Targets for high-intensity muon sources for cLFV experiments

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Outline

- Requirements from cLFV search experiments
  - $\mu \rightarrow e\gamma$ & $\mu \rightarrow eee$
  - $\mu$-$e$ conversation
  - Target material, shape, and cooling
- Muon transport
Muon cLFV Search Experiments

$\mu \rightarrow e\gamma \quad \& \quad \mu \rightarrow \text{eee}$

- Muons to be stopped on a target
- Target should be as thin as possible (100-200 $\mu$m) to suppress the multiple scattering effect on the decay particles
- Coincidence in the final state
  - $\mu \rightarrow e\gamma$
  - $\mu \rightarrow \text{eee}$
- Multi-layer stopping target is not preferred for the purpose of vertex finding
Requirements from Experiments

- Confidence-Type experiments ($\mu \rightarrow e \gamma \& \mu \rightarrow eee$) requires muon beam with minimum momentum spread at low energy
  - Surface muon is best
  - Target should be optimized to produce the surface muon beam
    - Only positive muon
  - Muon beam time structor
    - determined by the proton beam time structure
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  \[\sim 20\text{ ns}\]
PSI Target E

- Graphite target
- Radiation cooling

Target-E design

**TARGET CONE**
- Mean diameter: 450 mm
- Graphite density: 1.8 g/cm³
- Operating Temperature: 1700 K
- Irradiation damage rate: 0.1 dpa/Ah
- Rotational Speed: 1 Turn/s
- Target thickness: 60 / 40 mm
  - 10 / 7 g/cm²
- Beam loss: 18 / 12 %
- Power deposition: 30 / 20 kW/mA

**SPOKES**
To enable the thermal expansion of the target cone

**BALL BEARINGS (*)**
Silicon nitride balls
Rings and cage silver coated
Lifetime: 2 y
*) GMN, Nürnberg, Germany

Mike Seidel
Target Performance

- Standard target configuration is good enough
- R&D to improve muon stopping efficiency
  - Muon cooling
  - Angela Papa’s presentation “MuCool at PSI”
Muon cLFV Experiments

\(\mu\)-e conversion searches

- Muonic atom formation by stopping negative muons in a material
- Transition to 1S state by emitting X-ray
- “Decay” or “captured” with a lifetime of \(\sim 1\ \mu\) sec
- Signal electron identified with its characteristic energy emitted with a delayed timing
  - \(E_e = m_\mu - E_B - E_{\text{recoil}} \approx 100\) MeV
- DIO background

The spectrum shape and rate, we have carried out a detailed analysis of Coulombic-bound-state muon decay, including nuclear recoil. Implications for future experiments are briefly discussed.
Requirements from $\mu$-e Conversion Experiments

- As many muons as possible
- The muon stopping target should be thin but multi-layer type is acceptable
  - No need of exact vertex finding thanks to one electron in the final state
  - This arrow us to use a larger momentum range of the muon beam
- DeeMe is an exception since they adopt a different method to perform the search
Principle of DeeMe
Principle of DeeMe

Production Target

Protons

Proton Stopping Target

Pion Collection

Pion Decay -- Muon Collection

Muons

Electron Detector

Spectrometer

105 MeV/c

Detector

105 MeV/c
J-PARC MLF Target

- Shunske Makimura’s presentation for more details
- Fixed target (Polycrystalline graphite) had been used in the period from 2009 to 2014, Water cooling & thermal conduction
- Rotating target operational from 2014. Radiation cooling
- R&D of SiC as a future option → more muon (for all muon users) & another material for muonic atom formation (for DeeMe)
- Beam size 16mm in $2\sigma$
COMET & mu2e

- Both employ MELC idea
- Pion production target in the gradient magnetic field
- Collect low-momentum pions/muons emitted backward
- Target can be thick along the beam direction
  - $\sim 3 \times \sigma_{\text{beam}}$ in the orthogonal direction
- Rotating scheme cannot be used
  - Active cooling
  - Radiation cooling (doing nothing)
COMET
Phase I & Phase II

- See Y. Yuan’s presentation for more details of the setup and physics goal
- Phase-I sensitivity < 10
  - The pion production target should be simple and robust to start the experiment timely
- Phase-II sensitivity < 10
  - more time for R&D to achieve higher muon production efficiency
  - Metal target with active cooling
  - mu2e target R&D

3.2kW in Phase I
56kW in Phase II
COMET Phase-I Target

- Accept 8GeV 3.2kW proton beam
- Produce and transport as many low-momentum muons as possible
  - 1-2 interaction length with an optimized diameter
    - Larger diameter reduces pion emission from the target
- Simple & refractory
  - Radiation cooling rather than active cooling using water/gas to simplify the system
- Graphite (IG-43) with 4cm diam. and 60cm length
  - Refractory material and so is tolerant to high temperature operation
- Experience in T2K
COMET Phase-I Target Design

- Radiation cooling
- Support structure for Phase I
  - Same interface with Phase II target support
  - Graphite spoke & Titanium ring
- Target Installation
  - Alignment & Replacement scenario
- Monitor
  - Temperature censor and/or Infrared monitor
- Possibility to use heavier material
  - SiC: 3.22 g/cm³
- Preliminary study indicate more then 30% increase of muon stops in COMET Phase-I configuration
COMET Phase-II & mu2e
Target Design

- Target – located inside the Production Solenoid (PS)

C. Densham
Comments on Muon Transport

- Curved solenoid technology
- COMET & Mu2e Muon Transport
- MUSIC (Dai Tomono’s presentation on Friday)
- Solenoid beam line study at PSI
Curved Solenoid Muon Transport

- Center of the charged particle helix drift depending on the charge and momentum
- Momentum & charge selection
COMET Curved Solenoid Installation
Solenoid Beam Line @ PSI

**Solenoid Beamline: HiMB@EH**

<table>
<thead>
<tr>
<th>Component</th>
<th>Rate</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>1.3 x 10^{11} μ⁺/s</td>
<td></td>
</tr>
<tr>
<td>Capture</td>
<td>3.4 x 10^{10} μ⁺/s</td>
<td>C ~ 26%</td>
</tr>
<tr>
<td>Transmission</td>
<td>1.3 x 10^{10} μ⁺/s</td>
<td>T ~ 40%</td>
</tr>
<tr>
<td>Total</td>
<td>~ 0.4%</td>
<td>Total ~ 10%</td>
</tr>
</tbody>
</table>

Gain due to high capture and transmission efficiency

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Andreas Knecht  
HINT2015 Workshop, 13. - 15. 10. 2015
Summary

- Targets for high-intensity muon sources for cLFV experiments
- Graphite target with radiation cooling have been used in many facilities
  - SiC
- Future experiments (mu2e & COMET Phase II) will use metal target to achieve better pion production efficiency
  - Need active cooling
- Muon transport should optimized accordingly