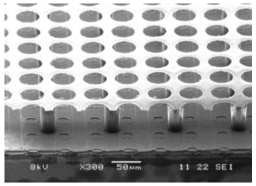

Micro Pattern Gas Detectors in High Energy Physics

J. Kaminski
Universität Bonn

ICHEP 2010
July 22nd - 28th 2010
Paris, France

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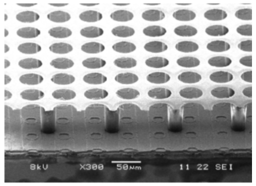
PHYSICS AT THE TERA SCALE
Helmholtz Alliance



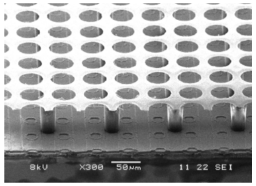
Contents

Short overview over Micro Pattern Gas Detectors - MPGDs

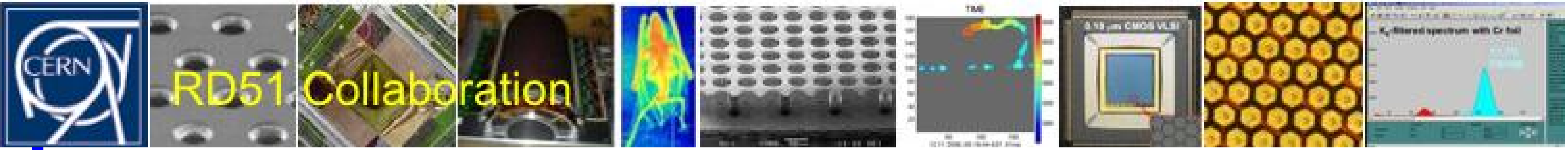
New developments in Micromegas production techniques
Combining abstract ID 438 and 518 (both from CEA/Saclay)

New developments in GEM production techniques

Example: Linear Collider TPC
Abstract ID 938 (by LCTPC Collaboration)



RD51

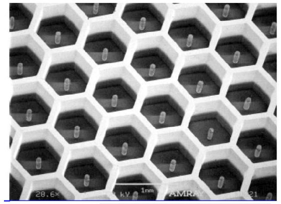


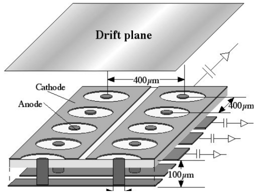
Founded in April 2008 the collaboration already counts ~430 authors from 73 institutes in 25 countries.

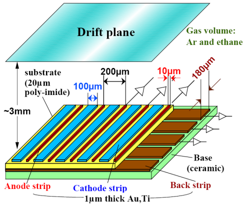
The collaboration aims at facilitating the development of advanced gas-avalanche detector technologies and associated electronic-readout systems, for applications in basic and applied research.

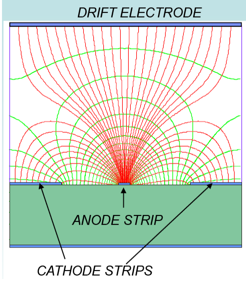
WG1: Technological Aspects and Development of New detector Structures
WG2: Common Characterization and Physics Issues
WG3: Applications
WG4: Simulations and Software Tools
WG5: MPGD Related Electronics
WG6: Production
WG7: Common Test Facilities

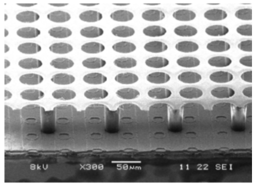
VERY active field of R&D





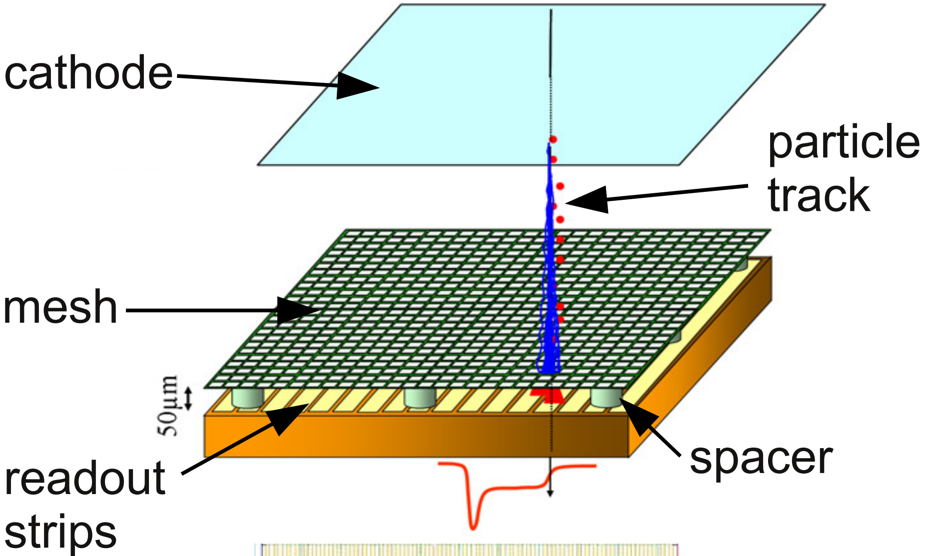


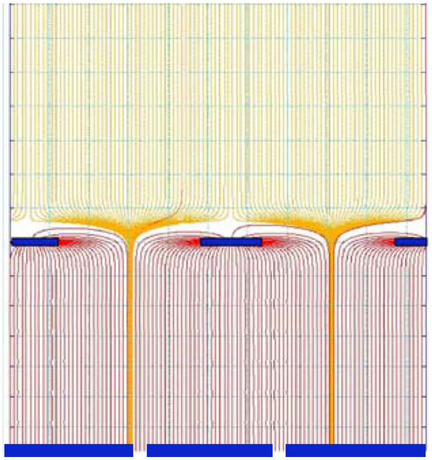




The Favorites

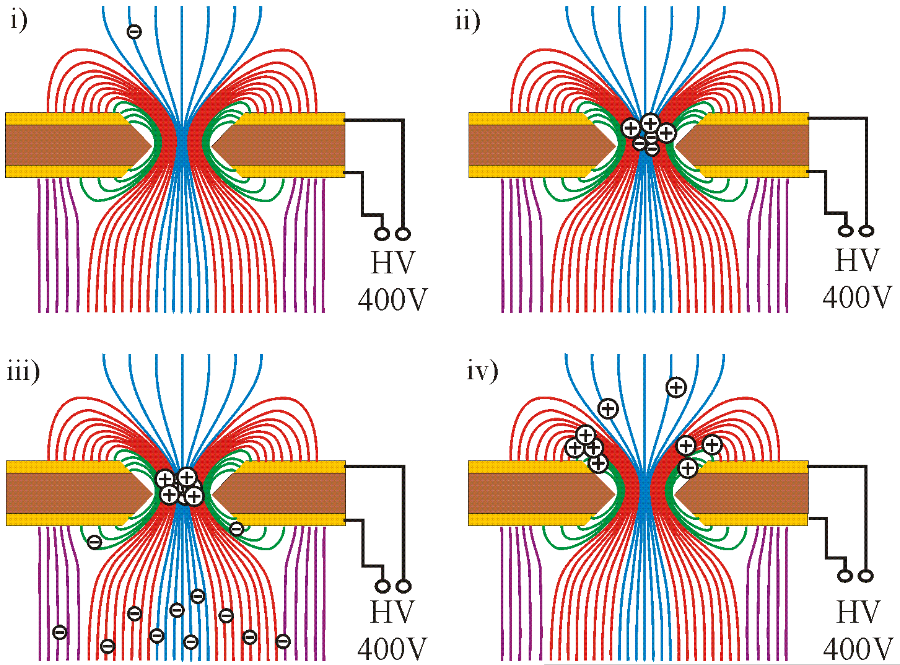
Micro-Mesh Gaseous Detectors

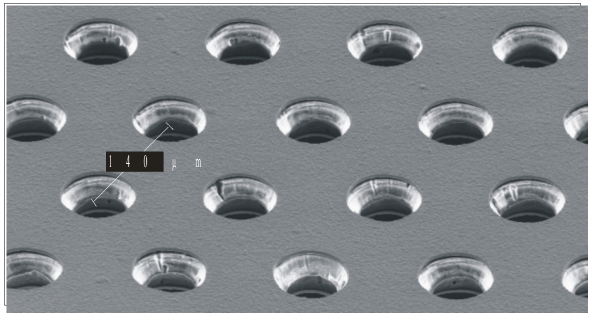


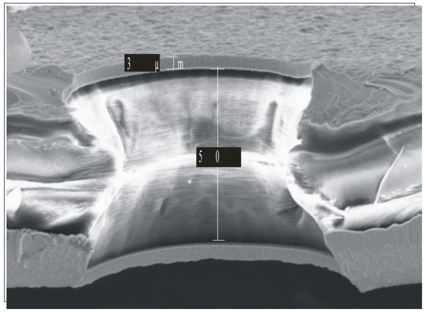


Y., Giomataris et al.,
Nucl. Instrum. Meth. A376:29-35,1996.

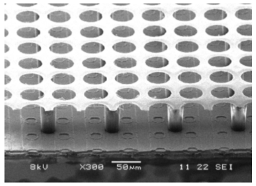
Gas Electron Multipliers







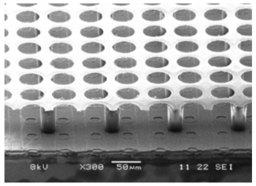
F. Sauli, Nucl. Instrum. Meth. A386:531-534,1997.



Advantages of MPGD

- Small pitch of gas amplification regions (i.e. holes)
  => improves spatial resolution, reduction of $E \times B$-effects
- No preference in direction (as with wires)
  => all 2 dim. readout geometries can be used
- No ion tail => very fast signal (O(10 ns))
  => good timing and double track resolution
- Direct e^--collection on pads
  => small transverse width
  => good double track resolution
- Ion back drift can be reduced significantly
  => continuous readout is possible

Applications in thin tracking devices - e.g. COMPASS
photon detection - e.g. CAST
large volume drift chambers - e.g. LCTPC

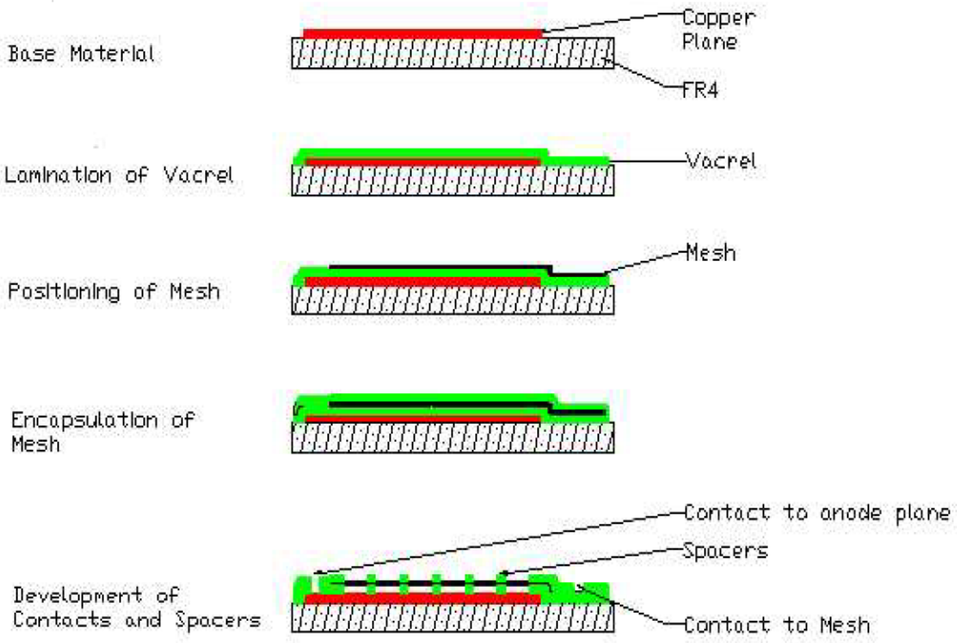


Production of Micromegas

First Micromegas had quartz spacers between mesh and readout
many test followed: e.g. with fishing lines

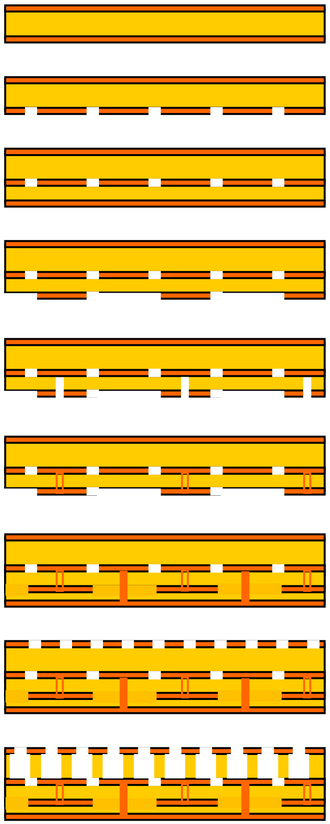
IMPORTANT: optimize for high gains and good energy resolution
=> keep gap between grid and anode as precise as possible

1. Bulk-Micromegas

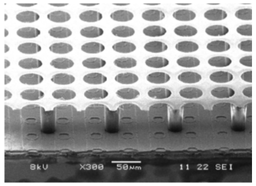


Bulk Micromegas produced by lamination of a woven grid (30 µm thickness) on an anode with a photoimageable film

2. Microbulk-Micromegas

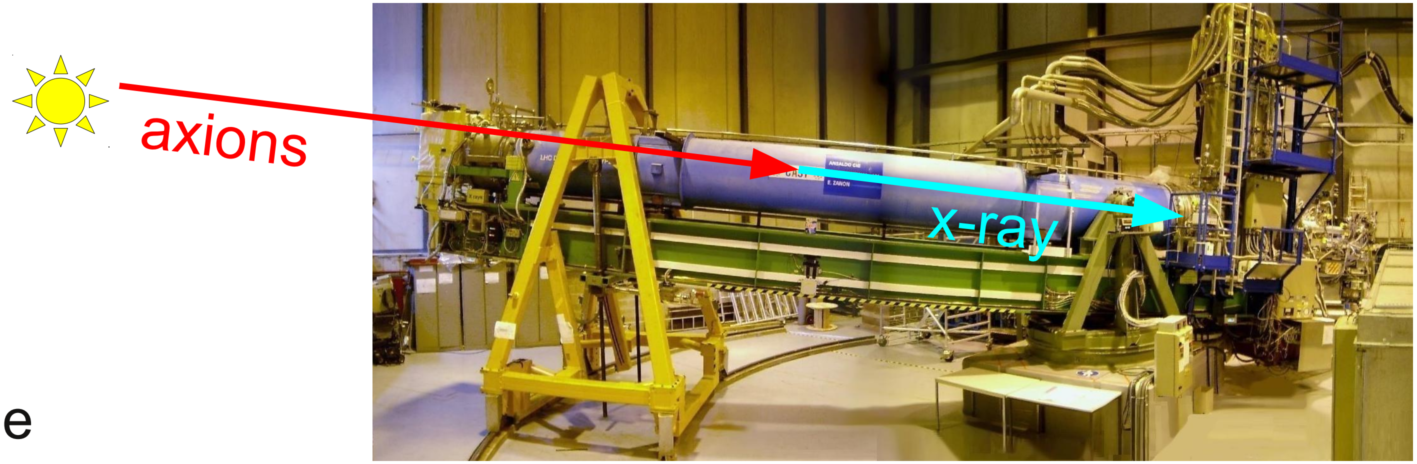


Kapton foil, Cu-coated
Construction of readout pads
Attachment of 2. kapton foil
Construction of readout lines
Etching of kapton
Vias construction
2. layer of Cu-coated kapton
Production of mesh holes
Kapton etching and cleaning



CAST

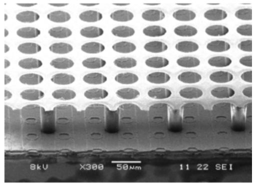
Axions (if existing) should be generated in the sun.
In strong magnetic fields they are converted to x-ray photons via the inverse Primakoff-effect



- CAST uses an LHC prototype (dipole) superconducting magnet (B = 9.0T).
- The magnet can follow the sun during sunset and sunrise for ~ 2 h.
- 4 x-ray detectors cover the openings of the two magnet bores:
  1 x-ray telescope (mirror optics and CCD), 3 Micromegas detectors
- To improve the sensitivity of the experiment the detectors need
  good energy resolution, high stability and low background

=> Bulk- and Microbulk-Micromegas have been tested

Microbulk-Detectors have been chosen for the upgrade.

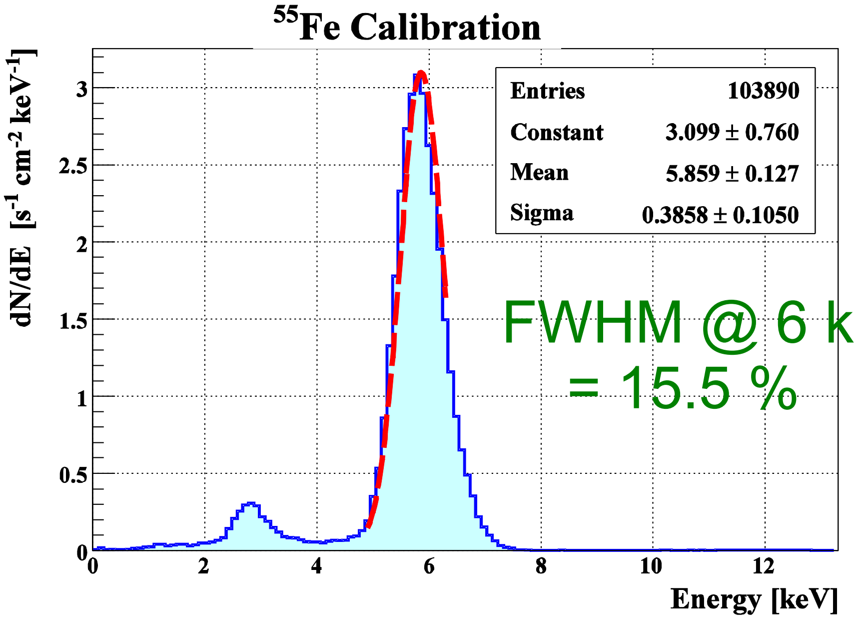


CAST

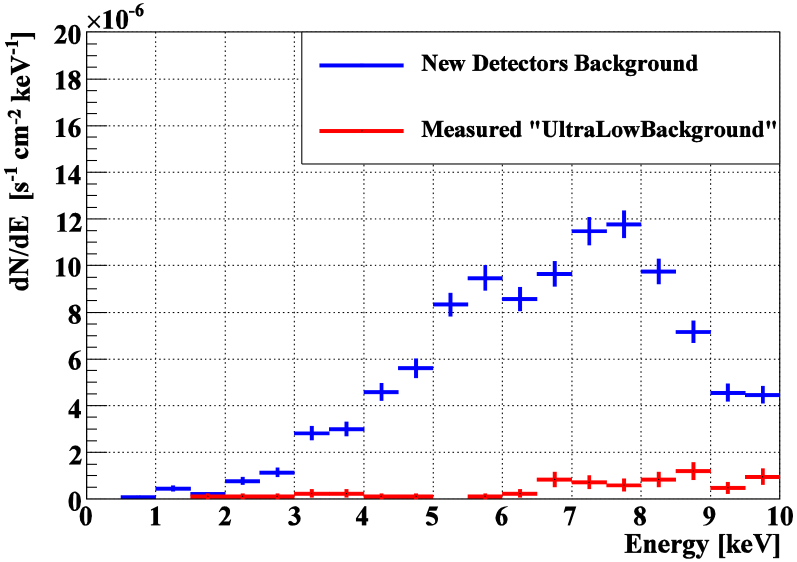
Detector characteristics:

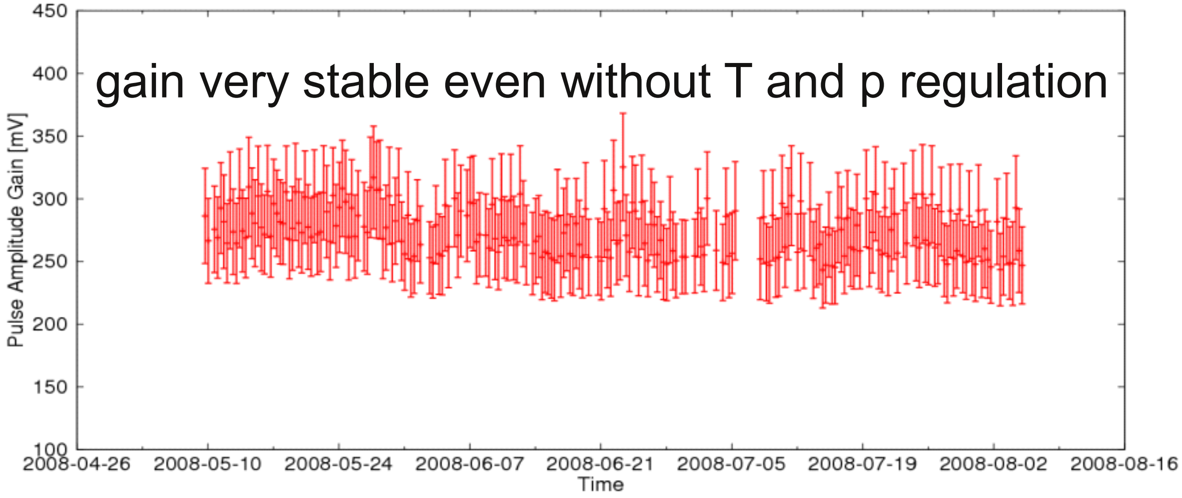
- 6×6 cm² active area,
- 106+106 strips with 550 µm pitch
- 3 cm drift
- 1.43 bar Ar:iButane 97.7:2.3 (non flammable)

Background of Microbulk-detectors dropped from 10^{-5} s^{-1} keV^{-1}cm^{-2} down to $2\cdot10^{-7}$ s^{-1} keV^{-1}cm^{-2}(!)

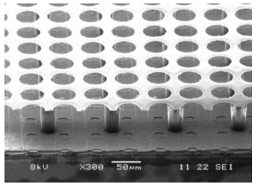


FWHM @ 6 keV = 15.5 %



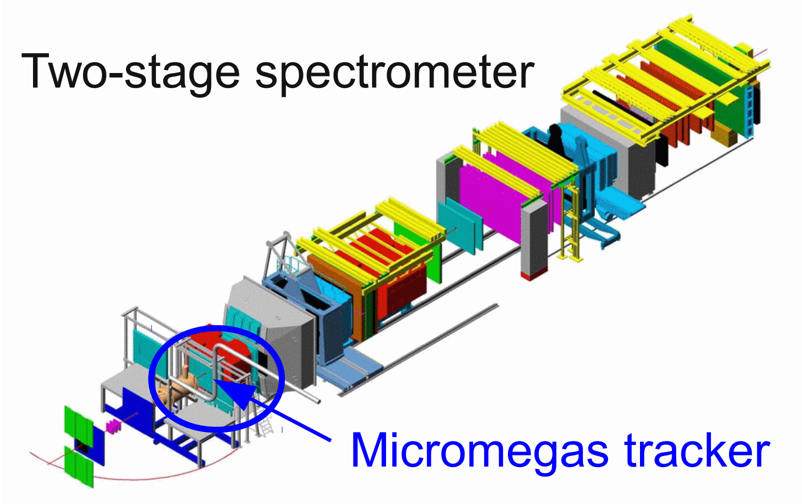


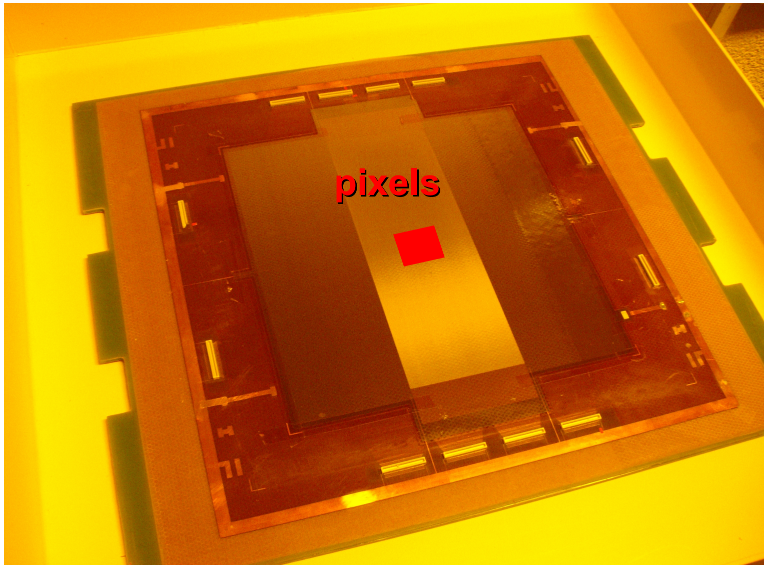
gain very stable even without T and p regulation



COMPASS Upgrade

COmmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

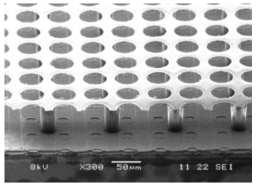




During the upgrade of the COMPASS the Micromegas tracking detectors are to be replaced by improved versions:

1.) Increase active area by adding 1 mm^2 pads to the beam area (rates ~100 kHz/mm^2)
2.) Increase robustness by using bulk technology
3.) Use integrated electronics based on APV with discharge protection
4.) Reduce discharge rate from present probability of less than 10^{-6} per hadron by a factor of 10 to 100

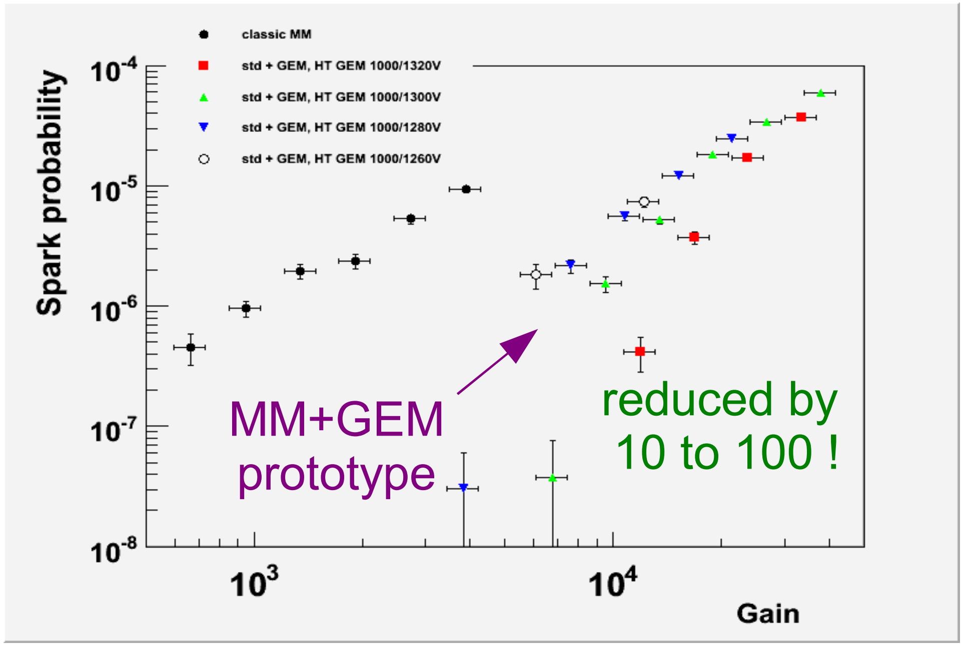
Similar beam conditions at CLAS12
=> groups are collaborating to develop detectors with low discharge rates



COMPASS Upgrade

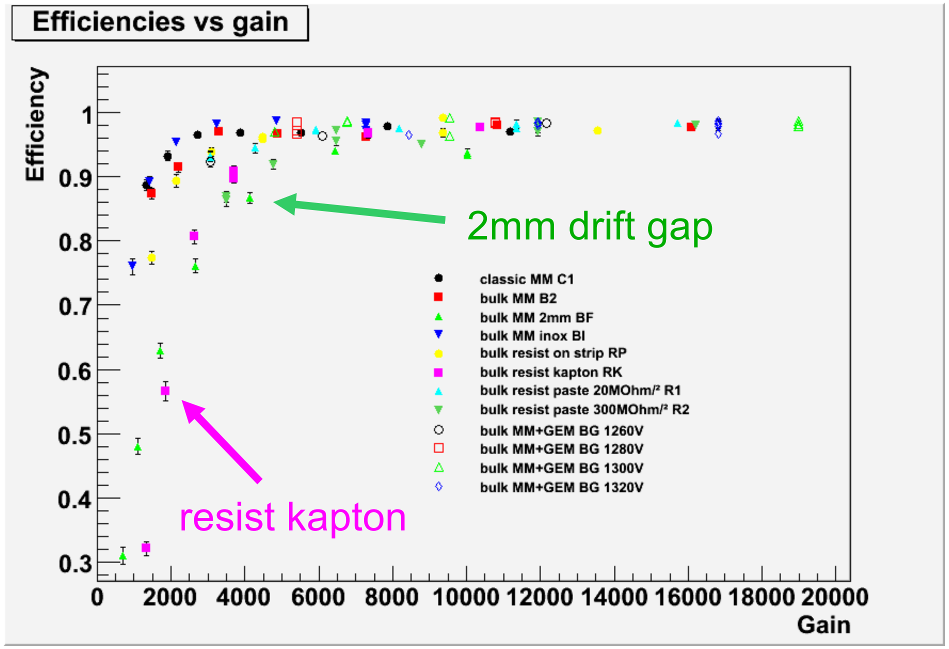
Test of various detector in hadron test beam at CERN:

- Standard Micromegas detector (Cu mesh)
- Bulk Micromegas with 30µm inox mesh
- Bulk-Micromegas with reduced drift gap (2mm only)
- Bulk-Micromegas with GEM preamplification
- 4 Bulk-Micromegas with resistive layers: resistive paste on strips, resistive paste on isolant, carbon-loaded kapton



MM+GEM prototype

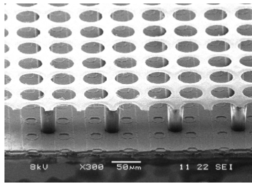
reduced by 10 to 100 !



2mm drift gap

resist kapton

Goal of reduction in discharge rate is reached with resistive layers and GEMs!



(Micro)Bulk-Micromegas

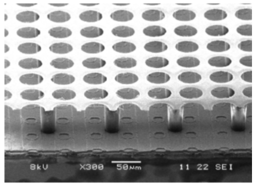
Very compact detector ('all-in-one'):
readout anode and gas amplification stage are combined to one device

Due to well controlled distance anode-mesh the detectors show:

- Excellent energy resolution (down to 11 % FWHM at 6 keV)
  Microbulk detectors better, since the mesh is thinner
- Time stability of gain and energy resolution
- High radiopurity (low background)
- Low mass
- Radiation resistance
- Detector materials have low neutron interaction cross-sections

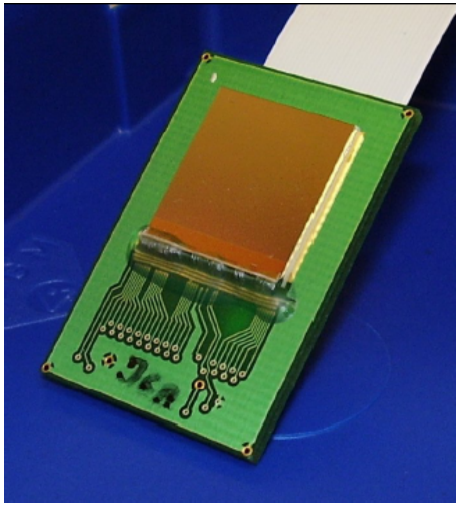
=> used in a number of experiment: CAST, NEXT, n_TOF, T2K

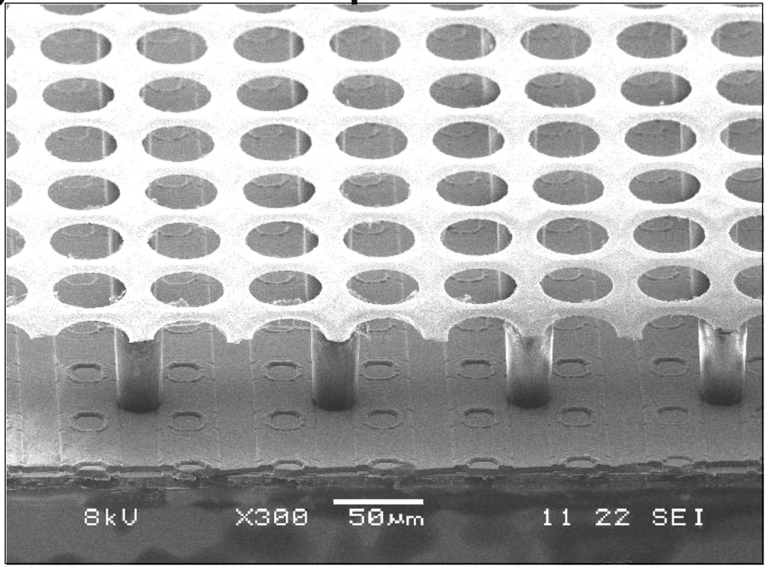
Process can be applied to large areas, e.g. TPC at T2K: O(10 m^2)



InGrid

Micromegas ontop of a pixelized readout chip: bump bond pads for Si-pixel detectors serve as charge collection pads



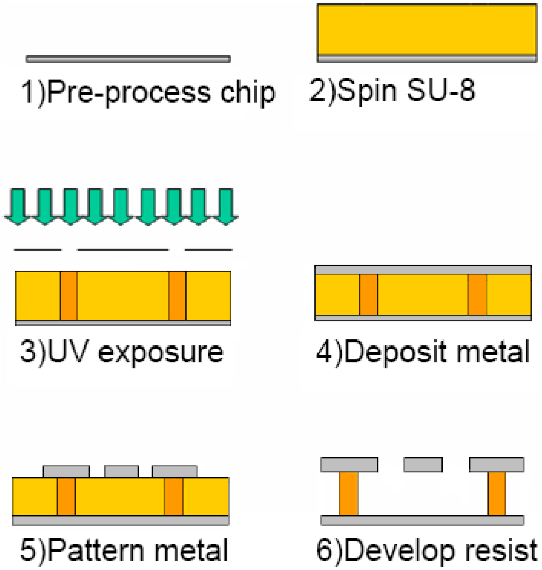


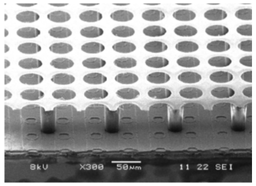
Timepix derived from Medipix-2

256 × 256 pixel of size 55 × 55 µm²

Each pixel can be set to:

- Hit counting
- TOT ≈ integrated charge
- Time between hit and shutter end





MESA+ Institute for Nanotechnology

InGrid

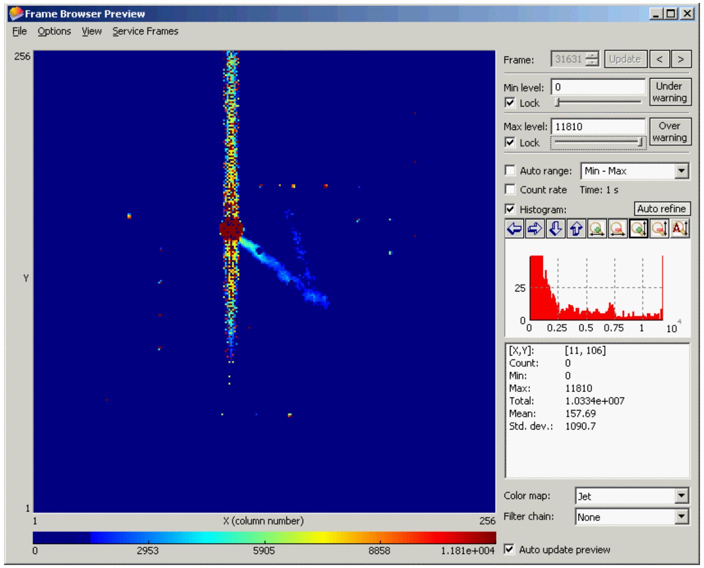
NIKHEF

<u>Protection layer:</u> high resistive material

15 µm aSi:H (~10^{11} Ω·cm)

8 µm Si_XN_Y (~10^{14} Ω·cm)

MESA+: InGrid



Frame: 31631 Update < >

Min level: 0 Under warning

☑ Lock

Max level: 11810 Over warning

☑ Lock

☐ Auto range: Min - Max

☐ Count rate Time: 1 s

☑ Histogram: Auto refine

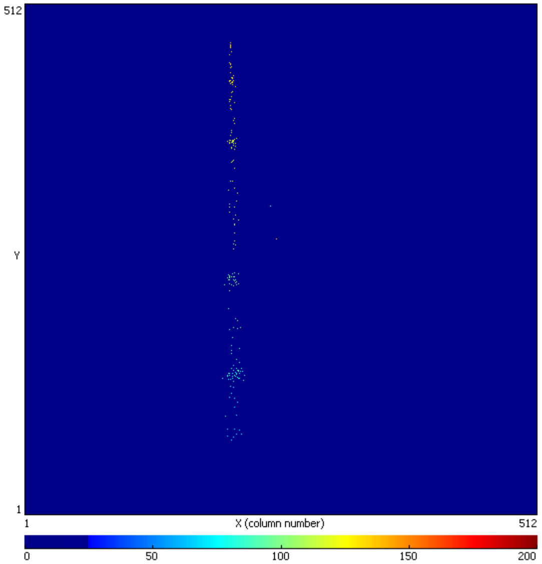
[X,Y]: [11, 106]
Count: 0
Min: 0
Max: 11810
Total: 1.0334e+007
Mean: 157.69
Std. dev.: 1090.7

Color map: Jet

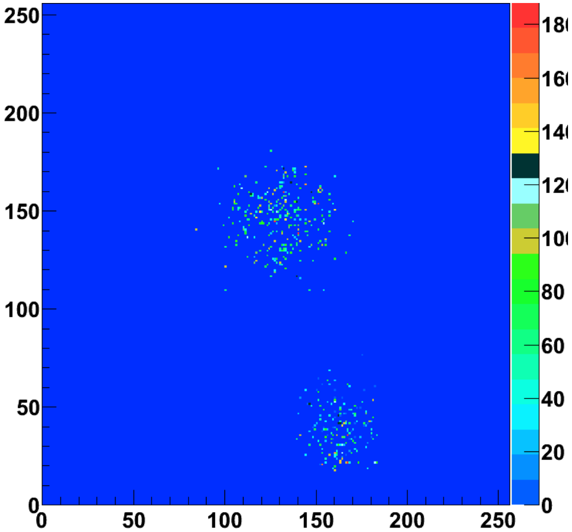
Filter chain: None

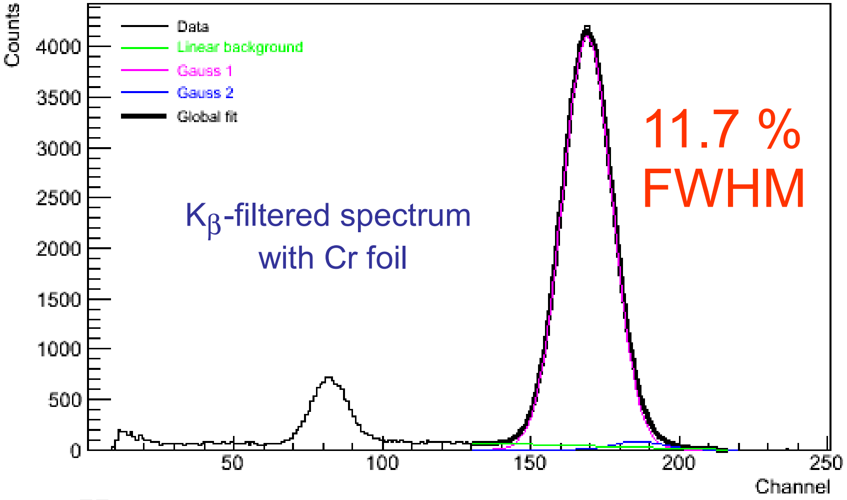
☑ Auto update preview

chip survives several 1000 discharges induced by α-particles and hadron beam of PS, CERN



^{55}Fe photons converting in Ar:iButane 95:5





^{55}Fe spectrum in $Ar:CH_4$ 90:10

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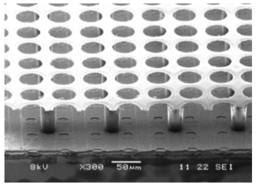
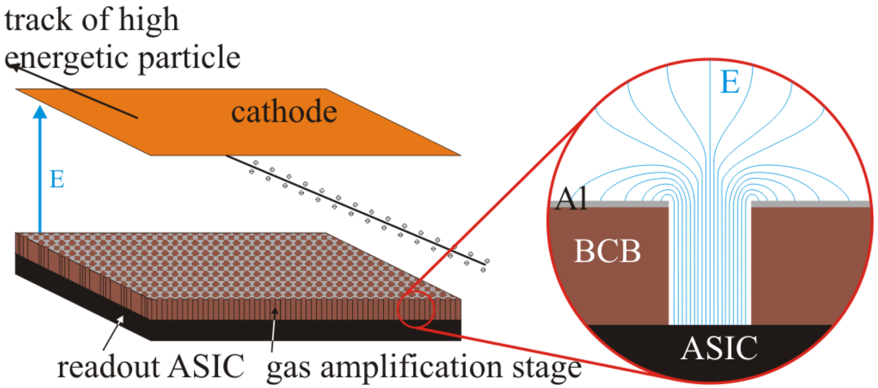
ICHEP 2010, Paris
J. Kaminski



GEMGrid

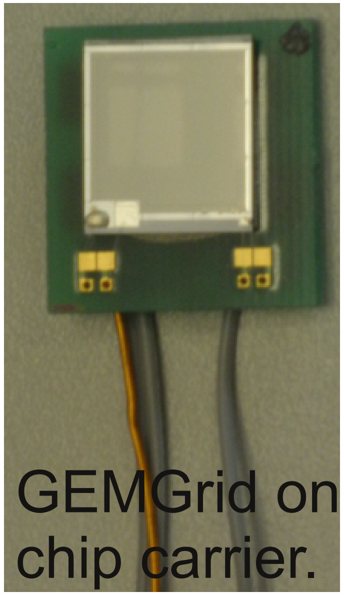
At GEMGrid the grid rests on a solid insulating layer with holes → more mechanical stability

At University of Twente production based on single chips, new wafer based production is established at IZM, Berlin



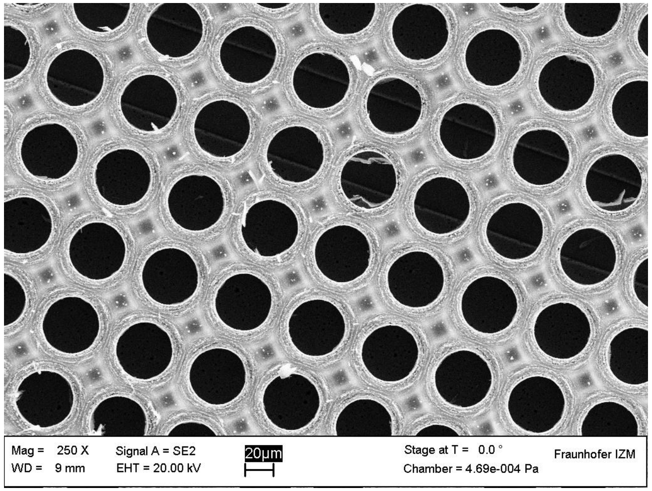
First dummy detectors on bare Si- wafer tested:

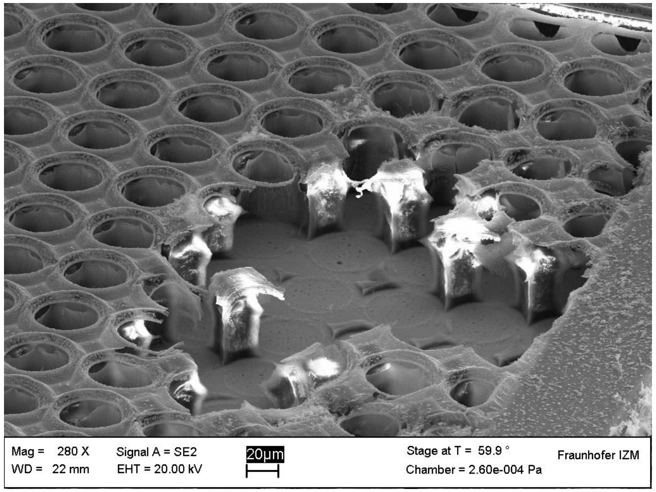
- Stand up to 400 V on grid
- Show signals correlated with sources

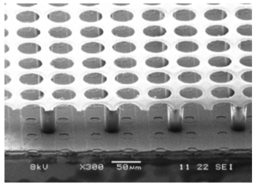


GEMGrid on chip carrier.

signals of ^{90}Sr

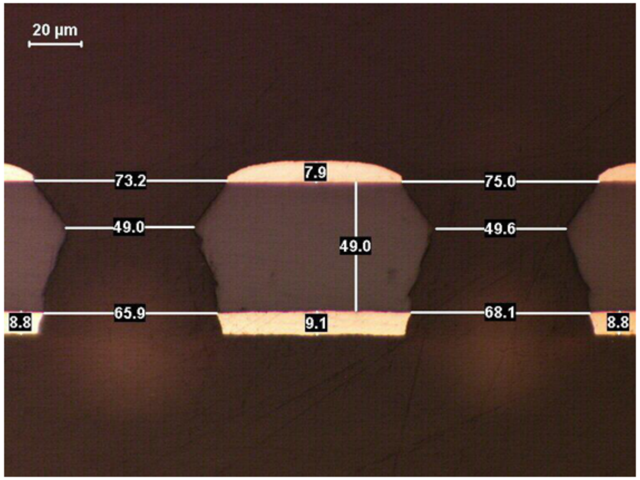






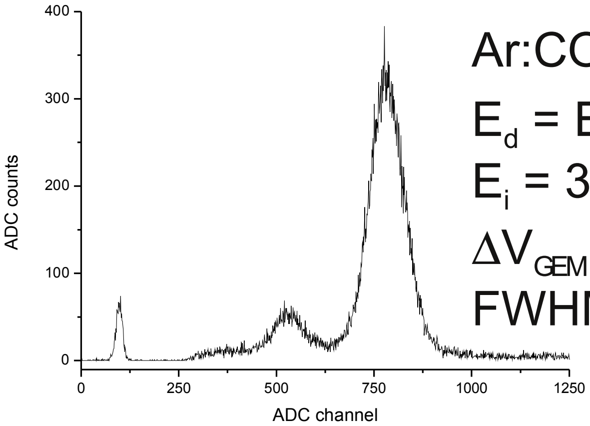
Large Area GEM

For GEM areas larger than 40×40 cm^2 the standard production process with 2 masks is not feasible anymore → need single mask process



- The base material is only 457 mm wide
- Get larger width by splicing GEMs
- 2 mm wide kapton overlay on GEM edges
- Pressed and heated up to 240 °C

Cu x-ray spectrum with double GEM



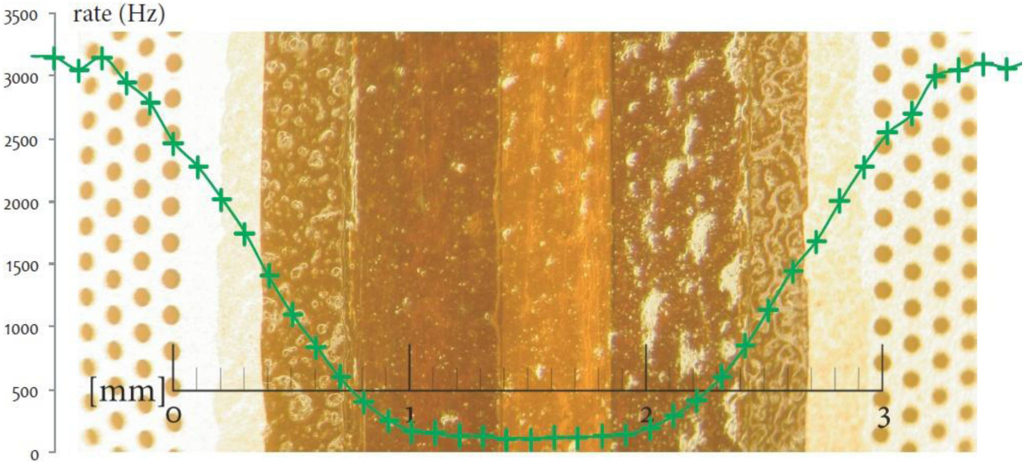
Ar:CO$_2$ 70:30

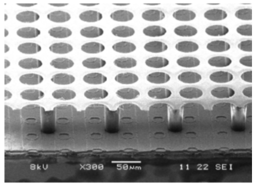
$E_d = E_t = 2$ kV/cm

$E_i = 3$ kV/cm

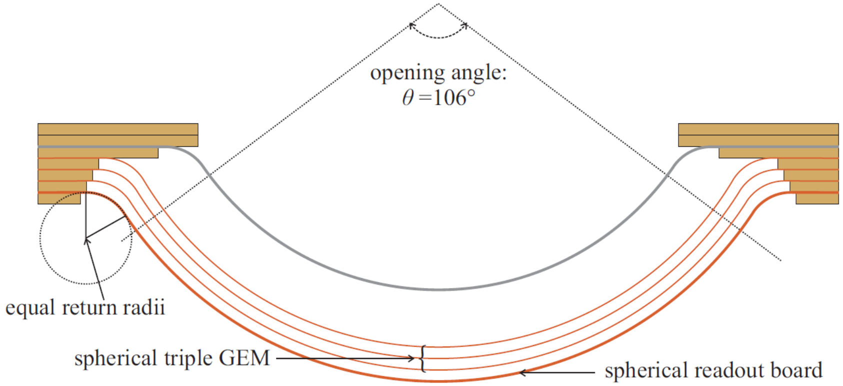
$\Delta V_{GEM} = 400$ V

FWHM/peak = 15.9 %





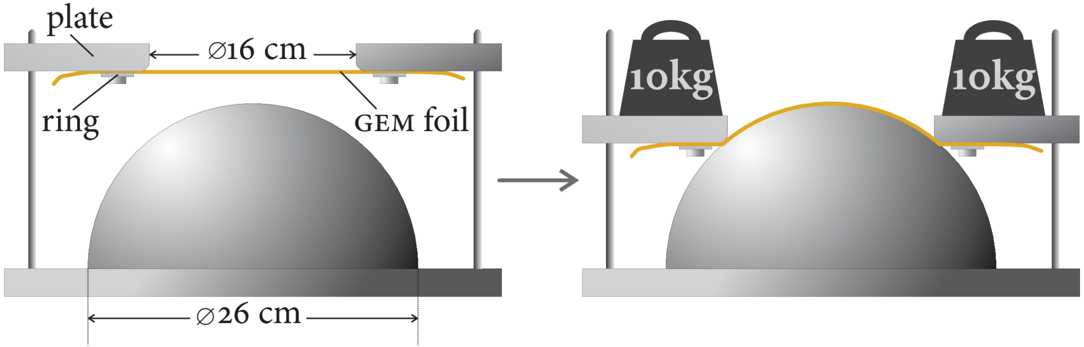
Spherical GEMs

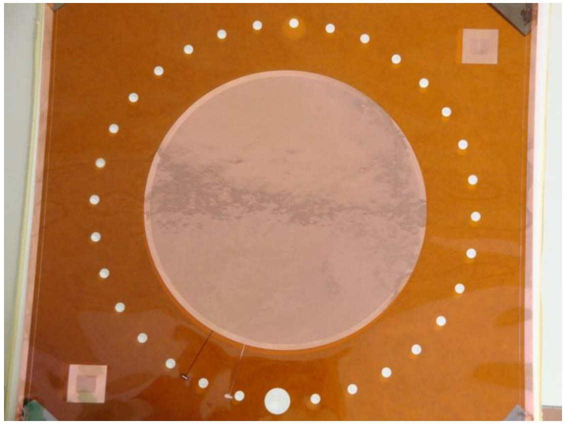


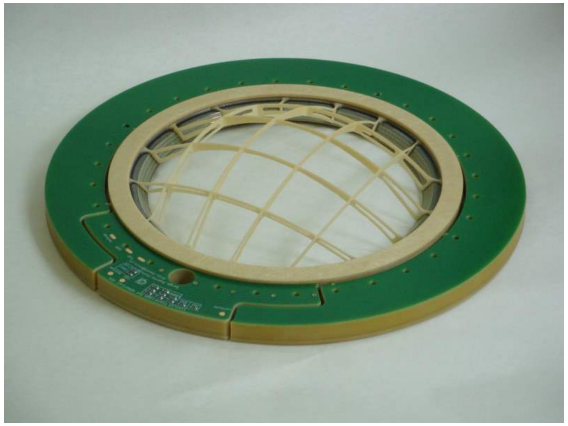
planar detectors cause a parallax error in radial experiments (e.g. x-ray scattering)

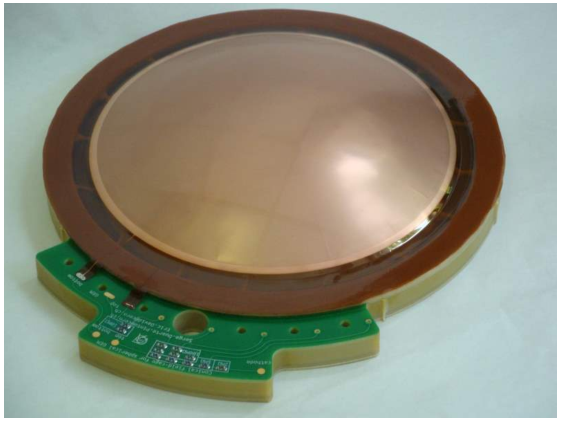
→ develop spherical GEMs

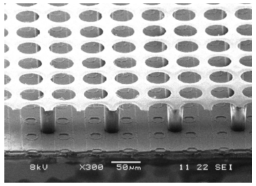
- Use standard GEM
- At vacuum (~10^{-2} mbar)
- And 350°C heat
- GEMs are pressed over mold
- GEMs stand HV!





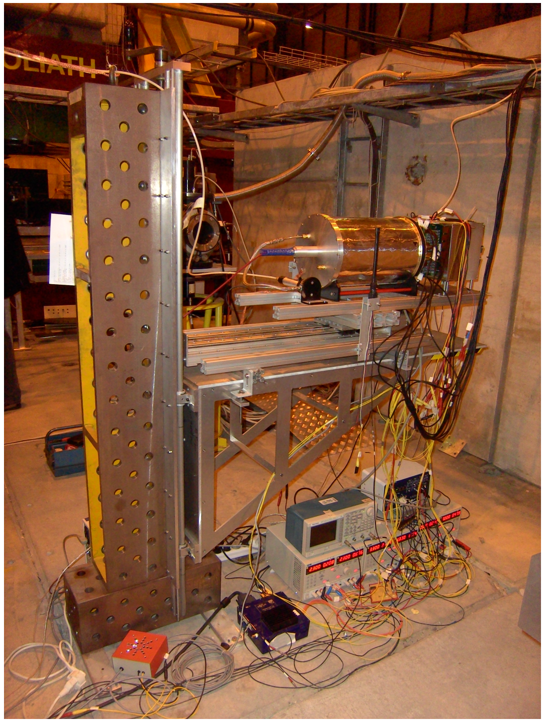


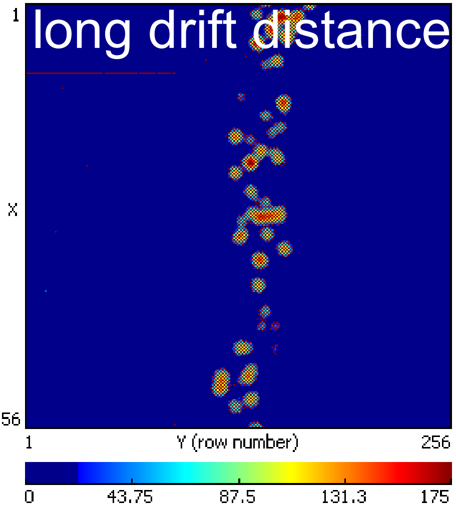




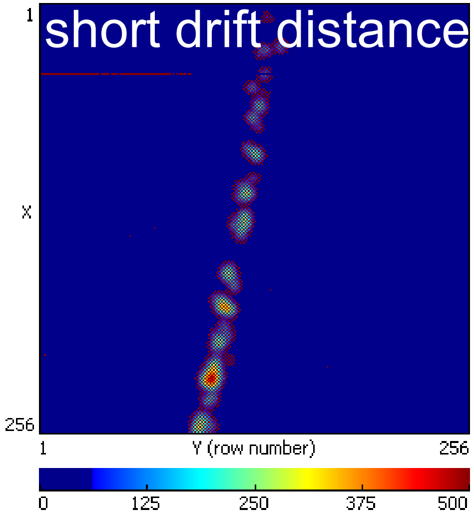
Pixelized Readout of GEMs

Place Timepix chip below a triple GEM stack, all spacing are 1 mm

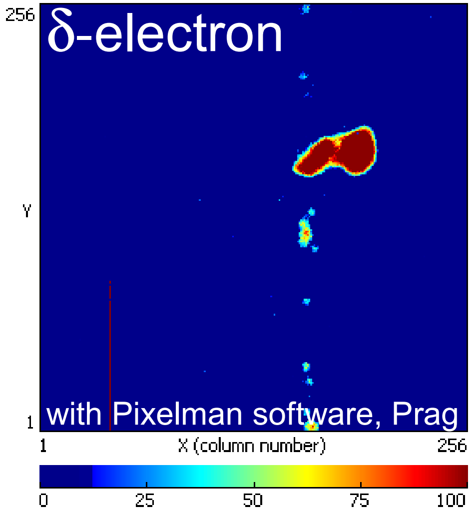




long drift distance



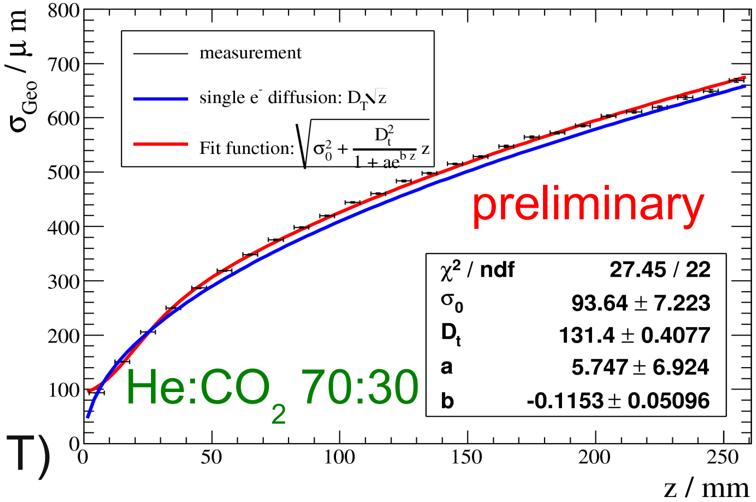
short drift distance

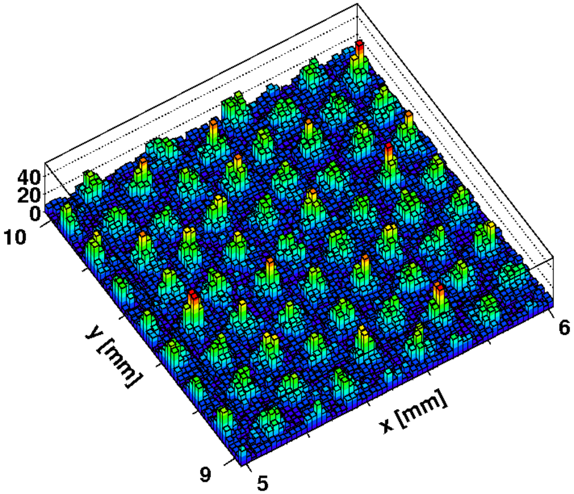


δ-electron

with Pixelman software, Prag

Spatial resolution of single electrons

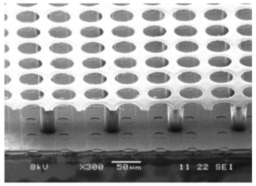




'Electron-tomography' of a GEM

Gas: Ar or He:CO$_2$ 70:30

Good performance with cosmic rays, electron and hadron test beams and in high magnetic fields (B = 4 T)



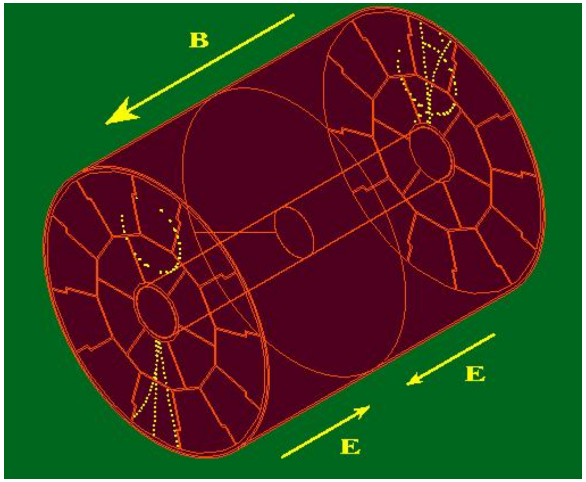
LC-Detectors

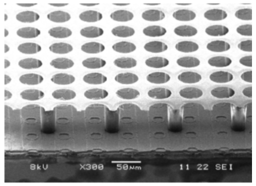
International Linear Collider (ILC) / Compact Linear Collider (CLIC):
e^+e^- colliders @ $\sqrt{s}$ = 500 GeV – 1TeV / 3TeV

Both accelerators require very precise multi-purpose detectors.
Concept of particle flow is considered optimal reconstruction scheme.
=> need low material budget tracking detectors with high precision, high efficiency and robust particle identification.

TPC is chosen as tracking detector for some detector concepts:

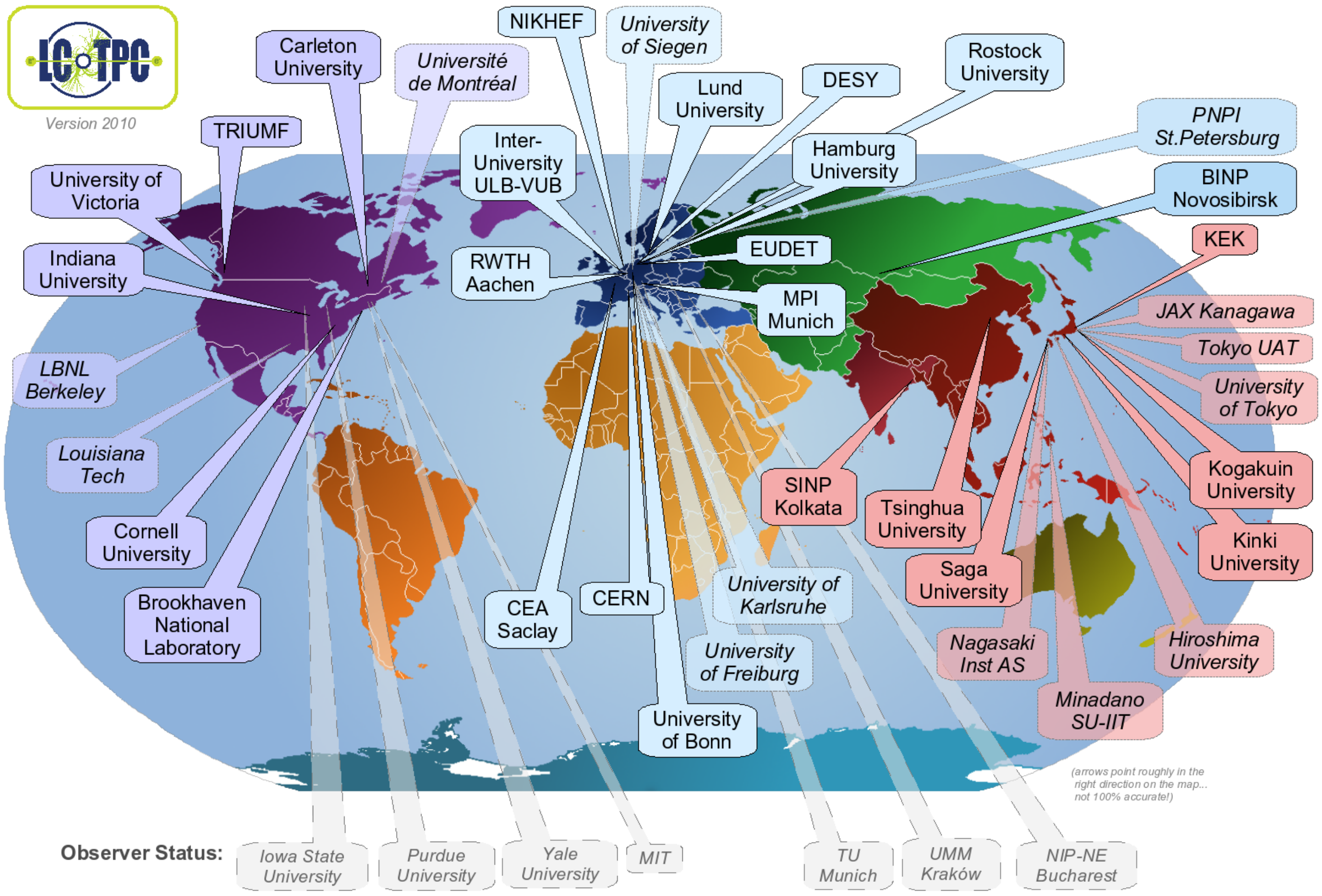
- Good spatial resolution ($\sigma_{\text{point}} \approx 100\ \mu\text{m}$)
- Large number of measurements (200)
- True 3-dimensional detector (no ambiguities)
- High granularity (10^9 voxels)
- Good energy resolution with dE/dx (5%)
- Low material budget
- Very homogeneous (only gas)





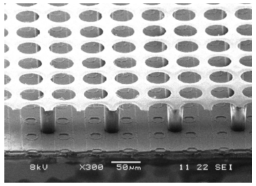
LCTPC - Collaboration

38 Institutes from 12 countries have signed MoU
7 institutes have an observer status



R&D in 3 phases:

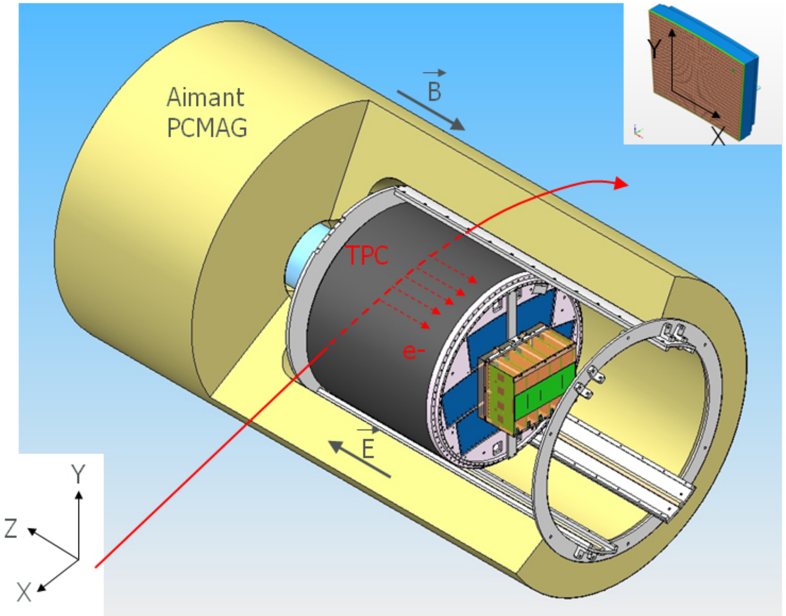
1. Demonstration Phase
   test feasibility with small scale detectors at individual labs
2. Consolidation Phase
   a medium size prototype was built to compare results and study integration Issues
3. Design Phase
   design of final detector

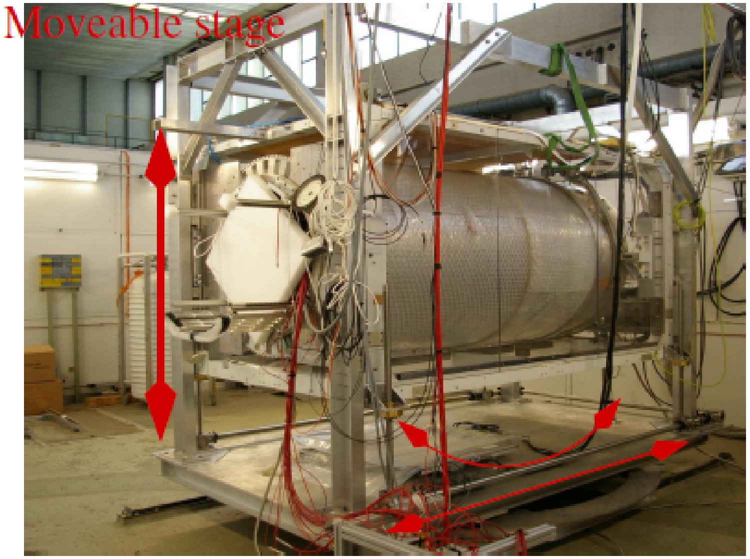


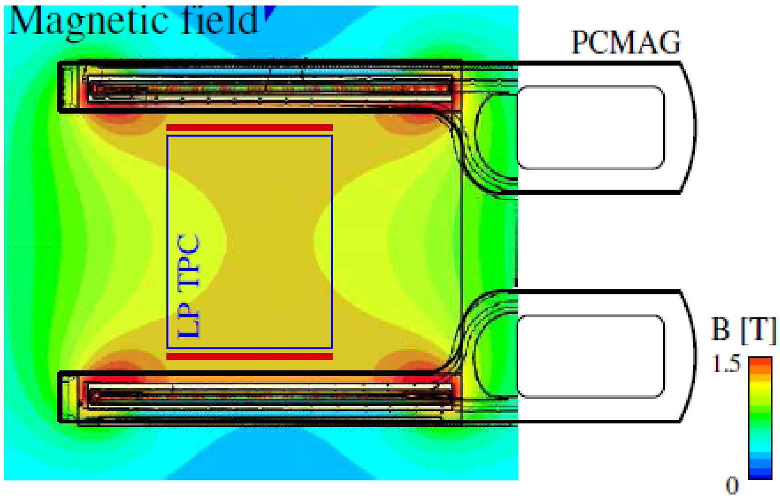
EUDET Facility

EUDET Setup for TPC R&D

PCMAG with B < 1.25 T
  bore diameter: 85 cm
LP support structure
Electron test beam with
  beam energy E = 1- 6 GeV
Field cage (see next slide)



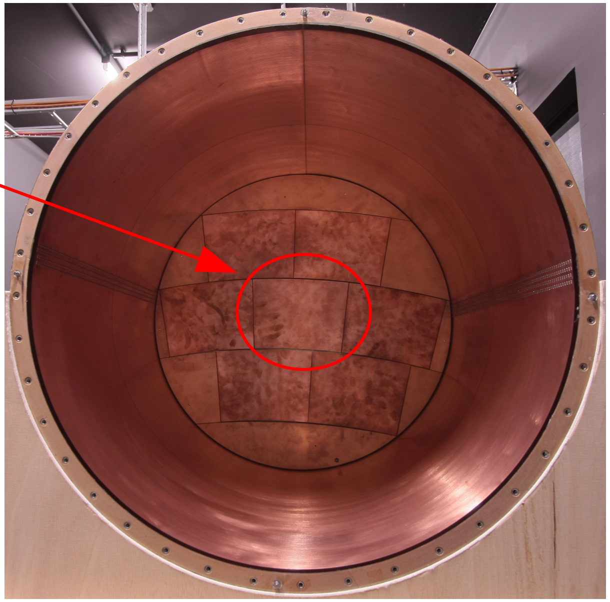




EUDET Large Prototype

<u>LP Field Cage Parameter:</u>

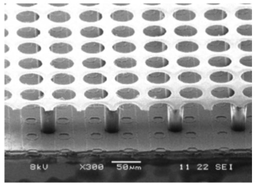
length = 61 cm
inner diameter = 72 cm
up to 25 kV at the cathode
=> drift field: E ≈ 350 V/cm
made of composite
materials: 1.24 % X_0



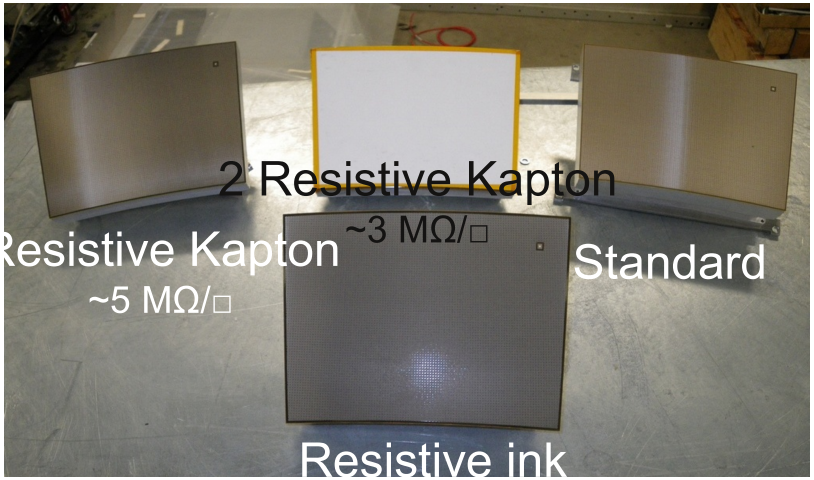
<u>Modular End Plate</u>

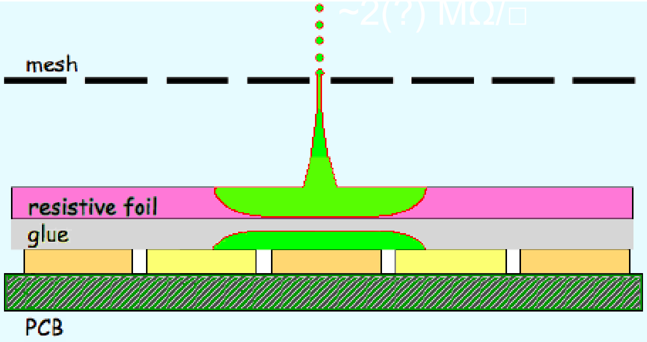
first end plate for the LP
made from Al
7 module windows
→ size ≈ 22 × 17 cm^2

Large Prototype has been built to compare different detector readouts under identical conditions and to address integration issues.

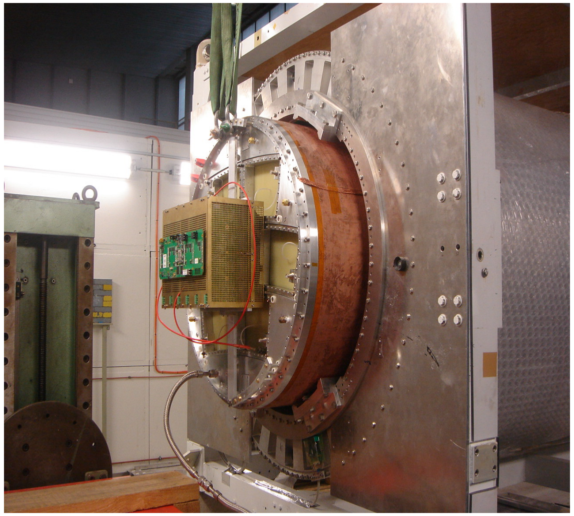


Micromegas Modules



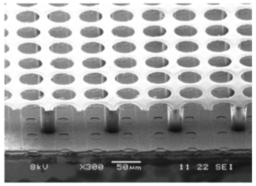


cover readout pads with resistive foil to broaden signal shape

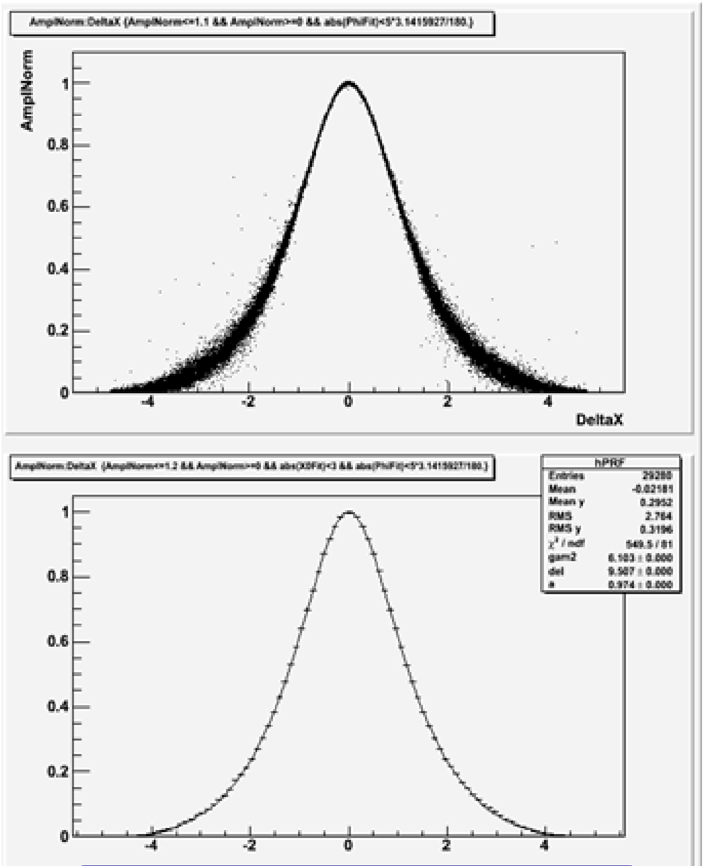


Micromegas Module

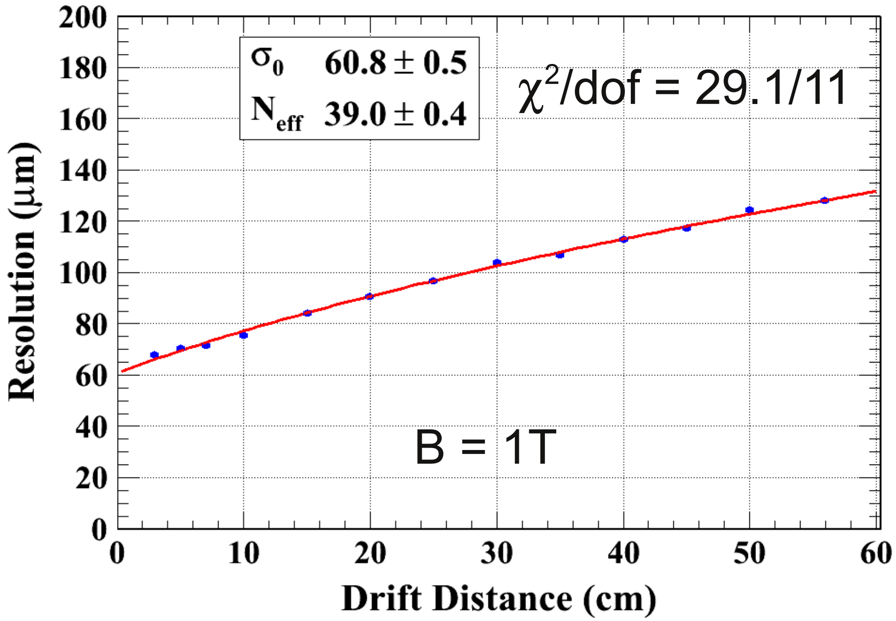
- 3×7 mm^2 large pads
- 24 row with 72 pads
  → 1728 pads per module
- Testing resistive foil / carbon loaded kapton (O(1MΩ/□))
- AFTER electronics (T2K)



Performance of Micromegas Modules



CLK



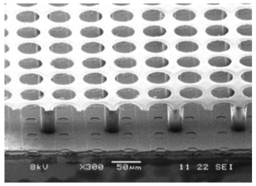
<u>Results (CLK Modules)</u>

resolution parametrized as $\sigma = \sqrt{\sigma_0^2 + D_t^2/N_{eff} \cdot z}$

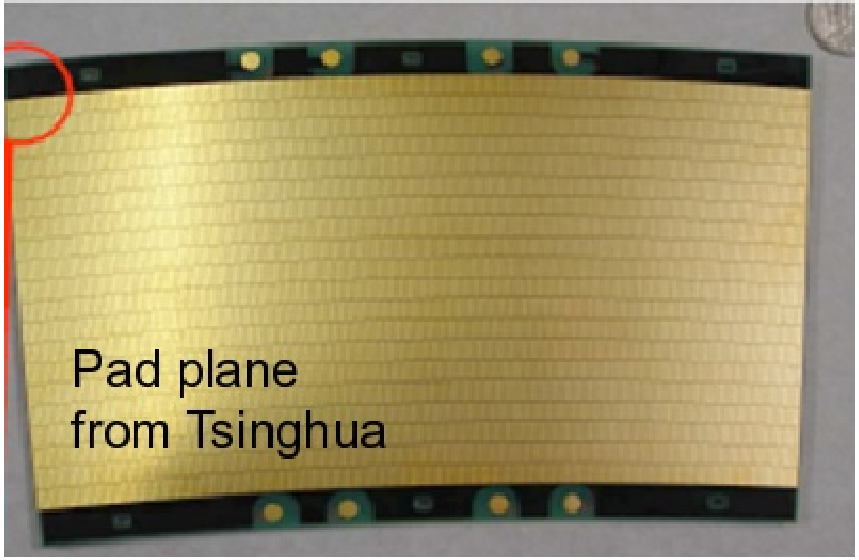
Combining results (e.g. B = 0T, B = 1T):

→ $\sigma_0 = 59 \pm 2\ \mu m$

→ $N_{eff} = 38 \pm 0.8$ per pad height



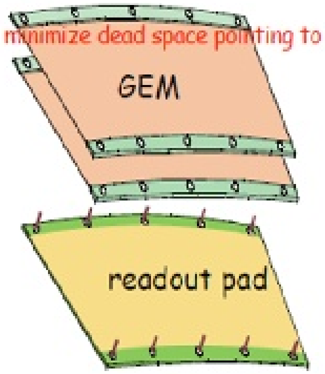
GEM-Modules

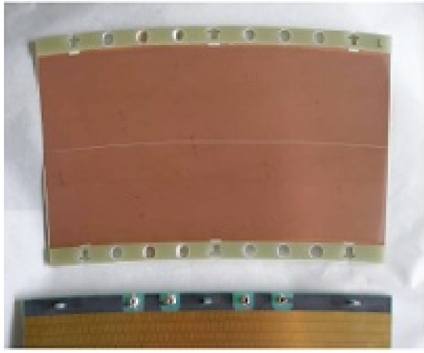


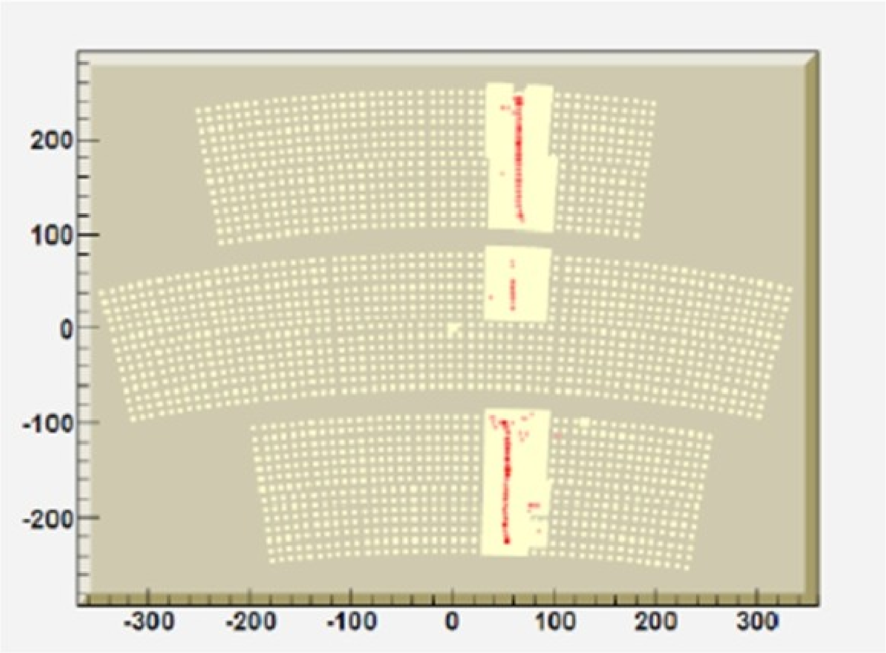
<u>GEM Module</u>

1.2×5.4mm^2 pads - staggered
28 pad rows (176-192 pads/row)
about 5000 ch. per module

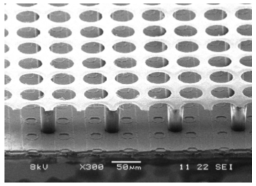
2 GEMs, 100μm thick



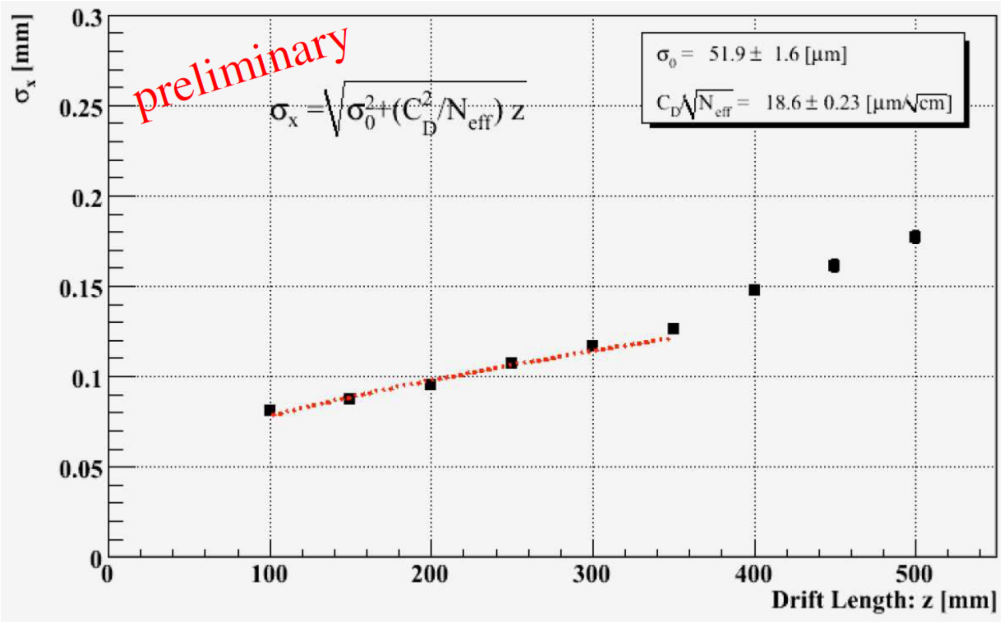




ICHEP 2010, Paris
J. Kaminski



Performance GEM-Modules



<u>First Results (GEM Modules)</u>

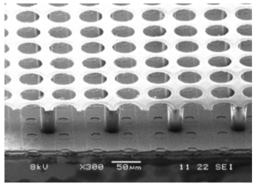
setup: E = 5 GeV, B = 1T

resolution parametrized as $\sigma = \sqrt{\sigma_0^2 + D_t^2/N_{eff} \cdot z}$

→ σ_0 = 51.9 ± 1.6 µm

→ N_{eff} = 21 ± 2 per pad height (4.1 mm^{-1})

=> GEM and Micromegas modules show similar performance



Conclusion & Outlook

Development of Micro Pattern Gaseous Detectors is a very active field. This is underlined by the formation of a new collaboration at CERN: RD51.

New techniques for producing Micro Pattern Gaseous detectors.
→ Techniques are also valid for large area detectors

Performance such as stability, energy resolution, point resolution and reduced discharge probability have been demonstrated.

A large number of different applications have been identified (e.g. LCTPC) and preparation for detector installation are ongoing.