Alignment Position Error (APE) Estimation using Width of Normalized Residual Distributions

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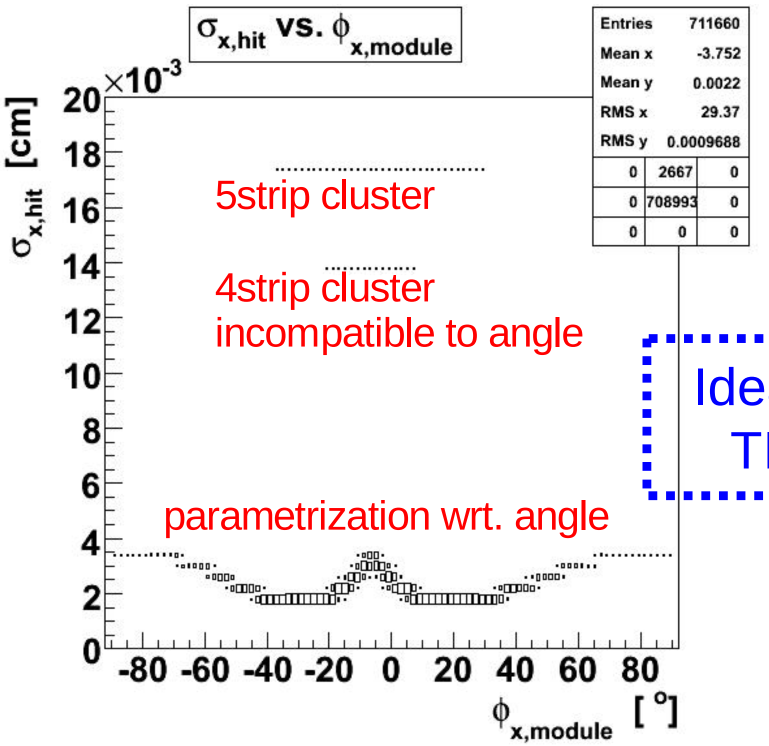
Overview

- Implementation of APE in track reconstruction
- Influence of misalignment on normalized residuals
- Method of APE estimation from normalized residual distributions
- Setup of simulated MC events and misalignment
- Results

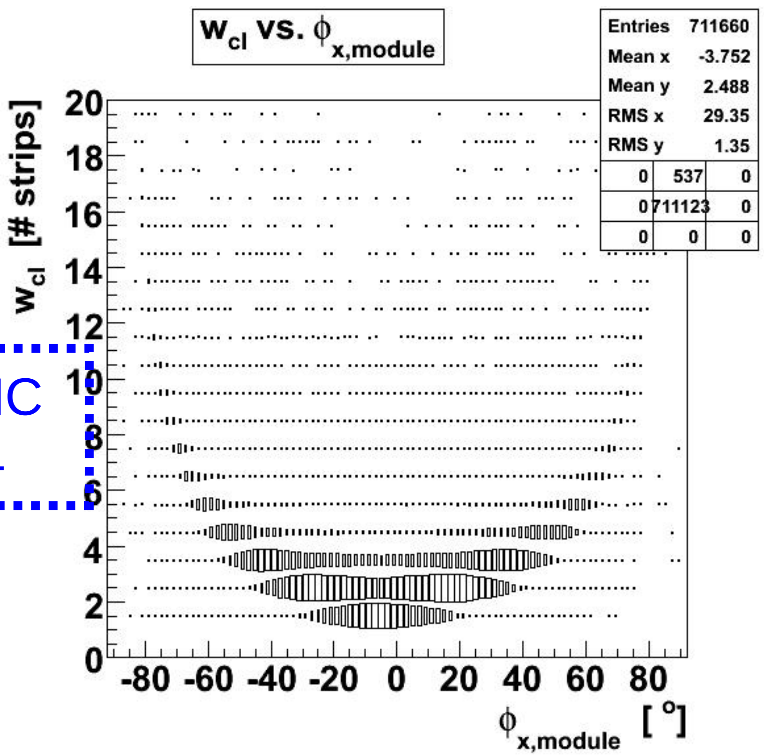
Hit reconstruction

- Local reconstruction with cluster parameter estimator (CPE): Current implementation for Hit *i*
  - Position x_{hit} as barycentre of strip charges of clusters
  - Error σ_{hit} based on track incident angle ϕ_{module} (almost) regardless of cluster width w_{cl} and shape
  - If cluster is wider than track projection allows, huge error assigned

$$\sigma_{\text{hit}} = w_{\text{cl}} \cdot pitch \cdot \sqrt{12}$$



Ideal cosmic MC
TIB layer 3+4



Implementation of alignment precision in track reconstruction

- Global reconstruction
  - Depending strongly on alignment parameters **p**
  - Track j – parametrisation **q** leading to track prediction x_{track} and error σ_{track}

- Uncertainty of alignment parameters σ_{align} – inclusion in track reco:
  - 2 translations (σ_x, σ_y) in module's plane
  - Quadratical addition to intrinsic resolution per coordinate

$$\sigma_{\text{eff}}^2 = \sigma_{\text{hit}}^2 + \sigma_{\text{align}}^2$$

- Individual values for every module possible

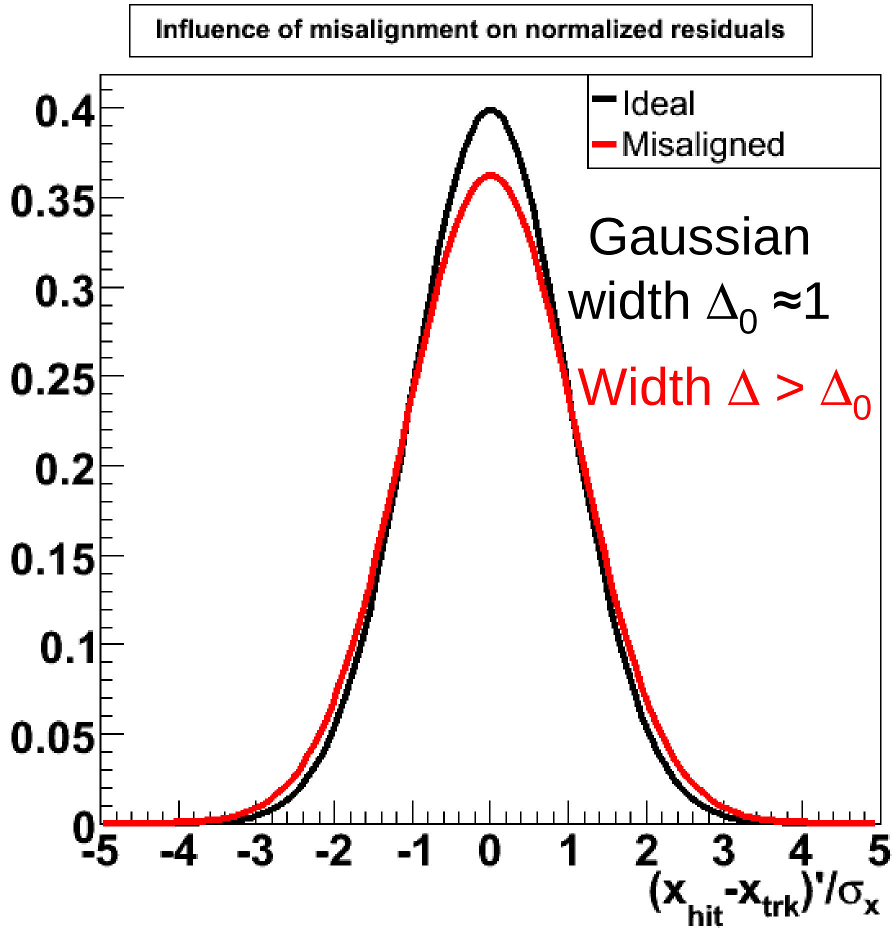
Normalized residuals and misalignment I

- Regard residuals with hit under study excluded from track fit
  - Errors of track and hit become independent

$$\frac{r_{ji}}{\sigma_{ji,\mathrm{tot}}} = \sigma^{-1}_{ji,\mathrm{tot}}\left(x'_{ji,\,\mathrm{track}}\left(\mathbf{p},\mathbf{q}_j\right) - x'_{ji,\,\mathrm{hit}}\right)$$

$$\begin{aligned}\sigma^2_{\mathrm{tot}} &= \sigma^2_{\mathrm{track}} + \sigma^2_{\mathrm{eff}} \\ &= \sigma^2_{\mathrm{track}} + \sigma^2_{\mathrm{hit}} + \sigma^2_{\mathrm{align}}\end{aligned}$$

- Perfect alignment: approx. gaussian with width $\Delta_0 \approx 1$
- Also non-gaussian effects present
- Misalignment: Refit tracks with APE set to zero
  - Broadened width Δ is measure for misalignment

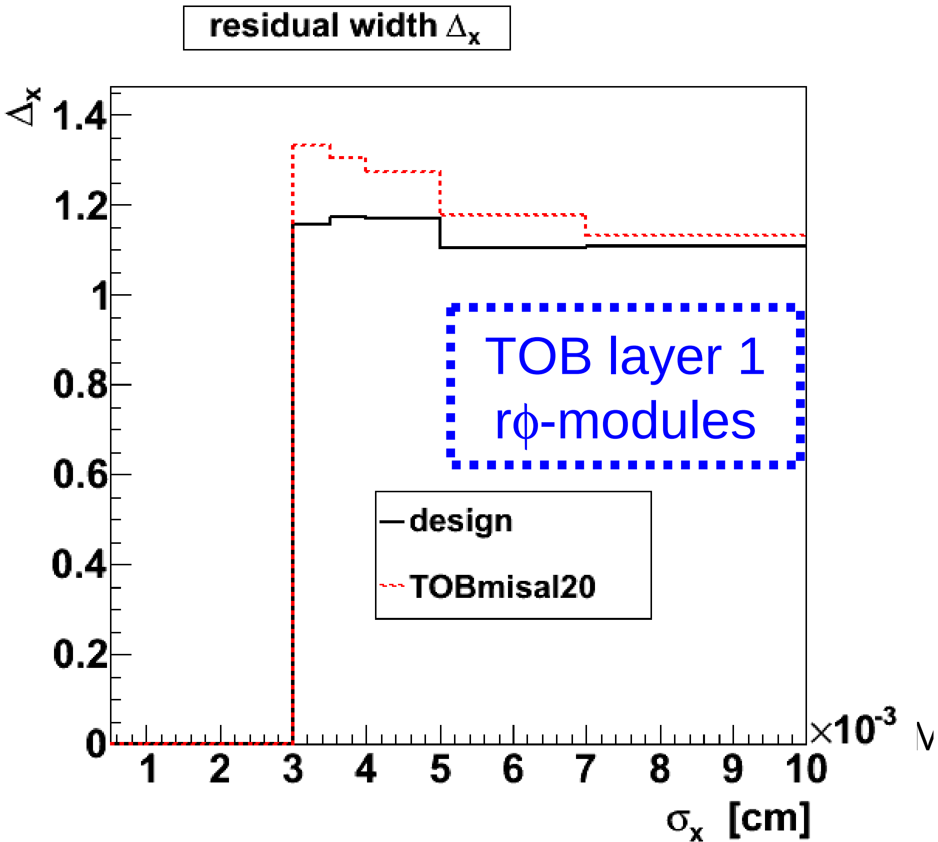


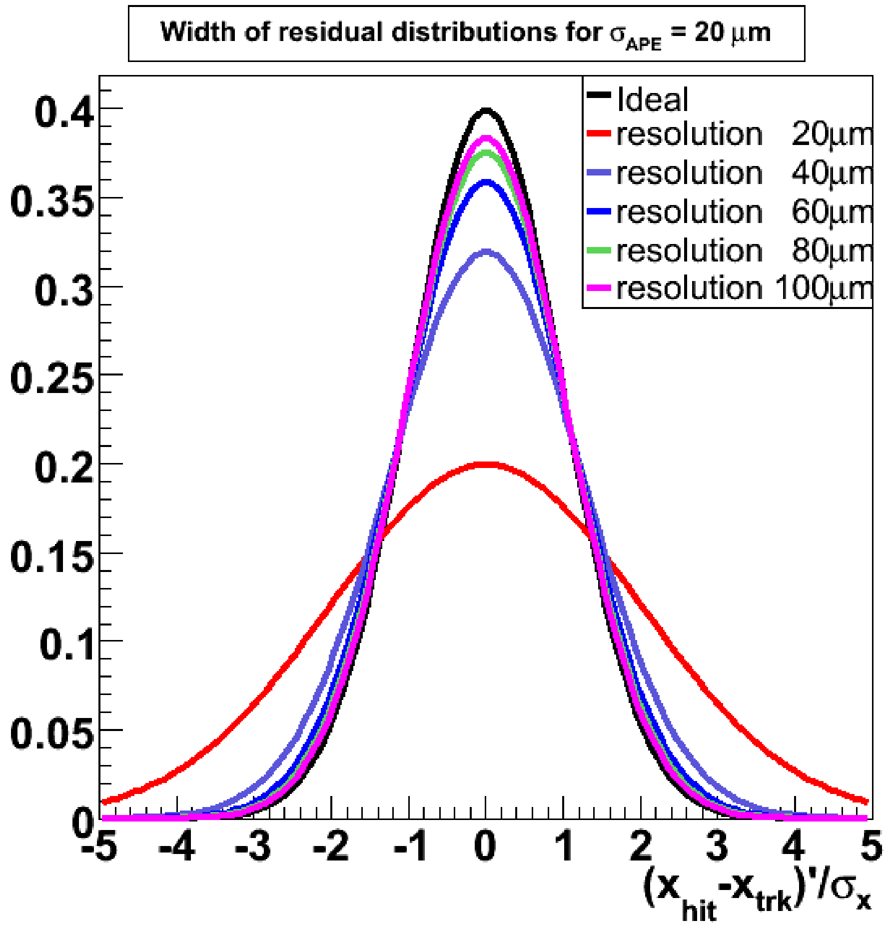
Normalized residuals and misalignment II

- But: influence of misalignment depends on residual resolution σ (without APE)

$$\sigma^2 = \sigma_{\mathrm{track}}^2 + \sigma_{\mathrm{hit}}^2$$

- Need to regard normalized residual distribution in small intervals of residual resolution





Method for estimating alignment precision

- Regard 10 different residual resolution intervals independent
- Take width Δ_i from ideal MC (fit gaus to core distribution)
  - Ideal width Δ_0: (Entry*resolution^2)-weigthed mean over all intervals
- Take broadened width Δ from data (fit gaus to core distribution)
- Estimate alignment precision, so that residual error σ reduces width to ideal value

$$\boxed{\Delta \cong \Delta_0}$$

$$\begin{aligned} \sigma^2 &= \sigma^2_{\text{track}} + \sigma^2_{\text{eff}} \\ &= \sigma^2_{\text{track}}(\sigma_{\text{align}}) + \sigma^2_{\text{hit}} + \sigma^2_{\text{align}} \end{aligned}$$

Correlation of errors of all hits per track → iterations necessary

- For σ~constant it is valid:

$$\sigma_{\text{Align}} = \sqrt{(\Delta^2 - \Delta_0^2)} \cdot \sigma$$

- Calculate APE per bin and take entry-weighted mean

Setup of MC analysis

- 10 mio. Events generated with particle gun with 10GeV < p < 300GeV, and flat in η (Ideal conditions, design geometry, vertex smearing)
  - Simulated 5,000,000 pions / 5,000,000 antipions
  - Reconstructed (exactly 1 track): 4,275,323 / 4,273,696
  - HighPurity: 4,254,289 (85,1%) / 4,252,279 (85,0%)

- Control distributions compared for full set of pions with full set of antipions
  - Very similar, small differences in tails (probably statistical)

- Misalignment introduced, refitted without outlier rejection
  - Gaussian smearing of localX of all TOB modules with sigma=20µm

- Tight track and hit selection

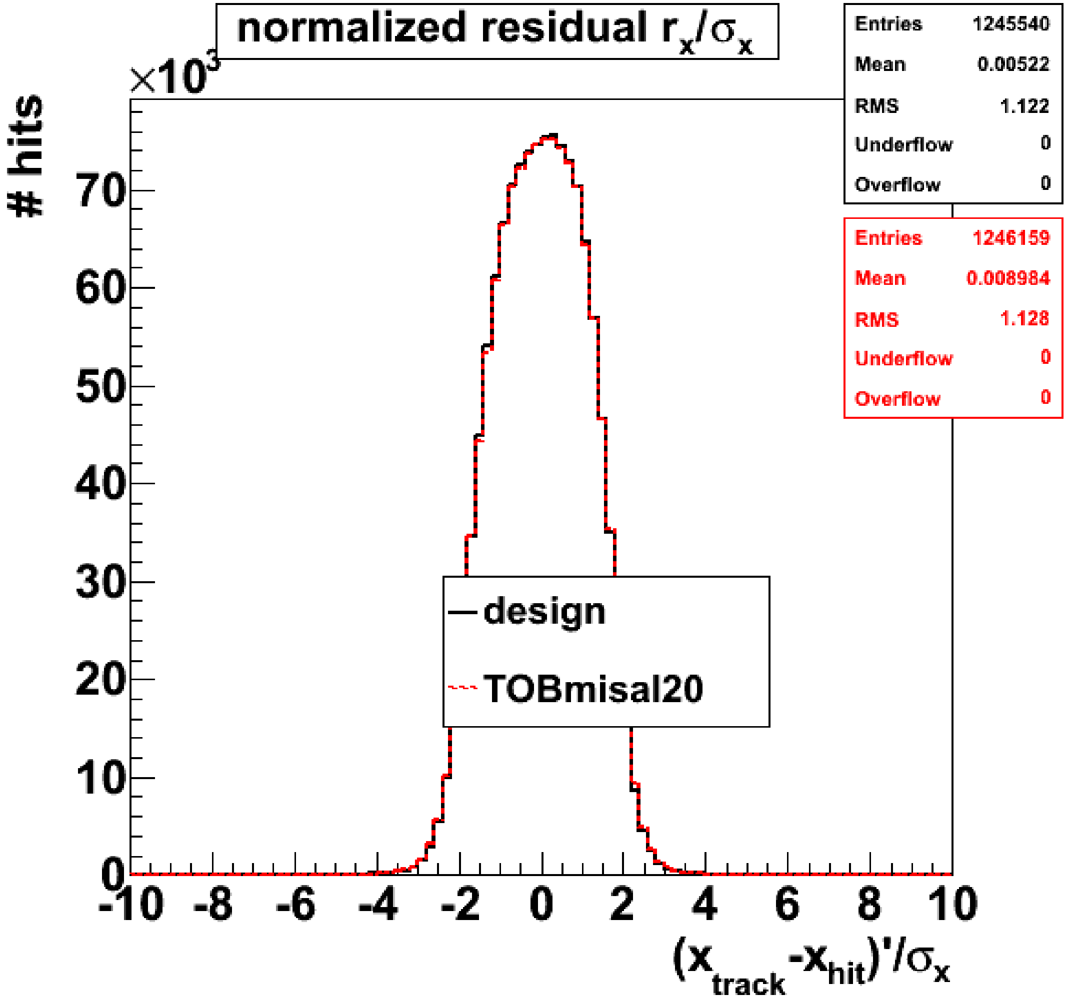
Setup of APE estimation tool

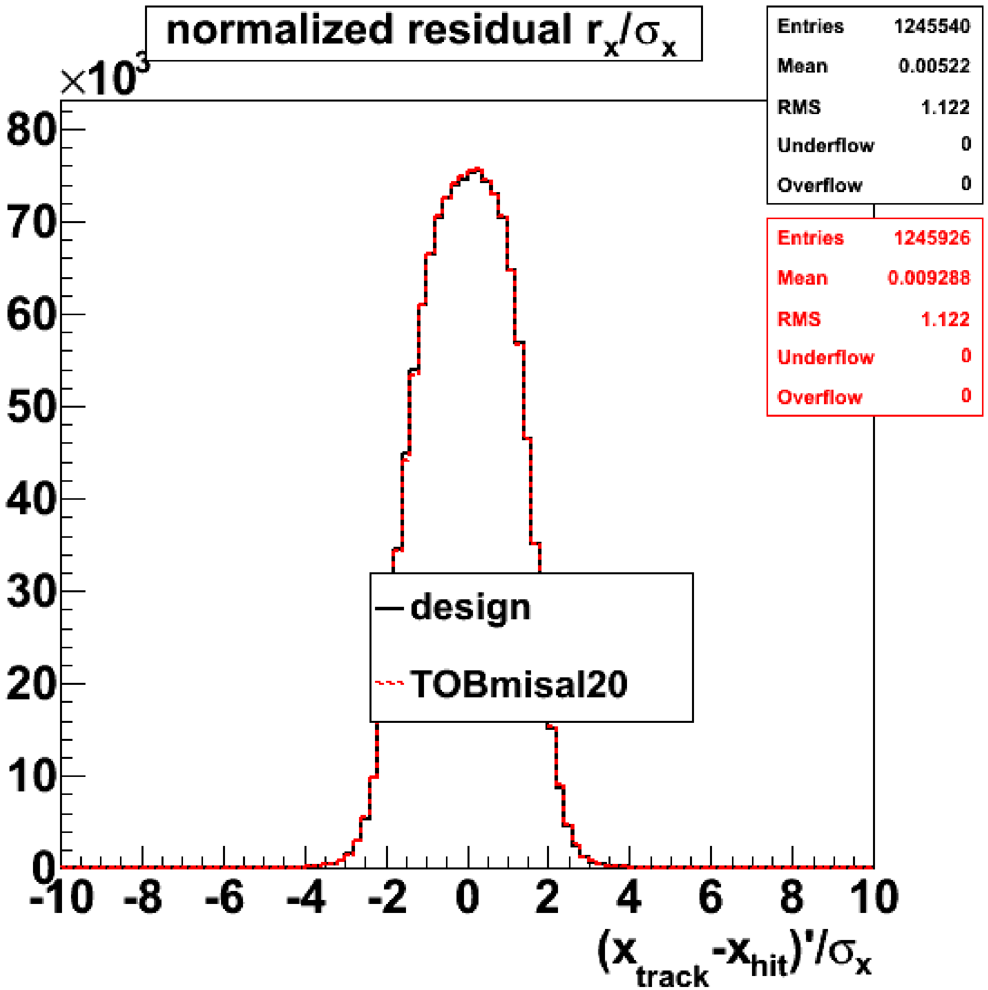
- Group modules in different “sectors”:
  12 in TIB, 16 in TOB
  - Separated by layers
  - Further separation by orientation (inwards, outwards pointing)
  - Further separation of $r\phi$- and stereo-modules
- Scale calculated correction by factor 0.6 to avoid overestimation
- At least 1000 entries per regarded residual resolution interval
- Result after 11 iterations shown

- Following plots show important quantities before (left plot) and after (right plot) iterative APE estimation procedure the sublayers
  - TIB layer 4 out (see influence of neighbouring misalignment)
  - TOB layer1 $r\phi$ in, TOB layer 4 out, TOB layer 6 in

TIB layer 4 outwards, normalized residuals

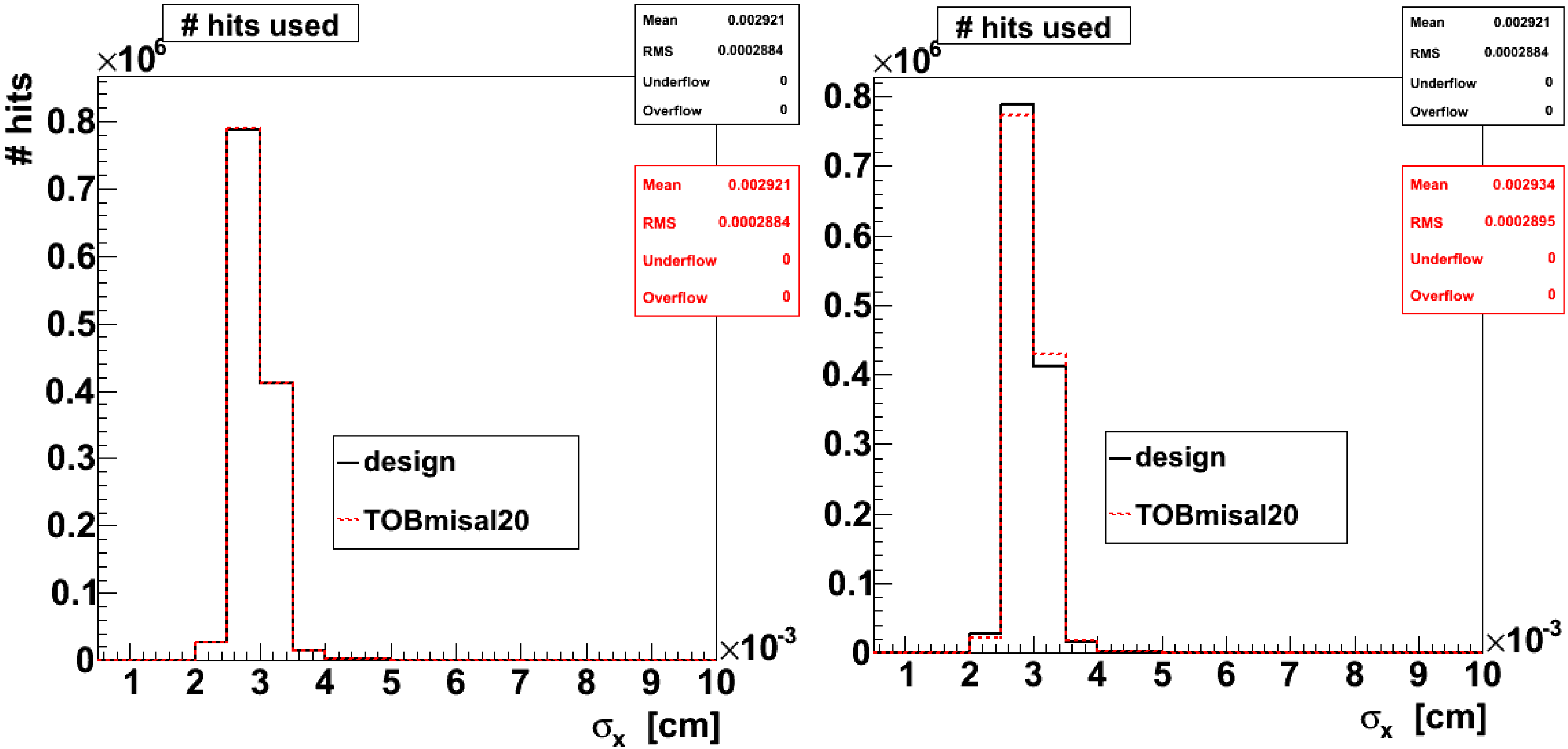
- bla





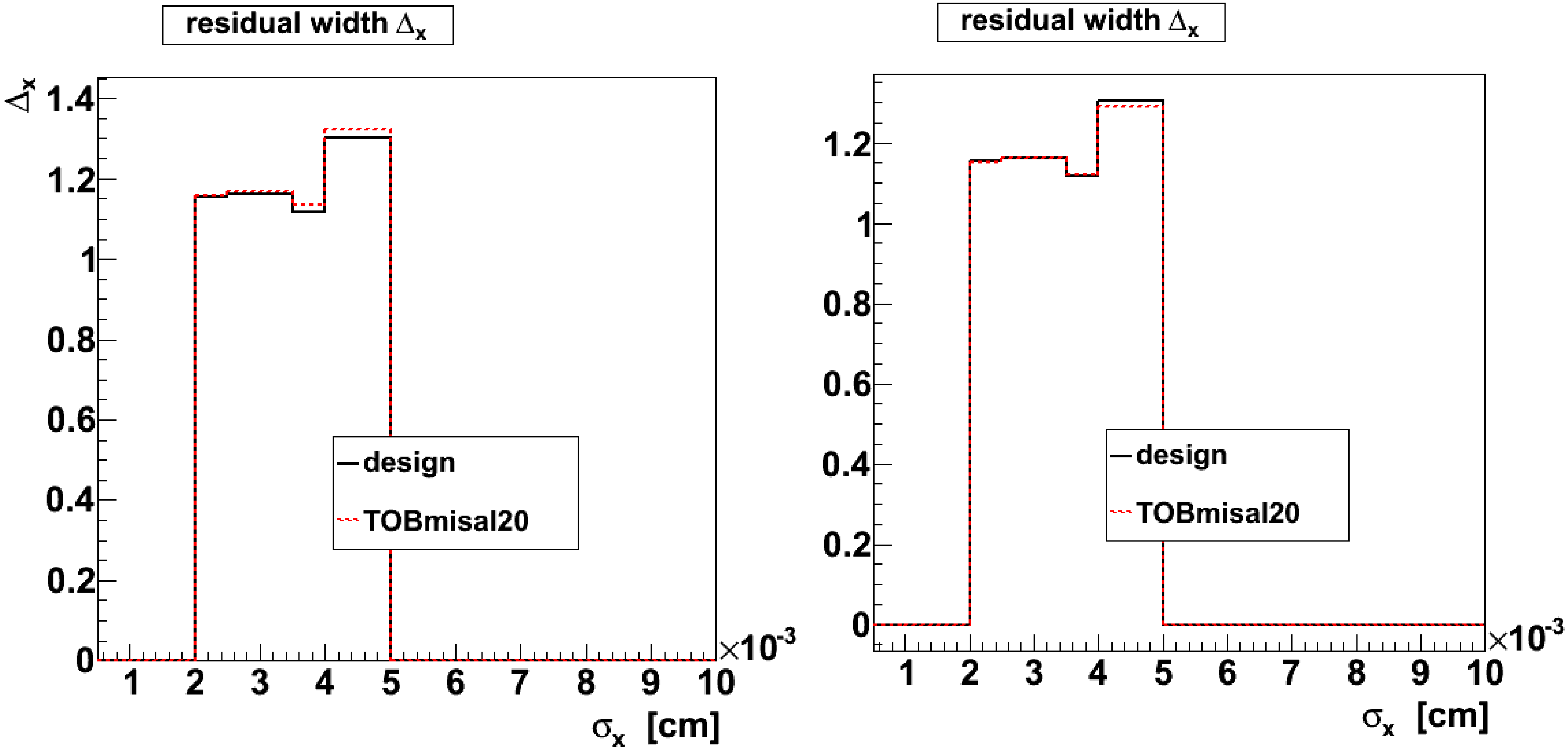
TIB layer 4 outwards, entries in residual resolution intervals

- bla



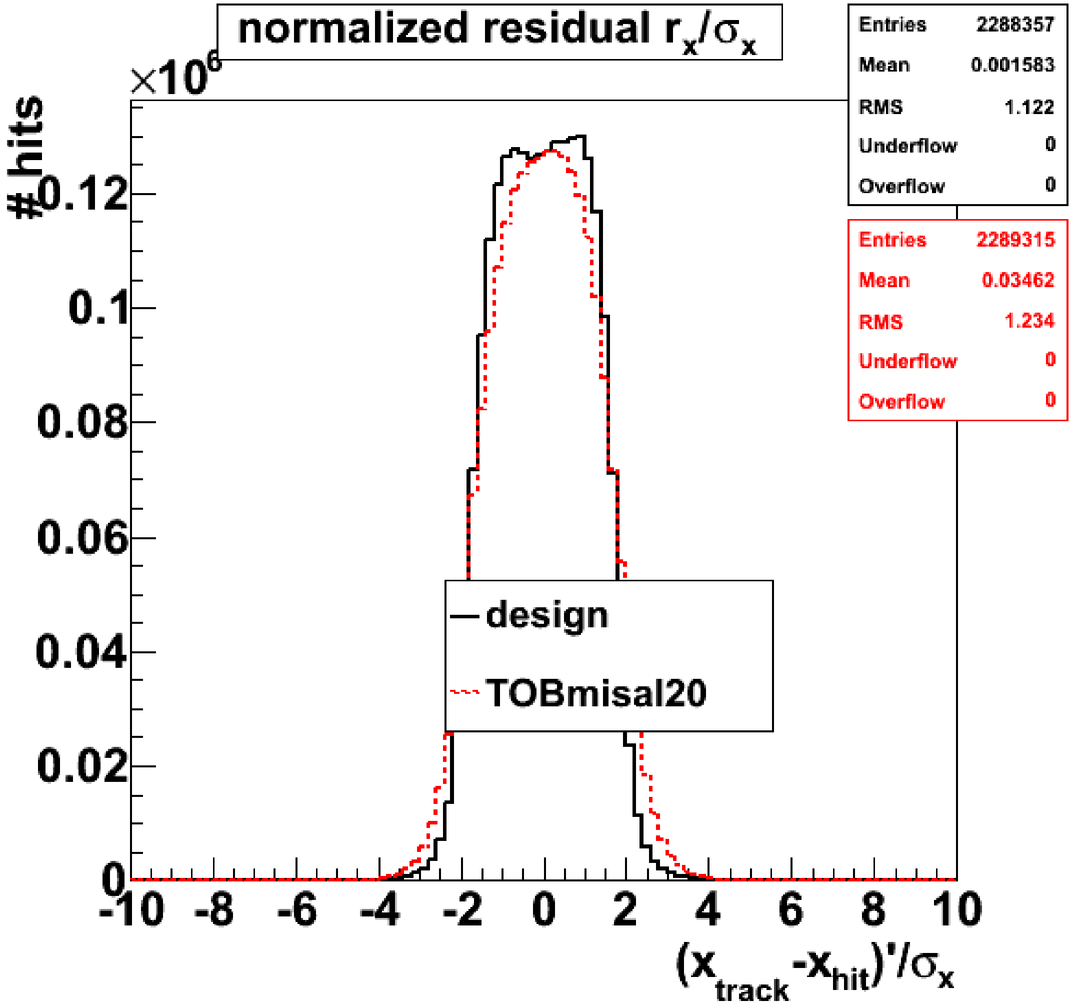
TIB layer 4 outwards, residual width wrt. residual resolution

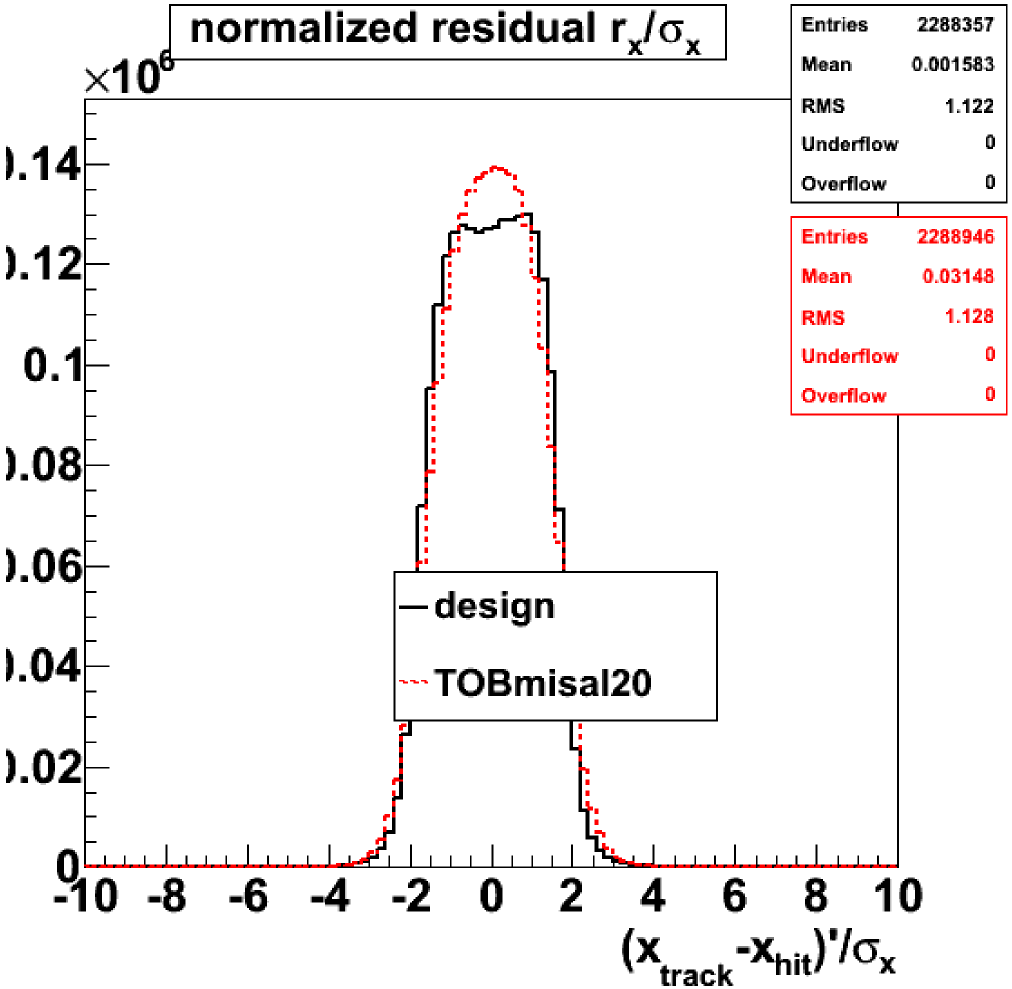
- bla



TOB layer 1 inwards, normalized residuals

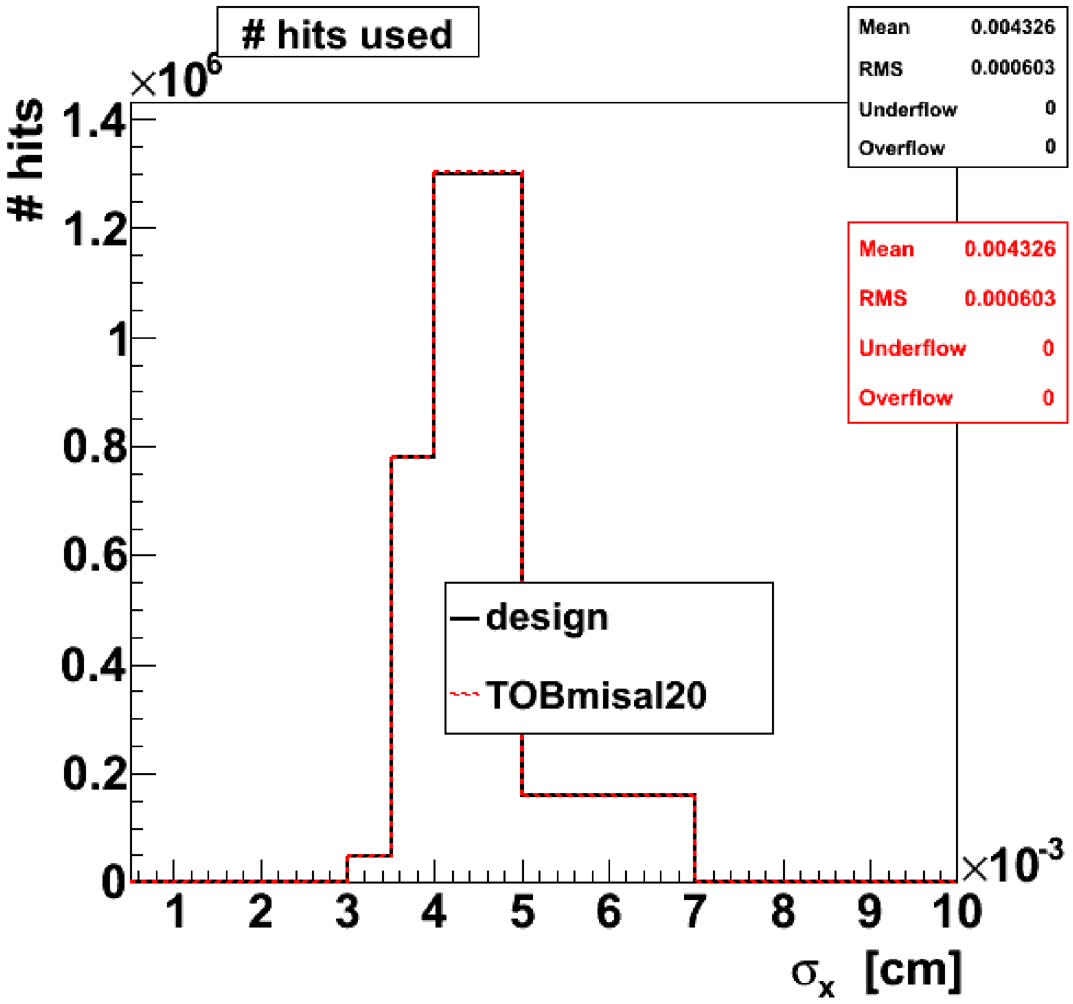
- bla

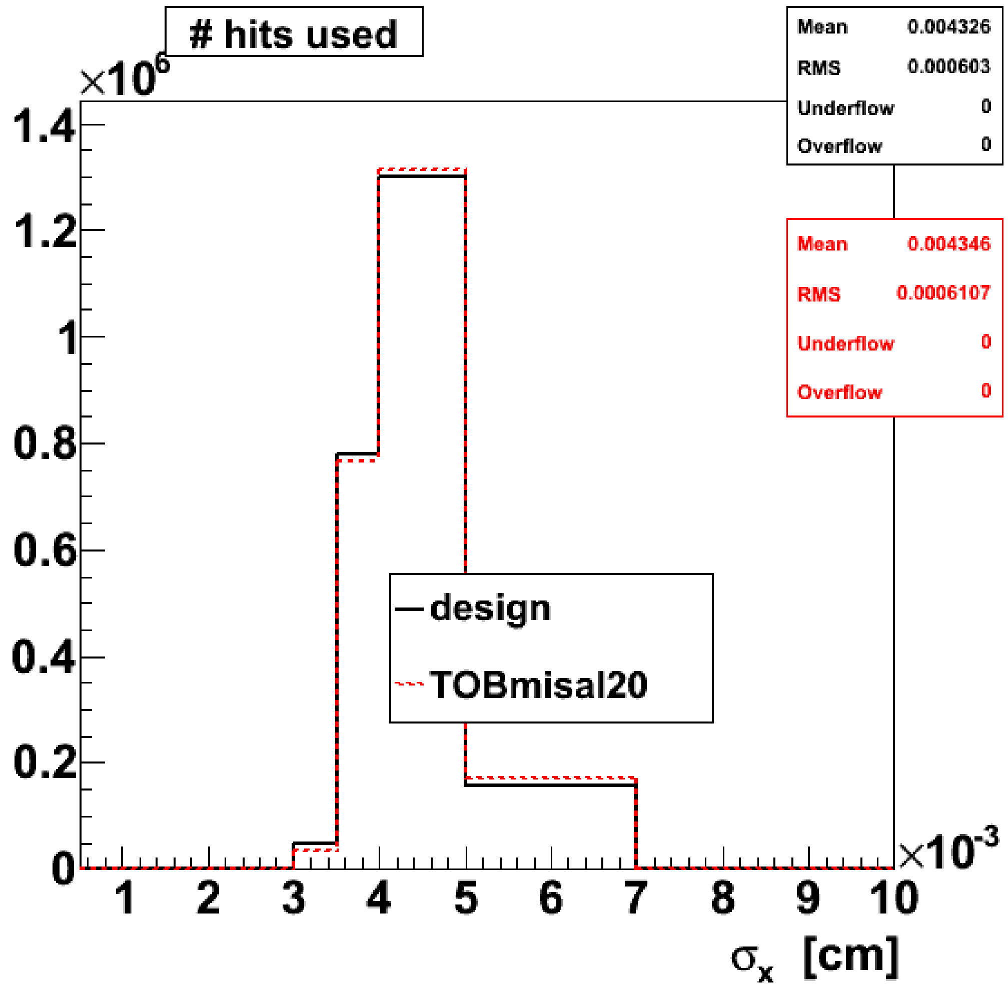




TOB layer 1 inwards, entries in residual resolution intervals

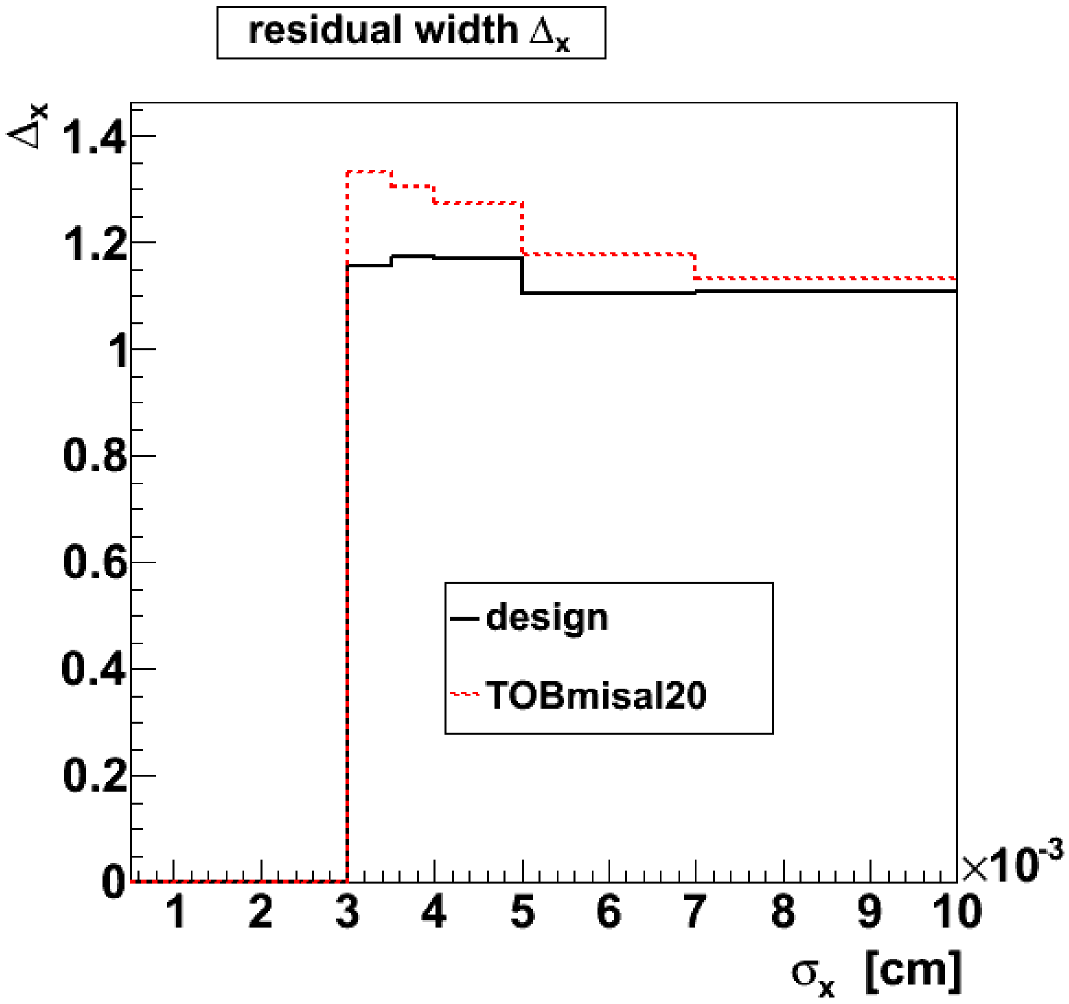
- bla

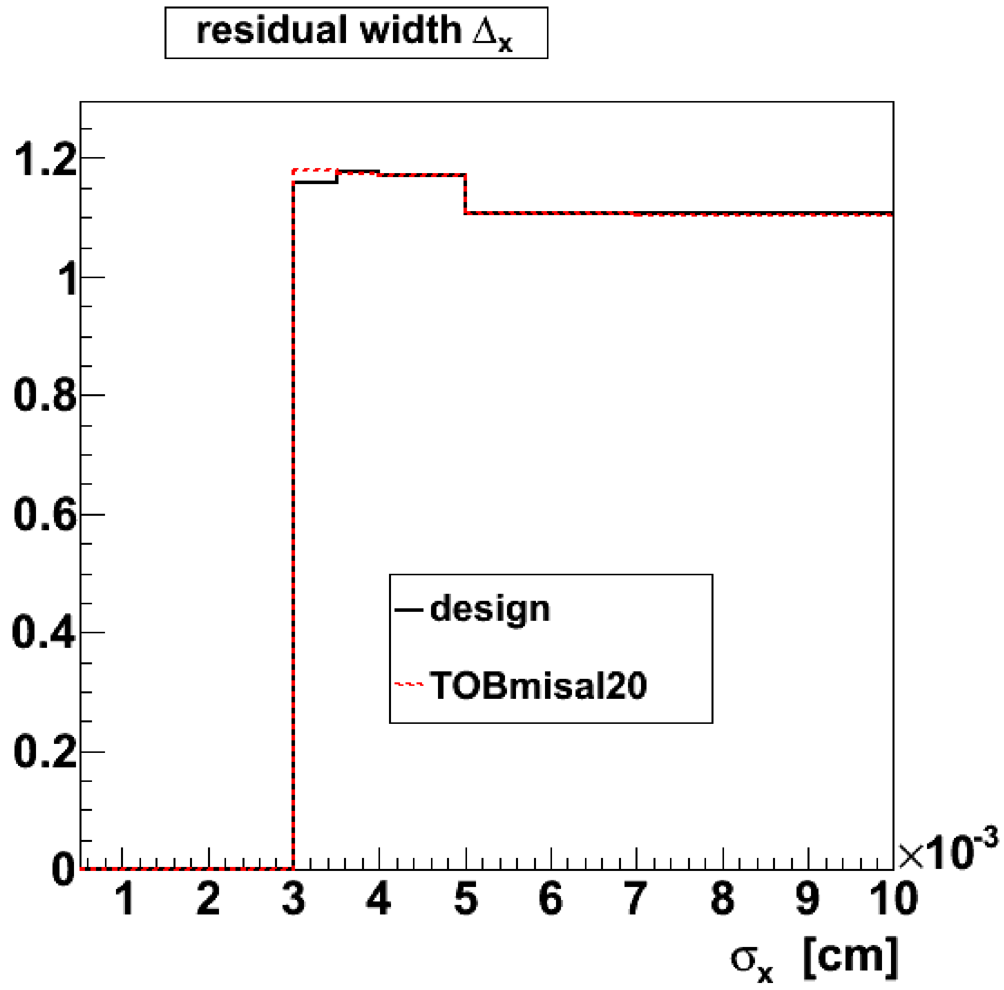




TOB layer 1 inwards, residual width wrt. residual resolution

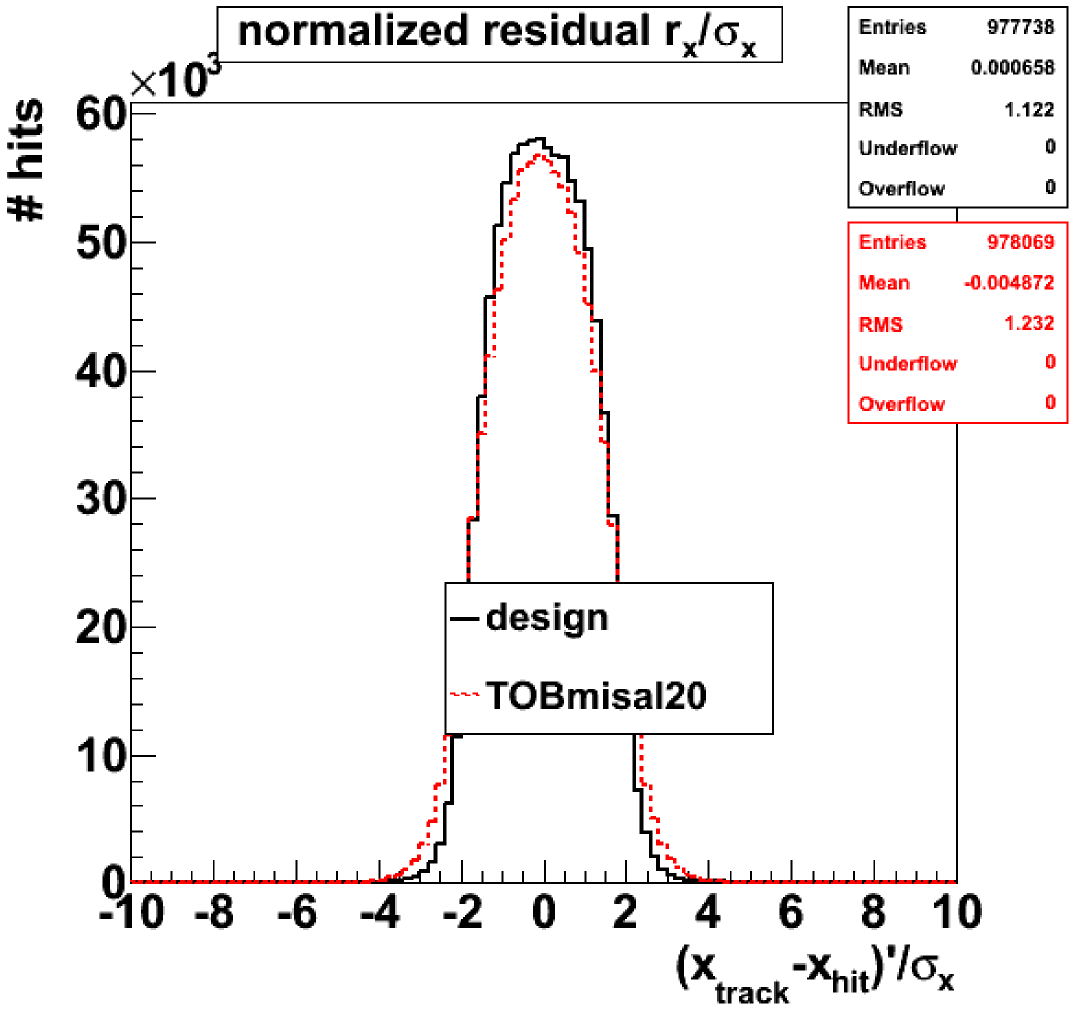
- bla

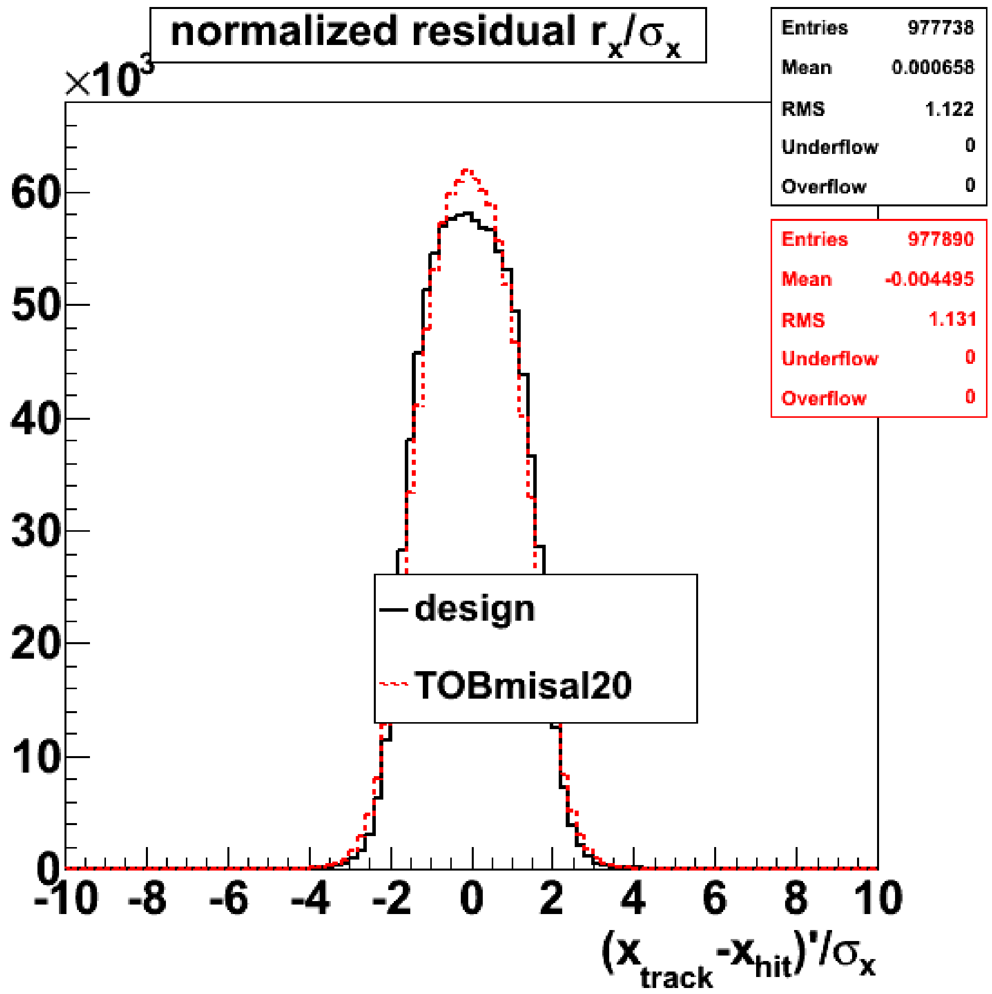




TOB layer 4 outwards, normalized residuals

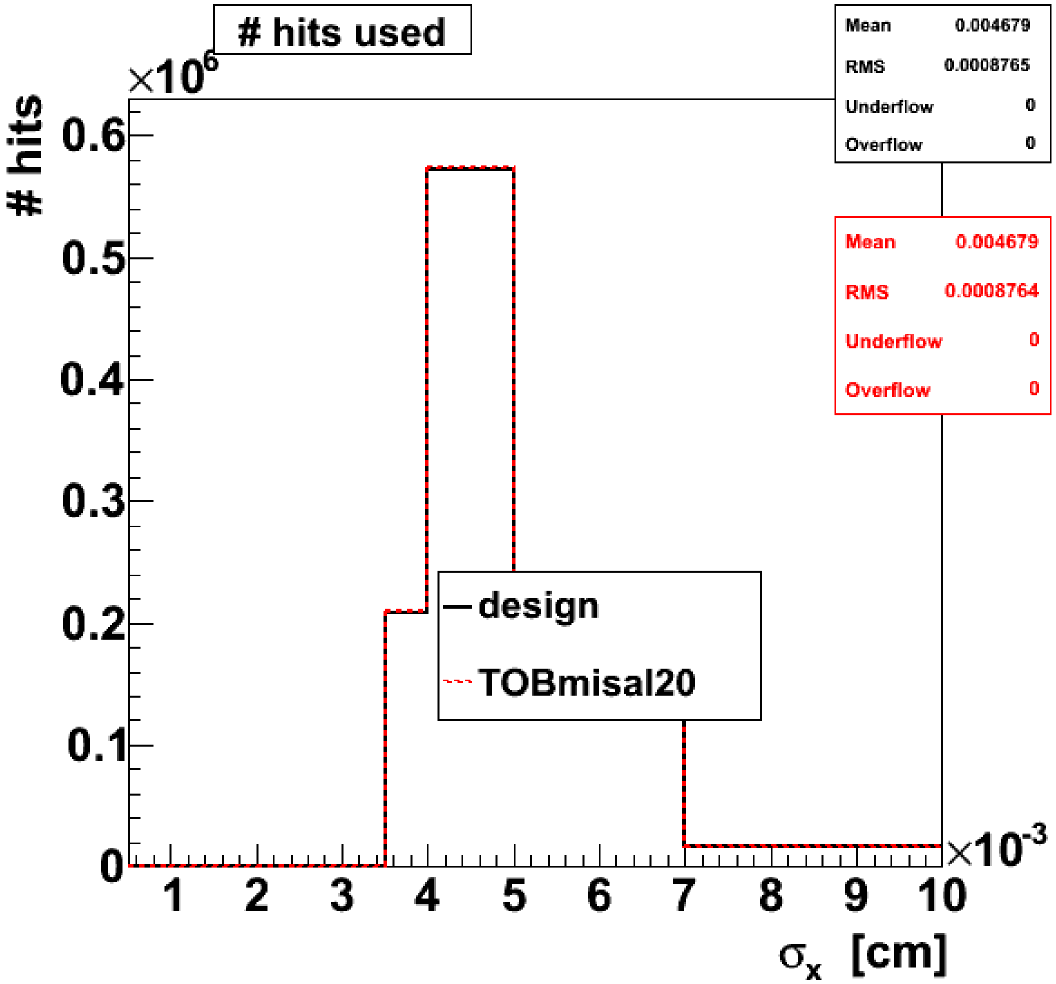
- bla

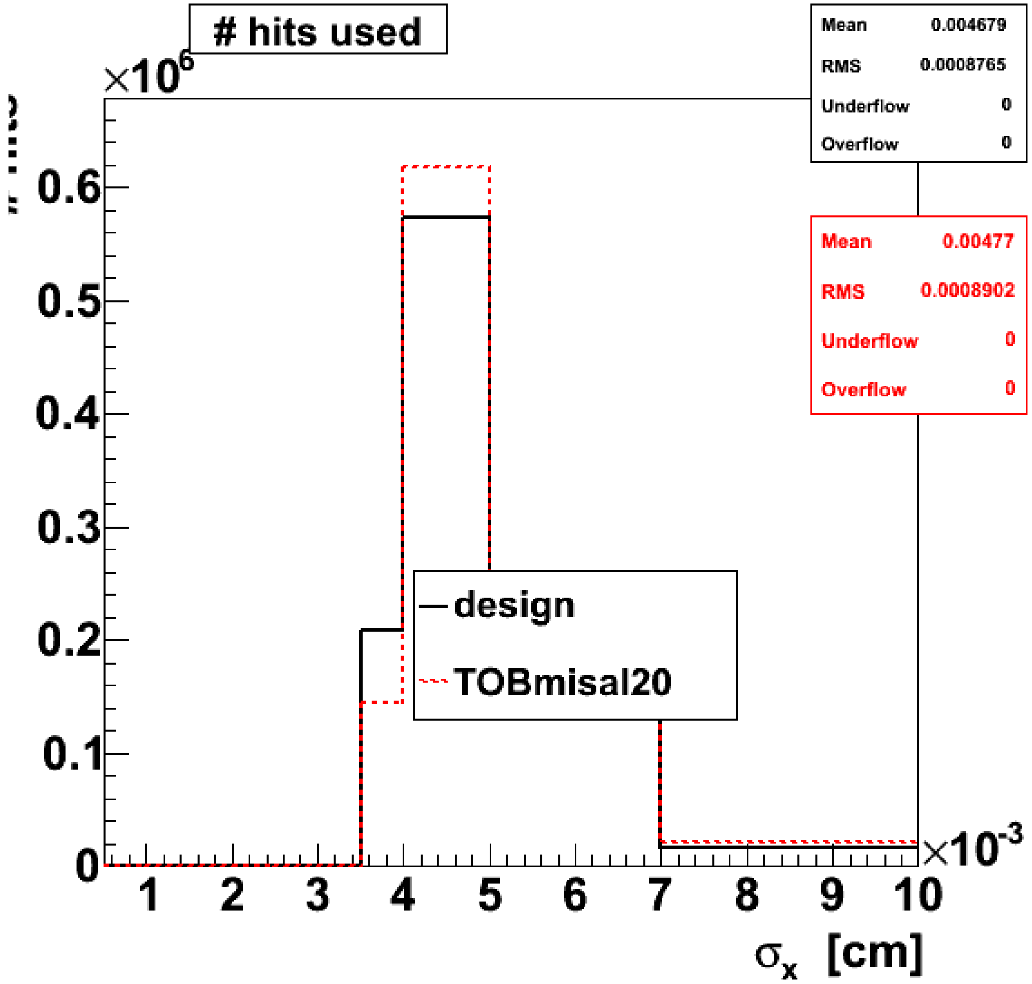




TOB layer 4 outwards, entries in residual resolution intervals

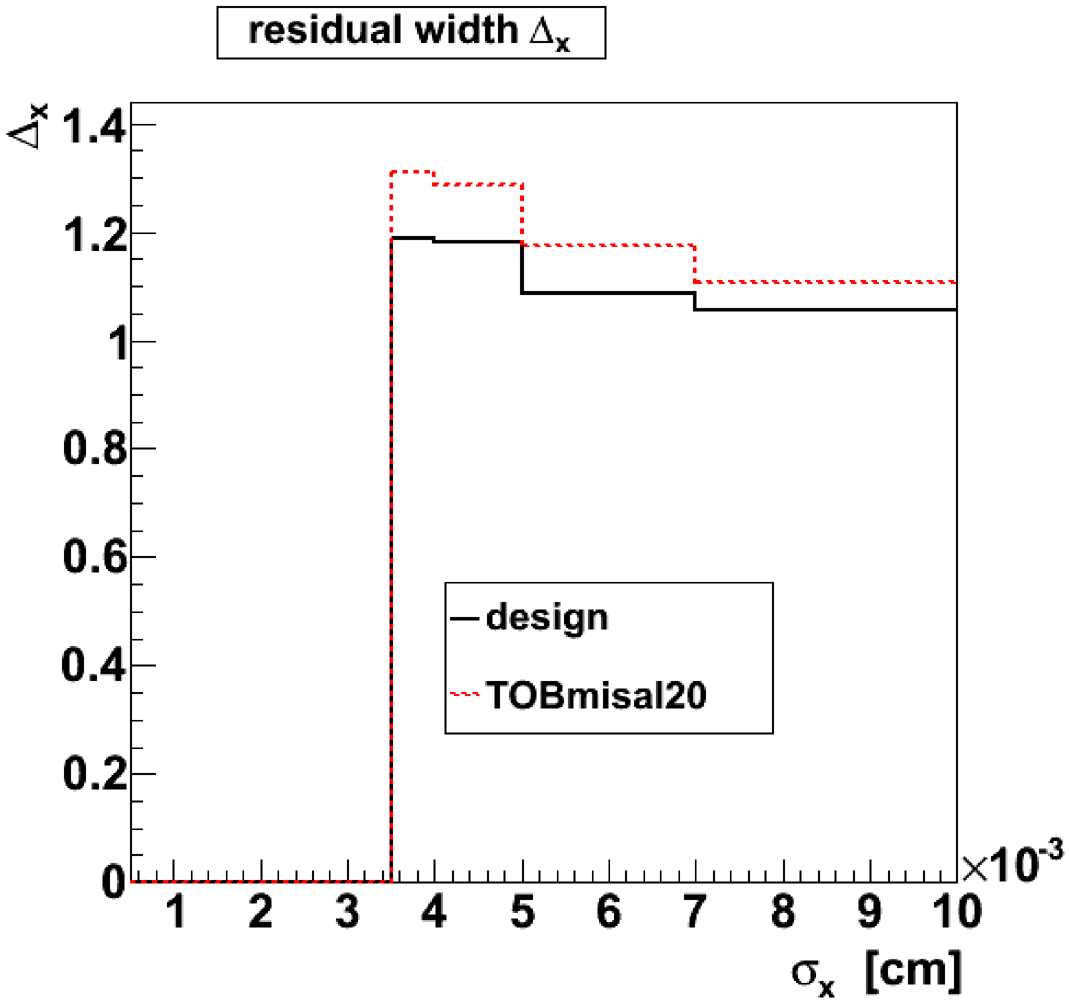
- bla

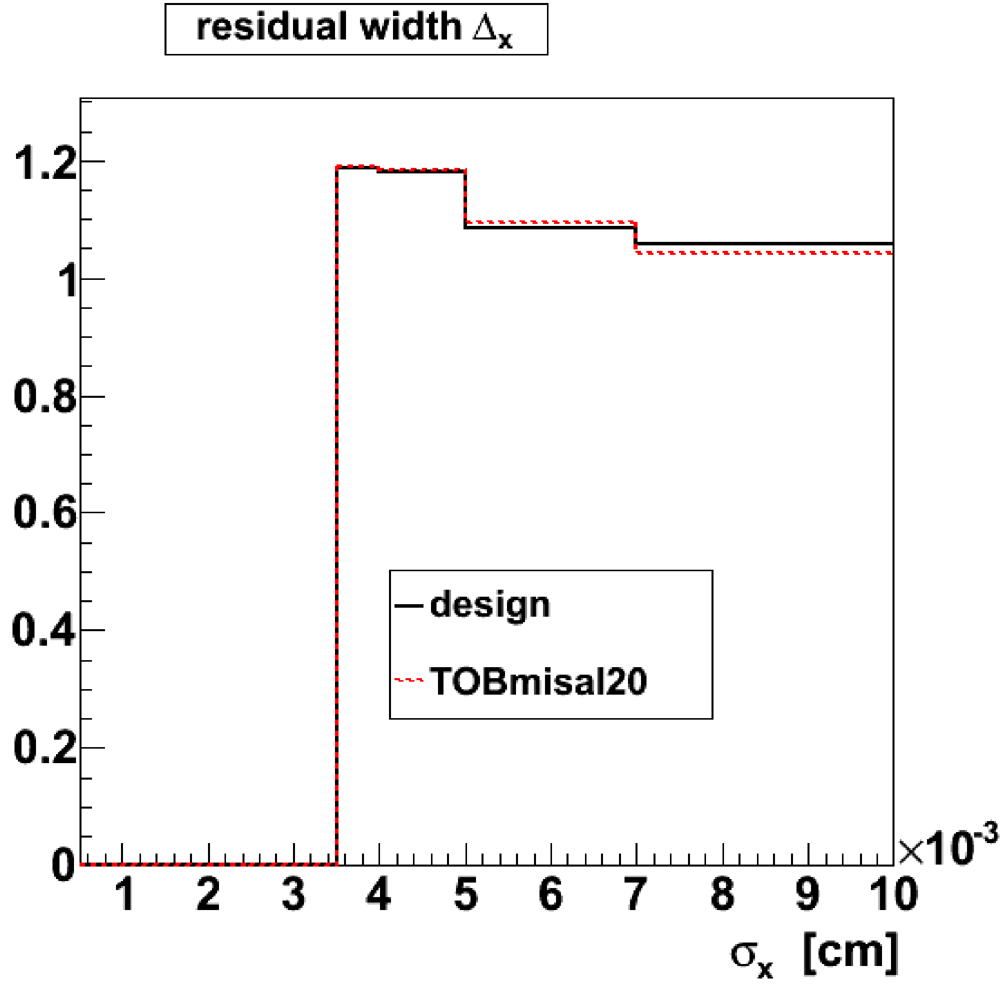




TOB layer 4 outwards, residual width wrt. residual resolution

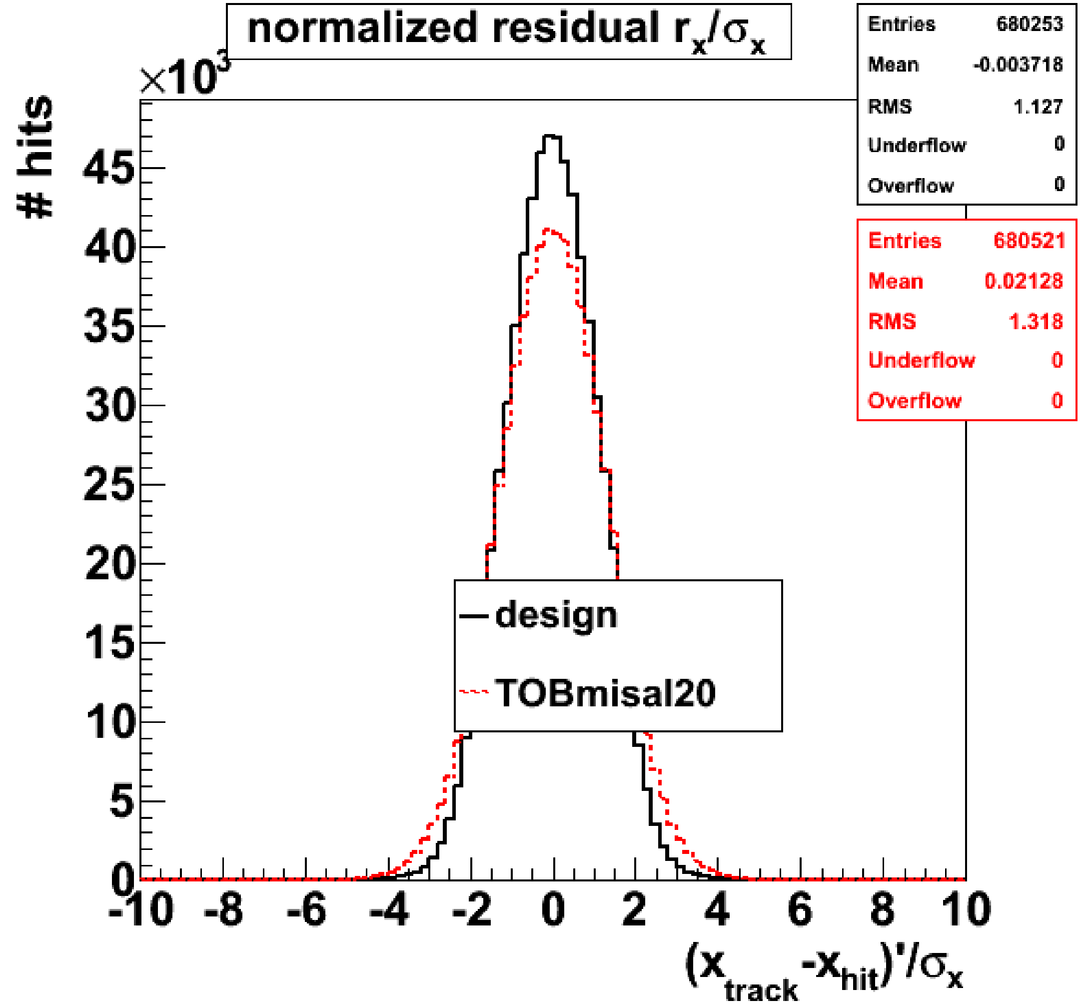
- bla

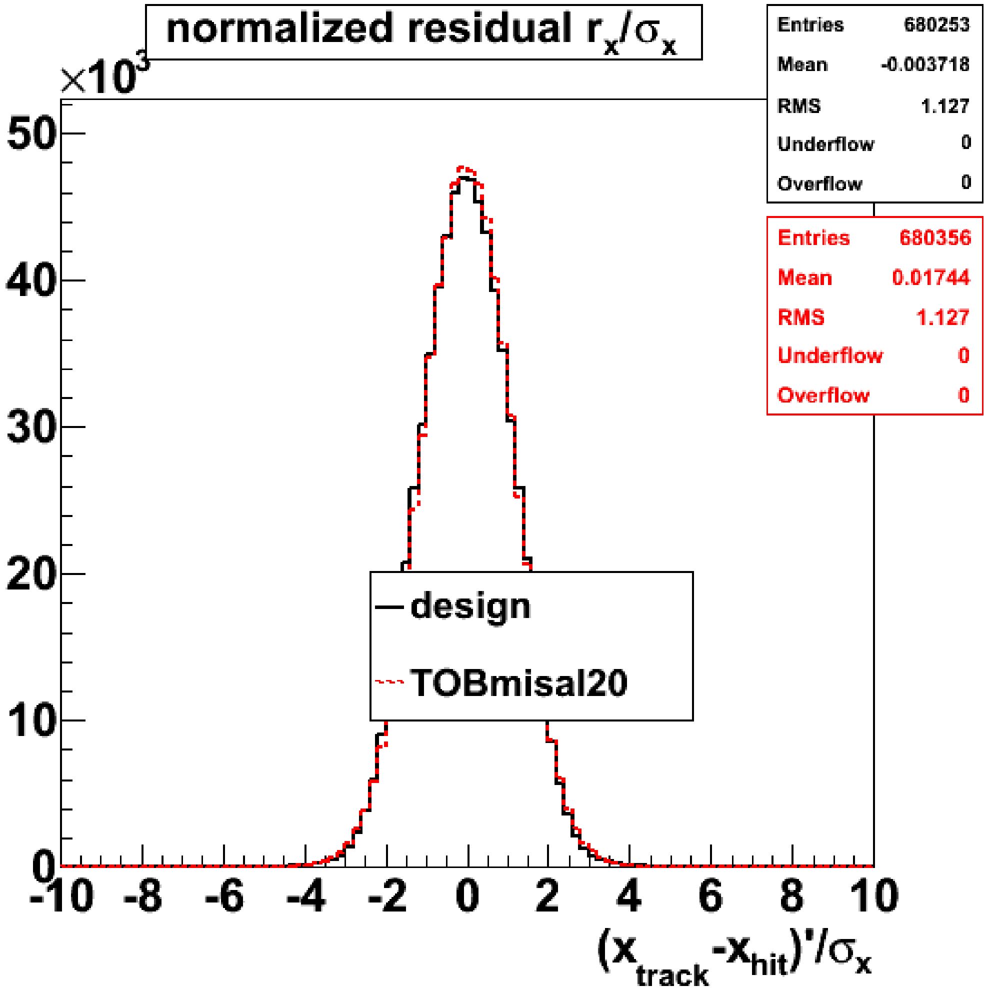




TOB layer 6 inwards, normalized residuals

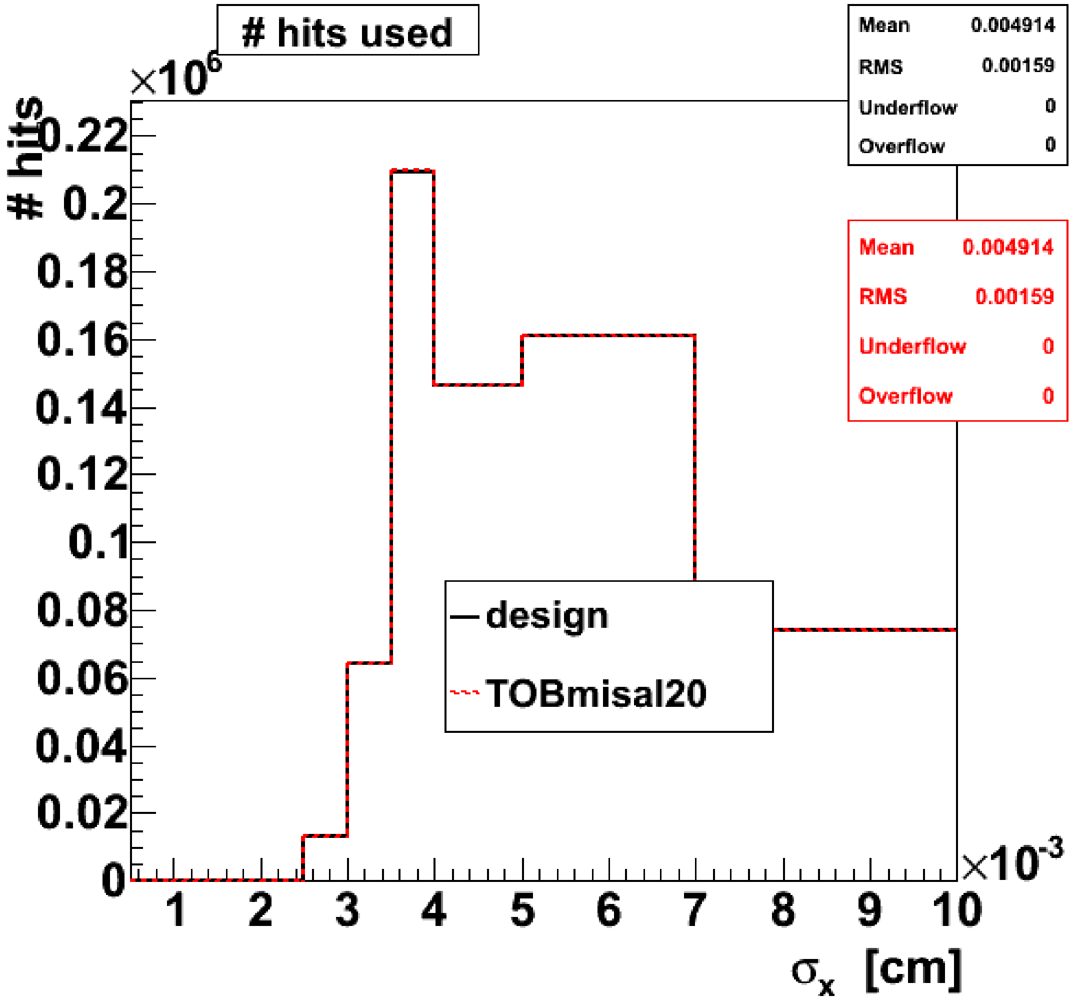
- bla

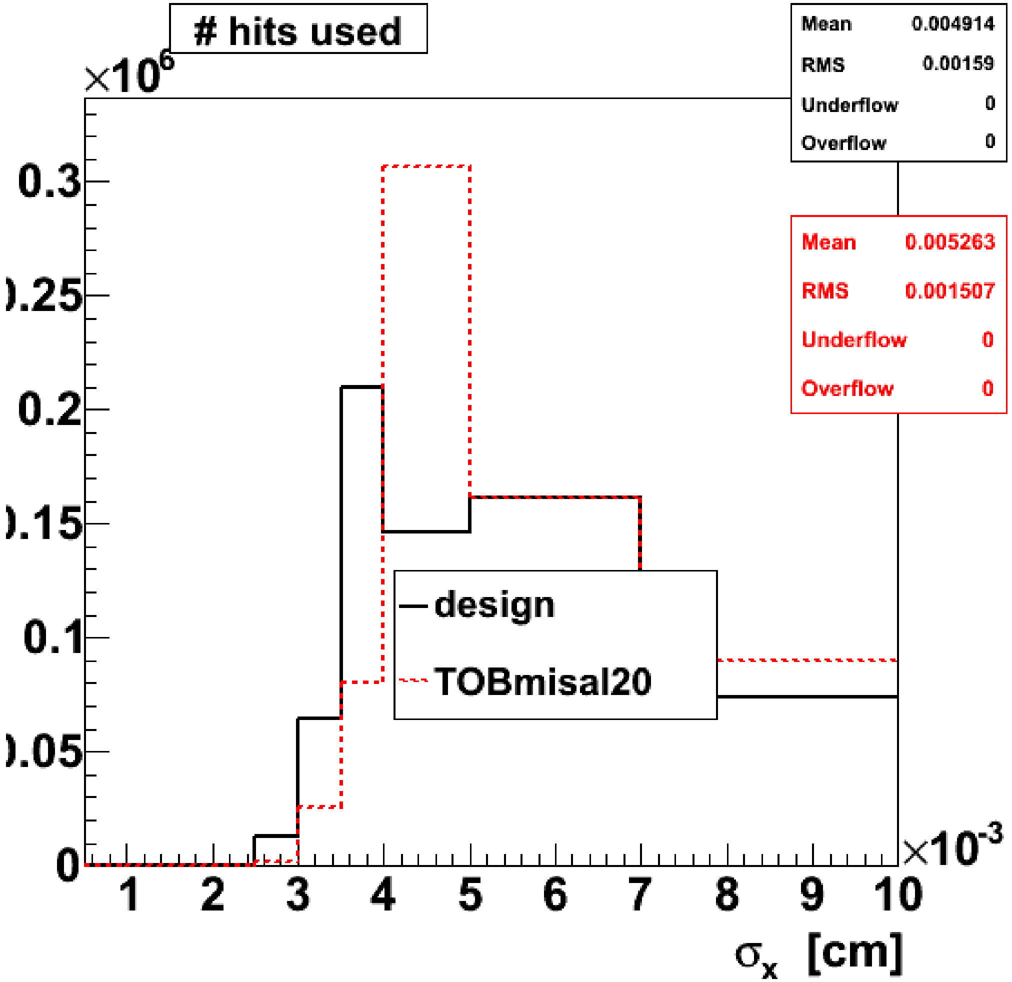




TOB layer 6 inwards, entries in residual resolution intervals

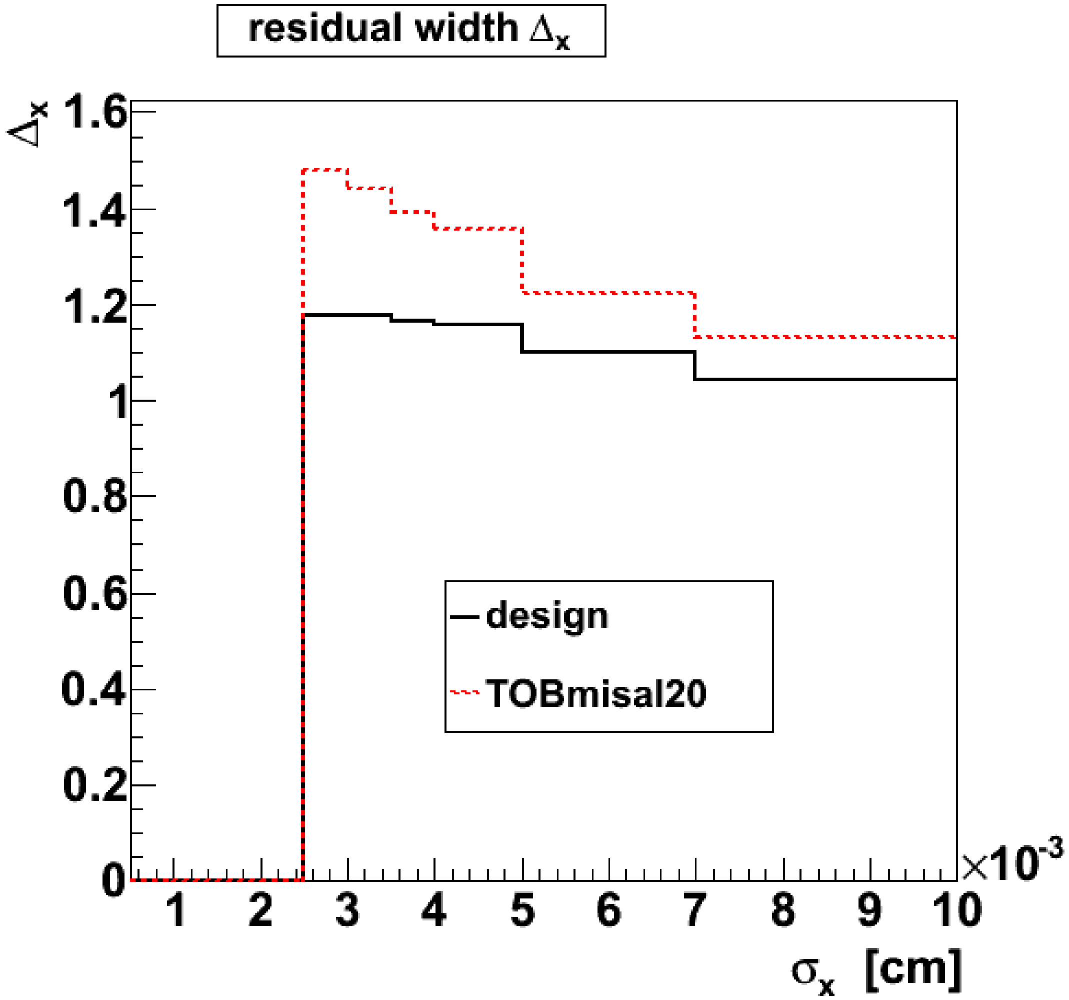
- bla

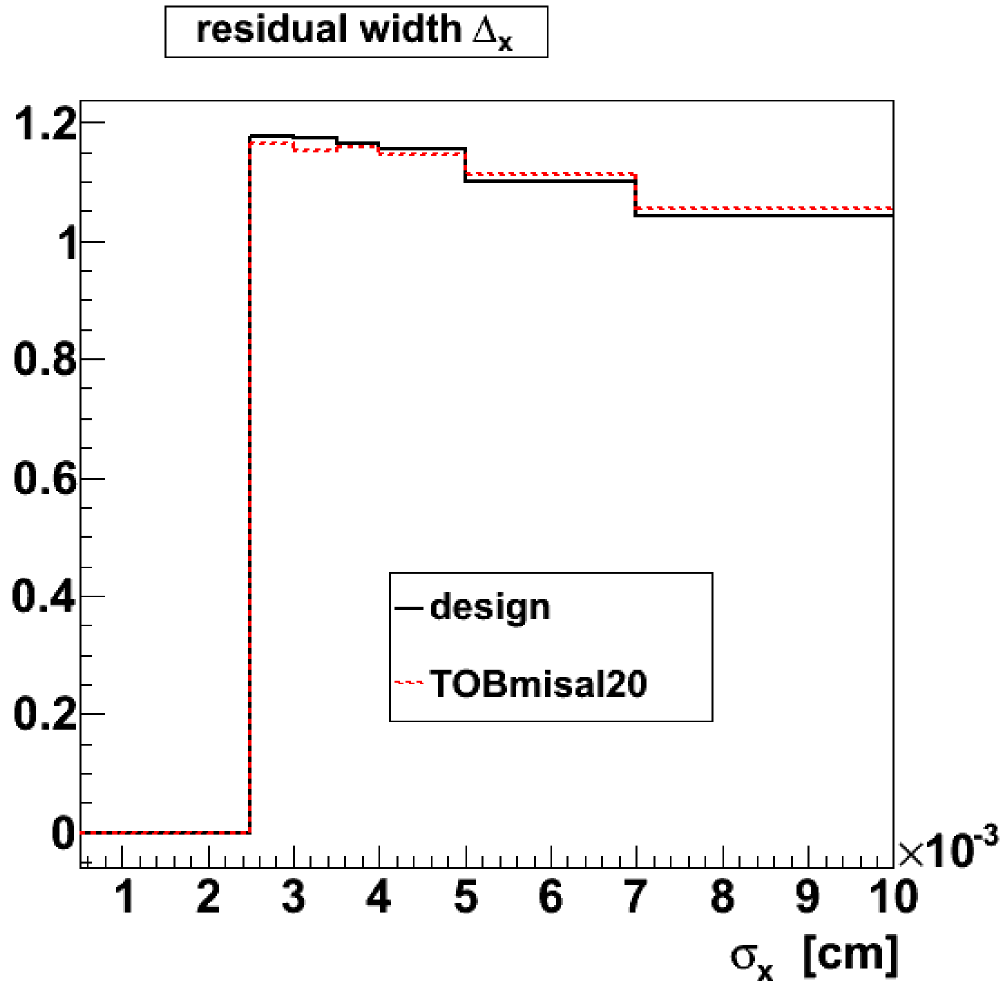




TOB layer 6 inwards, residual width wrt. residual resolution

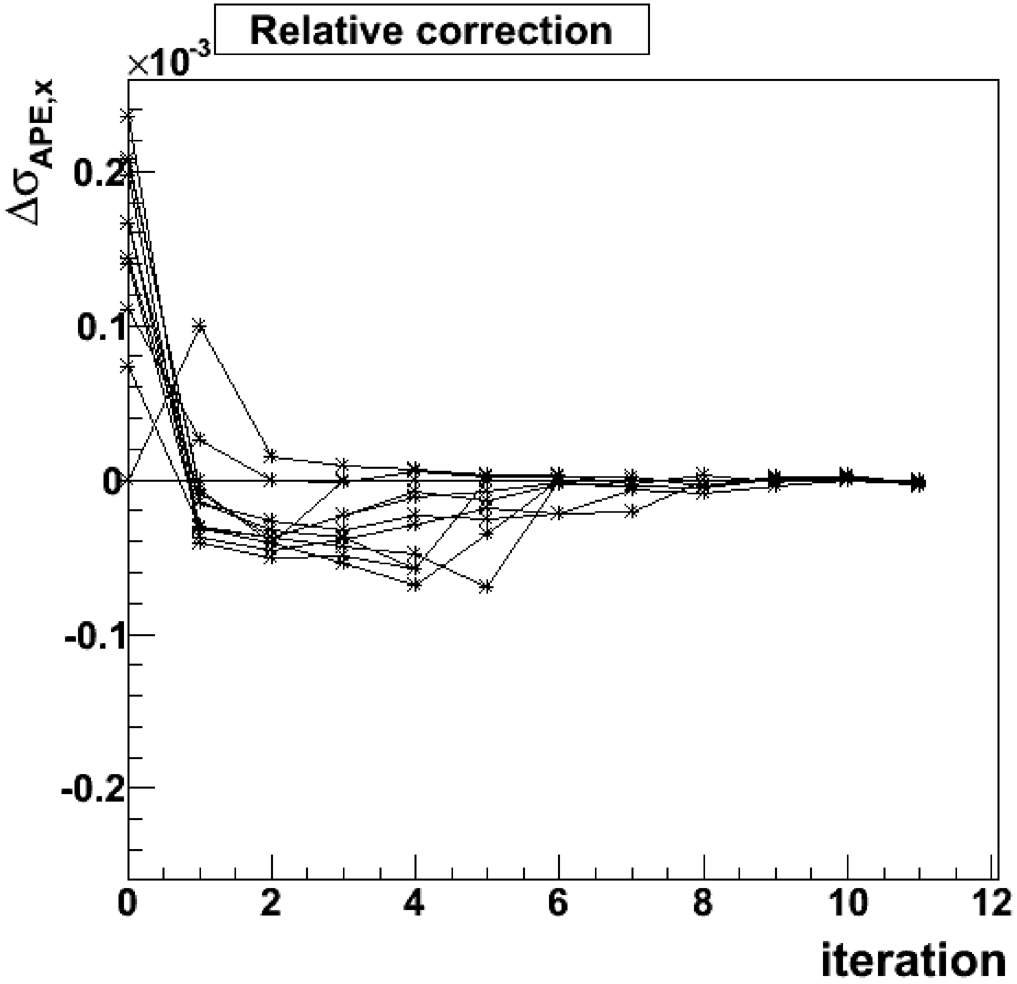
- bla

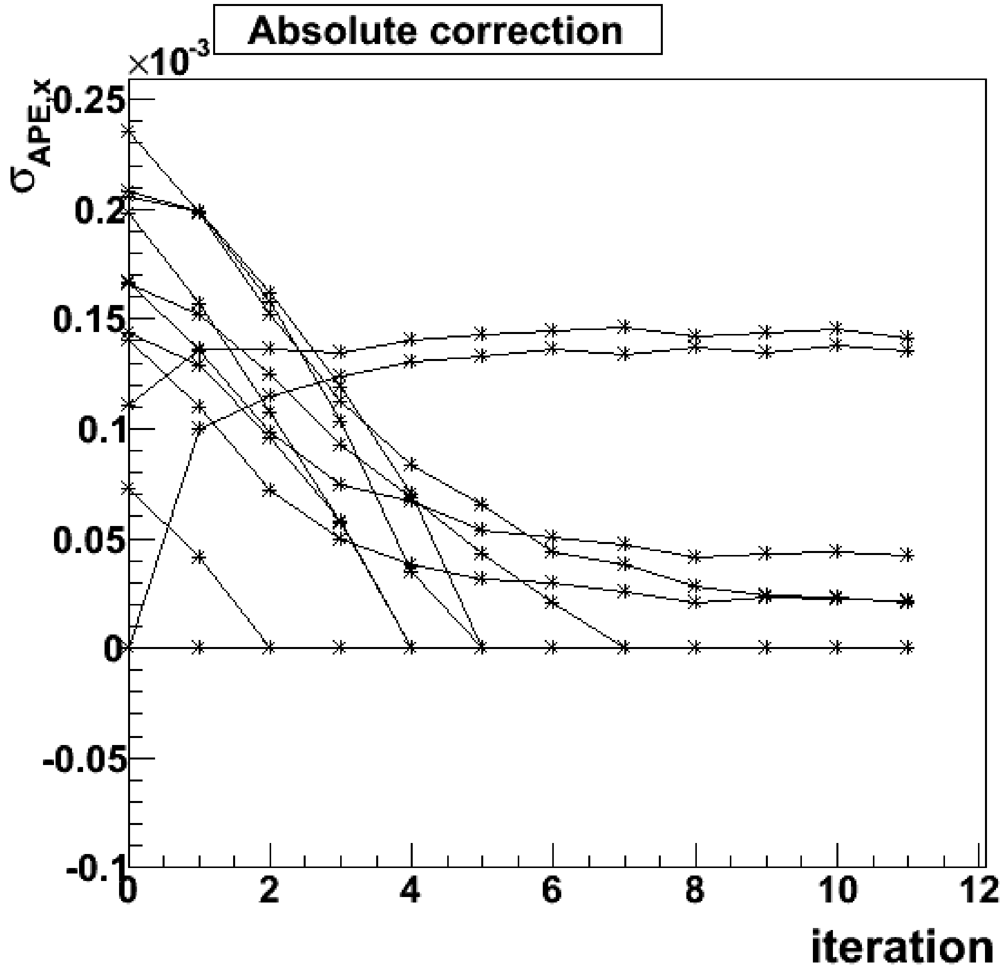




Result in TIB

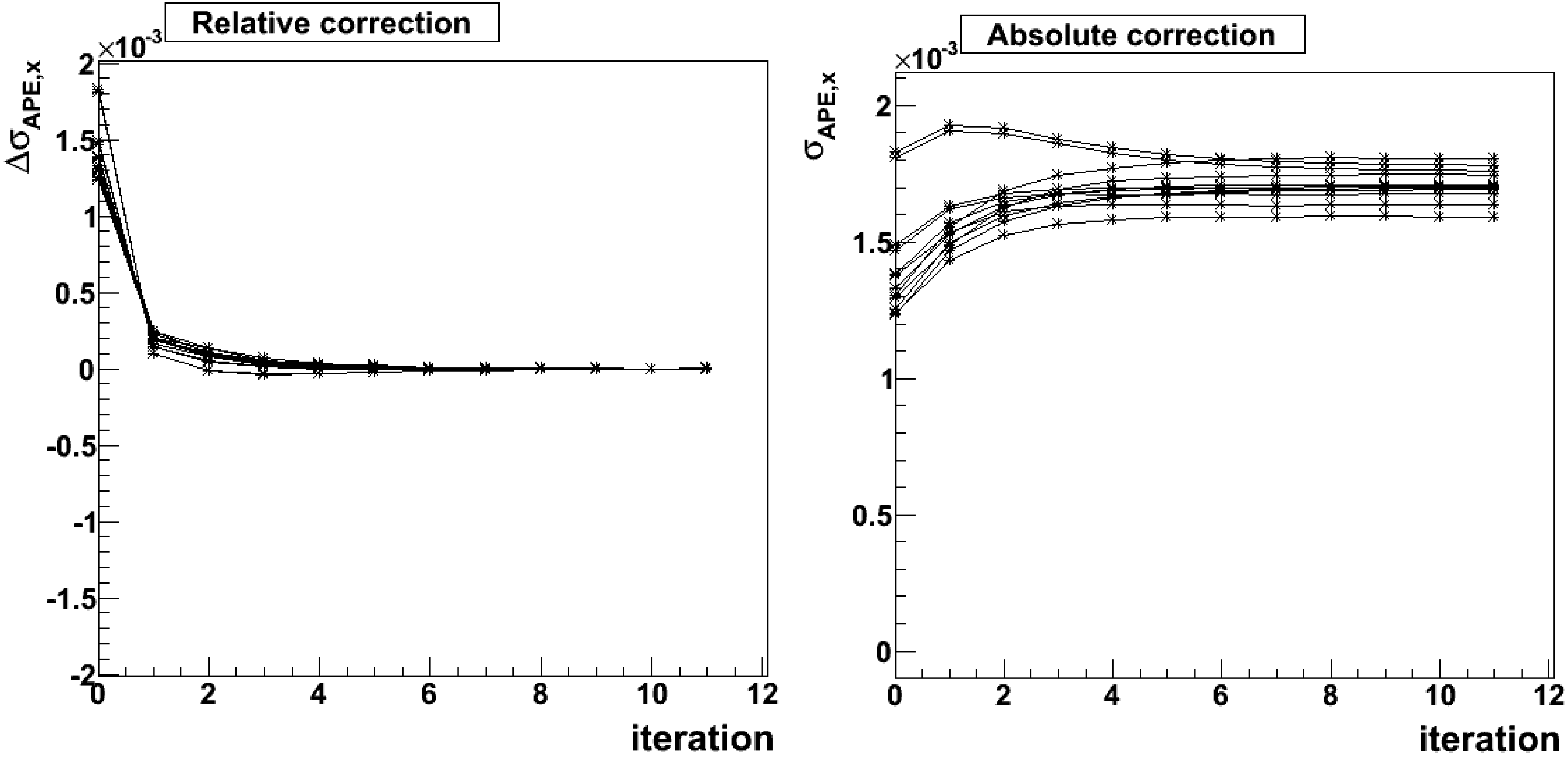
- bla





Result in TOB

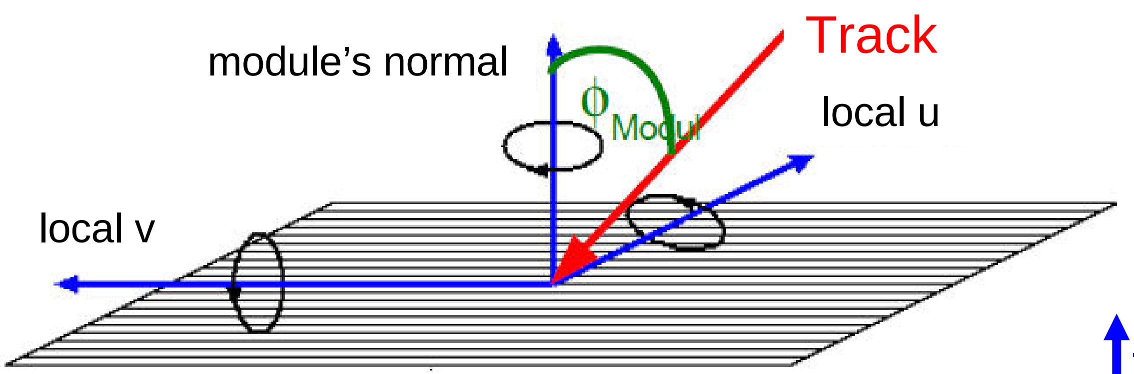
- bla

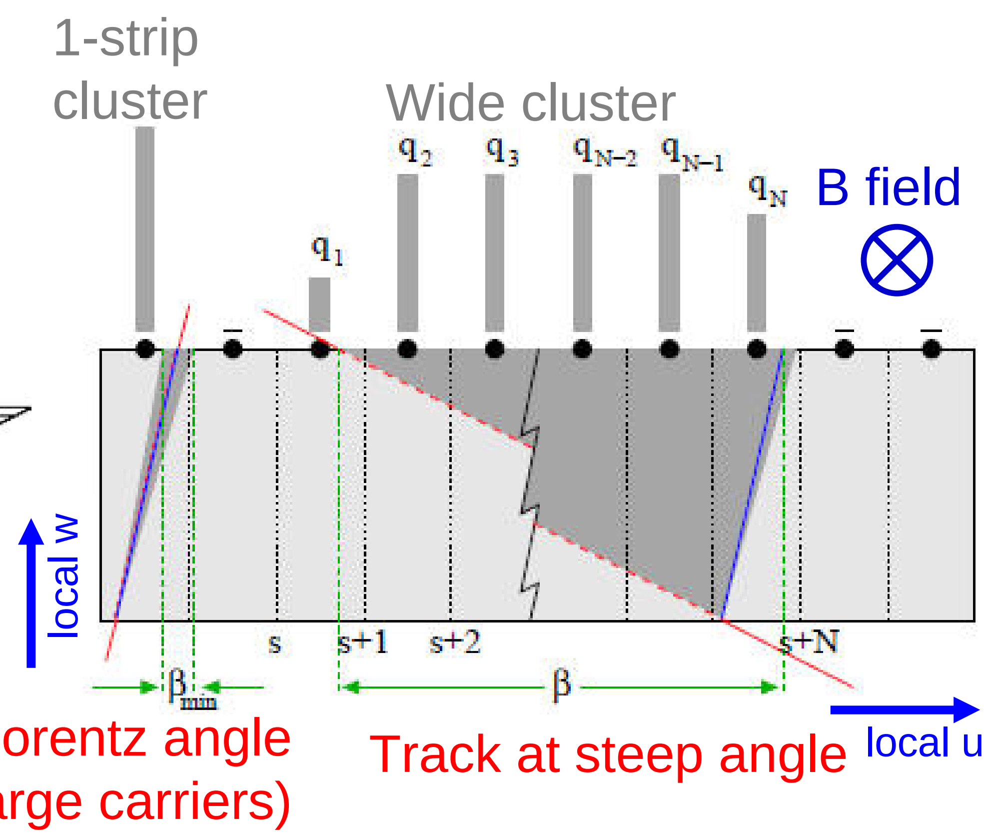


--- BACKUP ---

Incident angle & cluster width

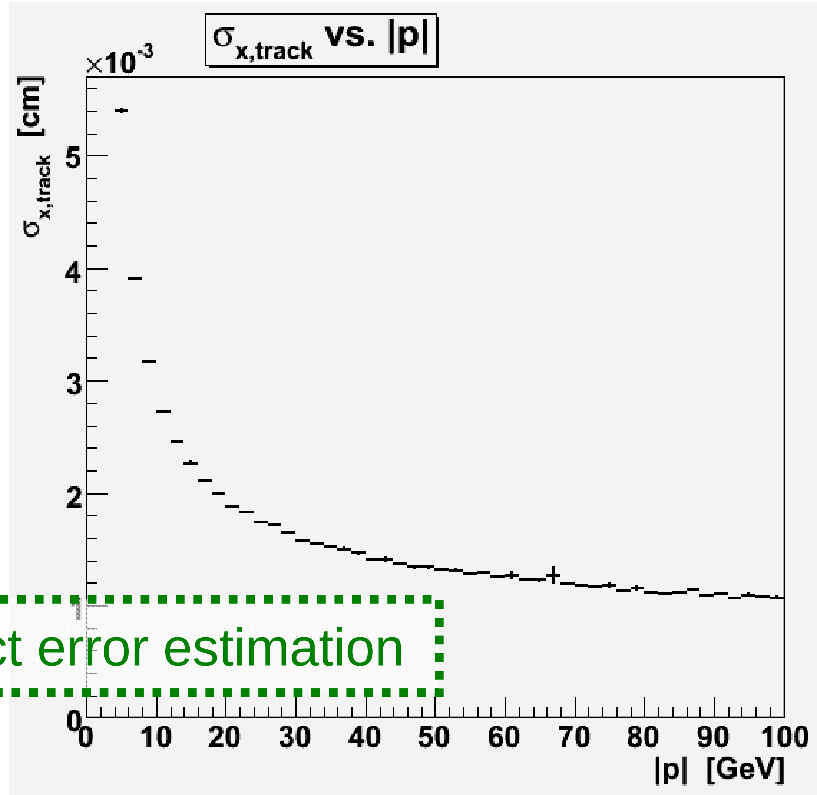
- No. of strips (pixels) with induced charge dependent on incident angle perpendicular to strips (related to module's normal)
  - B field → drift of charge asymmetric (Lorentz angle)
- Parametrisation of hit position and error adjusted for collisions
  - From interaction region
  - Small angles in general

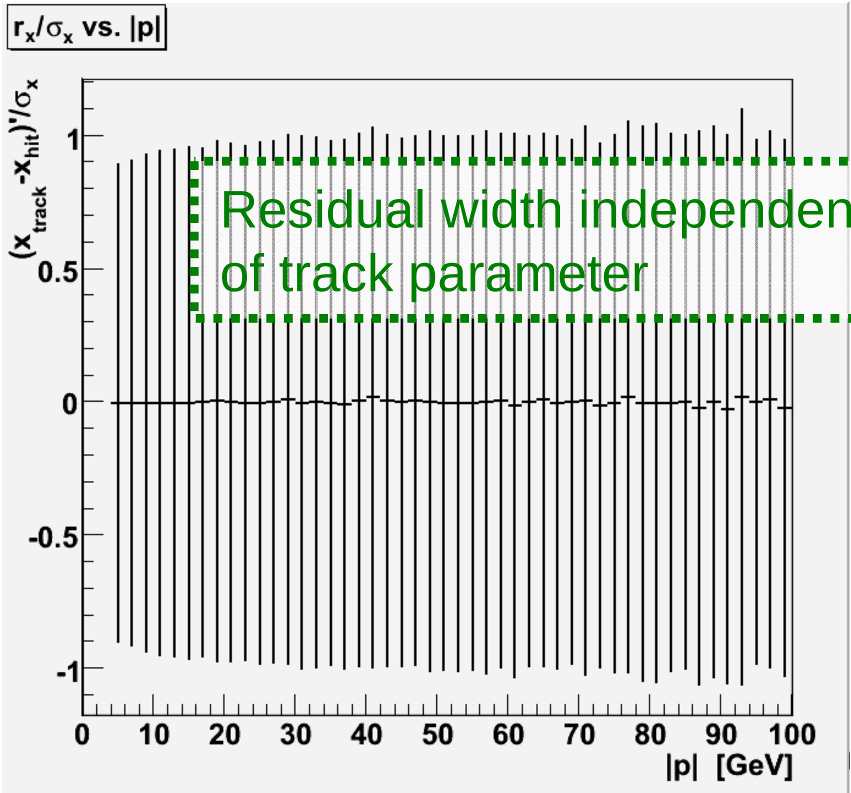




Dependency of residual width on track parameters

- Look at relevant hit parameters in intervals of track parameter
  - Error of track extrapolation: Decrease with increasing momentum, Multiple scattering $\sigma_{MS} \sim p^{-1}$



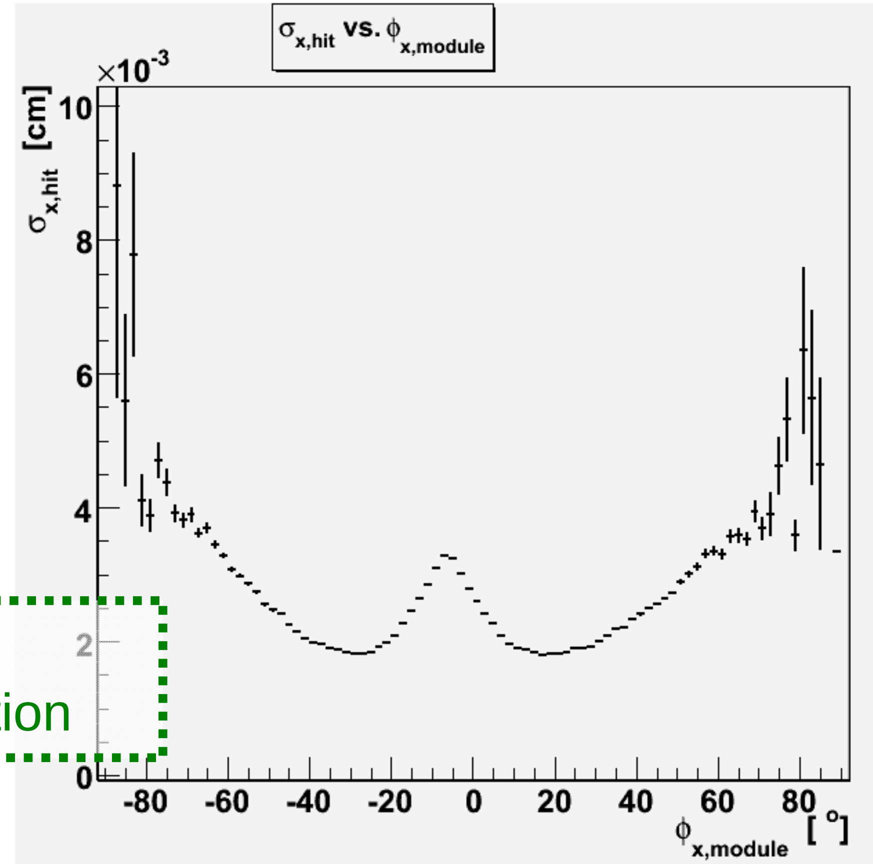


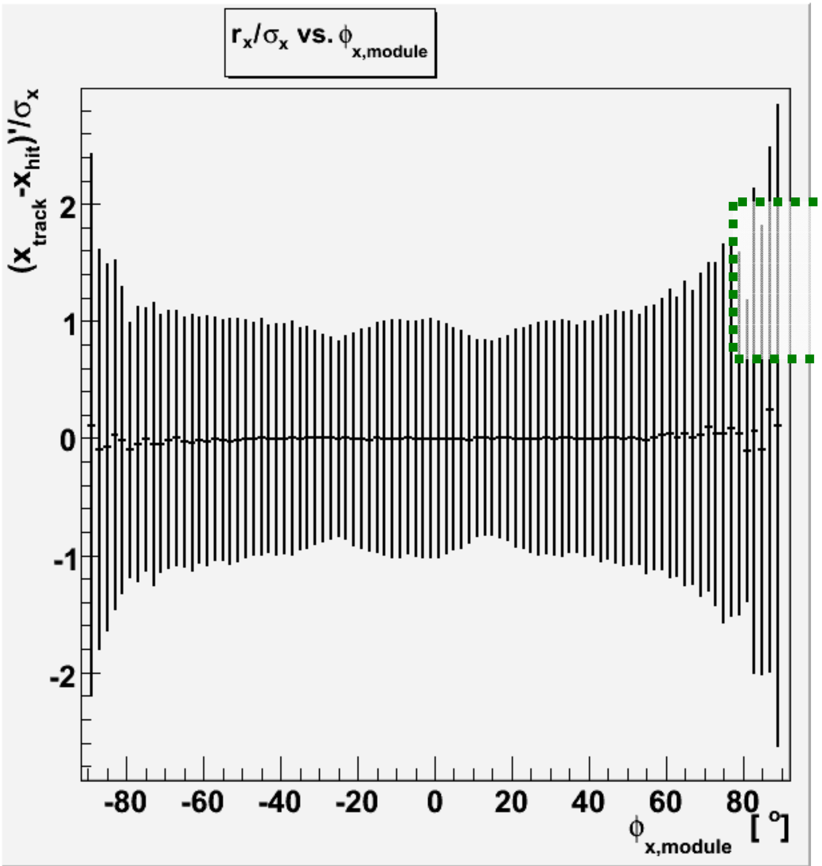
Residual width independent of track parameter ⟺ Correct error estimation

- Width of normalised residual distribution: Error bars - RMS per momentum interval almost const. ≈1 for $p > 10$ GeV, Mean close to 0

Dependency of residual width on hit parameters

- Intervals of hit parameter
  - Hit error:
    maximum precision: 2-strip cluster
    → minimal at about ±20°
    (Lorentz angle → asymmetry)

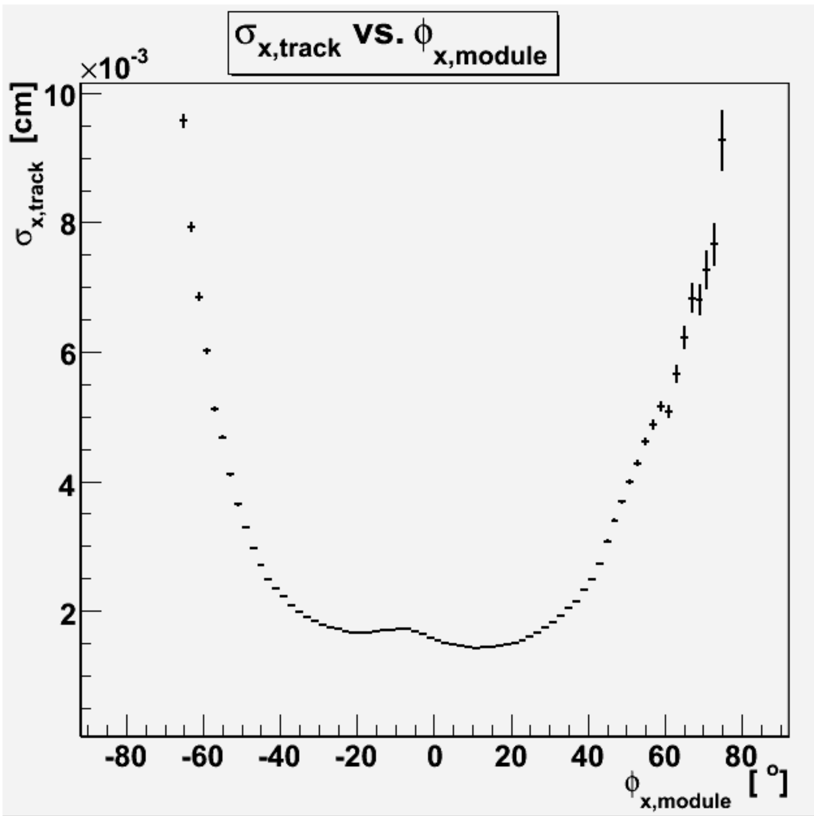




Problem in hit parametrisation

  - Normalised residual width:
    For steep angles clear broadening visible
    → cut on huge angles reasonable (expected)
    Obvious discrepancy also for other angles
    → indication for inaccurate error valuation

Incident angle perpendicular to strips



Incident angle parallel to strips