FCC-hh Tracker Layout & Pattern Recognition

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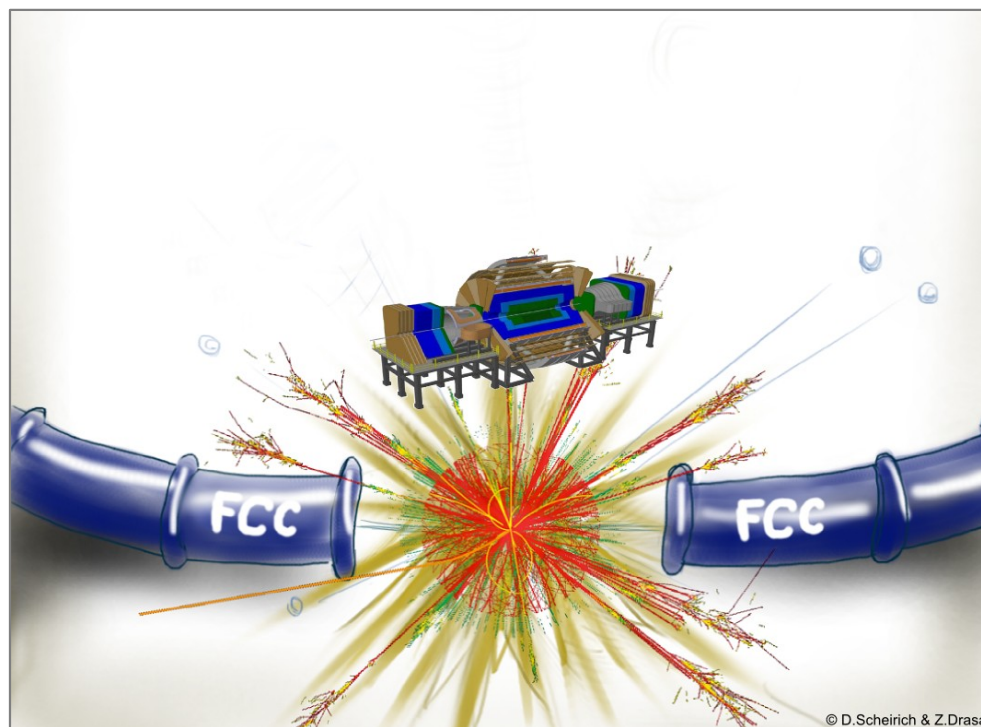
Zbyněk Drásal

CERN

With M. Mannelli

Introduction

- **How to analytically "evaluate" pattern recognition capabilities** of given tracker layout and **compare different layouts** in "automatized" way?

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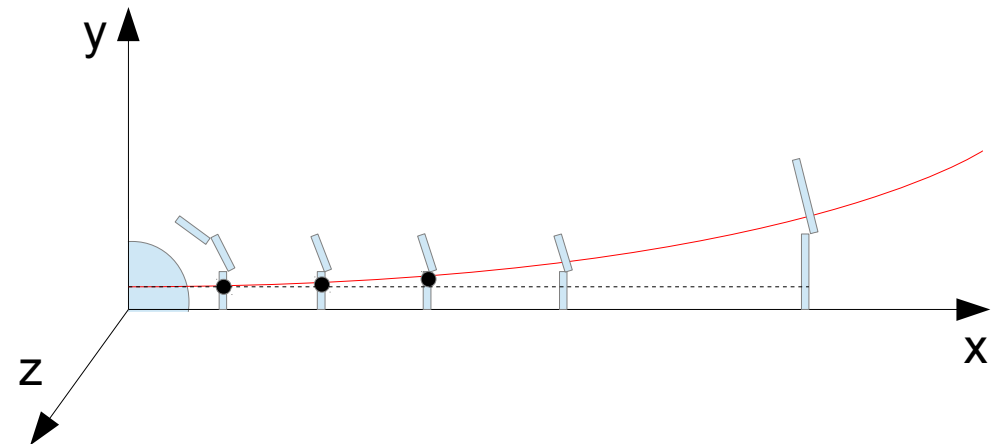- **How to analytically "evaluate" pattern recognition capabilities** of given tracker layout and **compare different layouts** in "automatized" way?

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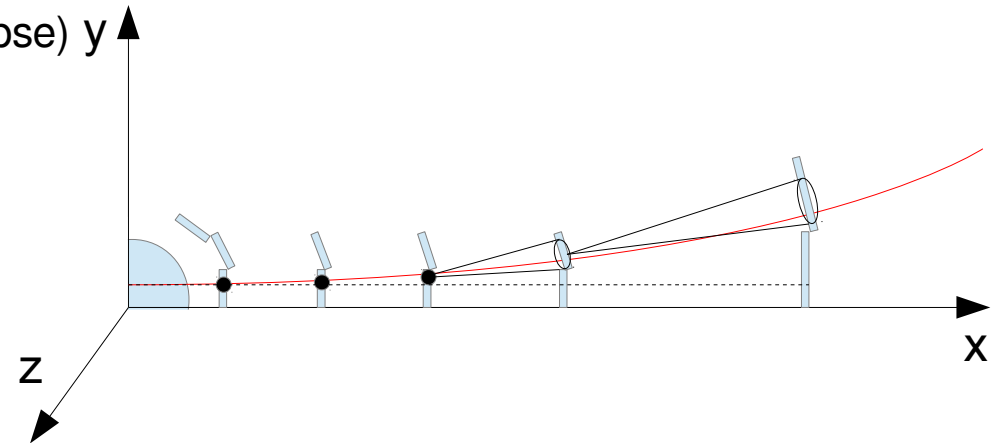 - Plot all layer-to-layer/layer-to-disc/disc-to-disc propagated $\sigma_{r\phi}$, σ_z quantities:

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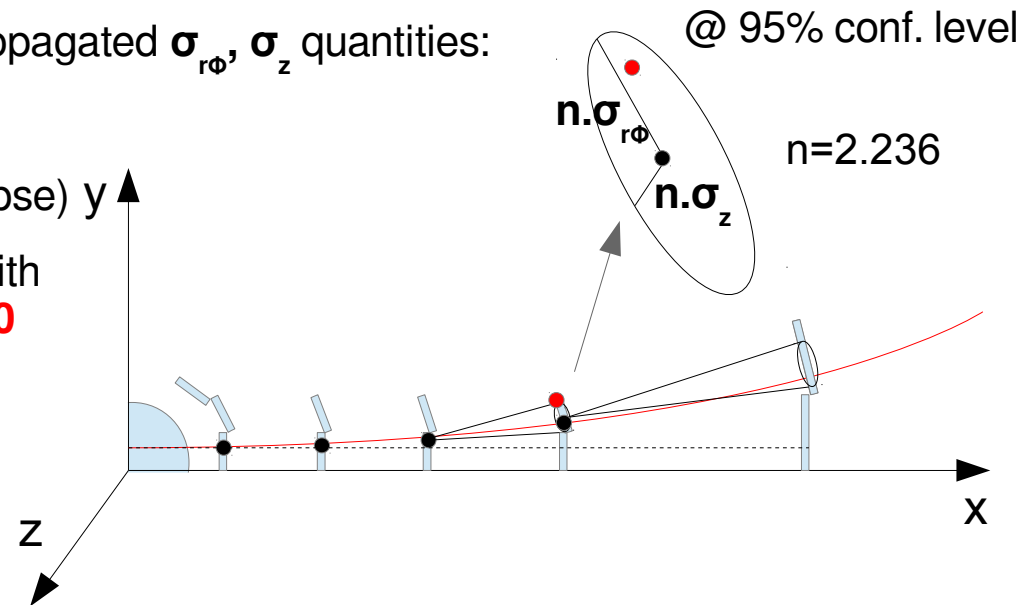 → Propagate $\sigma_{r\phi}$, σ_z to the **i-th layer** (use error ellipse)

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@ 95% conf. level

n.σ$_{r\phi}$

n.σ$_z$

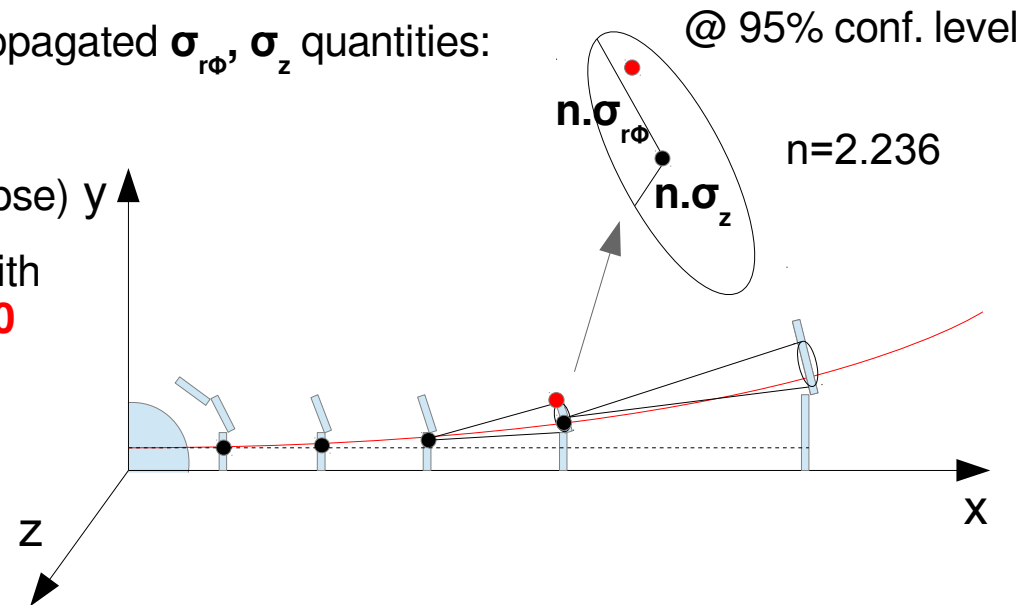n=2.236

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    n=2.236

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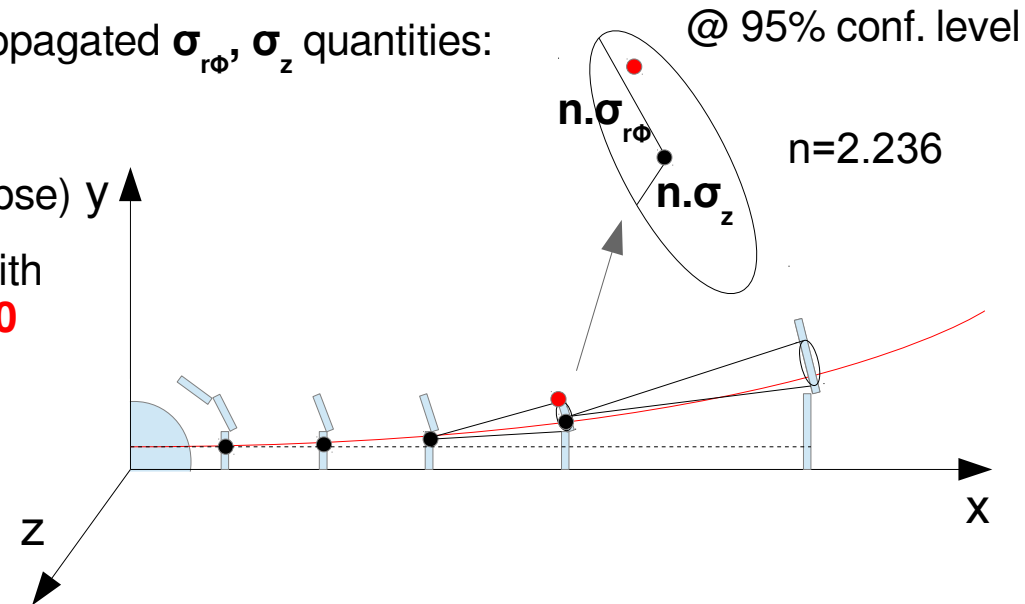$$p = 1 - \prod_{i=4}^{N}(1 - p^i_{\mathrm{bkg95\%}})$$

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  – **To quantitatively evaluate the overall tracker performance**, calculate a probability that the track has been found with any ambiguity:

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  → Check "weak" spots in geometry & optimize:

  - module resolution, tilt, layer/disc positions, ...

$$p = 1 - \prod_{i=4}^{N}(1 - p^i_{\text{bkg95\%}})$$

Overview of Math. Technique

- Using the propagator technique, one may estimate the resolutions at any det. plane:

  - The key statistical concept: **error propagation**

    - Assume to have $V_{ij} = cov(x_i, x_j)$ ($x_i \rightarrow$ track parameters, e.g. d_0, z_0, ρ, $cotg(\vartheta)$, φ_0)

    - Assume a new set of parameters $\vec{y} = \vec{y}(\vec{x})$, e.g. $d_{[r,z]}/z_{[r,z]}$,... The question is, what is the cov. matrix in a new parametrization?

      $$\mathbf{V[\vec{y}(\vec{x})] = J \cdot V \cdot J^T} \text{ (where } \mathbf{J} \text{ stands for Jacobian)}$$

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$$\sigma_z^2 = \sigma_{z_0}^2 + 2\text{cov}(z_0, \text{cotg}\vartheta)\Delta r + \sigma_{\text{cotg}\vartheta}^2 \Delta r^2$$

$$\sigma_d^2 = \frac{\Delta r^4}{4}\sigma_\rho^2 + \Delta r^3 \text{cov}(\rho, \varphi_0) + \Delta r^2 \text{cov}(\rho, d_0) + \Delta r^2 \sigma_{\varphi_0}^2 + 2\Delta r\,\text{cov}(\varphi_0, d_0) + \sigma_{d_0}^2$$

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  - **Comment** ➙ **all effects included:** magnetic field, multiple scattering ➙ Out-in approach cross-checked with results @ $\eta=0$ (by Estel, Lictoy) $\to$ **OK**
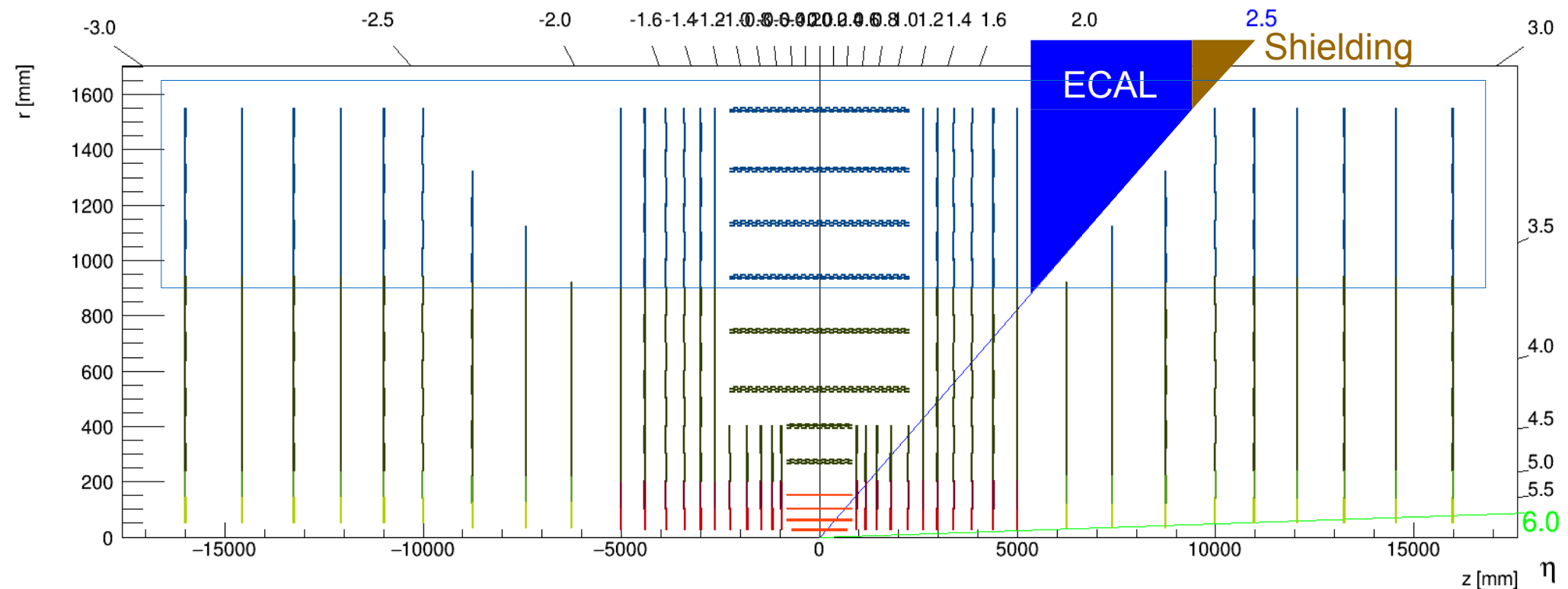
Geometry: Option3_v02 as a Starting Point
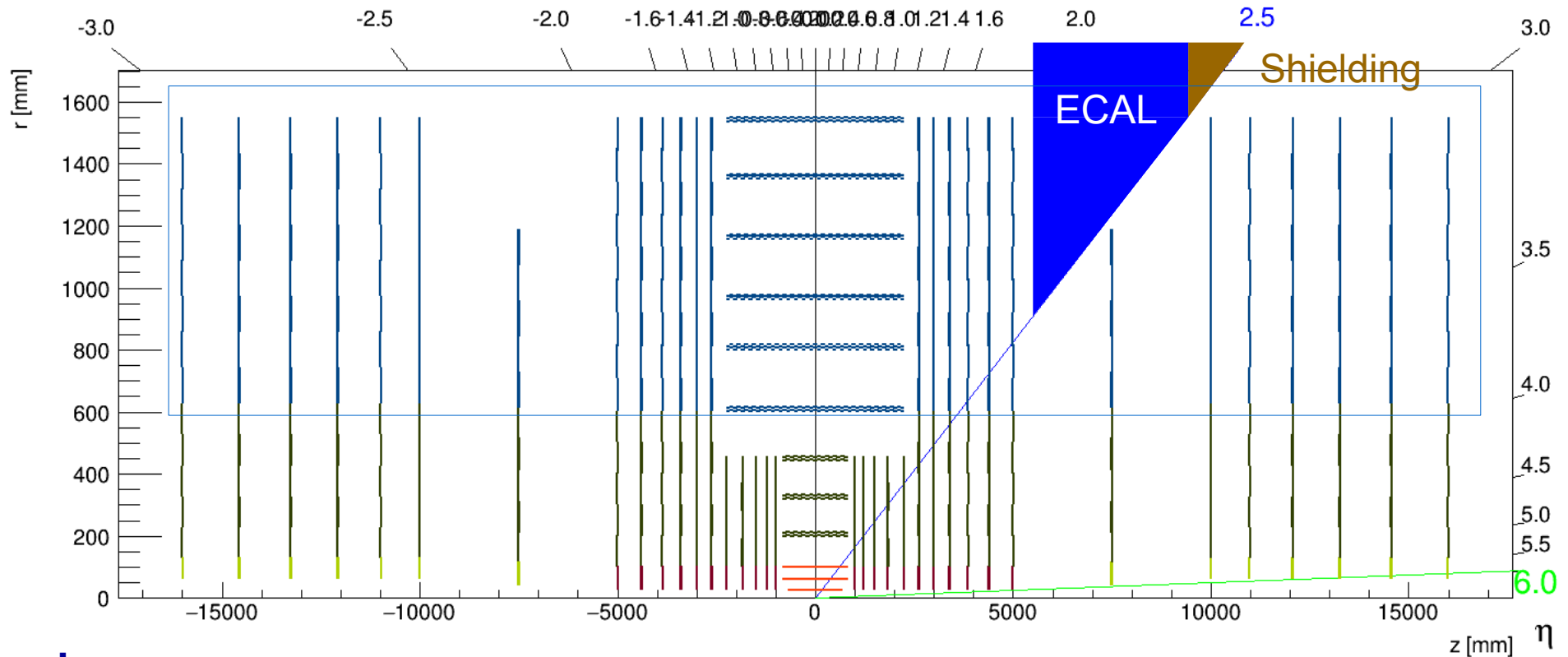
- **Issues:**
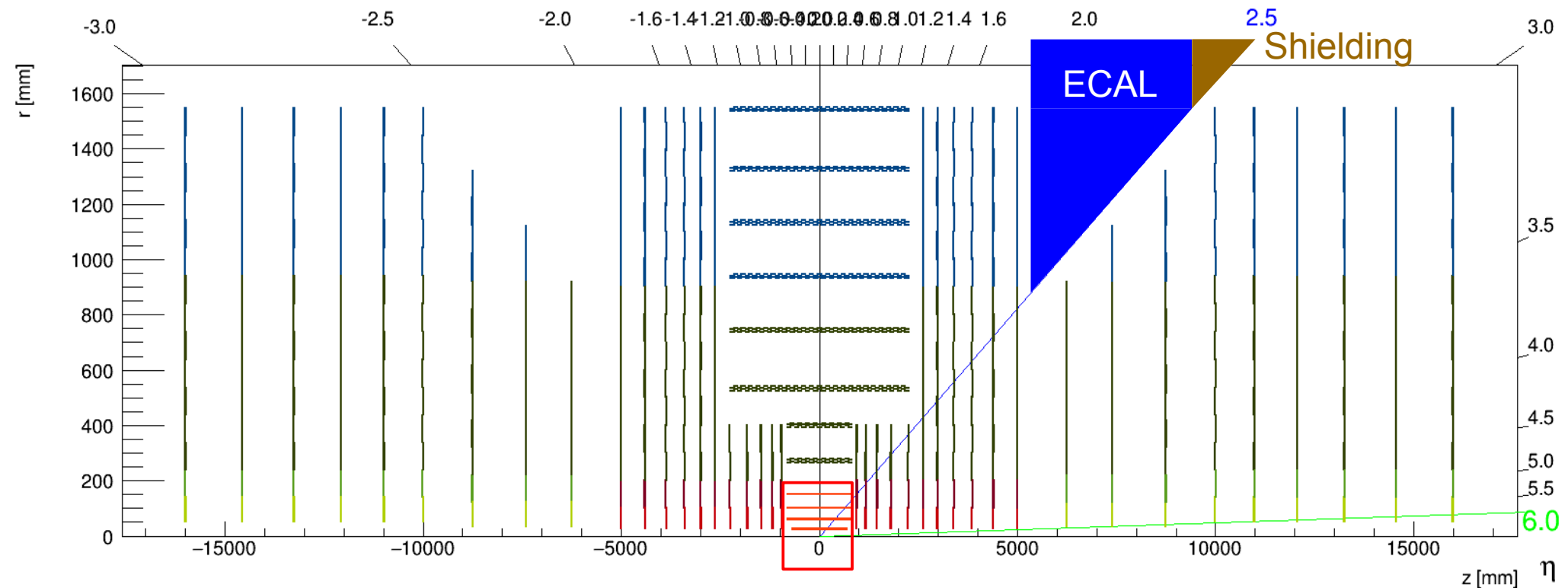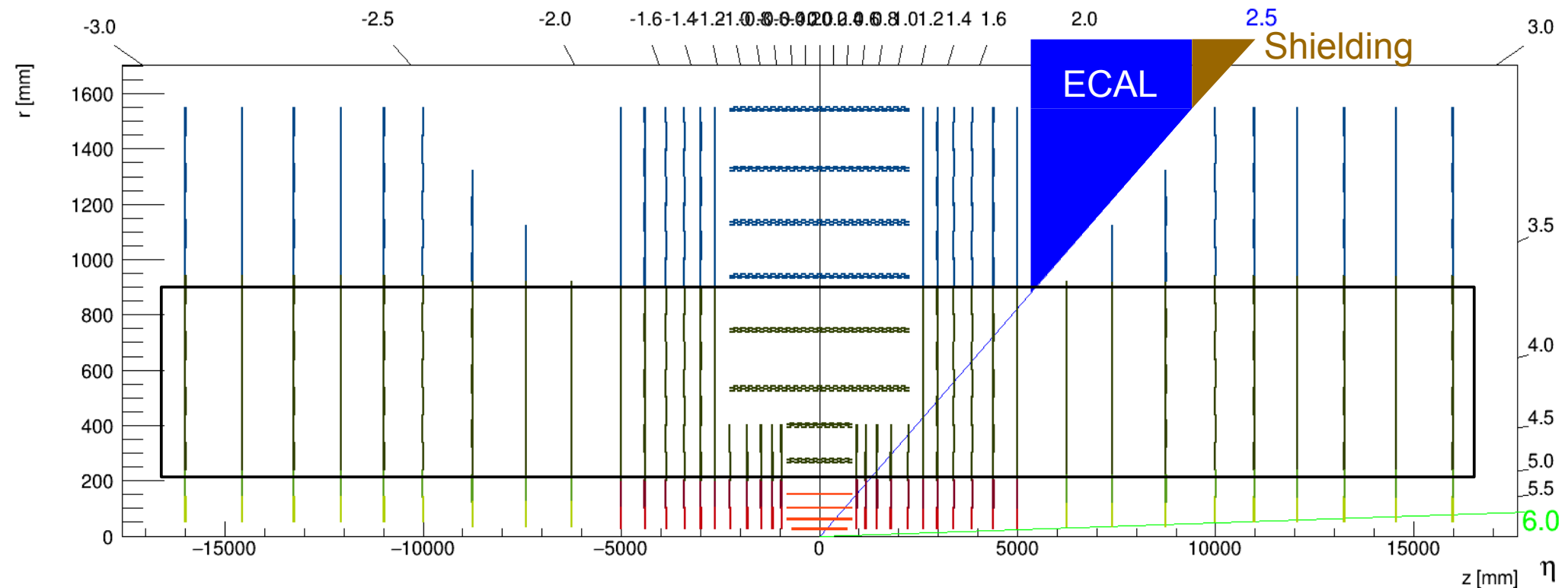 - **Strip detectors (blue)**: 100um res. in Z unrealistic ➞ start with **strip length 5cm ~ res. 14.4mm**

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- ## Issues:

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  - **B field: 6T ➔ 4T:** low energy bkg particles spread-out up-to higher radii ➔ **1% occupancy** reasonably achievable @ **R~900mm** (instead of 600mm)

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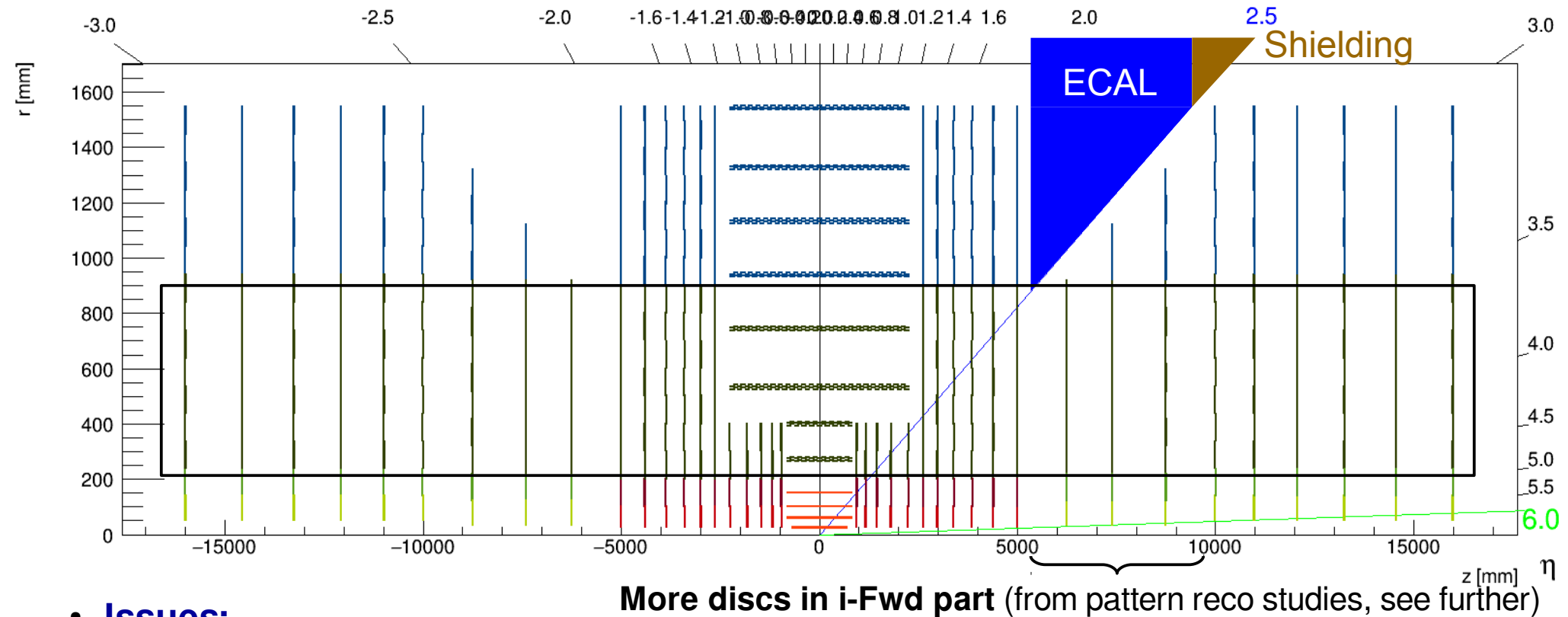
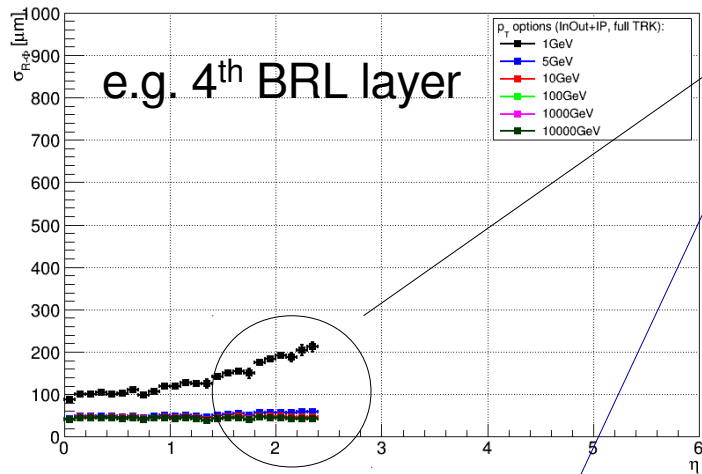# Geometry: Option3_v02 as a Starting Point

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More discs in i-Fwd part (from pattern reco studies, see further)

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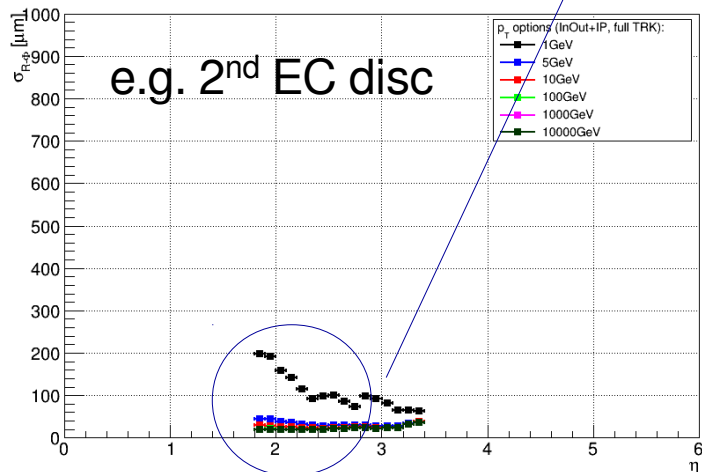
R-Φ: Understanding Pattern Recognition

- **Propagator in R-Φ** (illustration of typical examples):

Inner_BRL_0_L_4 In-Out approach: an extrapolated $\sigma_{R-\Phi}$ from previous layers/discs

e.g. 4th BRL layer

Inner_ECAP_D_2 In-Out approach: an extrapolated $\sigma_{R-\Phi}$ from previous layers/discs

e.g. 2nd EC disc

BRL: Why propagation **degrades** with higher η?
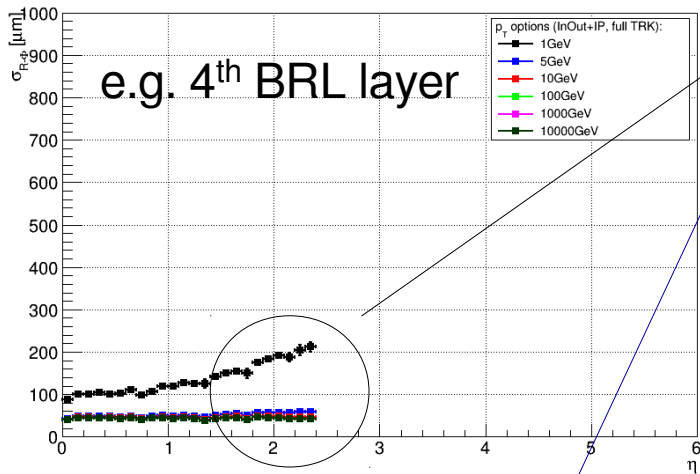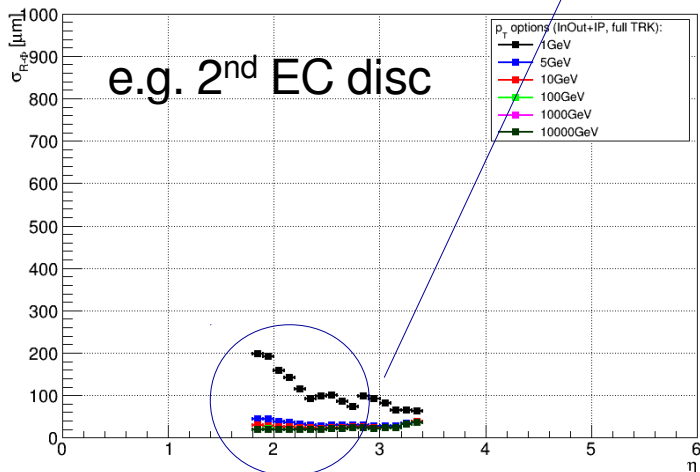
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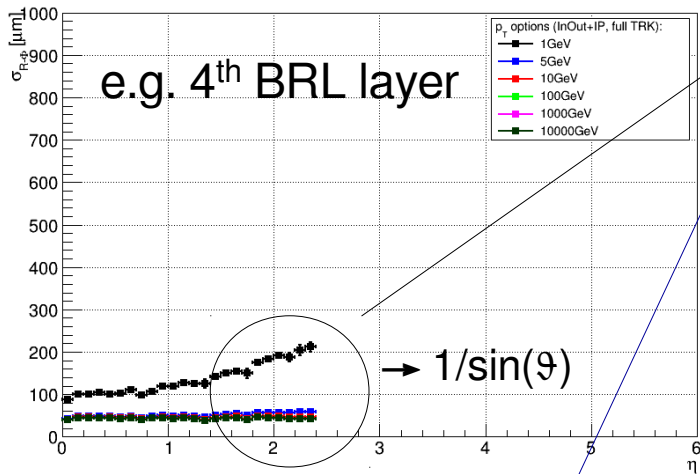**BRL:** Why propagation **degrades** with higher η?

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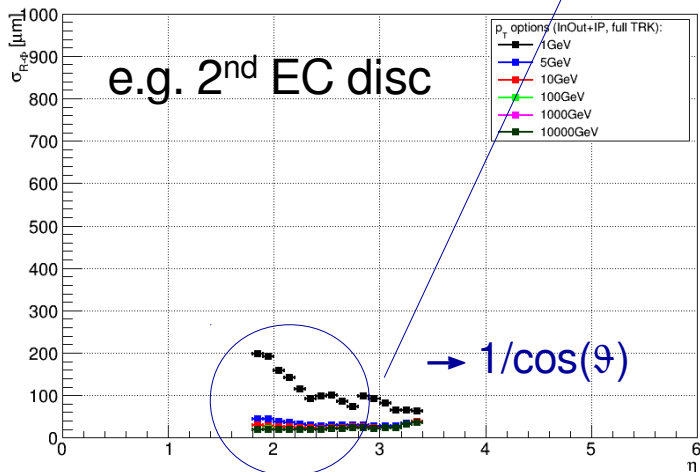
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$$
\begin{aligned}
\sigma_{\mathrm{MS}}^2 &\approx \langle \vartheta_{p_T}^2 \rangle \boxed{\frac{d/X_0}{\sin(\vartheta + \alpha)}} f_L \\
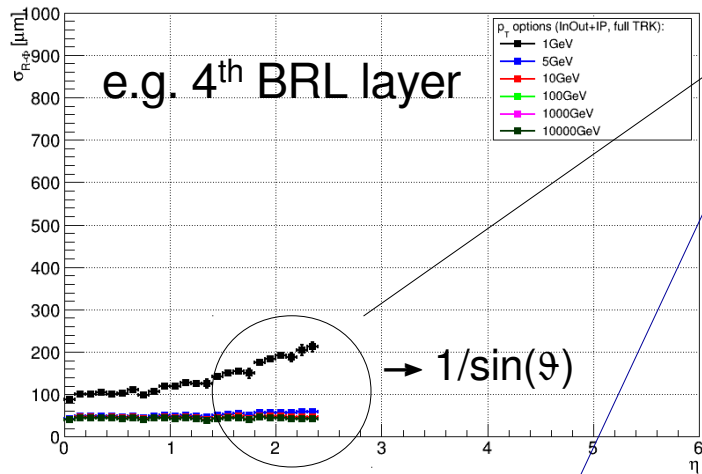\langle \vartheta_{p_T}^2 \rangle &= \left(\frac{13.6\,\mathrm{MeV}}{\beta p_T c} \right)^2 \left(1 + 0.038 \ln \frac{d/X_0}{\sin(\vartheta + \alpha)} \right)^2 \\
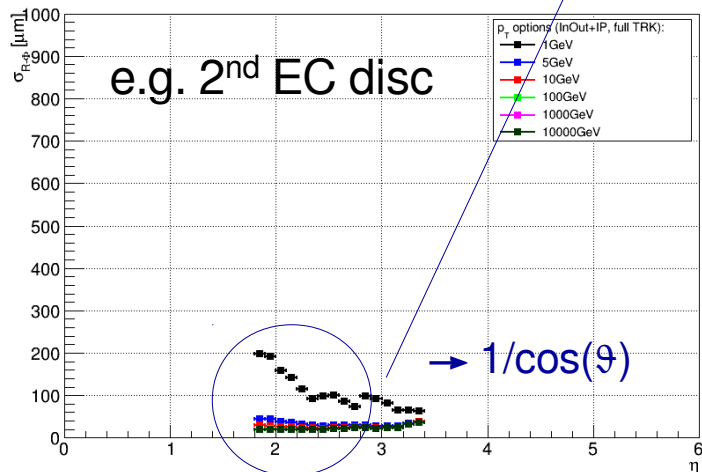f_L &= \left(\frac{\Delta R}{1} \right)^2 \text{ proj. in } R\Phi
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- **EC** modules → res. in R-Φ given by combination of R & Φ:

$$
\begin{aligned}
\sigma_{R\Phi} &= \sqrt{\sigma_{R\Phi_{\mathrm{loc}}}^2 + (A/\sqrt{1 - A^2} \sin\alpha)^2 \sigma_{Z_{\mathrm{loc}}}^2} \\
A &= \Delta r / 2R
\end{aligned}
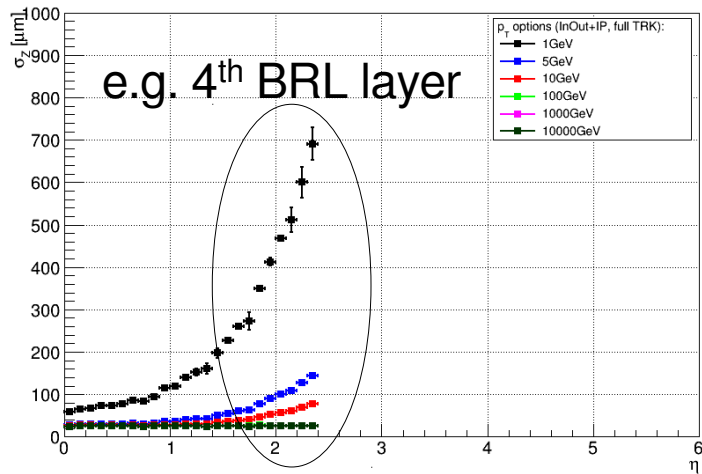$$

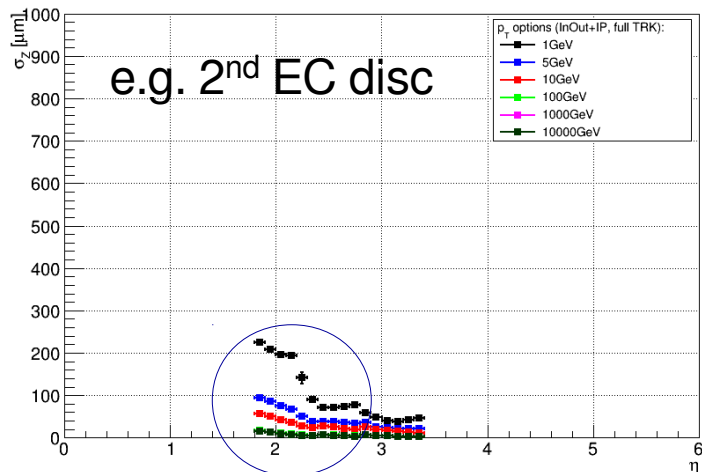**Problem: "long" strips**

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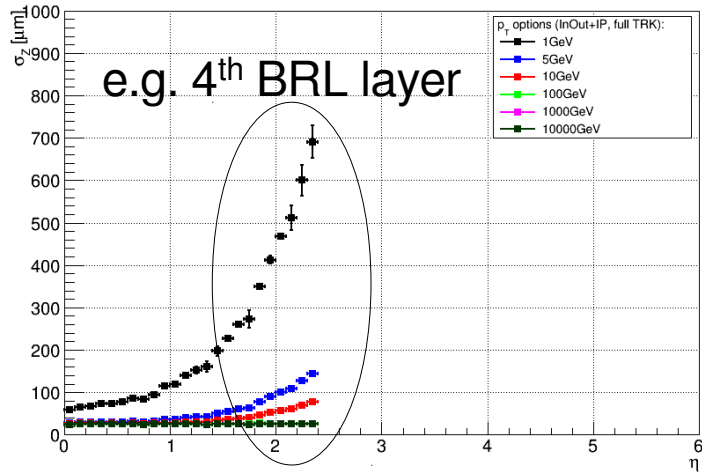
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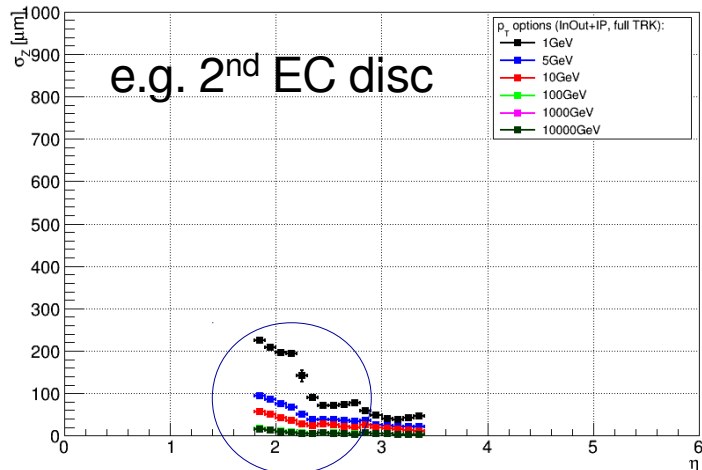
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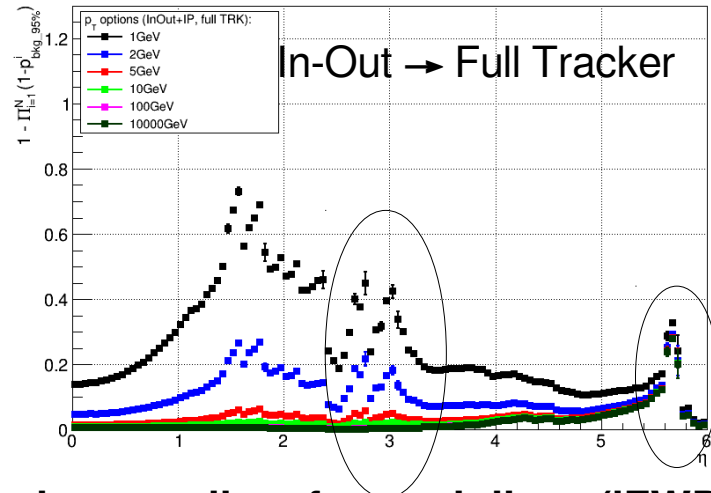 - → $\alpha = 0$ for BRL
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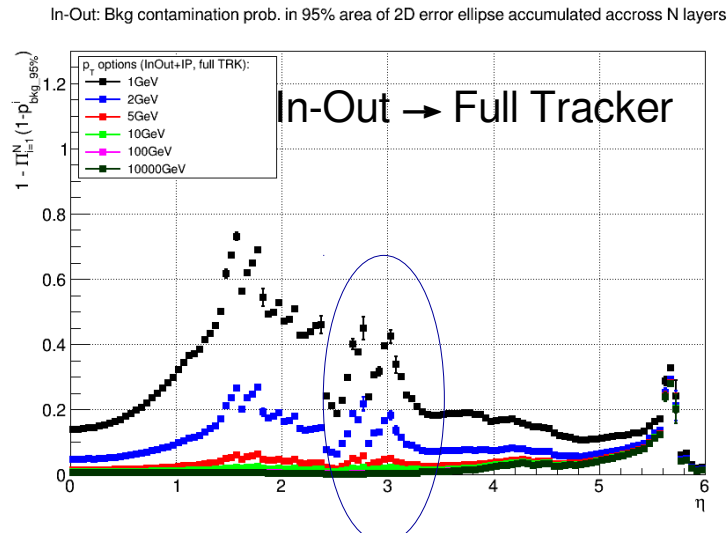
In-Out: Bkg contamination prob. in 95% area of 2D error ellipse accumulated accross N layers

- **Missing intermediate forward discs (iFWD)** between central & forward tracker (also shown by Estel)
  → **Solution:** Use 3 instead of 1iFWD disc, @ z=6.25m, 7.40m, 8.75m

Pattern Recognition Results & Conclusion

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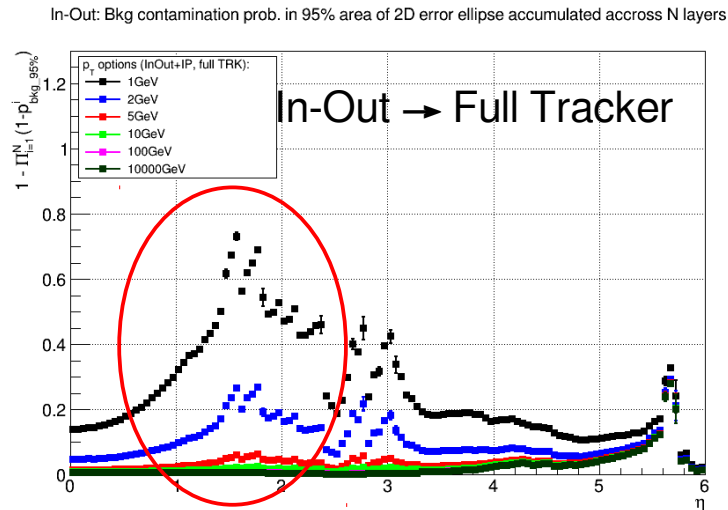 - → **Solution:** Use 3 instead of 1iFWD disc, @ z=6.25m, 7.40m, 8.75m

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- **Effect of barrel modules tilt & material:** Non-tilted modules increase it's material & "projection" effect with increasing eta! (Namely important for BRL & high occupancy region)
  - → **Solution:** Tilt BRL pixel & macro-pixel modules (area with high occupancy) by $(\pi/2 - \vartheta)$ + small angle to increase the cluster size. "Avoid" tilting of 1st BRL layer to keep the best d_0 & z_0 resolution!

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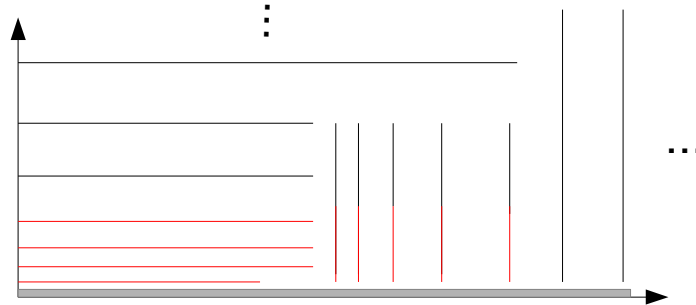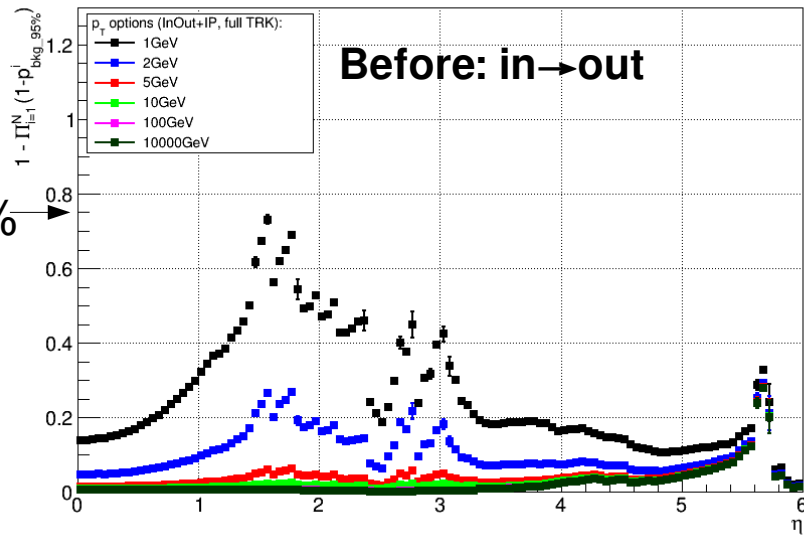

Before: in→out

75%
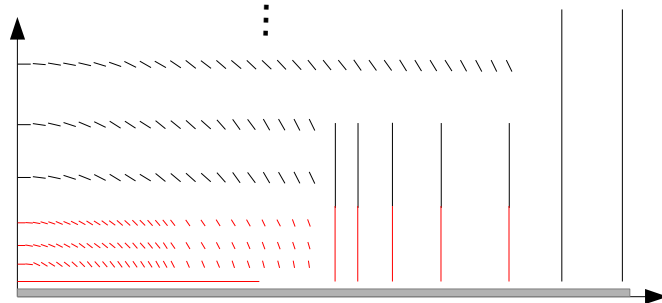
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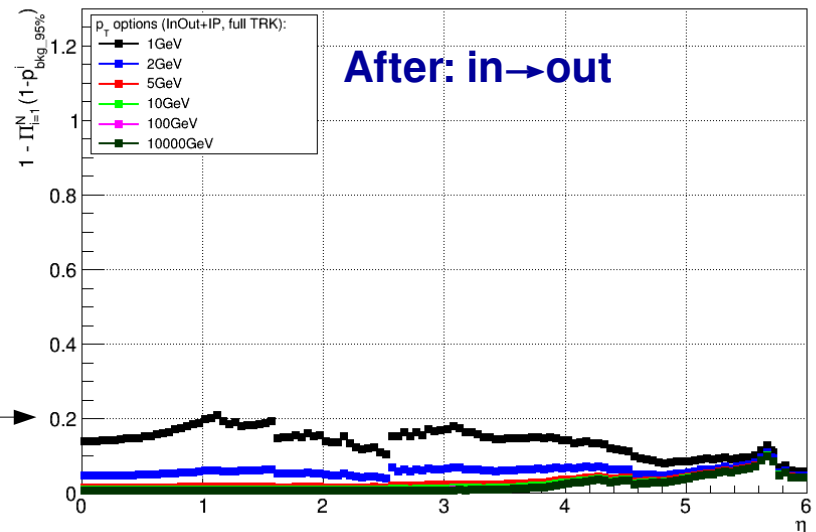**Before: in→out**

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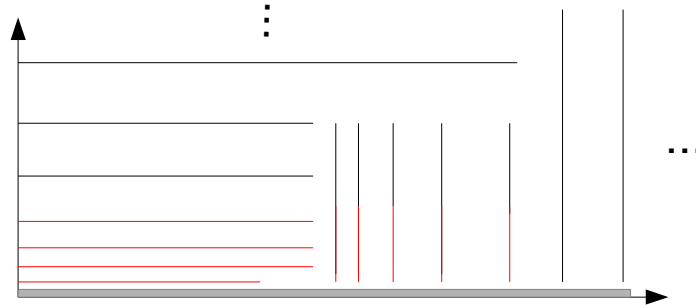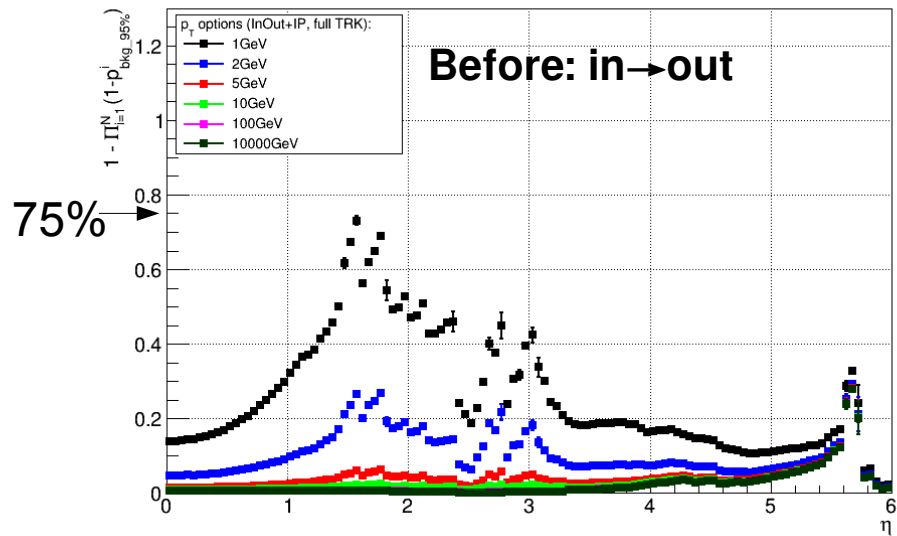
All corrections applied
but modules simulated ideally (as infinitesimally short)

In-Out: Bkg contamination prob. in 95% area of 2D error ellipse accumulated accross N layers

After: in→out

20%

Summary & Outlook

- **Pattern recognition in high pile-up ~ 1000 →** an optimized geometry layout provides **an improvement by factor of 3-4** in track finding purity:

  - **Critical eta region: 1.0-2.5 (transition area between BRL & EC)**

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- **Outlook:**

  - **Finish tilted layout** (update results using new Fluka results by Ilaria) & make more realistic assumptions on support & services

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