X/X_0 imaging of Belle II modules

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GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

VolkswagenStiftung

Measurements of SVD and PXD modules

Motivation

- Low material budget is an essential part of the belle II ladder development especially for PXD part
- Mean material budget of PXD ladder ≈ 0.1-0.2 %
- Small regions (i.e. bump bonds and capacitances) of highly increased material (worst case: 1%)
- Long term goal: Find out if tracking can be improved by using more detailed/accurate detector model based on X/X_0 measurements

Results in this talk

- X/X_0 Imaging of area near APV25 chips and cooling pipe
- X/X_0 Imaging of balcony, switchers and passives on the DEPFET modules

Overview of X/X_0 data

DESY test beam campaign in november 2015

- X/X_0 measurements on two Belle II modules
- Large statistics at beam energy of 4 GeV

DEPFET Dummy Module

- Including a switcher and 4 capacitors in measurement region
- Total of $\approx$ 108 mio tracks
- calibration for this data-set: 14 mio tracks

SVD Origami module

- 3 different measurement regions
- cooling pipe, APV25 chips etc visible
- Total of $\approx$ 26+98+29 mio tracks

X/X_0 Measurements

Basic idea

Reconstruct kink angle distributions on central plane $\rightarrow$ width of distribution depends on X/X_0.

Definition of λ

- Finite angle resolution on target plane $\rightarrow$ gaussian with standard deviation of σ_{err} as resolution function on target
- Expected value σ_{err} is affected by systematical errors (slightly wrong m26 resolution, additional multiple scattering within telescope, 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 on metal grid with appropriate MSC model

- Reconstructed multiple scattering angle distribution given by

$$f_{\mathrm{reco}} = f_{\mathrm{MSC}}(\theta) * \frac{1}{\lambda\,\sigma_{\mathrm{err}}\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{\theta}{\lambda\,\sigma_{\mathrm{err}}}\right)^2\right)$$

- f_{MSC} depends on many material and particle beam parameters
- Target with well known material profile allows λ calibration
- Find λ by simultaneous fit of reconstructed angle distributions

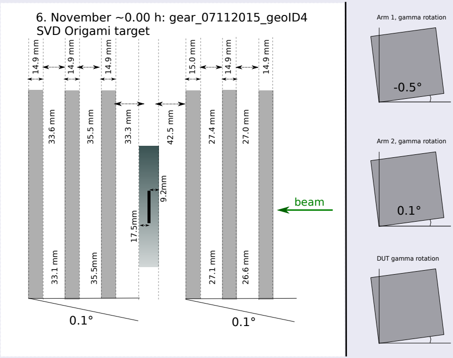
Second step: Measurement on materials

- Use optimal calibration factor in other X/X_0 measurements

Setup of telescope for SVD X_0 measurements

- EUDET telescope with 6 M26 planes (3 μm resolution per plane)
- Spacings chosen like this to keep the angle reco error σ_{err} small

schematic setup of telescope



Setup of telescope for SVD X_0 measurements

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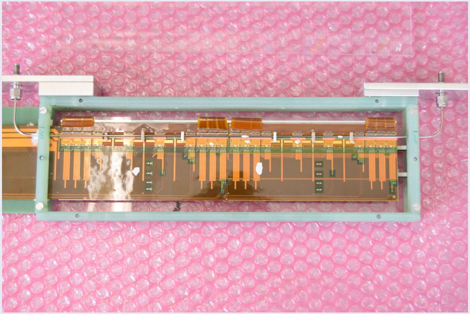
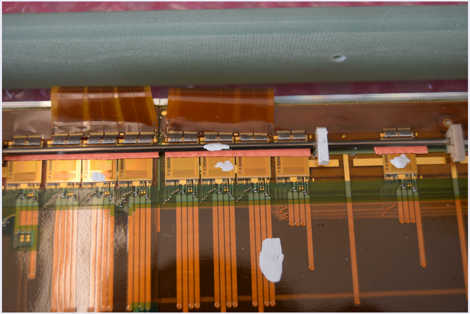
SVD Origami module



Setup of telescope for SVD X_0 measurements

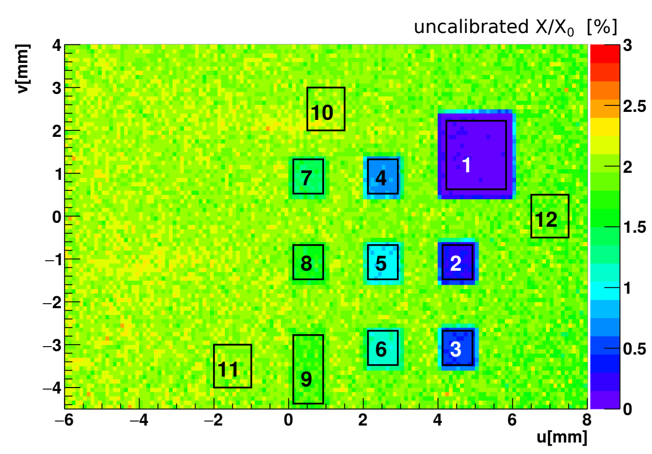
- EUDET telescope with 6 M26 planes (3 μm resolution per plane)
- Spacings chosen like this to keep the angle reco error σ_{err} small
- Measurements on 3x3 calibration metal grid and SVD Origami module

X/X_0 Measurement area



Selection of measurement areas for calibration

Run 230 to 234 (4 GeV)

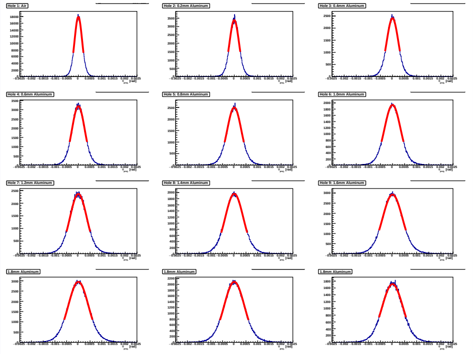


SVD Calibration @ 4 GeV (HL model)

Calibration results SVD

- Simultaneous fit of 12 multiple scattering angle distributions
- Fit results: $\lambda = 1.171 \pm 0.003$

Fitted kink angle distributions

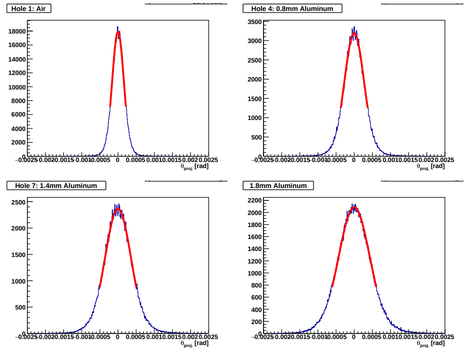


SVD Calibration @ 4 GeV (HL model)

Calibration results SVD

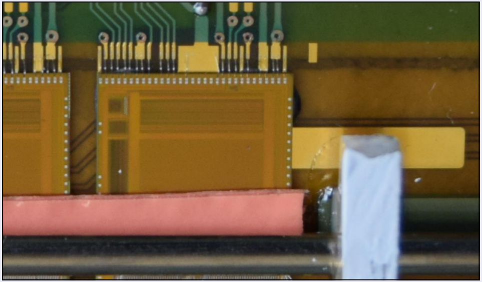
- Simultaneous fit of 12 multiple scattering angle distributions
- Fit results: $\lambda = 1.171 \pm 0.003$
- rather large value ($\lambda \approx 1.1$ typical value at DESY)

Fitted kink angle distributions

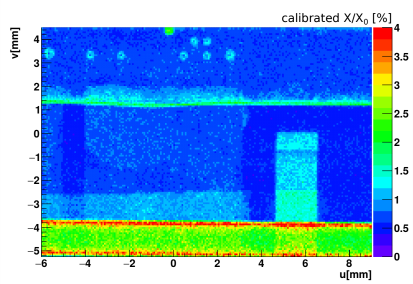


SVD X/X_0 image

photograph of SVD



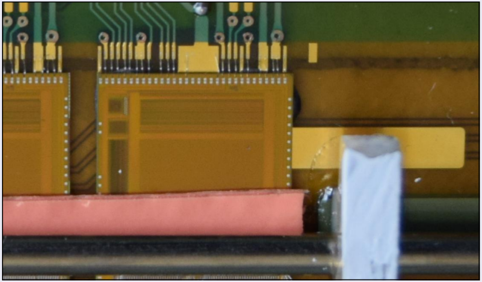
X0 image (4GeV, 75 μm^2 pixels)



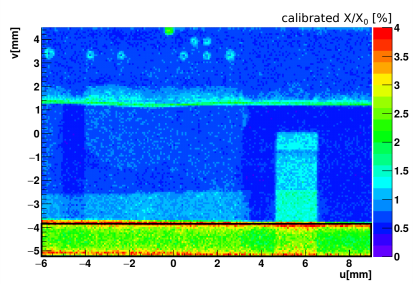
visible structures

SVD X/X_0 image

photograph of SVD



X0 image (4GeV, 75 μm^2 pixels)

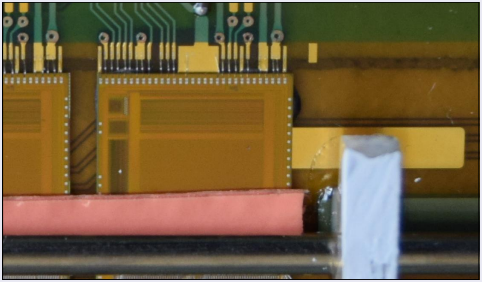


visible structures

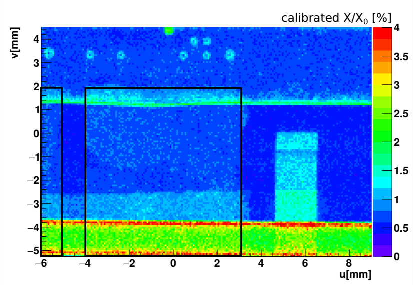
cooling pipe,

SVD X/X_0 image

photograph of SVD



X0 image (4GeV, 75 μm^2 pixels)

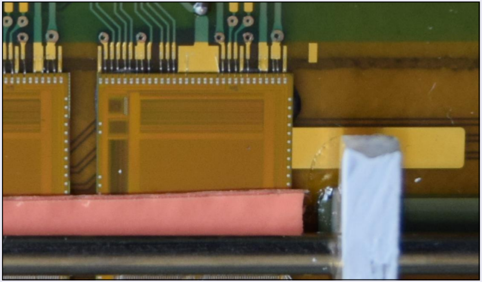


visible structures

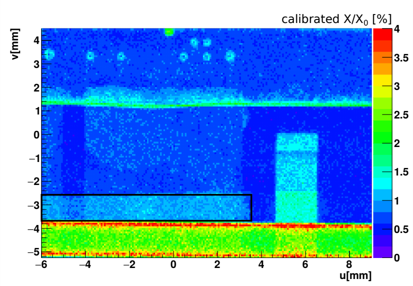
cooling pipe, APV25 chip,

SVD X/X_0 image

photograph of SVD



X0 image (4GeV, 75 μm^2 pixels)

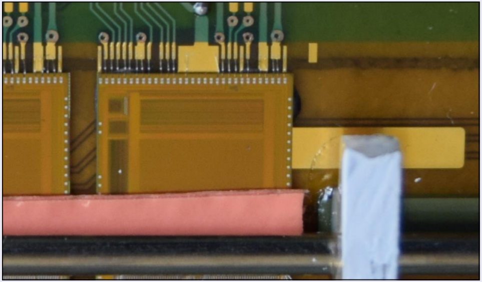


visible structures

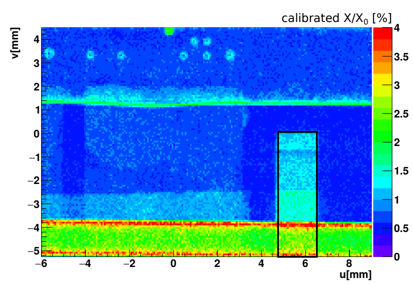
cooling pipe, APV25 chip, keratherm,

SVD X/X_0 image

photograph of SVD



X0 image (4GeV, 75 μm^2 pixels)

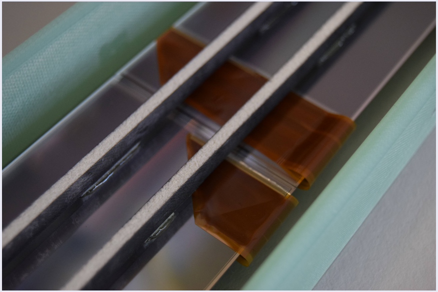


visible structures

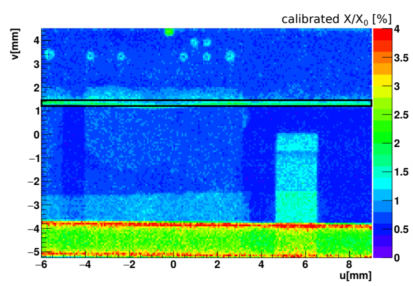
cooling pipe, APV25 chip, keratherm, plastic clamp,

SVD X/X_0 image

photograph of SVD



X0 image (4GeV, 75 μm^2 pixels)

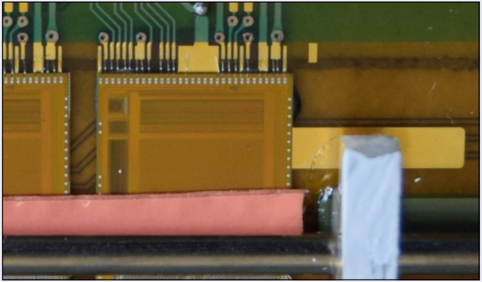


visible structures

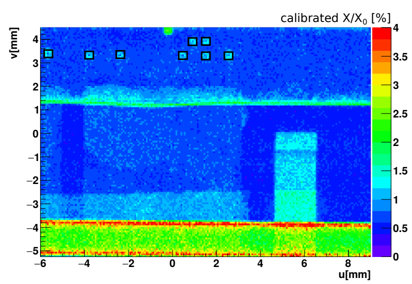
cooling pipe, APV25 chip, keratherm, plastic clamp, carbon fiber plies in edges of support structure on backside,

SVD X/X_0 image

photograph of SVD



X0 image (4GeV, 75 μm^2 pixels)

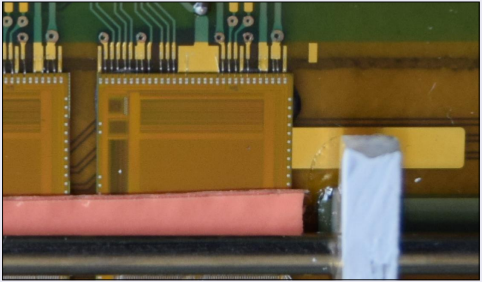


visible structures

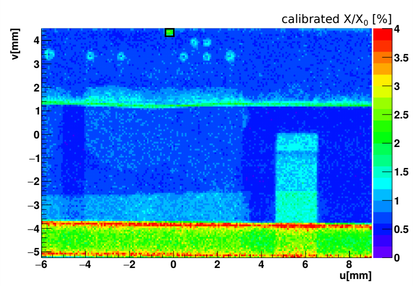
cooling pipe, APV25 chip, keratherm, plastic clamp, carbon fiber plies in edges of support structure on backside, metallizations (vias) and

SVD X/X_0 image

photograph of SVD



X0 image (4GeV, 75 μm^2 pixels)

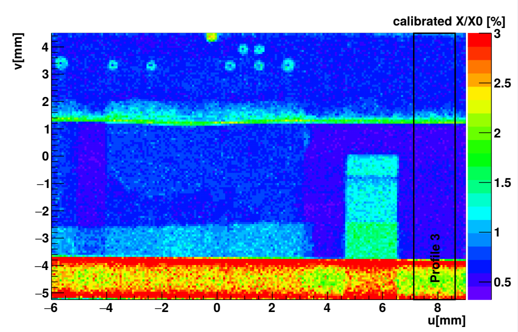


visible structures

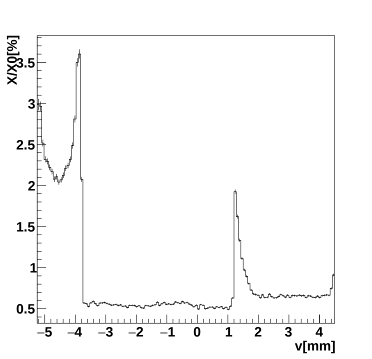
cooling pipe, APV25 chip, keratherm, plastic clamp, carbon fiber plies in edges of support structure on backside, metallizations (vias) and part of a capacity

Measurements of structures on the SVD

X0 image (4GeV, 75 μm^2 pixels)



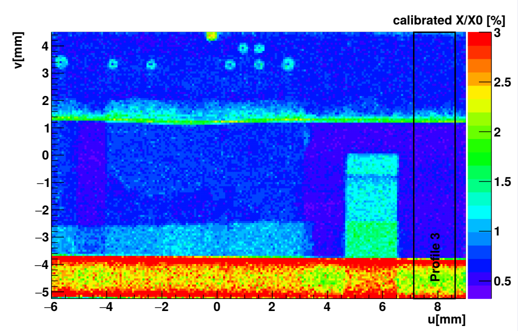
profile 3



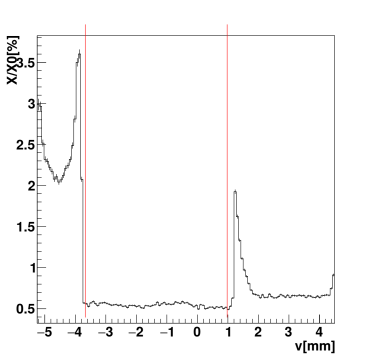
- Distance between the center of the beam pipe and the edge of support structure $\approx$ 5.5 mm
- Mechanically measured: $\approx$ 5.7 mm

Measurements of structures on the SVD

X0 image (4GeV, 75 μm^2 pixels)



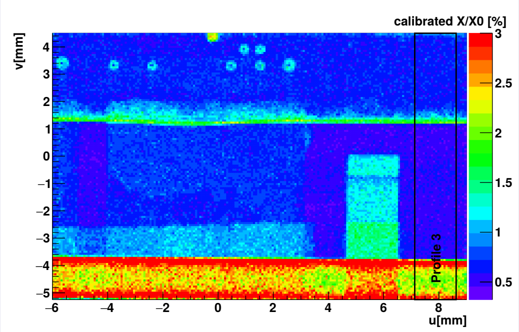
profile 3



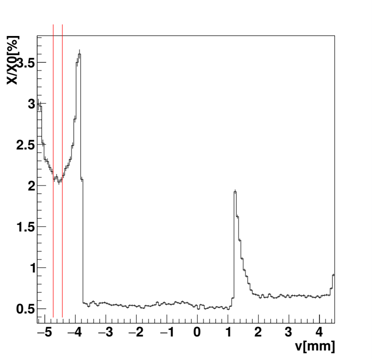
- Silicon sensor area: $(X/X_0)_{\mathrm{meas.}}$=(0.544±0.002)%
- Expected: 320 Si (0.342 %), Origami flex (≈ 0.188%), additional material budget due to glue between layers → $X/X_0 \approx 0.530\%$

Measurements of structures on the SVD

X0 image (4GeV,75 μm^2 pixels)



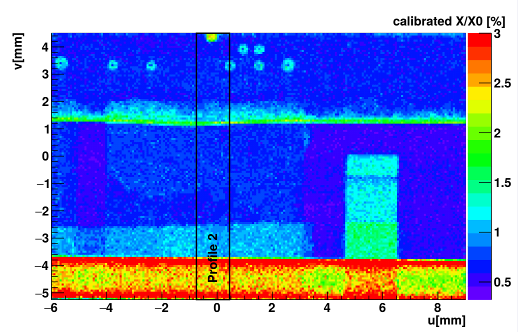
profile 3



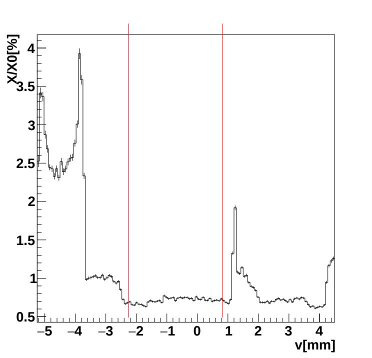
- Cooling pipe: $(X/X_0)_{\text{meas.}}$=(2.07±0.02)% in the center Substract material from sensor and origami: $(X/X_0)_{\text{pipe}}$=(1.53±0.02)%
- stainless steel → wall thickness d=(134±2)μm, ≈ 100 μm expected

Measurements of structures on the SVD

X0 image (4GeV,75 μm^2 pixels)



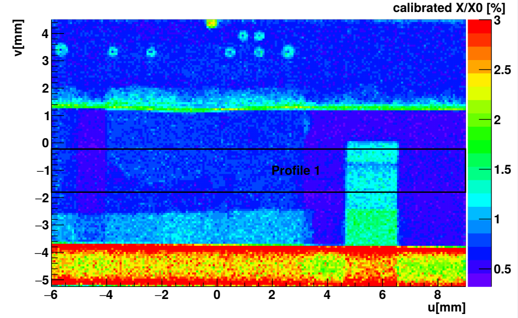
profile 2



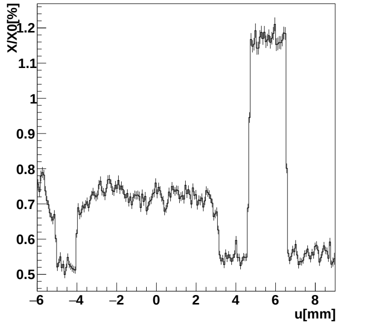
- APV25: $(X/X_0)_{\rm meas.}$=(0.713±0.002)
  $\rightarrow$ only APV: $(X/X_0)_{\rm APV}$=(0.169±0.003)%
- Expected: 100 μm Silicon and $\approx$ 9μm of Copper $\rightarrow$ $\approx$ 0.17%

Measurements of structures on the SVD

X0 image (4GeV,75 μm^2 pixels)



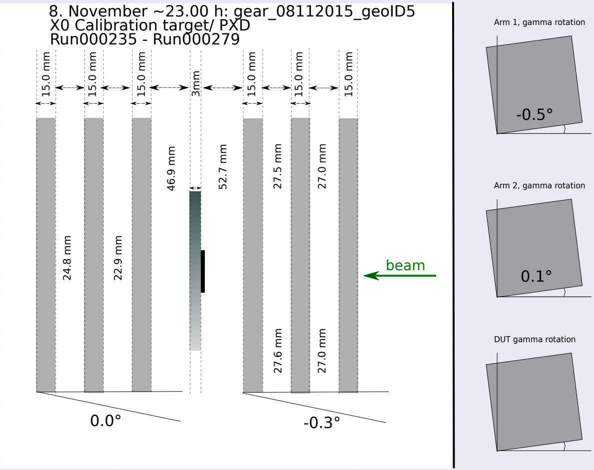
profile 1



- Distance between two neighbouring APVs ≈ 1mm (expected 1.05mm)
- Width of APVs ≈ 7 mm (expected 7.1 mm)
- Width of plastic clamp ≈ 2mm

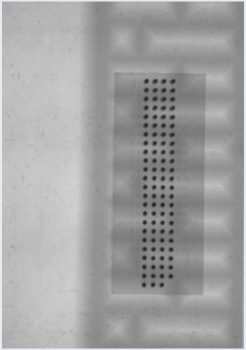
Setup of telescope for PXD X_0 measurements

schematic setup of telescope

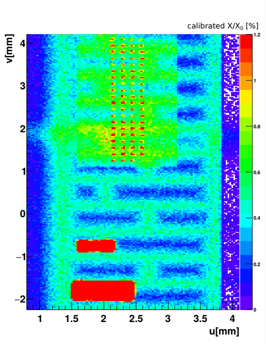


PXD X/X_0 image

X-ray of the switcher



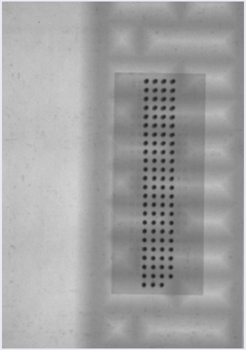
X0 image (4GeV,30 μm^2 pixels)



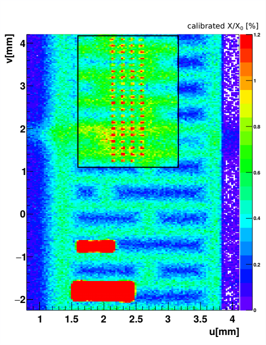
visible structures

PXD X/X_0 image

X-ray of the switcher



X0 image (4GeV,30 μm^2 pixels)

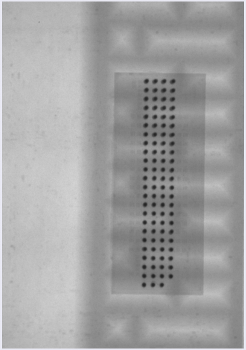


visible structures

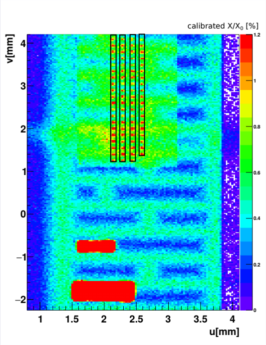
Switcher,

PXD X/X_0 image

X-ray of the switcher



X0 image (4GeV,30 μm^2 pixels)

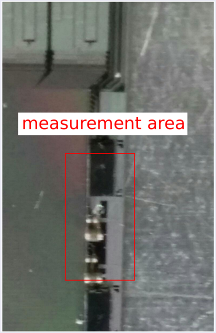


visible structures

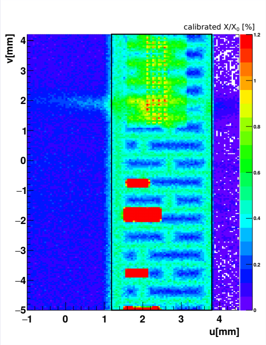
Switcher, bump bonds,

PXD X/X_0 image

photograph of SVD



X0 image (4GeV,50 μm^2 pixels)

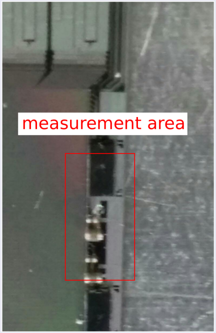


visible structures

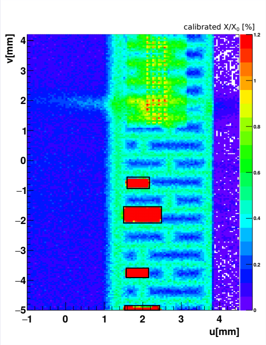
Switcher, bump bonds, balcony with grooves,

PXD X/X_0 image

photograph of SVD



X0 image (4GeV,50 μm^2 pixels)

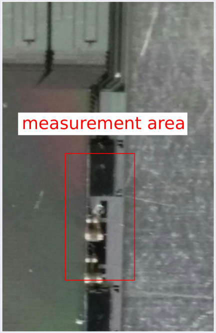


visible structures

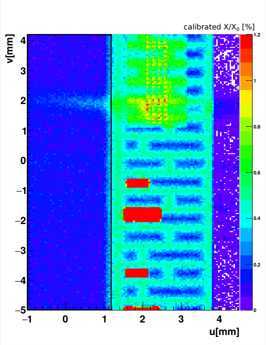
Switcher, bump bonds, balcony with grooves, capacities,

PXD X/X_0 image

photograph of SVD



X0 image (4GeV,50 μm^2 pixels)

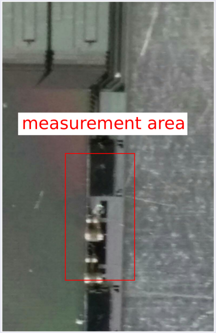


visible structures

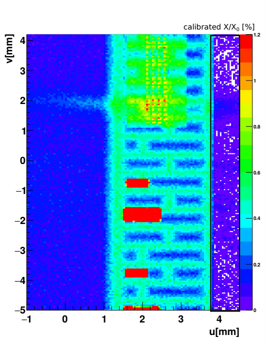
Switcher, bump bonds, balcony with grooves, capacities, sensitive area and

PXD X/X_0 image

photograph of SVD



X0 image (4GeV,50 μm^2 pixels)

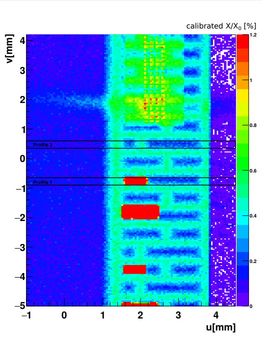


visible structures

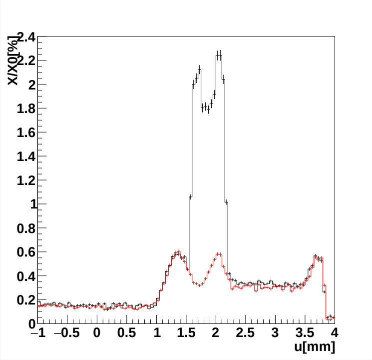
Switcher, bump bonds, balcony with grooves, capacities, sensitive area and air

Measurement of structures on the PXD

X0 image (4GeV,50 μm^2 pixels)



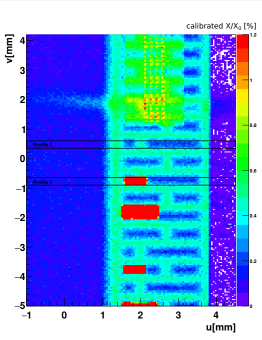
Both profiles



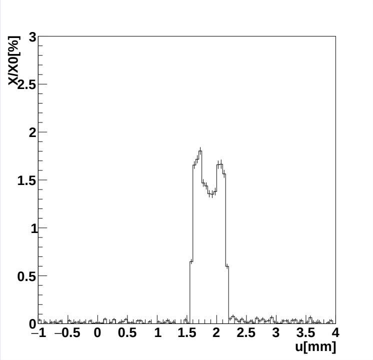
Use these two radiation length profiles to calculate the X/X_0 value of the small capacity without the influence of the groove

Measurement of structures on the PXD

X0 image (4GeV,50 μm^2 pixels)



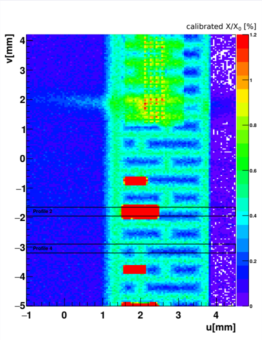
Difference between the profiles



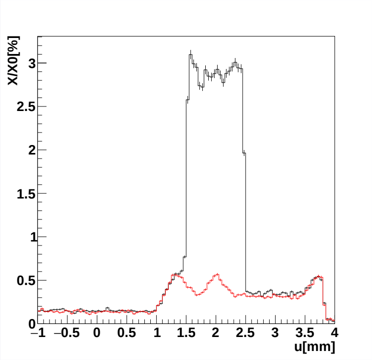
X/X_0 profile of the small capacity shows peaks at the edges: soldering material. The radiation length of the capacity itself is approx. 1.4 - 1.5 %

Measurement of structures on the PXD

X0 image (4GeV,50 μm^2 pixels)

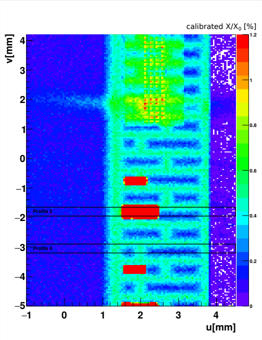


Both profiles

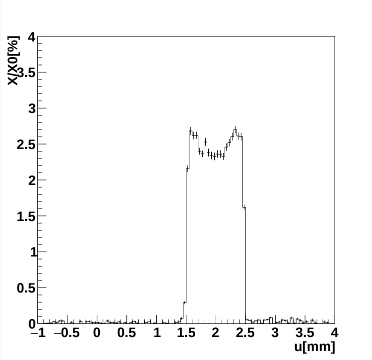


Measurement of structures on the PXD

X0 image (4GeV,50 μm^2 pixels)



Difference between the profiles



X/X_0 peaks at the edges for the large capacity as well. The radiation length of the capacity itself is approx. 2.3 - 2.4 %

Conclusion and Outlook

Conclusion

- X/X_0 measurements on SVD and PXD modules mostly consistent with expected material budget
- Still large systematical effects, indicated by large calibration factor λ, main issues: (Target-) Alignment, especially z-alignment, M26 digital effects
- In the PXD case: Statistics large enough (more than 100 mio tracks) for 30 $\mu\mathrm{m}^2$ pixels in X_0 image

Conclusion and Outlook

Outlook

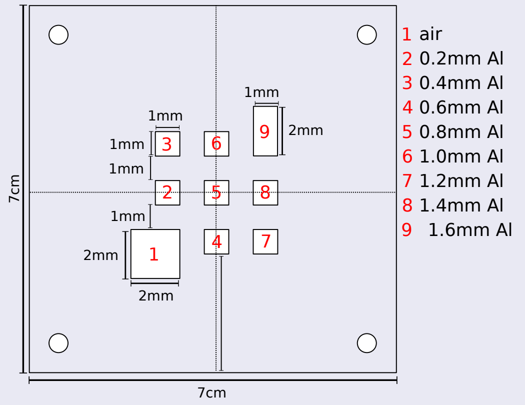
- Simulation studies of target misalignment
- Comparison between the currently employed detector model and a more detailed one with respect to tracking
  $\rightarrow$ What is the effect on the tracking procedure, when averaging the material budget of small structures? Is this effect relevant?

Thank you!

Backup Slides

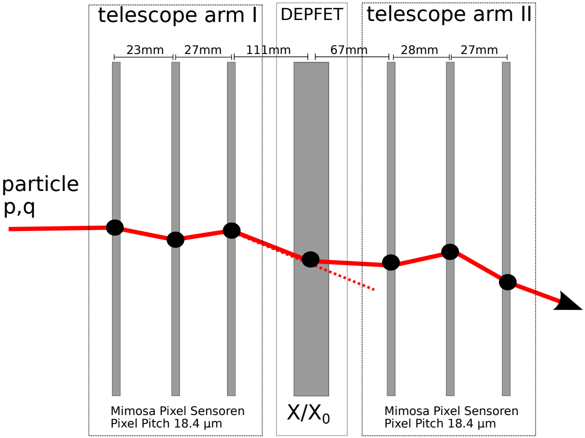
Aluminum grid

- 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



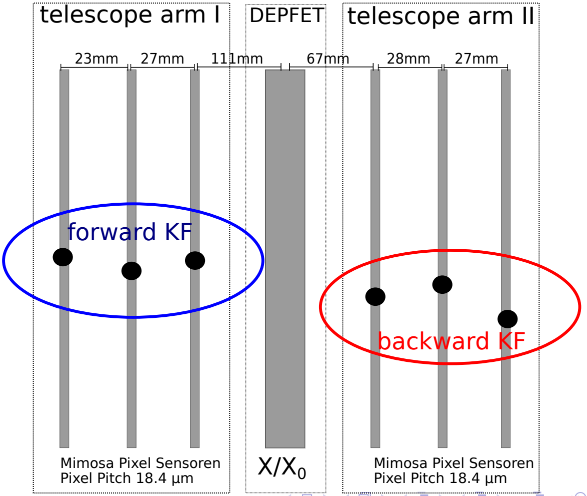
Reconstruction of MSC angles in a EUDET teleskop

- Reconstruct angles on the DEPFET
- Particle crosses sensor $\rightarrow$ hits



Reconstruction of MSC angles in a EUDET teleskop

- Reconstruct angles on the DEPFET
- Particle crosses sensor $\rightarrow$ hits
- Forward- backward Kalman Filter (KF) pair on hits
- hit on DEPFET not needed $\rightarrow X/X_0$ images
- Take MSC in air gaps into account



Reconstruction of MSC angles in a EUDET teleskop

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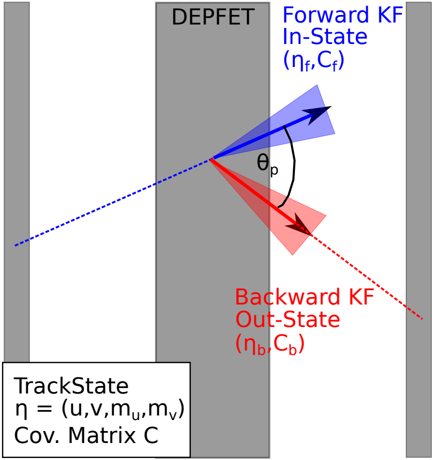
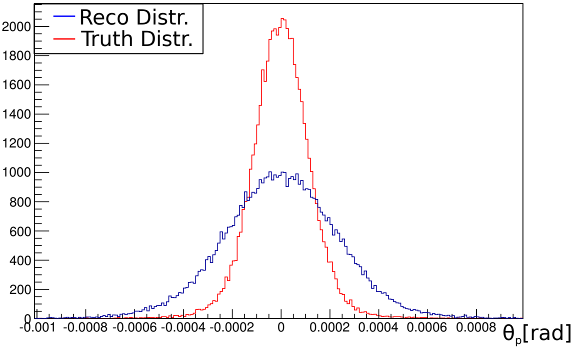
- Take MSC in air gaps into account
- θ_p calculated from (m_u, m_v)
- Reco error σ_{reco} from error propagation



Example of a reconstructed angle distribution

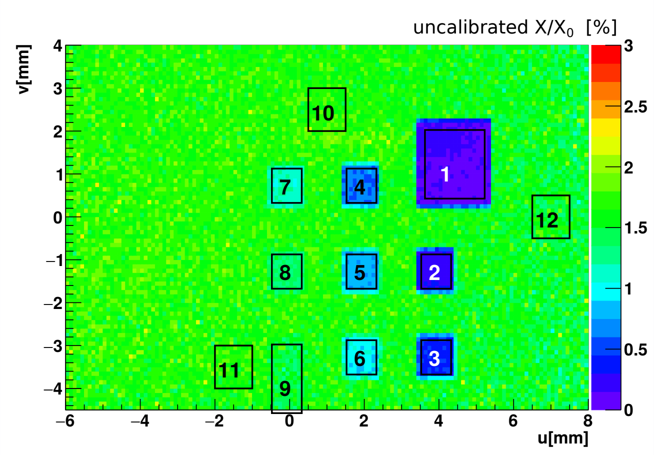


Composition of the Reco Distribution

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

Selection of measurement areas

Run 237 and 238 (4 GeV)

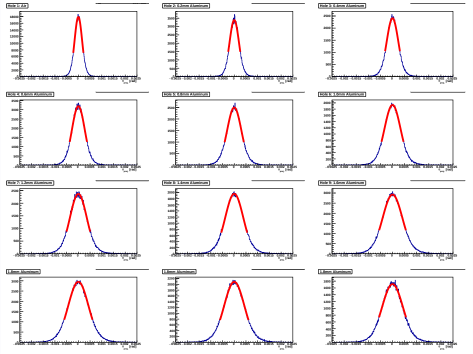


PXD Calibration @ 4 GeV (HL model)

Calibration results PXD

- Fit results:
  $\lambda = 1.1521 \pm 0.003$

Fitted kink angle distributions

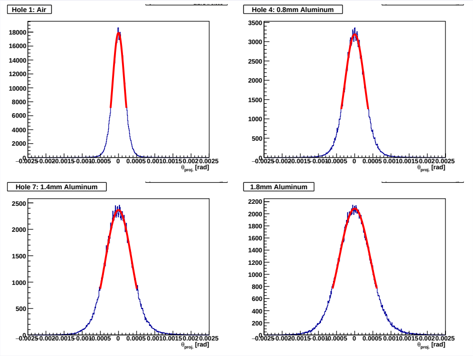


PXD Calibration @ 4 GeV (HL model)

Calibration results PXD

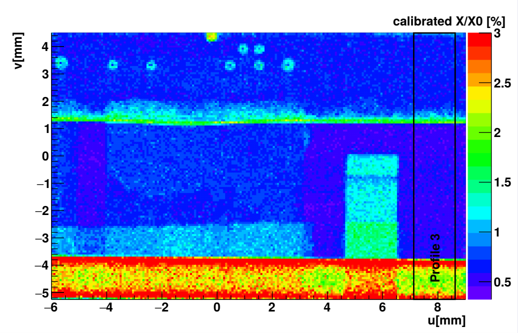
- Fit results:
  $\lambda = 1.1521 \pm 0.003$
- also quite large, but smaller than the calibration for the SVD geometry

Fitted kink angle distributions

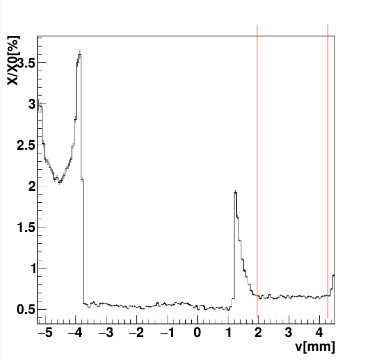


Additional SVD measurements

X0 image (4GeV,75 $\mu\mathrm{m}^2$ pixels)



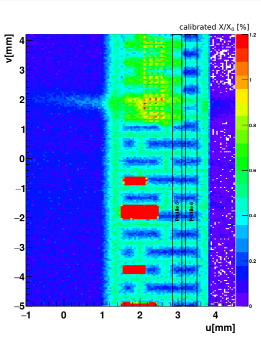
profile 3



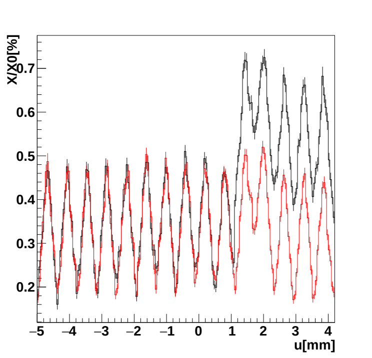
Effects of Airex core material in the support rips on the backside:
$(X/X_0)_{\mathrm{meas.}}$=0.653±0.002%, only airex core:
$(X/X_0)_{\mathrm{airex}}$=((0.653-0.544)±0.003) %=(0.109±0.003)%

Additional PXD measurements

X0 image (4GeV,50 μm^2 pixels)



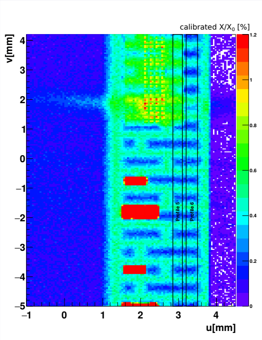
Both profiles



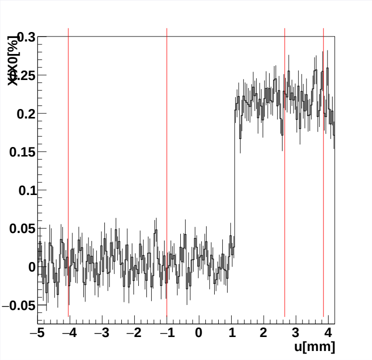
Use these two radiation length profiles to calculate the X/X_0 value of the switcher chip without the influence of the grooves

Additional PXD measurements

X0 image (4GeV,50 μm^2 pixels)



Difference between two profiles

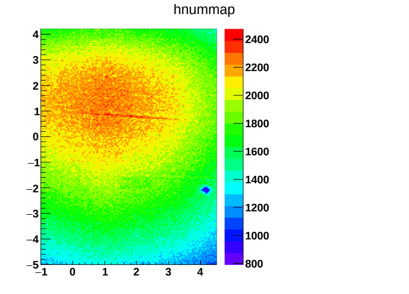


Switcher: $(X/X_0)_{\text{meas.}} = 0.220 \pm 0.004$ %

Expected ≈ 300 μm of Silicon: $(X/X_0)_{\text{Switcher}} = 0.33\%$

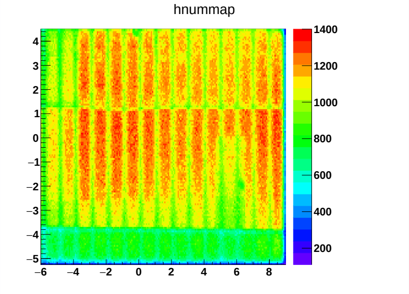
Number of tracks per pixel

Number of tracks PXD image (4GeV,50 $\mu\mathrm{m}^2$ pixels)



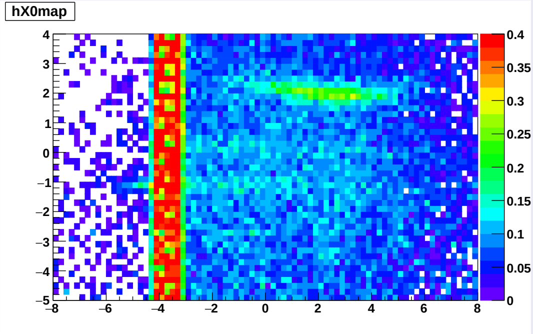
Number of tracks per pixel

Number of tracks SVD image (4GeV,75 μm^2 pixels)



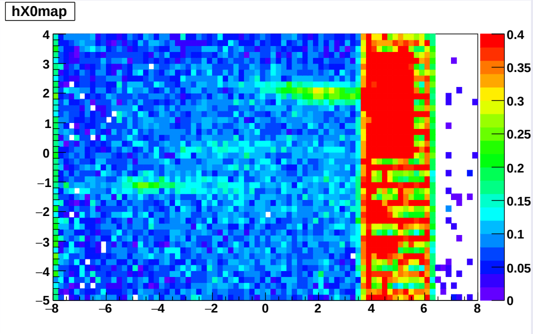
Strange structures independent of PXD position

PXD position1



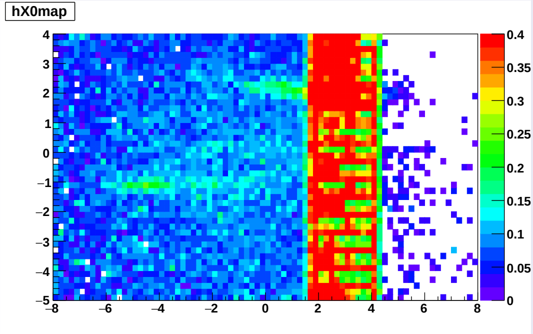
Strange structures independent of PXD position

PXD position2



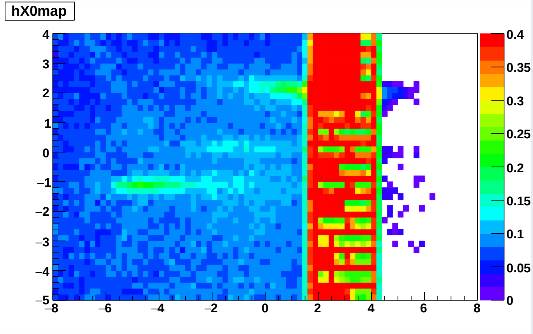
Strange structures independent of PXD position

PXD position3



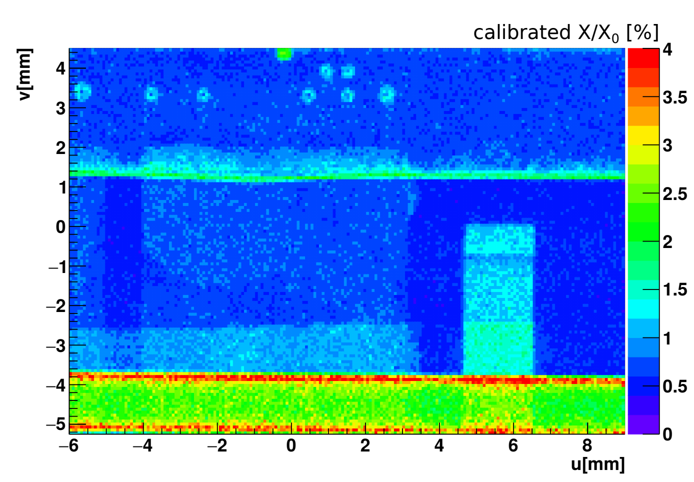
Strange structures independent of PXD position

PXD position3, higher statistic



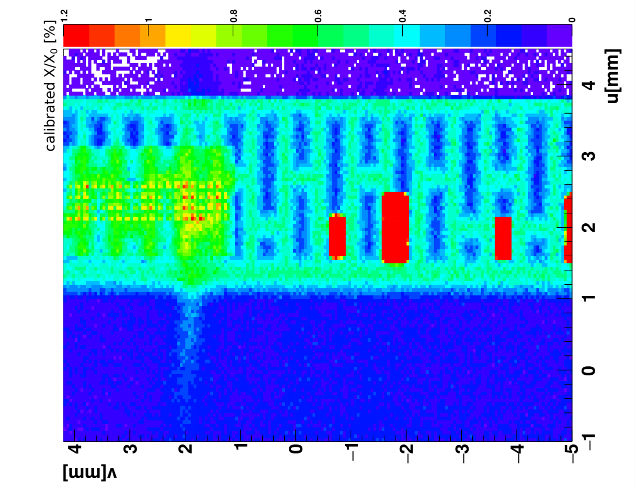
Full-sized images

SVD, 75 μm



Full-sized images

PXD, 50 μm



Full-sized images

PXD, 30 μm