



Toward the Final Design of a TPC for the ILD Detector

Keisuke Fujii, KEK
on behalf of the **D_RD_9** team



LC-TPC



ILD DBD Completed on March, 2013

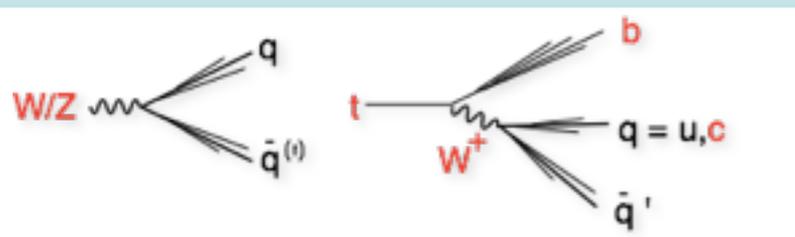


International Large Detector

Performance Goals as compared to LHC detectors

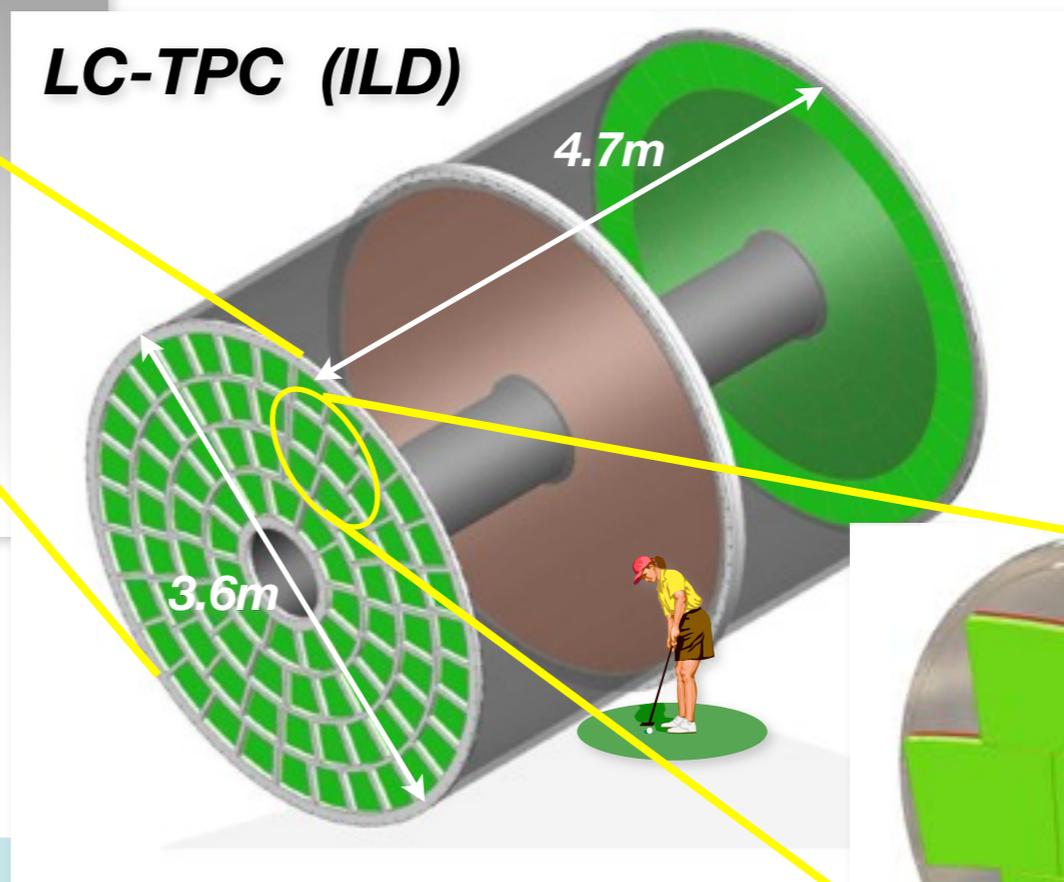
Vertex resolution	2-7 times better
Momentum resolution	10 times better
Jet energy resolution	2 times better

ILD : optimized for Particle Flow Analysis

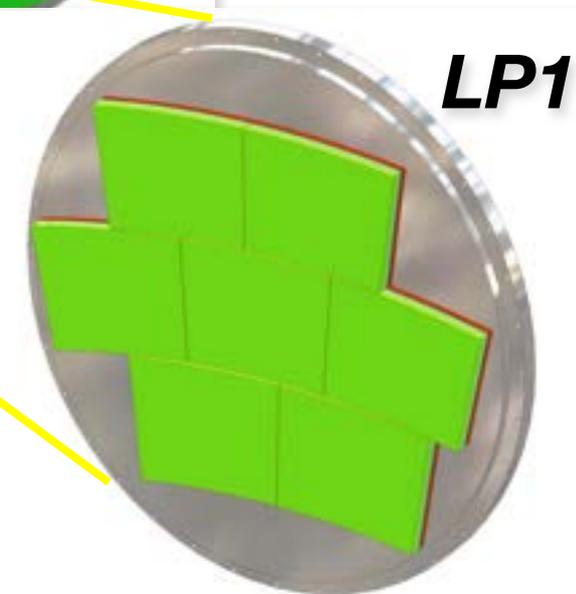


Highly efficient tracking in a jetty environment is an essential ingredient for PFA

LC-TPC (ILD)



Micro Pattern Gas Detector readout TPC provides pictorial 3D tracking by ~200 space points with $\sigma_{r\phi} \sim 100 \mu\text{m}$ and two-hit separation of ~2mm



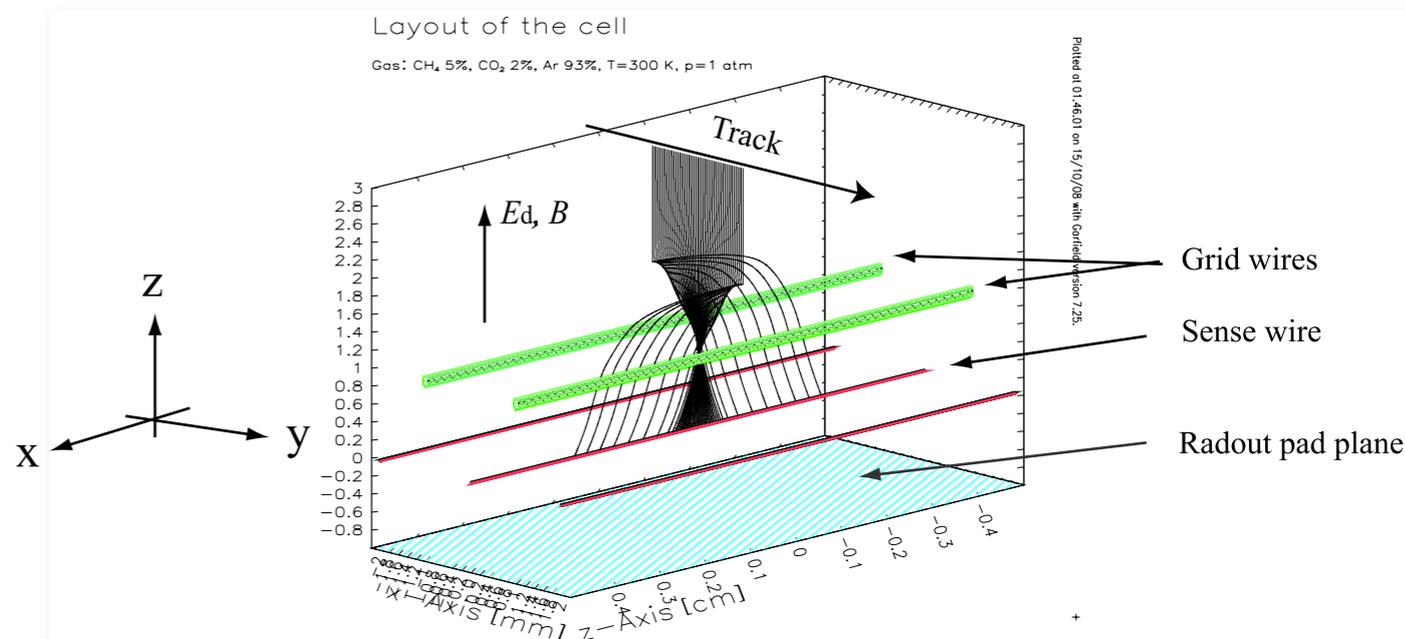
Large Prototype being tested at DESY



Why MPGD Readout?



- We need high (>3 T) B field to confine e^+e^- pair BG from beam-beam interactions, then $E \times B$ is too big for conventional MWPC readout
- 2mm 2-track separation is difficult with MWPC readout
- Thick frames are unavoidable for MWPC readout

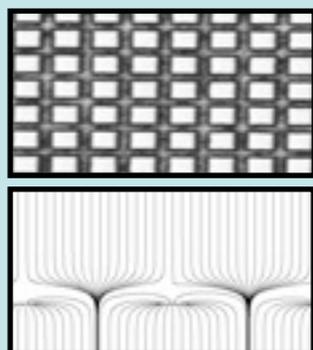


$E \times B$ spreads seed electrons along the sense wires, then avalanche fluctuation limits the spatial resolution!

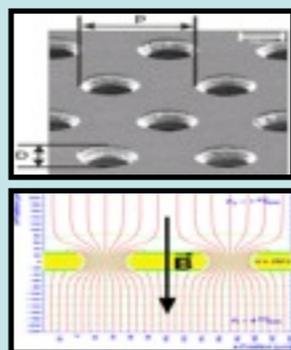


Micro-Pattern Gas Detectors

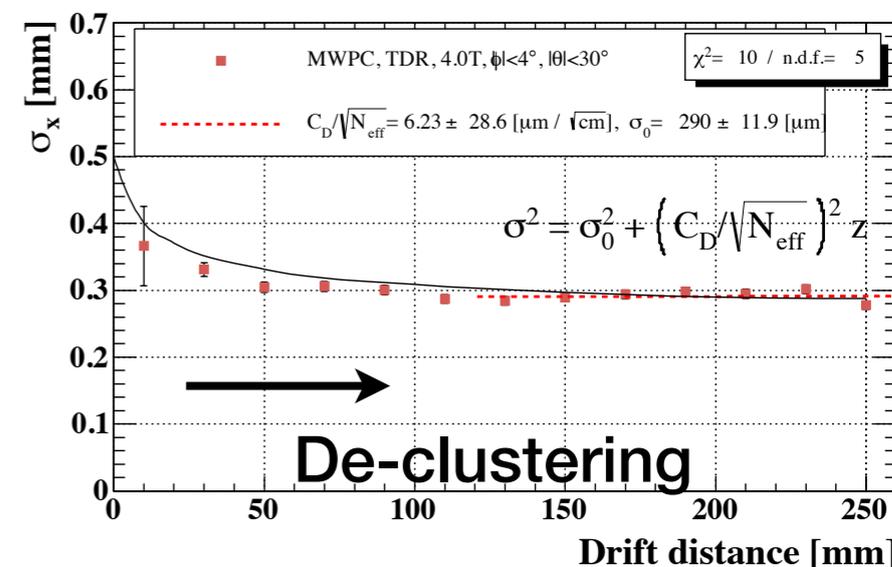
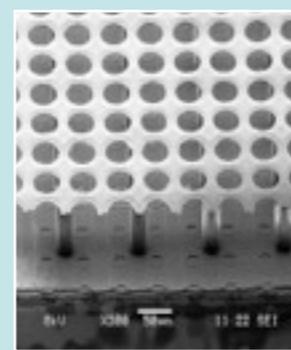
Micromegas



GEM



InGrid TimePix



Pre-LCTPC group incl. the FJ team, together, excluded MWPC option with a small prototype TPC!



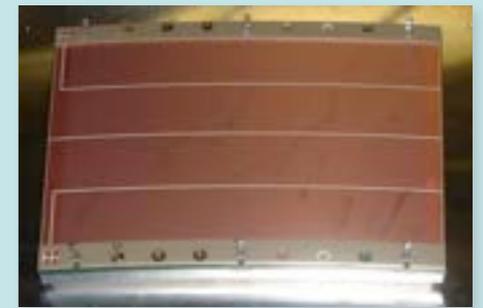
MPGD Options



After the initial stage of R&D with many small TPC prototypes, we are left with **three options** of MPGD TPC readout technologies for ILC, being tested at the Large prototype (LP) TPC at DESY.

I. Analog (Pad) TPC: Subject to the gas gain fluctuation in the gas amplification. Need to spread the avalanche charge for charge centroid.

Asian GEM module



(1) Multi layer GEM with the standard pad ($\sim 1 \times 5 \text{mm}^2$) readout :
(charge spread by diffusion)

Asian (KEK-Saga-Tsinghua) Module, DESY module

(2) Micromegas with the resistive-anode (pad: $\sim 3 \times 7 \text{mm}^2$) readout :

Saclay-Carleton Module

MM (resistive anode)

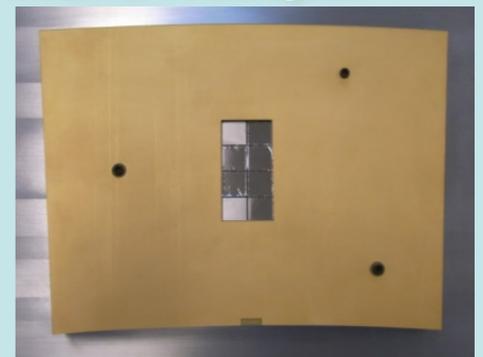


II. Digital (Pixel) TPC: Free from the gas gain fluctuation. Expect 20-30% improvement of position resolution in the case of digital readout.

No angular pad effect.

Theoretically the best but not yet ready for full implementation of a module.

InGrid+Timepix



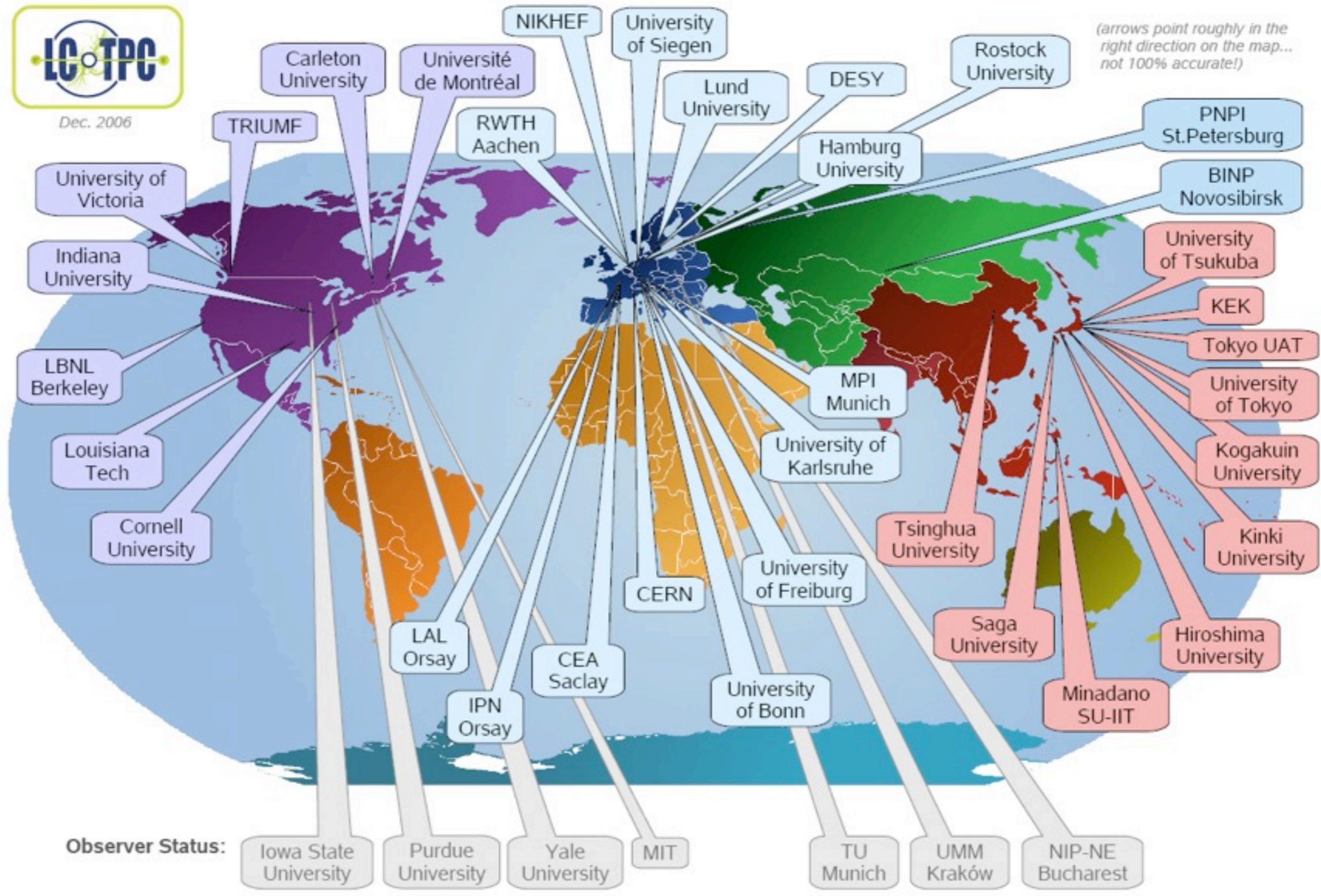
(3) InGrid Micromegas mesh on Timepix chips (pixel: $\sim 50 \times 50 \mu\text{m}^2$)

NIKHEF-Saclay Module, Bonn-module

→ being tested in **Large Prototype** at DESY



(arrows point roughly in the right direction on the map... not 100% accurate!)

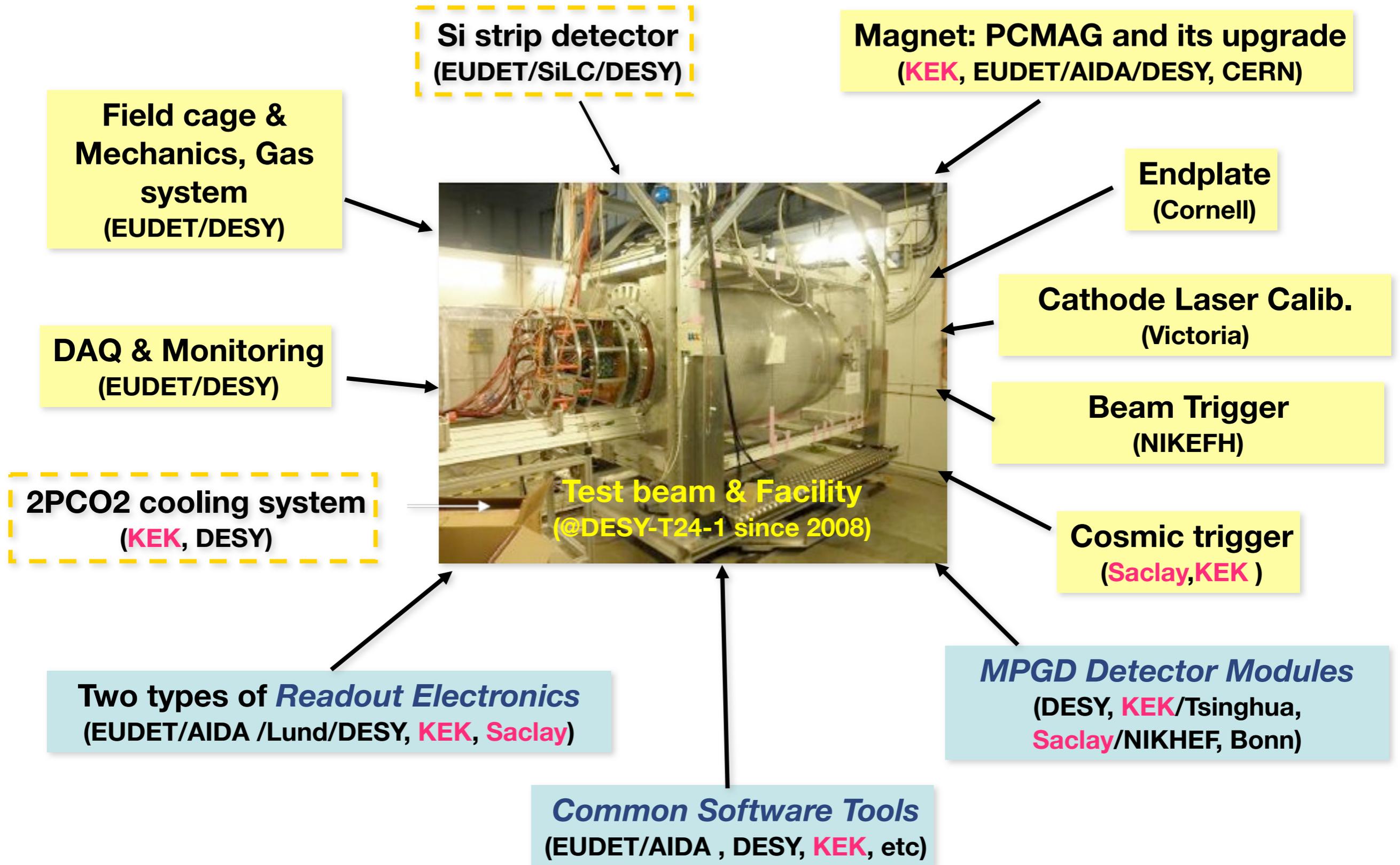


Observer Status: Iowa State University, Purdue University, Yale University, MIT



Large Prototype Test Beam Facility at DESY

LC TPC Collaboration

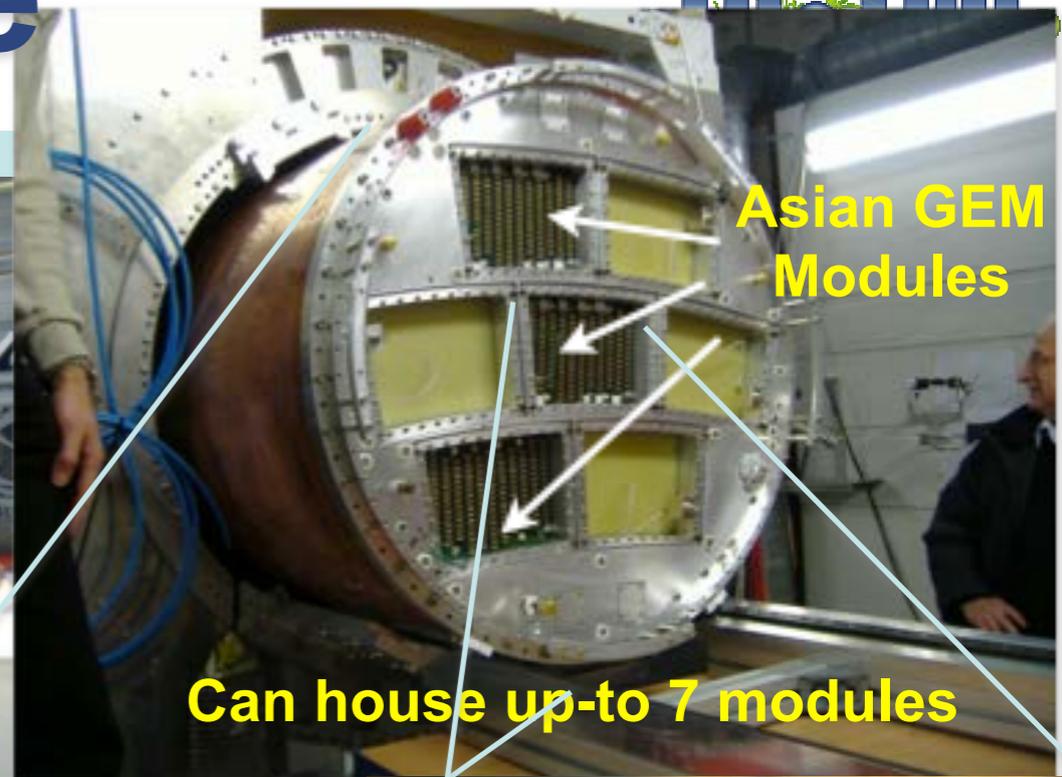




Large Prototype



GM cryo-coolers



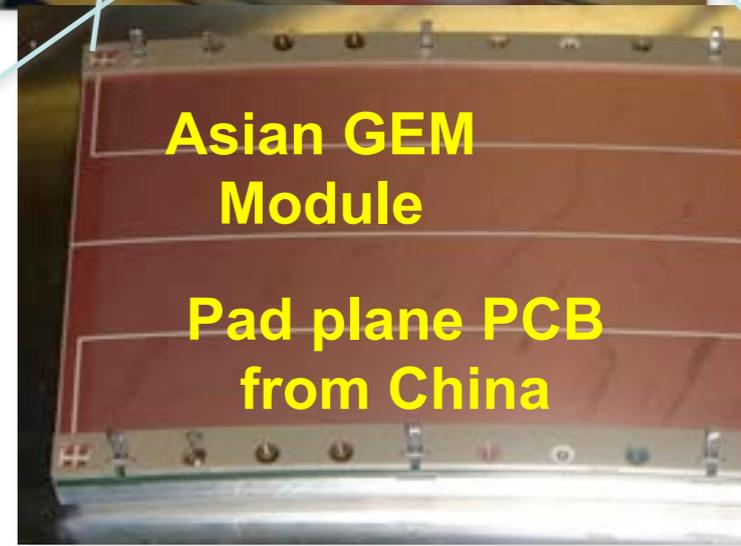
Asian GEM Modules

Can house up-to 7 modules



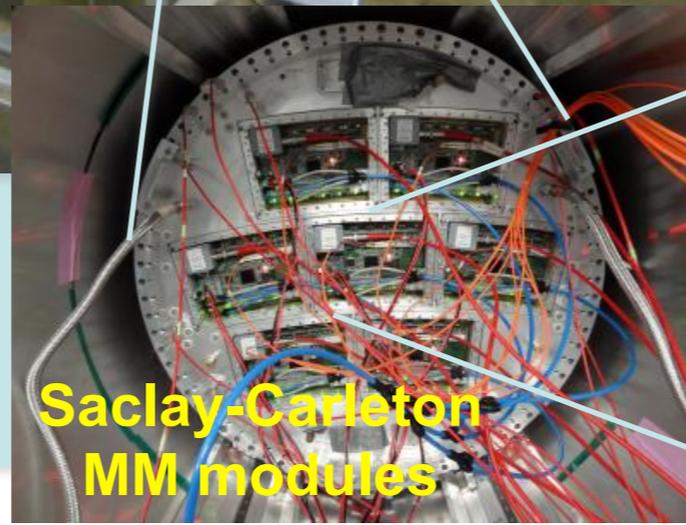
PCMAG from KEK modified by Toshiba under the framework of DESY-KEK collaboration in JFY2011 to allow Liq.He-less operation

Being used for test beam experiments since June 2012

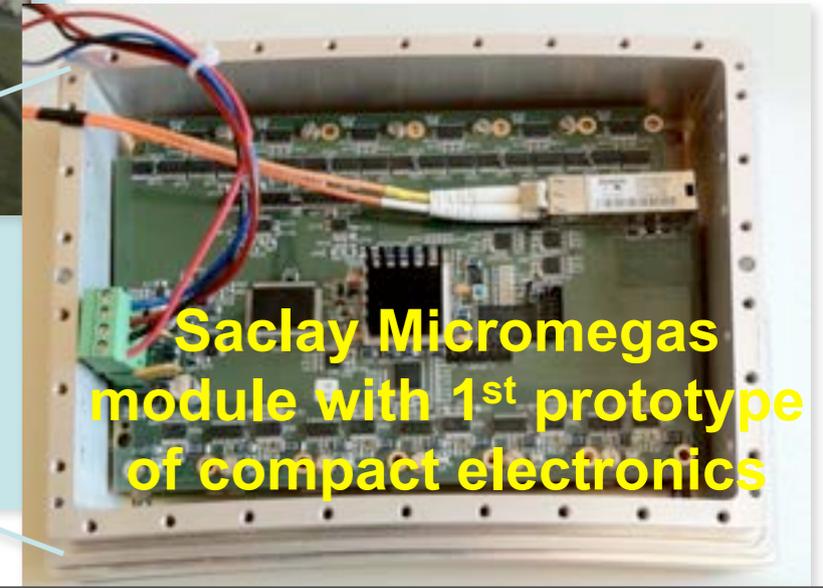


Asian GEM Module

Pad plane PCB from China



Saclay-Carleton MM modules



Saclay Micromegas module with 1st prototype of compact electronics



5GeV electron beam

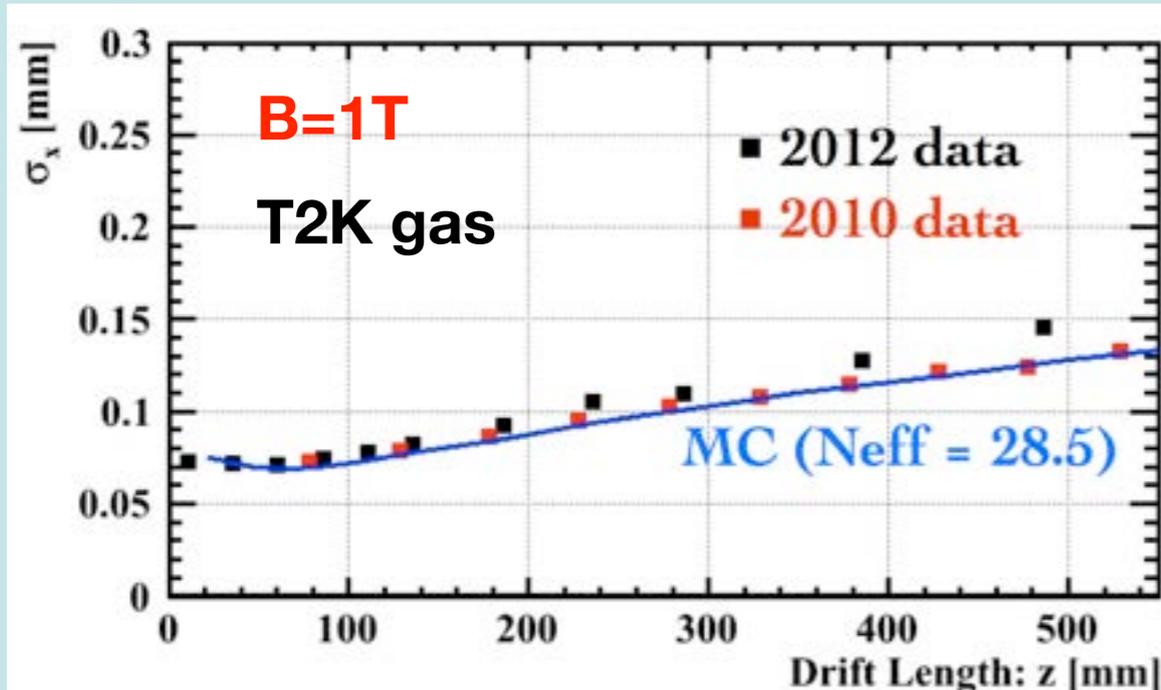
Large Prototype test beam



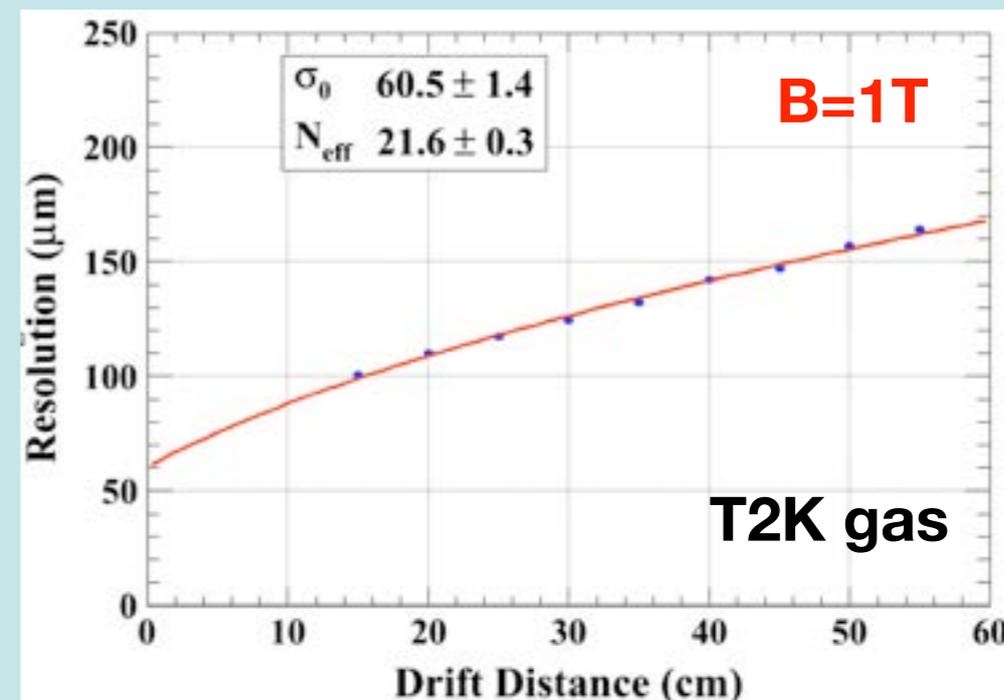
Spatial Resolution



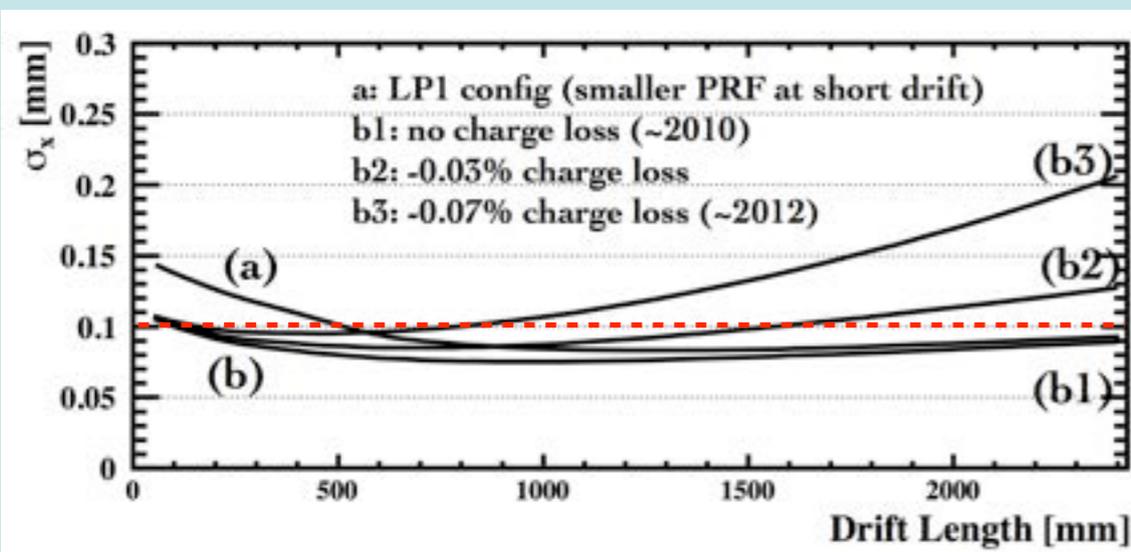
Asian GEM Module



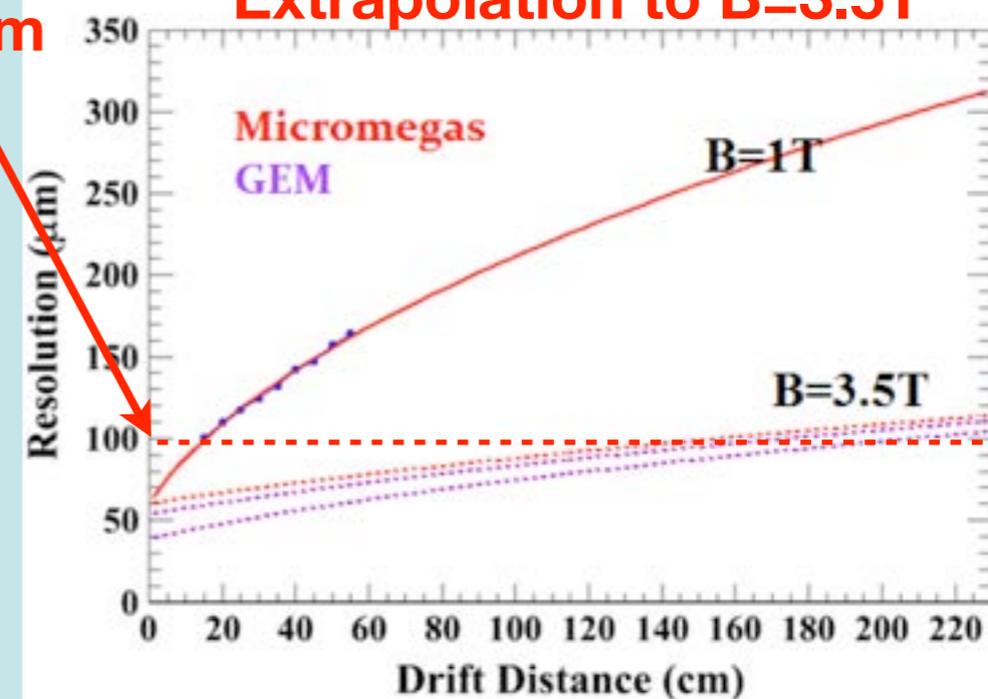
Saclay-Carleton MM Module



Extrapolation to B=3.5T



Extrapolation to B=3.5T



Both options seem to satisfy the $\sigma_{r\phi} = 100 \mu\text{m}$ requirement!



Resolution Formula



Since TPC operates on the nice and old “gas physics”; ionization, diffusion, gas amplification and fluctuation, etc., it is possible for the GEM TPC (option (1)) to formulate a fully analytic expression of its spatial resolution **to understand the LP TPC results, to optimize parameters of the GEM TPC, and to extrapolate them to the ILD TPC** (R. Yonamine / KF)

$$\sigma_x^2(z; w, L \tan \phi, C_d, N_{eff}, \hat{N}_{eff}, [f]) = [A] + \frac{1}{N_{eff}} [B] + [C] + \frac{1}{\hat{N}_{eff}} [D]$$

[A]: Hodoscope effect/S-shape at the short drift distances

$$[A] := \int_{-1/2}^{+1/2} d \left(\frac{\tilde{x}}{w} \right) \left(\sum_a (aw) \langle \langle F_a(\tilde{x} + y \tan \phi + \Delta x) \rangle_{\Delta x} \rangle_y - \tilde{x} \right)^2$$

diffusion-averaged & cluster position average charge centroid systematics

asymptotic formula ([B] term)

$$\sigma_x^2 = \frac{1}{N_{eff}} (\sigma_0'^2 + C_d^2 z)$$

The constant term also scales as 1/N_{eff}!

[B]: Diffusion + finite pad size term

$$[B] := \int_{-1/2}^{+1/2} d \left(\frac{\tilde{x}}{w} \right) \left\langle \left(\sum_a (aw) F_a(\tilde{x} + \Delta x) - \sum_a (aw) \langle F_a(\tilde{x} + \Delta x) \rangle_{\Delta x} \right)^2 \right\rangle_{\Delta x}$$

displacement due to diffusion for a single electron diffusion-averaged charge centroid

$$\approx [A]_{z=0} + \sigma_d^2$$

[C]: Electronics noise

$$[C] := \left(\frac{\sigma_G}{\bar{G}} \right)^2 \left\langle \frac{1}{N^2} \right\rangle_N \sum_a (aw)^2$$

$$N_{eff} := \left[\left\langle \sum_{i=1}^N k_i \left\langle \left(\frac{G_{ij}}{\sum_{i=1}^N \sum_{j=1}^{k_i} G_{ij}} \right)^2 \right\rangle_{G, \sum_{i=1}^N k_i} \right\rangle_{N,k} \right]^{-1}$$

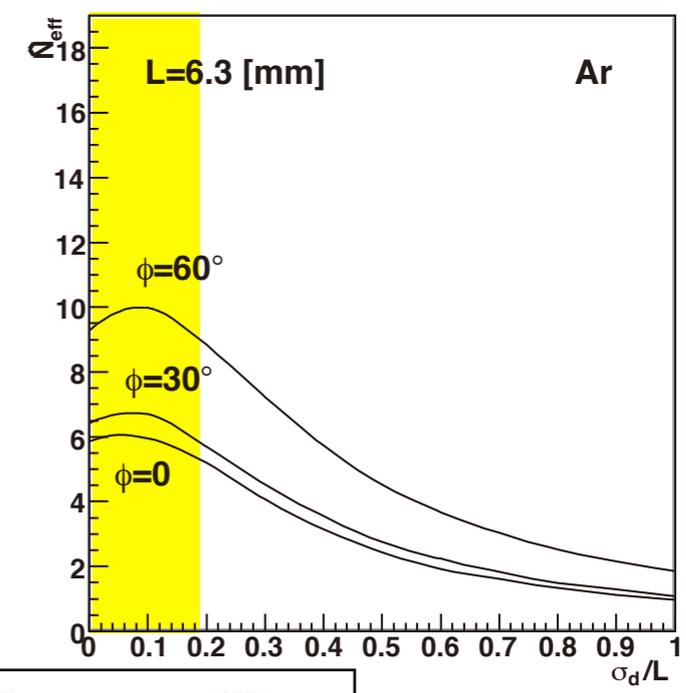
: effective # electrons

[D]: Angular pad effect

$$[D] := \frac{L^2 \tan^2 \phi}{12}$$

$$\hat{N}_{eff} \simeq \left[\left\langle \sum_{i=1}^N \left\langle \left(\frac{\sum_{j=1}^{k_i} G_{ij}}{\sum_{i=1}^N \sum_{j=1}^{k_i} G_{ij}} \right)^2 \right\rangle_{G, \sum_{i=1}^N k_i} \right\rangle_{N,k} \right]^{-1}$$

: effective # clusters



$$\hat{N}_{eff} \ll N_{eff}$$

$\sigma_{r\phi}$ quickly deteriorates with ϕ !



Tracking Codes for LP TPC and ILD TPC



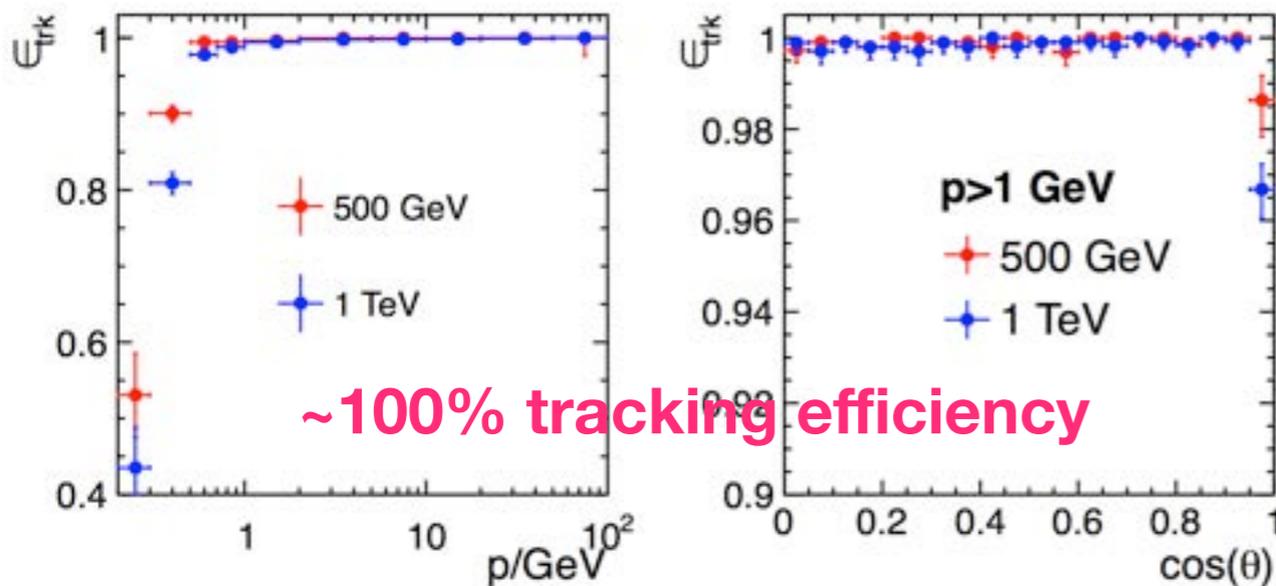
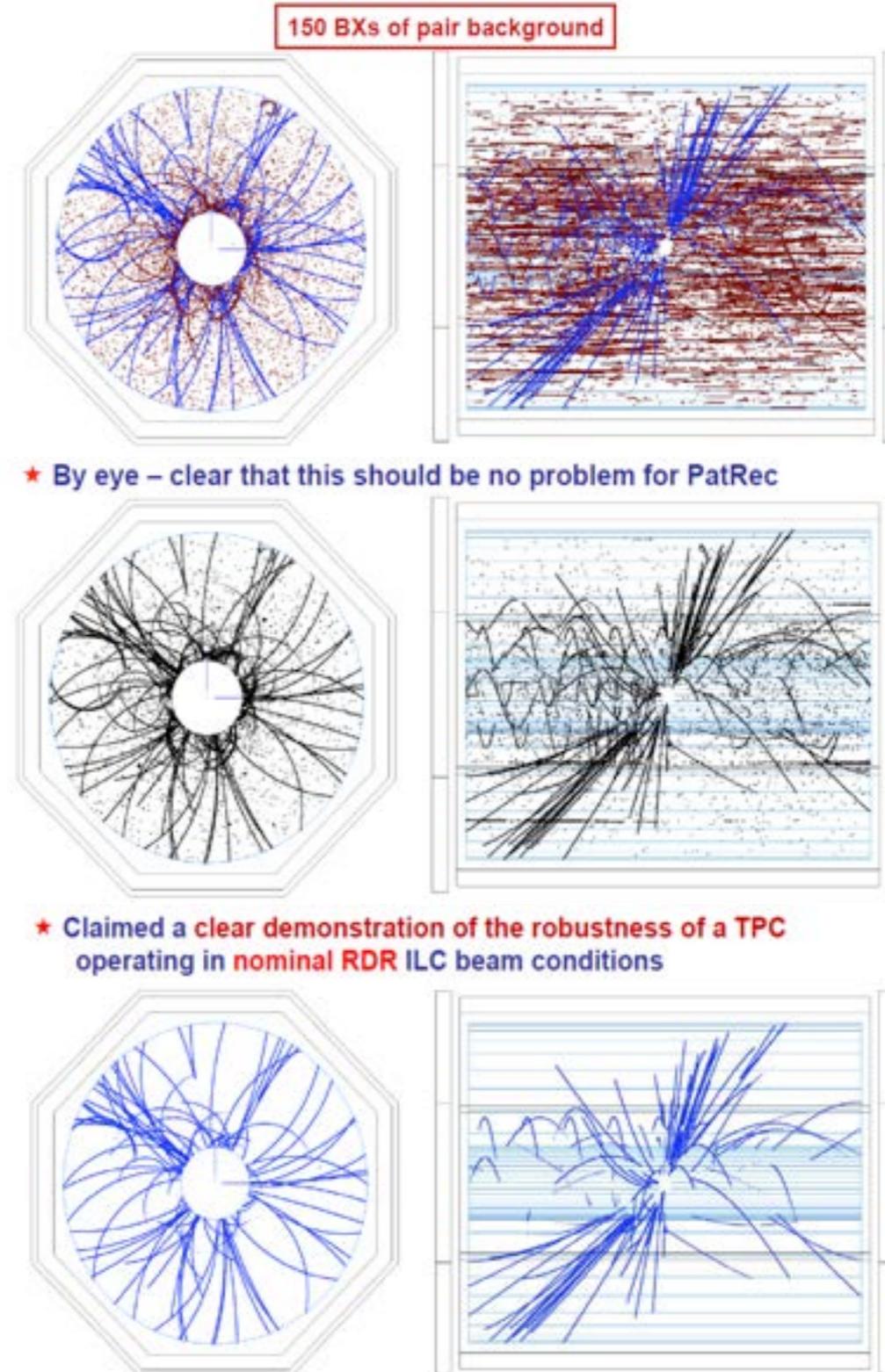
Tracking Code (MarlinTrk): now fully C++

KEK developed Kalman Filter Package (KalTest)

$e^+e^- \rightarrow t \bar{t}$ @1TeV

Reconstructed Tracks

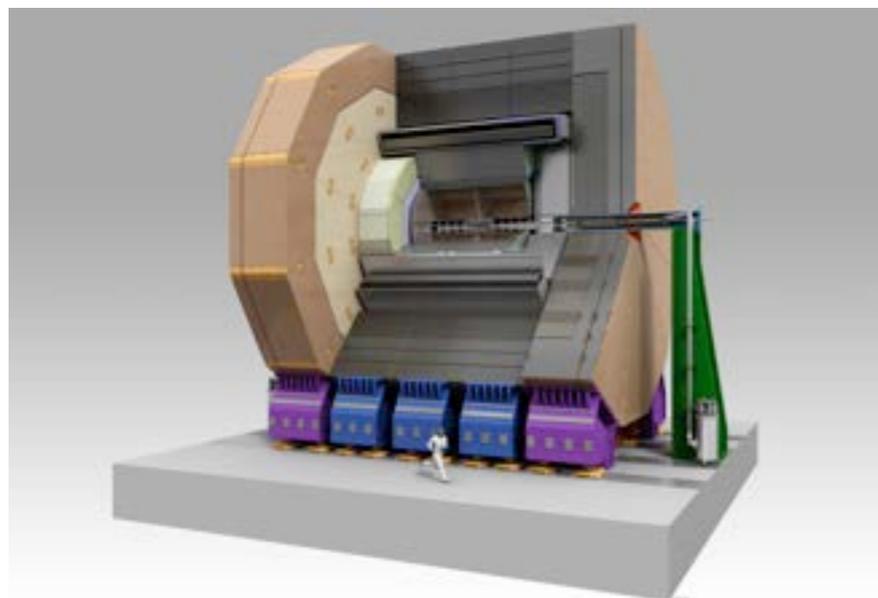
- The continuous tracking in TPC is very robust against the backgrounds (including the micro curlers) at ILC reaching 100% tracking efficiency ($> 1\text{GeV}/c$) except the forward region
- A Kalman filter based tracking code for TPC at ILC has been developed (Li Bo/ KF), and implemented in the MarlinTPC code for the beam test data analysis as well as to the new MarlinReco for the ILD physics simulation



Despite the more realism (cracks, support structures, and service materials) brought in to the simulator,

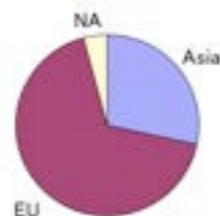
PFA performance is now better than that of Lol!

ILD Detailed Baseline Design



Letter of Intent (2009)

~700 signatories
~120 from Japan



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ILD DBD now completed in March 2013!
We are now entering the phase for
the Final Engineering Design!

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WORKSHOP 2012
 Kyushu University, Fukuoka, Japan
 23-25 May, 2012



Entering New Phase

D_RD_9



ILD Detailed Baseline Design now completed!

*We are now entering the phase for
the Final Engineering Design!*

In addition to further R&D towards engineering design of the GEM or MM module on each side, we need to work together on the following:

- Common tracking and analysis software R&D
- Gating Device
- 2-Phase CO₂ Cooling
- Readout Electronics: Analog-Digital mixed chip for (semi-)surface mounting



Common Tracking and Analysis Software

*to compare different technologies
on the equal footing
for eventual technology choice*



Kalman Filter Based Track Fitting in Non-uniform B Field



arXiv: physics.ins-det/1305.7300

Basic idea of the algorithm

To use the helical track model of KalTest in the non-uniform magnetic field, we have to:

- assume the magnetic field between two nearby layers is uniform;
- transform the frame to make the z axis point to the direction of magnetic field.

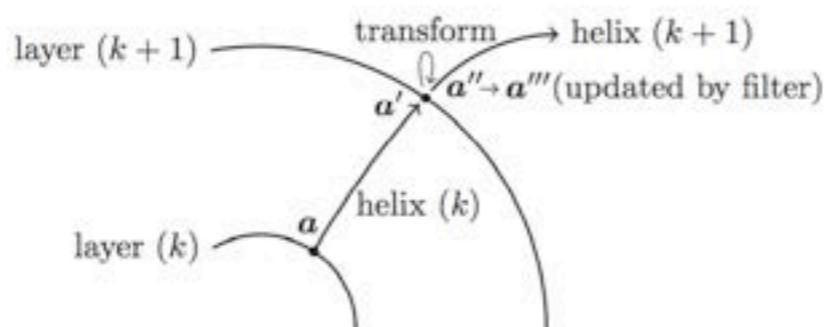
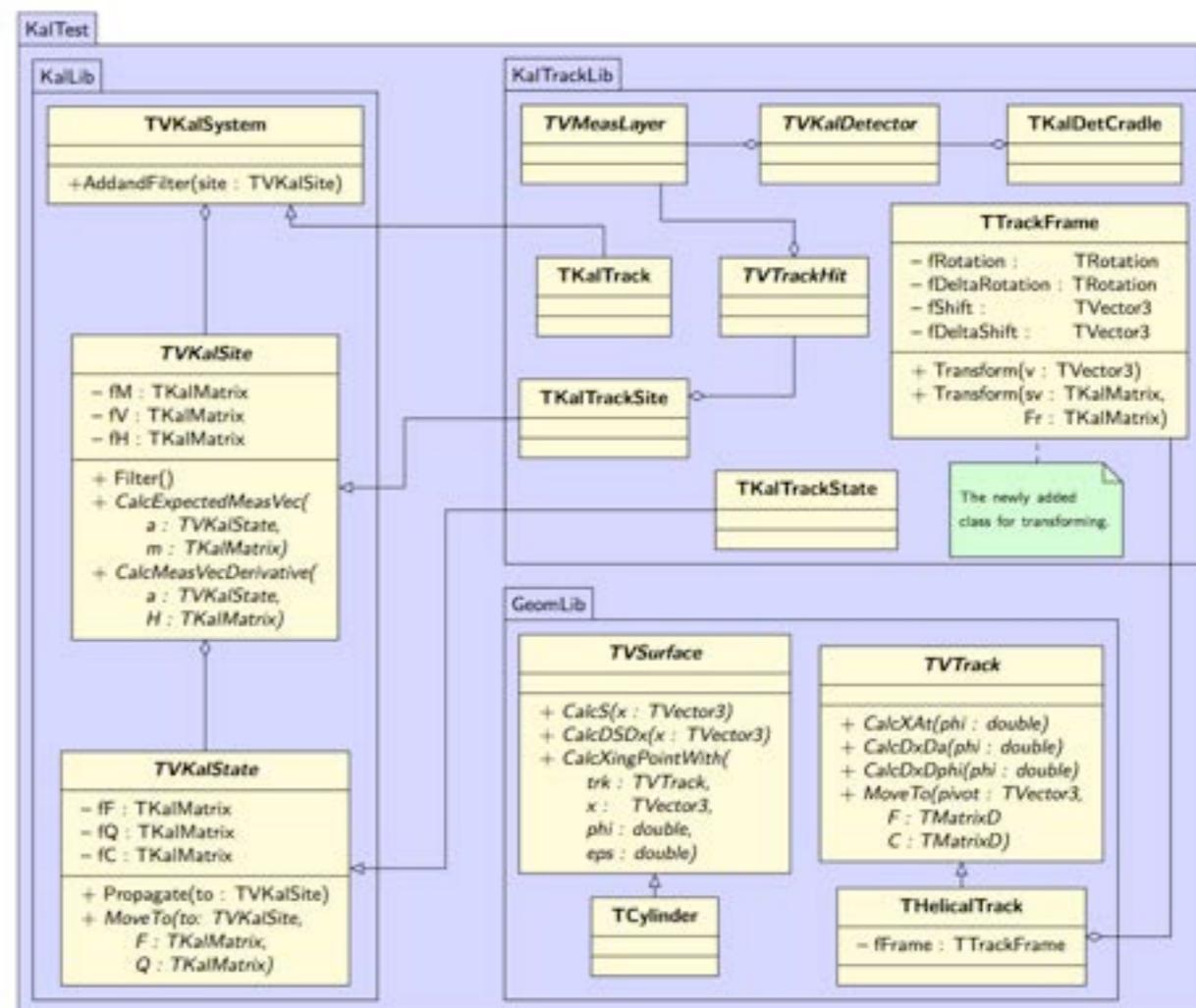


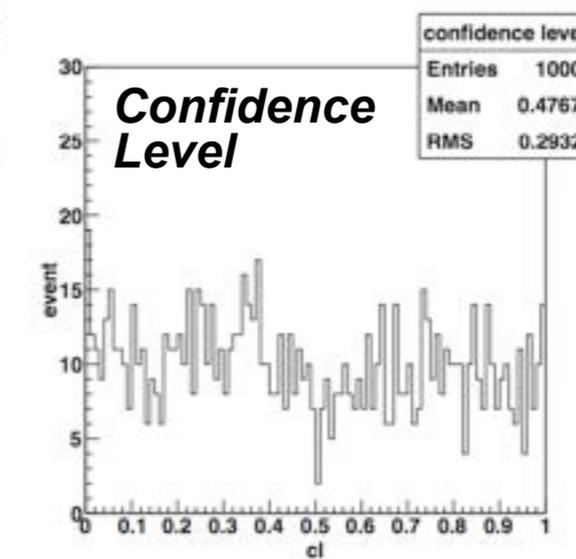
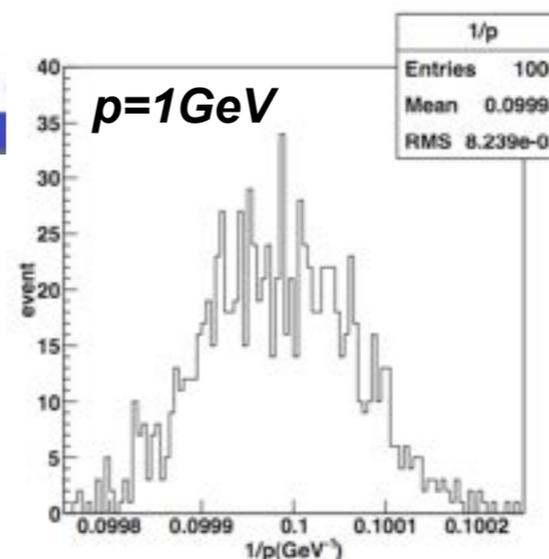
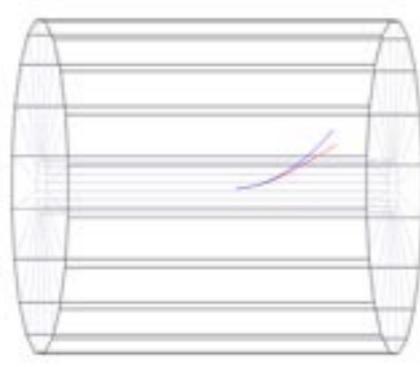
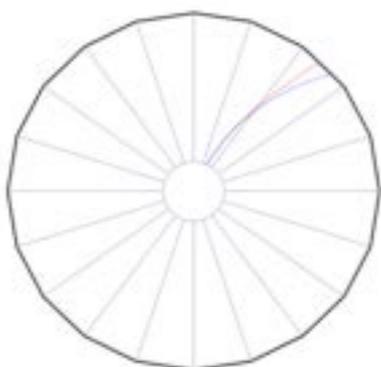
Figure 1 : The updated track propagation procedure.

Therefore we now have a **segment-wise helical track model**.



Track fitting in non-uniform magnetic field

June 1, 2013 2 / 10



Works in B field with >40% non-uniformity !



Ion Gate



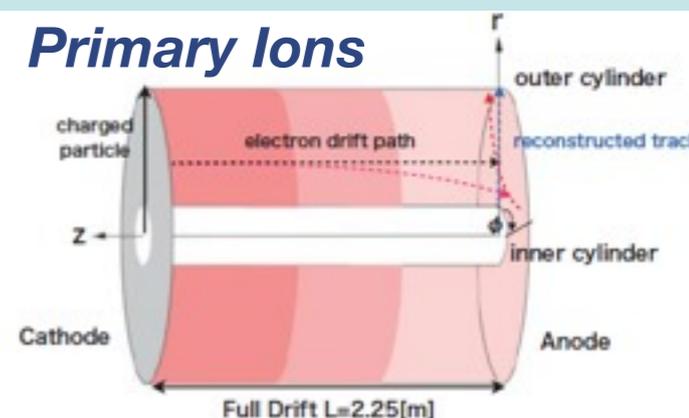
Solved the Poisson equation for the simulated ion density distribution with proper boundary conditions and then estimated the distortion of drift electron trajectory by the Langevin equation (D. Arai and KF)

	without Gating Device	with Gating Device
Primary Ion	8.5 μm	8.5 μm
Secondary Ion	60 μm	0.01 μm
sum	70 μm	8.5 μm

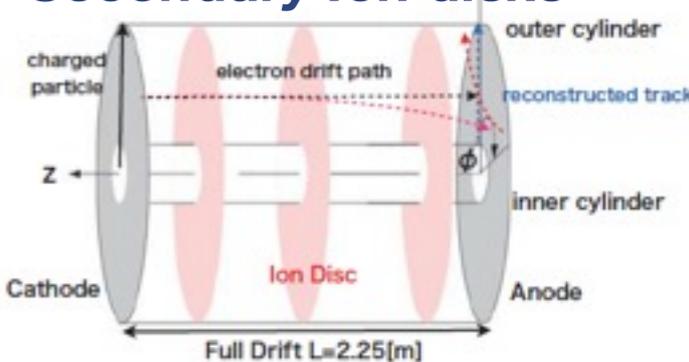
OK

Not OK

Primary Ions



Secondary Ion disks



For the secondary ions from the amplification, **we need an ion gate device** for the ion feed back ratio of $>10^{-3}$ (measured both for the triple GEM and Micromegas) at the gas gain of 1,000.

The current options of the ion gate are limited:

- The traditional **wire gate** is expected to work, but introduces mechanical complications to the MPGD modules. We also need to check ExB effect.
- Thin GEM gate** offers the **electron transmission** of only 50% @ 1T \rightarrow 30% loss in the point resolution (Japanese LC TPC group).
- Try a larger geometric aperture with new fabrication method?



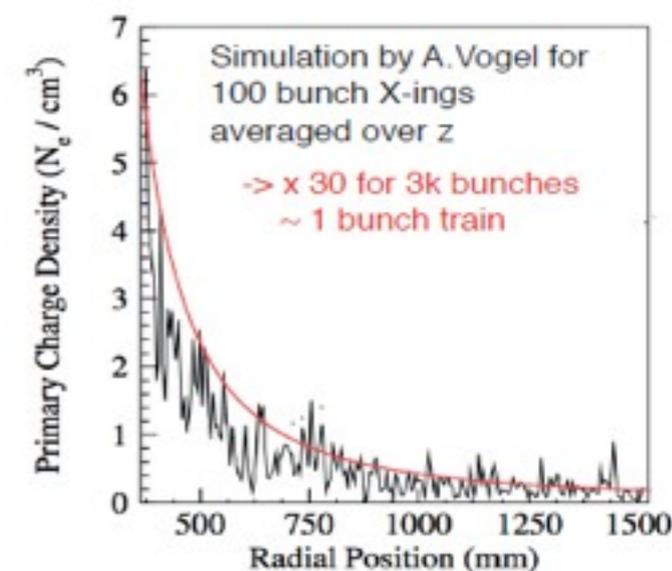
wire gate



GEM gate



New way?



No two-photon hadron BG included.
 \rightarrow underestimate



2P CO₂ Cooling

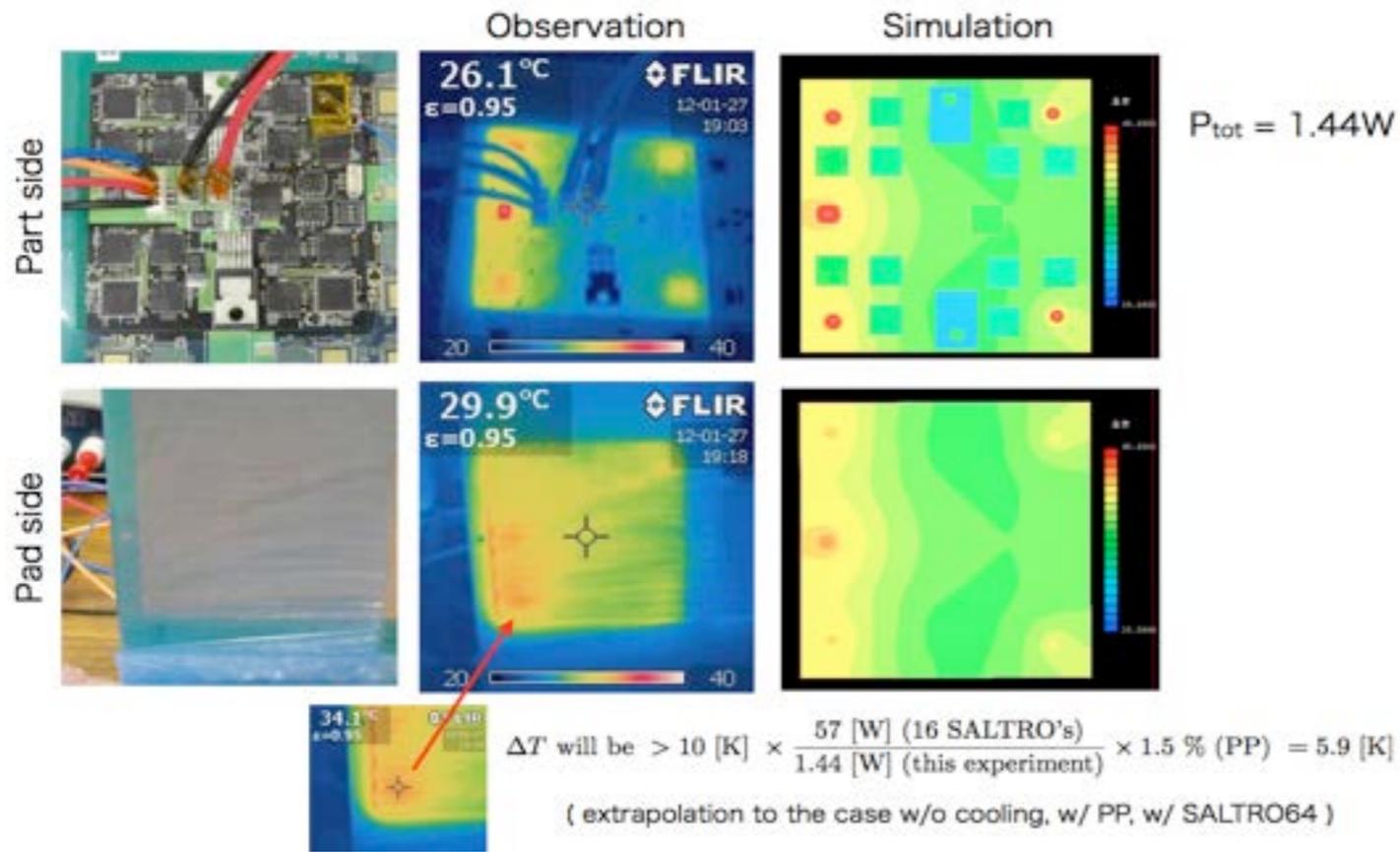


R&D on Power Pulsing and Cooling

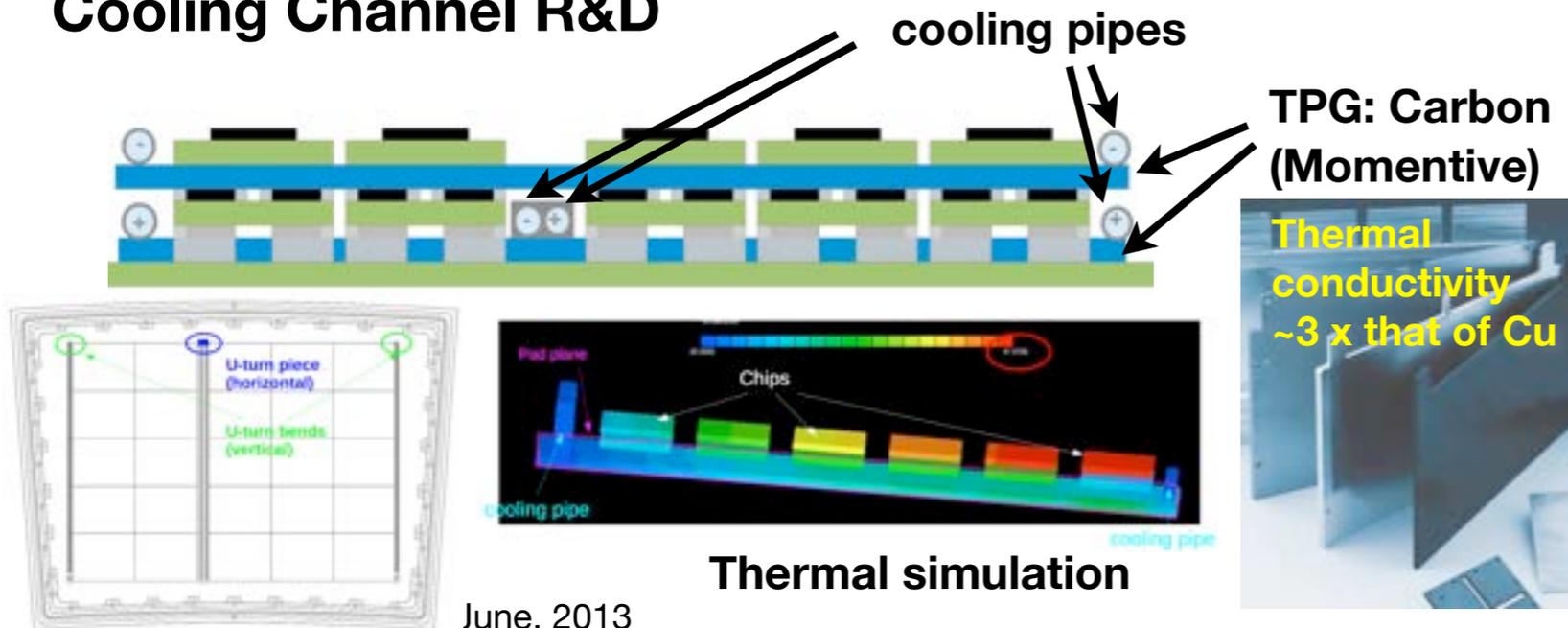


Test with Dummy Module

Comparison with simulation



Cooling Channel R&D



Open 2-Phase CO2 Cooling System for detector cooling tests at KEK



2-PCO2 Cooling Circulation System at KEK



The two phase CO2 cooling system for the LC TPC R&D (Delivered at NIKHEF)

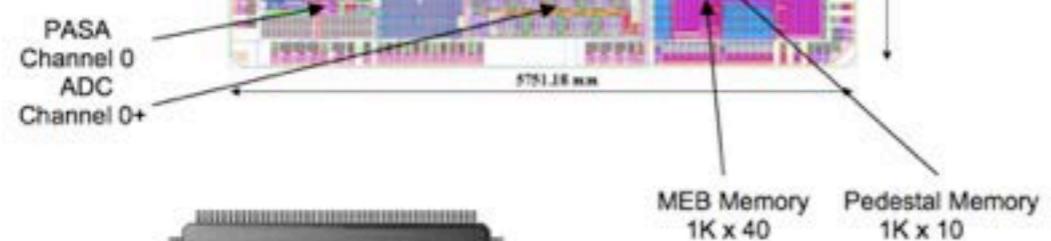
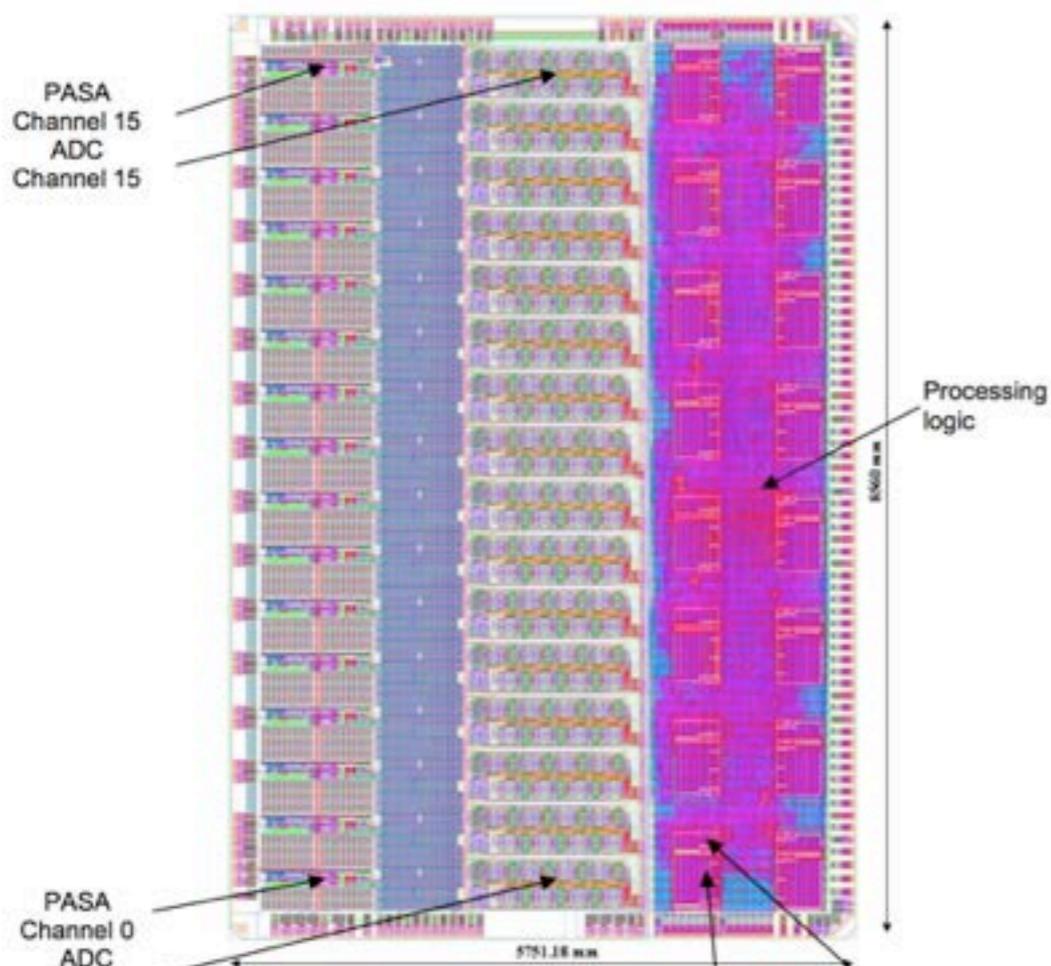


Readout Electronics

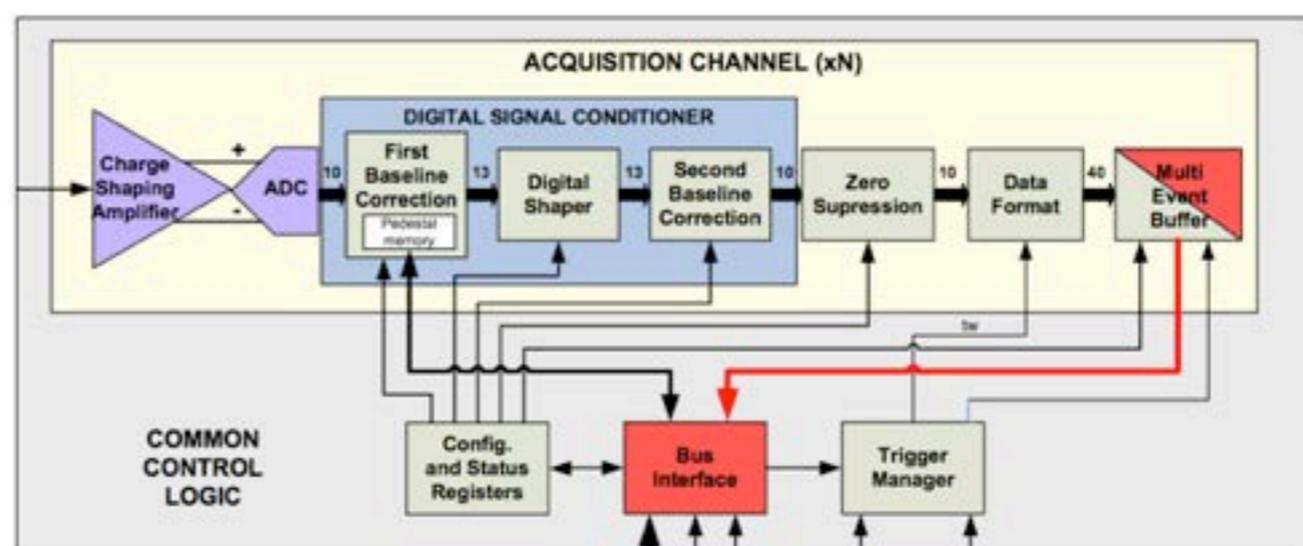


S-ALTRO 16 Development

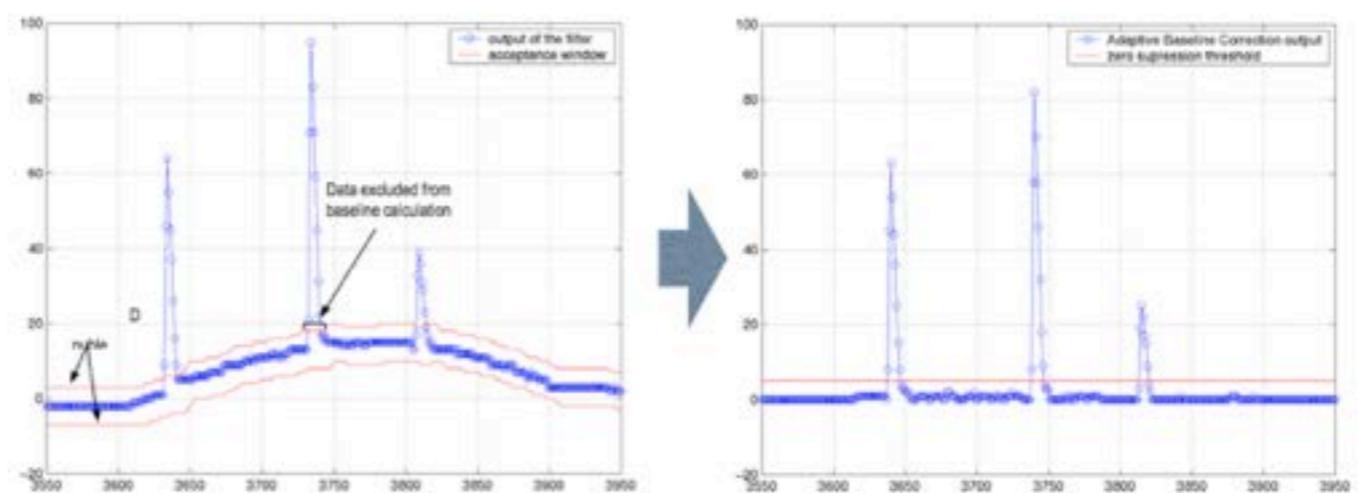
as a Pre-advanced Stage



Wire bonding package
24mm x 24mm x 1.4mm



Runs with Sampling Clock
Runs with Readout Clock



Example of baseline correction

- Received back from foundry: Q1/2011.
- Characterization done

Reference:
"S-ALTRO prototype" 27.07.2010

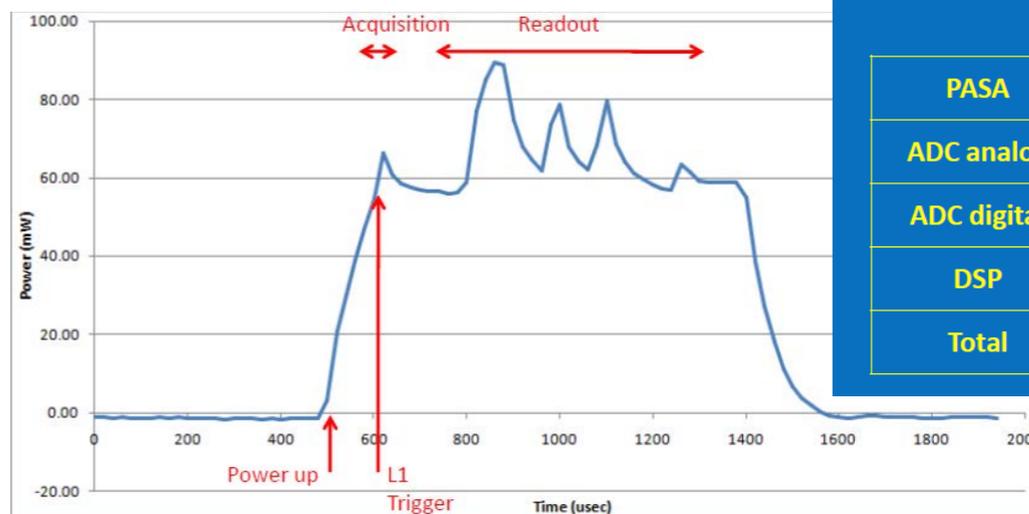


Gas detector Signal Processor ?

Our path not yet totally clear (definitely need collaboration)



S-ALTRO 16 Power Pulsing Test



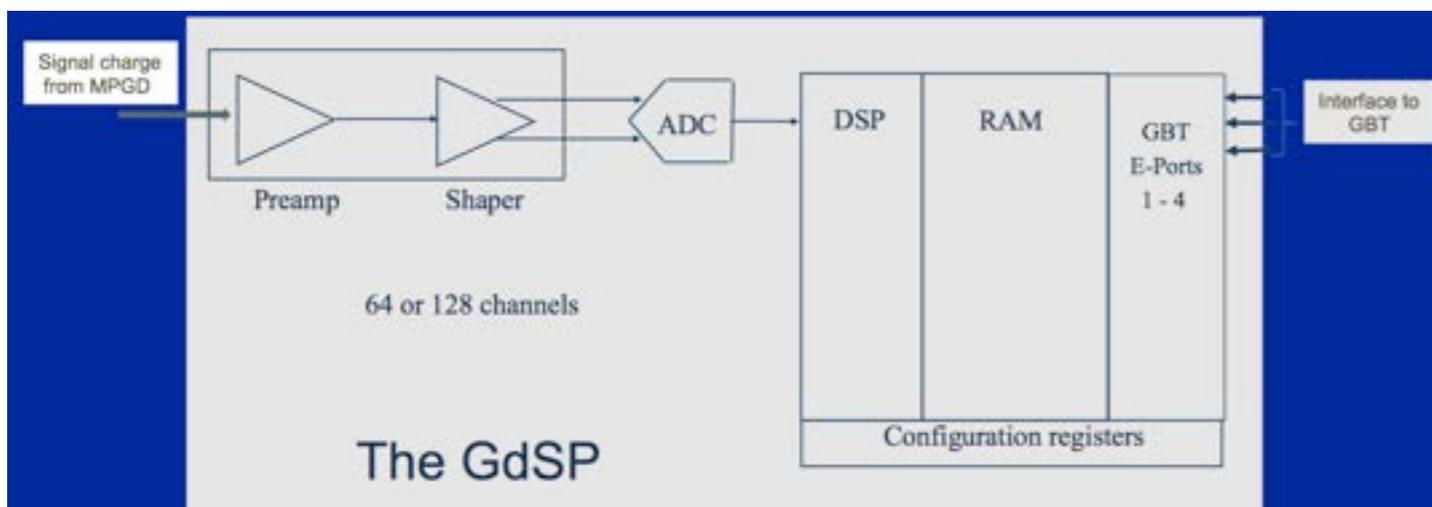
	Power (mW)
PASA	2.68
ADC analog	24.96
ADC digital	0.01
DSP	0.40
Total	28.1

S-ALTRO

- 756mW / chip if no power pulsing
- 28mW / chip if 5Hz power pulsing

Still too high!

Next Step



Natural successor of S-ALTRO chip

- Very low power ADC: 4mW/ch, complete revision of other sections, too, for **low power consumption**.
- S-ALTRO → GdSP 64 → 128ch / chip ?
- Optimized DSP
- Fully accommodates power pulsing
- Section-by-section power management
- Applications: CMS high- η , ILD-TPC, ...?



Summary



Now and Future



- The France-Japan collaboration on the LCTPC R&D has
 - clarified the basic principles to determine the spatial resolution through series of test beam experiments using a Large Prototype TPC and through development of an analytic resolution formula to understand their results, and
 - demonstrated that both the GEM and the resistive anode readout Micromegas modules meet the ILC's $\sigma_{r\phi}$ requirement.
- In addition to further R&D for solving remaining issues towards the engineering design of the GEM or MM module on each side, we need to work together on the following common issues:
 - Tracking and analysis software R&D,
 - Gating Device,
 - 2-Phase CO₂ Cooling, and
 - Readout Electronics: Analog-Digital mixed chip for (semi-)surface mounting.
- The France-Japan team has been the driving force of the LC-TPC collaboration. This tradition should continue towards the final design of the Linear Collider TPC.



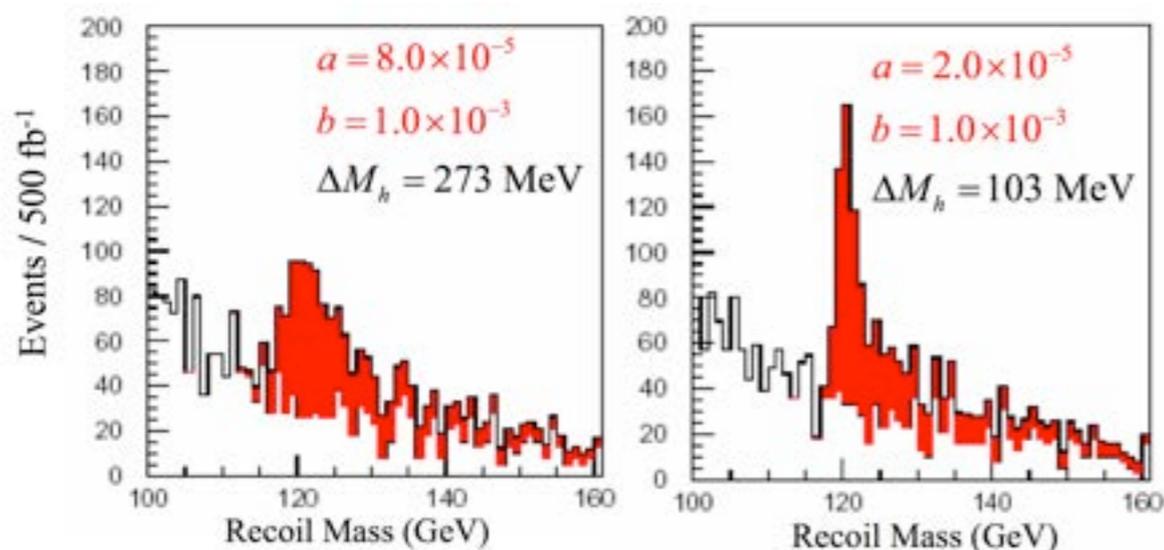
Backup



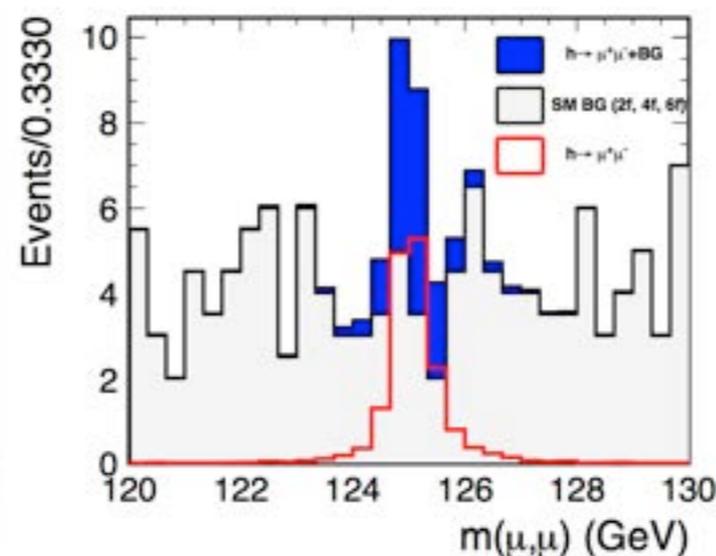
Performance Goals



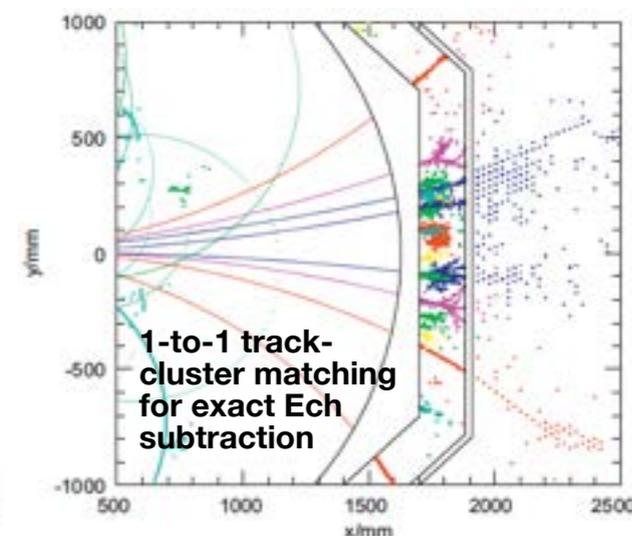
- Momentum Resolution:** $\sigma(1/p_t) = 2 \times 10^{-5} \text{ (GeV}^{-1}\text{)}$
>200 sampling points along a track with a spatial resolution better than $\sigma_{r\phi} \sim 100 \text{ }\mu\text{m}$ over the full drift length of >2m in B=3.5T (recoil mass, $H \rightarrow \mu^+ \mu^-$).
- High Efficiency:** 2-track separation better than $\sim 2\text{mm}$ to assure essentially 100% tracking efficiency for PFA in jetty events. High tracking efficiency also requires **minimization of dead spaces** near the boundaries of readout modules.
- Minimum material:** for PFA calorimeters behind, also to facilitate extrapolation to the inner Si tracker and the vertex detector



Recoil Mass Measurement



$H \rightarrow \mu^+ \mu^-$



Particle Flow Analysis