Overview, Herman's 7 questions

FCC Hadron Detector Meeting
Nov., 3rd, 2015

W. Riegler

Dates for Next Meetings

We have defined the dates for all FCC hadron detector meetings, leading up to the next FCC week in Rome (April 11-15, 2016).

Nov. 03, 2015
Dec. 09, 2015
Jan. 21, 2016
Mar. 03, 2016
Apr. 06, 2016

https://indico.cern.ch/category/6069/

FCC Software

In the last meeting we have defined a baseline parametrization for a DELPHES card that should be ready for physics studies.

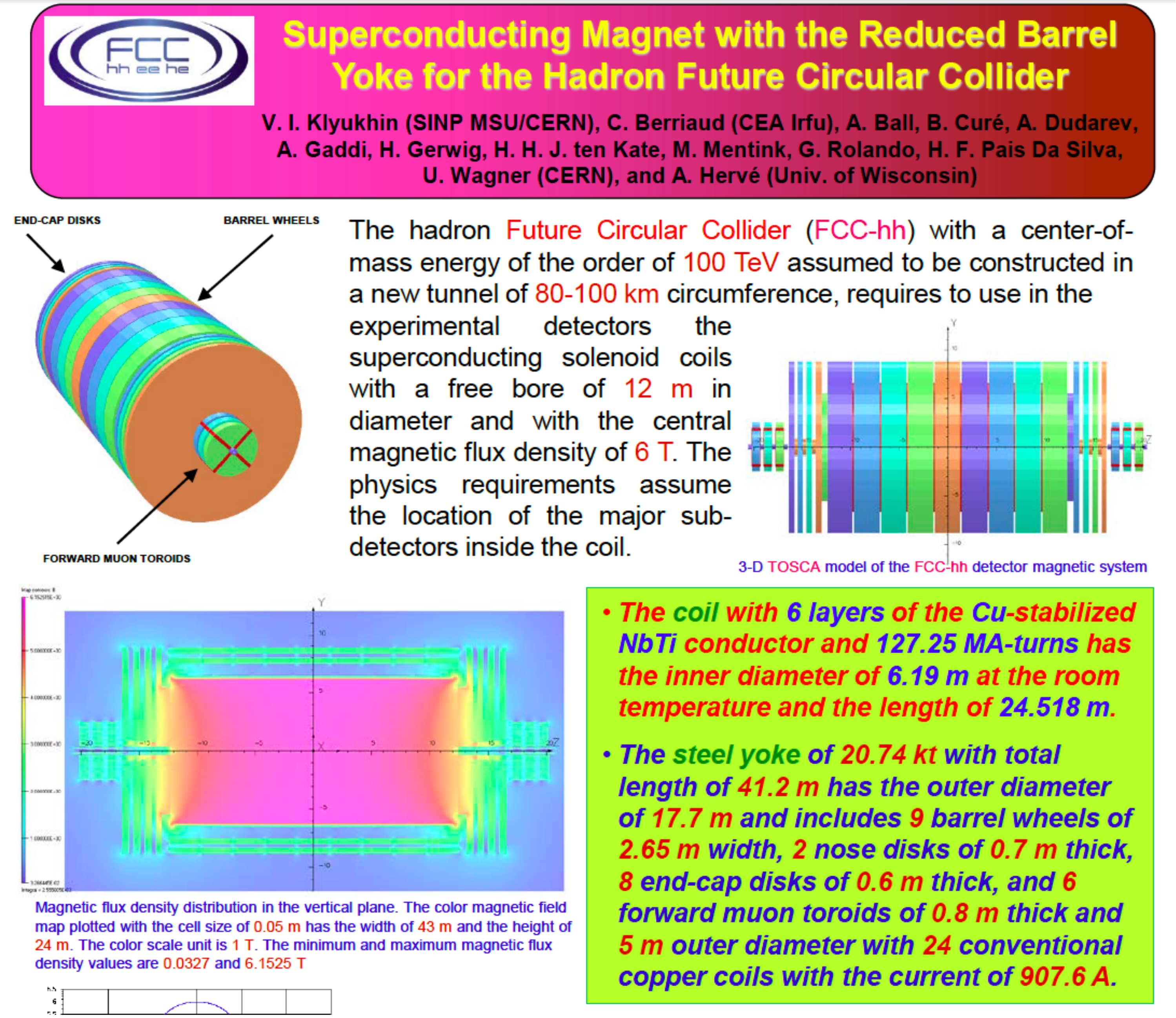
There is quite some activity on FCC simulation and software tools. As a next step we have to define clear goals for this effort (fast, full simulation, reconstruction …)

FCC-hh, FCC-ee, FCC-eh studies use the same FCC software framework.

The overall FCC software coordination is done by Benedikt Hegner.

The items related to FCC-ee software are coordinated by Colin Bernet.

For the FCC-hh issues, Clement Helsens agreed to take up this task.
→ See presentation by Clement.



Superconducting Magnet with the Reduced Barrel Yoke for the Hadron Future Circular Collider

V. I. Klyukhin (SINP MSU/CERN), C. Berriaud (CEA Irfu), A. Ball, B. Curé, A. Dudarev,
A. Gaddi, H. Gerwig, H. H. J. ten Kate, M. Mentink, G. Rolando, H. F. Pais Da Silva,
U. Wagner (CERN), and A. Hervé (Univ. of Wisconsin)

The hadron Future Circular Collider (FCC-hh) with a center-of-mass energy of the order of 100 TeV assumed to be constructed in a new tunnel of 80-100 km circumference, requires to use in the experimental detectors the superconducting solenoid coils with a free bore of 12 m in diameter and with the central magnetic flux density of 6 T. The physics requirements assume the location of the major sub-detectors inside the coil.

3-D TOSCA model of the FCC-hh detector magnetic system

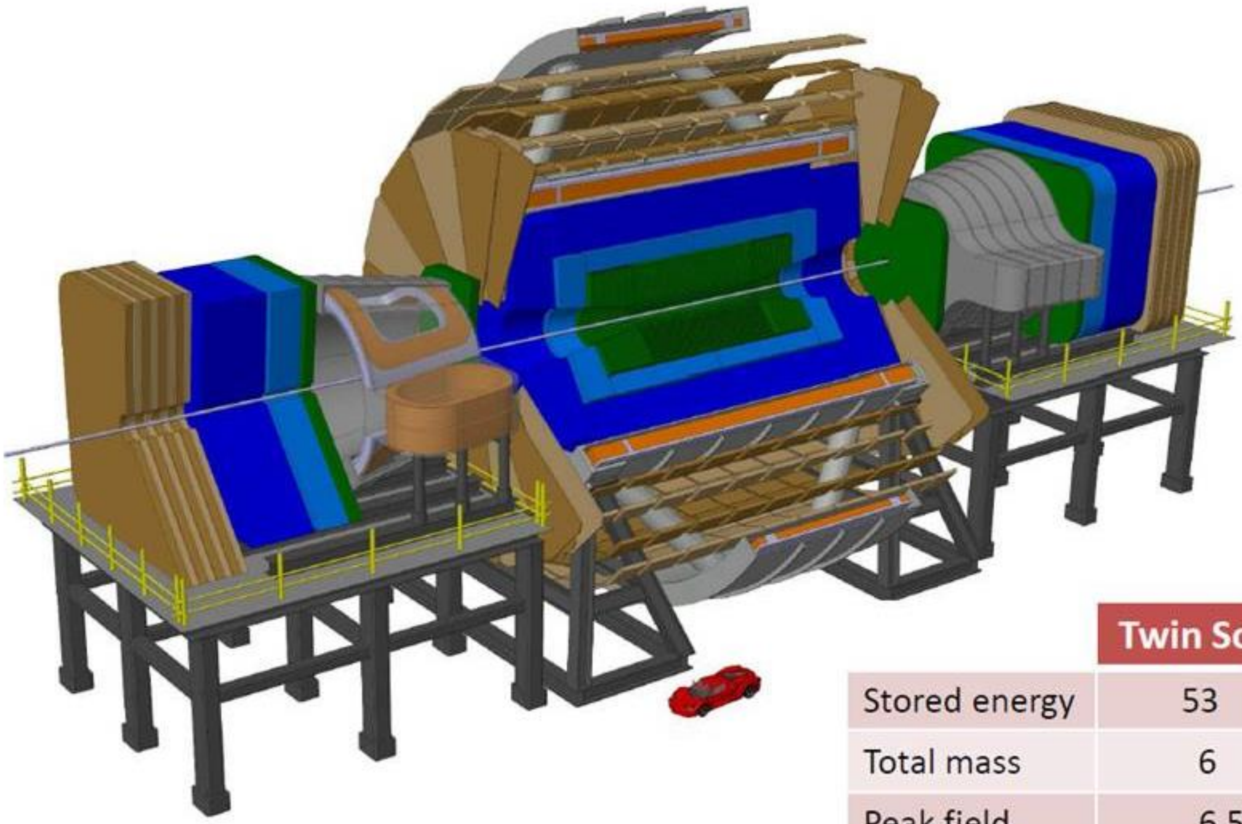
Magnetic flux density distribution in the vertical plane. The color magnetic field map plotted with the cell size of 0.05 m has the width of 43 m and the height of 24 m. The color scale unit is 1 T. The minimum and maximum magnetic flux density values are 0.0327 and 6.1525 T

- ***The coil with 6 layers of the Cu-stabilized NbTi conductor and 127.25 MA-turns has the inner diameter of 6.19 m at the room temperature and the length of 24.518 m.***
- ***The steel yoke of 20.74 kt with total length of 41.2 m has the outer diameter of 17.7 m and includes 9 barrel wheels of 2.65 m width, 2 nose disks of 0.7 m thick, 8 end-cap disks of 0.6 m thick, and 6 forward muon toroids of 0.8 m thick and 5 m outer diameter with 24 conventional copper coils with the current of 907.6 A.***

→ **Presentation in the next meeting, detector concept t.b.d.**

Twin Solenoid + Dipole Magnet System as Present Baseline

Matthias Mentink, Alexey Dudarev, Helder Filipe Pais Da Silva, Christophe Paul Berriaud, Gabriella Rolando,
Rosalinde Pots, Benoit Cure, Andrea Gaddi, Vyacheslav Klyukhin, Hubert Gerwig, Udo Wagner, and
Herman ten Kate

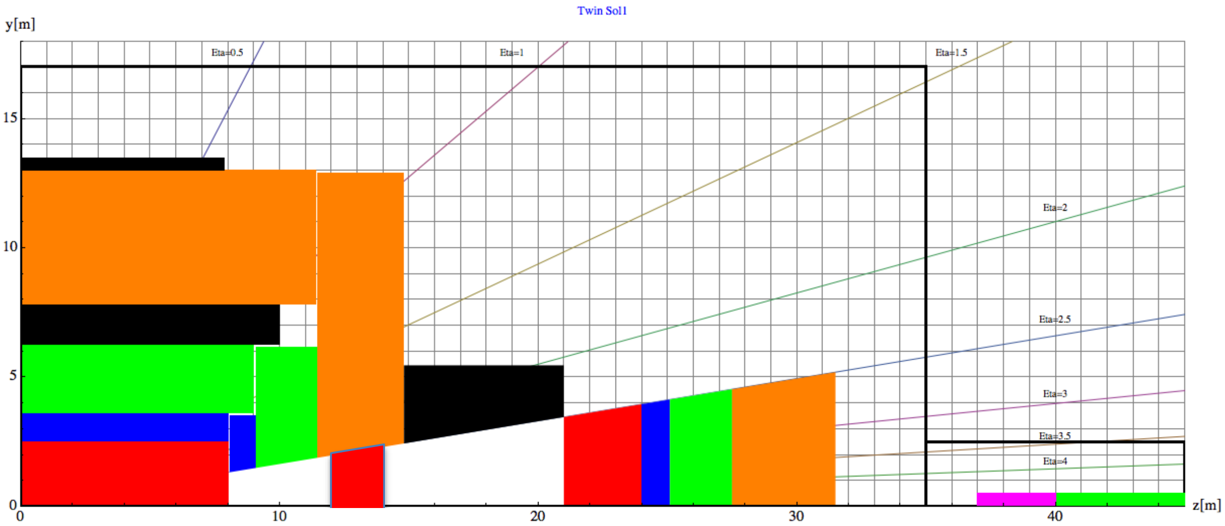


FCC Air core Twin solenoid and Dipoles

State of the art high stress / low mass design.

	Twin Solenoid	Dipole
Stored energy	53 GJ	2 x 1.5 GJ
Total mass	6 kt	0.5 kt
Peak field	6.5 T	6.0 T
Current	80 kA	20 kA
Conductor	102 km	2 x 37 km
Bore x Length	12 m x 20 m	6 m x 6 m

Baseline Geometry, Twin Solenoid



Barrel:

Tracker available space:
R=2.1cm to R=2.5m, L=8m

EMCAL available space:
R=2.5m to R= 3.6m → dR= 1.1m

HCAL available space:
R= 3.6m to R=6.0m → dR=2.4m

Coil+Cryostat:
R= 6m to R= 7.825 → dR = 1.575m, L=10.1m

Muon available space:
R= 7.825m to R= 13m → dR = 5.175m

Coil2:
R=13m to R=13.47m → dR=0.475m, L=7.6m

Endcap:

EMCAL available space:
z=8m to z= 9.1m → dz= 1.1m

HCAL available space:
z= 9.1m to z=11.5m → dz=2.4m

Muon available space:
z= 11.5m to z= 14.8m → dz = 3.3m

Forward:

Dipole:
z= 14.8m to z= 21m → dz=6.2m

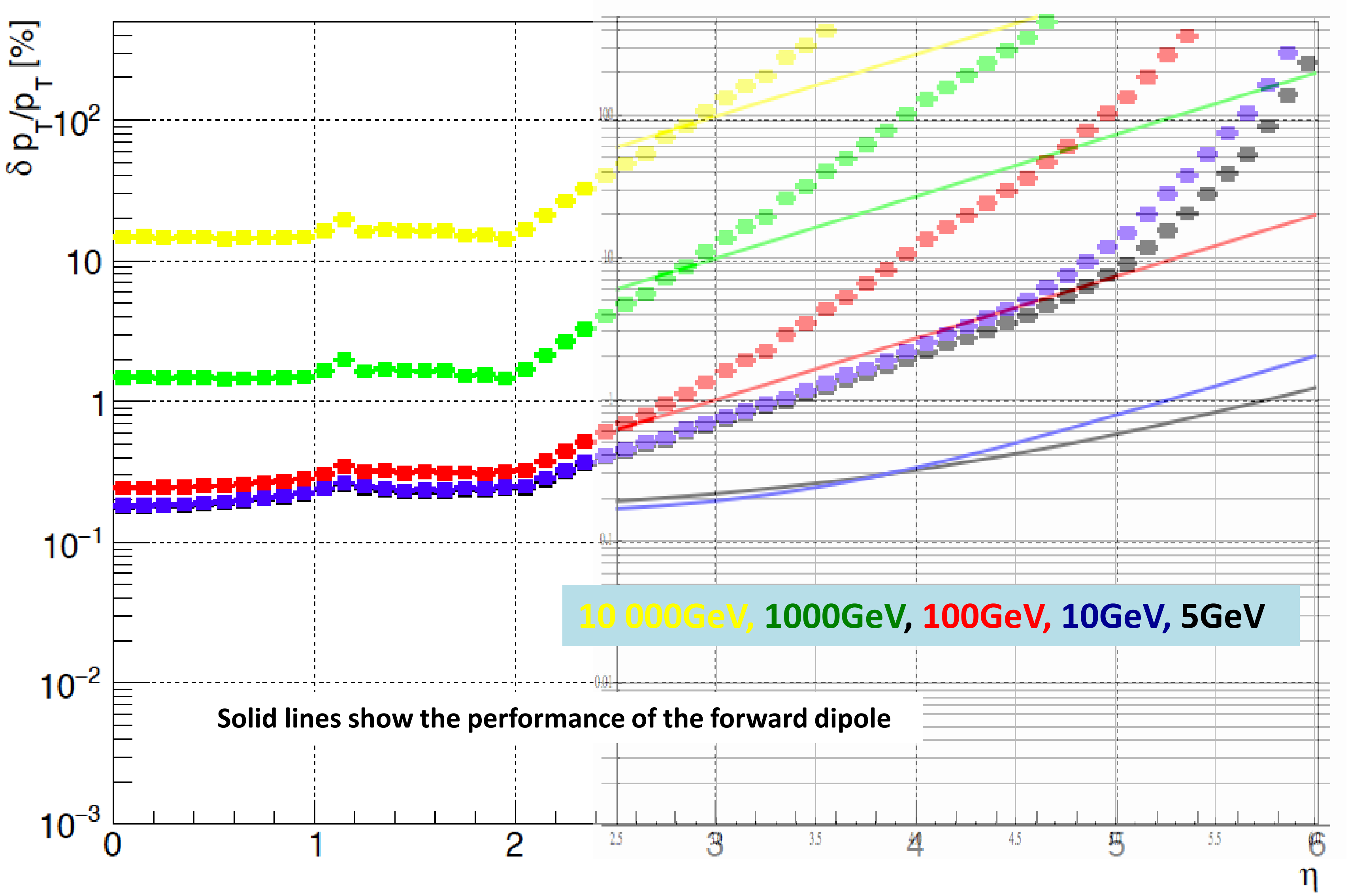
FTracker available space:
z=21m to R=24m, L=3m

FEMCAL available space:
Z=24m to z= 25.1m → dz= 1.1m

FHCAL available space:
z= 25.1m to z=27.5m → dz=2.4m

FMuon available space:
z= 27.5m to z=31.5m → dz=4m

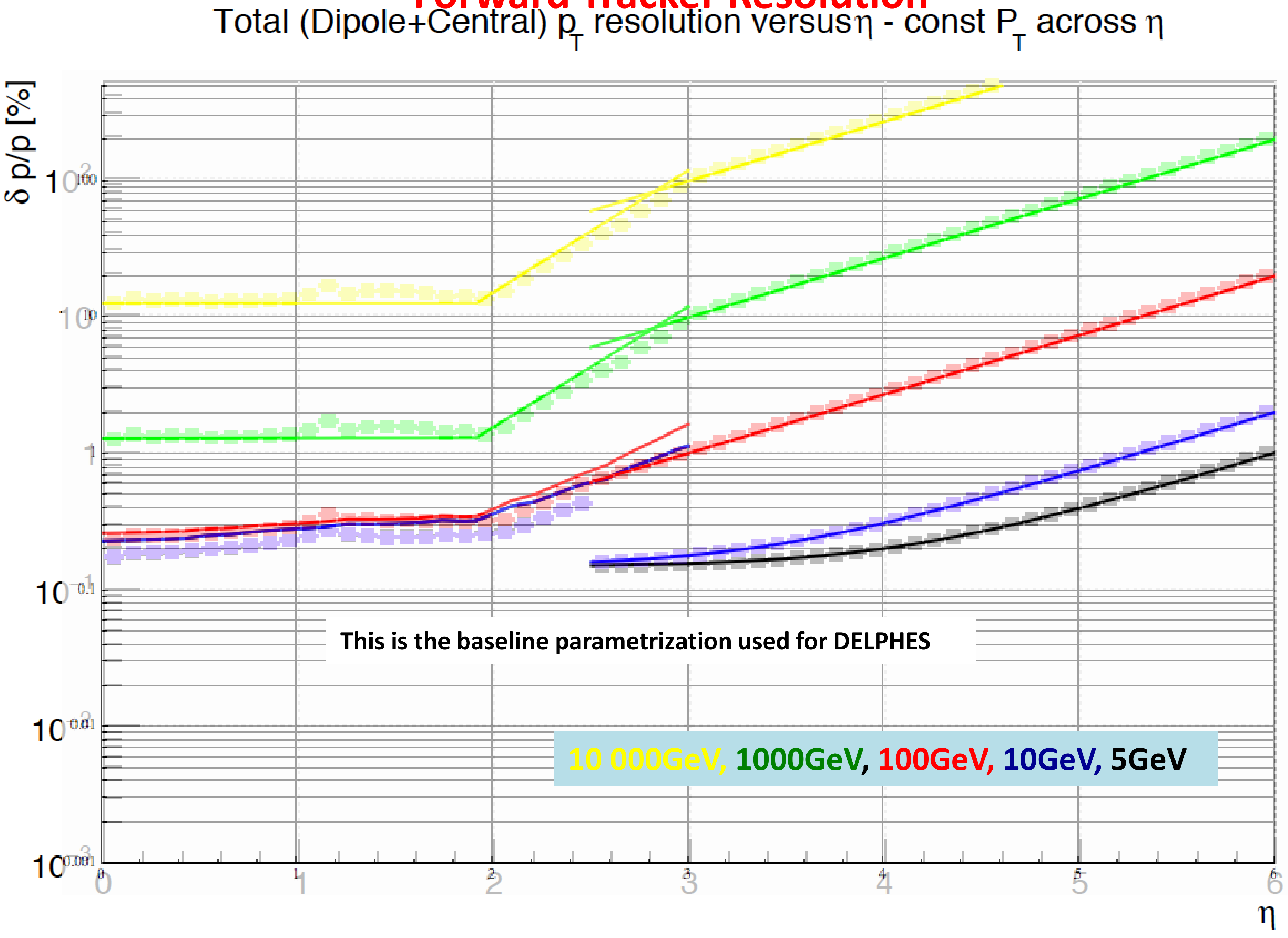
p_T resolution versus η - const P_T across η



10 000GeV, 1000GeV, 100GeV, 10GeV, 5GeV

Solid lines show the performance of the forward dipole

Forward Tracker Resolution

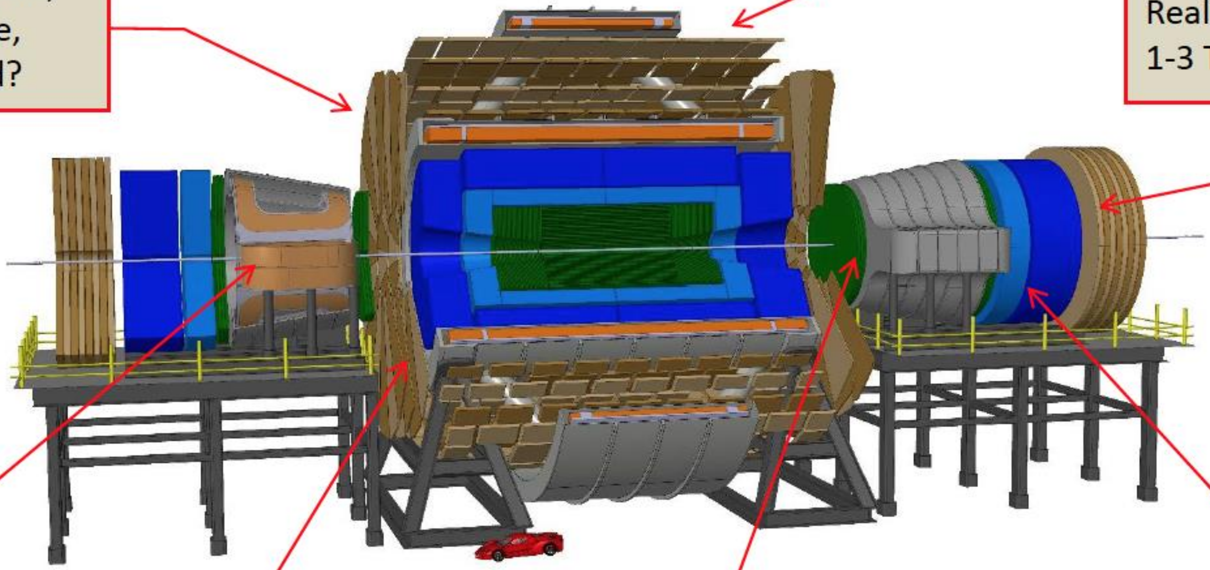


This is the baseline parametrization used for DELPHES

Herman's 7 Questions

Questions:

for fine tuning we need default specs.



(1) Now 30 Tm! for muon angle/sagitta, needed? Minimum gap?

(2) Muon system here, sagitta or just angle, axial depth needed?

(3) Muon system here, magnetized iron? Really needed, 1-3 Tm or more?

(4) Axial position of this dipole, now 10Tm, OK?

(7) Radiation shielding requirements?

(5) Tacker in front and back of the dipole. Axial depth?

(6) Depth of these calorimeters, determine axial extend, overall length

(1) Now 30 Tm! for muon angle/sagitta, needed?
Minimum gap?

- **As discussed in the last meeting, the angular measurement of the muon at the entrance of the spectrometer will give a very precise momentum measurement (order 3%). This only needs approximately 2-2.5m of space.**

- **A ‘standalone’ system with 3 stations for sagitta measurement will have a very hard time to compete with this angular measurement and the combined measurement with the inner tracker (→ see today’s talk by Sotiris)**

→ Since the overall dimension of the object is a critical parameter for the installation and realization of the object, a version with a minimum gap is clearly very interesting and might represent the optimum configuration.

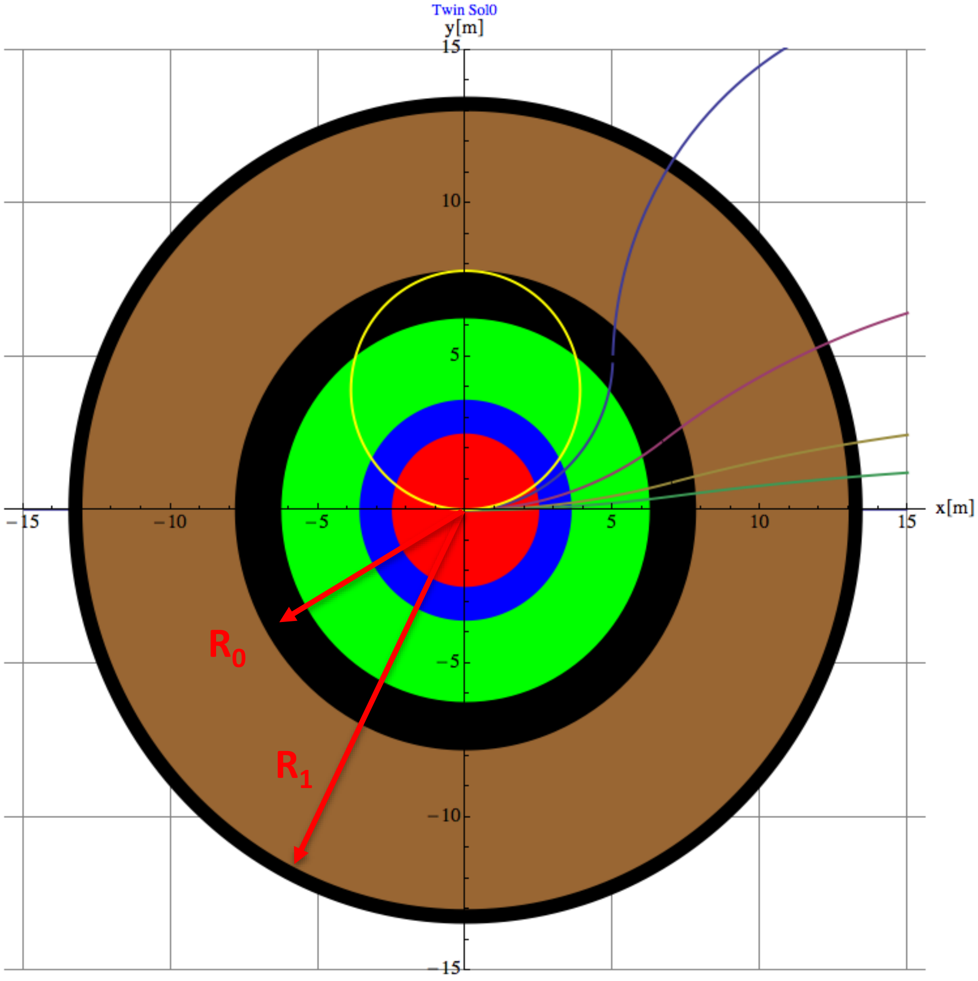
Muon Momentum can be measured by

1) The inner tracker

2) The track angle at the entrance of the muon system → Trigger

3) A sagitta measurement in the muon system (no iron → precise !)

4) The combined fit of inner tracker and outer layers of the muon system.



2) Track angle at the entrance of the muon system

$$\frac{\Delta p_T}{p_T} = \Delta\theta \sqrt{\left(\frac{2p_T}{0.3B_0R_0}\right)^2 - 1} \approx \frac{2p_T}{0.3B_0R_0}\Delta\theta \quad \text{for a large } p_T$$

10% at 10TeV, B_0=6T, R_0=6m
Δθ=50μRad

→ **2 stations at 1.5m distance with 50um position resolution**

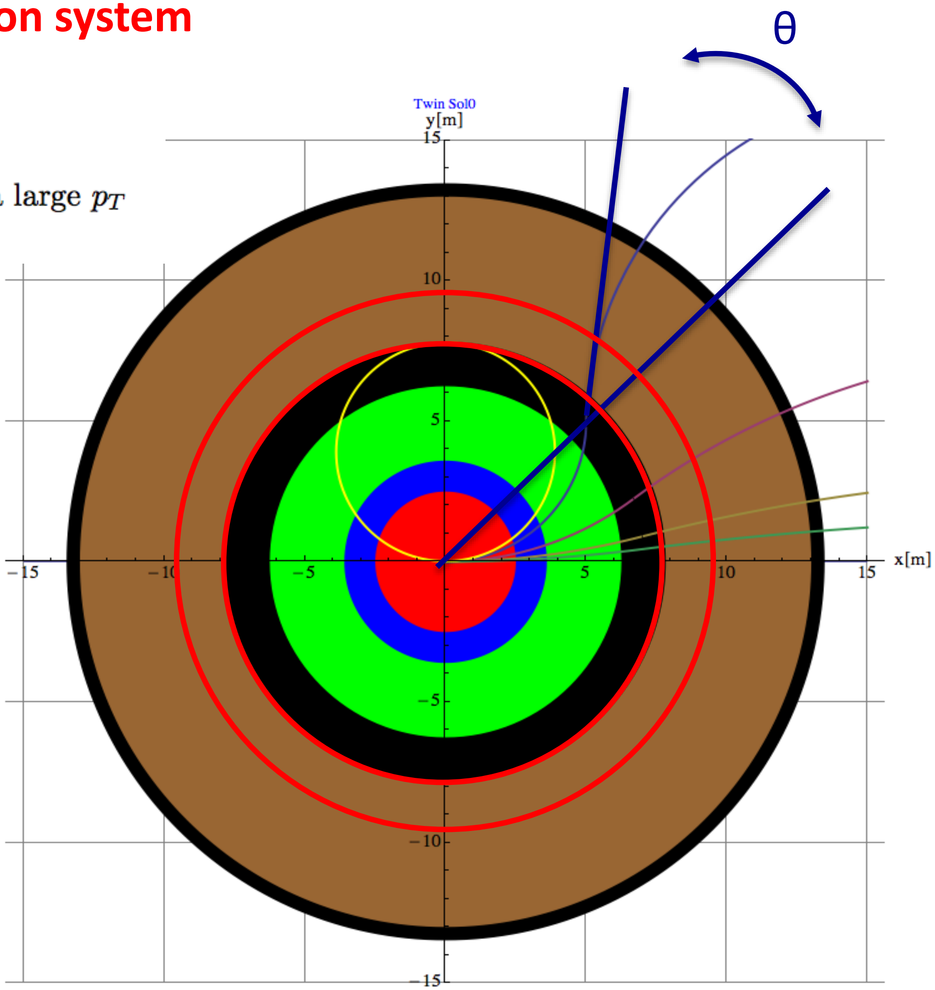
For low momentum, limit due to multiple scattering in the calorimeters and coil:

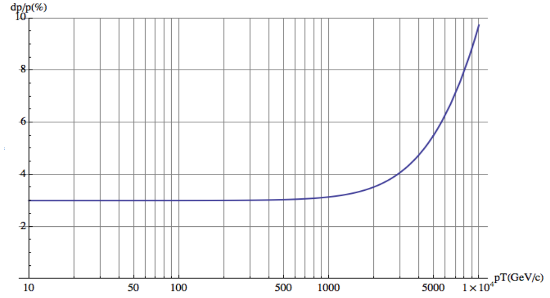
Calorimeter+Cryostat: 35X_0
HCAL: 110X_0
Coil: 5X_0
→ **x_{tot}/X_0 ≈150**

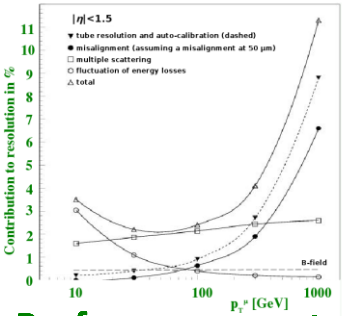
$$\frac{\Delta p_T}{p_T} = \frac{2 \times 0.0136}{0.3B_0R_0}\sqrt{\frac{x_{tot}}{X_0}}$$

B_0=6T, R_0=6m
→ **dp/p=3% !!!**

(CMS 9% because B_0R_0=1/3 of FCC value)

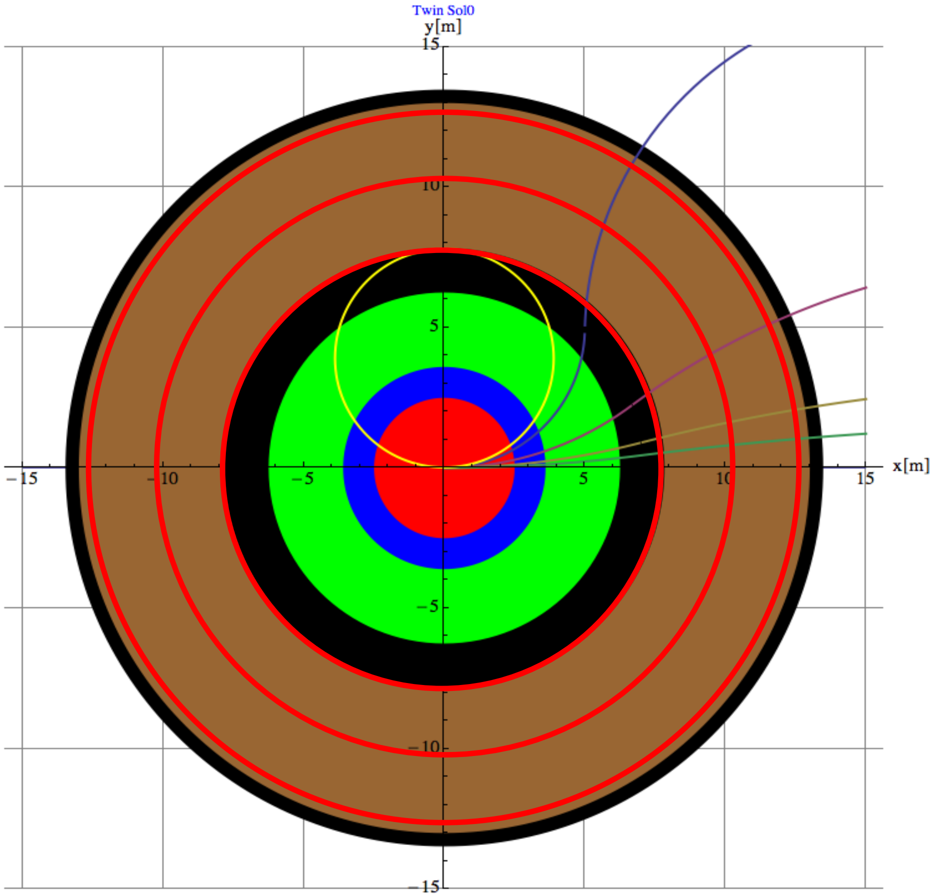






At eta=0 ATLAS type standalone Muon Performance up to 10TeV !!!

3) Sagitta measurement in the muon system



The return field is 2.45T

Measuring over the 5m lever arm with stations of sig=50um resolution we have

$dp_T/p_T = sig*p_T/(0.3*B*L^2)*8$
= 20% @ 10TeV

with possibly excellent performance at low p_T due to the absence of iron (vs. CMS) .

but very hard to beat the angular measurement at high p_T and the inner tracker at low p_T.

Surface > 5000 m^2

CMS sagitta measurement in the muon system is limited to dp_T/p_T = 20% due to multiple scattering alone.

Combined Measurement

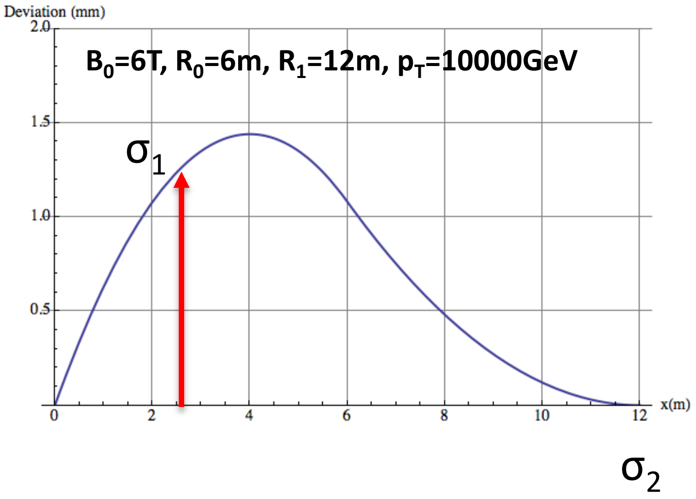
If the full flux is returned trough the muon system, the muon trajectory at the exit of the system points exactly to the IP !

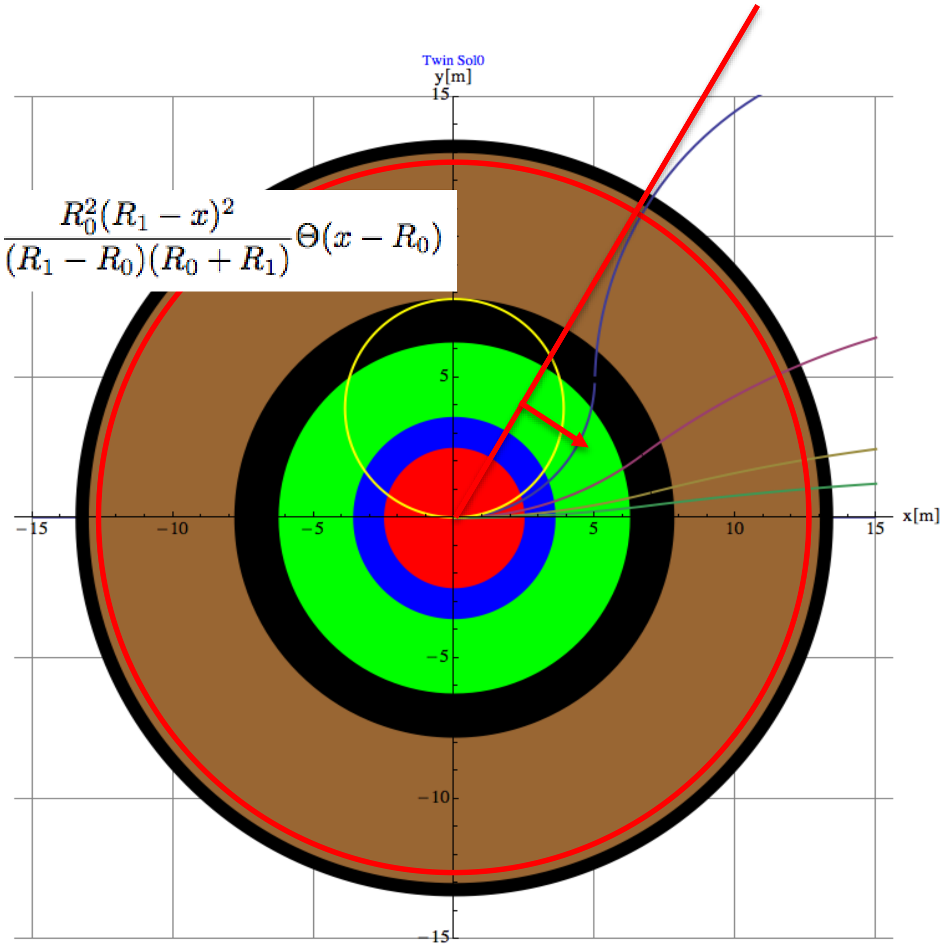
$$y_t(x) = \frac{0.3B_0}{2p_T}\left(x^2 - \frac{2R_0R_1}{R_0+R_1}x\right)\Theta(R_0-x) - \frac{0.3B_0}{2p_T}\frac{R_0^2(R_1-x)^2}{(R_1-R_0)(R_0+R_1)}\Theta(x-R_0)$$

The maximum excursion $y_t(x_0)$ is always at the same radial distance of x_0

$$x_0 = \frac{R_0R_1}{R_0+R_1} \qquad y_t(x_0) = -\frac{0.3B_0}{2p_T}x_0^2 = -\frac{0.3B_0}{2p_T}\left(\frac{R_0R_1}{R_0+R_1}\right)^2$$

For values below: x_0=4m, y_t(x0)=1.44mm
Ideal measurement point is at the peak, but y_t(2.4m)= 1.24mm still good !

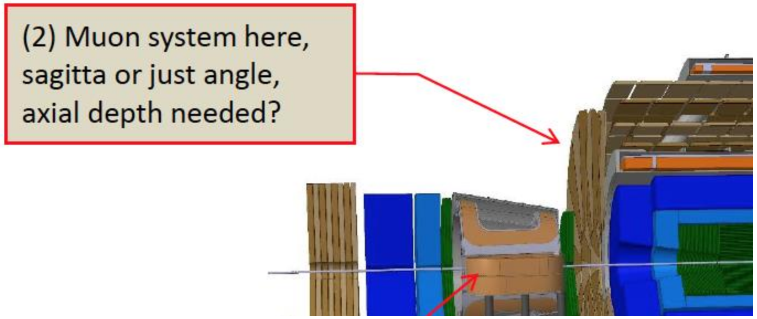




$\sigma^2=\sigma_1^2+(x/R_1\sigma_2)^2$

x=2.4m,R_1=12m, σ_1=50µm, σ_1=250µm,
σ=64µm, dp_T/p_T=5% at 10TeV !

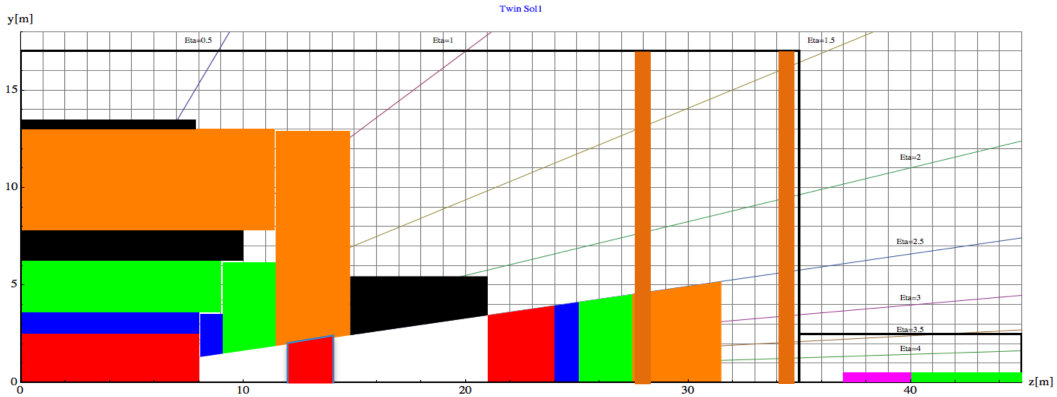
Measuring just in the last tracker layer and in the outermost muon station already beats the full inner tracker performance (14 layers, 23um).

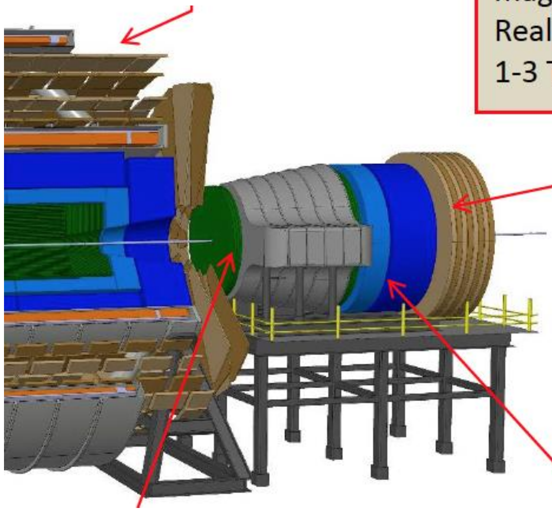


(2) Muon system here, sagitta or just angle, axial depth needed?

- **This question needs to be quantified.**
- **Again, the present thinking is that the angular measurement (for possible triggering) together with the the inner tracker measurement will be sufficient.**
- **A muon station at z-larger distance might be needed for the end cap region.**
- **Calculations on ‘field closure’ for the questions have been started by M. Mentink, multiple scattering questions →see talk of Sotiris.**

→ Quantified endcap muon performance for the next meeting.

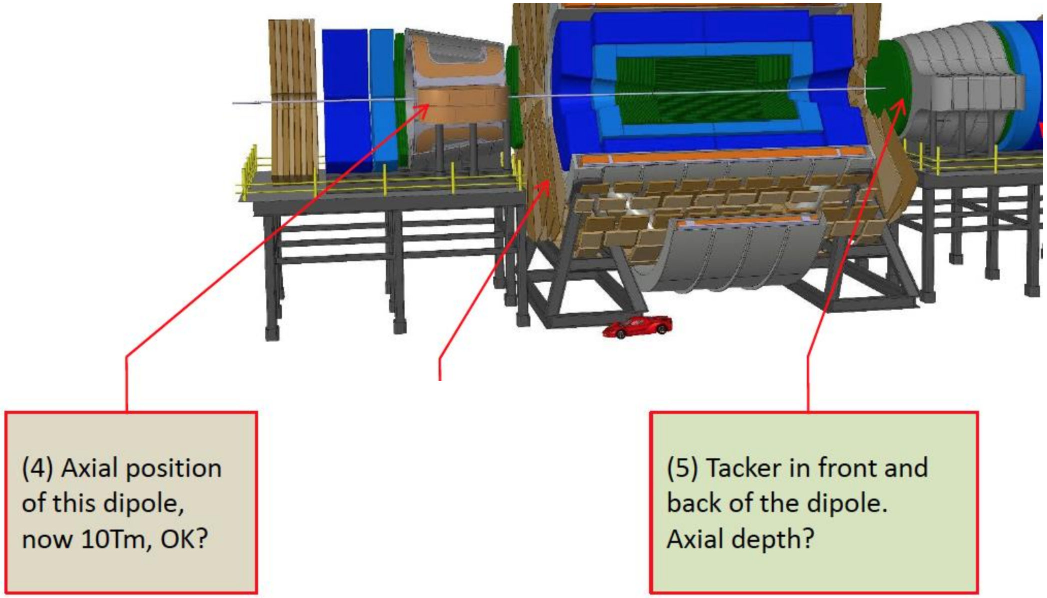




(3) Muon system here,
magnetized iron?
Really needed,
1-3 Tm or more?

- **Like in LHCb this system will act as muon trigger and muon identifier and the final precision measurement of the muons will be done with the forward tracker.**

→ Magnetization is not needed.



(4) Axial position of this dipole, now 10Tm, OK?

(5) Tacker in front and back of the dipole. Axial depth?

- **The present dipole layout and dipole strength are a good baseline.**

- **We assume tracking stations in front and behind the dipole.**

- **The field inhomogeneity due to the superposition of solenoid and dipole field needs B-field maps and calibration, which is ‘standard’ in present LHC operation.**

→ See next slides

At present we assume two stations in front of the dipole (z=12m, z=14m) and two stations behind the dipole magnet (z=22m, z=24m) .

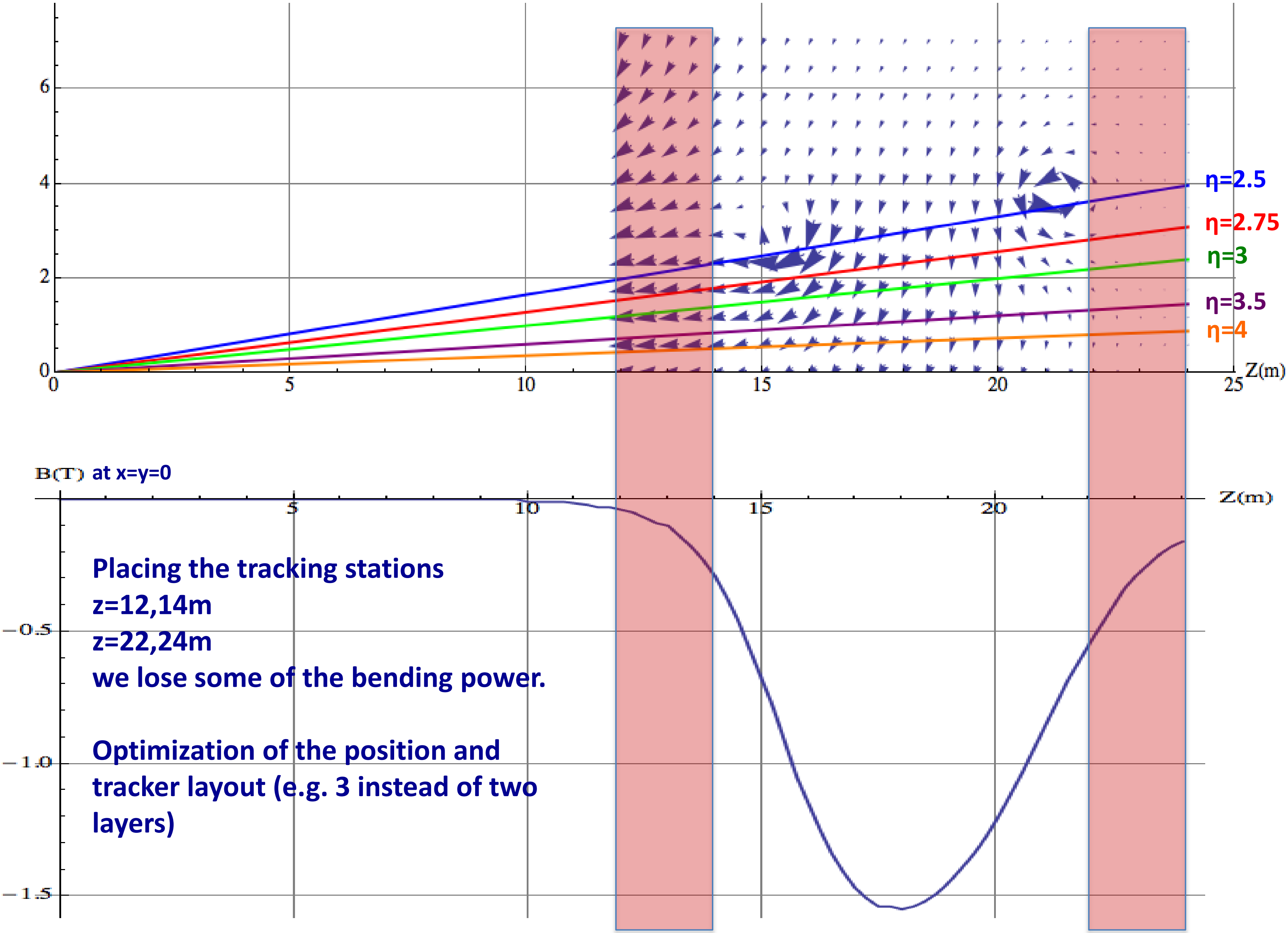
Having the stations outside the dipole has many practical advantages: (installation, secondaries …)

The key advantage is that the stations can be made ‘larger’ than the dipole opening, so one can use the entire dipole acceptance and has space for mechanics and electronics.

The exact position and radial extent of the upstream forward tracker has to be defined by the shielding of the end cap muon stations → see today’s talk by Ilaria Besana.

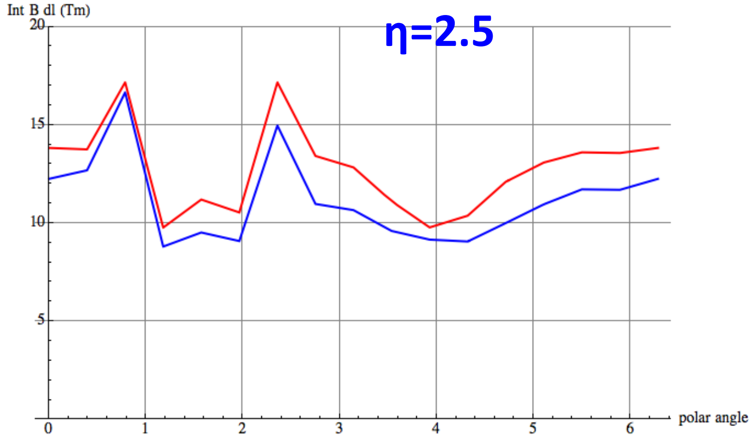
The exact position has to be optimized with respect to the field integrals (see next slide).

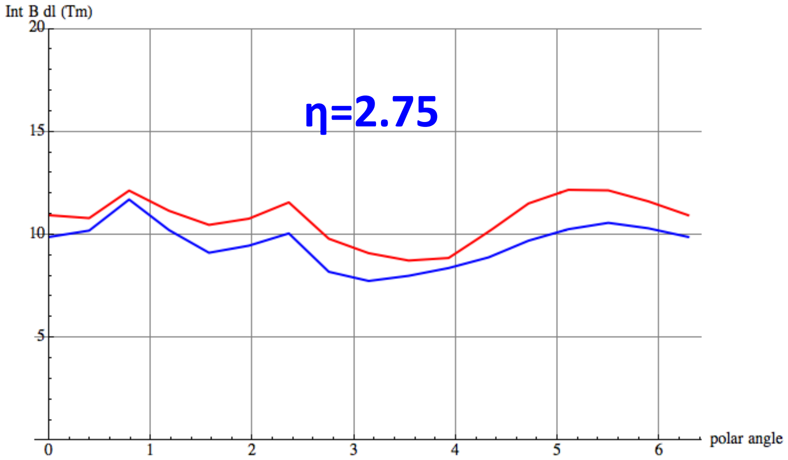
→ For the moment the available space for the forward tracker seems sufficient.

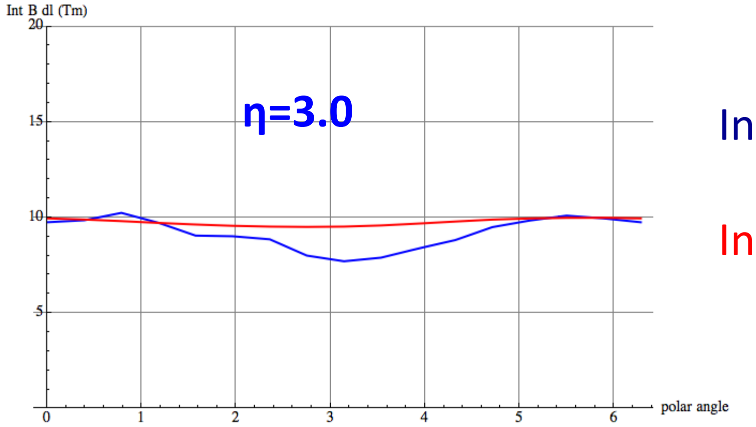


Placing the tracking stations
z=12,14m
z=22,24m
we lose some of the bending power.

Optimization of the position and tracker layout (e.g. 3 instead of two layers)

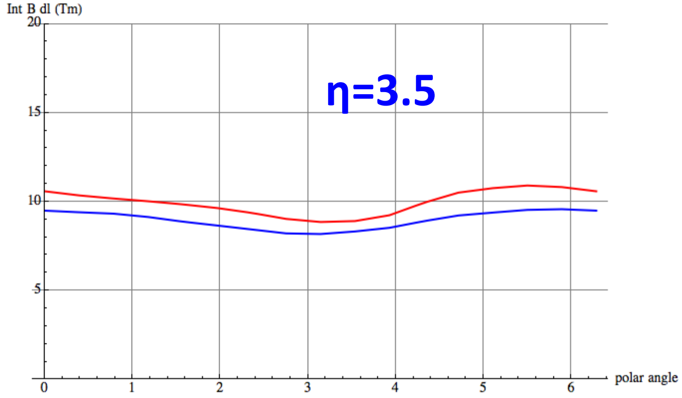


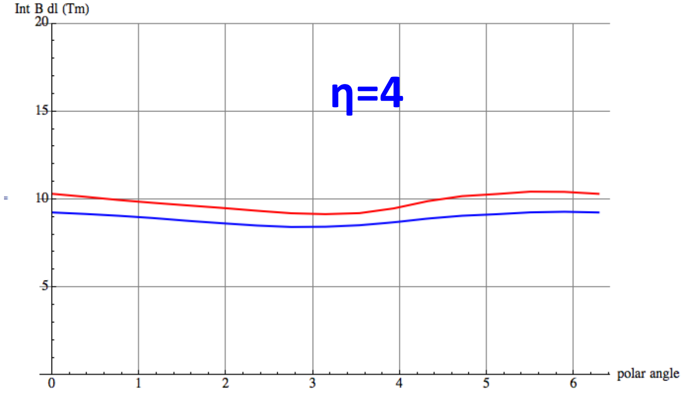




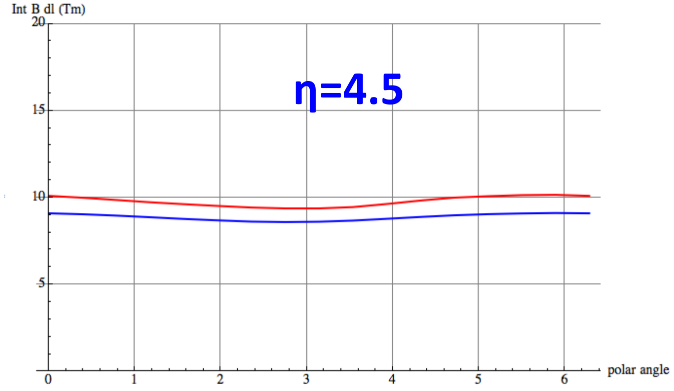
Int_14m^22mBdl

Int_12m^24mBdl



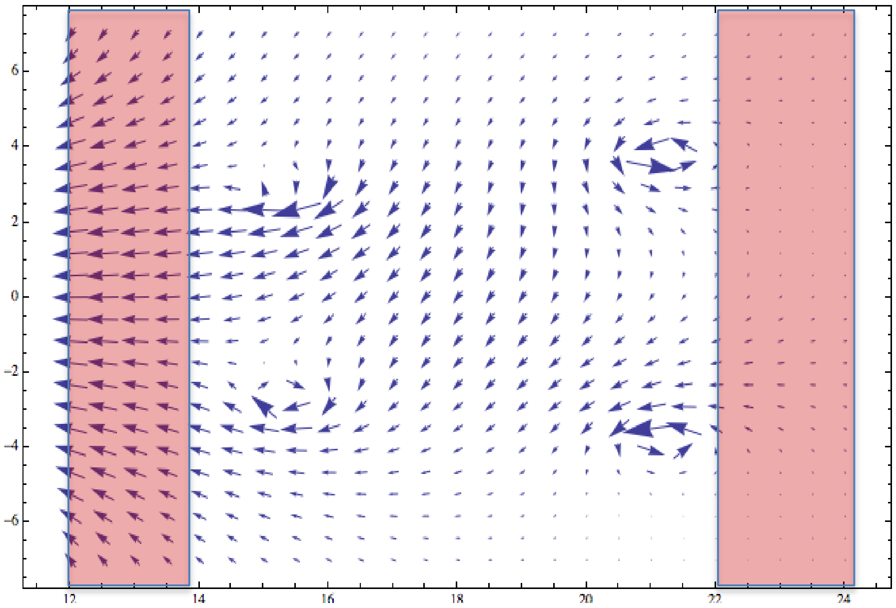


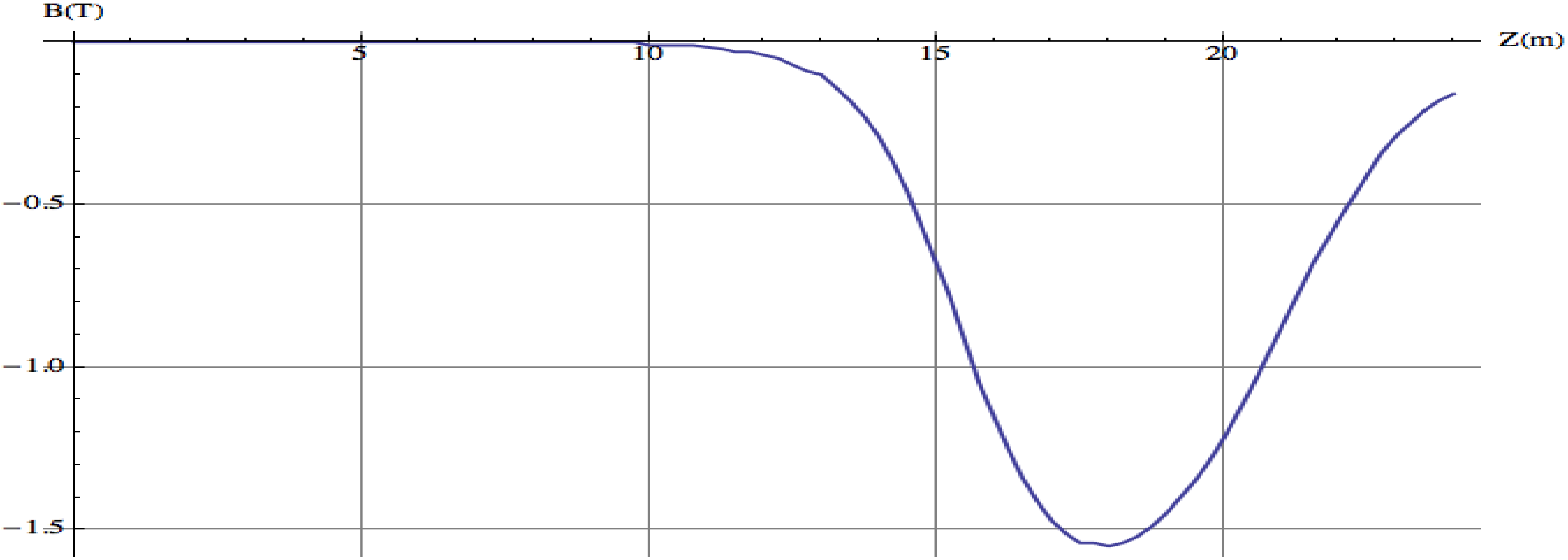
The tracker position must be optimized.

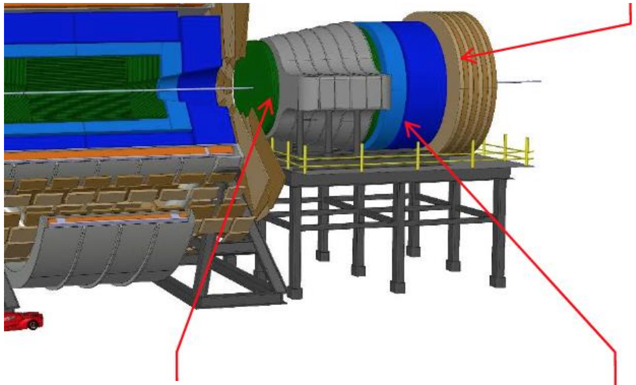


The superposition of the vertical dipole field and the solenoid field results in some 'inhomogeneity' of the dipole field.

Effect on radiation → see today's talk by Ilara Besana







(6) Depth of these calorimeters, determine axial extend, overall length

→ See today's presentation by Ilaria Besana

Conclusions

- Baseline detector layout for Twin Solenoid + Dipole exists
- Parametrized performance in DELPHES card exists
- FCC detector simulation goals must be defined (→ Clement)
- Muon performance must be studies (→ Sotiris)
- Radiation studies for baseline detector (→ Ilaria)
- More magnet systems coming (→ next meeting)