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2. Principle

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8. Summary

With correct inclusion of bulk scattering in the aerogels
Principle

Assume 2 CKOV1 detector units along the beam, each with a different aerogel radiator.

### Response table

#### Muons

<table>
<thead>
<tr>
<th></th>
<th>Mom. region 1</th>
<th>Mom. region 2</th>
<th>Mom. region 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiator 1</td>
<td>Off</td>
<td>On</td>
<td>Rejected by tracker</td>
</tr>
<tr>
<td>Radiator 2</td>
<td>On</td>
<td>On</td>
<td>Rejected by tracker</td>
</tr>
</tbody>
</table>

#### Pions

<table>
<thead>
<tr>
<th></th>
<th>Mom. region 1</th>
<th>Mom. region 2</th>
<th>Mom. region 3</th>
</tr>
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<tbody>
<tr>
<td>Radiator 1</td>
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</tr>
<tr>
<td>Radiator 2</td>
<td>Off</td>
<td>On</td>
<td>Rejected by tracker</td>
</tr>
</tbody>
</table>
Detection unit

4 EMI-9356 KA PMTs

Radiator

4 identical internally reflecting funnels
Exploded view

Radiator box (black polyacetal)

20-mm thick aerogel (440 mm x 440 mm)

Vessel made from bolted Nickel plated steel box and flanges

3-mm thick glass window (500 mm x 500 mm)
Dimensions of CKOV1

Existing PMT assemblies (with built-in mumetal shield)
Assume a square radiator built with Matsushita tiles of 110 mm x 100 mm x 10 mm

Compute fraction of good muons kept (or good muon losses) as a function of the size of the radiator

Radial distribution of MC muons and pions

Loss = 0.3 % at $a = 330$ mm

Loss = 0 if $a = 440$ mm

What amount of losses is acceptable?
Good muon beam spots vs z

Distributions of transverse coordinates for good muons at three z-positions

Linear plots

Beam spots at

• Z = 0 mm (entrance of CKOV1)  Blue diamonds

• Z = 355 mm (entrance of second radiator)  Magenta squares

• Z = 710 mm (exit of CKOV1)  Yellow triangles
Good muon beam spots vs z

Distributions of transverse coordinates for good muons at three z-positions

Semi-log plots

Beam spots at

- Z = 0 mm (entrance of CKOV1)  Blue diamonds
- Z = 355 mm (entrance of second radiator)  Magenta squares
- Z = 710 mm (exit of CKOV1)  Yellow triangles
Aerogel properties

Measurements by L. Cremaldi

- Scattering
  \[ \lambda_{\text{scatt}} (n=1.07) = 10.76 \text{ mm} \]
  \[ \lambda_{\text{scatt}} (n=1.12) = 7.54 \text{ mm} \]
  with dipole angular distr.

- Absorption
  Negligible

- Transmission \( \sim 1 - \) Scattering
Bulk scattering

\[ n = 1.07 \]

\[ n = 1.12 \]

\[ \lambda_{\text{scatt}} = 10.76 \text{ mm} \]

\[ \lambda_{\text{scatt}} = 7.54 \text{ mm} \]

for the same typical ray.
Beam files from T. Roberts (Aug 05 beam line design, Stage VI, no absorbers, no RF)

Particles tracked from the production target and observed at the position of CKOV1

- **Good Muons at CKOV1** Obtained by tracking 10 M primary pions from the target (reaching TOF2) 16000 events

- **Pions at CKOV1** Not allowed to decay
  Obtained by tracking 400 M primary pions from the target (through going pions reaching TOF2) 390 events
Radial and momentum distributions

\[ \pi/\mu \text{ ratio is larger than 1\% because} \]

a) pions were not allowed to decay
b) sample for \( \pi \)'s is 40 times larger than for \( \mu \)'s
c) No hadron interactions (i.e. could be different at other beam tunes)
Global efficiency $\varepsilon$

Since the geometrical photon collection probability substantially varies for different tracks, we use

$$N_{p.e.} \approx \varepsilon \, L \, N_0 \, \left< \sin^2 \theta_c \right>$$

where

$$\varepsilon = \varepsilon_{\text{geom}} \times \varepsilon_{\text{phys}}$$

$\varepsilon_{\text{geom}}$ is the geometric light collection probability (probability that a given light ray reaches a photodetector detector)

$\varepsilon_{\text{phys}}$ is the physical attenuation of light in the device (due to reflections, transmissions, absorptions)

for each particle generating Cherenkov light.
Apart from statistics, it is difficult to draw a conclusion...
$\varepsilon_{\text{phys}}$ distributions

Previous presentation (no bulk scattering)

Aerogel $n=1.07$

Aerogel $n=1.12$
\[ \varepsilon_{\text{global}} = \varepsilon_{\text{geom}} \times \varepsilon_{\text{phys}} \]

Aerogel \( n = 1.07 \)  

Aerogel \( n = 1.12 \)  

Previous presentation (no bulk scattering)
Response tables

Thresholds:
- Muons: 265 MeV/c (n = 1.07), 210 MeV/c (n = 1.12)
- Pions: 365 MeV/c (n = 1.07), 275 MeV/c (n = 1.12)

CKOV1

Theoretical trigger configurations

<table>
<thead>
<tr>
<th></th>
<th>MC sample size</th>
<th>I off II off</th>
<th>I on II off</th>
<th>I off II on</th>
<th>I on II on</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Muons</strong></td>
<td>16244</td>
<td>0.19 %</td>
<td>0%</td>
<td>94.68 %</td>
<td>5.13 %</td>
</tr>
<tr>
<td><strong>Pions</strong></td>
<td>380</td>
<td>45.14 %</td>
<td>0%</td>
<td>27.03 %</td>
<td>27.82 %</td>
</tr>
</tbody>
</table>

+ no electronic threshold
+ no high momentum cut
## Detected muons

### Fraction of good muons

<table>
<thead>
<tr>
<th>Trigger configurations</th>
<th>No electronic threshold</th>
<th>No momentum cut</th>
<th>$p_\mu &lt; 365$ MeV/c (from tracker)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I off</td>
<td>I off</td>
<td>0.19 %</td>
<td>0.19 %</td>
</tr>
<tr>
<td>II off</td>
<td>I off</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>I on</td>
<td>I off</td>
<td>94.63 %</td>
<td>94.64 %</td>
</tr>
<tr>
<td>II on</td>
<td>I on</td>
<td>5.12 %</td>
<td>5.13 %</td>
</tr>
</tbody>
</table>

### Fraction of good muons (same without bulk scattering)

<table>
<thead>
<tr>
<th>Trigger configurations</th>
<th>Threshold = 1 photoelectron</th>
<th>No momentum cut</th>
<th>$p_\mu &lt; 365$ MeV/c (from tracker)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I off</td>
<td>I off</td>
<td>2.08 % (1.20 %)</td>
<td>2.08 %</td>
</tr>
<tr>
<td>II off</td>
<td>I off</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>I on</td>
<td>I off</td>
<td>95.84 % (97.22 %)</td>
<td>95.85 %</td>
</tr>
<tr>
<td>II on</td>
<td>I on</td>
<td>2.02 % (1.52 %)</td>
<td>2.02 %</td>
</tr>
</tbody>
</table>
Momentum distributions of triggers

Threshold = 1 photoelectron

$I \leftarrow [ n = 1.07 ]$

$II \leftarrow [ n = 1.12 ]$

Muons

$\text{Threshold} = 1 \text{ photoelectron}$
For each configuration (samples normalised at the production target),

\[ Purity = 1 - \frac{\text{Pion}}{\text{Pion} + \text{Muon}} \]

### Purity matrix (same without bulk scattering)

<table>
<thead>
<tr>
<th></th>
<th>I off II off</th>
<th>I on II off</th>
<th>I off II on</th>
<th>I on II on</th>
</tr>
</thead>
<tbody>
<tr>
<td>No momentum cut</td>
<td>87.819 %</td>
<td>0%</td>
<td>99.983 %</td>
<td>99.683 %</td>
</tr>
<tr>
<td></td>
<td>(91.44 %)</td>
<td>(99.982 %)</td>
<td>(99.639 %)</td>
<td></td>
</tr>
<tr>
<td>( p_\mu &lt; 365 \text{ MeV/c} )</td>
<td>80.819 %</td>
<td>0%</td>
<td>99.984 %</td>
<td>100 %</td>
</tr>
</tbody>
</table>

### Purity matrix (same without bulk scattering)

<table>
<thead>
<tr>
<th></th>
<th>I off II off</th>
<th>I on II off</th>
<th>I off II on</th>
<th>I on II on</th>
</tr>
</thead>
<tbody>
<tr>
<td>No momentum cut</td>
<td>98.607 %</td>
<td>0%</td>
<td>99.983 %</td>
<td>99.351 %</td>
</tr>
<tr>
<td></td>
<td>(97.54 %)</td>
<td>(99.982 %)</td>
<td>(99.268 %)</td>
<td></td>
</tr>
<tr>
<td>( p_\mu &lt; 365 \text{ MeV/c} )</td>
<td>98.607 %</td>
<td>0%</td>
<td>99.988 %</td>
<td>100 %</td>
</tr>
</tbody>
</table>
L. Cremaldi: « In the simulation can you change the reflecting surfaces to purely diffuse reflectors (paint. Tyvek) and look at lightyields?“

References

S. P. Stoll, An investigation of the reflective properties of Tyvek papers and Tetratex PTFE films, Brookhaven Phenix Note #245, 1996.


Remarks.

- These are relative (and not absolute) reflectance measurements (with respect to an uncalibrated diffuser)

- The specular components are not evaluated (as seen from the aluminium and mylar reflectances): no indication of the relative importance of scattering and reflection.
Diffuse reflectors


**Absolute measurements**: calibrated detectors and light sources traceable to the Bureau des Poids et Mesures, Paris

Experimental setup

- Diffusive panel
- Aperture
- Photomultiplier on a turntable
- Mirror
- Light source, interference filters, focusing mechanism
- \( \theta_i = \) incidence angle
- \( \theta = \) measurement angle (variable)
\[ I(\theta) = A_d \cos \theta + A_r \exp \left[ -\frac{(\theta - \theta_r)^2}{2\sigma^2} \right] \]

\( \theta \) is measured about the perpendicular to the diffusing plane.

**Lambert scattering**

Specular reflection

Max if \( \theta = \theta_i = \theta_r \) (Descartes-Snell law)

Angular spectra of Bicron diffusive paint

\( \lambda = 450 \text{ nm} \)

\( \theta_i = 40^\circ \)

\( \lambda = 600 \text{ nm} \)

\( \theta_i = 70^\circ \)
Summary of experimental data

- Scattered intensity vs wavelength
  
  Panels 1 & 2 = white polycarbonates
  
  Panel 3 = Bicron diffusive paint (TiO₂)

- Scattered, reflected and absorption contributions vs angle of incidence

  Absorption = 1 - (Scattered + Reflected)

  Scattering is independent of θᵢ

- Relative light outputs (scattered + reflected) vs wavelength

  Panels 1 & 2 = white polycarbonates (deep blue and magenta)

  Panel 3 = Bicron diffusive paint (TiO₂)

← We choose the diffusing paint
At 400 nm

- Scattering is ~25% at all angles
- Reflection improves at grazing angles
- Light yield (Scattering + reflection) < 75% of the incident light in the best case

This simulation assumes the best possible case (all angles of incidence on the diffusing panels are 70°) i.e. light yield = 75%
Efficiencies: mirrors vs diffusers

Geometrical efficiency

Physical efficiency

Global efficiency

Efficiencies for diffusers corresponds to the most optimistic case ...
Detected muons: mirrors vs diffusers

### Fraction of good muons for diffusers (*Mirrors*)

<table>
<thead>
<tr>
<th>Trigger configurations</th>
<th>Threshold = 1 photoelectron</th>
<th>No momentum cut</th>
<th>$p_\mu &lt; 365$ MeV/c (from tracker)</th>
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<tbody>
<tr>
<td></td>
<td>I off II off</td>
<td>I off II off</td>
<td>I off II on</td>
</tr>
<tr>
<td>I off II off</td>
<td>6.34 % (2.08 %)</td>
<td>0.04 % (0 %)</td>
<td>92.58 % (95.84 %)</td>
</tr>
<tr>
<td>I on II off</td>
<td>92.58 % (95.84 %)</td>
<td>1.04 % (2.02 %)</td>
<td>1.04 %</td>
</tr>
<tr>
<td>I off II on</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I on II on</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Purity matrix for diffusers (*Mirrors*)

<table>
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<th>Threshold = 1 photoelectron</th>
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<tbody>
<tr>
<td></td>
<td>I off II off</td>
<td>I off II off</td>
<td>I off II on</td>
</tr>
<tr>
<td>I off II off</td>
<td>99.524 % (98.607 %)</td>
<td>0%</td>
<td>99.979 % (99.983 %)</td>
</tr>
<tr>
<td>I on II off</td>
<td>99.979 % (99.983 %)</td>
<td>99.120 % (99.351 %)</td>
<td>99.120 % (99.351 %)</td>
</tr>
<tr>
<td>I off II on</td>
<td></td>
<td></td>
<td></td>
</tr>
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<td></td>
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</table>

Most optimistic case for diffusers!
Summary

• Mechanical design 90% complete
  
  Simple and modular construction
  
  Low cost

• Evaluation of the optical performances with correct bulk scattering in the aerogels
  
  Replacing the mirrors with painted panels of the same shape results in
  
  • a serious loss of light reaching the detectors and
  
  • a subsequent degradation of the detection efficiency

• Detection efficiency and signal purity
  
  The design with mirrors discriminates pions from muons at the (1.2 - 1.8) x 10^{-4} level in the whole momentum range of MICE (depending on the electronic threshold and on a possible high-momentum cut based on tracker info).