Mu3e Progress Report @ BV51

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Introduction to Mu3e

$\mu \to eee$ in the standard model.
Introduction to Mu3e

$\mu \to eee$ in the standard model.

SM: $< 1 \times 10^{-54}$
The suppression comes from the neutrino masses.

Current best limit: $< 1 \times 10^{-12}$
(SINDRUM 1988)

Alternative models predict BR within reach of Mu3e ($< 1 \times 10^{-16}$).
Introduction to Mu3e — Signal in $r\phi$-view

Signal
SM: $< 1 \times 10^{-54}$
Introduction to Mu3e — Signal in \( r\phi \)-view

\[ \sum p_i = 0 \]

Signal
SM: \(< 1 \times 10^{-54} \]
Introduction to Mu3e — Signal in $r\phi$-view

Signal
SM: $< 1 \times 10^{-54}$

$$\sum p_i = 0$$
$$m_{\text{inv}} = m_\mu$$
Introduction to Mu3e — Signal in $r\phi$-view

Signal
SM: $< 1 \times 10^{-54}$

$\sum p_i = 0$
$m_{\text{inv}} = m_{\mu}$
$t_i = t_j \ \forall \ i, j$
**Introduction to Mu3e — Signal in $r\phi$-view**

**Signal**

**SM:** $< 1 \times 10^{-54}$

\[ \sum p_i = 0 \]

\[ m_{\text{inv}} = m_\mu \]

\[ t_i = t_j \quad \forall \, i, j \]

common vertex
Introduction to Mu3e — Signal in $r\phi$-view

Signal
SM: $< 1 \times 10^{-54}$

$$\sum p_i = 0$$
$$m_{\text{inv}} = m_\mu$$
$$t_i = t_j \; \forall i, j$$
common vertex

Radiative decay
SM: $3.4 \times 10^{-5}$

$$\sum p_i \neq 0$$
$$m_{\text{inv}} < m_\mu$$
$$t_i = t_j$$
common vertex
Introduction to Mu3e — Signal in $r\phi$-view

**Signal**

SM: $< 1 \times 10^{-54}$

$$\sum p_i = 0$$

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common vertex

**Radiative decay**

SM: $3.4 \times 10^{-5}$

$$\sum p_i \neq 0$$

$$m_{\text{inv}} < m_\mu$$

$$t_i = t_j$$

common vertex

**Accidental background**

$$\sum p_i \approx 0$$

$$m_{\text{inv}} \approx m_\mu$$

$$t_i \approx t_j$$

“bad vertex”
Mu3e detector
Mu3e detector

- Upstream beam-pipe
- Target
- Downstream beam-pipe
- Beam window
- Cables, busbars, helium ducts
- Scintillating fibre detector
- Pixel outer layers
- Upstream scintillating tile detector
- Downstream scintillating tile detector
- Upstream pixel recurl layers
- Downstream pixel recurl layers
Mu3e detector

Cables, busbars, helium ducts…
Mu3e detector

Scintillating fibre detector
Mu3e detector
Mu3e detector

Upstream scintillating tile detector

Downstream scintillating tile detector
Mu3e detector

- Beam window
- Cables, busbars, helium ducts...
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Disclaimer:

- Every sub-system is worth an own talk
- Will briefly present all systems
- A highly opinionated selection... blame is on me
Magnet

Superconducting magnet, cooled with 4 cryocoolers

Warm bore diameter: 1 m
Length: ≈ 3 m
Nominal field: 1 T

Final tests scheduled for March 2020 at company, deliver to PSI afterwards. This year: Commissioning of the magnet.
Mu3e is sharing the space at $\pi$E5 with MEG. A clever beam-line topology...
Beam line

allows to switch with reasonable effort.
Scintillating fibre detector

- 12 fibre ribbons at \( \approx 6 \text{ cm radius} \)
- 32.5 mm wide ribbons, 30 cm long
- SCSF-78MJ fibres, 250 µm diam., 3 layers \( \Rightarrow 0.2\%X_0 \)
- \( 2 \times 128 \) channel SiPM per ribbon
- MuTRiG ASIC for readout
- Time resolution: 355 ps (measured in test beam)

Institutes: UniGE, ETHZ, UniZH, PSI
Scintillating fibre detector

This year (highlights only):

- Ribbon production
- Construction of a detector covering half
- All electronics

Next year: final detector.
Scintillating tile detector

- EJ-228 scintillator
- \(6.5 \times 6.5 \times 5.0\) mm\(^3\)
- ESR reflecting foil, wrapped individually
- SiPM, one per tile
- 2912 tiles per station, 2 stations
- Time resolution: 36 ps (measured in test beam)

This year:
- Tile manufacturing
- Final electronics
- Commission 2 modules ("rings") at PSI

Institutes: KIP U Heidelberg
Scintillating tile detector

- Vertical milling
- Horizontal milling
- Edge milling using custom conical mill head
- Flip and freeze
- Milling from the bottom
- Matrix ready
Pixel detector

- Ultra-thin design: 0.115%\(X_0\) per layer
- 50 µm thin monolithic pixel sensor
- Two layer aluminium flex readout
- 20 × 20 mm\(^2\) active area per pixel
- < 250 mW/cm\(^2\) dissipated heat
- 1.14 m\(^2\) instrumented surface
- Vertex and recurl layers
- 2844 chips in total

Institutes: PI U Heidelberg, KIT, U Mainz, U Oxford, U Liverpool, U Bristol, PSI
**Pixel detector**

- Monolithic = sensor and readout electronics in same silicon substrate
- Zero-suppressed, no trigger, always on
- Fabricated in standard foundry process (TSI)
- Readout via thin aluminium flex
MuPix is a highly successful line of thin monolithic pixel chips.

- Highly efficient
- Low noise ($< 1 \text{ Hz per pixel}$)

This year:
- Characterisation of MuPix10 (submitted in Nov)
- Commissioning of manufacturing processes
- First module construction with MuPix10
Pixel detector: cooling

We are going to cool with helium (because of radiation length):

Simulation (ANSYS):

Lab measurement

Helium will be pumped using ultra-high-speed miniature turbo-compressors.
Did I forget something?
How we detect $\mu^+ \rightarrow e^+ e^- e^+$
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Data taking days

$\text{BR}(\mu \rightarrow e e e)$

<table>
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<tr>
<th>muon stops/s</th>
<th>10$^8$</th>
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<td>16.3% signal efficiency</td>
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SINDRUM 1988

$2 \times 10^{-15}$

SES

90% C.L.

95% C.L.
Beeam requests for 2020

Summary of our beam requests:

- **πE5**
  - 1+2 weeks (eoy): CMBL commissioning with magnet
  - 1+2 weeks (eoy): final detector demonstrators in magnet, DAQ integration
  - 2 weeks (early): irradiation study SiPM with Michel positrons

- **πM1**
  - 2 weeks: test new SciFi HW (ribbon + MuTrig2); high rate test new pixel chips
  - 1 week: high rate scans of MuPix10 pixel
  - 2 weeks: test of SciFi HW and pixel modules; preparation for integration test

eoy: end of year; early: can be soon after accelerator operation starts
Beyond phase-I: phase-II

To ultimately reach $< 10^{-16}$ we plan for Phase-II with 19 times higher muon rate.

- We will be one of the first users of HiMB
- No surprise: we are involved in CROSS activities
- Proposal: MuOns for Research in Europe
  - Study for high intensity muon production ($10 \times 10^{10}/s$)
  - Targets, proton beam, muon beam, experiment (physics, material science), ESS
  - Very important activity for us
Conclusions

- Mu3e is transitioning from an R&D effort to construction
- This year:
  - Magnet
  - Beam characterisation
  - First detectors to be commissioned
- Following year:
  - Full detector fabrication and commissioning
  - All infrastructure (helium cooling, computing etc.)
Conclusions

All this could not be made possible without a motivated, competent and active collaboration (in alphabetical order):

- CH: U Genève, ETH Zürich, U Zürich
- DE: U Heidelberg, KIT Karlsruhe, U Mainz
- UK: U Bristol, U Liverpool, U Oxford, UC London
- Hostlab: PSI

THANK YOU!