R&D for the TPC

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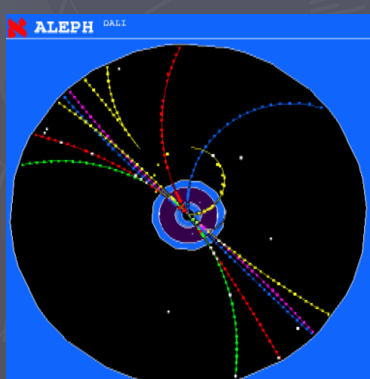
The ILD Meeting at Cracow
(24 Sept. 2013)

I apologize in advance that
I may miss the proper acknowledgements in this short talk.
I also borrow slides from others, in particular, Keisuke's.

MWPC TPC to MPGD TPC

ALEPH TPC

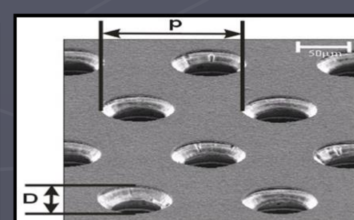


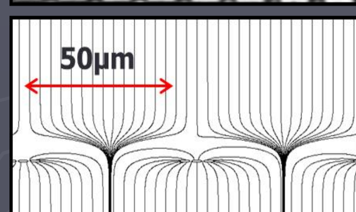
MWPC TPC: Many TPC were built with MWPC technology until now. Among them ALEPH TPC and DELPHI TPC at LEP greatly contributed in establishing the Standard Model. However , the large ExB effect around the anode wires of MWPC in the high magnetic field limit the rφ resolution even for the narrow anode wire pitch of 1mm.

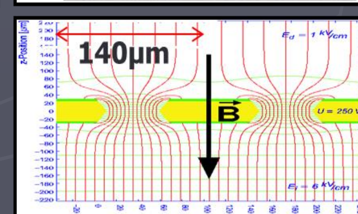
MPGD TPC: The Micro Pattern Gas Detectors (MPGD), which works as an excellent gas electron amplifier, have a finer structure of the order of 100μm achieving O(100μm) resolution.

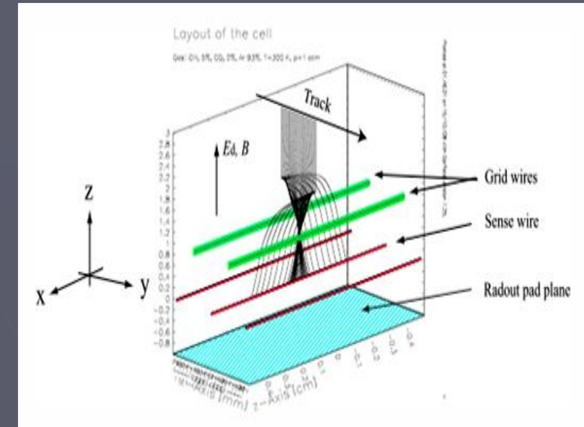
MicroMEGAS

GEM

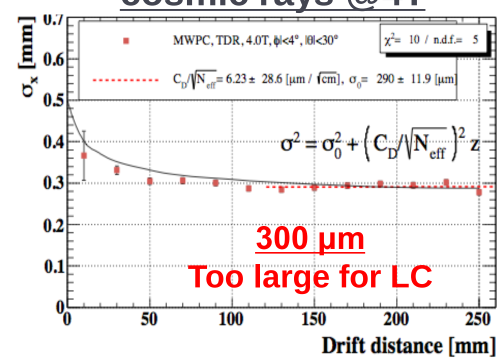




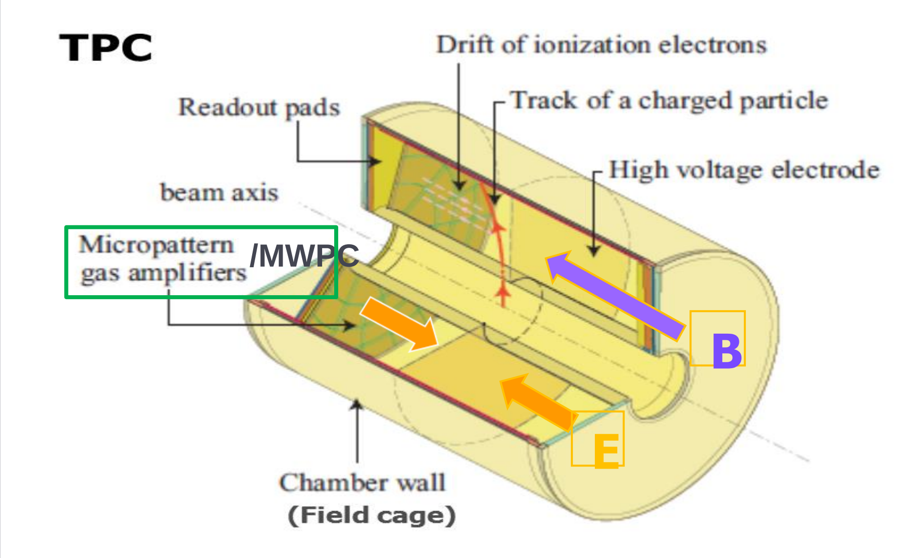




MP-TPC with MWPC: cosmic rays @4T



Time Projection Chamber (TPC)



Consists of:	**R&D/prototype**
(1) A field cage/gas container:	LP1 TPC field cage
(2) A central cathode:
(3)Two endplates:	LP1 and Space-frame prototype
(4)MPGD modules:	Different prototypes for LP beam test
(5)Readout electronics:	ALTRO, S-ALTRO16 (16ch version T2K and T2K compact (all for LP)
(6)50kV HV system and a gas system:
(7)Cooling & temperature control :	A test system of 2PCO2 cooling
(8)Software package:	Marlin 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.

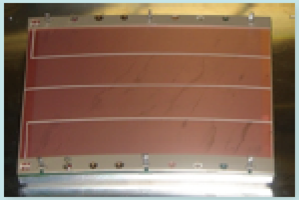
(1) Multi layer GEM with the standard pad (~1x5mm^2) readout : (charge spread by diffusion)
Asian (KEK-Saga-Tsinghua) Module, DESY module

(2) Micromrgas with the resistive-anode (pad: ~3x7mm^2) readout :
Saclay-Carleton Module

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.

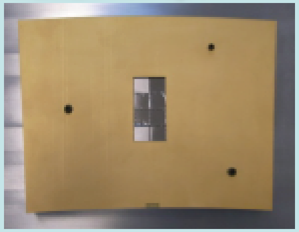
(3) InGrid Micromegas mesh on Timepix chips (pixel: ~50x50μm^2)
NIKHEF-Saclay Module, Bonn-module

Asian GEM module



MM (resistive anode)

InGrid+Timepix



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

Large Prototype

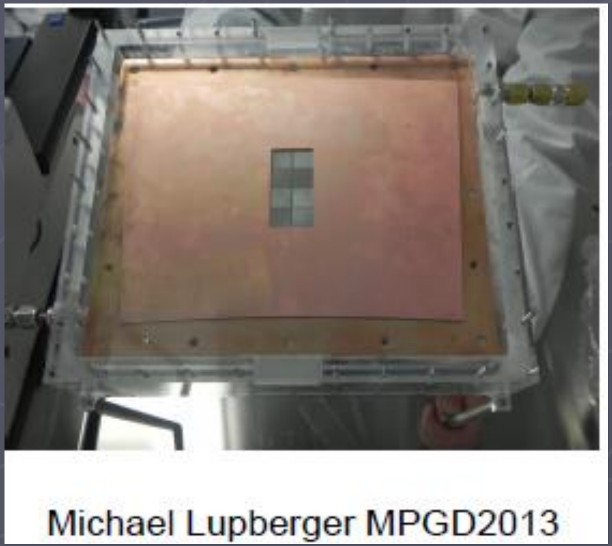
The Best MPGD TPC?

From the Principles of the Gas Physics and MPGD

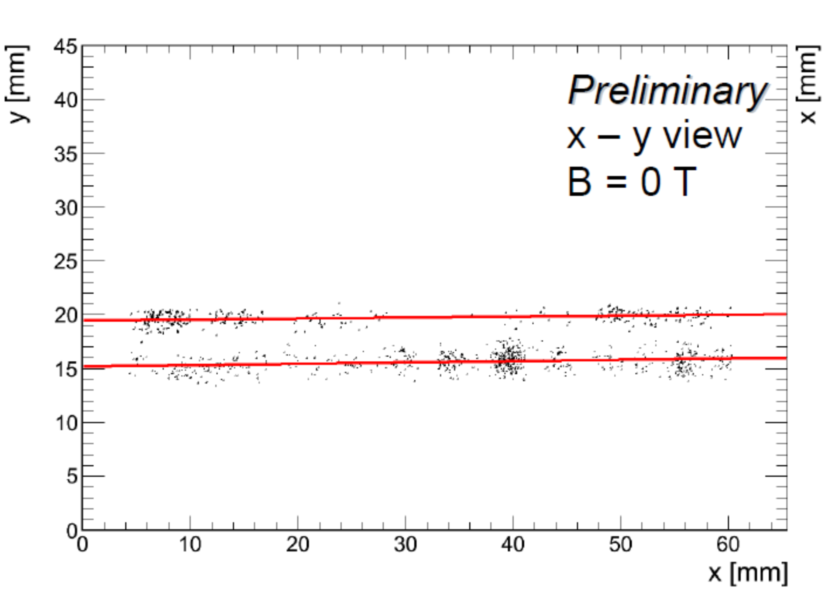
How to utilize all the information ionization electrons carry when No. of electrons and the diffusion are determined by TPC gas, the TPC lever arm, the max drift distance, and the magnetic field.

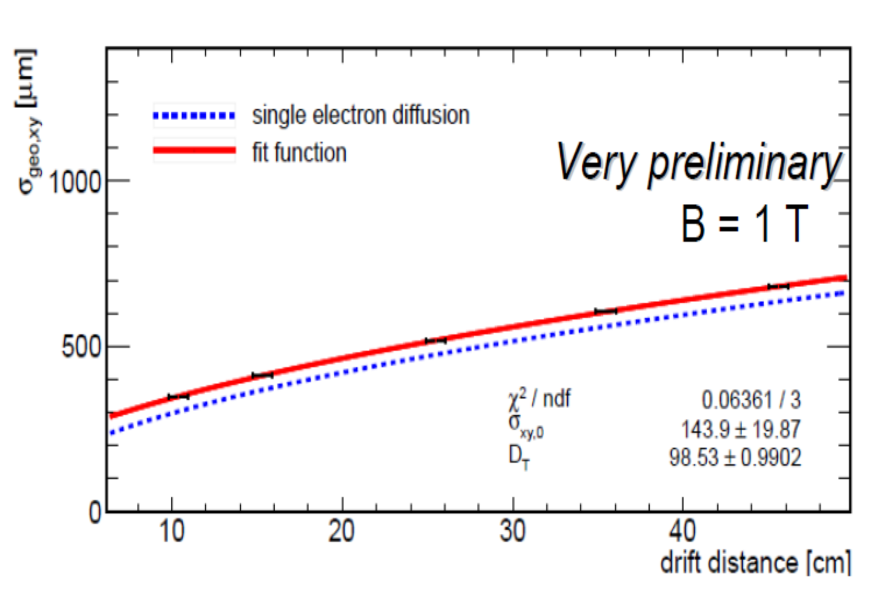
The Best: The Digital TPC (Grid Pix TPC)

Measure the arrival times and positions of all ionization electrons from all particle tracks individually by using the micromegas structure (the grid pix). Free from the gas gain fluctuation: some 30% improvement in the position resolution. Very elegant when realized!



Recent results: MPGD2013 (M. Lupberger):





To be done:

Dead region and distortion in the chip boundaries. Remove the wire bonding by **the silicon through holes** -> Timepix III.

Cooling and temperature control for TPC (a separate pixel-pad plate with cooling the time pixels might be bonded on?)

Miniaturized backend electronics of higher performance.

Position and time measurement of "all" electrons for the full drift distance of ILD TPC (the multi hit capability).

Ideas to implement the Ion gate?

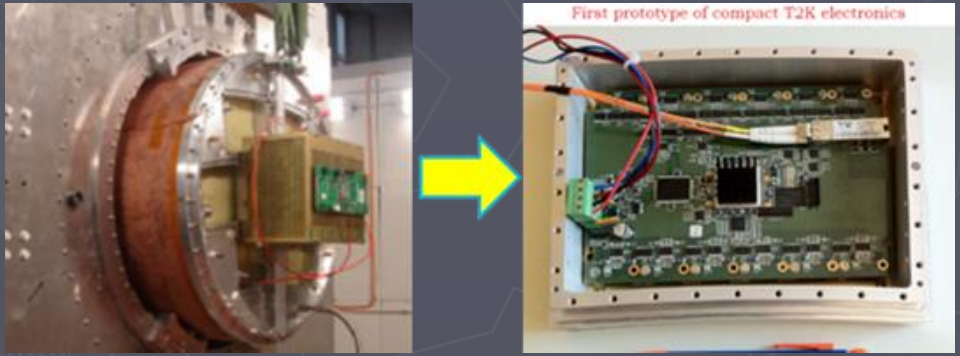
The Best MPGD TPC?

"Based on the Principles of the Gaseous TPC and MPGD"

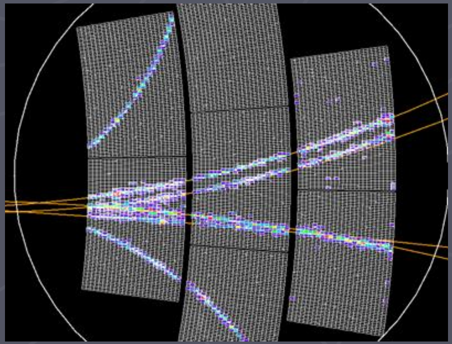
The second to the best: The Analog TPC (Pad TPC).

May be more practical at this moment. The Standard pad TPC. The position of electron obtained by the pulse heights of a few pads. Subject to the gas gain fluctuation. Use only a part of the electrons (the Effective No. of electrons Neff to obtain the hit point. Then a 30% degradation in the position resolution compared to the ideal digital TPC.

(1) Micromegas LP module with the resistive anode: With the nice compact T2K electronics. (Unfortunately the T2K electronics can not be used at ILD TPC.)



T2K electronics (Aug. 2012)



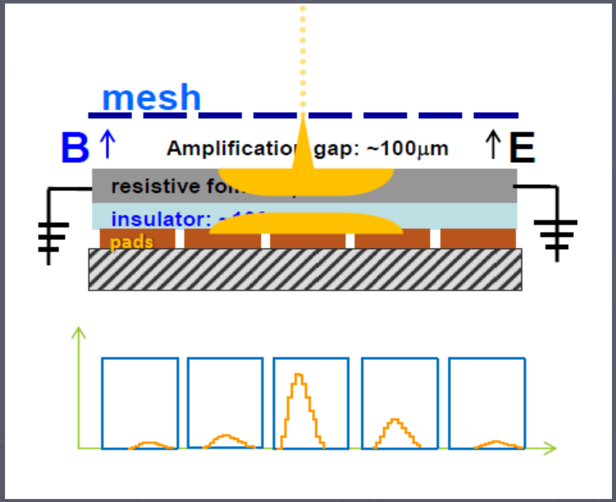
An event with the 7 modules In the beam test in 2012.

Charge dispersion by the resistive anode does not see real charges.

$$\frac{\partial \rho}{\partial t} = \frac{1}{RC}\left(\frac{\partial^2 \rho}{\partial r^2} + \frac{1}{r}\frac{\partial \rho}{\partial r}\right)$$

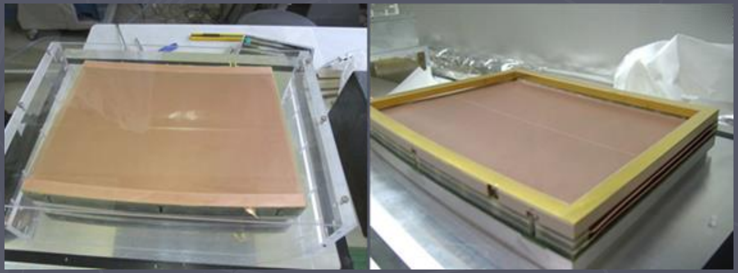
$$\Longrightarrow \rho(r,t) = \frac{RC}{2t} exp\left(\frac{-r^2 RC}{4t}\right)$$

$\rho(r,t)$: the surface charge density
R: the surface resistivity of the resistive layer
C: the capacitance per unit area.

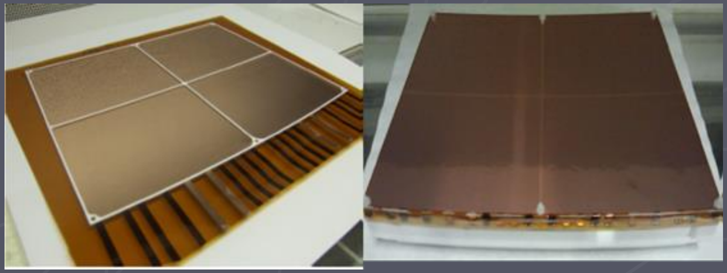


There has been aquestion if any effect of signal pile up due to the resistive anode in high occupancy? Nice to see a simulation results for ILC event + backgrounds.

(2) LP GEM modules with narrow pads (Pa d: 1mm wide):



Asian GEM module: Double thick (100μm) GEM without the side support in the sides of GEM. With (Left)/without(Right) a GEM ion gate (50% electron transmission).



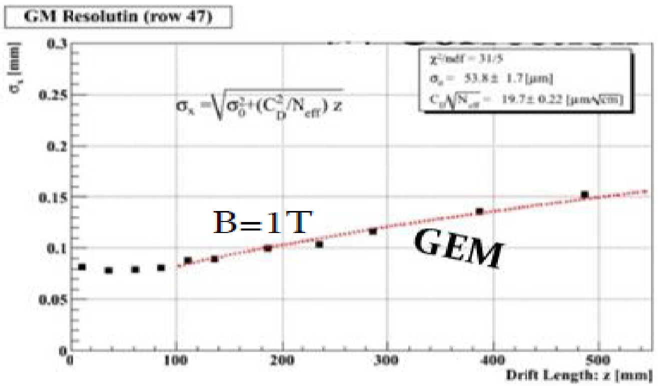
DESY GEM module: Triple CERN GEM with thin (1mmt) ceramic GEM frame (white)**.**

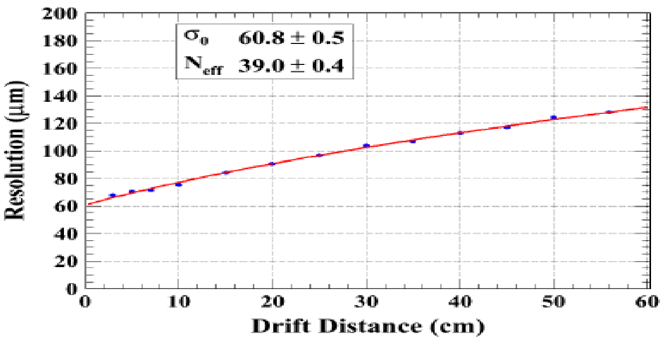
Resent results and Extrapolation to ILD TPC

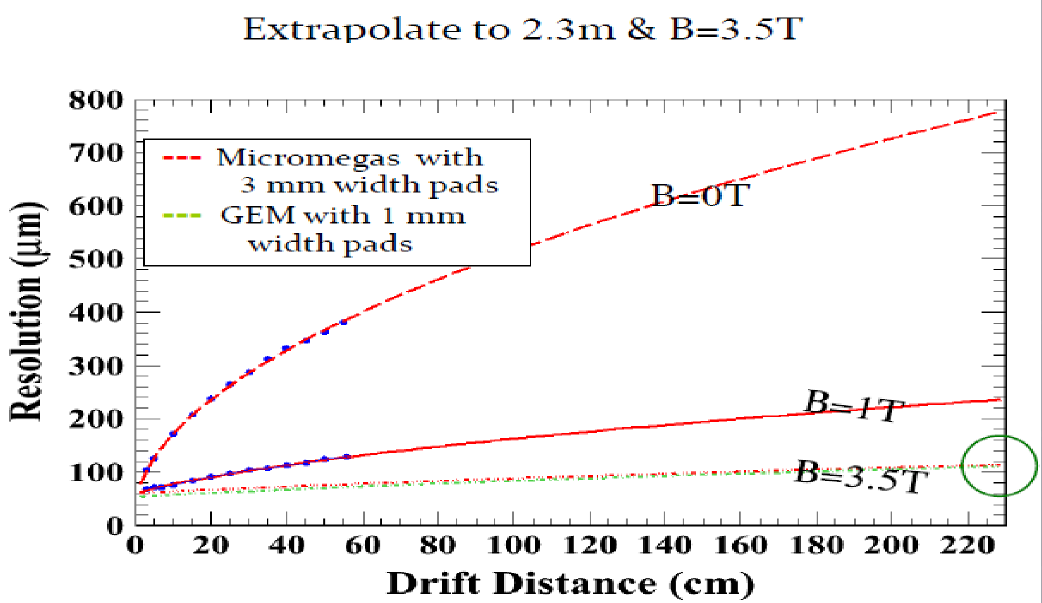
MPGD2013 (P. Colas)

$$\sigma = \sqrt{\sigma_0^{\,2} + \frac{C_d^2 \cdot z}{N_{eff}}}$$

Extrapolation of the spatial resolution







The DESY module yields similar spatial resolutions.

The extrapolation has been proved by the measurement in the 5T magnet (ILD DBD).

The extrapolation assumes a perfect TPC with no distortion, no dead region etc..

Resolution Formula for GEM TPC

K. Fujii
R. Yonamine

Since TPC operates on the nice and old "gas physics"; ionization, diffusion, gas amplification and fluctuation etc, we have derived for the GEM TPC (the option (1)) the full analytic presentation of the point resolution.

1. Charged particles ionize gas molecules. The electrons generated in this process are called seed electrons.

- Primary Ionization $P_{PI}(N)$: collision between incident particle and gas molecules
- Secondary Ionization $P_{SI}(M)$: further ionization by primary ionized electrons

N : # of primary clusters M : cluster size

2. The seed electrons drift toward the readout plane while diffusing.

$$P(\Delta x;\sigma_d)\frac{1}{\sqrt{2\pi}\sigma_d}\exp\left[-\frac{1}{2}\left(\frac{\Delta x}{\sigma_d}\right)^2\right]$$

$$\sigma_d^2 = C_d^2\, z$$

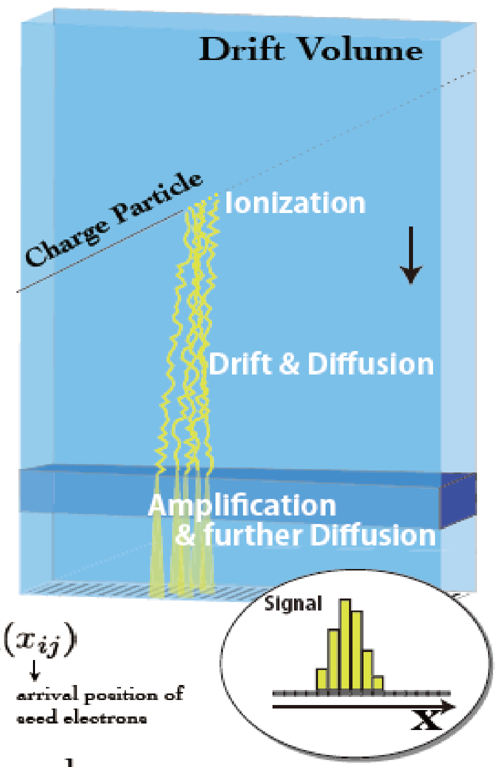
3. The Seed electrons are multiplied by a gas amplification device.

Polya distribution

$$P_G(G/\bar{G};\theta) = \frac{(\theta+1)^{\theta+1}}{\Gamma(\theta+1)}\left(\frac{G}{\bar{G}}\right)^{\theta}\exp\left(-(\theta+1)\left(\frac{G}{\bar{G}}\right)\right)$$

4. There may be further charge spread after gas amplification, and the charge spread is expressed by pad response function $F_a(x_{ij})$ and its width is specified by σ_{PRF}. This process is detector-specific.

x_{ij} ↓ arrival position of seed electrons



5. Finally the gas-amplified signals are readout with finite-width pads. We measure the coordinate of seed electrons with the charge centroid method.

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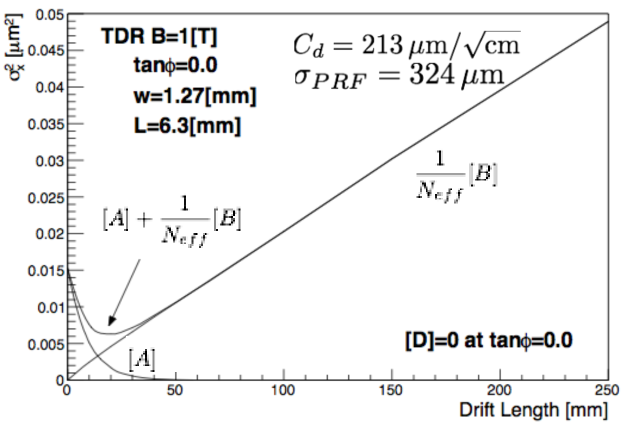
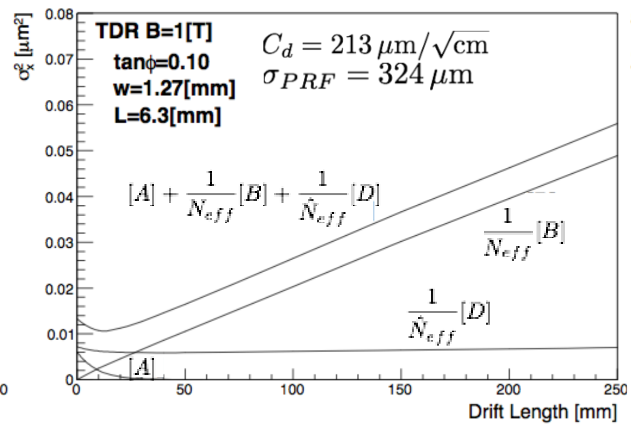
Some Examples from the Resolution Formula

Perpendicular track



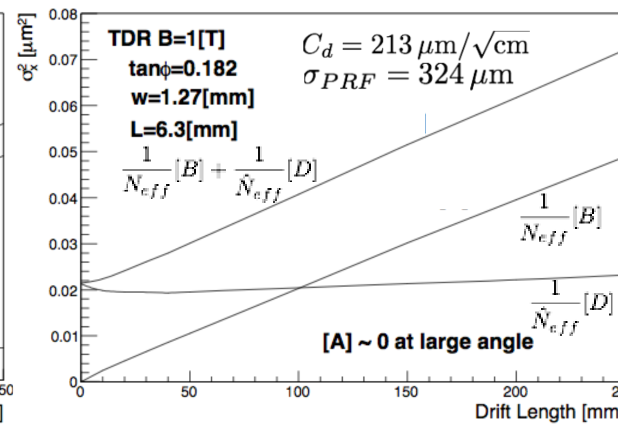
[D] is invisible.

Inclined track (tanφ=0.1)



[A] becomes smaller.
[D] becomes visible.

Inclined track (tanφ=0.18)



[A] becomes invisible.
[D] becomes sizable.

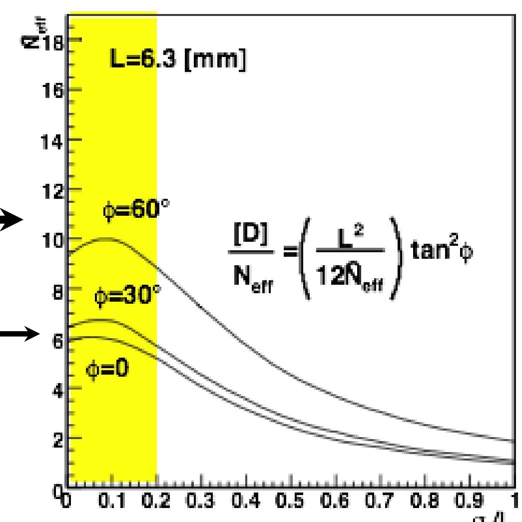
The σ_d/L will not exceed 0.2 for the LC-TPC.

$\hat{N}_{eff}$ is roughly constant in this range.

[D] term contribution is determined
not by N_{eff} but by $\hat{N}_{eff}$

$\hat{N}_{eff} \ll N_{eff}$ → **σ_x quickly deteriorates with angle.**

tanφ=0.18
-->φ=10°

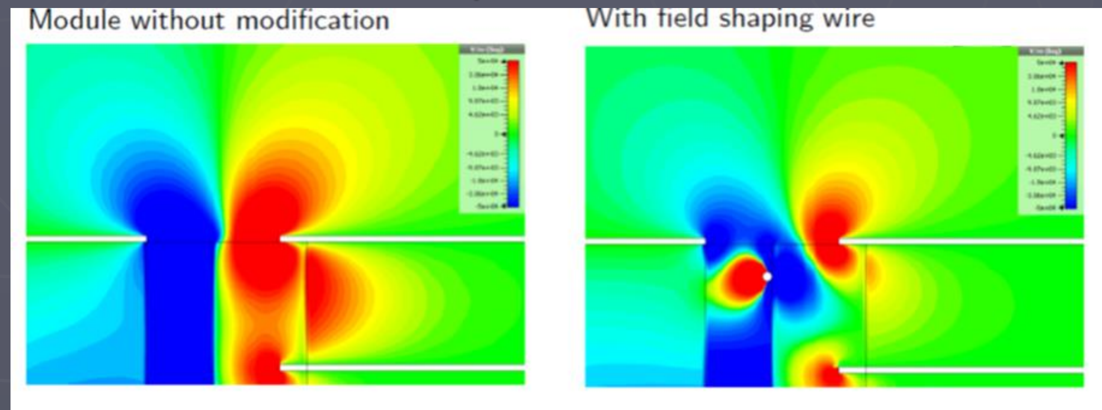


However some issues:

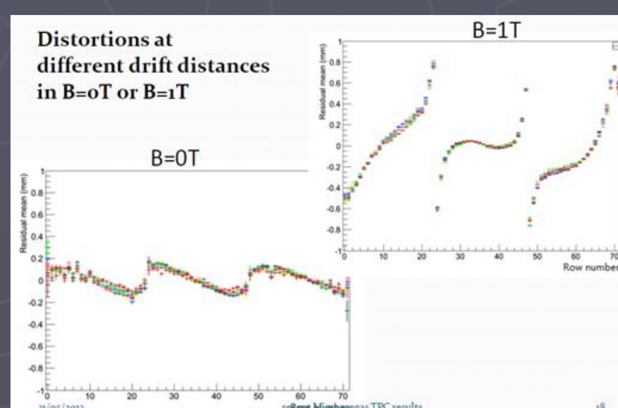
All the three pad modules see distortions of a similar pattern and of a similar size near the module boundaries. Improved module structures with additional field shaping electrodes at the module boundary should improve the distortion s well as proper alignments.

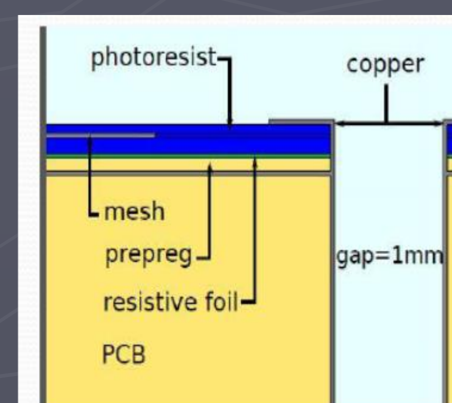
(K. Zenker for E-field simulations)

DESY GEM module:



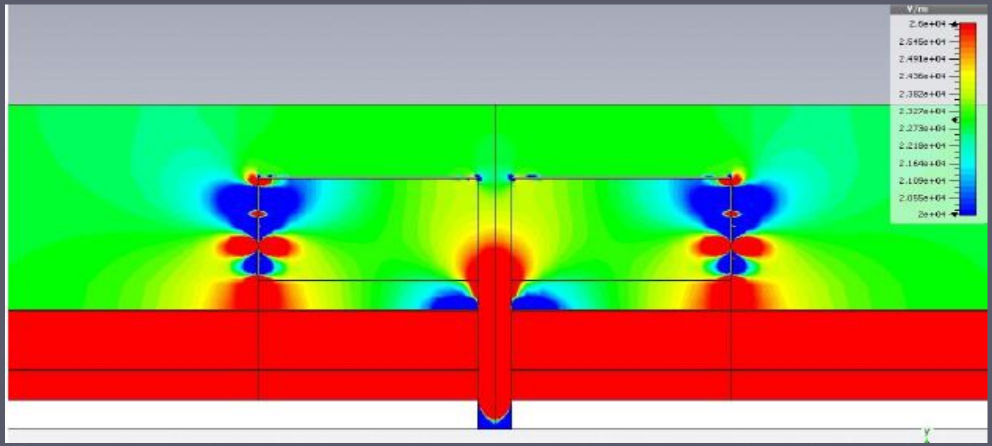
Micromegas module:



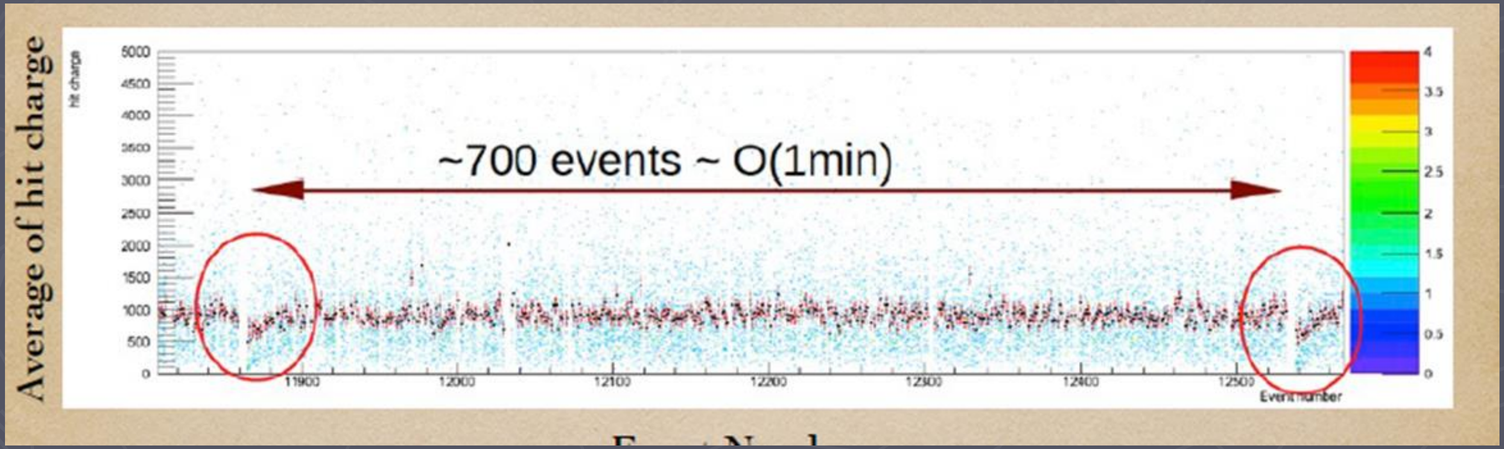


<u>Asian GEM module</u>:

In the Asian module, the upper and lower rims to stretch GEMs is wide and has 3 filed strips in the inner sides.



(2) The high micro-discharge rate of the Asian thick GEM, which would lead to a significant inefficiency of TPC, has to be avoided. Due to the specific GEM? We do not see the high micro discharge for the CERN GEM (50μt) of the DESY module. The micromegas is safe by using the resistive anode.

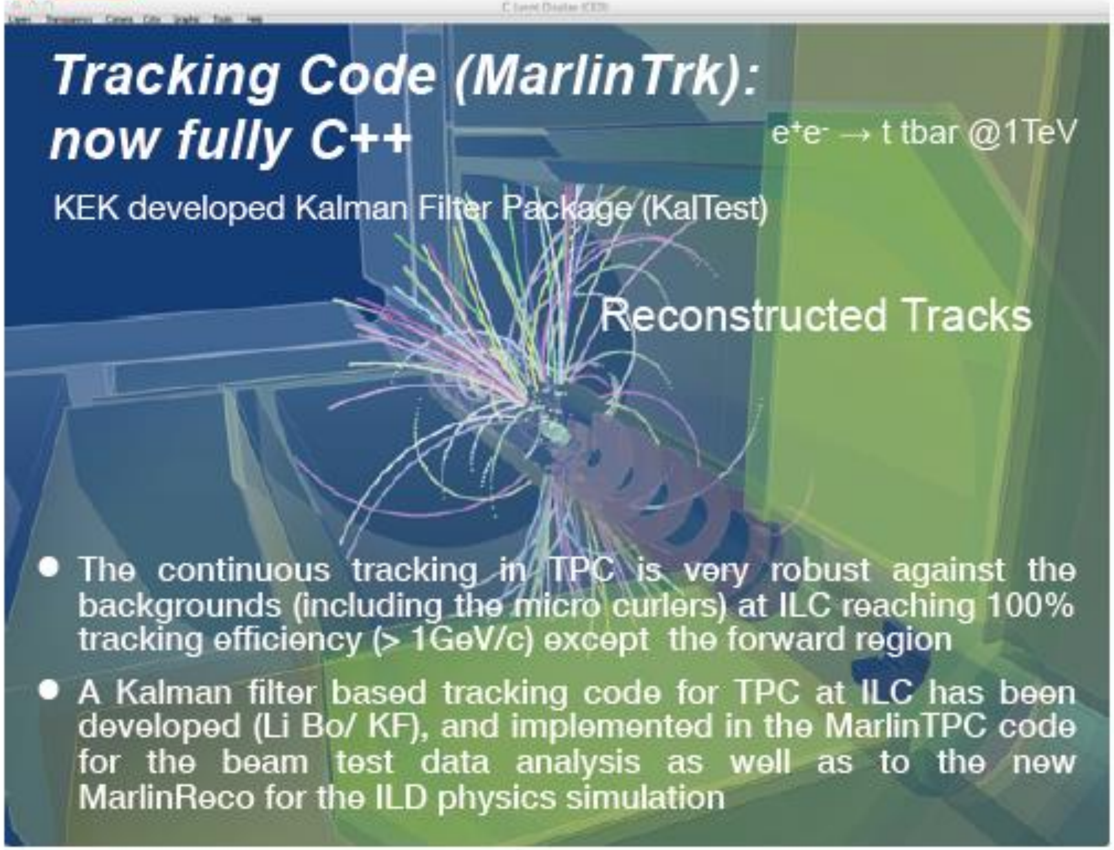


(3) How to mount the ion gate on the module (or not)? Which ion gate? This is a common problem for all three modules.

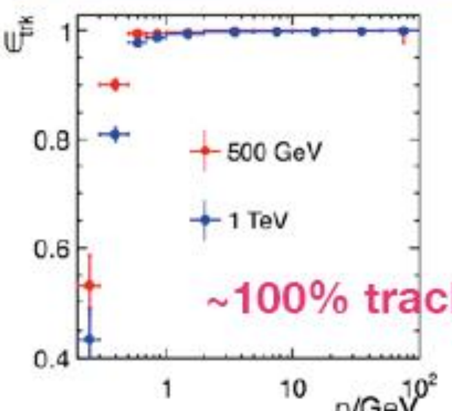
Tracking Codes for LP TPC and ILD TPC

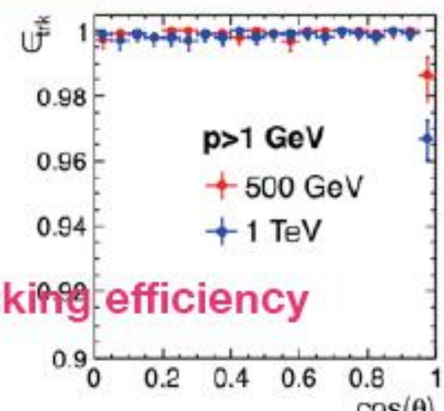
Tracking Code (MarlinTrk): now fully C++

KEK developed Kalman Filter Package (KalTest)

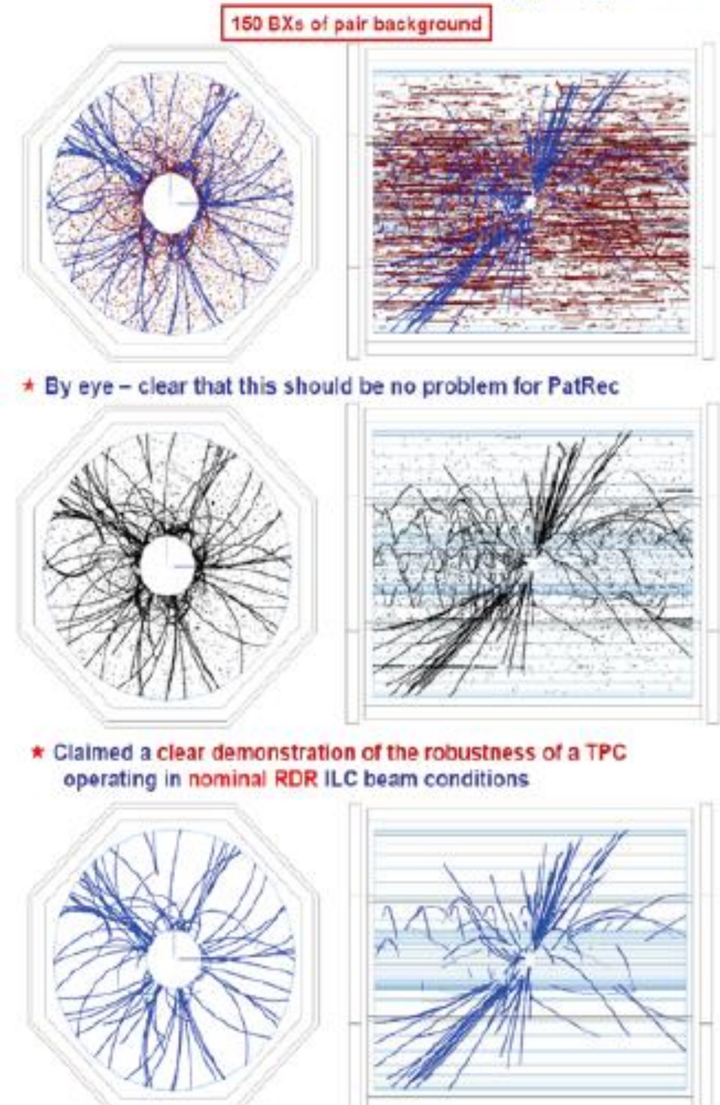


- The continuous tracking in TPC is very robust against the backgrounds (including the micro curlers) at ILC reaching 100% tracking efficiency (> 1GeV/c) except the forward region
- A Kalman filter based tracking code for TPC at ILC has been developed (Li Bo/ KF), and implemented in the MarlinTPC code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





~100% tracking efficiency



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

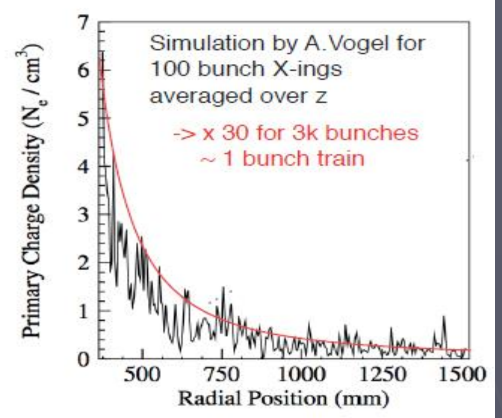
PFA performance is now better than that of LoI!

Positive Ions and Ion gate for ILC

- Solve the Passion equation for a given ion density distribution with proper boundary conditions. Then , estimate the distortion of drift electron trajectory by the Langevin equation.

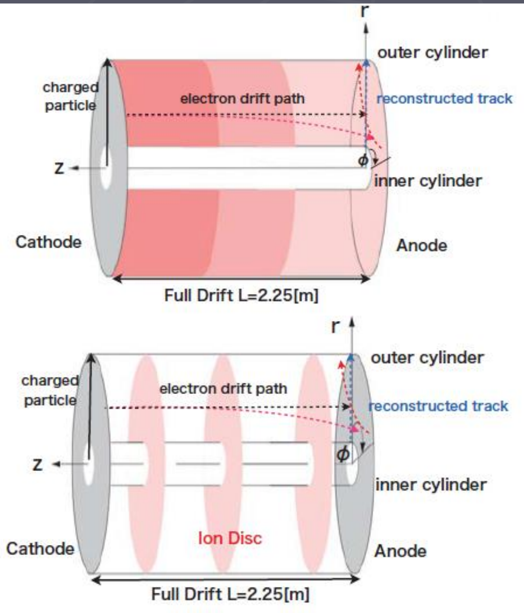
- Estimate the effect of he primary ions and the secondary ions from the amplification w/wo a gating device.

- **For the ion feed back ratio of >10^{-3} (measured both for the triple GEM and Micromegas) and the gas gain of 1,000, an efficinet ion gate device is mandatory.**



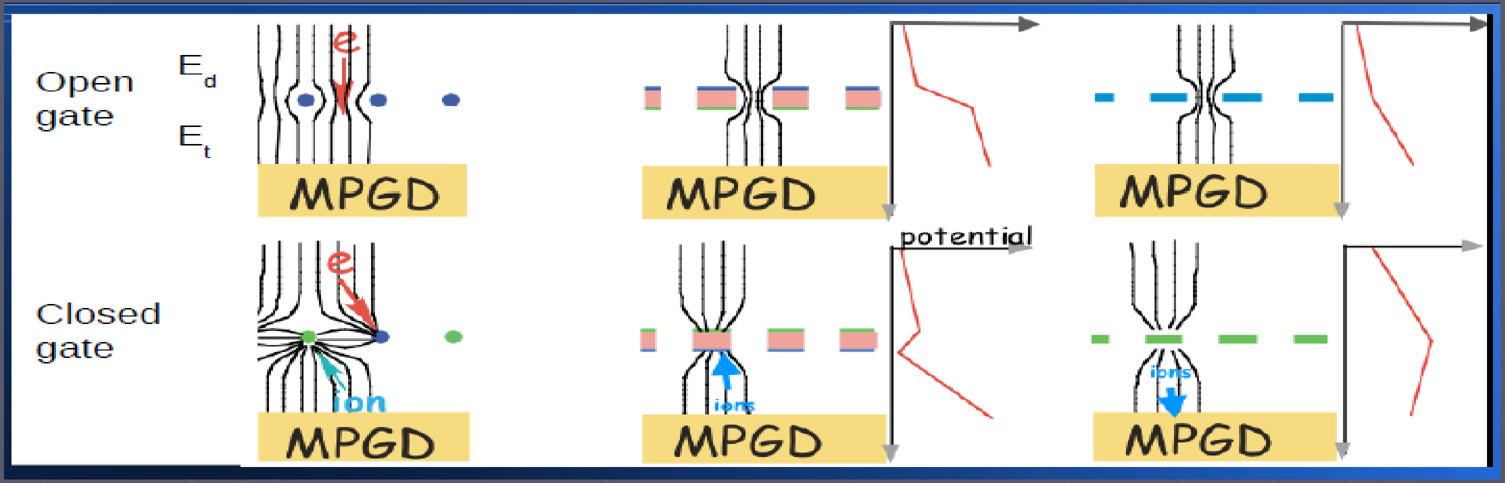
No two-photon hadron BG included.
-> underestimate

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



Ion gates for ILC

Possible options of the ion gate:



(1) Traditional wire gate
Local E-field change
On the module

(2) GEM gate
Local E-field change
On the module

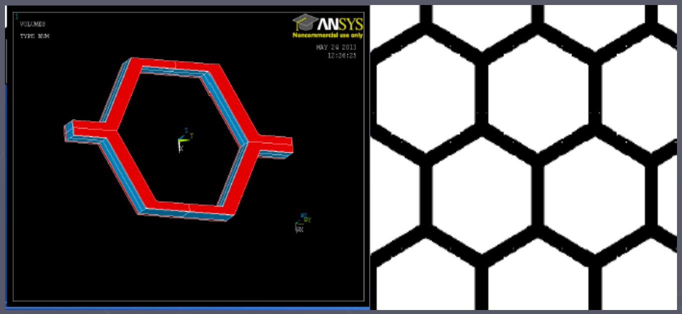
(3) Monopole wire/grid gate
Global E-field change
Also on the field cage

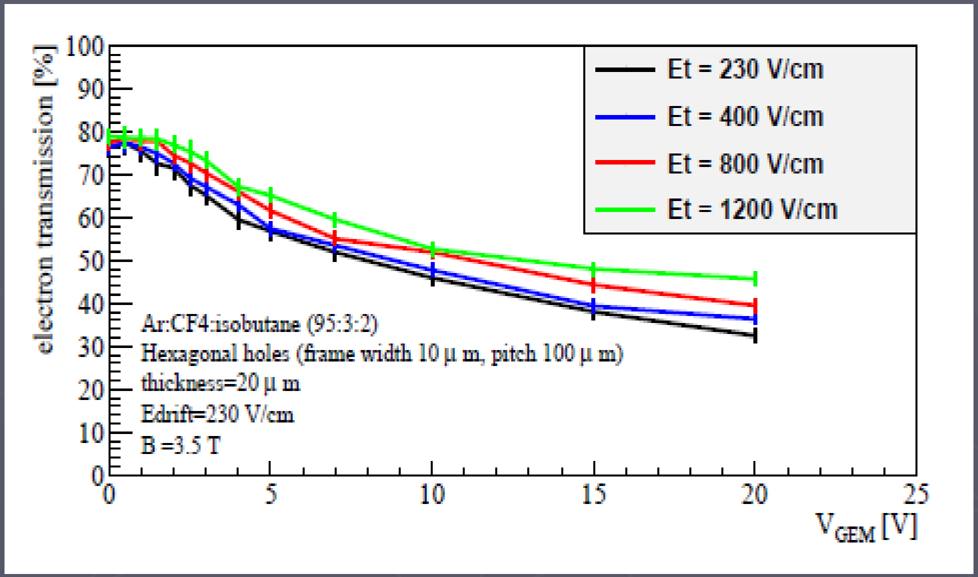
The electron transmission (open) of the current GEM gate (1) is 50%, thus deteriorates the point resolution by around 30%. This may be improved if we might be able to make a gate GEM with wider opening (>70%) . The electron transmission is proportional to the opening at high magnetic field (3.5T). The questions is if the gate GEM with very thin rim (10-30 μm) can be made and if it might be strong enough.

The option (1) has impacts to the module structure, and (3) is a brute force.

Some Studies of the Ion gates are Resumed:

(1) **GEM gate with a larger aperture:**

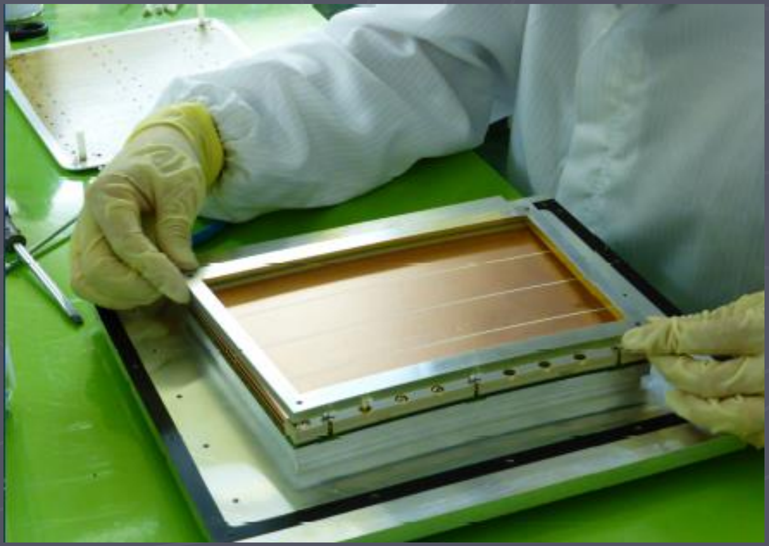




In high magnetic field and with a gas of high ωτ the geometrical aperture determines the electron transmission. (MPGD2013: P. Gros) The above Structure offer 81% aperture.

(2) Wire gate mock up:

A wire gate mock up to check possible Distortion due to the radial gate wires The test will be made using a laser beam.



TPC Electronics for Pad Readout

T2K electronics with After chip:

Nice results from R&D. Can not be use for ILD TPC because of the sampling depth.

PAC16 low-noise preamplifier with ALTRO:

Used for GEM modules in the LP- TPC beam test successfully.

S-ALTRO16 : The first low-noise digital-analog mix chip.

Power pulsing has been tested successfully at chip level.

Density: The bare chip size (3 mm^2/ch) is small but still not enough even if the 64ch version. Currently 16ch/chip.

Power: ADC takes large power : 30-40mW/ch Then 756mW/chip or 28mW/chip for 5Hz power pulsing (ILC).

GdSP: A project of a new digital-analog chip for MPGD (TPC) readout aiming at:

Very low power ADC: 4mW/chS-ALTRO →

64 -128ch / chip

Optimized DSP.

Fully accommodates power pulsing

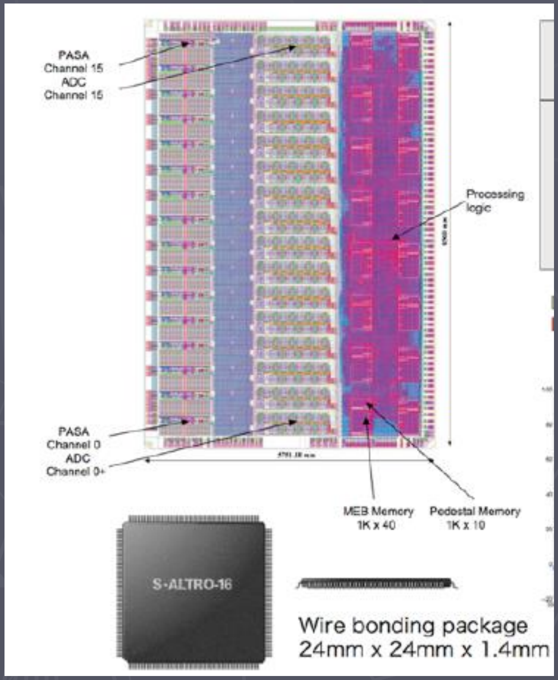
Section-by-section power management

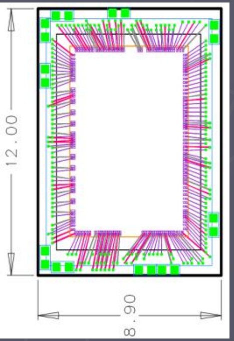
However the current status of the GdSP project /collaboration seems to be unclear.

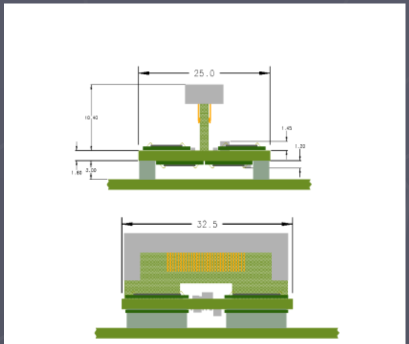
Implementaion of S-ALTRO16 for LP module

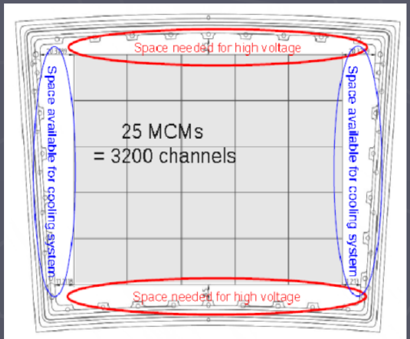
Difficulties from the low density (16ch/chip) and the high power (756mW/chip) of S- ALTRO16 chip:

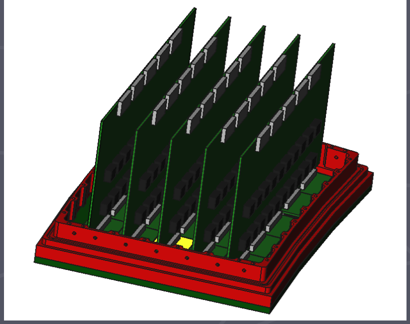
Double-sided mounting (8 chips) on the MCM board
One MCM board: 22Watt.
Vertical assembly of the low-voltage boards.
Accommodate 3200ch for one LP module (or a pad size of 1 x 8.4mm^2) with a big effort.









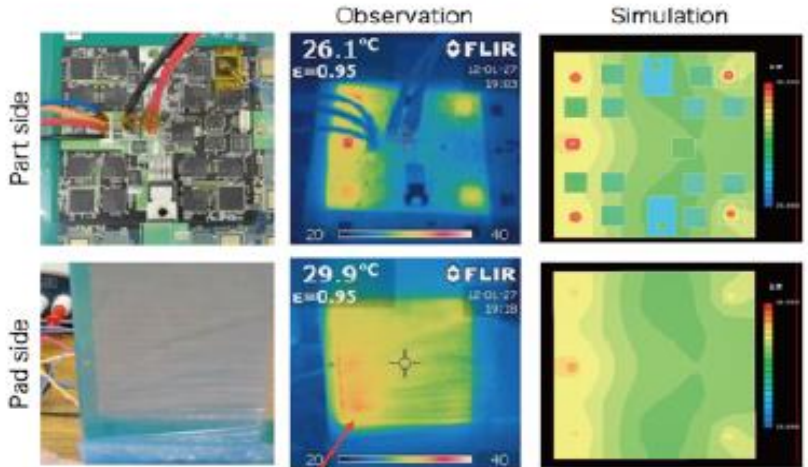


Implementaion of S-ALTRO16 for LP module

R&D on Power Pulsing and Cooling

Test with Dummy Module

Comparison with simulation

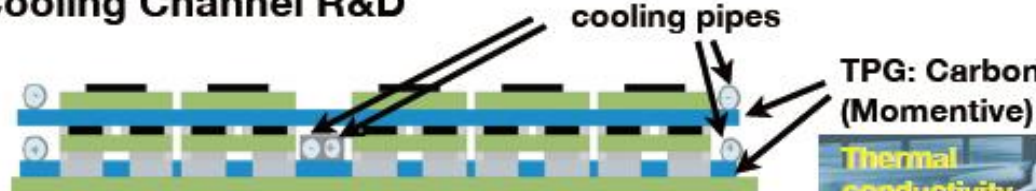


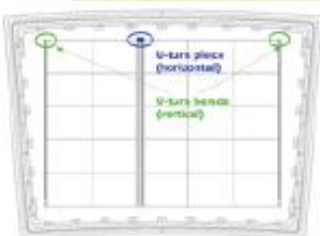
P_{tot} = 1.44W

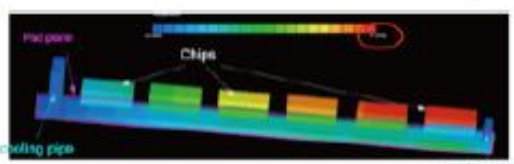
$$\Delta T \text{ will be } > 10\,[K] \times \frac{57\,[W]\ (16\ \text{SALTRO's})}{1.44\,[W]\ (\text{this experiment})} \times 1.5\,\%\,(PP) = 5.9\,[K]$$

(extrapolation to the case w/o cooling, w/ PP, w/ SALTRO64)

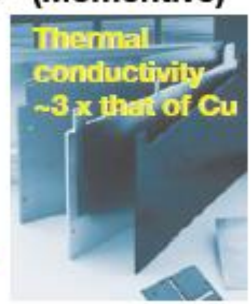
Cooling Channel R&D







Thermal simulation



June, 2013

Personal Comments

At the 500GeV LC, the pad-readout MPGD TPCs satisfy the requirements. Then we need to focus more on engineering aspects for stable and reliable operation solving the “Old and Nice Distortion Problem of TPC”.

We need to come up with a design of gate device. The default option is the old wire gate known to work.

To reduce the material budget in the TPC endplate, we need some drastic(?) approach to electronics mounting and cooling.

For the high energy (> 1TeV or more), we need a pixelised TPC, sovling the problem of the ditortion by the primary ions.

Fort he high energy (1TeV or more), the occupancy and the effect of (primary) ion have to be addressed carefully to judge if TPC, a very nice 3D detector, might still be one of the best detectors.

Next Steps: Personal proposal

TPC R&D before the LOI call by the ILC Lab.

Before LOI:

(0) Solve the current problems of the modules asp.

(1)The options of the gate device has to be prioritized, say in two years.

Note: For advanced options of gate, we will continue our R&D(s). There might be a small possibility of a GEM gate with larger (>70%) electron transmission. It is too early to estimate its probability of success.

(2) When the gate device is on the module, the modules with a gate is to be beam tested. This may take at least two years.

(3) An internal (LC TPC collaboration) review of the specifications of the ILD TPC MPGD module should be made.

Note: Based on all tests done with the LP modules (including ones with gates), we are better to review and agree on the specifications of the ILD TPC and its MPGD module. Besides the issues which have been discussed, there may be some issues in mounting a gate, to minimize the local distortions, and from the readout electronics.

Next Step: Personal proposal
TPC R&D before the LOI call by the ILC Lab.

(4) One year before the LOI, we prioritize our current MPGD options based on their performances by tests and simulations according to the specification.

(5)Design of the ILD TPC for LOI:

In parallel to the work on the MPGD modules, we design "all the components of ILD TPC" for LOI. At least we prepare the specifications, and draft but detailed drawings of all the components. We will perform simulations necessary to decide the specifications.

Note: To do this, we need to reorganize/restart our ILC TPC engineering group asp.

(6) A agreed specification and a progressive design of the ILD TPC readout electronics for LOI

Note: To do this again we need to organize our own electronics group "within the ILC TPC collaboration" asp (even if it might be a small group) to form any necessary collaboration with outside groups. We need to find more budget of our own.

(7) A plan and schedule of the ILD TPC construction has to be agreed.