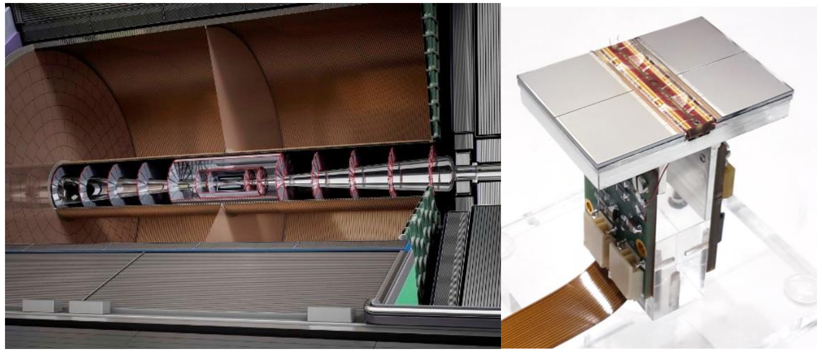
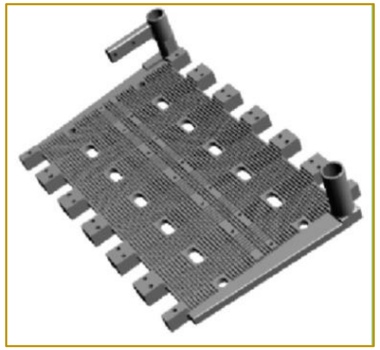
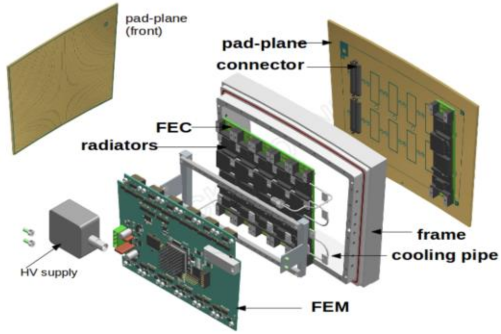
ECFA WG3 workshop : Tracking and vertexing



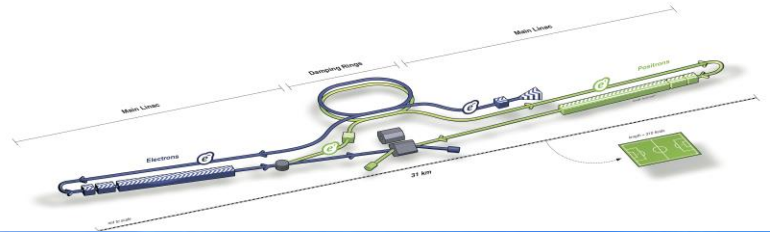


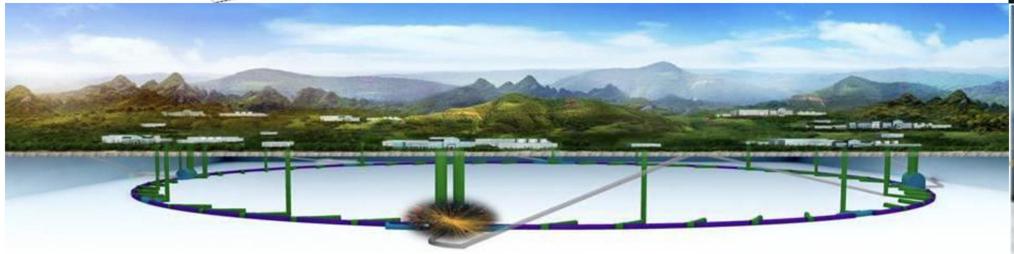


Conceptual designs and R&D challenges for TPCs

May 30, 2023

Paul Colas, CEA/Irfu U. Paris Saclay





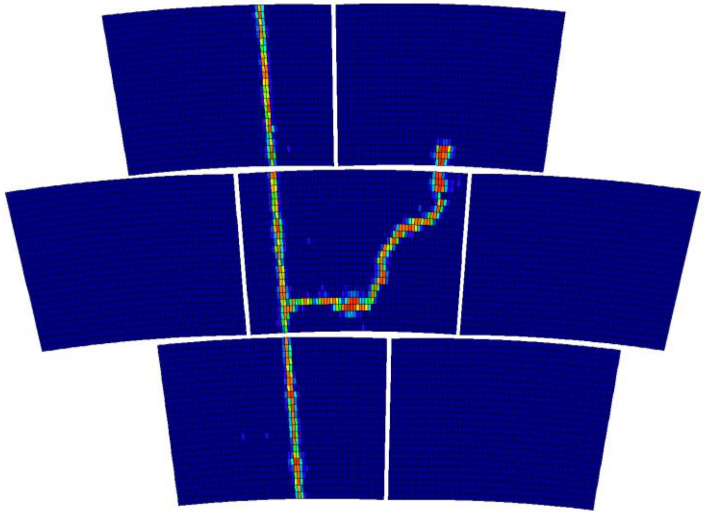
A TPC is an ideal main tracker, but challenging and slow, and can work only in a suitable environment.

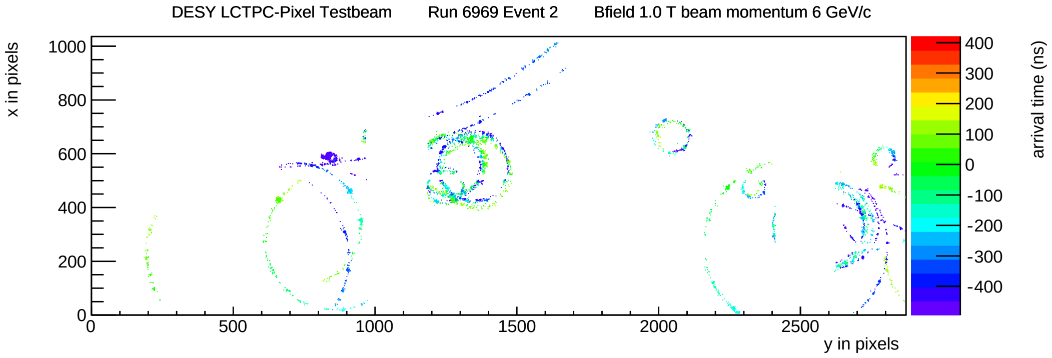
	LINEAR	CIRCULAR
EUROPE	CLIC	FCC-ee
ASIA	ILC	CEPC
	New technology + : polarization possible Upgradable in energy	Standard technology + : high luminosity Limited in energy Large tunnel Perspective : hh

And many more concepts… Energy recovery, cold copper, Linear Asymmetric,…

Conceptual designs

- There are two main conceptual designs: TPC with pads and Digital TPC
- Pads : sample the track with ~100 O(mm²) pads. They receive ~50-100 electrons each from the track (in an Ar mixture).
  - dE/dx (truncated mean charge) contributes to particle ID.
- Digital TPC (pixels) : detect all ionization electrons with ~100% efficiency on O(50µ) digital pixels.
  - dN/dx (cluster counting) contributes to particle ID.

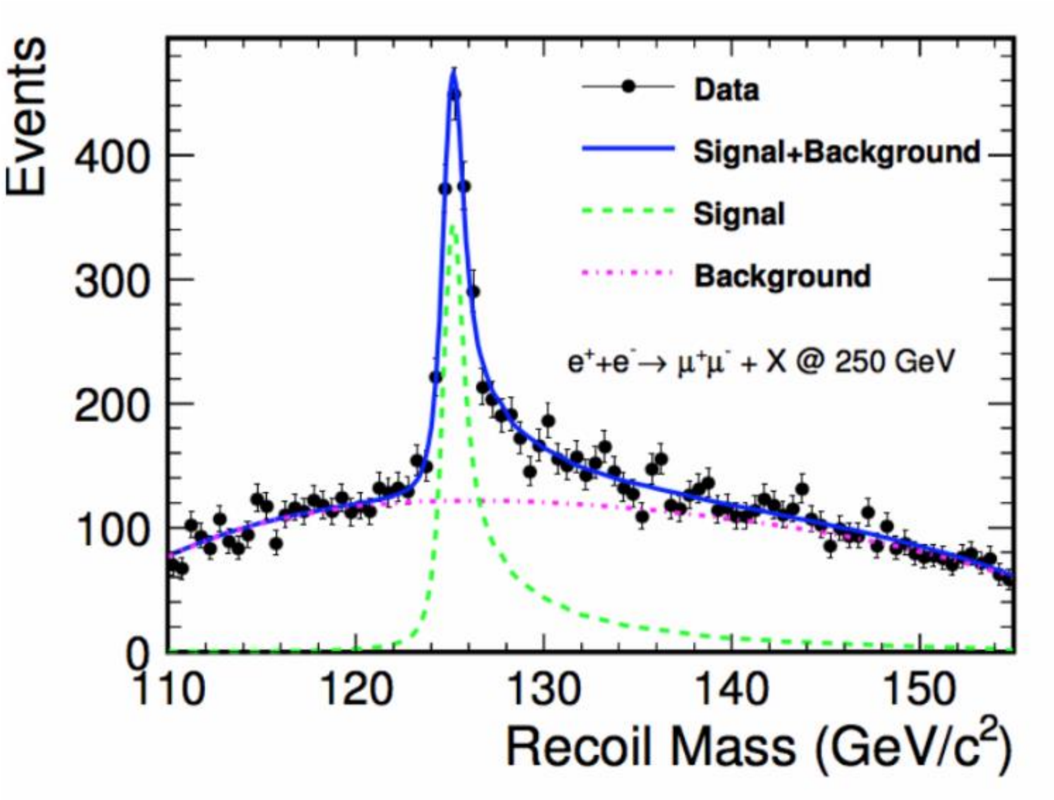


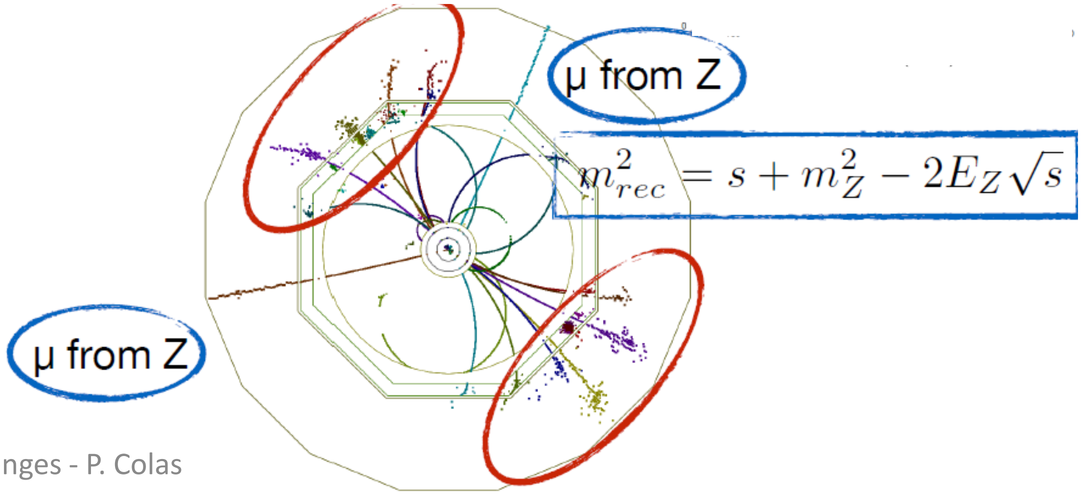


- In these two concepts, the drift space if the same (however the optimum gas mixture can be different, He giving better cluster separation than Ar, but less ionization)
- An important parameter is $\omega.\tau$. If large, it acts as a reduction factor for transverse diffusion. Can be up to ~15 for large magnetic fields and Ar CF4 gas mixtures. Essential to limit diffusion for large drift lengths

Resolution challenge

- To perform model-independent measurement of the Higgs branching fractions, the main tracker must have a momentum resolution of 2x10^{-5} (p/GeV)2
- This implies O(100µm) space resolution with ~200 measurement points, O(20 µm) systematics on sagitta, with matching module alignment and mechanics quality

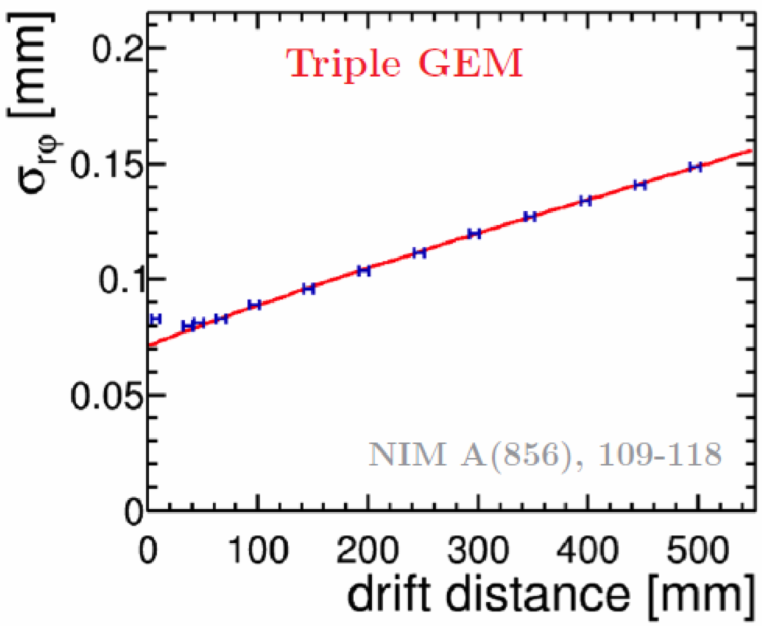




$$m^2_{rec} = s + m^2_Z - 2E_Z\sqrt{s}$$

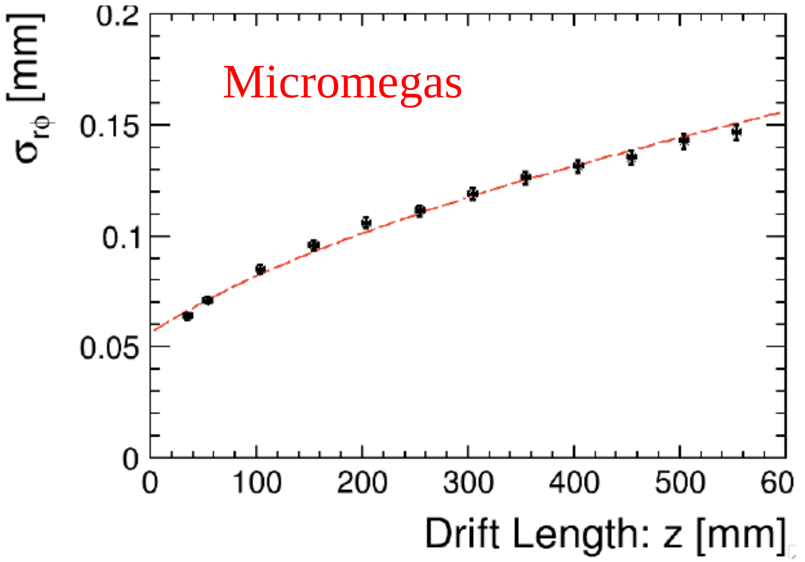
Resolution challenge

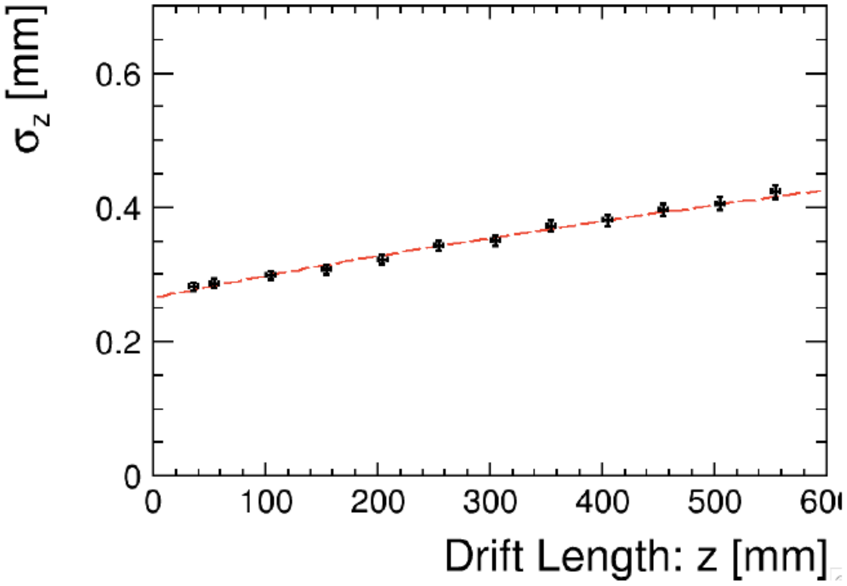
T. Ogawa, F. Müller



NIM A(856), 109-118

average of 24 Rows





The resolution goal is now proven with all technologies (GEM, Micromegas and Pixels)

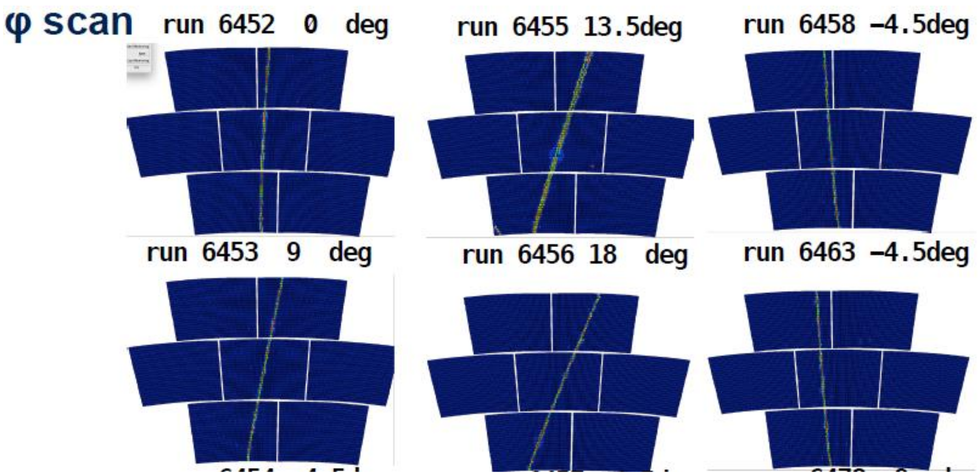
For GEMs, it requires ~1mm pads with enough diffusion in the amplification device.

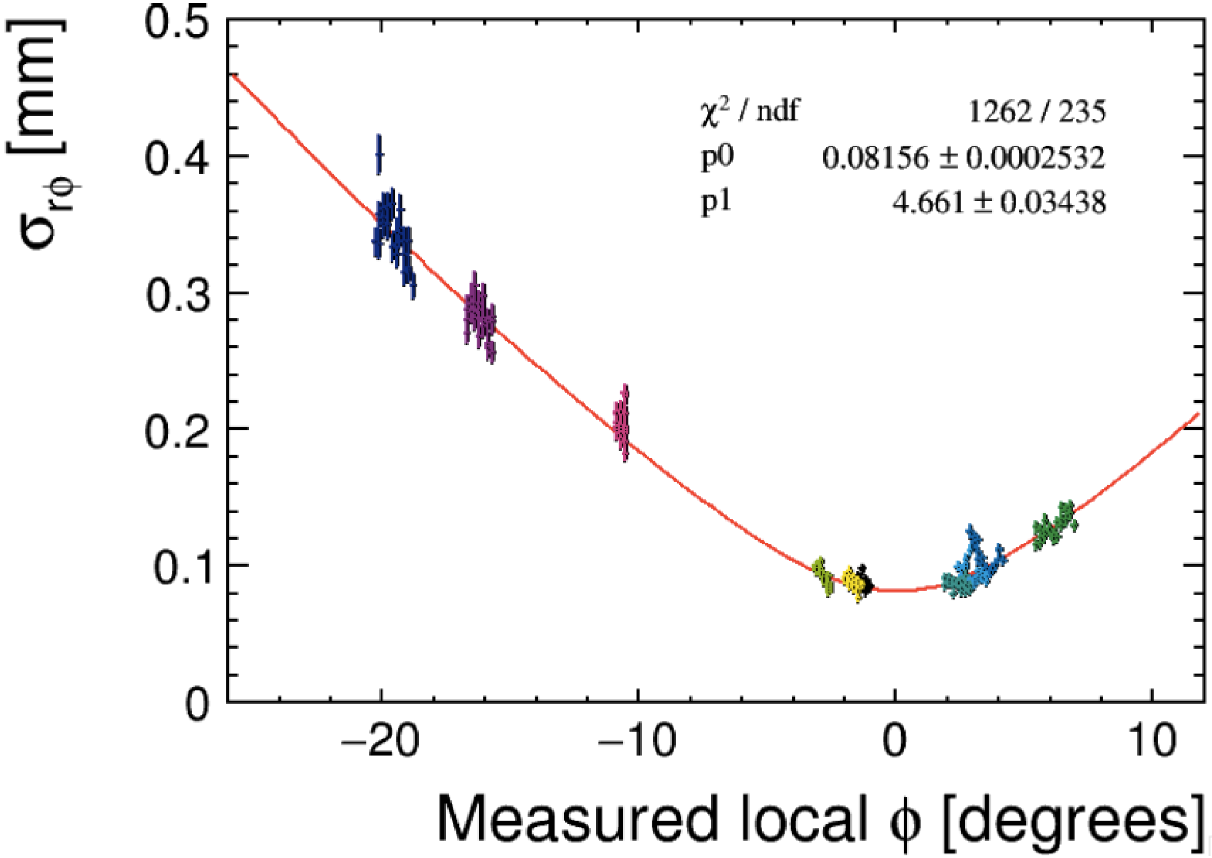
For Micromegas, it requires charge spreading by a resistive-capacitive anode.

For pixels, it requires <300µm pitch digital readout.

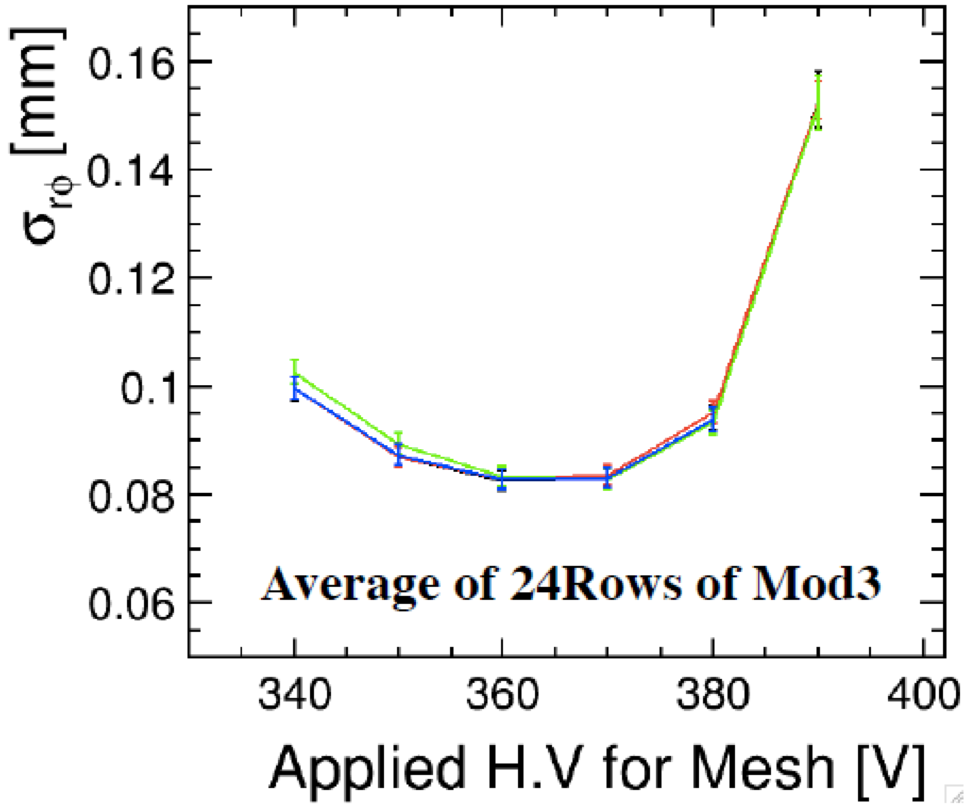
RESOLUTION vs AZIMUTH

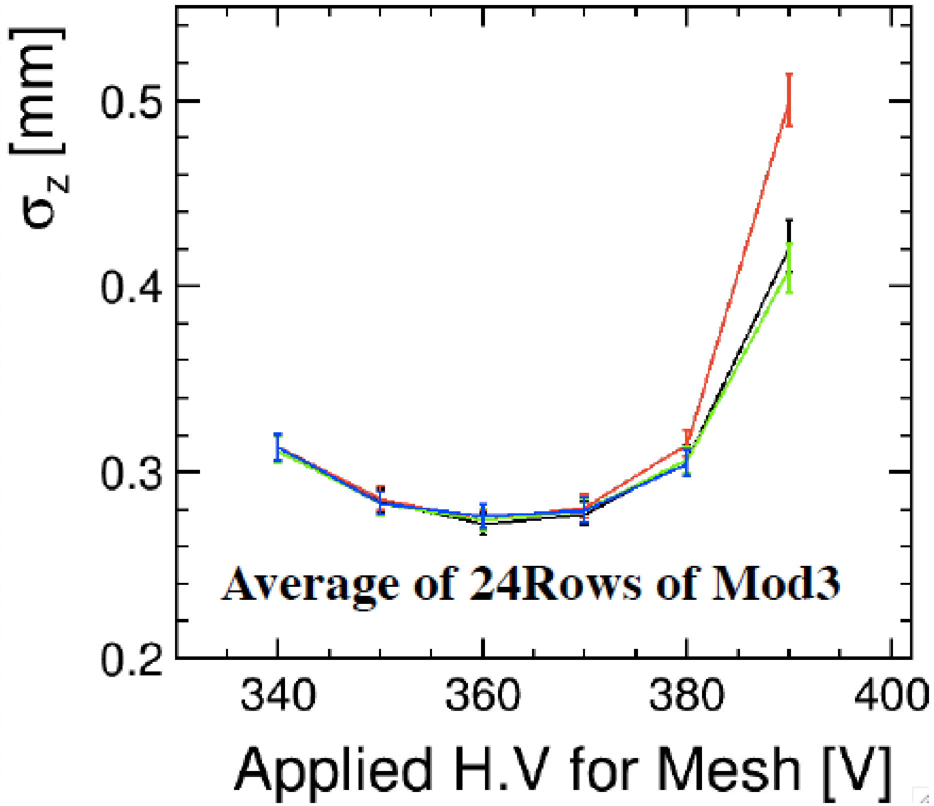
- The resolution dependence on angle has been measured and the ‘track-angle effect’ is well understood (The aspect ratio of the pads is 7/3)





Optimal voltage for the resolution

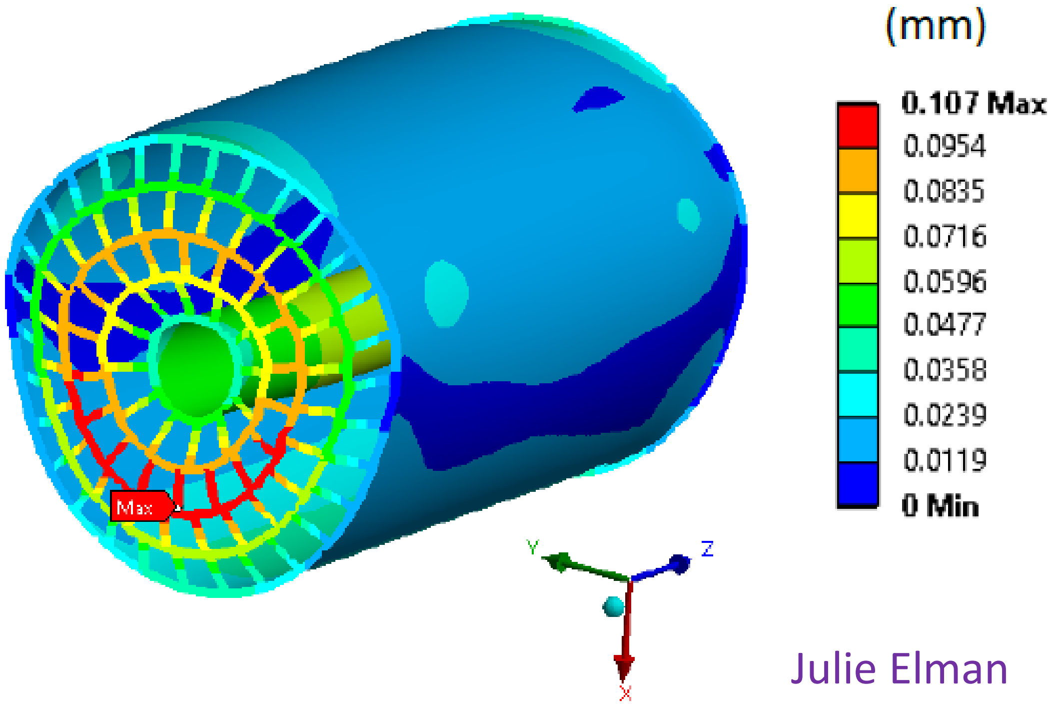




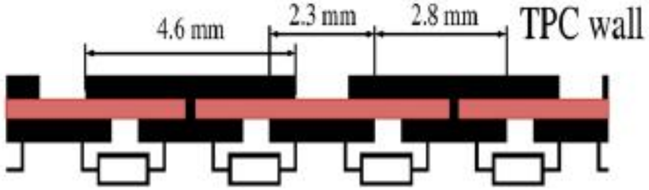
Mechanical challenges

The mechanical design must ensure small enough deformations under weight and pressure, and electric field homogeneity at the 10^{-4} level.

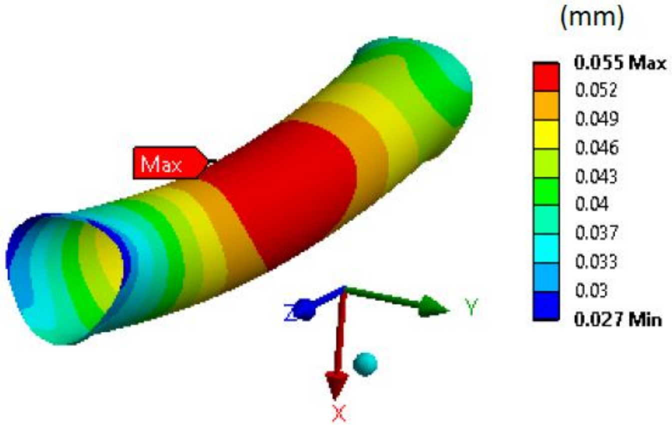
This imposes tough constraints on the field cage rigidity, on the design (mirror stips), and on the suspension



Julie Elman



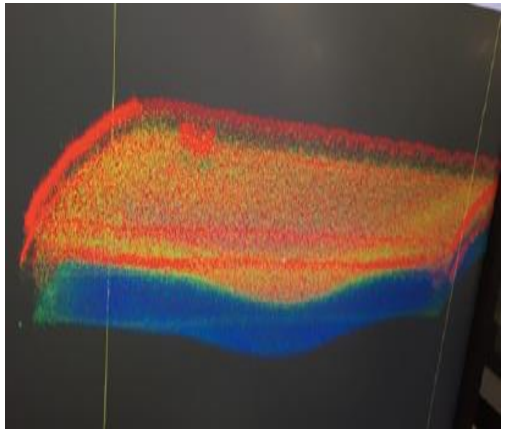
Peter Schade



Deformation of the inner field cage

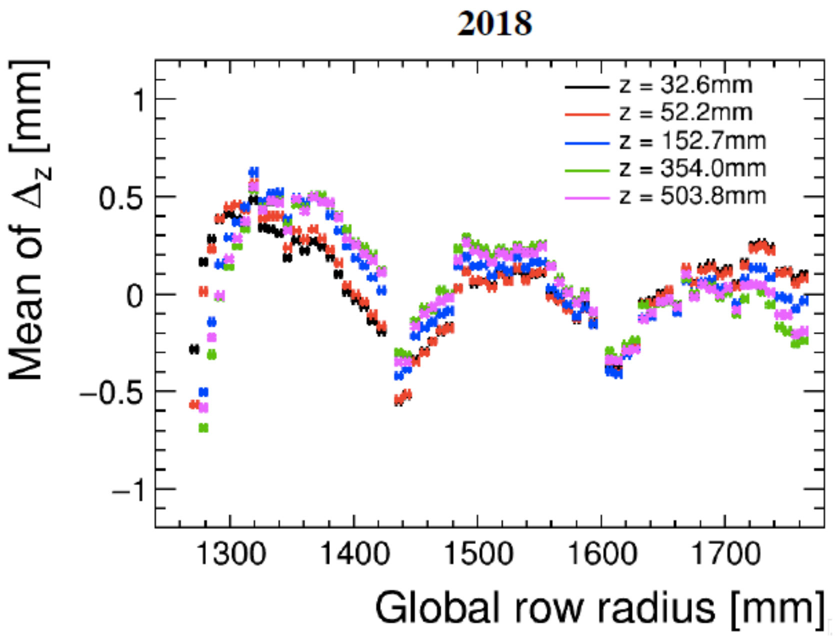
The distortion challenges : 1) Module flatness

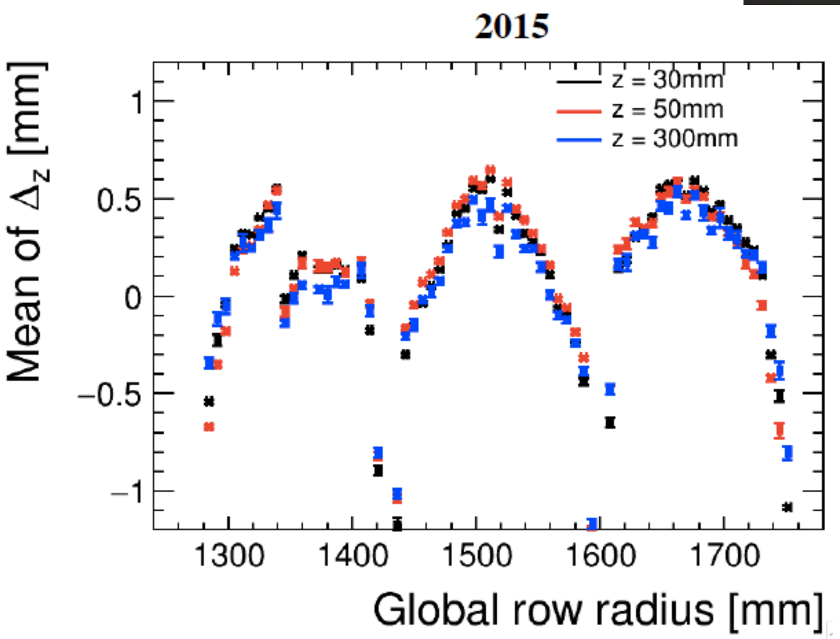
The modules have to be extremely flat. they can be deformed by the pressure if they are not rigid enough. This gives rise to ExB effects.



Residual in Z (2018 and 2015 MM)

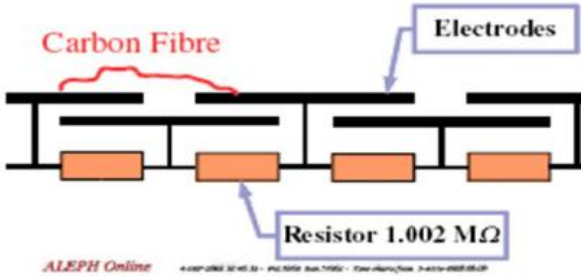
Data : Ed=230V/cm, B= 0 T

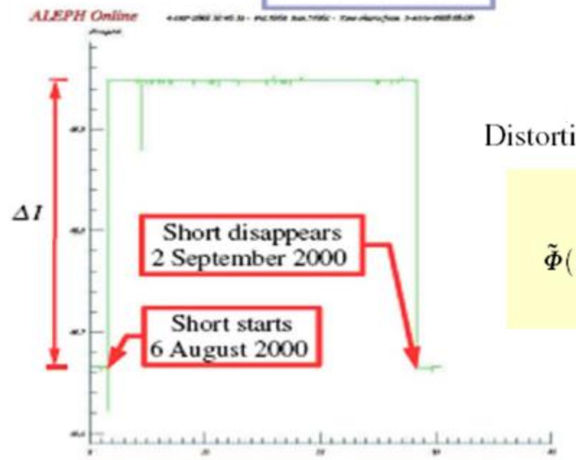




The distortion challenges : 2) field cage quality

- A simple short between two field shaping rings (as happened in ALEPH due to a tiny carbon fiber) can make a sizeable distortion

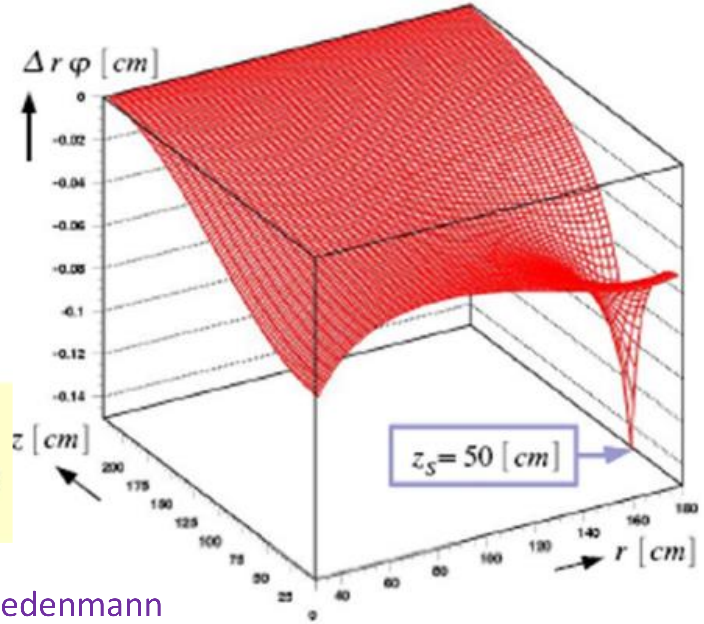




- Correct for distortion
- Remove the fiber

Distortionpotential

$$\tilde{\Phi}(r,\varphi,z) \simeq sign(z_S)\left(\frac{\Delta U_0}{U_0}\right)\sum_n \frac{\cos(\frac{n\pi}{z_M}z_S)}{n\pi}\sin(\frac{n\pi}{z_M}z)\,P_{0n,\,\substack{FCin\\FCout}}(\frac{n\pi}{z_M}r)\ ;$$



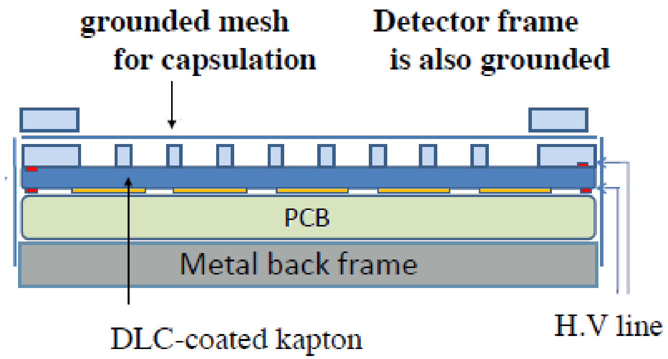
Ron Settles, Werner Wiedenmann

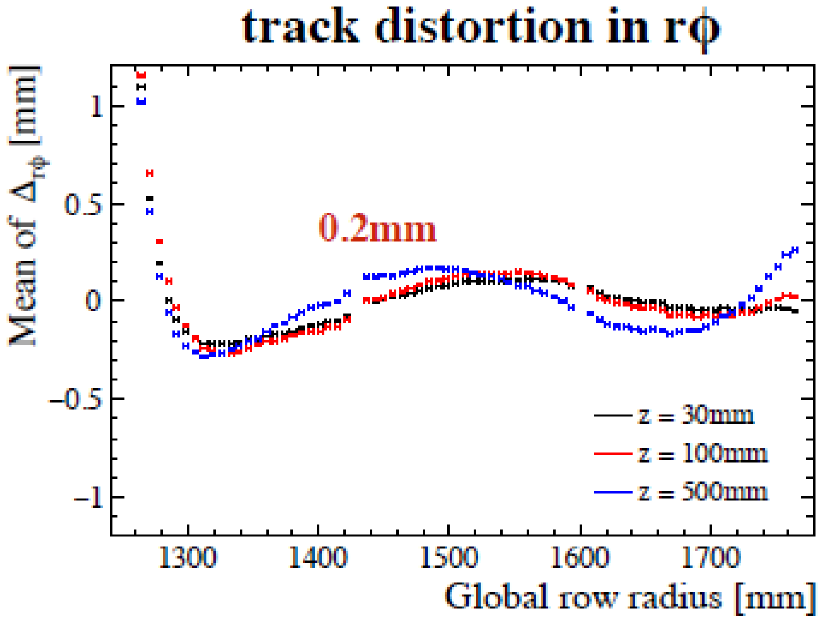
The distortion mitigation challenge : 3) module edges

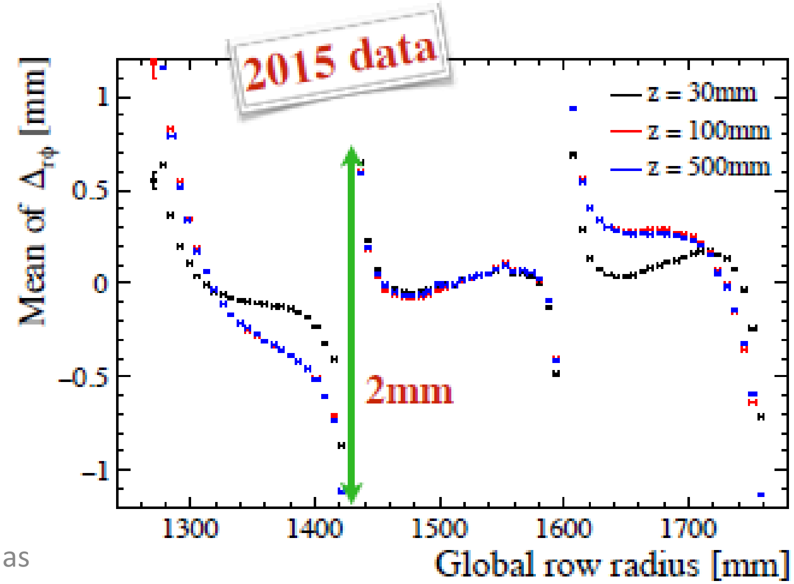
T. Ogawa, S. Ganjour

By grounding the mesh and encapsulating the anode at a positive potential, the amplification plane is an almost perfect equipotential, which allows the E-field to be very uniform, even close to the module boundary.

A reduction by an order of magnitude of the ExB distortions is observed.







The distortion challenges : space charge corrections

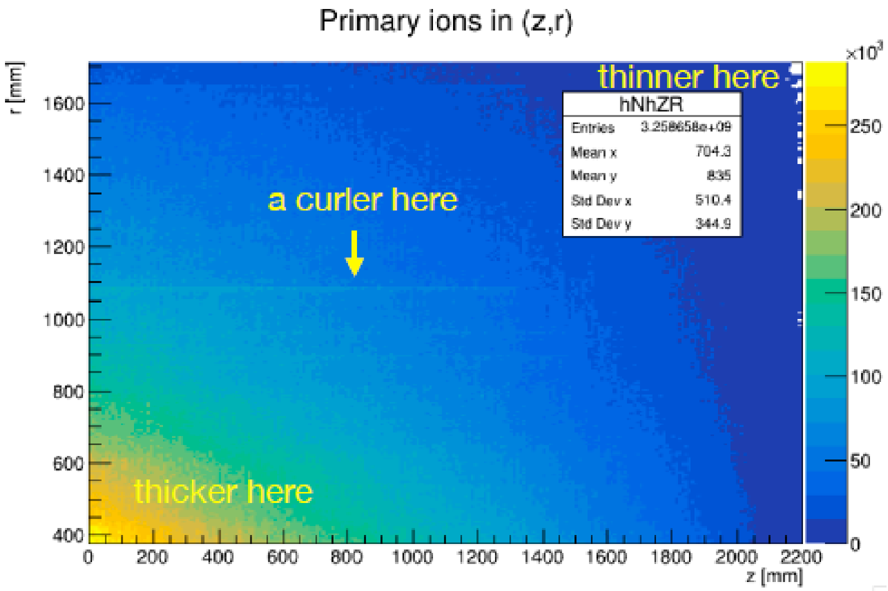
- Ions drifting in the gas are very slow (typically a few m/s)
- Primary ions from ionization in the gas (from event tracks of from machine background) or secondary ions created during amplification and back-flowing in the drift region, drift very slowly, producing space charge which distorts the trajectories of the electrons drifting from the tracks by creating a component transverse to the drift field
- This effect is common to all the amplification devices
- Calculated in 2011 by D. Arai and K. Fujii
- 2023 : New calculation in progress, adapt to Z pole

(K. Fujii, D. Jeans, S. Ganjour, Mingrui Zhao…)

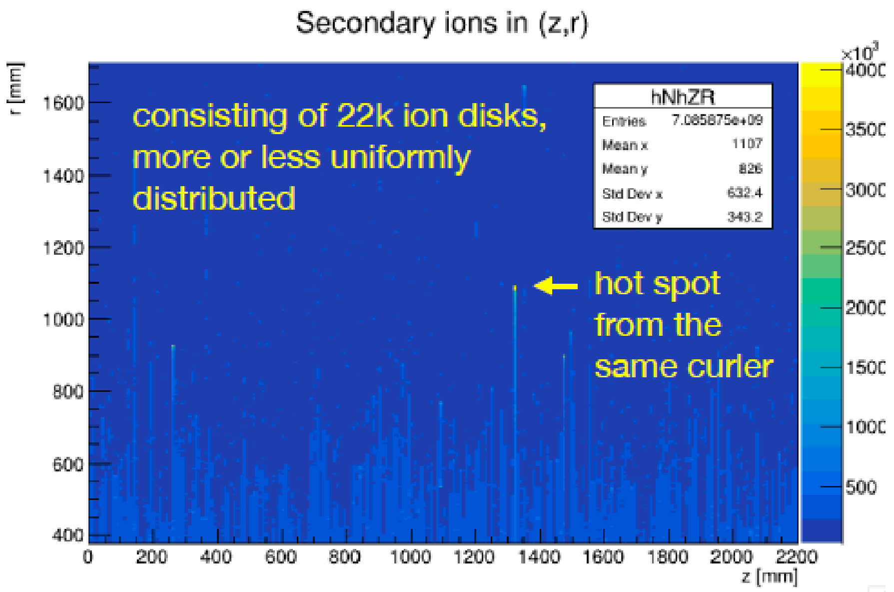
Positive ion density at the Z peak

- From hadronic Z decays (Toy MC by K.Fujii, full simulation by Daniel Jeans)
- 60 KHz of Z decays : 26 000 ion disks created in the amplification pile-up in the 0.44 s of flushing time of the ions (assuming 5 m/s ion drift velocity)
- In case of IBF=1, maximal distortions (at small radius) are 330 µm and they are stable enough to be corrected for

Primary Ions



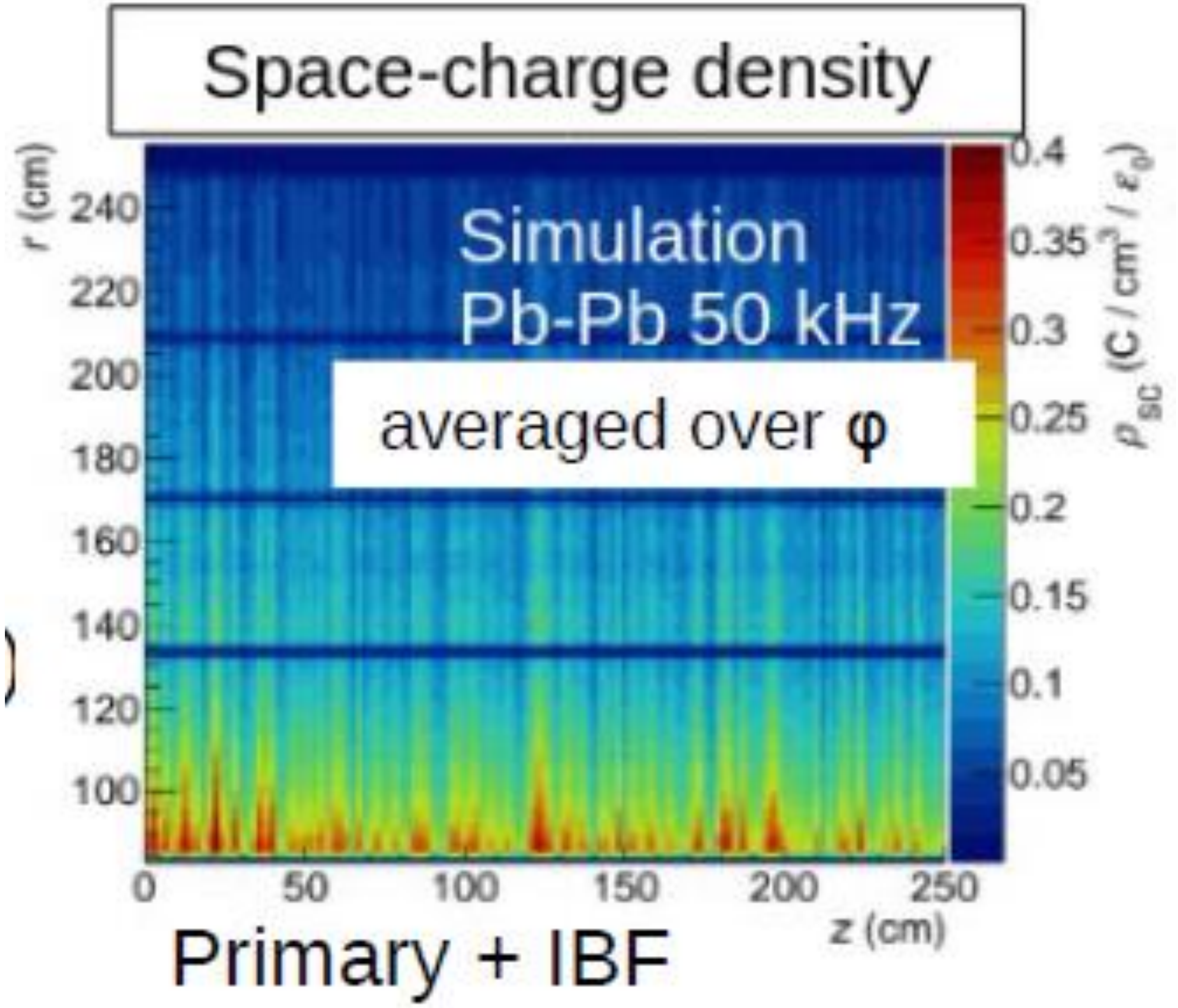
Ion Back Flow



Similar situation in ALICE at LHC Run3. IBF~1%, gain=2000.
200 ms ion drift

50 kHz lead-lead collisions.
-> the ions of 10 000 collisions pile-up in a TPC length.

Space-charge density cause distortions up to several cm, varying with instantaneous luminosity and fluctuating. Measurement of the space charge (from integrated currents) necessary.



ALICE, Jens Wiechula, LCTPC collaboration meeting, Jan 18, 2023.

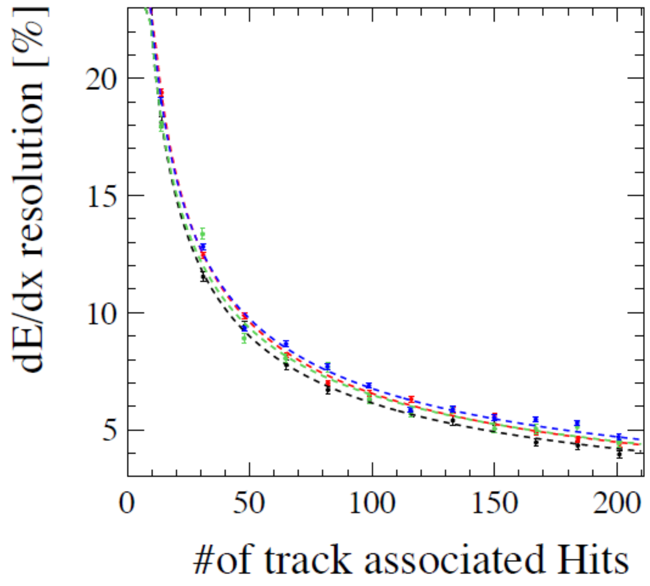
The dE/dx challenge

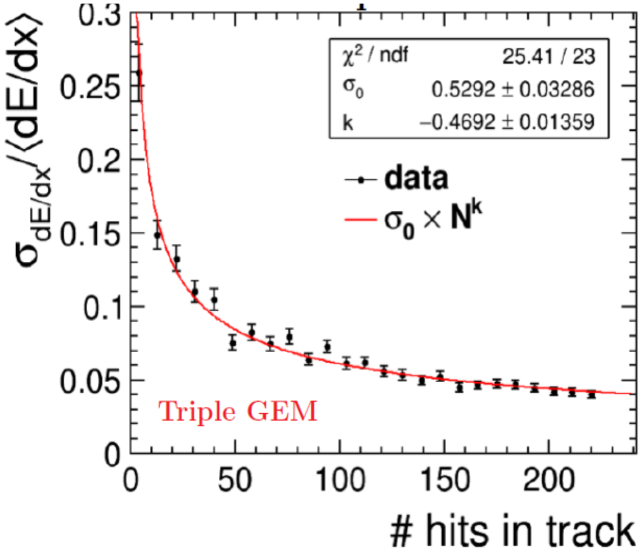
dE/dx is an essential tool for particle identification, necessary in b physics and in Higgs physics.

It has been proven to be possible with the 3 technologies (Micromegas, GEM and pixels)

Pixel allow cluster counting, which improves the achiveable resolution.

For 1.35 m electron tracks, we obtain:
4.6 % for Micromegas
4.5 % for GEMs
3.5 % for pixels





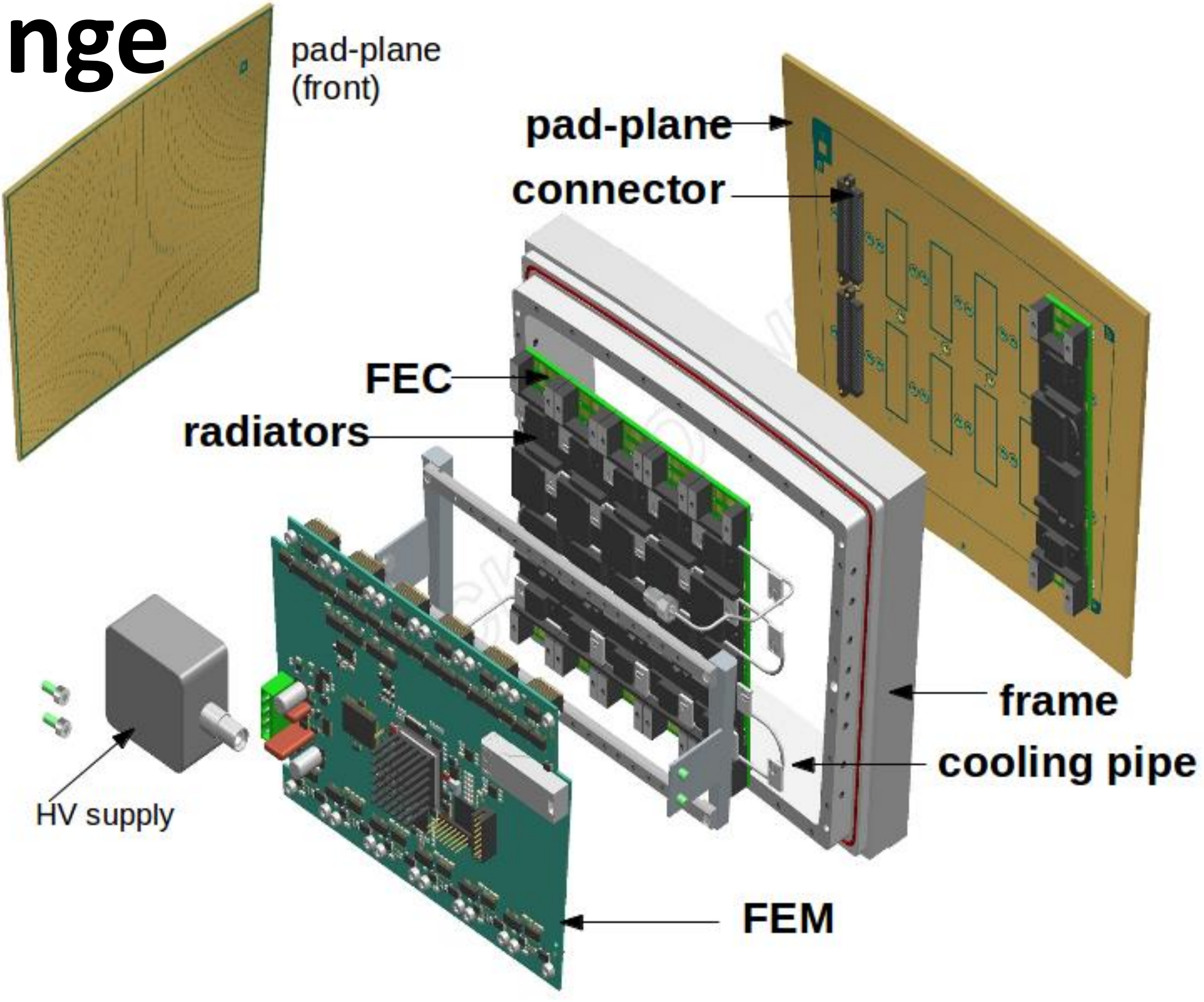
The power consumption challenge

- The total power consumption is estimated to be about 6 kW per endplate, which can be provided easily with a sufficient number of 32A copper cables. However the supplies must be as close as possible to the detector : for 50 m cables, the same power is dissipated in the cables.
- For Gridpix, early estimates give 60 kW per endplate. Recent attempts show that an order of magnitude reduction could be made at the cost of degraded z resolution.
- To meet the low consumption requirement, 65 nm electronics at low voltage has to be developed, with a low-consumption ADC (9 bits are enough?)

The integration challenge

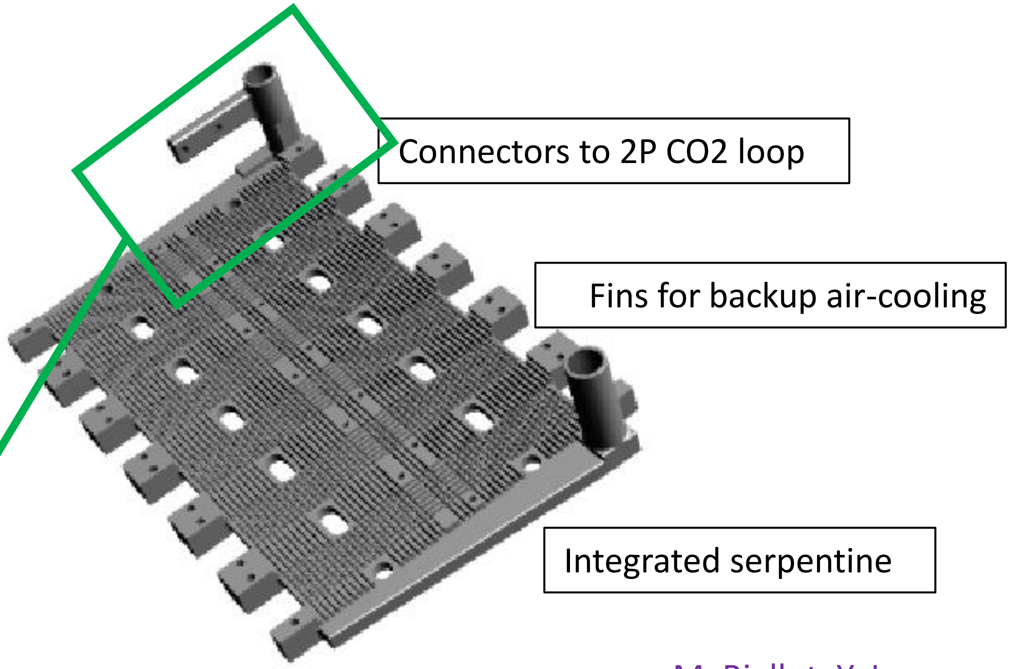
Integrate the readout of 2000 channels per module (8000 in the future) so that the only connections to outside are:

- A low voltage
- A HV
- A signal fiber
- A CO2 cooling pipe



The cooling challenge

- 2-phase CO2 cooling meets it. It allows removing heat at nearly room temperature in a pipe at 50-60 bar
- A 3D-printed cooling plate with an integrated serpentine has been tested

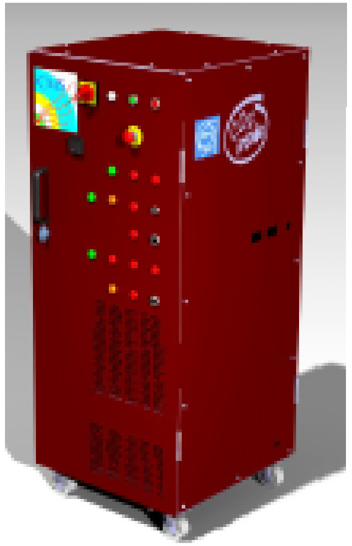


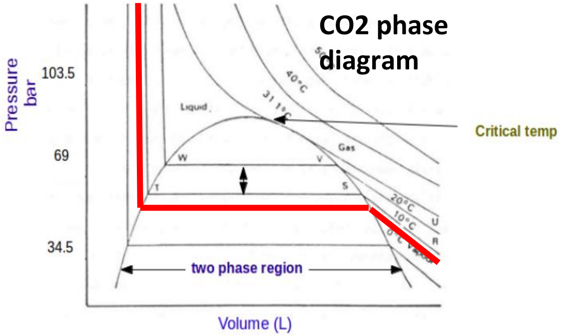
Connectors to 2P CO2 loop

Fins for backup air-cooling

Integrated serpentine

M. Riallot, Y. Jan





CO2 phase diagram

The ion backflow challenge

- The possibility of gating exists only at ILC. For other colliders (continuous beam or high rate bunch crossings) gating is not possible.
- There is a natural ion backflow suppression in Micromegas, but not sufficient at the Z pole.
- Other possibilities might exist : double meshes?, graphene?
- NEEDS R&D!

Conclusion

- Many of the challenges have been met.
- However specific R&D is needed to cope with the huge backflow in high luminosity continuous machines (CEPC, FCC) and a lot of work is needed to estimate the beam backgrounds and mitigate them
- At ILC, the beam time structure allows gating between train crossings.