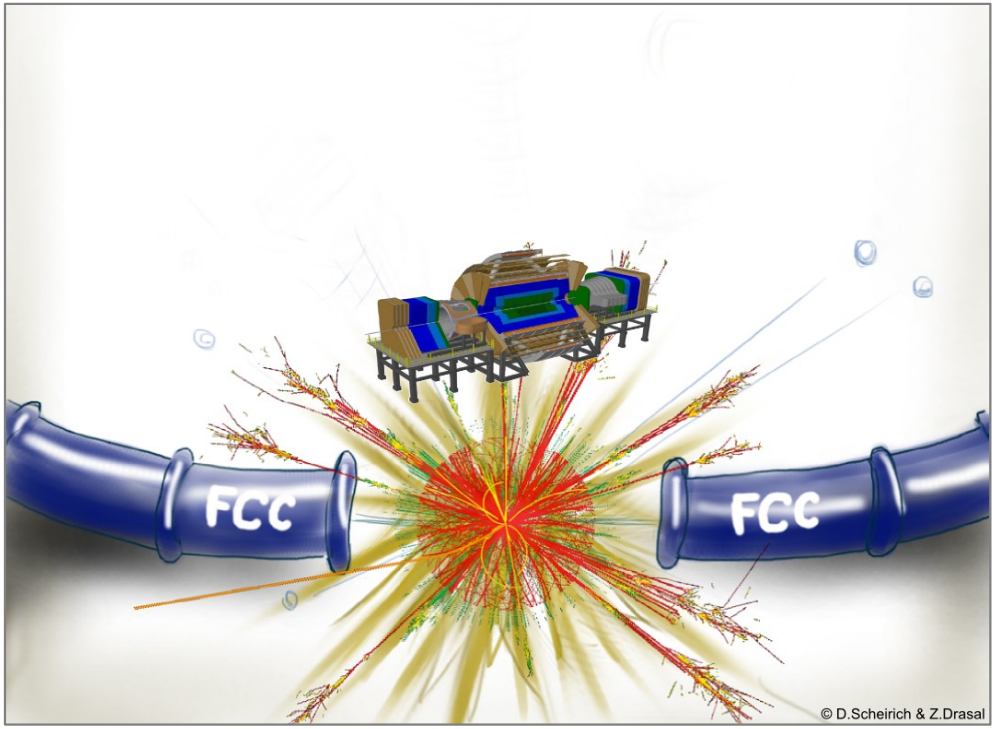
FCC-hh Tracking: Effect of Non-uniform B Field?



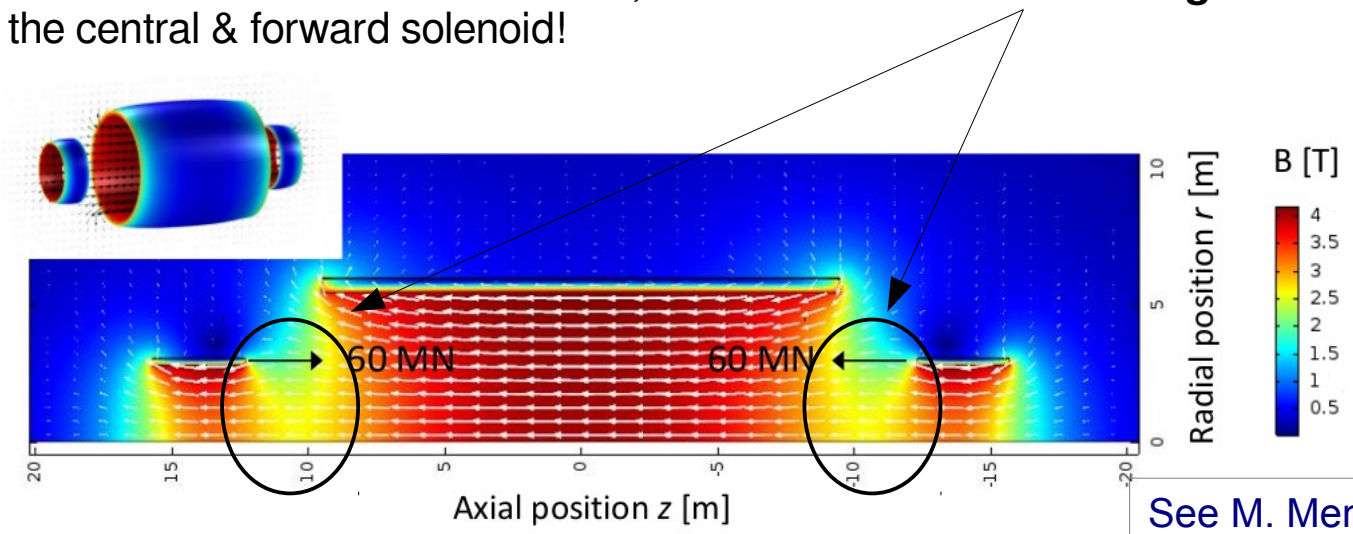
Zbyněk Drásal
CERN

Introduction

- Up-to now all tracker studies performed within tkLayout framework in an approximation of uniform mag. field ...
  - Reasonable estimate for the central tracker, but **NOT for the forward region** affected by the gap between the central & forward solenoid!

Introduction

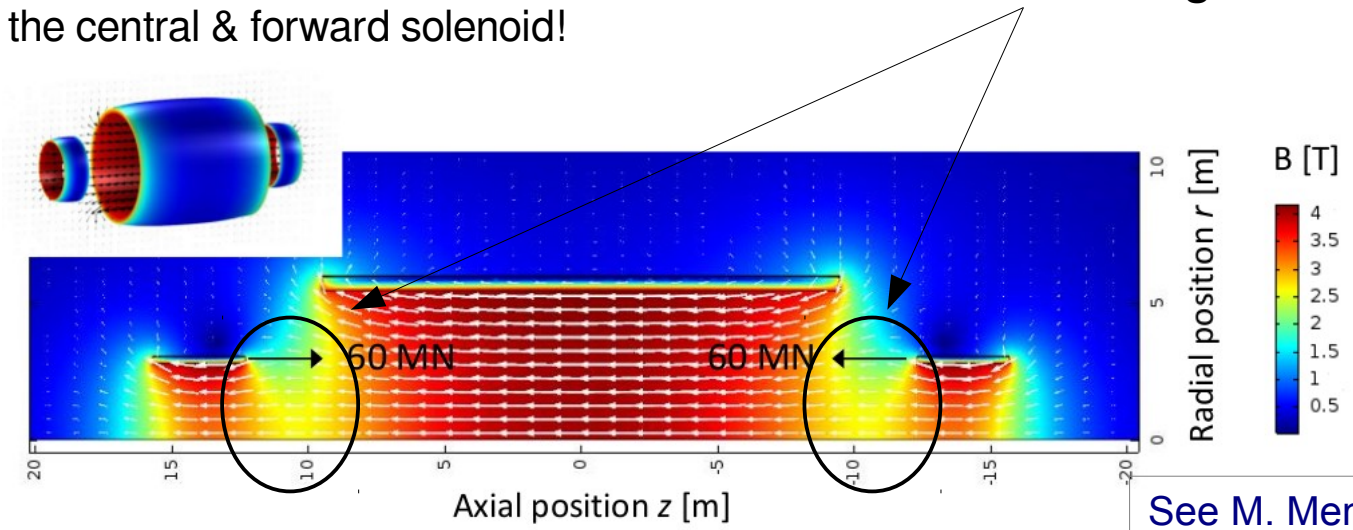
- Up-to now all tracker studies performed within tkLayout framework in an approximation of uniform mag. field ...
  - Reasonable estimate for the central tracker, but **NOT for the forward region** affected by the gap between the central & forward solenoid!



See M. Mentink's talk on magnet

Introduction

- Up-to now all tracker studies performed within tkLayout framework in an approximation of uniform mag. field ...
  - Reasonable estimate for the central tracker, but **NOT for the forward region** affected by the gap between the central & forward solenoid!

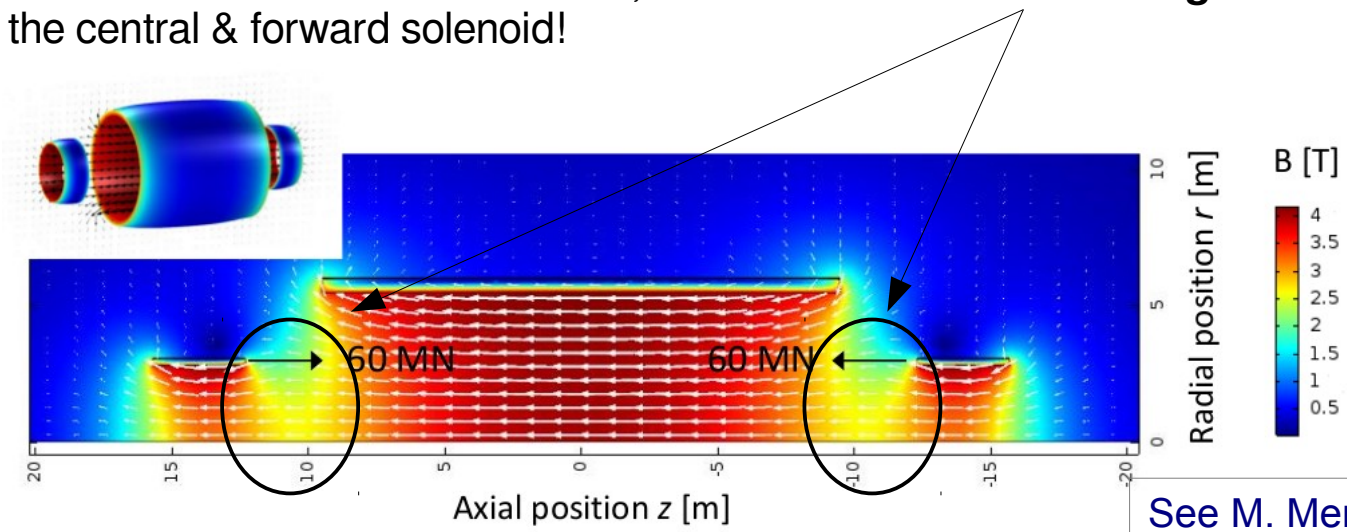


See M. Mentink's talk on magnet

  - So, the question is: "How much do we lose with a non-uniform B field in the forward region?"

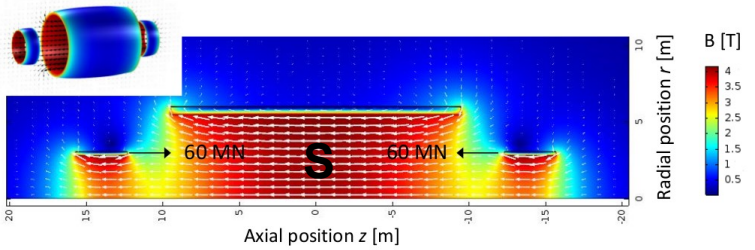
Introduction

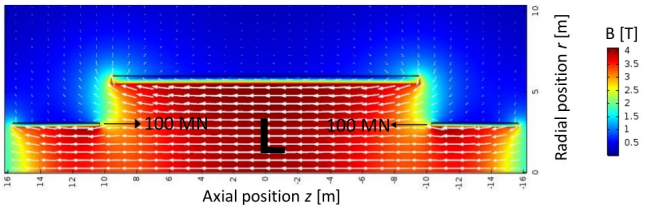
- Up-to now all tracker studies performed within tkLayout framework in an approximation of uniform mag. field ...
  - Reasonable estimate for the central tracker, but **NOT for the forward region** affected by the gap between the central & forward solenoid!



See M. Mentink's talk on magnet

  - So, the question is: "How much do we lose with a non-uniform B field in the forward region?"
    - **2 main options** studied: **Short ("S")** versus **long ("L") FWD solenoid**

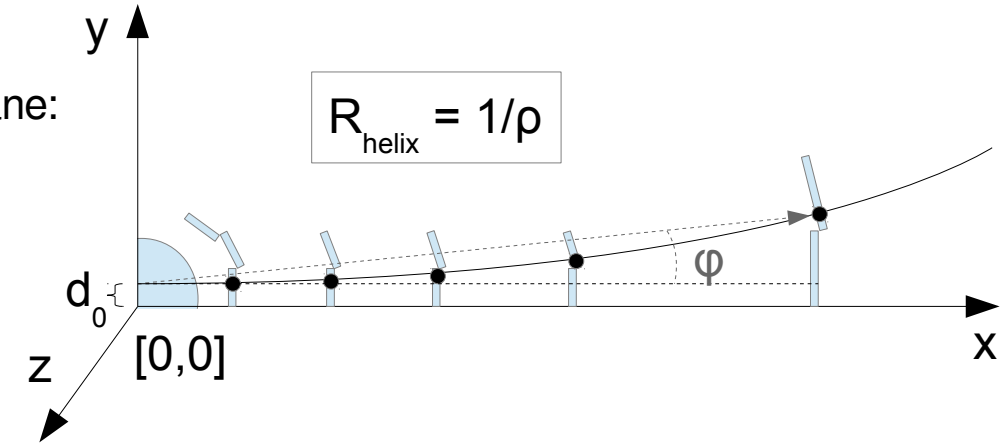




Mathematical Approach: Uniform B Field

- TkLayout & tracking in uniform B field:
  - Track approximated by **parabola** in X-Y plane: (valid up-to p_T~1GeV/c)

$$y_i = \frac{1}{2}\rho x_i^2 - \varphi_0 x_i + d_0$$



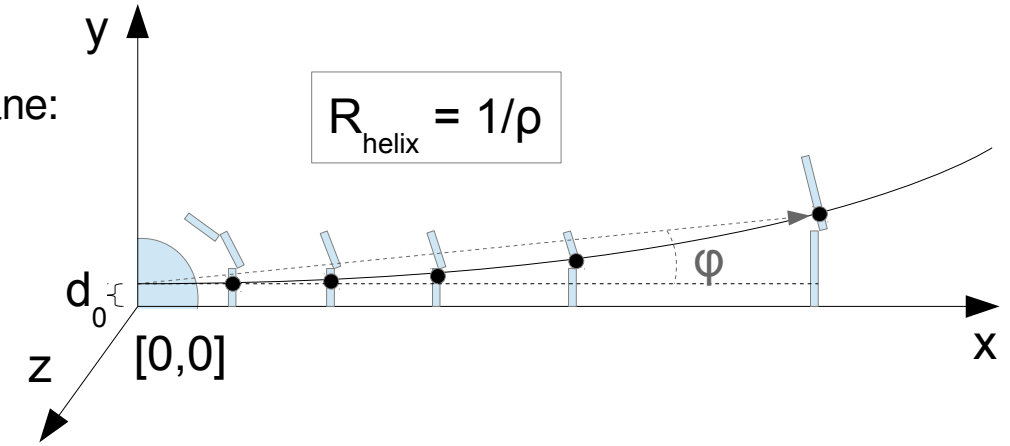
Mathematical Approach: Uniform B Field

- TkLayout & tracking in uniform B field:
  - Track approximated by **parabola** in X-Y plane: (valid up-to p_T~1GeV/c)

$$y_i = \frac{1}{2}\rho x_i^2 - \varphi_0 x_i + d_0$$

  - B field assumed to be uniform:

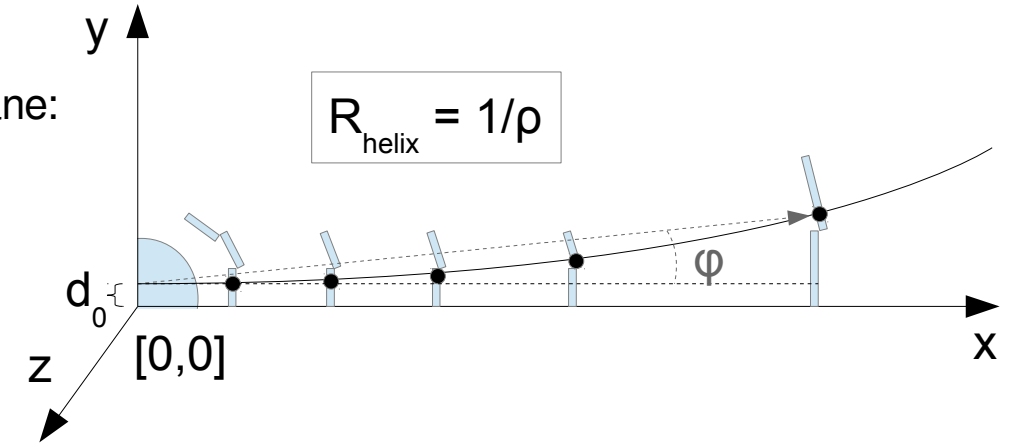
$$\rho[\mathrm{m}^{-1}] = \frac{0.3B[\mathrm{T}]}{p_T[\mathrm{GeV/c}]}$$



Mathematical Approach: Uniform B Field

- TkLayout & tracking in uniform B field:
  - Track approximated by **parabola** in X-Y plane: (valid up-to p_T~1GeV/c)

$$y_i = \frac{1}{2}\rho x_i^2 - \varphi_0 x_i + d_0$$



  - B field assumed to be uniform:

$$\rho[\mathrm{m}^{-1}] = \frac{0.3B[\mathrm{T}]}{p_T[\mathrm{GeV/c}]}$$

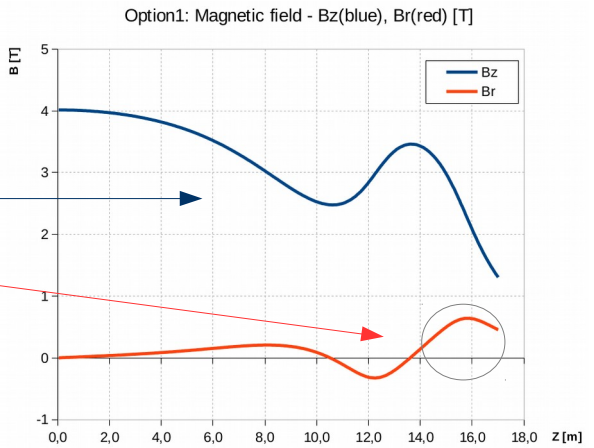
  - Global χ2 technique applied & parameters ($\vartheta_i = (\rho, \varphi_0, d_0)$) cov. matrix calculated:

$$\mathrm{cov}(\vartheta_i, \vartheta_j) = \left(A^T V^{-1} A\right)^{-1}, A_{ij} = \left.\frac{\partial y_i(\vartheta_j)}{\partial \vartheta_j}\right|_{\vartheta=\hat{\vartheta}}$$

    - Used matrix formalism
    - V ≡ variance matrix → generally non-diagonal due to a combined effect of multiple scattering & measurement precision (measurement errors)

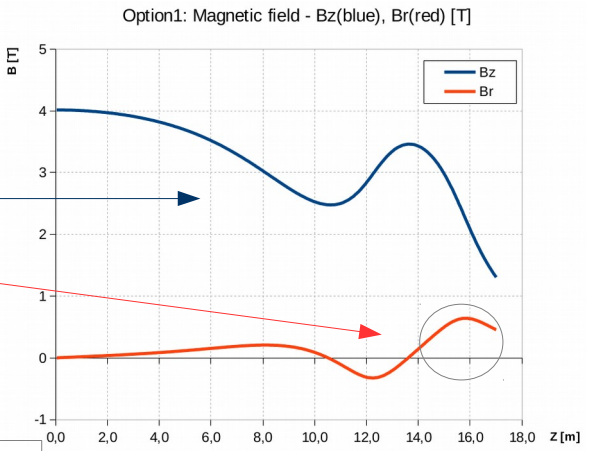
Mathematical Approach: Non-uniform B Field

- How shall we proceed with a **non-uniform** B field?
  - Several **simplifications** necessary **for analytical calculations:**
    - Assume **B** as a function of **z** only: **B = B(z)**
    - B = B(r) ~ 0 → not fully true in the very FWD region!
    - B expressed @ R=1.55m → the worst scenario assumed!



Mathematical Approach: Non-uniform B Field

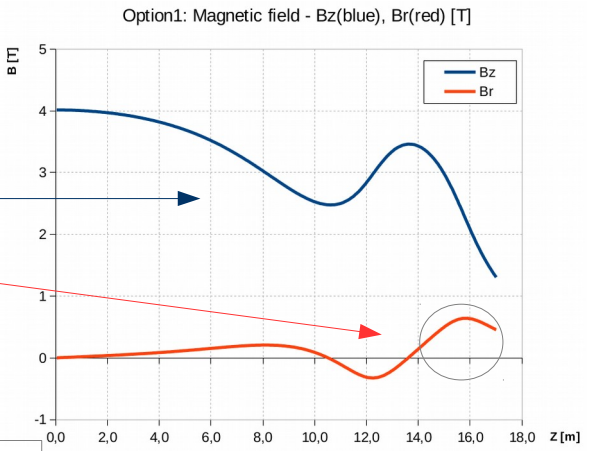
- How shall we proceed with a **non-uniform** B field?
  - Several **simplifications** necessary **for analytical calculations:**
    - Assume **B** as a function of **z** only: **B = B(z)**
    - B = B(r) ~ 0 → not fully true in the very FWD region!
    - B expressed @ R=1.55m → the worst scenario assumed!
  - **Consequences:**
    - $\vec{F} = q(\vec{v} \times \vec{B}) \rightarrow |\vec{p}| = \text{const.} \xrightarrow{B=B(z)} |p_T| = \text{const. along path}$



Mathematical Approach: Non-uniform B Field

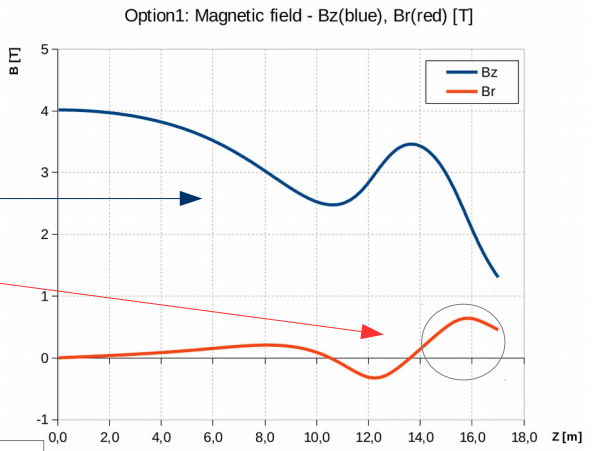
- How shall we proceed with a **non-uniform** B field?
  - Several **simplifications** necessary **for analytical calculations:**
    - Assume **B** as a function of **z** only: **B = B(z)**
    - B = B(r) ~ 0 → not fully true in the very FWD region!
    - B expressed @ R=1.55m → the worst scenario assumed!
  - **Consequences:**
    - $\vec{F} = q(\vec{v} \times \vec{B}) \rightarrow |\vec{p}| = \text{const.} \xrightarrow{B=B(z)} |p_T| = \text{const. along path}$
    - Track in X-Y plane can be then approximated by **a set of parabolas in N intervals** (x_0,x_1), (x_1,x_2), ..., (x_{N-1},x_N) with radius dependent on actual position:

$$\rho(z)[\mathrm{m}^{-1}] = \frac{0.3B(z)[\mathrm{T}]}{p_T[\mathrm{GeV/c}]}$$



Mathematical Approach: Non-uniform B Field

- How shall we proceed with a **non-uniform** B field?
  - Several **simplifications** necessary **for analytical calculations:**
    - Assume **B** as a function of **z** only: **B = B(z)**
    - B = B(r) ~ 0 → not fully true in the very FWD region!
    - B expressed @ R=1.55m → the worst scenario assumed!
  - **Consequences:**



- $\vec{F} = q(\vec{v} \times \vec{B}) \rightarrow |\vec{p}| = \text{const.} \xrightarrow{B=B(z)} |p_T| = \text{const. along path}$

- Track in X-Y plane can be then approximated by **a set of parabolas in N intervals** (x_0,x_1), (x_1,x_2), ..., (x_{N-1},x_N) with radius dependent on actual position:

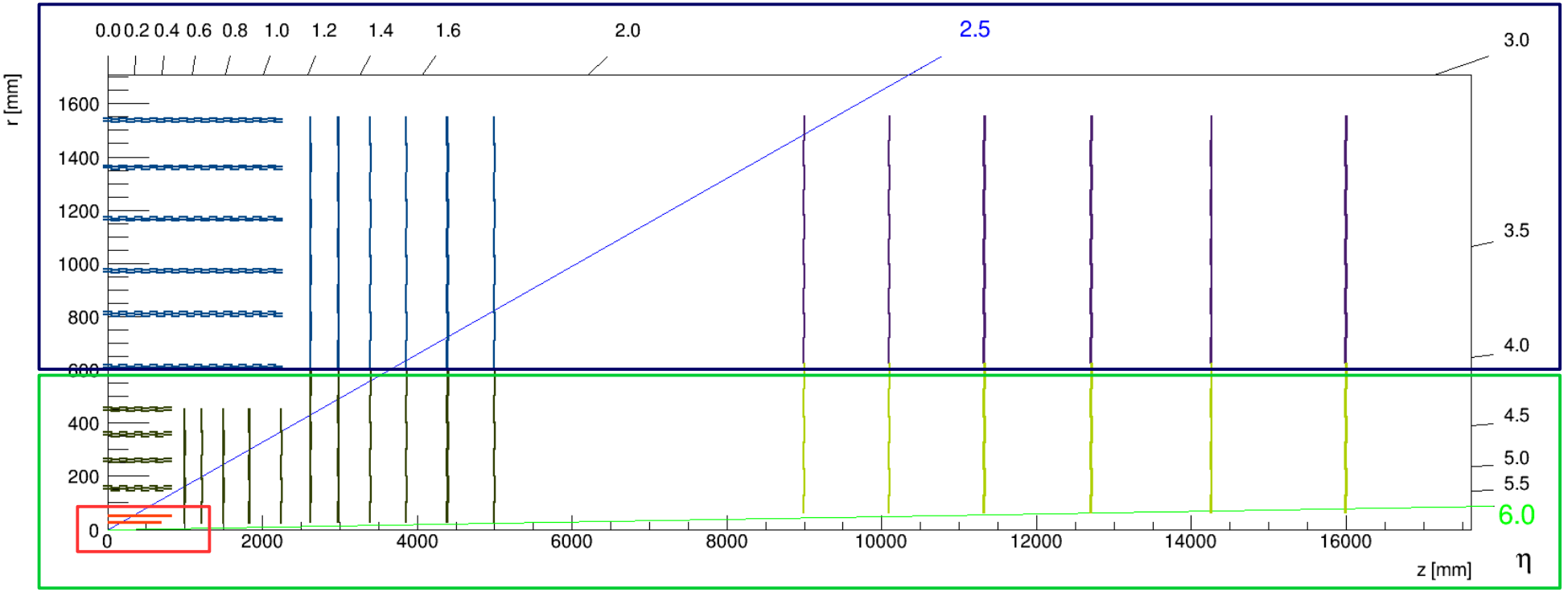
$$\rho(z)[\mathrm{m}^{-1}] = \frac{0.3B(z)[\mathrm{T}]}{p_T[\mathrm{GeV/c}]}$$

- For measurement $x_i \in (x_{k-1}, x_k)$ with B approximated as B_k in (x_{k-1}, x_k) the final **function** reads:

$$y_i = \frac{1}{2}\frac{B_k}{B_1}\rho x_i^2 - \left[\rho \sum_{j=1}^{k-1} \frac{(B_{j+1} - B_j)}{B_1} x_j + \varphi_0\right] x_i + \left[\frac{\rho}{2} \sum_{j=1}^{k-1} \frac{(B_{j+1} - B_j)}{B_1} x_j^2 + d_0\right]$$

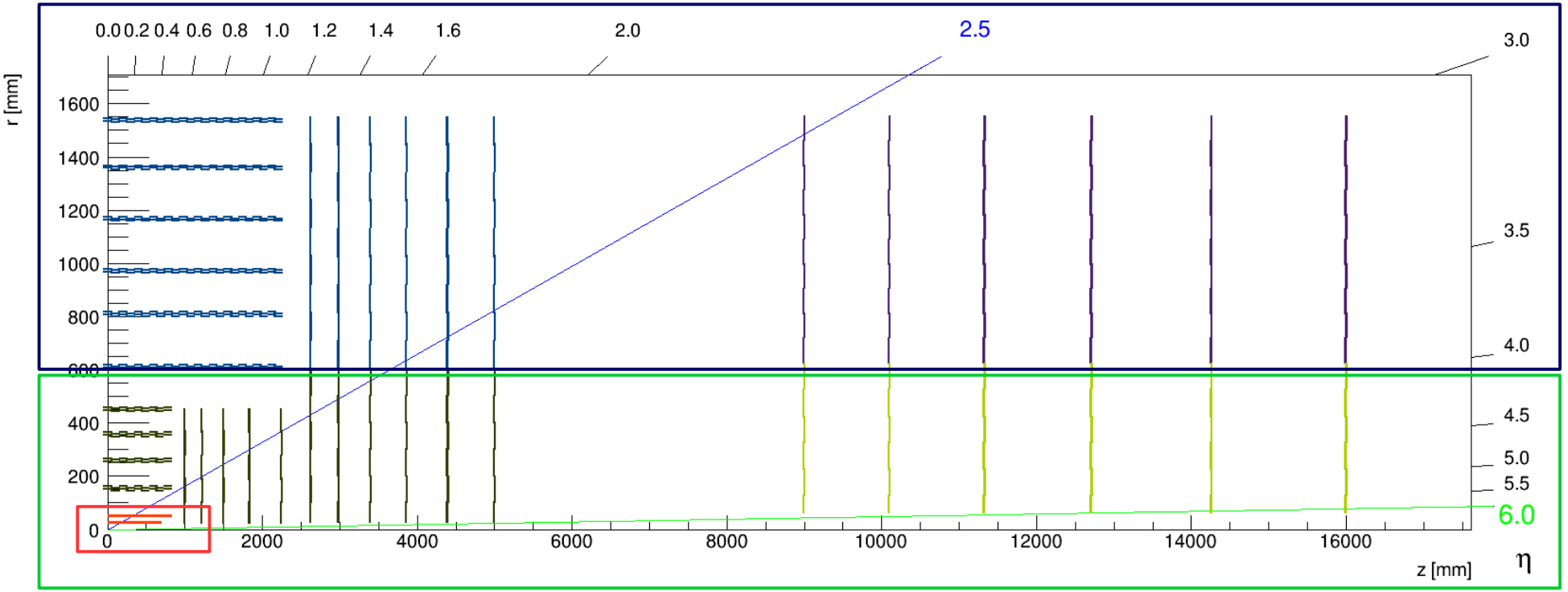
FCC-hh Tracker in Non-uniform B Field

- Let's use the tkLayout global χ2 technique (matrix formalism with a new complex form for y_i) & apply it to the FCC-hh tracker geometry:



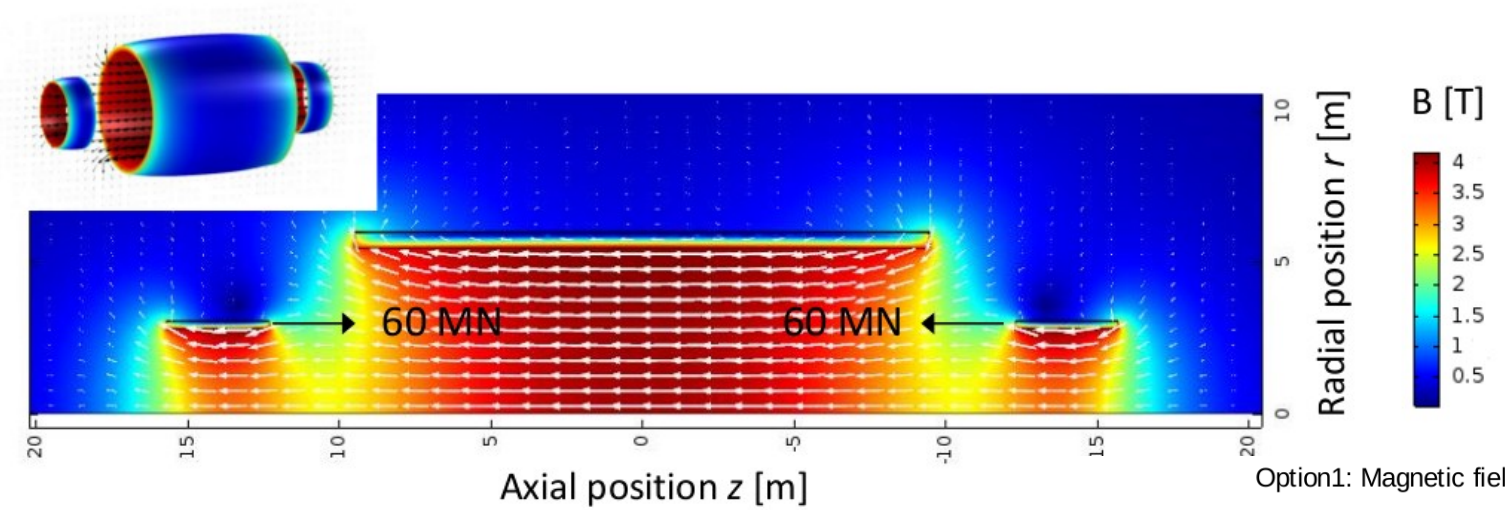
FCC-hh Tracker in Non-uniform B Field

- Let's use the tkLayout global χ2 technique (matrix formalism with a new complex form for y_i) & apply it to the FCC-hh tracker geometry:



- Resolution:
  - **10x15µm²** (0.5% x/x_0 BRL only, EC 1.5% x/x_0),
  - **10x30µm²** (1.5% x/x_0), **10x100µm²** (3.0% x/x_0)

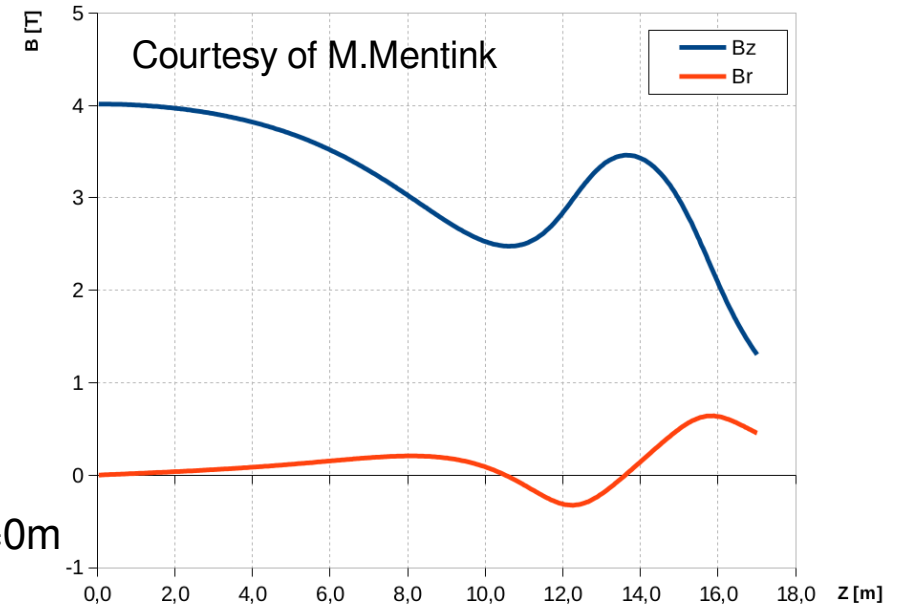
Option1: “Short” FWD Solenoid



Option1: Magnetic field - Bz(blue), Br(red) [T]

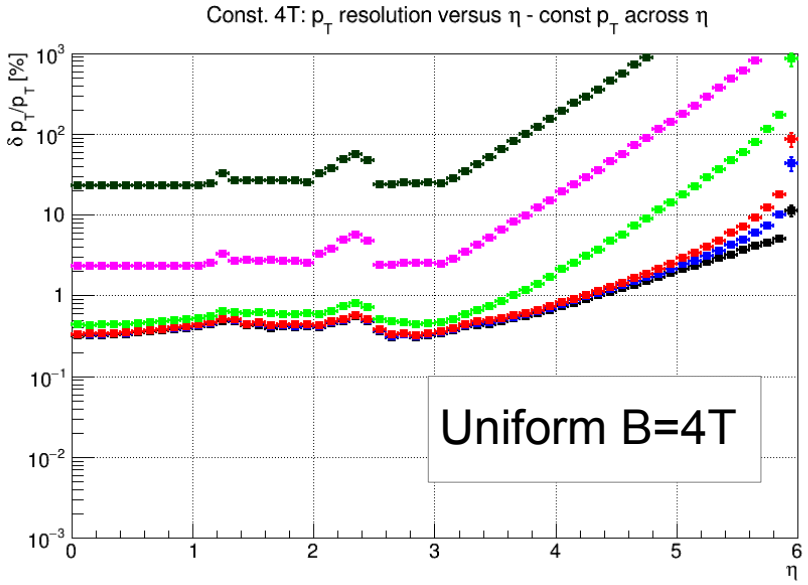
Bz @ R=1.55m

Br @ R=1.55m

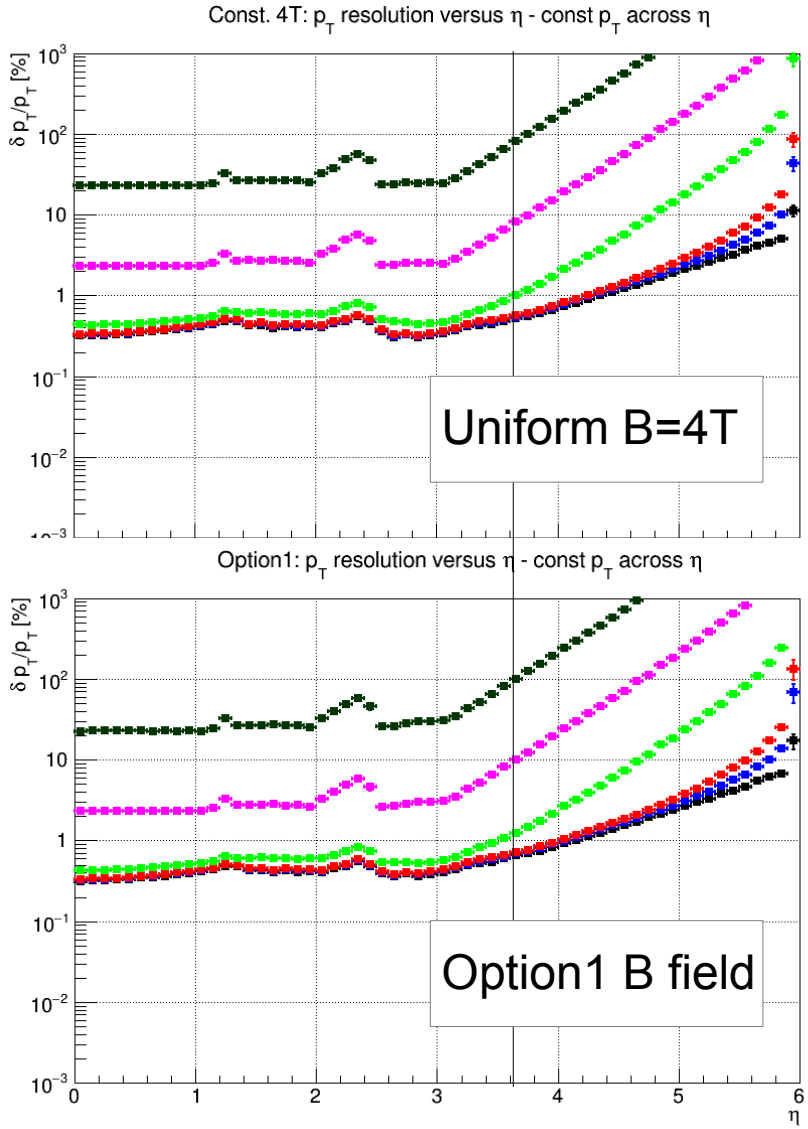


- **Comment:** For the FWD solenoid (z=12-16m) Bz @ R=0m would in reality provide the worst case scenario!

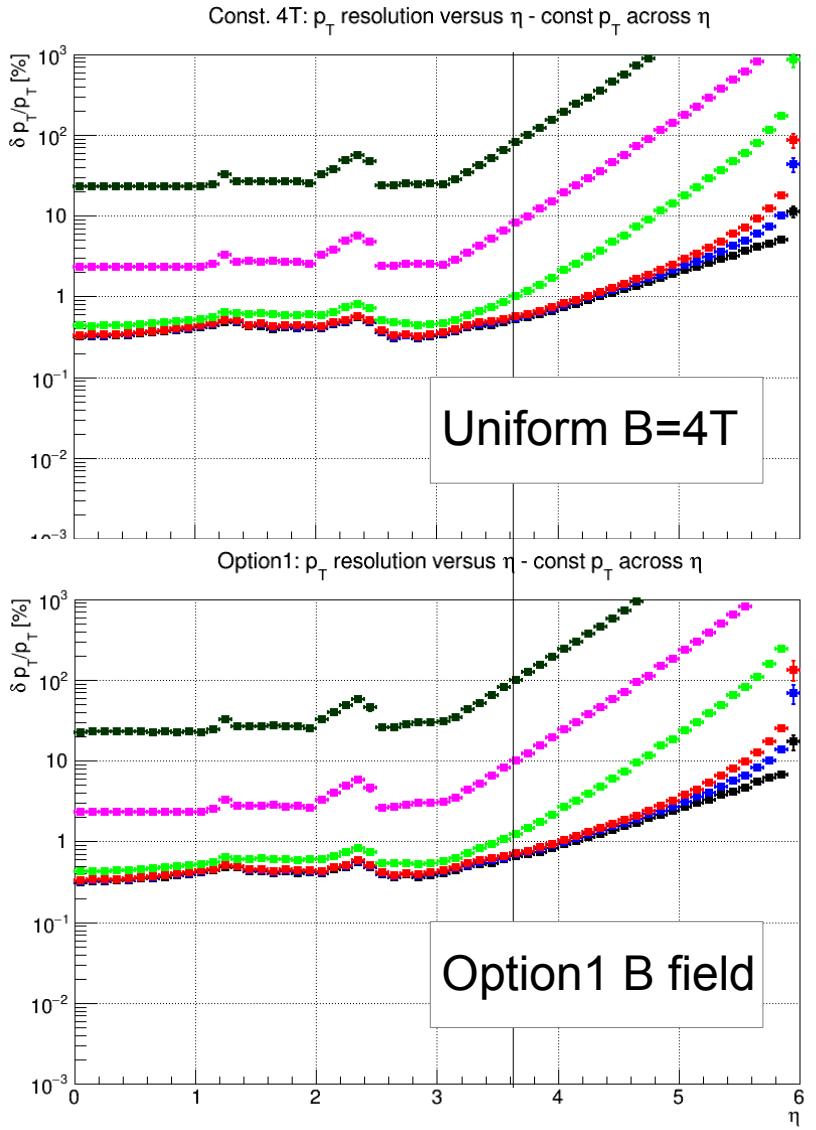
Option1 Results

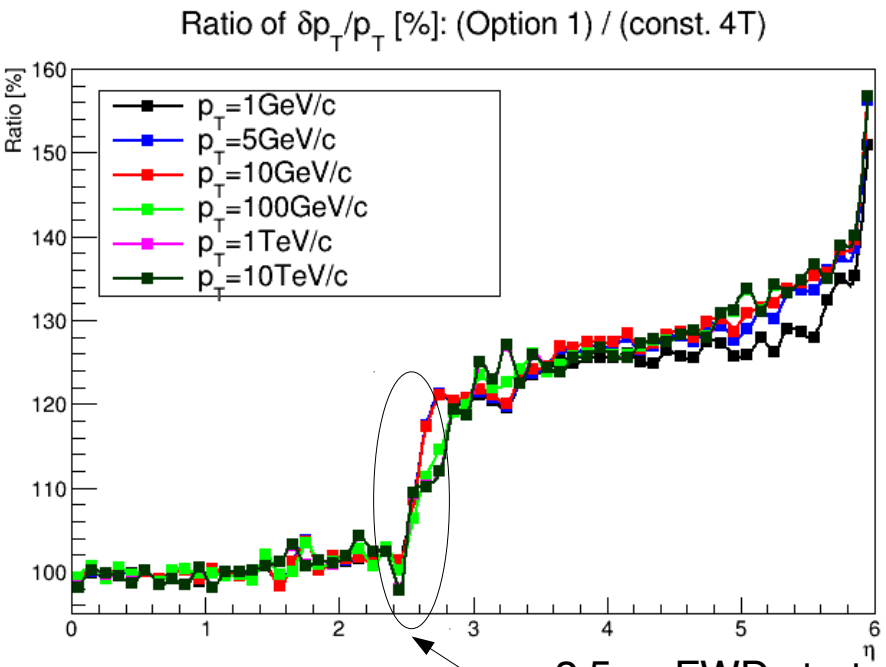


Option1 Results

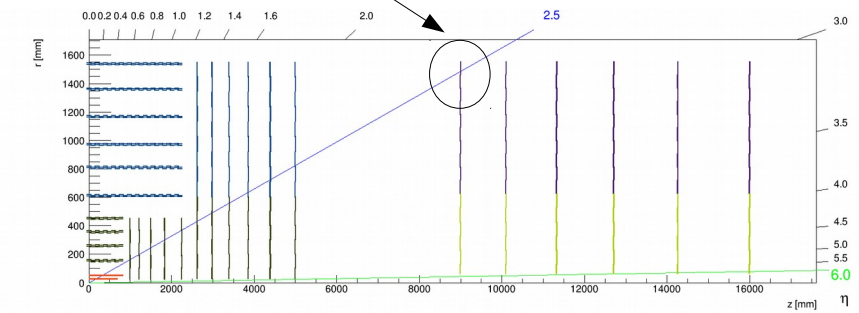


Option1 Results

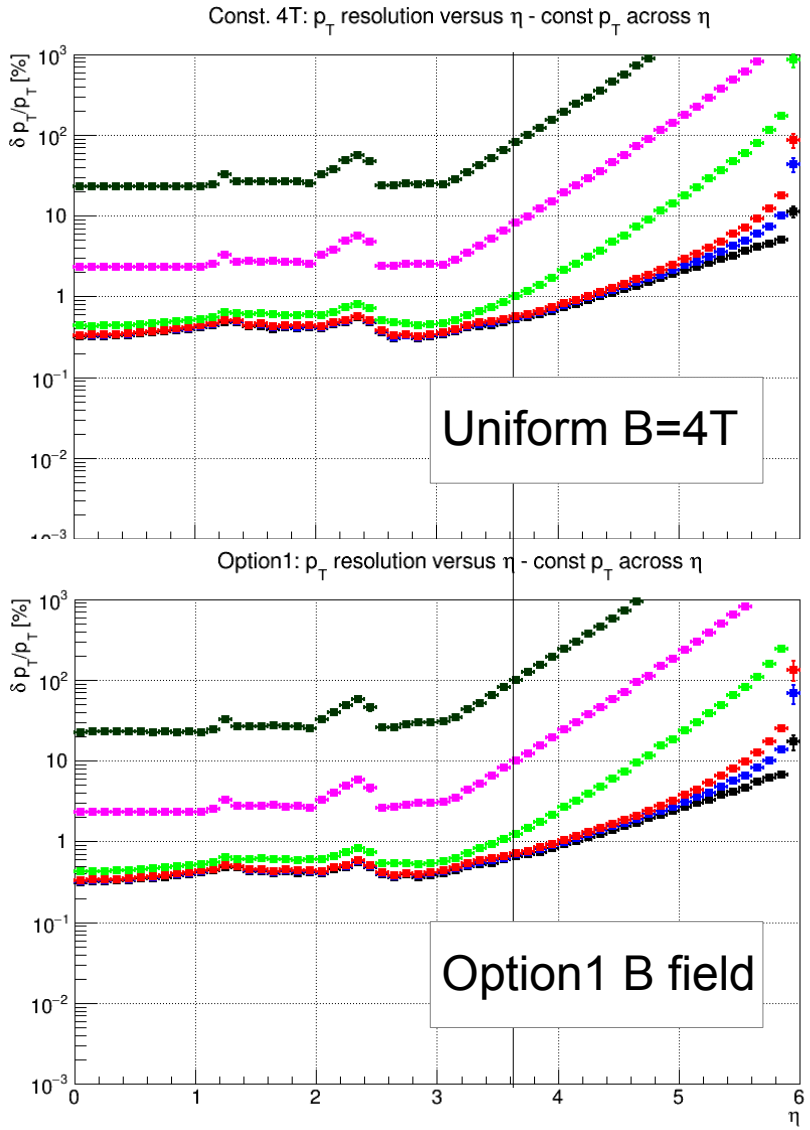


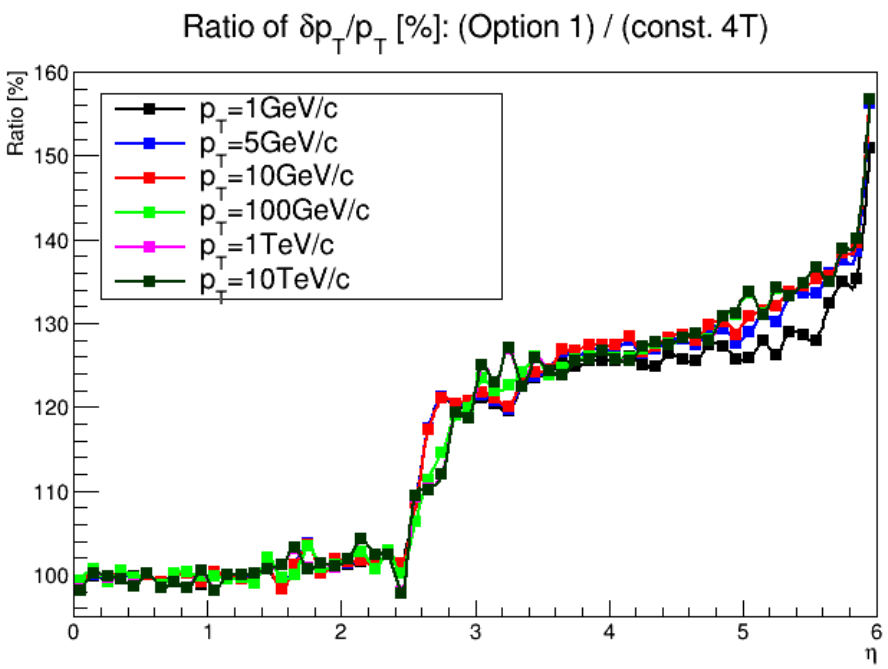


η=2.5 → FWD starts to play role



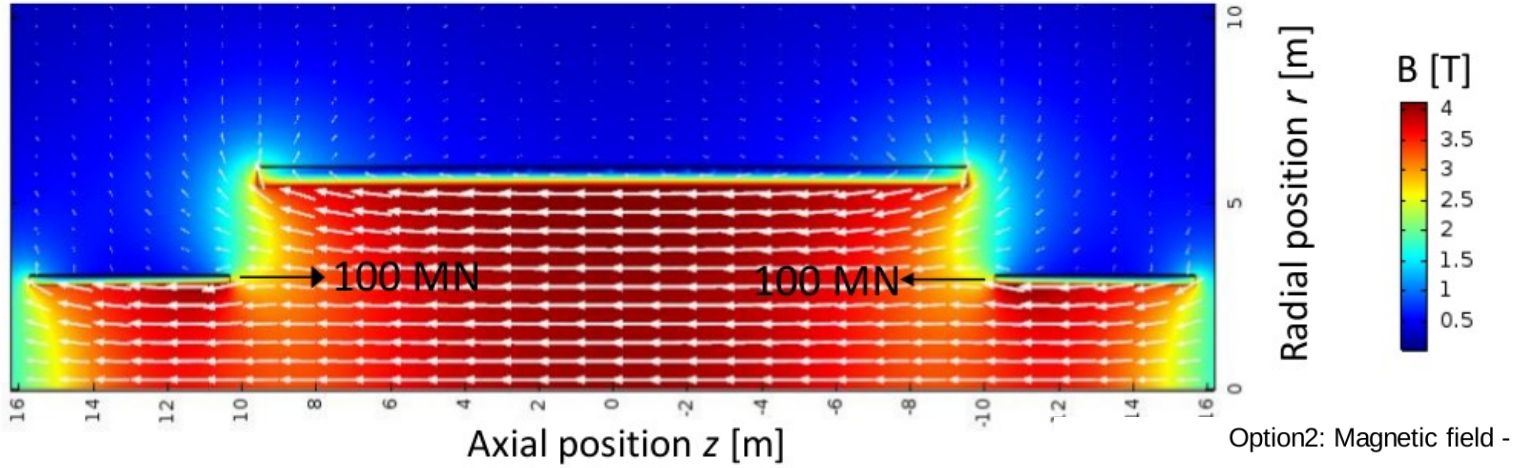
Option1 Results





- Resolution **degrades by ~ 25-30% @ η>2.5 (FWD)**
- Comment:
  - Ratios depicted → curves used to “lead an eye” only
  - Follow curves with $p_T \geq 5$GeV/c (due to simplification used in the approach: errors projection on virtual meas. planes by line only, not by helix → OK for $p_T \geq 5$GeV/c)

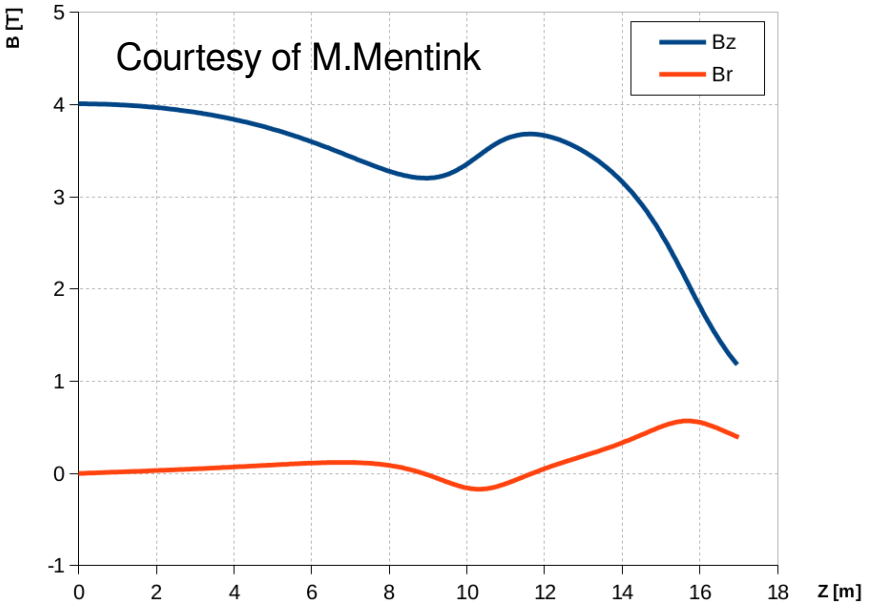
Option2: “Long” FWD Solenoid



Option2: Magnetic field - Bz(blue), Br(red) [T]

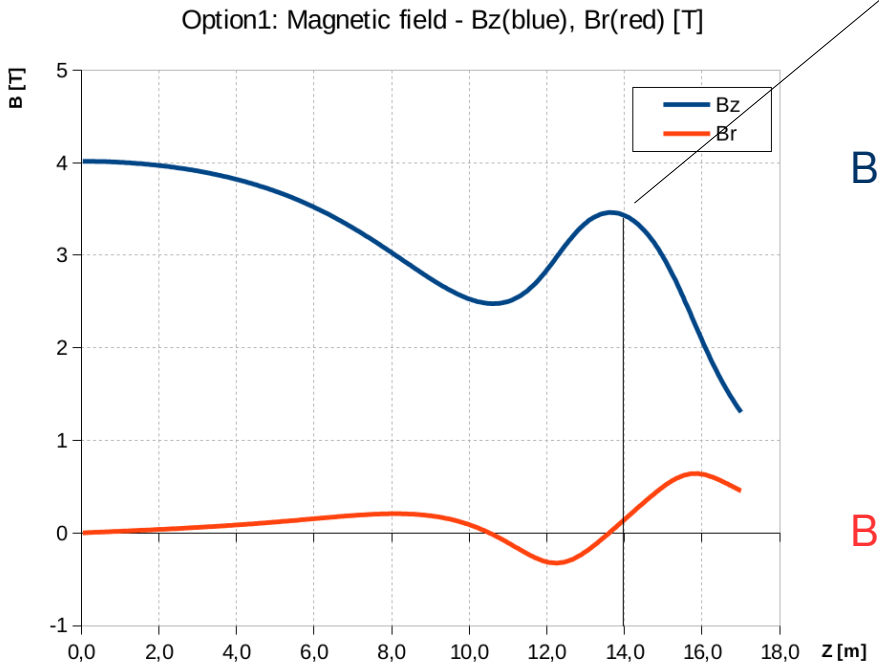
Bz @ R=1.55m

Br @ R=1.55m



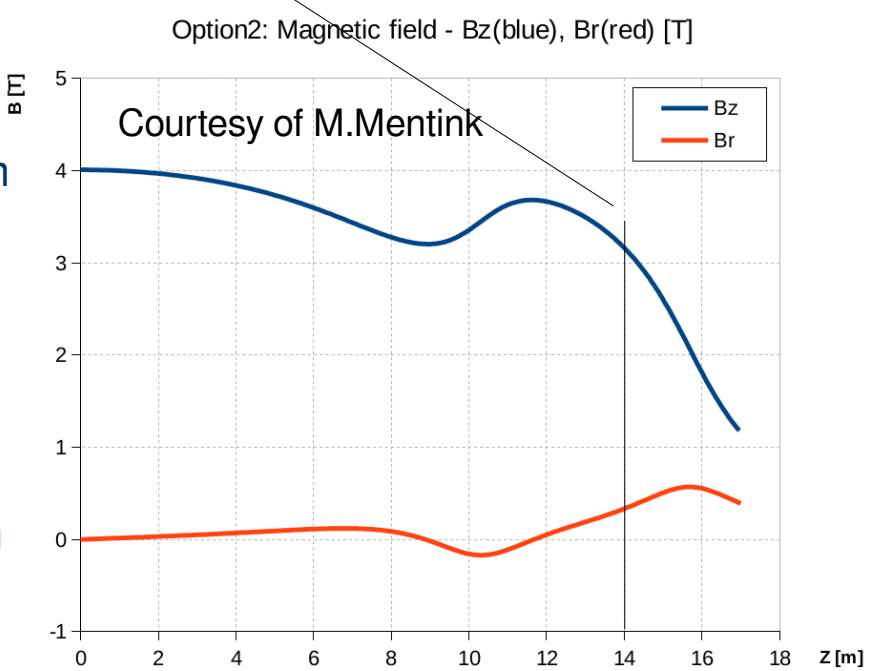
Compersion: Option1 versus Option2

- Why such a difference @ 14-16m?
- Is it possible to have a more uniform B field @ 12-16m?

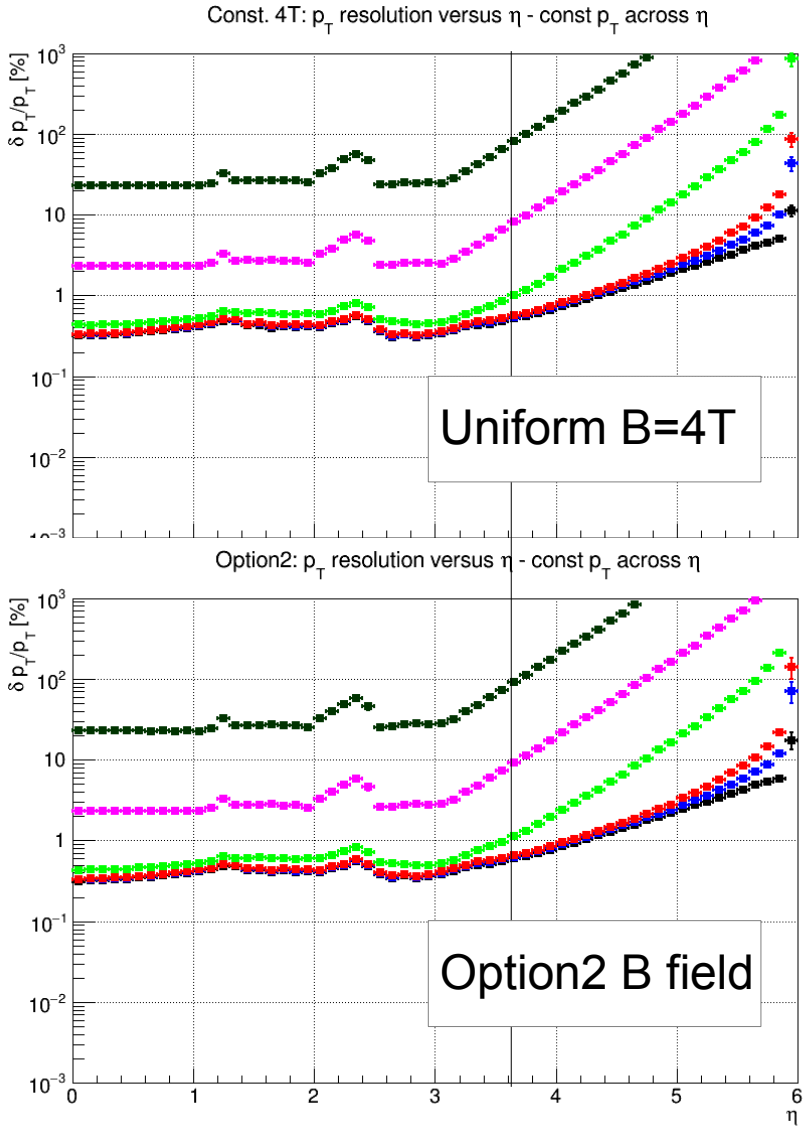


Bz @ R=1.55m

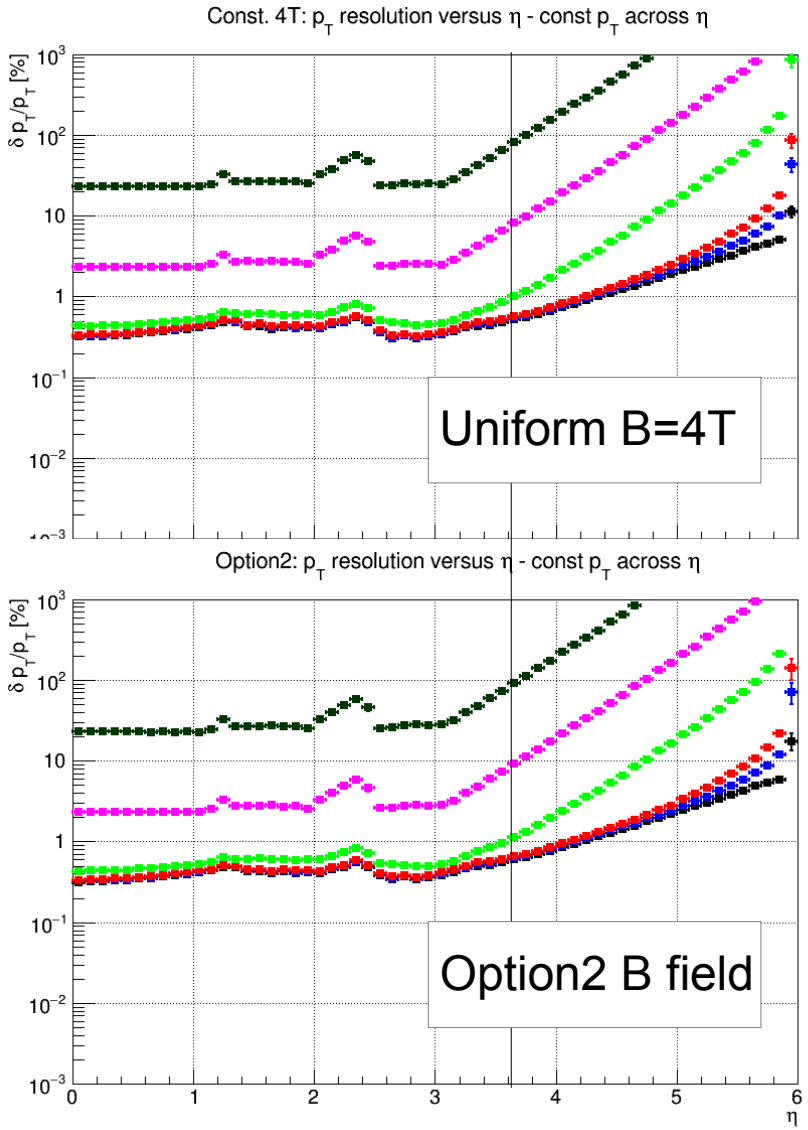
Br @ R=1.55m

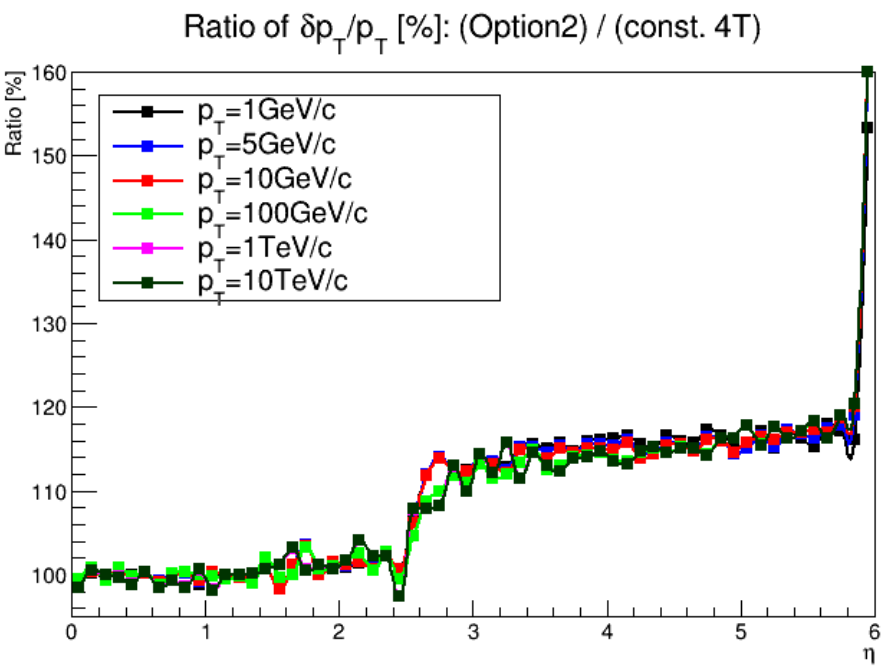


Option2 Results



Option2 Results





- Resolution **degrades by ~ 15% @ η>2.5 (FWD)**
- Comments as for Option1 studies ...

Conclusions & Outlook

- An approximate analytical approach developed to calculate **$\Delta p_T/p_T$ in a non-uniform solenoid mag. field**
  - Only approximative estimates may be provided → Need for final verification by full sim & ACTS
- **2 main magnet scenarios** studied & estimates of their performance made:
  - Option1 - "**Short**" **FWD solenoid** → $\Delta p_T/p_T$ degraded by ~ **25-30%** wrt uniform B field (4T) scenario
  - Option2 - "**Long**" **FWD solenoid** → $\Delta p_T/p_T$ degraded by ~ **15%** wrt uniform B field (4T) scenario

→ Using the approximative model the Option2 shows a **benefit of ~15% in $\Delta p_T/p_T$** compared to Option1 → one should carefully compare cost & technology challenges to make the final decision

→ One should realize that approximately half of the detector eta coverage is going to be influenced by the FWD solenoid...