X/X_0 measurements at the CERN SPS test beam 2014

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X/X_0 Measurement at CERN

first step: Calibration on metal grid

- calibrated angle reconstruction error ${\sigma^*}_{\text{err}} = \lambda \cdot \sigma_{\text{err}}$, λ: calibration factor
- core width of multiple scattering (MSC) projected angle distribution is then given by

$$\sigma = \sqrt{{\sigma_{\text{measured}}}^2 - \lambda^2 \cdot {\sigma_{\text{err}}}^2}$$

- Calculate $X/X_0(\sigma)$ by using an appropriate MSC model
- optimize λ by comparing the measured values to the grid

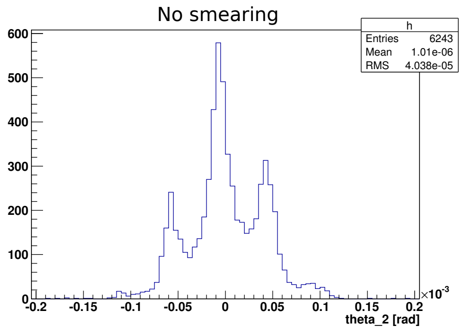
second step: Measurement on DEPFET

- Use this optimal λ in the DEPFET X/X_0 measurements

X/X_0 analysis issues at CERN I

Peaks in kink angle distributions

Caused by digital readout of M26 pixels and discretization of hit position



effects dependent on:

- width of the MSC angle distribution $\rightarrow$ beam energy
- telescope setup
- (γ) misalignment of the telescope planes
- size of the measurement area

X/X_0 analysis issues at CERN I

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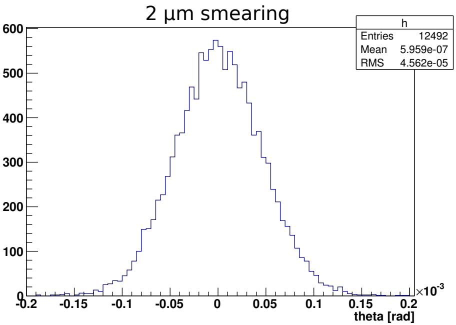


effects reduced by:

- merging distributions of both projected angles
- adding artificial gaussian noise to the reco hit position (smearing)

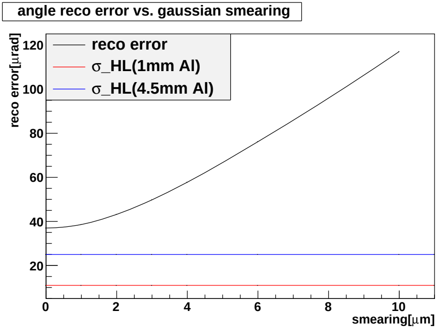
X/X_0 analysis issues at CERN II

Effects of adding artificial noise

The addition of gaussian noise also increases the covariances of the hit position. This effectively worsens the spatial and kink angle resolution.

General problem at CERN: $\sigma/\sigma_{\text{err}}$ is very small

- σ_{err} should be of the same order as σ $\rightarrow$ smearing ≥ 4 shouldn't be used
- smearing of $\approx 2\mu$m seems to be a good choice



MSC models

Highland (HL) model

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

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

Frühwirth model

$$\sigma = \sqrt{\mu_2(d')} \cdot \sqrt{(0.851 + 0.0331 \ln d' - 0.001825(\ln d')^2)} \qquad (2)$$

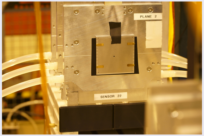
$$\text{with} \quad \sqrt{\mu_2(d')} = \sqrt{225 \cdot 10^{-6} \cdot d'/p^2}, \; d' = \frac{X}{h(Z) \cdot X_0}$$

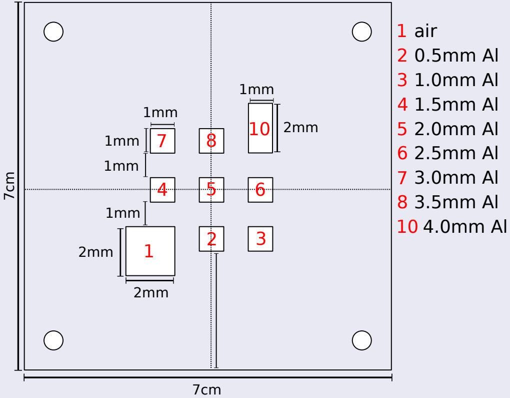
$$\text{and} \quad h(Z) = \frac{Z+1}{Z} \cdot \frac{\ln(287\, Z^{-1/2})}{\ln(159\, Z^{-1/3})}$$

R. Frühwirth,Nuclear Instruments and Methods, 2001

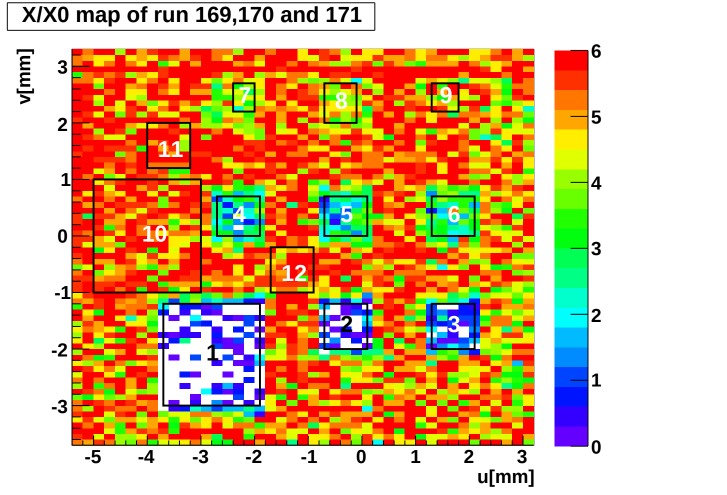
Aluminum grid

- 0.5 mm thick aluminum layers, with different hole configurations
- taped to M26 frame
- increase of material budget by 0.56 % per hole



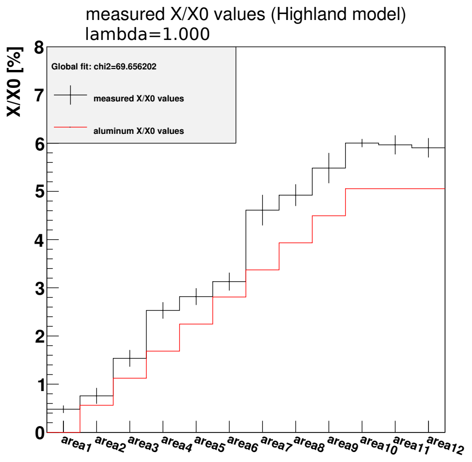


Selection of measurement areas



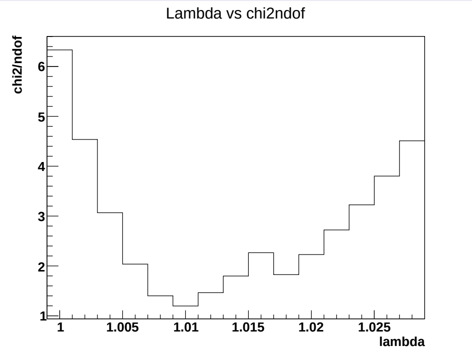
Calibration (HL model)

- Comparison between measured and real X/X_0 values via χ^2 test



Calibration (HL model)

- Comparison between measured and real X/X_0 values via χ^2 test
- best fit: $\lambda = 1.010 \pm 0.002$



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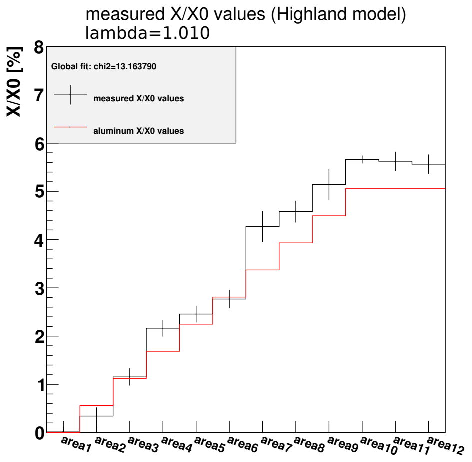
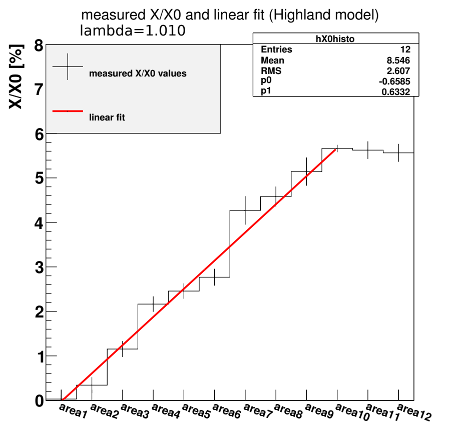


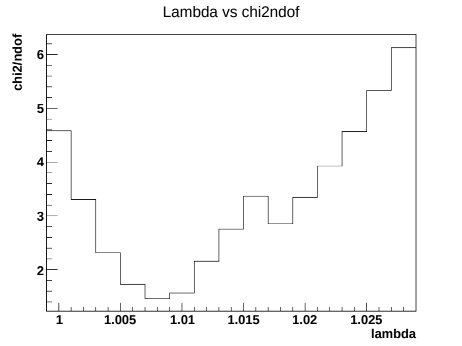
Calibration (HL model)

- Comparison between measured and real X/X_0 values via χ^2 test
- best fit: $\lambda = 1.010 \pm 0.002$
- but linear fit: slope=$(0.63 \pm 0.01)\%$ $\rightarrow$ too large
- $\rightarrow$ Use Frühwirth model



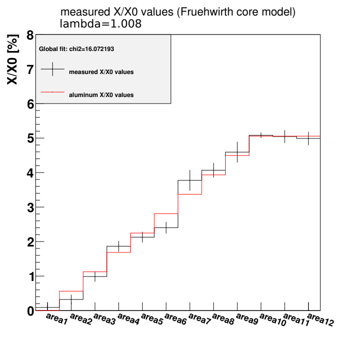
Calibration (Frühwirth model)

- best fit:
  $\lambda = 1.008 \pm 0.002$



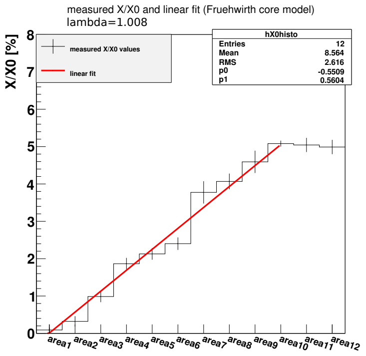
Calibration (Frühwirth model)

- best fit:
  $\lambda = 1.008 \pm 0.002$
- large X/X_0 difference for area 3 $\rightarrow$ 4 and area 6 $\rightarrow$ 7



Calibration (Frühwirth model)

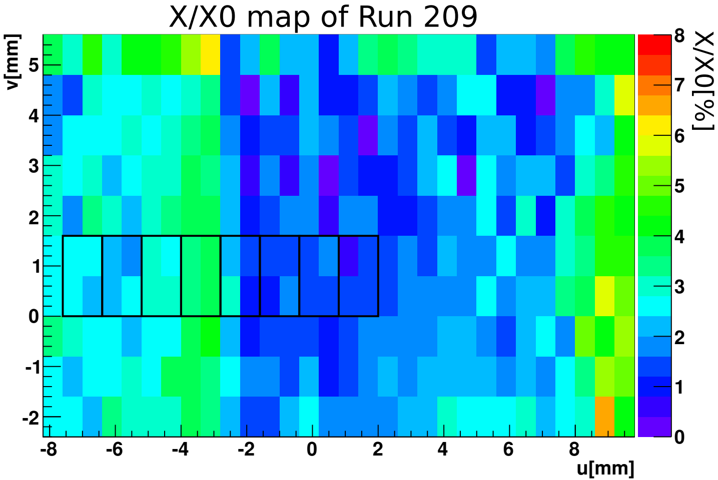
- best fit: $\lambda = 1.008 \pm 0.002$
- large X/X_0 difference for area 3 $\rightarrow$ 4 and area 6 $\rightarrow$ 7
- Linear fit: slope=$(0.56 \pm 0.01)\%$ $\rightarrow$ very close to expected value



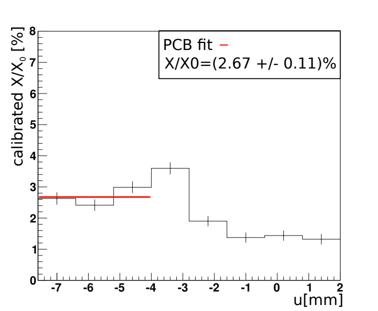
Calibration results

Use this MSC model and λ=1.008±0.002 for further X/X_0 analysis

X/X_0 map of Run 209



Preliminary DEPFET X/X_0 measurements



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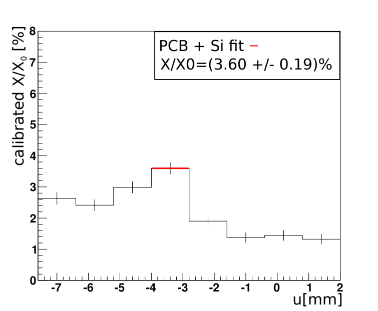

thick Si X/X_0

$X/X_0(\text{thickSi}) = 0.93 \pm 0.22\%$

expected: 0.45 %

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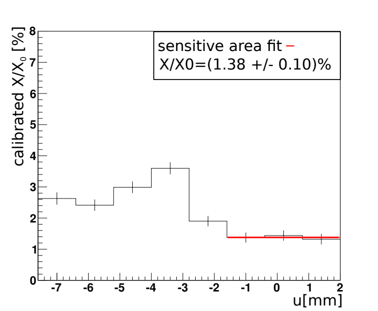

thick Si X/X_0

X/X_0(thickSi) $= 0.93 \pm 0.22\%$
expected: 0.45 %

X/X_0 difference

X/X_0(PCB-thinSI) $= 1.29 \pm 0.15\%$
expected: $\approx$ 1.4-1.5 %

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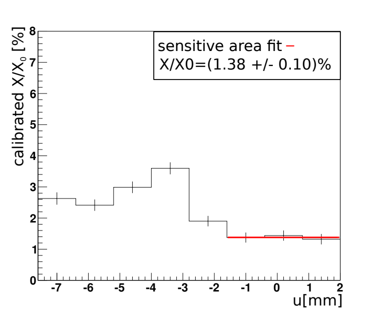

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Conclusion and Outlook

Conclusion

- Radiation length resolution of $\Delta X/X_0 = 0.1$ % using bins of $(500\ \mu m)^2$ at a beam energy of 120 GeV
- Calibration via aluminum grid works well, differences between Highland and more sophisticated MSC models can be seen
- Main problem of X/X_0 analysis at CERN: Gaps in kink angle distributions caused by digital readout of M26 telescope sensors
- gaussian smearing of the hit position is a temporary solution of this problem

Conclusion and Outlook

Outlook

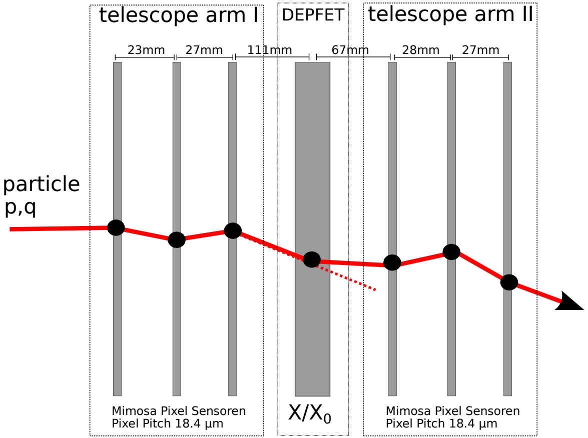
- gaussian smearing of hit position worsens the angle resolution and should be eventually replaced by another procedure
  $\rightarrow$ more detailed study of the effects of digital readout
- calibration measurements can be used to study difference between MSC models
- Reapeat calibration measurements at lower beam energies of 3-4 GeV (DESY) $\rightarrow$ $\Delta X/X_0$ will get even smaller

Thanks for your attention!

Backup Slides

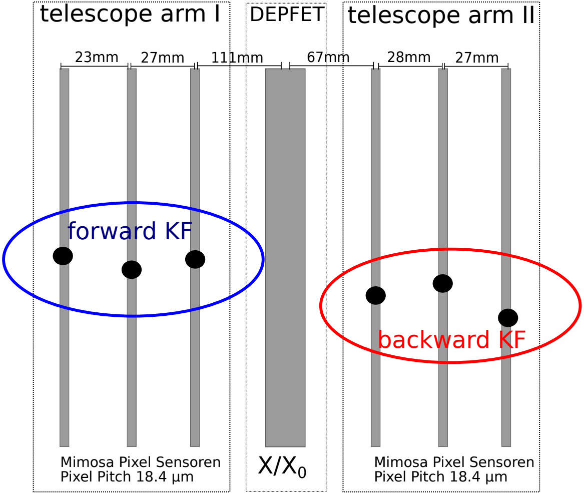
Reconstruction of MSC angles in a EUDET teleskop

- Reconstruct angles on the DEPFET
- Particle crosses sensor → hits



Reconstruction of MSC angles in a EUDET teleskop

- Reconstruct angles on the DEPFET
- Particle crosses sensor → hits
- Forward- backward Kalman Filter (KF) pair on hits
- hit on DEPFET not needed → maps
- Take MSC in air gaps into account



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- Particle crosses sensor $\rightarrow$ hits
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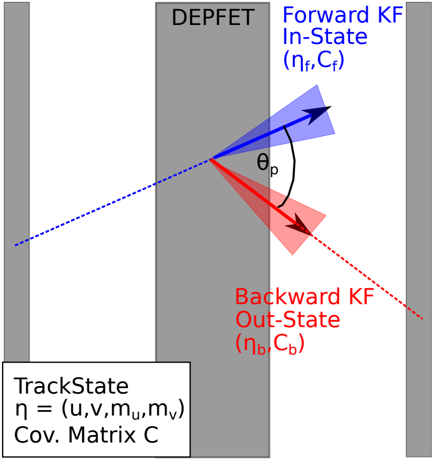
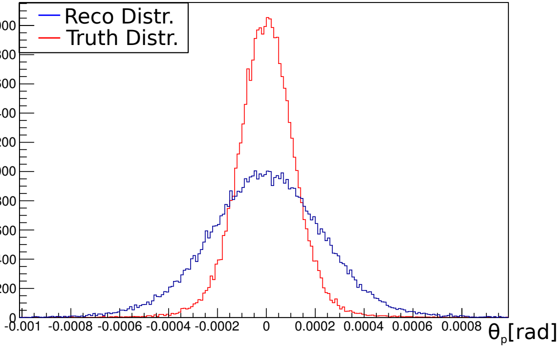
- Take MSC in air gaps into account
- θ_p calculated from (m_u, m_v)
- Reco error σ_{reco} from error propagation



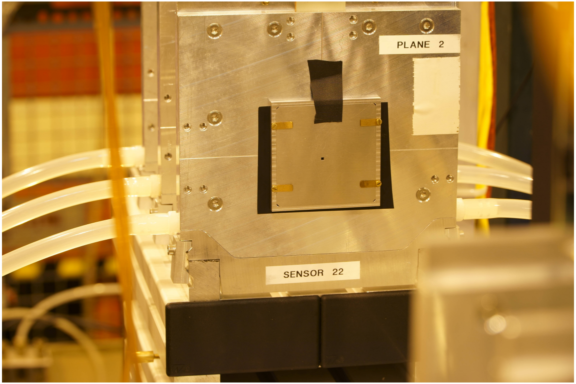
Example of a reconstructed angle distribution



Composition of the Reco Distribution

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

alu grid pictures



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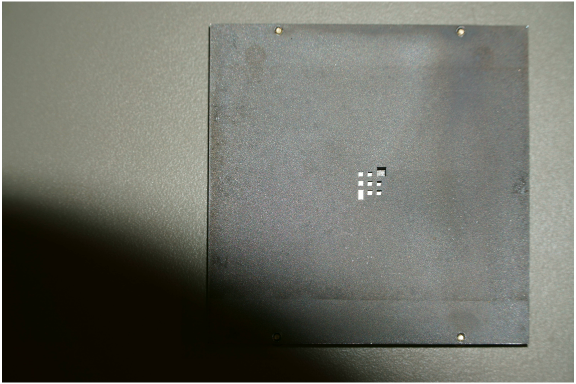
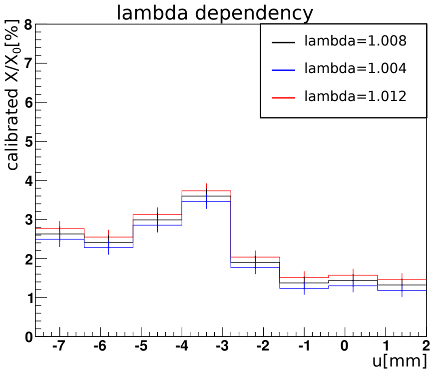
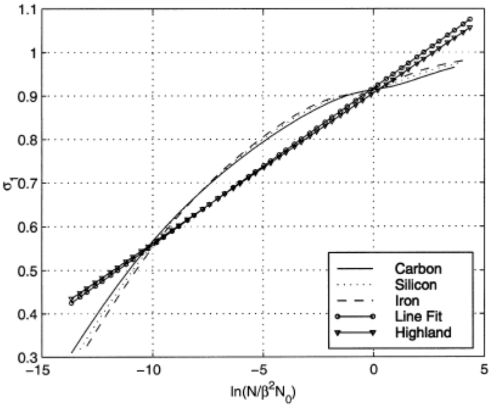


λ dependency of X/X_0 measurement



Small deviations from real calibration factor can have large effects on X/X_0 measurements

multiple scattering models



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