Toward the technology choice for the TPC of the ILD detector

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TPC is the central tracker for International Large 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%

Project Evolution

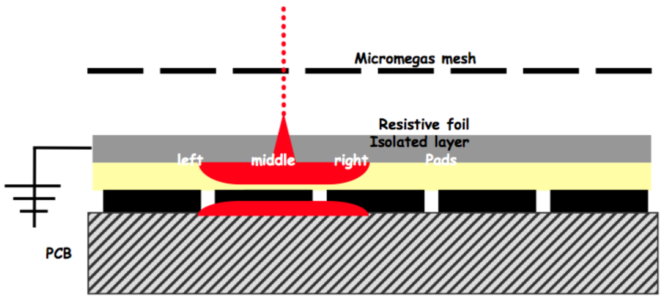
- The feasibility of a MPGD TPC for the LC was demonstrated
  - ILD detector baseline document was completed in March 2013
- **Main issues towards final design were pushed forward with Large Prototype (LP) of the TPC in the past five years**
  - first test beam experiment of the large -aperture GEM-like gating device
  - key issues of the engeneering design: CO_2 cooling, track distortions, etc
- **Now one has to resolve remaining issues towards technology choice for the ILD TPC**
  - single hit, momentum and dE/dx resolution with Large Prototype 2 (LP2)
  - optimization of the GEM-like gating device and measurement of ion-stopping power
  - 2-phase CO_2 cooling (micro-cooling circuit option)
  - mitigate and correct field distortions
  - new module design with common pad structure and power-pulsing electronics
  - simulation of the effect of the resistive anode layer for Micromegas
  - minimize the GEM discharge rate and gain uniformity

Prototype Technologies (Resistive Micromegas)

☞ Pad size limits transverse resolution

➠ use resistive anode to spread charge

➠ pad 3x7mm^2, small N_{ch}



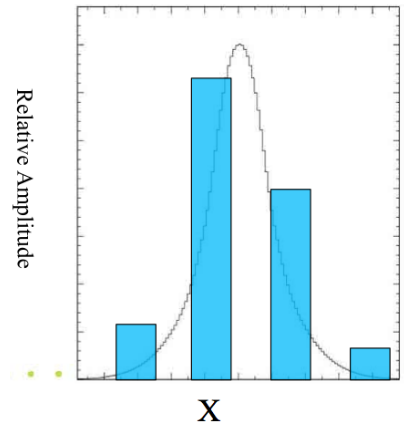
☞ **Charge density function** of time dependent charge dispersion on 2D continuous RC network:

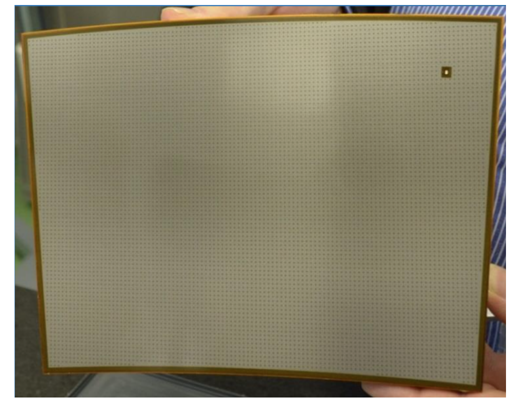
$$\rho(\mathbf{r},\mathbf{t}) = \frac{\mathbf{RC}}{\mathbf{2t}}\,\mathbf{exp}[-\frac{-\mathbf{r}^2\mathbf{RC}}{\mathbf{4t}}]$$

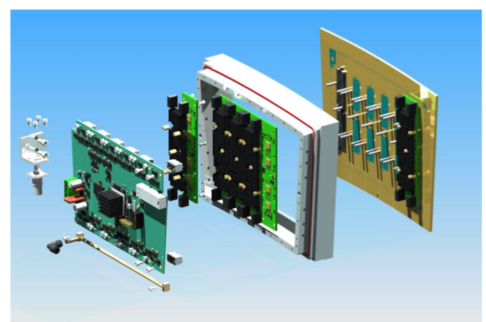
R- surface resistivity

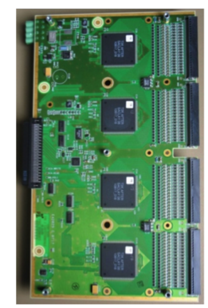
C- capacitance/unit area

Relative fraction of charge seen by pads fitted by Pad Response Function (PRF)







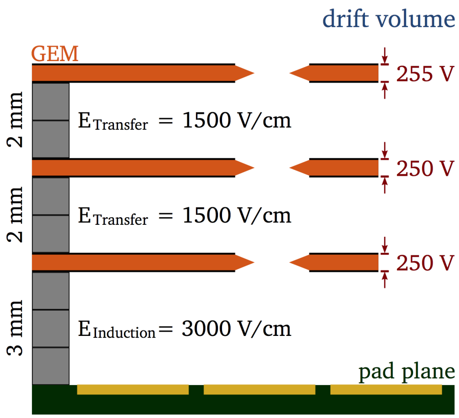


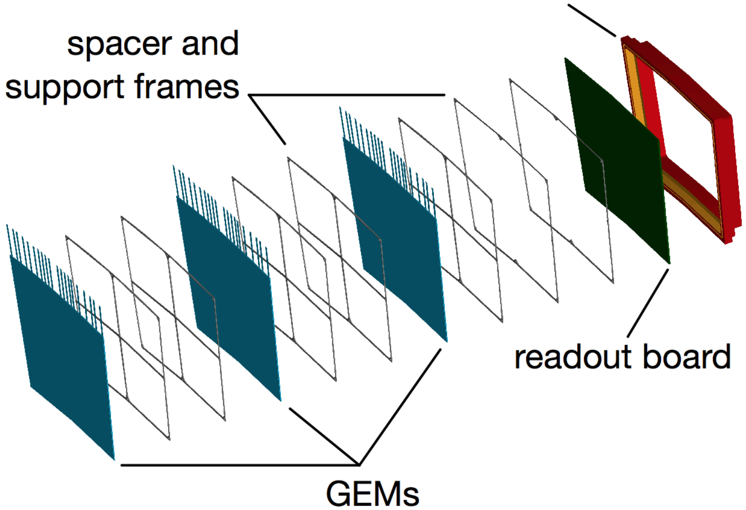
☞ **MM: T2K readout concept**

➠ 72-channel AFTER chip (12-bit)

Prototype Technologies (GEM)

Triple GEM Modules (European GEM)

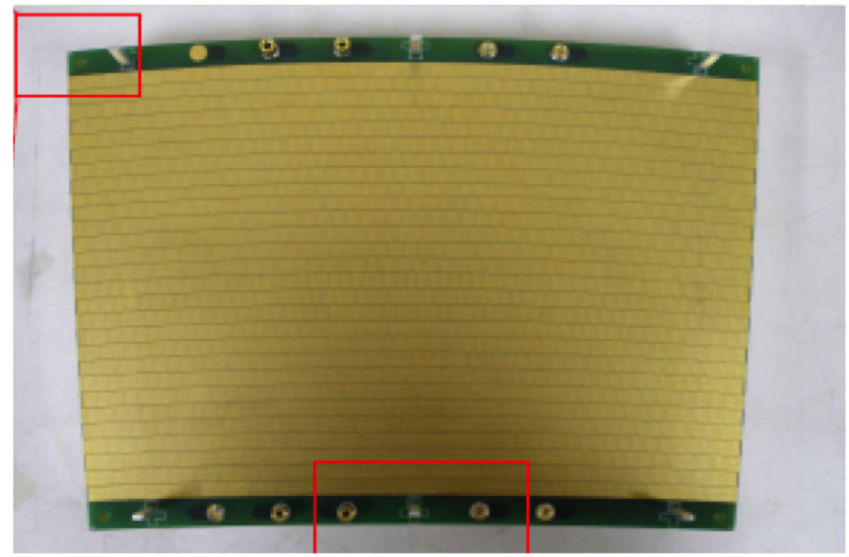


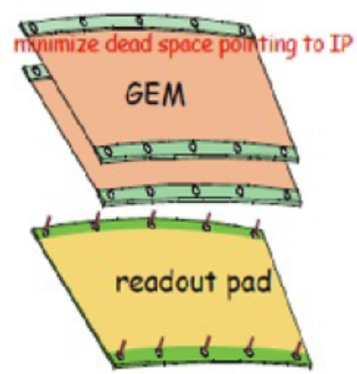


☞ **GEM: modified ALTRO readout**

➠ 16-channel ALTRO chip (10-bit)

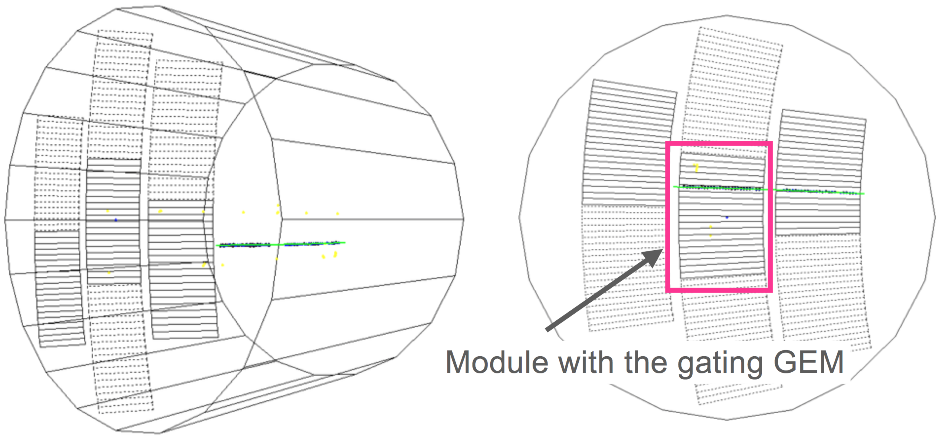
Double GEM Modules (Asian GEM)



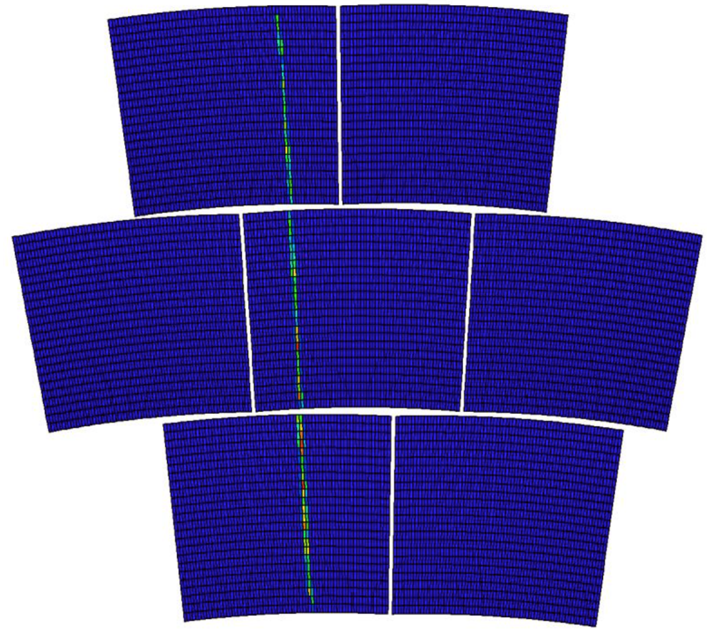


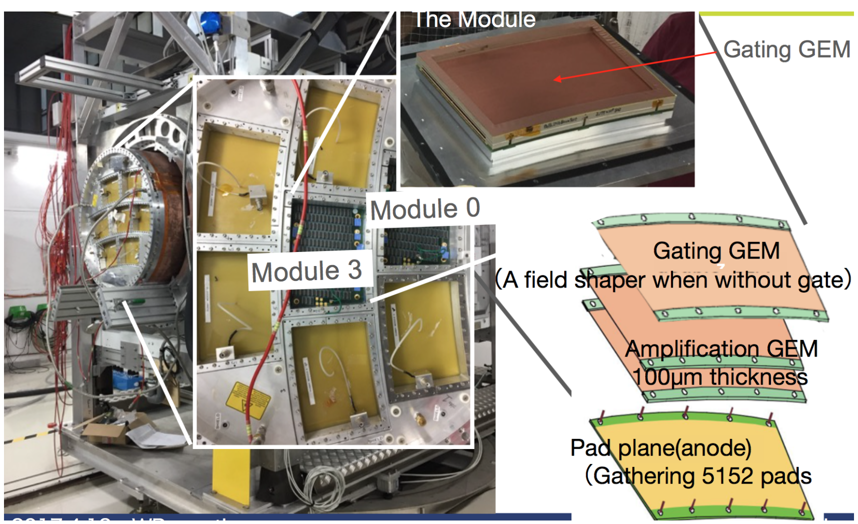
Discharge probability can be mastered (use of resistive coatings, several step amplification, segmentation)

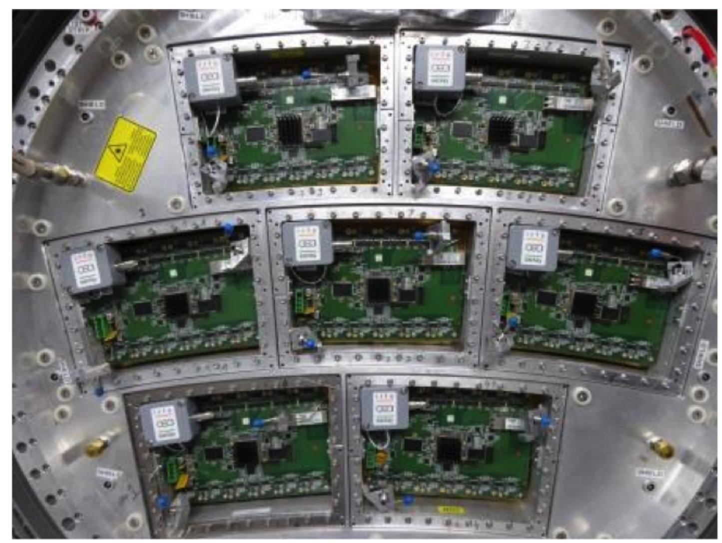
GEM (Japan)

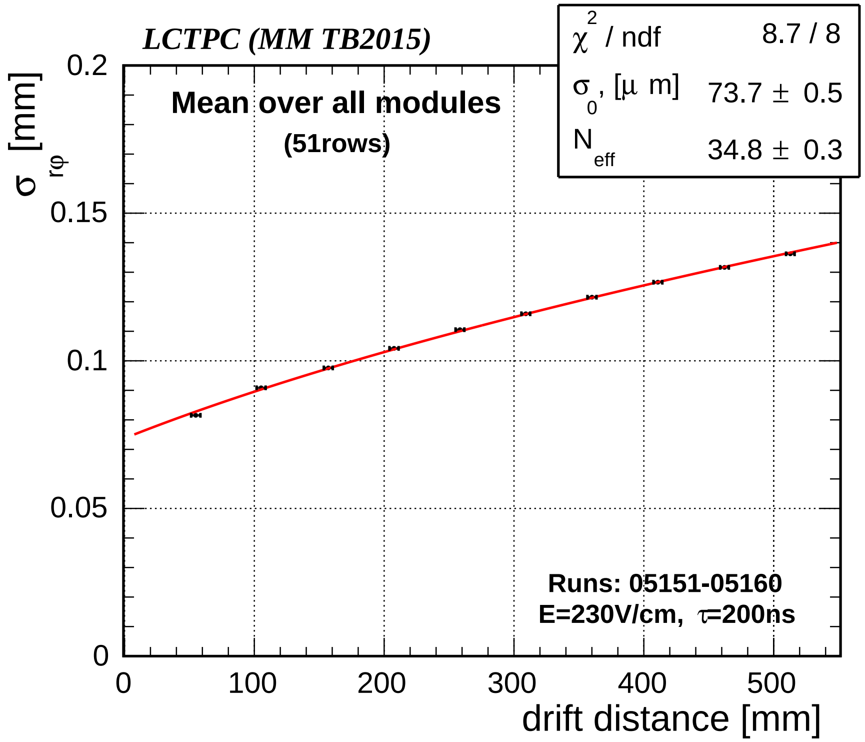


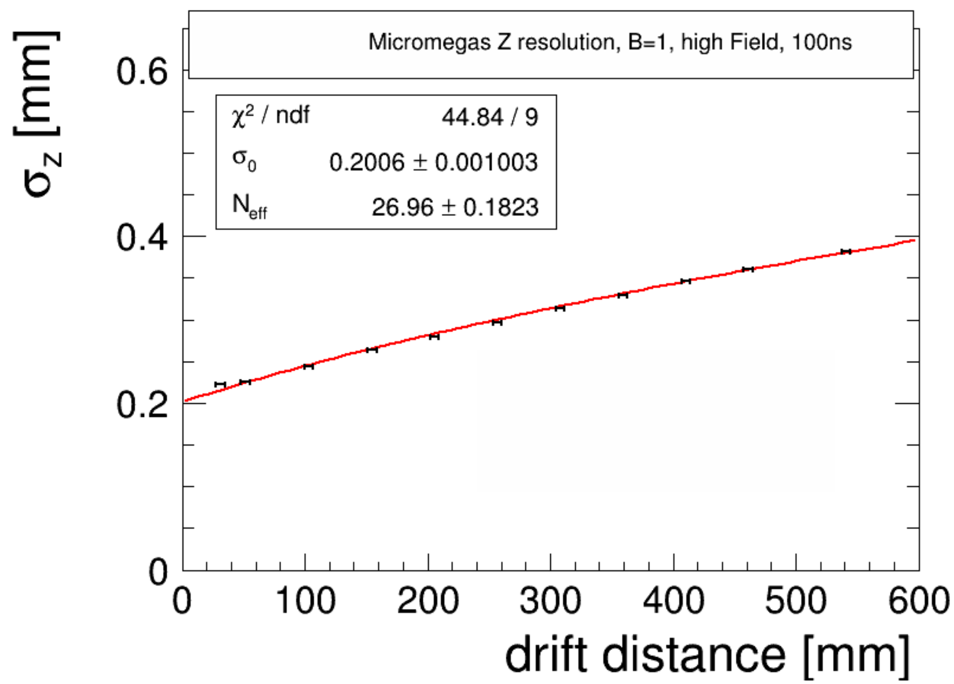
MicroMegas (France)





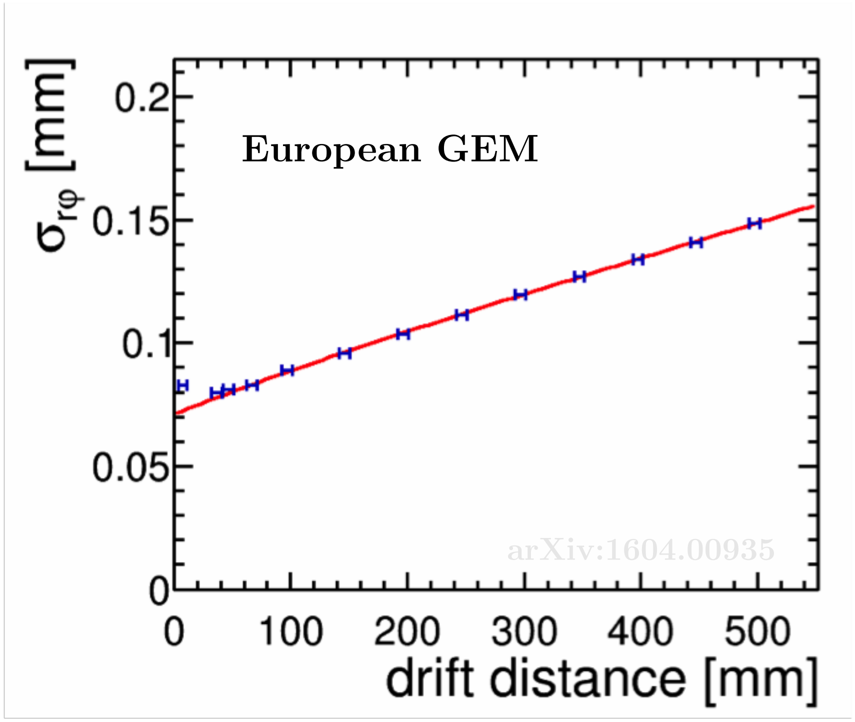


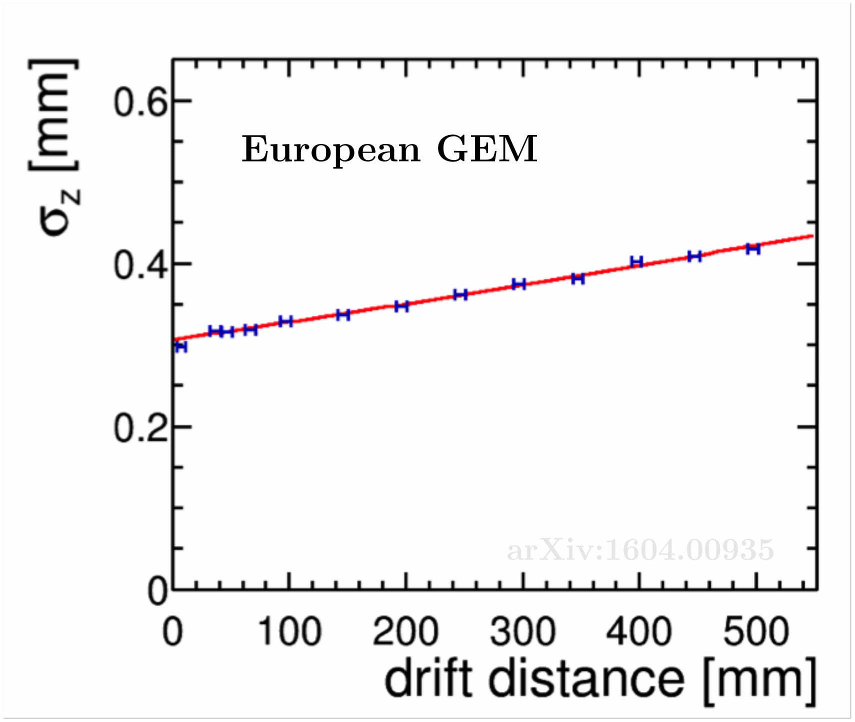


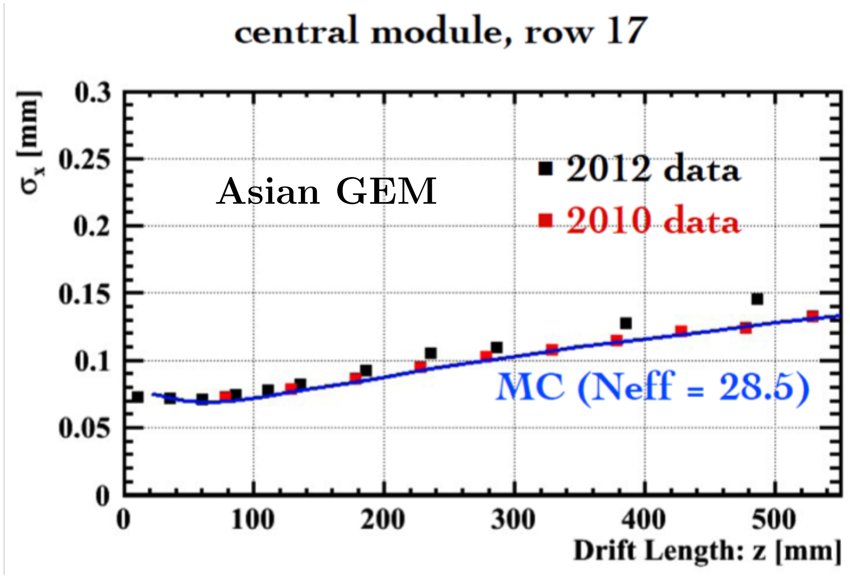


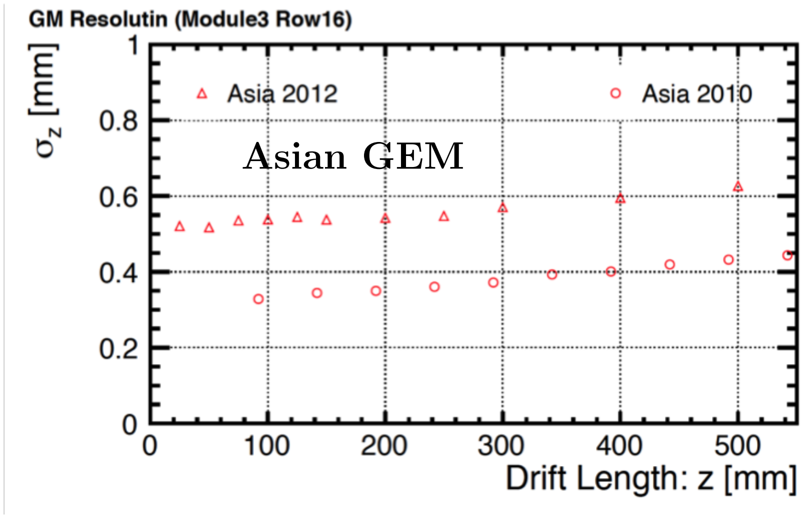
☞ **Endplate fully equipped (all MM modules populated)**

- optimized shaping time and mesh voltage
- resistive layer to spread charge
- two type of resistive layers: **Carbon-Loaded Kapton (CLK) and Black Diamond (BD)**
- full CO_2 cooling system in 2014-15 testbeam


European GEM
$\sigma_{r\varphi}$ [mm]
drift distance [mm]
arXiv:1604.00935


European GEM
σ_z [mm]
drift distance [mm]
arXiv:1604.00935

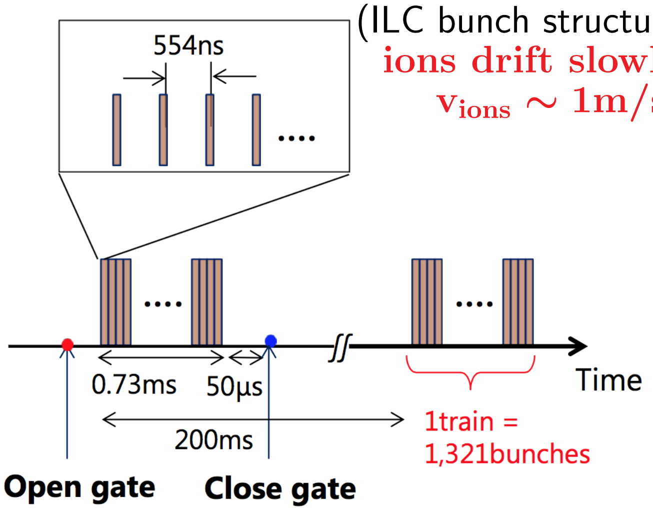

central module, row 17
Asian GEM
2012 data
2010 data
MC (Neff = 28.5)
σ_x [mm]
Drift Length: z [mm]

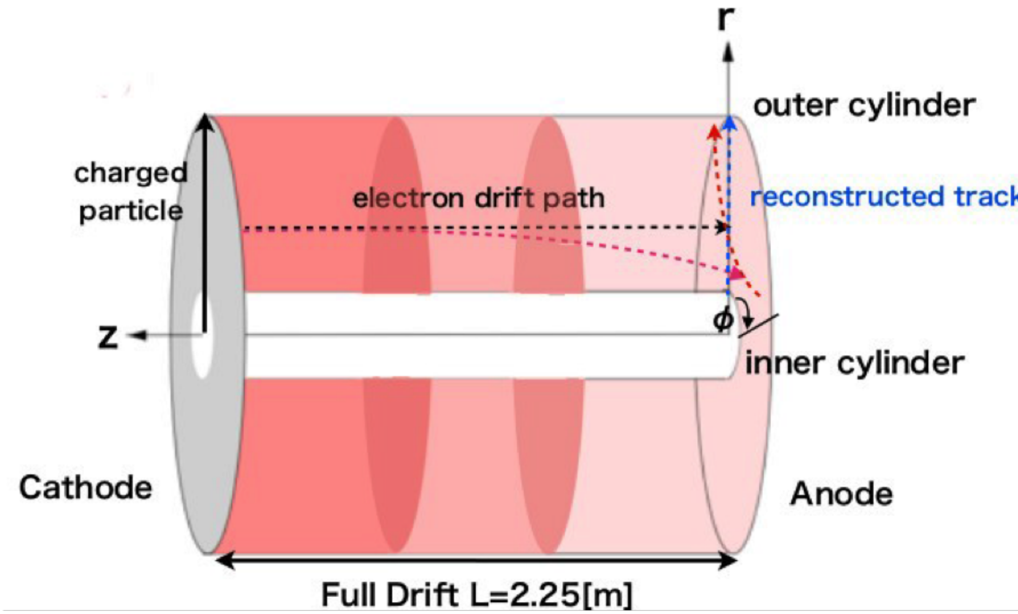

GM Resolutin (Module3 Row16)
Asia 2012
Asia 2010
Asian GEM
σ_z [mm]
Drift Length: z [mm]

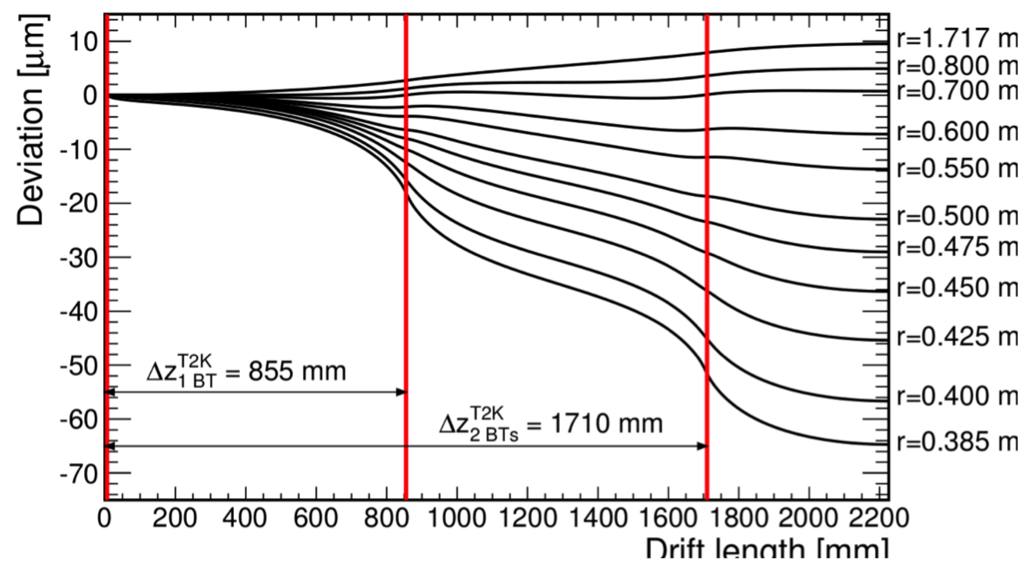
Ion Space Charge can deteriorate the position resolution of TPC

- ☞ **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=3** for the case of 2 ion disks

(ILC bunch structure)
ions drift slowly
$v_{ions} \sim 1$m/s



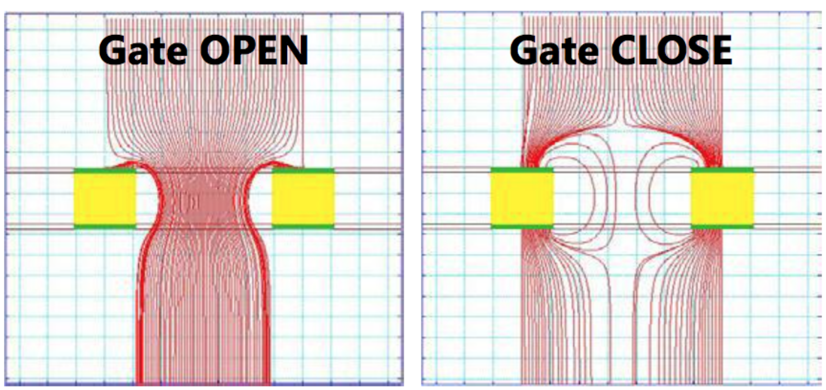




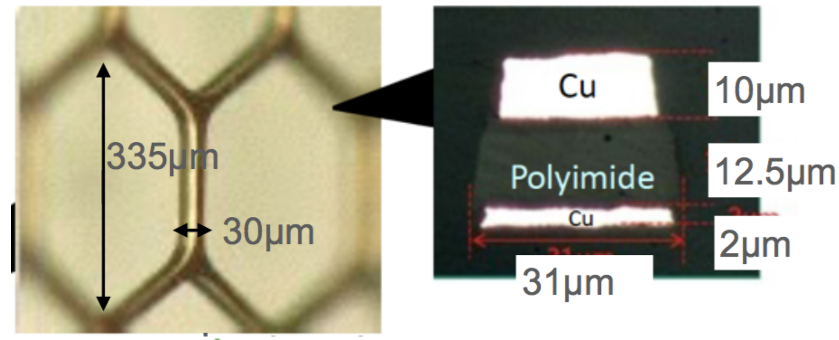
Gate is needed!

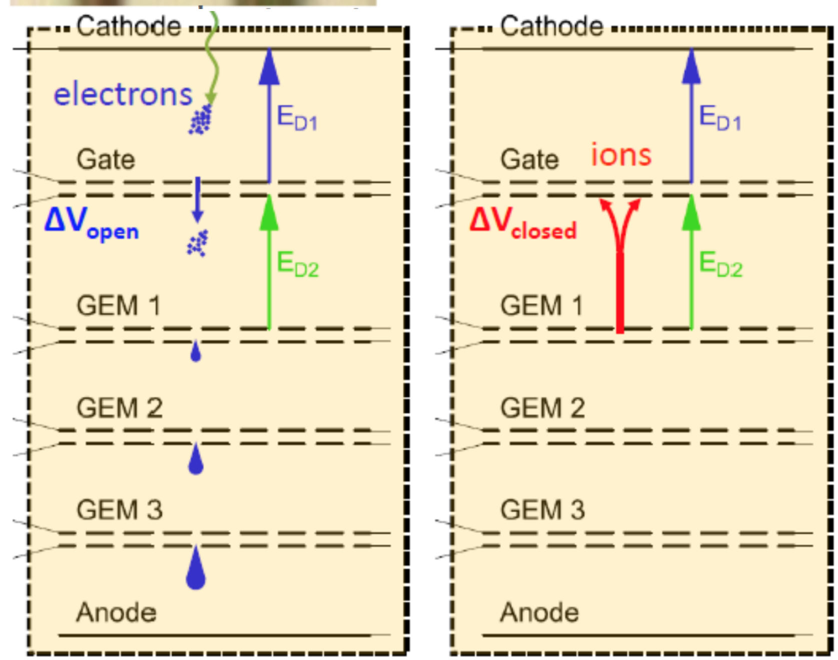
Gating: open GEM to stop ions while keeping transparency for electrons (see Y. Aoki talk)

- 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



- Simulating in hardware an **ion disk** with a UV lamp making photo-electric effect on the cathode



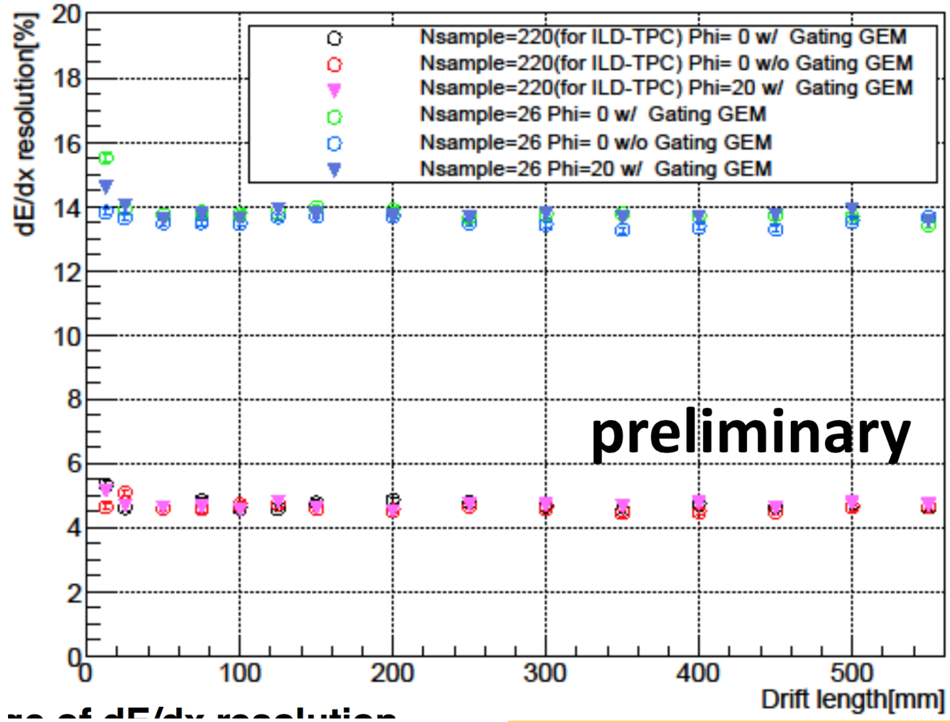


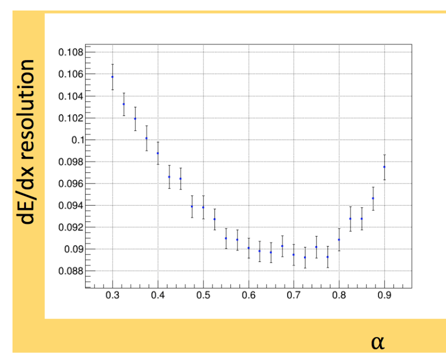
The ions must be stopped before penetrating too much the drift region

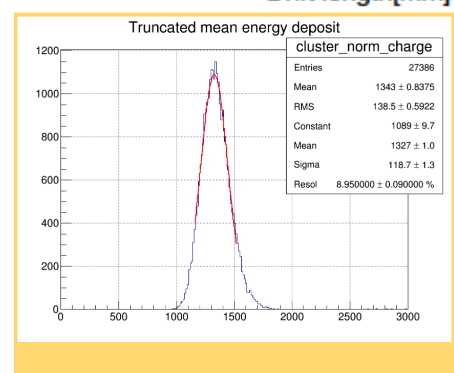
Measurement of ion-stopping power is needed!

Measuring dE/dx resulution with LP test beam data and extrapolating to ILD TPC

- Test arbitrary track lengths by randomly combining hits from several real tracks to a pseudo track in test beam setup
  - allows extrapolating dE/dx resolution to the ILD TPC tracks of 130 cm
- Estimated dE/dx resolution with **70% truncated mean** for ILD TPC
  - GEM: $\sigma_{\mathrm{dE/dx}} = 4.7\%$ for 220 hits
    - → no degradation due to gating GEM
    - → good agreement with simulation
  - MM: $\sigma_{\mathrm{dE/dx}} = 5.0\%$ for 200 hits
    - → no significant degradation due to resistive foil







(see A. Shoji, P. Colas talks)

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

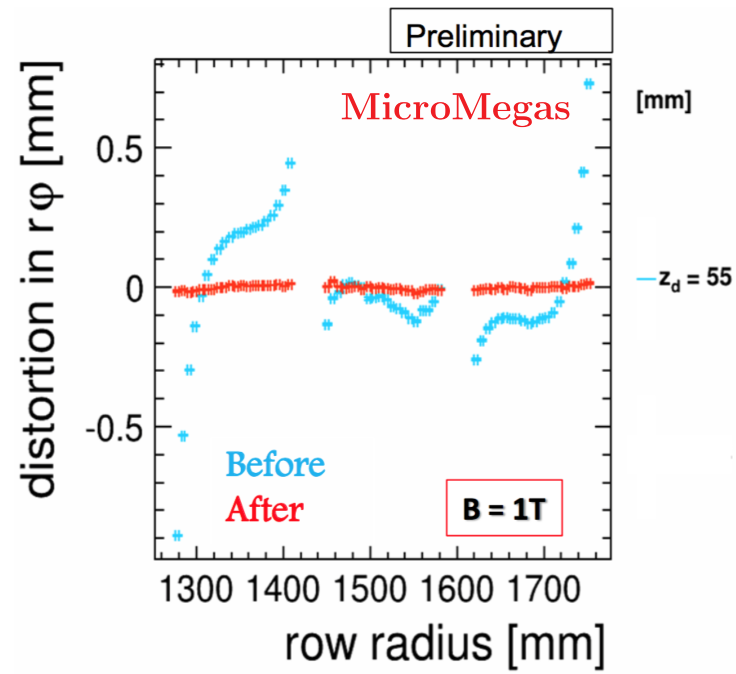
☞ **Module frames at ground while the top GEM or Micromesh is at HV**

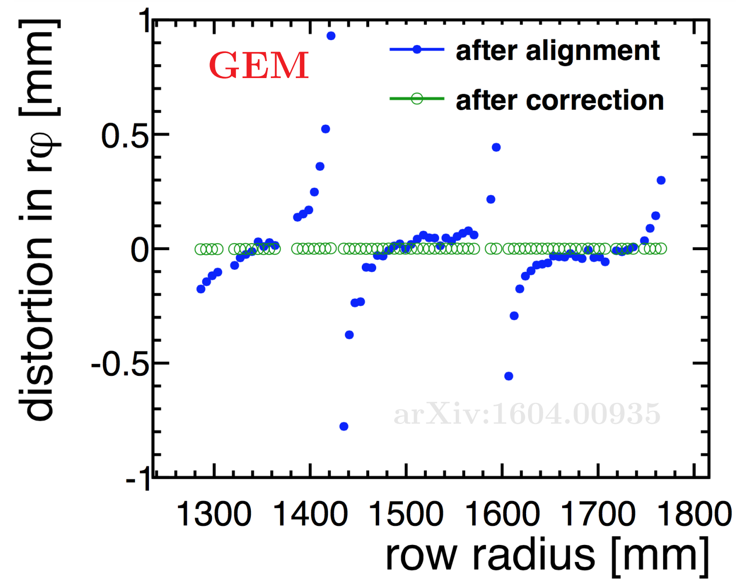
- induces distortions of **about 0.5 mm**
  - ➔ worth to minimize at design level
  - ➔ new design should suppress this effect
- accounted as systematic residual offsets
- determined on a row-by-row basis
- correct residuals to zero at **about 20μm**

☞ Good agreement with simulations

- E and B field inhomogeneity at module boundaries and near the edges of the magnet

Possible countermeasures: 4 MM modules with new grounding approach will be tested at LP2 this november at DESY



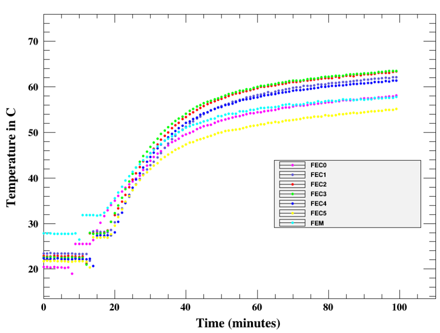


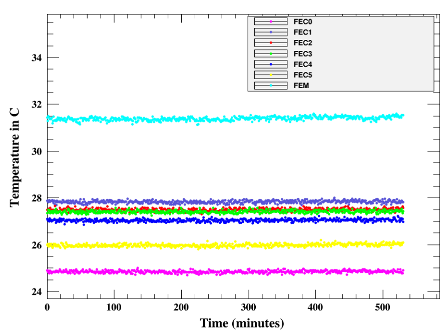
2-Phase CO_2 Cooling

Cooling of the electronic circuit is required due to power consumption

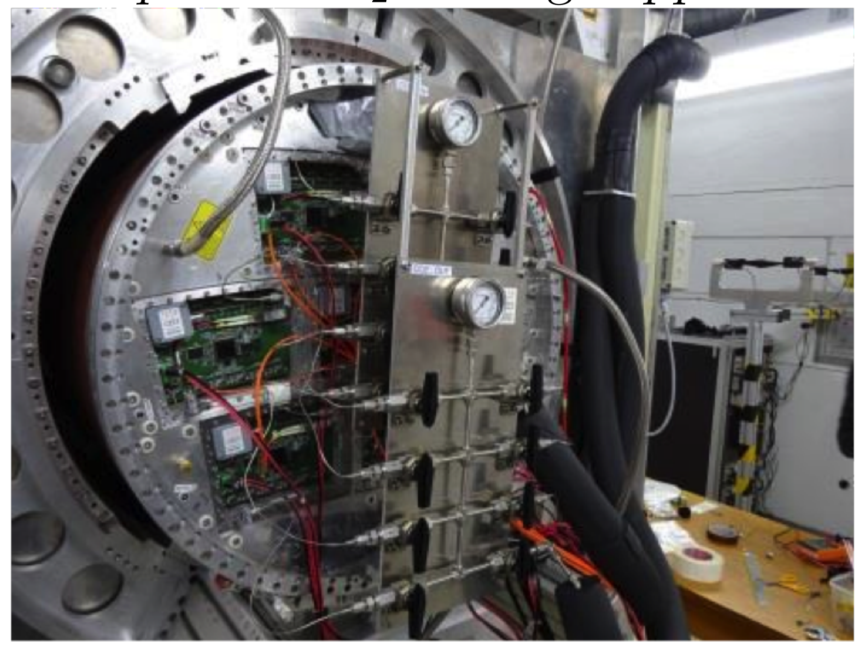
- Temperature of the circuit rises up to 60°C
  - ➠ cause a potential damage of electronics
  - ➠ covect gas to TPC due to a pad heating
- A 2-Phase CO_2 cooling with the KEK **cooling plant TRACI** was provided to 7 MM modules during 2014/15 beam tests at DESY
  - ➠ **10°C at P=45 bar** system operation

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





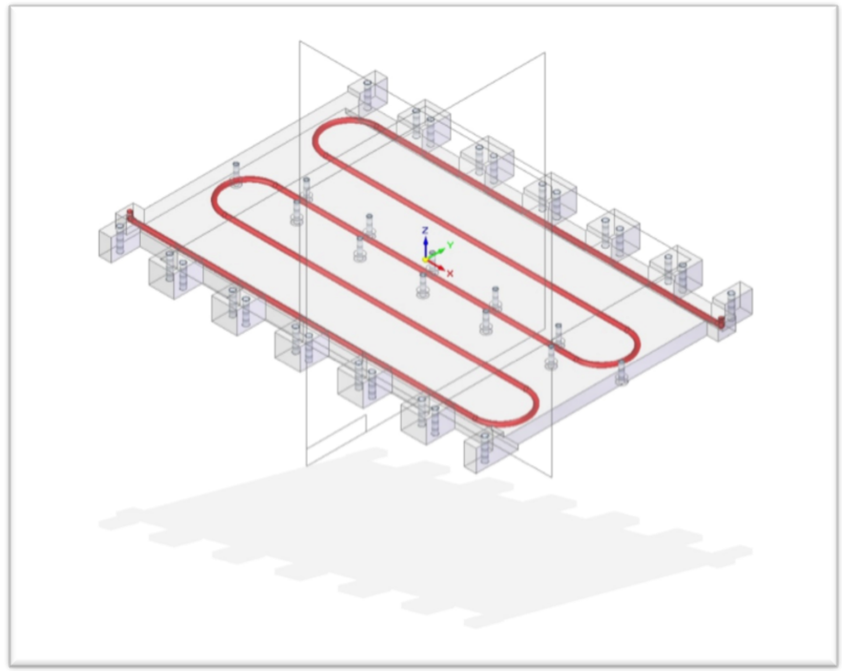
2-phase CO_2 cooling support



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

- **ILD TPC Requirements**
  - **about 1kW heat transfer** (half cilinder)
    → power pulsing at room T
  - $\Delta T \simeq 1°C$ over the gas volume
    → uniform pad plane temperature
  - **less material** comparing to existing experiments

Development of micro-channel cooling plate in PCB piping with 3D printing technology



- **Saclay project "COSTARD"**
  - cooling plate by metallic additive fabrication by laser using sintered powder of Al with a 0.8 mm inner-diameter serpentine
    → test possibility to remove the powder residuals from the serpentine
    → test pressure up to 100 bar
    → develop connection to pipes

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

- **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

- Main issues toward final design were significantly pushed forward with Large Prototype (LP) of the TPC for both technologies
- **Current efforts could be engaged on the possible consequences of the expected "expression of interest" of the Japanese governement this year, as an input to the European Strategy Update**
- **The R&D work within the LCTPC collaboration is in a phase of engineering toward the technology choice of a TPC for the ILD detector**
  - further beam tests will be carried our with **the LP2 upgraded** with new end-plate and equipped with additional large area strip telescope
  - it allowed us to identify points requiring common active R&D to be pursued
    - ➔ single hit, momentum, dE/dx resolutions with LP2
    - ➔ GEM-like gating device and ion-stopping power
    - ➔ 2-phase CO_2 micro-cooling circuit
    - ➔ engineering aspects, electronics and simulation
- **Special thanks to P. Colas, K. Fujii A. Sugiyama**

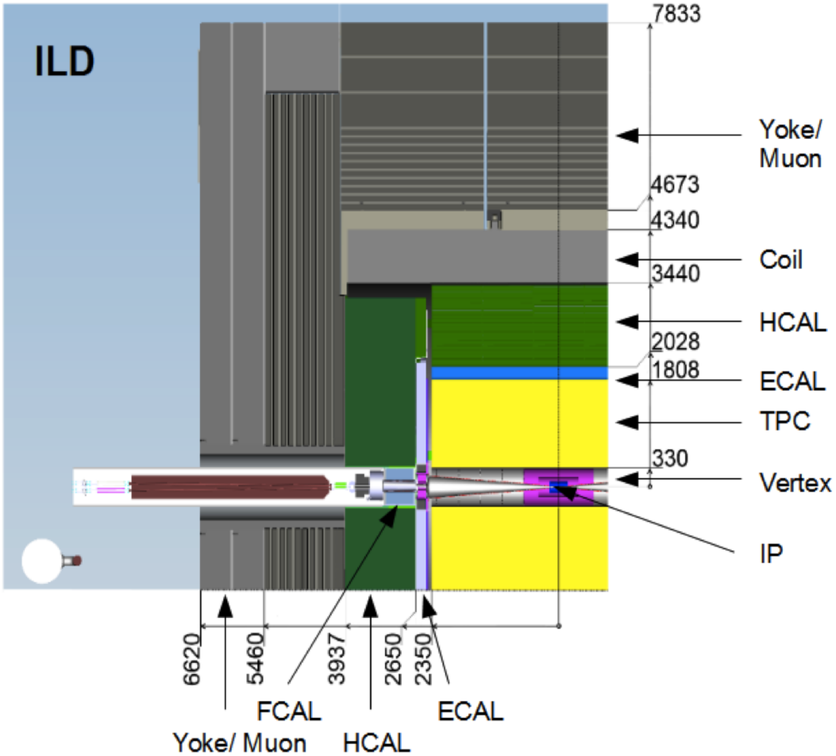
Backup

International Linear Collider (ILC) project in Japan:

- starts at 250 GeV as a Higgs factory
- upgradeable to 1 TeV
- ILC is planned with two experiments
- TPC is the central tracker for International Large Detector (ILD)

ILD components:

- vertex detector
- few layers of silicon tracker
- **gaseous TPC**
- ECAL/HCAL/FCAL
- superconducting coil (3.5 or 4 T)
- muon chambers in iron yoke



ILD requirements:

- momentum resolution: $\boldsymbol{\delta(1/p_T) \leq 2 \times 10^{-5} GeV^{-1}}$
- impact parameters: $\sigma(r\phi) \leq 5\mu m$
- jet energy resolution: $\sigma_E/E \sim 3-4\%$

☞ Technology choise for TPC readout: **Micro Pattern Gas Detector (MPGD)**

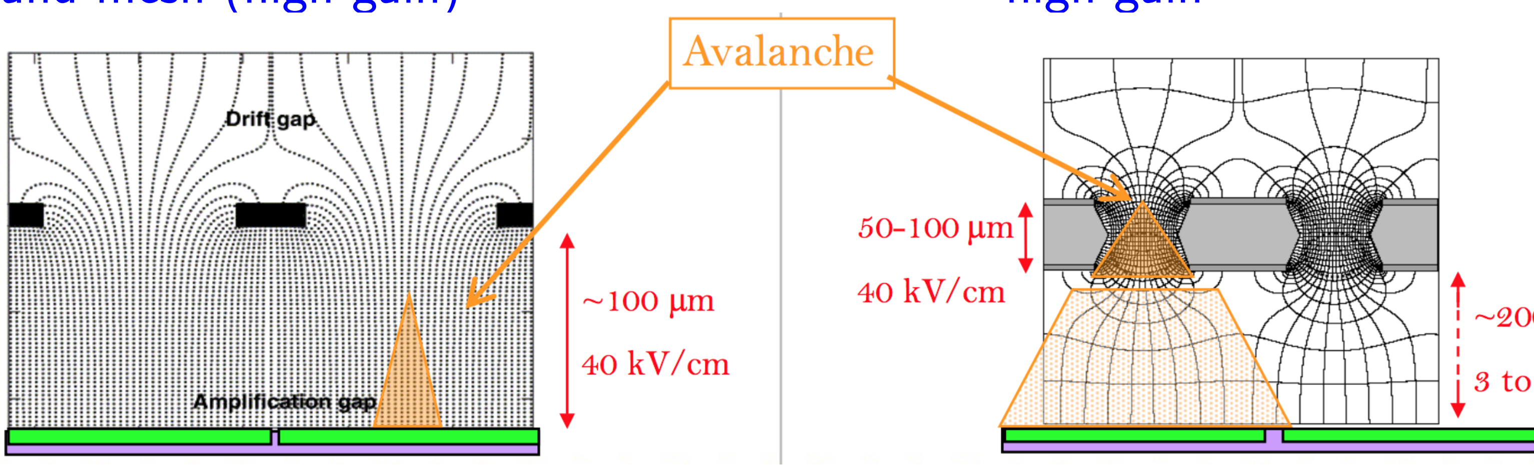
- **no ExB effect, better ageing, low ionback drift**
- easy to manufacture, MPGD more robust mechanically than wires

☞ **Resistive Micromegas (MM)**

- MICROMEsh GAseous Structure
- metalic micromesh (pitch ∼50 μm)
- supported by 50 μm pillars
- multiplication between anode and mesh (high gain)

☞ **GEM**

- Gas Electron Multiplier
- doublesided copper clad Kapton
- multiplication takes place in holes,
- 2-3 layers are needed to obtain high gain

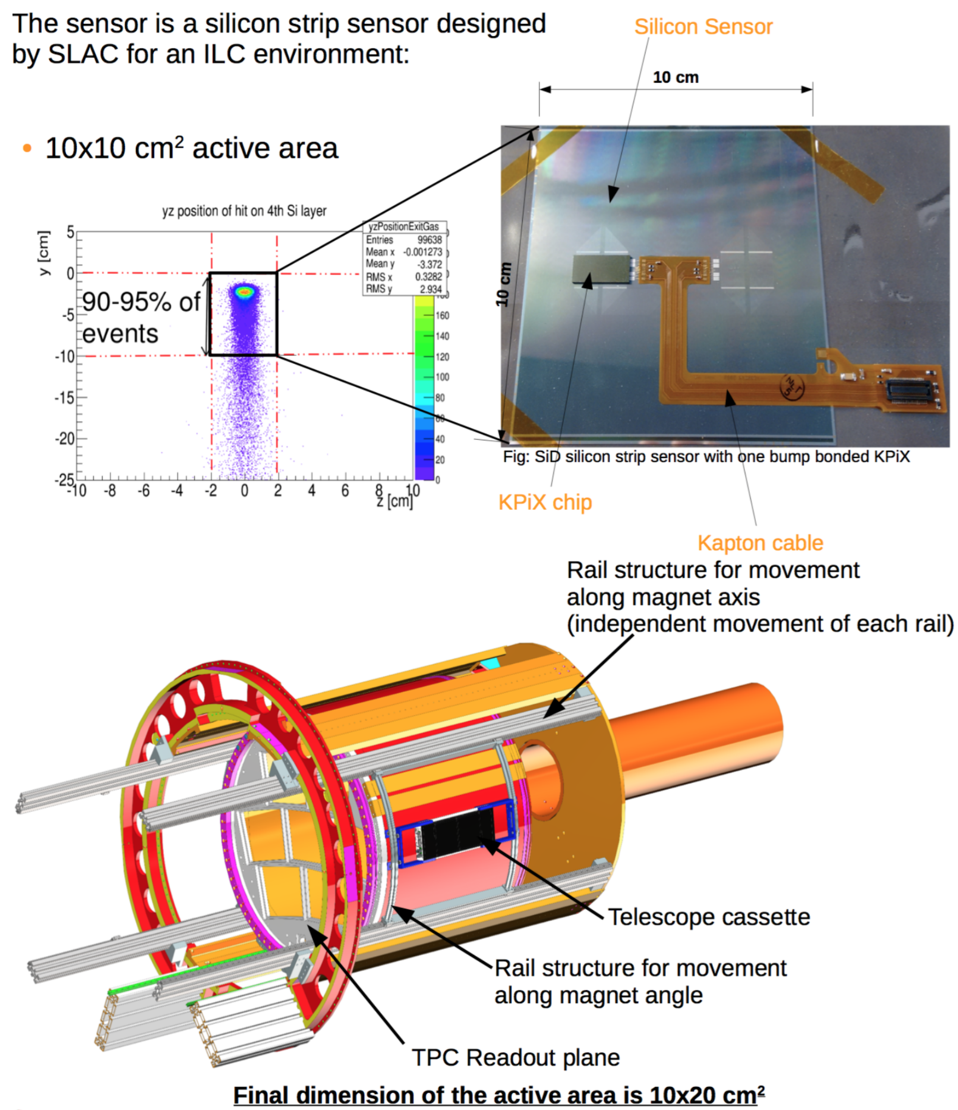


Discharge probability can be mastered (use of resistive coatings, several step amplification, segmentation)

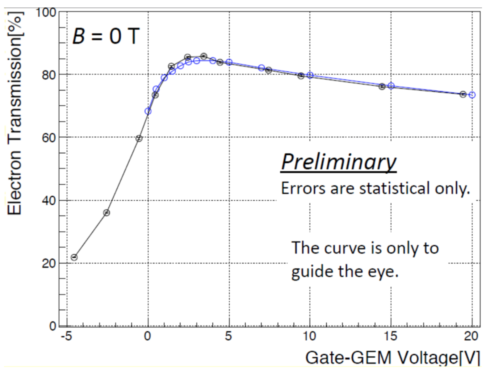
☞ **Further studies toward the technology choice will be carried out with upgraded LP2**

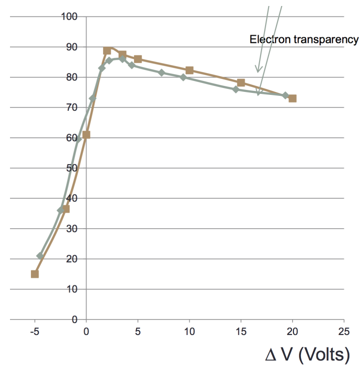
- new mechanical design of **endplate:** no space between modules
- new large area strip telescope within solenoid with **Si sensor:** (LYCORIS, see M. Wu talk)
  - → $10\text{x}10\ \text{cm}^2$ active area
  - → $320\ \mu\text{m}$ thickness
  - → $0.3\%\text{X}_0$ material budget
  - → $25\ \mu\text{m}$ strip pitch to meet momentum resolution
  - → integrated pitch adapter and digital readout (KPiX)

System is under final review before send off to production and funded by EU AIDA2020



Electron transmission rate as a function of GEM voltage measured with Fe^{55}

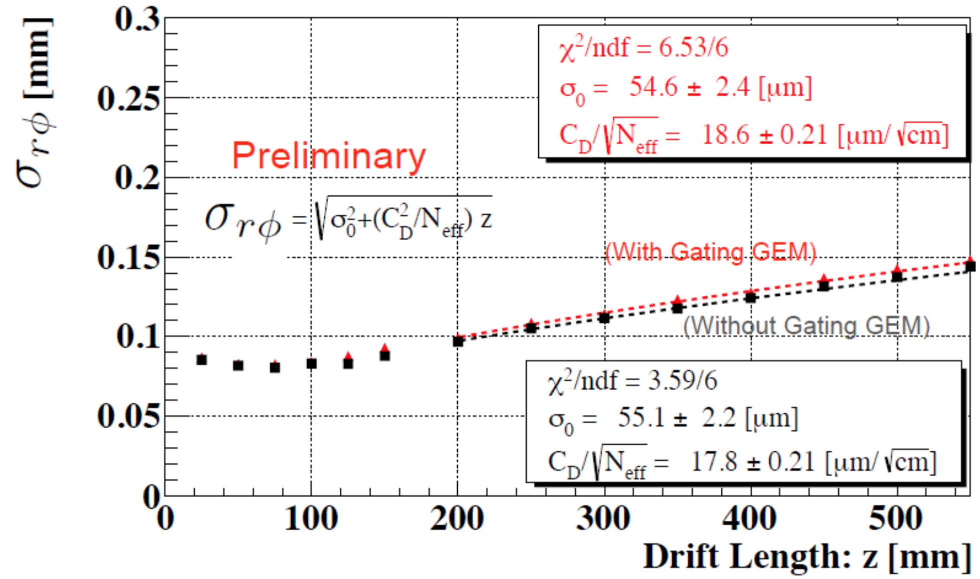




- ☞ Measurements with GEM (at KEK) and MM (at CERN) are consistent
- ☞ Extrapolation to 3.5 T shows acceptable transmission for electrons (80%)
- ☞ Estimate ion-stopping power based on electron-stopping power measured with a laser beam ⇒ better than 10^{-4}

Measurement of ion-stopping power is needed!

A module with a gating GEM has also been tested in beam in November 2016



The results are consistent with no more degradation than expected (10%)

GEM gating seems to be a possible solution for the gating at ILC

2-Phase CO_2 Cooling

About 26 W power consumption is currently measured per MM module

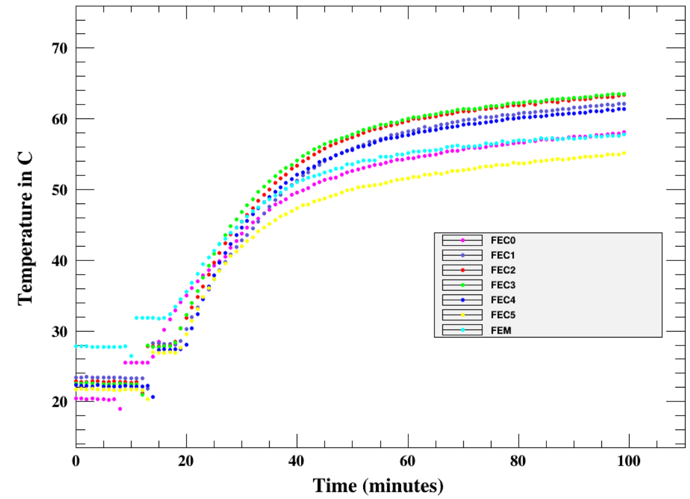
- Temperature of the circuit rises up to 60°C
  - cause a potential damage of electronics
  - covect gas to TPC due to a pad heating

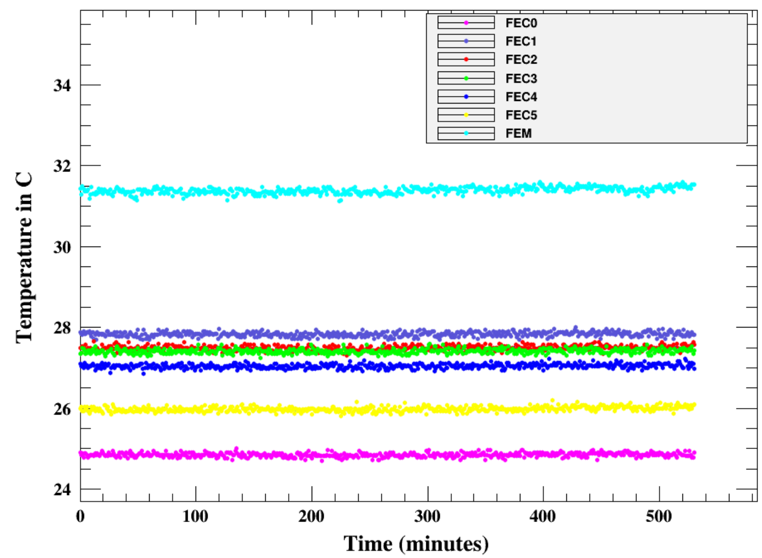
Cooling of the electronic circuit is required!

- **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

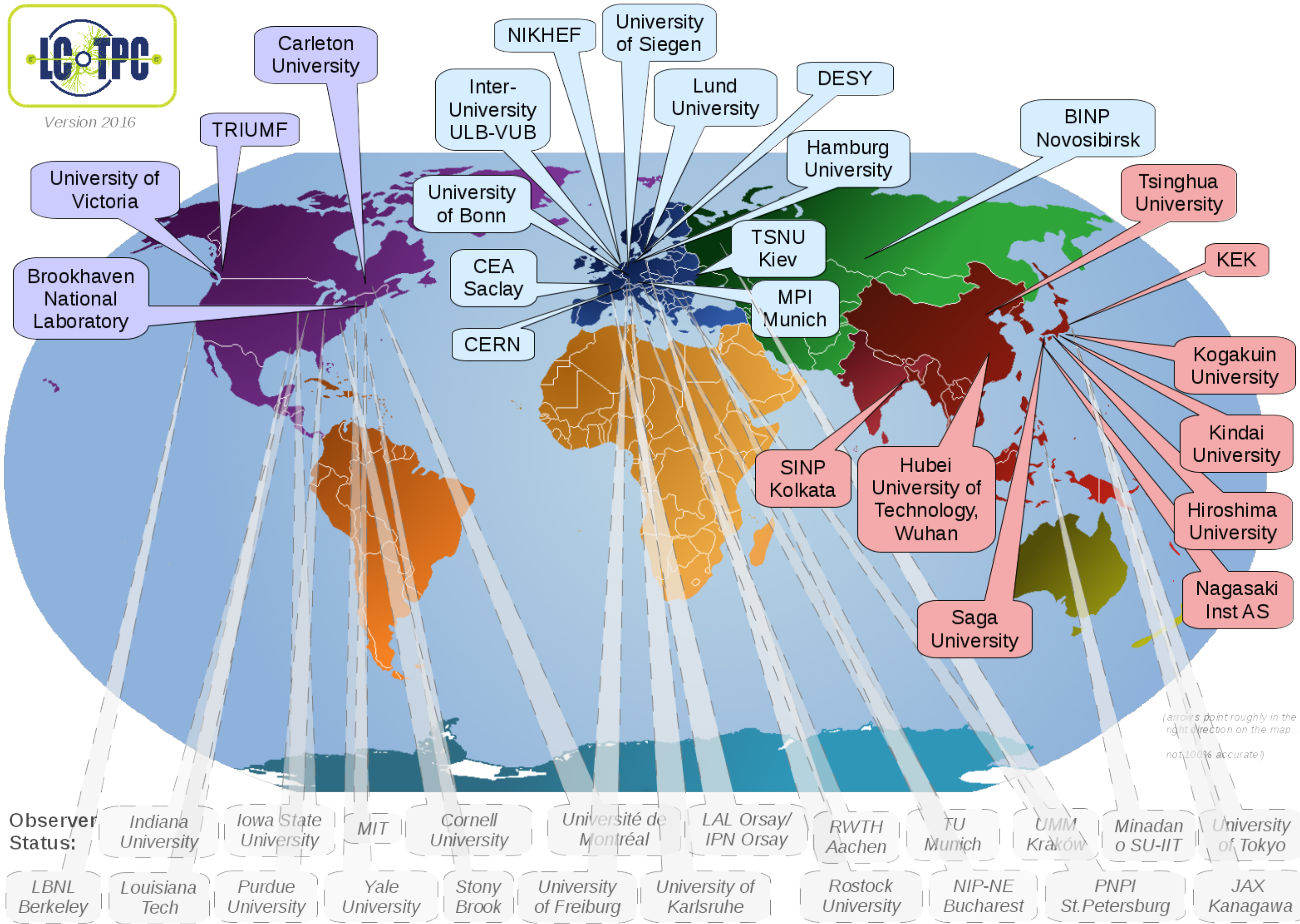
Module 6 (S3B)





LCTPC Collaboration

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



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