Tracker TPC:
MicroMegas Status

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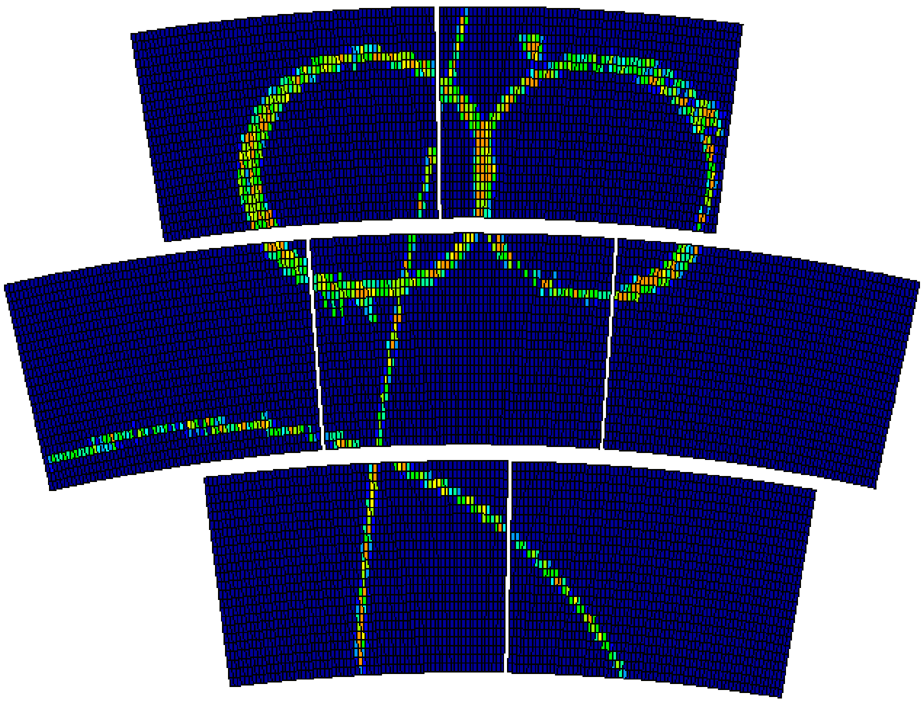

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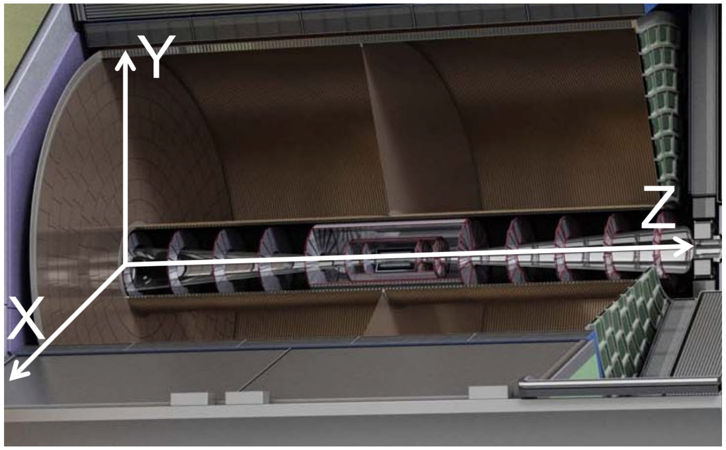
TPC is the central tracker for International Linear Detector (ILD)

- Large number of 3D points
  - ➠ **continuous tracking**
- Particle identification
  - ➠ **dE/dx measurement**
- Low material budget inside the calorimeters (PFA)
  - ➠ barrel: $\sim \mathbf{5\%X_0}$
  - ➠ endplates: $\sim \mathbf{25\%X_0}$
- **Two gas amplification options:**
  - ➠ Gas Electron Multiplier (GEM)
  - ➠ MicroMegas (MM)
    - → pad-based charge dispersion readout
    - → direct readout by the TimePix chip



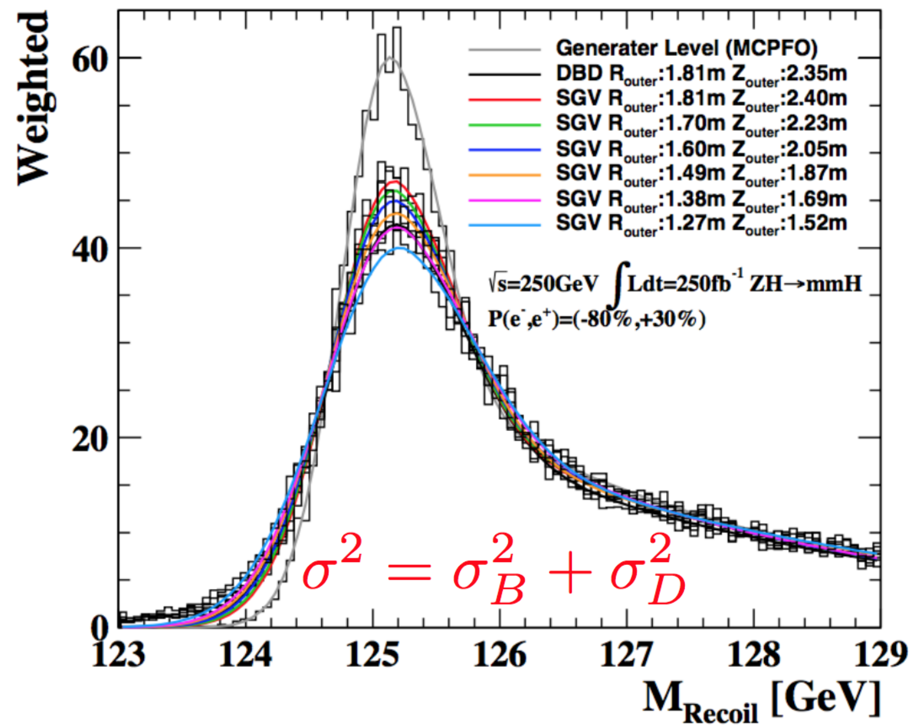
TPC Requirements in 3.5 T

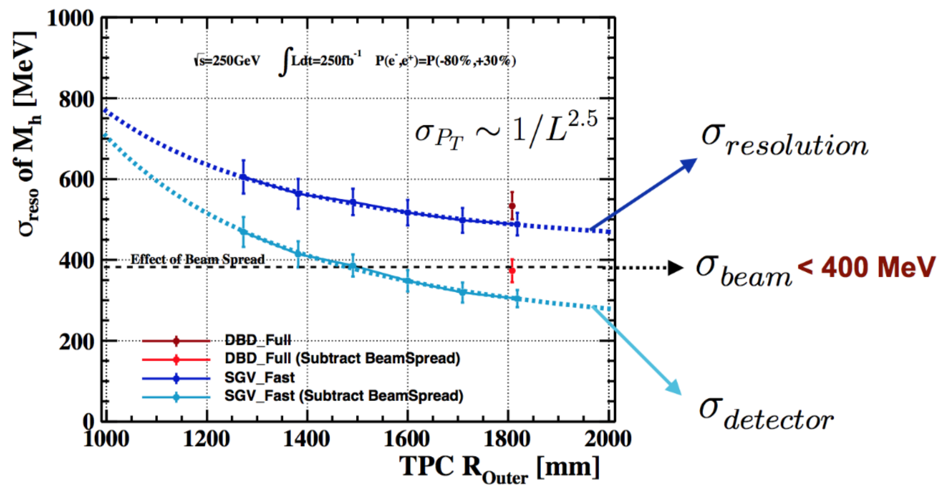
- **Momentum resolution:**
  - ➠ $\delta(1/\mathrm{p_T}) \leq 9 \times 10^{-5}\mathrm{GeV}^{-1}$
- **Single hit resolution:**
  - ➠ $\sigma(\mathrm{r}\phi) \leq 100\mu\mathrm{m}$ (overall)
  - ➠ $\sigma(\mathrm{Z}) \simeq 400\mu\mathrm{m}$
- **Tracking efficiency:**
  - ➠ 97% for $\mathrm{p_T} \geq 1\mathrm{GeV}$
- **dE/dx resolution:** 5%

$$\frac{\sigma(p_T)}{p_T} = \sqrt{\frac{720}{N+4}}\left(\frac{\sigma_x p_T}{0.3BL^2}\right)$$

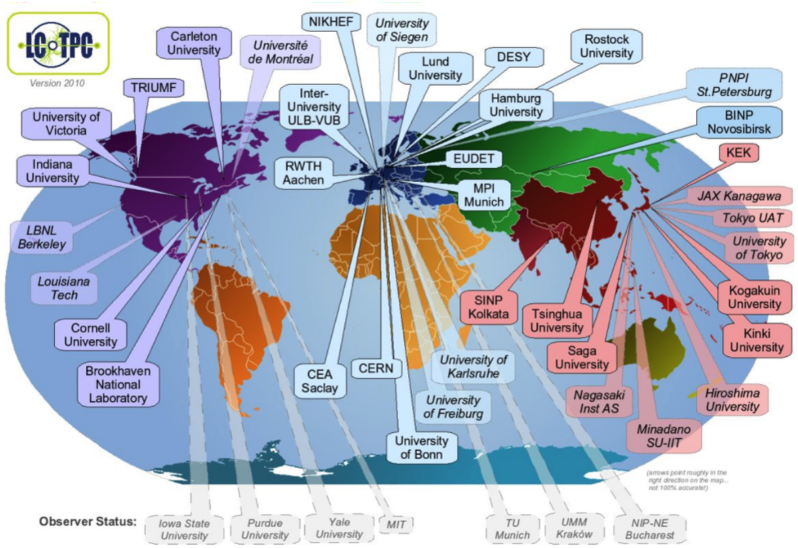
- TPC point resolution is x10 worse than Si
  - would need x100 more points
  - not always practical
  - larger tracking volume
  - include 2 inner Si layers (SIT) and 1 outer Si layer (SET, ETD)

- **ILC flagship measurement**
  - recoil mass $e^+e^- \rightarrow \mathbf{Z(ll)X}$
  - driven by both **beam spread** (σ_B) and **momentum resolution** (σ_D)
  - $\sigma_B = 400$ MeV from TDR
  - $\sigma_D = 300$ MeV at $R_{out} = 1.8$ m
  - $\sigma_D = 400$ MeV at $R_{out} = 1.4$ m





Extensive R&D for ILC TPC is active research area of the LCTPC Collaboration



The EUDET/AIDA test beam (TB) facility at DESY provide a 6 GeV electron beam

☞ **Large Prototype (LP) TPC** consists of a field cage equipped with an endplate with 7 windows to receive up to **7 fully equipped modules**

French activity encompases the MicroMegas readout for ILD TPC

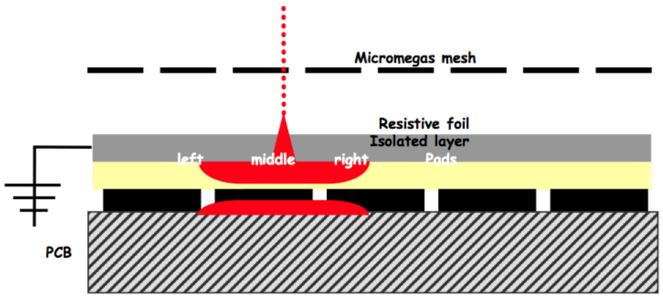
☞ *Prehistory of TB with MM modules:*

- **Mar 2010:** one-module setup
- **May 2011:** cross-talk problem
- **Jul 2012:** multi-module setup with 6 operated modules; coherent noise
- **Jan-Feb 2013:** multi-module setup with 7 fully operated modules; many disconnected pads
- **Feb 2014:** same as in 2013 with some pads' connection problem

☞ Last beam test of 7 MM modules took place at DESY, 1–14 March, 2015

- **Involved groups:**
  - ➔ Bonn, Carleton, DESY, KEK, Saclay

Prototype Concepts

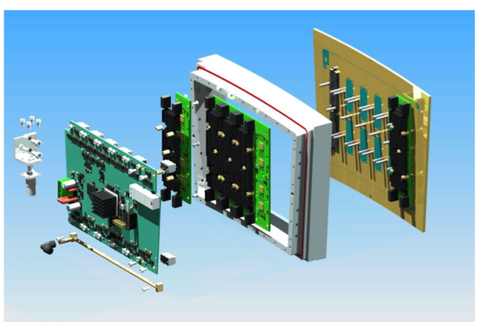


☞ Charge density function

$$\rho(r,t) = \frac{RC}{2t}\exp[-\frac{-r^2RC}{4t}]$$

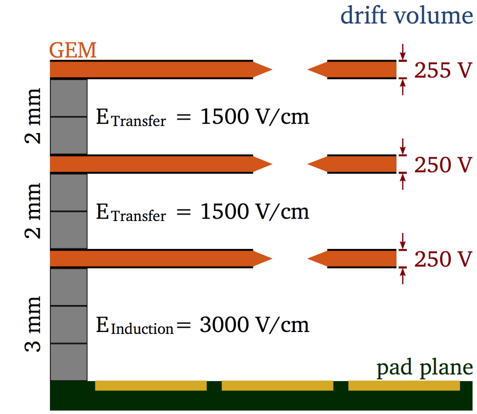
R- surface resistivity

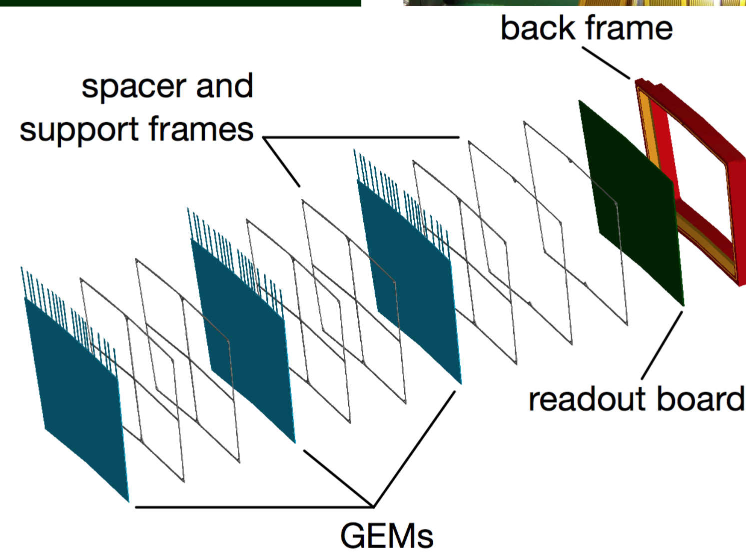
C- capacitance/unit area



☞ MM: T2K readout concept

➠ 72-channel AFTER chip (12-bit)



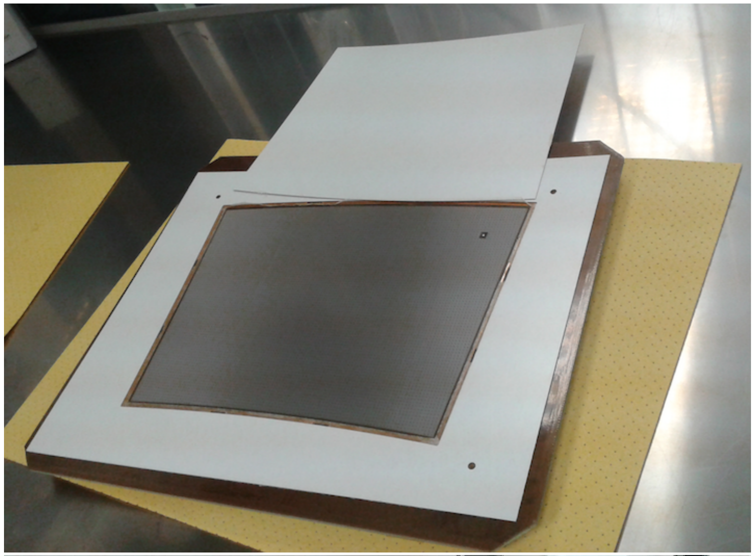


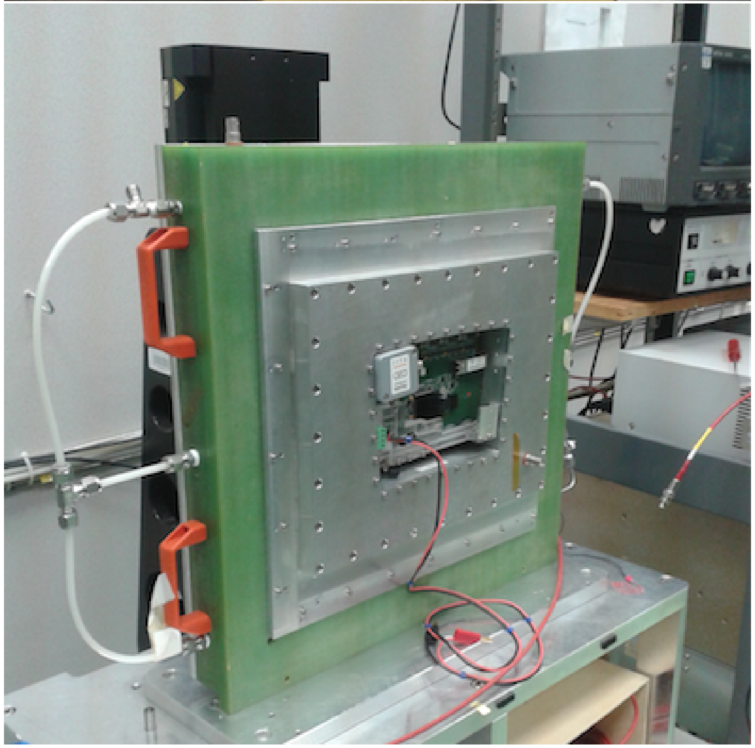
☞ GEM: modified ALTRO readout

➠ 16-channel ALTRO chip (10-bit)

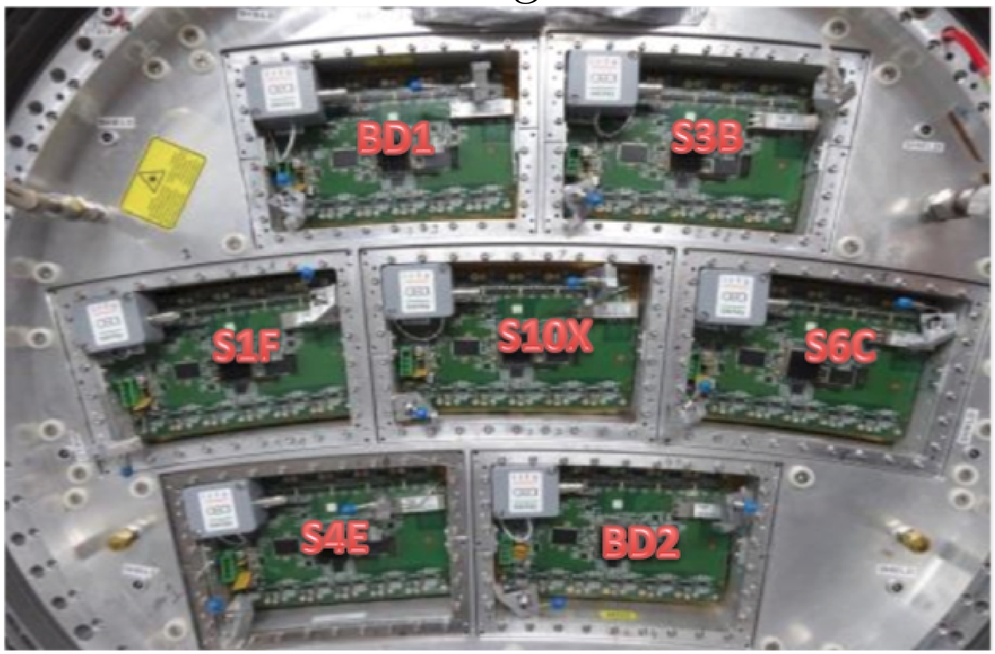
Module test setup at CERN

- Module assembly and test using ^{55}Fe x-ray source
  - calibration, pedestal, etc
  - generic test of workability with ZS
  - homogeneous gas gain across the module (mesh uniformity)
- New type modules were prepared and tested (Jan-Feb., 2015): **BD1 and BD2**
  - new PCB with resistive kapton (CLK) to disperse the charge
  - very solid (Diamond-Like Carbon) and uniform
  - pecisely determined resistivity (5 MOhm/$\square$)
  - procurement of DLC can be done in Japan

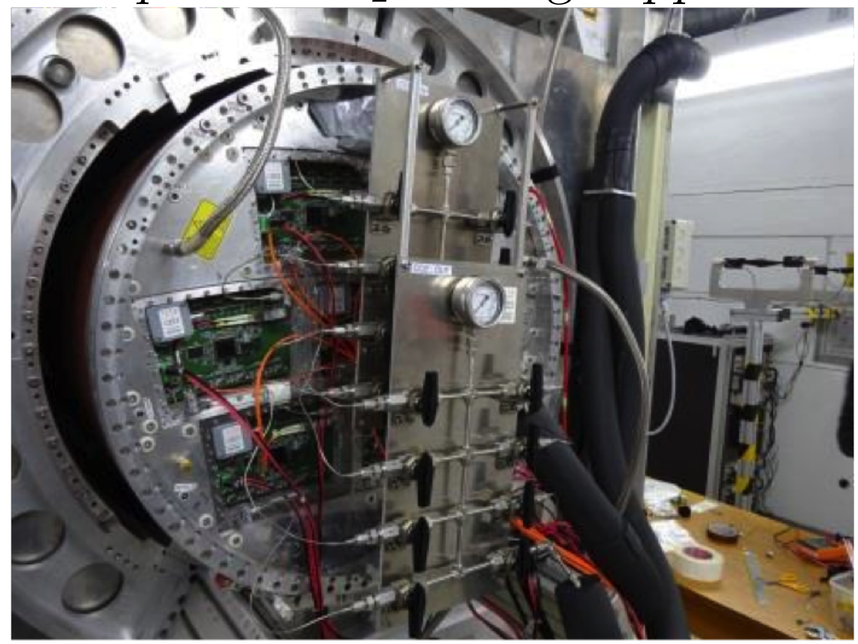




Baseline module configuration for TB2015



2-phase CO_2 cooling support

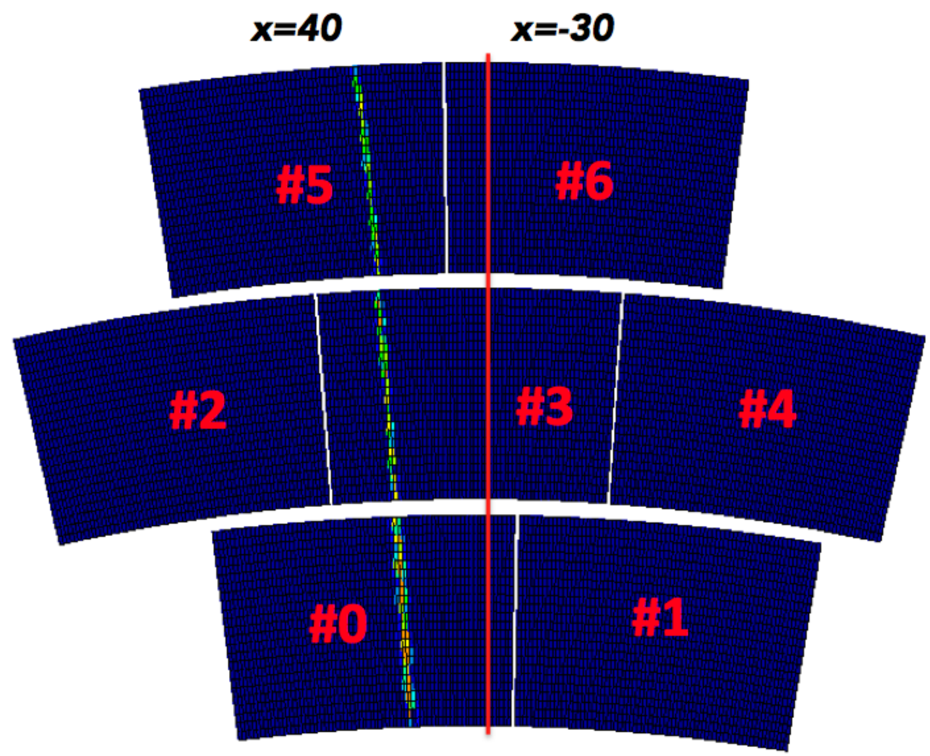


- ☞ Equipped with 7+2(spare) MM modules for this test beam
- ☞ Use KEK **cooling plant TRACI** made in NIKKEF for CO_2 cooling
  - ➠ **10°C at P=45 bar** system operation

About 30°C stable temperature was achieved during operation of 7 MM modules

- **7 MM modules** with charge dispersion by resistive anode
  - pads of the size 3×7 mm^2
  - 24 rows with 72 pads each
  - 1728 pads per module
- **Beam data taking program:**
  - magnetic field: B=0, 1 T
  - drift field: E=140, 230 V/cm
  - z-scan [5-50]cm every $\Delta z = 5\,\mathrm{cm}$
  - shaping time τ-scan: 100-1000 ns
  - ZS: 4.5σ (baseline) and 3σ
  - beam energy scan [1-5] GeV
  - varying θ angle up to 30°
- **Cosmic data:** cover a whole LP volume (T_0 calibration)

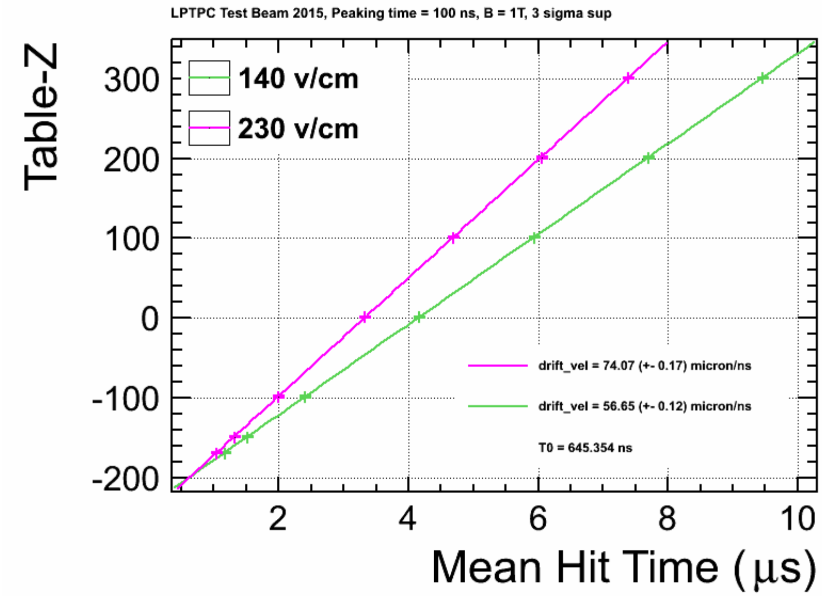
View from inside

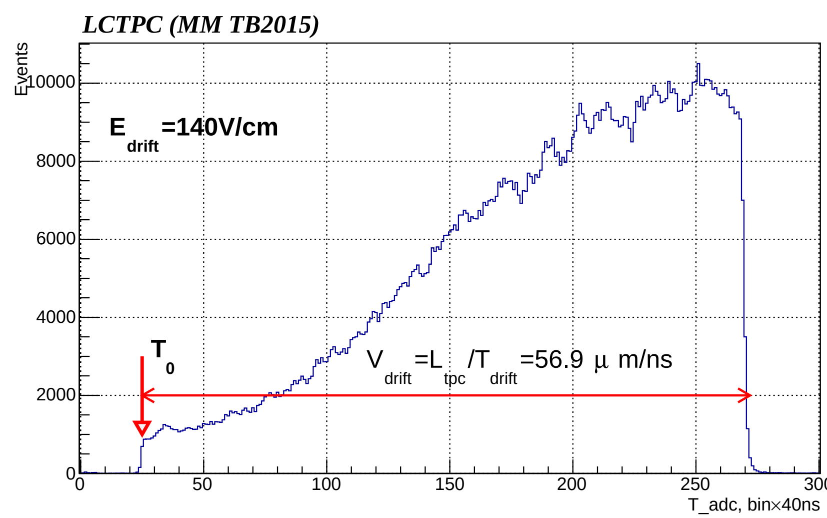


x=40: baseline beam setup
x=-30: complementary beam setup (B=0T data at x=-30)

- ☞ Prototype operates with T2K gas
  - ➠ Ar(95%), CF_4(3%), iC_4H_{10}(2%)
  - ➠ gas purity: 60 ppm O_2, 100 ppm H_2O
  - ➠ deploy `Magboltz` calculations
- ☞ Absolute T_0 calibration:
  - ➠ **beam trigger:** dedicated z-scan at $V_{drift} = 140, 230$ V
    → $T_0 = 645$ns from fit
  - ➠ **cosmic trigger:** accumulate a whole LP volume data events
    → $T_0 = 22 \times 40\text{ns} = 880\text{ns}$

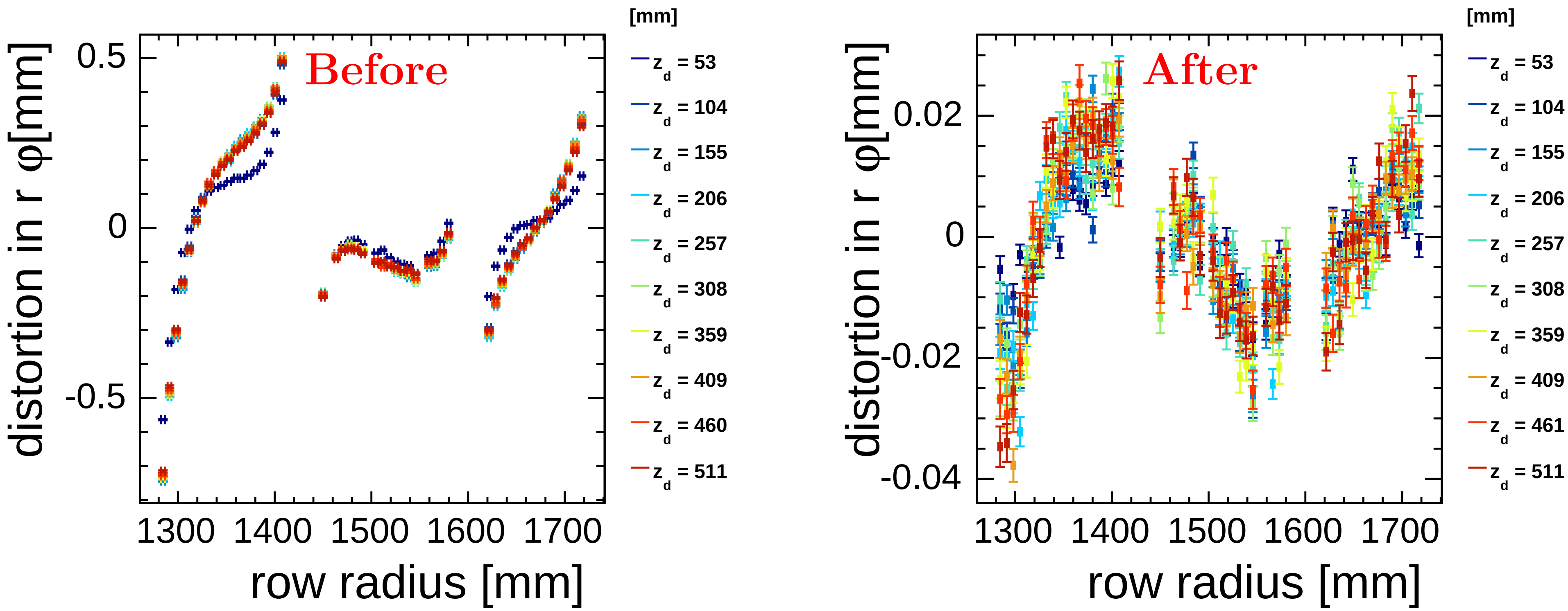
About 250 ns differnce for T_0 between 2 trigger configurations





	E=140 V/cm	E=230 V/cm
V_d `Data`	$56.7 \pm 0.1 \mu m/ns$	$74.1 \pm 0.2\ \mu m/ns$
V_d `Magboltz`	$57.9 \pm 1.0 \mu m/ns$	$75.5 \pm 1.0 \mu m/ns$
$D_\perp$ `Magboltz`	$74.5 \pm 2.5 \mu m/\sqrt{cm}$	$94.8 \pm 3.1 \mu m/\sqrt{cm}$

Distortions



☞ Non-uniform E-field near **module boundaries** induces **ExB effects**

- reach about 0.5 mm at boundaries
  - ➔ worth to minimize at design level
- accounted as systematic residual offsets
- determined on a row-by-row basis from residuals
- correct resuduals to zero at about 20μm

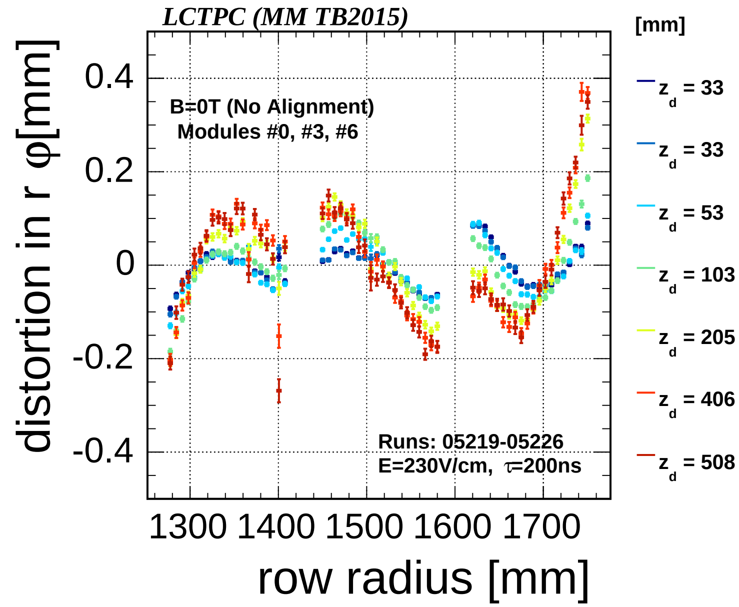
Module Alignment

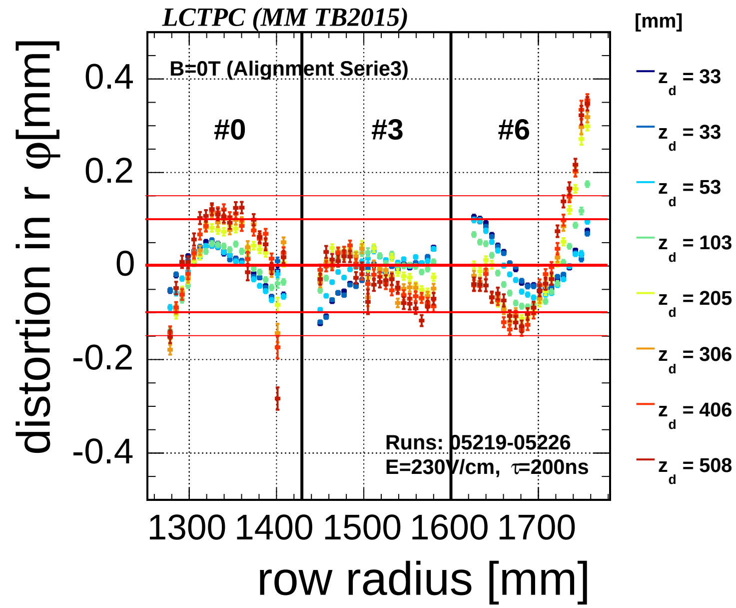
Residual offsets are due to distortions (ExB) and misalignment (multi-module setup)

☞ **Alignment is accounted as overall rotations (θ) and shifts (x and y)**

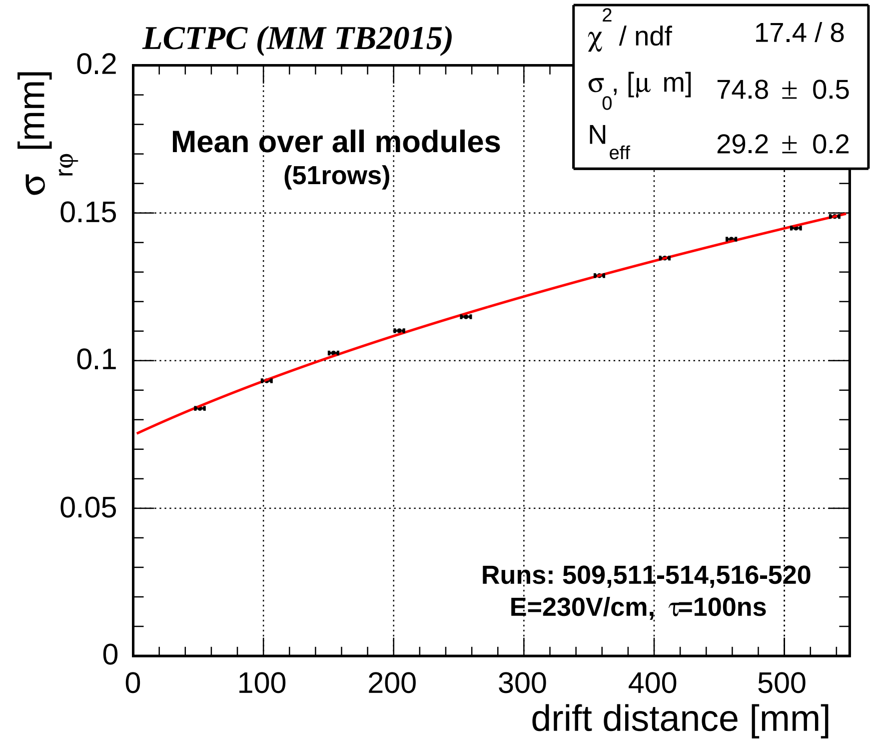
- uses all data at B=0T to exclude ExB effects
- corrections are obtained in an iterative procedure unless they are within errors (**3 serie**)
- determined in module-by-module basis
- uses multi-dimensional χ^2 minimization with **Millipede II** interfaced to **GBL tracks**

Available TB data allowed us to study the whole set of systematic effects relevant to the multi-module setup

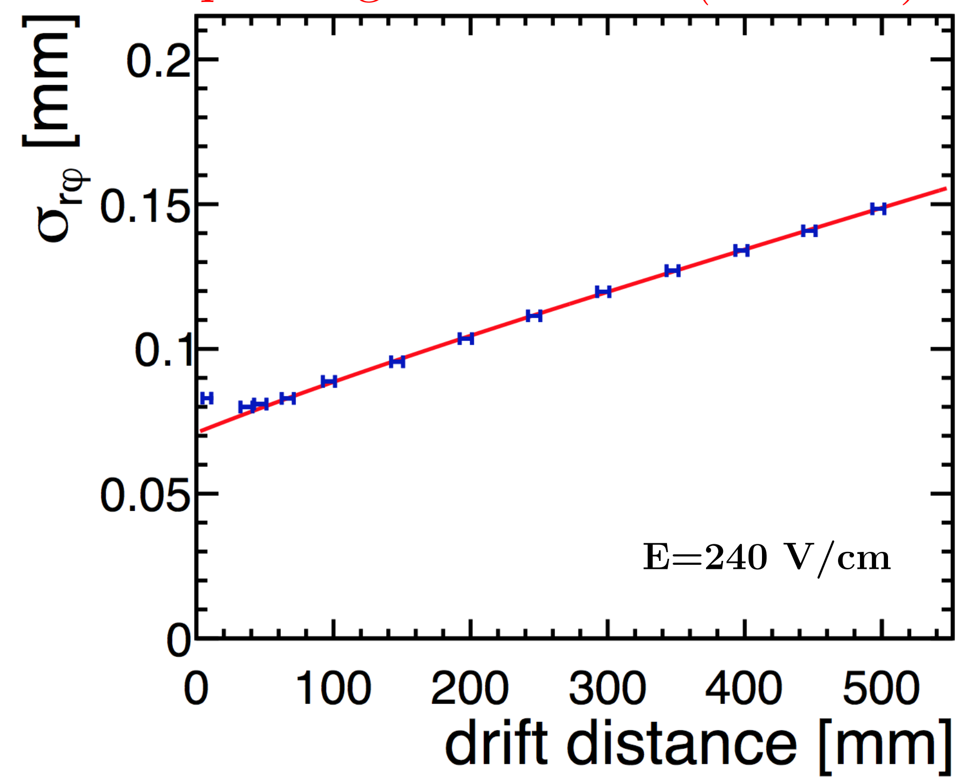




MM peaking time 100 ns (AFTER)



GEM peaking time 120 ns (ALTRO)



☞ **Fit data with:** $\boldsymbol{\sigma(z) = \sqrt{\sigma_0^2 + \frac{D_\perp^2}{N_{eff}} z}, \; \sigma_0^2 = b^2/N_{eff}}$

- σ_0 - the resolution at z=0, N_{eff} - the effective number of electrons
- Magboltz calculations of $D_\perp$ at about 3% precision

- We do not plan to make any big hardware investment before beginning of 2017
- We have presently **no intent to take more data** with the same configuration
- However, **several possibilities** are still opened
  - if there is an endplate II to be tested, or
  - if we have an idea of a fixup for distortions
- **Priority in the next two years**
  - to analyze the data (MarlinTPC)
  - to understand distortions systematically
  - to work on simulations
  - publications (this year)
- **As far as hardware is concerned**
  - design of a **large module** with cooling and high channel density
  - **gating** with a large aperture GEM, by doing ion back-flow measurements
  - simulating in hardware an **ion disk** using a UV lamp

☞ A vast R&D program carried out by LCTPC collaboration in the past

- EUDET/AIDA facility at DESY allows a variety of measurements with LP TPC
- vast amount of data taken in various configuration were accumulated
- major systematic effects relevant to multi-mudule setup were studied
- number of technical issues have been tested and demonstraited
  - ➔ 2-phase CO_2 cooling long-term operation at 30°C of electronic circuit

☞ Publications on behalf of LCTPC collaboration

- MM: possibly paper on 2010 one-module setup (could be short)
- MM: detailed paper on 2015 analysis (possibly within one year)
- GEM: draft is available for LCTPC collaboration wide review

☞ Preparation for next beam tests

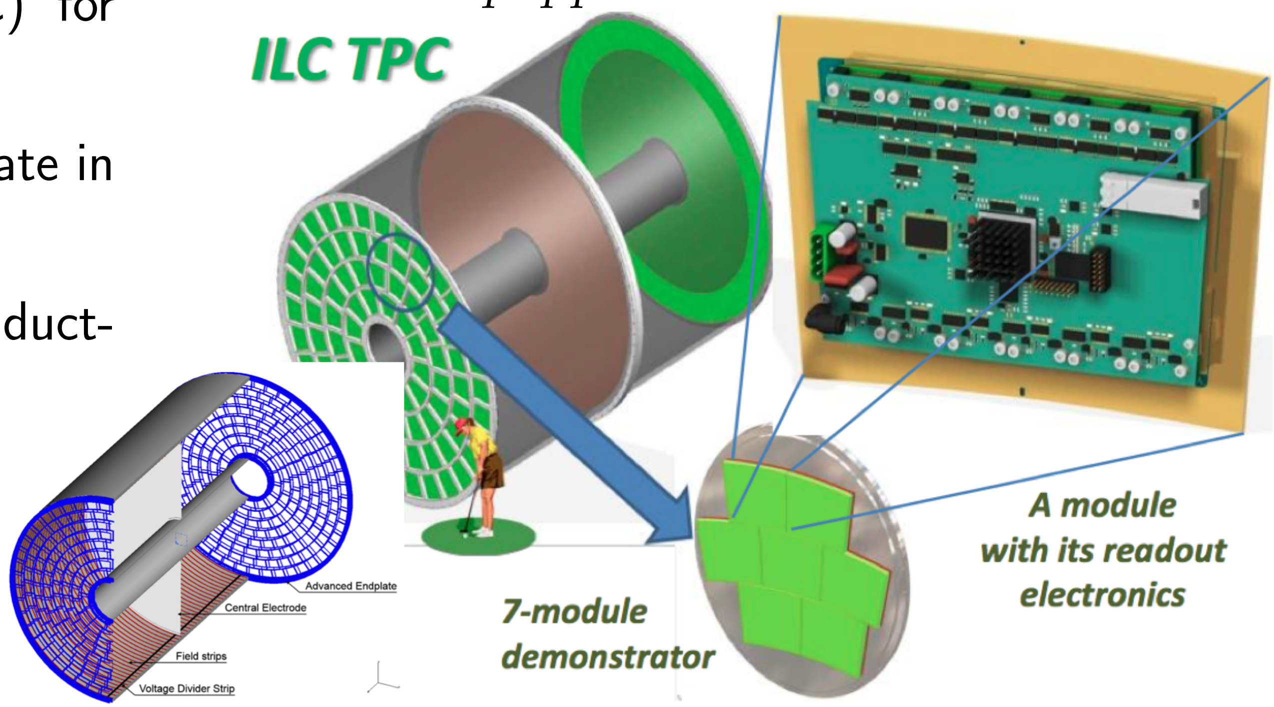
- module with **common pad structure** is being discussed
- integration for **gating and ion back flow** tests
- possibly production of endplate II to address distortions

Backup

The EUDET/AIDA test beam facility at DESY provide a 6 GeV electron beam

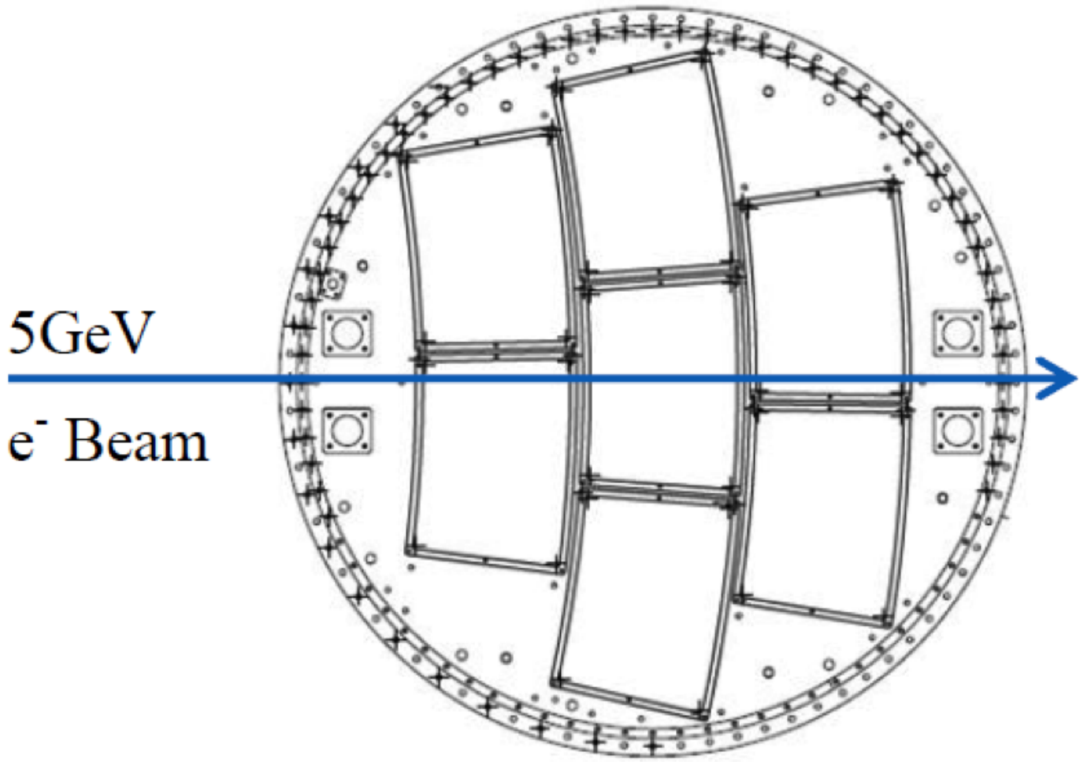
- Setup was designed for a Large TPC Prototype (LPTPC) for the ILC experiment
- LP readout modules operate in a strong magnetic field
  - provides a superconducting solenoid magn
    ⌀85 cm and
    a length ∼1 m
  - a magnetic field strength of up to **1.25 T**

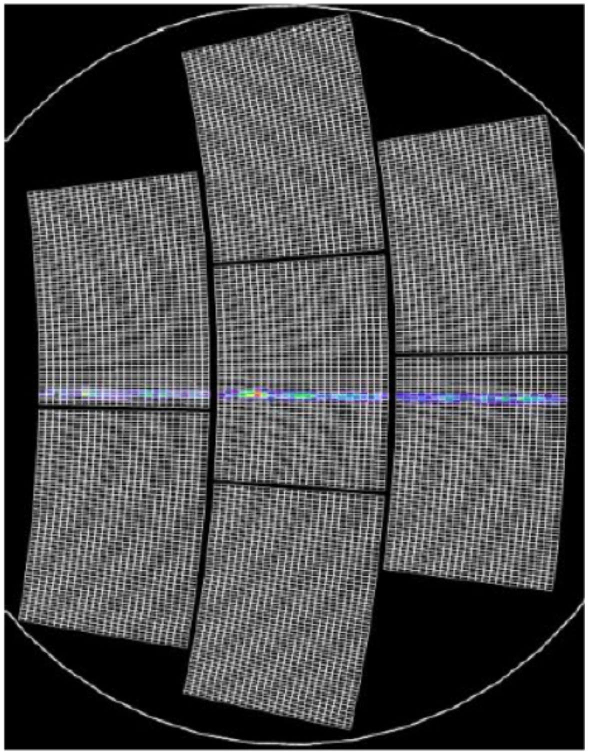
Consists of a field cage equipped with an endplate with 7 windows to receive up to 7 fully equipped identical modules

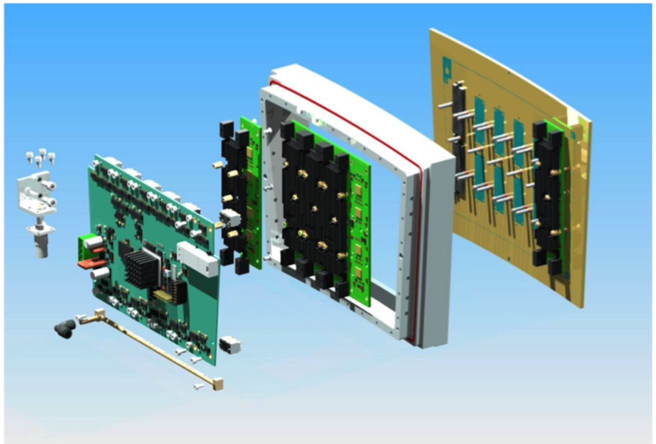


Different layouts are considered for ILD: 4-wheel and 8-wheel scheme

Multi-module setup





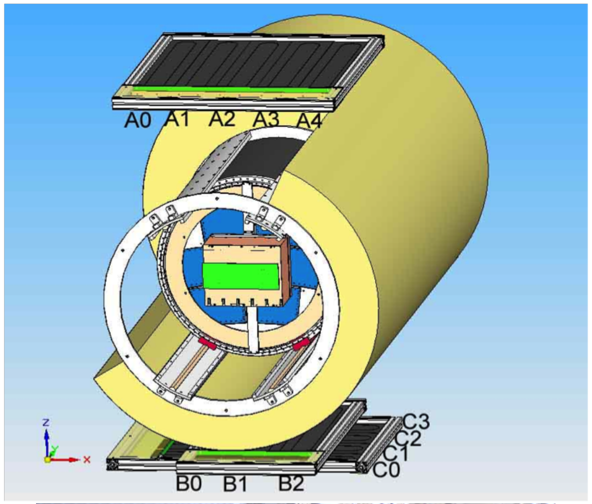


A multi-module detector sensitive to misalignment and distortions

☞ Low material budget is required for ILD-TPC

- endplates: $\leq \mathbf{0.25X_0}$
- current MM module design: $\mathbf{d/X_0 \simeq 0.24}$

Trigger and DAQ



- **Beam, Laser, and Cosmic** triggers are deployed
  - A cosmic trigger based on
    - 12 scintillator plates
    - readout by silicon PMs
    - SiPM signal discrimination and coincidence logic with NIM modules
- **DAQ -** *120 Hz maximum event taking rate* (designed and produced at CEA-Saclay)
  - 6 AFTER chips are digitized in parallel by 8-channel ADC at 20 MHz
  - 4 sequential iterations are needed to readout a FEMi
  - each iteration takes 79 x 511 clock cycles at 20 MHz
  - irreducible dead-time of 8 ms

About 26 W power consumption is currently measured per MM module

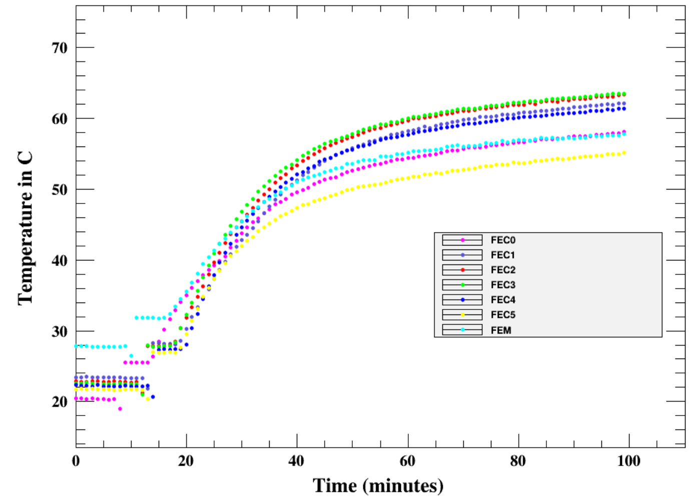
Module 6 (S3B)

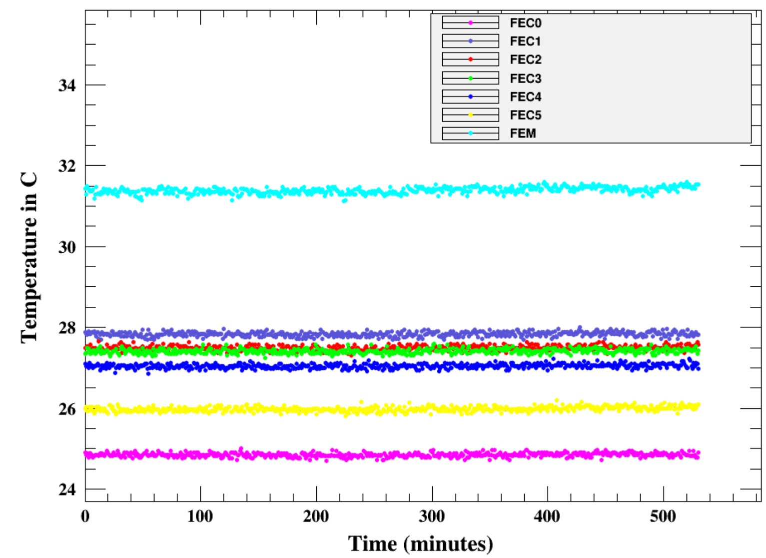
- Temperature of the circuit rises up to 60°C
  - cause a potential damage of electronics
  - covect gas to TPC due to a pad heating

Cooling of the electronic circuit is required!

- **Principle:** CO_2 has a much lower viscosity and a much larger latent heat than all usual refrigerants
  - **the two phases** (liquid and gas) can co-exist at room temperature under pressure
  - very small pipes suffice
  - hold high pressure with low material
- **10°C at P=45 bar** system operation

About 30°C stable temperature was achieved during operation of 7 MM modules





Readout system for the MM prototype TPC is conceptually identical to what is deployed in the T2K experiment

(designed and produced at CEA-Saclay)

- **72-channel AFTER chip**
  - charge signal amplification
  - shaping (100 ns)
  - waveform sampling in a 511-time-bin SCA
- 4 AFTER chips are mounted on a Front-End Card (FECi)
- 6 FECi are digitalized and read-out by FE Mezzanine (FEMi)
- Each FEMi communicates with a Data Concentrator Card (DCC) over duplex optical link
- DCC transfers events to DAQ PC via a Gigabit Ethernet port