TRIDENT optimization

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Issues addressed since last presentation (15 January):

1. Progress on window between gas radiators
   - Main technical issue that is required to demonstrate feasibility
2. Optimization of resolution and photon yield
   - Previously not well focused for CF$_4$ in RICH-2 region
   - Was wasting photons due to partially-instrumented modules
3. Reduction of peak occupancy
   - Was higher than expected (partly due to bug, now fixed)

RICH meeting, 25 February 2013
1. Window

- Baseline solution 10-mm thick glass: FEA study by Matthew Brock
- Maximum displacement = 2 mm, maximum stress = 3 N/mm² (i.e. a safety factor of ~10)
- Main issue is material choice, to maintain good transmission after irradiation
- Provided by Matthias Karacson at the window

- Each square 20 × 20 cm
  Peak dose is close to the beam pipe

- Excluding |x| < 40 cm and |y| < 20 cm
  Maximum dose: 2 kGy
  \[\equiv 200 \text{ kRad}\]
  (i.e. 20 kRad/year)
Effect on acceptance

- Effect on angular acceptance of obscuring region close to beam pipe:
- Only $C_4F_{10}$ yield affected, gives inner acceptance of $\sim 25$ mrad (i.e. same as for RICH-1)
- $CF_4$ unaffected due to tilt of focusing mirror → inner acceptance will be defined by beam tube (i.e. same as for RICH-2)
Quartz glass

- Matthew is in touch with Heraeus
  Natural quartz glass looks feasible
  [M. Hoek, RICH2010]
- May well match requirements for the TORCH radiator, too
  In that case would have stringent requirements on surface quality,
  for reflections: for now just used as window
- Propose to simplify naming:
  call the overall concept TRIDENT
  (Twin-Ring IDENTification system)
- Could use borosilicate glass
  for outer region to limit cost
  (before TORCH is implemented)
Reflection losses

- Have implemented Fresnel coefficients for transmission through window in ray-tracing program, for each photon

- **Reflection coefficient depends on photon polarisation:**
  \( R_s \) corresponds to polarisation in plane of interface, \( R_p \) in orthogonal plane

- Cherenkov light is polarised in plane containing photon and track
  Polarisation turns out to be favourable: average transmission through window = 94%

- For now have assumed 90% transmission, to cover additional losses in window material and/or frame

- Cherenkov light generated in the window: 70% trapped inside (→ TORCH) rest emitted at large angle > 45° and none hits the TRIDENT detector plane
Alternative approach

• Brainstorming from Olav Ullaland: Reason for substantial window is to resist hydrostatic pressure difference between the two radiator gases

• Could avoid that by choosing gases of same density

• \( nC_4H_{10} \) has same refractive index as \( C_4F_{10} \), but is less dense than \( CF_4 \)

• 85:15 mixture of \( nC_4H_{10} \) and \( C_4F_{10} \) would match density of \( CF_4 \)

• Could then use a thin Mylar foil as gas separator (or even rely on laminar flow to keep the gases apart…)

Roger Forty

TRIDENT studies
Drawbacks

1. Chromatic aberration of $nC_4H_{10}$ is worse than that of $C_4F_{10}$
   
   Without Mylar foil:
   
   $\sigma_{\text{chromatic}} = 0.43 \text{ mrad} \rightarrow 0.86 \text{ mrad}$

2. Mylar cuts off spectrum at ~ 330 nm
   
   With Mylar, $\sigma_{\text{chromatic}} \rightarrow 0.64 \text{ mrad}$
   
   But lose ~ half of photons from both $C_4F_{10}$ and $CF_4$ radiators

3. $nC_4H_{10}$ is flammable…

   Suggest to keep this idea as a fall-back, in case a problem is encountered with baseline glass/quartz window solution
2. Optimization

- Optics as previously presented was not optimal for CF$_4$ in RICH-2 region → increase radius of curvature of focusing mirror 750 cm → 800 cm
- Use full footprint along $z$, apart from 5 cm for entrance/exit windows
Detector plane

- Adjusted detector plane layout, where each square represents a module of PMTs $13.8 \times 13.8 \, \text{cm}^2$

- Initially designed for $4 \times 4$ array per module similar to those used in beam tests, with $1.5 \times$ demagnification from lenses:

- Realized that the same lens arrangement can be adjusted to give different demagnification factors, by adjusting distance from PMT → can maintain full coverage over plane
Adjusting demagnification

- Arrange 3×3, 4×4 and 5×5 arrays of PMTs to fit same module dimension. Requires demagnification factors of 2.0, 1.5, and 1.2 respectively.

- Achieved with (pleasingly simple) geometry: \( h = \frac{3R}{2}, R, \) and \( \frac{R}{2} \) where \( h \) is the height of the lens, and \( R \) its radius of curvature.

- Implemented the following lens arrangements in ray-tracing program. Find that 96% of photons are focused into the active area of the PMTs. Lens for 3×3 quite large, but would be made from (cheap) borosilicate glass.

[Dimensions in mm]

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Photon angle of incidence

• Minor complication: average angle of incidence of photons varies over detector plane
  → PMT positions must be adjusted relative to lens, to match average angle
  Image shift per unit ≈ 0.5 mm

• Can be achieved in two ways:
  1. Mounting PMTs on a slightly different pitch to the lenses
     → lens and PMT planes decoupled
  2. Or, tapering the lenses slightly
     → lens/PMT units are all identical, but no longer lie on a plane

Assume the first solution for now
Performance update

- With 3×3 modules covering most of the detector plane, achieve full coverage (rather than wasting photons) while keeping ≈ same number of PMTs as previous solution with half-instrumented 4×4 modules in outer region

- Effect on resolution: increases $\sigma_{\text{pixel}}$ by $\times 4/3$, but still not limiting contribution

- Use 4×4 and 5×5 modules only to reduce occupancy where needed (by factors 16/9 = 1.8 and 25/9 = 2.8, respectively)

- Performance comparison (average over flat distribution of tracks in acceptance):

<table>
<thead>
<tr>
<th>Radiator</th>
<th>RICH-1</th>
<th>RICH-2</th>
<th>TRID</th>
<th>Updated TRIDENT</th>
</tr>
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<tbody>
<tr>
<td>$\langle N_{\text{pe}} \rangle$</td>
<td>$C_4F_{10}$</td>
<td>$CF_4$</td>
<td>$C_4F_{10}$</td>
<td>$CF_4$</td>
</tr>
<tr>
<td>30</td>
<td>22</td>
<td>27</td>
<td>25</td>
<td>mrad</td>
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<td>$\sigma_{\text{emission}}$</td>
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<td>0.2</td>
<td>0.39</td>
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<tr>
<td>$\sigma_{\text{chromatic}}$</td>
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<td>0.5</td>
<td>0.43</td>
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<td>$\sigma_{\text{pixel}}$</td>
<td>0.6</td>
<td>0.2</td>
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<td>0.33</td>
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<tr>
<td>$\sigma_{\text{track}}$</td>
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<tr>
<td>$\sigma_{\text{total}}$</td>
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<td>0.78</td>
<td>0.70</td>
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<td>$p_{3\sigma}(K-\pi)$</td>
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<td>73</td>
<td>94</td>
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</tbody>
</table>
3. Full simulation

- Occupancy study requires the full simulation
  Previously looked at reconstructed *tracks* (& had bug in geometry)
- Sajan Easo has now dumped information for all *particles* entering TRIDENT, from full simulation (*B* events)
- Ray trace all photons to detector plane
- Reflected photons from the window only $\approx 5\%$ → not a problem

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**“Signal” photons**

**Reflection background**

(32 overlaid events)
Occupancy

- Plot number of hits in each module (one bin/module)
- First assuming $3 \times 3$ PMT modules over full detector plane → shows raw occupancy distribution
- Then introduce $4 \times 4$ and $5 \times 5$ modules in central region (for specific layout shown earlier) → distribution spread out
  
  Peak occupancy reduced by factor $\approx 3$
Luminosity dependence

• Convert maximum hit count to an occupancy per channel: divide by 32 events $\times$ 9 PMTs $\times$ 64 channels per PMT $\rightarrow$ 8.7 % (peak value)

• This was for a MC sample generated at $2 \times 10^{33}$ cm$^2$s$^{-1}$

  Average occupancy over full detector plane = 3.5 %

• Repeat for other luminosity samples and plot against the corresponding $\mu$ value (provided by Sajan):

  $\rightarrow$ Occupancy is under control

(Will be updated with higher statistics)
Conclusions

- Layout of TRIDENT optimized to improve resolution and photon yield, while decreasing peak occupancy.

- Improved performance: $\text{C}_4\text{F}_{10}$ gives higher yield & resolution than RICH-1. CF$_4$ maintains RICH-2 performance, but extends it to full acceptance.

- Peak occupancy < 10% at maximum upgrade luminosity of $2 \times 10^{33}$ cm$^2$s$^{-1}$. Achieved while limiting number of PMTs, through the use of lenses (which would not be possible in RICH-1, due to its pixel-size limitation).

- Key point is the flexibility & robustness of the TRIDENT approach. Similar performance could be achieved using only $4 \times 4$ modules (partially instrumenting outer region, removing lenses in innermost region).

- Specific layout presented requires a total of 3344 PMTs compared to 3712 for previous baseline of unchanged RICH-1 + RICH-2, 4864 for modified RICH-1 solution [Framework TDR] i.e. 30% fewer.