Toward the final design of a TPC for the ILD detector (D_RD_9)

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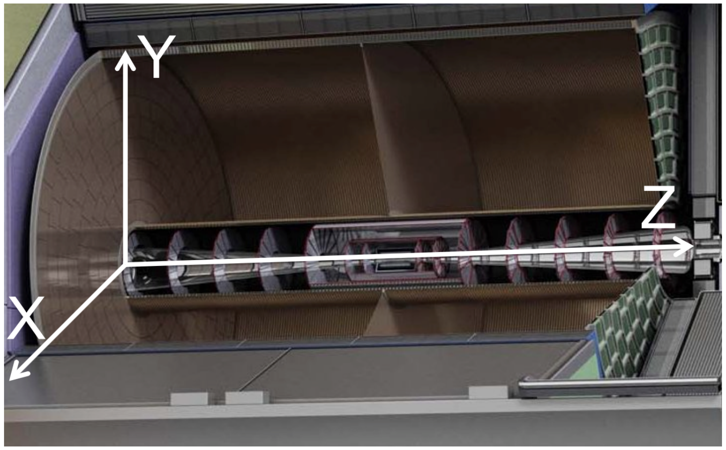
- **The feasibility of a MPGD TPC for the Linear Collider (LC) was demonstrated in D_RD_2 project**
  - Construction and tests of a MPGD TPC endplate prototype for the LC
  - ILD detector baseline document was completed in March 2013
- **D_RD_9 project started in April 2013**
  - running in mid-term phase now
  - **Bordeaux 2014:** software, analysis of beam test data
  - **Okinawa 2015:** steps toward an engeneering design
  - finalizing remaining issues for **a TPC of the ILD detector**

➔ ion backflow and gating
➔ cooling (micro-cooling circuit option)
➔ design of new electronics and power pulsing test
➔ mitigate and correct field distortions
➔ simulation of the effect of the resistive foil

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



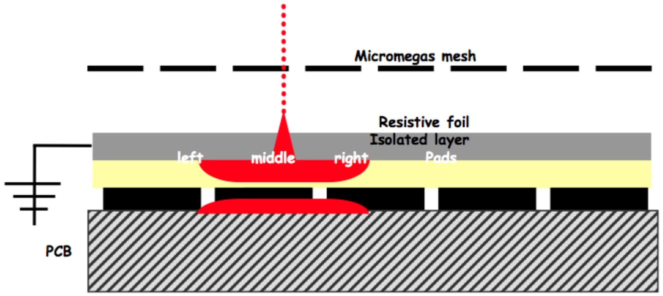
- Large number of 3D points
  - **continuous tracking**
- Particle identification
  - **dE/dx measurement**
- Low material budget inside the calorimeters (PFA)
  - barrel: $\sim \mathbf{5\%X_0}$
  - endplates: $\sim \mathbf{25\%X_0}$

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

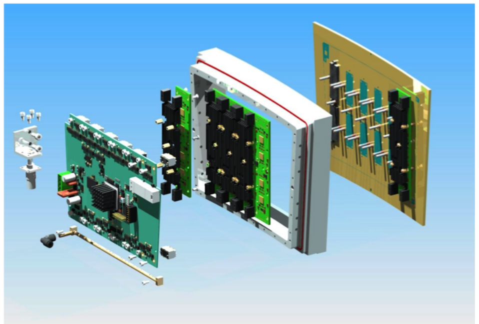


☞ **Charge density function**

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

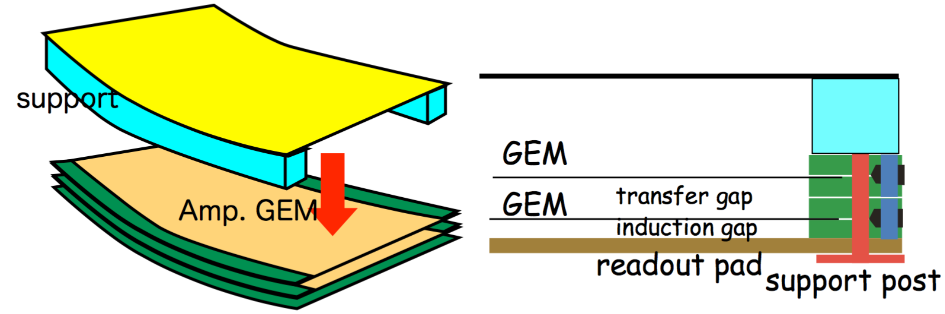
R- surface resistivity

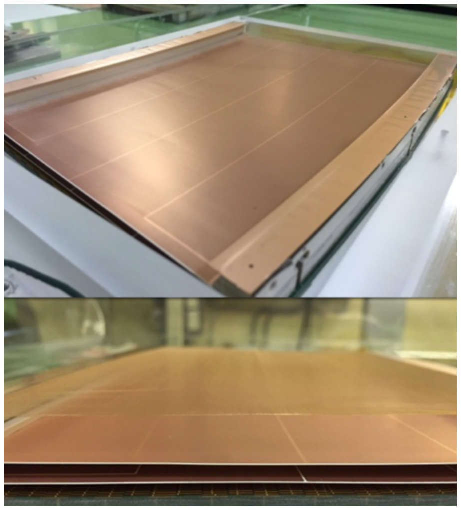
C- capacitance/unit area

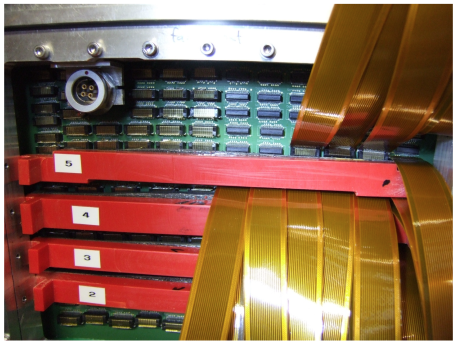


☞ **MM: T2K readout concept**

➠ 72-channel AFTER chip (12-bit)



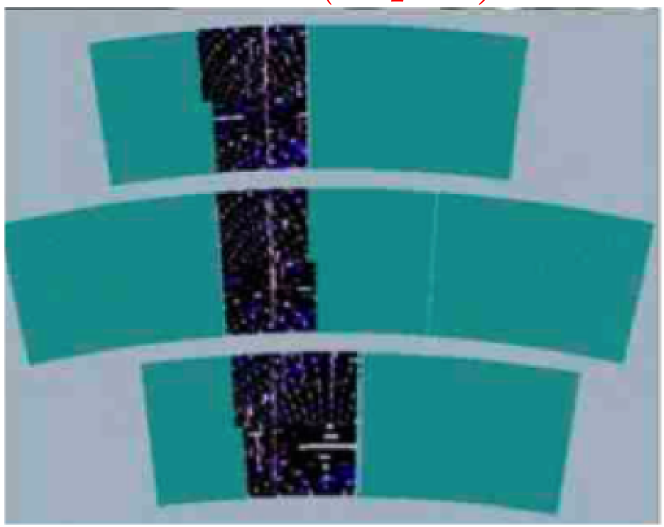




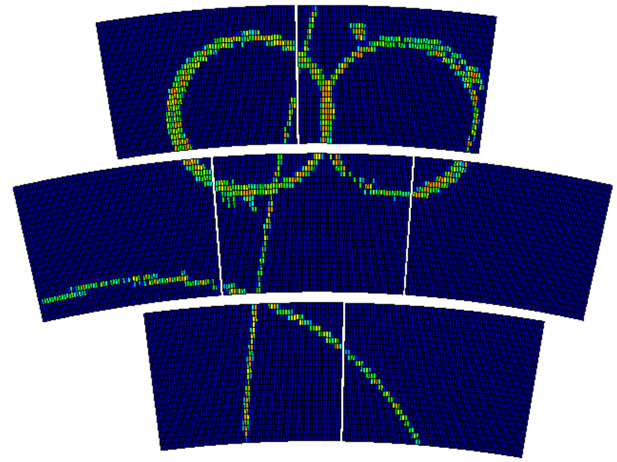
☞ **GEM: modified ALTRO readout**

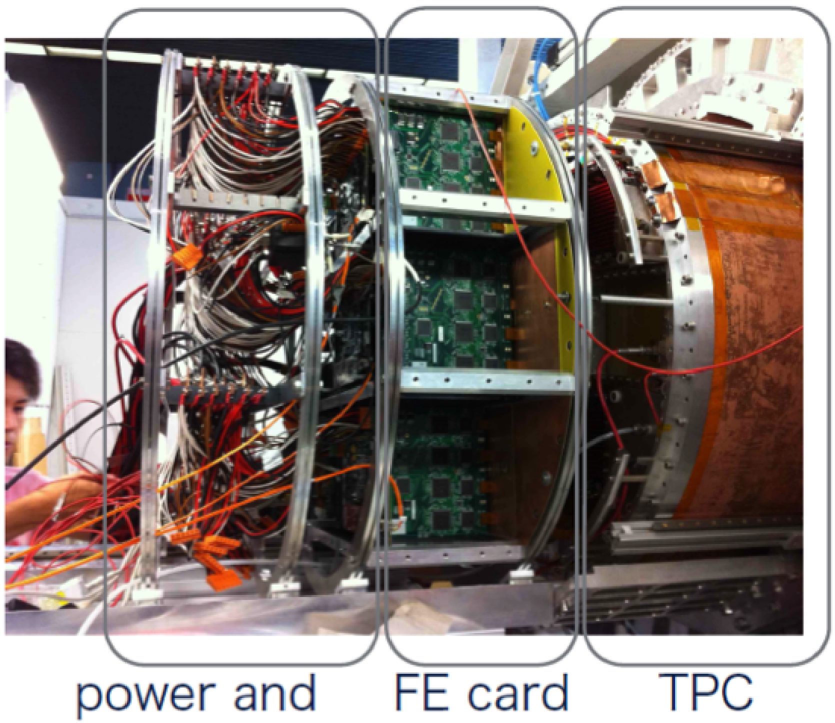
➠ 16-channel ALTRO chip (10-bit)

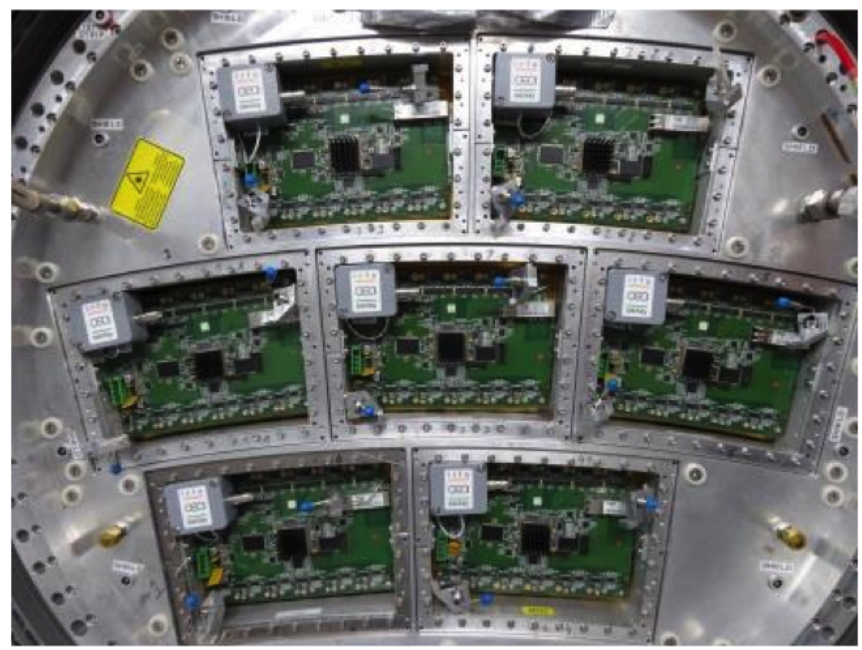
GEM (Japan)



MicroMegas (France)

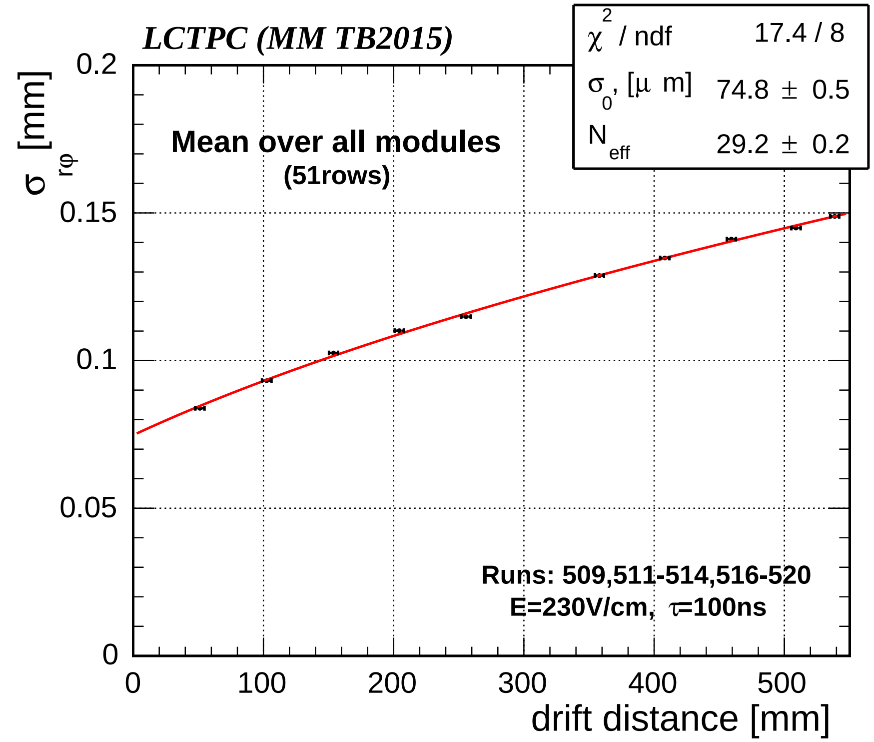




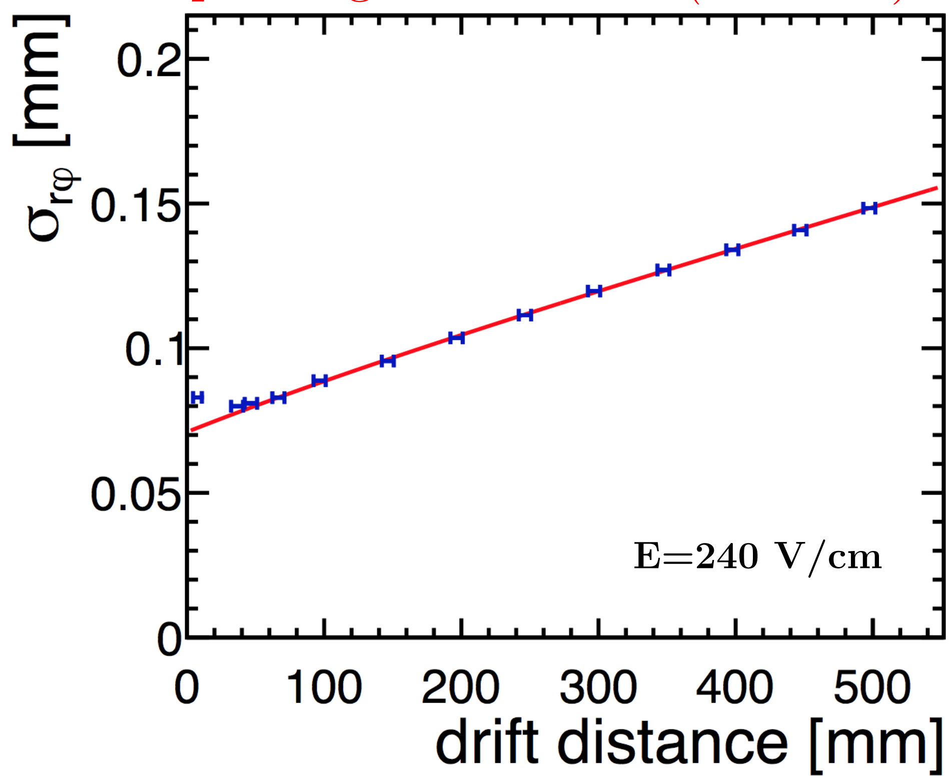


$r\phi$ Resolution

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 $\mathrm{D}_\perp$ at about 3% precision

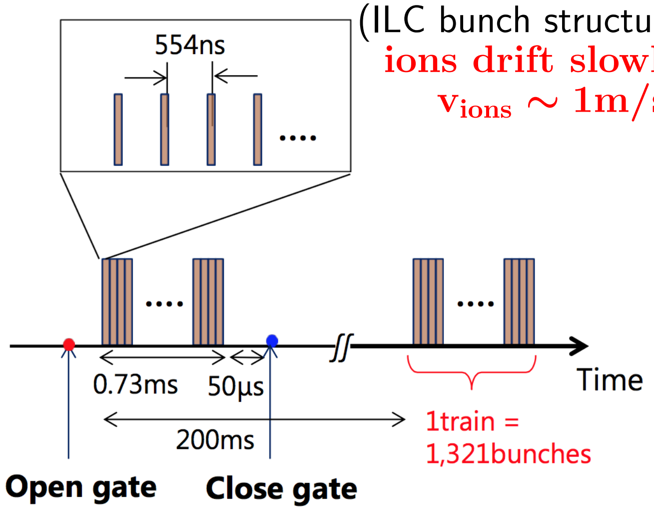
Ion Space Charge can deteriorate the position resolution of TPC

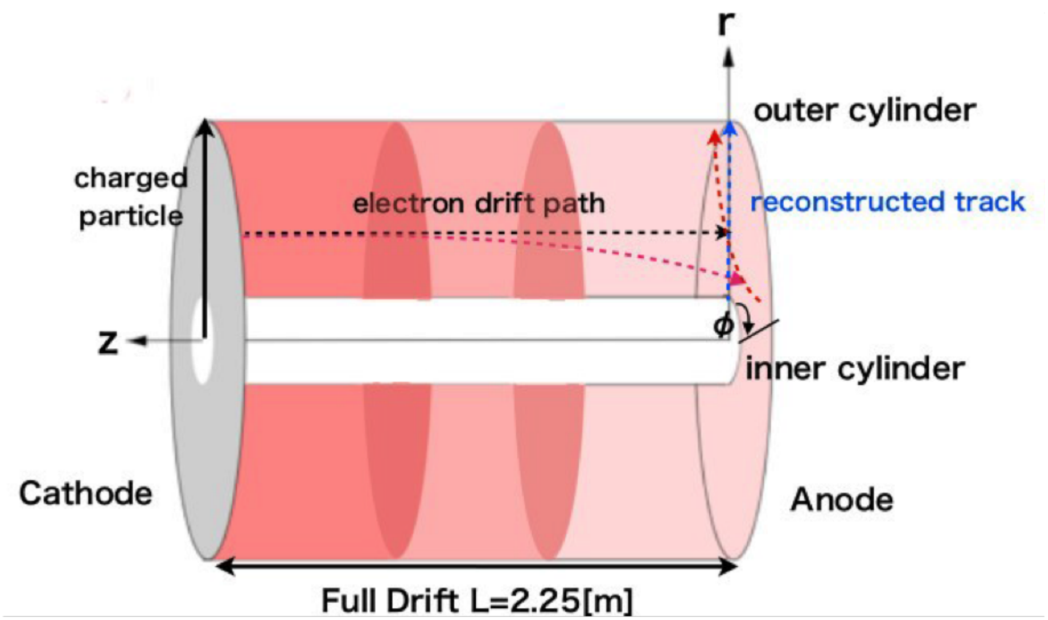
- **Primary ions** yield distortions in the E-field which result to O($\leq 1\mu$m) track distortions
- **Secondary ions** yield distortions from backflowing ions generated in the gas-amplification region:
  - 60 μm for **IBFxGain=1** for the case of 2 ion disks

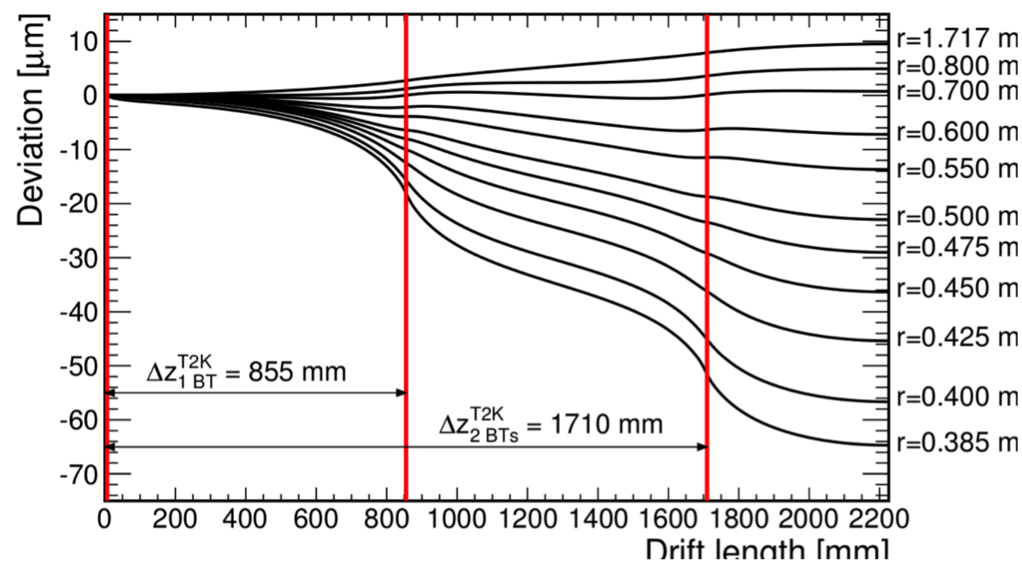
(ILC bunch structure)

ions drift slowly

$\mathbf{v_{ions} \sim 1m/s}$







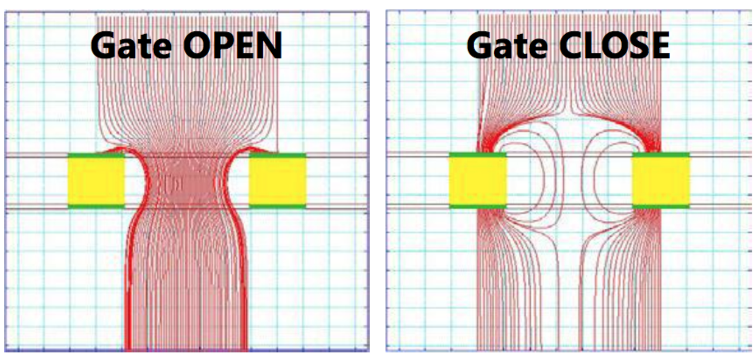
Gate is needed!

Ion Gating

Gating: open GEM to stop ions while keeping transparency for electrons

☞ A large-aperture gate-GEM with **honeycomb-shaped holes**

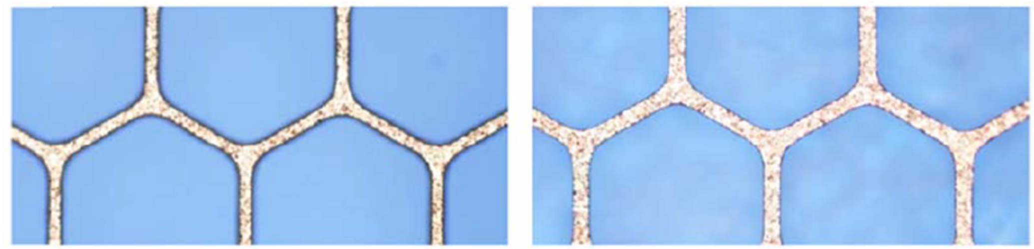
- **produced in Japan**
- handed to Saclay for transparency measurements with MM
- use test setup at CERN

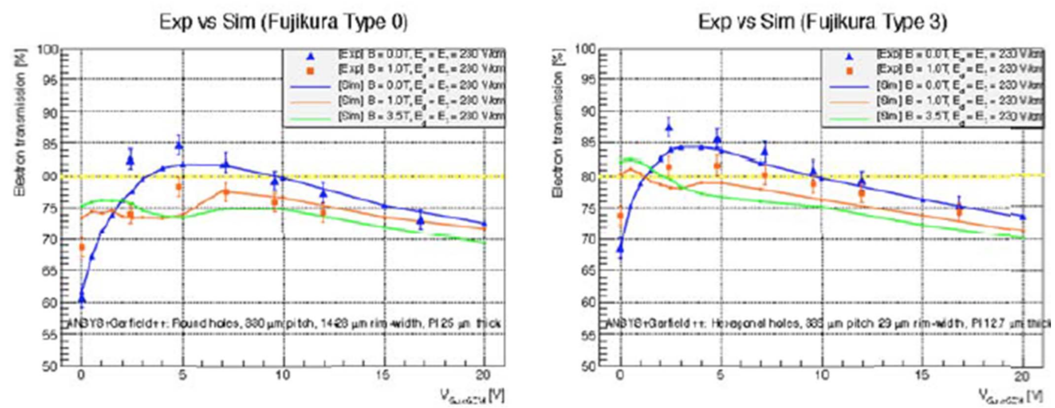


☞ **French team:** simulating in hardware an **ion disk** with a UV lamp

Electron transmission as a function of GEM voltage

(carried out by Saga group)





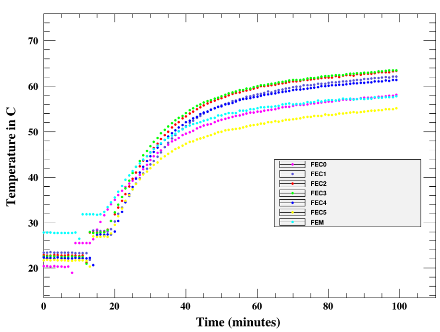
Extrapolation to 3.5 T shows acceptable transmission for electrons (80%)

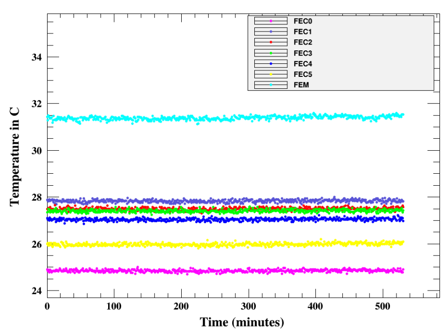
Simulation shows that ion stopping power better than 10^{-4} at 10 V reversed biases

Cooling of the electronic circuit is required due to power consumption

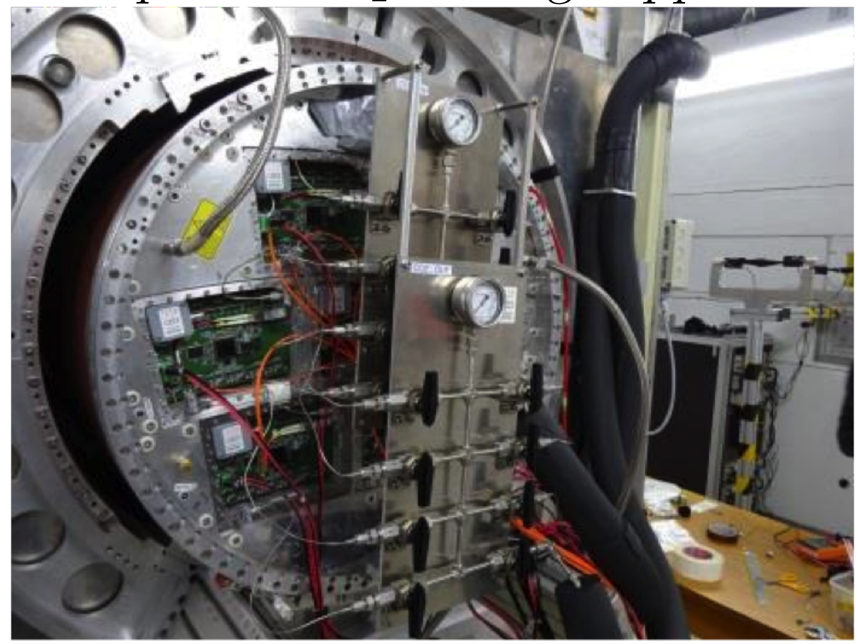
- Temperature of the circuit rises up to 60°C
  - cause a potential damage of electronics
  - covect gas to TPC due to a pad heating
- A 2-Phase CO_2 cooling with the KEK **cooling plant TRACI** was provided to 7 MM modules during 2014/15 beam tests at DESY
  - **10°C at P=45 bar** system operation

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





2-phase CO_2 cooling support



- Thermal behavior and effect of cooling have been simulated
  - *D.S. Bhattacharya et al.,* **JINST 10 P08001, 2015"**

Cooperation for industrial contacts for the ***micro-cooling circuit*** *option*

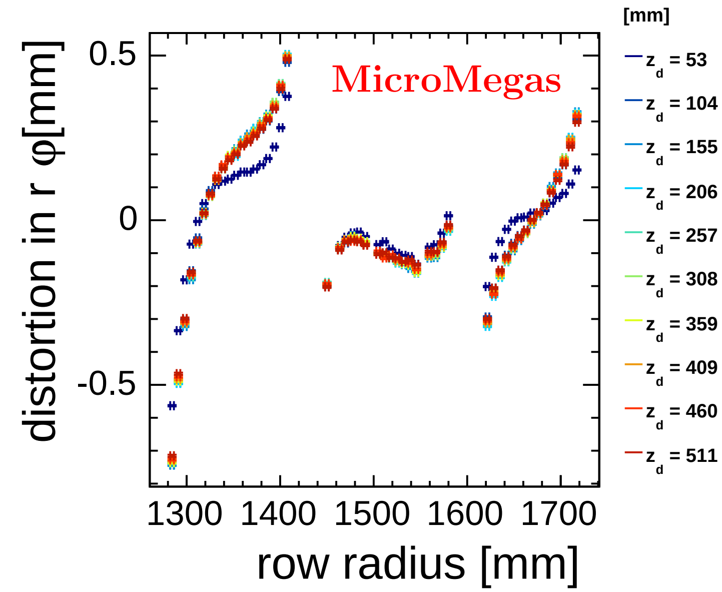
Electronics

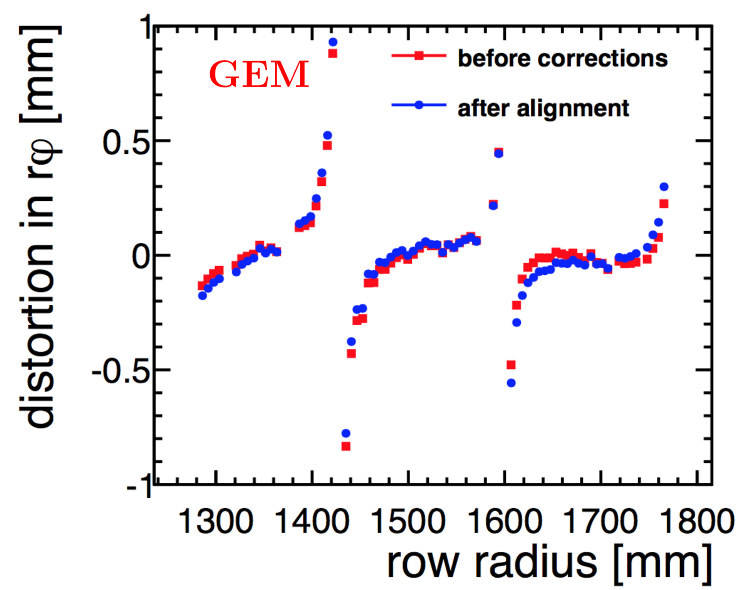
- **The beam test electronics are not those to be used in the ILD detector**
  - AFTER (T2K chip) is not extrapolable to **Switched Capacitor Array (CSA)** depths of 1 bunch train
  - ALTRO does not satisfy power consumption requirements
- **S-Altro 16 has to evolve**
  - improve packing factor (probably 65 nm)
  - lower power consumption
  - power pulsing from the beginning
- Common Front End for Gas Detector Signal processor development within AIDA
  - the 130 nm work has finished
  - **present work within AIDA 2020**
- Design of a **large GEM and MM modules** with cooling and high channel density has been started
  - performance study with the same electronics and pad's structure
  - dedicated power pulsing test

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

- ☞ Track distortions from the Large Prototype
  - ➠ 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
  - ➠ correct residuals to zero at **about 20μm**
- ☞ Good agreement with simulations
  - ➠ E and B field inhomogeneity at module boundaries and near the dges of the magnet

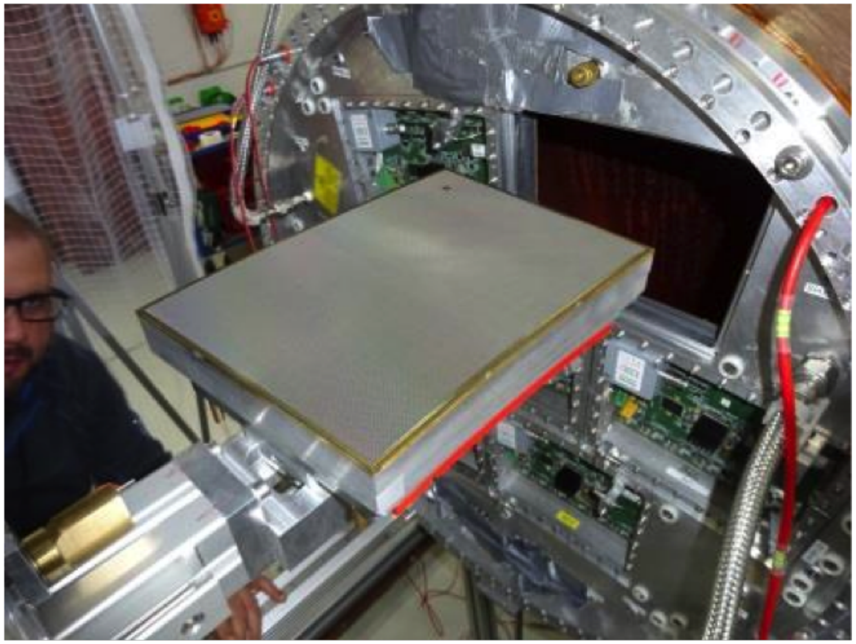
In this project we will refine the simulations and work on possible countermeasures



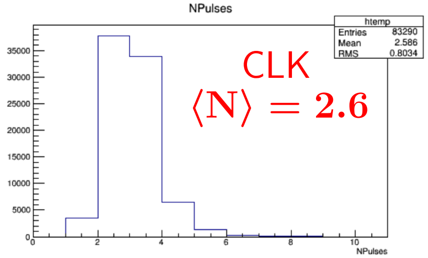


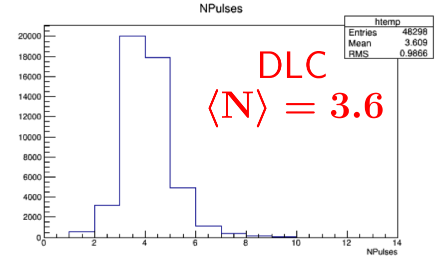
Procurement of PCB with resistive kapton (CLK) is troublesome

- ☞ New type modules were tested in 2015
  - ➠ **Diamond-Like Carbon (DLC)**
  - ➠ very solid, uniform, more robust, easier to achieve the required resistivity
  - ➠ pecisely determined resistivity **(5 MOhm/□)**
- ☞ Simulation of **the charge spreading** in the resistive anode layer
  - ➠ potential effect on the performance
    - ➔ relatively slow charge evacuation
    - ➔ charge sharing beween adjacent readout pad raws
  - ➠ implementation of the physics processes including Pile Up (PU) events



DLC spreads better the charge





Procurement of DLC can be done in Japan

Members, Funds

Spending on French Funds				
Description	**€/unit**	**Nb of units**	**Total (€)**	**Provided by:[1]**
Okinawa/FJPPL P. Colas	1162	1 travel	1162	Irfu
5 days	148/day	5 days	740	irfu
KEK/AWLC15 S. Ganjour	1043	1 travel	1043	Irfu
13 days	115/day	13 days	1500	Irfu
KEK/AWLC15 M. Titov	914	1 travel	1004	Irfu
9 days	90/day	9 days	810	Irfu
Total			6259	

Spending on KEK Fund				
Description	**k¥/Unit**	**Nb of units**	**Total (k¥)**	
Travel K. Fujii	220	2 travel	220 (440)	1 travel counted to ILC_Top
Visit to France	20/day	9 days	90 (180)	1/2 counted to ILC_Top
Okinawa/FJPPL K.Fujii	35	1 travel	35	
	11/day	3 days	33	
Total			688	

Additional spending on French funds		
Provided by:[2]	**Type**	**€**
AIDA	EU funding	3700
CEA	Dotation	9400
Total		13100

Additional spending on Japan funds		
Provided by:[3]	**Type**	**k¥**
IPNS/KEK	Equipment	4000
Saga (grant-in-aid)	Equipment	2000
Total		6000

Request for April 2016 to March 2017

	French Group			Japanese Group		
	Name	**Title**	**Lab./Organis.[2]**	**Name**	**Title**	**Lab/Organis.[3]**
Leader	S. Ganjour	Dr.	CEA/Irfu	K. Fujii	Dr.	KEK
Members	P. Colas	Dr.	CEA/Irfu	T. Fusayasu	Dr.	Saga Univ.
	D. Attie	Dr.	CEA/Irfu	K. Kato	Dr.	Kinki Univ.
	I. Giomataris	Dr.	CEA/Irfu	M. Kobayashi	Dr.	KEK
	A. Giganon	Mr.	CEA/Irfu	T. Matsuda	Dr.	KEK
				A. Sugiyama	Dr.	Saga Univ.
				T. Takahashi	Dr.	Hiroshima Univ.
				T. Watanabe	Dr.	Kogakuin Univ.
				T. Ogawa	Mr.	Sokendai/KEK

Funding Request from France				
Description	**€/unit**	**Nb of units**	**Total (€)**	**Requested to[4]:**
Visit to Japan	150/day	25 days	3750	Irfu
Travels	1200	3 travel	3600	Irfu
Total			7350	

Funding Request from KEK				
Description	**k¥/Unit**	**Nb of units**	**Total (k¥)**	**Requested to:**
Travel	200	2 travel	400	KEK
Visit to France	20/day	14 days	280	KEK
Travel + per diem	900	1	900	KEK
Total			1580	

☞ **AIDA 2020** has been granted
- ➠ contains a gaseous detector part
- ➠ spans 2015-2018

☞ Saclay applied to an **EU RiSE grant (GANDALF project)**
- ➠ fund travels to Japan for 4 years
- ➠ includes TPC R&D

- **The French-Japan R&D work within the LCTPC collaboration is in a phase of engineering toward the final design of a TPC for the ILD detector**

- **It also allowed us to identify a few points requiring common active R&D to be pursued in the next few years**
  - ion backflow and gating
  - field distorsions at module boundaries
  - GEM and MM modules with common electronics
  - effect of the resistive foil

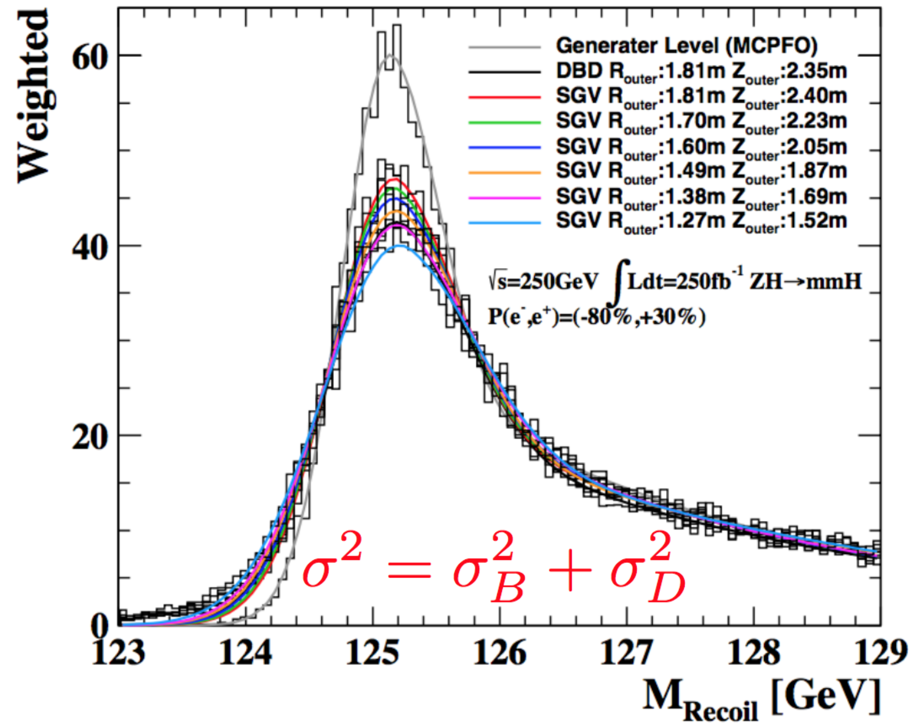
- **Special thanks to P. Colas, T. Matsuda, and A. Sugiyama**

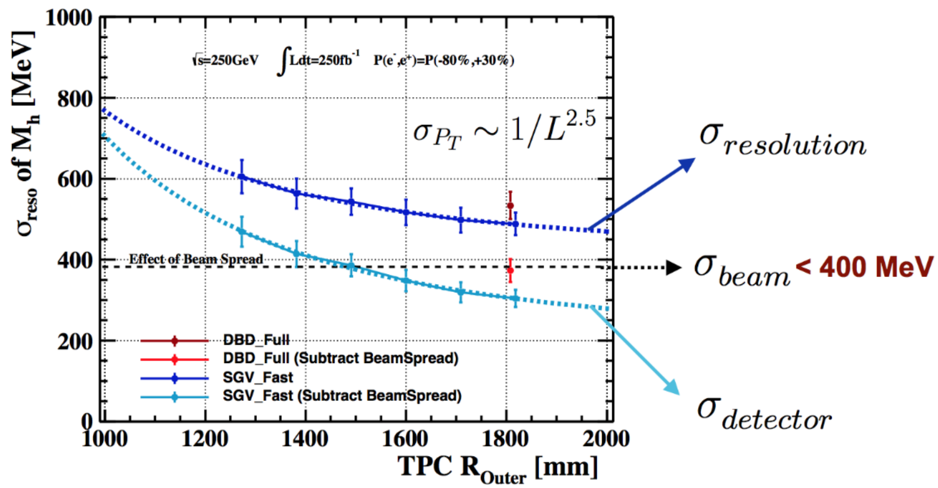
Backup

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

- ☞ 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)

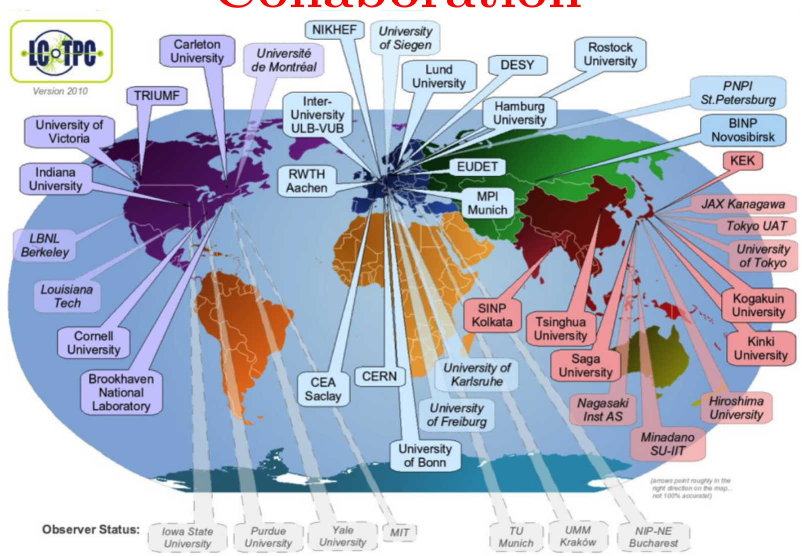
- ☞ **ILC flagship measurement**
  - ➠ recoil mass $e^+e^- \rightarrow \mathbf{Z(ll)X}$
  - ➠ driven by both **beam spread** ($\boldsymbol{\sigma}_B$) and **momentum resolution**($\boldsymbol{\sigma}_D$)
  - ➠ $\boldsymbol{\sigma}_B = 400$ MeV from TDR
  - ➠ $\boldsymbol{\sigma}_D = 300$ **MeV** at $R_{out}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





LCTPC Collaboration

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

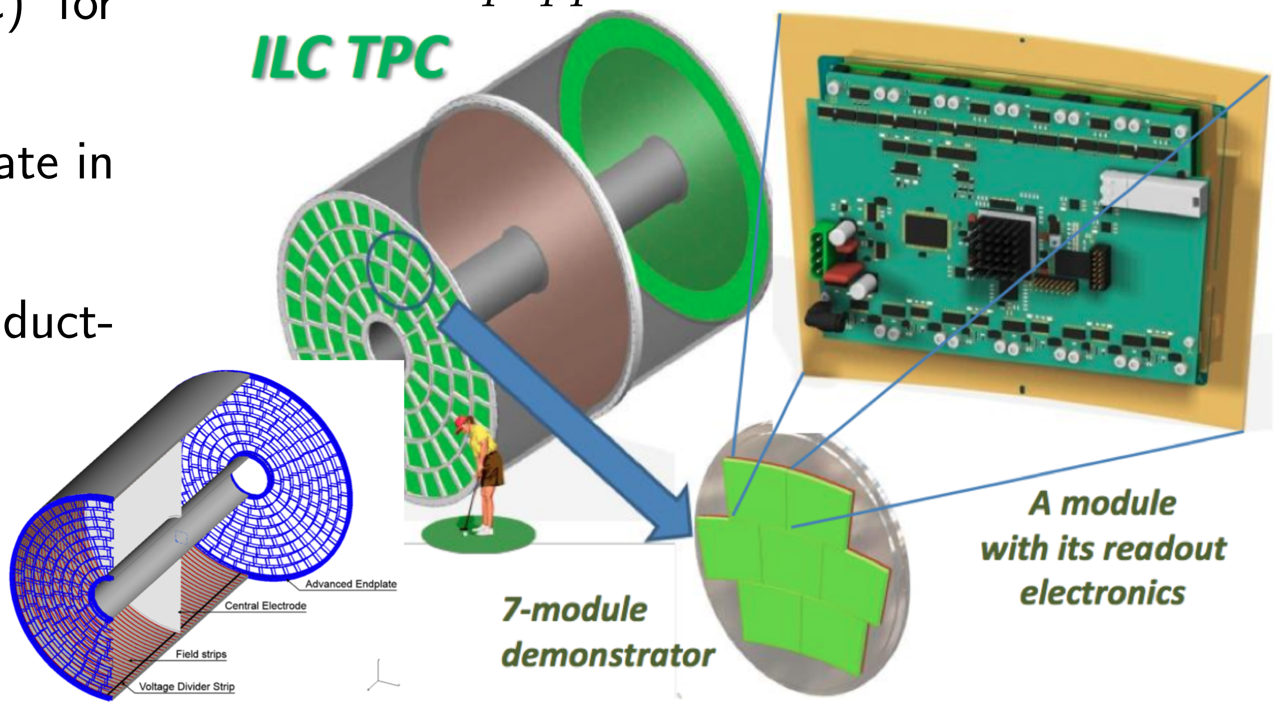
- **Involved groups:**
  - ➔ Bonn, Carleton, DESY, KEK, Saclay

Facility

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

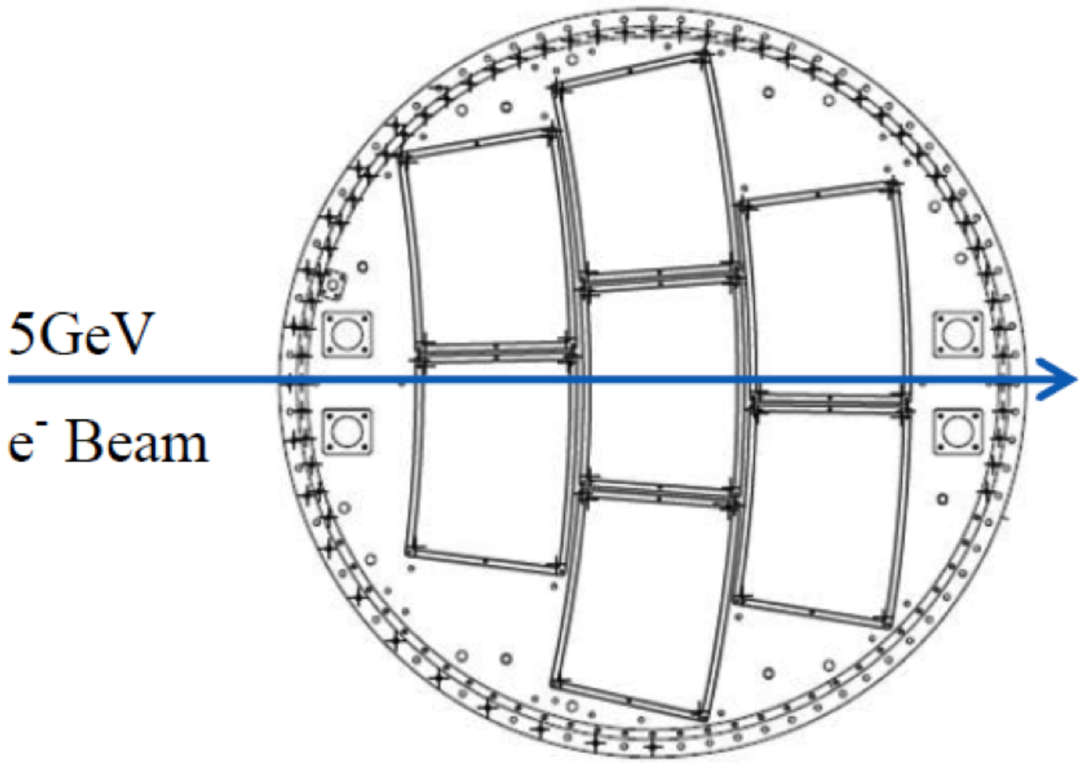
- Setup was designed for a Large TPC Prototype (LPTPC) for the ILC experiment
- LP readout modules operate in a strong magnetic field
  - provides a superconducting solenoid magn
    $\varnothing 85\,\mathrm{cm}$ and
    a length $\sim 1\,\mathrm{m}$
  - a magnetic field strength of up to **1.25 T**

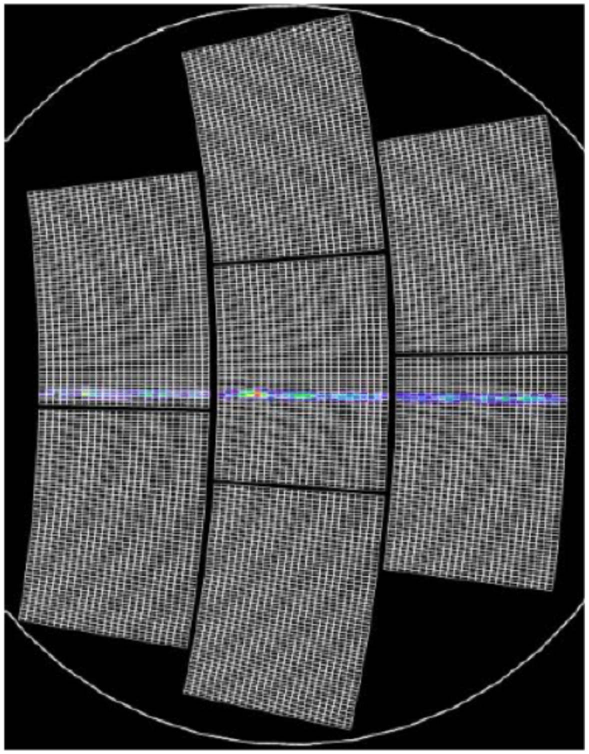
Consists of a field cage equipped with an endplate with 7 windows to receive up to 7 fully equipped identical modules

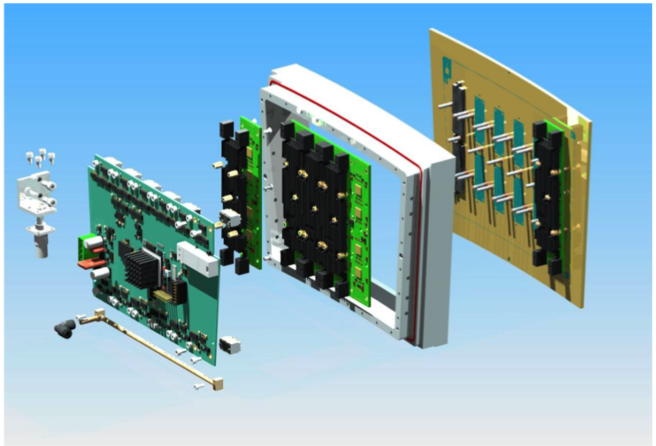


Different layouts are considered for ILD: 4-wheel and 8-wheel scheme

Multi-module setup







A multi-module detector sensitive to misalignment and distortions

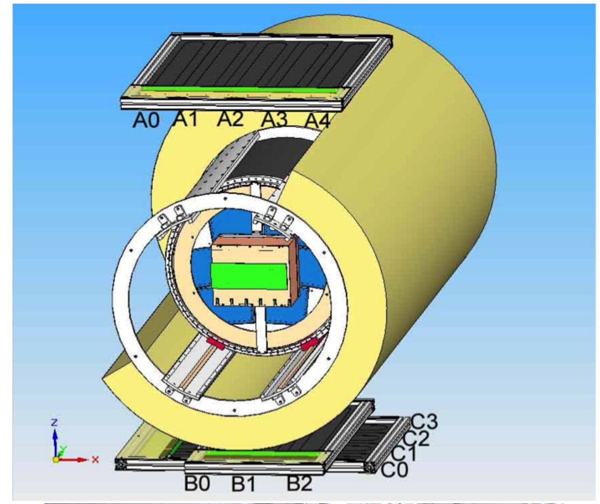
☞ Low material budget is required for ILD-TPC

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

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



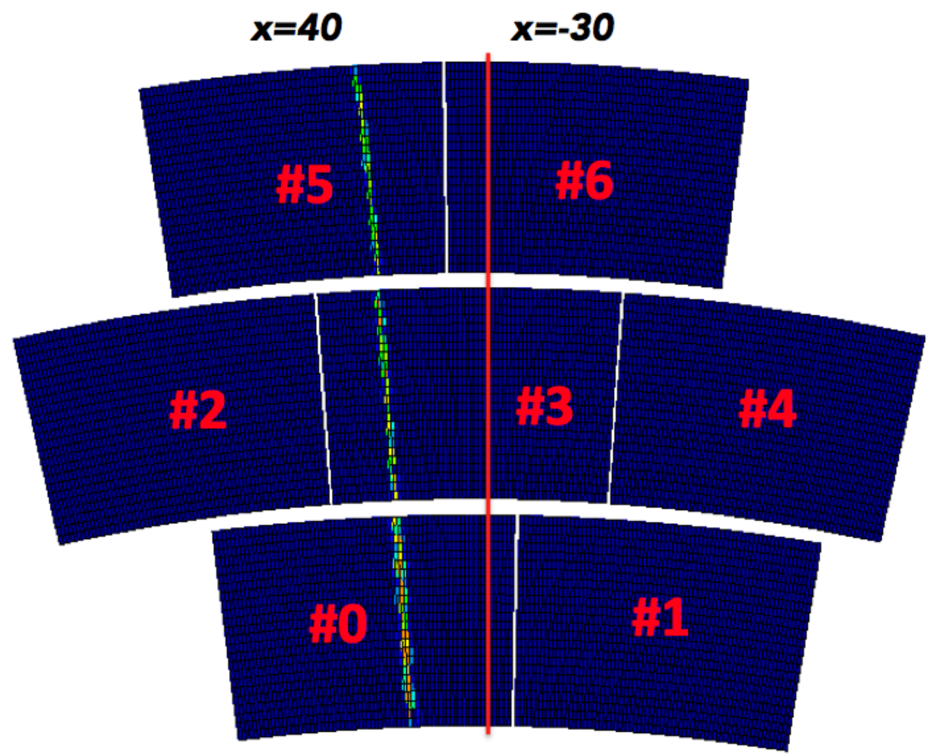
☞ **DAQ** - *120 Hz maximum event taking rate* (designed and produced at CEA-Saclay)

- ➠ 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

Data Taking Program

- **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)

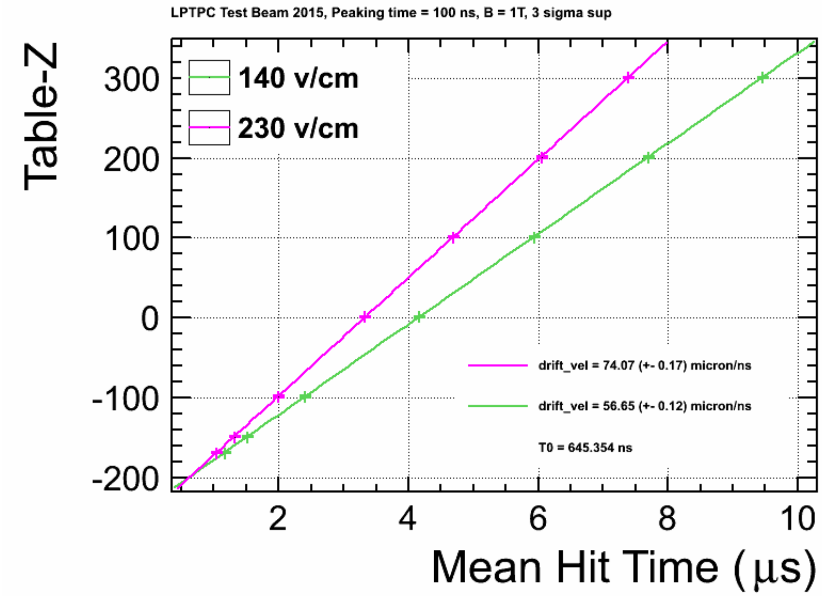
☞ Prototype operates with T2K gas

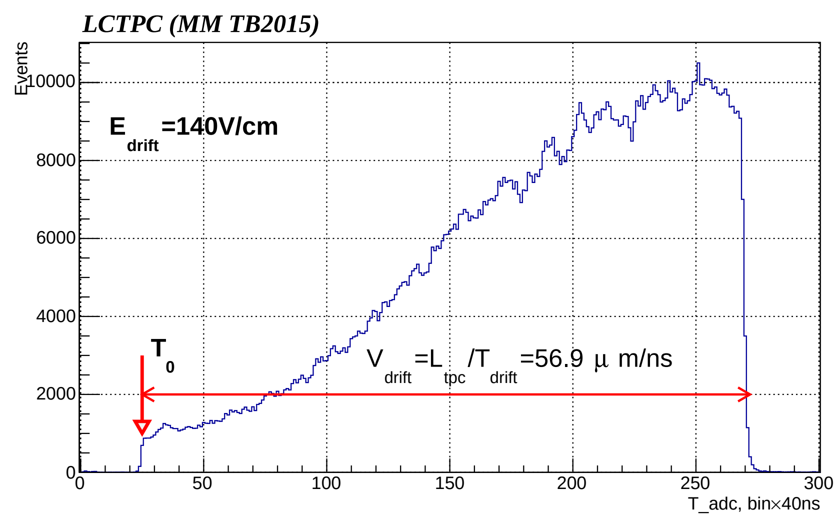
- Ar(95%), CF_4(3%), iC_4H_{10}(2%)
- gas purity: 60 ppm O_2, 100 ppm H_2O
- deploy `Magboltz` calculations

☞ 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





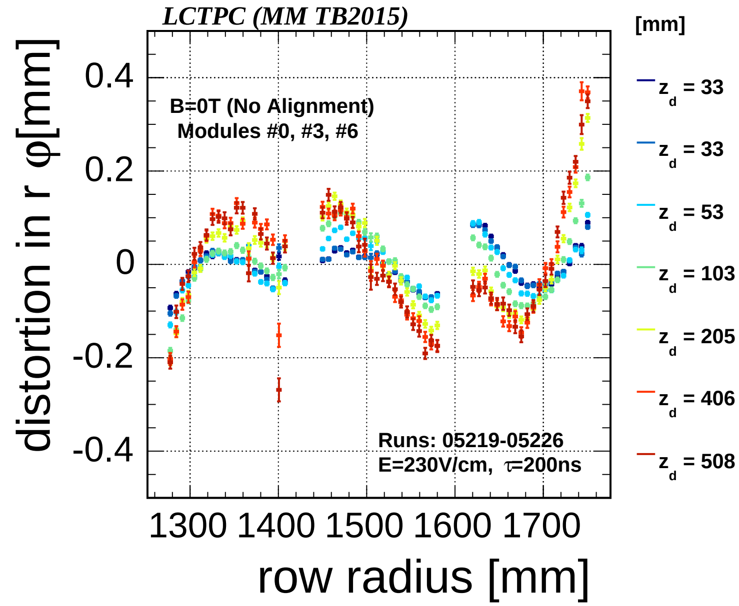
	E=140 V/cm	E=230 V/cm
V_d `Data`	$56.7 \pm 0.1\mu m/ns$	$74.1 \pm 0.2\ \mu m/ns$
V_d `Magboltz`	$57.9 \pm 1.0\mu m/ns$	$75.5 \pm 1.0\mu m/ns$
$D_\perp$ `Magboltz`	$74.5 \pm 2.5\mu m/\sqrt{cm}$	$94.8 \pm 3.1\mu m/\sqrt{cm}$

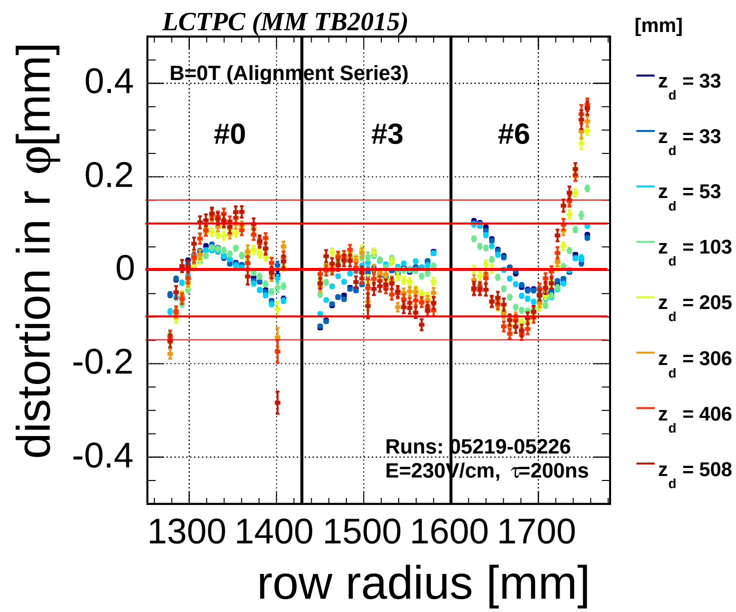
Residual offsets are due to distortions (ExB) and misalignment (multi-module setup)

☞ **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**

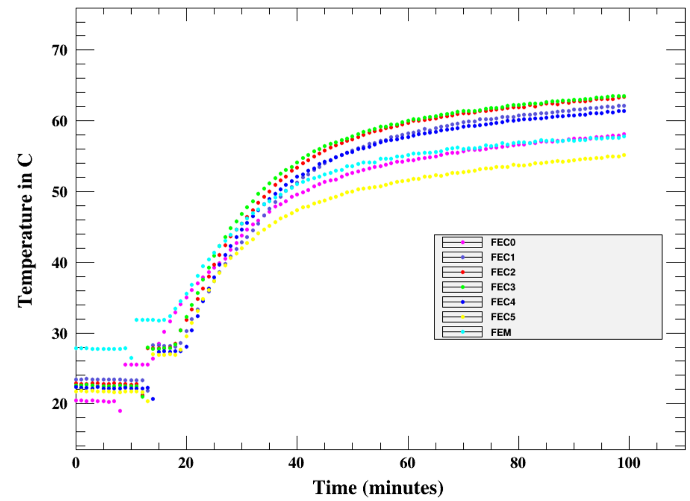
Available TB data allowed us to study the whole set of systematic effects relevant to the multi-module setup





About 26 W power consumption is currently measured per MM module

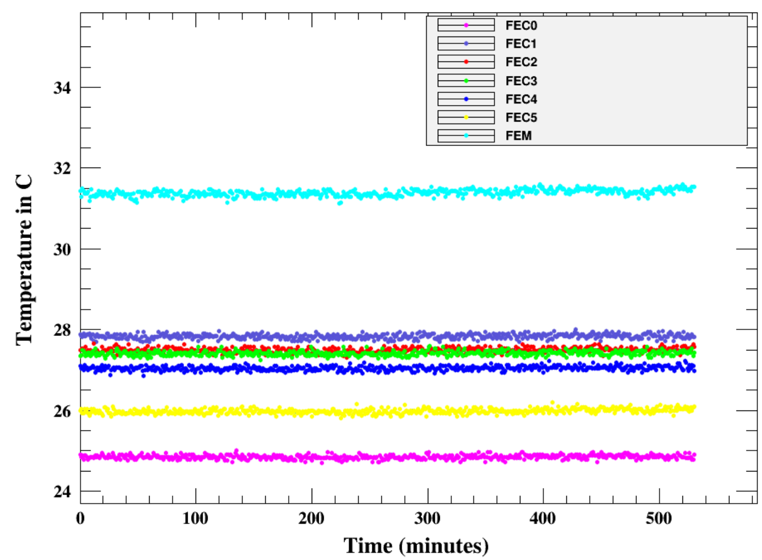
Module 6 (S3B)



- ☞ 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