TPC Development by the LCTPC Collaboration for the ILD Detector at ILC

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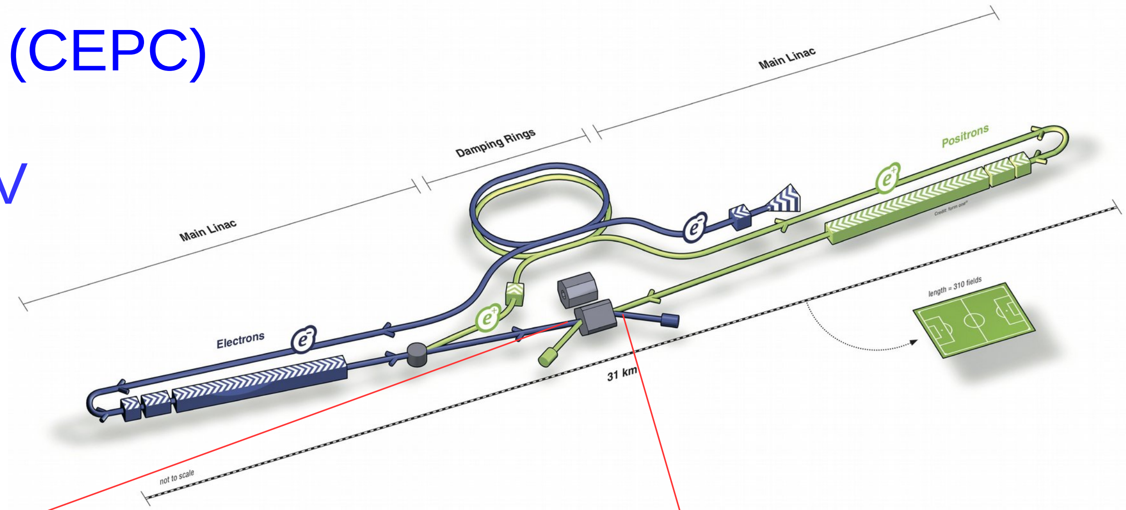
for LCTPC

CPAD Instrumentation Frontier Workshop
Stony Brook, NY
18-22.03.2021

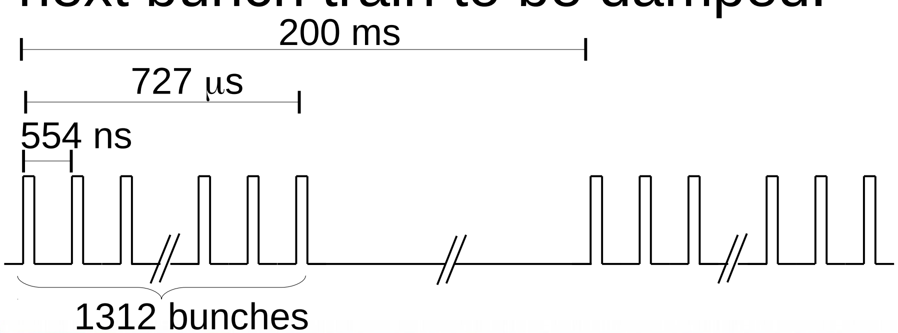
UNIVERSITÄT BONN

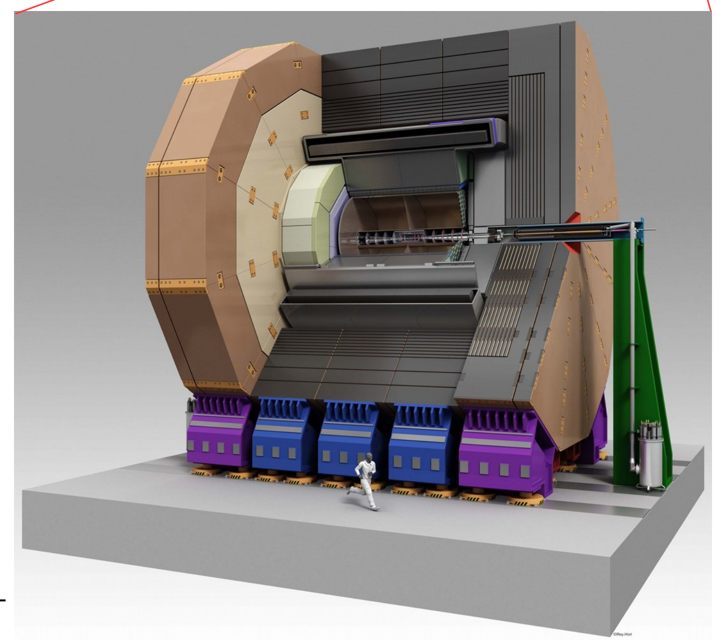
International Linear Collider

International Linear Collider (ILC) /
Chinese Electron Position Collider (CEPC)
are both e^+e^- colliders with:
$\sqrt{s}$ = 250 GeV – 1TeV / 90-240 GeV
Overall length of 30 km / 100 km



<u>Bunch structure (example ILC):</u>
Damping takes 0.2 s, once all the particles are damped, extraction and collision start.
But when the damping ring is empty, it takes again 0.2 s for next bunch train to be damped.

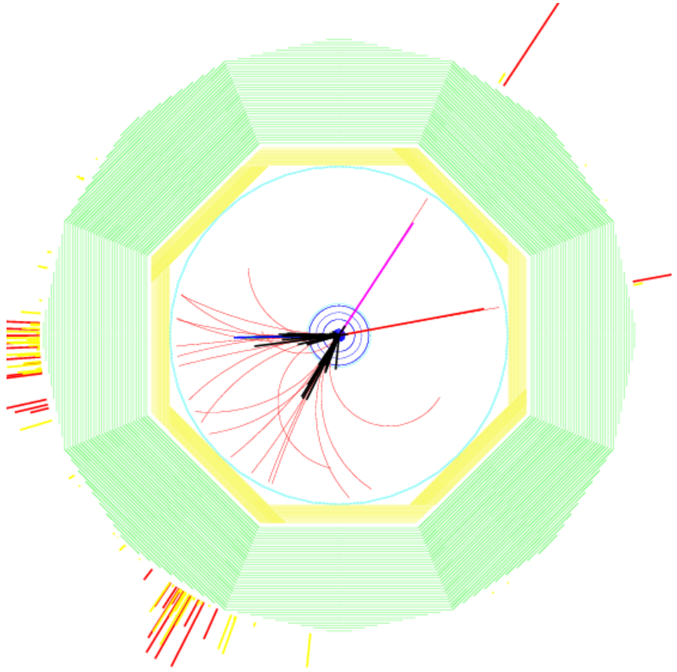




International Large Detector
- Standard HEP detector
- TPC as main tracker
- Interchanged with SiD by push and pull principle

ILD-TPC Requirements

Requirements are driven by benchmark processes, in the case of ILD – TPC the most stringent measurement is the Higgs-recoil measurement:



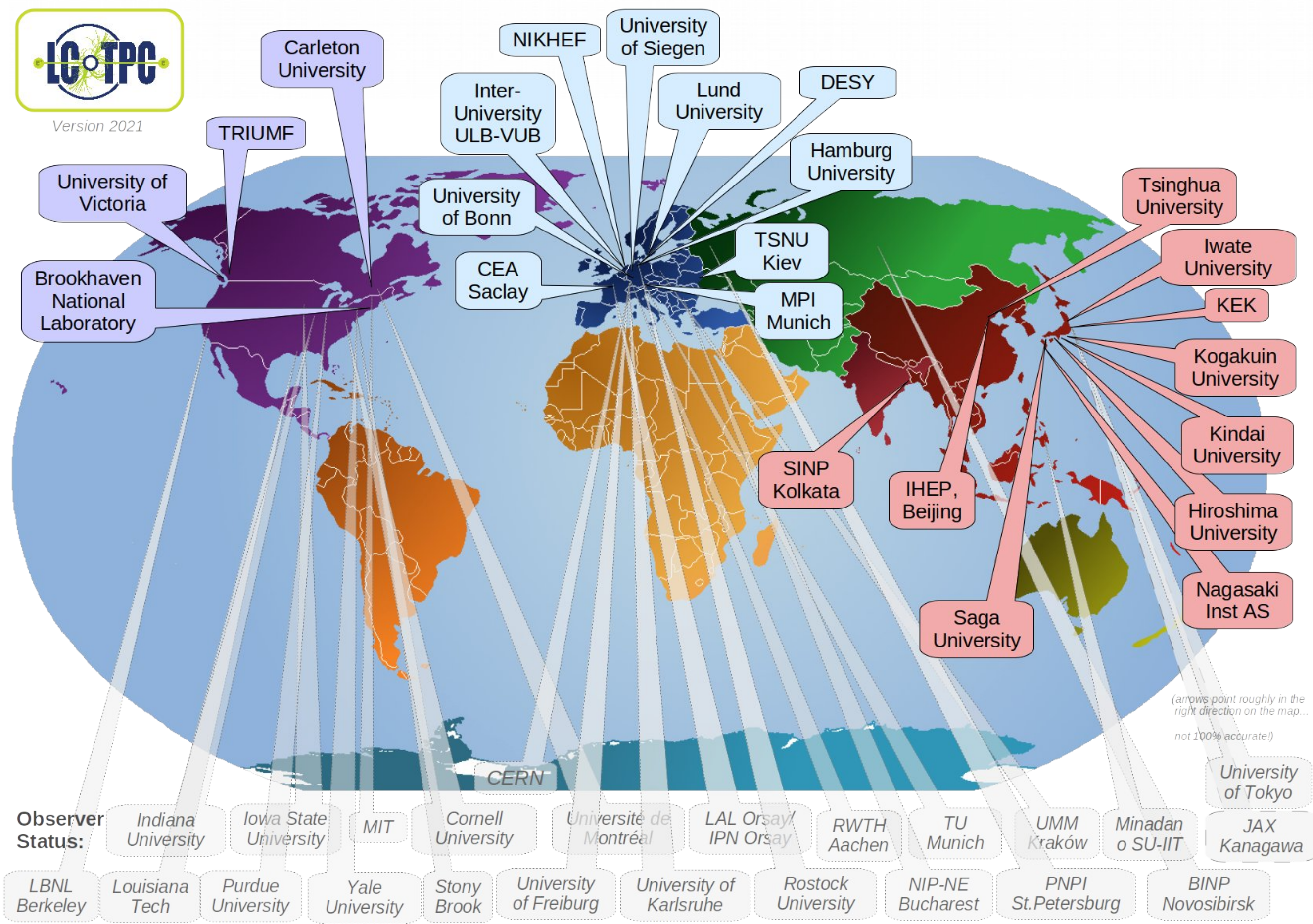
Requirements of TPC from ILC TDR vol. 4

Parameter			
Geometrical parameters	r_{in}	r_{out}	z
	329 mm	1808 mm	± 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 $r\phi$	$\simeq 60\ \mu$m for zero drift, $< 100\ \mu$m 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)		

In addition: very high efficiency for particle of more than 1 GeV.

These requirements can not be fulfilled by conventional wire-based read out.
New Micropattern-based readouts have to be applied.

LCTPC Collaboration



LCTPC-collaboration studies MPGD detectors for the ILD-TPC:
24 Institutes from
11 countries
+ 24 institutes with
observer status

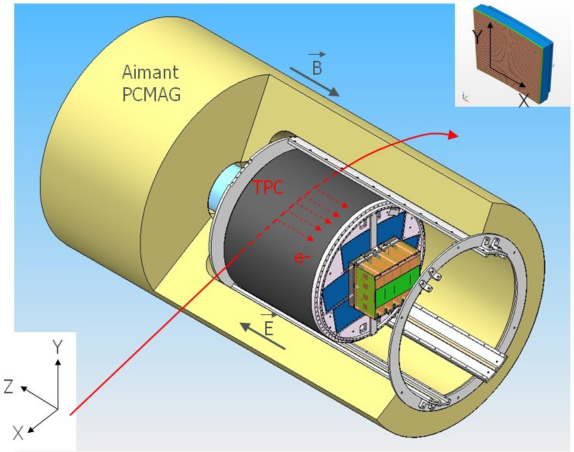
Various gas amplification stages are studied: GEMs, Micromegas, GEMs with double thickness and GridPixes.

MPGDs in TPCs

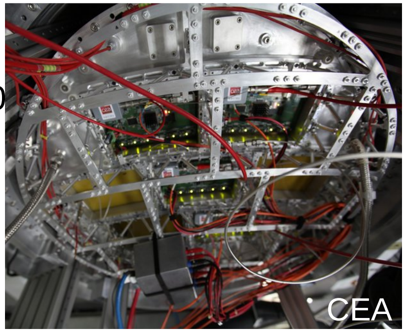
- Ion backflow can be reduced significantly
- Small pitch of gas amplification regions
  => strong reduction of E×B-effects
- No preference in direction
  => all 2 dim. readout geometries possible

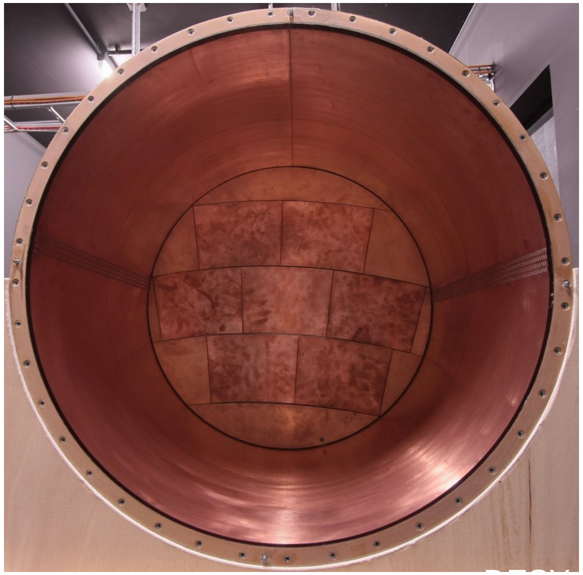
Test setup at DESY

PCMAG: B < 1.2 T, bore diameter: 85 cm
Electron test beam: E = 1- 6 GeV
LP support structure
Beam and cosmic trigger



<u>LP Field Cage Parameter:</u>
length = 61 cm
inner diameter = 72 cm
up to 25 kV at the cathode
=> drift field: E ≈ 350 V/cm
made of composite materials: 1.24 % X_0





<u>Modular End Plate</u>
two end plates for the LP made from Al
7 module windows (one is space frame)
→ size ≈ 22 × 17 cm^2 (ILD: 240 modules/endcap)

Large Prototype has been built to compare different detector readouts under identical conditions and to address integration issues.

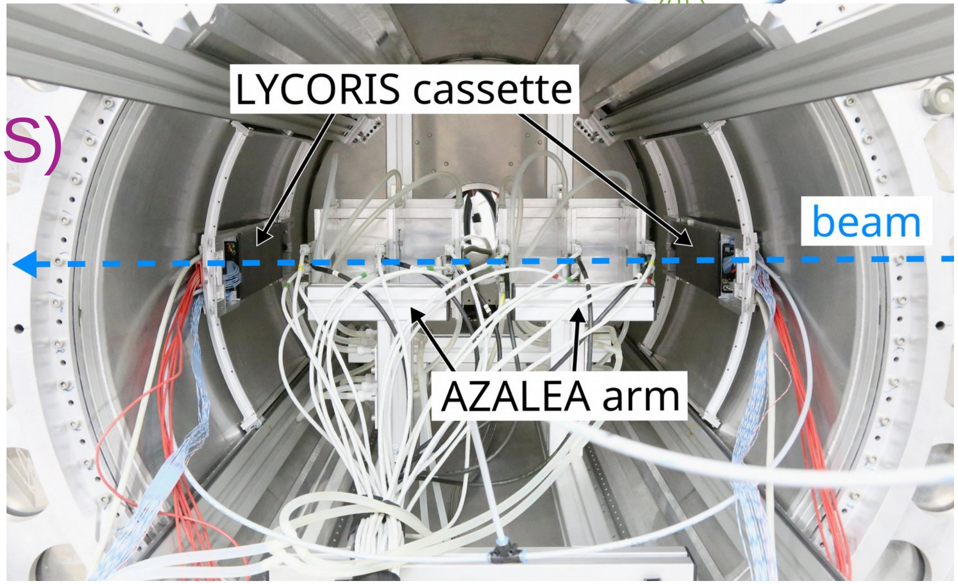
JINST 5:P10011,2010

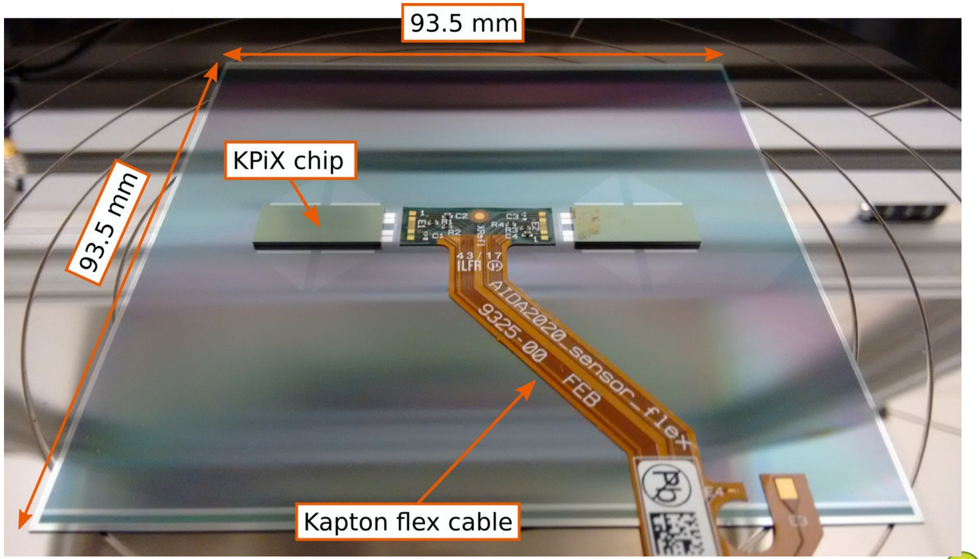
Setup at DESY

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

- An external silicon tracker (LYCORIS) for the Large Prototype (LP) is advanced and first test beams have been performed. But there is still work to integrate everything. All groups will redo measurements with newest module types to study distortions.

- Current field cage shows misalignments of the axis to the endcaps.
  → Construction of an improved field cage for the LP.
  → Also important for learning to build the final detector.



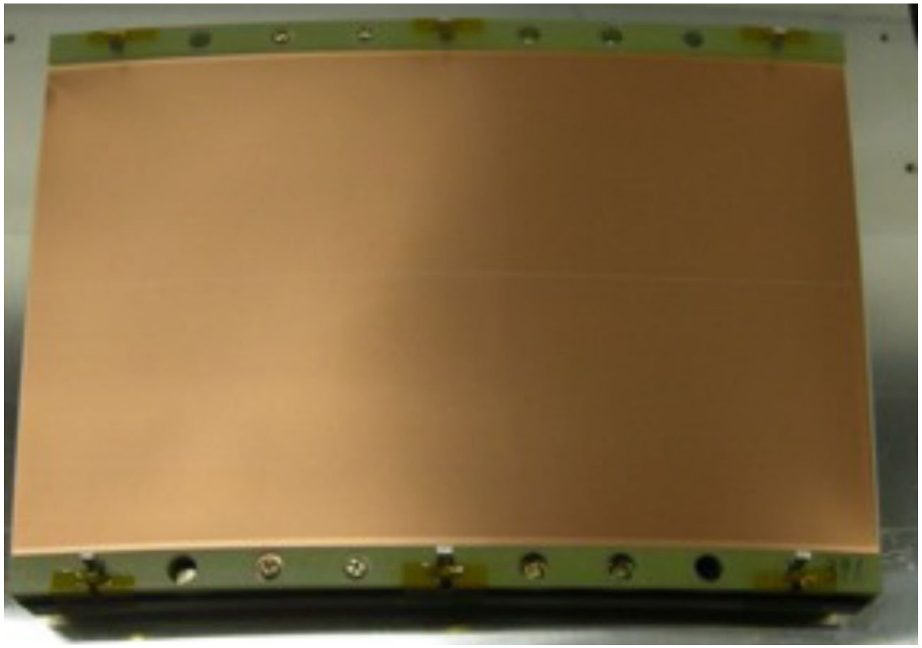


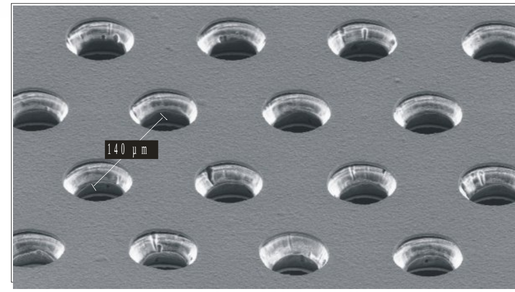
GEM Modules (I)

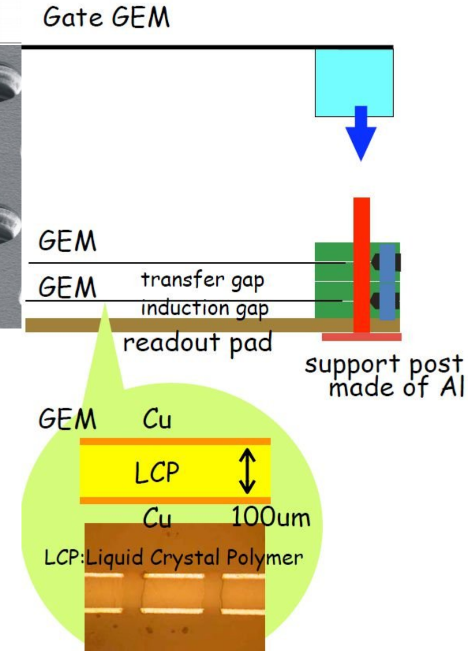
GEMs: copper-insulator- copper sandwich with holes

2 configurations are being tested:

- double GEMs with 100µm LCP insulator
- triple GEMs with ‘standard CERN GEMs’

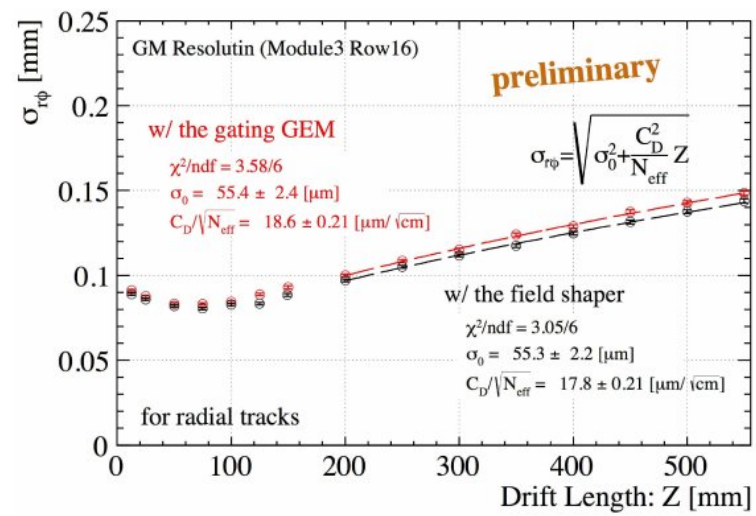






GEM Modules 1:

- 2 GEMs made of 100 µm thick LCP
- $1.2\times5.4\text{mm}^2$ pads



Design idea of GEM Modules 1:

- Minimize insensitive area pointing towards IP => no frame at modules sides
- Use thicker GEMs to give more stability
- Broader arcs at top and bottom

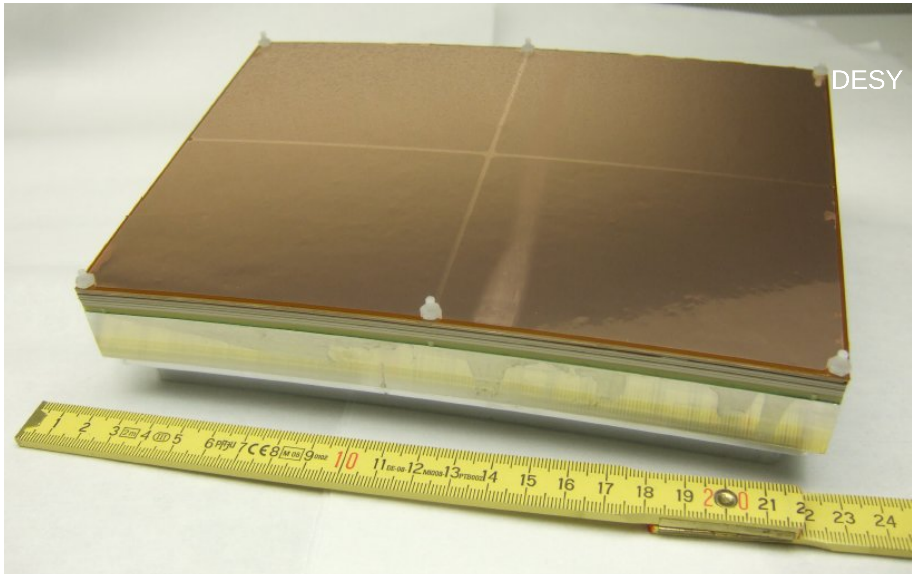
NIM A608 (2009) 390-396

GEM-Modules (II)

<u>Design idea:</u>

Minimize dead area

Do not use frame to stretch GEMs, but a 1 mm grid to hold GEM



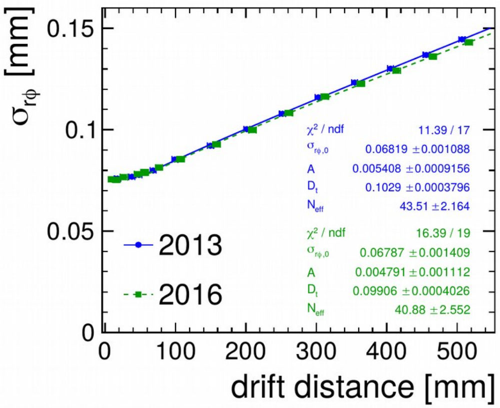
Spatial resolution published in first publication. Now, double track resolution and dE/dx performance is scrutinized. Also, in dependence on the pad sizes.

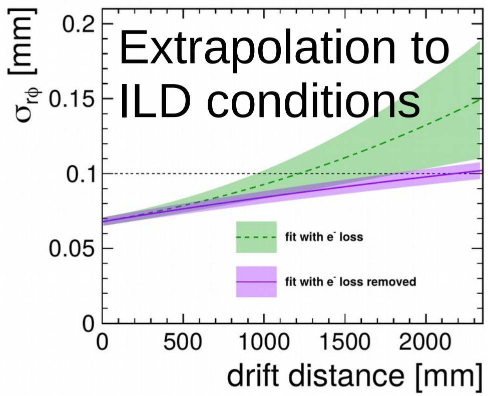
<u>2 iterations of modules built:</u>

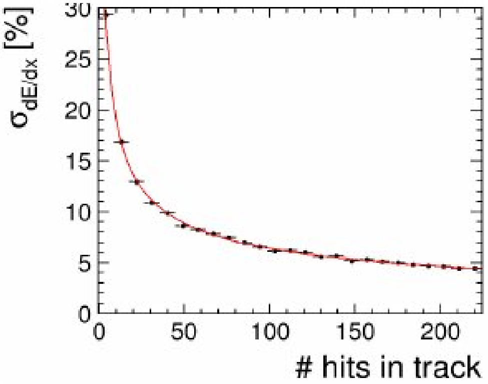
$1.26 \times 5.85 mm^2$ pads – staggered

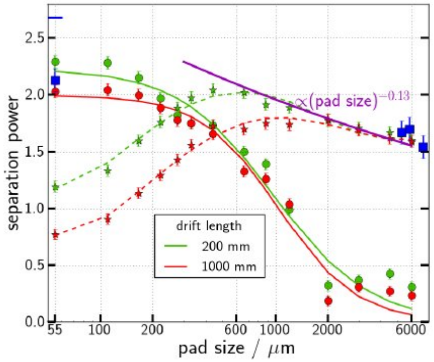
Field shaping wire on side of module

New publication in preparation:





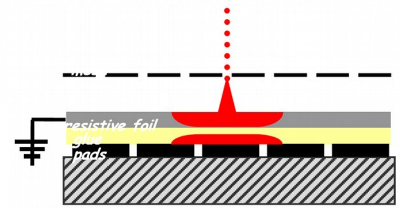




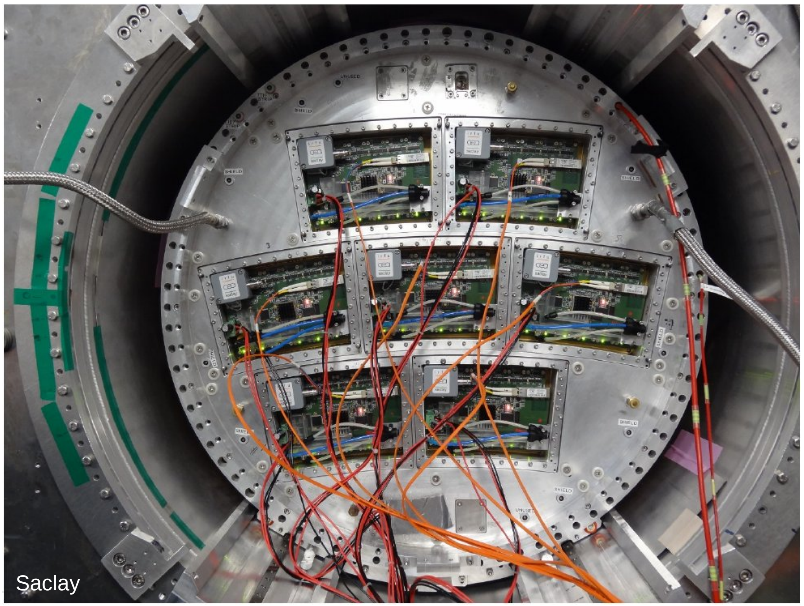
First publication:
NIM A856 (2017) 109-118

Resistive Micromegas

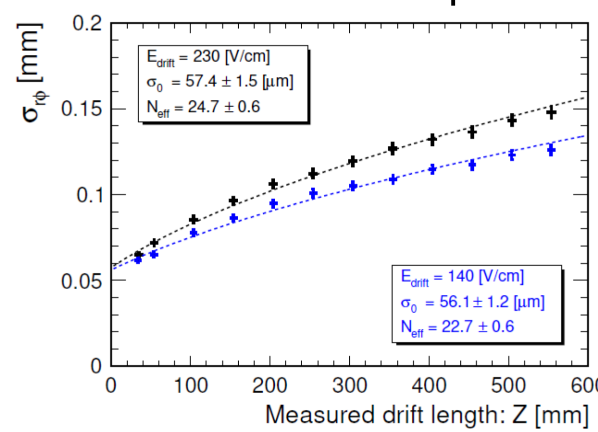
<u>Resistive Micromegas:</u> Bulk-Micromegas with 128 µm gap size between mesh and resistive layer

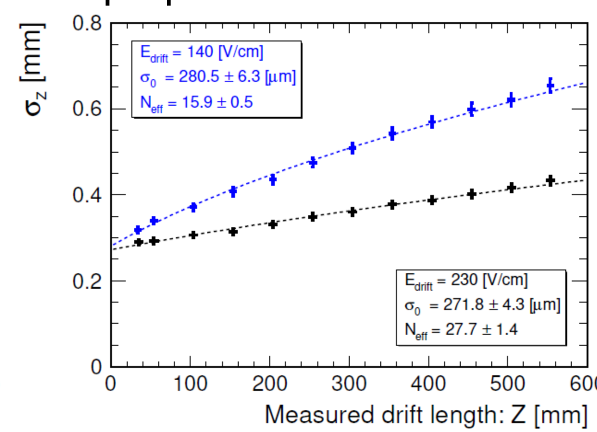


NIM A581(2007) 254



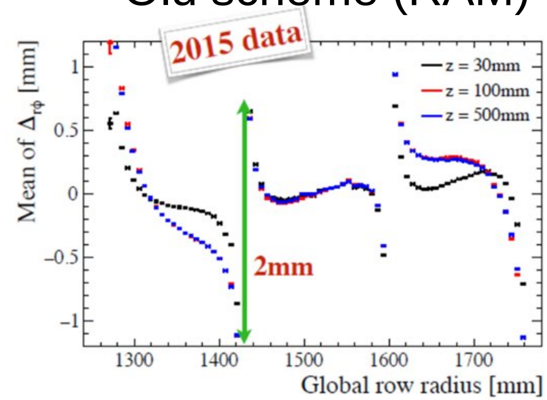
New publication in preparation:



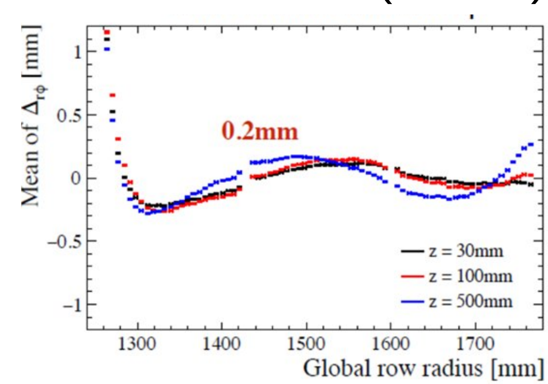


A new HV scheme of the module places grid on ground potential and reduces field distortions significantly.

Old scheme (RAM)



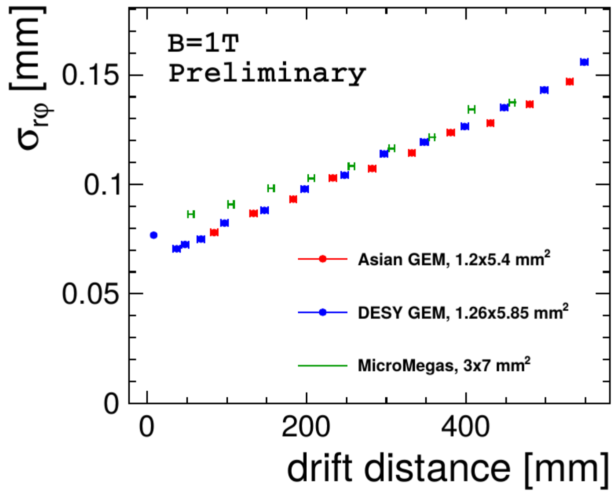
New scheme (ERAM)



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 with

- a more final design and
- a more comparable design.

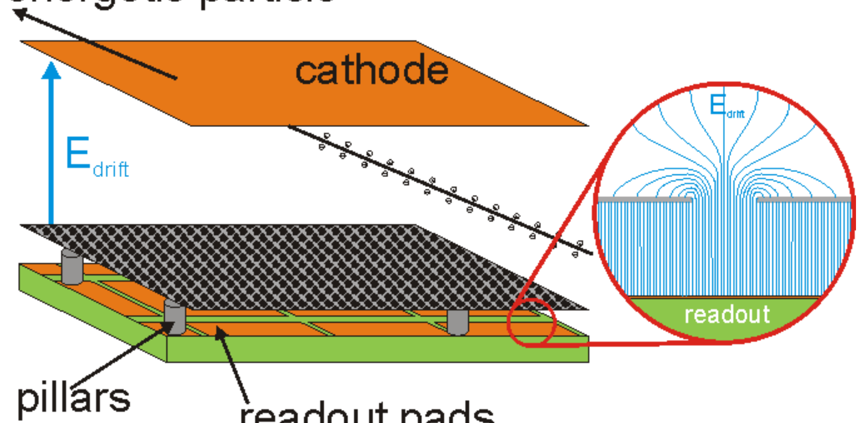


These common modules should have a

- common readout electronics (sALTRO),
- 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.

Improving Micromegas: GridPix



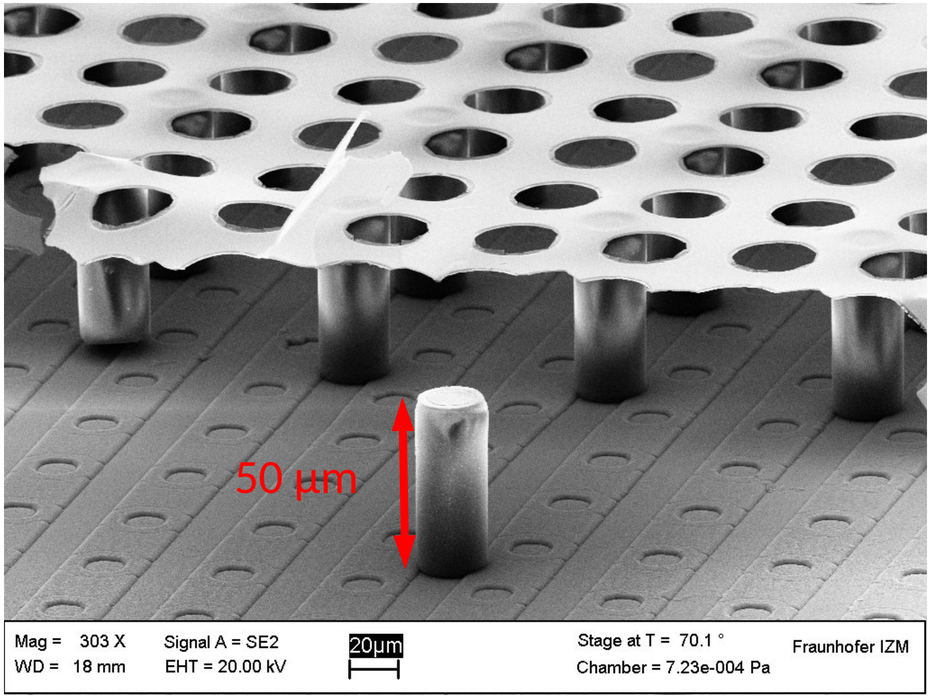
Could the spatial resolution of single electrons be improved?

Ar:CH_4 90:10 → D_t = 208 µm/√cm
→ σ = 24 µm

Ar:iButan 95:5 → D_t = 211 µm/√cm
→ σ = 24 µm

Smaller pads/pixels could result in better resolution!
At NIKHEF the GridPix was invented.

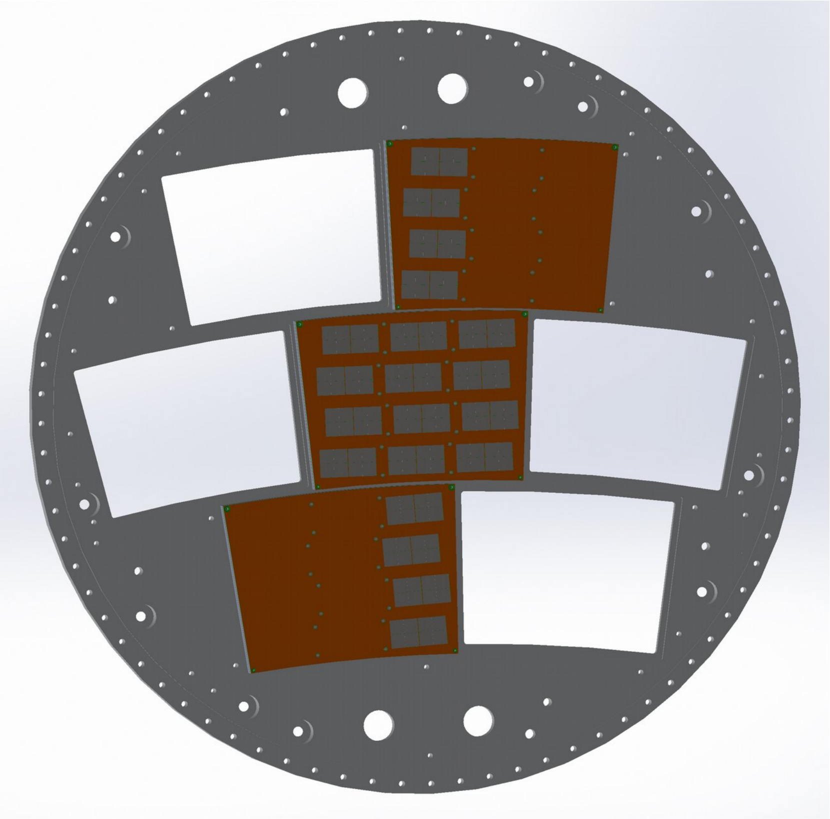
Standard charge collection:
Pads / long strips
Instead: Bump bond pads are used as charge collection pads.



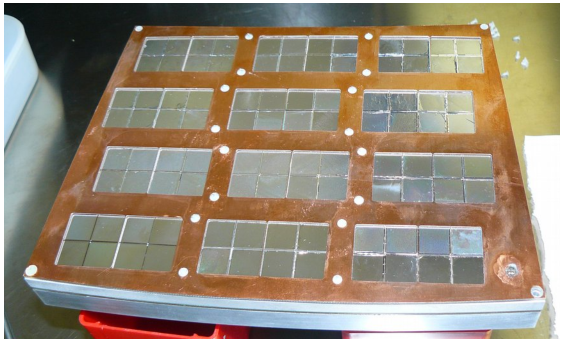
- Lower occupancy → easier track reco
- Removal of δ-rays and kink removal
- Improved dE/dx (4% seems possible)
- No angular pad effect

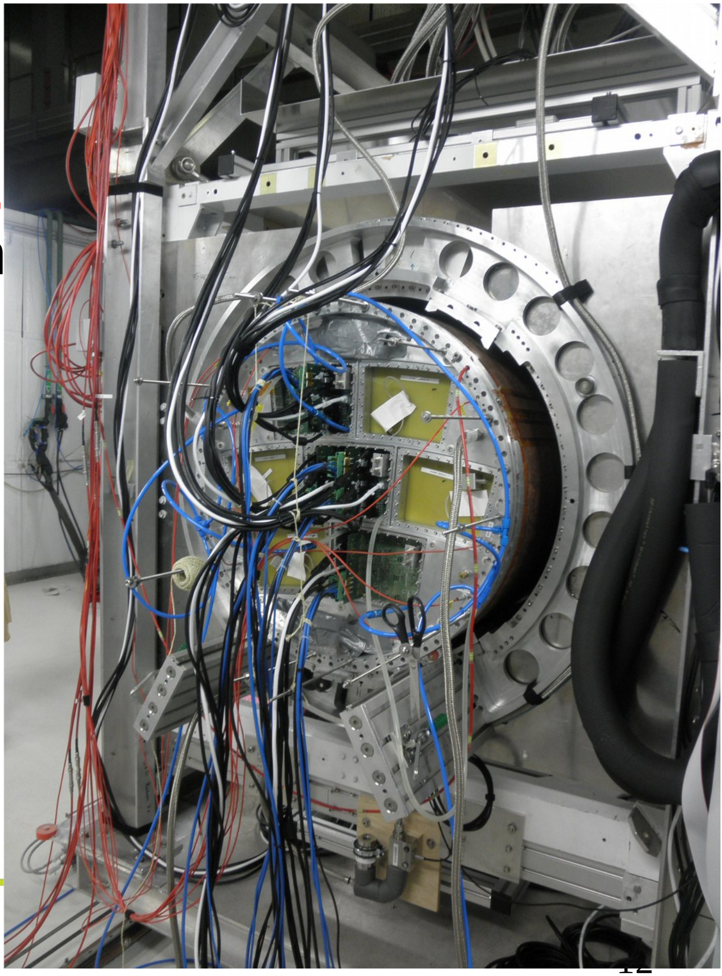
Large Scale Readout

To readout the TPC with GridPixes:
~100-120 chips/module 240 module/endcap (10 m²) → 50000-60000 GridPixes
Demonstration of mass production: One LP-module covered completely with GridPixes (96 → coverage 50%) and two partially covered modules.
In total 160 GridPixes covered an active area of 320 cm².



The test beam was a huge success: A pixel TPC is realistic.
During the test beam we collected ~10^6 frames at a rate of 4.3-5.1 Hz.

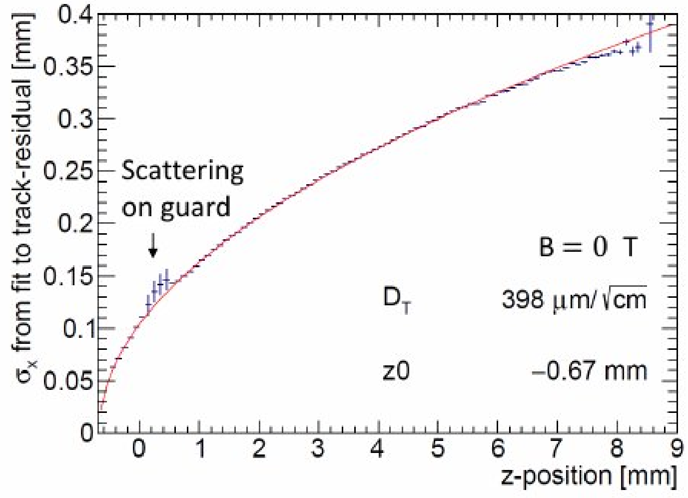


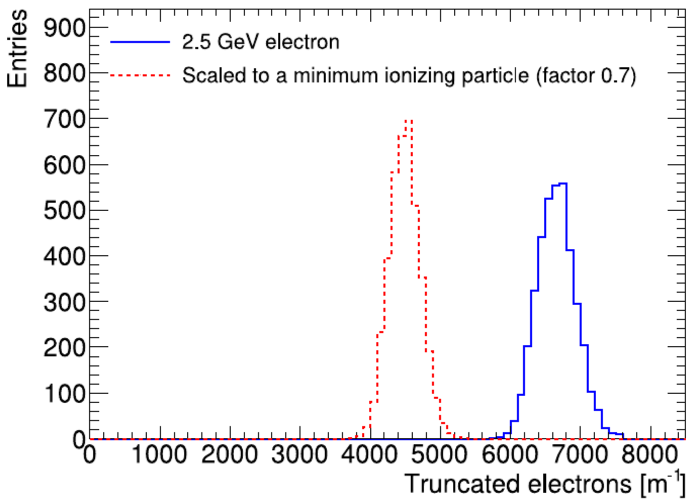


IEEE TNS 64 (2017) 1150

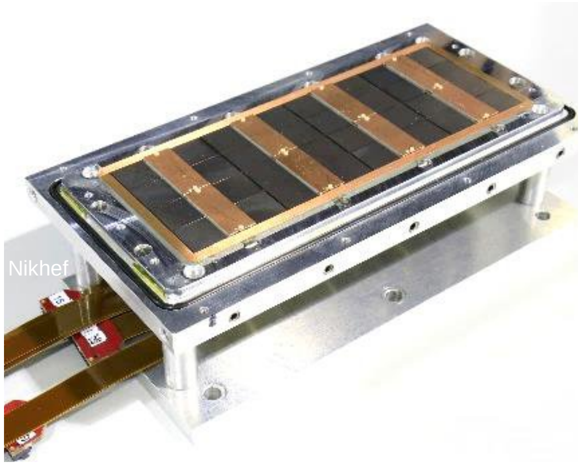
Timepix3-based GridPix

GridPix detector have moved from Timepix to Timepix3 ASICs. Tests with single and quad devices have been successfully done and published.





A first module with 32 GridPixes has been constructed and will be tested in a planned test beam at DESY - including a test in a magnetic field. A complete LCTPC module would consist of about 100 GridPixes.

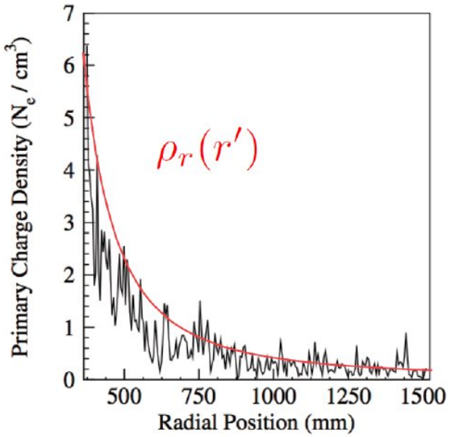


The ion back flow of the module has been measured and can be further reduced by applying a double grid. Also the resistivity of the protection layer will have to be reduced.

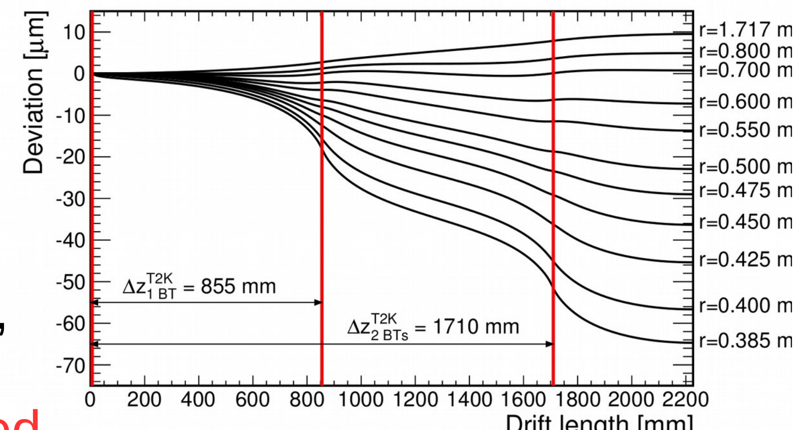
NIM A908 (2018) 18-23
NIM A956 (2020) 163331

Ion Feedback and Gating

Primary ions create distortions in the electric field which result in O(<1µm) track distortions including a safety margin of estimated BG.

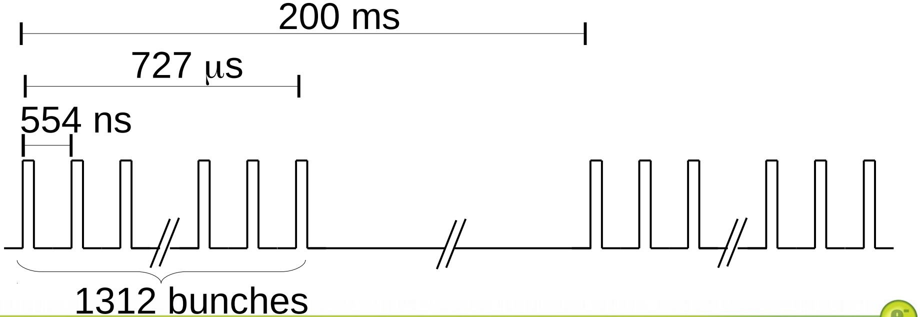


- Machine induced background has 1/r shape
- Ions from gas amplification stage build up discs
- Track distortions are 20 µm per disc without gating device, if IBF is 1/gain
- Total: 60 µm => Gating is needed



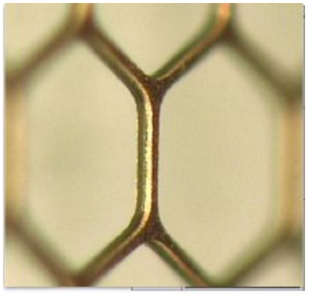
- Wire gate is an option
- Alternatively: GEM-gate
- Simulation show:
  Maximum electron transparency is close to optical transparency
- Fujikura Gate-GEM Type 3
  Hexagonal holes: 335 µm pitch,
  27/31 µm rim
  Insulator thickness 12.5 µm

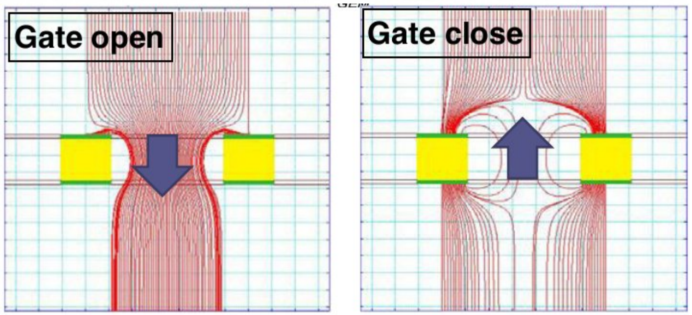
<u>Bunch structure at ILC:</u>
Damping takes 0.2 s, once all the particles are damped, extraction of bunch train starts.



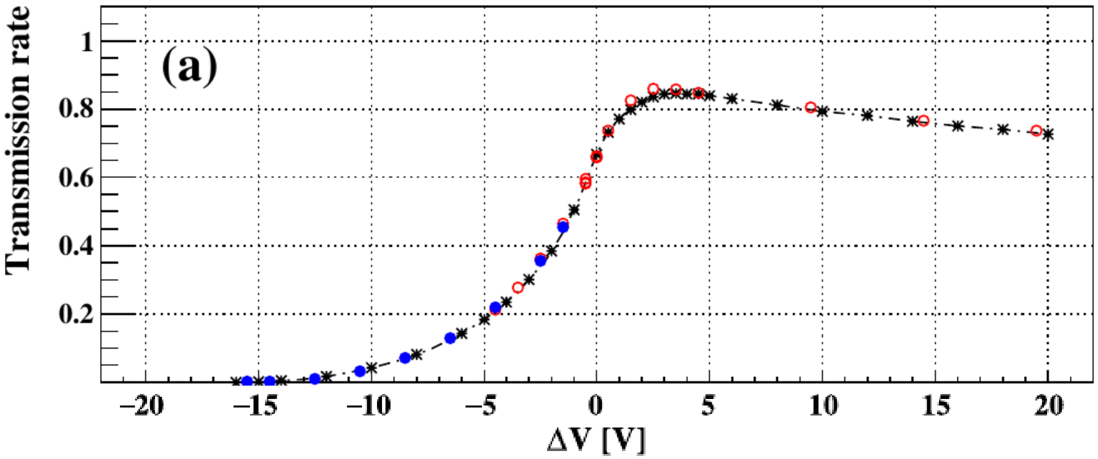
Gating GEM

The gating GEM is a favorite, which has large holes (Ø 300 µm) and thin strips inbetween (30 µm).





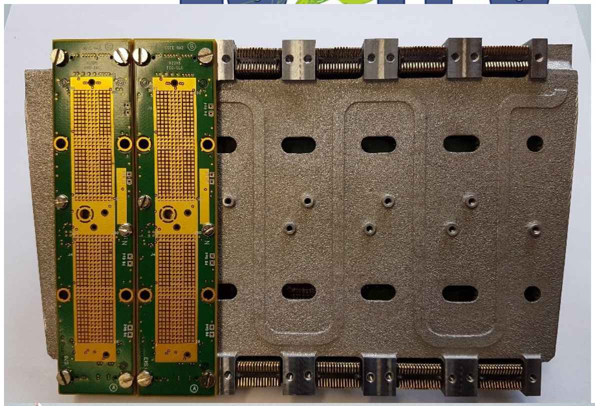
The electron transparency has been determined with different measurements and corresponds to 82 % as expected from simulations.



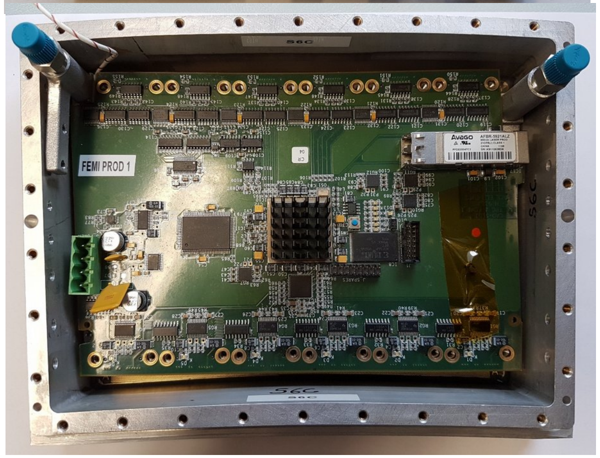
The ion blocking power still has to be determined and quantified. First measurements have been initiated for this, but no results yet. Also a fast HV switching circuit has to be developed. The gate should also be tested in B = 3.5-4 T.

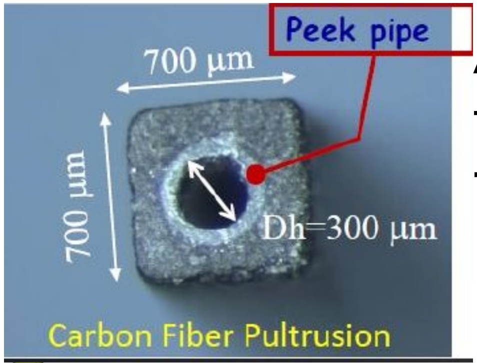
Cooling

Despite the power pulsing, the readout electronics will require a cooling system. 2-phase CO_2-cooling is a very interesting candidate. A fully integrated AFTER-based solution has been tested on 7 Micromegas modules during a test beam.

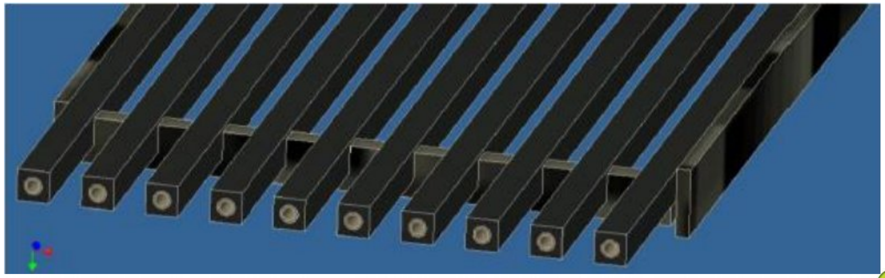


To optimize the cooling performance and the material budget, 3D-printing is an attractive possibility for producing the complex structures required. A prototype for a full module is available now at CEA, Saclay. It will be increased to 4 modules until 2021.

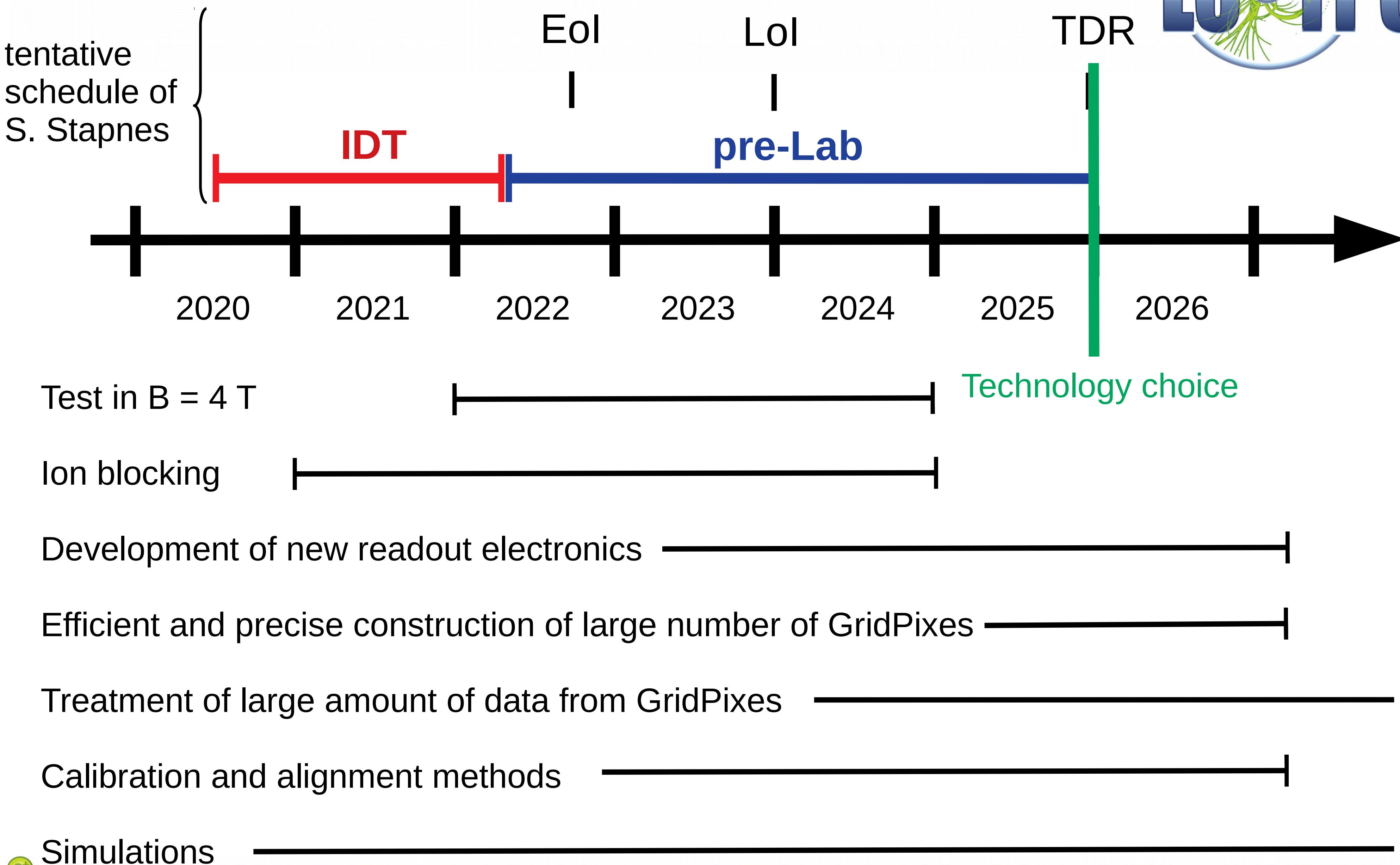




Alternatively, Lund is exploring micro channel cooling together with Pisa. These consists of pipes with Ø 300 µm in carbon fiber tubes.



Timeline


tentative schedule of S. Stapnes
EoI
LoI
TDR
IDT
pre-Lab
2020
2021
2022
2023
2024
2025
2026
Technology choice
Test in B = 4 T
Ion blocking
Development of new readout electronics
Efficient and precise construction of large number of GridPixes
Treatment of large amount of data from GridPixes
Calibration and alignment methods
Simulations

Summary

- Continue GEM, Micromegas and pixel tests at the LP in preparation for the preliminary design of the TPC during the pre-Lab phase.

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

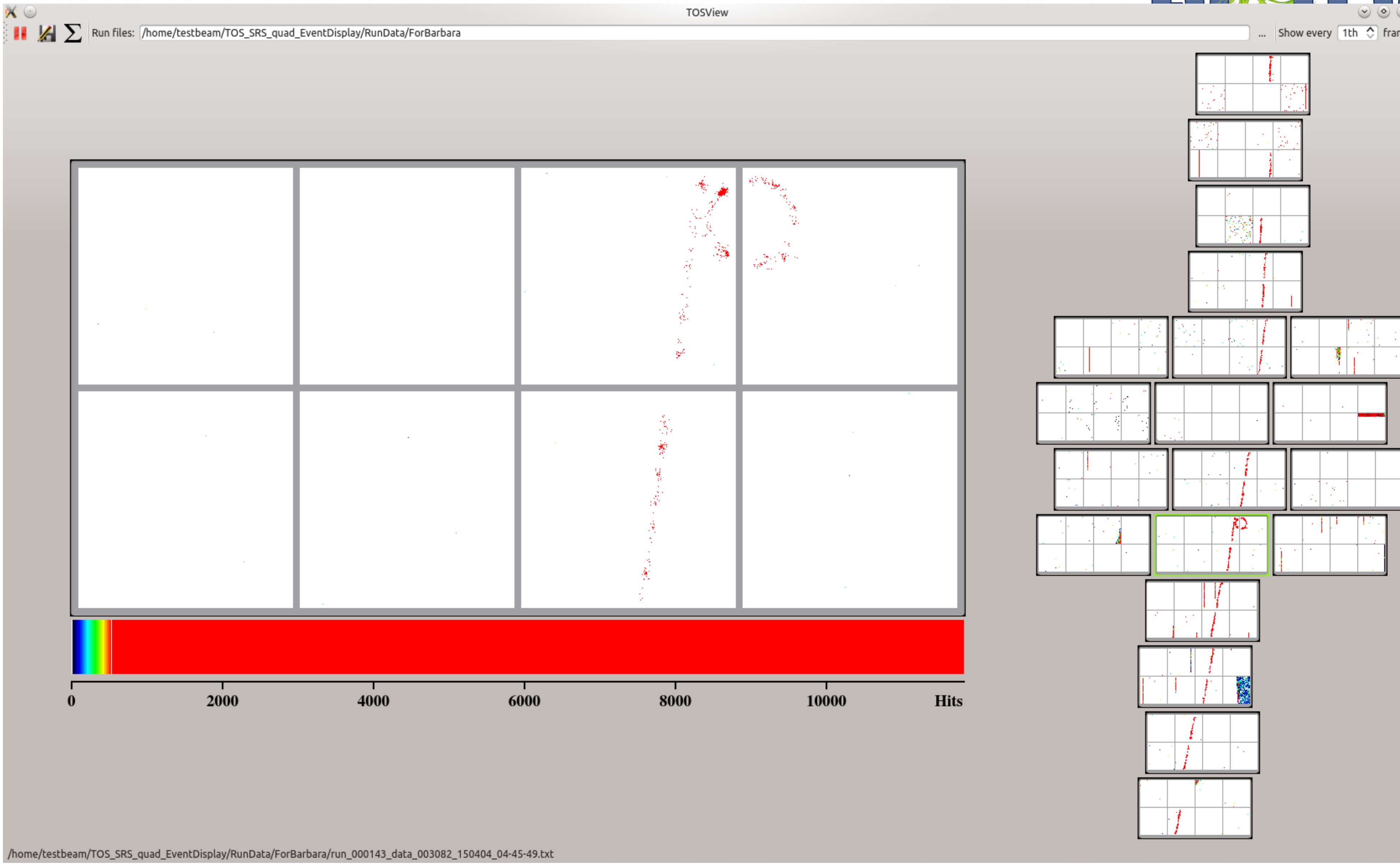
- Synergies with T2K / ALICE / CEPC/ EIC allow us to continue R&D and of course we learn from their experiences and R&D. We are also open for people interested in applications beyond the scope of ILC.

- Continue electronics, cooling and powerpulsing development.

- Many simulations are still necessary to understand the detailed requirements of the final detector (e.g. number of ADC bits, pad sizes, etc.), but also new ideas for old challenges are welcome.

Backup

Online Event Display (1)



Online Event Display (2)