TPC:
status and open questions.

Annika Vauth

Hamburg, 28.08.15

125th ILC@DESY General Project Meeting

Motivation

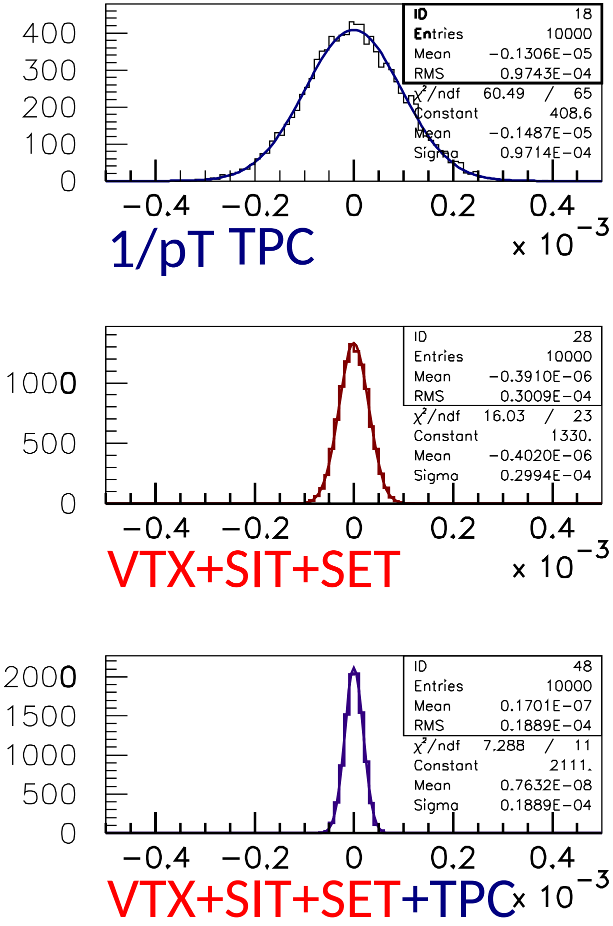
Readout technologies

Other open questions

Next steps

Requirements ILD TPC.

- **Momentum resolution**
  $\sigma(1/p_t) = 2 \times 10^{-5}$ /GeV
  (TPC alone 10^{-4} /GeV)
  single point resolution $\sigma_{r\phi} < 100\,\mu\mathrm{m}$
- **Tracking efficiency**
  close to 100% down to
  low momenta for Particle Flow
  $\approx$ 200 points along track in TPC
- **Minimum material**
  in front of calorimeter
  TPC: less than $0.05 X_0$ (barrel)
  / $0.25 X_0$ (endcaps)



1/pT TPC

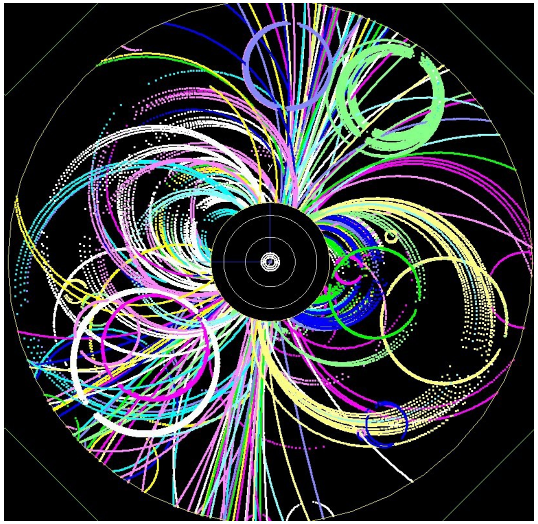
VTX+SIT+SET

VTX+SIT+SET+TPC

J. Timmermans, LCTPC WP meeting 207

Detector design / optimisation
→ study technologies & impact on physics performance

Requirements ILD TPC.



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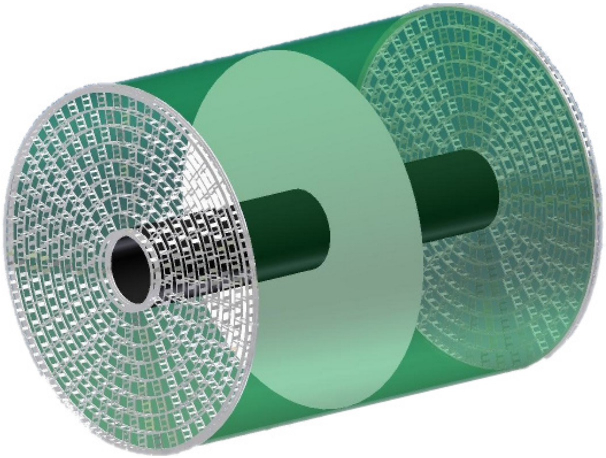
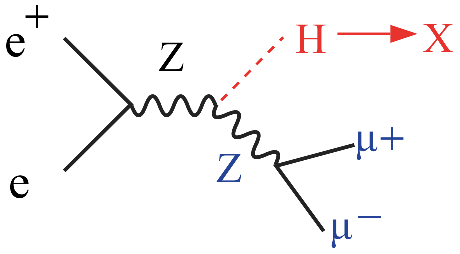


Cornell University (2010)

Detector design / optimisation
→ study technologies & impact on physics performance

TPC - physics performance (1).

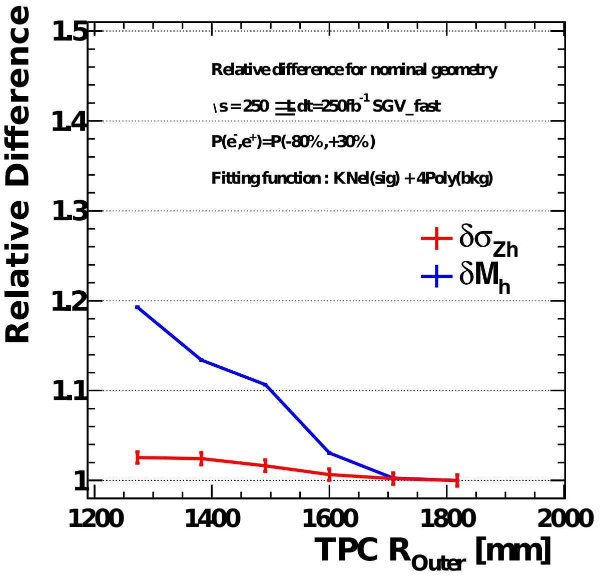


Example 1: momentum resolution

Higgs leptonic recoil mass measurement:
peak width from beam energy spread
and momentum resolution

TPC outer radius matters: $\sigma_{\mathrm{pt}} \sim 1/BL^{2.5}$

radius reduced from 1.8m → 1.4m:
ΔM_H gets worse by 12% ($\sqrt{s} = 250\,\mathrm{GeV}$)
even worse (25%) at $\sqrt{s} = 350\,\mathrm{GeV}$



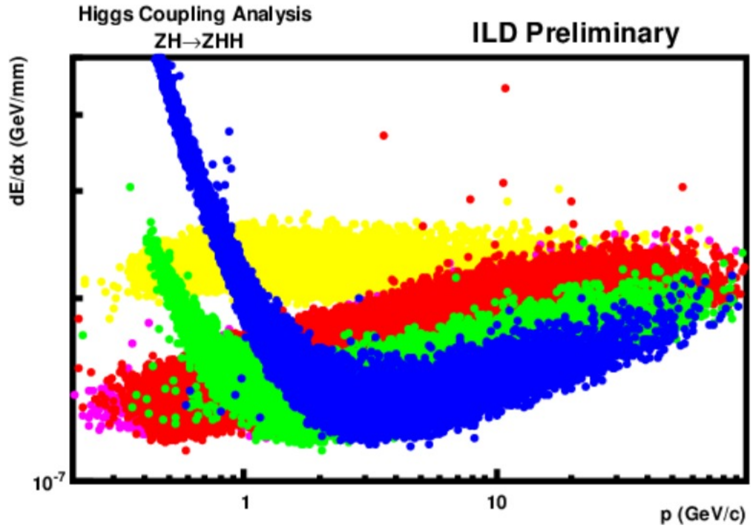
optimization study Tomohisa Ogawa

Need more integrated luminosity to get the same precision
Other possibility: increase B-field

very detailed study of length / radius / B-field regarding performance and cost: see e.g. talk M. Berggren, ALCW2015

TPC - physics performance (2).

Example 2: dE/dx



particle ID study Masakazu Kurata

Higgs coupling analysis :
$HH \rightarrow bb\ WW^* \rightarrow bb\ l\nu jj$

include dE/dx (and shower profile)
in lepton ID for isolated lepton

signal detection efficiency almost the same
background rejection efficiency improved

Single lepton ID	Cut based	Old likelihood	New likelihood
Signal (%)	98.1	98.1	97.8
ttbar – all hadronic(%)	7.9	3.1	2.3

M. Kurata

Improvement of all-hadronic event rejection: $\sim$ 30%

assuming 5% dE/dx resolution for TPC - needs to be studied in detail

TPC - physics performance.

We need to look at

- impact on high momentum tracking
- impact on low momentum tracking
- momentum resolution in prototypes
- two tracks separation
- dE/dx
- advantages from continuous tracking

$\Rightarrow$ impact of TPC performance on physics studies?

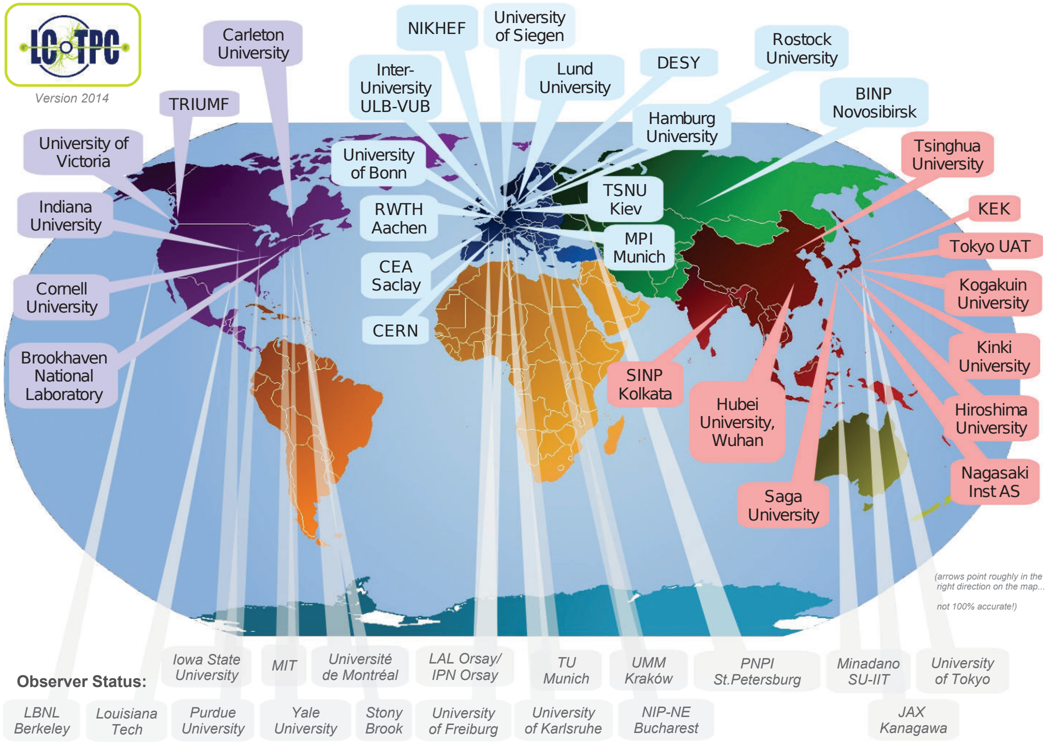
Motivation

Readout technologies

Other open questions

Next steps

LCTPC collaboration.

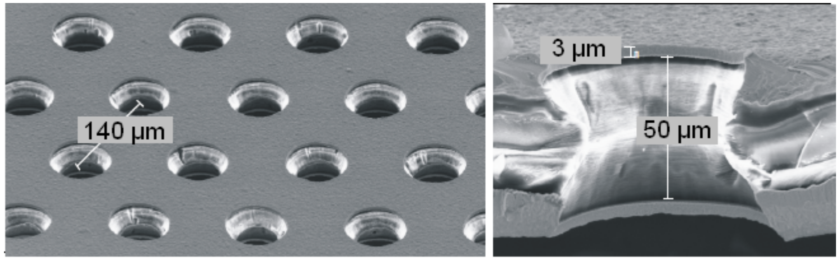


(arrows point roughly in the right direction on the map... not 100% accurate!)

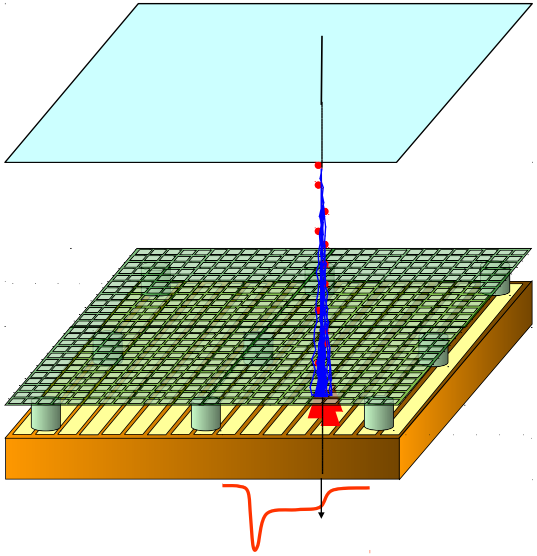
Detector options.

Micro-pattern gas detectors as amplification structures

- Micro-Mesh Gaseous Detectors (MicroMeGas)
- Gas Electron Multipliers (GEM)



F. Sauli, NIM A386 1997



Y. Giomataris et al., NIM A376 1996

Different readout options

- anode plane with pads (Asian GEM module: 1.2 mm × 5.4 mm pads in 28 rows, DESY GEM module: 1.26 mm × 5.85 mm pads in 28 rows, Micromegas module: ∼3 mm × 7 mm pads in 24 rows)
- pixel readout (TimePix chip: 256x256 pixel, size: 55 µm × 55 µm)

Current status and projects.

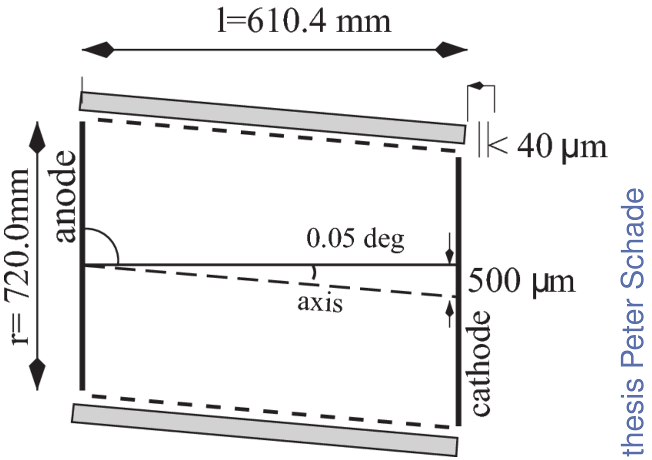
Different combinations of amplification and readout technologies being investigated

Various prototype modules :

- GEM modules with pad readout (DESY, Japanese groups)
- Micromegas modules (Saclay+Carleton)
- TimePix modules (Bonn, NIKHEF+Saclay)

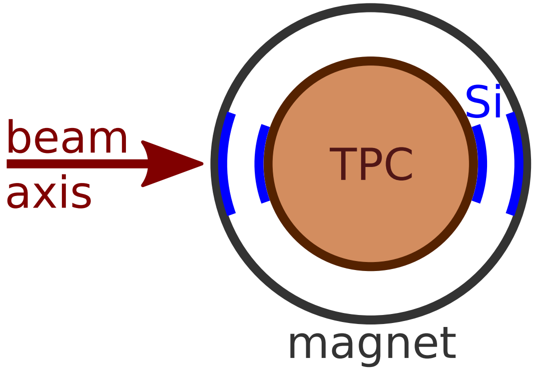
For module tests: infrastructure at DESY testbeam
large prototype for 7 modules (module size $\sim 17 \times 23\,\mathrm{cm}^2$)

Common testbeam infrastructure.



Recent and future improvements of TPC testbeam infrastructure

- external reference tracker
  for momentum measurements:
  essential due to beam spread
  and scattering in magnet
- new large prototype:
  prepare for use of light-weight endplate,
  ($\sim 16\% X_0 \rightarrow \sim 8\% X_0$)
  second field cage in preparation
  (better E-field homogeneity, ...)

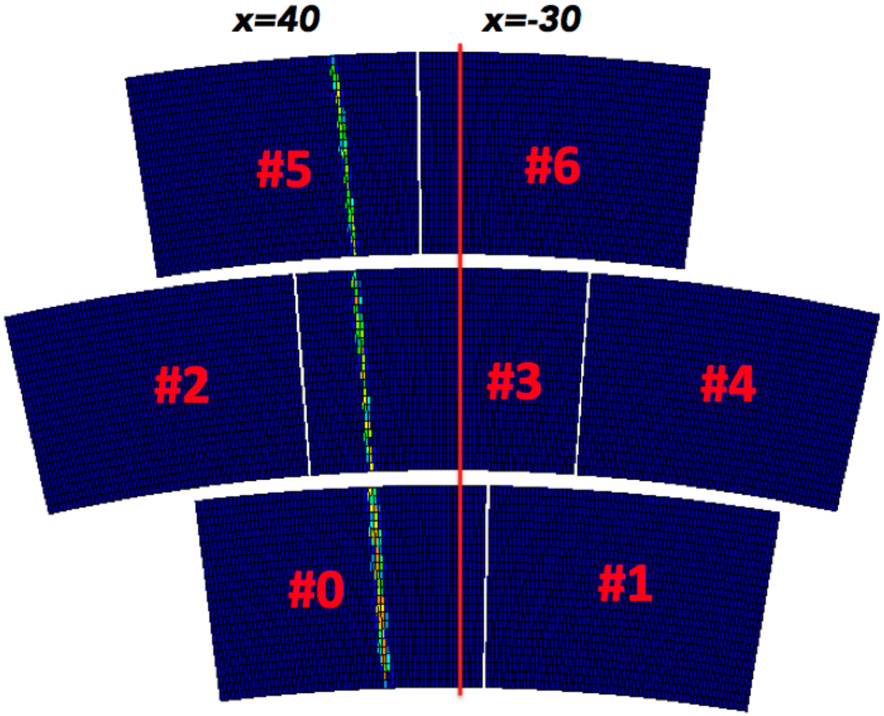


- ... more, e.g. CO_2-cooling, movable stage calibration, mounting tool for the modules.

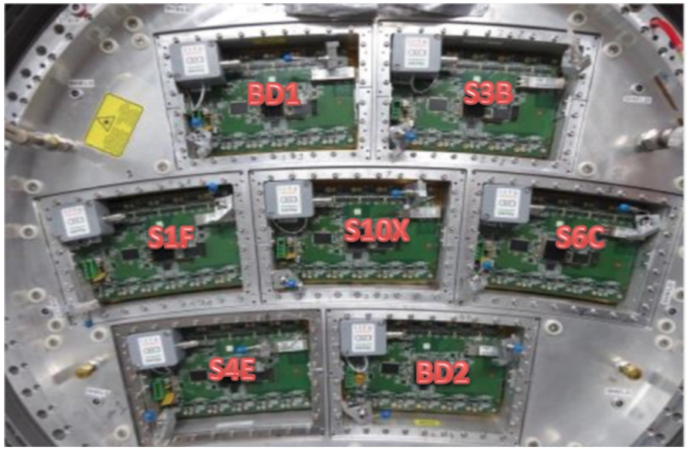
Testbeam 2015: Micromegas (1).

Testbeam beginning of March 2015

7 modules: 5 carbon-loaded kapton, 2 “black diamond“ (Diamond-like carbon))



S. Ganjour, ALCW2015

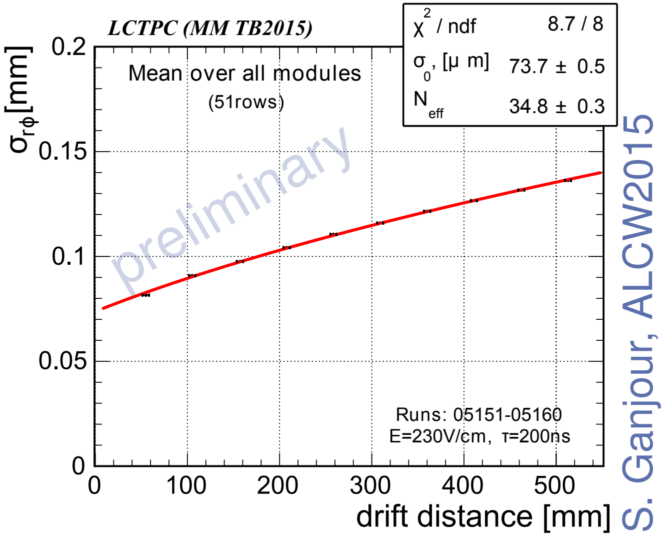


S. Ganjour, ALCW

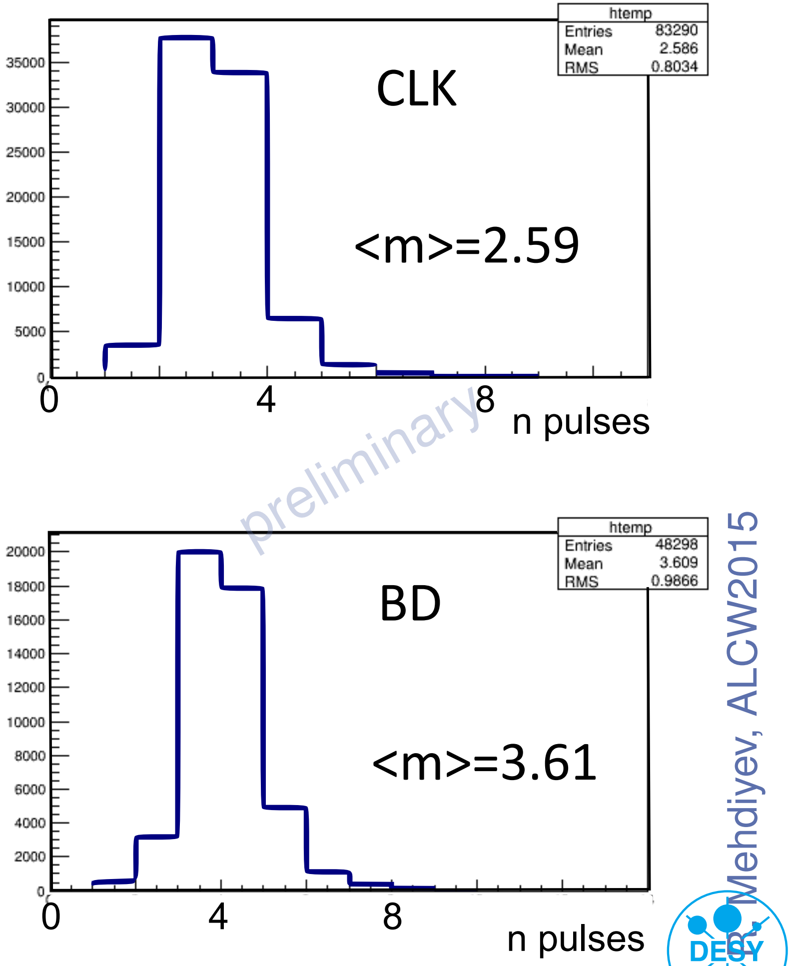
Testbeam 2015: Micromegas (2).

Analysis of testbeam data in progress

examples: point resolution



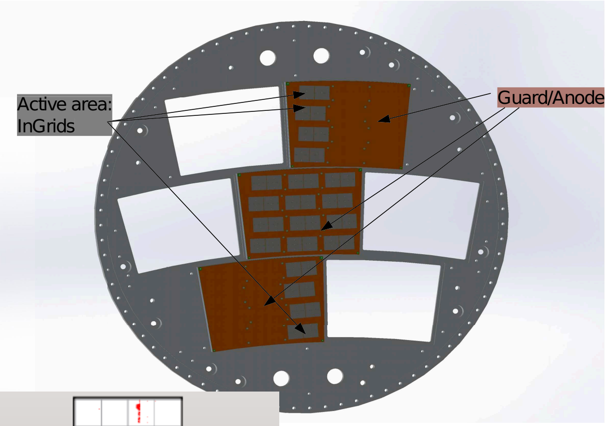
pulses per hit



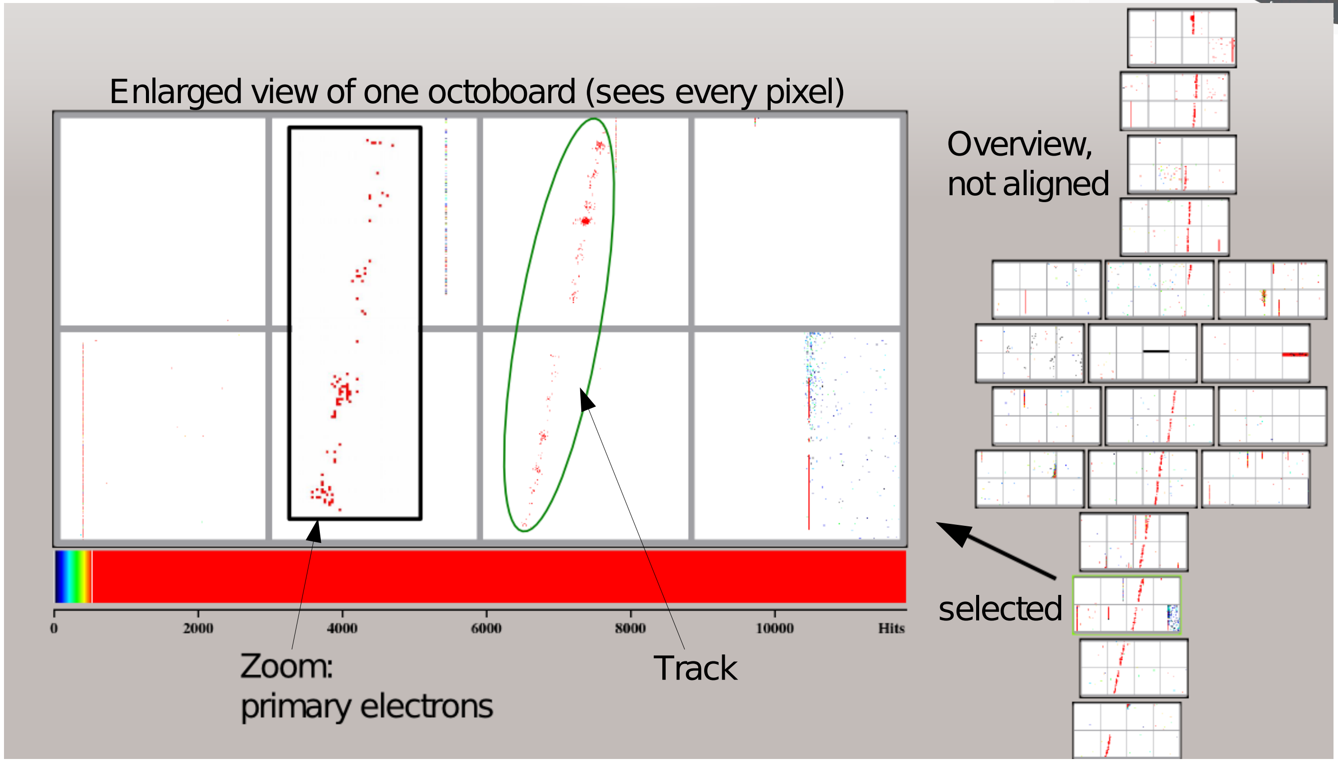
Testbeam 2015: pixel (1).

Testbeam in March / April 2015

3 modules (1x96, 2x32 InGrids)
$\approx$ 10 mio. channels



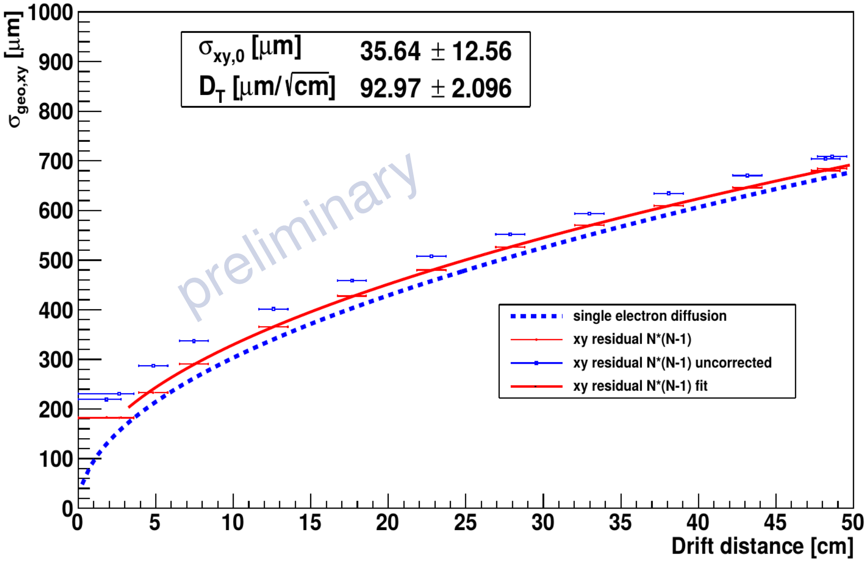
M. Lupberger, ALCW



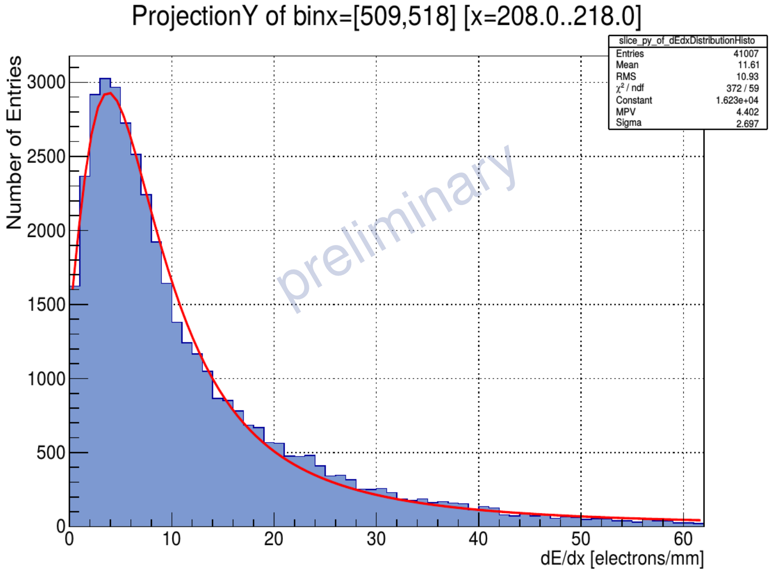
Testbeam 2015: pixel (2).

Analysis of testbeam data in progress

examples: point resolution



dE/dx single chip



M. Lupberger, LCTPC-pixel meeting 19

Readout modules: current status.

Basic requirements like point resolution met similarly well

Different issues remain to be addressed
(e.g. high-voltage stability of GEM-modules,
show that pile-up in the resistive anode won't be a problem at ILC for Micromegas-modules,
readout frequency and space coverage for pixel modules, ...)

Open questions common to all module desings:

- local distortions
- long term stability?
- ion gate studies

Next steps.

Analyse the data taken with current modules,
learn from it → improved new designs

General module design similar for all readout technologies

(same aluminium backframe as basis, mount them to large prototype endplate, ...)

In addition, discuss common implementations of

- gating
- electronics (S-ALTRO16), pad plane
- unite the two GEM modules?

Motivation

Readout technologies

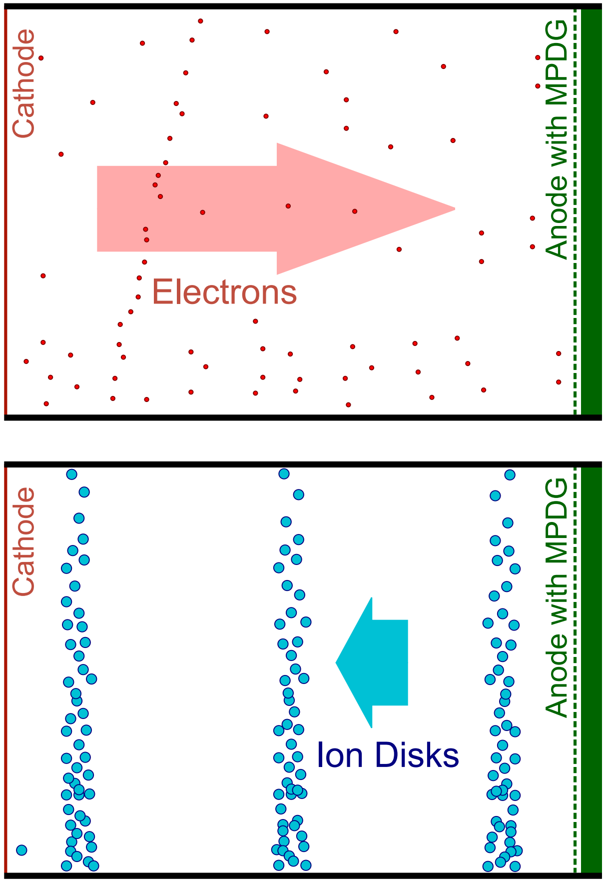
Other open questions

Next steps

Ion back flow / gating.

Secondary ions from gas amplification region distort drift field

- 1 ms bunch train every 200 ms: disk of positively charged ions from amplification stage drifts back into the TPC volume after each bunch train
- very slow drift of ions → up to three disks simultaneously in ILD TPC → field distortions (up to 60 µm)
- to prevent those ions from entering into the drift region: gating system wires, mesh, special GEMs, ...?



Ion back flow / gating.

a) “traditional“ wire gate

high transmission, but need to check distortion due to the radial wires

b) wire mesh or grid with reversible voltage

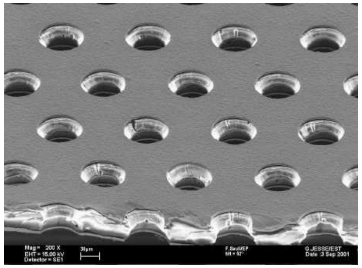
simulation study started

c) dedicated GEM as a gate

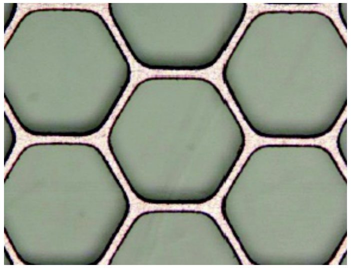
transparency of more than 70% - 80% possible for large GEMs? challenge: fabricate a GEM gate with large optical aperture, stable enough to stretch onto module
10 cm × 10 cm sample promising (∼80% optical transparency),

prototype module in preparation (fall 2015)

Standard GEM
~23%



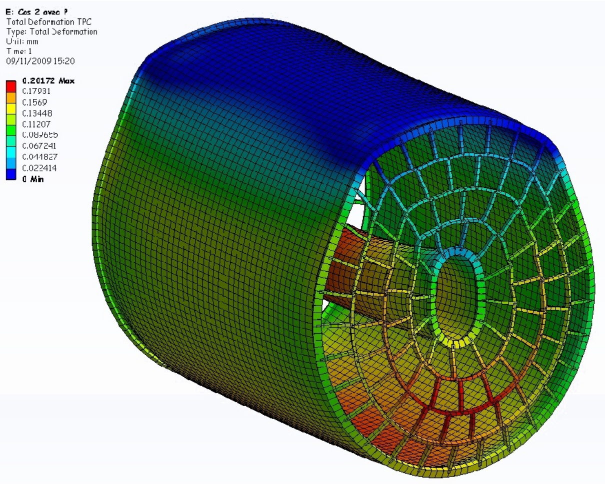
Gate GEM 1
~85%



for more details see e.g. talk by Katsumasu Ikematsu @ LCTPC collaboration meeting April 2015

Some more items from the To-Do list.

- power & cooling studies
- mechanics & integration
- DAQ
- long-term HV stability
- aging
- design of ILD TPC
  (integration, support, cabling, ...)



Chosing a technology.

Reconsider performance parameters
need input/checks from ILD performance studies

- Single point resolution rφ (as function of r?)
- Single point resolution z
- Two-hit separation (as function of r?)
- dE/dx
- cost

→ What is needed / feasible?

Motivation

Readout technologies

Other open questions

Next steps

Plans for the near future.

(2013-15) Test construction techniques, measurements at DESY testbeam, develope correction
(2016-17) improved modules, tests with new fieldcage, thinned endplate, external detector
Possibly simulate a jet-like environment?

Select technologies → working model for LCTPC design

(2017-18) prototype for LCTPC endcap module design: mechanics, electronics, cooling, power pulsing, gating

Long time scales.

- 2015-17 technology decisions
- 2017-19 design of readout electronics
- 2018-19 design of ILD TPC and TDR (for the ILD tracking system)
- 2019-23 prototyping, production: electronics
- 2020-23 prototyping, production: modules
- 2020-23 production: field cage, endplate and related things
- 2024-25 TPC integration and test
- 2026 TPC Installation into the ILD detector
- 2027 ILC commissioning

from LC-DET-2014-01 - of course, depends on ILC time line

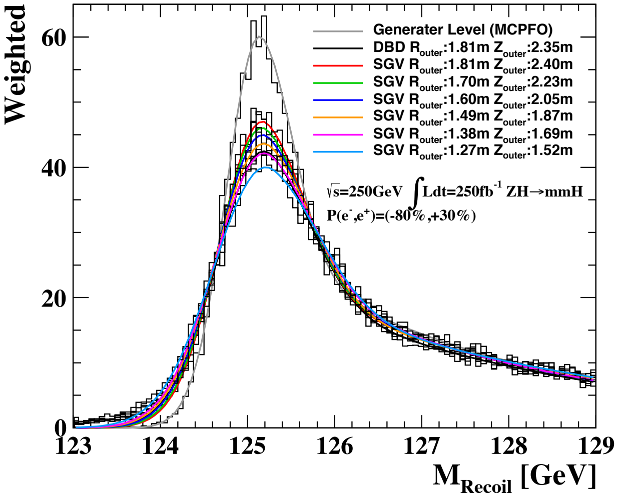
Backup Slides.

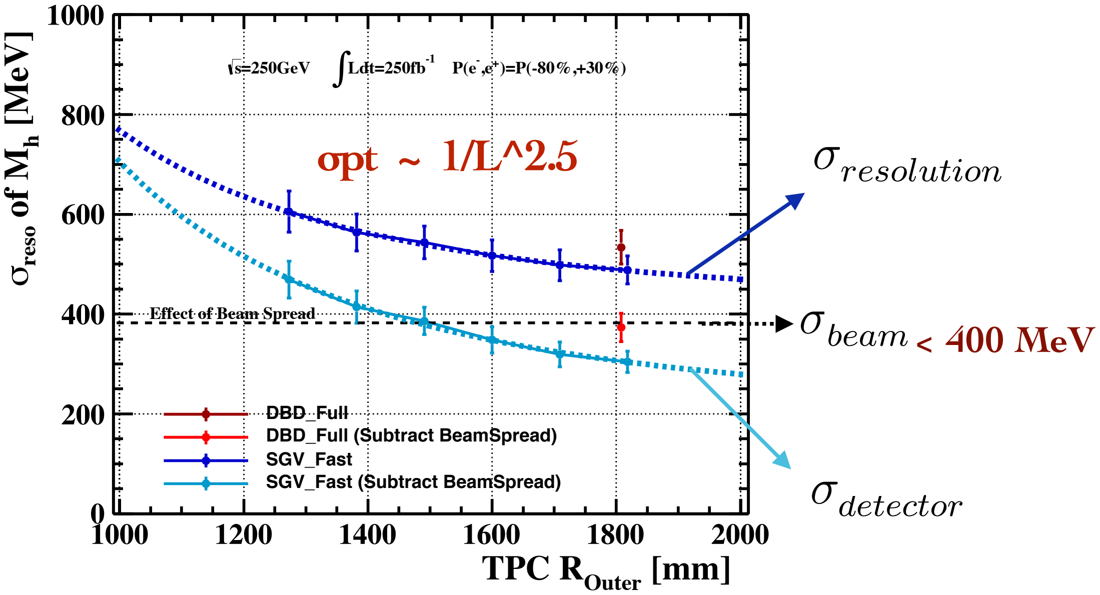
Resolution at √s=250GeV

1. **Contributions from beam spread and detector resolution.**

⇨ $\sigma^2_{resolution} = \sigma^2_{beam} + \sigma^2_{detector}$

Fit only peak region withGPET





— Detector contribution ($\sigma_{detector}$) is 300 MeV (at TPC outer R 1.8 m).
400 MeV (at TPC outer R 1.4 m).

⇨ Resolution degrades ~ 33 % (R: 1.8 m ⇒ 1.4 m).

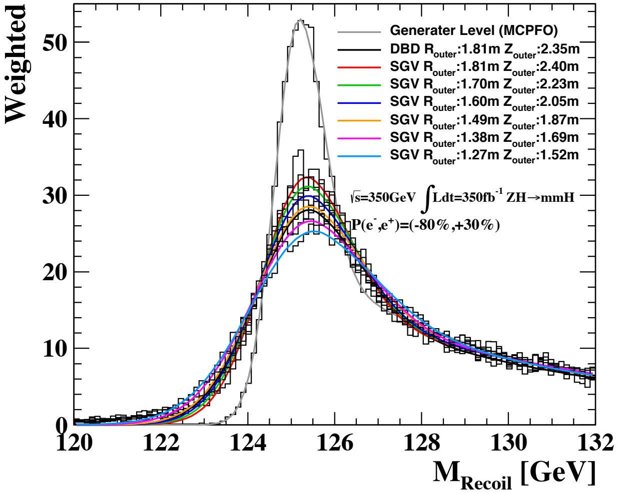
— **Including beam spread.** ⇨ **Resolution degrades ~ 10 % (R: 1.8 m ⇒ 1.4 m).**

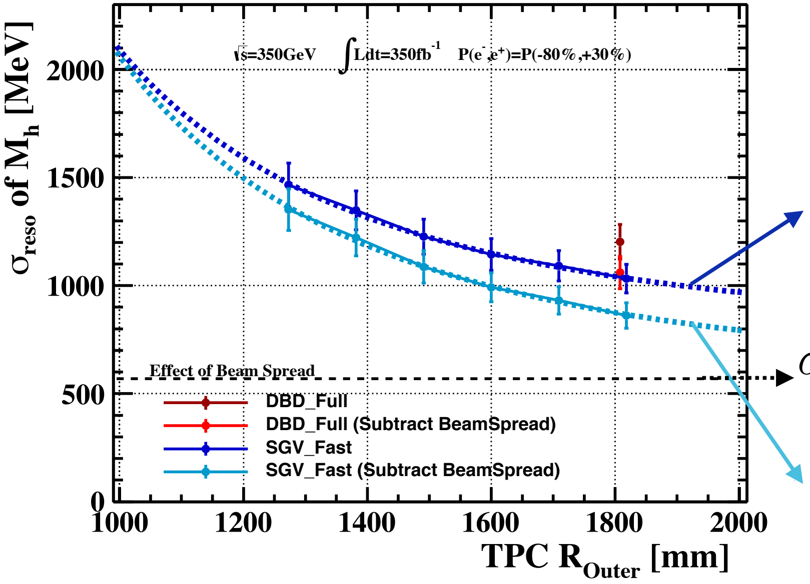
Resolution at √s=350GeV

1. **Contributions from beam spread and detector resolution.**

$$⇨ \sigma^2_{resolution} = \sigma^2_{beam} + \sigma^2_{detector}$$

Fit only peak region withGPET





$\sigma_{resolution}$

σ_{beam} **< 600 MeV**

$\sigma_{detector}$

– Detector contribution ($\sigma_{detector}$) is 850 MeV (at TPC outer R 1.8 m).
1200 MeV (at TPC outer R 1.4 m).

⇨ <u>Resolution degrades ~ 41 % (R: 1.8 m ⇨ 1.4 m).</u>

– Including beam spread. ⇨ <u>Resolution degrades ~ 25 % (R: 1.8 m ⇨ 1.4 m).</u>

※ Detector contribution is more dominant, compared with 250GeV.

Results ILD plots: TPC 220 pads; R_{SET} = 1811 mm

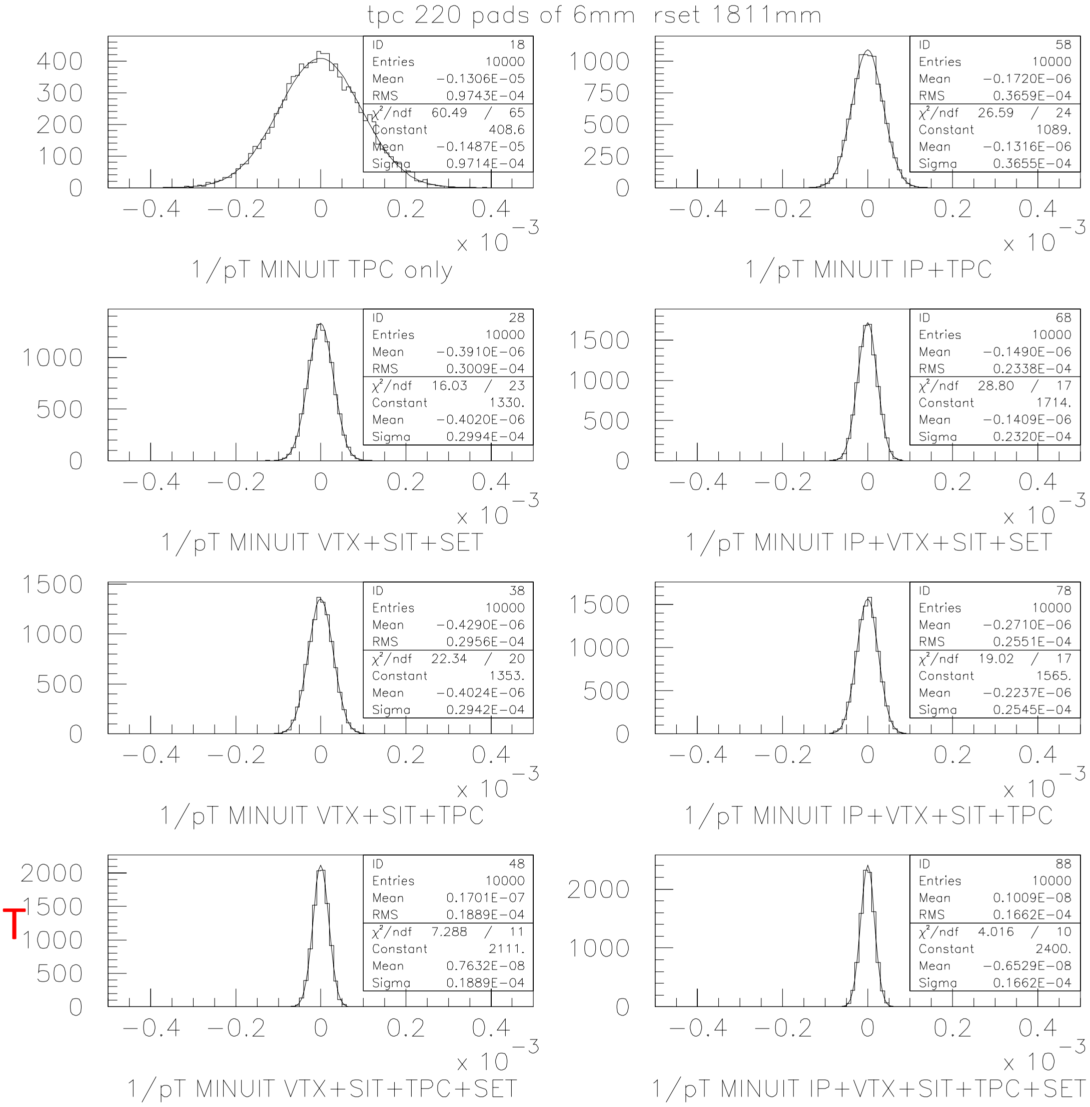
Without IP **With IP**

TPC only

VTX+SIT+SET

VTX+SIT+TPC

VTX+SIT+TPC+SET



ILD $1/p_T$ resolution summary

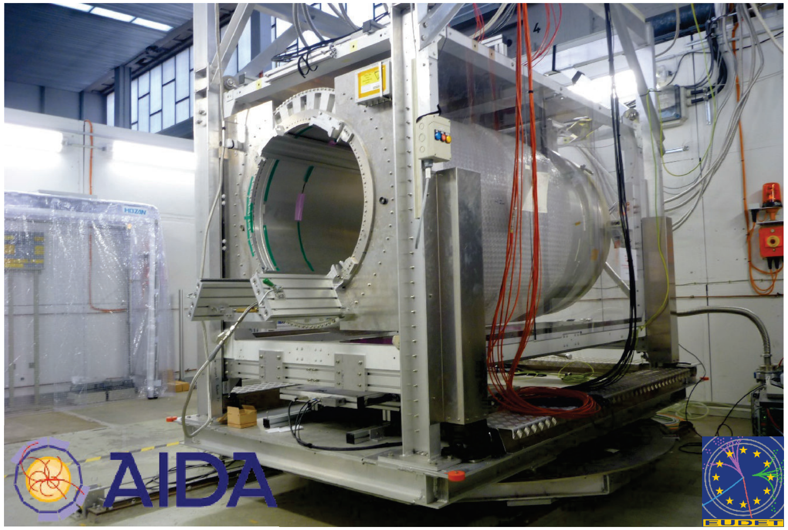
(in units of 10^{-5} GeV^{-1})

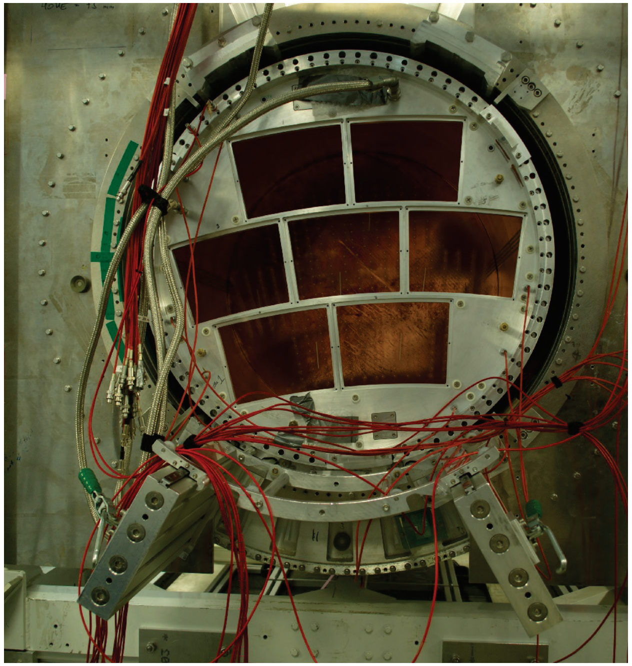
	TPC 220 pads **R_{SET}=1811mm**	**TPC 200 pads** **R_{SET}=1691mm**	**TPC 180 pads** **R_{SET}=1571mm**	**TPC 160 pads** **R_{SET}=1451mm**
TPC only	9.71	12.3	16.2	21.1
VTX+SIT+SET	2.99	3.26	3.59	3.91
VTX+SIT+TPC	2.94	3.47	4.07	4.82
VTX+SIT+TPC+SET	1.89	2.15	2.52	2.93

+ IP constraint	**TPC 220 pads** **R_{SET}=1811mm**	**TPC 200 pads** **R_{SET}=1691mm**	**TPC 180 pads** **R_{SET}=1571mm**	**TPC 160 pads** **R_{SET}=1451mm**
TPC only	3.66	4.42	5.45	6.90
VTX+SIT+SET	2.32	2.55	2.81	3.03
VTX+SIT+TPC	2.55	2.98	3.47	4.06
VTX+SIT+TPC+SET	1.66	1.88	2.20	2.49

Testbeam Setup

- Area T24/1 at DESY II testbeam facility
- PCMAG
  - Thin coil and wall ($0.2X_0$), no return yoke
  - (Operational) field up to 1T
- Large TPC Prototype:
  - Light weight; made of composite materials
  - Sensitive Volume: ∅ 72cm, L= ~58cm
  - Modular end plate by U Cornell
    - Up to 7 read-out modules
    - Size/shape similar as foreseen for the final detector
- HV, gas and slow control systems
- Cosmic and beam trigger
- Laser calibration system (cathode pattern illumination) another one thought of: laser beam "web"





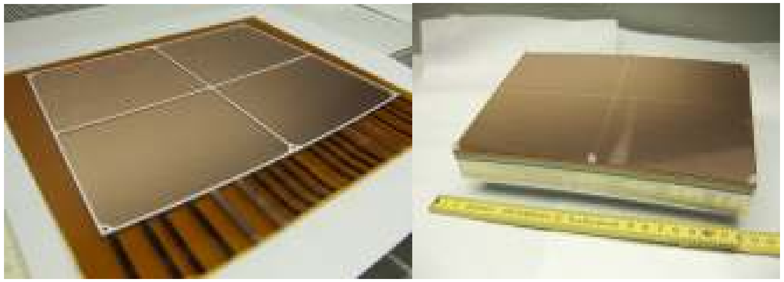
GEMs with Pads

Asian GEM module:

- 2 GEMs, 100 µm thick, without side support
- $1.2 \times 5.4\ \mathrm{mm}^2$ pads, 28 pad rows

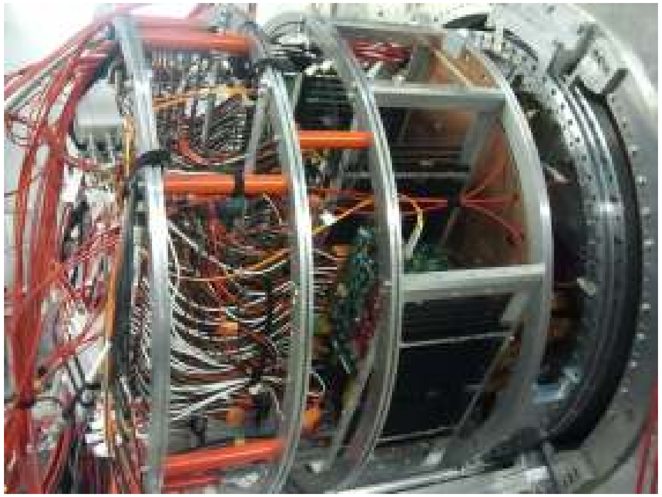
DESY GEM module:

- Triple CERN GEM, 50 µm thick, with thin ceramics frame
- $1.26 \times 5.85\ \mathrm{mm}^2$ pads, 28 rows



About 5000 pads per module for both module types

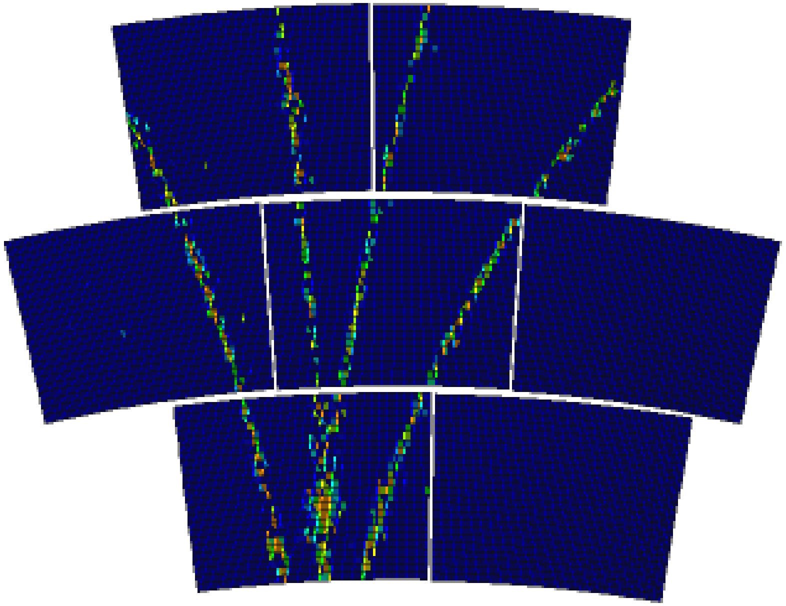
ALTRO (modified ALICE TPC) readout electronics $\approx$ 10000 channels

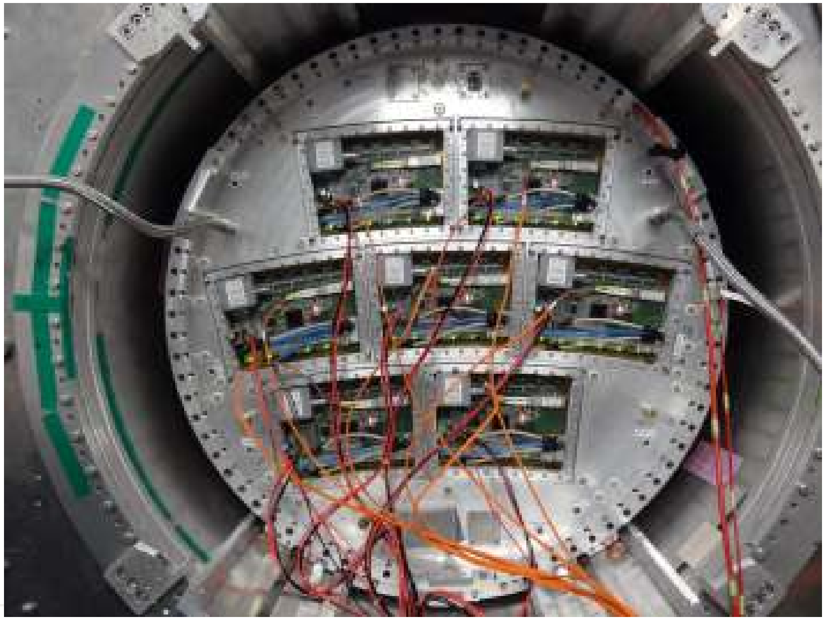


Next step: SALTRO (improved integration)

Micromegas with Pads

Compact AFTER (T2K) electronics mounted directly on the back side of each Micromegas module





- 3×7 mm^2 large pads
- 24 rows with 72 pads
- 1728 pads per module
- Resistive foil to spread charge

Fully equipped endplate with 7 modules with 12000 channels

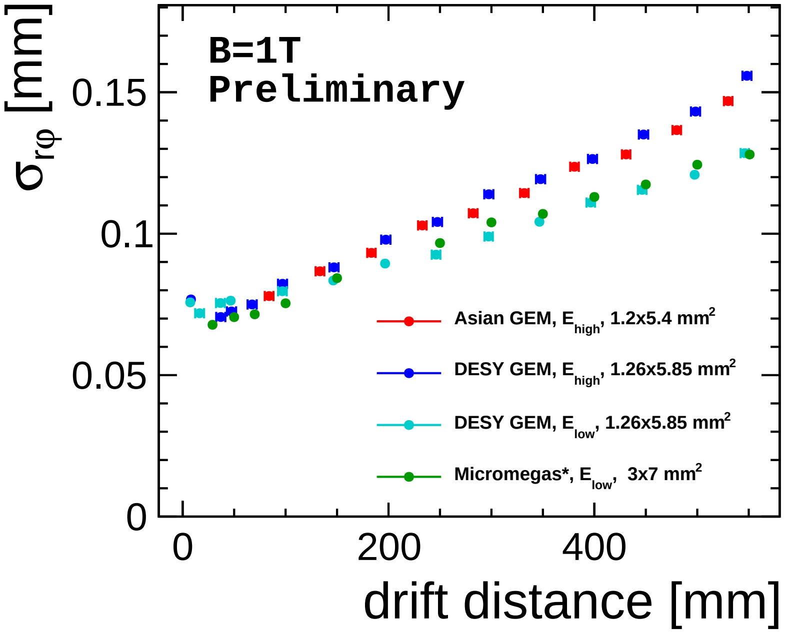
ICHEP2014

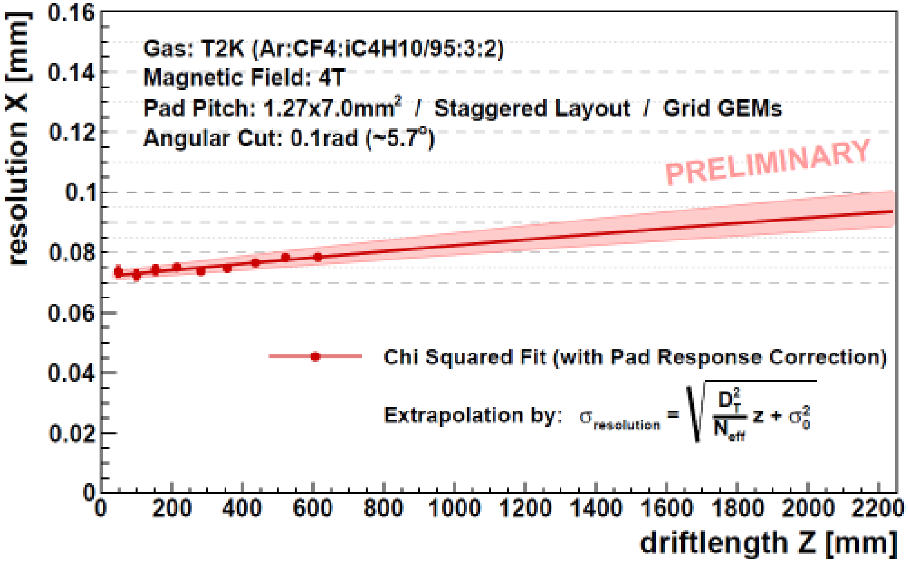
Results: Point Resolution

Different modules in the LP

- B=1 T, T2K Gas: Ar(95%)CF$_4$(3%)iC$_4$H$_{10}$(2%)
- E$_{\text{low}}$=130-140 V/cm:
  → minimal transverse diffusion
- E$_{\text{high}}$=230-240 V/cm:
  → maximum drift velocity

All modules show comparable resolution.





Extrapolation from small GEM prototype data at 4T meets requirements for single point resolution.

ICHEP2014

Common pad plane (I)

Common pad plane?

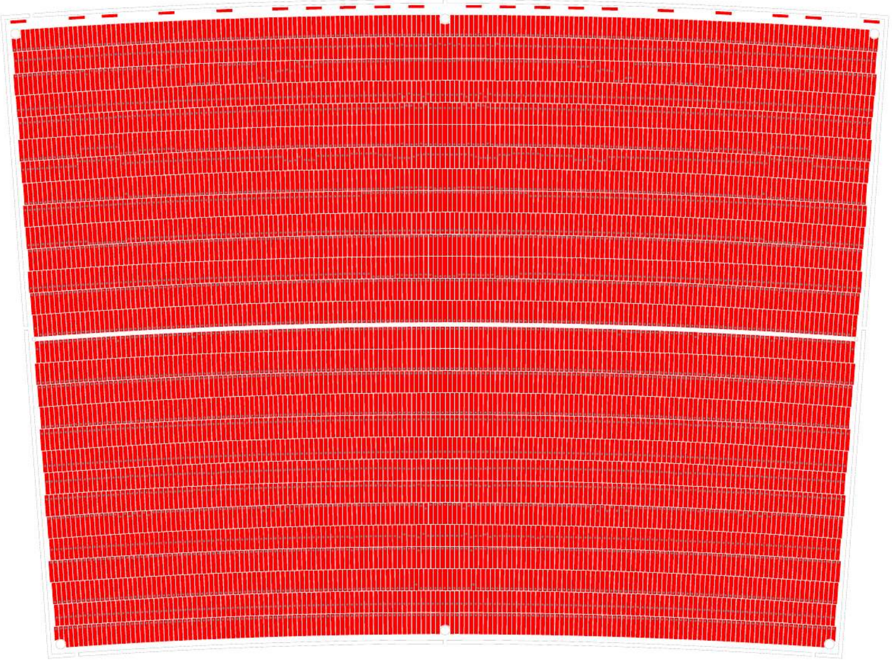
- Number of pads given by SALTRO-16: 3200 => 1.26 * 8.8 mm² staggered?
- We should decide what make most sense
  - full coverage = 1.26*8.8 mm² staggered?
  - cover only 1/2 of modules – left/middle/right with nominal pads 1*6 mm²
  - What other possibilities?

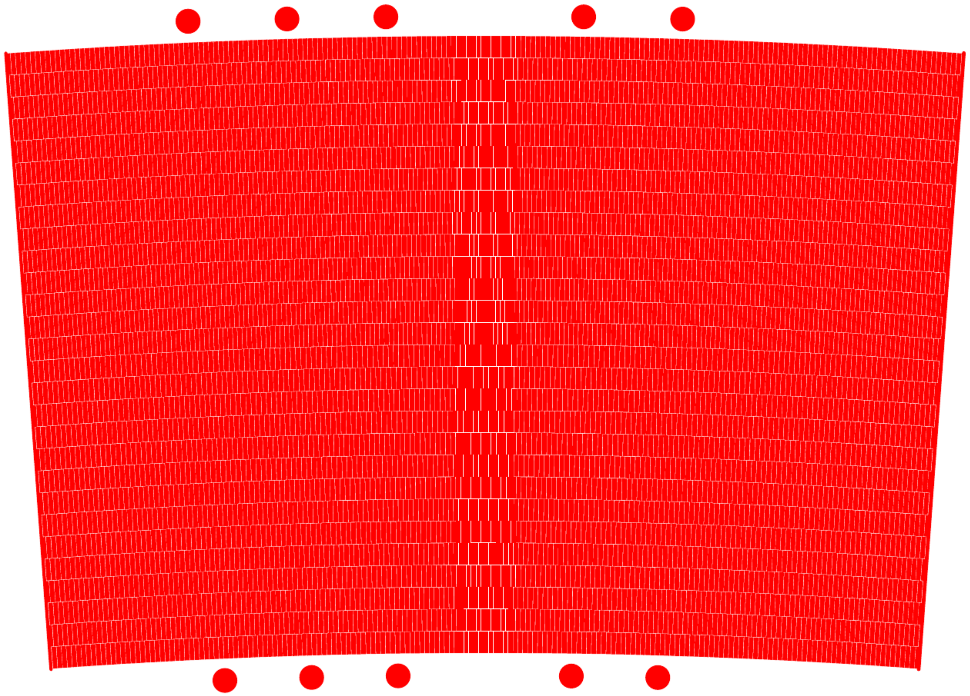
- If we have a gating grid – what impact does this have on the module design.
  - Can we still have no frames on sides?
  - How many contacts do we need? 2?

Micromegas Module

- 3×7 mm^2 large pads, 24 row with 72 pads → 1728 pads per module
- Grounding at border, 3 mm frames
- 1 HV contact in the center

Common pad plane(II)





DESY modules:
1.26 × 5.85mm^2 pads - staggered
28 pad rows, 4829 channels per module
Thin frames – 1mm all around
20 HV connectors at top

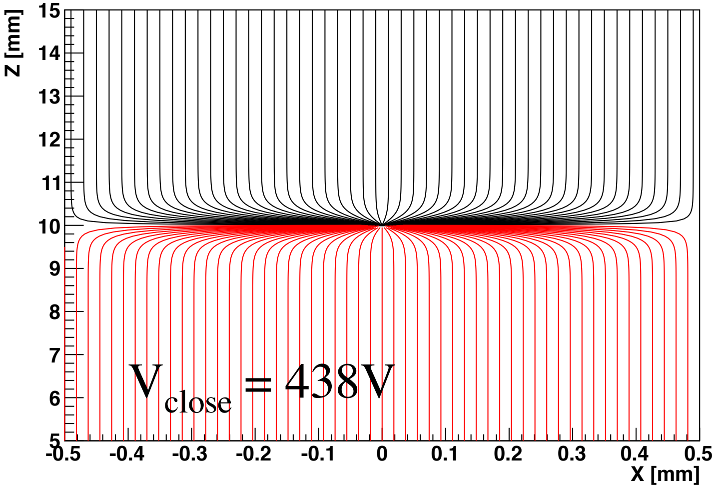
Asian module:
1.2×5.4 mm^2 pads - staggered
28 pad rows (176-192 pads/row)
5152 pads per module
1 cm wide frames at top/bottom
No frames at sides

Conventional wire-grid as a gating device

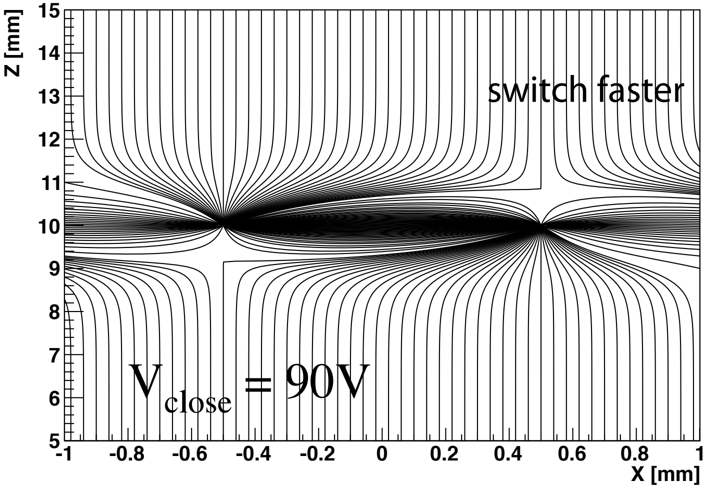
- **Wire-gating system is an option**
  - Traditional gating system
  - Two possible voltage schemes for the “closed” configuration of the wire-gate: mono-potential and alternate-potential

- fairly high voltage in the gate
- voltage depends strongly on the distance of the gate from the MPGD

- voltages required are relatively small and strongly dependent on the wire spacing
- more sophisticated structure to have two electrically isolated grids



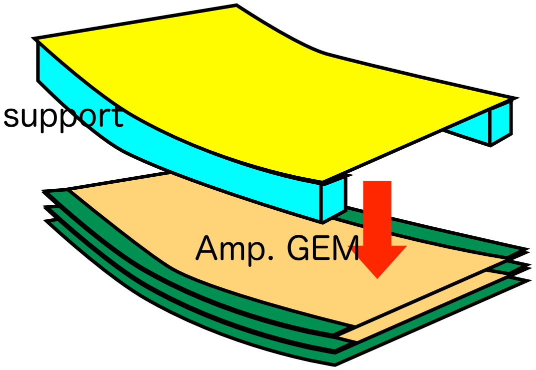
By increasing the potential on all the wires, the drift field between the gate and the amplification is reversed. The positive ions will then drift back and be neutralised on the MPGD.

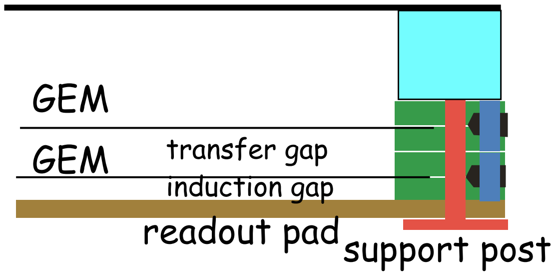


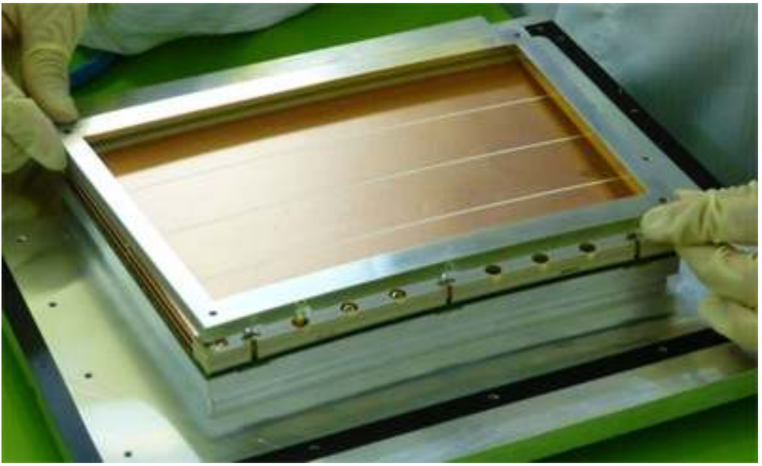
By shifting the voltage alternately on every second wire, we can create an electric field that will make the ions drift towards the wires, where they will be neutralised.

Conventional wire-grid as a gating device?

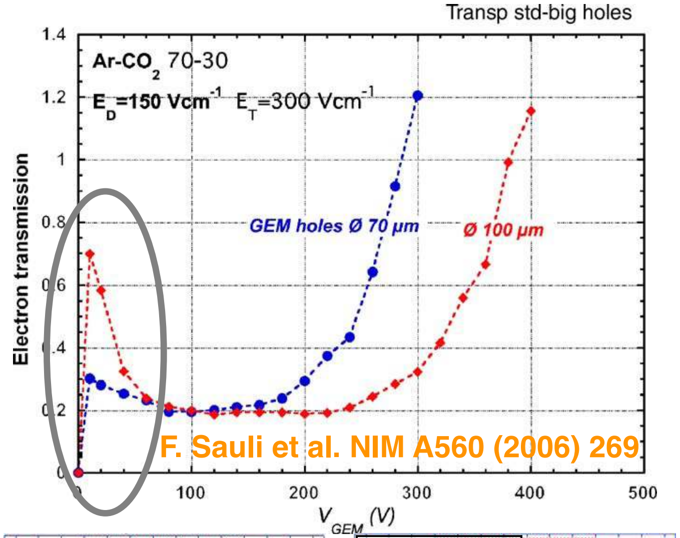
- **Wire-gating system may be a (fallback) option**
  - Traditional gating system
  - Conventional transverse wires would require a structure creating dead angular regions => would put the wires radially
  - Wires can create field distortions, and in particular ExB effects...
  - **Our 1st prototype**:
    - 30μm wires, 2mm pitch, radial => spot welded on stainless steel frame => frame still too big!
    - **performance tests of the 1st prototype by using UV-laser tracks has been finished!!**
- **Its implementation above the amplification GEMs or Micromegas would not be elegant!**



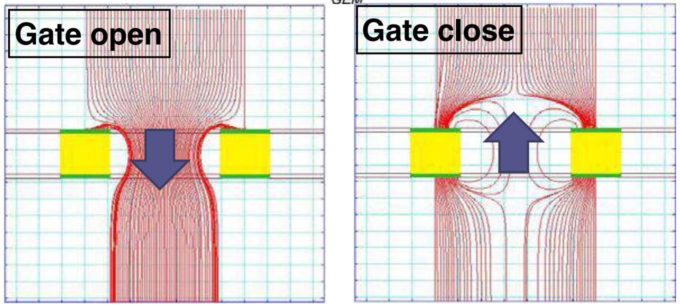




GEM as a gating device



F. Sauli et al. NIM A560 (2006) 269



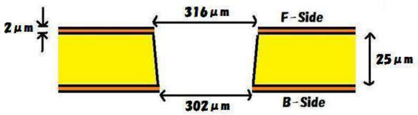
- **GEM operated in low voltage mode**
  - Electron transmission film = without a function of gas amplification
  - Gate having a GEM-like structure (initially proposed by F. Sauli in 2006)
    - Gate-GEM can easily be used as a closed gate by reversing the electric field in GEM hole
  - GEM-gating device would be most adapted for the module structure of ILD-TPC!
- **Requirement for Gate GEMs of ILD-TPC**
  - **Goal: 80% electron transmission** = corresponding the **deterioration in the spatial resolution ~O(10%)** for the ILD-TPC nominal electric field configuration
  - Operated in a 3.5 T axial magnetic field, and in a gas with a high mean free time (τ) of drift electrons between collisions with gas molecules => Motion of electrons is strongly restricted to the direction of the magnetic field => **high optical transparency of the gate is required** to ensure its high transmission rate of the electrons in the open state

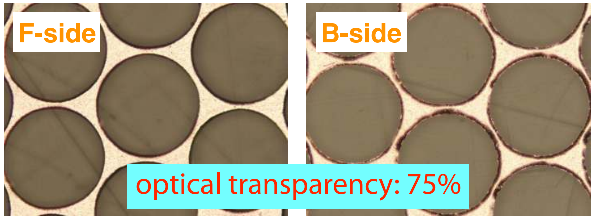
ordinary amplifying GEMs (e.g. CERN standard): not suitable because of their poor optical transparency

Large-aperture Gate-GEM samples

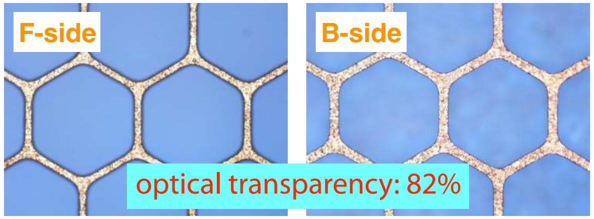
- **High optical transparency = Minimize rim width of GEM holes**
  - To achieve high electron transmission: 30 μm rim width & 330 μm pitch in honeycomb structure (= 80~85% optical transparency) required
- **Fujikura Gate-GEM Type 0 sample**
  - Round holes / Direct UV-laser drilling (1 x 1 cm^2)
  - 14 μm (F-side) - 28 μm (B-side) rim width & 330 μm pitch with PI thickness 25 μm
- **Fujikura Gate-GEM Type 3 sample**
  - Hexagonal holes / UV-laser ablation (10 x 10 cm^2)
  - 27 μm (F-side) - 31 μm (B-side) rim width & 335 μm pitch with PI thickness 12.5 μm

UV-laser drilling

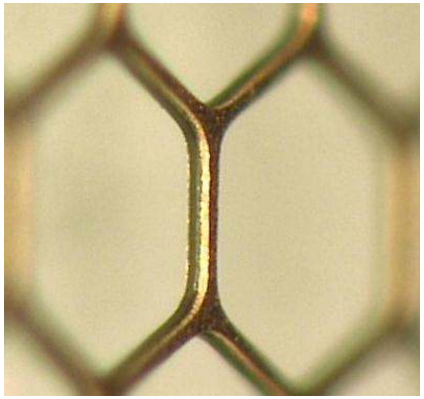




optical transparency: 75%

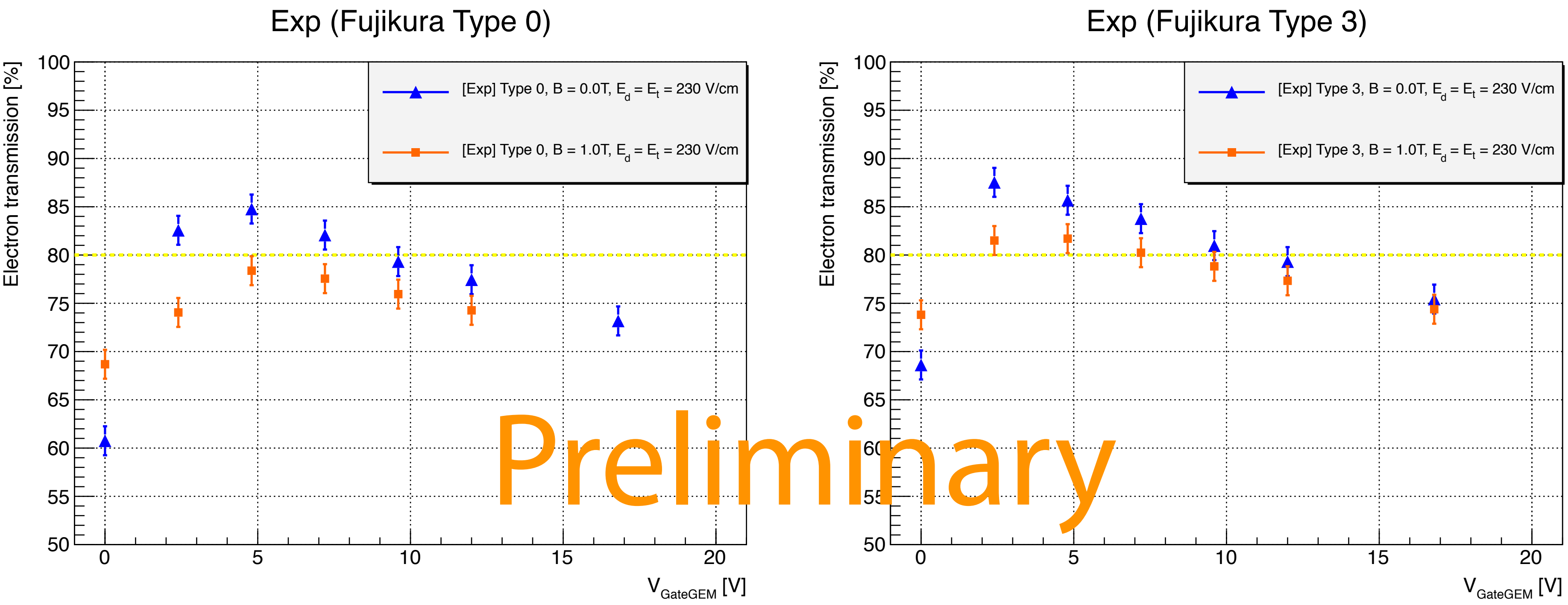


optical transparency: 82%



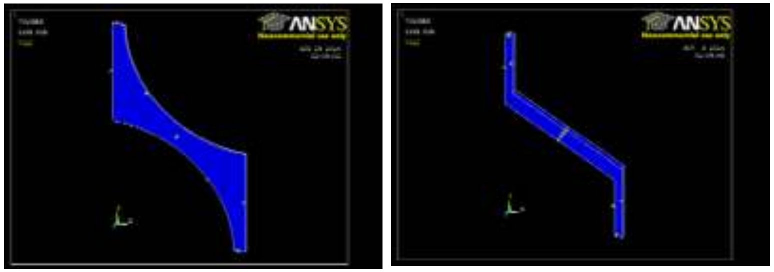
These 2 different samples: tested with a test chamber installed in a 1 Tesla solenoid magnet at KEK cryo center

Results for electron transmission meas.

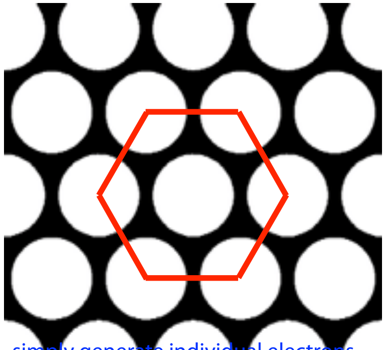


Evaluation of the measurement results and extrapolation to 3.5 T can be also discussed by a simulation

Combination of ANSYS and Garfield++ (microscopic tracking), has been used to understand quantitatively the data from the electron transmission measurements



field calculations were done using finite element calculations with ANSYS



simply generate individual electrons above the GEM hole in the drift region

See whether electrons arrive below the Gate-GEM (in the transfer region) or somewhere on the Gate-GEM