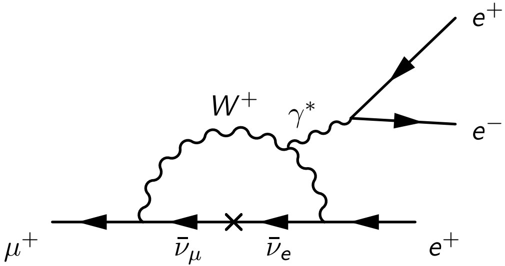
Mu3e Progress Report @ BV51

Frank Meier
Paul Scherrer Institute

January 28, 2020

Introduction to Mu3e

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



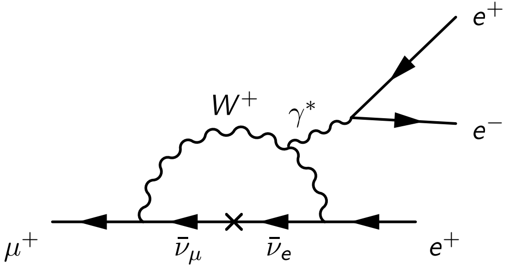
Introduction to Mu3e

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

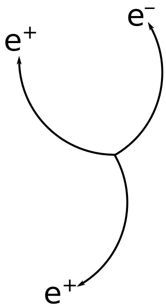
SM: $< 1 \times 10^{-54}$
The suppression comes from the neutrino masses.

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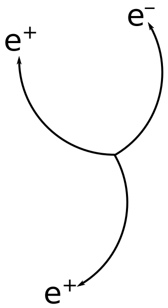
Introduction to Mu3e — Signal in $r\phi$-view



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$\sum p_i = 0$

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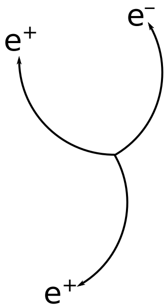

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$m_{\text{inv}} = m_\mu$

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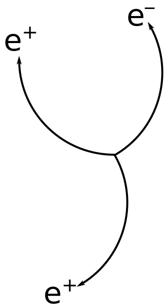

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$t_i = t_j \quad \forall\, i, j$

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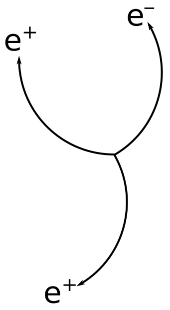

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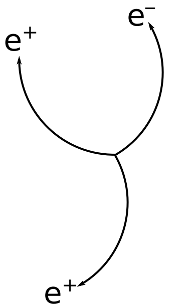

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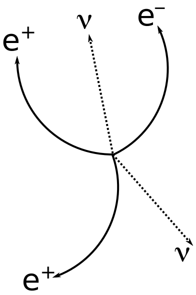
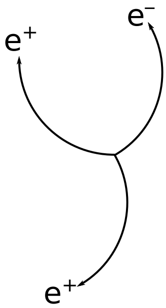


Radiative decay
SM: 3.4×10^{-5}

$\sum p_i \neq 0$
$m_{\text{inv}} < m_\mu$
$t_i = t_j$
common vertex

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



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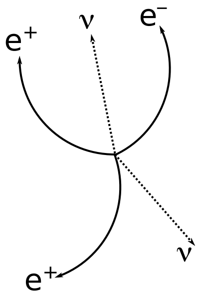

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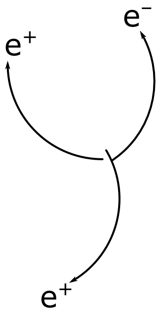
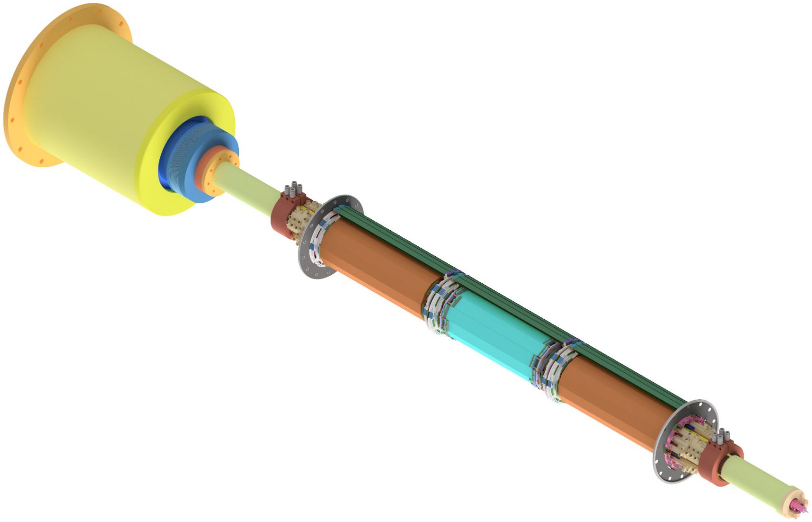


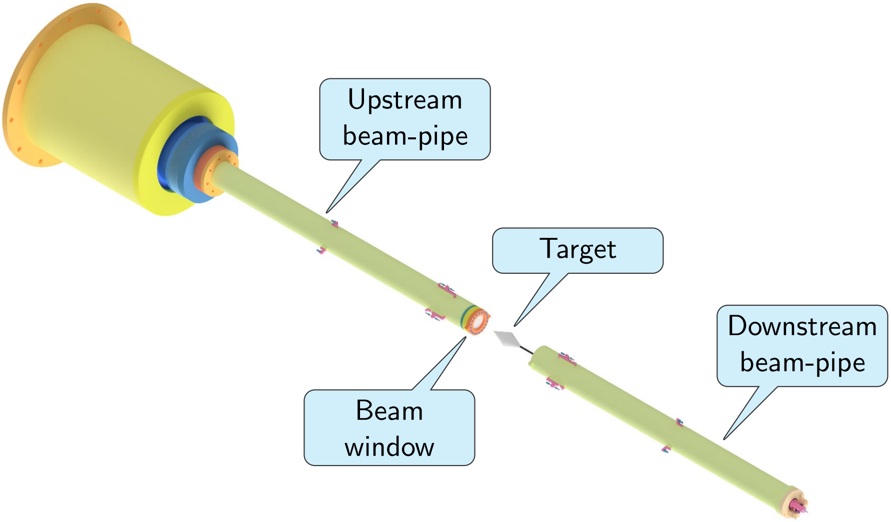
Accidental
background

$\sum p_i \approx 0$
$m_{\text{inv}} \approx m_\mu$
$t_i \approx t_j$
"bad vertex"

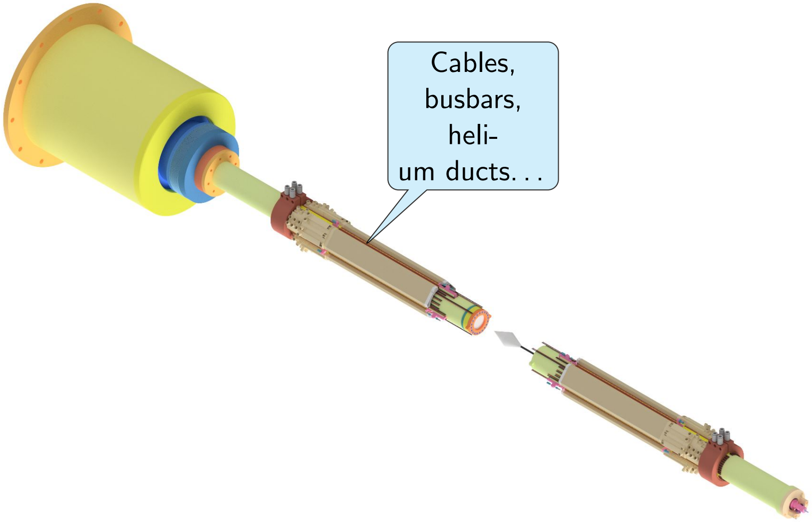
Mu3e detector



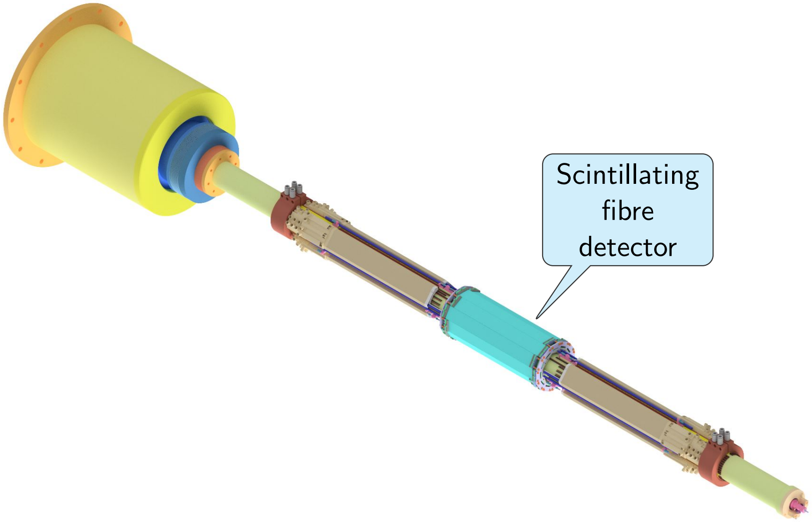
Mu3e detector



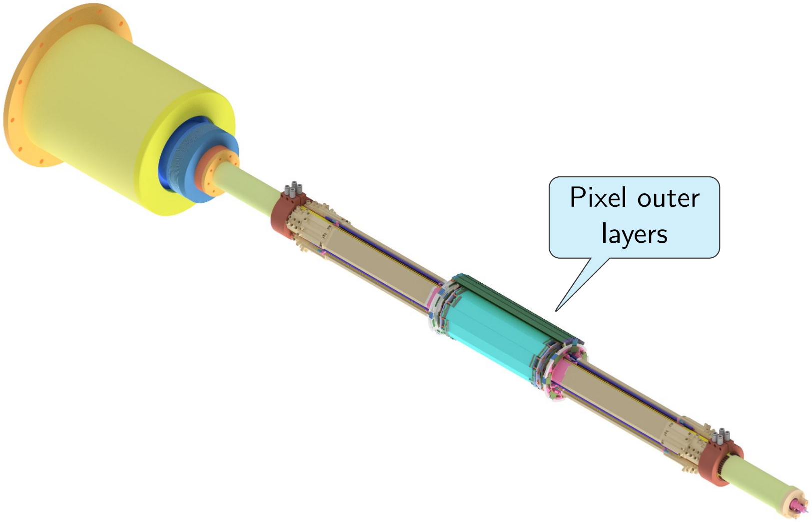
Mu3e detector



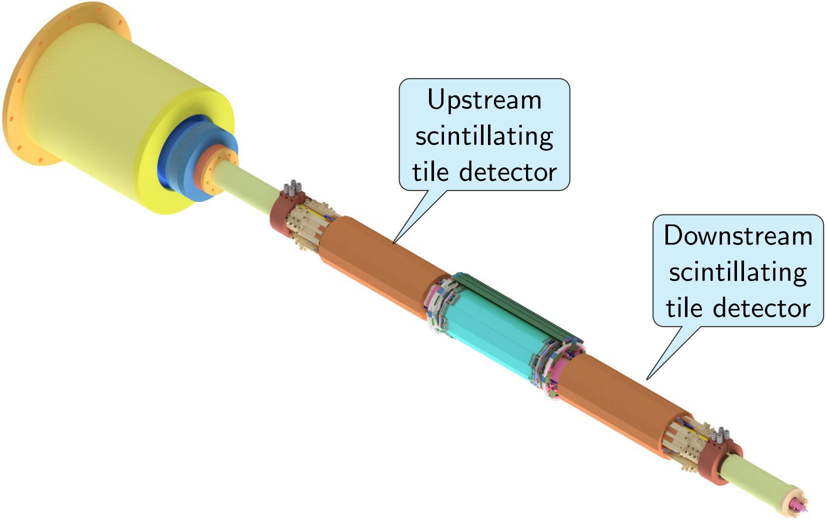
Mu3e detector



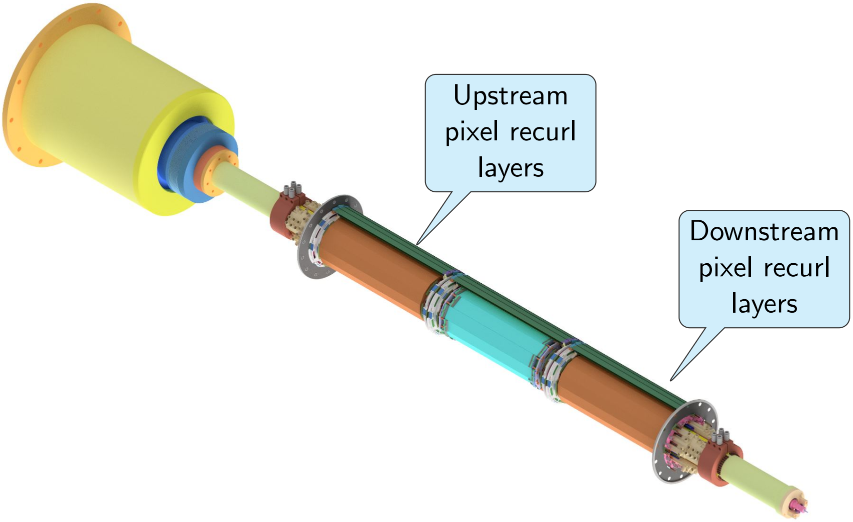
Mu3e detector



Mu3e detector



Mu3e detector

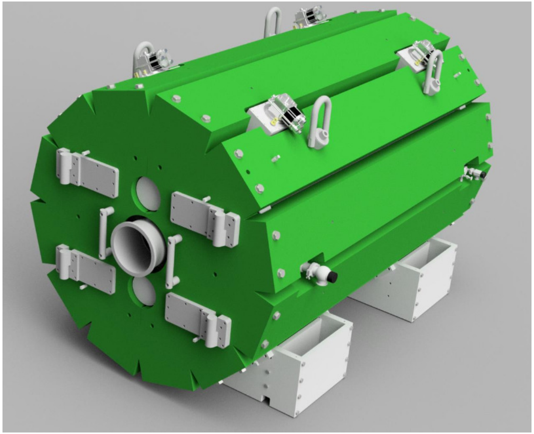


Mu3e detector

Disclaimer:

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

Magnet

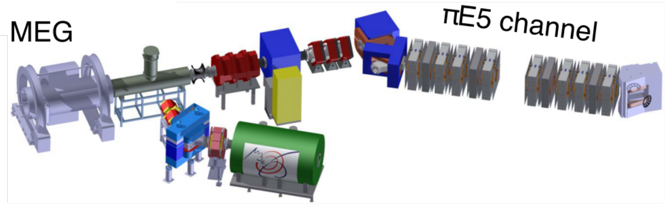


Superconducting magnet, cooled with 4 cryocoolers

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

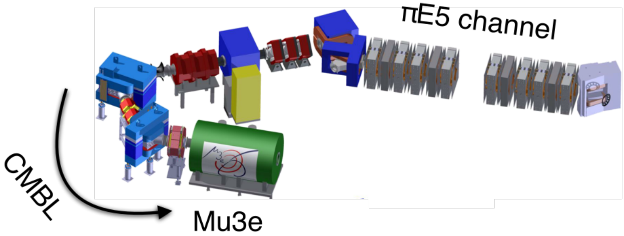
Final tests scheduled for March 2020 at company, deliver to PSI afterwards.
This year: Commissioning of the magnet.

Beam line



Mu3e is sharing the space at πE5 with MEG. A clever beam-line topology. . .

Beam line



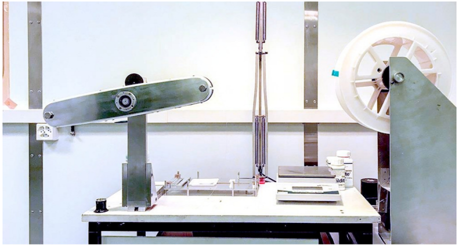
. . . allows to switch with reasonable effort.

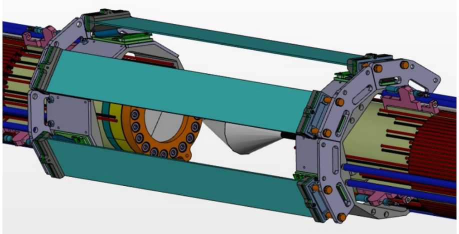
Scintillating fibre detector

- 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 $\Rightarrow 0.2\% X_0$
- 2×128 channel SiPM per ribbon
- MuTRiG ASIC for readout
- Time resolution: 355 ps (measured in test beam)

Institutes: UniGE, ETHZ, UniZH, PSI

Scintillating fibre detector



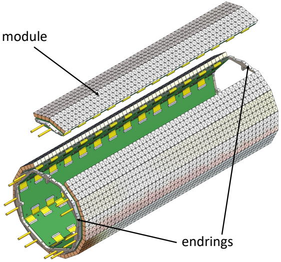


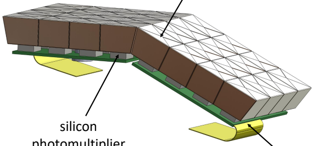
This year (highlights only):

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

Next year: final detector.

Scintillating tile detector





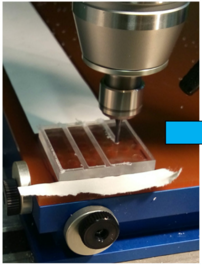
- EJ-228 scintillator
- $6.5 \times 6.5 \times 5.0\,\mathrm{mm}^3$
- ESR reflecting foil, wrapped individually
- SiPM, one per tile
- 2912 tiles per station, 2 stations
- Time resolution: 36 ps (measured in test beam)

This year:

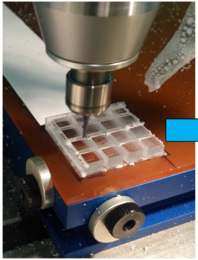
- Tile manufacturing
- Final electronics
- Commission 2 modules („rings“) at PSI

Institutes: KIP U Heidelberg

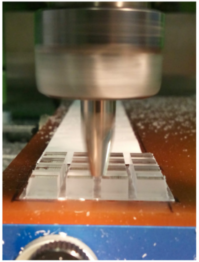
Scintillating tile detector



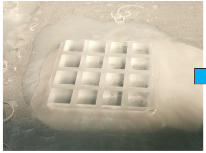
vertical milling



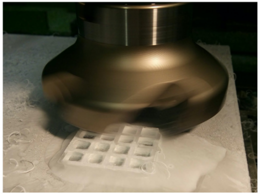
horizontal milling



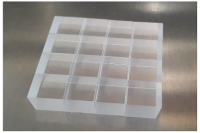
edge milling using custom conical mill head



flip and freeze

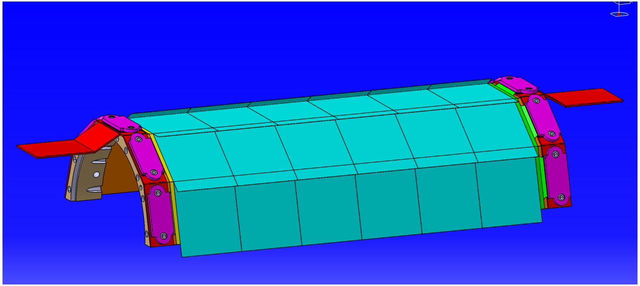


milling from the bottom



matrix ready

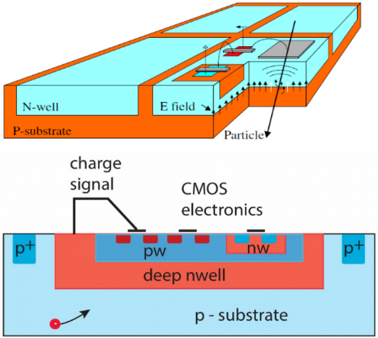
Pixel detector



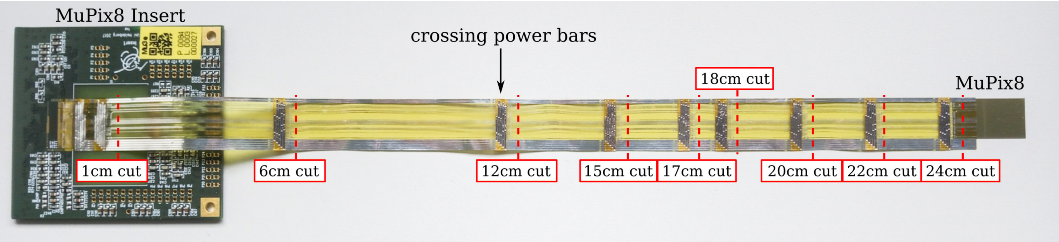
- Ultra-thin design: 0.115%X_0 per layer
- 50 µm thin monolithic pixel sensor
- Two layer aluminium flex readout
- $20 \times 20\,\mathrm{mm}^2$ active area per pixel
- $< 250\,\mathrm{mW/cm}^2$ dissipated heat
- $1.14\,\mathrm{m}^2$ instrumented surface
- Vertex and recurl layers
- 2844 chips in total

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

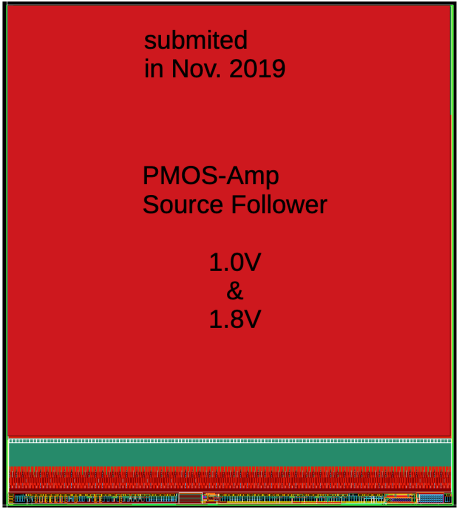
Pixel detector



- 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



Pixel detector



MuPix is a highly successful line of thin monolithic pixel chips.

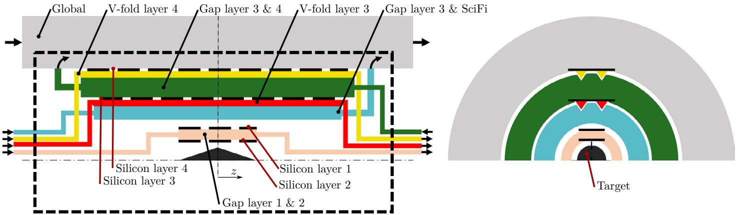
- Highly efficient
- Low noise ($< 1\,\mathrm{Hz}$ per pixel)

This year:

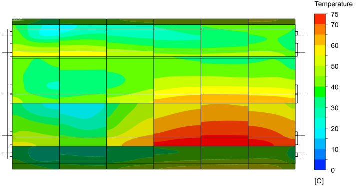
- Characterisation of MuPix10 (submitted in Nov)
- Commissioning of manufacturing processes
- First module construction with MuPix10

Pixel detector: cooling

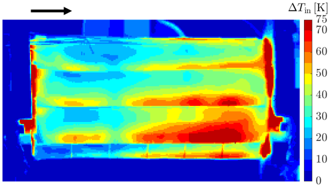
We are going to cool with helium (because of radiation length):



Simulation (ANSYS):



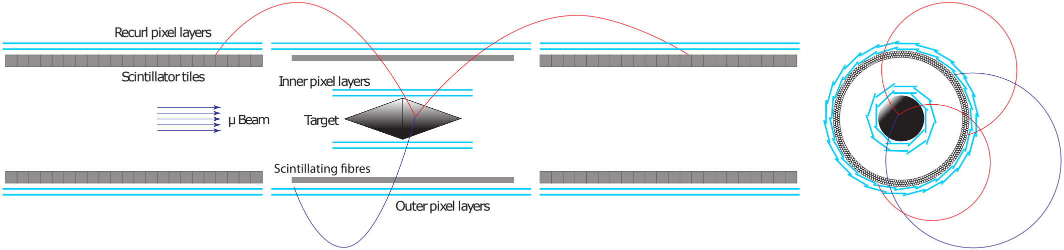
Lab measurement



Helium will be pumped using ultra-high-speed miniature turbo-compressors.

Did I forget something?

How we detect $\mu^+ \to e^+e^-e^+$



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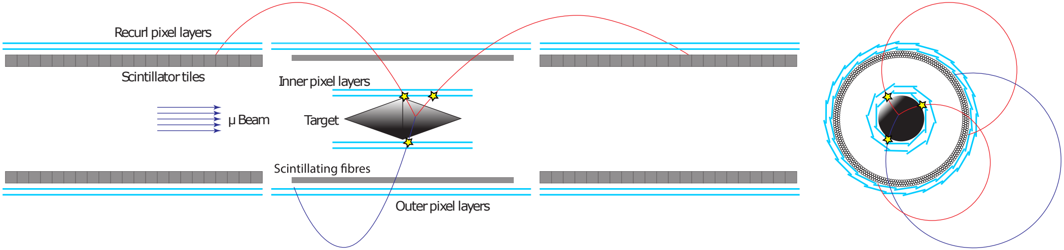

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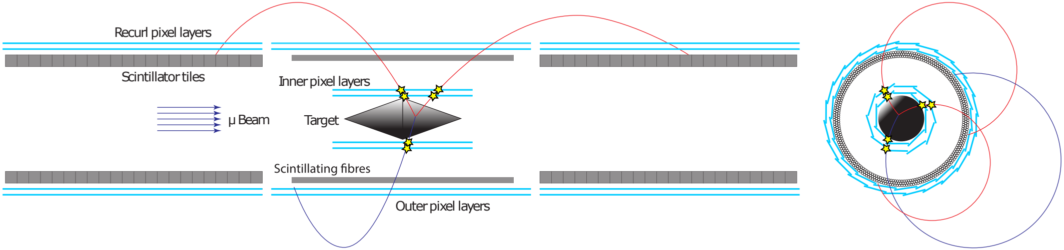

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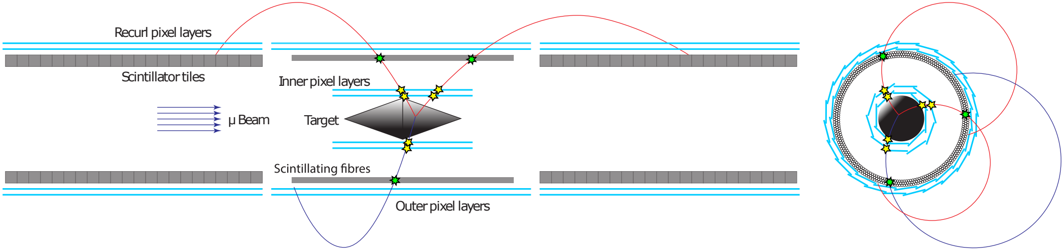

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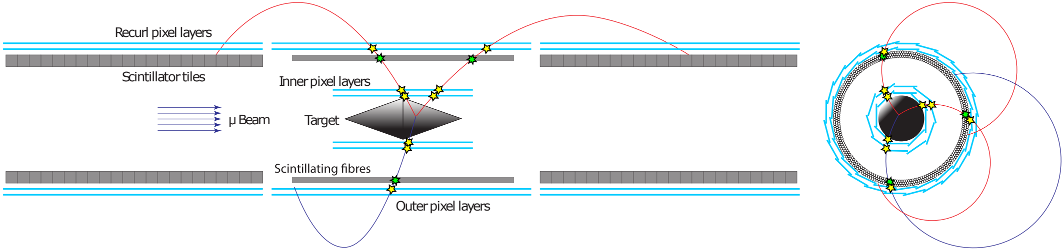

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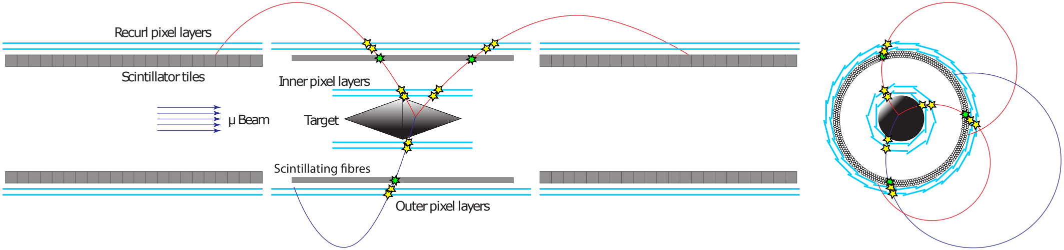

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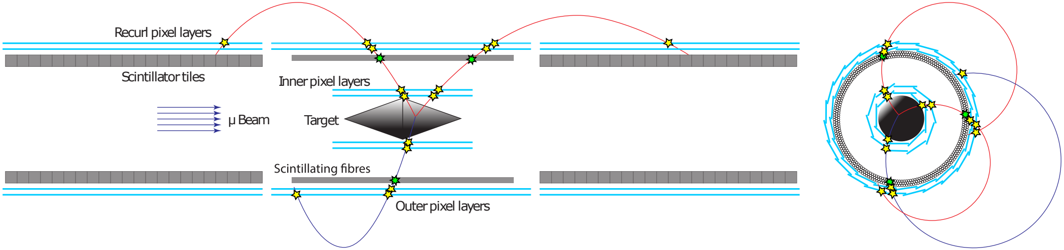

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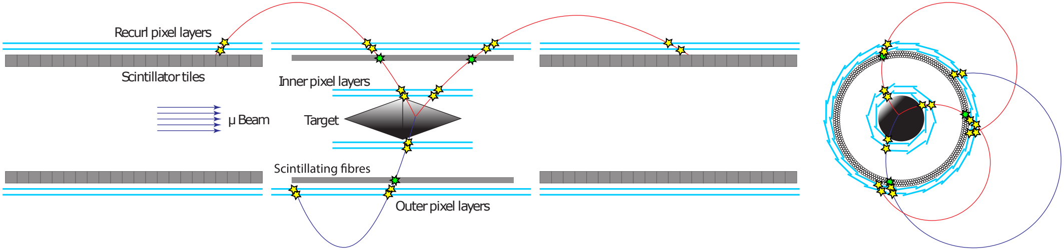

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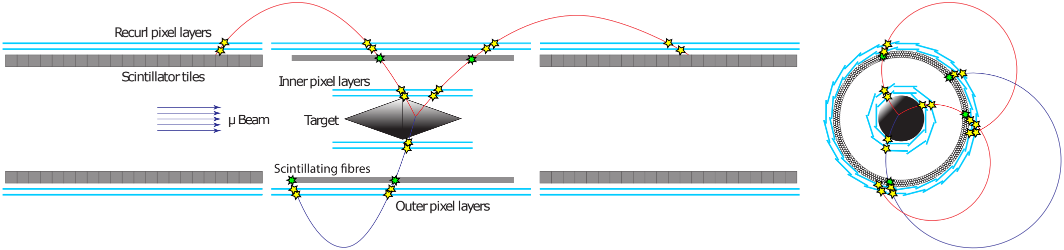

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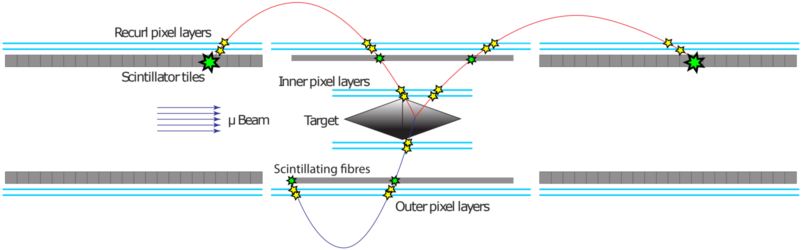

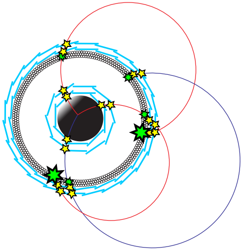

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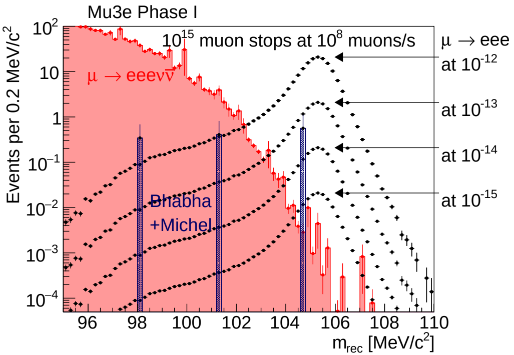

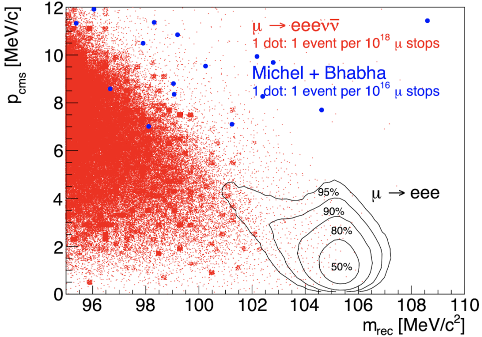

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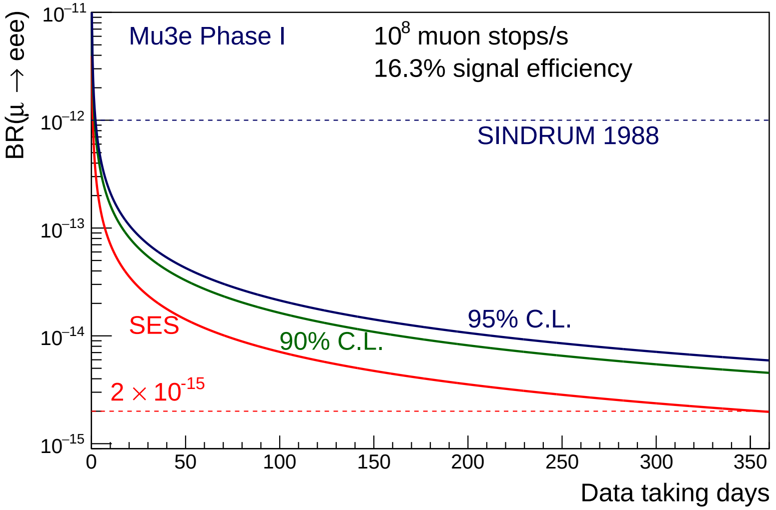


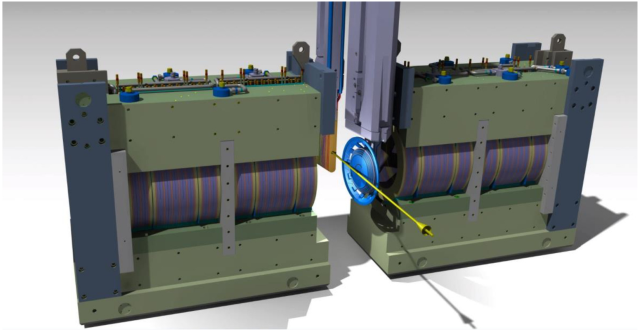
Beeam requests for 2020

Summary of our beam requests:

- πE5
  - **1+2 weeks (eoy):** CMBL commissiong 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: **M**u**O**ns for **R**esearch in **E**urope
  - Study for high intensity muon production (10×10^{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
  - Beamcharacterisation
  - 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!