Performances of RPCs in the BaBar experiment

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for the BaBar collaboration
The IFR collaboration of the BaBar experiment

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**CONSULTING EXPERTS**
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- M. Lazzari - **Turin**

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The Instrumented Flux Return (IFR)

- **IFR:**
  - 342 barrel RPCs
  - 432 endcap RPCs
  - 32 cylindrical RPCs

- **Total surface covered:**
  - about 2000 m²

- **Gas mixture:**
  - Argon 60.5 %
  - Freon 35 %
  - Isobutane 4.5 %

- **Electronics:**
  - about 50000 channels
  - threshold about 40 mV
RPC used in the IFR

- RPC operating in streamer mode
- Bakelite resistivity: $10^{11} - 10^{12} \, \Omega/cm$
- Graphite resistivity: about 100 KΩ/
- RPCs filled 3 times with a mixture of 70% linseed oil and 30% n-pentane. Air flushed for 60 hours after each filling
- Differences respect to L3 experiment:
  - New shape of spacers
  - Single gap vs bigap
  - Double readout
- Gas flow 2 volumes per day

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Brief IFR history

- RPCs produced at General Tecnica Factory (7/96 - 11/97)
- All the chambers have been tested in Frascati:
  - dark current
  - single rate
  - efficiency
- sent to SLAC, assembled more chambers in single layers and tested again (12/96-12/97)
- chamber insertion 6/97-12/97
- first cosmic tests on the detector 12/98
RPC performances at Frascati
Test station

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RPC #

HV (Volts)

Dark current

HV (kV)

I (µA)

ε (%)
Summary of the first results

- Single rate < 1 KHz/m²
- Currents 3-20 μA
- Excellent detection efficiency (> 96 %)
- No correlation found between performances and bachelite resistivity
- Similar results found in tests done at SLAC
Temperature effects

- At beginning of summer 1999 was clear that the environment temperature was greater than expected (about 28-31 °C degrees in the experimental hall, 29-33 °C inside the iron slots of the IFR)
- RPC dark currents start to increase
- Chambers with dark current greater than 200 µA were disconnected
- Cooling system installed in October 1999 and completed in the endcap by January 2000
- Temperature stabilised at 19-21 degrees inside the detector
- Disconnected chambers were reconnected
Efficiency history

1999

Barrel

Forward E.C.

Backward E.C.

June 99

Jan. 00

July 00

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Efficiency vs HV

Barrel Sextant 0

Layer 5

Layer 6

Layer 7

Layer 8
Efficiency map

Good RPC

Spacers!

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Tests done

Physical removal of RPC is very hard. Several tests have been carried on the detector:

- Increased gas flow
- Lowered discriminator threshold
- Put weights over inefficient regions

No effect!

Gas composition was regularly tested: stable

Classification of RPCs as function of the measured performances shows several different behaviours
RPC classification

Quality distribution vs production batch

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Test station and R&D

- In order to try to reproduce the effects seen in Babar, several test station have been set-up: SLAC, Frascati, Napoli, Oregon.

- **Main goals:**
  - study current vs temperature correlation
  - reproduce efficiency reduction after temperature cycling

- **Interesting results from SLAC test station:**
  - 9 RPCs post babar production were tested inside an oven
  - RPCs were subjected to heating cycles at 36° C.
  - permanent effects both on dark current and efficiency seen after few days
SLAC test stand results

Individual Chamber Efficiencies

<table>
<thead>
<tr>
<th>Efficiency - Chamber 5n</th>
<th>0.7</th>
<th>0.75</th>
<th>0.8</th>
<th>0.85</th>
<th>0.9</th>
<th>0.95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (minutes)</td>
<td>0 5000 10000 15000 20000 25000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Individual Chamber Currents

<table>
<thead>
<tr>
<th>Chamber</th>
<th>Currents</th>
</tr>
</thead>
<tbody>
<tr>
<td>cham 1</td>
<td>25 µA, 50 µA, 75 µA, 100 µA, 125 µA, 150 µA, 175 µA, 200 µA, 225 µA</td>
</tr>
<tr>
<td>cham 2</td>
<td>25 µA, 50 µA, 75 µA, 100 µA, 125 µA, 150 µA, 175 µA, 200 µA, 225 µA</td>
</tr>
<tr>
<td>cham 5</td>
<td>25 µA, 50 µA, 75 µA, 100 µA, 125 µA, 150 µA, 175 µA, 200 µA, 225 µA</td>
</tr>
<tr>
<td>cham 6</td>
<td>25 µA, 50 µA, 75 µA, 100 µA, 125 µA, 150 µA, 175 µA, 200 µA, 225 µA</td>
</tr>
<tr>
<td>cham 7</td>
<td>25 µA, 50 µA, 75 µA, 100 µA, 125 µA, 150 µA, 175 µA, 200 µA, 225 µA</td>
</tr>
<tr>
<td>cham 8</td>
<td>25 µA, 50 µA, 75 µA, 100 µA, 125 µA, 150 µA, 175 µA, 200 µA, 225 µA</td>
</tr>
</tbody>
</table>

Time (min)

Room temperature

I (µA)
Autopsy of the RPC tested at SLAC

- Several drops of oil found all around the bakelite surface
- Most of these drops span between the 2 mm gap
Autopsy of RPCs on the babar experiment

- At the end of 2000, 12 chambers of the forward endcap have been replaced with RPCs of new production:
  - New RPCs developed for Atlas, CMS, Argo … have less oil inside.
  - 12 babar chambers replaced available for tests and autopsy

- Several old RPCs have been opened in order to study the oil surface
  - same drops of oil as in chamber tested in lab
  - the oil seems not polymerised, it is sticky

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Autopsy of RPCs on the babar experiment

- Oil drops spanning gap
- Linseed oil around button
- Linseed oil along frame

RPC 70% efficiency

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RPC studies

- The RPC problems seem to be related to the missing polymerisation of the linseed oil and the formation of oil droplets under the action of high temperature and high current.

- Several studies have been carried out to understand the problems.
Analysis of RPC components

- Jerry Va’vra made several tests on single components of the RPC to study behaviour under temperature cycling
  - bakelite
  - fresh linseed oil
  - g-10 (RPC frame)
  - polycarbonate (RPC buttons)

- No long term effects have been found. All the processes are reversible.

- Analysis of a sample of linseed oil taken from a babar RPC shows lower resistivity:
  - \((2.1 \cdot 10^8 \ \Omega \cdot \text{cm} \text{ vs } 76.7 \cdot 10^8 \ \Omega \cdot \text{cm of fresh linseed oil})\)
  - heating at 60° C in air increase the resistivity

- Jerry Va’vra suggest that the linseed oil could be decomposed under the action of high currents.

  Molecules inside linseed oil R-COOH could dissociate under HV in \(H^+ R-COO^-\) this could increase conductivity

- water coming from tubing of BaBar gas system could enhance the process.
Chemical analysis of linseed oil

M. Lazzari

- **Linseed oil basics:**
  - Mixture of triglycerides, formed by one molecule of glycerol and three molecules of linear fatty acids
- The oil layer is cured forming a hard stable film because of oxidation followed by polymerisation
- Photons can break some bonds creating free fatty acids with lower molecular weight

- **Chemical Analysis Fourier Transform Infrared Analysis (FTIR):**
  - Extraneous compounds found in some chamber
    - Free fatty acids
    - Phthalates
- Free fatty acids and phthalates inhibit the polymerisation of the oil
- More studies should be carried out in order to correlate linseed oil properties and RPC performances

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Attempts to recover damaged chambers

Changguo Lu made several tests on damaged BaBar RPCs to try to recover performances. The idea is:

- Current goes through linseed oil (droplets, frame, buttons) and short electrodes reducing locally the electric field.
- Not cured linseed oil has lower volume resistivity
- Oxygen treatment could increase oil resistivity → dark current reduction, efficiency improvement

The answer seems: NO long term improvement

Short term oxygen treatment doesn’t help. Repeated operations could work, but after enough time efficiency go back to initial value

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Attempts to recover chambers (..Continue)

Flowing O₂ inside the gas mixture: initial benefits are lost during time.
Performances of the new RPCs

- The New RPCs tested inside the IFR endcap have been produced with few small differences:
  - new bakelite treatment (smoother surface) developed for Argo and LHC
  - new oiling procedure:
    - 60 % eptane, 40 % linseed oil (vs 30 % n-pentane, 70 % linseed oil)
    - single filling (vs 3)
  - As a result the oil layer thickness was about 6 \( \mu \text{m} \), hard and dry

Very smooth surface

no linseed oil around buttons
New RPCs performances

- New RPCs are working since 9 months
- We should divide the sample of New RPCs in two subsamples:
  - innermost layers (no beam background)
  - outermost layers (photons and particle showers coming from beam)
- Innermost layers show very good performances: low dark current, high detection efficiency
- Outermost layers suffer from high background.

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New RPCs Outer layers performances

High background is present on outer layers

- Single rate still high without beam.
  
  Layer 18: 35 Khz/m²
- Efficiency is going down
- Investigation is in progress

![EFFICIENCY VS TIME (DAYS)](image)

Layer 17
Layer 18
RPC 1
RPC 2
RPC 1
RPC 2
NO
Beam
Conclusions

- RPCs in BaBar deteriorated their performances under the influence of high temperature and high current;
- Big effort has been dedicated to reproduce and understand the problems:
  - Linseed oil seems not cured,
  - under the action of HV, droplets can be created, shorting electrodes,
  - No success, up to now, in trying to cure linseed oil flowing O₂.
- RPCs of new production work well under controlled environmental conditions (low temperature);
- Some problem, still to be better investigated, are evident for RPCs under high background conditions;

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