Application of Highly Resistive Material to Particle Detection

Sung Keun Park
Korea Univ., UCDavis
New Trends after Wire Detectors

- Resistive Plate Chambers (RPCs)--Good time resolution
- Variation of RPCs (mRPC, gRPC)--Fast timing, High rate capability
- Micropattern Gas Detectors (MPGDs)--Good spatial resolution
- Variation of MPGDs (GEM, MICROMEGAS)--High rate + Spatial resolution
INTRODUCING OUR LATEST DETECTOR DEVELOPMENT TOOL

Model 2262 Multi-Input, 10-Bit, 40/80 Megasample/sec Waveform Digitizer

Developed for Jet, Image and Time Projection Chamber (TPC) Systems in High Energy Physics and Heavy Ion experiments, LeCroy’s Model 2262 Waveform Digitizer offers precision analysis of both chamber performance and readout electronics.

Bi-polar inputs permit simultaneous sampling from sense wires or pads. The DC-coupled 40 MHz analog bandwidth and 10-bit resolution means that the details of the chamber signals will not be lost. Up to four signals at 40 megasamples/sec or two signals at 80 megasamples/sec are captured by a single-wide CAMAC (IEEE-586) module. External timebases may also be used.

The Model 2262 is compatible with GPIB (IEEE-488) operation and works with IBM PC*-based software for easy, user-oriented, waveform display and control. Support and accessory modules are available. Contact LeCroy worldwide for more information and detailed specifications.

LeCroy— for the performance, service and support you can count on today and in the future.
KODEL establishes Korea as major physics player

Marking the emergence of Korea as a major player on the world physics scene, the Korea Detector Laboratory (KODEL) was established this year under director Sung Keun Park of Korea University, Seoul. Its aim is to carry out research and development for high-energy physics detectors and international high-energy physics programmes, and to provide the infrastructure for the ever-increasing scope of major international high-energy physics projects.

About 11 Korean universities have links with KODEL and participate in the research at Brookhaven, CERN, DESY (Hamburg), Fermilab, GSI (Darmstadt), and KEK (Japan).

A guest of honour at the KODEL opening ceremony was 1992 Physics Nobel prize-winner Georges Charpak of CERN. His lecture was televised throughout the country.

Georges Charpak (right) at the new Korea Detector Laboratory (KODEL) with (right to left) KODEL director Sung Keun Park, Kwangsook Sim and Juntaek Rhee.

While at KODEL, Charpak stressed the importance of research and development for high-energy physics detectors in Korea, and Korea’s collaboration with CERN in the LHC Collider project.

At a news conference Charpak affirmed that present economic problems could be alleviated by higher investment in basic research to provide a solid foundation for future technological advancement.

Charpak also met with the Korean Prime Minister, the Minister of Science and Technology and the Minister of Information and Communication, and gave a talk to the Korean Physical Society entitled “Recent advances on gaseous detectors and their applications for medicine and biology”, a subject for which his enthusiasm never wavers.

KODEL produces prototypes of forward resistive plate chamber for the CMS detector at the LHC and is obtaining very encouraging results. It will be the main Korean laboratory for mass production of these units.
Principle of Operation of RPC

\[ n = n_0 e^{-\lambda} \]

\[ \frac{dn}{dx} = n \eta dx \]

\[ \frac{n}{p} = Ae^{(-\beta E)} \]

\[ q_e = \sum_{j=1}^{n} \frac{q_{al}}{\eta d} n_{j} M_{j} k \left[ e^{\eta(d-x_j)} - 1 \right] \]

\[ <q_e> = 2 \sum_{j=1}^{n} \frac{q_{al} \mu e^{\eta d}}{\eta d} \left( \frac{\lambda}{\lambda + \eta} \right)^{j} \]

- \( n_0 \): initial size of clusters (electrons)
- \( n \): size of clusters (electrons)
- \( \eta = \alpha - \beta \): effective Townsend coefficient
- \( \beta \): attachment coefficient
- \( E \): effective field
- \( P \): gas pressure
- \( A, B \): constants in Koreff's approximation
- \( q_{al} \): induced charge at signal pick-up strip
- \( \mu \): average initial size of clusters
- \( q_e \): electron's charge
- \( d \): gap width
- \( M \): gain fluctuation factor
- \( k = (\xi_n d/s) / (\xi_n d/s + 2) \)
- \( \lambda \): average cluster density
Comparison of Model with Data

## RPCs as Muon Trigger Detectors

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Operating mode</th>
<th># gaps</th>
<th>Gap width (mm)</th>
<th>Electrodes material, $\rho(\Omega\text{cm})$</th>
<th>Gas mixture (%)</th>
<th>Readout</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaBar</td>
<td>Streamer</td>
<td>1</td>
<td>2</td>
<td>Oiled bak, $10^{11} \sim 10^{12}$</td>
<td>60Ar/35C_{2}H_{2}F_{4}/5C_{4}H_{10}</td>
<td>strips xy</td>
</tr>
<tr>
<td>Belle</td>
<td>Streamer</td>
<td>2</td>
<td>2</td>
<td>glass, $10^{12} \sim 10^{13}$</td>
<td>30Ar/62C_{2}H_{2}F_{4}/8C_{4}H_{10}</td>
<td>strips xy</td>
</tr>
<tr>
<td>ALICE TRI</td>
<td>Streamer</td>
<td>1</td>
<td>2</td>
<td>oiled bak., $\approx 3 \times 10^{9}$</td>
<td>51Ar/41C_{2}H_{2}F_{4}/7C_{4}H_{10}/1SF_{6}</td>
<td>strips xy</td>
</tr>
<tr>
<td>ATLAS</td>
<td>Prop.</td>
<td>1</td>
<td>2</td>
<td>oiled bak., $\approx 10^{10}$</td>
<td>96.7C_{2}H_{2}F_{4}/3C_{4}H_{10}/0.3SF_{6}</td>
<td>strips xy</td>
</tr>
<tr>
<td>CMS</td>
<td>Prop.</td>
<td>2</td>
<td>2</td>
<td>oiled bak., $\approx 10^{10}$</td>
<td>96C_{2}H_{2}F_{4}/3.5C_{4}H_{10}/0.5SF_{6}</td>
<td>strips x</td>
</tr>
<tr>
<td>STAR</td>
<td>Prop.</td>
<td>5</td>
<td>0.22</td>
<td>glass, $\approx 10^{13}$</td>
<td>95C_{2}H_{2}F_{4}/5C_{4}H_{10}</td>
<td>pads</td>
</tr>
<tr>
<td>ALICE TOF</td>
<td>Prop.</td>
<td>10</td>
<td>0.25</td>
<td>glass, $10^{12} \sim 10^{13}$</td>
<td>90C_{2}H_{2}F_{4}/5C_{4}H_{10}/5SF_{6}</td>
<td>pads</td>
</tr>
<tr>
<td>Categories</td>
<td>Requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Resolution</td>
<td>~1ns</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>&gt;95%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate Capability</td>
<td>~2kHz/cm2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise Rate</td>
<td>0.5 ~ 5 Hz/cm2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Strip Multiplicity</td>
<td>1.5 ~ 3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Avalanche Charge</td>
<td>2.5 ~ 5 pC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Charge Threshold</td>
<td>200fC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistivity</td>
<td>1~6 x10^10 ohm cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NIMA 508, 147 (2003)
CMS FRPC Prototype in 1998
CMS FRPC Prototype

MF2-1 Beam Test (1998)
CERN Beam Test at GIF in 1998
More Prototypes for CMS FRPC in 1999
Gamma ray transmission imaging detectors using a double gap resistive plate chamber.


Fig. 2. 2 mm double gap RPC manufactured for the gamma ray transmission images.

Fig. 3. Cross-sectional view of the double gap RPC with two-dimensional read-out strips.

Fig. 6. Gamma ray transmission images for objects in a 0.5 mm thick stainless steel cabinet.

Fig. 7. Gamma ray transmission image for the computer monitor.
Collaboration works for the Forward RPCs
Korea, Belgium, CERN, China, India, Italy, Pakistan, Poland, Russia ...
3. Collaboration for the Forward RPC upgrades

Korean Group:

1. Production and the tests for RPCs gaps (Phase I)
2. Participation of the detector assem. for high $\eta$ RPCs

Will use the current detector production site and the facilities in Korea University (used for the previous production for the RE).
At CERN

Cosmic tests for the new RPCs at the site in the ISR
(used for the previous detector assembly and tests)
RE1 in $\eta < 1.6$
RE1/2 & RE1/3 : 144 RPCs

RE2 in $\eta < 1.6$
RE2/2, RE2/3, RE3/2, RE3/3 288 RPCs

RE2/2 & RE2/3
on the back of YE1

RE3/2 & RE3/3
on the back of YE3
Current CMS RPC System

- RPCs System for the Compact Muon Solenoid (CMS/TDR LHCC/CERN 97-32)
  - RPCs in Barrel + Forwards cover $\eta < 2.1$
  - The angular coverage $\approx 3\pi$

- Barrel RPCs
  - 6 stations (layers)
  - Fully covering up to $\eta = 0.8$
  - Partially covering up to $\eta = \approx 1.2$

- Forward RPCs
  - 2 wings (RE+, RE-)
  - 4 stations (RE1, RE2, RE3, RE4) in each wing
  - Covering $0.92 < \eta < 2.1$

- 3 stations of Forward RPCs in $\eta < 1.6$
  - Prepared for the first CMS/LHC run

Full construction of RPCs
  - as described in CMS TDR
CMS Experiment at LHC, CERN
Run 136087 Event 39967482
Lumi section: 314
Mon May 24 2010, 15:31:58 CEST

Muon $p_T =$ 27.3, 20.5 GeV/c
Inv. mass = 85.5 GeV/c$^2$
Upgrade Trigger improvements

RPC L1 Trigger Efficiency
- 3 layers
- 4 layers

09/02/2012

Dott. Pigi Paolucci - I.N.F.N. of Napoli (ITALY) - RPC 2012
Conference (INF)
Forward RPC Upgrade Project

- RE4/3 assembly & QC2-3
- RPC trigger
- FEB & DB
- Gas gaps assembly & QC2
- Bakelite Sheets
- RE4 Install. & Comm., QC5
- RE4 QC4
- RE4/2 assembly & QC2-3
- Honeycomb boxes, strips
GAP Production for Upgrade at KODEL

HPL arrived at KODEL

Saturday, March 17, 2012
HPL for RE4/2 CMS FRPC
RE4/2 and RE4/3 CMS FRPC Dimensions
Electrodes from Silkscreen Coating

Applying the same procedures and tools used for the CMS Forward RPCs

1. Graphite coating for RPC electrodes
   - Silkscreen method
   - Surface resistivity of electrode ranges from 50 to 200 kΩ/square
Uniformity of the Surface Resistivity

Silkscreen printing on the whole surface area of a HPL sheet
Array of fifty 10x10cm² surface electrodes

Regions masked by tape

Copper tapes

Ave. = 97.42 kOhm
Sigma = 21.84 kOhm
Electrodes Coated with Graphite
PET film coating for protection of graphite electrodes
- 1 layer of 200 micron PET film, Ethylene Vinyl Acetate base glue
3. Gap assembly

- multi-layered metric tables and shelves for the assembly and glue curing
- Glue curing time: 24 hours
- Glue: DP460, 3M production
- Selection of spacers: 2 mm +/- 20 µm
- Use spacer jigs for the location of spacers
  Accuracy of positions < 1 mm
Leakage and Pressure Test
KODEL Robot Checking Leakage and Spacers
Pressure Test Results from KODEL Robot
### QC steps

1. **Leak test (maxi. \( p \) drops allowed):**
   - 0.2 \( \sim \) 0.4 hPa with +20 hPa
2. **Pop spacer test (no pop spacer allowed)**

#### Table 1: Visual Inspections

<table>
<thead>
<tr>
<th>Bar code label</th>
<th>Good</th>
<th>Not good</th>
<th>Description of the problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas tight and sealed pipes</td>
<td>( \bigcirc )</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Edges and gas corner flow</td>
<td>( \bigcirc )</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Inlet (FMD)</td>
<td>( \bigcirc )</td>
<td>Minor scratches</td>
<td></td>
</tr>
<tr>
<td>HV cable</td>
<td>( \bigcirc )</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>GND cable</td>
<td>( \bigcirc )</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

#### Table 2: Leak Test

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Pressure drop (kPa)</th>
<th>Certified</th>
<th>Leak Limits</th>
<th>Allowed</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.11</td>
<td>Yes</td>
<td>9.4/3 BT</td>
<td>9.4/3 BT</td>
</tr>
</tbody>
</table>

#### Table 3: Pop spacers

<table>
<thead>
<tr>
<th>Number of spacers</th>
<th>Number of popped spacers</th>
<th>Largest shift (kPa)</th>
<th># of pop-spacers allowed</th>
<th>Certified</th>
<th>Not certified</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.60</td>
<td>0</td>
<td>1.1</td>
<td>3 MPa</td>
<td>Yes</td>
<td>Not certified</td>
</tr>
</tbody>
</table>
Oiling for curing noises

- Linseed oil + heptane
  (Ratio : 40 % + 60 %)
- Polymerization with air
  Rate : 60 – 100 liter/h/gap
  Period : 72 – 96 hours
  Humidity : 40%
**120-hour HV test**
*(gas circulation is not included)*

QC steps: HV test

- Selection criteria for qualified gaps at three levels
  1. At 6.0 \(i < 1.5 \mu A\) for all type gaps
  2. At 10.0 kV
     \(i < 5.0 \mu A\) for cut gaps
     \(i < 10.0 \mu A\) for full gaps
  3. At 9.6 kV after 120 h
Packing and Shipping from KODEL
Three Assembly Sites
# Limits of Current Double-Gap RPCs

For 2-gap RPCs, aging study with an intensive gamma rate > 3 kHz cm\(^{-2}\)  
→ The high gamma rate caused Fast Degradation of gaps  
(H. C. Kim et al., NIM A602 (2009) 771)

### Table 1: Rates at CMS and ATLAS muon trigger

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LHC</th>
<th>HL-LHC</th>
<th>Forward Region</th>
<th>Rates Hz/cm(^2)</th>
<th>High Luminosity</th>
<th>(10(^{35}) cm(^2)/s) Phase II</th>
</tr>
</thead>
<tbody>
<tr>
<td>s 14 TeV</td>
<td>14 TeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L (10^{34})/cm(^2) s</td>
<td>(10^{35})/cm(^2) s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bunch spacing 25 ns</td>
<td>12.5 ns</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>interactions/crossing (\approx 12)</td>
<td>(\approx 62)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dN/d(\eta) crossing 75</td>
<td>375</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMS particle flux 1(^{st}) muon layer (\eta \approx 2.4)</td>
<td>(\approx 1) kHz/cm(^2)</td>
<td>(\approx 10) kHz/cm(^2)</td>
<td>RB</td>
<td>30</td>
<td>Few 100</td>
<td>kHz (tbc)</td>
</tr>
<tr>
<td>CMS particle flux 1(^{st}) muon layer (\eta \approx 2.4)</td>
<td>(\approx 1) kHz/cm(^2)</td>
<td>(\approx 10) kHz/cm(^2)</td>
<td>RE 1, 2, 3, 4 (\eta &lt; 1.6)</td>
<td>30</td>
<td>Few 100</td>
<td>kHz (tbc)</td>
</tr>
<tr>
<td>ATLAS particle flux 1(^{st}) muon layer (\eta \approx 2.4)</td>
<td>(\approx 1 - 10) kHz/cm(^2)</td>
<td>(\approx 1 - 15) kHz/cm(^2)</td>
<td>Expected Charge in 10 years</td>
<td>0.05 C/cm(^2)</td>
<td>0.15 C/cm(^2)</td>
<td>(\sim) C/cm(^2)</td>
</tr>
<tr>
<td>ATLAS particle flux 1(^{st}) muon layer (\eta \approx 2.4)</td>
<td>(\approx 1 - 10) kHz/cm(^2)</td>
<td>(\approx 1 - 15) kHz/cm(^2)</td>
<td>RE 1, 2, 3, 4 (\eta &gt; 1.6)</td>
<td>500 Hz ∼ kHz</td>
<td>Few kHz</td>
<td>Few 10s kHz</td>
</tr>
<tr>
<td>Total Expected Charge in 10 years</td>
<td>((0.05 - 1)) C/cm(^2)</td>
<td>few C/cm(^2)</td>
<td></td>
<td></td>
<td></td>
<td>Several C/cm(^2)</td>
</tr>
</tbody>
</table>

From Archana’s talk
R&D for High Rates

RE1/1 RPCs for high-\( \eta \) triggers

- 72 RE1/1 RPCs at YE1:
- High priority among RPCs in \( 1.6 < \eta < 2.1 \)
- Advantage of RE1/1: RPCs closest to \( pp \) collision vertex with presence of strong magnetic fields.
- Expect an effective rejection of the beam-related backgrounds (Gammas, neutrons, charged pions...) for the muon triggers.

Have to insert trigger detectors in the CMS end-cap noses

Insert via rails

Rotate in place
1) Standard 2-gap **phenolic** RPC: first six RE1/1 RPCs in CMS

*Phenolic* plate (~10^{10}Ωcm) instead of glass (~10^{13}Ωcm)

Expected maximum rate: 300 ~ 400 Hz/cm² @ $L = 10^{34}$ cm² s^{-1}

1. Standard procedure for the detector manufacture
2. Cosmic ray test for the detector quality assurance
First 2-gap RE1/1 Detector at ISR

Configuration of 6 RE1/1 RPCs in a 60 degree sector

Covered by shielding box  FEB flat cable layout  Signal cable layout

Currents of upper gaps (low-eta section)
Currents of upper gaps (high-eta section)
Currents of lower gaps

Efficiency

[Graphs and diagrams showing current and efficiency data]
4 RE1/1 RPC module installed in the CMS nose-cone (2009)

- Final result: Chamber 1, 2, 5, 6 is OK
- Chamber 3, 4 were rejected because of high and unstable current of bottom gap
Multi-Gap RPC R&D

R & D of HPL multi-gap RPCs

Direction → Smaller detector charges

1. To reduce aging at high rate background
2. To enhance high rate capability

Higher rate capability ← lower avalanche charge
- Rate capability ~ $1/\rho$
- Smaller $q_e$ → higher rate capability
  (actually related to $Q_e$)

Typical glass multi-gap RPCs
- $q_e < 1 \text{ pC} \ (\sim 0.5 \text{ pC})$
- $\rho = 10^{12} \sim 10^{13} \ \Omega \text{ cm for normal glass}$
  $\quad = 10^9 \sim 10^{10} \ \Omega \text{ cm (ceramic & low res. glass)}$

Then, what if multi-gap RPCs with
  high-pressure laminated (HPL) plates?
- $q_e \sim 1 \text{ pC}$
- Phenolic HPL → $\rho = 10^{10} \sim 10^{11} \ \Omega \text{ cm}$
- Oiling required to reduce noises
2. Constructions of prototype detectors

**Detector structures**

Oiled Phenolic Multigap Panel-type RPCs for CMS high-\(\eta\) triggers

Panel-shape multigap RPCs
- Two separated gas envelopes + a strip panel
  - Each gas envelope ~ 2 gaps in 4-gap RPCs
  - 3 gaps in 6-gap RPCs

Prototype detectors

4-gap RPC: \(45 \times 45 \text{ cm}^2\) (active area)
- HPL: 2 mm
- Coin spacers: \(1000 \pm 10 \mu\text{m}\) (Polycarbonate)
- Strip pitch = 27 mm

6-gap RPC: \(15 \times 29 \text{ cm}^2\) (active area)
- HPL: 1 mm
- Coin spacers: \(660 \pm 10 \mu\text{m}\) (Polycarbonate)
- Strip pitch = 20 mm
Gas mixture

95.7% C₂H₂F₄ + 3.5% iC₄H₁₀ + 0.5% SF₆
+ 0.3% water vapor in mass ratio
Flow rates ~ 1.8 l/h

Gamma rays source

200-mCi $^{137}$Cs (born in Nov. 2001)
- 5.5 GBq for the 4-gap RPC test (2011)
- 5.8 GBq for the 6-gap RPC test (2009)

Mean distance ~ 45 cm
- Max. gamma-rates in the test
  1.50 kHz cm⁻² for 4-gap RPC
  \( N_\gamma = 145 \text{ kHz cm}^{-2} \)
  \( \varepsilon_\gamma = 0.0103 \)
  2.02 kHz cm⁻² for 6-gap RPC
  \( N_\gamma = 152 \text{ kHz cm}^{-2} \)
  \( \varepsilon_\gamma = 0.0133 \)
Avalanche pulse limit

- For 2-gap RPCs: \( g < 10 \text{ nC} \) for CMS Barrel RPCs
  \( g < 20 \text{ nC} \) for CMS Forward RPCs
  (no termination)
- For 4-gap RPCs: \( g < 10 \text{ nC} \) (no termination)
- For 6-gap RPCs: \( g < 5 \text{ nC} \) (no termination)

<table>
<thead>
<tr>
<th></th>
<th>2-gap RPCs</th>
<th>4-gap RPCs</th>
<th>6-gap RPCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Each gap thickness</td>
<td>2.0 mm</td>
<td>1.0 mm</td>
<td>0.66 mm</td>
</tr>
<tr>
<td>Total gap thickness</td>
<td>4.0 mm</td>
<td>4.0 mm</td>
<td>4.0 mm</td>
</tr>
<tr>
<td>( \langle g \rangle ) at ( \text{mid of plateau} )</td>
<td>4.0 nC (Thr~200 fC)</td>
<td>1.5 nC (Thr~150 fC)</td>
<td>0.9 nC (Thr~100 fC)</td>
</tr>
<tr>
<td>Type of resistive plates</td>
<td>HPL</td>
<td>HPL</td>
<td>HPL</td>
</tr>
<tr>
<td>Thickness of HPL</td>
<td>2.0 mm</td>
<td>2.0 mm</td>
<td>1.0 mm</td>
</tr>
<tr>
<td>Resistivity of HPL</td>
<td>( 1 \times 10^{10} \Omega \text{cm} ) (for CMS)</td>
<td>( \sim 10^{10} \Omega \text{cm} ) (Italian HPL)</td>
<td>( \sim 10^{11} \Omega \text{cm} ) (Korean HPL)</td>
</tr>
</tbody>
</table>
# MPGD in Running Experiments

<table>
<thead>
<tr>
<th>Exp.</th>
<th>#</th>
<th>Type</th>
<th>Readout</th>
<th># of ch.</th>
<th>Size (cm²)</th>
<th>Gas</th>
<th>$\sigma_{\text{space}}$ (µm)</th>
<th>$\sigma_{\text{time}}$ (ns)</th>
<th>$\varepsilon$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPASS</td>
<td>22</td>
<td>GEM</td>
<td>2-D strips</td>
<td>1536</td>
<td>31×31</td>
<td>Ar/CO₂ (70/30)</td>
<td>70</td>
<td>12</td>
<td>&gt;97</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>MM</td>
<td>1-D strips</td>
<td>1024</td>
<td>40×40</td>
<td>Ne/C₂H₆/CF₄ (80/10/10)</td>
<td>90</td>
<td>9</td>
<td>&gt;97</td>
</tr>
<tr>
<td>LHCb</td>
<td>24</td>
<td>GEM</td>
<td>pads</td>
<td>192</td>
<td>10×24</td>
<td>Ar/CO₂/CF₄ (45/15/40)</td>
<td>4.5</td>
<td></td>
<td>&gt;97</td>
</tr>
<tr>
<td>TOTEM</td>
<td>40</td>
<td>GEM</td>
<td>pads + strips</td>
<td>1536 + 256</td>
<td>30 × 20</td>
<td>Ar/CO₂ (70/30)</td>
<td>~70 (θ)</td>
<td></td>
<td>&gt;92</td>
</tr>
</tbody>
</table>

also CAST, NA48, PHENIX …
Micromegas and GEM

Basic structure
2 ~ 3 GEM plates: for the amplification of X-ray signals
Two dim. microstrips (~ 100 μm spacing: to pickup the avalanche images)

Gain

Drift cathode
GEM 1
TRANSFER 1
3 mm
~20
GEM 2
TRANSFER 2
3 mm
~20
GEM 3
COLLECTION
3 mm
~8000
Readout PCB
Amplifier

Electrons:
Drift Field
Diffusion Losses
~40%
~60%
Induction Field
Anode

Cathode
Ions
Ion trap

53
GEM timing performance

$E_i = 3 \text{KV/cm}$
$E_{i1} = E_{i2} = 3.0 \text{ KV/cm}$

GEM efficiency performance

Efficiency Plateau

- **Standard GEM**: $\text{Ar(70):CO}_2(30) \text{ [gaps 3/2/2/2]}$
- **Standard GEM**: $\text{Ar(45):CO}_2(15) : \text{CF}_4(40) \text{ [gaps 3/2/2/2]}$
- **Standard GEM**: $\text{Ar(45):CO}_2(15) : \text{CF}_4(40) \text{ [gaps 3/1/2/1]}$
- **Single Mask GEM**: $\text{Ar(45):CO}_2(15) : \text{CF}_4(40) \text{ [gaps 3/2/2/2]}$
NewFlex Visit
GEM Production

**Test Condition**

1) Base Material
   - Nippon Mining & Metals, Kaneka PI, NPI 2MIL 5um Cu

2) Cr Layer Remove
   - Potassium Permanganate, 65°C, 1min (65g/L)

3) PI Etchant
   - Ethylene Diamine55%, Water 45%, 70g/L KOH
   - Temperature : 64~66°C
   - Treatment time : 140sec

**Specification**

1) Cu Diameter : 70±5um
2) Uniformity : ±2um (Panel)
3) PI Diameter : 55±5um
1) Best Results
   : 70°C 1min

2) Images

3) Sectional Images

Saturday, March 17, 2012
GEM Production
KOREAN GEMs: CONNECTIONS OVERVIEW And GENERAL ORGANISATION
Gain VS Voltage

Output Current (nA)

Single GEM detector-Korean GEM-config 3/2-3/2-CO2 (70/30)

Temperature: 22.7 °C
Humidity: 40 %RH
Pressure: 965.9 hPa

Rate: 80 kHz
Collimator: 1 cm

E1: 30 kV/cm
d: 3 kV/cm
Spark Voltage: 540 V
Max Gain: 3700

Variation: 4.9%

Discharge

Time (min)

Iron 55: Spectrum and Count Rate

Xray Gen (Cu) / Iron 55
GEM Application Potential

Using the lower GEM signal, the readout can be self-triggered with energy discrimination:

A. Bressan et al,
F. Sauli, Nucl. Instr. and Meth.A 461(2001)47

FAST X-RAY IMAGING

9 keV absorption radiography of a small mammal (image size ~ 60 x 30 mm²)
GEM Image Amplifier (GIA) Design

Subject

X-ray

CsI x-tal

Lens

γ-cathode

Optical-back-converter

GEM detector

CCD camera

Scintillator: CsI

Σ-20 photo-converter

Optical-back-converter:
Conclusions

1. Lessons from the past invaluable
2. Value the students participation
3. We were hungry and foolish.
4. We are ready to move to upslope.
5. We will be in the high eta area.