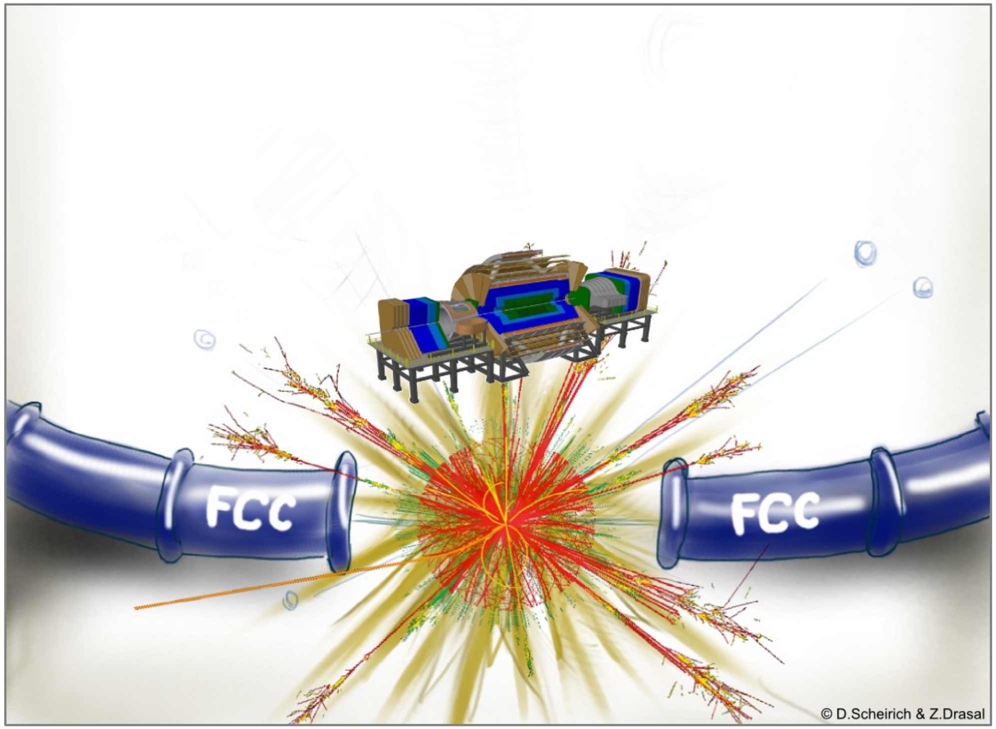
Studies on Tracker Z-resolution Requirements



Zbyněk Drásal
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Introduction

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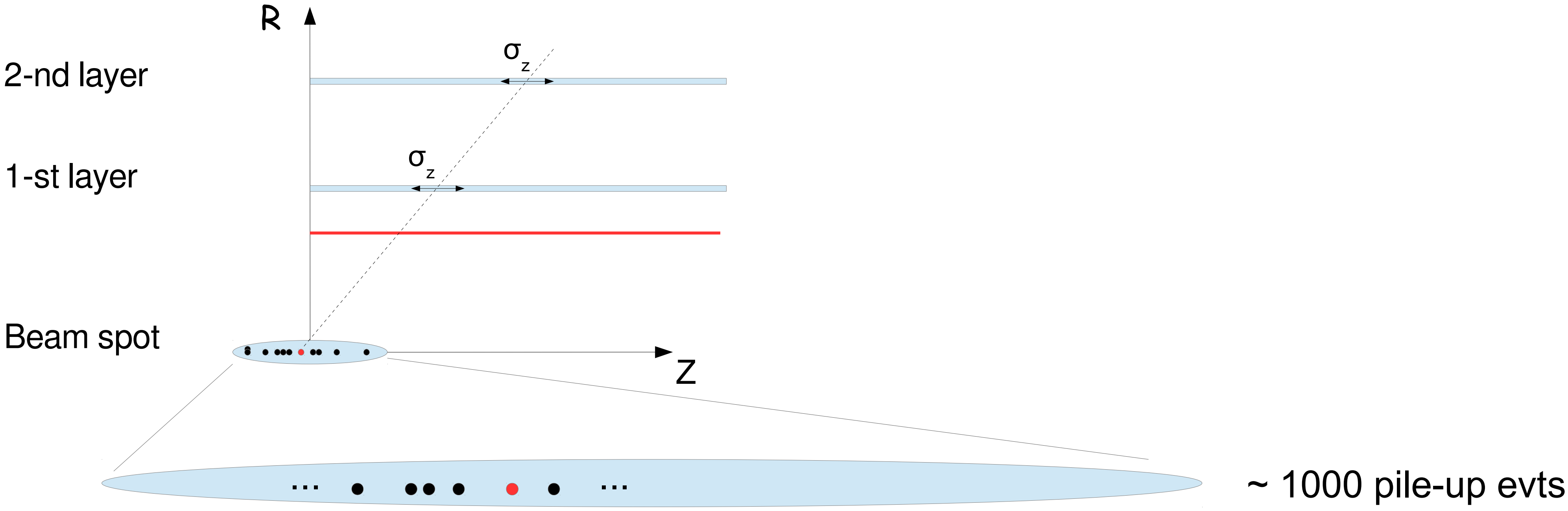

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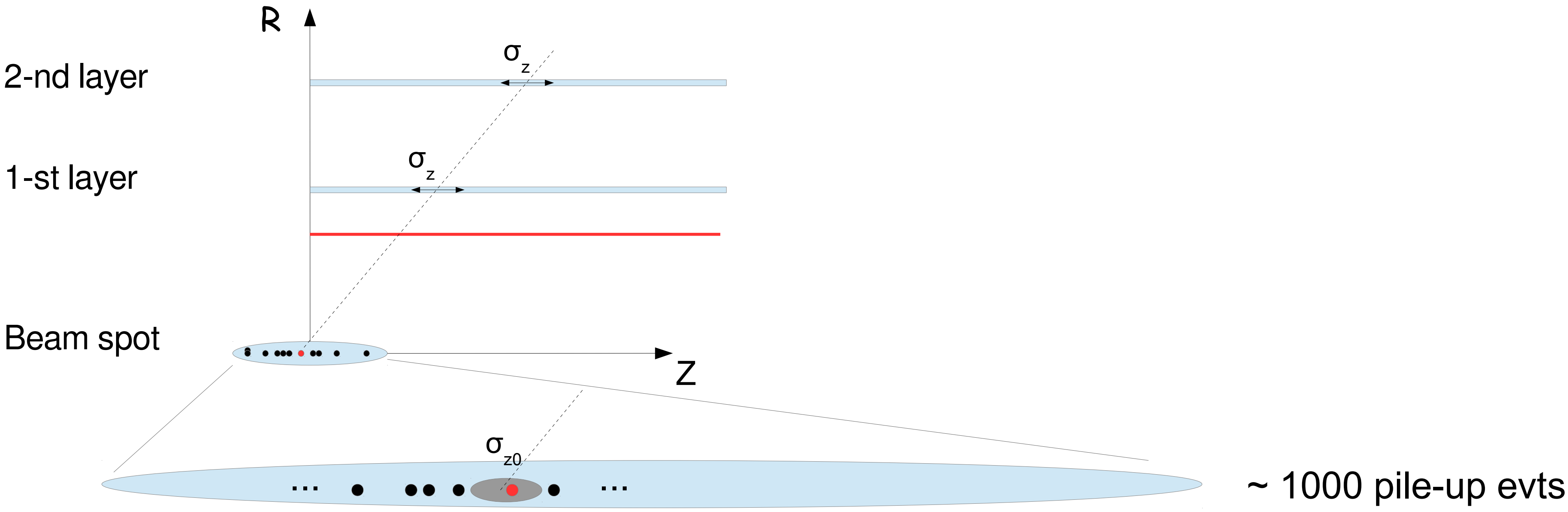

→ **Z_0 resolution needs to "sufficiently small" not to cover several pile-up vertices**

Beam-spot Simulation

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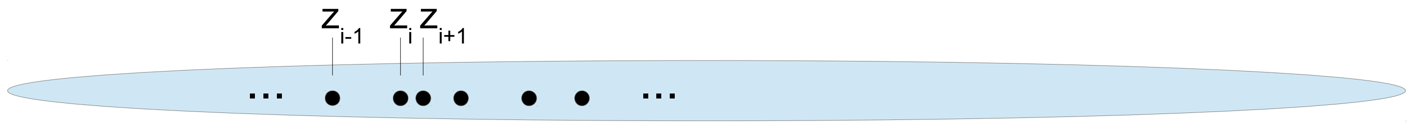
  - Beam spot sizes (courtesy of F. Cerutti): σ_{long} ~ 80mm, σ_{trans} ~ 1.6 – 6μm (Gauss. profile)

    → simulate N pile-ups Gaussian distributed in Z: G(μ=0,σ~80mm)

    → sort them from -Z to +Z

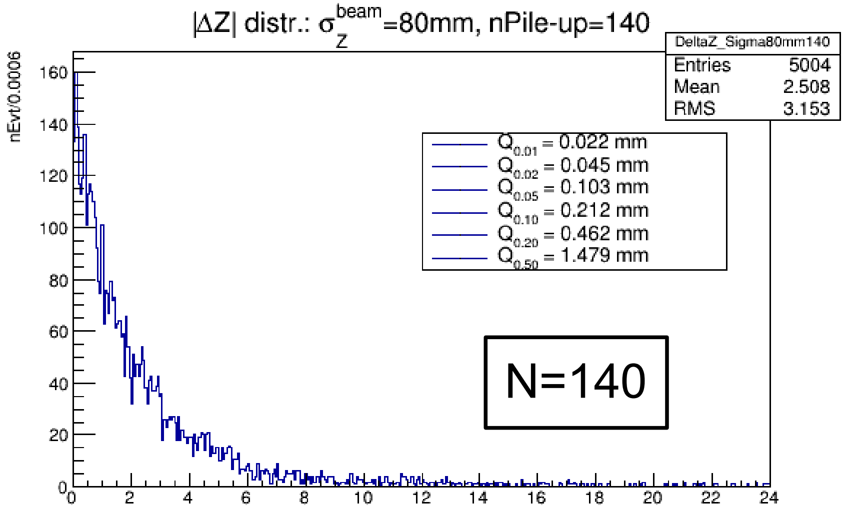
    → calculate distribution of closest neighbours (so called order-statistics): $|z_{i+1}-z_i|$

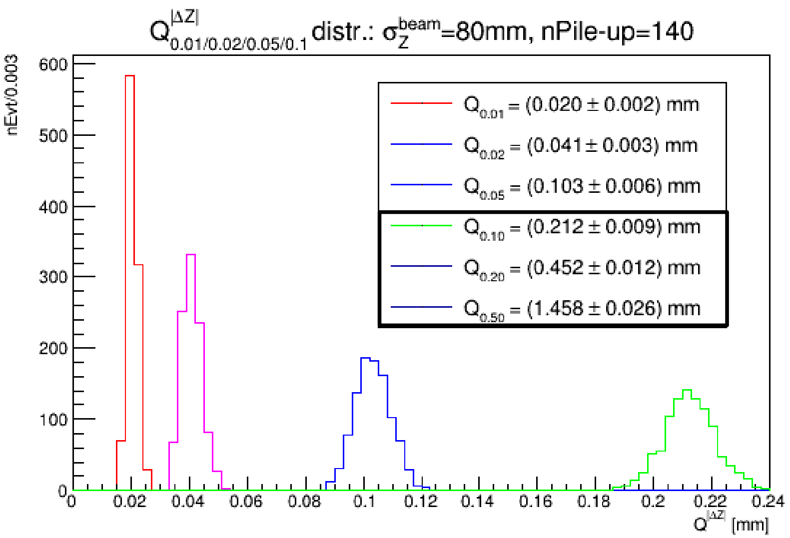


    → use quantiles to quantify the required Z_0 resolution: $\delta(Z_0)$

Pile-Ups Distribution in Z

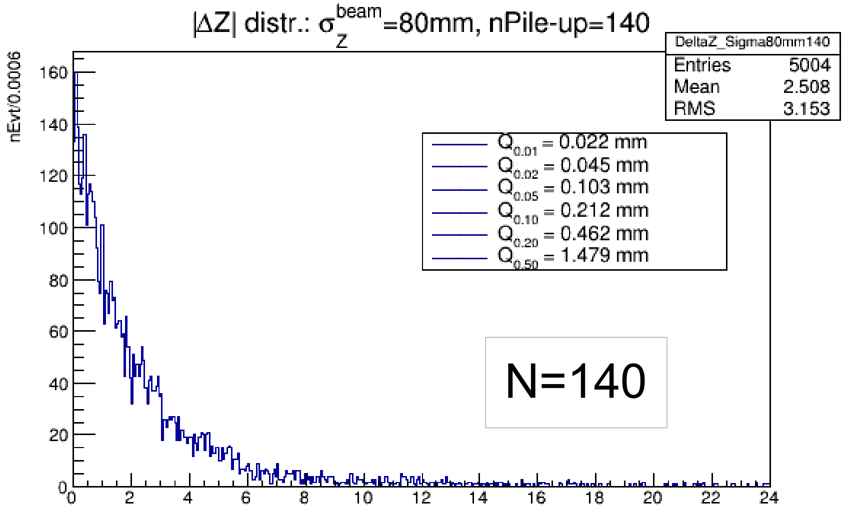
- Several pilu-up scenarios studied, let's compare N=140 (Phase 2 upgrade)

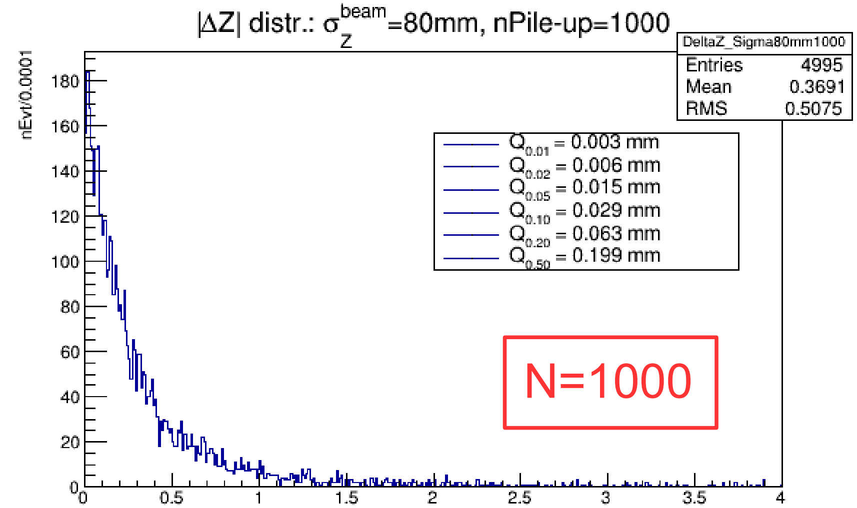


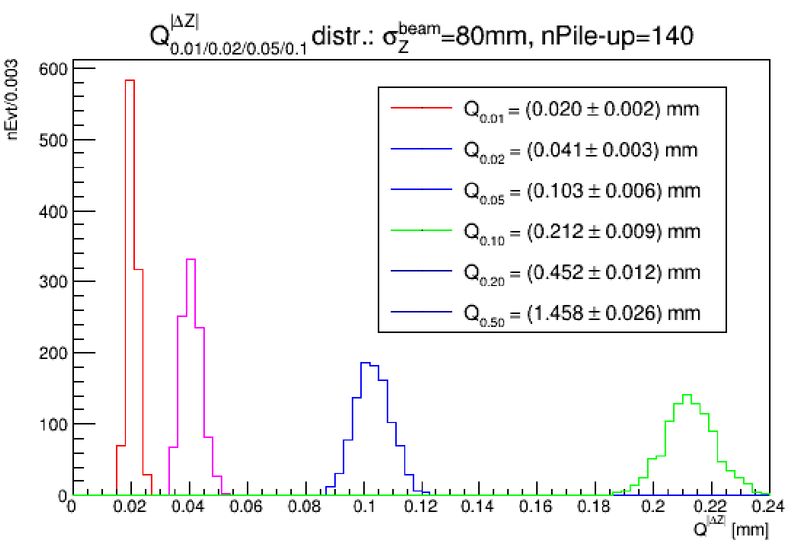


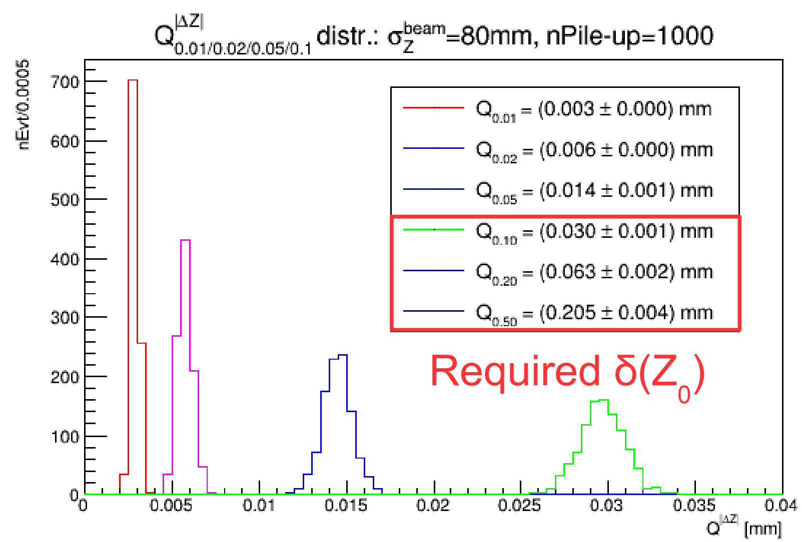
Pile-Ups Distribution in Z

- Several pilu-up scenarios studied, let's compare N=140 (Phase 2 upgrade) & N=1000



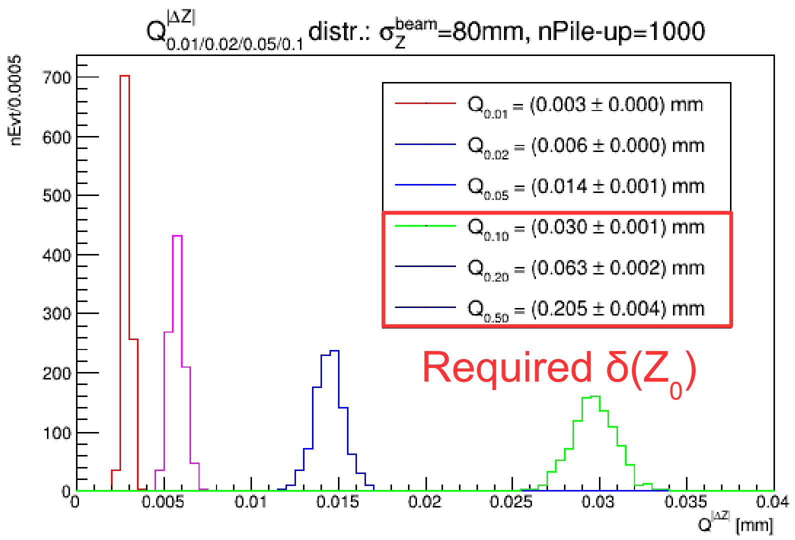






Pile-Ups Distribution in Z

- Comment: Would the timing information help or do we have to rely on Z-res. only?



ΔZ requirement: ~ 30 - 200μm → Δt: ~ 0.1 – 0.7 ps

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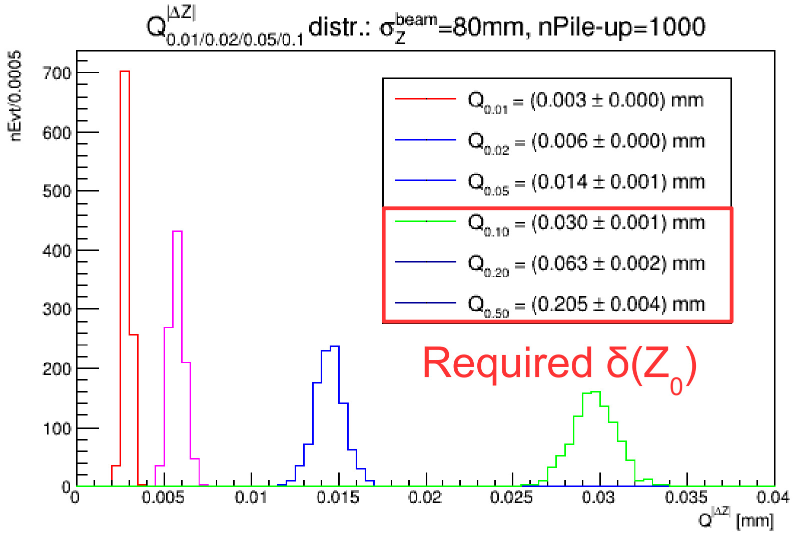

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- **Conclusion:** Compared to Phase 2 upgrade the FCC-hh tracker is required to have much better Z_0-resolution ~ 50μm & simultaneously provide such fine Z_0-resolution up-to higher η!

How to Determine the Granularity in Z?

- In first approximation ($\sin(\Delta\varphi) \sim \Delta\varphi$) one fits a line: $\mathbf{z_i = cotg(\theta).r_i + z_0}$ (r_i = layer/ring radii)
  - in reality: $\mathbf{z = cos(\theta).s + z_0}$, approx. valid for $p_T \gtrsim 1$GeV (pixel only), $p_T \gtrsim 4$GeV (full tracker)
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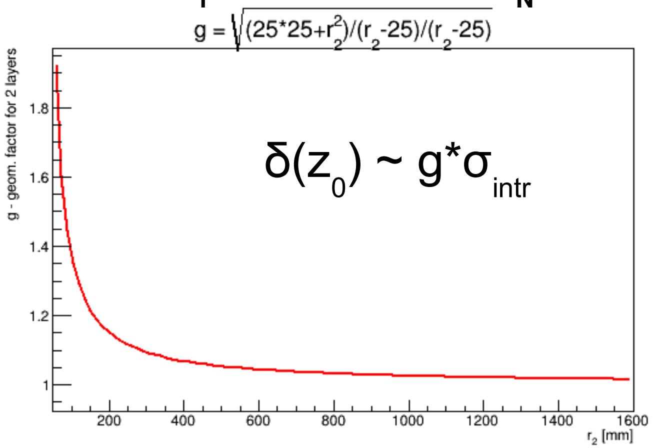
  - method of global $\chi 2$ fit applied
- Z_0 resolution: $$\sigma_Z \approx \sigma \sqrt{\frac{1}{n} + \frac{\bar{r}^2}{\sum_{i=1}^{n} r_i^2 - n\bar{r}^2}}$$ affected by several factors:
  - Tracker lever-arm (particularly important: r_1, r_N)
  - Number of measurement planes
  - Intrinsic resolution & measurement plane tilt (barrel versus disc configuration)
  - Material budget (particularly effect of beam-pipe & 1st layer important!)

Granularity in Z & Lever-arm Effect

- Intuitively easier to demonstrate in 2-layer approximation:

$$\sigma(z_0)^2 = \frac{r_1^2 V_{22} + r_2^2 V_{11} - 2 r_1 r_2 V_{12}}{(r_1 - r_2)^2}$$

a) Fixed r_1=25 → modify r_N (no material assumed here)



→ r_N = 450mm (pixel) → 1600mm (tracker): improvement by ~ 4%

→ **small effect**

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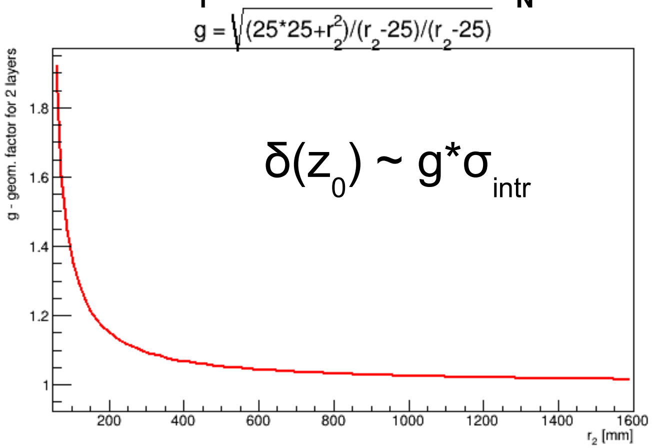

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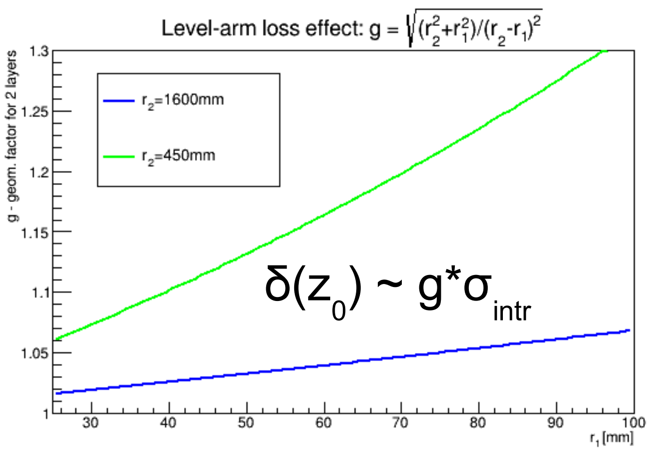
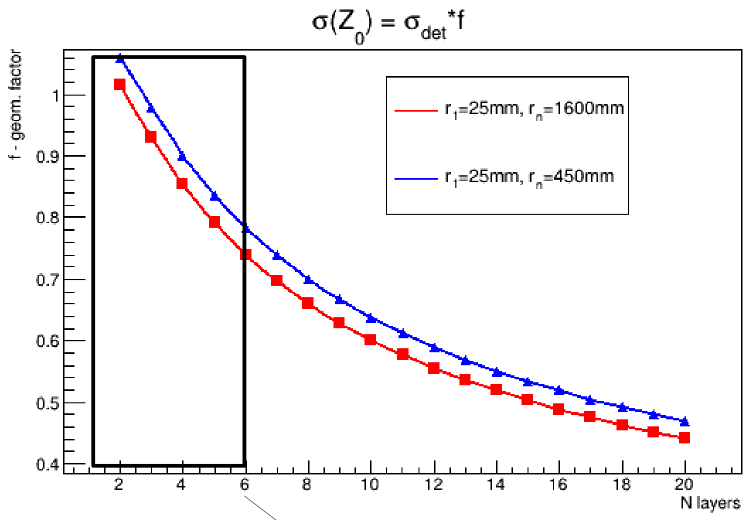


→ r_1 = 25mm → 60mm (hit loss in 1st layer): degrades by ~ 10%

→ **much bigger effect** → reasonable to „back-up“ the first layer

Granularity in Z & Number of Meas. Planes

- Scaling factor of Z resolution with respect to #layers:



The highest improvement in this region, then generally a **milder effect**

→ **$N_{pixel\ layers}$ set to 6**
First 2 layers positioned close to the beam-pipe & other with spacing ~100mm,
PXL ends @ the boundary of ~ r=500mm (see slides on Aug 31st)

→ More optimization needed using pattern recognition studies

Granularity in Z & Intrinsic Resolution

- Plane resolution in Z generally depends on plane tilt (α=0 for barrel, α=90 for disc) & track θ-angle (error propagated to Z direction → affects tilted planes only):

$$\sigma_z = (\cos(\alpha) + D \sin(\alpha))\sigma_{z-intr}, D = cotg(\theta)/\sqrt{(1-A^2)}, A = r_i/2R, (r_i = |\vec{r_{meas}} - \vec{0}|)$$

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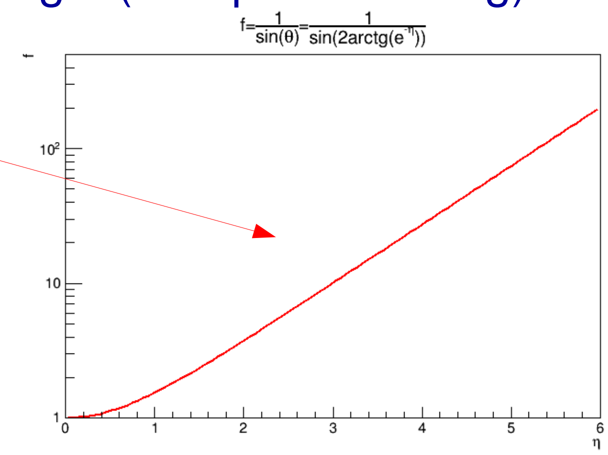
→ **BRL planes:**

– optimal Z-res., but MS significantly increases with η ~ 1/sin(θ)



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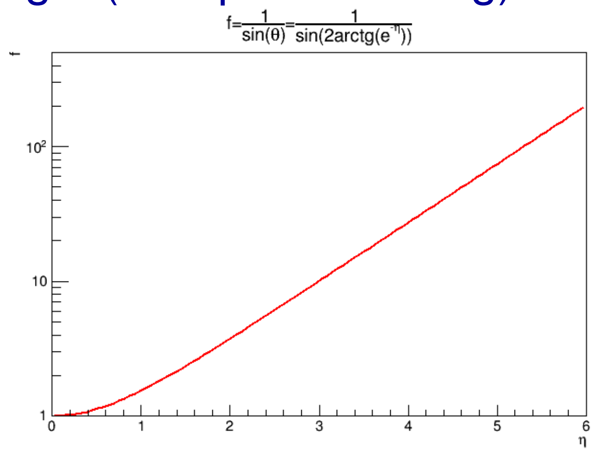

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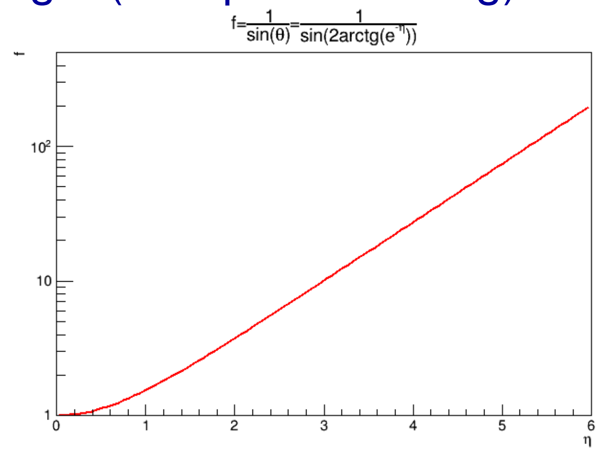
→ **Which one is optimal?**



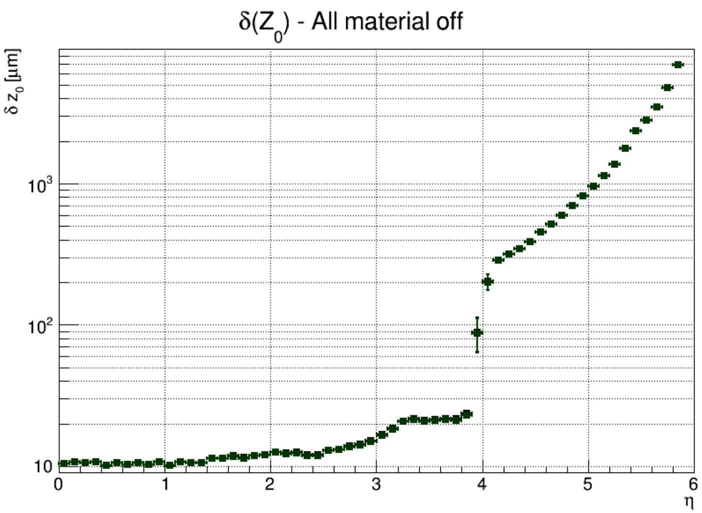
- **Conclusion:**

→ Preliminary results show that “**long**” **BRL planes provide better performance than any tilted**

→ First 2 pxl BRL layers extended **up-to η=4 (1st layer)** and **η=3.5 (“back-up” 2nd layer)**, but **very low material budget** ~ **0.5-1.0% x/x0 per layer** necessary!

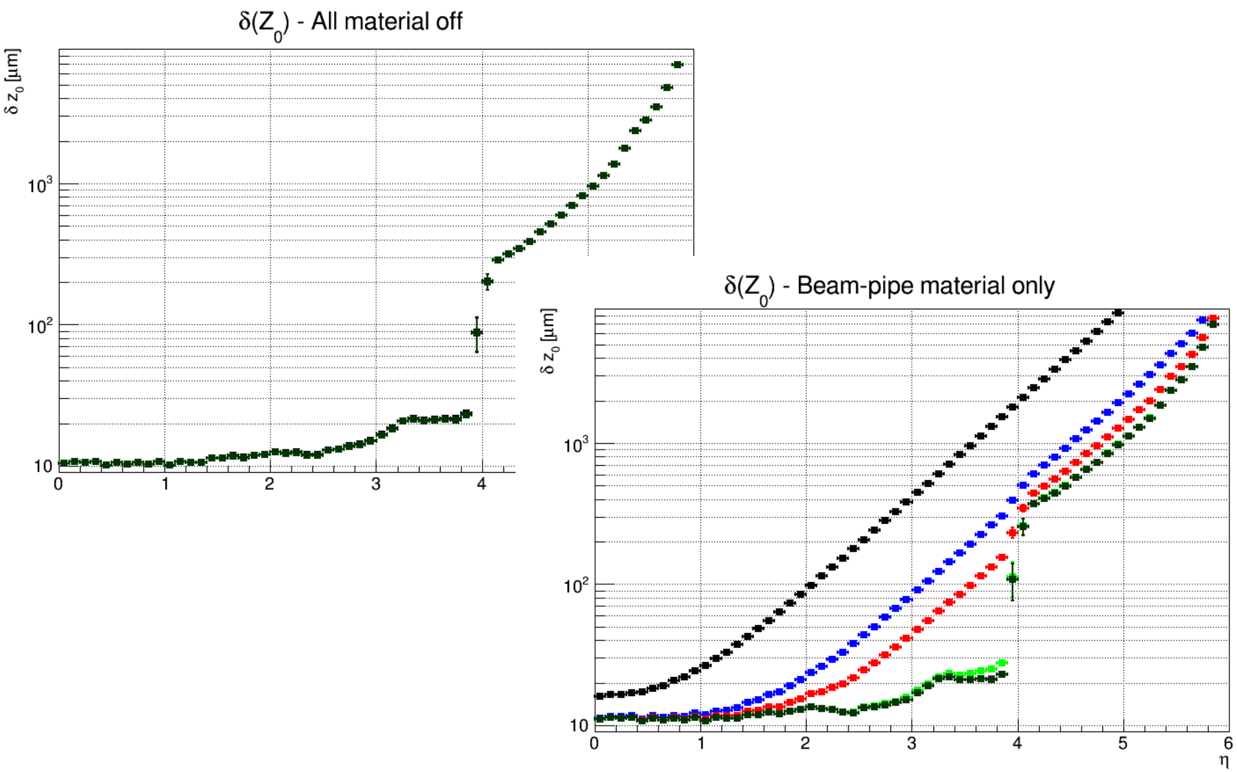
Z_0 Impact Parameter Study → MB Effect

- **No material**



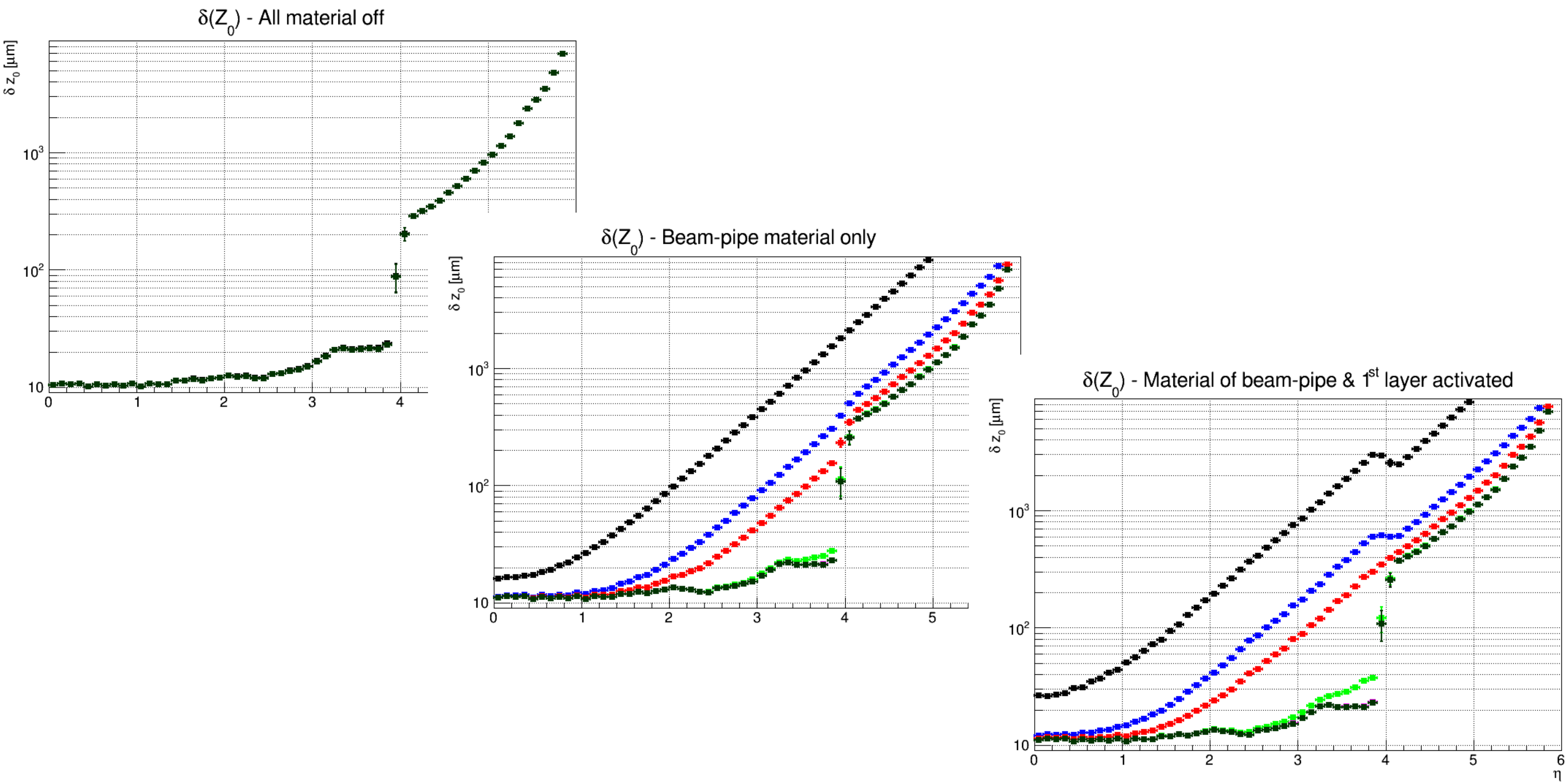
Z_0 Impact Parameter Study → MB Effect

- **No material → beam-pipe only**



Z_0 Impact Parameter Study → MB Effect

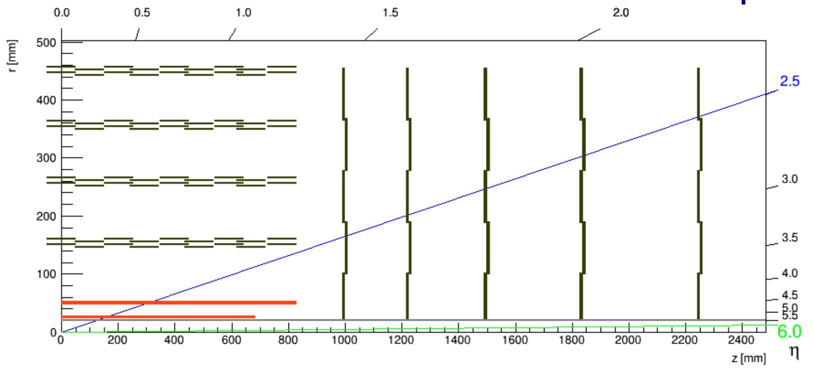
- **No material → beam-pipe only → beam-pipe+1st layer material effect** (the rest det. Transparent)



→ Material budget of **beam-pipe & the closest BRL layer** have **the most significant impact!**

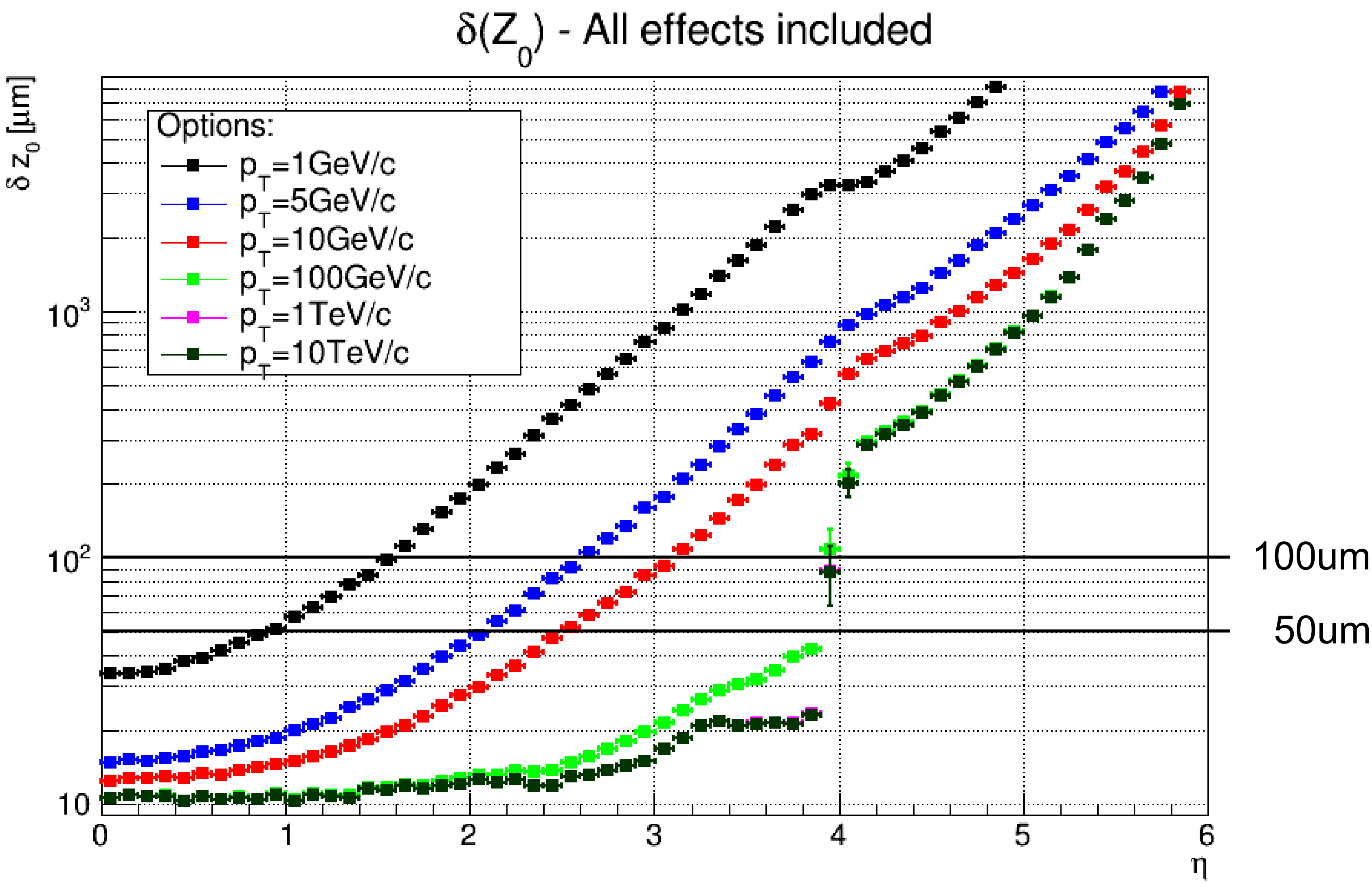
Final “Optimized” Geometry Layout

- Inner detector (pixel):
  - 1st & 2nd BRL layer: $\sigma_{R\text{-}\phi}$=10µm, σ_Z=15µm, x/x_0 = 0.5% per layer
  - 3rd-6th BRL layer: $\sigma_{R\text{-}\phi}$=10µm, σ_Z=30µm, x/x_0 = 1.5% per layer
  - 1st ring @ 1st & 2nd ECap disc: $\sigma_{R\text{-}\phi}$=10µm, σ_Z=15µm, x/x_0 = 1.5% per layer
  - All other rings @ ECap discs: $\sigma_{R\text{-}\phi}$=10µm, σ_R=30µm, x/x_0 = 1.5% per layer
- Outer detector & Fwd detector:
  - All BRL layers: $\sigma_{R\text{-}\phi}$=10µm, σ_Z=100µm, x/x_0 = 3.0% per layer
  - All rings up-to r<600mm: $\sigma_{R\text{-}\phi}$=10µm, σ_Z=30µm, x/x_0 = 1.5% per layer
  - All rings above r>=600mm: $\sigma_{R\text{-}\phi}$=10µm, σ_Z=100µm, x/x_0 = 3.0% per layer
- **More details will be available at** http://fcc-tklayout.web.cern.ch/fcc-tklayout



For illustration – Only geometry of inner detector has changed ...

Z_0 Impact Parameter Resolution



Conclusions

- **Current results based on simplified approach show that:**
  - The tracker impact parameter resolution in Z_0 should be @ level **$\delta(Z_0)$ ~ 50μm up-to full tracker coverage**!
  - Such resolution **can't be achieved due to high material effect** (mainly due to beam-pipe & first layer) for **η higher than ~ 2.5**
  - By combination of reasonable granularity in Z, which have been optimized, & low material budget for first 2 measurement planes **satisfactory results are achieved up-to η ~ 2.5**
  - Timing information seems not to be applicable to solve these issues (requirements ~ 0.1-1.0ps)
  - On the other hand, in vertexing one uses more than 1 track, so these limits are the most stringent ones
- **Plans:**
  - Try to find more optimal layout & pushing the eta boundary to higher value by mixing the advantages of BRL layers & low material effect of tilted layers → **find optimal tilted layout, if possible**
  - **Optimize number of layers** by studying simplified pattern recognition capabilities