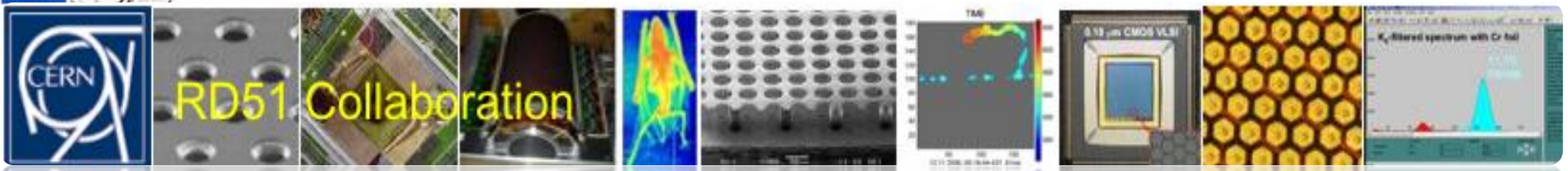
Development of Micro Pattern Gas Detectors for HEP and Nuclear Physics

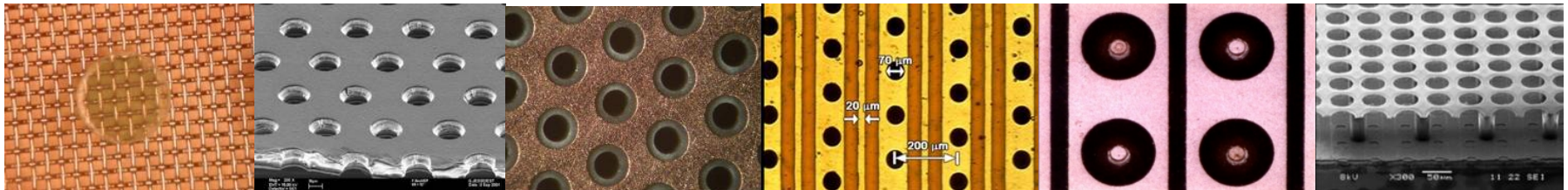


Theodoros Geralis,
NCSR Demokritos, Greece
On behalf of the RD51 Collaboration

OUTLINE

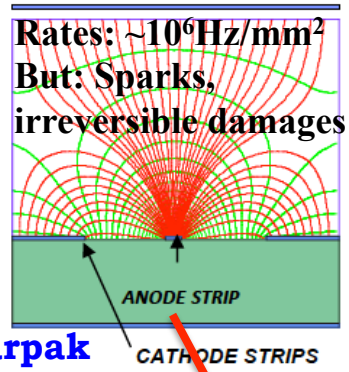
- **RD51/MPGD history**
- **Organization/Infrastructures**
- **Technological achievements**
- **Applications**

ICNFP2017 Conference, 17 – 29 Aug 2017, Kolymbari, Crete, Greece

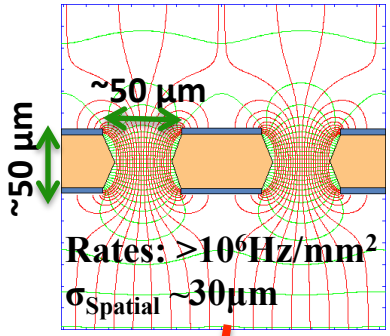


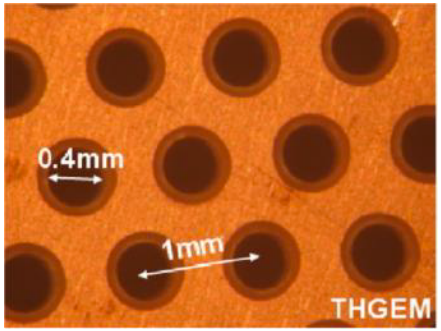
From Multi-Wire Proportional Chambers to Micro Pattern Gaseous Detectors

MSGC: Oed 1988

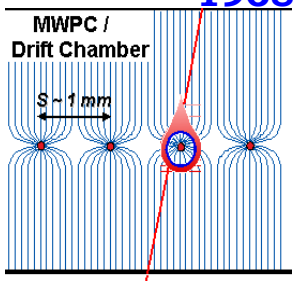


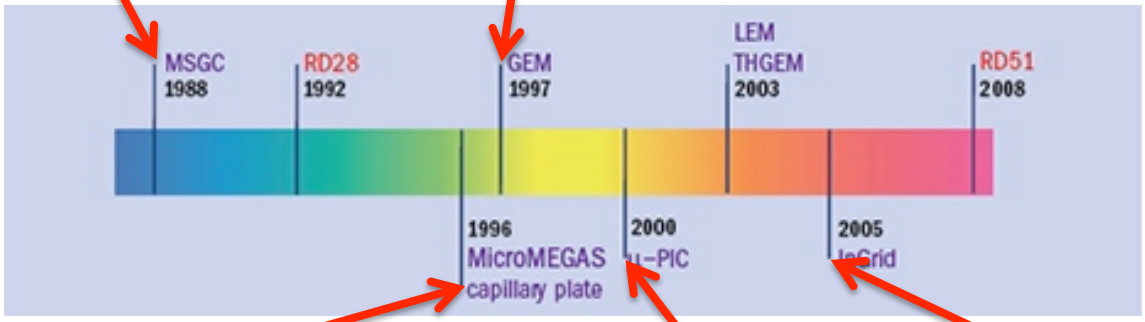
GEM:Sauli 1997





MWPC: Charpak 1968

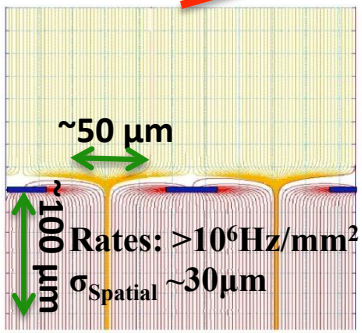




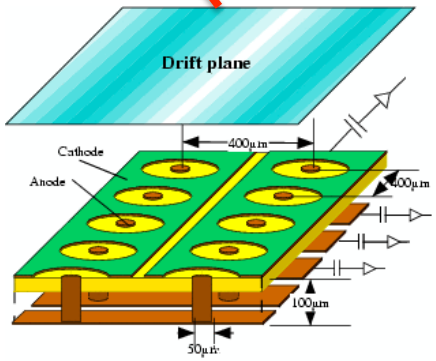
RD51 Collaboration:

86 Institutions

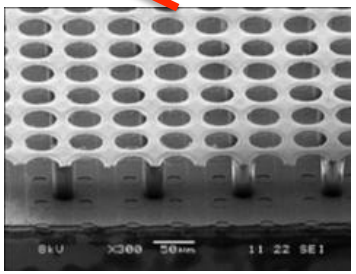
500 Scientists



Micromegas: Giomataris 1996



μ-PIC

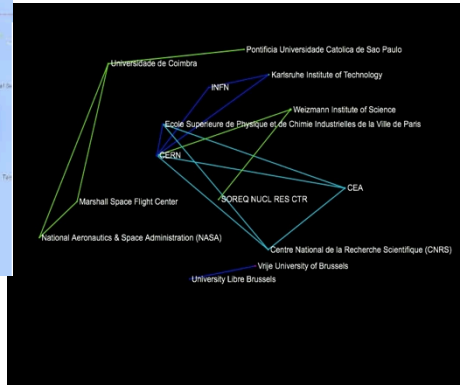


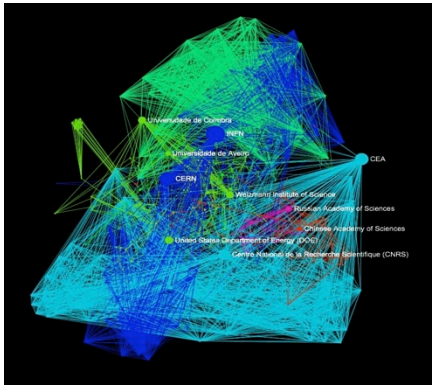
Ingrid

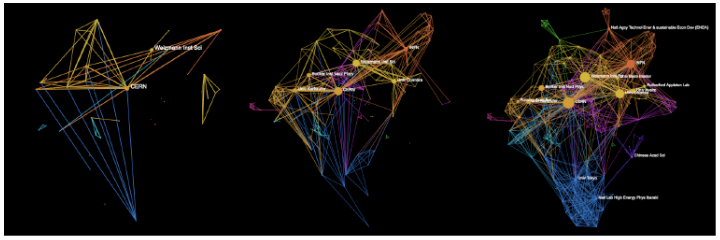
The RD51 Collaboration

Main objectives:

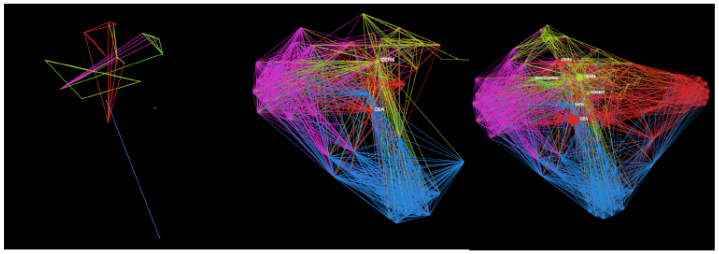
- MPGD technological development
  - Provide the collaboration framework
  - Develop common simulation packages
  - Develop common read out electronics
- Access to "MPGD know-how"
- Foster Industrial production







Gem 2000 Gem 2006 Gem 2014



Micromegas 2000 Micromegas 2006 Micromegas 2014

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

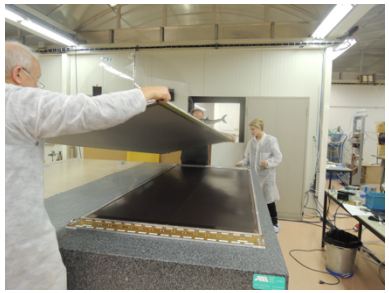
Map: **RD51**	
Current year:	2015
Organisations:	717
Clusters:	12
Publications:	1059

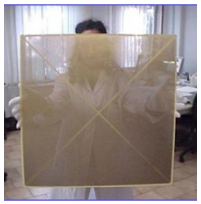
→ huge growth in interest in the MPGD technologies

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

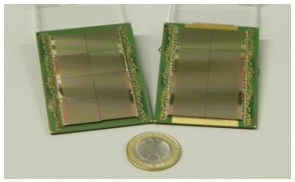
RD51 Collaboration

Technological Aspects
New Detector Structures



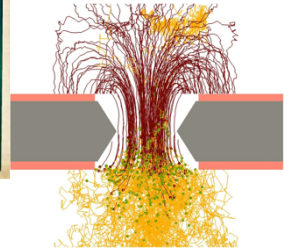


WG1:



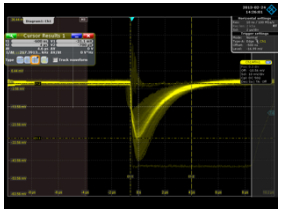
Detector Physics and
Performance
RD51 Common Projects

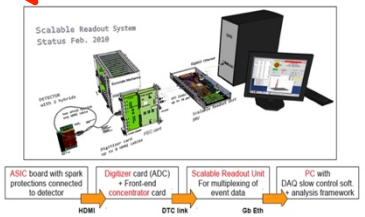
WG2:



WG5:

MPGD
Electronics





RD51

WG4:

Modeling of Physics
Processes
Software Tools

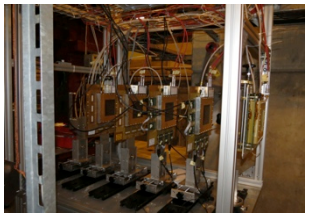
WG7:

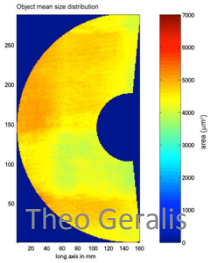
WG6:

WG3:

Applications, Training
and Dissemination

Common Test Facilities



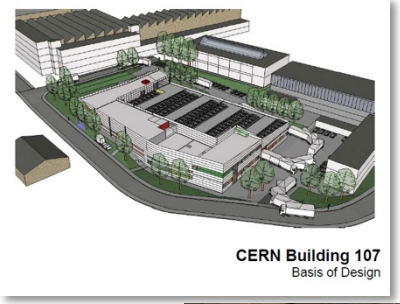


Production and
Industrialization

RD51 related infrastructures:

1) EP DT MPT Workshop (Head: Rui De Oliveira)

The heart of the MPGD Globe: Design, prototyping, production
New infrastructure (building, MPGD production machines, clean room etc) will be soon ready



2) GDD Laboratory (RD51)

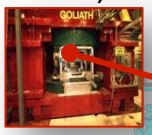
The Detector R&D laboratory:

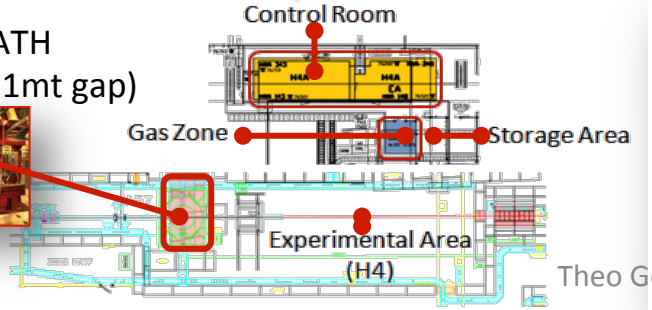
- **Permanent users (ALICE, ATLAS, ESS)**
- **Temporary Users stations**
- **Cosmic stands, X-ray and radioactive sources**
- **Clean room, Workshop**
- **Vacuum and Gas System**
- **MPGD Electronics support**
- **15 visiting groups, synergies with companies**

Laboratory (140m^2)

3) Test Beam Area (SPS/H4 semi permanent RD51 area)

GOLIATH
(1.5T Max, 1mt gap)





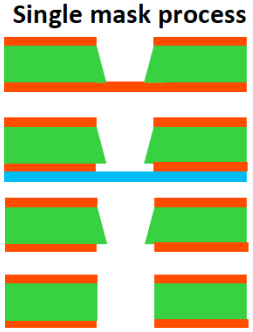
R&D for Experiment
HEP Experiments:
LHC upgrades
CERN & Others
Applications
Electronics

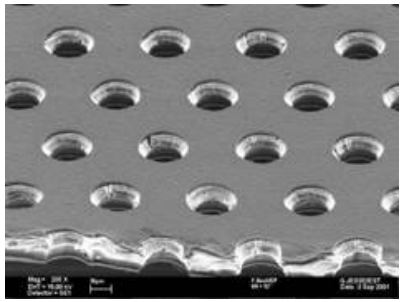
Organize test beam
3 times (2 weeks)/year

RD51 Technological achievements (I)

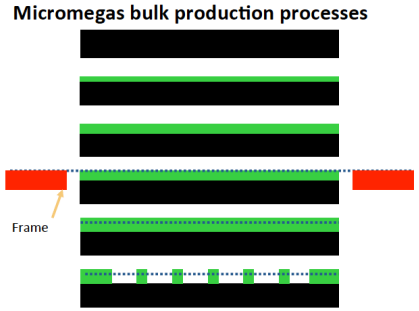
- **Large MPGDs production/industrialization of GEM, THGEM, Micromegas:**

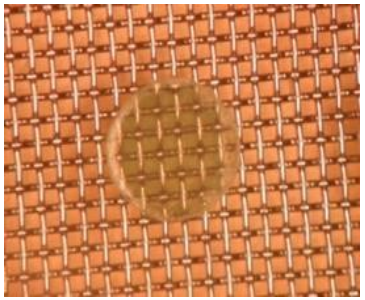
single mask GEM





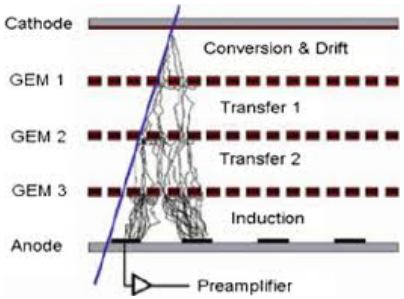
Bulk Micromegas



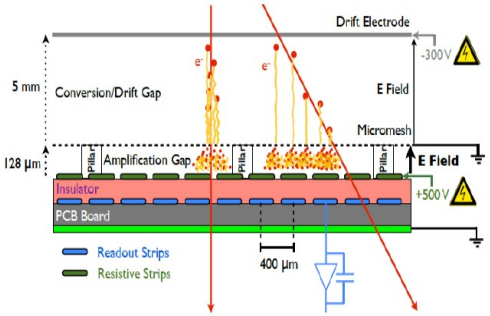


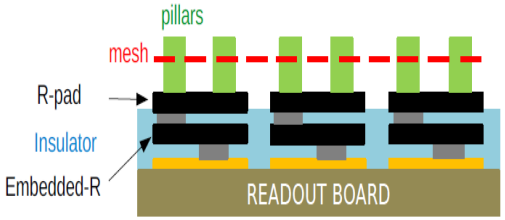
- **High rates and spark mitigation:**

Staged Gain: multiple layers
GEM, THGEM, MHSP



Resistive coating, buried resistors
Micromegas, RETGEM, RPWELL



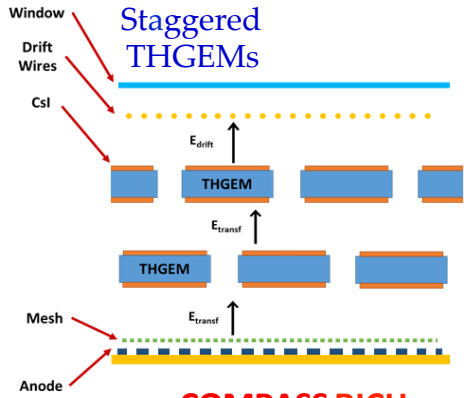


RC-constant controlled with embedded R-pattern

RD51 Technological achievements (II)

- **Ion Back Flow (IBF)**, Application in TPCs (field distortion) and photon detection (photocathode protection): Multiple Layers

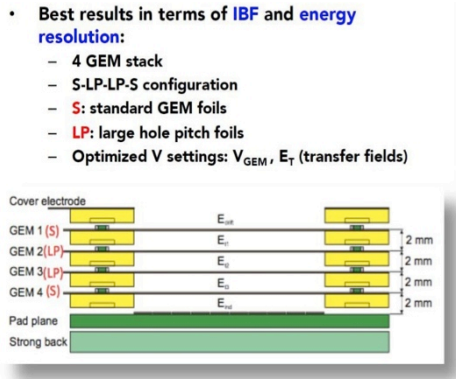
Hybrid: THGEM+ CsI and MM



COMPASS RICH

IBF ~ 5. 10^{-2}

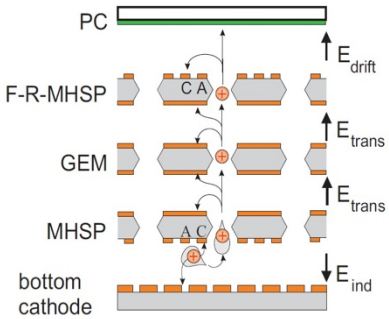
Multi layer GEM



ALICE TPC

IBF ~ (5 – 25) . 10^{-3}

stack MHSP/GEM/F-R-MSHP



IBF ~ (1-3) . 10^{-4}

- **Radiation hardness**

  LHC MPGD Upgrades (ATLAS NSW project - Resistive Micromegas and CMS GEM muon chambers) proven to withstand the equivalent of 10 years of operation at the HL-LHC. Irradiation with: neutrons, X-rays, α and β .

RD51 Technological achievements (III)

- **Sealed detectors** (purity) for space and non-laboratory applications

- **Physics simulations and tools**

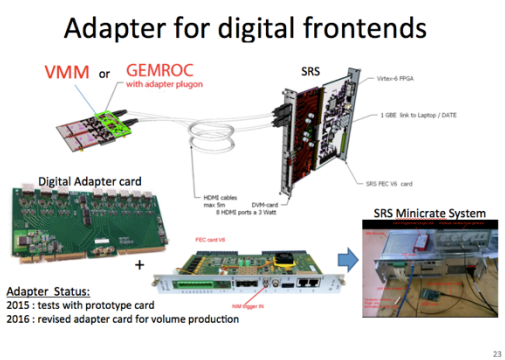
  Software tools: Magboltz (transport equations), Degrad (cluster size), Garfield++ (speeding up), optimization of charging up simulation

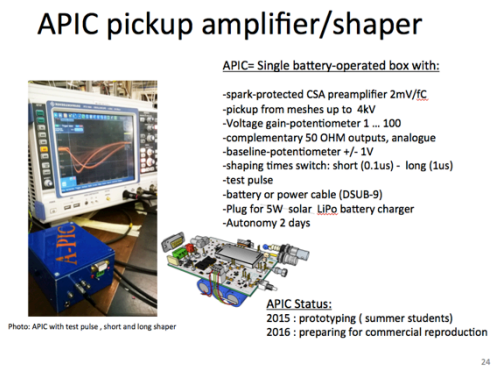
  Modeling of Physics processes: Penning in Ne mixtures, CO2 impact, GEM gas gain dependence on hole diameter, impact of mesh geometry to micromegas

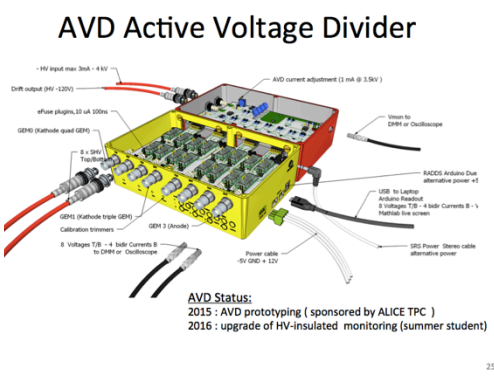
- **Read-out electronics**

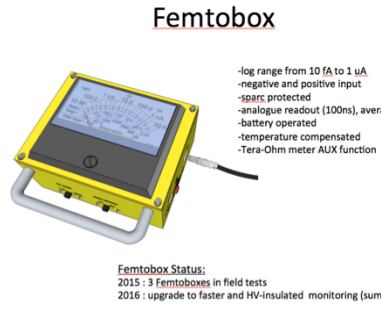
  Scalable Readout System: Development of the readout system for MPGDs adaptable to various FE ASIC chips (APV25, VMM2, GEMRoc)

  Development of generic electronic devices for MPGDs:









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**

MPGD Technologies: LHC experiments Upgrades

Challenges: Ultra high rates, radiation harsh environment, longevity, large area detectors

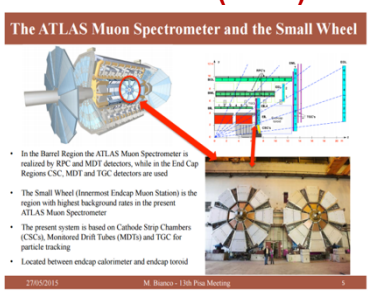
Present:

TOTEM (GEM), LHCb (GEM)

Future:

ATLAS Muon System NSW (μM), Muon tagger μ-PIC, CMS Muon System (GEM), ALICE (GEM TPC), FCC Collider (GEM, THGEM, Micromegas, μ-PIC, InGrid)

ATLAS NSW (mm)



The ATLAS Muon Spectrometer and the Small Wheel

- In the Barrel Region the ATLAS Muon Spectrometer is realized by RPC and MDT detectors, while in the End Cap Regions CSC, MDT and TGC detectors are used
- The Small Wheel (Innermost Endcap Muon Station) is the region with highest background rates in the present ATLAS Muon Spectrometer
- The present system is based on Cathode Strip Chambers (CSCs), Monitored Drift Tubes (MDTs) and TGC for particle tracking
- Located between endcap calorimeter and endcap toroid

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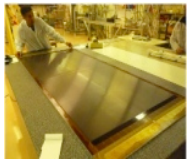

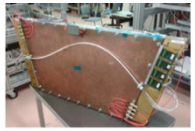

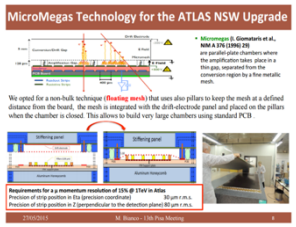

MicroMegas Technology for the ATLAS NSW Upgrade

- Micromegas (I. Giomataris et al., NIM A 376 (1996) 29) are parallel-plate chambers where the amplification takes place in a thin gap, separated from the conversion region by a fine metallic mesh.

We opted for a non-bulk technique (**floating mesh**) that uses also pillars to keep the mesh at a defined distance from the board, the mesh is integrated with the drift-electrode panel and placed on the pillars when the chamber is closed. This allows to build very large chambers using standard PCB.

Requirements for a μ momentum resolution of 15% @ 1TeV in Atlas

Precision of strip position in Eta (precision coordinate) 30 μm r.m.s.

Precision of strip position in Z (perpendicular to the detection plane) 80 μm r.m.s.

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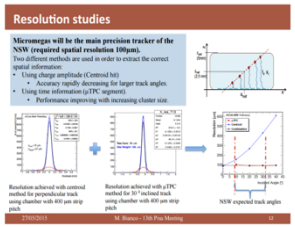

Resolution studies

Micromegas will be the main precision tracker of the NSW (required spatial resolution 100μm).

Two different methods are used in order to extract the correct spatial information:

- Using charge amplitude (Centroid hit)
  - Accuracy rapidly decreasing for larger track angles.
- Using time information (μTPC segment).
  - Performance improving with increasing cluster size.

Resolution achieved with centroid method for perpendicular track using chamber with 400 μm strip pitch

Resolution achieved with μTPC method for 30° inclined track using chamber with 400 μm strip pitch

NSW expected track angles

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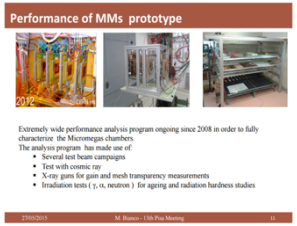

Performance of MMs prototype

Extremely wide performance analysis program ongoing since 2008 in order to fully characterize the Micromegas chambers.

The analysis program has made use of:

- Several test beam campaigns
- Test with cosmic ray
- X-ray guns for gain and mesh transparency measurements
- Irradiation tests (γ, α, neutron) for ageing and radiation hardness studies

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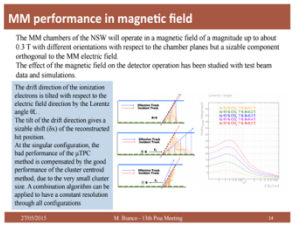

MM performance in magnetic field

The MM chambers of the NSW will operate in a magnetic field of a magnitude up to about 0.3 T with different orientations with respect to the chamber planes but a sizable component orthogonal to the MM electric field.

The effect of the magnetic field on the detector operation has been studied with test beam data and simulations.

The drift direction of the ionization electrons is tilted with respect to the electric field direction by the Lorentz angle θL.

The tilt of the drift direction gives a sizable shift (δx) of the reconstructed hit position.

At the singular configuration, the bad performance of the μTPC method is compensated by the good performance of the cluster centroid method, due to the very small cluster size. A combination algorithm can be applied to have a constant resolution through all configurations

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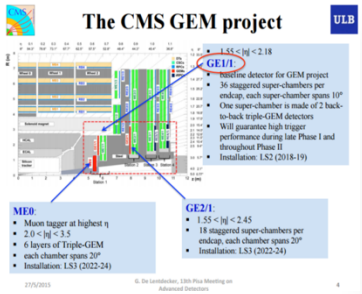
CMS (GEM)



The CMS GEM project

GE1/1:
- 1.55 < |η| < 2.18
- baseline detector for GEM project
- 36 staggered super-chambers per endcap, each super-chamber spans 10°
- One super-chamber is made of 2 back-to-back triple-GEM detectors
- Will guarantee high trigger performance during late Phase I and throughout Phase II
- Installation: LS2 (2018-19)

ME0:
- Muon tagger at highest η
- 2.0 < |η| < 3.5
- 6 layers of Triple-GEM
- each chamber spans 20°
- Installation: LS3 (2022-24)

GE2/1:
- 1.55 < |η| < 2.45
- 18 staggered super-chambers per endcap, each chamber spans 20°
- Installation: LS3 (2022-24)

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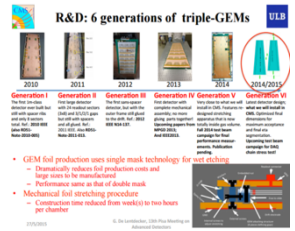

R&D: 6 generations of triple-GEMs

2010	2011	2012	2013	2014	2014/2015
Generation I	**Generation II**	**Generation III**	**Generation IV**	**Generation V**	**Generation VI**
The first 1m-class detector ever built but still with spacer ribs and only 8 sectors total. Ref.: **2010 IEEE (also RD51-Note-2010-005)**	First large detector with 24 readout sectors (3x8) and 3/1/2/1 gaps but still with spacers and all glued. Ref.: 2011 IEEE. Also **RD51-Note-2011-013.**	The first sans-spacer detector, but with the outer frame still glued to the drift. Ref.: **2012 IEEE N14-137.**	First detector with complete mechanical assembly; no more gluing parts together! **Upcoming papers from MPGD 2013; And IEEE2013.**	Very close to what we will install in CMS. Features re-designed stretching apparatus that is now totally inside gas volume. **Fall 2014 test beam campaign for final performance measurements. Publication pending.**	Latest detector design; **what we will install in CMS.** Optimized final dimensions for maximum acceptance and final eta segmentation. **Upcoming test beam campaign for DAQ chain stress test!**

- GEM foil production uses single mask technology for wet etching
  - Dramatically reduces foil production costs and large sizes to be manufactured
  - Performance same as that of double mask
- Mechanical foil stretching procedure
  - Construction time reduced from week(s) to two hours per chamber

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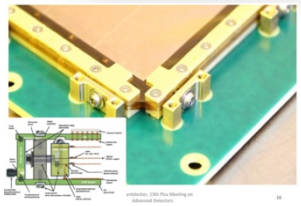

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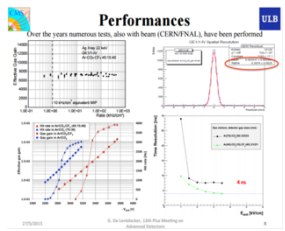

Performances

Over the years numerous tests, also with beam (CERN/FNAL), have been performed

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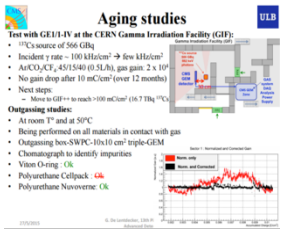

Aging studies

Test with GE1/1-IV at the CERN Gamma Irradiation Facility (GIF):

- ^{137}Cs source of 566 GBq
- Incident γ rate ~ 100 kHz/cm² → few kHz/cm²
- Ar/CO$_2$/CF$_4$:45/15/40 (0.5L/h), gas gain: 2 x 10^4
- No gain drop after 10 mC/cm² (over 12 months)
- Next steps:
  - Move to GIF++ to reach >100 mC/cm² (16.7 TBq ^{137}Cs)

Outgassing studies:

- At room T° and at 50°C
- Being performed on all materials in contact with gas
- Outgassing box-SWPC-10x10 cm² triple-GEM
- Chomatograph to identify impurities
- Viton O-ring : Ok
- Polyurethane Cellpack : ~~Ok~~
- Polyurethane Nuvoverne: Ok

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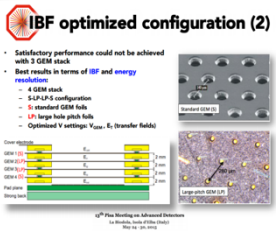
ALICE (GEM)

Content

- The ALICE upgrade strategy
- ALICE TPC overview
- Operation from RUN1 to RUN3
- GEM readout for the TPC
- Ion backflow optimization
- Prototype tests
- Expected performance in RUN3
- Read-out electronics
- Summary and Outlook



IBF optimized configuration (2)

- Satisfactory performance could not be achieved with 3 GEM stack
- Best results in terms of IBF and energy resolution:
  - 4 GEM stack
  - S-LP-LP-S configuration
  - S: standard GEM foils
  - LP: large hole pitch foils
  - Optimized V settings: V_{GEM}, E_T (transfer fields)

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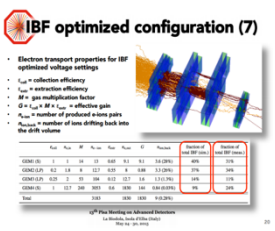

IBF optimized configuration (7)

- Electron transport properties for IBF optimized voltage settings
- ε_{coll} = collection efficiency
- ε_{extr} = extraction efficiency
- M = gas multiplication factor
- $G = \varepsilon_{coll} \times M \times \varepsilon_{extr}$ = effective gain
- $n_{e\text{-}ion}$ = number of produced e-ions pairs
- $n_{ion,back}$ = number of ions drifting back into the drift volume

	ε_{coll}	$n_{e,in}$	M	$n_{e\text{-}ion}$	ε_{extr}	$n_{e,out}$	G	$n_{ion,back}$	fraction of total IBF (sim.)	fraction of total IBF (meas.)
GEM1 (S)	1	1	14	13	0.65	9.1	9.1	3.6 (29%)	40%	31%
GEM2 (LP)	0.2	1.8	8	12.7	0.55	8	0.88	3.3 (26%)	37%	34%
GEM3 (LP)	0.25	2	53	104	0.12	12.7	1.6	1.3 (1.3%)	14%	11%
GEM4 (S)	1	12.7	240	3053	0.6	1830	144	0.84 (0.03%)	9%	24%
Total				3183		1830	1830	9 (0.29%)		

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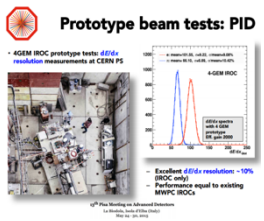

Prototype beam tests: PID

- 4GEM IROC prototype tests: dE/dx resolution measurements at CERN PS
  - Excellent dE/dx resolution: ~10% (IROC only)
  - Performance equal to existing MWPC IROCs

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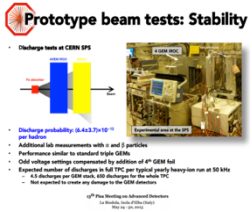

Prototype beam tests: Stability

- Discharge tests at CERN SPS
- Discharge probability: (6.4±3.7)×10^{-12} per hadron
- Additional lab measurements with α and β particles
- Performance similar to standard triple GEMs
- Odd voltage settings compensated by addition of 4th GEM foil
- Expected number of discharges in full TPC per typical yearly heavy-ion run at 50 kHz
  - 4.5 discharges per GEM stack, 650 discharges for the whole TPC
  - Not expected to create any damage to the GEM detectors

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GEM / Micromegas : Technology Developments Highlights

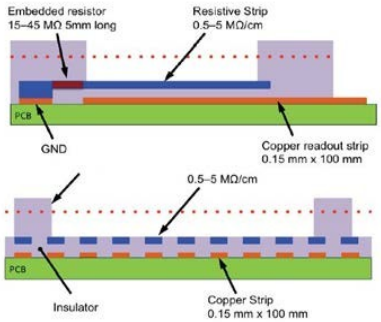
MM for the ATLAS Muon System Upgrade:

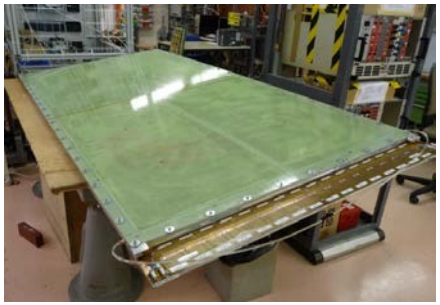
Standard Bulk MM suffers from limited efficiency at high rates due to discharges induced dead time

Solution: Resistive Micromegas technology:

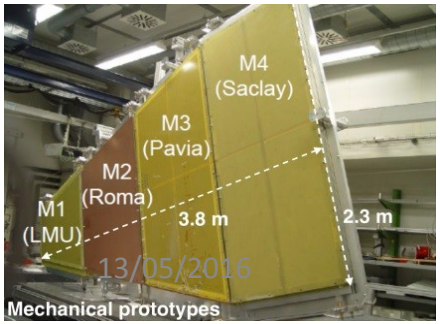
→ Add a layer of resistive strips above the readout strips

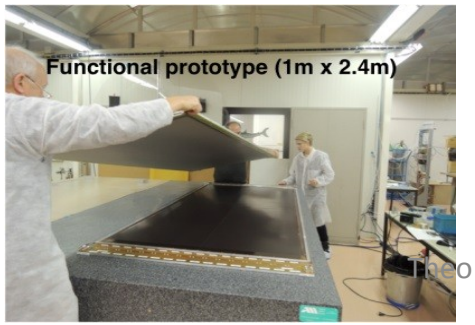
❖Spark neutralization/ suppression (sparks still occur, but become inoffensive)





2.4 x 1m^2
MM resistive chamber constructed and characterized at CERN RD51 lab

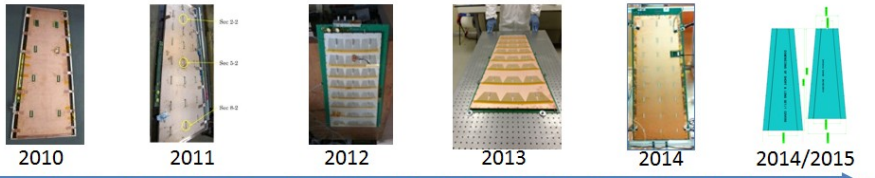




GEMs for the CMS Muon System Upgrade:

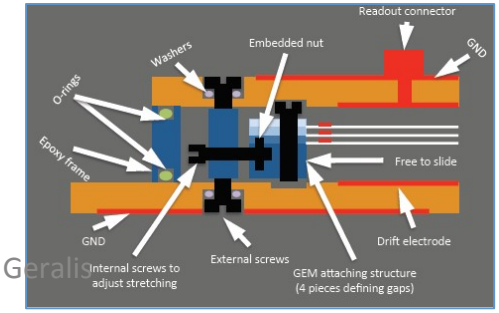
Single-mask GEM technology (instead of double-mask)
→ Reduces cost /allows production of large-area GEM

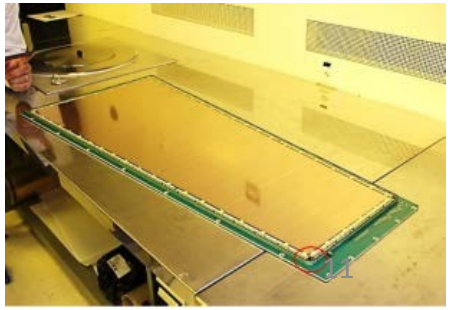
→ R&D: 6 generations of triple-GEM detectors



2010	2011	2012	2013	2014	2014/2015
Generation I	**Generation II**	**Generation III**	**Generation IV**	**Generation V**	**Generation VI**
The first 1m-class detector ever built but still with spacer ribs and only 8 sectors total. **Ref.: 2010 IEEE (also RD51-Note-2010-005)**	First large detector with 24 readout sectors (3x8) and 3/1/2/1 gaps but still with spacers and all glued. **Ref.: 2011 IEEE. Also RD51-Note-2011-013.**	The first sans-spacer detector, but with the outer frame still glued to the drift. **Ref.: 2012 IEEE N14-137.**	First detector with complete mechanical assembly; no more gluing parts together! **MPGD 2013; and IEEE2013.**	Nearly final CMS design: stretching apparatus that is now totally inside gas volume. **Ongoing test beam campaign for final performance measurements.**	Latest detector design; **to be installed in CMS.** Optimized final dimensions for max. acceptance and final eta segmentation. **Ongoing test beam campaign for DAQ**

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

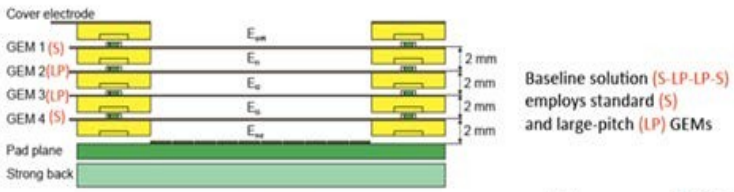


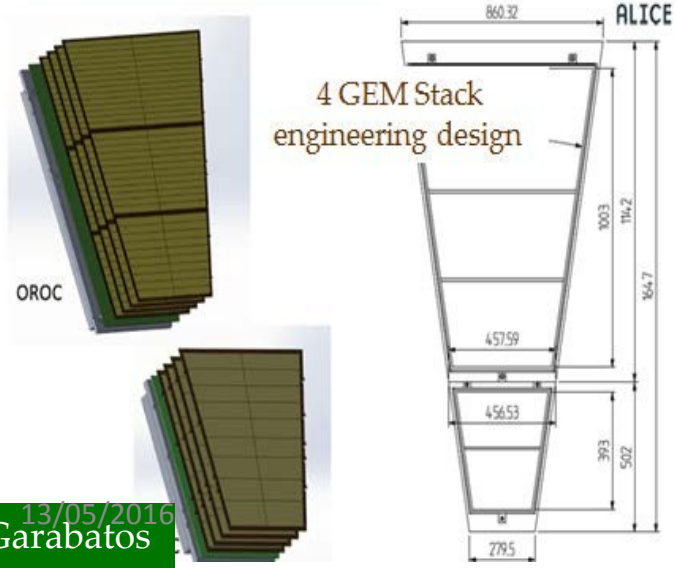


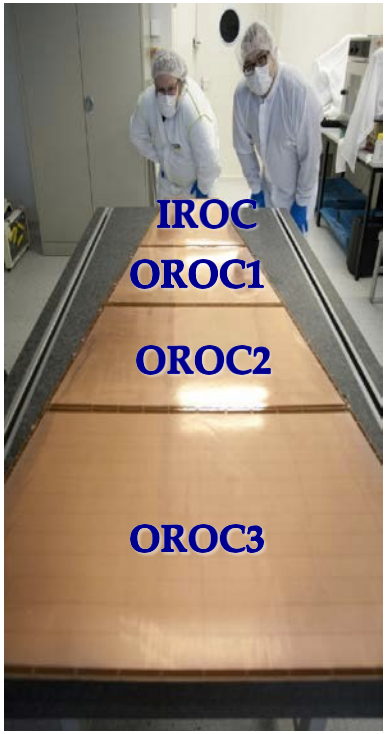
ALICE Time Projection Chamber Endplate Upgrade with GEMs

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



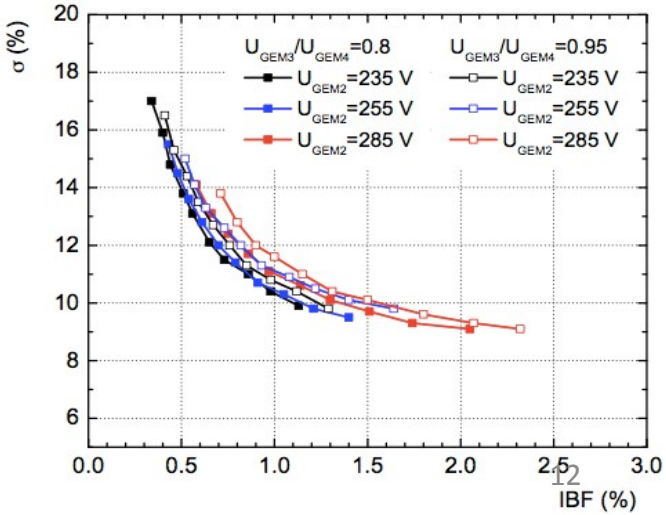




Preproduction:

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



MPGD Technologies: Hadron and Nuclear and Heavy Ion Physics experiments

Challenges: Ultra High rates, IBF

Present:

COMPASS (GEM, μ Megas, THGEM RICH), rates: 100kHz/mm^2

First experiment to use MPGDs (GEM, Micromegas and recently THGEM)

KEDR (GEM), Rates: 1MHz/mm^2

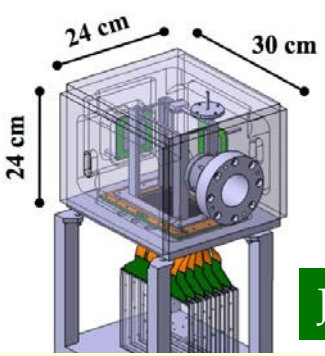
CLAS12: Cylindrical MM

Future: JLAB: SBS, pRad, SoLID (GEM, NP, tracking), JPARC: E42, E45 (Hadron Physics, ACTAR TPC

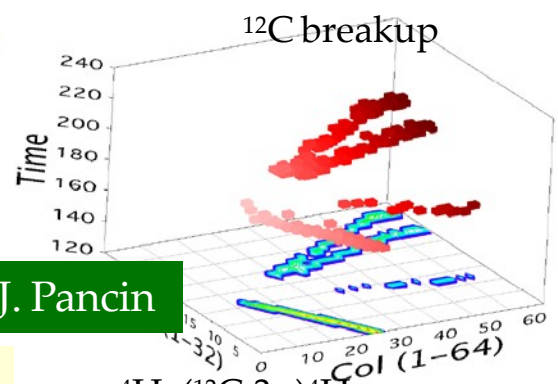
The ACTAR TPC Project

(gas is used as a secondary target for nuclear reactions):

Goal: Nuclear structure with rare-isotope beams



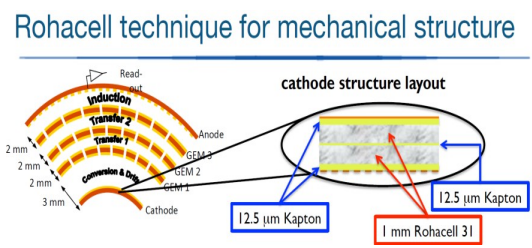
MM-based readout



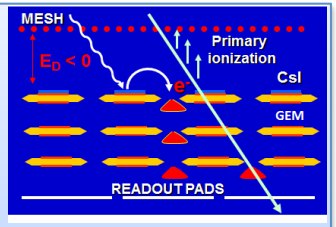
J. Pancin

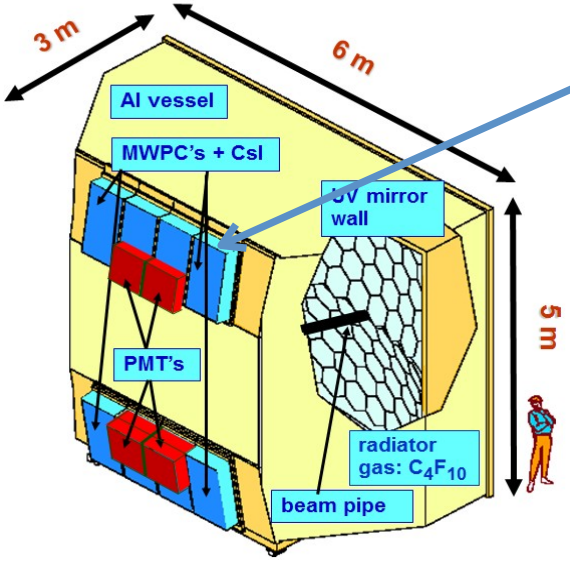
^{4}He(^{12}C,3α)^{4}He

Cylindrical GEM for BESIII Experiment @ e+e- collider Beijing

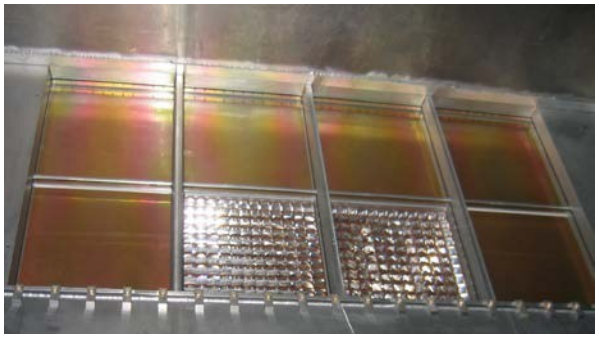


MPGD Technologies: Photon detection
Challenges: IBF photocathode protection
Present:
COMPASS (THGEM RICH)
Future: JLAB: SBS, pRad, SoLID (GEM, NP, tracking), JPARC: E42, E45 (Hadron Physics, ACTAR TPC



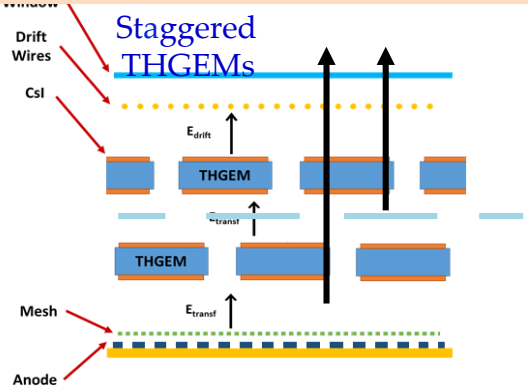


MWPC's + CsI



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.

MPGD Technologies: Neutron detectors (ITER spallation sources, Beam diagnostics)

Challenges: Low mass detectors

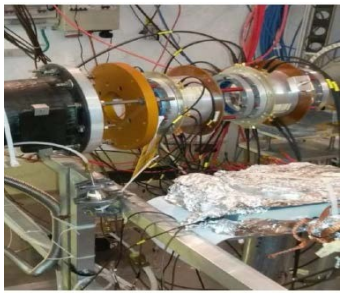
Present:

nTOF

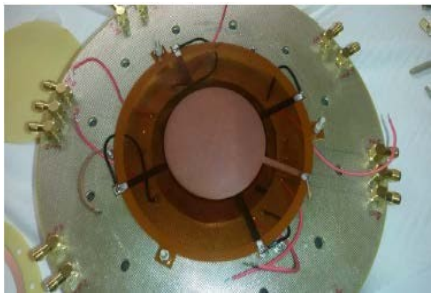
Future:

ESS (macromolecular chrystallography, neutron scattering)

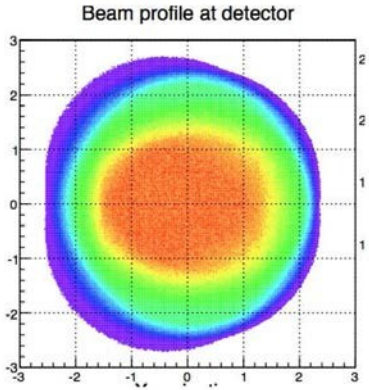
nTOF at CERN



Installation on NTOF



4 pad detector



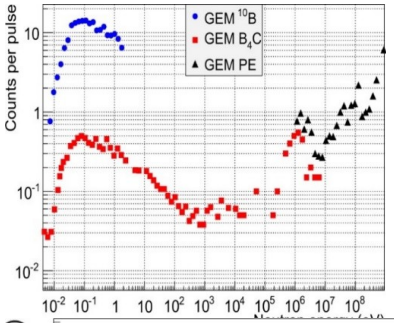
μMegas detector:

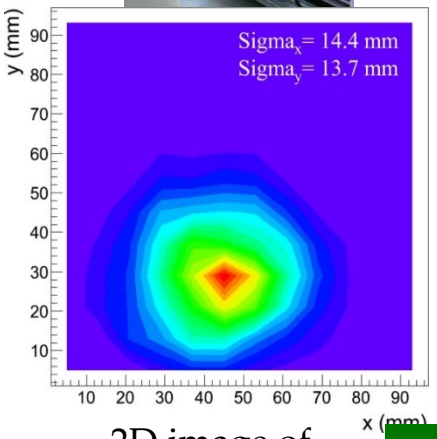
2 D reconstructed image

T. Papaevangelou

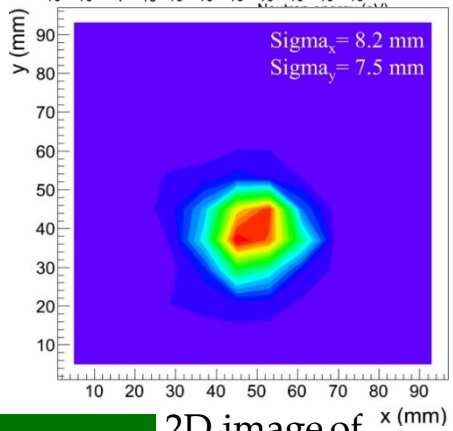
μM Neutron Monitor applied to fission reactor

GEM detector





2D image of thermal neutron

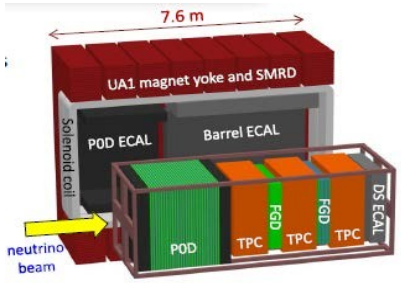


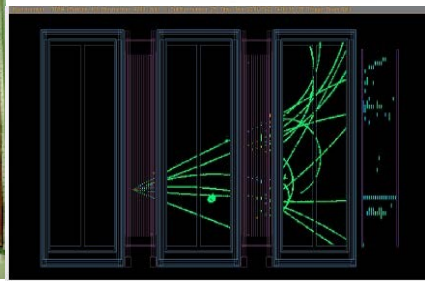
F. Murtas

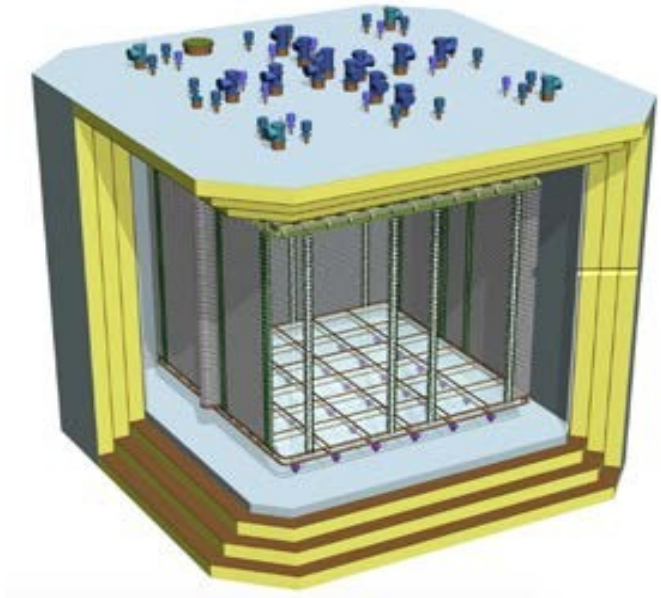
2D image of fast neutron

MPGD Technologies: Neutrino Physics
Challenges: Large area TPCs
Present:
T2K (Japan), first large scale neutrino experiment with MPGD (9 m^2 TPC with micromegas)
Future:
LBNO-DEMO (LAr TPC THGEM), DUNE 720 m^2 (LAr TPC THGEM), Ship (26 m^2 micromegas, GEM, mRWELL)

T2K experiment







- 72 Micromegas,120k channels (since 2009)
- Charge, momentum and dE/dx PID)
- Spatial resolution : 0.6 mm
- Momentum res.: 9% at 1 GeV
- dE/dx: 7.8 % (distinguish μ/e, identify ν_e)

MPGD Technologies: Dark Matter detection

Challenges: Ultra low background detectors < 10^{-7}cnts/keV/cm^2

Present:

CAST (Micromegas μ bulk and Ingrid), NEWAGE (Kamioka, TPC GEM, μ PIC)

Future:

PANDA-X(TPC μ bulk micromegas, DARWIN (THGEM GMPT), IAXO (μ bulk micromegas)

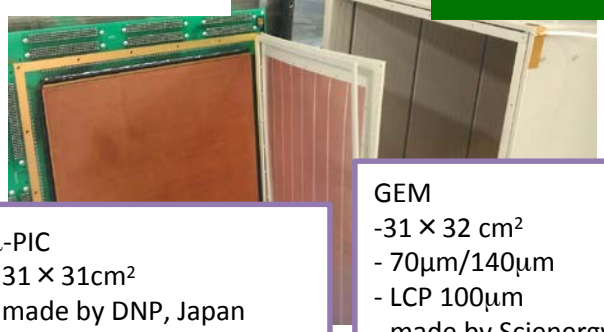
NEWAGE

μ-PIC based TPC with electronics

Only DM experiment with 3-D tracks

NEWAGE-0.3b'

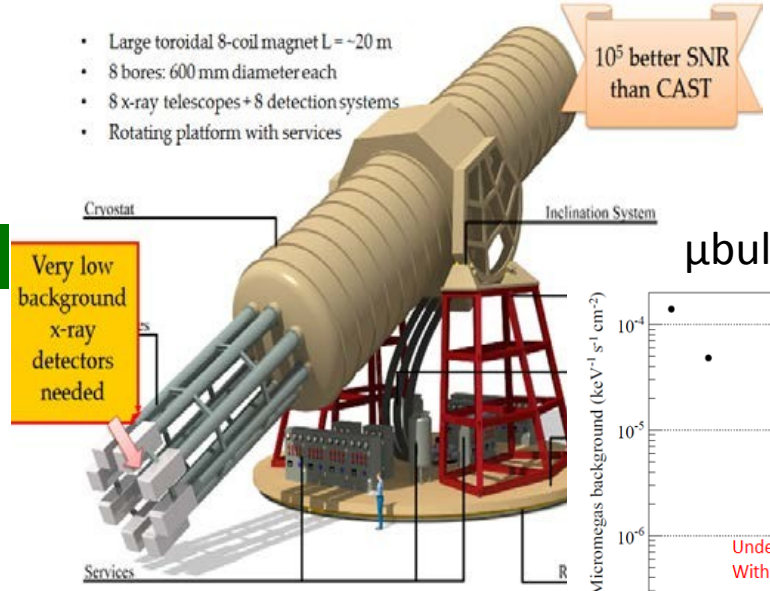
K. Miuchi, A. Ochi



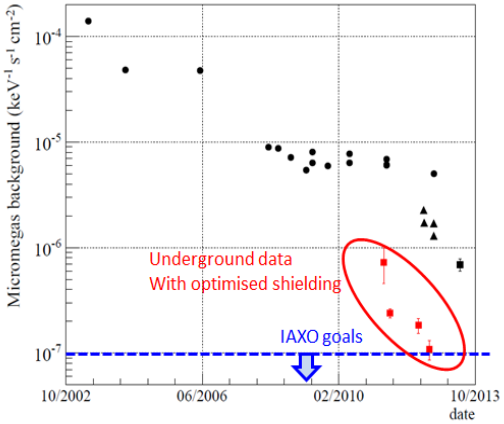
μ-PIC
- 31 × 31cm²
- made by DNP, Japan

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

IAXO: Axion searches



μbulk background



MPGD Technologies: X and γ ray detection and polarimetry

Astrophysics and fusion plasma monitor

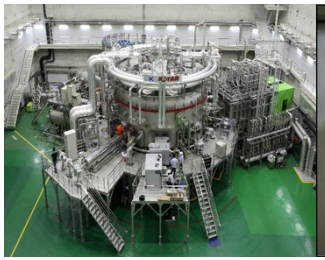
Challenges: Track photoelectrons and low energy e

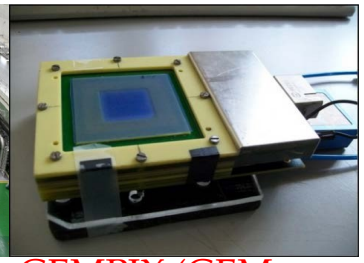
Present:

KSTAR Korea (Plasma monitor), SMILE II (γ-ray imaging, GEM and μPIC) , ETCC camera (GEM and μPIC) environmental γ ray monitoring

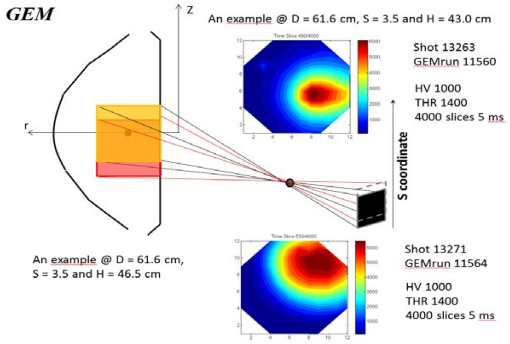
Future:

PRAXyS (TPC GEM x-ray polarimetry), CALISTE (piggy back micromegas, X-ray polarimetry)

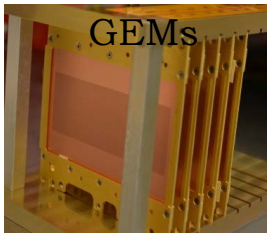


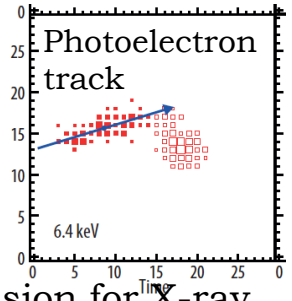


KSTAR Tokamak GEMPIX (GEM + Timepix) for fusion



PRAXyS X-ray polarimetry

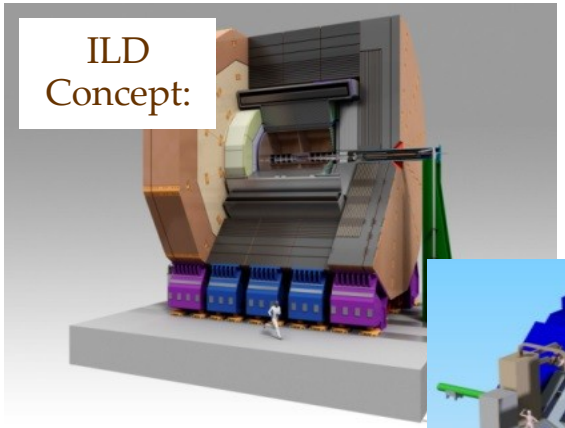


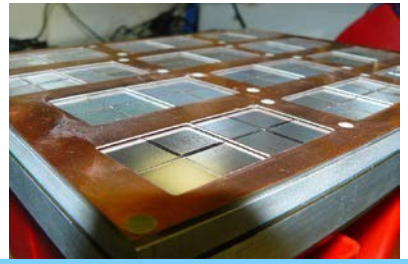


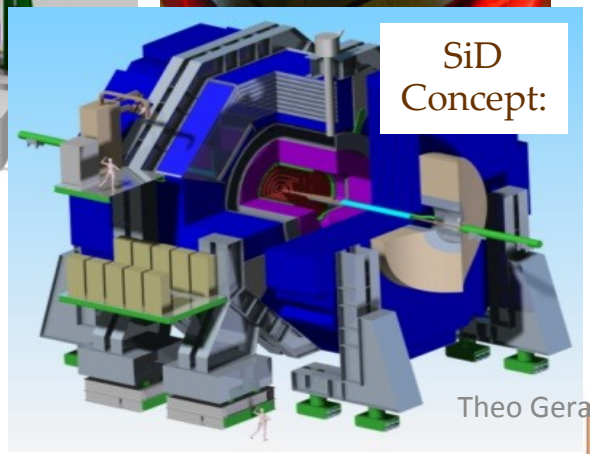
- The first dedicated mission for X-ray polarimetry in astrophysics
- US-Japan joint mission (NASA lead)
- The space craft carries two identical **GEM-TPC**

MPGD Technologies for the International Linear Collider

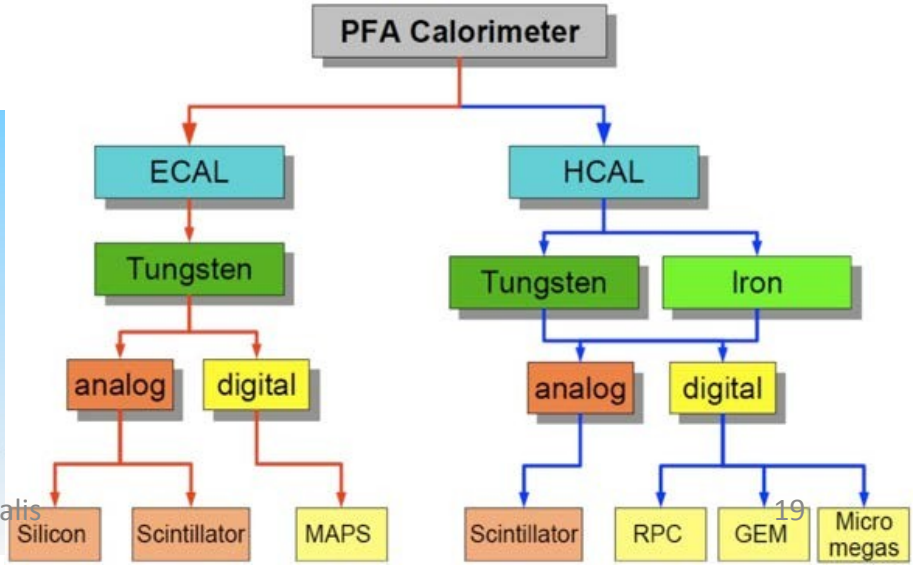
Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements/ Remarks
ILC Time Projection Chamber for ILD: Start: >2030	High Energy Physics (tracking)	Micromegas GEM (pads) InGrid (pixels)	Total area: ~ 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







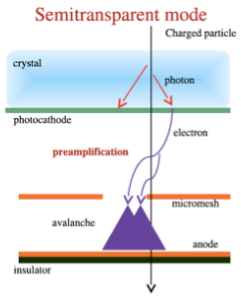
Particle Flow Calorimetry (ILD/SiD):



Generic Detector R&D

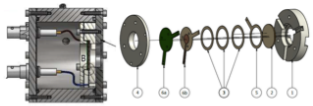
Collaboration with Saclay and Princeton

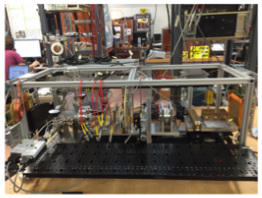
Fast timing with MM

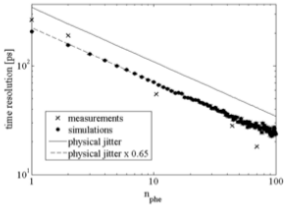


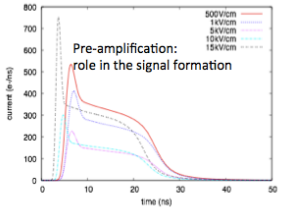
Aim at < 50ps resolution
- Cherenkov radiator
- Photocathode
- 200um drift
- MicroMeGas

R&D on:
- photocathode protection
- photocathode alternatives
- secondary emitter materials









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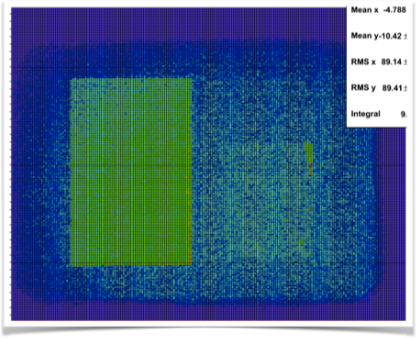
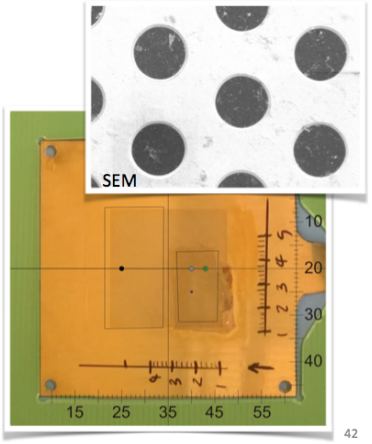
Collaboration with UCL

Graphene

Membrane opaque to ions and transparent to electrons
- solution of the ion back-flow in gaseous detectors
- protective layer on photocathodes
- enhancement of electron emission

~99% (suspended) graphene tri-layer coverage





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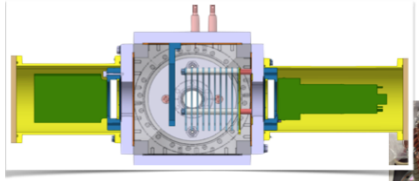
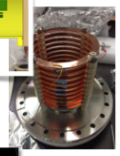
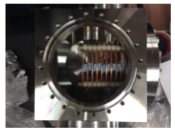
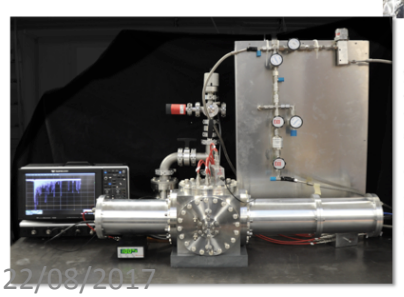
GEM optical readout and OTPC

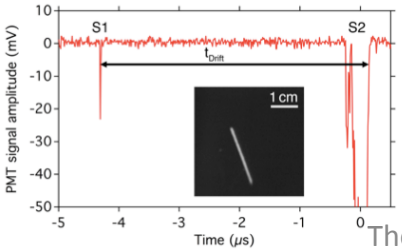




Study:
- Visible (near UV and near IR) scintillation of gasses
- Event topology study
- Imaging







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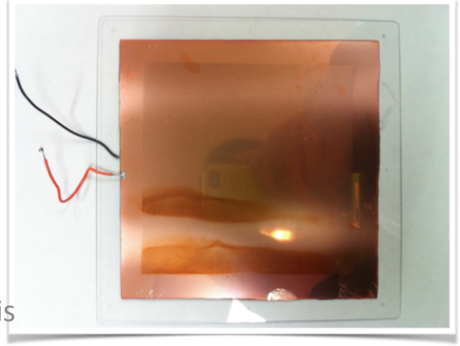
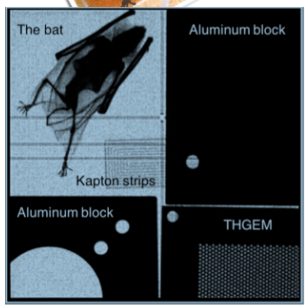
Collaboration with Tokyo University

Glass GEM

Photo Etchable Glass 3 (PEG3):
Rigid (self sustained structure)
'Laser assisted etching' opens new possibilities
Slightly conductive (milder charge-up)
Clean and low outgassing (sealed operation)

Imaging with electronic readout





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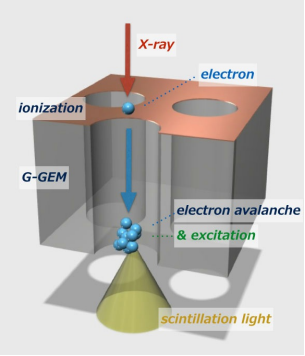
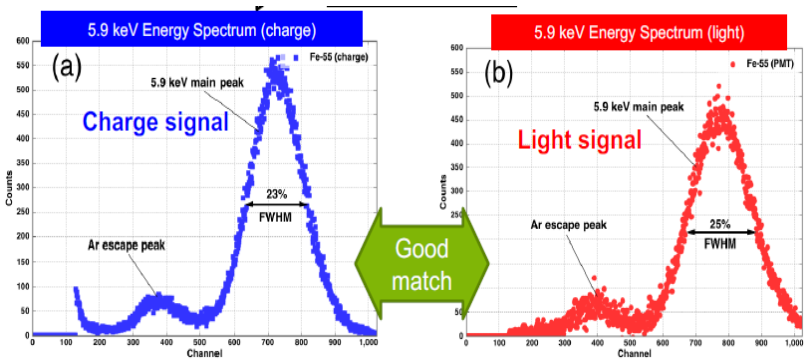
Optical Readout of MPGDs: Concepts and Applications

Scintillating Readout of Glass GEM:

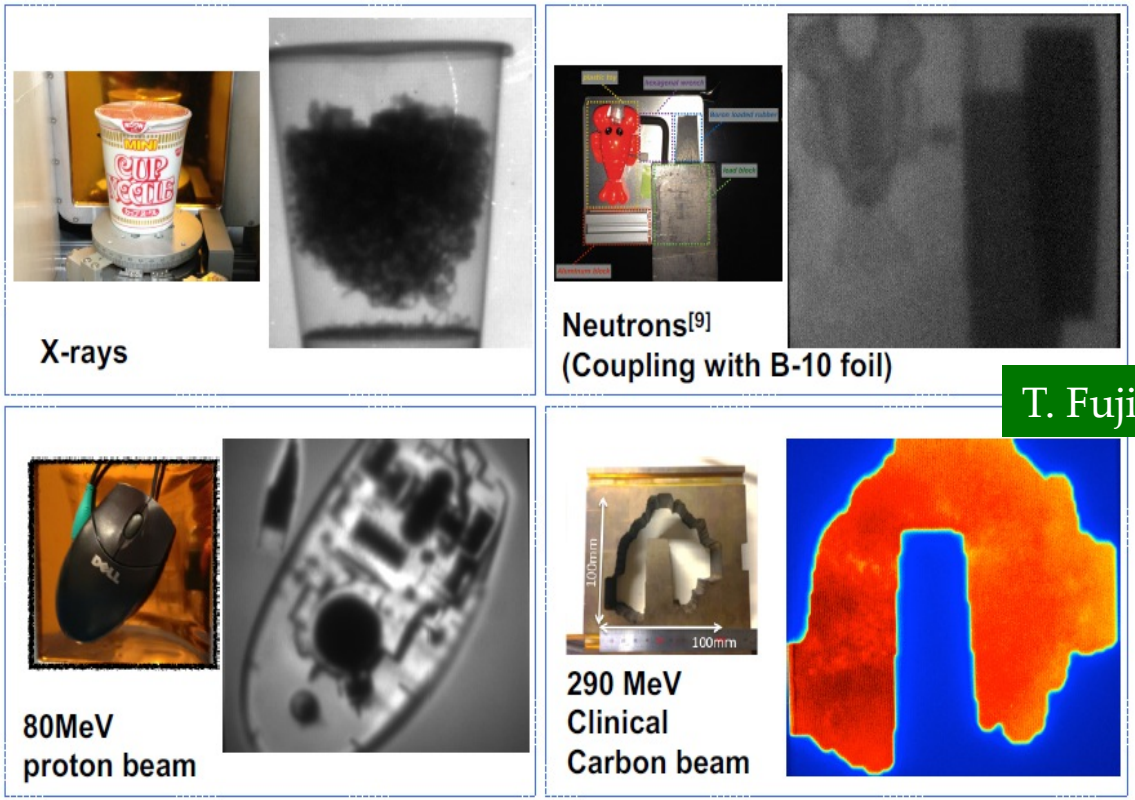
Glass GEM × scintillation gas × mirror × optical camera:

- Convert radiation into visible light
- Optical mirror to prevent the CCD from irradiated directly with X-rays





Radiography with various radiation sources:

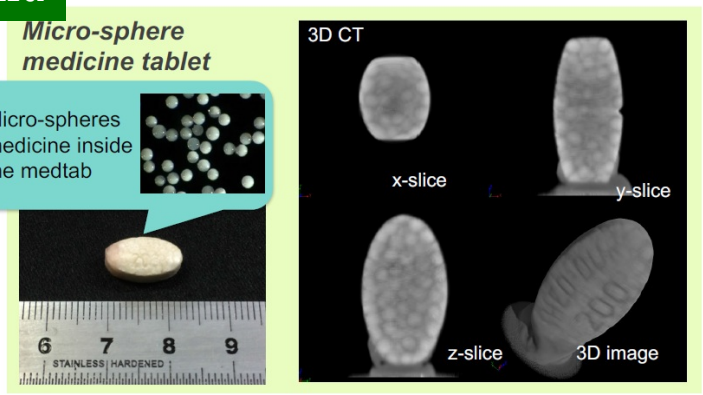


T. Fujiwara

Table 1. Comparison with inorganic scintillators

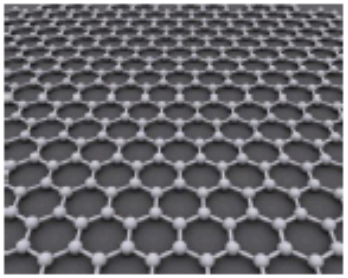
Scintillator	Photons	
CsI(Tl)	59,000 ph/MeV	Ultra high yield (orders of three)
NaI(Tl)	38,000 ph/MeV	high photon yield with low energy depositing radiation
SrI	115,000 ph/MeV	
Glass GEM + Ar/CF_4	85,000 ph/keV	

3D CT of Medicine Tablet:

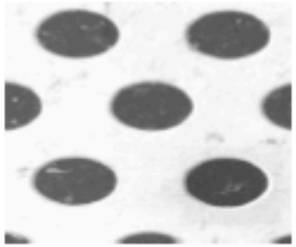


RESNATI

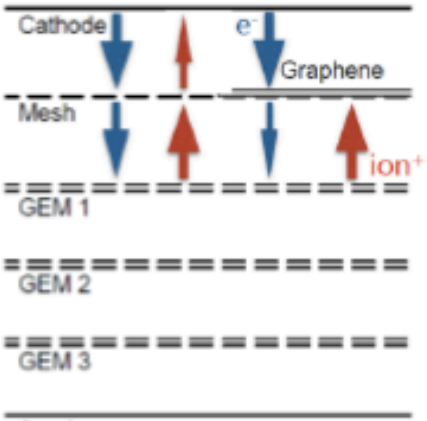
ION BLOCKING w GRAPHENE ON GEM

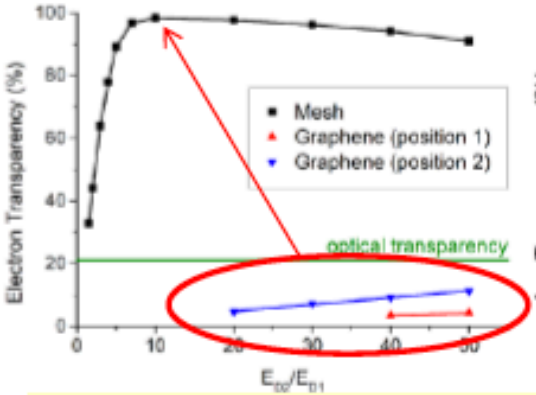


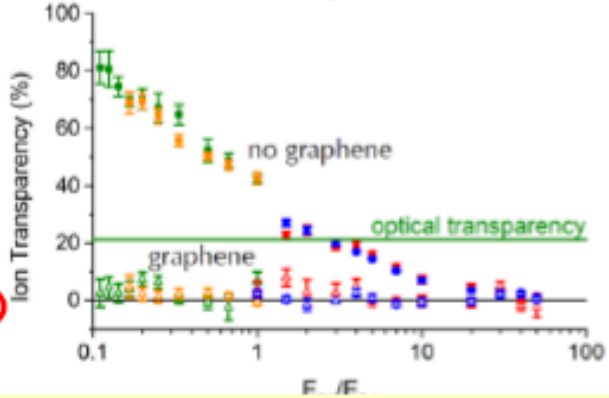
Graphene on "GEM"

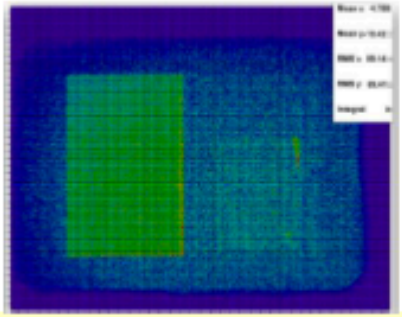


Graphene: opaque to ions and
UNDER SOME CONDITIONS:
transparent to electrons







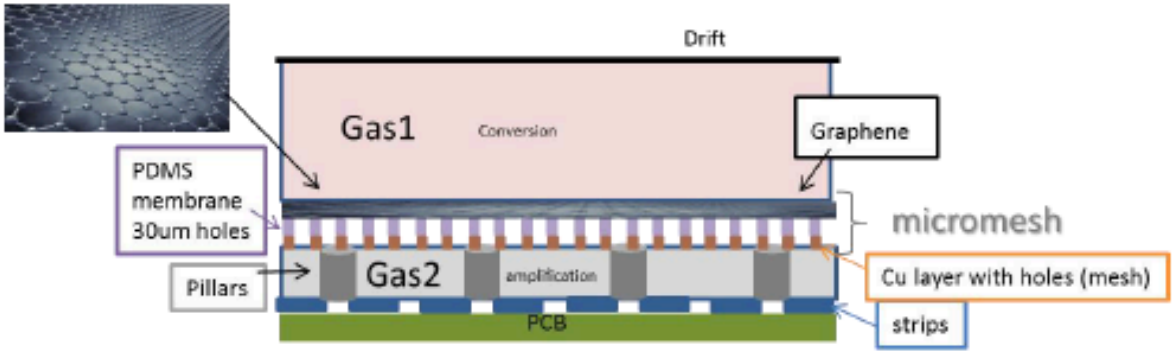


Coating GEM w GRAPHENE: need to increase e- Energy > 10kV/cm. Did not succeed to transmit e- via 3-layer Graphene. Literature: yet unclear (to our community) "directions"

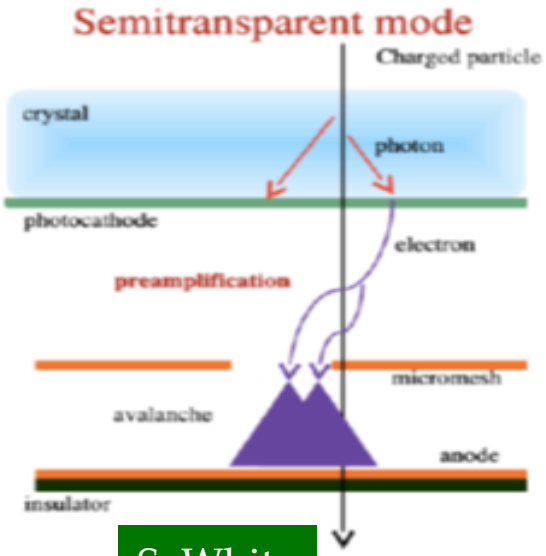
➔ **consult with surface chemists!**

GRAPHENE:
2-GASES MM detector

GERALIS



Gaseous Detector Timing, the "Picosecond Detector Concept"

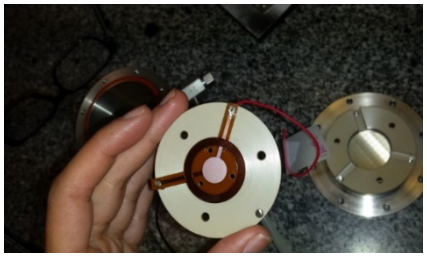


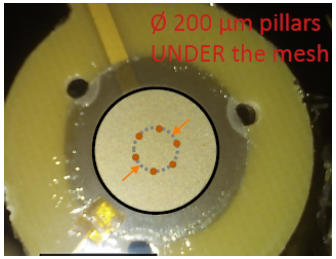
S. White

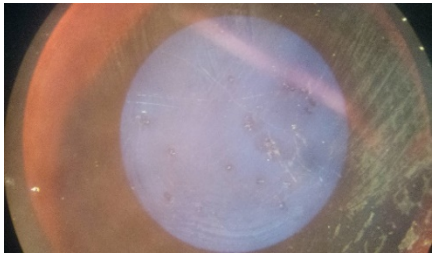
Small Drift: low diffusion, low primary ionization in gas
Pre-amplification: longitudinal diffusion reduced, effects of primary ionization in gas reduced

Aim at < 50ps resolution
- Cherenkov radiator
- Photocathode
- 200um drift
- MicroMeGas

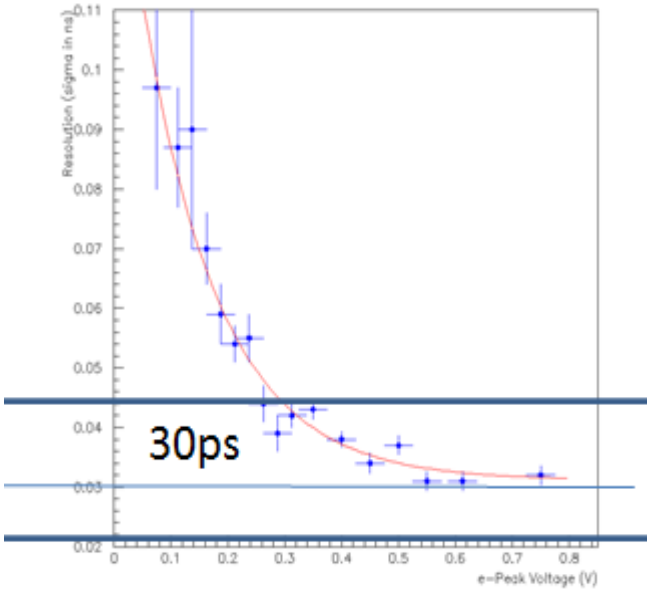
R&D on:
- photocathode protection
- photocathode alternatives
- secondary emitter materials



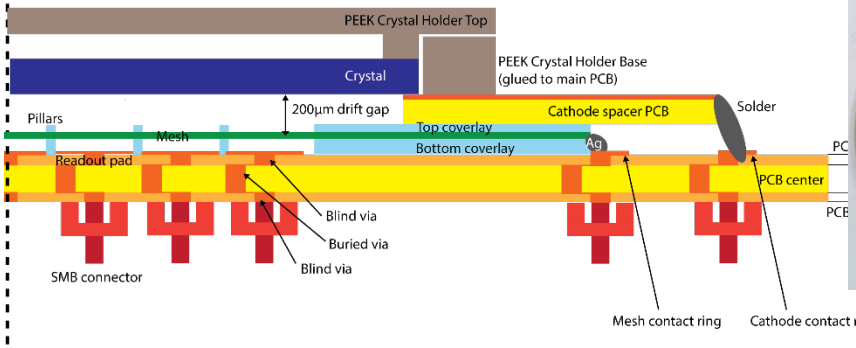


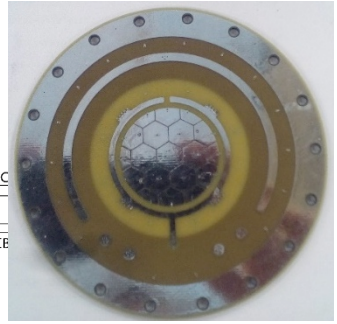


2016 Test-Beam @ CERN:



- Detector scaling (towards applications):





- Diamond as photocathode or secondary emitter..
  .. On the way of understanding what we need

E. Oliveri

MPGD Conferences and Special focus events

MPGD Conferences since 2009:
1st MPGD2009, Kolymbari, Greece
2nd MPGD2011, Kobe, Japan
3rd MPGD2013, Zaragoza, Spain
4th MPGD2015, Trieste, Italy
5th MPGD2017, Temple University, USA

1st MPGD2009, Kolymbari, Greece
80 participants, 60 abstracts

Special focus MPGD events. Most recent :
- Academia-Industry Matching event:
  Second special workshop on **neutron detection** with MPGDs, CERN, March 2015
- Rd51 Academia-Industry Matching event:
  Special workshop on **photon detection** with MPGDs, CERN, June 2015
- Topical workshop on **resistive electrodes**, CERN, Dec. 2015
- Topical workshop on **discharges** in MPGDs, CERN, March 2016
- MPGD **Applications Beyond Fundamental Science** Workshop, Aveiro, Portugal, Sept. 2016
- RD51 mini-week, **Precise timing workshop**, cern, Feb 2017.

- Schools, visits, events

CONCUSIONS

MPGD technologies have received enormous boost over the last decade

MPGDs are used in many scientific domains

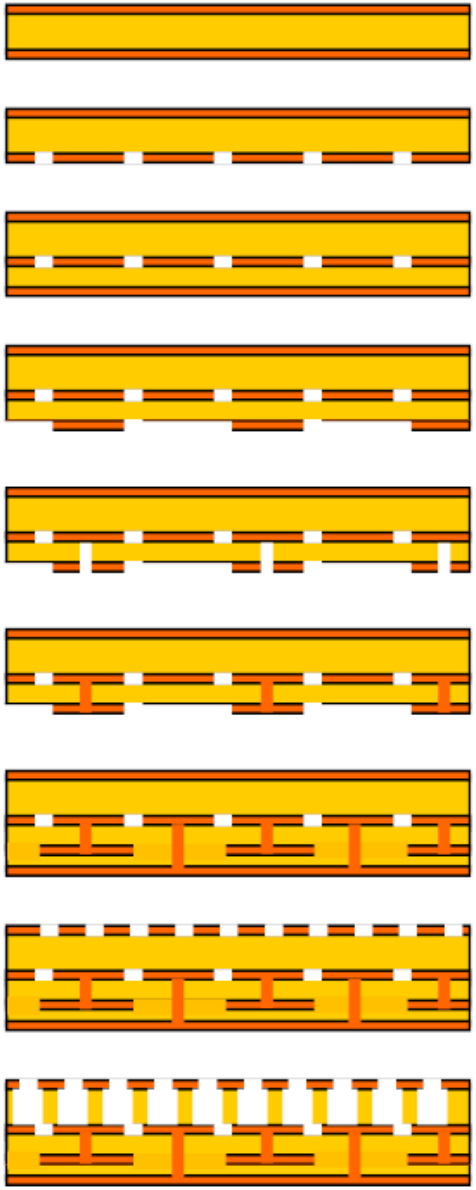
MPGDs are used in many applications beyond Particle Physics

Exciting field for creative new ideas, attractive for young scientists !

BACKUP

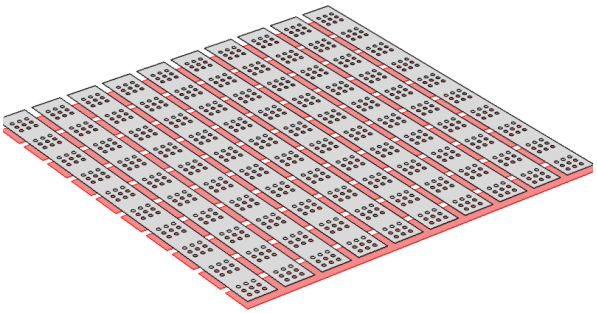
Building a Microbulk with x – y readout (Regular way): Lengthy and very delicate process

- ✓Kapton foil (50 μm), double Cu-coated (5 μm)
- ✓Construction of readout strips/pads (Photolithography)
- ✓Attachement of a single-side Cu-coated foil
- ✓Construction of readout lines
- ✓Etching of kapton
- ✓Vias construction
- ✓2nd Layer of Cu-coated kapton
- ✓Photochemical processing of mesh holes
- ✓Kapton etching
- ✓Cleaning



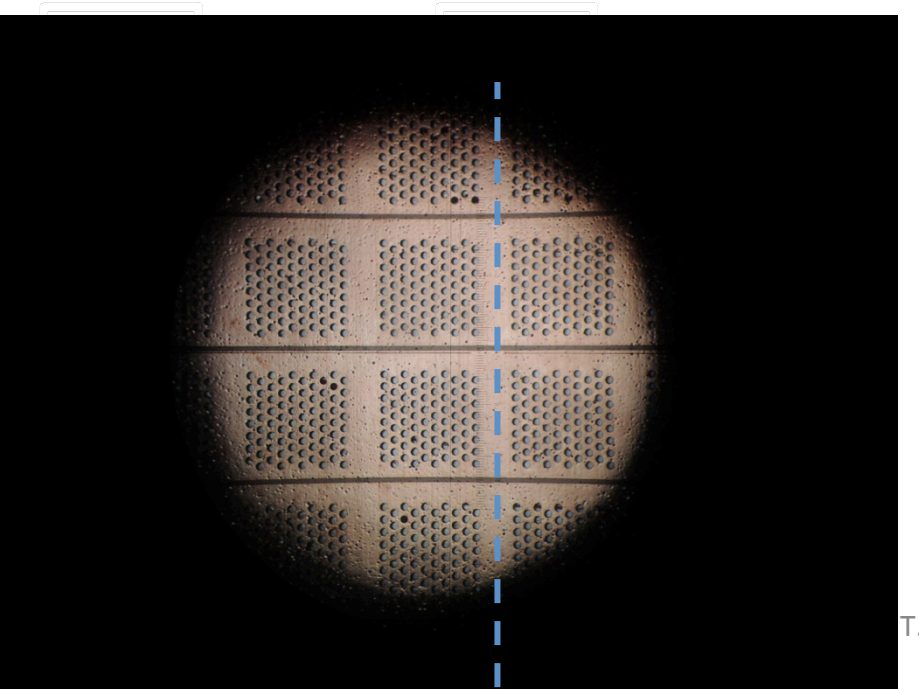
Collaboration: Demokritos, Saclay, Zaragoza, CERN

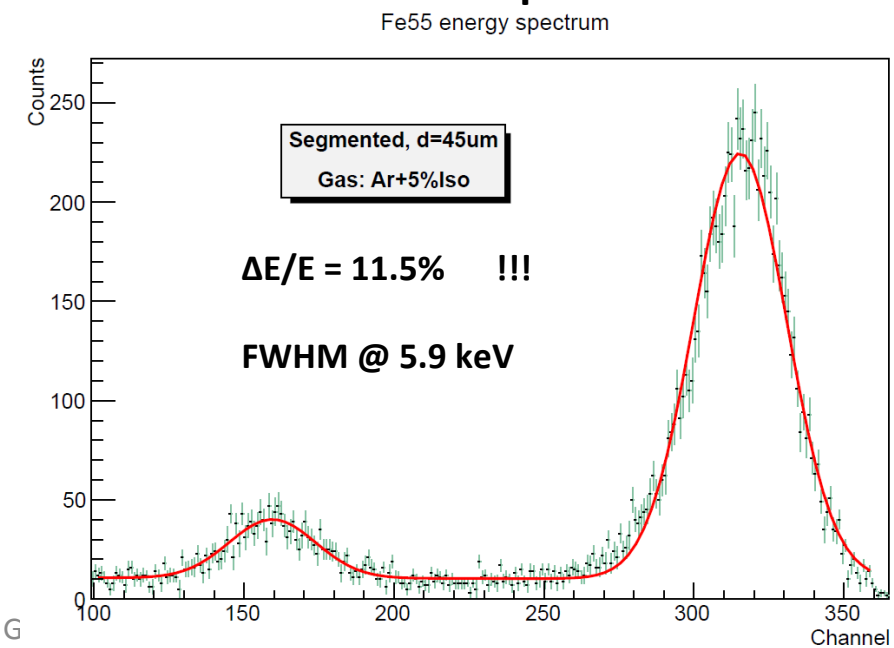
Microbulk Micromegas with segmented mesh



1) **Real x-y structure**
2) **Mass minimization**
3) **Production Simplification**
4) **Large surface detectors**

Thinnest neutron detector ever:
Thickness : 2 x 5 µm



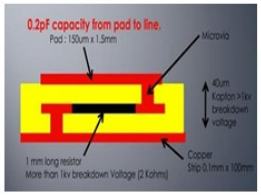


T. G

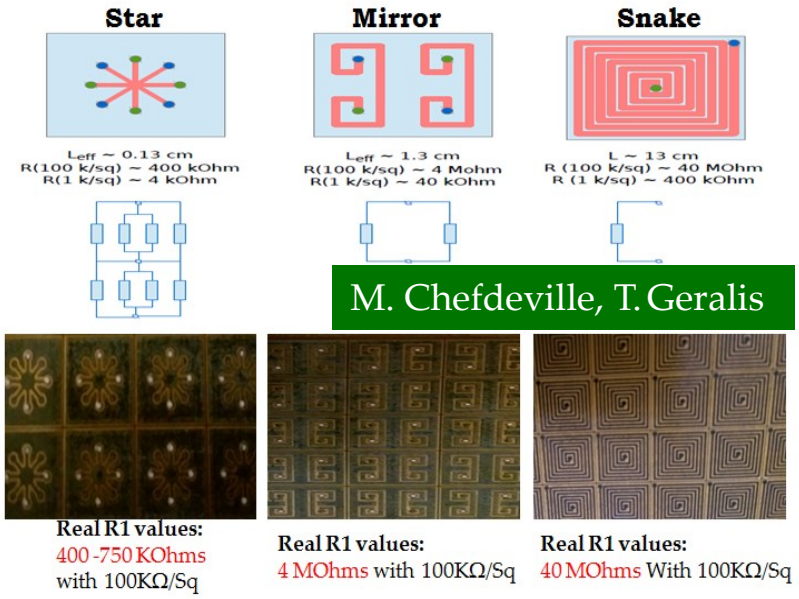
ILC DHCAL Particle Flow Calorimetry: Resistive Micromegas

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

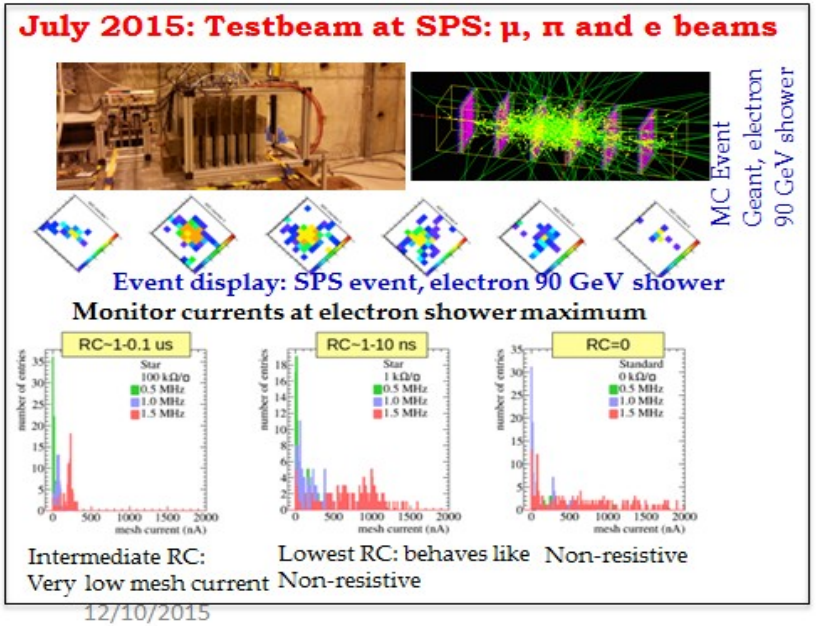


M. Chefdeville, T. Geralis

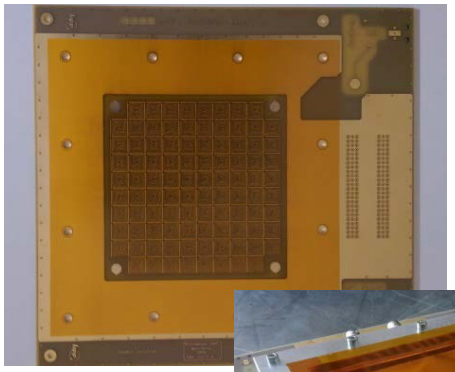
Real R1 values: 400 -750 KOhms with 100KΩ/Sq

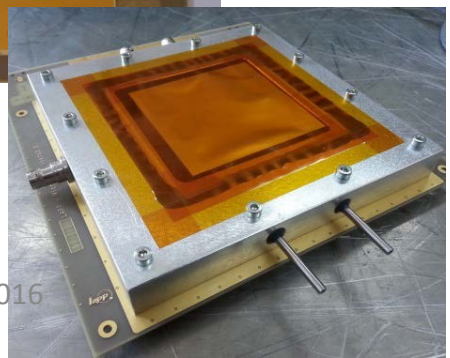
Real R1 values: 4 MOhms with 100KΩ/Sq

Real R1 values: 40 MOhms With 100KΩ/Sq



12/10/2015

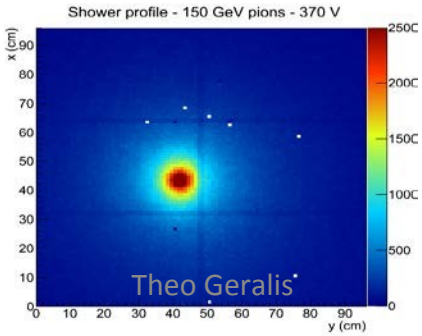




PCB with pads & resistive pattern

Use at future LC or the HL-LHC:

- Operation at high rates
- Suppress discharges, preserve linearity
- High 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