Nuclear physics (tracking, extremely low mass detectors, photon detection, TRD, neutron detection)

Stefano Levorato (CERN and INFN)

29.04.2021

ECFA Detector R&D Roadmap Symposium of Task Force 1 | Gaseous Detectors

Gaseous based detectors at large

Primary choice for large-area coverage with low material budget + dE/dx measurement

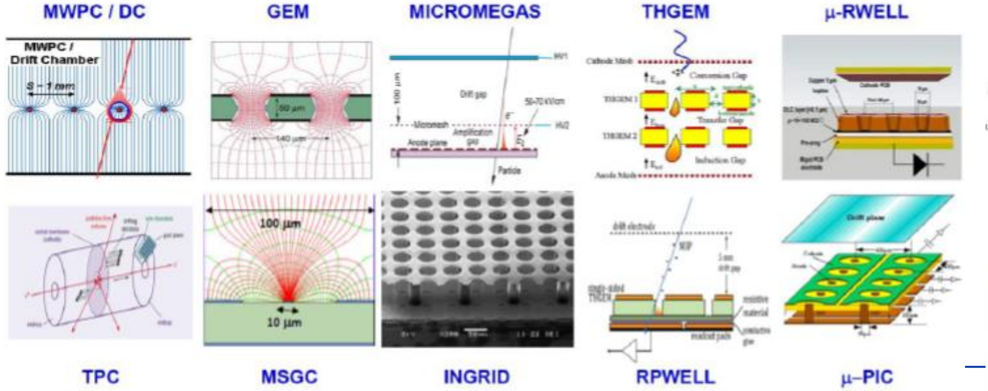
- Fixed target Experiment: Tracking (AMBER/MPGD, NA64/Straws, NA60+/GEM muon tracker) , ISOLDE/CERN: TPC (ACTAR-TPC,SPECMAT/Micromegas Based TPC), RICH-PID (AMBER/MPGD)

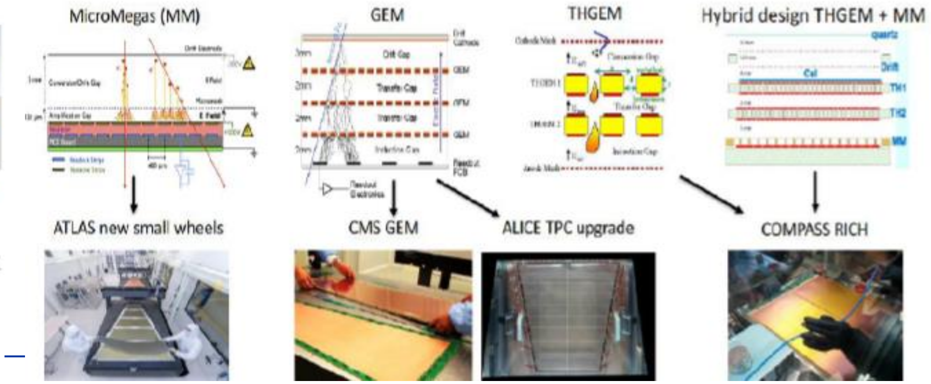
- HL-LHC Upgrades: Tracking(ALICE TPC/MPGD); Muon Systems: RPC, CSC, MDT, TGC, GEM, Micromegas;

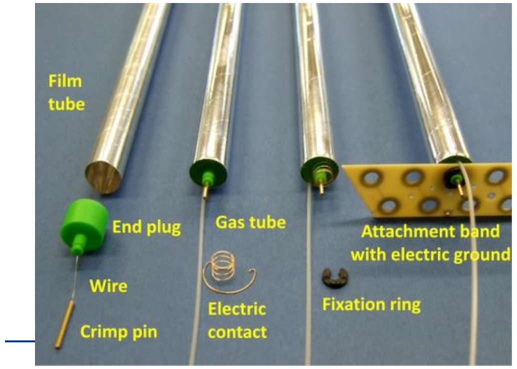
- Future Hadron Colliders: FCC-hhMuon System (MPGD, rates are comparable with HL-LHC)Future Lepton Colliders: Tracking(FCC-ee/ CepC-Drift Chambers; ILC / CePC-TPC with MPGD readout) Calorimetry(ILC, CepC–RPC or MPGD), Muon Systems

- Future Election-Ion Collider: Tracking(GEM, mWELL; TPC/MPGD), RICH (THGEM), TRD(GEM)

- Neutron detection







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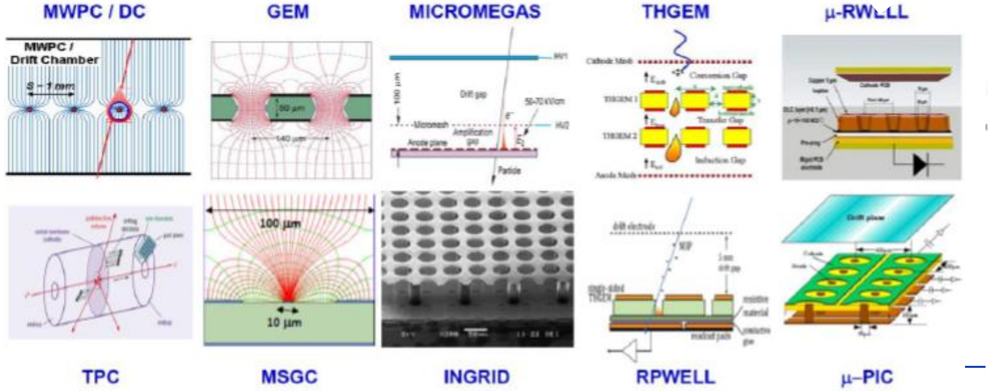
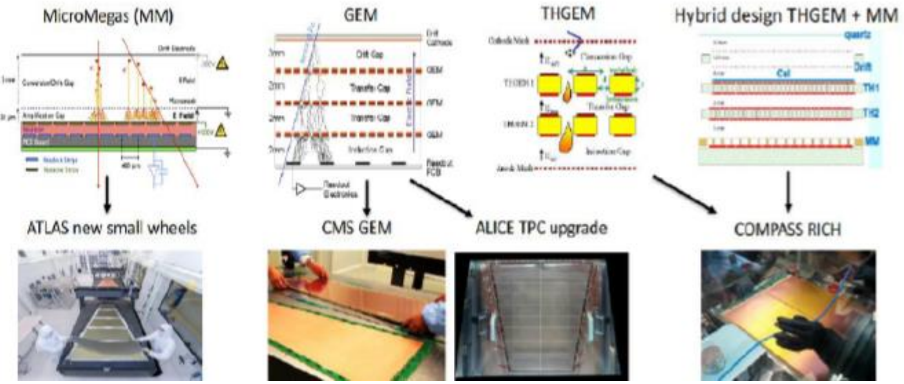
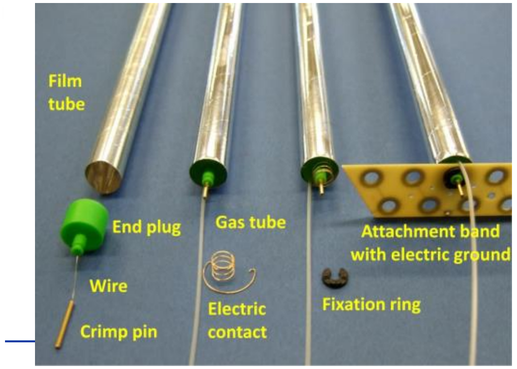
MPGDs but not only



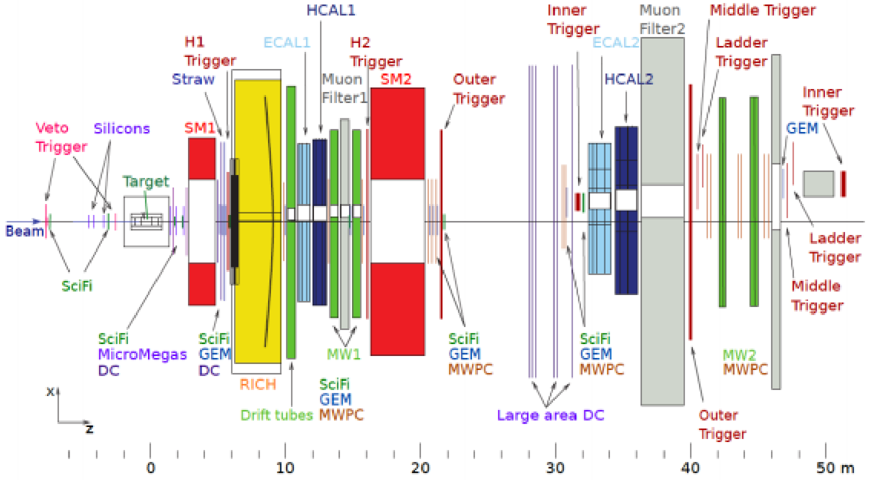




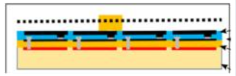
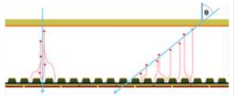
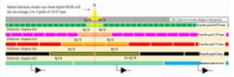
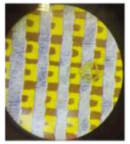
Gaseous based detector: tracking

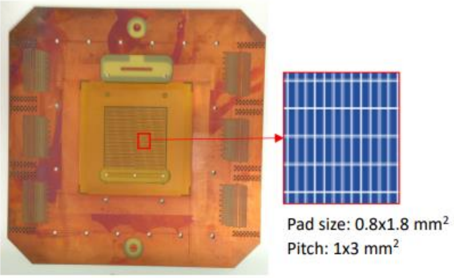
Amber tracker

Larger acceptance coverage of the existing COMPASS MWPC trackers
Particle rate largely dependent on detector position and distance from beam interaction region.
Detector's size: 0.5 – 2m   MPGD based trackers study ongoing

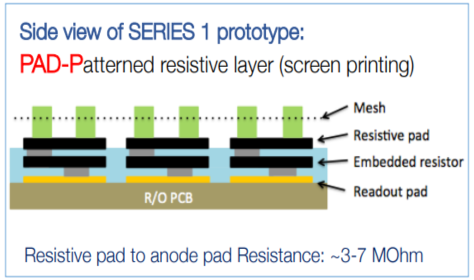


Looking into : Micromegas based trackers: able to cover both the high-rate central beam area and the external part of the aperture with a single detector taking advantage of the MPGDs anode flexibility

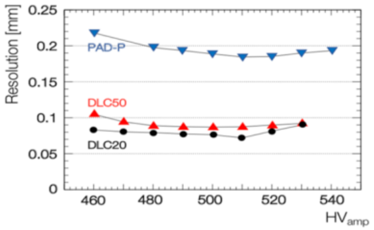
High rate (centre)		High resolution low channel count (periphery)		Low material budget anode
Resistive high granularity Micromegas	µRWELL	Capacitive charge sharing	"Zig-zag"	Al on polymer PCB
				
DOI: 10.1088/1748-0221/15/09/C09043	•DOI: 10.1088/1748-0221/14/05/P05014	https://indico.cern.ch/event/989298/contributions/4217765/	https://indico.cern.ch/event/843711/contributions/3581711/	https://indico.cern.ch/event/872501/contributions/3731237/attachments/1985339/3307907/bortfeldt_200211.pdf

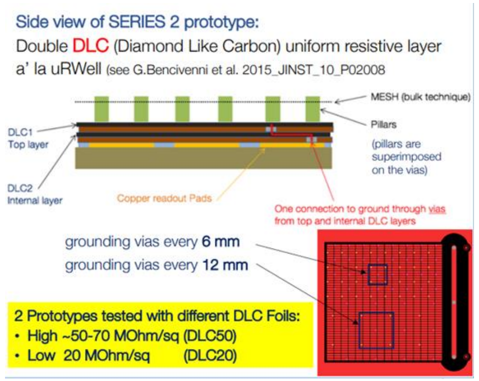

Pad size: 0.8x1.8 mm^2
Pitch: 1x3 mm^2

JINST (2020) 012028 IOP Publishing doi:10.1088/1742-6596/1498/1/012028


Side view of SERIES 1 prototype:
PAD-Patterned resistive layer (screen printing)

Resistive pad to anode pad Resistance: ~3-7 MOhm




Side view of SERIES 2 prototype:
Double DLC (Diamond Like Carbon) uniform resistive layer a' la uRWell (see G.Bencivenni et al. 2015_JINST_10_P02008

2 Prototypes tested with different DLC Foils:
- High ~50-70 MOhm/sq (DLC50)
- Low 20 MOhm/sq (DLC20)

There are significant challenges in producing a large area mixed technologies detector
A combination of the ongoing technological R&Ds would satisfy AMBER requirements

Gaseous based detector low mass: tracking

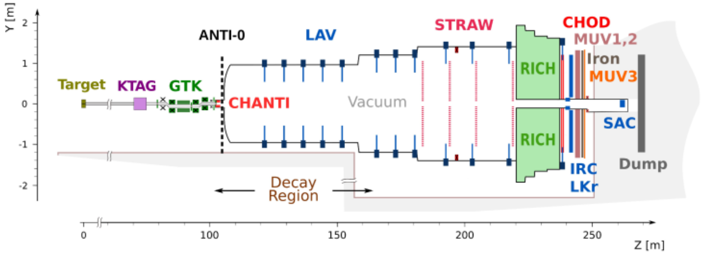
Increased rate capability and improved momentum resolution

Current NA62 straw spectrometer:

- **Straw diameter: 9.8 mm**
  - Material: 36 μm thick PET
  - Plating: 50 nm copper + 20 nm gold
  - Wire: 30 μm tungsten wire
- **Gas: Ar+CO_2 (70:30)**
- **4 chambers, 7168 straws in vacuum**
  - ~30 straw hits per track
- **Total material budget: 1.7% X_0**
  - Dominated by the PET (70%)
- **Single straw timing performance:**
  - Maximum drift time: ~150 ns
  - Leading time resolution: 3-4 ns
  - Trailing time resolution: ~30 ns

New straw detector, main features:

- Smaller straw diameter: 4.8 mm
  - Maximum drift time reduced to ~80 ns
  - Trailing time resolution improved to ~6 ns
- Keeping the 4 chambers layout, ~21000 straws
  - Number of hits per track increased to ~40
- Thinner straw material: 19 or 12 μm thick PET
- Lower total material budget: 1.0 – 1.5% X_0
  - Depending on the PET thickness option
  - Still dominated by the straw wall (60 – 70%)



From Hans Danielsonn

Gaseous based detector: tracking

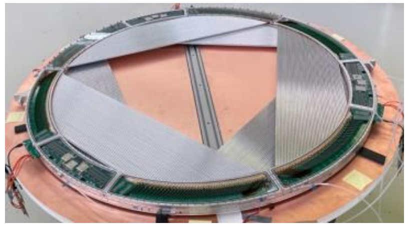
CPAD Instrumentation Frontier Workshop 2021, Dan Ambrose University of Minnesota

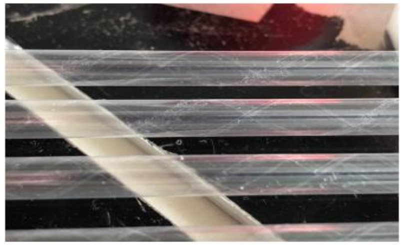
Mu2e tracker

Low-mass STRAW tracker

electron trajectory in a 1T magnetic field

Hit rate: > 5MHz/channel, 500 ns after proton bunch hits production target
Operation time: > 10 yrs
20,736 straws 6 μm Mylar + 3 μm adhesive + 6 μm Mylar double helical wrap
High radiation survival (structure & electronics) 5 mm diameter
Lengths: 45 to 120 cm Inner wall coating: 500Å Al + 200Å Au, Outer wall coating: 500Å Al





Pressurized 8 μm Mylar Straws

8 μm Mylar Straw

Tracker must be improved → ~2028 – 2030
Looking into : Thinner straws, different geometry and technologies, gas

3.5 μm Mylar + 1 μm adhesive + 3.5 μm Mylar double helical wrap straws

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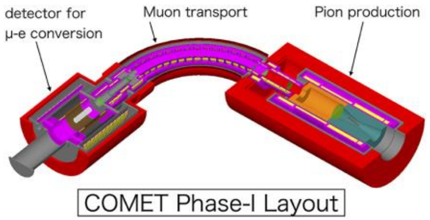
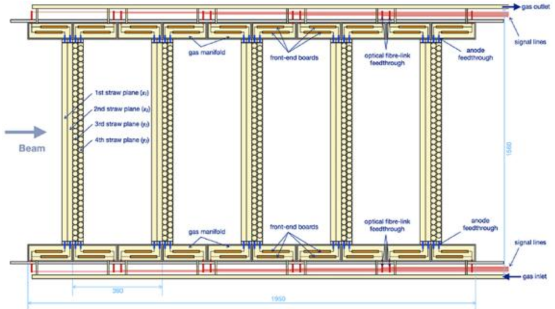
COMET Muon Conversion Experiment in J-PARC

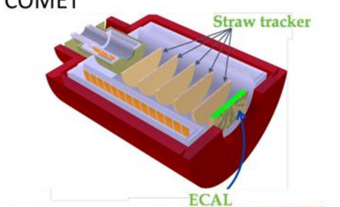
StrECAL COMET Phase-II detector

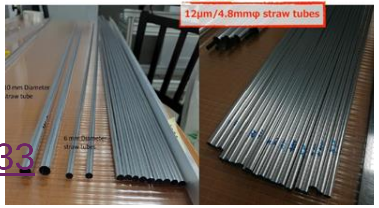


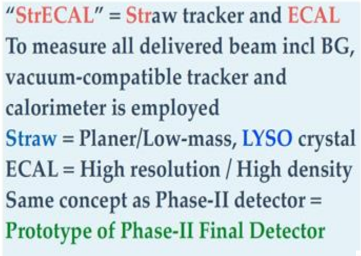
COMET Phase-I Layout



COMET







"StrECAL" = Straw tracker and ECAL
To measure all delivered beam incl BG, vacuum-compatible tracker and calorimeter is employed
Straw = Planer/Low-mass, LYSO crystal
ECAL = High resolution / High density
Same concept as Phase-II detector = Prototype of Phase-II Final Detector

9.75 mm diameter conducting straws, metalized polyimide film of 20 μm thickness. Anodic wires 25 μm diameter gold plated Tungsten wire. The baseline choice of the gas is Ar/Ethane (50:50).

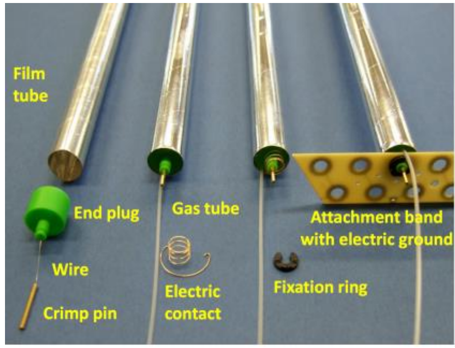
	NA62	COMET Phase-I	New Straw
Straw Wall Thickness	36 μm	20 μm	12 μm
Straw Diameter	9.8 mm	9.8 mm	4.8 mm
Metal Deposition	Cu+Au, 70nm	Al, 70 nm	*Al, 70 nm
Photo			
Current Status	In Operation	Under Construction	Just Developed

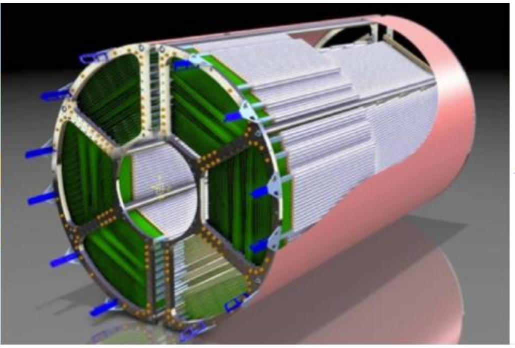
Ultra thin straw tube chambers operating in vacuum

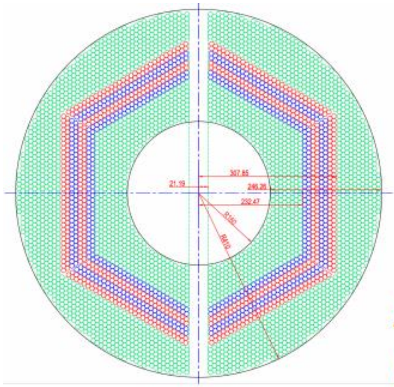
Front. Phys., 20 November 2018 | https://doi.org/10.3389/fphy.2018.00133

Gaseous based detector: tracking

PANDA Drift Chamber: GSI



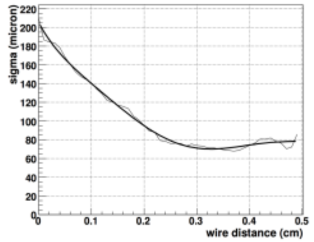




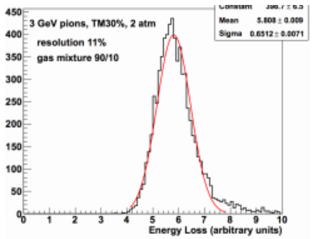
- 10 mm Mylar straw tubes
  (27 µm + 2×0.03 µm Al)
- 20 µm W-<<re(Au) s. w.
- 4636 tubes
- 26 layers
  (18 axial, 4+4 ±2.9° stereo)
- 90% Ar + 10% CO_2 at 2 bar
- B-field 2.0 T

$$\Delta\varphi = (1.8 \oplus 3.4/p_t) \times 10^{-3}$$

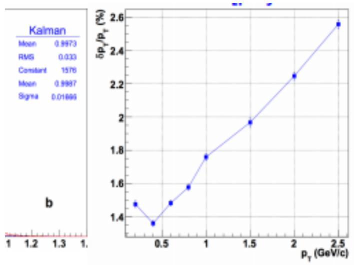
$$\Delta\vartheta = (4.0 \oplus 1.5/p_t) \times 10^{-3}$$

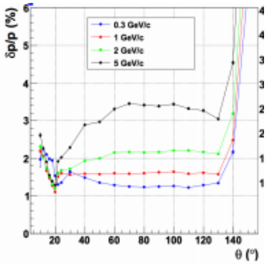


$\sigma_{r\varphi} \approx 100$ µm



$\sigma_{dE/dx}/dE/dx \approx 11\%$





$$\Delta p_t/p_t = (0.9p_t \oplus 1.4) \times 10^{-2}$$

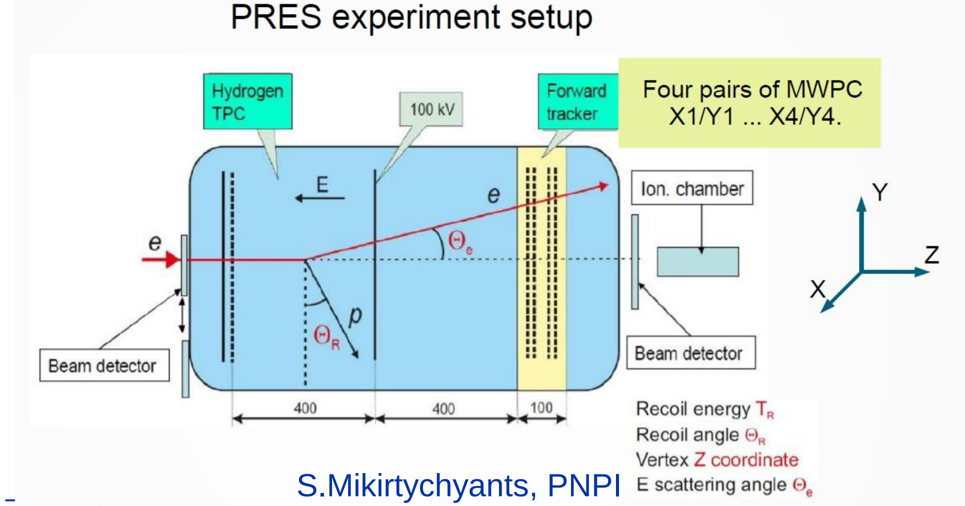
https://panda-wiki.gsi.de/pub/Tracking/WebHome/panda_tdr_trk.pdf

09:50 Drift chambers, straw tubes, TGC, CSC and other wire chambers

Speaker: Dr Peter Wintz (Forschungszentrum Jülich)

PRES MAINZ

An example among several TPCs/active targets used in nuclear physics



Sensitive area 600x600 mm (octagone)

MWPCs operated @ 20 bar gas mixture pressure

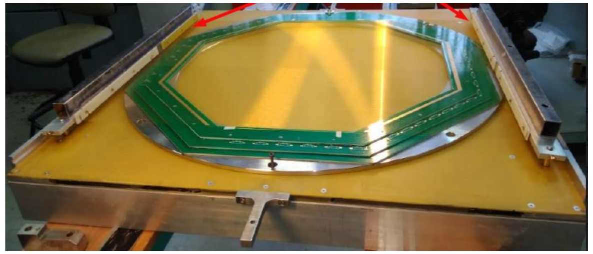
Wire cathodes (ϕ 50 micron, step 0.5 mm)

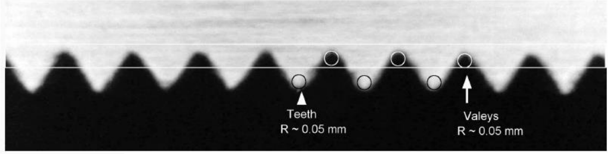
Space resolution ~ 50 micron

a. Gas gain > 300

b. At High Voltage < 6 kV

High efficiency (~100%) in whole sensitive area, low (~1%) in the central





Wire position linearity 0.0045%

S.Mikirtychyants, PNPI
2nd Meeting of the PRES Collaboration
30-31 March 2021

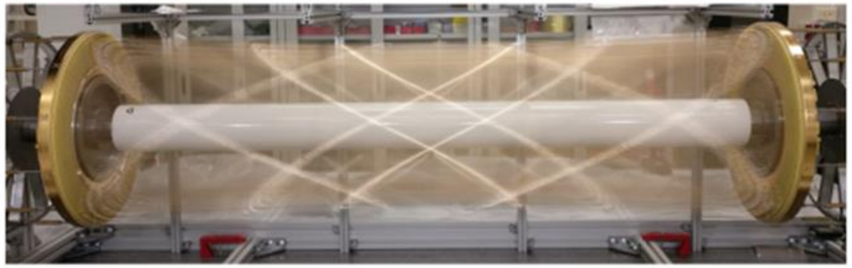
Gaseous based detector: tracking and more

The IDEA drift chamber (DCH)

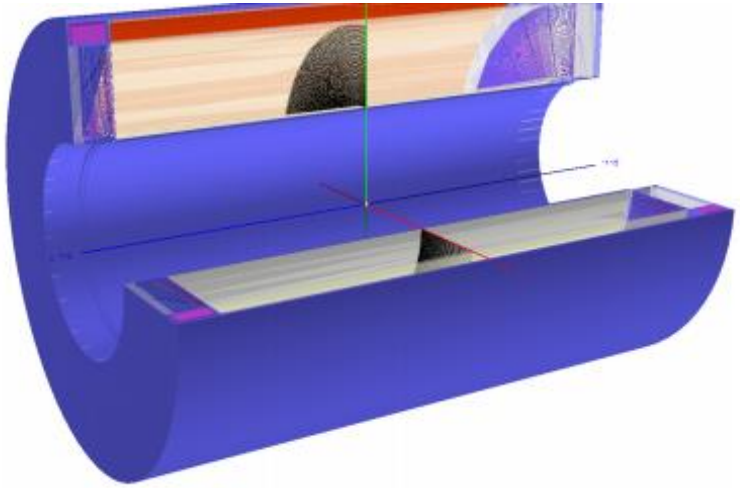
11:20 TPCs at future lepton and lepton-hadron colliders (TPC, drift chambers, large volume gaseous detectors)

Speaker: Piotr Gasik (GSI - Helmholtzzentrum fur Schwerionenforschung GmbH (DE))

Approach at construction technique of high granularity and high transparency Drift Chambers

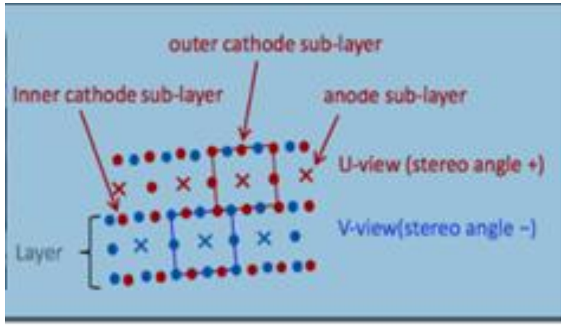


The wire net created by the combination of + and – orientation generates a more uniform equipotential surface



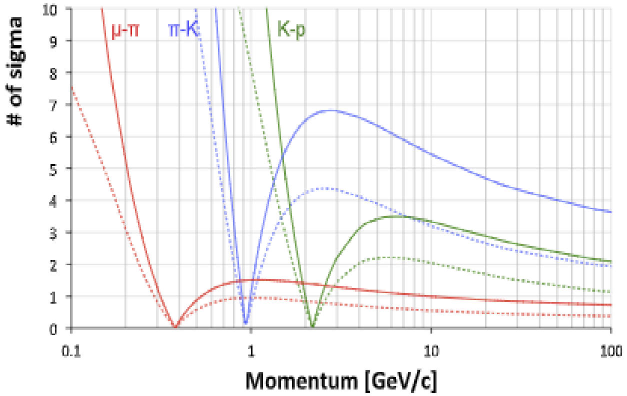
sense wires:	20 mm diameter W(Au) =>	56448 wires
field wires:	40 mm diameter Al(Ag) =>	229056 wires
f. and g. wires:	50 mm diameter Al(Ag) =>	58464 wires
	343968 wires in total	

- High wire number requires a non standard wiring procedure and needs a feed-through-less wiring system.
- A novel wiring procedure developed for the construction of the ultra-light MEG-II drift chamber



The dE/dx with cluster counting, a desirable achievement not yet reached and in need of R&D

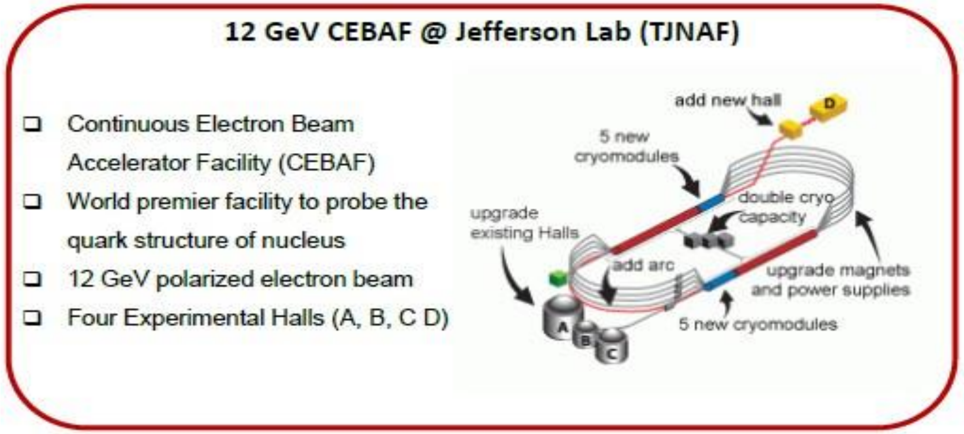
Particle Separation (dE/dx vs dN/dx)



Kondo Gnanvo

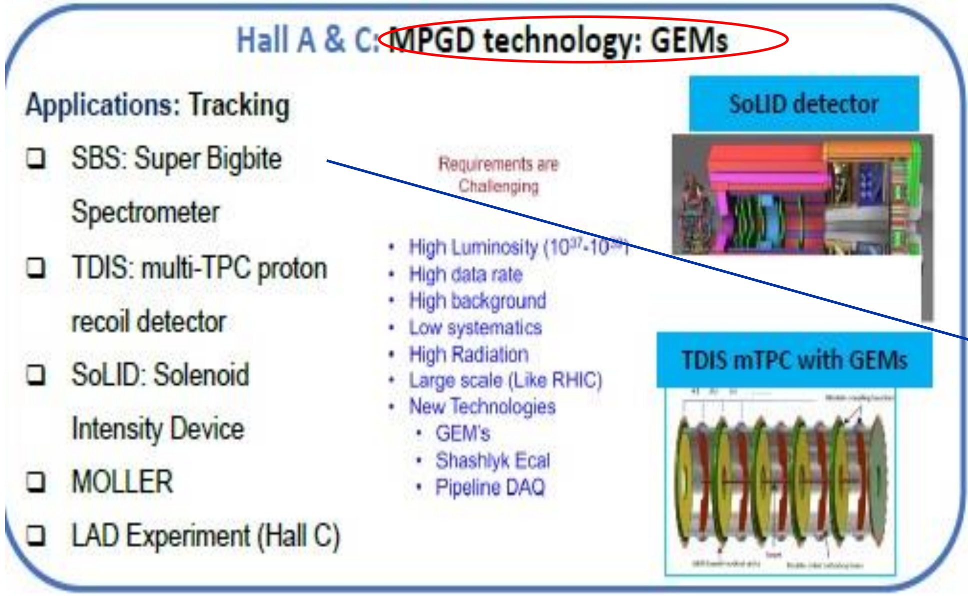
Gaseous based detector: tracking

JLAB



12 GeV CEBAF @ Jefferson Lab (TJNAF)

- ❑ Continuous Electron Beam Accelerator Facility (CEBAF)
- ❑ World premier facility to probe the quark structure of nucleus
- ❑ 12 GeV polarized electron beam
- ❑ Four Experimental Halls (A, B, C D)



Hall A & C: MPGD technology: GEMs

Applications: Tracking

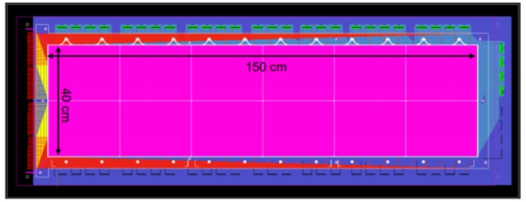
- ❑ SBS: Super Bigbite Spectrometer
- ❑ TDIS: multi-TPC proton recoil detector
- ❑ SoLID: Solenoid Intensity Device
- ❑ MOLLER
- ❑ LAD Experiment (Hall C)

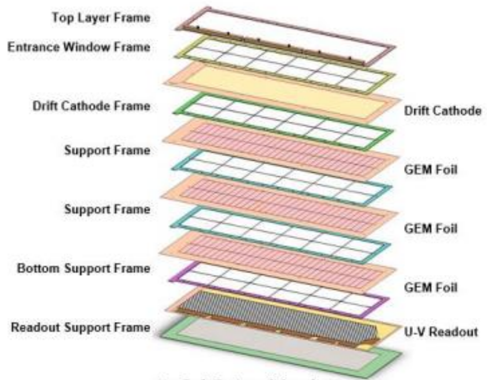
Requirements are Challenging

- High Luminosity (10^{37}-10^{39})
- High data rate
- High background
- Low systematics
- High Radiation
- Large scale (Like RHIC)
- New Technologies
  - GEM's
  - Shashlyk Ecal
  - Pipeline DAQ

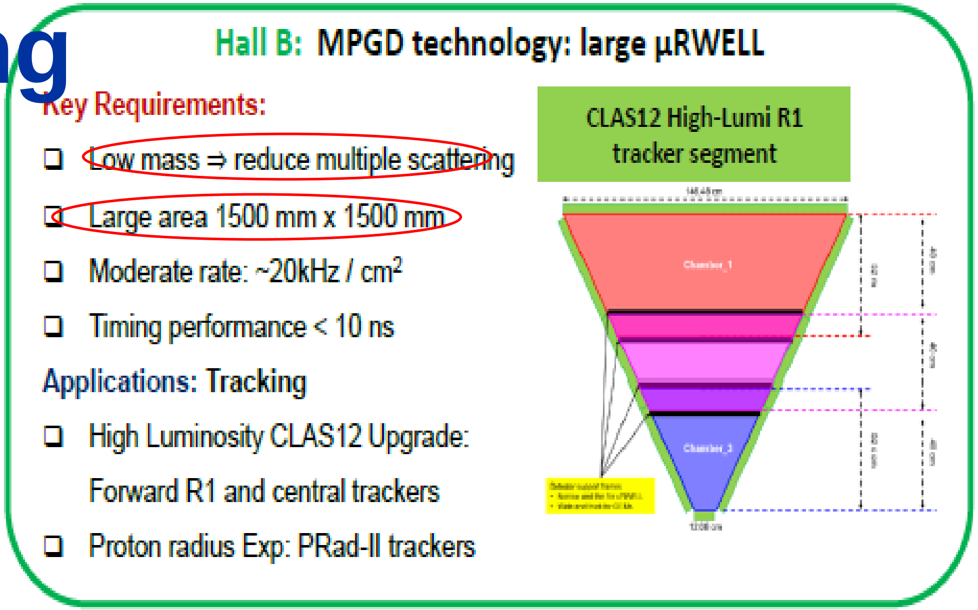
The proposed concepts feature MPGD detectors

GEM, Micromegas, μWELL → large synergy and complementarity for MPGD needs and R&D for Future Frontier Colliders and Nuclear Physics





Exploded view of chamber



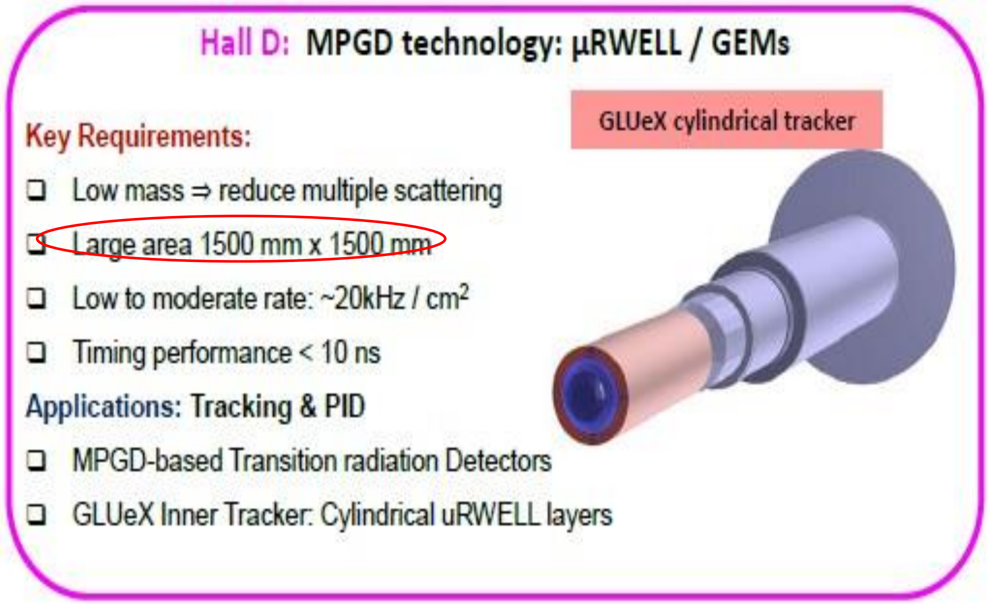
Hall B: MPGD technology: large μRWELL

Key Requirements:

- ❑ Low mass ⇒ reduce multiple scattering
- ❑ Large area 1500 mm x 1500 mm
- ❑ Moderate rate: ~20kHz / cm^2
- ❑ Timing performance < 10 ns

Applications: Tracking

- ❑ High Luminosity CLAS12 Upgrade: Forward R1 and central trackers
- ❑ Proton radius Exp: PRad-II trackers



Hall D: MPGD technology: μRWELL / GEMs

Key Requirements:

- ❑ Low mass ⇒ reduce multiple scattering
- ❑ Large area 1500 mm x 1500 mm
- ❑ Low to moderate rate: ~20kHz / cm^2
- ❑ Timing performance < 10 ns

Applications: Tracking & PID

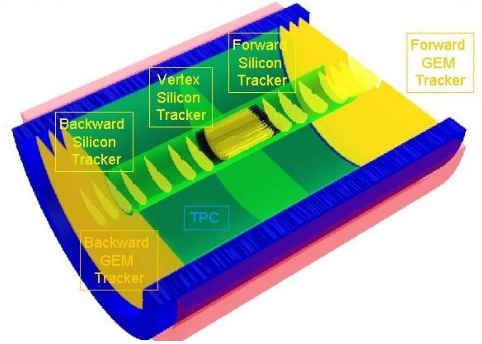
- ❑ MPGD-based Transition radiation Detectors
- ❑ GLUeX Inner Tracker: Cylindrical uRWELL layers

Kondo Gnanvo, status of the EIC R&D

Gaseous based detector: tracking

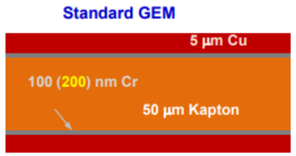
Low material budget requests: potential applications for EIC MPGD-based Tracking

In a lightweight triple-GEM the material budget is dominated by the Cu of GEM foils

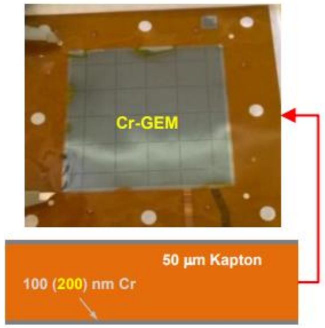


Detector Requirements

- Vertex (central): $\sigma_{xyz} \sim 20\mu m$, $d_0(z) \sim d_0(\varphi) \sim (20/p_T \text{ GeV} + 5)\ \mu m$
- Resolution
  - central: $\sigma(p_T)/p_T \sim 0.05\% \cdot p_T \oplus 0.5\%$
  - fwd/bwd ($1 < |\eta| < 2.5$): $\sigma(p_T)/p_T \sim 0.05\% \cdot p_T \oplus 1\%$
  - fwd/bwd ($2.5 < |\eta| < 3.5$): $\sigma(p_T)/p_T \sim 0.1\% \cdot p_T \oplus 2\%$
- Material budget: $X/X0 \lesssim 5\%$
- Minimum p_T: 100 MeV/c pions, 135 MeV/c Kaons

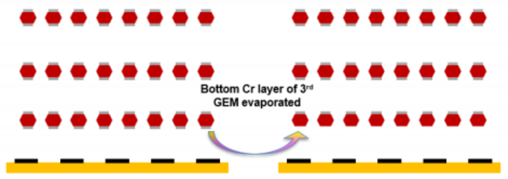


→ 100 nm residual Cr layers as electrodes, Cr-GEM



X-ray rate = 12 MHz/cm2 Significant damages on GEM response after day #2

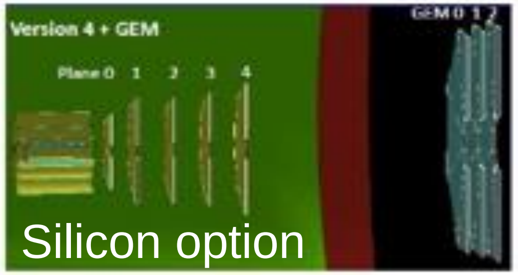
X-ray rate = 3 MHz/cm2 No Significant damages on GEM (95 days of operation)



Cr layer at the bottom of 3rd Cr-GEM vanished

⇨ small discharges @ high rate or high detector gain (within RD51 investigation heat released during spark or plasma etching process)

Option: light (Cr) GEMs for the most external disks



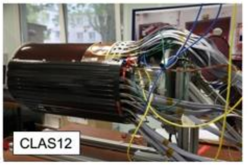
Silicon option

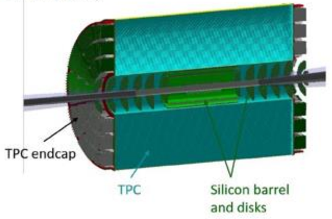
Hybrid option

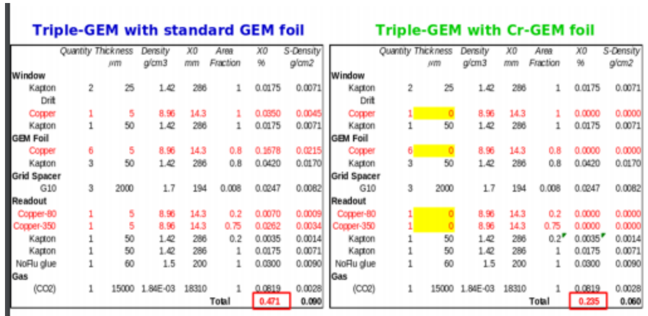
silicon vertex + TPC (barrel), 7 silicon disks for back/forward

option 1: TPC + external layer of MPGD, supports tracking + time

option 2: coaxial layers of µ–RWELLs







Triple-GEM with standard GEM foil

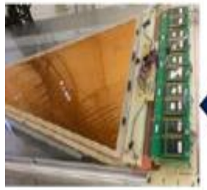
	Quantity	Thickness µm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Drift							
Copper	1	5	8.96	14.3	1	0.0350	0.0045
Kapton	1	50	1.42	286	1	0.0175	0.0071
GEM Foil							
Copper	6	5	8.96	14.3	0.8	0.1678	0.0215
Kapton	3	50	1.42	286	0.8	0.0420	0.0170
Grid Spacer							
G10	3	2000	1.7	194	0.008	0.0247	0.0082
Readout							
Copper-80	1	5	8.96	14.3	0.2	0.0070	0.0009
Copper-350	1	5	8.96	14.3	0.75	0.0262	0.0034
Kapton	1	50	1.42	286	0.2	0.0035	0.0014
Kapton	1	50	1.42	286	1	0.0175	0.0071
NoFlu glue	1	60	1.5	200	1	0.0300	0.0090
Gas							
(CO2)	1	15000	1.84E-03	18310	1	0.0819	0.0028
					Total	**0.471**	**0.090**

Triple-GEM with Cr-GEM foil

	Quantity	Thickness µm	Density g/cm3	X0 mm	Area Fraction	X0 %	S-Density g/cm2
Window							
Kapton	2	25	1.42	286	1	0.0175	0.0071
Drift							
Copper	1	0	8.96	14.3	1	0.0000	0.0000
Kapton	1	50	1.42	286	1	0.0175	0.0071
GEM Foil							
Copper	6	0	8.96	14.3	0.8	0.0000	0.0000
Kapton	3	50	1.42	286	0.8	0.0420	0.0170
Grid Spacer							
G10	3	2000	1.7	194	0.008	0.0247	0.0082
Readout							
Copper-80	1	0	8.96	14.3	0.2	0.0000	0.0000
Copper-350	1	0	8.96	14.3	0.75	0.0000	0.0000
Kapton	1	50	1.42	286	0.2	0.0035	0.0014
Kapton	1	50	1.42	286	1	0.0175	0.0071
NoFlu glue	1	60	1.5	200	1	0.0300	0.0090
Gas							
(CO2)	1	15000	1.84E-03	18310	1	0.0819	0.0028
					Total	**0.235**	**0.060**

About 50% reduction in the amount of material in a EIC-FT-GEM with Cr-GEM

0.471 X0 0.235 X0



End cap Trackers: (GEMs, µRWELL, µMegas)

☐ Low mass & large area 200 cm x 50 cm

☐ Moderate rate: ~kHz / cm²

☐ No technical challenges:

Barrel Tracker: (µRWELL, µMegas)

☐ Low mass & large cylindrical MPGD layers

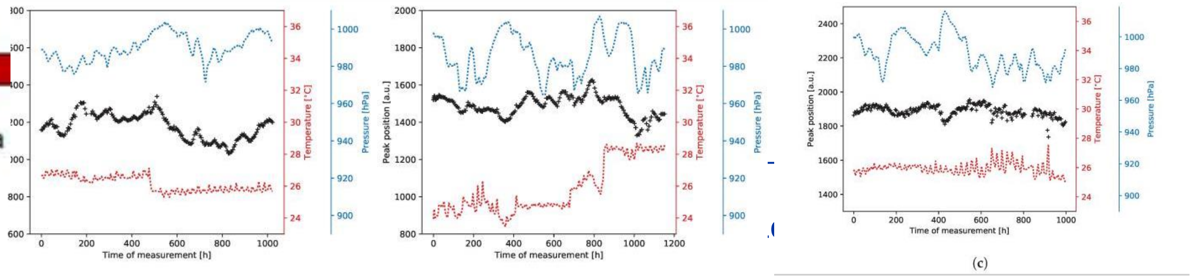
☐ Moderate rate: ~kHz / cm²

☐ Timing performance < 10 ns

☐ Technical challenges: Low mass & large area

Investigation of Copper-Less Gas Electron Multiplier Detectors Responses to Soft X-rays

GEM Detector with 100, 10, 5 nm Chromium-Clad Foils: doi: 10.3390/s20102784

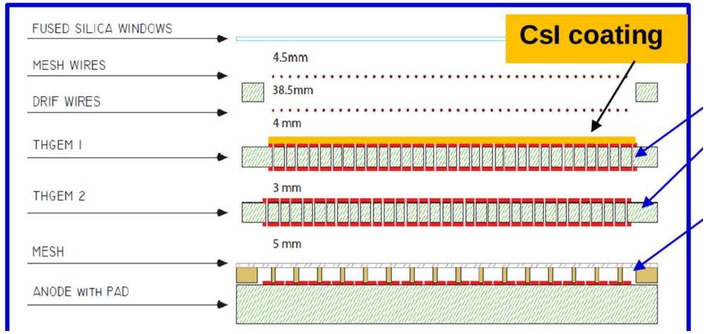


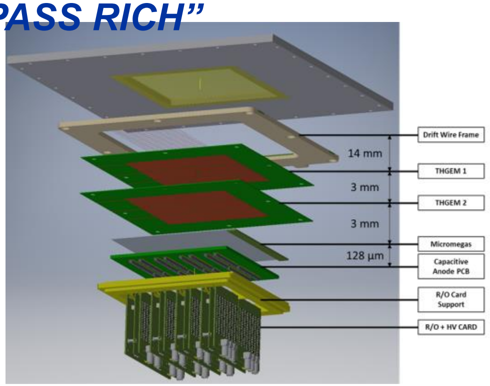
Gaseous based detector: photon detection

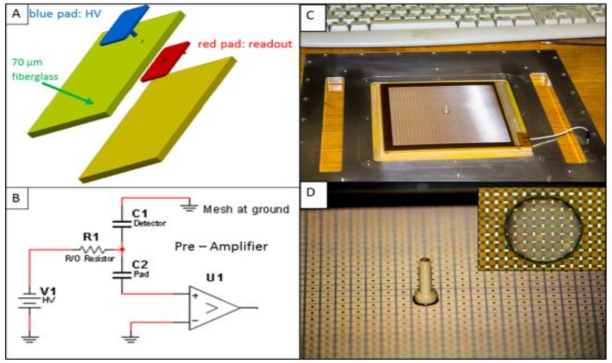
M. Blatnik et al.IEEE Transactions on Nuclear Science, vol. 62, no. 6, pp. 3256-3264, Dec. 2015, doi: 10.1109/TNS.2015.2487999.

Single photon detection MPGD @ EIC (RICH)

“after the positive experience with COMPASS RICH”



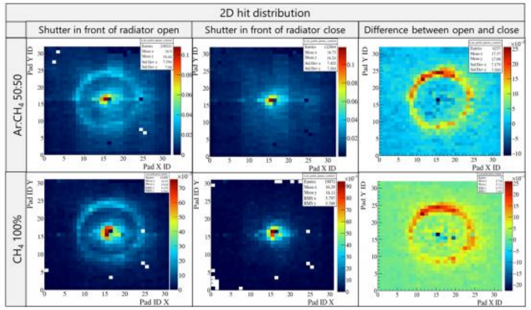




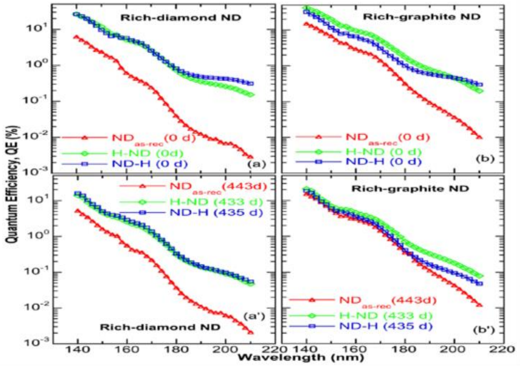
HIGH momentum RICH detector @ EIC / AMBER @ CERN

Double THGEM + Micromegas approach CsI photoconverter (Stage I) studies performed with Ar/CH4 mixtures, towards a windowless approach using CF4 and **HND photoconverting layer**

AIDA-2020-NOTE-2020-006

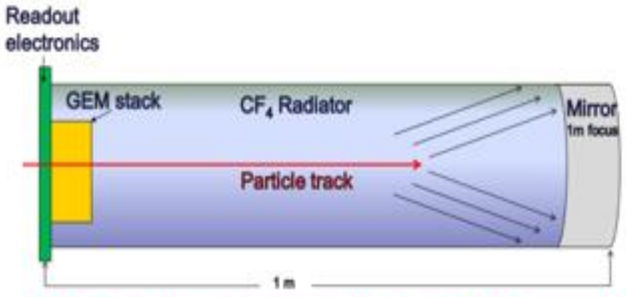


JINST 15 (2020) C09052



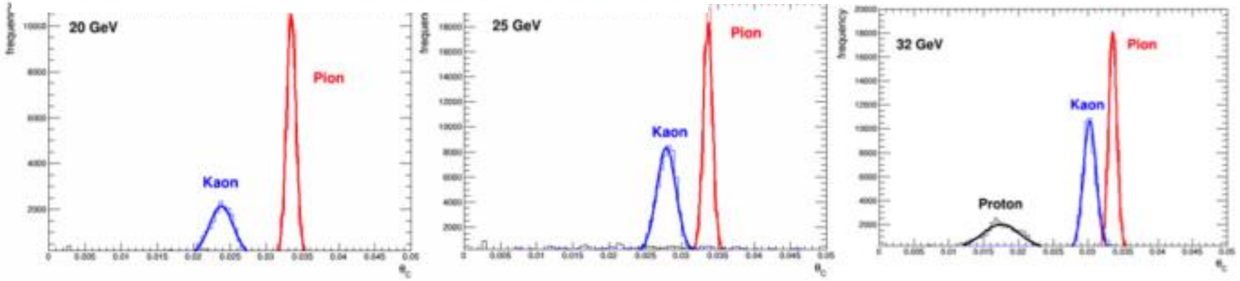
Quintuple GEM based RICH

- CsI Photocathode on top GEM
- Mirror in deep UV -> MgF2 coating
- Single Photon Capability ->quintuple GEM stack
- Radiator choice: CF4



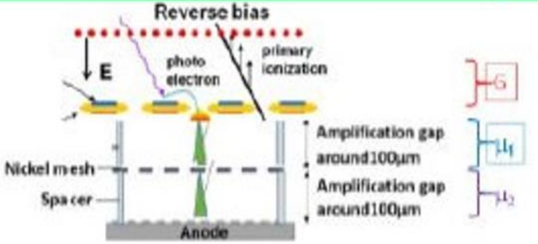
Ref: IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 62, NO. 6, DECEMBER 2015

- Small Ref. Index: Particle identification (PID) reaching out to high momenta
- The windowless technology + wave-length-tuned mirror: Minimize the loss of photons



Add an e/π capability to the central tracker, in the form of a hadron-blind detection (HBD)

ePID with HBD++: 2-stack Micromegas



K. Gnanvo (eRD6 and eRD22: Detector R&D programs for EIC)

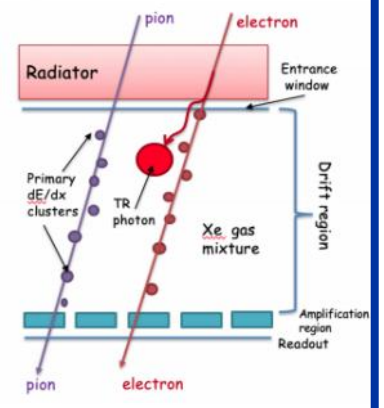
http://eicug.org/web/sites/default/files/EIC_HANDBOOK_v1.1.pdf

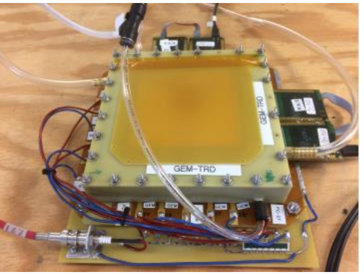
Gaseous based detector: TRD

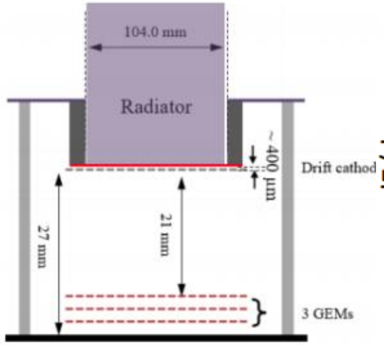
Transition Radiation Detector for electron ID in the hadron endcap of the future EIC detector

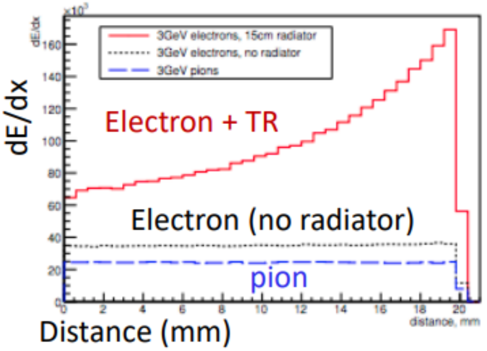
❑ A GEM TRD/Tracker

- 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



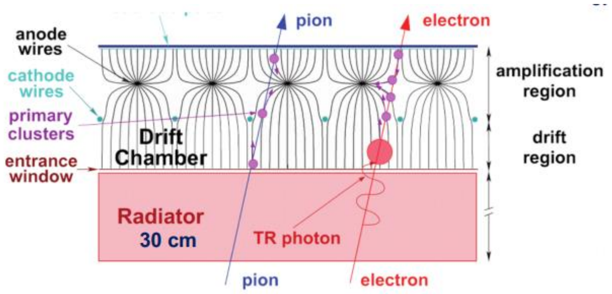


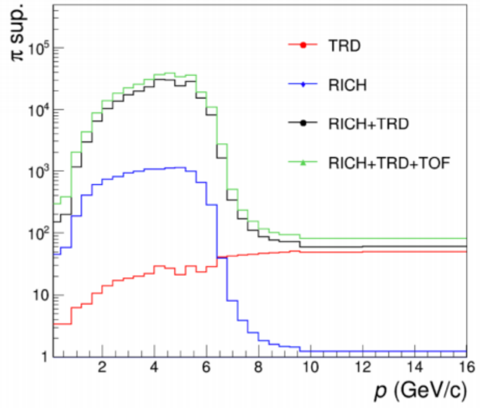




Transition Radiation Detector for CMB: intermediate detector concept at FAIR/GSI

High rate application. Drift distance reduced to 5 mm. Pad readout. Total energy is counted





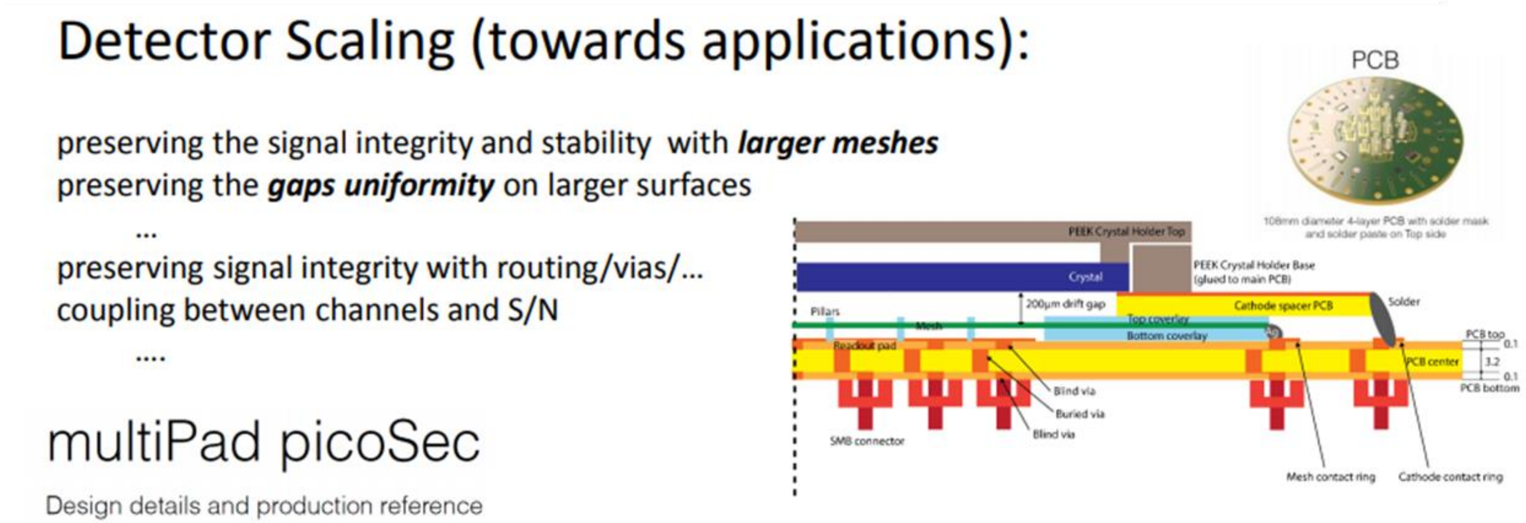
Pion suppression factor as a function of particle momentum.

TRD will be used for tracking of all charged particles with a position resolution of 300−500 μm in both directions, x and y, perpendicular to the beam direction

counting rates of up to 100 kHz/cm2

Gaseous based detector: photons for fine resolution

The picoSec project



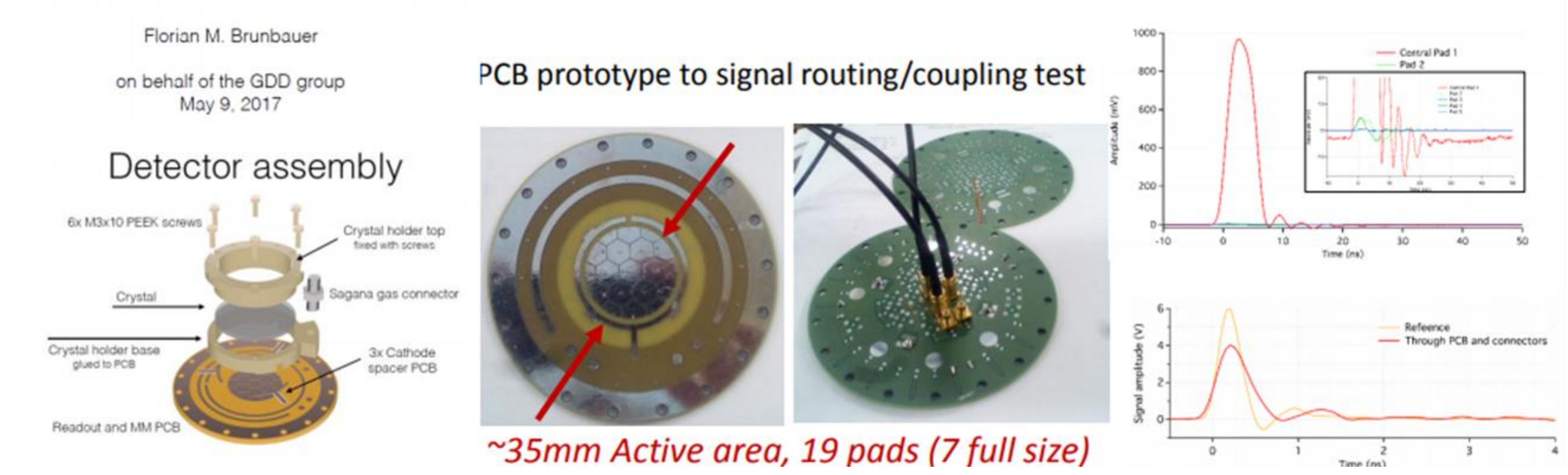
Detector Scaling (towards applications):

preserving the signal integrity and stability with ***larger meshes***
preserving the ***gaps uniformity*** on larger surfaces

…

preserving signal integrity with routing/vias/…
coupling between channels and S/N

….



multiPad picoSec

Design details and production reference

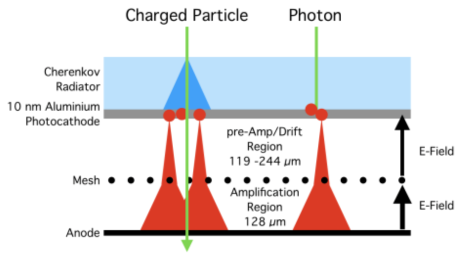
Florian M. Brunbauer

on behalf of the GDD group
May 9, 2017

Detector assembly

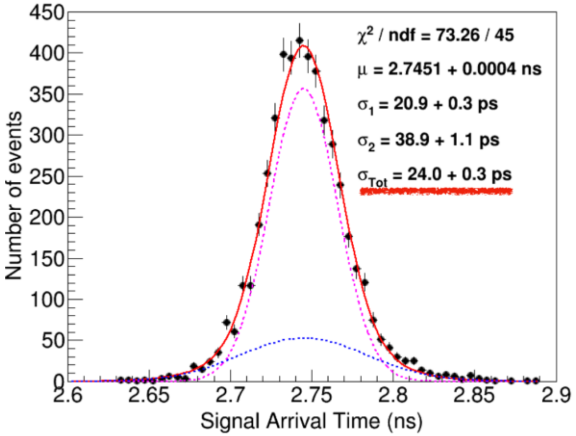
PCB prototype to signal routing/coupling test

~35mm Active area, 19 pads (7 full size)



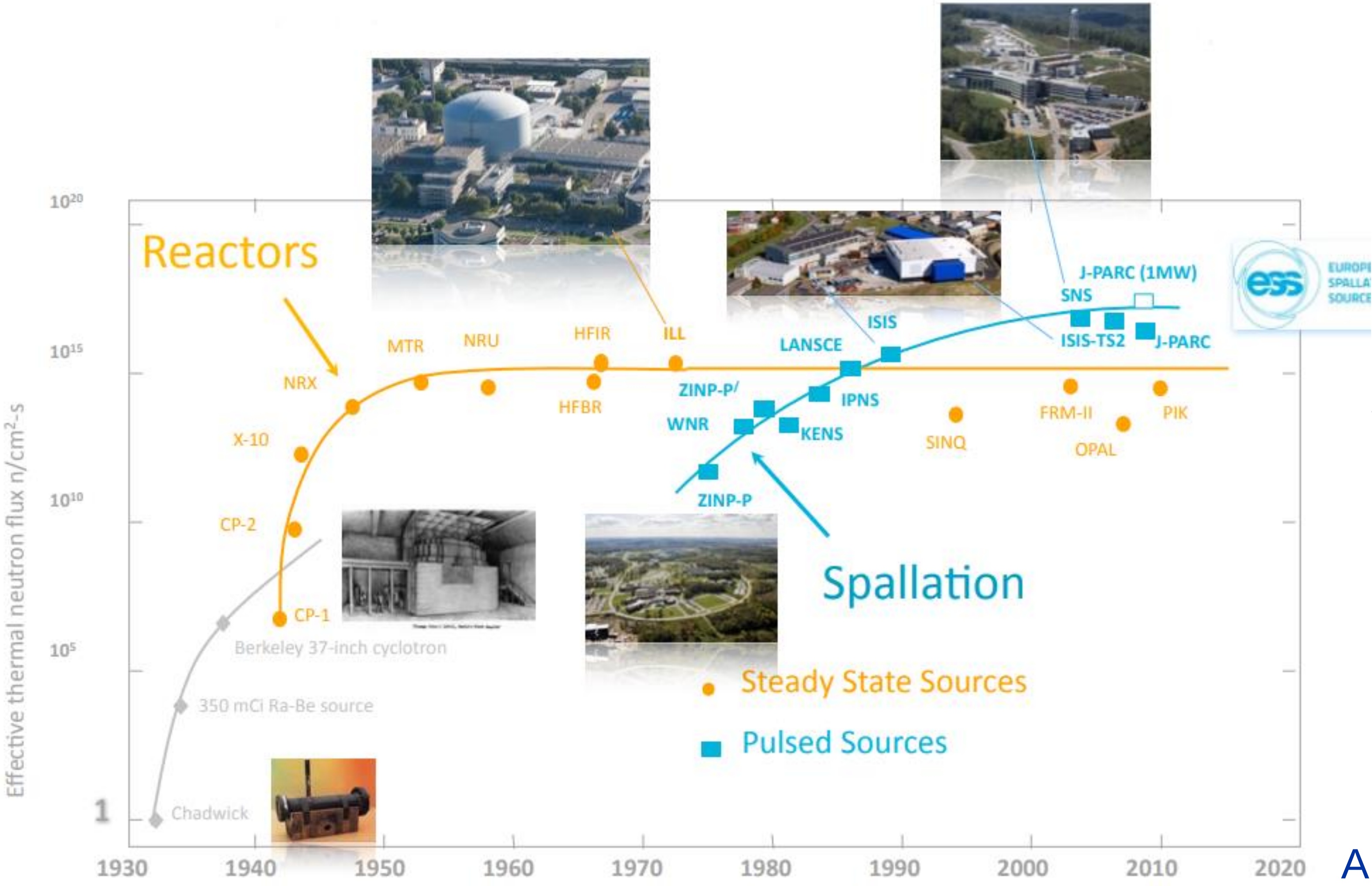
Assembly and gain uniformity measurements of the new large area PICOSEC detector, RD51 Collaboration meeting, Antonia Utrobicic

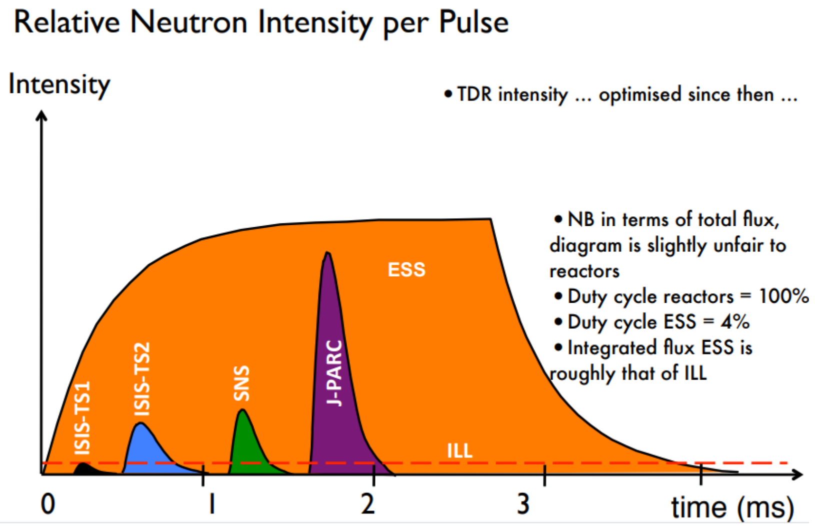
3rd Academy-Industry Matching Event on Photon Detection and RD51 Mini-Week. S Withe



Micromegas based detector coupled to a photocathode for time resolution in the ten-pico second time scale! Combining the timing and photon detection! Large possibilities for future application, EIC but not only

Gaseous based detector: neutron detection





- TDR intensity … optimised since then …
- NB in terms of total flux, diagram is slightly unfair to reactors
- Duty cycle reactors = 100%
- Duty cycle ESS = 4%
- Integrated flux ESS is roughly that of ILL

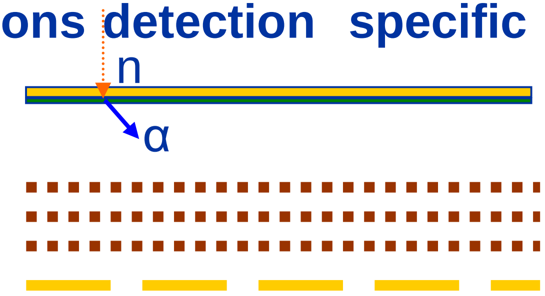
Instrument	Wavelength range [Å]	Time resolution [μs]	Detector area [m^2]	Spatial resolution [mm]	Rate sample [n/s/cm^2]
SANS	3 - 20	100 [μs]	[10 - 18]	5	10^9
REFL	2 - 23	100 [μs]	0.41	0.5	10^9
DIRECT	0.8 - 20	10 [μs]	73.12	10 - 20	10^7
INDIRECT	1 - 8	[μs]	2.4	5	10^{10}
DIFF	0.5 - 20	10-100 [μs]	26.692	2 - 10	10^9
NMX	1.8 - 3.5	[ms]	1.08	0.2	10^8
IMAGING	1 - 10	[μs]	1	0.014-1	10^8
ENG	0.1 - 7	10 [μs]	6.4925	5	10^7

An interesting challenge for the detector technology.

Gaseous based detector: neutron detection

New requirements for better resolution (position and time) rate capabilities, lower background, larger area/lower costs, Differences between HEP and neutrons detection specific R&D is needed for neutrons.

- Fast Neutrons: Polyethylene converter + Aluminium
  - Neutrons are converted in protons through elastic scattering on hydrogen
- Thermal Neutrons: ^{10}Boron converter
  - Neutrons are detected using the productus (alpha,Li) from nuclear reaction $^{10}B(n,alpha)7Li$



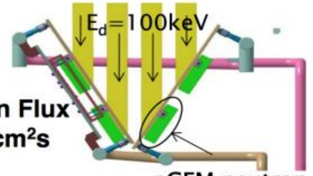
Triple GEM Detector

Low efficiency detector (few % maximum)

Thermal (E_{peak} = 3.5 meV) neutron flux: 7.88 x 10^8 n/s cm^2

CNSEM (Close Contact Neutron Surface Emission Mapping) diagnostic for ITER NBI Prototypes (SPIDER & MITICA)

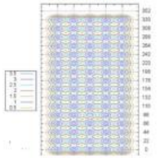
Deuterium Beam (100 Kev)



Neutron Flux 10^{10} n/cm^{2}s

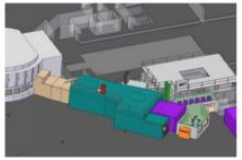
nGEM neutron Detector

Deuterium Beam composition: 5x16 beamlets



Aim: Reconstruct **Deuterium beam profile** from neutron beam profile. **Angular resolution and directionality property needed**

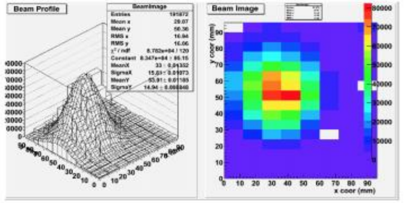
Beam monitor for **ChipIr** @ ISIS and **ESS**

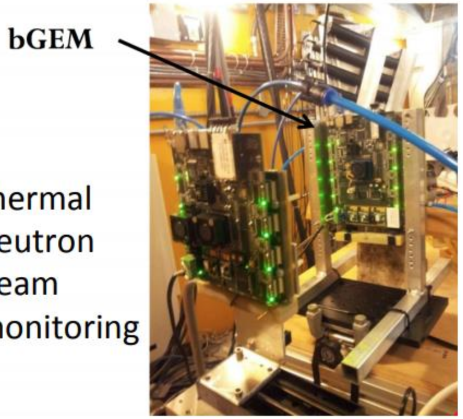


ChipIr CAD model at ISIS-TS2

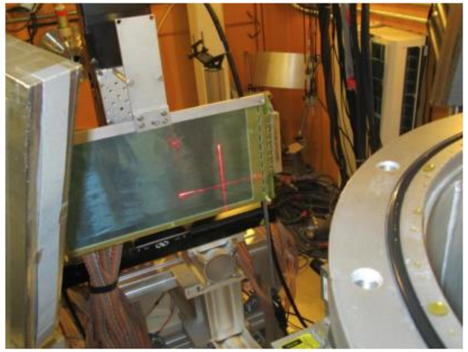
ESS Model

Aim: Construct large area, real-time and high rate beam monitors for fast neutron lines

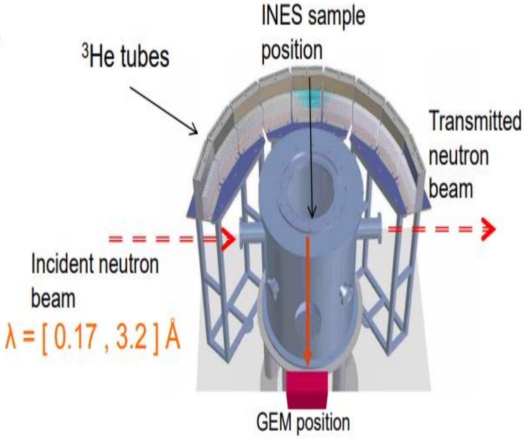




thermal neutron beam monitoring



Deuterium beam diagnostic (Nuclear Fusion)



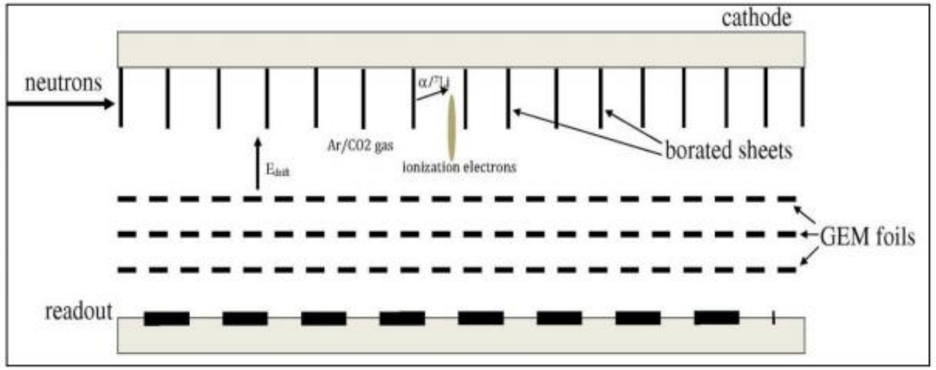
Neutron diffraction ISIS DAE→

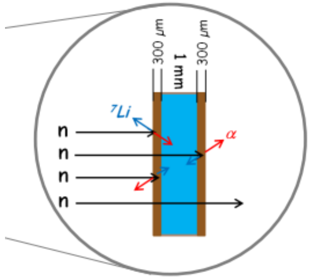
Comparable results to 3He tubes in a real diffraction experiment

Exploiting GEM characteristics and performance

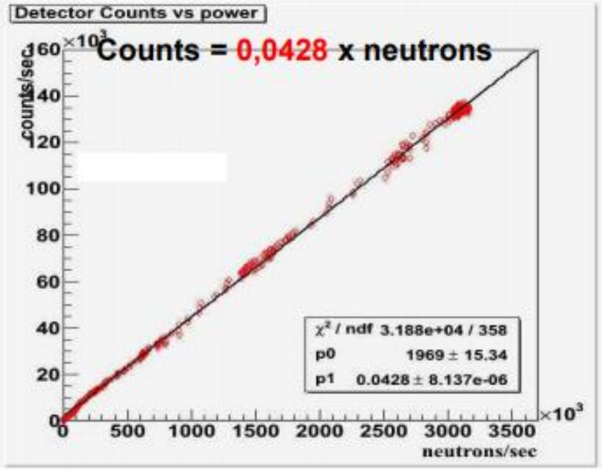
Gaseous based detector: neutron detection

- BAND or side GEM detector a further step towards a high efficiency GEM based neutron detector



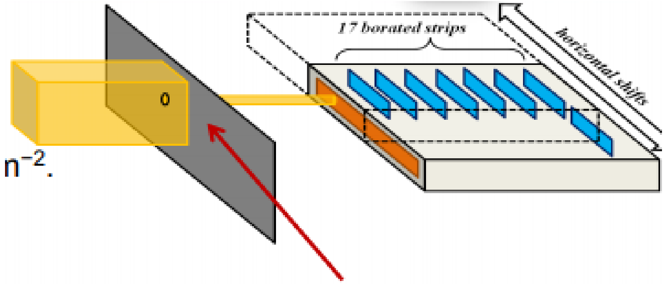


TRIGA Power: 1 MW (variable)
Beam line: radial channel
Flux @ 1 MW: $\phi = (2{,}3 \pm 0.2) \times 10^6$ $ncm^{-2}s^{-1}$
Spectrum: Maxwell-Boltzmann at 25 meV
FWHM ~ 70 meV



HFIR Power: 85MW
beam line:CG1A
(detector test station)
estimated flux: 2 × 10^6 n cm^{-2}.
λ_P~ 4.23 Å (**E**~4.57 meV)
FWHM ~0.11 Å
irradiation area: 5 × 5 cm^2
angular divergence: < 1°

n^{-2}.



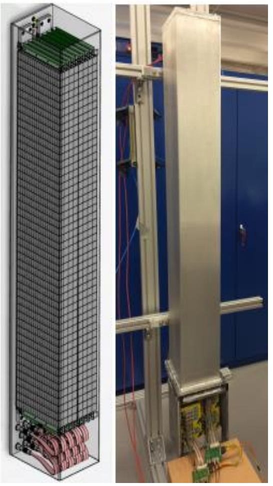
borated aluminum mask with a hole 2,5 mm in diameter

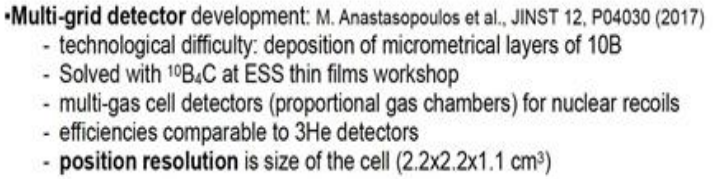
Comparison with ³He gas tube at pressure	S-GEM	³He Tube
Overall mean counts [s^{-1}]	1863	6011
Background mean counts [s^{-1}]	21	1586
Signal/Background	87.7	2.8
Efficiency [%]	31	99

G Croci, MPGD and gaseous neutron detectors: techniques and applications MPGD2019

Gaseous based detector: neutron detection

Multi-Grid detector for neutron spectroscopy ESS





- **Multi-grid detector** development: M. Anastasopoulos et al., JINST 12, P04030 (2017)
  - technological difficulty: deposition of micrometrical layers of 10B
  - Solved with $^{10}B_4C$ at ESS thin films workshop
  - multi-gas cell detectors (proportional gas chambers) for nuclear recoils
  - efficiencies comparable to 3He detectors
  - **position resolution** is size of the cell (2.2x2.2x1.1 cm^3)

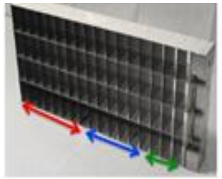
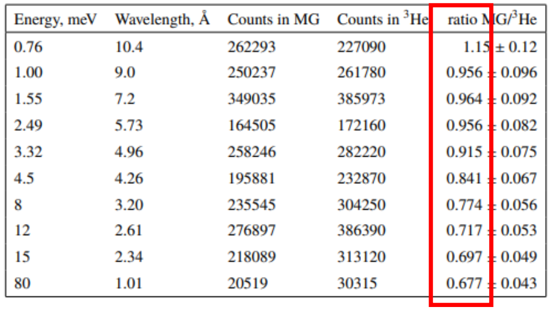
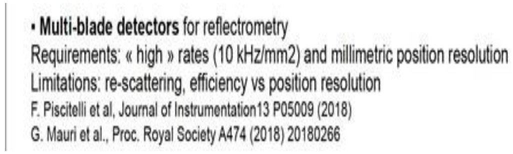


Figure 2. A grid. The three regions of different thicknesses of boron layers are shown by the arrows. The coated blades are the vertical components in the image. The length of the grid is approximately 20 cm.



Energy, meV	Wavelength, Å	Counts in MG	Counts in ^{3}He	ratio MG/^{3}He
0.76	10.4	262293	227090	1.15 ± 0.12
1.00	9.0	250237	261780	0.956 ± 0.096
1.55	7.2	349035	385973	0.964 ± 0.092
2.49	5.73	164505	172160	0.956 ± 0.082
3.32	4.96	258246	282220	0.915 ± 0.075
4.5	4.26	195881	232870	0.841 ± 0.067
8	3.20	235545	304250	0.774 ± 0.056
12	2.61	276897	386390	0.717 ± 0.053
15	2.34	218089	313120	0.697 ± 0.049
80	1.01	20519	30315	0.677 ± 0.043

Estia and FREIA: planned for the European Spallation neutron reflectometry



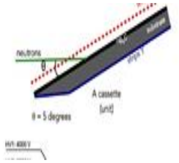
- **Multi-blade detectors** for reflectrometry

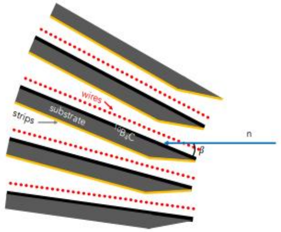
Requirements: « high » rates (10 kHz/mm2) and millimetric position resolution

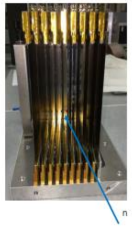
Limitations: re-scattering, efficiency vs position resolution

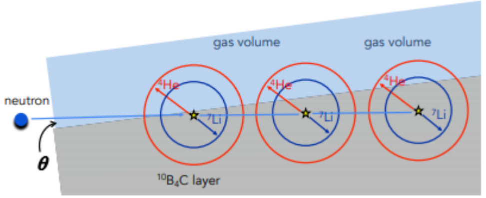
F. Piscitelli et al, Journal of Instrumentation13 P05009 (2018)

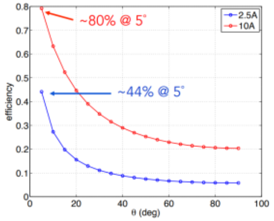
G. Mauri et al., Proc. Royal Society A474 (2018) 20180266



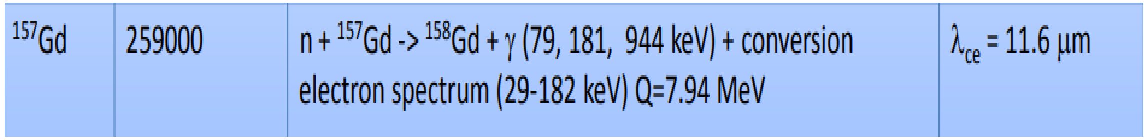




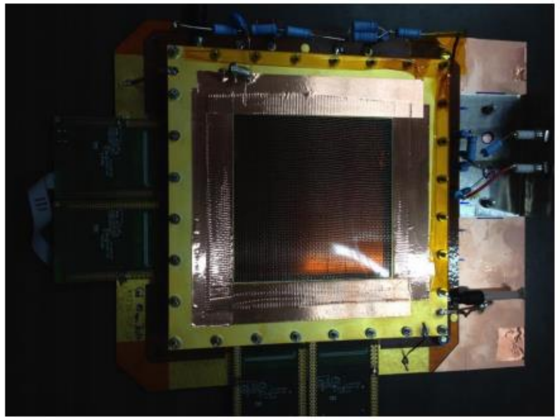




Gd based neutron detector

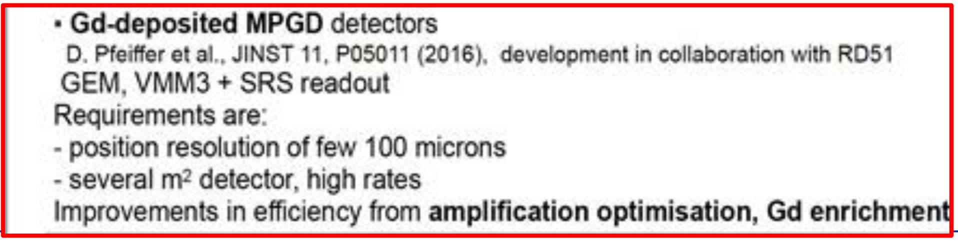


^{157}Gd	259000	n + ^{157}Gd -> ^{158}Gd + γ (79, 181, 944 keV) + conversion electron spectrum (29-182 keV) Q=7.94 MeV	λ_{ce} = 11.6 μm



- Standard triple-GEM detector operated at gain of 5000 (730 uA)
- 250 um natural Gd as cathode with 50 um thick Cu tape
- 10 mm drift gap
- Drift field of 700 V/cm

First Measurements with New High-Resolution Gadolinium-GEM Neutron Detectors D. Pfeiffer https://arxiv.org/abs/1510.02365



- **Gd-deposited MPGD** detectors

D. Pfeiffer et al., JINST 11, P05011 (2016), development in collaboration with RD51

GEM, VMM3 + SRS readout

Requirements are:

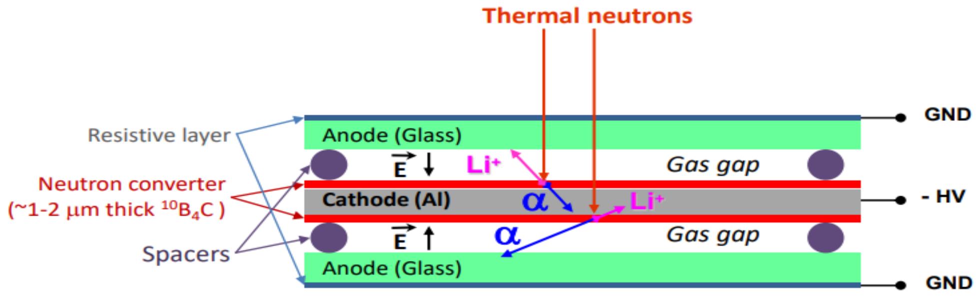
- position resolution of few 100 microns
- several m^2 detector, high rates

Improvements in efficiency from **amplification optimisation, Gd enrichment**

Gaseous based detector: neutron detection

ESS: high precision neutron detectors with high counting rate capability. RPC based neutron imaging detector

Double gap hybrid RPC



$$n + {}^{10}B \rightarrow \begin{cases} {}^{7}\mathrm{Li}(0.84\ \mathrm{MeV}) + {}^{4}\mathrm{He}(1.47\ \mathrm{MeV}) + \gamma(0.47\ \mathrm{MeV}), & 94\% \\ {}^{7}\mathrm{Li}(1.01\ \mathrm{MeV}) + {}^{4}\mathrm{He}(1.78\ \mathrm{MeV}), & 6\%. \end{cases}$$

RP1 and **RPC2**: Low resistivity glass

RP3 and **RPC4**: Float glass

Gas gap: 0,35 mm

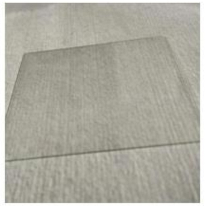
Cathode (100 mm x 100 mm): **Al Plate** (0.5 mm thick) with a **1.15 µm thick layer of $^{10}B_4C$**

RPC5 (ceramics on the back side)

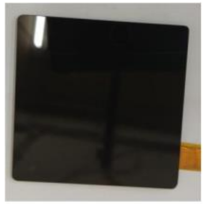
Float glass
0.28 and **0.35 mm** thick
ρ ≈ 10^{13} Ω cm at 24 °C

Low resistivity glass
1 mm thick
ρ ≈ 4 ×10^{10} Ω cm at 24 °C

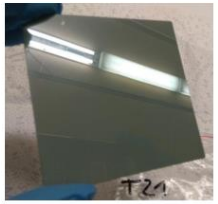
Ceramic composite
2 mm thick,
ρ ≈ 2 × 10^{10} Ω cm at 24 °C



Commercial glass

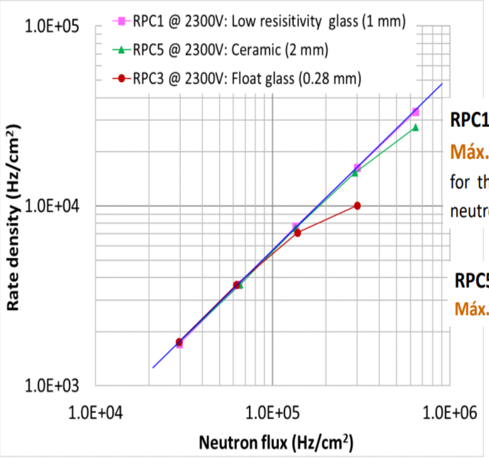


Yi Wang, Tsinghua University, Beijing



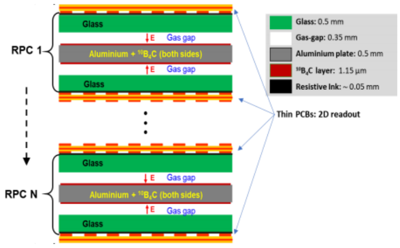
L. Naumann, HZDR, Dresden-Rossendorf

RPC1: resistivity glass and RPC5: Ceramics)



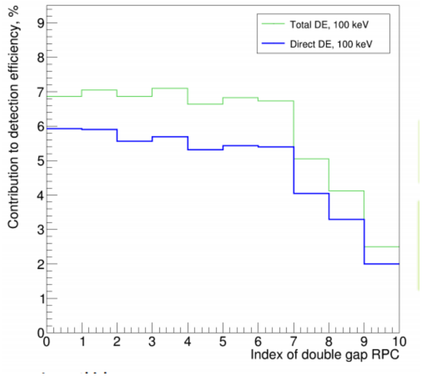
RPC1 (low resistivity glass): Máx. Rate > 30 kHz/cm² for the maximum available neutron flux

RPC5 (ceramics): Máx. rate > 15 kHz/cm²



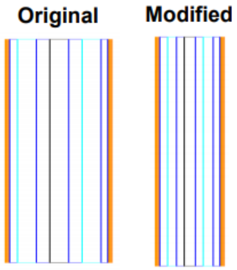
Multi-parameter optimization in ANTS2

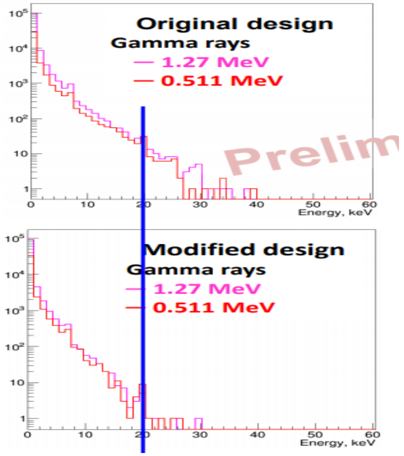
[Morozov et al., arXiv:2002.02284 [physics.ins-det]]



Layer thicknesses:
0.34 (t1,t2); 0.39 (t3,t4); 0.44 (t5,t6); 0.54 (t7,t8); 0.60 (t9,t10); 0.83 (t11,t12); 1.19 (t13,t14); 1.25 (t15,t16); 2.07 (t17,t18) and 3.33µm (t19,t20).

RPC design	Original	Modified
Gas gap width	0.35 mm	0.2 mm
Al plate thickness	0.5 mm	0.3 mm
Glass thickness	0.5 mm	0.25 mm





Gamma sensitivity < 10^{-6} 0,511 MeV

XV Workshop on Resistive Plate Chambers and related detectors RPC2020)
University of Rome "Tor Vergata" , 10 - 14 February 2020

Gaseous based detector: considerations

- Large synergy and complementarity for gaseous based tracking detector (mostly MPGD based **but not only**) between Nuclear Physics Experiments, Energy Frontier Colliders and Future Facilities → Common R&D needed, fundamental the coordination of R&D activities and the share of the knowledge
- Medium and high energies fixed target experimental set-ups cover mainly the forward direction due to the boost of the particles. High flux of secondaries for long operation time→ surface coverage, time and space resolution are largely dependent on the detector position w.r.t the target region. Allows to exploit the performance of the different detection principles/technologies: **flexibility, important benchmarking for FC**
- Colliders require a further step: nonplanar geometries and very high integration level due to the space constrains imposed. Fully integrated detector Electronics + Redout elements may become an essential key-element, towards fully integrated detectors
- Both technologies developed under generic R&D and/or experiment-oriented programs at the Energy Frontier are needed
- Large production of low mass detectors, MPGD but not only, is a challenging task for the next years, common needs R&D : material deposition control, robustness to discharges, discharges control. Synergic R&D

Gaseous based detector: considerations

- Gaseous based photon detection is the way when large (~m^2) coverage is needed. MPGD used in closed geometry opened the way to more performing photon detection technology capable to exploit the high rate low IBF characteristics and magnetic field insensitivities of gaseous detector
- The IBF reduction is an important step forward to the use of large photon detectors in the next experimental setups, but still the quest for more robust photocathode is the way towards a breakthrough
- Many interesting idea have been proposed, realized and successfully tested; some have reached the maturity to be employed THGEMs +CsI.
- The use of photon detection (keV) for the TRD may open to interesting synergies: GEM TRD based detector with the possibility to exploit the microTPC mode for future EIC applications …. Even more… Timepix like approach
- MPGD based neutron detector are the response to the needs of the next generation of neutron experiments, which push the envelope of performance.
- Not only ^{3}He issue, MPGDs flexibility is a key ingredient, Boron/Gd converter proven to be a valid alternative
- Neutron detectors can be specialized for the classes of instruments → both generic R&D i.e. substrate and coating as well as dedicated R&D for detector optimization needed
- R&Ds needs for neutron detection are specific Software optimization tools, Substrate R&D and material deposition studies, background sensitivity….