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SuperKEKB Commissioning Detector
FANGS
Belle II Collaboration

FANGS

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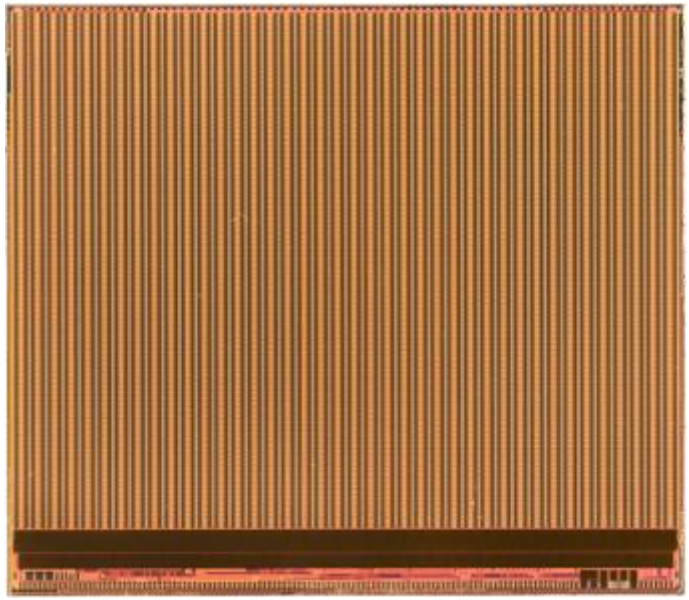
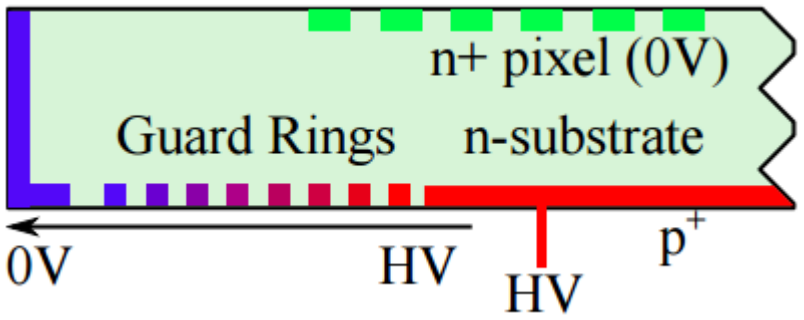
FANGS: FE-I4 ATLAS Near Gamma Sensors



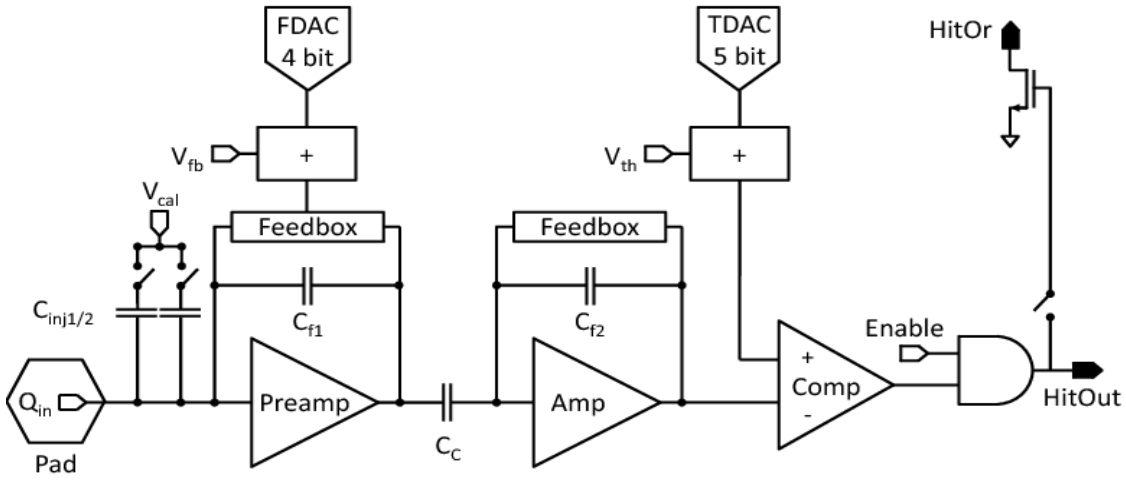


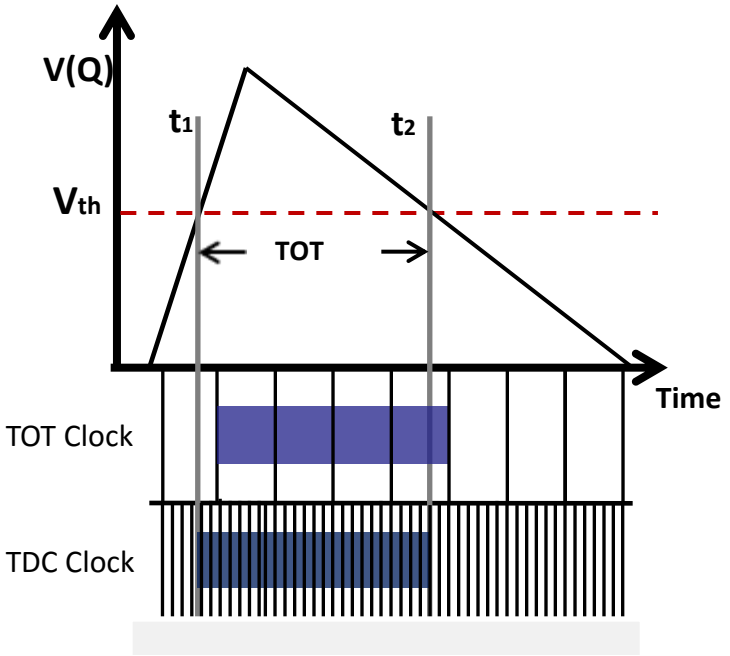
- FE-I4 read out chip
  High hit rates and radiation hard
  IBM 130 nm CMOS process
  Read out for 80x336 pixels
  Thickness=150 µm
  Physical size=**21x19 mm²**

- Sensor:
  n-in-n planar
  Pitch=**50x250 µm²**
  Thickness=200 µm
  Physical size=19x20 mm²
  HV=60 V
  Power=1.2 W

- **Background radiation measurements in Phase 2:**
  - Sensitive to low keV X-rays
  - Ability to measure high particle rates

TDC Method

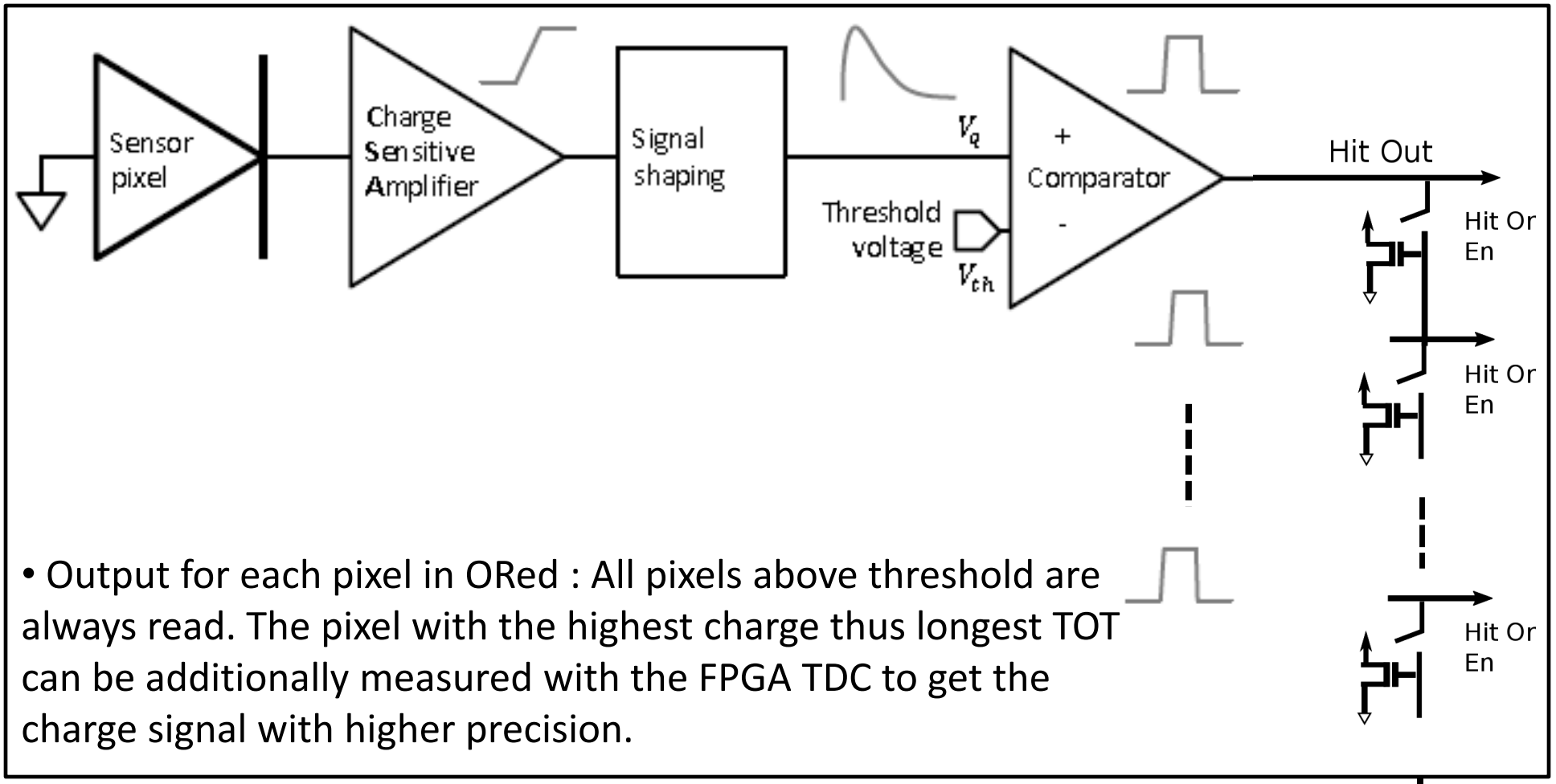




- Two stage amplifier → Discriminator with adjustable threshold.
- Time over threshold **(TOT)** with 40 MHz clock.
- Time to digital converter **(TDC)** uses 640 MHz FPGA clock.
- Output of each pixel is ORed.
- Internal charge injection circuit for threshold tuning and calibration

→ Both, high speed and adequate energy resolution achieved at the same time

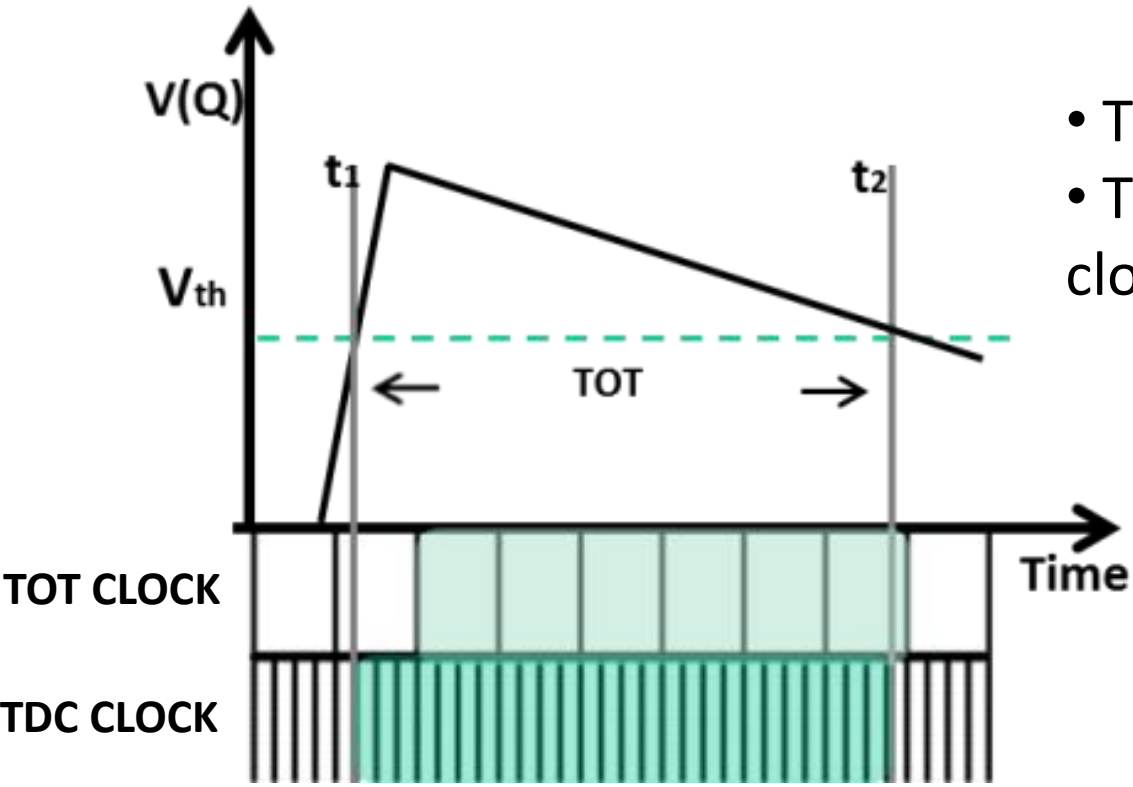
Pixel Schematic



- Output for each pixel in ORed : All pixels above threshold are always read. The pixel with the highest charge thus longest TOT can be additionally measured with the FPGA TDC to get the charge signal with higher precision.

- Hit Bus also used as self trigger

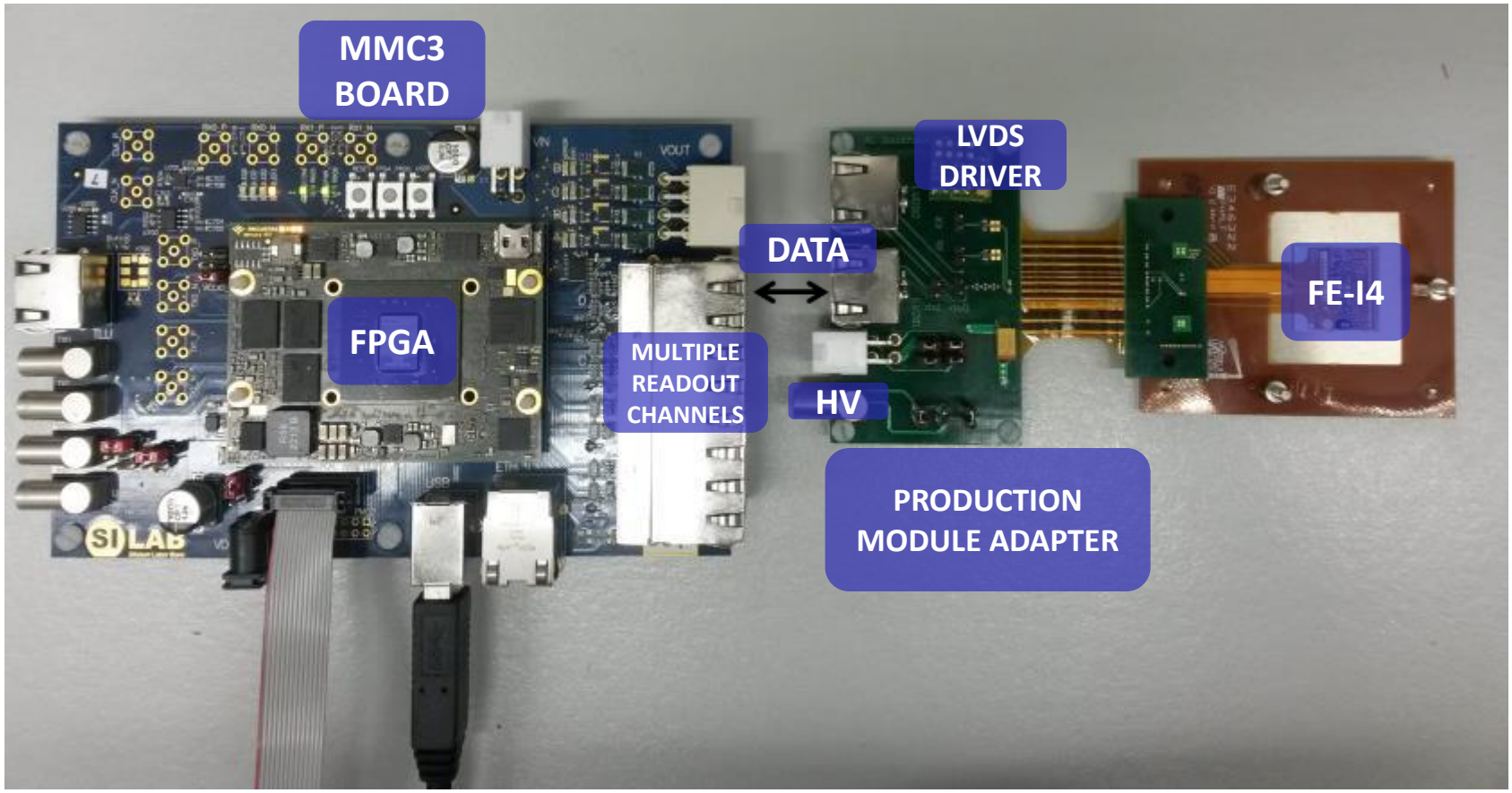
TDC Method



- TOT Method uses 40MHz clock:4 bit
- TDC Method uses FPGA's 640 MHz clock:16 bit

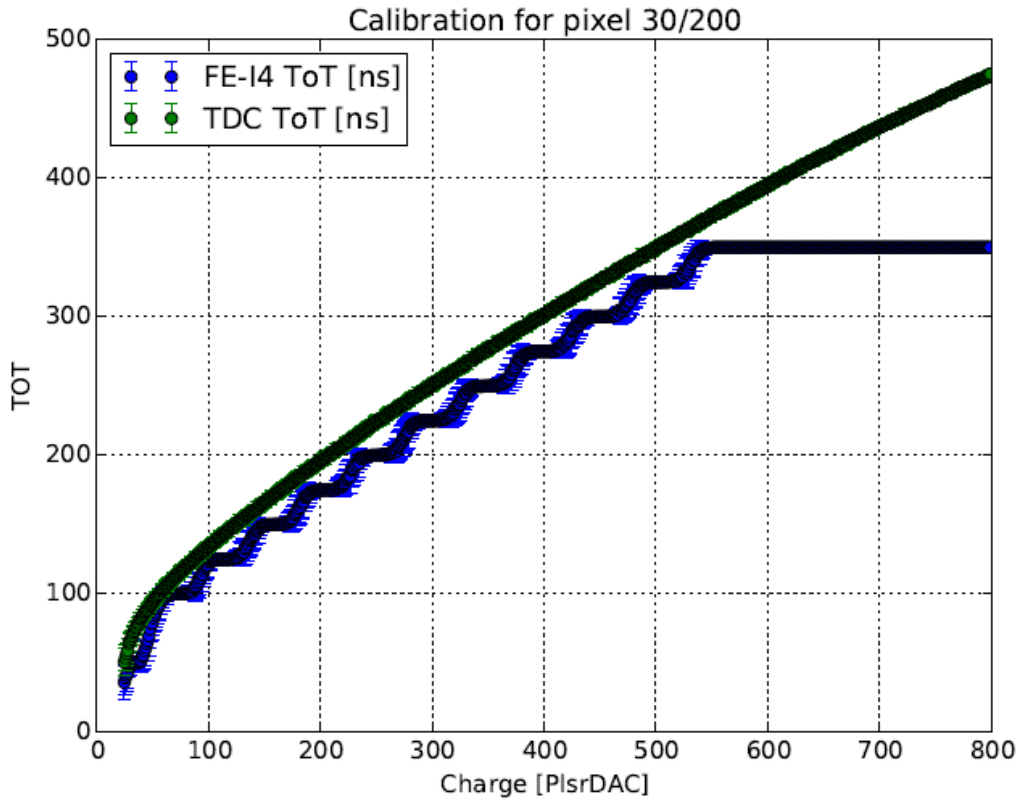
- Improved resolution
- Limited to **one** pixel per readout
- HitOr signal transmitted separately

Experimental Setup



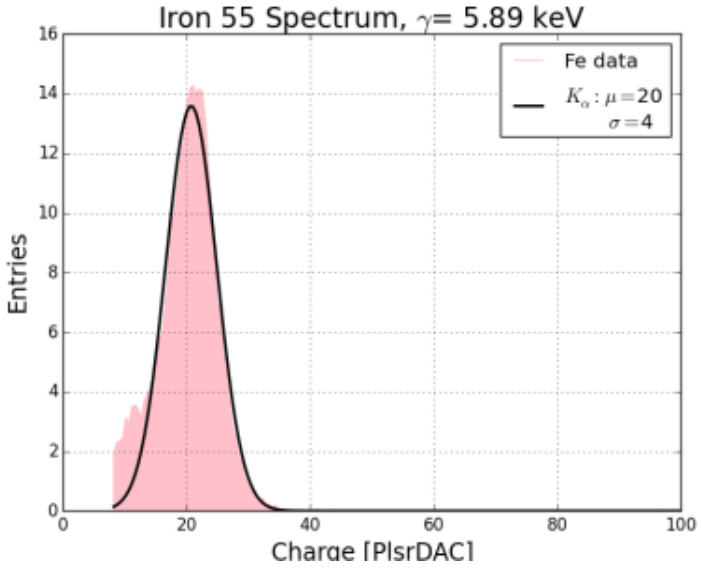
- MMC3: New data acquisition system for the BEAST experiment
  - Multiple FE read out in parallel
  - Faster FPGA; TDC Method may be improved
- Single ended HitOr signal converted to an LVDS signal.

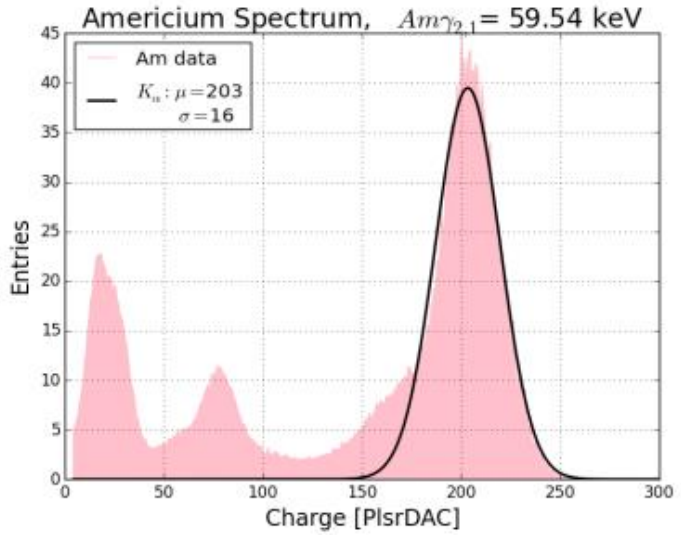
Pixel-per-pixel Calibration of Hit Or Signal

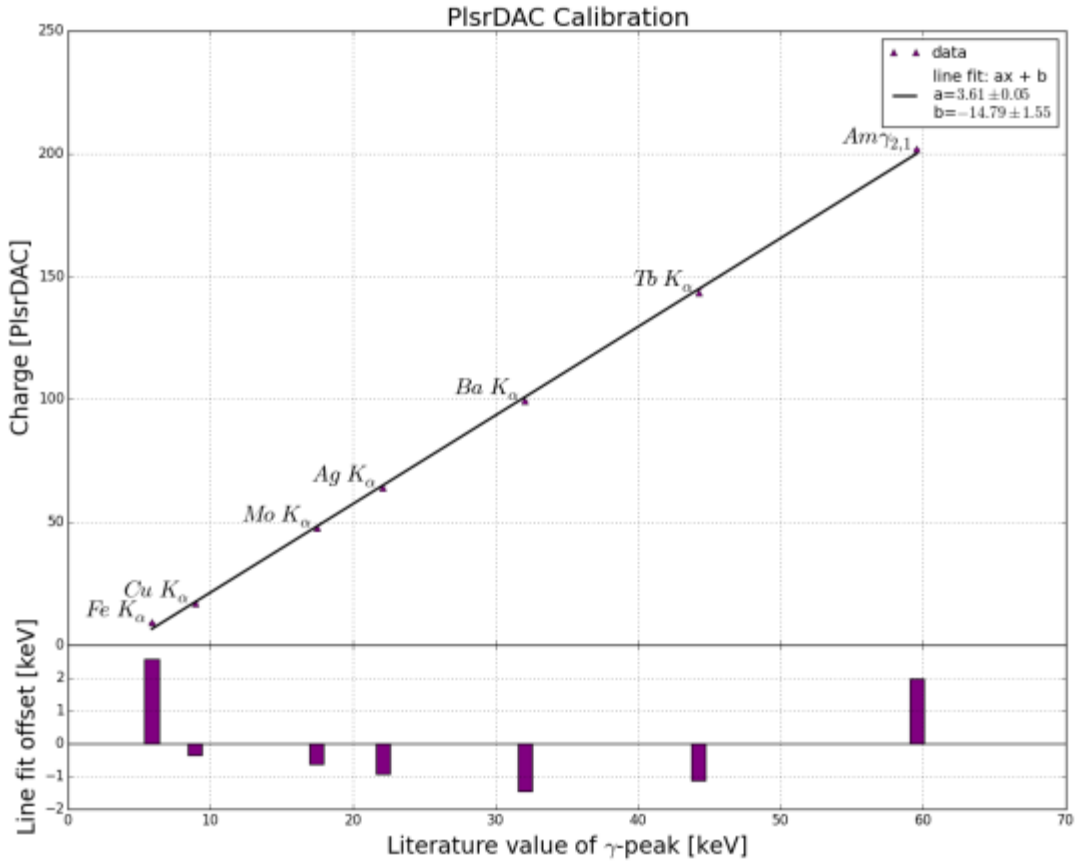


- Precise energy resolution requires pixel per pixel calibration
- Internal charge injection in units of PlsrDAC
- V_{th} and TDC as a function of charge different for each pixel.

Calibration and Dynamic Range

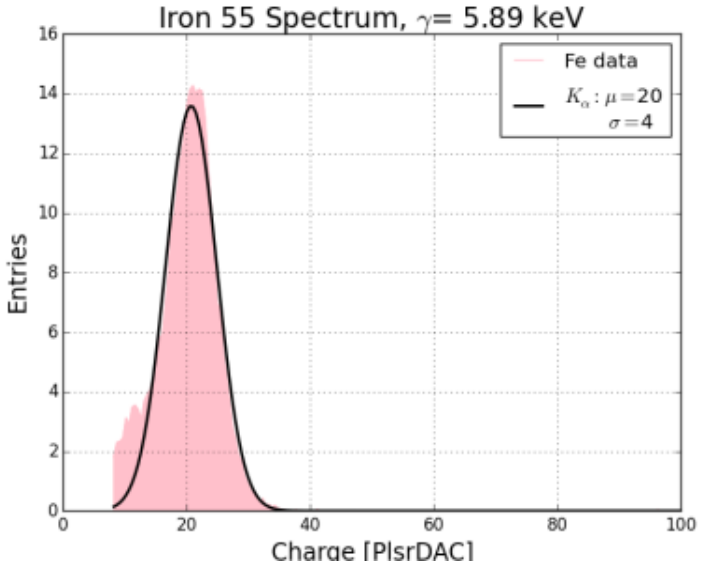


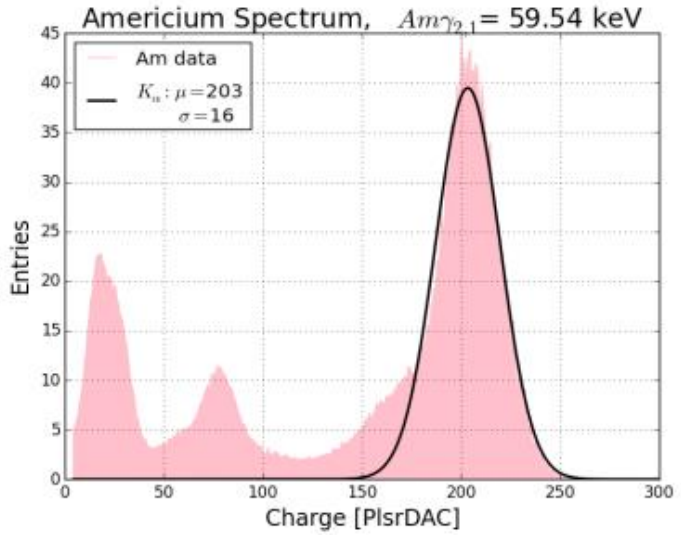


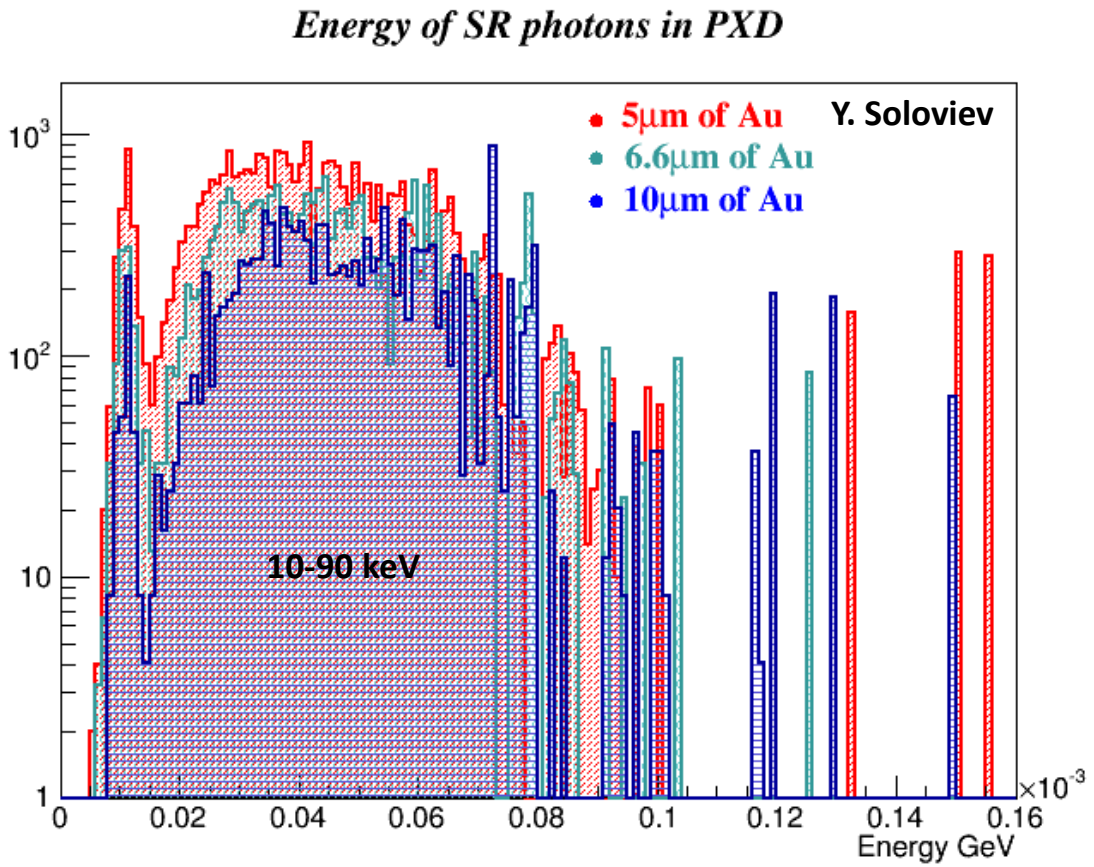


- Dynamic range 10-60 keV (wider also possible)
- Lowest measured plsrDAC value ~ 7
  - Threshold of ~1000 electrons feasible

Calibration and Dynamic Range







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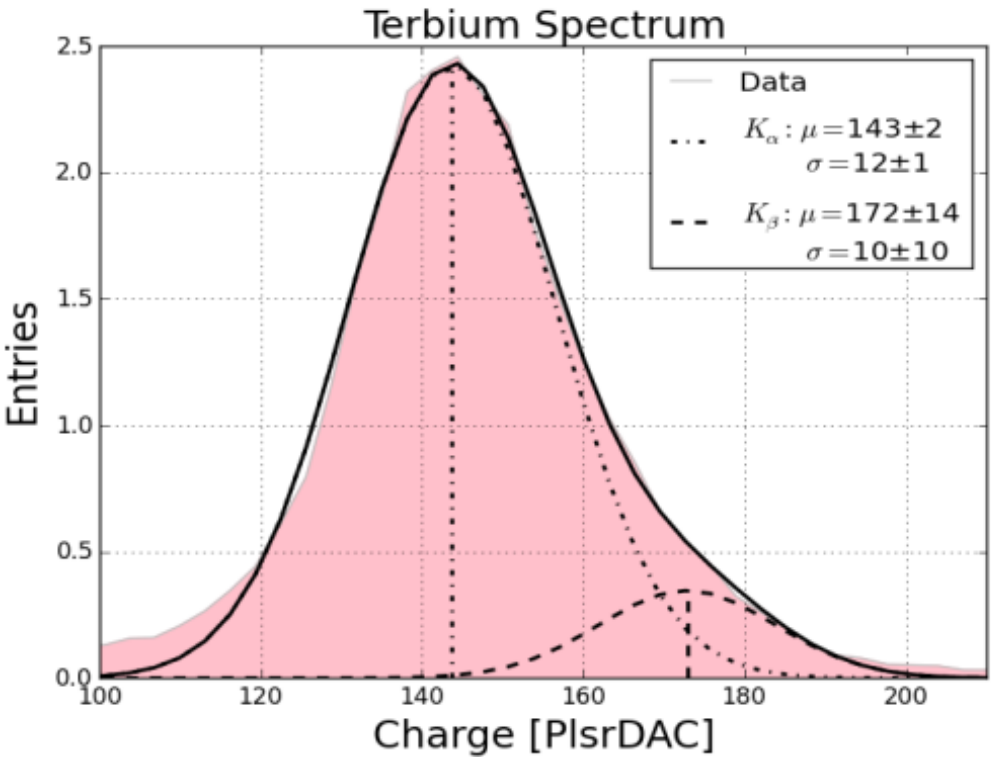
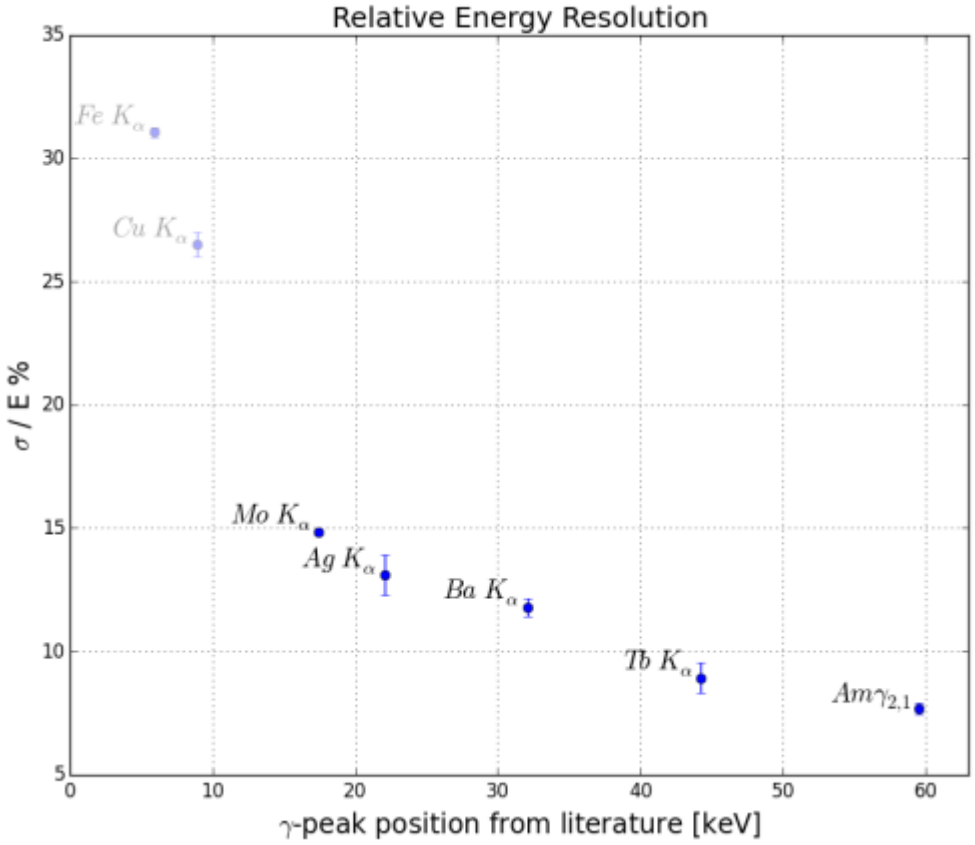
Energy Resolution

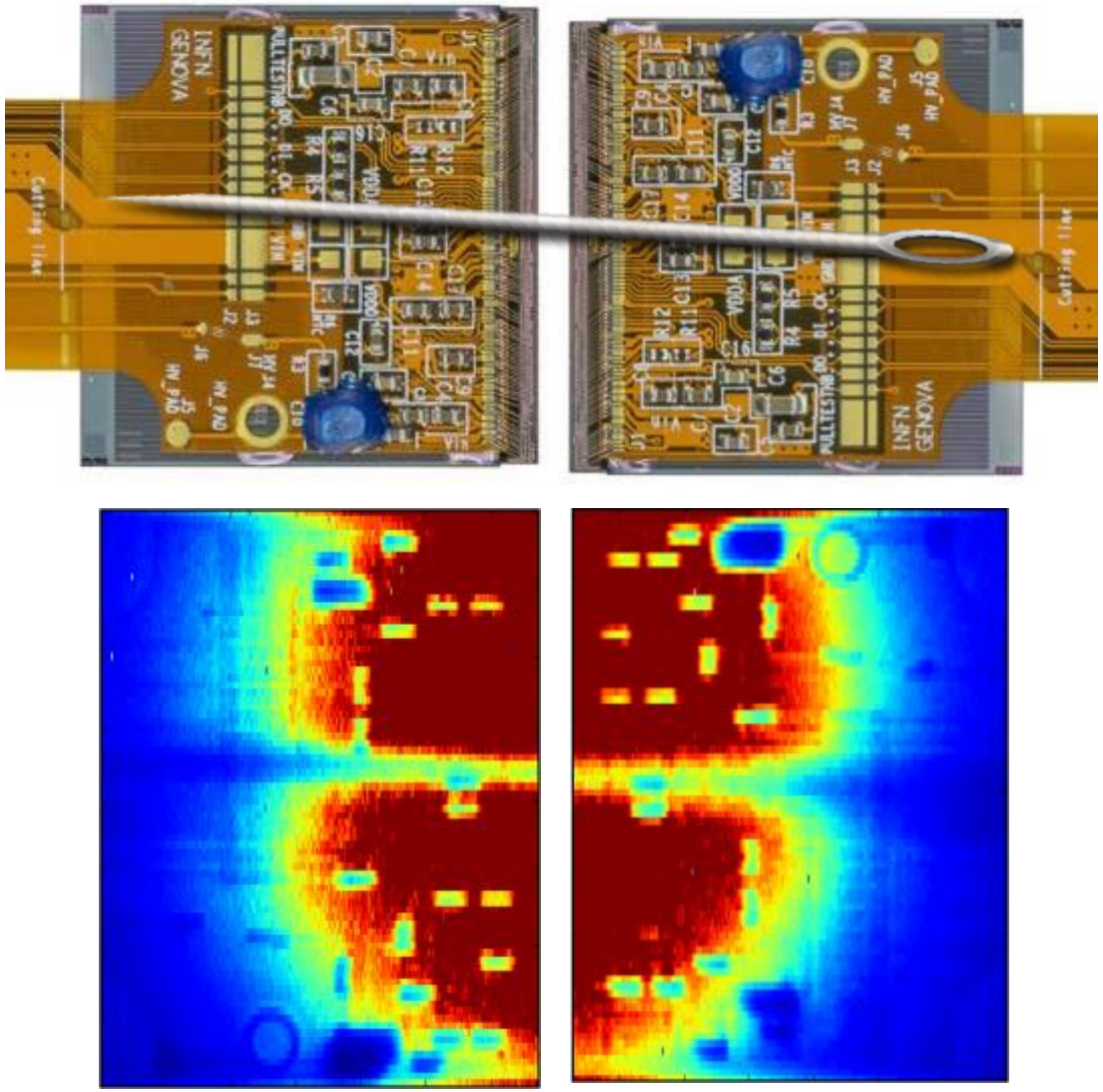




- Terbium K_α=44.2 keV, K_β =50.7 keV
- ΔE = 6.4 keV

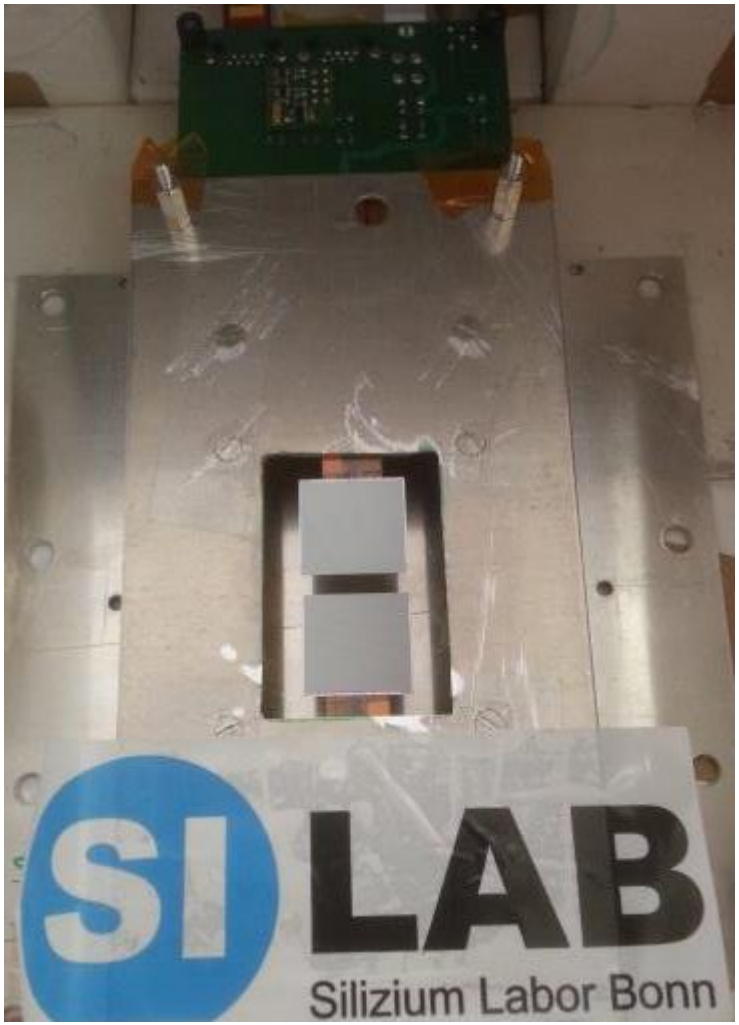
- Adequate energy resolution
- Better than 15 % above 10 keV

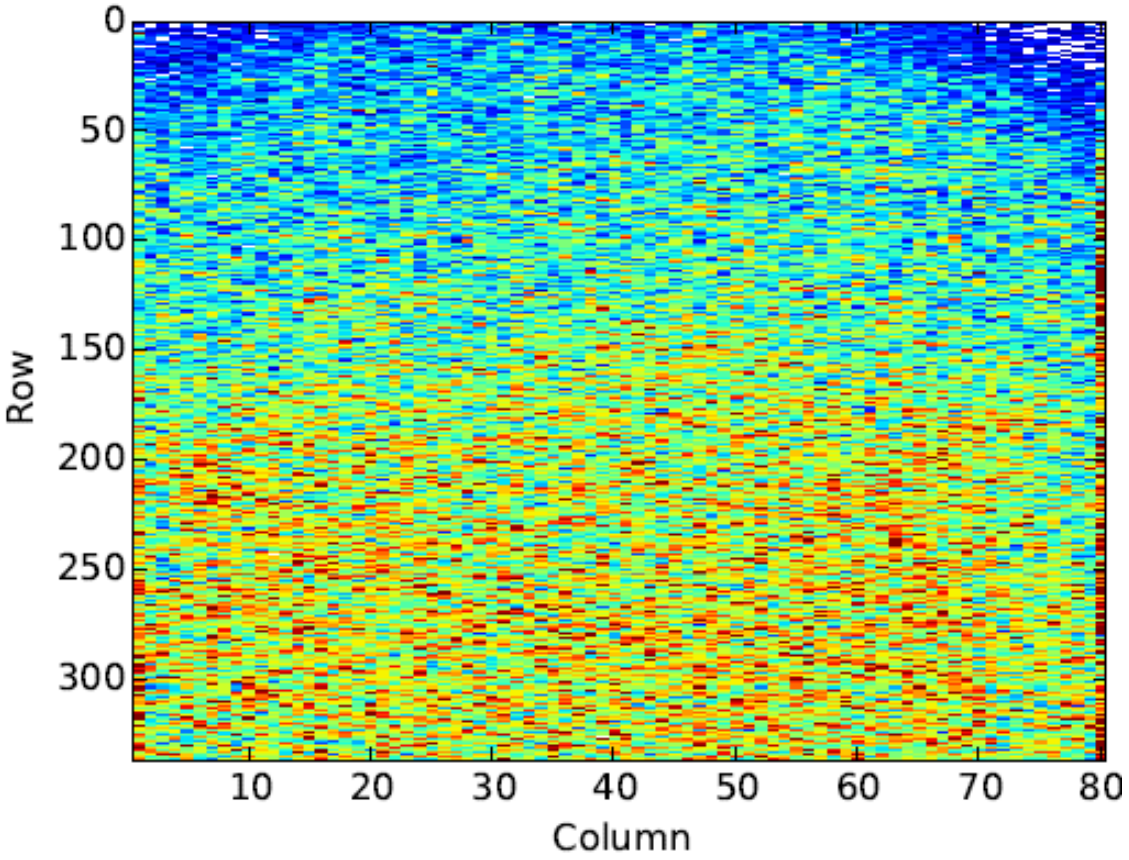
Multiple Chip Readout



- Hit map two FE under Sr90 illumination
- Multiple module parallel readout with MMC3
- Current stave design prompted by absorption of flex components

Backside Illumination

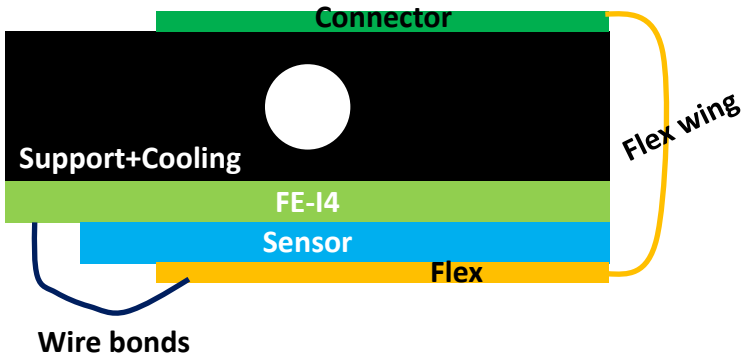


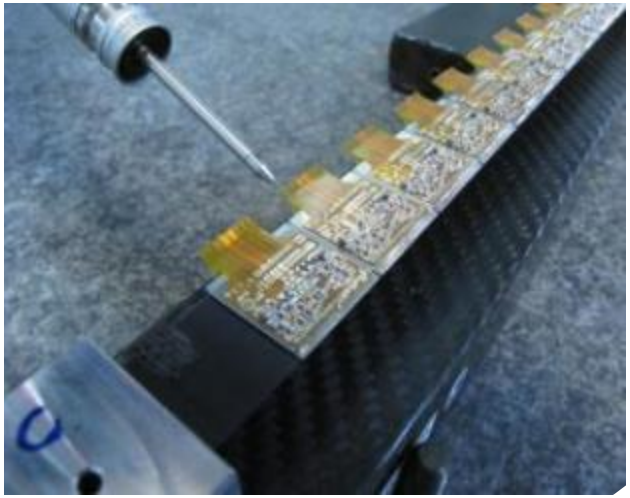


- Effect of components is eliminated by taking a source scan via backside (FE) illumination
- For BEAST, no material in front of the sensor; kapton running parallel to the modules

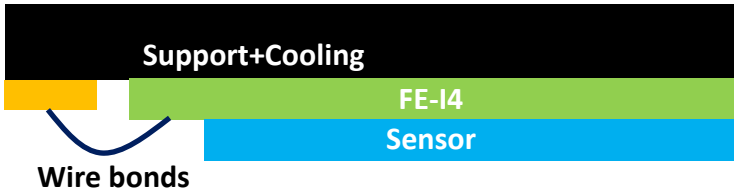
FANGS Stave Design Concept

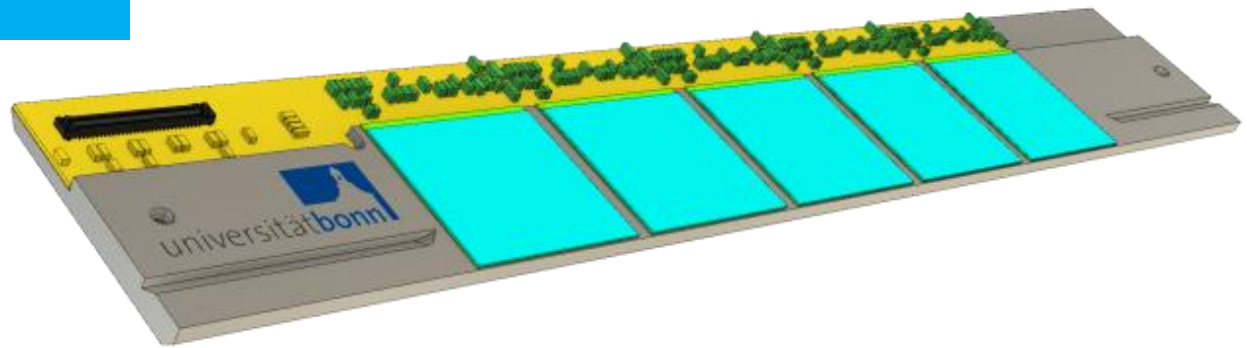
- Initial concept, following IBL stave design



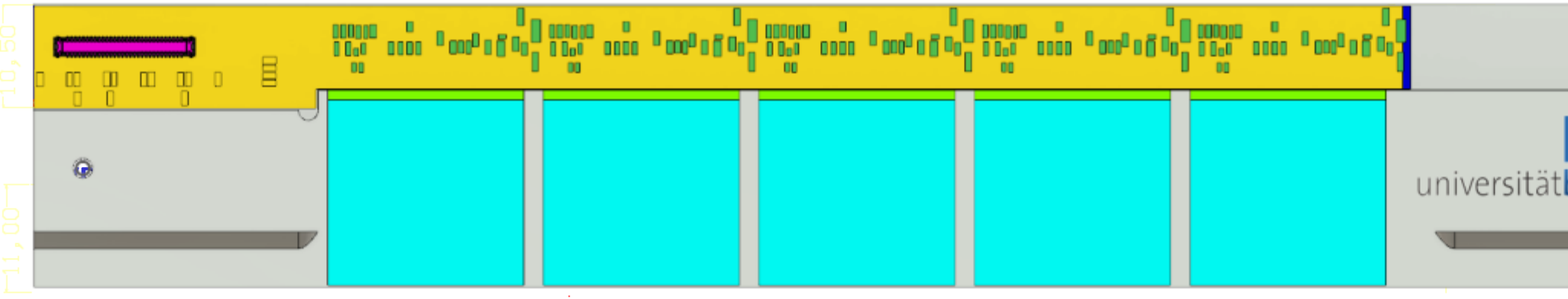


- Revised design, adapted to BEAST needs



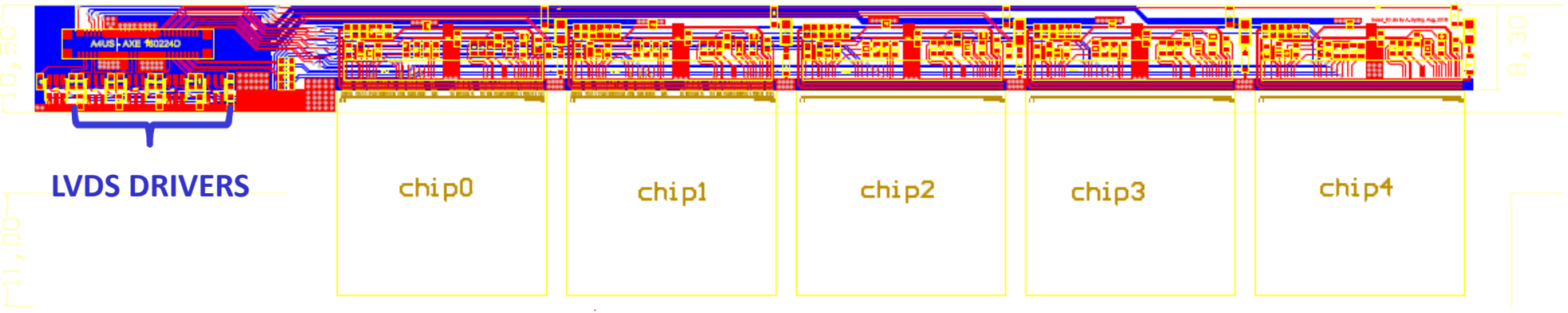


Kapton Design



- Flex design for a single stave of 5 FE-I4 chips
- LVDS drivers converting single ended HitOr signal to differential signal for propagation over long cables
- Drivers positioned in backward direction shielded from radiation behind the PXD cooling block
- Radiation hardness to be investigated

Kapton Design



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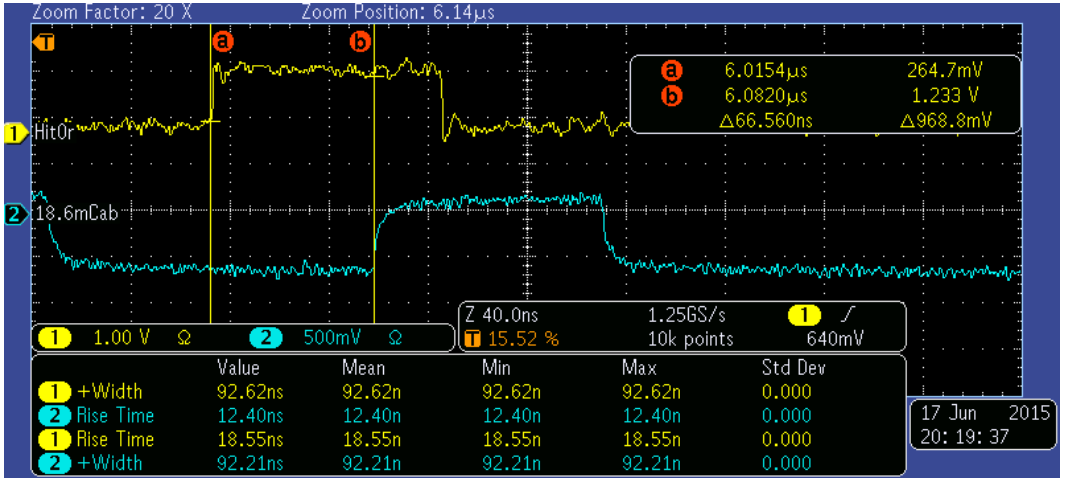
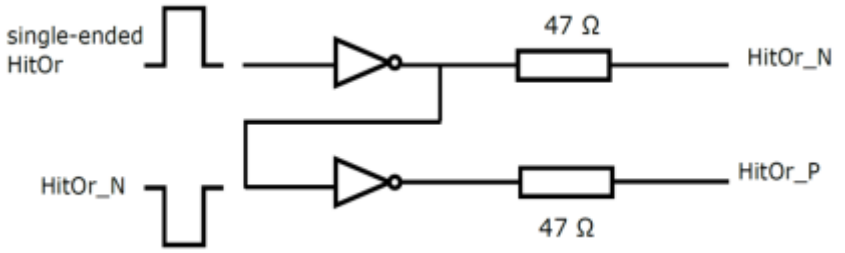
Hit Or Delay and Signal Quality Measurements

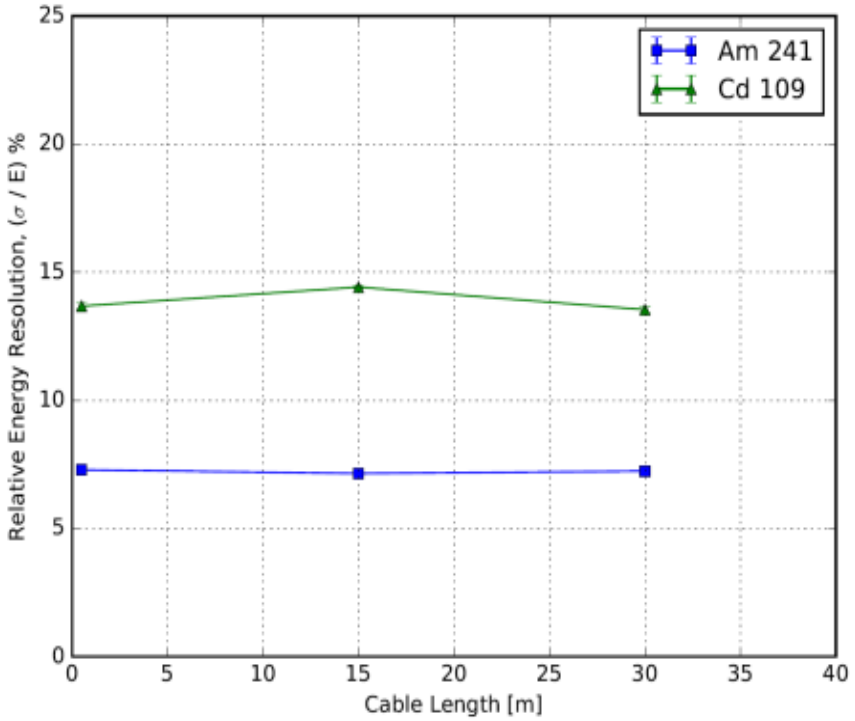


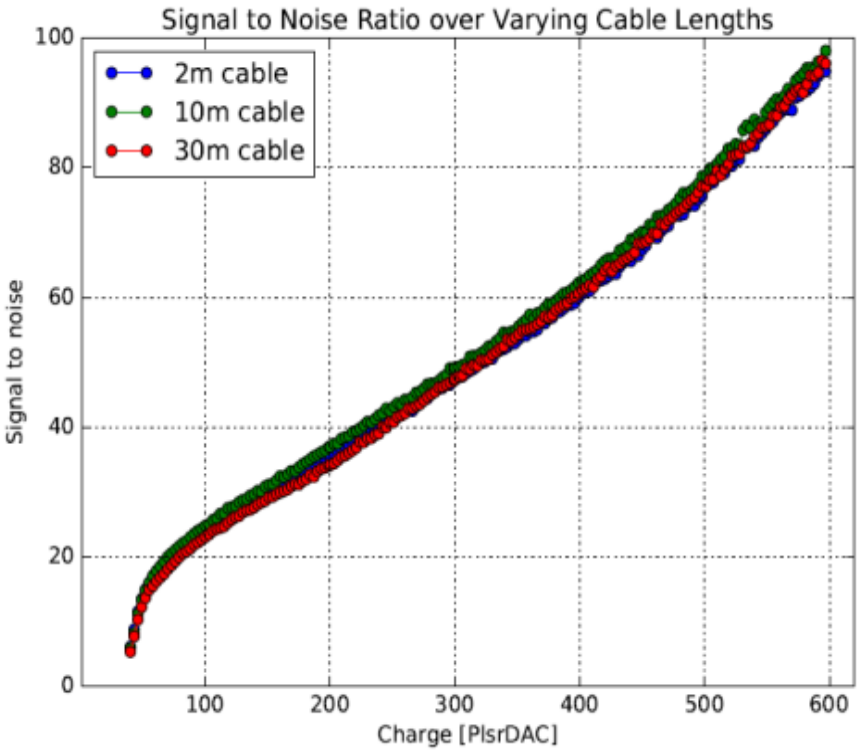
- Propagation delay of HitOr over a 19 m CAT 7
- Signal integrity maintained with delay of ~60 ns
- Improvement pulse shape under investigation



- Convert single ended HitOr to differential

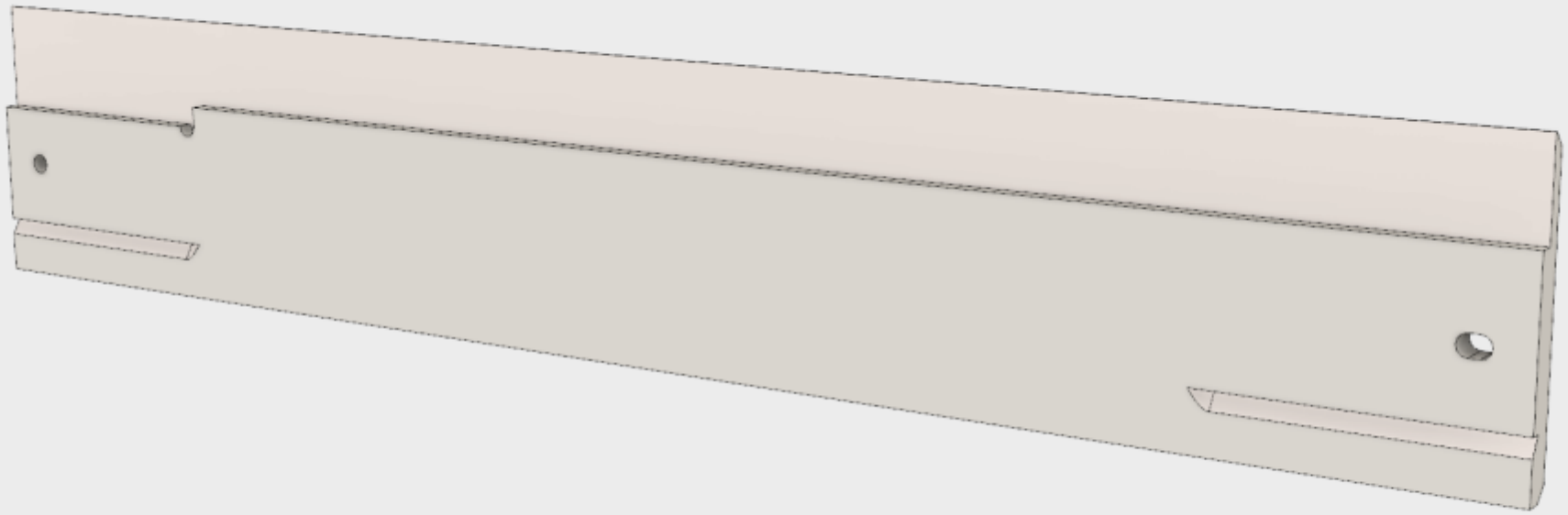
Signal Integrity





- Signal integrity maintained over 20 m cable
- Proper resolution over this range

FANGS Stave Assembly



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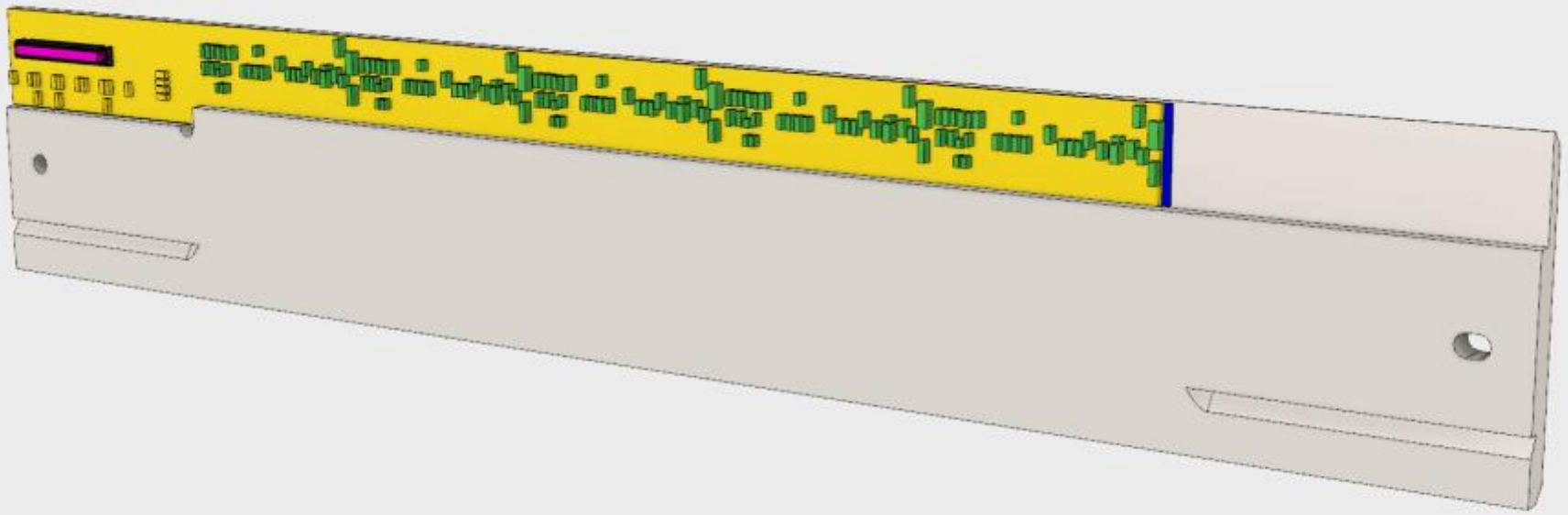

FANGS Stave Assembly

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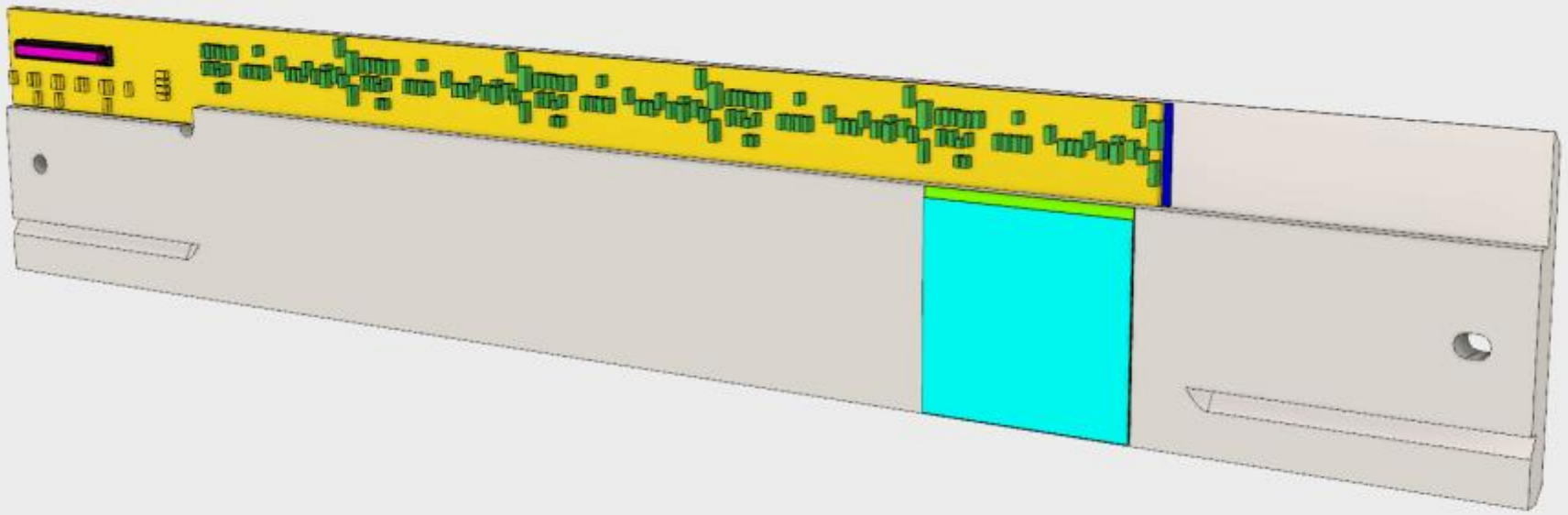

FANGS Stave Assembly

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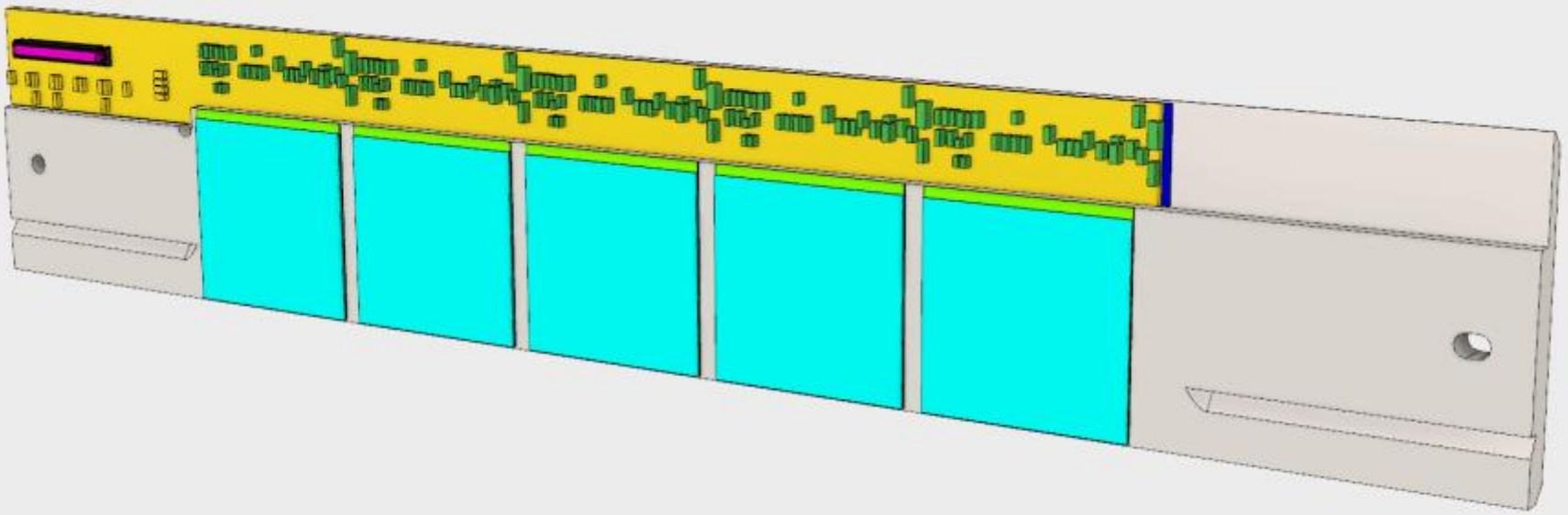
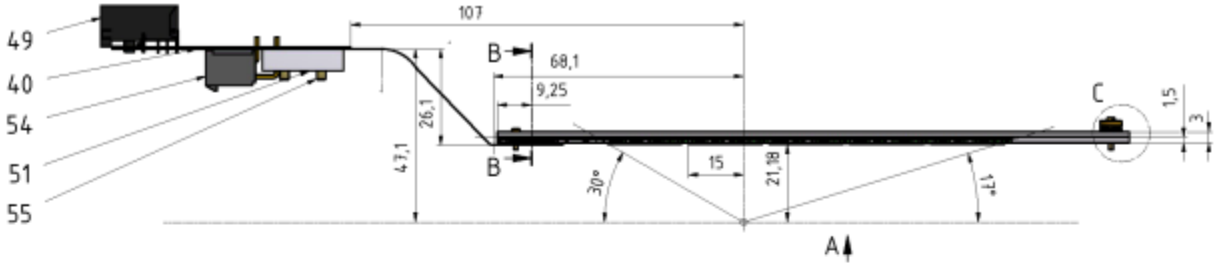
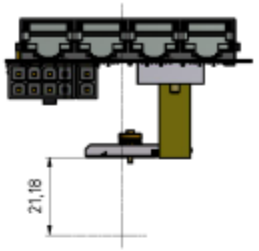
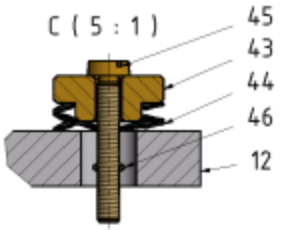
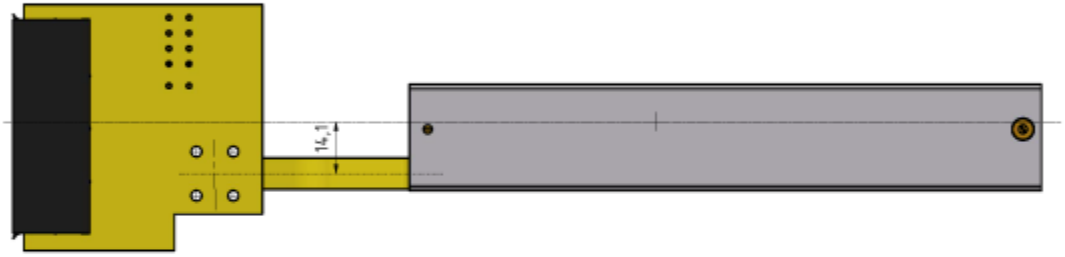


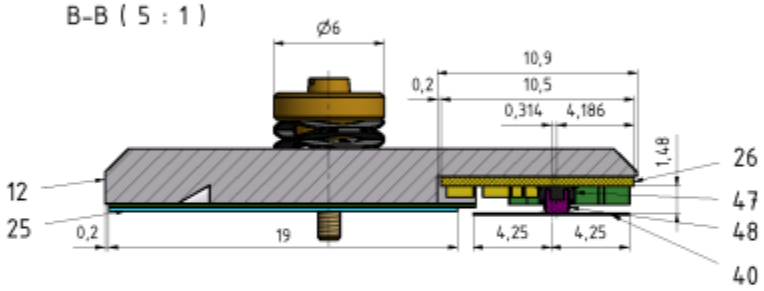
FANGS Stave Fully Equipped

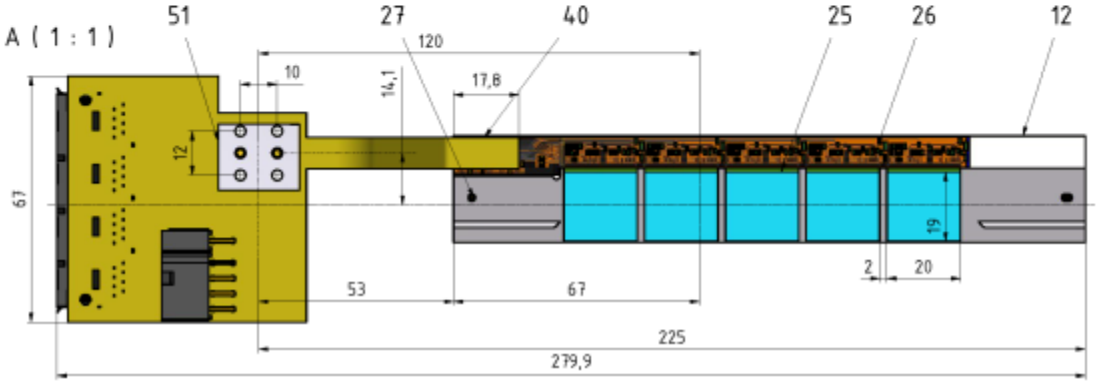


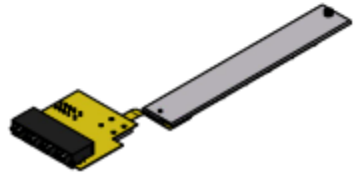












FANGS System

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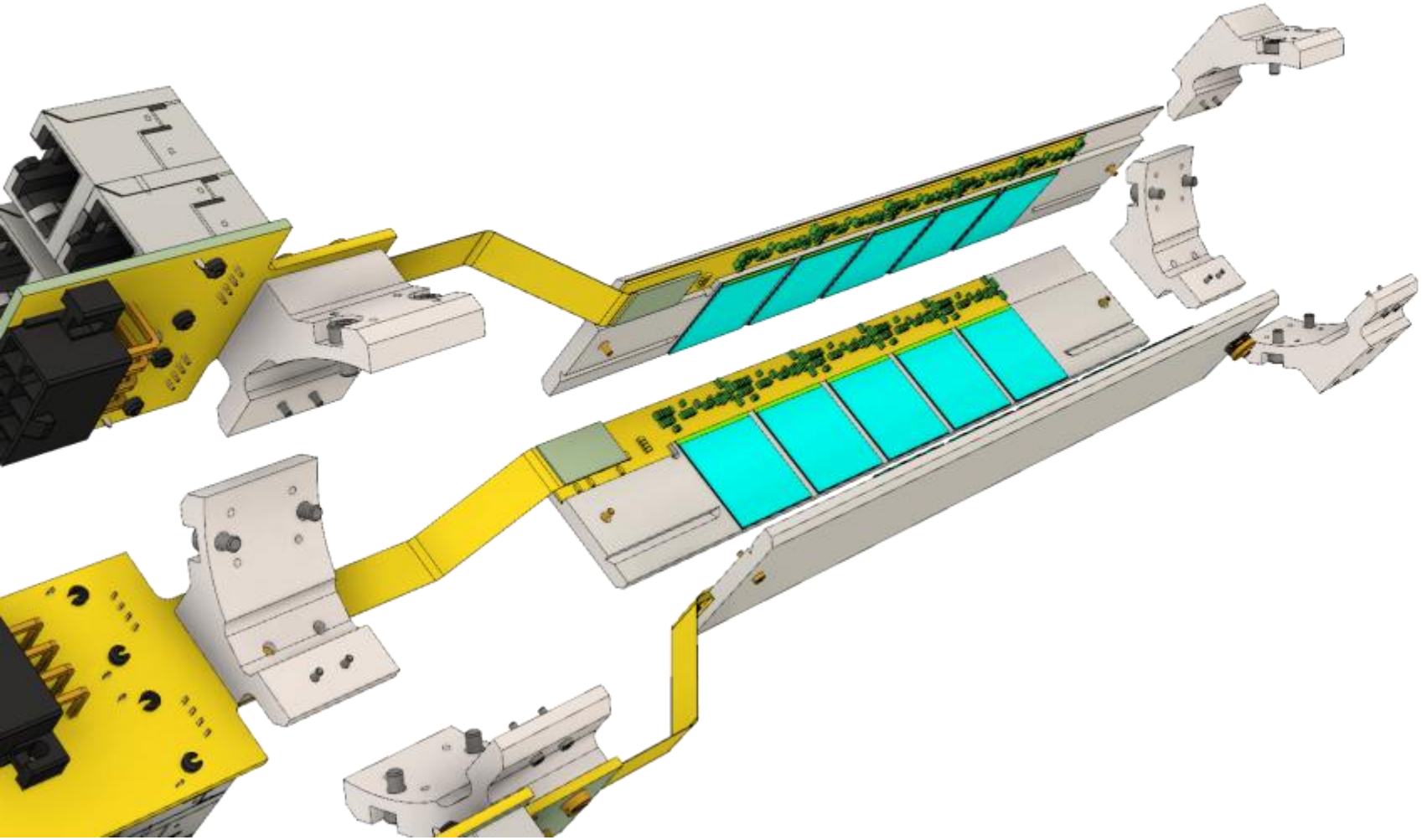
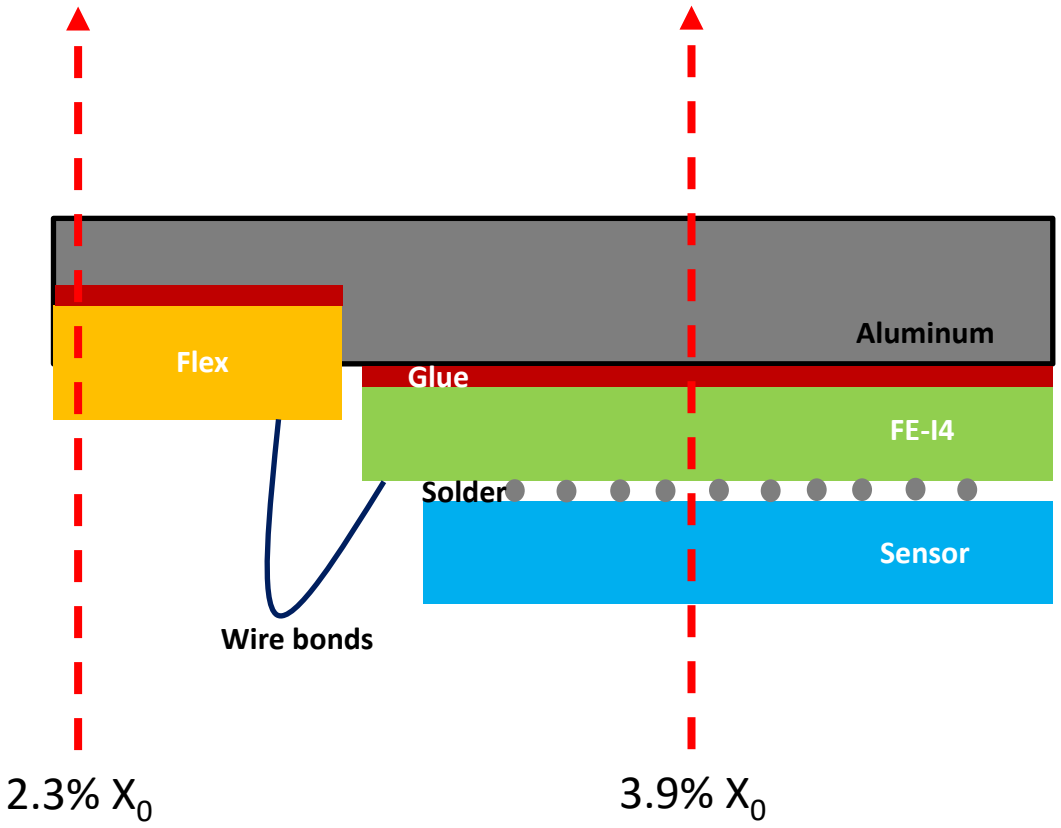
3 Staves: Covering 90^o , 180^o , 270^o in ϕ, *full* acceptance in θ



Aluminum Stave Material Budget



- Low and flat material budget distribution
- No impact in outer detectors
- Further reduction possible if strong physics arguments

- Support:
3 mm thick Aluminum → 3.4%X_0

- Glue:
50 µm thick Epoxy → 0.014%X_0

- FE-I4
150 µm thick Silicon → 0.16%X_0

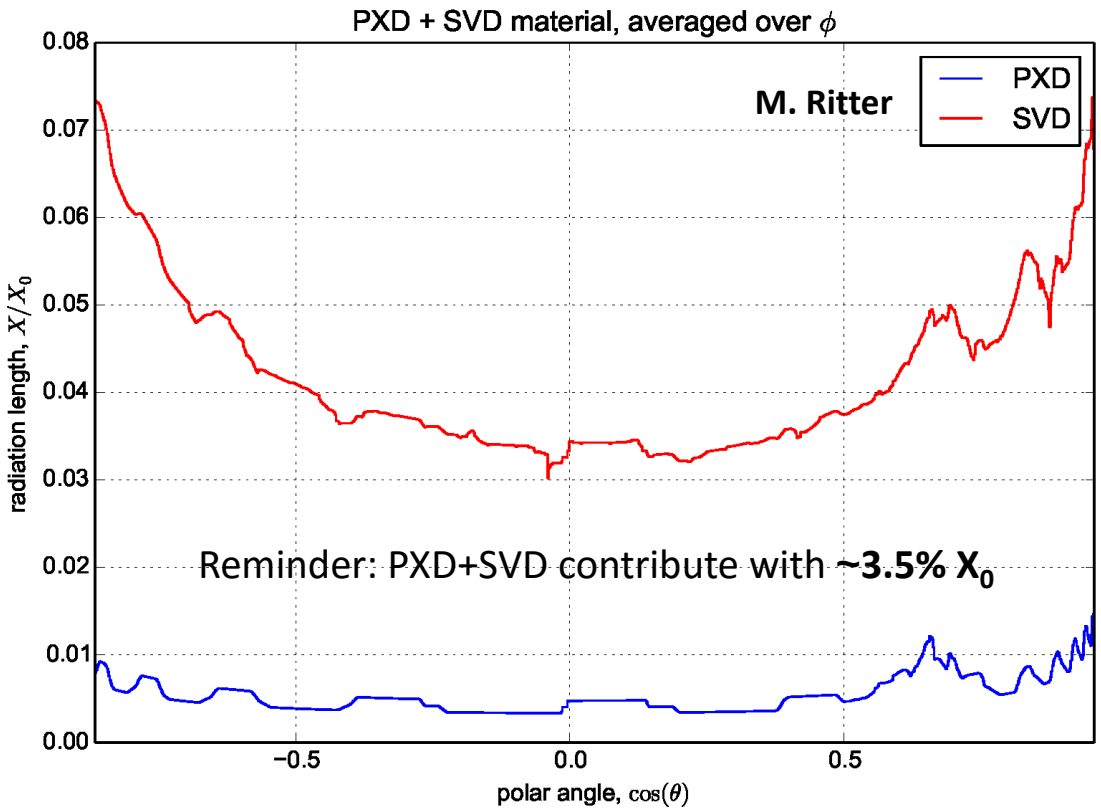
- Sensor:
200 µm thick Silicon → 0.21%X_0

- Solder balls
25 µm thick SnAg → 0.17%X_0 (3.3% of the area)

- Flex
100 µm thick polymide → 0.035%X_0
70 µm Cu (2 layers) → 0.50%X_0
50 µm thick Epoxy → 0.014%X_0

$Total_{Max}$: 3.9% X_0

Aluminum Stave Material Budget



- Low and flat material budget distribution
- No impact in outer detectors

- Support:
3 mm thick Aluminum → 3.4%X_0

- Glue:
50 µm thick Epoxy → 0.014%X_0

- FE-I4
150 µm thick Silicon → 0.16%X_0

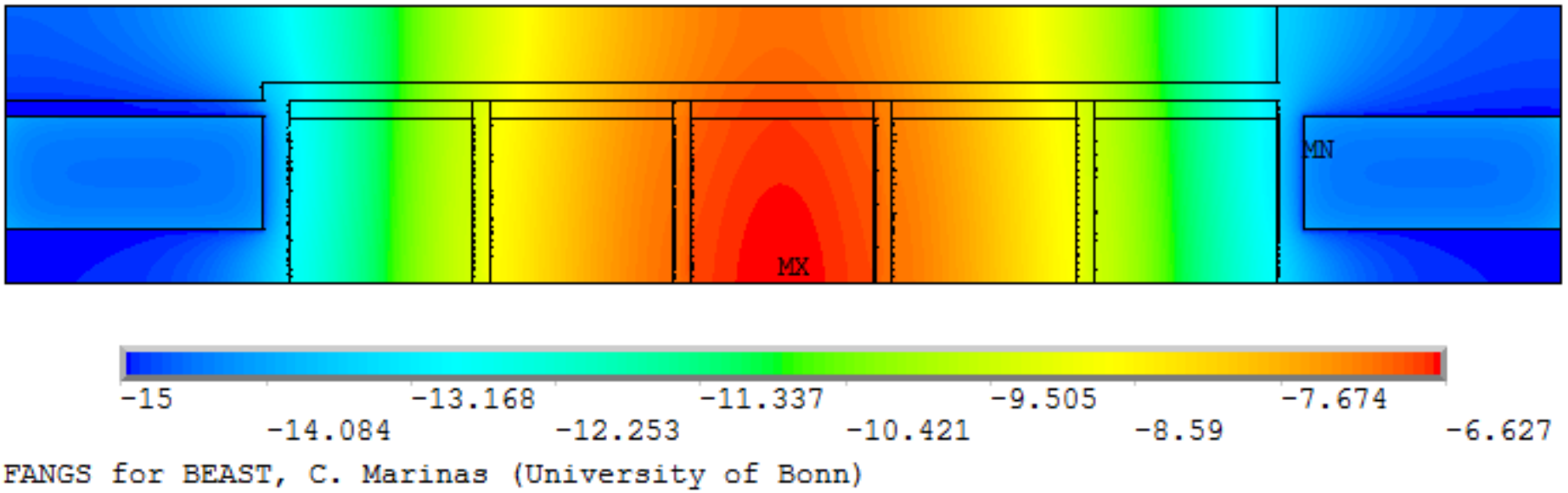
- Sensor:
200 µm thick Silicon → 0.21%X_0

- Solder balls
25 µm thick SnAg → 0.17%X_0 (3.3% of the area)

- Flex
66 µm thick polymide → 0.023%X_0
24 µm Cu (2 layers) → 0.17%X_0

$Total_{Max}$: 3.9% X_0

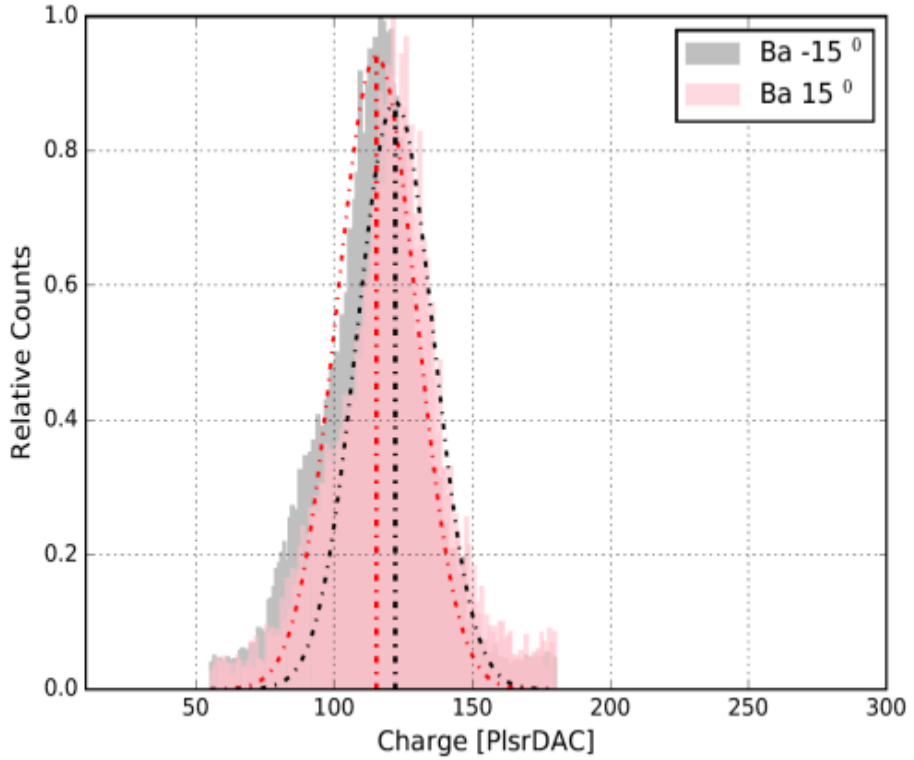
FEA of the FANGS Stave

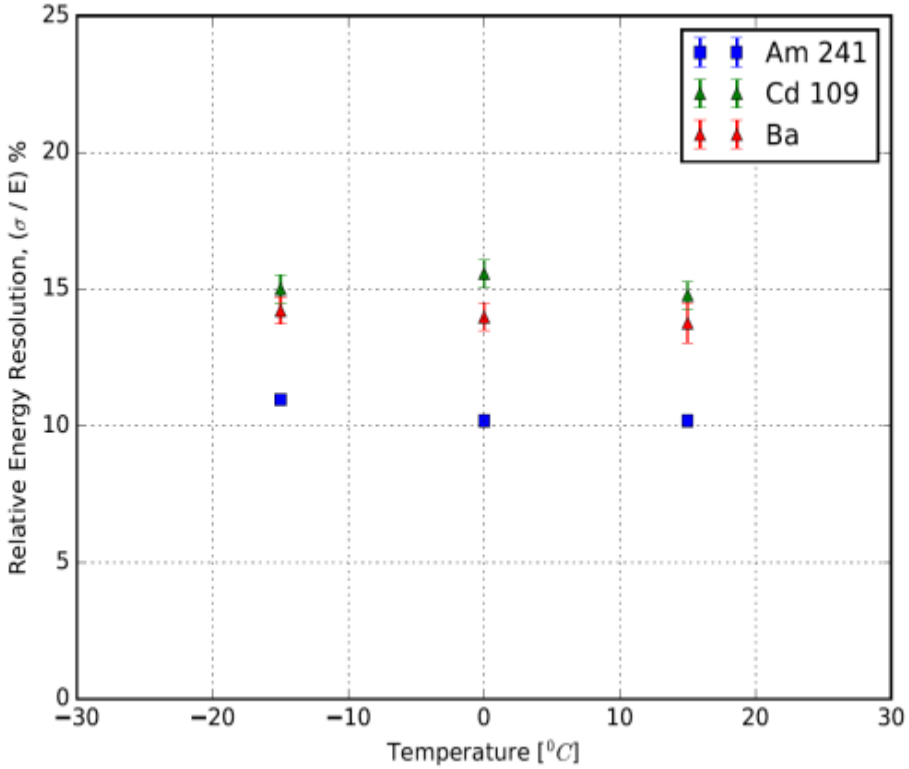


- Maximum temperature = -7 ^{o}C
- Maximum ΔT within one sensor = 5 ^{o}C
- Power = 1.2 W each FE
- Cooling block = -15 ^{o}C
- Environment = 20 ^{o}C at 2 m/s

- Proper heat handling
- Low and flat temperature profile

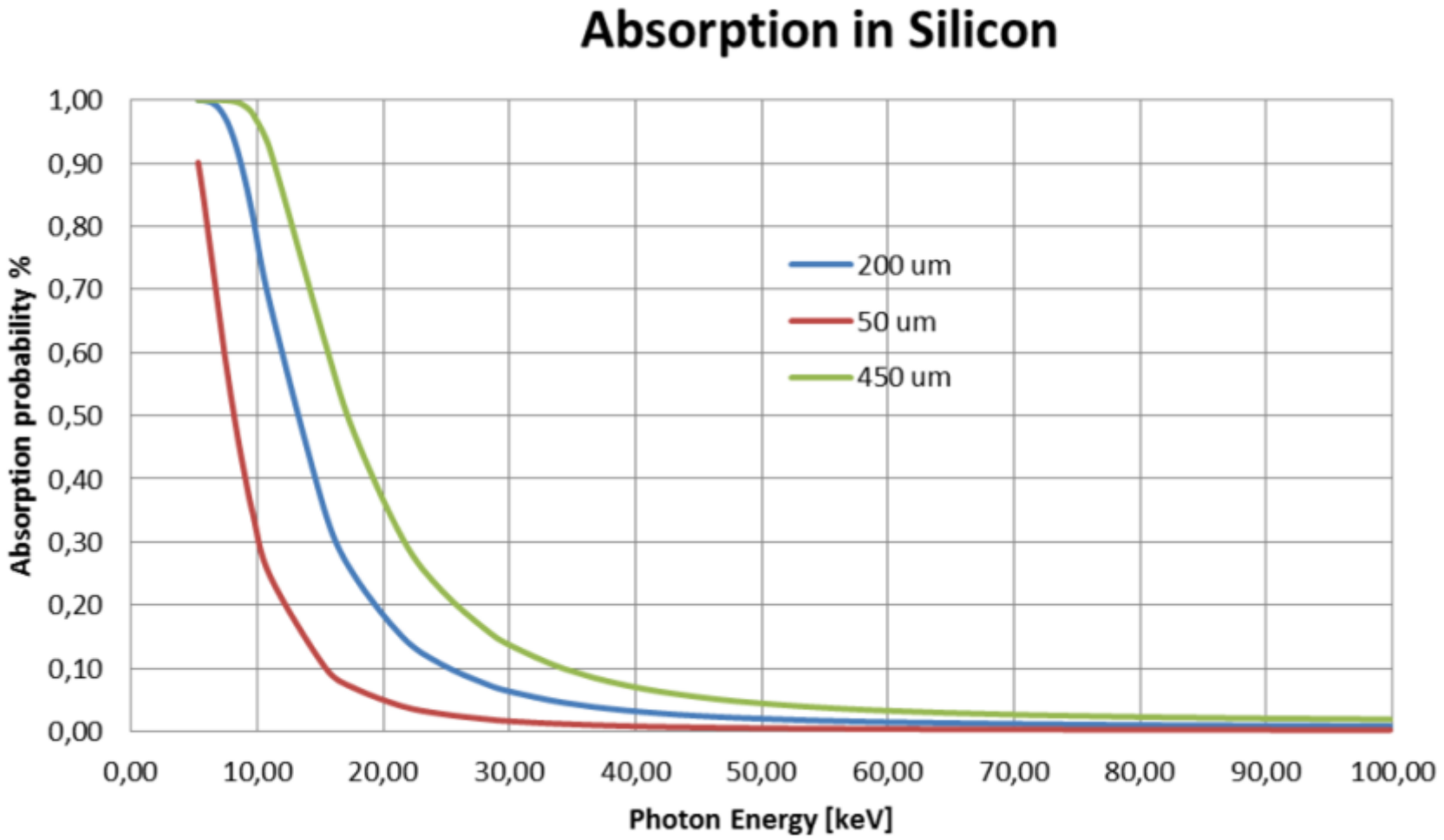
Energy Resolution with Temperature





- No performance degradation is observed over the expected temperature range

Absorption Coefficient X-rays



Phase 2 Set Up

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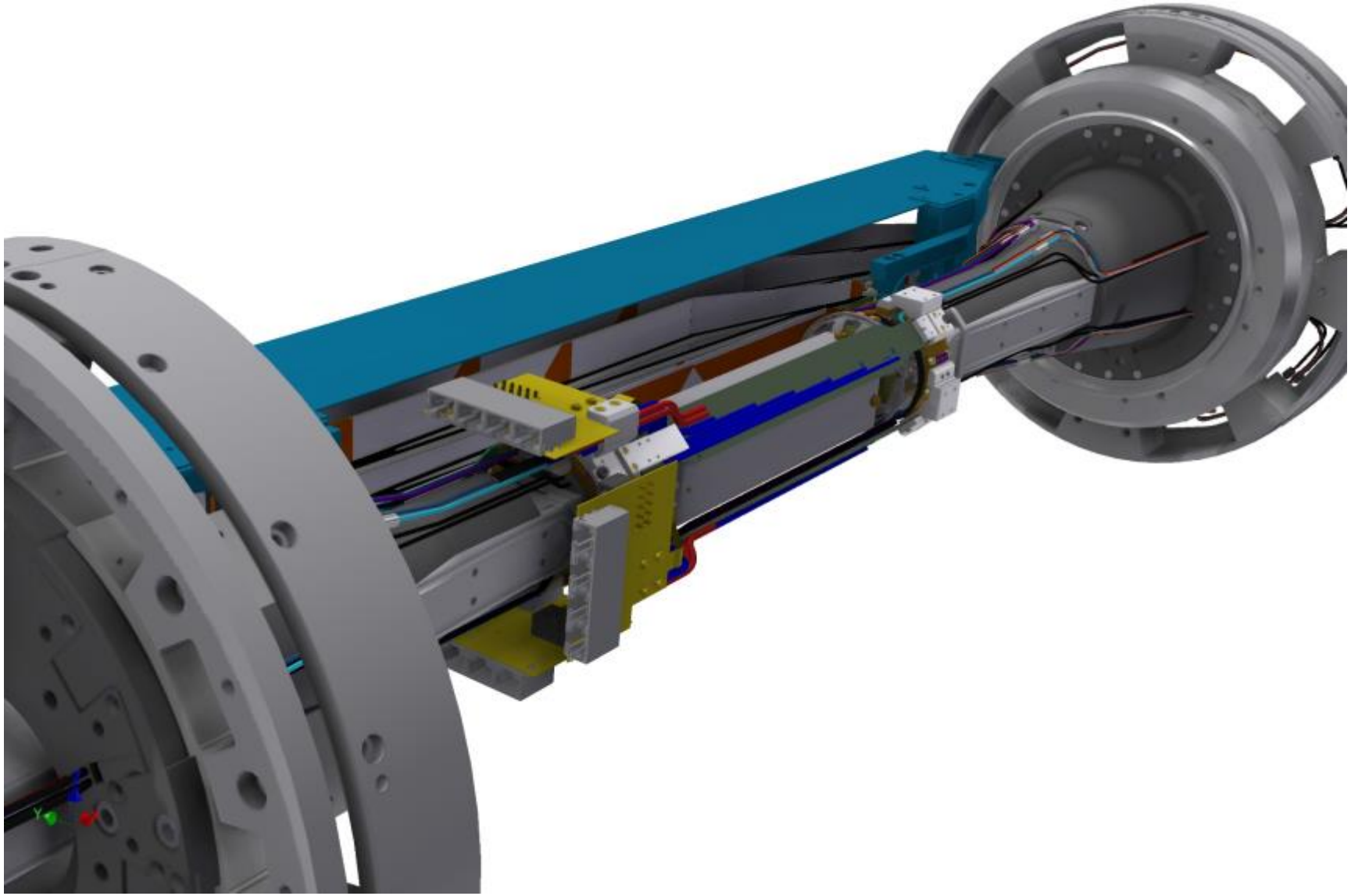

Conclusion

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- Front end has been tuned to cover the expected energy range with sufficient **resolution** for Beast Phase 2
- **Multiple-FE DAQ** demonstrated
- **20 m long cables** tested
- Finalized design of Kapton flex and intermediate boards.
- **Mechanical** concept and **cooling** management are finalized
- Mass production will follow. FANGS to be ready by the end of the year for integration

NEXT:

- Radiation hardness flex electrical components
- More realistic environment

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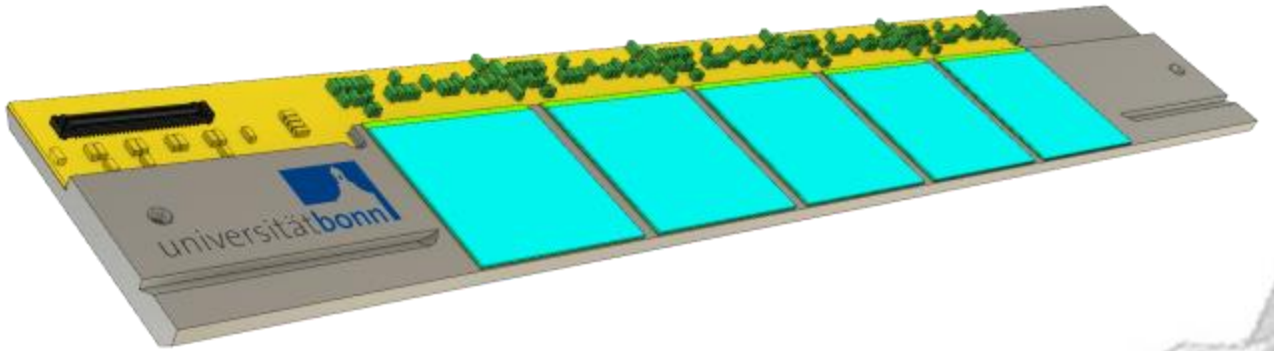
Silizium Labor Bonn

Thank you



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