Gaseous Detector R&D

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PPTAP Detectors Workshop
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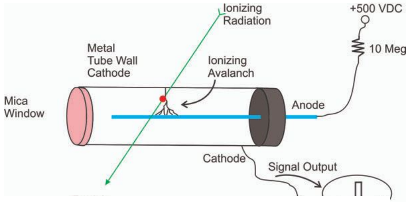
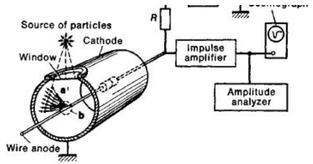
Brief history of Gaseous Detectors

Ionisation chamber (~1890)

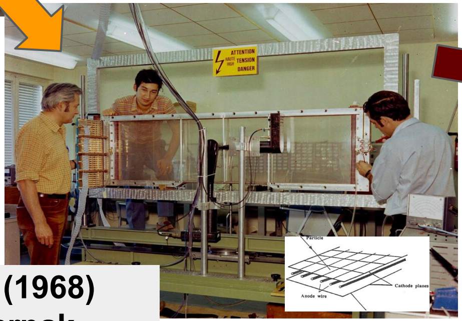
Geiger-Muller tube (1908))



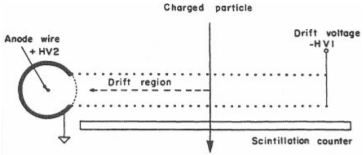
Proportional Counter (~1930)



Spark Chamber
S.Fukui, S.Miyamoto
(~1958)

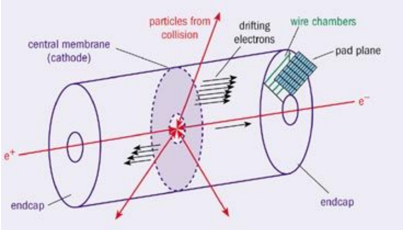


MWPC (1968)
G.Charpak
Nobel prize 1992



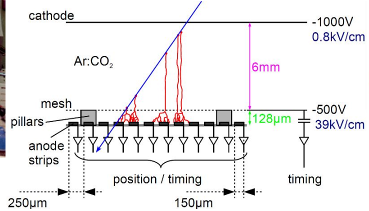
Drift Chambers

Time
Projection
Chambers
D.Nygren
(1970s)

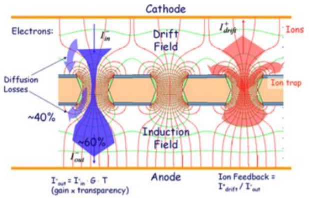


Micro-Pattern Gas Detectors

- **MSGC**
- **MicroMegas**
- **GEM**
- **GridPix**

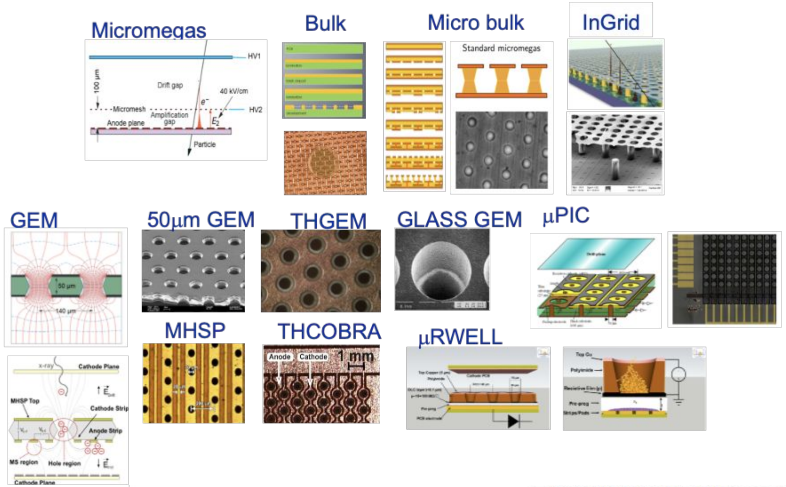


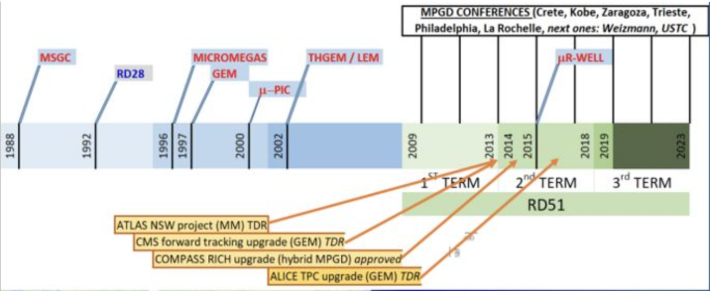
MicroMegas detector
I.Giomataris (1996)



GEM detector
F.Sauli (1997)

Micro-Pattern Gaseous Detectors (MPGDs)

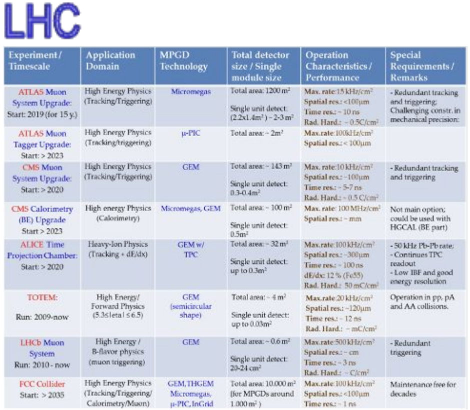




- High rate capability → Up MHz/mm^2 (MIPs)
- High gain → Up to ~10^6
- High spatial resolution → < 100μm
- Good time resolution → ~ns in general
  - Excellent in cases→ < 100 ps
- Excellent radiation hardness
- Good ageing properties
- Ion backflow reduction
- Photon feedback reduction
- Large volume/area → tenths of L / m^2
- Low material budget
- Low cost

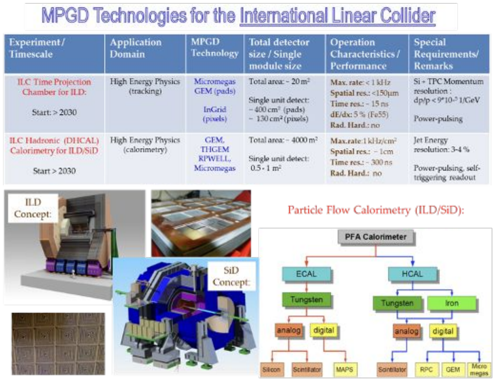
Adapted from E.Oliveri
[ECFA Detector R&D 2021]

Application of MPGDs in physics and beyond



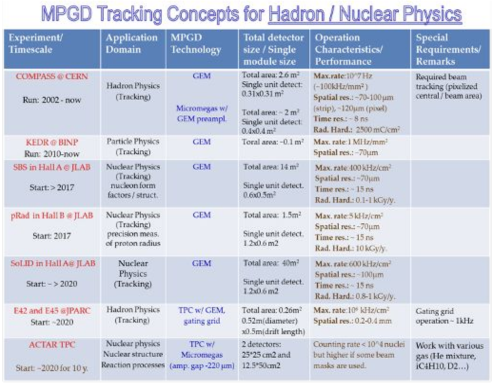
LHC

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements / Remarks
ATLAS Muon System Upgrade: Start: 2019 (for 15 y.)	High Energy Physics (Tracking/Triggering)	Micromegas	Total area: 1200 m^2 Single unit detect: (2.2x1.4m^2) - 2-3 m^2	Max. rate: 15 kHz/cm^2 Spatial res.: <100μm Time res.: ~ 10 ns Rad. Hard.: ~ 0.5C/cm^2	- Redundant tracking and triggering; Challenging constr. in mechanical precision:
ATLAS Muon Tagger Upgrade: Start: > 2023	High Energy Physics (Tracking/triggering)	μ-PIC	Total area: ~ 2m^2	Max.rate: 100kHz/cm^2 Spatial res.: < 100μm	
CMS Muon System Upgrade: Start: > 2020	High Energy Physics (Tracking/Triggering)	GEM	Total area: ~ 143 m^2 Single unit detect: 0.3-0.4m^2	Max. rate: 10 kHz/cm^2 Spatial res.: ~100μm Time res.: ~ 5-7 ns Rad. Hard.: ~ 0.5 C/cm^2	- Redundant tracking and triggering
CMS Calorimetry (BE) Upgrade Start > 2023	High energy Physics (Calorimetry)	Micromegas, GEM	Total area: ~ 100 m^2 Single unit detect: 0.5m^2	Max. rate: 100 MHz/cm^2 Spatial res.: ~ mm	Not main option; could be used with HGCAL (BE part)
ALICE Time Projection Chamber: Start: > 2020	Heavy-Ion Physics (Tracking + dE/dx)	GEM w/ TPC	Total area: ~ 32 m^2 Single unit detect: up to 0.3m^2	Max.rate: 100 kHz/cm^2 Spatial res.: ~300μm Time res.: ~ 100 ns dE/dx: 12 % (Fe55) Rad. Hard.: 50 mC/cm^2	- 50 kHz Pb-Pb rate; - Continues TPC readout - Low IBF and good energy resolution
TOTEM: Run: 2009-now	High Energy/ Forward Physics ($5.3 \leq \|eta\| \leq 6.5$)	GEM (semicircular shape)	Total area: ~ 4 m^2 Single unit detect: up to 0.03m^2	Max.rate: 20 kHz/cm^2 Spatial res.: ~120μm Time res.: ~ 12 ns Rad. Hard.: ~ mC/cm^2	Operation in pp, pA and AA collisions.
LHCb Muon System Run: 2010 - now	High Energy / B-flavor physics (muon triggering)	GEM	Total area: ~ 0.6 m^2 Single unit detect: 20-24 cm^2	Max.rate: 500 kHz/cm^2 Spatial res.: ~ cm Time res.: ~ 3 ns Rad. Hard.: ~ C/cm^2	- Redundant triggering
FCC Collider Start: > 2035	High Energy Physics (Tracking/Triggering/ Calorimetry/Muon)	GEM, THGEM Micromegas, μ-PIC, InGrid	Total area: 10.000 m^2 (for MPGDs around 1.000 m^2)	Max.rate: 100 kHz/cm^2 Spatial res.: <100μm Time res.: ~ 1 ns	Maintenance free for decades



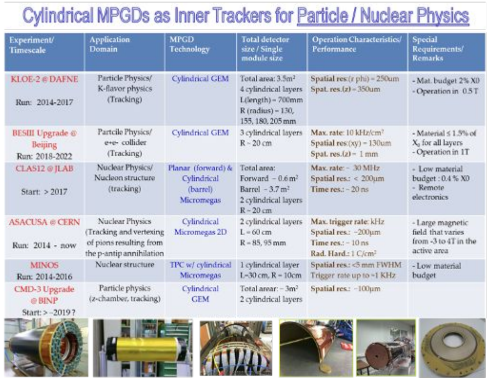
MPGD Technologies for the International Linear Collider

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements/ Remarks
ILC Time Projection Chamber for ILD: Start: > 2030	High Energy Physics (tracking)	Micromegas GEM (pads) InGrid (pixels)	Total area: ~ 20 m^2 Single unit detect: ~ 400 cm^2 (pads) ~ 130 cm^2 (pixels)	Max. rate: < 1 kHz Spatial res.: <150μm Time res.: ~ 15 ns dE/dx: 5 % (Fe55) Rad. Hard.: no	Si + TPC Momentum resolution : dp/p < 9*10^{-5} 1/GeV Power-pulsing
ILC Hadronic (DHCAL) Calorimetry for ILD/SiD Start > 2030	High Energy Physics (calorimetry)	GEM, THGEM RPWELL, Micromegas	Total area: ~ 4000 m^2 Single unit detect: 0.5 - 1 m^2	Max.rate: 1 kHz/cm^2 Spatial res.: ~ 1cm Time res.: ~ 300 ns Rad. Hard.: no	Jet Energy resolution: 3-4 % Power-pulsing, self-triggering readout



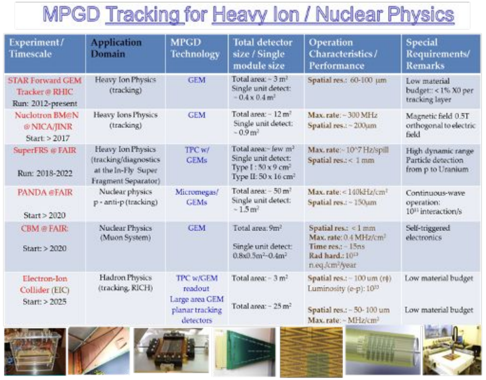
MPGD Tracking Concepts for Hadron / Nuclear Physics

Experiment/ Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics/ Performance	Special Requirements/ Remarks
COMPASS @ CERN Run: 2002 - now	Hadron Physics (Tracking)	GEM Micromegas w/ GEM preampl.	Total area: 2.6 m^2 Single unit detect: 0.31x0.31 m^2 Total area: ~ 2 m^2 Single unit detect: 0.4x0.4 m^2	Max.rate: 10^7 Hz (~100kHz/mm^2) Spatial res.: ~70-100 μm (strip), ~120μm (pixel) Time res.: ~ 8 ns Rad. Hard.: 2500 mC/cm^2	Required beam tracking (pixelized central / beam area)
KEDR @ BINP Run: 2010-now	Particle Physics (Tracking)	GEM	Toral area: ~0.1 m^2	Max. rate: 1 MHz/mm^2 Spatial res.: ~70μm	
SBS in Hall A @ JLAB Start: > 2017	Nuclear Physics (Tracking) nucleon form factors / struct.	GEM	Total area: 14 m^2 Single unit detect. 0.6x0.5m^2	Max. rate: 400 kHz/cm^2 Spatial res.: ~70μm Time res.: ~ 15 ns Rad. Hard.: 0.1-1 kGy/y.	
pRad in Hall B @ JLAB Start: 2017	Nuclear Physics (Tracking) precision meas. of proton radius	GEM	Total area: 1.5m^2 Single unit detect. 1.2x0.6 m2	Max. rate: 5 kHz/cm^2 Spatial res.: ~70μm Time res.: ~ 15 ns Rad. Hard.: 10 kGy/y.	
SoLID in Hall A@ JLAB Start: ~ > 2020	Nuclear Physics (Tracking)	GEM	Total area: 40m^2 Single unit detect. 1.2x0.6 m2	Max. rate: 600 kHz/cm^2 Spatial res.: ~100μm Time res.: ~ 15 ns Rad. Hard.: 0.8-1 kGy/y.	
E42 and E45 @JPARC Start: ~2020	Hadron Physics (Tracking)	TPC w/ GEM, gating grid	Total area: 0.26m^2 0.52m(diameter) x0.5m(drift length)	Max. rate: 10^6 kHz/cm^2 Spatial res.: 0.2-0.4 mm	Gating grid operation ~ 1kHz
ACTAR TPC Start: ~2020 for 10 y.	Nuclear physics Nuclear structure Reaction processes	TPC w/ Micromegas (amp. gap ~220 μm)	2 detectors: 25*25 cm2 and 12.5*50cm2	Counting rate < 10^4 nuclei but higher if some beam masks are used.	Work with various gas (He mixture, iC4H10, D2…)



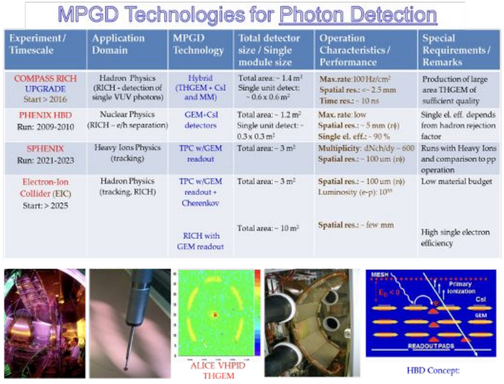
Cylindrical MPGDs as Inner Trackers for Particle / Nuclear Physics

Experiment/ Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics/ Performance	Special Requirements/ Remarks
KLOE-2 @ DAFNE Run: 2014-2017	Particle Physics/ K-flavor physics (Tracking)	Cylindrical GEM	Total area: 3.5m^2 4 cylindrical layers L(length) = 700mm R (radius) = 130, 155, 180, 205 mm	Spatial res.(r phi) = 250um Spat. res.(z) = 350um	- Mat. budget 2% X0 - Operation in 0.5 T
BESIII Upgrade @ Beijing Run: 2018-2022	Partcile Physics/ e+e- collider (Tracking)	Cylindrical GEM	3 cylindrical layers R ~ 20 cm	Max. rate: 10 kHz/cm^2 Spatial res.(xy) = 130um Spat. res.(z) = 1 mm	- Material ≤ 1.5% of X_0 for all layers - Operation in 1T
CLAS12 @ JLAB Start: > 2017	Nuclear Physics/ Nucleon structure (tracking)	Planar (forward) & Cylindrical (barrel) Micromegas	Total area: Forward ~ 0.6 m^2 Barrel ~ 3.7 m^2 2 cylindrical layers R ~ 20 cm	Max. rate: ~ 30 MHz Spatial res.: < 200μm Time res.: ~ 20 ns	- Low material budget : 0.4 % X0 - Remote electronics
ASACUSA @ CERN Run: 2014 - now	Nuclear Physics (Tracking and vertexing of pions resulting from the p-antip annihilation	Cylindrical Micromegas 2D	2 cylindrical layers L = 60 cm R = 85, 95 mm	Max. trigger rate: kHz Spatial res.: ~200μm Time res.: ~ 10 ns Rad. Hard.: 1 C/cm^2	- Large magnetic field that varies from -3 to 4T in the active area
MINOS Run: 2014-2016	Nuclear structure	TPC w/ cylindrical Micromegas	1 cylindrical layer L=30 cm, R = 10cm	Spatial res.: <5 mm FWHM Trigger rate up to ~1 KHz	- Low material budget
CMD-3 Upgrade @ BINP Start: > ~2019 ?	Particle physics (z-chamber, tracking)	Cylindrical GEM	Total arear: ~ 3m^2 2 cylindrical layers	Spatial res.: ~100μm	



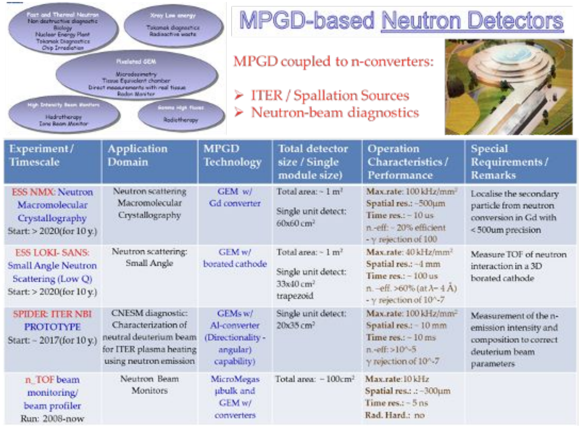
MPGD Tracking for Heavy Ion / Nuclear Physics

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements/ Remarks
STAR Forward GEM Tracker @ RHIC Run: 2012-present	Heavy Ion Physics (tracking)	GEM	Total area: ~ 3 m^2 Single unit detect: ~ 0.4 x 0.4 m^2	Spatial res.: 60-100 μm	Low material budget:: < 1% X0 per tracking layer
Nuclotron BM@N @ NICA/JINR Start: > 2017	Heavy Ions Physics (tracking)	GEM	Total area: ~ 12 m^2 Single unit detect: ~ 0.9 m^2	Max. rate: ~ 300 MHz Spatial res.: ~ 200μm	Magnetic field 0.5T orthogonal to electric field
SuperFRS @ FAIR Run: 2018-2022	Heavy Ion Physics (tracking/diagnostics at the In-Fly Super Fragment Separator)	TPC w/ GEMs	Total area:~ few m^2 Single unit detect: Type I : 50 x 9 cm^2 Type II: 50 x 16 cm^2	Max. rate:~ 10^7 Hz/spill Spatial res.: < 1 mm	High dynamic range Particle detection from p to Uranium
PANDA @FAIR Start > 2020	Nuclear physics p - anti-p (tracking)	Micromegas/ GEMs	Total area: ~ 50 m^2 Single unit detect: ~ 1.5 m^2	Max. rate: < 140kHz/cm^2 Spatial res.: ~ 150μm	Continuous-wave operation: 10^{11} interaction/s
CBM @ FAIR: Start: > 2020	Nuclear Physics (Muon System)	GEM	Total area: 9m^2 Single unit detect: 0.8x0.5m^2-0.4m^2	Spatial res.: < 1 mm Max. rate: 0.4 MHz/cm^2 Time res.: ~ 15ns Rad hard.: 10^{13} n.eq./cm^2/year	Self-triggered electronics
Electron-Ion Collider (EIC) Start: > 2025	Hadron Physics (tracking, RICH)	TPC w/GEM readout Large area GEM planar tracking detectors	Total area: ~ 3 m^2 Total area: ~ 25 m^2	Spatial res.: ~ 100 um (rϕ) Luminosity (e-p): 10^{33} Spatial res.: ~ 50- 100 um Max. rate: ~ MHz/cm^2	Low material budget Low material budget



MPGD Technologies for Photon Detection

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements / Remarks
COMPASS RICH UPGRADE Start > 2016	Hadron Physics (RICH - detection of single VUV photons)	Hybrid (THGEM + CsI and MM)	Total area: ~ 1.4 m^2 Single unit detect: ~ 0.6 x 0.6 m^2	Max.rate: 100 Hz/cm^2 Spatial res.: <~ 2.5 mm Time res.: ~ 10 ns	Production of large area THGEM of sufficient quality
PHENIX HBD Run: 2009-2010	Nuclear Physics (RICH ~ e/h separation)	GEM+CsI detectors	Total area: ~ 1.2 m^2 Single unit detect: ~ 0.3 x 0.3 m^2	Max. rate: low Spatial res.: ~ 5 mm (rϕ) Single el. eff.: ~ 90 %	Single el. eff. depends from hadron rejection factor
SPHENIX Run: 2021-2023	Heavy Ions Physics (tracking)	TPC w/GEM readout	Total area: ~ 3 m^2	Multiplicity: dNch/dy ~ 600 Spatial res.: ~ 100 um (rϕ)	Runs with Heavy Ions and comparison to pp operation
Electron-Ion Collider (EIC) Start: > 2025	Hadron Physics (tracking, RICH)	TPC w/GEM readout + Cherenkov RICH with GEM readout	Total area: ~ 3 m^2 Total area: ~ 10 m^2	Spatial res.: ~ 100 um (rϕ) Luminosity (e-p): 10^{33} Spatial res.: ~ few mm	Low material budget High single electron efficiency

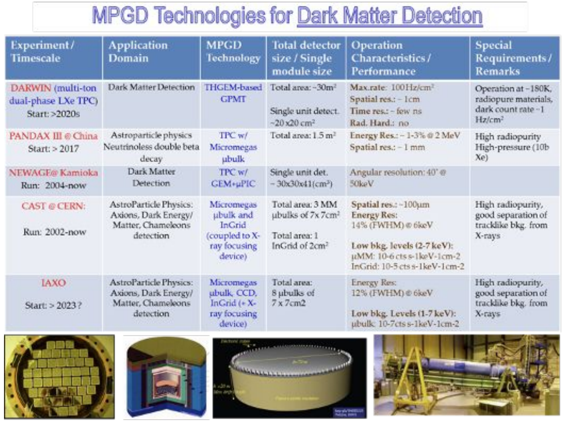


MPGD-based Neutron Detectors

MPGD coupled to n-converters:

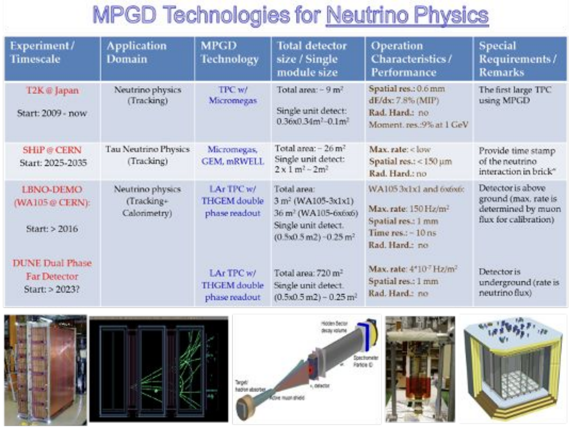
- ITER / Spallation Sources
- Neutron-beam diagnostics

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size)	Operation Characteristics / Performance	Special Requirements / Remarks
ESS NMX: Neutron Macromolecular Crystallography Start: > 2020(for 10 y.)	Neutron scattering Macromolecular Crystallography	GEM w/ Gd converter	Total area: ~ 1 m² Single unit detect: 60x60 cm²	Max.rate: 100 kHz/mm² Spatial res.: ~500µm Time res.: ~ 10 us n.-eff: ~ 20% efficient - γ rejection of 100	Localise the secondary particle from neutron conversion in Gd with < 500um precision
ESS LOKI- SANS: Small Angle Neutron Scattering (Low Q) Start: > 2020(for 10 y.)	Neutron scattering: Small Angle	GEM w/ borated cathode	Total area: ~ 1 m² Single unit detect: 33x40 cm² trapezoid	Max.rate: 40 kHz/mm² Spatial res.: ~4 mm Time res.: ~ 100 us n. –eff. >60% (at λ~ 4 Å) - γ rejection of 10^-7	Measure TOF of neutron interaction in a 3D borated cathode
SPIDER: ITER NBI PROTOTYPE Start: ~ 2017(for 10 y.)	CNESM diagnostic: Characterization of neutral deuterium beam for ITER plasma heating using neutron emission	GEMs w/ Al-converter (Directionality - angular) capability)	Single unit detect: 20x35 cm²	Max.rate: 100 kHz/mm² Spatial res.: ~ 10 mm Time res.: ~ 10 ms n.-eff: >10^-5 γ rejection of 10^-7	Measurement of the n-emission intensity and composition to correct deuterium beam parameters
n_TOF beam monitoring/ beam profiler Run: 2008-now	Neutron Beam Monitors	MicroMegas µbulk and GEM w/ converters	Total area: ~ 100cm²	Max.rate: 10 kHz Spatial res.: .: ~300µm Time res.: ~ 5 ns Rad. Hard.: no	



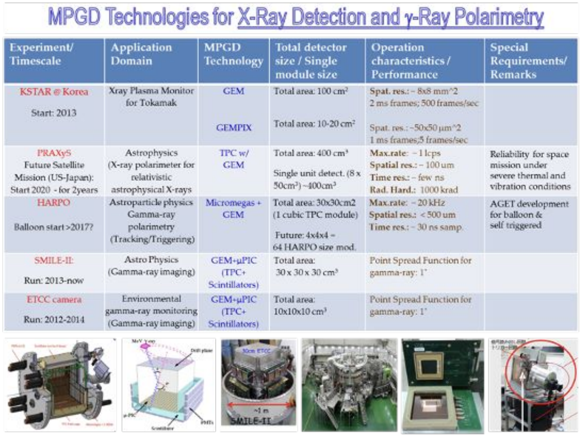
MPGD Technologies for Dark Matter Detection

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements / Remarks
DARWIN (multi-ton dual-phase LXe TPC) Start: >2020s	Dark Matter Detection	THGEM-based GPMT	Total area: ~30m² Single unit detect. ~20 x20 cm²	Max.rate: 100 Hz/cm² Spatial res.: ~ 1cm Time res.: ~ few ns Rad. Hard.: no	Operation at ~180K, radiopure materials, dark count rate ~1 Hz/cm²
PANDAX III @ China Start: > 2017	Astroparticle physics Neutrinoless double beta decay	TPC w/ Micromegas µbulk	Total area: 1.5 m²	Energy Res.: ~ 1-3% @ 2 MeV Spatial res.: ~ 1 mm	High radiopurity High-pressure (10b Xe)
NEWAGE@ Kamioka Run: 2004-now	Dark Matter Detection	TPC w/ GEM+µPIC	Single unit det. ~ 30x30x41(cm³)	Angular resolution: 40° @ 50keV	
CAST @ CERN: Run: 2002-now	AstroParticle Physics: Axions, Dark Energy/ Matter, Chameleons detection	Micromegas µbulk and InGrid (coupled to X-ray focusing device)	Total area: 3 MM µbulks of 7x 7cm² Total area: 1 InGrid of 2cm²	Spatial res.: ~100µm Energy Res: 14% (FWHM) @ 6keV Low bkg. levels (2-7 keV): µMM: 10-6 cts s-1keV-1cm-2 InGrid: 10-5 cts s-1keV-1cm-2	High radiopurity, good separation of tracklike bkg. from X-rays
IAXO Start: > 2023 ?	AstroParticle Physics: Axions, Dark Energy/ Matter, Chameleons detection	Micromegas µbulk, CCD, InGrid (+ X-ray focusing device)	Total area: 8 µbulks of 7 x 7cm2	Energy Res: 12% (FWHM) @ 6keV Low bkg. Levels (1-7 keV): µbulk: 10-7cts s-1keV-1cm-2	High radiopurity, good separation of tracklike bkg. from X-rays



MPGD Technologies for Neutrino Physics

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements / Remarks
T2K @ Japan Start: 2009 - now	Neutrino physics (Tracking)	TPC w/ Micromegas	Total area: ~ 9 m² Single unit detect: 0.36x0.34m²~0.1m²	Spatial res.: 0.6 mm dE/dx: 7.8% (MIP) Rad. Hard.: no Moment. res.:9% at 1 GeV	The first large TPC using MPGD
SHiP @ CERN Start: 2025-2035	Tau Neutrino Physics (Tracking)	Micromegas, GEM, mRWELL	Total area: ~ 26 m² Single unit detect: 2 x 1 m² ~ 2m²	Max. rate: < low Spatial res.: < 150 µm Rad. Hard.: no	Provide time stamp of the neutrino interaction in brick"
LBNO-DEMO (WA105 @ CERN): Start: > 2016	Neutrino physics (Tracking+ Calorimetry)	LAr TPC w/ THGEM double phase readout	Total area: 3 m² (WA105-3x1x1) 36 m² (WA105-6x6x6) Single unit detect. (0.5x0.5 m2) ~0.25 m²	WA105 3x1x1 and 6x6x6: Max. rate: 150 Hz/m² Spatial res.: 1 mm Time res.: ~ 10 ns Rad. Hard.: no	Detector is above ground (max. rate is determined by muon flux for calibration)
DUNE Dual Phase Far Detector Start: > 2023?		LAr TPC w/ THGEM double phase readout	Total area: 720 m² Single unit detect. (0.5x0.5 m2) ~ 0.25 m²	Max. rate: 4*10⁻⁷ Hz/m² Spatial res.: 1 mm Rad. Hard.: no	Detector is underground (rate is neutrino flux)



MPGD Technologies for X-Ray Detection and γ-Ray Polarimetry

Experiment/ Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation characteristics / Performance	Special Requirements/ Remarks
KSTAR @ Korea Start: 2013	Xray Plasma Monitor for Tokamak	GEM GEMPIX	Total area: 100 cm² Total area: 10-20 cm²	Spat. res.: ~ 8x8 mm^2 2 ms frames; 500 frames/sec Spat. res.: ~50x50 µm^2 1 ms frames;5 frames/sec	
PRAXyS Future Satellite Mission (US-Japan): Start 2020 - for 2years	Astrophysics (X-ray polarimeter for relativistic astrophysical X-rays	TPC w/ GEM	Total area: 400 cm³ Single unit detect. (8 x 50cm³) ~400cm³	Max.rate: ~ 1 kcps Spatial res.: ~ 100 um Time res.: ~ few ns Rad. Hard.: 1000 krad	Reliability for space mission under severe thermal and vibration conditions
HARPO Balloon start >2017?	Astroparticle physics Gamma-ray polarimetry (Tracking/Triggering)	Micromegas + GEM	Total area: 30x30cm2 (1 cubic TPC module) Future: 4x4x4 = 64 HARPO size mod.	Max.rate: ~ 20 kHz Spatial res.: < 500 um Time res.: ~ 30 ns samp.	AGET development for balloon & self triggered
SMILE-II: Run: 2013-now	Astro Physics (Gamma-ray imaging)	GEM+µPIC (TPC+ Scintillators)	Total area: 30 x 30 x 30 cm³	Point Spread Function for gamma-ray: 1°	
ETCC camera Run: 2012-2014	Environmental gamma-ray monitoring (Gamma-ray imaging)	GEM+µPIC (TPC+ Scintillators)	Total area: 10x10x10 cm³	Point Spread Function for gamma-ray: 1°	

Maksym Titov, Conference Summary, 5th International Conference on Micro-Pattern Gas Detectors (MPGD2017), Temple University, Philadelphia

5th International Conference on Micro-Pattern Gas Detectors (MPGD2017) and RD51 Collaboration Meeting
Temple University, Philadelphia, USA
May 22-26, 2017

Topics

- MPGD Technologies
- MPGD Related Technologies (RPC's, TPC's, etc.)
- Applications at present and future nuclear and particle physics facilities
- Commercial and production applications

Conference Summary / Perspectives

Maxim Titov, CEA Saclay, France

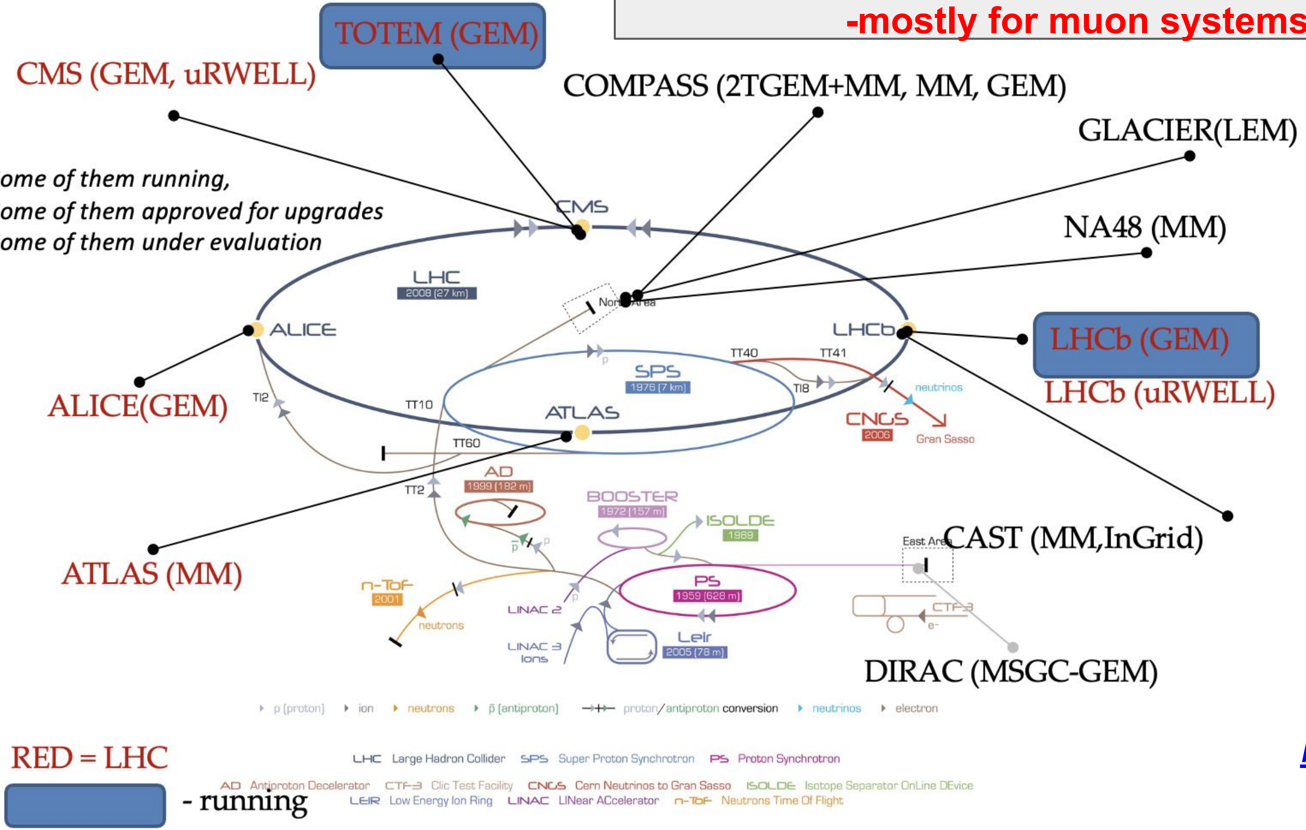
5th International Conference on Micro-Pattern Gaseous Detectors, September 22-26, 2017, PA, USA

Adapted from E.Oliveri
ECFA Detector R&D 2021

MPGDs in CERN experiments

MPGDs have been chosen for all LHC upgrades
-mostly for muon systems-

Some of them running,
Some of them approved for upgrades
Some of them under evaluation



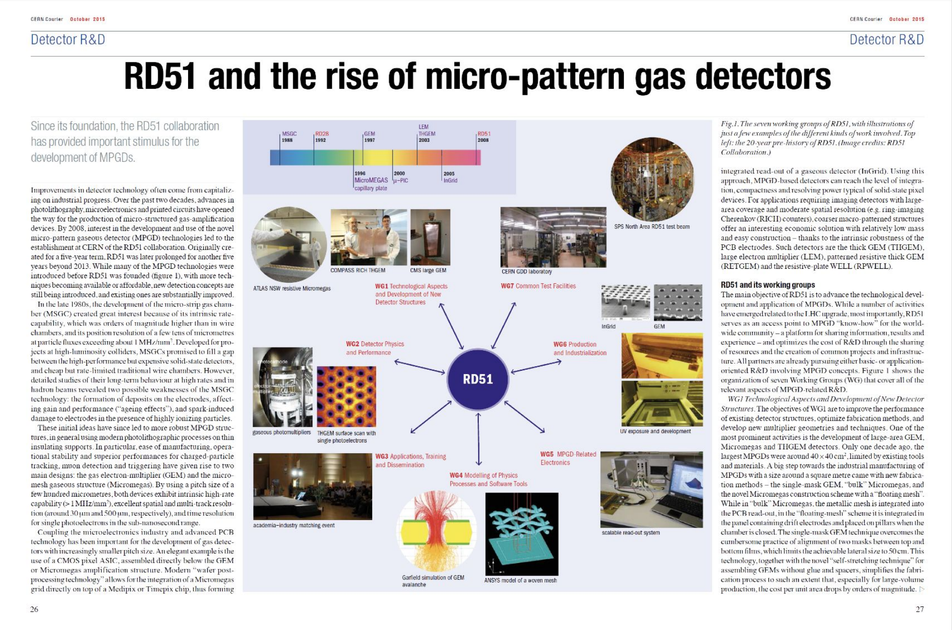
From M.Titov

RD51 collaboration
Development of Micro-Pattern
Gas Detectors Technologies

https://rd51-public.web.cern.ch/welcome

The RD51 collaboration - CERN

~ 450 authors, 75 Universities and Research Laboratories from 25 countries in Europe, America, Asia and Africa



CERN Courier October 2015

Detector R&D

RD51 and the rise of micro-pattern gas detectors

Since its foundation, the RD51 collaboration has provided important stimulus for the development of MPGDs.

Improvements in detector technology often come from capitalizing on industrial progress. Over the past two decades, advances in photolithography, microelectronics and printed circuits have opened the way for the production of micro-structured gas-amplification devices. By 2008, interest in the development and use of the novel micro-pattern gaseous detector (MPGD) technologies led to the establishment at CERN of the RD51 collaboration. Originally created for a five-year term, RD51 was later prolonged for another five years beyond 2013. While many of the MPGD technologies were introduced before RD51 was founded (figure 1), with more techniques becoming available or affordable, new detection concepts are still being introduced, and existing ones are substantially improved.

In the late 1980s, the development of the micro-strip gas chamber (MSGC) created great interest because of its intrinsic rate-capability, which was orders of magnitude higher than in wire chambers, and its position resolution of a few tens of micrometres at particle fluxes exceeding about 1 MHz/mm^2. Developed for projects at high-luminosity colliders, MSGCs promised to fill a gap between the high-performance but expensive solid-state detectors, and cheap but rate-limited traditional wire chambers. However, detailed studies of their long-term behaviour at high rates and in hadron beams revealed two possible weaknesses of the MSGC technology: the formation of deposits on the electrodes, affecting gain and performance ("ageing effects"), and spark-induced damage to electrodes in the presence of highly ionizing particles.

These initial ideas have since led to more robust MPGD structures, in general using modern photolithographic processes on thin insulating supports. In particular, ease of manufacturing, operational stability and superior performances for charged-particle tracking, muon detection and triggering have given rise to two main designs: the gas electron-multiplier (GEM) and the micro-mesh gaseous structure (Micromegas). By using a pitch size of a few hundred micrometres, both devices exhibit intrinsic high-rate capability (> 1 MHz/mm^2), excellent spatial and multi-track resolution (around 30 μm and 500 μm, respectively), and time resolution for single photoelectrons in the sub-nanosecond range.

Coupling the microelectronics industry and advanced PCB technology has been important for the development of gas detectors with increasingly smaller pitch size. An elegant example is the use of a CMOS pixel ASIC, assembled directly below the GEM or Micromegas amplification structure. Modern "wafer post-processing technology" allows for the integration of a Micromegas grid directly on top of a Medipix or Timepix chip, thus forming integrated read-out of a gaseous detector (InGrid). Using this approach, MPGD-based detectors can reach the level of integration, compactness and resolving power typical of solid-state pixel devices. For applications requiring imaging detectors with large-area coverage and moderate spatial resolution (e.g. ring-imaging Cherenkov (RICH) counters), coarser macro-patterned structures offer an interesting economic solution with relatively low mass and easy construction – thanks to the intrinsic robustness of the PCB electrodes. Such detectors are the thick GEM (THGEM), large electron multiplier (LEM), patterned resistive thick GEM (RETGEM) and the resistive-plate WELL (RPWELL).

Fig. 1. The seven working groups of RD51, with illustrations of just a few examples of the different kinds of work involved. Top left: the 20-year pre-history of RD51. (Image credits: RD51 Collaboration.)

RD51 and its working groups

The main objective of RD51 is to advance the technological development and application of MPGDs. While a number of activities have emerged related to the LHC upgrade, most importantly, RD51 serves as an access point to MPGD "know-how" for the worldwide community – a platform for sharing information, results and experience – and optimizes the cost of R&D through the sharing of resources and the creation of common projects and infrastructure. All partners are already pursuing either basic- or application-oriented R&D involving MPGD concepts. Figure 1 shows the organization of seven Working Groups (WG) that cover all of the relevant aspects of MPGD-related R&D.

WG1 Technological Aspects and Development of New Detector Structures. The objectives of WG1 are to improve the performance of existing detector structures, optimize fabrication methods, and develop new multiplier geometries and techniques. One of the most prominent activities is the development of large-area GEM, Micromegas and THGEM detectors. Only one decade ago, the largest MPGDs were around 40 × 40 cm^2, limited by existing tools and materials. A big step towards the industrial manufacturing of MPGDs with a size around a square metre came with new fabrication methods – the single-mask GEM, "bulk" Micromegas, and the novel Micromegas construction scheme with a "floating mesh". While in "bulk" Micromegas, the metallic mesh is integrated into the PCB read-out, in the "floating-mesh" scheme it is integrated in the panel containing drift electrodes and placed on pillars when the chamber is closed. The single-mask GEM technique overcomes the cumbersome practice of alignment of two masks between top and bottom films, which limits the achievable lateral size to 50 cm. This technology, together with the novel "self-stretching technique" for assembling GEMs without glue and spacers, simplifies the fabrication process to such an extent that, especially for large-volume production, the cost per unit area drops by orders of magnitude. ▷

26

27

Members from the UK
10 members, 3 institutes

Alexander DEISTING	Royal Holloway College
Pawel MAJEWSKI	Science and Technology Facilities Council STFC
Timothy David MARLEY	Science and Technology Facilities Council STFC
Mohammad NAKHOSTIN	Science and Technology Facilities Council STFC
Konstantinos NIKOLOPOULOS	University of Birmingham
Ioannis KATSIOULAS	University of Birmingham
Tom Neep	University of Birmingham
Ioannis MANTHOS	University of Birmingham
Robert James WARD	University of Birmingham
Jack Paul MATTHEWS	University of Birmingham

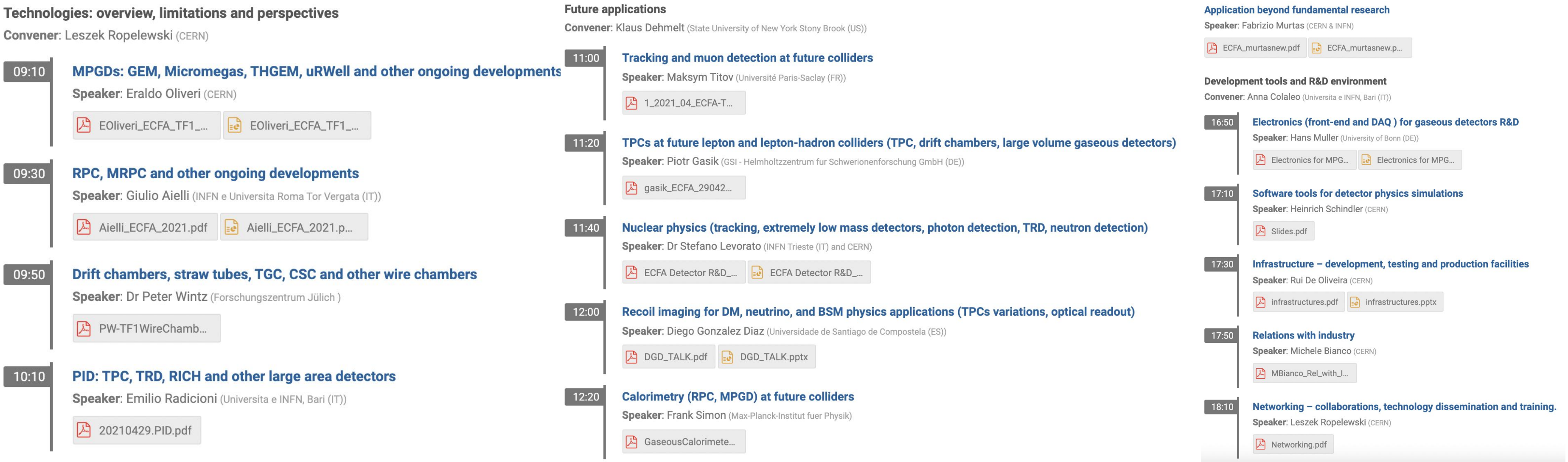
Gaseous Detectors don’t stop with MPGDs

https://indico.cern.ch/event/999799/

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

Thursday 29 Apr 2021, 09:00 → 19:40 Europe/Zurich

Anna Colaleo (Universita e INFN, Bari (IT)) , Anna Colaleo (Universita e INFN, Bari (IT)) , Leszek Ropelewski (CERN)



Technologies: overview, limitations and perspectives

Convener: Leszek Ropelewski (CERN)

09:10 **MPGDs: GEM, Micromegas, THGEM, uRWell and other ongoing developments**
Speaker: Eraldo Oliveri (CERN)
EOliveri_ECFA_TF1_... EOliveri_ECFA_TF1_...

09:30 **RPC, MRPC and other ongoing developments**
Speaker: Giulio Aielli (INFN e Universita Roma Tor Vergata (IT))
Aielli_ECFA_2021.pdf Aielli_ECFA_2021.p...

09:50 **Drift chambers, straw tubes, TGC, CSC and other wire chambers**
Speaker: Dr Peter Wintz (Forschungszentrum Jülich)
PW-TF1WireChamb...

10:10 **PID: TPC, TRD, RICH and other large area detectors**
Speaker: Emilio Radicioni (Universita e INFN, Bari (IT))
20210429.PID.pdf

Future applications

Convener: Klaus Dehmelt (State University of New York Stony Brook (US))

11:00 **Tracking and muon detection at future colliders**
Speaker: Maksym Titov (Université Paris-Saclay (FR))
1_2021_04_ECFA-T...

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))
gasik_ECFA_29042...

11:40 **Nuclear physics (tracking, extremely low mass detectors, photon detection, TRD, neutron detection)**
Speaker: Dr Stefano Levorato (INFN Trieste (IT) and CERN)
ECFA Detector R&D_... ECFA Detector R&D_...

12:00 **Recoil imaging for DM, neutrino, and BSM physics applications (TPCs variations, optical readout)**
Speaker: Diego Gonzalez Diaz (Universidade de Santiago de Compostela (ES))
DGD_TALK.pdf DGD_TALK.pptx

12:20 **Calorimetry (RPC, MPGD) at future colliders**
Speaker: Frank Simon (Max-Planck-Institut fuer Physik)
GaseousCalorimete...

Application beyond fundamental research
Speaker: Fabrizio Murtas (CERN & INFN)
ECFA_murtasnew.pdf ECFA_murtasnew.p...

Development tools and R&D environment

Convener: Anna Colaleo (Universita e INFN, Bari (IT))

16:50 **Electronics (front-end and DAQ) for gaseous detectors R&D**
Speaker: Hans Muller (University of Bonn (DE))
Electronics for MPG... Electronics for MPG...

17:10 **Software tools for detector physics simulations**
Speaker: Heinrich Schindler (CERN)
Slides.pdf

17:30 **Infrastructure – development, testing and production facilities**
Speaker: Rui De Oliveira (CERN)
infrastructures.pdf infrastructures.pptx

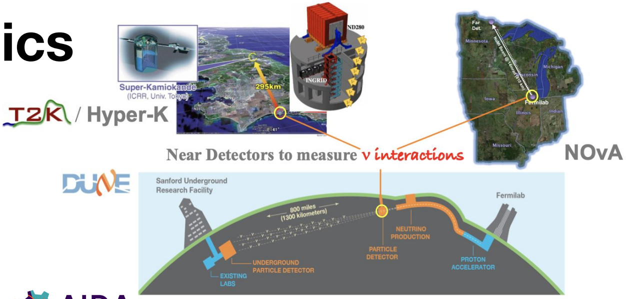
17:50 **Relations with industry**
Speaker: Michele Bianco (CERN)
MBianco_Rel_with_I...

18:10 **Networking – collaborations, technology dissemination and training.**
Speaker: Leszek Ropelewski (CERN)
Networking.pdf

R&D in the UK

High pressure TPC with optical readout for *ν*-physics

Towards a neutrino-nucleus cross section experiments



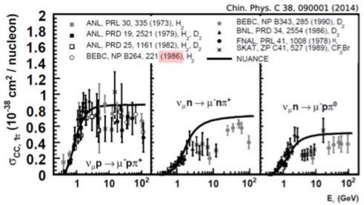
(Fermilab Neutrino Seminar 01/04/21 Xianguo LU, Oxford)

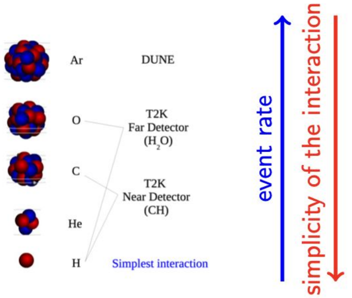
Gas is the target for *ν*s to scatter and the detection medium for the interaction's final state particles

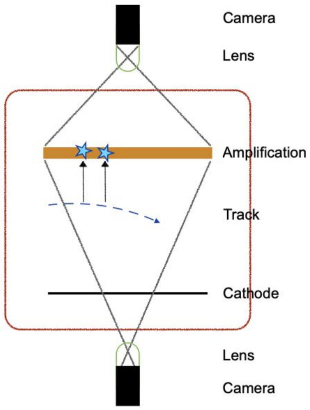
A neutrino-nucleus scattering experiment in its own right at a strong neutrino source

A powerful component of a near detector at a long baseline neutrino oscillation facility

Different gas mixture can be used for different physics experiment. Example: Hydrogen rich targets for new data of ν-H scattering.





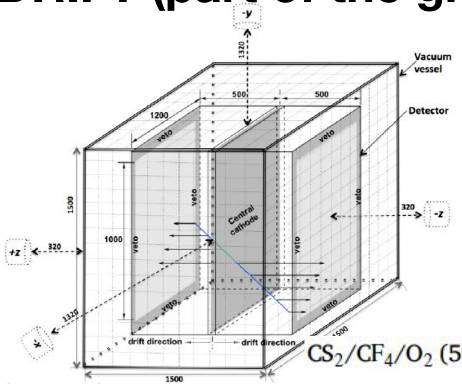


Stitched optical readout (4 CCD cameras) + **electronic signals** from meshes used for amplification

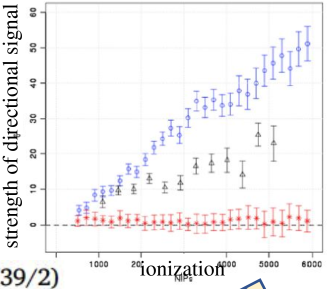
Advantages:

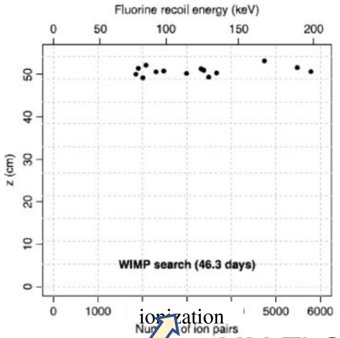
- Coverage of the full solid angle and low momentum threshold for particle detection.
- Threshold in gas is lower than in liquid, which makes a gas TPC better suited to measure low-momentum final state particles produced in interactions of a ν-beam with the gas atoms / molecules
- A gas TPC can be easier magnetised than a liquid one
- Exchanging the gas and thus the target inside a TPC allows for a rich physics program measuring scattering on gas atoms

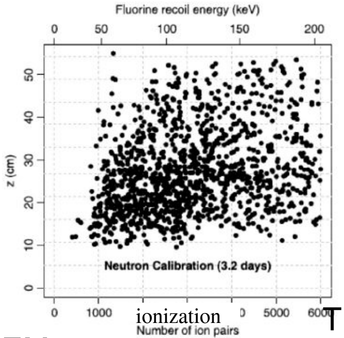
DRIFT (part of the global CYGNUS effort for directional Dark Matter detection)

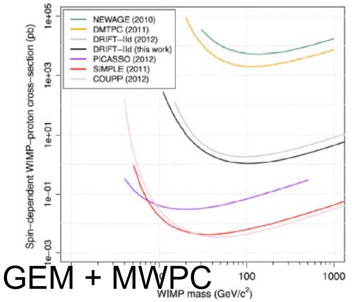


$CS_2/CF_4/O_2$ (59/39/2)









Goal: Obtain the best possible electron/nuclear recoil separation capability and directionality at ~20-40 mbar.

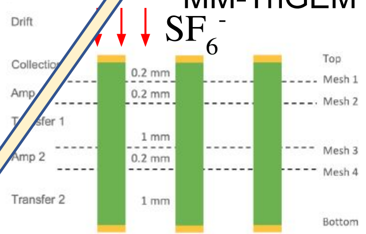
TPC characteristics:

- Read out with criss-crossing wires.
- Use negative ions to reduce diffusion and fine-grained. longitudinal information for estimating track direction.
- Use minority carriers for z-fiducialization (e.g., O_2^-).

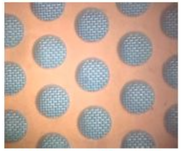
R&D towards a DDM observatory:

- Replace CS_2 by SF_6 mixtures (works in pure gas since SF_5^- allows event fiducialization, and higher number of F-atoms),
- Multiplication in SF_6 more difficult due to higher electron affinity.
- Requires developing new amplification structures!

MM-ThGEM

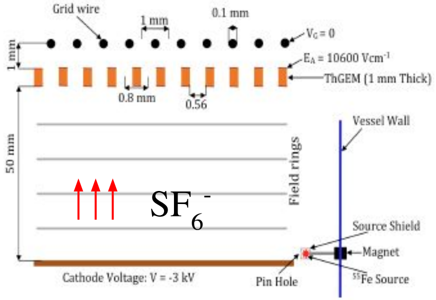


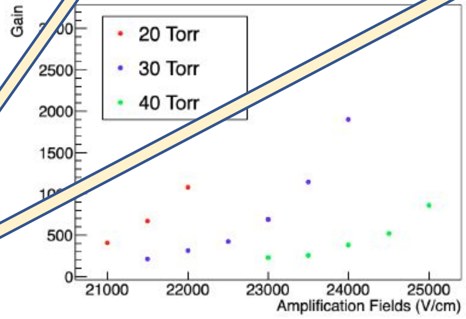
(a) Cross-section of the MMThGEM with the field names (left), plane names (right) and the gap widths (centre-left)

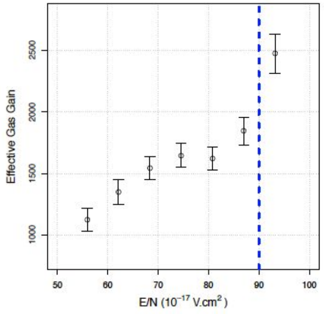


(b) Close-up picture of the MM-ThGEM holes from above

ThGEM + MWPC





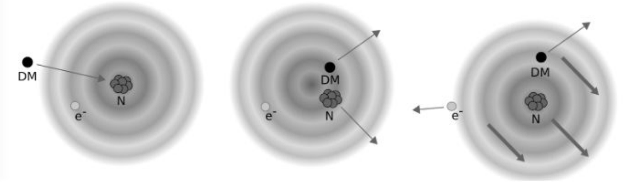


Optical Time Projection Chamber for the observation of the Migdal effect in nuclear scattering

MIGDAL
Migdal In Galactic Dark mAtter expLoration

University of Birmingham
GDD Gas Detectors Development Group
Helsinki Institute of Physics
Imperial College London
LIP
The University of New Mexico
University of Oxford
Royal Holloway University of London
Science & Technology Facilities Council Rutherford Appleton Laboratory
The University Of Sheffield.

Atomic effect predicted by A. Migdal in 1939



Migdal Effect - nucleus moves relative to the electron cloud. Individual electron might be ejected leading to ionisation.


Regular Article - Experimental Physics | Open Access | Published: 30 March 2018

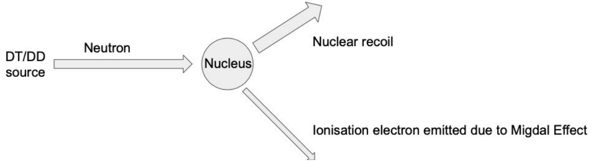
Migdal effect in dark matter direct detection experiments

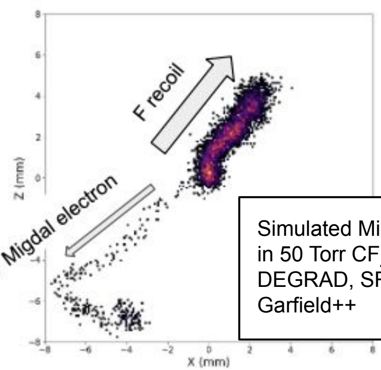
Masahiro Ibe, Wakutaka Nakano, Yutaro Shoji & Kazumine Suzuki

Journal of High Energy Physics **2018**, Article number: 194 (2018) | Cite this article

Experimental Goal

Observation of two tracks (Migdal electron and nuclear recoil) originating from the same vertex in a low pressure gaseous detector using a high intensity DT/DD neutron generator.

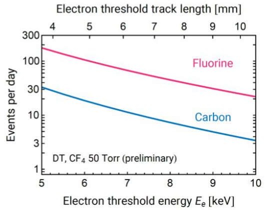




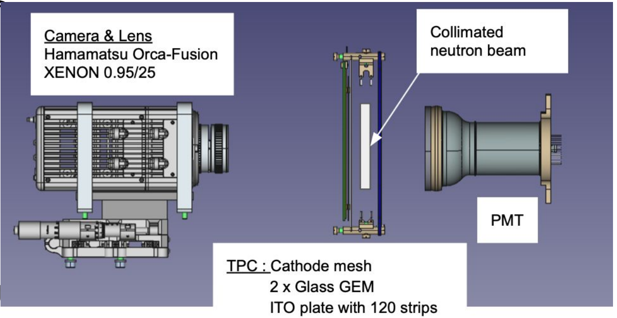
Simulated Migdal event in 50 Torr CF_4 using DEGRAD, SRIM and Garfield++

We are seeking the first observation of the Migdal effect by detection of the Migdal electrons in CF_4- based gas mixtures including noble gases

Expected number of Migdal events in CF_4 using DT generator



Taking into account energy distribution and rates of the events with C and F recoils in the fiducial region over one day of exposure to neutron from DT generator.


Camera & Lens
Hamamatsu Orca-Fusion
XENON 0.95/25

Collimated neutron beam

PMT

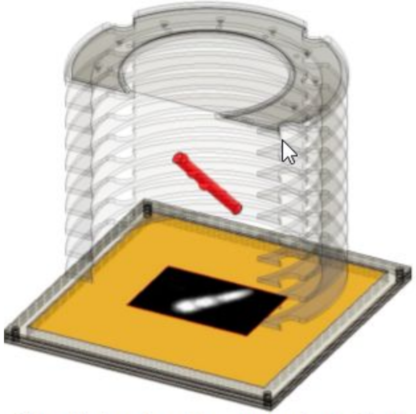
TPC : Cathode mesh
2 x Glass GEM
ITO plate with 120 strips

Dark Matter searches and Migdal Effect -> sensitivity extension to low mass region

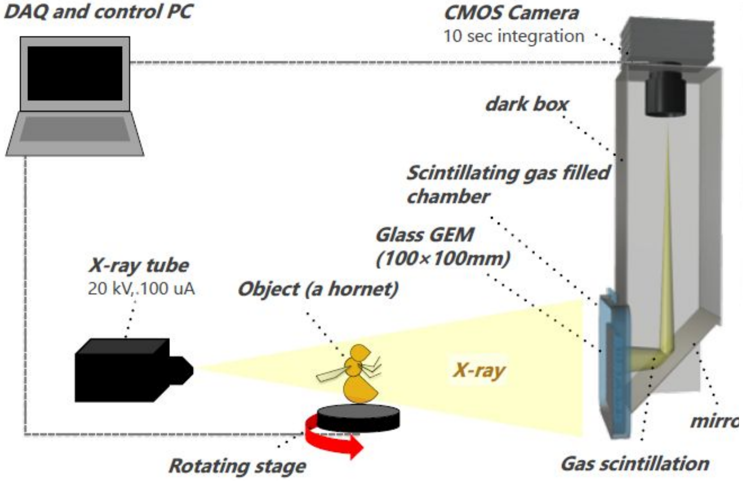
Huge attention by DM community with almost 100 citations of Ibe's paper since 2018 (this includes major experiments searching for WIMPs)

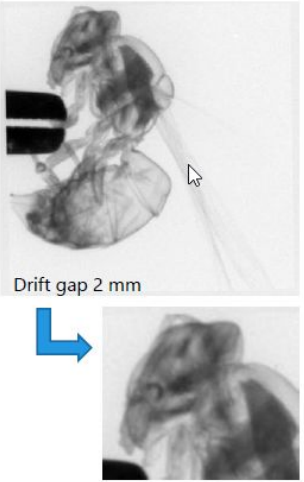
MIGDAL O-TPC and Glass-GEM applications

Not only application in Physics research !



3D alpha track reconstruction (schematic)



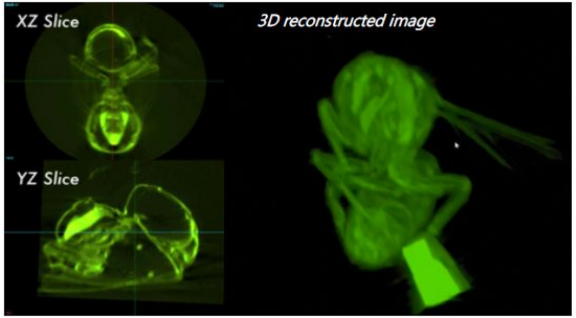


T.Fujiwara's presentation

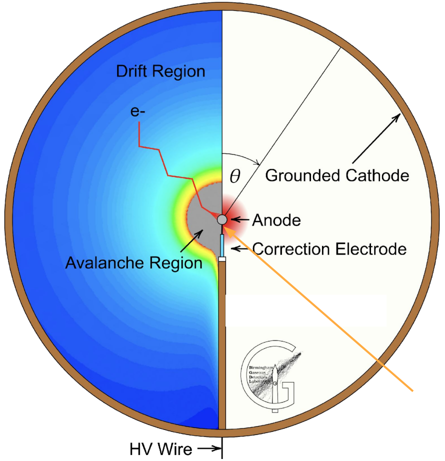
PEG3 G-GEM

H. Takahashi, Nucl.Instrum.Meth.A 724 (2013) 1-4

- X-ray imaging
- Medical imaging
- Neutron detection



NEWS-G and the Spherical Proportional Counter



$$E(r) = \frac{V_0}{r^2}\frac{r_A r_C}{r_C - r_A} \approx \frac{V_0}{r^2} r_A$$

r_A = *anode ball radius*
r_C = *cathode radius*

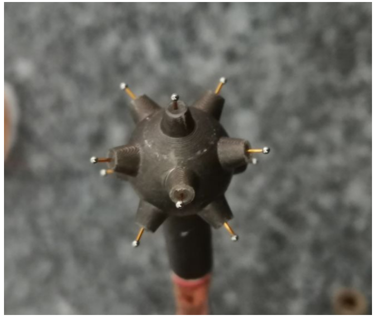
$C \approx r_a = 1\text{ mm} < 1\text{pF}$

UG Electroformed layer

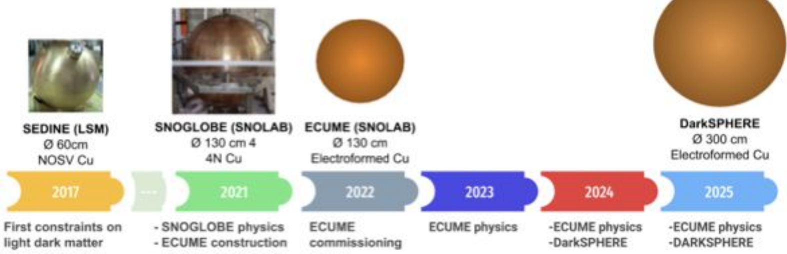
Central sensor is key
(years of evolution!)

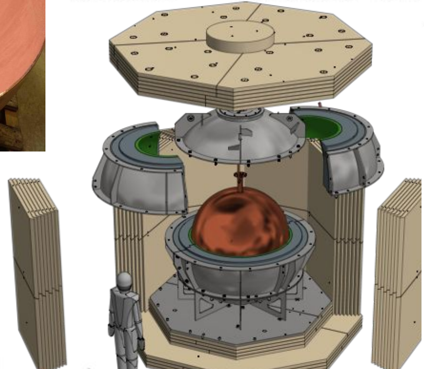
- **Large volume** read out with a small number of channels
- **Single electron threshold** due to:
  - Low capacitance
  - High gain
- **Radio-pure construction**
- **Background rejection handles**
- Flexible operation
  - **Swappable gases-targets**
  - Variable pressure choice

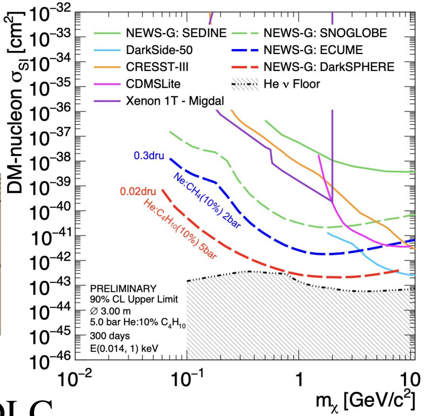
Ideal for rare-event searches! DM, 2β0v, CEvNS



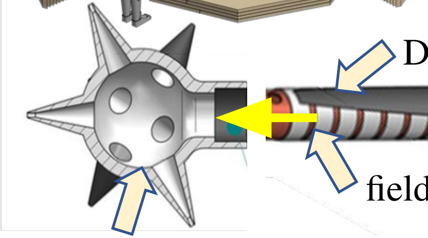
ACHINOS (v.1)







JINST 3 (2008) P09007
JINST 15 (2020) P11023



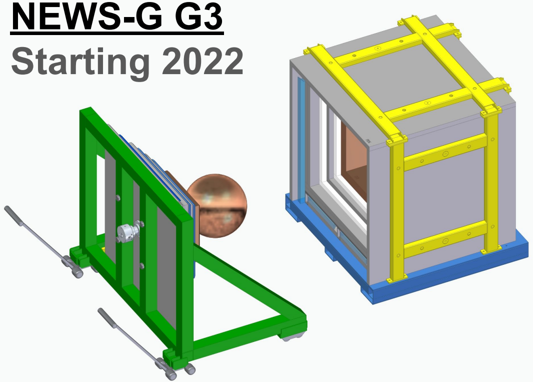
Adaptative field (high enough field both close and far from the anode)

ACHINOS (new version)

Spherical Proportional Counter - Spin offs

NEWS-G G3

Starting 2022

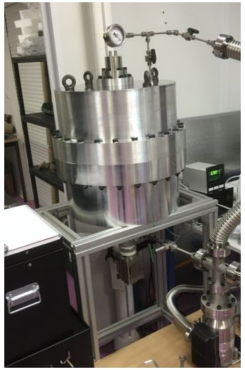


SPC for CEvNS physics in reactors

- Beyond Standard Model:
  - Measurement of a non-zero neutrino magnetic moment
  - Search for sterile neutrinos.

- Monitoring reactor neutrino fluxes
- Study of reactor anti-neutrino energy spectrum, below the Q-value of the inverse beta decay process

R2D2 (Rare Decays with a Radial Detector)



An R&D project investigating the use of a Xenon filled SPC to search for 0νββ

JINST 13 (2018) P01009

JINST 16 (2021) 03, P03012

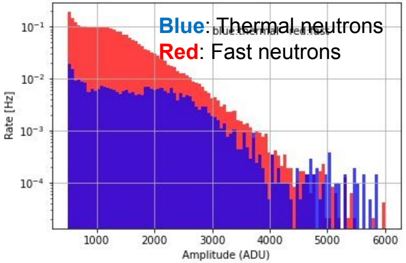
Goal: demonstration of the required energy resolution to search for 0νββ can be achieved (1% FWHW at Qββ of 2.458 MeV)

Fast neutron detection with a N_2-filled SPC

- Alternative to 3He for fast neutrons
- Simple Safe Robust
- Measurements started at UoB and Boulby UG lab
- Principle proved

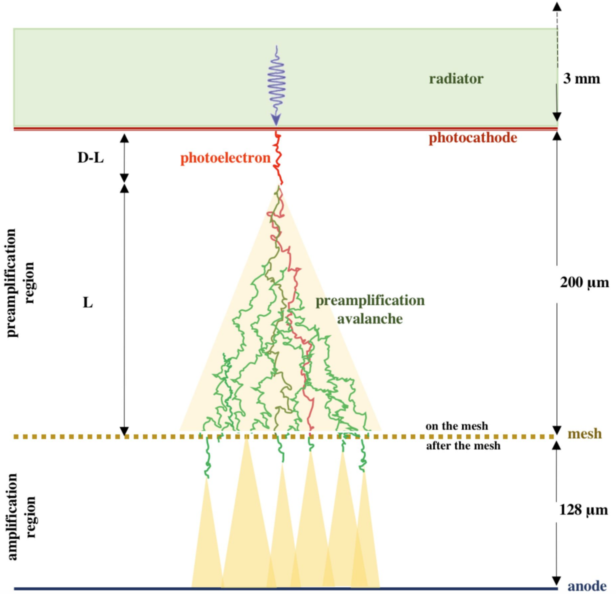
Nucl.Instrum.Meth.A 847 (2017) 10-14

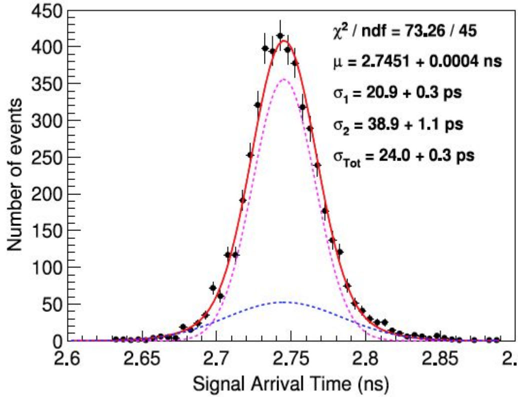
NSS/MIC 2019, 1-3



PICOSEC Micromegas for precise timing

PICOSEC
Micromegas





24ps time resolution

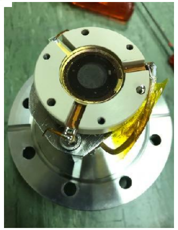
NIM-A 903(2018) 317-325

MOTIVATION:

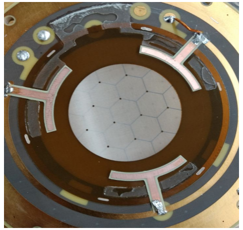
- Mitigation of pile-up in present and future colliders
- Extended TOF systems

✔ **Micromegas + Cherenkov radiator + photocathode** → synchronous photo-electrons enter Micromegas

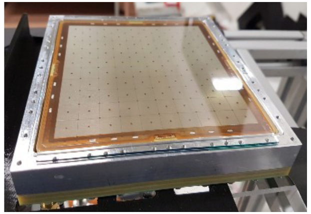
✔ **Small drift gap** & high field → avalanches start as early as possible with minimal time jitter → Timing resolution a **few tens of ps**



Single-pad



Multi-pad



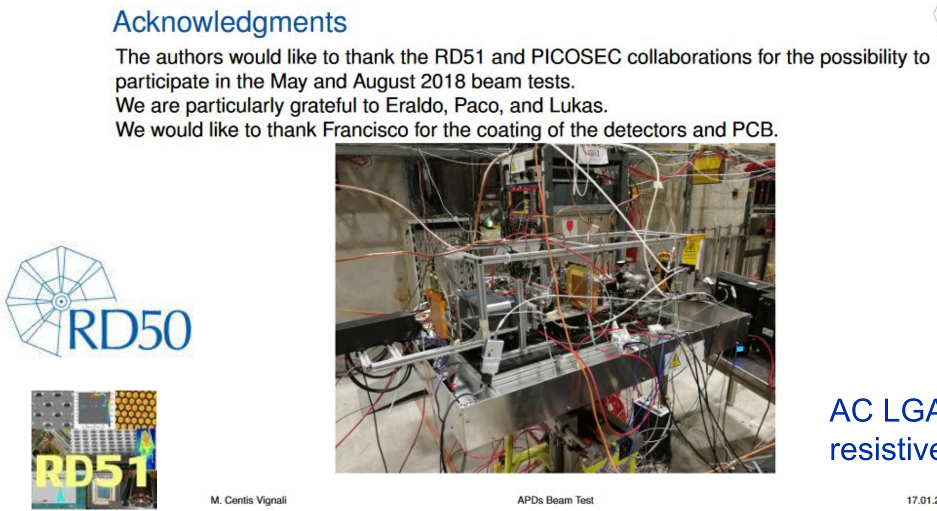
10x10 cm^2

Simulation studies and modeling: NIM-A 993 (2021) 165076
Results of the multi-pad prototype: NIM-A 993 (2021) 165049

Synergies

Synergies successfully explored with MPGD technologies. Specially within RD51 collaboration with common facilities (lab/beam/workshop) and tools (modelling/electronics)
To be fostered as well between different technologies (facilities, modelling, electronics,…) …

Sharing of facilities/instrumentation: Timing/RD50 on RD51 timing telescope in beam @ H4/SPS



Acknowledgments

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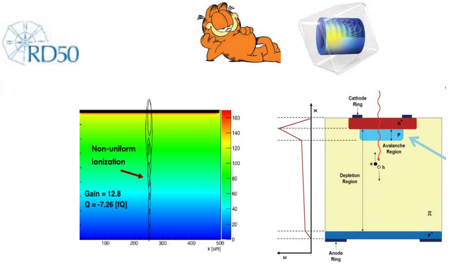
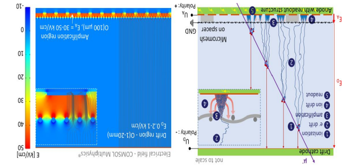
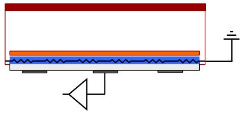
We are particularly grateful to Eraldo, Paco, and Lukas.
We would like to thank Francisco for the coating of the detectors and PCB.

M. Centis Vignali APDs Beam Test 17.01.2019 3 / 18

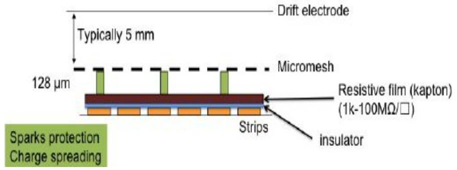
Sharing of tools (modelling): LGAD (Si) & MicroMegas (gas) almost identical concept/signal formation







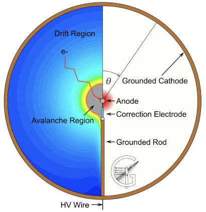
AC LGAD with resistive layer

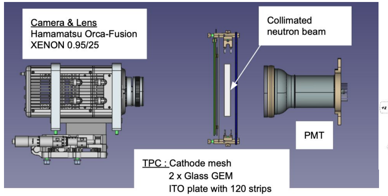


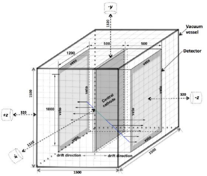
AC mm with resistive layer

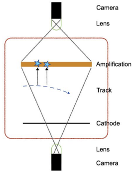
Adapted from E.Oliveri
ECFA Detector R&D 2021

Summary

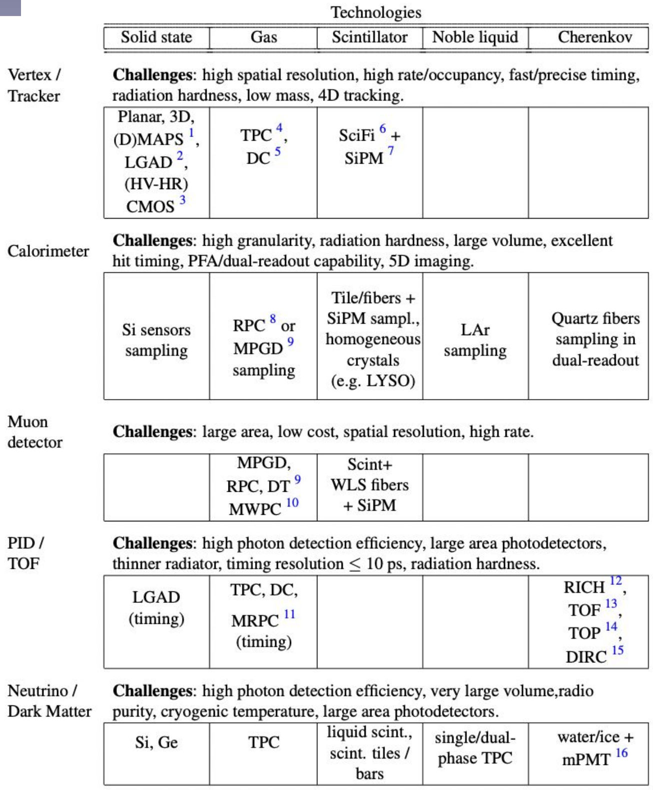








- Gaseous detectors are a very versatile with numerous advantages, behind numerous great discoveries in Physics
- Gaseous detector development capabilities opens up numerous physics applications in a very diverse set fields
- Gaseous detectors greatly complement other detector technologies developed in the UK
- Gaseous detectors can bring down the cost of physics projects in many cases
- R&D on gaseous detectors is relatively low cost
- Funding opportunities at the level of 10-100k£ would have a major impact

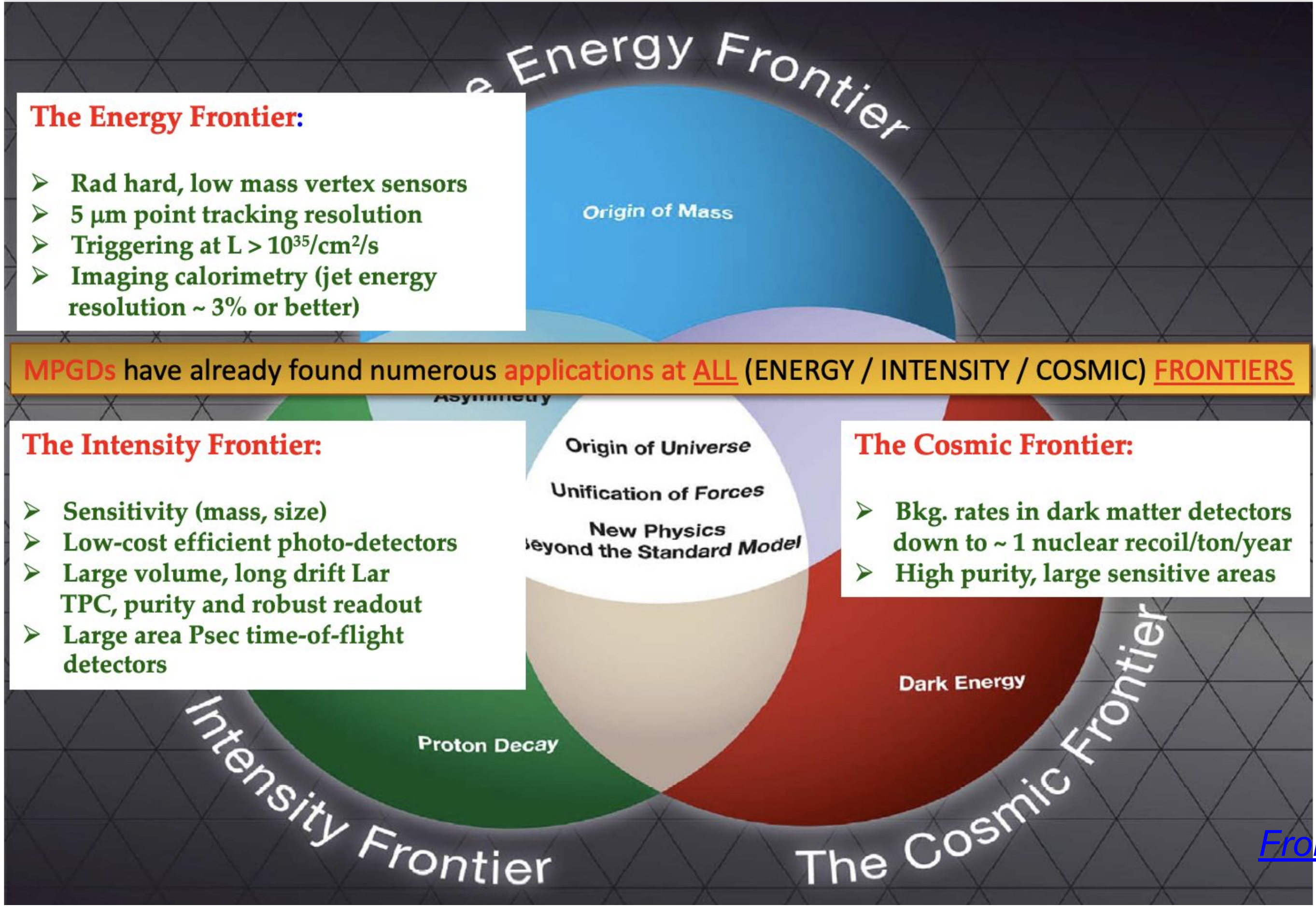


	Technologies				
	Solid state	Gas	Scintillator	Noble liquid	Cherenkov
Vertex / Tracker	**Challenges**: high spatial resolution, high rate/occupancy, fast/precise timing, radiation hardness, low mass, 4D tracking.				
	Planar, 3D, (D)MAPS[1], LGAD[2], (HV-HR) CMOS[3]	TPC[4], DC[5]	SciFi[6] + SiPM[7]		
Calorimeter	**Challenges**: high granularity, radiation hardness, large volume, excellent hit timing, PFA/dual-readout capability, 5D imaging.				
	Si sensors sampling	RPC[8] or MPGD[9] sampling	Tile/fibers + SiPM sampl., homogeneous crystals (e.g. LYSO)	LAr sampling	Quartz fibers sampling in dual-readout
Muon detector	**Challenges**: large area, low cost, spatial resolution, high rate.				
		MPGD, RPC, DT[9] MWPC[10]	Scint+ WLS fibers + SiPM		
PID / TOF	**Challenges**: high photon detection efficiency, large area photodetectors, thinner radiator, timing resolution ≤ 10 ps, radiation hardness.				
	LGAD (timing)	TPC, DC, MRPC[11] (timing)			RICH[12], TOF[13], TOP[14], DIRC[15]
Neutrino / Dark Matter	**Challenges**: high photon detection efficiency, very large volume,radio purity, cryogenic temperature, large area photodetectors.				
	Si, Ge	TPC	liquid scint., scint. tiles / bars	single/dual-phase TPC	water/ice + mPMT[16]

Physics Briefing Book 2020

Extra slides

Challenges for MPGD Technologies: Experimental Opportunities



The Energy Frontier:

- Rad hard, low mass vertex sensors
- 5 µm point tracking resolution
- Triggering at L > 10^{35}/cm^2/s
- Imaging calorimetry (jet energy resolution ~ 3% or better)

MPGDs have already found numerous applications at ALL (ENERGY / INTENSITY / COSMIC) FRONTIERS

The Intensity Frontier:

- Sensitivity (mass, size)
- Low-cost efficient photo-detectors
- Large volume, long drift Lar TPC, purity and robust readout
- Large area Psec time-of-flight detectors

The Cosmic Frontier:

- Bkg. rates in dark matter detectors down to ~ 1 nuclear recoil/ton/year
- High purity, large sensitive areas

From M.Titov