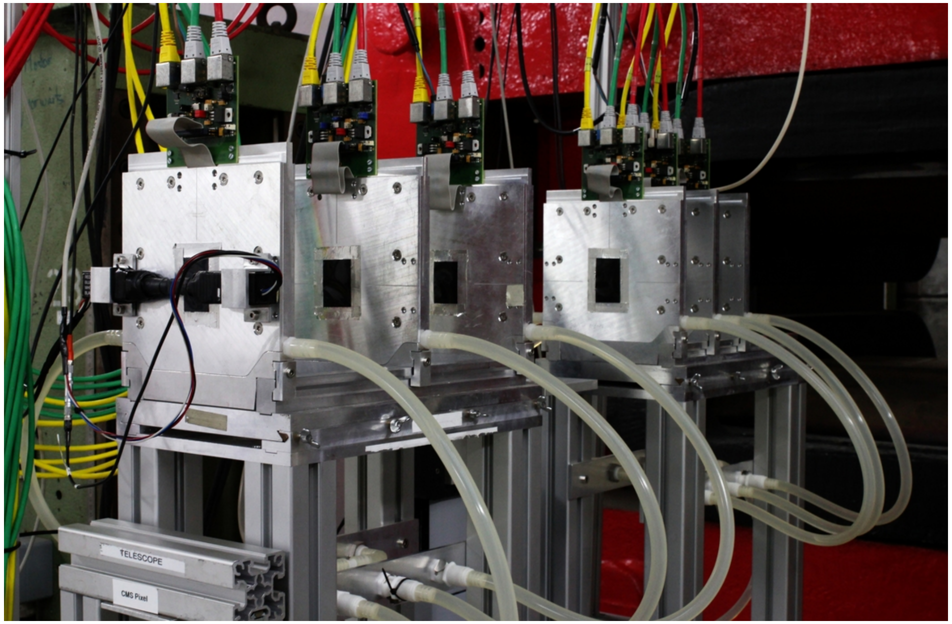
Intrinsic resolution studies with the DATURA beam telescope

Iterative pull analysis

Hendrik Jansen

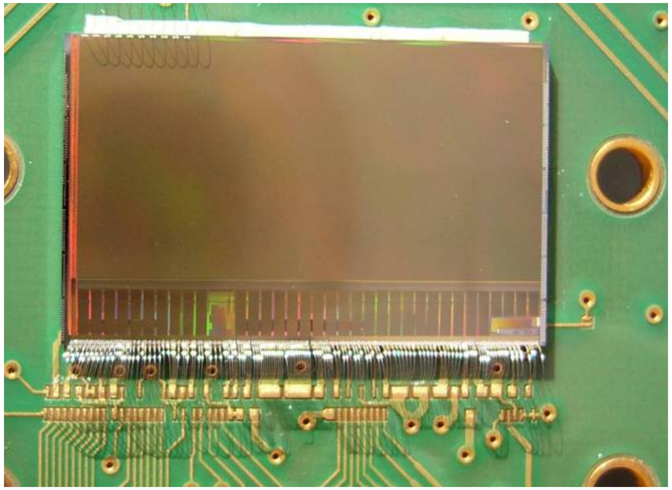
DATURA

- Located at DESY TB hall 21
- 6 Mimosa 26 sensors
- EUDET TLU
- 4 scintillators
- NI-based DAQ system
- PI x-y-phi stage for DUT
- CMS pixel or ATLAS FE-I4 reference plane
- … (See talk by JDE Wednesday 14:40)



→ Measure the intrinsic resolution of pixel planes
→ Predict/Optimise set-up dependent track resolution

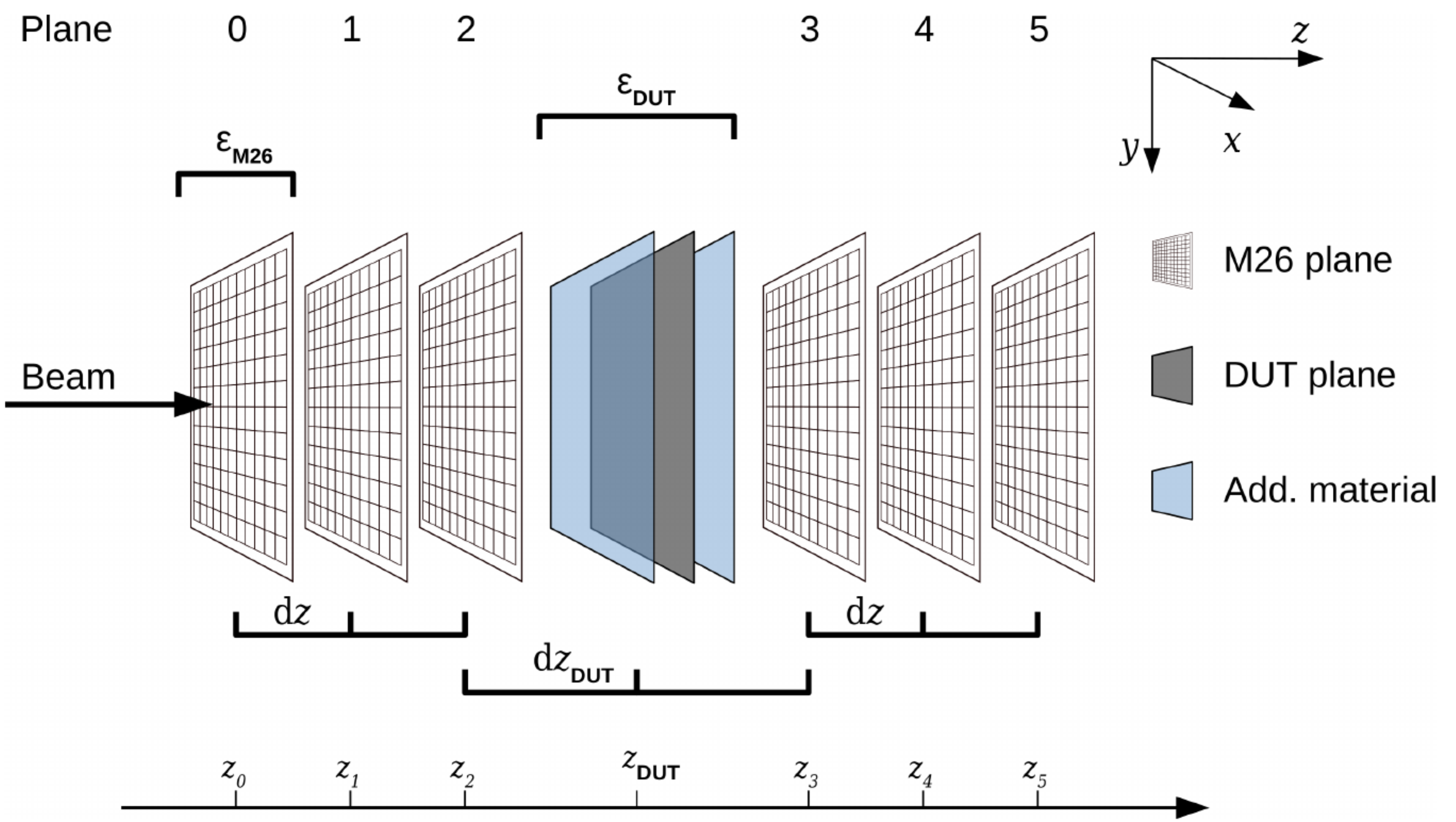
Mimosa 26 pixel sensors



- AMS 350 nm CMOS
- 18.4 um x 18.4 um
- 1152 x 576 pixels
- Roughly 10 mm x 20 mm
- Thickness: specs 50 um, measurement (55 pm 3) um
- HR epitaxial layer of 10 um thickness
- Binary resolution 5.3 um, improved by charge sharing
- Protected by 25 um Kapton on each side
- Material budget of sensor plus Kapton: ε = 7.5e-4

Measurement geometries

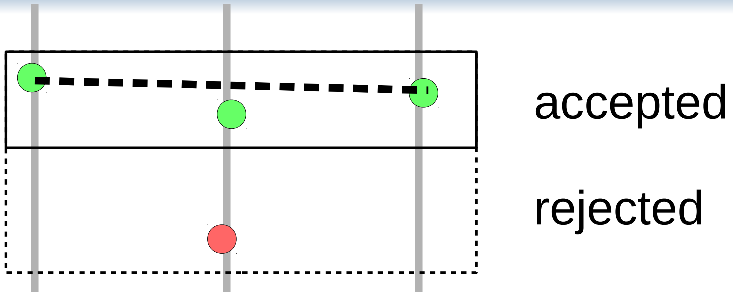
- Plane spacing dz = 20 mm (narrow) or 150 mm (wide)
- Total material budget: 4.8e-3 and 7.0e-3, respectively



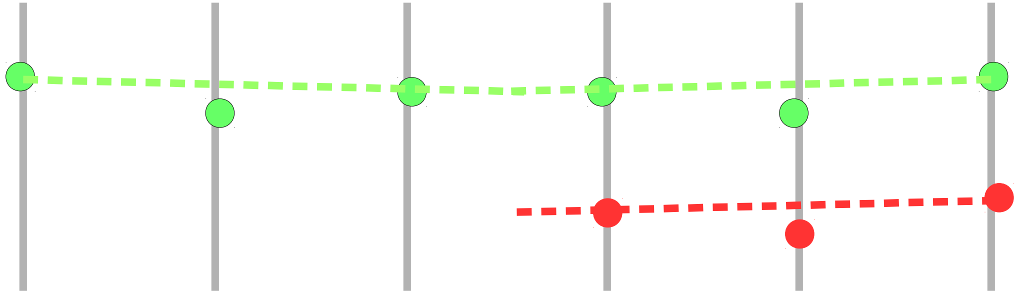
Offline analysis and reconstruction

- EUTelescope is based on the ILCSoft framework:
  - generic data model (LCIO)
  - geometry description (GEAR)
  - central event processor (Marlin)
- Marlin allows for modular composition of analysis chain
- Build-in job submission framework
- Steering of analysis via XML files loaded at runtime
- EUTelescope provides processors for full track reco including:
  - Alignment with Millepede-II
  - Deterministic Annealing Filter (DAF)
  - General Broken Lines (GBL) ← Used herein

Data analysis flow



- Start with raw Mimosa26 data
- Hot pixel search
- Cluster formation, remove clusters with hot pixels
- Track triplets built for up- and downstream plane trio
- Isolation cut on triplets
- Match up- and downstream triplets in the centre
  → track with 6 hits
- Feed tracks to Millepede
  for alignment
  (multiple times if needed)

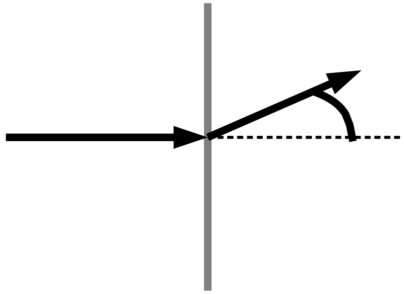


Multiple scattering

- Average deflection predicted by Highland

$$\Theta_0 = \frac{13.6\,\mathrm{MeV}}{\beta c p} \cdot z\sqrt{\varepsilon} \cdot \left(1 + 0.038 \ln\left(\varepsilon\right)\right)$$

- Literature offers other models, too, HL most popular
- Questionable if rad. length is a good measure for deflection



- Distribution assumed to be Gaussian, maybe not true for thick scatterers
- Non-Gaussian tails
- Overall accuracy of Highland ~11%

GBL

http://www.desy.de/~kleinwrt/GBL/doc/cpp/html/

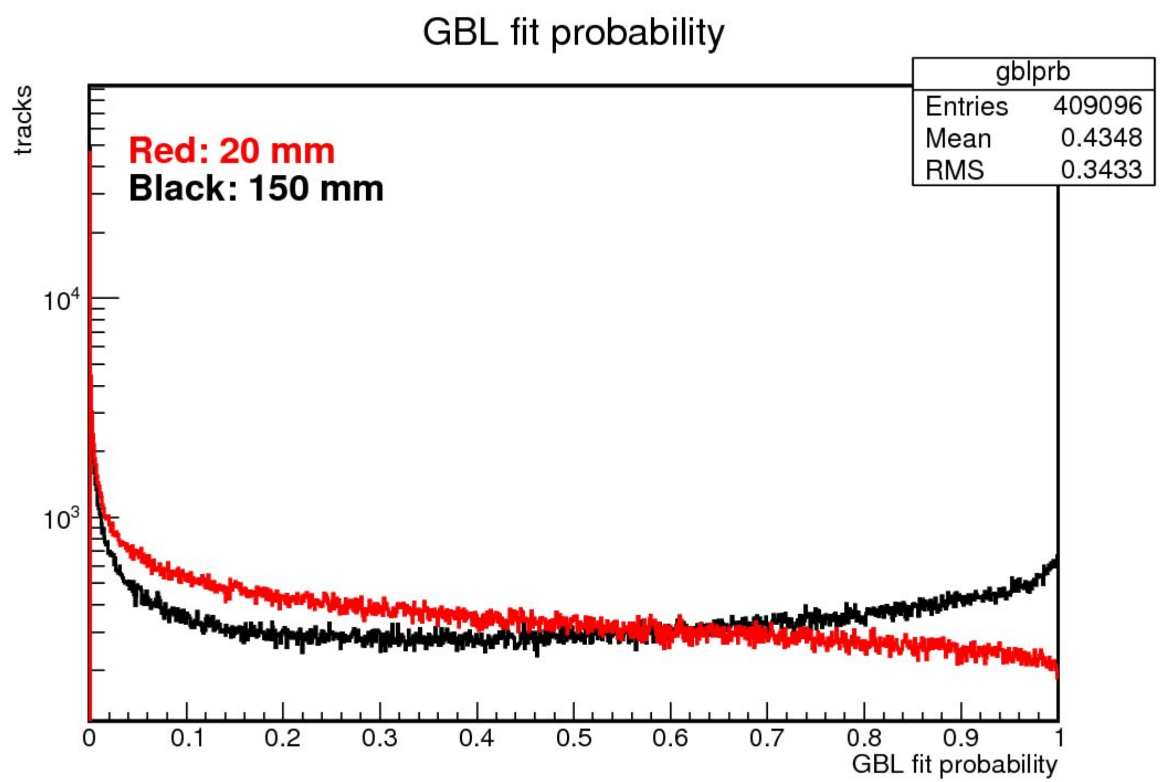
- Allow for kinks at scatterers
- Propagate measurement error and kink error from point to point along trajectory
- Perform chi2 minimisation to find track parameters
- Available also for set-ups with magnetic fields
- Track model does not include bremsstrahlung, non-Gaussian tails or non-linear effects
- Inputs: Measurement error, geometry, scattering estimate
- Outputs: residual, res. error, res. width estimate, kinks, etc.

V. Blobel, C. Kleinwort, and F. Meier. Fast alignment of a complex tracking detector using advanced track models. Computer Physics Communications, 182(9):1760 – 1763, 2011.

C. Kleinwort. General broken lines as advanced track fitting method. Nucl. Instr. Meth. Phys. Res. A, 673:107–110, May 2012.

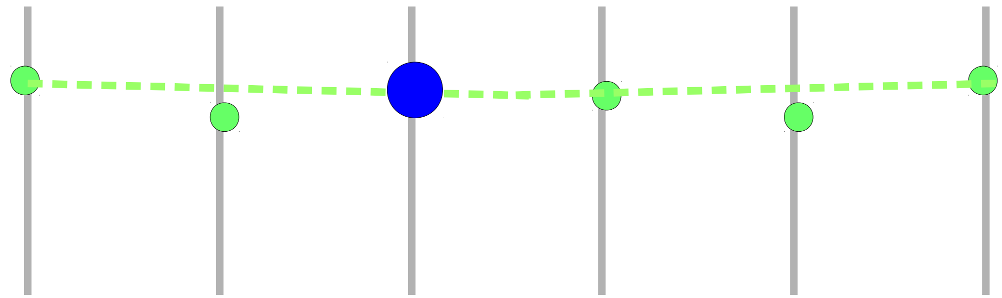
Track cleaning

- Cut on tracks: prob < 0.01 (0.1) for 20 mm (150 mm) - model less valid for larger amount of material budget
- Use robust statistics (down-weighting of out-layers) only if you don't have enough data (and if you know what you are doing)
- If track collection is not cleaned, “bad” tracks affect the measured intr. reso.



Residuals

- Biased and unbiased tracks are different!



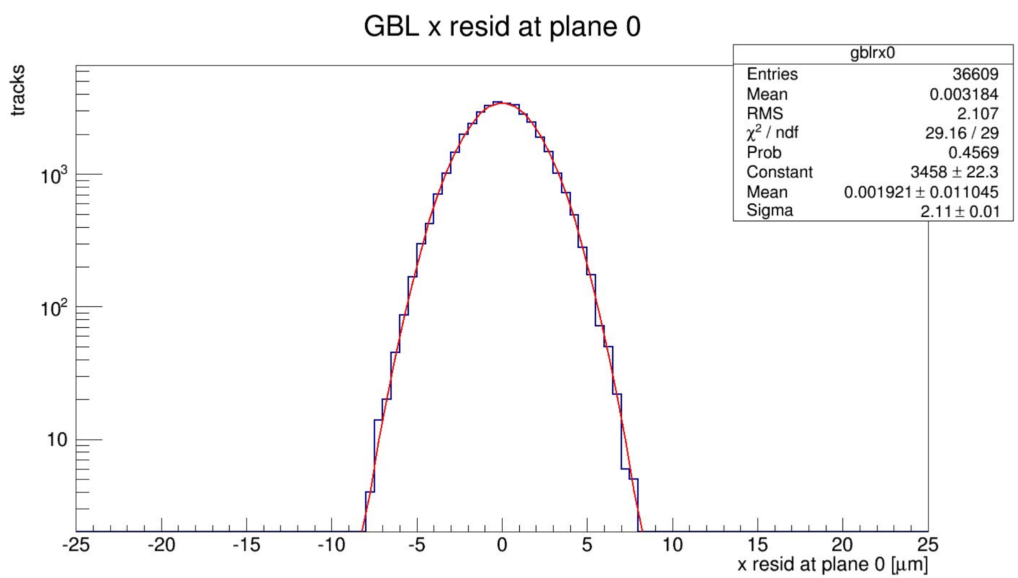
- Use track fits for residual and pull distribution

$$\boxed{r_{\mathrm{b}}^2(z)} = \sigma_{\mathrm{int}}^2(z) - \boxed{\sigma_{\mathrm{t,b}}^2(z)}$$
$$\boxed{r_{\mathrm{u}}^2(z)} = \sigma_{\mathrm{int}}^2(z) + \boxed{\sigma_{\mathrm{t,u}}^2(z)}$$

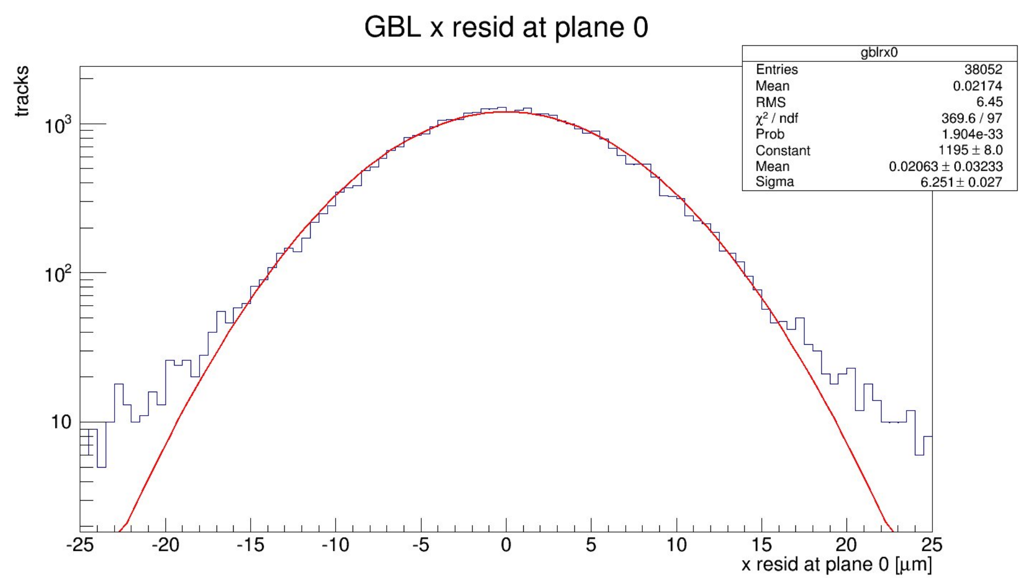
Different!

Residuals II

BIASED



UNBIASED



Pulls and track resolution

- Normalise residual by expected residual width

$$\mathrm{pull_b} \equiv p_\mathrm{b} = \frac{r_\mathrm{b}}{\sqrt{\sigma^2_\mathrm{int} - \sigma^2_\mathrm{t,b}}}$$

Pull is N(0,1) if
- estimate for intrinsic resolution matches true value
- material budget is accurate
- deflection due to multiple Coulomb scattering is accurately described

→ repeat track fit varying σ_{int} by pull width
→ pull → N(0,1) and σ_{int} converges

Pulls and track resolution

- Normalise residual by expected residual width

$$\mathrm{pull}_{u} \equiv p_{u} = \frac{r_{u}}{\sqrt{\sigma^2_{\mathrm{int}} + \sigma^2_{\mathrm{t},u}}}$$

Pull is N(0,1) if
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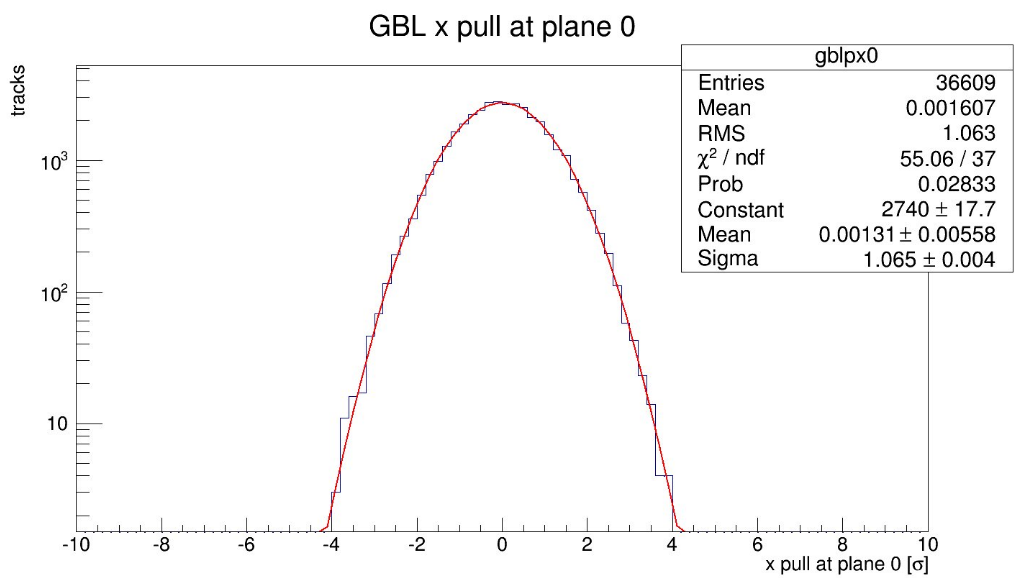
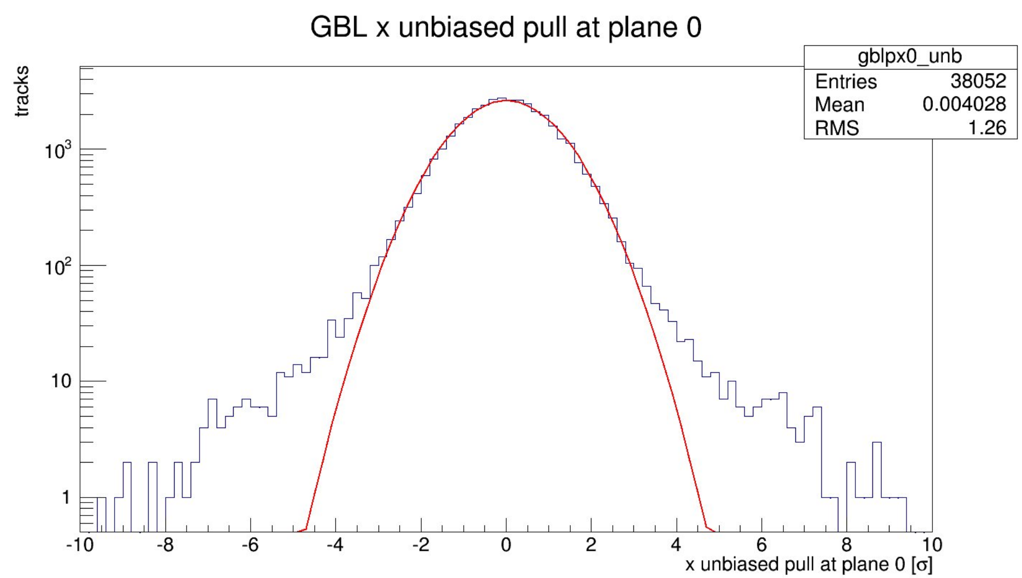
Pulls and track resolution II

BIASED

UNBIASED

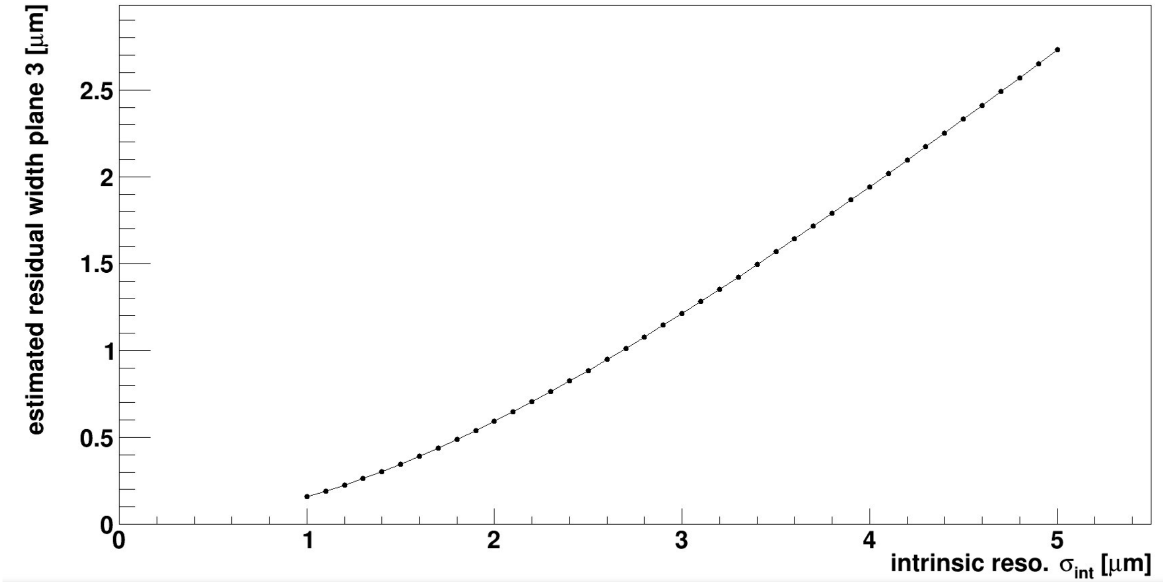




→ Increase σ_{int} by 6%, re-fit the tracks

Pulls and track resolution III

- Residual estimate as function of intr. resolution:



- Systematics affect unbiased track reso. relatively equal
- But $\sigma_{t,b} < \sigma_{t,u}$

$$\mathrm{pull_b} \equiv p_\mathrm{b} = \frac{r_\mathrm{b}}{\sqrt{\sigma_\mathrm{int}^2 - \sigma_\mathrm{t,b}^2}}$$

→ absolute error smaller
→ what about the residual?

Pulls and track resolution IV

- r_b seems to be more sensitive to changes in σ_{int} than r_u (only heuristic argument …)

- In total: Smaller absolute uncertainty and reasonable sensitivity of r_b makes biased tracks my favoured choice

- Some numbers:
uncertainty on σ_t @ 3 GeV, threshold 6

	10% HL	5% E
20 mm	3%	0.3 %
150 mm	1%	0.1 %

Intrinsic resolution

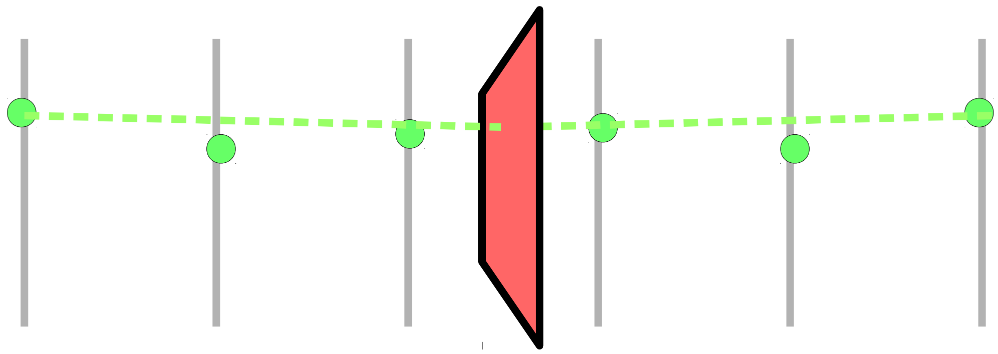
- The iterative method converges i.e. estimator for σ_{int} converges against the true value
- We find energy independent, preliminary value of

$$\sigma_{int} = 3.35 \pm 0.1\% \text{ (stat)} \pm \text{systematic (last slide)}$$

- Control sys. uncert. further by comparing set-ups
- Increases for lower thresholds (more noise hits)
- Increases for higher thresholds (smaller clusters)
- Optimum is 5 – 6, probably a tune of 5.5

Track resolution predictions

- Using 6 planes, assuming DUT in the centre



Track resolution predictions

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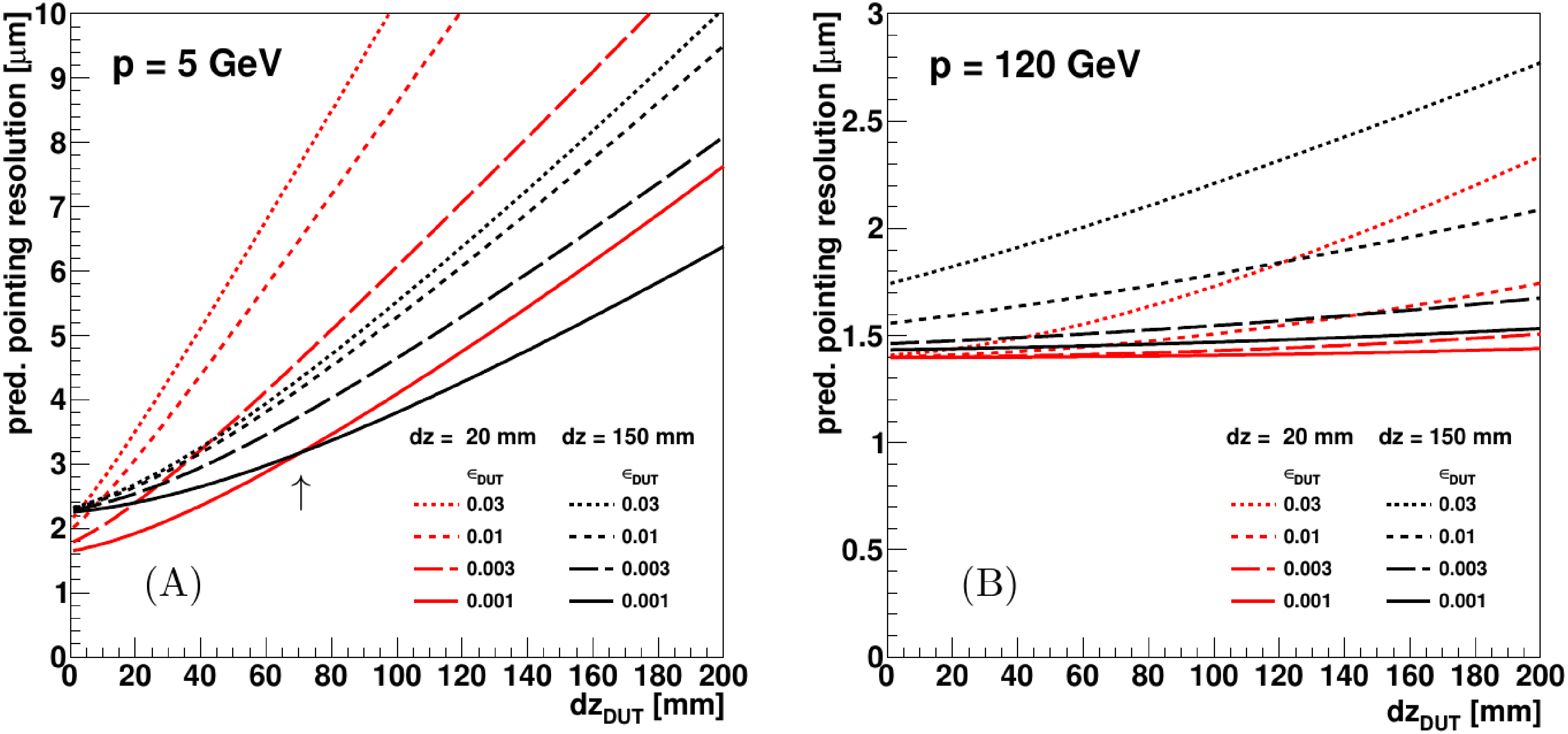
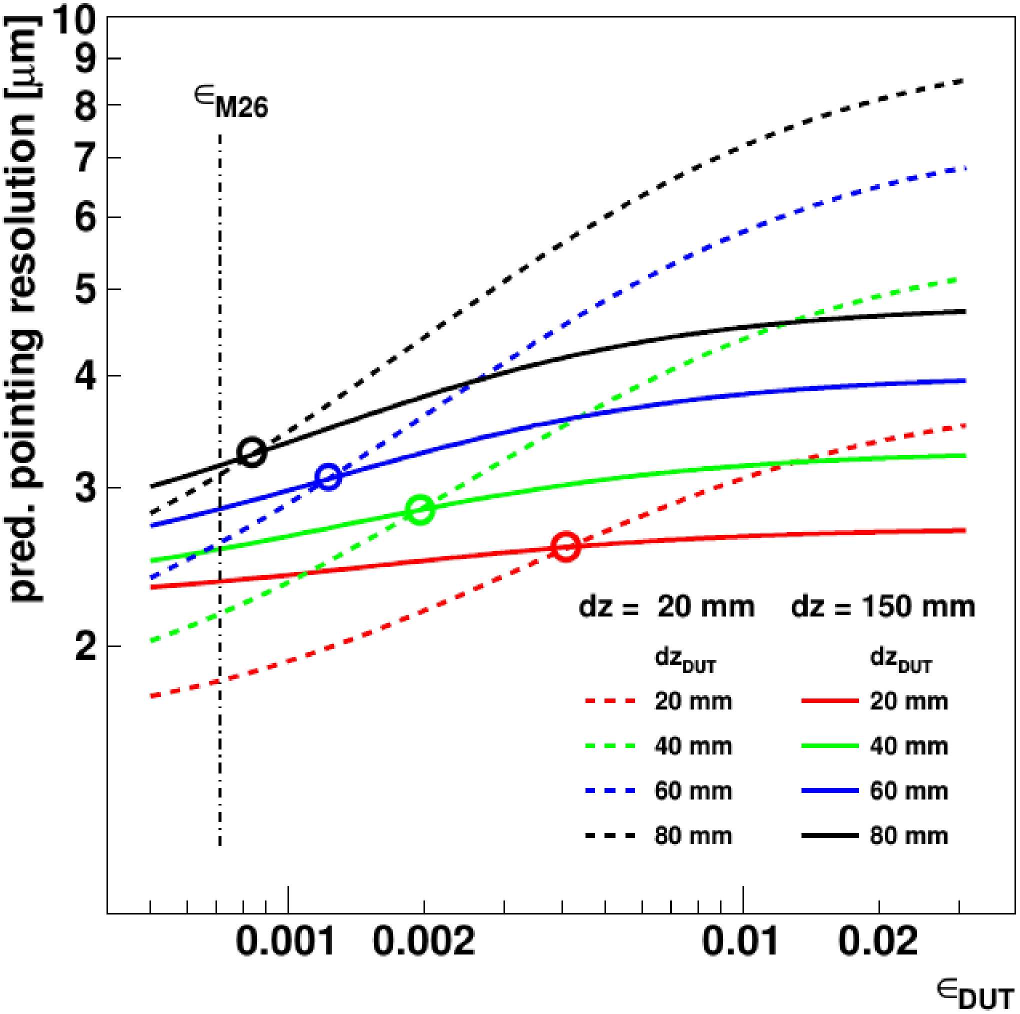


Track resolution predictions

- Using 6 planes, assuming DUT in the centre
- Wide set-up offers superior track resolution with thicker DUTs and vice versa.
- Intersection is function of material budget

→ Optimise resolution prior to your test beam



Conclusion

- Intrinsic resolution σ_{int} = 3.35 um at threshold 6
- Track resolution at DUT for 5 GeV beam is

  ~4.5 um for dz = 80 mm, dz_{DUT} = 150 mm, ε_{DUT} = 0.03
  ~2.0 um for dz = 20 mm, dz_{DUT} = 20 mm, ε_{DUT} = 0.002

- Quickly simulate your set-up with GBL before your TB!

- Paper almost finished, to be cited for all publications making use of EUDET-type beam telescopes

Back-up

Prob biased vs unbiased