A TPC for the International Large Detector

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Workshop on Neutrino Near Detectors
based on gas TPCs
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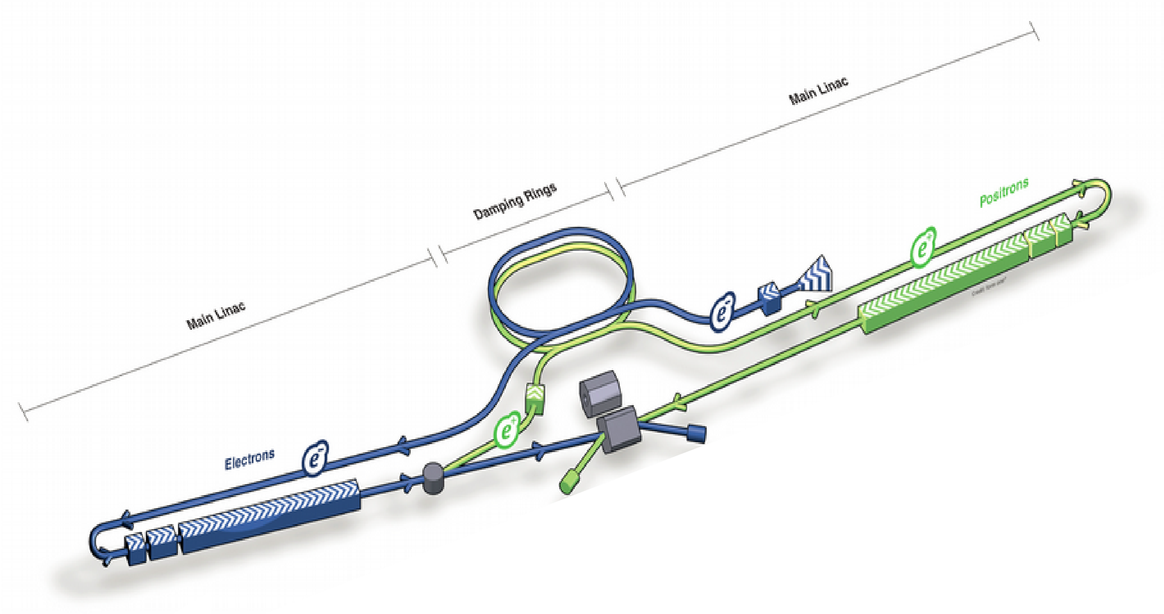
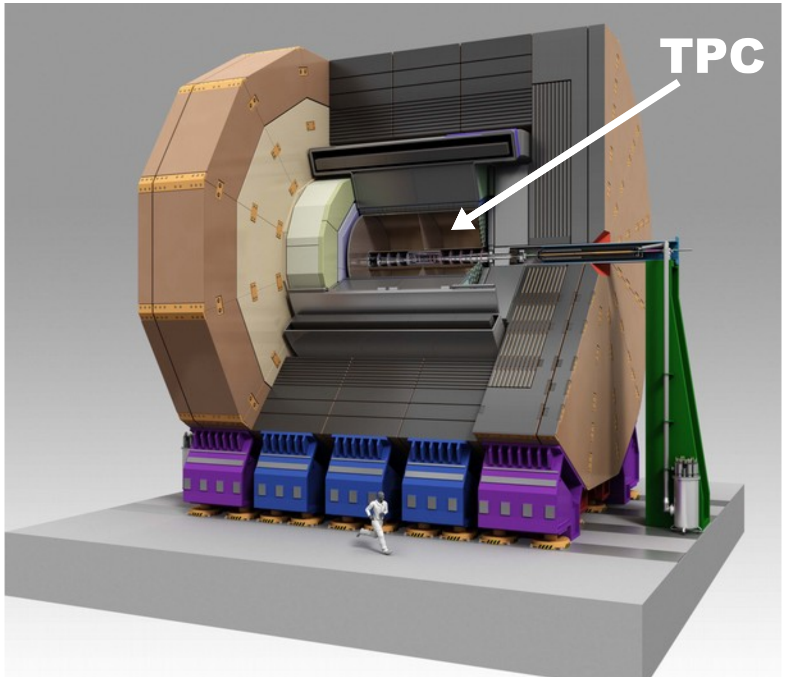
HELMHOLTZ | ASSOCIATION

DESY

International Linear Collider

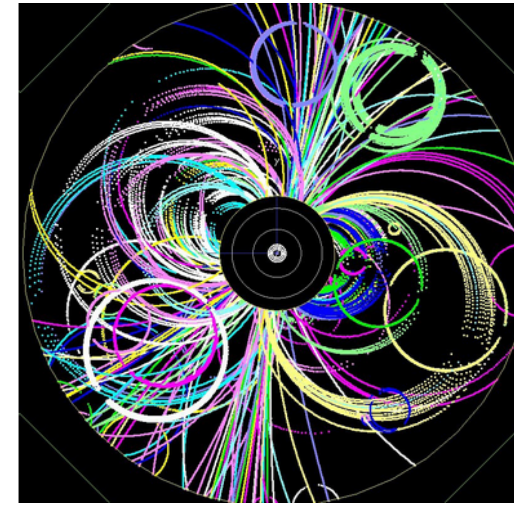
- e^-/e^+ collider with center of mass energies up to 500 GeV (upgradeable to 1 TeV)
- Detectors optimized for multi-jet final states with high track multiplicities
  - Very good momentum resolution for individual tracks
- Two detector concepts planned for the ILC
- The International Large Detector (ILD) foresees a large TPC as the central tracker

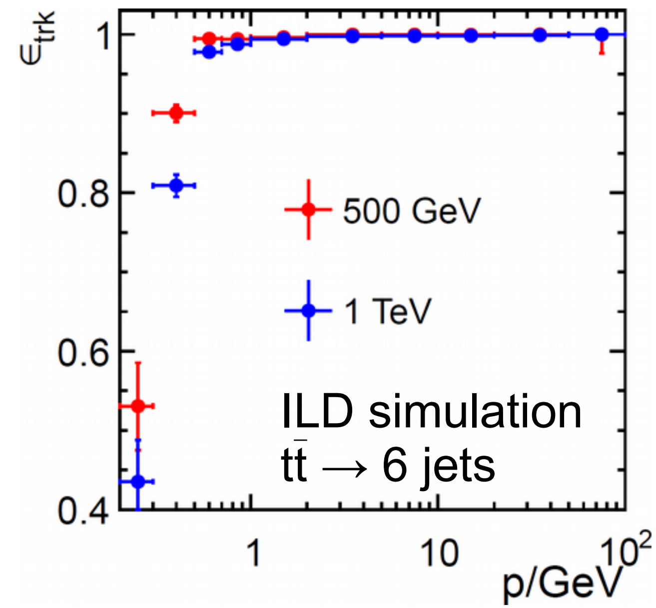


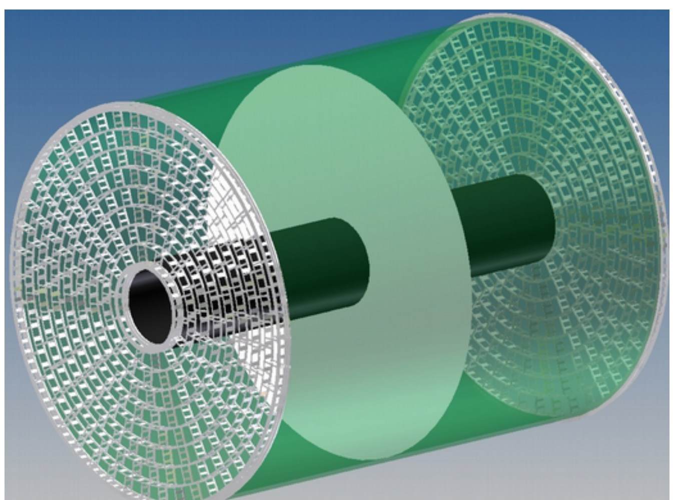


ILD TPC

- Why a TPC for the ILD?
  - 200 individual track points
    → Excellent pattern recognition capabilities
    → Tracking efficiency > 99 % (above 1 GeV even in dense track environments)
  - Minimal material budget to enable the calorimetry concept based on particle flow
- ILD TPC Parameters
  - Length 2 x 2.35 m, radius ~1.8 m, 3.5 T magnetic field

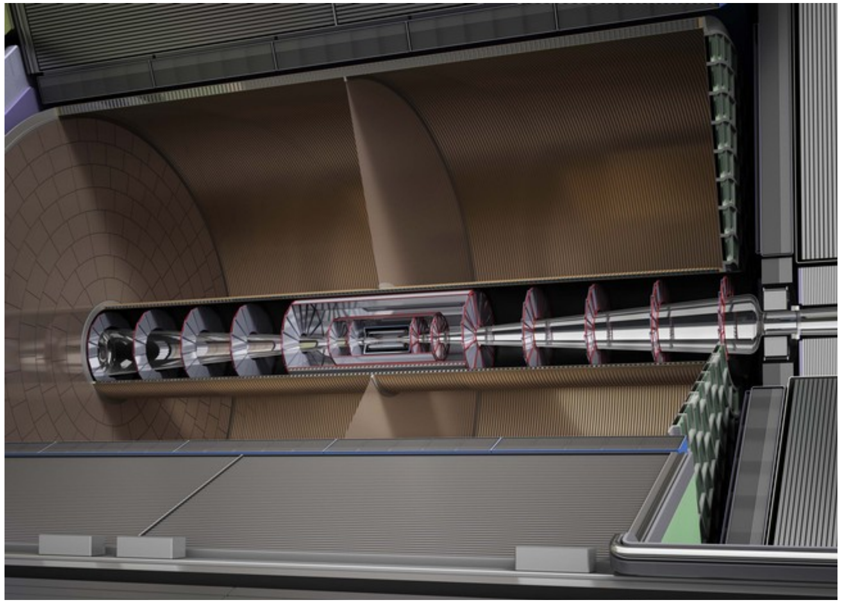


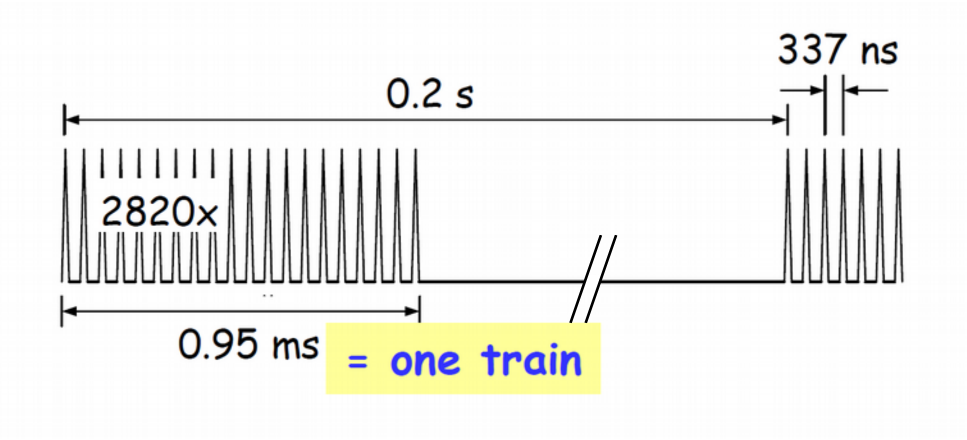




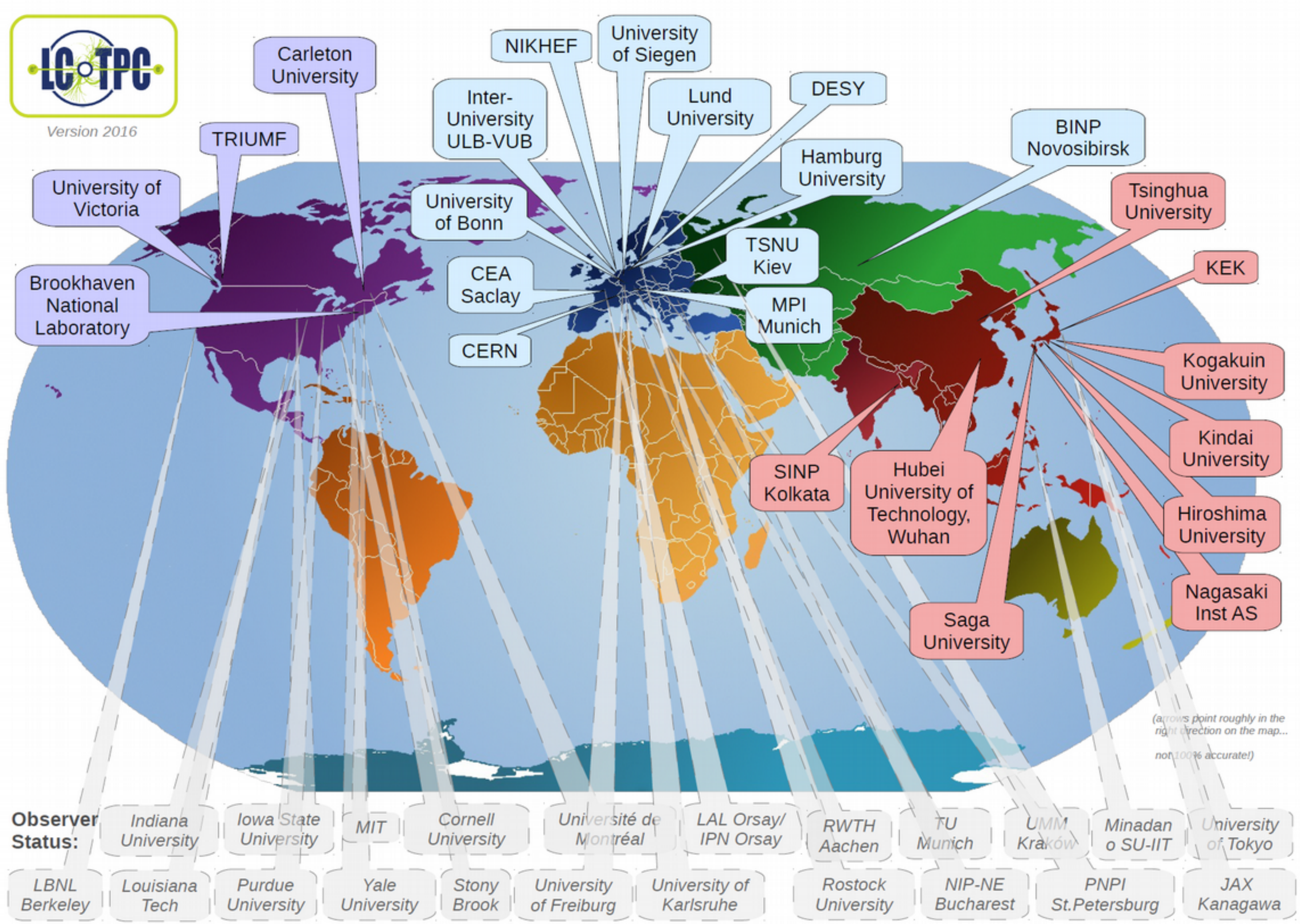
ILD TPC Challenges

- The advantages of a TPC can be interpreted as technological challenges
- ILD requirements
  - High tracking efficiency in dense track environments:
    - 2-hit resolution in rφ = 2 mm and z = 6 mm
      → Small pads (1 x 6 mm^2) and fast timing
  - Minimal material budget
    - Barrel ~ 5% X_0, end caps ~ 25% X_0
    → Integration of electronics and cooling
    → Power pulsing for readout electronic
  - Momentum resolution: $(1/p_T) \sim 10^{-4}$ GeV^{-1}
    → σ (rφ) ≤ 100 μm (full drift)
  - Ion back flow suppression ~ 10^{-4}
  - σ (Z) = 400 μm to 1400 μm





LCTPC Collaboration

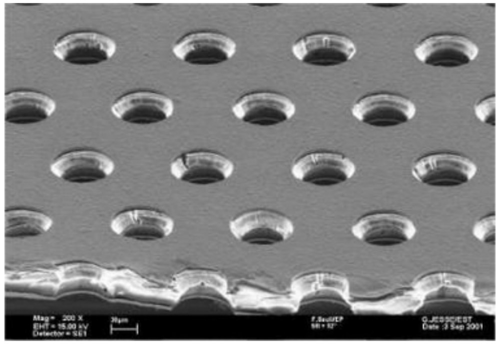


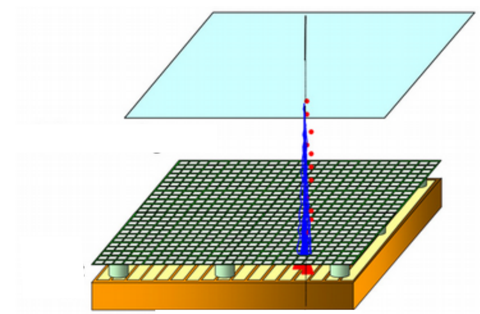
Total of 12 countries from 25 institutions members + several observer institutes

MPGD Readout Module Options

Amplification technology

GEM





Micromegas

DESY GEM

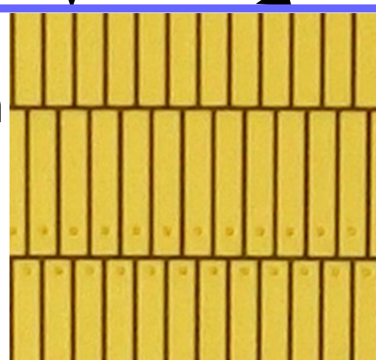
Asian GEM

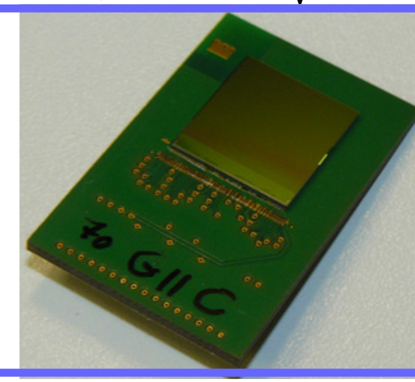
GEMPix

resistive Micromegas

GridPix

Pads with analog readout ~ 10 mm^2





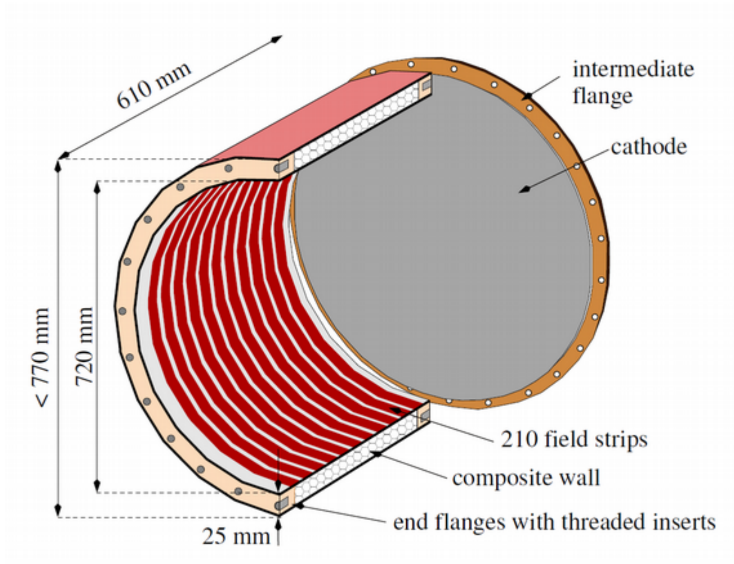
Digital Pixel chip ~ 55 x55 μm^2

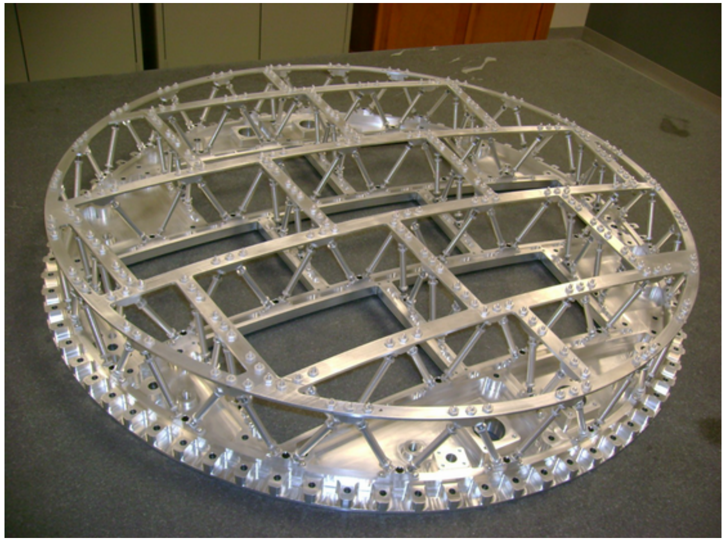
Readout technology

A Common Test Bench: Large Prototype and MarlinTPC

- Proof of principle with small prototypes (10 x 10 cm^2)
- Transition to ILD size readout module (~ 23 x 17 cm^2)
- Large Prototype has been built to compare different detector readouts under identical conditions and to address integration issues
  - L = 57 cm, D = 72 cm
  - Up to 25 kV (E < 350 V/cm)
  - Made of composite materials

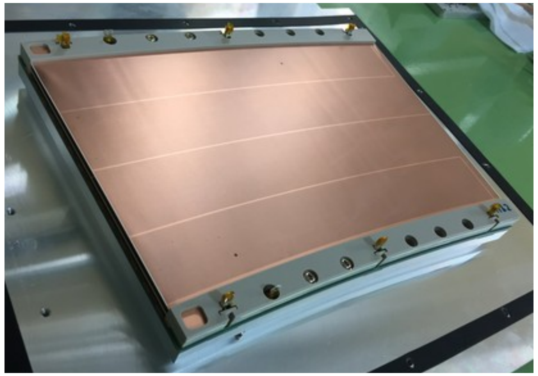
  → **1.2 % X_0**
- **Modular end plate with 7 module windows fulfills material budget**
- MarlinTPC: common software framework for simulation and prototype data analysis
  - Better comparability
  - Synergies

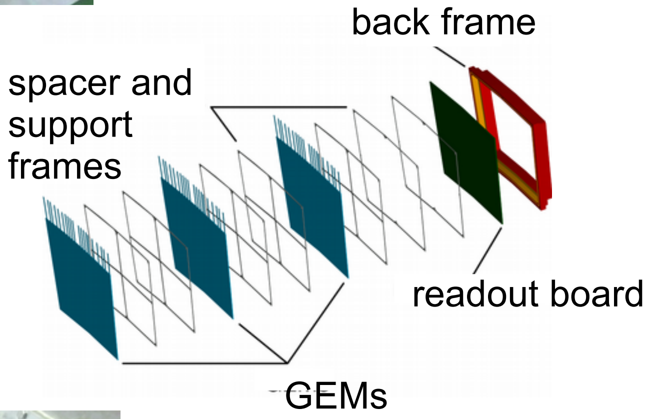


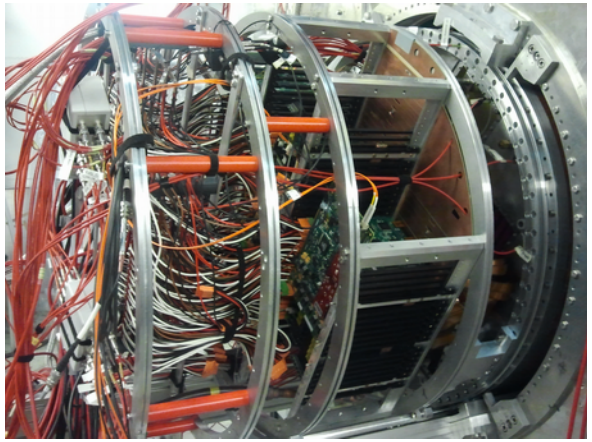


GEMs with Pads

- Asian Module
  - 2 GEMs, 100 µm thick
  - Large support structures at the top and bottom for GEM stretching, not frames at the side
  - $1.2 \times 5.4\ mm^2$ pads, 28 pad rows
- DESY Module
  - 3 GEMs, standard CERN GEMs
  - Maximize sensitive area (95 %) by using thin ceramic frames as integrated support structure
  - $1.25 \times 5.85\ mm^2$ pads, 28 pad rows
- ALTRO (modified ALICE TPC) readout electronics
  - 10000 channels
  - About 5000 pads per module for both module types

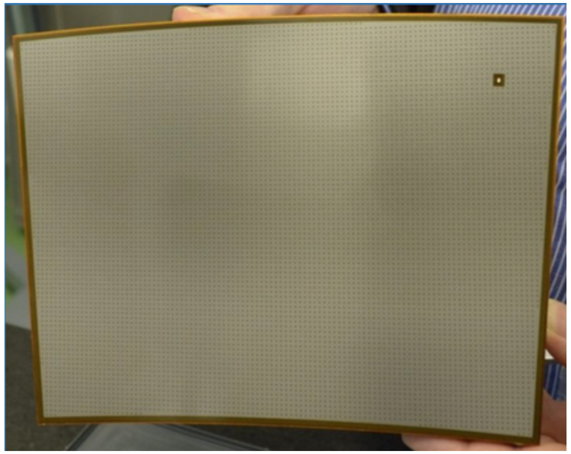


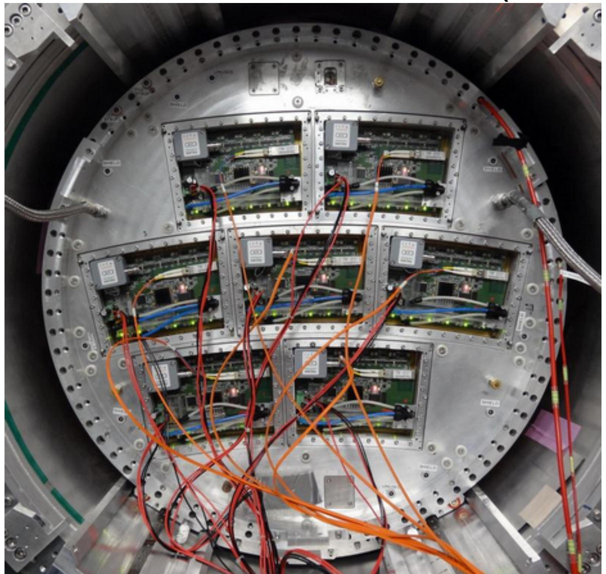


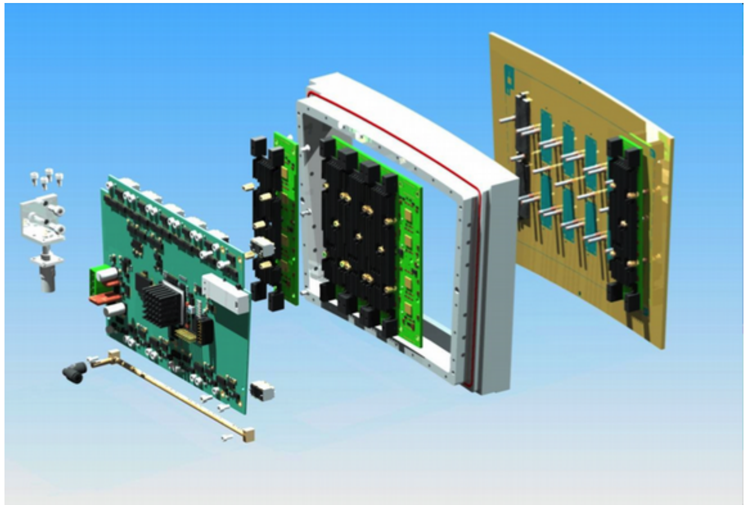


Micromegas with Pads

- Spatial resolution goal requires charge sharing
  - Small sized charge cloud in the amplification compared to GEM → resistive layer
    - Carbon-Loaded Kapton (CLK) and Black Diamond (BD)
- Pad size: 3 x 7 mm^2, 24 rows, 1728 pads
- AFTER readout system (T2K)
  - **Integrated readout scheme with 2PCO2 (two phase $C0_2$) cooling fulfills 25% X_0 goal**
  - Measurements with 7 Modules (12000 channels)





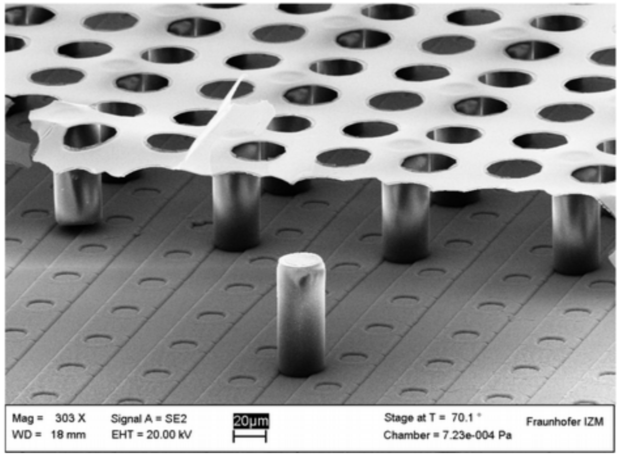


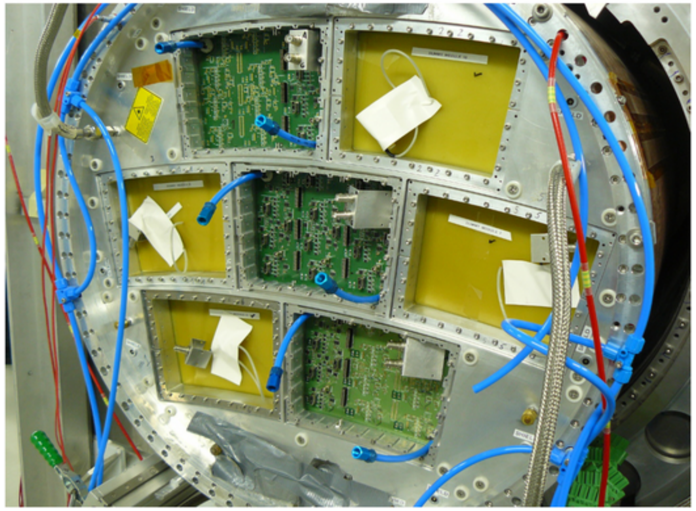
Micromegas with Pixel (GridPix)

- Use the electrodes of a readout chip as the charge-collecting anode
- Timepix chip
  - 55 µm pixel pitch
  - 2 cm^2 active area
- Micromegas with post-processing procedure (InGrid)

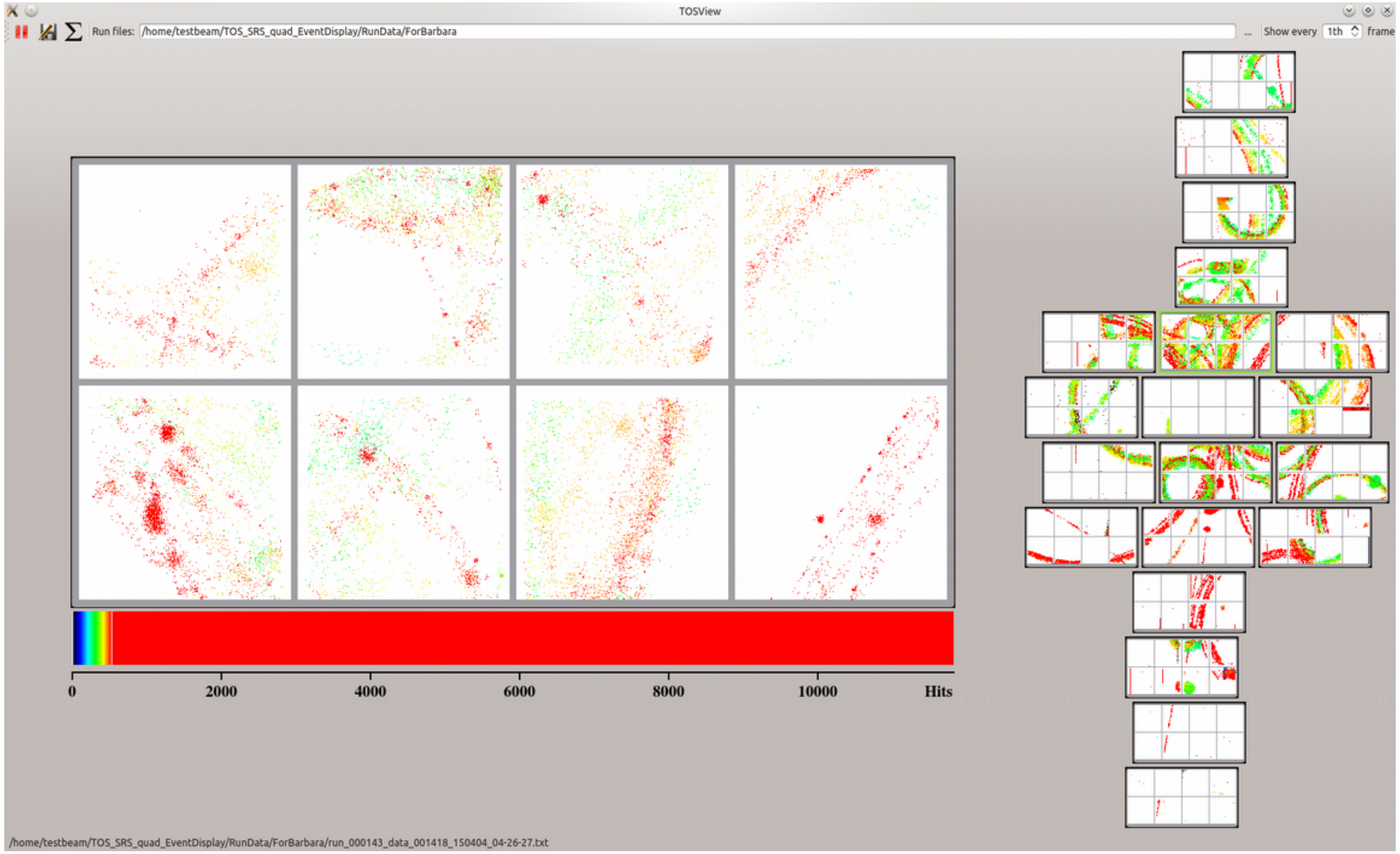
  → perfect alignment of holes and readout pads

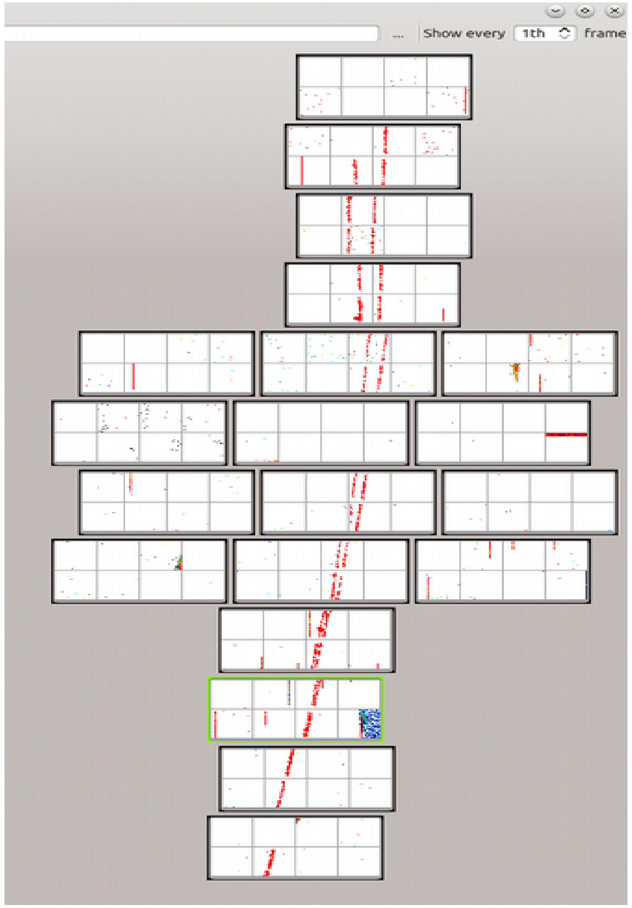
  → single electron detection efficiency ~ 100 %
- **Scalability demonstrated last year**
  - Module equipped with 96 readout chips
- Scalable Readout System (SRS from RD51)
- Next step: Timepix3 successor chip
  - Better time resolution
  - Charge and time measurement at the same time





GridPix Event Displays





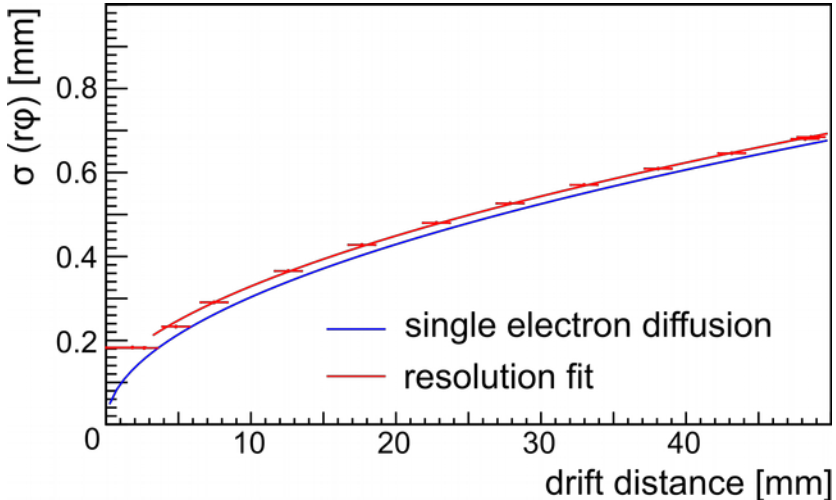
Transverse Spatial Resolution

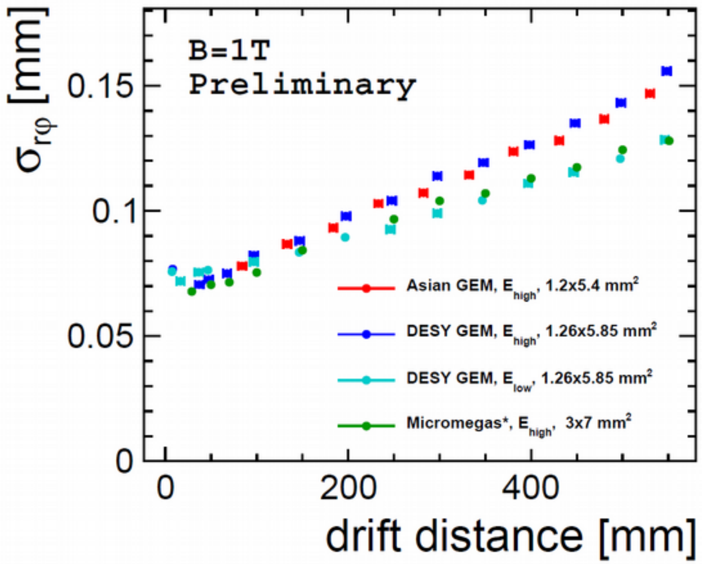
- B = 1 T, T2K gas, E_{drift} = 240 V/cm (maximal drift velocity)

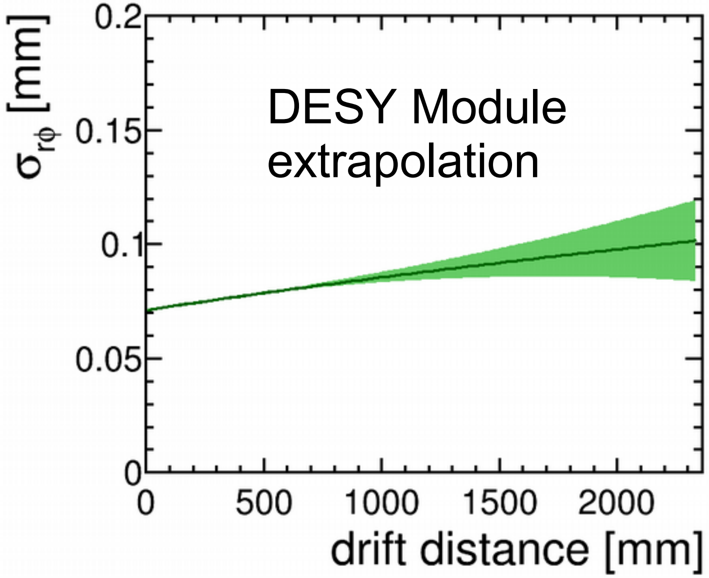
$$\sigma_{r\varphi/z}(z)=\sqrt{\sigma^2_{0,r\varphi/z}+\frac{D^2_{T/L}}{N_{eff}}\cdot z}$$

- **All pad based modules show similar spatial resolution results (N_{eff} ~ 35 e)**
- **All extrapolations to 3.5 T magnetic indicate feasibility of 100 µm resolution goal**
- GridPix solution measures single electrons

~100 track points per cm (15000 track points in ILD)





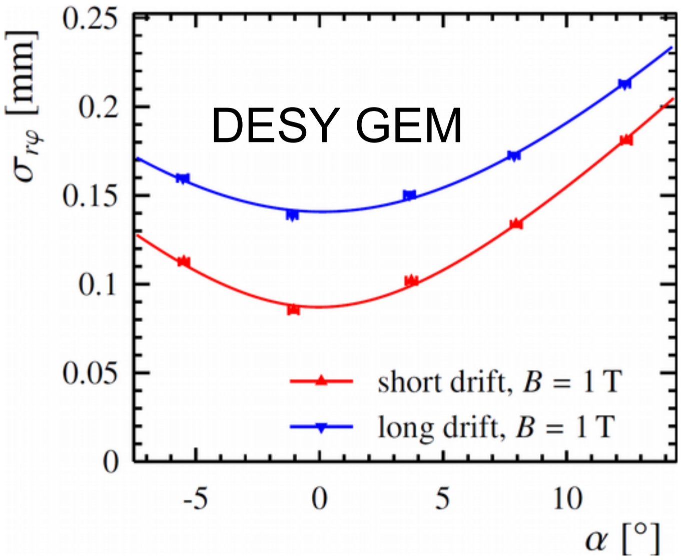


Pixel Readout Advantages

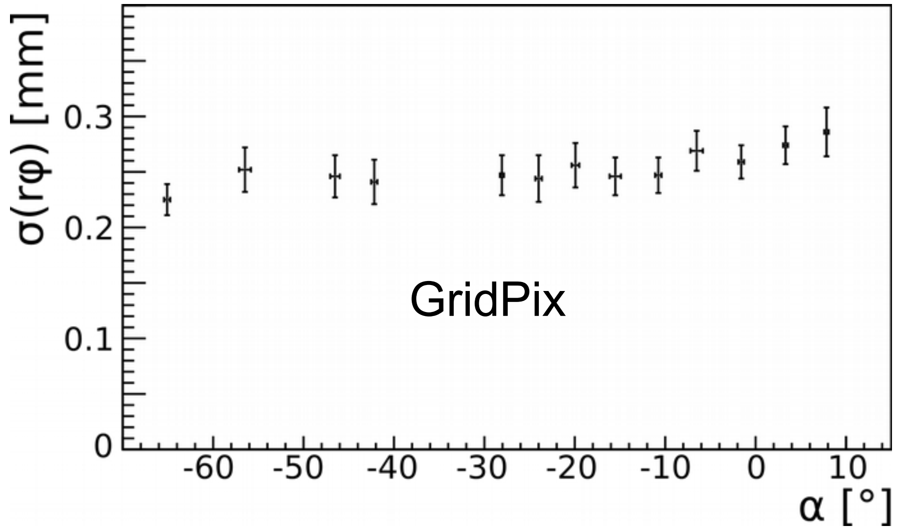
- Track angle with respect to the pad orientation deteriorates the spatial resolution

$$\sigma_{r\varphi}(\alpha, z) = \sqrt{\sigma_{r\varphi}^2(z) + \frac{L_{pad}^2}{12\, N_{clu}} \cdot \tan^2(\alpha)}$$

  α : angle in rφ-plane between pad and track direction

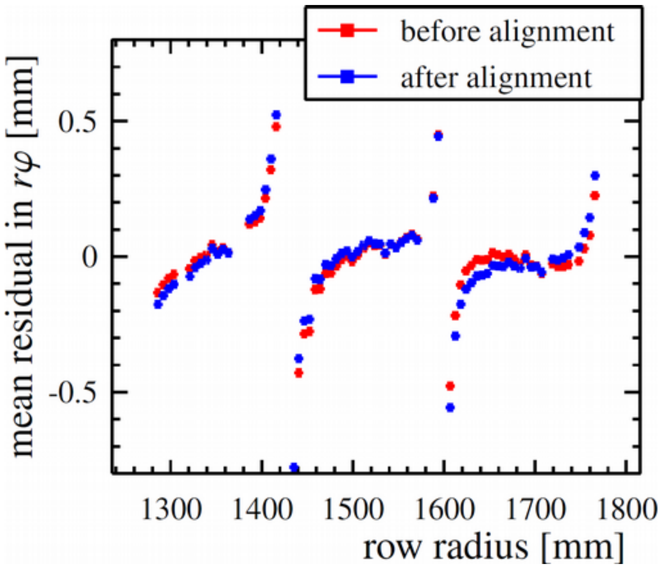


- Pixel readout not influenced by angular pad effect
  - Better momentum resolution for low energy particles
- Computational very expensive due to extreme number of space points
  - New tracking algorithms needed
  - Cost vs benefits



The Next Years

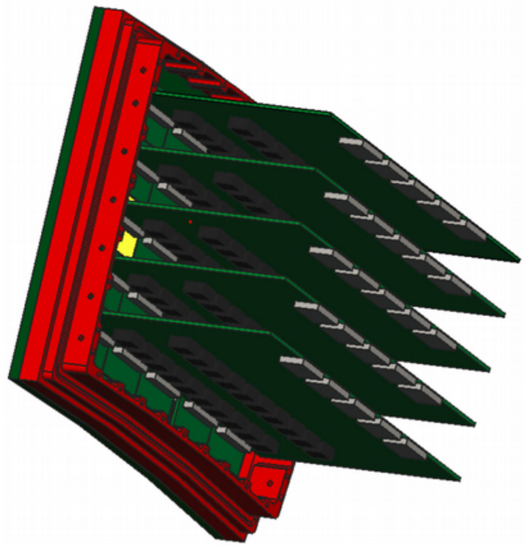
- **>** Cooling concept:
  - 2PCO2 with Micromegas Module was a first start
  - Temperature control for the complete TPC
- **>** Reduction of field distortions at module boundaries
  - DESY module introduced a guard ring (optimization ongoing)
- **> Electronics**
- **> Ion Gate**
- **>** Development of an integrated mechanical concept of the TPC in ILD
- **>** Simulation studies
  - Optimization of module size
    - minimization of edge effects vs performance degradation from module failure
    - Stability of the end plate
    - Maximal size of the (fragile) gate
  - Optimization of pad size
    - Occupancy vs Double- hit resolution

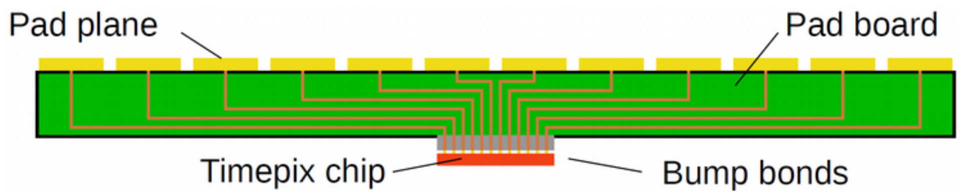


Future Electronics

- Usage of two different readout historically
  - Both not suited for ILD (integration and power pulsing)
    - charge sensitive preamplifier (~ 150 ns shaping)
    - a fast ADC (~ 9 bit at 40 MHz)
    - and a digital signal processing for online data analysis
    - P < 8 mW/channel (power pulsing)
    - Channel footprint 6 mm² (4 mm² without infrastructure)
  - Common development in the future (once the ILC time schedule is known)
- Next step: S-ALTRO (talk by Anders Oskarsson)
  - Much better integration but just 3200 channels per module
  - Still not the final solution
  - Independent development of a new chip within LCTPC?
- New idea: pads with pixel chip readout
  - Proof of principle study with Timepix and variable pad sizes
  - Input capacitance limits

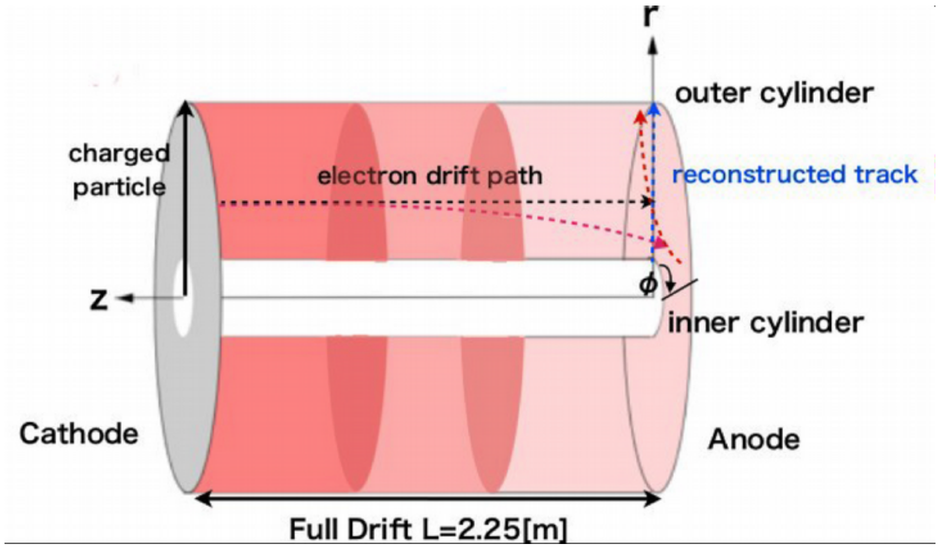
S-ALTRO readout setup

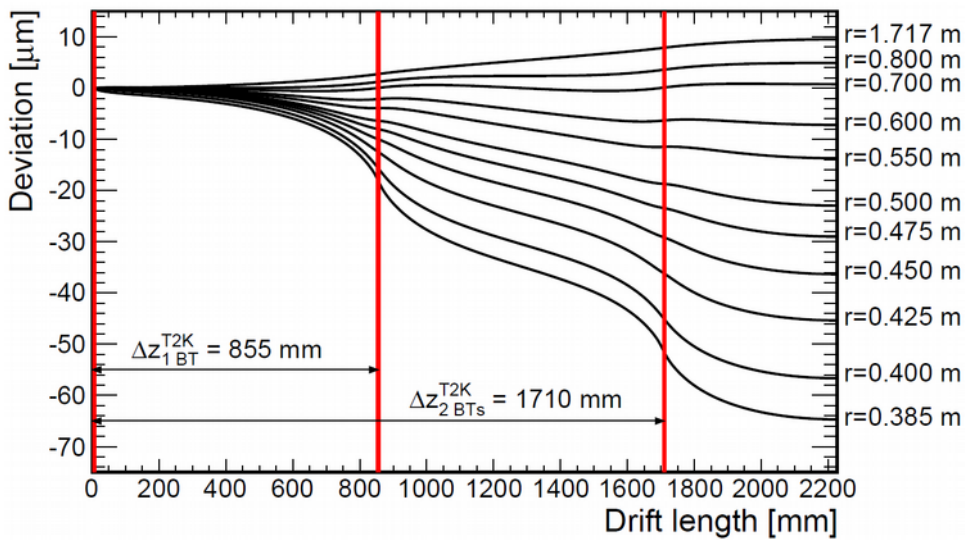




Ion Back Flow

- Ion Space Charge deteriorates the position resolution due to E-field distortions
  - Primary ions: O(10 µm) track distortions
  - Secondary ions: disk of ions for every bunch train crossing
  - O(60 µm) assuming IBF ratio of 1
- Intrinsic IBF suppression of MPGDs not sufficient to reach the IBF goals of 10^{-4}
- Gate needed
- Wire grid would introduce large material budget (support for the stretching forces)



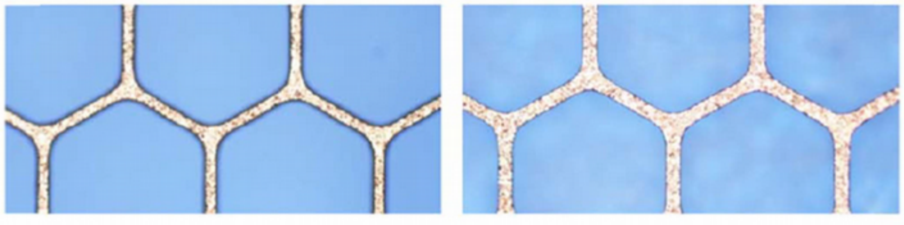


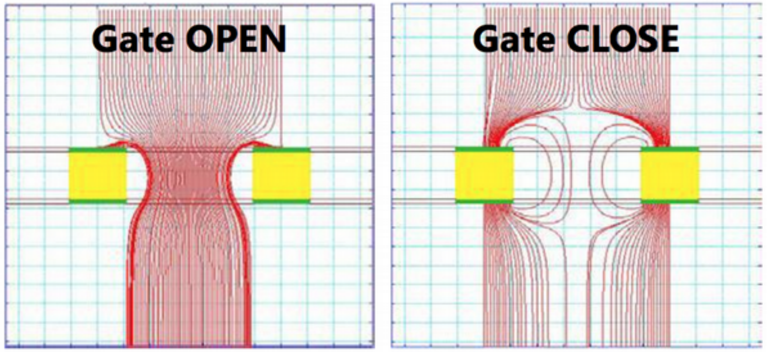
MPGD Gate

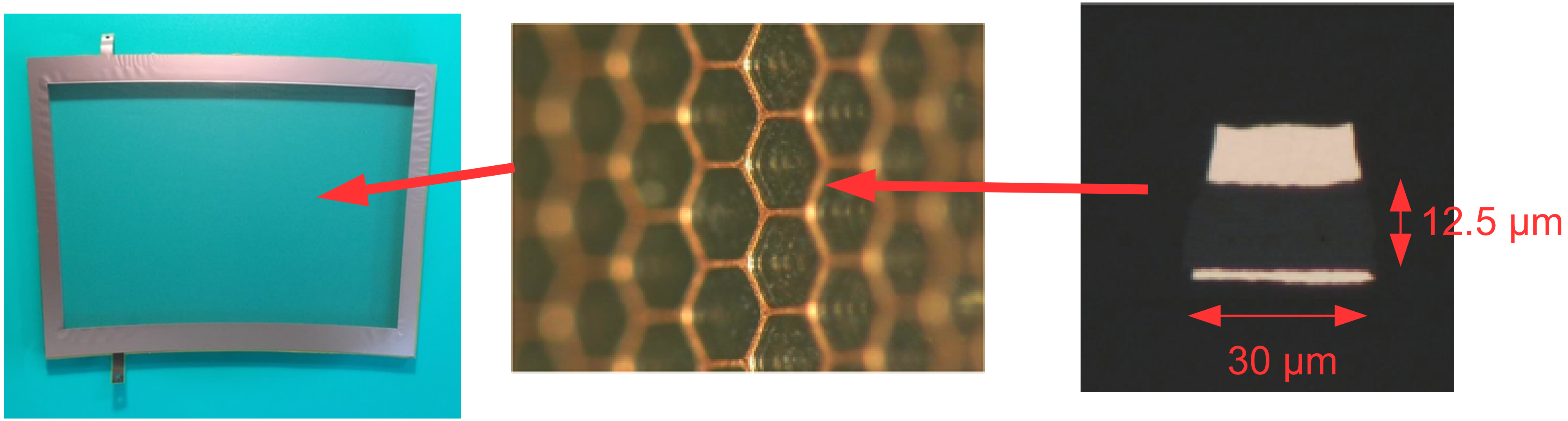
- High optical transparency required:

  → Large aperture GEM with honeycomb-shaped holes

- The transmission rate at B = 3.5 T is expected to be close to the optical aperture ratio (82%)
- Ion stopping power better than 10^{-4} at 10 V reversed biases in simulation
- Current test beam measurements with module size gating GEM







Conclusion and Outlook

- Status:
  - Feasibility of MPDG readout module demonstrated
  - Design of field cage, end plate and module within the material budget possible
  - Single point resolution meets requirements of ILD
  - First module sized GEM gates available
- The next few years:
  - Module optimizations: pad size and module size
  - Module development: finalization of (GEM) gate, distortion suppression (module edges)
  - Improve electronics: integration, cooling, power pulsing
    - Independent development of a readout chip within LCTPC in the future?
  - Study of large field cage: HV stability, temperature control, material budget, cathode design

Backup

Two-phase CO2 Cooling

- Very large latent heat and heat capacity makes CO^2 an excellent cooling medium
- Room temperature operation avoids water condensation
- High pressures (60 bar at 20C)
- Low viscosity allows very small pipe diameter
- Easy & safe to operate
- TRACI: Transportable Refrigeration Apparatus for CO^2 Investigation
  - TRACI 2a build by Nikhef/CERN and acquired by our KEK colleagues for LCTPC
- This system works with a Lewa pump (instead of Gather gear pump):

  → More reliable operation

  → Performance degradation at colder temperatures:
  - less cooling power (not relevant for LCTPC setups)
- First operation at testbeam in 2014 successful

Alignment and Field-Distortion Correction

- Detector alignment with Millepede II was established
  - Rotations and displacements in the $r\varphi$-plane
  - Linear deviations
- Only 0 T data and exclusion of outer rows to minimize the impact of local field distortions and *E x B* effects
- < 80 µm in $y(\varphi)$ and < 250 µm in $x(r)$
  - Within production and measurement accuracies
- Remaining displacements interpreted as local field distortions
- Correction with independent data set