Flex-Prints for the Mu3e Experiment

Sebastian Dittmeier
on behalf of the Mu3e Collaboration
Physikalisches Institut - Universität Heidelberg

DPG-Frühjahrstagung
Hamburg – 29 February 2016

Mu3e - Experimental Concept

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

- Muons are **stopped** on Mylar target

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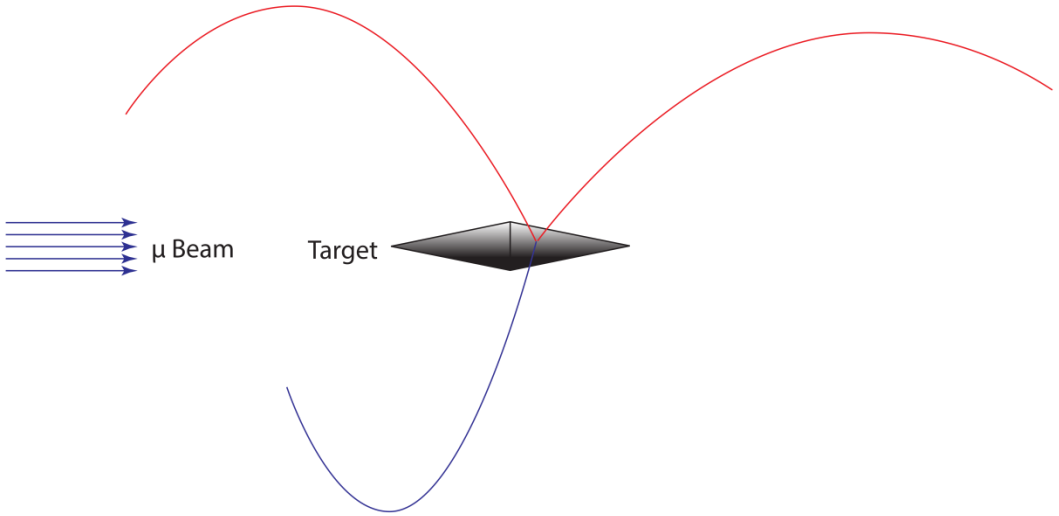

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- Decay at rest in a solenoidal magnetic field of $\mathbf{B = 1T}$
- Low momentum electrons $\boldsymbol{p_e \leq 53\ MeV/c}$

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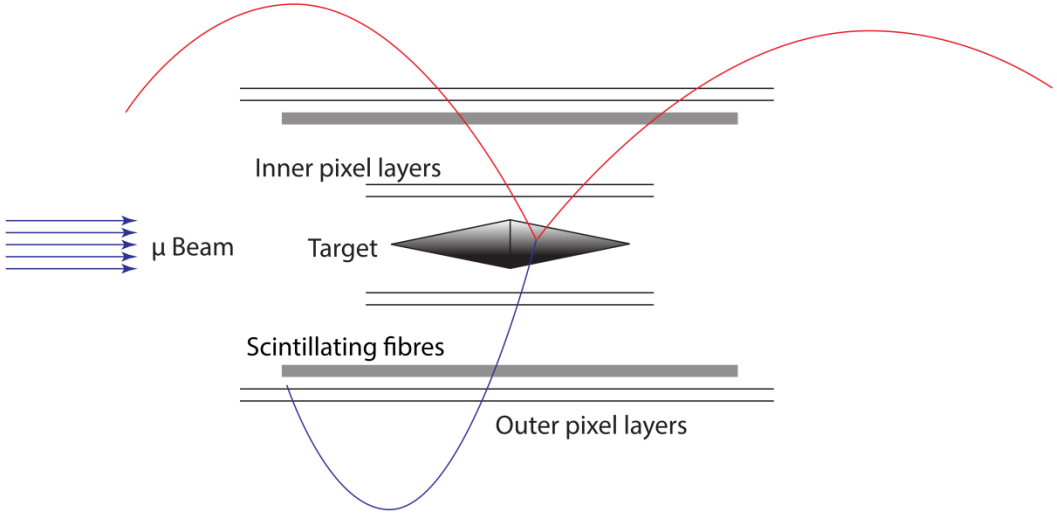

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➢ **Multiple Coulomb scattering dominates momentum resolution**

➢ Thin silicon pixel sensors (**HV-MAPS**) for tracking

➢ Scintillating fibres and tiles for precise timing

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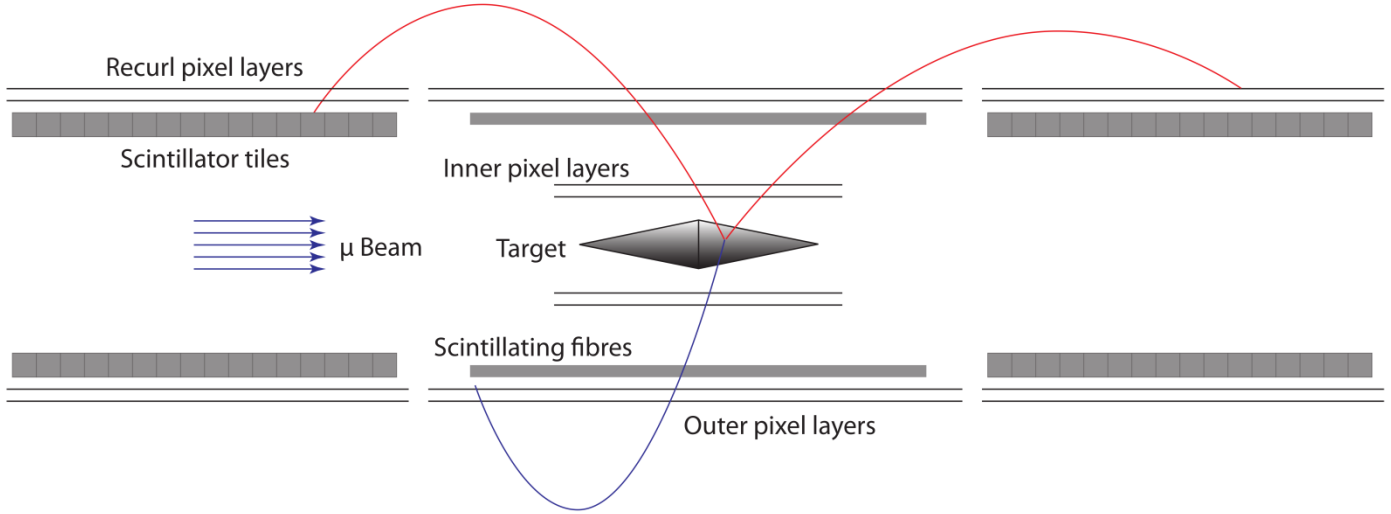

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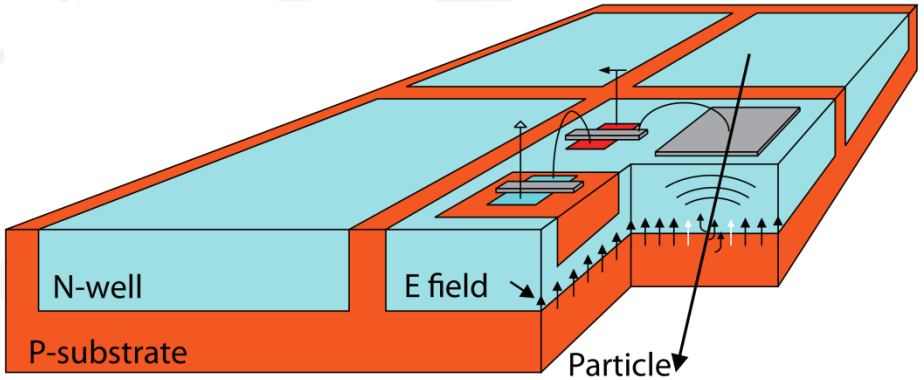
HV-MAPS

High Voltage Monolithic Active Pixel Sensors

- 180 nm HV-CMOS technology
  reverse biased HV ≤ 90 V
- Charge collection via drift
- Depletion zone $\sim 10 - 20\ \mu m$
  Can be thinned to $50\ \mu m$
- Integrated digital readout

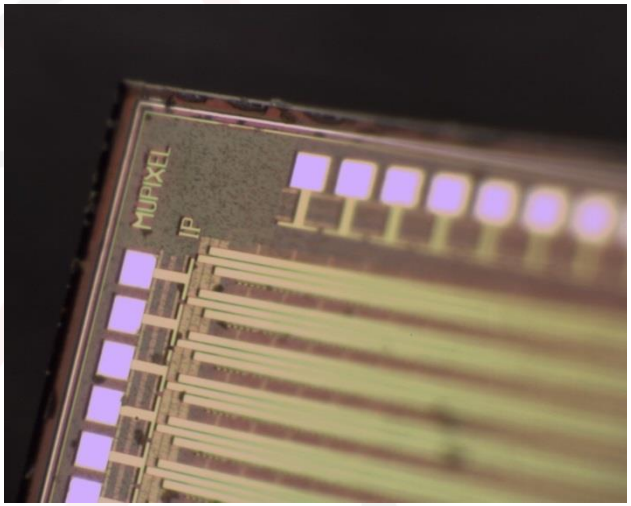


I. Peric et al., NIM A 582 (2007)

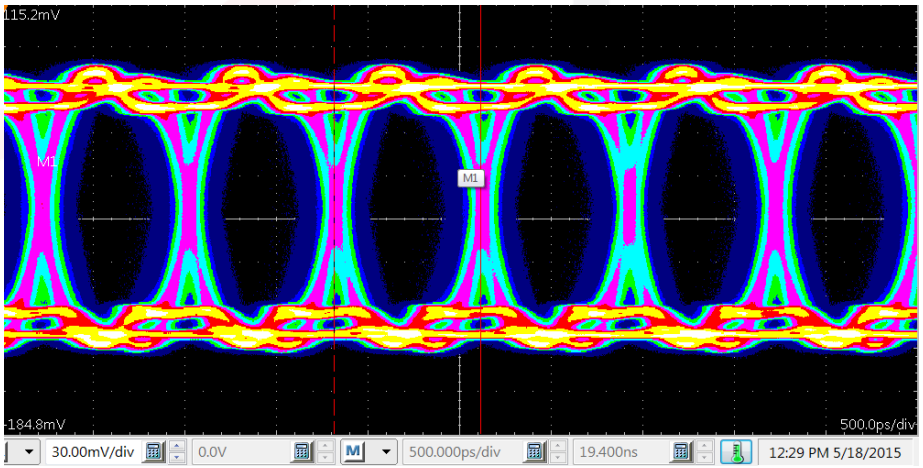
HV-MAPS

High Voltage Monolithic Active Pixel Sensors

- Latest prototype: **MuPix7**
  - Pixel size 103 x 80 μm^2
  - Integrated state machine
  - Serial data output at 1.25 Gb/s
  - Successfully operated at various test beams, also as a beam telescope



- More on **MuPix7**
  T 72.1 – T 72.3
- More on **MuPix Telescope**
  T 99.5



Material Budget for Mu3e

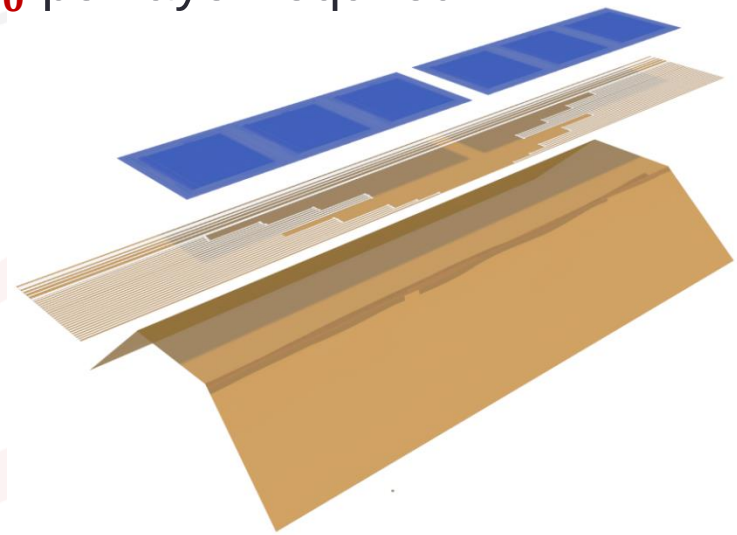
Momentum resolution

- Dominated by multiple Coulomb scattering
- ➢ Material budget of $x \leq 1‰\, X_0$ per layer required

Material budget per layer

HV-MAPS ($50\ \mu m$) $\sim 0.5\ ‰\ X_0$
+ Flex-print ($50 - 100\ \mu m$)
+ Kapton support structure ($25\ \mu m$)

$\sim$ 1‰ radiation length per layer



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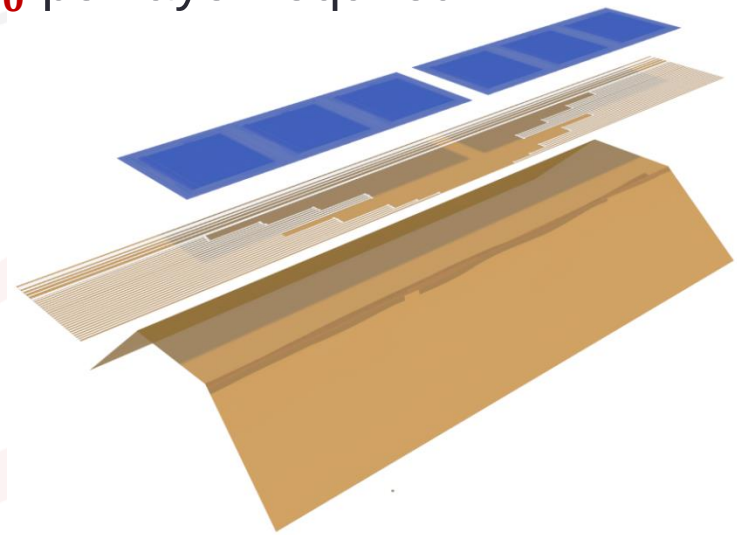

Flex-print options

- Dielectric: Polyimide film ($142\ \mu m \sim 0.5\ ‰\ X_0$)
- Metal: Aluminium ($44\ \mu m \sim 0.5\ ‰\ X_0$)
  Copper ($7\ \mu m \sim 0.5\ ‰\ X_0$)

Specific conductance

$\sigma_{Al} = 37 \cdot 10^6$ S/m
$\sigma_{Cu} = 58 \cdot 10^6$ S/m

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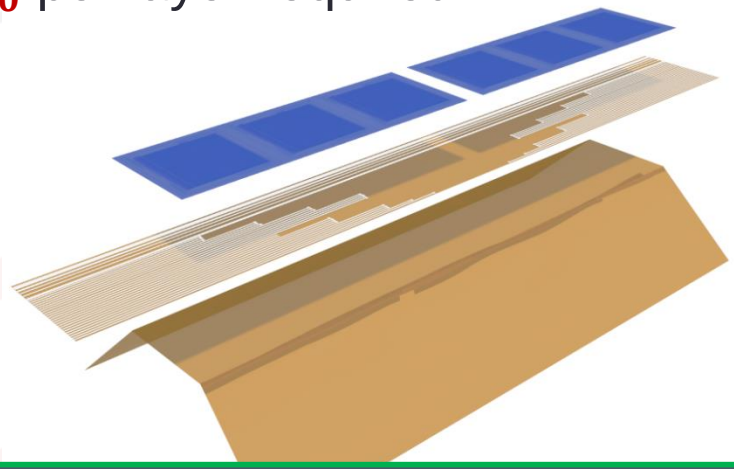

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Aluminium saves us a factor 4 in material!

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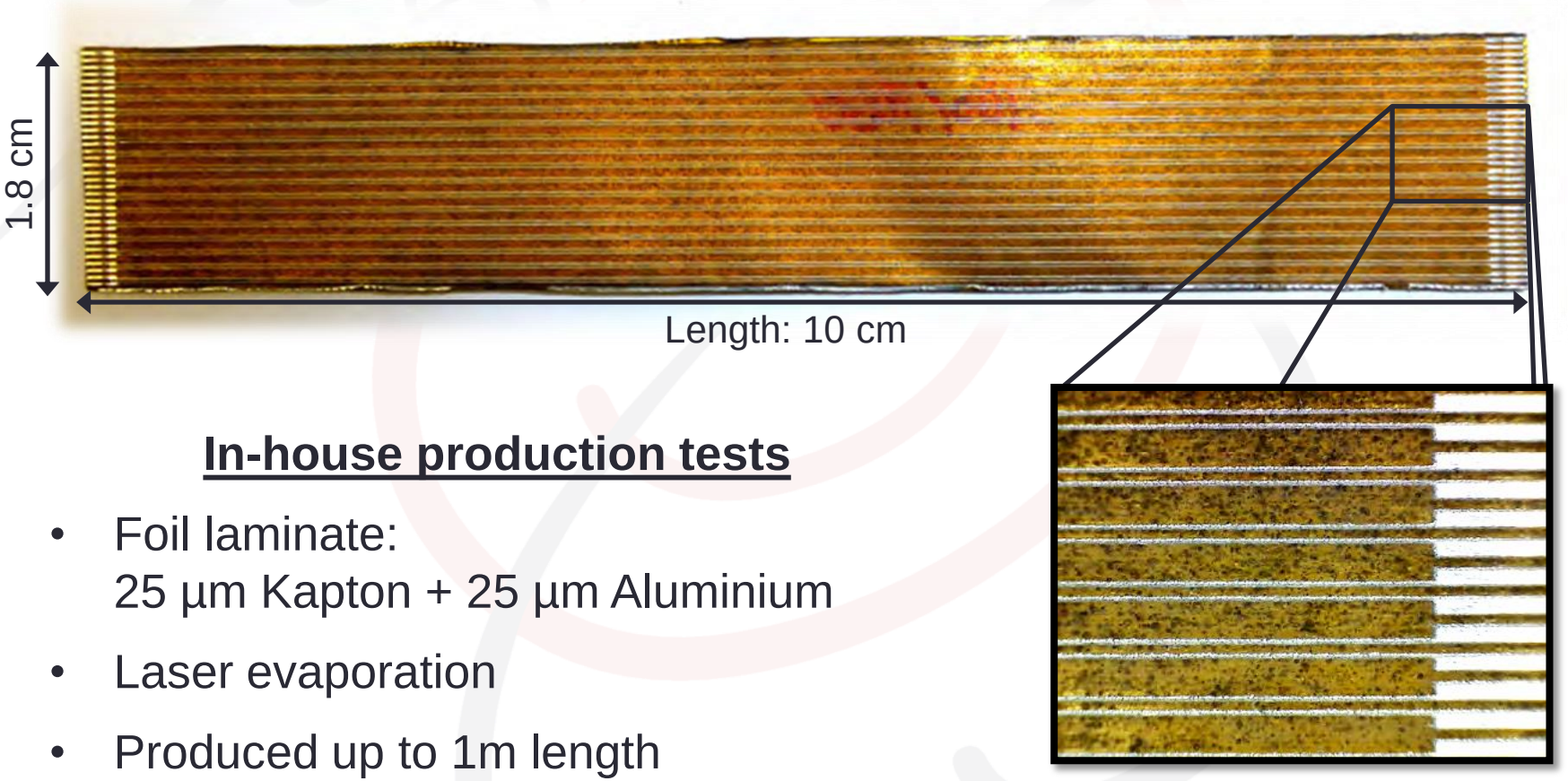
Flex-Print Prototype Production



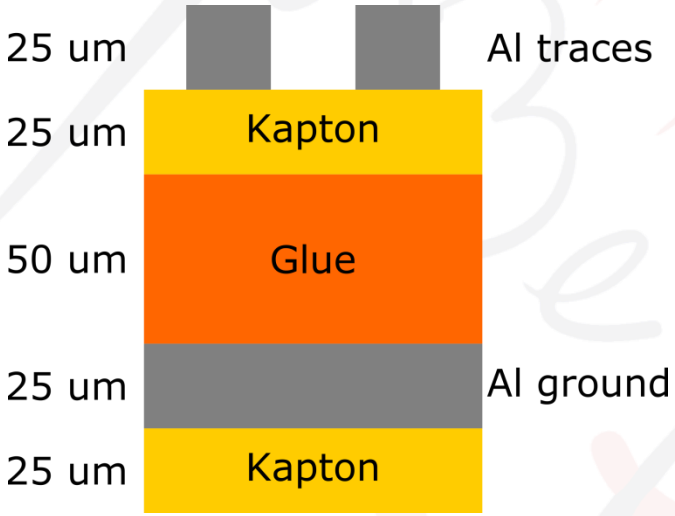
In-house production tests

- Foil laminate:
  25 µm Kapton + 25 µm Aluminium
- Laser evaporation
- Produced up to 1m length

Trace parameters

Width: 120 µm
Separation: 120 µm

Impedance Matching of Prototypes



- Crucial for fast data transmission: Impedance matching
  $Z_0 = 50\ \Omega, Z_{diff} = 100\ \Omega$
- Ground plane: Additional Al layer
- This configuration $\sim 0.8\ ‰\ X_0$

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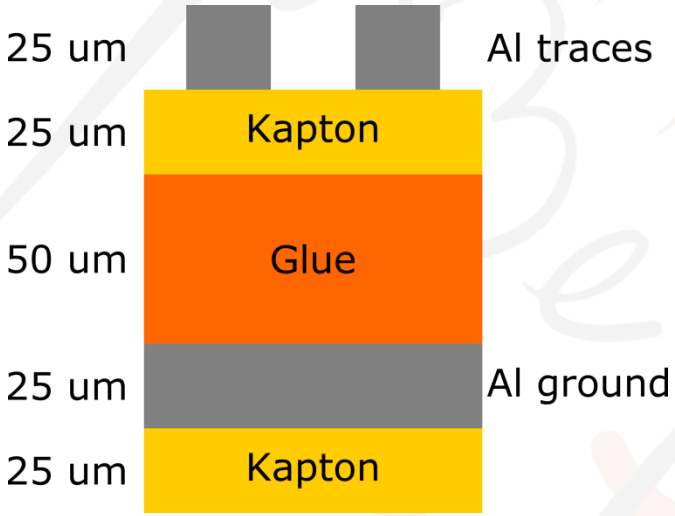

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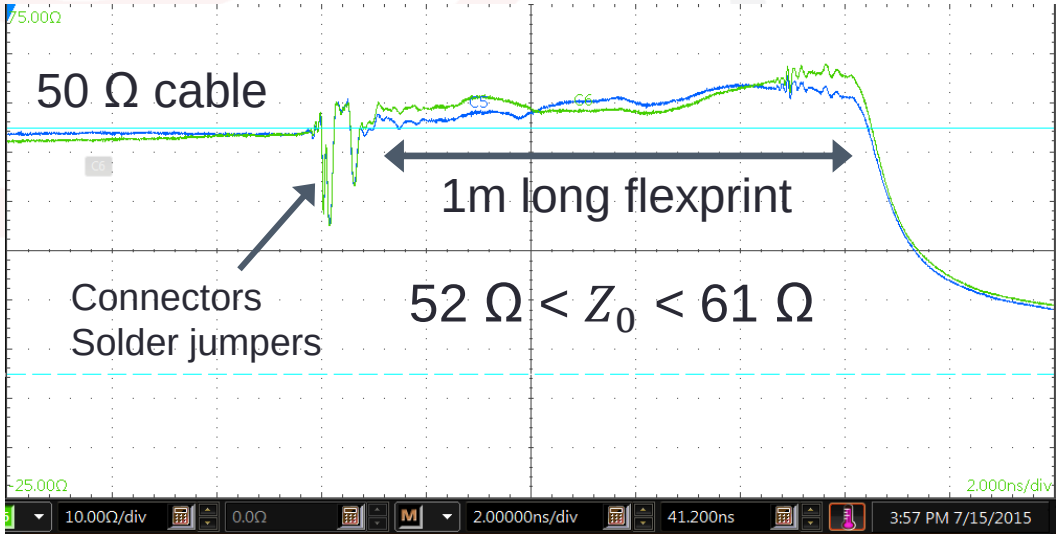
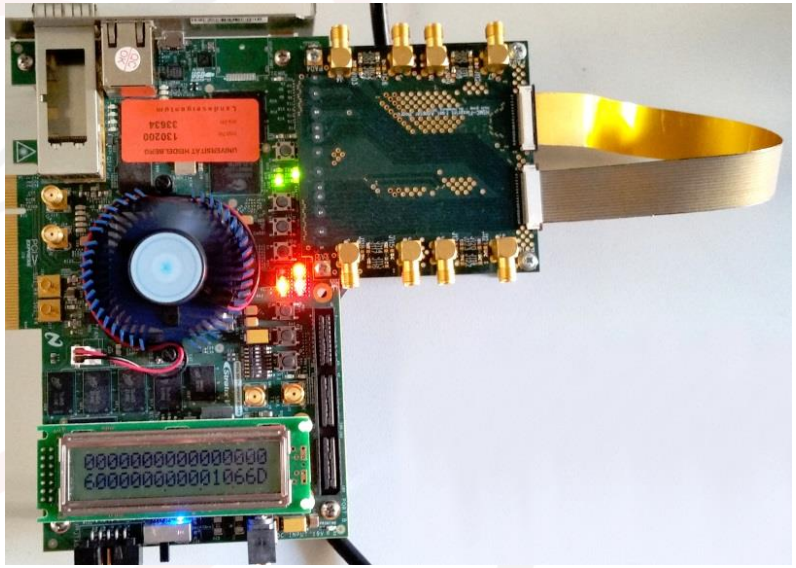
Time Domain Reflectometry

Impedance can be measured by observing reflections of input signal



Bit Error Rate Tests

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



Cable length	Data rate	Channels	Errors	Run time	BER
20 cm	1.6 Gbps	7	0	512 h	$\leq 1.8 \cdot 10^{-16}$ @ 95% CL
20 cm	3.2 Gbps	5	36	398 h	$1.6 \cdot 10^{-16}$
100 cm	1.6 Gbps	7	0	6 h	$\leq 1.2 \cdot 10^{-14}$ @ 95% CL

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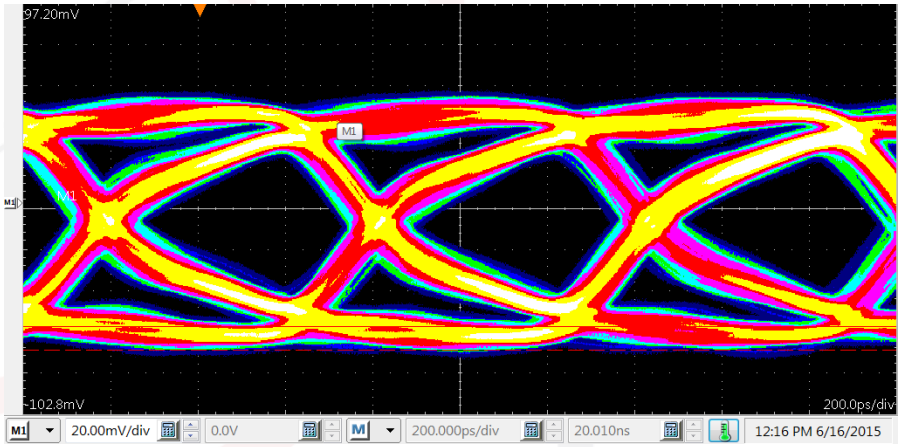

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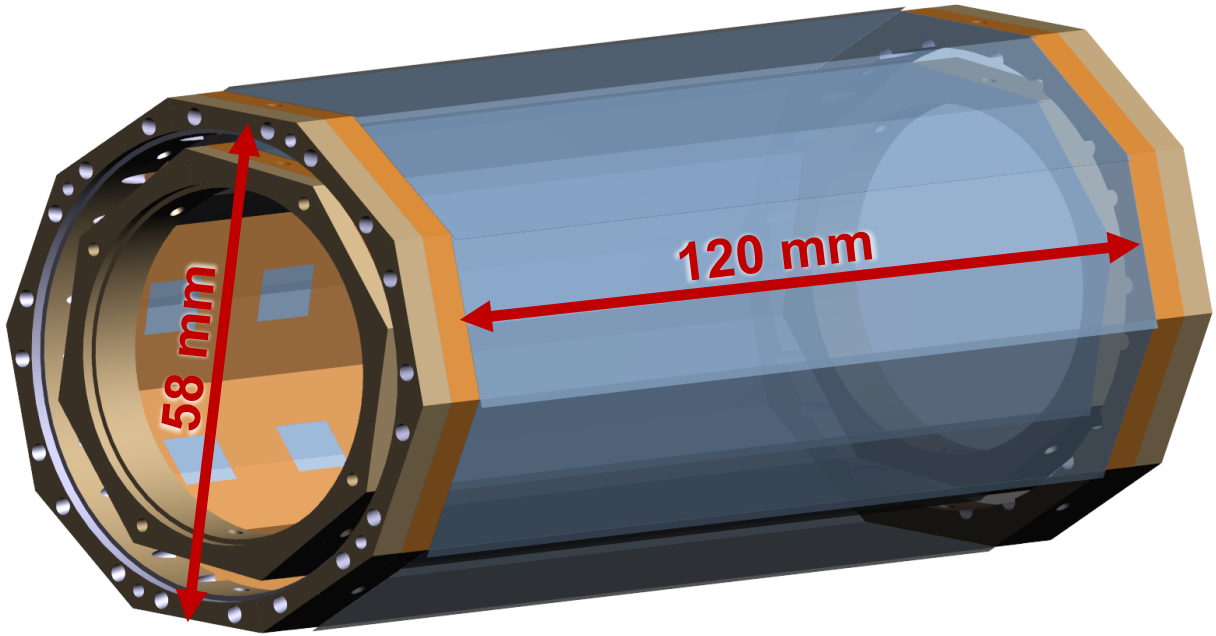
Towards Detector Integration

Next big steps

- Next MuPix prototype (MuPix8) – large sensor ($1.3 \times 2.3\ \mathrm{cm}^2$)
- Integration with flex-print
- Build first vertex modules



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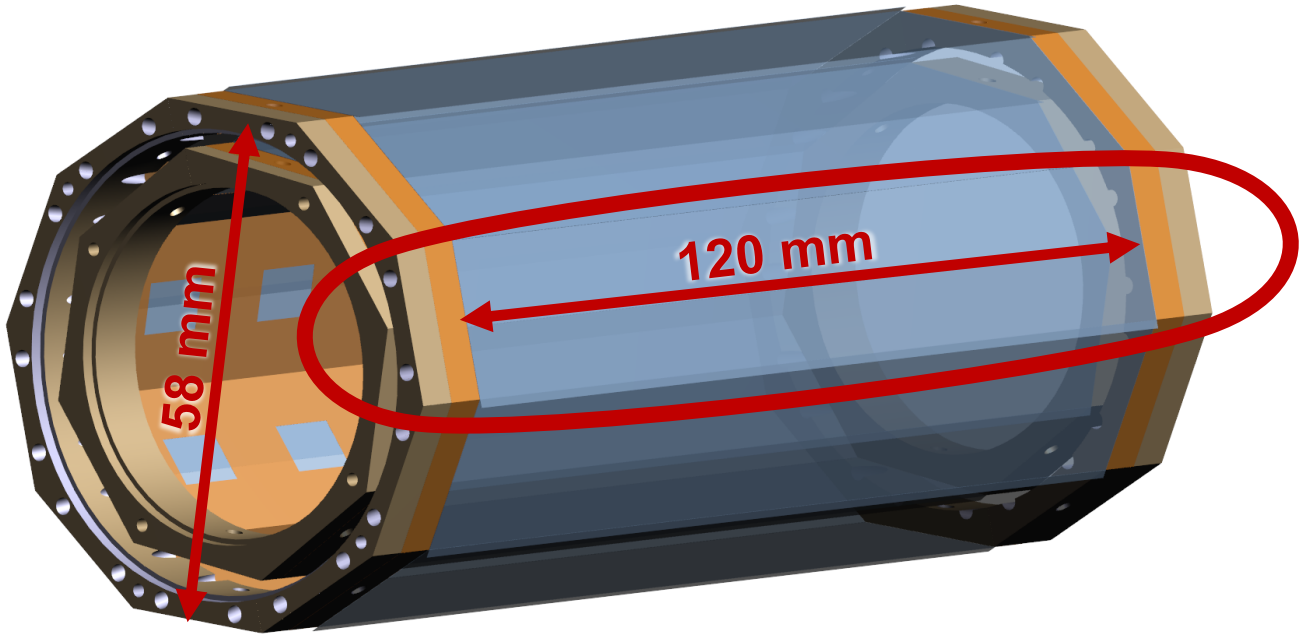
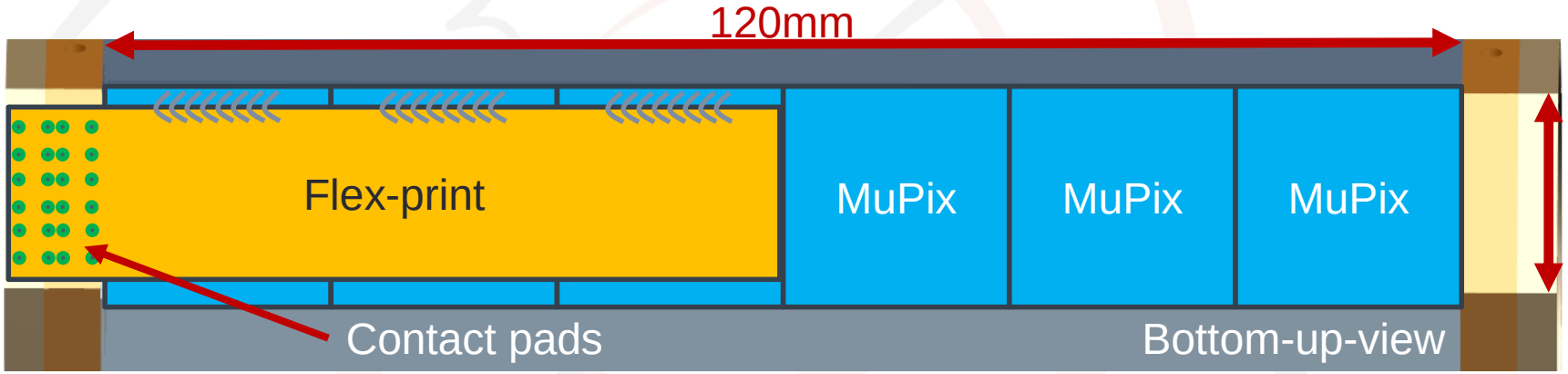


Flex Print Design Studies

Vertex module: One flex-print connects three MuPix sensors



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- Interconnect for all signals:
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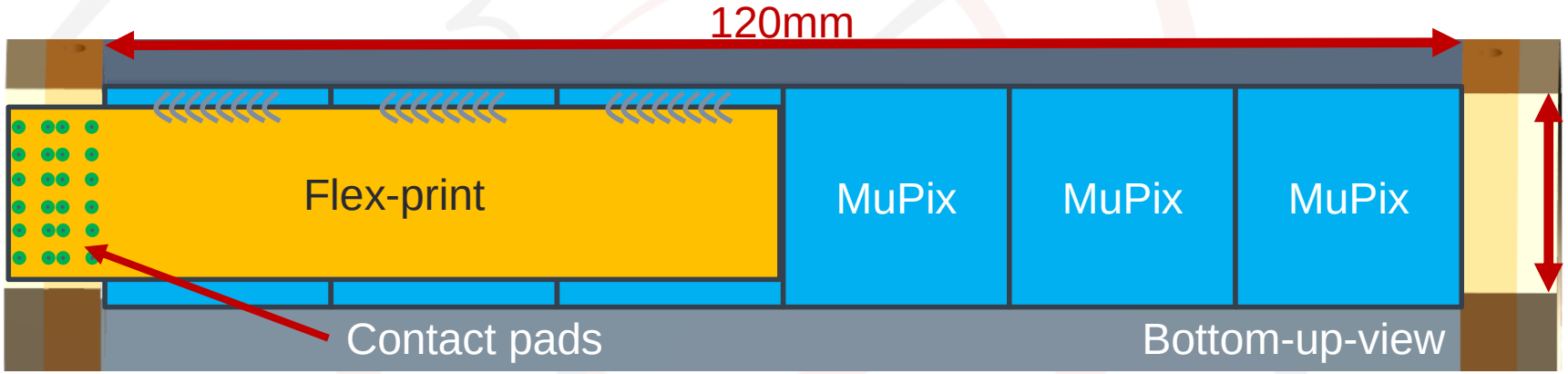

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- Interconnect for all signals:
  - Common signals as bus
  - Individual signals per chip (data output, …)
- Current assumption ~ 75 contacts at end ring
- At least two conducting layers required!
- Flex-print production with our laser setup is too coarse ($\geq 120\ \mu m$)

Flex Print Design Options

Two layer aluminium (LTU Ltd.)

- $14\mu m$ Al + $10\mu m$ polyimide per layer
- Structures $\geq 65\mu m$
- Dielectric spacing $45\mu m$

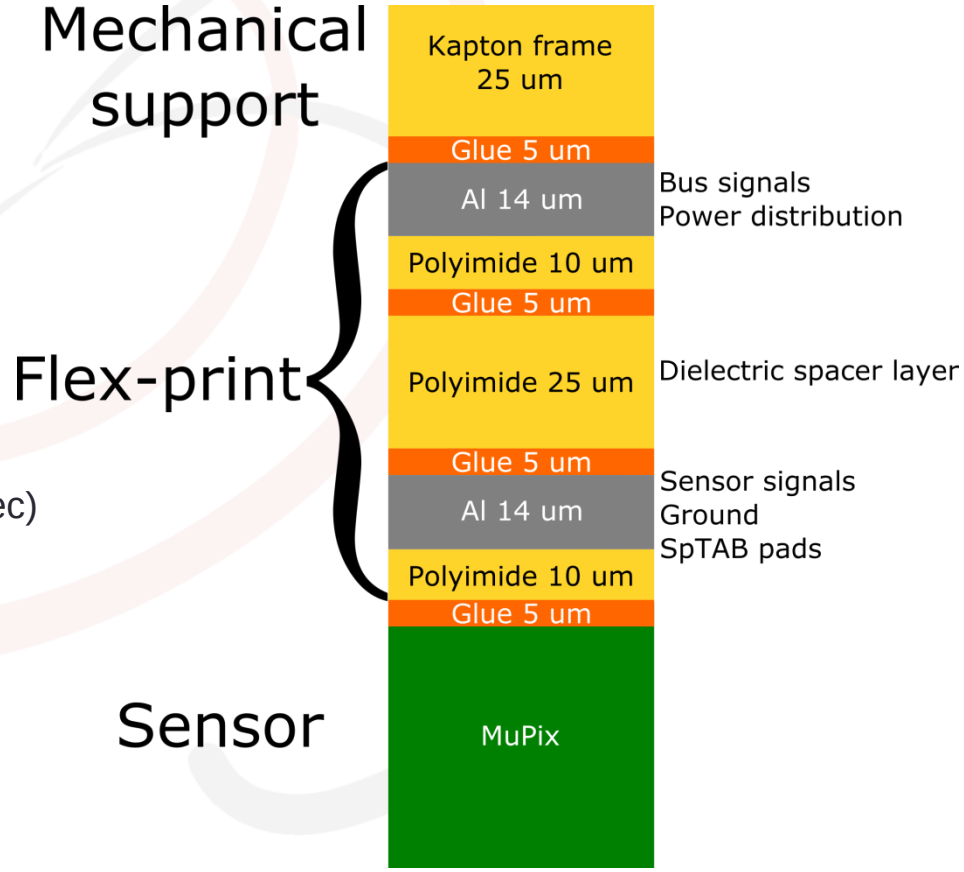
➢ Low material budget $\sim 0.55‰\ X_0$

Copper & aluminium laminate (HighTec)

- Copper layers thin ($\sim 2\mu m$)
- Structures $\leq 15\mu m$

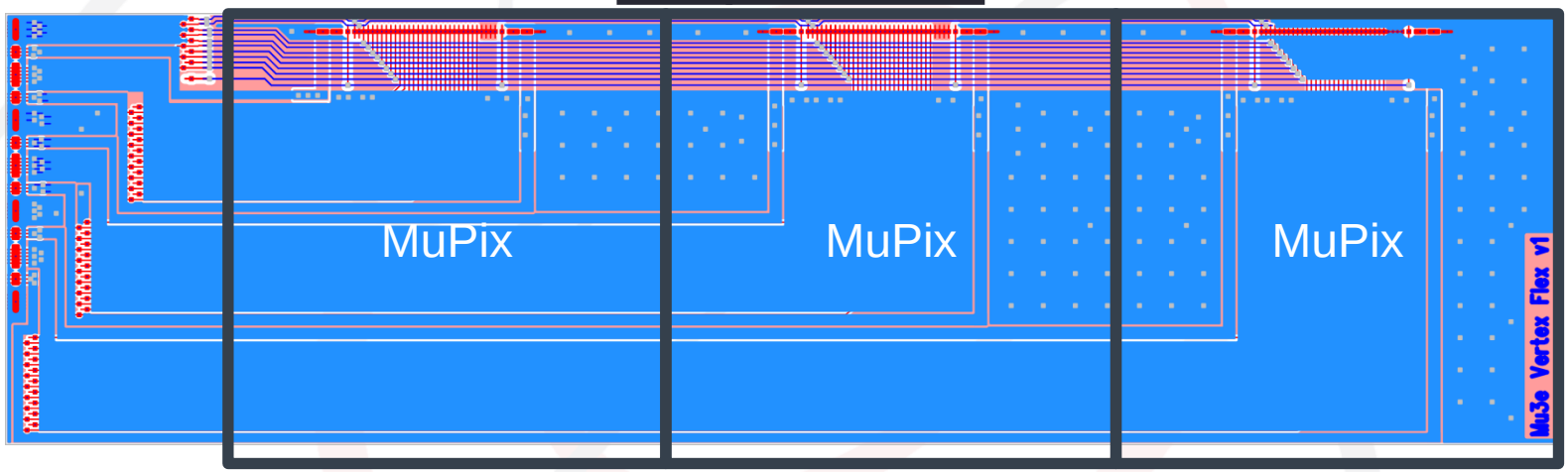
➢ Little Cu coverage

➢ Low material budget $\sim 0.65‰\ X_0$

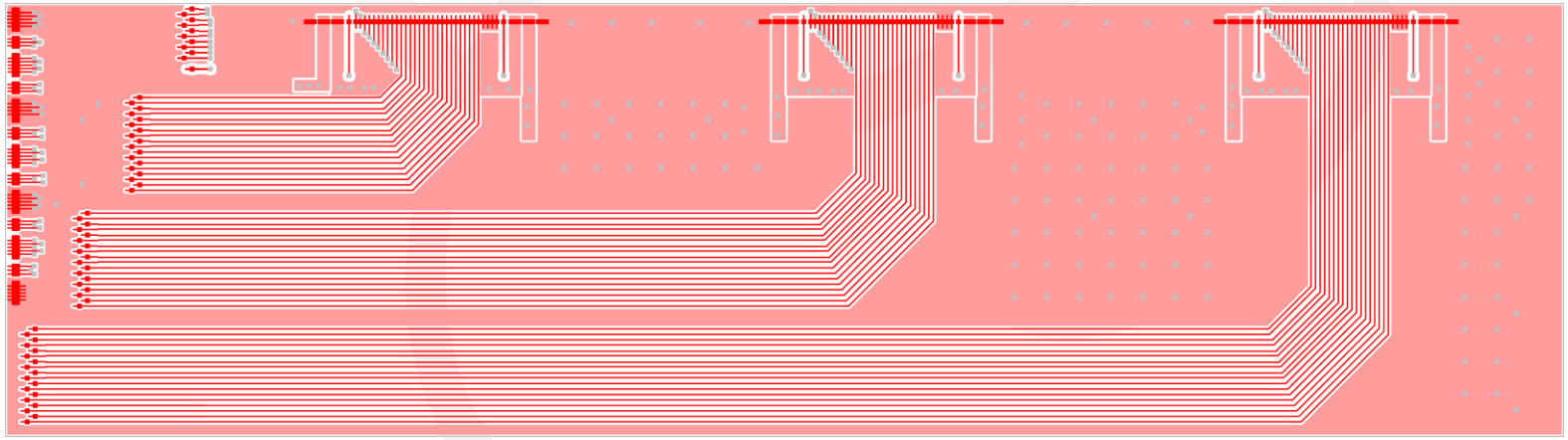


Two Layer Aluminium Option

Composite View



Bottom Layer



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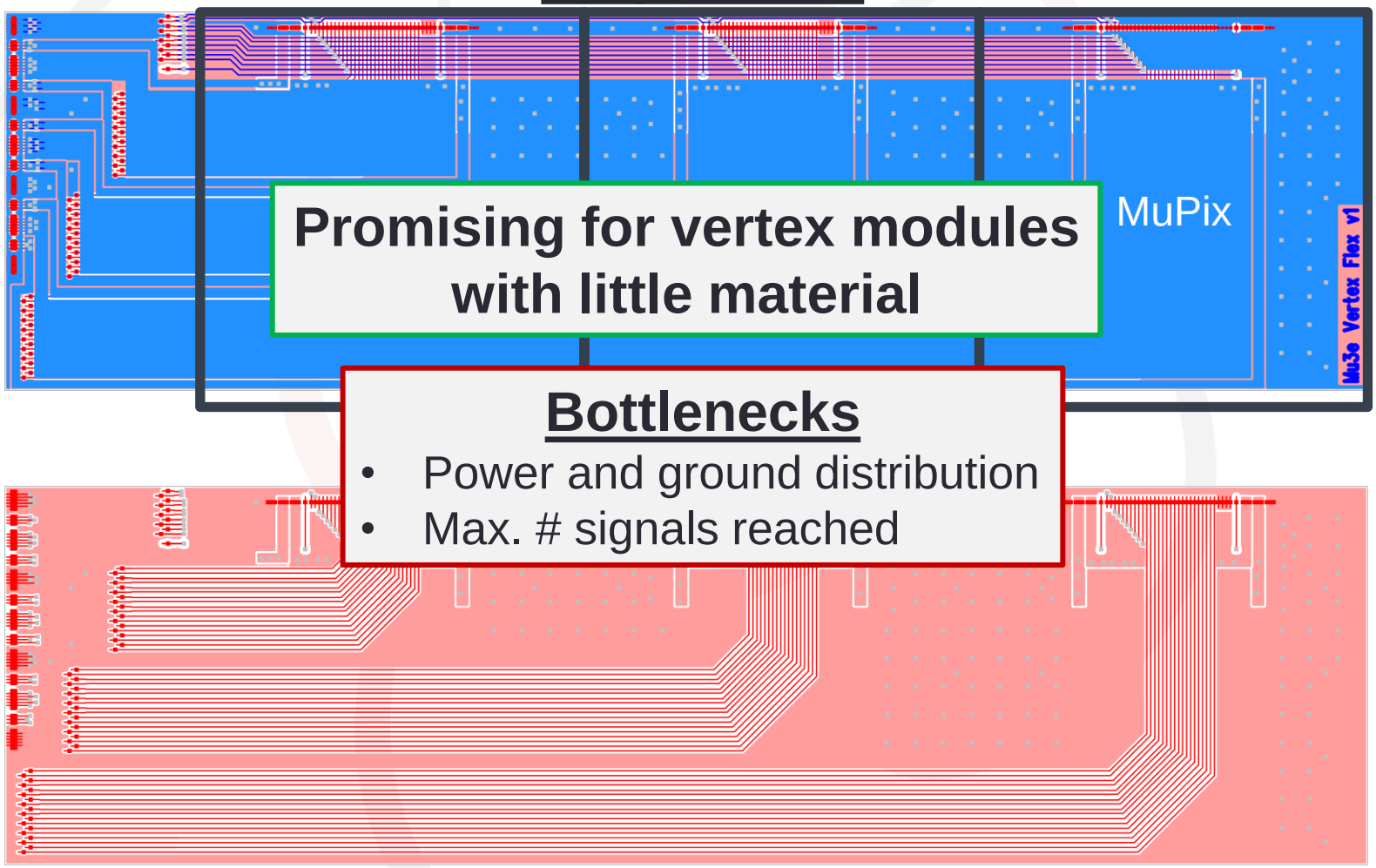


Promising for vertex modules with little material

Bottlenecks

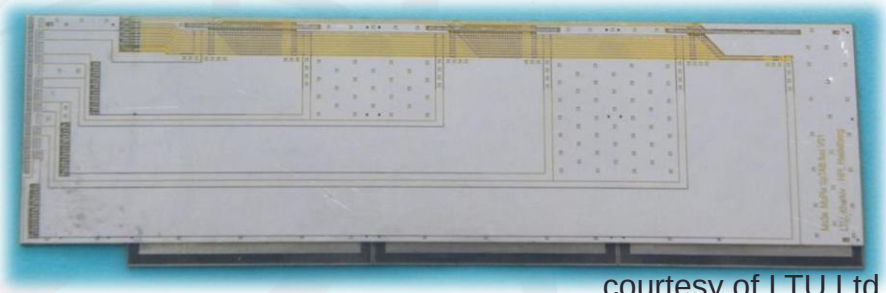
- Power and ground distribution
- Max. # signals reached

Summary

- Mu3e: Search for cLFV
- Tracking detector using HV-MAPS
- Readout and powering via flex-prints
- Prototyping: Flex prints up to 100 cm
- Up to 3.2 Gbps data transmission successful
- Study of flex-print design for vertex modules

Outlook

- First dummy modules are in production



courtesy of LTU Ltd.

- Set up to test flex-prints

➢ First vertex modules with MuPix8

- More on **MuPix7** *T 72.1 – T 72.3*
- More on **MuPix Telescope** *T 99.5*
- More on **Mu3e:** *T 22.4, T 22.5, T 42.5 –7, T 43.3, T 75.7, T 98.1, T98.5*

Backup

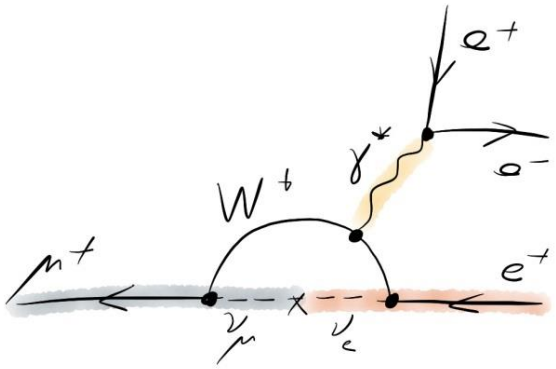
The Mu3e Experiment

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

Standard Model

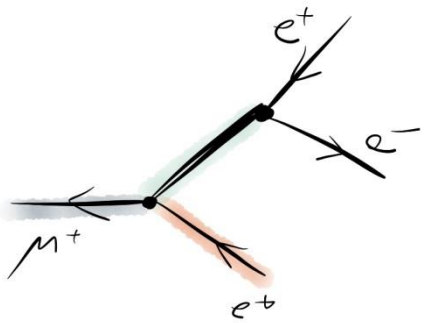
Highly suppressed branching ratio

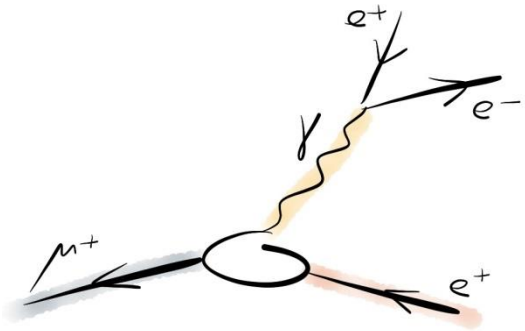
$\mathbf{BR_{SM} < 10^{-54}}$



Probe physics beyond SM

Any observation is a clear sign for new physics!





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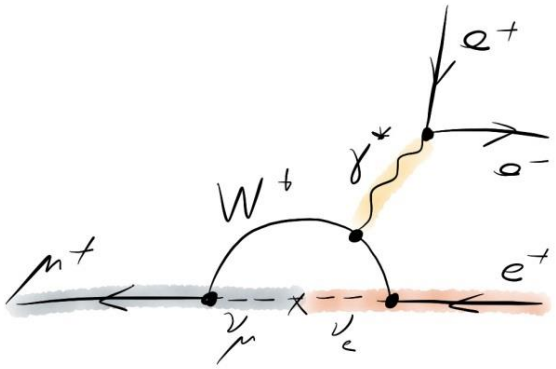

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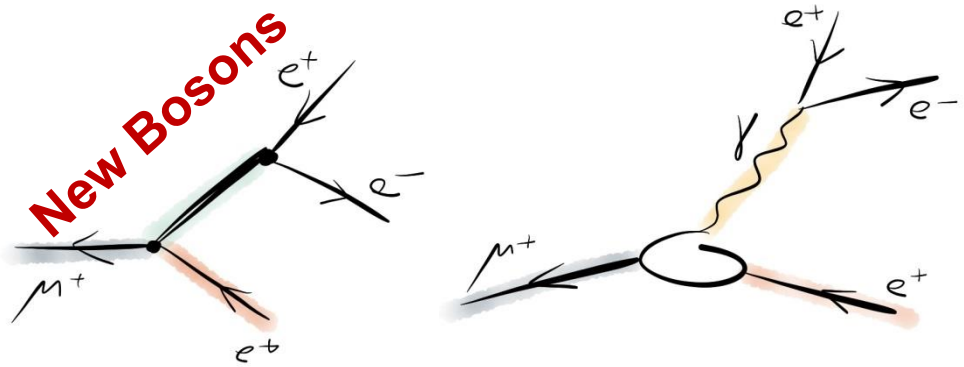

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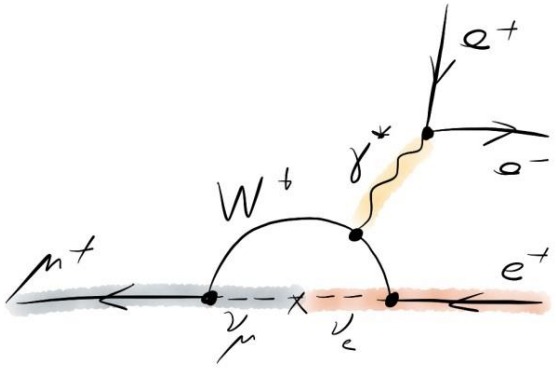

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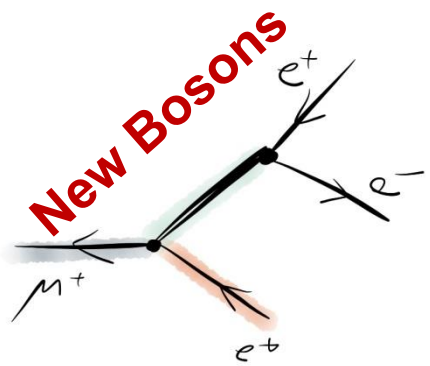
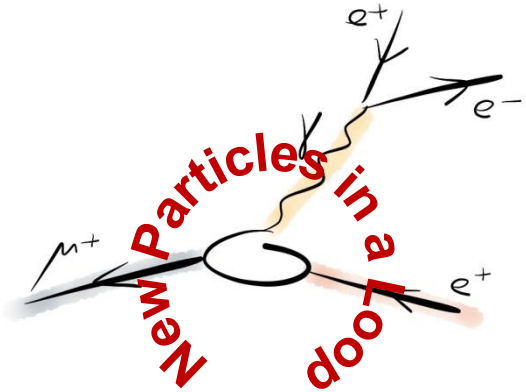




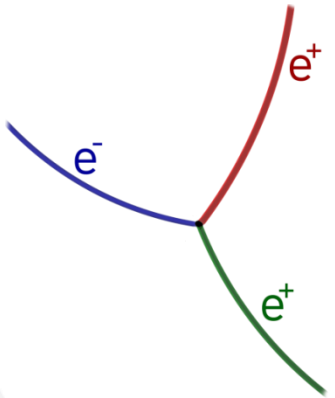
The Mu3e Experiment

Current limit on $\mu^+ \rightarrow e^+ e^- e^+$

$\mathbf{BR_{meas} < 10^{-12}}$ (SINDRUM 1988)

Goal of Mu3e

Enhance sensitivity to $\mathbf{BR < 10^{-16}}$



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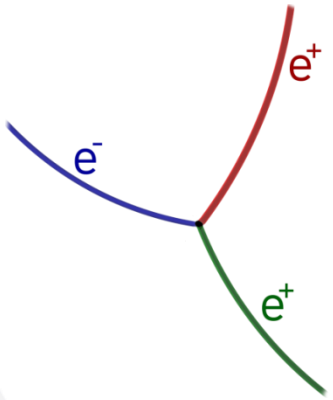

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How to achieve this in a reasonable time?

- High muon rate $\mathcal{O}(\mathbf{10^9\ s^{-1}})$

➢ Beamline at PSI (CH)

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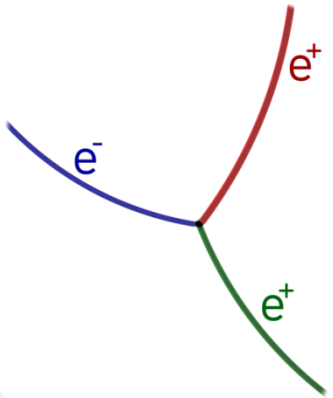

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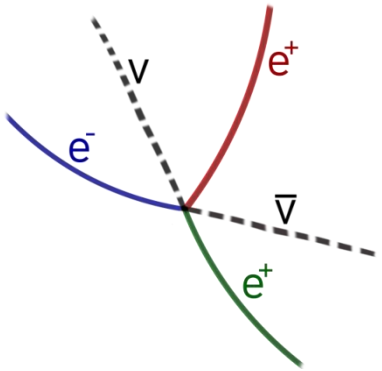
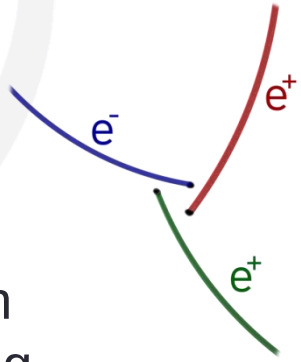


What are the main backgrounds?

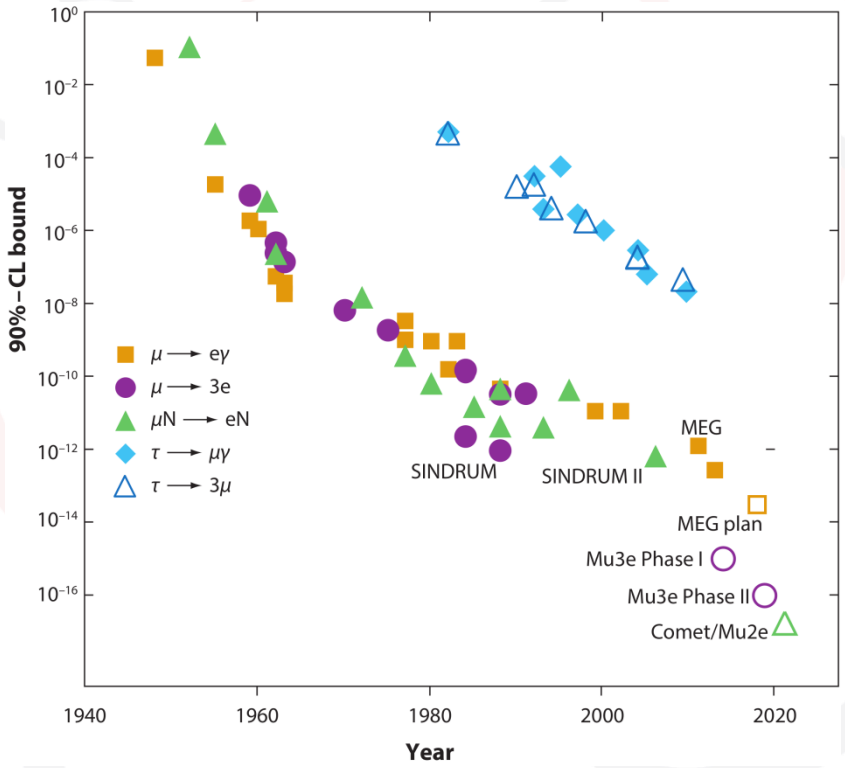
- Radiative SM decay $\mu^+ \to e^+e^-e^+\nu\bar{\nu}$
- Accidental combinations

➢ Excellent momentum and vertex resolution

➢ Fast detector electronics and precise timing

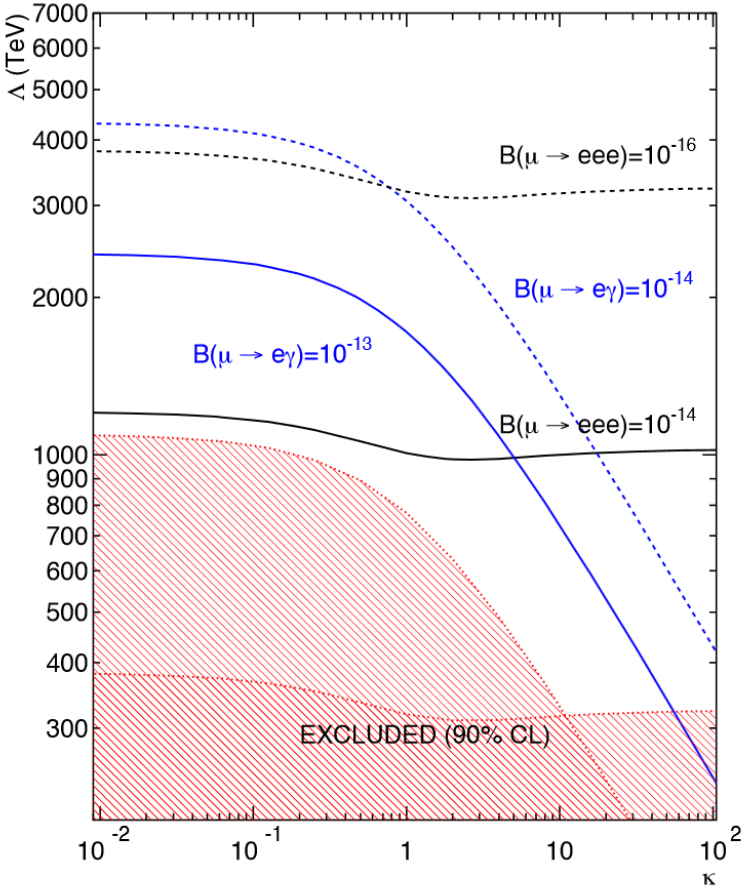


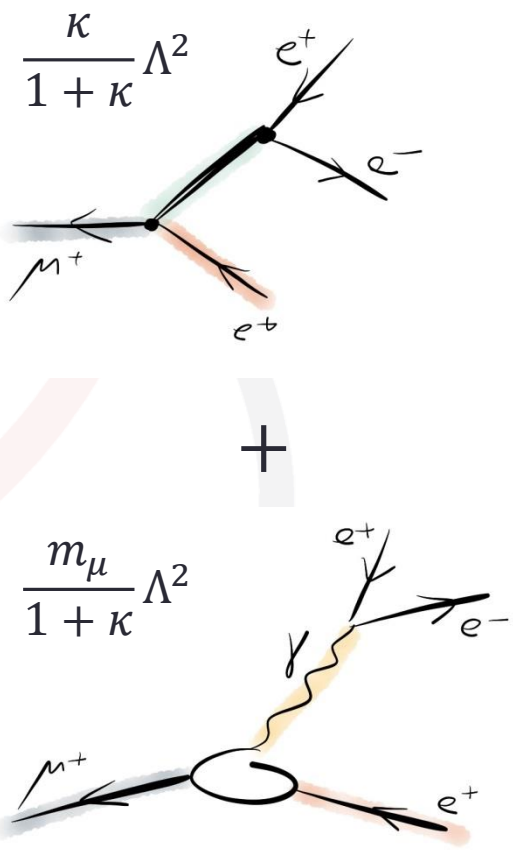
History of CLFV Experiments



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

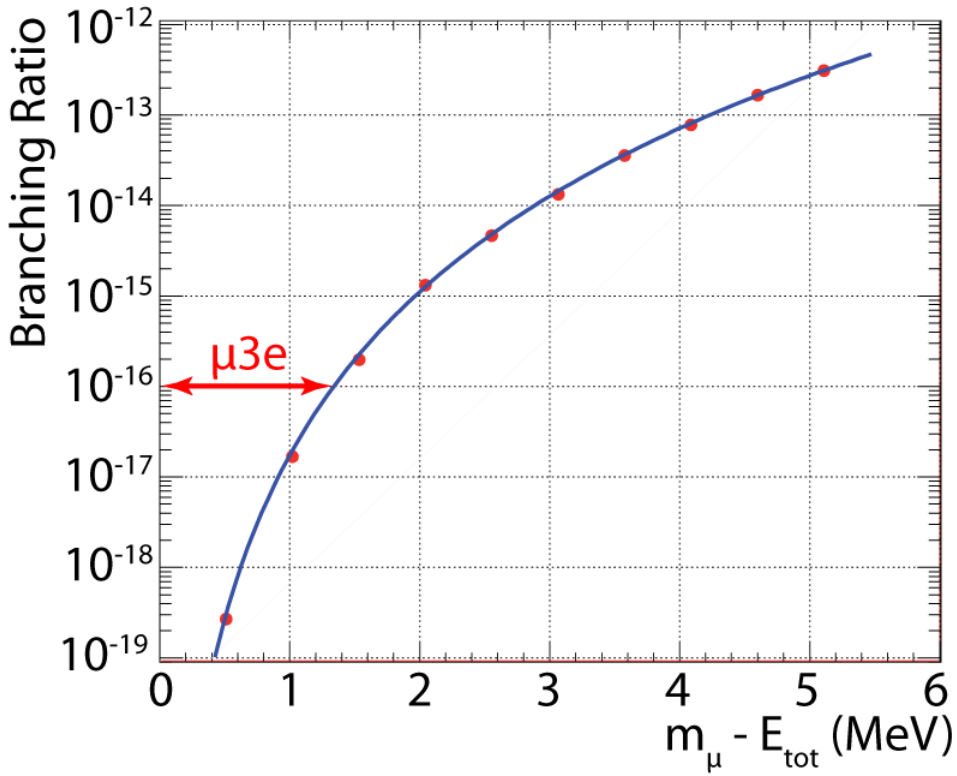
Searching for New Physics with Mu3e





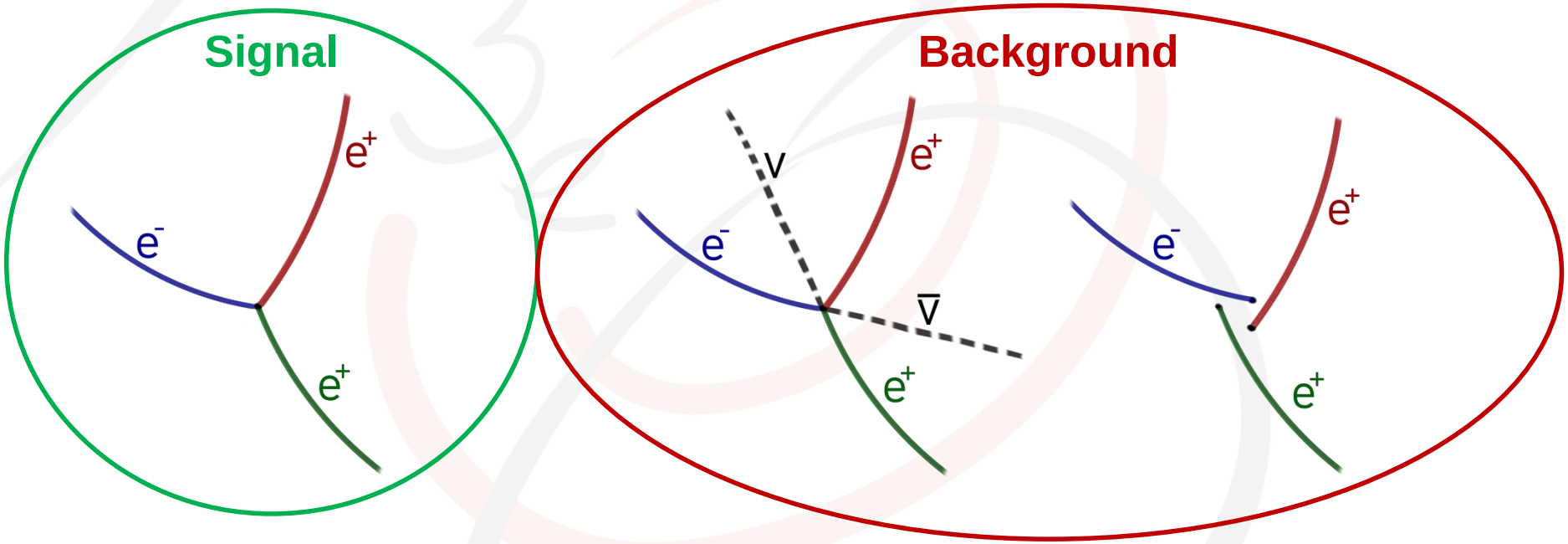
André de Gouvêa, Petr Vogel,
Lepton flavor and number conservation, and physics beyond the standard model,
Progress in Particle and Nuclear Physics, 71 (2013) 75-9

Momentum Resolution Requirement



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

Event Topologies



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

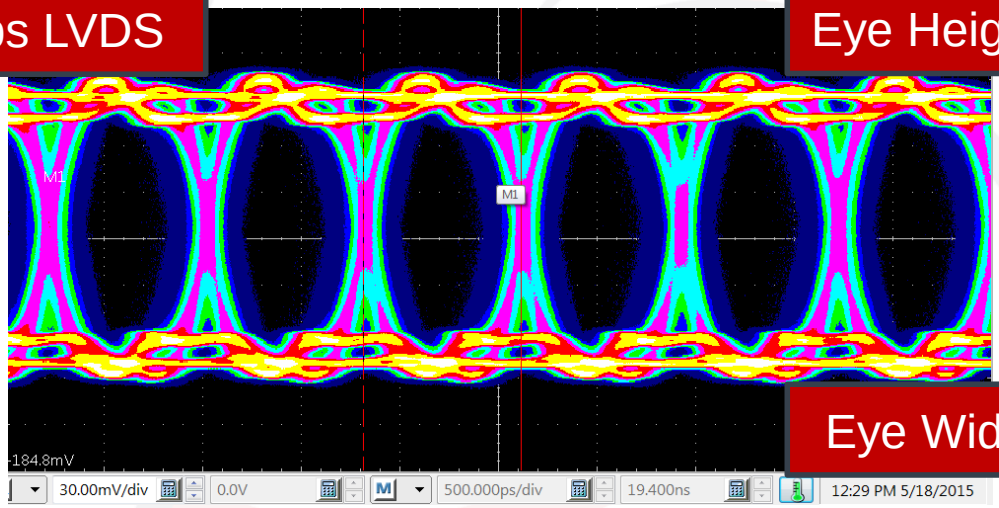
- Common vertex
- Coincident
- $\sum \vec{p} \neq 0$
- $\sum E \neq m_\mu$

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

Serial Readout of the MuPix7

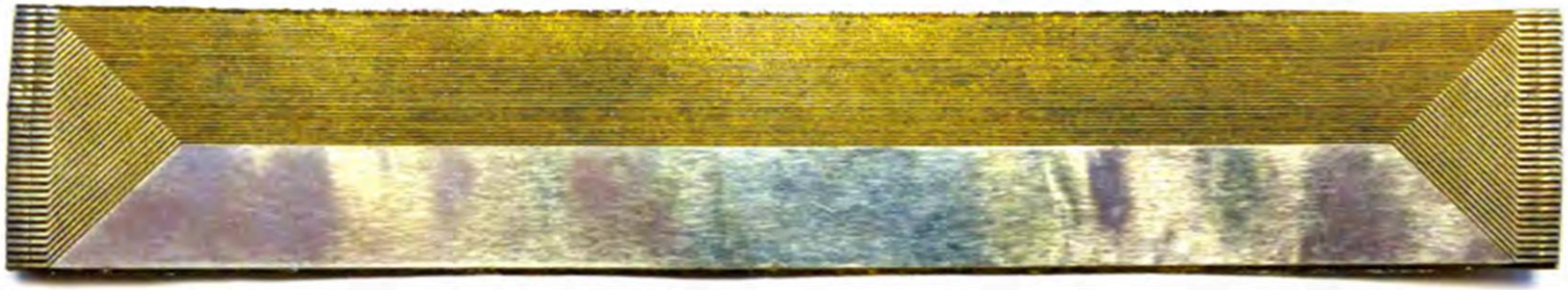
1.25 Gbps LVDS

Eye Height > 100 mV

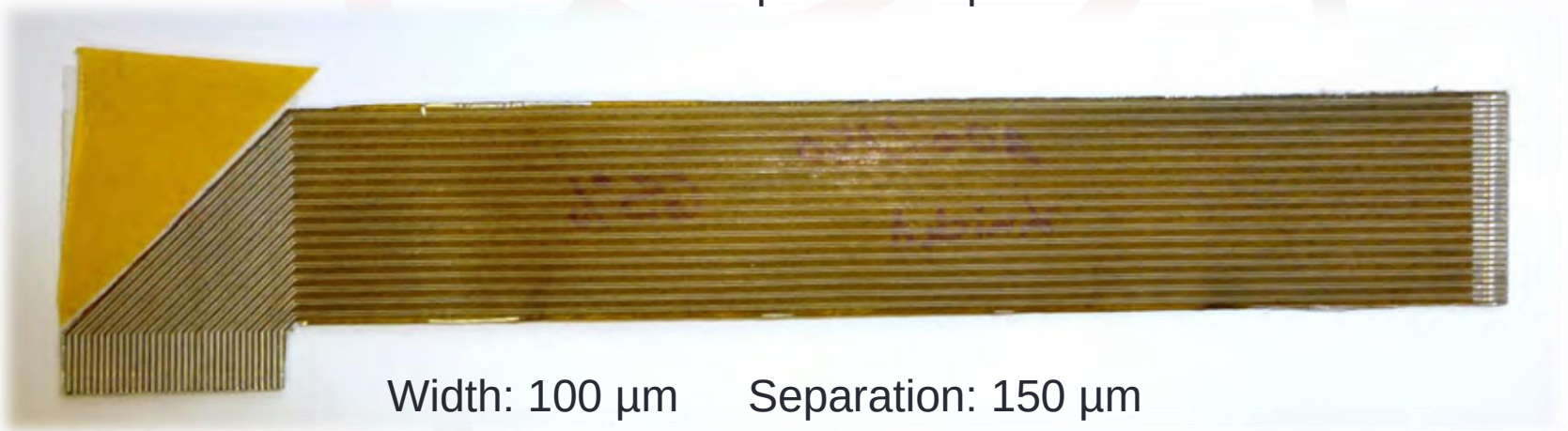


Eye Width > 0,65 UI

More Flexprint Prototypes



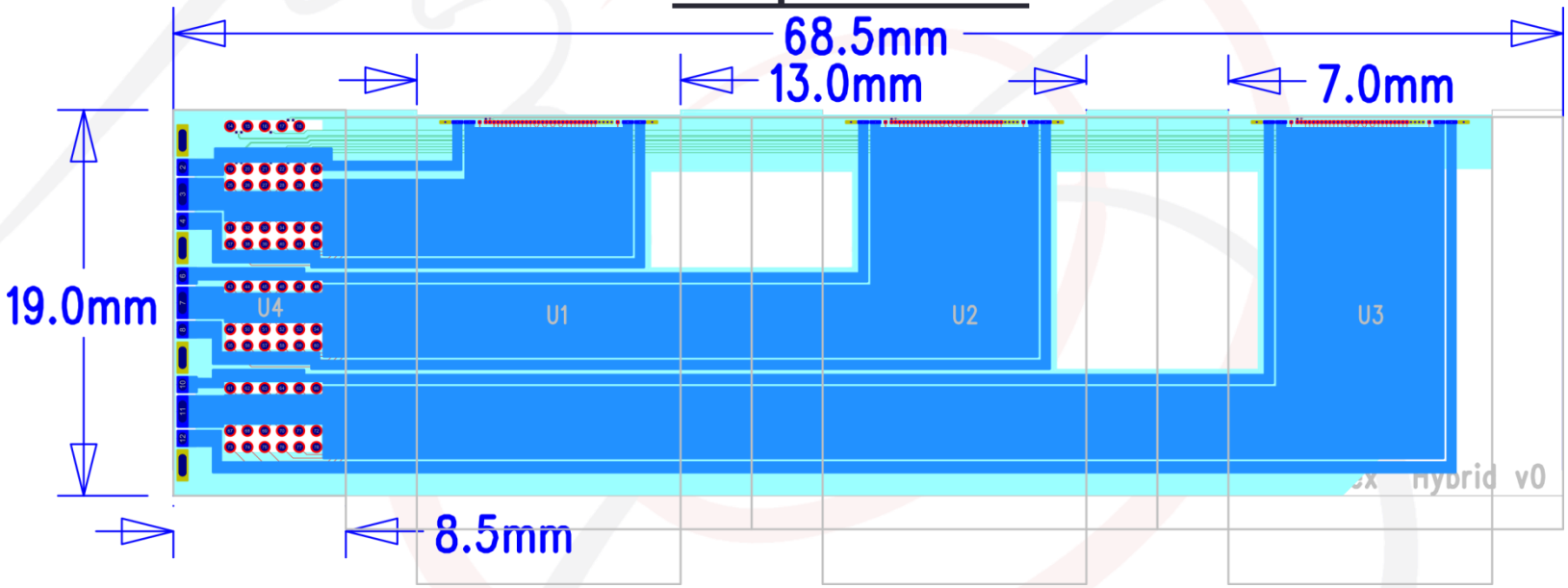
Width: 100 µm Separation: 150 µm
Between pairs: 150 µm



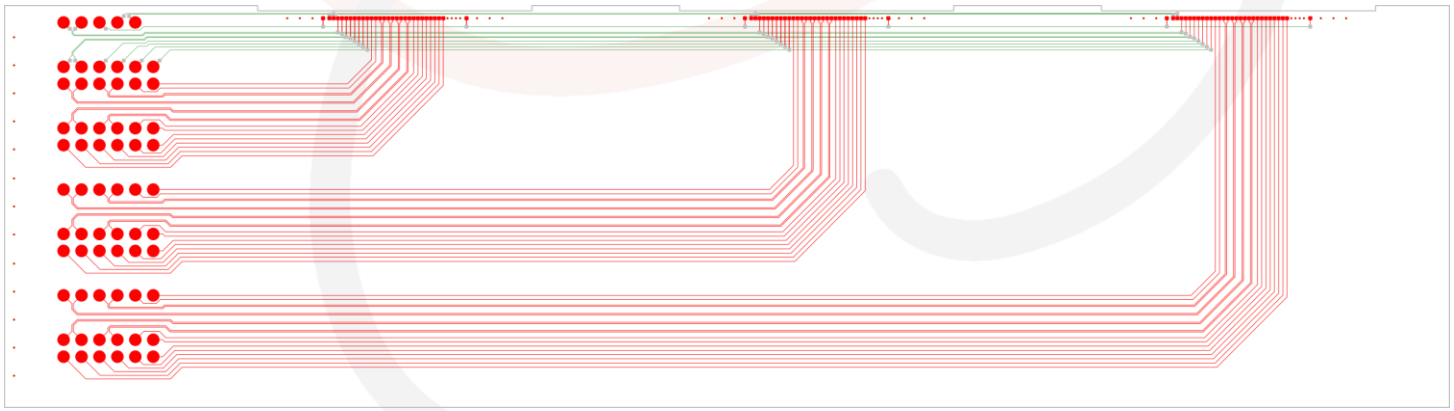
Width: 100 µm Separation: 150 µm
Between pairs: 650 µm

Copper Aluminium Laminate Option

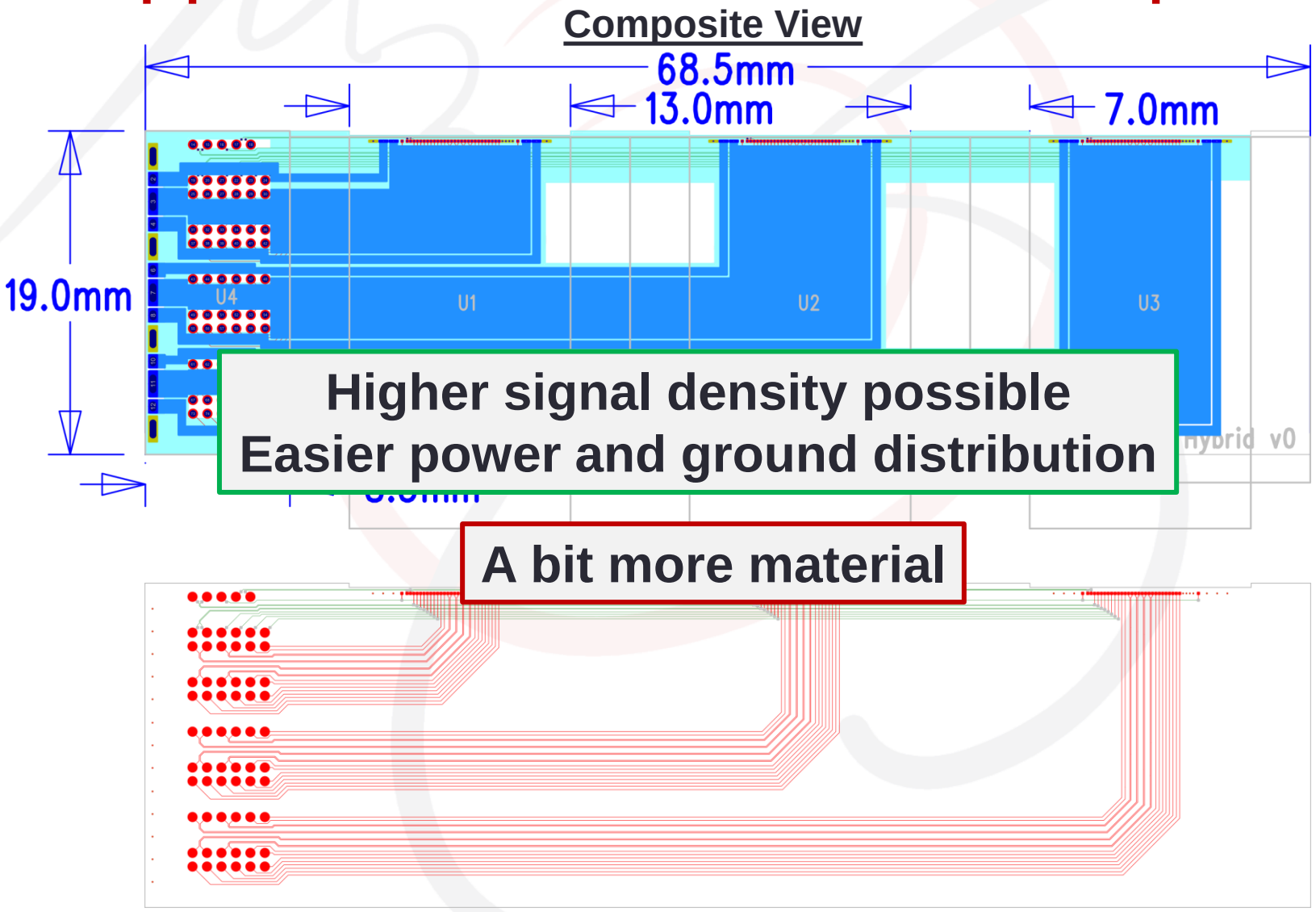
Composite View



Inner Cu Layers



Copper Aluminium Laminate Option



Higher signal density possible
Easier power and ground distribution

A bit more material

Assumption: Signals for MuPix8