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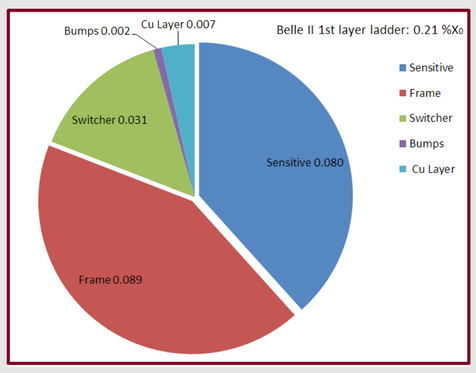
Radiation length imaging with high resolution telescopes

Introduction

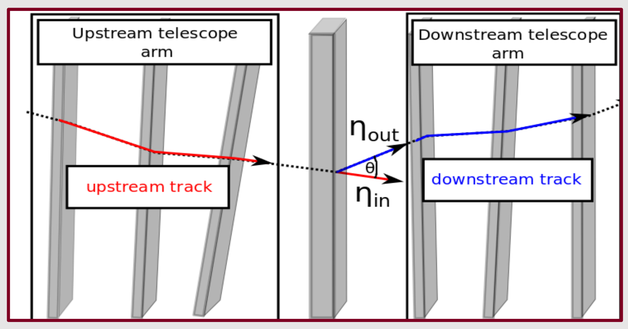
- Modern vertex detectors like the VXD vertex detector for Belle II are required to have a very low material budget
- Mean radiation length X/X_0 of a Belle II pixel detector (PXD) ladder ~ 0.2%
- Mean value can't be used in tracking, need to find balance between detailed detector model and speed
- The independent radiation length imaging method shown here can be employed to test detector models



X/X_0 imaging

Basic Idea: Reconstruct multiple scattering kink angles on a central target plane
→Width of angle distributions depends on radiation length X/X_0

- Experimental setup: High resolution tracking telescope with at least 6 sensor planes and monoenergetic particle beam (~GeV)
- Divide particle trajectory in two parts: Up- and downstream track
- Use a forward backward Kalman filter pair to estimate track states: In-state before the scattering and out-state afterwards
- X/X_0 Imaging: Subdivide target plane into small areas and sort the calculated angle according to the intersection point

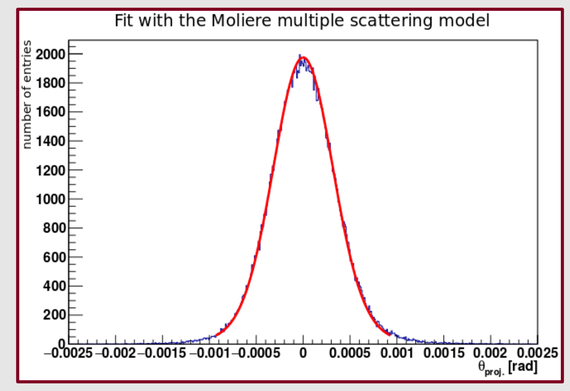


Fit of angle distributions

- Fit function for reconstructed angle distributions:

$$f(\vartheta) = f_{\mathrm{MSC}}(\theta, p, X, X_0) * \frac{2}{\sqrt{\pi}} e^{-\frac{(\theta)}{\lambda\sigma_{\mathrm{noise}}}},$$

with the beam energy p, the thickness X, the radiation length constant X_0, the telescope resolution σ_{reso} and the calibration factor λ.



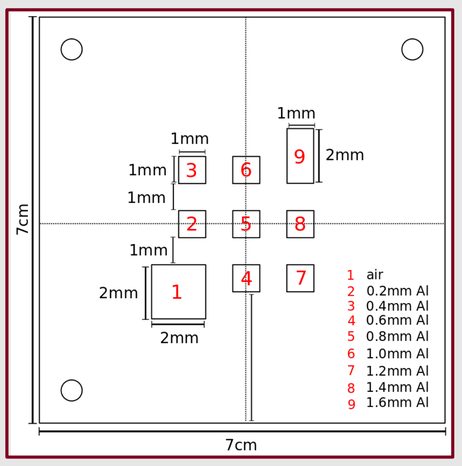
Calibration of the telescope angular resolution

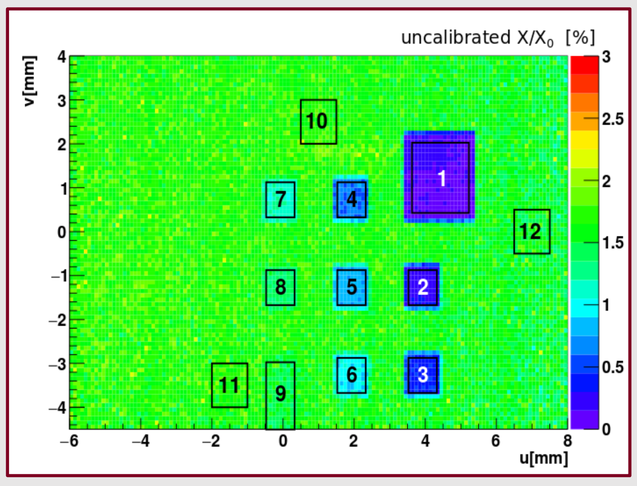
The telescope angle resolution σ_{reso} affected by systematical errors such as:

- Wrong beam energy
- Wrong beam energy
- Telescope and target misalignment
- Simplified multiple scattering model in tracking

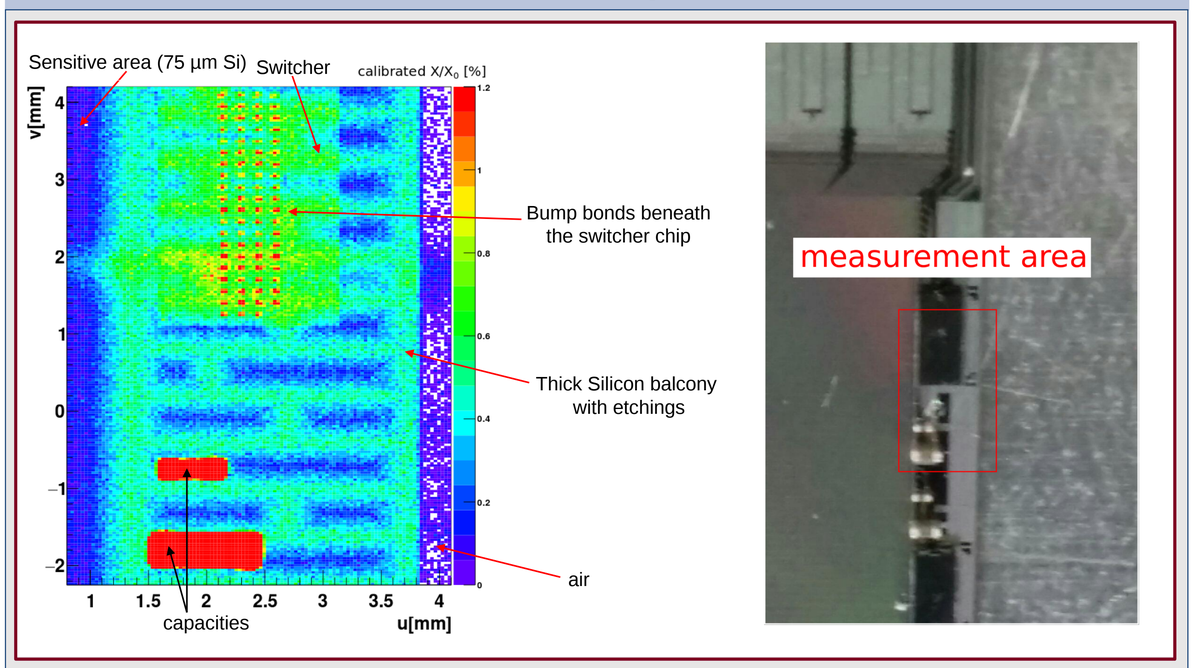
→calibration of σ_{reso} necessary

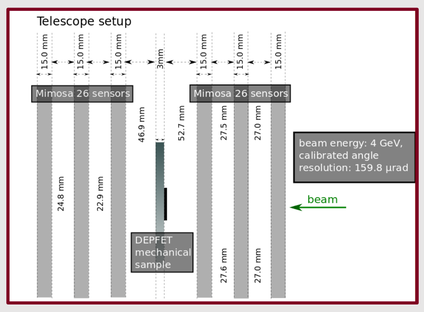
- Introduce calibration factor λ: calibrated angle resolution given by: $\sigma'_{\mathrm{reso}} = \lambda \cdot \sigma_{\mathrm{reso}}$
- Define a number of well known measurement areas on a calibration target and reconstruct angle distributions
- Construct fit functions to describe the angle distributions, the only free parameter is λ
- Perform a simultaneous fit of all selected angle distributions
- λ should be close to 1.0 (0.8<λ<1.2), otherwise the systematical errors are very large





PXD mechanical sample X/X_0

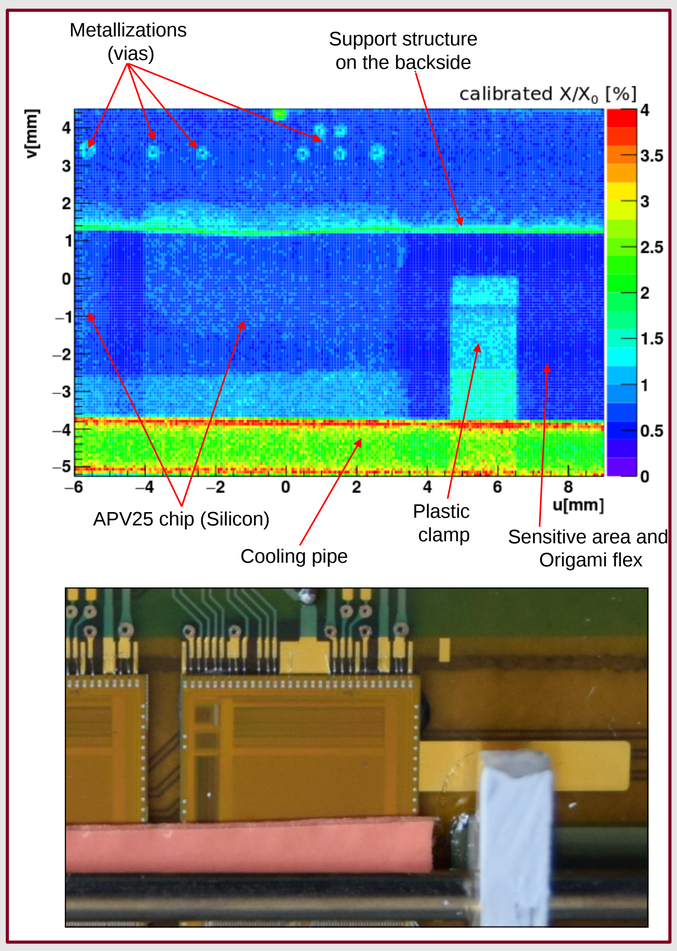


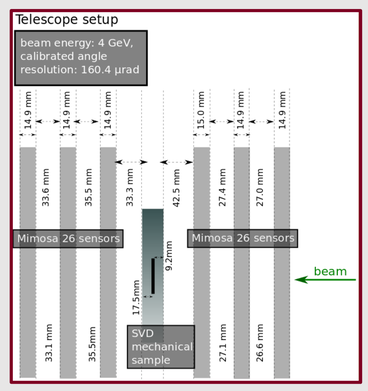


Results

- 30 µm pixels, ~ 100 mio tracks
- Capacities: ~1.4 % and ~2.3 % substructures visible
- Balcony (thickest point): 0.505 +/- 0.005 %

Silicon strip vertex detector (SVD)





Results

- 75x75 µm² pixels, 29 mio tracks
- APV: 0.169 +/- 0.003 %
  Expected: 0.170 %
  broadness: 7.0 mm
- Beam pipe wall thickness
  d = 134 µm
  diameter of pipe: 1.5 mm
- Sensitive area: 0.544 +/- 0.002 %
  Expected: 0.530 %

Summary & Outlook

- Developed method to measure radiation length of passive material within a high resolution tracking telescope
- After Calibration of angle resolution X/X0 measurements with uncertainties below 1 ‰
- Pixel size determined by number of tracks, need ~2000 tracks per pixel
- Comparison between VXD detector model and these results → Influence on tracking quality?

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