Update on X_0 imaging of Belle II modules

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September 10th 2015, 8th Belle II VXD Workshop

Measurements of Belle II asics

Motivation

- Low material budget is an essential part of the belle II ladder development
- Mean material budget of ladder ≈ 0.1-0.2 %
- Small regions (i.e. bump bonds) of highly increased material (worst case: 1%)

Goal

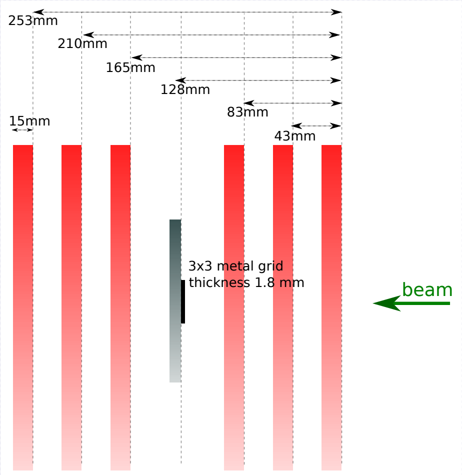
- Imaging of balcony and switchers on the DEPFET modules

Updates since Seeon meeting

- Beam energy calibration with precision of a few ‰
- Detailed analysis of Switcher image

Setup of Telescope for X_0 measurements

- Setup DESY test beam in March 2015
- Spacings chosen this way to keep the angle reco error σ_{err} small



Setup of Telescope for X_0 measurements

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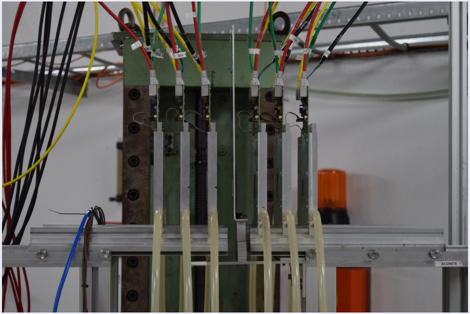
- Beam energy between 2 and 5 GeV and large rate $\rightarrow$ Mainly results from 4 GeV data here



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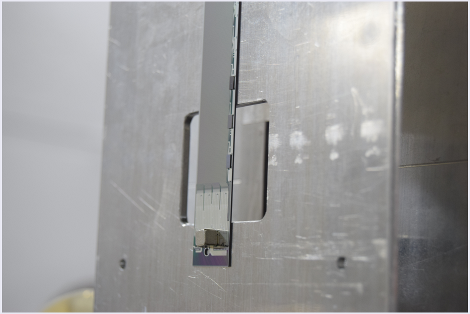
- Spacings chosen this way to keep the angle reco error σ_{err} small
- Beam energy between 2 and 5 GeV and large rate $\rightarrow$ Mainly results from 4 GeV data here
- Measurements on 3x3 metal grid and DEPFET Dummy with switcher and balcony



Procedure of X/X_0 Measurements

Definition of λ

- Finite angle resolution on target plane → 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

Definition of μ

calibrated beam energy $p^{*} = \mu \cdot p$,
with λ, μ: calibration factors and p, σ_{err} expected values

Procedure of X/X_0 Measurements

First step: Calibration on metal grid with Moliere model

- Reconstructed multiple scattering angle distribution given by

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

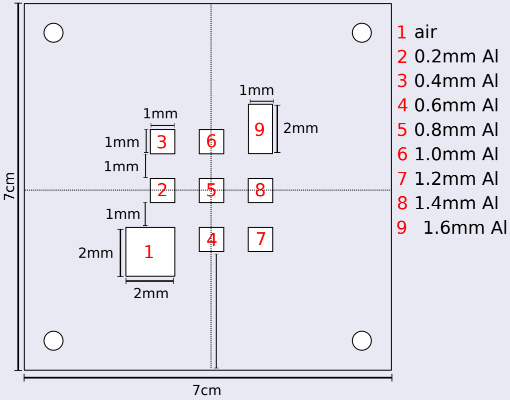
- f_{Moliere} depends on many material and particle beam parameters and on μ
- Target with well known material profile allows λ,μ calibration
- Find λ,μ by simultaneous fit of reconstructed angle distributions

Second step: Measurement on materials

- Use these optimal factors in other X/X_0 measurements

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



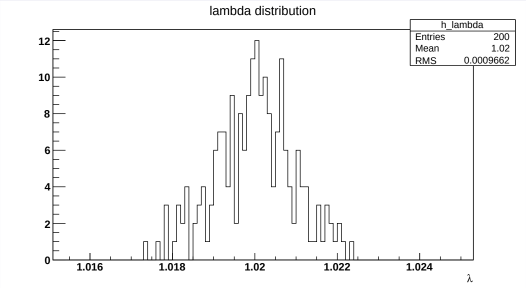
Calibration fit with Moliere model: Toy study

Procedure of Toy study

- Simulate 12 angle distributions for different alu thickness on metal grid 200 times
- 75k tracks for each measurement area
- 4 GeV electrons, metal grid as on the previous slide
- Perform simultaneous fit on the different angle distributions
- Compare fitresults to simulation parameters (λ=1.02, μ=1.0)

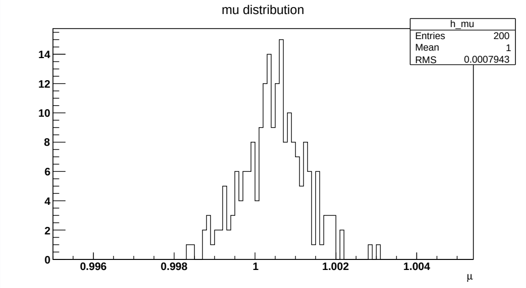
Calibration fit with Moliere model: Toy study

- center of lambda distribution at $\lambda = 1.02$



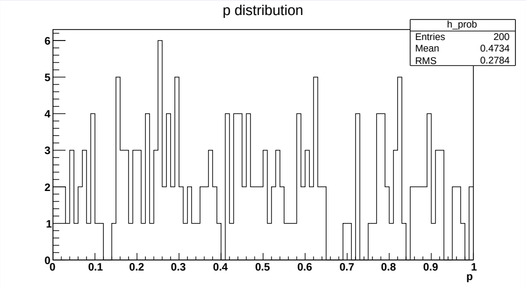
Calibration fit with Moliere model: Toy study

- center of lambda distribution at $\lambda = 1.02$
- Very small offset in μ distribution



Calibration fit with Moliere model: Toy study

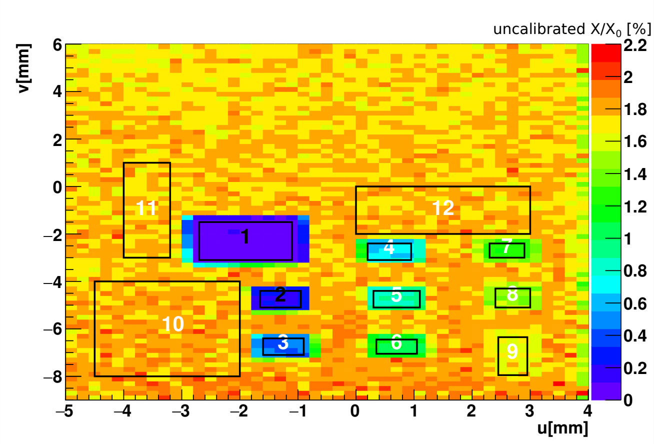
- center of lambda distribution at $\lambda = 1.02$
- Very small offset in μ distribution
- p value has uniform distribution



$\rightarrow$ calibration of μ and λ with a uncertainty of below 1 permil possible

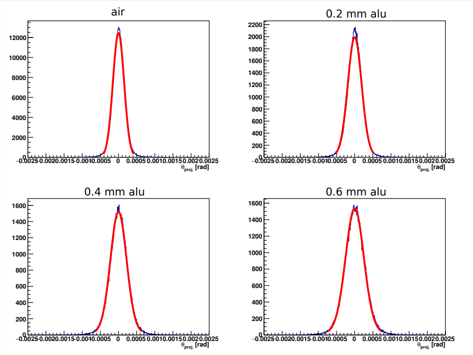
Selection of measurement areas

Run 10 and 11 (4 GeV)



Calibration @ 4 GeV (Moliere model)

- Simultaneous fit of 12 multiple scattering angle distributions



Calibration @ 4 GeV (Moliere model)

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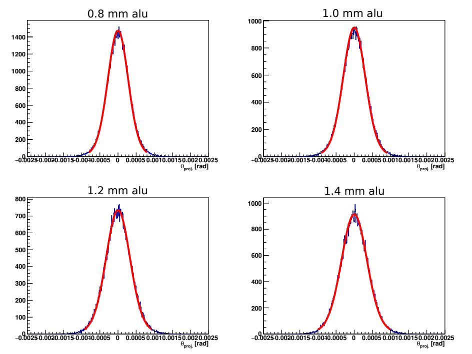
- Fit results:
  $\lambda = 1.145 \pm 0.001$,
  $\mu = 1.020 \pm 0.001$



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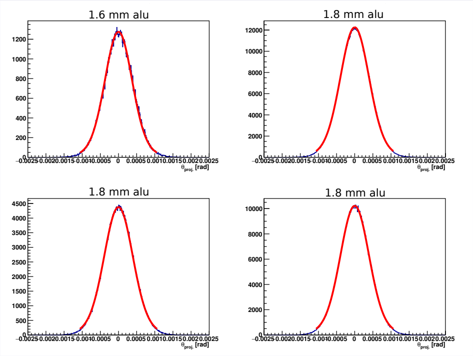
- μ close to 1.0, $\lambda \approx 1.1$ typical value at DESY



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  $\lambda = 1.145 \pm 0.001$,
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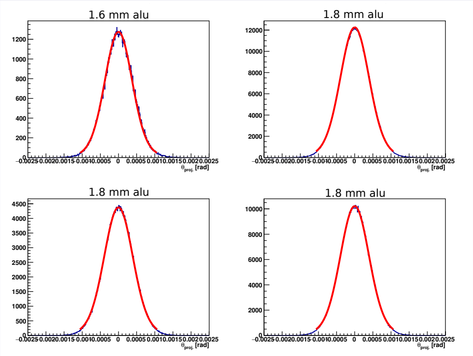
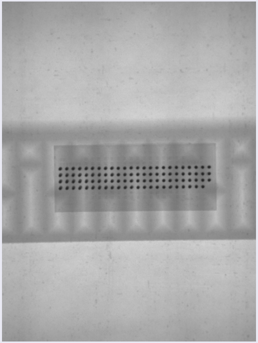
- μ close to 1.0,
  $\lambda \approx 1.1$ typical value at DESY
- beam energy 2 % larger than expected

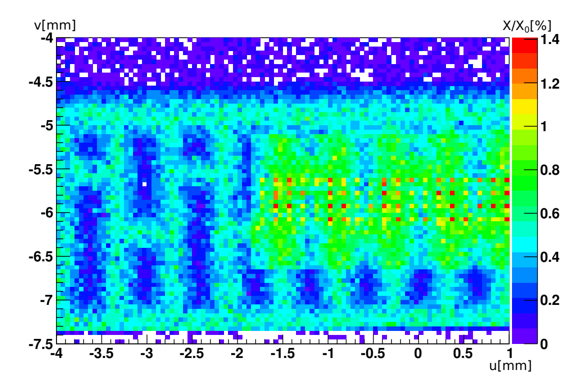


Measurements on DEPFET Dummy module

X-ray image of switcher



X0 image of switcher (4GeV, 50 μm^2 pixels)



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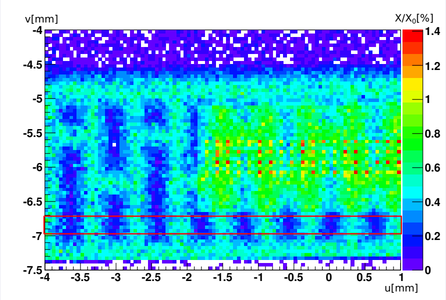

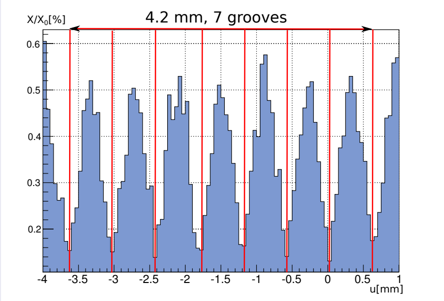

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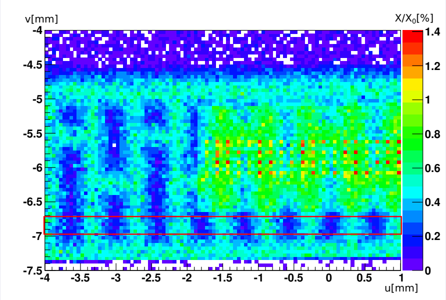
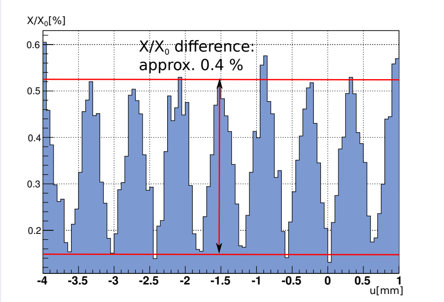


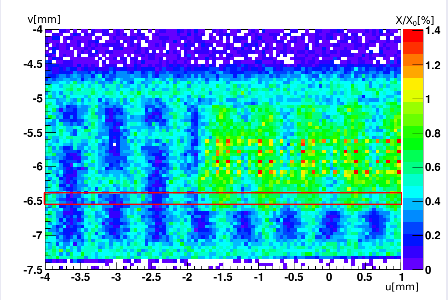


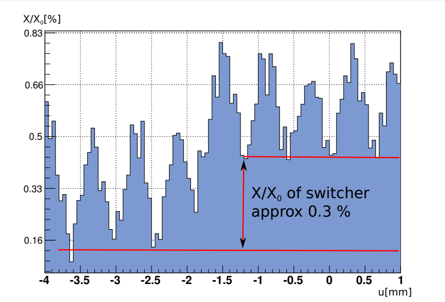
grooves measurement results

Size of grooves (in u direction) ≈ 0.6 mm

X/X_0 difference between thinnest and thickest point ≈ 0.4 %

Measurements on DEPFET Dummy module

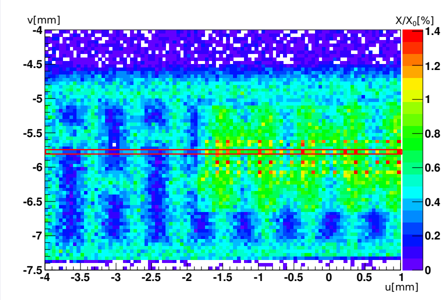


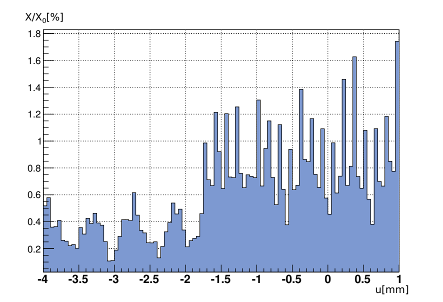


switcher X/X_0 estimation results

$(X/X_0)_{\text{switcher}} \approx 0.3\%$, expected value: 0.35%

Measurements on DEPFET Dummy module: Bump bonds





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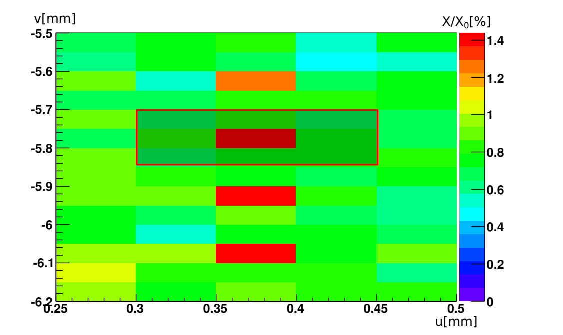


bump bond X/X_0 estimation results

Mean distance in u and v 150 μm,

$(X/X_0)_{\mathrm{bump}} \approx 0.9 \pm 0.2\%$, expected value: $\approx 0.7\%$

Conclusion and Outlook

Conclusion

- calibration of 4 GeV successful, $\lambda = 1.145 \pm 0.001$, $\mu = 1.020 \pm 0.001$
- Switcher image based on 4 runs with 22 Mio tracks
- bump bond structures below switcher can be seen
- telescope z alignment still seems to be a minor issue

Conclusion and Outlook

Outlook

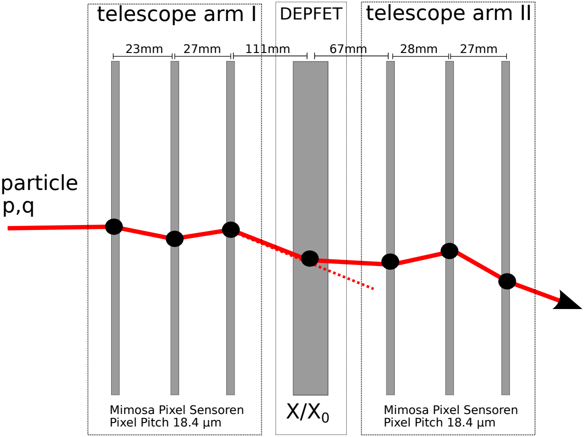
- Further systematical studies of alignment
- detailed measurements of the rest of the data, 2 GeV beam has a much larger rate → statistical errors will be much smaller in the near future

Thanks for your attention!

Backup Slides

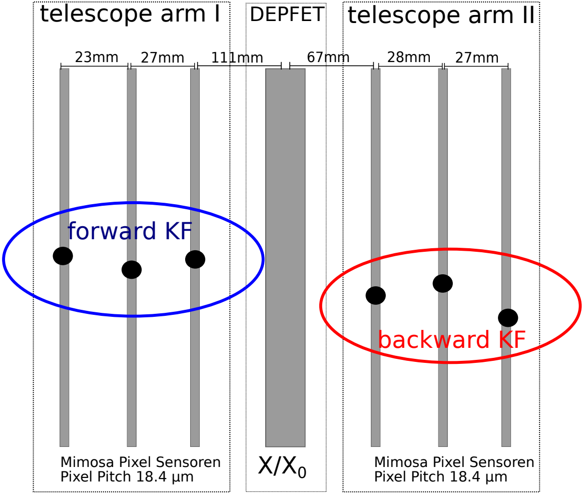
Reconstruction of MSC angles in a EUDET teleskop

- 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 $\rightarrow$ hits
- Forward- backward Kalman Filter (KF) pair on hits
- hit on DEPFET not needed $\rightarrow$ maps
- Take MSC in air gaps into account



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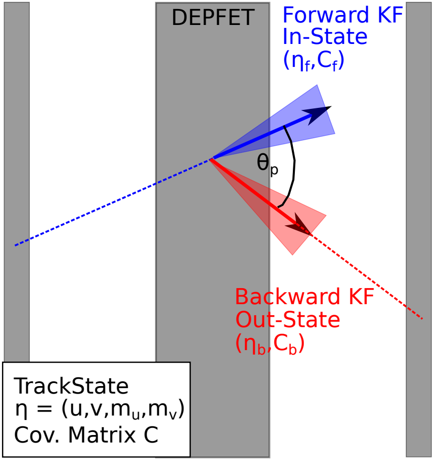
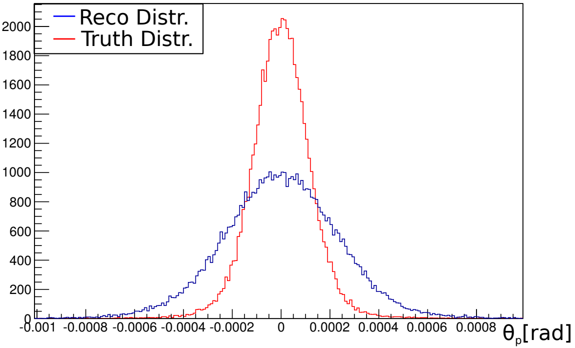
- Take MSC in air gaps into account
- θ_p calculated from (m_u, m_v)
- Reco error σ_{reco} from error propagation



Example of a reconstructed angle distribution

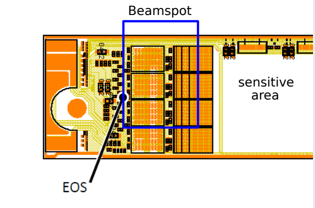


Composition of the Reco Distribution

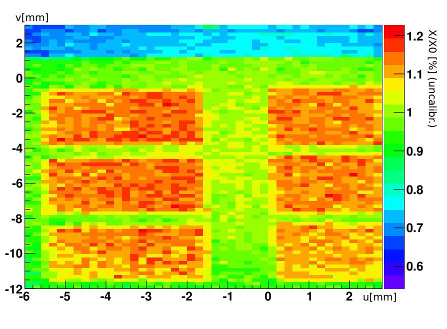
Reconstructed MSC angle distribution is a convolution between the truth MSC distribution and a Gaussian noise distribution caused by the reconstruction errors

Measurements on Broken PXD module I

beamspot position on EOS

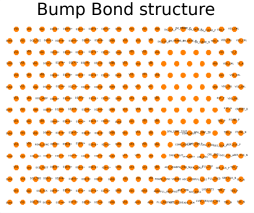


Complete X0 map (2GeV, 200μm pixels)



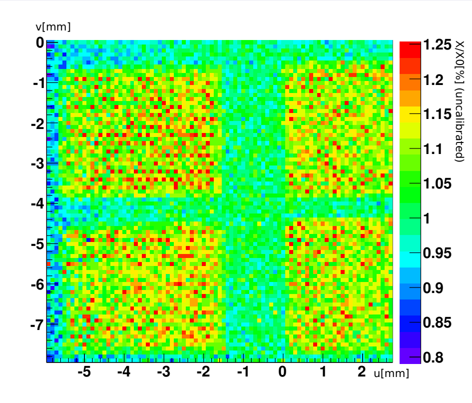
End-of-staves, 3 DHPs and parts of 3 DCDs visible

Measurements on Broken PXD module II



- bump bond diameter $\approx 100\ \mu m$
- bump bond pitch 180 and 200 μm

image of DHP and DCD (2 GeV, 100 μm pixels)



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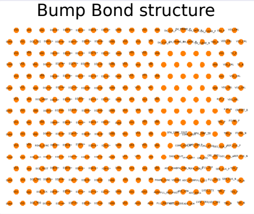

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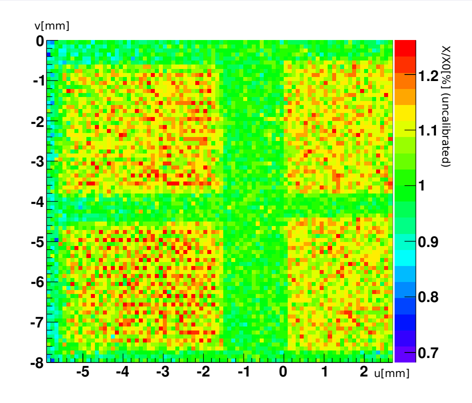

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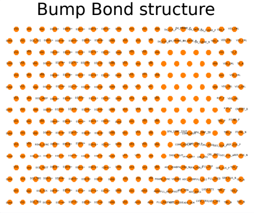

- bump bond diameter ≈ 100 μm
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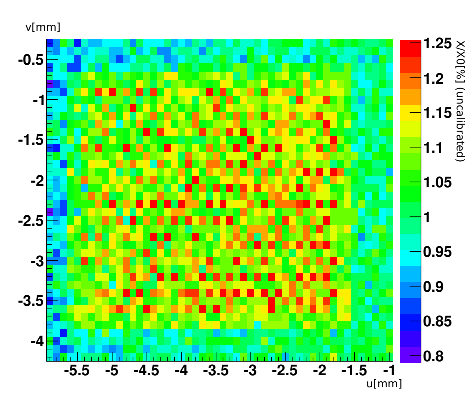
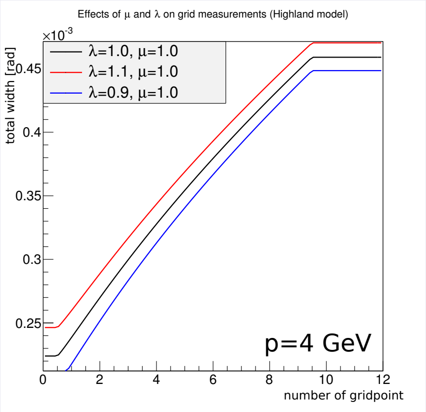


Discrimination between λ and μ

- depicted: total width as a function of thickness given by grid points
- points 10,11,12: whole thickness (1.8mm alu)
- p=4 GeV, σ_{err}=234 μrad
- variation of λ, μ
- μ and λ clearly distinctive



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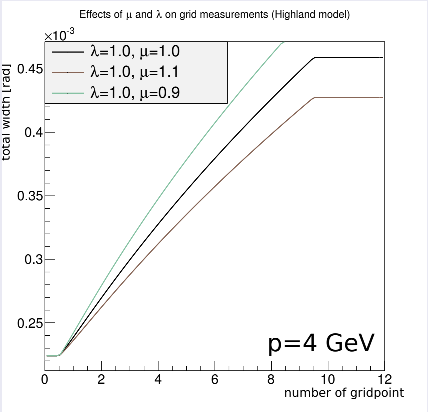
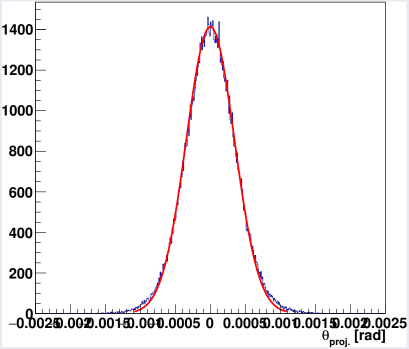


Highland Formula

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

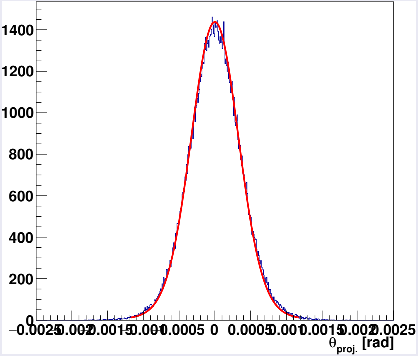
Angle distribution fits

Highland model (Gaussian fit)



- Fast gaussian fit
- problem: Fit range must be limited due to tails

Moliere model



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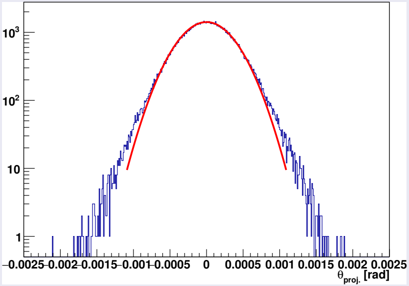

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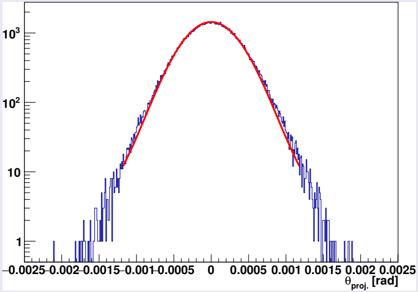

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