ICHEP 2022 BOLOGNA

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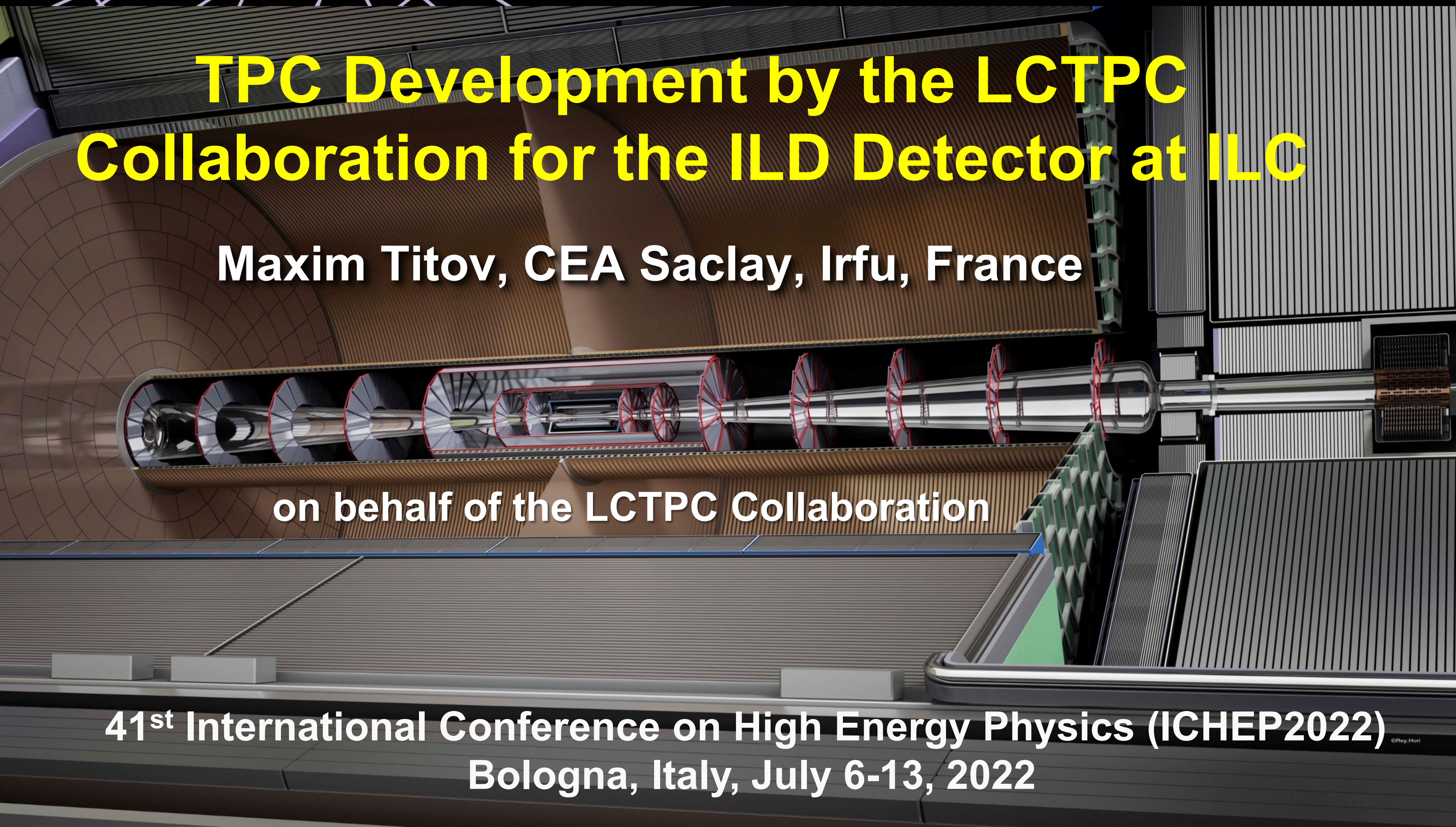

TPC Development by the LCTPC Collaboration for the ILD Detector at ILC

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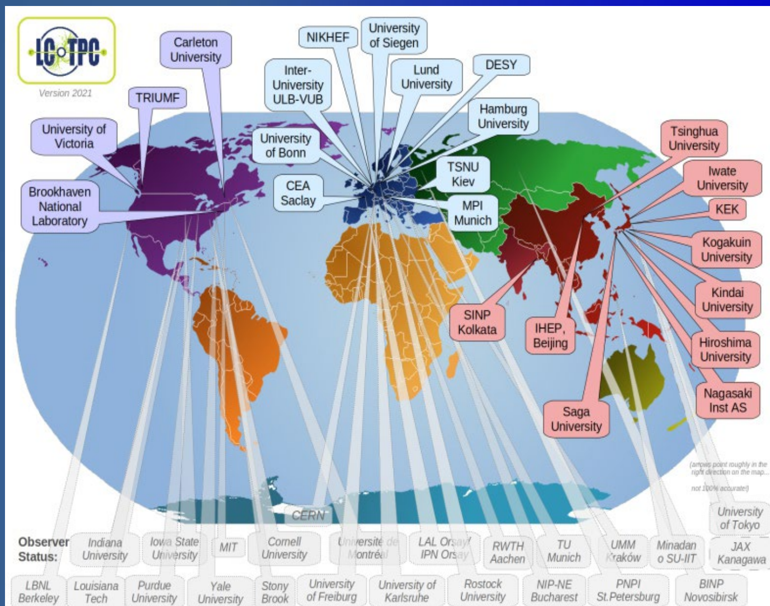
on behalf of the LCTPC Collaboration

41st International Conference on High Energy Physics (ICHEP2022)
Bologna, Italy, July 6-13, 2022

Time Projection Chamber R&D: LCTPC Collaboration

LCTPC collaboration focus: MPGD-based readouts of TPCs for the ILD detector at ILC
@ generic TPC R&D for other future colliders.



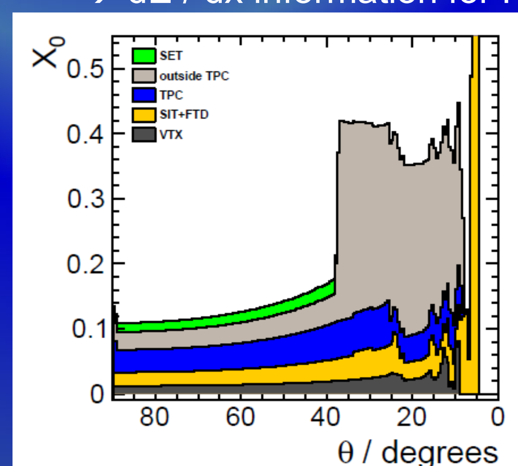
Micro-Pattern Gaseous Detectors (MPGD) provide several benefits:

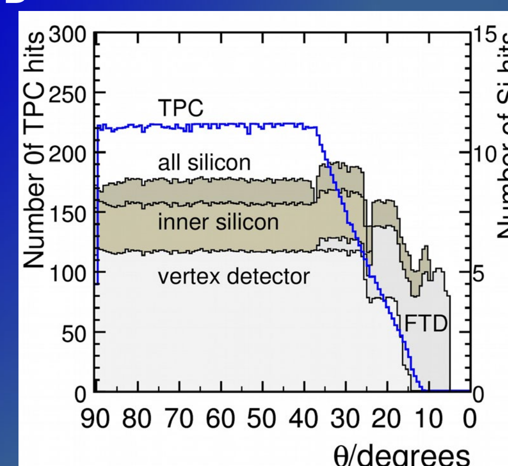
- ✓ Signifiant reduction of Ion backflow
- ✓ Small pitch of gas amplification regions
  → strong reduction of E×B-effects
- ✓ No preference in direction
  → all 2 dim. readout geometries

TPC requirements from ILC TDR:
(driven by Higgs recoil-mass measurement):

Parameter			
Geometrical parameters	r_{in} 329 mm	r_{out} 1808 mm	z $\pm$ 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	$\sim 1 \times 6$ 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)		

TPC with MPGD readout for the ILD Detector at ILC:
High hit redundancy (200 hits / track)
→ 3D tracking / pattern recognition;
→ dE / dx information for PID

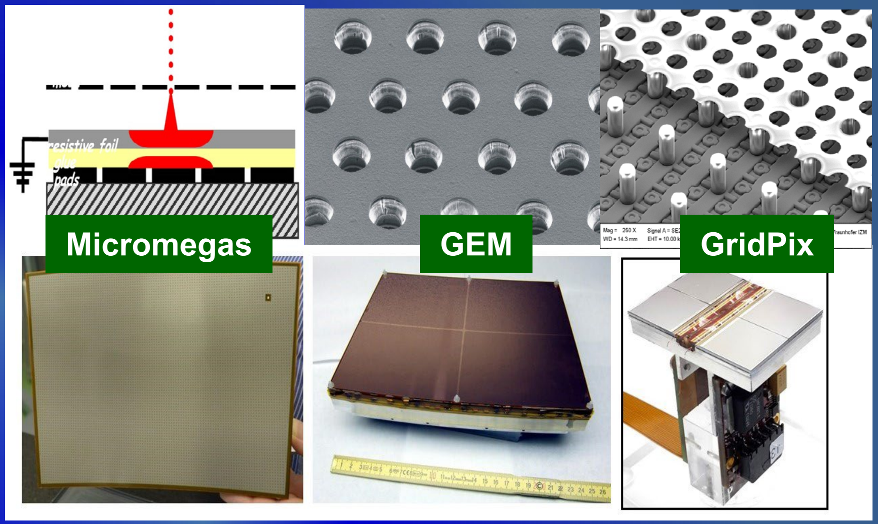




ILC TPC (10m² Endcaps) with MPGD-Based Readout

Three Baseline Technologies (GEM, MM, GridPix):

- ✓ Standard "pad readout" (~ few mm²): 8 rows of detector modules (17×23 cm2); 240 modules per endcap
  - → Triple-GEMs with 'standard CERN GEMs"
  - → Double-GEMs (laser-etched) 100μm thick ("Asian")
  - → Bulk MM (128 μm) with resistive anode
- ✓ Pixel readout (55x 55mm²): ~100-120 chips per module → 25000-30000 per endcap (GridPix)
  GridPix: MM with 1 μm Al-grid over pixel CMOS ASIC
  - 55 μm pitch of readout pixels
  - resistive layer for ASIC protection

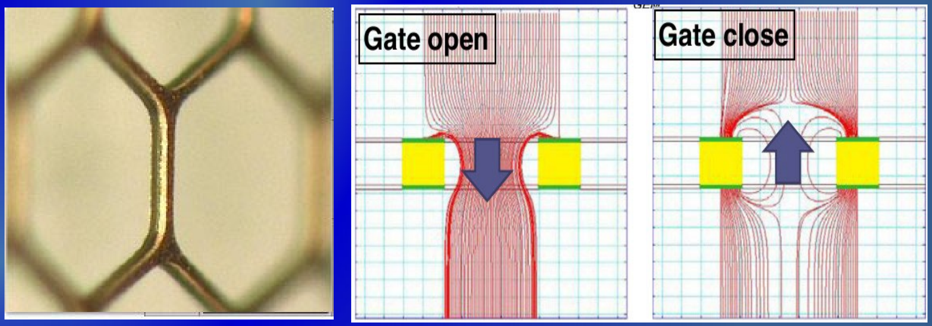


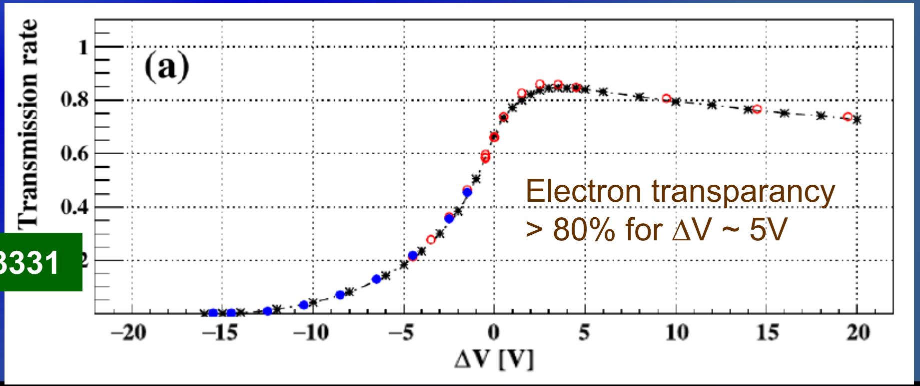
Common Developments:

- ✓ **Gating scheme, based on large-aperture GEM**

- → Exploit ILC bunch structure (gate opens 50 us before the first bunch and closes 50 us after the last bunch)
- → Suppress machine-induced background and ions from gas amplification
- → gating GEM has large holes (Ø 300 μm) and thin strips in-between (30 μm).

- ✓ Electron transparency of 82 % and good ion blocking power

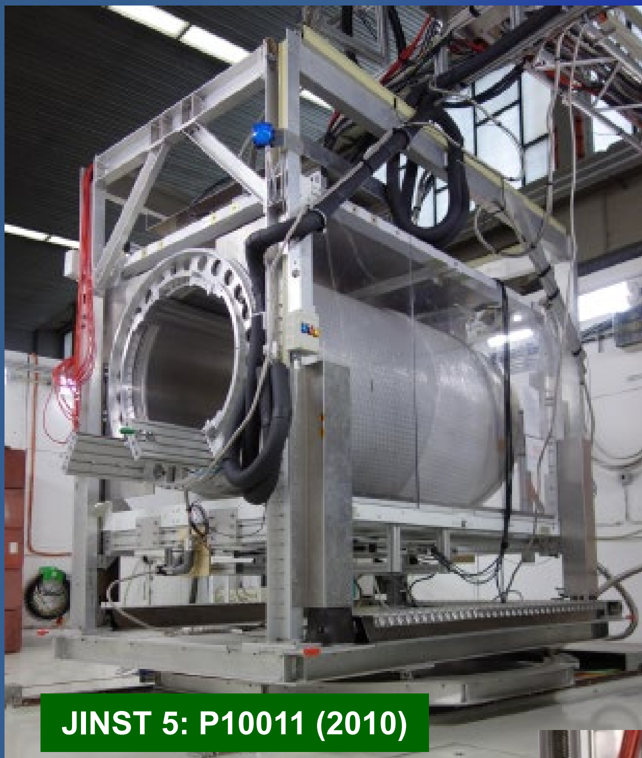




NIM A956 (2020) 163331

- → Gating should be tested in B = 3.5-4 T
- → Fast HV switching circuit has to be developed

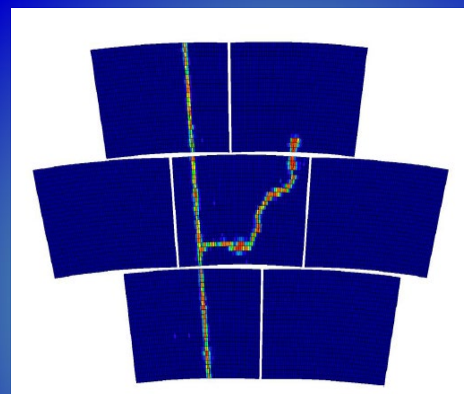
Test Setup "Large TPC Prototype" for the ILC at DESY



JINST 5: P10011 (2010)

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

Future developments: construction of an improved field cage for the LP
→ important for learning to build the final detector
→ resistor chain and HV stability studies

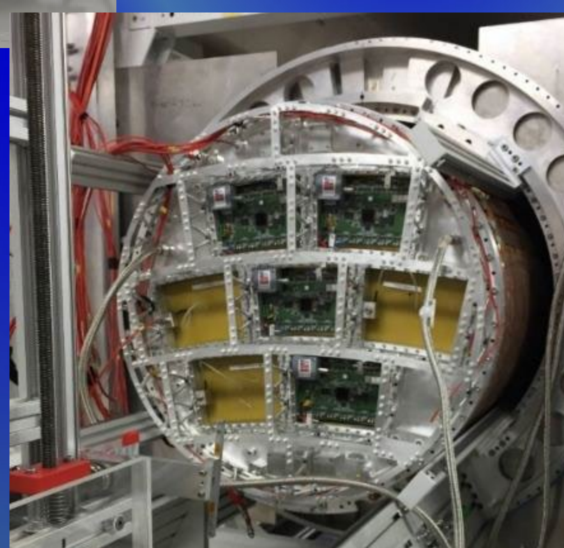


- PCMAG: B < 1.2 T, bore O: 85 cm
- Electron test beam: E = 1- 6 GeV
- LP support structure (3D movable)
- Beam and cosmic trigger
- Silicon tracker inside PCMAG
  → LYCORIS (single point res.: 7 μm)

JINST 16: P10023 (2021)

LP Field Cage Parameters:

- length = 61 cm, inner O = 72 cm
- drift field up to E ≈ 350 V/cm
- made of composite materials: 1.24 %X0



Modular End Plate:

- two end plates for the LP made from Al
- Each endplate has 7 module windows
  → size of module ≈ 22 × 17 cm^2 each
  (ILD: 240 modules / endcap)

- ALTRO based electronics (7212 ch.)

Optimization of Gas Electron Multiplier Readout

Two implementations:

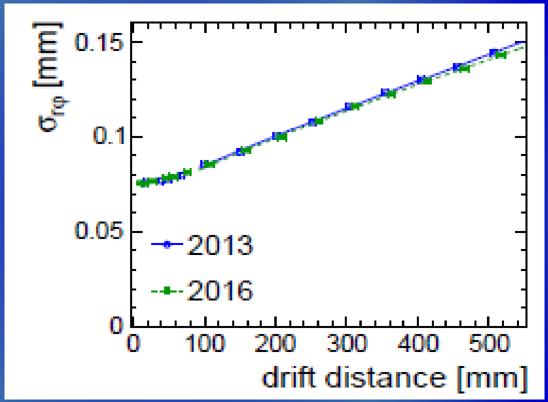
- ✓ Double LCP GEMs (100 μm thick)
  → use thicker GEMs to ensure more stability (no frames at module sides)

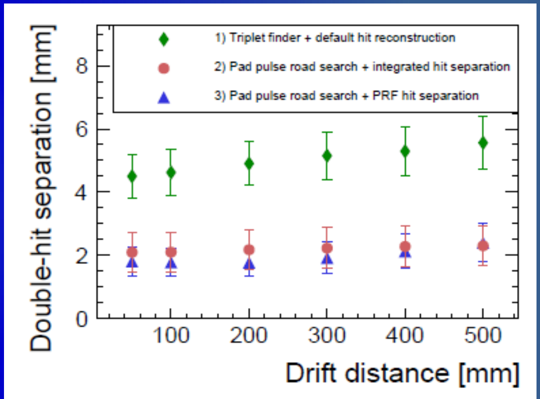
- ✓ Triple CERN GEMs on thin grids
  → Do not use frame to stretch GEMs, but a 1 mm grid to hold GEM
  → 2 iterations of modules built

New paper publsihed in 2022:

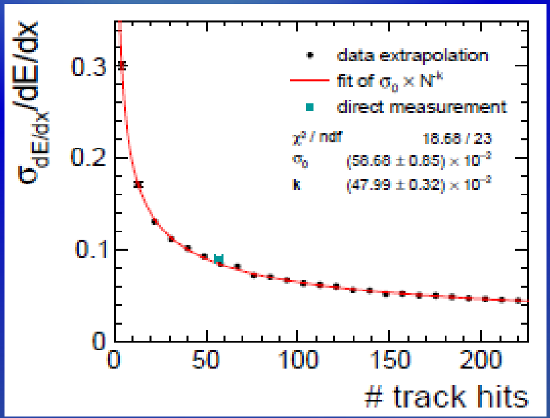
arXiv: 2205.12160

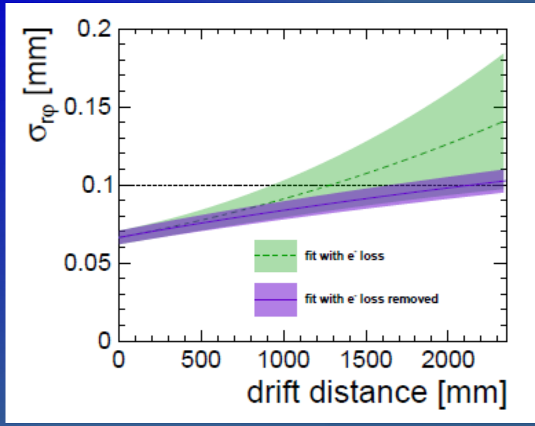
- ✓ 1.26 × 5.85mm² pads – staggered
- ✓ dE/dx performance optimization (also depending from pad size)
- ✓ Field shaping wire on side of module to compensate the field distortions





Extrapolation to the ILD TPC dimensions:



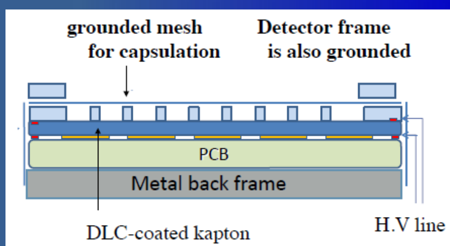


Optimization of Resistive Anode Micromegas Readout

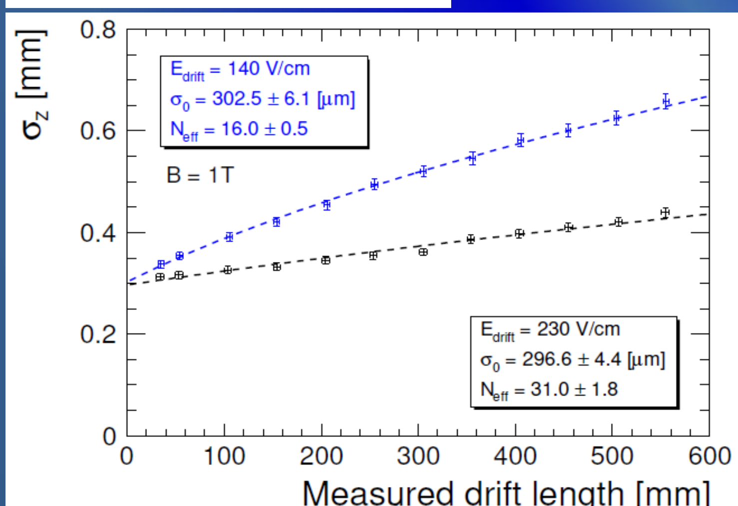
NIMA581 (2007) 254

- ✓ **Use of Diamond-like Coating (DLC) in MM TPC**
  - Suppress sparks
  - Spread the charge allowing larger pads for the same spatial resolution

- ✓ **New HV design (ERAM) with inverted HV config.;**
  - grounding the mesh and encapsulating anode DLC (covering along the borders by 5 mm photoresist) → reduces field distortions between modules by factor of ~10

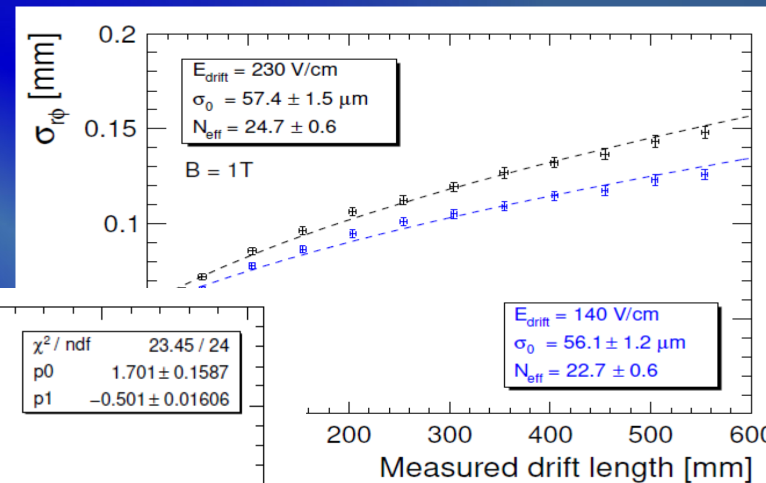


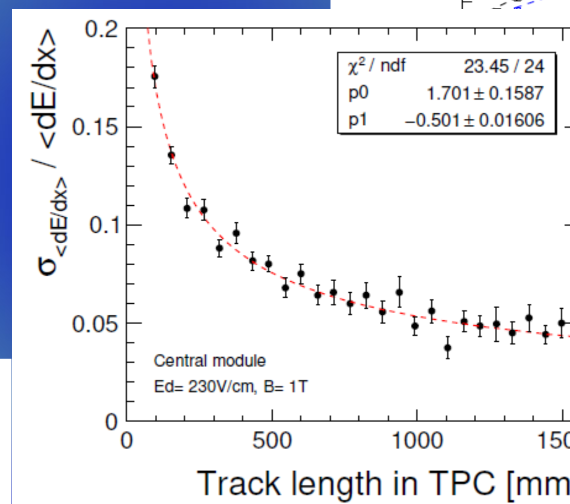
Common ERAM developments with T2K TPC:



DESY Test-Beam in Nov. 2018:

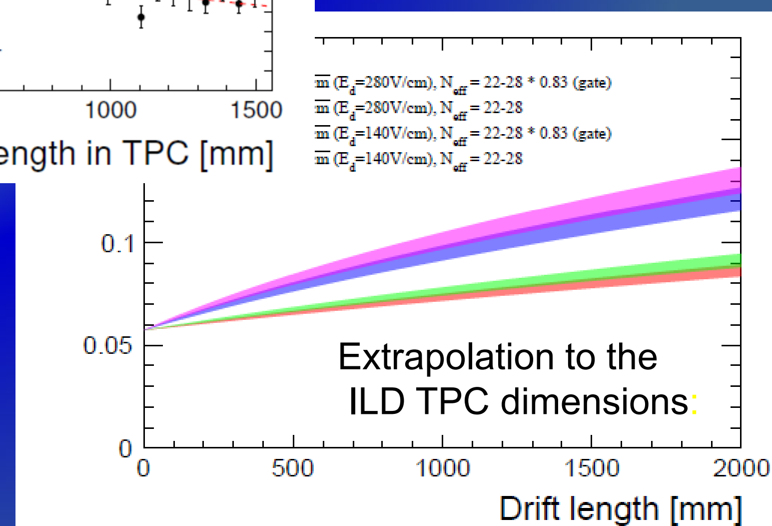
Tests of 4 modules with a new ERAM scheme





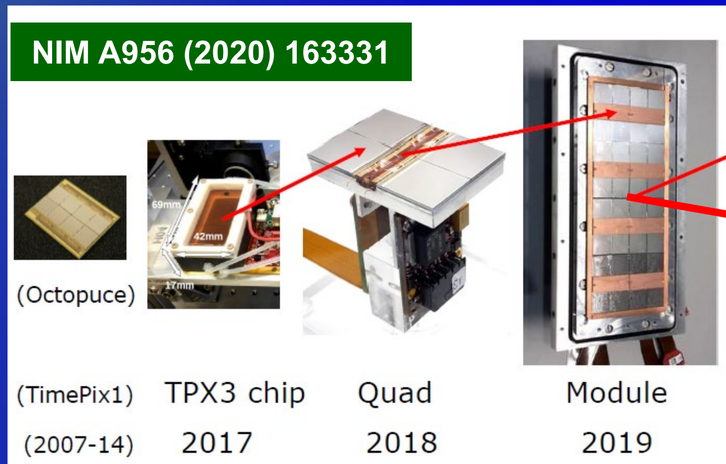
New publication in preparation (preliminary results)

DESY Test-Beam @ LP TPC (Nov. 2018): new ERAM scheme



Towards Large-Scale Pixel "GridPix" TPC

Testbeams with GridPixes:
160 GridPixes (Timepix) & 32 GridPixes (Timepix3)

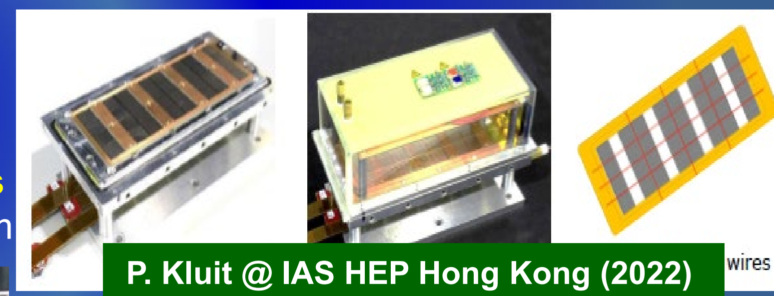


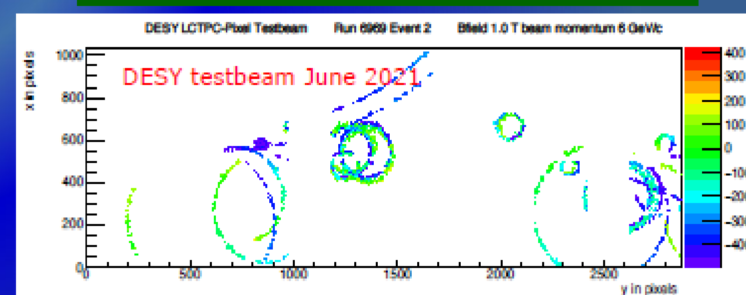
A PIXEL TPC IS REALISTIC!

Physics properties of pixel TPC:

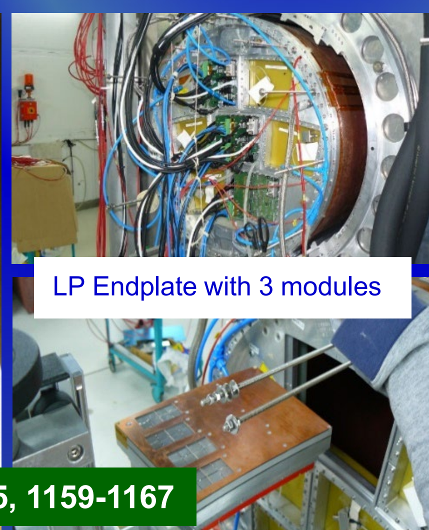
- Improved dE/dx by cluster counting
- Improved meas.of low angle tracks
- Excellent double track seperation
- Lower occupancy @ high rates
- Fully digital read out (TOT)

Quad board (Timepix3) as a building block
→ 8-quad detector (32 GridpPixs) with a field cage at test-beam @DESY in June 2021:





3 modules for LP TPC @ DESY: 160 (1 x 96 & 2 x 32) GridPixs
320 cm² active area, 10,5 M. channels, new SRS Readout system



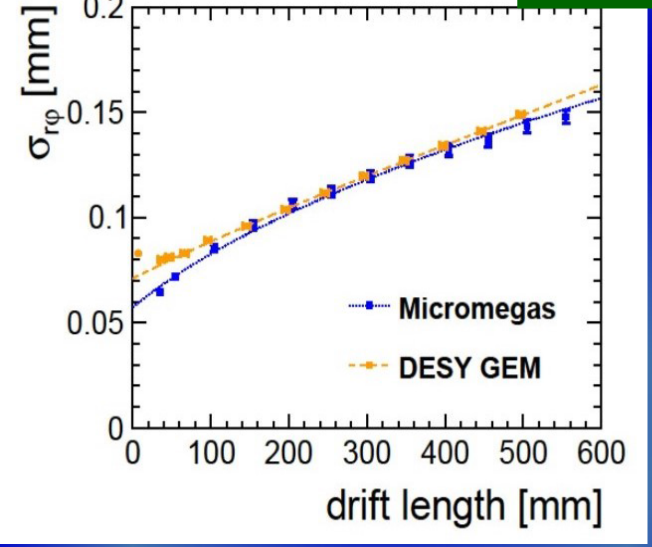
- ✓ ion back flow can be further reduced by applying a double grid.
- ✓ Protection layer resistivity to be reduced
- ✓ New Timepix4 developments

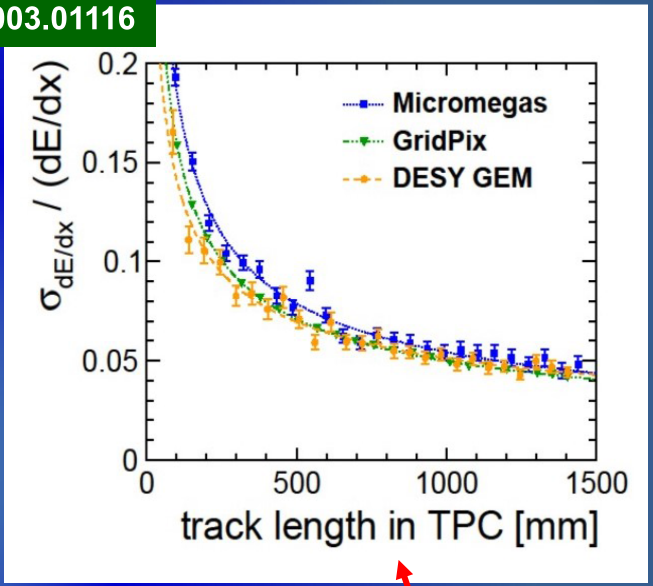
ILC TPC Performance: Technology Comparison

Target requirement of a spatial resolution of 100 μm in transverse plane and dE/dx resolution < 5% have been reached with all technologies (GEM, MM and GridPix)

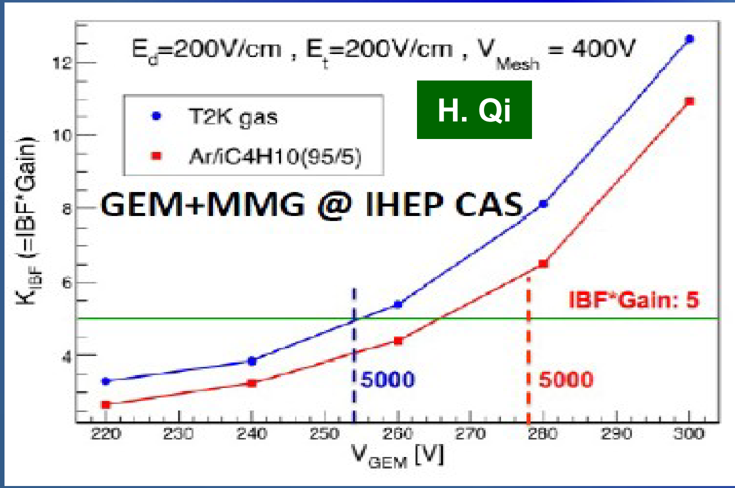
- ✓ GEM: ~ 4-6 mm^2 pads & sufficient diffusion in multi-GEM structure
- ✓ MM: 20 mm^2 pads & charge spreading using resistive-anode readout
- ✓ Gridpix: 55x55 μm^2 pixels with digital readout

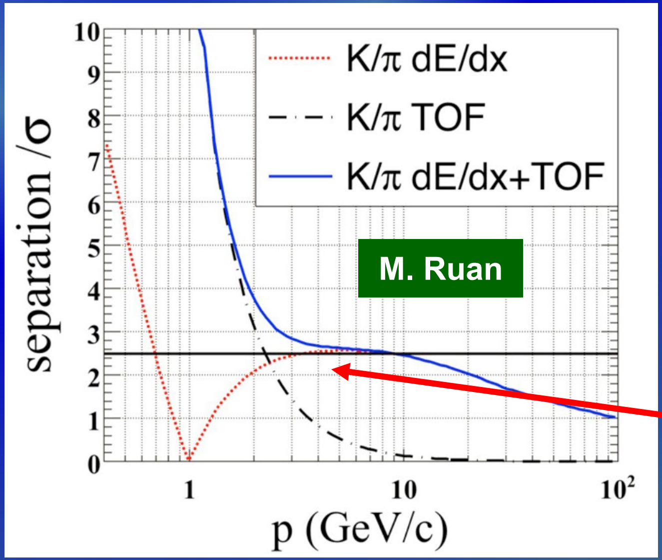
arXiv: 2003.01116





Micromegas + GEM studies for CEPC / FCC-ee to minimize ion backflow (gating is not possible)





dE/dx ~ <4 % can be achieved with Gridpix (cluster-counting)

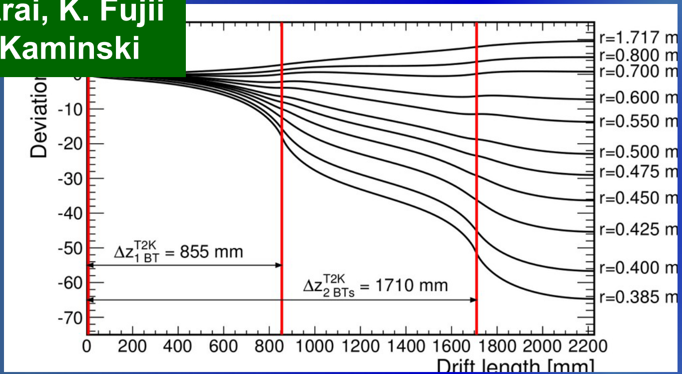
Added value of TIME information for ILC: dE/dx combined with ToF (SiW-ECAL) for K-PID

Pixel TPC for Z-Pole Running at CEPC and FCC-ee

Track Distortions in ILC TPC @ 250 GeV (L~10^{34} cm^{-2}):

- At ILC beam-beam effects are dominant: primary ion density 1-5 ions/cm^3 → track distortions < 5 μm
- Gas amplification 10^3 → ILC without gating leads to track distortions of 60 μm → gating device is needed

D. Arai, K. Fujii
J. Kaminski



Track distortions @ CePC / FCC-ee:

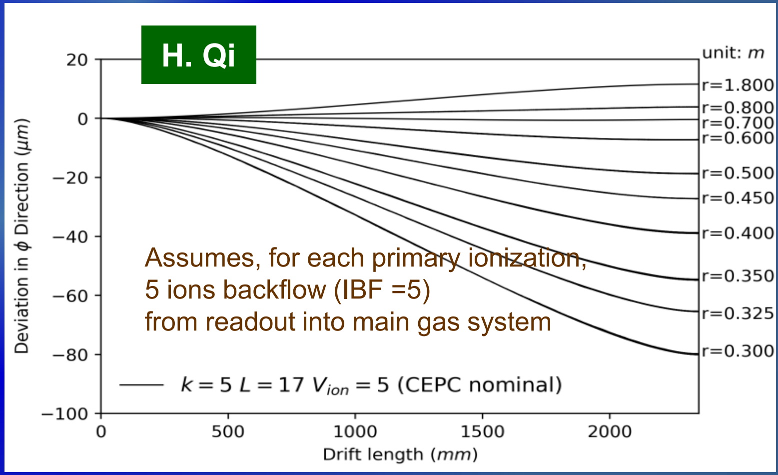
- ✓ HZ-pole running → γγ-background is very small → pad / pixels are OK – ion bkg. comparable to ILC @ 250 GeV
- ✓ Z-pole running (@10^{36})→ primary ion density 1000 ions/cm^3 → serious tracks distrotions O(mm); space charge effects could be calibrated (e.g. ALICE) ???
- ✓ Study pixel - TPC to replace pad - TPC for Z-pole running @ CEPC

Crucial considerations for FCC-ee / CEPC @ Z pole running:

- 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;

- ✓ Ion backflow (IBF) can give a lot of additional charge → so IBF must be controlled (IBF = 5/1.5 → 80 / 14 um)
- ✓ Measuring IBF for Gridpix is a priority, expected $\mathcal{O}$(1‰)

H. Qi

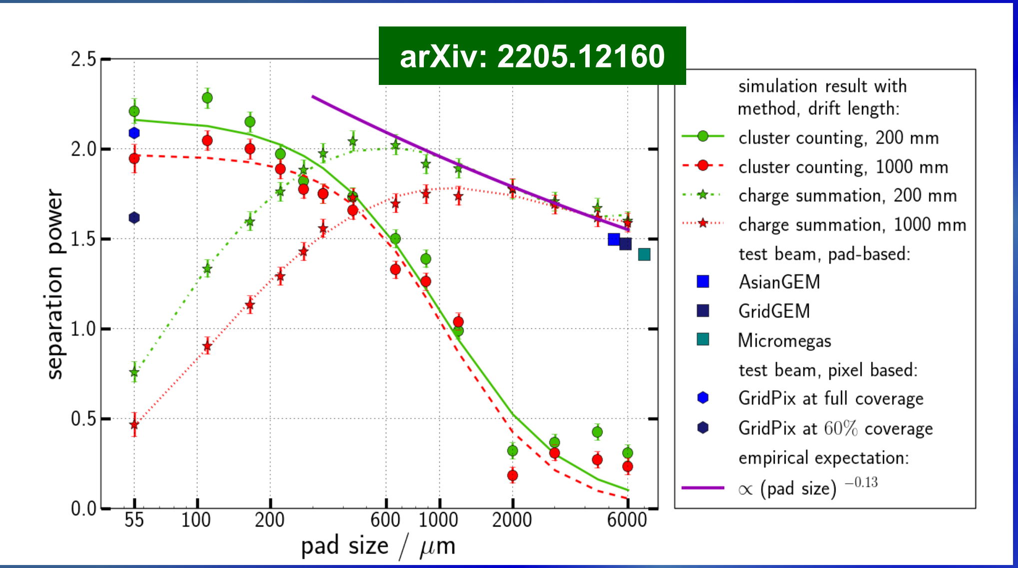


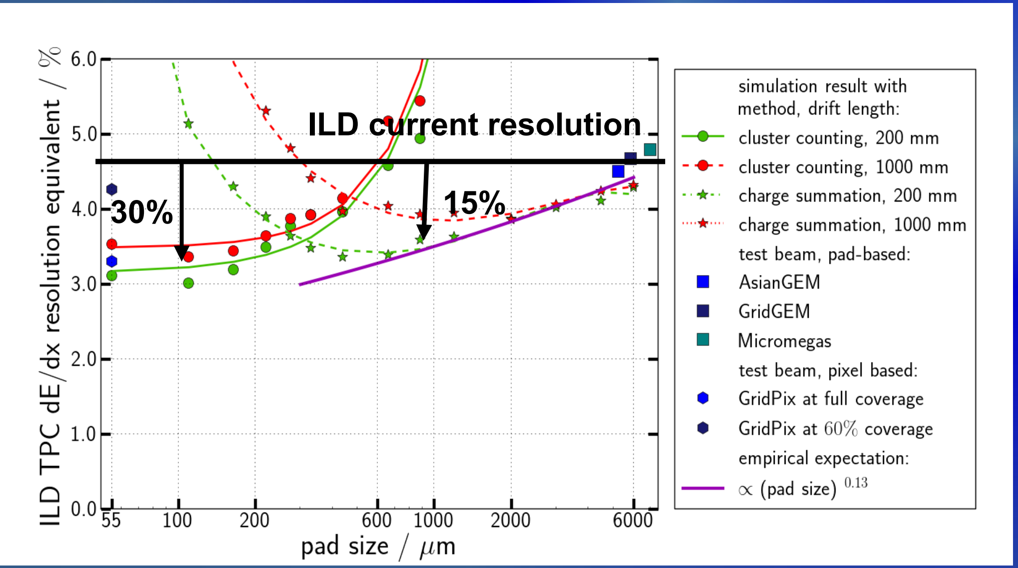
Future R&D needed:

- Optimal pad size to improve track resolution;
- Pixel size > 200 um or large → cost reduction

Cluster Counting / Charge Summation / Granularity

Simulation of PID with gaseous tracking and timing in ILD Prototype





B. Dudar, U. Einhaus

Current full ILD reconstruction:

- ✓ 6 mm pads → 4.6 % dE/dx resolution
- ✓ 6 mm → 1 mm: 15% improved resolution via charge summing (dE/dx)
- ✓ 6 mm → 0.1 mm: 30% improved res. via cluster counting (dN/dx)

✓ **Cluster Counting promises a few times better dE/dx resolution & separation power:**

→ in time (small drift cells): requires very fast electronics

→ in space (TPC + pixelated endplates): requires good cluster finding algorithm

✓ Cluster Counting ia an attractive option and is complementary to classical dE/dx by the spread charge

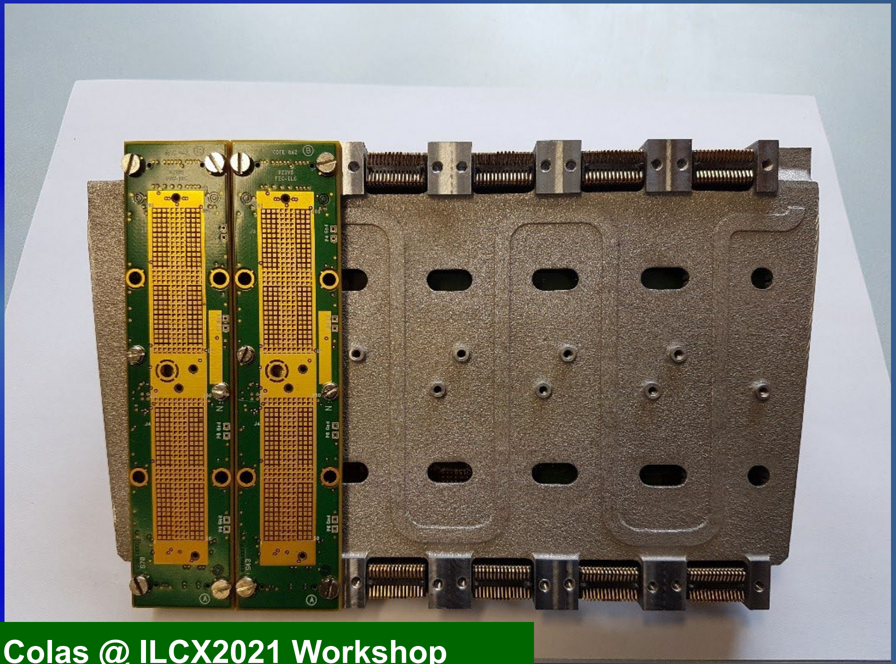
→ Some groups focus on it and ongoing for CEPC, FCC-ee…

3D-printed Monolithic Cooling Plate for TPC Using 2-Phase CO_2

- ✓ Despite power pulsing, readout electronics will require cooling → 2-phase CO2-cooling (proof-of principle with 7 MM modules demonstrated in 2015)

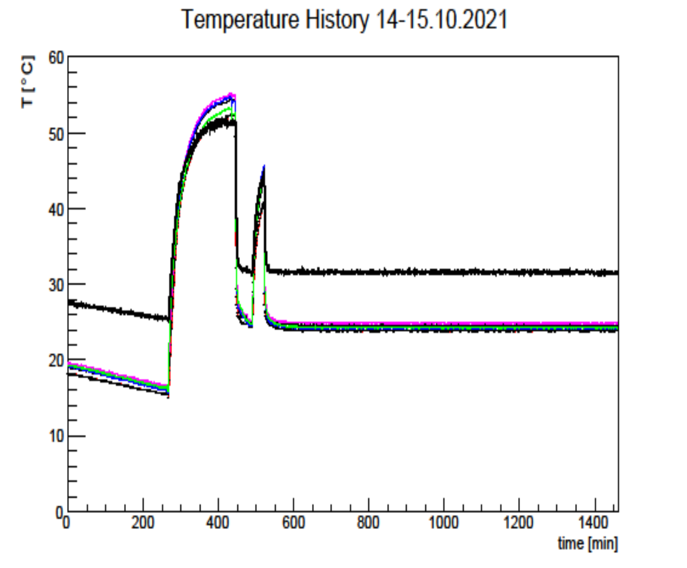
JINST 10 P08001 (2015)

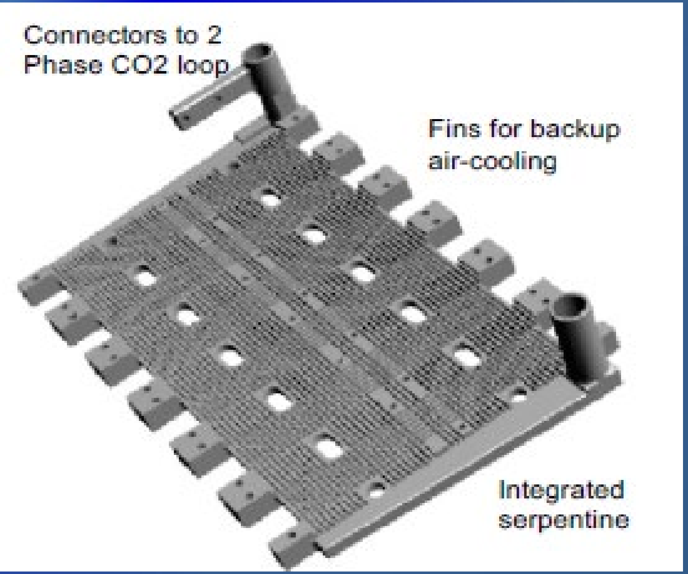
- ✓ 3D-printing of Aluminum is attractive to produce complex structures and optimize material budget
  → CEA Saclay prototype module tested at Large Prototype @ DESY in Oct. 2021 with TRACI (Transportable Refrigeration Apparatus for CO2 Investigation)
  → **Excellent performance: Cooling unit 2-phase CO_2 closed loop with 60 bar pressure**



P. Colas @ ILCX2021 Workshop

Lund & Pisa exploring micro channel cooling
→ O 300 µm pipes in carbon fiber tubes



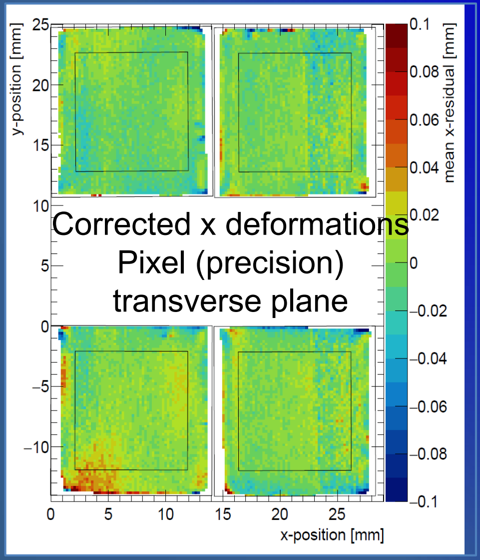


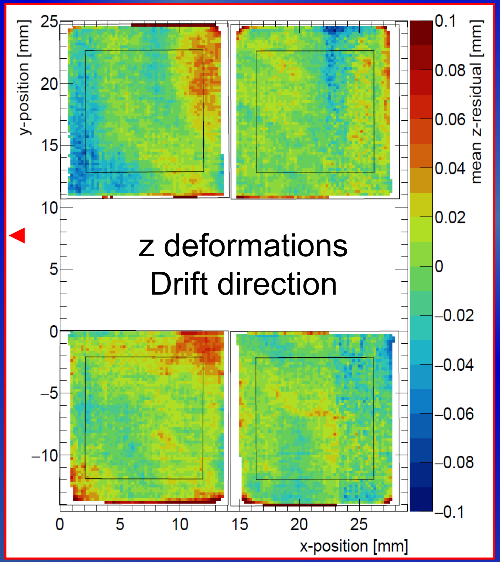
Critical Items for a TPC Readout Technology Choice

Several aspects are important:

- ✓ Minimize power consumption (detector/electronics)
- ✓ Cooling optimization (e.g. 3D-printed structures, 2-phase CO_2 cooling)
- ✓ Material budget (thin detector/radiation length)
- ✓ Minimize z- and xy-readout plane destortions

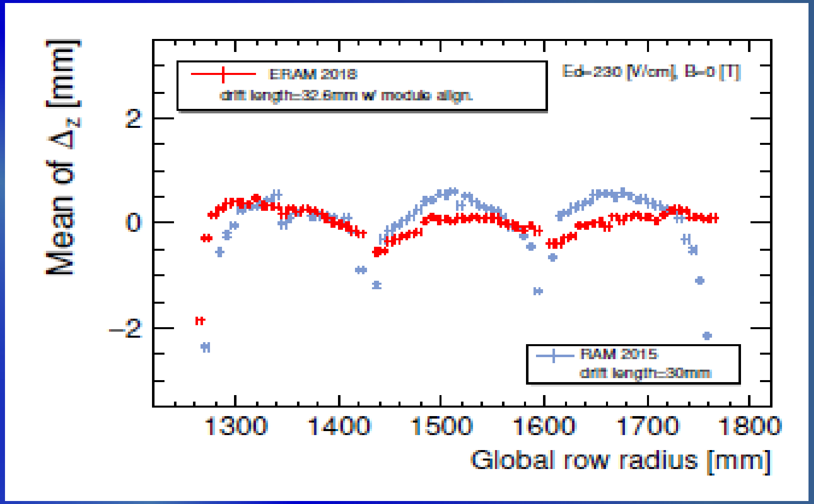
Deformation challenge: GridPix Technology
→ Quad / pixel module: Considerable effort to reach very high precision mechanical mounting (10-20 um) of the quad and 8-quad module



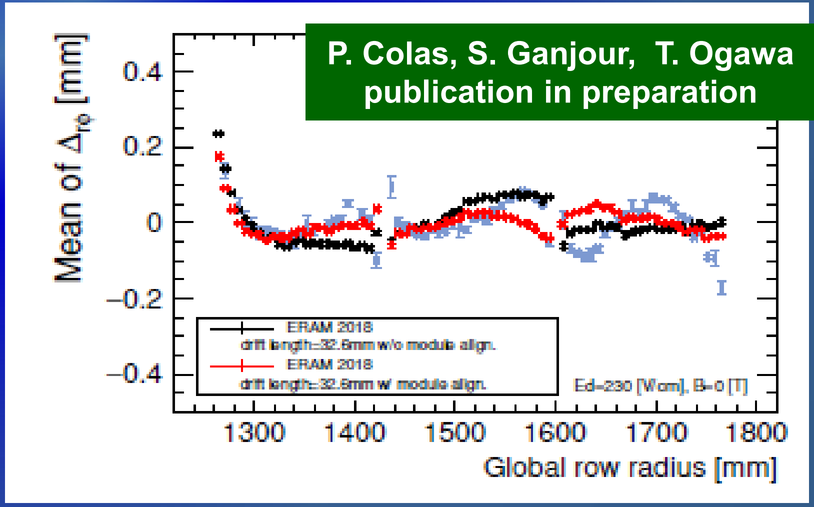


P. Kluit @ IAS HEP Hong Kong (2022)

❖ **MM Distortion challenge: module flatness**
→ control of mechanics (deformations if not rigid enough) → give rise to ExB effects



❖ **MM Distortion challenge: module edges**
→ xy-plane (new encapsulated ERAM scheme)



P. Colas, S. Ganjour, T. Ogawa publication in preparation

Summary and Outlook

- ✓ GEM and MM-pad based readout have a very similar tracking performance
  → next step: build a next generation common module, including a gating structure, to compare technologies and, in particular, ion blocking performance;

- ✓ Simulation studies are necessary to understand the detailed requirements of the final detector (e.g. number of ADC bits, pad sizes, etc.); development of calibration and alignment methods;

- ✓ Feasibility of large-scale GridPix development and production; handling of large amount of GridPix data;

- ✓ Development of new readout electronics with power-pulsing; optimization of cooling and material budget;

- ✓ Benefit from synergies with the TPC R&Ds from T2K / ALICE / CEPC / EIC experiments;

- ✓ LCTPC is open for groups interested in TPC applications beyond the ILC scope
  → effort is ongoing to investigate the feasibility of a MPGD-based TPC readout for CEPC & FCCee (mostly ion backflow and track distortions correction studies)

Many thanks to all LCTPC collaboration members for plethora of results
(some slides were re-used & updated from J. Kaminski talks @ VCI2022 / Elba2022)