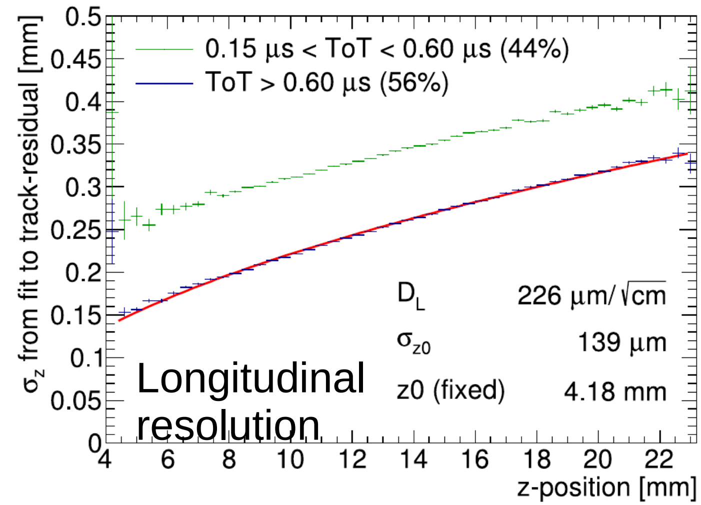


Detector operated in data driven mode.
Spatial resolution was as expected.

EUDET telescope with 6 layers of Mimosa detectors.







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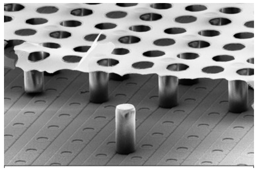
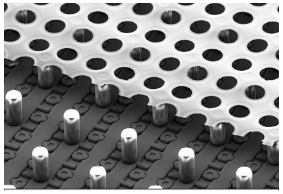
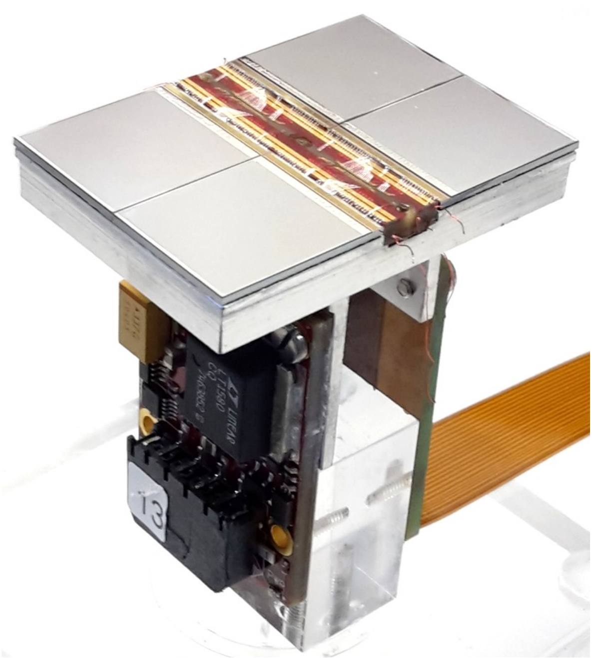
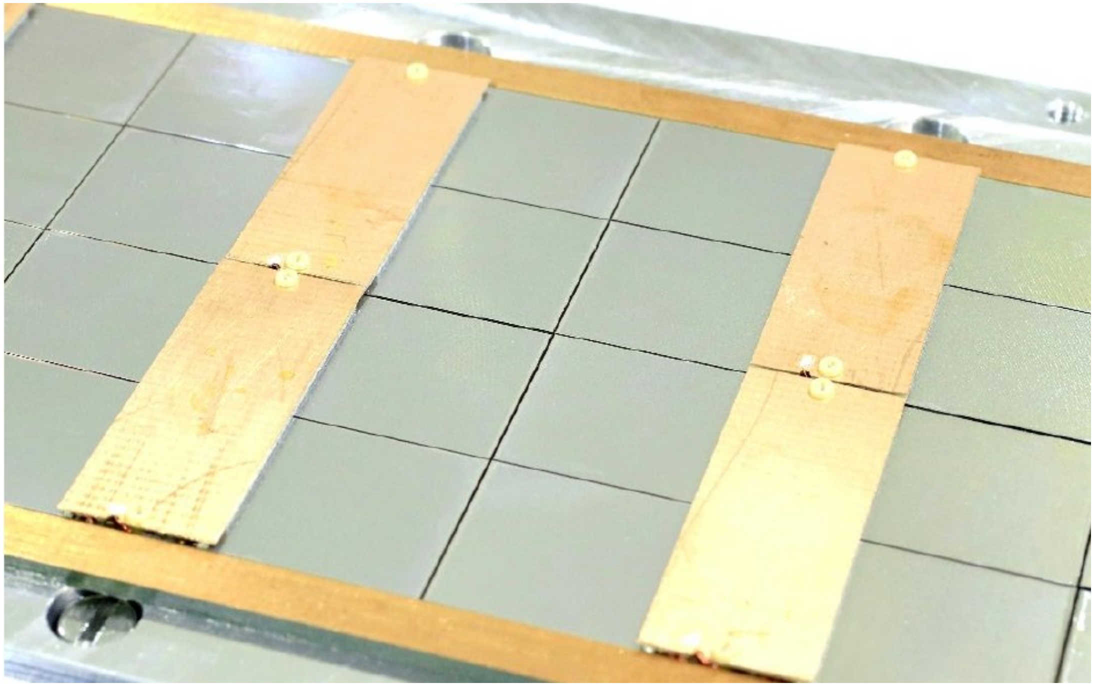
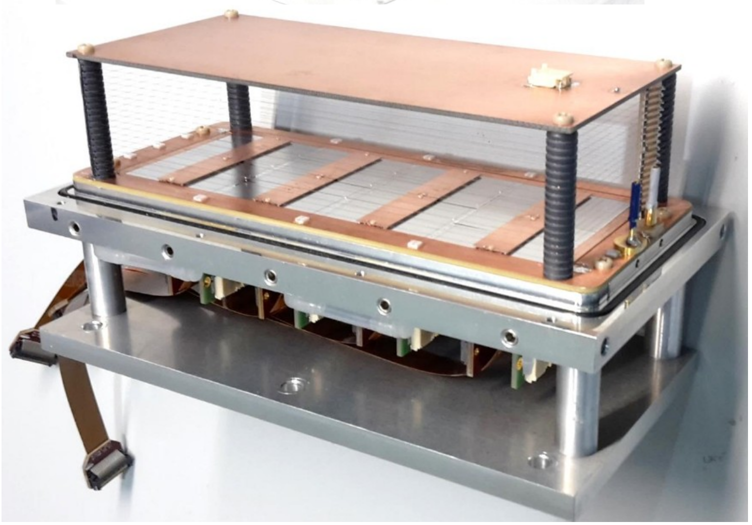


QUADs





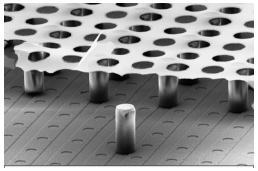




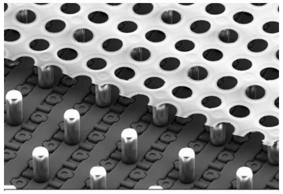
Quad has an active area of 68.9%
12 operational QUADs (from 14 produced)
8 QUADs mounted in test detector.
Testing has started: - HV is stable

Test beam at Bonn later this year.

Other Developments beyond LCTPC



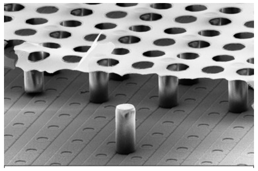
ALICE TPC



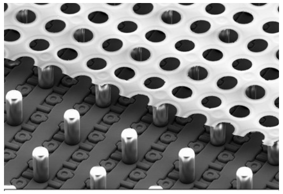
Length: 5 m
Diameter: 5 m
=> Volume: 90 m³
Ne:CO_2:N_2 85.7:9.5:4.8

The chamber was designed to study the heavy ion collisions at the LHC
(Pb with 2.7 TeV/nucleon → $\sqrt{s}$ = 574 TeV).
→ Expected multiplicity of 8000 tracks per event on average and up to a maximum of 20000 tracks per event
The drift field must have a value of 400 V/cm to limit the t_{drift} to 90 µs.

a) The central cathode has to be put to 100 kV →
For insulation an extra gas layer of N_2 was placed around the field cage.
Drift velocity is not saturated → all changes in parameters have to be prevented.
b) Temperature must be stable at a level of ΔT = 0.1 K
→ Heat shield towards
surrounding detectors, cool all electronics



TPC upgrade



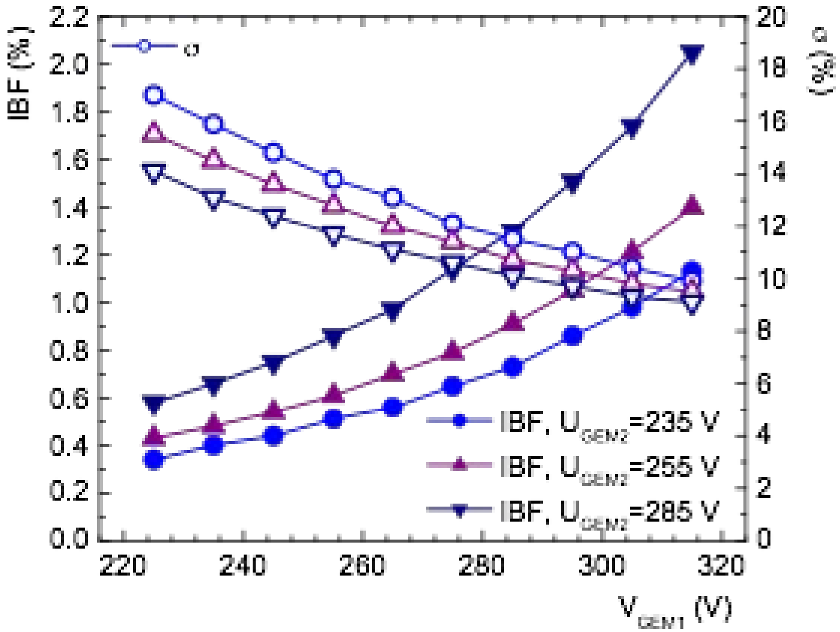
To allow for the higher luminosity (50 kHz Pb-Pb) starting from 2020 a continuous readout of the TPC is necessary. → using GEMs

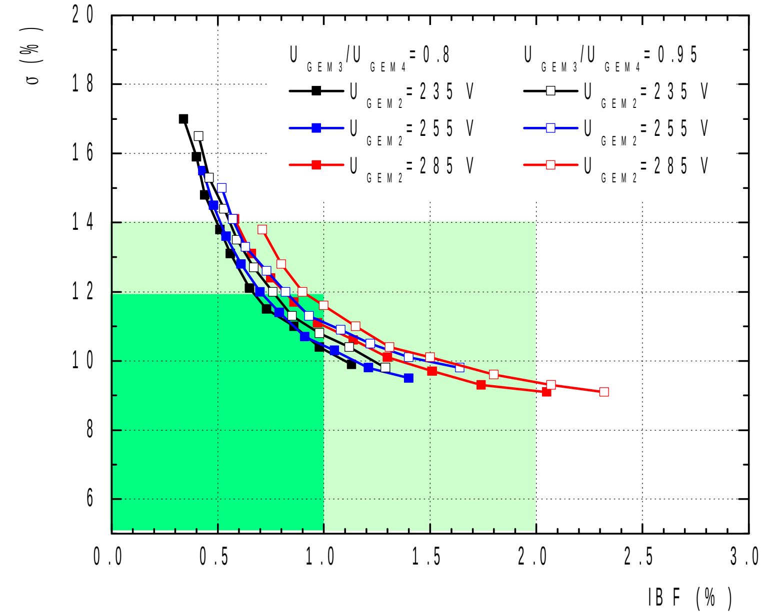
Optimization of two parameters at the same time is conflicting:

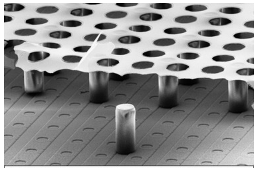
Best Value IBF ~ 0.6 % at an energy resolution of σ/E < 12 % for ^{55}Fe.

Upgrade goals have been reached with even a small margin for fine tuning (in case needed for the stability).

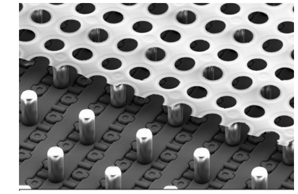
Much larger phase space has been scanned no significant improvements (no order of magnitude) are expected.



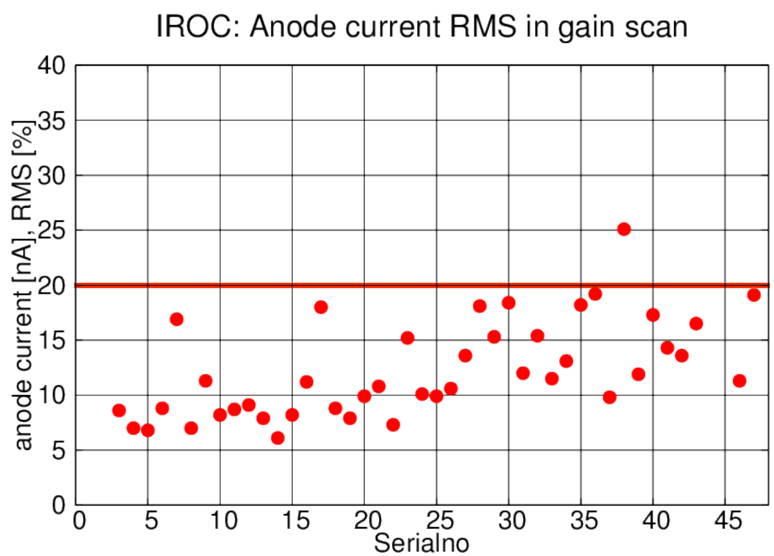


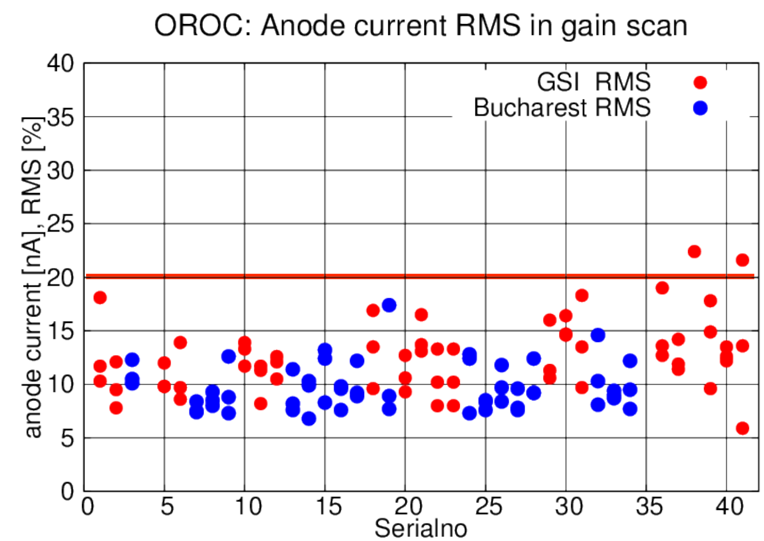


TPC upgrade



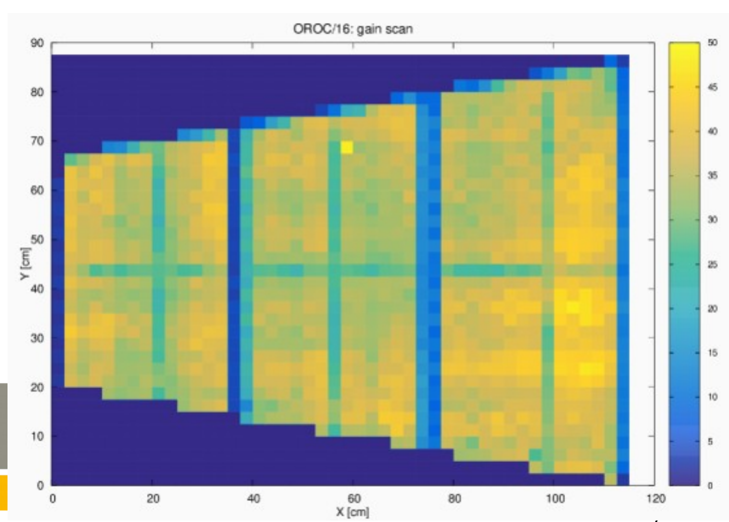
Most chambers have been built. Tight quality control shows that the requirements can be met.

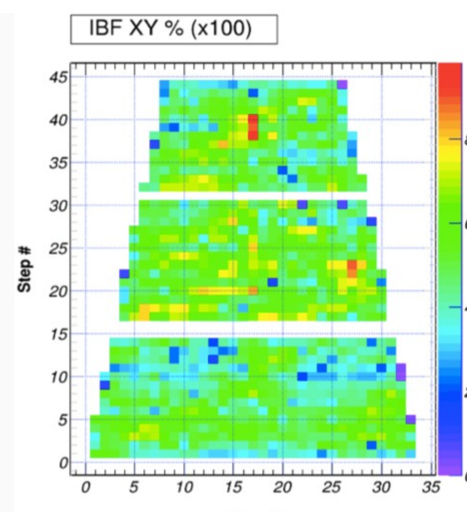




- Gain uniformity in all ROCs exceeds requirements (RMS<20 %)

nominal gain = 2000 in Ne-CO_2-N_2 (90-10-5);
requirement:
uniformity < 20%

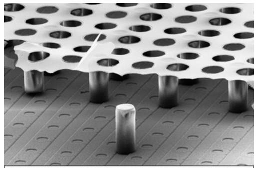




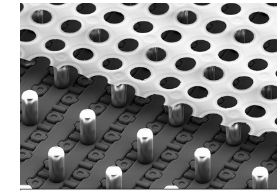
requirement:
ion back flow IBF < 1%
Ɛ uniformity < 20%

UNIVERSITÄT BONN

ALICE



Scalable Readout System



Idea of SRS: produce flexible readout electronics, which can handle different chips (new FPGA code, chip carrier), which many groups can use.

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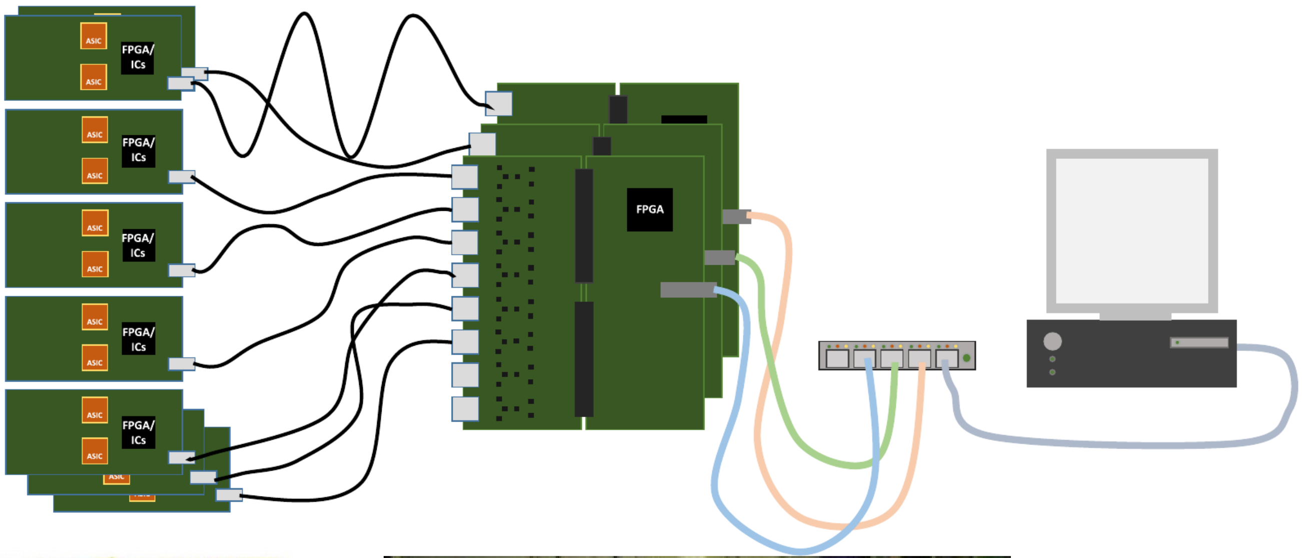
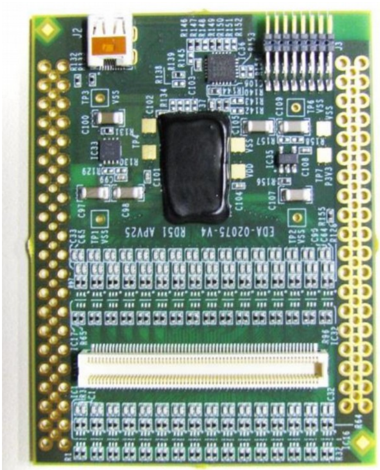
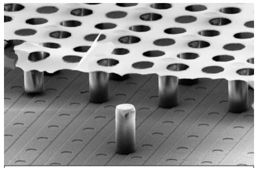


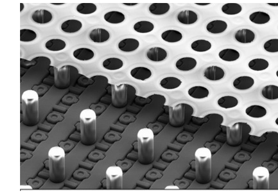
Many ASICs have already been implemented: APV25, VFAT, Beetle, Timepix, ...



The most successful combination sofar is the APV25, with more than 70 systems sold.
Price is about 2€/channel for small systems.
(larger systems are cheaper)



VMM in SRS



As the APV25 is not available anymore, a new ASIC well suited for a large number of gaseous detectors has been identified (VMM3a) and is being implemented in the SRS.

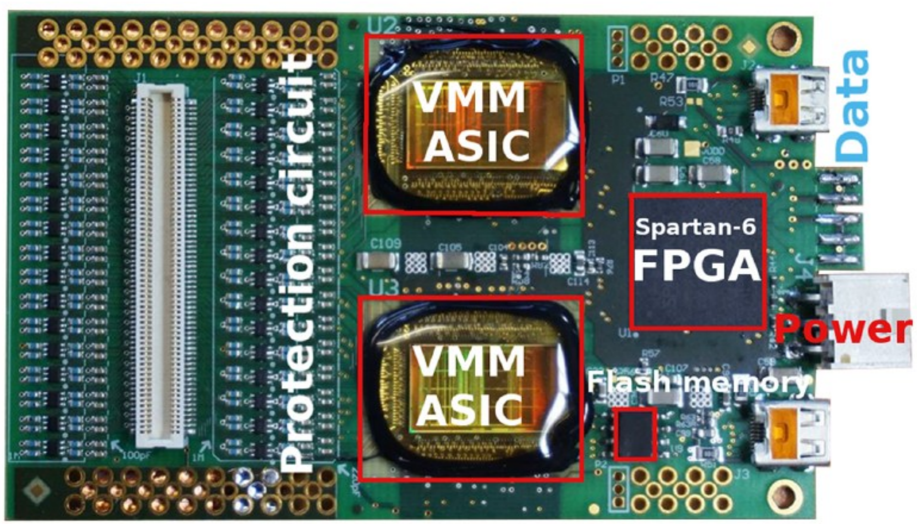
VMM3a was developed for NSW upgrade of ATLAS.

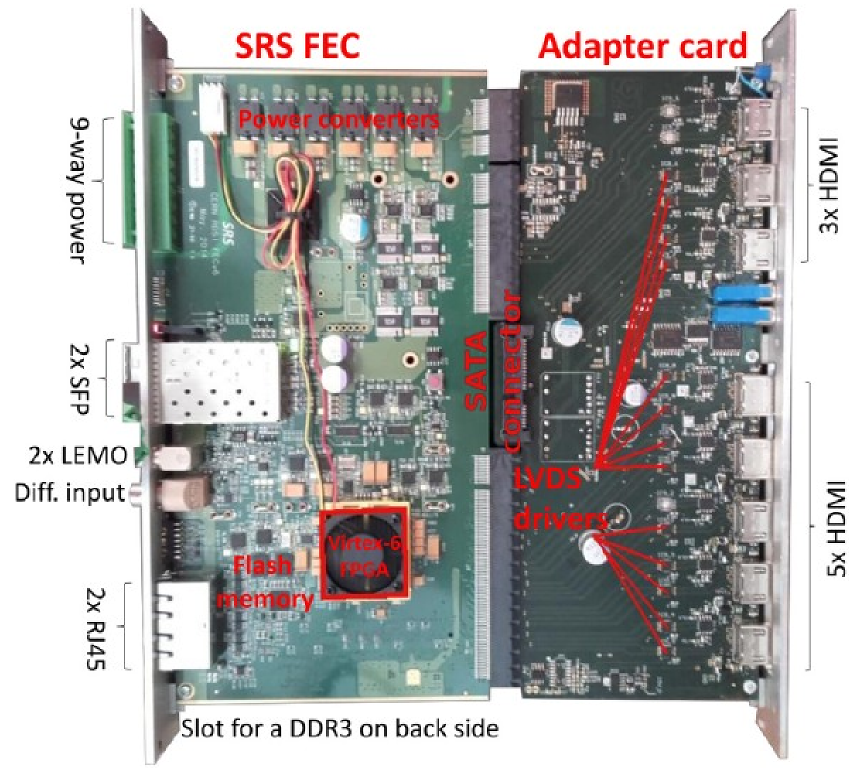
Final design of all components is ready, preparation for mass production of first batch has started. ASICs are expected for May.

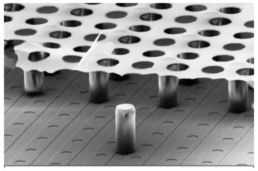
VMM3a: channels: 64

Input capacitance O(pF) - 3 nF

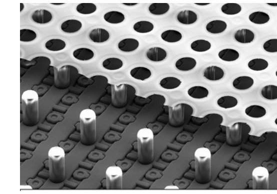
Peaking time, gain, polarity, threshold, timing precision can be programmed.







Conclusion



The research on TPCs with Micropattern Gaseous Detectors has been pioneered by the LCTPC collaboration.

Many important developments have been done in this framework, which have influenced many other experiments (ALICE TPC upgrade, T2K upgrade, …)

Excellent infrastructure at DESY test beam T24/1, which is open to other experiments/detectors.

Both the infrastructure and the ILD-TPC readout are being actively developed and new results are being produced.