R&D Projects of LCTPC

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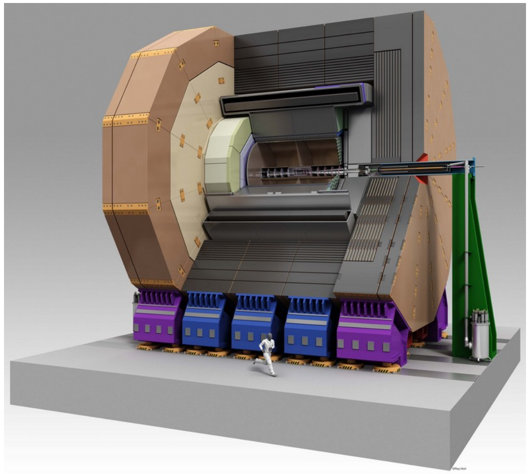
for LCTPC

ILD strategy discussion IV
19.4.2022

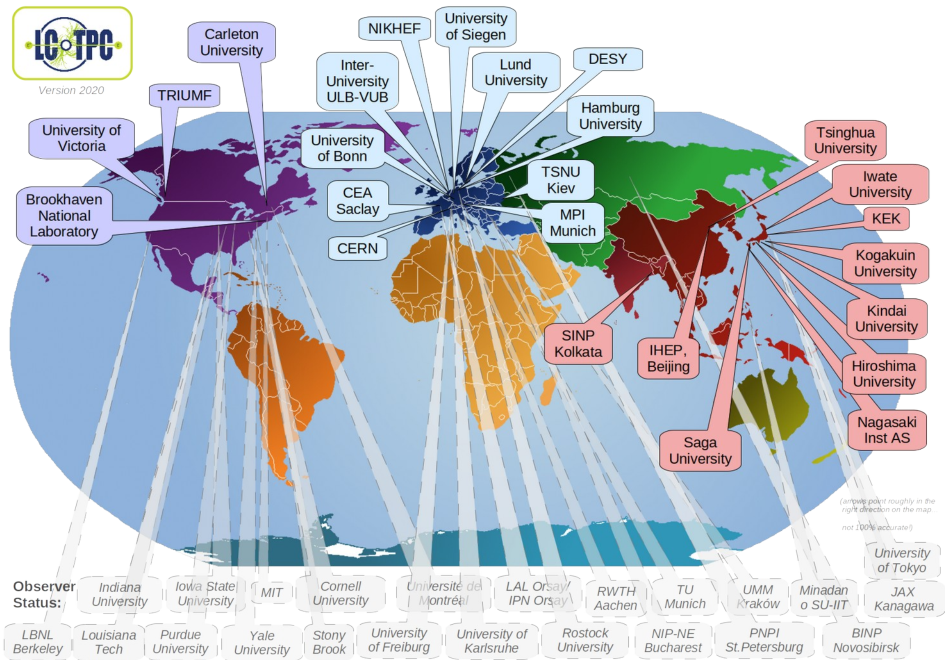
UNIVERSITÄT BONN

A TPC for ILD



International Large Detector
- TPC as main tracker

LCTPC studies a MPGD-based TPC



TPC Requirements :

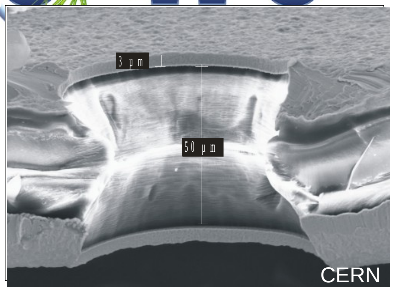
Parameter	
Geometrical parameters	r_{in} 329 mm; r_{out} 1808 mm; z ± 2350 mm
Solid angle coverage	up to $\cos\theta \simeq 0.98$ (10 pad rows)
TPC material budget	$\simeq 0.05\ X_0$ including outer fieldcage in r
	$< 0.25\ X_0$ for readout endcaps in z
Number of pads/timebuckets	$\simeq$ 1-2 $\times 10^6/1000$ per endcap
Pad pitch/ no.padrows	$\simeq 1\times$ 6 mm^2 for 220 padrows
σ_{point} in $r\phi$	$\simeq$ 60 μm for zero drift, $<$ 100 μm overall
σ_{point} in rz	$\simeq 0.4 - 1.4$ mm (for zero – full drift)
2-hit resolution in $r\phi$	$\simeq 2$ mm
2-hit resolution in rz	$\simeq 6$ mm
dE/dx resolution	$\simeq 5$ %
Momentum resolution at B=3.5 T	$\delta(1/p_t) \simeq 10^{-4}$/GeV/c (TPC only)

MPGDs in TPCs

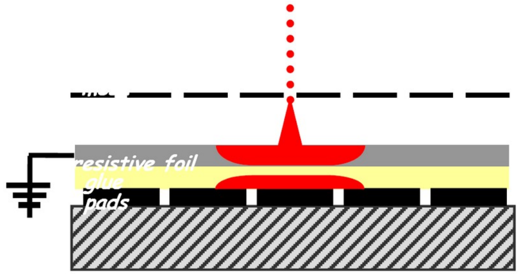
- Ion backflow is reduced significantly
- Small pitch of gas amplification regions
  => strong reduction of E×B-effects
- No preference in direction
  => all 2 dim. readout geometries possible

Three Baseline Technologies

GEMs: copper-insulator- copper sandwich, with holes
2 configurations are being tested:
- triple GEMs with ‘standard CERN GEMs’
- double GEMs with 100µm LCP insulator

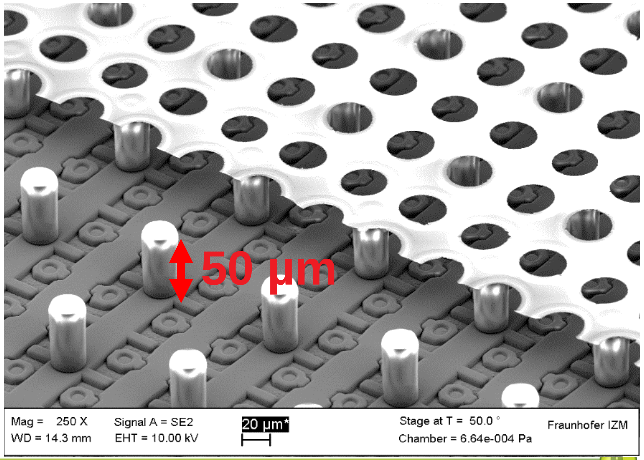


Resistive Micromegas: Bulk-Micromegas with 128 µm gap size between mesh and resistive layer



NIM A581(2007) 254

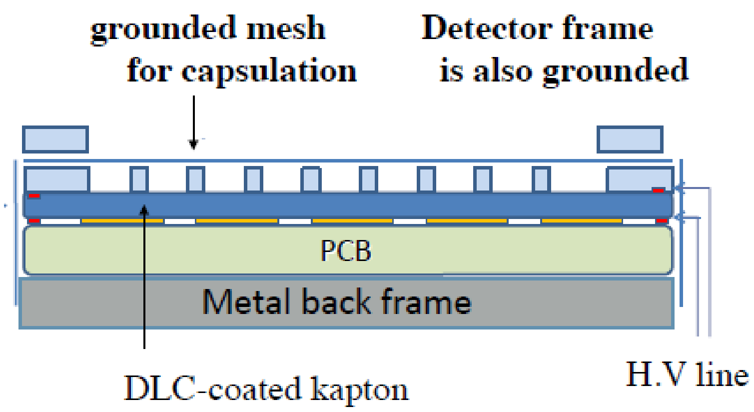
GridPix: Micromegas with 1 µm Al-grid over Pixel readout ASIC
- 55µm pitch of readout pixels
- resistive layer needed for protection of ASIC

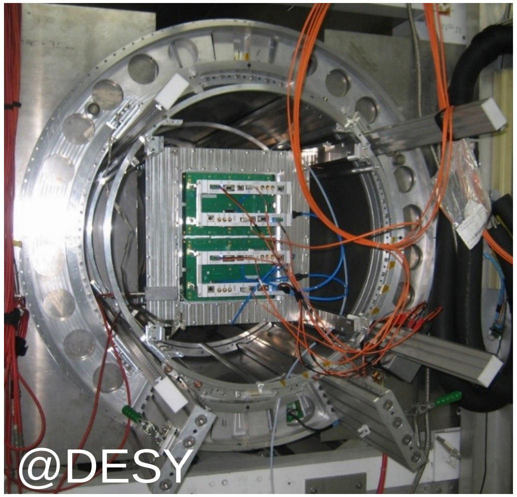


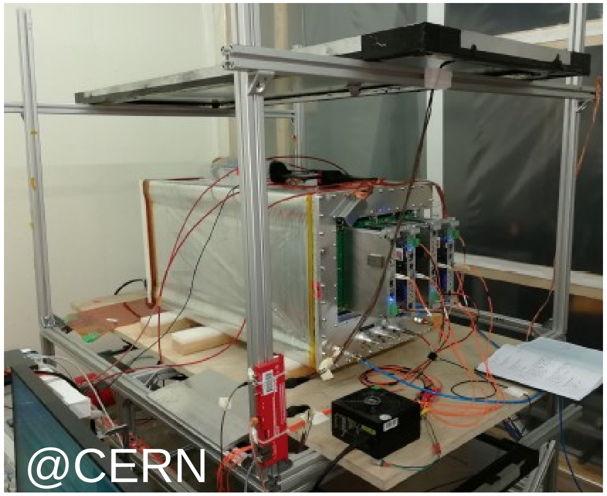
Optimization of Modules

Recent progress:

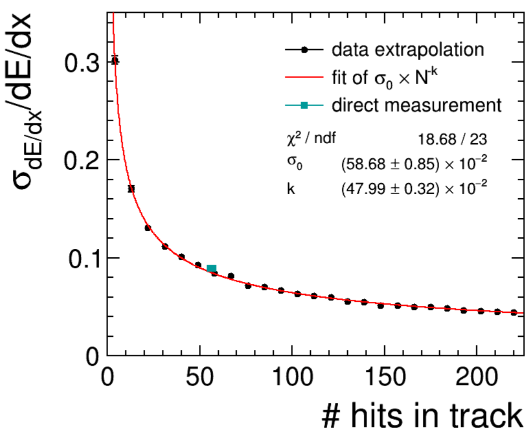
1.) Micromegas: Close collaboration of MM group with T2K group. Test beam with T2K detector in June and at CERN in December 2021.

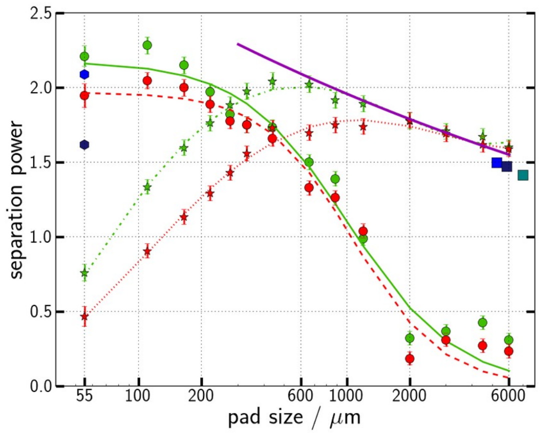






2.) GEM modules: dE/dx performance is scrutinized. Also, in dependence on the pad Sizes. A publication in JINST is prepared and in the final reading, expected to be submitted in April or May.



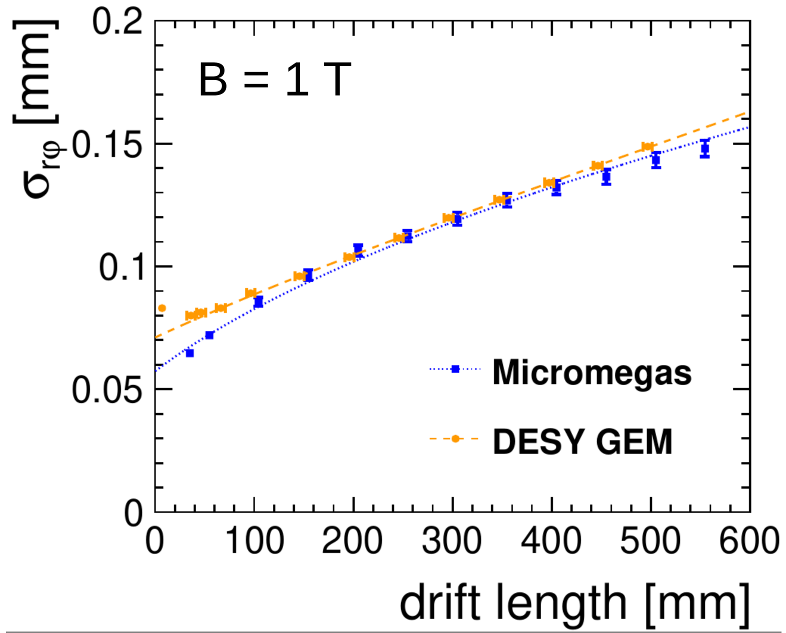


Detector Modules

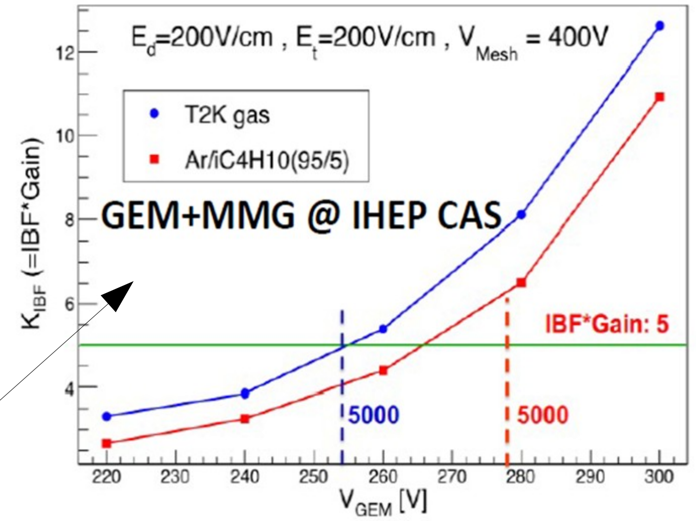
GEM and Micromegas groups have finished analysis of test beam data with previous set of detector modules. Both technologies show very similar performance. Now groups want to implement improvements in a new generation of modules. They are discussing new common modules, which should have a

- a more final design and
- a more comparable design.
- common readout electronics,
- an identical gating device (gating GEM) and
- possibly a common pad plane

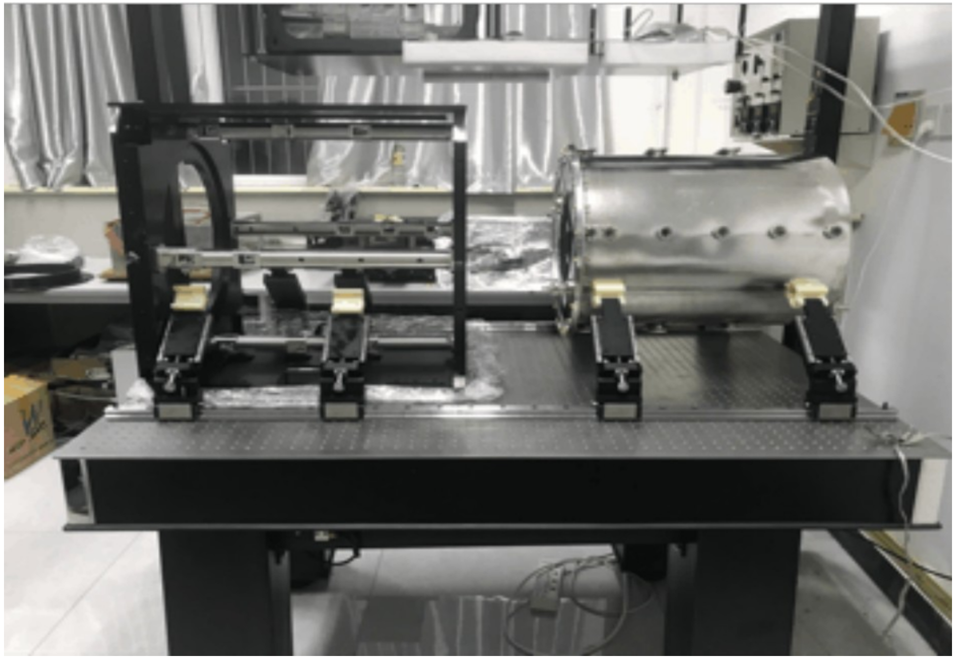
→ Only the gas amplification stage differs
=> better comparison of performance
for a technology decision.



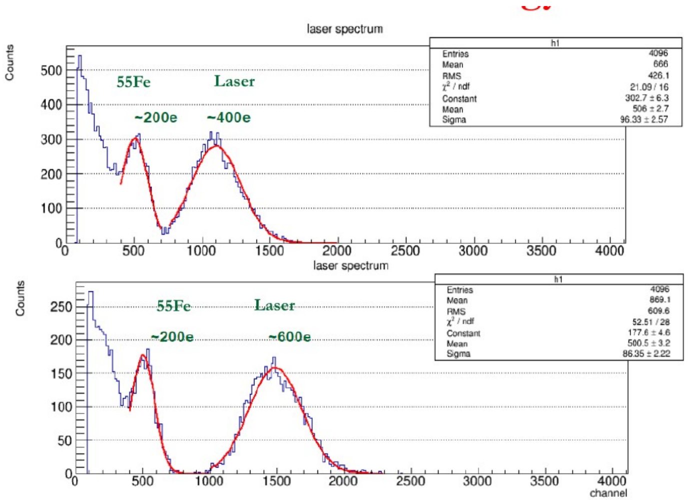
Also combined Micromegas + GEM readout is tested, which promises a lower ion backflow, if gating is not possible (e.g. at the CEPC).

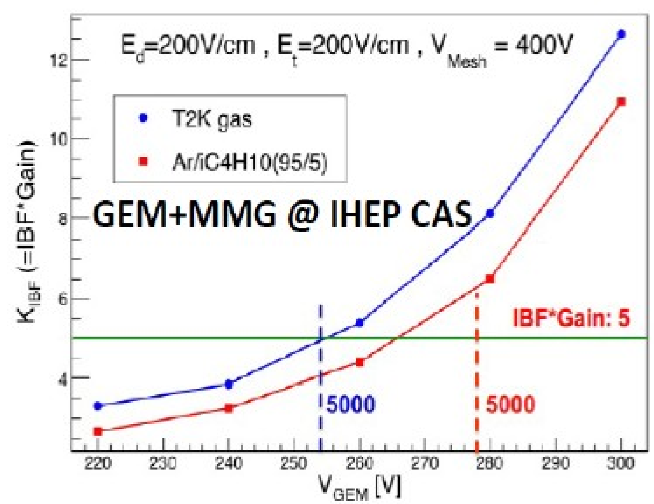


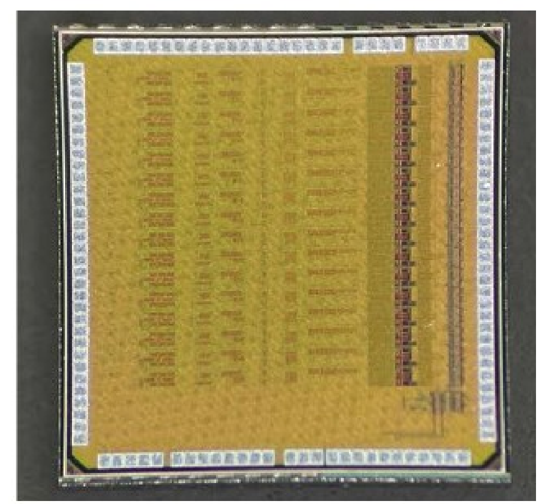
Dedicated CEPC studies at IHEP



- Setup in IHEP, Beijing
- Smaller prototype with 50cm drift length
- Studies with UV-laser and Fe^{55} to understand PID
- Detailed studies of IBF*Gain for various configurations of GEM+MM setup
- TPC-ASIC development together with U. Tsinghuan: Very low power consumption ASIC (2.33 mW/channel)



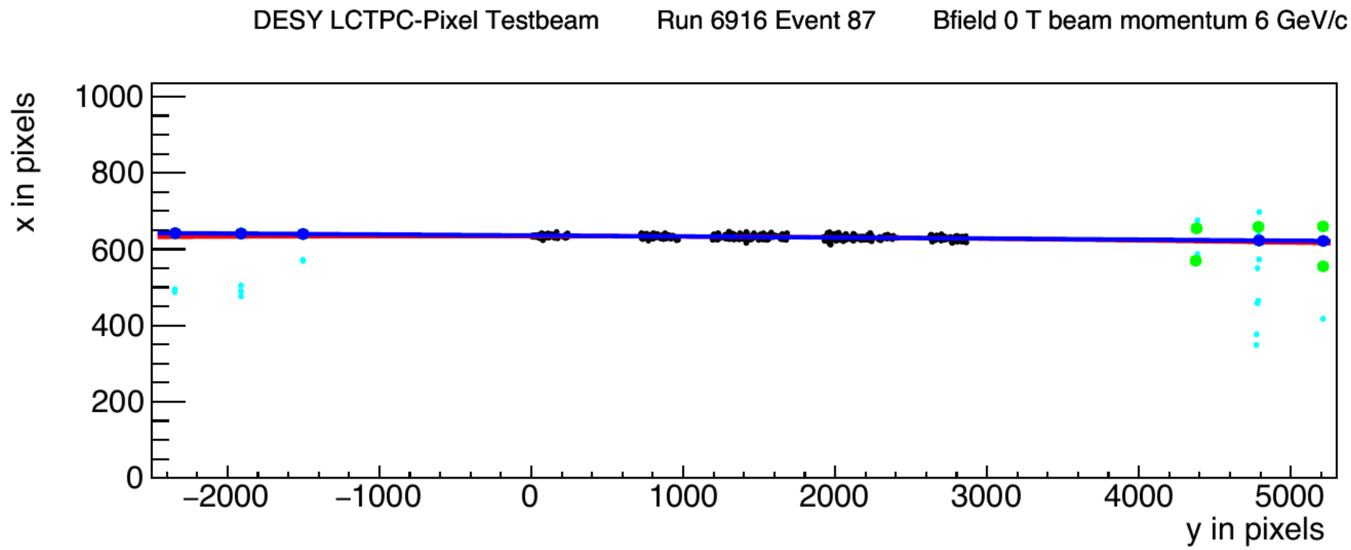


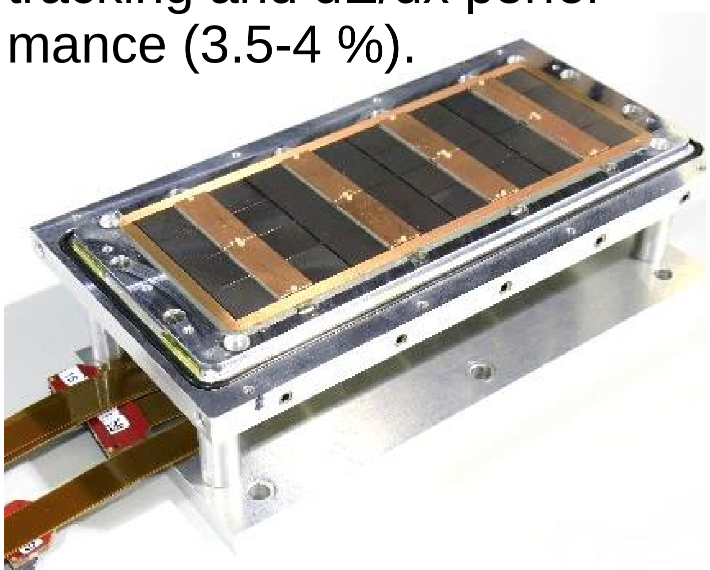


65nm ASIC芯片实物图

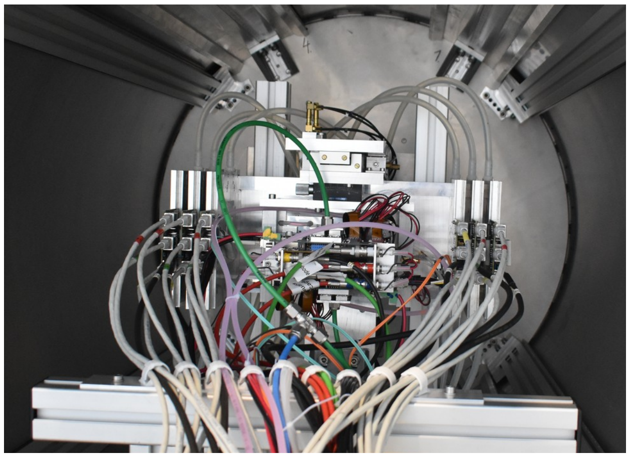
GridPix Detectors

Tests with Timepix3 based GridPixes have been done with single and quad devices have been and results are published. As expected the spatial resolution of single electrons is diffusion limited and the very high detection efficiency results in excellent tracking and dE/dx performance (3.5-4 %).





A first module with 32 GridPixes has been constructed and was in a test beam at DESY in June 2021.
- including a test in a magnetic field of B = 1 T.



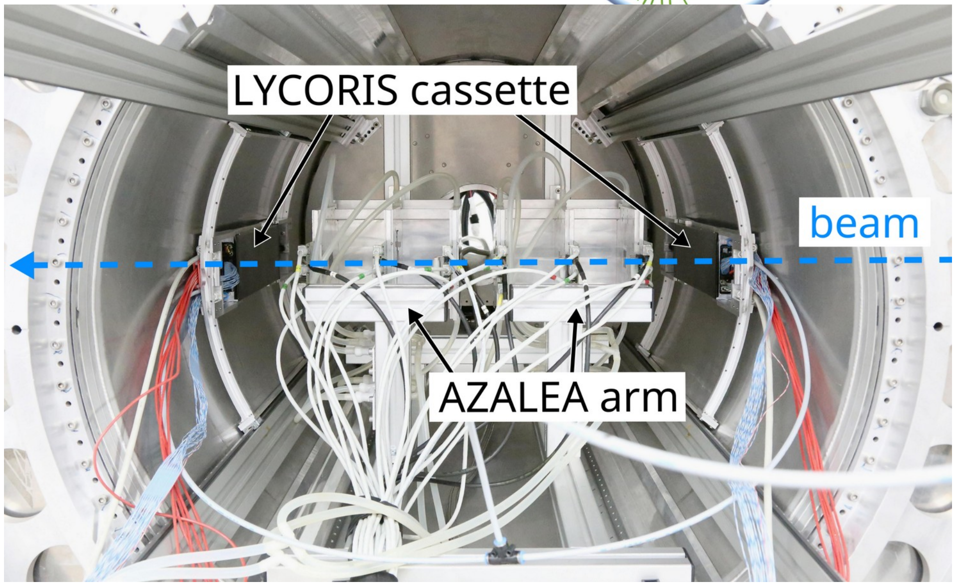
The ion back flow of the module has been measured and can be further reduced by applying a double grid. Also the resistivity of the protection layer will have to be reduced and Timepix4 development is observed.

NÌM A908 (2018) 18-23
NIM A956 (2020) 163331

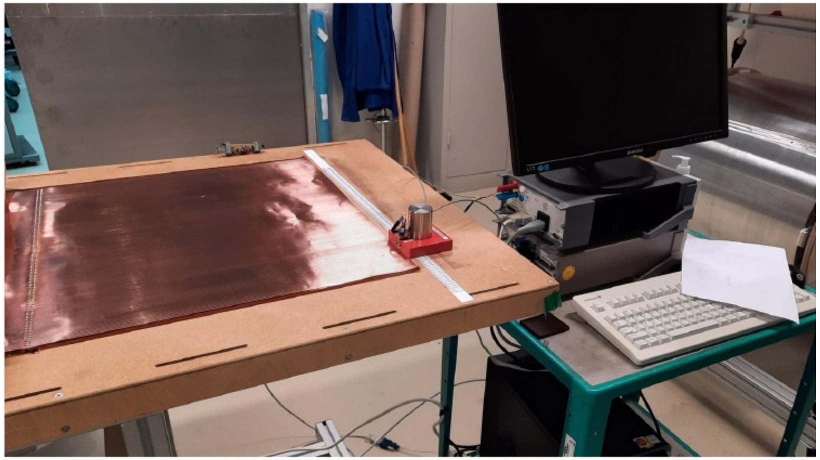
Setup at DESY

Further improvements of the test beam setup at DESY are in progress or finished:

- An external silicon tracker for the Large Prototype (LP) is finished and Qualified. Excellent spatial resolutions down to 7 µm have been demonstrated. Final work on software to improve user friendliness and introduction to DOOCS are ongoing.
  Many groups will redo measurements with newest module types to study distortions

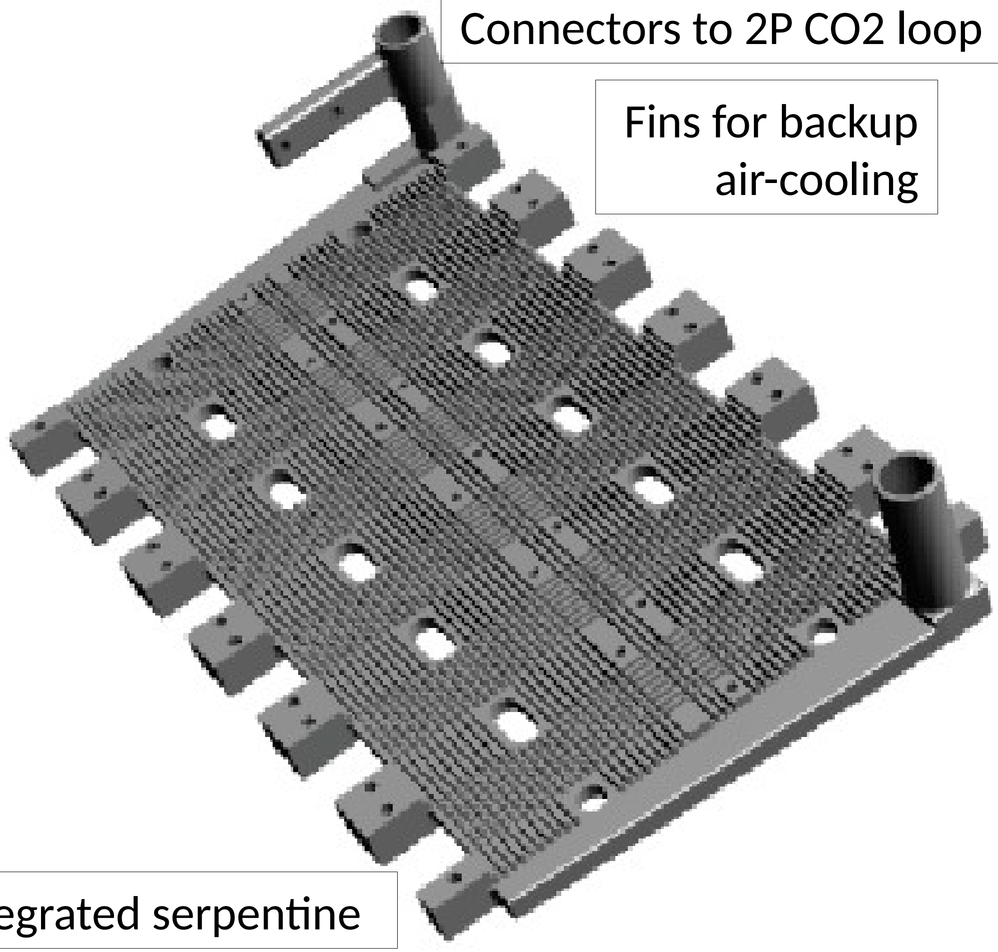


- Construction of an improved field cage for the LP.
  → Also important for learning to build the final detector.
  → Resistor chain and HV stability are being studied.



Cooling

First tests with a monolithic 3D printed cooling plate (aluminum) took place at DESY in October 2021. 2pCO2 cooling with TRACI (**T**ransportable **R**efrigeration **A**pparatus for **C**O2 **I**nvestigation)



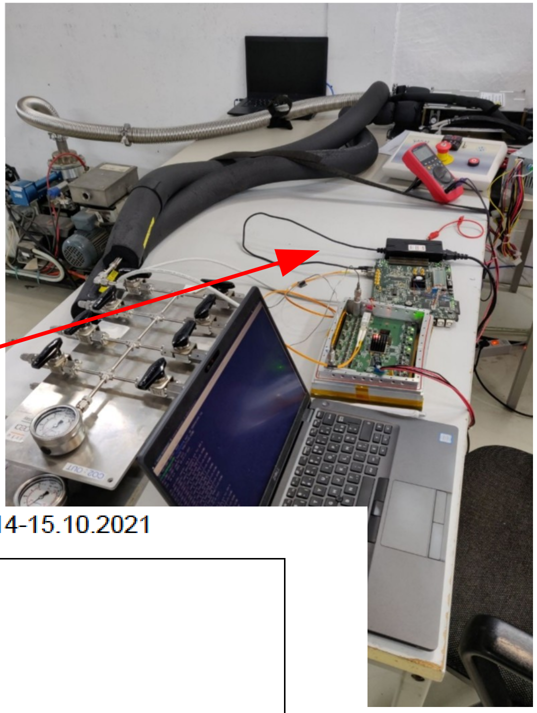
Connectors to 2P CO2 loop

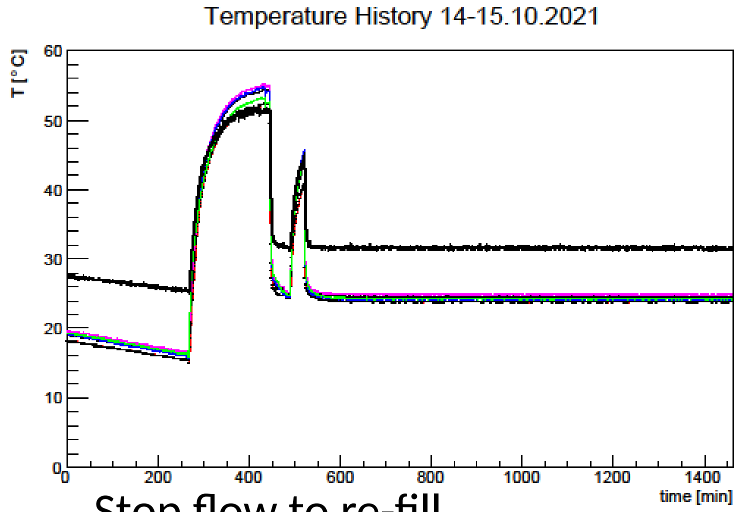
Fins for backup air-cooling

Integrated serpentine

1 week of tests

Detector





Stop flow to re-fill

What about Experiments at other Colliders (FCCee, CEPC)?

Crucial considerations are:

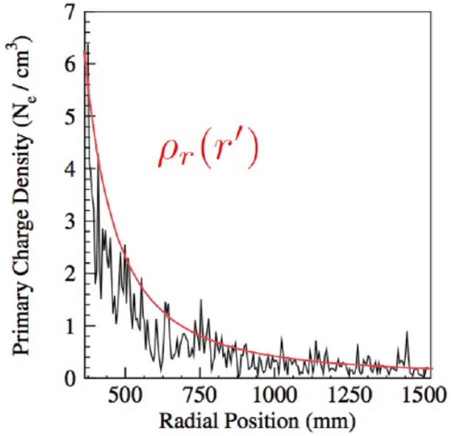
- primary ionization of the gas,
- ions from the gas amplification stage,
- power consumption (no power pulsing possible)
- operation at 2 T during the Z-peak running

=> In short: We think, that with R&D these challenges can be largely overcome, but in some settings (Tera Z) the performance will not be as good as in the ILC case.

=> Question to be determined: Is the excellent performance also necessary in these scenarios?

Primary Ions

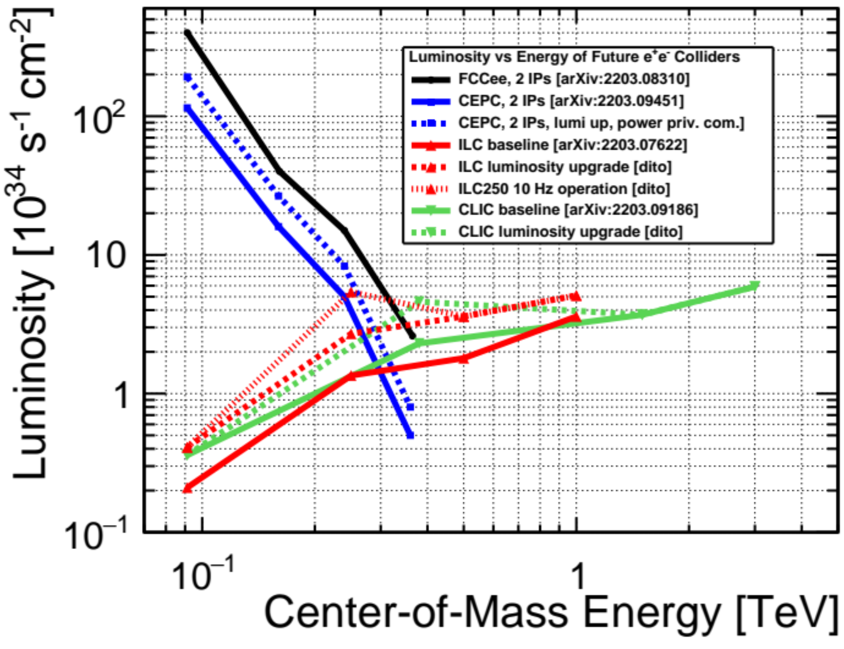
At the ILC we assume for Higgs studies that machine background contributes most ions. Density would be 1-5 ions/cm³ resulting in distortions of < 5 µm.



At circular machines the conditions are similar for Higgs studies (probably even less background!).

But in case of Tera-Z primary ions become an issue:

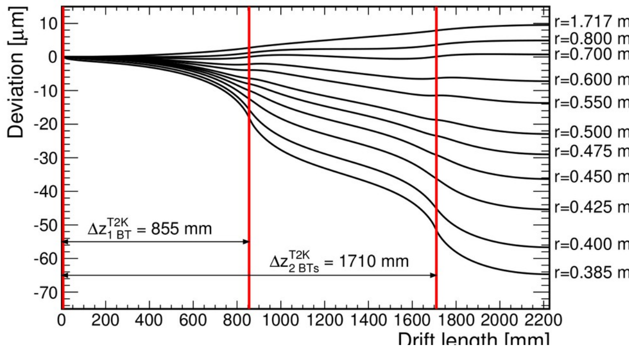
Luminosity: $L = 2 \cdot 10^{36}\ s^{-1}\ cm^{-2}$
→ rate of Z's 60000 s^{-1}
with multiplicity of 20 and 100 ions/cm
=> rough estimate gives ~1000 ions/cm³ on average. This will give serious track distortions (O(mm)).
→ could be calibrated (see ALICE) with Z→ µµ, (it still has to be studied to which level)

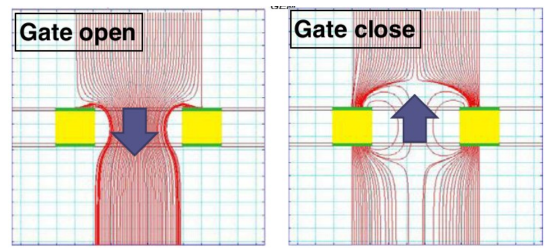


Ions from Gas Amplification

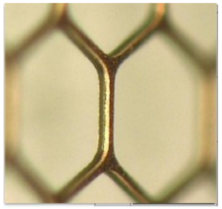
Gas amplification increases the number of ions by O(1000).
→ Usually TPCs have a gating device, such as wire based gating grid

ILC without a gating device → track distortions ~60µm
→ a gating GEM is foreseen.





But active gating is not possible at circular machines like CEPC or FCCee → different approach has to be studied.



There are combinations of MPGDs, which reduces the IBF to 1 % and some might do even better - in theory, but this has to be verified.

Also passive gating is possible: some field configuration, which additionally suppresses IBF with static electric fields. But like to loose also primary electrons → worse spatial resolution

Likely the secondary ions are not much of a problem either, but degrade spatial resolution a bit. Except in case of Tera-Z.

Power Pulsing / Cooling

Same challenges as everyone else:

=> no time between bunch trains,
→ power pulsing not possible
→ energy consumption of electronics will be higher by a factor of O(100)
→ more cooling needed.

=> The endplate will be thicker than 0.2 X_0.

If really necessary, number of pad rows or number of pads/pixels could be reduced at the price of worse performance.

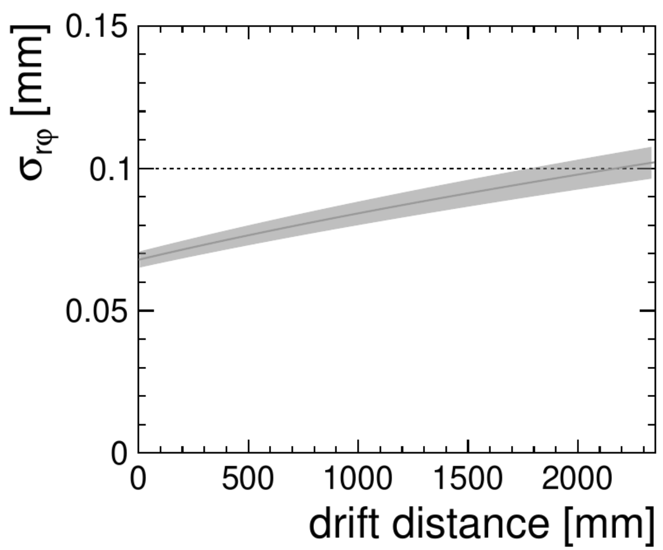
B = 2 T Running

Larger diffusion (larger D_T)

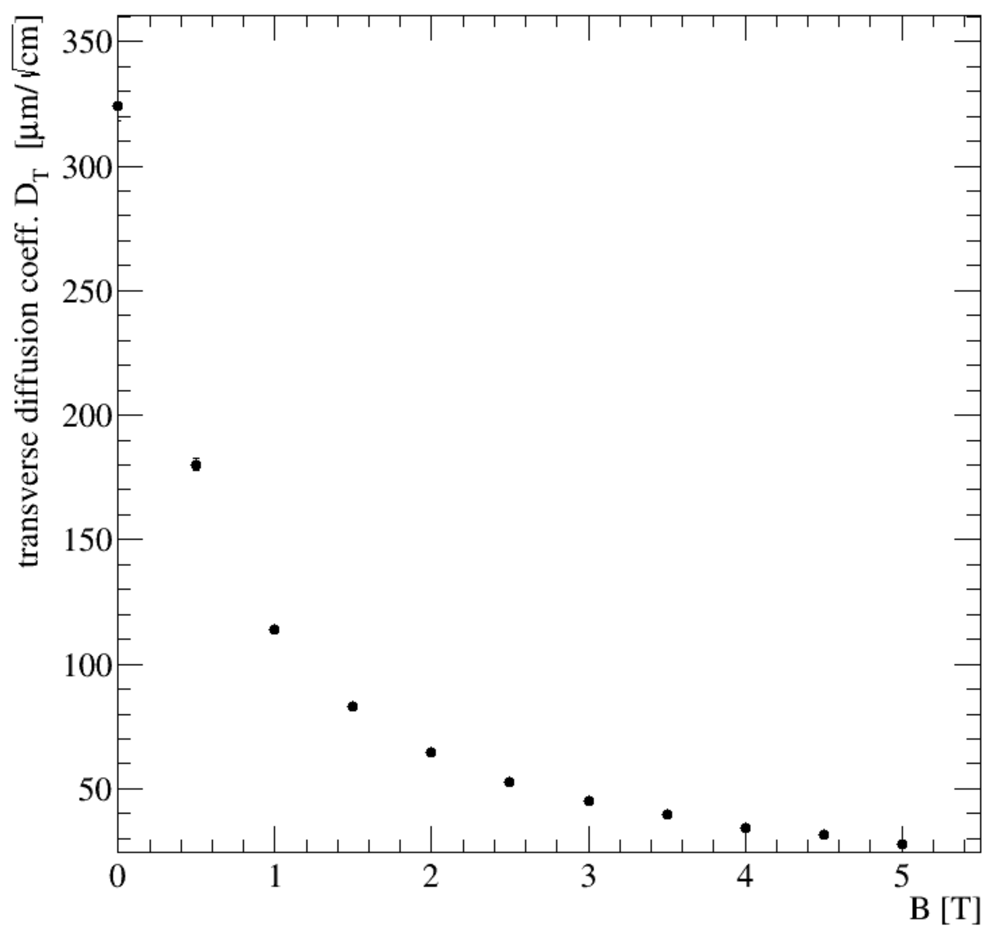
39 µm/√cm → 65 µm/√cm

→ degrading transverse spatial resolution.

$$\sigma = \sqrt{\sigma_0^2 + D_T^2 x}$$



Ar:CF_4:iC_4H_{10} 05:3:2 - D_T vs. B



What do we need?

People and money 

Besides, we should know, which detector requirements are necessary in the case of a circular machine. Also background conditions etc.

Is the good spatial resolution really necessary at Tera-Z, or can this be done by the SIT + SET, and the TPC is implemented for other reasons:

- track finding
- dE/dx
- increase tracking efficiency
- V0 and kink finding
- good performance at Higgs-energy

Summary

- Continue GEM, Micromegas and pixel tests at the LP in preparation for the preliminary design of the LCTPC after the green light.

- A gate should be included in the next-generation GEM, Micromegas and pixel modules.

- Synergies with T2K / ALICE / CEPC allow us to continue R&D and of course we learn from their experiences and R&D.

- For circular machines the ions have to be studied in much more detail again.