Prospects of X/X_0 measurements at the CERN SPS test beam

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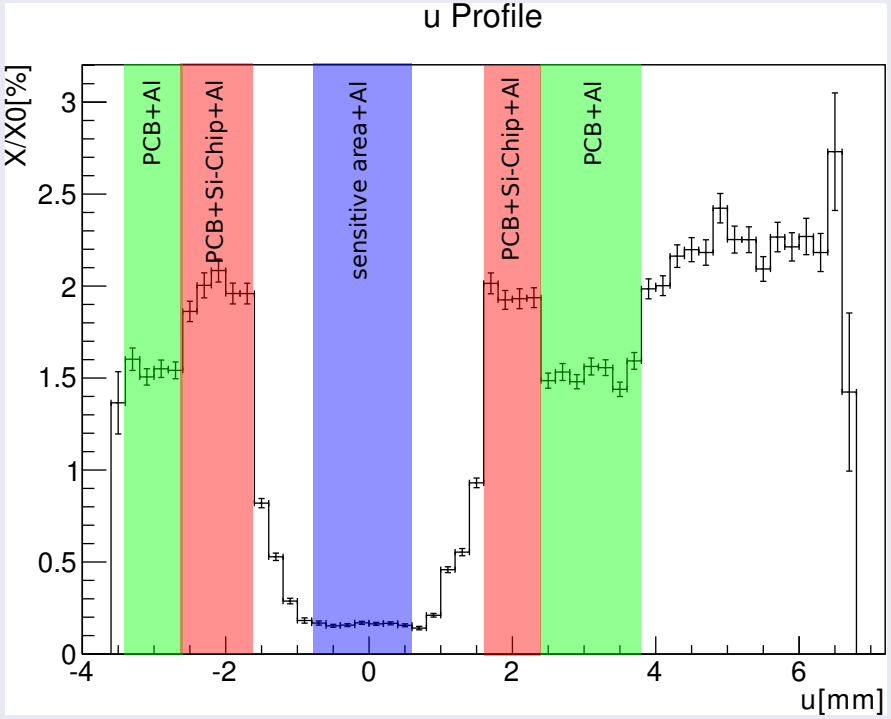
X/X_0 Measurement at CERN



- X/X_0 measurements with errors below 10 % at DESY, but does it also work at CERN SPS test beams?
- Main problem at CERN: small MSC distributions due to high beam energy

- But: Better angular resolution than at DESY
- What setup and beam energy should be used? And what angular resolution can be achieved in the best case?

Multiple scattering

Highland Formula(only small scattering angles)

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

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

CERN SPS, 120 GeV pions

- 150μm Si: σ_{HL}=3.4 μrad
- 100mm air: σ_{HL}=1.4 μrad
- 5mm alu: σ_{HL}=23.9 μrad

DESY, 4 GeV electrons

- 150μm Si: σ_{HL}=102.7 μrad
- 100mm air: σ_{HL}=42.8 μrad
- 5mm alu: σ_{HL}=717 μrad

Multiple scattering

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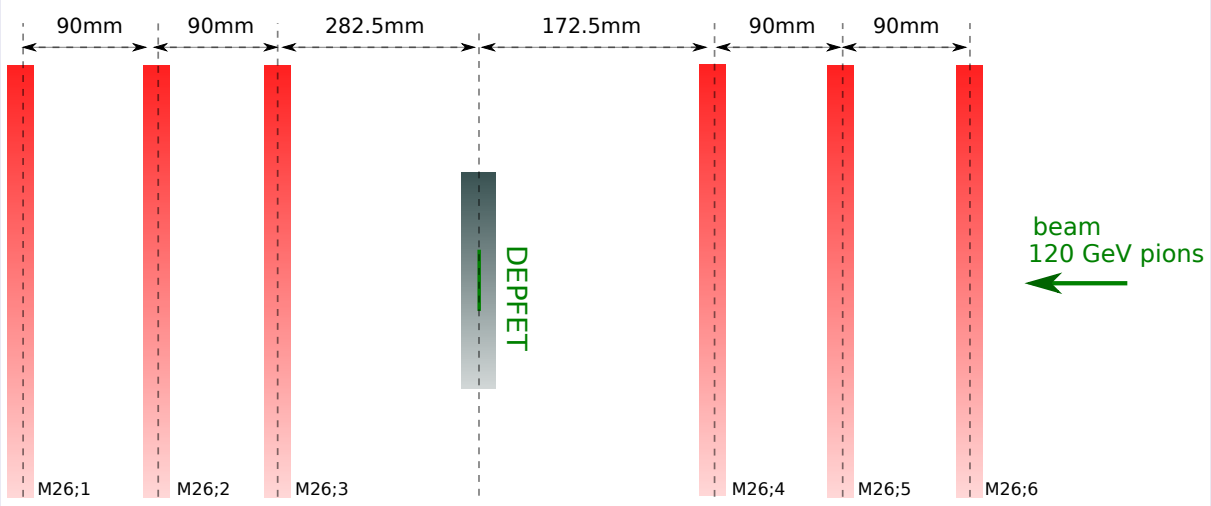
Consequences for MSC studies at CERN

- The MSC distribution on the central plane is very narrow
- Angle reconstruction error ($\widehat{=}$ telescope angular resolution) must be small and known extremely precisely

MC Simu Telescope setup

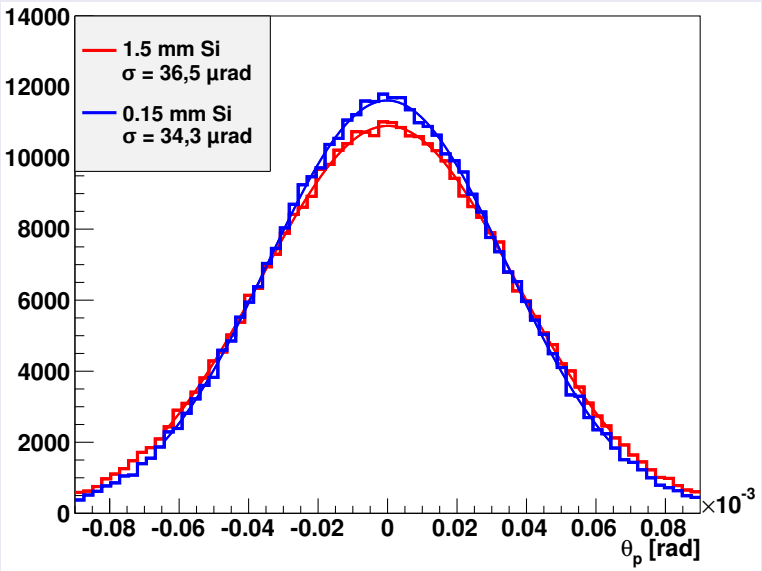


Angular resolution of this setup

- Setup of CERN Test Beam in October 2012
- $\sigma_{\mathrm{reco}} = 33.7\ \mu$rad for 120 GeV pions (without calibration)
- Typical angular resolution at DESY: 190 μrad

Example of reconstructed angle distributions

1.5 mm Si and 0.15 mm Si MSC angle distributions



- Distributions insensitive to (even large) X/X_0 changes
- $\sigma_{\mathrm{total}} = \sqrt{(\sigma_{\mathrm{reco}})^2 + (\sigma_{\mathrm{HL}})^2}$
- Problem: Both distributions completely dominated by angular resolution

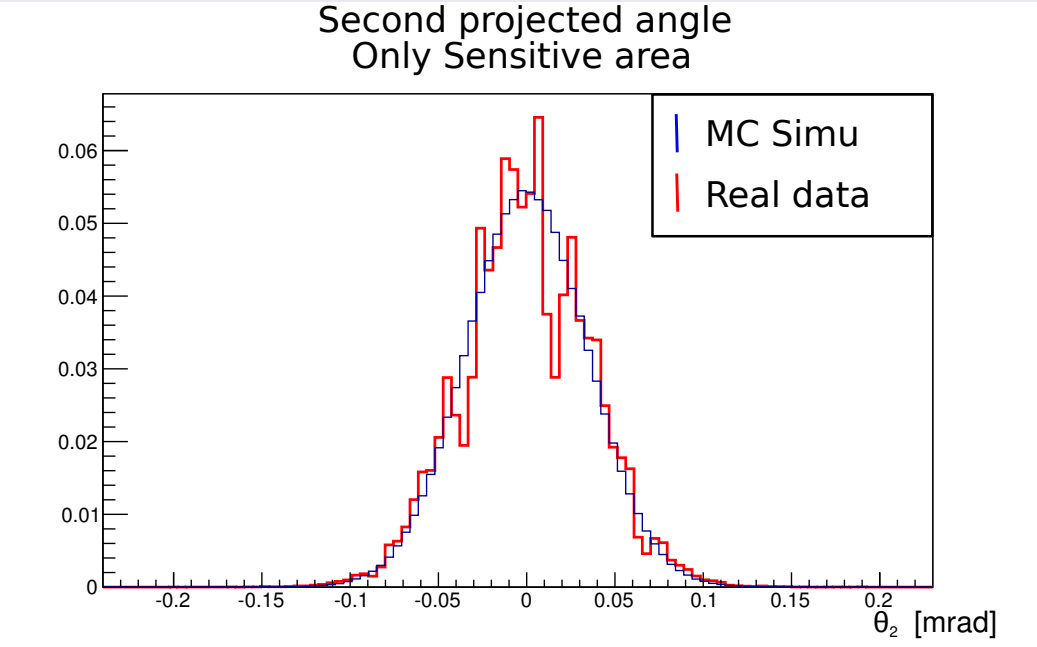
Solution

- Setup must be optimized to reduce influence of angular resolution
- Alternatively: Use thicker target materials or reduce beam energy

MSC angle distributions of Test Beam Run 73407

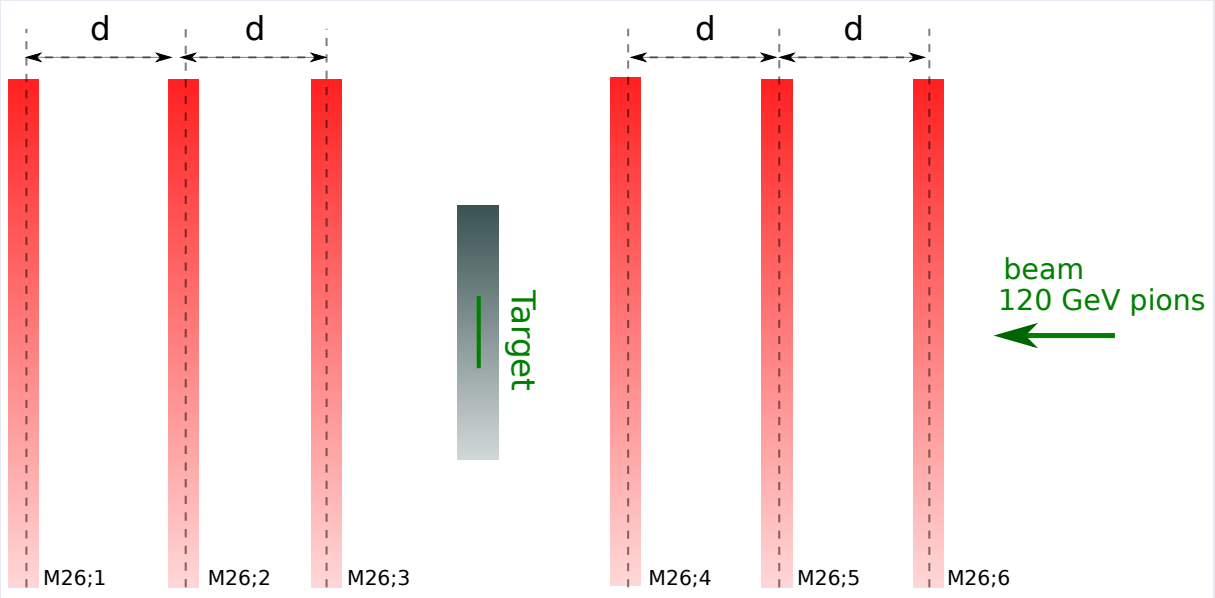
- October 2012 CERN TB setup $\rightarrow \approx$ 90 mm gaps between sensors
- Angular resolution: $\sigma_{\text{reco}}^{\text{exp.}} = 33.7\mu\text{rad}$

Comparison between MC Simulation and real data



- basic shapes of mc and data distributions are compatible
- But: Strange fluctuations in data distribution
- caused by misalignment?

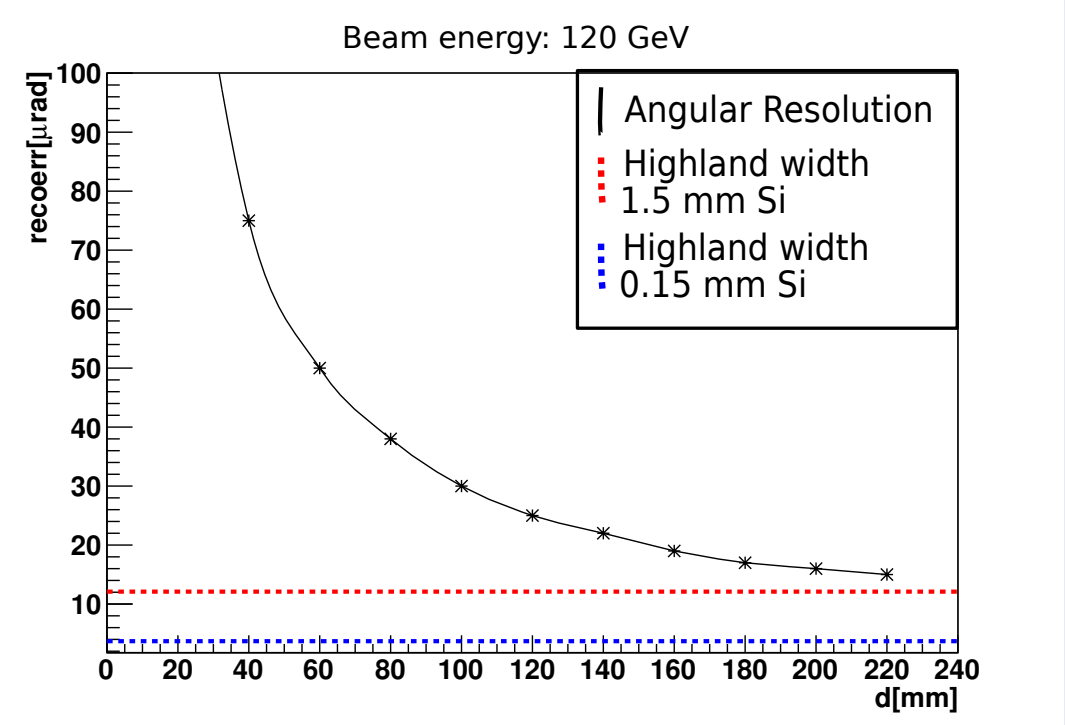
Optimal Setup for CERN SPS Test Beams



Telescope Setup

- Vary distance d between the M26 sensors
- max distance between Mimosas at CERN: $\approx$ 15 cm

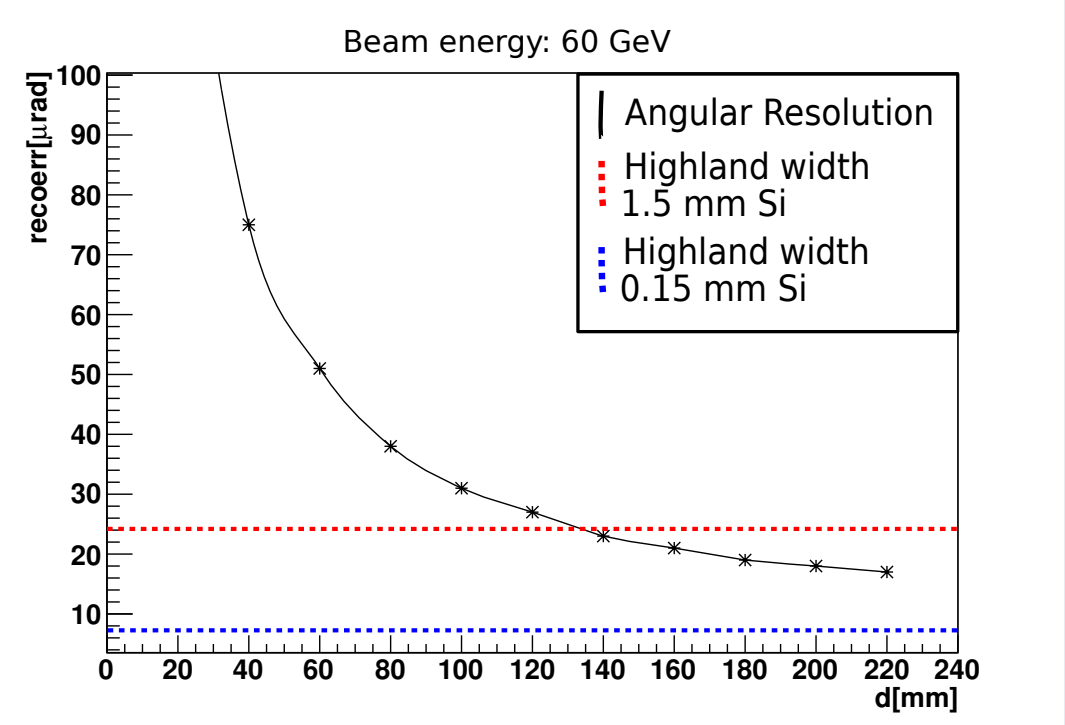
Optimal Setup for CERN SPS Test Beams



Optimal Setup at CERN TB

- Choose gaps as large as possible to optimize the telescope resolution
- Maximal realistic gap size: 15 cm $\rightarrow \sigma_{\mathrm{reco}} = 20.6\ \mu$rad

Optimal Setup for CERN SPS Test Beams



Optimal Setup at CERN TB

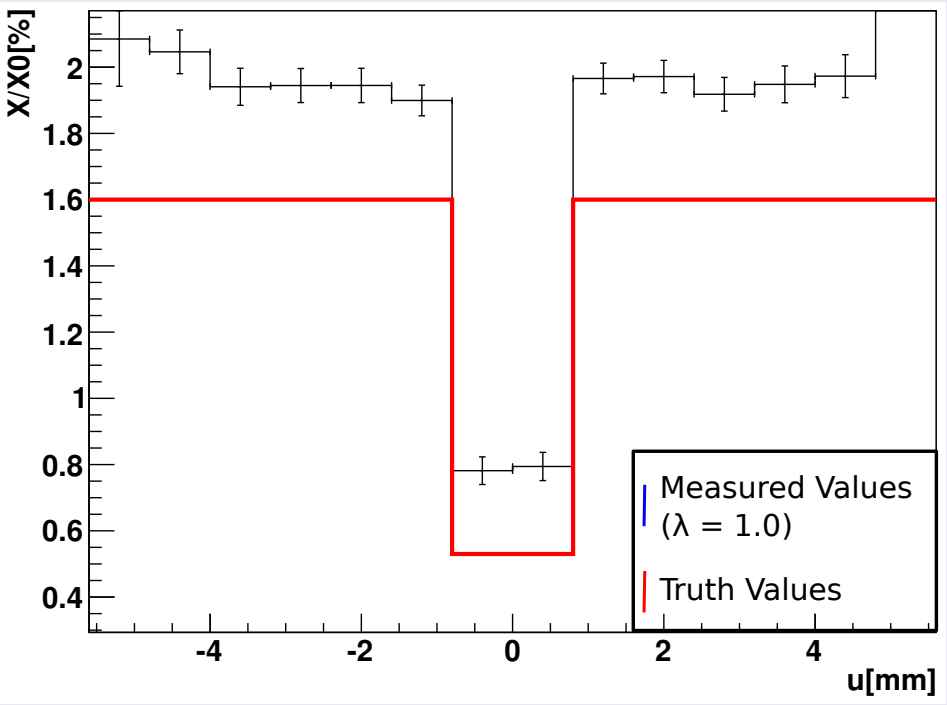
- If possible beam energy should be reduced → larger σ_{HL} values
- $\sigma_{\mathrm{reco}} = 22.2\ \mu$rad at 60 GeV and d=15cm

Calibration of the angular resolution

Calibration factor λ, $\sigma_{\mathrm{reco}} = \lambda \cdot \sigma_{\mathrm{reco}}^{\mathrm{exp.}}$

λ contains the influence of all systematical errors on the telescope angular resolution, for example errors due to neglecting MSC tails in the tracking

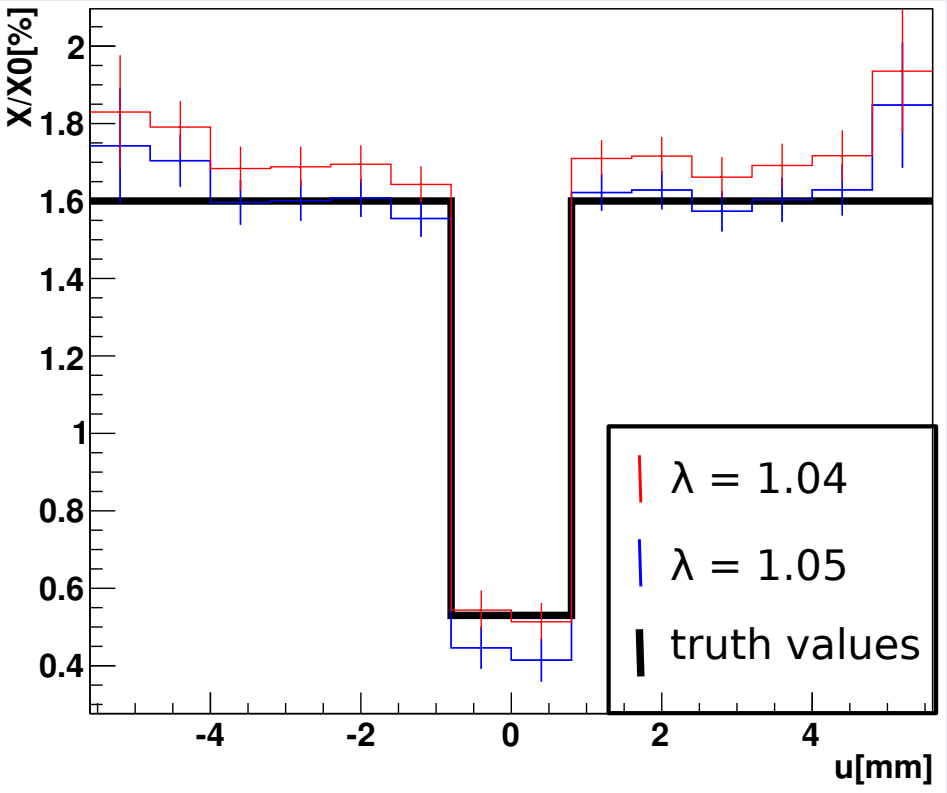
Radiation length u Profile for optimal setup (d=15cm, p=120GeV), simulation



- $\lambda = 1.0$
  $\rightarrow \sigma_{\mathrm{reco}} = 20.6 \mu\mathrm{rad}$
- 0.5 mm of Silicon between u=-0.8mm and u=0.8mm and 1.5 mm Si on the outside
- Radiation length is overestimated

Calibration of the angular resolution II

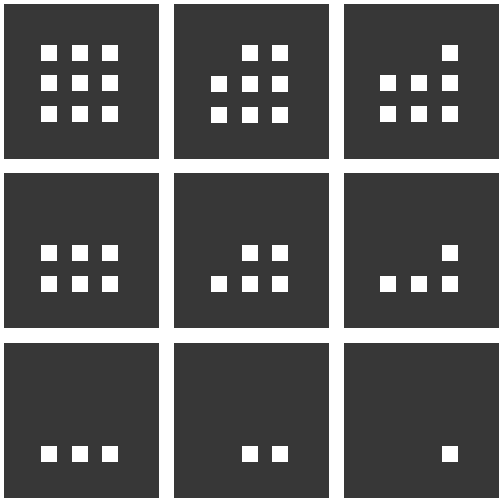
λ= 1.05 and λ=1.04 profile comparison



- statistical error of $\Delta X/X_0 \approx 0.05\%$
- Changing λ from 1.04 to 1.05 causes a 0.1 % X/X_0 change in this setup
- λ must be known up to a few permil to ensure a precise measurement

Alu target for calibration

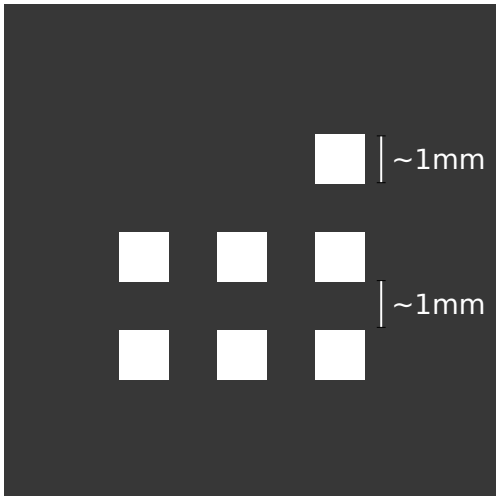
- Target consisting of 9 aluminum layers with different configurations of a 3×3 hole array in each layer



A very similar target has already been used at DESY for X/X_0 measurements

Alu target for calibration

- Target consisting of 9 aluminum layers with different configurations of a 3×3 hole array in each layer
- rectangular holes with ≈ 1mm side length
- distance between holes also ≈ 1mm



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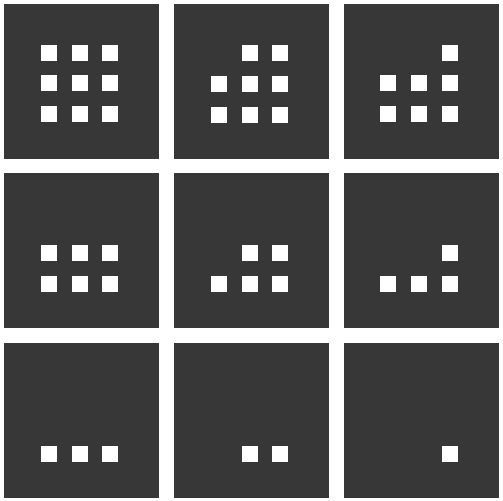

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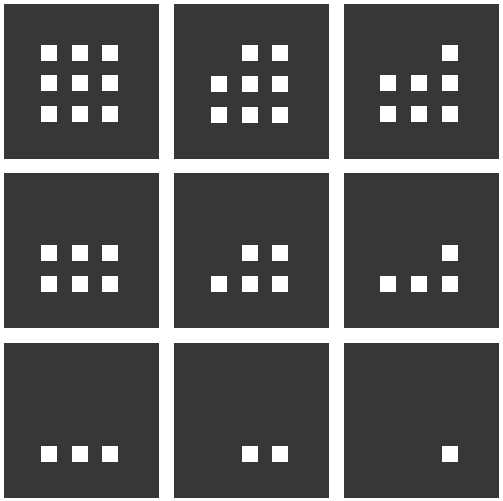
- Target consisting of 9 aluminum layers with different configurations of a 3×3 hole array in each layer
- rectangular holes with ≈ 1mm side length
- distance between holes also ≈ 1mm
- Thickness of layers should between 0.5 mm and 1 mm
- Position of target doesn't have a large effect on angle reconstruction
  → Attach alu target to inner M26 sensor



A very similar target has already been used at DESY for X/X_0 measurements

Conclusion

To optimize the X/X_0 measurement:

- Use large distances between M26 sensors (max distance ≈15 cm at CERN)
- Use lowest possible beam energy (if possible ≈ 60 GeV)
- Do calibration measurements with an aluminum target including a thickness profile

PXD6 Measurement

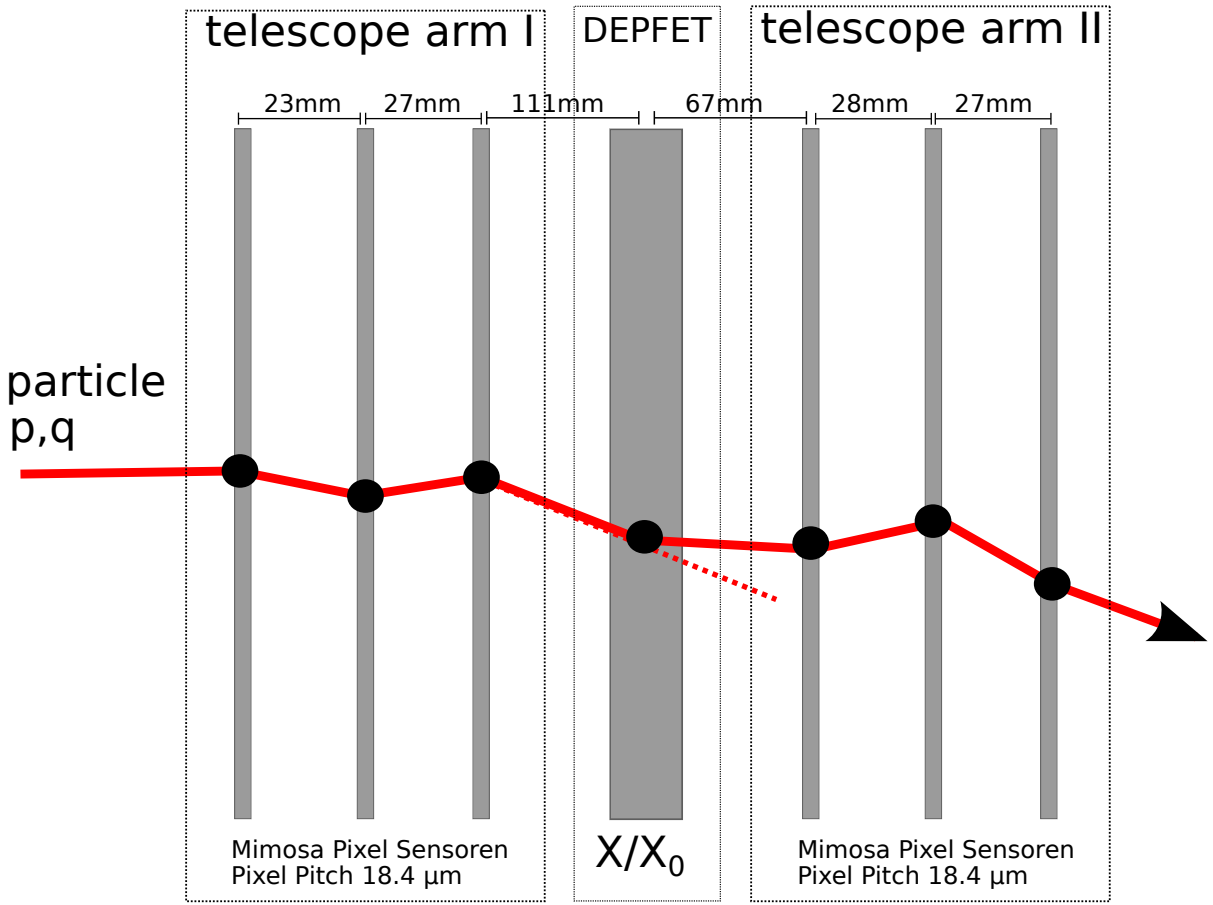
We plan to do a spatial resolved measurement of a PXD6 module including some of the surrounding ASICs

Thank you
for your attention!

Back Up Slides

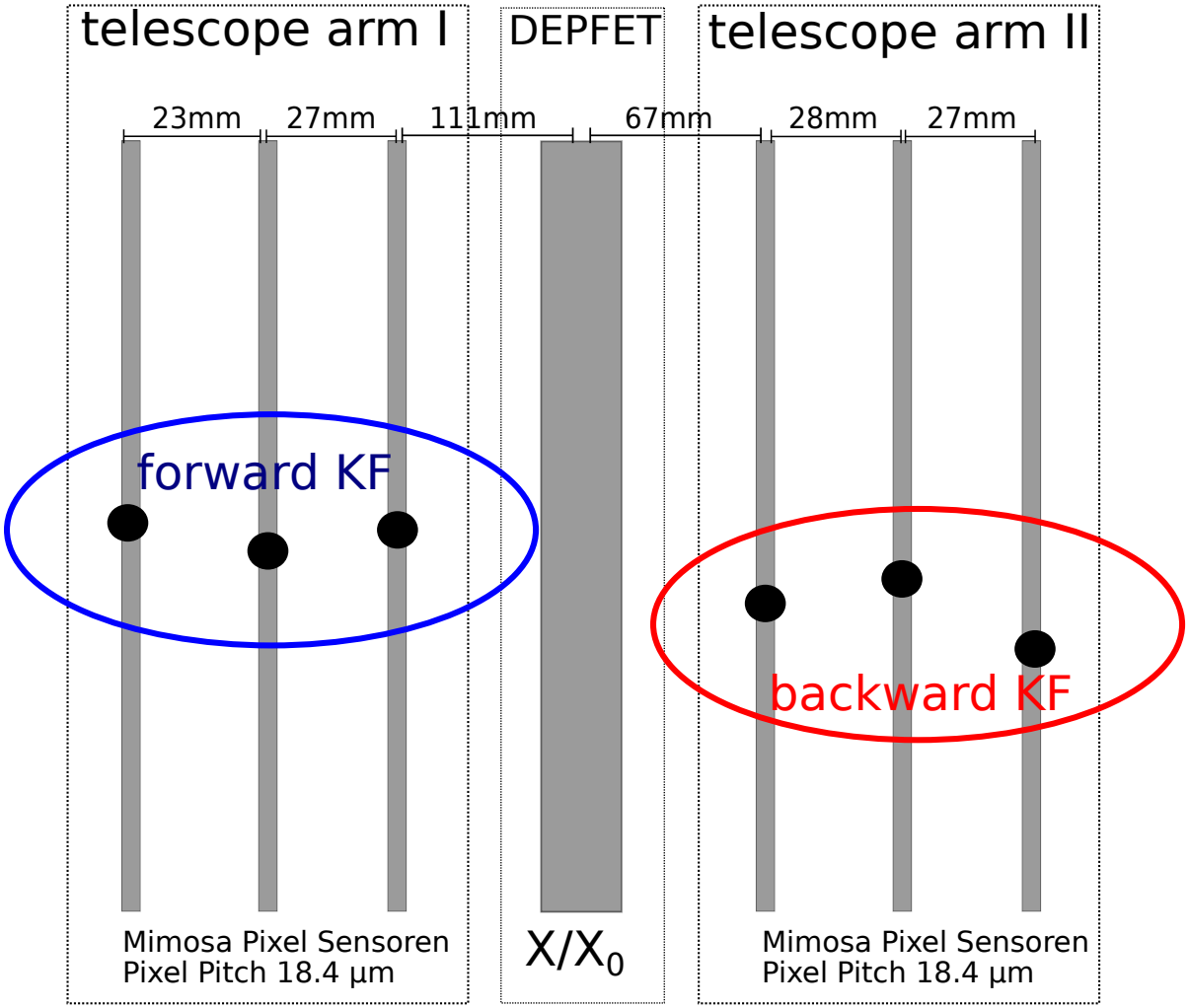
Reconstruction of MSC angles in a EUDET telescope

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



Reconstruction of MSC angles in a EUDET telescope

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



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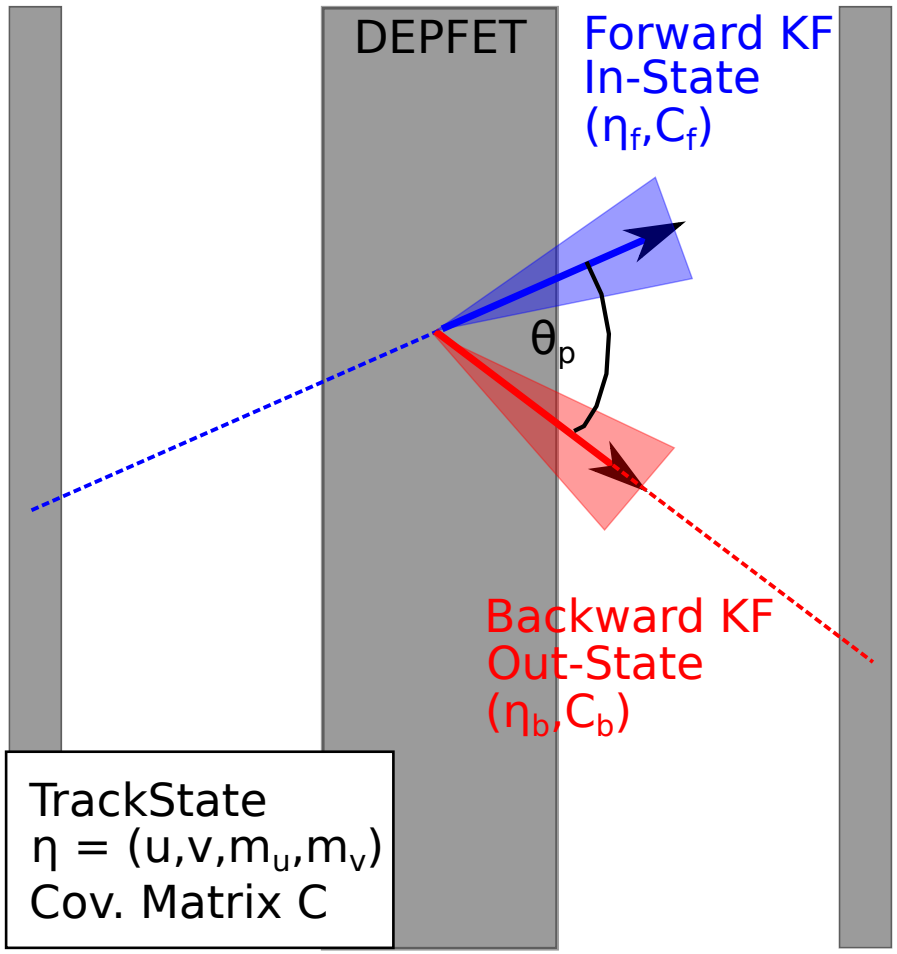
- θ_p calculated from (m_u, m_v)
- Reco error σ_{reco} from error propagation



Forward and Backward KF

Forward KF

- gives In-State
- prediction of track state on sensor i+1 based on tracks state i

$$\begin{aligned} \eta_{i+1} &= F_{i\to i+1}\eta_i \\ V_{i+1} &= F_{i\to i+1}V_iF^{\mathrm{T}}_{i\to i+1} \\ &+ Q_{\mathrm{F;i}} \end{aligned}$$

Backward KF

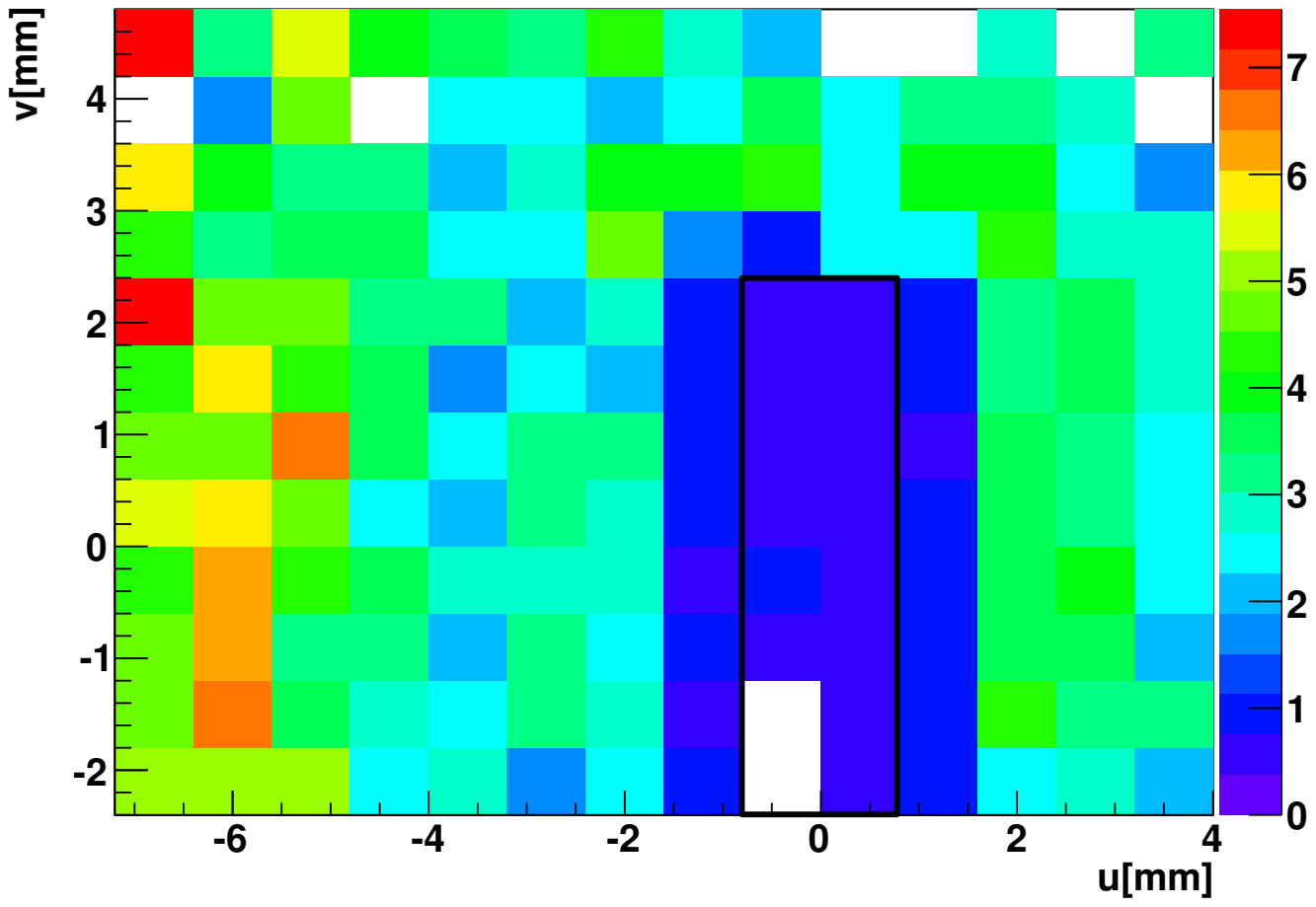
- gives Out-State
- prediction of track state on sensor i based on tracks state i+1

$$\begin{aligned} \eta_i &= F_{i+1\to i}\eta_{i+1} \\ V_i &= F_{i+1\to i}V_{i+1}F^{\mathrm{T}}{}_{i+1\to i} \\ &+ Q_{\mathrm{B};i+1} \end{aligned}$$

- F: Extrapolation matrix
- Q: MSC effects

DEPFET Hybrid 4 Map

H4 module, p=120 GeV



Results of 4 different configurations

sensor distance 9cm, p=120GeV

- $\sigma_{\mathrm{reco}}^{\mathrm{exp.}} = 33.7\mu$rad
- $\sigma_{\mathrm{HL}}(0.5\mathrm{mm\,Si})$=6.6 μrad
- $\sigma_{\mathrm{HL}}(1.5\mathrm{mm\,Si})$=12.1 μrad
- reliable measurement of 1.5 mm of Silicon possible

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- $\sigma_{\mathrm{HL}}(0.5\mathrm{mm\,Si})$=13.3 μrad
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