# GIGABIT DATA TRANSMISSION

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ATLAS HV-MAPS Workshop
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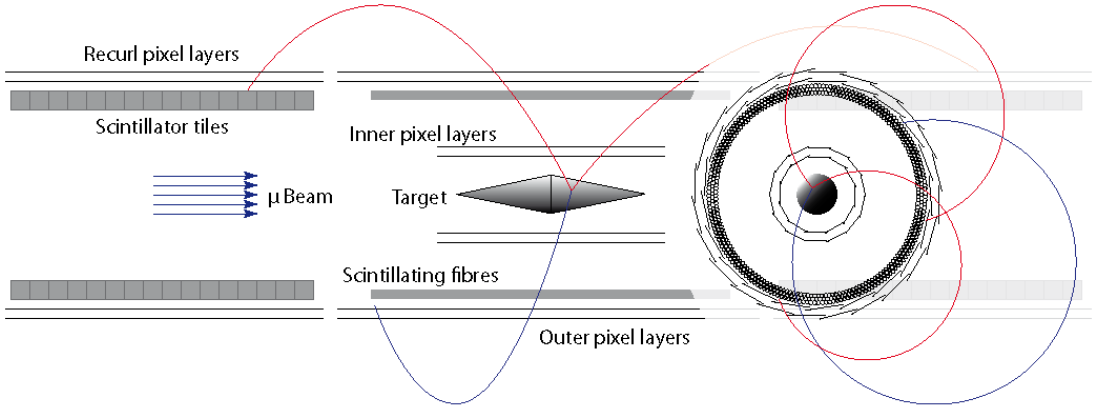
INTERNATIONAL MAX PLANCK RESEARCH SCHOOL

PT FS

FOR PRECISION TESTS OF FUNDAMENTAL SYMMETRIES

# Flex print studies – motivated by Mu3e experiment




Search for the decay $\mu^+ \rightarrow e^+e^+e^-$ with a sensitivity better than $10^{-16}$

Required:

- Excellent momentum resolution
- Good vertex resolution

→ Low material budget tracking detector using HV-MAPS

Online event reconstruction and filtering requires readout of all hits

# Flex print studies – motivated by Mu3e experiment

Data rates from simulations

| Phase I | | Phase II |
|---|---|---|
| • Most active sensors:<br>  • Size: $2\text{x}2\ \text{cm}^2$<br>  • Hit rate: $2\ \text{MHz/cm}^2$<br>• Raw hit data:<br>  **192 Mbps/sensor** | Increase → muon rate | • Most active sensors:<br>  • Size: $2\text{x}1\ \text{cm}^2$<br>  • Hit rate: $50\ \text{MHz/cm}^2$<br>• Raw hit data:<br>  **2400 Mbps/sensor** |

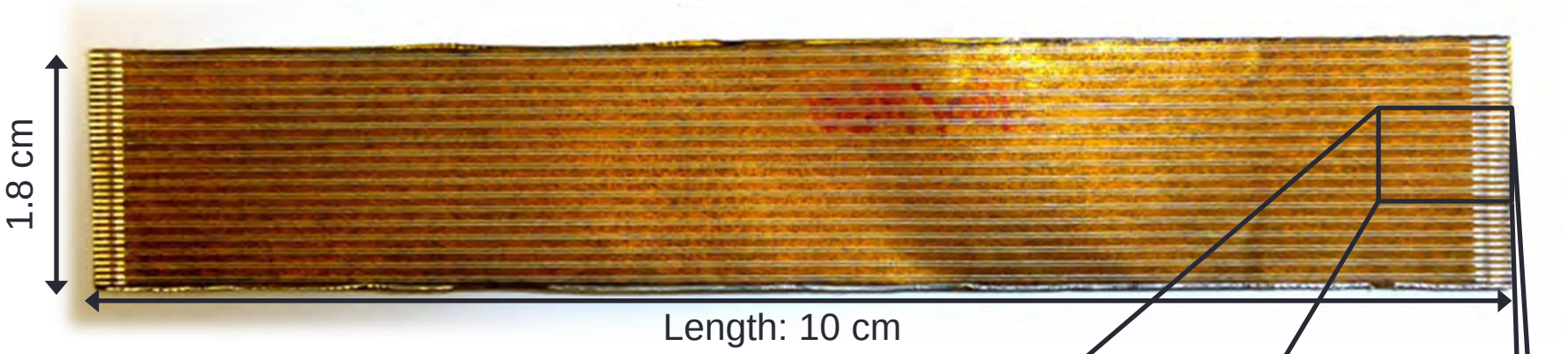
Not including protocol or noise in the sensor!

ATLAS
Pileup 140
Radius ~ 50 cm

→ We need a data transmission system with **Gbps** per link

→ Choice: **Kapton/Aluminum flex prints**
- Provide little material
- Fabrication studies in-house

# Flex print prototypes



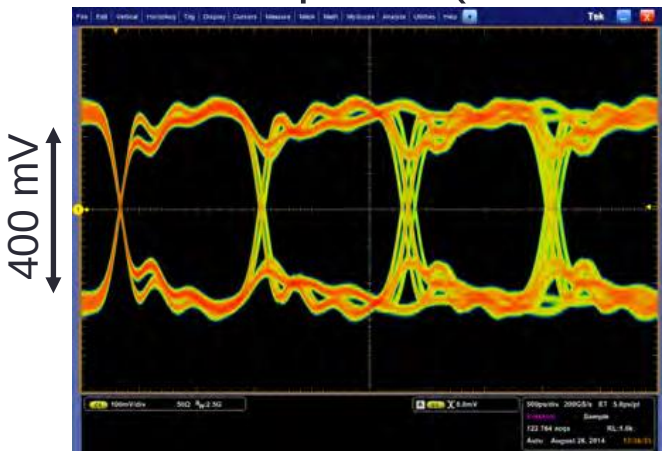

- 25 µm Kapton + 12 or 25 µm Aluminum
- Laser evaporation and cutting
- Ground plane
  - 25 µm Kapton + 12 µm Al
  - Reduce crosstalk
  - Enhance impedance
- Lengths up to 1m produced
- Current system: structures ~ 100 µm

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

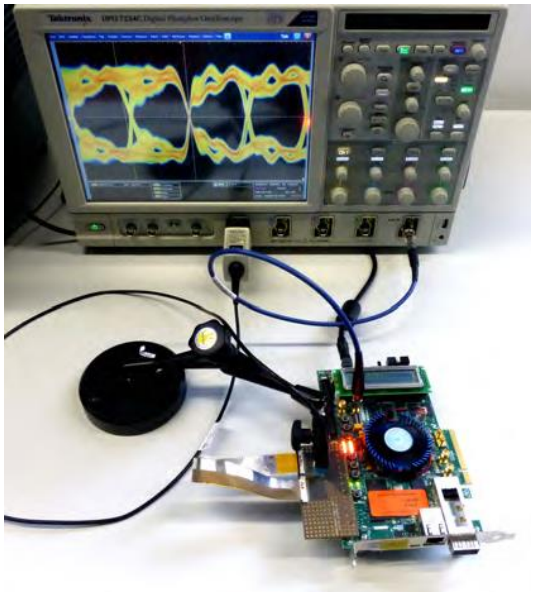
# Testing the flex prints

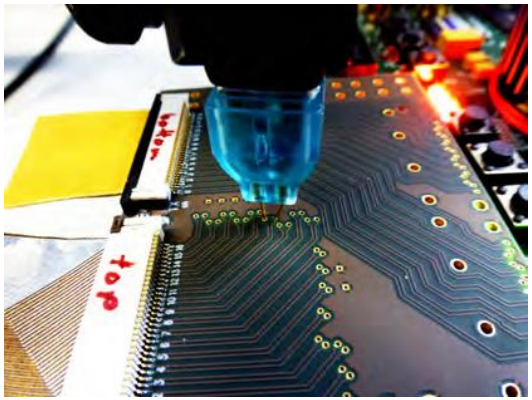
- Bit error rate test:
  - Altera Stratix V GS development kit
  - 8b10b encoded counter pattern
  - 17 LVDS links up to 1.6 Gbps

- Eye diagram measurement
  - Scope (2.5 GHz sampling rate)
  - Differential probe (3.5 GHz BW)



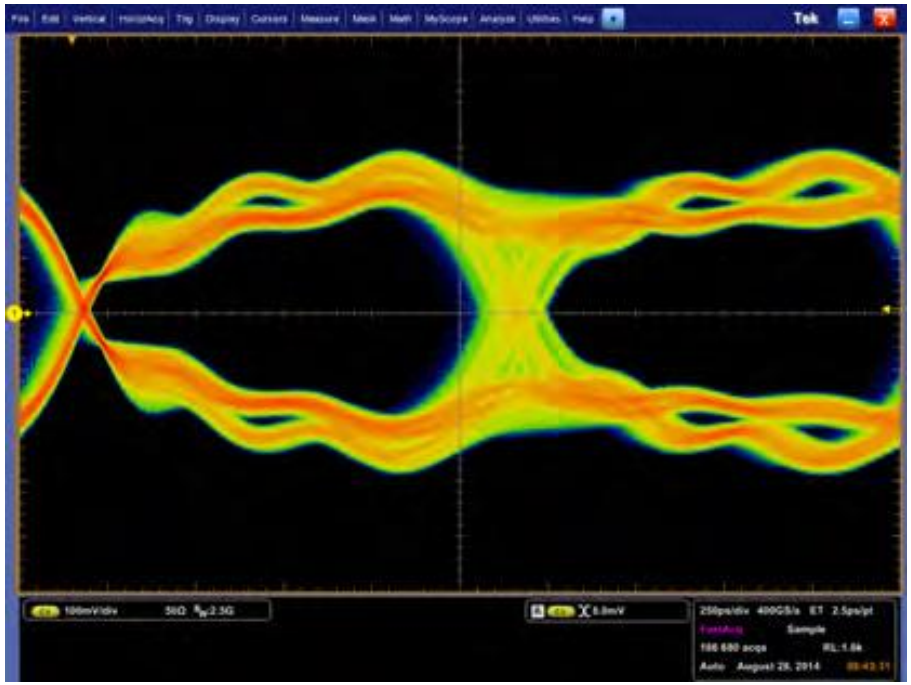

Signal transmitted from the FPGA without flex print



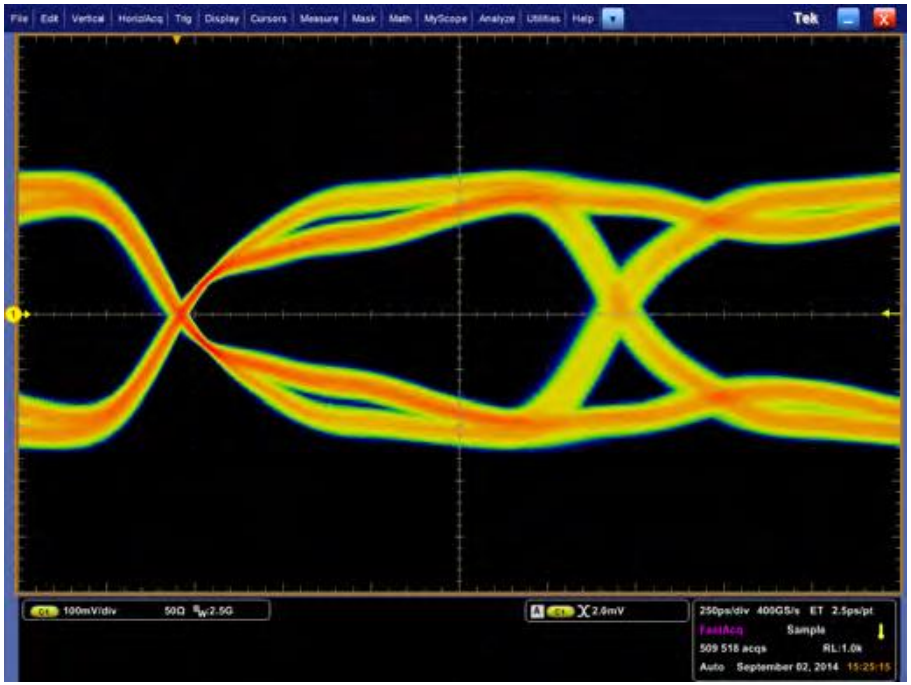


# Eye diagrams at 800 Mbps

LVDS transmitter: Altera Stratix V GS FPGA




30 cm long flex print
with ground plane
Trace width: 100 µm

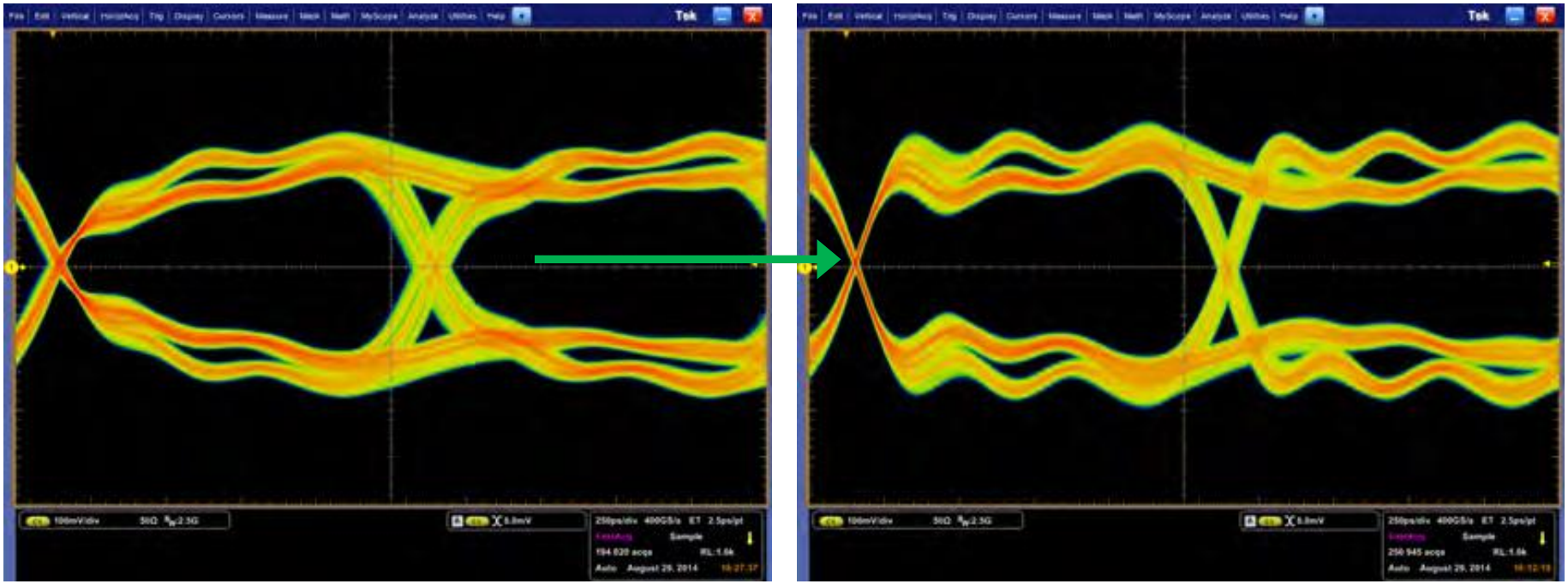


50 cm long flex print
with ground plane
Trace width: 150 µm

B.Sc. thesis by Jens Kröger

# Pre-emphasis (800 Mbps)

Edges can be sharpened using pre-emphasis




30 cm long Flexprint
with ground plane
Trace width: 100 µm

B.Sc. thesis by Jens Kröger

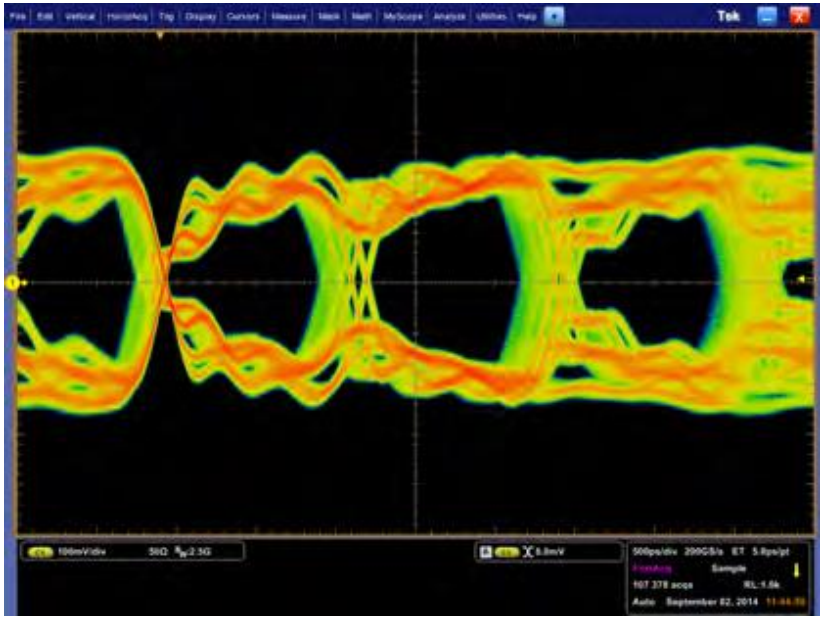
# Bit error rates

LVDS loopback test on Altera Stratix V GS FPGA

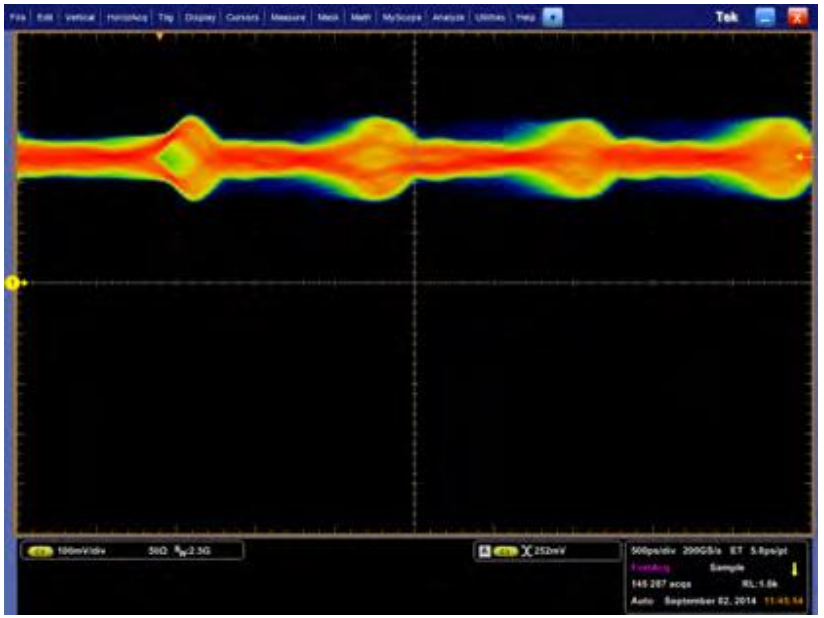
| Cable length | Ground plane | Data rate | BER |
|---|---|---|---|
| ≤ 50 cm | ✓ | 800 Mbps | $\leq 3 \cdot 10^{-13}$ |
| 20 cm | ✓ | 1600 Mbps | $\leq 2 \cdot 10^{-13}$ |
| 100 cm | ✗ | 800 Mbps | $2 \cdot 10^{-15}$ |

- But: Not all traces are properly connected!
- E.g.: 1m cable (trace width = 100 µm): 11/17 channels working
- Production issues:
  - Inhomogeneities of laser platform's z-position
  - Trace width at lower limit of our laser's resolution

# Crosstalk




800 Mbps data transmission

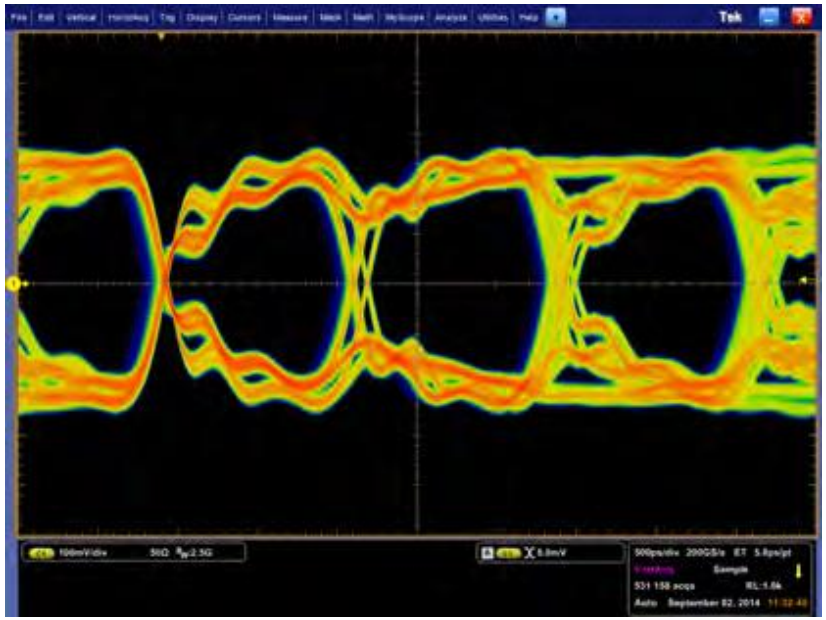


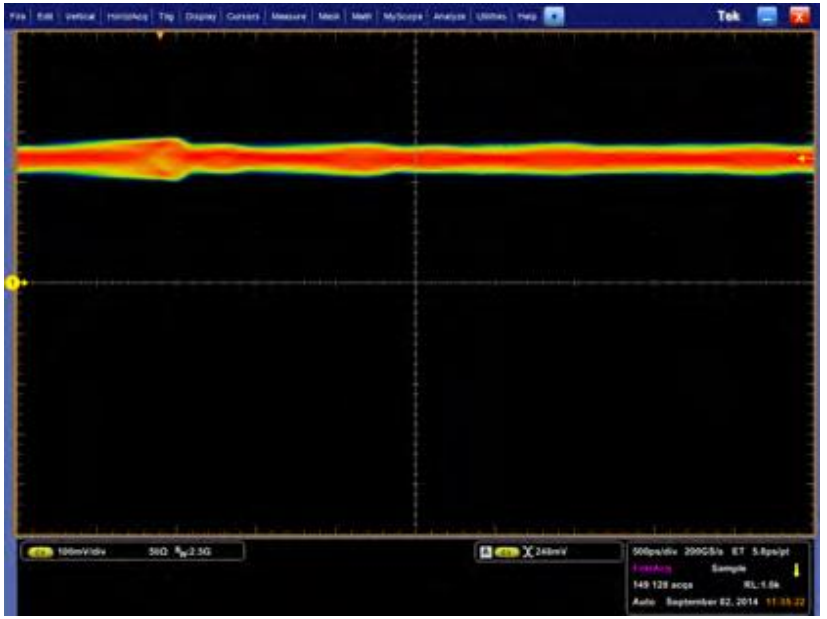
20 cm long Flexprint
No ground plane
Trace width: 100 µm

Crosstalk on adjacent trace

# Crosstalk

Crosstalk can be reduced by ground plane



800 Mbps data transmission

20 cm long Flexprint
With ground plane
Trace width: 100 µm

Less crosstalk on adjacent trace

B.Sc. thesis by Jens Kröger

# Summary

- Data rates up to 1600 Mbps transferred over 20 cm flex print
- Data rates up to 800 Mbps transferred over 100 cm

# Outlook

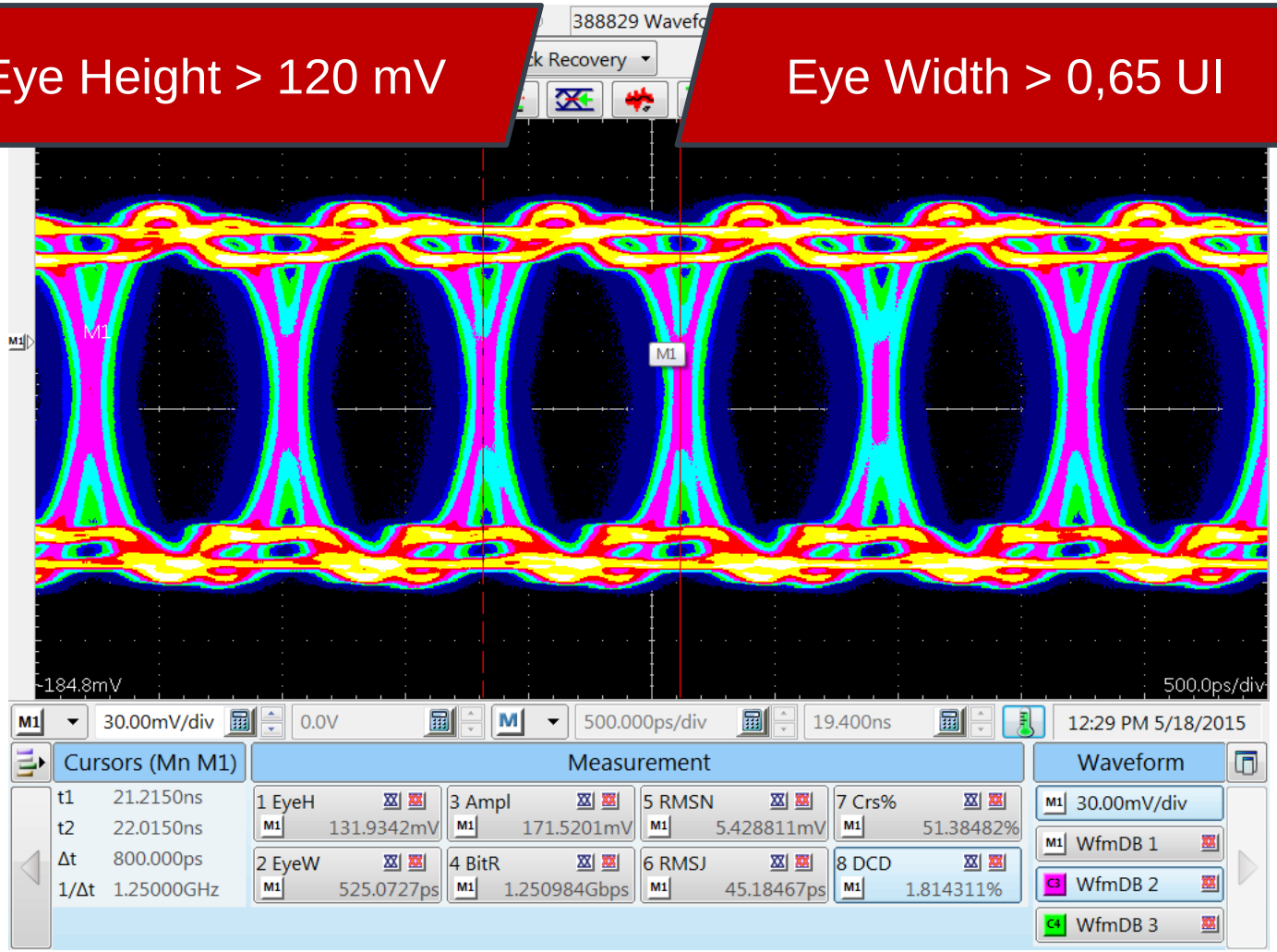
- Improve fabrication process
- 100 cm flex print with ground plane and increased trace width
- Tests of flex prints at data rates up to 10 Gbps
- Integration with MuPix sensor

# Backup

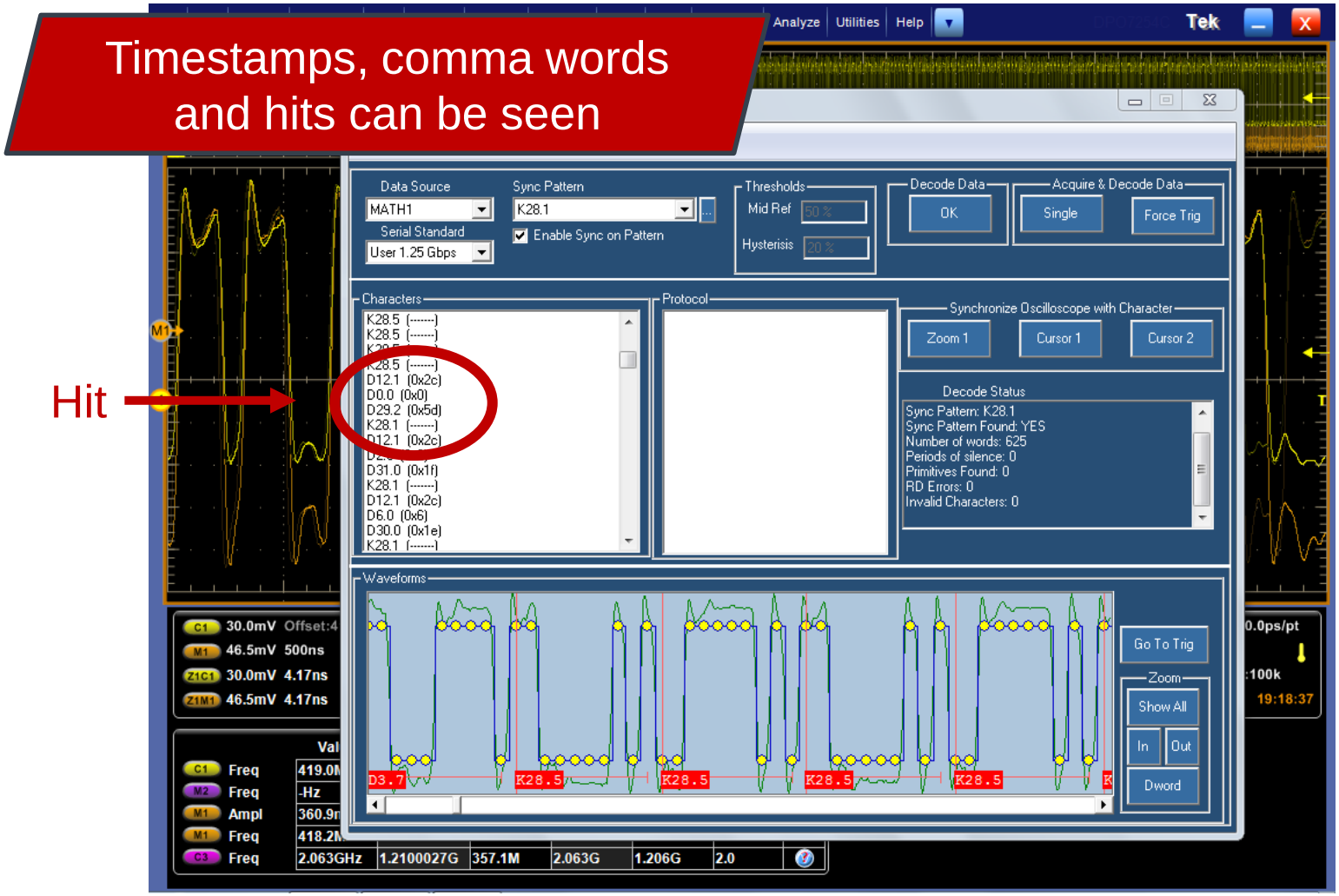
# MuPix7 eye diagram at 1.25 Gbps

Eye Height > 120 mV

Eye Width > 0,65 UI



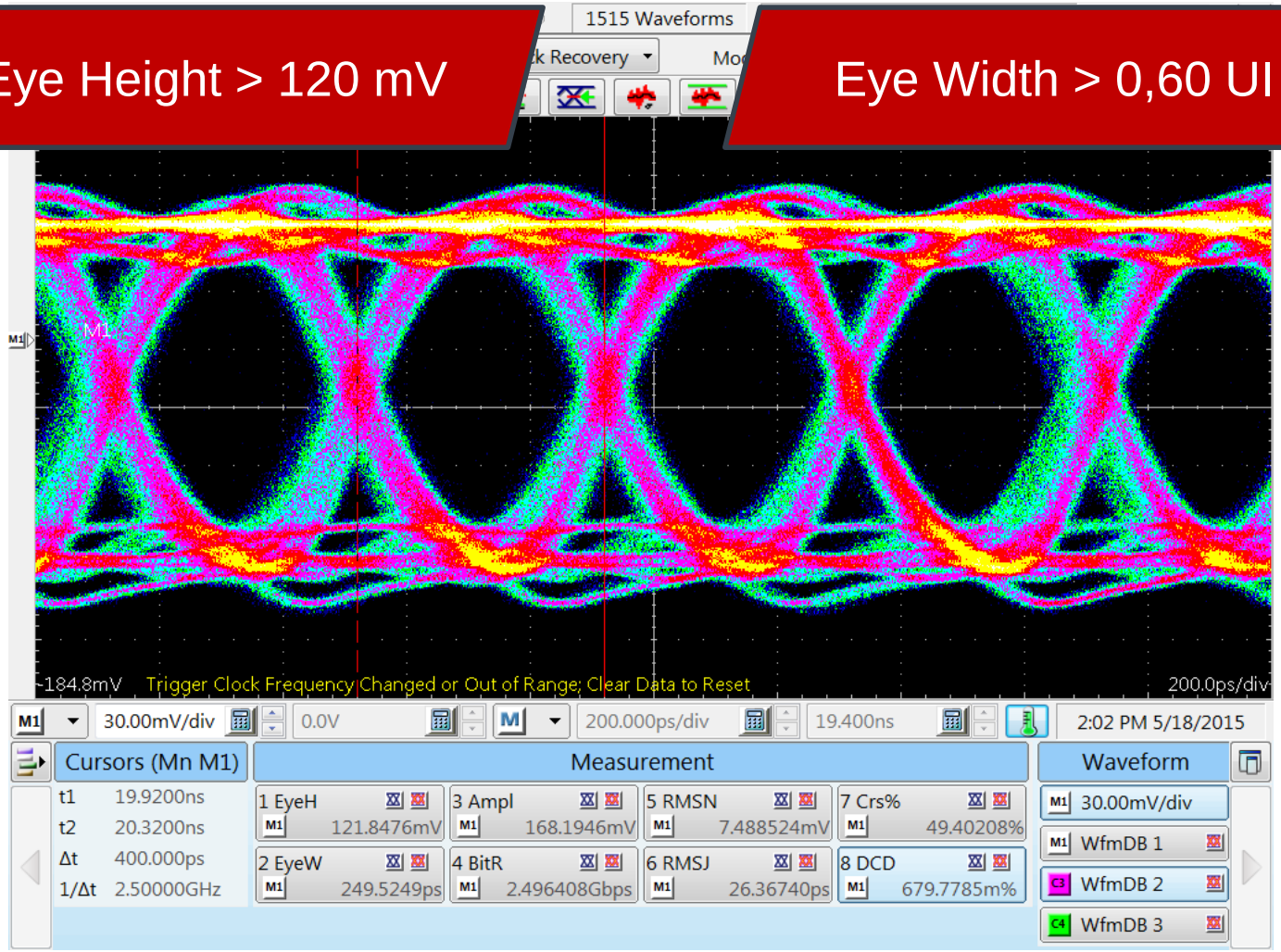
# MuPix7 data structure at 1.25 Gbps



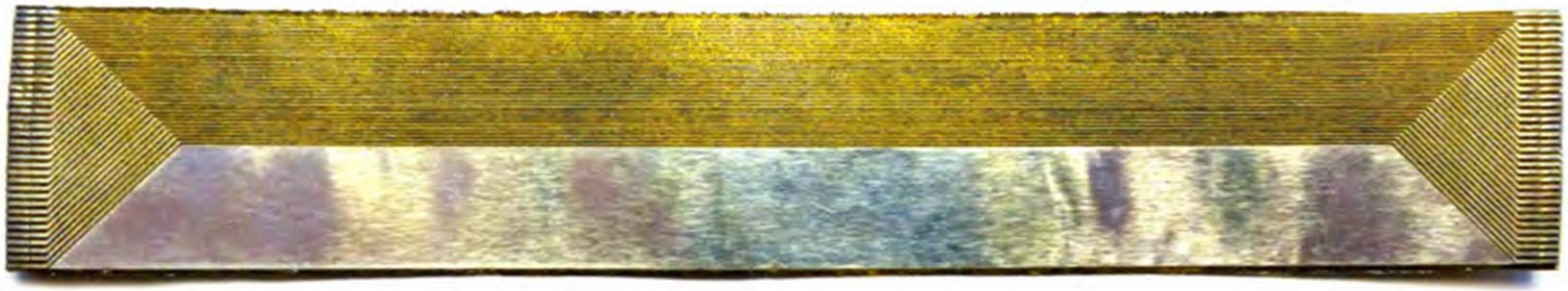
# MuPix7 eye diagram at 2.5 Gbps

Eye Height > 120 mV

Eye Width > 0,60 UI



# More Flexprint Prototypes

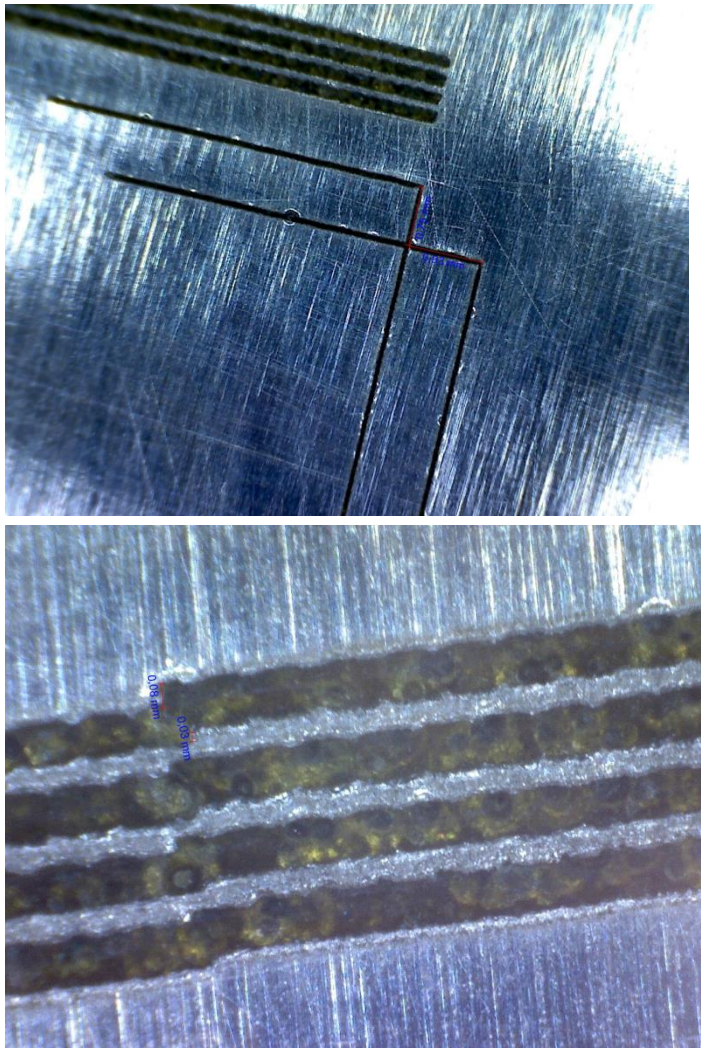


Width: 100 µm Separation: 150 µm
Between pairs: 150 µm

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

# 100 cm flex print prototyping

- Foil thickness:
  25 µm Kapton + 25 µm Aluminum
- Laser platform: $80 \times 46\ \mathrm{cm}^2$
- Piecewise production: $3 \times 33\mathrm{cm}$
- Edges to calibrate shifted foil
- Trace width: 100 µm
  Trace separation: 150 µm



Courtesy of Carsten Grzesik

# Material budget of flex prints

| 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 | $8.7 \cdot 10^{-5} + 1.3 \cdot 10^{-4}$ |
| ✗ | 25 µm | 25 µm | $8.7 \cdot 10^{-5} + 2.8 \cdot 10^{-4}$ |
| ✓ | 50 µm | 24 µm | $1.7 \cdot 10^{-4} + 2.7 \cdot 10^{-4}$ |
| ✓ | 50 µm | 50 µm | $1.7 \cdot 10^{-4} + 5.6 \cdot 10^{-4}$ |

# Material budget of flex prints

| 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

→ Values are overestimated