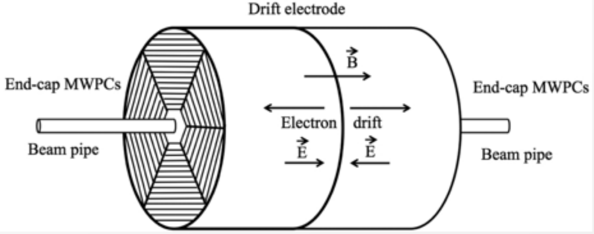
PId: TPC, TRD, RICH and other large area detectors

E. Radicioni

INFN

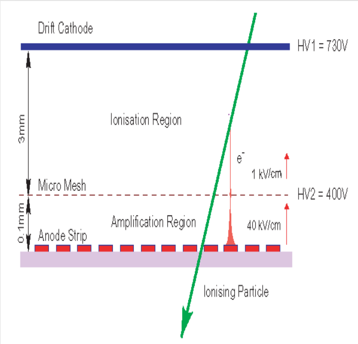
disclaimer

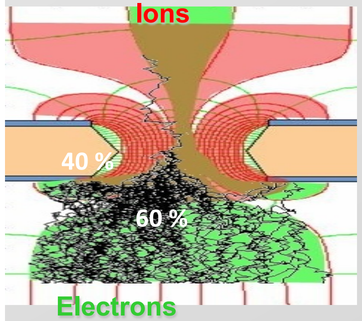
- Given the limited available time, I will only mention a few examples, without the intention of diminishing the many possible alternative ones.
- Rather than pretending to give an exhaustive list, examples are there to illustrate a concept.
- A synthesis of such a vast field is not obvious, so I have tried to identify a few themes.

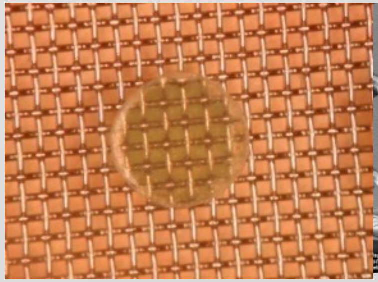


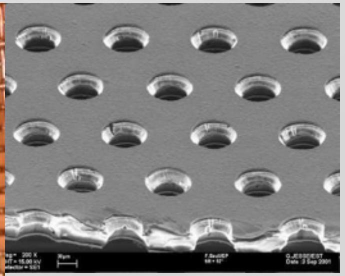
TPCs

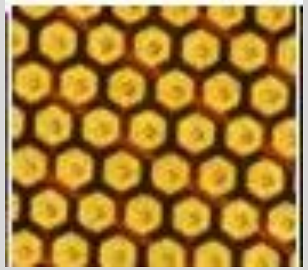
- TPCs have gone through a revolution in the last ~ 15 years, often linked to the use of MPGDs in the amplification stage
- MPGDs have allowed far more design freedom, and helped solve a number of long-standing limitations like
  - reduce pad-angle, track-angle, ExB effects
  - make a far smaller Pad Response Function (PRF) possible
  - drastically reduce the IBF in continuous (non-gated) operation
  - geometrical freedom (e.g. curved readouts)
- Pad planes have gone through the same metamorphosis, achieving much smaller structures, and matching the smallest PRFs
- Resistive layers can now help us to protect from spark, tune the PRF, etc

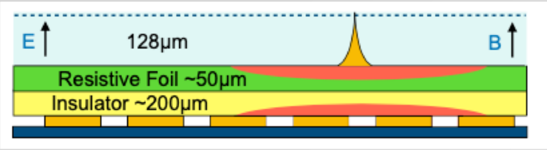




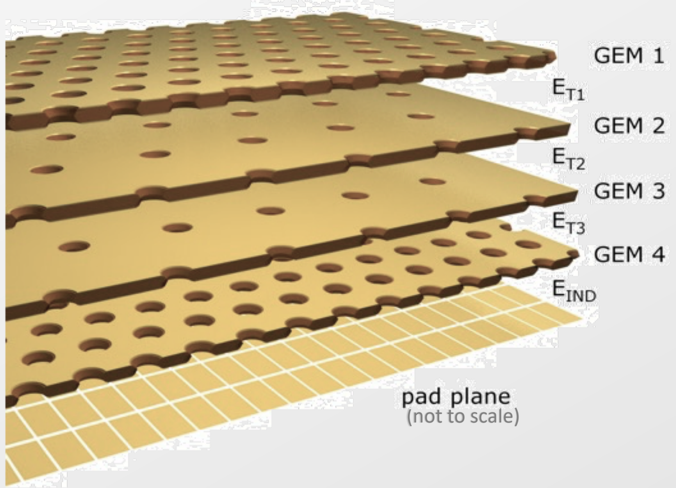








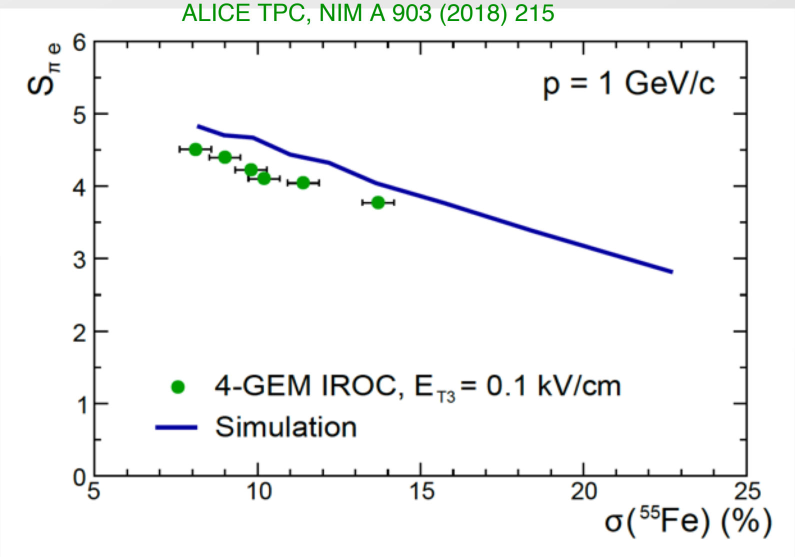
ALICE TPC

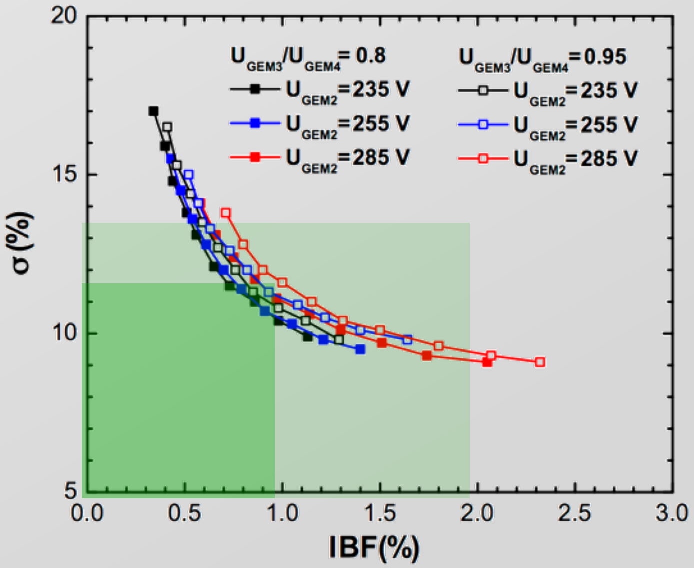


New Readout Chambers (GEM):

- < 1% IBF to allow continuous operation @ ≥ 50 KHz Pb-Pb
- PId performance via d*E*/dx preserved by fine tuning of the 4-GEM configuration (geometry and HV) to optimize IBF and energy resolution at the same time
- Confirmed with several test beams at CERN/PS
- Energy resolution compatible with MWPC TPC (~5.5% in pp and ~7% in Pb-Pb)

ALICE TPC, NIM A 903 (2018) 215

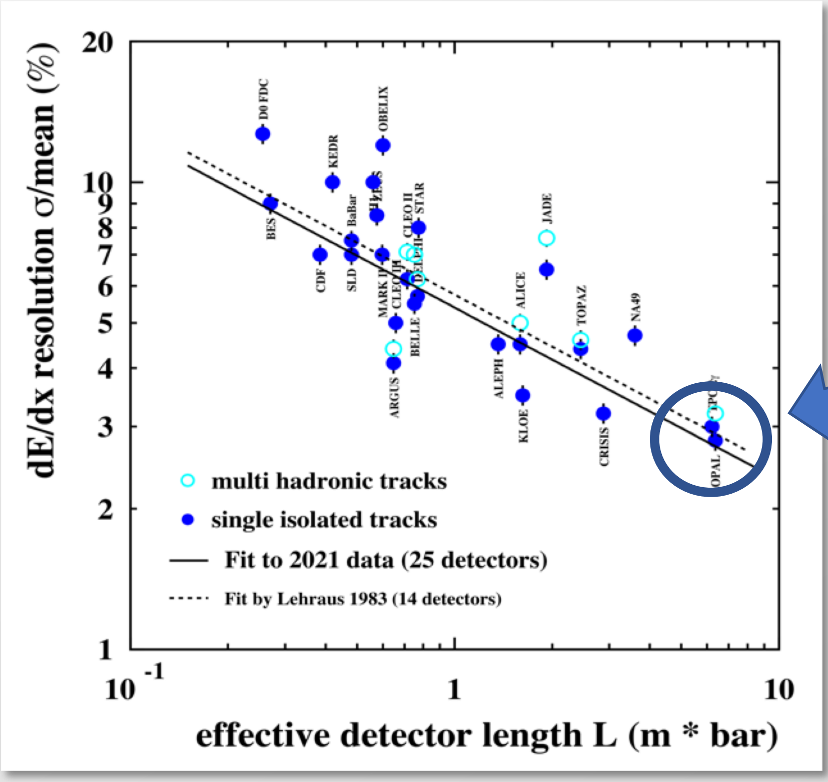




IBF in general: more extensively addressed by Fulvio's talk

dE/dx and dN_{cl}/dx

- **dE/dx** resolution around 5% are routinely reached, in excellent conditions and with accurate calibration. It relies on truncated mean techniques, or max likelihood.
- The dependency on P has not been exploited much since the first TPC



$$\sigma \sim n^{-0.46}(xP)^{-0.32}$$

Lehraus plot: 5.4% typical dE/dx resolution for 1m·bar track length. No significant change since 1983, i.e. since the first TPC

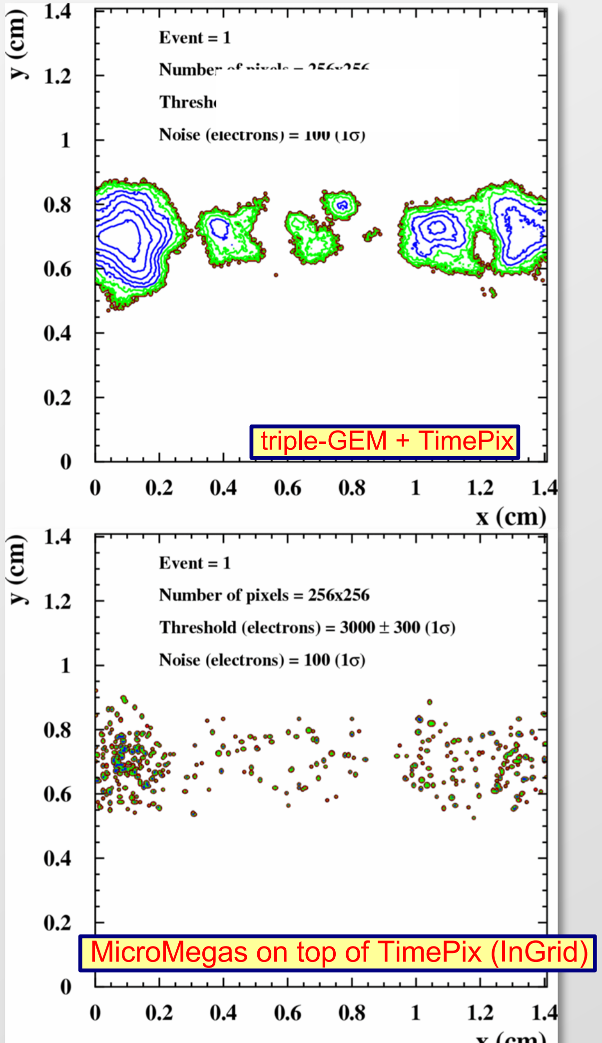
- interest in the P term is renewed where excellent PId is needed together with a large mass of gas (TPC-as-a-target)

Possibly in combination with optical readout, two issues require a fresh look

- suitable (modern) gas mixtures for high-P operation
- light pressure-containment vessels

dE/dx and dN_{cl}/dx

dN_{cl}/dx resolution is potentially better than dE/dx. Cluster counting requires fast electronics and sophisticated counting algorithms, or alternative readout methods. It has the potential of being less dependent on other parameters – however certain gasses (He, Ne) are better suited than others (Ar) due to their primary ionization characteristics



ILD-TPC simulated 100 GeV muon, 100 cm drift
identical events: same generated primary clusters/electrons

$$\sigma \sim (\delta \cdot L)^{-0.5} = \sqrt{N_{cl}}$$

- In cluster-counting mode there is a clear statistical advantage, even taking into account a cluster identification efficiency. There is the potential of better resolution by at least a factor 2 (theoretically)
- The application to future DCs will be mentioned by Piotr Gasik later today.

TPCs may hit intrinsic limitations, and not all TPCs may take advantage

- the relativistic rise is flattened out by a strict primary cluster count → a hybrid approach (dE/dx + dN/dx) may be better suited
- long drift lengths (long. diffusion + attachment) tend to de-cluster the primary ionization. Potential source of systematics.
- optimize the gas for longitudinal diffusion too!

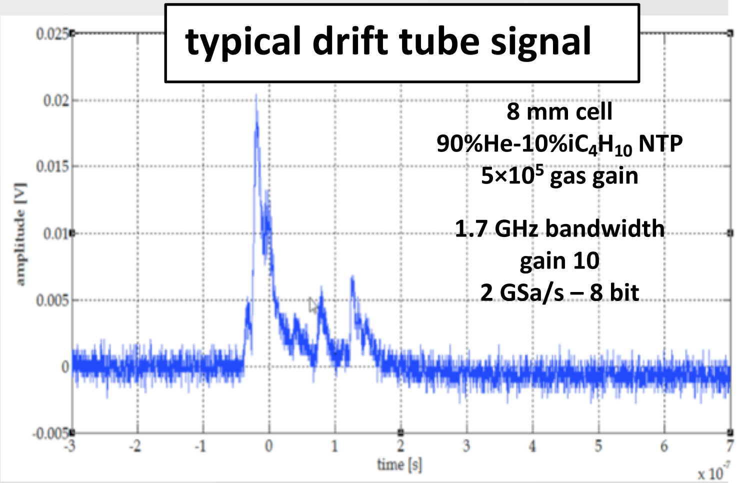
how to identify clusters and achieve dN/dx?

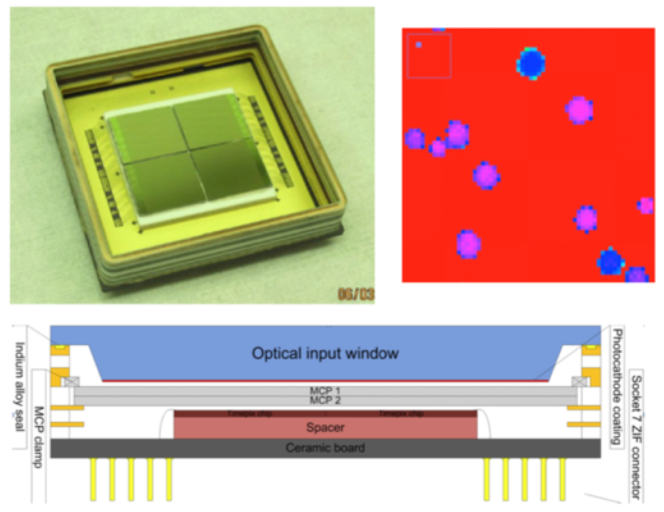
in time

- challenging fast-shaping electronics (~ ns needed)
- de-couple the charge collection from the cluster counting altogether
  - → optical, with ~(sub)ns continuous readout sensors

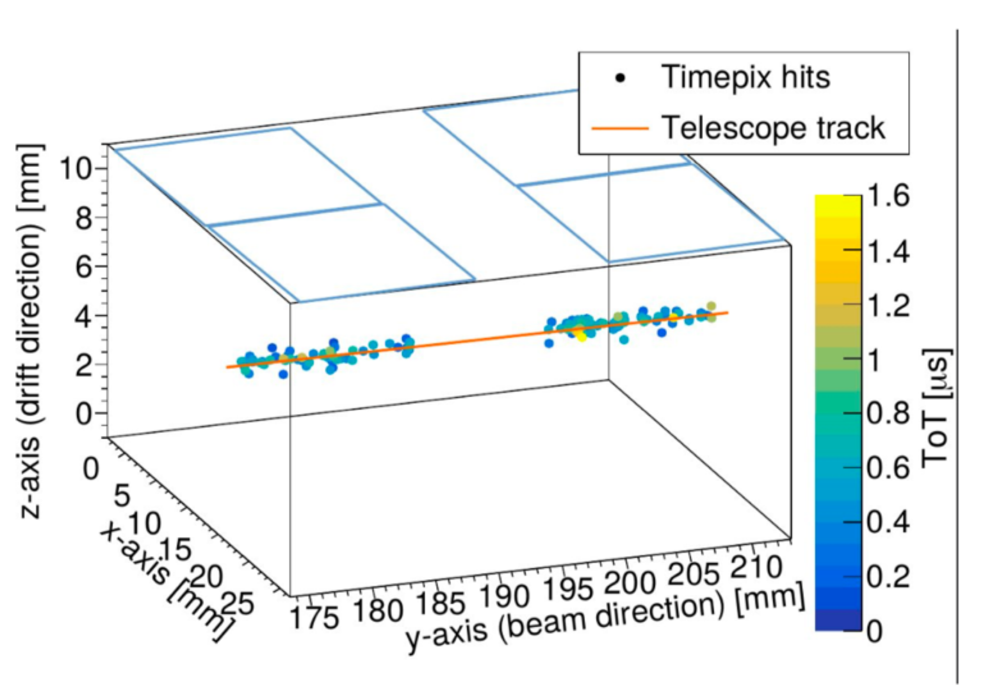
in space

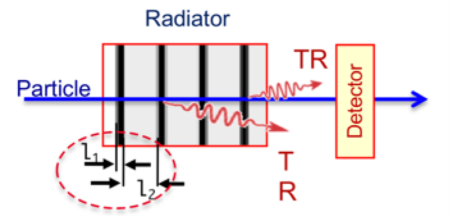
- GridPix-like readout
  - the extreme pixelization reveals the underlying cluster structure



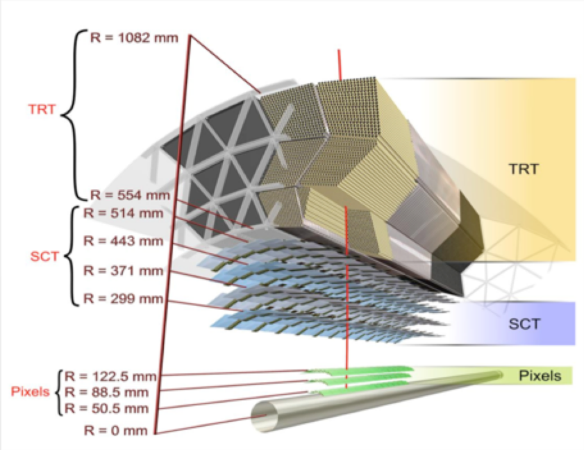


J Vallerga et al 2014 JINST 9 C05055

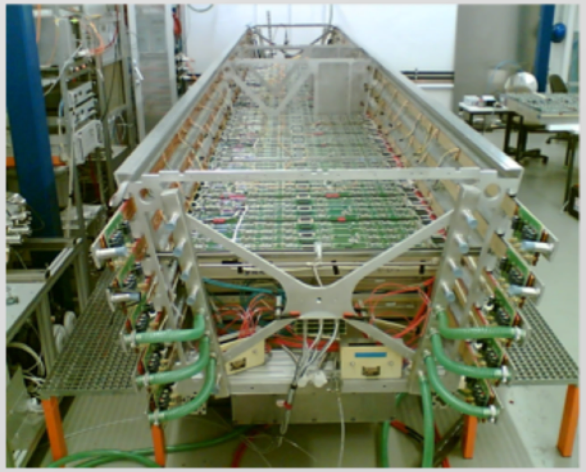


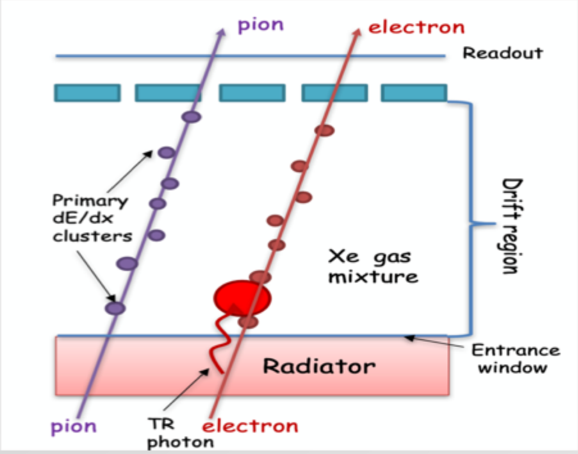


TRDs



- TRDs are (and will be) ubiquitous: ATLAS, ALICE, AMS ...
- Gas TRDs are considered a mature instrument for PId at high energies.
- The limitation of the gaseous detectors are related to the electron diffusion and photo/delta-electron production in the active gas. It is difficult to obtain a TR cluster size on the anode plane (or along the particle track) below few mm
- Due to the very small TR emission angle, the TR signal generated in a detector is overlapping with the ionization due to the specific energy loss dE/dx and a knowledge (and proper simulation) of dE/dx
- Advantage: dE/dx improves PId at low momentum, and tracking information is provided. The problem is how to separate the TR radiation and the ionization process.
- --> Simulation is of prime importance
- GEMs are making their way in the technique





TRDs

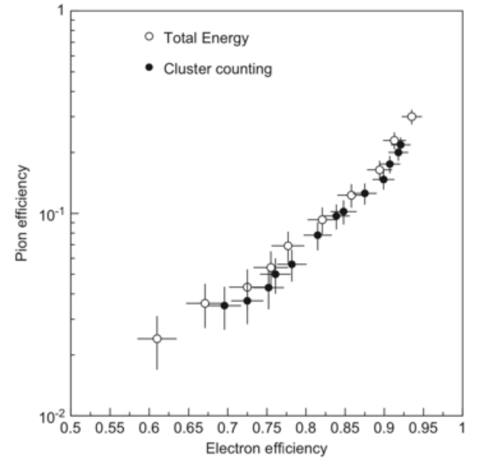
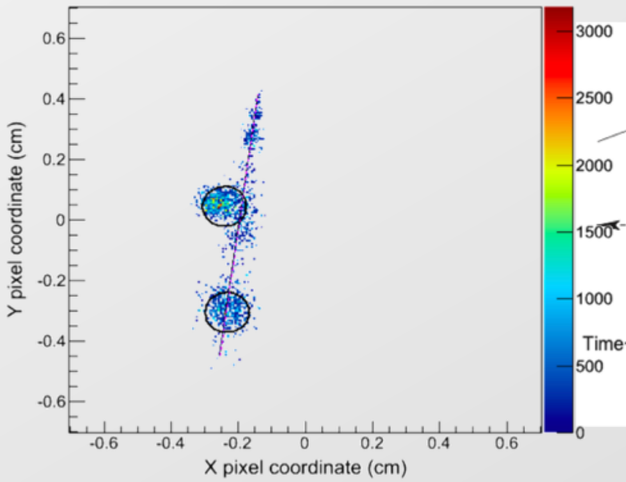
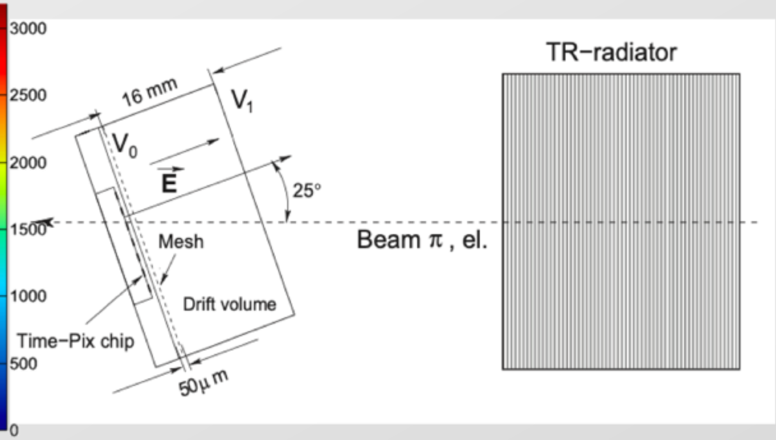


Fig. 13. Pion rejection factor for the cluster counting and total energy methods as a function of electron efficiency (data).





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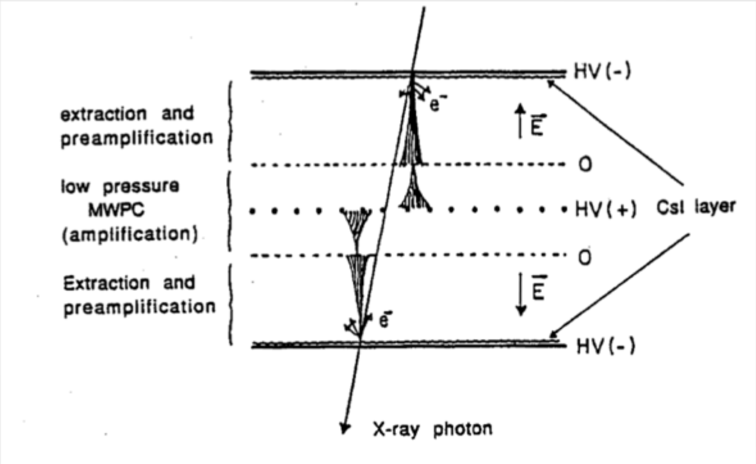
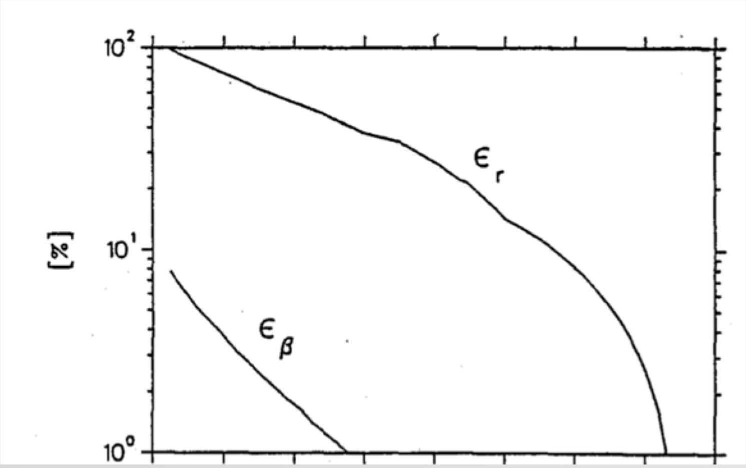
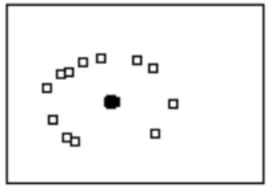
- an attempt has been made to improve cluster counting by means of a GridPix. Some improvement is possible, although not drastic.

- Potential improvement may be reached by differentiating the response to X-ray photons and to particle ionization
- Extensive R&D required!

R. Chechik, A. Breskin et al. IEEE Trans. Nucl. Sc. v39, V. 4 (1992) 728

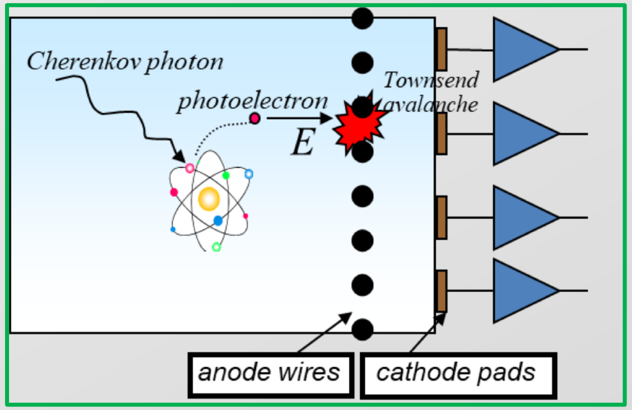


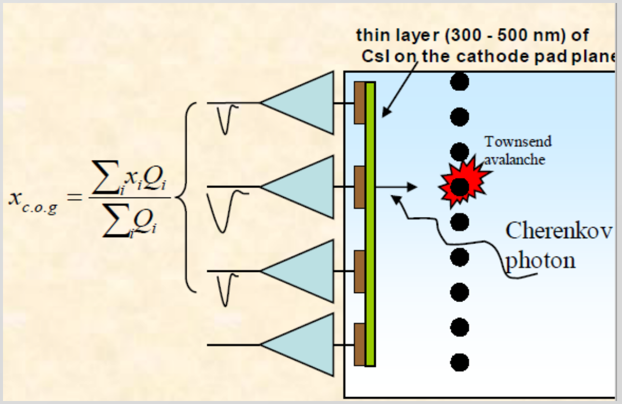


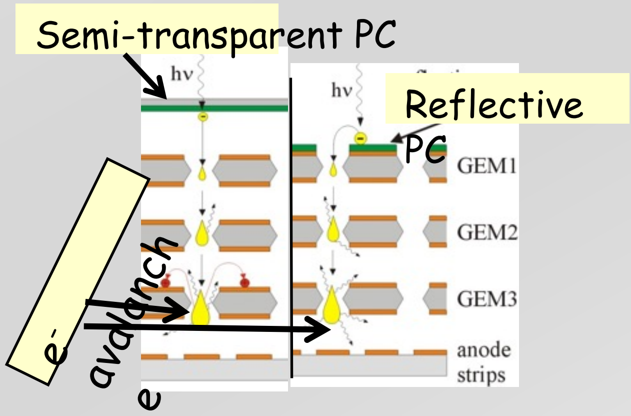


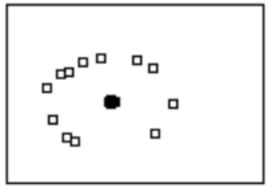
Ring Imaging Cherenkov

- from gas conversion, to CsI converters to MPGD structures
- addressing one after the other a number of issues:
  - long recovery time
  - photon feedback
  - IBF and photocathode aging by ion bombardment
  - low gain needing slow electronics, limited rate
- MPGDs changed the rule of the game addressing several issues at the same time



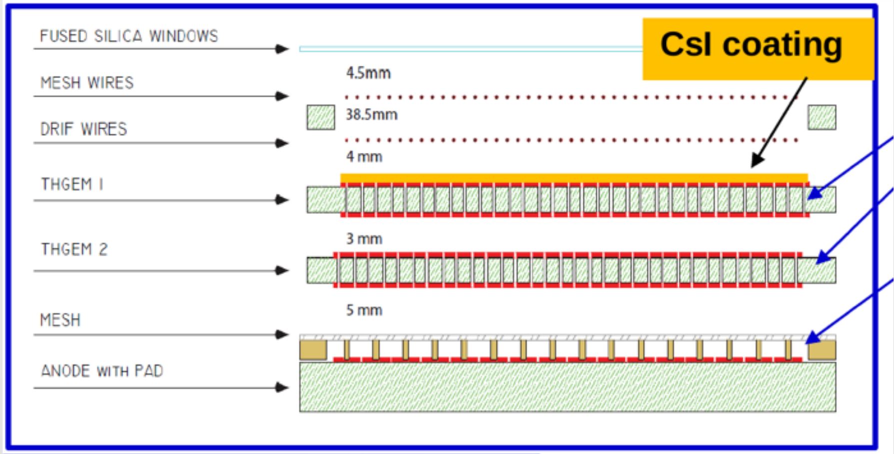


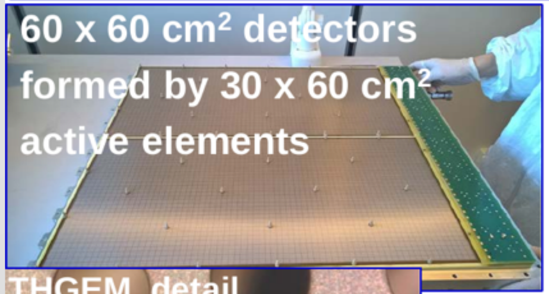


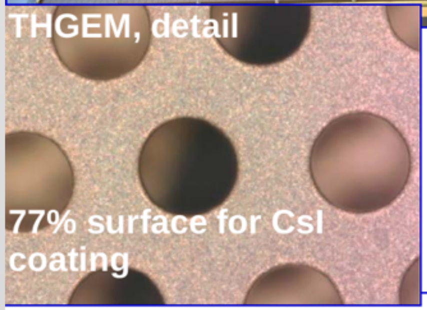


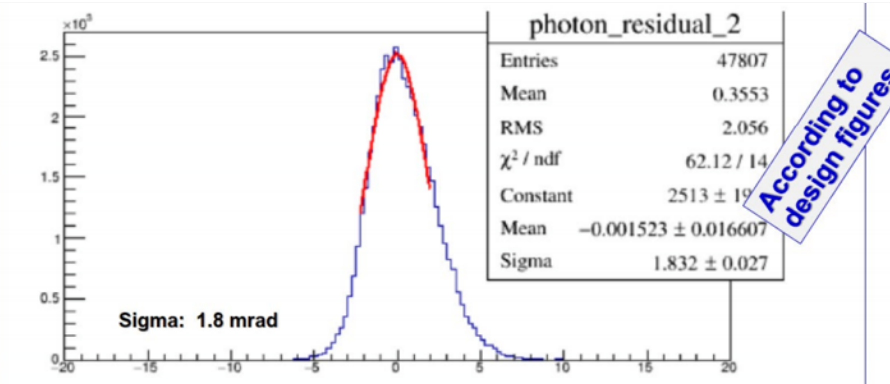
Compass RICH

- Hybrid approach, with CsI-coated THGEM and bulk MicroMegas allowed to reach
- Years of R&D and careful production & assembly have allowed
  - high gain
  - high rate
  - single photoelectron efficiency
  - excellent angular resolution
- Where from here?
  - new photocathode materials (DLC, nano-diamonds with better Q.E. and less prone to ion damage
  - IBF
- (see for more details later talks by Stefano and Fulvio)









Summary

- dE/dx in TPCs: pressure and alternative approaches
  - appropriate gas mixtures for hi-P operation
  - light vessels to mitigate the amount of X_0
  - optical readouts, including image-intensified TimePix
  - IBF
- dN/dx: not new, but renewed interest
  - special readouts: fast pre-shaping, or alternatives (optical / GridPix)
  - specific gas mixtures
- TR detectors
  - new approaches (dN/dx or enhanced gamma tagging)
  - most important: simulation tools
- CH detectors
  - new materials for photocathode
  - further addressing IBF