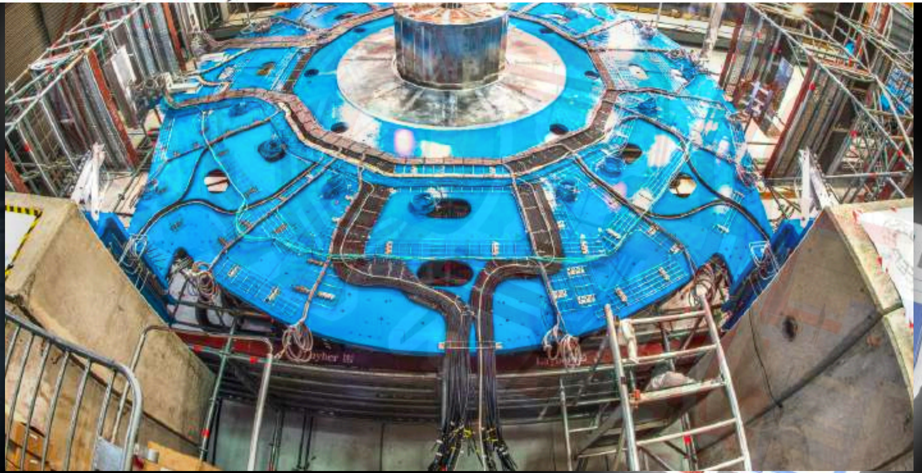
MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

Online High-end Workshop on "Software Tools and Techniques used in EHEP and its Applications”, under Karyashala, Accelerate Vigyan Scheme of SERB, DST (July 12 to 19, 2021)



GASEOUS DETECTORS

Current status, Trends and Applications

Archana Sharma

CERN, Geneva Switzerland

July 19, 2021

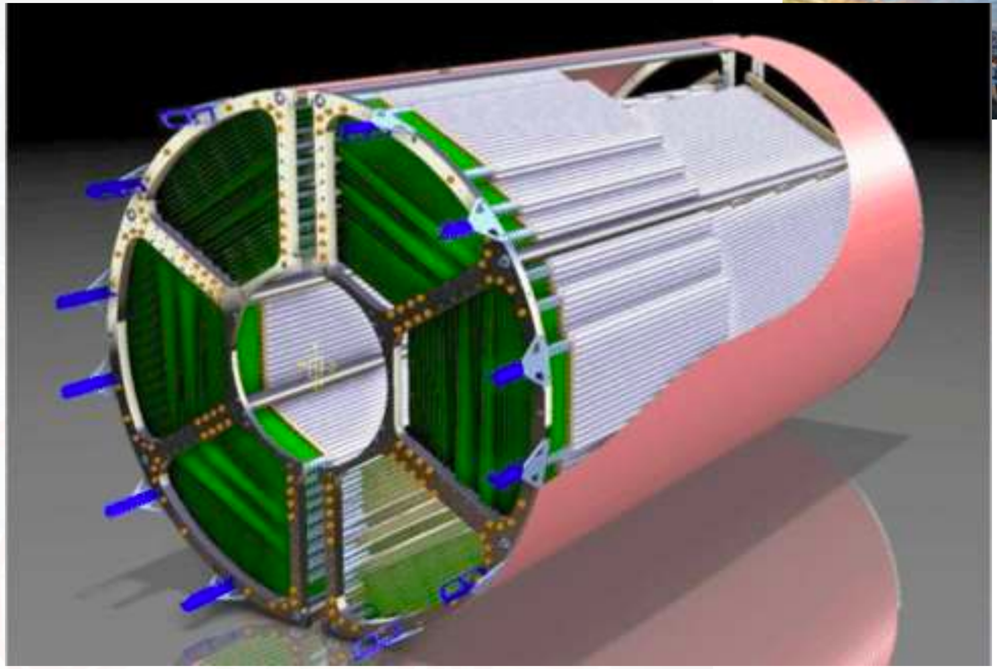
Straw Tube

Metallized tube as cathode, anode wire in center, gas filled tube

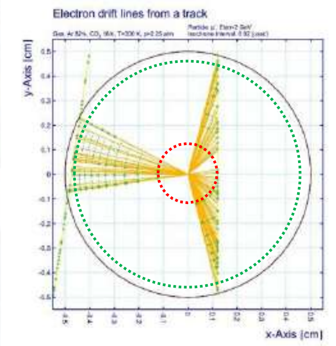
- Robust electrostatic configuration: shielded cell around wire
- Robust mechanical shape if thin-wall tube is pressurized

Specifications:

- Typical X/X0: ~ 0.045 %
- Spatial resolution: ~ 100-150 µm
- Drift time range: ~ 100-200 ns
- Rate limit: few KHz/cm^2
- Staggered multi-layers ® resolve ambiguities in 2D-tracking
- Stereo-layers ® 3D-tracking



Central Straw Tube Tracker with Energy Readout for the PANDA Experiment



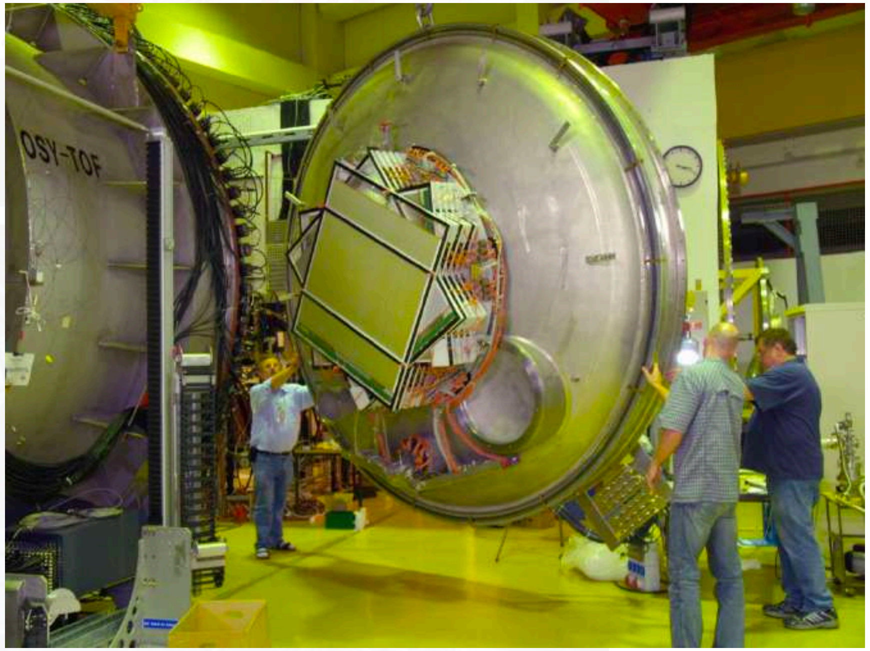
Developments

Thinner film walls to reduce material budget

Smaller diameter

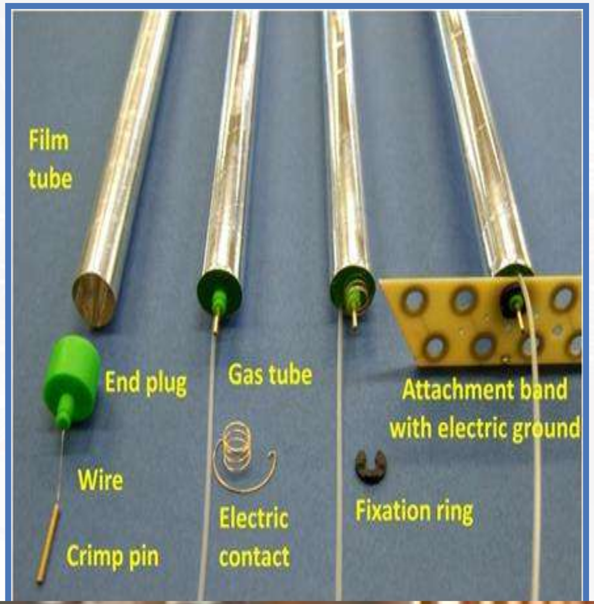
For fast timing and low occupancy

Minimised frame by self-supporting straw layers



Vacuum Straw Tube Tracker for the COSY-TOF Experiment

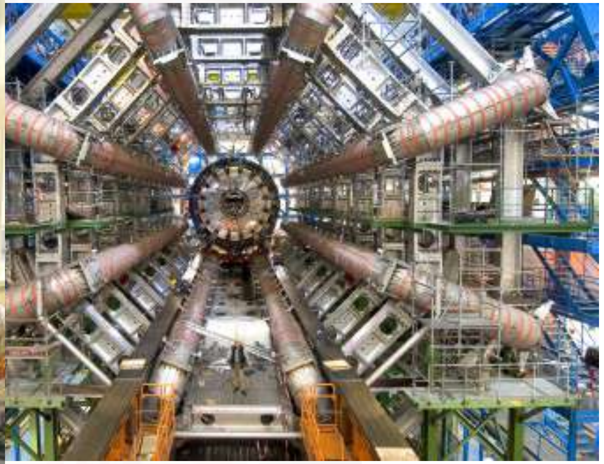
Straw Tube


Film tube
End plug
Gas tube
Attachment band with electric ground
Wire
Electric contact
Fixation ring
Crimp pin

Wire Chambers

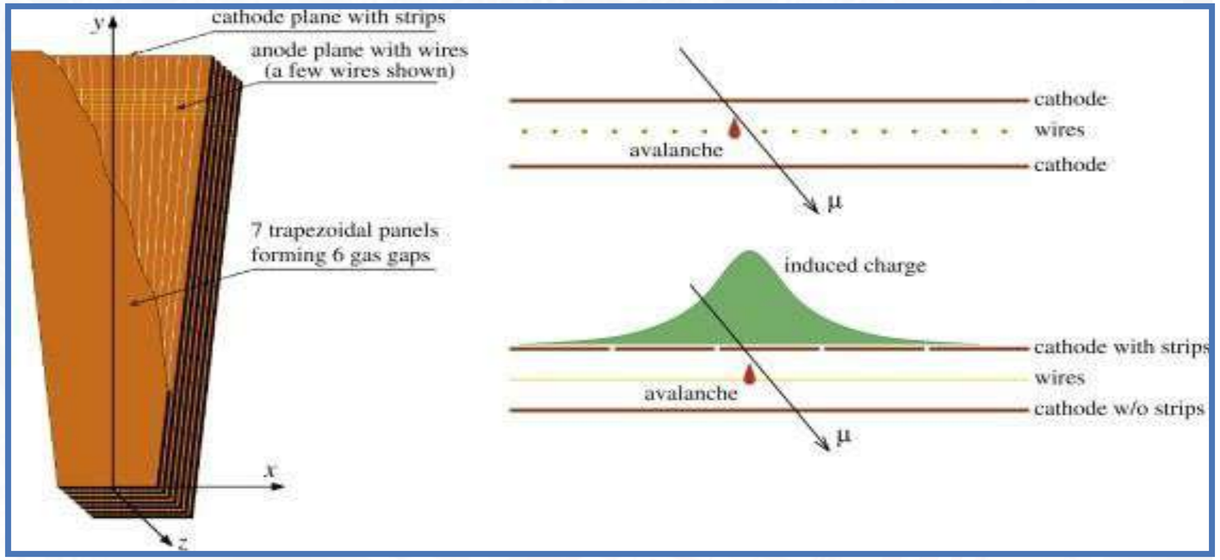
MDTs can also be used for making music!

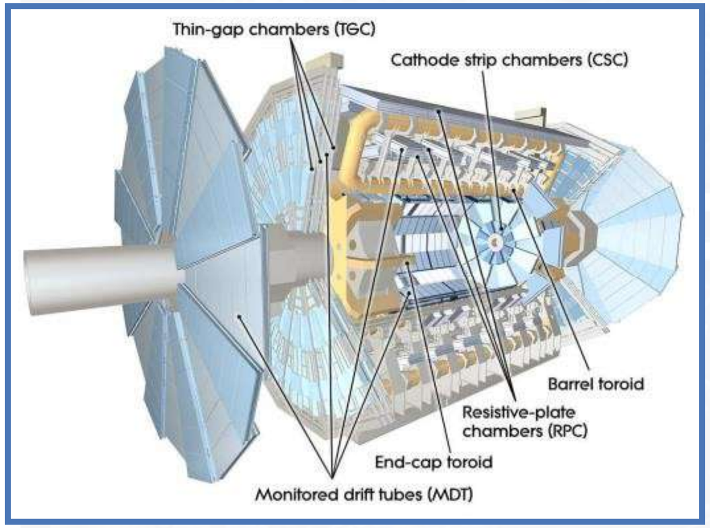
MDT pipe organ made by Henk Tieke from NIKHEF, Amsterdam.

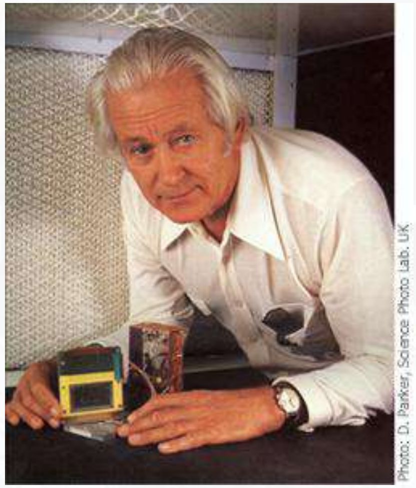


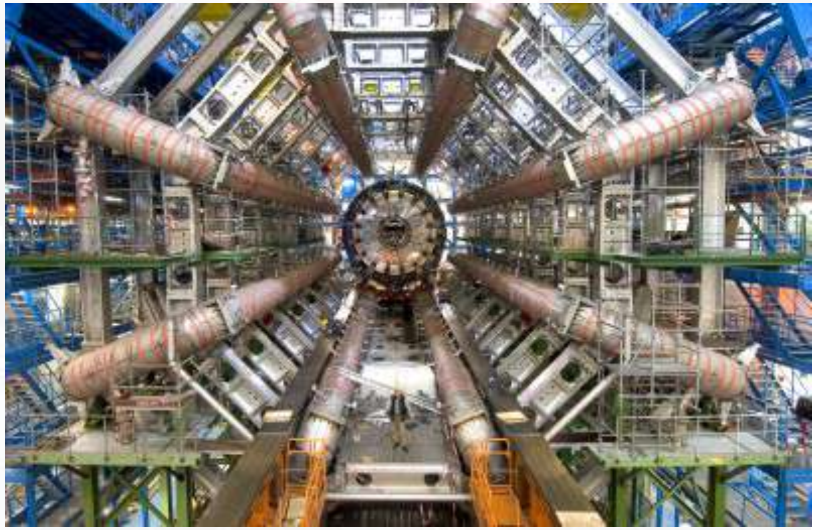
Multiwire Wire Chambers

- Straw Tubes
- Drift Chambers
- Cathode Strip & Thin Gap Chambers
- Many derivatives









Cathode Strip Chamber

- At CMS/ATLAS
- CSC: grid of anode wires and cathode strips
- Upgrade muon system in end caps for HL-LHC: L=5x10^{34} cm^{-2} s^{-1}
- CSC for precise muon tracking and triggering
- CMS: all endcap muon precision chambers are CSC

Specifications:

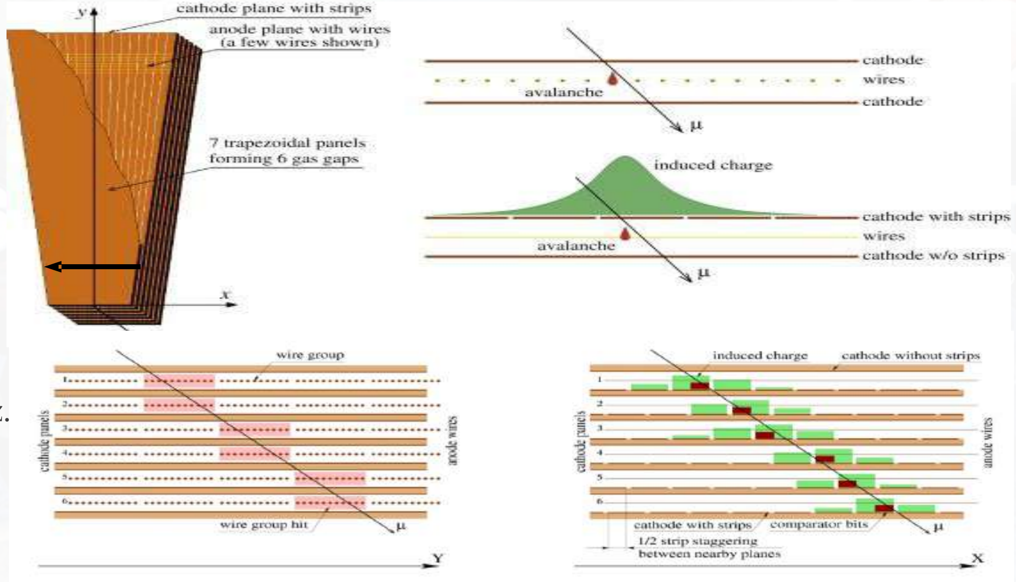
- CSC size: 3.3 x 1.5 / 0.8 m^2 (trapezoidal shape)
- Number of layers: 6 layers per chamber
- Anode-cathode gap: 4.75 mm
- Wire spacing: 3.12 mm
- Readout groups: 5 to 16 wires
- Number wire groups: 210´816
- Cathode strip width: 8-16mm (trapez.
- Number cathode strips: 266´112

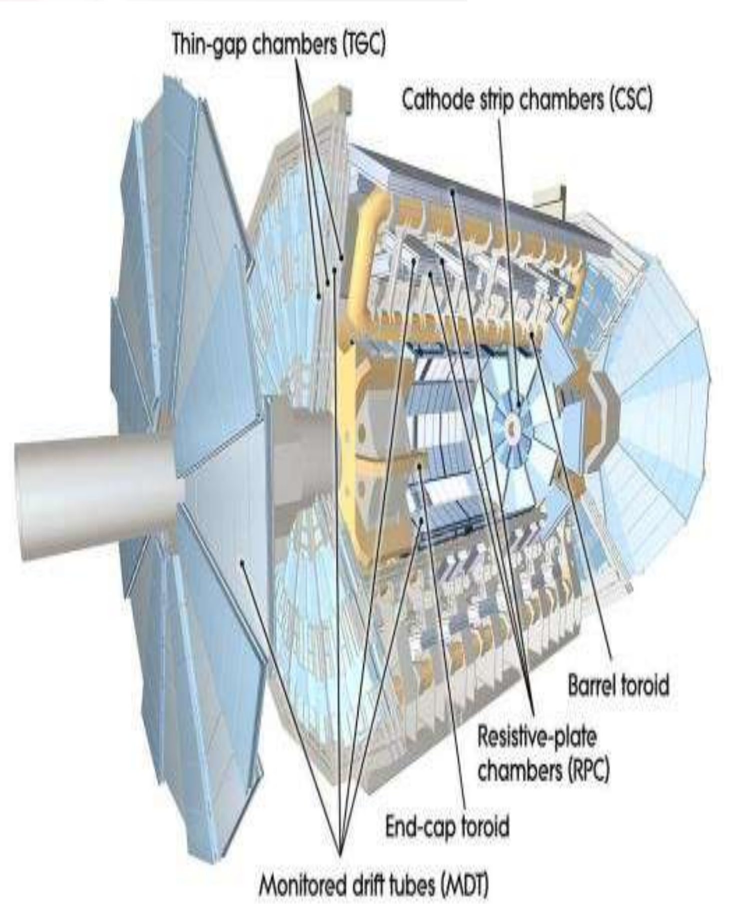
Thin Gap Chamber (TGC): smallest wire to cathode gap

- Small-strip Thin Gap Chambers (sTGC) upgrade the ATLAS muon endcap
- New Small Wheel upgrade: fast trigger (<25 ns) and high precision tracking

Specifications:

- sTGC trapez. size: 3.7 x 2.1 / 0.5 m2
- HV: 2.8 kV
- Gas mixture: CO2 (55%) + n-Pentane
- Wire pitch: 1.8 mm





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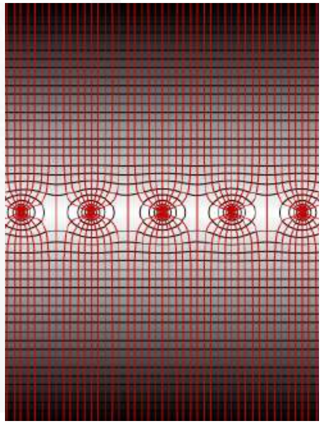
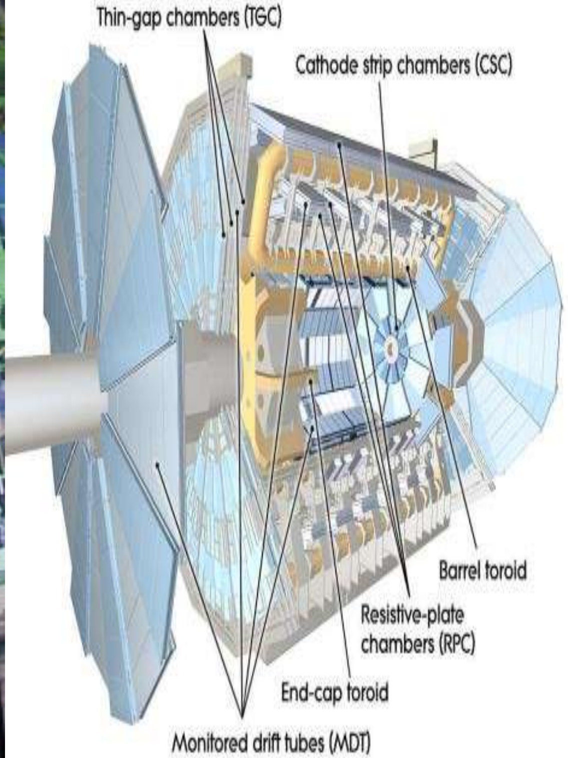
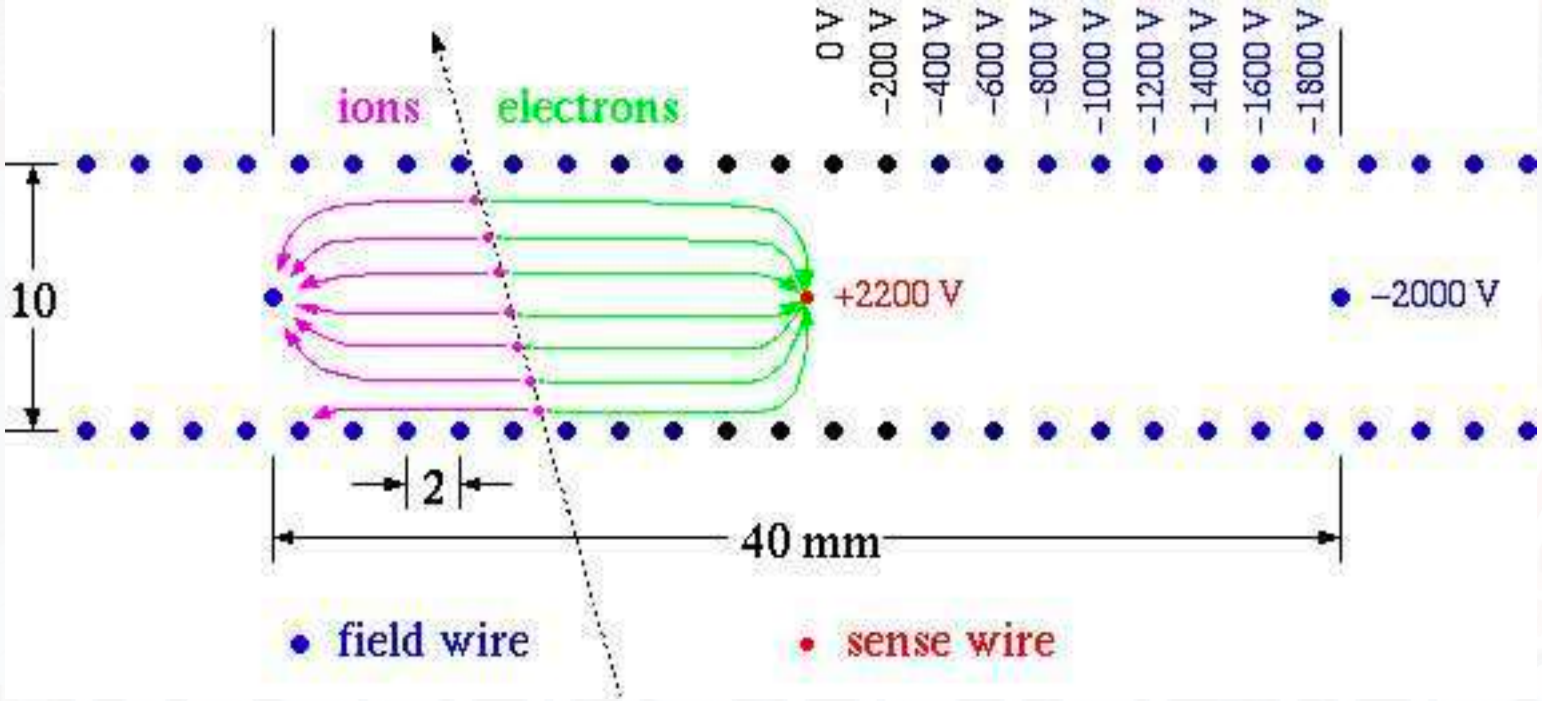




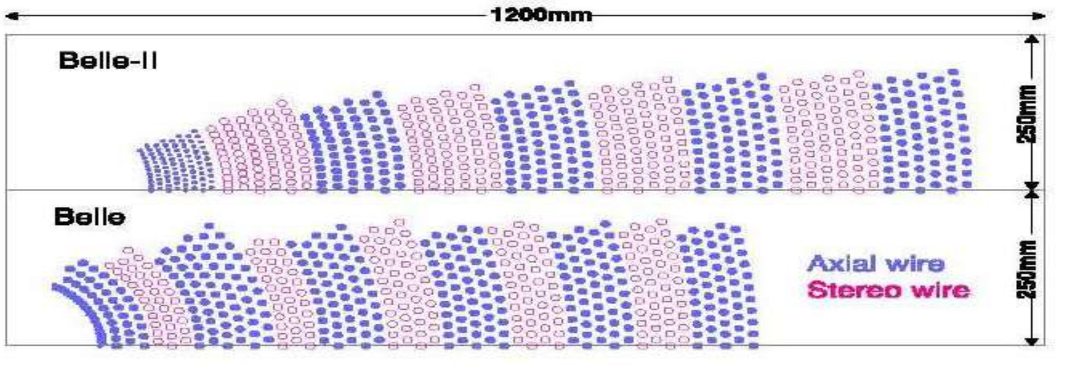
Drift Chamber



Drift Chamber

Belle II CDC at SuperKEKB Example

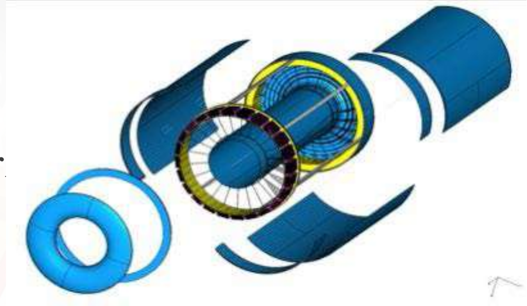
- Drift chamber at “extreme“ luminosity L= 8×1035 cm^{-2} s^{-1}
- e-e+ collider, E » 10.6 GeV
- 1.5 T solenoid B-field
- R = 160 - 1130 mm, 2300 mm length
- 14k anode wires (30µm W(Au), 129µm Al cathode wires
- 56 axial and stereo layers
- Drift gas He (50%) + C2H6
- s(pt) / pt ~ 0.1 %



IDEA(Planned) at FCC-ee

IDEA: full stereo, high resolution, ultra-light drift chamber

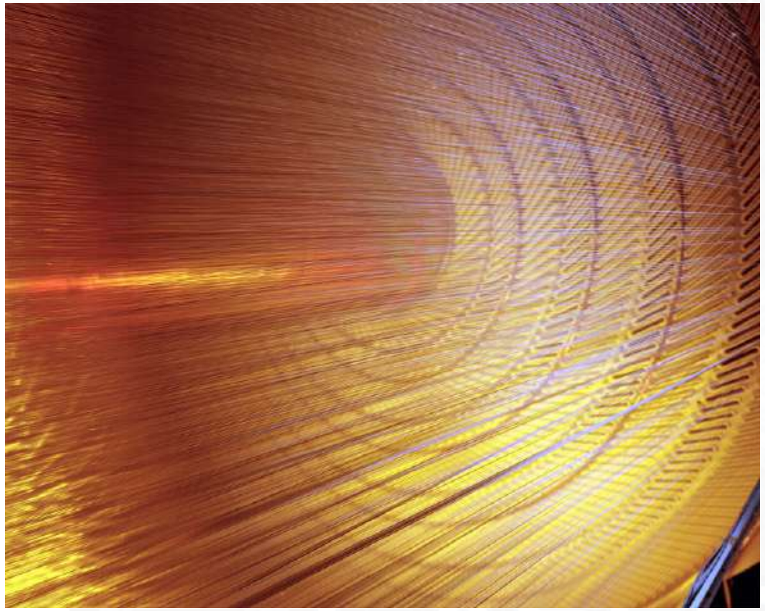
- 4000 mm length, 350-2000 mm radius in ~ 2T solenoid B-field
- 14 SL × 8 layers, 24 j-sectors
- 56k sense wires, 20 µm diameter W (-Au)
- ~290k field and guard wires, 40/50 µm diameter
- He(90%) + i-C4H10

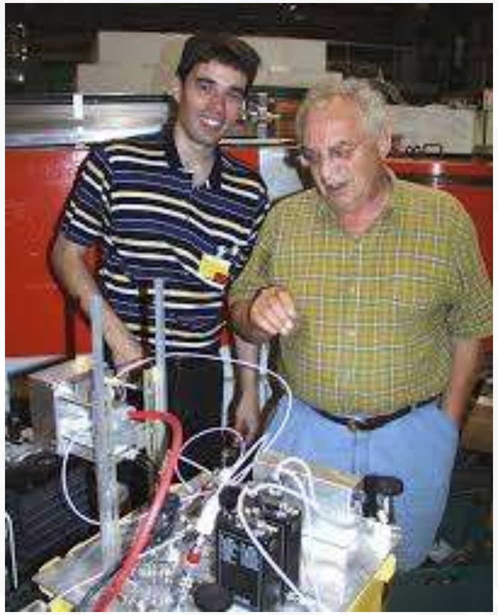


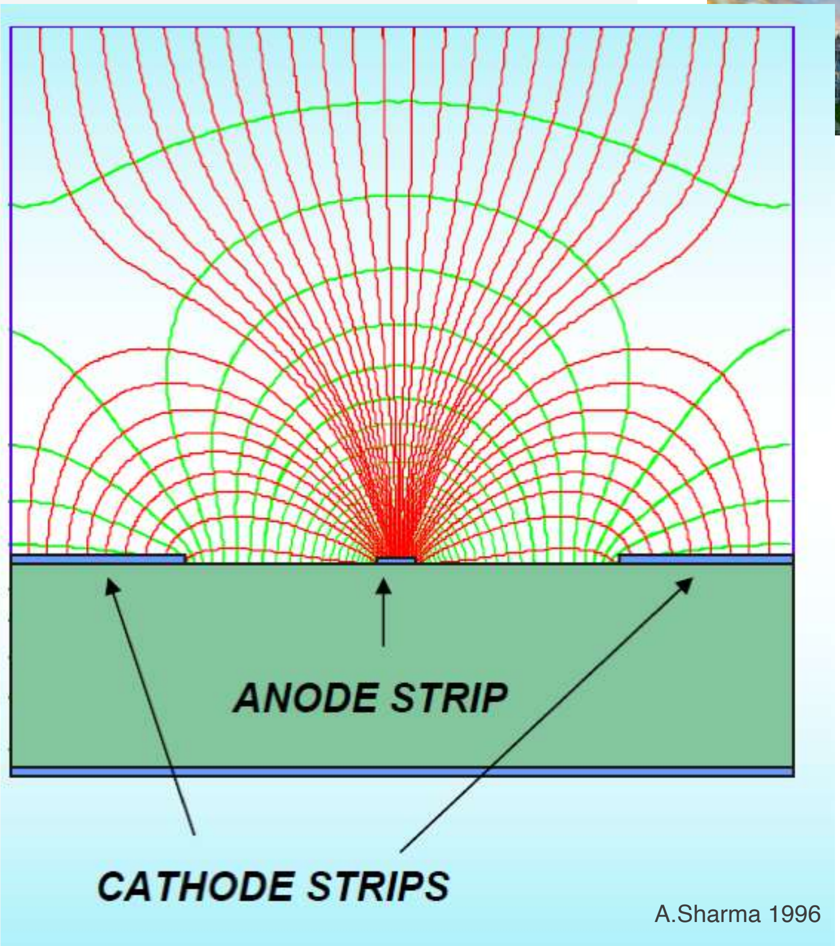
Mechanics design

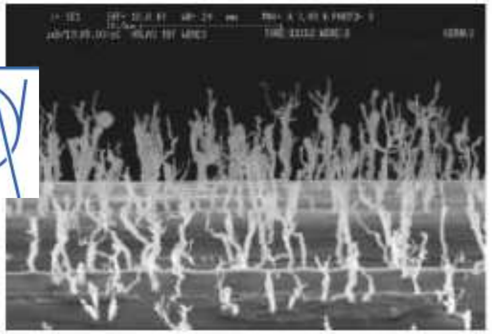
Construction of high granularity and high transparency and novel wiring method (MEG-II wiring robot technique), feedthrough-less. The wire support mechanical structure separated from gas volume envelope.

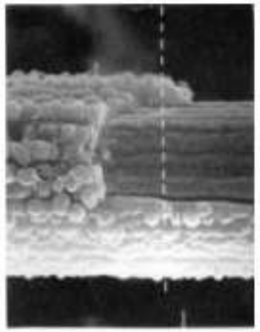
Wire chambers to microstrip..

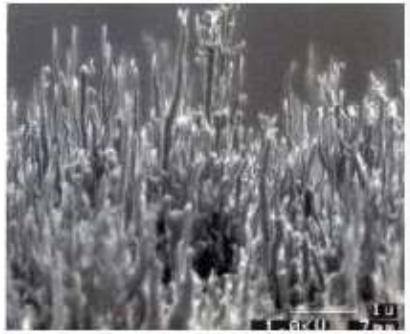


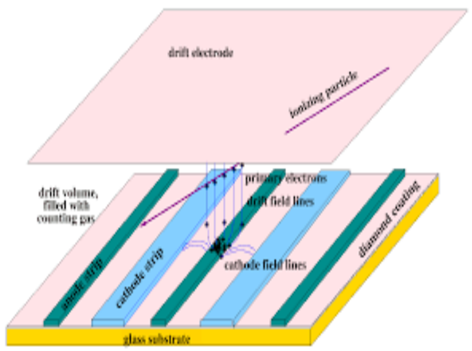


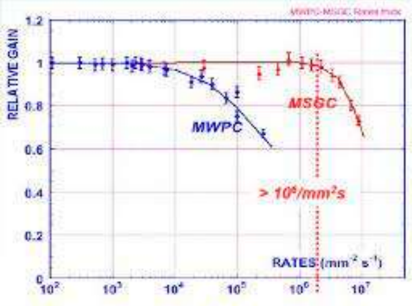












MPGD: GEM and Micromegas 1996-1997

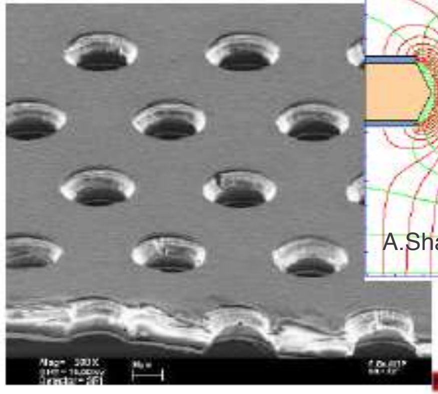
Gas Electron Multiplier (GEM)

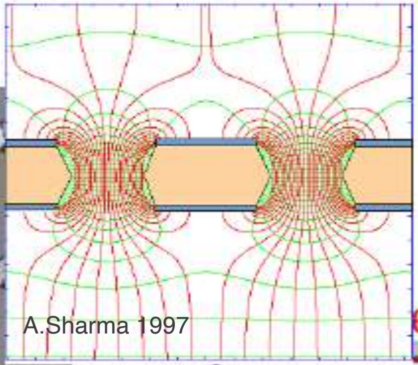
F. Sauli

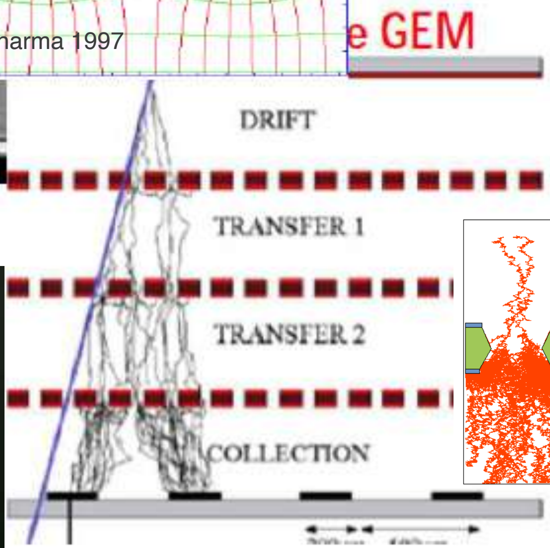
MICROMEGAS

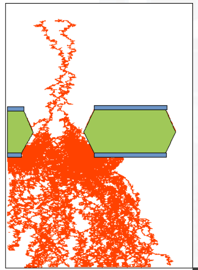
G. Charpak

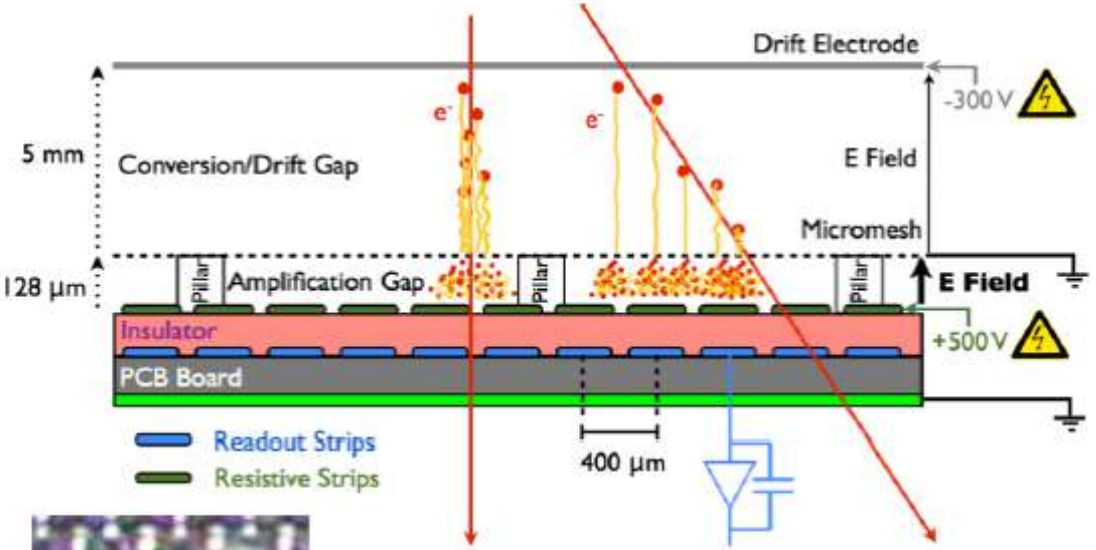
I. Giomataris

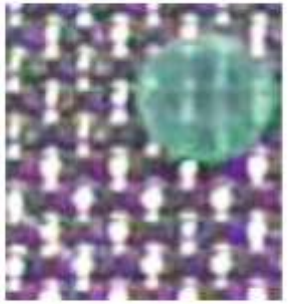












Biagi
Veenhof
And many others

MICROMEGAS : ATLAS

https://cds.cern.ch/record/2742986/files/ATL-MUON-PROC-2020-015.pdf

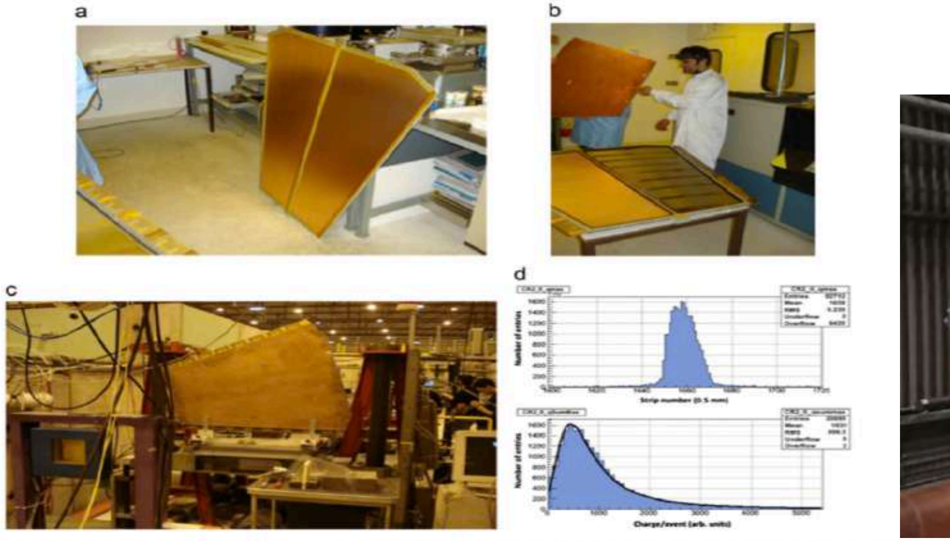


Fig. 38. (a) A large area module made with resistive Micromegas by the MAMMA collaboration. (b) Assembly of large resistive micromegas only the right half is instrumented. (c) Large resistive micromegas chamber in H6 test beam at CERN (d) hit distribution (on top) showing the beam profile and the charge distribution (bottom), adding all charges, showing essentially a Landau shape.

Large-Area Micromegas for ATLAS NSW Upgrade

Resistive MM for ATLAS NSW Muon Upgrade:

Standard Bulk MM suffers from limited efficiency at high rates due to discharges induced dead time
Solution: Resistive Micromegas technology:

- Add a layer of resistive strips above the readout strips
- Spark neutralization/suppression (sparks still occur, but become inoffensive)

Mechanical assembly of a sector. The sTGC wedges are visible on the outside, while the Micromegas double wedge is sandwhiched in between them.

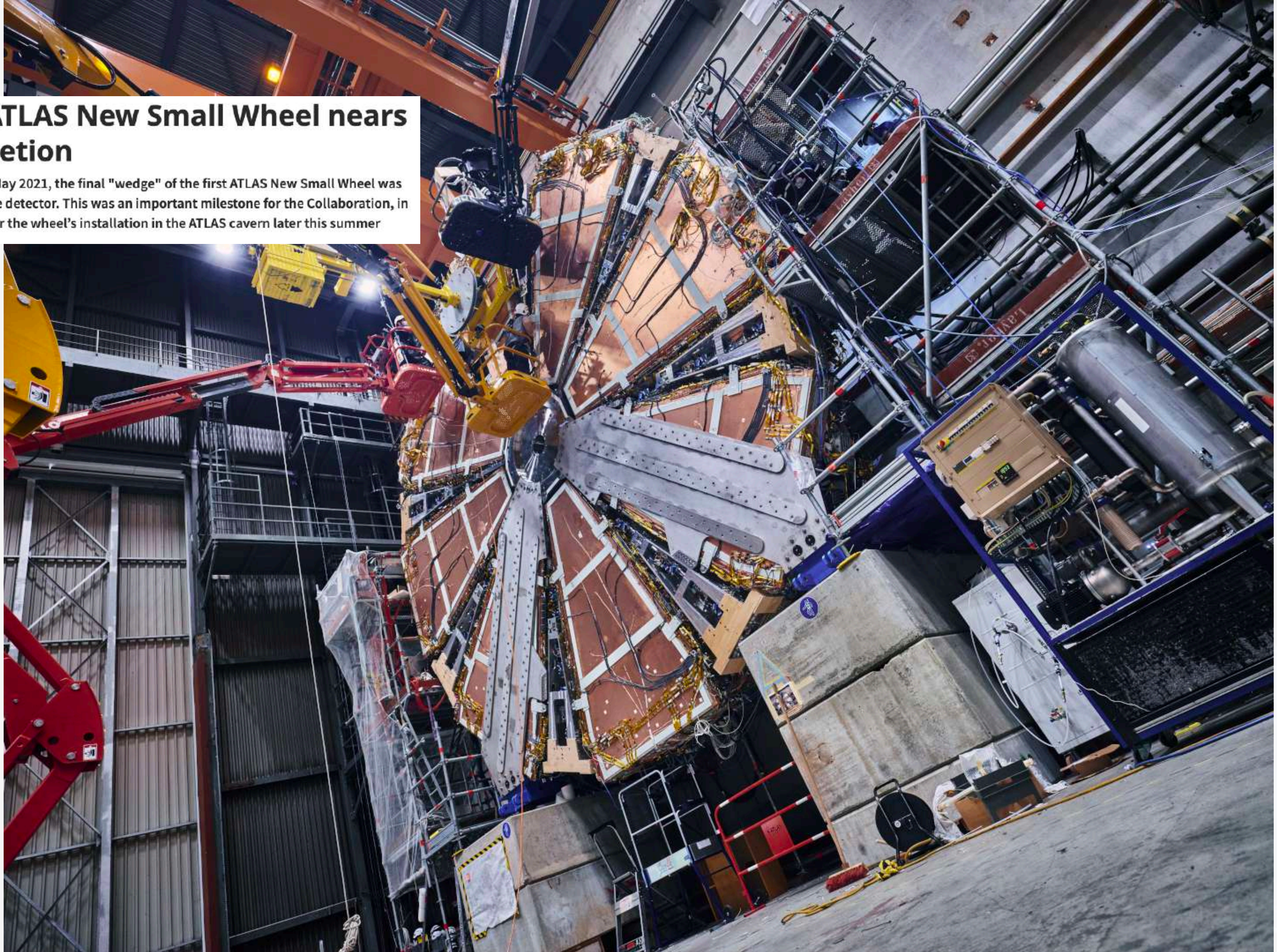
ATLAS HL-LHC Muon System: Very Forward Muon Tagger

For ATLAS muon tagger (High eta muon detector)

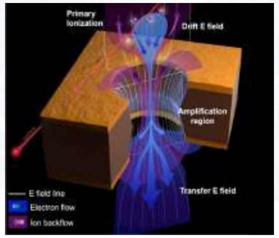
- Resistive materials & related architectures (μPIC, μ-RWELL, RPWELL, resistive MM)
- Pixelated Restitive MM Studies for high rates (~10's MHz/cm^2):

First ATLAS New Small Wheel nears completion

On Friday 28 May 2021, the final "wedge" of the first ATLAS New Small Wheel was installed in the detector. This was an important milestone for the Collaboration, in preparation for the wheel's installation in the ATLAS cavern later this summer



CMS Large-Area GEMs GE11 (GE2/1, ME0) for HL-LHC Upgrade



GE21 Detector System

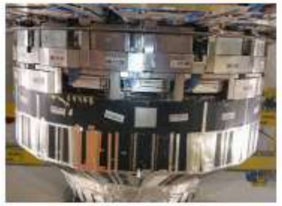
- 72 chambers arranged in 2 layers installed
- On-chamber and off-chamber
  - 4 triple GEM modules per chamber
- 20^0 Chambers, layout similar to GE1/1, but covering much larger surface. (1.62<h<2.43)
- hit rate < 2 kHz/cm² (GE1/1 was up to 5 kHz/cm²)

ME0 Detector System

- 36 Stacks 6 layers each
- 20^0 Stacks, Module Size comparable with GE1/1 chamb but covering high eta region (2<h<2.8)
- Background ~ 10^2 higher that GE2/1, very demanding from performance point of view

The GE1/1 project

N. Pozzobon 2019 JINST 14 C11031
JINST 15 (2020) P05023



BIRTH OF GE11 PROJECT

NIMA 972 (2020) 164104

GE11 proto. II

GE11 proto. IV

GE11 proto. VI - VII

SLICE TEST INSTALLATION AND COMMISSIONING

2009 — 2017

GE11 proto. I

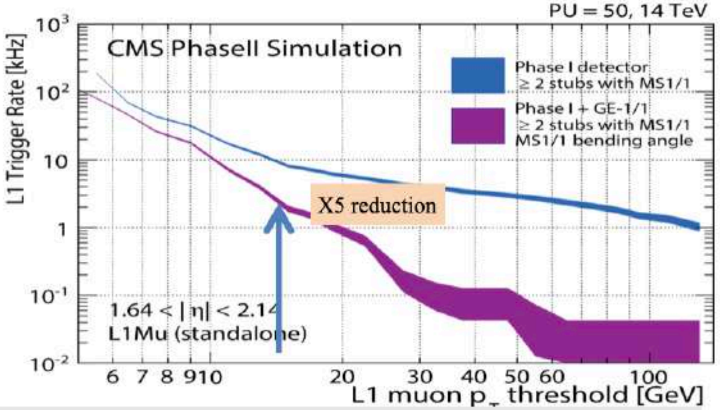
GE11 proto. III Mechanical stretching

GE11 proto. V

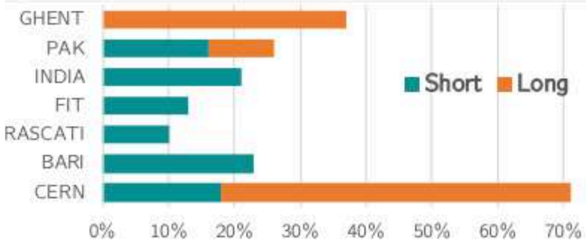
DAQ/ electronics prototyping

Large improvement from GE1/1 and GE2/1 stations

✓ Requirement precise $\Delta\phi$ meas.→spatial resolution



maintain 15 GeV online threshold, keep < 5 kHz rate, high efficiency



completed!

NEGATIVE ENDCAP INSTALLED!

POSITIVE ENDCAP INSTALLATION

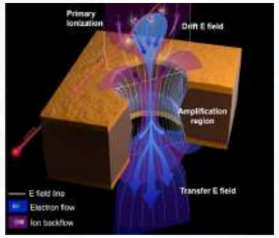
Oct-2017 — Dec-2018 — Jul-Oct 2019 — Jul-Sep 2020

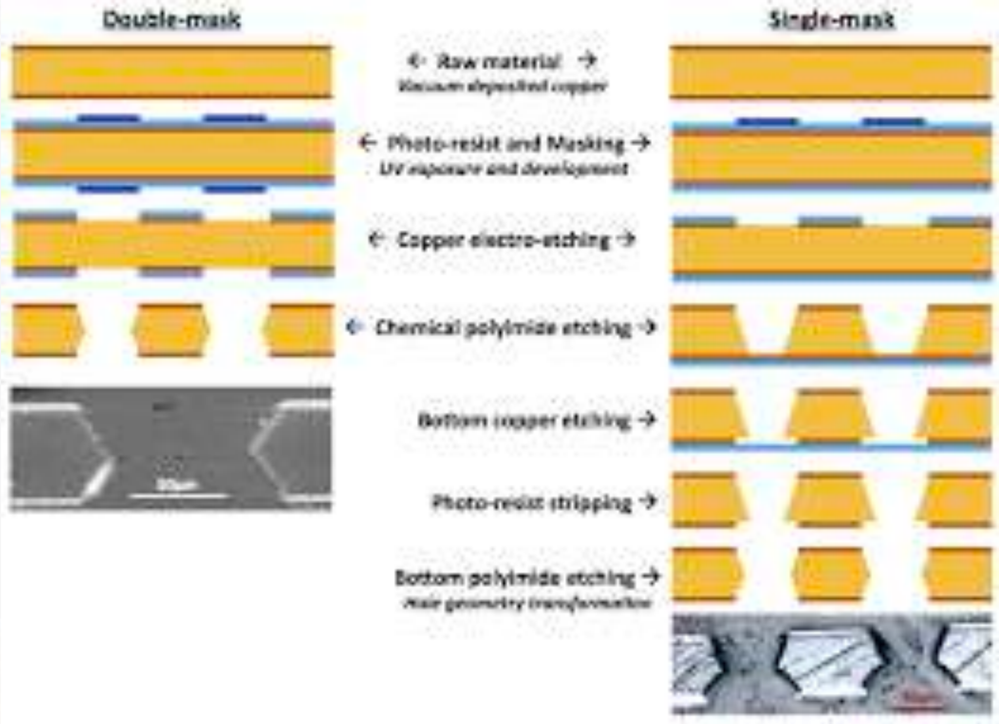
DETECTOR MASS PRODUCTION

SUPERCHAMBER PRODUCTION

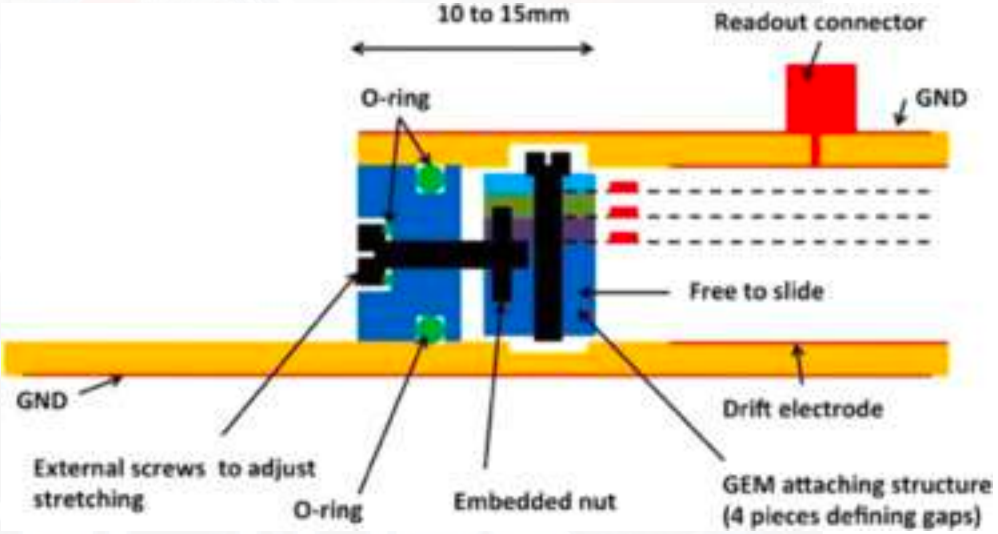
F.Simone; F. Fallavolita

CMS Large-Area GEMs GE11
Major Progress





Single mask



No Glue

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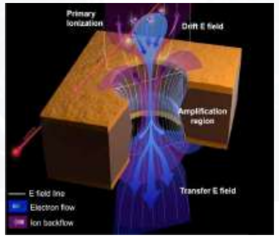

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project

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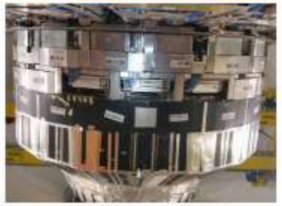

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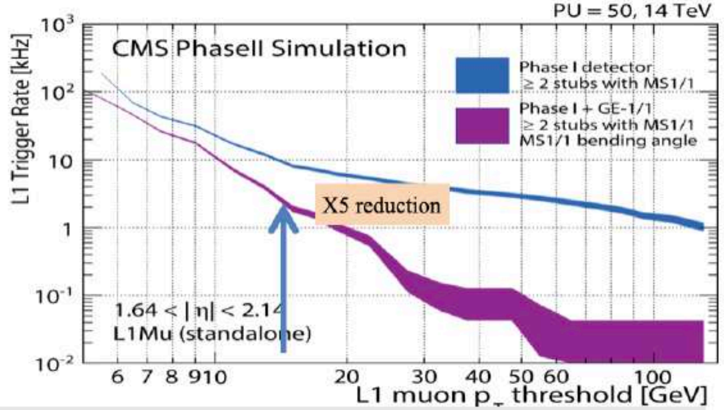
- GE11 proto. II
- GE11 proto. III Mechanical stretching
- GE11 proto. IV
- GE11 proto. V
- GE11 proto. VI - VII
- DAQ/ electronics prototyping
- SLICE TEST INSTALLATION AND COMMISSIONING
- 2017

GE11 TDR approved 30.9.2015

Large improvement from GE1/1 and GE2/1 stations

✓ Requirement precise Δϕ meas.→spatial resolution



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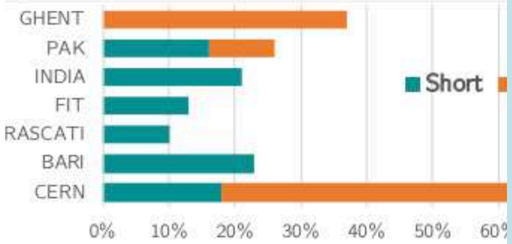

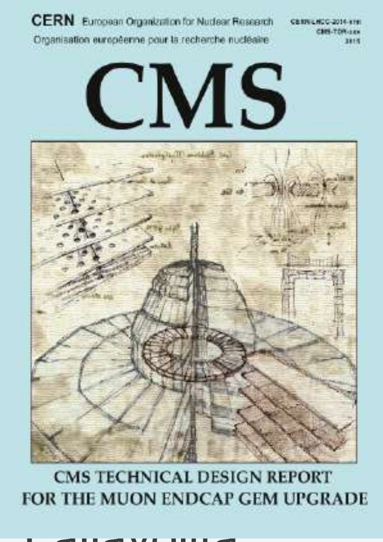

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Oct-2017 — Jul-Oct 2019 — Jul-Sep 2020

DETECTOR MASS PRODU[CTION] … [CHA]MBER PRODUCTION

iW… …ent University

F.Simone; F. Pallavolta

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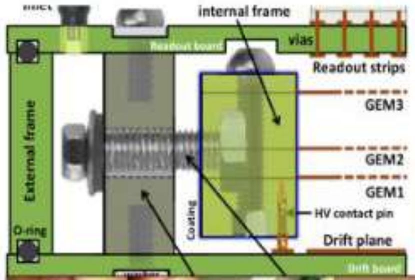
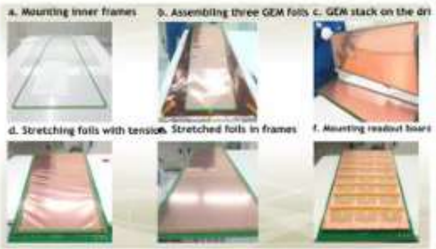
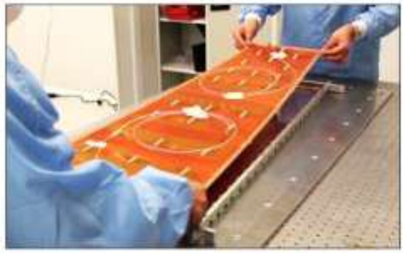
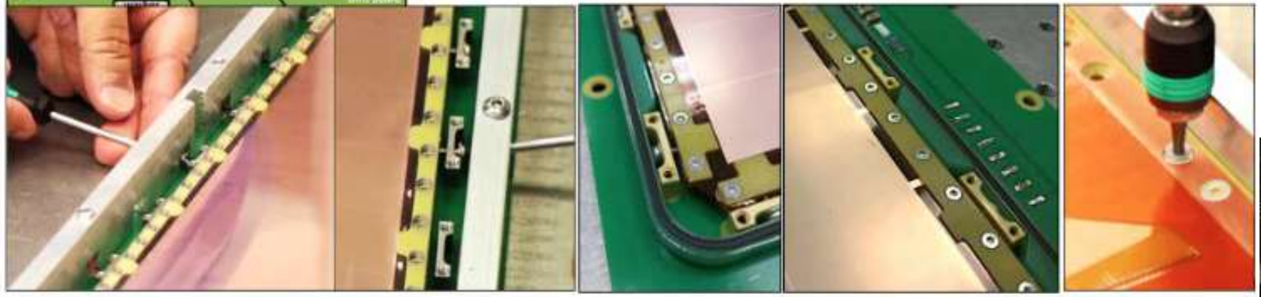


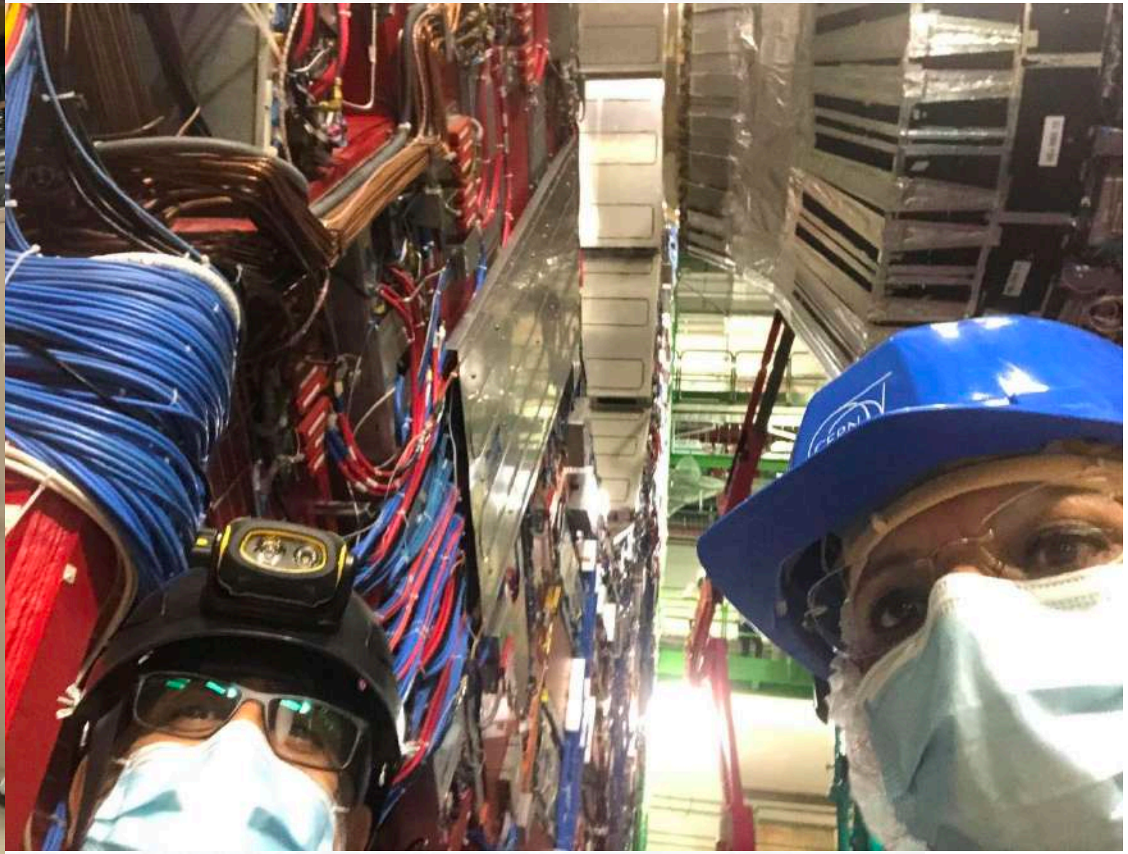


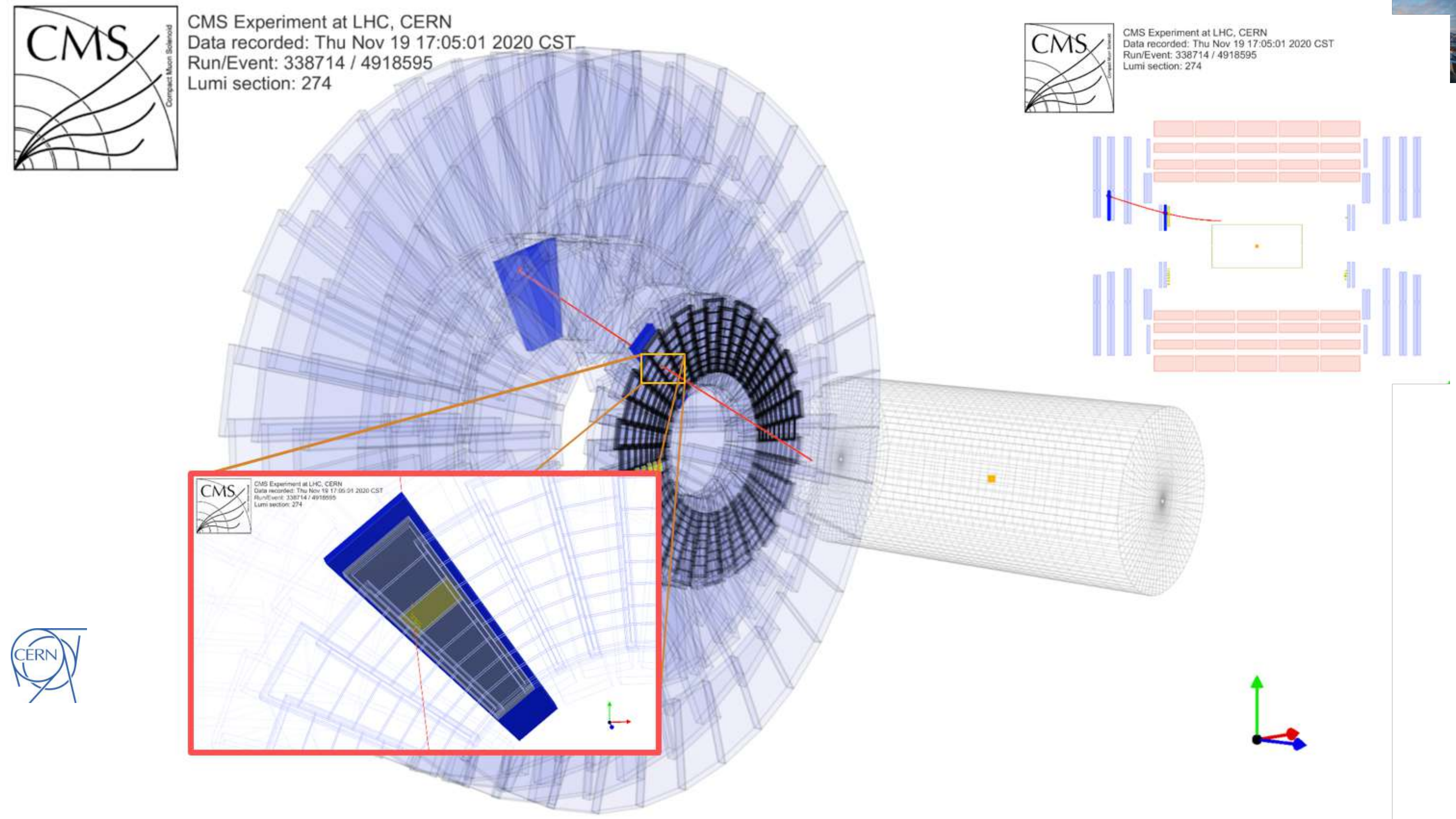





Gent, Belgium
Chandigarh, India
Bari, Italy
NCP Pakistan
CERN, Switzerland
Delhi, India
SINP, Kolkata
Aachen, Germany
Frascati, Italy
Florida, USA

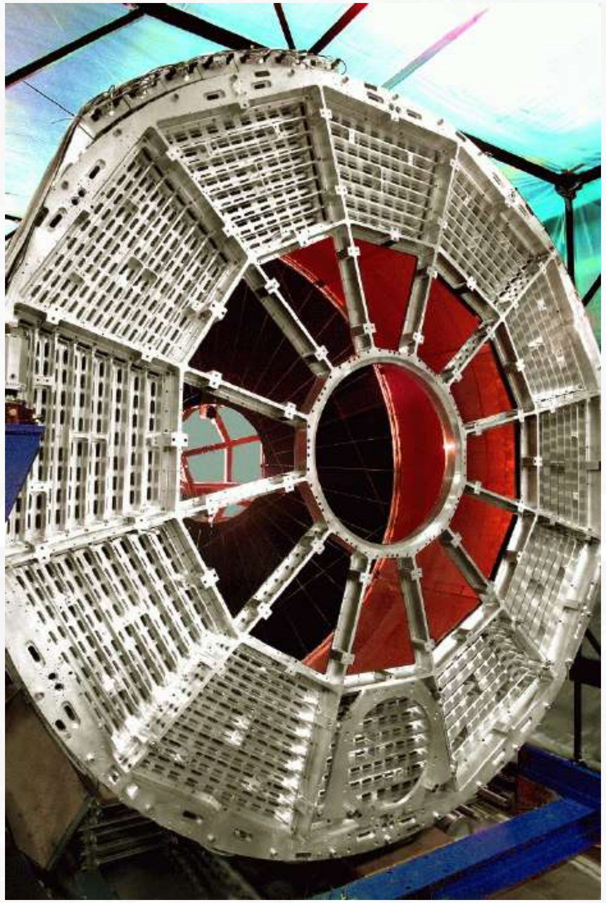

Brun-Mech
CMU 20t
HHLPR 585
RPC


CERN

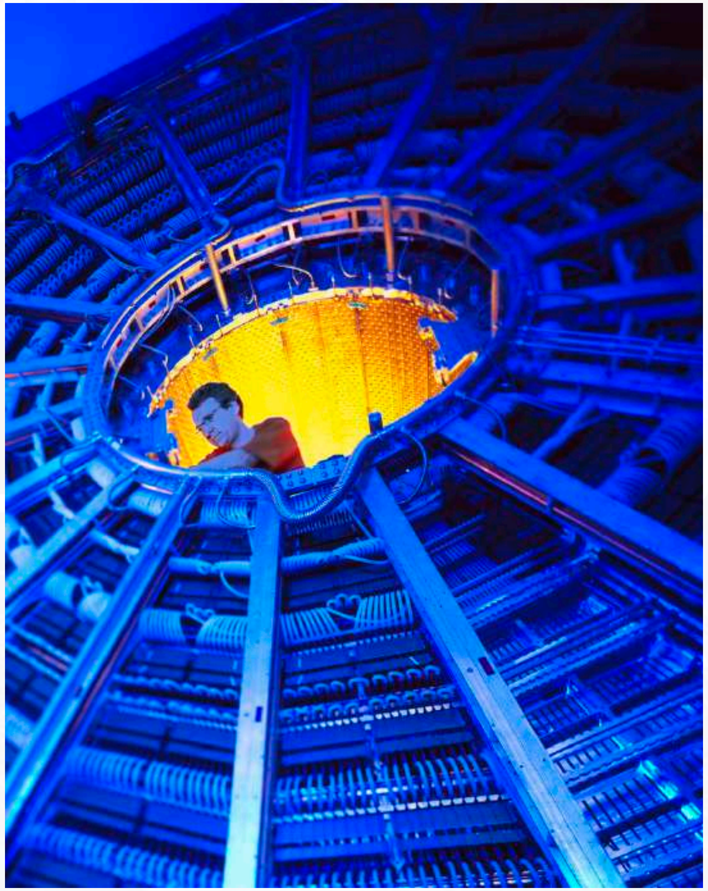

CMS
Compact Muon Solenoid
CMS Experiment at LHC, CERN
Data recorded: Thu Nov 19 17:05:01 2020 CST
Run/Event: 338714 / 4918595
Lumi section: 274
CERN

Modern TPCs

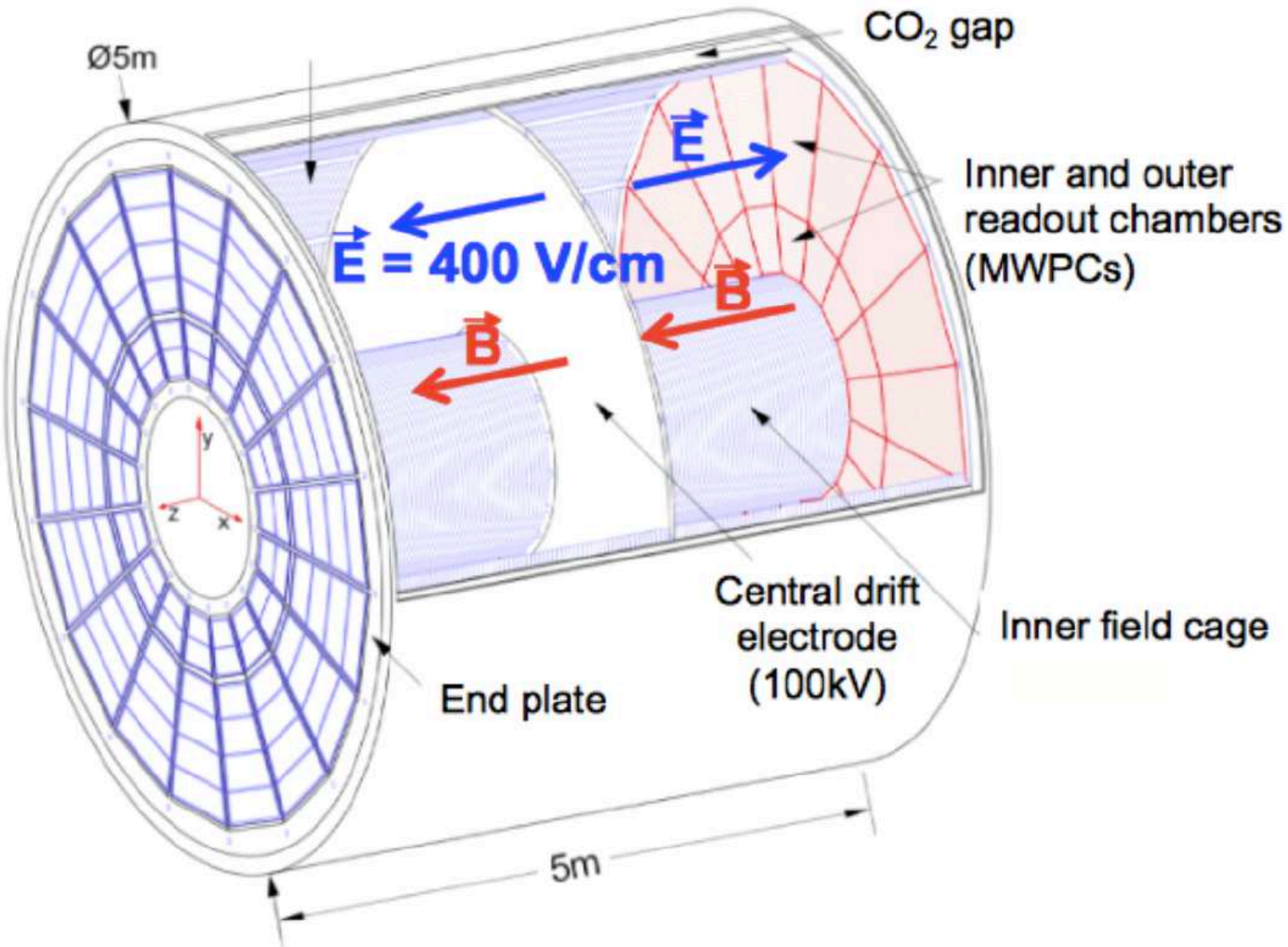
STAR



ALICE



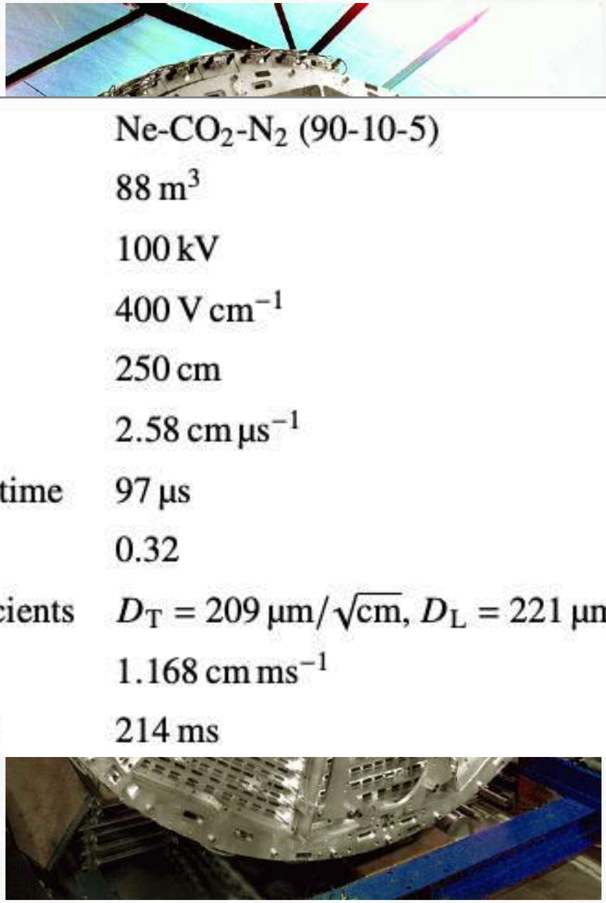
ALICE TPC IN NUMBERS



- Length 5 m
- Diameter 5 m
- Active volume 88 m^3
- B = 0.5 T
- Readout area 32 m^2
- Channels ~570 000

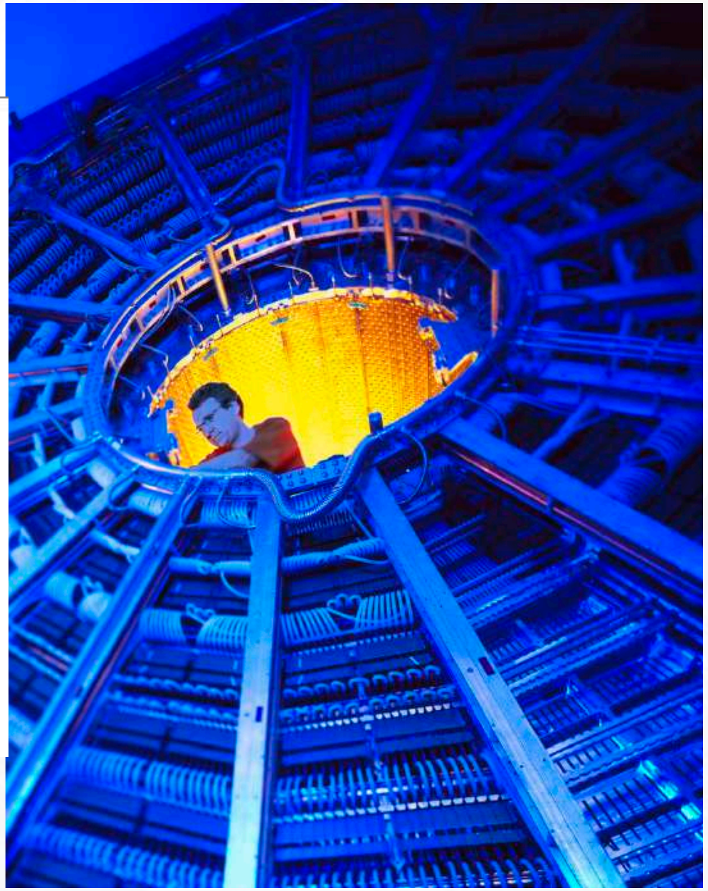
Modern TPCs

STAR



Detector gas	$Ne\text{-}CO_2\text{-}N_2$ (90-10-5)
Gas volume	$88\ m^3$
Drift voltage	100 kV
Drift field	$400\ V\ cm^{-1}$
Maximal drift length	250 cm
Electron drift velocity	$2.58\ cm\ \mu s^{-1}$
Maximum electron drift time	97 µs
$\omega\tau$ ($B = 0.5$ T)	0.32
Electron diffusion coefficients	$D_T = 209\ \mu m/\sqrt{cm}$, $D_L = 221\ \mu m/\sqrt{cm}$
Ion drift velocity	$1.168\ cm\ ms^{-1}$
Maximum ion drift time	214 ms

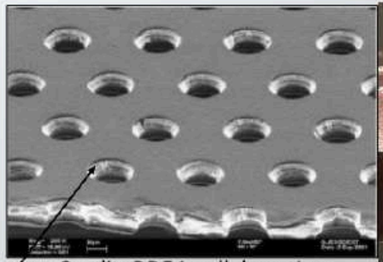
ALICE



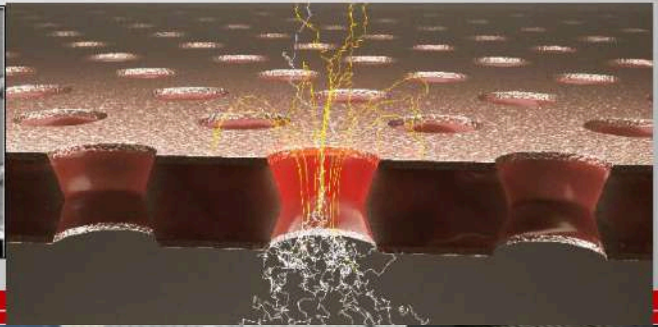
Replacement of the present MWPC-based readout chambers by detectors allow continuous operation without active ion gating

ALICE TPC Upgrade

- Novel Micro Pattern Gaseous Detectors (MPGD) – RD51 collaboration (http://rd51-public.web.cern.ch/rd51-public/)
- Result of a major R&D effort: Gas Electron Multiplier(GEM)
- A thin, metal-clad Kapton foil, chemically pierced with a high hole density
- Difference of potential between top and bottom side, high electric field inside the holes
- Electrons drift into the holes and multiply (avalanche), the GEMs can be cascaded



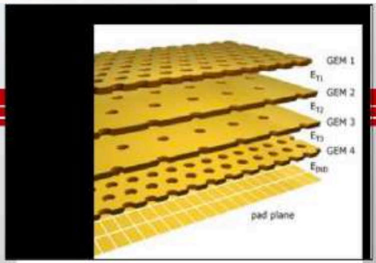
$50\mu m$ Credit: RD51 collaboration

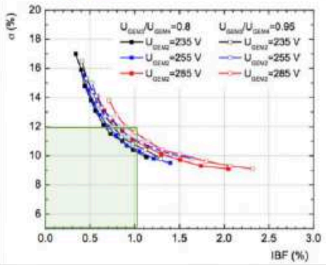


Erik Brücken, Timo Hildén: Garfield simulation

Readout Chambers

- Inner and Outer Readout Chambers (IROCs and OROCs)
- The result of several years of extensive R&D lead to quadruple GEM stacks, which have proven to provide sufficient ion blocking capabilities
- Upper limit of 1% for the fractional ion backflow(IBF)
- Preserve the intrinsic dE/dx resolution and keep the space-charge distortions at a tolerable level
- Total effective gain ~ 2000
- Position 1&4: Standard GEMs ($140\mu m$ pitch)
- Position 2&3: Large pitch ($280\ \mu m$ pitch)
- Optimizing the energy resolution and IBF

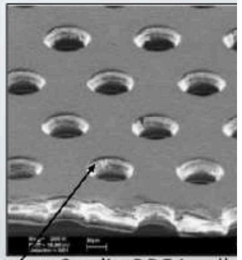




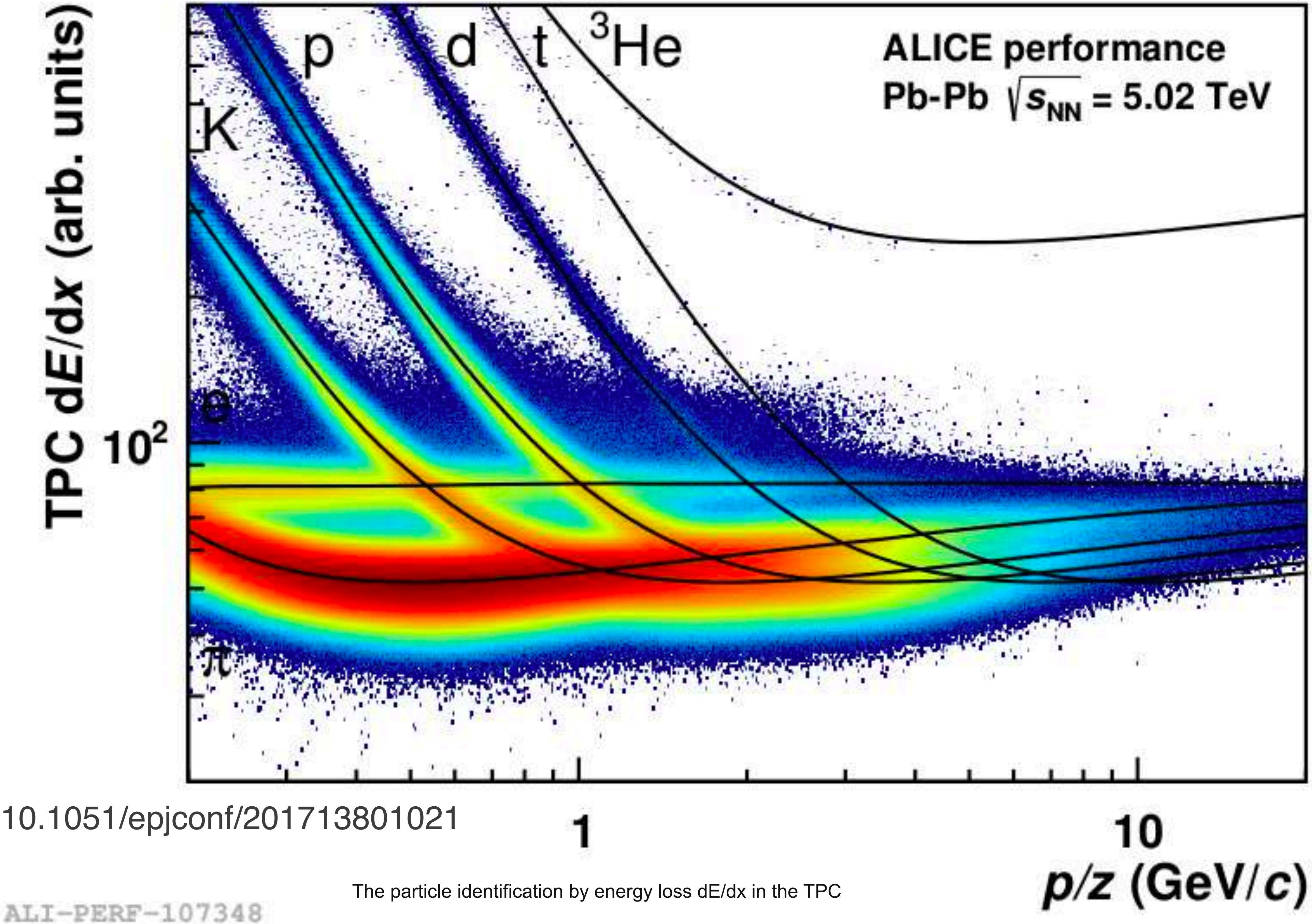
Reference: Technical Design Report for the Upgrade of the ALICE Time Projection Chamber, The ALICE Collaboration, 2014.

A

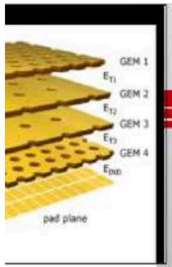
- Novel Micro Patte
- Result of a major
- A thin, metal-clad
- Difference of pote
- Electrons drift int

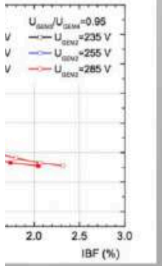


50μm Credit: RD51 colla



The particle identification by energy loss dE/dx in the TPC

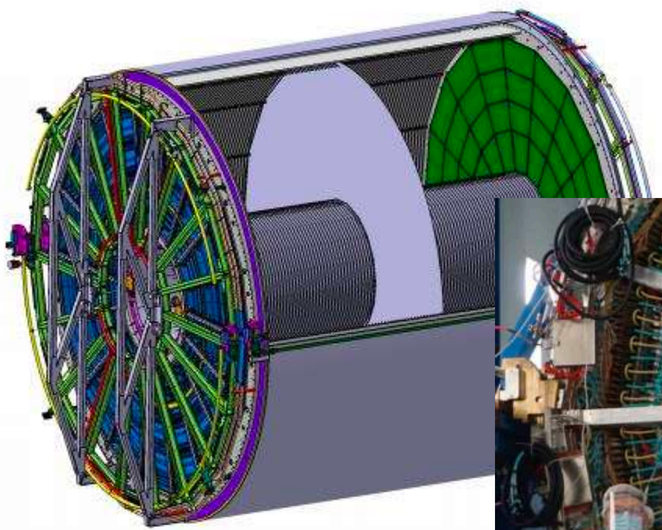




E Collaboration, 2014.

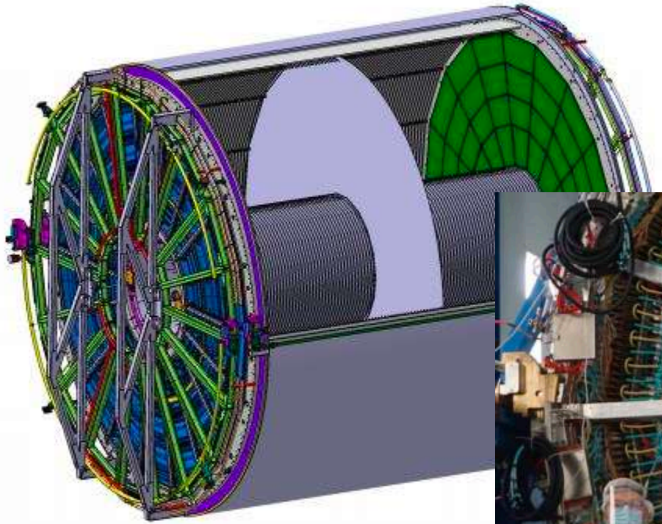
DO - 10.1051/epjconf/201713801021

ALICE TPC Upgrade



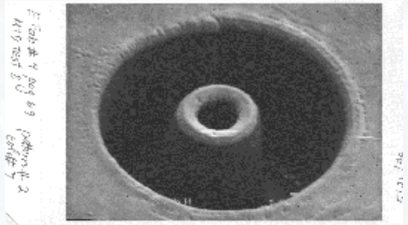
ALICE TPC Upgrade

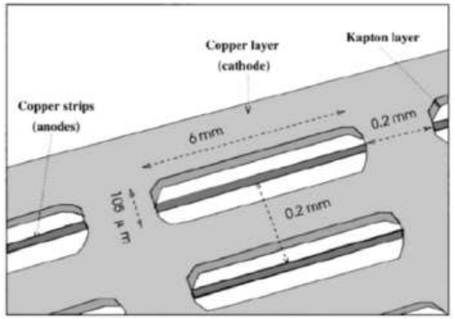
ALICE TPC collaboration et al 2021 JINST 16 P03022



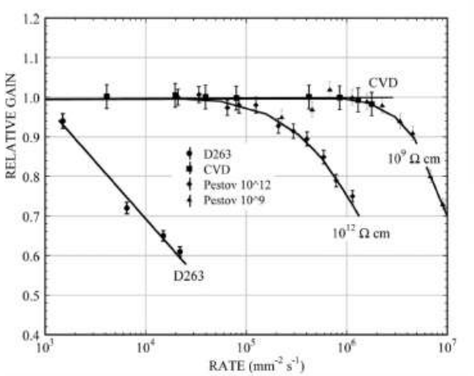
A true 3-dimensional tracking device
recording many signals along the trajectory of each particle
GEM-based detectors. The new devices, together with new readout electronics that feature a continuous readout mode, will allow to record all tracks produced at collision rates of 50 kHz in the LHC Pb-Pb system.

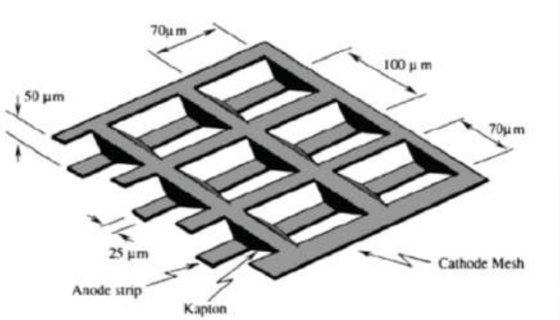
Micro Pattern Gas Detector Family

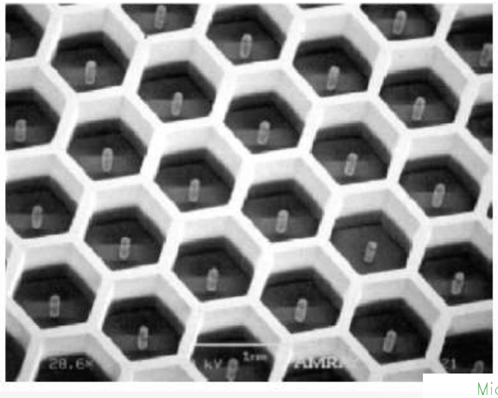


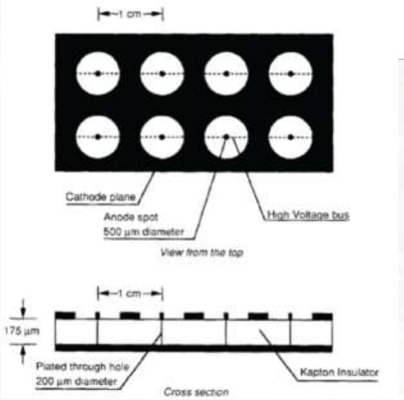


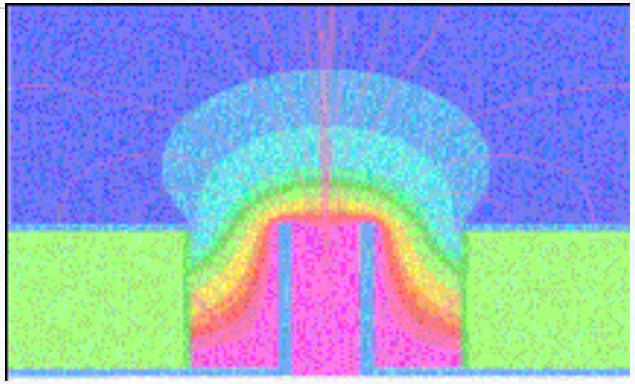
High-Rate Capability, High Gain, High Space Resolution, Good Time Resolution, Good Energy Resolution, Excellent Radiation Hardness, Good Ageing Properties, Ion Backflow Reduction, Photon Feedback Reduction

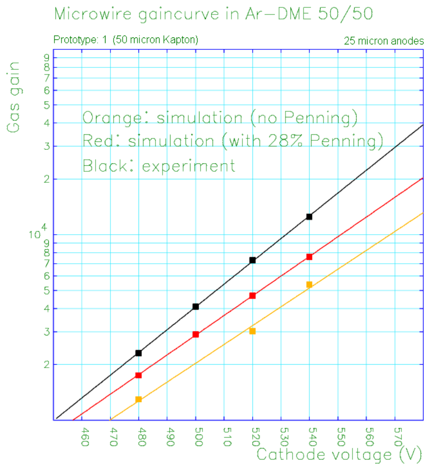




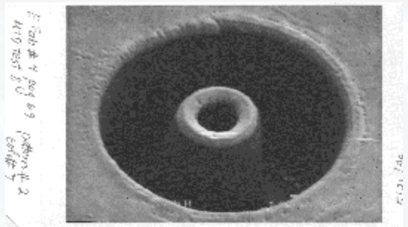




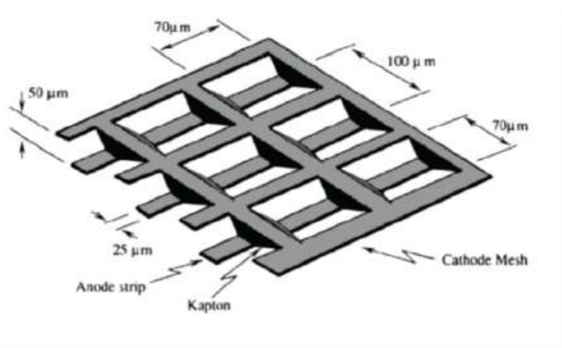




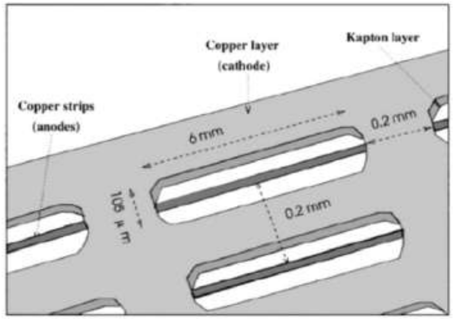
Micro Pattern Gas Detector Family

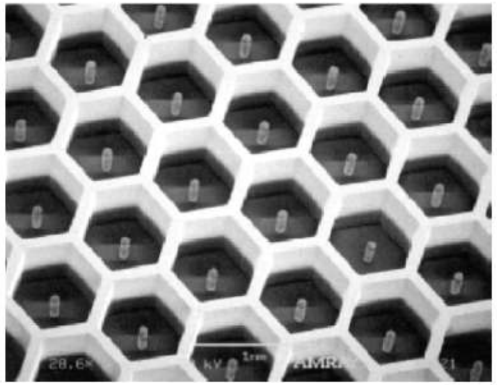


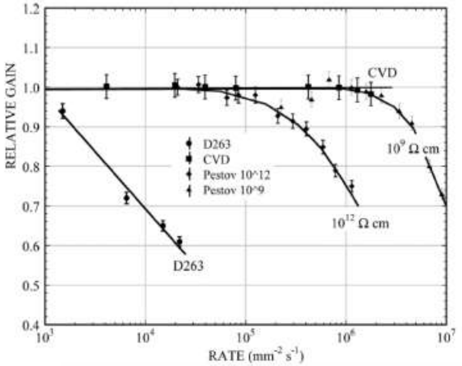
Micro-Wire (µDOT in 3D)
Micro-Pin Array (MIPA)
Micro-Tube
Micro Well
Micro CAT
Micro Trench
Micro Groove

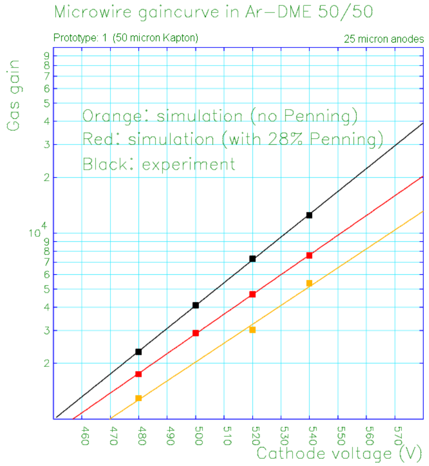


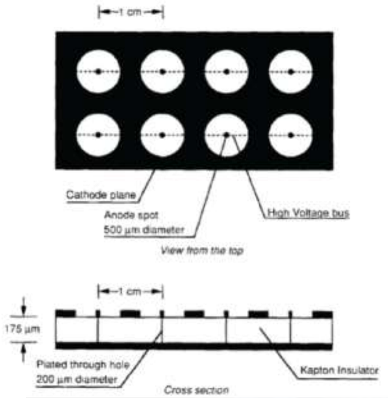
- Wide applications
- large variety of solutions (technologies/ architectures) integrated together)
- Large area detection systems realized today with MPGD technologies (HL-LHC)
- Future Work
- Improve performance, stability
- Developing innovative solutions
- Hybrid solutions, implementing new technologies,
- new manufacturing techniques, simplifying production/assembly

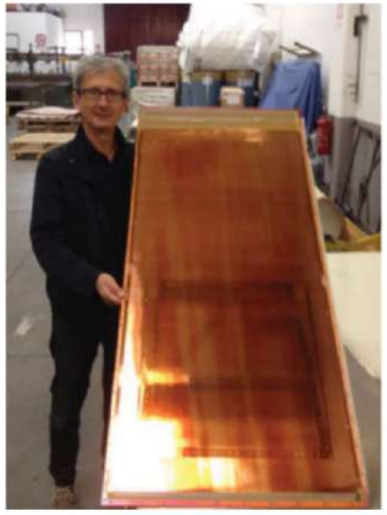




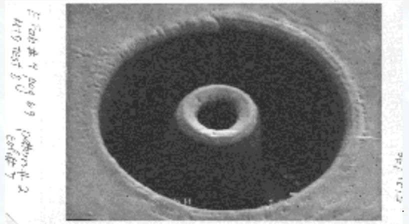




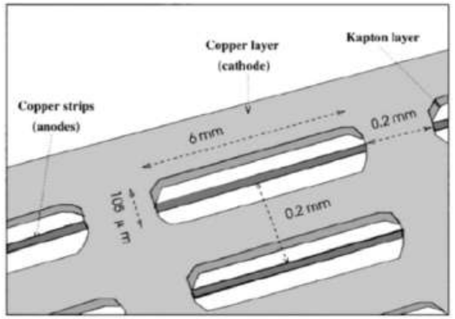




Micro Pattern Gas Detector Family
Resistive Surfaces

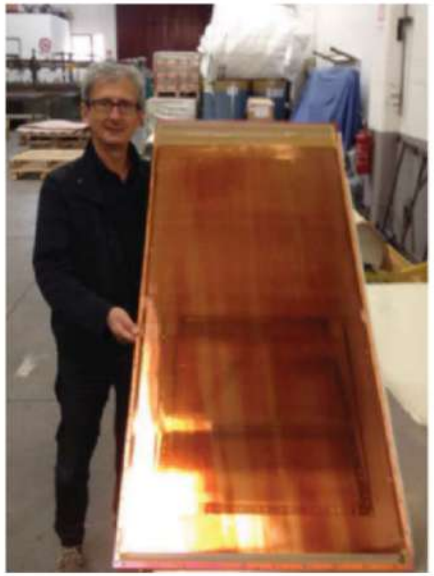


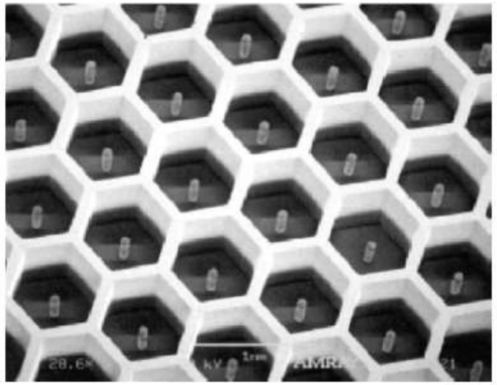
The technologies potentially

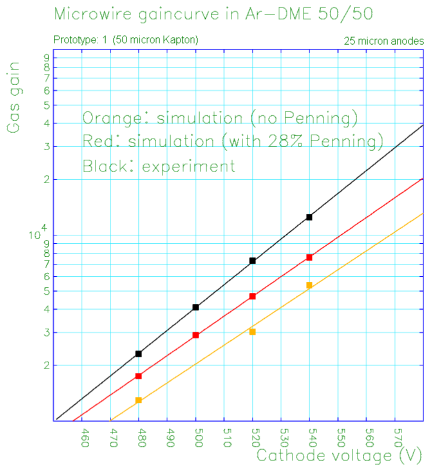


Lower Cost
Flexible substrate for cylindrical applications
Low mass detectors
Possibility to clean the detectors electrically
Easy engineering" (?)

Eventually simple assembly !

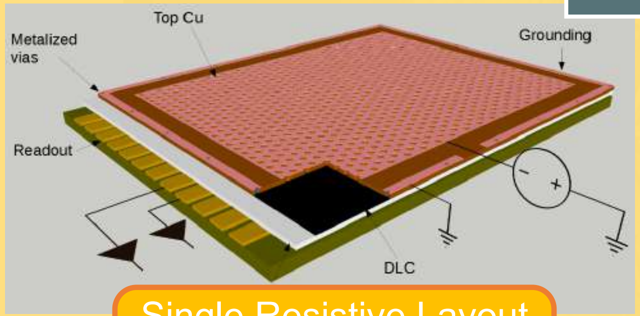


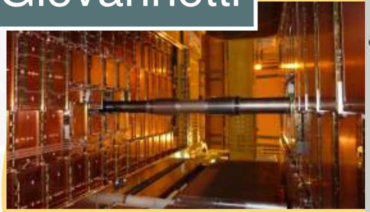


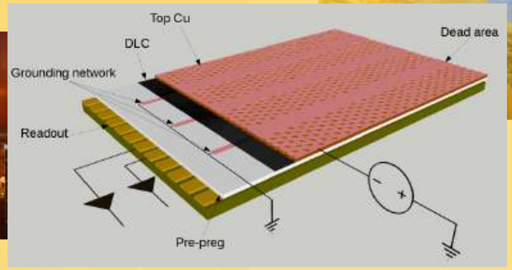


Rui De Oliveira; Giovanni Bencivenni; Matteo Giovannetti

The µ-RWELL detector

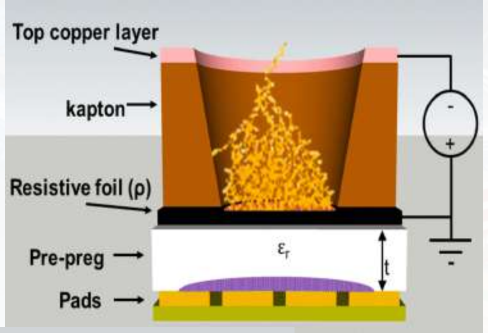






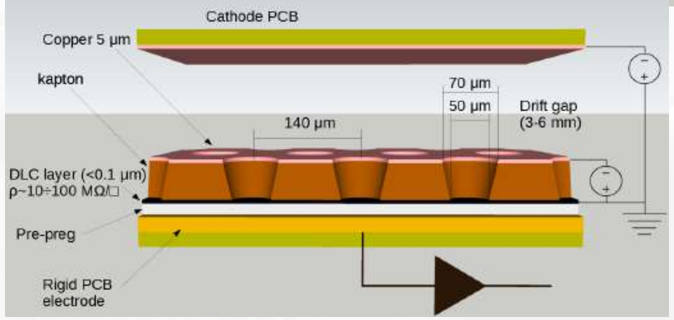
Single Resistive Layout

- Single stage MPDG
- Cost effective
- Spark protected through resistive stage (DLC)



High Rate Layouts

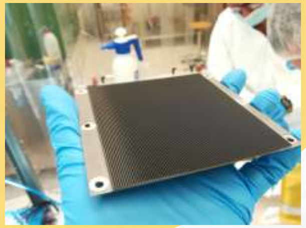
- HEP applications
- Up to 10 MHz/cm2 m.i.p. fluxes
- Extensive ageing tests



Non HEP application:

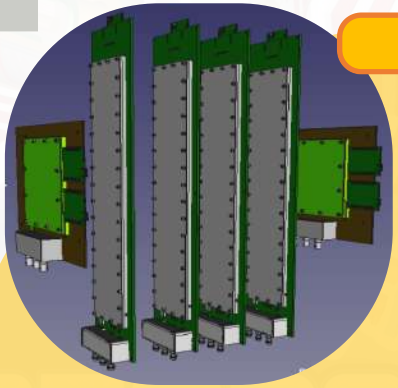
Thermal Neutron Detection with $^{10}B_4C$ converter coated on cathode:

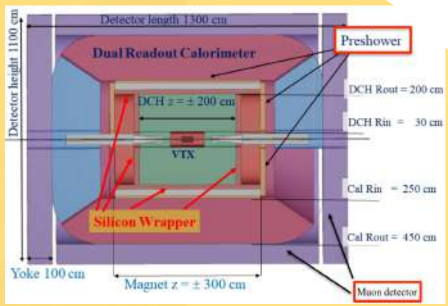
- Industrial application in probing heavy structure in motion
- Radioactive waste monitoring
- Radiation Portal (Homeland security)



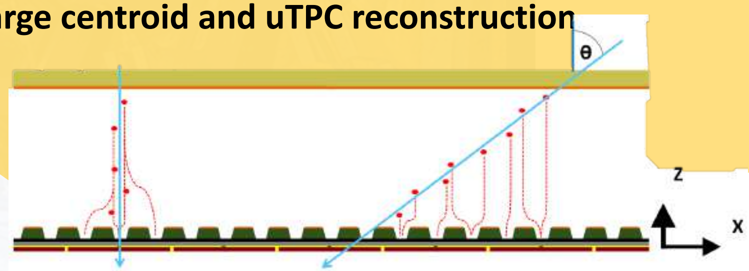
$$n+{}^{10}_{5}B \begin{cases} {}^{7}_{3}Li(1.02MeV)+\alpha(1.78MeV) & 6\% \\ {}^{7}_{3}Li(0.84MeV)+\alpha(1.47MeV)+\gamma(0.48MeV) & 94\% \end{cases}$$

Tracking

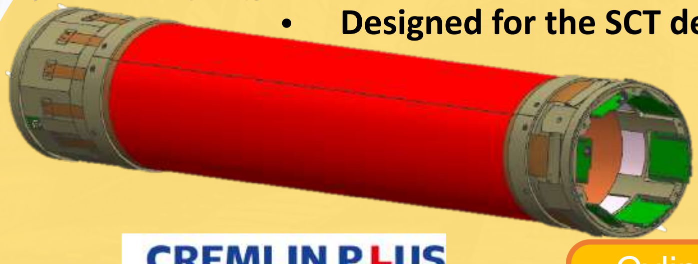




- Charge spread on readout
- up to 100 um resolution for 0-45°
- Charge centroid and uTPC reconstruction



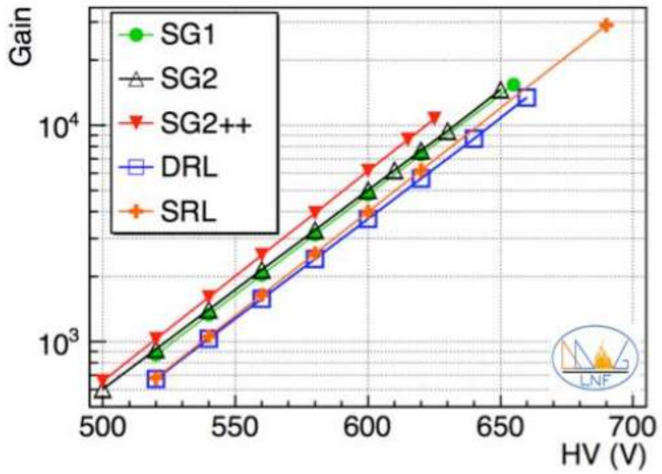
- Very low material budget (0.96% X_0) radial TPC tracker
- 3 modular roof-tiles
- Designed for the SCT detector



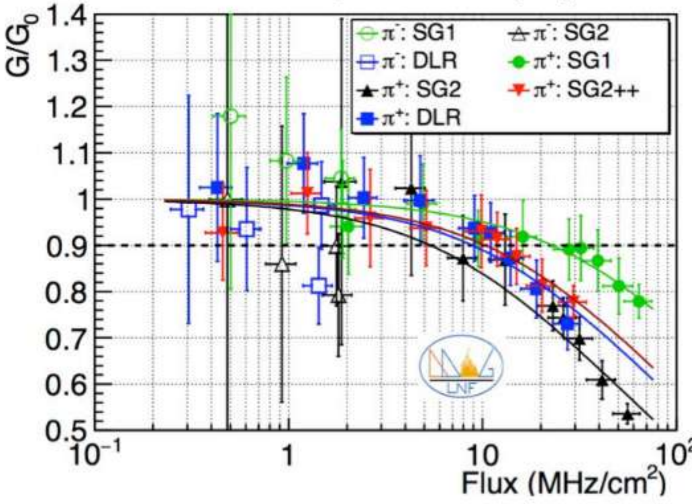
Cylindrical Geometry

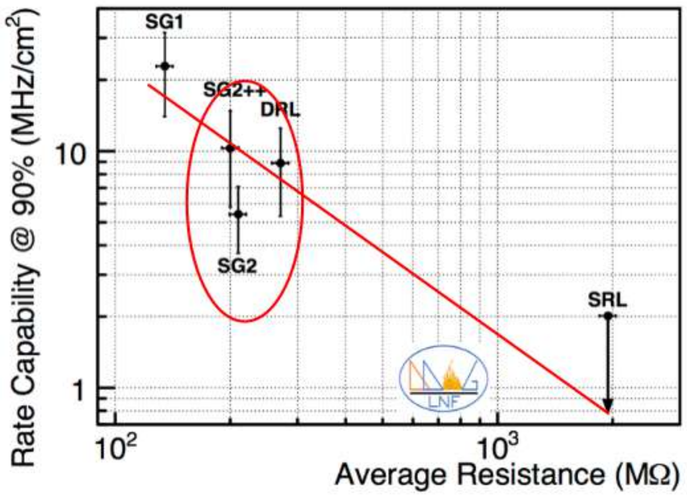
μ-RWELL performance overwiev

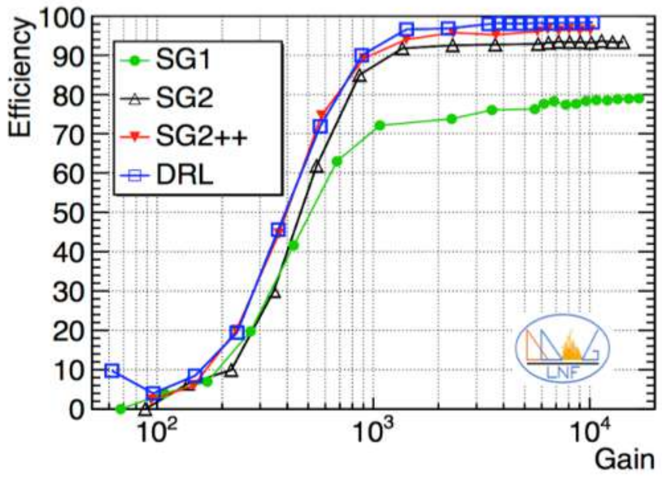
Gain up to ~ 10^4



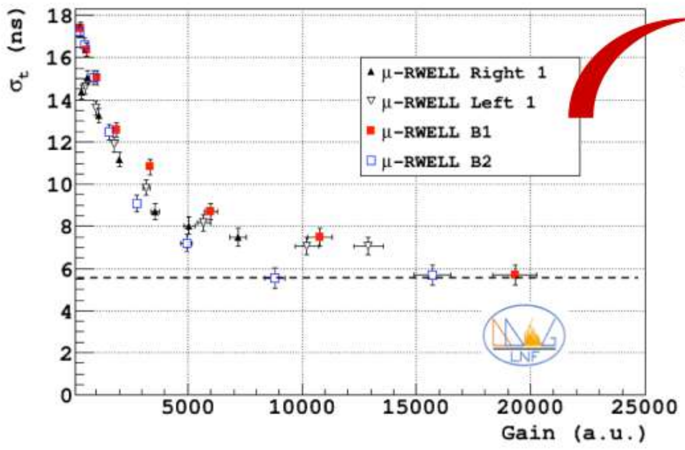
Rate capability (@ G = 5000) ~ 5-10 MHz/cm^2



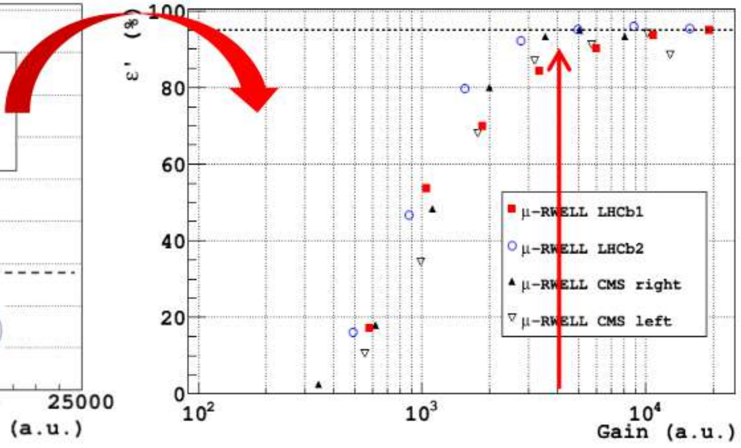




Efficiency ~ 98%



σ_t ~ 5-6 ns



Efficiency in 25 ns

Rui De Oliveira; Giovanni Bencivenni; Matteo Giovannetti

Creative Inner Tracker for Super Charm-Tau Factory

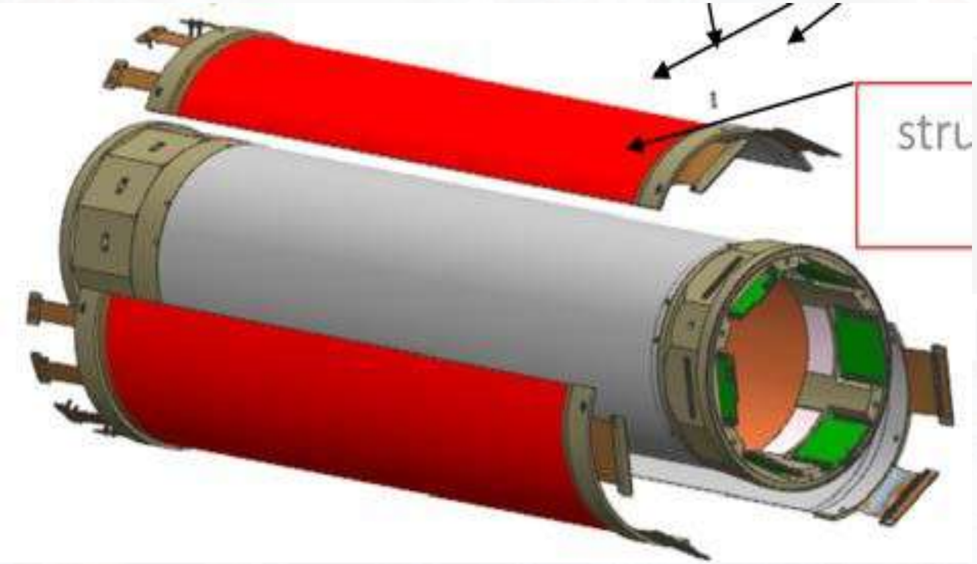
Inner Tracker: Cylindrical micro-RWELL or Compact TPC & MPGD readout

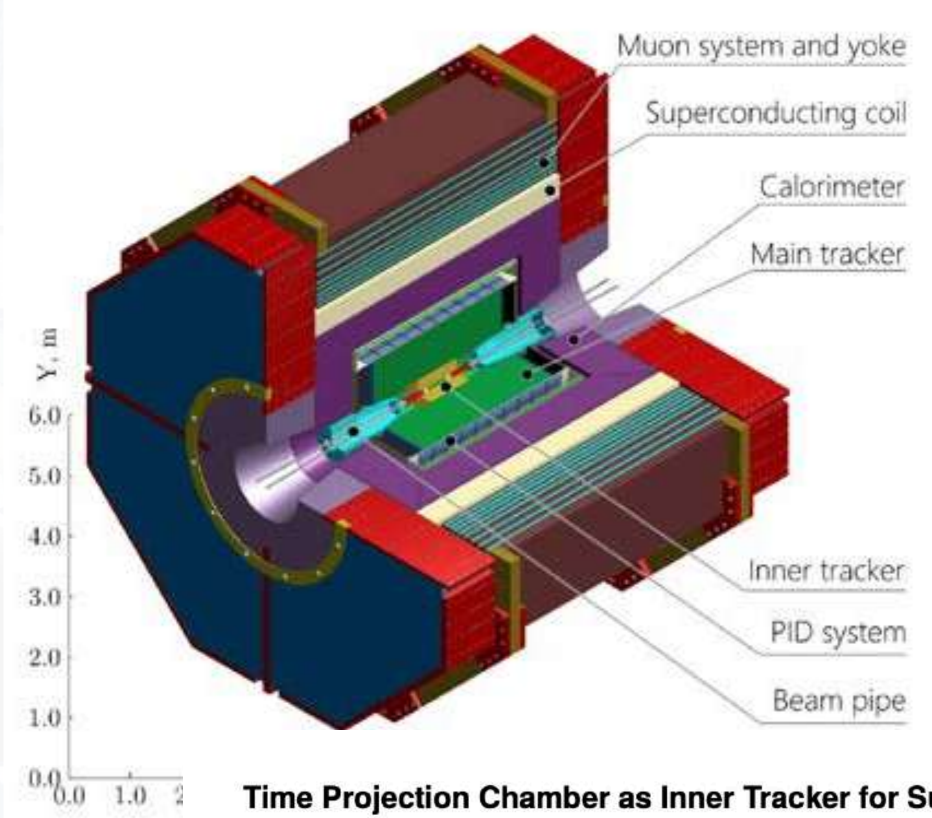
Compact TPC:

- Large number of hits per track
- Reliable dE/dx measurement
- Effective track reconstruction at high background rate must be proven

Cylindrical mRWELL:

- Modular roof-tile detector
- 4 layers
- Length 60 cm
- Diameter 10-40 cm





Time Projection Chamber as Inner Tracker for Super Charm-Tau Factory at BINP

V. K. Vadakeppattu[a] A. V. Sokolov[a,b] L. I. Shekhtman[a,b] T. V. Maltsev[a,b]

[a] *Novosibirsk State University*

[b] *Budker Institute of Nuclear Physics*

E-mail: vijayanandkv.anand@gmail.com

For comparison, with a gas mixture of Ne/CO2 (90/10) at 500 V/cm ~ 24000 tracks in TPC volume.
A mixture of Ar/CH4 (90/10) is of great interest, having at an electric field of only 125 V/cm the drift velocity of 5 cm/μs. That makes the design of the field cage much simpler. Another gas mixture Ar/CH4 (50/50), is interesting because it allows to maximize drift velocity, thereby minimizing the events overlap.

Resistive Pixelated Micromegas

The **Resistive High granUlarity Micromegas** project **(RHUM)**

M. Alviggi, M.T. Camerlingo, V. Canale, M. Della Pietra, C. Di Donato,

R. Di Nardo, S. Franchellucci, P. Iengo, **M. Iodice**, F. Petrucci, G.

R&D on Pixelated Micromegas

- R&D basic steps:
  - **Optimization of the spark protection resistive scheme**
  - **Implementation of Small pad readout** (for low occupancy under high irradiation)

Patterned DLC

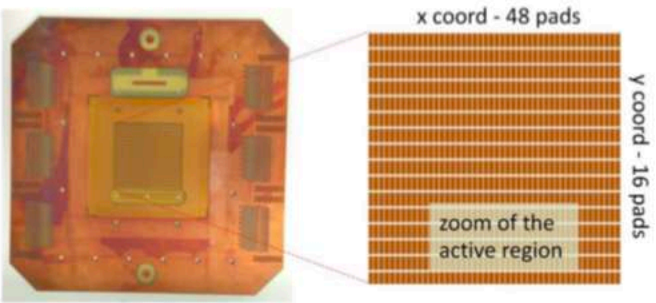
Aiming at:

- HIGH GAIN
- HIGH Rate Capability
- HIGH Granularity
- HIGH STABILITY – robustness

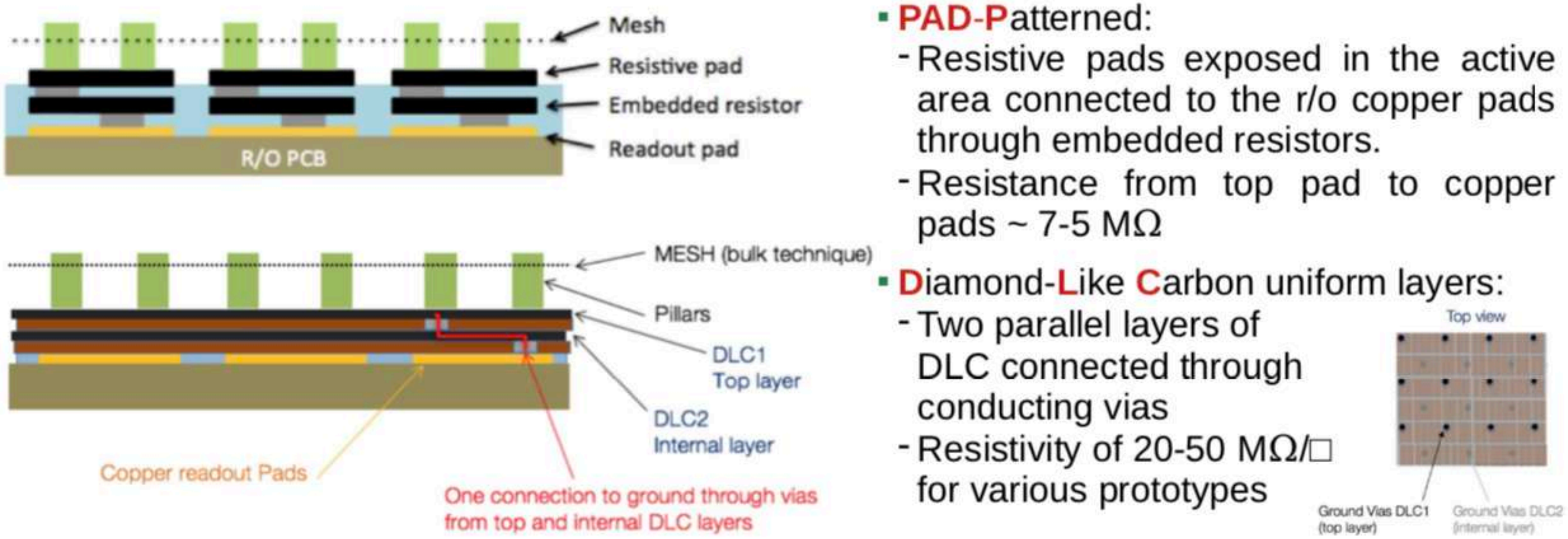
Layout

Current anode layout for the Small-pads detectors:

- plane segmented in a 48x16 matrix
- Small-pads dimensions 0.8x2.8 mm² (1x3 mm² pitch)
- Total active area of 4.8x4.8 cm²



Resistive schemes



- **PAD-P**atterned:
  - Resistive pads exposed in the active area connected to the r/o copper pads through embedded resistors.
  - Resistance from top pad to copper pads ~ 7-5 MΩ
- **D**iamond-**L**ike **C**arbon uniform layers:
  - Two parallel layers of DLC connected through conducting vias
  - Resistivity of 20-50 MΩ/□ for various prototypes

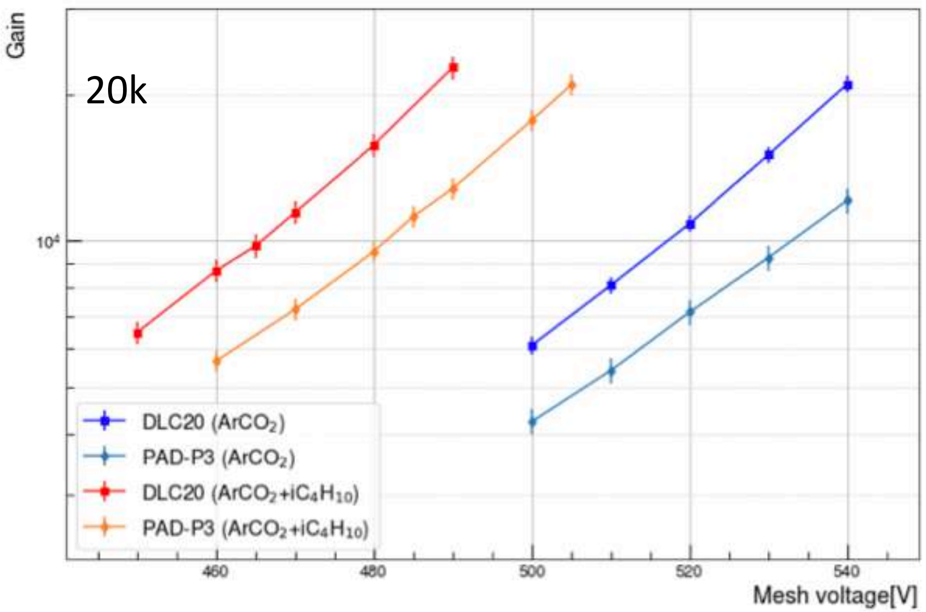
Proposed by M. Chefdeville SACLAY Group / G. Bencivenni

High-rate capabilities at High Gain with Ar/CO2/isobutane 93/5/2

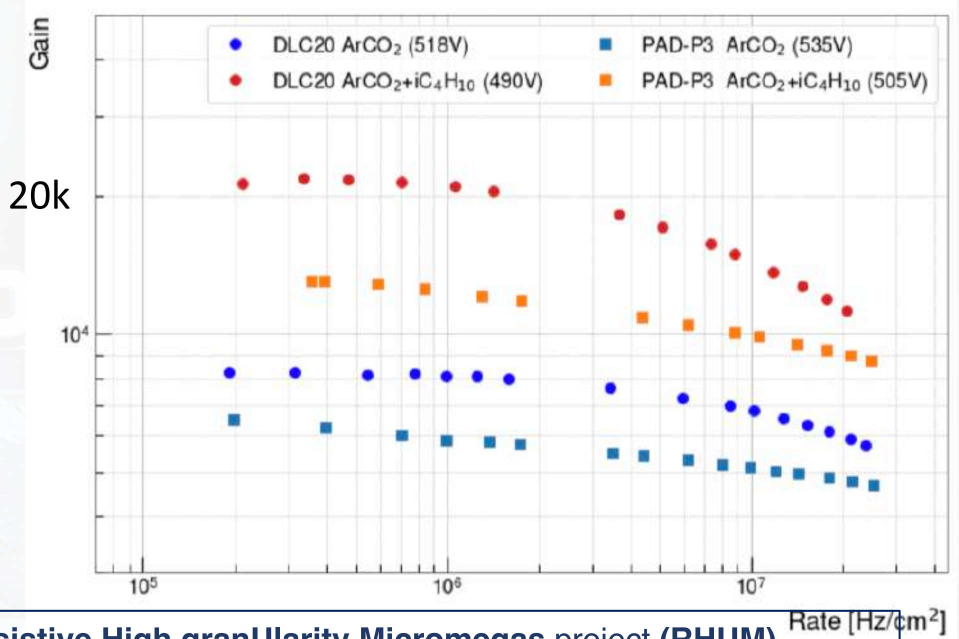
The stability range of the detectors is extended by adding a small portion of iso-butane:

Ar CO_2 iC_4H_{10} (93:5:2)

Tests carried out with the new gas mixture showed the possibility to reach **Gains above 20k** also in extremely high irradiation conditions. In terms of performances, this is an unprecedented result, as never before the Small-pad detectors were able to cope, **with excellent stability**, rates greater then O(10MHz/cm2) at such Gains.



TIPP



The **Resistive High granUlarity Micromegas** project **(RHUM)**

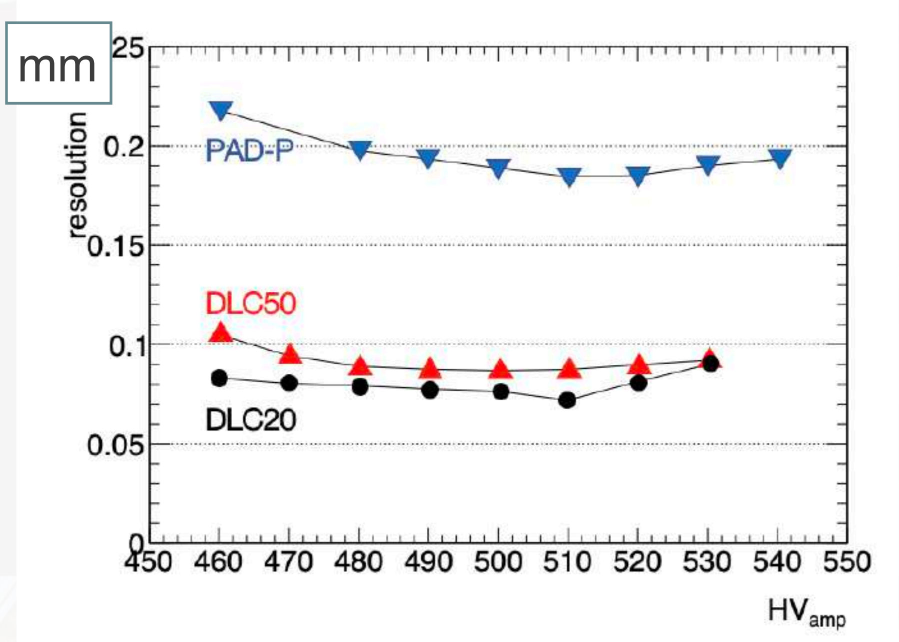
M. Alviggi, M.T. Camerlingo, V. Canale, M. Della Pietra, C. Di Donato, R. Di Nardo, S. Franchellucci, P. Iengo, M. Iodice, F. Petrucci, G. Sekhniaidze

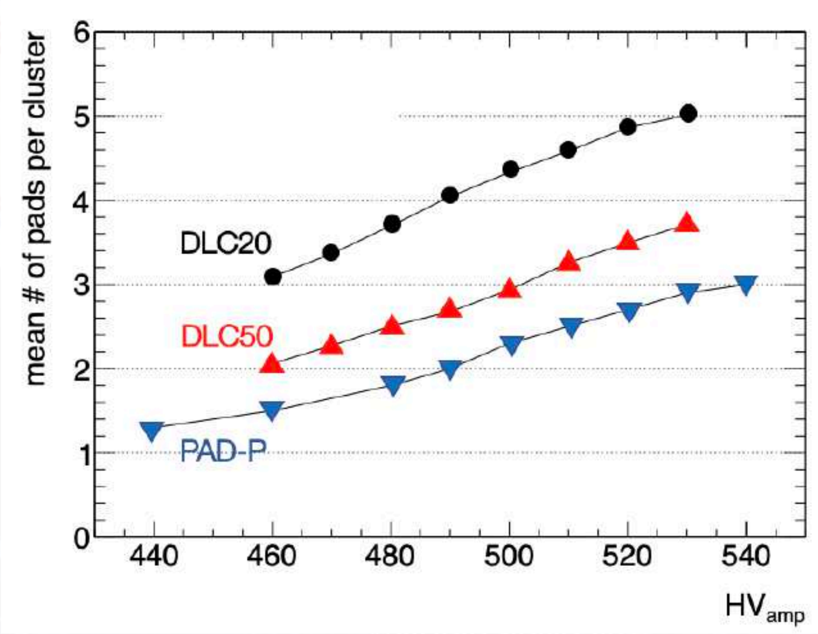
Spatial resolution (from Test-Beam)

(M.Alviggi, et al. JINST 13 (2018) no.11, P11019)

Position resolution:

Cluster residual wrt extrapolated position from external tracking chambers.





Cluster-size vs HV

Precision coordinate (pad pitch 1 mm)

Significant improvement of spatial resolution on the DLC prototypes (pad charge weighted centroid)

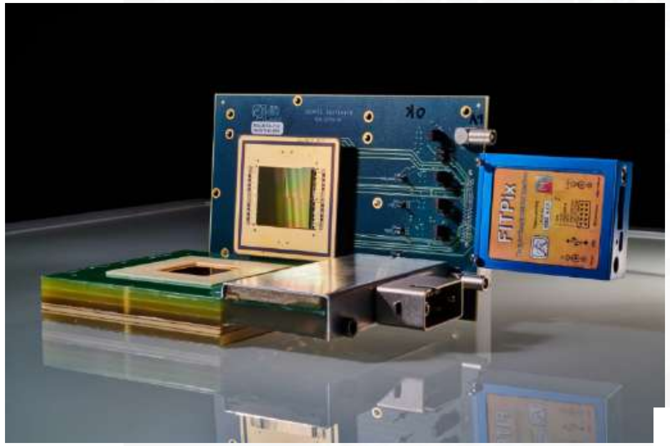
- More uniform charge distribution among pads in the clusters

- Larger Cluster size for DLC due to uniform layer. Larger clusters for lower resistivity (DLC_20 Mohm/sq Vs DLC_50 Mohm/sq)

Gas Detector Readout

For any possible application you need a portable DAQ system → FPGA

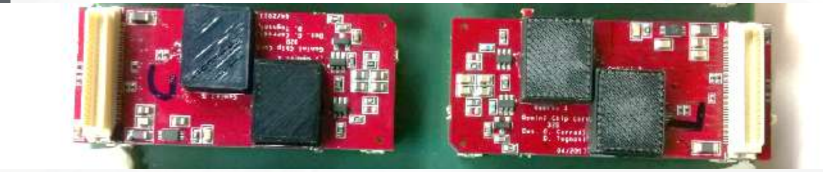
FITPix



Timepix (1, 3 or 4) Chip
Up to 512x512 pixels = 262 kch
55x55 um² pixels
FPGA FITPIX (USB)

10 ns

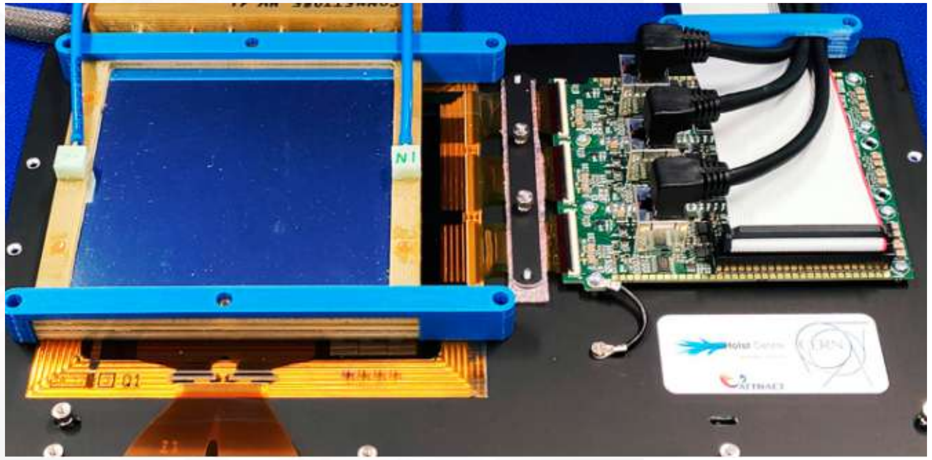
GEMINI + FPGA



Gemini Chip 16 ch
Gemini Board 32 or 64 ch
FPGA 256 ch (Ethernet or optical)

Nuclear Instruments

TNO TFT



Thin Film Transistor
480 x 640 pixels
126x126 um for each pixel
FPGA (Ethernet)
TFT+GEM Radiography 20 frames/sec
Treatment Plans

TNO innovation for life

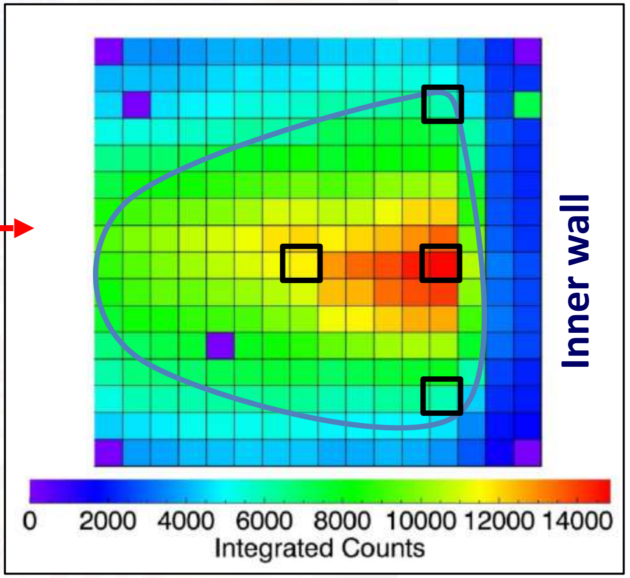
F. Murtas

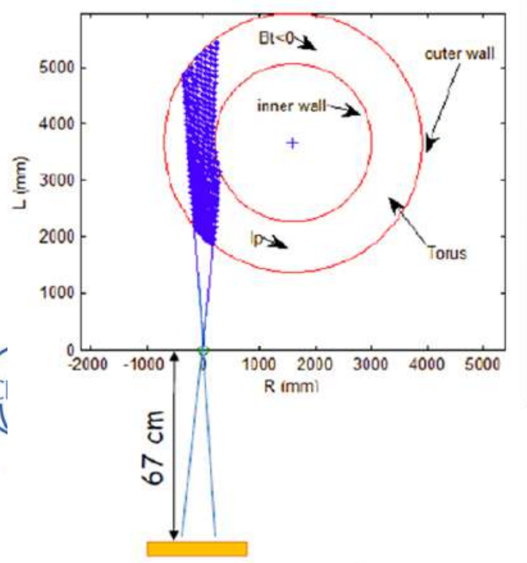
GEM X-ray Monitor for Tokamak : results @ EAST in CHINA

Data taken in the first week of April 2019

- 2D image of the Plasma
- Energy spectrum for each pixel
- Time evolution during the 9 s shot

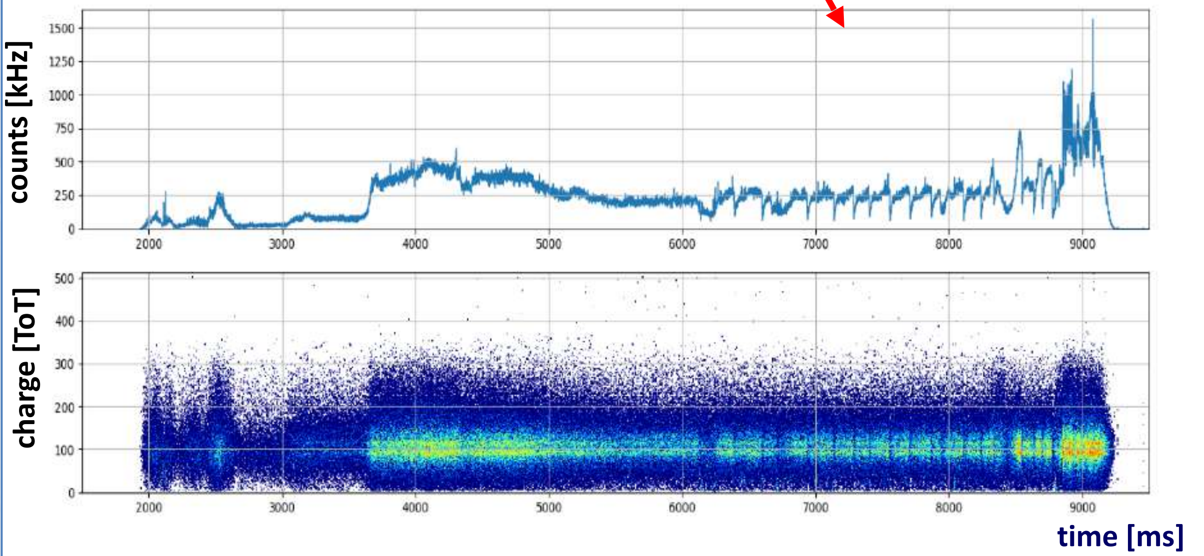
10x10 GEM 256 ch

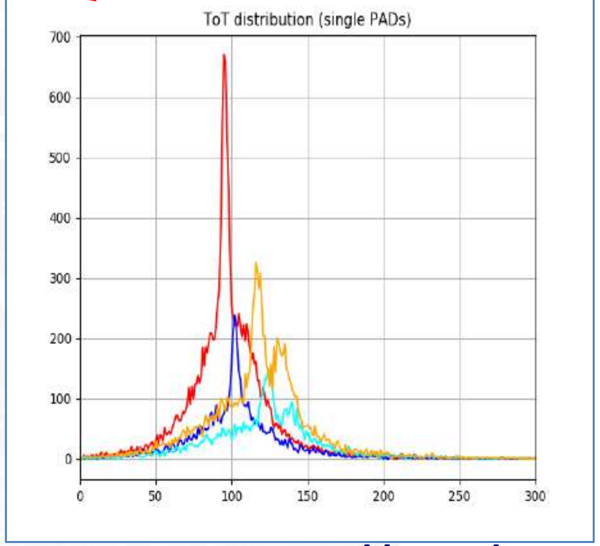




Shot n°83874

Space emission integrated for all the pulse duration e for all x-rays energies.





energy spectra pad by pad

F. Murtas

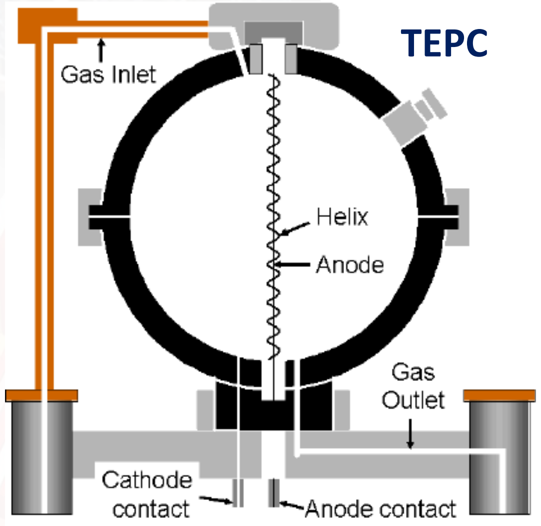
Microdosimetry with the GEMTissueEQuivalent

Microdosimetry:

- Statistical fluctuations of energy deposition become important at small scales (e.g. human cell)
- Important e.g. to qualify radiation fields for cancer therapy

Measurements in gas detectors:

1. Use tissue-equivalent (TE) gas: propane + CO_2 + N_2
2. (Low pressure) gas volume scales with density to tissue volume, standard detector: single channel TEPC
3. **GEMPix: operated with TE gas, pixel pitch equivalent to 100nm in**



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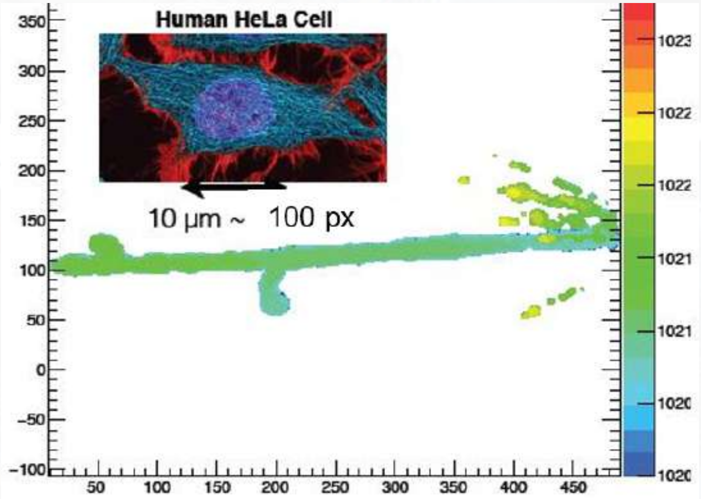
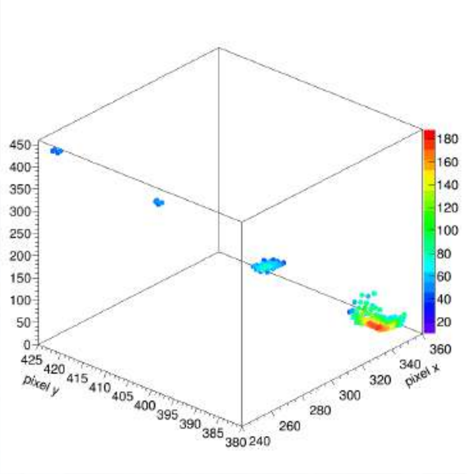
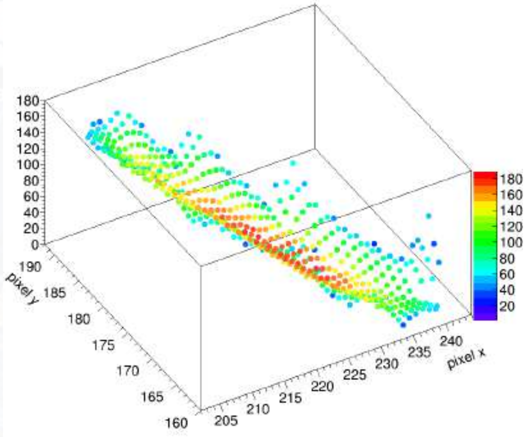


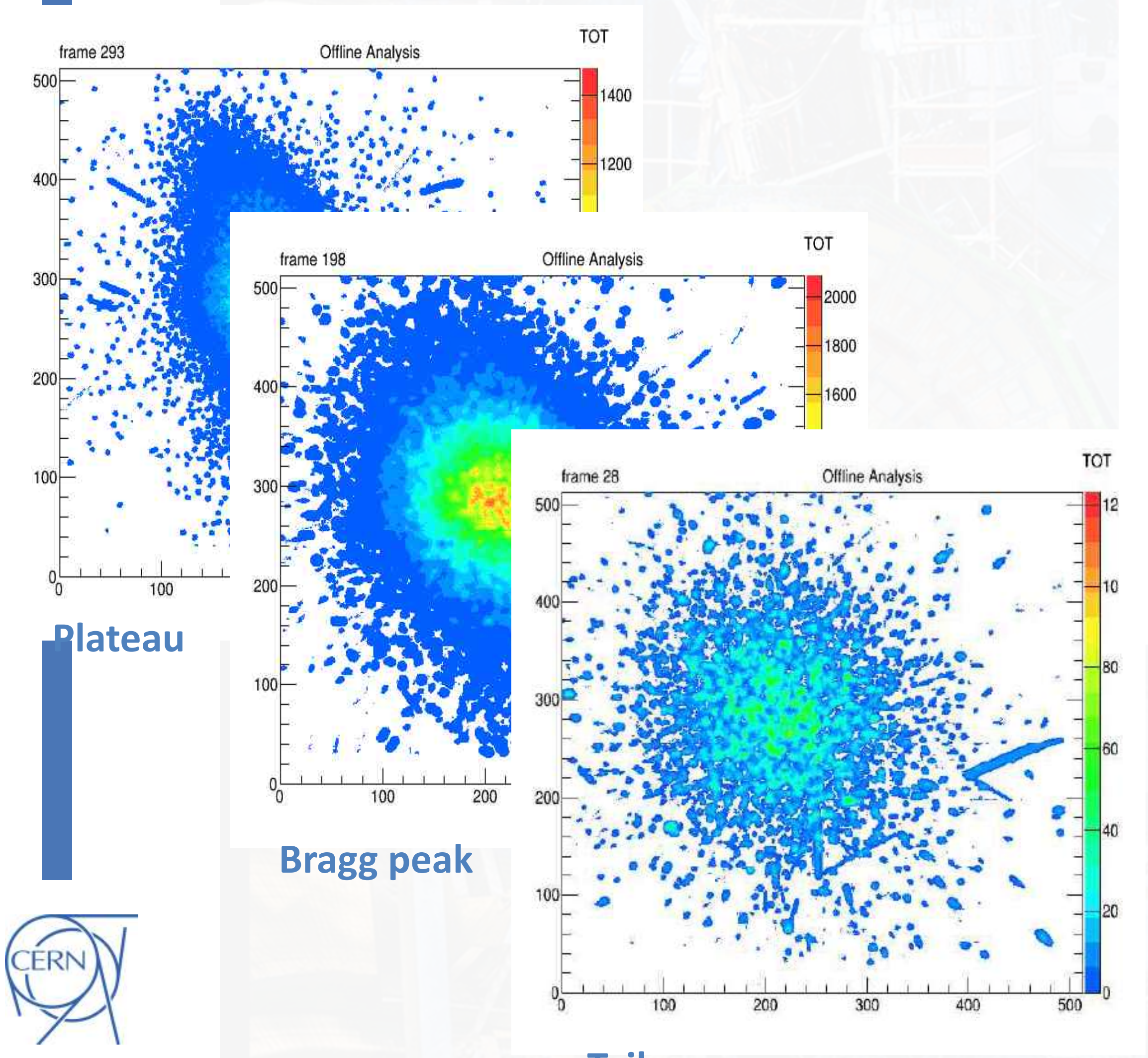


Cs-137: electron

Am-241: alpha



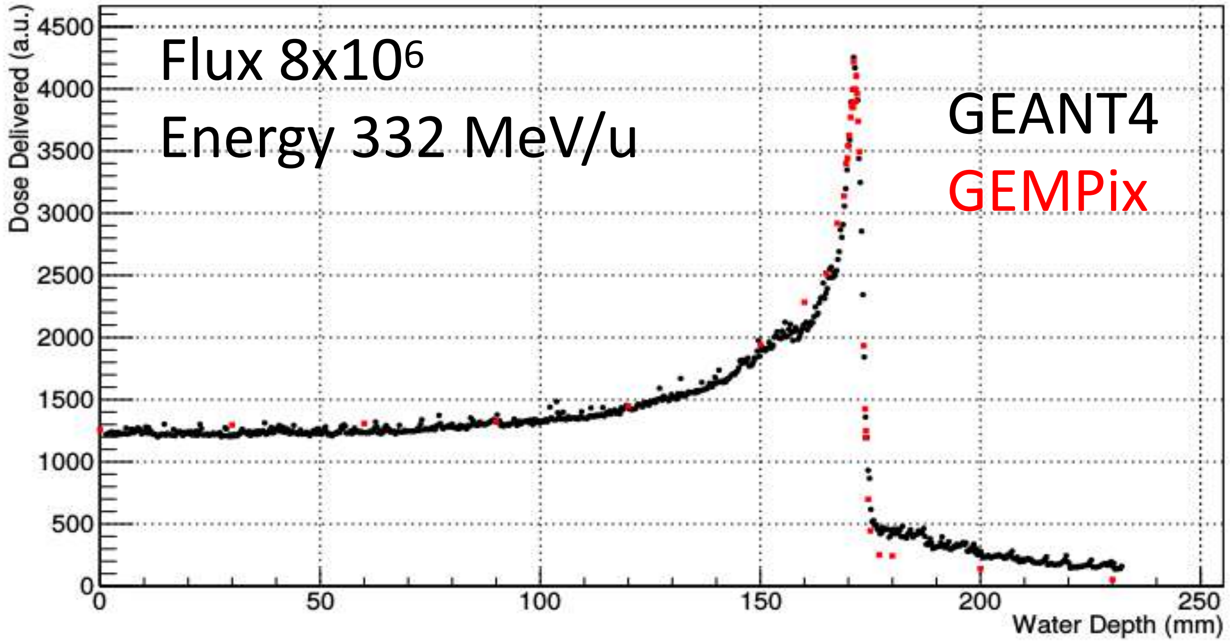
3D reconstruction (meas) of Bragg peak Carbon Ion Beam

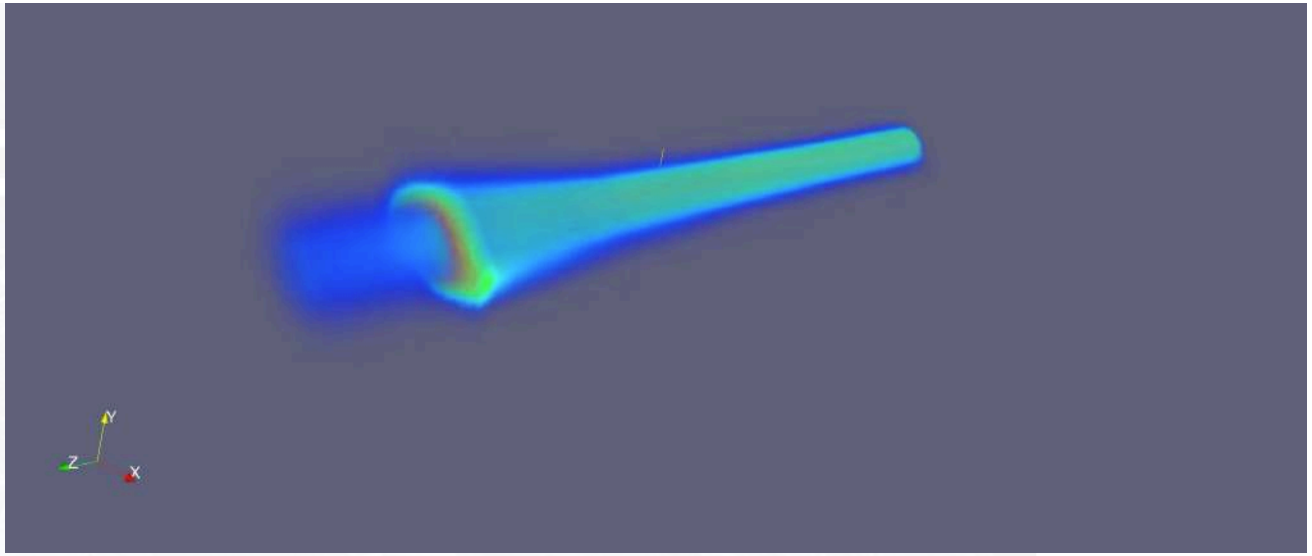


Plateau

Bragg peak

Tail

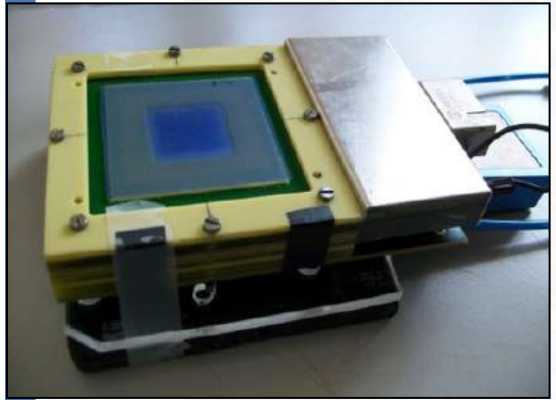


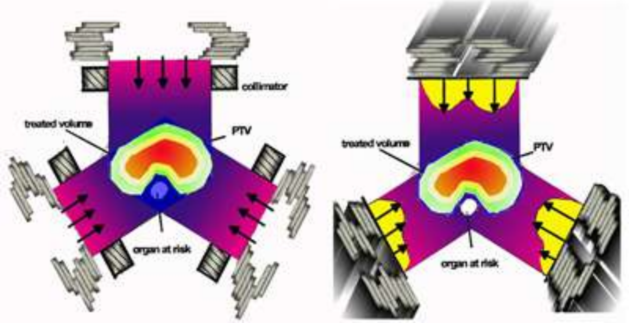


F. Murtas

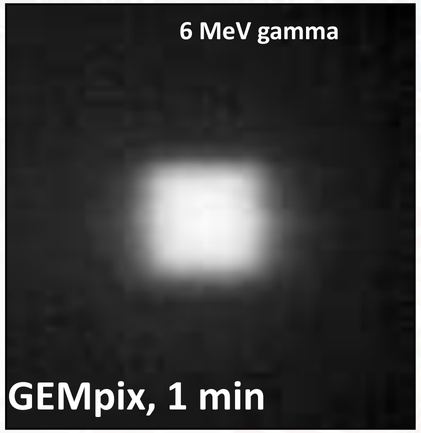
GEMPix for Radiotherapy

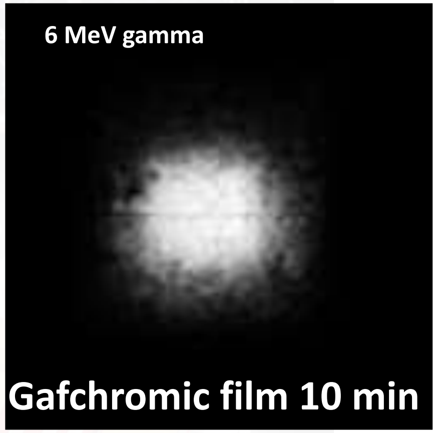
2D measurements of energy released in IMRT (Policlinico Tor Vergata Roma)

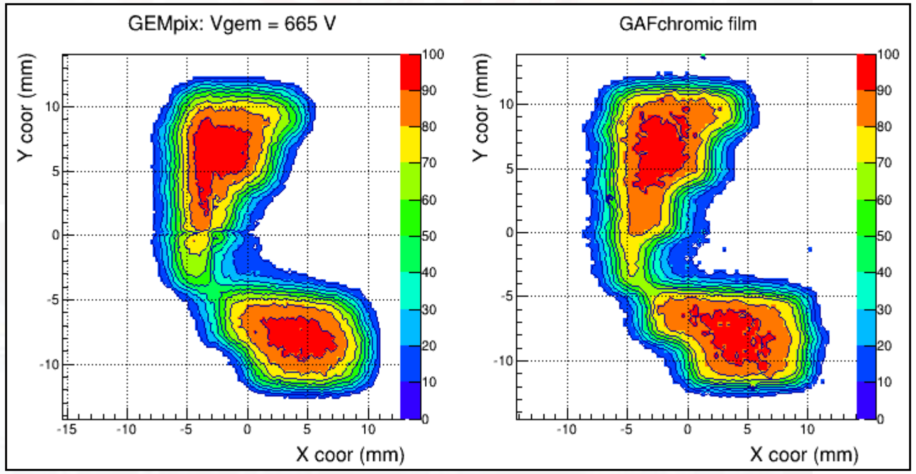


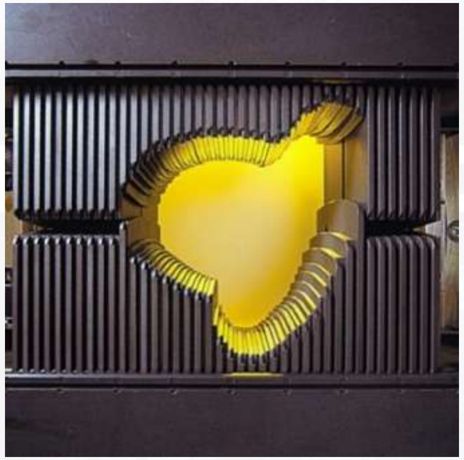


Intensity Modulated Radiation Therapy (IMRT)









G.Claps

F. Murtas

Real-time measurements with GEMPix allows fast Quality Assurance procedure

The RPC Family

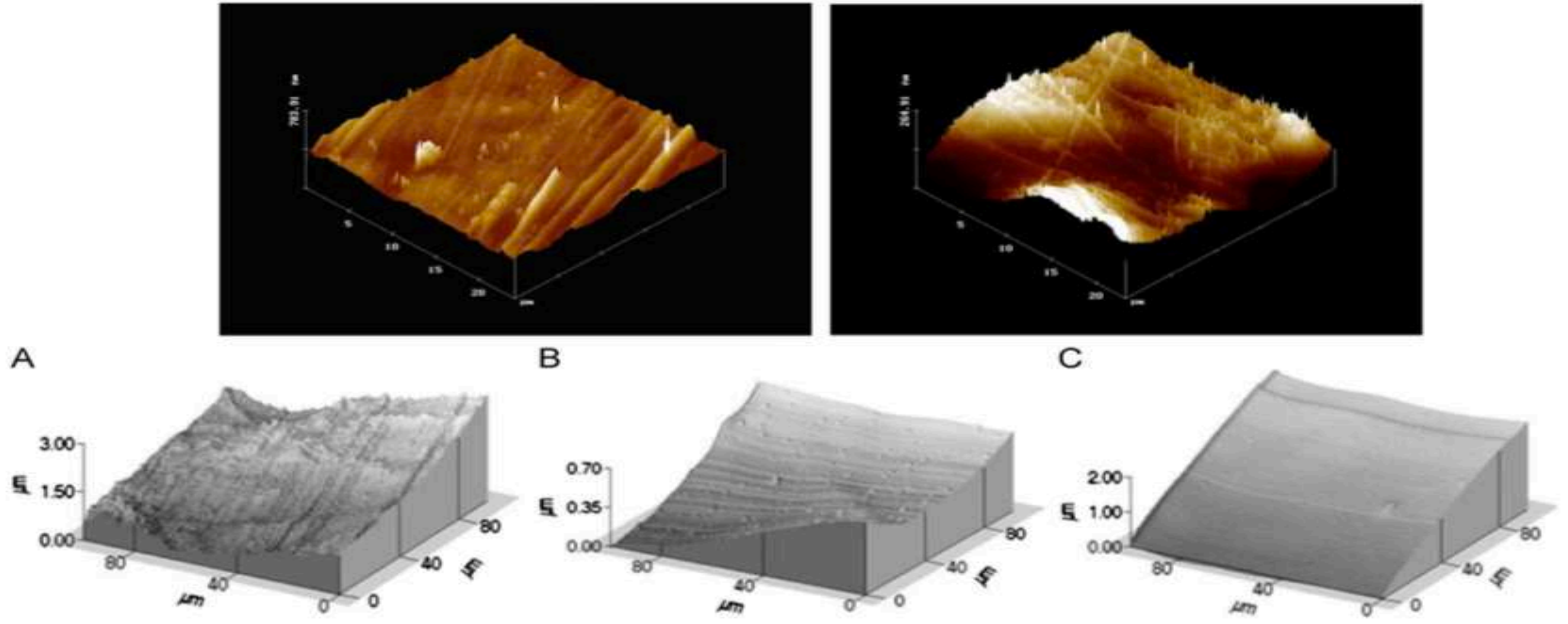


Fig. 53. Surface quality of (top left) Beijing phenol/melamine plastic laminate and (top right) Italian LHC like phenol/melamine plastic laminate. Comparison of the three photos (bottom) demonstrate the successive surface improvement due to the deposition of a uniform linseed oil layer; the scale is in µm.

Experiment	Area (m^2)	Electrodes	Gap(mm)	Gaps	Mode	Type
PHENIX	?	Bakelite	2	2	Avalanche	Trigger
NeuLAND	4	Glass	0.6	8	Avalanche	Timing
FOPI	6	Glass	0.3	4	Avalanche	Timing
HADES	8	Glass	0.3	4	Avalanche	Timing
HARP	10	Glass	0.3	4	Avalanche	Timing
COVER-PLASTEX	16	Bakelite	2	1	Streamer	Timing
EAS-TOP	40	Bakelite	2	1	Streamer	Trigger
STAR	50	Glass	0.22	6	Avalanche	Timing
CBM TOF	120	Glass	0.25	10	Avalanche	Timing
ALICE Muon	140	Bakelite	2	1	Streamer	Trigger
ALICE TOF	150	Glass	0.25	10	Avalanche	Timing
L3	300	Bakelite	2	2	Streamer	Trigger
BESIII	1200	Bakelite	2	1	Streamer	Trigger
BaBar	2000	Bakelite	2	1	Streamer	Trigger
Belle	2200	Glass	2	2	Streamer	Trigger
CMS	2953	Bakelite	2	2	Avalanche	Trigger
OPERA	3200	Bakelite	2	1	Streamer	Trigger
YBJ-ARGO	5630	Bakelite	2	1	Streamer	Trigger
ATLAS	6550	Bakelite	2	1	Avalanche	Trigger
ICAL	97,505	Both	2	1	Avalanche	Trigger

Complied by B. Satyanarayana
International Workshop on Outlook for INO, IICHEP and beyond Feb 19th 2021

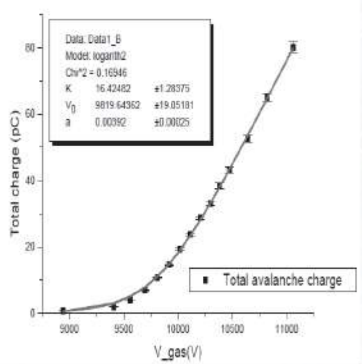
Present and future of RPCs and MRPCS

Resistive Plate chambers briefly

$$Q(V) = \ln\left(1 + e^{a(V - V_0)}\right)$$

$$Q(x) = \ln\left(1 + e^{\alpha x}\right)$$

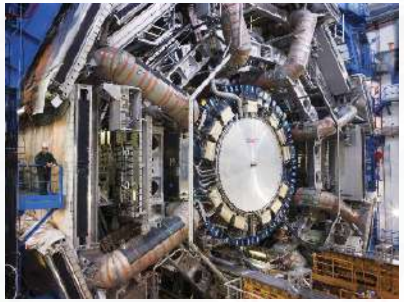
Integral logistic growth



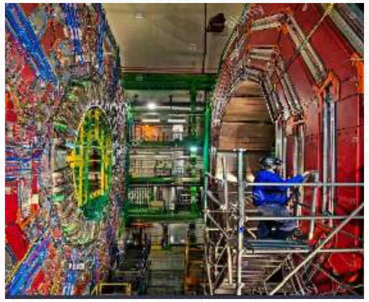
RPC and MRPC Common features

- Target and amplification coincide
- uniform field → prompt signal
- Target and amplification coincide
- high r electrodes → Spark less
- Uniform electrode → simple
- Working at atm. Pressure → simple
- Min 1 mm of target for full eff.
- Thin 0.1mm 2D localization
- Very quenching and electronegative Gases

State of the art of classic RPCs



ATLAS
LHC 7000 m²
HL-LHC1400 m²
Tracking trigger

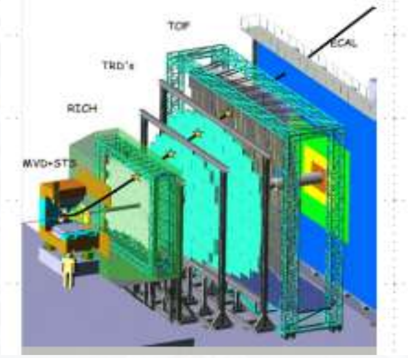


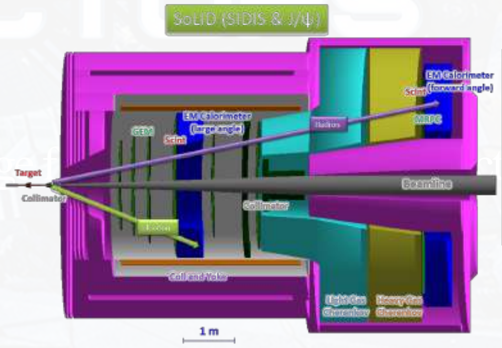
CMS
LHC 4000 m²
HL-LHC1000 m²
Tracking trigger

ALICE
LHC 144 m²
HL-LHC new RPCs
Tracking trigger

Applications in current and future HEP and NP experiments

CBM expected rate up to 10–25 kHz/cm2 in the central region

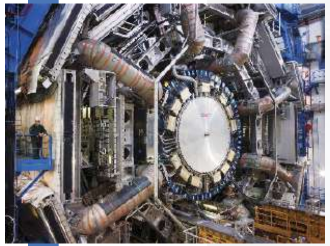




Mostly used as extensive (up to ~ 200 m²) TOF systems with time resolution up to 50 ps

STATE OF THE ART OF CLASSIC RPCS

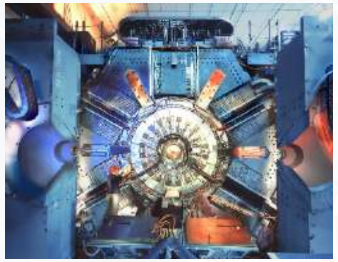
- (SOME OF)PRESENT AND RECENT PAST APPLICATION AT COLLIDERS
- PRESENT AND RECENT PAST COSMIC RAYS AND UNDERGROUND



ATLAS
LHC 7000 m^2
HL-LHC1400 m^2
Tracking trigger

CMS
LHC 4000 m^2
HL-LHC1000 m^2
Tracking trigger

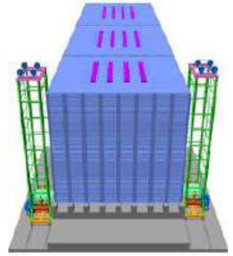
ALICE
LHC 144 m^2
HL-LHC new RPCs
Tracking trigger



BaBar
SLAC 2000 m^2
Instrum. iron
μ identifier

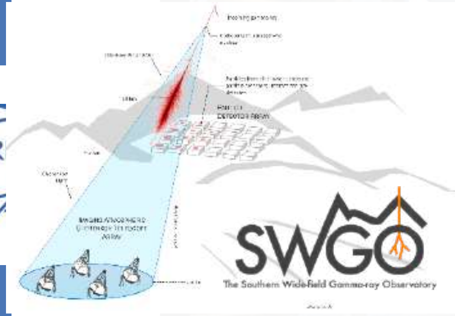
OPERA
CERN ν beam
Instrum. iron
μ spectrometer

ARGO Ybj
CR exp. 7000 m^2
4600 m altitude
3D reconstruct.

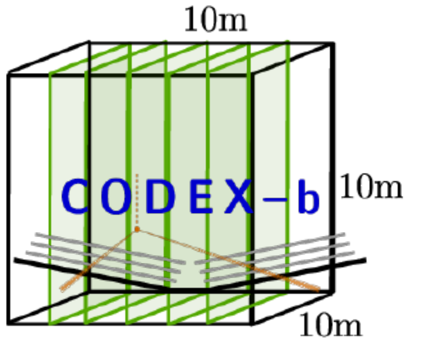


INO (staged)
ν observatory
150000 m^2
Instrum. Iron

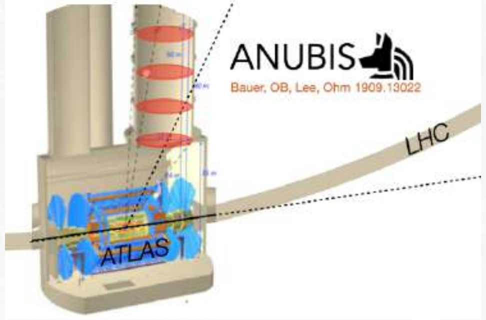
- ACTIVE PROPOSALS FOR FUTURE EXPERIMENTS USING PRESENT TECHNOLOGY



SWGO - STACEX
CR exp. 22500 m^2
5000 m altitude
3D reconstruct. +
Cherenkov



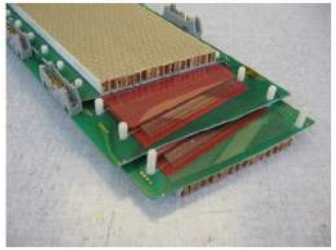
CODEX-B
HL-LHC. 3000 m^2
Search for DM
Sealed tracking
volume



ANUBIS
HL-LHC. 5500 m^2
Search for DM
Sealed tracking
volume

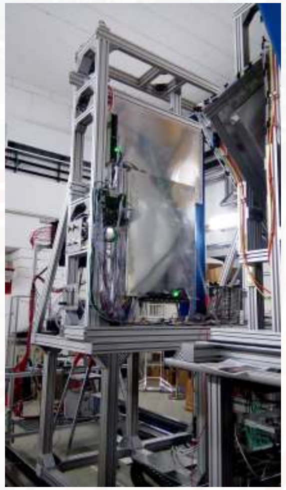
STATE OF THE ART OF MRPCS

- Applications in current and future HEP and NP experiments
- CBM expected rate up to 10–25 kHz/cm2 in the central region

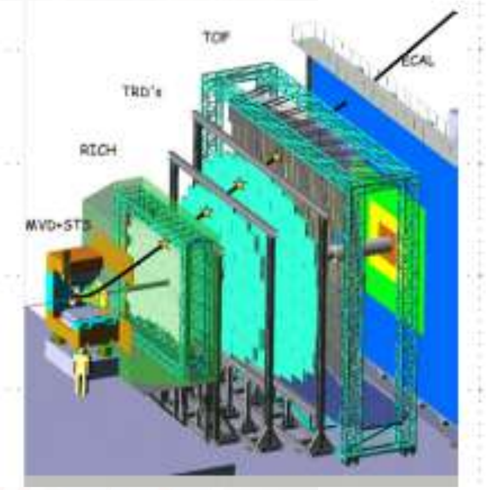


ALICE@CERN
10.1016/S0168-9002(01)01753-3

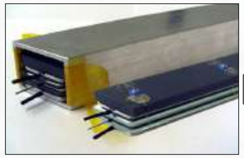
Mostly used as extensive up to ~ 200 m² TOF



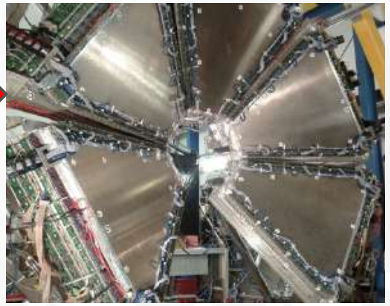
FD-HADES@GSI



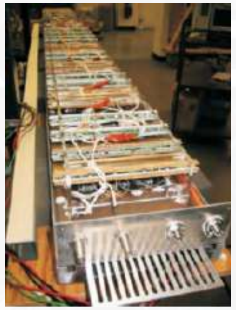
CBM@FAIR 10.1088/1748-0221/14/09/C09020

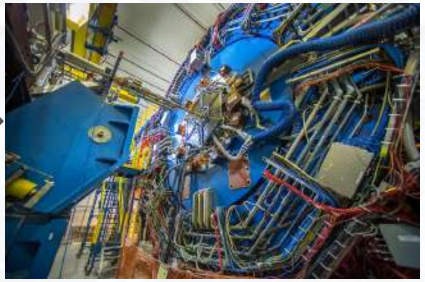


HADES@GSI
10.1016/j.nima.2008.12.090

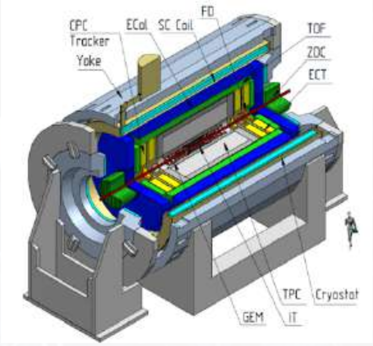


FOPI@GSI
10.1016/j.nima.2004.07.002

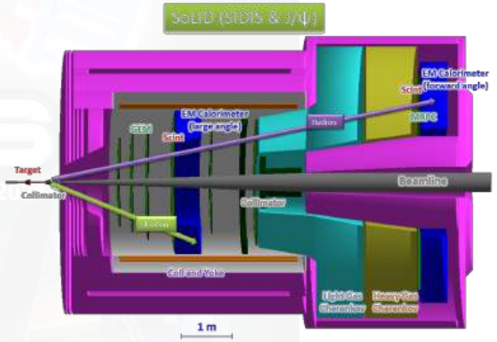




START@RHIC 10.1016/j.nima.2010.07.086

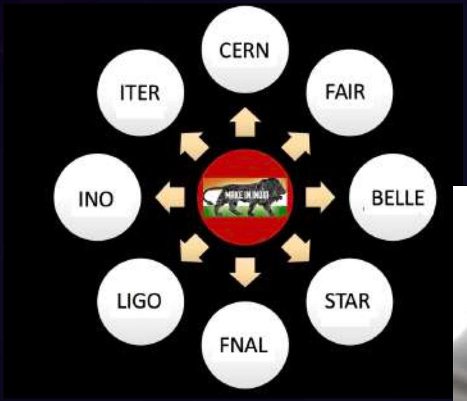


MPD, BM@N at NICA facility
10.1051/epjconf/201817112001



SoLID (Jefferson Labs)
arXiv:1409.7741v1 [nucl-ex] 26 Sep 2014

Muon tomography of large geological structures and PET


CERN
ITER
FAIR
INO
BELLE
LIGO
STAR
FNAL

Next Decade(s) The Quest for Large Area Systems at FCC

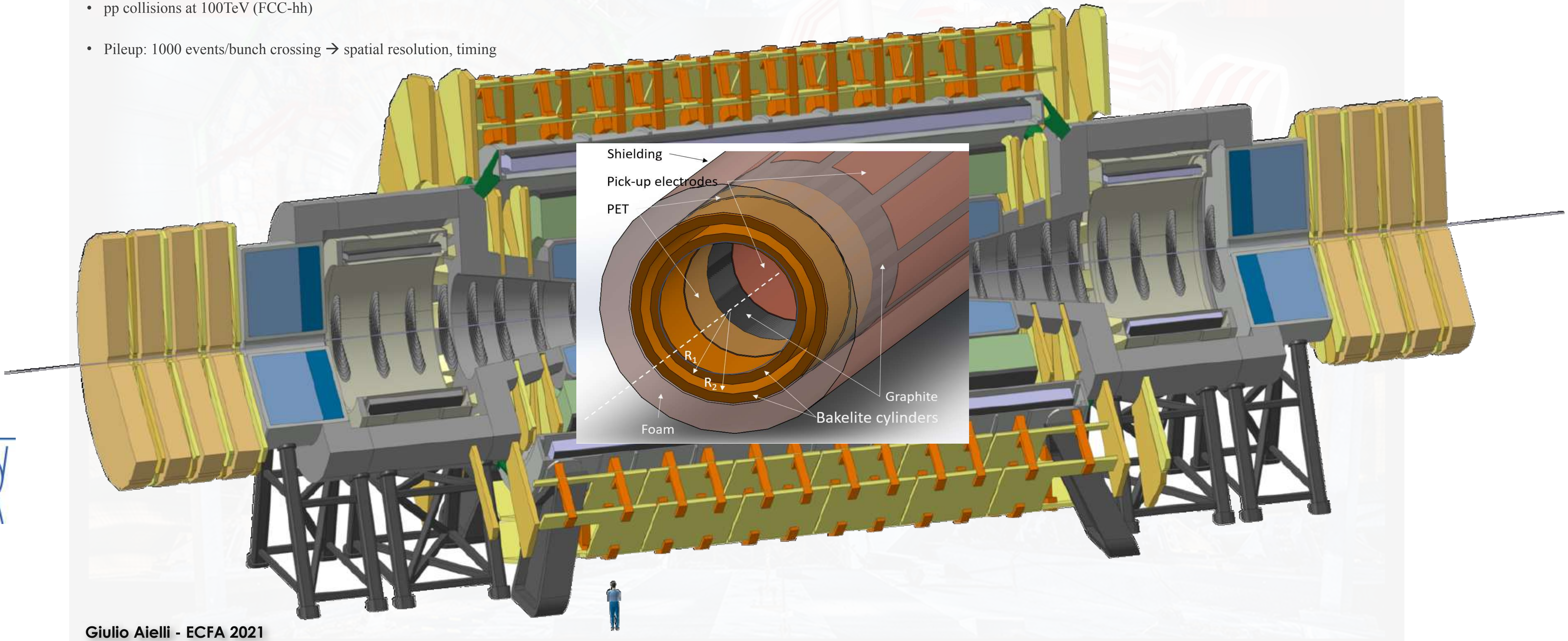
RPCs (all versions) are a strong candidate technology for FCC experiments

Key features:

- Better than 50ps time resolution (500 ps for single gap) Single Gap RPC Efficiency > 98%
- 2D tracking, resolution up to 0.1 mm
- Proportional response to high track density

Hardest challenge:

- pp collisions at 100TeV (FCC-hh)
- Pileup: 1000 events/bunch crossing → spatial resolution, timing



Next Decade(s)
The Quest for Large Area

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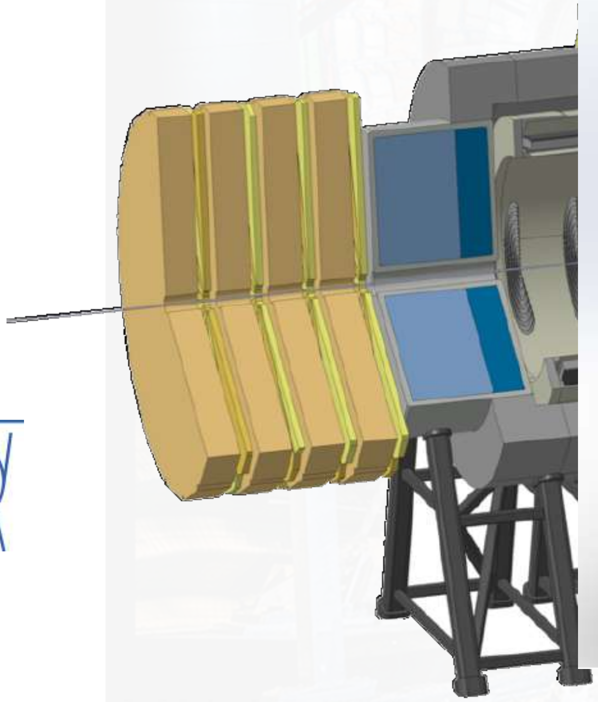
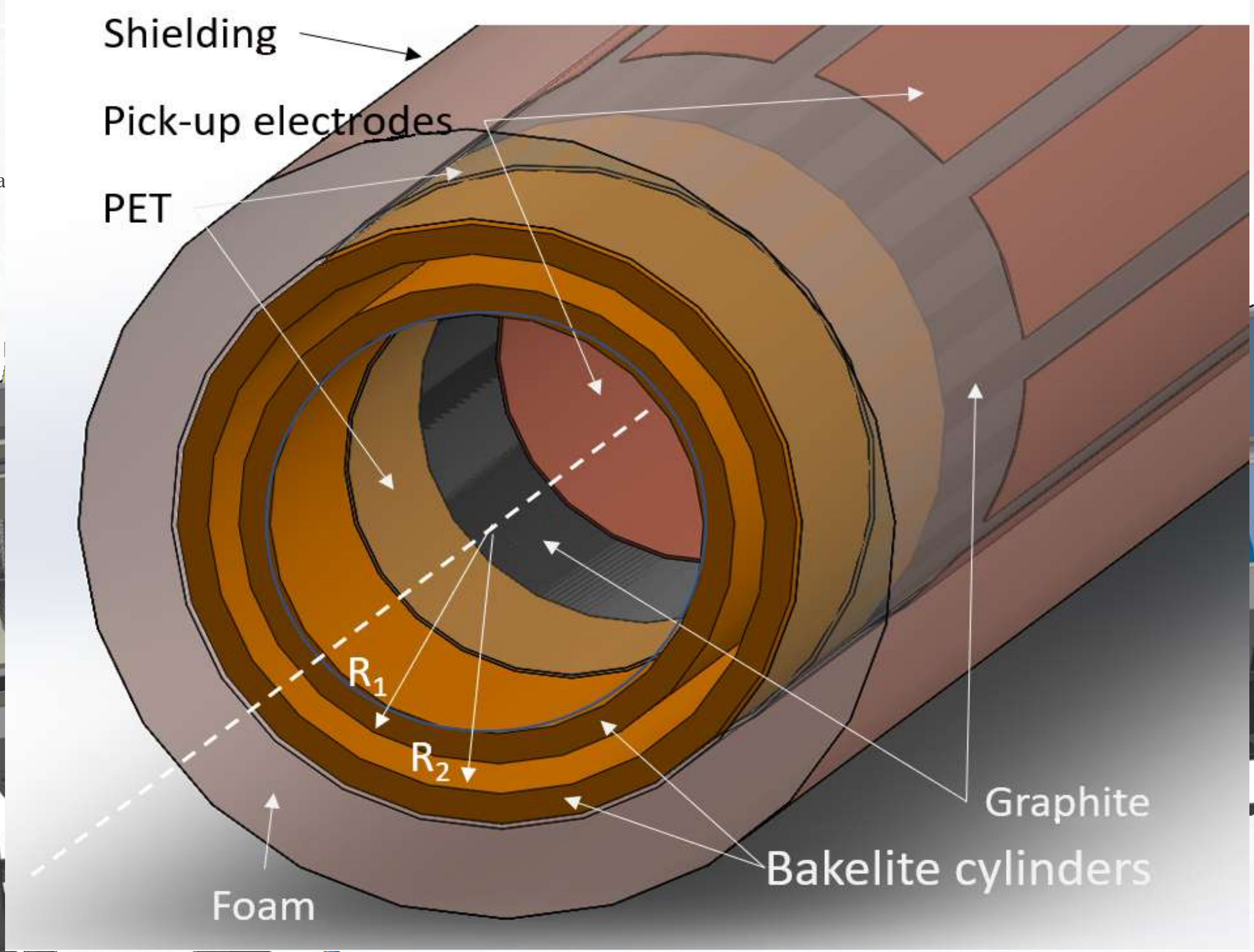
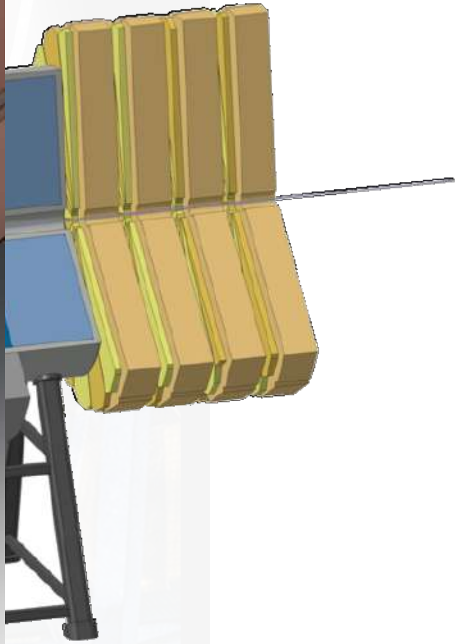






Outlook for RPCs

Present limits – time resolution

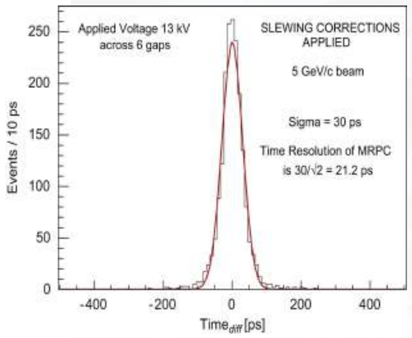
Time resolution is one of the main RPC features

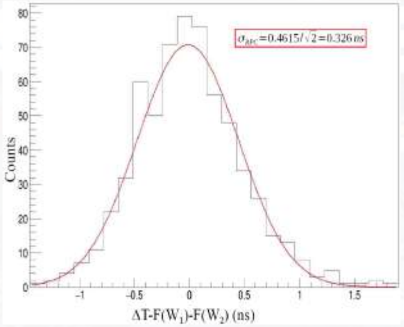
- Gold standards: MRPCs ~50 ps -- RPCs ~500 ps
- complex physics behind: cluster statistics, multiplication dynamics, electronic noise
- Empirically smaller gas gaps → higher resolution
- Smaller gas gaps can be operated at higher electric field and have a faster multiplication dynamics compressing noise fluctuations
- **Challenge: resolution beyond 50 ps**

with more and thinner gas gaps,

e.g, 20 ps with 24, 0.16 mm gaps [10.1016/j.nima.2008.06.013]

Thinner electrodes → higher signal

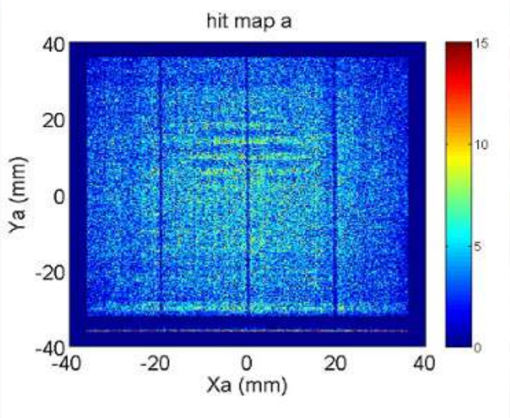


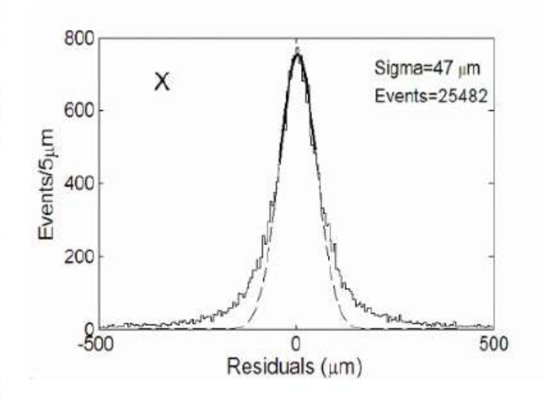


2D tracking challenge – for all RPCs

RPC generate signals with accurate position information → discharge cell footprint ~ 100mm2 (10.1088/1748-0221/7/11/P11012)

Same limitations of micro-pattern detectors coming from the readout system precision. Expensive readout electronics

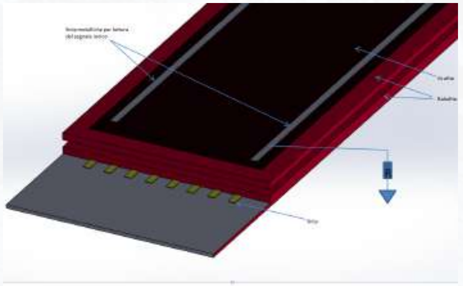


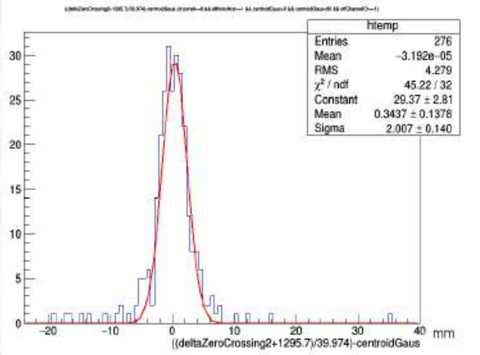


- **Planar drift chamber**

Measuring the impact position from the diffusion wave time walk difference on the graphite electrode Can reach sub mm precision. Suitable for large area low-rate environment (rate is limited to about 100 Hz/cm2) .

Very low-cost readout electronics



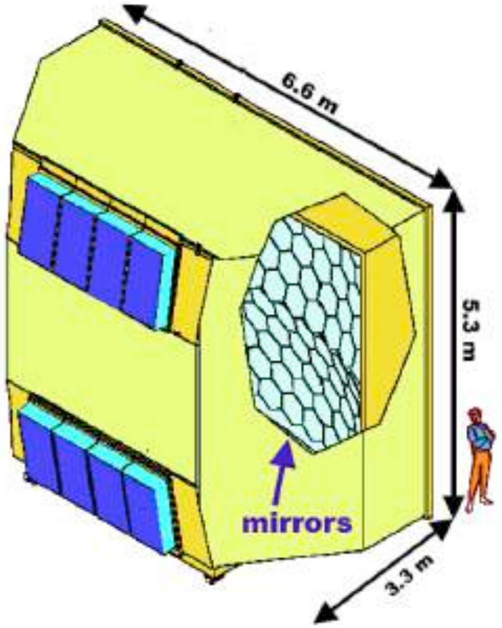


RICH

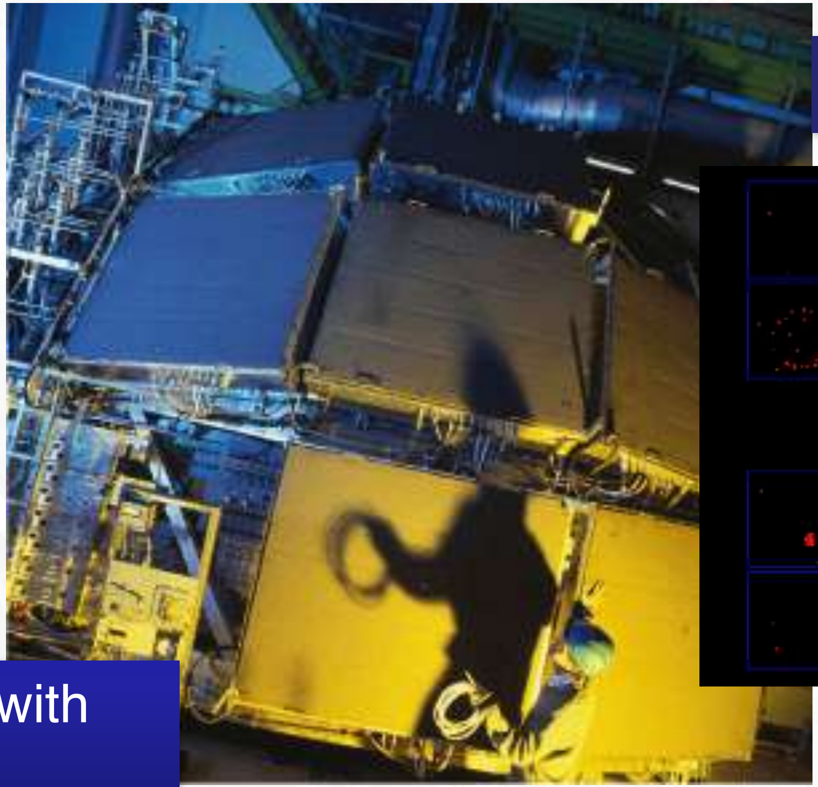
Cherenkov Radiation

*Radiation emitted when a charged particle (such as an electron) moves through a dielectric medium faster than **the phase velocity of light in that medium**.*

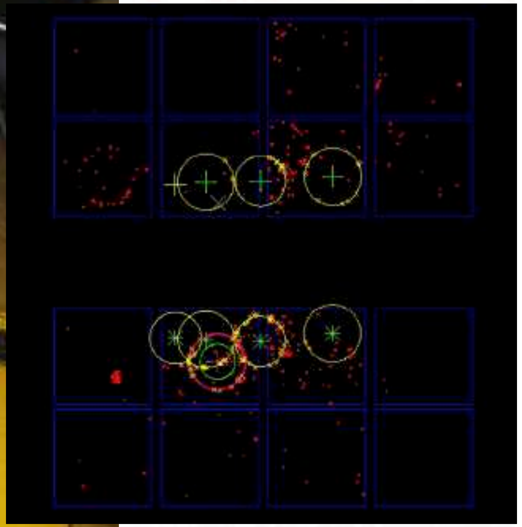
COMPASS RICH



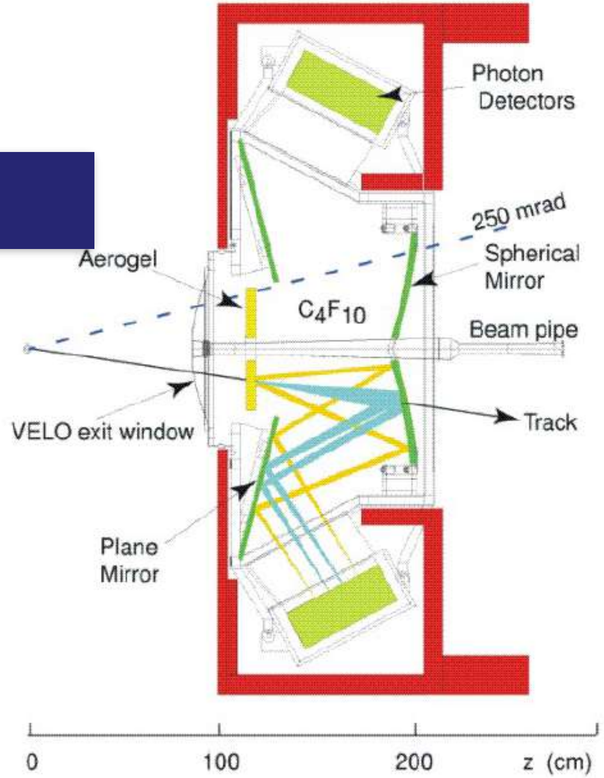
ALICE HMPID



Event Display



LHCb RICH Detector

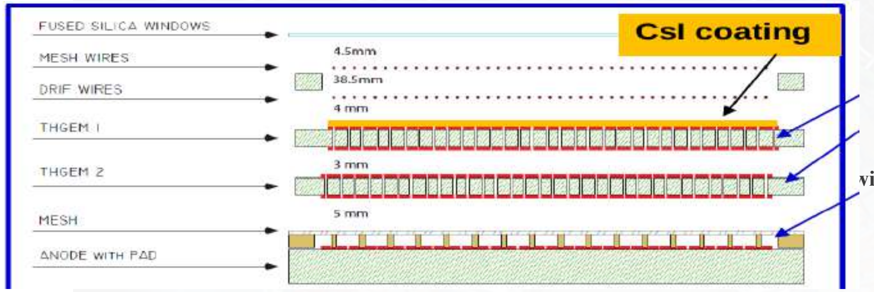


Array of 8 MWPCs with CsI photocathodes

Can be used for particle identification together with tracking detectors

Gaseous detector: photon detection

Single photon detection MPGD @ EIC (RICH)
"after the positive experience with COMPASS RICH"



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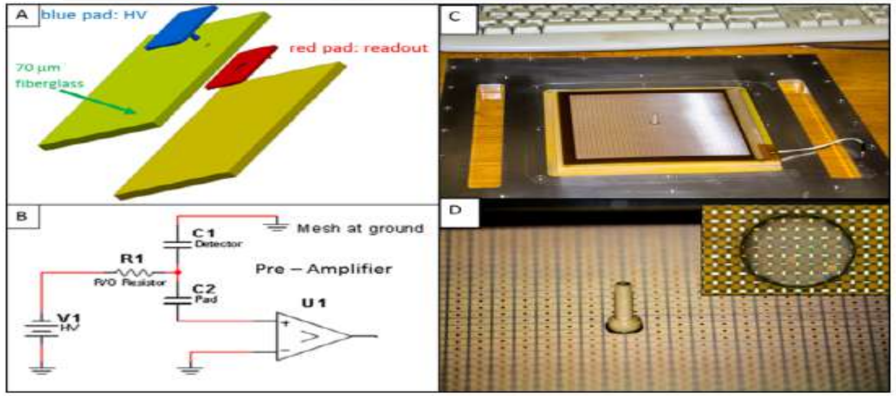
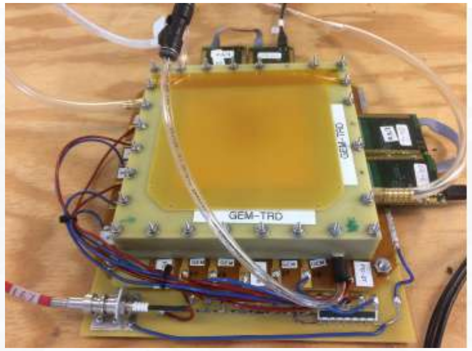


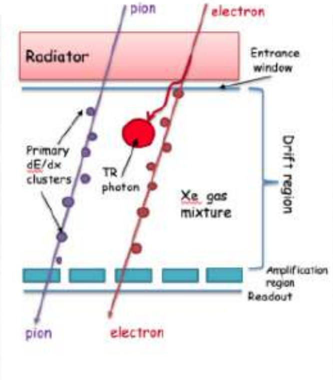
Gaseous detector: TRD

Transition Radiation Detector for electron ID in the hadron endcap of the

Future EIC detector

- A GEM TRD/Tracker
  - TRD provides high e/h rejection for electrons in 1-100 GeV range.
  - GEM tracker functions as a μTPC (21 mm drift gap)
    - Provides high resolution tracking
    - Low mass
  - Located behind RICH detector would help with RICH ring reconstruction

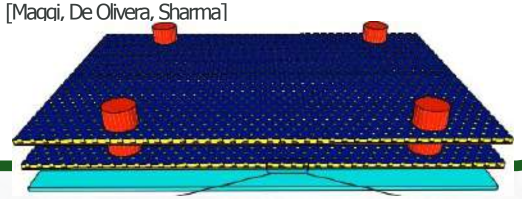




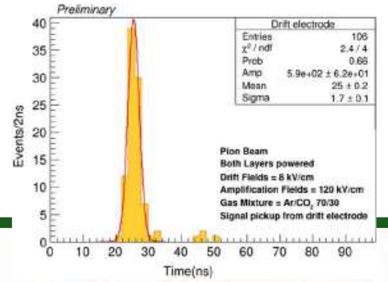
Timeline of the FTM development

2015
Concept and first GEM-based prototype at CERN

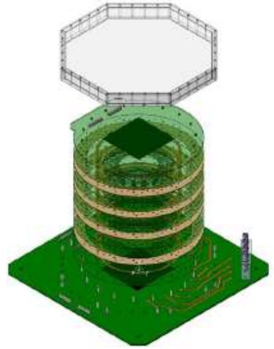
[Maggi, De Olivera, Sharma]



2016
Test beam at CERN [5]

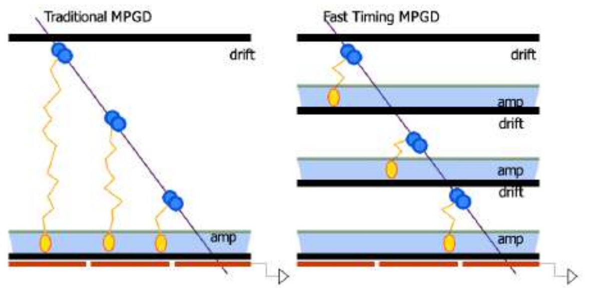


- Two-layer prototype
- Resolution of 1.7 ns measured
- Very thin drift gaps 250 µm
- Low gain
- Efficiency < 20%



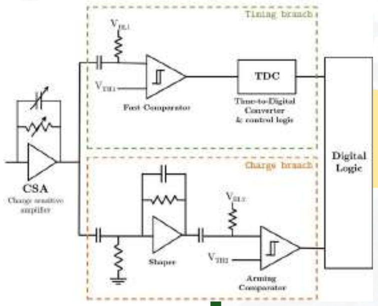
2016-17
Prototypes based on MicroMegas and THGEM

Goal: increasing gain and efficiency



Working principle in one sentence: reducing the RMS of the distance between creation point of the primary ionization cluster and amplification region
In principle, valid with any amplification structure

2018-19
Prototypes in Bari

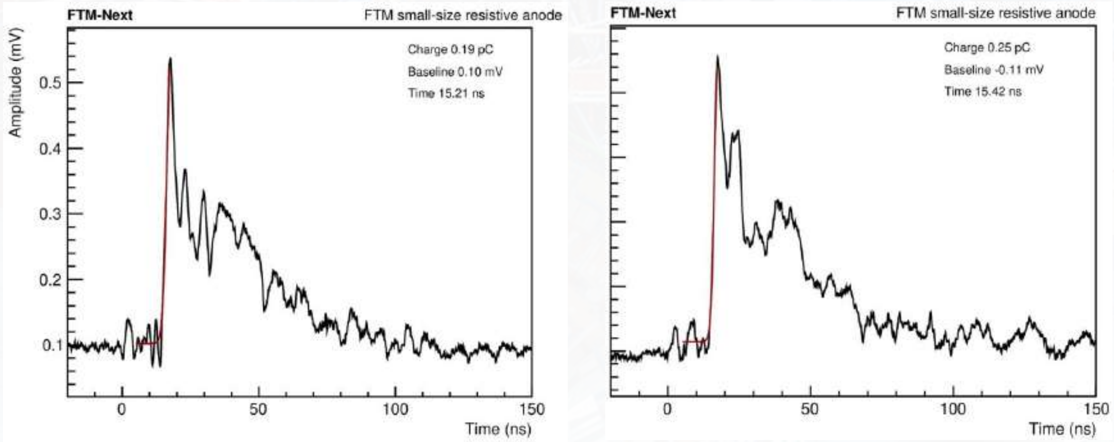


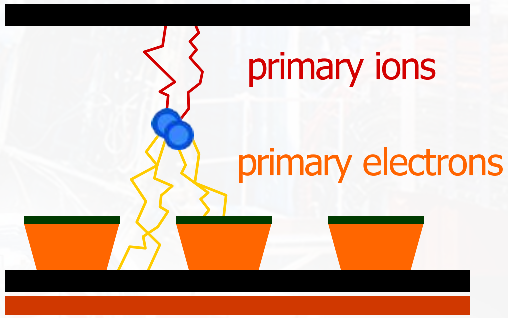
2020→
Small-size FTM

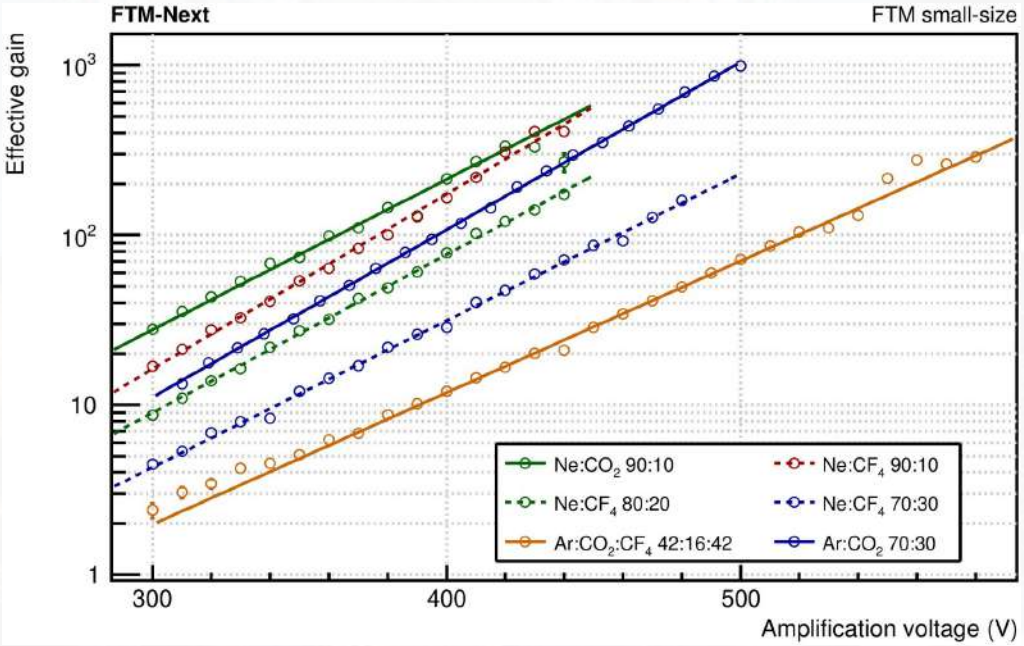
Goal: Demonstrate multi-layer principle with small-area

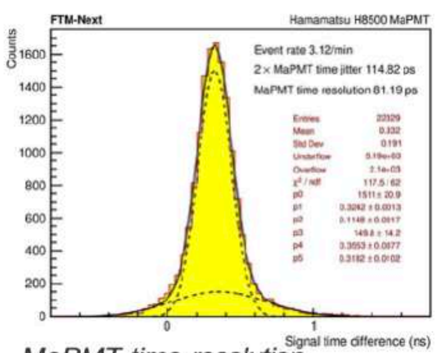
First results: signal and gain

Signal transparency: simultaneous readout of top and bottom electrodes

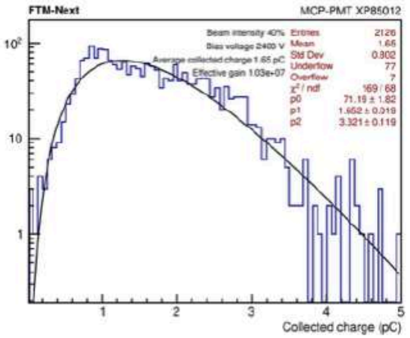








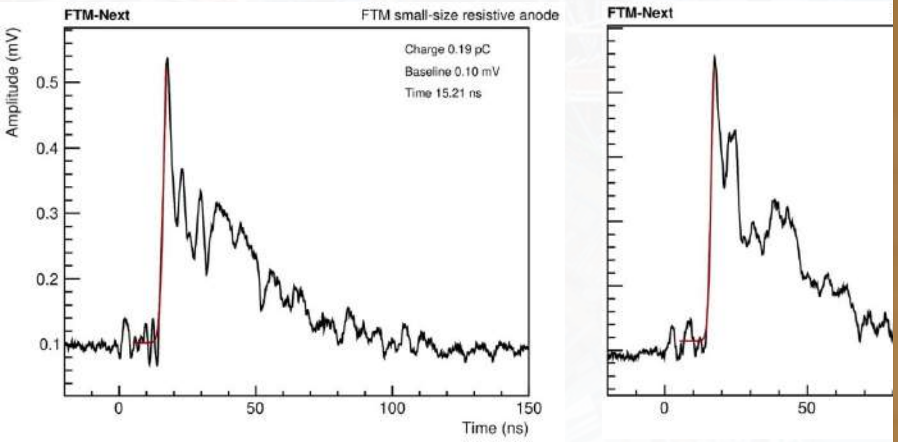
MaPMT time resolution measured in cosmic setup

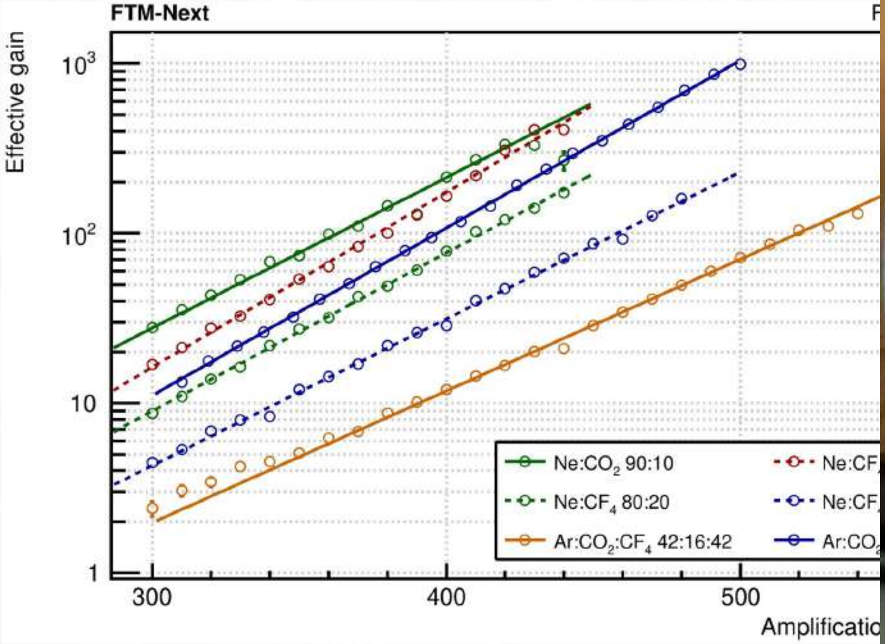


Single-photon MCP-PMT charge spectrum observed with UV laser

First results: signal and gai

Signal transparency: simultaneous readout of top and bott





Global Context: Atmospheric Changes

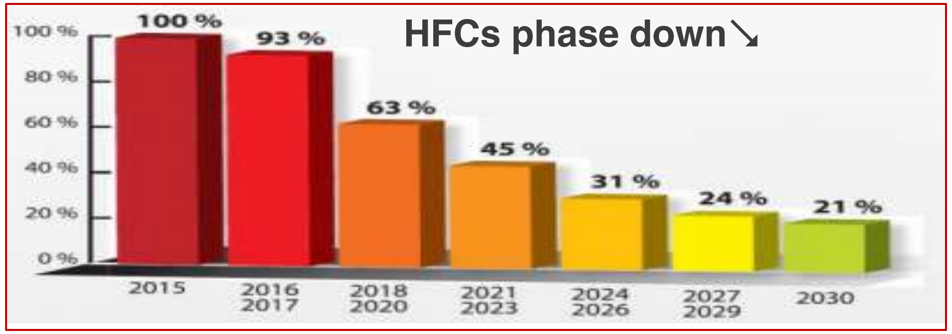
→ Ozone Depletion

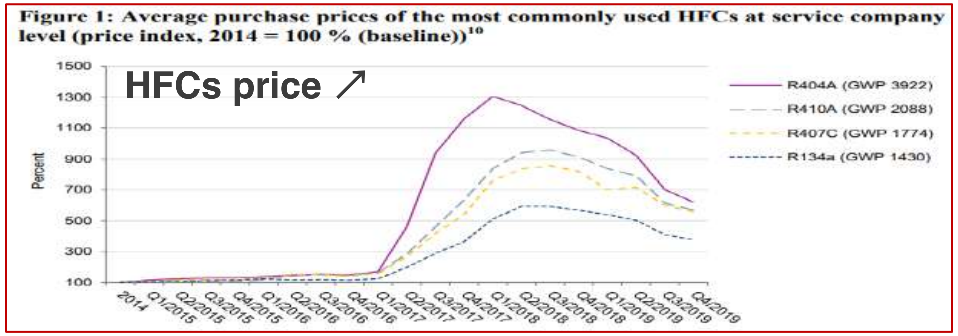
→ Global Warming

1988	1989	1990	1994	2005	2011	2012	2014	2015	2020	2050
ODS Phase out started EU	Entered into force Montreal Protocol 1987	ODS Phase out started USA	Convention entered into force UNFCCC 1992	Kyoto Protocol 1997 entered into force	CH Law CO_2 emission reduction	EU Directive Energy efficiency → Meet GHG reduction targets	EU Regulation → HFC Phase down started	COP21 Paris Agreement	EU Climate Strategy & Targets	EU Objective to be climate neutral

Response

- ODS ban from RPC detector conception finalization
- 2005 → ongoing: F-gas Recirculation /optimization/recuperation system for the detectors of large LHC experiments
- 2018 → ongoing: F-gas replacement +R&D
- 2019 → 2025: F-gas emission Workshop → Reduction Target: 28% by 2025
- 2020 → 2021: WG on F-gases → F-gases Policy proposal
- 2021: Workshop on mitigating F-gas in present & future experiments





https://ep-news.web.cern.ch/content/designing-gas-transport-parameters-future-hep-experiments

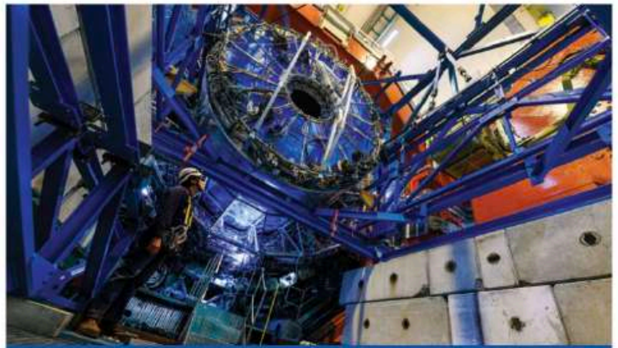
https://cerncourier.com/a/greening-gaseous-detectors/
https://ep-news.web.cern.ch/content/designing-gas-transport-parameters-future-hep-experiments

DETECTORS | MEETING REPORT

Greening gaseous detectors

28 May 2021

Thanks to their large volumes and cost effectiveness, particle-physics experiments rely heavily on gaseous detectors. Unfortunately, environmentally harmful chlorofluorocarbons known as freons play an important role in traditional gas mixtures. To address this issue, more than 200 gas-detector experts participated in a workshop hosted online by CERN on 22 April to study the operational behaviour of novel gases and alternative gas mixtures.



Large gas molecules absorb energy in vibrational and rotational modes of excitation

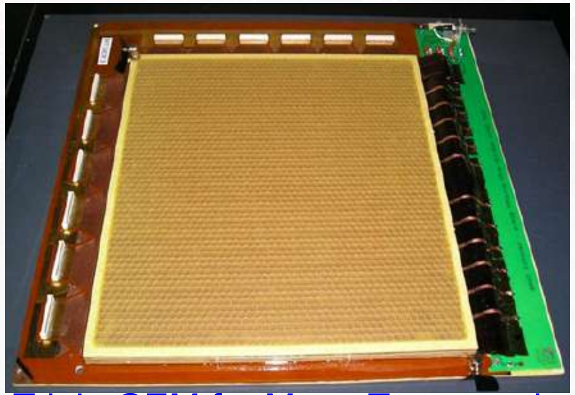
https://cerncourier.com/a/greening-gaseous-detectors/
https://ep-news.web.cern.ch/content/designing-gas-transport-parameters-future-hep-experiments

Designing gas transport parameters for future HEP experiments

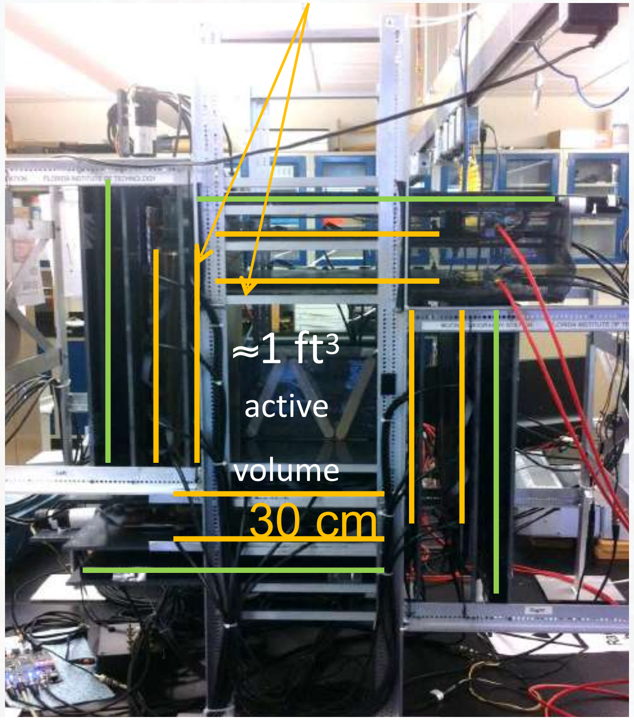
Archana Sharma (CERN) 21st Jun 2021

Muon Tomography for Homeland Security

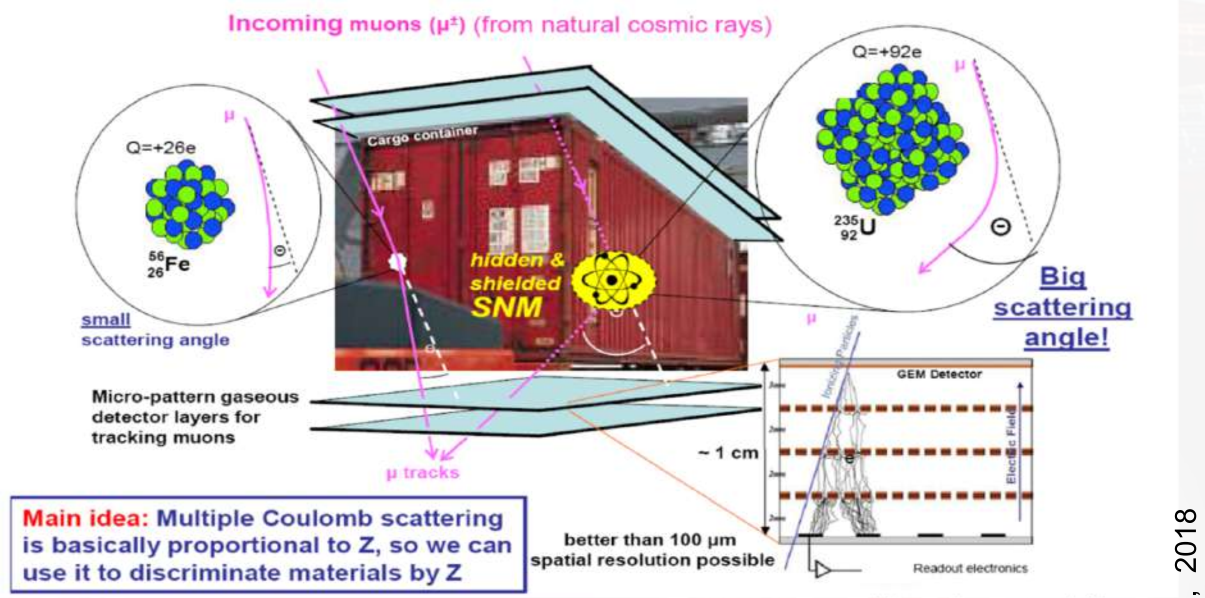
http://www.economist.com/node/21552169



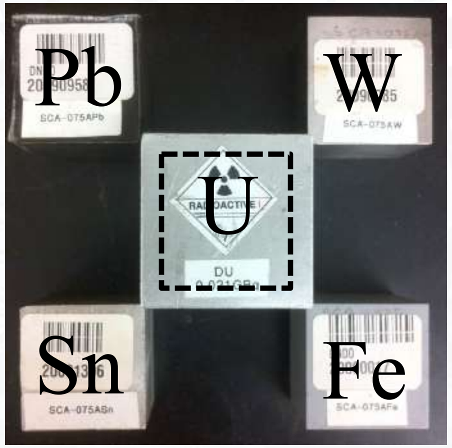
Triple GEM for Muon Tomography

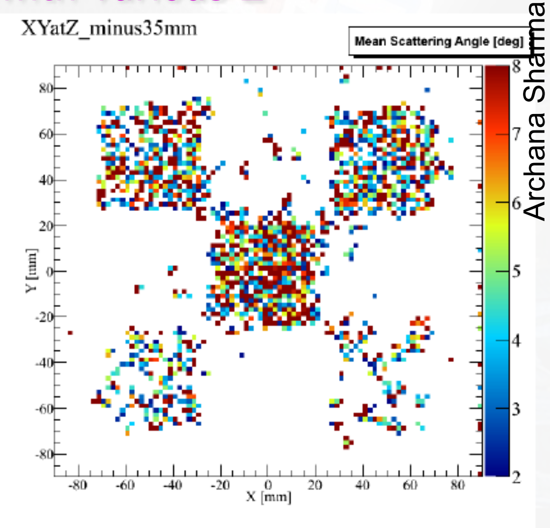


Florida Tech Cubic-Foot MT Prototype

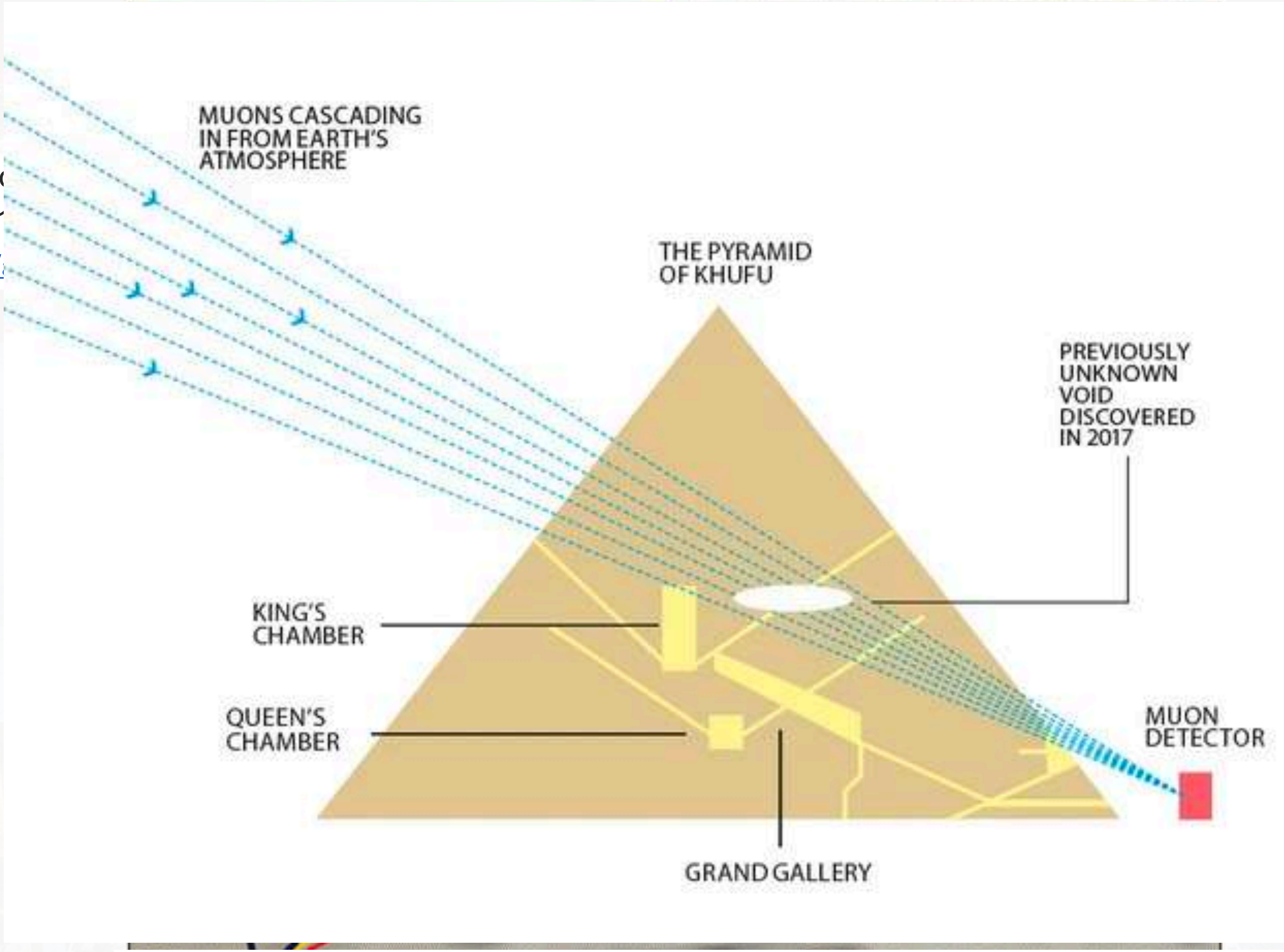


Principle of Muon Tomography (MT) based on Cosmic Ray Muons: Five targets with various Z



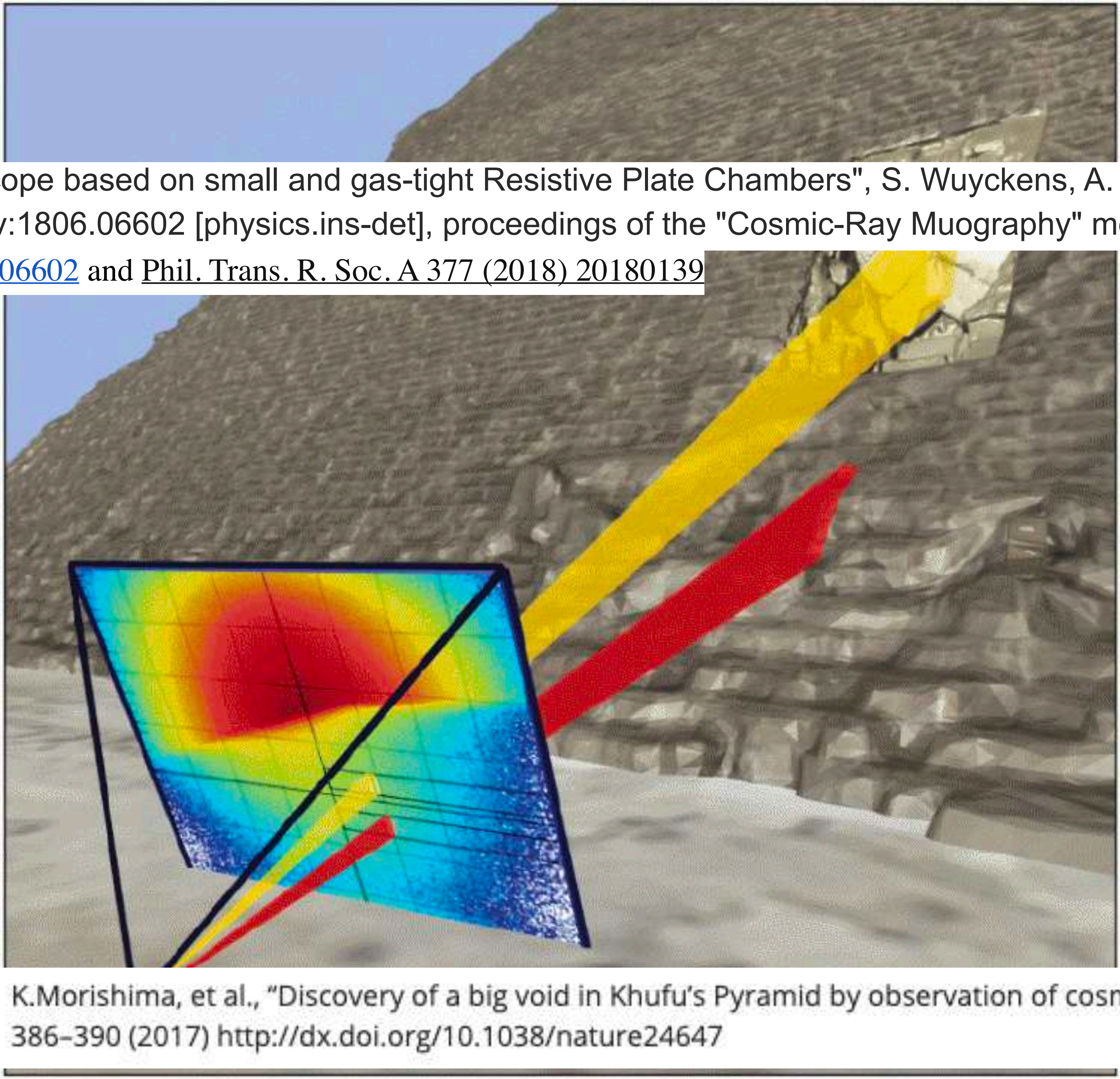


• "A portable mu… …nmanco, P. Demin, E. Cortina Gil (20… …g of the Royal Society. https://arxiv.org/…



K.Morishima, et al., "Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons.", Nature 552, 386–390 (2017) http://dx.doi.org/10.1038/nature24647

- "A portable muon telescope based on small and gas-tight Resistive Plate Chambers", S. Wuyckens, A. Giammanco, P. Demin, E. Cortina Gil (2018), arXiv:1806.06602 [physics.ins-det], proceedings of the "Cosmic-Ray Muography" meeting of the Royal Society. https://arxiv.org/abs/1806.06602 and Phil. Trans. R. Soc. A 377 (2018) 20180139



K.Morishima, et al., "Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons.", Nature 552, 386–390 (2017) http://dx.doi.org/10.1038/nature24647

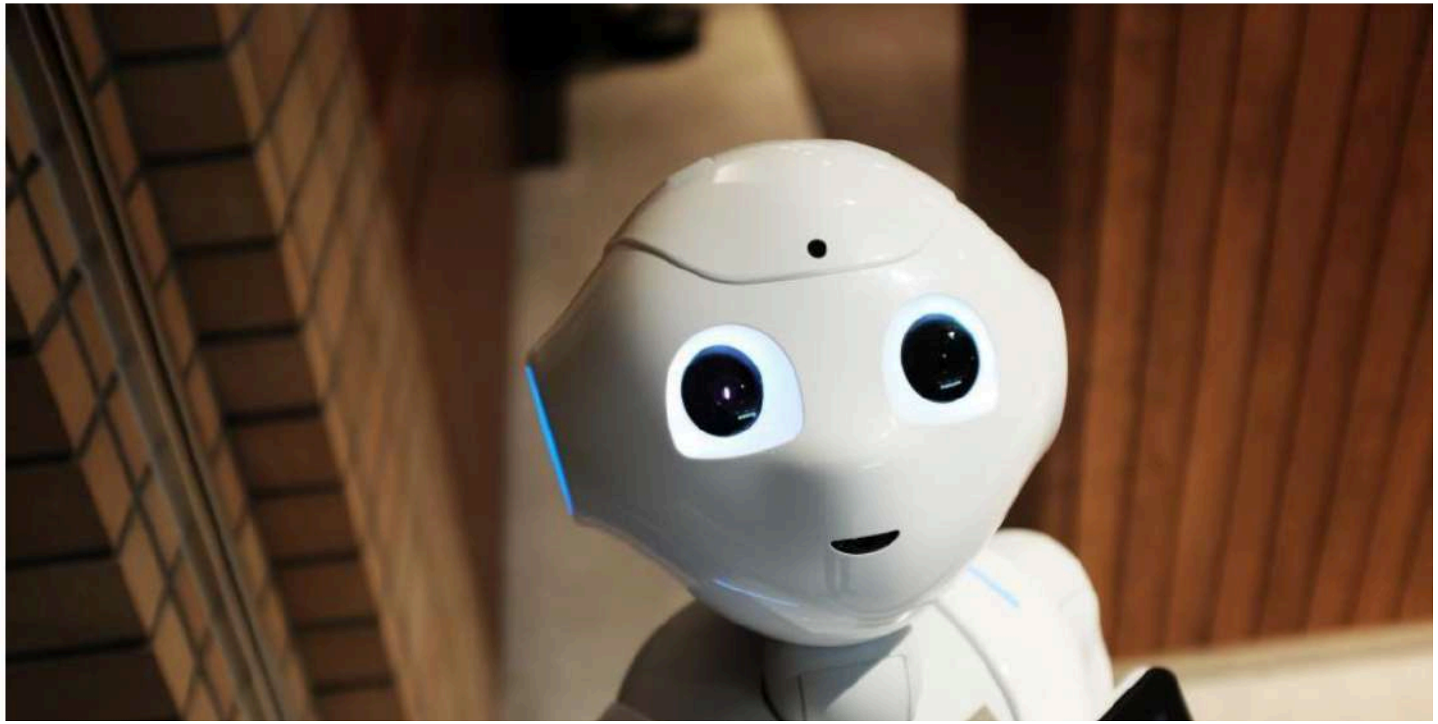
Major considerations for the future

- Big Detection Areas
- High Radiation Tolerances
- Measure High Intensity Particle Fluxes
- Medical Imaging (Big
- Detect Thermal Neutrons With High Efficiency
- Study On Micro Dosimetry
- Low Energy X-Rays
- Mechanics Electronics
- Many Other applications
- Simulations..

Gaseous Detectors Outlook beyond the next decades …

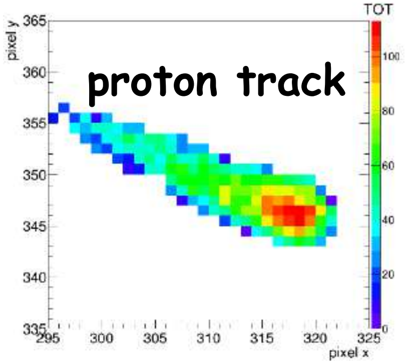
Hybrid detectors → Hybrid Readout → ASICS → Smart materials → On board imaging → Light Large Green systems

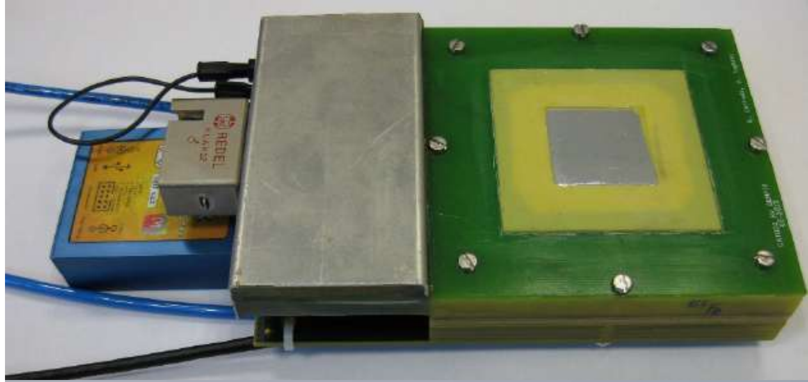
- In The Lab Of The Future, Robots Run Experiments While Scientists Sleep



THANK YOU

The GEMPix II





General overview:

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For quality assurance in hadron therapy:

Leidner, J., Ciocca, M., Mairani, A., Murtas, F. and Silari, M. (2020), A GEMPix-based integrated system for measurements of 3D dos distributions in water for carbon ion scanning beam radiotherapy. Med. Phys., 47: 2516-2525. https://doi.org/10.1002/mp.14119

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Curioni, A., et al, Measurements of ^{55}Fe activity in activated steel samples with GEMPix, 2017, https://doi.org/10.1016/j.nima.2016.12.059

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George, S.P. et al, Particle tracking with a Timepix based triple GEM detector, 2015, JINST10 P11003, http://dx.doi.org/10.1088/1748-0221/10/11/P11003

CERN

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