Gaseous Detectors

Status and Future Challenges

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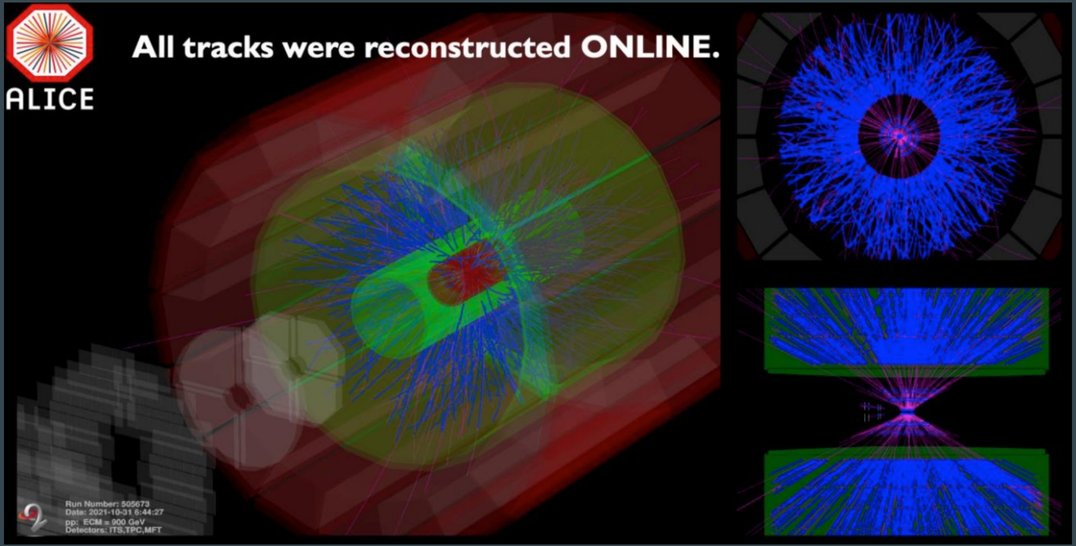
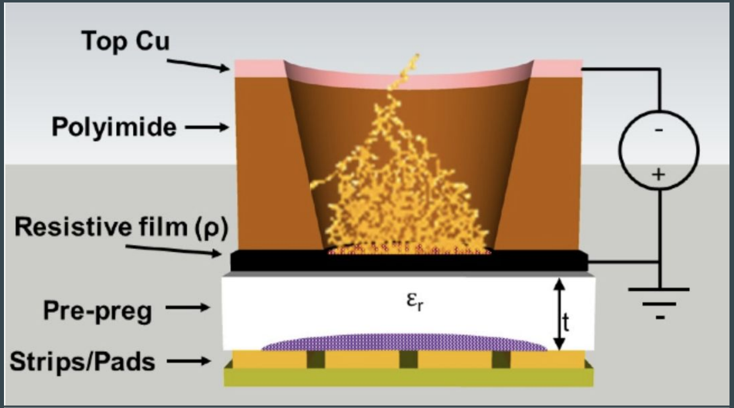
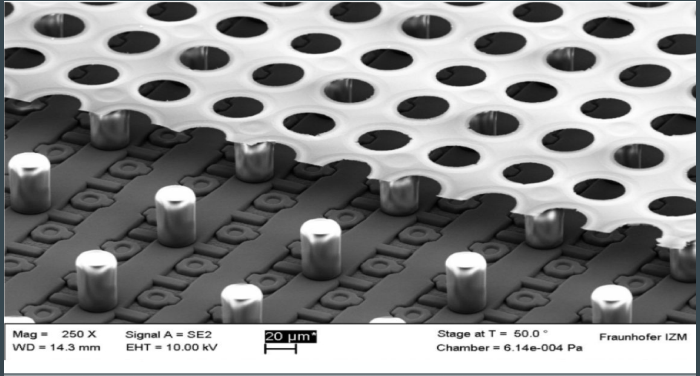
Ready for new challenges







From micro-patterns to large experiments, gaseous detectors are still largely exploited

Outline

- Timing
- Tracking
- TPC
- MPGD for neutron and hadron therapy
- MPGD integrated on asics
- Ageing of gaseous detectors

- Disclaimer:
  Many interesting topics not covered here, some are in the rapid talks
  We rely on the lively discussion to cover the missing points!

Timing detectors

RPC for trigger/tracking

Resistive Plate Chambers

- high and uniform electric field → prompt signal

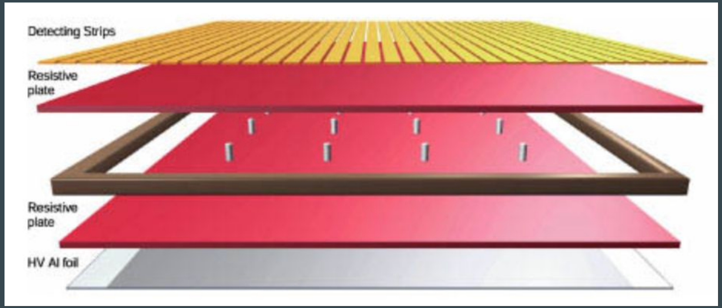
Used in LHC experiments (ATLAS, CMS, ALICE)

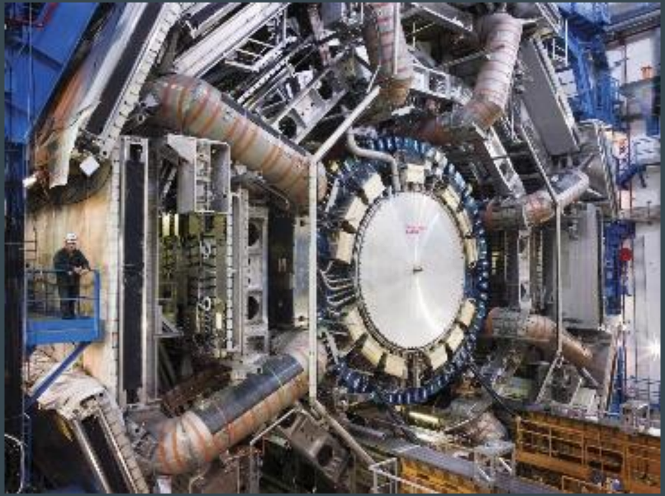
- bakelite electrodes 2mm thick separated by a 2mm gas gap
- time resolution ~1ns
- rate capability <1kHz/cm^2
- ageing certified for 10 y of LHC (ATLAS: 0.3 C/cm^2)

Improved performance in preparation for HL-LHC:

ATLAS BIS78 chambers (similarly for CMS iRPC)

- reduced electrode thickness 1.4 mm, gas gap 1 mm
- new FE with new chip, threshold as low as 1 fC
- rate capability and longevity x10
- time resolution ~400 ps



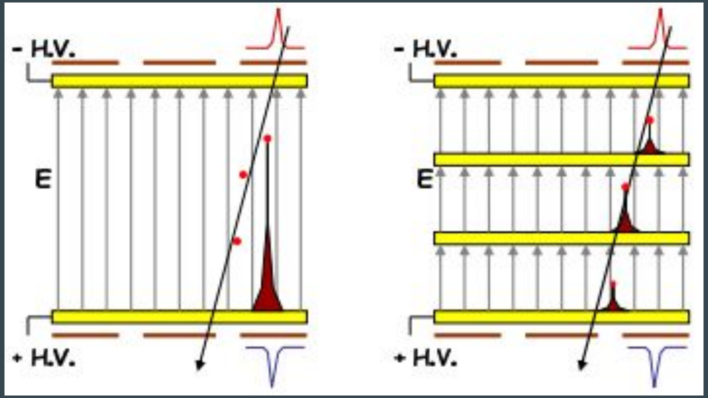


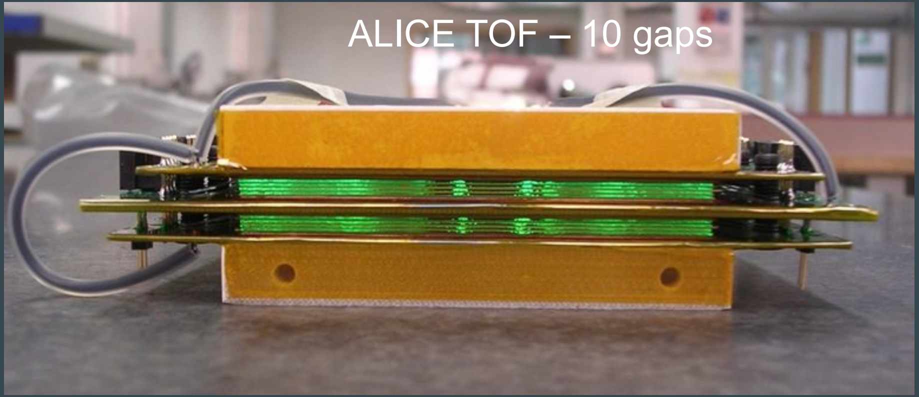
MRPC for TOF

Thinner gaps to reduce avalanche fluctuation

ALICE TOF specs and performance:

- glass electrodes ~500 μm, gas gaps 250 μm
- FE electronics based on NINO ASIC
- rate capability ~0.5 kHz/cm^2
- time resolution ~40 ps





Multi-gap RPCs used as large area TOF in several experiments
Application also in Muon Tomography and PET

Fast Timing MPGD: exploits same principle of MRPC
- several layers of GEM-like detectors

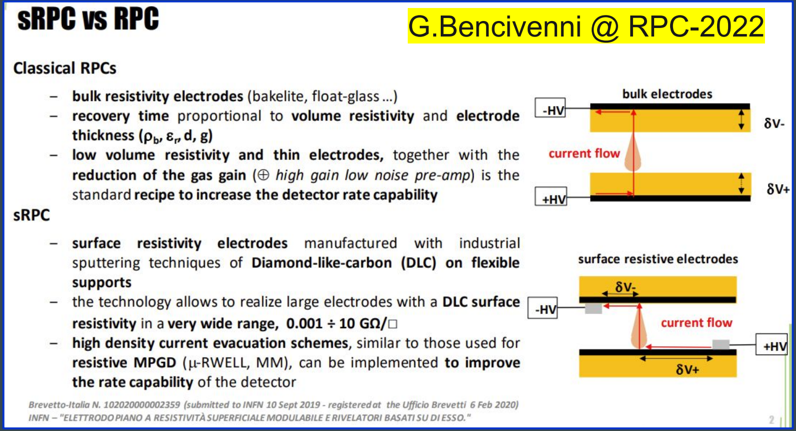
→ *see FireTalk by P.O.J.Verwilligen*

RPC/MRPC new electrodes

R&D driven by rate capability and longevity
Rate limited by voltage drop on electrodes:

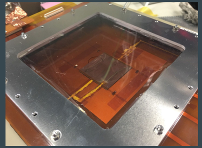
$$V_{eff} = V_{gen} - 2\,\rho\, d\, \langle Q \rangle\, \Phi$$

Diamond-Like Carbon electrodes
DLC film is deposited by sputtering
(typically 0.1 µm thick) graphite on polyimide foils



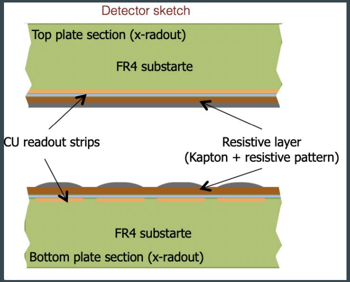
Single gap RPC
- prototype with 2mm gas gap
- cathode protected by UV-photons with urethane coating
- high stability (ΔV > 1kV) and good performance in terms of efficiency (~95%) and time resolution (~1 ns)

MRPC (prototype detector for MEG II)
Low material budget needed for on beam detector
- 4 gaps of ~400 µm
- 170 ps time resolution
- 1 MHz/cm^2 rate capability



RSD: Resistive Strip Detector
- First prototype with screen-printed resistive strips on Kapton (100 kΩ/▫ C-loaded polymer)
- Good resistivity uniformity reached

P. Iengo @ ICHEP-2020

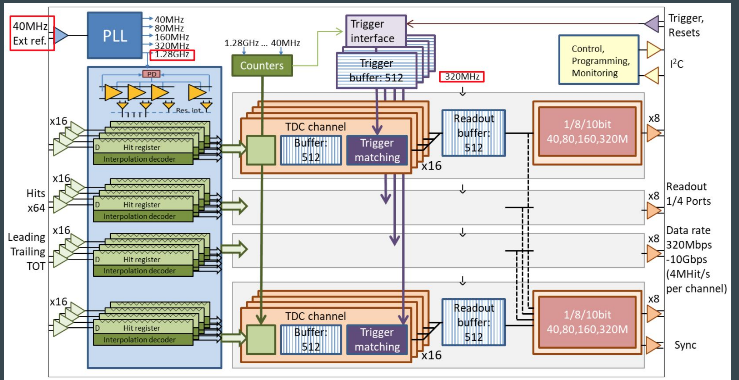


Semi Insulating Gallium Arsenide wafers:
low resistivity, crystal structure, thin electrode
- new material immune to ageing effects
- improve rate capability x10, just with 10^8 Ωcm resistivity
- medium size high rate application

→ *see FireTalk by A.Rocchi*

New electronics

PicoTDC - the successor of HPTDC
- low noise high resolution TDC

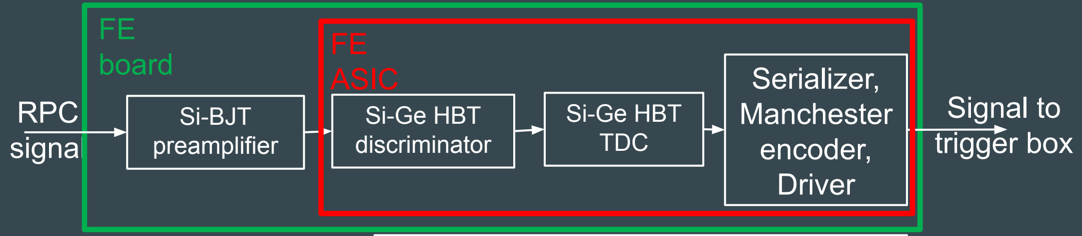


64 channels, 3ps or 12ps time binning, 200us dynamic range

ATLAS Phase2 RPC new Front-End electronics
- improved signal-to-noise ratio
- reduction 1/10 of average charge per count wrt current system
- rate capability from **1 kHz/cm^2 to 10 kHz/cm^2**
- minimum threshold of 0.3 mV
- detectable signal of 1-2 fC
- amplification + discrimination + TDC function implemented

Mixed technology of Silicon BJT for the discrete component preamplifier and a full custom ASIC in IHP BiCMOS technology

https://kt.cern/technologies/picotdc

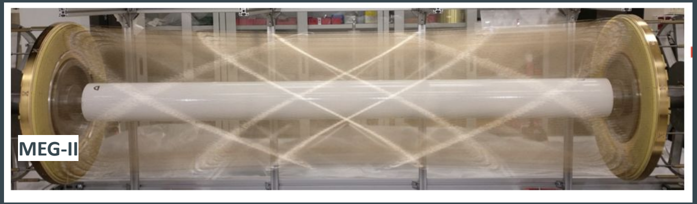


Total FE power consumption: 15mW/ch

Tracking detectors

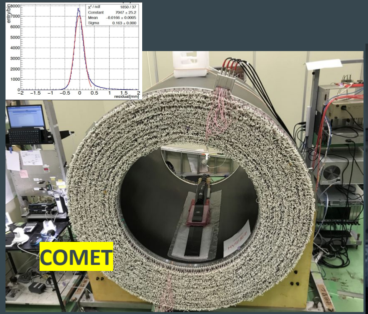
Wire-based trackers

- Gaseous detectors are still the primary choice as tracking detectors when spatial resolution of O(100 um) or worst is sufficient
  - Muon detector for large system
  - Central trackers
  - Low material budget
  - TPC



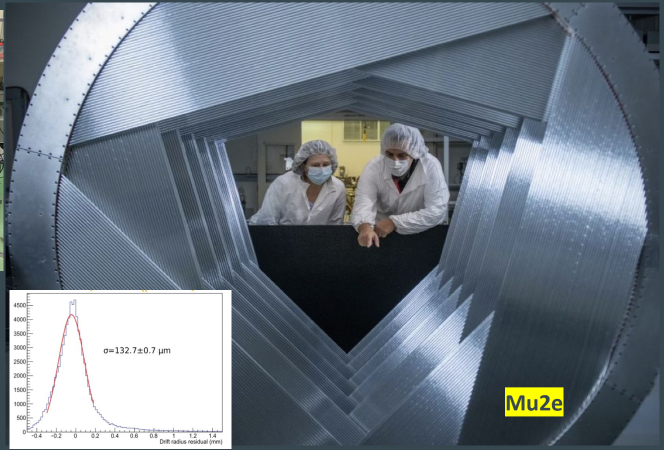
- Wire chambers valuable option for moderate rates
- Wire-based tracker
  - MEG-II @ PSI and COMET @ J-PARK

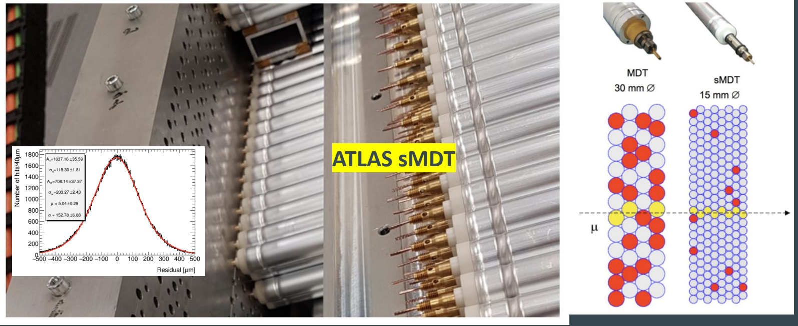
IDEA drift chamber for future lepton colliders (including super-τ/charm factories)
→ *See FireTalk by B. D'anzi*

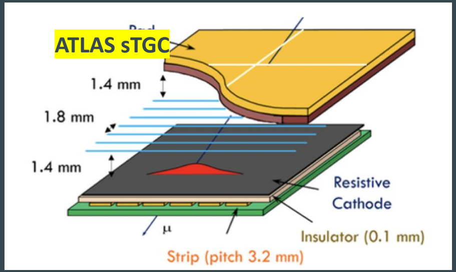


Straws:

NA62 / Mu2e / COMET



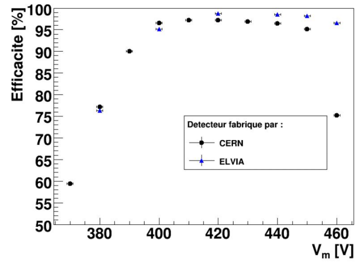


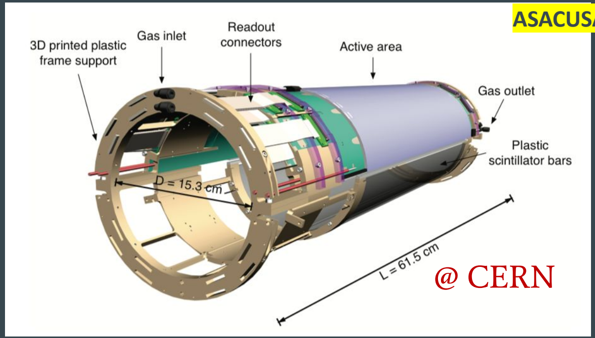


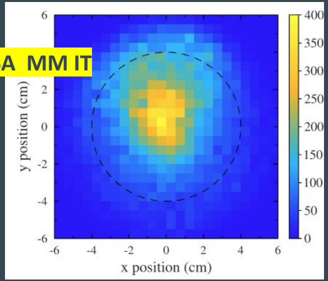
- Muon system
  - ATLAS sTGC (Phase1)
  - ATLAS sMDT (Phase-II)

Inner tracker MPGD

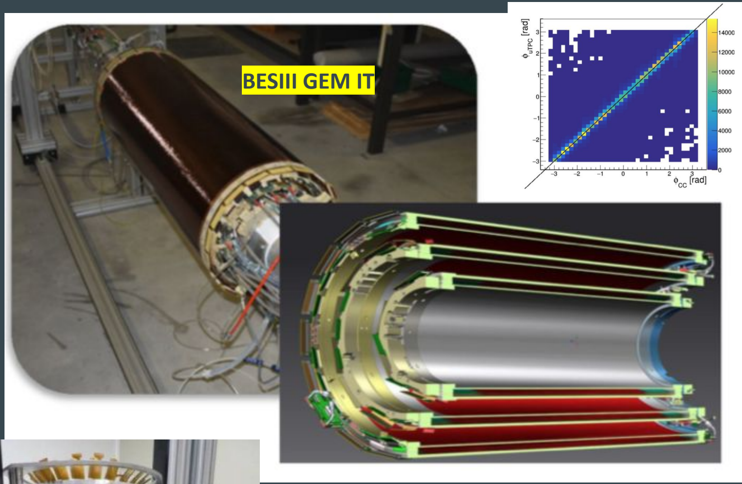
- MPGD satisfy increasing requests in rate capability
  - Inner trackers: Micromegas
  - Inner trackers: GEM

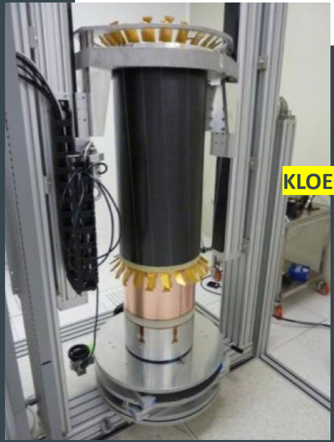






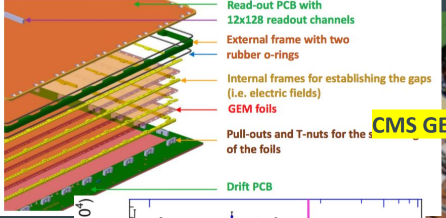
Fully reconstructed antiproton annihilation event

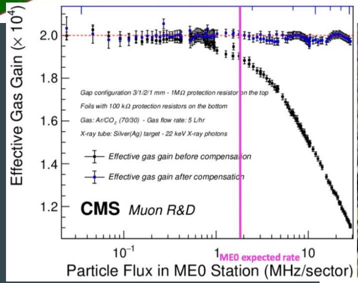


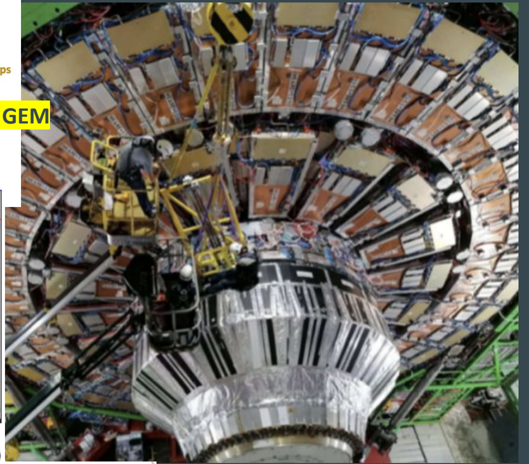


Large Apparatus: LHC Muon systems

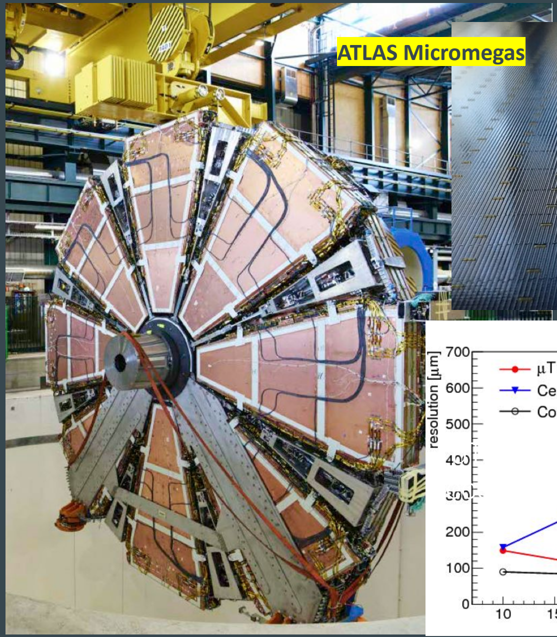
- MPGD widely used in next generation muon system
- LHC experiment upgrades
  - CMS EndCap (GEM, Phase-1+Phase2) – 224 m^2
  - ATLAS EndCap (NSW Micromegas, Phase-1) – 1280 m^2
  - LHCb Inner radius of Muon tracker (Phase-2)

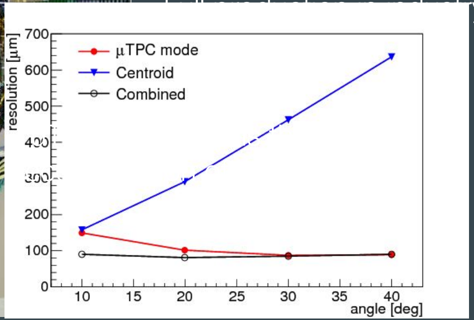


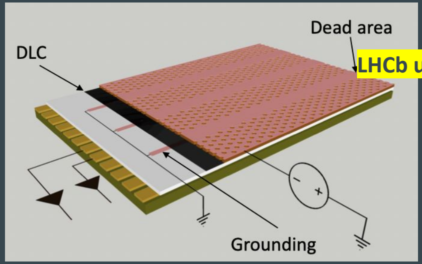


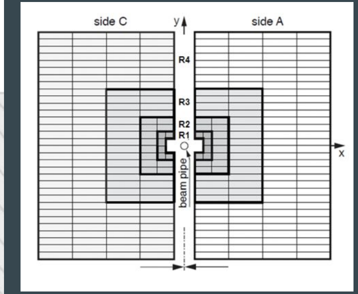


Voltage drop compensation









uRWell in R1 and R2

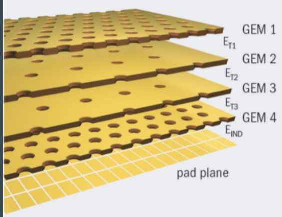
Introduction of resistive MPGD (ATLAS) opened the road to stable operations at high gain and to development of new structures

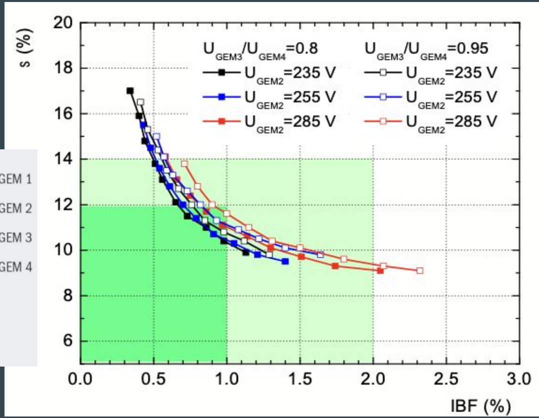
uRWell → rapid *talk by G. Bencivenni*, uPIC,
Pad Micromegas for high rate → rapid *talk by M.T. Camerlingo*

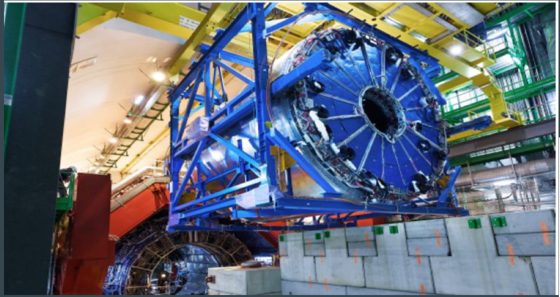
TPC

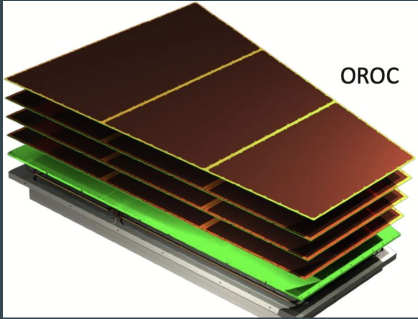
TPC

- ALICE new TPC: example of challenges for next generation TPC with high rates
- Developed a 4-GEM readout stage with staggered holes
  - Ion Back Flow reduction <1%
  - No gating and triggerless operation (1 → 50 kHz DAQ rate)

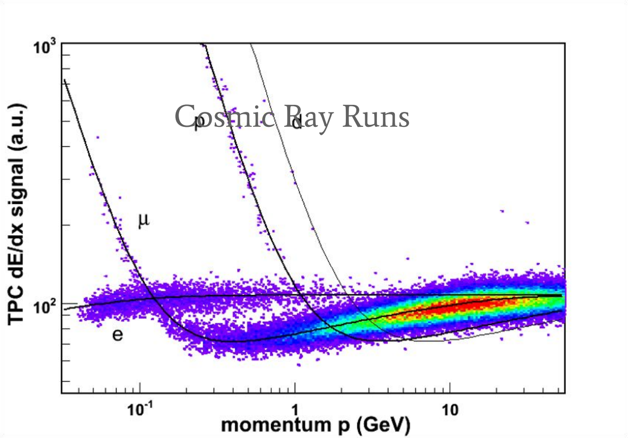


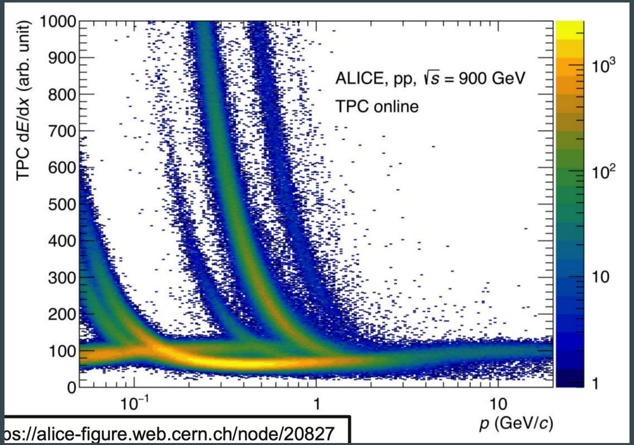






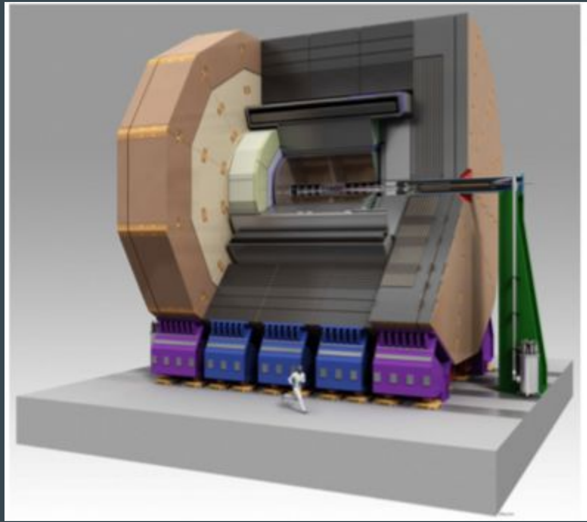
Bethe & Bloch distributions



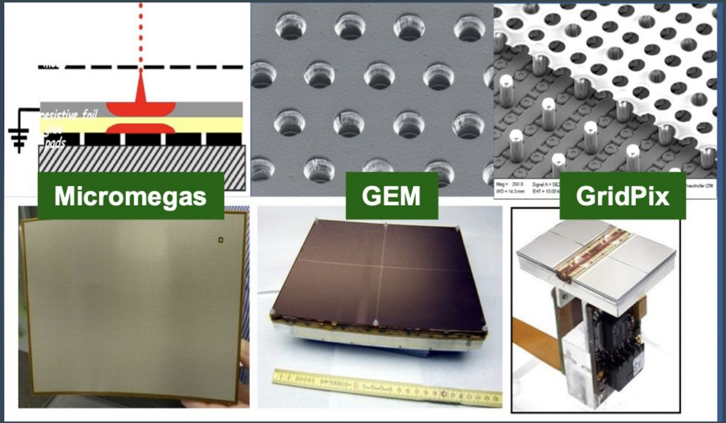


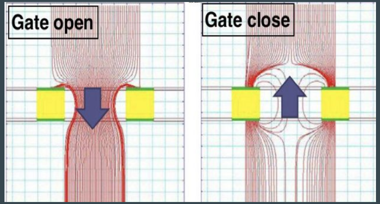
TPC

- TPC for ILC ~10 m^2. Three options under study
  - GEM / Micromegas / GridPix



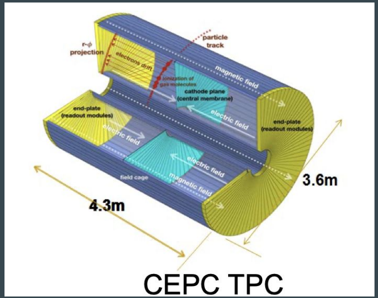
First development of large-scale Pixel GridPix

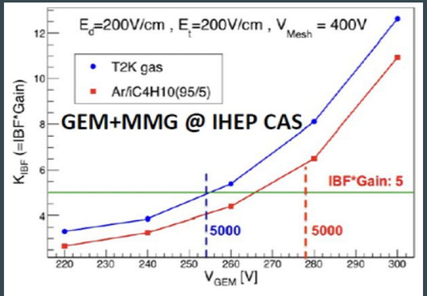




Gating scheme based on large-aperture GEM

- TPC for CEPC: good results for hybrid GEM+MM technology



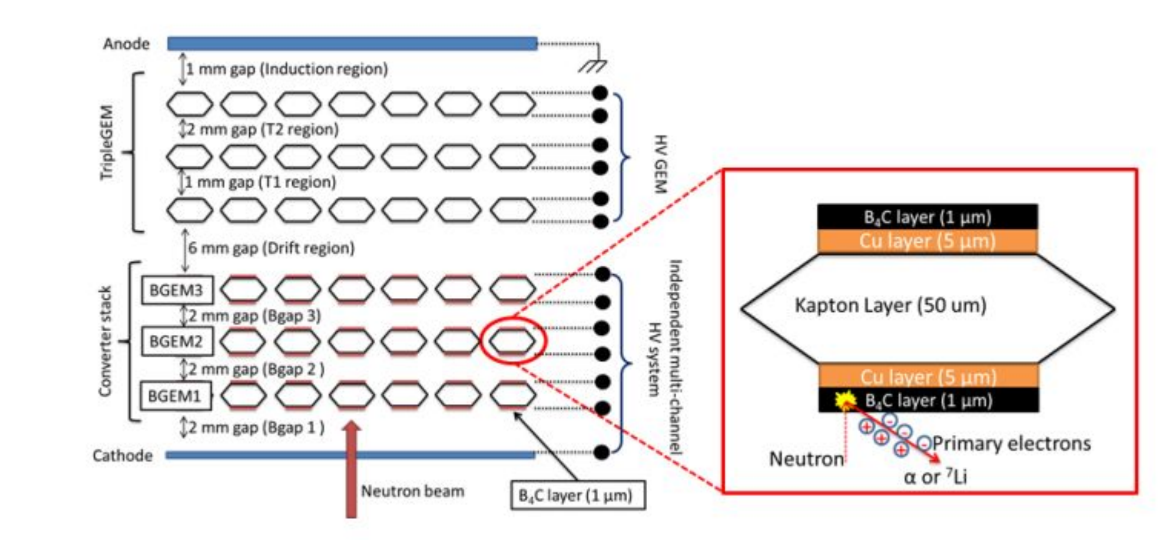


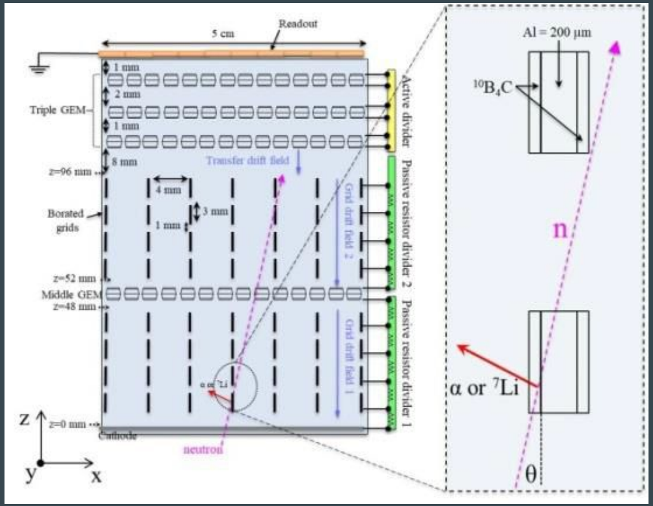
MPGD for neutrons and hadron therapy

MPGD for neutrons

GEM detectors for neutrons, conversion on **Boron**-coated electrodes

Different structures are proposed and tested for different applications;





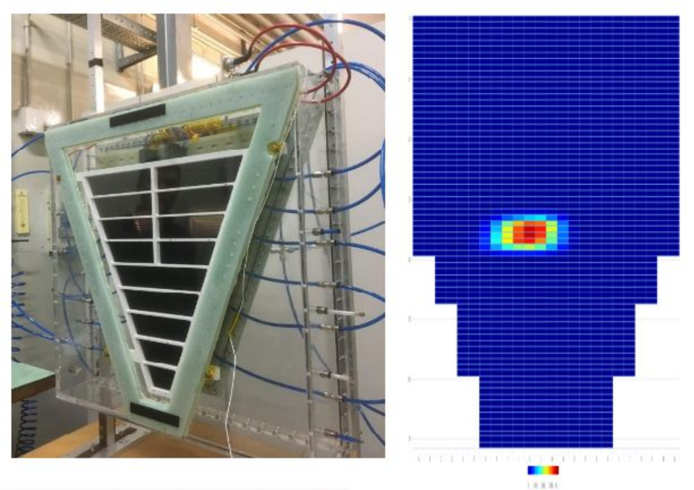
To increase the efficiency in thermal neutrons, orthogonal borated grid are used

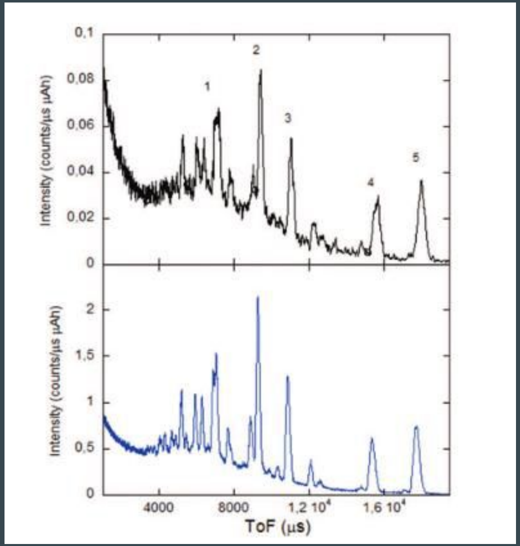
MPGD for neutrons

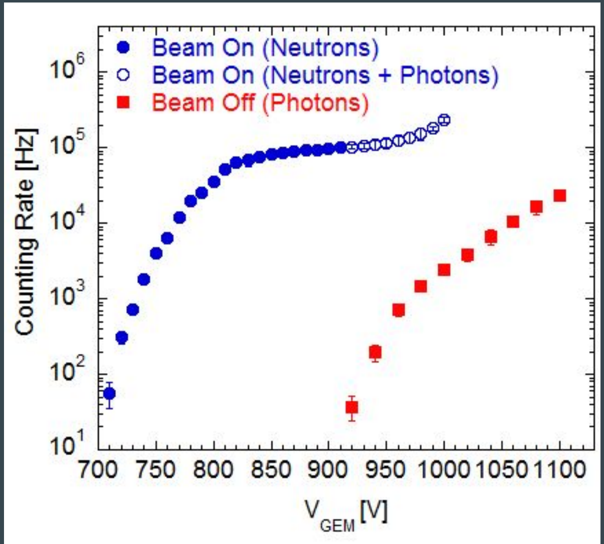
GEM detectors for neutrons, conversion on **Boron**-coated electrodes

- ➢ good time resolution (5 ns)
- ➢ high gamma rejection (>10^5)
- ➢ high rate capability O(10 MHz/cm^2)
- ➢ good spatial resolution O(mm)

good candidate for ^{3}He filled detector replacement

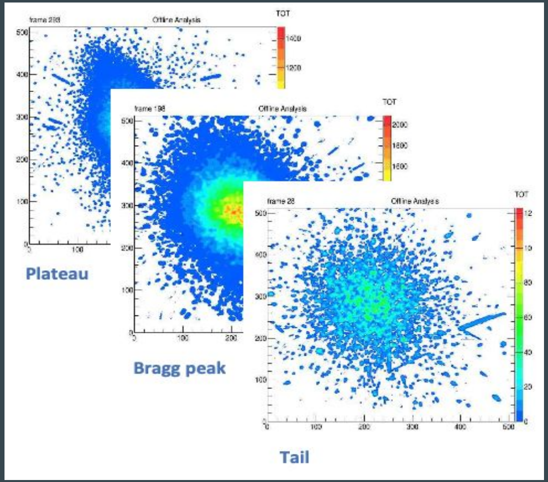


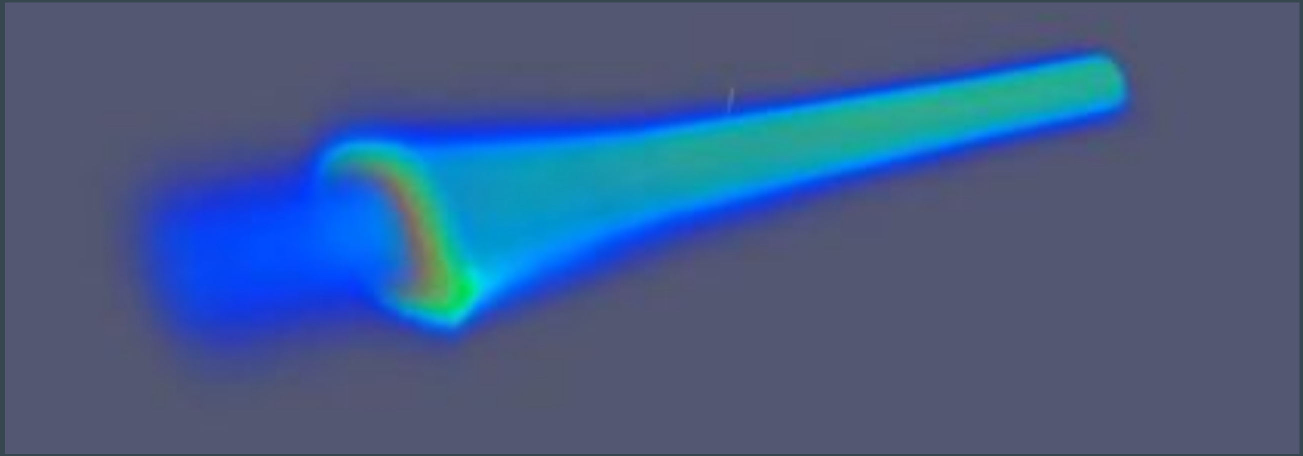


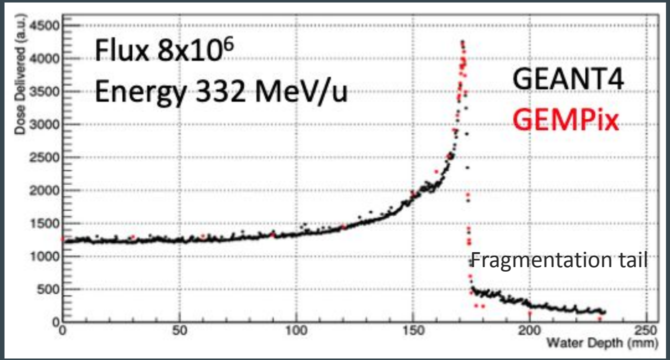


MPGD integrated on asics

GEMPix: Verification of treatment plan in hadron therapy





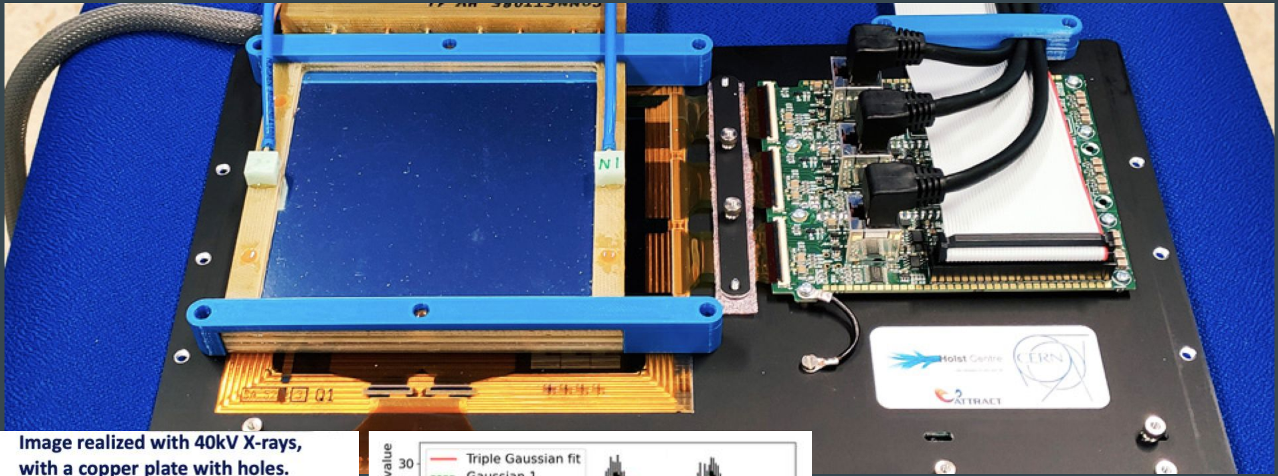


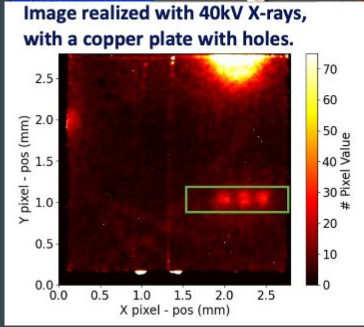
Combined use of **GEM** and **TimePix** (3D version of MediPix, a family of photon-counting pixel detectors) allows to measure the 3D energy deposition of a therapeutic beam in a water phantom

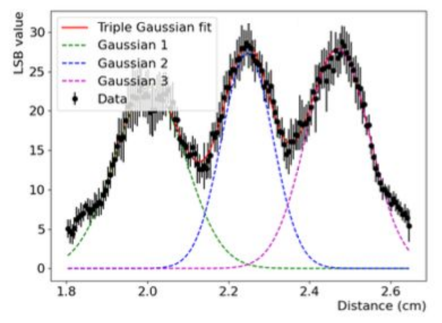
The beam is spread out with increasing depth in water Larger detector area of 20 cm x 20 cm needed to cover typical maximum radiation field

MPGD: LaGEMPix (optical readout)

LaGEMPix: optical photo detectors (Organic Photo-Diodes) on top of Thin Film Transistor. Sensitive to scintillation light with 120 μm^2 pixels

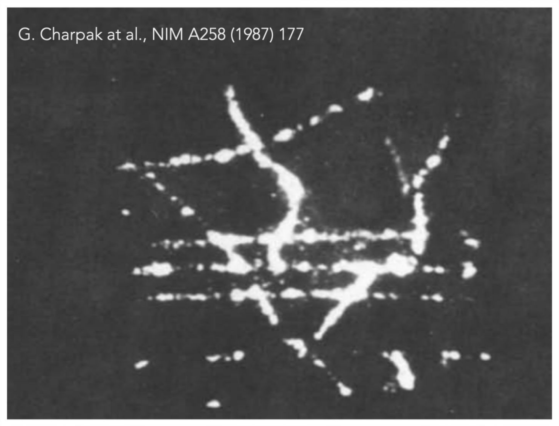






Area: 10x10cm^2

1.6 mm holes, with a pitch of 2.5 mm can be resolved



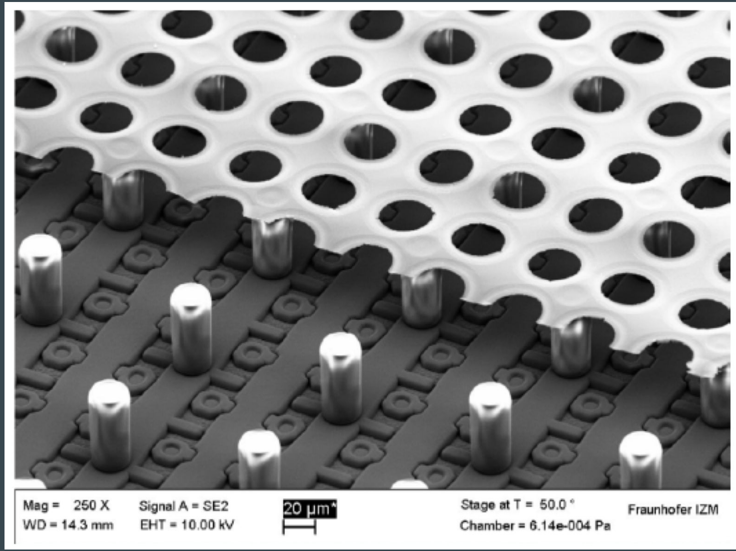
Scintillation light is produced by the gas during the multiplication process

TPC gassose a lettura ottica per eventi a bassa energia:
high sensitivity and high granularity GEM optical readout
→ *see FireTalk by F.DiGiambattista*

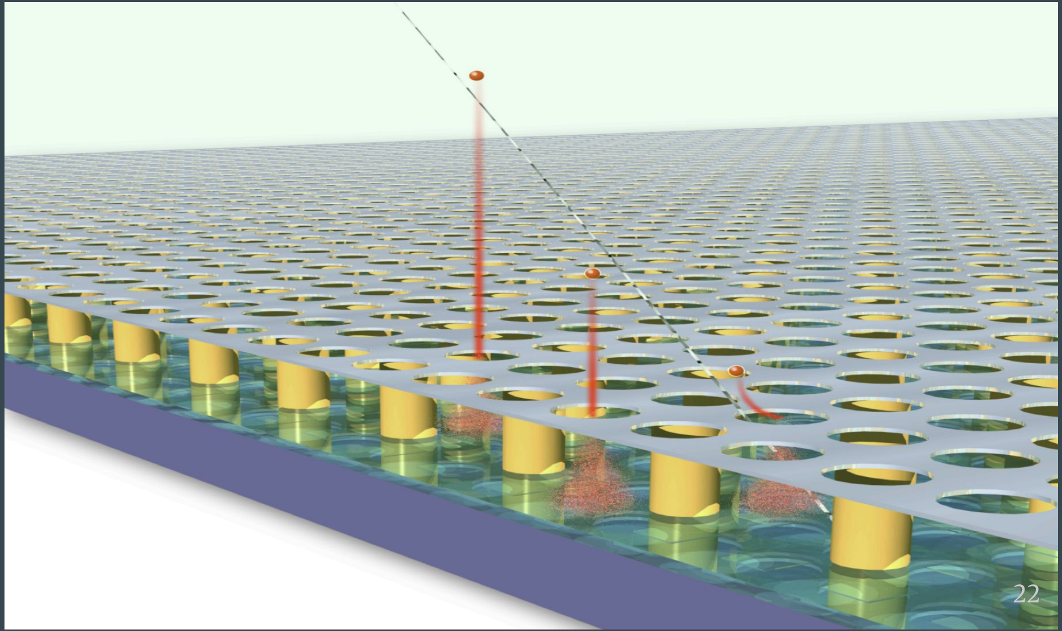
MPGD: GridPix (charge readout)

Micromegas on Timepix ASIC

- Bump-bond pads used for charge collection
- CMOS-ASIC designed by the Medipix collaboration
- GridPix based on Timepix 3:
  - 256 × 256 pixels with 55 × 55 μm² per pixel
  - Charge (ToT) and time (ToA) information with 1.56ns time resolution



Proposal for the TPC readout in ILC, experiment to study the electric dipole moment of the muon

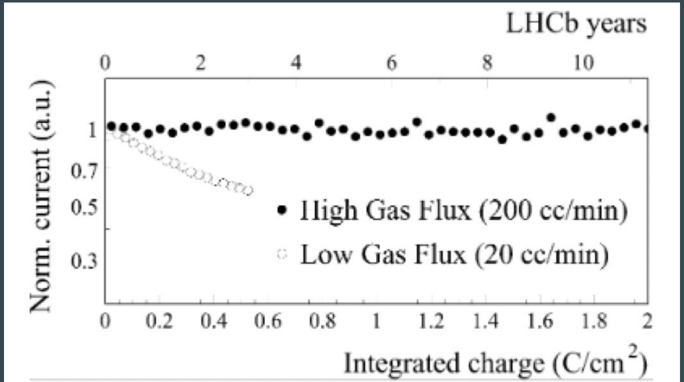


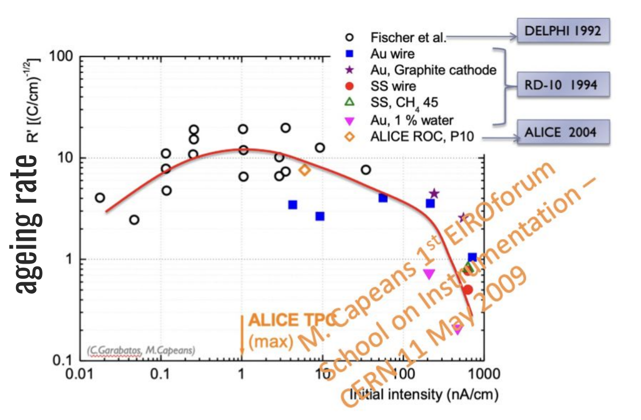
Ageing

Ageing

Ageing phenomena in gaseous detectors can be the subject of a dedicated conference (as it was in the past!). Here only few hints

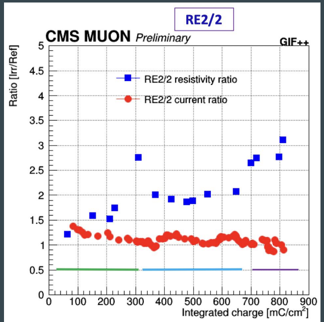
- Main source of classical ageing:
  - Degradation of material with integrated charge / time
  - Chemical effects of gas compounds
- Ageing is however a subtle phenomena, depending on many parameters (gas mixture, materials, operating conditions, rates…) and detector ageing must be studied for each specific application
- Example: relevance of controlling the operation parameters (e.g. gas flow) in GEM. LHCb test
- Ageing test must be long-term: acceleration might mitigate the aging effect (well known from wire chambers)

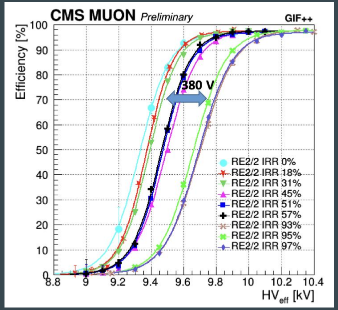




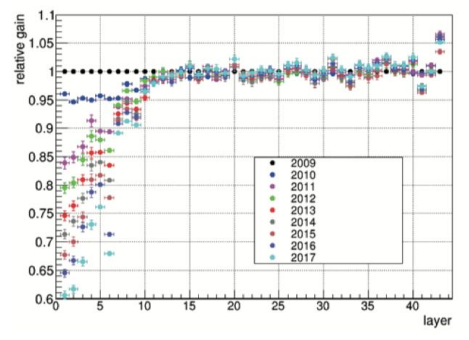
Ageing

- Ageing behavior of traditional gaseous detectors (wire chambers, RPC) well known
- Bakelite RPC
  - Surface degradation mainly due to F- radicals combining in HF → increase of dark current.
    Mitigation: reduce F-based gas components; increase gas flow
  - Increase of bulk resistivity → increase in working point
    Mitigation → restore rH value. Effect can be fully controlled





- Wire chambers
  - Deposits (whiskers) on the wire surface → distortion of pulse height spectra, gain loss, noise rate
    Mitigation: no hydrocarbons, no silicon material



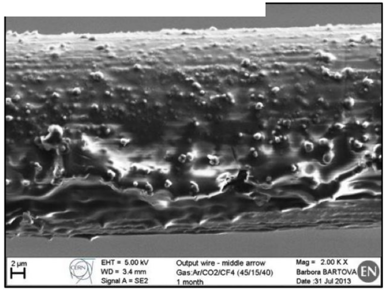
Performance degradation with time of wire-based BES IT

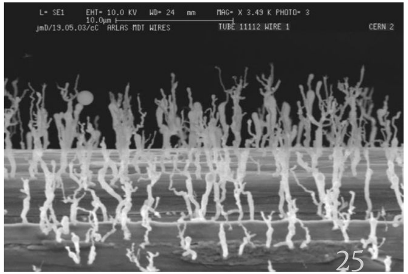
8. Conclusions on Gases

A. If we obtain regular purity gases, a basic conclusion of the workshop is that *Noble gas + hydrocarbon* mixture should not be trusted for more than[11,18,21,46] 0.01–0.05 C/cm. The *Noble gas + CO_2* mixture appears to behave about ten times better.[11,21,46]

J.Va'Vra,

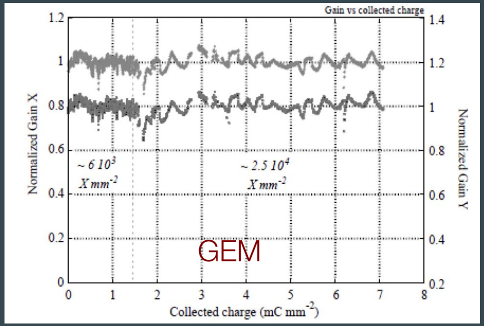
Typical aging phenomena on wire chambers

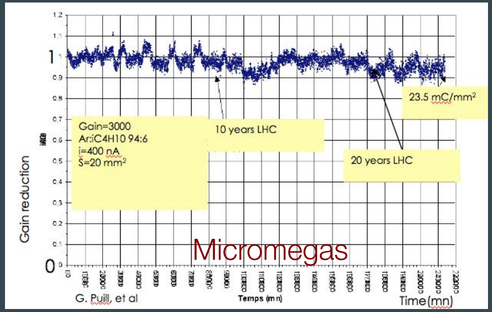




Ageing

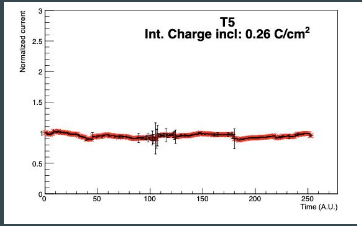
- MPGD better behavior compared with wire chambers
- Accelerated aging tests have been conducted on GEM, Micromegas and other MPGD with excellent results



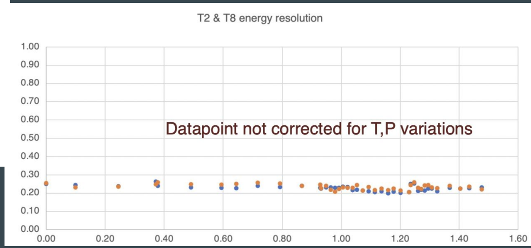


- New materials (resistive coating) and challenging detector operations (high rates, large integrated charge) calls for dedicated studies
- Effects of hydrocarbons must be re-evaluated for the specific application

Resistive Micromegas (ATLAS-like): 3-years exposure at GIF++
Total collected charge ~0.3 C/cm^2 → No sign of aging in Ar:CO2



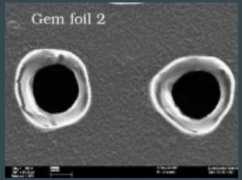
Gain



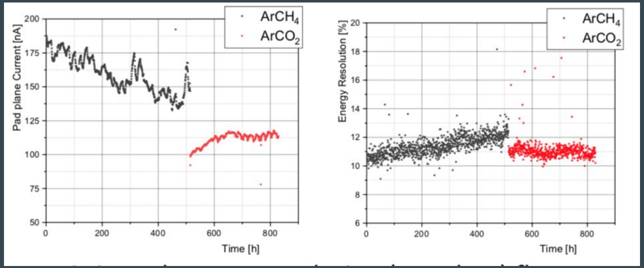
Energy resolution

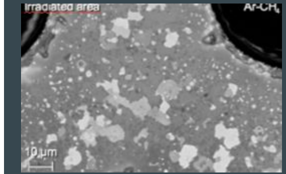
Test ongoing with 2% of iC4H10. Results from accelerated test (up to >1C/cm2) and from long-term test at GIF++ : no aging observed

Etching effect on Triple-GEM operated with CF4-based mixture at low flow



Gain | Energy resolution



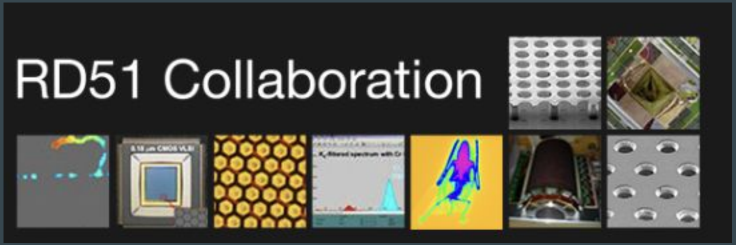


Aging in ALICE GEM prototype operated with hydrocarbons (CH4) in Ar 95% mixture. Aging stops when CH4 is replaced with CO2

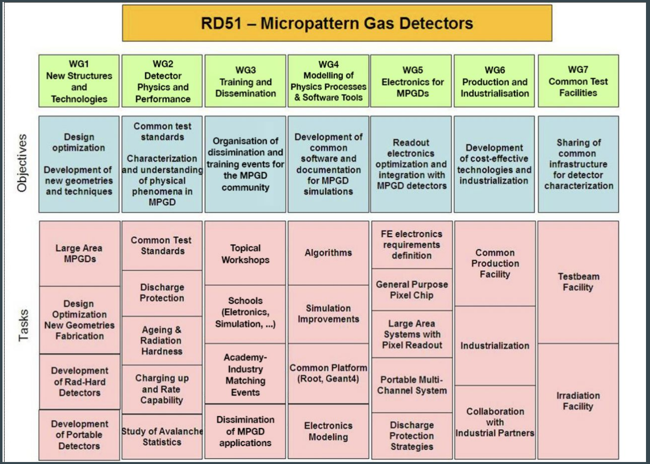
Thank you

Backup

- Development of Micro-Pattern Gas Detectors Technologies
- The proposed R&D collaboration, RD51, aims at facilitating the development of advanced gas-avalanche detector technologies and associated electronic-readout systems, for applications in basic and applied research. The main objective of the R&D programme is to advance technological development and application of Micropattern Gas Detectors.

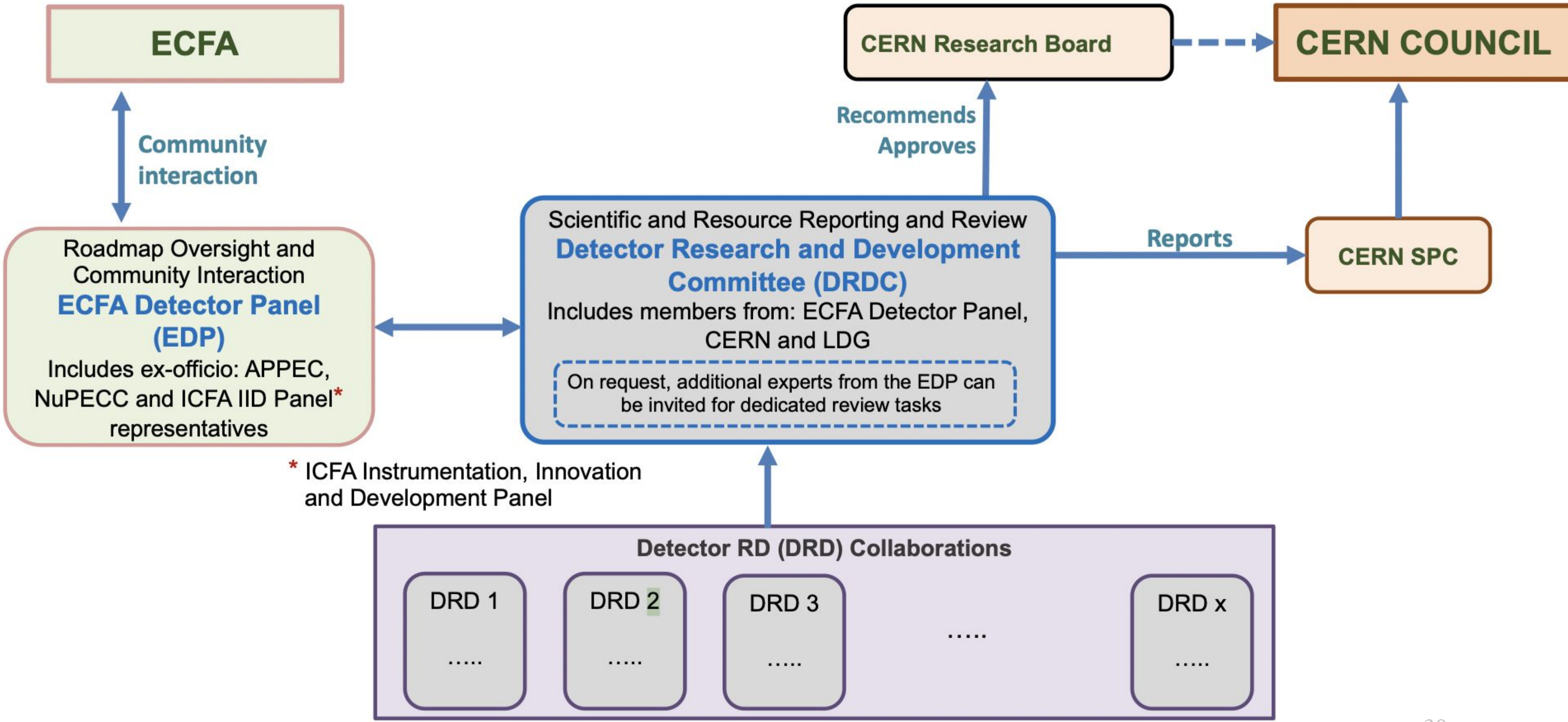


RD51 has a key role in promoting the development and dissemination of MPGD with common test facilities, tools (eg Garfield simulation tool) and cross-fertilisation between different groups and different expertise



ECFA
European Committee for Future Accelerators

Suggested Implementation Organisation



RD51 (DRD1) new structure

WG1: Technologies, limitations and challenges
Includes detector physics aspects

- MPGDs
- RPCs, MRPCs
- Large Volume Detectors (drift chambers, TPCs)
- Straw tubes
- New amplifying structures

WG2: Applications
full alignment with the ECFA detector R&D roadmap

- Muon systems
- Inner and central tracking with particle identification capability
- Calorimetry
- Photon detection
- Time of Flight systems
- TPCs for rare event searches
- Fundamental research applications beyond HEP
- Medical and industrial applications

WG3: Gas and material studies
Interdisciplinary working group

- Ageing
- Radiation hardness
- Eco-gases searches
- Light emission in gases
- Light (low material budget) materials
- Resistive electrodes
- Precise mechanics
- Photocathodes (novel, ageing, protection)
- Solid converters
- Novel materials (nanomaterials)

WG4: Detector physics, simulations, and software tools

- Detector properties studies (simulations)
- Software tools development and maintenance
- Detector design tools
- Gas cross-section data bases maintenance

RD51 (DRD1) new structure

WG5: Electronics for gaseous detectors

- Readout electronics (SRS, ASICs, fast electronics, pixel, and optical readout)
- HV systems
- Dedicated lab instrumentation

WG6: Detector production

- CERN MPT workshop
- Saclay MPGD workshop
- Novel detector production methods
- Industrialization

WG7: Common test facilities

Incudes development of common detector characterization standards

- General purpose detector development labs
- Ageing facilities
- Irradiation facilities
- Gas studies facilities
- Test beam facility

WG8: Training and dissemination

- Schools and trainings
- Topical workshops
- Knowledge transfer

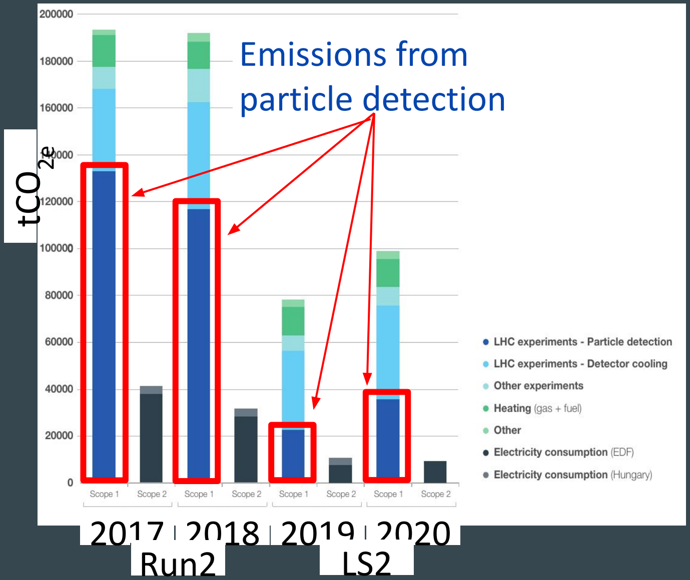
RPC environmental impact

RPC gas mixtures in use have a GWP > 1000 [CO_2 =1]
Main contribution is $C_2H_2F_4$/R134a (GWP=1430)
Not only an environmental issue, also cost and procurement: increasingly expensive and being phased out

Candidates for replacing R134a are being studied
 see FireTalk by A.Pastore

Where possible, transition to eco-friendly mixtures already done…

Total CERN emissions

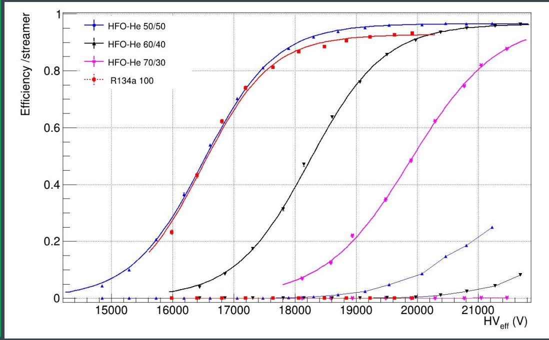


<u>Mixture used in the **EEE MRPCs**:</u>
R134a /SF6 98/2 GWP ≈1880

M.Abbrescia @ RPC-2022

<u>62 telescopes</u> with a flow of 2 l/h ≈ 10^6 l/year

The EEE Collaboration has started <u>3 important actions</u>:
- Gas flow reduction
- Gas recirculation system
- Eco-friendly gas mixtures (HFO/He)

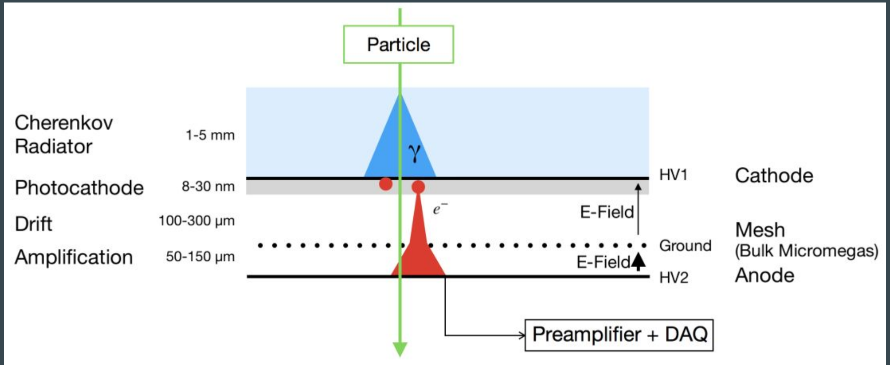


Timing detectors: other ideas

PICOSEC, two-stage detector made by a Micromegas coupled to a Cherenkov radiator and equipped with a photocathode
- time resolution ~25 ps in small prototypes

Application cases:
- timing layer in calorimeter
- TOF for particle identification

 see FireTalk by D.Fiorina



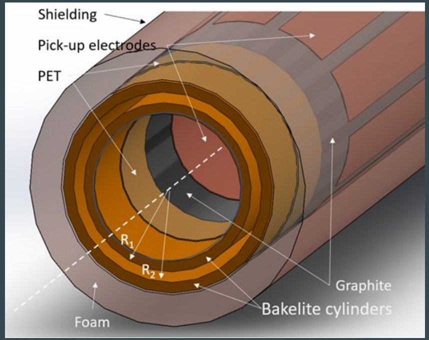
Resistive Cylindrical Chamber

Bakelite electrodes (prototypes with gap 1mm and 0.2mm)

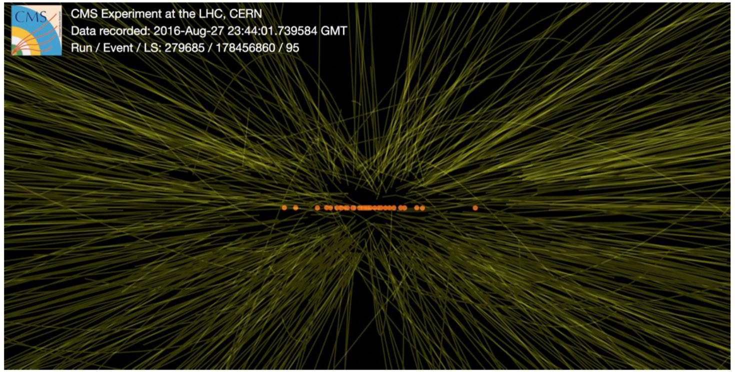
Cylindrical geometry, thin gap, recover efficiency with high pressure

Time resolution 170ps for 0.2mm gap

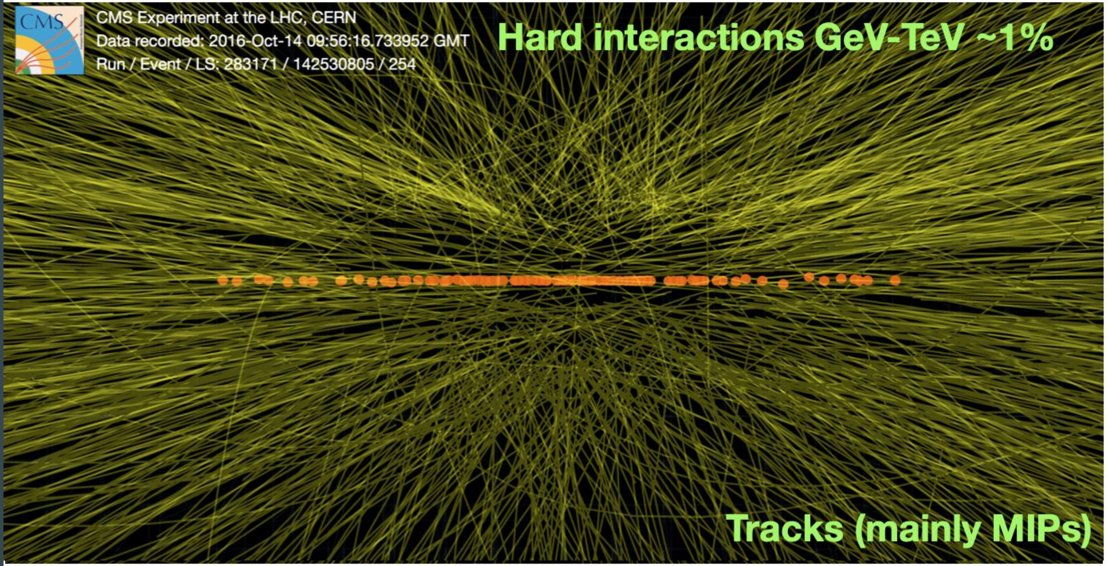
 see FireTalk by A.Rocchi



Time resolution to complement pile-up mitigation wherever



RUN 2: 40-60 interactions per bunch crossing



HL-LHC: 140-200 interactions per bunch crossing