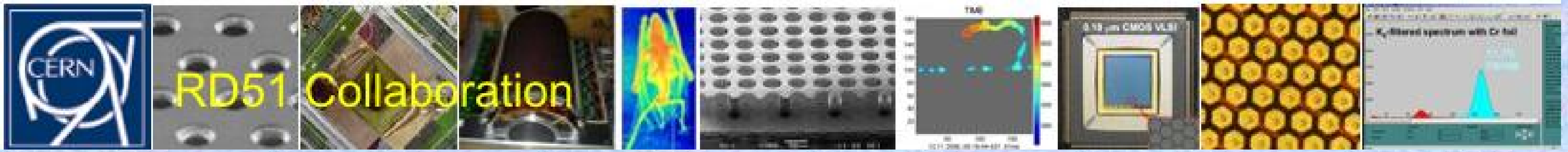


MPGD Concepts for Physics Projects at Energy / Intensity / Cosmic Frontiers

Maxim Titov, CEA Saclay, France

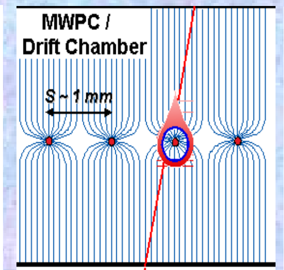
OUTLINE of the TALK:

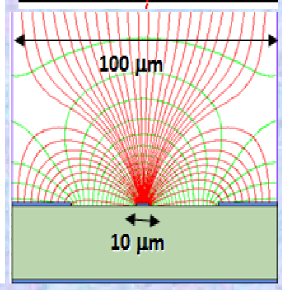
- Introduction: Rise of MPGD Technologies
- **MPGD Technologies for Present and Future:**
  - **Hadron / Nuclear Physics Experiments**
  - **Heavy Ion Facilities**
  - **High Energy Physics: Hadron / Lepton Colliders**
  - **Photon / Neutron Detection**
  - **Neutrino Physics / Dark Matters Detection**
  - **X-Ray Detection and γ-Ray Polarimetry**
- **Summary and outlook**

4th International Conference on Micro-Pattern Gaseous Detectors, October 12-15, 2015, Trieste, Italy

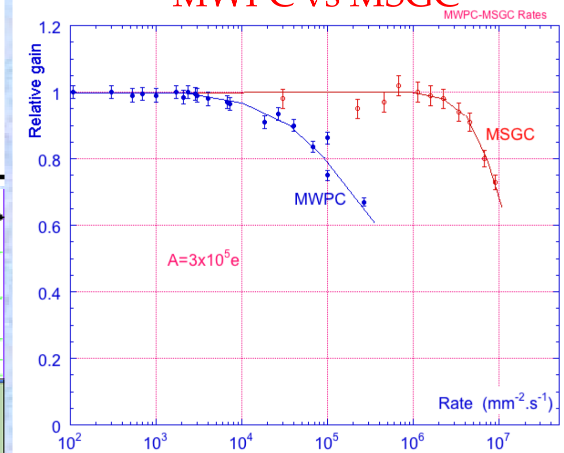
Micro-Pattern Gaseous Detector Technologies for Future Physics Projects

- Micromegas
- GEM
- Thick-GEM, Hole-Type and RETGEM
- MPDG with CMOS pixel ASICs ("InGrid")
- Micro-Pixel Chamber (μPIC)

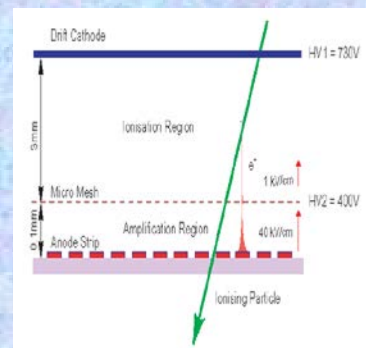


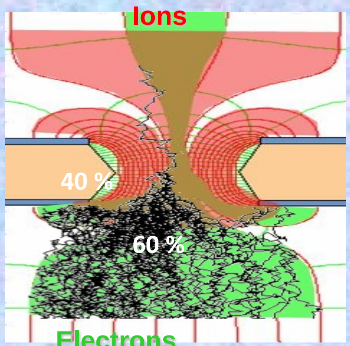


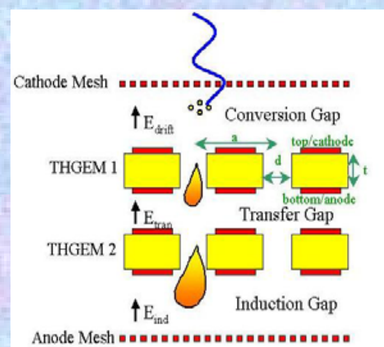
Rate Capability:
MWPC vs MSGC

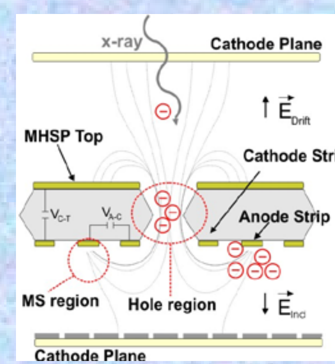


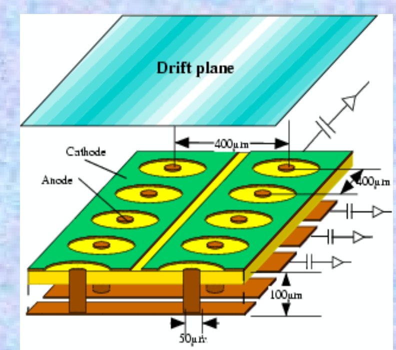
Micromegas | GEM | THGEM | MHSP | μPIC

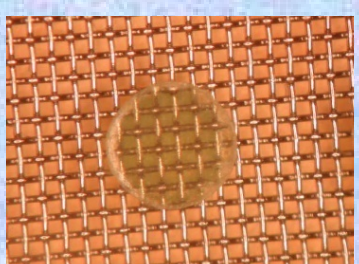


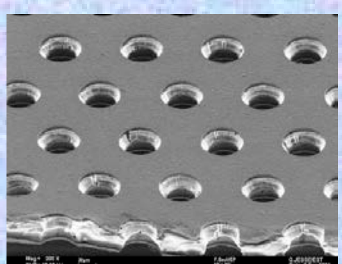


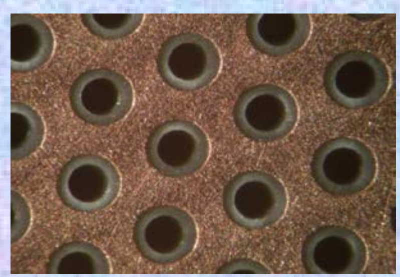


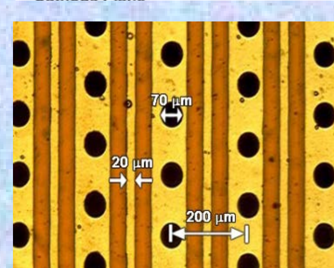


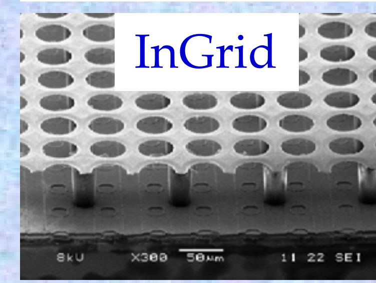








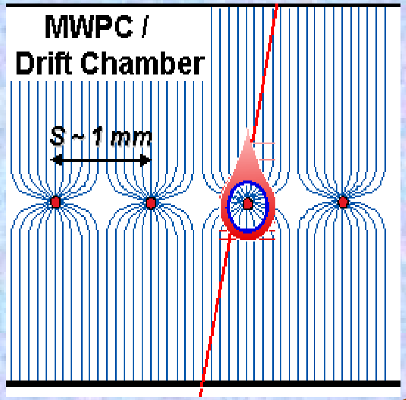


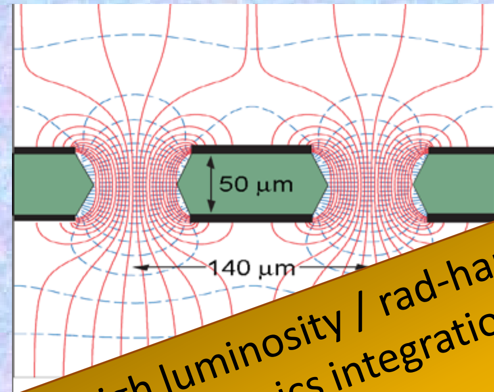


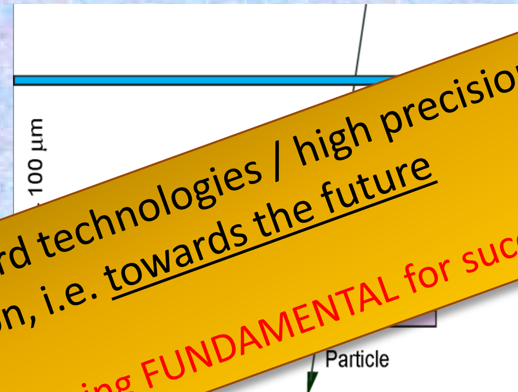
The Rise of Micro-Pattern Gas Detector Technologies

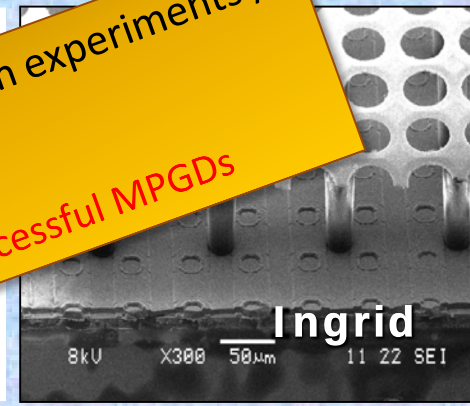
Wire Chambers, TPC, RPC → MPGD (GEM, Micromegas) → InGrid (3D)

YESTERDAY: — INTEGRATION → **TODAY:** — INTEGRATION → **FUT E:**





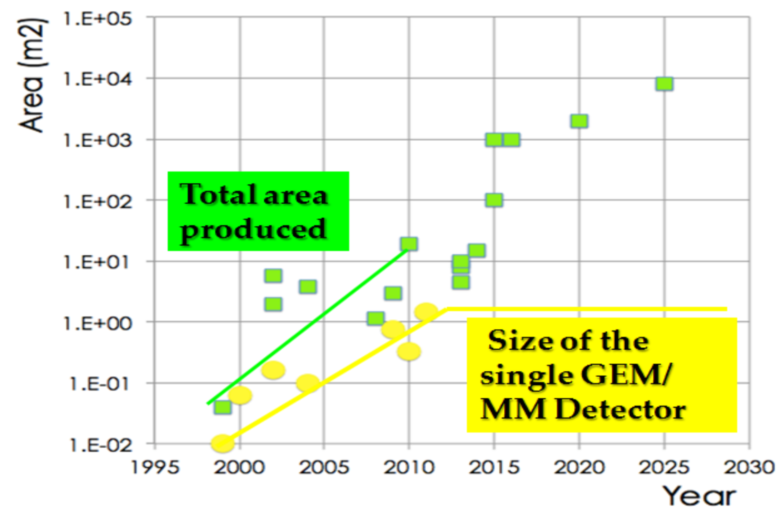




- Moving towards high luminosity / rad-hard technologies / high precision experiments / ultimate detector-electronics integration, i.e. towards the future
- Technological maturity and accurate engineering FUNDAMENTAL for successful MPGDs

MPGD Characte		MM
Active (Size of si Large Scale	.5 m² yes	~ 2 x 1 m² yes
Radiation Hardness	Similar to Si-strip det.	Similar to Si-strip. det.
High-Rate Capability	~ 50 MHz/cm²	Res MM:~10 MHz/cm²
Spatial resolution	<~30 µm ang. dep.: µTPC	<~30 µm ang. dep.: µTPC
Tracking efficiency	99%	98%
Timing Resolution	~3-5 ns (MIP) & CF_4 < 1-2 ns (UV - 1 ph.e)	3-5 ns (MIP) & CF_4 0.2–0.5 ns (UV–1 ph.e)

Advances in photolithography → Large Area MPGDs (~ m² unit size)



CERN Courier (5 pages) Volume, October 2015

CERN Courier October 2015
Detector R&D

RD51 and the rise of micro-pattern gas detectors

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

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

In the late 1980s, the development of the micro-strip gas chamber (MSGC) created great interest because of its intrinsic rate-capability, which was orders of magnitude higher than in wire chambers, and its position resolution of a few tens of micrometres at particle fluxes exceeding about 1 MHz/mm². Developed for projects at high-luminosity colliders, MSGCs promised to fill a gap between the high-performance but expensive solid-state detectors, and cheap but rate-limited traditional wire chambers. However, detailed studies of their long-term behaviour at high rates and in hadron beams revealed two possible weaknesses of the MS… technology: the formation of deposits on the elec… ing gain and performance ("ageing effe… damage to electrodes in the pres…

These initial ideas … tures, in genera… insulating supp… tional stability a… tracking, muon de… main designs: the g… mesh gaseous structu… few hundred microme… capability (> 1 MHz/mm… track resolution (around 30 μm and 5… y), and time resolution for single photoelectrons i… ub-nanosecond range.

Coupling the microelectronics industry and advanced PCB technology has been important for the development of gas detectors with increasingly smaller pitch size. An elegant example is the use of a CMOS pixel ASIC, assembled directly below the GEM or Micromegas amplification structure. Modern "wafer post-processing technology" allows for the integration of a Micromegas grid directly on top of a Medipix or Timepix chip, thus forming

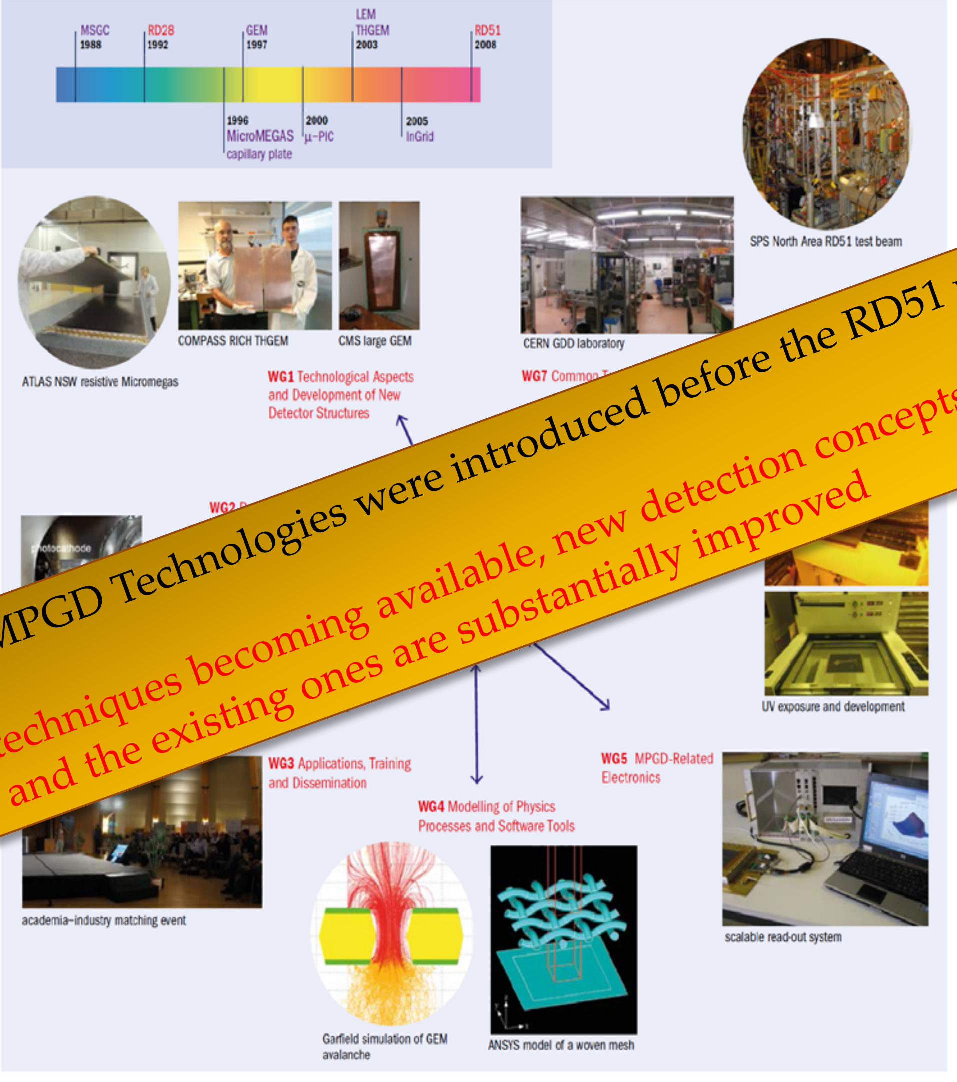


Fig. 1. The seven working groups of RD51, with illustrations of just a few examples of the different kinds of work involved. Top left: the 20-year pre-history of RD51. (Image credits: RD51 Collaboration.)

integrated read-out of a gaseous detector (InGrid). Using this approach, MPGD-based detectors can reach the level of integration, compactness and resolving pow… typical of solid-state pixel devices. For applications re… ing detectors with large-area coverage and … ution (e.g. ring-imaging Cherenk… o-patterned structures … h relatively low mass … ic robustness of the … GEM (THGEM), … istive thick GEM … ELL).

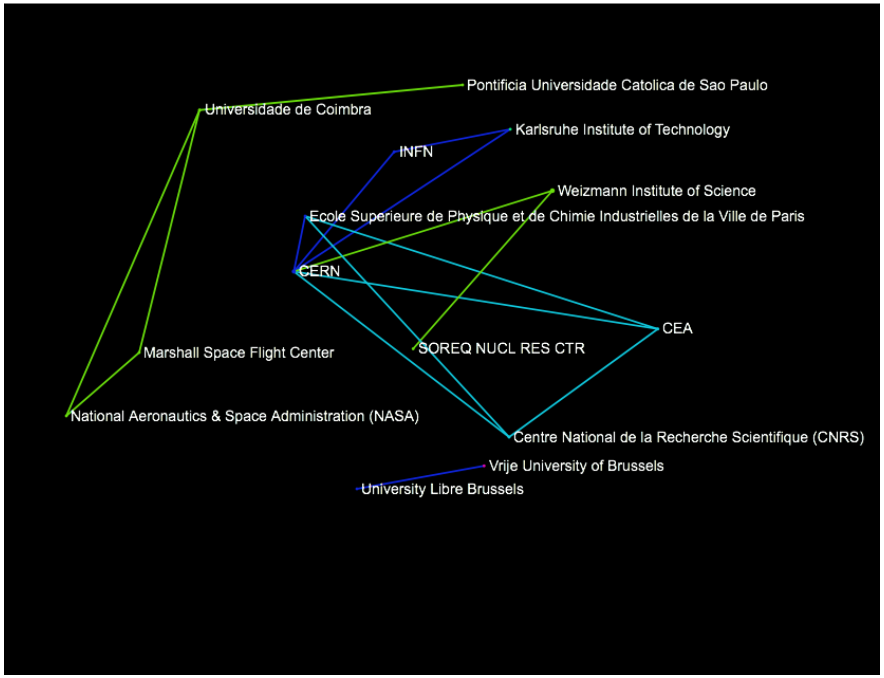
… e the technological devel… GDs. While a number of activities … to the LHC upgrade, most importantly, RD51 … access point to MPGD "know-how" for the world-wide community – a platform for sharing information, results and experience – and optimizes the cost of R&D through the sharing of resources and the creation of common projects and infrastructure. All partners are already pursuing either basic- or application-oriented R&D involving MPGD concepts. Figure 1 shows the organization of seven Working Groups (WG) that cover all of the relevant aspects of MPGD-related R&D.

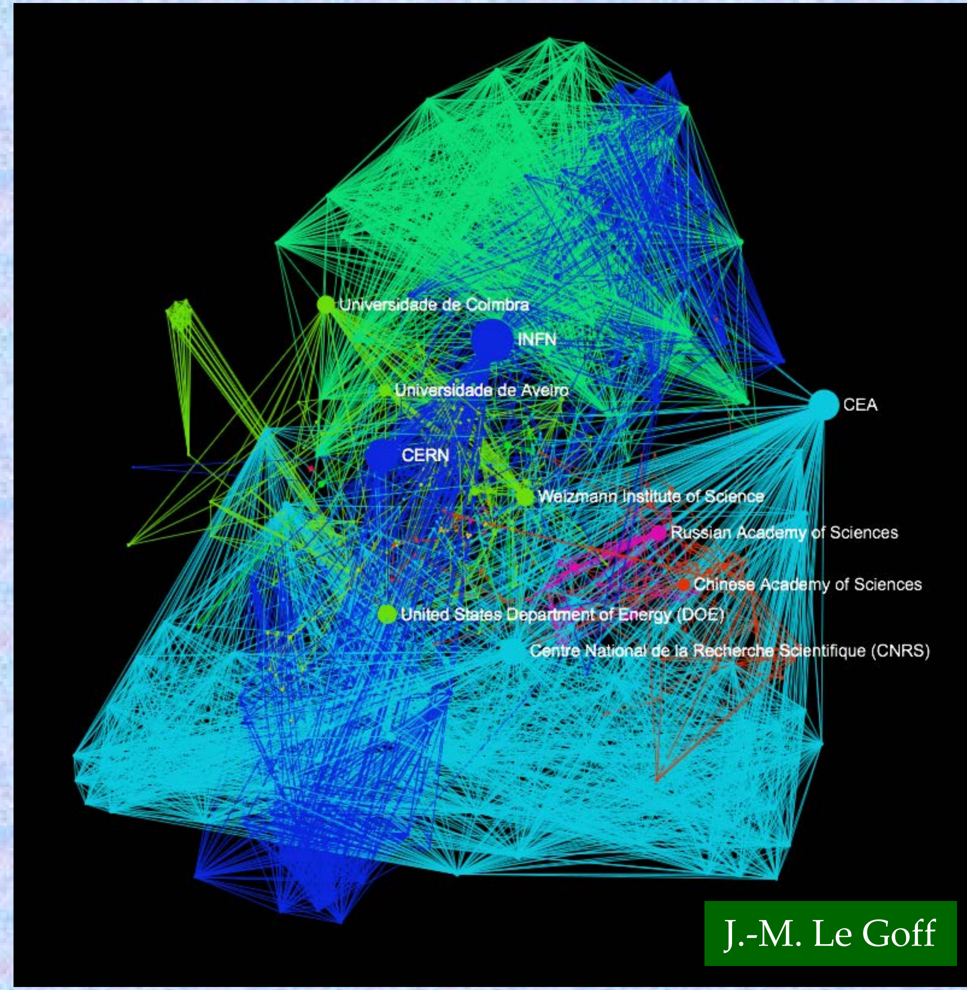
WG1 Technological Aspects and Development of New Detector Structures. The objectives of WG1 are to improve the performance of existing detector structures, optimize fabrication methods, and develop new multiplier geometries and techniques. One of the most prominent activities is the development of large-area GEM, Micromegas and THGEM detectors. Only one decade ago, the largest MPGDs were around 40 × 40 cm², limited by existing tools and materials. A big step towards the industrial manufacturing of MPGDs with a size around a square metre came with new fabrication methods – the single-mask GEM, "bulk" Micromegas, and the novel Micromegas construction scheme with a "floating mesh". While in "bulk" Micromegas, the metallic mesh is integrated into the PCB read-out, in the "floating-mesh" scheme it is integrated in the panel containing drift electrodes and placed on pillars when the chamber is closed. The single-mask GEM technique overcomes the cumbersome practice of alignment of two masks between top and bottom films, which limits the achievable lateral size to 50 cm. This technology, together with the novel "self-stretching technique" for assembling GEMs without glue and spacers, simplifies the fabrication process to such an extent that, especially for large-volume production, the cost per unit area drops by orders of magnitude. ▷

- Many of the MPGD Technologies were introduced before the RD51 was founded
- With more techniques becoming available, new detection concepts are being introduced and the existing ones are substantially improved

RD51 and the Rise of Micro-Pattern Gas Detectors

A fundamental boost is offered by RD51:
from isolate MPGD developers to a world-wide net





A combined map of organizations working with MPGDs built with collaboration-spotting software developed at CERN

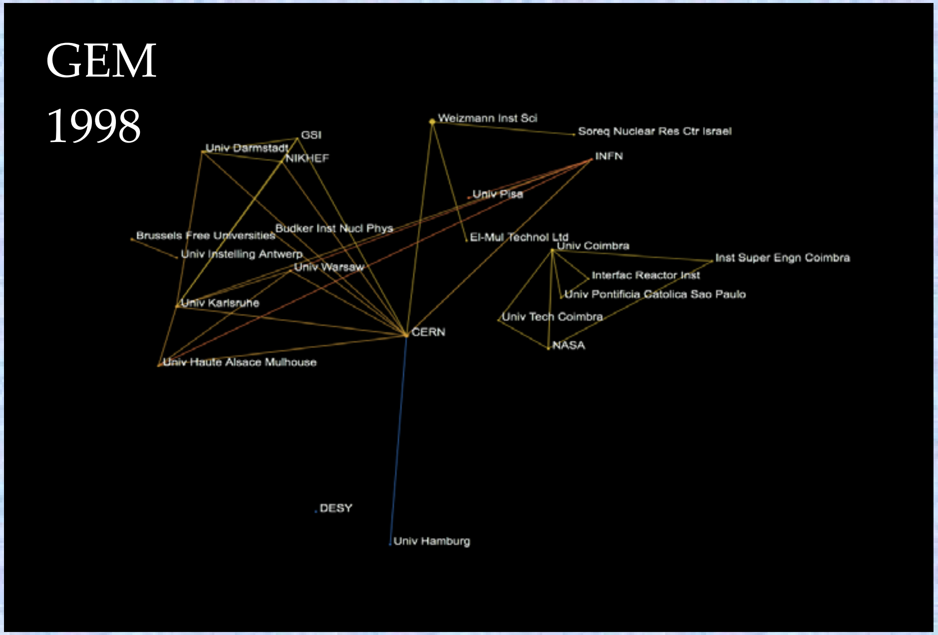
→ huge growth in interest in the MPGD technologies

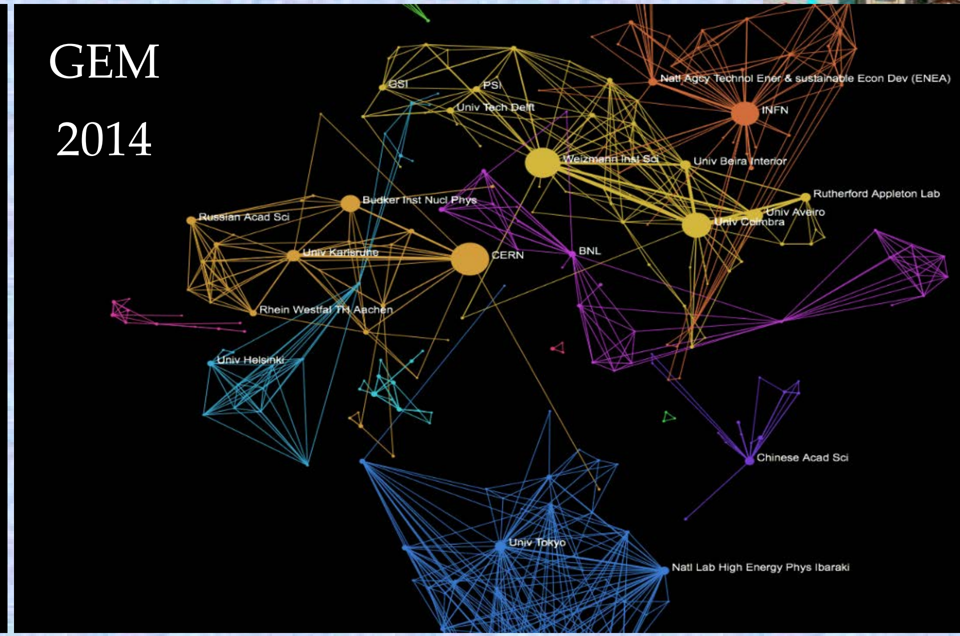
Map: **RD51**	
Current year:	1998
Organisations:	40/717
Clusters:	5
Publications:	35/1059

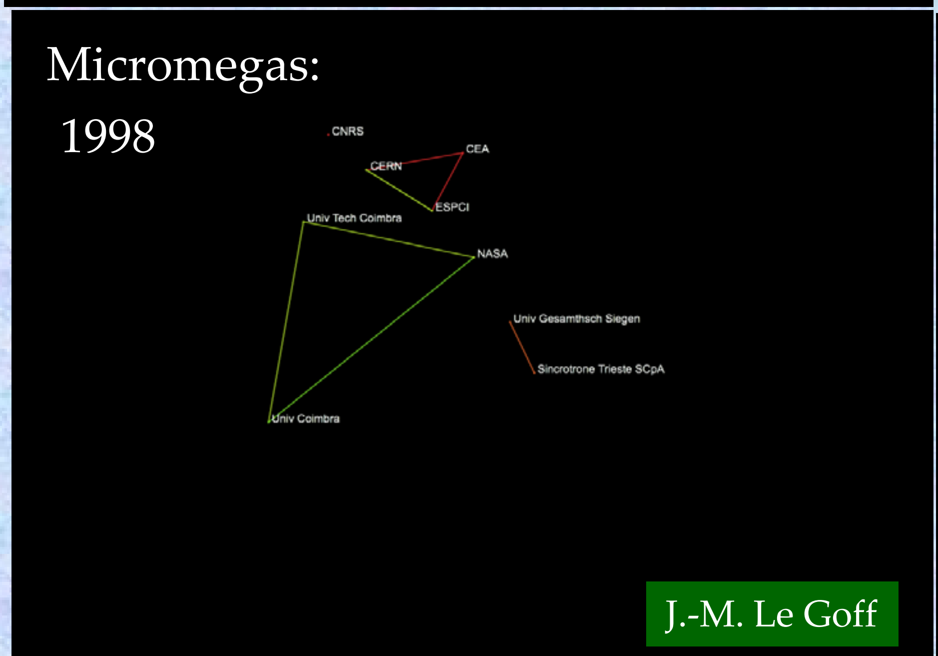
Map: **RD51**	
Current year:	2015
Organisations:	717
Clusters:	12
Publications:	1059

Collaboration Spotting Software:
http://collspotting.web.cern.ch/)

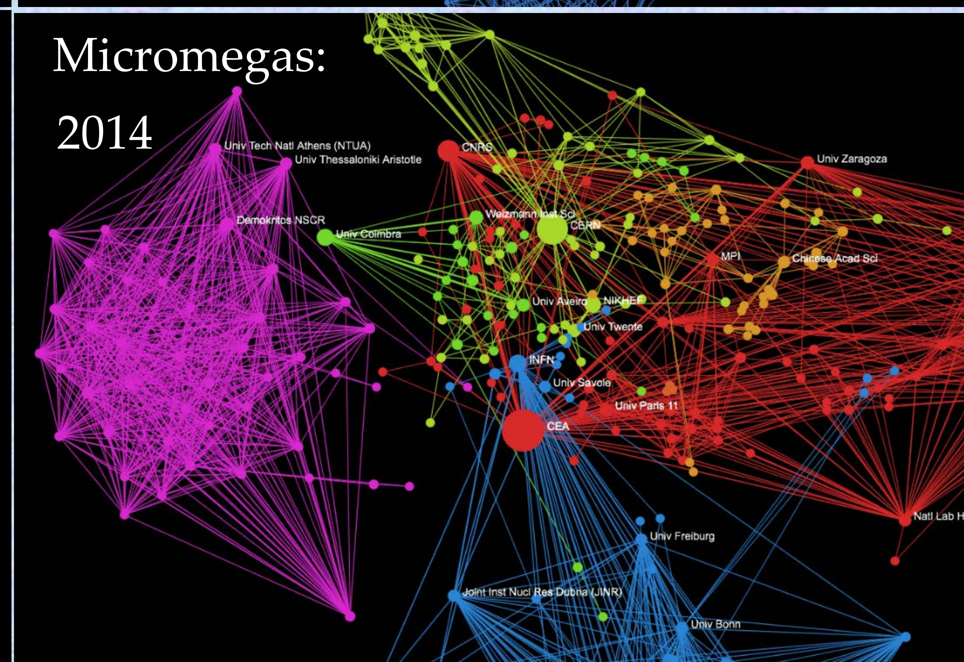
RD51 and the Rise of Micro-Pattern Gas Detectors



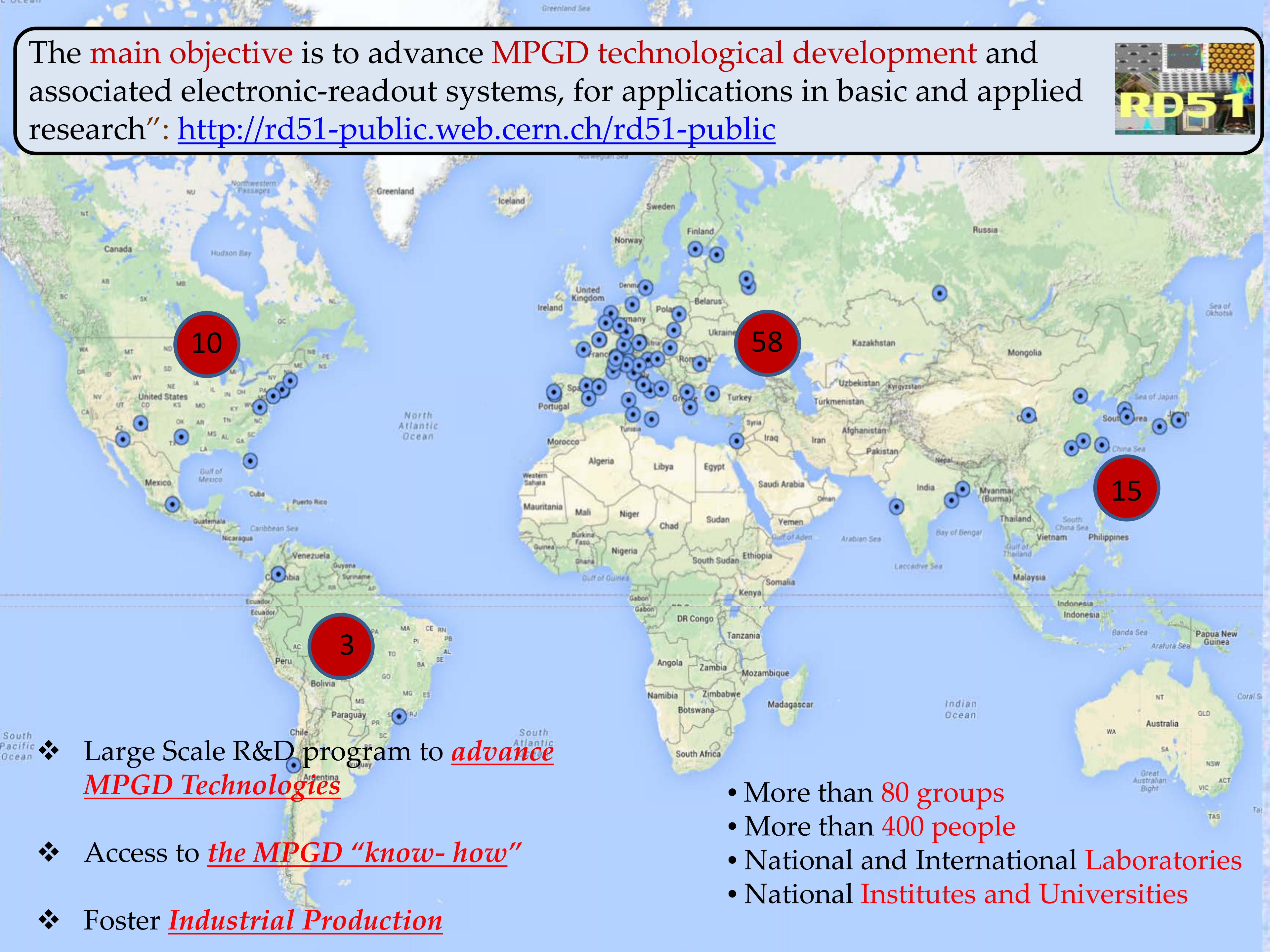




J.-M. Le Goff



The main objective is to advance MPGD technological development and associated electronic-readout systems, for applications in basic and applied research": http://rd51-public.web.cern.ch/rd51-public



- ❖ Large Scale R&D program to ***advance MPGD Technologies***
- ❖ Access to ***the MPGD "know- how"***
- ❖ Foster ***Industrial Production***

- More than 80 groups
- More than 400 people
- National and International Laboratories
- National Institutes and Universities

Challenges for Future Detectors: Experimental Opportunities

The Energy Frontier (LHC/LC/FCC):

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

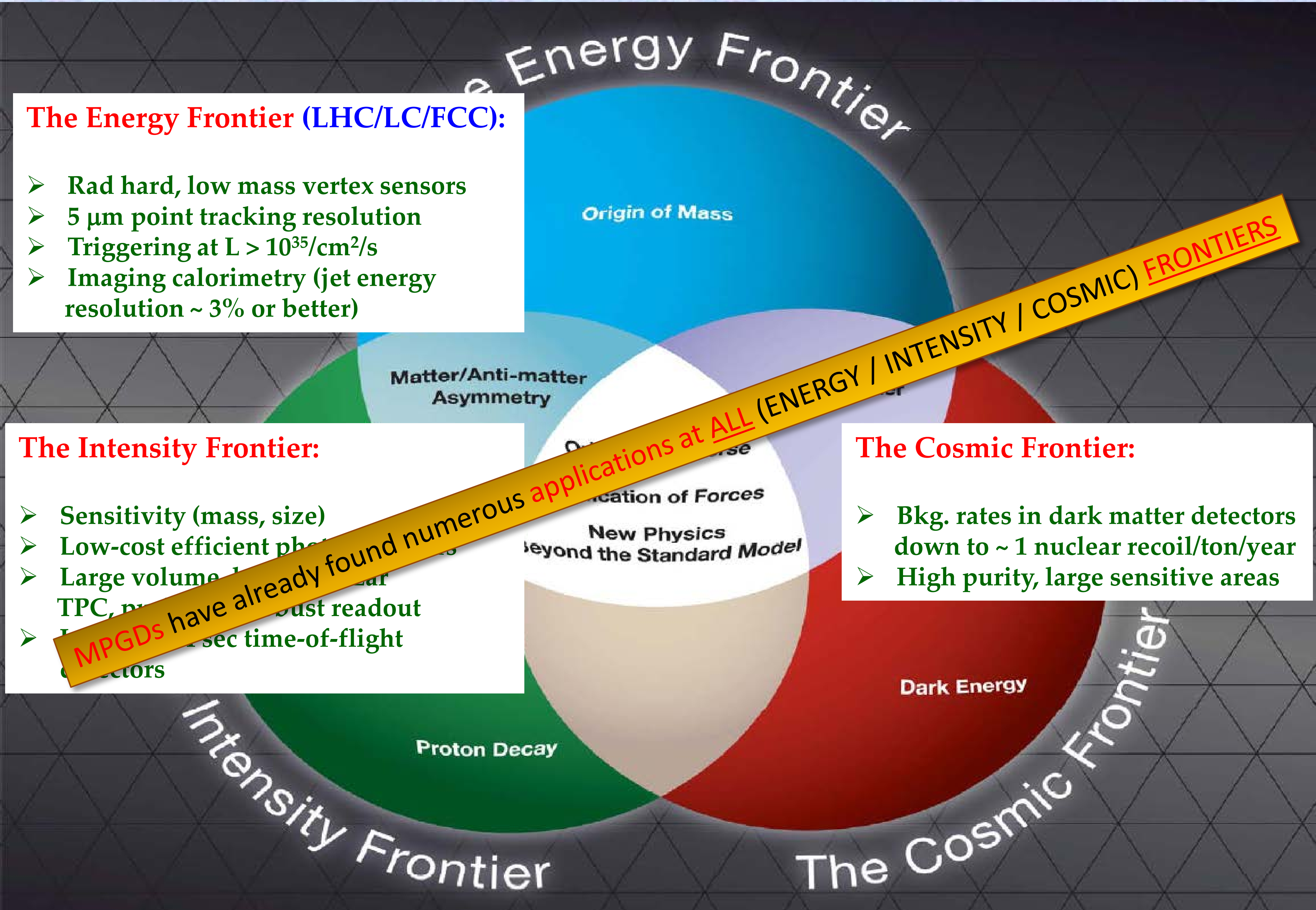
The Intensity Frontier:

- Sensitivity (mass, size)
- Low-cost efficient ph[illegible]s
- Large volume [illegible]ar TPC, p[illegible]bust readout
- [illegible] sec time-of-flight [illegible]ectors

The Cosmic Frontier:

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

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

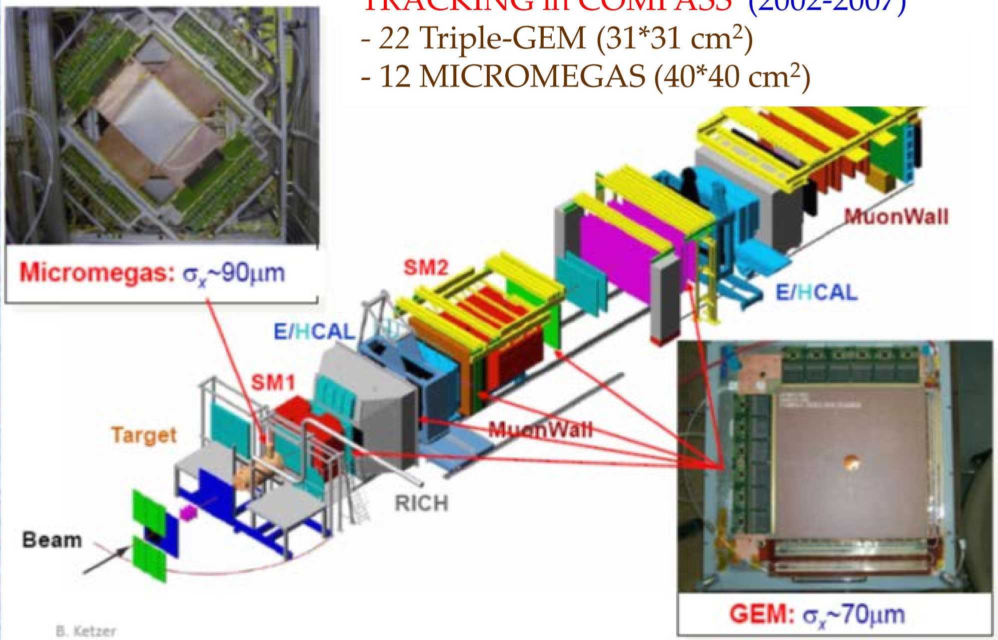


MPGD Tracking Concepts for Hadron / Nuclear Physics

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

COMPASS Experiment – First Large Scale Use of GEMs and Micromegas

TRACKING in COMPASS (2002-2007)
- 22 Triple-GEM (31*31 cm^2)
- 12 MICROMEGAS (40*40 cm^2)



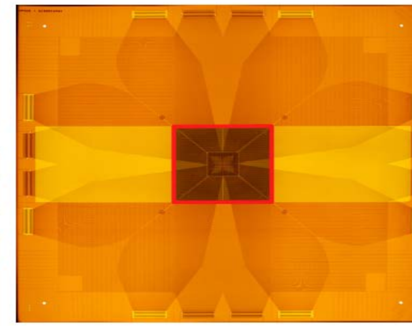
Since > 2008: Detectors active in beam area with pixel read-out (used for beam tracking)

Pixelised GEM:

Foil: 450 × 450 mm^2
- 3 conducting layers 5 μm Cu
- 2 intermediate layers 50 μm Polyimide

Centre: 32 × 32 mm^2
- 32 × 32 quadratic pixels

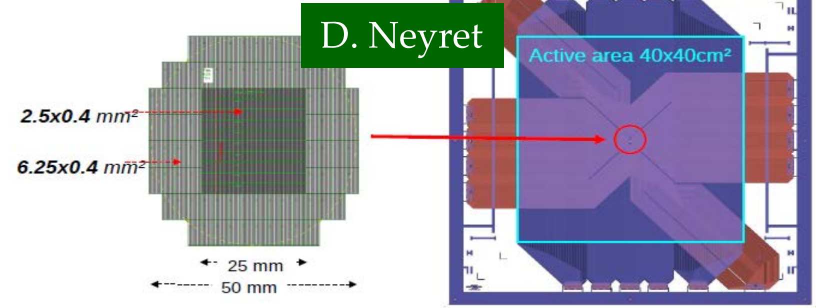
Periphery: 100 × 100 mm^2
- 2 layers, 512 strips each
- equal charge sharing
- pitch: 400 μm

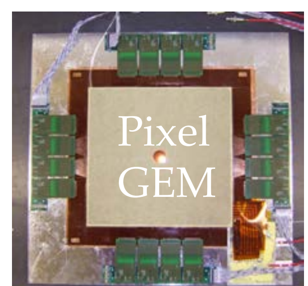


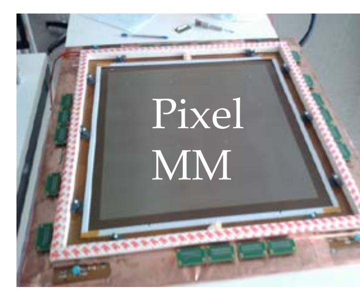
Pixelised MM with GEM preamplification:

1280 + 1280 channels

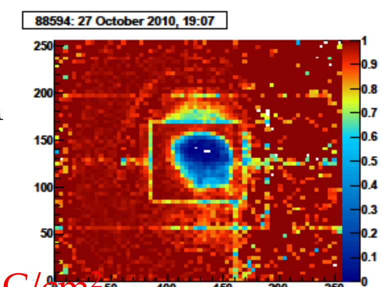
D. Neyret







Aging of PixelGEM Detectors:



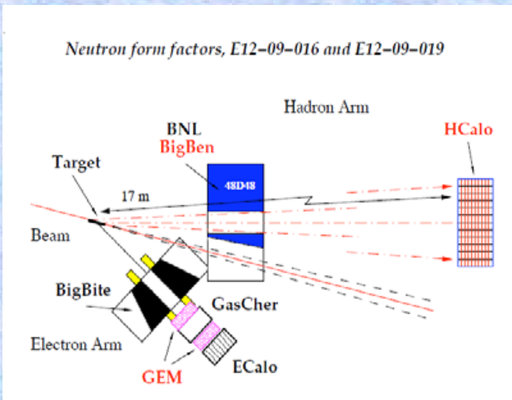
For some detectors from first batch
→ efficiency loss

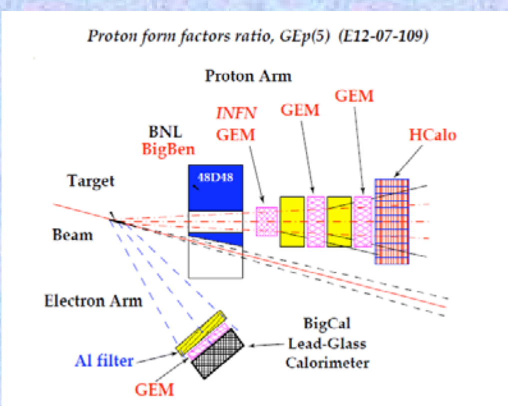
B. Ketzer

Total charge collected:
-2008/2009 (p beam): (500 ±20) mC/cm^2
- 2010/2011 (m beam): (1000±20) mC/cm

Tracked down to Si deposits on GEM; culprit were gas leaks that allowed Si from an outside sealant to migrate into chamber →
"OLD Lesson": Never, ever use materials containing Si

GEM Tracker of the SuperBigBite Spectrometer at Hall A @ JLAB





- **SBS Physics**
- Nucleon Form Factors (FFs) -
- Nucleon Structures
- **SBS detectors:**
- Large Luminosity & moderate acceptance
- Independent arm (re-configurable detectors)

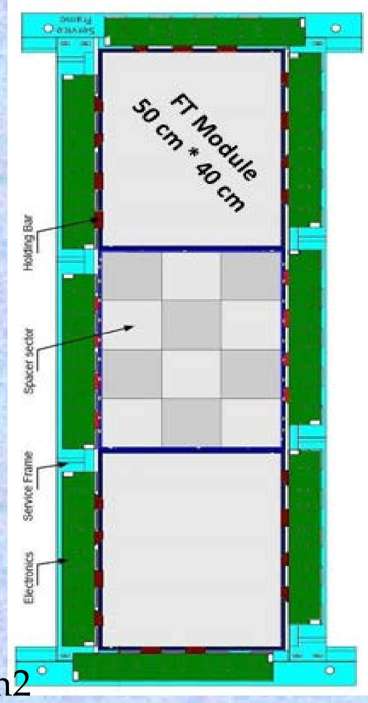
Front Tracker

- 6 layers of active area 150x50cm2

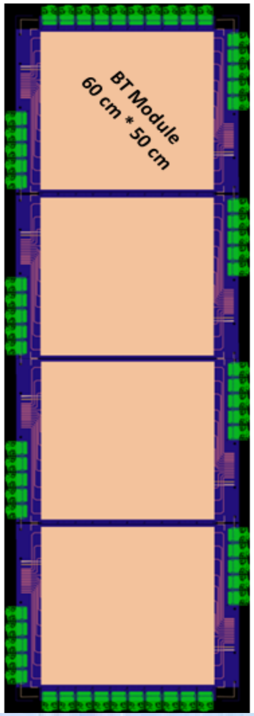
Back Tracker

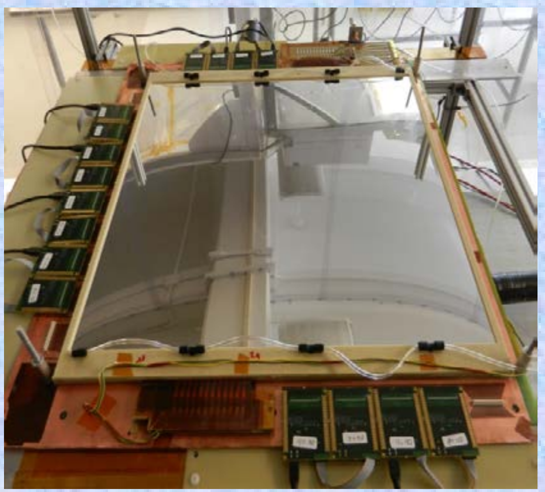
- 2*5 layers of active area 200x60 cm2

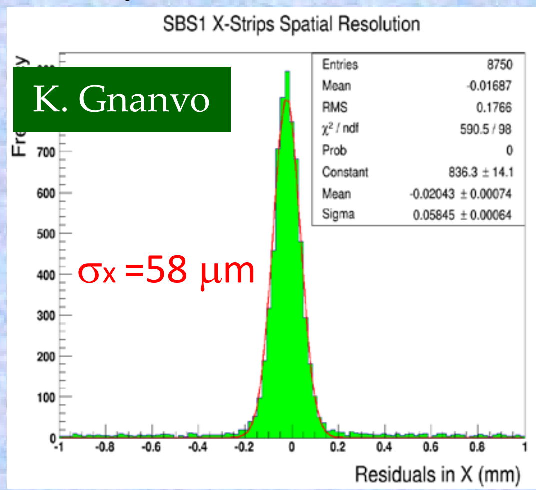
FT layer (1^{st} tracker)



BT layer (2^{nd} & 3^{rd} Trackers)



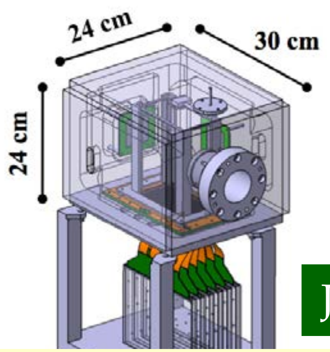


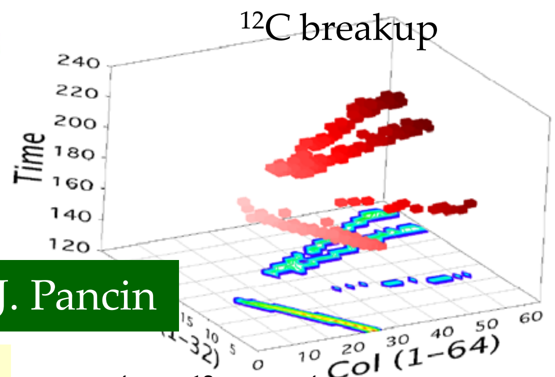


Several Examples of TPC Tracking in Nuclear Physics Projects

The ACTAR TPC Project:
(gas is used as a secondary target for nuclear reactions):

Goal: Nuclear structure with rare-isotope beams





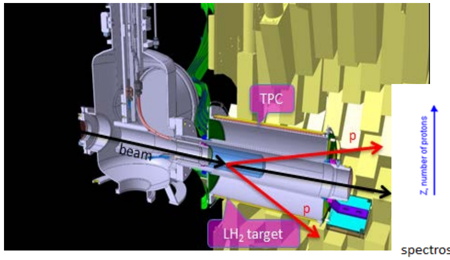
$^{4}He(^{12}C,3\alpha)^{4}He$

J. Pancin

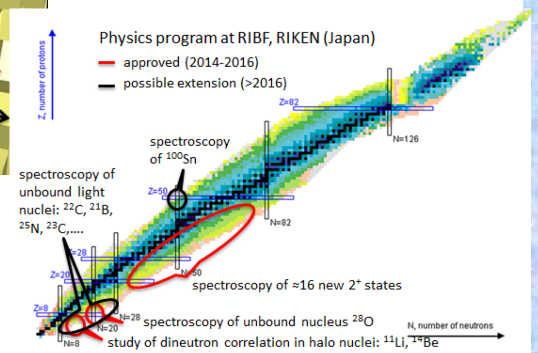
MM-based readout

The MINOS TPC: coupling liquid H2 target (10-20 cm) to a Vertex tracker (TPC)

GOAL: spectroscopy of the most exotic nuclei



A. Corsi



MM-based readout

HypTPC for J-PARC E42/E45 Experiments:

H. Sako

E42 (H-dibaryon search)

$K^{-}C \rightarrow K^{+}\Lambda\Lambda X \rightarrow K^{+}p\pi^{+}p\pi^{+}X$

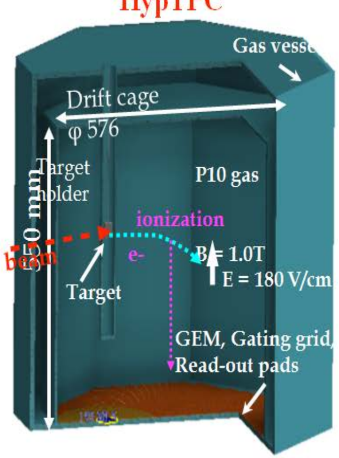
E45 (Baryon resonance measurements)

$\pi^{\pm}p \rightarrow \pi^{+}\pi^{\pm}n,\ \pi^{\pm}p \rightarrow \pi^{\pm}\pi^{0}p$

- High beam rate operation at 10^{6}Hz
- Ion backflow suppression with triple-stack GEMs and the gating grid
- Large acceptance
- with the target holder inside the drift volume

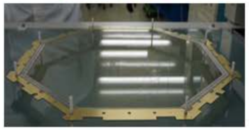
- HypTPC will complete in Jan 2016, and a beam test will be performed in Feb 2016

HypTPC

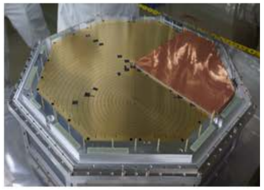


HypTPC (Oct 2015)

Gating grid



GEMs and pads

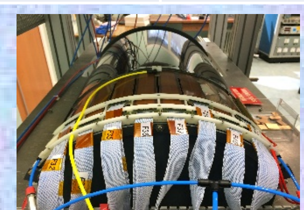


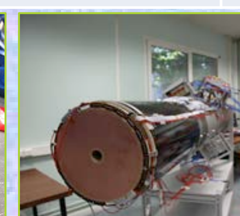
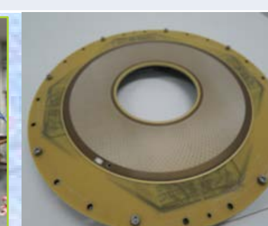
GEM-based readout

Cylindrical MPGDs as Inner Trackers for Particle / Nuclear Physics

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





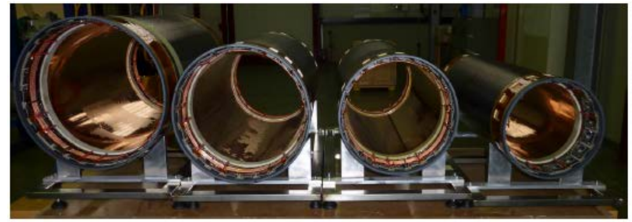



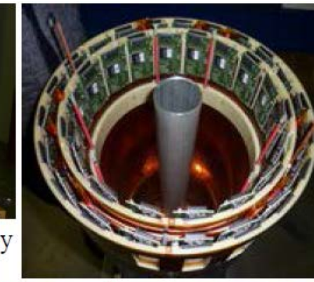
Cylindrical GEMs Inner Trackers for KLOE2 and BESIII Experiments

Cylindrical GEM Inner Tracker for the KLOE2:

8 years of R&D and construction:

- ❖ Intrinsic lightness and flexibility of the GEM allowed to develop a vertex detector with a total thickness of 2% of a radiation length



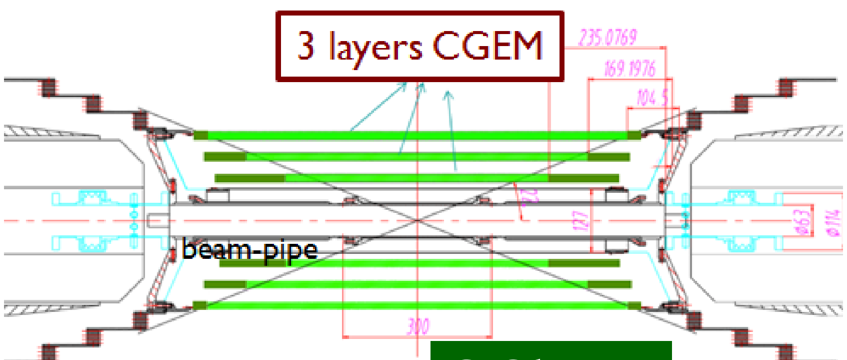


The final assembly of the KLOE-2 Inner Tracker, with the insertion of all the triple-CGEMs one into the other took place in March 2013

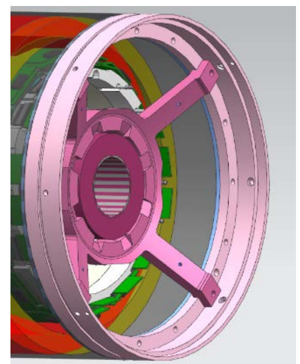
G. Bencivenni

Cylindrical GEM Inner Tracker for the BESIII:

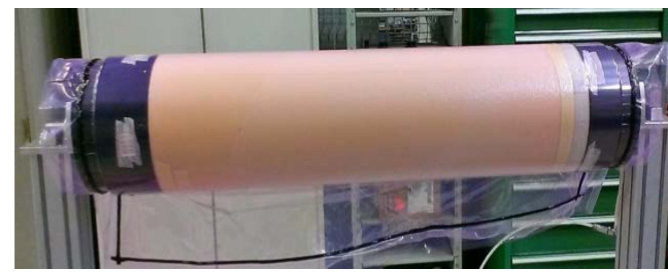
Replace the existing inner drift chamber with three layers of Cylindrical GEM.

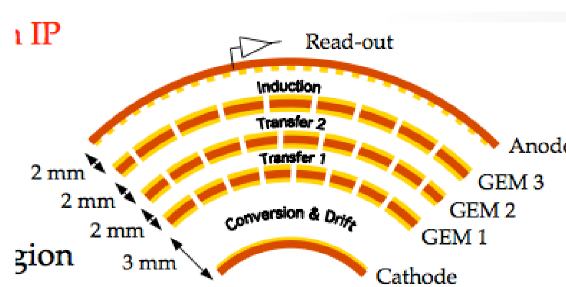


G. Cibinetto



- Active area
  - L1: length 532 mm
  - L2: length: 690 mm
  - L3: length: 847 mm
- Inner radius: 78 mm
- Outer radius: 178 mm





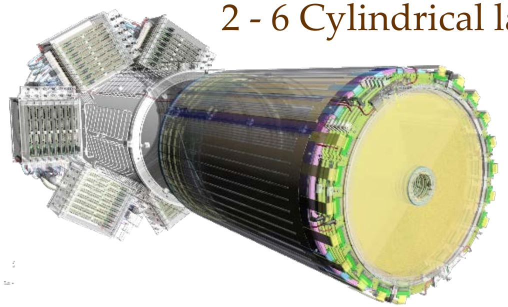
4th LNF Workshop on Cylindrical GEM Detectors: https://agenda.infn.it/conferenceDisplay.py?confId=9782

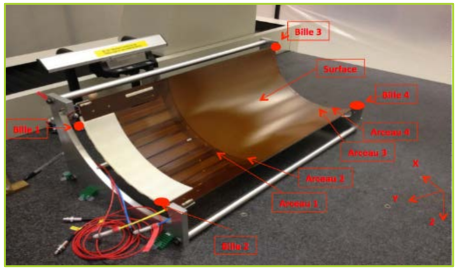
Cylindrical MM Inner Trackers for CLAS12 and ASACUSA Experiments

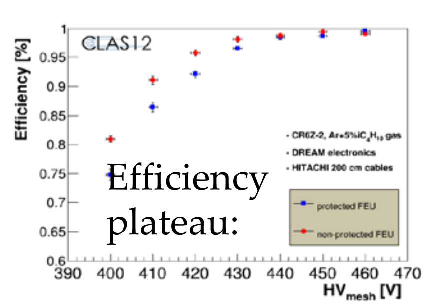
CLAS12 Central Tracker@ JLAB

GOAL: Study of the nucleon structure with high 12 GeV electron beam at high luminosity:

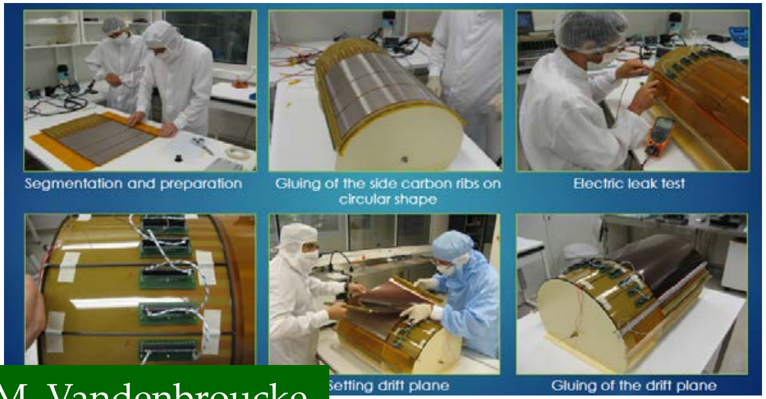
High rate ~ 10 MHz
2 - 6 Cylindrical layers







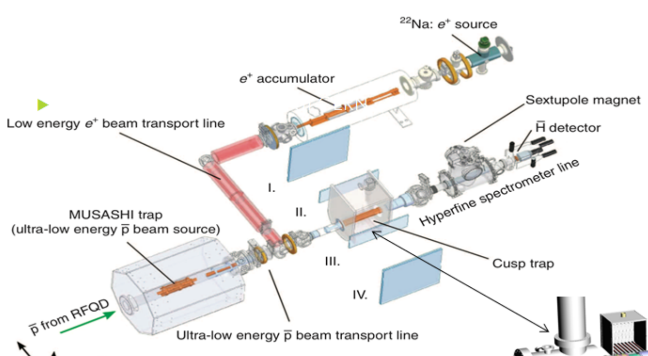
- 1st curved Micromegas
- 1st use in 5T field
- 1st use of remote elec
- Resistive technology; High rate (30 MHz)

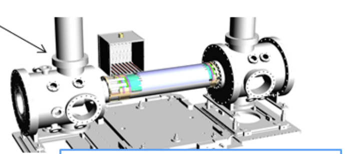


M. Vandenbroucke

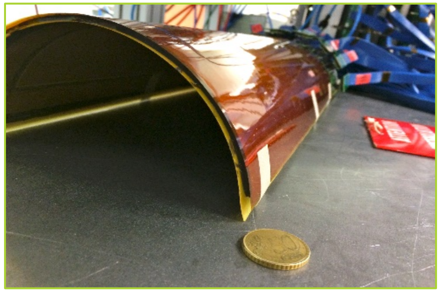
ASACUSA experiment : spectroscopy of anti-Hat the Anti-Proton Decelerator (AD) at CERN

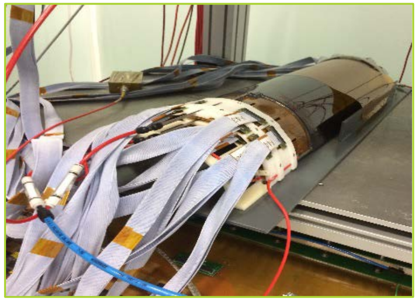
GOAL : Vertex reconstruction inside the EM trap where the anti-H is produced with ~1cm resolution

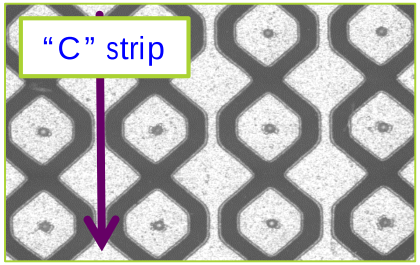


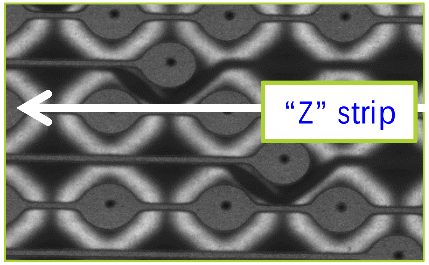

ASACUSA Micromegas Tracker

2 Cylindrical layers =
4 MM with 2D readout



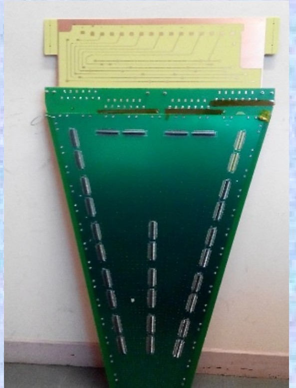
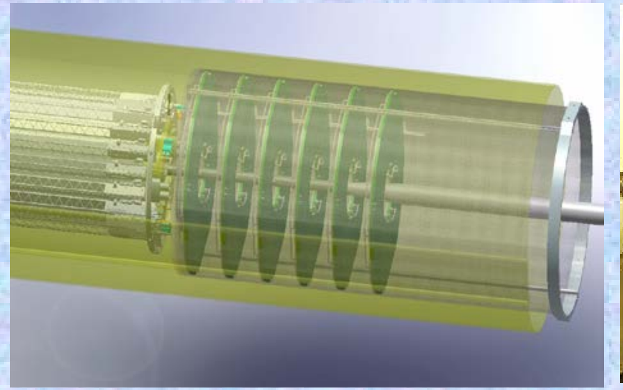






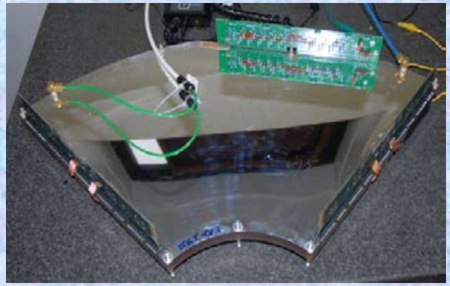
MPGD Tracking for Heavy Ion / Nuclear Physics

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

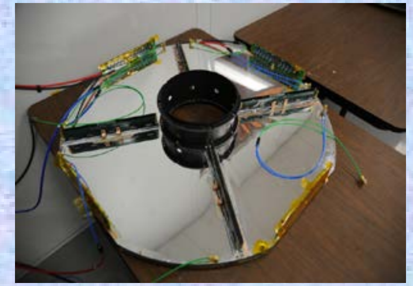





Layout:

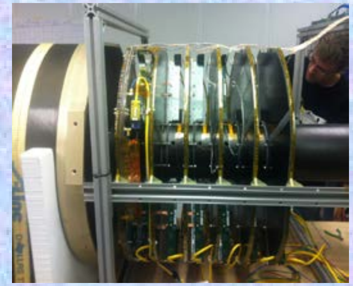
STAR Forward GEM Tracker (FGT)



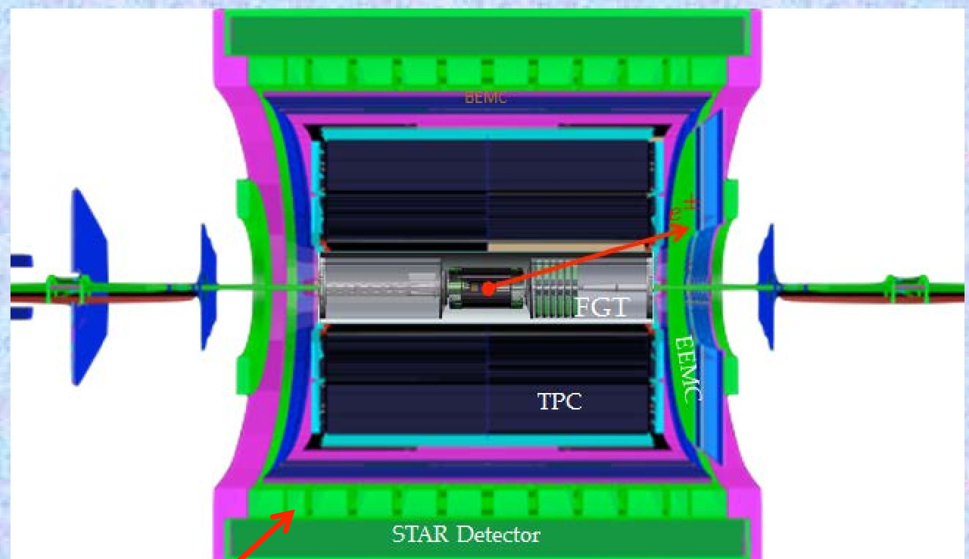
Quarter section

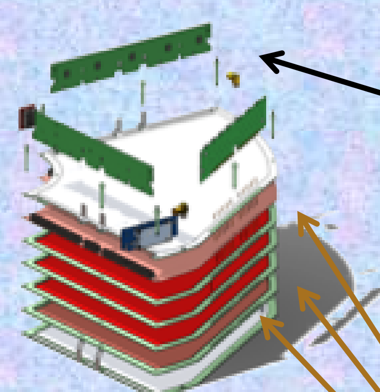


Disk

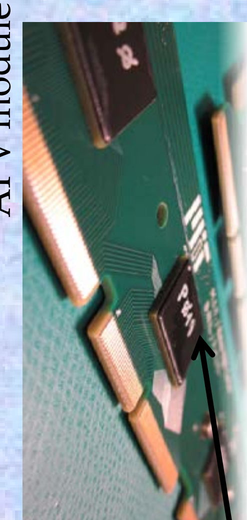


Quarter section

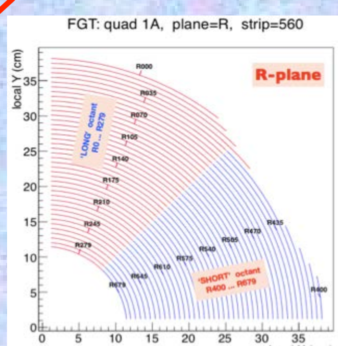




APV module



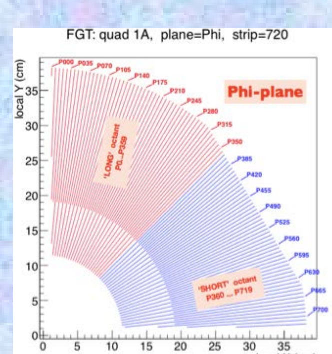
Packaged APV chip



Readout

Structure:

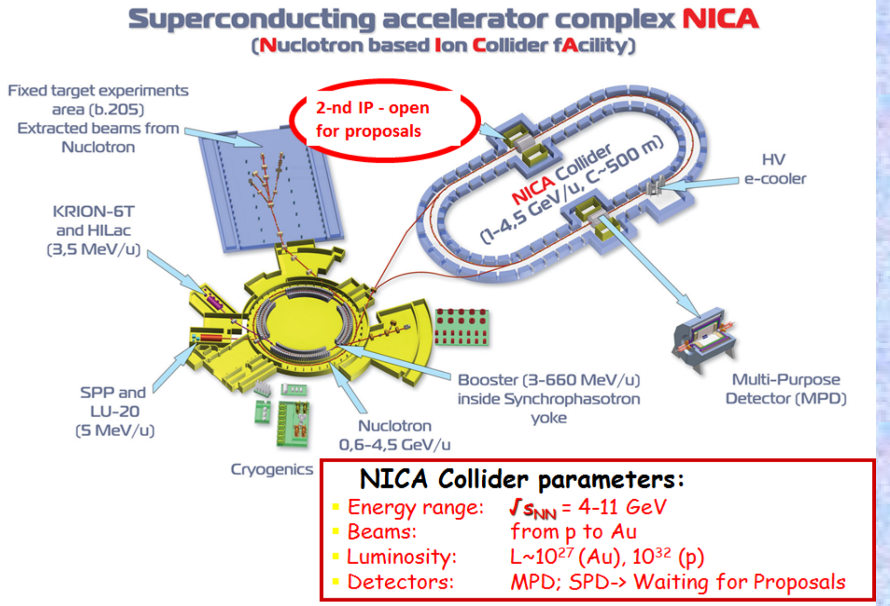
B. Surrow



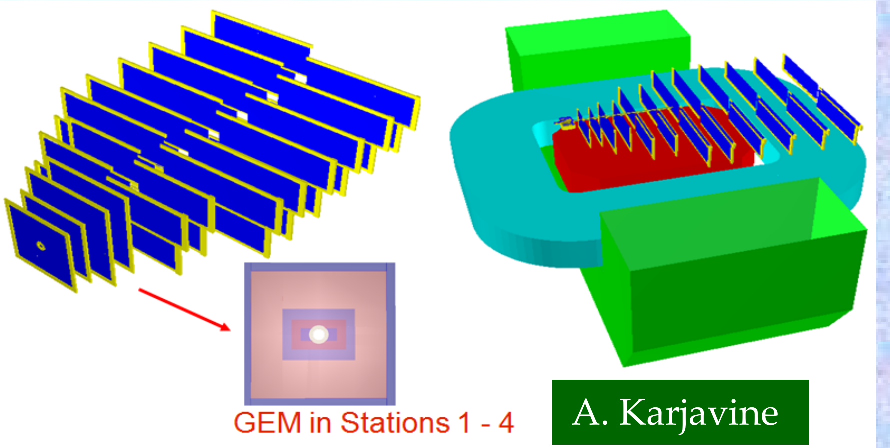
FGT GEM foil

Nuclotron-based heavy Ion Collider fAcility (NICA) @ Dubna

Study of hot and dense baryonic matter and Nucleon spin structure

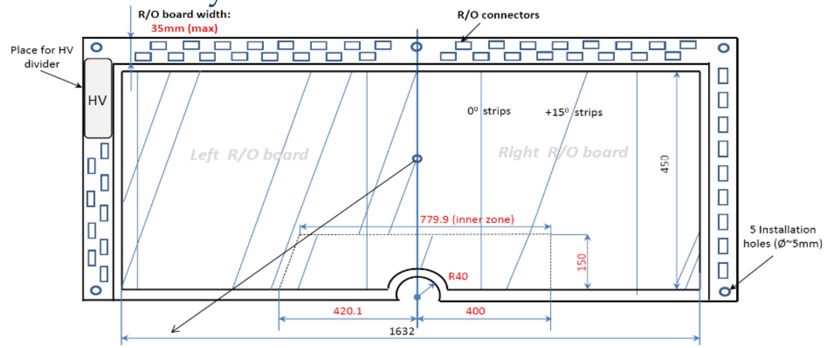


*B*M@N is the first step in the realization of the NICA heavy-ion programme

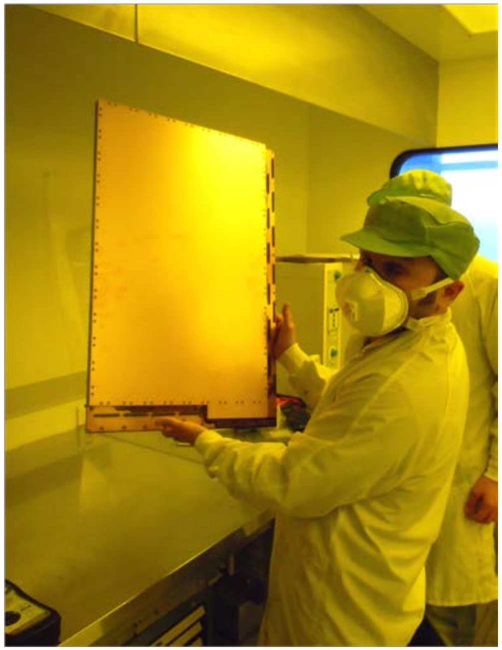


GEM Detectors for Baryonic Matter at Nuclotron (BM@N) Project:

Geometry of GEM detector 163 x 45 cm^2

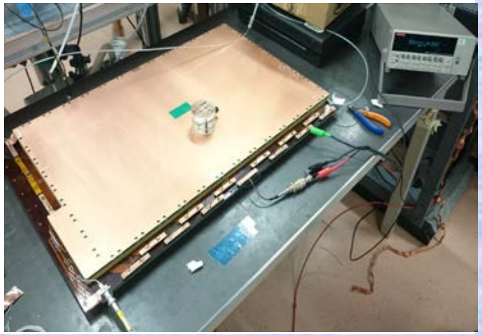


For tracking in technical run in beg 2016 plan to have 4+1 detectors 66 x 41 cm^2 and detector 163 x 45 cm^2

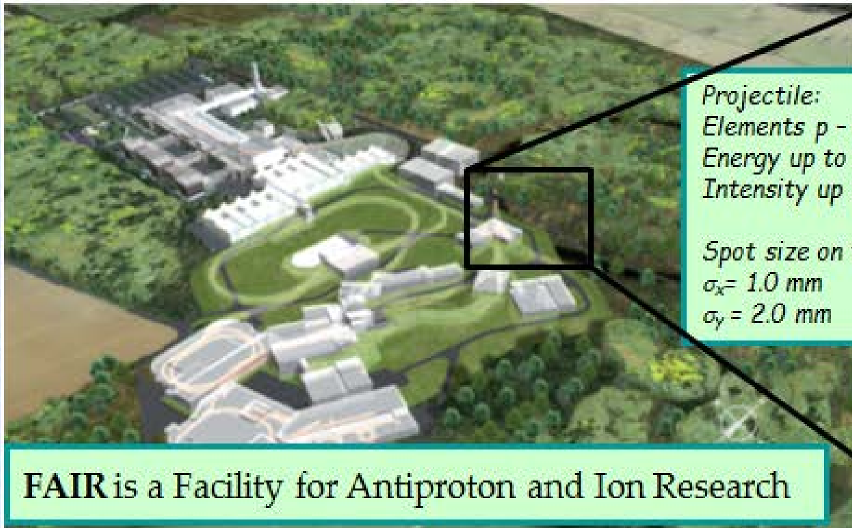


GEM detector 66x41 cm^2 produced at CERN workshop:

First GEM serial tests



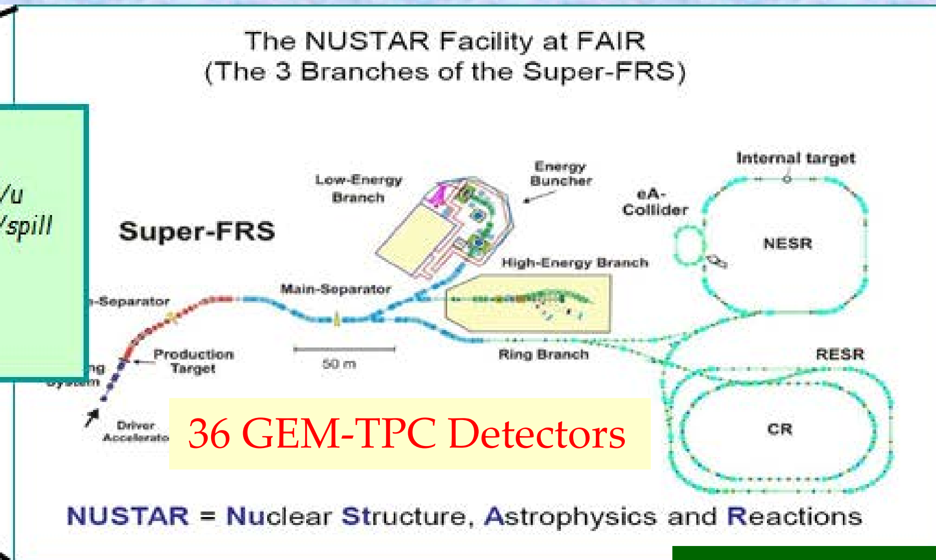
Facility for Antiptoton and Ion Research (FAIR): Diagnostic System for Super-FRS



Projectile:
Elements p - U
Energy up to 1.5 GeV/u
Intensity up to 10^{12} /spill

Spot size on target:
σ_x = 1.0 mm
σ_y = 2.0 mm

FAIR is a Facility for Antiproton and Ion Research



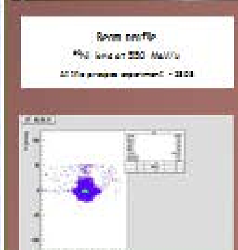
36 GEM-TPC Detectors

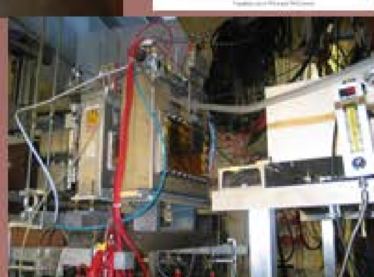
NUSTAR = Nuclear Structure, Astrophysics and Reactions

F. Garcia
(Finnish team)

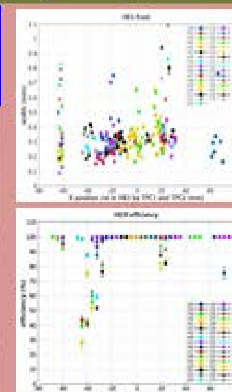
Prototype Development

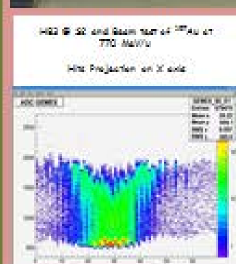
GEM-TPC HB1, with delayed lines



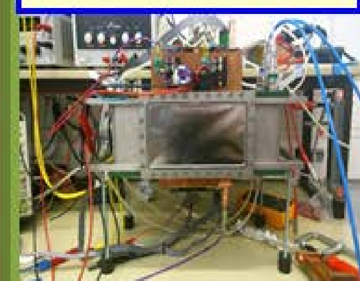


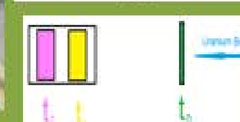
GEM-TPC HB3, with GEMEX readout

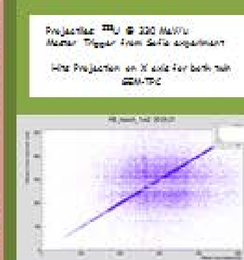




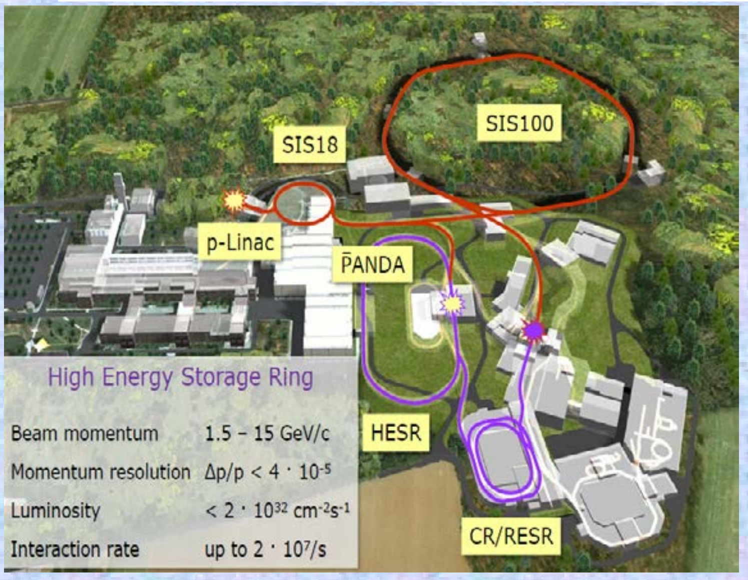
GEM-TPC HGB4, with GEMEX readout



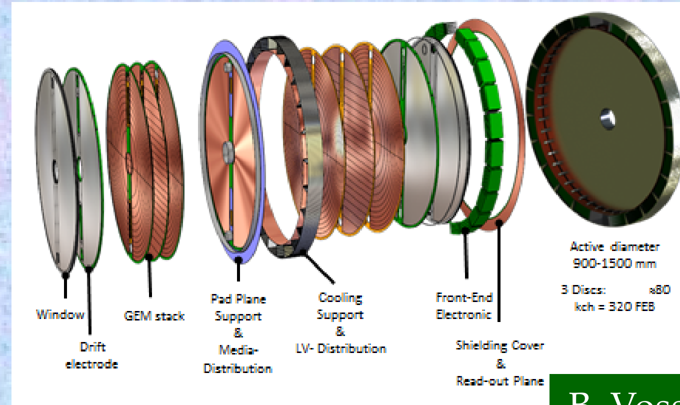




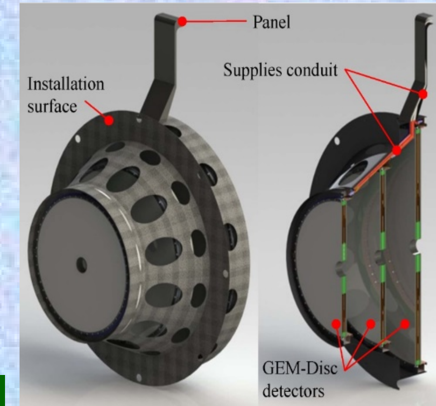
Facility for Antiptoton and Ion Research (FAIR): The PANDA GEM Tracker



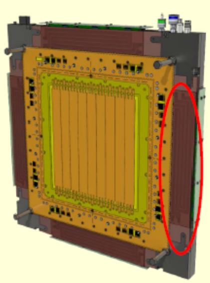
PANDA GEM-Tracker: Highly efficient detection of charged particles in forward direction (5-21°)



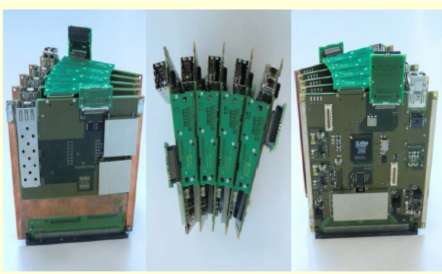
B. Voss



PANDA GEM-Tracker: Front-End Electronics

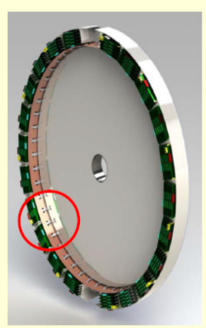


Square-shaped GEM2D detector prototype



High-density front-end boards (FEB) with local intelligence

- 80000 channels, 320 FEBs, operated in groups
- Development done at GSI
- Large synergies with other FAIR projects (SuperFRS, BioMat, ACC…)
- Tested in 2013/2014, revision pending
- System performance to be tested in 2016 together with the GEM2D demonstrator detector system



Circular-shaped GEM-Disc detector

Panda

3

PANDA GEM-Tracker: Mechanics

Exoskeleton (Riddle)

- Support and adjustment of the 200kg detector system with a precision of O(100μm)
- 2.3 kg carbon-fiber fabric in a single shell of Ø1450 x 1500 mm

Work performed by 7 students in close collaboration with several local technical universities

Panda

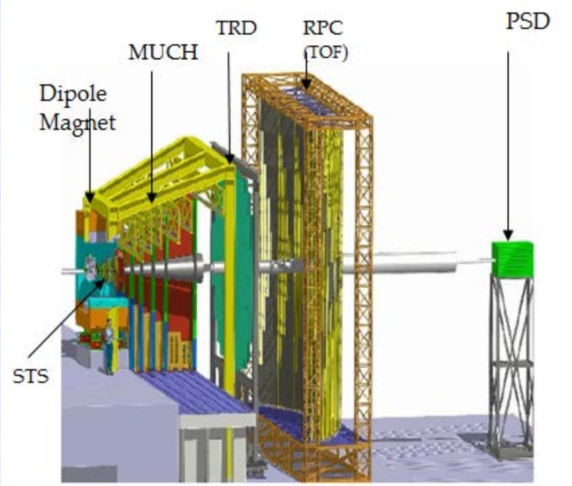
2

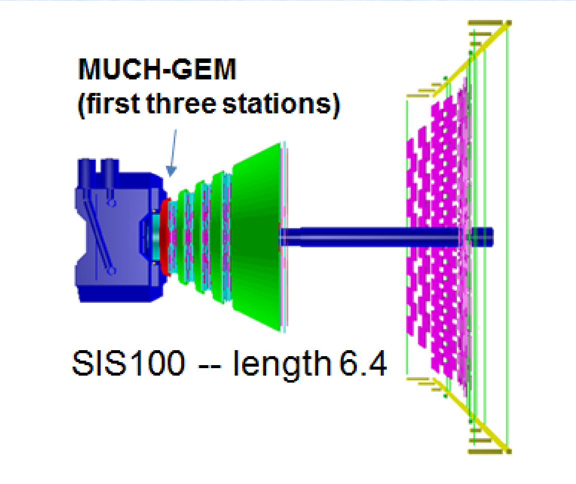
Facility for Antiptoton and Ion Research (FAIR): GEM Detector for CBM MUCH

CBM Muon Chamber (MUCH) based on novel concept of segmented absorbers and detector stations

Aim: to detect dimuon signals from low mass vector mesons and J/ψ

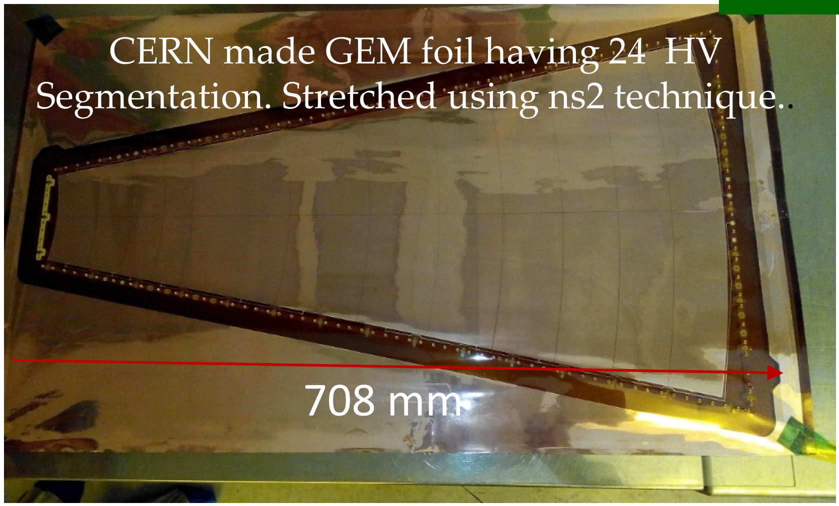
Experiments	Energy range (Au/Pb beams)	Reaction rates Hz
STAR@RHIC BNL	$\sqrt{s_{NN}}$ = 7 – 200 GeV	1 – 800 (limitation by luminosity)
NA61@SPS CERN	E_{kin} = 20 – 160 A GeV $\sqrt{s_{NN}}$ = 6.4 – 17.4 GeV	80 (limitation by detector)
MPD@NICA Dubna	$\sqrt{s_{NN}}$ = 4.0 – 11.0 GeV	~7000 (design luminosity of 10^{27} $cm^{-2}s^{-1}$ for heavy ions)
CBM@FAIR Darmstadt	E_{kin} = 2.0 – 35 A GeV $\sqrt{s_{NN}}$ = 2.7 – 8.3 GeV	10^5 – 10^7 (limitation by detector)



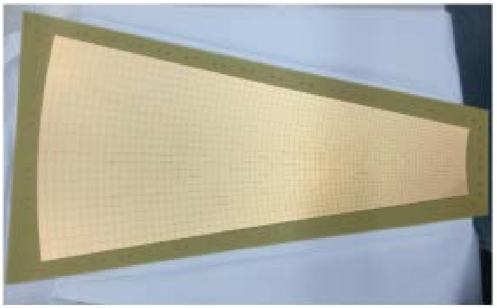


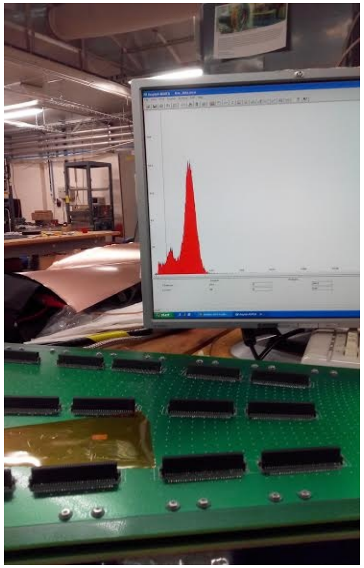
First Real size GEM Prototype for CBM MUCH:

A. Dubey



Readout PCB with projective geometry, Fabricated in India





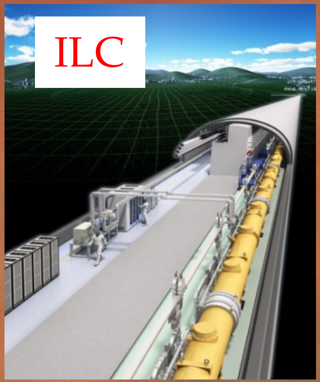
The Energy Frontier Lanscape: Present and Future (HL-LHC, LC, FCC)

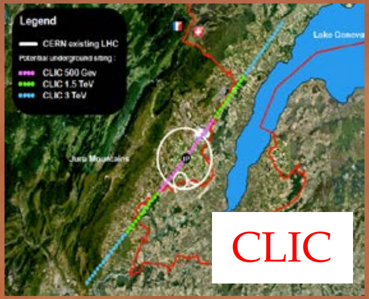
Lepton Collider is the essential complement to the LHC (the next highest priority machine)

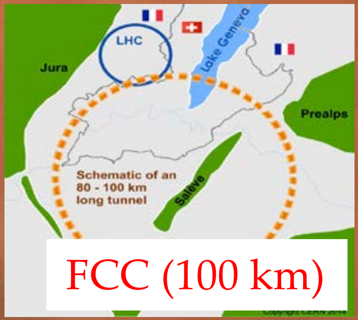
- HL-LHC: upgrade of the LHC
  → Increase in luminosity by factor of 10
- ILC: International Linear Collider
  → e+e- collider based on SRF technology ($\sqrt{s}$ = 0.25 – 1 TeV)
- CLIC
  → e+e- collider based on warm X-band technology ($\sqrt{s}$ = 0.5 - 3 TeV)
- Very recent proposals:
  → CERN: FCC (pp, ep, ee)
  → China: CepC, SppC

Lepton (Linear) Colliders

Hadron Colliders







MPGD Technologies for Energy Frontier Hadron Colliders (LHC, FCC)

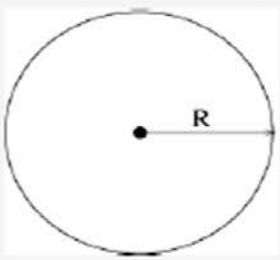
2nd ECFA HIGH LUMINOSITY LHC Experiments Workshop
Physics and technology developments
21st - 23rd OCTOBER 2014
Aix-les-Bains | France

Summary & conclusion

Christian Lippmann, 2nd ECFA High Luminosity LHC Experiments Workshop, Aix-les-bains, France, October 21-23 (2014)

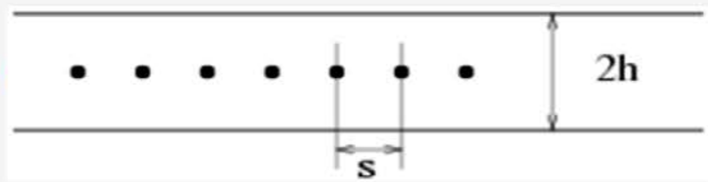
Geiger- Müller (1908), 1928
Drift Tube (1968)

1)



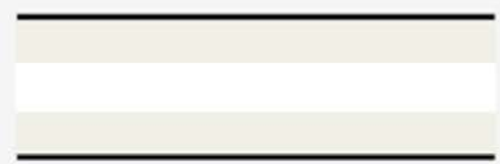
G. Charpak, 1968
Multi Wire Proportional Chamber

2)



R. Santonico, 1980
Resistive Plate Chamber

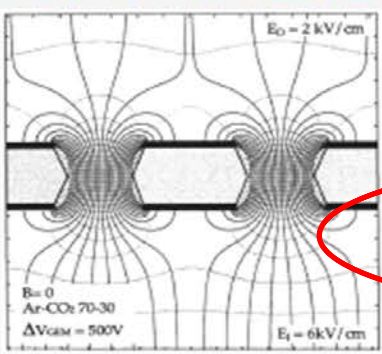
3)



… will at HL-LHC be joined by:

F. Sauli (1997)
Gas Electron Multiplier

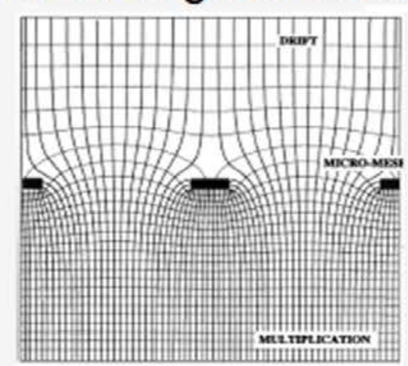
4)



1. **Upgrade without changing detectors**
   - ATLAS, CMS and LHCB: Largest part of the Muon systems
   - ALICE: Replace only electronics for TRD and Muon system
   - CMS: New electronics with better trigger capabilities for DT chambers
   - R&D: Run RPCs at lower gas gain with new low noise electronics
2. **Upgrade by scaling standard geometries**
   - ATLAS: sMDT (small Muon Drift Tubes) for BME (in LS1) and BIS (in LS2) regions
   - ATLAS: sTGCs (small-strip Thin Gap Chambers) for New Small Wheel
   - R&D: RPCs with thinner or lower resistivity electrodes
3. **Upgrade by introducing novel gas detectors** (Micro-Pattern Gas Detectors)
   - ATLAS: MicroMegas for New Small Wheel
   - ALICE (TPC), CMS (Forward Muon system) and LHCb (Muon system): GEMs

I. Giomataris et al. (1996)
Micro-mesh gaseous chamber

5)



C. Lippmann

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

GEM / Micromegas : Technology Developments Highlights

Development and optimization of large-area MPGDs for tracking and triggering

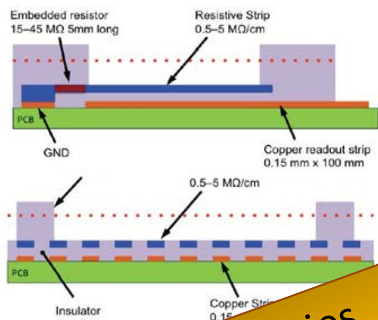
MM for the ATLAS Muon System Upgrade:

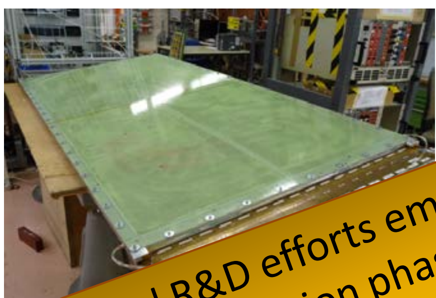
Standard Bulk MM suffers from limited efficiency at high rates due to discharges induced dead time

Solution: Resistive Micromegas technology:

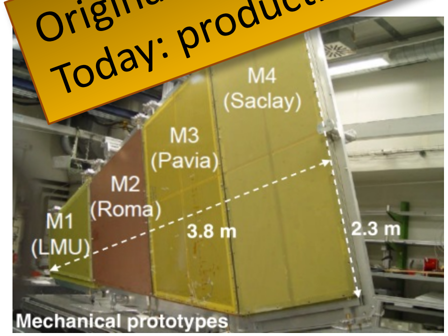
→ Add a layer of resistive strips above the readout strips

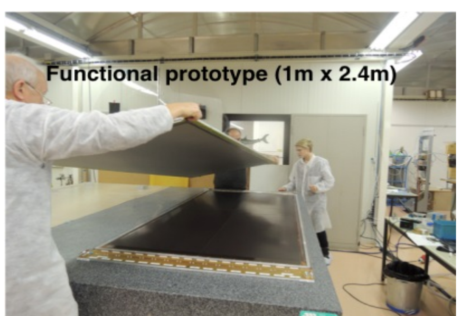
❖ Spark neutralization/ suppression (sparks still occur, but become inoffensive)





zed at CERN
RD51 lab



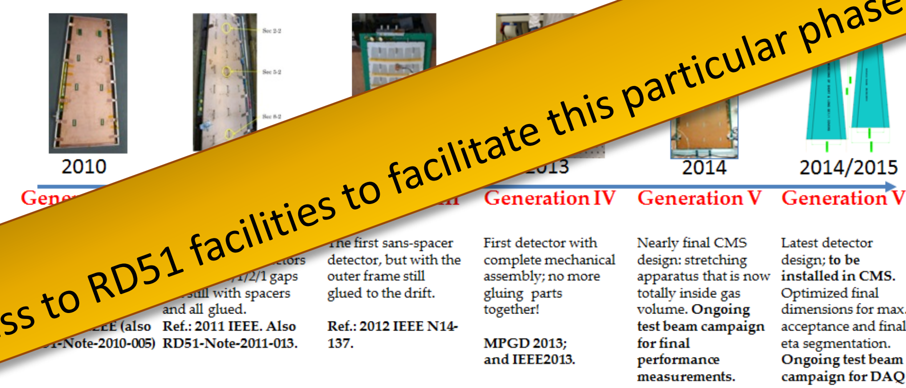


GEMs for the CMS Muon System Upgrade:

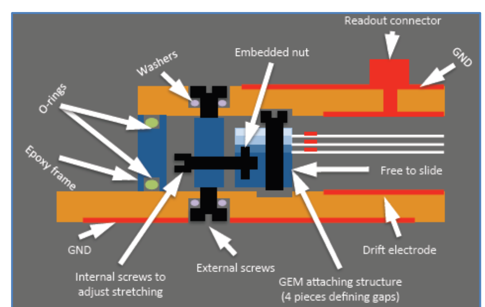
Single-mask GEM technology (instead of double-mask)

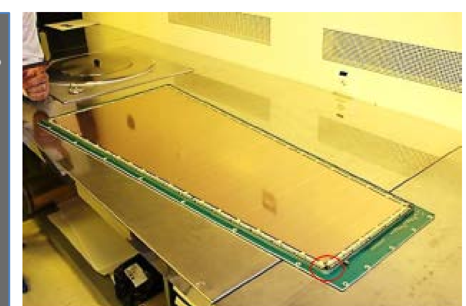
→ Reduces cost /allows production of large-area GEM

→ R&D: 6 generations of triple-GEM detecto



Assembly optimization: self-stretching technique: assembly time reduction from 3 days → 2 hours



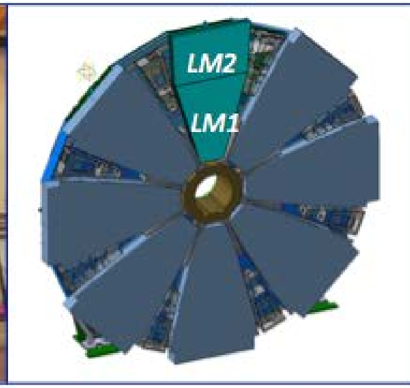


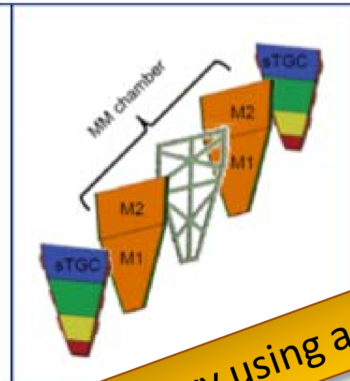
Original R&D efforts emerged from RD51 activities

Today: production phase under project control, access to RD51 facilities to facilitate this particular phase

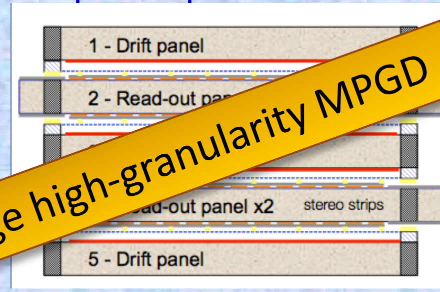
ATLAS Muon System: Small Wheel Upgrade with Micromegas

- Replacement of the present innermost endcap muon stations equipped with MDT and CSC in LS2 shutdown
- New Small Wheels (NSW): 16 layers per side, 128 Micromegas and 192 sTGC
  → reduction of fake muon trigger rate; improved rate capability for tracking
  → Combine precision and 2nd coordinate measurement & trigger functionality in a single device



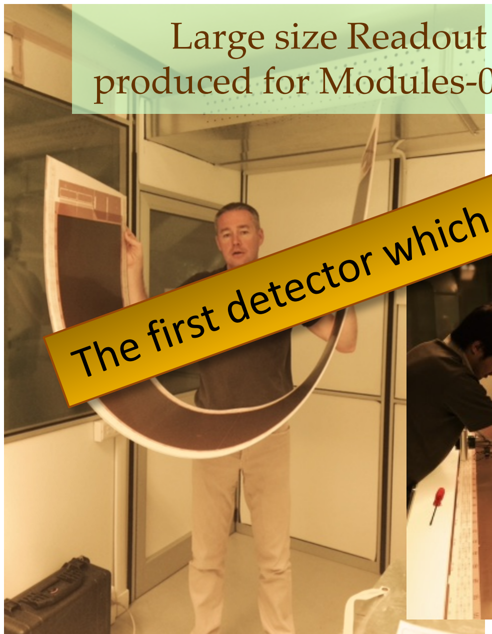


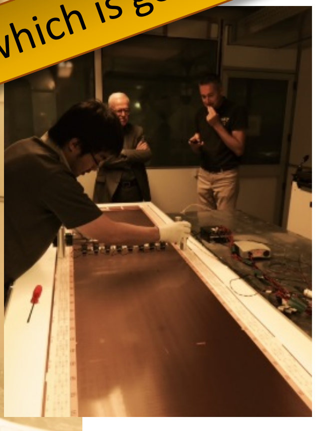
4 different types MM quadruplets 2-3 m^2



The first detector which is going to be mass-produced in industry using a large high-granularity MPGD

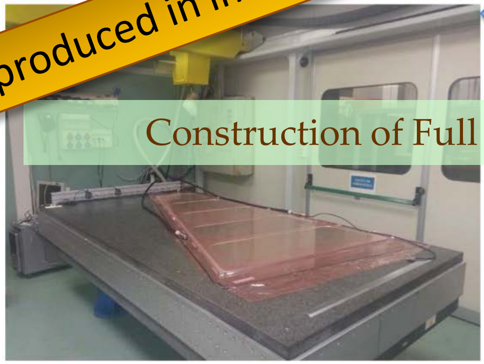
Large size Readout Boards produced for Modules-0 in industry

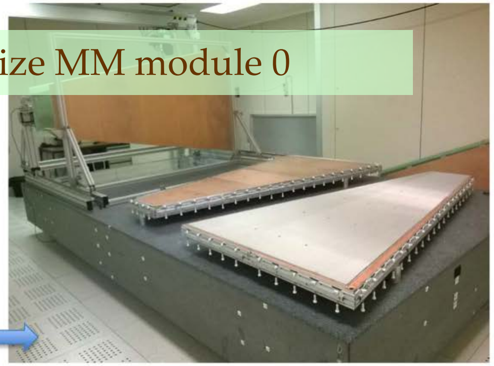




Rome 1 – drift panels, first module-0 panel produced

Construction of Full size MM module 0





Frascati – assembly of readout and drift panels into quadruplets

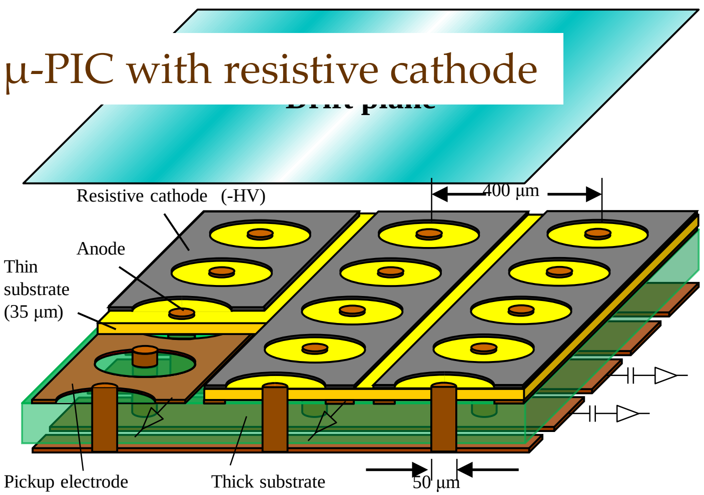
- Module-0 construction started in Germany as well, production site visit on Oct 17-19th
- First panels to be produced at CERN in the next weeks
- Saclay clean room for mass production: construction started, temporary facility for module-0 exists and currently being equipped
- Thessaloniki and Dubna will take over from CERN after module-0

S. Zimmermann

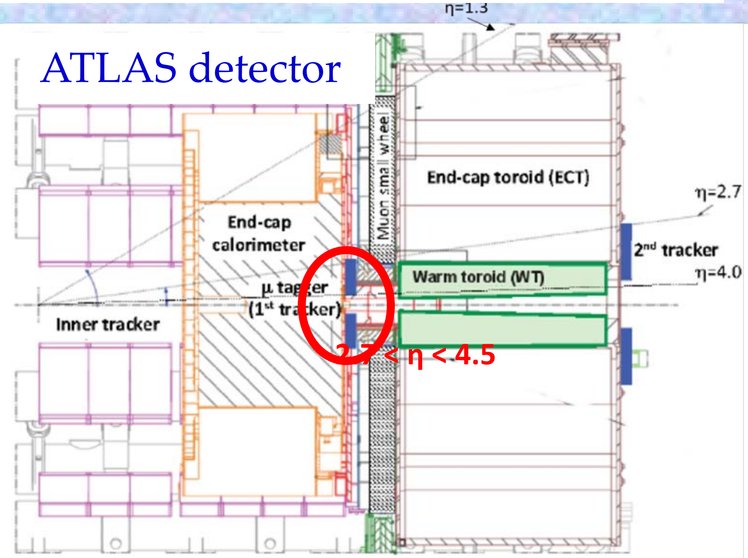
Micro-Pixel Chamber (μPIC) For ATLAS Muon HL-LHC Upgrade

- For ATLAS muon tagger (High eta muon detector)
  - Proposed for Phase II upgrade 2023~
  - Need high granularity ~ 0.1mm
  - BG rate > 100kHz/cm2 (HIP, gamma)
- Rate tolerant, Pixel type detector needed
- μ-PIC with resistive cathodes is proposed/studied

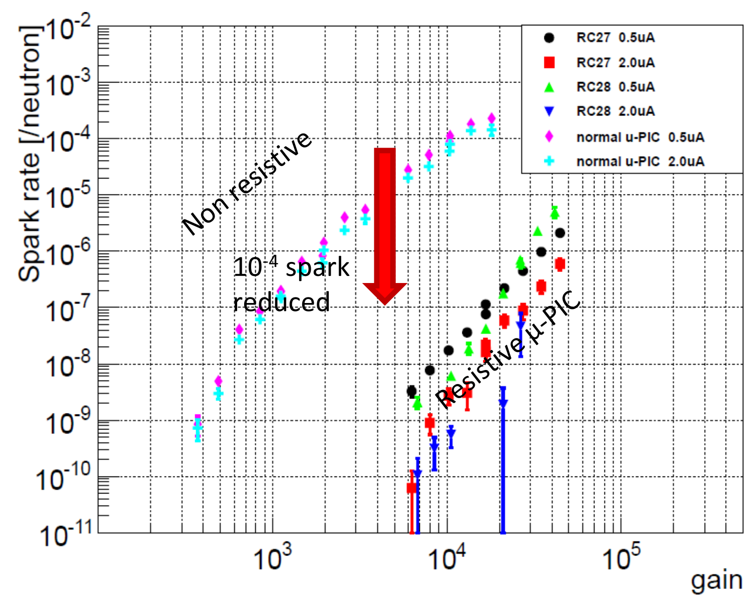
μ-PIC with resistive cathode



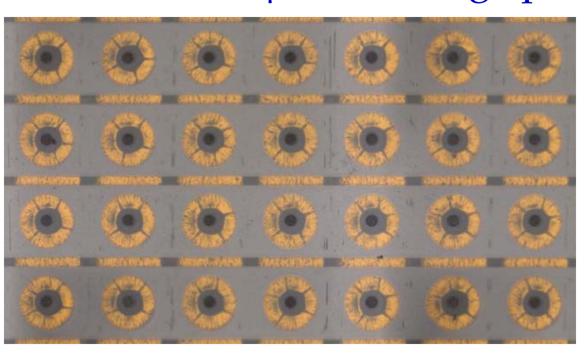
A. Ochi

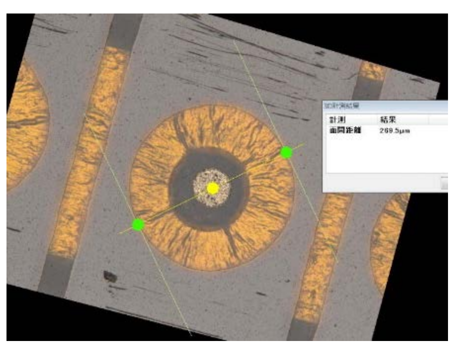


Spark rate reduction using resistive μ-PIC for fast neutron

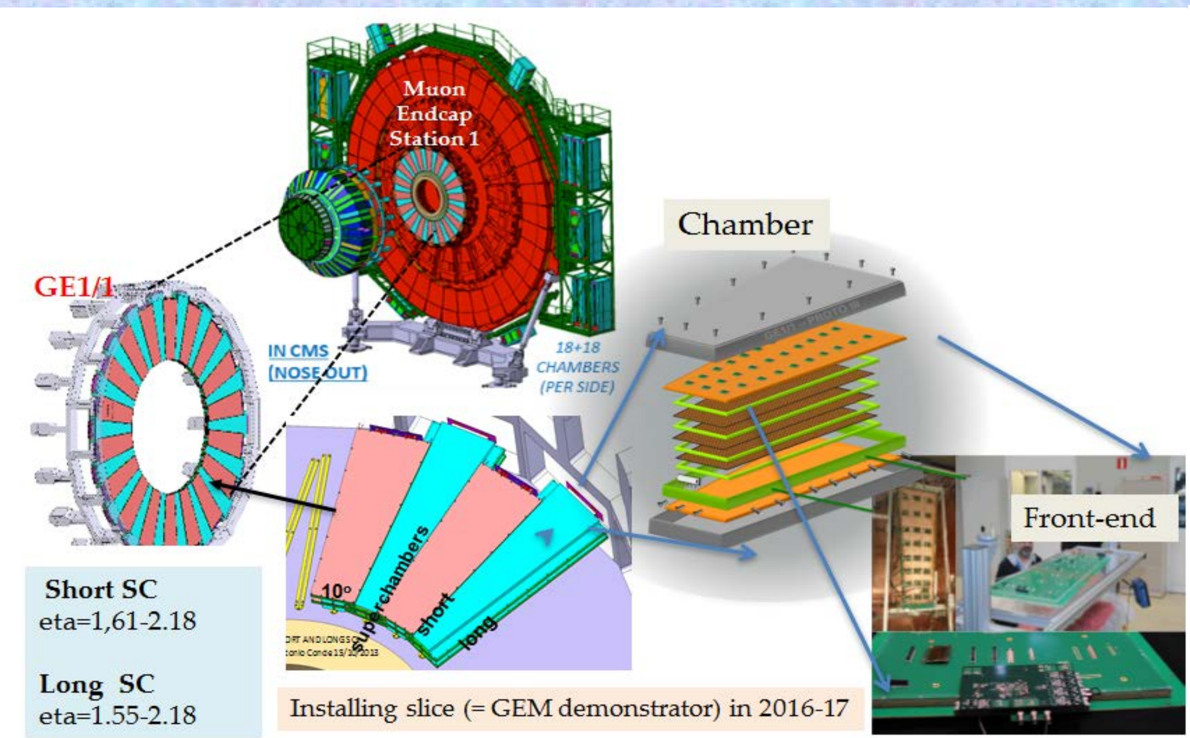


Resistive μ-PIC using sputtered carbon



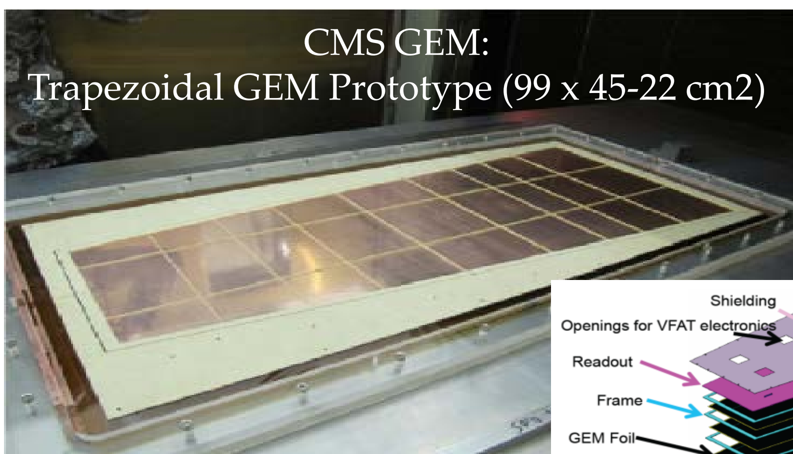


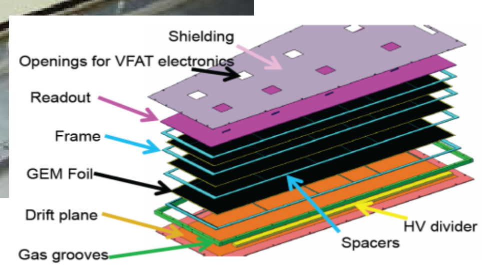
CMS Muon System: Muon Endcap GEM Upgrade (GE 1/1)

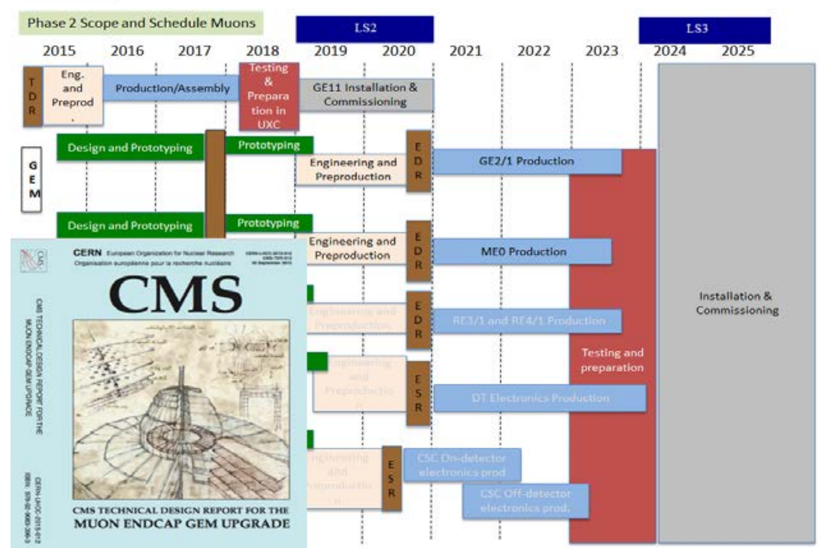


- Restore redundancy in muon system for robust tracking and triggering
- Ensure ~ 100% trigger efficiency in high PU environment in Run III
- **Install trapezoidal 3-GEM detectors in 1.5<|η|<2.2 endcap region:**
- 2 GEM chambers form a "**super chamber (SC)**";
- **144 total chambers** (36 super chambers in one station per endcap)

Approved by CERN LHCC:
TDR and Project Implementation Plan





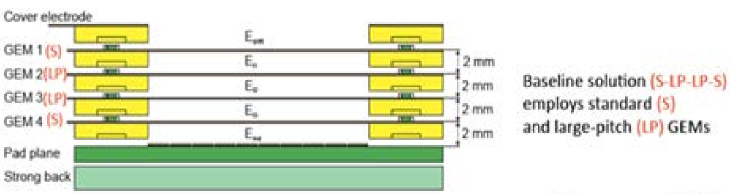


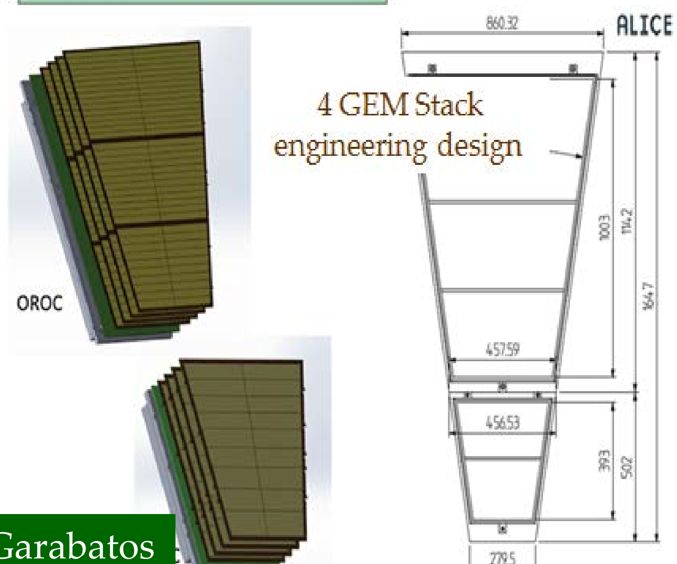
B. Dorney

ALICE Time Projection Chamber Endplate Upgrade with GEMs

ALICE TPC Upgrade → replace MWPC with 4-GEM (to limit space charge effects)

- Continuous TPC readout for 50 kHz Pb-Pb readout
- Maintain physics requirements:
  IBF < 1%, energy; σ(E)E < 12% achieved

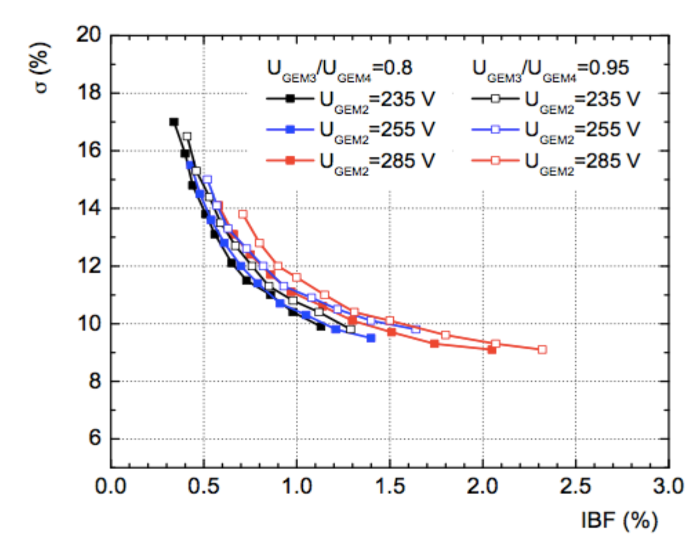




Preproduction:

Single-mask GEM allows for production of ~1 m foils

Ion Back Flow in a GEM system reduced from > 5 % (3 GEM) to < 1% (4 GEM)
→ discovered enhanced ion trapping at high rates

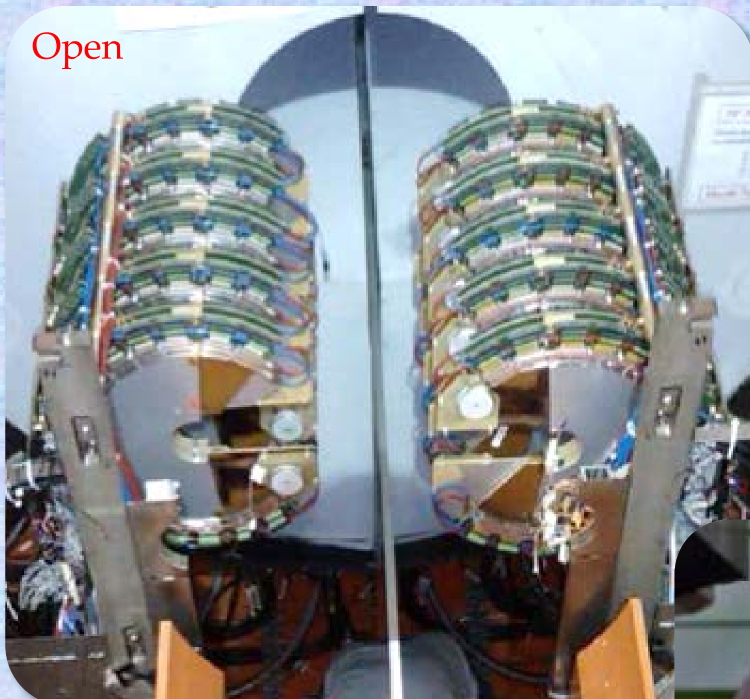


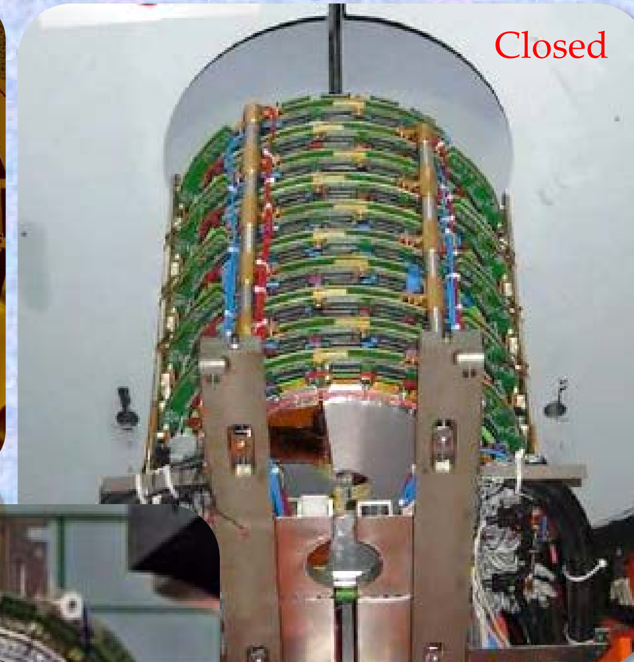
C. Garabatos

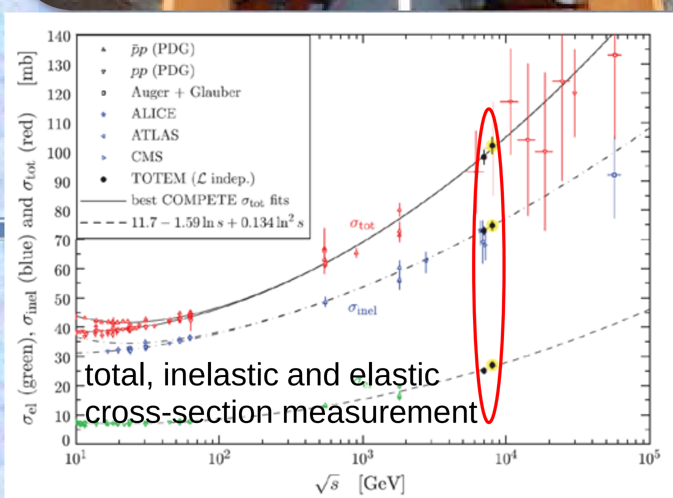
TOTEM GEM Tracker @ LHC

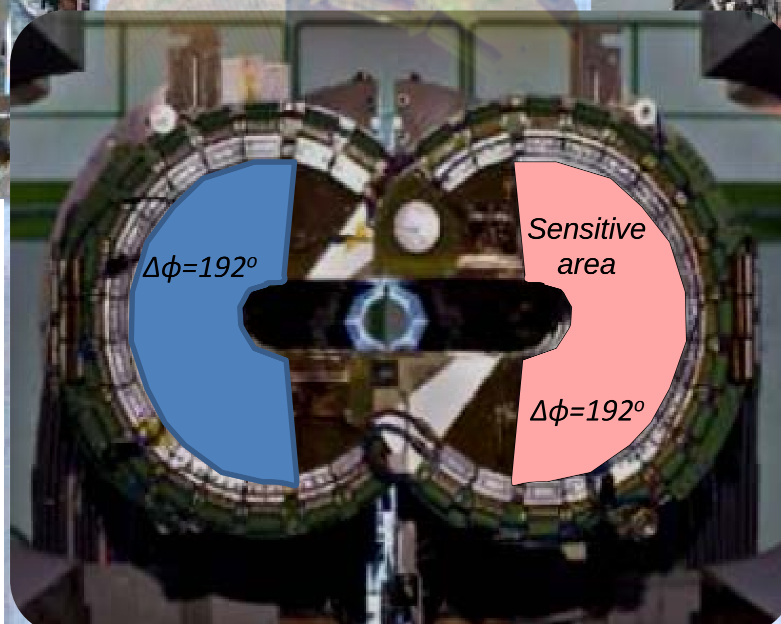
E. Oliveri

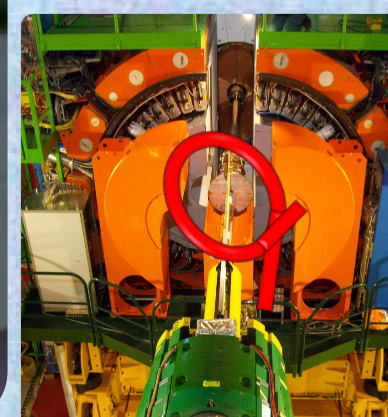
- Stable operation at very high rates up to 12 MHz/cm^2
- Achieved spatial (time) resolution: 135 μm (7 ns) at high intensity $2 * 10^8\ s^{-1}$



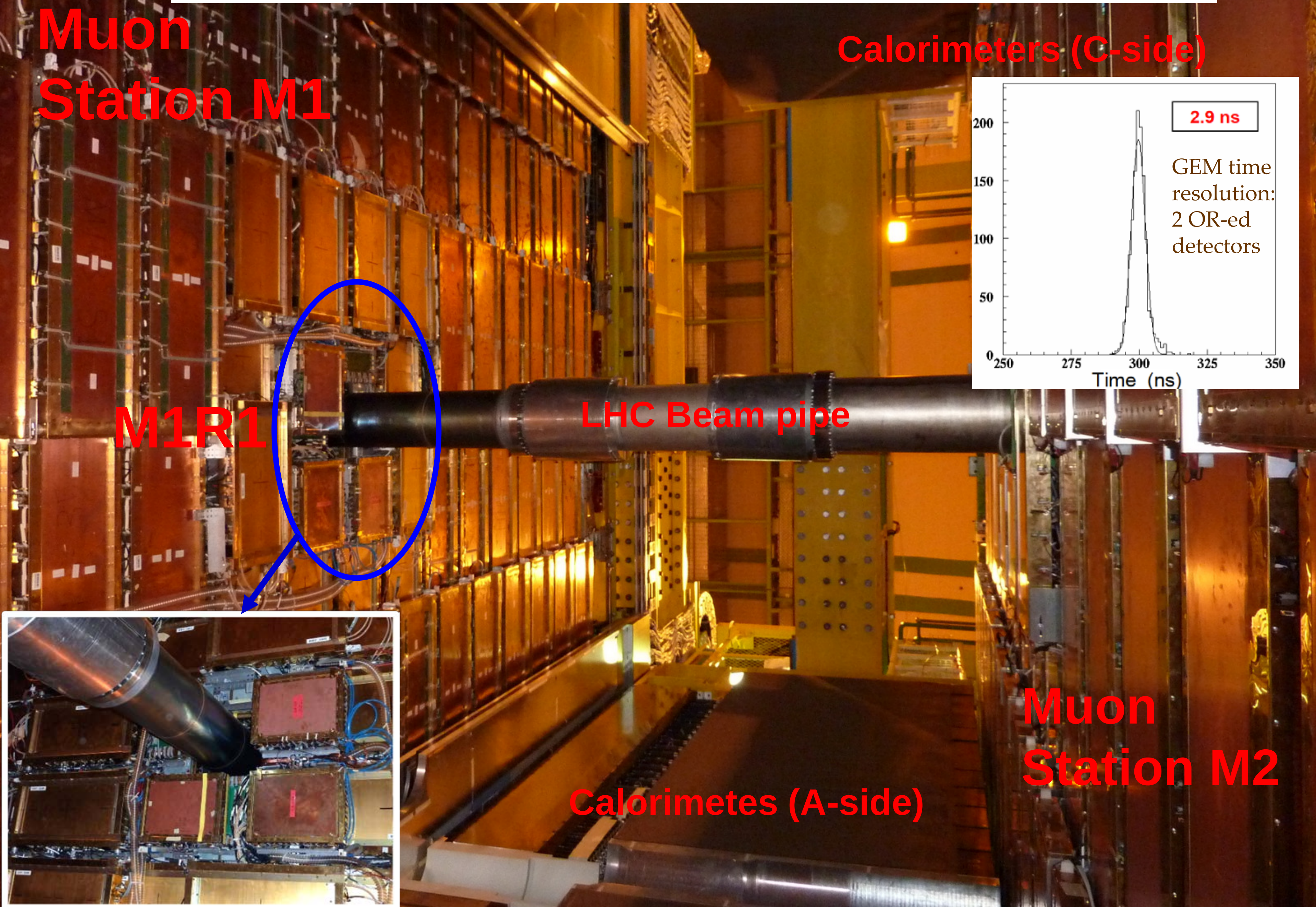








LHCb Muon System: GEM for M1R1 Central Region



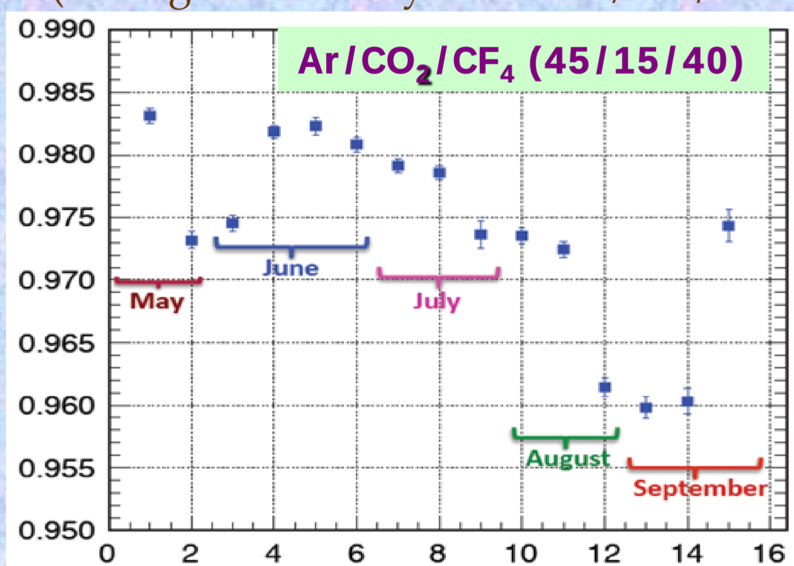
LHCb GEM Muon System Performance and Radiation Hardness

Integrated charges in 2012:

A18A2L: 18 mC/cm^2	A18A1L: 34 mC/cm^2	C18A1L: 31 mC/cm^2	C18A2L: 13 mC/cm^2
A18A2R: 12 mC/cm^2	A18A1R: 23 mC/cm^2	C18A1R: 17 mC/cm^2	C18A2R: 21 mC/cm^2
A17A2L: 50 mC/cm^2	Beam Pipe		C17A2L: 42 mC/cm^2
A17A2R: 59 mC/cm^2			C17A2R: 60 mC/cm^2
A16A2L: 35 mC/cm^2			C16A2L: n/a
A16A2R: 35 mC/cm^2			C16A2R: 35 mC/cm^2
A15A2L: 30 mC/cm^2	A15A1L: 33 mC/cm^2	C15A1L: 33 mC/cm^2	C15A2L: 34 mC/cm^2
A15A2R: 29 mC/cm^2	A15A1R: 36 mC/cm^2	C15A1R: 41 mC/cm^2	C15A2R: 18 mC/cm^2

Triple-GEM Efficiencies in 2012:

(average luminosity ~ 4 x 10^{32} /cm^2/s^{-1})



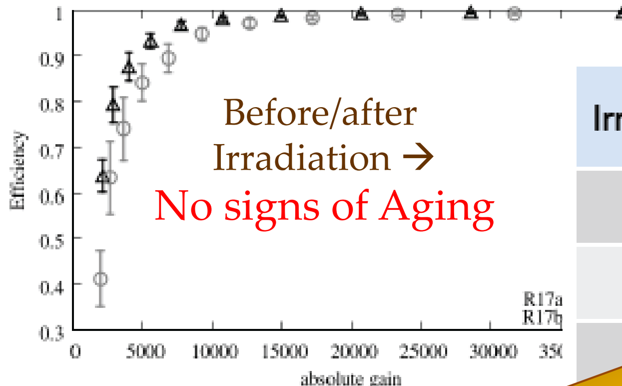
Integrated Luminosity 2012 ~1.5 /fb^{-1}:

- 120 mC/cm^2 total integrated charge (average) (2010 + 2011 + 2012 data taking periods)
- 60 mC/cm^2 in 2012 (max) - until Oct. 2012
- No indications of "classical" aging

G. Bencivenni, A. Cardini

MPGD Radiation Hardness Studies - Long Term Stability

ATLAS MM Aging Studies:
chambers exposed to different radiation "natures"



Before/after Irradiation →
No signs of Aging

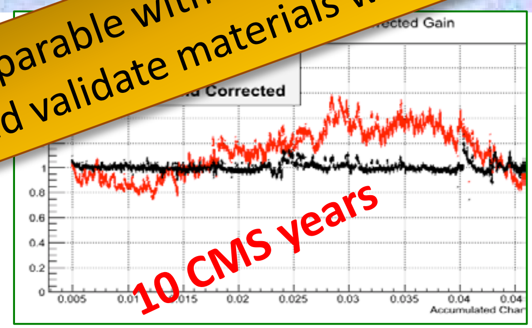
Irradiation with	Charge Deposit (mC/cm^2)
X-Ray	225
Neutron	[illegible]
[illegible]	[illegible]
[illegible]	2.4

F. Jeanneau

Radiation hardness of MPGDs is comparable with solid-state silicon sensors at the HL-LHC → still, it is important to develop and validate materials with resistance to ageing

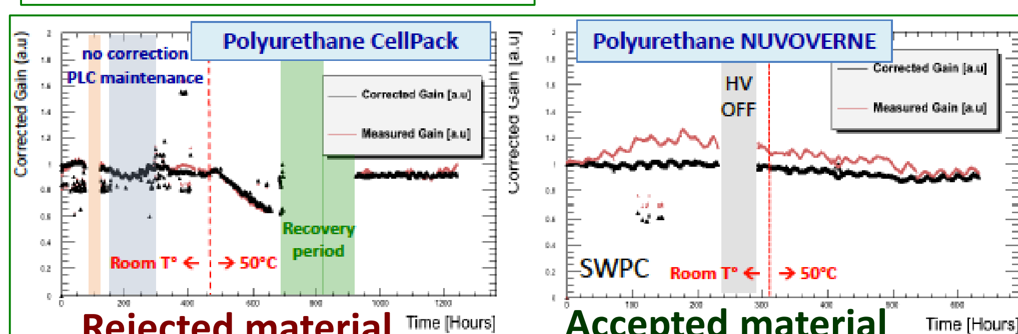
New Setup at CERN GIF++ (reach > 100 mC/cm^2)

J. Merlin



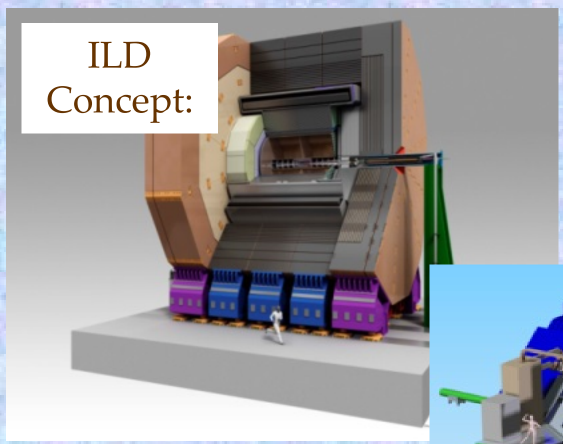
CMS Aging Studies at CERN GIF

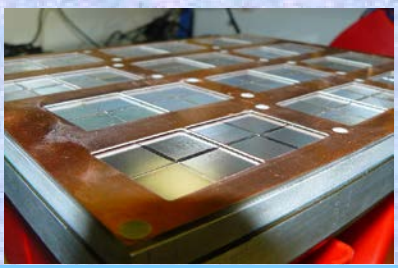
^{137}Cs source 566 GBq
Gamma emission 662 keV

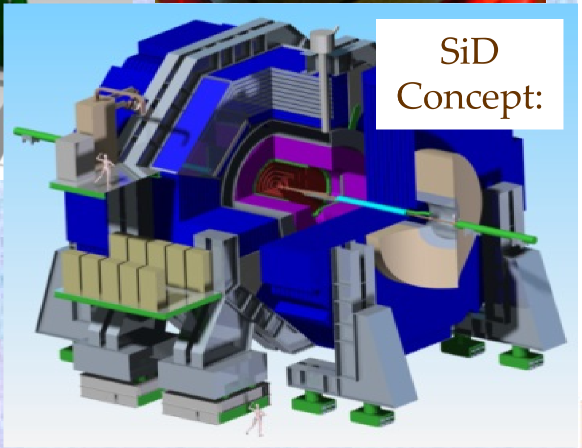


MPGD Technologies for the International Linear Collider

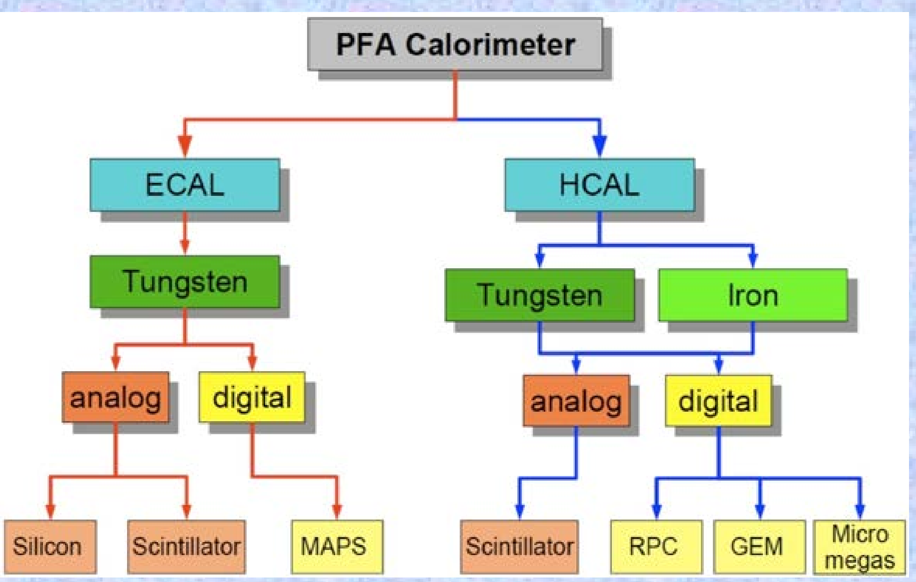
Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements/ Remarks
ILC Time Projection Chamber for ILD: Start: > 2030	High Energy Physics (tracking)	Micromegas GEM (pads) InGrid (pixels)	Total area: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



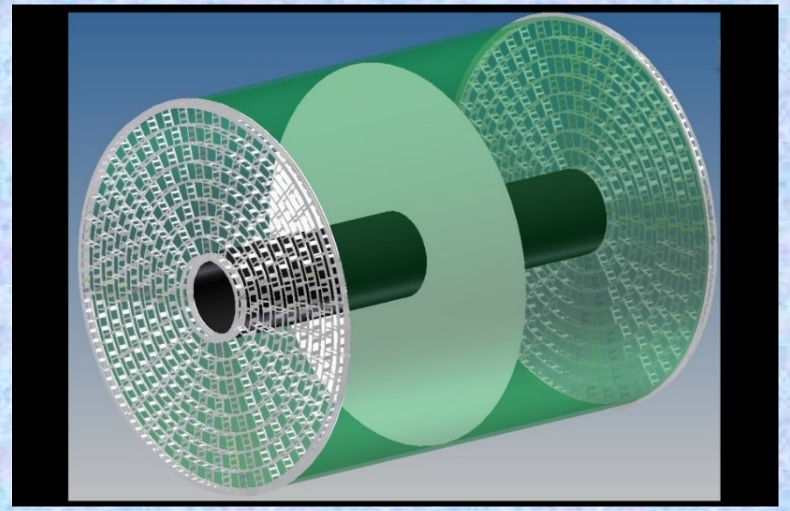




Particle Flow Calorimetry (ILD/SiD):

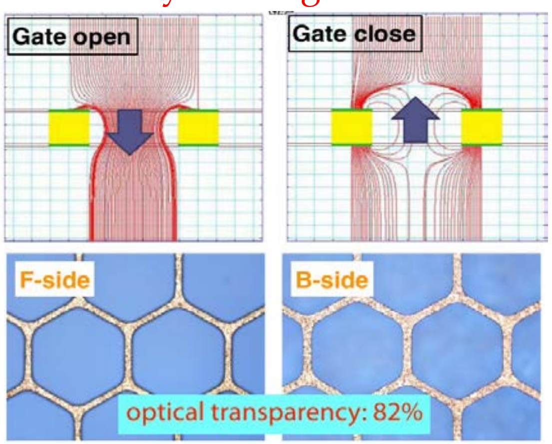


ILC Time Projection Chamber (TPC): MPGD-Based Readout



Primary ions create distortions in the electric field → O(10μm) track distortions

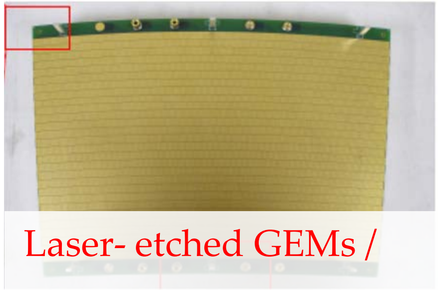
- Machine-induced bkg. and ions from gas amplification → track distortions 60 μm
  => Gating is needed
- Wire gate is an option
- Alternatively: GEM-gate



MPGDs are foreseen as TPC readout for ILC (endcap size~10 m^2):

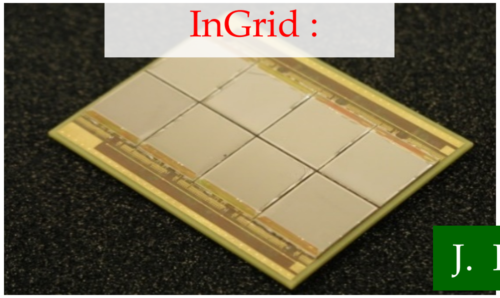
- Standard "pad readout" (1x 6 mm^2): 8 rows of det. modules (17×23 cm2); 240 modules per endcap
  - Wet-etched triple GEMs
  - Laser-etched double-GEMs 100μm thick ("Asian")
  - Resistive MM with dispersive anode
- "Pixel readout" (55x 55μm^2): ~100-120 chips per module → 25000-30000 per endcap
  - GEM + pixel readout
  - InGrid (integrated Micromegas grid with pixel readout)

Resistive MM /

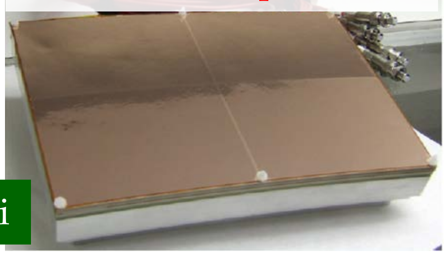


Laser- etched GEMs /

InGrid :



Wet-etched triple GEM:



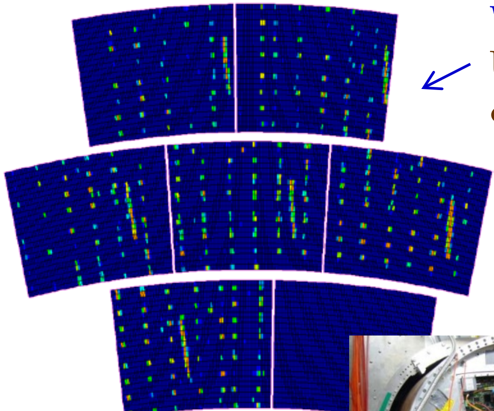
J. Kaminski

ILC Time Projection Chamber (TPC): Pad-Based Readout

Efforts to improve the modules design for MM/GEM technologies. Several test beams campaigns:

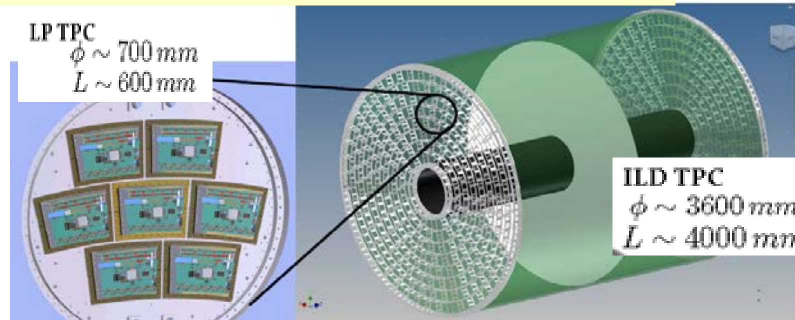
- 7 Micromegas modules with 2-phase C02 cooling

With beam and laser dots:
UV laser gererates MIP tracks & illuminate calibration spots

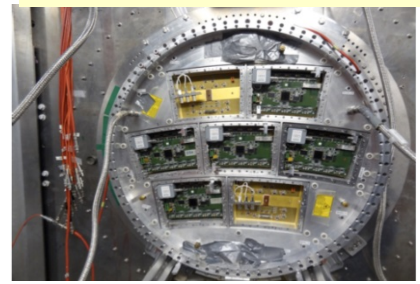


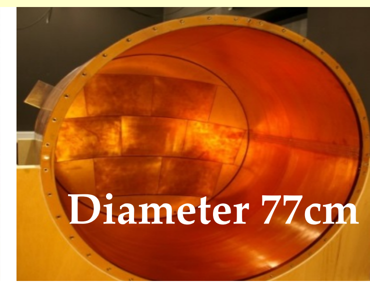
2P CO2 Cooling

J. Kaminski, P. Colas

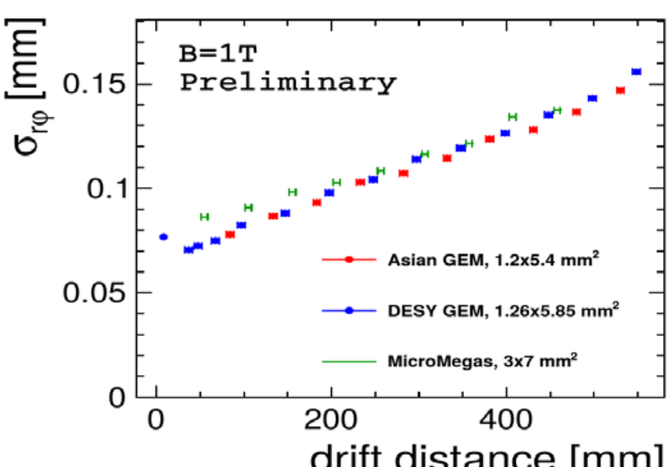


Large TPC Prototype with versatile endplate @ DESY



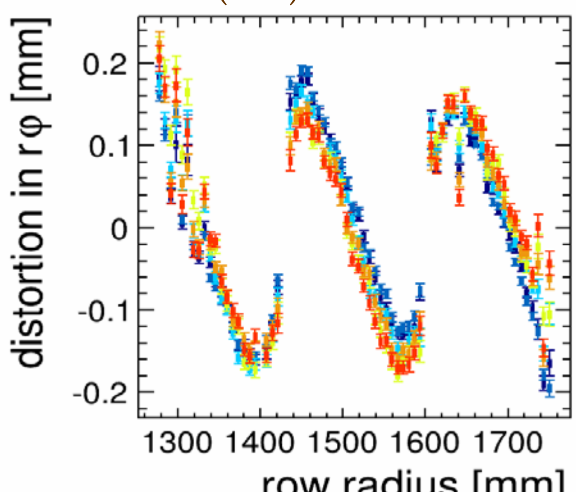


Transverse spatial resolution:

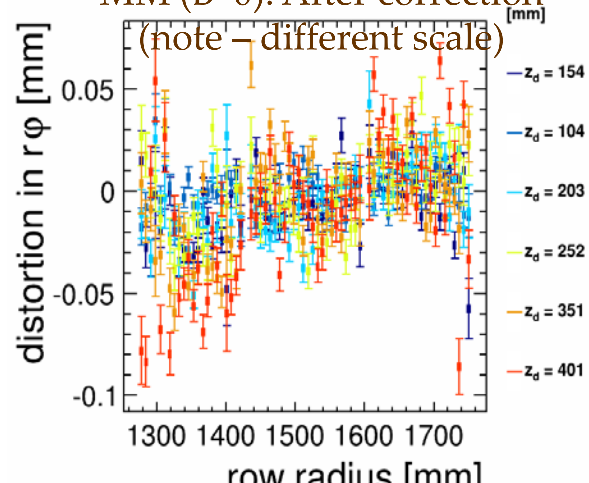


Alignment and distortion corrections:

MM (B=0): Before correction



MM (B=0): After correction (note – different scale)

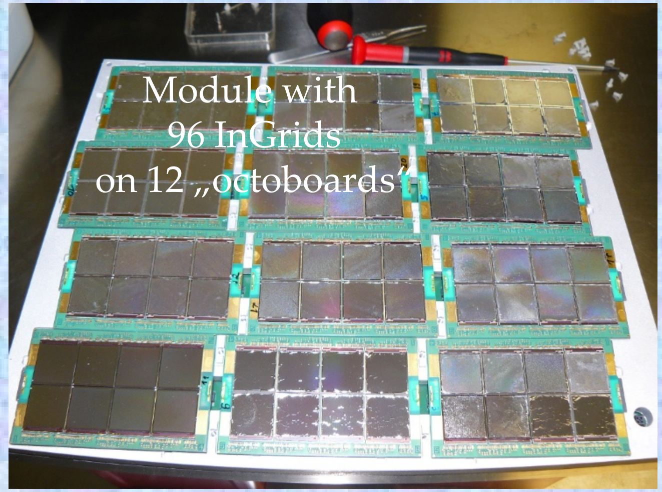


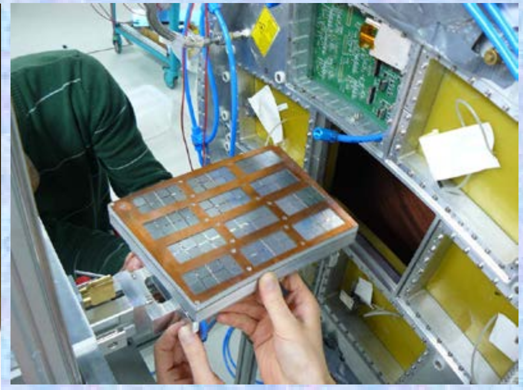
ILC Time Projection Chamber (TPC): Pixel-Based Readout

BREAKTHROUGH: feasibility shown in test-beam with 160 InGrids detectors

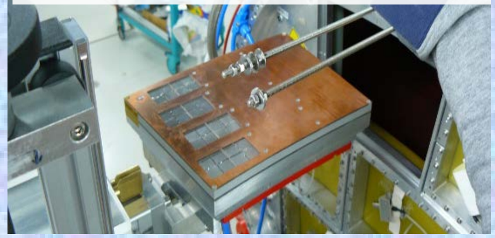
3 modules for LCTPC large prototype : 1 x 96 InGrid, 2 x 24 InGrids
320 cm² active area, 10,5 mio. channels, new readout system-
Readout 5 SRS FECs

By design:
- Single electron detection
- Time-of-arrival measurement
- High granularity; Uniform gas gain

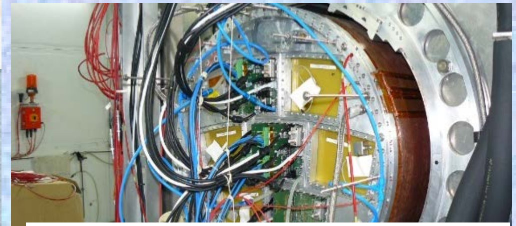




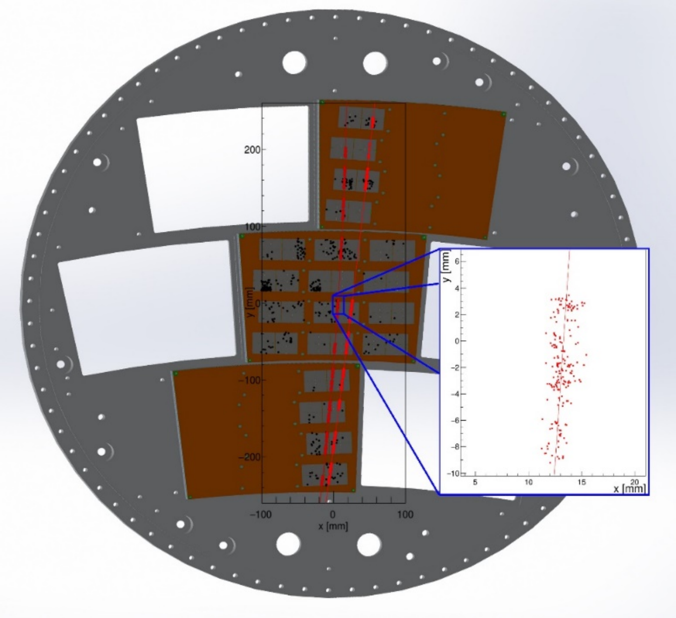
M. Lupberger



24 InGrid installation in LP



LP endplate with 3 modules



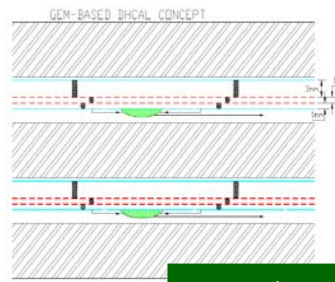
50 cm track length with about 3000 hits
→ each representing an electron from the primary ionisation.
→ demanding for track reconstruction, especially in case of curved tracks

- Physics properties of the TPC
→ field distortions; reliability
→ dE/dx resolution;delta identification
→ single point resolution
→ momentum measurement
→ Track angular effect

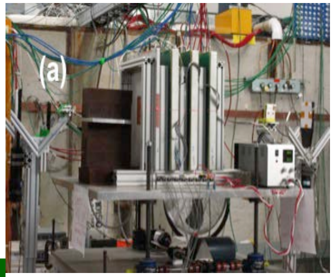
ILC DHCAL Particle Flow Calorimetry: GEM/ THGEM / RPWELL

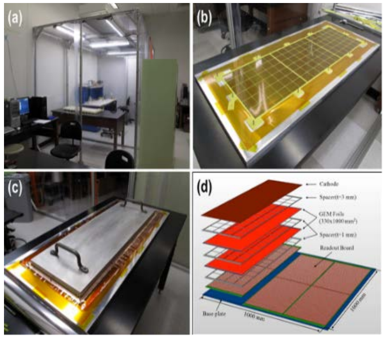
GEM for DHCAL:

- Series of double GEM chambers built
- Large scale (1m x 33cm) layers under construction (subject to funding)



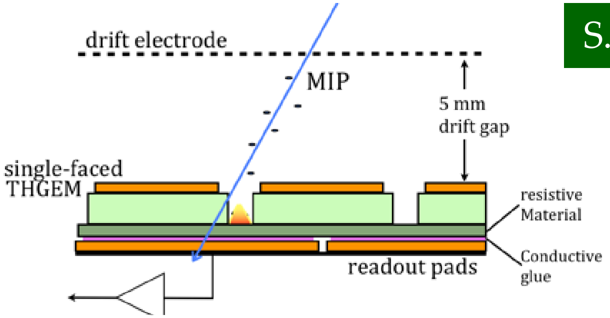
A. White





RPWELL for DHCAL: A Novel Architecture supported by the RD51 Common fund

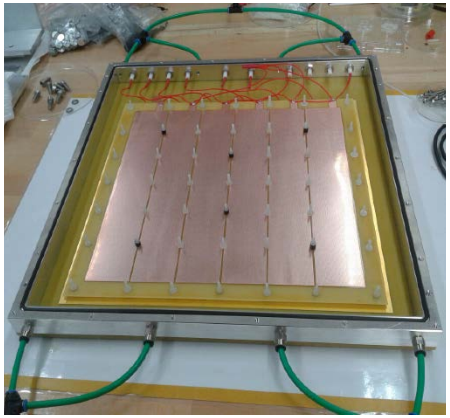
S. Bressler

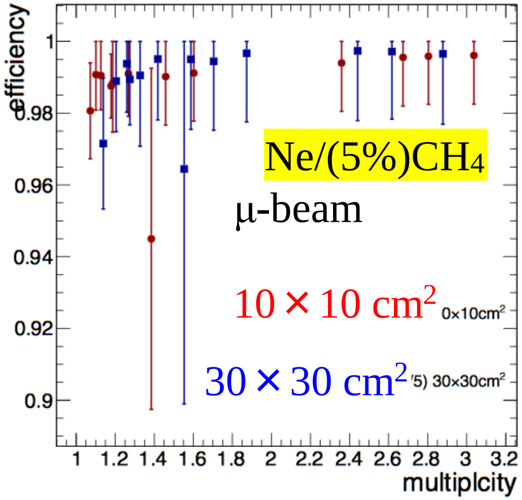


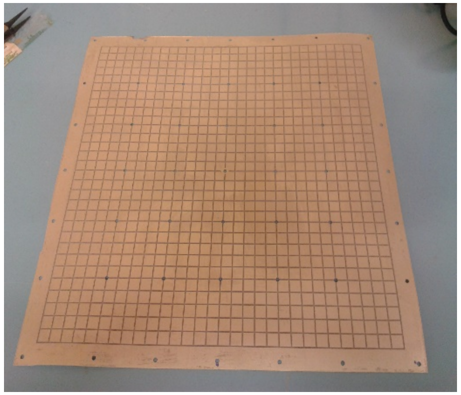
Common features with GEM/MM:

- ❑ from GEM it takes the amplifying scheme with the peculiarity of a *"well defined amplifying gap"* → ensuring very high gain uniformity.
- ❑ from Micromegas it takes the resistive readout scheme → strong suppression of the discharges.

Small ($10x10\ cm^2$) & medium ($30x30cm^2$) prototypes:







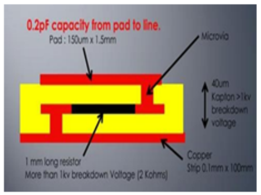
THGEM-based RPWELL:

- Robust again discharges
- Stiff support structure
- Potential to be extended to very large areas

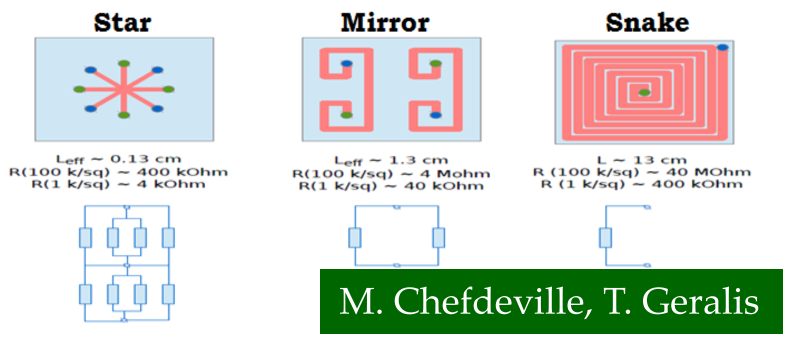
ILC DHCAL Particle Flow Calorimetry: Resistive Micromegas

Optimisation:
→ reduce resistivity and evacuation time but still suppress sparking

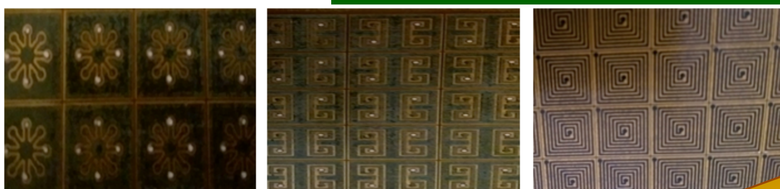
– "Vertical" evacuation of charge using buried resistors, proposed by Rui de Oliveira



– Ongoing program: Vary the RC, measure the linearity (rate & dE/dx scans), check sparking



M. Chefdeville, T. Geralis

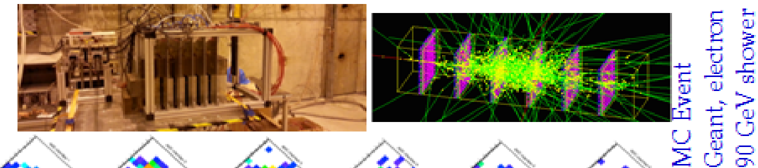


Real R1 values: 400 -750 KOhms with 100KΩ/Sq

Real R1 values: 4 MOhms with 100KΩ/Sq

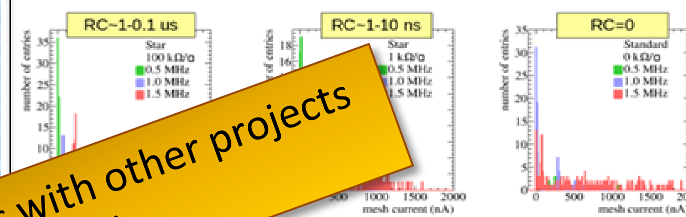
Real R1 valu[…] 40 M[…]

July 2015: Testbeam at SPS: μ, π and e beams



Event display: SPS event, electron 90 GeV shower

Monitor currents at electron shower maximum



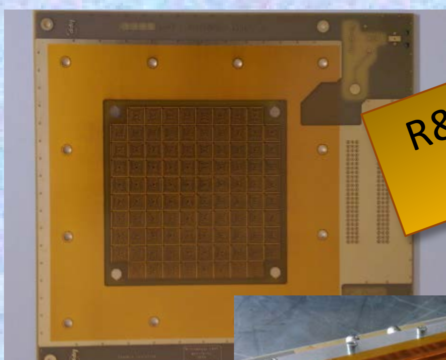
[…]mesh current

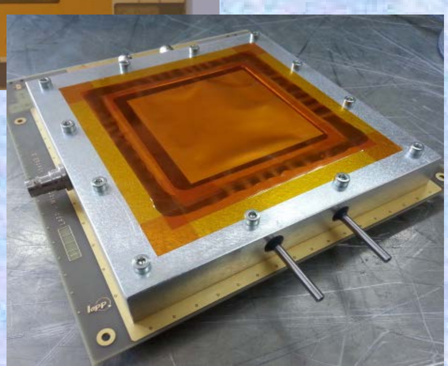
Lowest RC: behaves like Non-resistive

Non-resistive

12/10/2015

R&D oriented towards ILC, but synergies with other projects (e.g. CMS ECAL endcap upgrade)





PCB with pads & resistive pattern

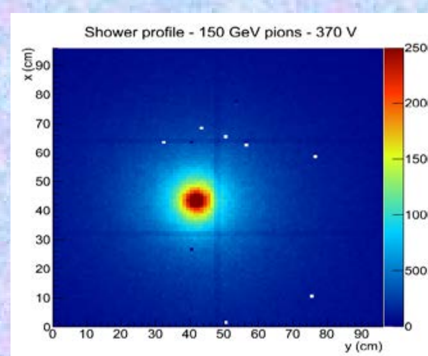
Use[…] HL-LHC:

[…]gh rates

[…] discharges, preserve linearity

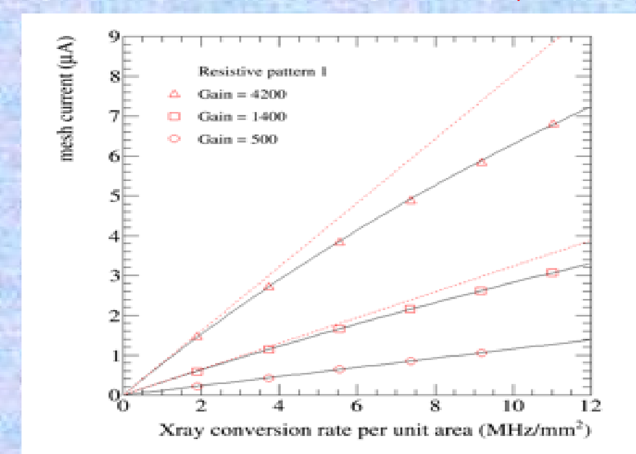
[…]gh granularity for PF calorimetry, Small pads ~1x1 cm^2,

- Large dynamic range (1 – 100s of MIPs)



Tests with X-rays, Cu 8 keV, at high rates: (intermediate RC, Gain=4000):

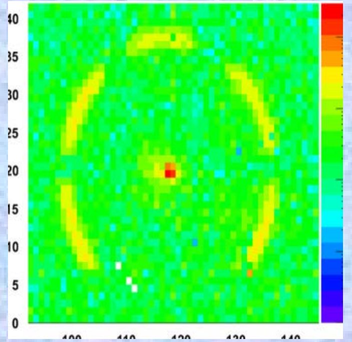
- Excellent linearity up to 1 MHz/mm^2
- 25% lower Gain at 10 MHz/mm^2



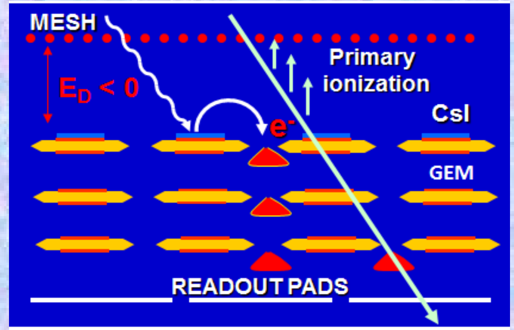
...If you are not sleeping yet ...

MPGD Technologies for Photon Detection

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements / Remarks
COMPASS RICH UPGRADE Start > 2016	Hadron Physics (RICH - detection of single VUV photons)	Hybrid (THGEM + CsI and MM)	Total area: ~ 1.4 m^2 Single unit detect: ~ 0.6 x 0.6 m^2	**Max.rate**:100 Hz/cm^2 **Spatial res.:** <~ 2.5 mm **Time res.:** ~ 10 ns	Production of large area THGEM of sufficient quality
PHENIX HBD Run: 2009-2010	Nuclear Physics (RICH – e/h separation)	GEM+CsI detectors	Total area: ~ 1.2 m^2 Single unit detect: ~ 0.3 x 0.3 m^2	**Max. rate**: low **Spatial res.:** ~ 5 mm ($r\phi$) **Single el. eff.:** ~ 90 %	Single el. eff. depends from hadron rejection factor
SPHENIX Run: 2021-2023	Heavy Ions Physics (tracking)	TPC w/GEM readout	Total area: ~ 3 m^2	**Multiplicity**: dNch/dy ~ 600 **Spatial res.:** ~ 100 um ($r\phi$)	Runs with Heavy Ions and comparison to pp operation
Electron-Ion Collider (EIC) Start: > 2025	Hadron Physics (tracking, RICH)	TPC w/GEM readout Large area GEM planar tracking detectors RICH with GEM readout	Total area: ~ 3 m^2 Total area: ~ 25 m^2 Total area: ~ 10 m^2	**Spatial res.:** ~ 100 um ($r\phi$) Luminosity (e-p): 10^{33} **Spatial res.:** ~ 50- 100 um **Max. rate**: ~ MHz/cm^2 **Spatial res.:** ~ few mm	Low material budget Low material budget High single electron efficiency



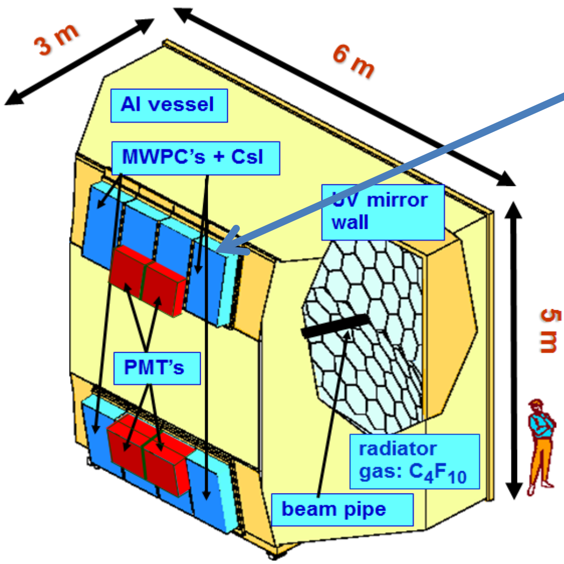
ALICE VHPID THGEM



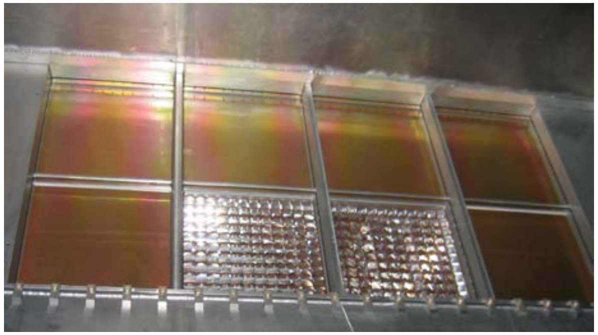
HBD Concept:

COMPASS RICH I Upgrade for 2016 Run II

❖ COMPASS RICH I: 8 MWPC with CsI (RD26 @ CERN) since 2000

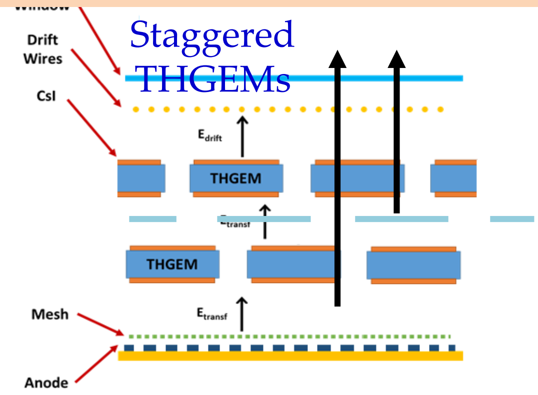


MWPC's + CsI



F. Tessarotto

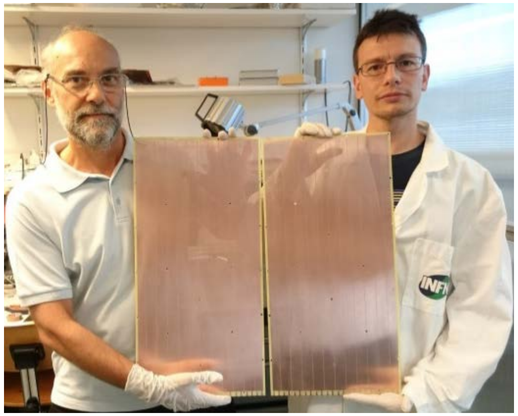
Hybrid: THGEM+ CsI and MM



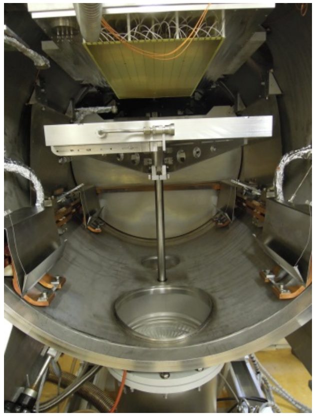
mass production ongoing

After a long-term fight for increasing electrical stability at high rates: MWPC robust operation is not possible at gain~10^5 because of photon feedback, space charge & sparks

PMTs not adequate → only small demagnification factor allowed; 5 m^2 of PMTs not affordable.

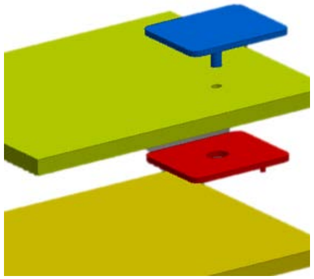


300 x 600 mm2 THGEMs

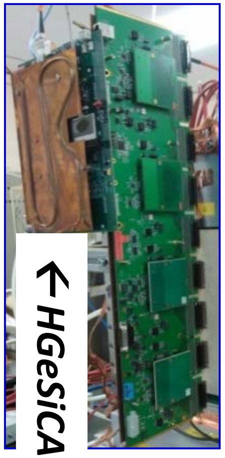


CsI deposit

Bulk Micromegas



Pad anode with capacitive coupling pad readout



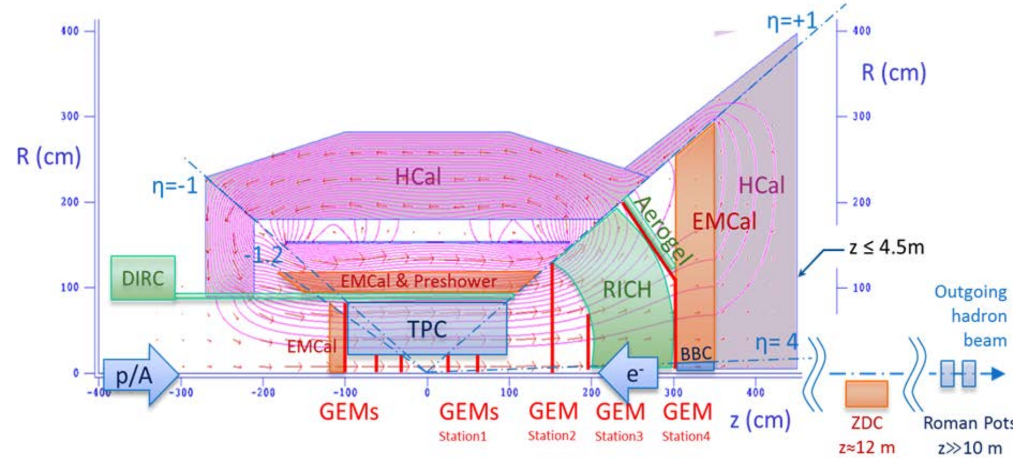
← HGeSiCA

APV25

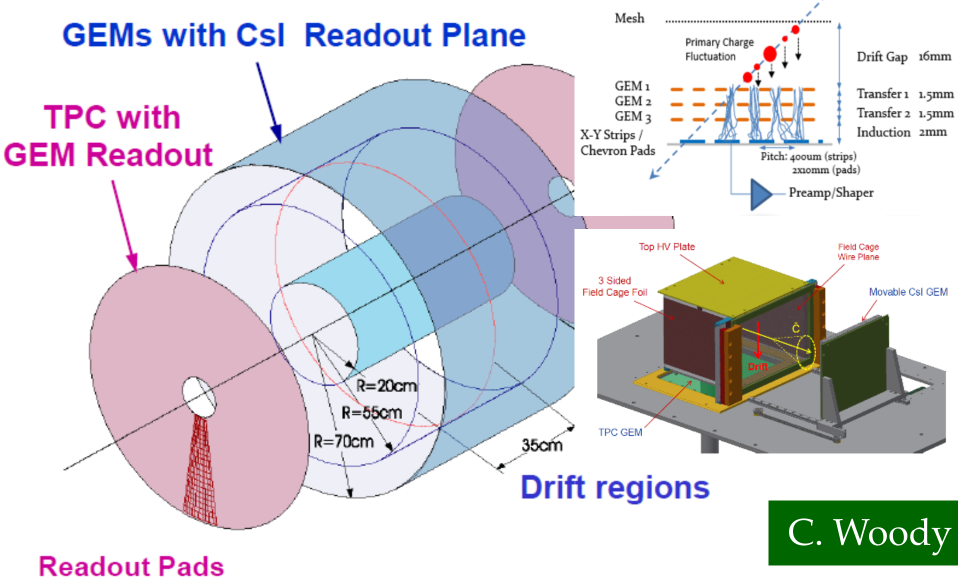
GEM Tracking for PHENIX Upgrade and Electron-Ion Collider

sPHENIX → eRHIC Detector

- $-1<\eta<+1$ (barrel) : sPHENIX + Compact-TPC + DIRC
- $-4<\eta<-1$ (e-going) : EM calorimeter + GEM trackers
- $+1<\eta<+4$ (h-going) :
  - $1<\eta<4$: GEM tracker + Gas RICH



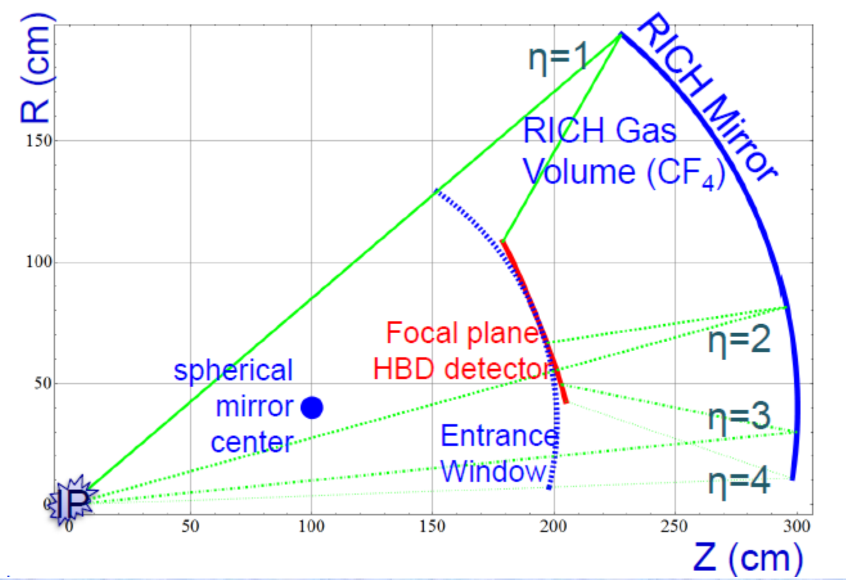
Developing short drift mini-TPC with GEMs
(to improve resolution at larger angles)
with Cherenkov Particle ID (use Cherenkov light produced in the *same* gas volume to identify electrons)

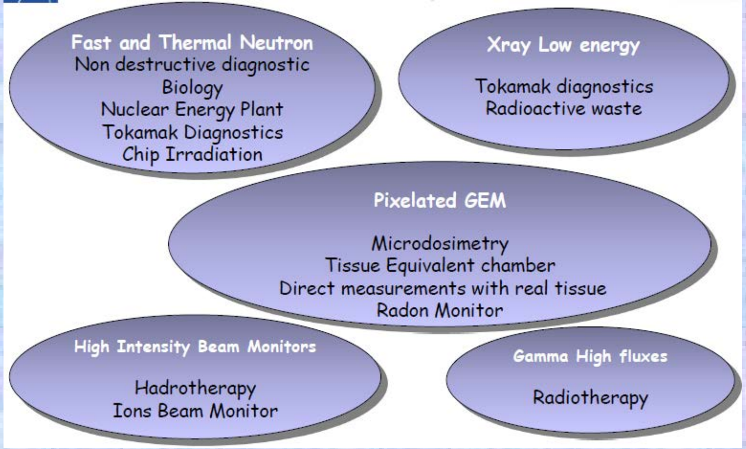


C. Woody

Focusing RICH for EIC:

→ Developing a Ring Imaging version of the HBD using dual radiators for particle ID





MPGD-based Neutron Detectors

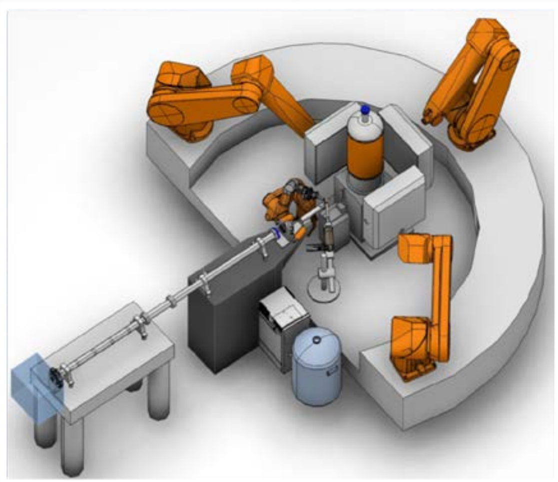
MPGD coupled to n-converters:

- ITER / Spallation Sources
- Neutron-beam diagnostics

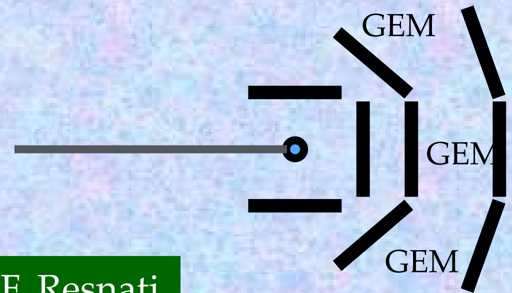
Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size)	Operation Characteristics / Performance	Special Requirements / Remarks
ESS NMX: Neutron Macromolecular Crystallography Start: > 2020(for 10 y.)	Neutron scattering Macromolecular Crystallography	GEM w/ Gd converter	Total area: ~ 1 m^2 Single unit detect: 60x60 cm^2	**Max.rate**: 100 kHz/mm^2 **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 m^2 Single unit detect: 33x40 cm^2 trapezoid	**Max.rate**: 40 kHz/mm^2 **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 cm^2	**Max.rate**: 100 kHz/mm^2 **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: ~ 100cm^2	**Max.rate**:10 kHz **Spatial res.:** .: ~300μm **Time res.:** ~ 5 ns **Rad. Hard.:** no	

GEM-TPC for Neutron Macromolecular Crystallography (NMX) @ ESS

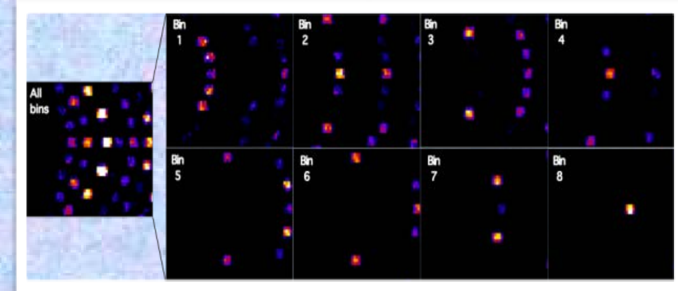
NMX Spectrometer::



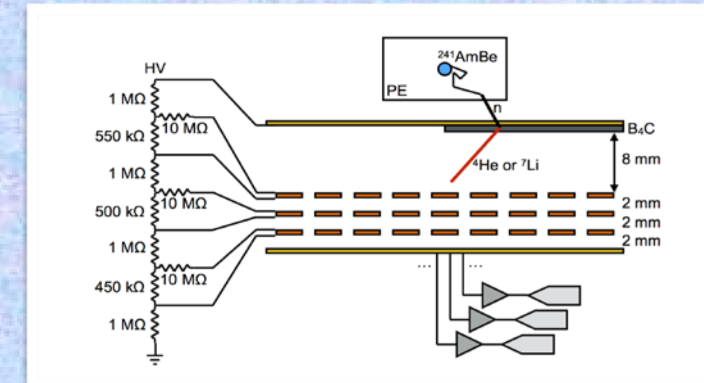
Time binned diffraction pattern (simulation) from a 5mm crystal of perdeuterated rubredoxin at 20cm from the detector (45°)



F. Resnati

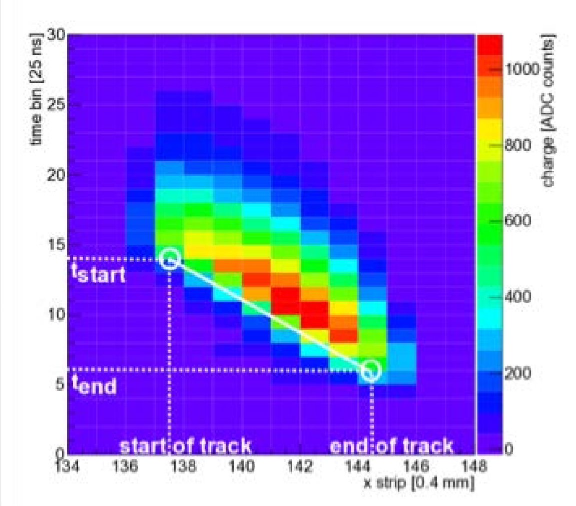


B(Gd)-GEM & uTPC concept

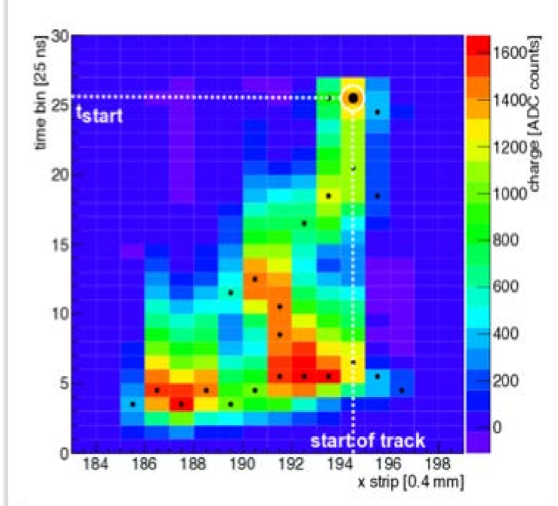


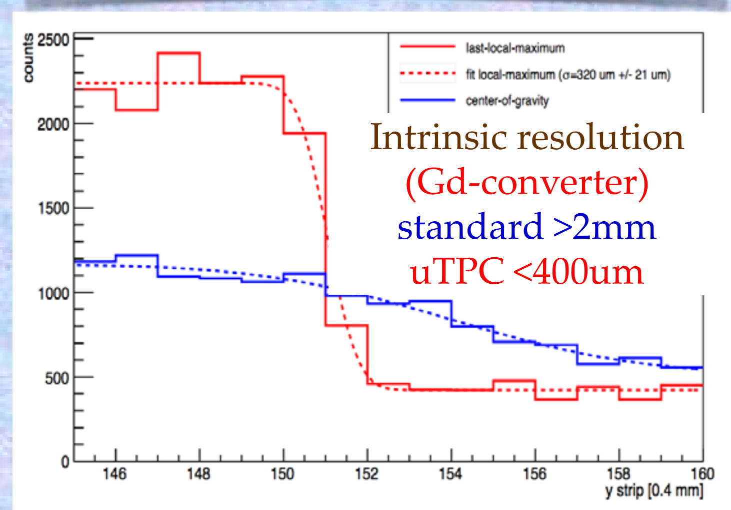
B(Ge)-GEM & uTPC results:

Straight track of alfa from ^{10}B conversion

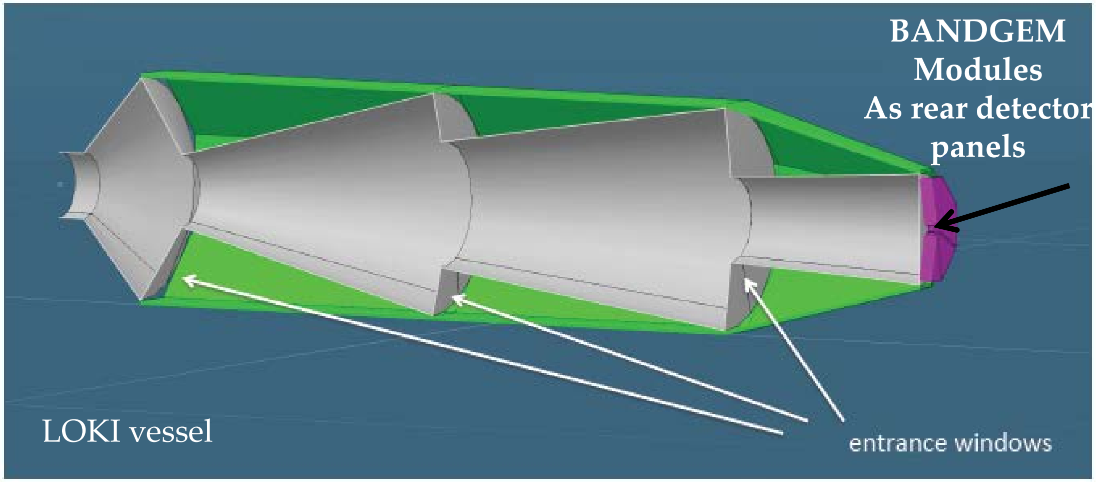


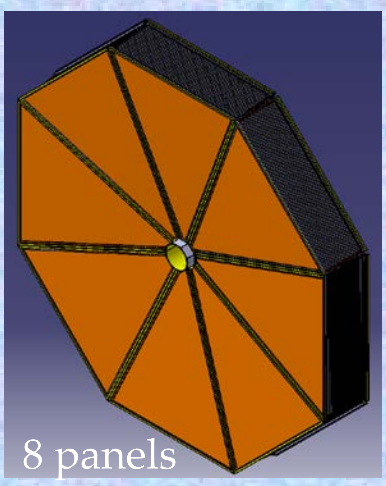
Curly track of electron from Gd conversion

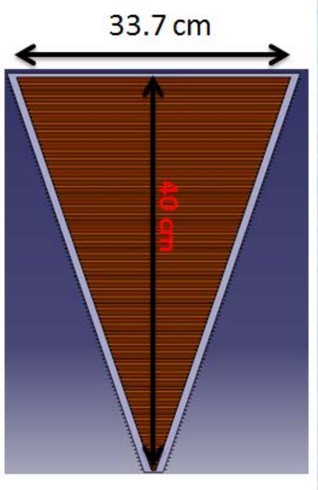




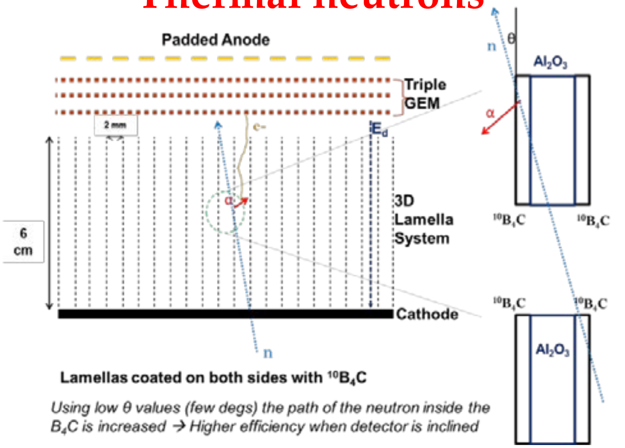
GEM for General Purpose LOKI-SANS Instrument @ ESS

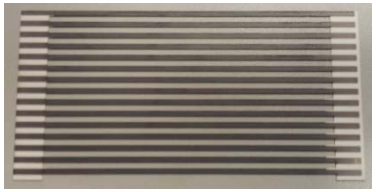


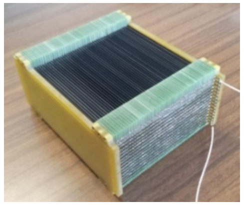




Triple GEM + 3D borated cathode
Thermal neutrons

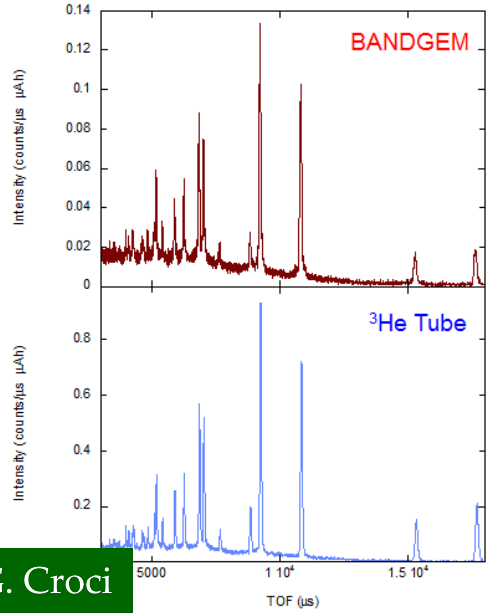




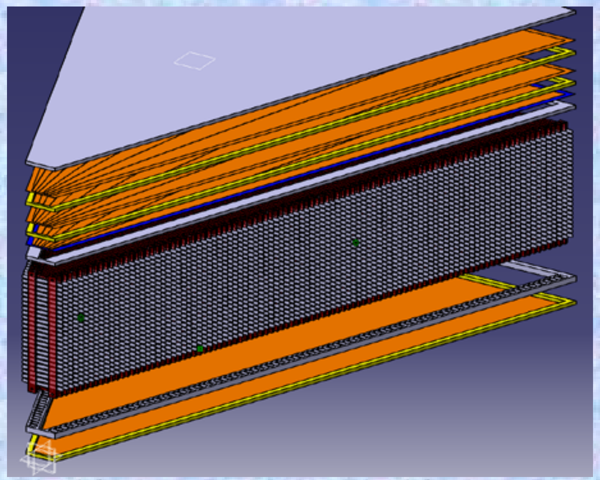


1[st] prototype

Diffraction measurement from a bronze sample
Same Measurement Time



G. Croci



Requirements for rear detector panel

- Rate Capability = 40 kHz/cm^2
- Time resolution bettter than 100 µs
- Efficiency of about 60% at 4 Å
- X-Y Space resolution of about 4 mm

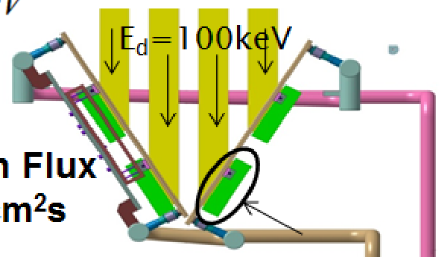
Fast Neutron Beam Monitors for ITER and Spallation Source ISIS (UK)

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

$d + d \rightarrow He^3 + n + 3.27\,MeV$

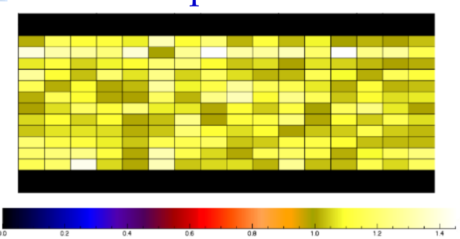
Deuterium Beam (100 Kev)

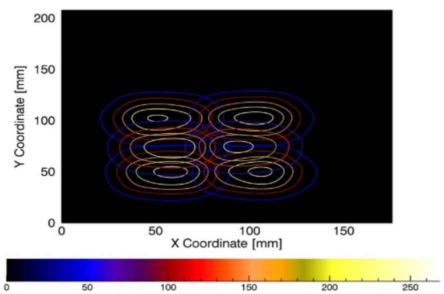
Neutron Flux 10^{10} n/cm^{2}s

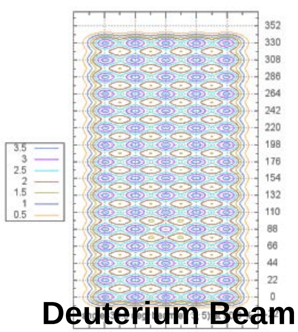


nGEM neutron Detector

Uniform response and capability to reconstruct multiple beamlets







Deuterium Beam composition: 5x16 beamlets (40 x 20 mm^2)

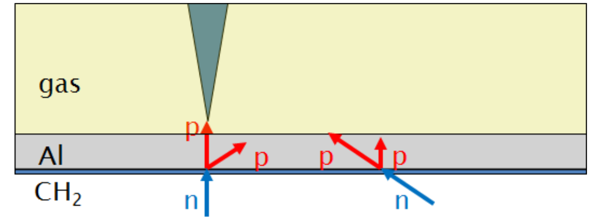
Aim: Reconstruct **Deuterium beam profile** from neutron beam profile.
Angular resolution and directionality property needed

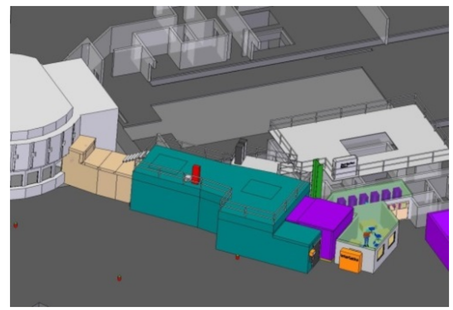
G. Croci

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

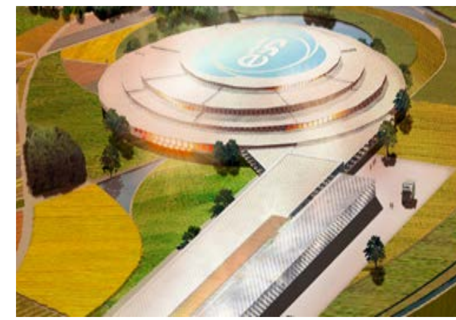
Fast neutron Converters:

- Polyethylene
- Al-layer (give directionality property)



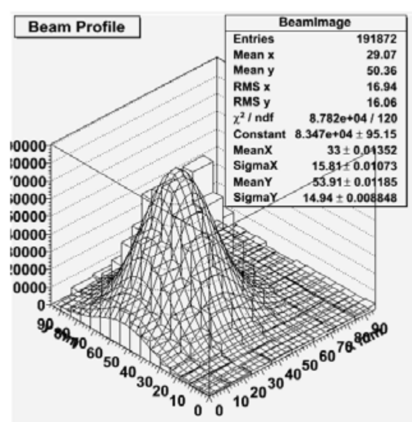


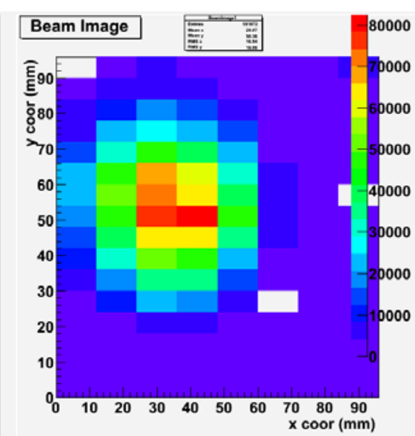
ChipIr CAD model at ISIS-TS2



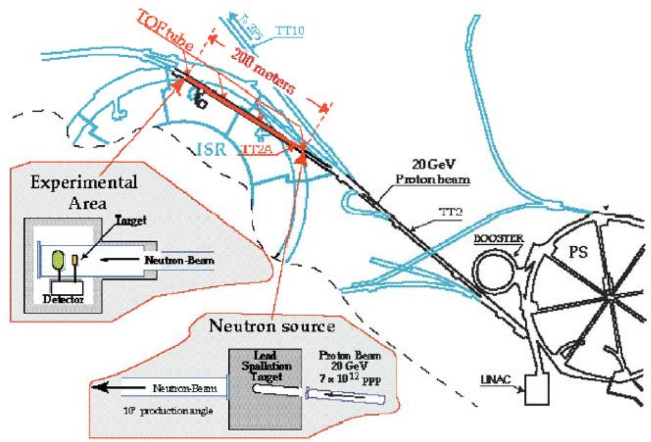
ESS Model

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





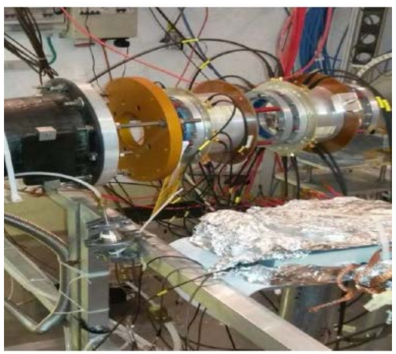
Beam Monitoring at nTOF @ CERN



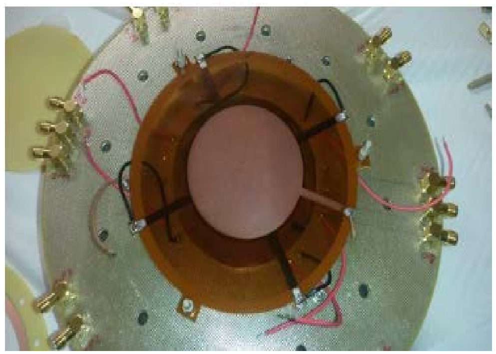
Neutron beam + state-of-the-art detectors make n_TOF UNIQUE for:

- Measuring **radioactive isotopes**
- Identifying/studying **resonances (at energies higher than before)**
- Extending **energy range** for fission (up to 1 GeV !)

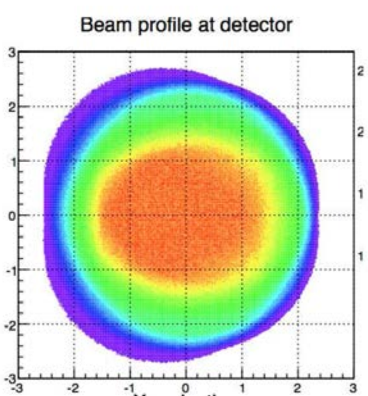
The energy of the neutrons can be determined from their Time of Flight



Installation on NTOF



4 pad detector



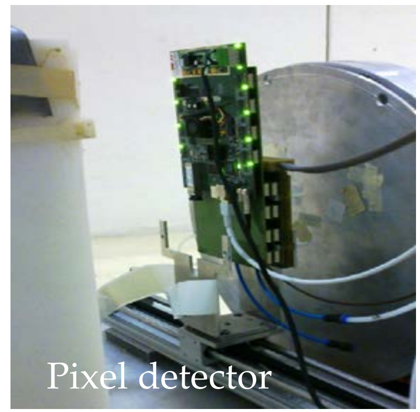
μMegas detector:

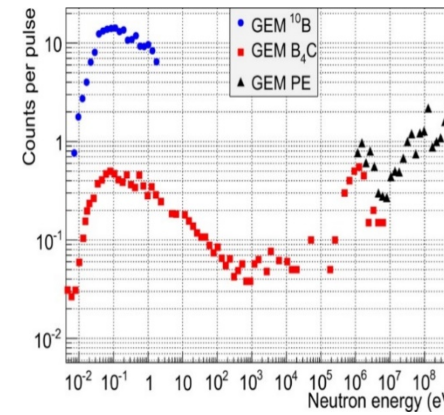
2 D reconstructed image

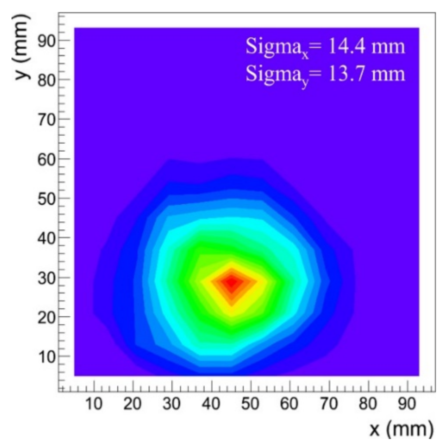
T. Papaevangelou

μM Neutron Monitor applied to fission reactor

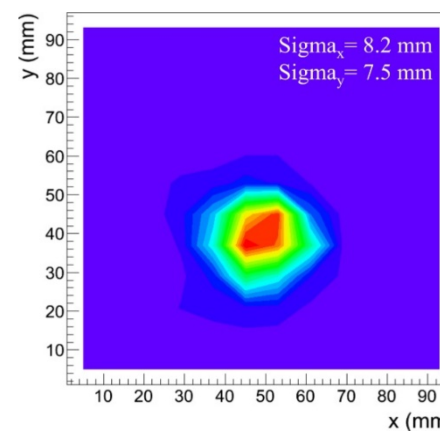
GEM detector







2D image of thermal neutron

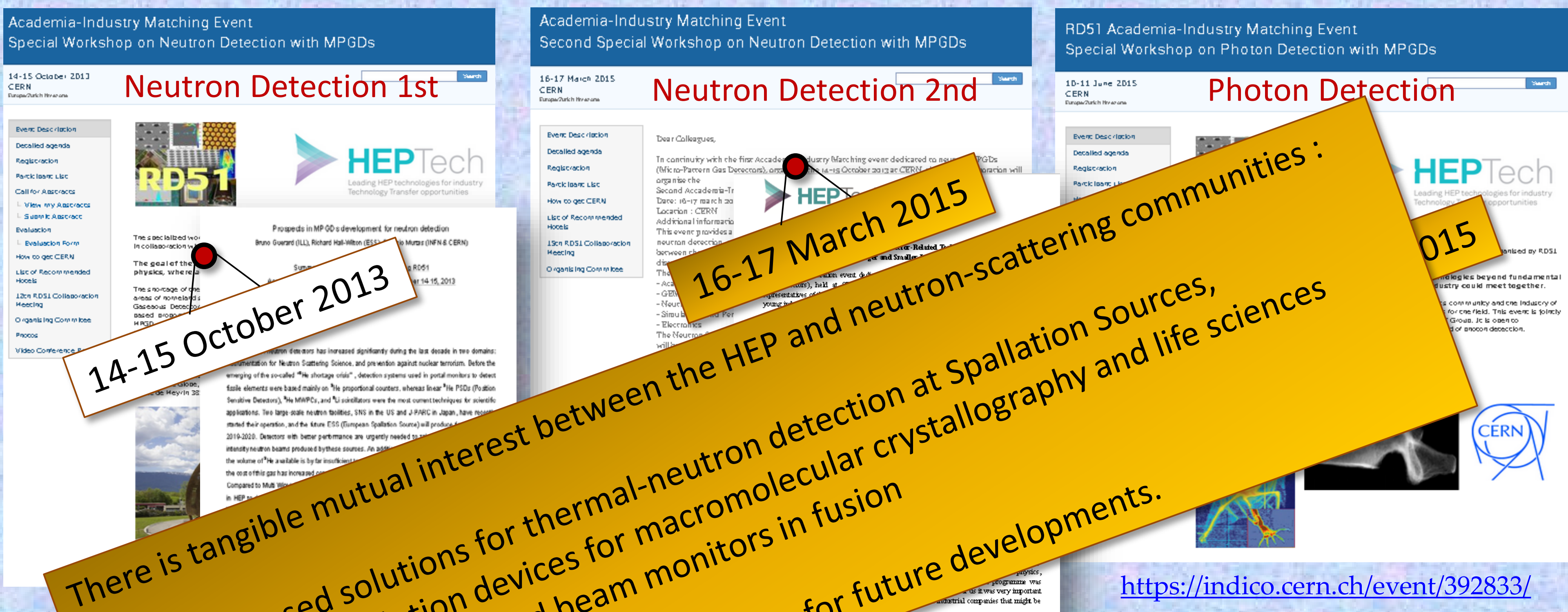


F. Murtas

2D image of fast neutron

MPGD-based Neutron /Photon Detection: RD51 Academia – Industry Matching Events

Platform: Research + industry + potential users to foster collaboration on dedicated applications



There is tangible mutual interest between the HEP and neutron-scattering communities :

- ➢ MPGD-based solutions for thermal-neutron detection at Spallation Sources,
- ➢ Novel high-resolution devices for macromolecular crystallography and life sciences
- ➢ Fast neutron MPGD-based beam monitors in fusion

represent a new frontier for future developments.

htt… Sun…

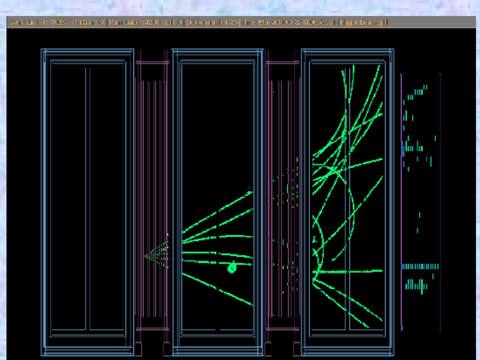
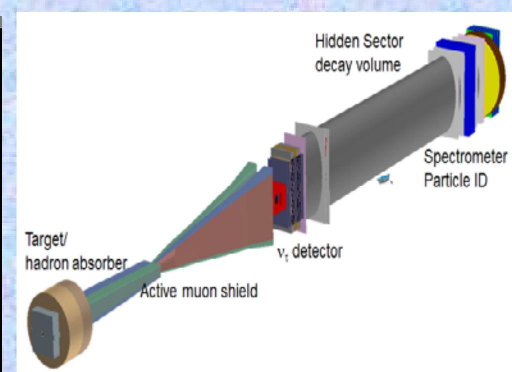
…n.ch/event/365840/ …ss release

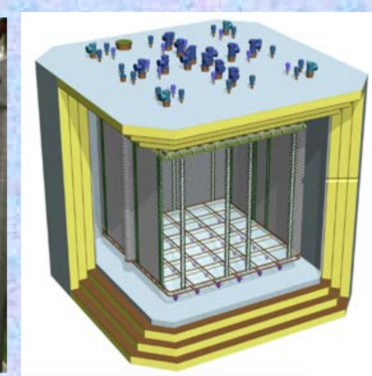
https://indico.cern.ch/event/392833/

(understanding requirements, applications, approaching new communities and technologies)

MPGD Technologies for Neutrino Physics

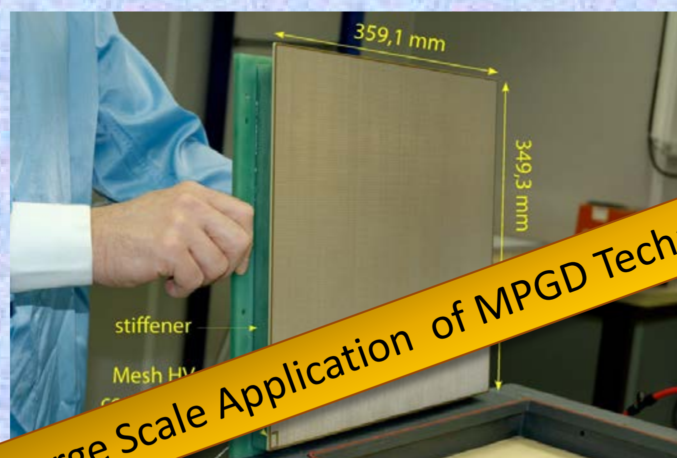
Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements / Remarks
T2K @ Japan Start: 2009 - now	Neutrino physics (Tracking)	TPC w/ Micromegas	Total area: ~ 9 m^2 Single unit detect: $0.36x0.34m^2$~$0.1m^2$	**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 m^2 Single unit detect: 2 x 1 m^2 ~ $2m^2$	**Max. rate**: < low **Spatial res.:** < 150 μm **Rad. Hard.:** no	Provide time stamp of the neutrino interaction in brick“
LBNO-DEMO (WA105 @ CERN): Start: > 2016	Neutrino physics (Tracking+ Calorimetry)	LAr TPC w/ THGEM double phase readout	Total area: 3 m^2 (WA105-3x1x1) 36 m^2 (WA105-6x6x6) Single unit detect. (0.5x0.5 m2) ~0.25 m^2	WA105 3x1x1 and 6x6x6: **Max. rate:** 150 Hz/m^2 **Spatial res.:** 1 mm **Time res.:** ~ 10 ns **Rad. Hard.:** no	Detector is above ground (max. rate is determined by muon flux for calibration)
DUNE Dual Phase Far Detector Start: > 2023?		LAr TPC w/ THGEM double phase readout	Total area: 720 m^2 Single unit detect. (0.5x0.5 m2) ~ 0.25 m^2	**Max. rate:** $4*10^{-7}$ Hz/m^2 **Spatial res.:** 1 mm **Rad. Hard.:** no	Detector is underground (rate is neutrino flux)

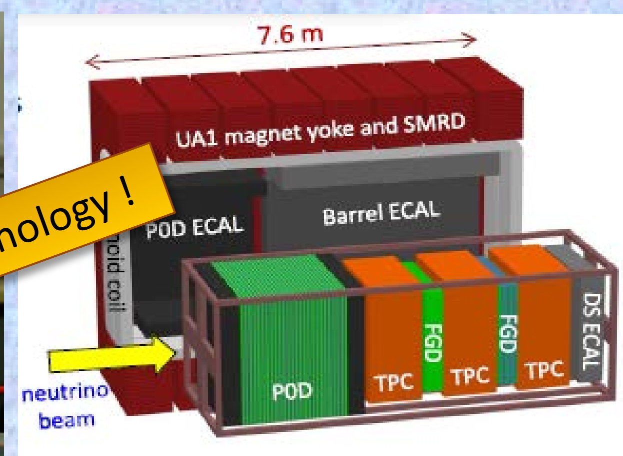




Three Large TPC for the T2K Near Detector

The T2K TPCs: the **FIRST** and the **LARGEST** TPCs equipped with MPGDs (Micromegas)





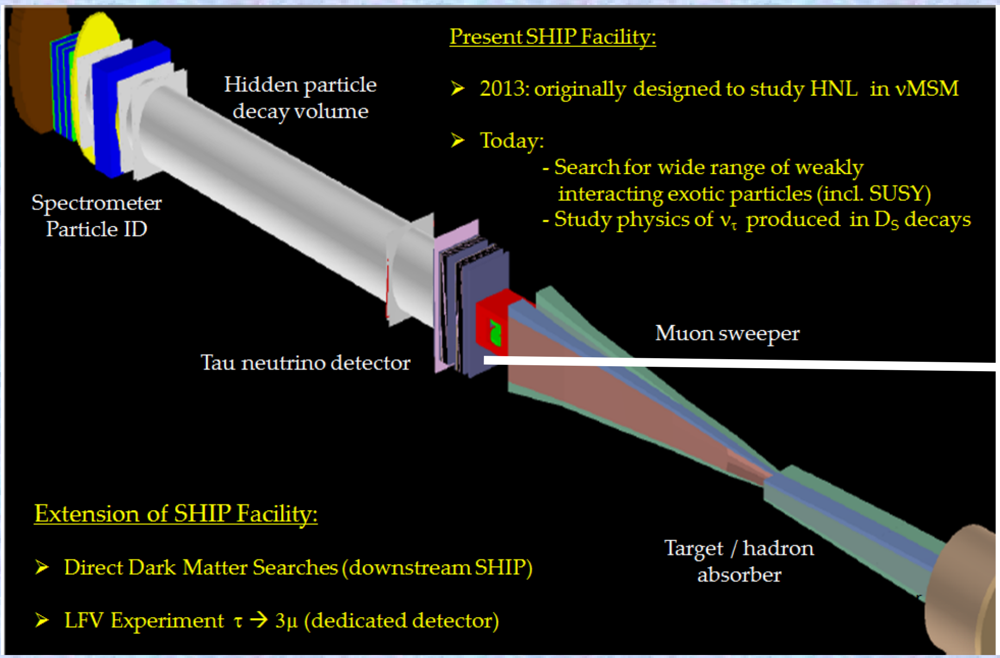
9 m^2 of MM - First Large Scale Application of MPGD Technology !

- ~9 m^2 equipped with bulk Micromegas detectors
- Playing a key role in the study of the neutrino flux and interactions (charge, momentum and dE/dx PID)
- Spatial resolution : 0.6 mm
- Momentum res.: 9% at 1 GeV (reconstruct ν-energy spectrum)
- dE/dx: 7.8 % (for MIPs to ditinguish μ/e, measure νe component)

72 Micromegas and 120k channels functioning flawlessly since 2009 (dead channels 144/124272)

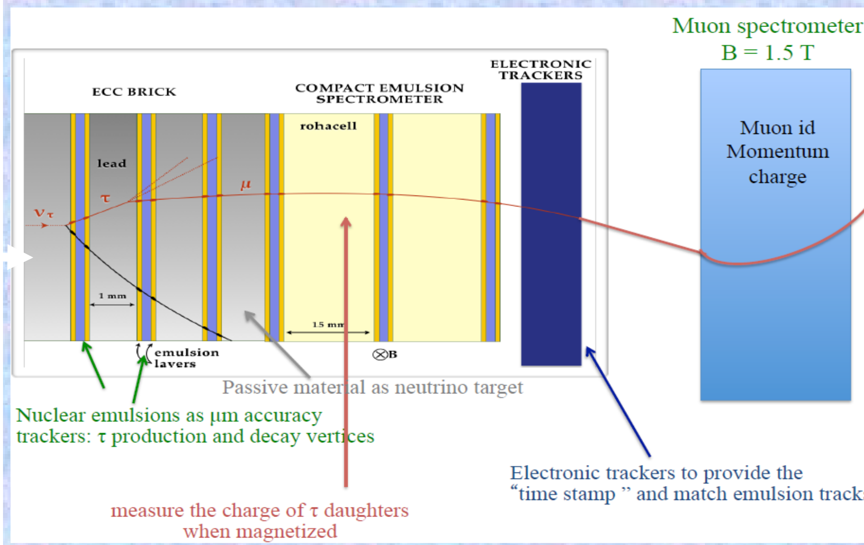
M. Zito

Electronic Target Tracker for Tau-Neutrino Detector at SHIP Facility @ CERN



Electronic Target Tracker Layout:

→12 planes with 2x1 m^2 surface



Target Tracker Requirements:

- Maximum thickness of the plane is 5-6 cm
- Capability of measuring the angle in each plane (efficiency versus the track angle: up to $tg(\theta) = 1$)
- Performance in magnetic field (RD51 is currently using GOLIATH magnet in the test-beam area);

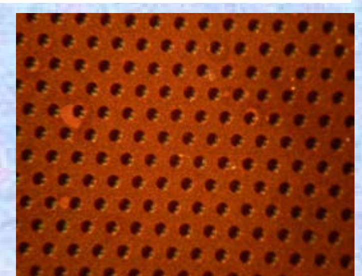
➢ Provide time stamp of the neutrino interaction in the brick

➢ Matching between the electronic detectors and the emulsion tracker

Four possible technologies:

- ❖ Scintillating fiber trackers (250 μm Scintillating fibres readout by SiPMs)
- ❖ GEM tracker
- ❖ Micromegas tracker
- ❖ Resistive RPWELL detector

Novel Architecture: μ-resistive WEEL



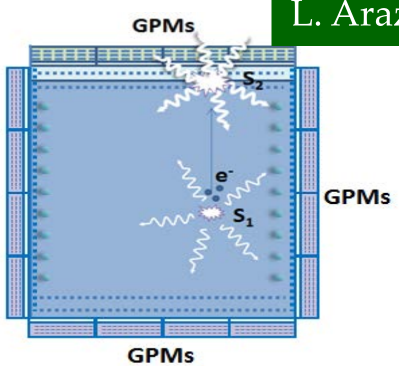
The Cryogenic Frontier: MPGDs for Neutrino Physics and Dark Matter Searches

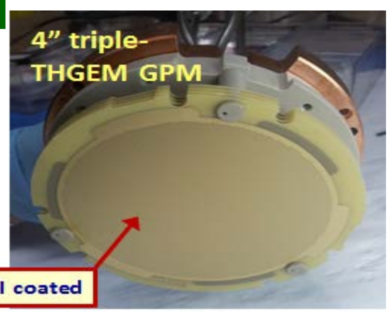
Concept: Detector of nuclear recoils of ultimate sensitivity for Coherent Neutrino-Nucleus Scattering and Dark Matter Search experiments

GPMs LXe TPCs for dark matter searches (within DARWIN):

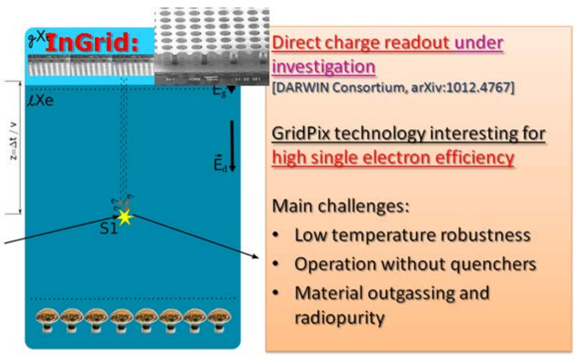
- Aim for 4π coverage – not practical with PMTs (cost, bulkiness) or SiPMs (dark count rate)
- Demonstration of 4" cryogenic triple-THGEM GPM with reflective CsI coupled to dual phase LXe TPC:

L. Arazi





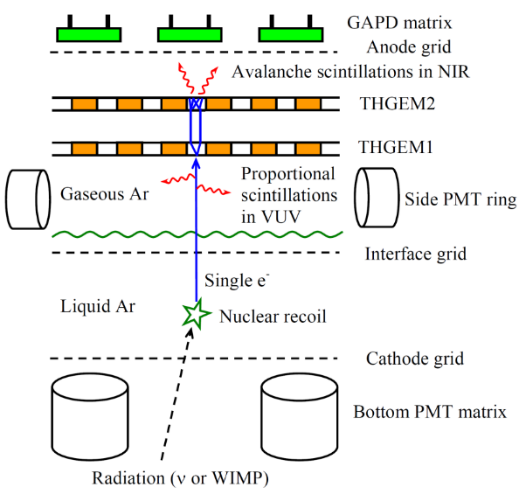
Earlier studies with InGrid (direct charge readout):



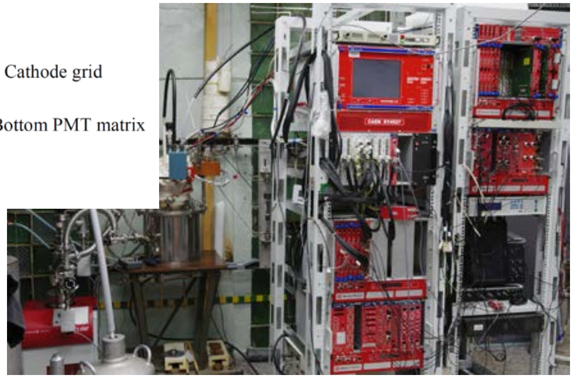
Two ideas for future large-scale MPGD-based noble-liquid detectors:

- Dual-phase TPCs with cryogenic large-area gaseous photomultipliers (GPMs)
- Single-phase TPCs with MPGDs immersed in the noble liquid.

Challenge: Single electron sensitivity to nuclear recoil-induced ionization – optimization to achieve simultaneously high gas gain and long-term stability

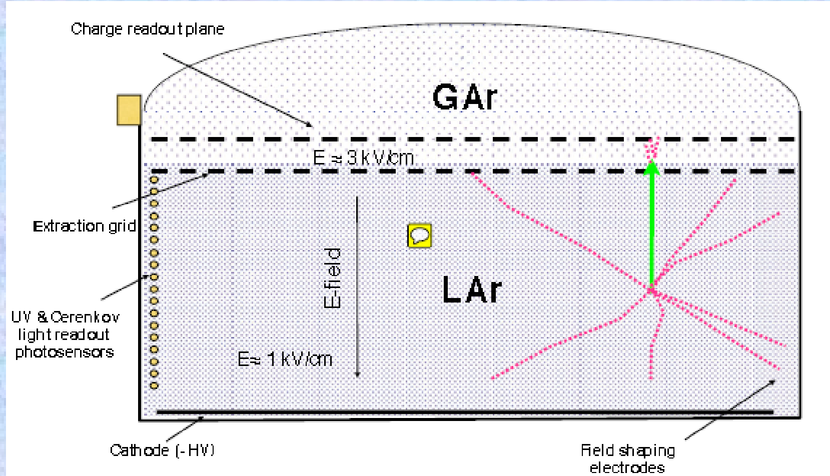


THGEM/GAPD-matrix multiplier with PMT readout of proportional EL of the ionization (S2) signal

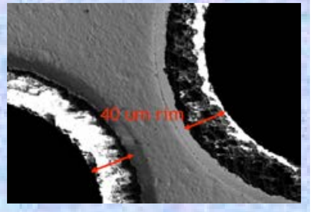


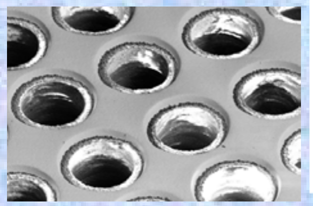
A. Buzulutskov

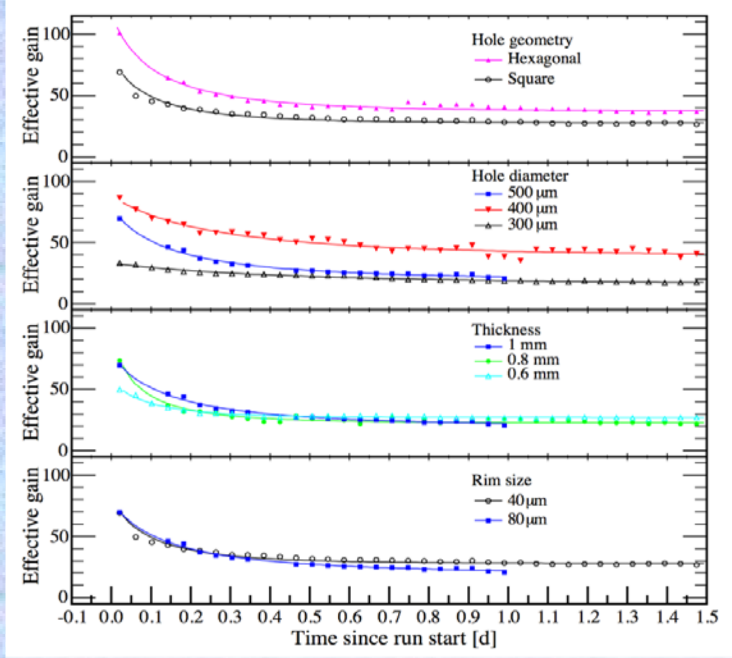
Double Phase LAr LEM/TPC for Neutrino Physics



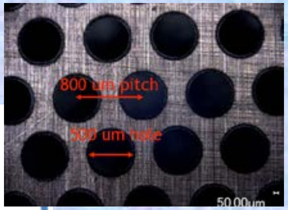
Stable gain over 20 and discharge free after charing-up

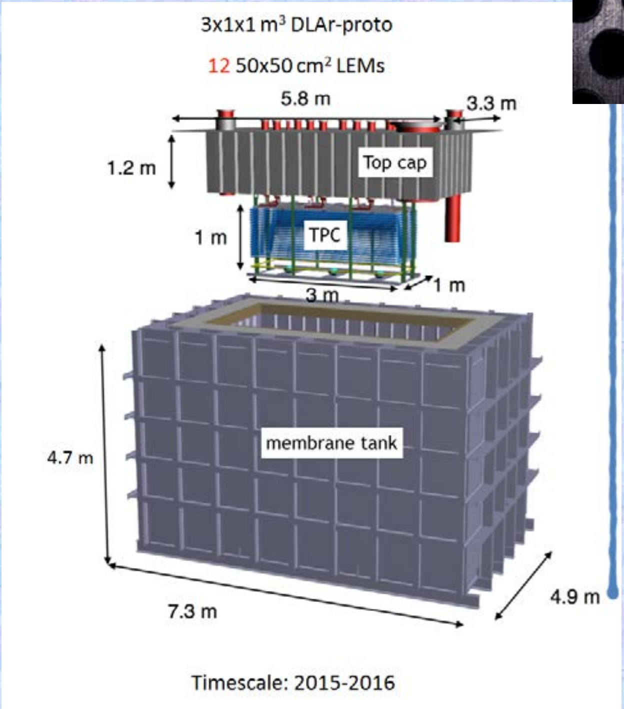






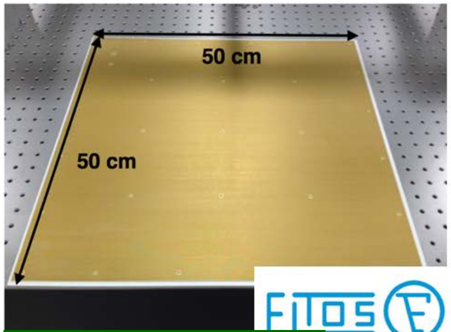
WA105 @ CERN:

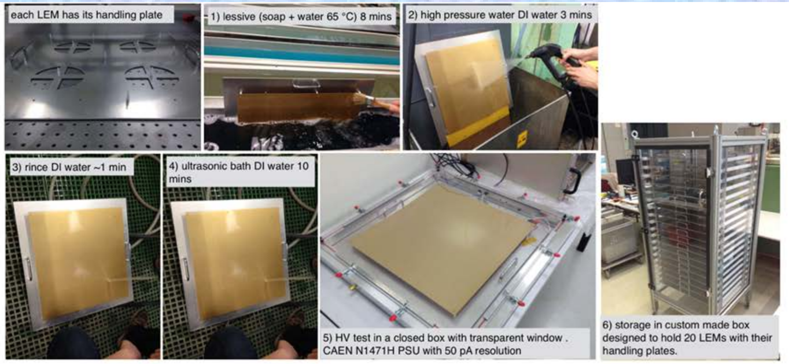




Well controlled quality of 50x50 cm2 LEM production and handing

production from ELTOS   Well defined hanging, cleaning/storage process

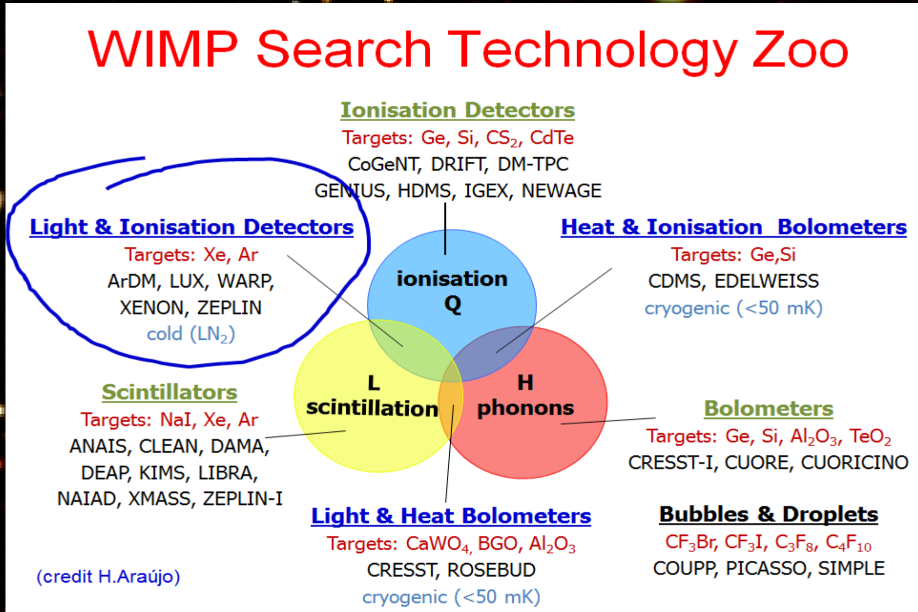




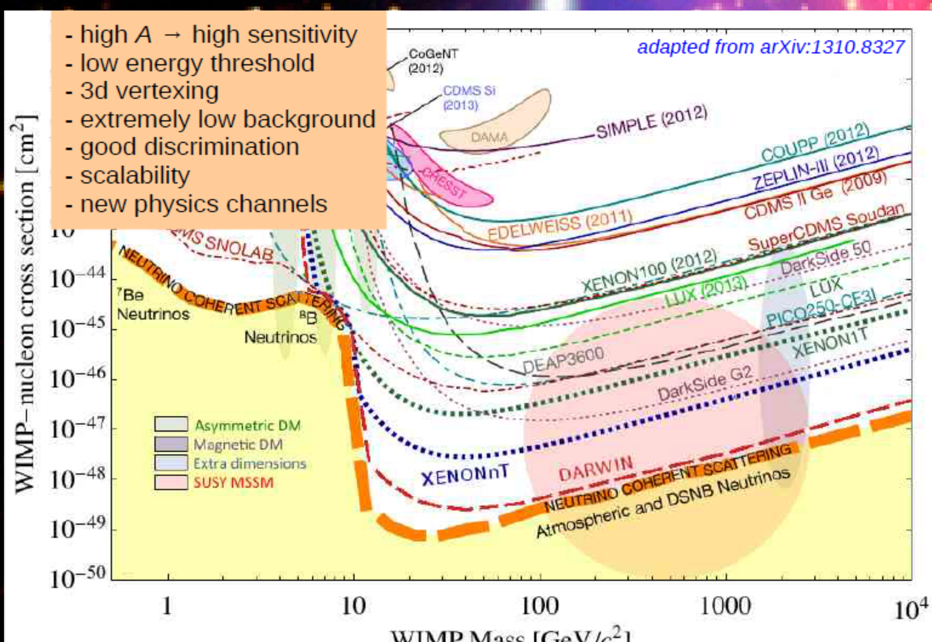
S. Wu, A. Rubbia

Same quality as the 10x10 cm2 LEM (discharge rate, breakdown voltage)

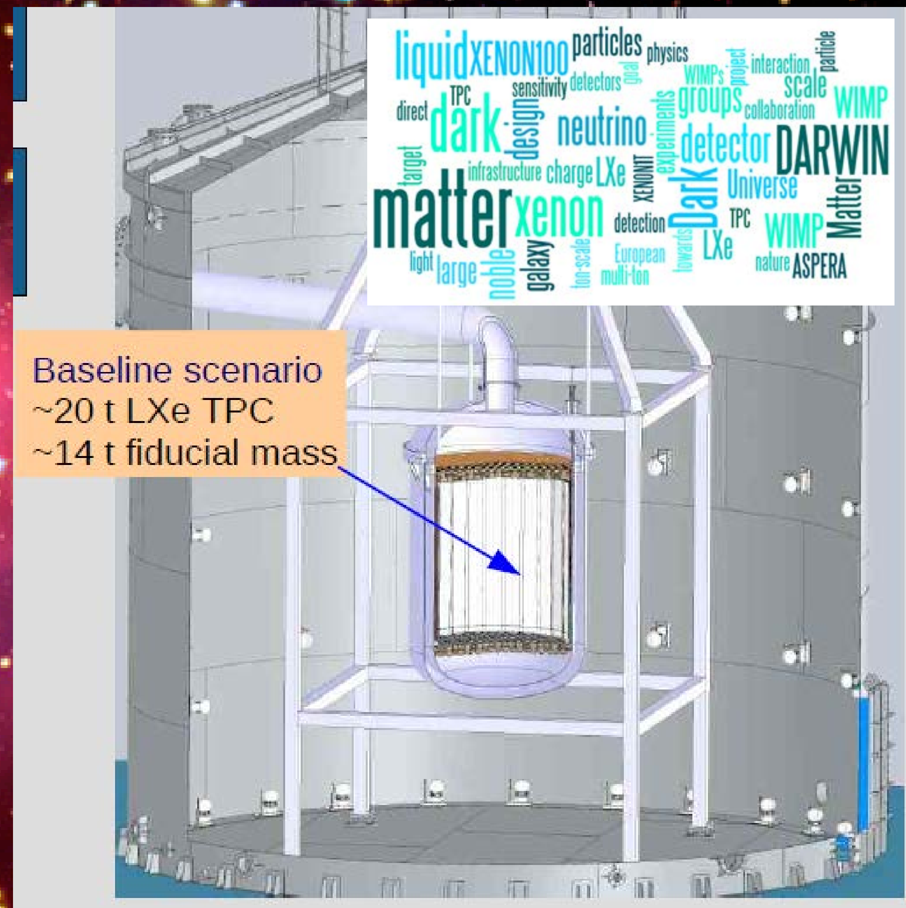
Cosmic Frontier: Searches for Dark Matter



- high A → high sensitivity
- low energy threshold
- 3d vertexing
- extremely low background
- good discrimination
- scalability
- new physics channels



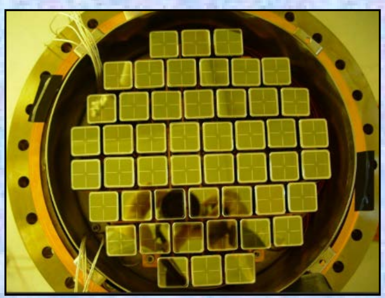
DARWIN – THE ULTIMATE WIMP DETECTOR

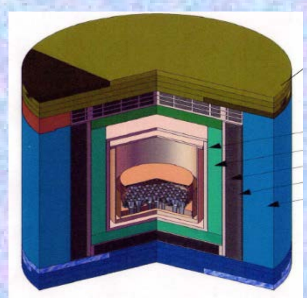


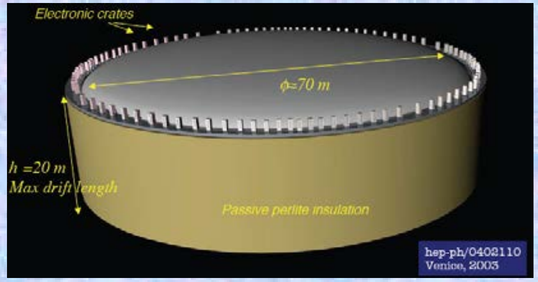
Dark Matter future will be driven by dual-phase LXe TPC → cost-effective technology that could be scaled to (very) large volumes

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: ~$30 m^2$ Single unit detect. ~20 x20 cm^2	**Max.rate:** 100 Hz/cm^2 **Spatial res.:** ~ 1cm **Time res.:** ~ few ns **Rad. Hard.:** no	Operation at ~180K, radiopure materials, dark count rate ~1 Hz/cm^2
PANDA-X @ China Start: > 2017	Astroparticle physics Neutrinoless double beta decay	TPC w/ Micromegas μbulk	Total area: 1.5 m^2	**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(cm^3)	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 7cm^2 Total area: 1 InGrid of 2cm^2	**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

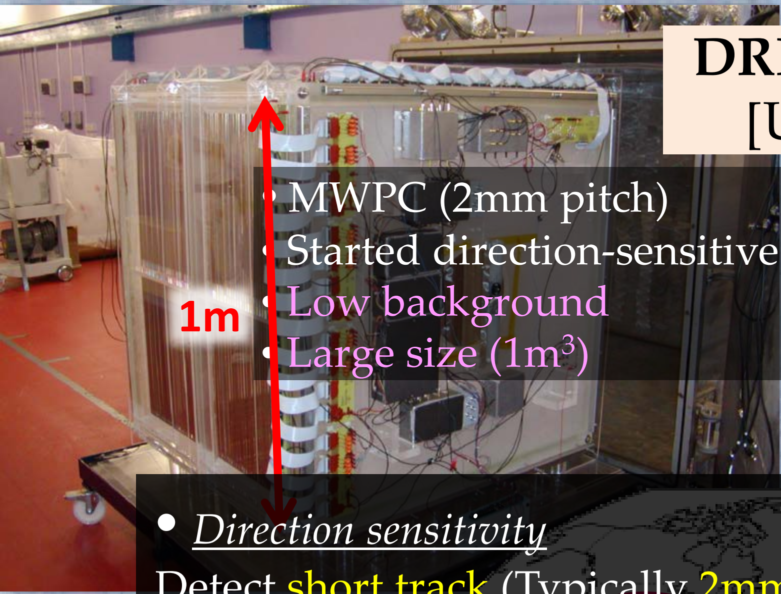






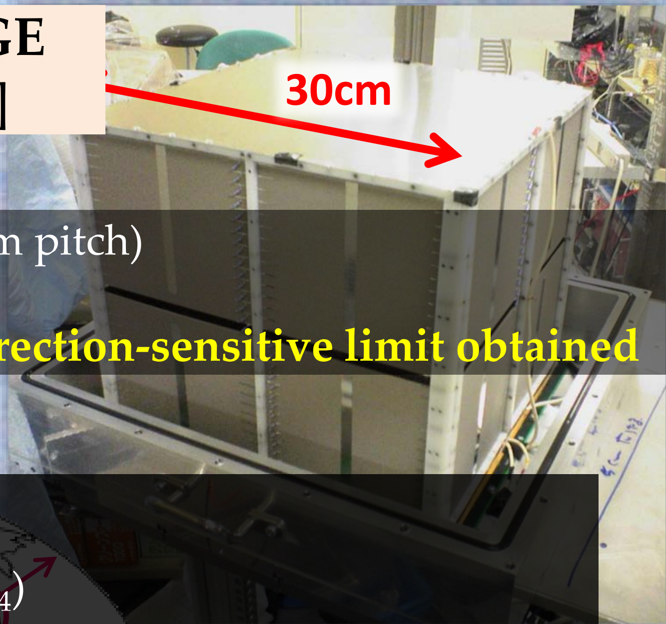
Underground Direction Sensitive Dark Matter Searches: Gaseous Detectors

DRIFT [UK]

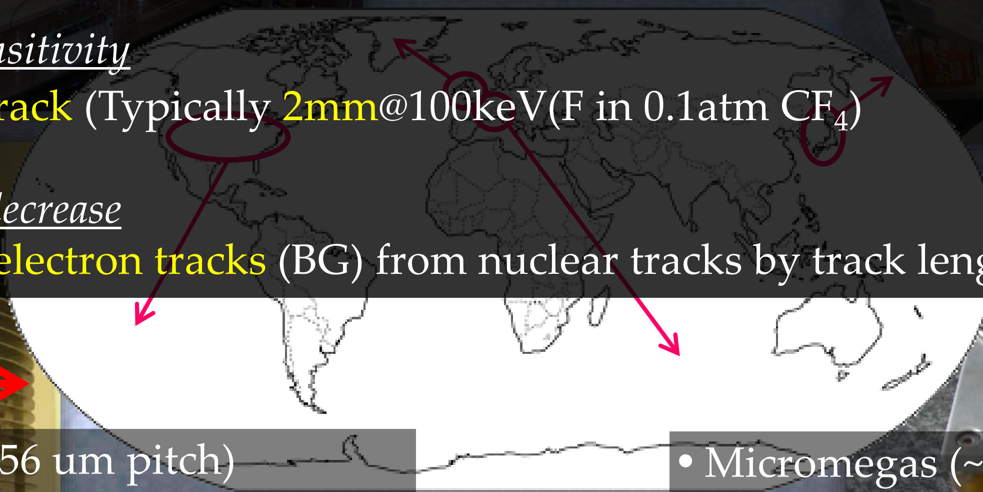


- MWPC (2mm pitch)
- Started direction-sensitive method
- Low background
- Large size ($1m^3$)

NEWAGE [Japan]



- μ-PIC (400um pitch)
- 3 D track
- **The best direction-sensitive limit obtained**

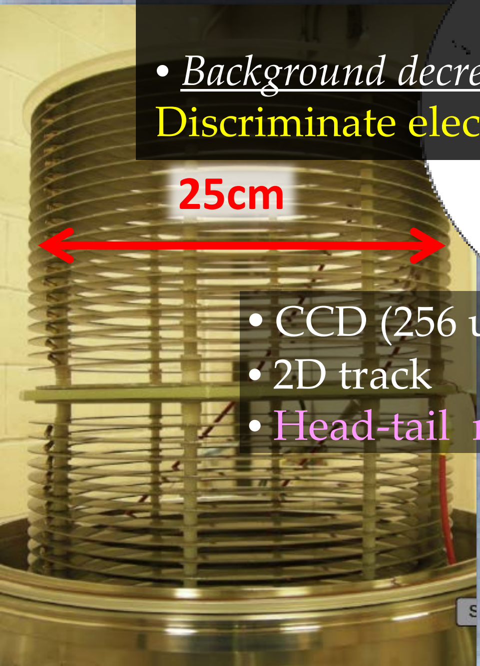


- *Direction sensitivity*

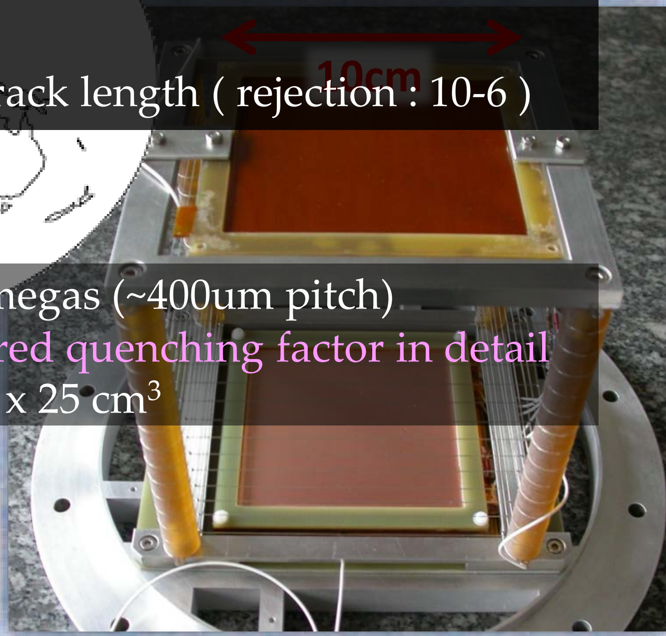
Detect short track (Typically 2mm@100keV(F in 0.1atm CF_4)

- *Background decrease*

Discriminate electron tracks (BG) from nuclear tracks by track length (rejection : 10-6)



- CCD (256 um pitch)
- 2D track
- Head-tail reconstruction



- Micromegas (~400um pitch)
- Measured quenching factor in detail
- 10 x 10 x 25 cm^3

DMTPC [USA]

MIMAC [France]

Direction Sensitive Dark Matter Searches: MIMAC and NEWAGE

NEWAGE:

μ-PIC based TPC with electronics
Only DM experiment with 3-D tracks

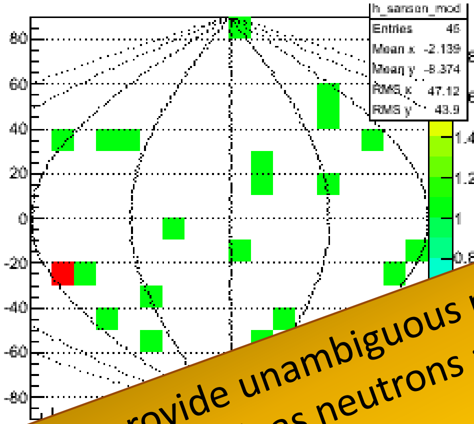
NEWAGE-0.3b'

K. Miuchi, A. Ochi

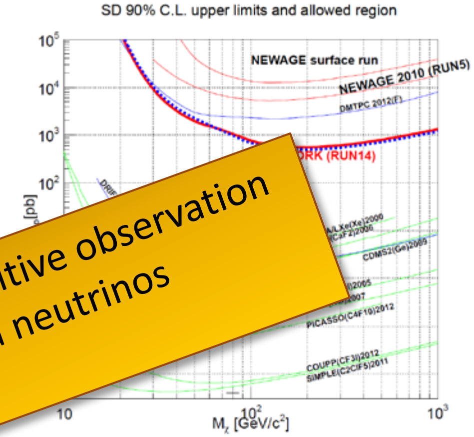
μ-PIC
- 31 × 31cm²
- made by DNP, Japan

GEM
-31 × 32 cm²
- 70μm/140μm
- LCP 100μm
- made by Scienergy, Japan

SKYMAP (underground measurement, F recoil)



LIMIT (PTEP2015)
the only result from direction-sensitive method



Direction sensitive WIMP recoil detection could provide unambiguous positive observation of DM in presence of insidious backgrounds, such as neutrinos and neutrinos
→ potential for MPGD technology

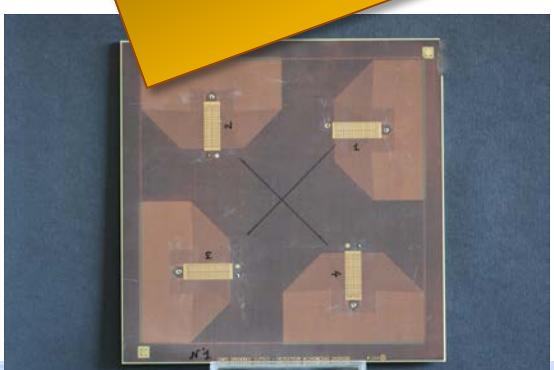
MIMAC:

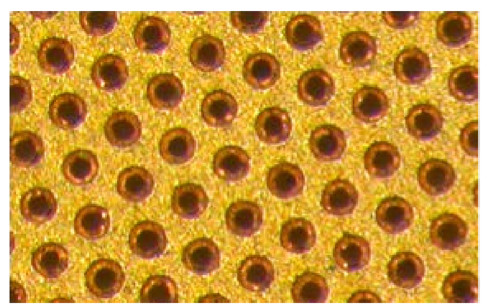
1m³ = 16 bi-chamb ... cm³)

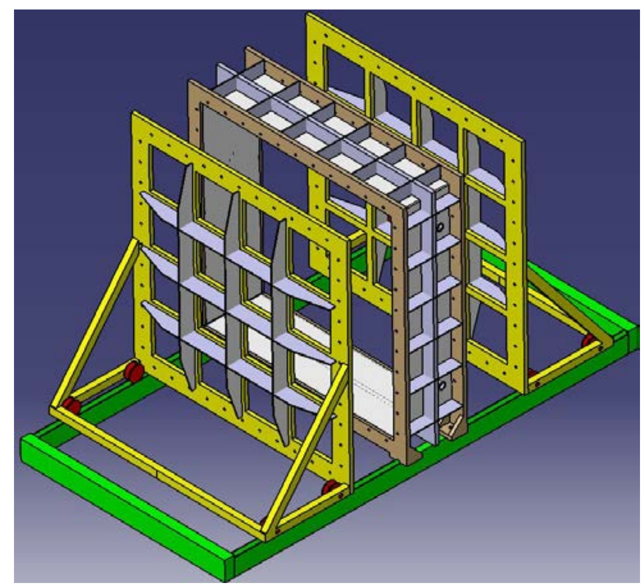
D. Santos

New 20...
(1024 c...

New technology anode 35x35cm^2
(resistive uM adaptation)
Only one big chamber



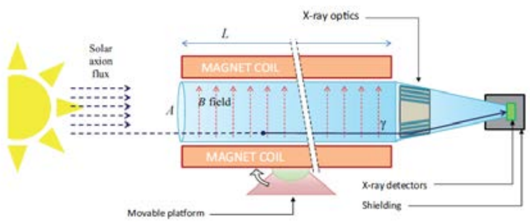




MPGDs Technology for Dark Matter Searches at CAST and IAXO

CAST Axion Telescope @ CERN:

Phase II: inserting gas (^4He, ^3He) inside the magnet bores to gain sensitivity to high axion masses



2 Micromegas X-ray detectors

LHC test magnet 9 T, 10 m

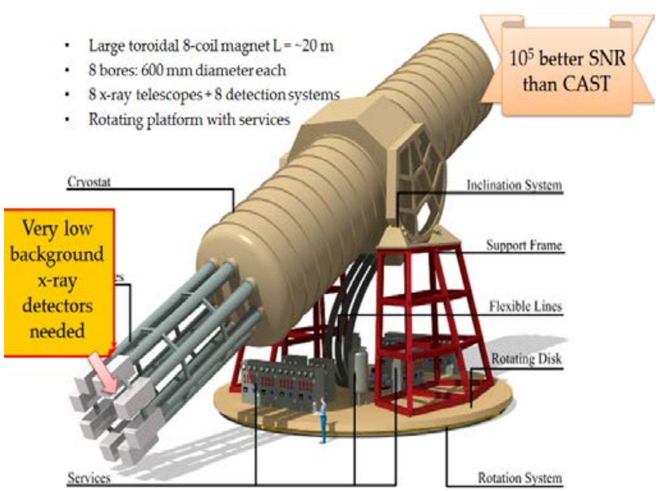
Platform to track the Sun (±8°V ±40°H) 3 h/day)

1 Micromegas + 1 Ingrid X-ray detectors (+ x-ray focusing optics)

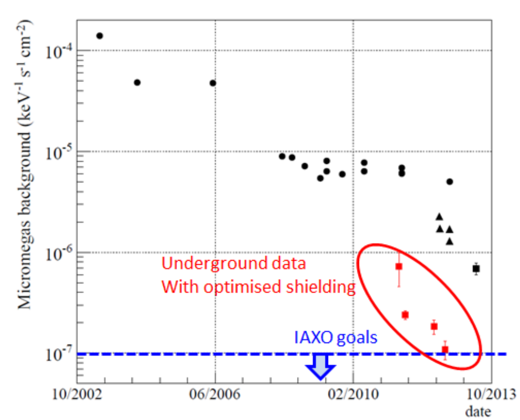
I. Irastorza
E. Ferrer Ribas

MPGD Detectors: Microbulk Micromegas (radiopurity, excellent background rejection)
InGrid (since Nov. 2014, X-ray detection down to 277 eV → First use of InGrid in the real experiment

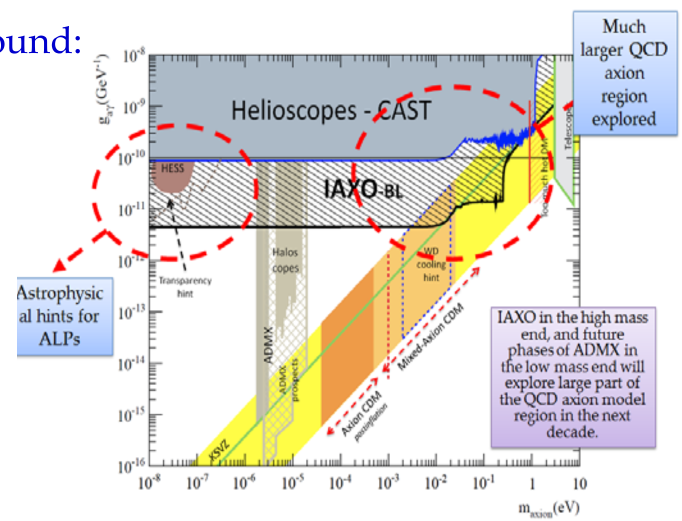
The International Axion Observatory (IAXO):



Evolution of MM CAST Background:

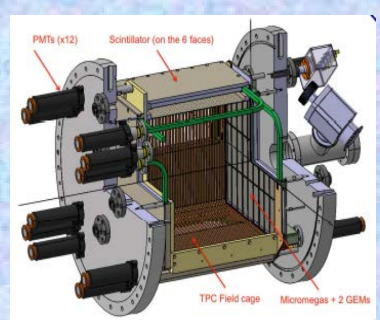


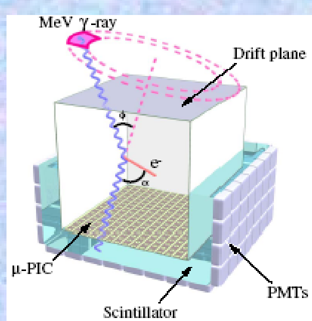
IAXO sensitivity prospects

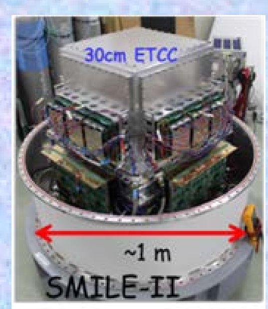


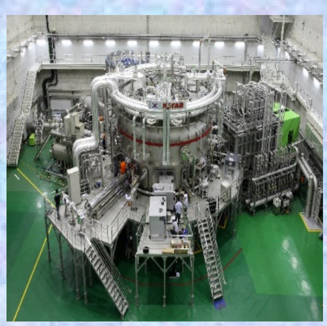
MPGD Technologies for X-Ray Detection and γ-Ray Polarimetry

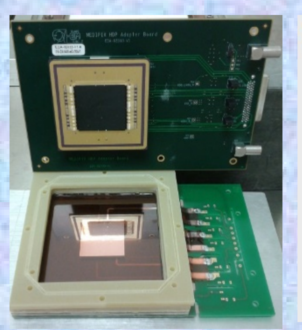
Experiment/ Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation characteristics / Performance	Special Requirements/ Remarks
KSTAR @ Korea Start: 2013	Xray Plasma Monitor for Tokamak	GEM GEMPIX	Total area: 100 cm^2 Total area: 10-20 cm^2	**Spat. res.:** ~ 8x8 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 cm^3 Single unit detect. (8 x 50cm^3) ~400cm^3	**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 cm^3	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 cm^3	Point Spread Function for gamma-ray: 1˚	





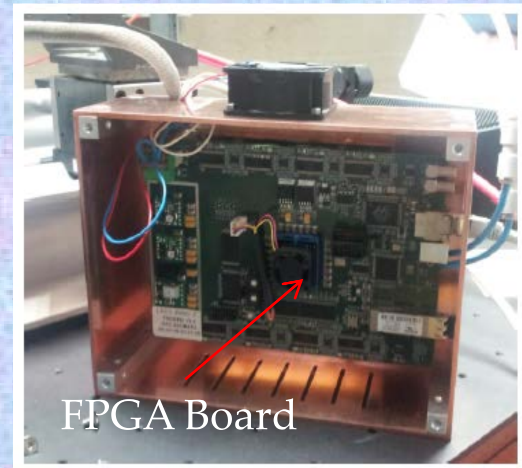




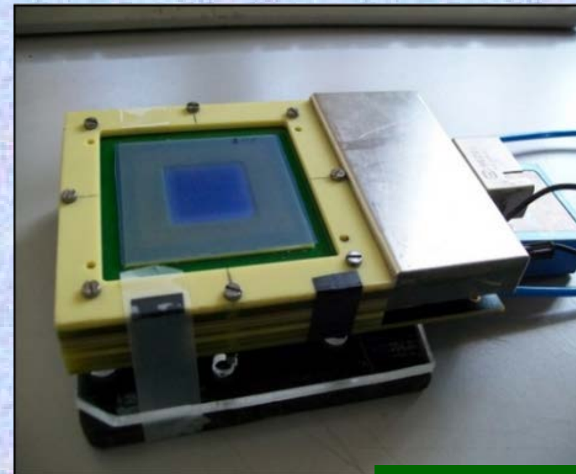


GEM (X-Ray) Detector for Tokamak Plasma Diagnostics

10x10 cm^2 GEM installed since 2013

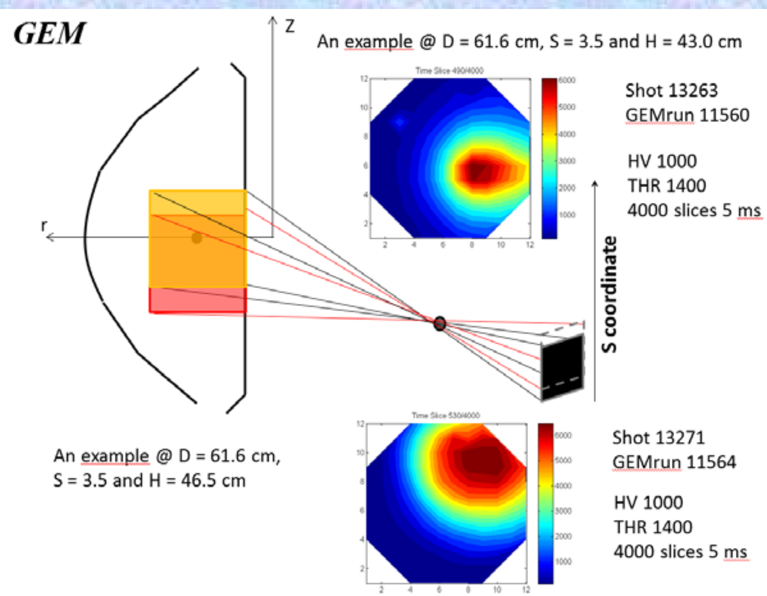


GEMPIX (GEM + Timepix)



F. Murtas,
D.Pacella,
G. Claps

Plasma images (GEM) measured in 2015:
Movie of 200 images per sec



GEMPIX for Fusion:

2015 measurement campaign:

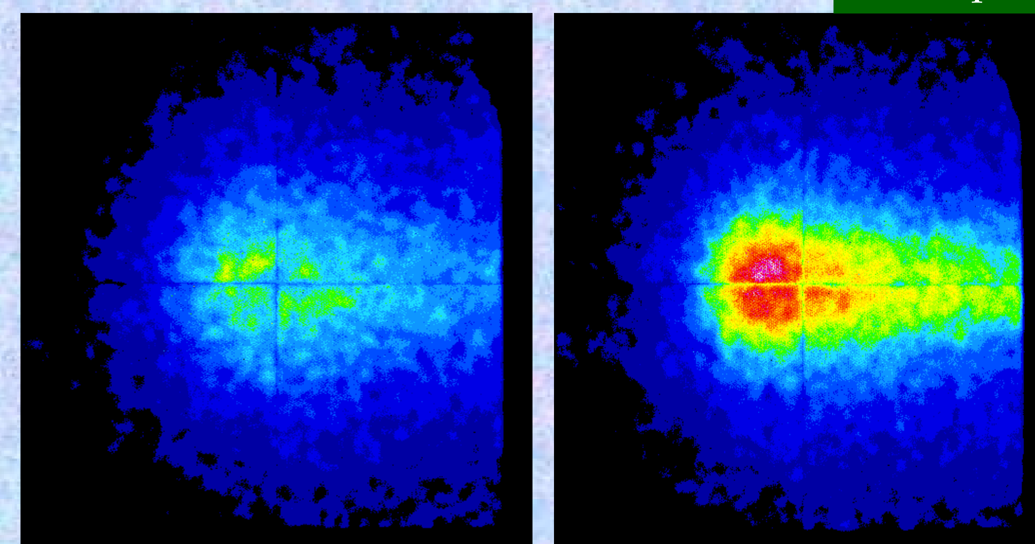
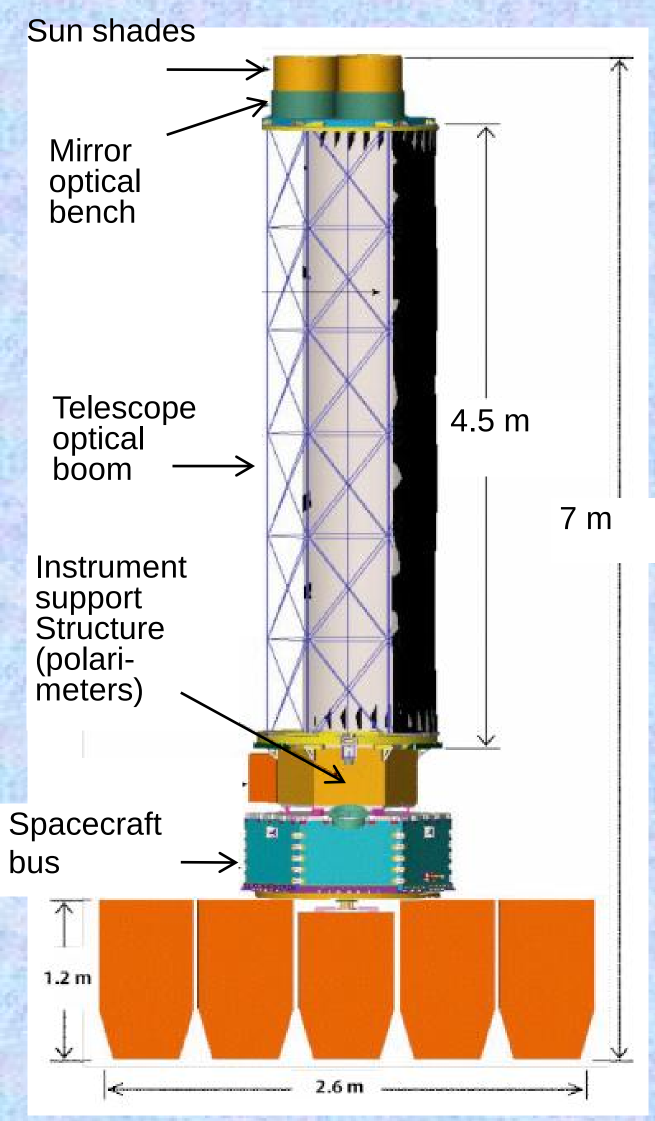
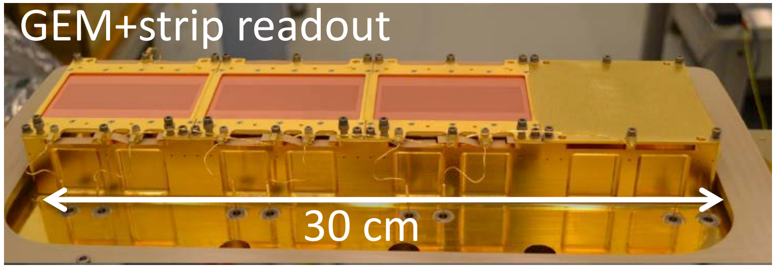
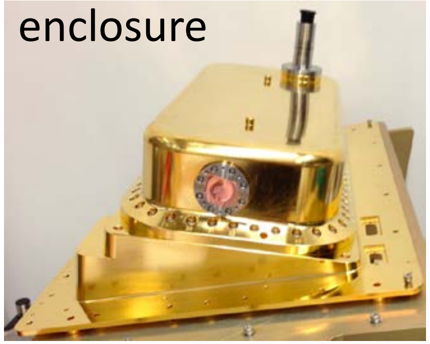


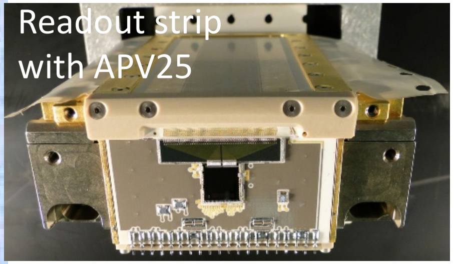
Image of KSTAR Plasma with spectroscopy measurements

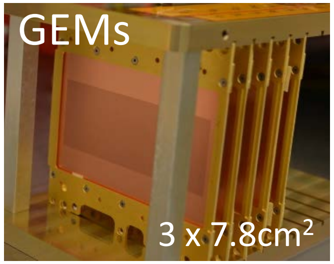
The PRAXys Project: Polarimetry for Relativistic Astrophysical X-Ray Sources

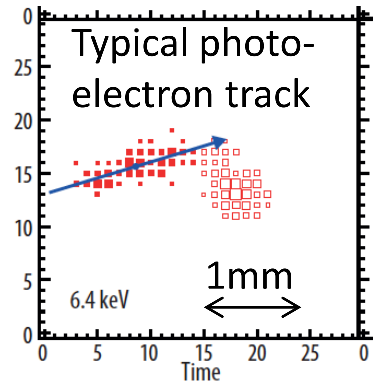












<u>Mission overview</u>

- The first dedicated mission for X-ray polarimetry in astrophysics
- US-Japan joint mission (NASA lead)
- The space craft carries two identical **GEM-TPC** polarimeter instruments (photoelectron tracking type X-ray polarimeter)

<u>Schedule</u>

- Proposed as NASA small explorer on December 18, 2014
- **Selected** for Phase A study on July 30, 2015
- Further selection will be done in February 2017
- Expected launch in June **2020** (two-years-life mission)

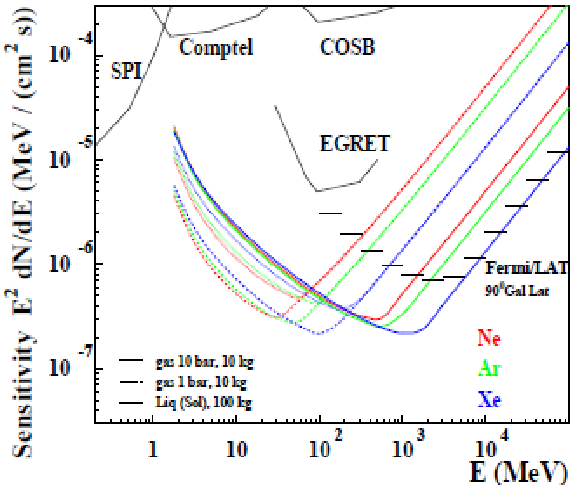
T. Tamagawa
(PRAXys team)

MPGDs Technologies for MeV-GeV Polarimeter and γ-Ray Telescope

HARPO: TPC as a γ-ray Telescope and Polarimeter:

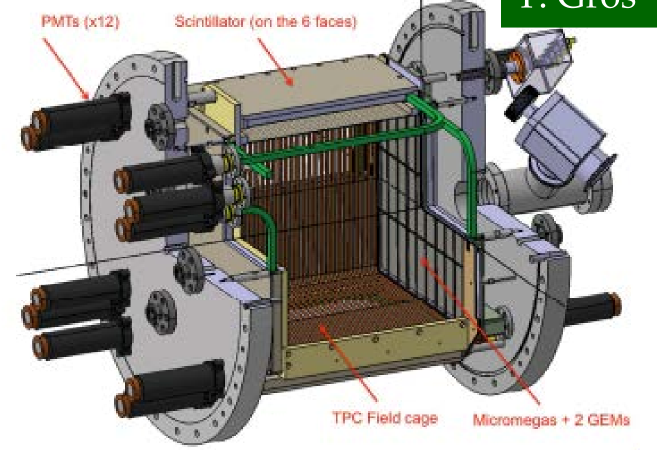
High-pressure TPC with MM:

- Fill 1-100 MeV sensitivity gap
- Improve the angular resolution
- Derive g-polarization from the azimuthal angle derived from e- and e+ tracks



HARPO demonstrator:

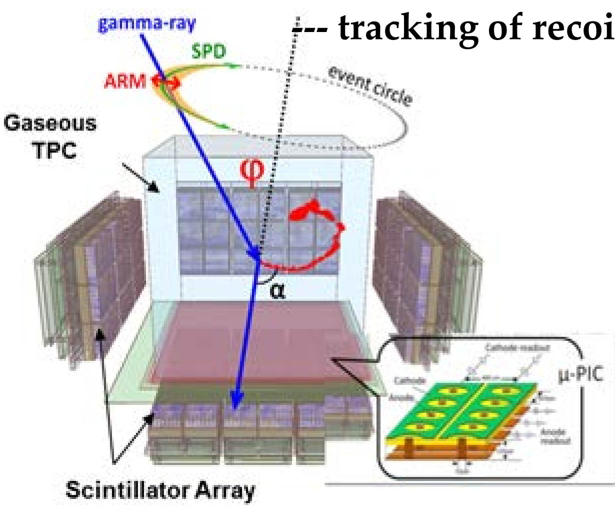
P. Gros

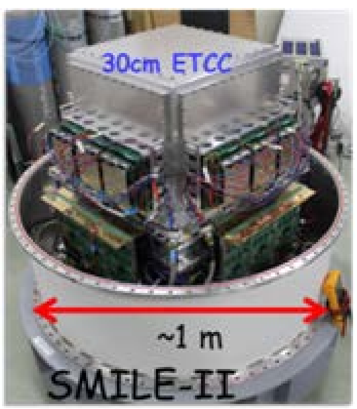


γ-Ray Imaging using μPIC+TPC:

30cm-cubic Gaseous Time Projection Chamber

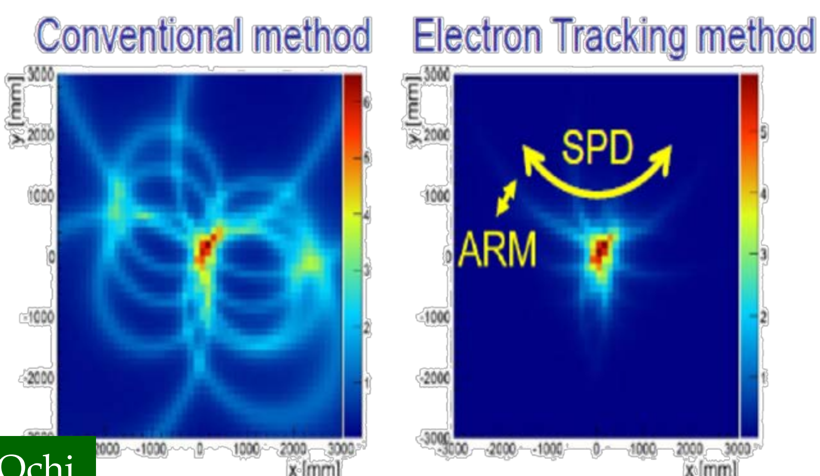
--- tracking of recoil electron ---





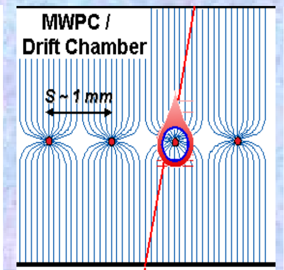
SMILE-II: A. Ochi

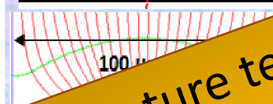
Fine 3D-electron tracking gives ϕ, and well-defined PSF (1-2°)

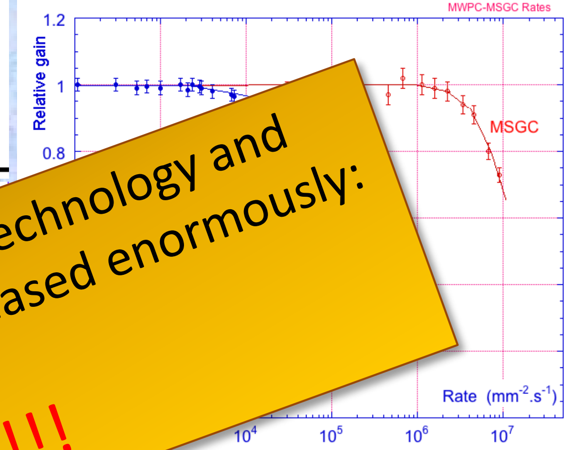


MPGD Technologies for Physics Projects: Summary and Outlook

- Micromegas
- GEM
- Thick-GEM, Hole-Type and RETGEM
- MPDG with CMOS pixel ASICs ("InGrid")
- Micro-Pixel Chamber (μPIC)





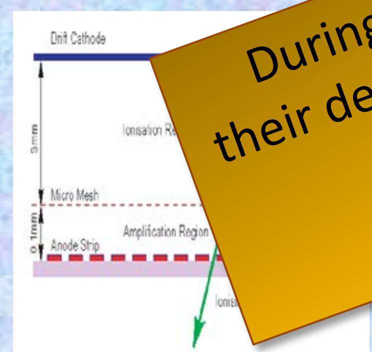


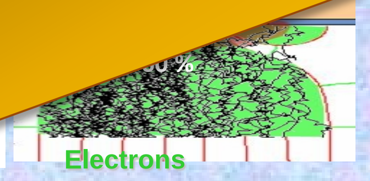
During the past 10 years, MPGDs became a mature technology and their deployment in operational experiments has increased enormously:

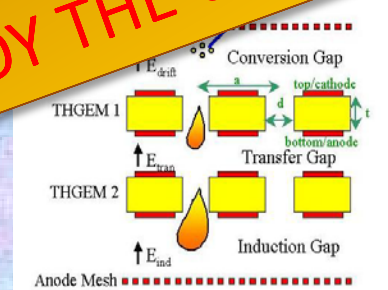
ENJOY THE CONFERENCE !!!

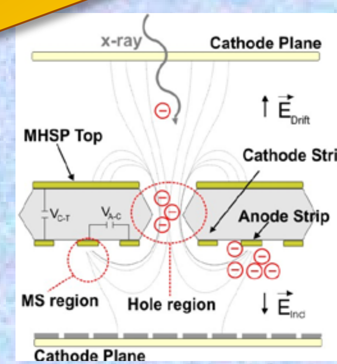
Micromegas

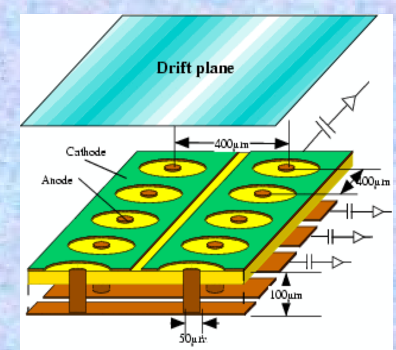
μPIC

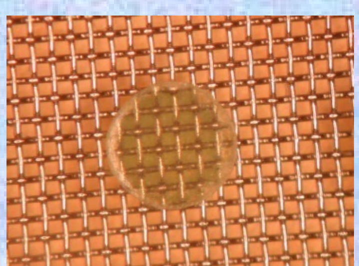


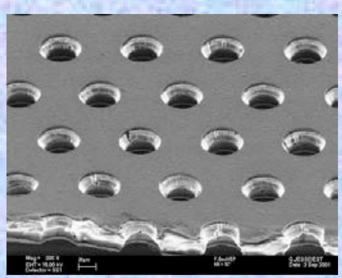


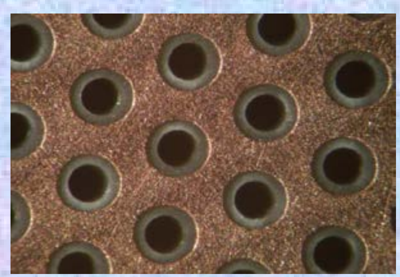


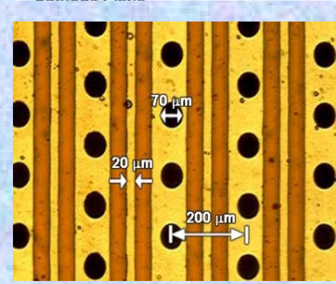


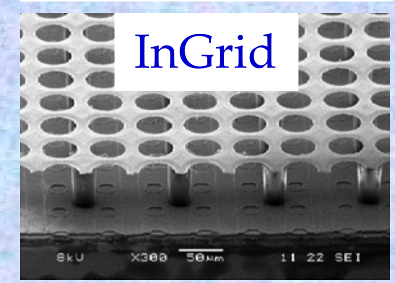












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