



Readout via Flexprints for the Mu3e Experiment

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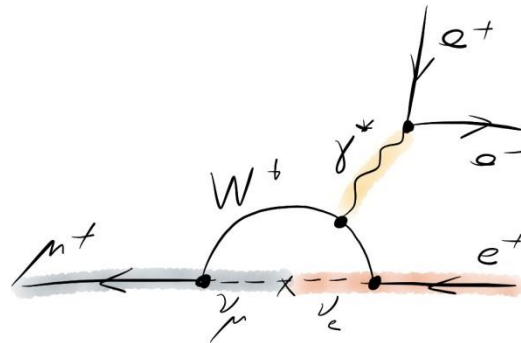
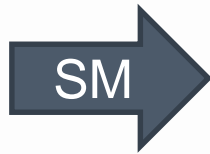


INTERNATIONAL
MAX PLANCK
RESEARCH SCHOOL

PT
FS
FOR PRECISION TESTS
OF FUNDAMENTAL
SYMMETRIES

The Mu3e Experiment

Search for the charged lepton flavor violating decay $\mu^+ \rightarrow e^+ e^+ e^-$

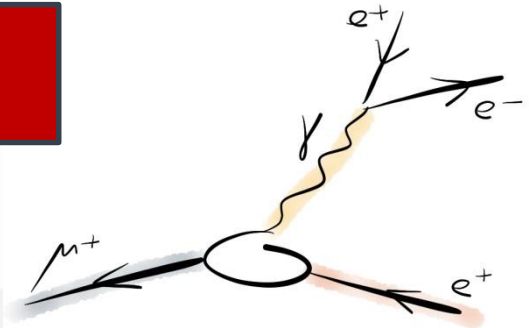
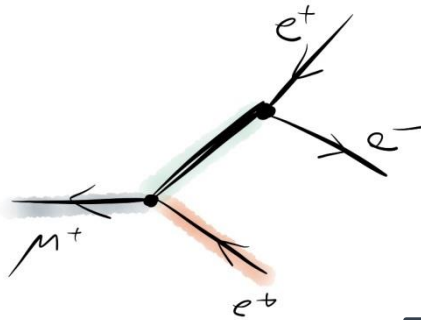


Highly suppressed:
 $BR_{SM} < 10^{-54}$

Any observation would be a
clear hint for new physics!

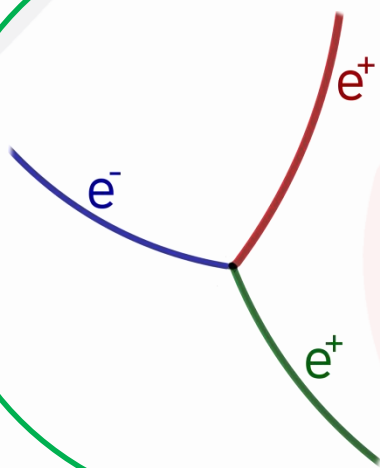
Current limit (SINDRUM 1988)
 $BR_{meas} < 10^{-12}$

Mu3e aimed sensitivity: $BR < 10^{-16}$



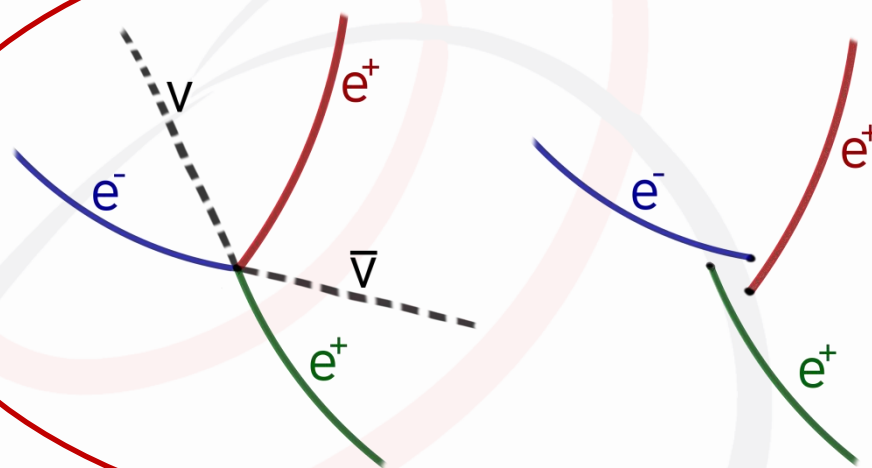
Event Topologies

Signal



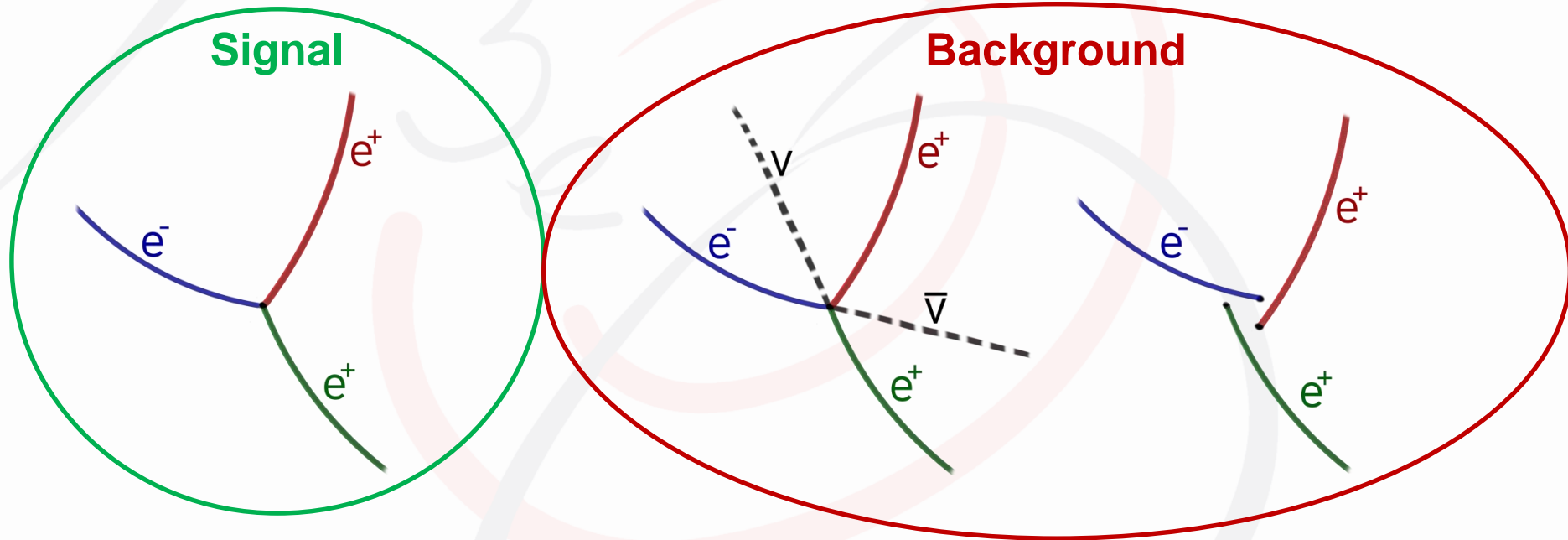
- Common vertex
- Coincident
- $\sum \vec{p} = 0$
- $\sum E = m_\mu$

Background



- Common vertex
- Coincident
- $\sum \vec{p} \neq 0$
- $\sum E \neq m_\mu$
- No common vertex
- Not coincident
- $\sum \vec{p} \neq 0$
- $\sum E \neq m_\mu$

Detector Requirements

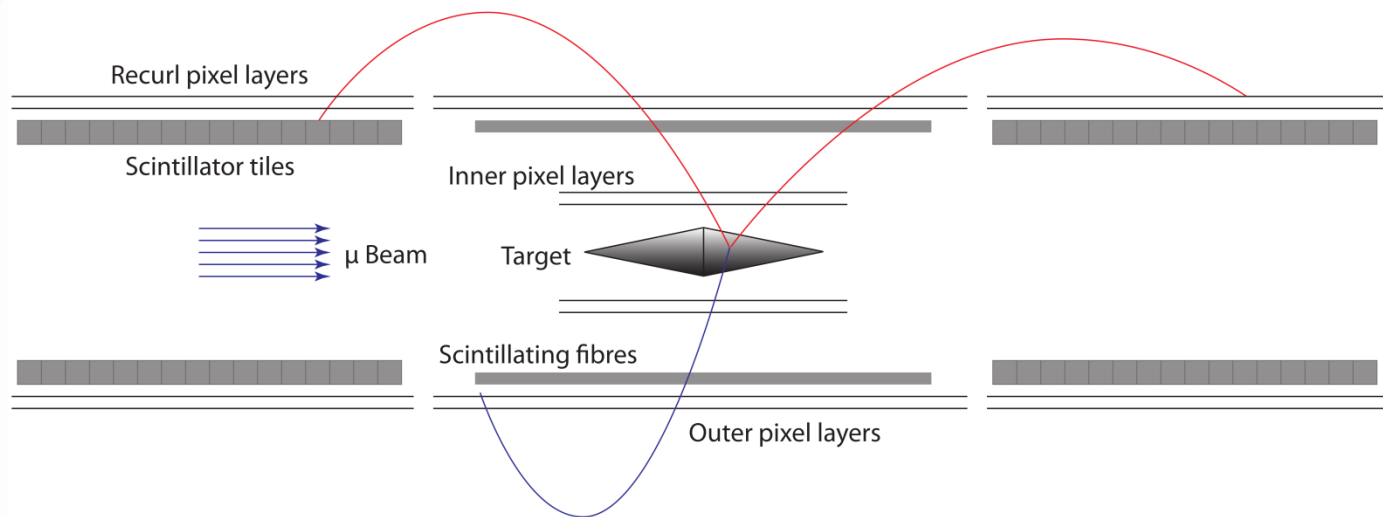


High **momentum**, **vertex** and **time resolution** are required
 $\sim 0.5 \text{ MeV}$ $\sim 200 \mu\text{m}$ $\mathcal{O}(100 \text{ ps})$

Low electron momentum $p < 53 \text{ MeV}$

Momentum resolution will be dominated by **multiple scattering**

Experimental Concept



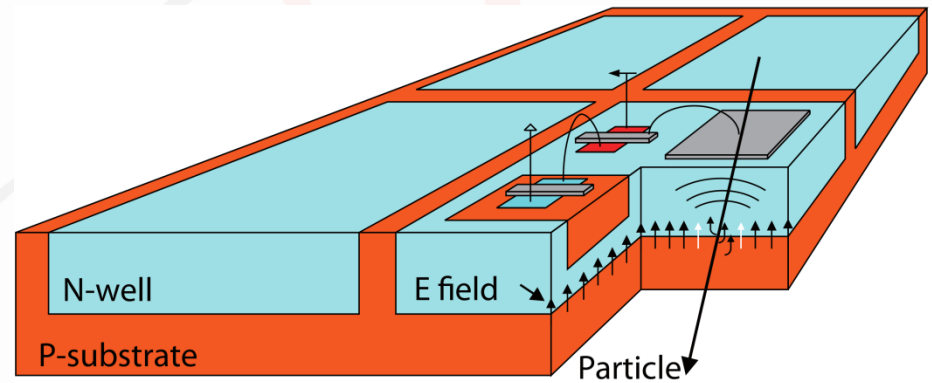
- High intensity muon beam at PSI: $10^7 - 10^8$ stopped μ^+ per second
- Solenoidal magnetic field $B = 1\text{T}$
- **Low material budget detector**
 - Pixel tracking detector: HV-MAPS
 - Timing detectors: scintillating fibres and tiles
 - Gaseous helium cooling

HV-MAPS

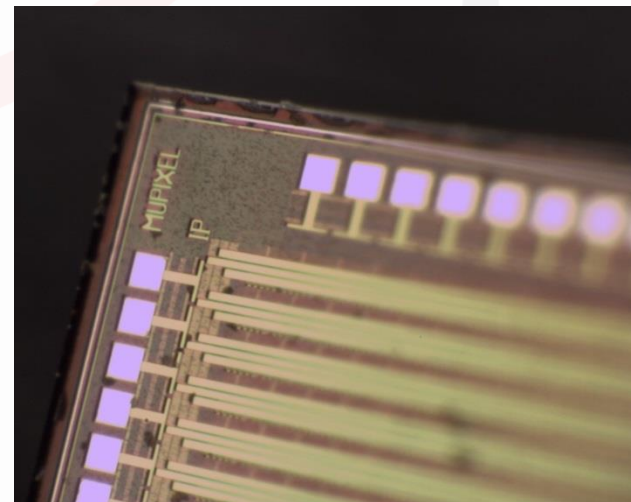
High Voltage Monolithic Active Pixel Sensors

- 180 nm HV-CMOS technology
HV \leq 90 V
- Charge collection via drift
- Depletion zone \sim 10 μ m
Can be thinned to 50 μ m
- Integrated digital readout

- Current prototype: **MuPix7**
 - Pixel size 103 x 80 μ m²
 - Integrated state machine
 - Zero suppressed data
 - Fast serial data output

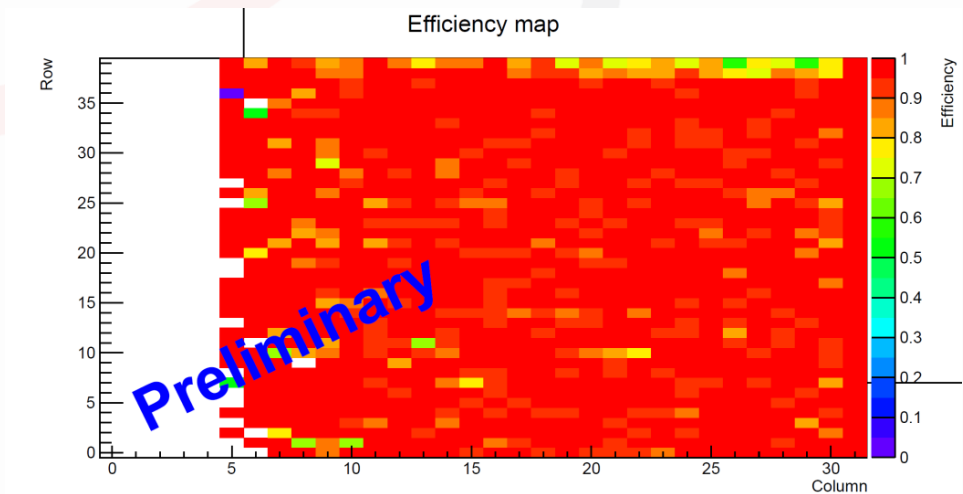
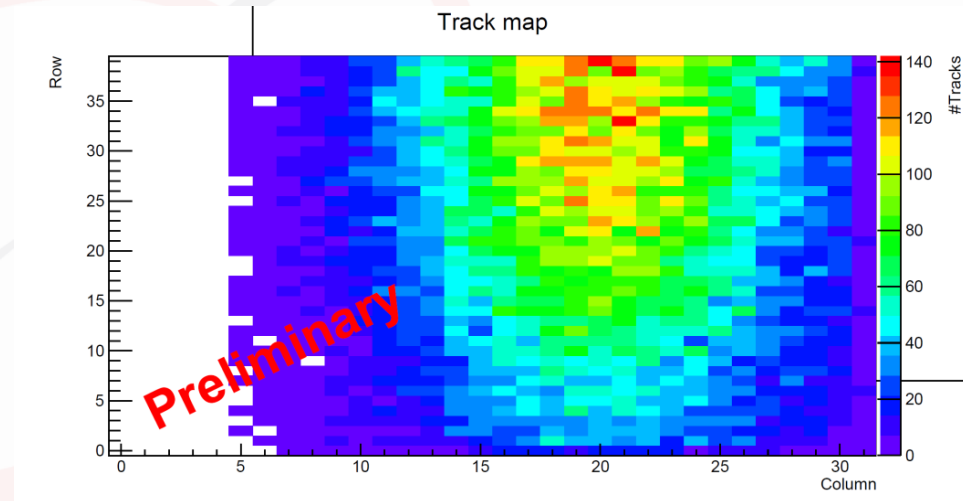
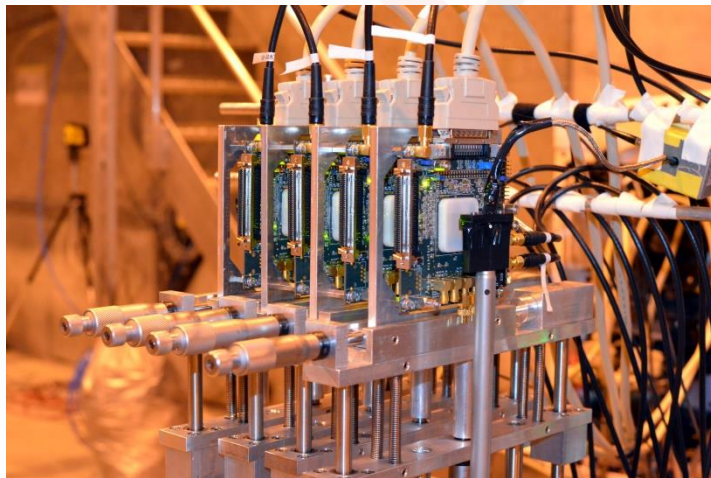


I. Peric, NIM A 582 (2007)



MuPix7 studies

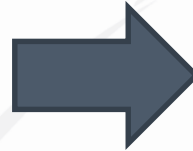
- Integration and performance: beam telescope with 4 sensor layers
- Beam test at SPS July 2015: Successfully operated serial readout of MuPix7



Detector Readout via Flexprints

Multiple scattering limits momentum resolution

**Flexprints made of
Kapton and Aluminium**

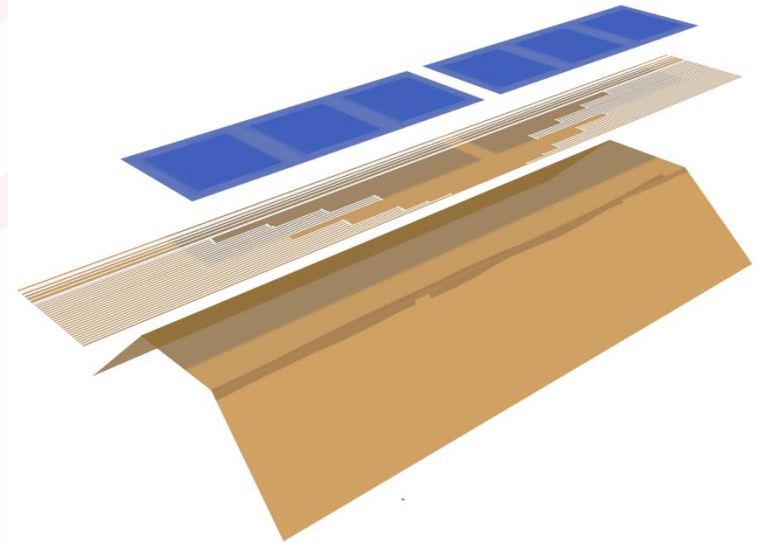


- Low material budget
- Data rates \sim Gbps
- Powering and control

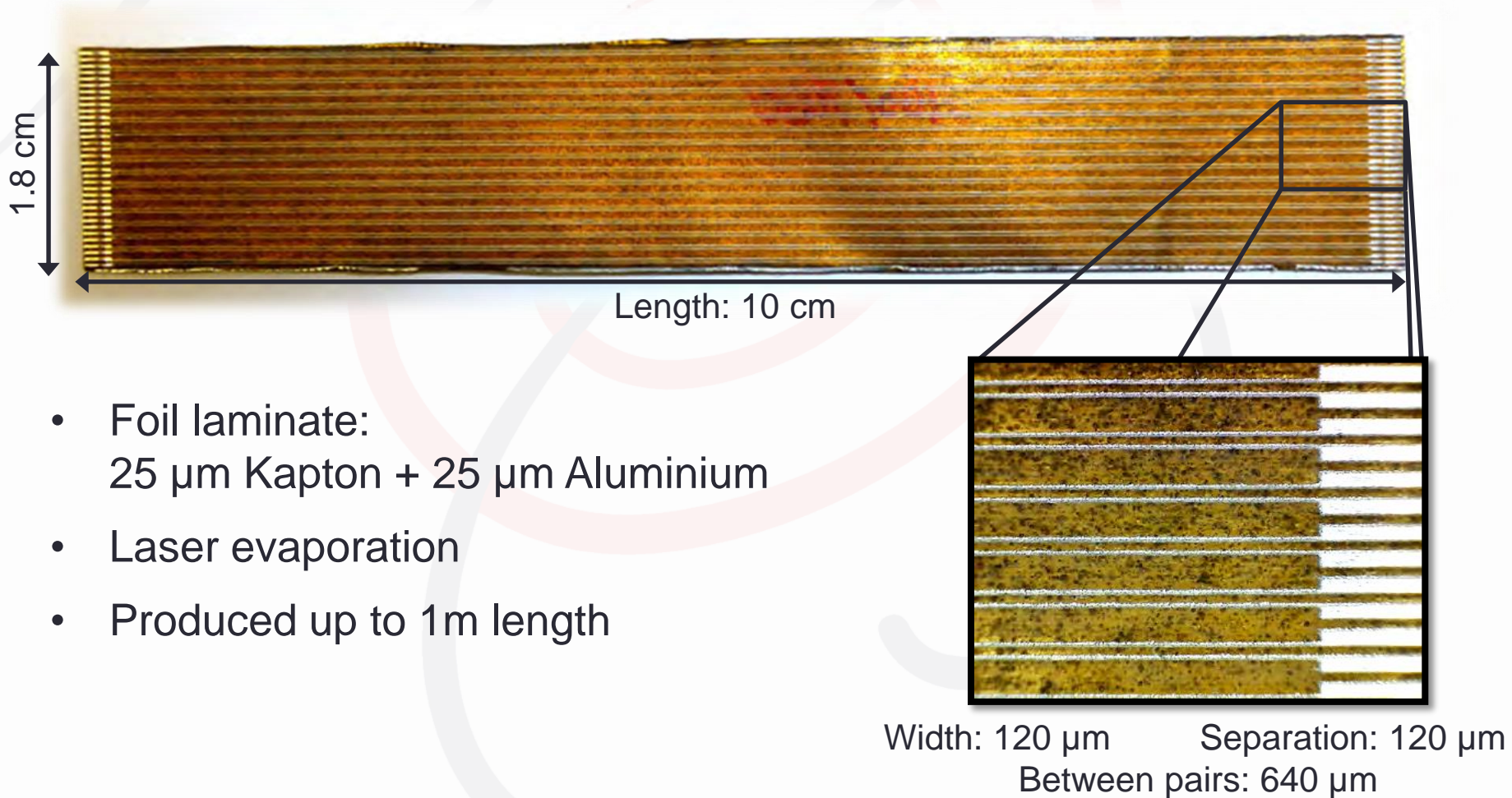
Material budget

HV-MAPS ($50 \mu\text{m}$)
+ Flexprints ($\sim 100 \mu\text{m}$)
+ Kapton support structure ($25 \mu\text{m}$)

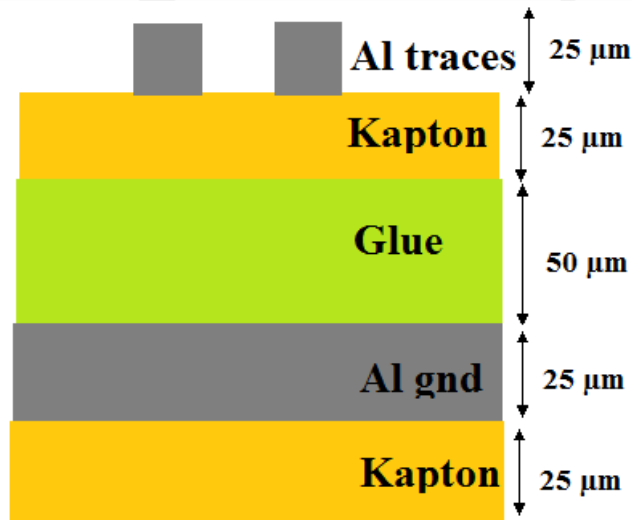
$\sim 1\text{‰}$ radiation length per layer



Flexprint Prototype Production



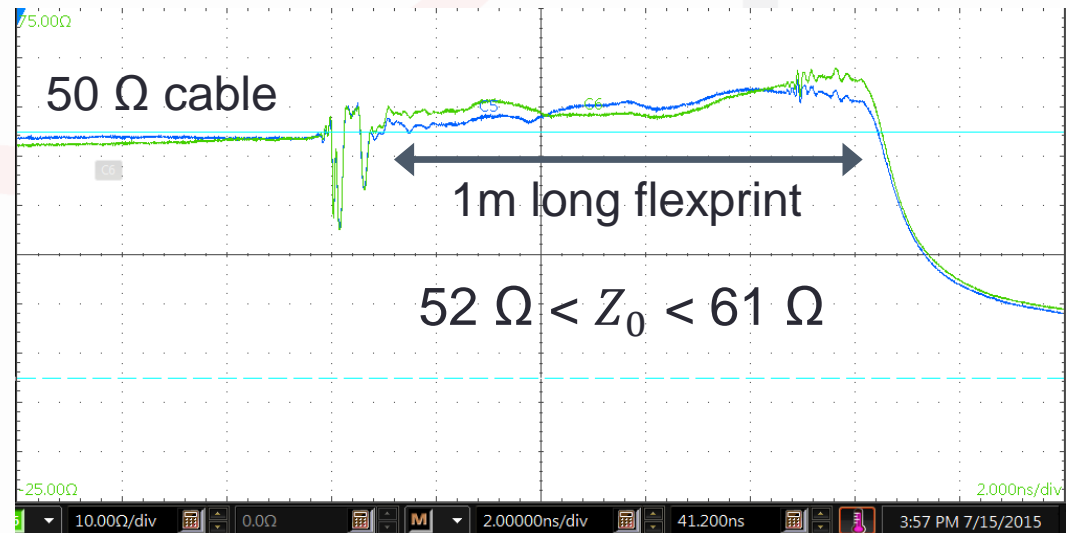
Impedance Matching



- Ground plane: Additional Al layer
- Also for power distribution
- Impedance must match 50 Ω to avoid signal distortions

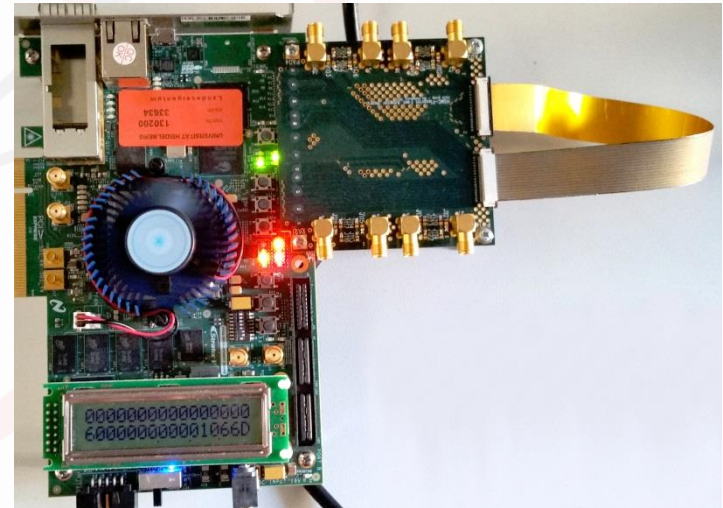
Time Domain Reflectometry

Reflections identify impedance mismatches



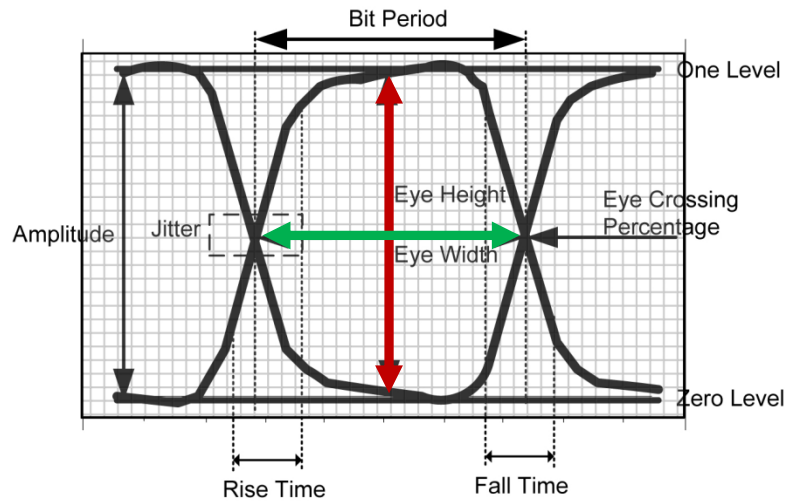
Bit Error Rate Tests

- Test quality of data transmission
- Altera Stratix V GS FPGA
- 8b10b encoded counter pattern
- 17 LVDS links up to 1.6 Gbps
- High speed transceivers up to 14.1 Gbps



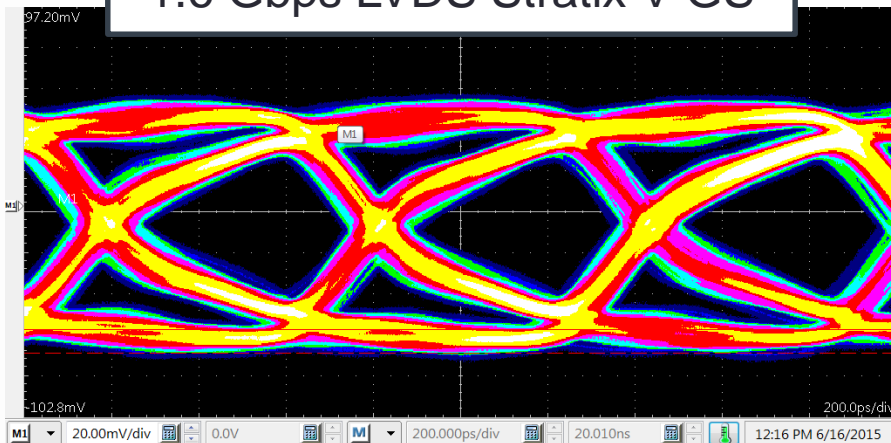
Cable length	Data rate	Errors	Run time	BER @ 95% CL
20 cm	1.6 Gbps	0	70 h	$\leq 9 \cdot 10^{-15}$
100 cm	1.6 Gbps	0	7 h	$\leq 9 \cdot 10^{-14}$
20 cm	2.0 Gbps	0	24 h	$\leq 2 \cdot 10^{-14}$

Eye Diagrams



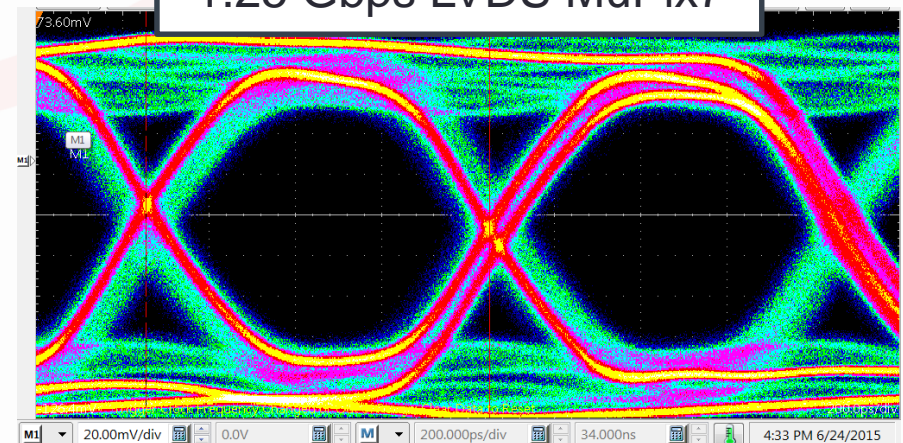
- Sampling digital data stream with oscilloscope
- Measure analog signal properties
- Test quality of data transmission

1.6 Gbps LVDS Stratix V GS



Eye Height ≈ 30 mV Eye Width $\approx 0,70$ UI

1.25 Gbps LVDS MuPix7



Eye Height ≈ 100 mV Eye Width $\approx 0,75$ UI

Summary

- Mu3e: Search for CLFV
- Tracking detector using HV-MAPS
- Serial readout of MuPix7 successfully operated
- Reliable flexprints up to 100 cm
- Up to 2.0 Gbps: no bandwidth limit

Outlook

- Mu3e: First data in 2017
- Test flexprints up to 10 Gbps
- Integration of MuPix sensors with flexprints

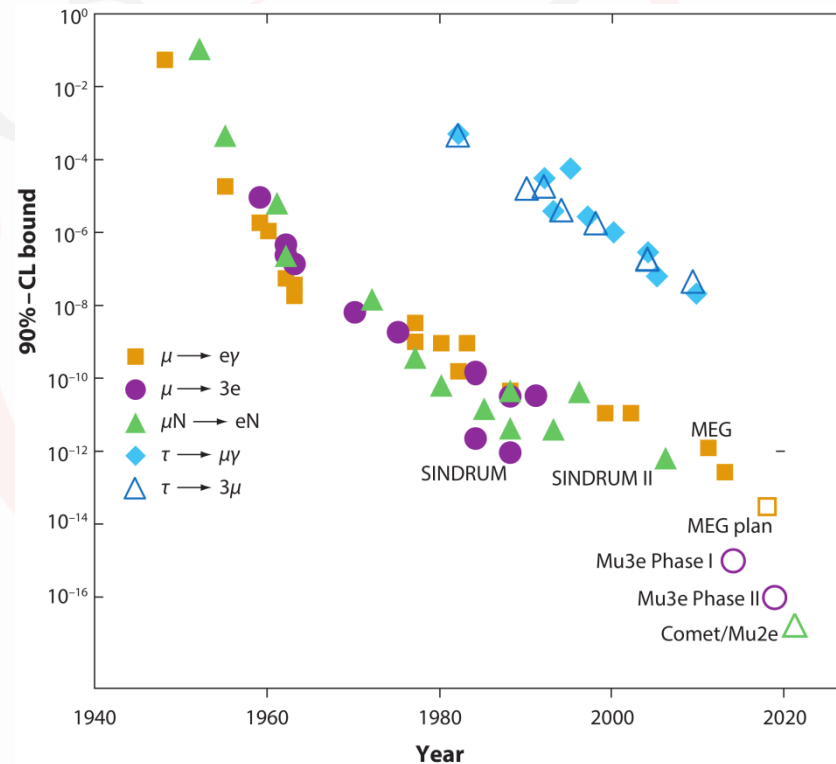


Test structure for wire bonding on flexprints

The background features the text 'Mu3e' in a light grey, cursive font, positioned in the upper left quadrant. Overlaid on this are several thick, curved lines in light grey and light red, creating a dynamic, swirling pattern. The word 'Backup' is centered in a bold, dark grey, sans-serif font, with a subtle reflection effect below it.

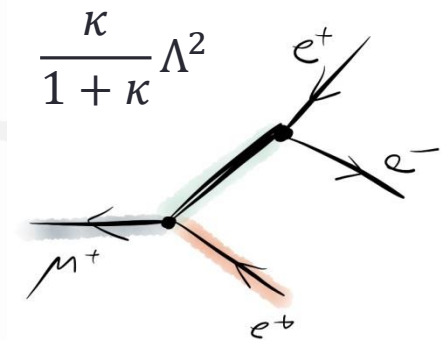
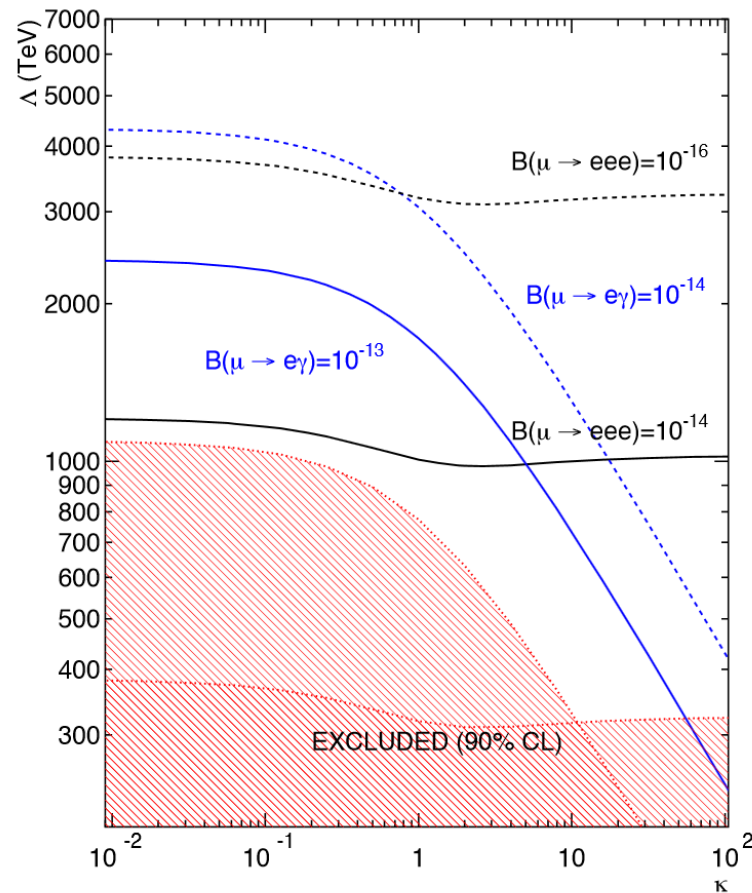
Backup

History of CLFV Experiments

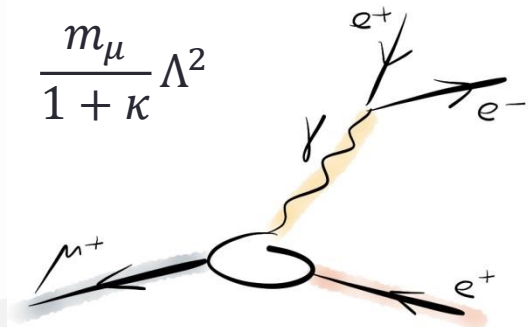


Updated from W.J Marciano et al., Ann.Rev.Nucl.Part.Sci. 58, 315 (2008)

Searching for New Physics with Mu3e



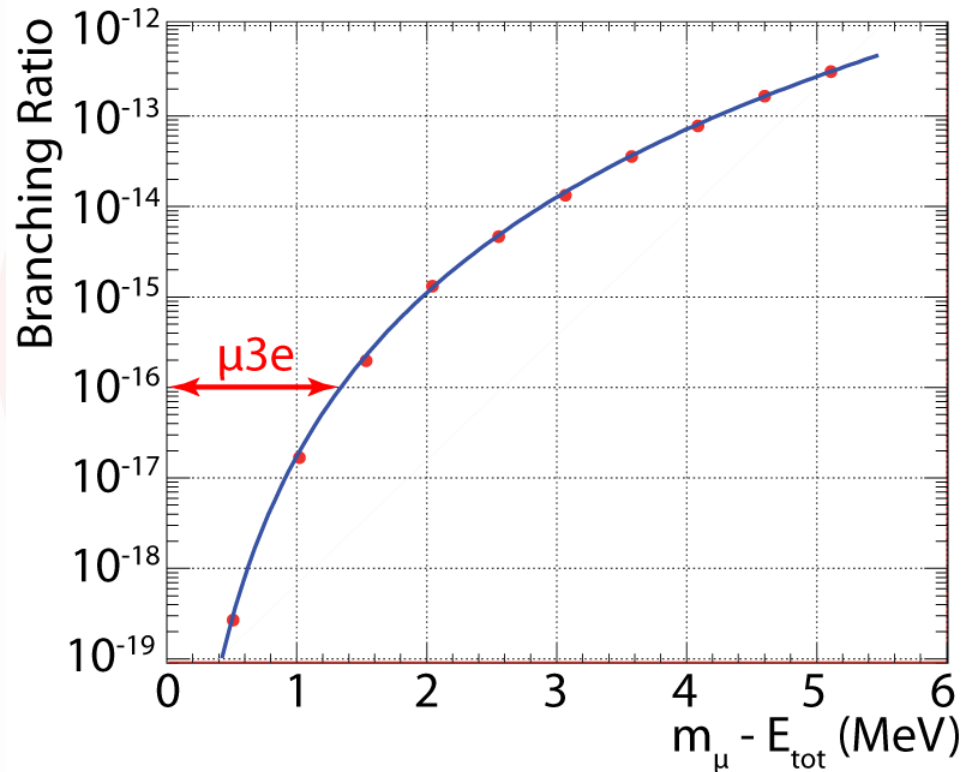
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André de Gouvêa, Petr Vogel,

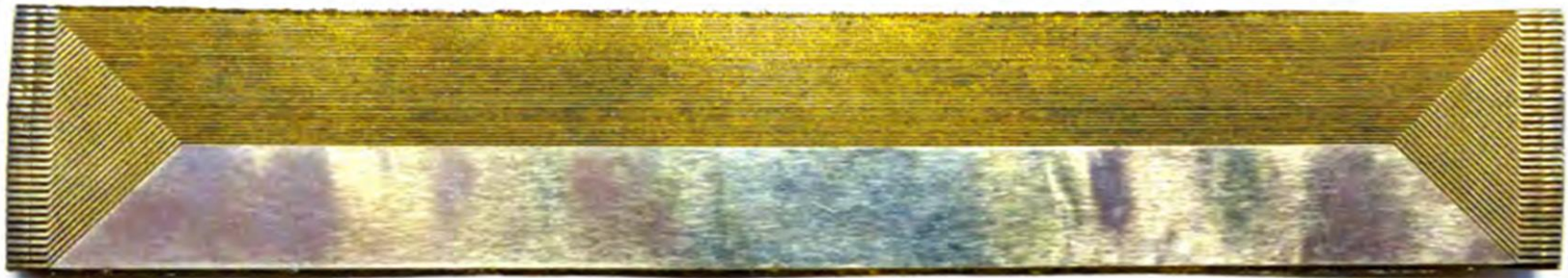
Lepton flavor and number conservation, and physics beyond the standard model,
 Progress in Particle and Nuclear Physics, 71 (2013) 75-9

Momentum resolution requirement

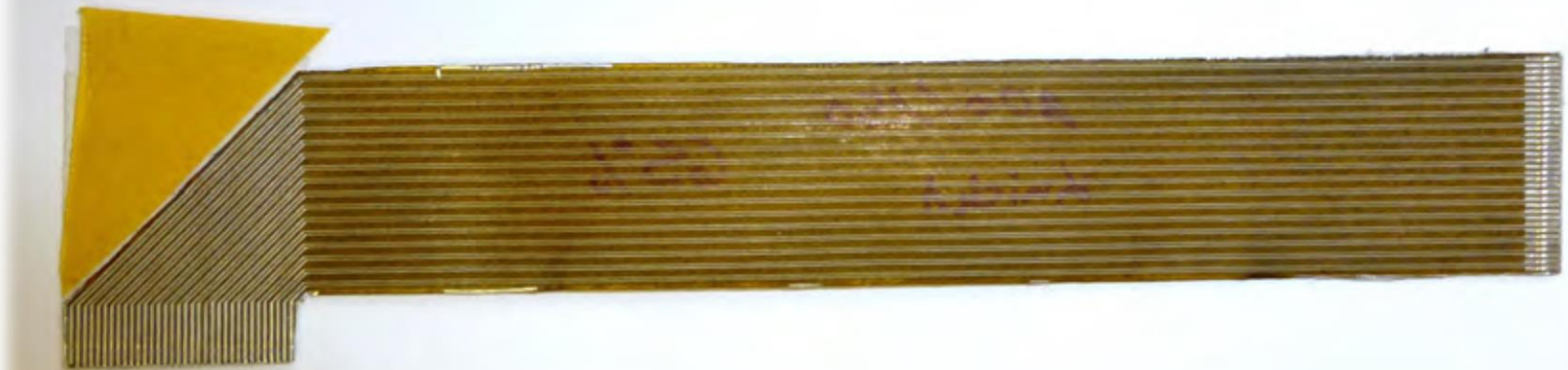


R.M Djilkibaev and R.V. Konoplich, Rphzs.Rev., D79 073004, 2009

More Flexprint Prototypes



Width: 100 μm Separation: 150 μm
Between pairs: 150 μm



Width: 100 μm Separation: 150 μm
Between pairs: 650 μm

Material budget of flexprints

Material	Radiation length X_0
Kapton	28.6 cm
Aluminum	8.9 cm
Copper	1.43 cm

Gnd plane	Kapton	Aluminum	x/X_0
✘	25 μm	12 μm	$2.2 \cdot 10^{-4}$
✘	25 μm	25 μm	$3.7 \cdot 10^{-4}$
✓	50 μm	24 μm	$4.4 \cdot 10^{-4}$
✓	50 μm	50 μm	$7.3 \cdot 10^{-4}$

x/X_0 for Kapton fully covered by aluminum