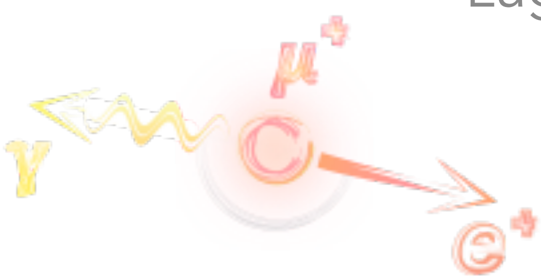
PAUL SCHERRER INSTITUT

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

In Search of Charged Lepton Flavor Violating Decays at PSI

Giada Rutar
Paul Scherrer Institut and ETH Zürich
on behalf of the MEG and Mu3e Collaborations

SPS Annual Meeting
Lugano August 2016



Why cLFV?

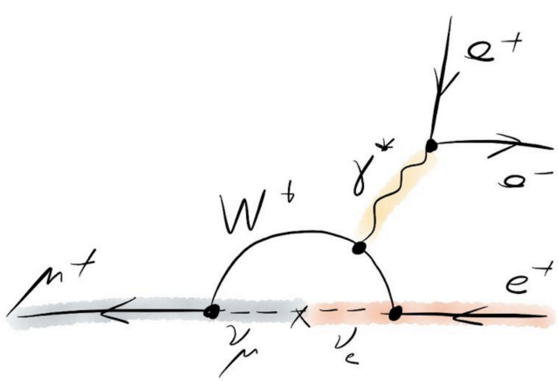
Lepton Flavor Violation observed in the **neutral** sector (ν-oscillations)

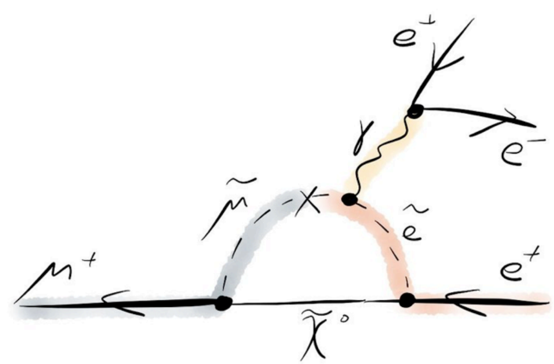
What about **charged** Lepton Flavor Violation?
Standard Model with massive neutrinos:

$$\mathcal{B}(\mu^+ \to e^+\gamma) \ll 10^{-50}$$

far beyond any exp. reach…

A cLFV signal would be clear evidence for new physics!
And if we don't observe it: Constrain new physics models

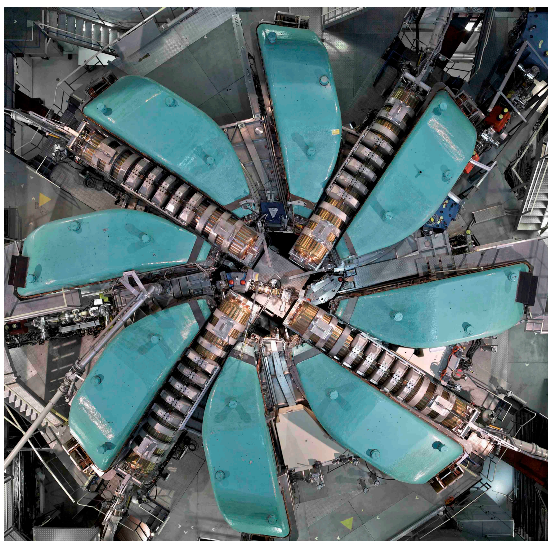




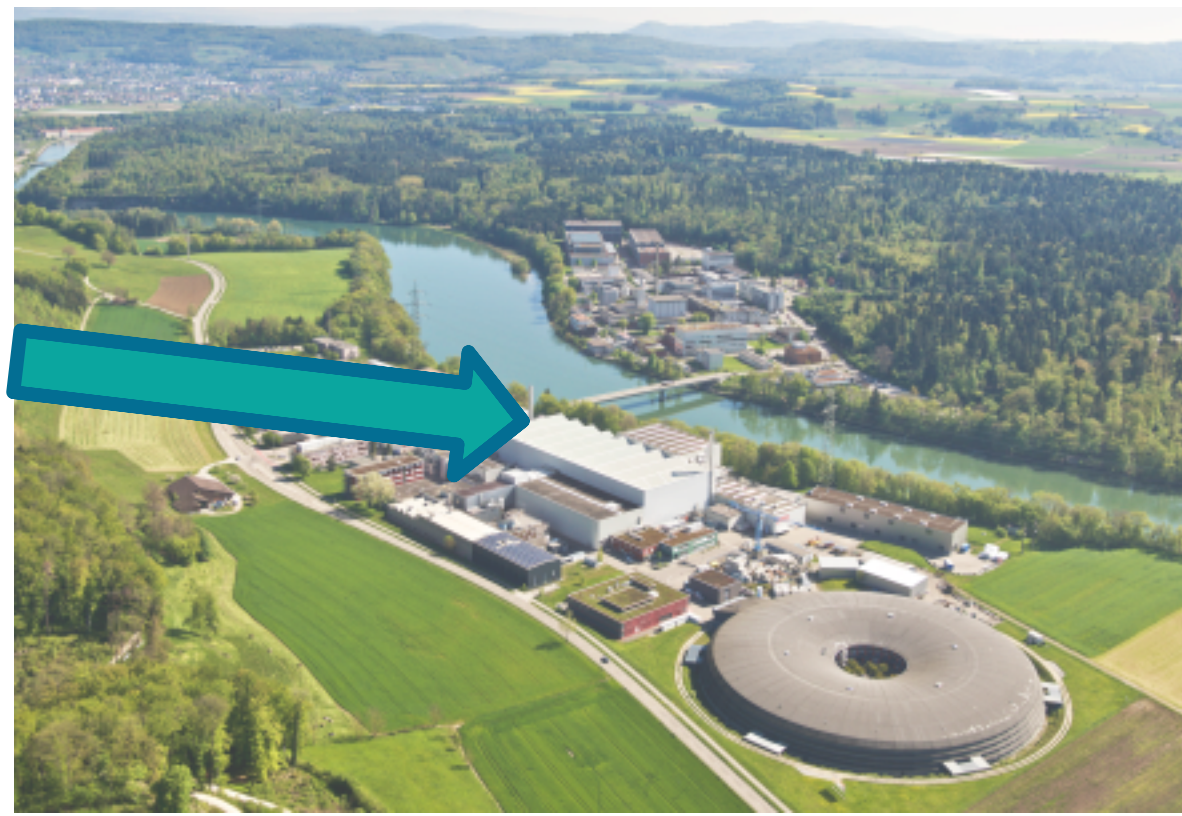
cLFV Experiments at the Paul Scherrer Institute

World's most intense continuous muon beams

O(10^8) μ/sec ➔ a unique place for cLFV searches!



HIPA facility:
590 MeV proton energy
2.3 mA proton current
1.4 MW power



Picture credits: Paul Scherrer Institut

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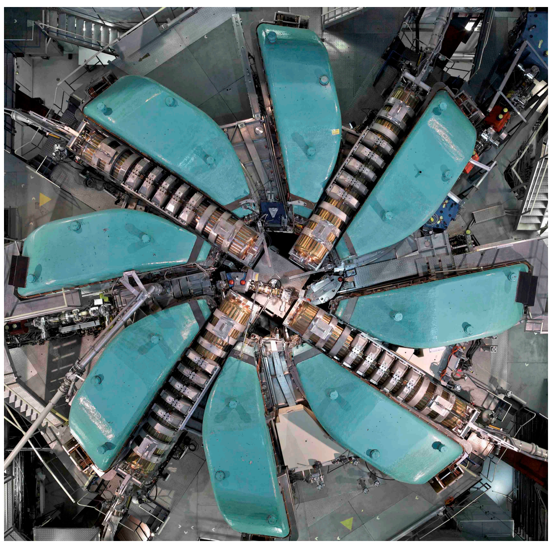

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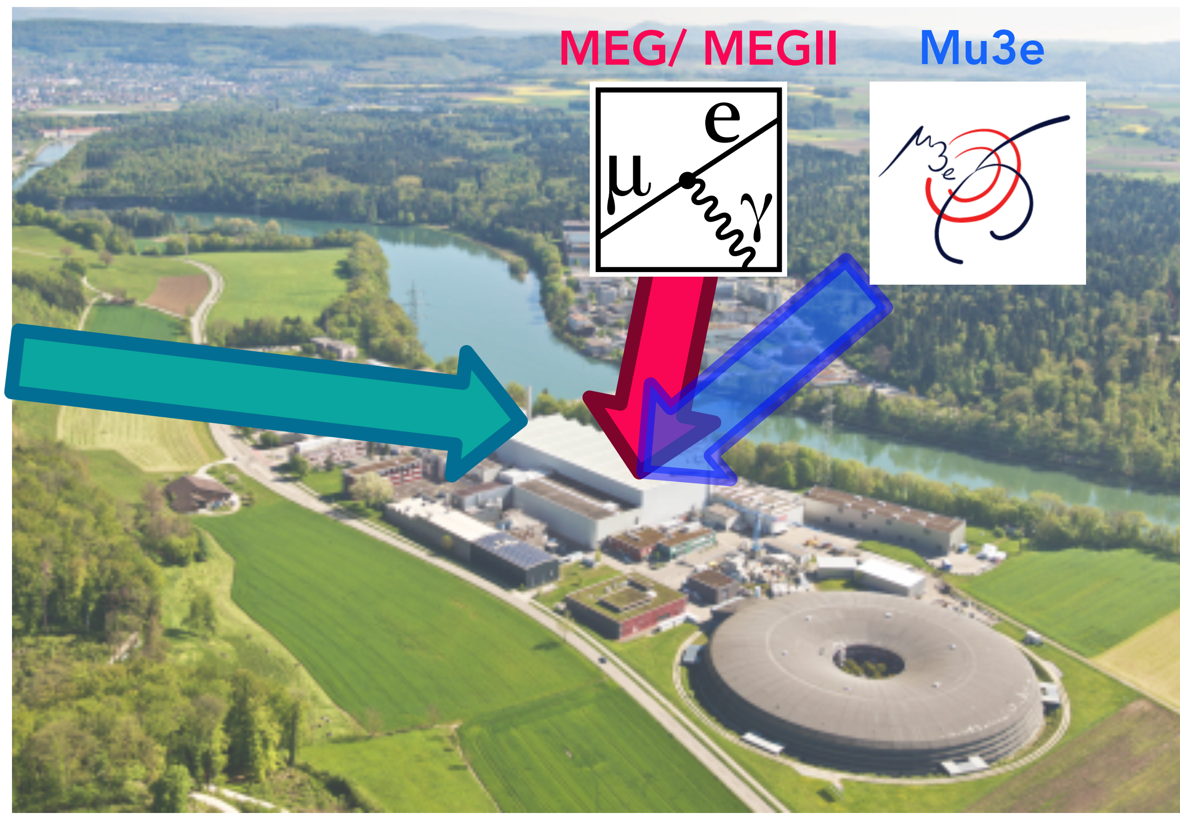


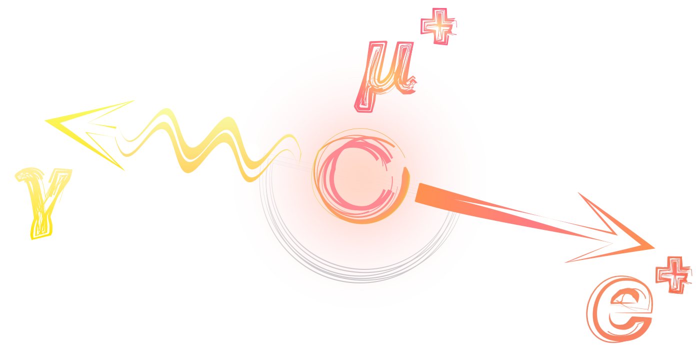
Picture credits: Paul Scherrer Institut

The MEG Experiment

Signal Signature

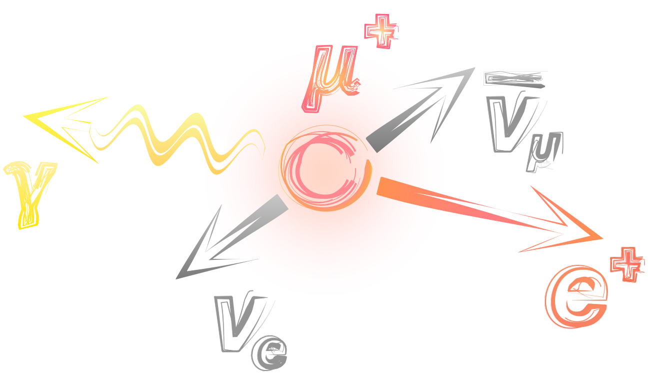
2-body-decay with e^+ and γ

- back-to-back ($\Theta_{e\gamma} = 0$)
- time-coincident ($t_{e\gamma} = 0$)
- monochromatic
  ($E_\gamma = E_{e+} = 52.8$ MeV)

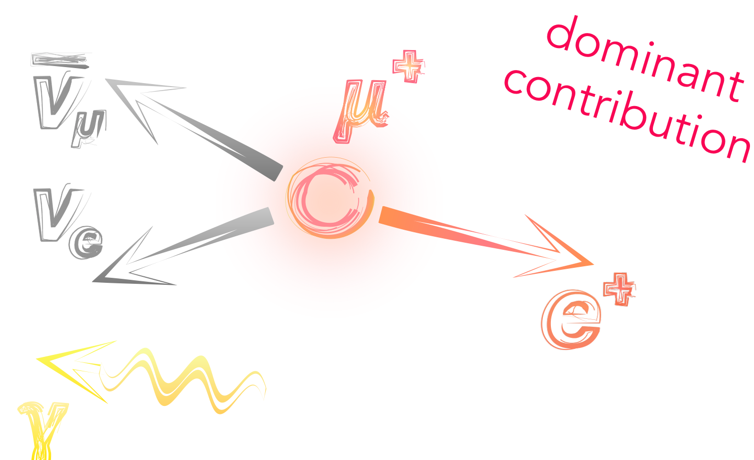


Backgrounds

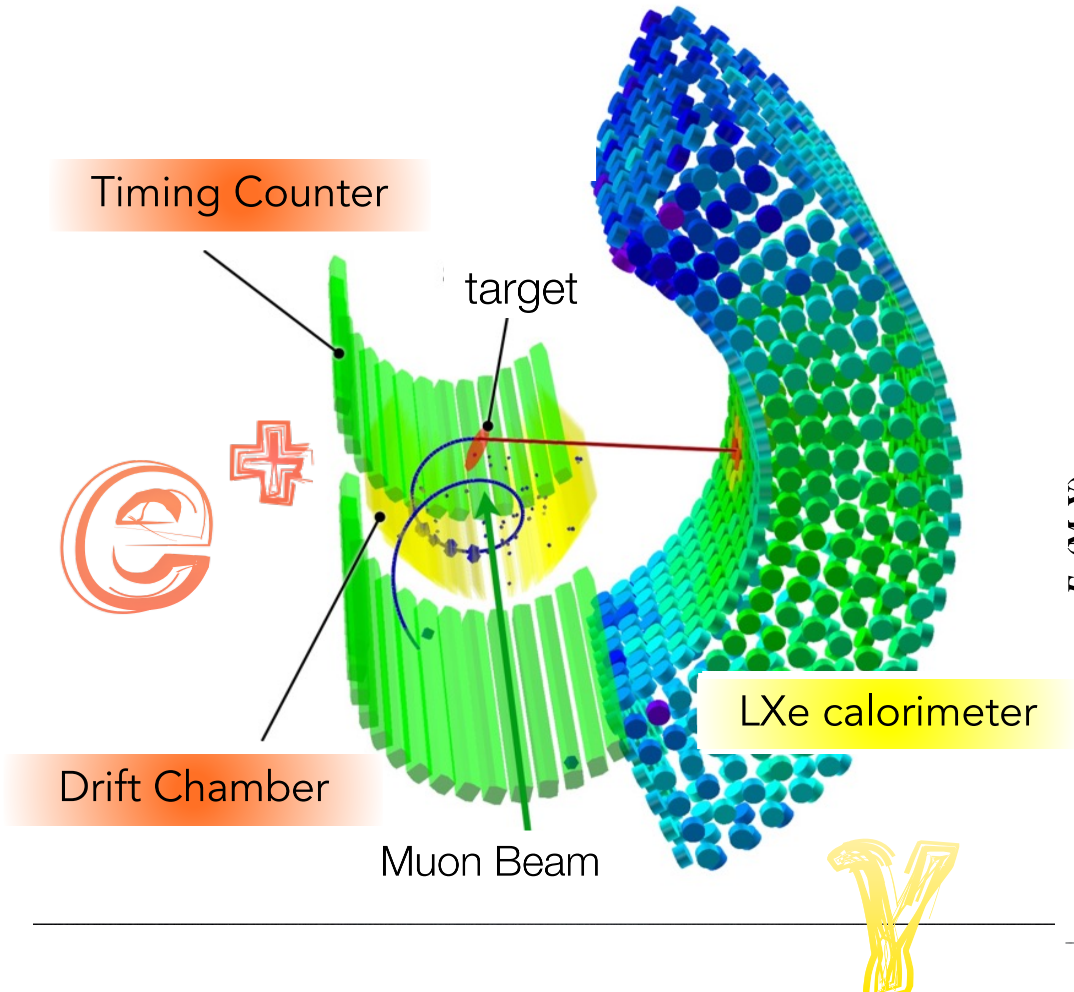
Radiative Muon Decay



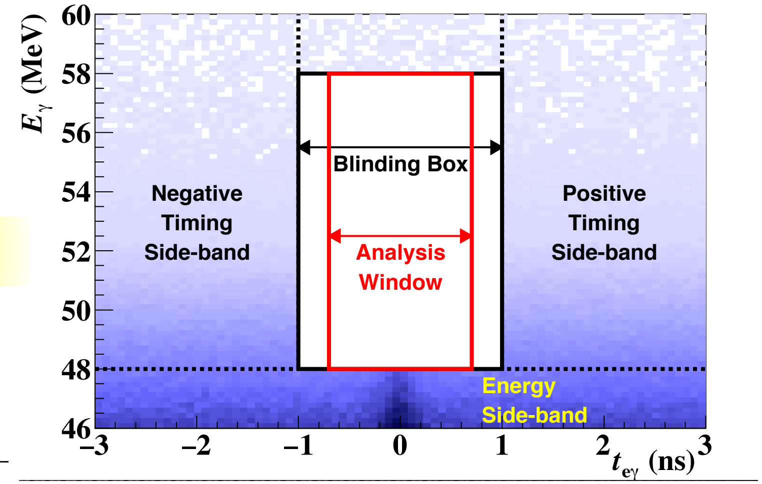
Accidentals



The MEG Experiment



Analysis strategy:
Blind maximum likelihood analysis based on the five observables
E_γ, E_e, $\theta_{e\gamma}$, $\phi_{e\gamma}$, $t_{e\gamma}$

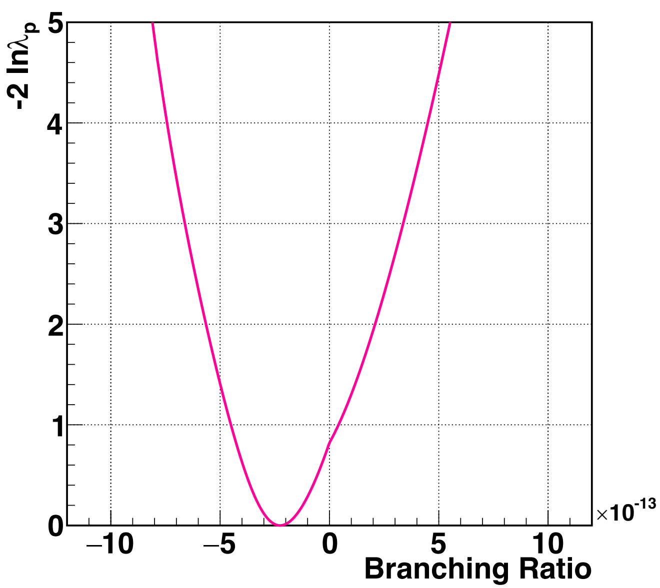


Final MEG Result

Best fitted BR consistent with the null-signal hypothesis

$$\mathcal{B}(\mu^+ \to e^+\gamma) < 4.2 \times 10^{-13}$$

90% C.L. upper limit on the BR



Full data set 2009-2013

≙ 7.5 x 10^{14} μ^+ stopped on target

Sensitivity: 5 x 10^{-13}

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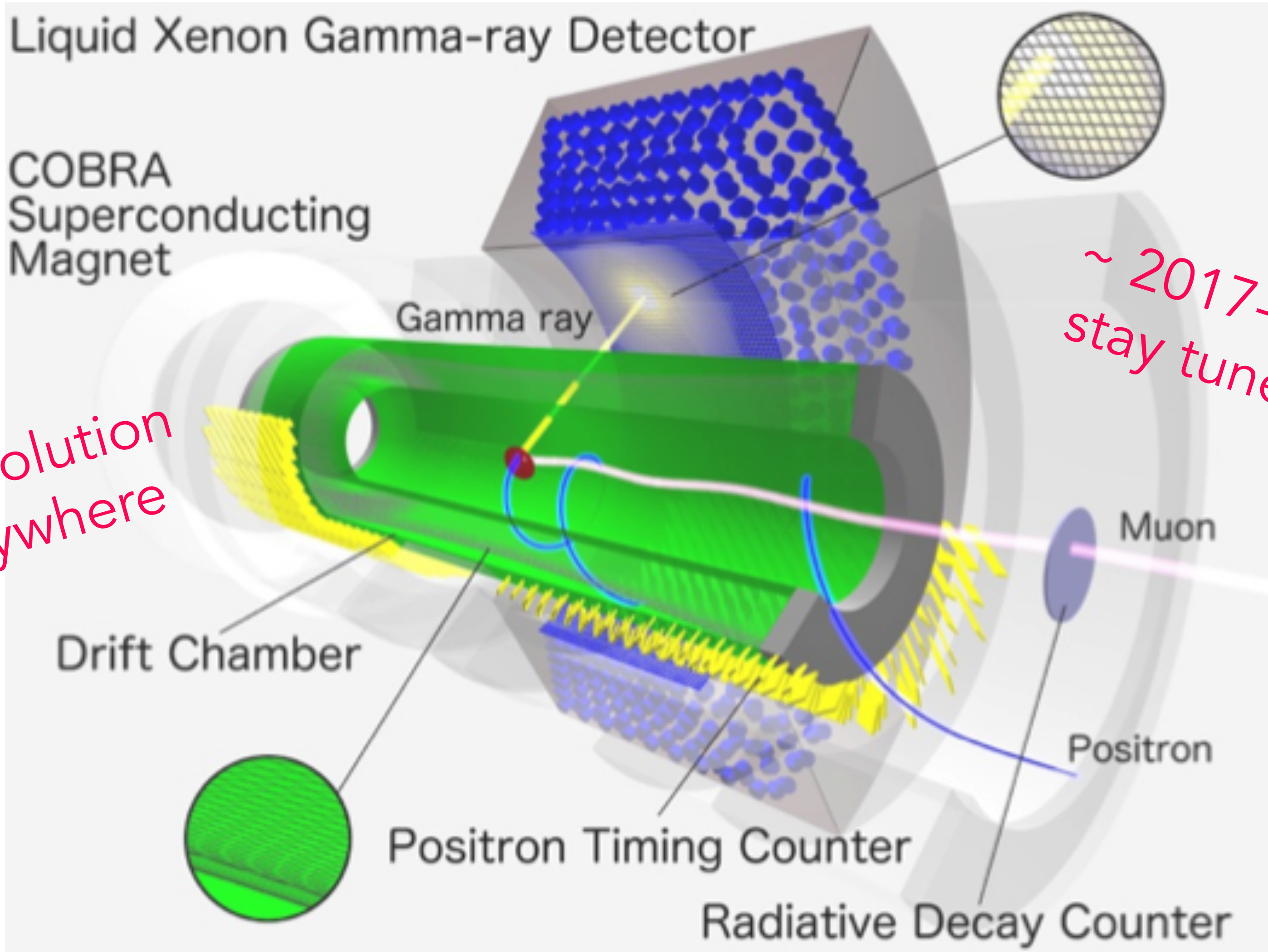
The MEGII Experiment

Sensitivity goal ≈ 5 $\times 10^{-14}$



x 2 resolution everywhere

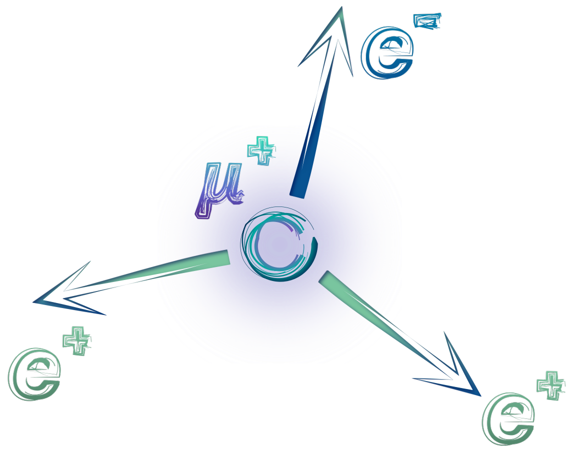
~ 2017-2020 stay tuned...

The Mu3e Experiment

Signal Signature

3-body-decay

- $\Sigma E_i = m_\mu$
- $\Sigma \mathbf{p}_i = \mathbf{0}$
- time-coincident



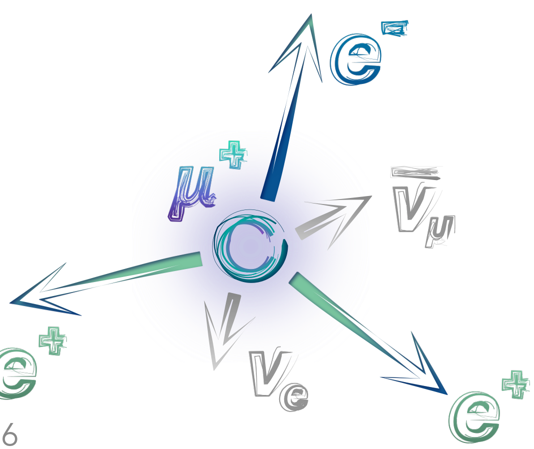
$\sigma_p \leq 0.5$ MeV/c

$\sigma_{time} \leq 1$ ns

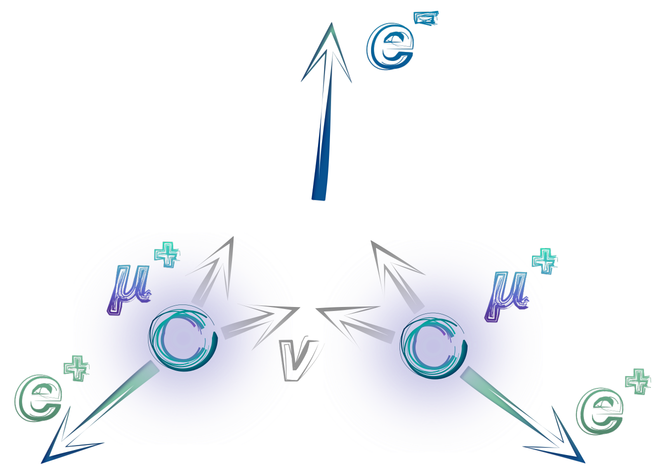
$\sigma_{vertex} \sim$ 200-300 μm

Backgrounds

Internal Conversion

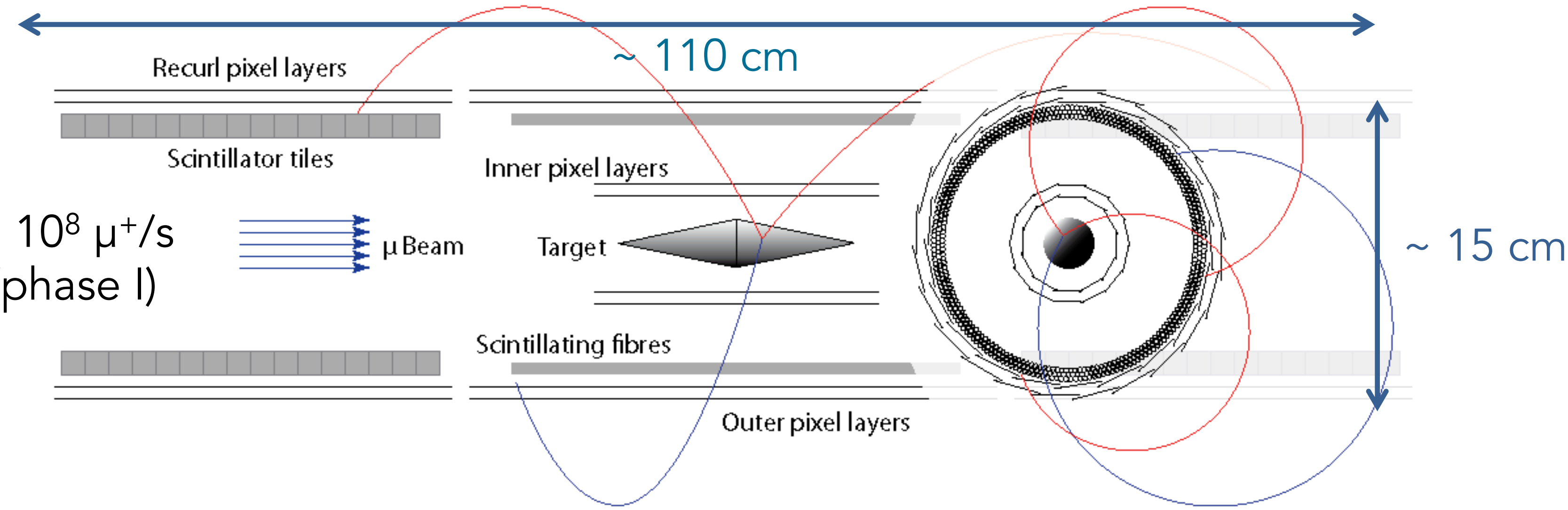


Accidentals



Experimental Layout
(Phase I)

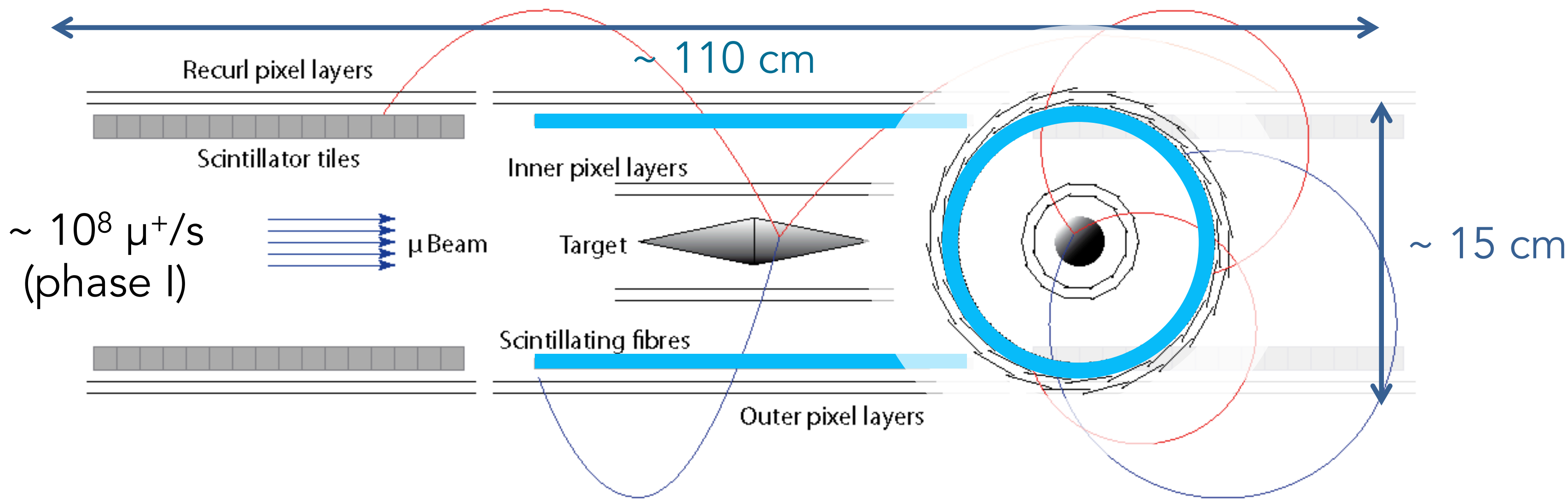
~ 10^8 μ^+/s
(phase I)



Phase I: Sensitivity goal ~10^{-15}, 10^8 μ^+/s
Phase II: Sensitivity goal ~10^{-16} , 10^9 μ^+/s

 Proposal: https://www.psi.ch/mu3e/DocumentsEN/ResearchProposal.pdf

Experimental Layout
(Phase I)



Scintillating Fiber Detector:

- Rejection of accidental background
- Unambiguous silicon hit assignment to tracks

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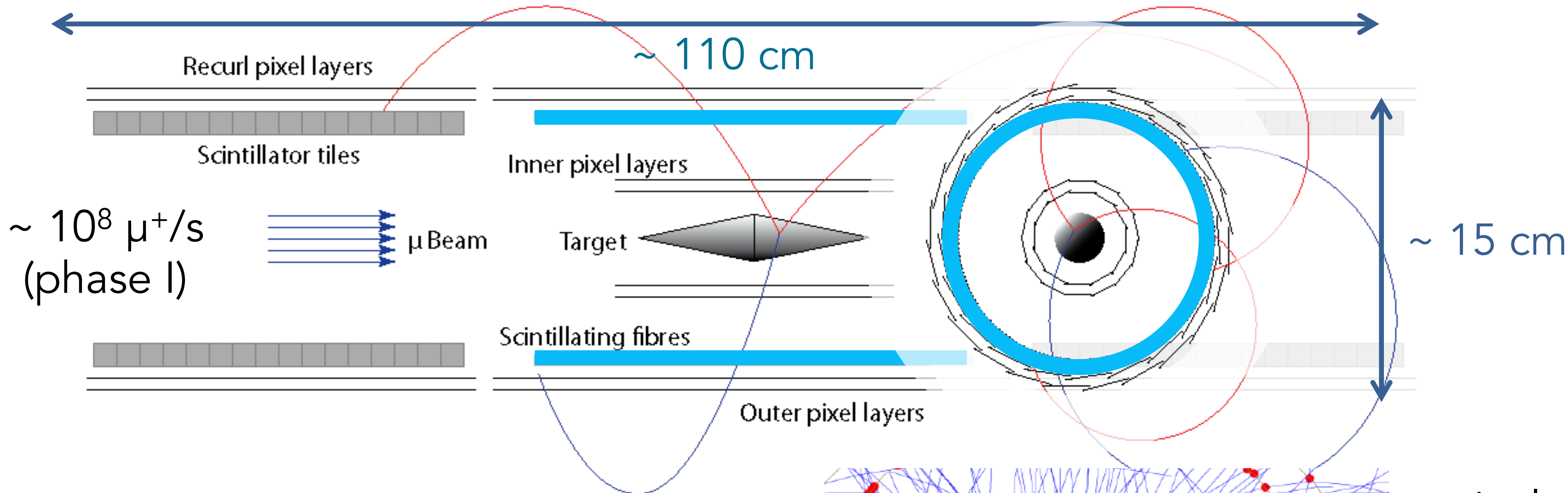
Experimental Layout
(Phase I)



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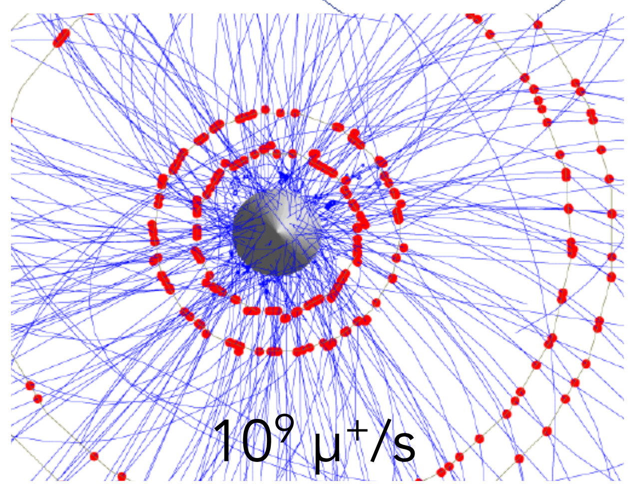

pixels
O(50 ns)

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Experimental Layout

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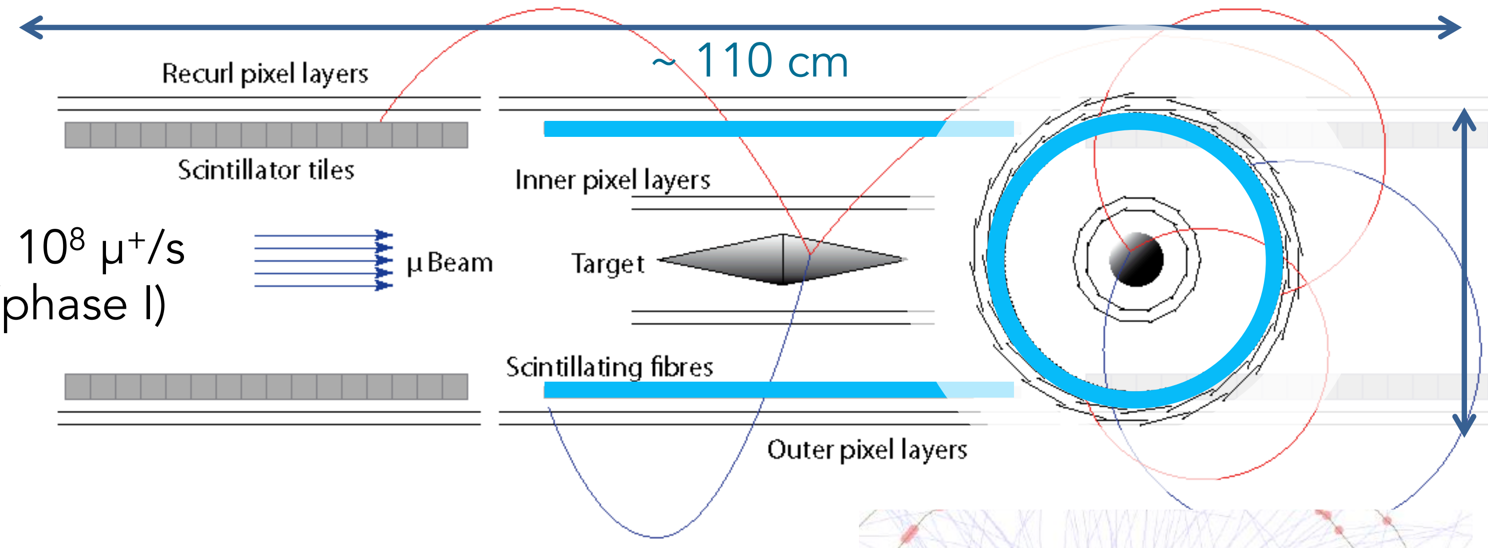

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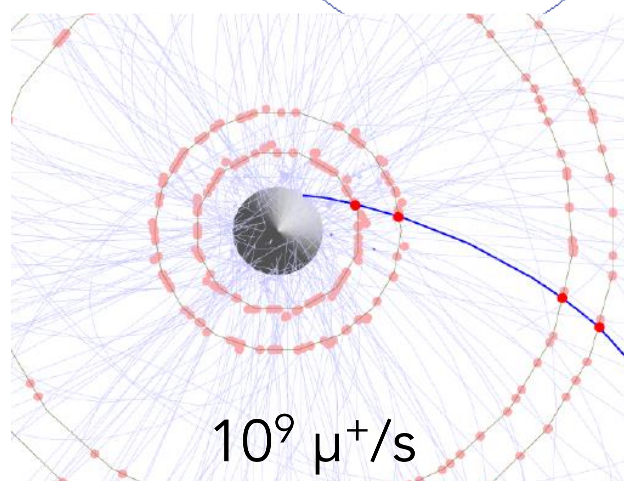

pixels O(50 ns)

+

scifi O(1 ns)

tiles O(100 ps)

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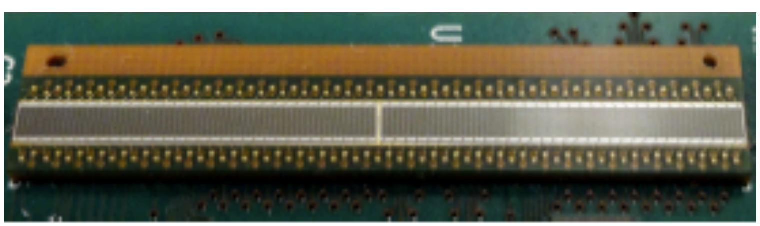
Scintillating Fiber Detector

Requirements:

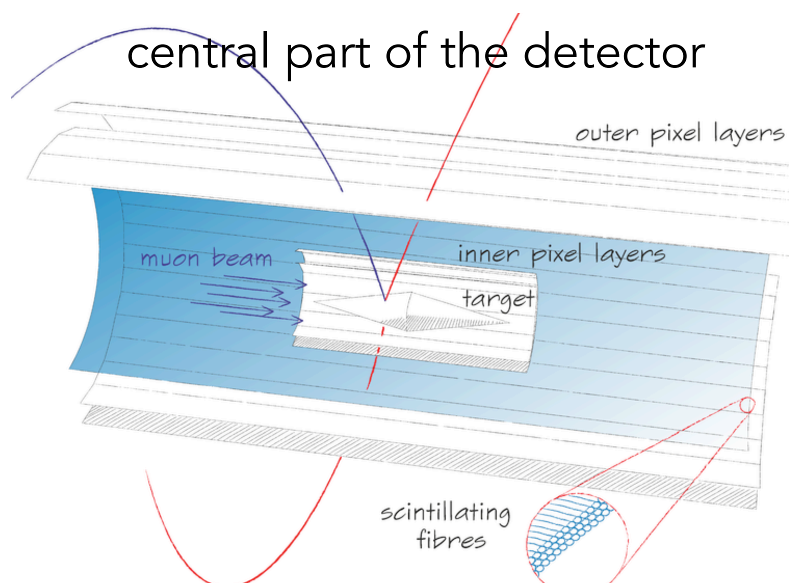
- timing resolution < 1 ns
- detection efficiency ~100 %
- as little material as possible (multiple scattering) → 3-4 layers of 250 μm thin fibers

not so easy….
expected energy deposit (MIP) ~ O(50 keV)
≅
handful detected photons per fiber layer

Baseline design:
~4'500 fibers of ~30 cm length arranged in ribbons, read out by Silicon Photomultiplier (SiPMs) arrays on both fiber ends

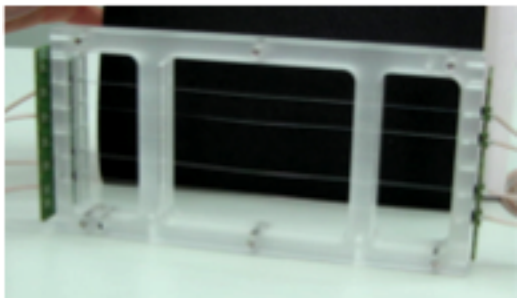


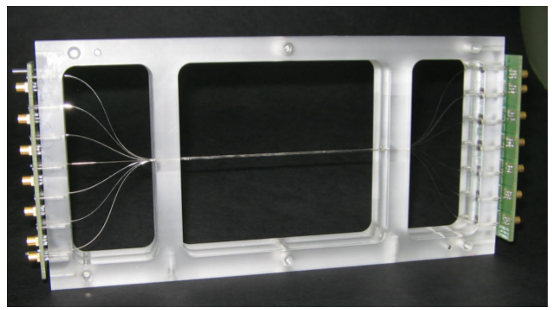
central part of the detector

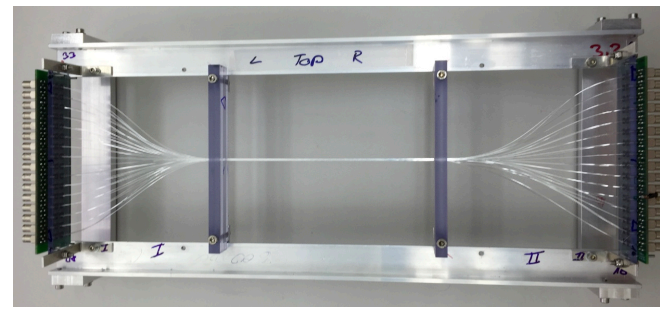


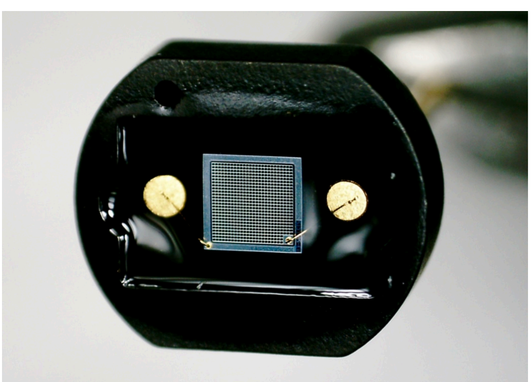
Prototype Studies

Bottom – up – approach









Hamamatsu 13360-1350-CS

Each fiber is ...

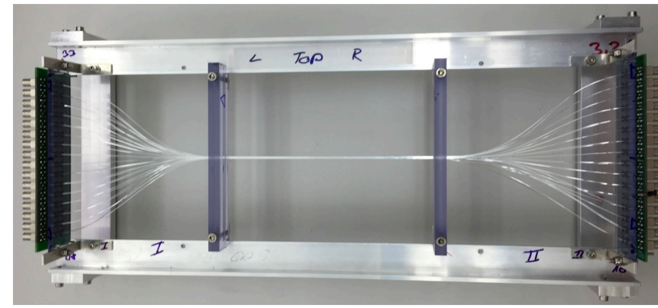
- ... **250 µm thin, squared, multiclad** (Saint-Gobain BCF-12)
- ... read out by a **SiPM on each of the two ends**
- ... **coated** with 100 nm Al to optically isolate the fibers (crosstalk among fibers < 1 %)

Prototype Studies

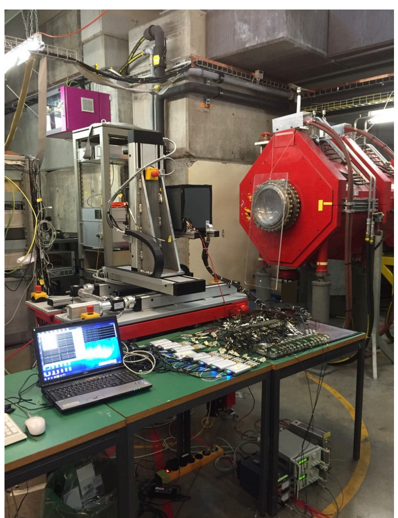
The Large Prototype

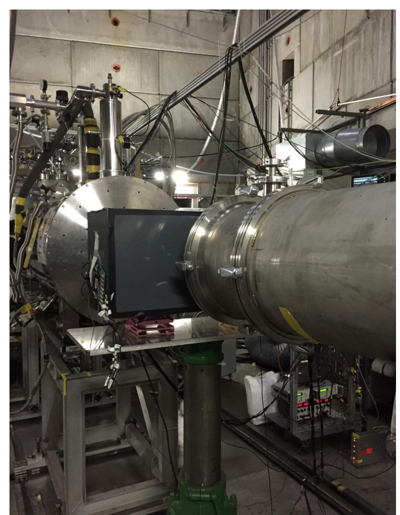
Several **test beam campaigns** at PSI beam lines (e, μ, π) and studies in the **laboratory** with a ^{90}Sr source:

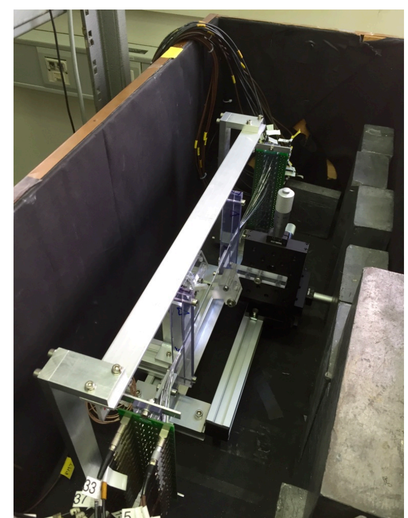
- Assess **individual fiber performance**
- Combine offline information from several SiPMs to **mimick a Mu3e fiber ribbon**



32 fibers, 64 channels



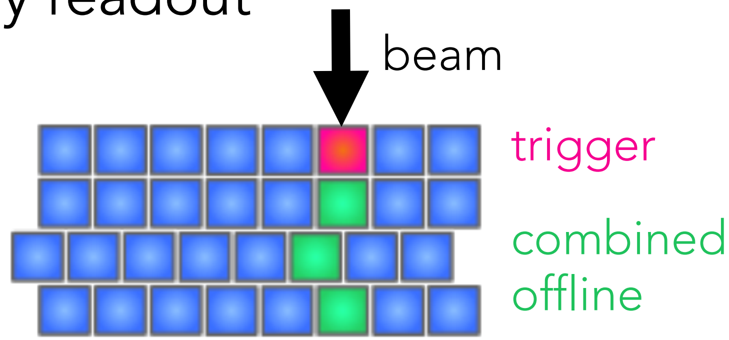


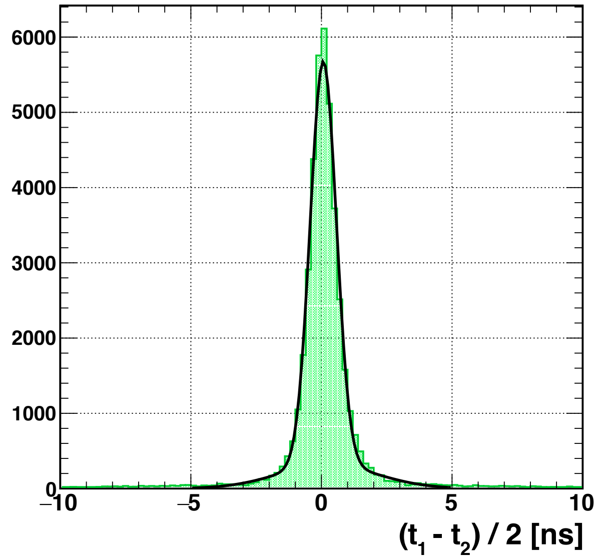


Prototype Studies

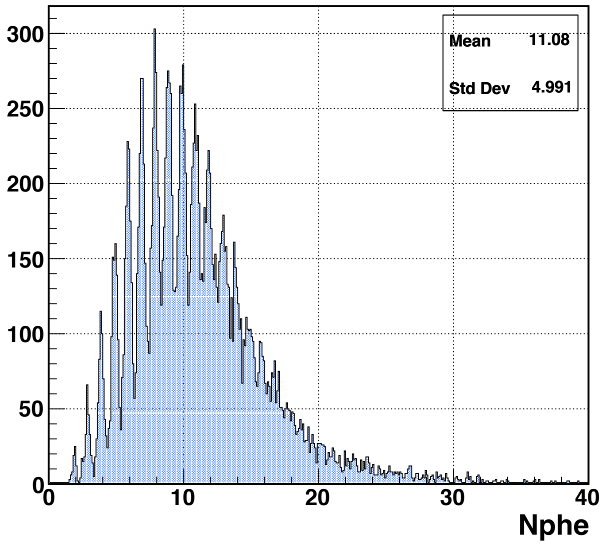
Three layers of fibers, „optimized array readout"

- **Efficiency > 95%**
- **Timing performance: σ_t ~ 550 ps**
- Ca. 11 photons per array channel (left + right)





threshold 0.5 Nphe



threshold 0.5 Nphe

Summary

- cLFV rare decay searches represent a powerful tool to look for new physics

- Paul Scherrer Institute: Searches for cLFV decays of the muon:
  - **MEG/ MEG II:** Most stringent upper limit on the $\mu \rightarrow e\gamma$ branching ratio, upgraded experiment is about to start

$$B(\mu^+ \rightarrow e^+\gamma) < 4.2 \times 10^{-13} \quad \text{@ 90\% C.L.}$$

Eur. Phys. J. C (2016) 76:434

  - **Mu3e:** Upcoming experiment looking for $\mu^+ \rightarrow e^+e^-e^+$ with a sensitivity goal of 10^{-15} during its first phase (~ 2018 onwards)