MPGDs: GEM, Micromegas, THGEM, μRWell and other ongoing developments

overview, limitations and perspectives

Eraldo Oliveri, CERN EP-DT-DD, Gas Detector Development (GDD) team

ECFA Detector R&D Roadmap Symposium of Task Force 1 Gaseous Detectors, 29th April 2021

Let me start with disclaimers

- I will do my best to be representative of a wide community but I apologize that, despite the effort, I'm sure I will be surely biased by my personal experience…
- I will surely forget something, please do not hesitate to comment…
- ECFA… mostly EU focused… probably a mistake.. But ok, too late now…
- If you will find something cute in the next slides.. It's probably not me but some smart input received by a colleague… ok, if there will be something inadequate… it's probably me…
- Given the rich schedule of the day, I will not go into technical details - here I may disappoint the expectations of the convenors (I apologize for this) - but I will focus more on potential inputs for discussion/roadmap coming from R&D groups working with MPGD…
- Because of this I have slightly changed the title of the talk to…

R&D on MPGDs: GEM, Micromegas, THGEM, µRWell and other ongoing developments

~~overview, limitations and perspectives~~

Collecting inputs for potential discussions and for roadmap

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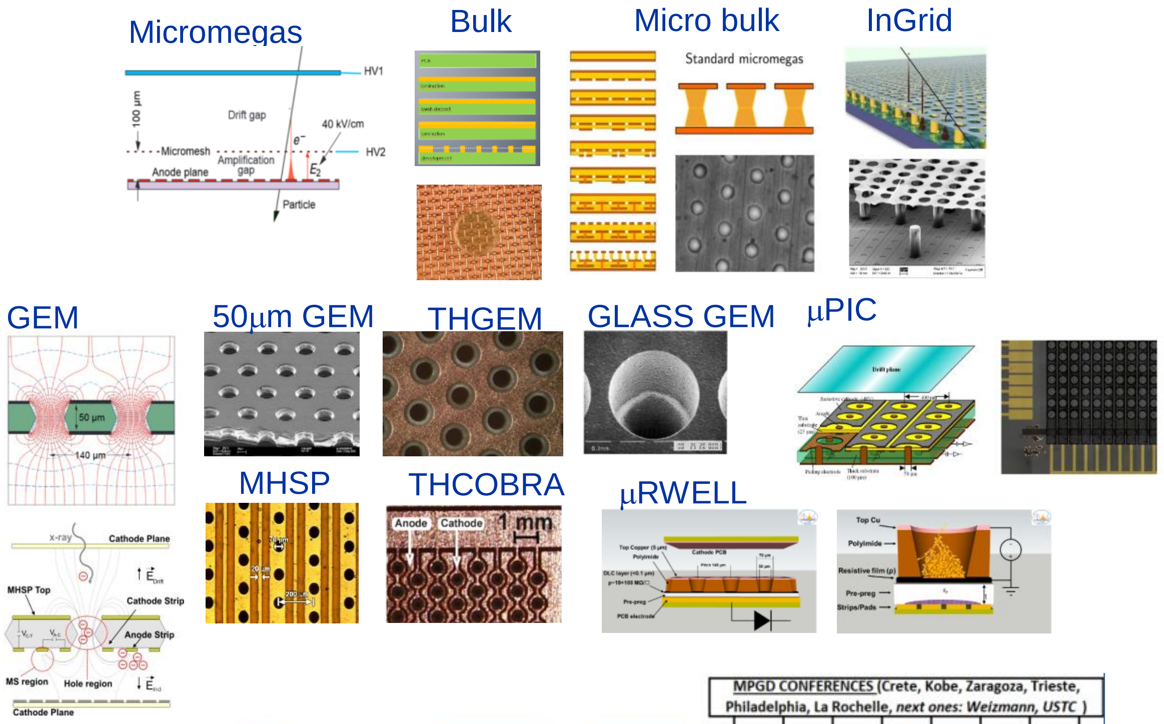
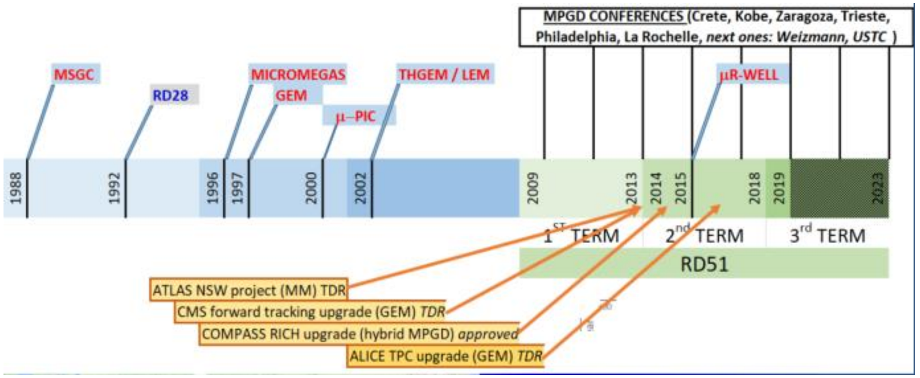
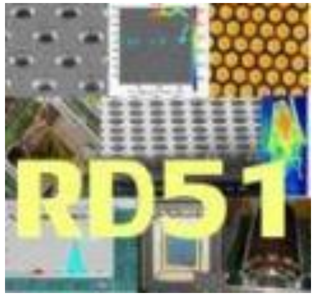
Micro Pattern Gas Detector Family





- High Rate Capability — Up to MHz/mm^2 (MIP)
- High Gain — Up to 10^5-10^6
- High Space Resolution — <100μm
- Good Time Resolution — In general few ns , sub-ns in specific configuration
- Good Energy Resolution — 10-20% FWHM @ soft X-Ray (6KeV)
- Excellent Radiation Hardness
- Good Ageing Properties
- Ion Backflow Reduction — % level sort of easy, below % in particular configuration
- Photon Feedback Reduction
- Large size — m^2
- Low material budget
- Low cost
- …



RD51 collaboration
Development of Micro-Pattern Gas Detectors Technologies

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

A large variety of applications

Table 11.1: Summary of promising technologies and their possible specific detector applications to address experimental challenges of approved and future projects.

	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]

1. (Depleted) Monolithic Active Pixel Sensor
2. Low Gain Avalanche Detector
3. (High Voltage - High Resistivity) CMOS
4. Time Projection Chamber
5. Drift Chamber
6. Scintillating Fiber tracker
7. Silicon Photomultiplier
8. Resistive Plate Chamber
9. MicroPattern Gaseous Detector
9. Drift Tube
10. Multi-Wire Proportional Chamber
11. Multi-gap Resistive Plate Chamber
12. Ring-Imaging Cherenkov detector
13. Time-Of-Flight detector
14. Time-Of-Propagation counter
15. Detection of Internally Reflected Cherenkov
16. multi-anode Photo-Multiplier Tube

Physics Briefing Book Input for the European Strategy for Particle Physics Update 2020, CERN-ESU-004, http://cds.cern.ch/record/2691414/files/Briefing_Book_Final.pdf

Covering all specific detector applications.

Different applications = different needs..

Different developments complement each others toward a general enrichment of the technologies…

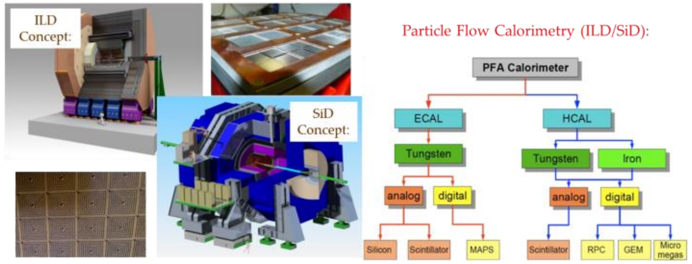
Probably the most exhaustive list I know…

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 m² Single unit detect: (2.2x1.4m²) – 2-3 m²	**Max. rate**:15 kHz/cm² **Spatial res.**: <100µm **Time res.**: ~ 10 ns **Rad. Hard.**: ~ 0.5C/cm²	- Redundant tracking and triggering; Challenging constr. in mechanical precision:
ATLAS Muon Tagger Upgrade: Start: > 2023	High Energy Physics (Tracking/triggering)	µ-PIC	Total area: ~ 2m²	**Max.rate**:100kHz/cm² **Spatial res.**: < 100µm	
CMS Muon System Upgrade: Start: > 2020	High Energy Physics (Tracking/Triggering)	GEM	Total area: ~ 143 m² Single unit detect: 0.3-0.4m²	**Max. rate**:10 kHz/cm² **Spatial res.**: ~100µm **Time res.**: ~ 5-7 ns **Rad. Hard.**: ~ 0.5 C/cm²	- Redundant tracking and triggering
CMS Calorimetry (BE) Upgrade Start > 2023	High energy Physics (Calorimetry)	Micromegas, GEM	Total area: ~ 100 m² Single unit detect: 0.5m²	**Max. rate**: 100 MHz/cm² **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 m² Single unit detect: up to 0.3m²	**Max.rate**:100 kHz/cm² **Spatial res.**: ~300µm **Time res.**: ~ 100 ns **dE/dx**: 12 % (Fe55) **Rad. Hard.**: 50 mC/cm²	- 50 kHz Pb-Pb rate; - Continues TPC readout - Low IBF and good energy resolution
TOTEM: Run: 2009-now	High Energy/ Forward Physics (5.3≤|eta|≤6.5)	GEM (semicircular shape)	Total area: ~ 4 m² Single unit detect: up to 0.03m²	**Max.rate**:20 kHz/cm² **Spatial res.**: ~120µm **Time res.**: ~ 12 ns **Rad. Hard.**: ~ mC/cm²	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 m² Single unit detect: 20-24 cm²	**Max.rate**:500 kHz/cm² **Spatial res.**: ~ cm **Time res.**: ~ 3 ns **Rad. Hard.**: ~ C/cm²	- Redundant triggering
FCC Collider Start: > 2035	High Energy Physics (Tracking/Triggering/ Calorimetry/Muon)	GEM,THGEM Micromegas, µ-PIC, InGrid	Total area: 10.000 m² (for MPGDs around 1.000 m²)	**Max.rate**:100 kHz/cm² **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 m² Single unit detect: ~ 400 cm² (pads) ~ 130 cm² (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 m² Single unit detect: 0.5 - 1 m²	**Max.rate**:1 kHz/cm² **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 m² Single unit detect: 0.31x0.31 m² Total area: ~ 2 m² Single unit detect: 0.4x0.4 m²	**Max.rate**:10^7 Hz (~100kHz/mm²) **Spatial res.**: ~70-100 µm (strip), ~120µm (pixel) **Time res.**: ~ 8 ns **Rad. Hard.**: 2500 mC/cm²	Required beam tracking (pixelized central / beam area)
KEDR @ BINP Run: 2010-now	Particle Physics (Tracking)	GEM	Toral area: ~0.1 m²	**Max. rate**:1 MHz/mm² **Spatial res.**: ~70µm	
SBS in Hall A @ JLAB Start: > 2017	Nuclear Physics (Tracking) nucleon form factors / struct.	GEM	Total area: 14 m² Single unit detect. 0.6x0.5m²	**Max. rate**:400 kHz/cm² **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: 1.5m² Single unit detect. 1.2x0.6 m2	**Max. rate**:5 kHz/cm² **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: 40m² Single unit detect. 1.2x0.6 m2	**Max. rate**:600 kHz/cm² **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: 0.26m² 0.52m(diameter) x0.5m(drift length)	**Max. rate**:10⁶ kHz/cm² **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

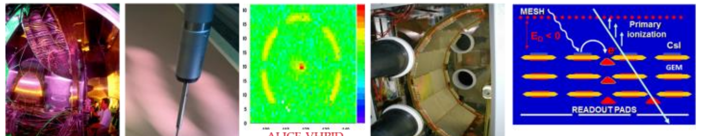
Experiment/ Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics/ Performance	Special Requirements/ Remarks
KLOE-2 @ DAFNE Run: 2014-2017	Particle Physics/ K-flavor physics (Tracking)	Cylindrical GEM	Total area: 3.5m² 4 cylindrical layers L(length) = 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/cm² **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 m² Barrel ~ 3.7 m² 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/cm²	- 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: ~ 3m² 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 m² Single unit detect: ~ 0.4 x 0.4 m²	**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 m² Single unit detect: ~ 0.9 m²	**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 m² Single unit detect: Type I : 50 x 9 cm² Type II: 50 x 16 cm²	**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 m² Single unit detect: ~ 1.5 m²	**Max. rate**: < 140kHz/cm² **Spatial res.**: ~ 150µm	Continuous-wave operation: 10¹¹ interaction/s
CBM @ FAIR: Start: > 2020	Nuclear Physics (Muon System)	GEM	Total area: 9m² Single unit detect: 0.8x0.5m²–0.4m²	**Spatial res.**: < 1 mm **Max. rate**: 0.4 MHz/cm² **Time res.**: ~ 15ns **Rad hard.**: 10¹³ n.eq./cm²/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 m² Total area: ~ 25 m²	**Spatial res.**: ~ 100 um (rϕ) Luminosity (e-p): 10³³ **Spatial res.**: ~ 50- 100 um **Max. rate**: ~ MHz/cm²	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 m² Single unit detect: ~ 0.6 x 0.6 m²	**Max.rate**:100 Hz/cm² **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 m² Single unit detect: ~ 0.3 x 0.3 m²	**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 m²	**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 m² Total area: ~ 10 m²	**Spatial res.**: ~ 100 um (rϕ) Luminosity (e-p): 10³³ **Spatial res.**: ~ few mm	Low material budget High single electron efficiency

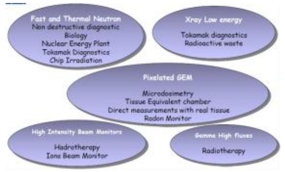


ALICE VHPID THGEM

HBD Concept:

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

Probably the most exhaustive list I know…



MPGD-based Neutron Detectors

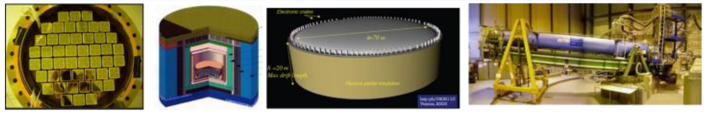
MPGD coupled to n-converters:

- 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	

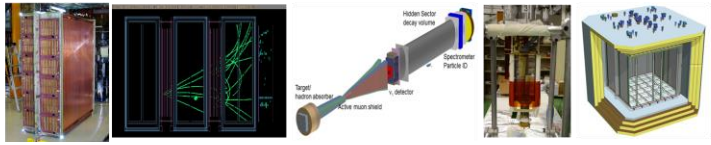
MPGD Technologies for Dark Matter Detection

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



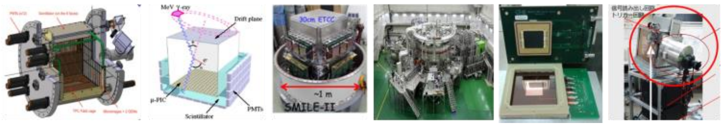
MPGD Technologies for Neutrino Physics

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 DUNE Dual Phase Far Detector Start: > 2023?	Neutrino physics (Tracking+ Calorimetry)	LAr TPC w/ THGEM double phase readout 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 Total area: 720 m² 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 **Max. rate**: 4*10⁻⁷ Hz/m² **Spatial res.**: 1 mm **Rad. Hard.**: no	Detector is above ground (max. rate is determined by muon flux for calibration) 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 lcps **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

https://indico.cern.ch/event/581417/contributions/2558346/attachments/1465881/2266161/2017_05_Philadelphia_MPGD2017-ConferenceSummary_25052017_MS.pdf

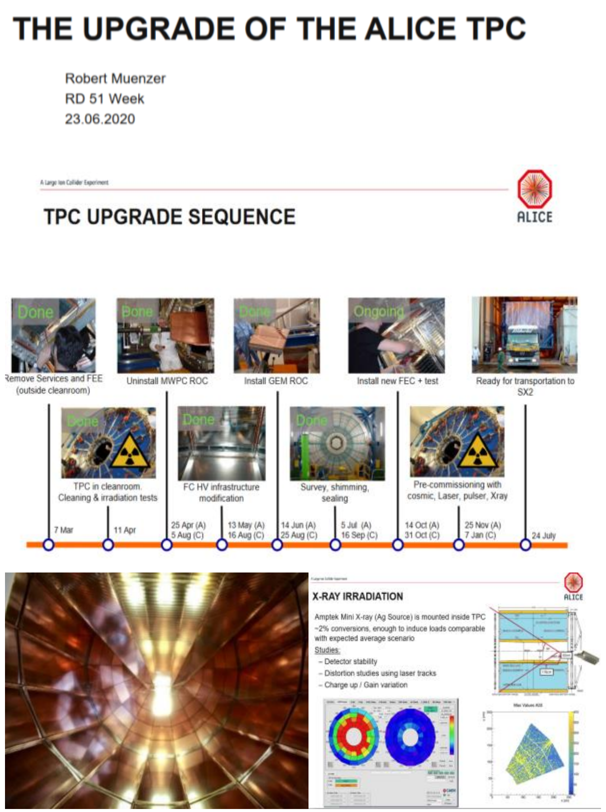
Impressive compilation.

Thanks Maxim….

Some update needed (table ref. to 2017)

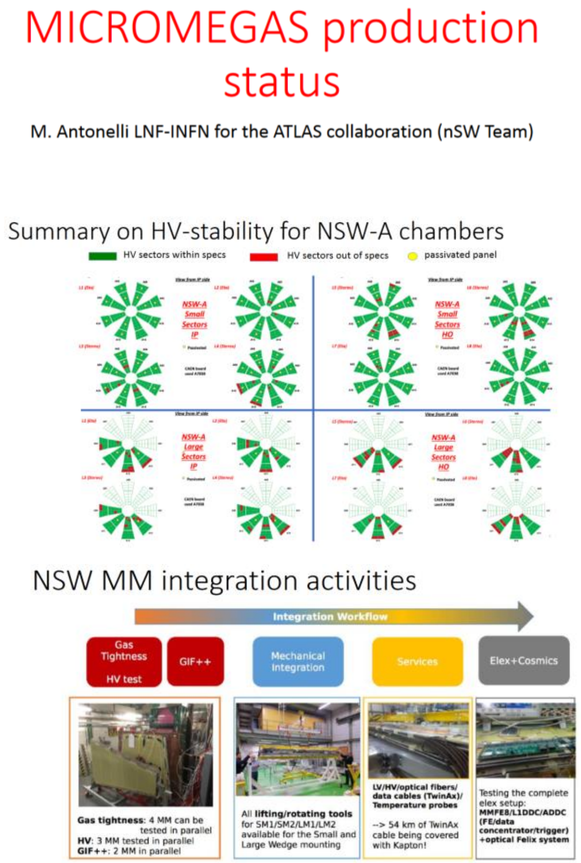
Please check if you are not there and send us the missing info

Today with several lessons learned in the context of large systems



https://indico.cern.ch/event/911950/contributions/3876016/attachments/2061878/3459117/2020_06_18_ALICE_TPC_2.pdf

https://indico.cern.ch/event/911950/contributions/3876019/attachments/2061863/3458939/fsimone_GE11status_RD51.pdf



https://indico.cern.ch/event/911950/contributions/3876018/attachments/2062109/3459460/MMstatus_RD51.pdf

Future R&D…

Several topics … many of them discussed during the day in more details…

Improving performances: rate, space resolution with limited number of channels, timing, high gain…

Resistive layers/electrodes: stability, space resolution, simple/single stage…

Large area MPGD/Si hybrid detectors …

Optical readout, pixelated readout, electronics integration, Single electron sensitive TPC readout systems, …

Material budget, radiation hardness, minimized dead areas…

Gas mixtures, ions,…

New material: converters (secondary emitters, photocathodes), protection layers…

New manufacturing techniques for new structures and fast prototyping (etching, 3D,..)..

Simplified structures with simplified production processes..

Some inputs for potential discussions/comments…

Inputs/discussions from/with: Giovanni Bencivenni, Michele Bianco, Shikma Bressler, Gianluigi Cibinetto, Paul Colas, Klaus Desh, Esther Ferrer Ribas, Francisco Garcia Fuentes, Paolo Giacomelli, Diego Gonzalez Diaz, Paolo Iengo, Mauro Iodice, Jochen Kaminski, Bernhard Ketzer, Stefano Levorato, Thomas Papaevangelou, Emilio Radicioni, Lev Shekhtman, Fulvio Tessarotto, Harry van der Graaf, Joao Veloso, Piet Verwilligen

+

Several people I'm normally in contact with at CERN and in RD51

I apologize if not all in.. or if something has been erroneously ☺ distorted…

Input 1: Detector R&D groups / Recognition

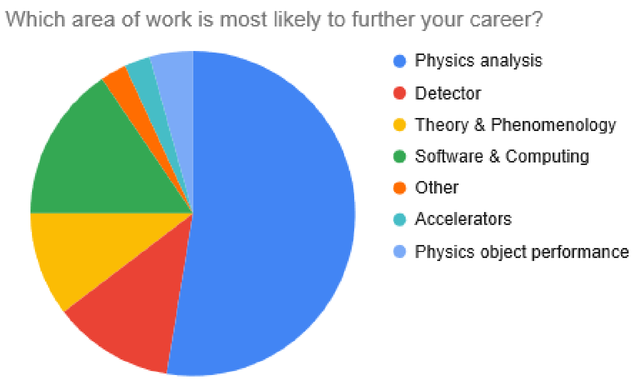
- **Hard to preserve knowledge and know-how, people, equipment, infrastructures,..**
- **Difficulties on being funded if not well attached to a project …**
- **When attached to a project, sometime difficult to preserve the investment done because of a different project phases (moving from instance from R&D to “installation, commissioning, operation”)…**
- **End of a project can be the end, i.e. everyone busy (lost) in new proposal/applications/calls…**
- **Difficulties on getting people and offering a perspective: not the best entry point for a career (*) – sometimes hard to get students or post-doc - trained researchers have often to leave…**

Report on the ECFA Early-Career Researchers Debate on the 2020 European Strategy Update for Particle Physics

The ECFA Early-Career Researchers

February 6, 2020

https://cds.cern.ch/record/2708708/files/2002.02837.pdf



(*) Early-Career Researcher (PHD and post-DOC) perception

Input 2: Steering processes should support creativity and flexibility…

Even though resources are limited, MPGD technologies should allow us to keep diversity and flexibility…

Important to optimize the way we do R&D more than the activities…

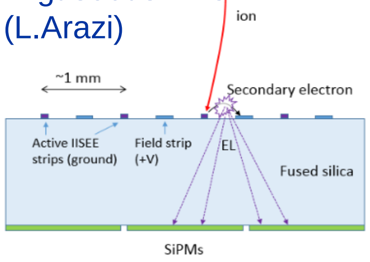
A well distributed dissemination of different technologies can boost creativity and offer the safest/best scenario to develop strategic technologies to their best …

"Plan for sufficient flexibility......even if impossible(*)" **E. Heijne , Perspectives on future development (TBC), ECFA Detector R&D Roadmap Symposium of Task Force 7 Electronics and On-detector Processing, https://indico.cern.ch/event/1001692/**

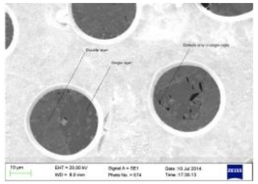
Input 3 / R&D needs (I): New Technologies or New architectures

Different needs to be covered: risky / longer time scales / interdisciplinary support / going to unknown fields/tools.. for the first … Easy/fast/efficient access to existing/known technologies/tools/infrastructures for the second one…

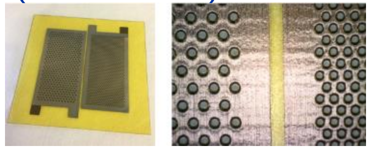
Positive Ion Detection in gaseous TPC (L.Arazi)



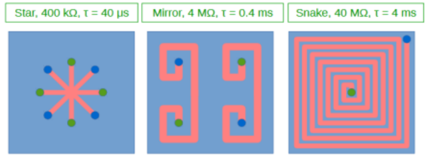
Charge transfer properties through graphene (P.Thuiner)



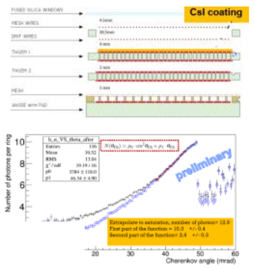
3D printed THGEM (F. Brunbauer)



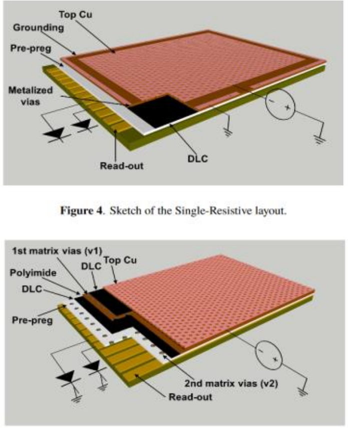
Scream mm (M. Chefdeville)



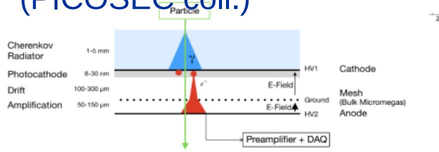
COMPASS RICH-1 (Compass)



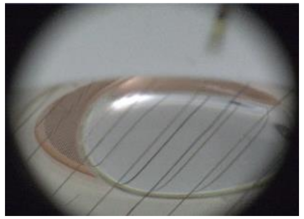
uRWELL (G. Bencivenni)



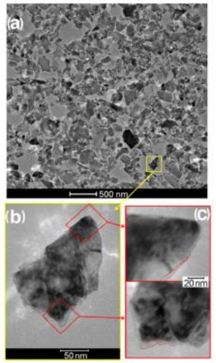
PICOSEC mm (PICOSEC coll.)



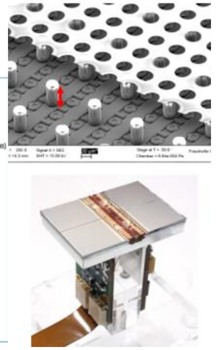
Bubble-assisted Liquid Hole-Multipliers (E. Erdal)



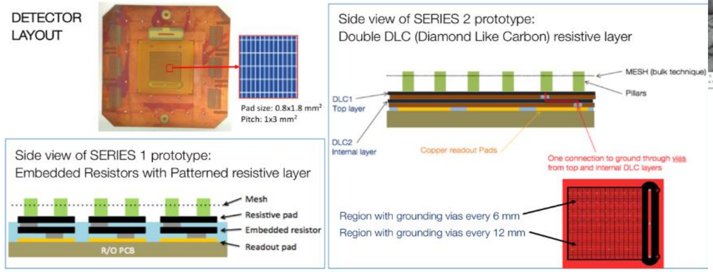
Nanodiamond photocathode (A. Valentini)



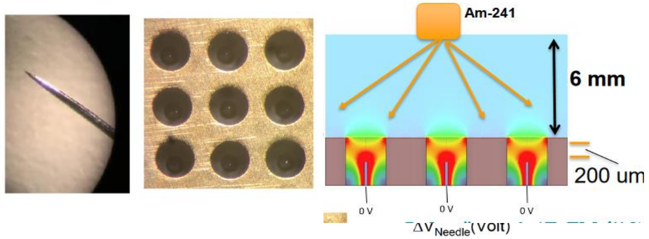
GridPix (J. Kaminski)



Small pad resistive mm (M. Iodice)



TIP-HOLE prototype (M. Cortesi)



Input 3 / R&D needs (II): different R&D phases

freedom

↑

If you ask

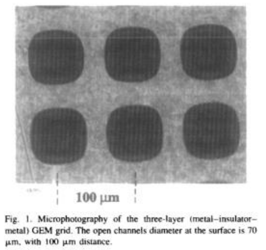
↓

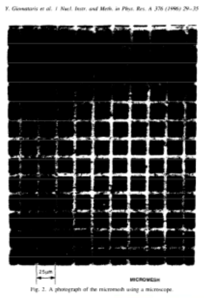
Well defined..
requirements,
conditions,
…

- **Generic & Blue Sky R&D (generic/prototyping)**
  Can be a small single group…

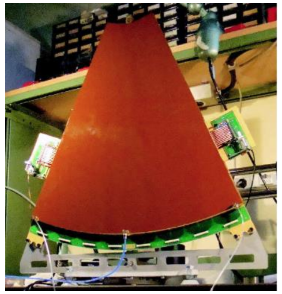
- **Project Driver R&D (prototyping/engineering)**
  Normally some small/proto collaboration …

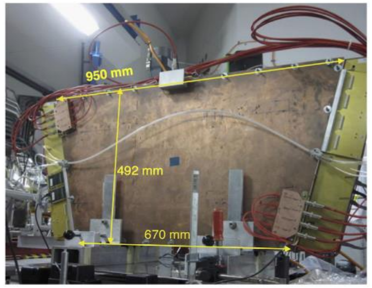
- **Integration R&D (engineering)**
  Normally a collaboration…

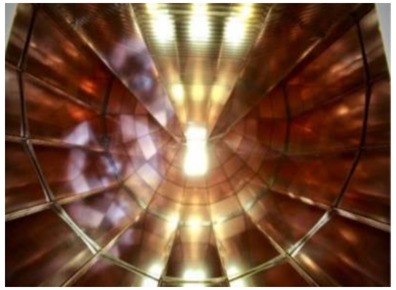


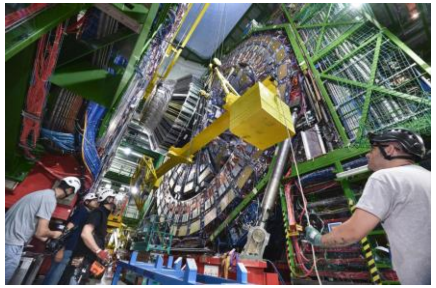


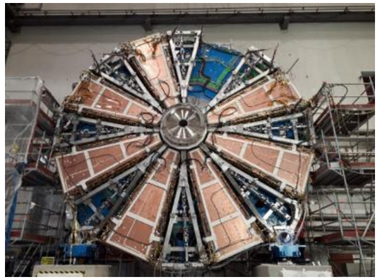
1996/1997











2021

Each phase requires specific expertise and knowledge…
The groups associated to each phase have different needs..
Important to properly support all of them according to their needs…
Important to have proper overlapping between them and between the groups leading each phase…
Despite the fact that the role of the first one is crucial (development of new technologies, seed for the rest) , it is often the harder one to support(*).

(*) Quoting E. Meschi, ECFA symposia TF7*: "We don't know what to do with it… but if you will do it, we cannot stay without"*

Input 4: Centers of excellence…

- **You need years of experience to create R&D teams and laboratories…**

A few examples…
Not exhaustive..
Apologize for the missing ones

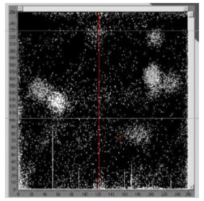
NIKHEF | irfu cea saclay | INFN Istituto Nazionale di Fisica Nucleare Sezione di Trieste | universidade de aveiro theoria poiesis praxis | UNIVERSITÄT BONN Rheinische Friedrich-Wilhelms-Universität Bonn | LAPP Laboratoire d'Annecy de Physique des Particules

INFN LNF Istituto Nazionale di Fisica Nucleare | מכון ויצמן למדע WEIZMANN INSTITUTE OF SCIENCE | LIP | AG Ketzer | CERN | GDD | …

- **Fundamental in R&D and in training/formation of new generation of detector physicists.**

- **International responsibility to support and protect this and to prevent funding fluctuations killing precious heritages (you can attach to each of the previous lab fundamental R&D and key detector physicists…)**

NIKHEF



2003, GEM+MediPix
CMOS pixel sensor

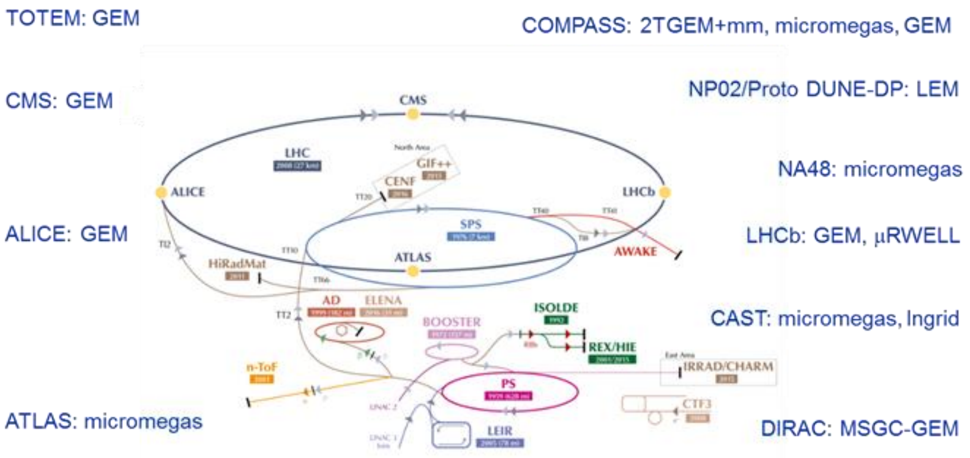
First RD51
CM @ Nikhef

NIKHEF
MPGD ageing
Fred Hartjes
NIKHEF

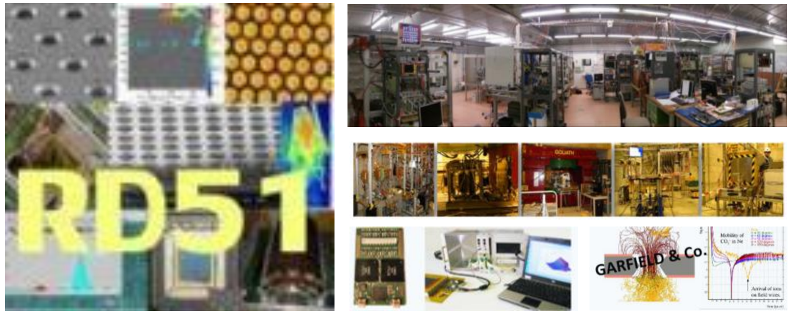
LC TPC

One example/Nikhef:
Difficulties on preserving people/ activities despite the role played by the group in our field….

Input 5: Importance of R&D collaborations / Centralized Facilities…



MPGD technologies spread over experiments (existing or planned)



International collaboration on MPGD
Started in 2008 (white paper/CERN)
Common facilities (lab/GDD, test beam/SPS)
developments (simulation/electronics) and
workshop (MPT) @ CERN

EP-DT
Detector Technologies

Micro Pattern Technology (MPT) workshop
Research/Development/Production of MPGD

Thin Film and Glass lab

Irradiation Facilities

EP-DT-FS Gas Group

Gas Group

GDD Gas Detector Development team
R&D on MPGD,
RD51 Support

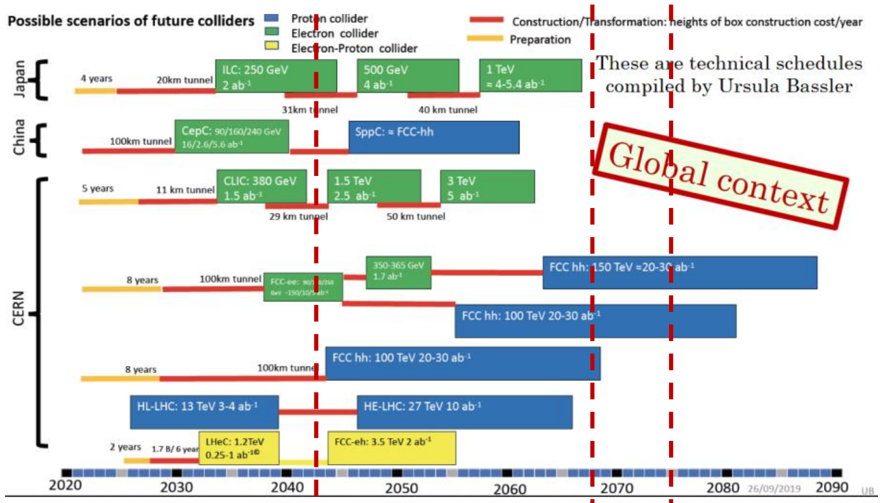
EP R&D

Strategic R&D on MPGD (large systems, novel solution, framework and tools)

Technological developments often need large infrastructures

Input 6: Future timelines & Knowledge Transfer

Timeline from Jorgen D'Hondt, Report from the ECFA chair, 15 Nov 2019



Around my retirement (maybe optimistic)

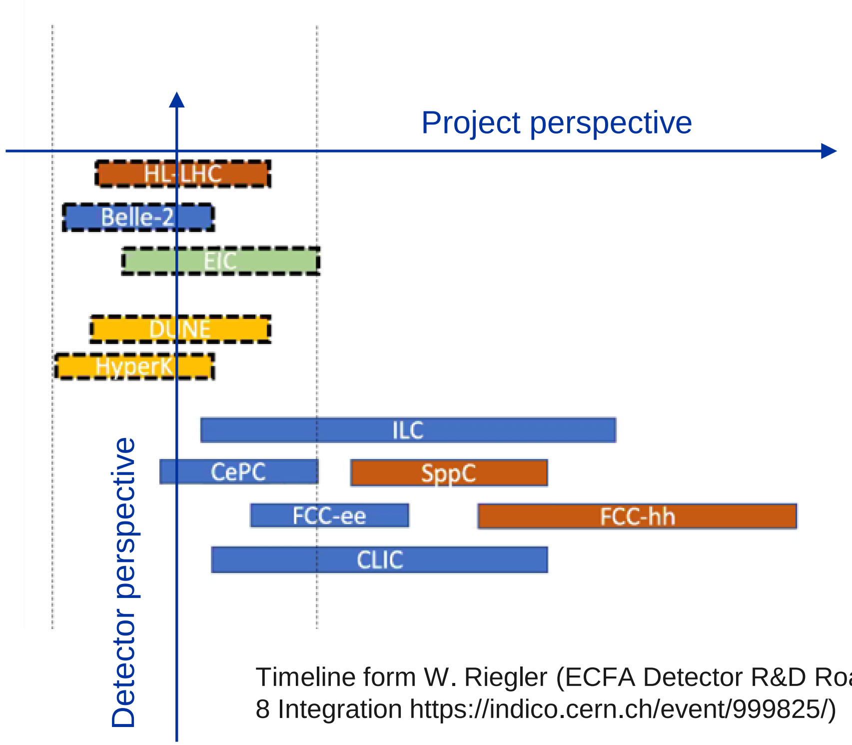
My son will be 50 years old (older than me now)

I will be 100 years old 😄

LHC Upgrades called back experienced team from first LHC detectors…

Preserve expertise and trained teams in these timescales…

We often learn/know how to build a proper detector system the day after the installation…



Timeline form W. Riegler (ECFA Detector R&D Roadmap Symposium of Task Force 8 Integration https://indico.cern.ch/event/999825/)

In project perspective you may not see all phases (R&D, installation, commissioning, operation)…

Maybe useful to explore as well detectors and technological perspectives (crossing projects funding)..

We should not “miss” experiments that can preserve the expertise and be a valid test-bench future experiments…

Input 7: Technology Transfer

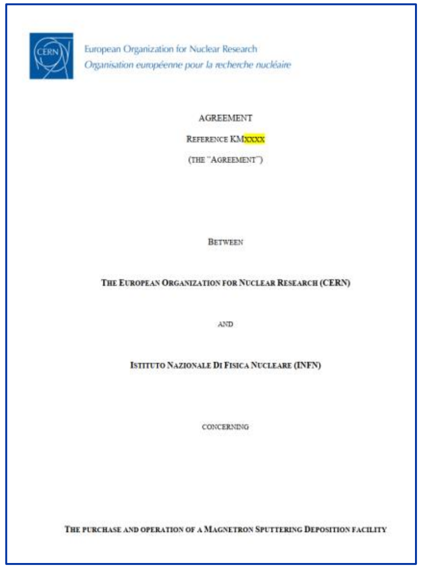
Infrastructure – development, testing and production facilities
Speaker: Rui De Oliveira (CERN)

Micro Pattern Technology (MPT) workshop
Research/Development/Production of MPGD

- **Key role played by CERN EP-DT MPT workshop**
- **Aspects covered by MPT:**
  A. New developments (MPGD structures and architectures)
  B. Production for R&D
  C. Production for experiments and large (large for us large but not for industry) volumes

Relations with industry
Speaker: Michele Bianco (CERN)

- **C → TT toward industry explored/done/ongoing…**
- **A & B (& C) → consolidating cooperation and sharing with MPT workshop** →
  - sharing between CERN & INFN of a DLC sputtering machine (costs and use sharing / personnel training)
- **A & B → TT towards/between institutes & national laboratories workshops… (MPT/Saclay/LNF/ LNGS/FTD Bonn/… ? …)**



European Organization for Nuclear Research
Organisation européenne pour la recherche nucléaire

AGREEMENT
REFERENCE KMxxxx
(THE "AGREEMENT")

BETWEEN

THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

AND

ISTITUTO NAZIONALE DI FISICA NUCLEARE (INFN)

CONCERNING

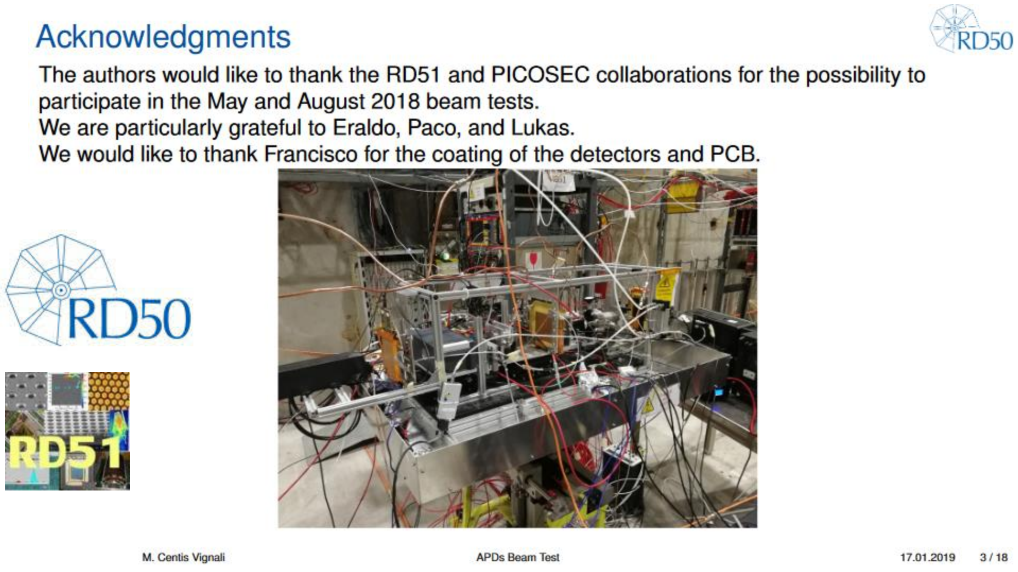
THE PURCHASE AND OPERATION OF A MAGNETRON SPUTTERING DEPOSITION FACILITY

C.I.D: the joint CERN-INFN DLC facility

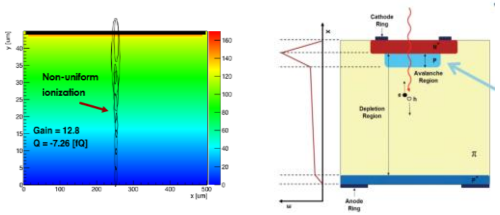
Input 8: Fostering synergies
(ECFA context: between Task Forces, Solid/Gas in this slide)

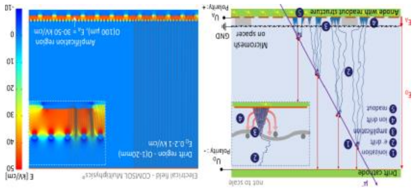
Synergies successfully explored within MPGD technologies.. strongly done in the context of RD51 collaboration with common facilities (lab/beam/workshop) and tools (modelling/electronics)…
To be fostered as well between different technologies (facilities, modelling, electronics,…) …

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

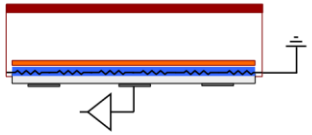


Sharing of tools (modelling): LGAD (Si) & micromegas (gas) almost identical concept/signal formation

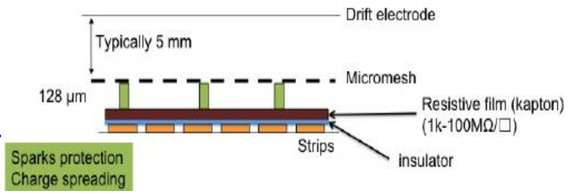




AC LGAD with resistive layer



AC mm with resistive layer



Ongoing activity (Cartiglia/Riegler) EP-RD DOCT (D. Janssens) on signal induction with garfield++ (H. Schindler) and time dependent weighting fields.

EP R&D

++

Conclusion (I)

- **Micro Patter Gas Detectors cover an impressively wide spectrum of applications (thanks to the large variety of solutions (technologies/architectures) that can be integrated together)…**

- **Large area detection systems realized today with MPGD technologies (LHC upgrades)…**

- **Future R&D lines… wide scenario: improving performances, stability, developing innovative solutions, hybrids solutions, implementing new technologies, new manufacturing techniques, simplifying production/assembly…**

Conclusion (II)

- **Recognition for detector R&D groups:**
  - Big difficulties on funding… in particular for generic/blue sky R&D…
  - In case of project driven activities, it is sometime hard to preserve what achieved (project phase)…
  - Huge time/efforts on proposal/applications/calls…
  - Hard to get students/post doc and offer them a perspective…
- **Steering/Coordination/Efficiency… creativity/flexibility to be preserved**
- **All different R&D needs (new technologies/new architectures, generic/project/integration) to be identified/covered …**
- **Centers of excellence.. A common patrimony (not local) to be preserved… fundamental in R&D & training..**
- **Centers of excellence / collaborations / centralized facilities (MPGD@CERN: experiments, RD51, EP-DT (MPT, TFG, GIF++, GDD), EP-RD) fundamental in K&T transfers/synergies**
  - Knowledge Transfer (to cope with timelines of future experiments)
  - Technology Transfer (to cope with R&D and production)
  - Synergies (common infrastructures/facilities/tools/…)
- **Last input: 50% if TF1 symposia contribution from Italy/Italians… maybe useful to elaborate this**

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