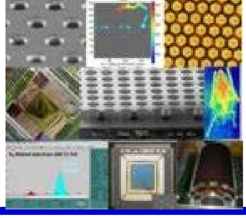
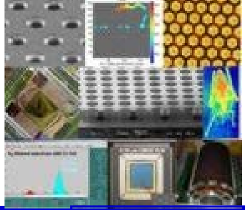


The status and perspectives of the MPGDs

and of the dedicated Collaboration RD51

S. Dalla Torre



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  - PRINCIPAL ARCHITECTURES
  - NOVEL ARCHITECTURES
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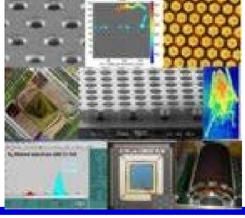
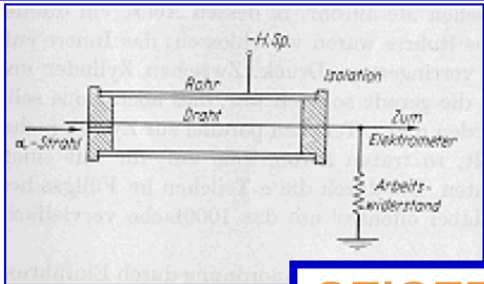
  - APPLICATIONS
  - FRONTIER R&D
- CONCLUSIONS

All subjects illustrated by examples:
a fully comprehensive review is impossible !

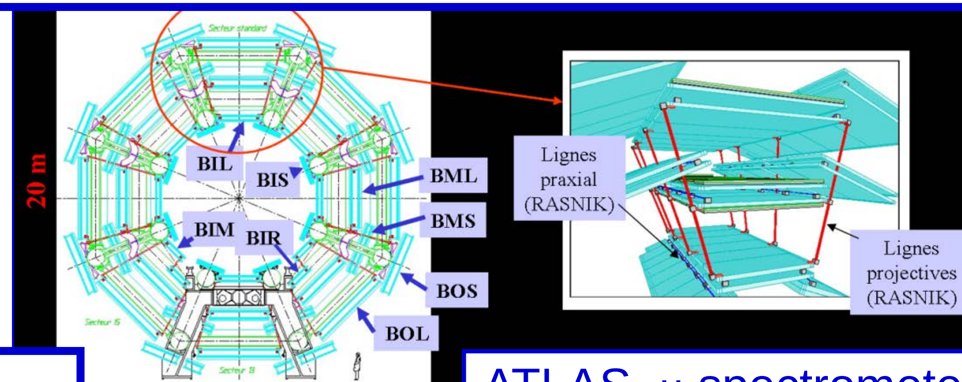


GAS DETECTORS & FUNDAMENTAL RESEARCH

STILL NOWADAYS THE ONLY WAY TO INSTRUMENT LARGE VOLUMES AT MODERATE COSTS AND LIMITED MATERIAL BUDGET; THEY OPERATE IN B FIELD

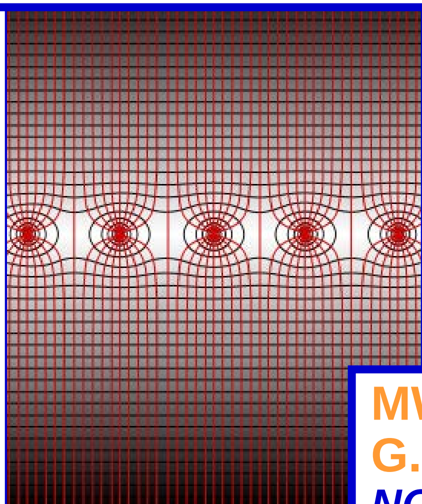


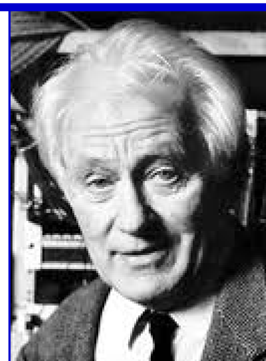
GEIGER counter
Rutherford, Geiger 1908



ATLAS, μ spectrometer

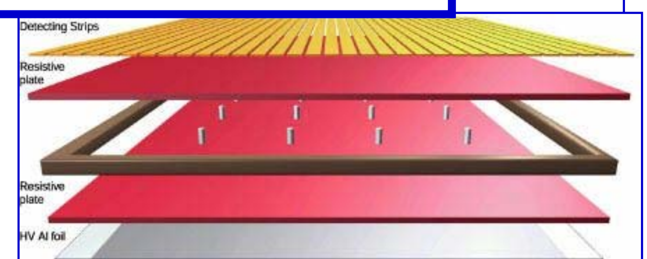
the only approach to achieve good space resolution before introducing the Si trackers

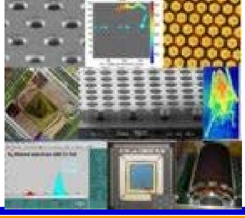




MWPC,
G. Charpak, 1968
NOBEL prize in 1992

Time resolution record in extended counters
RPC: $\sigma_t \leq 1$ ns
trigger in ALICE, ATLAS, CMS



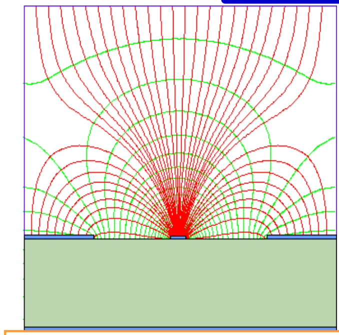


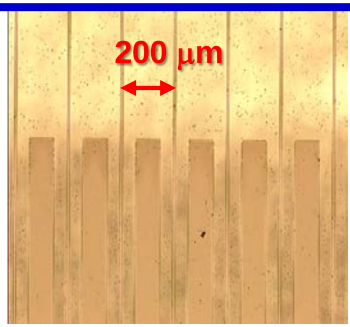
MPGDs: THE EARLY DAYS

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

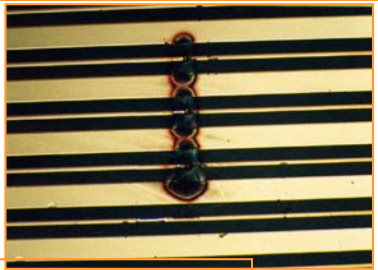
MSGC - MicroStrip Gas Chamber

A. Oed, NIMA 263(**1988**) 351

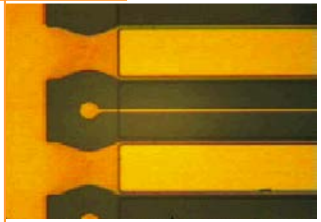




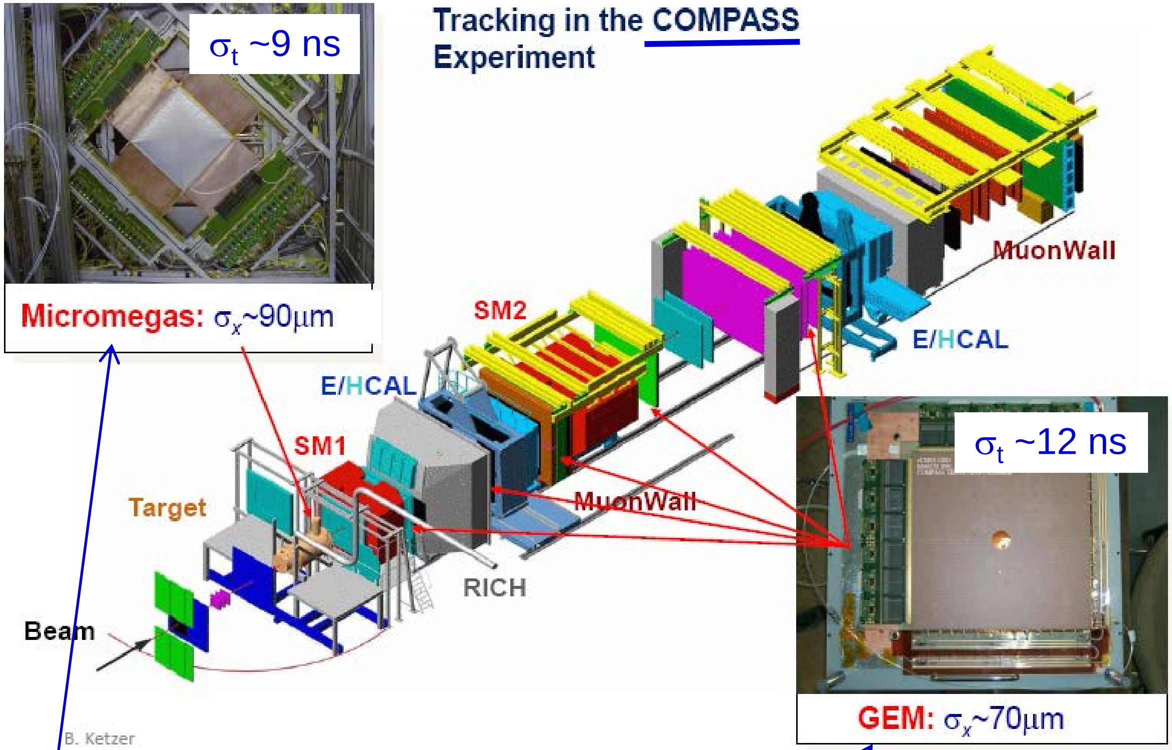
- **High E-values at the edge between insulator and strips → damages**
- **Charge accumulation at the insulator → gain evolution vs time**



Later (~ 1999-2000): Passivation of the cathode edges → MSGC operational !

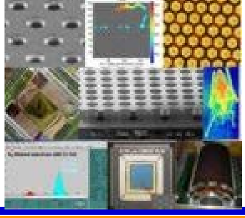


First Large Scale Use of GEMs and MICROMEGAs



MICROMEGAS (MM) :
Y. Giomataris et al,
NIMA A376 (**1996**) 29

GEM:
F.Sauli, NIMA A386 (**1997**) 531



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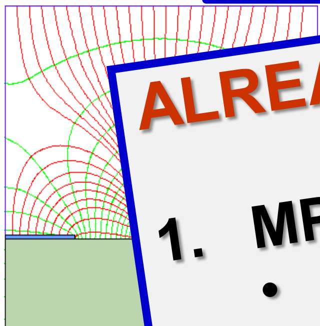


•High E…
insulato…
•Charge…
insulato…

Later (~ 199…
Passivation…
cathode edg…
→ MSGD
operational !

slide by **W. Riegler, CERN Academ…**

ALREADY SOME LESSONS:

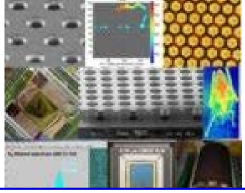
1. **MPGDs, why?**
   - **High rates (granularity & occupancy, signal formation time)**
   - **Fine space resolution**

   → **Moving towards high luminosity / high precision experiments, i.e. towards the future**

2. **MPGDs, how?**
   - **Mastering the industrial processes of photolithography makes MPGDs possible**
   - **Technological maturity and accurate engineering are FUNDAMENTAL ingredients for successful MPGDs**

…et al,
NIMA A376 (**1996**) 29

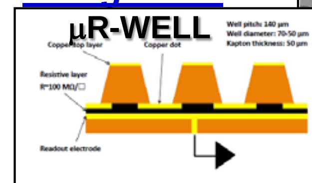
GEM:
F.Sauli, NIMA A386 (**1997**) 531

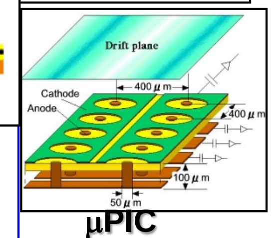


MPGDs NOWADAYS

▪ DEVELOPMENT

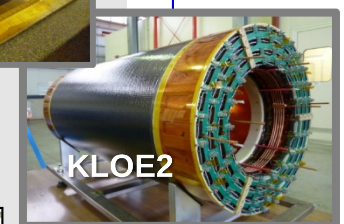
- Consolidation of the better established technologies
  - GEM: single mask for <u>large size</u>; mechanical stretching for <u>mass production</u>
  - MICROMEGAS: resistive anode for reliability of <u>large size</u> and <u>at high rate</u>
- Novel architectures
  - μPIC, μR-WELL, GRIDPIX, hybrids, …

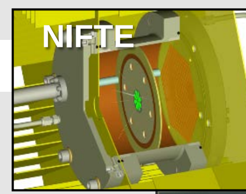


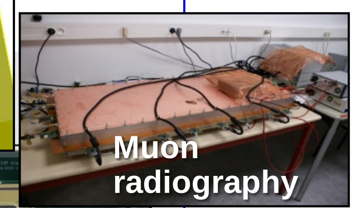


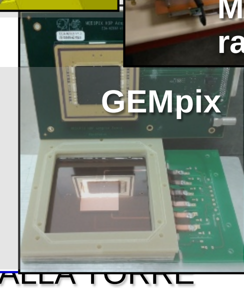
• DISSEMINATION by recent <u>examples</u>

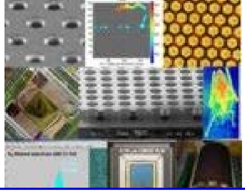
- In HEP
  - ALICE, TPC read-out, 130 m² to be instrumented
  - ATLAS, small wheels, 1200 m² to be instrumented
  - CMS, forward detectors, 1000 m² of GEM foils to be instrumented
  - COMPASS RICH, 4.5 m² hybrid MPGDs for single photon detection
  - KLOE2 & BES III, cylindrical GEMs
- In fundamental research, beyond HEP
  - LBNO-DEMO (WA105), 3 m² of THGEM PCBs
  - TPC read-out in low-energy nuclear physics (NIFTE)
- Beyond fundamental research
  - n-detection: D20 diffractometer @ ILL, neutron GEM @ ISIS, n-detection at ESS
  - Muon radiography for geological and archeological studies
  - Medical sector: GEMPIX detector











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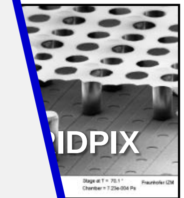
  - μPIC, μR-WELL, GRI…

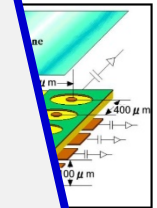
• DIS…

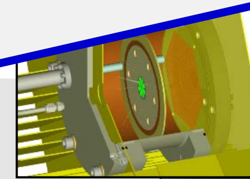
A remarkable flourishing of activity

where a fundamental boost is offered by the technological collaboration RD51:

from isolated MPGD developers to a world-wide net

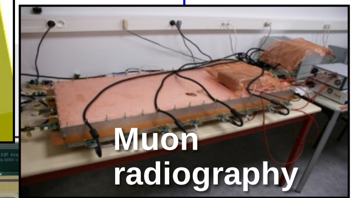


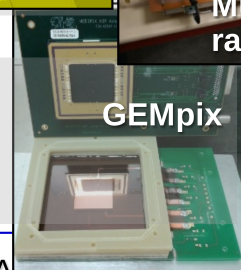




…clear physics (NIFTE)

- …al research
  - …ection: D20 diffractometer @ ILL, neutron GEM @ ISIS
  - Muon radiography for geological and archeological studies
  - Medical sector: GEMPIX detector





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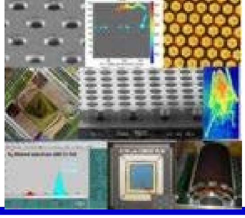


RD51

"The proposed R&D collaboration, RD51, aims at facilitating the development of advanced gas-avalanche detector technologies and associated electronic-readout systems, for applications in basic and applied research." (RD51 proposal, 28/7/ 2008)

First term: 2009-2013, second term: 2014-2018, preparing a proposal for a third term

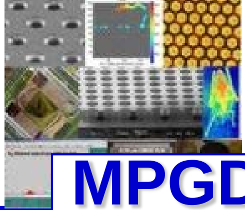
Unique in providing support for R&D related & non–related to experiments

SUPPORT

- **Common infrastructures** (GDD lab, common test beam)
- **Electronics** (read-out, dedicated instrumentation)
- **Simulation** (Garfield maintenance, update and development)
- Scientific cultural reference, know-how entry point, MPGD net-working

SPECIFIC MPGD PROJECTS

- **resources** (financial, manpower) **from the Institutes participating in the project**
- **support from RD51:** cultural, know-how, infrastructure, tools
- **from the specific projects to RD51**: the feedback from their experience and progress



RD51 – HOW ?

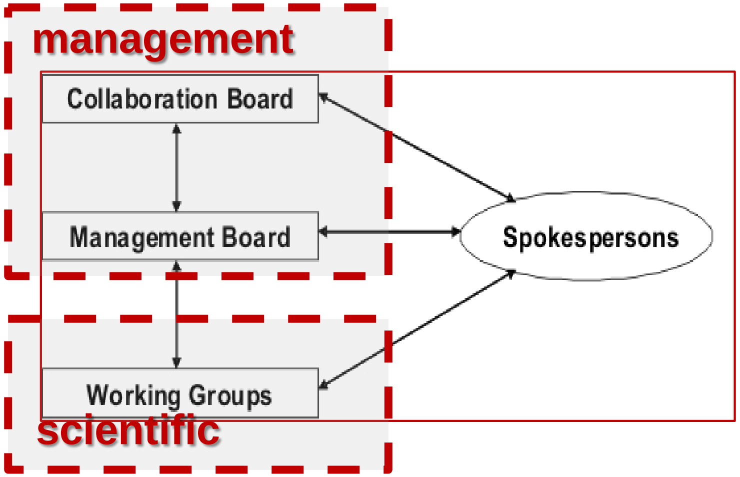
MPGD community integration: 91 Institutes, ~500 members

- From CERN
- From Europe (including Russia, Israel)
- From Korea, Japan, India, China
- From USA, South America

Organization

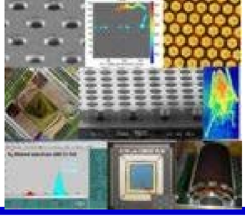
- Members of the RD51 Management Board (MB):
- two Co-Spokespersons: Silvia Dalla Torre, Leszek Ropelewski
- CB Chairperson and its deputy: Joao Veloso, Atsuhiko Ochi
- Scientific Secretary: Maxim Titov
- Technical Coordinator: Eraldo Oliveri
- MB members: Amos Breskin, Paul Colas, Klaus Dehmelt, Ioannis Giomataris, Supratik Mukhopadhyay, Emilio Radicioni, Hans Taureg (Finances), Yorgos Tsipolitis, Andy White

- Working Groups Conveners:
- WG1 - New Structures and Technologies (Paul Colas, Filippo Resnati)
- WG2 - Detector Physics and Performance (Diego Gonzalez Diaz, Max Chefdeville)
- WG3 - Training and Dissemination (Fabrizio Murtas, Joao Veloso)
- WG4 - Modeling of Physics Processes and Software Tools (Ozkan Sahin, Rob Veenhof)
- WG5 - Electronics for MPGDs (Jochen Kaminski, Hans Muller)
- WG6 - Production and Industrialization (Fabien Jeanneau, Hans Danielsson, Rui de Oliveira)
- WG7 - Common Test Facilities (Eraldo Oliveri, Yorgos Tsipolitis)



MEETINGS *(always with options for videoconference access)*

- *2 Collaboration meetings / y (one outside CERN)*
- *2 miniweeks / y*



RD51 ACTIVITY

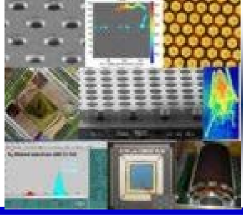
Enlarging the community & the applications portfolio: HEP & beyond

WG1	WG2	WG3	WG4	WG5	WG6	WG7
New Structures & Technologies	Detector Physics and Performance	Training and Dissemination	Modelling of Physics Processes and Software Tools	Electronics	Production & Industrialization	Common Test Facilities

R & D of the MPGD technologies

- Technology consolidation
- physical phenomena in MPGDs
- novel architectures

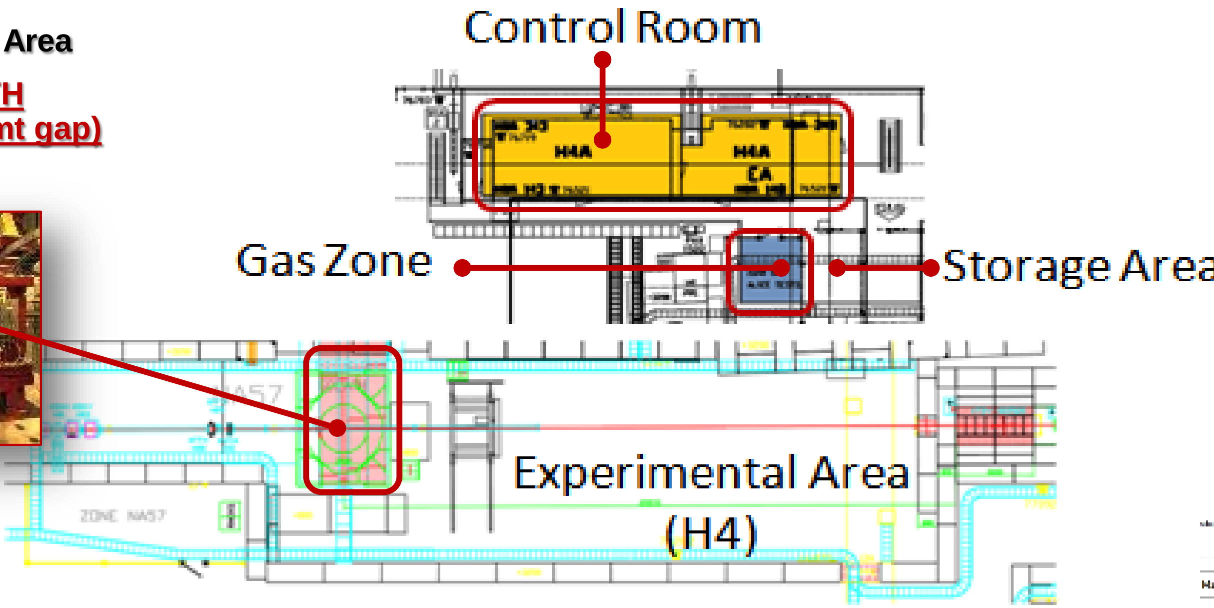
tools:
Facilitating MPGD progress and dissemination



RD51 COMMON TEST BEAM FACILITY

EHN1-H4 North Area

GOLIATH
(1.5T Max, 1mt gap)



RD51 Semi-Permanent Installation

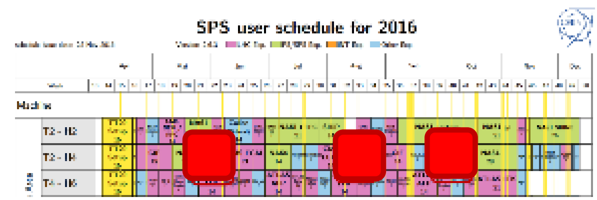
Provided:
- **Gas distribution**
- **Magnet, meas.ed B**
- **monitoring P,T**

2016 RD51 Test Beams :
3 periods of 2 weeks
10 different groups in total with several running in parallel

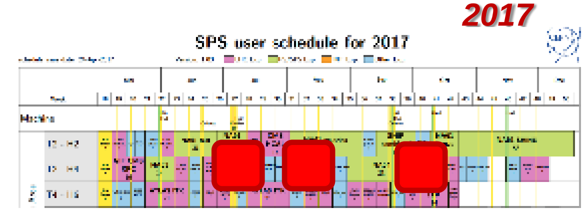
2017 RD51 & GIF++ Test beams:
3 periods of about 2 weeks
7 different groups in total with several running in parallel

2018 RD51 & GIF++ Test beams:
3 periods, 5 weeks in total
similar number of setups foreseen

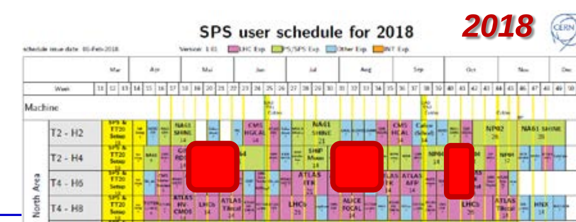
2016

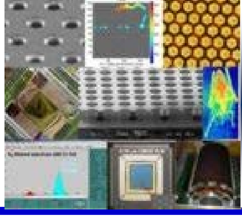


2017



2018



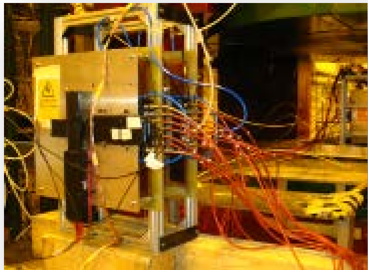


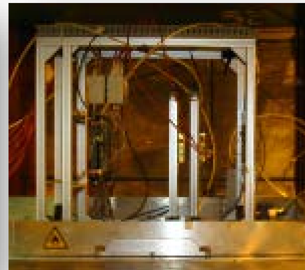
RD51 COMMON TEST BEAM FACILITY

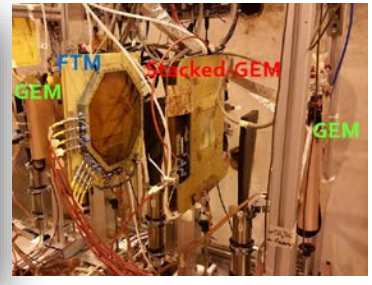
2016

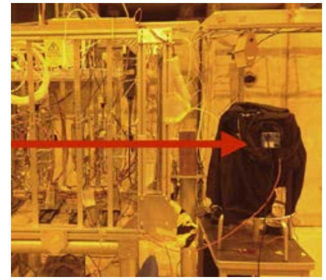
June

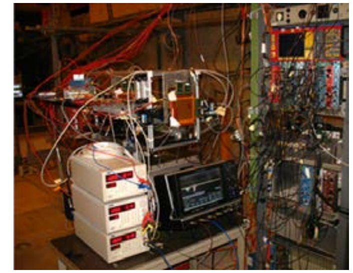
BESIII (Cylindrical GEM) | μRWell | CMS GEM&FTM | Optical readout (GEM) | PICOSEC





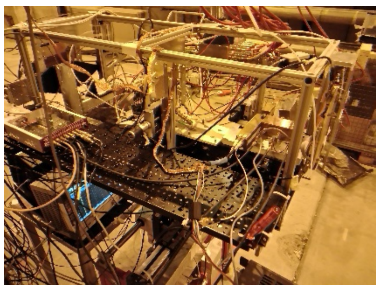


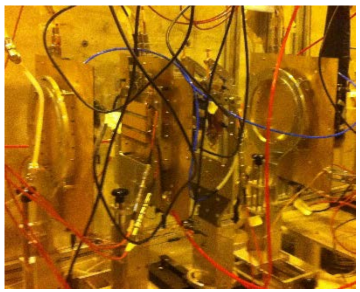


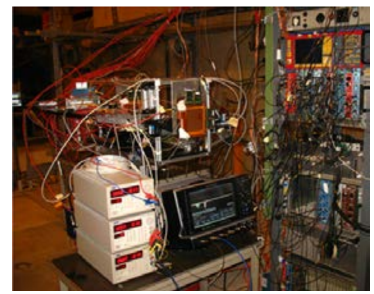


August

Hyperfast Silicon | RPWELL | MUST^2 | R-PHI mm (srEDM) | PICOSEC

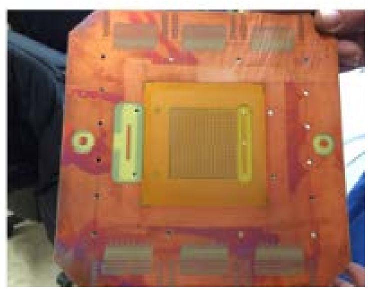


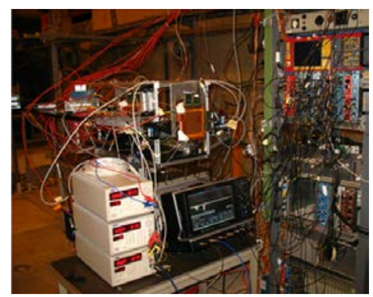




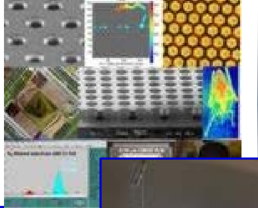
October

BESIII (Cylindrical GEM) | R-PHI mm (srEDM) | Small Pads ResMM | PICOSEC

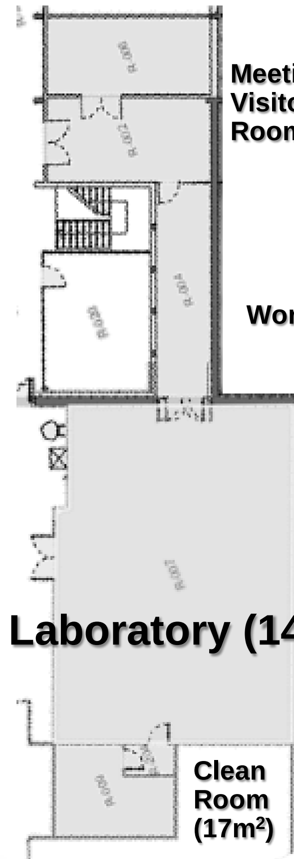




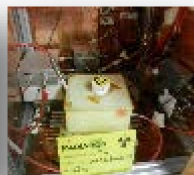
SHIP Emulsion and MM



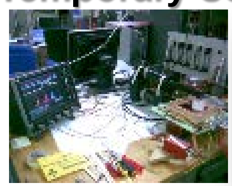
EP-DT-DD GDD Laboratory (Detector R&D)



Permanent Users (ALICE, ATLAS, ESS) stations

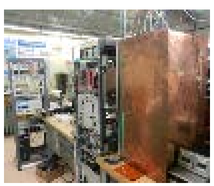
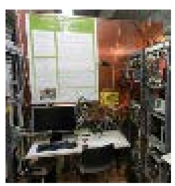




Temporary Users Working stations

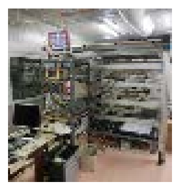


Active (X-Ray) and Radioactive Sources



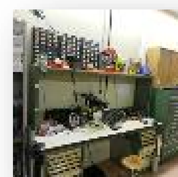



Cosmic Stands



Clean Room

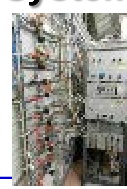
Workshops



Optical Readout & Measurements

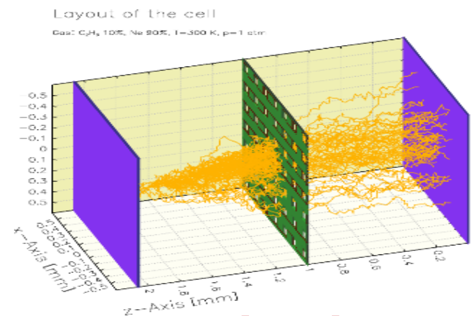

Vacuum Systems

Gas & Monitoring Systems




MPGD Electronics


SIMULATION

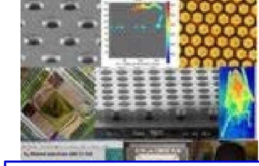


- **GARFIELD → GARFIELD ++**

  R. Veenhof, NIMA419 (1998) 726; http://garfield.web.cern.ch/garfield

  - **Maintenance (a service to the whole gas detector community !)**
  - **Interface to software packages, generic & specific**
    - **electron and photon transport using cross sections provided by Magboltz**
    - **ionization processes in gases, provided by Heed, MIP**
    - **ionization and electron transport in semi-conductors**
  - **Description of the physical phenomena, continuos improvements (ions, e-, photons)**
    - **Ion mobility, diffusion, recombination, e^- cross sections**
    - **Photons (UV emission, IR production, trapping, absorption, photocathodes)**

- **MPGD specific:**
  - **dramatic E variations over microscopic distances (~ the e^- mean free path)**
  - **open dielectric surfaces**
    - **Simulation of the charging-up phenomena, material properties**

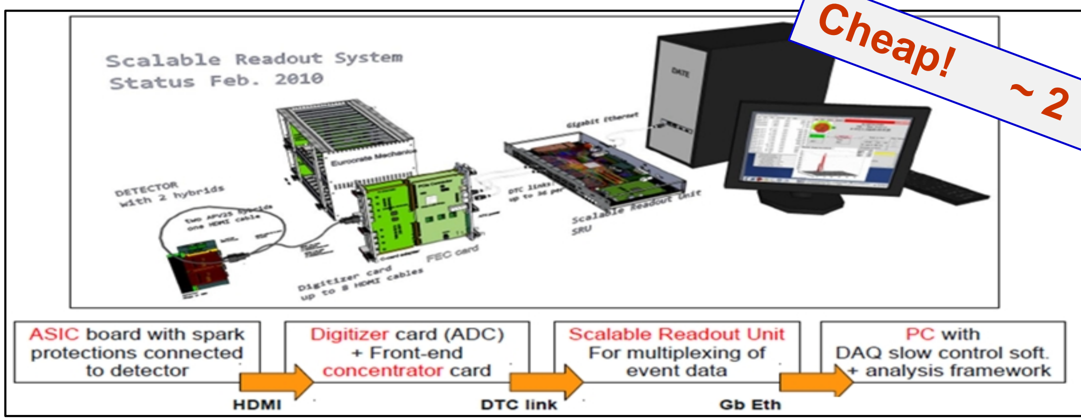


ELECTRONICS FOR MPGDs

SRS - Scalable Readout System

- Interfacing different FE: APV25, VMM3 (NEW !!!)
- Scalable: ~100 ch.s → ~100 k ch. (ATLAS NSW project)
- So successful, to be used outside MPGDs (SiPM, ALICE Ecal, …)
  - 54 groups around the world are using SRS
- SRS components now produced by industry (NEW !!!)

VMM3 RD51 hybrid under test



Cheap! ~2 €/ch + FE

SRS procurement from 2017+

INHOUSE production RD51: stopped !

CERN Store: continued for team account owners only

NEW SRS production and purchase licencies* 2017

No team account ? ask CERN/KT for SRS purchase licence

Direct SRS sales starting in 2017:

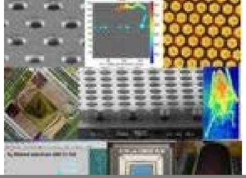
SAMWAY Electronics: http://www.samwayelectronic.com

SAMWAY — FEC and ADC cards, Eurocrates, SRS-ATCA mezzanines etc

SRS Technology: http://www.srstechnology.ch

SRS Technology — APIC, hybrids, Powerbox, DVMcards, SRU, AVD etc

More electronic tools: APIC, pre-amplifier-shaper box, ready for industrial production
FEMTO, femtoamper meter with real-time output
ADV, active voltage divider and generator for multilayer MPGDs



NETWORKING & TRAINING

BY RECENT EXAMPLES

Workshop: applications beyond science
AVEIRO, September 2016

MPGD Applications Beyond Fundamental Science Workshop and the *18th RD51 Collaboration Meeting*, Aveiro, Portugal

Precise Timing Workshop
CERN, 21-22 February 2017

TUESDAY, 21 FEBRUARY

09:00 → 13:00 **Precise timing workshop**

09:00 **Welcome**

This workshop is intended to address the needs of a rapidly developing interest group in RD51 for fa
results from the RD51 PICOSEC project demonstrate feasibility of MPGD-based timing devices in the

HEPTech | GSI | network | TRADE & INVEST

ACADEMIA-INDUSTRY MATCHING EVENT

Nanotechnology & High-Energy Physics: From Material to Innovation

Academia and Industry coming together to identify innovative synergies between the broad fi Energy Physics (HEP) and Nanotechnology. This event will bring together nanotechnology and physics researchers and industrialists to:

- **Showcase new developments in nanotechnology and HEP**
- **Address the needs of industry**
- **Provide an opportunity for collaborative R&D and technology transfer partnerships**

Organizing Committee: Tiago Rodrigues de Araujo (CERN), Martina Bauer (GSI), Jero (ILL), Tatiana Correia (KTN), Andrea Crottini (EPFL), Tobias Jean-Marie Le Goff (CERN), Symeon Kokovidis (CERN), Valladares Pacheco (KTN/HEPTech), Leszek Ropelewski ((Jaime Segura (ILL), Alicja Surowiec (GSI), Christina Trautmann

20-21 October 2016
GSI Helmholtzzentrum für Schwerionenforsch
Darmstadt, Germany
https://indico.cern.ch/event/503276/

CERN | DESY | EPFL | FAIR | NEUTRONS FOR SCIENCE | KTN | NANORA Nano Regions Alliance

Contribution to academy-industry matching event, GSI October 2016

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

Meeting Home Page: https://phys.cst.temple.edu/mpgd2017/

May 22 - 25, 2017: MPGD2017 Conference — May 26, 2017: RD51 Collaboration Meeting

Previous conferences:

- MPGD2009, Crete, Greece
- MPGD2011, Kobe, Japan
- MPGD2013, Zaragoza, Spain
- MPGD2015, Trieste, Italy

RD51 Open Lectures and Mini Week

11 Dec 2017, 12:00 → 15 Dec 2017, 18:30 Europe/Zurich
593-R-010 - Salle 11 (CERN)
Eraldo Oliveri (CERN), Spyros Tzamarias (Aristotle University of Thessaloniki (GR))

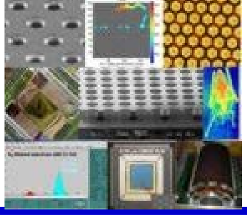
Description: *Monday 11th December, 14:00 - Wednesday 13th December 12:30*

RD51 Open Lectures: Signal generation, modelling and processing

W. Riegler, R. Veenhof, F. Resnati, S. Tzamarias

Purpose of the lectures is to discuss new developments on the methods and tools used to describe the signal generating processes as well as techniques of analysing data of gaseous detectors. The lectures are geared towards people who are doing, or intend to do, research and developments on gas-based detectors but are also open to anyone interested on the subject.

3-day school on detector data analysis, CERN Dec. 2017



A CRITICAL POINT: MPGD-RELATED TT

Production of detector components at CERN, updated mid 2017 (presently the main producer)

- Production

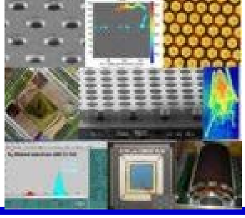
•SBS tracker	GEM 600mm x 500mm	150 GEM
•ALICE TPC upgrade	GEM 600mm x 400mm	350 GEM
•CMS muon	GEM 1.2m x 450mm	450 GEM
•BESIII	GEM 600mm x 400mm	30 GEM +read-out
•SOLID	GEM 1.1m x 400mm	8 GEM + 2 read-out
•CLAS 12	Micromegas 500mm x 500mm	30 Micromegas
•CBM	GEM 1m x 450mm	100 GEMs
•BM@N	GEM detectors 1.8m x 0.6m	12 full detectors
•Bonus 12	GEM	30 GEMs
•European Spallation Source	GEM	9 GEMs
•sPhoenix TPC Stonybrook	GEM	100 m2
•CMS GE2/1	GEM	prototype
•C rad industry	GEM	prototype
•Beomocular industry	GEM	10 GEMs
•Mcube muon detectors	Micromegas	12 x 50cm x50cm

- R&D
- ATLAS resistive Micromegas Muon large pitch
- ATLAS resistive Micromegas embedded resistors for high granularity high rate
- CMS FTM multiple resistive well detectors for sub ns time resolution
- CMS R-well Muon detectors
- Resistive micro gap for calorimetry
- Embedded front end electronics in read-out boards

CMS production :
> 170 GEM already produced
Production rate
20 GEM/month

ALICE production:
> 260 GEM already produced
Production rate
40 GEM/month

GEM UV tight “fridge” containing one batch of 14 GEM (1.8m x 0.6m max)



A CRITICAL POINT: MPGD-RELATED TT

Industrial production of detector components, status

- **GEMs**
  - **TECHTRA (PL)**
    - 10 x 10 cm^2 GEM foils, yield 90%
    - Complete 10 x 10 cm^2 detectors (30 x 30 coming)
    - Large GEMs foils (CMS-size) in progress, promising status, present yield 30% & long production time
  - **MICROPACK (IND)**
    - 10 x 10 cm^2 GEM foils, yield ~ 80%
    - 30 x 30 cm^2 GEM foils, in preparation; CERN evaluation in Spring 2017
  - **KCMS-MECARO (ROK)**
    - Well-equipped workshop
    - Gem foils up to 30 x 30 cm^2 successfully produced
    - Large GEMs foils (CMS-size) BEING EVALUATED → production
  - **TECH-ETCH (USA)**
    - Successful in the past up to 40 x 40 cm^2
    - Apparently production abandoned (lacking users' interest ?)
- **BULK MICROMEGAS**
  - **ELVIA (F)**
    - 16 working detectors of 50 x 50 cm^2 built
  - **ELTOS (I)**
    - TT ongoing, 10 x 10 cm^2 produced
- **THGEMs**
  - **ELTOS (I)**
    - 60 x 30 cm^2 produced for COMPASS RICH, in house post processing
    - 60 x 30 cm^2 produced for WA105 (prototype of a cryogenic double-phase Ar detector)

A CRITICAL POINT: MPGD-RELATED TT

FRESH INCOURAGING NEWS from CMS mu system upgrade

(A. Colaleo, deputy PM, private communication)

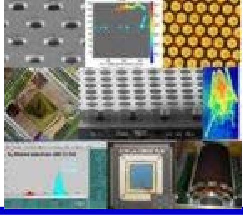
Validation of a second production line in Korea- Mecaro on-going in CMS.

- **First 2 batches of GEM foils delivered:**
  - **no major issues found**
    - **quality**
    - **Uniformity same as CERN foils**

CERN Bd904: 1st GE1/1-size detector built Korean foils

- **First CMS GEM GE11 detector built with Korean foils at CMS CERN Lab:**
- **Preliminary QC tests are ok**
- **Aging test starting at CERN GIF++."**

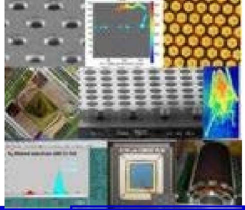
20



A CRITICAL POINT: MPGD-RELATED TT

Production of detector components by industry, how should it work

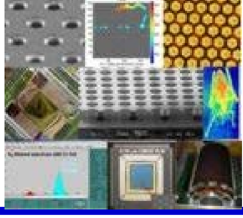
- Relevant ONLY for large productions, namely in case of Large-Size Projects (LSP)
- The decision makers are the LSPs (having responsibility for scientific aspects & related financial resources)
  - *LSPs have to identify resources to cover the industrial cost of the learning/training process*
- Potential producers contacted by RD51 or by the LSPs
- RD51 facilitates the know-how transfer
  - also formal agreement with CERN required
- RD51 is willing to contribute to validation of the products
  - if requested by the LSPs
- The involvement of the LSP people remain central
- The final decision is taken by LSPs



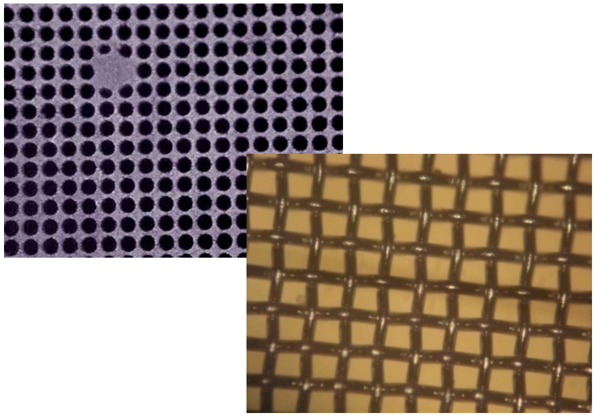
OUTLOOK

- INTRODUCTION
- RD51
- MPGD TECHNOLOGIES
  - PRINCIPAL ARCHITECTURES
  - NOVEL ARCHITECTURES
  - NOT ONLY TRACKING
- MPGD-RELATED ACTIVITIERS
  - APPLICATIONS
  - FRONTIER R&D
- CONCLUSIONS

All subjects illustrated by examples:
a fully comprehensive review is impossible !

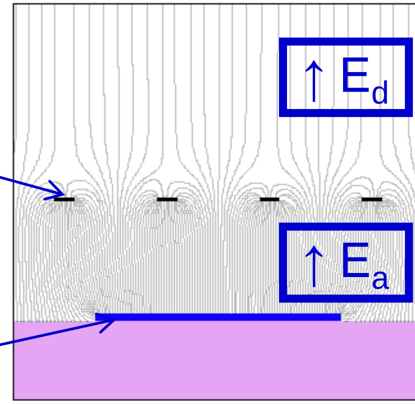


MICROMEGAS, the principle



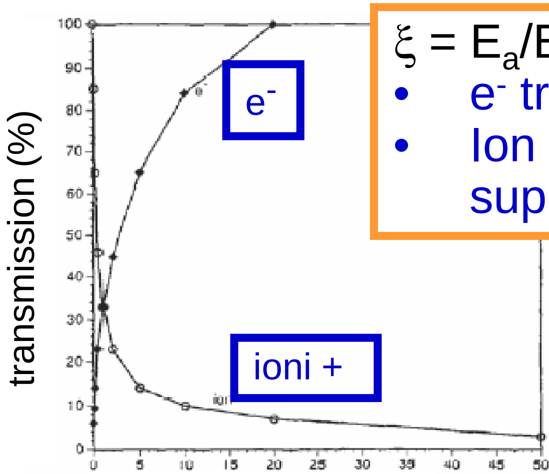
mesh (cathode)

R-O strip (anode)



Ionization & drift (gap ~ 3-5 mm)

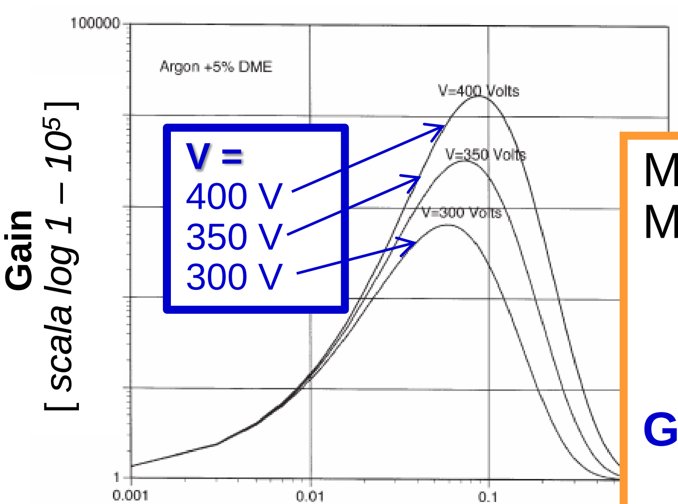
Parallel Plate (gap ~ 100 μm)



$\xi = E_a/E_d > 20$ →

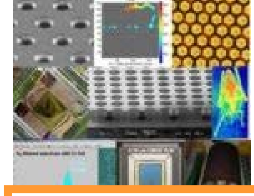
- e^- transparency
- Ion backflow suppression

Y. Giomataris et al, NIMA A376 (1996) 29



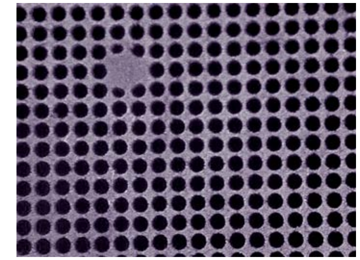
MICROMEGAS Must be operated at peak conditions: **Gap (gas)** & **V** are **correlated**

Y. Giomataris, NIMA A419 (1998) 239



MICROMEGAS, construction

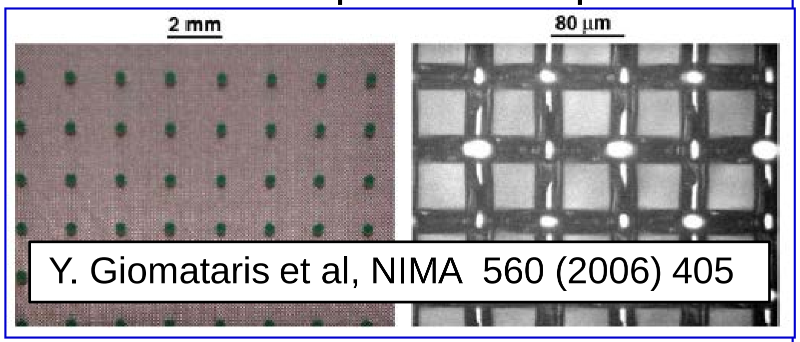
construction challenge: preserve the thin gap homogeneity by insulating spacers



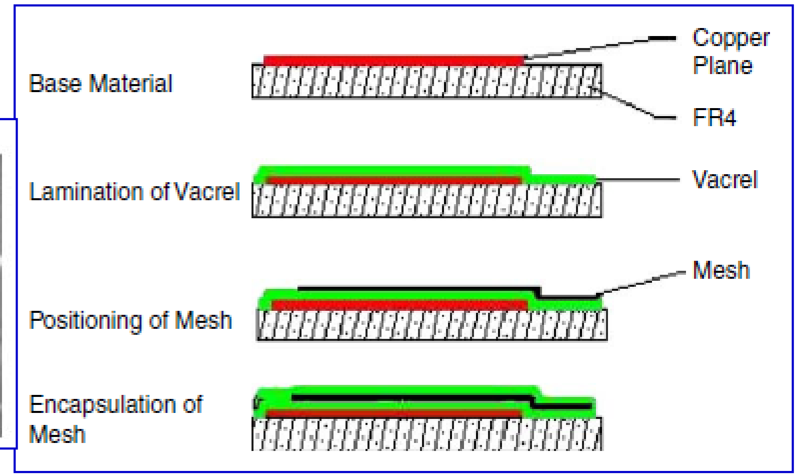
1) Nichel mesh by **elettroformation** + **quartz fibers,** diameter: 75 μm

2) a **metalized polyimide micromesh** by chemical etching supported by small **pillars** by photoresist material

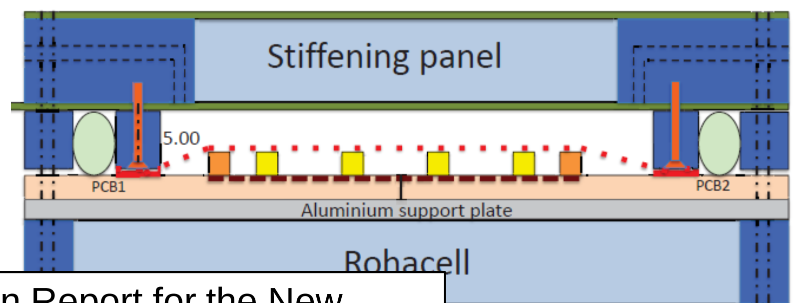
3) Bulk micromegas: pre-stretched steel mesh laminated together with a photoresist layer and the PCB; photoresist then removed apart where pillars are formed

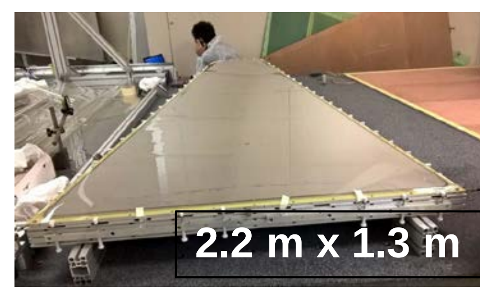


Y. Giomataris et al, NIMA 560 (2006) 405



4) Grow **pillars at the anode** surface, keep the **mesh in place by mechanical tension (ATLAS-NSW)**

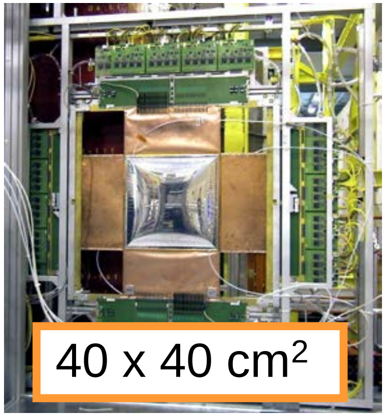




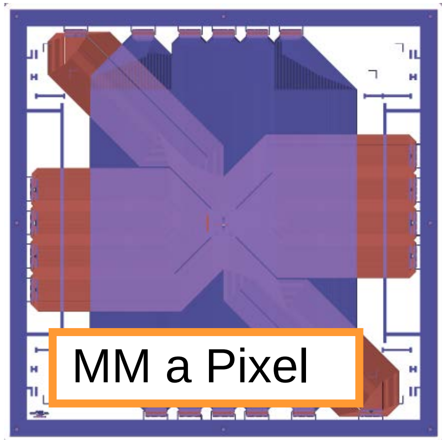
The ATLAS Collaboration, "Technical Design Report for the New Small Wheel," CERN-LHCC-2013-006 / ATLAS-TDR-020, June 2013

MICROMEGAS & experiments

Non exhaustive example list

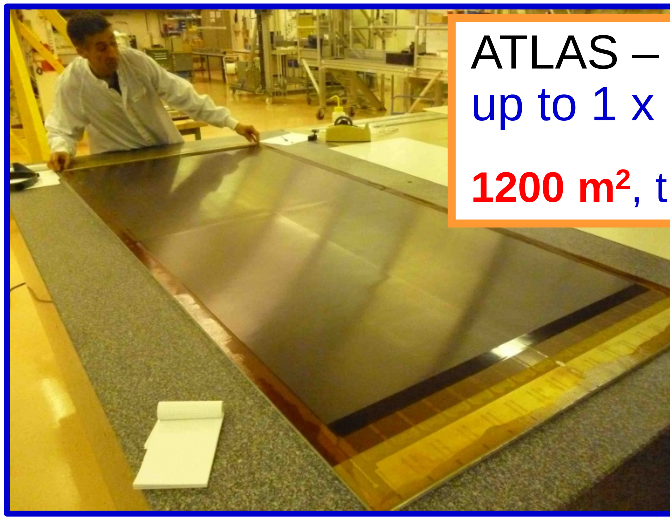


40 x 40 cm^2



MM a Pixel

COMPASS

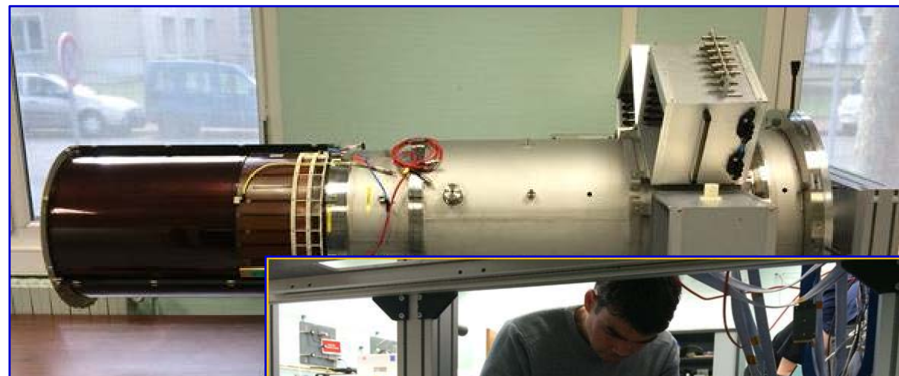


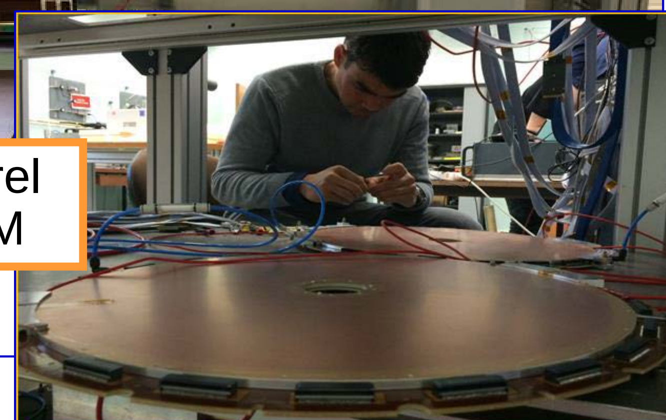
ATLAS – NSW project
up to 1 x 2.5m^2

1200 m^2, tracking & trigger

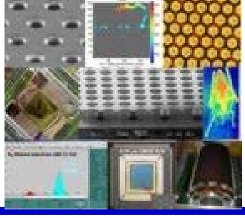
T2K : TPC read-out

CAST





CLAS12: barrel & end-cap MM

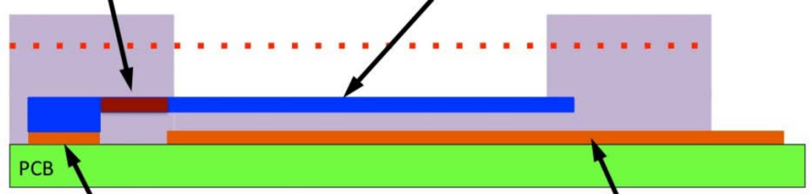


MICROMEGAS: recent developments

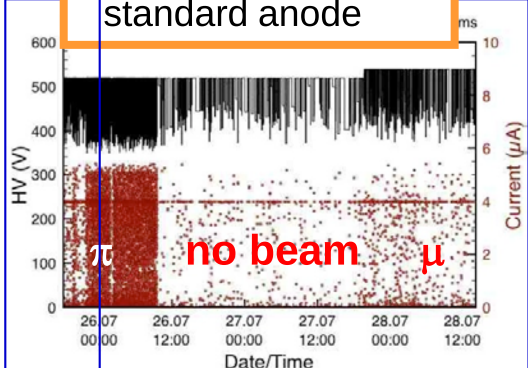
mitigating / overcoming **the high discharge rate**

Resistive Anodes

Developed within the ATLAS-NSW project

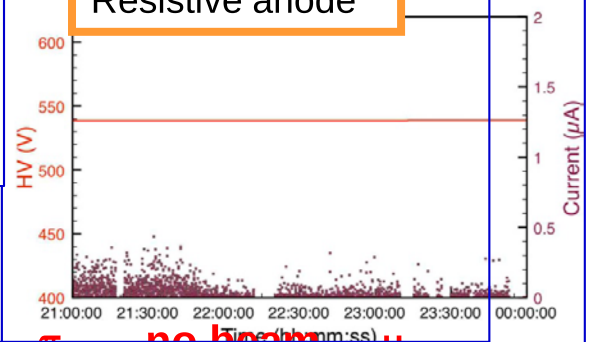


standard anode



beam: π, μ
120 GeV/c

Resistive anode

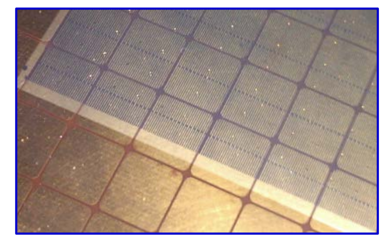


π no beam μ

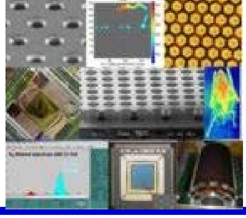
J. Wotschack
CERN Det. seminar,
18/11/2011

Resistive strips, how?

- Photolitography
- Screen printing

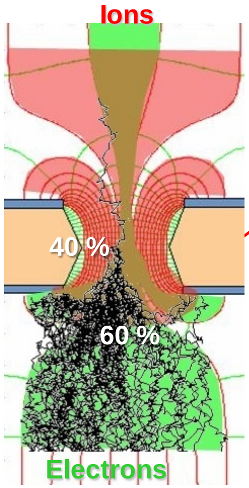


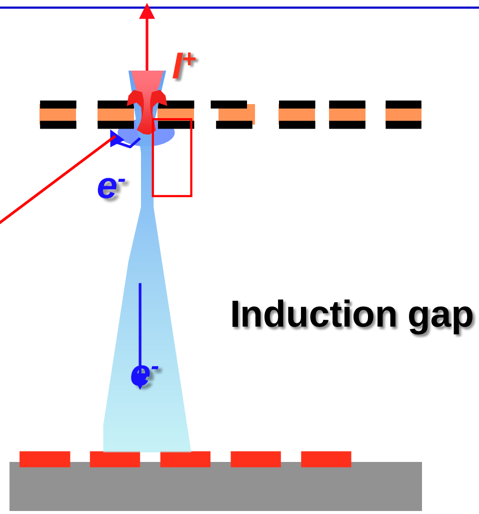
- Sputtering

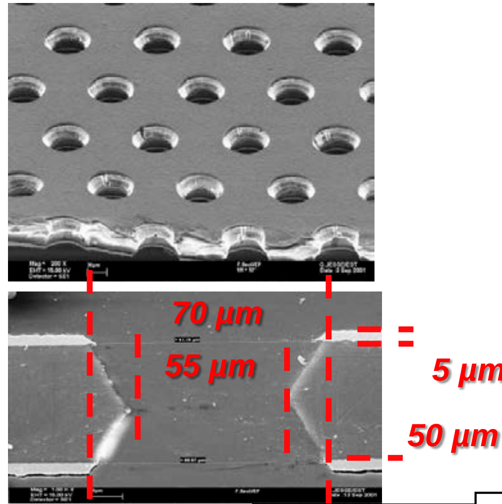


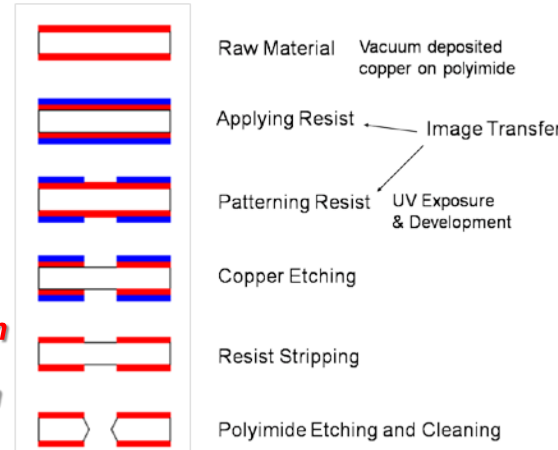
GEMs, principle & construction

Metalized polyimide foil,
Holes by etching

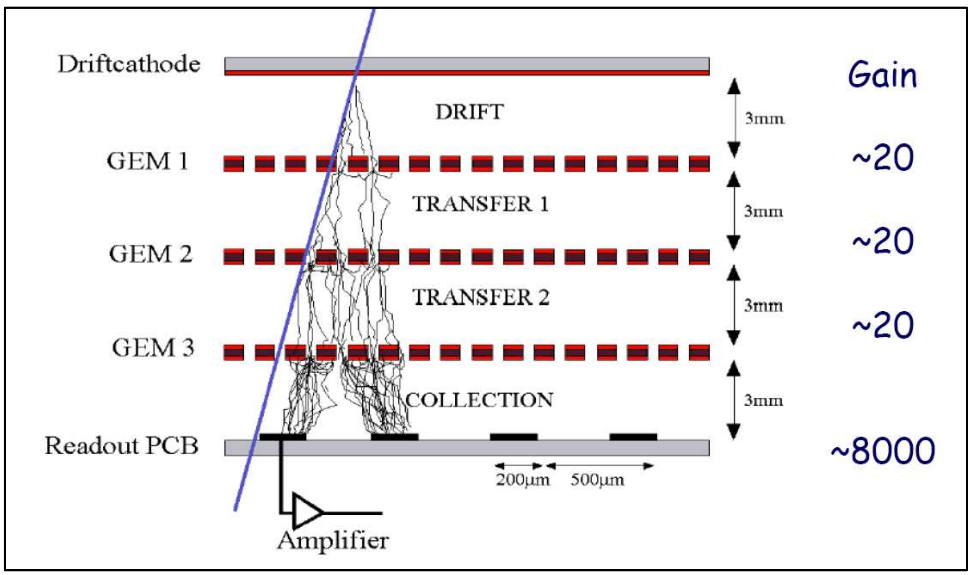


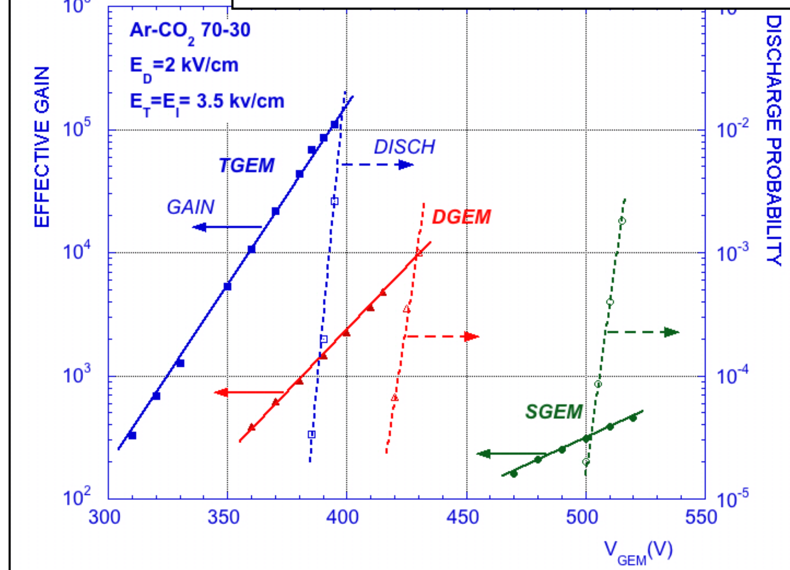






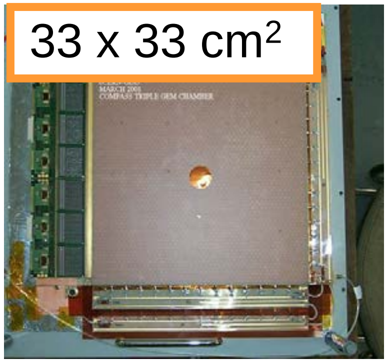
S. Bachmann et al., NIMA A479(2002)294





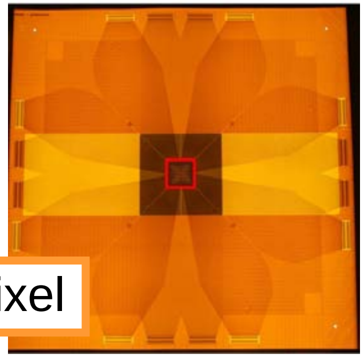
GEMs & EXPERIMENTS

Non exhaustive example list

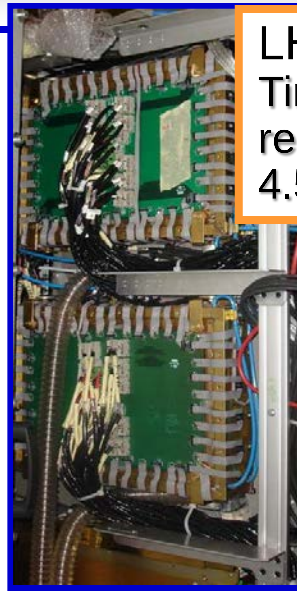


33 x 33 cm^2

COMPASS



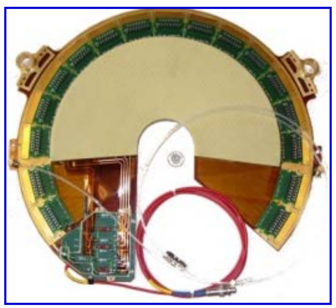
GEM a Pixel

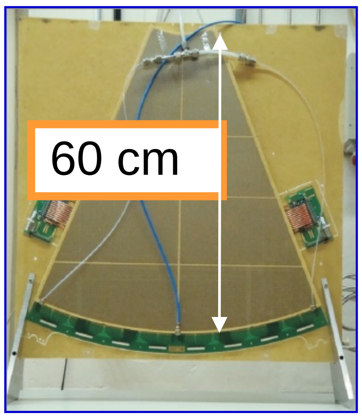


LHCb
Time resolution: 4.5 ns rms

KLOE2: Cylindric triple GEM

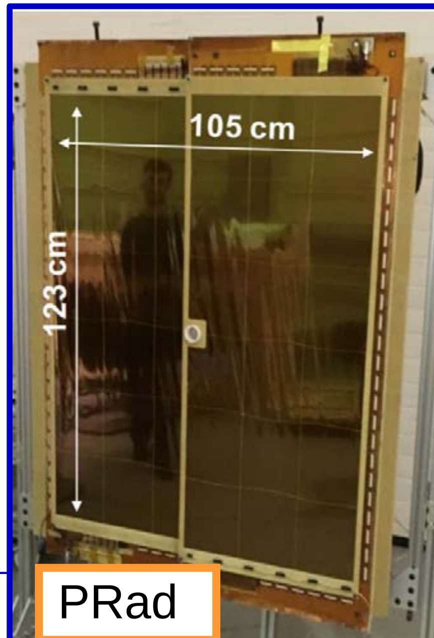
BESIII, second cyclindric GEM



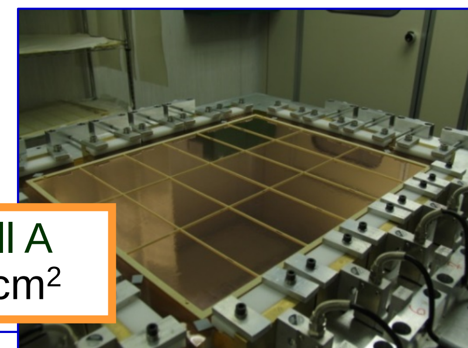


60 cm

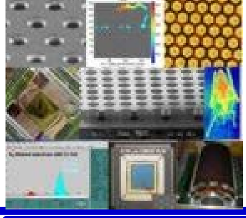
TOTEM



PRad



JLab Hall A
40 x 50 cm^2

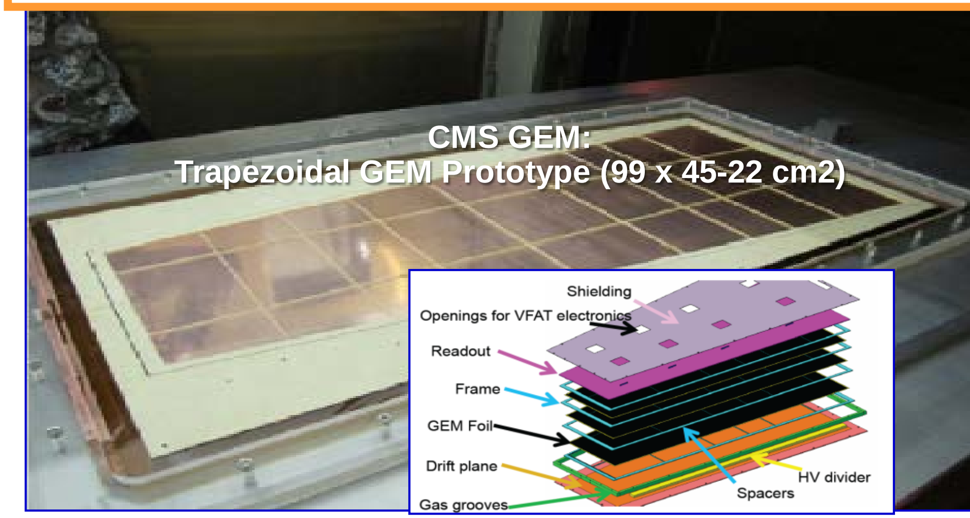


GEMs & EXPERIMENTS, more

Non exhaustive example list

STAR - Forward GEM Tracker

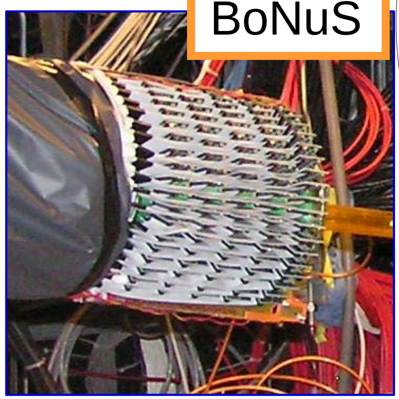
CMS forward muon spectrometer : tracking & trigger

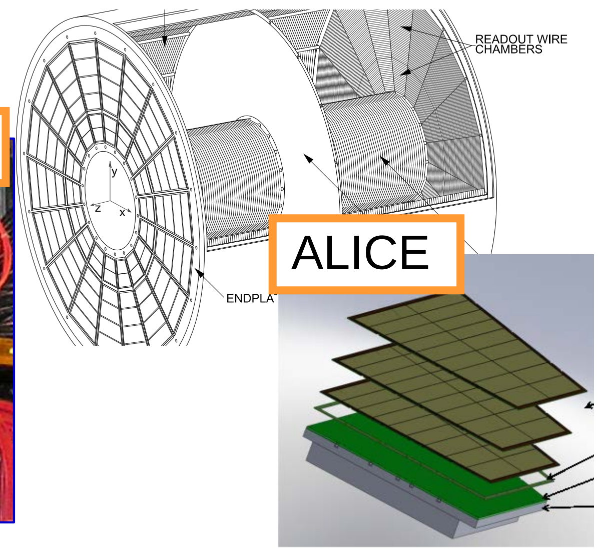


Super BigBite spectrometer

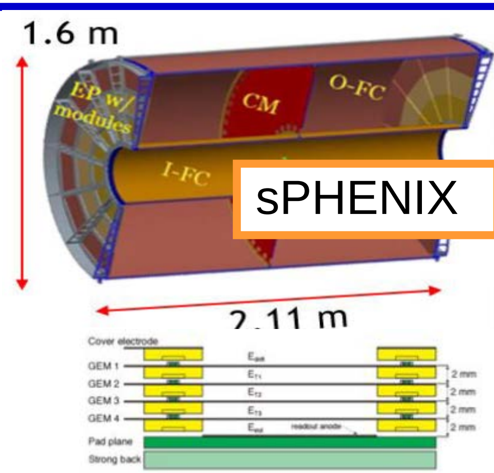
R-O TPC

BoNuS



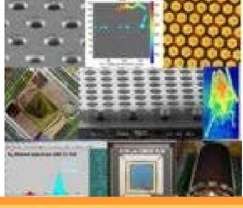


ALICE



sPHENIX

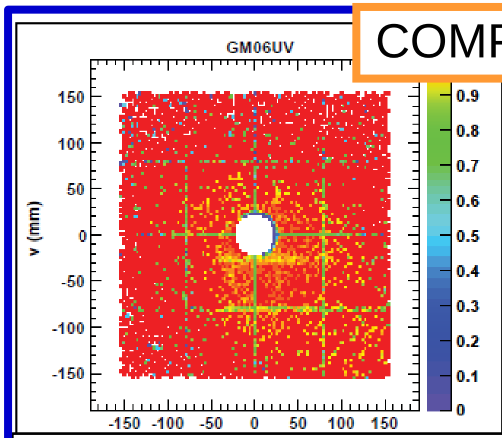
Quad-GEM Gain Stage
Operated @ low IBF

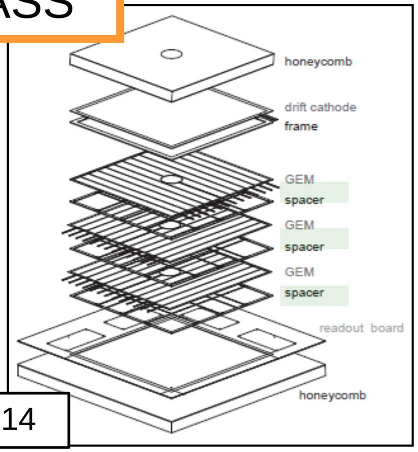


GEMs, spacers vs stretching

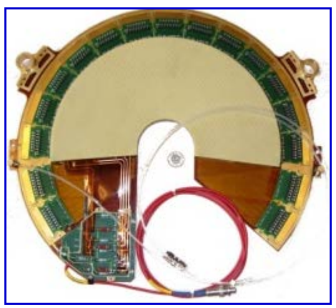
GEM detectors w/ spacers

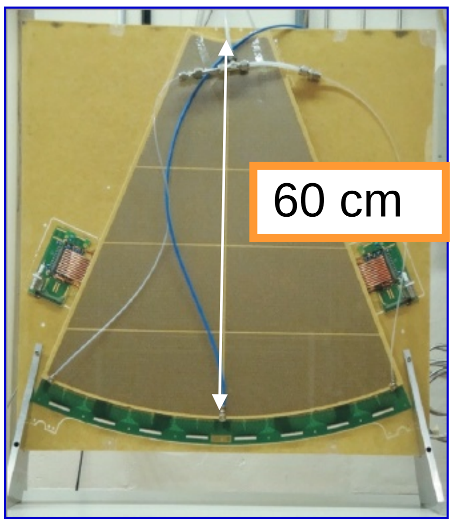
COMPASS





B. Ketzeret al, NIMA A535 (2004) 314



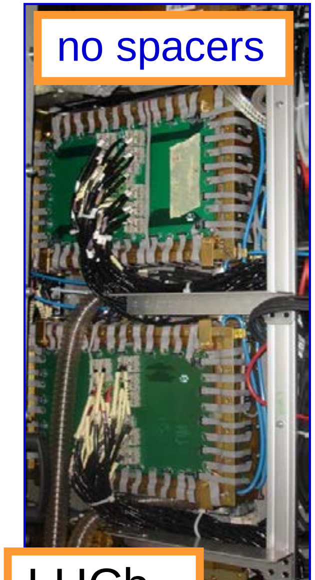


60 cm

TOTEM

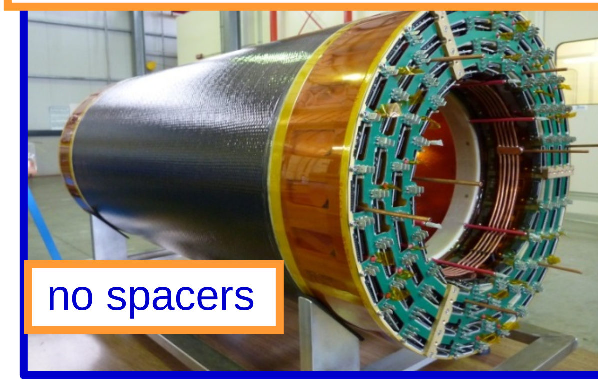
Emphasis on GEM foils stretching

no spacers



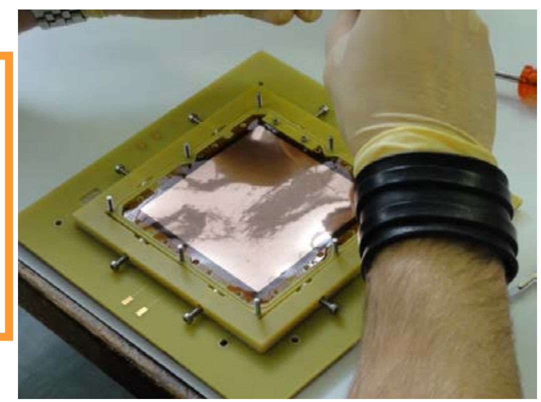
LHCb

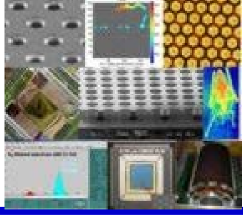
KLOE2: Triple cylindrical GEM
assembly completed 14/3/2013



no spacers

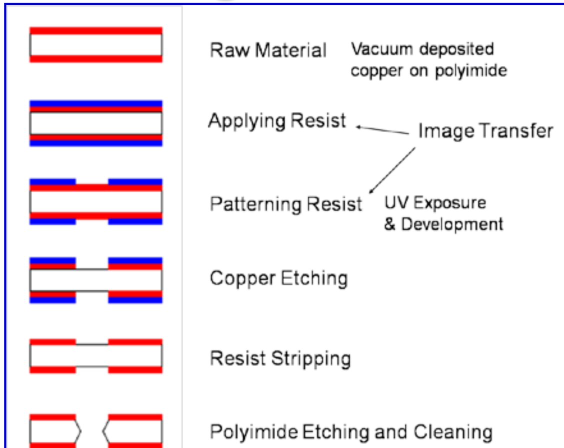
CMS upgrade:
mechanical
stretching
for mass
production

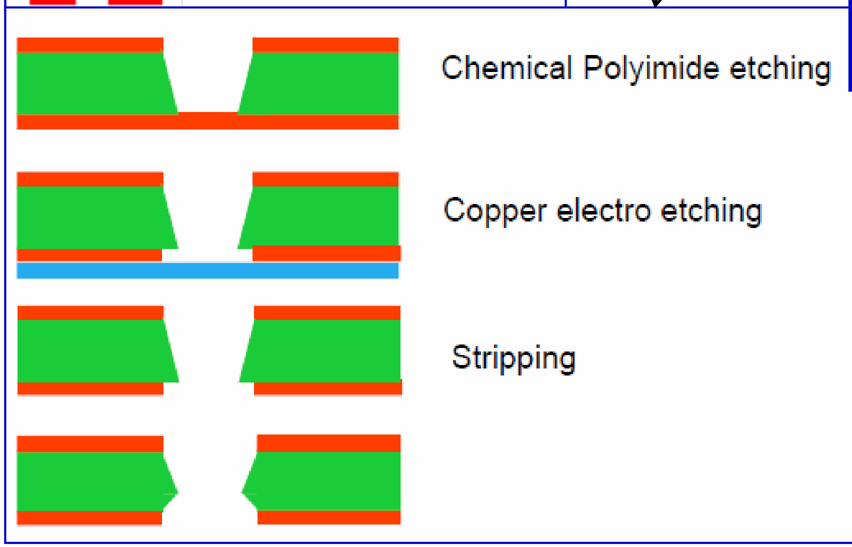




GEMs, large foils

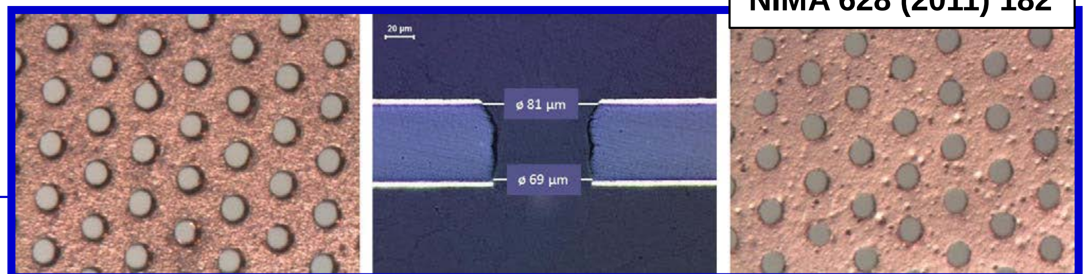
Single mask: the way towards large size





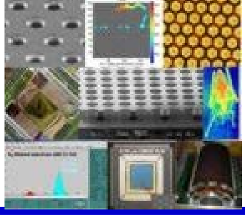
- standard (double mask)
- single mask

M. Villa et al., NIMA 628 (2011) 182



The path:

- TOTEM upgrade
- KLOE2
- CMS

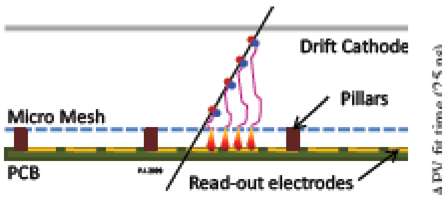


ALGORITHMS FOR IMPROVED PERFORMANCE

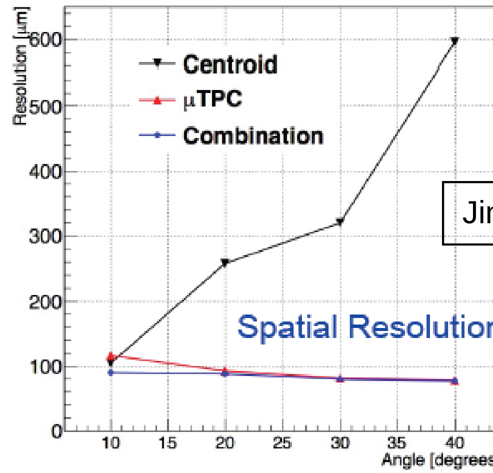
for a more powerful tracking

MM operated in µTPC mode

- Development in the context of ATLAS NSW



Single Segment Reconstruction in a Micromegas

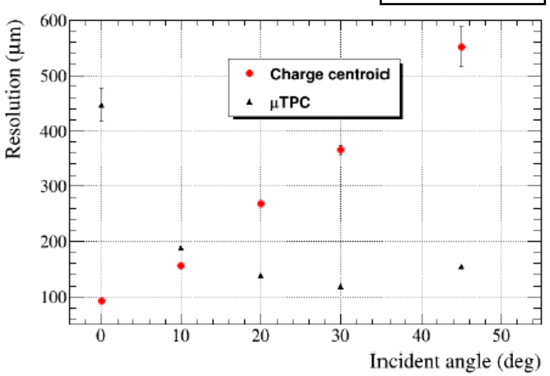


Spatial Resolution

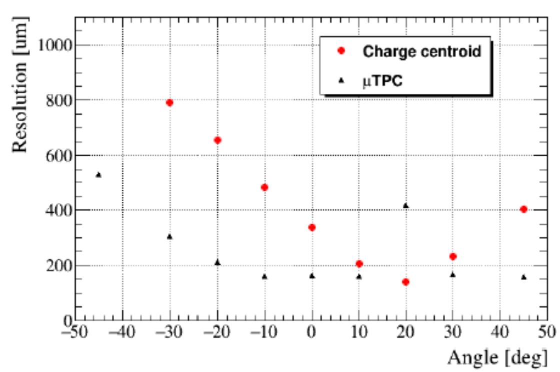
Jinst10 (2015) C02026.

More recently a µTPC approach has been introduced also for GEMs

B=0



B = 1T



Jinst12 (2017) C07038

MPGD trackers, performance

MICROMEGAS

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

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

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

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

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

GEM

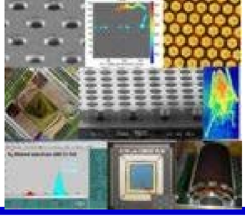
Space resolution
- COMPASS, ~70μm (NIMA 577 (2007) 455)

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

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

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

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



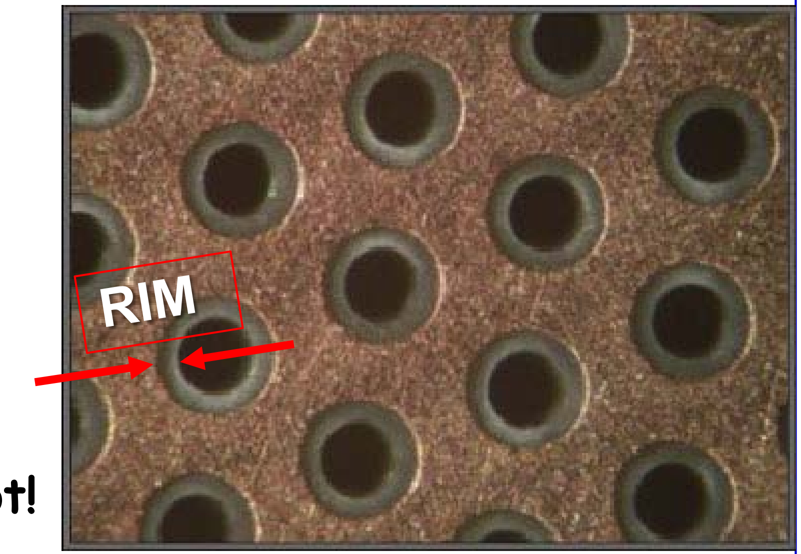
THGEM (LEM), HOW and WHY

PCB technology, thus:

- robust
- mechanically self supporting
- industrial production of large size boards (1€/1k holes; 1-2 M holes/1m²)
- large gains have been immediately reported (rim !)

About PCB geometrical dimensions:

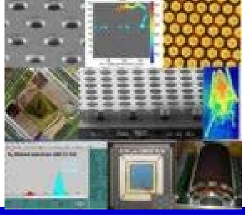
Hole diameter :	0.2 - 1 mm
Pitch :	0.5 - 5 mm
Thickness :	0.2 - 3 mm



Comparing to GEMs

- Geometrical dimensions X ~10
  - But e⁻ motion/multiplic. properties do not!
  - Larger holes:
    - dipole fields and external fields are strongly coupled
    - e⁻ diffusion plays a minor role

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

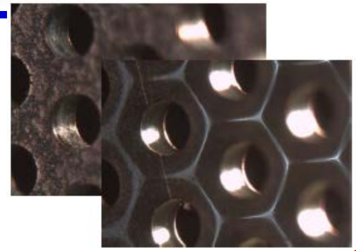


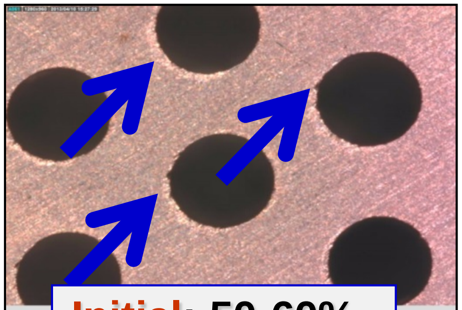
THGEM CONSOLIDATION

Engineering aspects

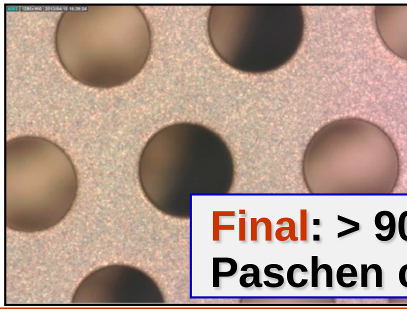
polishing (Pumice Powder)
ultrasonic bath (~1 h) @ 50-60 ºC in Sonica

Polyurethane Treatment

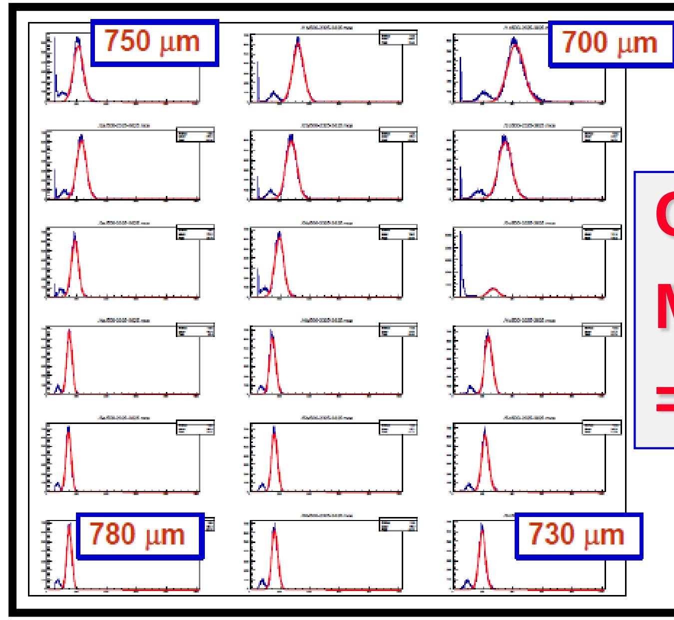




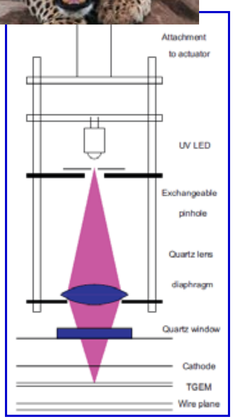
Initial: 50-60% Paschen curve



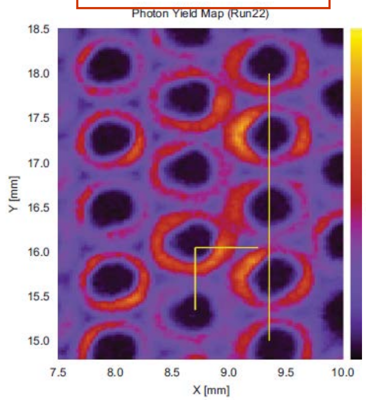
Final: > 90% Paschen curve



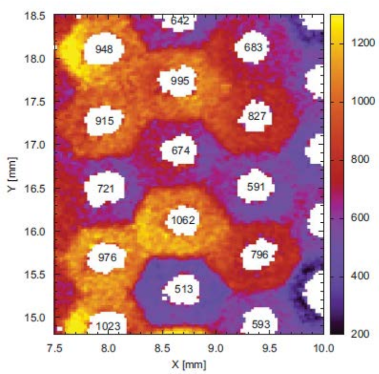
GAIN Max/Min = 2.9



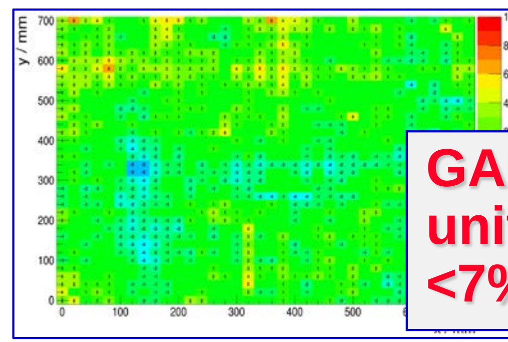
Effiency map



Gain map

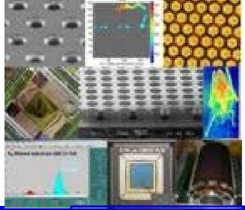


G.Hamar and D. Varga, NIMA 694(2012)16



GAIN uniformity <7% r.m.s.

Selecting uniform of the fiberglass plates: ± 15 µm



OUTLOOK

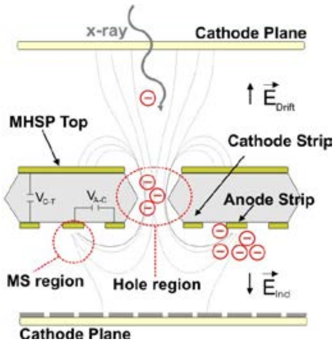
- **INTRODUCTION**
- **RD51**
- **MPGD TECHNOLOGIES**
  - **PRINCIPAL ARCHITECTURES**
  - **NOVEL ARCHITECTURES**
  - **NOT ONLY TRACKING**
- **MPGD-RELATED ACTIVITIERS**
  - **APPLICATIONS**
  - **FRONTIER R&D**
- **CONCLUSIONS**

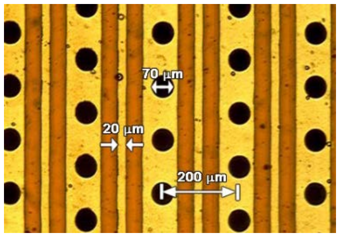
All subjects illustrated by examples:
a fully comprehensive review is impossible !

NOVEL ARCHITECTURES BY IMAGES

(1) (TH)GEM-derived

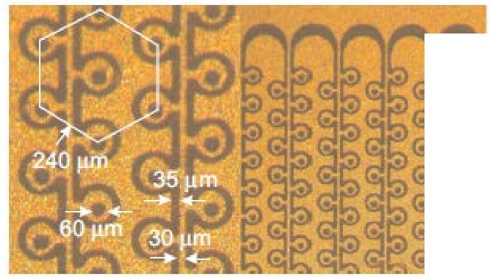
Towards gas PMTs by
- **Extrer ıely reduced (~10^{-4}) IBF to PC**
- **Non outgassing materials**



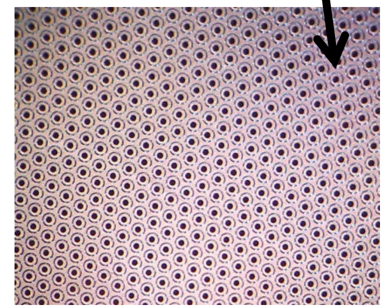


MHSP

&



COBRA

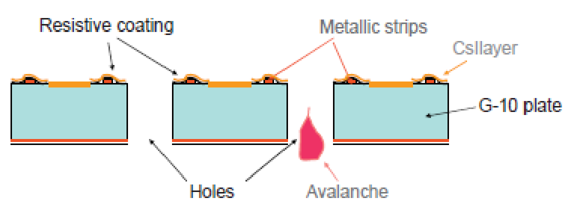


Glass GEM

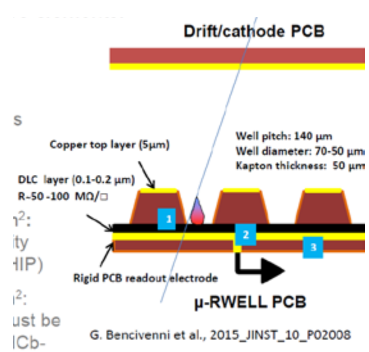
Limit the discharge damages

Re-GEM: electrodes by resistive kapton

RTGEM

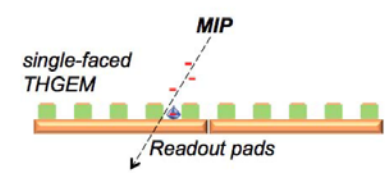


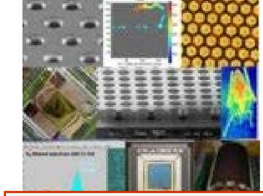
µR-WELL



WELL THGEM

- Cu coated in one sides
- No induction gap - electrode attached to the anode

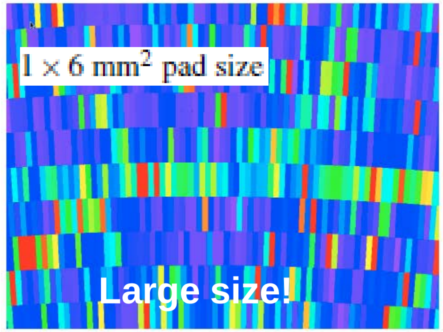


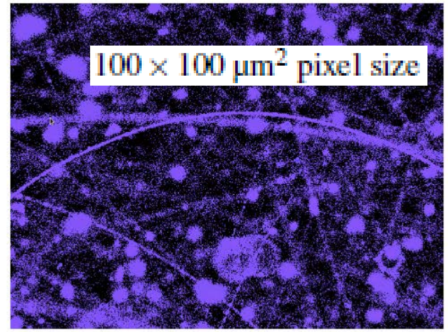


NOVEL ARCHITECTURES BY IMAGES

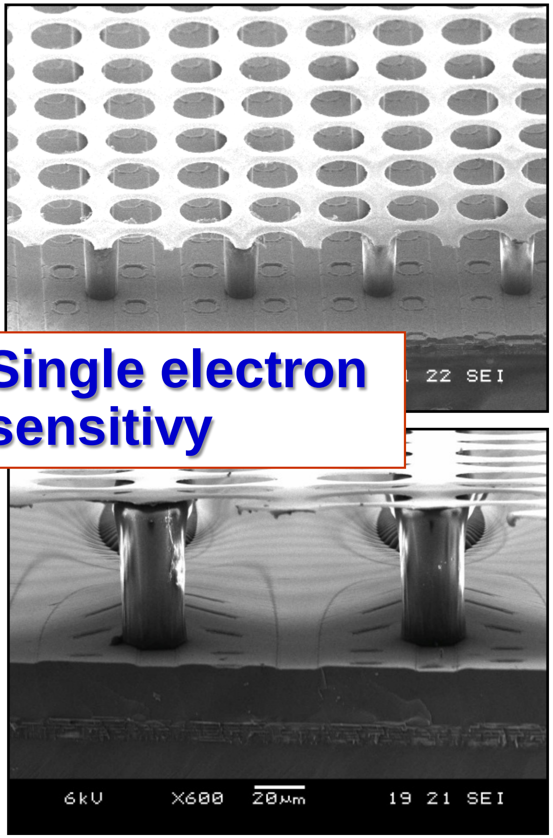
(2) MM-derived

Simulations for CLIC, M. Killenberg, LCD-Note-2013-005





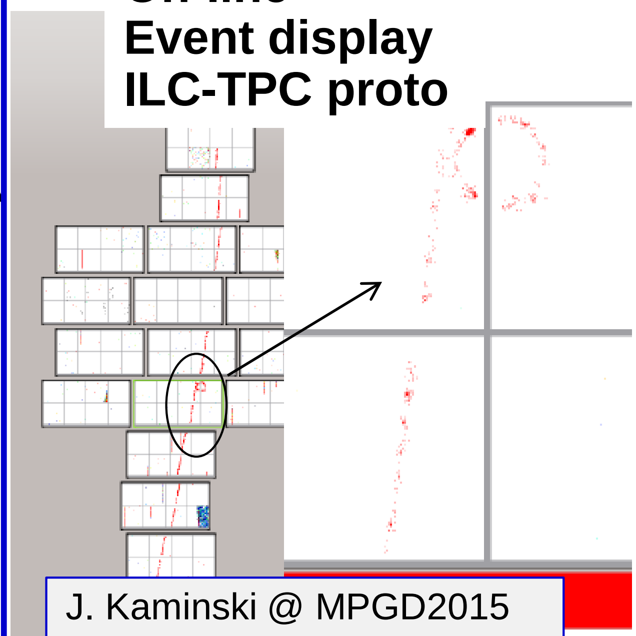
Timepix chip + SiProt + Ingrid



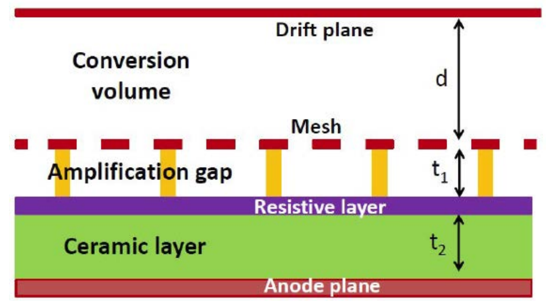
Single electron sensitivy

GRIDPIX

On-line Event display ILC-TPC proto

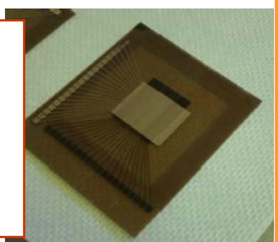


J. Kaminski @ MPGD2015



Piggy Back: read-out separated from the active volume

Microbulk:
Low material budget,
radioactive pure



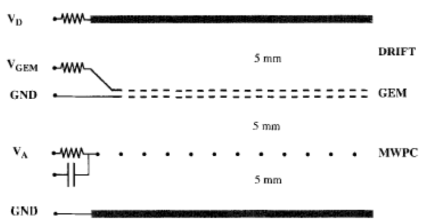
NOVEL ARCHITECTURES BY IMAGES

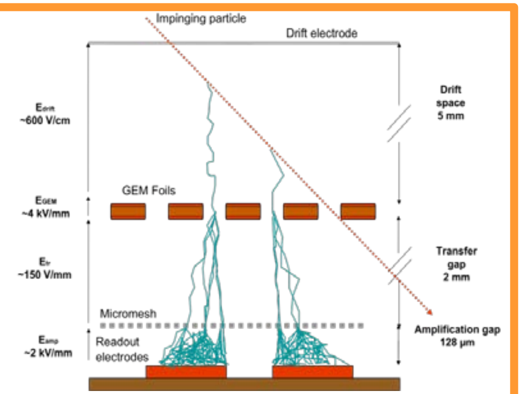
(3) hybrids

Towards gas PMTs: IBF control

Since the beginning
(Sauli et al.):

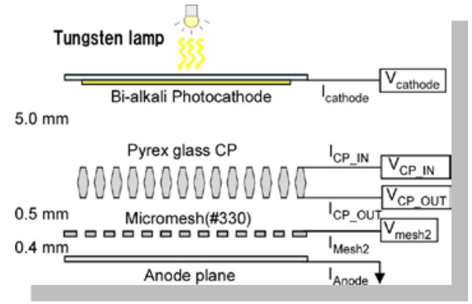
- **GEM + MWPC, GEM + MSGD**
  (NIMA 396 (1997) 50)



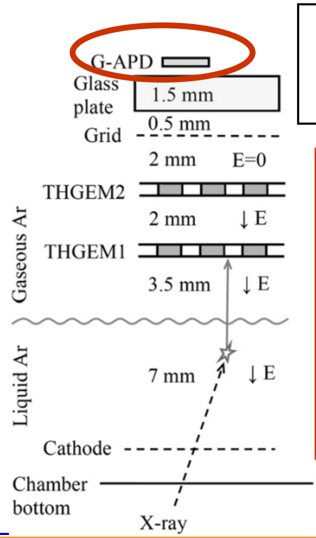


MM w GEM pre-amplification

GAS PMT



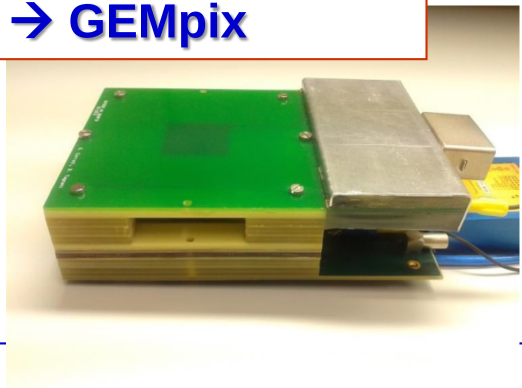
GEM pre-amplification: control the discharge rate in tracking



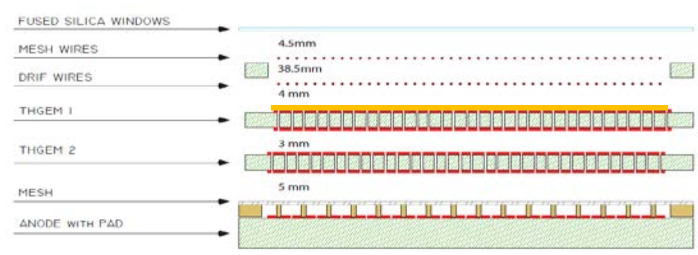
A. Bondaret al., NIMA 628 (2011) 364

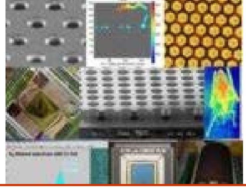
THGEM + G-APD
Detect electroluminescent light

GEM + medipix → GEMpix



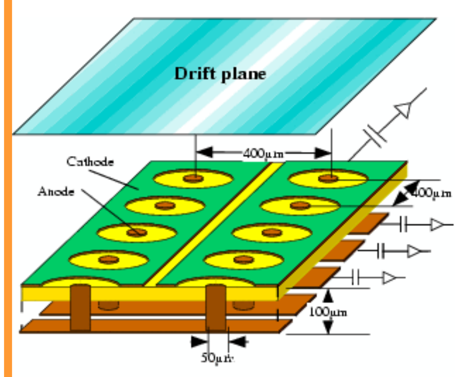
THGEM + MM for single photodetection: IBF control





(4) novel geometries

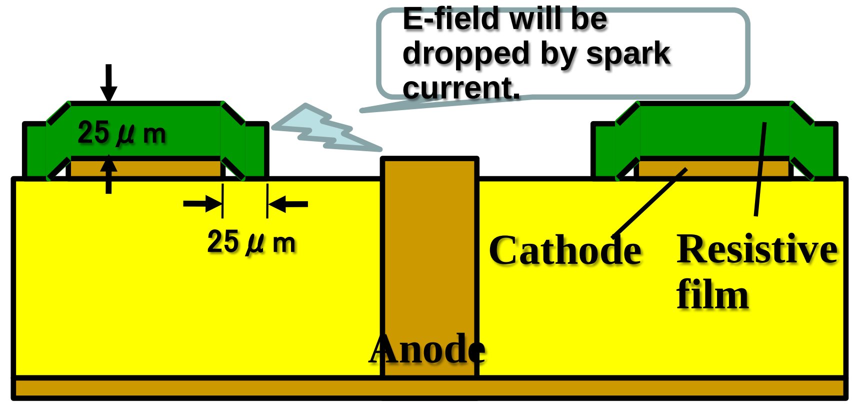
General purpose tracking: fundamental research & applications
Motivation:
- **use PCB technology for mass production,**
- **no floating structure**



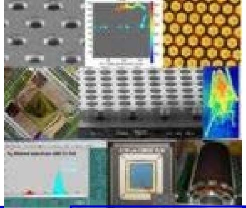
μPIC

A.Ochi and T.Tanimori,
NIMA 471 (2001) 264

Spark-tolerant structure



Resistive μPIC



OUTLOOK

- INTRODUCTION
- RD51
- MPGD TECHNOLOGIES
  - PRINCIPAL ARCHITECTURES
  - NOVEL ARCHITECTURES
  - NOT ONLY TRACKING
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  - APPLICATIONS
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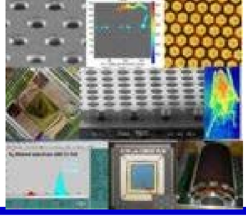
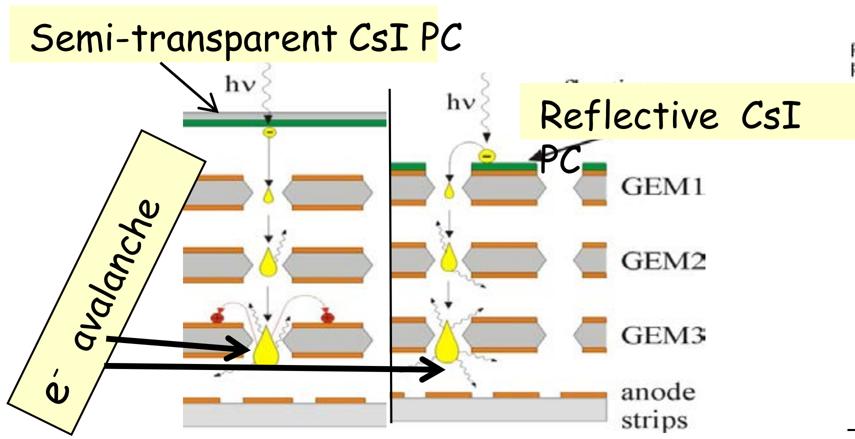
- CONCLUSIONS

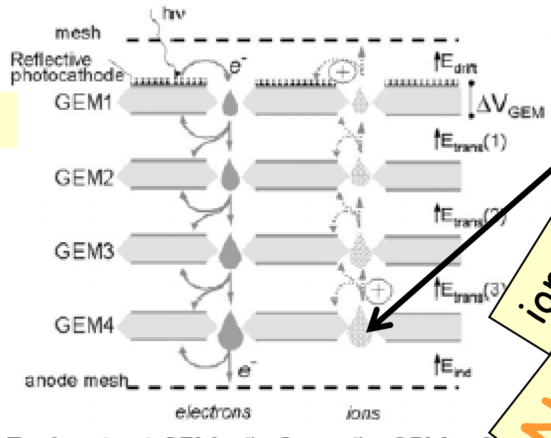
**All subjects illustrated by examples:
a fully comprehensive review is impossible !**



WHY PHOTON DETECTION BY MPGDS?

… first ideas



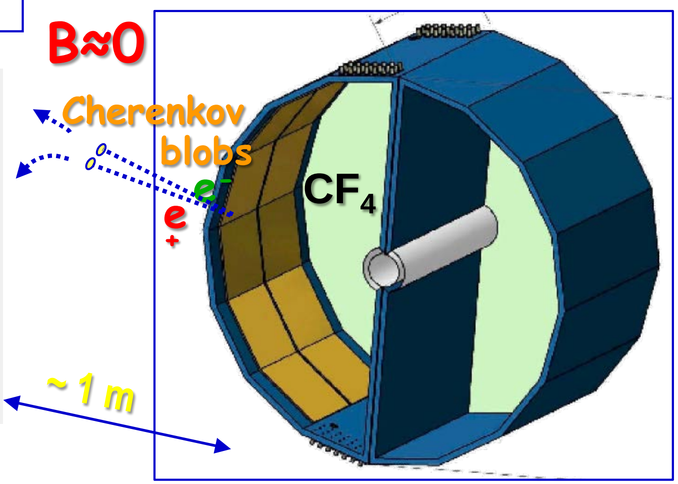


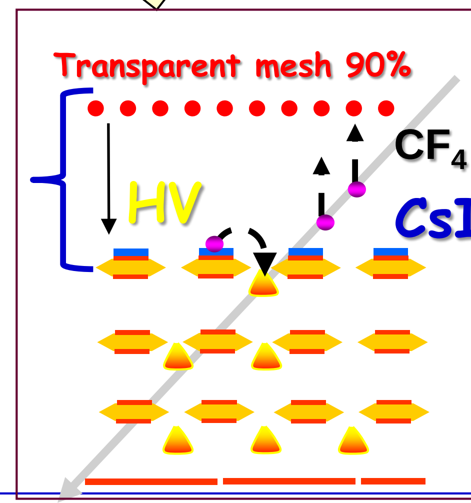
NO photon feedback
Reduced ion feedback
Signal by e motion: fast !

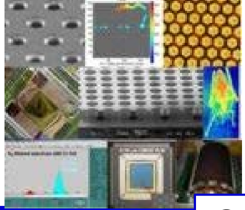
… and first application

PHENIX HBD,
a threshold Cherenkov counter
(window-less)

B≈0

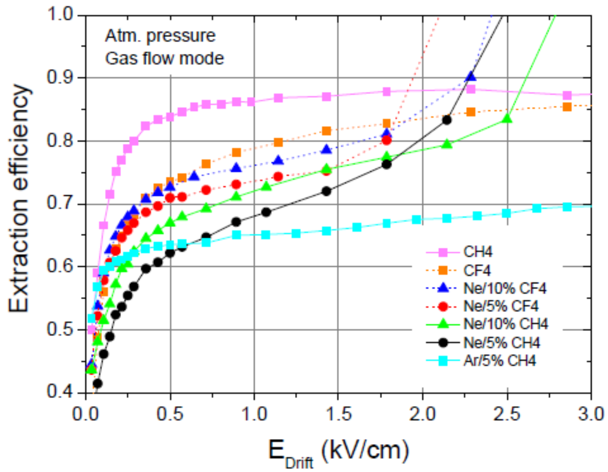






THE DILEMMA

C. D. R. Azevedo et al., 2010 *JINST* 5 P01002



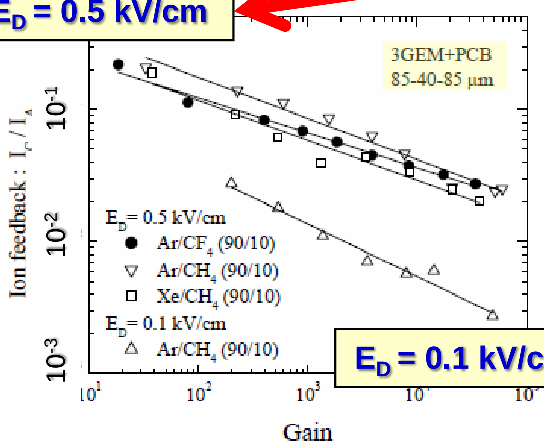
In front of the photocathode:

E > 0.5 - 1 kV/cm
needed for effective photoelectron extraction in gas atmosphere

E ~ 1 kV/cm needed for good photoelectron extraction

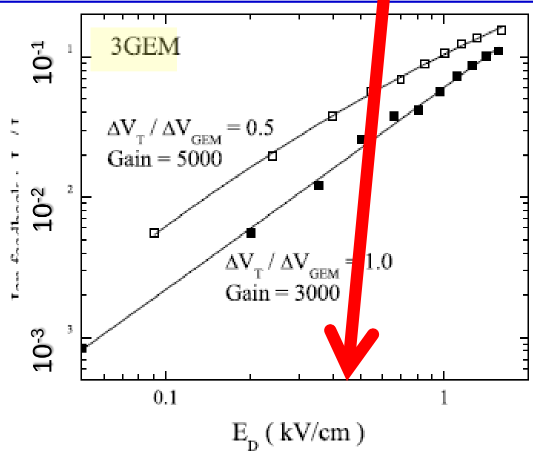
Tension between the 2 requirements !

E_D = 0.5 kV/cm



E_D = 0.1 kV/cm

A. Bondar et al., NIMA 496 (2003) 325



A. Breskin et al., NIMA 478 (2002) 225d

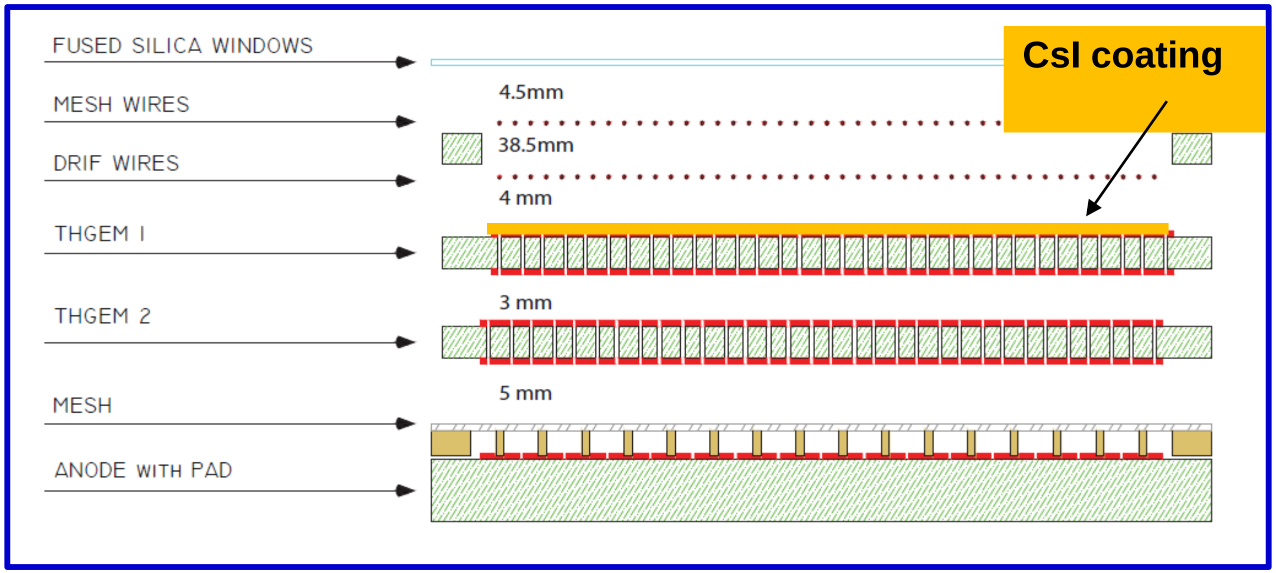
When E > 0.5 - 1 kV/cm in front of the photocathode,

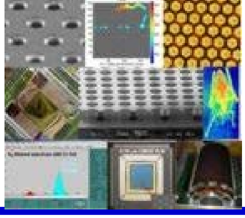
then non negligible Ion BackFlow (IBF)

THE DILEMMA and COMPASS RICH PDs

Hybrid architecture (intrinsic MM IBF control) :

2 THGEM layers +
1 MICROMEGAS (MM) stage
→ IBF rate: 3%
in large size detectors (60 x 60 cm^2)





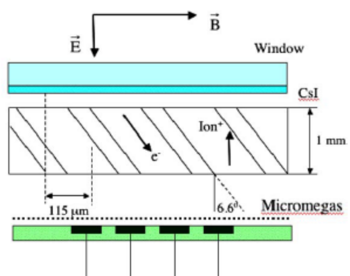
GASEOUS PMTs

- **photocathodes for visible light**
  - Chemical reactivity (gas purity better than ppm level needed → UHV materials and sealed detectors)
  - PC stability under ion bombardment - work function lower than CsI one
  - AGEING CsI: -16% QE at 25μC/mm² — F.Tokanai et al., NIMA 628 (2011) 190
    Bilkaly: -20% QE at 0.4μC/mm² — T.Moriya et al., NIMA 732 (2013) 263

By capillary plates

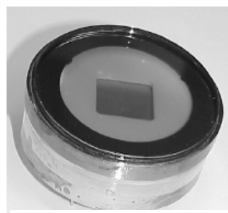
MCP coupled to Micromegas

Inclined to reduce more the IBF (tested with CsI)



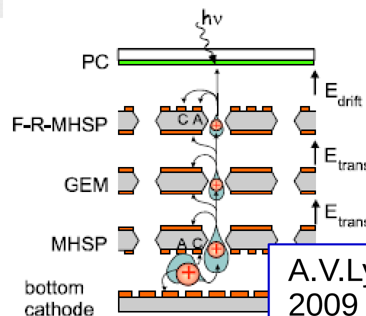
J.Va'vra and T. Sumiyoshi, NIMA, 435 (2004) 334

By GEMs



Multiple GEM sealed

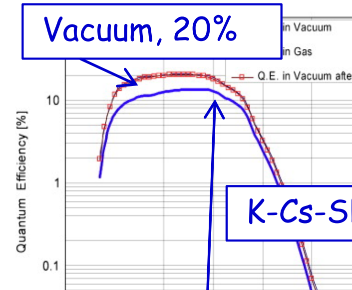
R.Chechik et al., NIMA 502 (2003) 195



K-Cs-Sb not sealed PD

A.V.Lyashenko et al., 2009 JINST 4 P07005

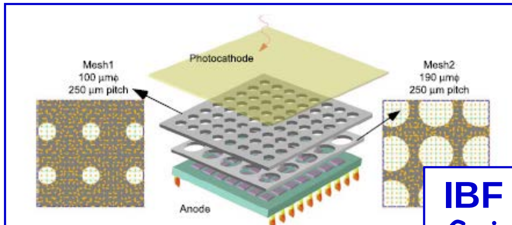
By MMs



In collaboration with HAMAMATSU, (now abandoned ?)

Ar (90%)+CH_4 (10%) 12% (stable) after 1.5 y

F. Tokanai et al., NIMA 610 (2009) 164

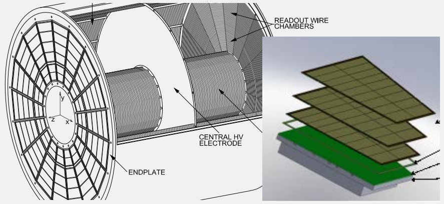


IBF : 6 ×10^{-4}
Gain : 10^4

F. Tokanai et al., NIMA (2014) in press

TPC R-O, ONCE MORE IBF PRESCRIPTIONS

ALICE TPC



IBF modifies the electric field in front of the detector

→ **Distorted information (in particular at high rates)**

- **Requirements for ALICE TPC:**
  - **IBF < 1% at Gain = 2000 → ε (=IBF x G) = 20**
  - ***Preserve good dE/dx measurement***

Conflicting requirements !

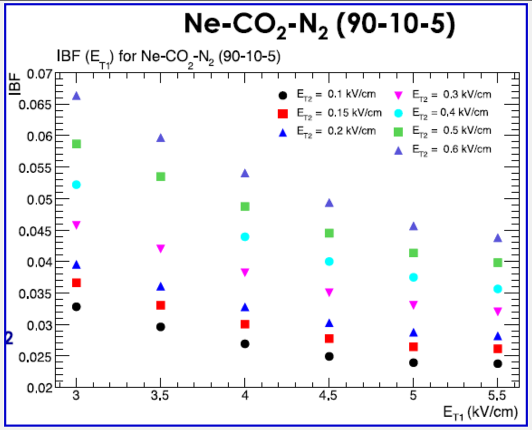
- **MPGDs considered:**

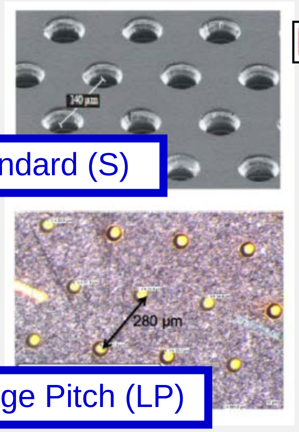
- use 4 layers alternating standard(S) and Large Pitch (LP) GEMs
- Selected option:
  IBF = 0.6 % $\sigma_E/E \approx 9.5\%$

A. Mathis, MPGD2015

Hybrid:
- 2 GEM + 1 MM

IBF ≈ 2.5 % with 3-GEM in $Ne-CO_2-N_2$

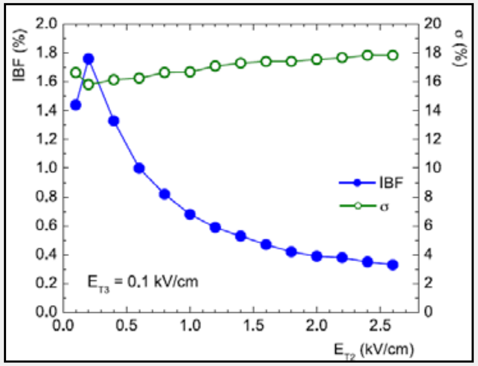


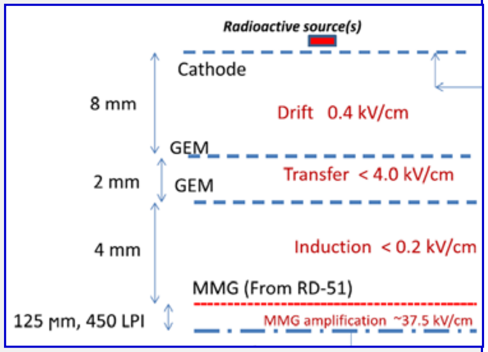


Standard (S)

Large Pitch (LP)

Baseline solution with S-LP-LP-S





IBF < 0.2 % using 3 component gas mixtures

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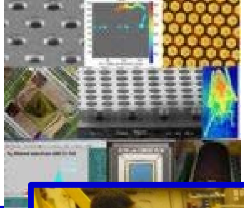


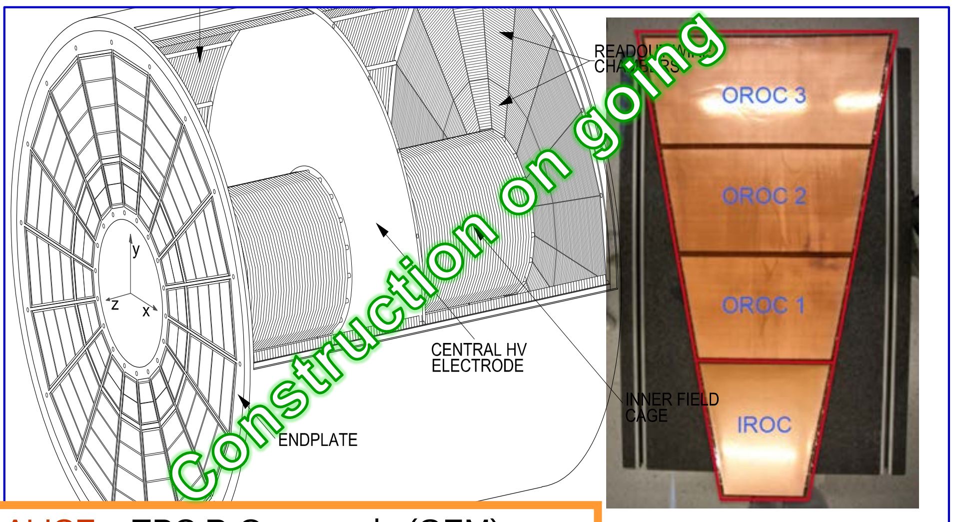
MPGDs & UPGRADE OF CERN EXPERIMENTS

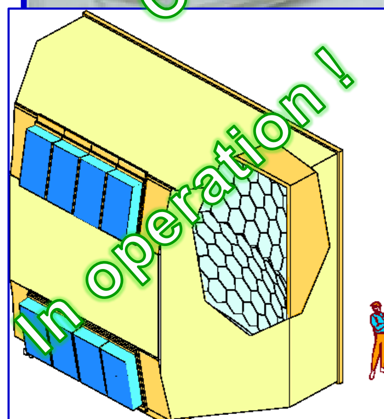
CMS – forward muon spectrometer (GEM)
Goal: ~1.2 x 2 m^2

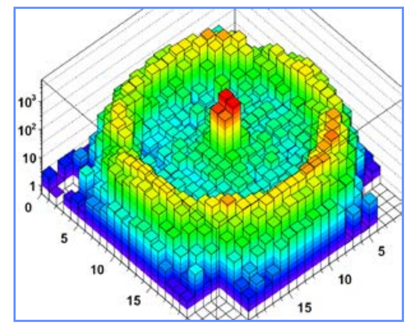
1000 m^2 of GEM foils, tracking & trigger

ATLAS – NSW project (MM)
Detector size: ~1 x 2.5m^2

New Small Wheel,
ATLAS muon system,
1200 m^2, tracking & trigger







ALICE – TPC R-O, upgrade (GEM)
size: ~.9 x 1.6 m^2

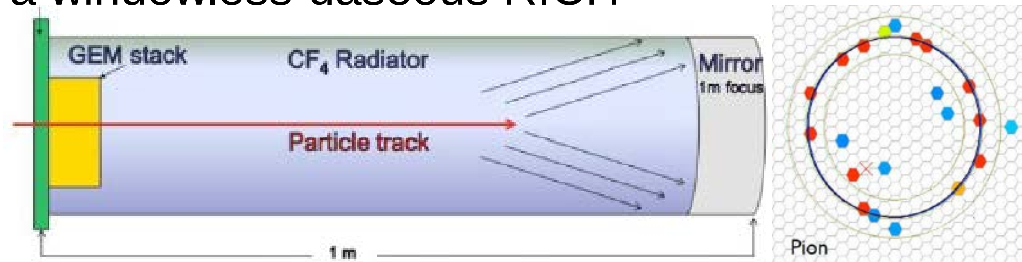
130 m^2 of GEM foils

COMPASS RICH-1 upgrade
Hybrid MPGD-based photon detectors

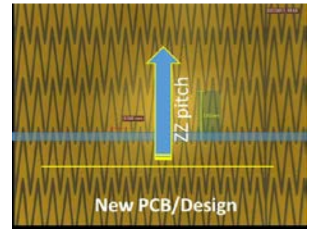
4.5 m^2 of MPGD multipliers (THGEM, MM)

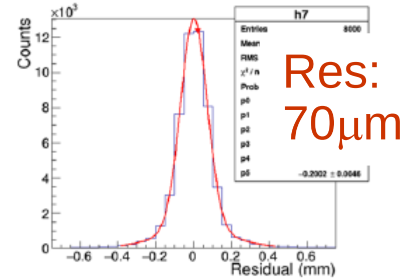
MPGD R&D for EIC

Quintuple GEM photon detector for a windowless gaseous RICH

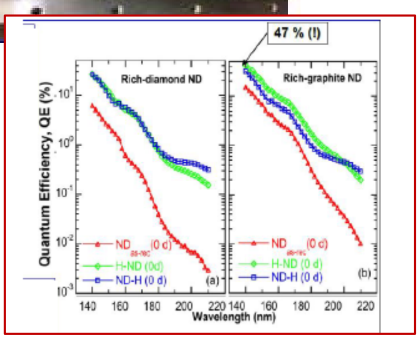


Zigzag GEM read-out for low channel count preserving fine space resolution in TPC r-o

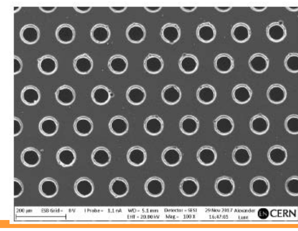




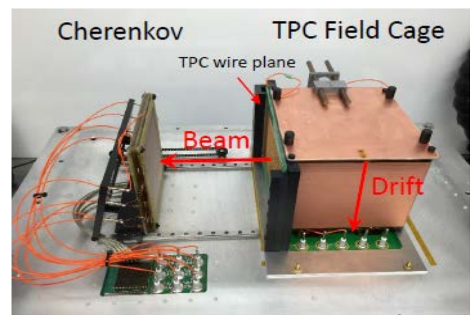
RICH r-o with hybrid MPGDs with miniaturized pads and novel nanodiamond photoconverter

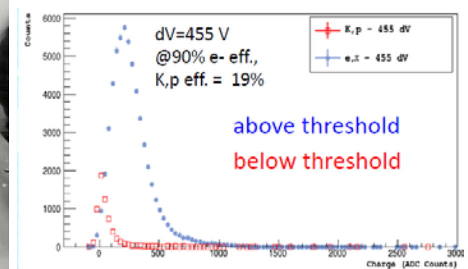


Low material-budget with **ultra-low mass Chromium GEM foils**

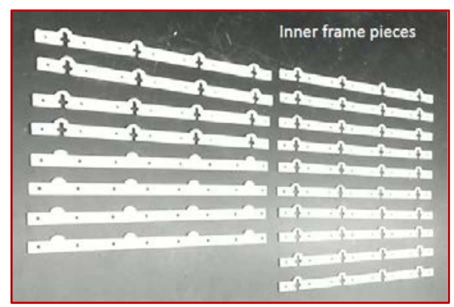


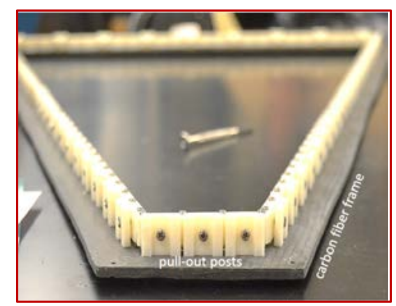
Extended e-PID with **a GEM-based Cherenkov TPC**





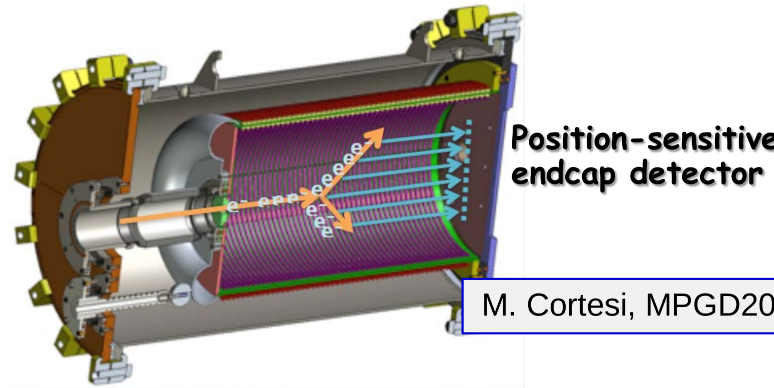
Large-size GEM detectors with low-mass low-cost 3-D ABS printed components





MPGDs in LOW ENERGY NUCLEAR PHYSICS

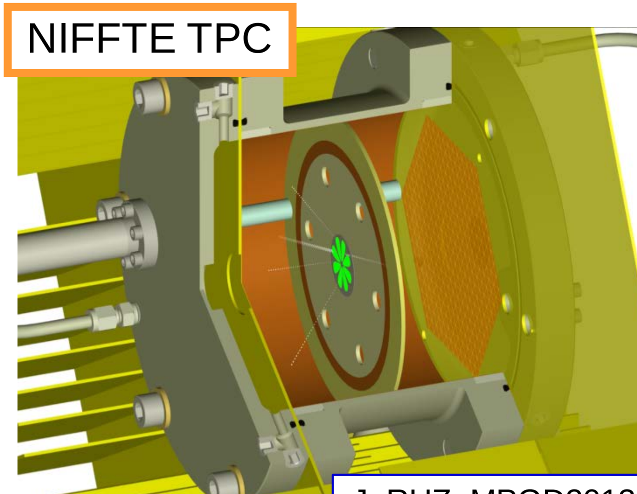
HYBRID MPGD (THGEM + MM) operated IN LOW-PRESSURE H, D, He, FOR Active Target –TPC @ National Superconducting Cyclotron Facility (NSCL), MICHIGAN



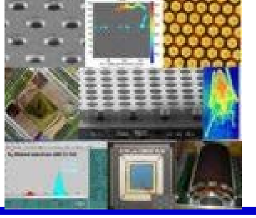
M. Cortesi, MPGD2015

Neutron Induced Fission Fragment Tracking Experiment (NIFFTE) is a double-sided TPC with micromegas readout designed to measure the energy-dependent neutron-induced fission cross sections of the major and minor actinides at Los Alamos LANSCE

NIFFTE TPC



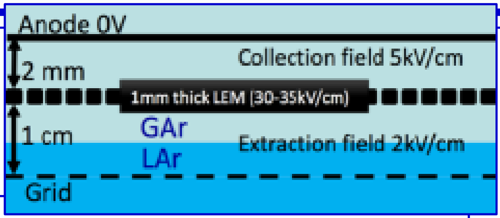
J. RUZ, MPGD2013

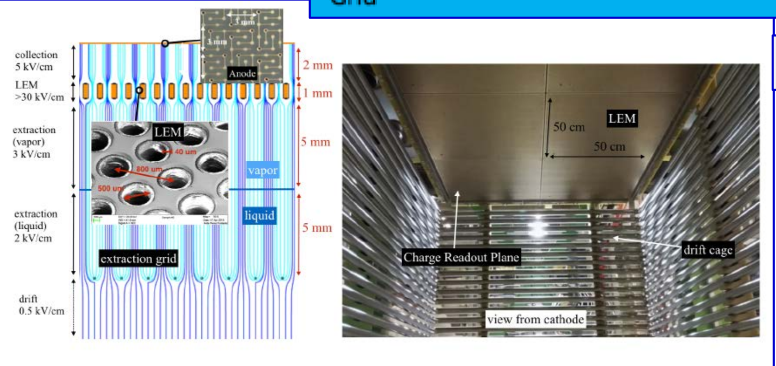


MPGDs & DETECTION OF RARE EVENT

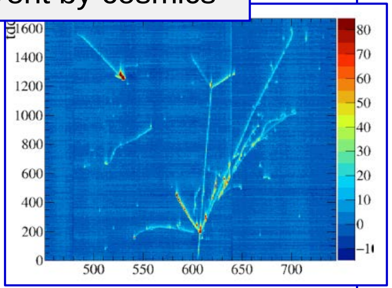
WA105 (3x1x1 m³ LAr prototype) (LBNO-DEMO)

- double phase for read-out by LEMs (THGEM)
- Top: 50 x 50 cm² LEMs, 2-D anode
- PMT plane, bottom



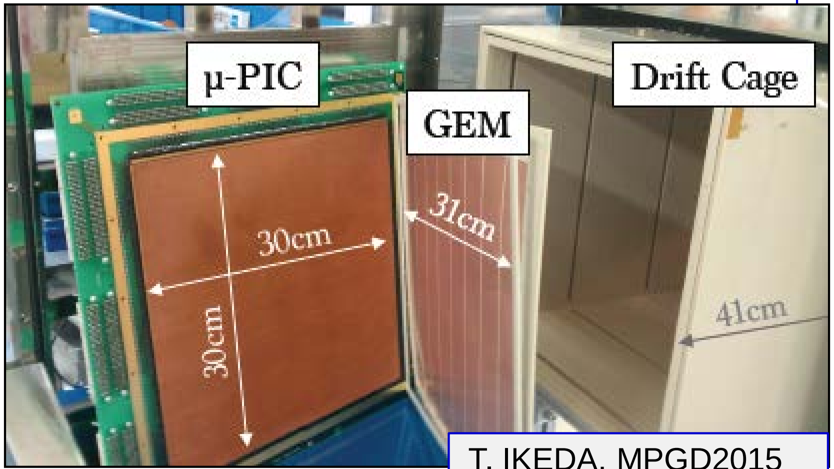


event by cosmics



NEWAGE0 Detector @ Kamioka mine

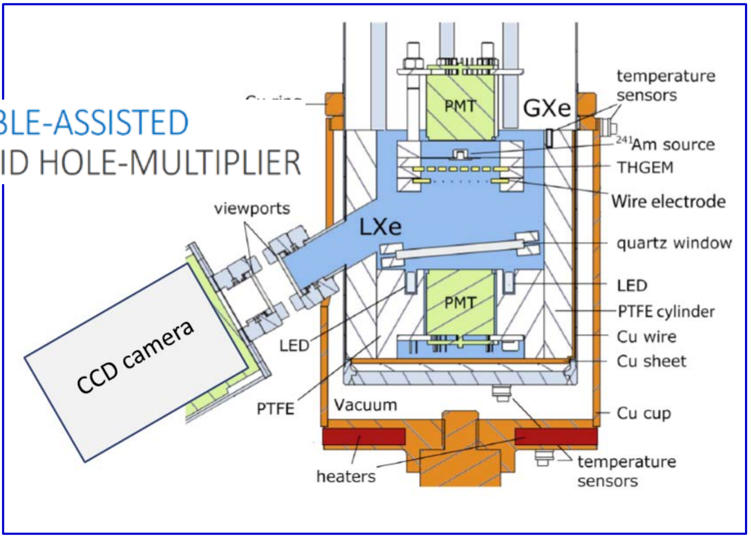
- Negative-Ion TPC using μ-PIC + GEM for Directional Dark Matter search
- Absolute z to define the fiducial volume (background rejection)
- Self-triggering: absolute z from 2 measured times: ions & e-
- Gases under study: CS_2, SF_6

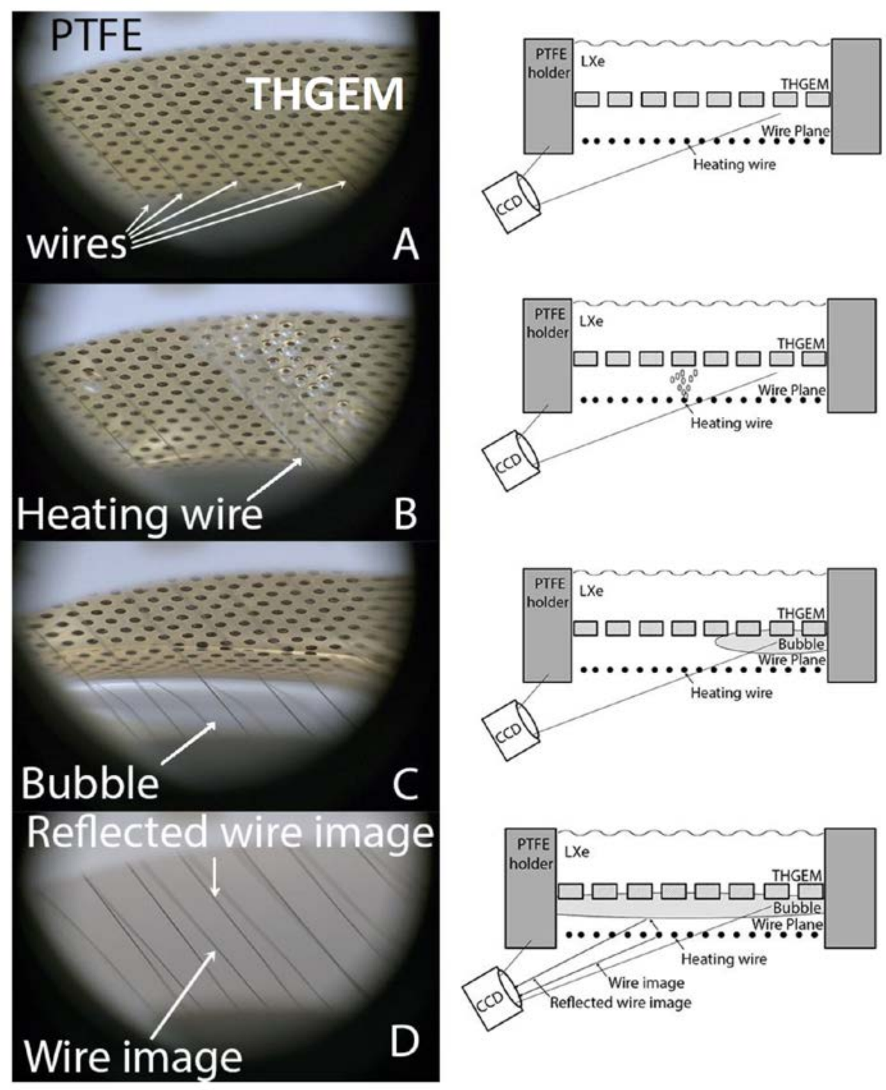


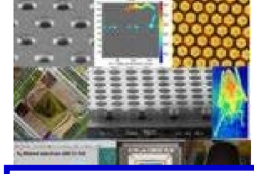
T. IKEDA, MPGD2015

MPGDs operated in LXe

THGEMs for rare event noble liquid detectors



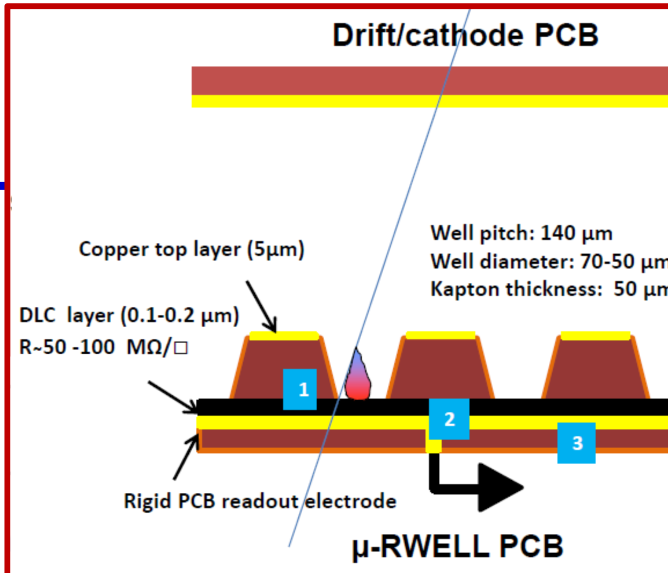




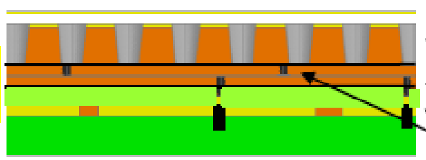
µR-WELL

Compact, single amplification stage

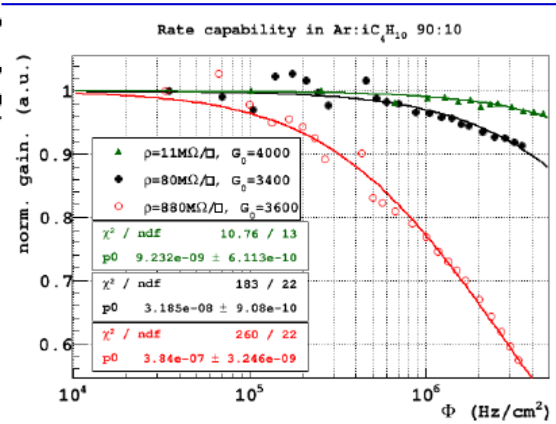
- Thanks to the resistive plane:
  - very realiable
  - almost completely *discharge-free*
  - adequate for high particle rates O(1MHz/cm^2) thanks to the *segmented-resistive-layer*
- performance:
  - gain ≥10^4
  - rate capability > 1 MHz/cm^2
  - space resolution < 60 µm
  - time resolution < 6 ns



G. Bencivenni et al., 2015_JINST_10_P02008



High rate version:
Double resistive layer and multiple connections

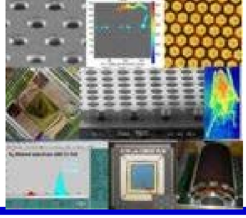


Rate capability up to 10^7 Hz/cm^2

Perspectives

single-resistive layer (moderate-rate):
- Quickly progressing towards large-size (ind. Partners: ELTOS, MDT)

double-resistive layer (high rate):
- suitable for LHCb-Muon upgrade

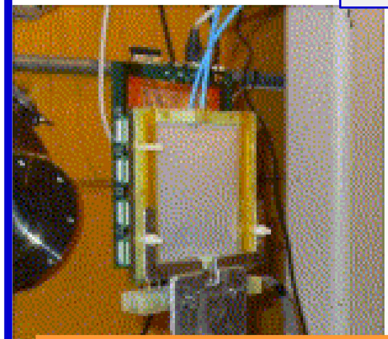


n DETECTION

F. Murtas, MPGD2013

PRESENT

D20 difractometer @ILL, MSGD

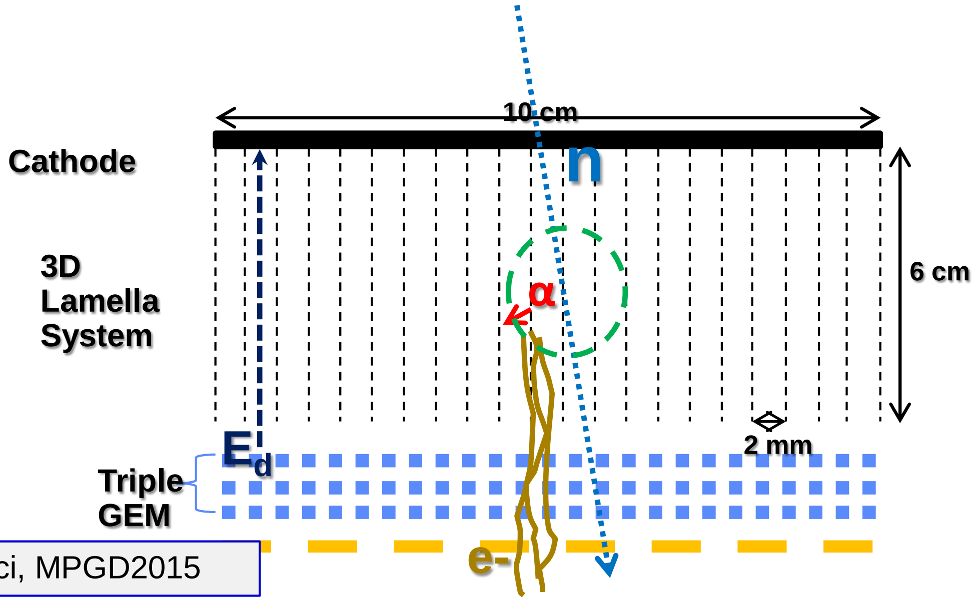


Neutron GEM (@ ISIS)

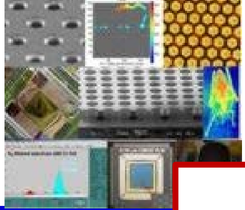
FUTURE

The BAND-GEM detector for ESS:

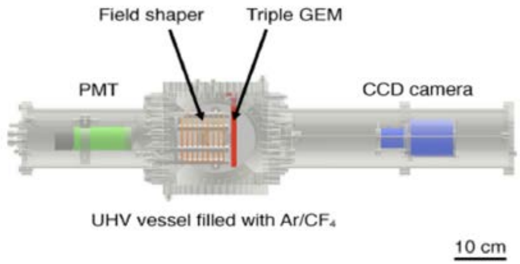
Lamelle with $^{10}B_4C$ coating



G. Croci, MPGD2015

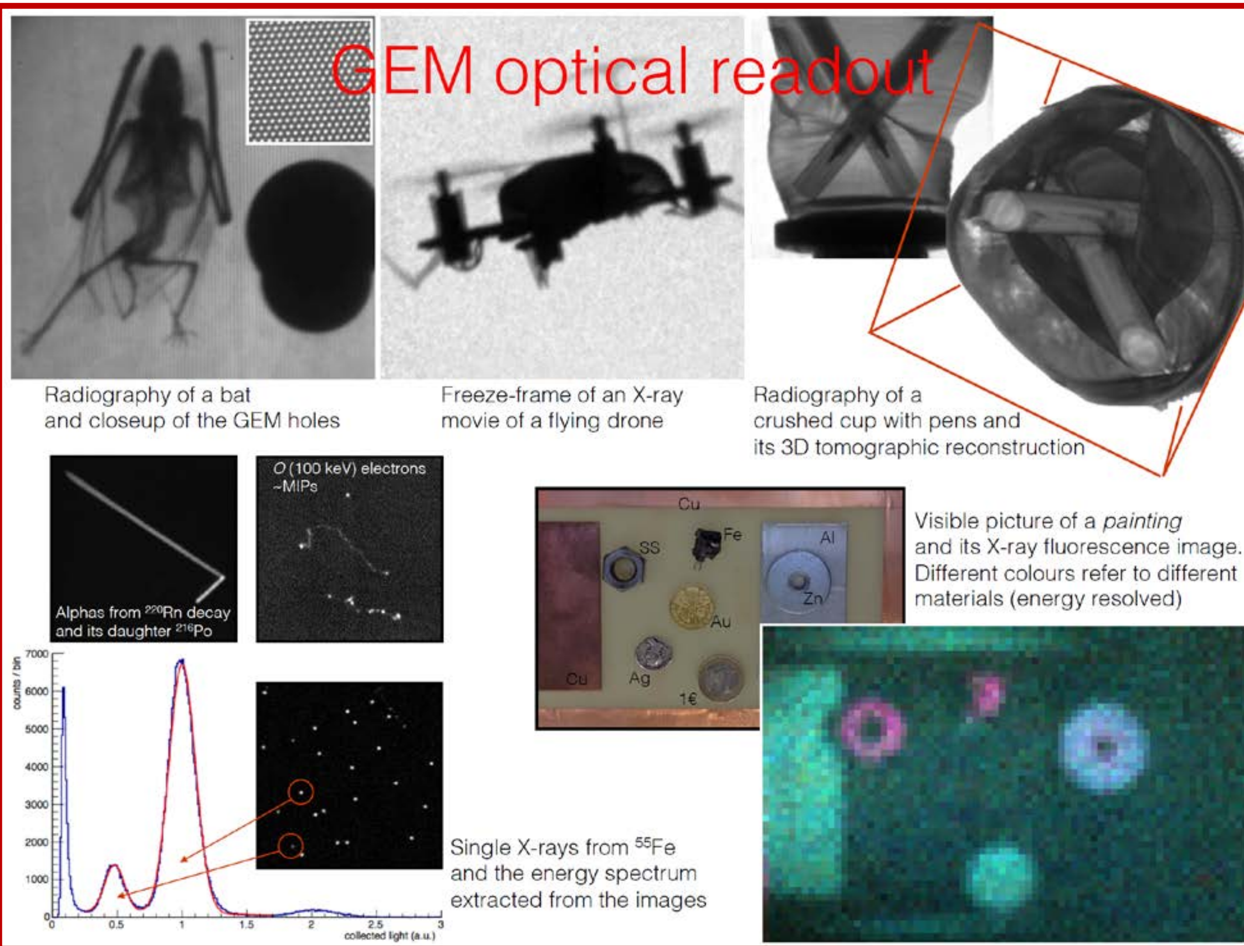


GEM OPTICAL READ-OUT



Camera → 2D projection of the track

PMT → Projection of the track in 3rd dimension



TECHNOLOGY BRIEF

CERN technology

Find out more at kt.cern or Tiago.Araujo@cern.ch

Optical readout system for gas-based detectors

By coupling CERN's Gaseous Electron Multiplier (GEM) detector technology with a Charge-Coupled Device (CCD) camera, CERN's optical readout system can record the light emitted during the electron avalanche using the detector as a scintillating pate.

Features

- Sensitive to: charged particles; X-rays (1-15keV, extendable), neutrons
- Single events down to MIPs
- Radiography - imaging and energy resolved
- Fluoroscopy and Fluorescence - imaging and energy resolved

Applications

- UV imaging , Neutron imaging , γ - imaging
- X-ray crystallography – possibly over large surfaces
- Spatially resolved X-ray fluorescence - e.g., artworks in order to unveil underlying paintings over large surfaces
- 3D Medical Imaging - e.g., small animals or targeted anatomy (mammography)

Benefits of Working with CERN

Outputs of the world's leading scientific research institute

Research-developed and experimentally-validated technologies

World-class infrastructures and facilities

Possibility of using CERN labels for your branding and marketing

muon and δ-ray

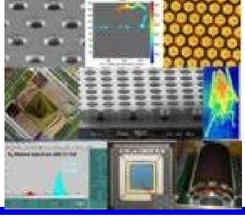
Acquisition (<1 s) no processing time

CT and 3D imaging

IP Status: Patented

Technology Readiness Level: First generation Prototype

Technology Domain: Detector technology



Measurements of ^{55}Fe in Radioactive Waste with GEMPix

Radioactive waste treatment

- CERN needs to treat considerable amounts (several hundreds of m^3 per year)
  - Cables, magnets, concrete blocks, targets, detector components, steel supports, …
- Large fraction: metallic waste → ^{55}Fe
- Radiological characterisation necessary for treatment

Sample preparation

The sample is reduced to a powder with a milling machine (to reduce background from sample)

Filtered with a mesh

The sample is inserted below the detector for the measurement

The powder is attached to a double tape in a small plastic box of 3x3 cm^2 size

F.Murtas, M.Silari, J.Leidner, J.Alozy, M Campbell

Radiological analysis: ^{55}Fe

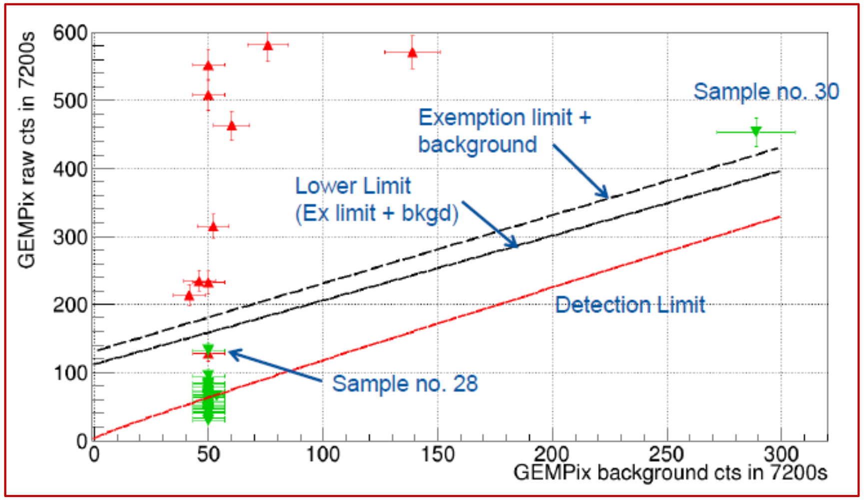
- Current Swiss exemption limit: 30 Bq/g
  → will be increased to 1 kBq/g
- Standard method: radiochemical analysis, performed by external companies, 2-month delay for results

^{55}Fe 2.7 years

↓ 5.9 keV X-rays

^{55}Mn

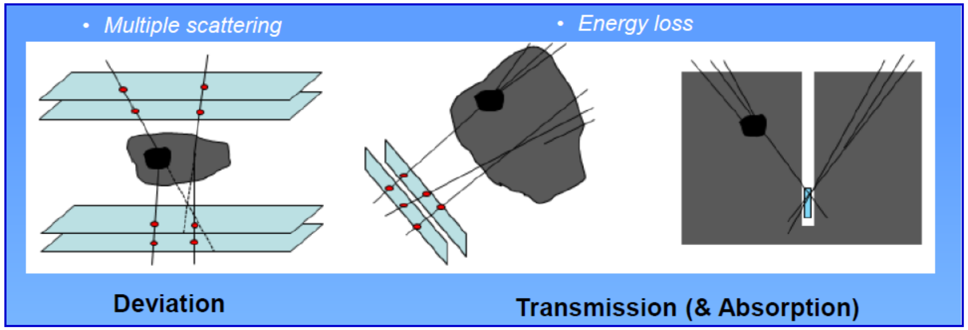
2-h measurements:
GEMPix has adequate sensitivity

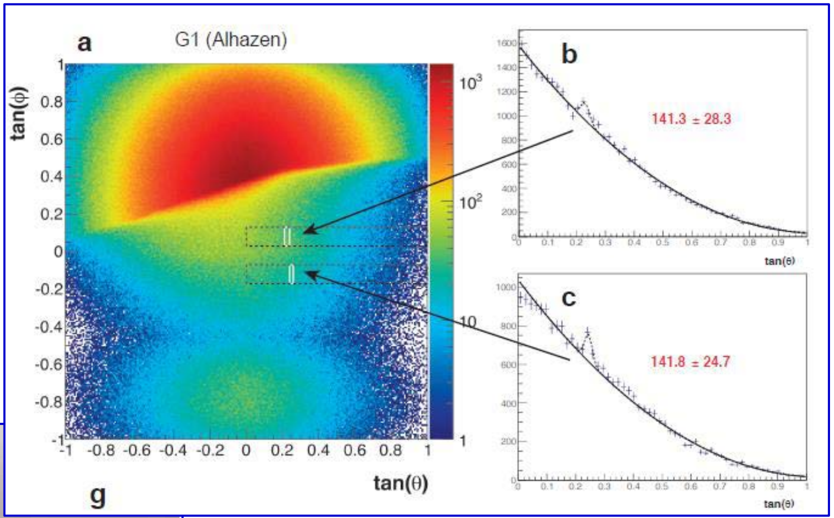


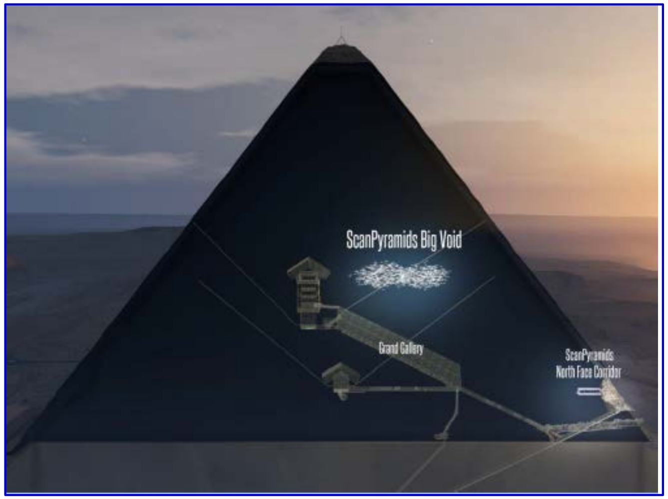
Muography of Pyramids with MICROMEGAS

Muography principle

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

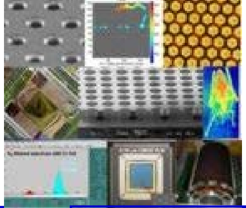






Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons

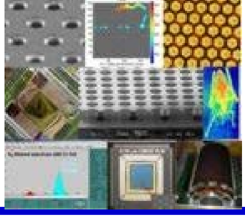
Nature 552 (2017) 386



OUTLOOK

- INTRODUCTION
- RD51
- MPGD TECHNOLOGIES
  - PRINCIPAL ARCHITECTURES
  - NOVEL ARCHITECTURES
  - NOT ONLY TRACKING
- MPGD-RELATED ACTIVITIERS
  - APPLICATIONS
  - FRONTIER R&D
- **CONCLUSIONS**

All subjects illustrated by examples:
a fully comprehensive review is impossible !



MPGDs & RD51

- **MPGDs: born within HEP,**
  now required for <u>rare event physics</u> and <u>low energy nuclear physics</u>

- **Applications <u>beyond fundamental research</u>**
  - **Already facts!**
  - **A part the Geiger counter, for the first time gaseous detectors leave labs to match society requirements**

- **RD51, a fundamental ingredient of MPGD success:**
  - **Development and consolidation of technologies**
  - **Support, cultural and by tools/infrastructure**
  - **4π action for dissemination**
    - **Schools, thematic workshops, academy-industry matching events, conferences, successful use in experiments**
  - **An advanced model of information/know-how transfer in a genuine <u>world-wide networking</u>**