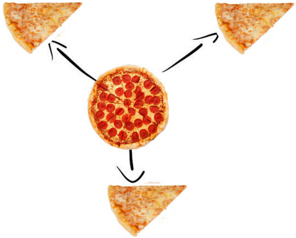
HV-MAPS for the Mu3e–Experiment

Fabian Förster



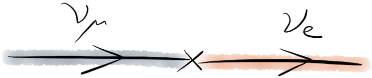
IFAE Pizza Seminar

Institut de Física d'Altes Energies

24. November 2015

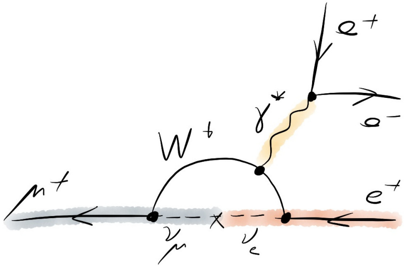
Lepton Flavour Violation

Neutral LFV



- not allowed in Standard Model
- extending SM by adding mass to neutrinos

Charged LFV



- has never been observed for any flavour

History of LFV Searches

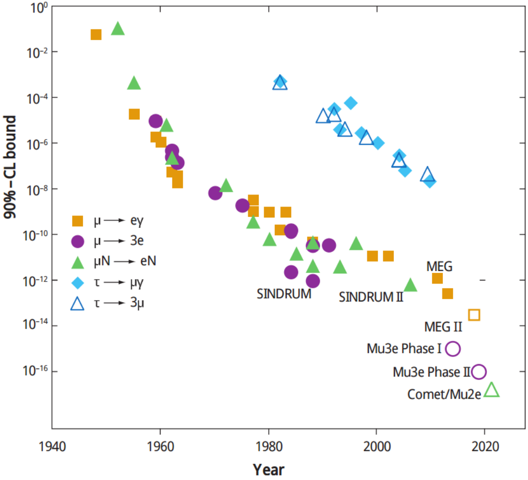
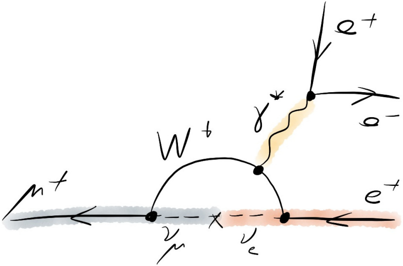


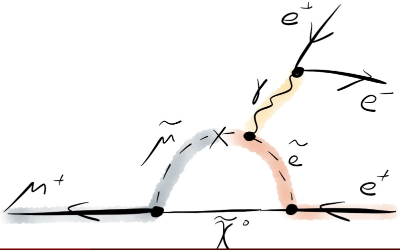
Figure: Adapted from Marciano et al. [Ann.Rev.Nucl.Part.Sci.58, 2008]

$\mu^+ \to e^+e^+e^-$ in the Standard Model and more

Standard Model:



Supersymmetry:



- In the Standard Model suppressed by $\left(\Delta m_\nu^2 / m_W^2\right)^2$ with a Branching fraction $< 10^{-54}$

Observable rate only from New Physics:

- SUSY, Little Higgs models, Seesaw models,..

Goal: 10^{-16}

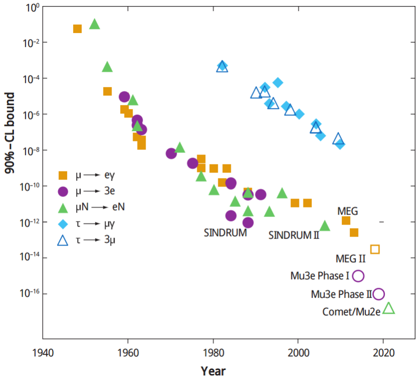
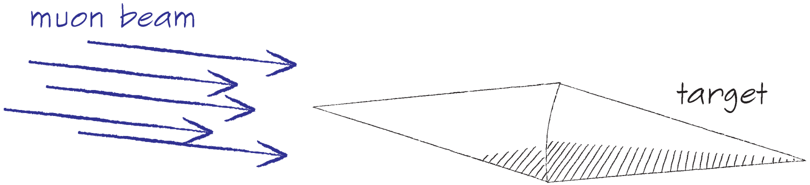


Figure: Adapted from Marciano et al. [Ann.Rev.Nucl.Part.Sci.58, 2008]

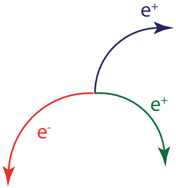
- Goal: Find or exclude $\mu^+ \rightarrow e^+e^+e^-$ up to 10^{-16}
- 10^{-15} in Phase I (existing beamline)
- 10^{-16} in Phase II (new beamline)
- Previous limit: 10^{-12} by SINDRUM (1988)

Basic Idea: Stop Muons and let them Decay



Event Topology

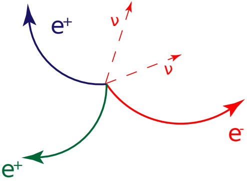
Signal:



- Common vertex
- $\sum \vec{p}_i = 0$
- $p < 53\,\mathrm{MeV}$

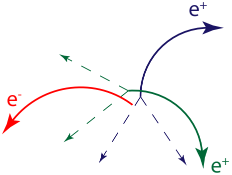
Backgrounds:

Internal Conversion



- Common vertex
- $\sum \vec{p}_i \neq 0$
- In time

Combinatorical



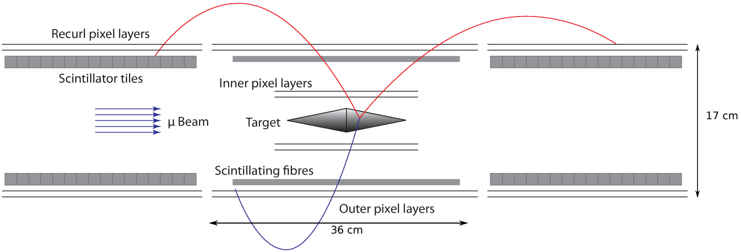
- No common vertex
- Out-of-time

Requires $\sigma_p < 0.5\,\mathrm{MeV}$

$\sigma_t < 1\,\mathrm{ns}$

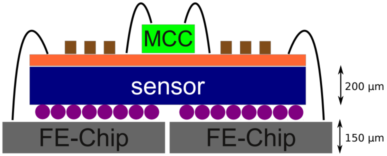
Low material budget

Detector Concept



- High intensity Muon Beam at PSI: $10^7 - 10^8 \mu^+$ Decays/s
- Solenoidal magnetic field $B = 1\,\mathrm{T}$
- **Low material budget detector:**
  - Pixel tracking detector: HV–MAPS
  - Timing detectors: scintillating fibres and tiles
  - Gaseous helium cooling

Latest ATLAS Tracker Module: IBL



Hybrid technology:

- 200–230 µm sensor
- 150 µm readout Chip

Advantages:

- optimize sensor and chip separately
- high signal

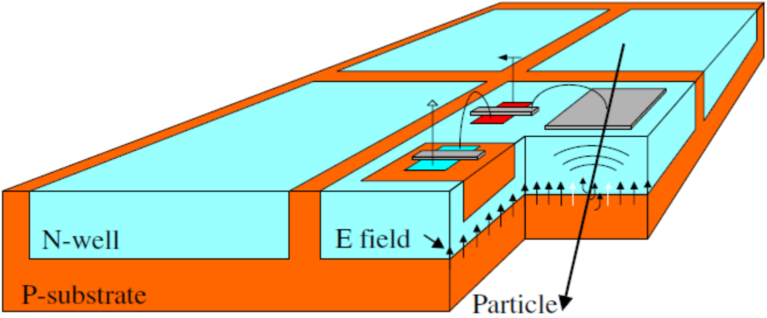
Disadvantages:

- expensive
- high noise
- complex production
- **high material budget (1.5 % radiation length)**

Fast and thin sensors: HV-MAPS

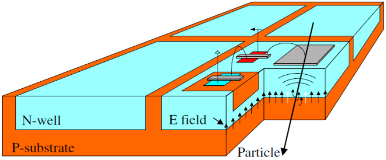
HV-**M**onolithic **A**ctive **P**ixel **S**ensor:

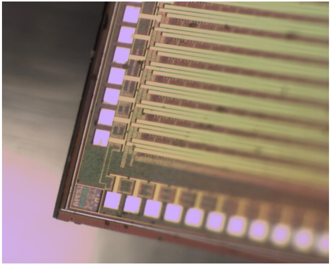
- Use of high voltage commercial process (automotive industry)



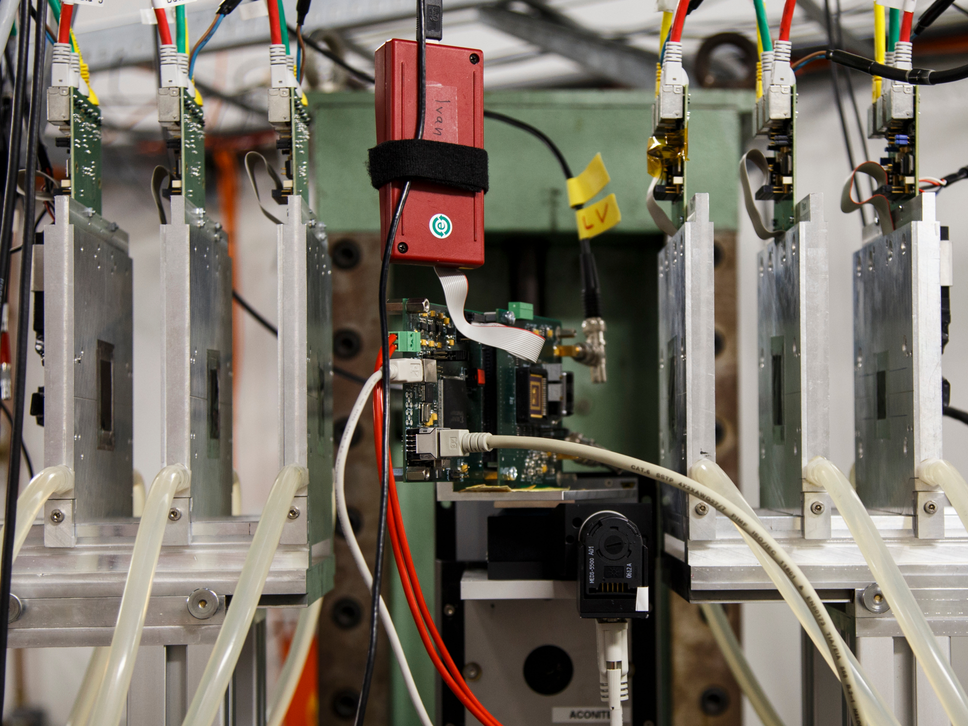
Fast and thin sensors: HV-MAPS

- 180 nm HV-CMOS process (HV $\leq$ 90 V)
- Charge collection via drift ($\sim$ 10 ns)
- Integrated digital readout
- Depletion zone 10 µm
  Can be thinned down to 50 µm
- Pixel size: 80 µm $\times$ 80 µm
- Chip size: 2 cm $\times$ 2 cm

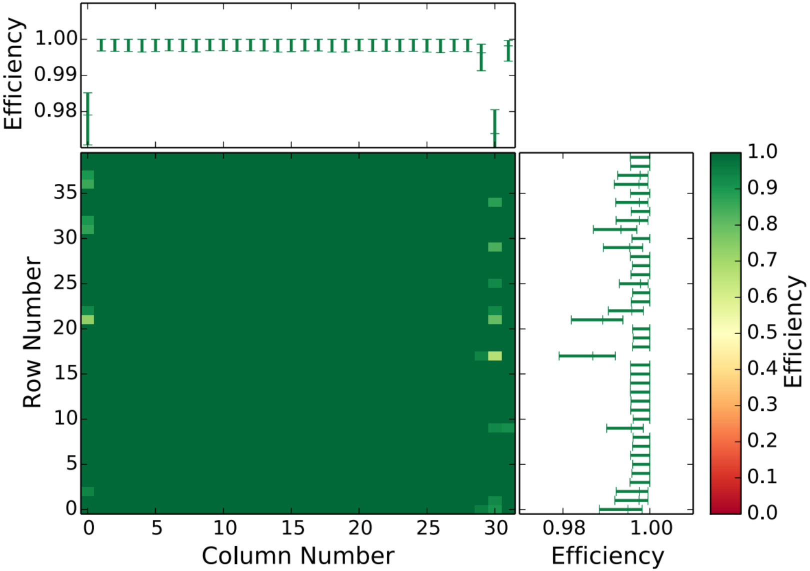




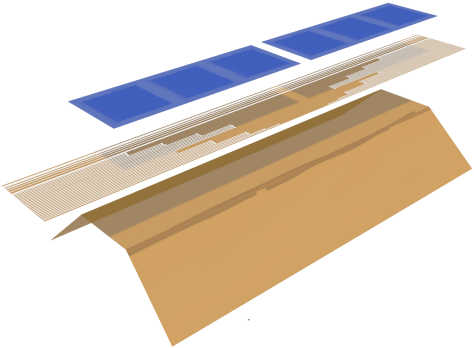
[I.Peric, NIM A 582 (2007)]


Ivan
LV
HEDS-5500 A01
0612 A

Test beam at DESY: 99% efficiency



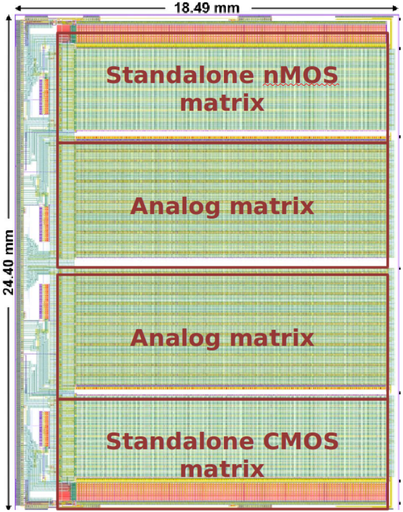
Mechanics



- 50 µm Silicon (HV–MAPS)
- 25 µm Kapton^{TM} flexprint with aluminium traces
- 25 µm Kapton^{TM} frame as support
- Less than 1 ‰ of radiation length per layer (IBL: 1.5 % radiation length)

HV-MAPS for ATLAS at IFAE

H35 Demo:



HV-MAPS (350 nm AMS) as possible upgrade for outer tracking layer in ATLAS:

First demonstrator: H35 Demo

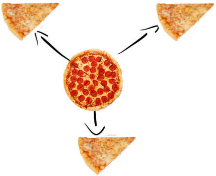
- Design: I. Peric, R. Casanova et al. (submission October 2015, delivery early 2016)

Pizza Talk Raimon (Development of Monolithic Pixel Detectors for ATLAS): http://indico.ifae.es/conferenceDisplay.py?confId=166

- Development new readout at IFAE (C. Puigdengoles, E. Cavallaro, F. Foerster, et al.)

Summary

- New experiment search for $\mu^+ \rightarrow e^+e^+e^-$ with sensitivity $< 10^{-16}$
- Thin active pixel sensors: HV-MAPS
- Start in 2016
- HV-MAPS also possible for ATLAS - IFAE participating



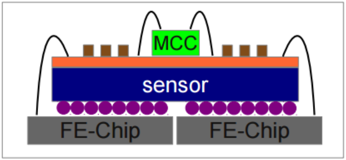
The Mu3e Collaboration

- DPNC, Geneva University
- Physics Institute, Heidelberg University
- KIP, Heidelberg University
- IPE, Karlsruhe Institute of Technology
- Paul Scherrer Institute
- Physics Institute, Zürich University
- Institute for Particle Physics, ETH Zürich
- Institute for Nuclear Physics, JGU Mainz

Hybrid versus Monolithic

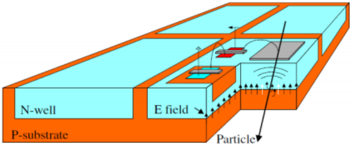
Hybrid design

- high signal
- high noise
- lot of material
- many interconnections
- minimum pixel size limited by bump bonds
- expensive (connections!)
- complex production



Monolithic design

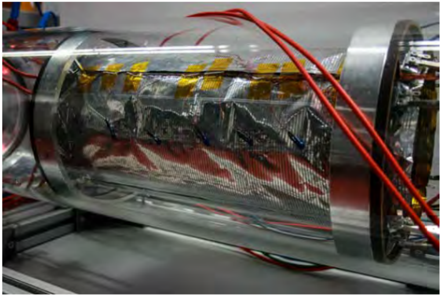
- low signal — can be increased!
- low noise
- 50 µm thickness possible → Mu3e
- only few connections
- minimum pixel size only limited by features size ~4x4 µm² for 180nm
- cheap CMOS process
- easier (faster) to construct?

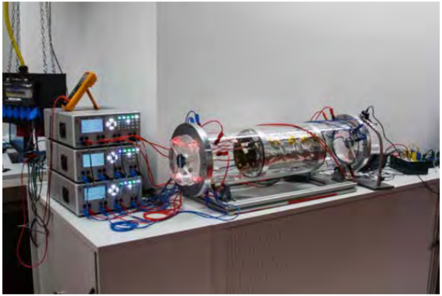


Cooling

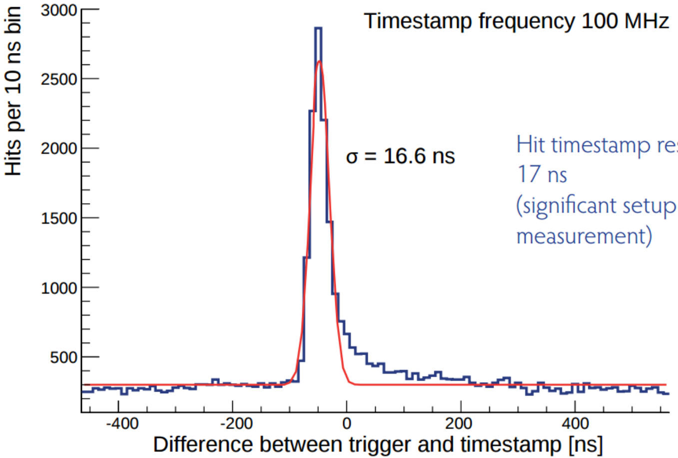
- Add no material:
  Cool with gaseous Helium
  (low scattering, high mobility)
- ~ 150 mW/cm^2 - total 2 kW
- Simulations: Need ~ several m/s flow

- Full scale heatable prototype built
- 36 cm active length
- No visible vibrations





Time resolution



Hit timestamp resolution better than 17 ns
(significant setup contribution in the measurement)