

A novel experiment searching for the lepton flavour violating decay

$\mu \rightarrow eee$

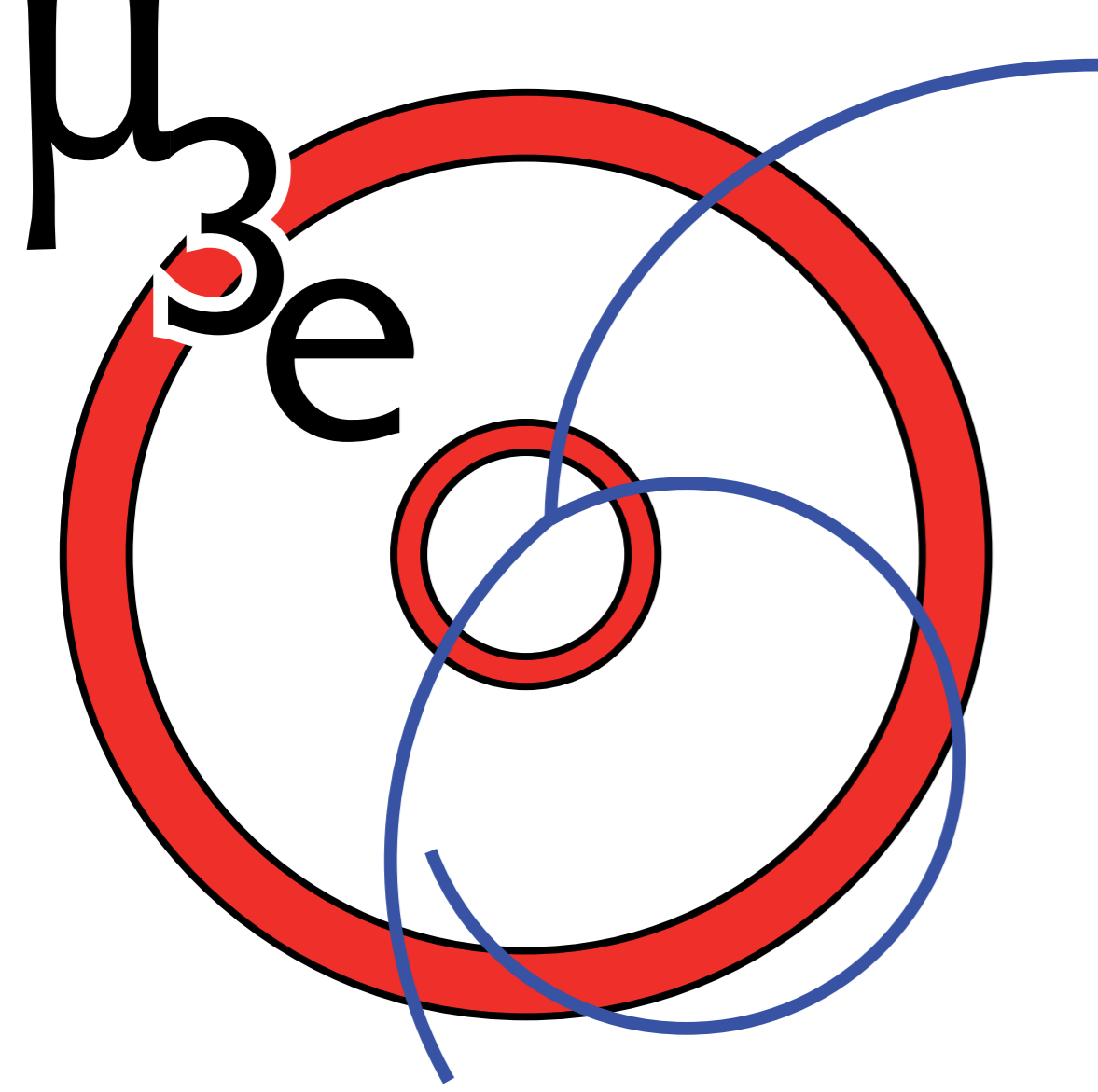
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Abstract

Since the discovery of neutrino oscillations it is known that lepton flavour is not conserved. Lepton flavour violating processes in the charged lepton sector have so far however eluded detection. They are heavily suppressed in the standard model of particle physics, an observation would be a clear signal for new physics and could help to understand the source of neutrino masses and CP violation.

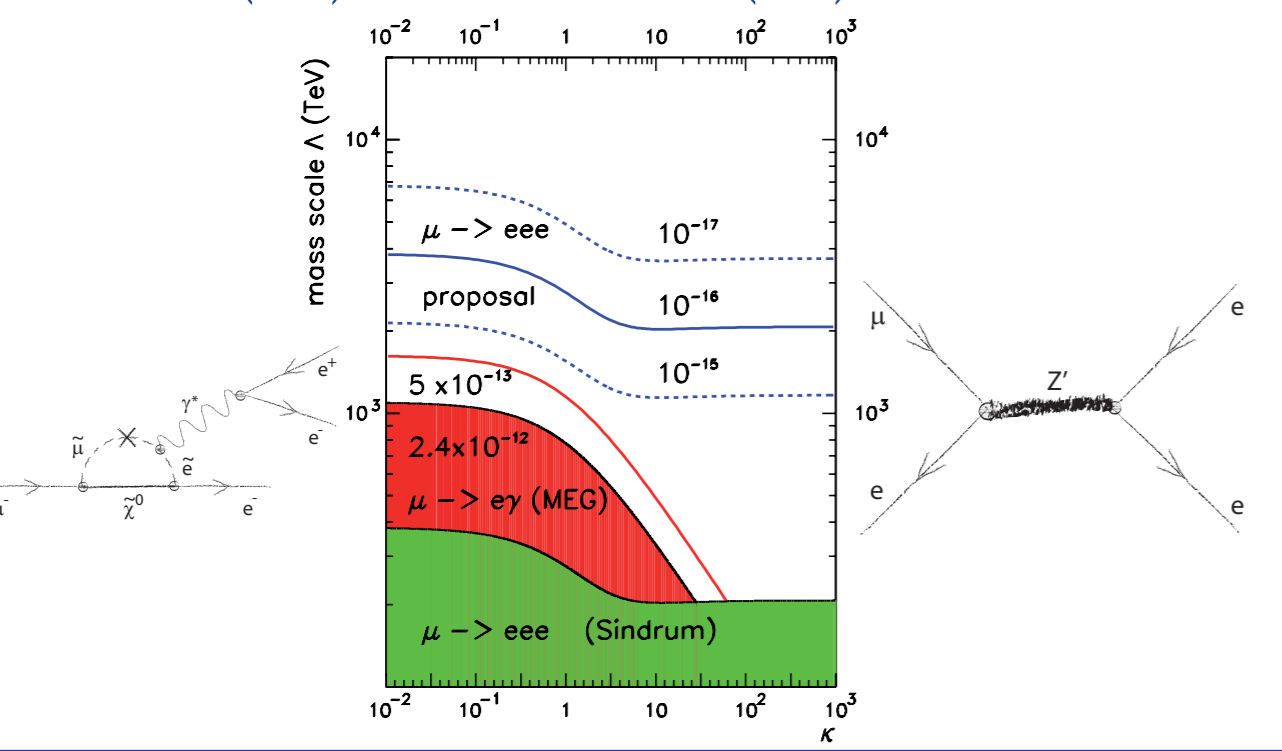
We propose a novel experiment searching for the decay $\mu \rightarrow eee$ with the aim of ultimately reaching a sensitivity of 10^{-16} , an improvement by four orders of magnitude compared to previous experiments. The technologies enabling this step are thin high-voltage monolithic active pixel sensors for precise tracking at high rates and scintillating fibres for high resolution time measurements.



Theory

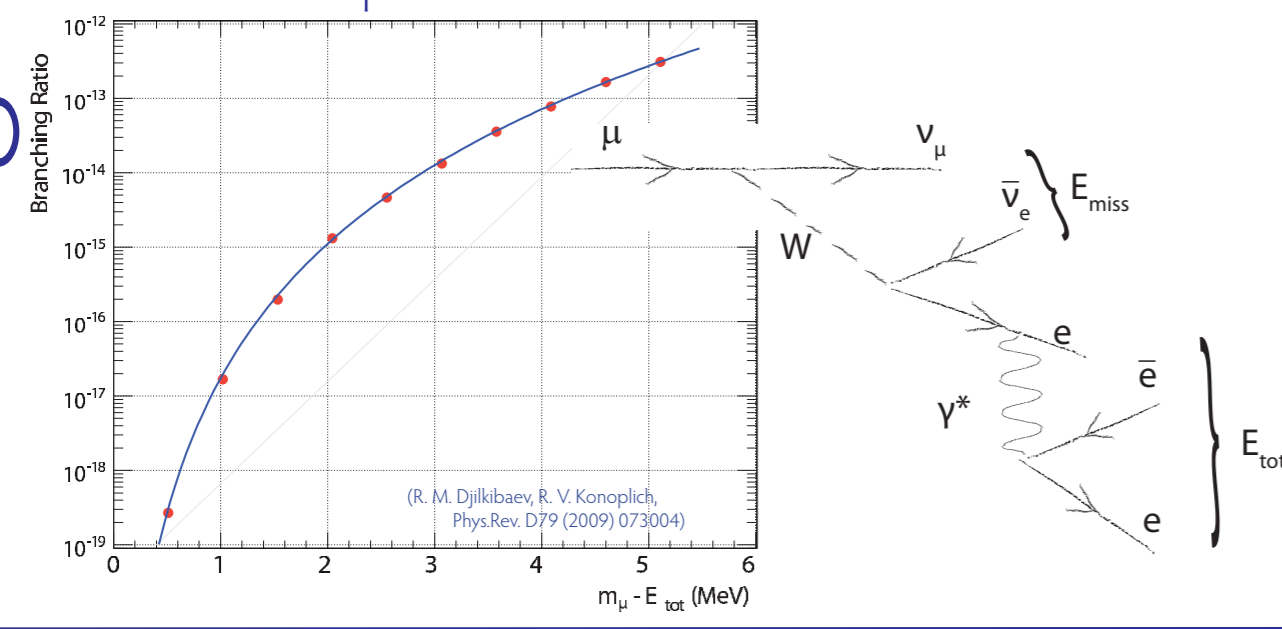
In the Standard Model (SM) of elementary particle physics, the decay $\mu \rightarrow eee$ can occur via lepton mixing, is however suppressed to unobservably low branching fractions of $O(10^{-50})$. Any observation of $\mu \rightarrow eee$ would thus be a clear signal for new physics, and indeed many models predict enhanced lepton flavour violation, e.g. supersymmetry, grand unified models, left-right symmetric models, models with an extended Higgs sector, large extra dimensions etc. LFV can proceed either via loops or at tree level. Introducing a common Λ and a relative strength κ between the dipole term and the 4-fermion contact interaction gives a simplified Lagrangian:

$$L_{LFV} = \frac{m_\mu}{(\kappa+1)\Lambda^2} A_R \bar{\mu}_R \sigma^{\mu\nu} e_L F_{\mu\nu} + \frac{\kappa}{(\kappa+1)\Lambda^2} (\bar{\mu}_L \gamma^\mu e_L) (\bar{e}_L \gamma^\mu e_L)$$



Backgrounds

The main sources of background are accidental coincidences of tracks from Michel decays with electron-positron pairs from Bhabha scattering, photon conversion etc. and the radiative decay with internal conversion $\mu \rightarrow eee\nu$ (BR 3.4×10^{-5}). The first requires excellent vertex and timing resolution, the second the best possible momentum resolution.



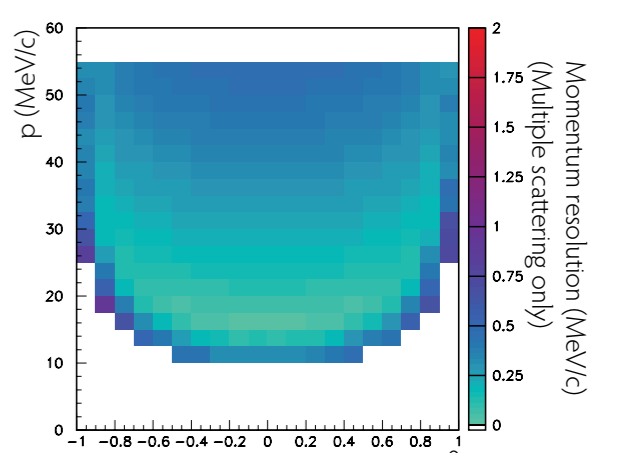
Challenges

- High rates
- Excellent momentum resolution
- Great vertex resolution
- Good timing resolution
- Extremely low material budget

Tracking

Use central part of detector for track finding, vertexing and timing. The best resolution despite multiple scattering is obtained from tracks curling half turns in the ~ 1 T field.

Momentum resolutions ~ 0.3 MeV/c are thus possible over a wide kinematic range, making a three track mass resolution ~ 0.3 MeV/c possible

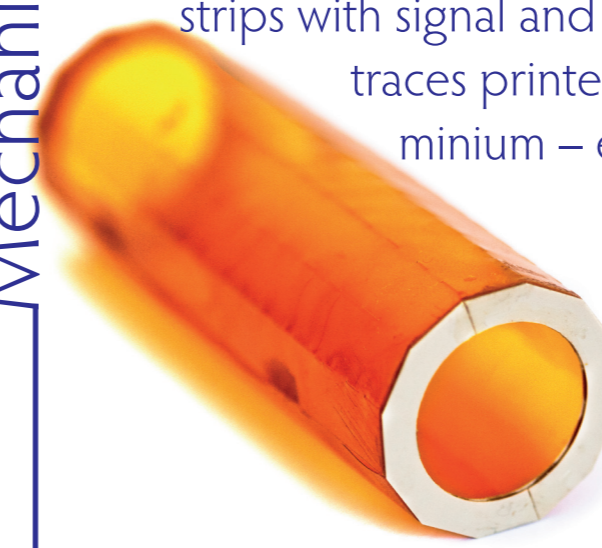


Detector Concept

Long Tube For a high acceptance of recurling particles, the detector needs to be a long (>1 m) tube. However only the central ~ 25 cm need to be thin, simplifying mechanics and allowing for precise timing in thick scintillator tiles

Mechanics

Sensors supported on $25 \mu\text{m}$ Kapton™ strips with signal and power traces printed in Aluminium – extremely light and surprisingly sturdy

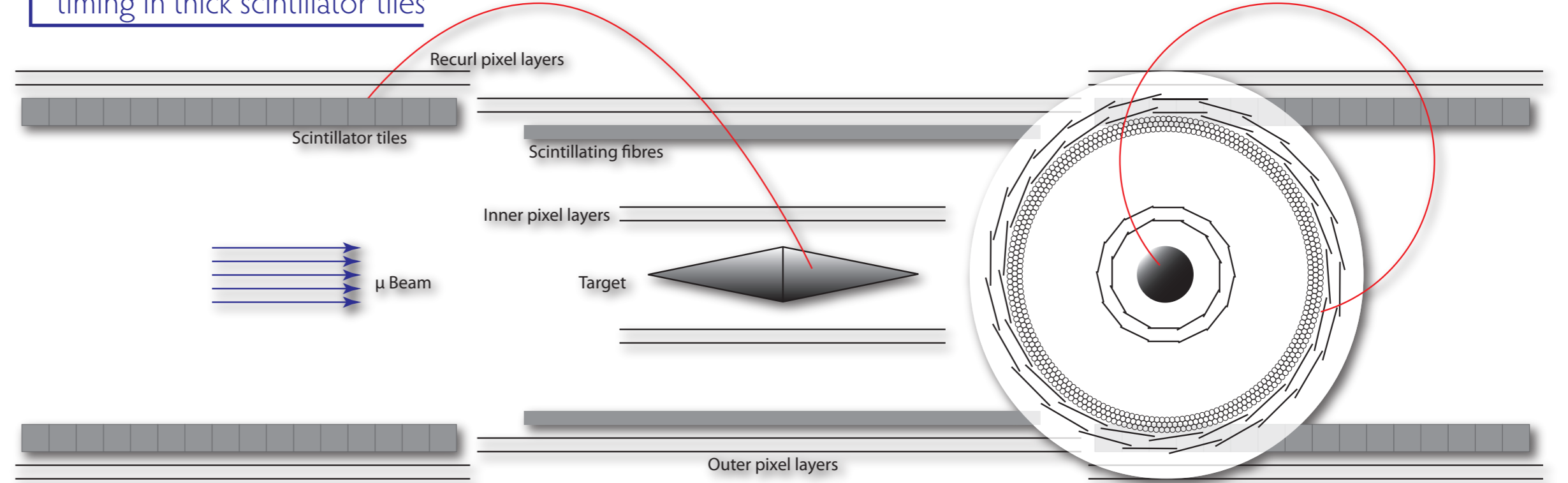


target

Double cone target made from $70 \mu\text{m}$ Aluminium – large area for good vertex separation

Timing

$250 \mu\text{m}$ scintillating fibres in the central region for first timing measurement
 • Precise timing from ~ 1 cm thick scintillating tiles in the recurl tubes

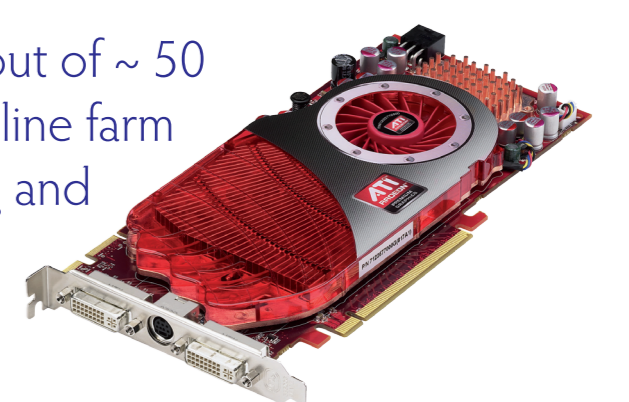


Pixel Sensors

- $80 \mu\text{m}$ pixels
- Sensors cut to 2×6 or 1×6 cm
- Thinned to $< 50 \mu\text{m}$
- Thickness of 4 pixel layers $\sim 2\% X_0$
- Total ~ 200 Million pixels
- Cooled by helium atmosphere
- maximum readout frequency ~ 20 MHz
- binary readout

Readout

- Triggerless readout of ~ 50 Gbyte/s to an online farm
- Fast track finding and reconstruction on GPUs ($> 10^9$ tracks/s)
- Reduction to ~ 50 Mbyte/s for offline storage and analysis.

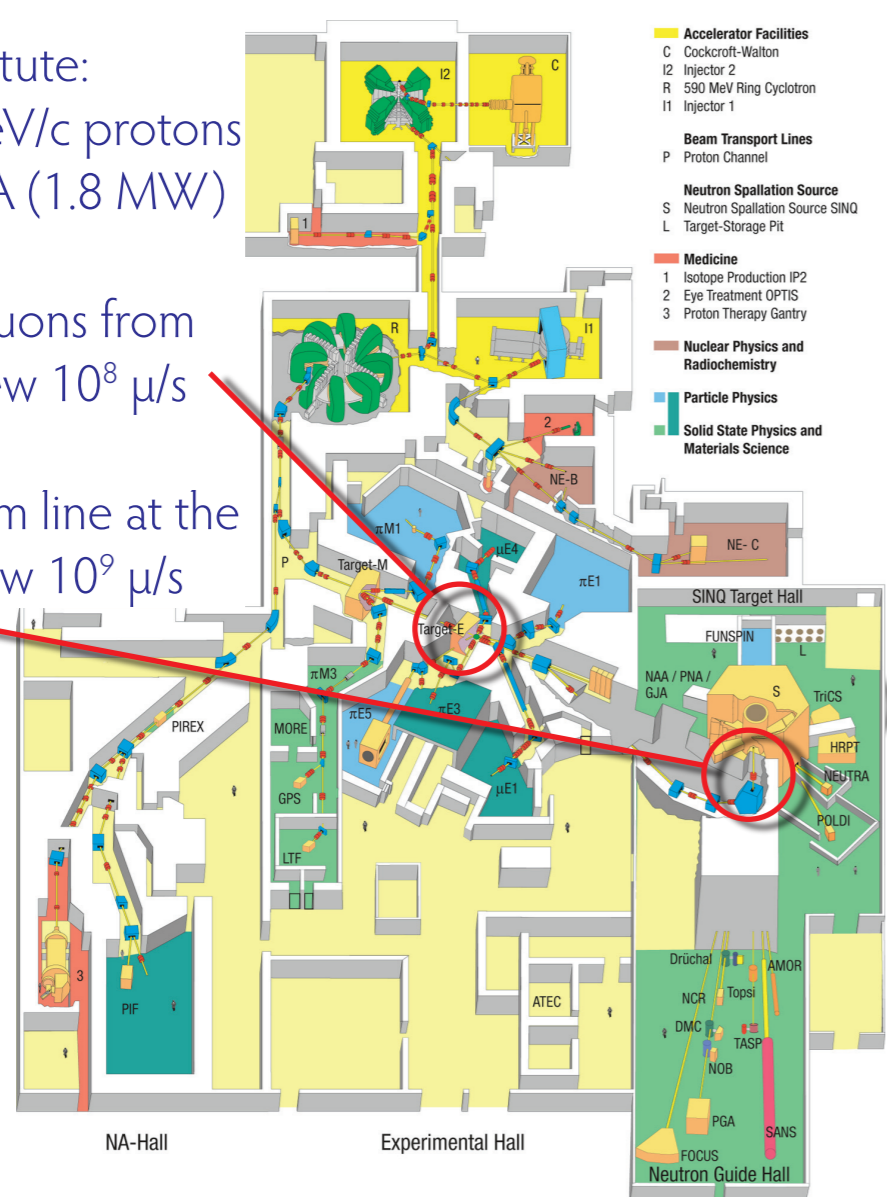


μ beams at PSI

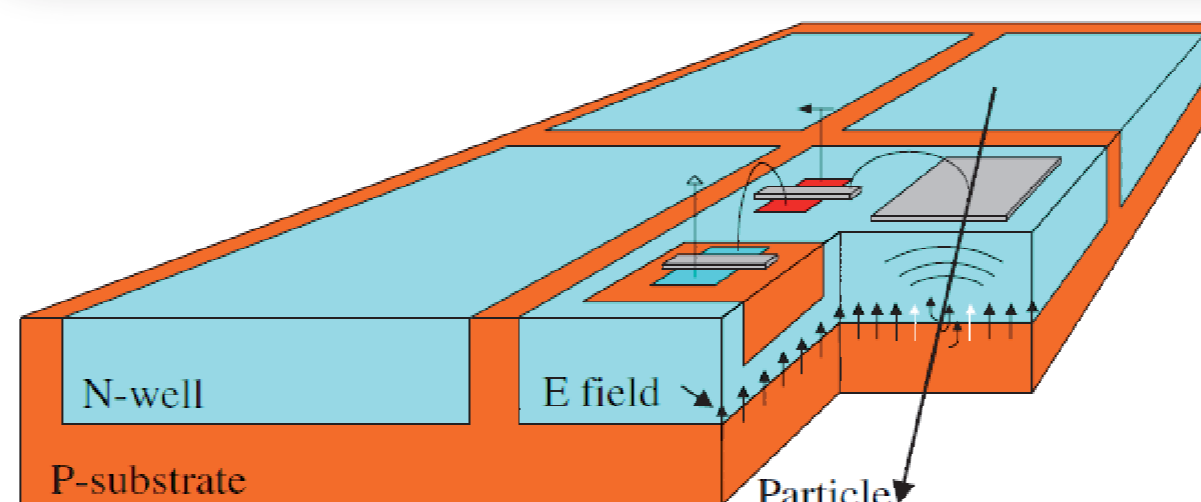
Paul Scherrer Institute:
 2.2 mA of 590 MeV/c protons
 Future: up to 3 mA (1.8 MW)

Phase I: Surface muons from target E, up to a few $10^8 \mu\text{s}$

Phase II: New beam line at the neutron source, few $10^9 \mu\text{s}$ possible



HV MAPS



Using a commercial 180 nm CMOS process originating in the automotive industry, high voltage monolithic active pixel sensors housing the pixel electronics inside a deep N-well can be implemented. The high voltage (~ 50 V) leads to a small depletion zone with fast charge collection. Most of the substrate is passive and can be thinned away down to $< 50 \mu\text{m}$.

Ref.: I. Peric, A novel monolithic pixelated particle detector implemented in high-voltage CMOS technology Nucl.Instrum.Meth., 2007, A582, 876

Outlook

(Preliminary schedule)

- 2011 Simulation studies, feasibility of mechanics, forming of a proto-collaboration
- 2012 Letter of intent to PSI, Tracker prototype, technical design
- 2013 Technical design report, detector construction
- 2014 Installation and commissioning at PSI
- 2015 Data taking at up to a few $10^8 \mu\text{s}$
- 2016+ Construction of new beamline at PSI
- 2017+ Data taking at up to $3 \cdot 10^9 \mu\text{s}$