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April 2016
HighRR Lecture Week
Detector Technology & System Integration session
Outline

- General introduction to MPGD working principles; motivations for their development
- Examples of MPGDs in HEP
- Tuning of MPGD parameters
  - ALICE TPC upgrade (GEM)
  - ATLAS Forward Muon Spectrometer (MM)
- MPGD production process and critical points
- Large area detector production for HEP. Solutions adopted
General introduction to MPGD working principles;
motivations behind their development
Gas Detectors
Gas Detectors

Energy loss due to electromagnetic interactions

Gas volume

Charged Particles

Anode

Cathode
Gas Detectors

Energy loss due to electromagnetic interactions

Gas volume

Charged Particles

Edrift

Cathode

Anode
Gas Detectors

Energy loss due to electromagnetic interactions

Charged Particles

Gas volume

Cathode

Anode

Edrift

Egain
Gas Detectors

Charge collected – log scale

- Ion chamber region
- Proportional counting region
- Geiger region

Voltage applied – linear scale

- Edrift
- Egain

Onset of continuous discharge

Energy loss due to electromagnetic interactions

Alpha particles

Beta particles

Not used
Gas Detectors

Ionization chambers

Simplest gas detector
No multiplication G=1
Primary electrons collected

Applications:
- **Nuclear industry**: output proportional to radiation dose (if high enough)
- Medical radiation measurement
- Smoke detector (alpha source in air)
Gas Detectors

Massive photoemission
Full detector affected

Need high resistor to quench the discharge or gas quenchers
Often self-substaining discharges. Need HV cut

Very low rate capability (used in dosimetry)
Gas Detectors

Single wire proportional counter
[Rutherford, E. and Geiger, H. (1908)]

Gas Detectors

Electric field:
\[ E(r) = \frac{CV_0}{2\pi \varepsilon_0 r} \]

Charge collected – log scale

Voltage applied – linear scale

Ionization region
Proportional counting region
Geiger region

Onset of continuous discharge

Alpha particles
Beta particles

MPGD work in proportional regime
“Traditional” wire gas detectors (1)

Advantages:
- Large areas at low prices
- Flexible geometries
- Good spatial, energy resolution

HEP experiments, large areas:
- muon spectrometer
- TPC readout
Advantages:
- Large areas at low prices
- Flexible geometries
- Good spatial, energy resolution

Limitations:
1) Slow ion motion
   Fast gain drop at high fluxes: (<10 kHz/cm²)
   Space charge accumulation, distortion of E field.
   Screening effect for next event
2) Limited multi-track separation
   Minimum wire distance ~1mm (mechanical instabilities due to electrostatic repulsion)
3) Aging
   Permanent damage of anode structure after long term exposure to radiation.
   Formation of solid deposits
   Gain drops and instabilities

Deposited polymers on the wire
How to improve gas detectors?

- Slow ion motion
- Limited multi-track separation

Reduce multiplication region size:
  - Faster ion evacuation
  - Higher spatial resolution
How to improve gas detectors?

Slow ion motion
Limited multi-track separation

Reduce multiplication region size
- Faster ion evacuation
- Higher spatial resolution

Micro Pattern Gas Detectors (MPGD)

First MPGD: Micro Strip Gas Chamber (MSGC) OED, 1988

- Reduction of the size of the detecting cell (~100 um) using chemical etching techniques
- Same working principle as proportional wire chambers
  - Conversion region (low E drift field)
  - High E field in well localized regions where multiplication happens
How to improve gas detectors?

Reduce multiplication region size
- Faster ion evacuation
- Higher spatial resolution

Micro Pattern Gas Detectors (MPGD)

First MPGD: Micro Strip Gas Chamber (MSGC) OED, 1988

New problems to take into account!!!

SPARKS
- High field close to both electrodes
- Inter-electrode space is on micron scale, i.e. very sensitive to dust
- Thin electrodes can be seriously damaged

DIELECTRIC MATERIAL
- Movement of charges when HV is applied
- Charging up
Micro Strip Gas Chamber (MSGC)

Advantages of MSGC
Small pitch between anode and cathode strips:
- Fast ion collection
- Spatial reso \(\sim 50\mu m\)
- Two track reso \(\sim 500\,\mu m\)
- High rate capability \(\sim 10^6\) Hz/mm

Pitch > 1 mm mechanical and electrostatic forces
Pitch \(\sim 100\,\mu m\) lithography technology

A. Oed
GRENOBLE
Micro Strip Gas Chamber (MSGC)

Advantages of MSGC
Small pitch between anode and cathode strips:
- Fast ion collection
- Spatial reso ~50μm
- Two track reso ~500 μm
- High rate capability ~10^6 Hz/mm

Pitch > 1 mm mechanical and electrostatic forces
Pitch ~ 100 μm lithography technology

Multi wires
Micro Strips, different substrates

A. Oed
GRENOBLE
Micro Strip Gas Chamber (MSGC)

Problems

1) Destructive discharges

Efficiency plateau too close to the discharge probability!!!
Micro Strip Gas Chamber (MSGC)

Problems

1) Destructive discharges

Efficiency plateau too close to the discharge probability!!!

2) Aging
   Thin wire problem

3) Time evolution of the gain:
   charging up, polarization, movement of charges in the substrate
Rapid development of many different MPGD structures to improve performances and solve MSGC problems
Today: holes and meshes

F. Sauli, NIM. A386(1997)531

GEM (std, Thick, glass, ...)

I. Giomataris et al., NIM A 376 (1996) 29

Micromegas (bulk, micro bulk, resistive, ..)
Today: holes and meshes

GEM (std, Thick, glass, ...)  
- F. Sauli, NIM A386(1997)531

Micromegas (bulk, micro bulk, resistive, ..)  
- I. Giomataris et al., NIM A 376 (1996) 29

- Aging: OK (no thin wires)
- Spark protection: multiple amplification stage, resistive electrodes
Gas Electron Multiplier (GEM)

Initially developed as a preamplifier stage for an MSGC.

Polliamide (kapton)
Gas Electron Multiplier (GEM)

Initially developed as a preamplifier stage for an MSGC....

Multiple GEMs → high gains (> $10^5$) before discharges, lower voltage for each GEM, spread of the avalanche.

- GAIN
- DISCHARGE PROBABILITY
- $^{241}$Am α source: Ar-$\text{CO}_2$ 70:30
- $E_1 = 2$ kV cm$^{-1}$
- $E_2 = E_3 = 3.5$ kV cm$^{-1}$

Polylamide (kapton)
GEM readout

- Electrons collected on patterned readout boards. Typically 2-3 mm diameter electron shower at the readout.
- A fast signal can be detected on the lower GEM electrode for triggering or energy discrimination.
- Characteristic unique of GEMs:
  - Full decoupling of the charge amplification structure from the charge collection and readout structure.
  - Both structures can be optimized independently.
  - Not only planar shape.

GEM principle

Avalanche Process in GEM: microscopic view

Time (0.2ns/step, From 0 to 0.8ns)

Incoming $\mu^+$

Avalanche

Time (1ns/step, From 1 to 5ns)

Electrons Drift and Diffusion

Time (400ns/step, From 10 to 1600ns)

Ions Drift and Diffusion

Garfild simulation, S. Dildick & R Veenhof
GEM family (R&D ongoing)

Thick GEM
Diamond GEM
Cylindrical GEM

Multilayer thick GEM

Glass GEM

...... And many others ....
Parallel plate field
- Amplification in a thin (100 um) gap,
- Conversion and amplification regions separated by a fine metallic mesh.
- Geometrical inefficiency (~1%) from pillars.
- High rate applications. Ions created in amplification gap are captured by the mesh
Micromegas family (R&D ongoing)

Resistive strips MM

Embedded resistors MM

Ingrid

Piggy back resistive MM

Cylindrical MM

Microbulk MM

...... And many others ....
MPGD are mostly used in forward regions of HEP experiments where the rate or radiation are too high for normal wire chambers.

Examples
MPGD are mostly used in forward regions of HEP experiments. They were used when the rate or radiation are too high for normal wire chambers.

Every LHC experiment (will) use MPGD.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Type</th>
<th>Region</th>
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</thead>
<tbody>
<tr>
<td>LHCb</td>
<td>3 GEM (MS – fw)</td>
<td></td>
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<tr>
<td>TOTEM</td>
<td>3 GEM (tracker – fw)</td>
<td></td>
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<tr>
<td>CMS</td>
<td>3 GEM (MS- fw)</td>
<td></td>
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<tr>
<td>ALICE</td>
<td>4 GEM (TPC)</td>
<td></td>
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<tr>
<td>ATLAS</td>
<td>res MM (MS- fw)</td>
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Running

LS2 Upgrades (2018-19)
**Requirements of M1**
- Rate Capability up to 0.5 MHz/cm²
- Station Efficiency 96% in a t 20 ns
- Low material budget (before calo)
- radiation hardness

**GEM choice**
R&D work done on 2000-2003

(RPC much faster but lower rate capability)

Two double chambers, triple-GEM detectors in OR

GEM foils: 20x24 cm²

Readout:
Pad 10x25 mm²
To measure inelastic produced charged particles
Very forward region  CMS 5.3<|\eta|<6.5

Requirements
- Rate Capability  MHz/cm² at L= 10^{33} cm⁻²s⁻¹
- Radiation hardness
- Efficiency >97%
- Time resolution < 10 ns
- Space resolution < 100 μm

GEM choice
Each side:  20 triple GEM chambers.  Readout: strips (tracking) and pads (triggering)
GEM @ CBM muon (FAIR)

Construction in progress @ CERN

Test beam at GSI

Muon detectors requirements

- High collision rate
- High track density
- Radiation resistant (high neutron dose \( \sim 10^{13} \) n.eq./sq.cm/year)
- Large area detector
- Readout in a self triggered mode

For the first two stations, which demand a high rate capability, **GEM will be used.**

*TDR approved in 2014*
MM @ CLASS12 FW tracker (JLAB)

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

Installation in progress
- 1st curved Micromegas
- 1st use in 5T field
- Resistive technology
- High rate (30 MHz)

Barrel

Endcap

Sébastien Procureur CEA-Saclay

Integration of MVT and SVT in Dec. 2015
Two examples of detector optimization R&Ds
Example on how to tune an MPGD to fulfil the physics requirements

ALICE TPC upgrade
TPC Time Projection Chamber

Filled with high purity gas
Electron amplification with Multi Wire proportional Chamber at the endplates
XY coordinate from pad/strips RO plane
Z coordinate from drift

Critical points:
homogeneous drift speed (gas purity, constant E, ion backflow)

1974, David Nygren

TPC as **central tracker** for many experiments
- SLAC (PEP)
- LEP (ALEPH, DELPHI)
- RHIC (STAR)
- LHC (ALICE)
- ILC ?? (ILD)
TPC ion blocking, gating grid

When a trigger appears

Primary electrons

\[ I^+ \sim 1000 \text{ times slower than } e^- \]

- **Open grid**: let electrons in (100 $\mu$s)
- **Closed grid**: blocks ions created in the avalanche process and not triggered signals from the drift

Need closed time: **180 $\mu$s** (time ions takes to drift to the gating grid in Ne based mixtures)

Rate limitation $\sim$3.5KHz
ALICE TPC upgrade

**PHYSICS REQUIREMENTS:**
- Increase of rate up to 50 kHz Pb-Pb (20 μs).
- Not possible standard gating (max rate ~3kHz)
- Need new RO chamber who allow s continuous RO
- **Ion back-flow <1%** at G=2000 to keep space charge of TPC at tolerable level.
- Preserve dE/dx resolution of the old chamber for particle ID (Ω/E (Fe55) <12% )
- Stable operation at LHC (not redundancy!!)

A lot of R&D in the last 3-4 years

4 GEM foils (Approved in 2014).
Total area 32.5 m², up to 112 cm in length
Detector R&D studies

**Configuration tried:**
-- 3 GEMS
-- 4 GEMS
-- 4 GEMS different pitch
-- 1 MM + 2 GEMs

**Lab measurement**
-- Ion BackFlow (vs E fields, rate, gain)
-- Energy resolution (spectrum Fe55 X ray source)
-- Discharge probability (alpha source, testbeam hadronic showers)

**Many parameters to be tuned:**
dV each GEM (Gain, E reso, spark probability)+ E transfer fields (Ion Backflow).

**E reso:** collection all primary electrons, good extraction, high transfer field
**Ion blocking:** low transfer field
Detector R&D: E reso, IBF

Configuration tried:
X 3 GEMS
X 4 GEMS
✓ 4 GEMS different pitch
✓ 1 MM + 2 GEMs

Only a small window where requirements are satisfied

PHISICS REQUIREMENTS:
- Ion back-flow <1% at G=2000
- $\Omega/E$ (Fe55) <12%
- Stable operation at LHC (not redundancy!!)

ALICE Upgrade TPC TDR
Addendum to the ALICE Upgrade TPC TDR
Detector R&D: discharge probability

2 real size prototypes, tested at the SPS (CERN) with pion beam + Fe target

- Ion Back Flow
- Energy resolution
- Spark rate

Discharge probability MM prototype 2-3 order magnitude higher than 4GEM prototype

Final decision for the 4 GEM TPC readout

ALICE Upgrade TPC TDR
Addendum to the ALICE Upgrade TPC TDR
ALICE TPC upgrade

Addendum to the ALICE Upgrade TPC TDR
How to cope with sparks in micromegas

ATLAS new small wheel case
Replacement of current wire detectors to cope with luminosity increase in Run3

Why the Micromegas choice

- Rate capability $15 \text{ kHz/cm}^2$ ($L \approx 5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$)
- Spatial resolution $\leq 100$ um, $\Theta_{\text{trk}} < 30^\circ$
- Radiation resistance, no ageing

Big surface

The only MPGD that can achieve such dimensions: Micromegas

... But....
a long R&D phase to fight against sparks
Resistive strips micromegas

Inacceptable high spark rate in LHC operation conditions
High Voltage drops -> dead times

Sparks still occur but become inoffensive
No High Voltage drops
Very small current up to G~2*10^4

T. Alexopoulos et al, NIM A640 (2011)
Resistive strips micromegas

Gas: Ar:CO₂ (93:7) (safe & cheap)

- 300 V

Drift electrode

Drift gap 5 mm

v_{drift} = 47 \mu m/\text{ns}

Insulator (Kapton)

Amplification gap 128 \mu m

Readout strips pitch \approx 400 \mu m

PCB (FR4)

Charged Particle

Output Signal

Output Signal

Output Signal

Output Signal
Inclined tracks, spatial resolution

The $\mu$-TPC
Micromegas with $\mu$-TPC readout

Requirements

- Rate capability 15 kHz/cm$^2$ 
  \( (L \approx 5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}) \)
- Spatial resolution $\leq 100$ um, $\Theta_{\text{trk}} < 30^\circ$
- Radiation resistance, no ageing
- Big surface

- Spatial resolution rapidly decreases with $\Theta$ when charge centroid is used
Micromegas with $\mu$-TPC readout

Requirements

- Rate capability $15 \text{ kHz/cm}^2$
  $(L \approx 5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1})$
- Spatial resolution $\leq 100 \text{ um}$, $\Theta_{\text{trak}} < 30^\circ$
- Radiation resistance, no ageing
- Big surface

- Spatial resolution rapidly decreases with $\Theta$ when charge centroid is used
- Measuring arrival time of the signal opens a new dimension
GEM and micromegas Fabrication at CERN
MPGD fabrication at CERN

Micro Pattern Technology workshop
~20 persons
Making PCBs since 1955

People deeply involved in design and production of standard MM and GEM

Rui, supervisor

Some of the people involved in some steps of GEMs and MM (standard PCB steps)
MPGD fabrication at CERN

Base material

Copper

dielectric

Copper

Micro pattern

Photolithography

Same technique, equipment as standard printed circuits boards (PCB) fabrication
MPGD fabrication at CERN

Photolithography

Same technique, equipment as standard printed circuits boards (PCB) fabrication

+ process optimization for MPGD

Many years of continuous R&D (e.g. GEM etching, MM pillars, resistive strips)

Technology transfer to external industries ongoing (detector fabrication for big experiments)
Photolithography (1)

Chemically etch away the unwanted copper in order to create the wanted image.

- Copper
- dielectric
- Copper
- Image/circuit design
- Base material
- PCB
Photolithography (2)

Design the (complementary) image and print the film

Files préparation, design
And Film printing

Software UCAM
The 2 Designers Adapt the Design coming from the BE to our Production
Or Design themselves a Complete Project

2 designers to prépare the films

2 photo plotters

Film

Film developer

Link: A. Teixeira CERN Ph-DT seminar 2015
Photolithography (3)

Embed the base material into a photosensitive material (photoresist)

**Lamination**

Copper/Epoxy/Copper

Substrate + Photoresist

Pass between 2 hot rollers

Laminator
Max Width 600 mm

3 solid photoresists
30 μm: standard
20 μm: Gem
15 μm: fine line

Link: A. Teixeira CERN Ph-DT seminar 2015
Photolithography (4)

Film on top of the photoresist

UV exposure

Film on top of the photoresist

Development (sodium carbonate)

UV Exposure and development

UV Exposure

Development

After Exposure

After Development

Link: A. Teixeira CERN Ph-DT seminar 2015
Photolithography (5)

Etching (ferric chloride)

Copper Etching

2 copper etching machines

Before Etching

After Etching

After Stripping

Stripping (alcohol)

Link: A. Teixeira CERN Ph-DT seminar 2015
Other used processes

**Photolithography (6)**

- **CNC drilling machine**  
  (ThickGEM, final cut...)

- **Press**  
  For multilayer circuits

- **Kapton etching**  
  Ethylene and soap Tank for large detectors

- **Cleaning/de-chroming baths**

- **Micro-etching baths**  
  Fial passivation  
  Thin lines  
  RIM thickGEMs

…….. AND MANY MORE ..
CERN patent

GEM production steps
GEM std technique: double mask

Production steps

1) Base material

2) Top, Bot mask alignment, UV irradiation

3) Cu etch

4) Kapton etc

Examples

COMPASS (CERN)  TOTEM (CERN)  LHCb-μ trigger (CERN)

50um copper clad Polyimide
Rolls of 100m x 0.6m
Polyimide: APICAL NP or AV
One supplier: LSMtron (Korea)
GEM std technique: double mask

1) Base material

2) Top, Bot mask alignment, UV irradiation

3) Cu etch

4) Kapton etc

Film with holes to be aligned under microscope (precision ~ um)
Impossible for large foils!!!
Max size: 40*40 cm^2

Electric Field and performance strongly related to the hole shape

Mask misalignment

copper electrodes
polyimide

mask misalignment
Micromegas production steps
Standard bulk MM

**BULK MICROMEGAS**
Mesh is trapped by pillars.

**ADVANTAGES**
Constant amplification gap, maintained by pillars
Not worries about readout plane flatness

**WEAK POINTS**
Dust: if trapped between mesh and RO during production → short, spark, leakage current. Dead detector

Bigger the surface, higher probability to trap dust during production
Making MM pillars

- Read-out board with Cu strips and resistive strips
- Laminated Photoimageable coverlay
- SS Stretched mesh on metal frame
- Laminated Photoimageable coverlay
- Exposure Development + cure
Photolithography for micro structures,
Example of critical points

• **More precision**, line width/isolation in the final product
  → thinner the photoresist (30 um stnd, 20 um GEM, 15 um fine lines) and Cu
  → more fragile, more defect sensitive

• **Many parameters to tune:**
  • Image accuracy: film print high resolution, film temperature and material (deformation)
  • Vacuum between film and photosensitive material
  • UV irradiation time
Micro structures, Example of critical points

Perfect exposure
Polymerization of photoresist where film is transparent. Final Cu shape = film image

Under exposure
Not enough photoresist protection during etching. Breaking-delaminating. Too much etching, irregular shape

Over exposure or not perfect vacuum
Too much polymerization of photoresist. Bad result

UV exposure

After UV exposure

Development:

Etching

Result
Photolithography for micro structures, Example of critical points

• **More precision**, line width/isolation in the final product
  → thinner the photoresist (30 um stnd, 20 um GEM, 15 um fine lines) and Cu
  → more fragile, more defect sensitive

• **Many parameters to tune:**
  • Image accuracy: film print high resolution, film temperature and material (deformation)
  • Vacuum between film and photosensitive material
  • UV irradiation time
  • Photoresist development (chemical bath concentration, day dependent. To be tuned with development speed)
  • etching time. Same as before
  • raw material thickness disuniformities
  • cleanness during lamination photoresist (cleanroom), well water washing after each chemical process
Micro structures, Example of critical points
Dust and cleaning problems

(big) Dust in the UV irradiation

Not well developed after UV irradiation

Not well washed after a chemical bath

Forgotten in a chemical bath during lunchtime...
Technological problem: Not easy to scale in dimensions

Large number of large area detectors
Micro-precision in macroscopic structures..

10 cm\*10 cm  \hspace{1cm}  2 m \* 1 m
In the last few years boost on R&D activities to develop large area MPGD Compatible with experiment demands (RD51 project, ATLAS MM, CMS GEM)
Technological problem:
Not easy to scale in dimensions

Large area GEM production:
Single Mask technique

Max size standard technique
40*40 cm²

Bigger GEM, PRAD (USA)
1.6m * 0.6m
GEM new technique: single mask

Double mask

1) Base material

2) Top, Bot mask alignment, UV irradiation

3) Cu etch

4) Kapton etc

Film with holes to be aligned under microscope (precision ~ um)
Impossible for large foils!!!
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Mask misalignment

copper electrodes

polyimide

mask misalignment
GEM new technique: single mask

Double mask

1) Base material
2) Top, Bot mask alignment, UV irradiation
3) Cu etch
4) Kapton etc

Single mask

1) Same base material
2) Top mask ONLY UV irradiation
3) Cu top etch
4) Kapton etch
5) Cu bot electro etch
6) Second kapton etch

Examples

CMS muons (CERN)
KLOE2 cylindrical GEM (Frascati ITALY)
PRAD (USA)

2m x 60cm due to Base material
Equipment
Technological problem: Not easy to scale in dimensions

ATLAS Micromegas

1) Floating mesh

2) Screen printing resistive strips
**Bulk**

Mesh embedded in pillars

- Self supporting
- Constant amplification gap even if RO plane not perfectly flat
- Cylindrical detectors

- Production in clean room mandatory to avoid dust trapping
- Difficult large area production
MM floating mesh (ATLAS)

**Bulk**

- Mesh embedded in pillars
- Self supporting
- Constant amplification gap even if RO plane not perfectly flat
- Cylindrical detectors
- Production in clean room mandatory to avoid dust trapping
- Difficult large area production

**Floating mesh**

- Mesh separated from pillars
- Need strong mechanical supports
- Planarity to be controlled! (to guarantee amplification gap constant)
- Large sizes (~ 2m) (ATLAS)
- Easy to open and clean
- Lower cost (industrial production)
….. Life is not so easy …..

First cosmic measurement of ATLAS big floating mesh MM. Inefficiency

Electrostatic force push the mesh toward the pillars but if non-flatness RO board over short distance → smaller amplification field

Stringent requirements of μ-level flatness during production
Resistive layers for mass production

Photolithography

- Possibility to go down to 100 μm pitch
- Time consuming for industrial production
- If fails, to throw away the full RO board

Standard technique used for R&D on first resistive MM prototypes
Resistive layers, photolithography

Resistive paste manual deposition

Optical check and curing
Resistive layers, photolithography

Resistive paste manual deposition

Optical check and curing

Sandpaper to eliminate extra R paste and reach Cu level

After curing

After sandpaper

Etch etra Cu

Final result

Photolithography

Possibility to go down to 0.1mm pitch
Resistive layers, photolithography

BIG detectors

Feasible but complicated for industrial production, time consuming
Resistive layers for mass production

Photolithography
- Possibility to go down to 100 µm pitch
- Time consuming for industrial production
- If fails, to throw away the full RO board

Screen printing
- Pitch > 400 µm
- Automatic machine (industry)
Resistive layers, screen printing
Resistive layers for mass production

Readout circuit

Resistive strips, screen printed on kapton foils

PCB

Thin solid cast Glue (12um)

PCB

High pressure, High temp gluing

PCB

mesh

Pillar creation
Screen printing mass production

R&D at CERN, Japan’s industry (mass production)

Carbon paste deposition

Automatically controlled squeegee

After printing

Drying 2h @ 170°

A. Ochi’s presentation @ RD51 coll. meeting
Detector cleaning (R&D phase)

Opening mechanical structure needed

Going to the CERN workshop for the

Powder capturer in clean room

Chemical cleaning baths

De-mineralised water
Questions?
silvia.franchino@cern.ch
Grid manufactured by SERITEC (Switzerland) – stretch @ 15 N.cm
ATLAS NSW

Stretching mesh 15 N cm
ATLAS quadruplet layout
Resistive strips MM, rate capability

Gain ≈ 5000

Clean signals up to >1 MHz/cm², but some loss of gain
Quality problems

- Unexpected delay and unsatisfactory quality of the boards from both companies

First few boards received in July/August

Main observed problems:

1. Bubbles/dust between kapton and PCB in active area
2. Deviation in the dimension of the copper pattern
3. Missing or weakly attached pillars (homogeneity of pillar heights resulted not to be an issue)
4. Inaccurate edge cutting and drilling
5. Strip cut badly repaired
6. Bad metallization/plating of the connector pad
7. Missing or bad HV connection lines

P. Iengo (CERN)
Kloe2 inner tracker @ DAPHNE

First cylindrical MPGD

Installed in 2013
Chromic acid Bath

- Chromic acid: 80 g/l
- Sulfuric acid H2SO4: 3cc/l
- Room temp

Etched electrode

+V $\rightarrow$ 0.7 to 1.3V

Current control

Depending on size

From 0.5A (10x10 cm²) up to 6A (1/2 m²)
Kapton etching chemistry (60 degrees)

- 2/3 Etyldiamine (C₂H₈N₂)
- 70 g/L Potassium hydroxide (KOH)
- 1/3 H₂O

Development

Sodium Carbonate
**Laser, plasma, chemical etching**

- **Chemical etching**
  - Adjustable angle
  - Easy inspection
  - Lowest cost
  - Mass production in study
  - Many possible suppliers

- **Laser etching**
  - Cylindrical hole shape
  - No charging up
  - Many materials
  - Mass production in study
  - Uniformity

- **Plasma etching**
  - Many materials
  - Many techniques
  - Medium cost
  - Uniformity

- Bi-conical shape
- Possible charging up
- Apical NP only

- Carbonization
- One possible supplier
- Long processing time
- High processing cost
- Laser cost

- No on going R&D
- Isotropic etching
- Difficult to clean
- Lower breakdown voltage

R. De Oliveira (CERN)
Multi-Wire Proportional Chamber (MWPC)

From H-C Shultz-Coulon lectures
Large triple-GEM assembly (CMS, CBM)

Electrical test before starting. No sparks, no leakage current

New self-stretching technique

- Roll to capture dust

- Screws pull and stretch foils

- Detector Base

- Drift

- 3 GEM foils

- Readout board
ALICE GEM gluing

Heidelberg GEM gluing school
Figure 3.5: Left: Optical transparency of two standard GEM foils. Right: Illustration of the interference pattern that occurs when the foils are slightly rotated.

Figure 3.6: Left: Optical transparency of two standard GEM foils after rotation of one foil by 90°. Right: Illustration of the randomization of the relative hole positions.
ion space-charge density:
\[ \sim n_{\text{prim}} \times \text{gain} \times IBF \times \frac{1}{v_{\text{ion}}} \]

\[ \rightarrow \text{baseline mixture Ne-CO}_2-N_2 (90-10-5) \]

- requirement: \( IBF \leq 1\% \),
  i.e. \( \varepsilon = \text{gain} \times IBF < 20 \)
  at gain = 2000
Detector R&D studies

Many parameters to be tuned:

**dV each GEM** (Gain, E reso, spark probability) + **E transfer fields** (Ion Backflow).

![Graphs showing variations in detector performance parameters](image-url)