Summary

Roberto Cardiarelli and Ingo Deppner
A little bit of statistics

56 Talks (4 days)
26 Poster (3 h)

our time budget for this summary is 20 min => 14 s/contribution

from 20 different countries

Indeed a international conference
Outline

• Discussed topics

• 2 selected challenge which affects the RPC as well as the MRPC community in near future
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What were the most shown formulas on this conference?
Outline

- Discussed topics

- 2 selected challenge which affects the RPC as well as the MRPC community in near future

What were the most shown formulas on this conference?

$$\phi_{\text{max}} \leq \frac{\Delta V}{\rho d \bar{q}}$$

GWP (C$_2$H$_2$F$_4$) ~ 1430  
GWP (SF$_6$) ~ 22800
Discussed topics

- New experiment
  - Roberto Cardiarelli/Ingo Deppner

- New detector ideas
  - Roberto Cardiarelli

- New detector application
  - Ingo Deppner

- Eco-friendly gas mixtures for RPC detectors
  - Ingo Deppner

- Detector R&D
  - Ingo Deppner

- RPC@LHC
  - Ingo Deppner

- Detector electronics and simulation
  - Roberto Cardiarelli
RPC@LHC

- ALICE muon system + upgrades, 1 presentation
- ATLAS muon system + upgrades, 3 presentations
- CMS muon system + upgrades, 2 presentations

**Observed issues during Run2:**
- All 3 experiments experienced gas leaks and mitigation was only partially possible - some chambers could be repaired others were switched off
- HV, LV problems reported, PS connectors and cables replaced

**Upgrades:**
- All 3 experiments have upgrade programs for Run4 und beyond to cope with the HL-LHC conditions
- Prototypes with increased rate capability installed during LS2 and being tested during Run 3
- A higher luminosity leads to higher detector aging -> long term stability tests at anticipated detector load required
New Experiments

- **CEE (CSR-external Target Experiment), Lanzhou/China**
  Gap size 160 μm, 24 gaps, time resolution 30 ps, discussed issues: reflections

- **R3B (Reaction with Relativistic Radioactive Beams), GSI/Darmstadt/Germany**
  Gap size 300 μm, 12 gaps, time resolution 100 ps, discussed issues: calibration

- **HADES TOF Forward Detector, GSI/Darmstadt/Germany**
  Gap size 260 μm, 4 gaps, glass 2 mm -> 1 mm, time resolution 90 ps – 160 ps depending on rate, discussed issues: rate capability (material thickness, temperature), conclusion: 0.6 kHz/cm² @ 31℃

- **π20 spectrometer (Japan Proton Accelerator Research Complex J-PARC) Tokai/Japan**
  TOF-RPC: Gap size 260 μm, 10 gaps, time resolution 60 ps - 70 ps, discussed issues: HV electrode
  TOF-tracker: Gap size 260 μm, 5 gaps, strip pitch 5 mm, spatial resolution 3.8 mm

- **CBM-TOF (Compressed Baryonic Matter) FAIR/Darmstadt/Germany**
  Gap size 200 – 250 μm, 10 -12 gaps, time resolution 40 - 60 ps, discussed issues: high rate capability and gas aging

- **CALICE SDHCAL Calorimeter**, discussed issues: including timing information => RPC -> MRPC

- **CBM-MuCH (Compressed Baryonic Matter) FAIR/Darmstadt/Germany**
  Gap size 2 mm, 1 gap, requirement ~30 kHz/cm², discussed issues: Test results obtained at GIF++ -> 90% efficiency at ~ 2.72MHz/cm²

- **ANUBIS, CODEX-β /CERN** Physics beyond SM
  discussed issues: construction and usage of BIS7 chambers, first counter test results are promising

- Cosmic ray experiments – Rinaldo

- **MATUSLA**

  see summary by Roberto Cardiarelli
New detector application

**Tomography**

Gammas (\(^{137}\)Cs source) 5\% efficiency@HV=12.1kV in a 7-cm deep vertical mode Detector

Position resolutions in the vertical \(~2\) mm and in the Scanning direction \(~2\) mm or better

**PET**

2 presentations
- Radial resolution better than 1 mm
- Sensitivity of 0.09 %
- Thickness of MRPC limited

**Muography**

Transmission tomography
1 presentation

Scattering tomography
2 presentations
High granularity needed
Innovative method to reduce elec. Channels while keeping the granularity presented
Detector R&D

Sealed (M)RPCs (3 presentations)

• Reduced gas flow for sealed counter (helps only for low flux)
• Mitigation of chamber aging and gas pollution
• X-Ray test indicate that sealing the counter, introducing squared spacers and increasing the gas flow is minimize the gas pollution and mitigates chamber aging

Extensive R&D on BIS78 RPCs designed for the ATLAS upgrade:
- Gas gap 1mm, FE threshold 1-4 fC, 3 independent singlets providing 3D+t particle localization
- stable running at low threshold, reached time resolution $\frac{280 \text{ ps}}{\sqrt{3}} = 160 \text{ ps}$
- test with eco friendly gases

Longevity studies, Long term stability test at GIF++
- No Evidence of any aging effect has been observed

Study of ionic signal properties with different read-out methods

RPC Background Studies at CMS Experiment
Eco-friendly mixtures for RPC detectors

7 presentations on eco friendly gases for wide gaps RPCs
1 contribution eco friendly gases for thin gap MRPC

The Problem:
• (M)RPC uses very eco-unfriendly gas - contribution to global warming -> governmental restriction
• EU HFC phase down => availability ↓ => price ↑

<table>
<thead>
<tr>
<th>Gas</th>
<th>Trigger RPCs</th>
<th>Timing MRPCs</th>
<th>GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>R134a</td>
<td>94.7%</td>
<td>85% - 98%</td>
<td>1430</td>
</tr>
<tr>
<td>Iso-Butane</td>
<td>5%</td>
<td>0% - 5%</td>
<td>20</td>
</tr>
<tr>
<td>SF6</td>
<td>0.3%</td>
<td>2% - 10%</td>
<td>22800</td>
</tr>
</tbody>
</table>

How to reduce greenhouse gas usage

- Optimization of current technologies
  - Gas recirculation
  - Particular attention to operation
  - Improved controls and monitoring

- Gas Recuperation
  - Membrane separation
  - Pressure swing
  - Cryogenic/cold separation

- Alternative Gases
  - New eco-friendly gases, HFOs, ...

- Gas disposal
  - GHGs destruction

Figure E5.1 Progress of the EU HFC phase-down
Eco-friendly mixtures for RPC detectors

Replace R134a and SF6 with eco-friendly gases
R134a (C2H2F4) -> C3H2F4ze + CO₂ or He
SF6 -> Novec 5110 or (Cl-HFO) or Novec 4710 or or C3H2ClF3

Many parameters as function of an enormous amount of different mixtures investigated.

- Change in working point
- Increase of streamer probability
- Increase in dark current
- Sensitive to UV light

Long term stability test at high irradiation essential in order to guaranty the longevity of the counter
How to increase the rate capability of (M)RPCs

\[ \phi_{max} \leq \frac{\Delta V}{\rho \cdot d \cdot \bar{q}} \]

\( \Phi_{max} \) = maximum particulate flux
\( \Delta V \) = allowable voltage drop at the resistive electrode, which do not compromise performance.
\( \rho \) = electrode resistivity
\( d \) = electrode thickness
\( q \) = average charge per avalanche

a) Minimization of the average charge per avalanche \( \bar{q} \)
   - decreasing the gap size
   - decreasing the working high voltage
   - increasing the quencher concentration in the gas

b) Decreasing the bulk resistivity \( \rho \)
   - select resistive material with lower bulk resistivity
     1) float glass: \( \rho = 3 \times 10^{12} \ \Omega \text{cm} \)
     2) low resistivity glass/Bakelite/Si-GaAs: \( \rho \approx 10^{10} \ \Omega \text{cm} \)
     3) ceramics: \( \rho \approx 10^{9} \ \Omega \text{cm} \)
   - increase temperature (25 K -> one order if magnitude)

c) Decreasing the glass thickness \( d \)

d) Go for sRPC (not a RPC any more)
• We thank all speakers for excellent presentations
• We thanks all poster presenter for explaining very well their work
• We thanks the auditorium for the questions, lively discussion and valuable input
• Especially we thanks the organizers for the perfect organization of this RPC2022 workshop