X0 imaging of PXD & SVD sensors: Review of material budget estimations

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GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

VolkswagenStiftung

Material distribution on SVD and PXD modules

Motivation

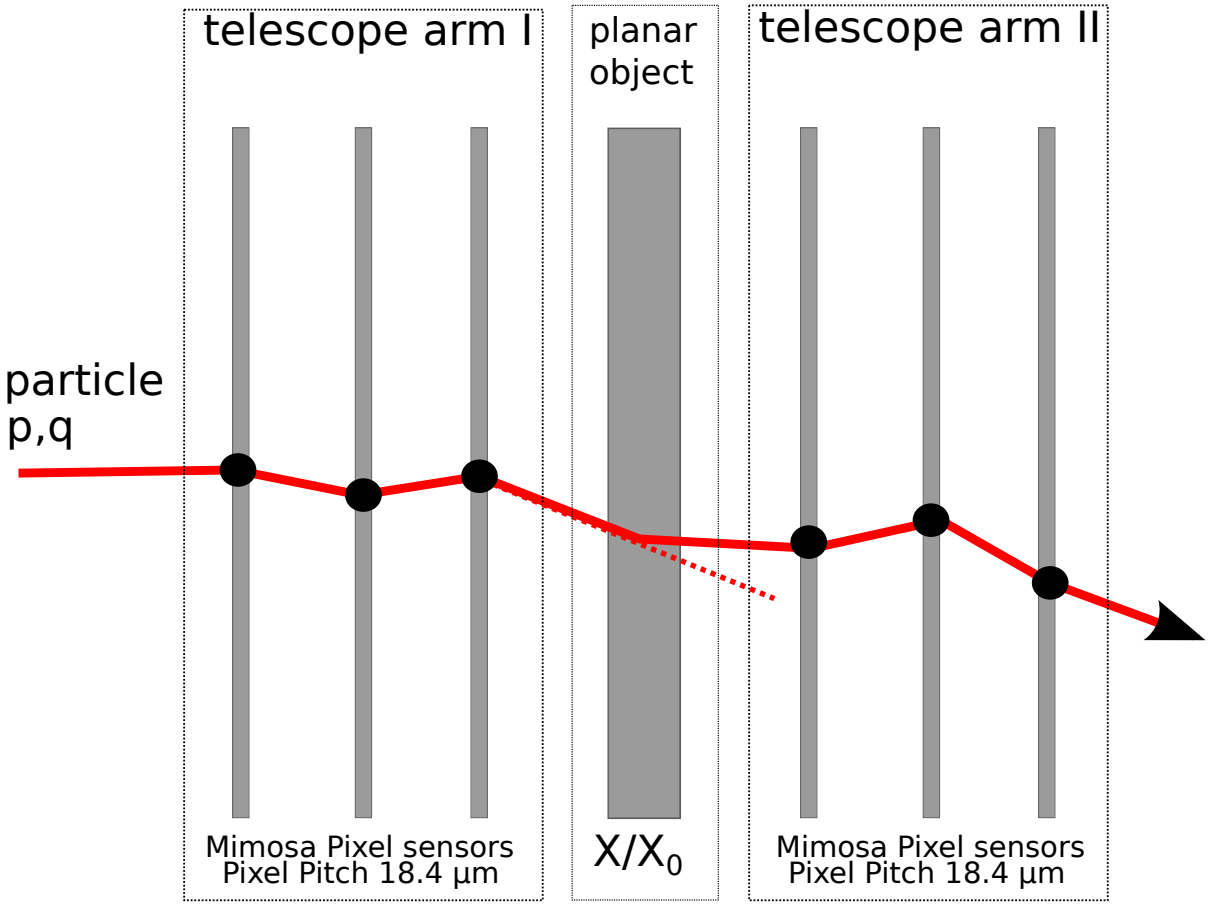
- Low material budget is an essential part of the belle II ladder development especially for the PXD
- Complex stacks of many material layers especially in the SVD part
- Cross-check the belle2 software detector model by comparing BASF2 material scans to X/X_0 measurements of belle II modules

Goal

Find discrepancies in detector model and find out impact on vertex resolution of the belle II detector

Reconstruction of multiple scattering angles

- Planar object centered in high resolution telescope
- Multi GeV particle beam → telescope sensor hits



Reconstruction of multiple scattering angles

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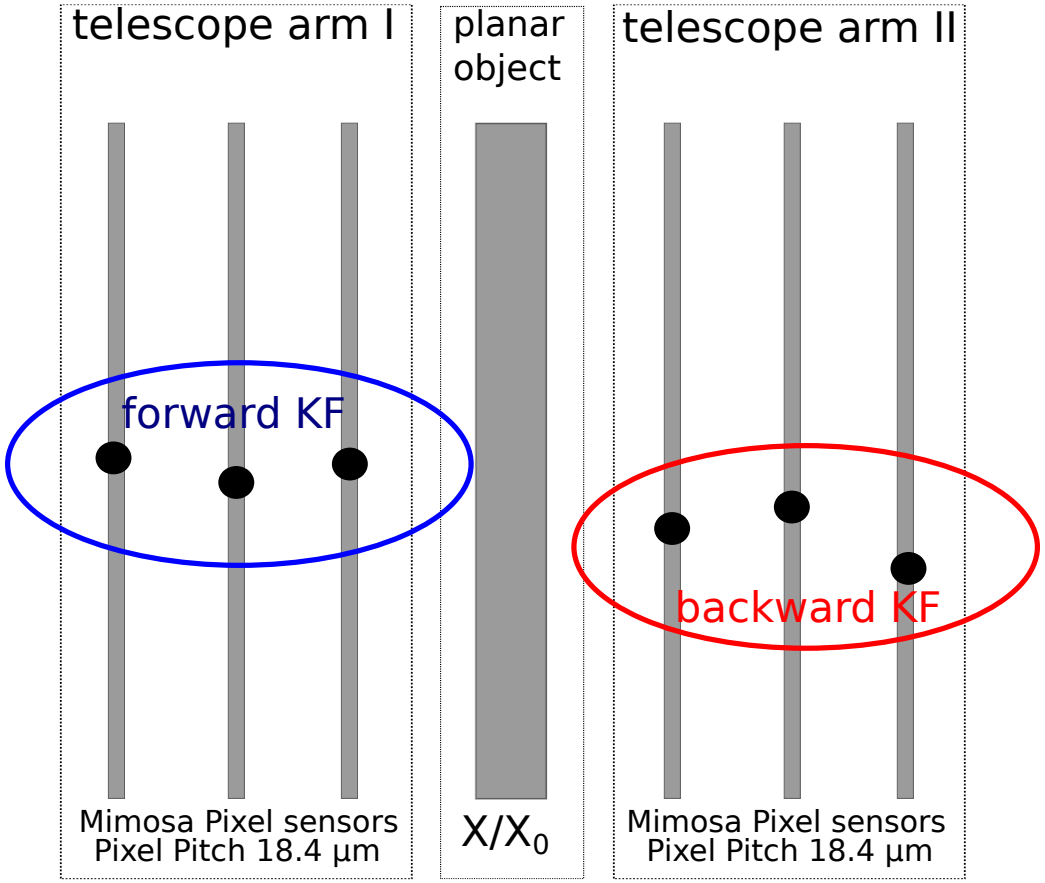
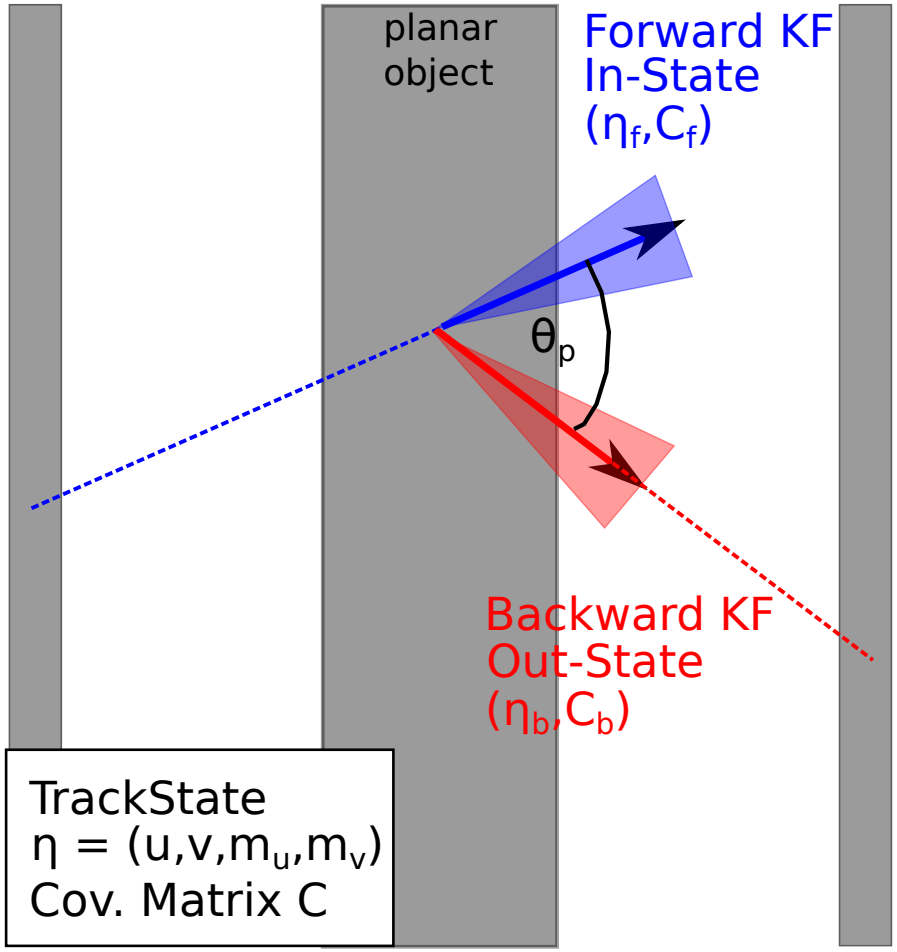
- Forward- backward Kalman Filter (KF) pair on hits



Reconstruction of multiple scattering angles

- Planar object centered in high resolution telescope
- Multi GeV particle beam $\rightarrow$ telescope sensor hits
- Forward- backward Kalman Filter (KF) pair on hits
- θ_p calculated from track slopes (m_u, m_v)
- angle reco. error σ_{reco} derived from error propagation



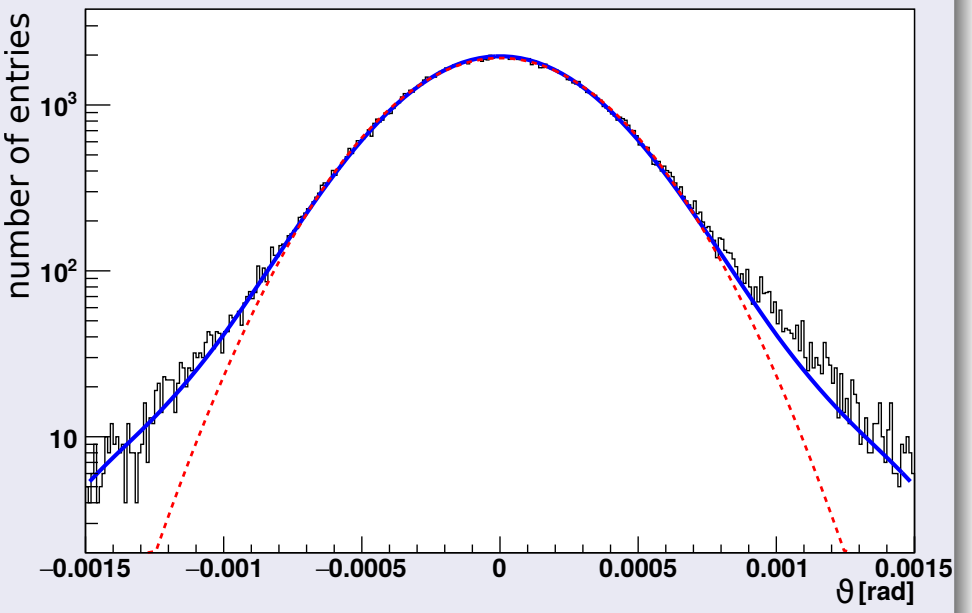
X/X_0 Measurements

Basic idea

Reconstruct kink angle distributions in pixels on central plane → width of distribution depends on radiation length X/X_0. Reconstructed scattering angle distribution consists of two parts:

First part: Multiple scattering distribution $f_{\text{scatt.}}$

- Most prominent models: Moliere and the Highland model
- Highland: Gaussian distribution, no description of non-gaussian-tails, parameter X/X_0
- Moliere: Describes whole distribution, parameters: X, density ρ, Z



X/X_0 Measurements

Basic idea

Reconstruct kink angle distributions in pixels on central plane $\rightarrow$ width of distribution depends on radiation length X/X_0. Reconstructed scattering angle distribution consists of two parts:

Second part: Angle resolution function f_{err}

- Finite angle resolution on target plane $\rightarrow$ gaussian with standard deviation of σ_{err} as resolution function f_{err} on target
- Expected value σ_{err} is affected by systematical errors (slightly wrong telescope sensor resolution, additional multiple scattering within telescope, wrong beam energy, etc)
- Introduce λ factor: calibrated angle reconstruction error $\sigma^*{}_{\mathrm{err}} = \lambda \cdot \sigma_{\mathrm{err}}$, λ should be close to 1.0

X/X_0 Measurements

First step: Calibration with aluminum target

- Reconstructed multiple scattering angle distribution given by

$$\begin{aligned} f_{\text{reco}} &= f_{\text{scatt.}}(\theta) \otimes f_{\text{err}}(\theta, \lambda, \sigma_{\text{err}}) \\ &= f_{\text{scatt.}}(\theta) \otimes \frac{1}{\lambda\,\sigma_{\text{err}}\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{\theta}{\lambda\,\sigma_{\text{err}}}\right)^2\right) \end{aligned}$$

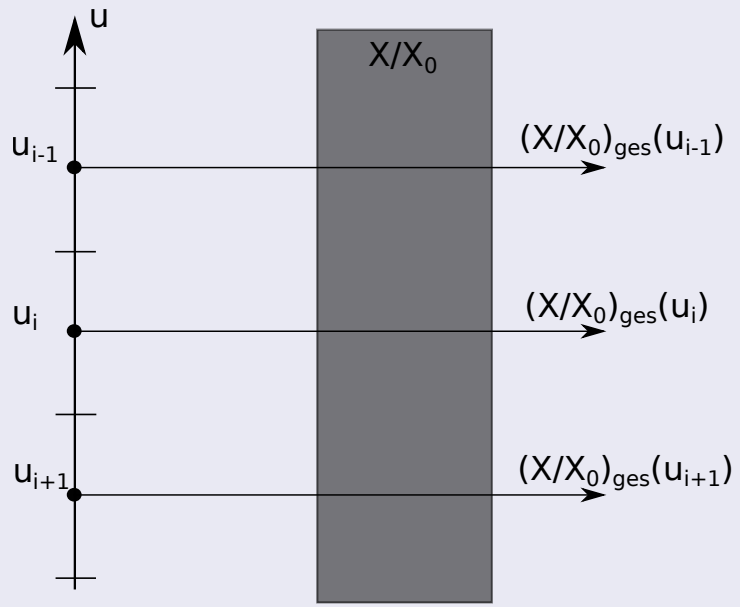
- $f_{\text{scatt.}}$ depends on material and particle beam parameters
- Target with well known material profile allows λ calibration via simultaneous fit of reconstructed angle distributions

Second step: Measurement on materials

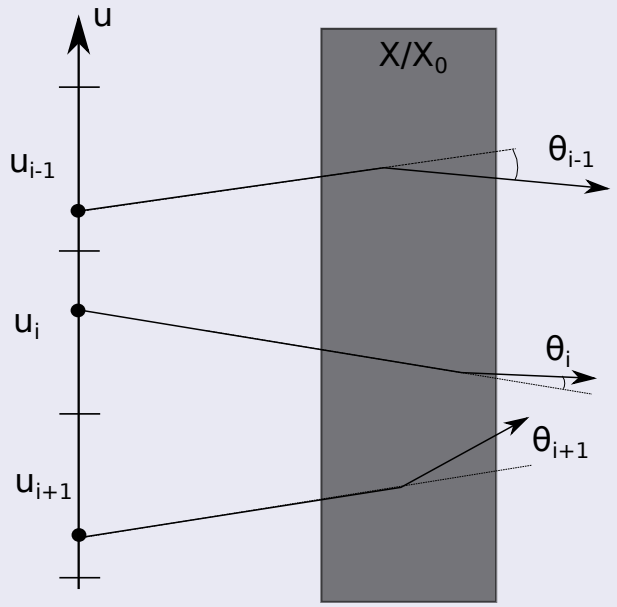
- Use optimal calibration factor in other X/X_0 measurements

BASF2 planar material scan

BASF2 planar material scan



X0 measurement



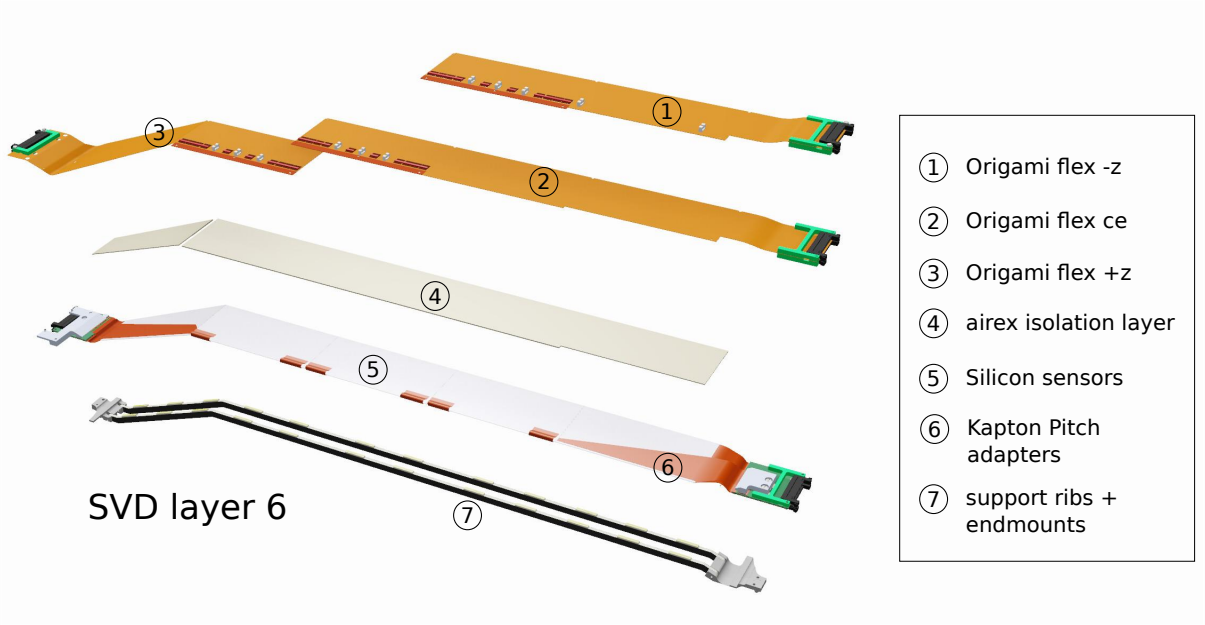
- BASF2 MaterialScan module can be used to do a planar scan of geant 4 detector model
- Define a measurement grid: Geantinos move on parallel paths through material in a given range
- Total Radiation length of material in flight path is computed

SVD geometry

SVD ladder setup

- slanted and backward modules
- +z Origami: readout in + z direction
- ce and -z Origami: backward readout → stack of two Origami flex layers in -z module region

Exploded view of SVD layer 6



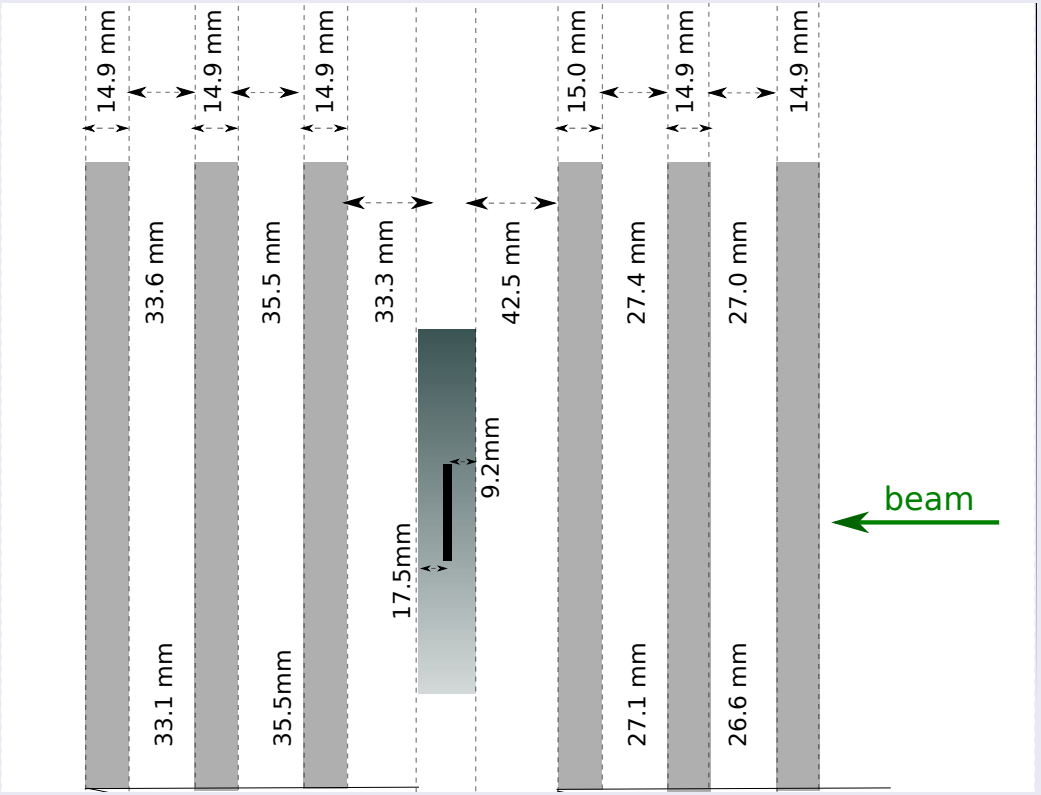
2-DSSD module

Consists of ce and -z origami module, measurement of material distribution on 2-DSSD transferable to all other SVD Origami modules

Setup of telescope for X/X_0 measurements

- Test beam campaign in Nov. 2015
- EUDET telescope with 6 M26 planes with 18 μm pixel pitch $\rightarrow$ resolution of hit coordinates $\approx$ 3 μm
- Beam energy of 4 GeV
- Spacings chosen like this to optimize angular resolution σ_{err} on central plane
- In this case $\sigma_{\mathrm{err}} \approx 140\,\mu$rad
- calibration factor $\lambda = 1.171 \pm 0.003$
- Approximately 30 mio tracks in ce Origami region (only one flex layer)

setup of the telescope



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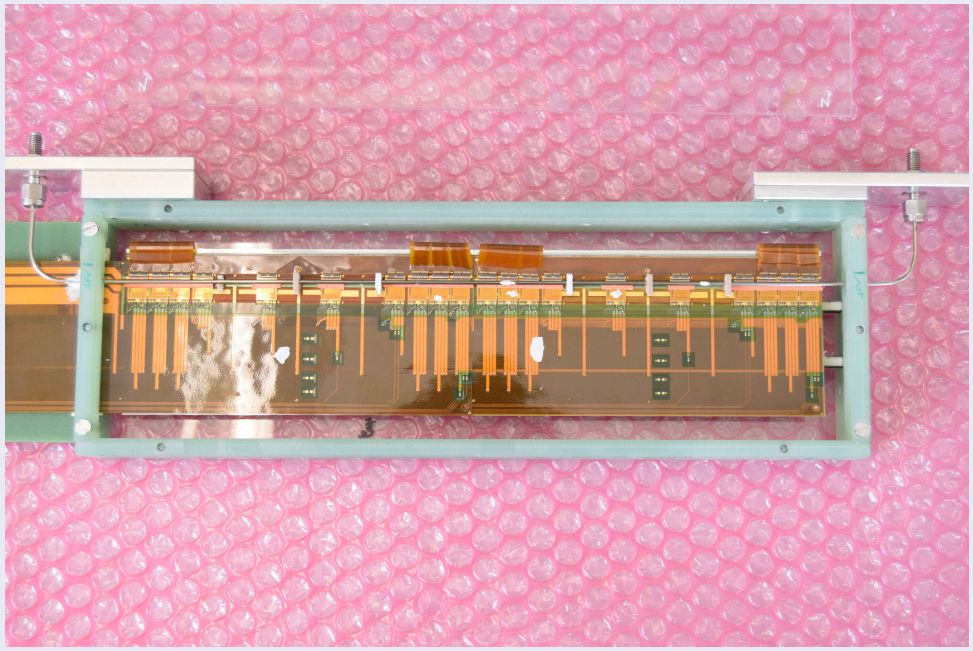

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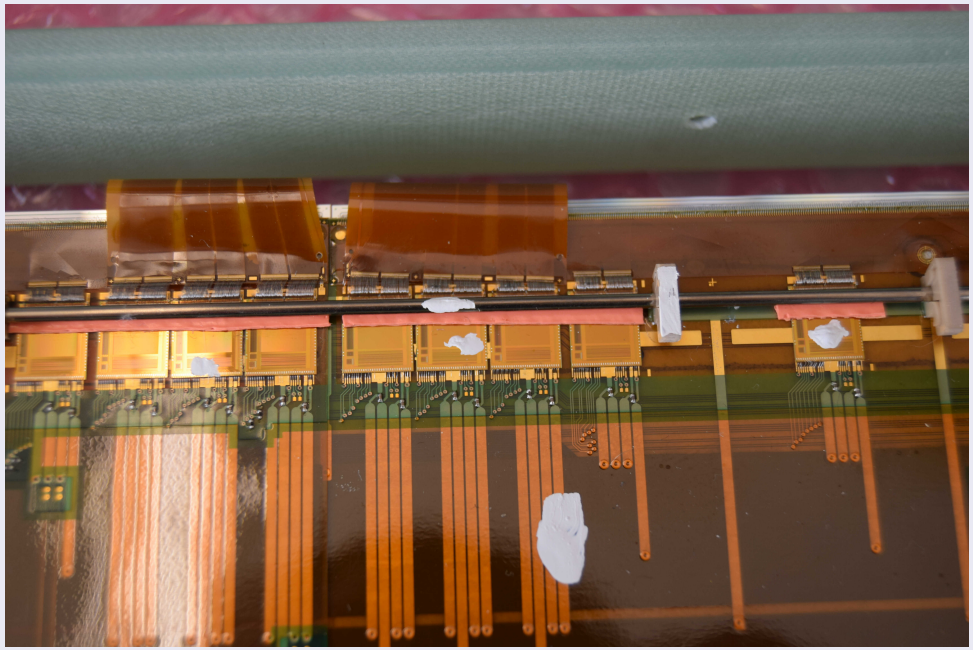
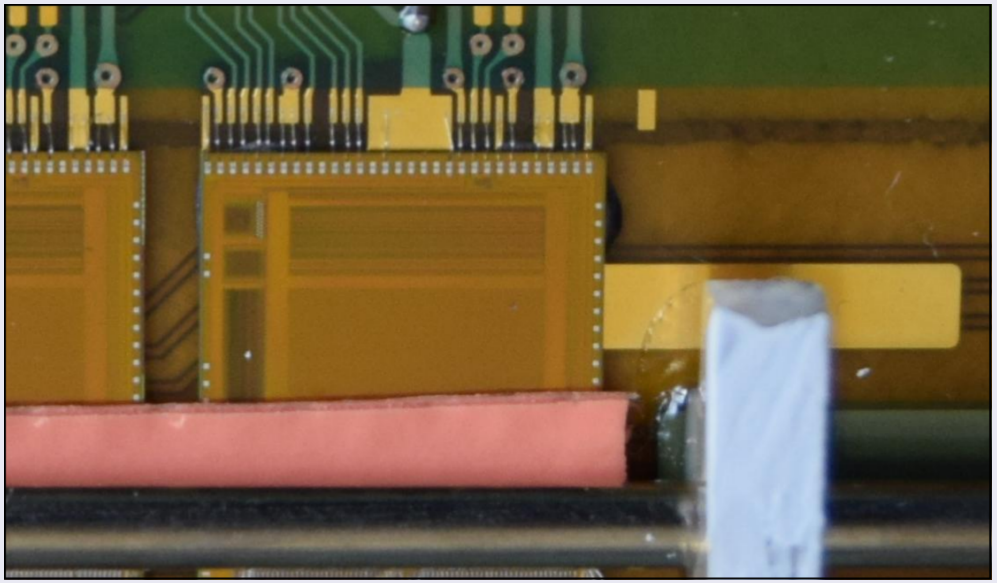
X/X_0 Measurement area

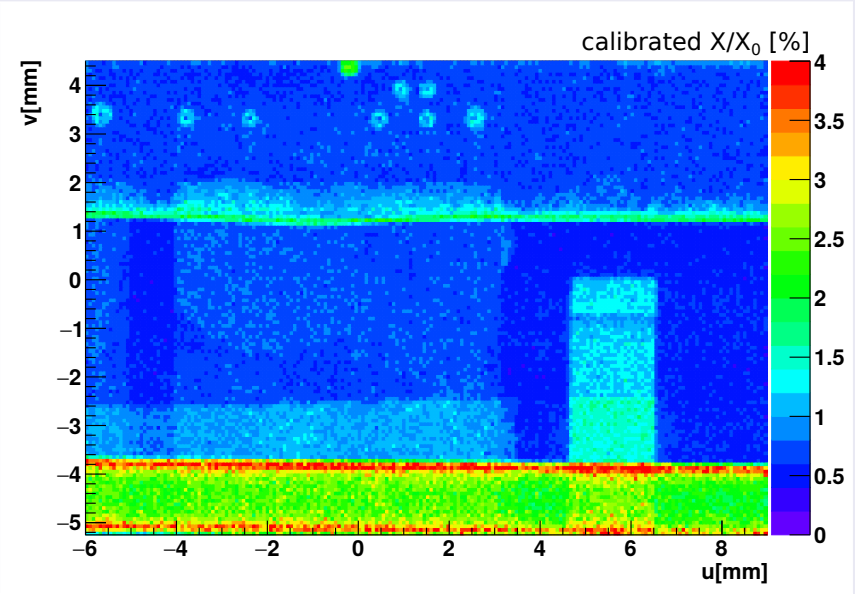


SVD X/X_0 image

photograph of SVD



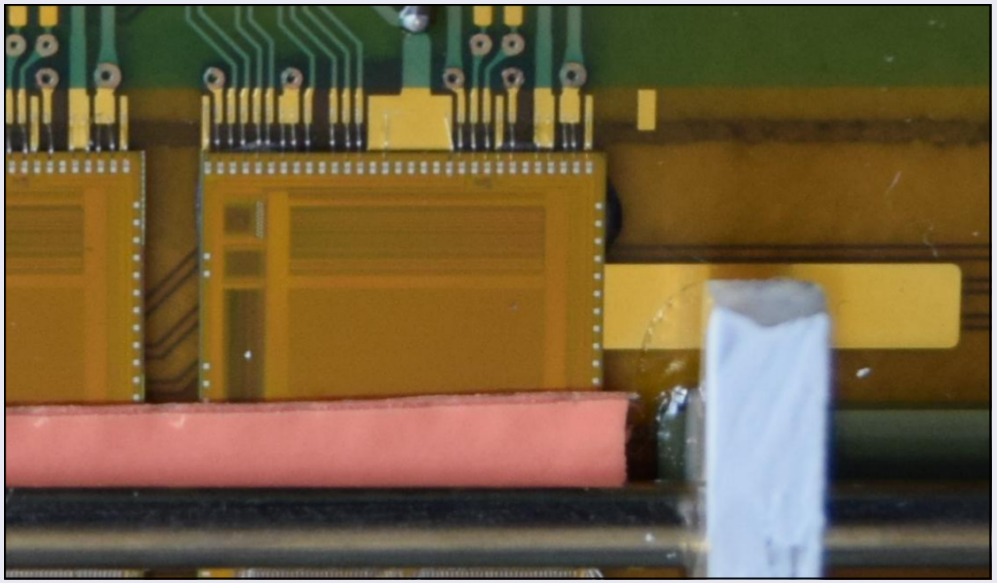
X0 image (4GeV, 75 μm^2 pixels)



visible structures

SVD X/X_0 image

photograph of SVD



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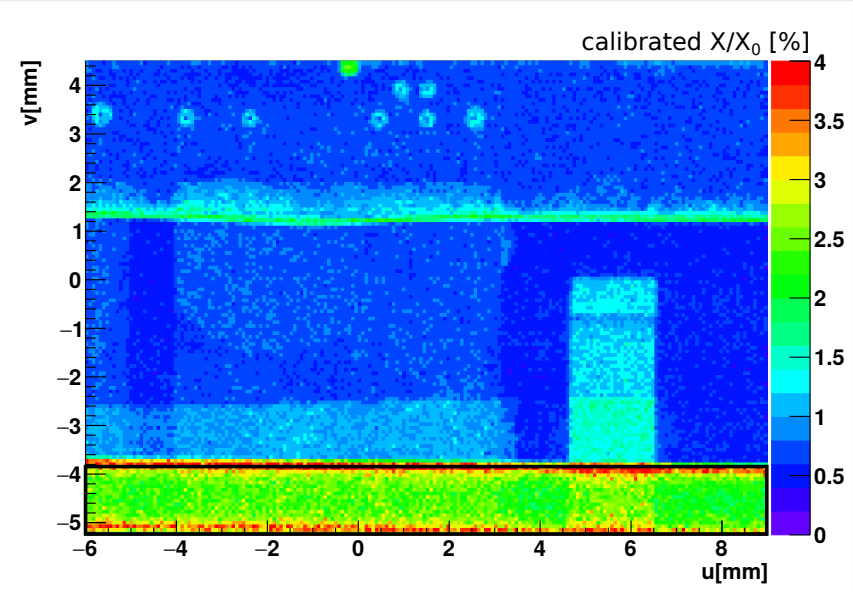

visible structures

cooling pipe,

SVD X/X_0 image

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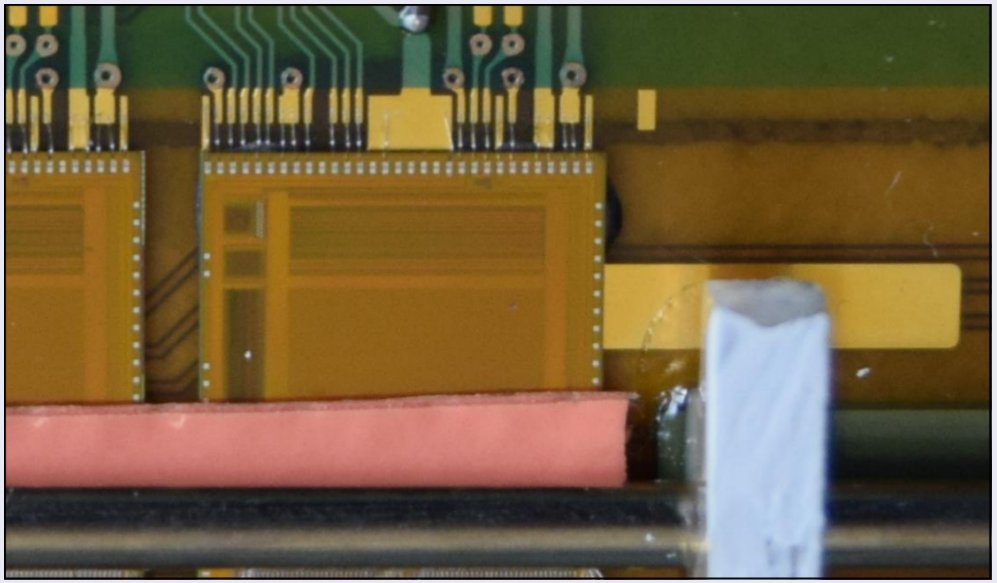

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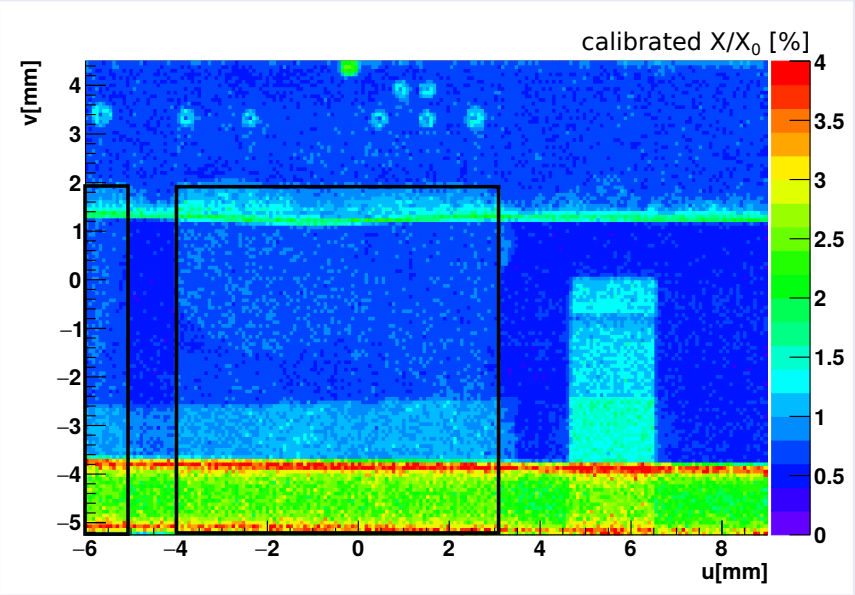
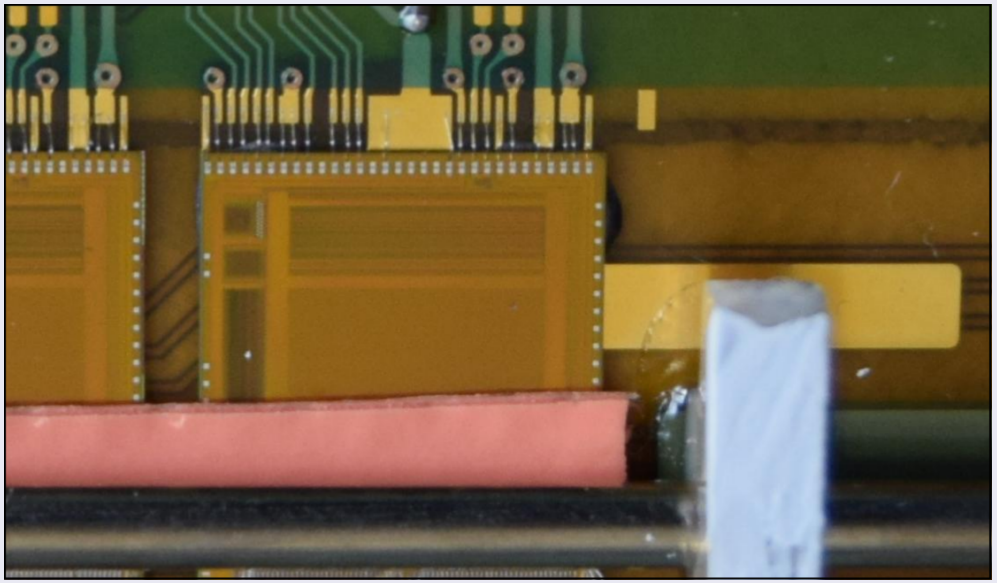


visible structures

cooling pipe, APV25 chip,

SVD X/X_0 image

photograph of SVD



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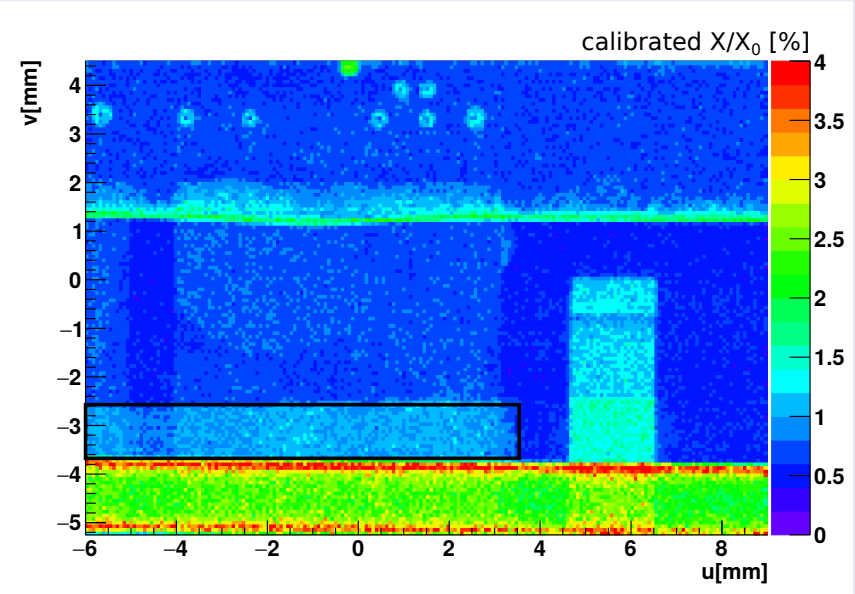

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cooling pipe, APV25 chip, keratherm,

SVD X/X_0 image

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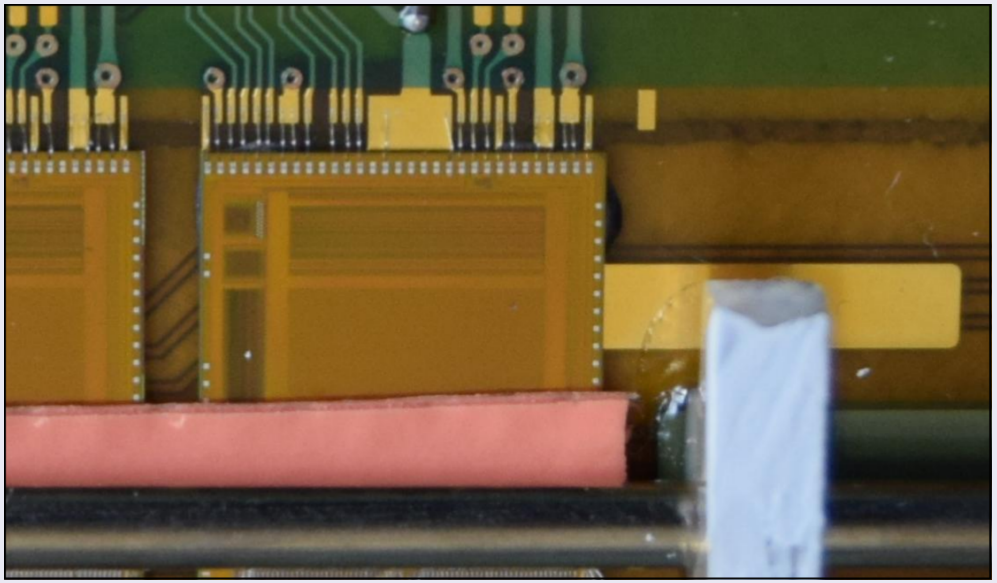

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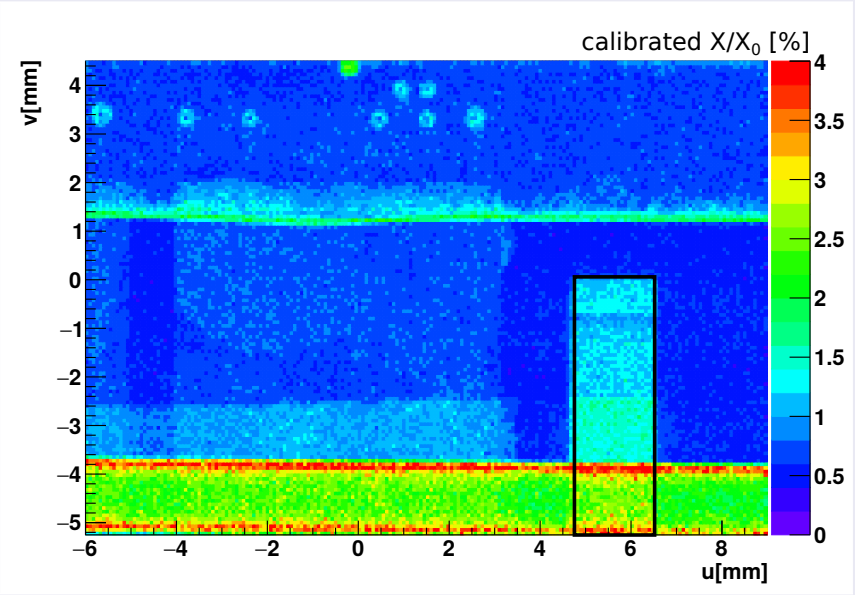
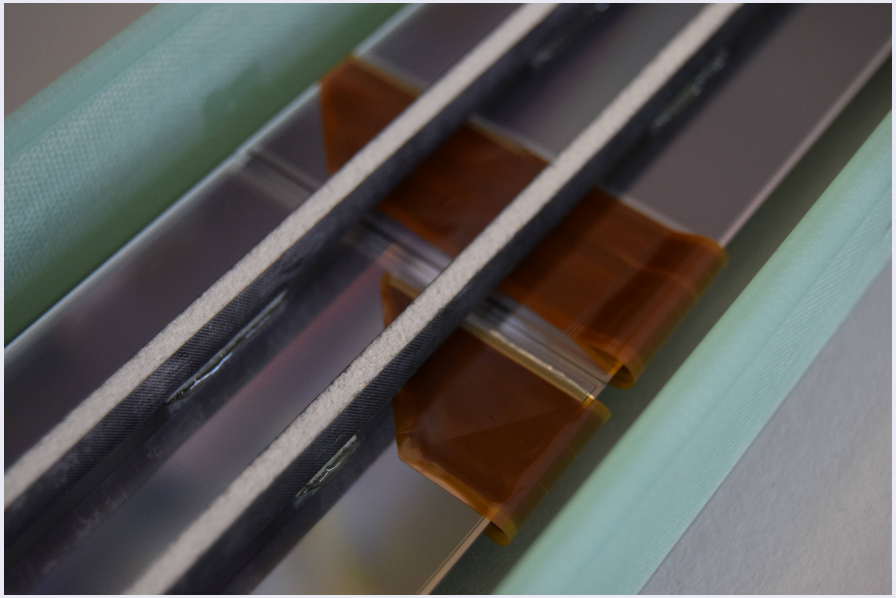


visible structures

cooling pipe, APV25 chip, keratherm, plastic clamp,

SVD X/X_0 image

photograph of SVD (backside)



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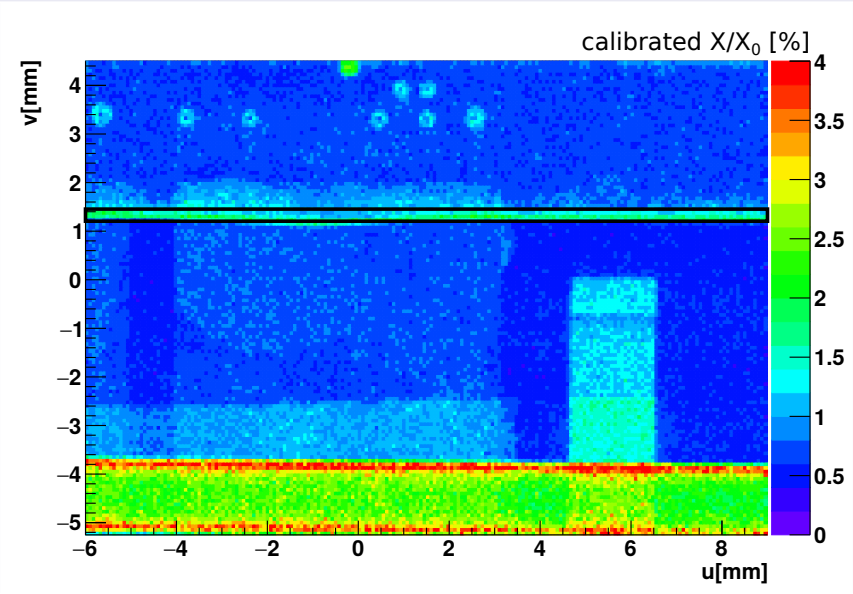
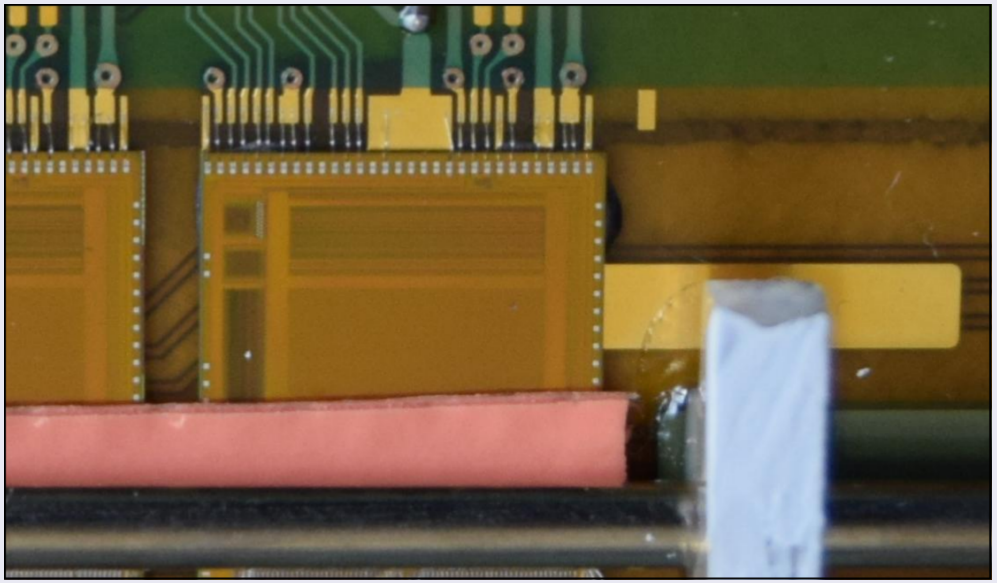


visible structures

cooling pipe, APV25 chip, keratherm, plastic clamp, carbon fiber plies in edges of support structure on backside,

SVD X/X_0 image

photograph of SVD



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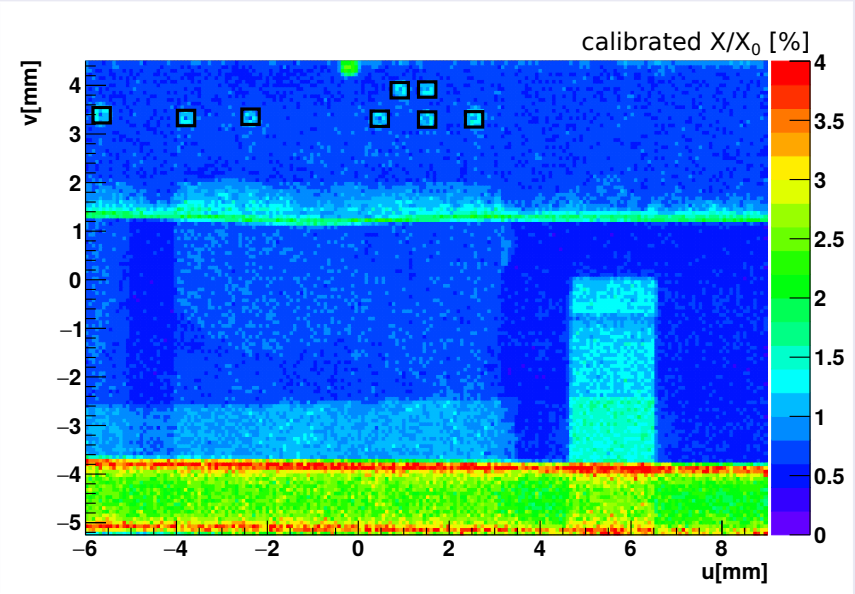
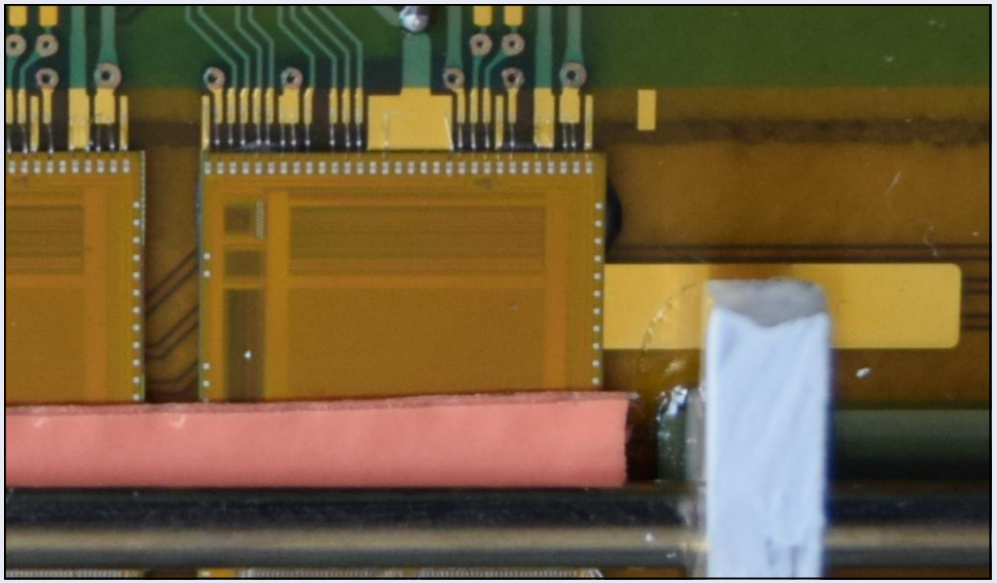


visible structures

cooling pipe, APV25 chip, keratherm, plastic clamp, carbon fiber plies in edges of support structure on backside, metallizations (vias) and

SVD X/X_0 image

photograph of SVD



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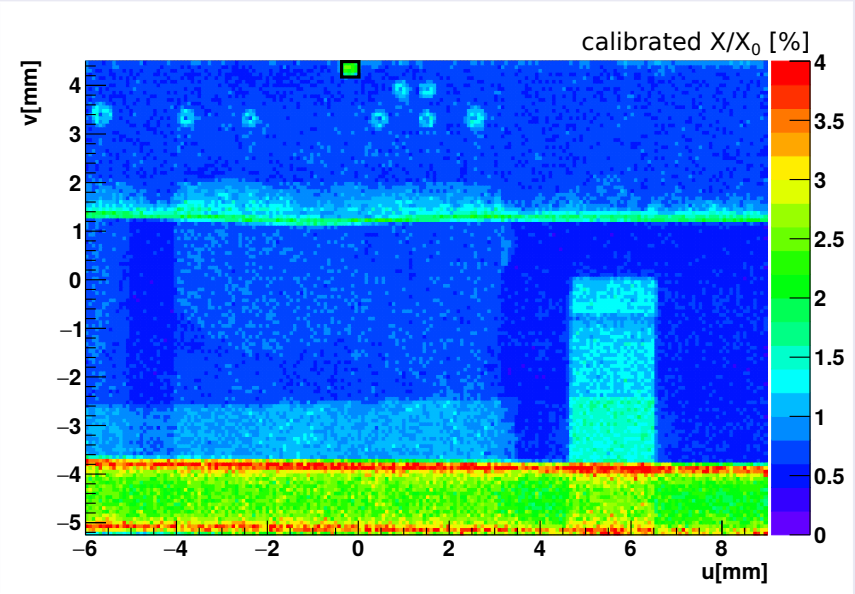
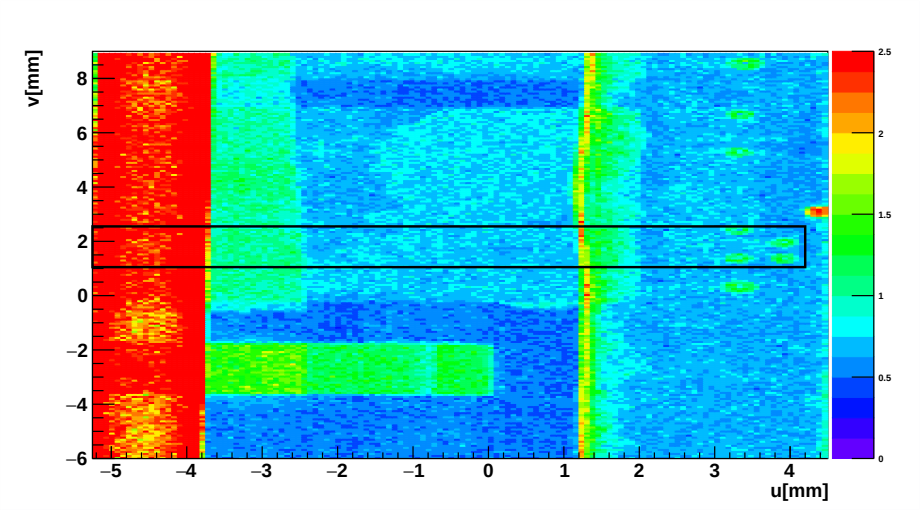


visible structures

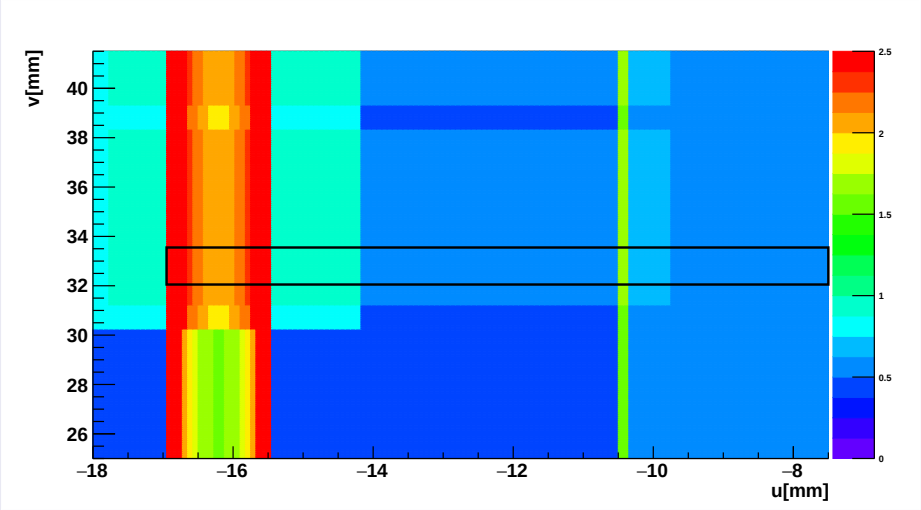
cooling pipe, APV25 chip, keratherm, plastic clamp, carbon fiber plies in edges of support structure on backside, metallizations (vias) and part of a capacity

SVD: Material scan - X/X_0 measurement comparison

X0 image with u profile



Material scan with u profile



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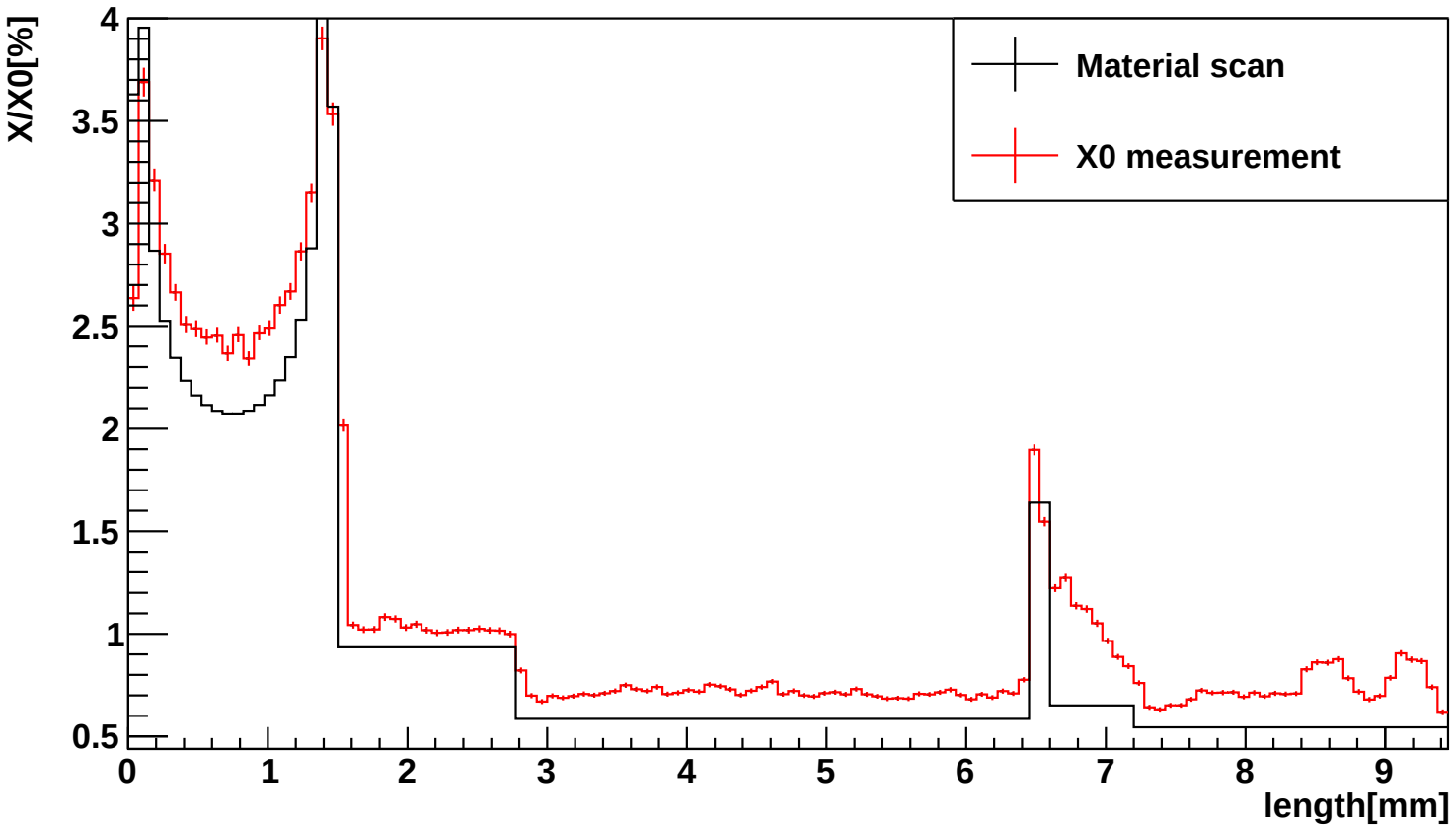

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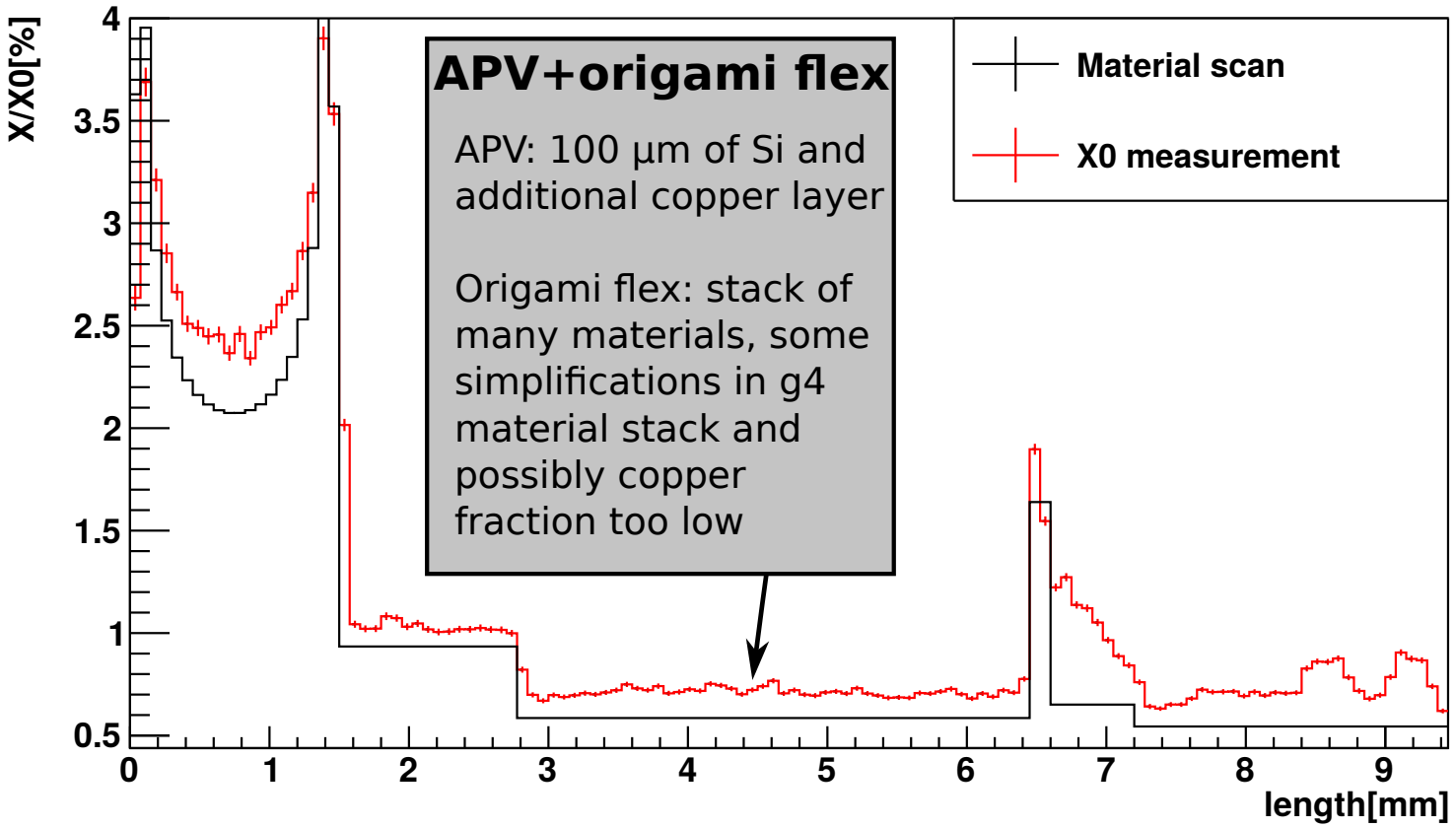

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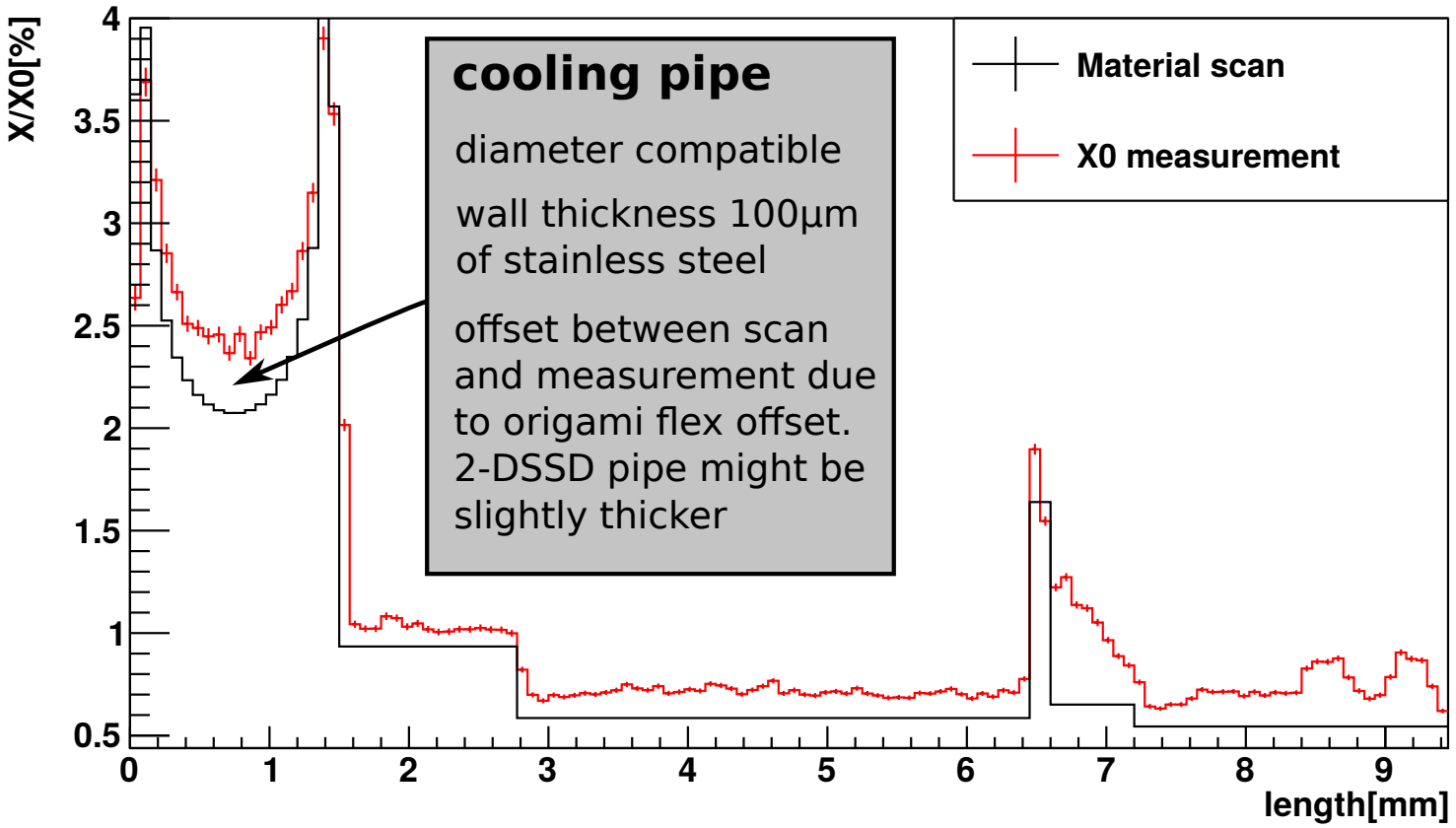

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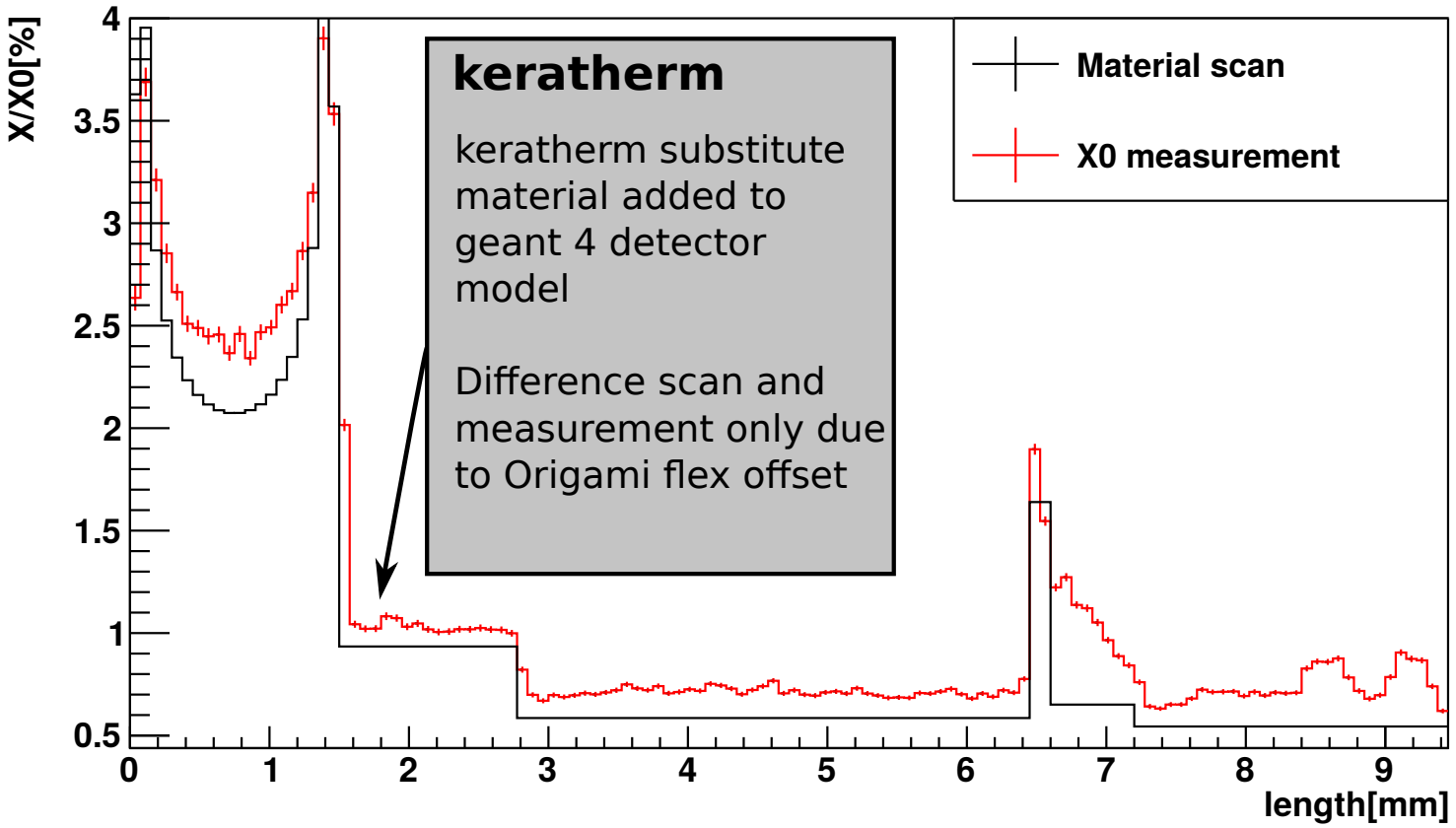

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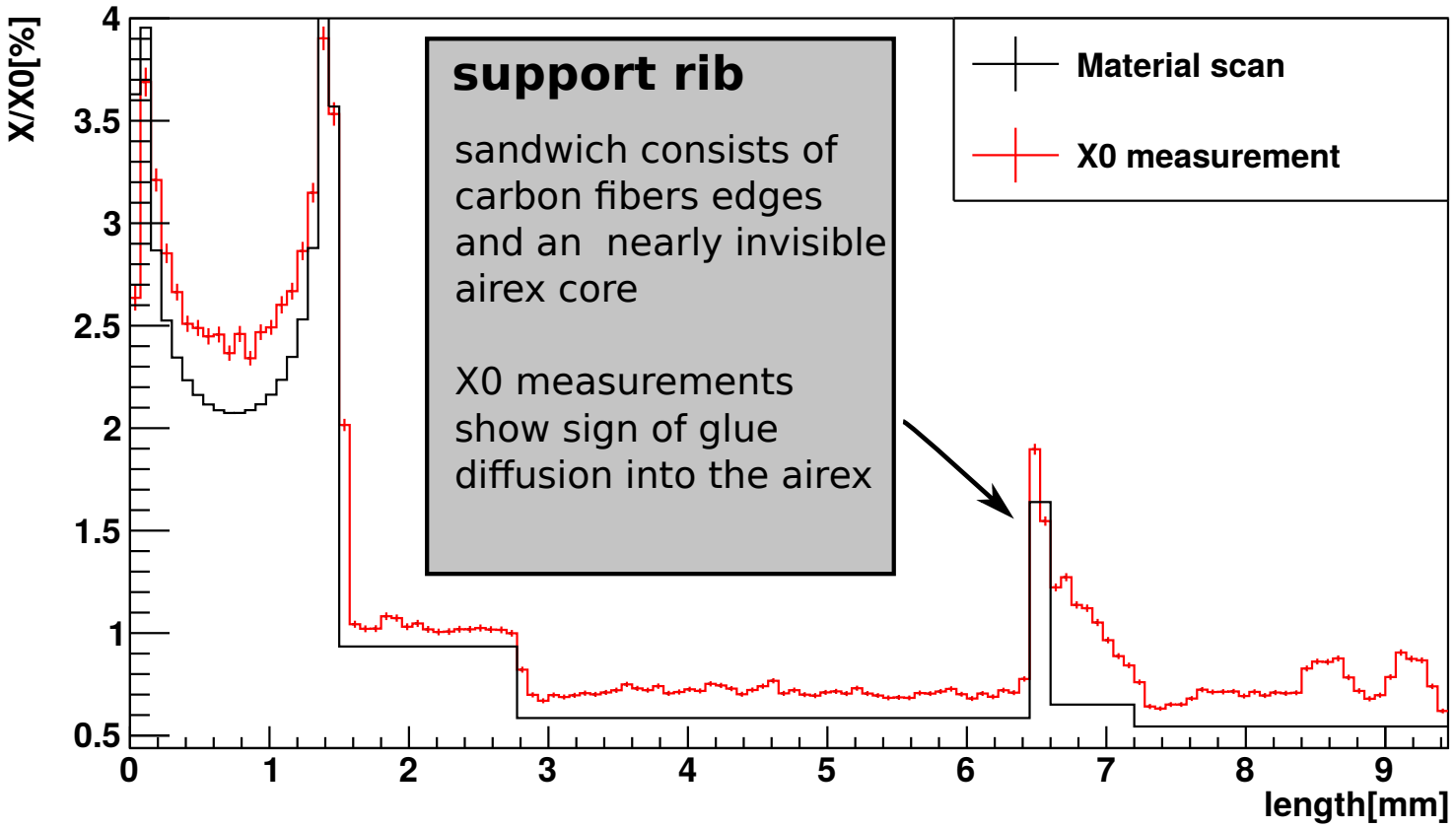
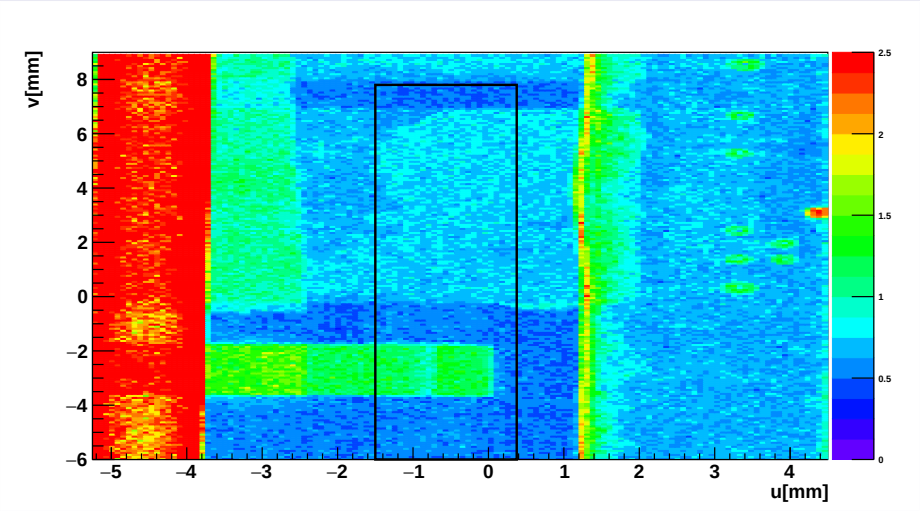
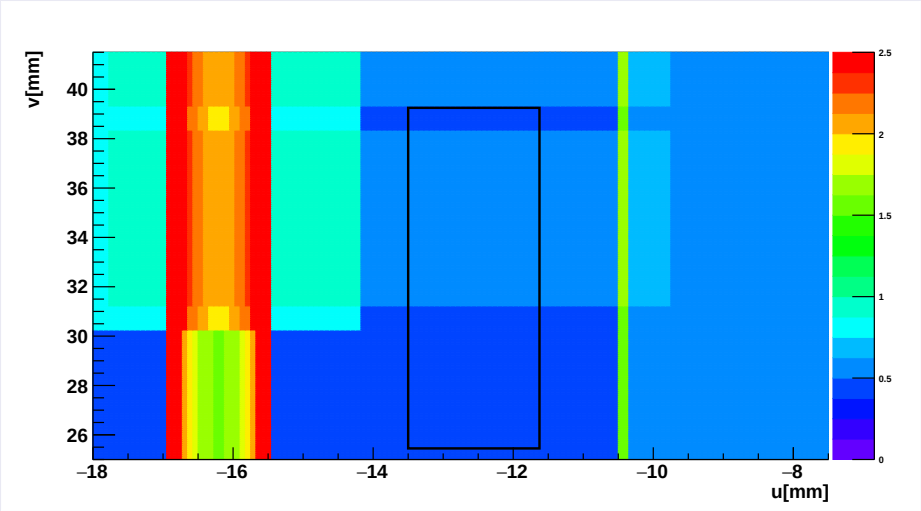


SVD: Material scan - X/X_0 measurement comparison

X0 image with v profile



Material scan with v profile



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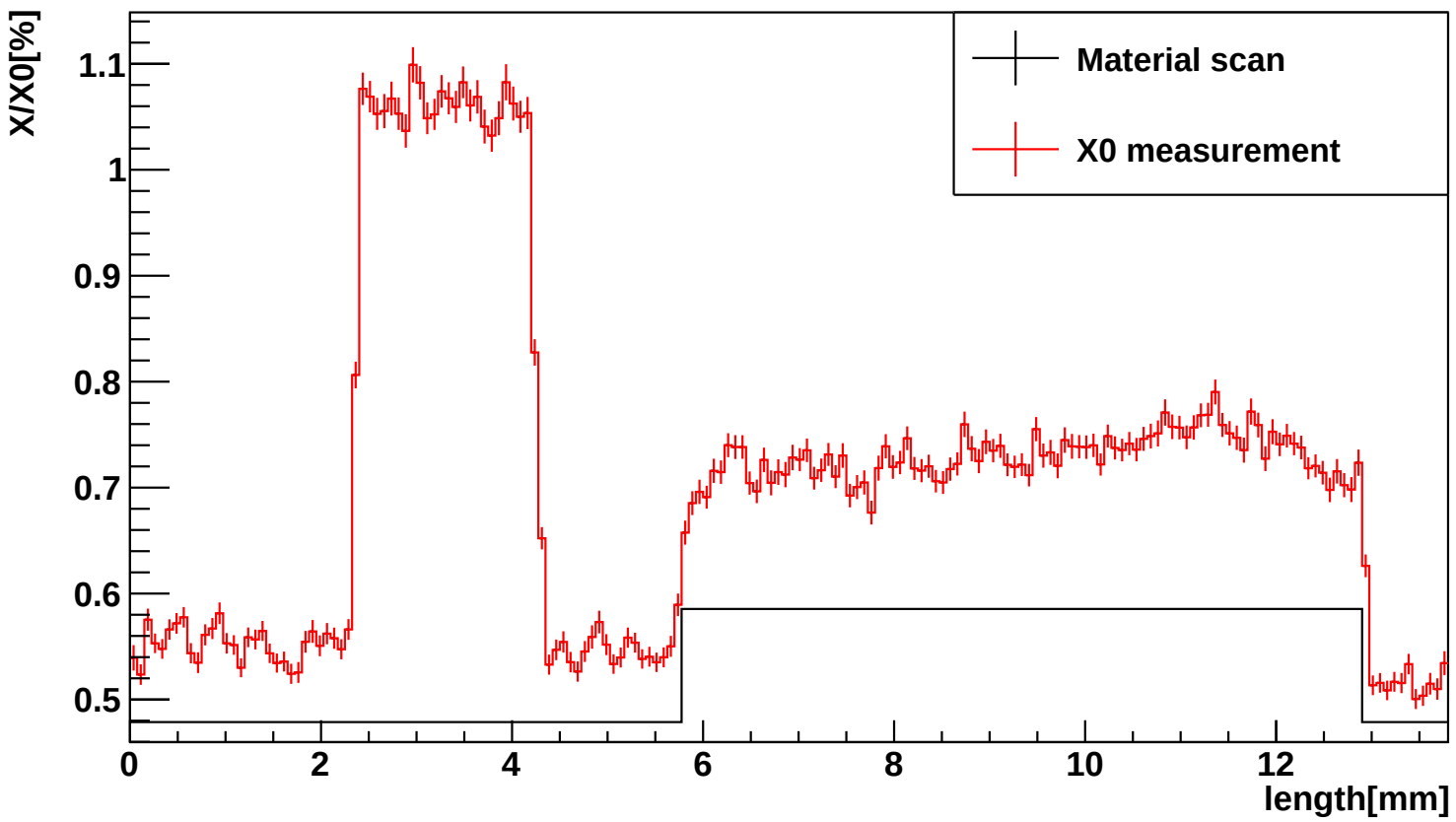

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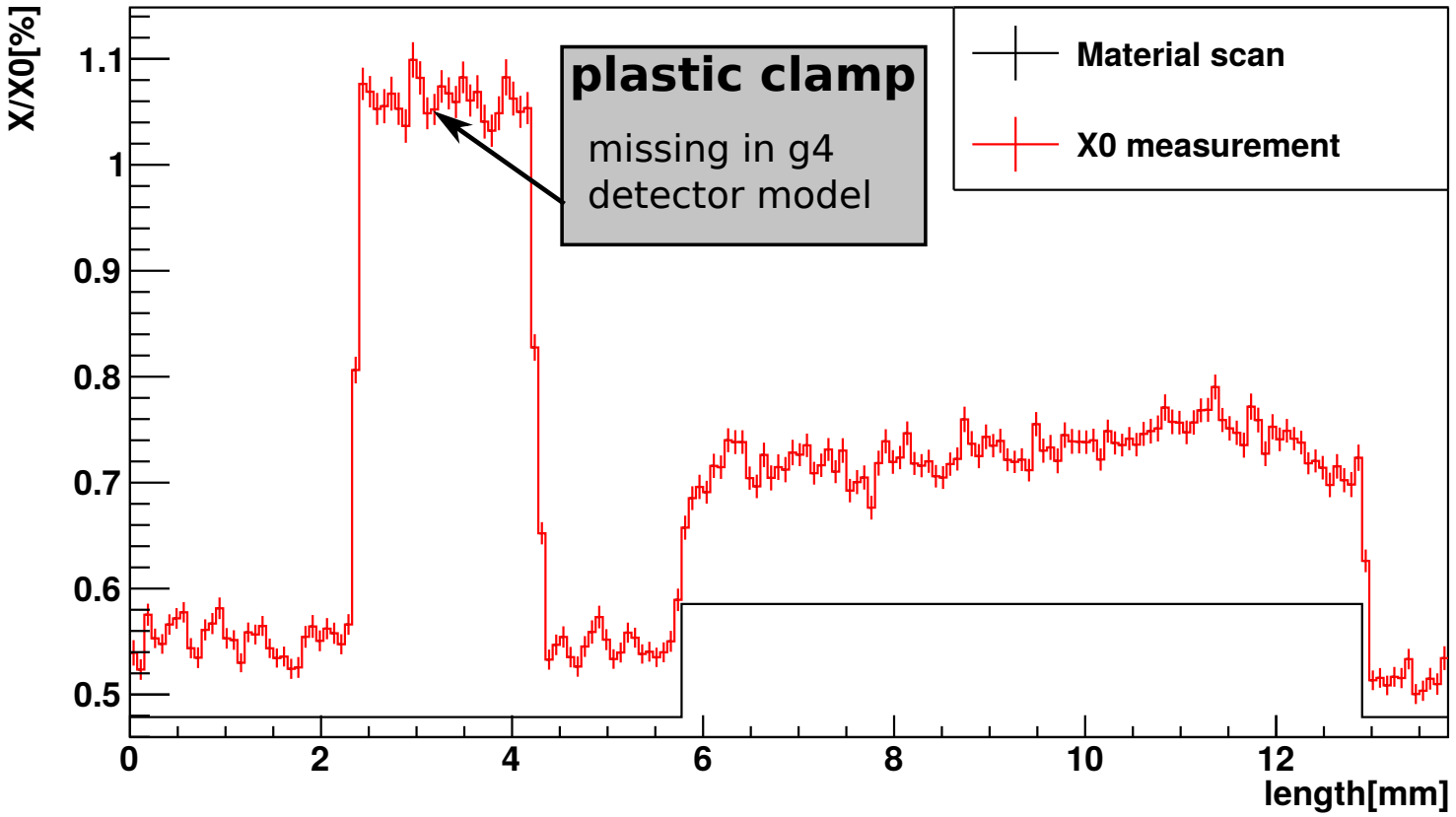

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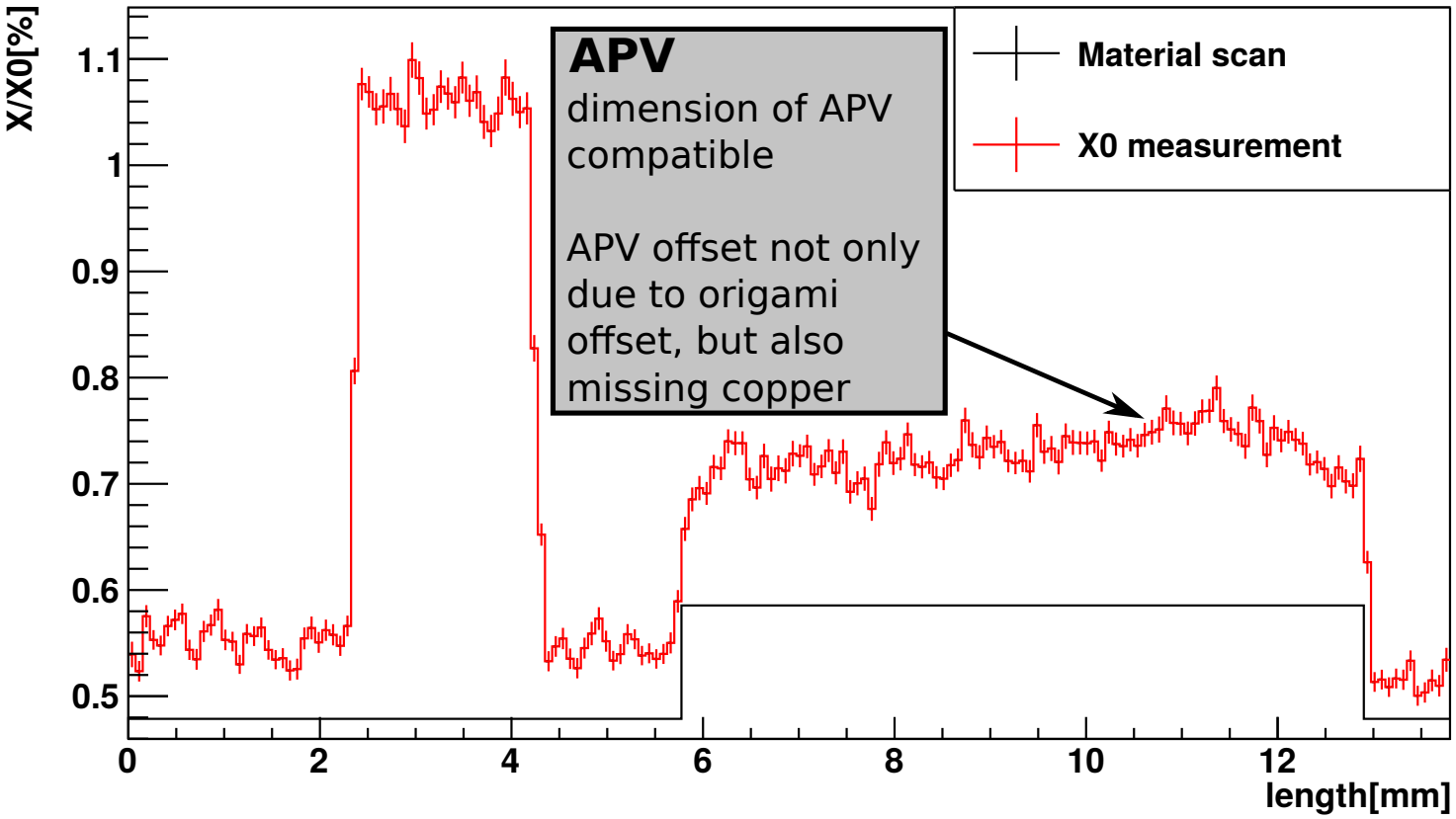
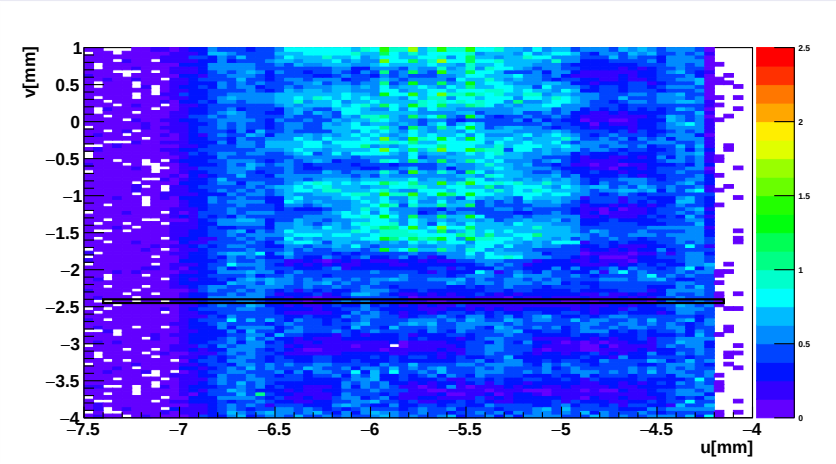
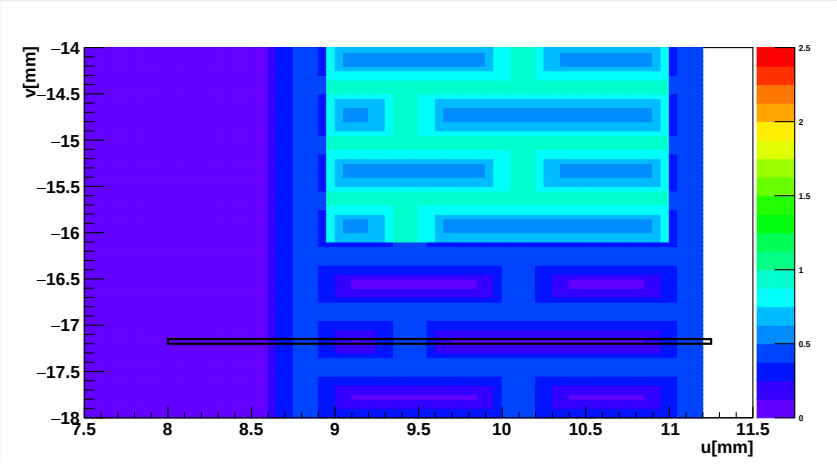


PXD X/X_0 image

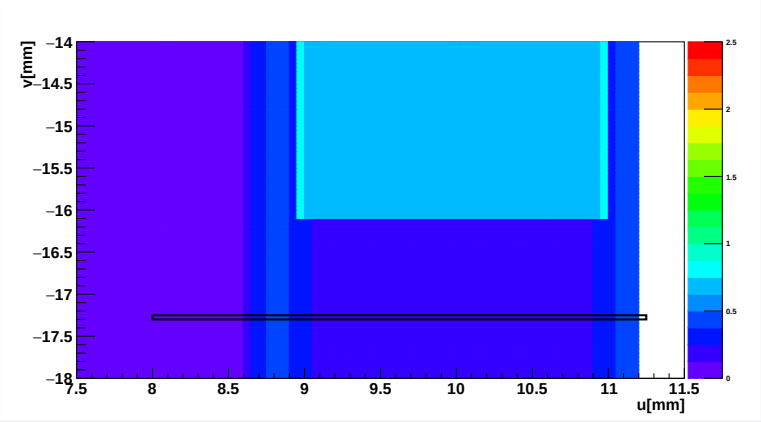
X0 image



Material scan with grooves

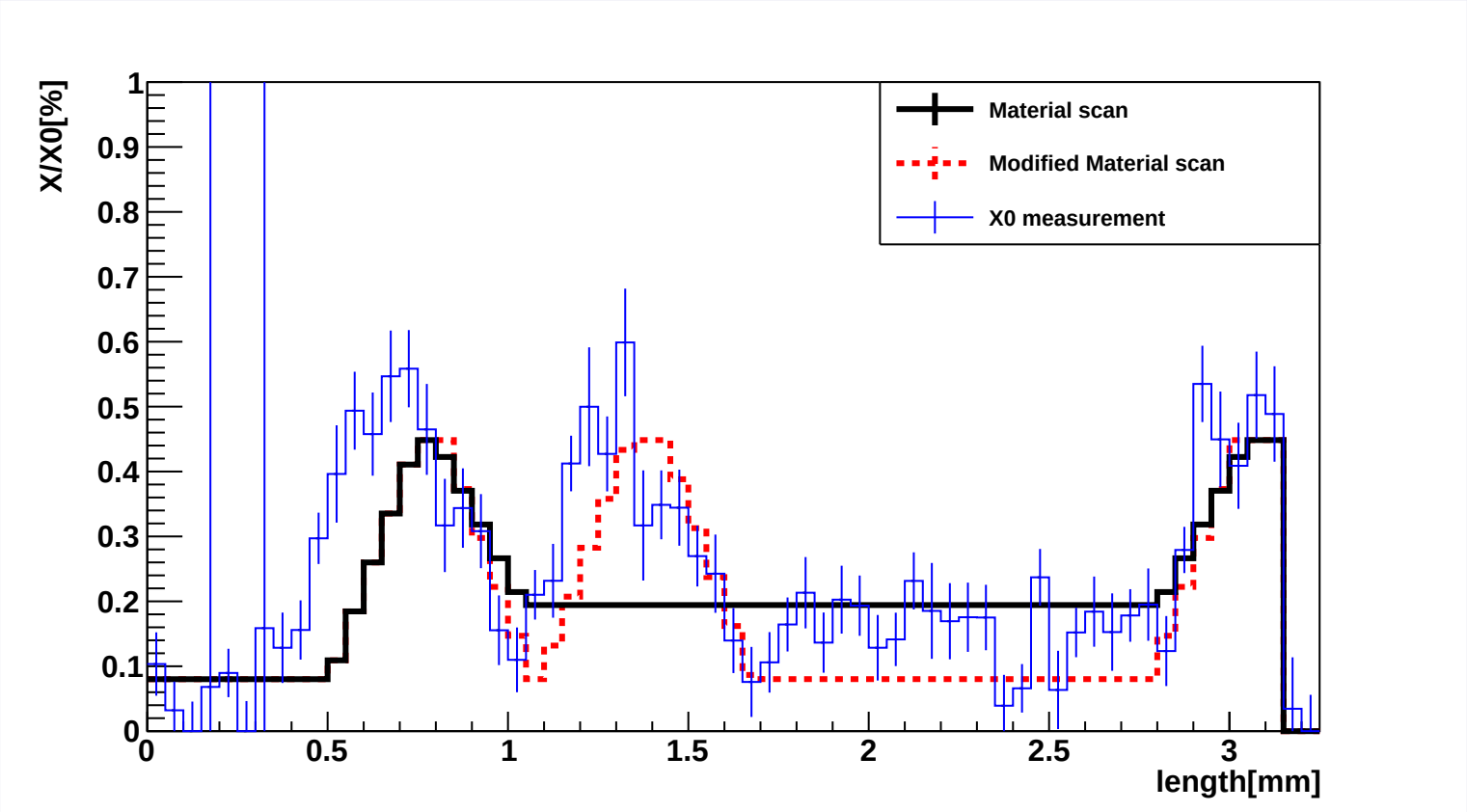


Material scan without grooves



PXD X/X_0 image

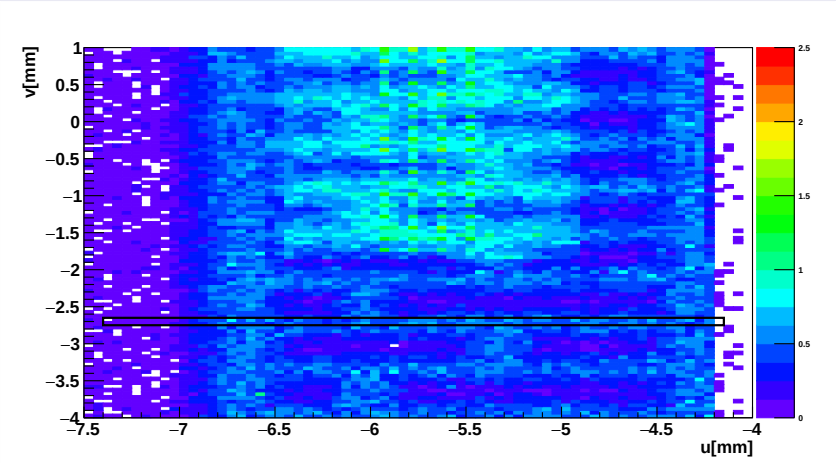
u profile comparison



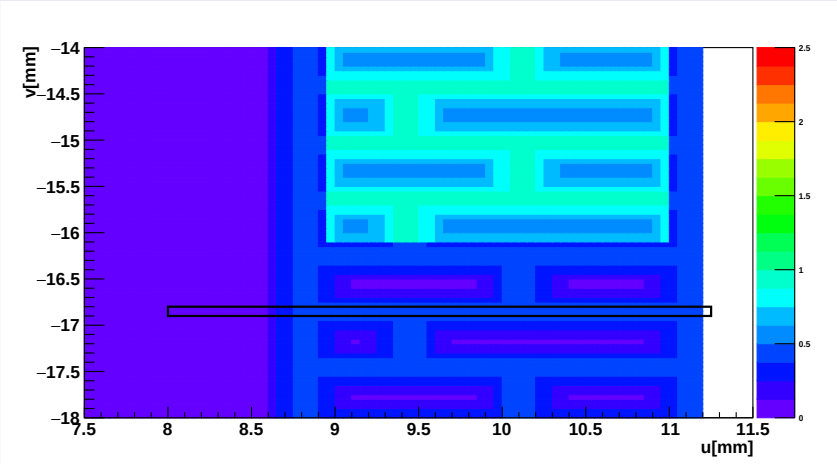
Balcony thickness in material scan 420 μm (specifications: 525 μm), 4-5 μm copper layer in balcony region is missing

PXD X/X_0 image

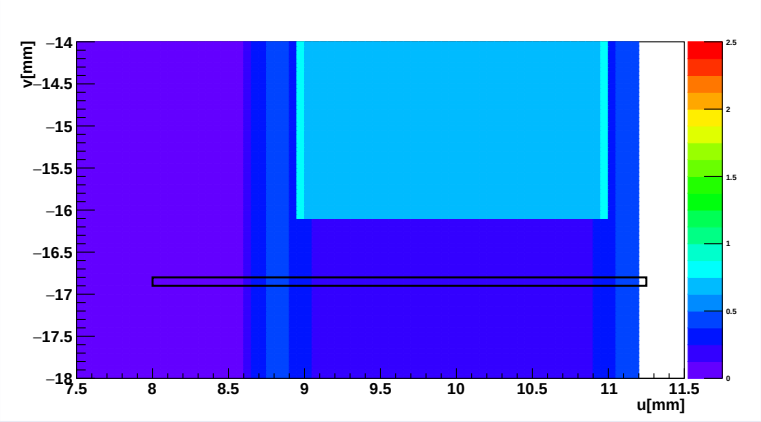
X0 image



Material scan with grooves

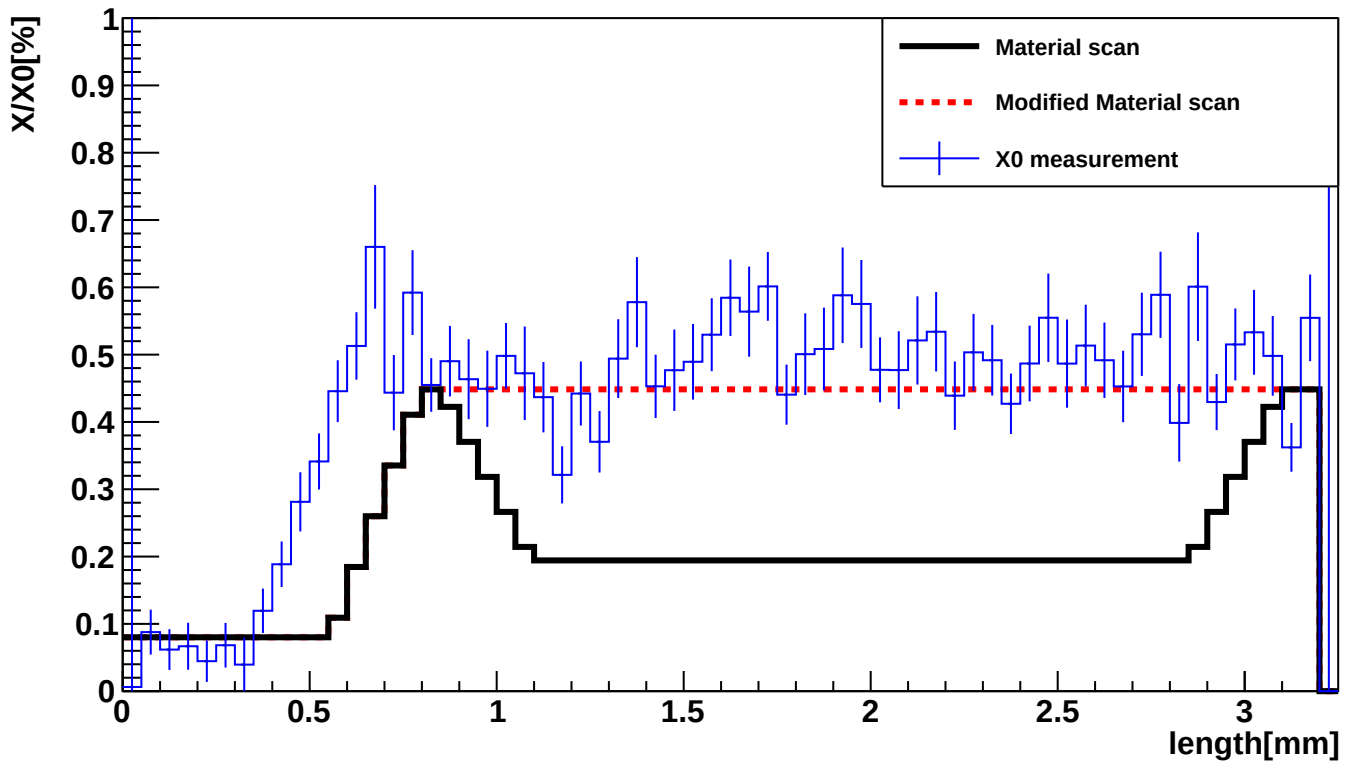


Material scan without grooves



PXD X/X_0 image

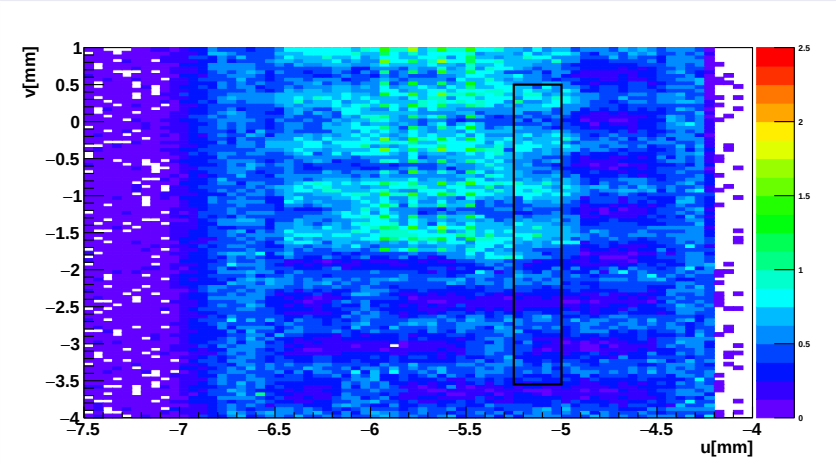
u profile comparison



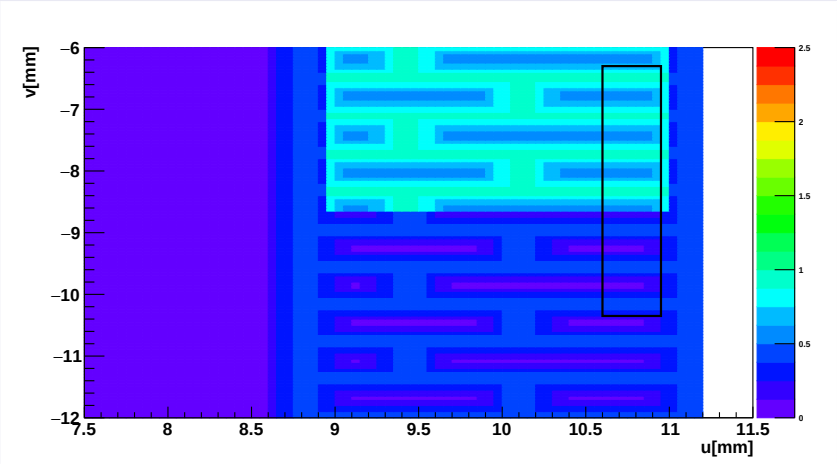
Balcony thickness in material scan 420 μm (specifications: 525 μm), 4-5 μm copper layer in balcony region is missing

PXD X/X_0 image

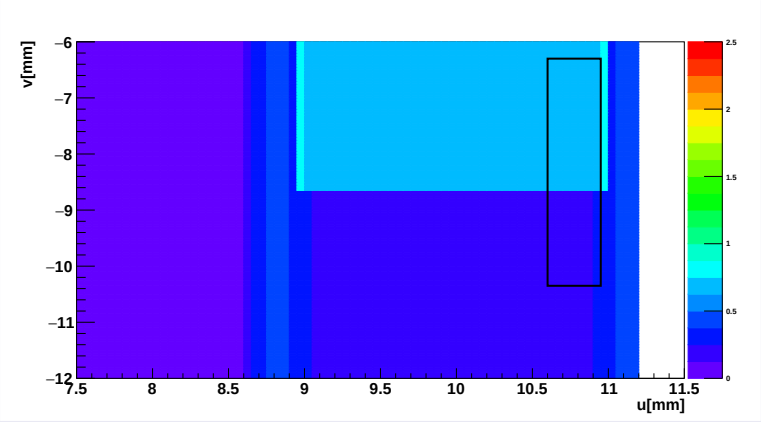
X0 image



Material scan with grooves

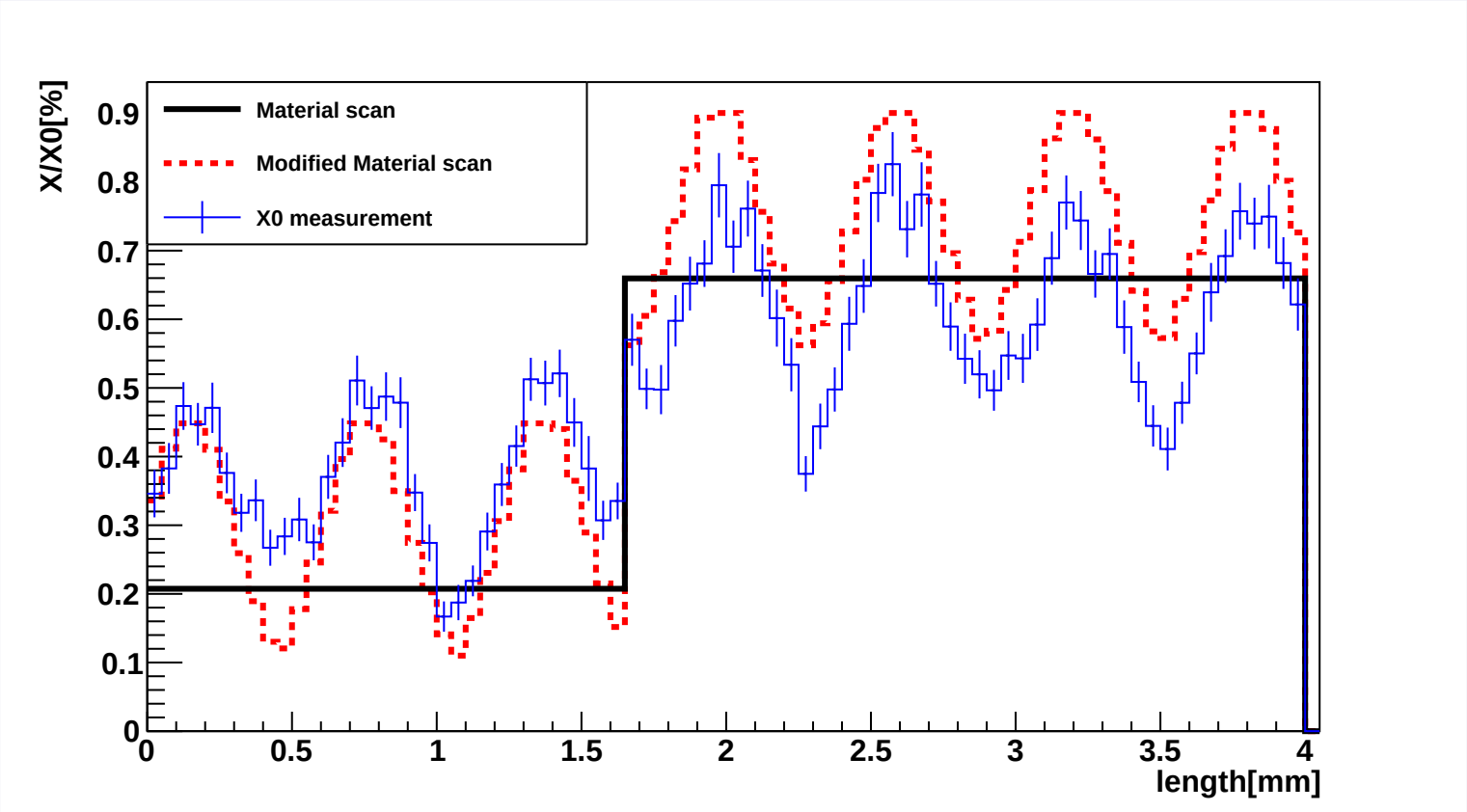


Material scan without grooves



PXD X/X_0 image

u profile comparison



Balcony thickness in material scan 420 μm (specifications: 525 μm), 4-5 μm copper layer in balcony region is missing and switcher 400 μm (appr. 300 μm ecpected)

Conclusion and Outlook

Conclusion

- More information on the X/X_0 measurements can be found at `http://arxiv.org/abs/1609.02402`
- Comparing material scans and X/X_0 measurements gives us the opportunity to do a quantitative cross check of the geant4 belle II detector model
- Some missing structures (SVD Keratherm, capacities) and mismodelled regions (PXD balcony thinning, SVD cooling pipe) have been identified, work still ongoing

Conclusion and Outlook

Outlook

- Find out which discrepancies are relevant for vertex resolution
- Do additional measurements in order to have X/X_0 measurements that are transferable to the VXD detector as a whole

Further SVD measurements

- Second measurement on the 2-DSSD module, this time in both the ce and -z region
- Measurement of pure kapton pitch adapter and Origami flex

Further PXD measurements

- Measurement from switcher balcony across the sensitive area to the balcony on the other side
- Measurement should be done near connection region between forward and backward module

Thank you!

Backup Slides

SVD Inconsistencies

Origami flex Specifications

- stack of 75 μm of polymide, 50 μm of epoxy glue, 50 μm, 30 μm of solder resist and 15-27 μm of copper
- Some unknown amount of glue between Origami flex, airex insulation layer and silicon sensor

Origami flex geant 4 model

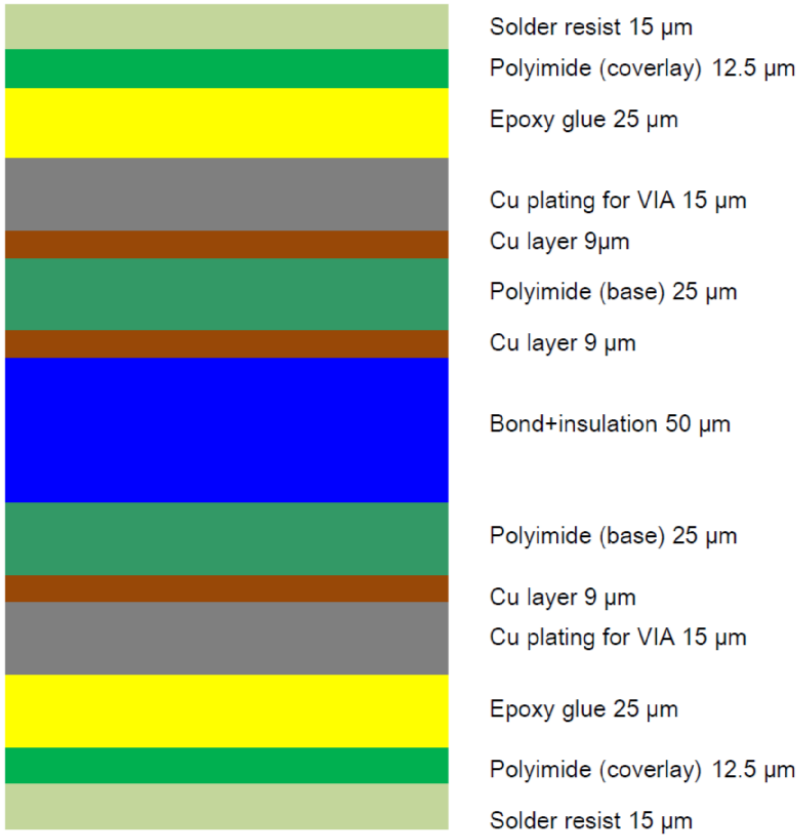
- 200 μm of Kapton Hybrid, which consists of 90 % kapton, 9 % copper and some small amount of Ni and Au
- 200 μm of this material yield an radiation length of 1.2 %

Some simplifications in the geant 4 detector model and copper fraction probably too low

SVD Inconsistencies

origami flex materials

3. Layer Stack-up



SVD Inconsistencies

APV Specifications

- 100 μm of Silicon and additional layer of 5 to 9 μm of copper
- X/X_0 between 1.42 % and 1.69 %

APV geant 4 model

- 100 μm of Silicon, no copper
- $X/X_0 = 0.11\,\%$

Copper layer beneath APVs is missing and should be included

SVD Inconsistencies

Cooling pipe specifications

- diameter: 1.6 mm, wall thickness of 100 μm, consists of stainless steel ($X_0 = 17.7$ mm)
- X/X_0 in center region (2 x wall thickness) 1.13 %

Cooling pipe geant 4 model

- diameter 1.6 mm, wall thickness 50 μm, iron

wall thickness in geant 4 detector model changed to 100 μm for this presentation

SVD Inconsistencies

Keratherm specifications

- 4 x 31.5 mm^2 pad with thickness of 1 mm
- radiation length unknown

Keratherm geant 4 model

- not included in geant 4 detector model

As a dummy material for the Keratherm we included a 320 μm thick Silicon block with the correct dimensions to the geant 4 geometry. The thickness of the SIlicon was determined in such a way, that it matches the X/X_0 measurements. The Keratherm pads should be added in some other way in the future.

PXD Inconsistencies

Balcony Specifications

- The thickness of the unthinned Silicon balcony is 525 μm
- There is a 4-5 μm copper layer in the balcony region
- grooves

Balcony geant 4 model

- Unthinned balcony is 420 μm of Silicon
- no copper layer
- no grooves, but a large region with a mean thickness of Silicon in the grooves region

The Silicon and copper layer should be included/changed in the geant 4 detector model, grooves have already been included on the switcher balcony for this presentation

PXD Inconsistencies

Switcher Specifications

- Size: Newest revision 1.9 x 3.6 mm^2
- 300 μm of Silicon

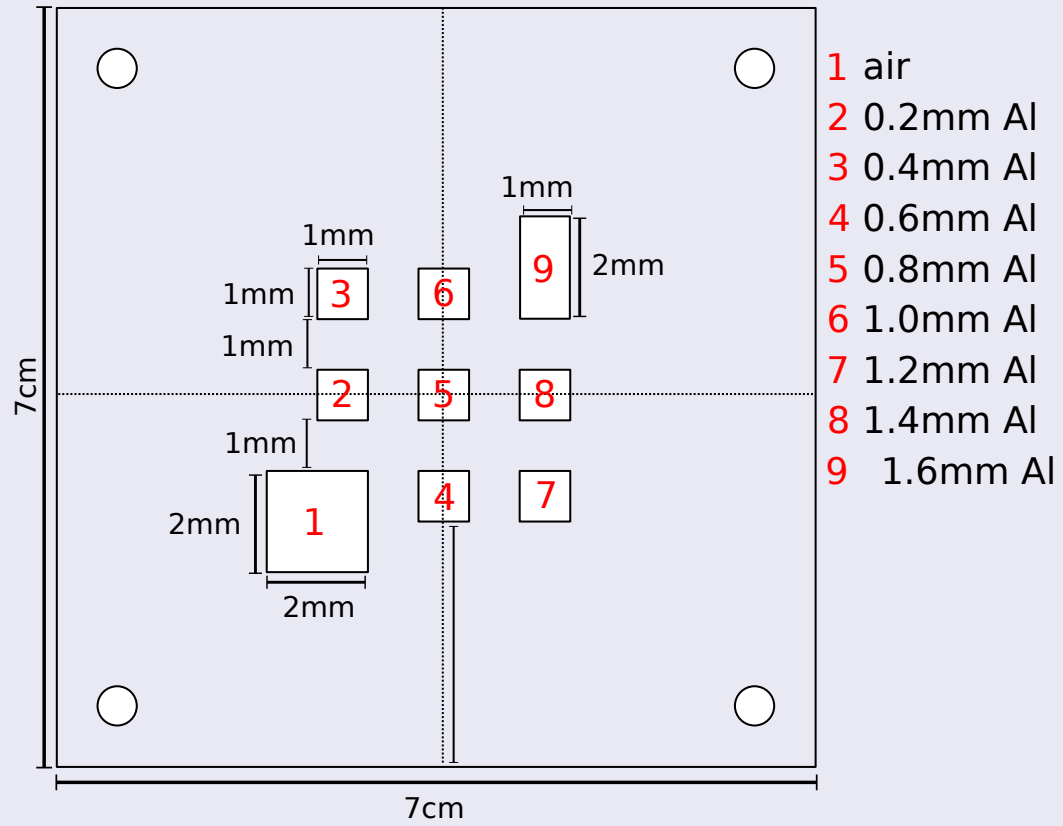
Switcher geant 4 model

- Size: 2.035 x 3.6 $mathrmmm^2$
- 400 μm of Silicon, small fraction of gold (6 permille)

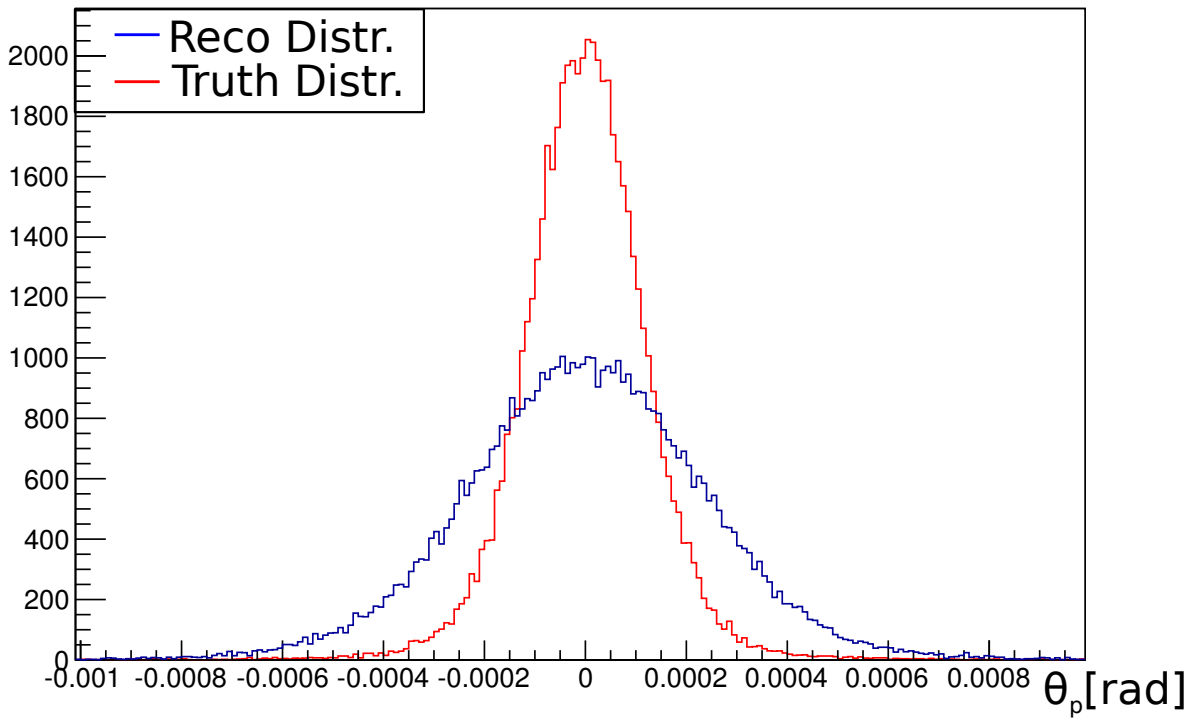
Switcher dimensions and thickness should be corrected

Aluminum grid

- 0.2 mm thick aluminum layers, with different hole configurations
- taped to metal plate within telescope arms
- increase of material budget by 0.22 % per hole



Example of a reconstructed angle distribution



Composition of the Reco Distribution

Reconstructed MSC angle distribution is a convolution between the pure MSC angle distribution and a Gaussian noise distribution caused by the reconstruction errors

MSC models

Highland (HL) model

$$\sigma = \frac{0.0136 \cdot q[e]}{\beta \cdot p\,[\mathrm{GeV}]} \cdot \sqrt{\frac{X}{X_0}} \left(1 + 0.0038 \ln\left(\frac{X}{X_0}\right)\right)$$

V. L. Highland, *Some practical remarks on multiple scattering*, Nuclear Instruments and Methods,1975

Moliere model

$$\begin{aligned} f(\theta)\,\mathrm{d}\theta &= \frac{1}{\chi_c\sqrt{B}}\left(\frac{2}{\sqrt{\pi}}e^{-\frac{\theta}{\chi_c\sqrt{B}}} + \frac{f_1(\theta)}{B} + \frac{f_2(\theta)}{B^2}\right)\mathrm{d}\theta \text{ , where} \\ \chi_c &= \frac{22.9\,z\,Z}{p\,c\,\beta}\cdot\sqrt{\frac{\rho\,X}{A}} \ . \end{aligned}$$

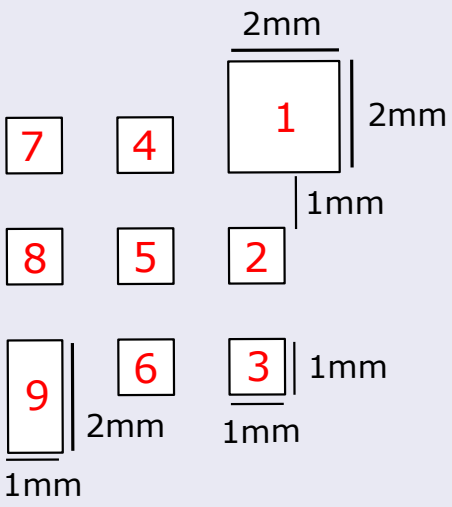
Correction terms f_1 and f_2. Values can be calculated or taken from a table (see paper by Moliere).

Moliere, Z. Naturfschg 1948

Selection of measurement areas for calibration

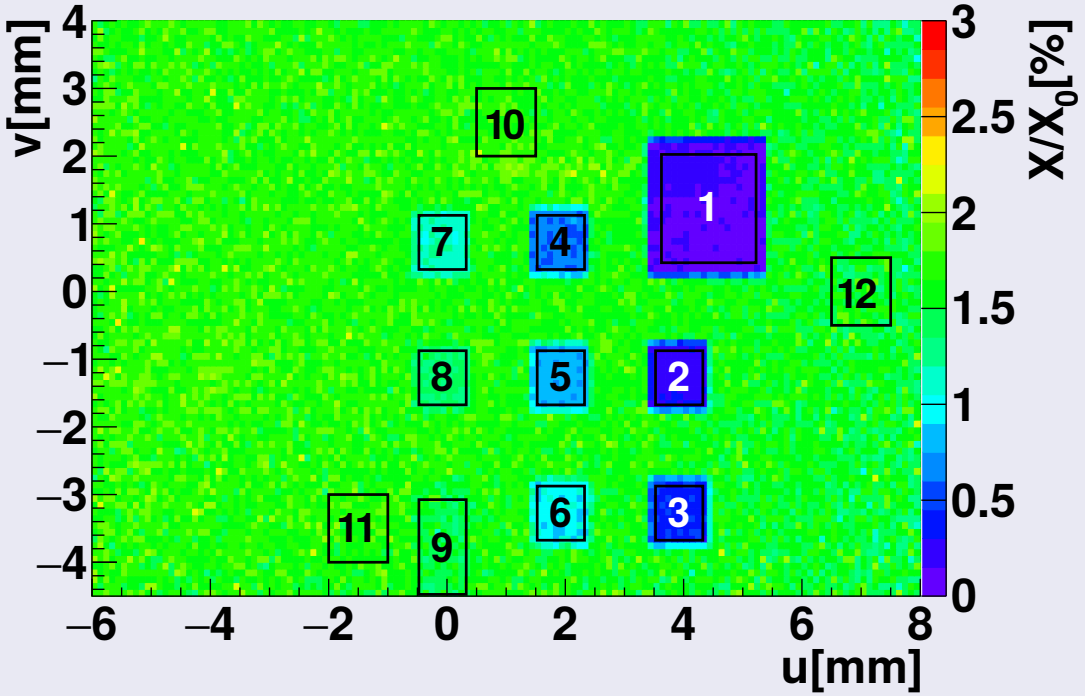
Picture of calibration target

1 air
2 0.2mm Al
3 0.4mm Al
4 0.6mm Al
5 0.8mm Al
6 1.0mm Al
7 1.2mm Al
8 1.4mm Al
9 1.6mm Al



total thickness 1.8mm Al

X/X_0 image of calibration target

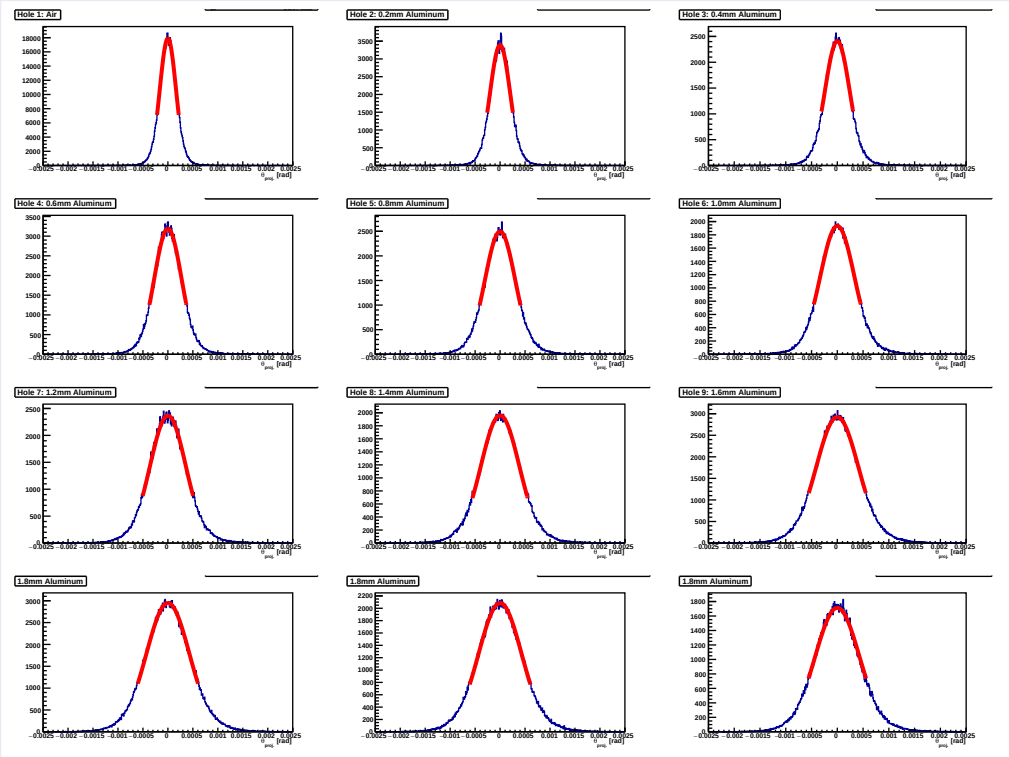


Calibration for SVD data set @ 4 GeV

Calibration results SVD

- Simultaneous fit in 12 regions
- Highland model was used
- Result: $\lambda = 1.171 \pm 0.003$

Fitted kink angle distributions



Calibration for SVD data set @ 4 GeV

Calibration results SVD

- Simultaneous fit in 12 regions
- Highland model was used
- Result: $\lambda = 1.171 \pm 0.003$
- rather large value (typical: $\lambda \approx 1.1$)

Fitted kink angle distributions