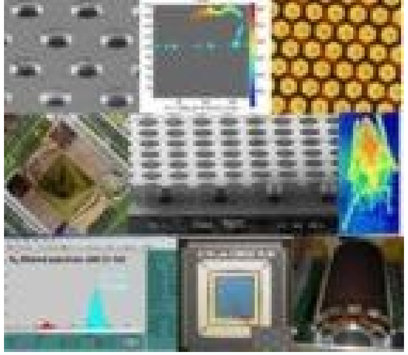


State-of-the-art Micro-Pattern Gaseous Detectors (**RD51**)

24-29 May 2021 – TIPP 2021

Silvia Dalla Torre, INFN - Trieste

MAJOR CREDITS

ECFA Detector R&D Roadmap
(https://indico.cern.ch/event/957057/program)

Symposium of Task Force 1
"Gaseous Detectors", 29 April 2021
(https://indico.cern.ch/event/999799/)

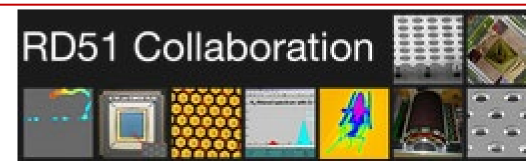
- Organized by TF1 conveners:
  - Anna Colaleo (INFN, Bari)
  - Leszek Ropelewski (CERN)

I am in debt to Anna, Leszek, the whole TF1 team and all the speakers at the Symposium

MPGD2019

I am in debt to all the speakers at the Conference

RD51



I am in debt to all the RD51 collaborators

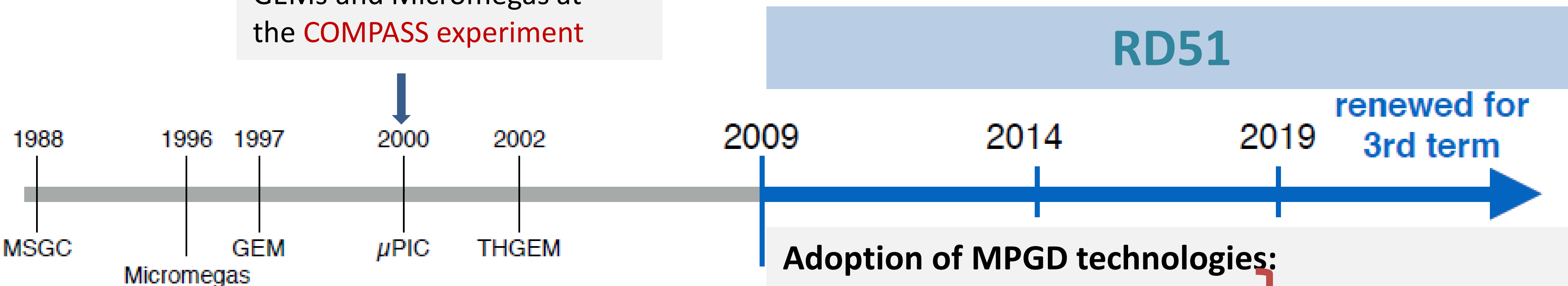
OUTLOOK

- MPGDs, historical hints
- MPGD, technologies
- MPGDs, applications
- MPGDs, present technological frontiers
- RD51, a collaboration for MPGD development and dissemination
  - Also a model for progressing in detector R&D

The field is so rich that it is impossible to be exhaustive !
→ Only examples

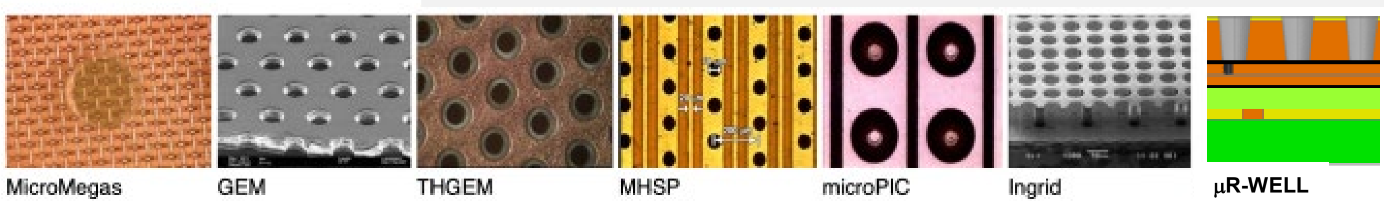
MPGDs history & RD51

First **large-scale application** of GEMs and Micromegas at the COMPASS experiment



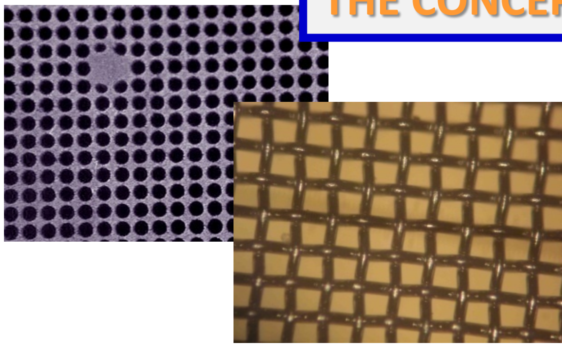
Adoption of MPGD technologies:

LHCb forward tracking (GEM
ATLAS NSW (Micromegas)
CMS forward tracking update (GEM)
ALICE TPC upgrade (GEM) } LHC
COMPASS RICH upgrade (hybrid MPGD) HEP @ CERN
KLOE2 & BESIII (GEM) HEP worldwide
LBNO-DEMO (THGEM) ν-physics
n-detection at ESS (GEM) non-HEP research
Muon radiography (Micromegas) beyond fundamental research
…



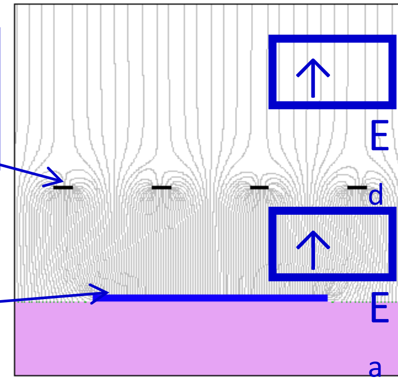
MPGD TECHNOLOGIES: MICROMEGAS

THE CONCEPT



mesh (cathode)

R-O strip (anode)



Ionization & drift (gap ~ 3-5 mm)

Parallel Plate (gap ~ 100 μm)

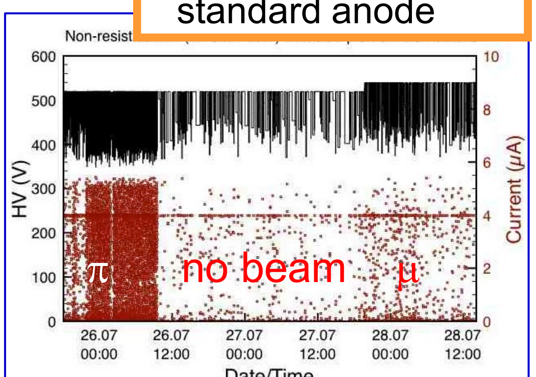
DISCHARGE RATE, THE ENEMY AND THE WAY-OUT

Resistive Anodes

Developed within the ATLAS-NSW project

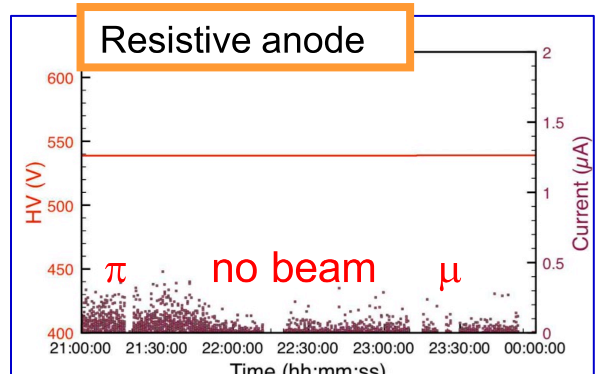
J. Wotschack
CERN Det. seminar, 18/11/2011

standard anode



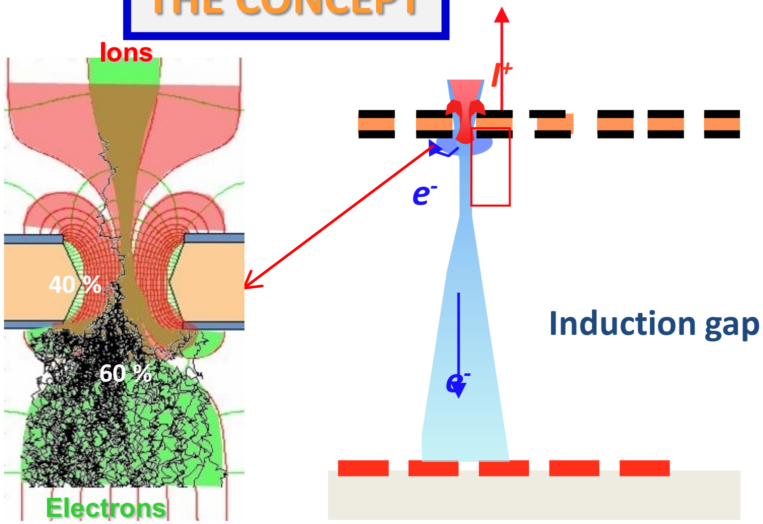
beam: π, μ
120 GeV/c

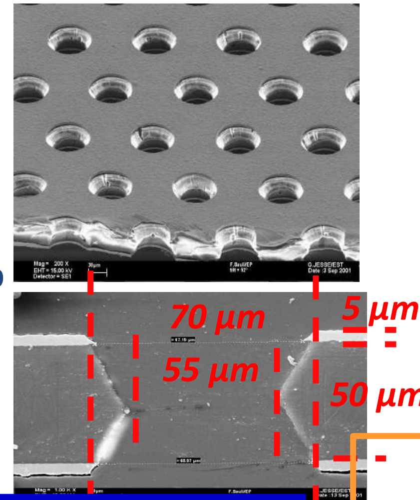
Resistive anode



MPGD TECHNOLOGIES: GEM

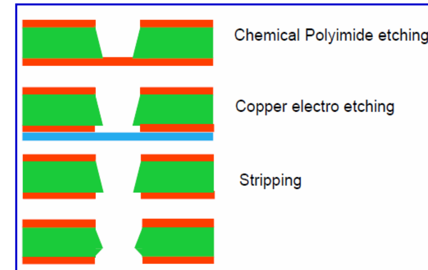
THE CONCEPT



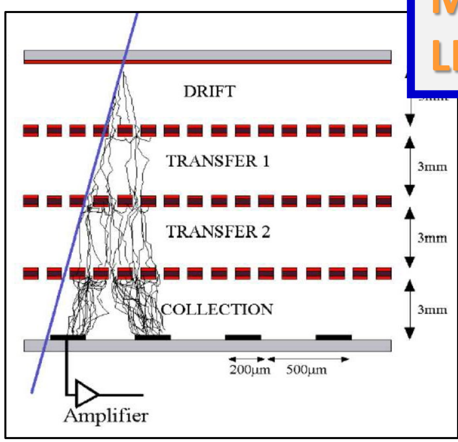


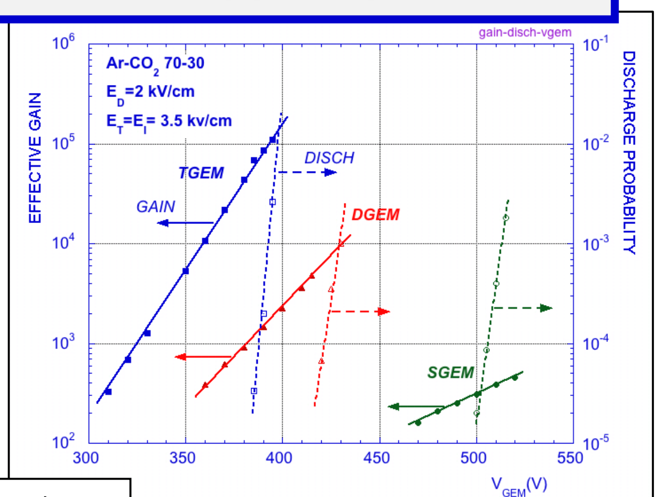
LARG-SIZE FOILS

Single mask production to misalignments, adopted for **TOTEM, KLOE2, CMS**



MULTILAYER ARCHITECTURE TO LIMIT THE DISCHARGE RATE

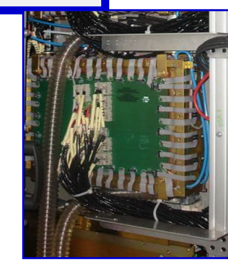


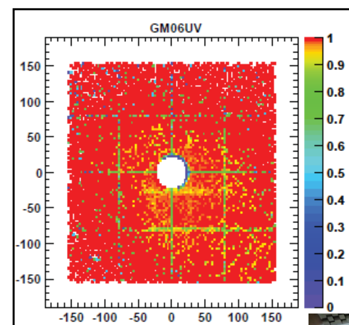


S. Bachmann et al., NIMA A479(2002)294

MASS PRODUCTION

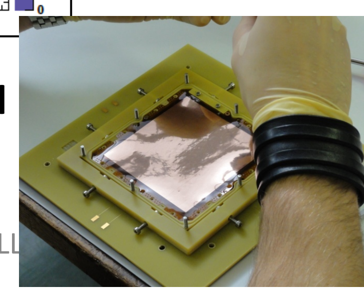
Spacers between foils (COMPASS, TOTEM)





Stretching and gluing (LHCb, KLOE2)

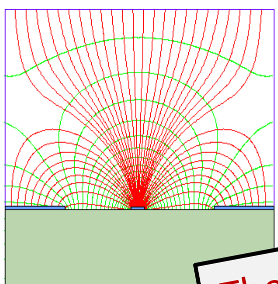
Mechanical stretching (CMS)

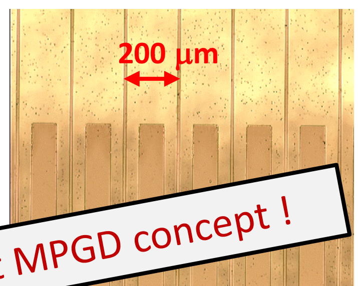


MPGD – TECHNOLOGIES, more

MSGC - MicroStrip Gas Chamber

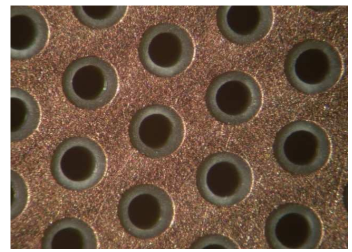
A. Oed, NIMA 263(1988) 351





The first MPGD concept !

THGEM or LEM

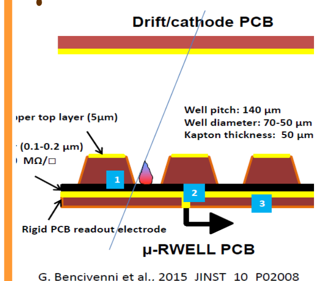


A different technology

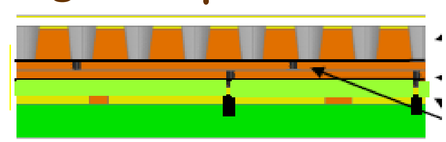
- PCB industry
- **Robust**
- Self-supporting plates

introduced in // by different groups:
L. Periale et al., NIM A478 (2002) 377.
P. Jeanneret, PhD thesis, Neuchatel U., 2001.
P.S. Barbeau et al, IEEE NS50 (2003) 1285
R. Chechik et al., NIMA 535 (2004) 303

μR-WELL

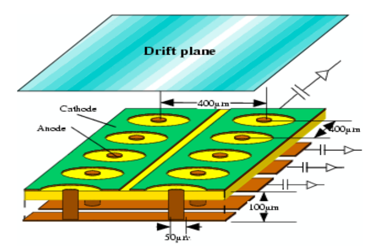


high rate μR-WELL



NIMA 858 (2020) 162050

μPIC



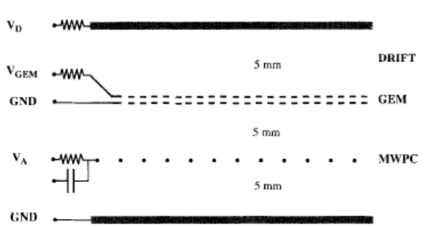
NIMA 471 (2001) 264

Novel architectures with emphasis on industrial production options

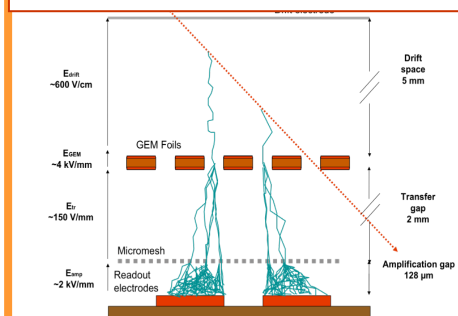
MPGD – TECHNOLOGIES, more: HYBRID DETECTORS

Since the beginning

- GEM + MWPC, GEM + MSGC (NIMA 396 (1997) 50)



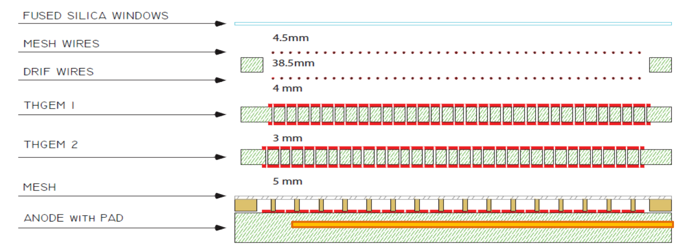
GEM pre-amplification: control the discharge rate in tracking



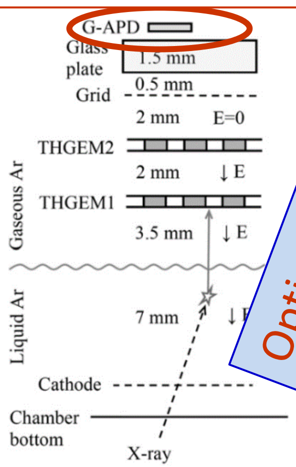
MM w GEM pre-amplification

Coupling MPGD technologies
To reduce discharge rate or IBF rate

THGEM + MM
for single photodetection: IBF control



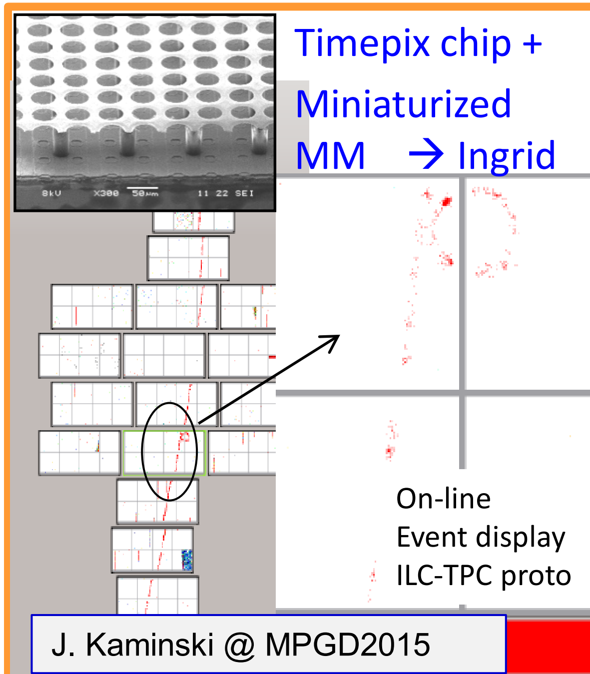
THGEM + G-APD for electroluminescence



Optical readout

A. Bondaret al.,
B. NIMA 628 (2011) 364

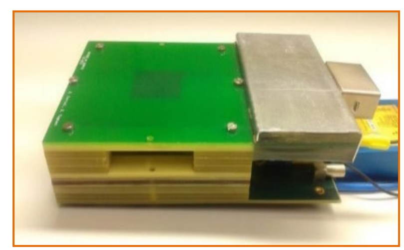
Timepix chip + Miniaturized MM → Ingrid



On-line Event display ILC-TPC proto

J. Kaminski @ MPGD2015

Coupling with high granularity solid state sensors



GEM + medipix
→ GEMpix

MPGD PERFORMANCE

Never used in an experiment, so far

MICROMEGAS

Space resolution
- **COMPASS, ~90μm** (NIMA 577 (2007) 455)

Time resolution
- **COMPASS, ~ 9 ns** (NIMA 577 (2007) 455)

Gain
- **COMPASS: G ~ 6400** (NIMA 469 (2001) 133)
- **T2K TPC: G ~ 1500** (NIMA 637 (2011) 25)

Material budget
- **COMPASS, 0.3 % X0** (NIMA 577 (2007) 455)

Rate capability
- **ATLAS-NSW resistive, lin. up to 100kHz/cm^2** (2013 JINST 8 C12007)
- **COMPASS pixelated with GEM pre-amplification, operated up to ~1·10^5/s/mm^2** (D. Neyret, MPGD2015)

GEM

Space resolution
- **COMPASS, ~70μm** (NIMA 577 (2007) 455)

Time resolution
- **COMPASS, ~ 12 ns** (NIMA 577 (2007) 455)
- **LHCb 4.5 ns** (dedicated effort) (NIMA 535 (2004) 319)

Gain
- **COMPASS, G ~ 8000** (B. Ketzer, pr. comm.)
- **LHCb, G ~ 4000** (NIMA 581 (2007) 283)
- **Phenix HBD: G ~ 4000** (NIMA 646 (2011) 35)

Material budget
- **COMPASS, 0.4 % X0** (NIMA 577 (2007) 455)
- **COMPASS pix.ed, 0.2 % X0** (NP B PS 197 (2009) 113)

Rate capability
- **COMPASS pixelated, stable up to 1.2·10^5/s/mm^2** (NP B PS 197 (2009) 113)

μ–RWELL

(NIMA 858 (2020) 162050)

Space resolution
- **~60-80 μm**

Time resolution
- **~5-6 ns** (JINST 12 (2017) C06027)

Gain
- **> 10^4**

Material budget
- **< 1%X0** (G. Bencivenni private comm.) **(different for the various schemes)**

Rate capability
- **≥10 MHz/cm^2 (high-rate version)**

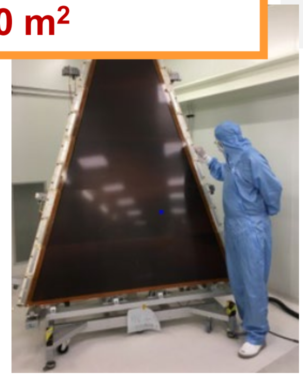
MPGD gain record in experiment

(NIMA 936 (2019) 416)

Hybrid (2 THGEMs + MM) photon detectors of COMPASS RICH:

GAIN: ~15000

DISSEMINATION
@ CERN, major LHC exp.s

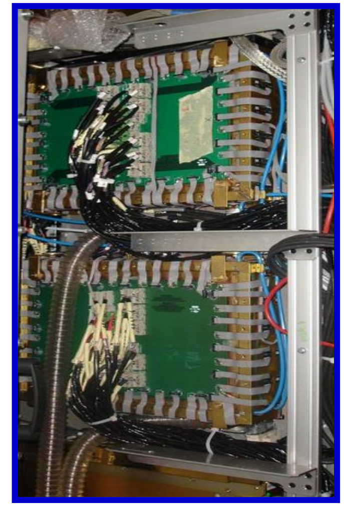


ATLAS
New Small Wheels (MICROMEGAS)
1200 m²

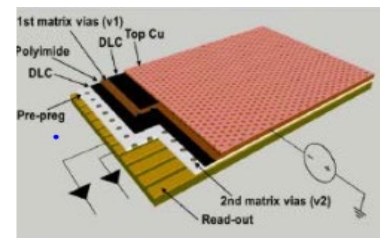
CMS
Muon system (GEMs)
220 m²

ALICE
TPC upgrade GEMs
32 m²

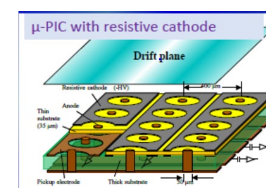
LHCb
Forward tracking, GEMs

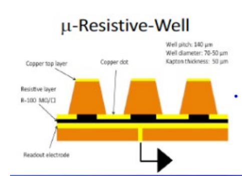


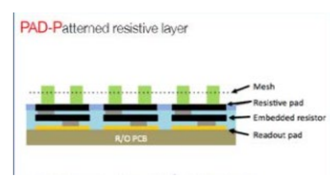
Muon upgrade
By high-rate μ_RWELL
90 m²

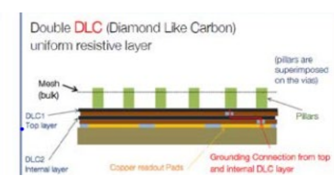


ATLAS - HL-LHC
Options for the very forward muon tagger:
μ-PIC, μ_RWELL, pixelized resistive MM



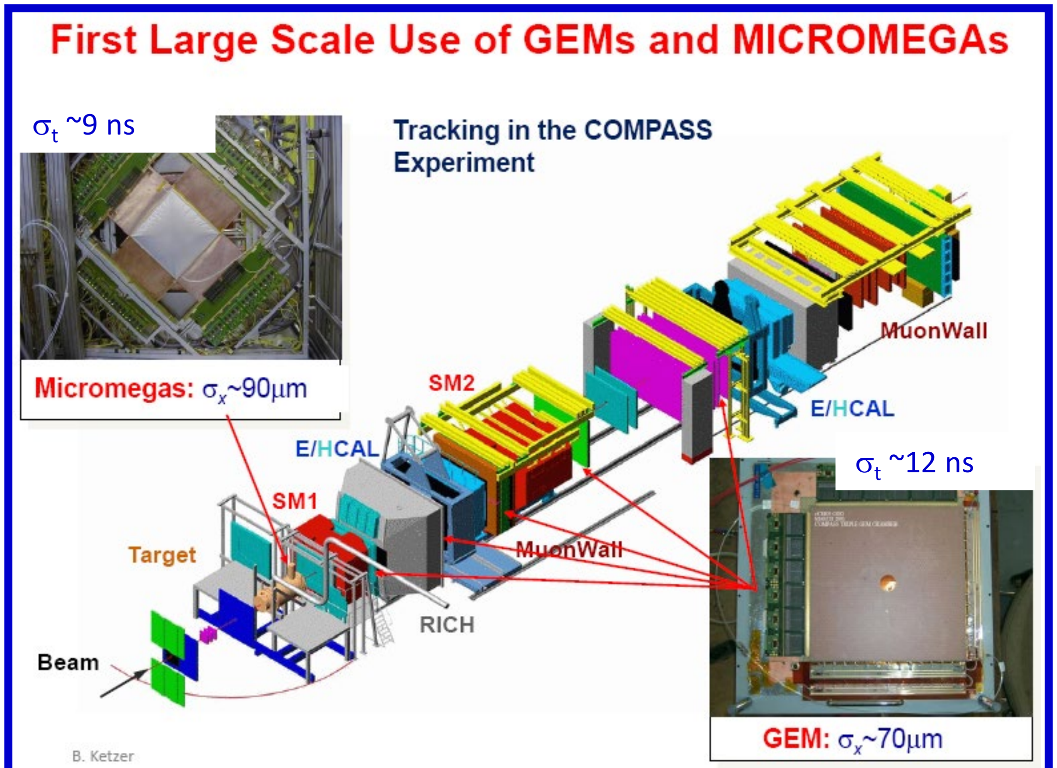




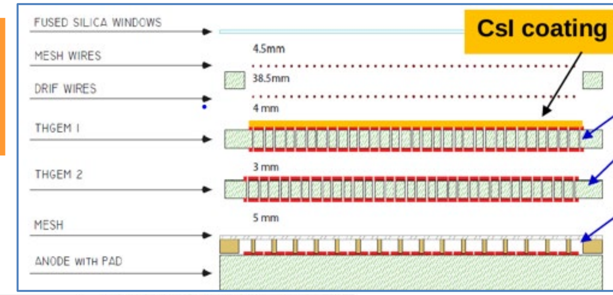


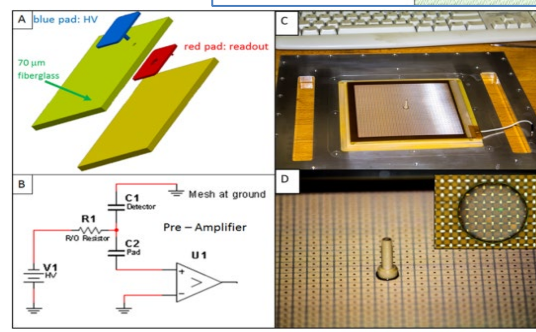
DISSEMINATION, @ CERN, beyond main LHC exp.s

slide by W. Riegler,
CERN Academic Training, April 2008

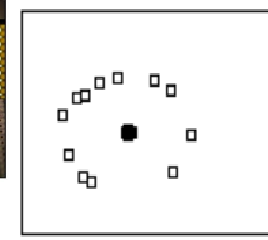


COMPASS RICH
photon detector upgrade

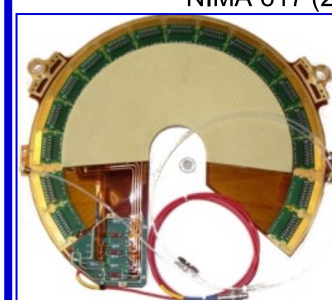


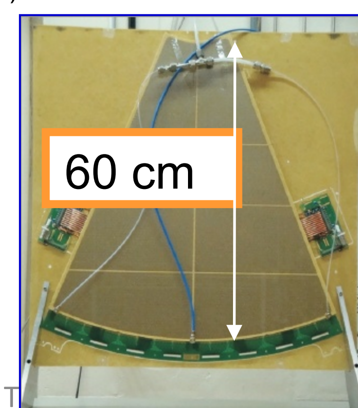


NIMA 936 (2019) 416



NIMA 617 (2010) 151



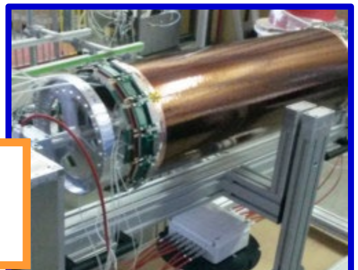


TOTEM

DISSEMINATION, around the world

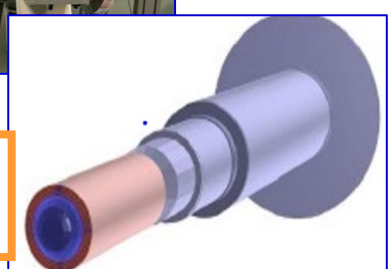
go cylindric !

Frascati, KLOE2
Cylindric triple GEM



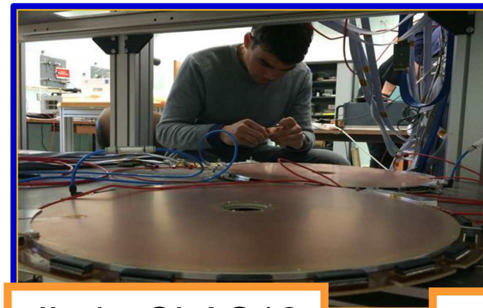
Beijing,
BESIII (GEMs)

Jlab, CLAS12 barrel (MM)

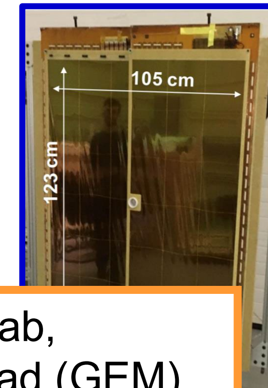


Jlab, GLUeX
μ-RWELL/GEM

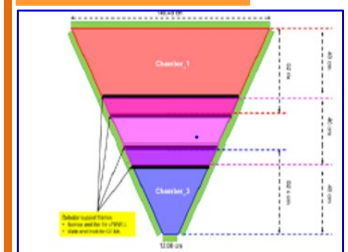
MPGDs in US labs



JLab, CLAS12
end-cap (MM)

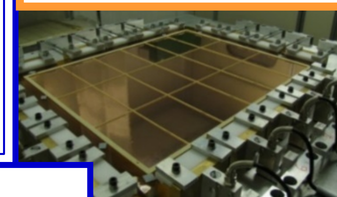


JLab,
Prad (GEM)

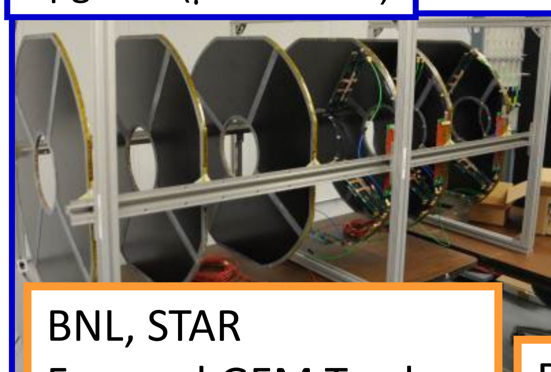


JLab, CLAS12
upgrade (μ-RWELL)

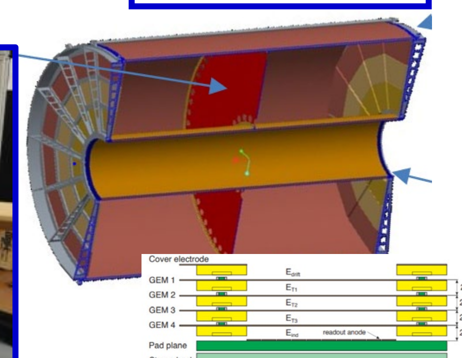
JLab Hall A (GEM)
40 x 50 cm^2



Jlab, Super
BigBite (GEM)



BNL, STAR
Forward GEM Tracker

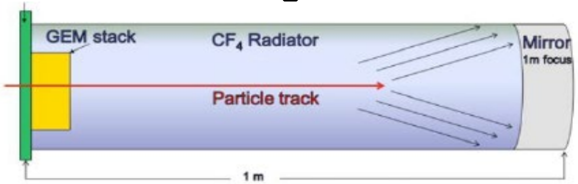


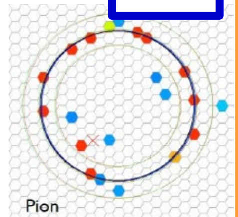
BNL, sPHENIX TPC (GEM)

DISSEMINATION, MPGDs options for **the EIC**

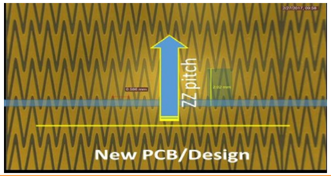
Quintuple GEM photon detector for a windowless gaseous RICH

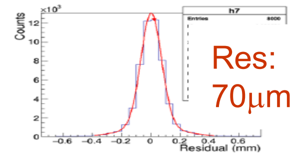
PID





Zigzag GEM read-out for low channel count preserving fine space resolution in TPC r-o



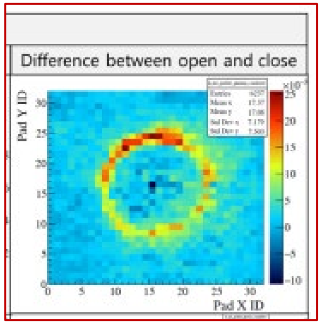


Res: 70μm

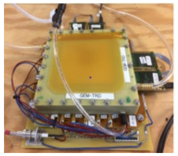
Tracking

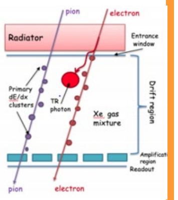
RICH r-o with hybrid MPGDs with miniaturized pads and novel nanodiamond photoconverter

PID



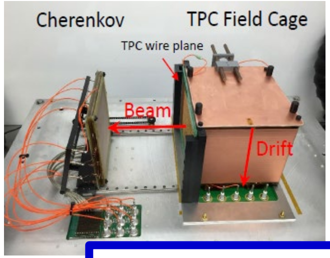
GEM-TRD

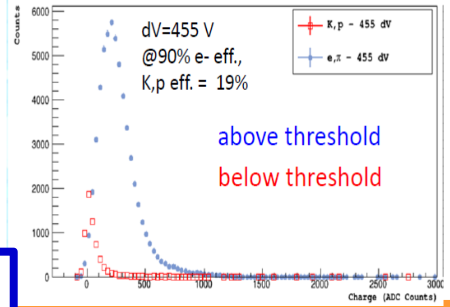




PID

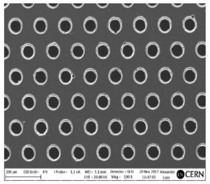
Extended e-PID with a GEM-based Cherenkov TPC





Tracking & PID

Low material-budget with ultra-low mass Cr GEM foils

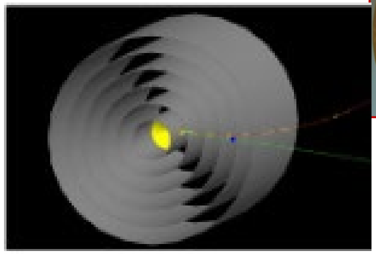


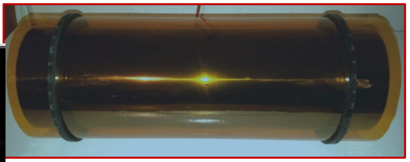
Tracking

Set of coaxial cylindrical MM / μ-RWELL

For tracking in the barrel region

Tracking





DISSEMINATION, FUTURE COLLIDERS IN A COMPILATION by M. Titov

TRACKING

Experiment / Timescale	Application Domain	Gas Detector Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements/ Remarks
ILC TPC DETECTOR: START: > 2035	e+e- Collider Tracking + dE/dx	MM, 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 %	Si + TPC Momentum resolution : dp/p < $9*10^{-5}$ 1/GeV Power-pulsing
CEPC TPC DETECTOR START: > 2030	e+e- Collider Tracking + dE/dx	MM, GEM (pads) InGrid (pixels)	Total area: ~ $2x10 m^2$ Single unit detect: up to 0.04 m^2	**Max.rate**:>100 kHz/cm^2 **Spatial res.:** ~100µm **Time res.:** ~ 100 ns **dE/dx:** <5%	- Higgs run - Z pole run - Continues readout - Low IBF and dE/dx
SUPER-CHARM TAU FACTORY START: > 2025	e+e- Collider Inner Tracker	Inner Tracker / (cylindrical µRWELL, or TPC / MPDG read.	Total area: ~ 2 - 4 m^2 Single unit detect: 0.5 m^2	**Max. rate**: 50-100 kHz/cm^2 **Spatial res.:** ~<100 µm **Time res.:** ~ 5 -10 ns **Rad. Hard.:** ~ 0.1-1 C/cm^2	Challenging mechanics & mat. budget < 1% X0
ELECTRON-ION COLLIDER (EIC) START: > 2025	Electron-Ion Collider Tracking	Barrel: cylindrical MM, µRWELL Endcap: GEM, MM, µRWELL	Total area: ~ 25 m^2	Luminosity (e-p): 10^{33} **Spatial res.:** ~ 50- 100 um **Max. rate**: ~ kHz/cm^2	Barrel technical challenges: low mass, large area Endcap: moderate technical challenges

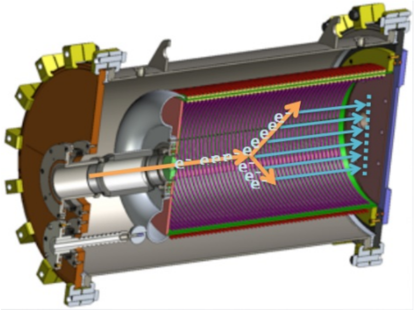
eCal pre-shower

Experiment / Timescale	Application Domain	Gas Detector Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements/ Remarks
FCC-ee and/or CEPC IDEA PRESHOWER DETECTOR START: >2030	Lepton Collider Tracking	µ-RWELL	Total area: 225 m^2 Single unit detect: (0.5x0.5 m^2) ~0.25 m^2	**Max. rate:** 10 kHz/cm^2 **Spatial res.:** ~60-80 µm **Time res.:** 5-7 ns **Rad. Hard.:** <100 mC/cm^2	

MUON SYSTEM

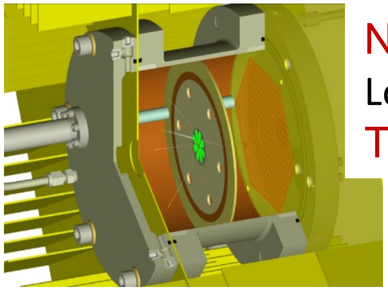
Experiment / Timescale	Application Domain	Gas Detector Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements/ Remarks
FCC-ee and/or CEPC IDEA MUON SYSTEM START: >2030	Lepton Collider Tracking/Triggering	µ-RWELL RPC	Total area: 3000 m^2 Single unit detect: ~0.25 m^2	**Max. rate:** <1 kHz/cm^2 **Spatial res.:** ~150 µm **Time res.:** 5-7 ns **Rad. Hard.:** <10 mC/cm^2	
FCC-hh COLLIDER MUON SYSTEM START: > 2050	Hadron Collider Tracking/Triggering	All HL-LHC technologies (MDT, RPC, MPGD, CSC)	Total area: 3000 m^2	**Max. rate**: < 500 kHz/cm^2 **Spatial res.:** <100 µm **Time res.:** ~ 3 ns **Rad. Hard.:** ~ C/cm^2	Redundant tracking and triggering;
MUON COLLIDER MUON SYSTEM START: > 2050	Muon Collider	RPC or new generation fast Timing MPGD	Total area: ~ 3500m^2 Single unit detect: 0.3-0.4m^2	**Max.rate:** <100 kHz/cm^2 **Spatial res.:** ~100µm **Time res.:** <10 ns **Rad. Hard.:** < C/cm^2	Redundant tracking and triggering

DISSEMINATION, low energy nuclear physics



Low Pressure Active Target –TPC, Hybrid MPGD (THGEM + MM)
@ *NSCL*, MICHIGAN

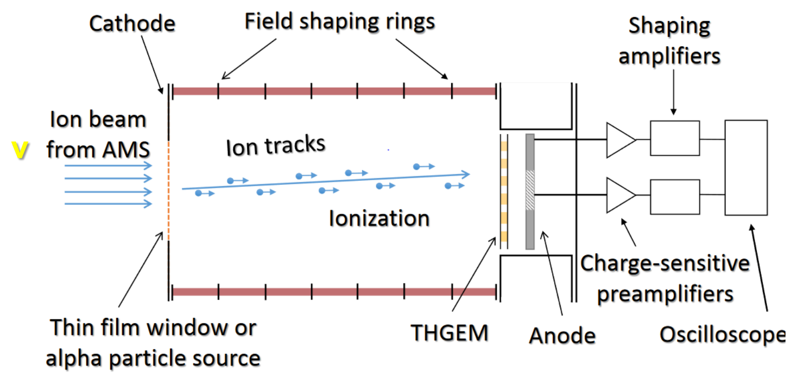
M. Cortesi, MPGD2015



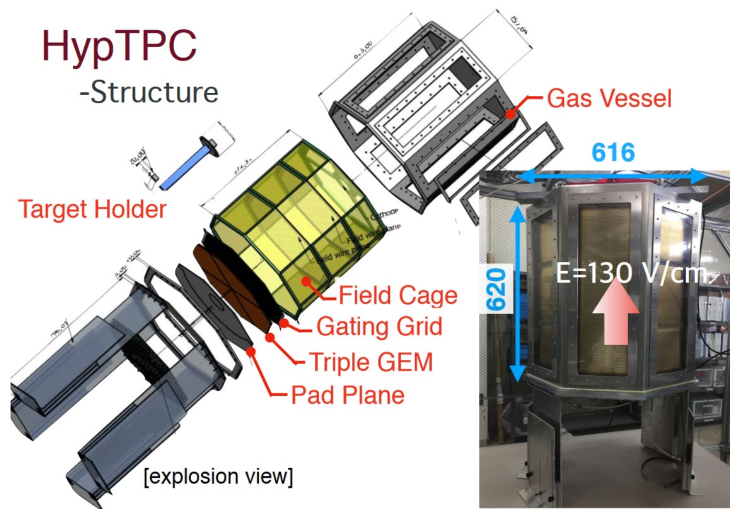
NIFFTE @
Los Alamos LANSCE
TPC with MM

J. RUZ, MPGD2013

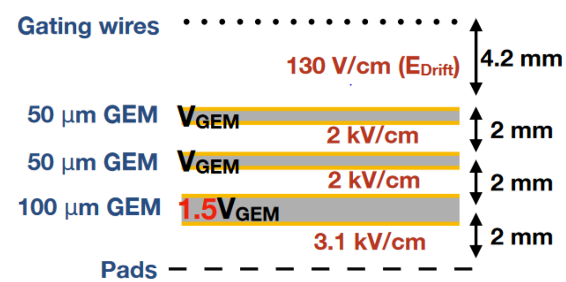
Accelerator mass spectrometry (THGEM)
@ Budker Institute, Novosibirsk



Schematic layout of the low-pressure TPC



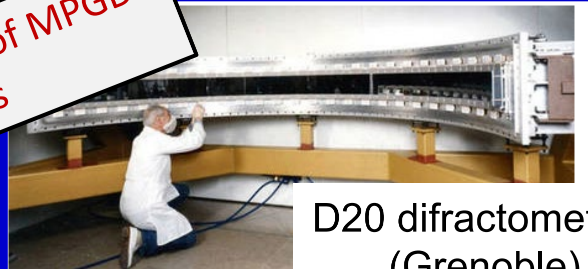
E42 experiment @ J-PARC, Tokai for H-dibaryon search with HypTPC
Sensors: GEMs with non-standard geometry



DISSEMINATION, neutron detection

Main credits: G. Croci, MPGD2019

The first use of MPGDs @ n-facilities



D20 difractometer @ILL (Grenoble), MSGC

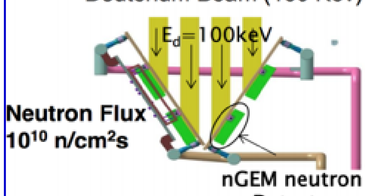
GEM & GEM-derived detectors playing a major role for n detection (^{3}He shortage)

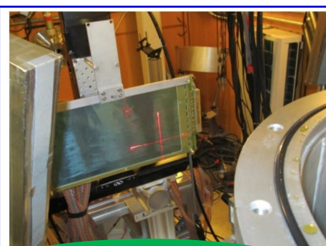
- Fast Neutrons: Polyethylene converter + Aluminium
  - Neutrons are converted in protons through elastic scattering on hydrogen
- Thermal Neutrons: ^{10}Boron converter
  - Neutrons are detected using the productus (alpha,Li) from nuclear reaction ^{10}B(n,alpha)7Li

Triple GEM Detector
Low efficiency detector
(few % maximum)

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

Deuterium Beam (100 Kev)





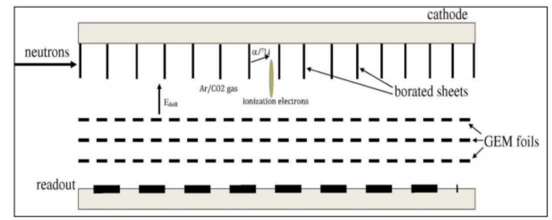
Deuterium beam diagnostic (Nuclear Fusion)

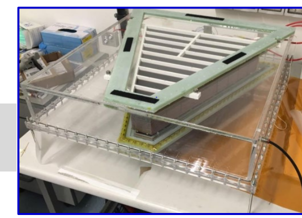
Beam monitor for **ChipIr** @ ISIS and **ESS**

thermal neutron beam monitoring

New architectures to increase the efficiency for ESS

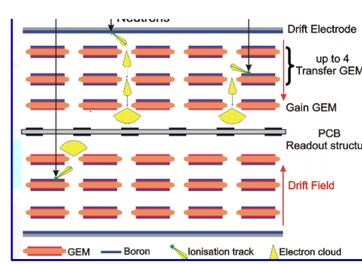
Band-GEM

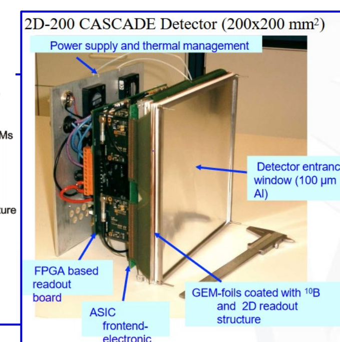




Efficiency : 40-50 %

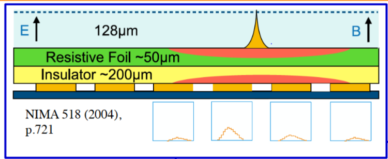
Cascade GEM



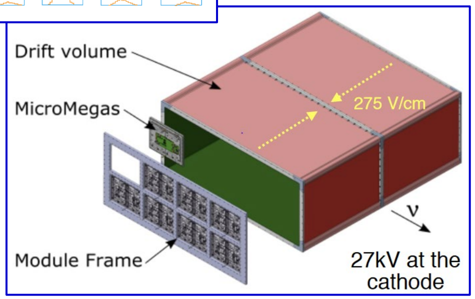


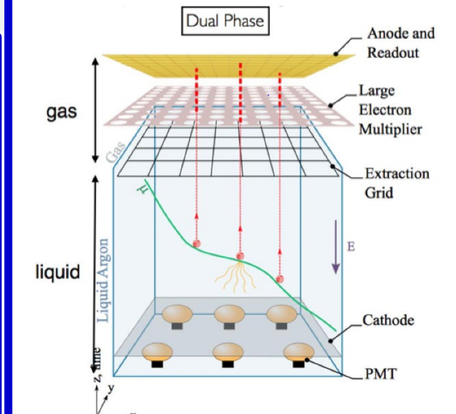
DISSEMINATION, ν-physics, rare events, astrophysics

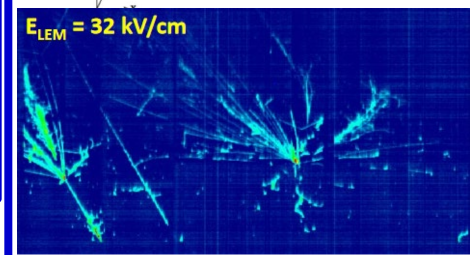
T2K : TPC read-out by MM, resistive MM in the upgrade to increase space resolution



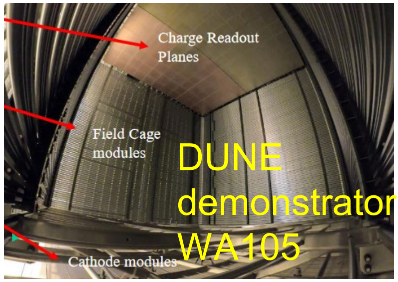
D. Attie, MPGD2019



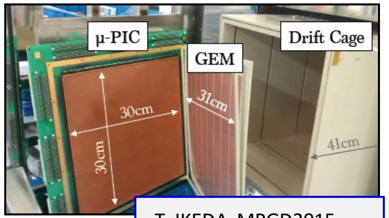




DUNE double-phase read-out by LEM (= THGEM)



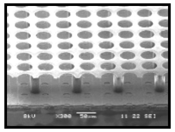
D. Autiero, 2020



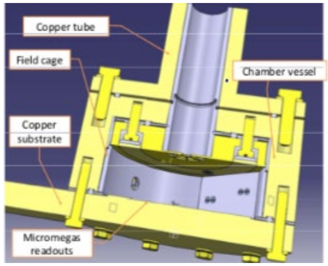
T. IKEDA, MPGD2015

NEWAGE0 Detector @ Kamioka mine
Negative-Ion TPC With μ-PIC for Directional Dark Matter Search

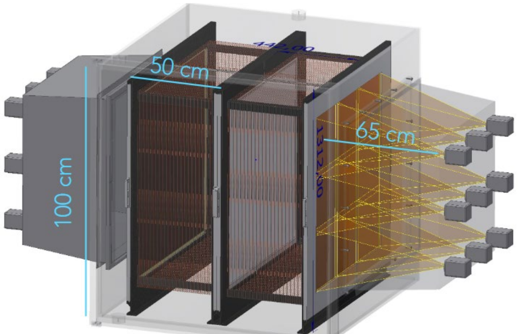
IAXO International Axion Observatory sources, using Ingrid technology



2014 JINST 9 T05002

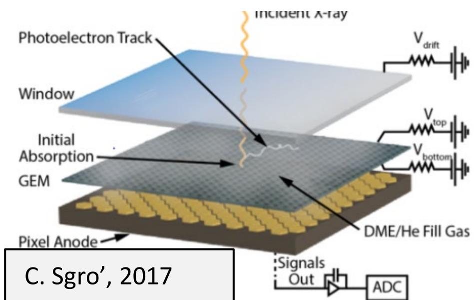


Cygno for *Directional Light Dark Matter* search by detecting electroluminescence in GEMs



D. Pinci, MPGD2019

NASA IXPE: X-ray polarimetry to study acceleration processes in astrophysical sources, using 50μm pitch GEMs



C. Sgro', 2017

DISSEMINATION, BEYOND FUNDAMENTAL SCIENCE

Main credit: F. Murtas, TF1 symposium, 29 April 2021

An introduction

Gas detectors for sure are not portable devices like Timepix.
Timepix Family is one of the best example of detector with wide applications beyond fundamental research

But when you need :

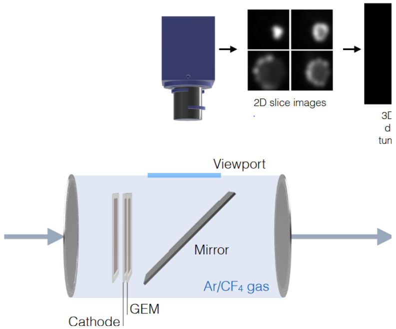
- big detection areas,
- high radiation tolerances
- measure high intensity particle fluxes,
- medical imaging (big areas)
- detect thermal neutrons with high efficiency
- study on micro dosimetry
- low energy Xrays

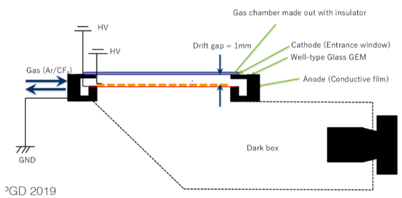
then you need gas detectors, in spite of the need of HV and gas supply systems

examples: medical, cultural-heritage, muography, radioactive wastes
(plasma fusing and nuclear plants already mention with other n-detectors)

DISSEMINATION, BEYOND FUNDAMENTAL SCIENCE

Hadron therapy monitoring detecting electroluminescence from GEMs





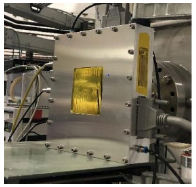
Glass GEM, T. Fujiwara MPGD 2019

Proton radiography with GEMs and MM-TPC

NIMA 718 (2013) 160

30x30cm^2 active area

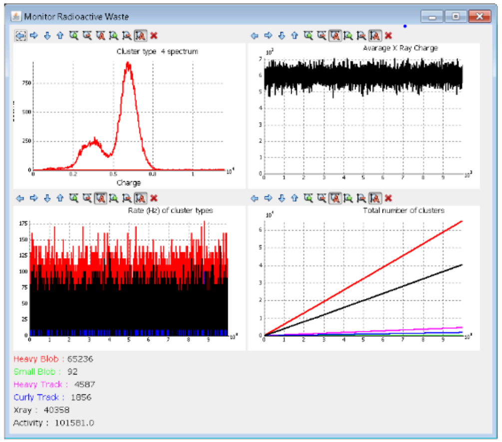
J. Bortfeldt, MPGD2019



Measurement of radioactive waste

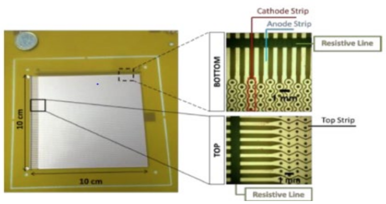
ARDENT

X-ray Energy real-time measurement



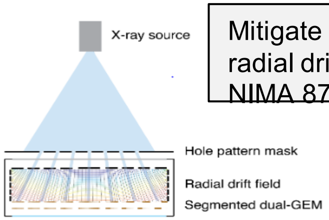
Activity higher than 10 Bq/g of ^{55}Fe
GEMPix : 2 hours of data acquisition
Medipix :10 hours of data acquisition
External companies : days …

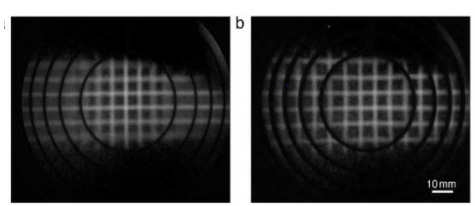
X-ray fluorescence for cultural heritage



THCOBRA, J. Anal. At. Spectrom., 2015,30, 343

Mitigate parallax error by radial drift field in GEMs, NIMA 875 (2017) 16





Muography

Applications:
vulcanology, archeology, civil engineering, nuclear reactor monitoring

MM telescope

Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons

Nature 552 (2017) 386

TECHNOLOGICAL FRONTIERS, GO RESISTIVE !

Main credit: M. Iodice, TF1 symposium, 29 April 2021

MOTIVATIONS:

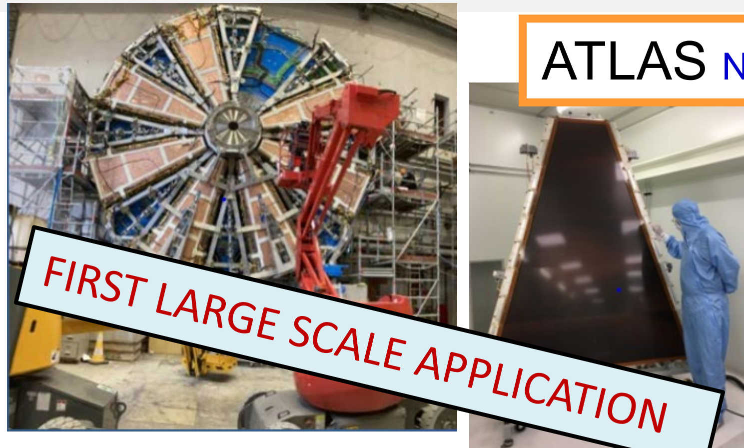
- operation at high gain for single e and precise timing
- long-term detector stability: tens of C/cm^2
- operation at high rate: 10 MHz/cm^2 (and beyond)

THE ENEMY: DISCHARGES

- Mechanical imperfections
- Micrometric structures in MPGD
- Transition from avalanche to streamer mode for too many ionization electrons

A WAY-OUT

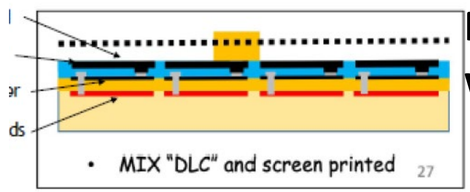
Diverging processes can be quenched by means of resistive electrodes



ATLAS New Small Wheels

MM:
born non-resistive,
Consolidated
with resistivity

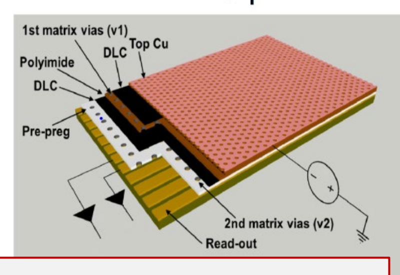
NEW FRONTIER IN RATE CAPABILITY



Pixelated resistive bulk Micromegas with integrated electronics

M. Iodice, TF1 symposium, 29 April 2021

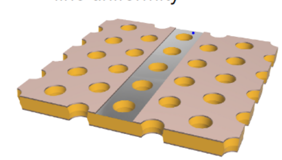
Double DLC µRwell



A new technology, born resistive

DLC in SECTORS SEPARATION:

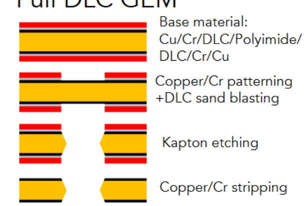
preserve the electric field line uniformity



F. Sauli "RESTORING EFFICIENCY IN GEM SECTOR SEPARATIONS"
https://indico.cern.ch/event/843711/
And A.P. Marques, et al. NIM A 961 (2020) 163673

ONGOING R&D

Full DLC GEM



Still ISSUES with low adhesion of Cr on DLC

R. De Oliveira, RD51 October2019
https://indico.cern.ch/event/843711

Improving of GEM stability with resistivity, under study

Current developments on Resistive MPGD - DLC

- Diamond Like Carbon (DLC) coatings: properties of DLC have offered new possibilities opening the way to develop new detector structures.
- Stable and mechanically robust material

For DLC see also:
RD51 DLC Workshop Report
RD51-NOTE-2021-002
and references therein

Carbon dry sputtering → DLC

- Sputtered carbon
  - Diamond like, and amorphous structure
  - It means, carbon particles of molecular size!
- Fine structure with proper resistivity is available
  - with liftoff method

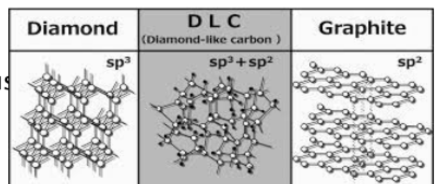
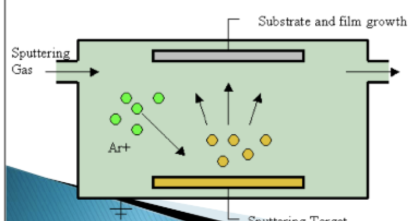


Image from Tribology International Vol 37, 11-12, p907



Random mixture of sp3 (diamond like) and sp2 (graphite like) carbon makes conductive paths of molecular size.

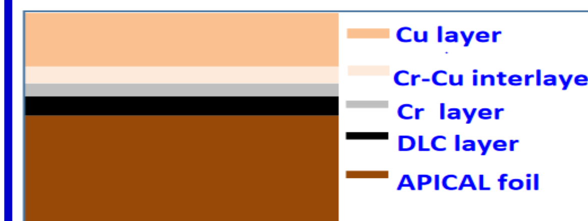
A. Ochi,
RD51 mini-week
CERN 05/12/2018

Mastering DLC technology

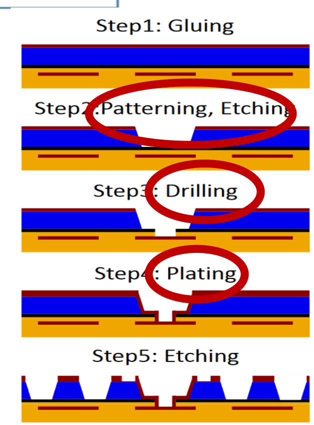
Y. Zhou, Y. Lv (USTC)

Cu-coated DLC manufacture

Cr & Cu co-deposition (a few nm)



PEDP technique for large-area µ-RWELL



Y. Zhou, Y. Lv (USTC)

TECHNOLOGICAL FRONTIERS, FINE TIME RESOLUTION

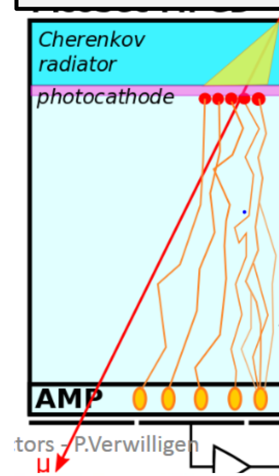
MOTIVATIONS:

- Mitigation of pile-up in present and future colliders
- Extended TOF systems
- … and medical applications (PET)

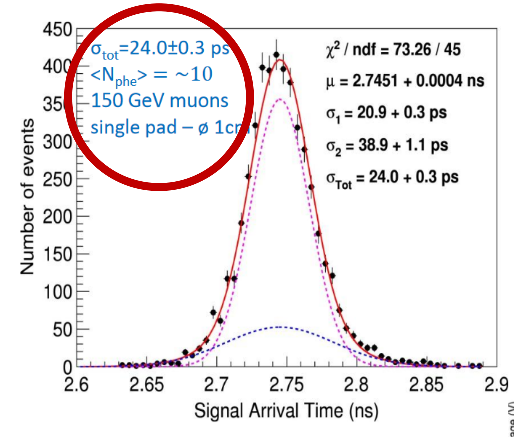
THE major OBSTACLE:

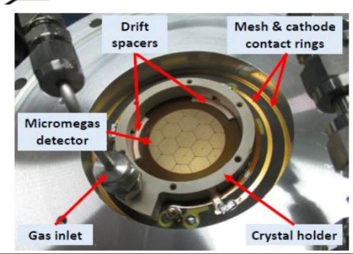
- fluctuations in primary ionization

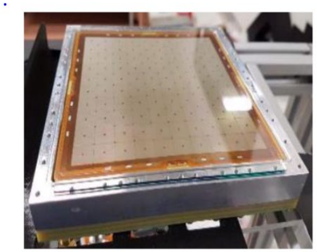
PicoSec MPGD



NIM A903 (2018) 317–325







Single pad	multipad	10 x 10 cm^2

TECHNOLOGICAL FRONTIERS, CONTROL ION BACK-FLOW (IBF)

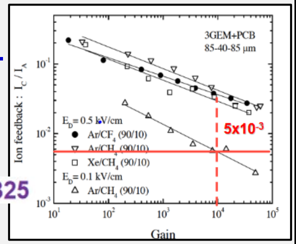
Main credit: F. Tessarotto, TF1 symposium, 29 April 2021

MOTIVATIONS

- in Photon Detectors (PD)
  - photocathode ion bombardment
- in TPC
  - space charge → field distortion

MPGD technologies and optimized IBF reduction

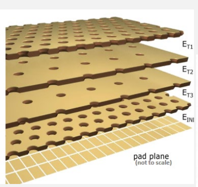
- Triple GEMs with staggered holes, IBF <1%

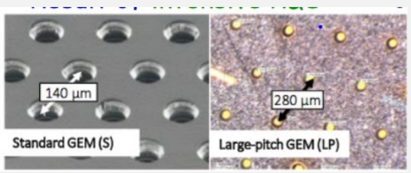


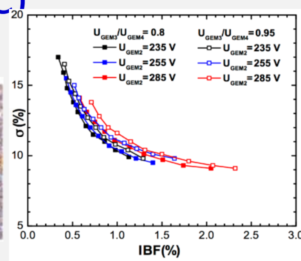
A. Bondar *et al.*, NIM A 496 (2003) 325

- Quadruple GEMs with non-standard geometry (ALICE TPC)

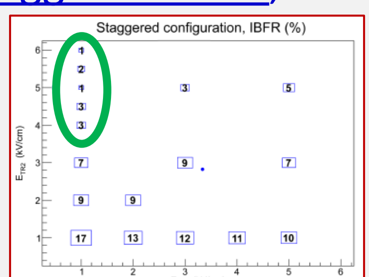
JINST 16 (2021) P03022





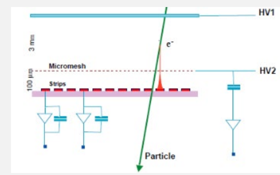


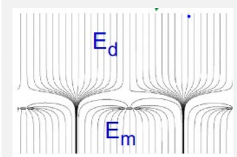
- Triple THGEMs with staggered holes, IBF~1 %

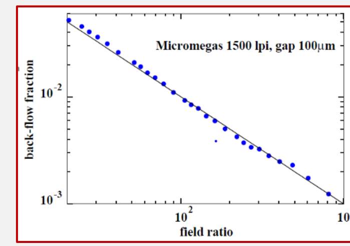


2013 *JINST* **8** P01021

- MICROMEGAS, intrinsic ion blocking properties

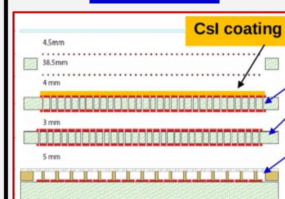




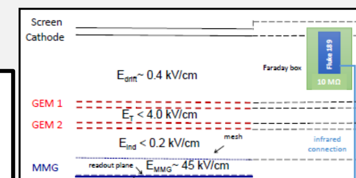


P. Colas et al. NIM A 535 (2004) 226

- Hybrid architectures

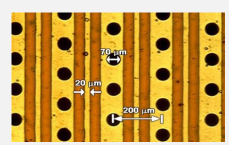


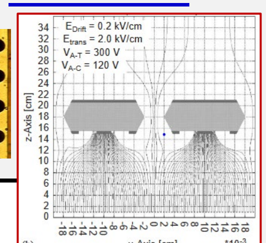
2 THGEMs & 1 MM COMPASS RICH
NIMA 936 (2019) 416



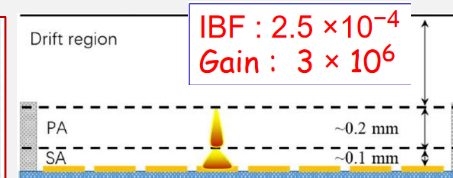
2 THGEMs & 1 MM Proposal for ALICE TPC
R. Majka, IEEE-NSS 2015

- WORLD RECORDs





MHSP
IBF ~ 10^{-4}
NIMA 548 (2005) 375



IBF : 2.5×10^{-4}
Gain : 3×10^{6}

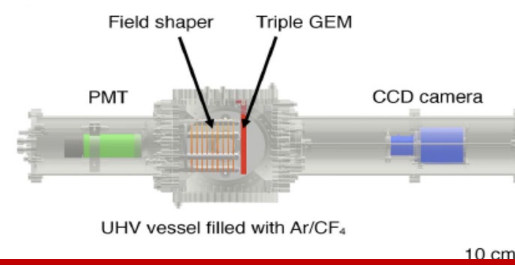
DMM
IBF: 2.5 10^{-4}
NIM A 976 (2020) 164282

TECHNOLOGICAL FRONTIERS, OPTICAL R-O

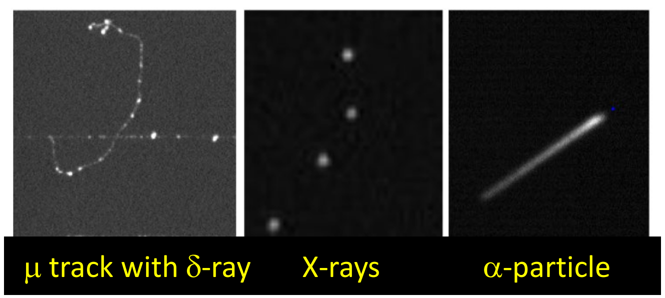
Main credit: F. Brunbauer, TF1 symposium, 29 April 2021

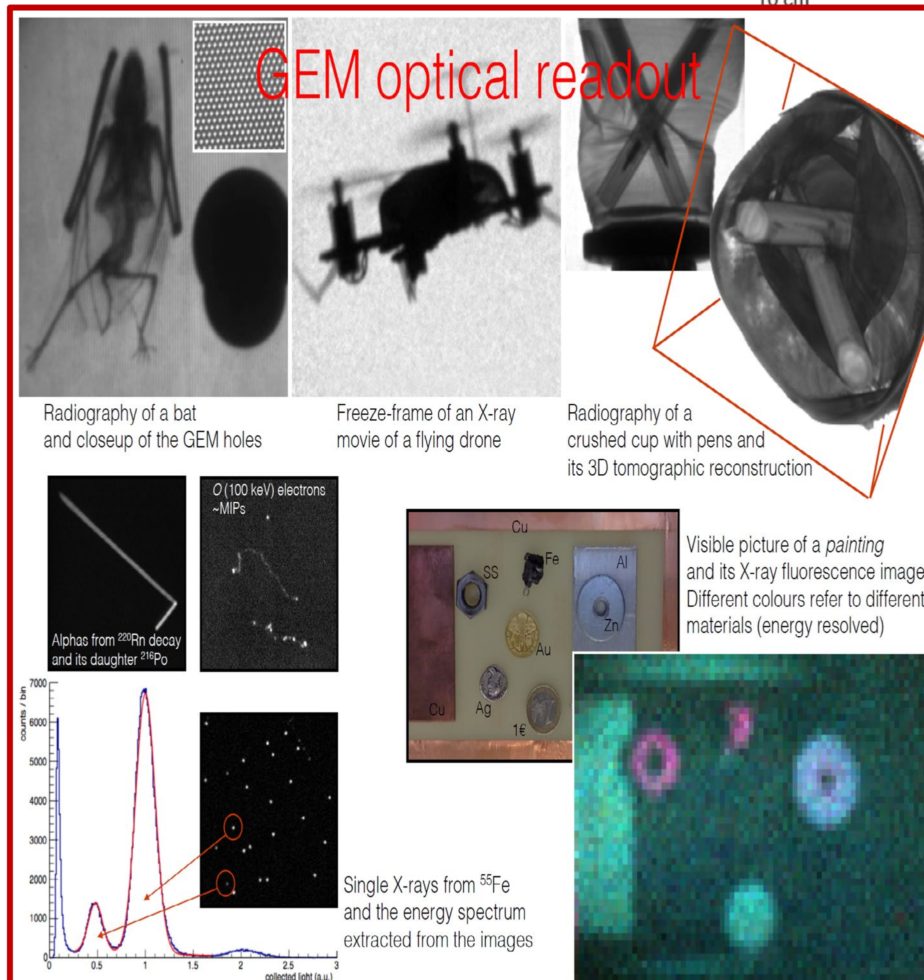
MOTIVATIONS:

- Pixellated readout approaches (optical, hybrid, ASICs) offer unprecedented levels of detail in recorded events



High-rate of images with bubble chamber resolution





TECHNOLOGICAL FRONTIERS, OPTICAL R-O

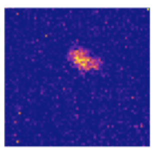
Optical TPCs

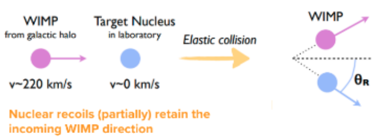
Atmospheric pressure Optical TPC

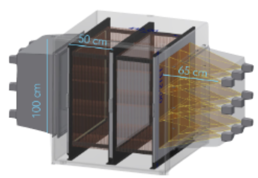
CYGNO Experiment

Rare event searches, directional dark matter

Triple GEM with **CMOS + PMT/SiPM** readout requiring low radioactivity background



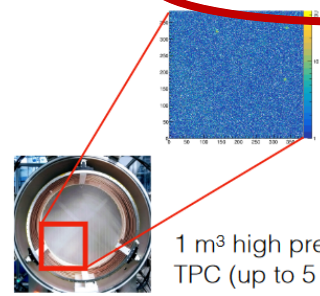




D. Pinci et al., CYGNO: Triple-GEM Optical Readout for Directional Dark Matter Search, MPGD 2019
https://indico.cern.ch/event/757322/contributions/3396494/attachments/1841021/3018431/Cygno_MPGD19.pdf

High Pressure TPC

Towards a neutrino-nucleus cross section experiments



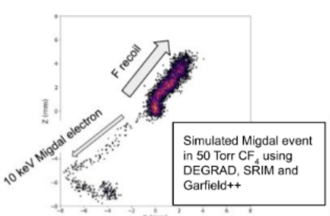
Stitched optical readout (4 CCD cameras) + **electronic signals** from meshes used for amplification

1 m³ high pressure TPC (up to 5 bar)

A. Deisting, HPTPC, https://arxiv.org/pdf/2102.06643.pdf

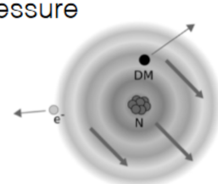
Low-pressure TPC with optical+electronic readout

MIGDAL
Migdal In Galactic Dark mAtter expLoration



Migdal effect search in low-pressure CF_4 for DM searches n

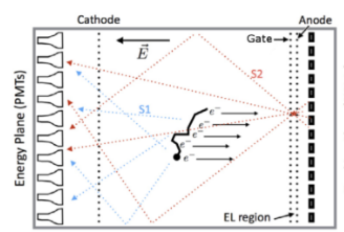
CMOS + electronic readout of **transparent strip anode**



P. Majewski, RD51 Mini-Week 2020, https://indico.cern.ch/event/872501/contributions/3730586/attachments/1985262/3307758/RD51_mini_week_Pawel_Majewski_ver2.pdf

High Pressure Xe gas TPC with electroluminescent amplification

next



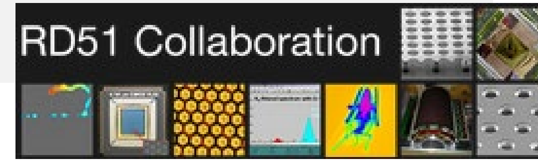
Neutrinoless double beta decay searches in ^{136}Xe

PMTs for energy measurement & t_0 from S1, **SiPM-based tracking** plane recording electroluminescence

https://next.ific.uv.es/next/experiment/detector.html
L. Arazi, Status of the NEXT project, https://doi.org/10.1016/j.nima.2019.04.080

10

RD51



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

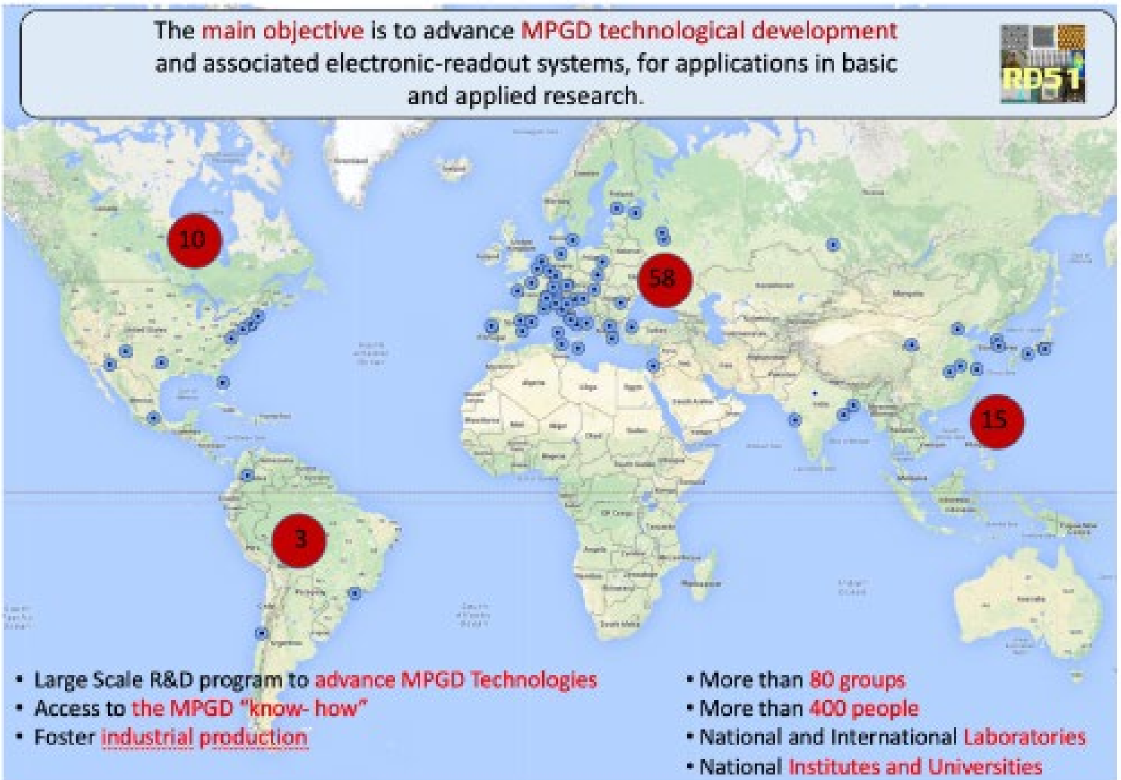
[RD51 web-page, first lines]

HOW?

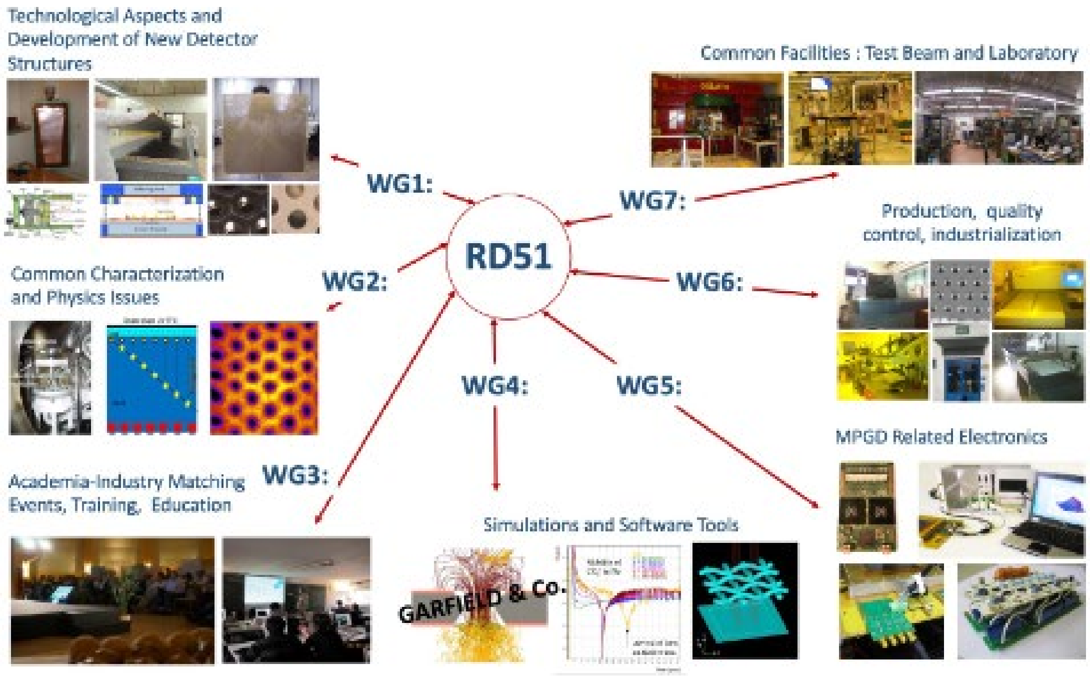
Networking by collaborations, technology dissemination and training

Main credit for this section: L. Ropelewsky, TF1 symposium, 29 April 2021

RD51, THE COLLABORATION



RD51, THE STRUCTURE



- R&D support for the experiments and **LHC upgrades** WG1
- Generic R&D (new structures, ideas, detector physics) – RD51 Common Projects WG2 Development of new structures and consolidation of the existing structures
- Applications and dissemination; Academia-Industry matching events, training, education WG3
- Development and Maintenance of Software & Simulation Tools; basic studies & software support for the RD51 community WG4
- Development and Maintenance of the SRS Electronics; An extended support for the SRS including new developments and implementations of additional features WG5
- MPGD Production and QA Control; Industrialization - GEM, Micromegas, Thick GEM; WG6
- Maintenance of the RD51 Lab and Test-Beam Infrastructure WG7

RD51, CERN based infrastructure

GDD web site

EP-DT-DD GDD Laboratory available for the RD51 collaboration

Permanent installations : CMS, ALICE, ATLAS, ESS
More than 15/20 groups per year coming to perform measurements

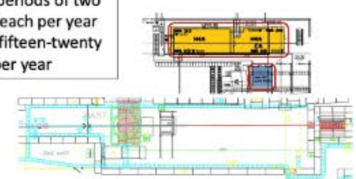
Clean Rooms

Mechanical and Electronic Workshop

Technical support
MPGD Detectors
Gas system and services
Readout electronics (std and custom
RD51 SRS
Radioactive Sources
Interface with CERN services (RP, gas, metrology, irradiation facilities,…)

Semi permanent test beam facility
in the SPS extraction Line

Three periods of two weeks each per year
About fifteen-twenty users per year



Goliath Magnet

Rd51 trackers

Slow Control System (HV/LV)

Examples of the test beam user teams

CMS (GEM) | WIS/A/C(WELL, THGEM) | ATLAS NSW (mm) | BESS III & SHIP (GEM) | LAPP/DEM/IRFU(mm) | ALICE TPC (GEM and mm)

RD51, CERN based infrastructure

MPT workshop @ CERN

MPGD Projects

•SBS tracker	GEM 600mm x 500mm
•ALICE TPC upgrade	GEM 600mm x 400mm
•CMS muon	GEM 1.2m x 450mm
•ATLAS NSW muon	Micromegas 2m x 1m
•COMPASS pixel Micromegas	GEM & Micromegas 500mm x 500mm
•BESIII	GEM 600mm x 400mm
•KLOE	GEM 700mm x 400mm
•SOLID	GEM 1.1m x 400mm
•CLAS 12	Micromegas 500mm x 500mm
•LSBB (geoscience)	Micromegas 1m x 500mm
•Prad	GEM 1.5m x 55cm
•CBM	GEM 1m x 450mm
•ASACUSA	Micromegas

•Most of them are still at the R&D phase but some are already in production:

•ATLAS NSW	1300 m2
•SBS Tracker	100 GEMs
•ALICE TPC upgrade	350 GEMs
•COMPASS pixel Micromegas	20 GEM + Micromegas
•BESIII	15 GEM
•CLAS 12	30 Micromegas
•CMS	450 GEM

New Capabilities

UV exposure unit limited to 2m x 0.6m → 2.2m x 1.4m

Resist developer limited to 0.6m width → 1.2m
Resist stripper "
Copper etcher "
Dryer "

GEM electro etch limited to 1m → 2m

GEM polyimide etch limited to 1m → 2m

Ovens limited to 1.5m x 0.6m → 2.2m x 1.4m

Laminator limited to 0.6m width → 1.2m

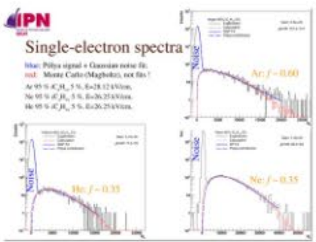
installation of the new infrastructure (to produce 2x1m² Bulk MM & 2x0.5m² GEM)

Construction of the new workshop's building

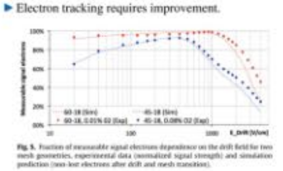
CERN Building 107
Basis of Design

RD51, TOOLS

Modelling of Physics Processes and Software Tools

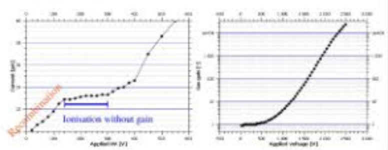
IPN
Single-electron spectra


Mesh transparency
- Electron tracking requires improvement.

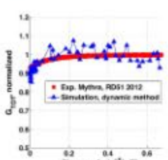


- [Fabian Kuger et al. 10.1016/j.nima.2015.11.011]

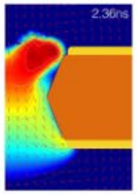
AGH University of Science and Technology
High-precision data from AGH
- Current reference is taken at the ionisation level.
- Main source of error: ~5 %.



Charging-up of a GEM
- Gain changes as a result of the charge deposits.
- Electron tracking to be refined.



- [Pedro Correia et al. 10.1088/1748-0221/9/07/P07025]



Gas detector simulation: new areas
- Discharges and Resistive layers.
- Ion diffusion.
- Refinement of ionisation esp. at low energy.
- Integration of boundary element methods.

Support for the detector simulation sofware

Electronics for gaseous detectors

RD51 SRS Electronics School (February 3 – 5, 2014)

Tremendous amount of work →

Fantastic school organization by Hans, Eraldo and team of 12 speakers and supervisors

→ VERY WELL RECEIVED BY PARTICIPANTS

THANK YOU VERY MUCH !!!

SRS frontend ASICSs

2009 → 2014

APV 128-ch. analogue
100% designed for RD51 SRS
HW and FW RD51 property
4 revisions
still going strong
about 2000 produced
distributed via CERN store
Export restrictions !

VFAT 128 ch digital
designed by RD51
excessive noise in V1
xferred to CMS

Beetle: 128 ch analogue
Design RD51/WIS
production difficulties
with 4-layer bonding
..to be continued (ALICE /Focal)

VMM-2: 2x 64 ch digital
HW and FW
Mini2 design by RD51
under test
by IFIN/ATLAS NSW
-> talk by Sorin Martoiu

Letter of compliance reqired

Analogue

Digital

RD51, TRAINING & TECHNOLOGICAL DISSEMINATION

RD51 schools

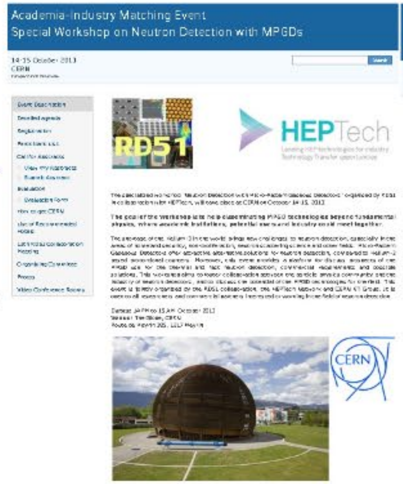
MPGD assembly

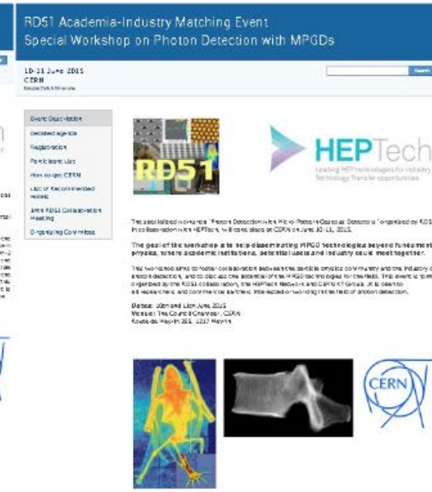
MPGD Simulation

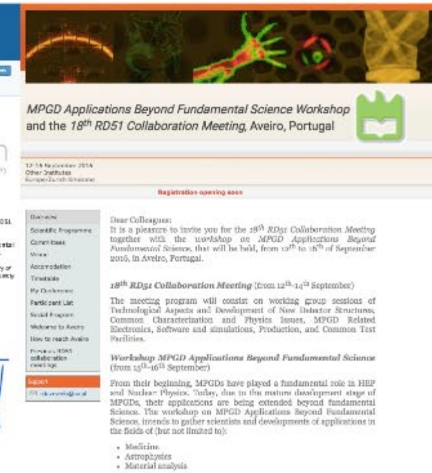
MPGD Electronics

XII ICFA School (Bogota, Colombia)

Danube School on Instrumentation in Elementary Particle & Nuclear Physics (Novi Sad Serbia)





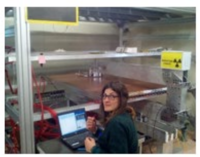


RD51, THE VISION: two-folded actions

Direct support to experiments

- ***Facilities Lab and Beam*** (one example... ATLAS NSW micromegas)

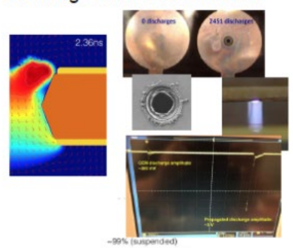
ATLAS NSW - RD51 mm trackers (GDD lab)



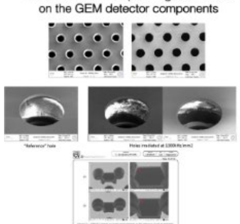
ATLAS NSW - Cosmic stands (GDD lab)

RD51/GDD Lab

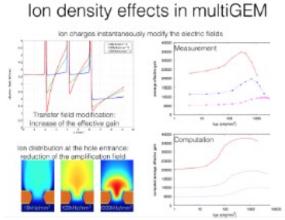
Discharge studies ALICE/CMS



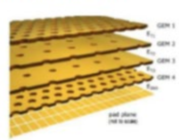
Effect of extreme operating conditions on the GEM detector components

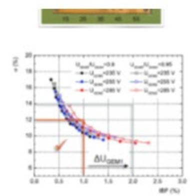


Ion density effects in multiGEM



ALICE TPC IBF





SUPPORT TO GENERIC R&D AND BLE-SKY, the dark-side of the moon: needed and, nevertheless, marginally supported or ignored

Current and previous RD51 Common Projects

Discharge Consortium in quest for Spark-Less-Avalanche-Microstructures

Pixelated resistive bulk Micromegas with integrated electronics

Resistive materials and resistive-MPGD concepts & technologies

Modular & General purpose Ultra Low Mass GEM Based Beam Monitors

DLC based electrodes for future resistive MPGDs

Study of negative ion mobility and ion diffusion for Negative Ion TPCs

Development of modular multilayer GEM units

Sampling Calorimetry with Resistive Anode MPGDs (SCREAM)

New Scintillating gases and structures for next-generation scintillation-based gaseous detector

CONCLUSIONS

I have presented FACTS about MPGDs (by examples)

- Even if the gallery could not be exhaustive, the DISSEMINATION and FERTILITY of the field is self-evident

- The RD51 approach to network in detector R&D has make possible the MPGD blossom and it is a possible model also for other detector R&D domains

THANK YOU