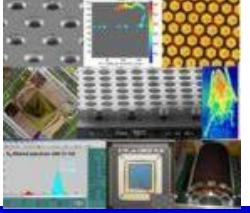


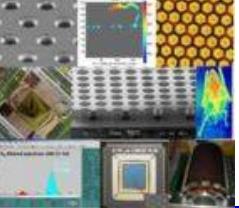
Micro Pattern Gas Detector Technologies and Applications: the work of the RD51 Collaboration

S. Dalla Torre



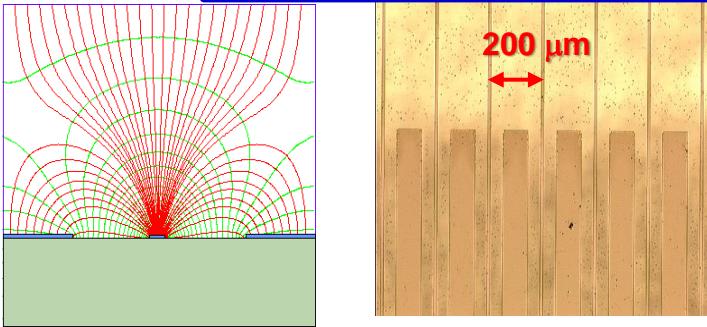
INTRODUCTION

MPGDs: THE EARLY DAYS

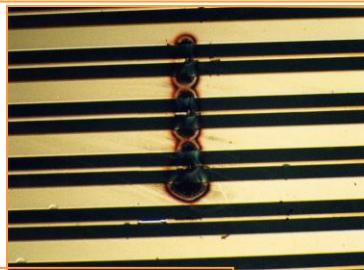


MSGC - MicroStrip Gas Chamber

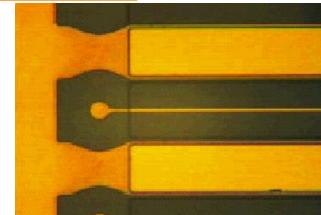
A. Oed, NIMA 263(1988) 351



- 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
→ MSGD
operational!



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

First Large Scale Use of GEMs and MICROMEGAs



Tracking in the COMPASS
Experiment

Micromegas: $\sigma_x \sim 90 \mu\text{m}$

E/HCAL

Target

Beam

S. Ketzer

SM1

RICH

SM2

MuonWall

E/HCAL

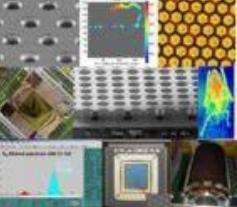
$\sigma_t \sim 12 \text{ ns}$

GEM: $\sigma_x \sim 70 \mu\text{m}$

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

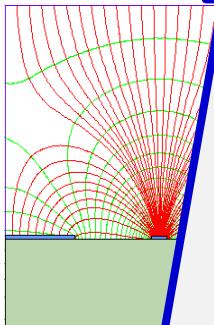
GEM:
F.Sauli, NIMA A386 (1997) 531

MPGDs: THE EARLY DAYS



MSGC - Mi

Strip Gas Chamber



- High E insulator
- Charge insulator

ALREADY SOME LESSONS:

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

First Large Scale Use of GEMs and MICROMEGAs

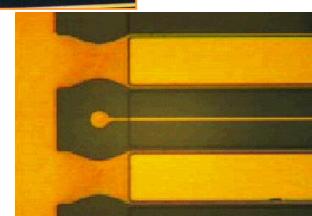
1. Why MPGDs?

- High rates (granularity, signal formation time)
- Fine space resolution
- Lithographic techniques – HighTech production
→ large series

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



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



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

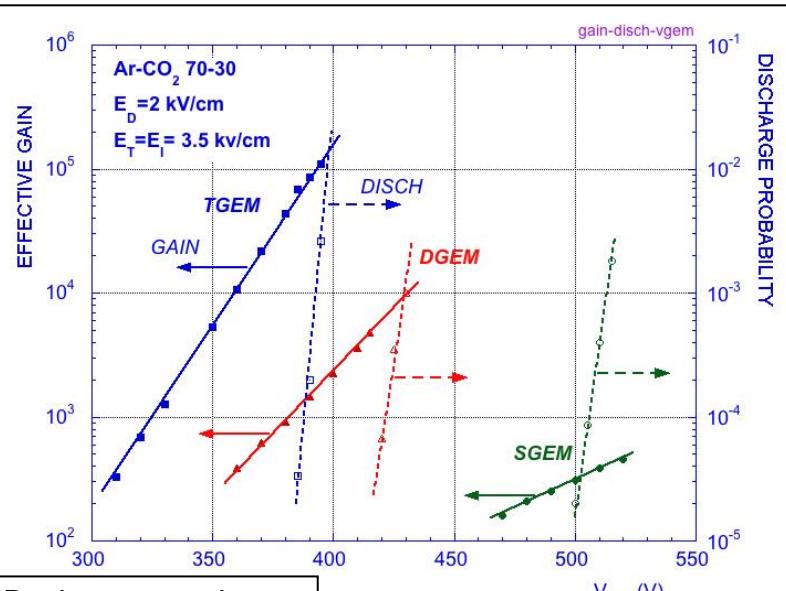
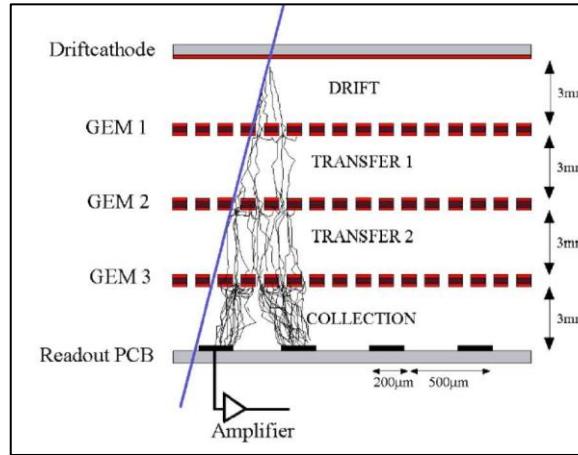
GEM.
F.Sauli, NIMA A366 (1997) 531

MPGD developments

Silvia DALLA TORRE

THE ENEMY: THE DISCHARGE RATE

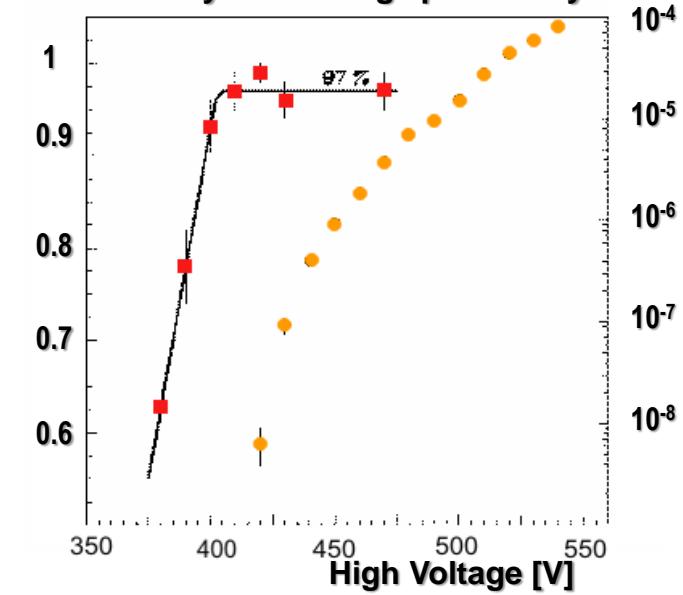
GEM



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

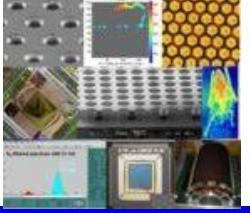
MM

efficiency & discharge probability



Discharges:

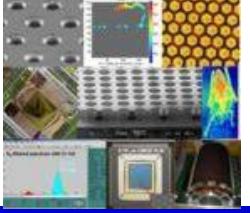
- **Detector damages**
- **F-E damages**
- **Dead-time**



MPGDs in the recent years

- **Consolidation of the established architectures**
 - novel ingredients & technological progress
- **Flourishing of novel architectures answering specific requirements**
- **Wide application portfolio**
 - HEP – LHC experiments
 - nuclear physics
 - beyond fundamental research

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



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, now 5-year prolongation till the end of 2018

RD51 serves as an access point to MPGD "know-how" for the world-wide community

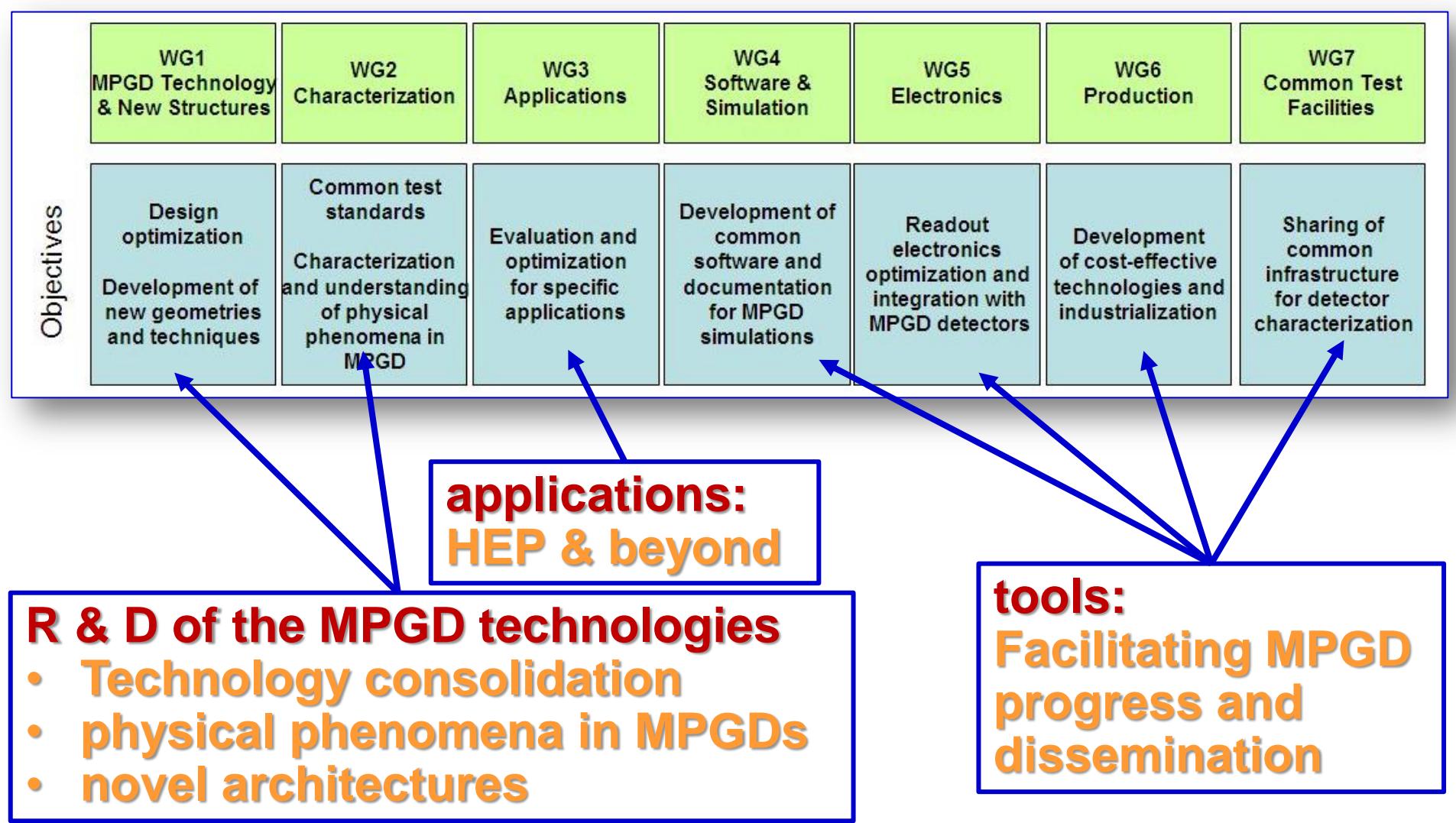
L. Ropelewski, M. Titov
114th LHCC Meeting, CERN, 12-13 June 2013

Unique in providing:

- Space and resources for non – project related R&D
- tools for the word-wide MPGD community AND BEYOND



RD51 activity

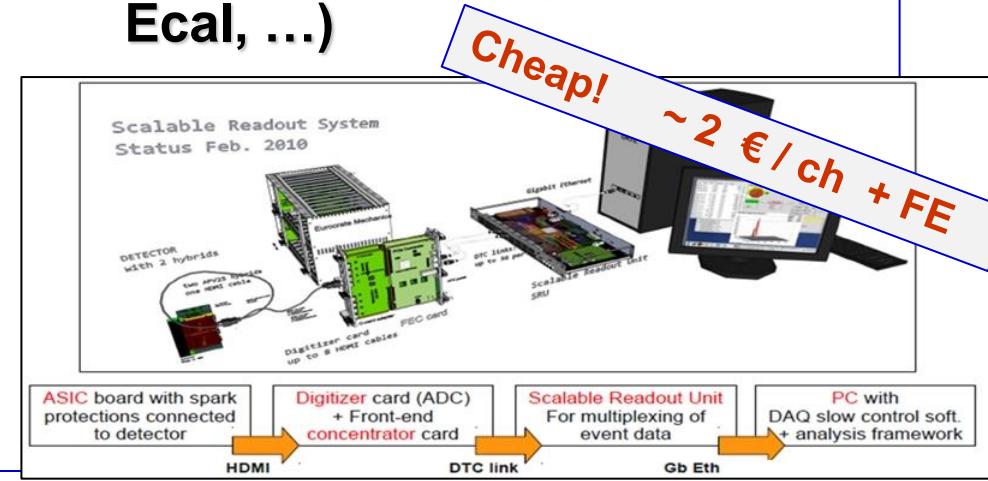


SIMULATION

- **GARFIELD → GARFIELD ++**
 - R. Veenhof, NIMA419 (1998) 726;
<http://garfield.web.cern.ch/garfield>
- **Maintenance**
(service to the whole gas detector community)
- **physics (ions, e-, photons)**
- **MPGD specific:**
 - dramatic E variations over short distances, comparable with the e mean free path
 - open dielectric surfaces

SRS - Scalable Redout System

- **Common Hardw. & softw.**
- **Interfacing different FE:**
APV25, VFAT, Beetle, VMMx, Timepix
- **Scalable:** ~100 ch.s → ~100 k ch. (ATLAS MAMMA project)
- **So successful, to be used outside MPGDs (SiPM, ALICE Ecal, ...)**



RD51 TOOLS 2/2

TEST infrastructures

■ RD51-GDD lab

- (flammable) gases
- Sources
- 2 Xray stations
- Clean room
- GEMs and MICROMEGAS
- CMS, ATLAS, ALICE, ...



■ Common test beam at SPS

- Gases, cables, DAQ, ...
- Several RD51 groups each year



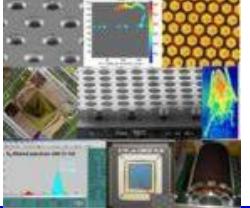
@ CERN a reference workshop

- ‘96: GEM 50 x 50mm with a gain of 10.
- ‘97: GEM 100 x 100mm with gain of 1000.
- ‘98: GEM 400 x 400mm; 1D and 2D readouts; micro-groove and micro-well detectors.
- ‘00: 3D GEM readout; 1D readout for Micromegas in COMPASS.
- ‘01: PIXEL GEM readout; 2D Micromegas readout.
- ‘03: PIXEL Micromegas readout.
- ‘04: Bulk Micromegas detector 100mm x 100mm. Micro BULK detectors
- ‘06: Half cylindrical GEM detector.
- ‘08: first large GEM 1.2m x 0.4m. First spherical GEM
- ‘09: first large BULK Micromegas 1.5m x 0.5m
- ‘11: First resistive Bulk Micromegas 100mm x 100mm
- ‘12: First 30cm x 30cm NS2 GEM detector
- ‘12: First 1m² Resistive Micromegas
- ‘12: First 2m² Resistive Micromegas
- ‘12: First NS2 GEM detector 1.2m x 0.5m
- ‘12: Full cylindrical GEM detector
- ‘13: GEM 2m x 0.5m ?? Micromegas 3.4m x 2.2m ??

R. De Olivera,
MPGD13

New lab@ CERN
(bld 107):
Completed !





INDUSTRIAL PRODUCTION

GEM

Techtra

- Polish company
- Making GEM since 10 years
- Licensed by CERN
- Setting up equipment for large GEM production since 1 year
- 30cm x 10cm GEMs already produced
- First delivery of 30 GEMs last week

UPLUS/Mechronics

- Korean company
- Making GEM since a few months
- Licensed By CERN
- 30cm x 30cm GEMs already produced (characterization in progress)
- Willing to ramp up to large size

Tech-etch

- US company
- Making GEM since 15 years
- Many small and medium sizes GEM have been produced
- Recently involved in STAR experiment (80 GEMs 40cmx40cm)
- Willing to ramp up to large size
- Licensed by CERN

Scienergy

- Japanese company
- Making GEM since 6 years
- Top quality laser drilled GEM up to 30cm x 30cm
- Licensed by CERN

MICROMEGAS

ELTOS

- Resistive 10cm x10cm BULK Micromegas → OK
- Large single side read-out boards and drift (2mx0.5m) → OK
- Screen printing of large area → in progress
- Pillars on large area → OK

ELVIA (see Fabien talk in WG6)

- Resistive 40cm x 40cm BULK Micromegas → OK
- Embedded resistor BULK detectors → in progress (see Damien talk WG6)
- Large single side read-out boards and drift (2mx0.5m) → OK
- Screen printing of large area → in progress
- Pillars on large area → OK

THGEM

ELTOS

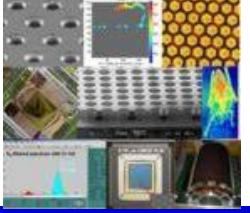
- 10 holes/ sec drilling machine
- They have produced 60cm x 60cm just for mechanical purpose
- They have produced 80cm x 40cm working THGEM
- They are able to produce RIMs.
- The final cleaning should still be performed by the user or CERN
- Long polishing or PU coating are not yet available in industry

• Mass production costs are still difficult to predict (cleaning technology transfer should be organized)

Print Electronics

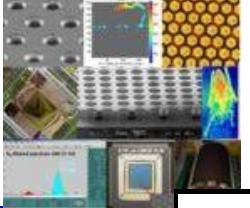
- Israel
- Many pieces made for Weismann institute
- Little information on the capabilities

R. De Olivera, MPGD213



CONSOLIDATION OF ESTABLISHED ARCHITECTURES

(new ideas & technological progress)



STATUS (in experiments)

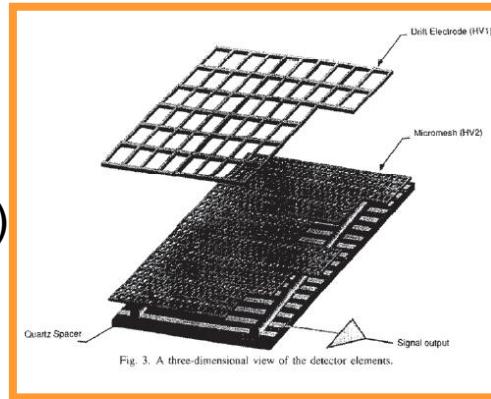
	MICROMEGAS		GEM	
SPACE RESOLUTION	COMPASS: ~ 90 um	NIMA 577(2007) 455	COMPASS: ~ 70 um	NIMA 577(2007) 455
TIME RESOLUTION	COMPASS: 9 ns	NIMA 577(2007) 455	COMPASS: 12 ns LHCb: 4.5 ns dedicated effort	NIMA 577(2007) 455 NIMA 535 (2004) 319
GAIN	COMPASS: ~6400 T2K: ~1500	NIMA 577(2007) 455 NIMA 637(2011) 25	COMPASS: ~8000 LHCb: ~4000 TOTEM: ~8000 PHENIX HBD: ~4000	B. Ketzer, priv. comm. NIMA 581 (2007) 283 G. Catanesi, priv. comm. NIMA 646(2011) 35
MATERIAL BUDGET	COMPASS: 0.3% X0	NIMA 577(2007) 455	COMPASS: 0.4% X0 COMPASS: 0.2% X0 (pixelized GEMs)	NIMA 577(2007) 455 NP B PS 197 (2009) 113
RATES	MAMMA-ATLAS: > 100 kHz / cm^2	MPGD2013	COMPASS: 12 MHz / cm^2 (pixelized GEMs)	NP B PS 197 (2009) 113
NO AGEING TILL	MAMMA-ATLAS: X-rays: 225 mC / cm^2 n: 0.5 mC / cm^3 gamma: 15 mC / cm^4 alphas: 2.4 mC / cm^5	VCI 2013	LHCb: 2 C / cm^2 high gas flux	NPB PS 150 (2006) 159

MICROMEGAS, construction

the challenge: keep uniform the thin gap by insulating spacers

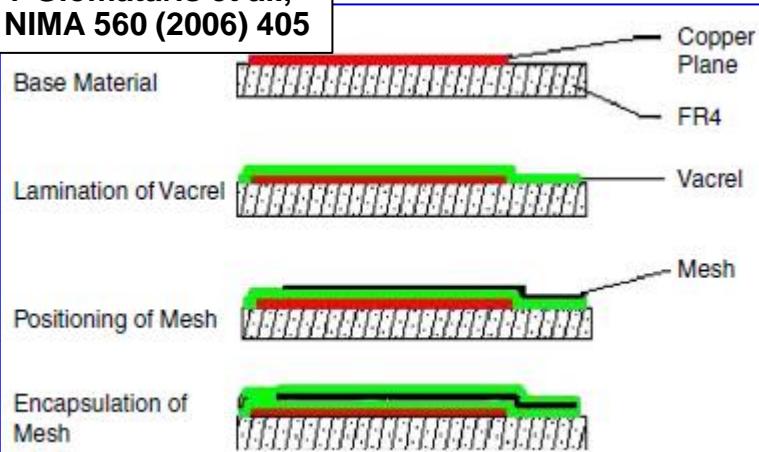
- 1) electroformed **Ni mesh** + quartz fibres (75 µm)

Y Giomataris et al., NIMA 376 (1996) 29



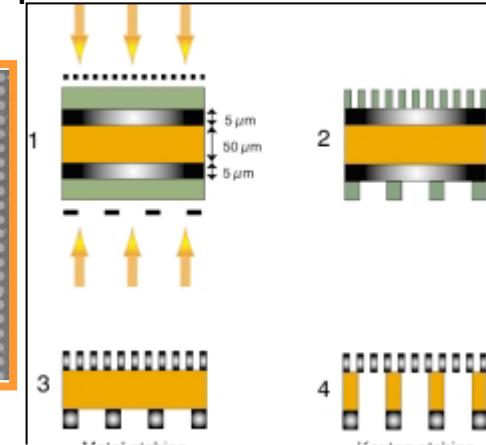
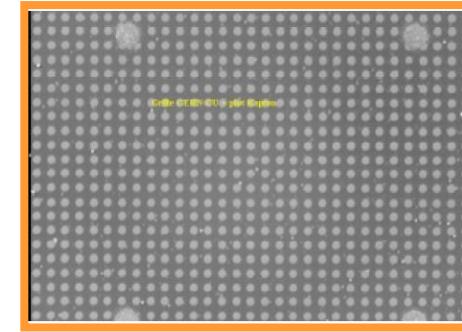
- 3) **Bulk micromegas**: pre-stretched steel mesh laminated together with a PCB support and a photoresistive layer, later removed apart where pillars are formed

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



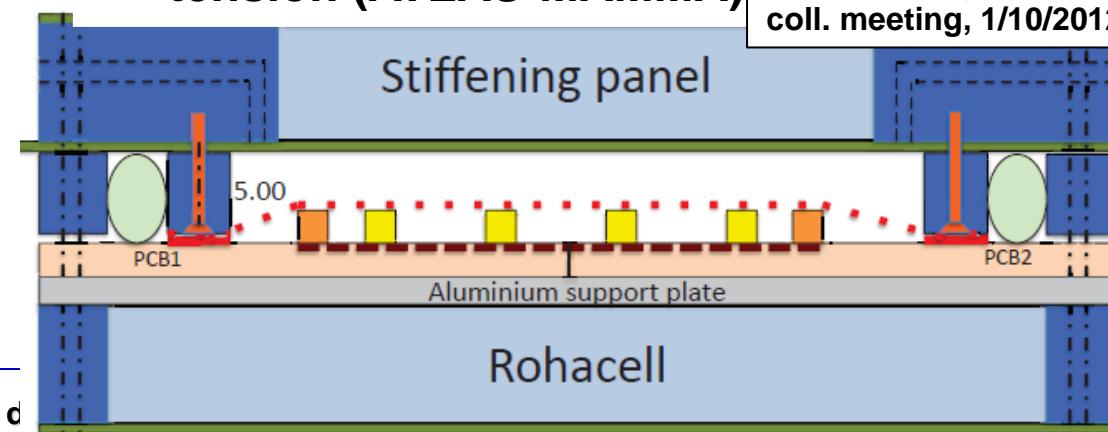
- 2) Etched metalized **polyimide foil**; pillars (spacers) produced during etching

A. Delbart et al., NIMA 461 (2001) 84



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

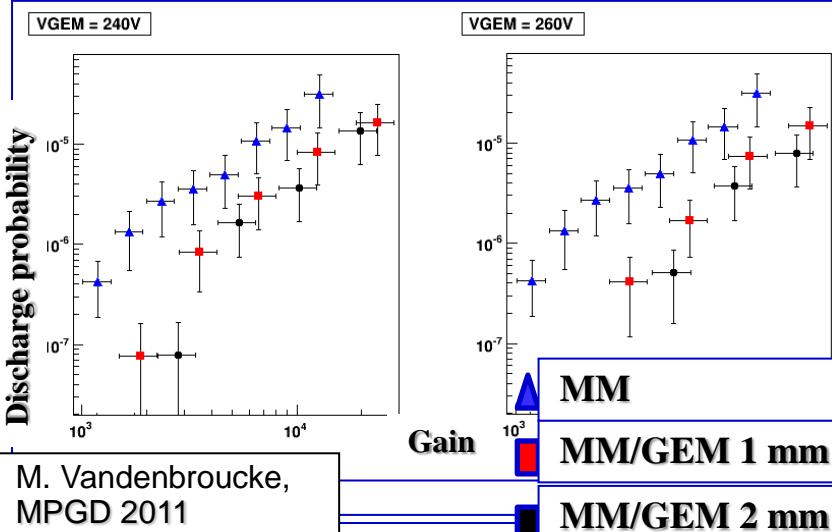
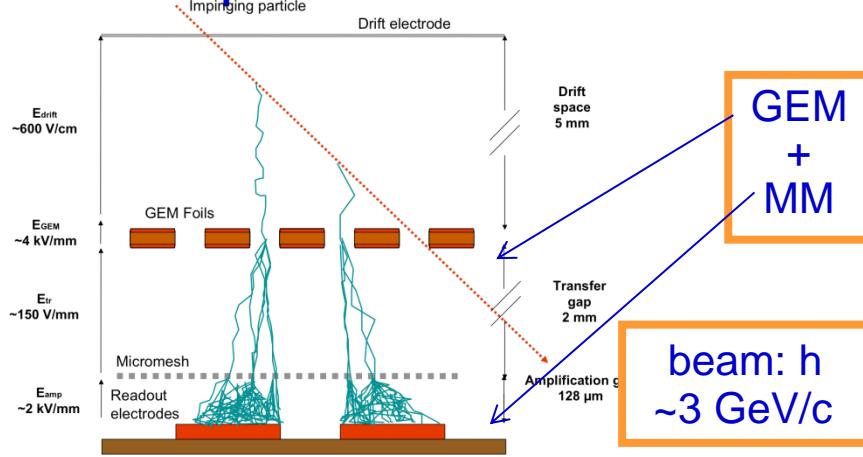
J.Wotschack, RD51 coll. meeting, 1/10/2012



MICROMEGAS, overcoming discharges

Hybrid Structures

- For experiments COMPASS and CLAS12

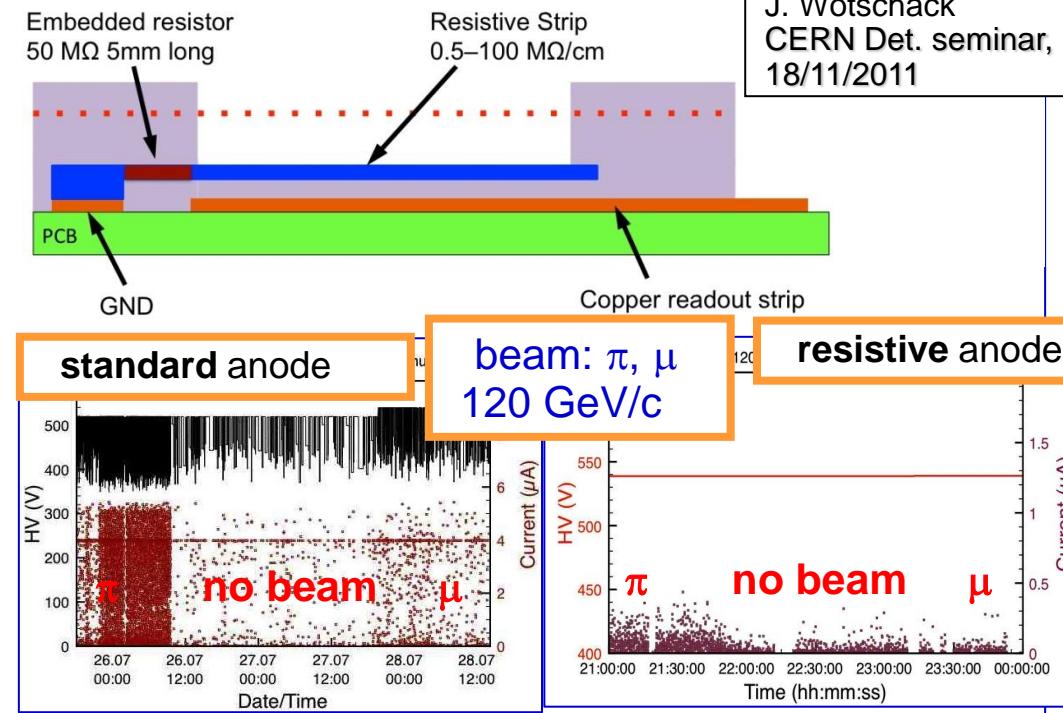


TIPP14, Amsterdam 2-6/6/14

MPGD deve

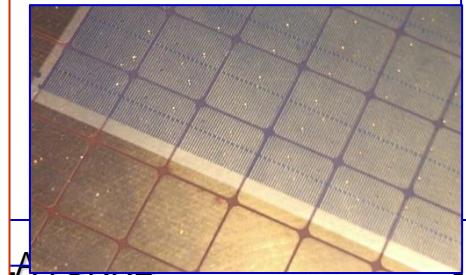
Resistive Anodes

- Developed within the ATLAS-MAMMA project



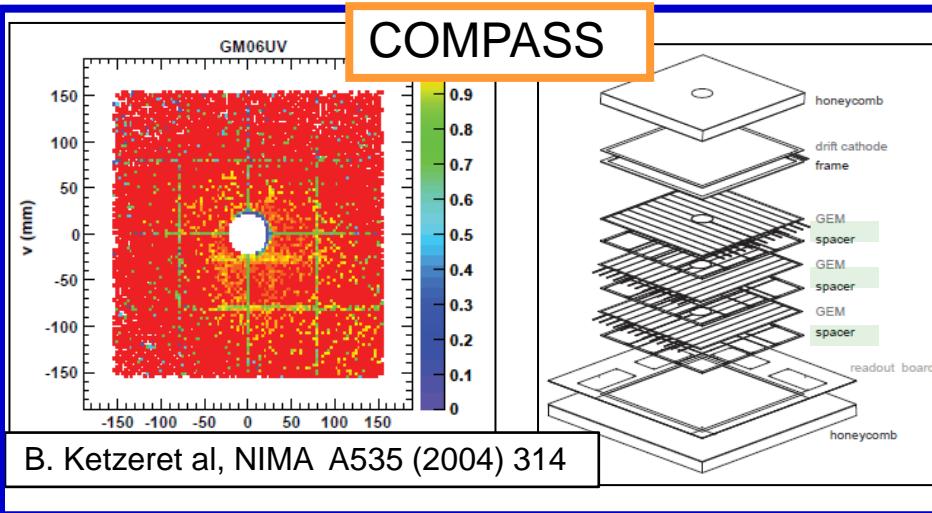
Resistive anode, implementation:

- Photolithography
- Screen printing
- By sputtering

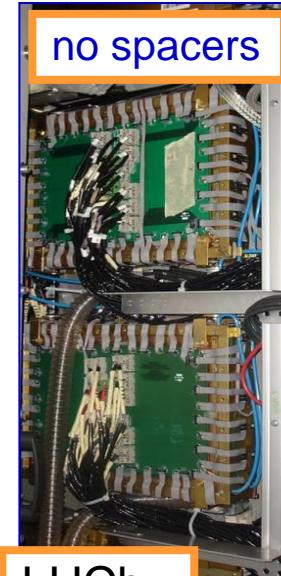


GEMs, spacers & stretching

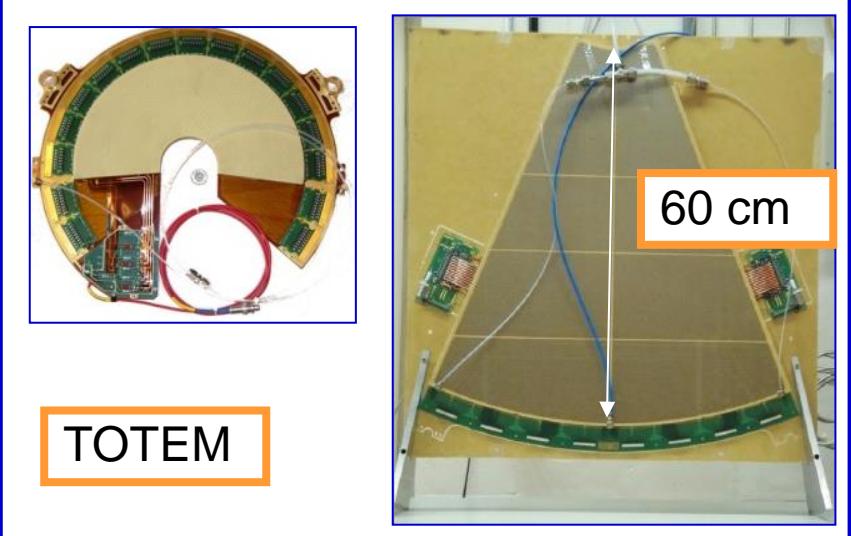
GEM detectors w/ spacers



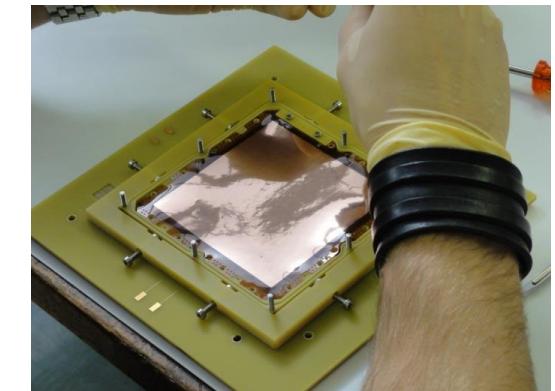
Emphasis on GEM foils stretching



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

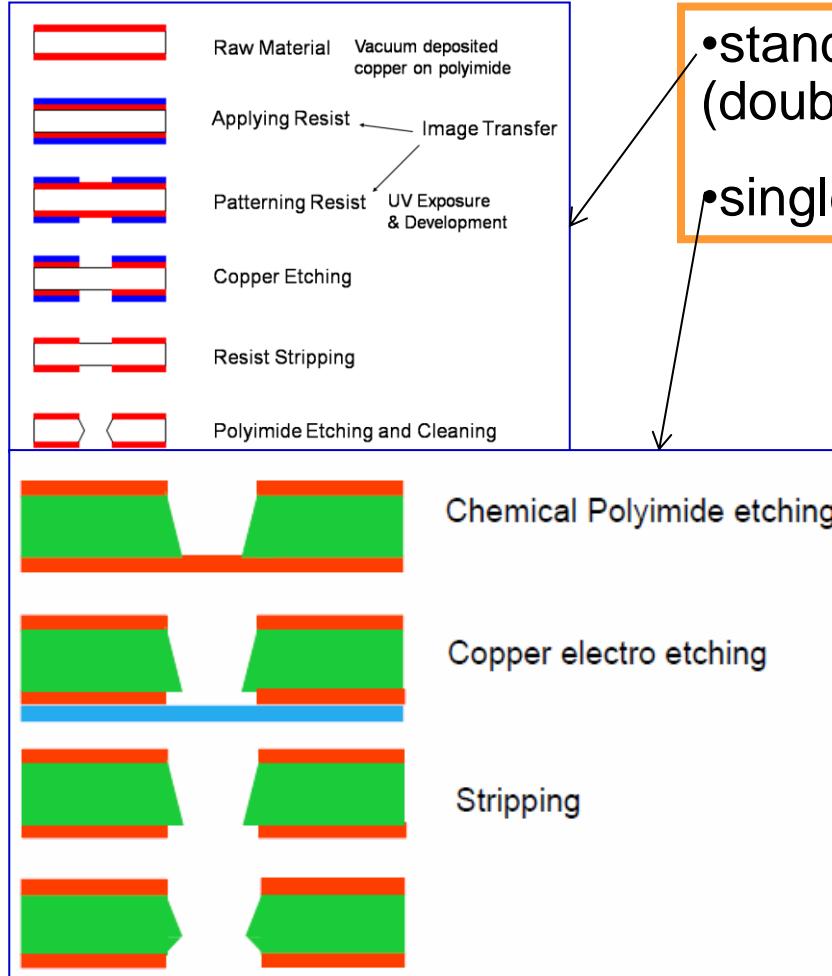


CMS upgrade:
mechanical
stretching
for mass
production

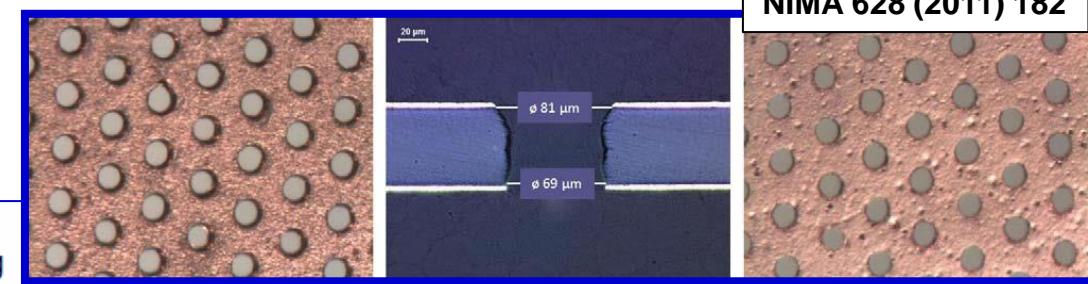


GEMs, large foils

- **Single mask: the way towards large size**



- standard (double mask)
- single mask



The path:

- TOTEM upgrade
- KLOE2
- CMS
- CBM

PIXELIZED R-O for HIGH RATE

Pixelised GEMs (used in COMPASS)

Foil: $450 \times 450 \text{ mm}^2$

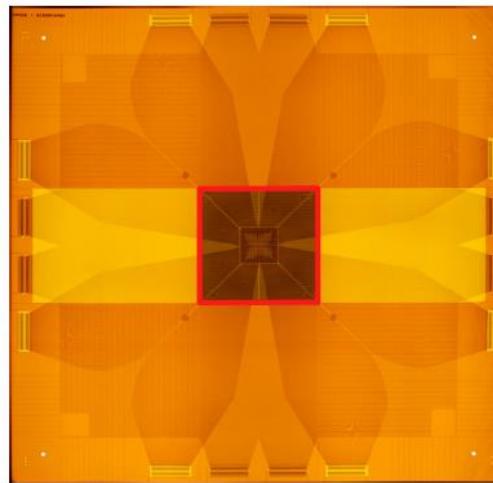
- 3 conducting layers
 $5 \mu\text{m}$ Cu
- 2 intermediate layers
 $50 \mu\text{m}$ Polyimide

Centre: $32 \times 32 \text{ mm}^2$

- 32×32 quadratic pixels

Periphery: $100 \times 100 \text{ mm}^2$

- 2 layers, 512 strips each
- equal charge sharing
- pitch: $400 \mu\text{m}$

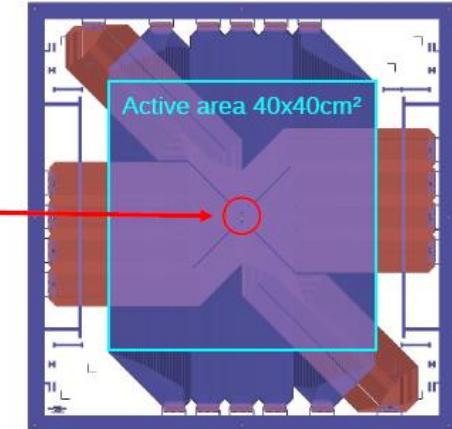
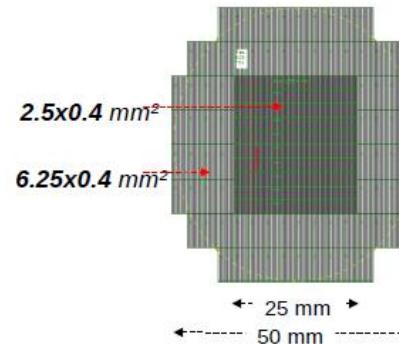


- stable operation in particle flux up to $1.2 \cdot 10^5 / \text{s/mm}^2$
- extremely thin: $0.2\% X_0$
- spatial resolution: $90 \mu\text{m}$

A. Austregesilo et al.,
NP B PS 197 (2009) 113

Pixelised MICROMEGAS (to be used in COMPASS)

1280 + 1280 channels



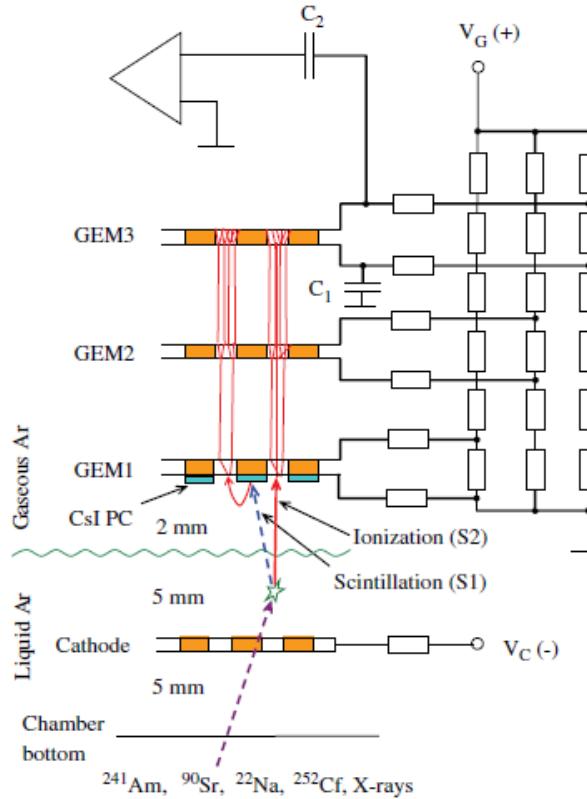
D.Neyret, RD51 Coll.
Meeting, Oct 2012

THE CRYOGENIC FRONTIER

Main physics goals:

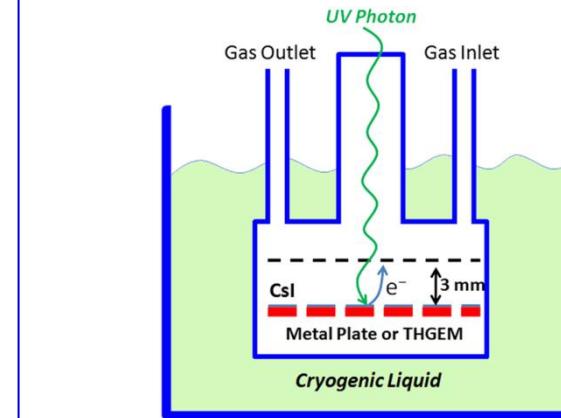
- Neutrino detectors
- Dark matter

GEM

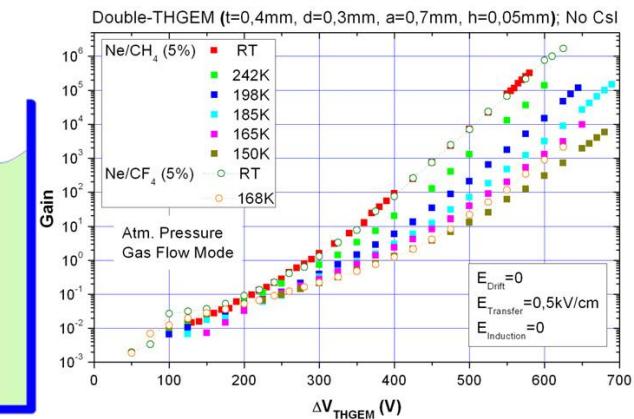


A. Bondar et al., NIMA 581 (2007) 241

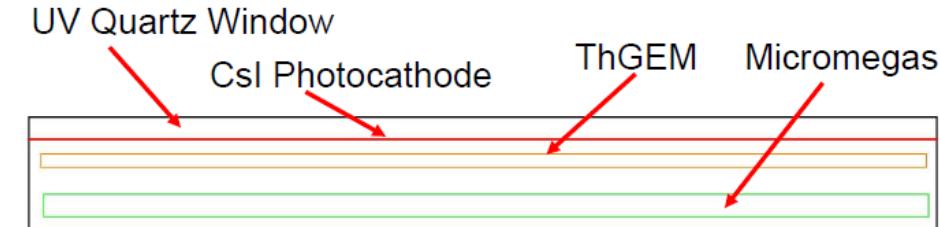
THGEM



A. Breskin et al., NIMA 639 (2011) 117

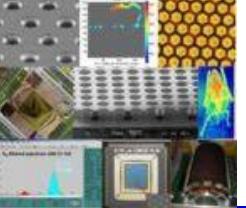


Hybrid: THGEM + MM



K. L. Giboni, seminar at KEK, Nov 2011

ESTABLISHING THGEMs 1/3



PCB technology, thus:

- robust
- mechanically self supporting
- industrial production of large size boards
- economic

Comparing to GEMs

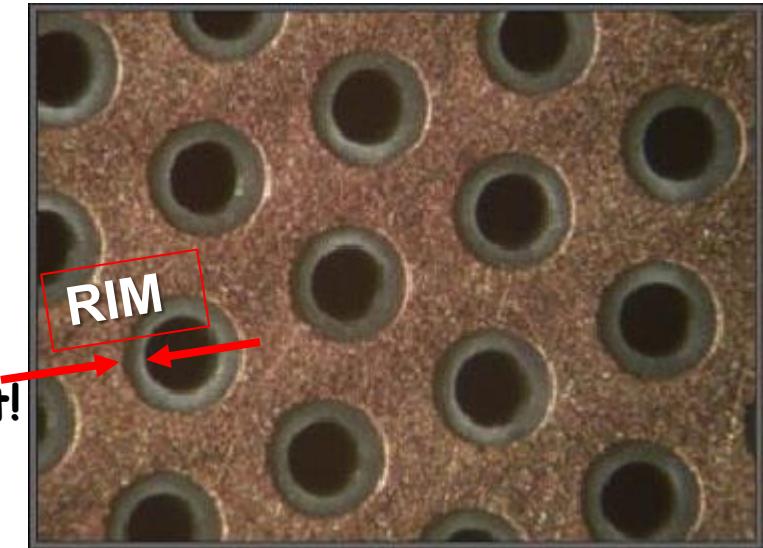
- Geometrical dimensions $\times \sim 10$
 - But e^- motion/multiplic. properties do not!
 - Larger holes: dipole fields and external fields are strongly coupled

About gain:

- Large gains are easily obtained (rim !)

About PCB geometrical dimensions:

Hole diameter :	0.2 - 1 mm
Pitch :	0.5 - 5 mm
Thickness :	0.4 - 3 mm



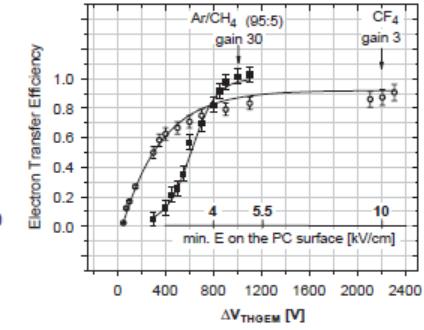
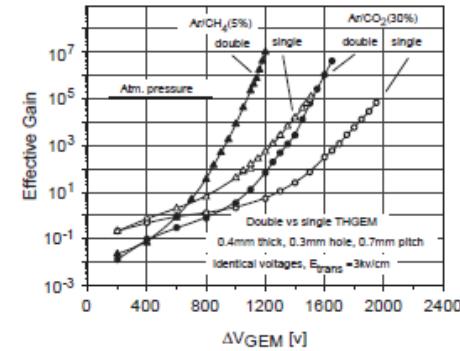
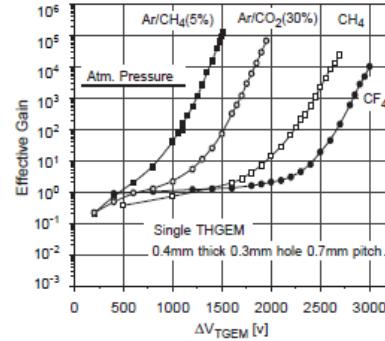
introduced in // by different groups:

- 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

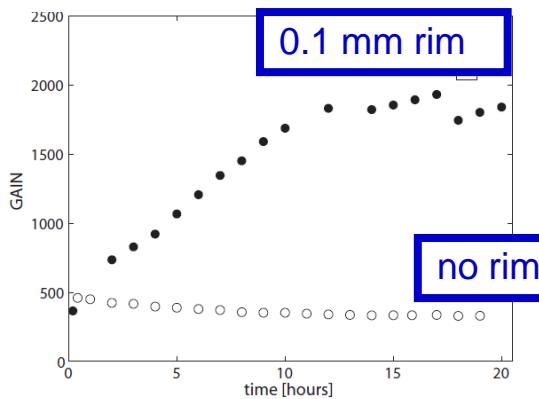
ESTABLISHING THGEMs 2/3

The first phase of the systematic studies is entirely due to the Weizmann group

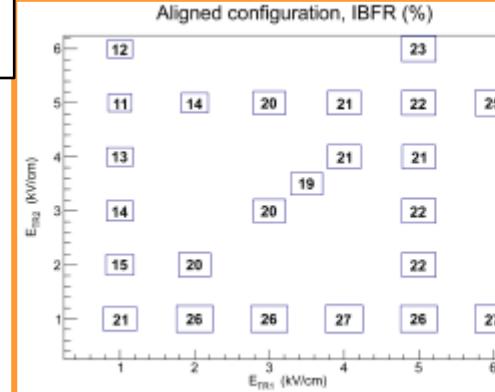
R. Chechik et al., NIMA 553
(2005) 35



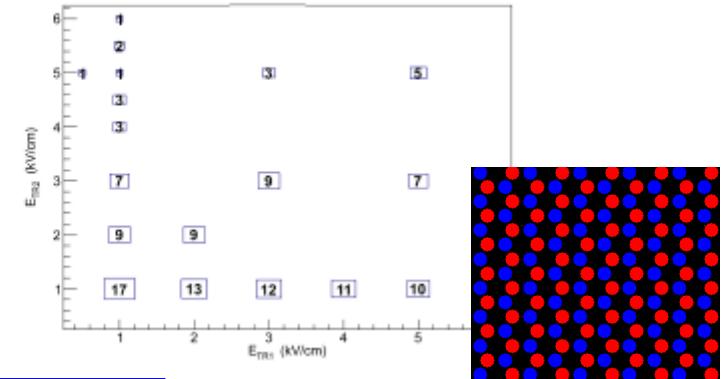
Gain vs time



M. Alexeev et al.,
NIMA 617 (2010) 396



Staggered configuration, IBFR (%)

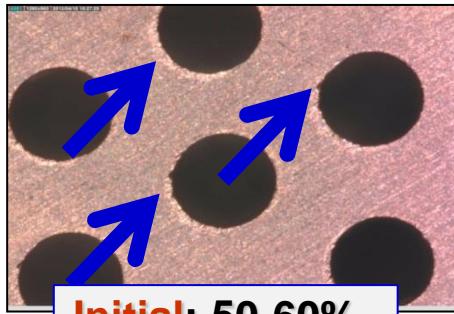


Tripple THGEM: Ion Back Flow by staggering plates

M. Alexeev et al., JINST 7
(2012) C002014

ESTABLISHING THGEMs 3/3

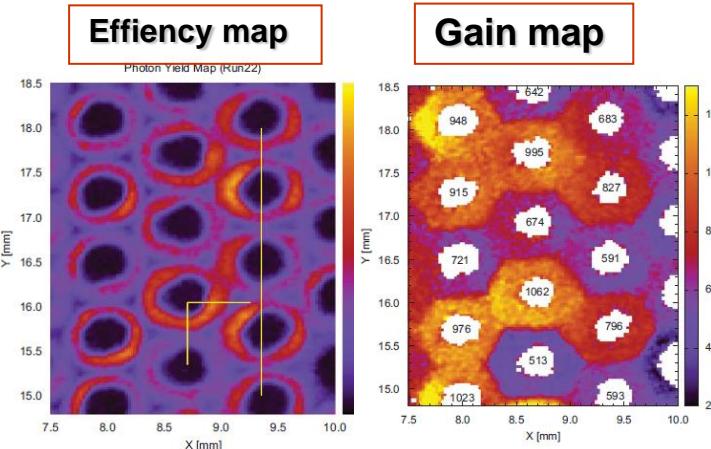
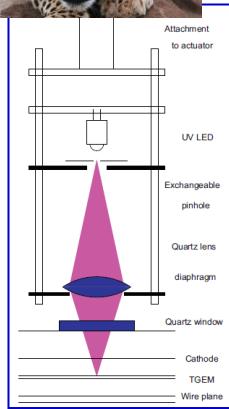
polishing (Pumice Powder)
 ultrasonic bath (~1 h) @ 50-60 °C in
 Sonica



Initial: 50-60%
Paschen curve

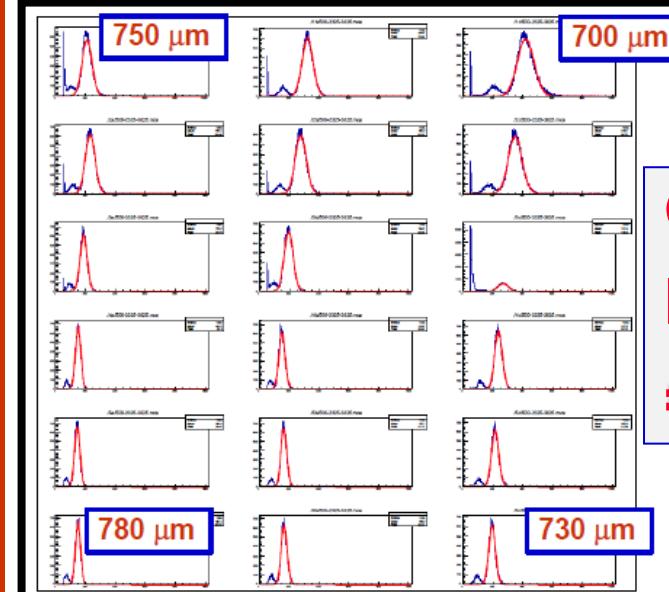


Final: > 90%
Paschen curve

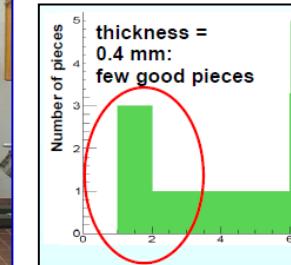


G.Hamar and D. Varga, NIMA 694(2012)16

Engineering aspects

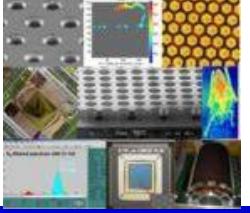


GAIN
Max/Min
 $= 2.9$



GAIN
Max/Min
 $= 1.6$

Selecting uniform fiberglass plates



NOVEL ARCHITECTURES

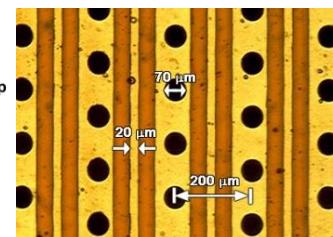
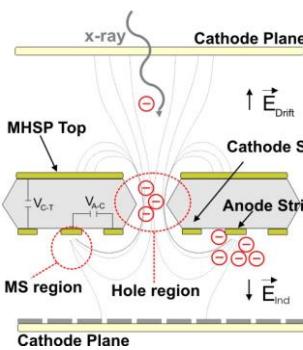
(non exhaustive)

NOVEL ARCHITECTURES BY IMAGES

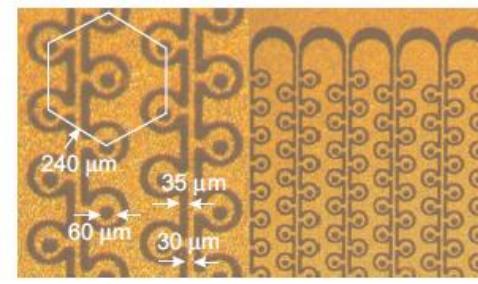
(1) GEM-derived

Towards gas PMTs by

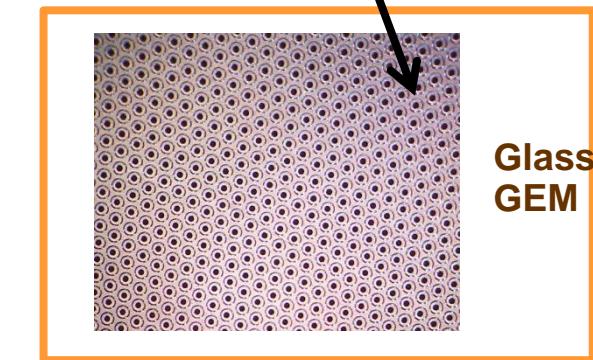
- Extremely reduced ($\sim 10^{-4}$) IBF to PC
- Non outgassing materials



&



COBRA



Glass GEM

Limit the discharge damages



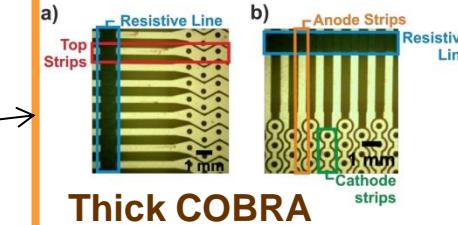
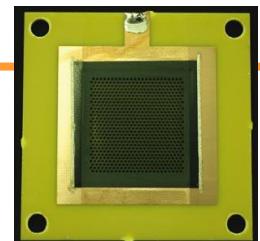
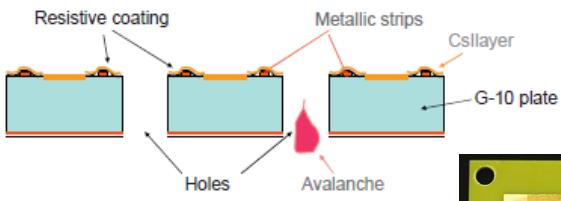
Re-GEM: electrodes by resistive kapton

A different technology

- PCB industry
- Robust
- Self-supporting plates



THGEM

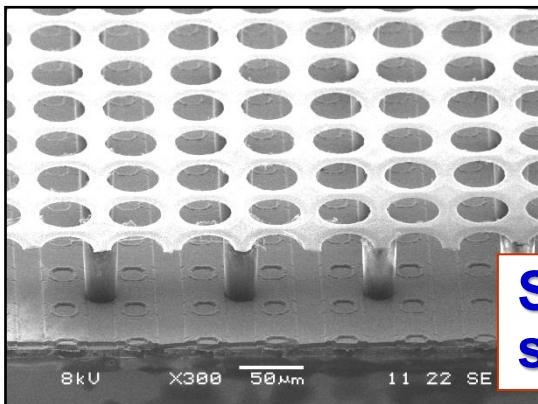


Thick COBRA

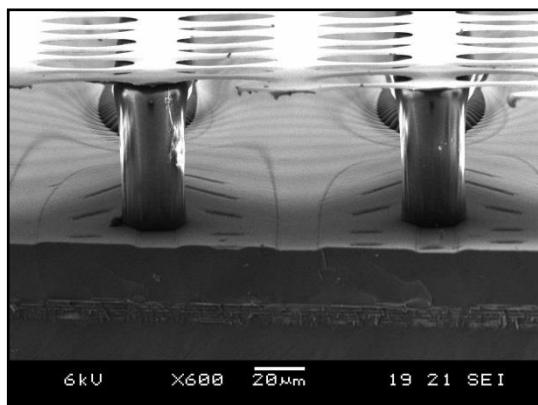
NOVEL ARCHITECTURES BY IMAGES

(2) MM-derived

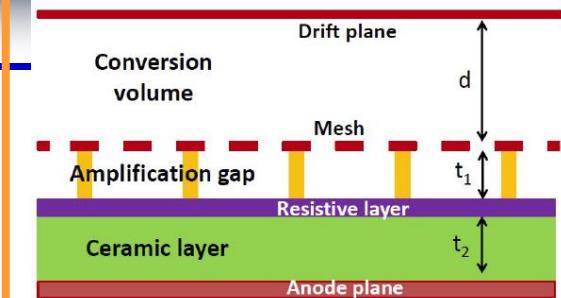
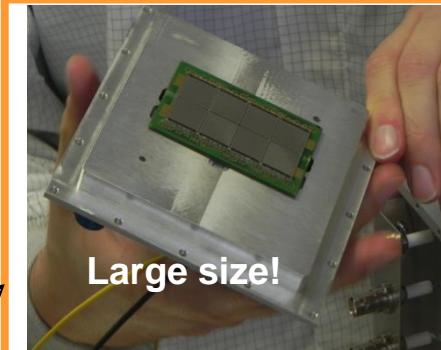
Timepix chip + SiProt + Ingrid



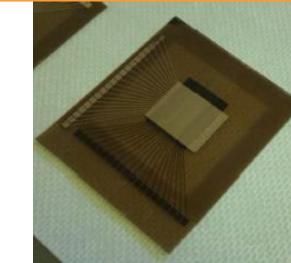
Single electron sensitivity



GRIDPIX

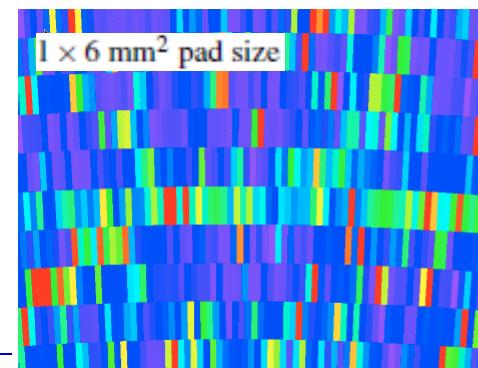


Piggy Back: read-out separated from the active volume

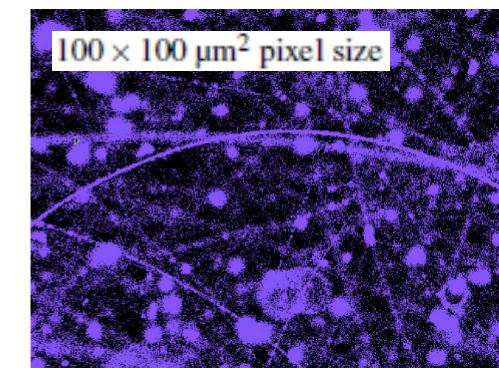


Microbulk:
Low material budget,
radioactive pure

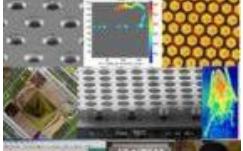
Simulations for CLIC, M. Killenberg, LCD-Note-2013-005



MPCD developments



Silvia DALLA TORRE

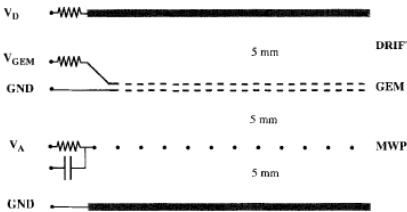


NOVEL ARCHITECTURES BY IMAGES

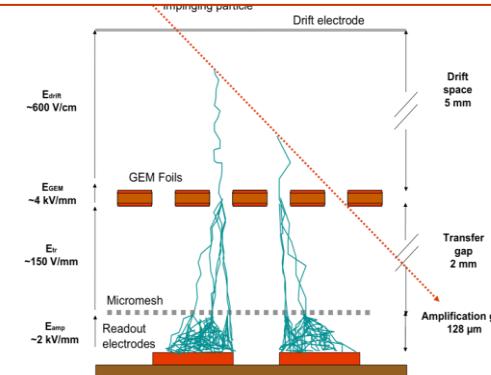
(3) hybrids

Since the beginning
(Sauli et al.):

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



GEM pre-amplification:
control the discharge rate in tracking



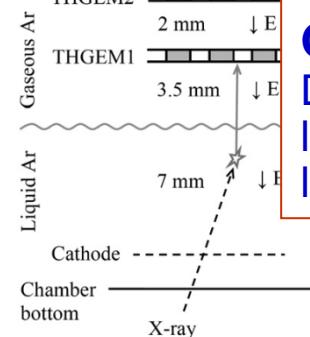
MM w GEM pre-amplification



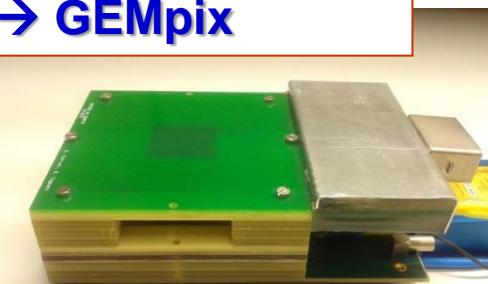
A. Bondare et al.,
NIMA 628
(2011) 364

THGEM + G-APD

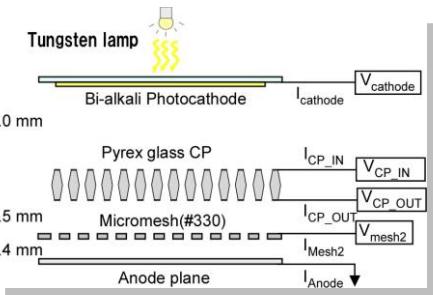
Detect
luminescence
light



GEM + medipix
→ **GEMpix**

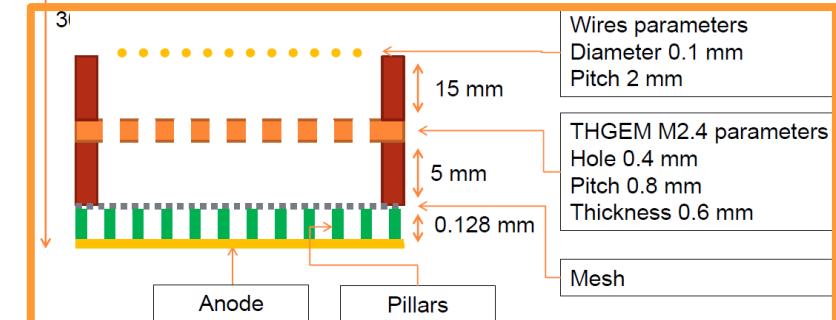


Towards gas PMTs:
IBF control



GAS PMT

THGEM + MM
for single photodetection: IBF control

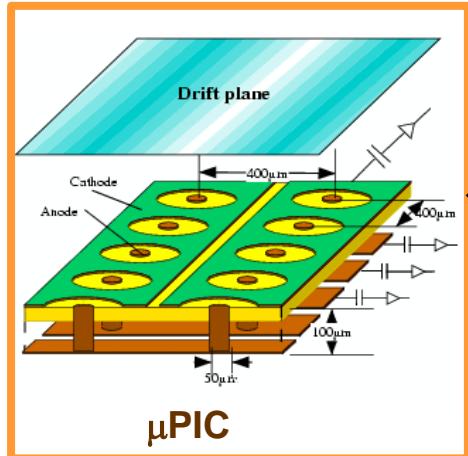


(4) novel geometries

General purpose tracking: fundamental research & applications

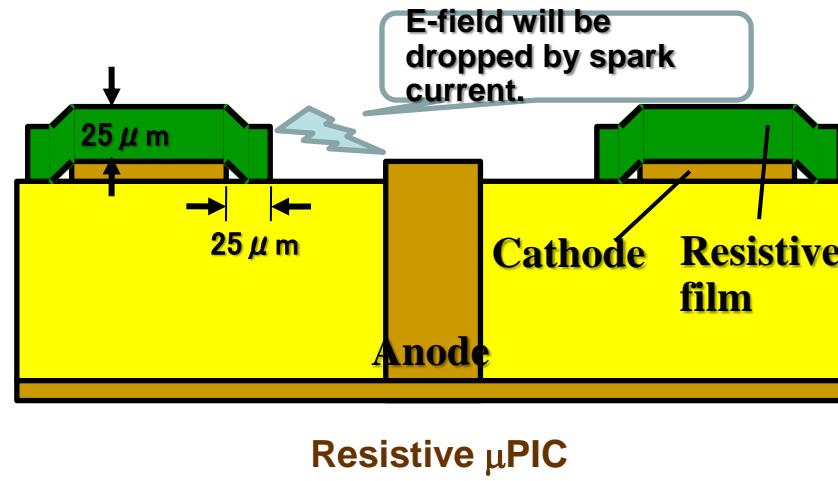
Motivation:

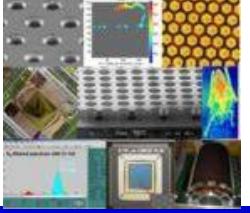
- use PCB technology for mass production,
- no floating structure



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

Spark-tolerant structure





APPLICATIONS

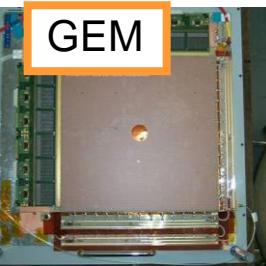
HEP & PARTICLES

Completed / Running Experiments

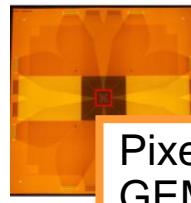
COMPASS



GEM

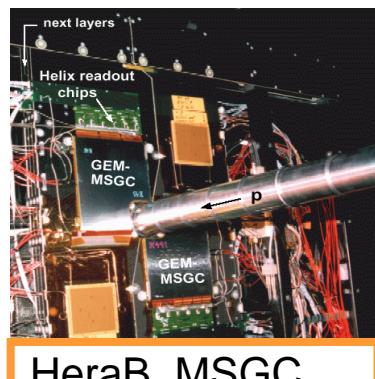
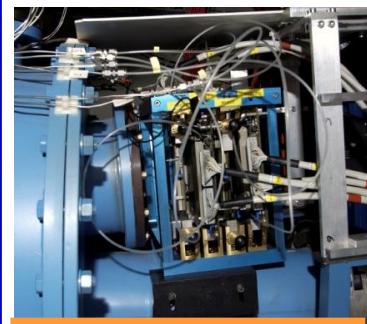


MM



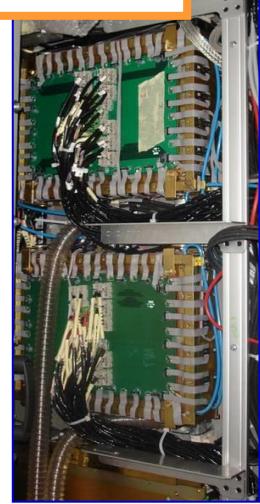
Pixel
GEM

DIRAC, MSGC



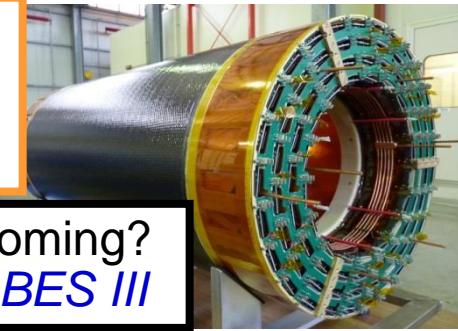
HeraB, MSGC

LHCb,
GEM



KLOE2:
triple cylindrical
GEM

assembled: 14/3/2013



Other cylinders coming?
CMD-3 detector, BES III

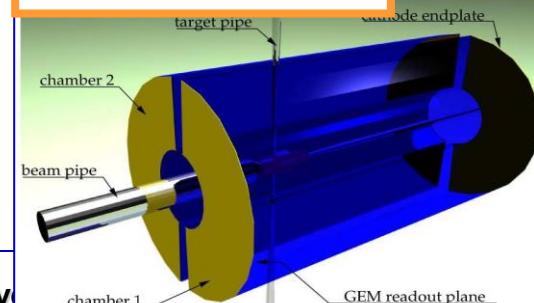
MM, T2K
TPC read-out



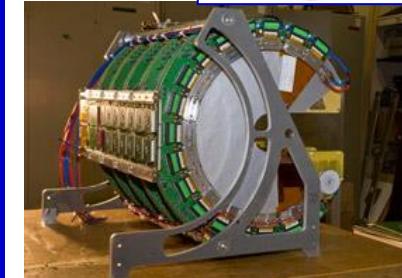
CAST, MM

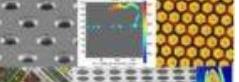


PANDA → FoPi



TOTEM,
GEM





Future @ CERN LHC & more

HEP & PARTICLE

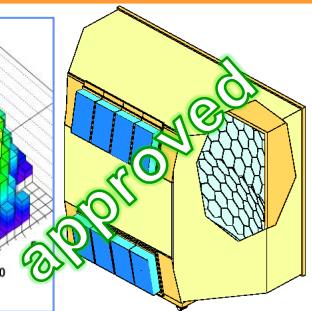
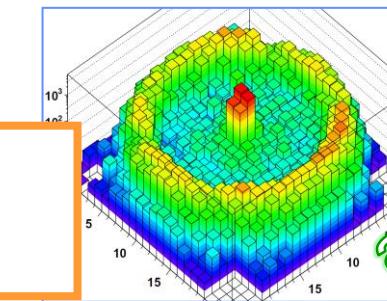


ATLAS – MAMMA project (MM)
Goal: $\sim 1 \times 2.5 \text{ m}^2$

New Small Wheel,
ATLAS muon system,
1200 m², tracking & trigger

COMPASS RICH-1 upgrade

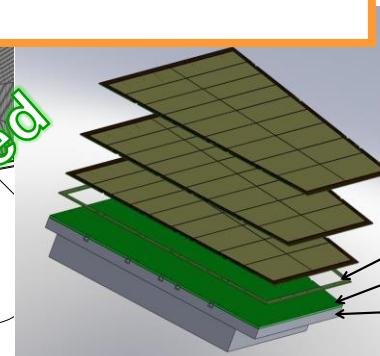
12 m² of THGEM plates



**A NEW FRONTIER: THE MASS PRODUCTION
→ INDUSTRIALISATION IS AN ABSOLUTE MUST**

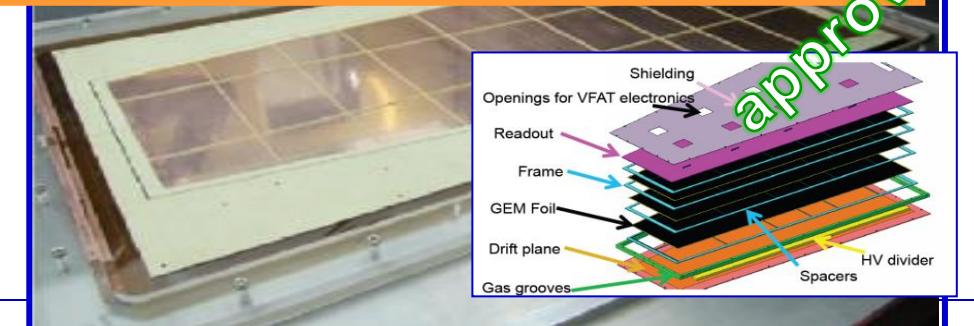
ALICE – TPC r-O, upgrade (GEM)
Goal: $\sim 0.9 \times 1.2 \text{ m}^2$

130 m² of GEM foils



CMS – forward muon spectrometer (GEM)
Goal: $\sim 1.2 \times 2 \text{ m}^2$

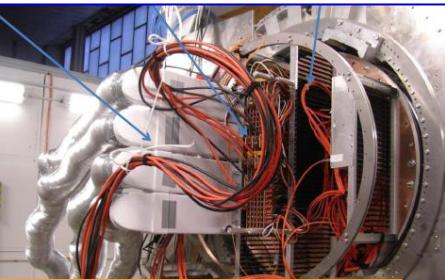
1000 m² of GEM foils, tracking & trigger



HEP & PARTICLES

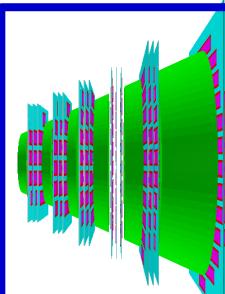
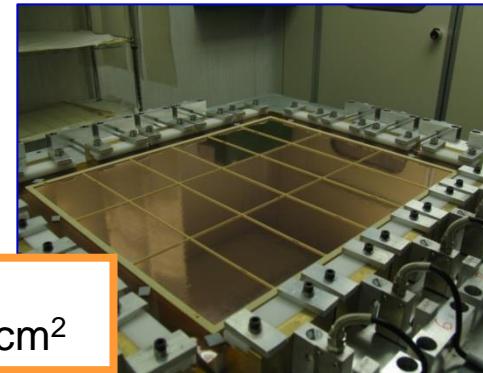
More about Future

ILC TPC, MM



ILC TPC, GEM

JLab Hall A
GEM $40 \times 50 \text{ cm}^2$

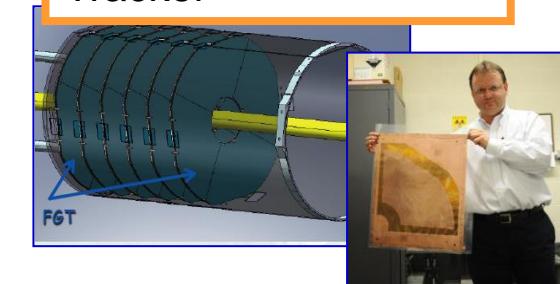


CBM: GEMs
for tracking

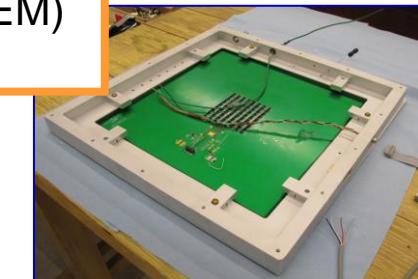
MPGD developments

Silvia DALLA TORRE

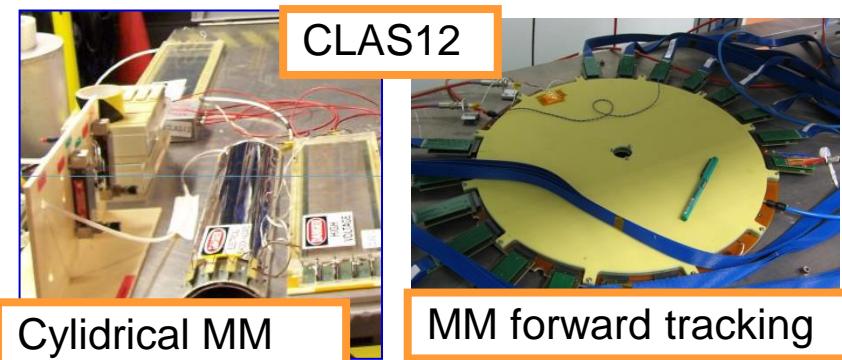
STAR - Forward GEM Tracker



H calorimetry(GEM)
(ATLAS, ILC)



CLAS12

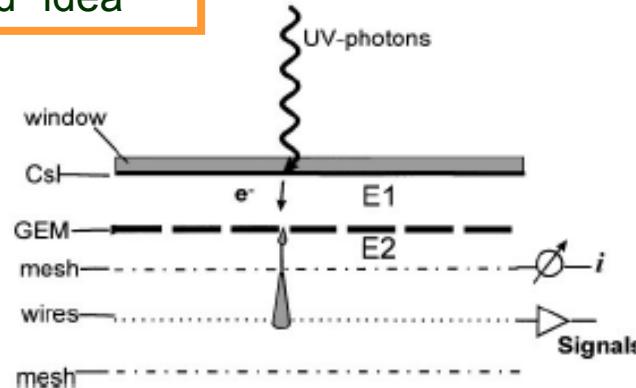


MM forward tracking

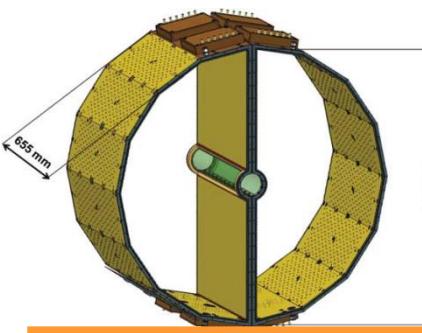
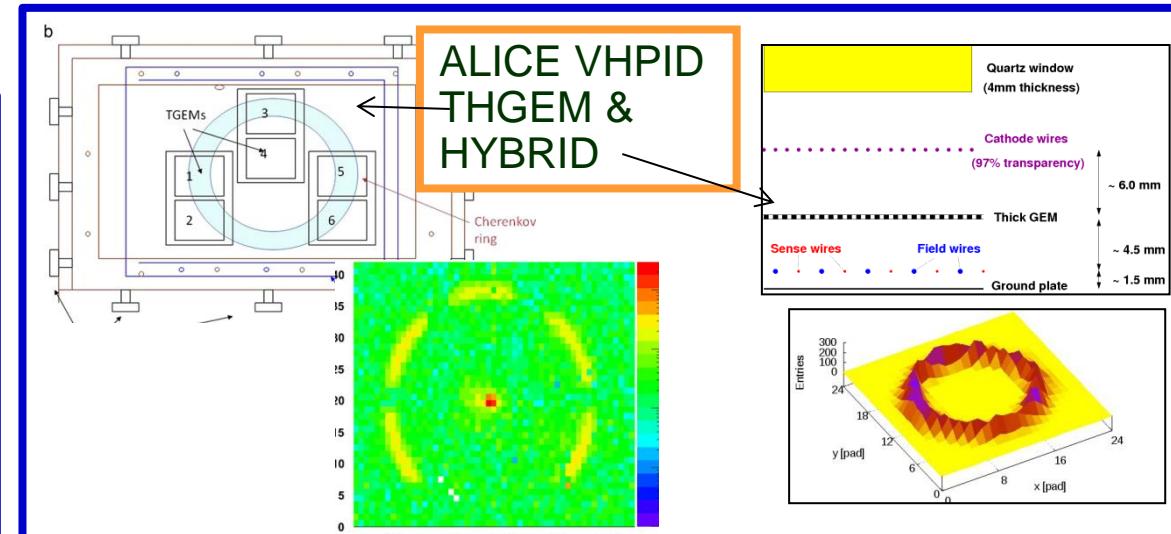
HEP & PARTICLES

PHOTON detection

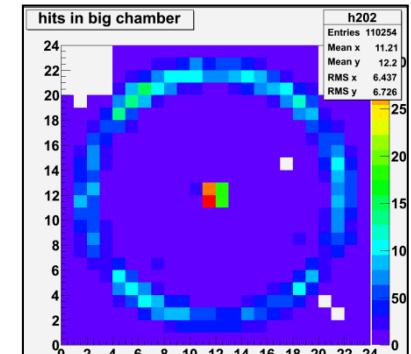
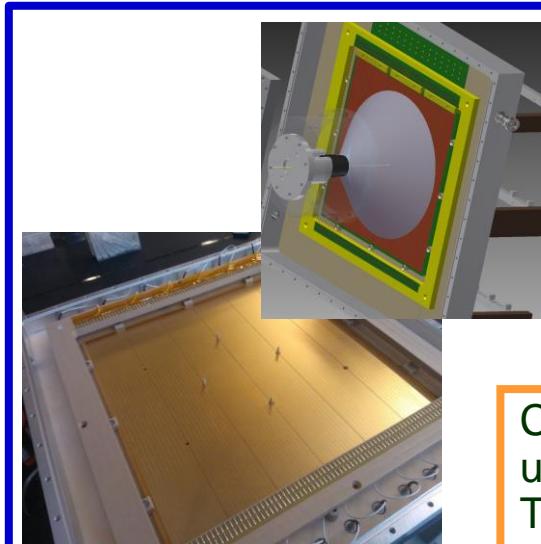
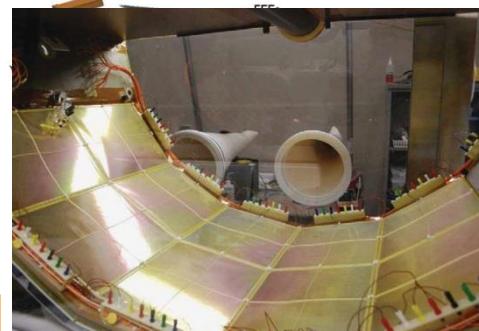
An “old” idea



R. Chechwik et al., NIM A 419 (1998) 423



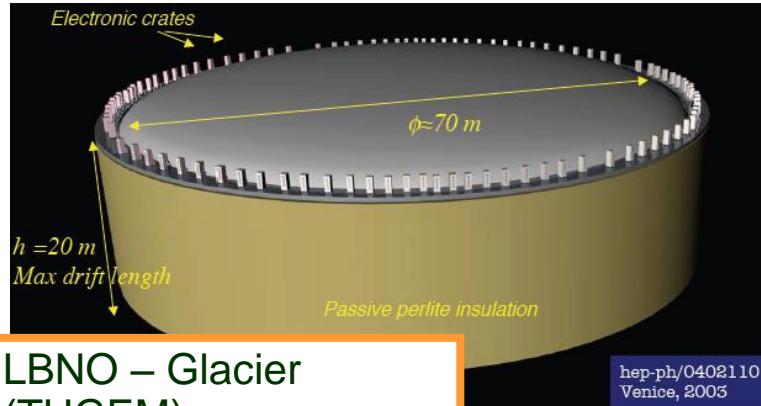
PHENIX HBD, GEM



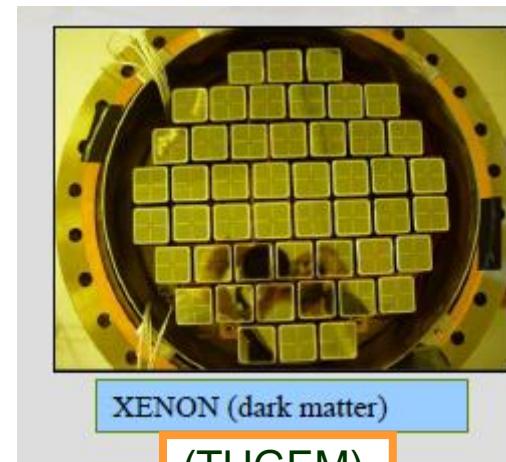
COMPASS, RICH-1
upgrade by
THGEM detectors

HEP & PARTICLES

Very rare events

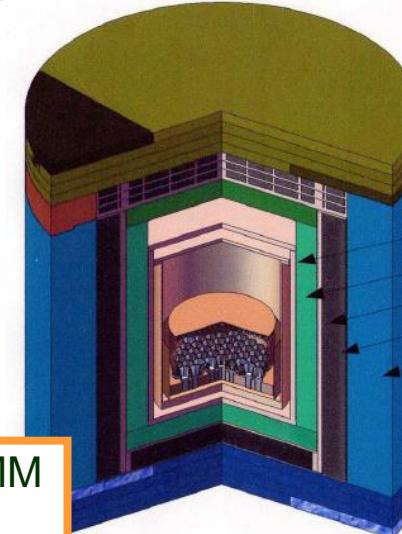
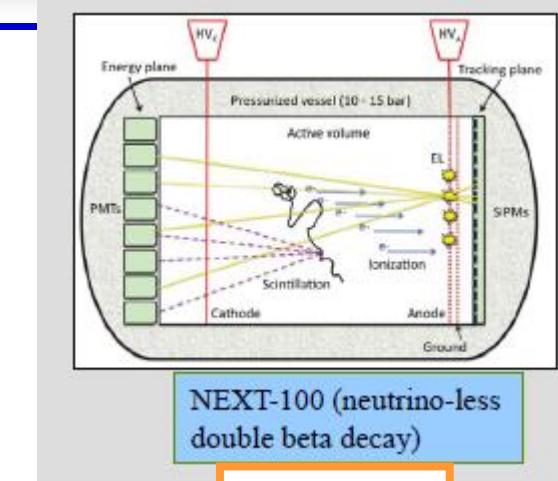


LBNO – Glacier
(THGEM)



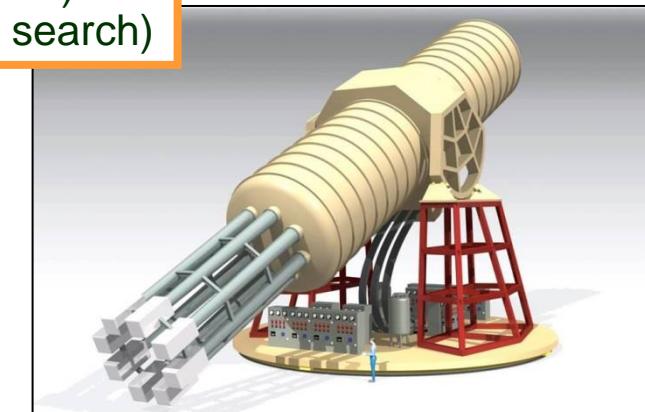
XENON (dark matter)

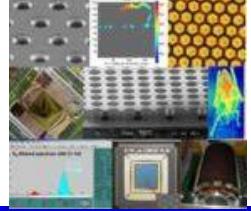
(THGEM)



Panda-X, THGEM + MM
(dark matter)

IAXO (MM)
(assion search)





LOWER ENERGIES & EXOTIC APPLICATIONS 1/3

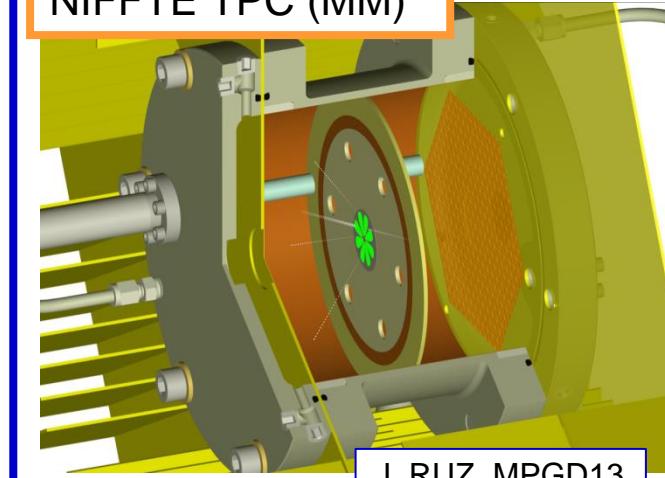
Just a flavour



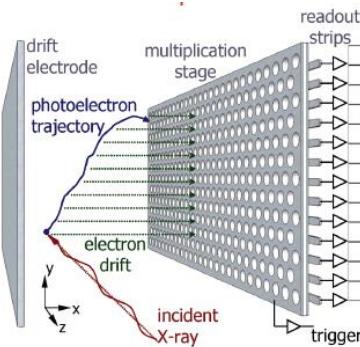
n detection:
D20 diffractometer @ILL, MSGD



NIFFTE TPC (MM)



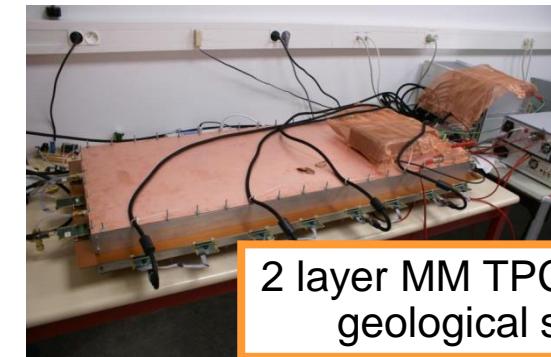
J. RUZ, MPGD13



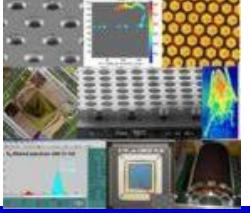
GEMS - NASA mission
GEM TPC for
X-ray polarimetry



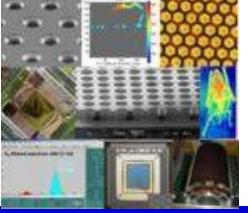
Neutron
beam
diagnostics:
GEM (@
ISIS)



2 layer MM TPC for
geological studies



CONCLUSIONS



MPGDs:

**Impressive progress and
enormous potentiality!
... and a marvelous professional
adventure**