Recent Performance Studies of the GEM-based TPC Readout (DESY Module)

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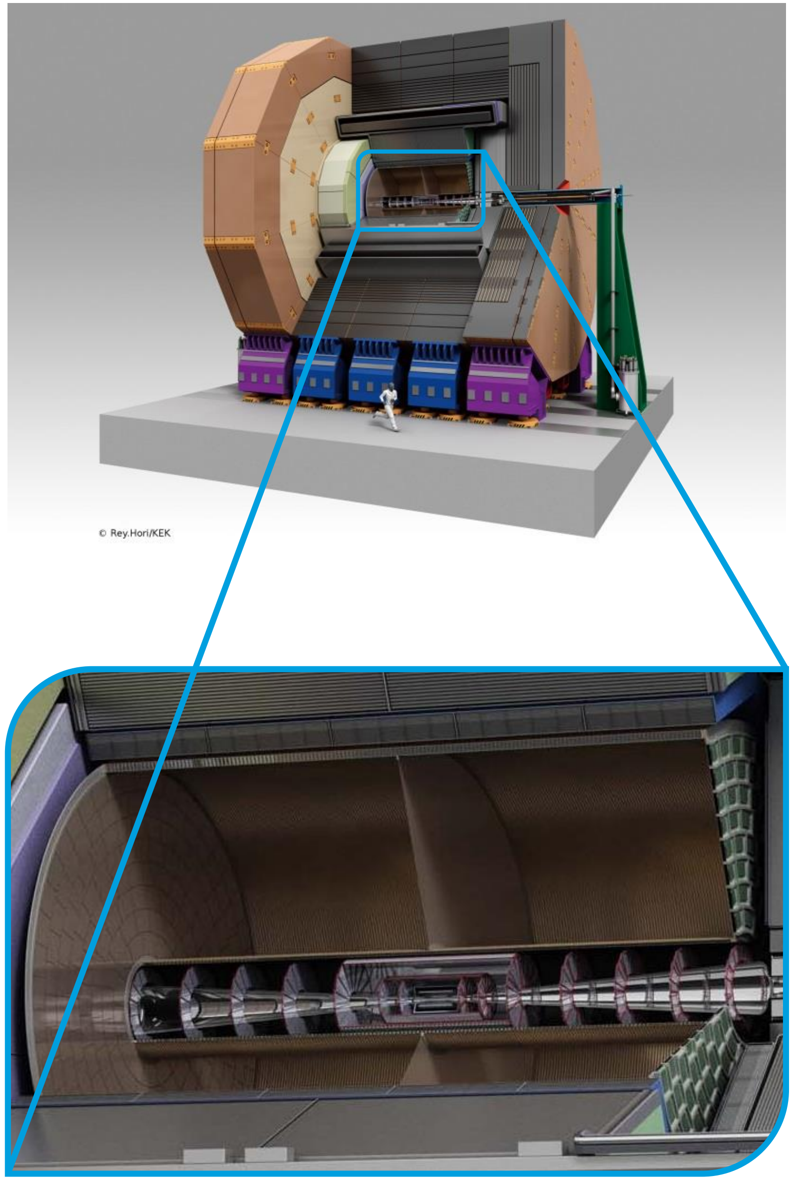
Overview

- DESY GEM Modules
- Test Beam 2016 and dE/dx Results
- Studies of Pad Size Regarding dE/dx
- High-Granularity Pad Readout With Timepix
- Large Prototype TPC Field Cage V2
- Towards a Beam Telescope for PCMAG

The International Large Detector

ILD

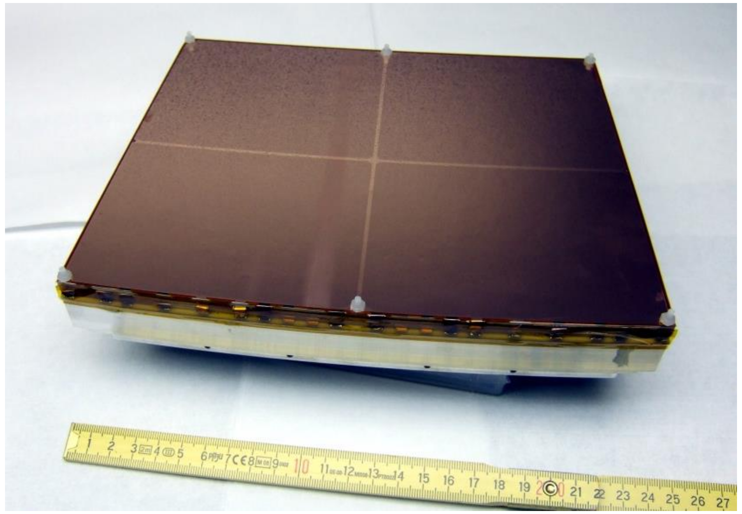
- Developed for precision measurements at ILC
- Optimized for particle flow reconstruction
- **TPC with MPGD readout as main tracking detector**
  - ~220 track points → continuous tracking & high redundancy
  - Near 100% tracking efficiency even for low momentum particles
  - Minimal material: 5% X_0 in barrel, 25% X_0 in endcaps
  - 3.5 T solenoid field
  - Momentum resolution required: $\sigma_{1/p_{\mathrm{T}}} = 10^{-4}$ GeV^{-1} (TPC only)
    → point resolution in transverse direction: $\sigma_{r\varphi} = 100$ µm
  - ~5% $\mathrm{d}E/\mathrm{d}x$ resolution allowing good particle identification

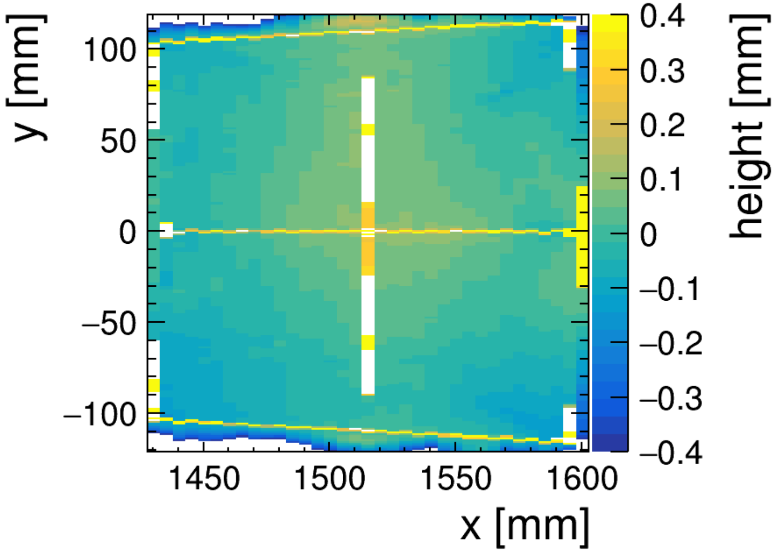


The DESY GridGEM Module

Design Goals

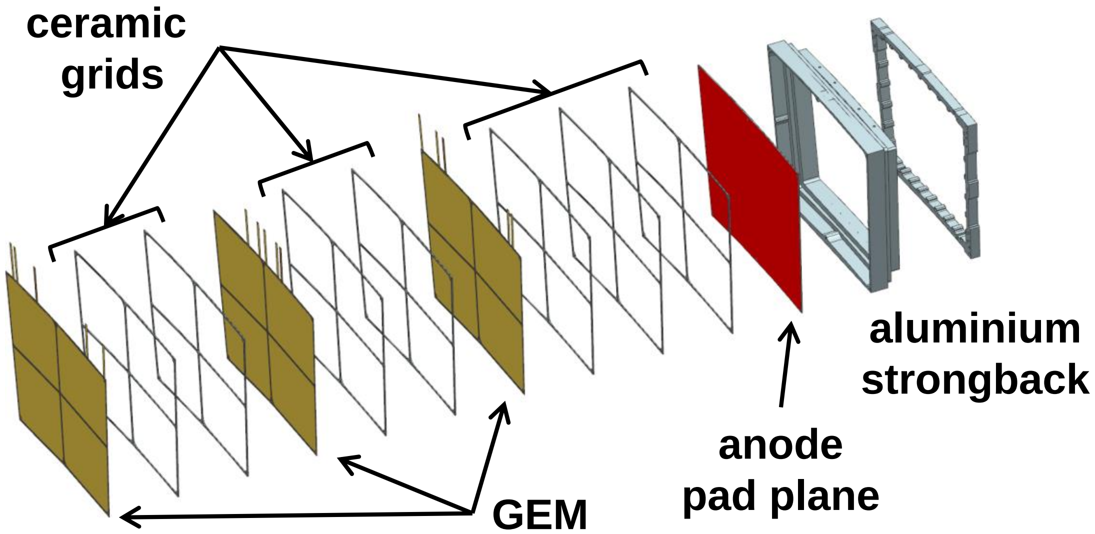
- Maximum sensitive area
- Minimal gaps
- Minimal material





Design Choices

- Integrated, self supporting GEM amplification structure
  - 3 GEM stack supported by thin ceramic grids
- Segmented readout anode:
  - ~5000 pads ($1.26 \times 5.85\,\mathrm{mm}^2$) in 28 rows
  - ~95% sensitive area
- Size and shape as planned for ILD TPC ($\sim 17 \times 23\,\mathrm{cm}^2$)
- Custom ALTRO system as readout electronics



The LCTPC Setup at the DESY II Test Beam Facility

DESY II

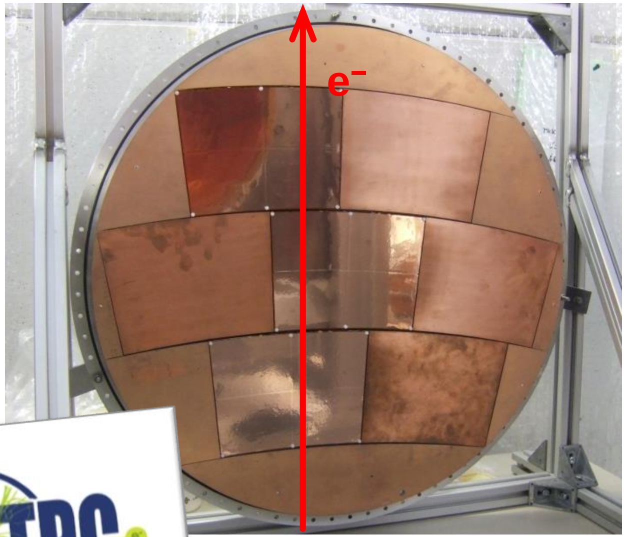
- 1 GeV to 6 GeV electrons

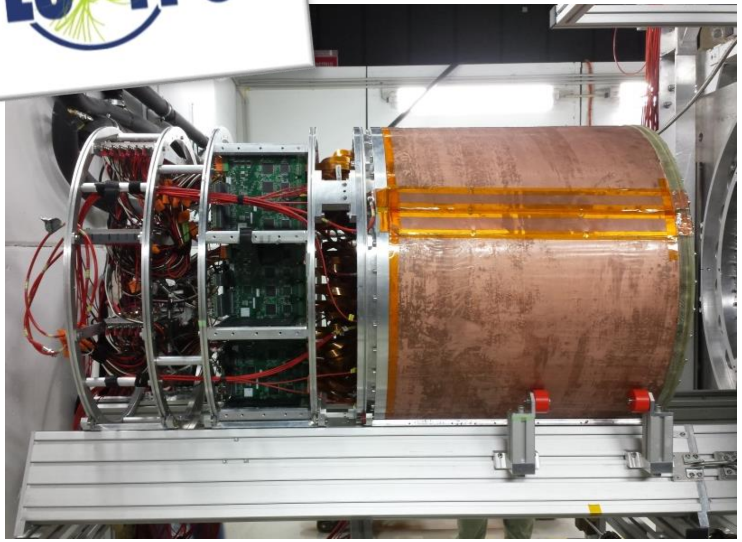
PCMag

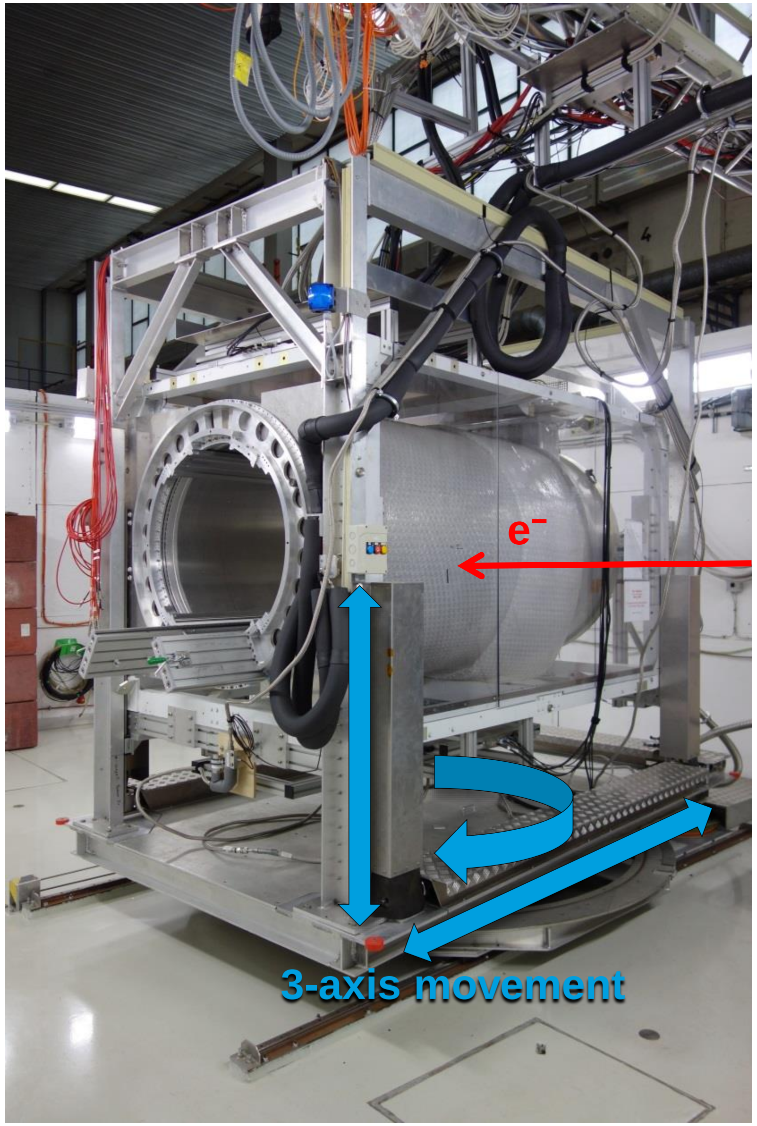
- 1 T superconducting solenoid
- 3-axis moveable stage
- 20% X_0 wall thickness
- 85 cm usable inner diameter

Large TPC prototype

- 75 cm diameter
- 57 cm maximum drift length
- Endplate with space for 7 modules in 3 rows

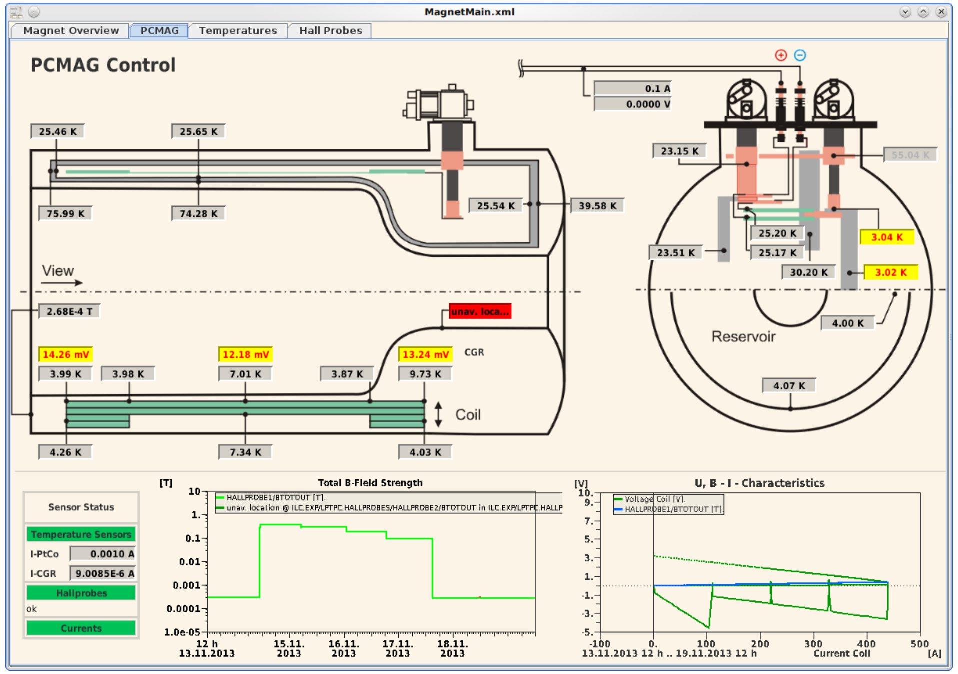


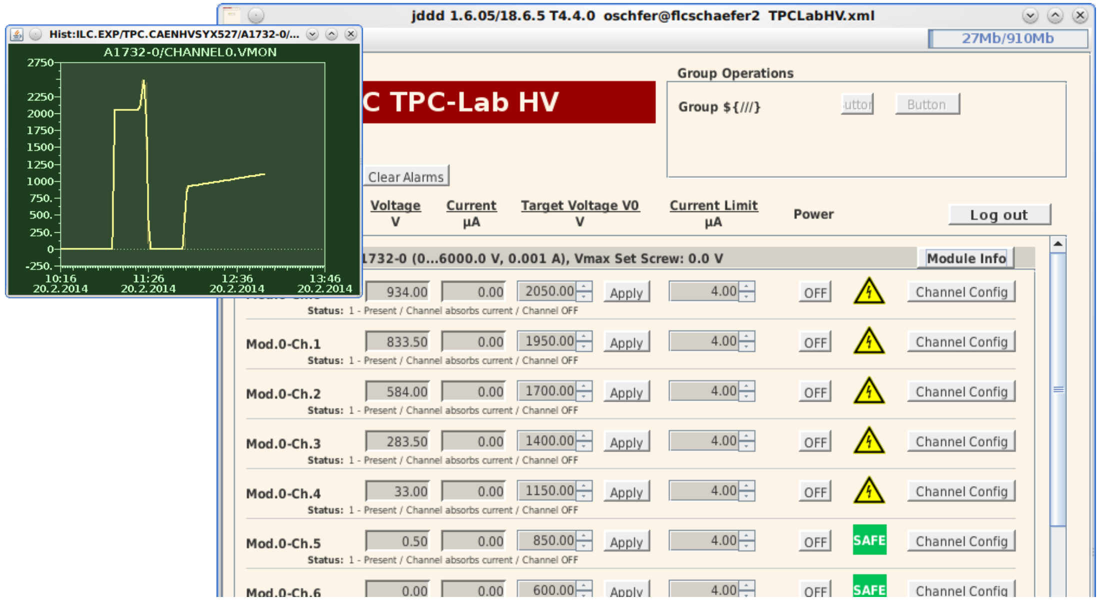




DOOCS for Slow Control

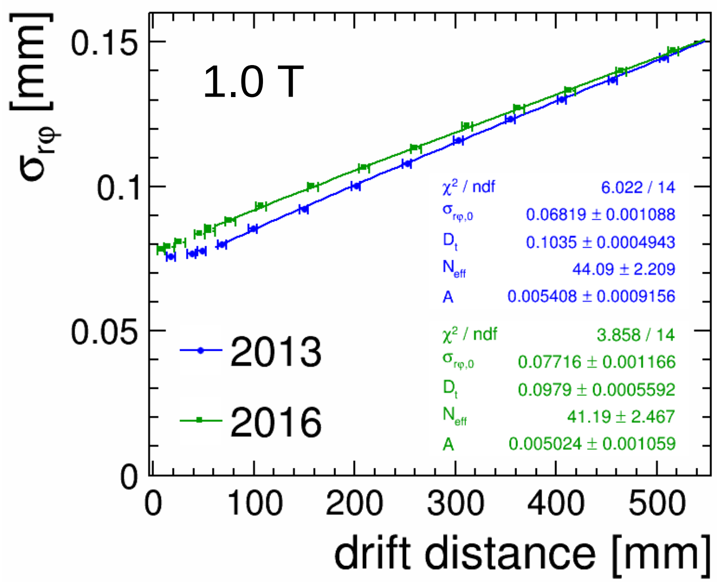
- Control System developed for new Accelerators (Flash, XFEL) at DESY since 1990’s
- Used since 2006 to control our experimental setups (with ILC in mind)
- Very lively development since start of XFEL
- Inspiration for new techniques going in both directions between accelerator and experiment
- Use of several protocol interfaces and even integration of TINE (EPICS, TANGO)
- See talk by Maria Teresa Núñez Pardo de Vera, tomorrow about Control and Data Acquisition systems at Petra III experiments

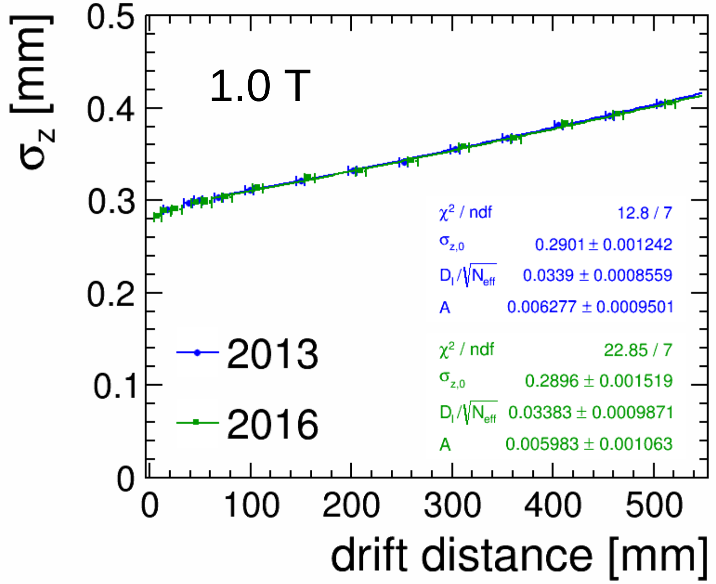


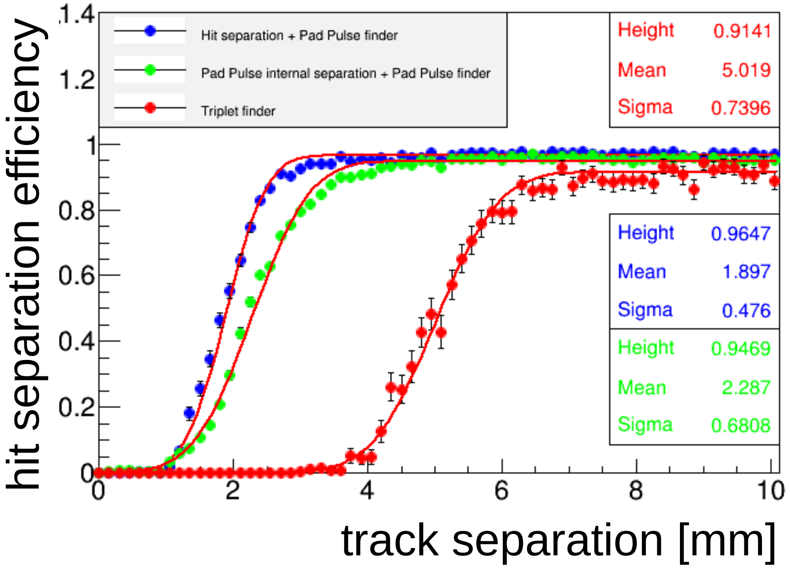


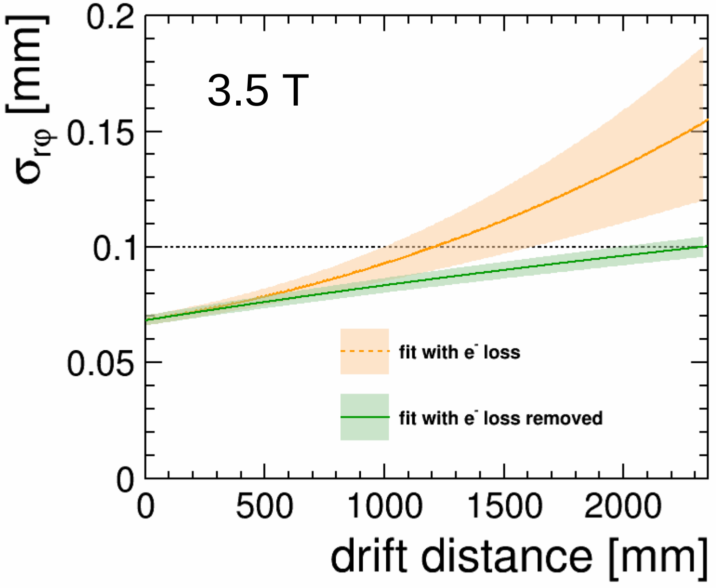
Established System Performance

- Point resolution measured repeatedly in two beam test campaigns.
- Small discrepancy in $\sigma_{r\varphi,0}$ and D_{t} under investigation.
- Extrapolation consistently reaches point resolution goal of $\sigma_{r\varphi} < 0.1\ \mathrm{mm}$ in the full ILD TPC.
- Double hit separation algorithm was developed.
- Double hit resolution goal of $< 2\ \mathrm{mm}$ achieved.



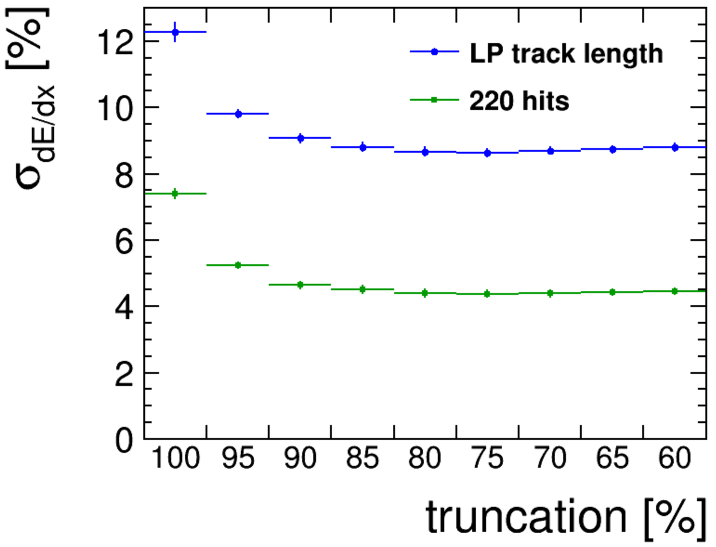


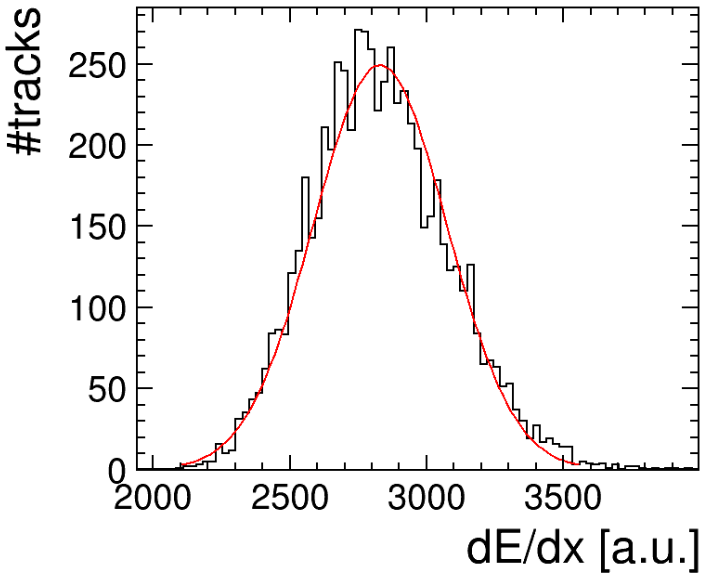


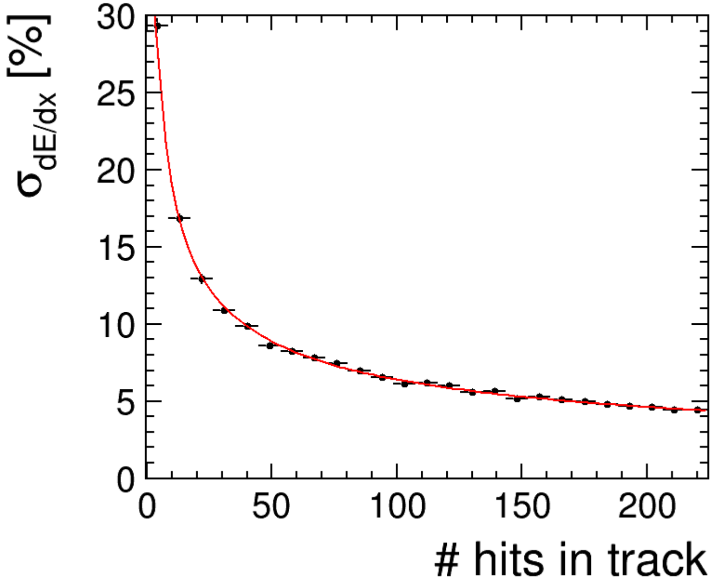


Determining the $\mathrm{d}E/\mathrm{d}x$ Resolution

- Around 55 valid hits per track in prototype.
- Best track $\mathrm{d}E/\mathrm{d}x$ estimator is 75% truncated mean.
- $\mathrm{d}E/\mathrm{d}x$ resolution from Gaussian fit in this sample is $(8.62 \pm 0.14)\%$.
- Extrapolate to longer tracks by combining hits from multiple tracks.
- Expected power law dependency found $\sigma \propto N^k$ with $k = -0.47 \pm 0.01$
- Resolution at full ILD TPC size of 220 hits is $(\mathbf{4.4} \pm \mathbf{0.1})\%$.
- Consistent with results from other technology options.







Better d*E*/d*x*?

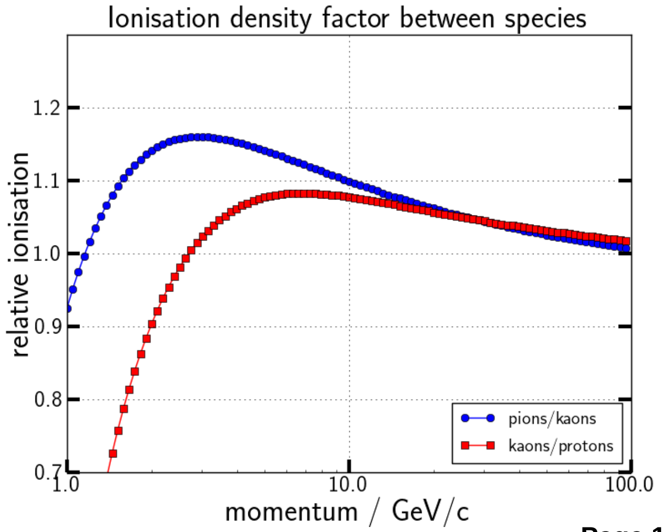
- Charge Summation Method:
  - Charge produced on a certain track distance is Landau distributed.
  - Smaller pads give more measurements per track and better statistics
  - On very small pads threshold effects degrade charge measurement accuracy
- Cluster Counting Method:
  - The number of ionization events on this distance is Poisson distributed → smaller RMS → better correlation → better particle identification.
  - Counting clusters allows for improved particle separation compared to conventional charge summation.
  - Depends on fraction of identified clusters (counting efficiency).
  - Need sufficient readout granularity to identify clusters!
- Is there an optimal pad size?

Pad Size Optimisation

- Detailed simulation of TPC processes with MarlinTPC in iLCSoft: ionisation, drift, amplification, digitisation (i.e. electronic readout)
- Reconstruction in MarlinTPC (sufficient for charge summation method)
- Cluster identification via external astronomy software 'Source Extractor‘, which returns 'hits' for tracking [http://www.astromatic.net/software/sextractor]
- Good estimator for comparison was found to be ‘Kaon-Pion-Separation Power’

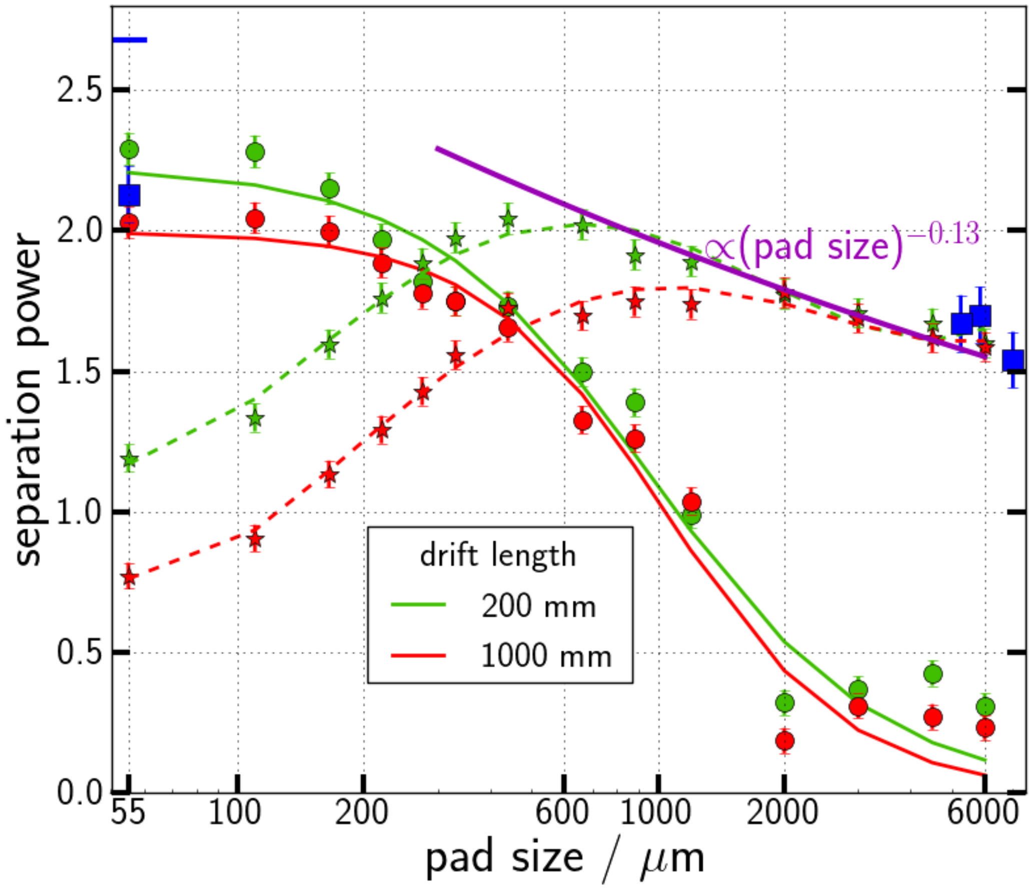
$$S = \frac{|\mu_\pi - \mu_K|}{\sqrt{(\sigma_\pi^2 + \sigma_K^2)/2}}$$

- Setup:
  - Track of 30 cm in x-dir., varying drift in z-dir.
  - Anode length (x): 30 cm; height (y): 256 pads
  - Parametrised T2K gas (Ar : CF_4 : Iso-C_4H_{10} = 95 : 3 : 2) for ionisation, drift, amplification and charge cloud distribution
  - MC Muons used with cluster distance factor of 1.03 for pions, 1.19 for kaons



Pad Size Optimization

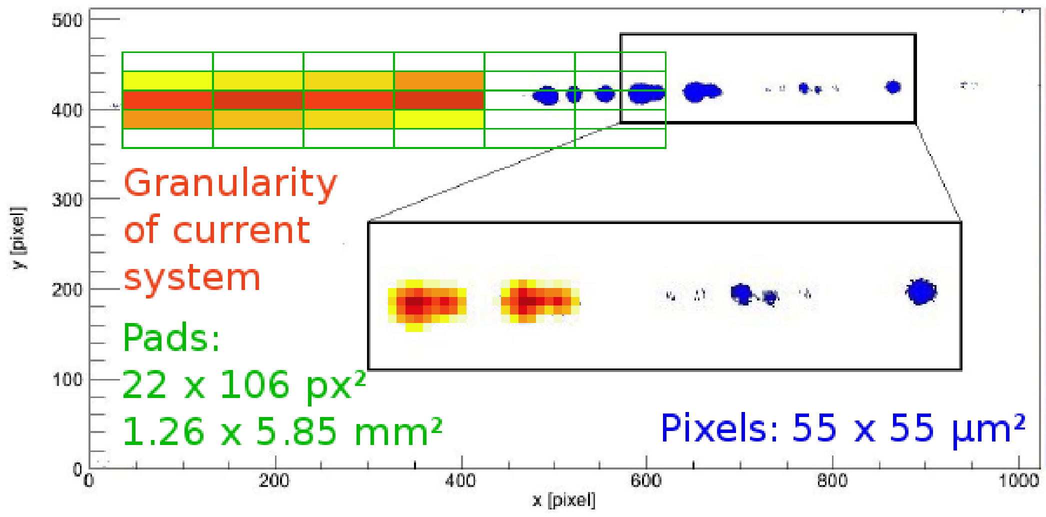
- Legend:
  - Squares: Experimental Results
  - Circles: Simulation Cluster Counting
  - Stars: Simulation Charge Summation
- Discussed effects for both methods can be seen
- Down to about 500 µm charge summation performs better than cluster counting
- Smaller gain in separation power for even smaller pads, where cluster counting performs better

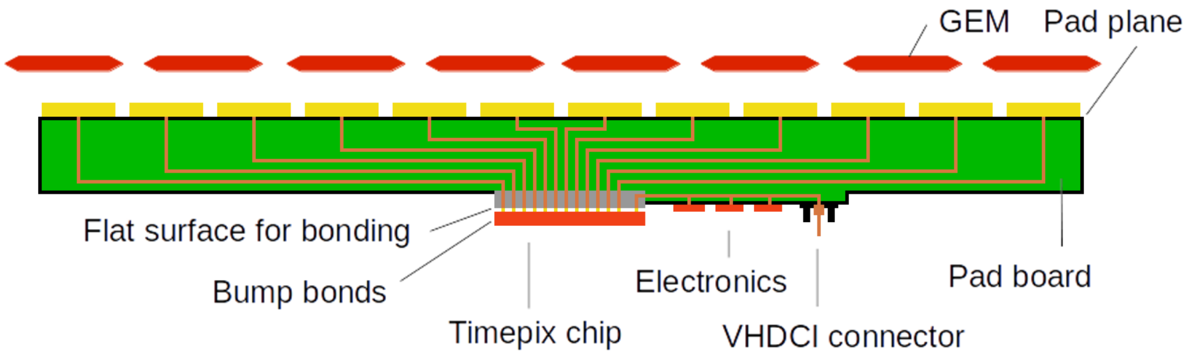


ROPPERI

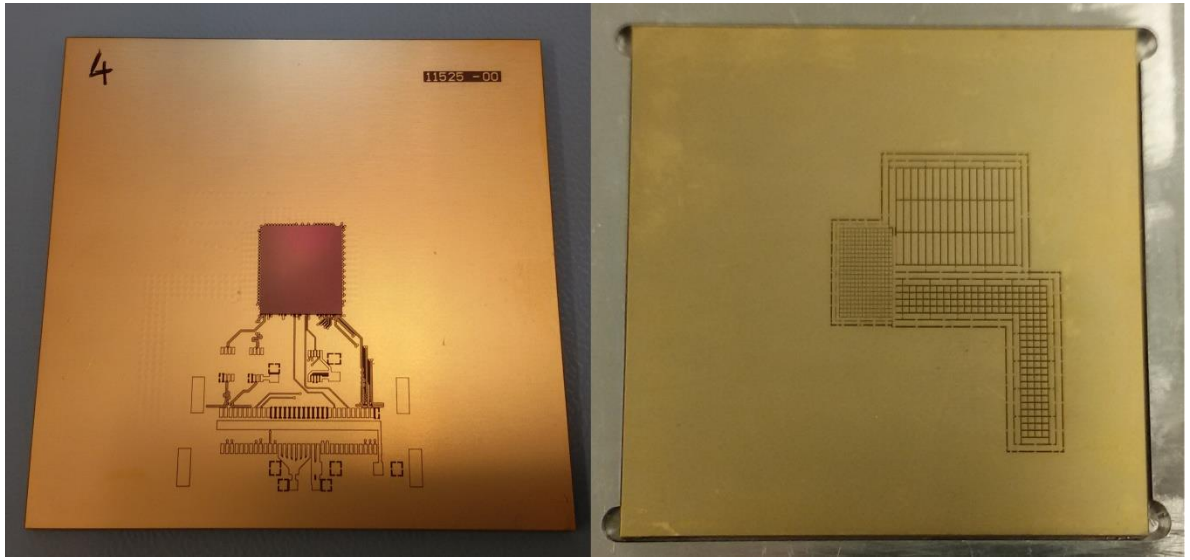
Readout Of a Pad Plane with ElectRonics designed for pIxels

- Goal: combine advantages of existing TPC readouts:
  - Small footprint and high granularity of pixels
  - Large coverage and high flexibility of pad plane
- Explore 'intermediate' granularity of a few 100 µm
- How? GEMs, small pads, Timepix chip as readout electronics
- Connections from pads to chip are routed through the board, then bump bonded to the chip
- Timepix wirebond pads for the communication channels are on the same side as the pixels → also bump bonded, back to the board
- Timepix: 65,536 pixels, 55 µm pitch



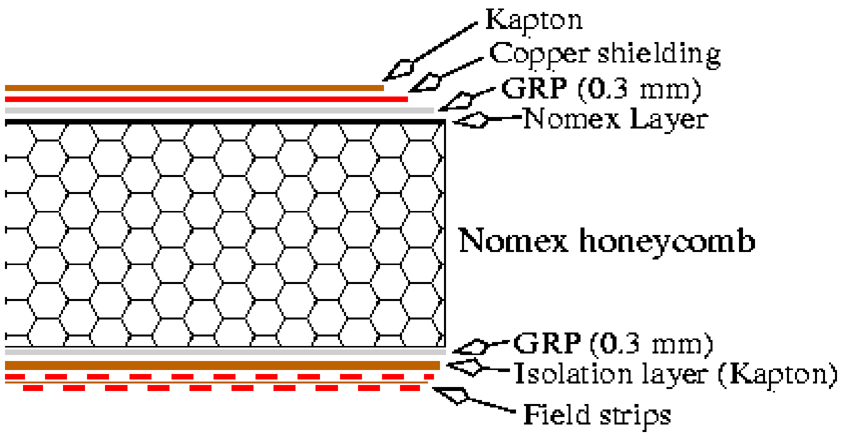


ROPPERI Prototype Results

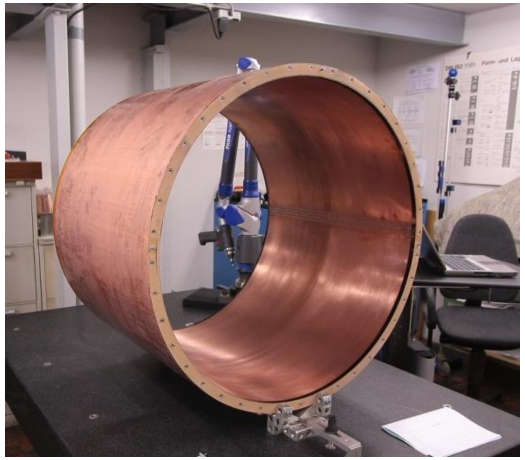


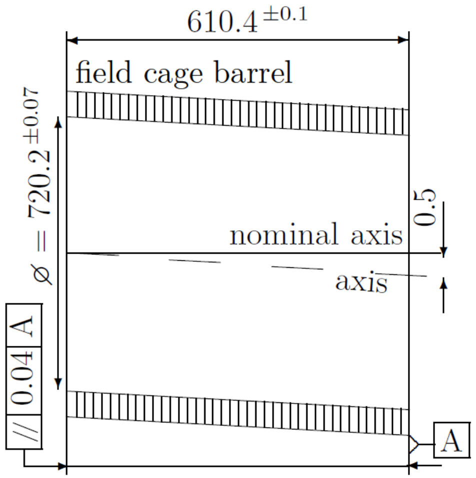
- Prototype board to test different pad sizes and line lengths
- 7 boards bonded, 6 worked for at least some time, 3 worked in the end
- Clear signs of temperature issue breaking connections
- Data taken: 'threshold campaigns‘ → for different thresholds, runs with 100-200 frames
- Worst pads and lines about 11 times as noisy as bare Timepix, with a known ENC of ~ 90 electrons
- Worst case estimation: 1000 electrons noise, typically 10k ... 20k electrons signal
  → S/N ≥ 10

Large Prototype TPC Field Cage - V2

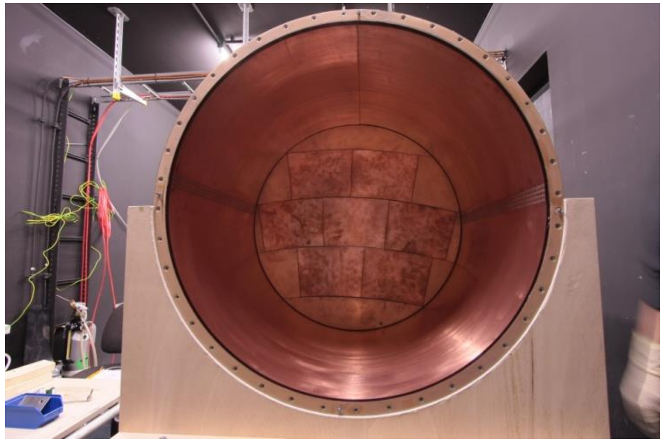


- Challenge of a high-precision TPC field cage:
  - Low material, high HV stability, high mechanical precision
- Why a new TPC prototype field cage?
  - Current field cage built by external company: Skewed by ~ a factor 10 too much → field homogeneity not within specs
  - Want to gain in-house experience for building the big ILD TPC
  - Verifiable material budget
- New workshop at DESY with precision mandrel for construction including vacuum bag ready

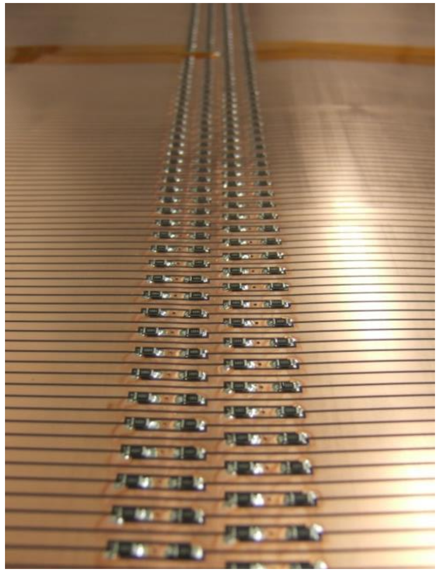




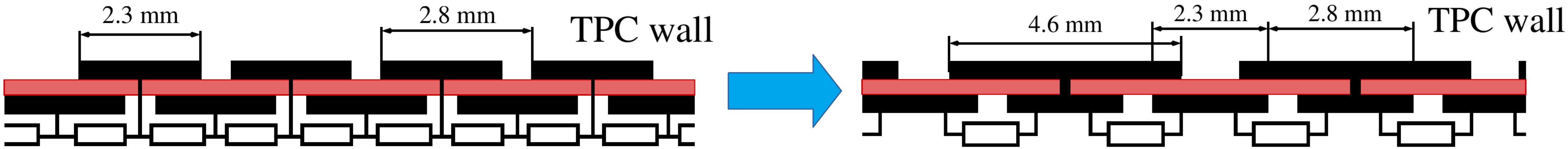
Large Prototype TPC Field Cage - V2



- Detailed work procedure being finalized
- Last missing material being procured
- Final HV test of sample walls ongoing

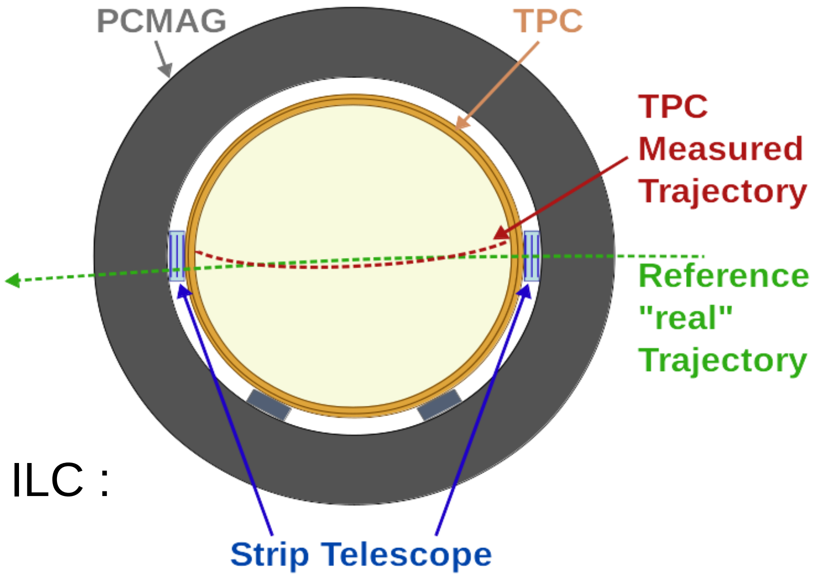


- First field cage: No production site could do a two sided field strip foil of the required size (61 cm x ~226 cm)
- Meanwhile: full size possible @CERN
- Expected to arrive end of this month
- New foil with a simpler field strip pattern → negligible impact on field homogeneity: distortion reach ~7 mm instead of ~5 mm from wall



Towards a Beam Telescope for PCMAG

- A new large area strip telescope within the Test Beam Area 24/1 solenoid:
- Telescope specs defined by use case for TPC, complementary to existing EUDET Telescopes and user demands:
  - Larger area ~10x10 cm².
  - Spatial resolution requirements better than:
  - σ_{Bend}= ~10 µm.
  - $\sigma_{Opening}$= ~1 mm.
- Standard ATLAS and CMS tracker sensors not usable
- Hybrid-Less silicon strip sensor designed by SLAC NATIONAL ACCELERATOR LABORATORY for the ILC :
  - A strip pitch of 25 µm., ~7 micron tracking resolution.
  - An integrated pitch adapter and digital readout (KPiX).
  - Directly bump bonded to sensor surface.
  - Thickness of 320 µm, material budget of 0.3% X0.



The Beam Telescope “Lycoris”

- Telescope system fully assembled since May
- Three test beam campaigns this year, two with the full system
- Telescope basically works, also in conjunction with another detector (Telescope with Mimosa sensors)
- Operation somewhat unstable
- Noise problems to be investigated
- Some way to go, until software and setup are ready for productive use

Conclusion & Outlook

- Point and double track resolution of DESY GEM Module fulfill design requirements of the ILD TPC
- dE/dx resolution likewise up to specs and can be improved by higher granularity readout
- Pad size of about 500 µm seems to be a good choice for that
- ROPPERI showed the way towards such readouts with higher granularity
- A new, improved field cage for the Large Prototype TPC is foreseen to be ready in spring 2020
- Lycoris beam telescope has been fully assembled and successfully tested
- More work to be done for productive use at DESY Test Beam Facility

What to do in future?

- Studies with gating GEM on DESY Module
- So far stable operation for three weeks of beam test – what about long term stability?

Backup

Hardware: Noise data

- Absolute noise drop width is difficult to interpret
  → compare ROPPERI system to bare Timepix
  → compare large pads, long lines to small pads, short lines
- Largest pads about 11 times as noisy as bare Timepix, with a known ENC of ~ 90 electrons
- Estimate for the signal/noise:
  - Assume 1000 electrons noise
  - 1.2 x 1.2 mm² pads receive between 10k and 20k electrons from GEMs at usual amplification voltages
  - → S/N >= 10