Testbeam Measurement for the MU3E Experiment

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The MU3E Experiment:

- Search for $\mu^+ \rightarrow e^+e^-e^+$
- Charged Lepton Flavor Violation (LFV)
- Proposed Sensitivity: Branching Ratio (BR) $< 10^{-16}$
- Indirect New Physics Search
\[ \mu^+ \rightarrow e^+ e^+ e^- \] in the Standard Model

**Features:**
- Lepton Flavor Violating
- Via Neutrino Mixing
- But: Heavily Suppressed
- Expected BR < \(10^{-50}\)
- Current Limit BR < \(2.4 \times 10^{-12}\)

**Importance:**
- Any Observable BR must come from New Physics

\[ \rightarrow \text{Very Sensitive to New Physics} \]
The MU3E Experiment

Experimental Concept

1. High Intensity Muon Beam (Low Energy)
2. Stop Muons in Target
3. Observe All Decay Electrons
4. Find Three Matching Tracks

up to $2 \times 10^9$ muons / s

→ Many, Low Momentum Electrons $p < 53$ MeV

Existing / Future Beamlines
Paul Scherrer Institut, Switzerland
Signal

- Three Electrons (2x e+, 1x e-)
- Common Vertex
- Coincident in Time

\[ (\sum P)^2 = m_\mu^2 \]
The MU3E Experiment

Backgrounds

Internal Conversion

\[ (\sum P_e)^2 \neq m_\mu^2 \]

Requires:
- high momentum resolution

\[ \rightarrow \text{Suppress Below BR < 10}\text{-}16 \]

\[ \rightarrow \text{Fast, Precise, Low Momentum Electron Tracker} \]

Combinatorial Background

\[ e^+ \rightarrow e^- + e^- \]

Requires:
- high vertex resolution
- good momentum resolution
- additional timing information
The MU3E Detector

Magnetic Field: ~ 1T
Multiple Scattering

Short Tracks

\[ \Theta_{MS} = \frac{13.6 \text{ MeV}}{p} \sqrt{\frac{x}{X_0}} \]

Example:
- \( p = 35 \text{ MeV} \)
- \( x = 200 \mu\text{m Silicon} \)
- \( \Omega \cdot R = 5 \text{ cm} \)
- \( \Delta y = 1 \text{ mm} \)

Semi Circle

In First Order / Fixed Momentum: Reduced Effect from Scattering

Low Momentum \( \rightarrow \) Minimal Material Budget

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High Voltage MAPS

MAPS:
- Monolithic
- Active
- Pixel Sensors

- integrated readout
- very small active zone
- charge collection via drift (fast)
- thinable down to 50μm
MUPIX Prototype 2

- Designed by Ivan Peric (ZiTi Mannheim)
- 42x36 Pixels @ 39x30 \( \mu \text{m}^2 \)
- Binary Hits (Single Threshold)
- already tested by colleagues at PI (laser, radioactive sources, ...)

Problems:
- Efficiency?
- Resolution?
- Response to Minimal Ionizing Particles (MIPs)?

- Requires Testbeam Measurements
Testbeam Setup

SPS Testbeam at CERN

Testbeam August 2012
- Testbeam Area T4-H8A
- 180 GeV/c pions
- TIMEPIX Beam Telescope

But: ~ few hours of data taking

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MUPIX sensor

beam spot

~ 1cm
Telescope Alignment

Track Based Alignment

Position Resolution $\sim 5\mu m$

Track Residuals (First 4 Telescope Layers)

- C09-W0108: $\delta = 3.8\mu m$
- C10-W0108: $\delta = 4.1\mu m$
- J06-W0087: $\delta = 4.5\mu m$
- F11-W0108: $\delta = 4.5\mu m$
Mostly Single Hit Cluster

- Very Little Charge Sharing
- Expected: Small Active Volume

No Significant Threshold Dependence

- Expectation: Fewer Big Cluster for Higher Thresholds
- Limited Statistics
Hit Efficiency

How to Calculate:
1. Extrapolate Track to MUPIX plane
2. Check for Close-By Clusters (less than 2 pixel away)
3. Keep Closest Cluster
4. Ratio Tracks w/ or w/o Cluster

Problems:
- Some Dead Pixels
Resolution

- Independent of Threshold
- Combination of Pixel Size and Telescope Resolution

\[ \sigma = \sqrt{\sigma_{\text{Telescope}}^2 + \frac{d_{\text{Pixel}}^2}{12}} \]

Track Residuals
Summary & Outlook

The MU3E Experiment

- Search for Charged LFV \( \mu^+ \to e^+e^-e^+ \)
- Planned Sensitivity BR < 10\(^{-16} \)
- New Detector Design
- New Pixel Sensor

What's Next?

- Finalize Testbeam Analysis
- New Prototype: MUPIX v3
- First Data Taking ~ 2014

Testbeam Measurements

- Cluster Size, Efficiency, Resolution, ...

Thank You. Questions?
Backup
Bethe-Bloch

- $dE/dx$ (MeV g^{-1} cm^2)

- $\beta\gamma = p/Mc$

- Muon momentum (GeV/c)

- Pion momentum (GeV/c)

- Proton momentum (GeV/c)

180 GeV/C pions

J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012)
New Physics Diagrams

Generic Tree Level

Supersymmetry