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

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TYL-FJPPL Workshop
Institut Pluridisciplinaire Hubert CURIEN (IPHC), Strasbourg
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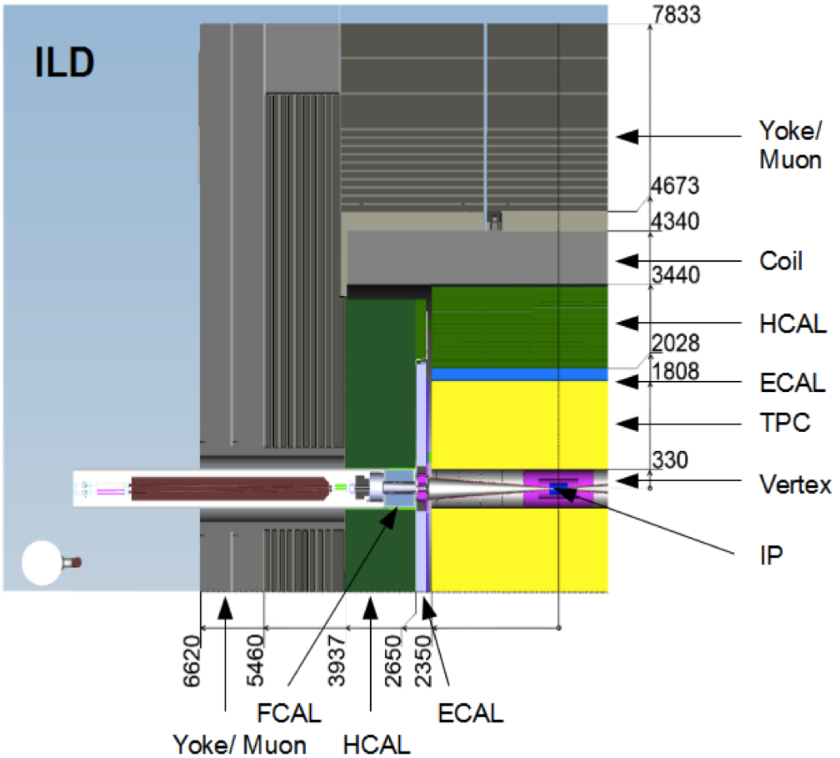
☞ International Linear Collider (ILC) project in Japan:

- energy range (baseline design): staged project starting at 250 GeV (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: $\sigma_E/E \sim 3-4\%$

- **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**
  - **Bordeaux 2014:** software, analysis of beam test data
  - **Okinawa 2015:** steps toward an engeneering design
  - **Seoul 2016:** running in final phase
- **We demand 1 year prolongation of the project**
  - need to finalize remaining issues
    - ➔ **ion backflow and gating**
    - ➔ cooling (micro-cooling circuit option)
    - ➔ mitigate and correct field distortions
  - lack of funding and manpower
  - decision about ILC will be taken in about 1 year

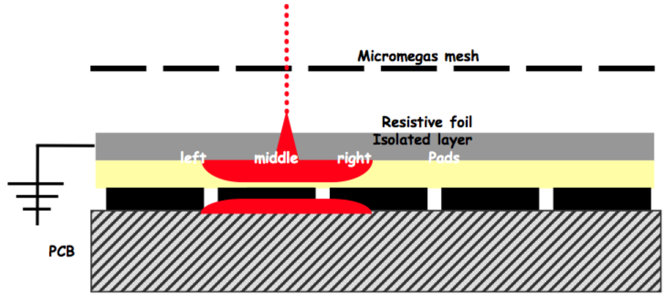
TPC is the central tracker for International Linear Detector (ILD)

- Large number of 3D points
  - **continuous tracking**
- Particle identification
  - **dE/dx measurement**
- Low material budget inside the calorimeters (PFA)
  - barrel: $\sim 5\%X_0$
  - endplates: $\sim 25\%X_0$
- **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:**
  - → $\delta(1/p_T) \leq 9 \times 10^{-5} GeV^{-1}$
- **Single hit resolution:**
  - → $\sigma(r\phi) \leq 100\mu m$ (overall)
  - → $\sigma(Z) \simeq 400\mu m$
- **Tracking efficiency:**
  - → 97% for $p_T \geq 1GeV$
- **dE/dx resolution:** 5%

Prototype Technologies

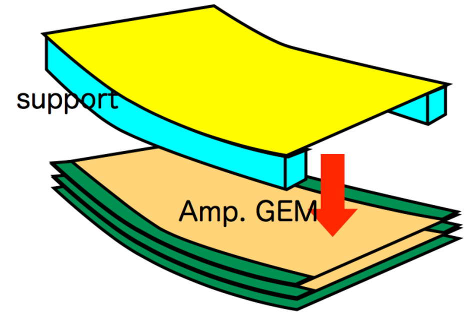


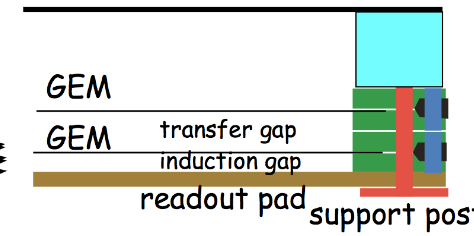
☞ **Charge density function**

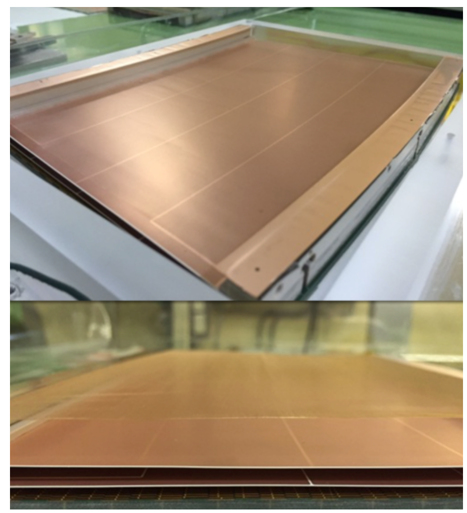
$$\rho(r,t) = \frac{RC}{2t}\exp[-\frac{-r^2 RC}{4t}]$$

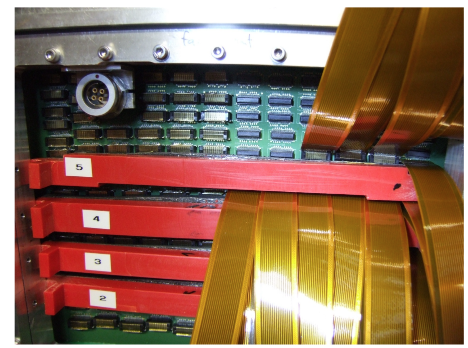
R- surface resistivity

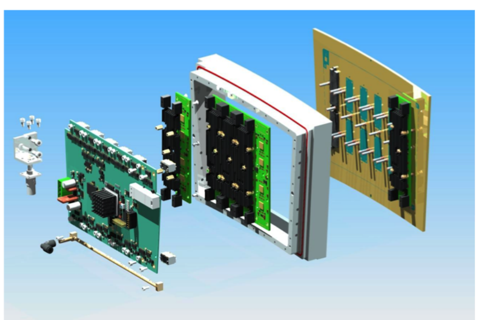
C- capacitance/unit area











☞ **MM: T2K readout concept**

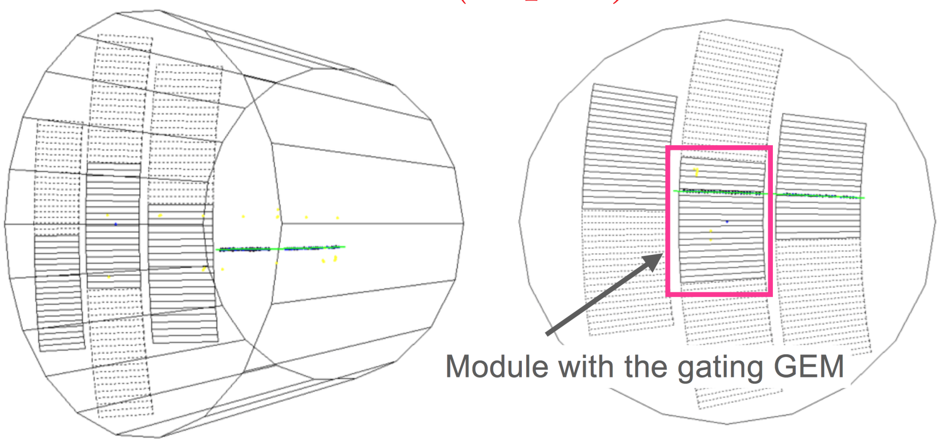
➠ 72-channel AFTER chip (12-bit)

☞ **GEM: modified ALTRO readout**

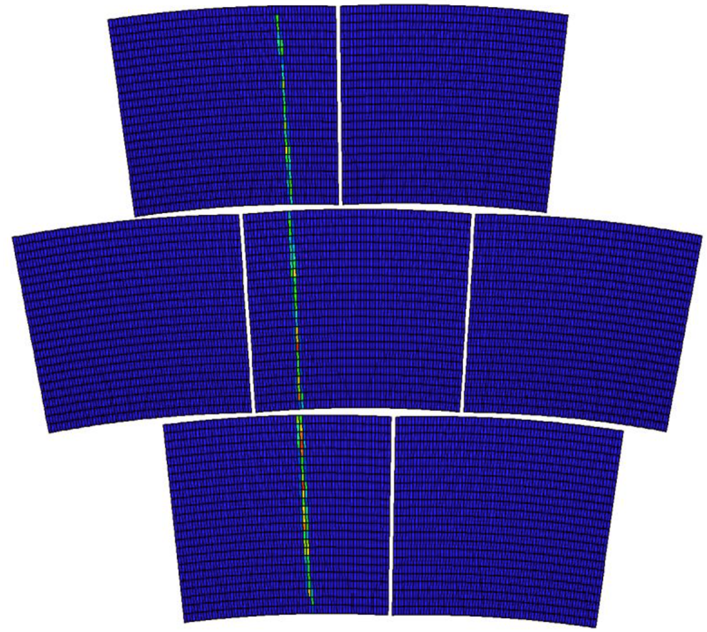
➠ 16-channel ALTRO chip (10-bit)

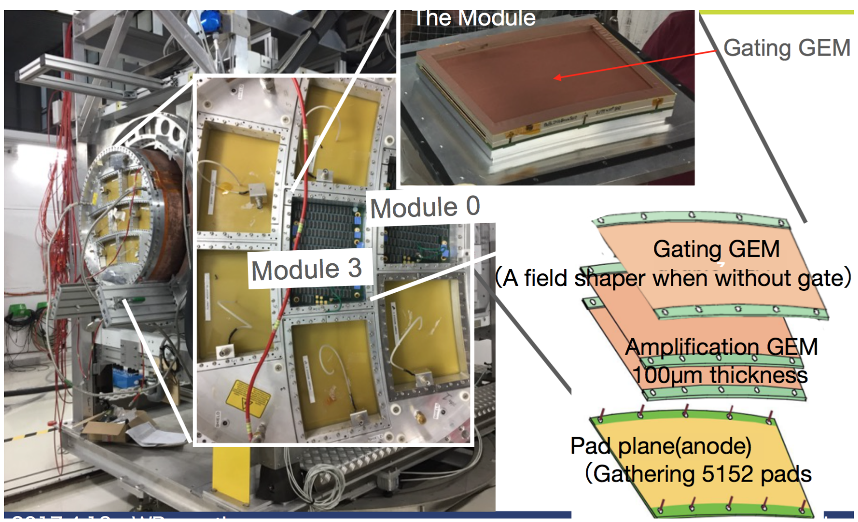
TPC Large Prototype at DESY

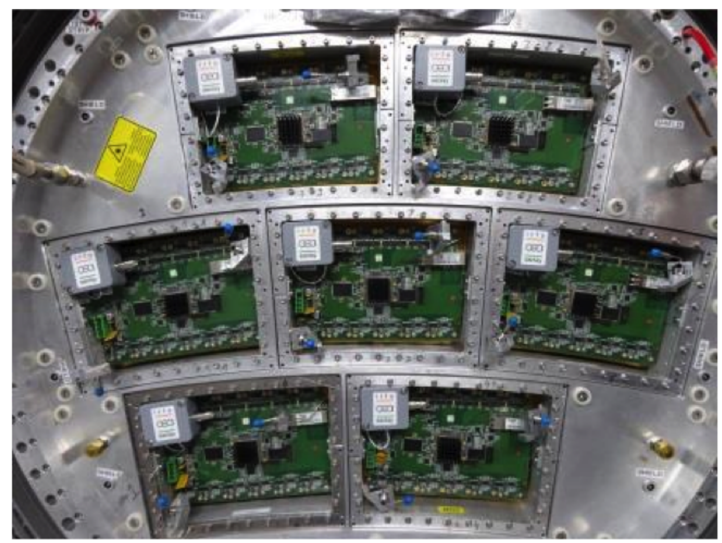
GEM (Japan)



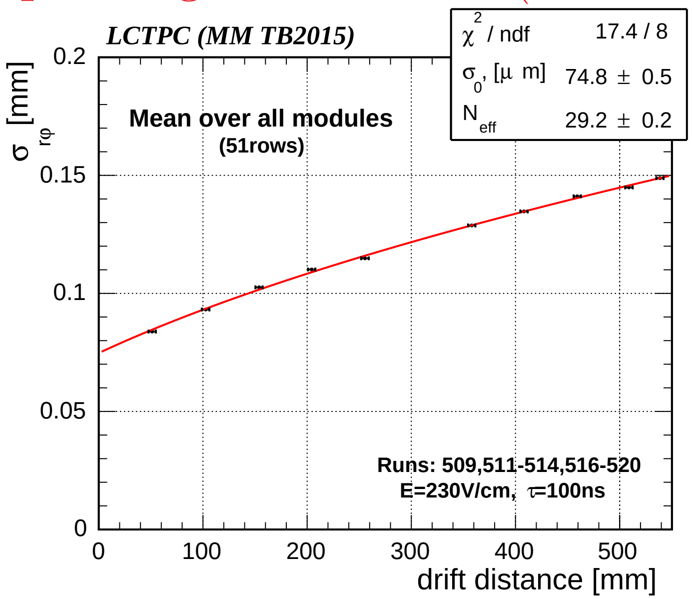
MicroMegas (France)



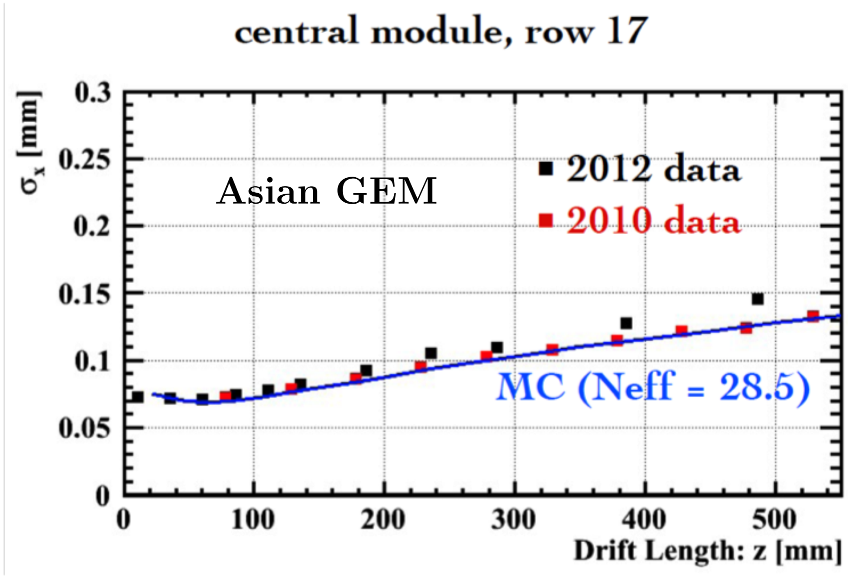


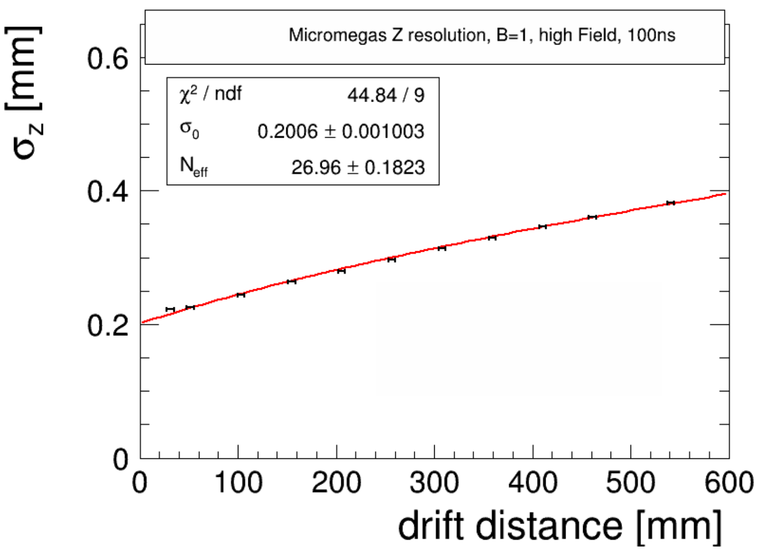


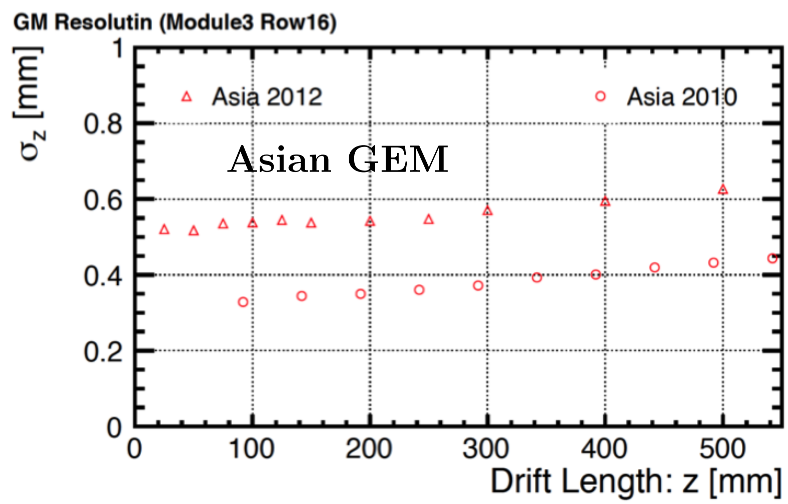
MM peaking time 100 ns (AFTER)



GEM peaking time 120 ns (ALTRO)

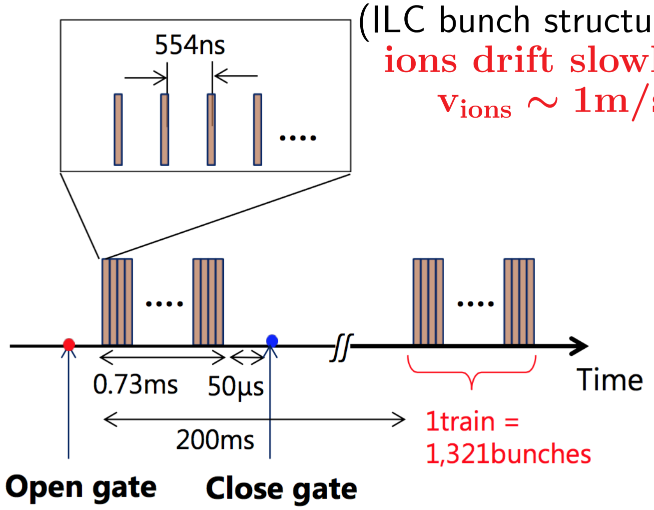






Ion Space Charge can deteriorate the position resolution of TPC

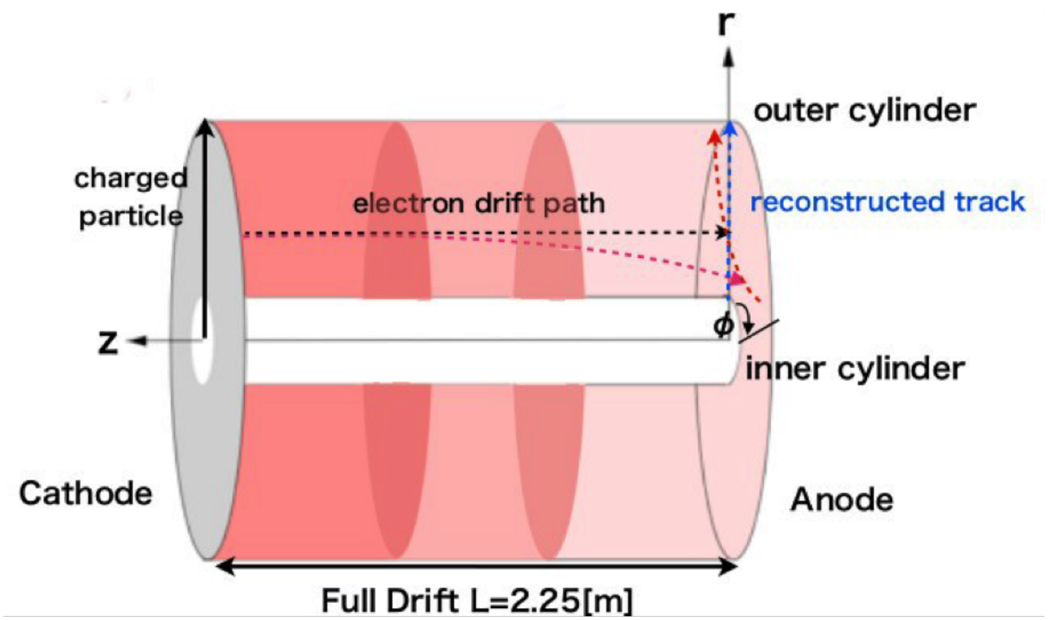
- **Primary ions** yield distortions in the E-field which result to O($\leq 1\mu$m) track distortions
- **Secondary ions** yield distortions from backflowing ions generated in the gas-amplification region:
  - 60 μm for **IBFxGain=1** for the case of 2 ion disks

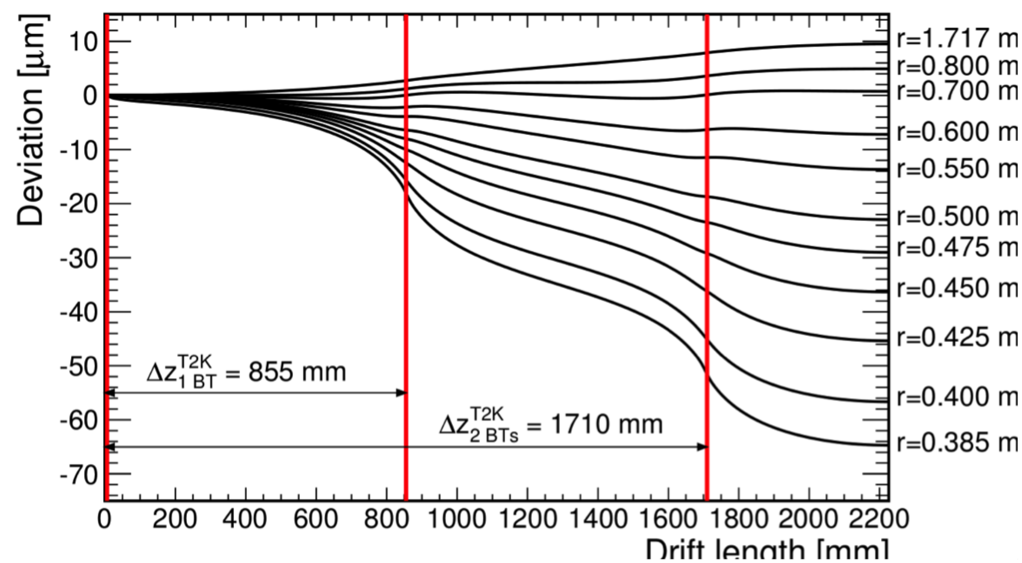


(ILC bunch structure)

ions drift slowly

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

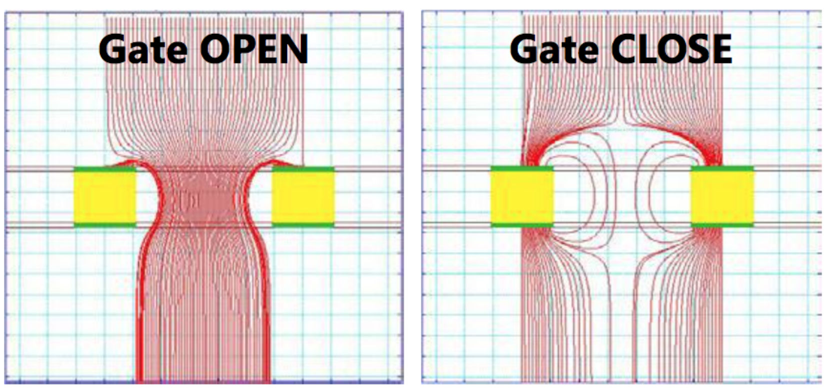




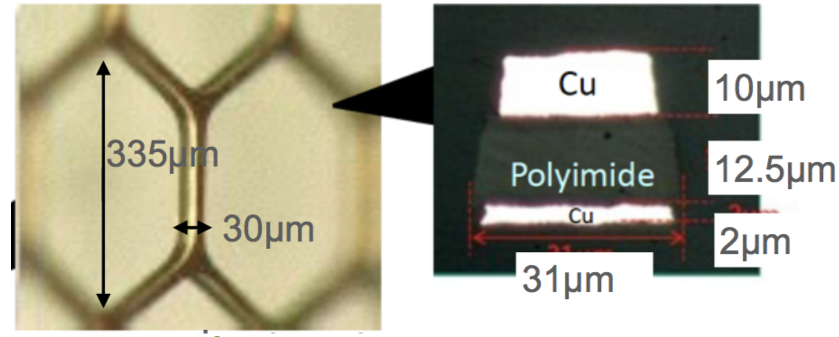
Gate is needed!

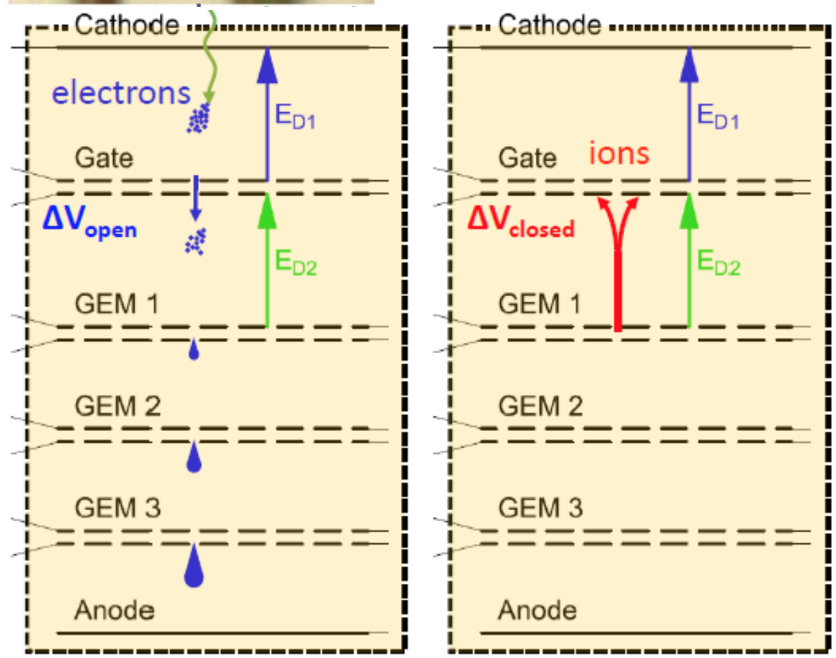
Gating: open GEM to stop ions while keeping transparency for electrons

- 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



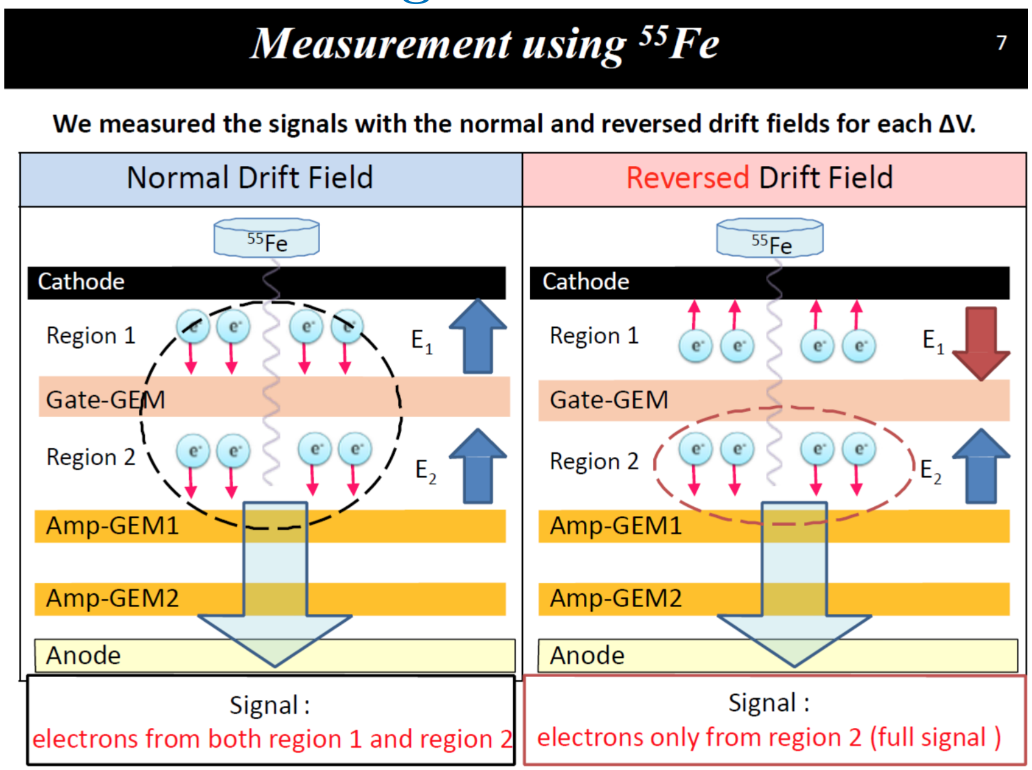


The ions must be stopped before penetrating too much the drift region

The device to stop them must be transparent to electrons

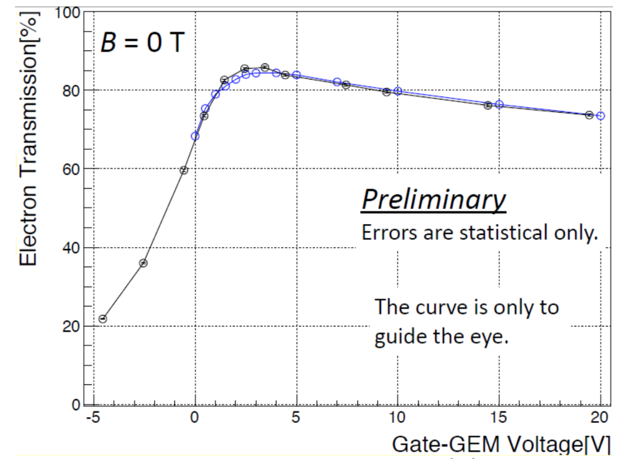
GEM gating –Large aperture GEM transparency

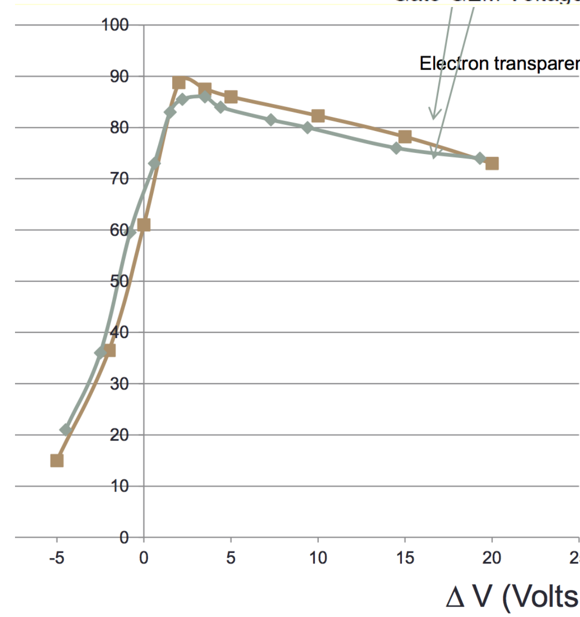
Electron transmission rate as a function of GEM voltage measured with Fe^{55}



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

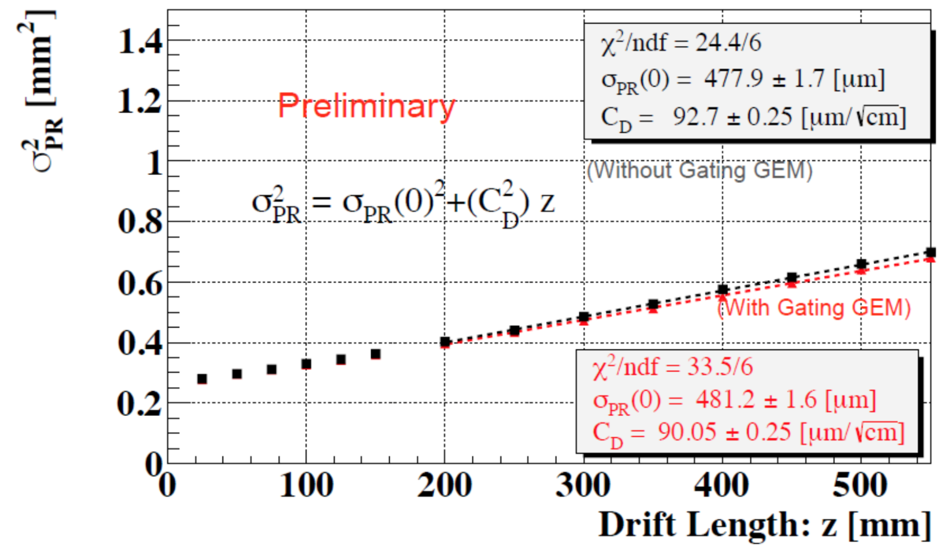


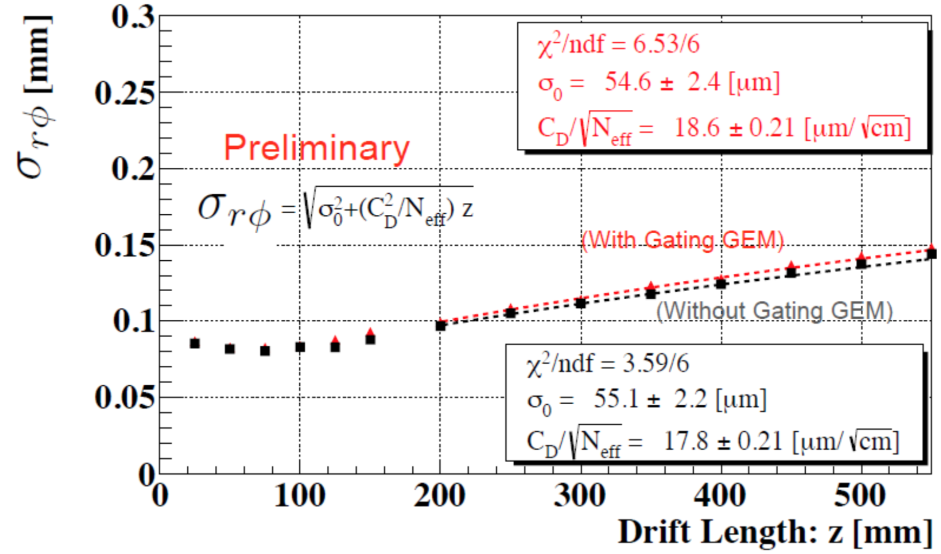


Measurement in Japan with GEM and measurement at CERN with MM are consistent

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

- ☞ **2016.10.31-11.13 (beam time) at DESY TPC Large Prototype**
  - ➠ **the first beam test** of a GEM-readout TPC module with a gating GEM
  - ➠ 15 participants from Japan, France, Germany, China
- ☞ The results are consistent with no more degradation than expected (10%)
- ☞ The analysis is still in progress



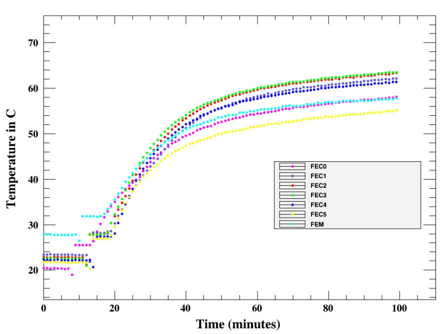


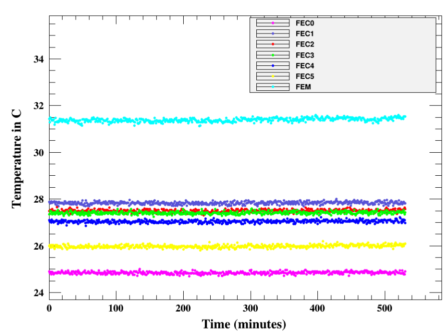
GEM gating seems to be a possible solution for the gating at ILC

Cooling of the electronic circuit is required due to power consumption

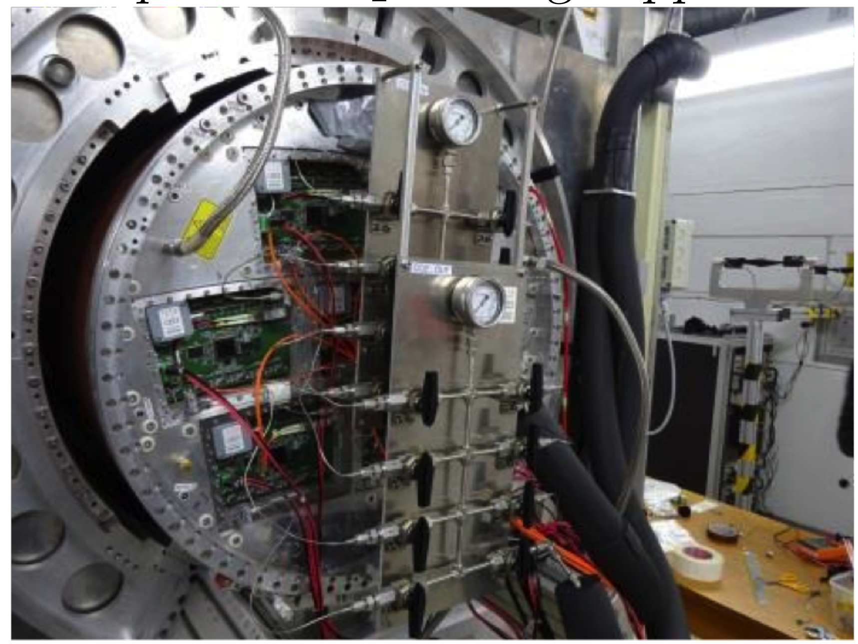
- ☞ Temperature of the circuit rises up to 60°C
  - ➠ cause a potential damage of electronics
  - ➠ covect gas to TPC due to a pad heating
- ☞ A 2-Phase CO_2 cooling with the KEK **cooling plant TRACI** was provided to 7 MM modules during 2014/15 beam tests at DESY
  - ➠ **10°C at P=45 bar** system operation

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





2-phase CO_2 cooling support



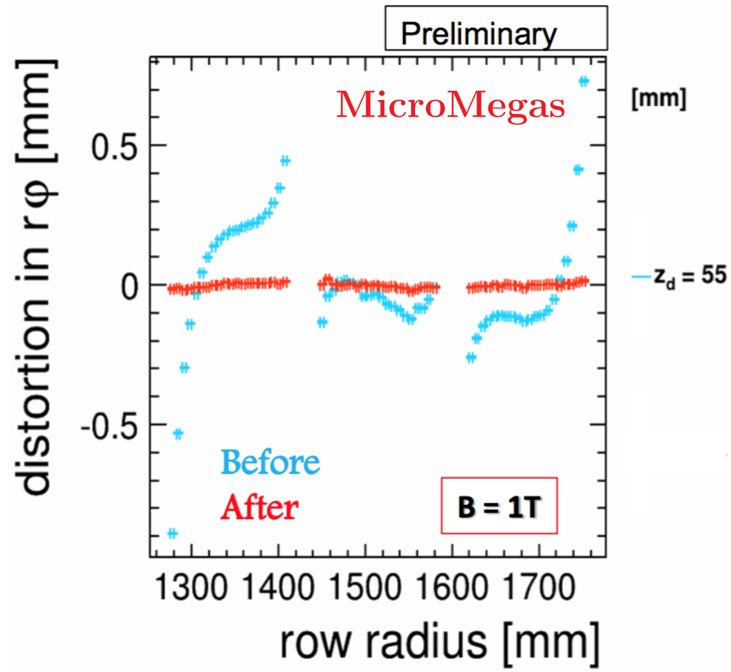
- ☞ Thermal behavior and effect of cooling have been simulated
  - ➠ *D.S. Bhattacharya et al.,* **JINST 10 P08001, 2015"**

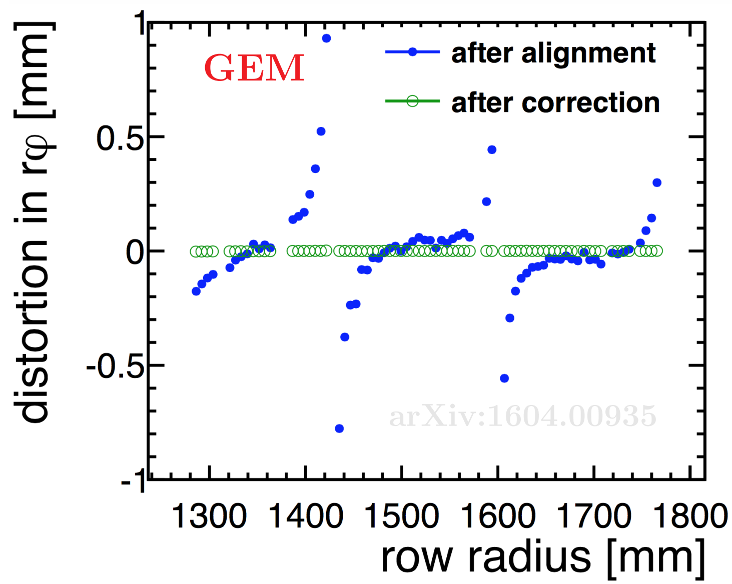
Cooperation for industrial contacts for the ***micro-cooling circuit*** *option*

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

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





☞ **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

☞ **Final design based on S-Altro 16 requires a renewed project**

- current effort on being made at Lund University
- this is not in the final form
- could still use it to test cooling, power-pulsing, etc

Design of a **large GEM and MM modules** *with cooling and high channel density has been started*

Members, Funds

Spending on French Funds				
Description	€/unit	Nb of units	Total (€)	Provided by:[1]
KEK/LCWS (Morioka) S. Ganjour	172/day	14 days	2408	IRFU/E-JADE
14 days	676	1 travel	676	IRFU/E-JADE
KEK/LCWS (Morioka) P. Colas	179/day	14 days	2506	IRFU/E-JADE
14 days	628	1 travel	628	IRFU/E-JADE
KEK/TYL-FJPPL (Seoul) S. Ganjour	146/day	11 days	1606	IRFU
11 days	1191	1 travel	1191	IRFU
Total			9015	

Spending on KEK Fund				
Description	k¥/Unit	Nb of units	Total (k¥)	Provided by:
France (Saclay) K. Fujii / 7 days	109	2 travel	218	KEK
TYL-FJPPL (Seoul) K. Fujii / 2 days	40	1 travel	40	KEK
France (Saclay) A. Sugiyama / 1 day	190	1 travel	190	KEK
France (Saclay) Y. Aoki / 3 days	160	1 travel	160	KEK
France (Saclay) R. Yonamine / 3 days	165	1 travel	165	KEK
France (Saclay) T. Ogawa / 14 days	400	1 travel	400	Sokendai University
France (Saclay) K. Fujii / 3 days	173	1 travel	173	IPNS/KEK
Total			1346	

Additional spending on French funds			Additional spending on Japan funds		
Provided by:[2]	Type	€	Provided by:[3]	Type	k¥
IRFU/CEA	Consumables	23000	IPNS/KEK	Equipment	4000
IRFU/CEA	Travel	25000			
Total		48000	Total		4000

Request for April 2017 to March 2018

	French Group			Japanese Group		
	Name	Title	Lab./Organis.[2]	Name	Title	Lab/Organis.[3]
Leader	S. Ganjour	Dr.	IRFU/CEA	K. Fujii	Dr.	KEK
Members	P. Colas	Dr.	IRFU/CEA	T. Fusayasu	Dr.	Saga Univ.
	D. Attie	Dr.	IRFU/CEA	K. Kato	Dr.	Kinki Univ.
	I. Giomataris	Dr.	IRFU/CEA	M. Kobayashi	Dr.	KEK
	A. Giganon	Mr.	IRFU/CEA	T. Matsuda	Dr.	KEK
	V. Sharyy	Dr.	IRFU/CEA	A. Sugiyama	Dr.	Saga Univ.
	B. Tuchming	Dr.	IRFU/CEA	T. Takahashi	Dr.	Hiroshima Univ.
				T. Watanabe	Dr.	Kogakuin Univ.
				S. Narita	Dr.	Iwate Univ.
				K. Negishi	Dr.	Iwate Univ.
				T. Ogawa	Mr.	Sokendai/KEK
				Y. Aoki	Miss	Sokendai/KEK
				A. Shoji	Miss	Iwate Univ.

Funding Request from France				
Description	€/unit	Nb of units	Total (€)	Requested to[4]:
Visit to Japan	150/day	45 days	6750	IRFU/E-JADE
Travels	1000	3 travel	3000	IRFU/E-JADE
Total			9750	

Funding Request from KEK				
Description	k¥/Unit	Nb of units	Total (k¥)	Requested to:
Travel	200	4 travel	800	KEK
Visit to France	20/day	28 days	560	KEK
Travel + per diem	600	1	600	
Total			1960	

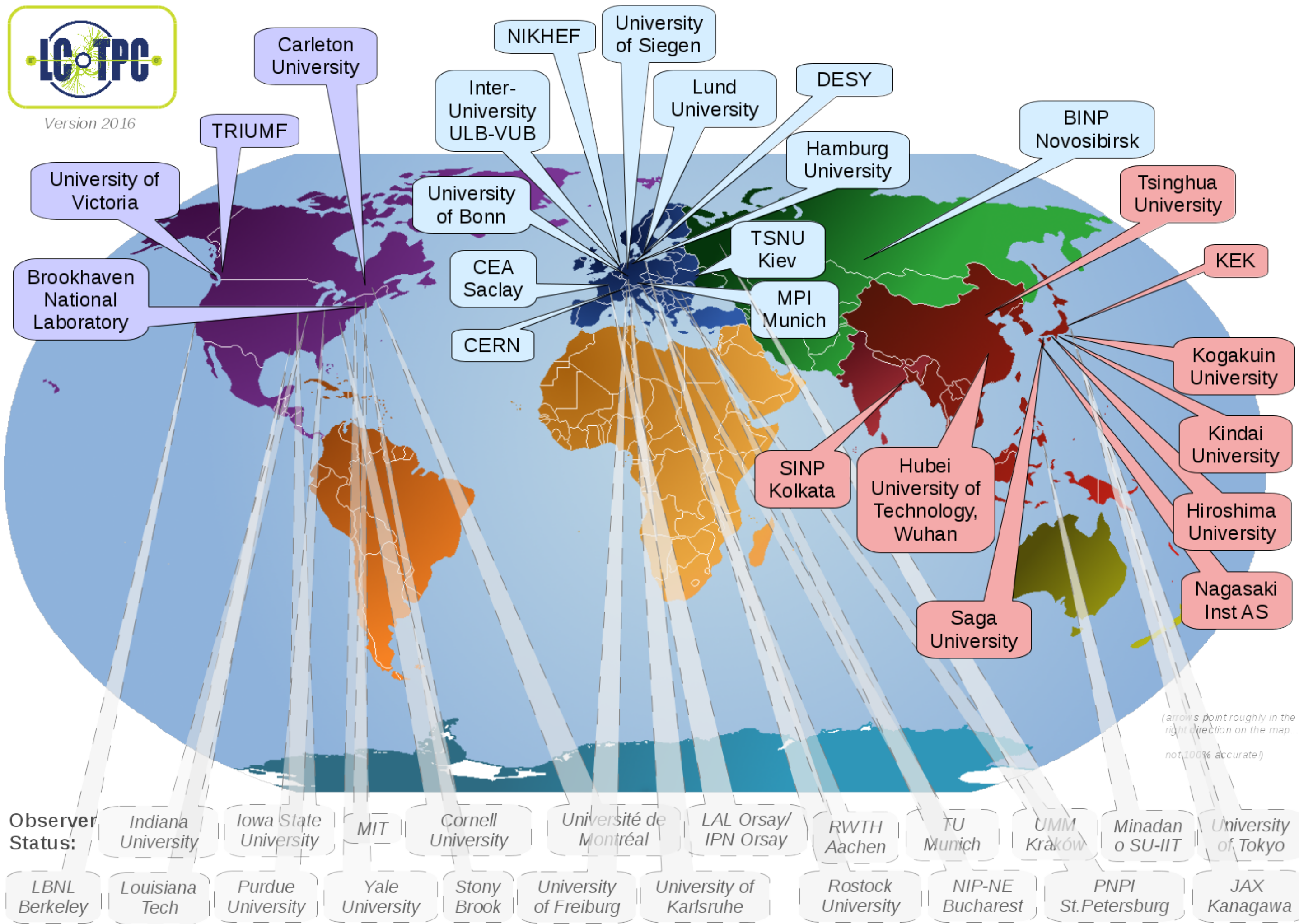
- **AIDA 2020** has been granted
  - contains a gaseous detector part
  - spans 2015-2018
- Saclay applied to an **EU RiSE grant (GANDALF project)**
  - fund travels to Japan for 4 years
  - includes TPC R&D

Conclusions

- **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**
  - ➠ this is also a preparation for the technology choice
- Despite very difficult conditions, the R&D is in progress:
  a module with a gating GEM has been tested
  - ➠ the results are consistent with no more degradation than expected
  - ➠ GEM gating seems to be a possible solution for the gating at ILC
- **We demand one year extension of the D_RD_9 project to finalize the remaining issues before ILC decision is taken**
- **Special thanks to P. Colas and A. Sugiyama**

Backup

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

Micro Pattern Gas Detectors (MPGDs)

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

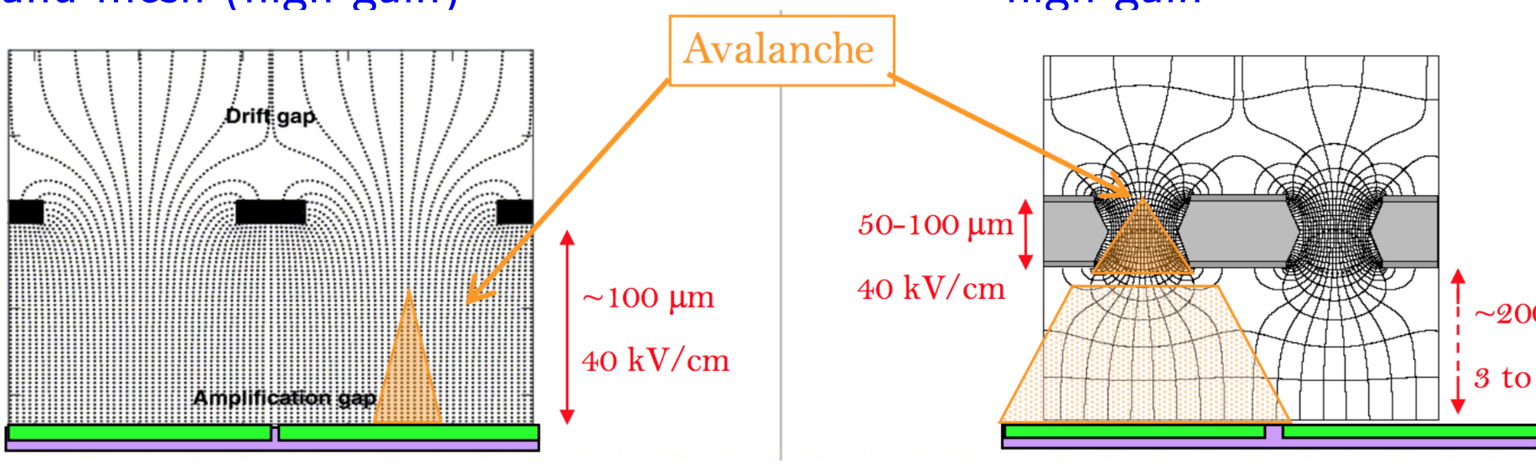
- **no ExB effect, better ageing, low ionback drift**
- easy to manufacture, MPGD more robust mechanically than wires

☞ **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)

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)