FCC-hh Detector Studies

Albert De Roeck

January 15

(Material from W. Riegler)

Baseline Parameters

The present working hypothesis is:

- peak luminosity baseline: 5E34
- peak luminosity ultimate: <= 30E34

- integrated luminosity baseline ~250 fb-1 (average per year)
- integrated luminosity ultimate ~1000 fb-1 (average per year)

An operation scenario with:

- 10 years baseline, leading to 2.5 ab-1
- 15 years ultimate, leading to 15 ab-1

would result in a total of 17.5 ab-1 over 25 years of operation.

Since the operation scenario is somewhat arbitrary we quote O(20ab-1) as total integral luminosity over the lifetime.

Luminosity goals for a 100-TeV pp collider

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Abstract

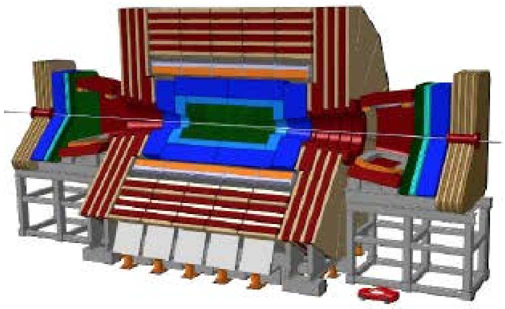
We consider diverse examples of science goals that provide a framework to assess luminosity goals for a future 100-TeV proton-proton collider.

Important discussion on luminosity: An integrated luminosity goal of 20ab^{-1} matches very well the 100TeV c.m. Energy

FCC Magnet System Concepts

H. Ten Kate et al.

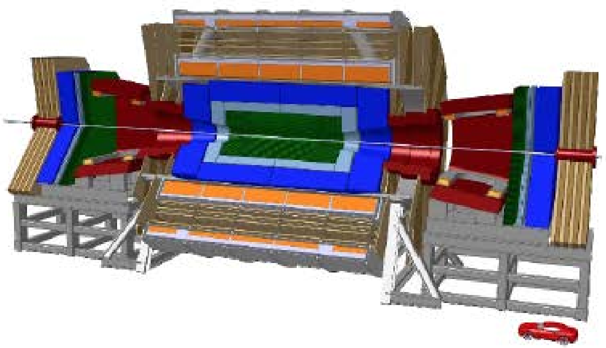
Inclusion of Dipoles in the Forward region for momentum measurement over a large eta range.



(1) Solenoid with light yoke + Forward Dipoles

Huge mass,
Iron very expensive,

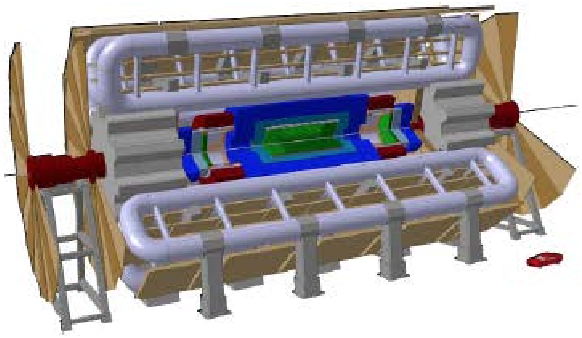
→ Seems not feasible



(2) Twin Solenoid, no yoke + Forward Dipoles

Shielding Solenoid, very large system

→ Used as baseline



(3) Solenoid + three toroids + internal Forward Dipoles

The ATLAS 'standalone' Muon Toroid was motivated by things like:

- **worries that trackers might not work at LHC rate**
- **Space for excellent HCAL, good jet calorimetry**
- **Independent magnet system**

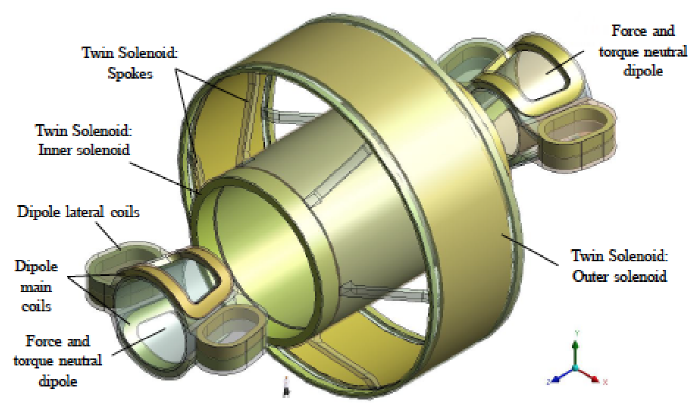
→ No real motivation

Design of a 56 GJ Twin Solenoid & Dipoles Detector Magnet System for the Future Circular Collider

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

***Abstract*—An aggressive low mass and high stress design of a very large detector magnet assembly for the Future Circular Collider (FCC-hh), comprising a "Twin Solenoid" and two dipoles, is presented. The twin solenoid features two concentric solenoids. The inner solenoid provides 6 T over a free bore of 12 m and a length of 20 m, enclosing the inner particle trackers as well as electron and hadron calorimeters. The outer solenoid reduces the stray field of the inner solenoid and provides additional bending power for high-quality muon tracking. Dipoles are included providing 10 Tm of bending power in a 6 m mean free bore covering the forward directions for $\eta \geq 2.5$ particles. The overall length of this magnet assembly is 43 m.**

The presence of several separate magnets in the system presents a challenge in terms of forces and torques acting between them. A rigid support structure, part of the cold mass, holds the



Twin solenoid + Dipole is being engineered in detail.

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

V. I. Klyukhin, A. Ball, C. Berriaud, B. Curé, A. Dudarev, A. Gaddi, H. Gerwig, A. Hervé, M. Mentink, G. Rolando, H. F. Pais Da Silva, U. Wagner, and H. H. J. ten Kate

Abstract– **The conceptual design study of a hadron Future Circular Collider (FCC-hh) with a center-of-mass energy of the order of 100 TeV in a new tunnel of 80-100 km circumference assumes the determination of the basic requirements for its detectors. A superconducting solenoid magnet of 12 m diameter inner bore with the central magnetic flux density of 6 T is proposed for a FCC-hh experimental setup. The coil of 24.518 m long has seven 3.5 m long modules included into one cryostat. The steel yoke with a mass of 21 kt consists of two barrel layers of 0.5 m radial thickness, and 0.7 m thick nose disk, four 0.6 m thick end-cap disks, and three 0.8 m thick muon toroid disks each side. The outer diameter of the yoke is 17.7 m; the length without the forward muon toroids is 33 m. The air gaps between the end-cap disks provide the installation of the muon chambers up to the pseudorapidity of ±3.5. The conventional forward muon spectrometer provides the measuring of the muon momenta in the pseudorapidity region from ±2.7 to ±4.6. The magnet modeled with Cobham's program TOSCA. The total Ampere-turns in the superconducting solenoid coil are 127.25 MA-turns. The stored energy is 43.3 GJ. The axial force onto each end-cap is 480 MN. The stray field at the radius of 50 m off the coil axis is 14.1 mT and 5.4 mT at the radius of 100 m. All other parameters presented and discussed.**

I. Introduction

THE hadron Future Circular Collider (FCC-hh) [1] 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 setups the superconducting solenoid coils with a free bore of 12 m in diameter and with the central magnetic flux density of 6 T. The future progress in the tracking detectors will allow measuring the momenta of the prompt muons inside the inner tracker, if the muon system will indicate the charged tracks are really the muons. In this case, the barrel part of the external muon system could be simplified using rather thin steel yoke with the main purpose to eliminate the low momentum muons arising from the hadron decays in flight, and the punch through hadrons to ensure the prompt muon identification. The magnetic flux density bending component integral of about 3.5 T·m will be enough to perform this task.

The physics requirements assume the location of the major sub-detectors inside the superconducting coil. The sub-detectors are the inner tracker of 5 m outer diameter with the length of 16 m, the electromagnetic calorimeter with the outer diameter of 7.2 m and the length of 18.2 m, and the hadronic calorimeter with the outer diameter of 12 m and the length of at least of 23 m.

II. Model Description

Fig. 1 presents a three-dimensional (3-D) FCC-hh detector magnetic system model based on the CMS magnet experience [2], [3], and developed and calculated with Cobham's program TOSCA [4].

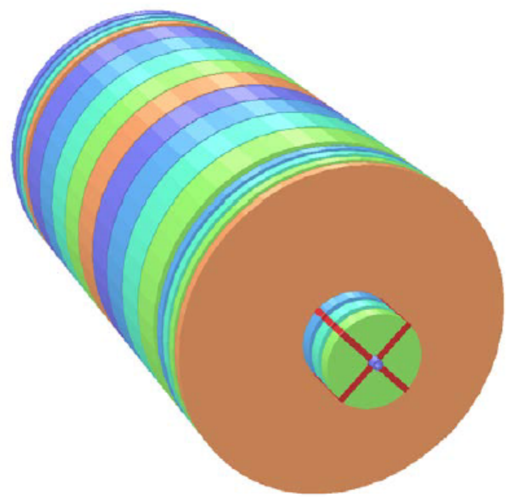
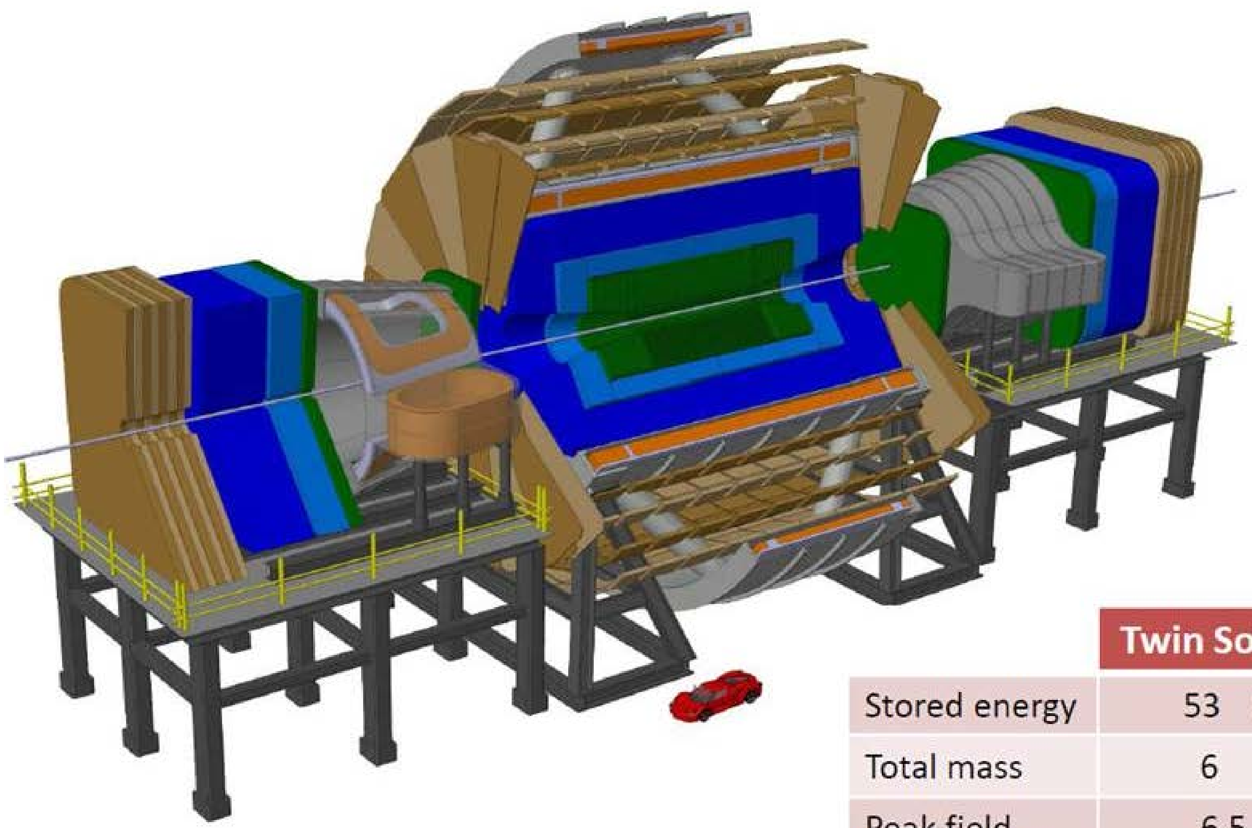


Fig. 1. 3-D model of the FCC-hh detector magnetic system.

Alternative magnet systems with partial passive shielding are being investigated.

Baseline Twin Solenoid + Dipole Magnet System

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



	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

FCC Air core Twin solenoid and Dipoles

State of the art high stress / low mass design.

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

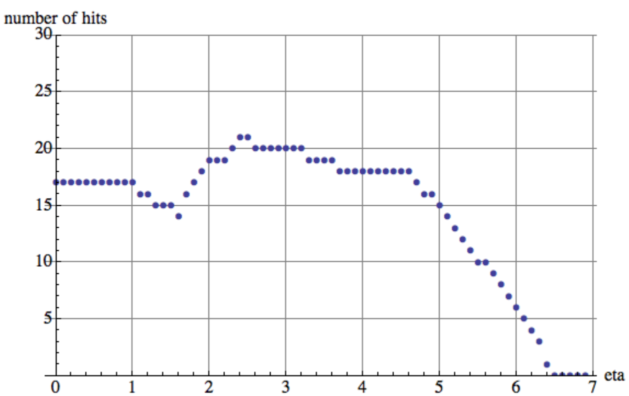
FHCAL available space:
z= 25.1m to z=27.5m → dz=2.4m

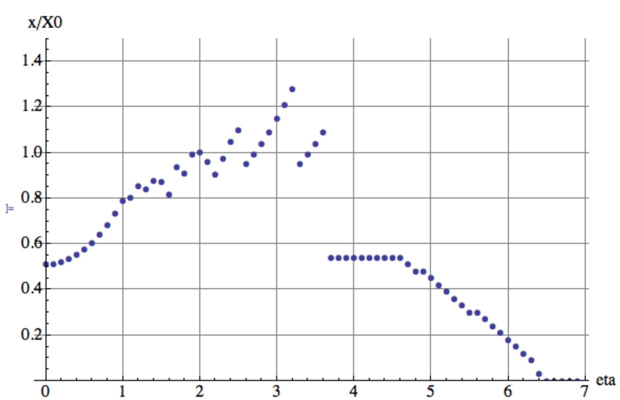
FMuon available space:
z= 27.5m to z=31.5m → dz=4m

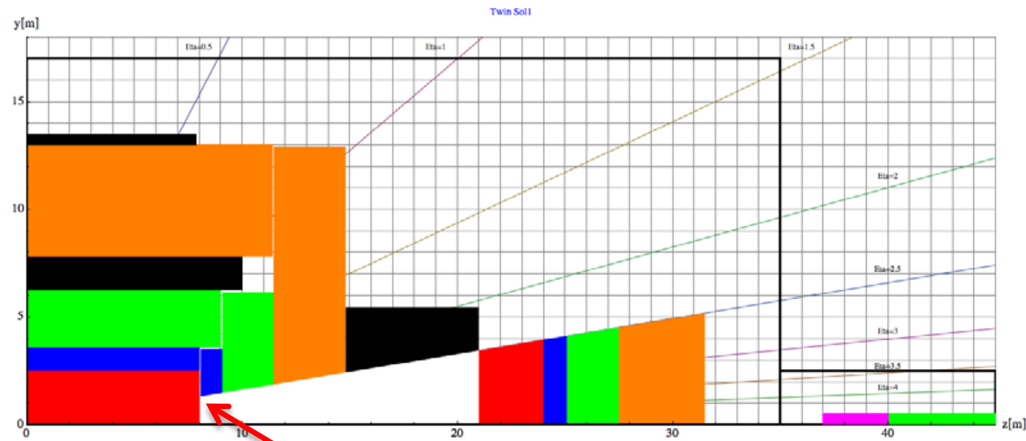
Tracker

Material composition in Volume (%):
Si 20%, C 42%, Cu 2%, Al 6%, Plastic 30%
X_0 of this mix: 14.37cm

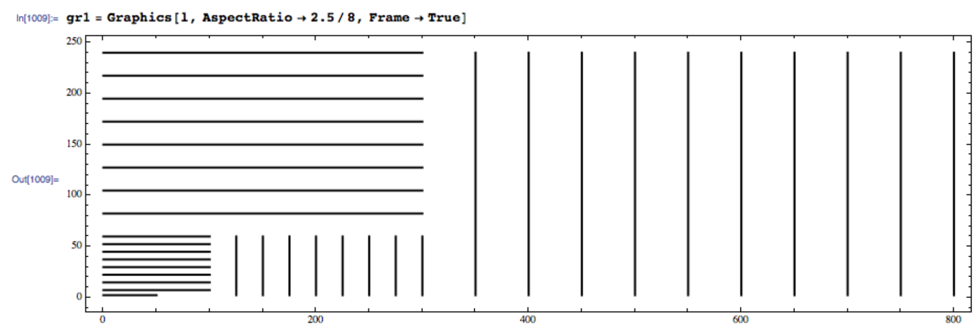
We assume 3% of radiation length per layer, i.e. each layer has a thickness of 0.43cm.



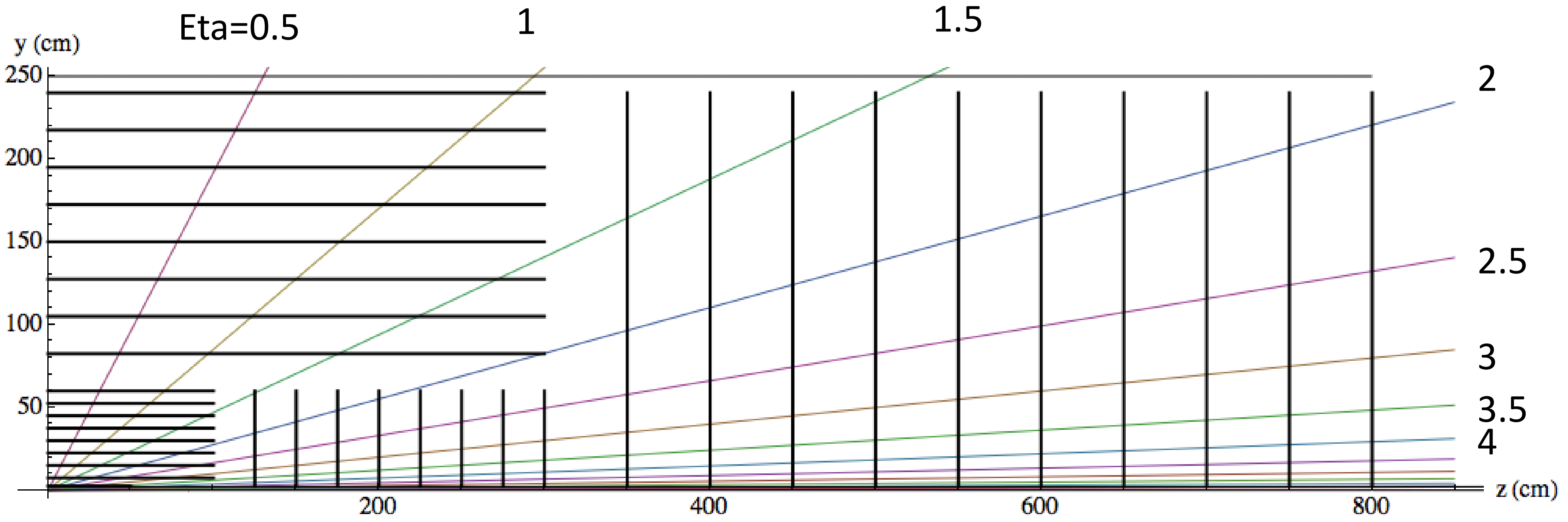




R_{out}=2.4m
Half the leaver arm at eta=2.6→ L=8m



Basic Tracker Geometry



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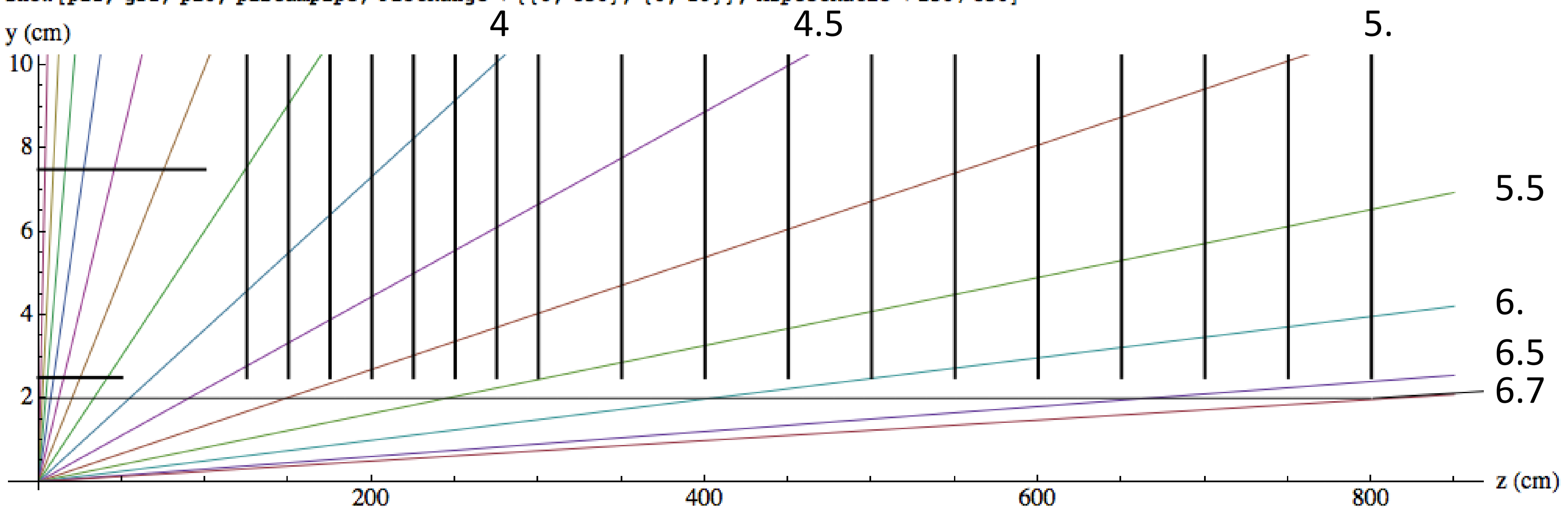
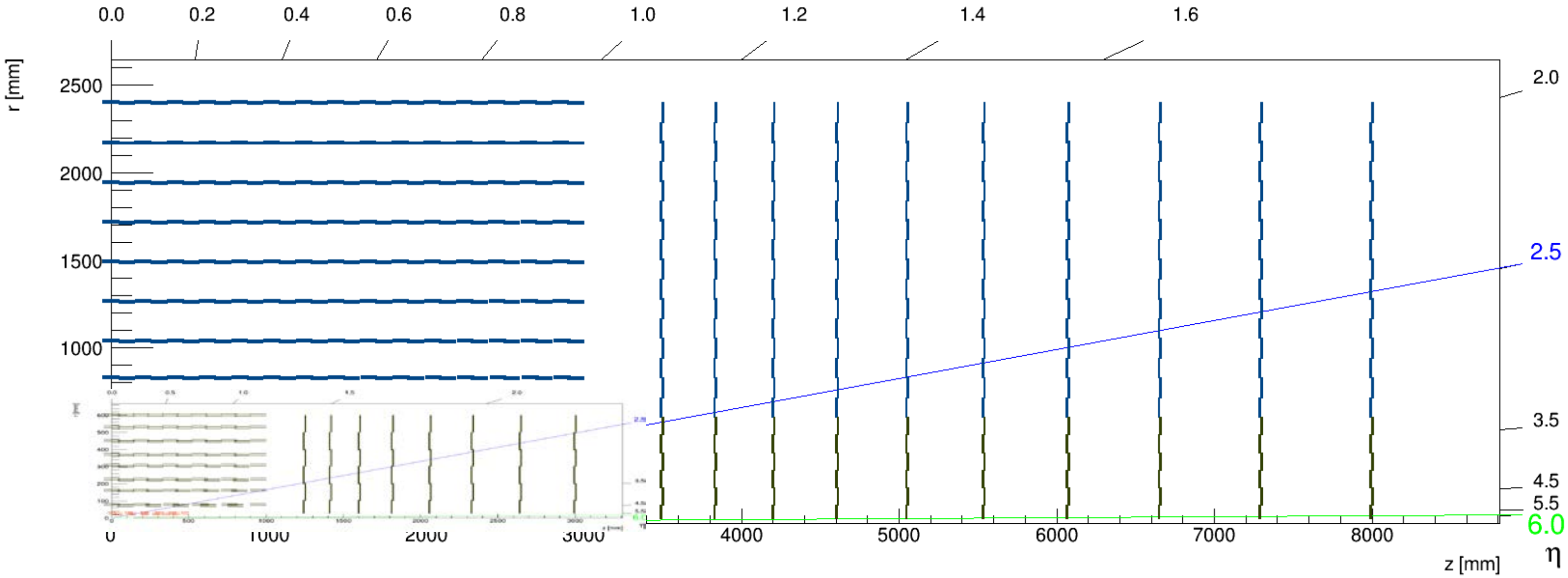
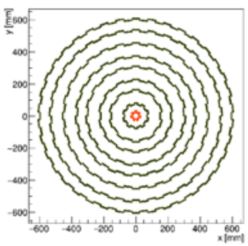
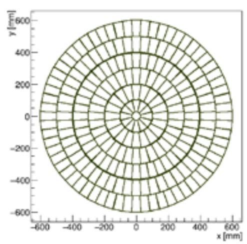
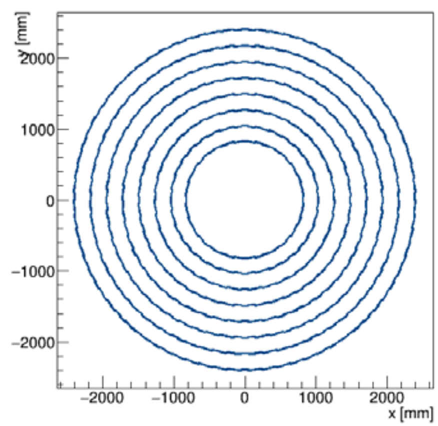


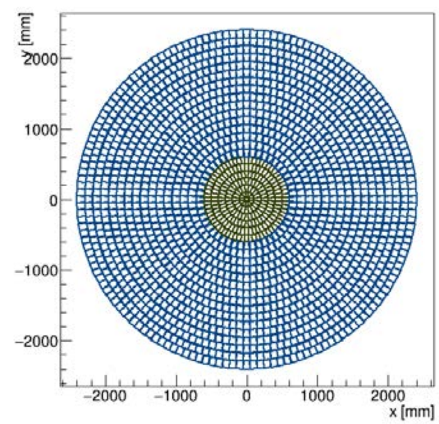
Basic Tracker Geometry

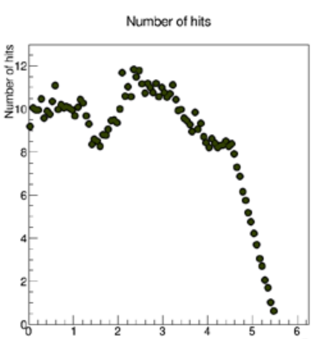


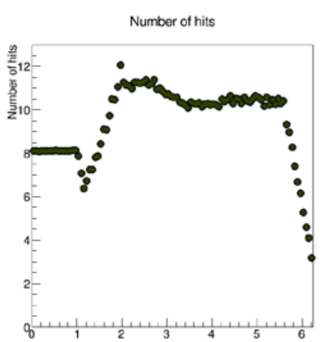






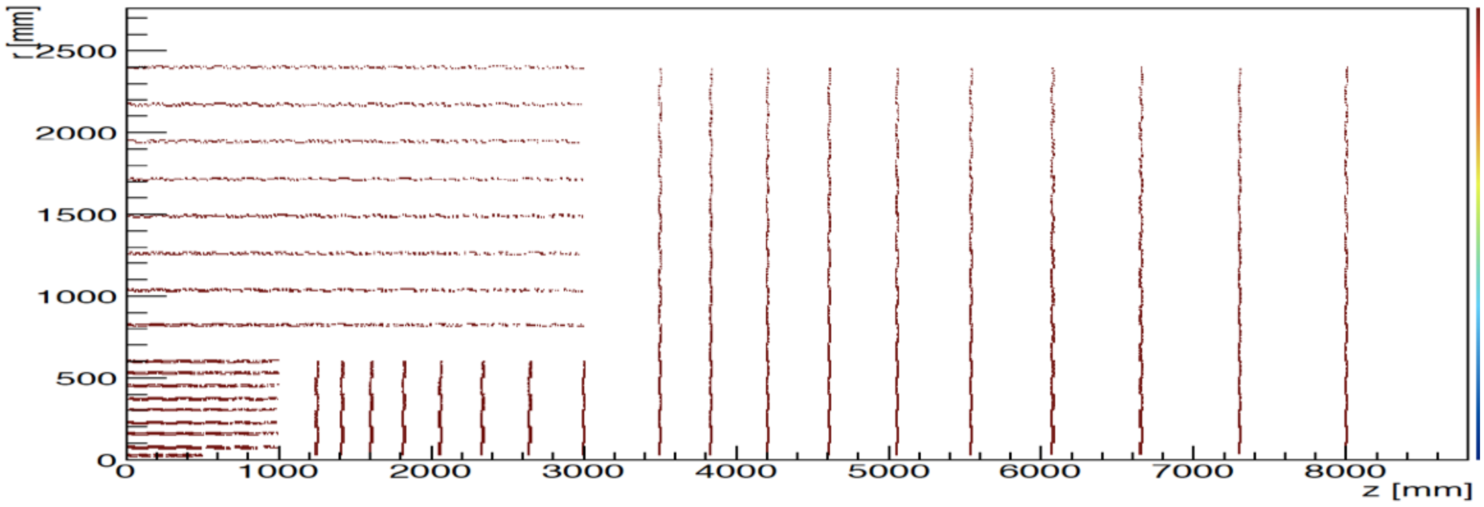


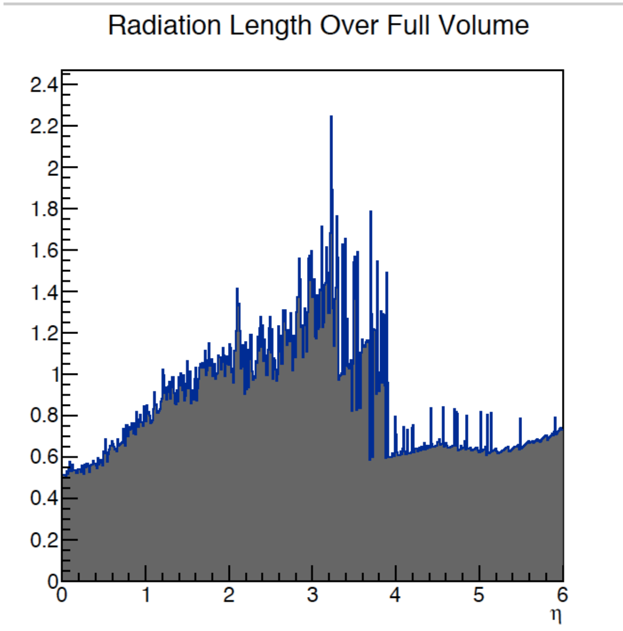


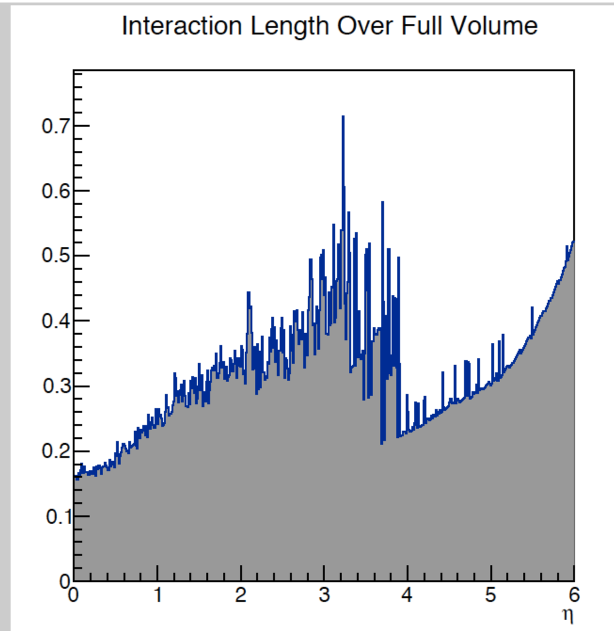


Z. Drasal, M. Manelli: Realistic Layout with correct modules using TKLayout (CMS PhaseII upgrade tool)

Tracker

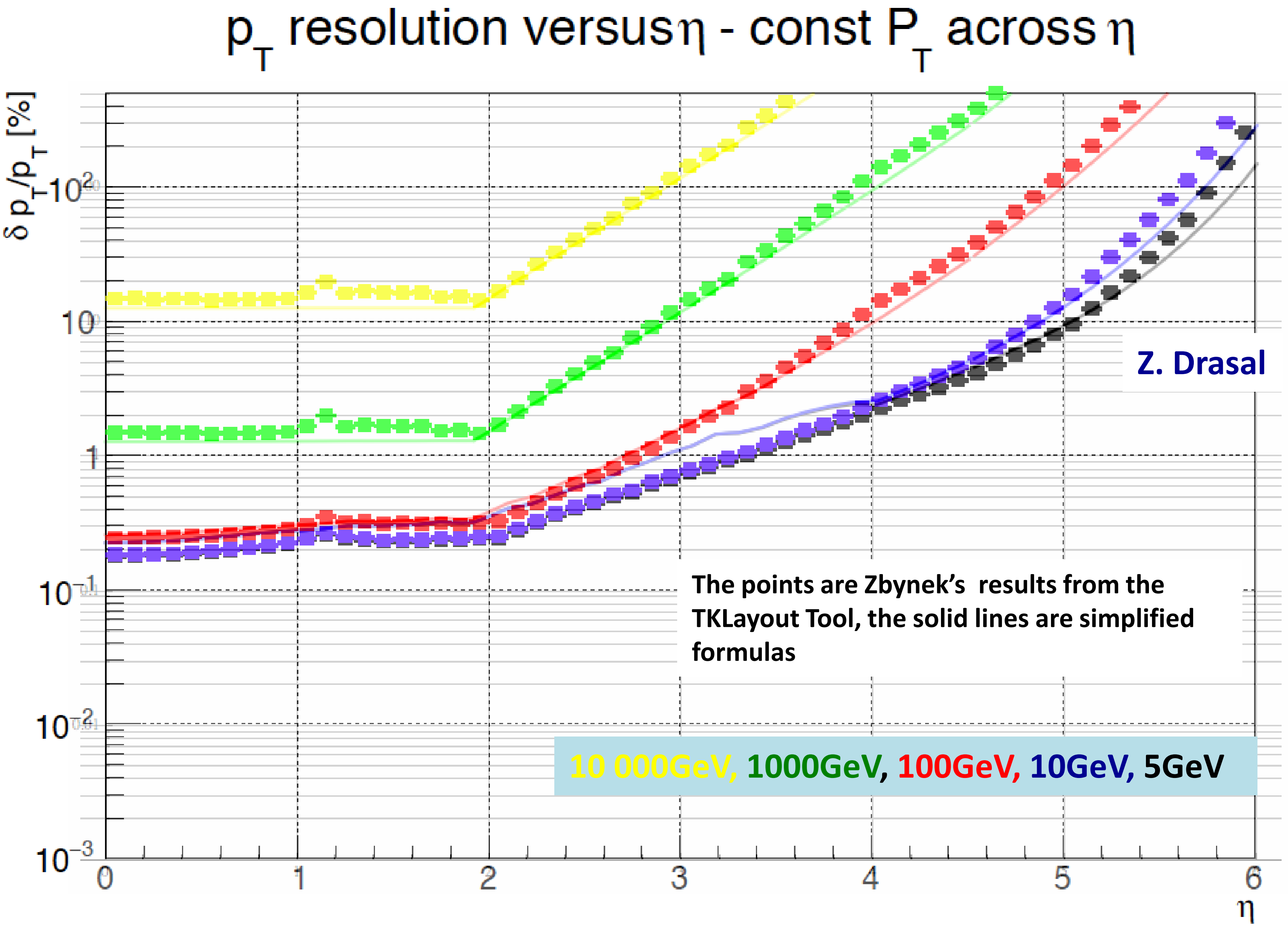






Z. Drasal,
M. Manelli

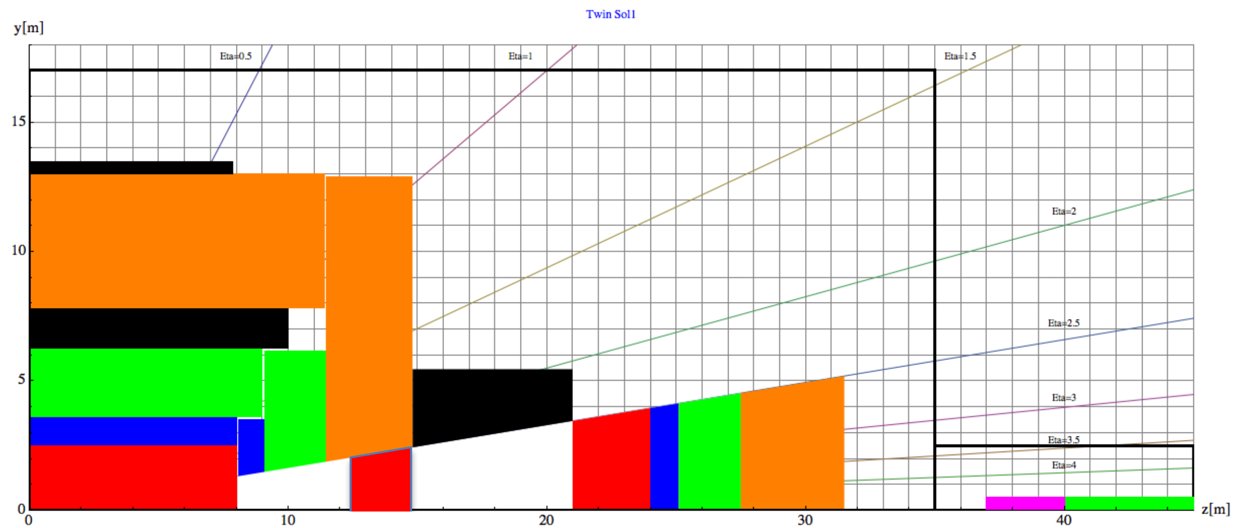
Tracker Resolution

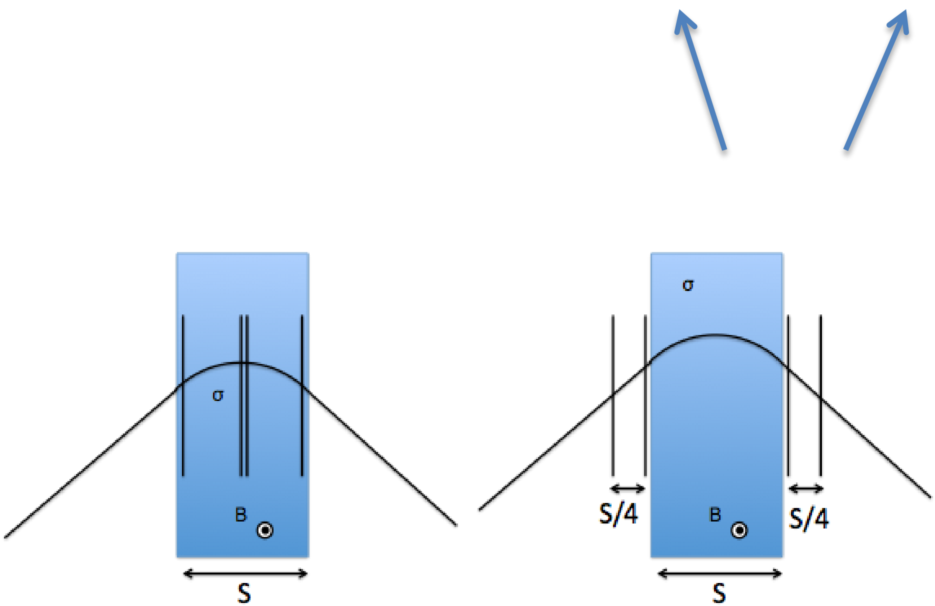


Note: 10% at 10TeV from large BL^2 and 0.3% at low momenta due to large BL !!

Forward Tracking

Forward Tracking Resolution, Position Resolution





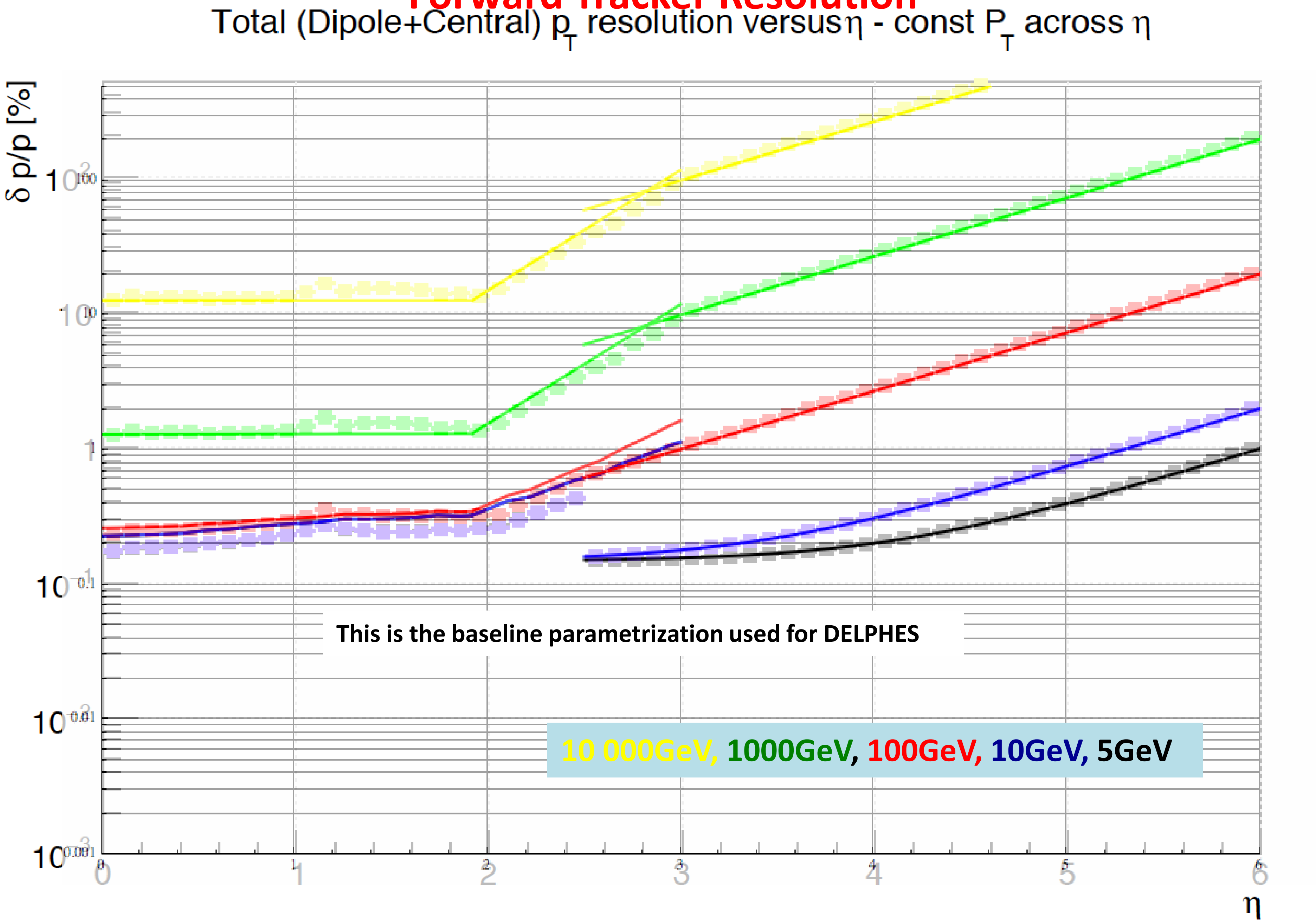
Using 4 tracking stations INSIDE dipole with constant magnetic field and length S, the optimum spectrometer resolution is achieved by placing 2 stations in the center and one on each end to measure the sagitta.

The same performance is achieved by placing the chambers outside the dipole at separation of S/4.

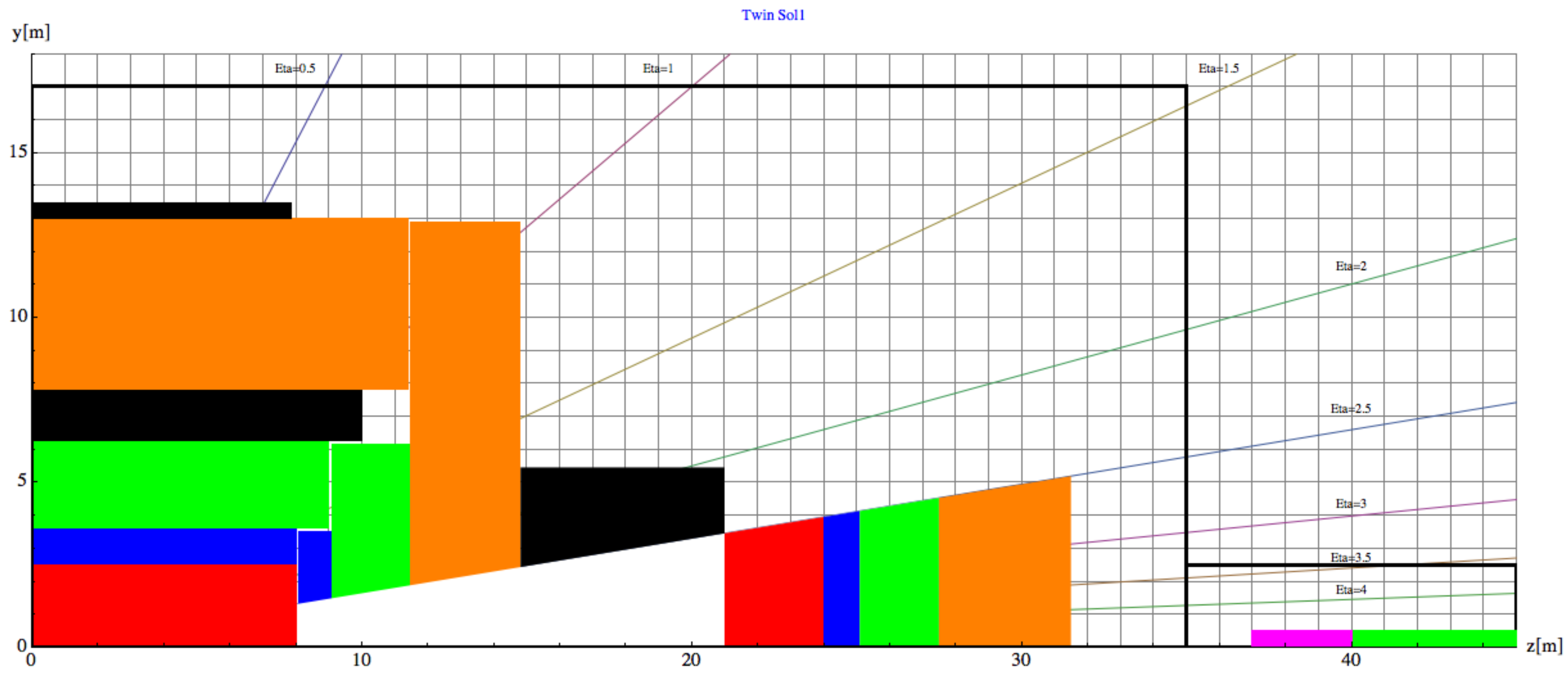
This is what LHCb uses, because if space is available it is easier to implement the detectors outside, and also avoid occupancy from loopers in the field (details on catching Ks etc. are of curse to be considered …)

We use this idea for now (is also easier to calculate ! It is just the Int B dl that counts)

Forward Tracker Resolution



Calorimeter Granularity



ECAL: granularity : 0.0125 x 0.0125 for eta<2.5,
0.025 x 0.025 for eta<4.0,
0.05 x 0.05 for eta<6.0

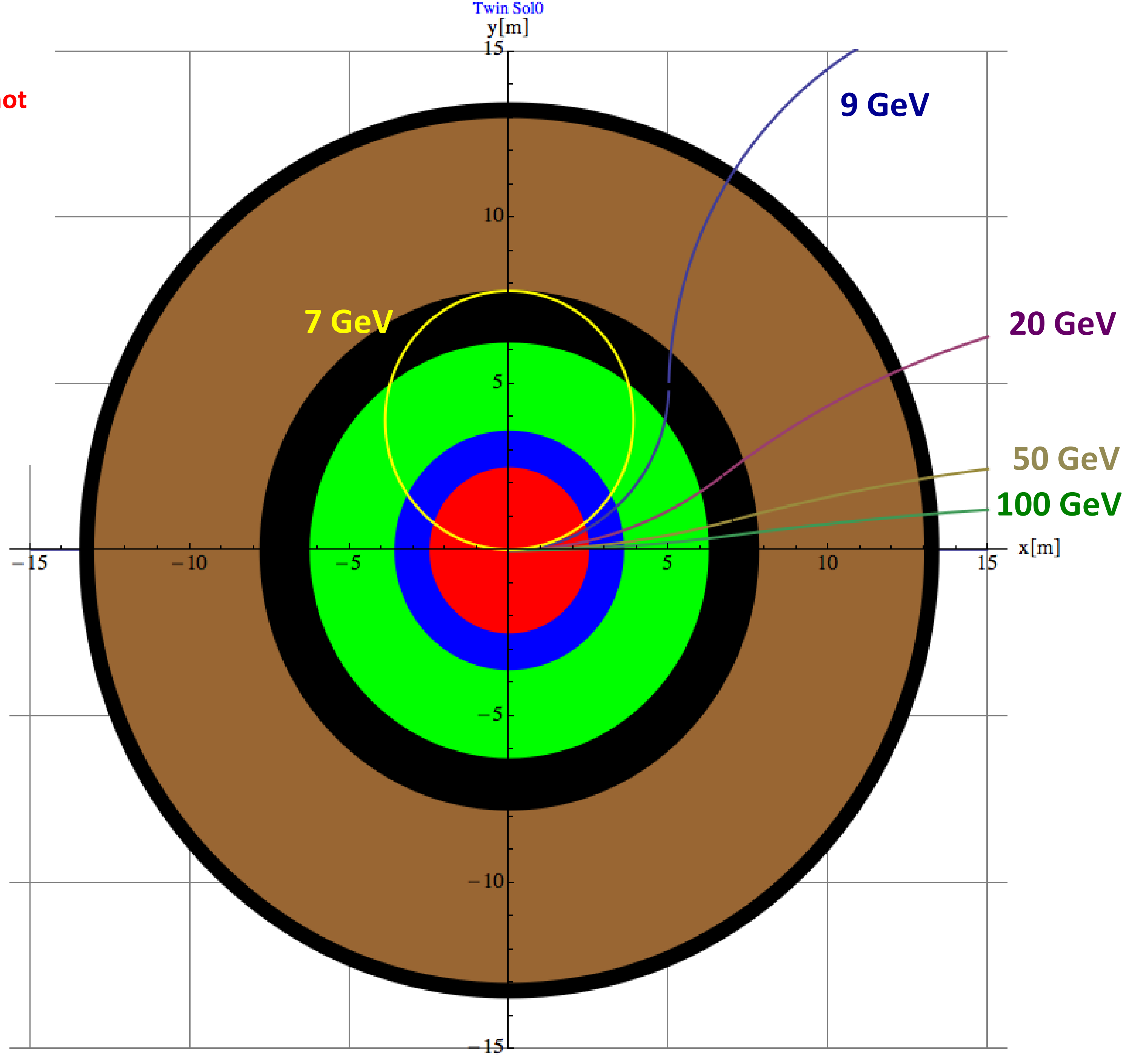
HCAL: granularity : 0.05 x 0.05 for eta<2.5,
0.1 x 0.1 for eta<4.0,
0.2 x 0.2 for eta<6.0

Muon System

At B_0=6T and R_0=6m, Muons below 7GeV do not enter the muon system.

No Muon Trigger below 7GeV.

Possibly muon ID with HGCAL.



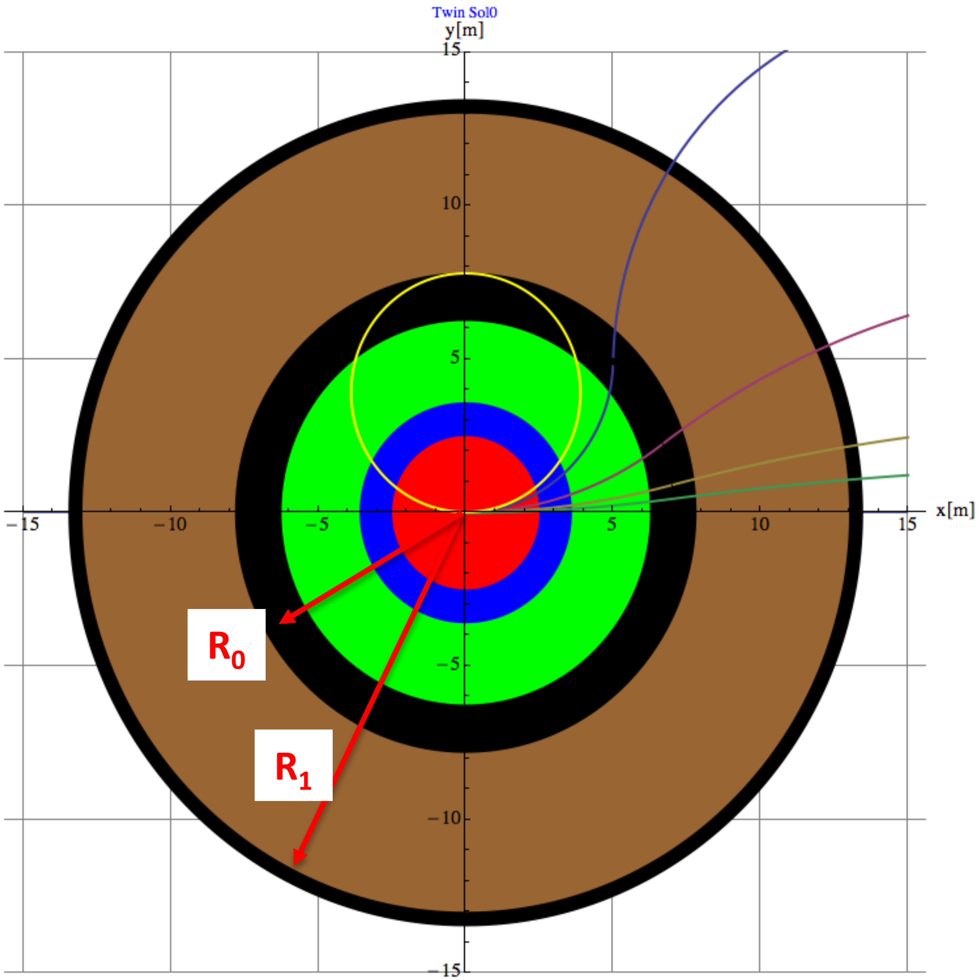
Muon Momentum can be measured by

1) The inner tracker
→ resolution plots from before

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

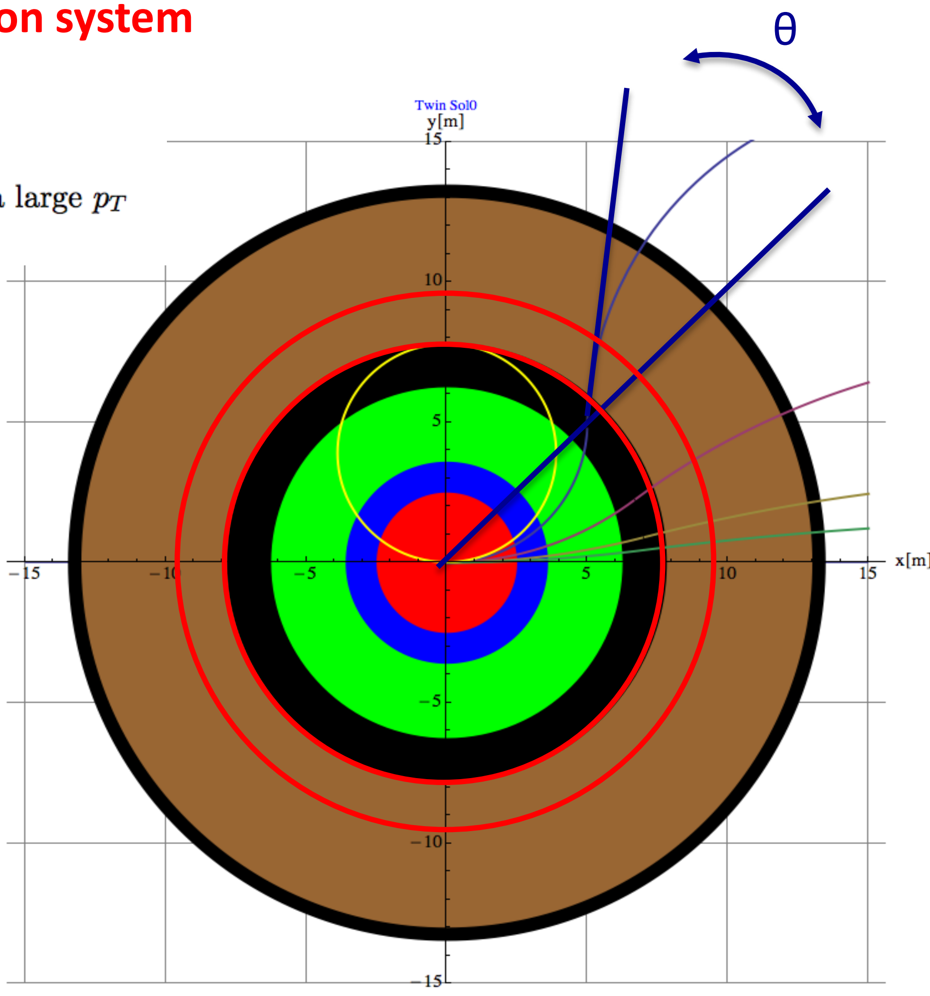
For low momentum, limit due to multiple scattering in the calorimeters and coil:

Calorimeter+Cryostat: 35X_0
HCAL: 110X_0
Coil: 5X_0
→ $x_{tot}/X_0 \approx 150$

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

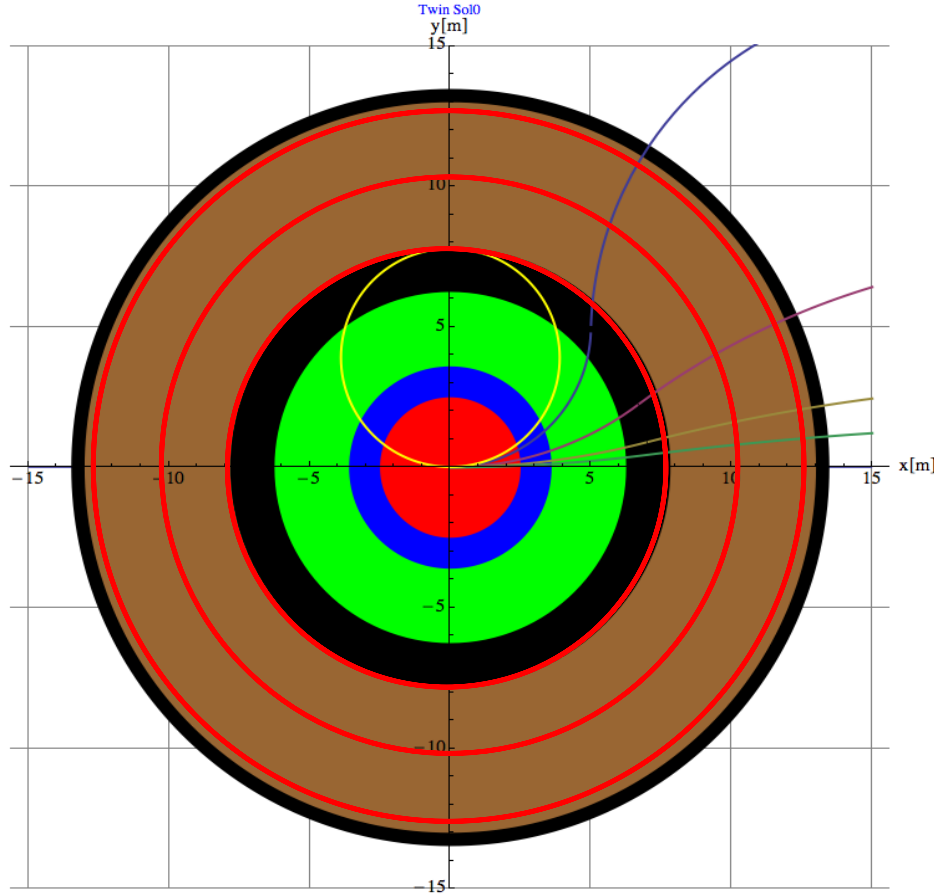
B_0=6T, R_0=6m
→ dp/p=3% !!!

(CMS 9% because B_0R_0=1/3)



Excellent resolution for a possible muon trigger.

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.

FCC Detector Radiation Studies

M. I. Besana, F. Cerutti, A. Ferrari, W. Riegler, V. Vlachoudis

FLUKA simulations for the baseline geometry assuming
$L=3x10^{35}$ $cm^{-2}s^{-1}$, L=30 ab^{-1}

B-Field from Twin Solenoid+Dipole

Very Rough Estimate for Silicon Detectors

Estimate for radiation load of first Pixel Layer at r=3.7cm:

HL-LHC 3ab^{-1}
1MeVneq Fluence = 1.5×10^{16} cm^{-2}
Dose = 5MGy

FCC 3ab^{-1}
1MeVneq Fluence = 3×10^{16} cm^{-2}
Dose = 10MGy

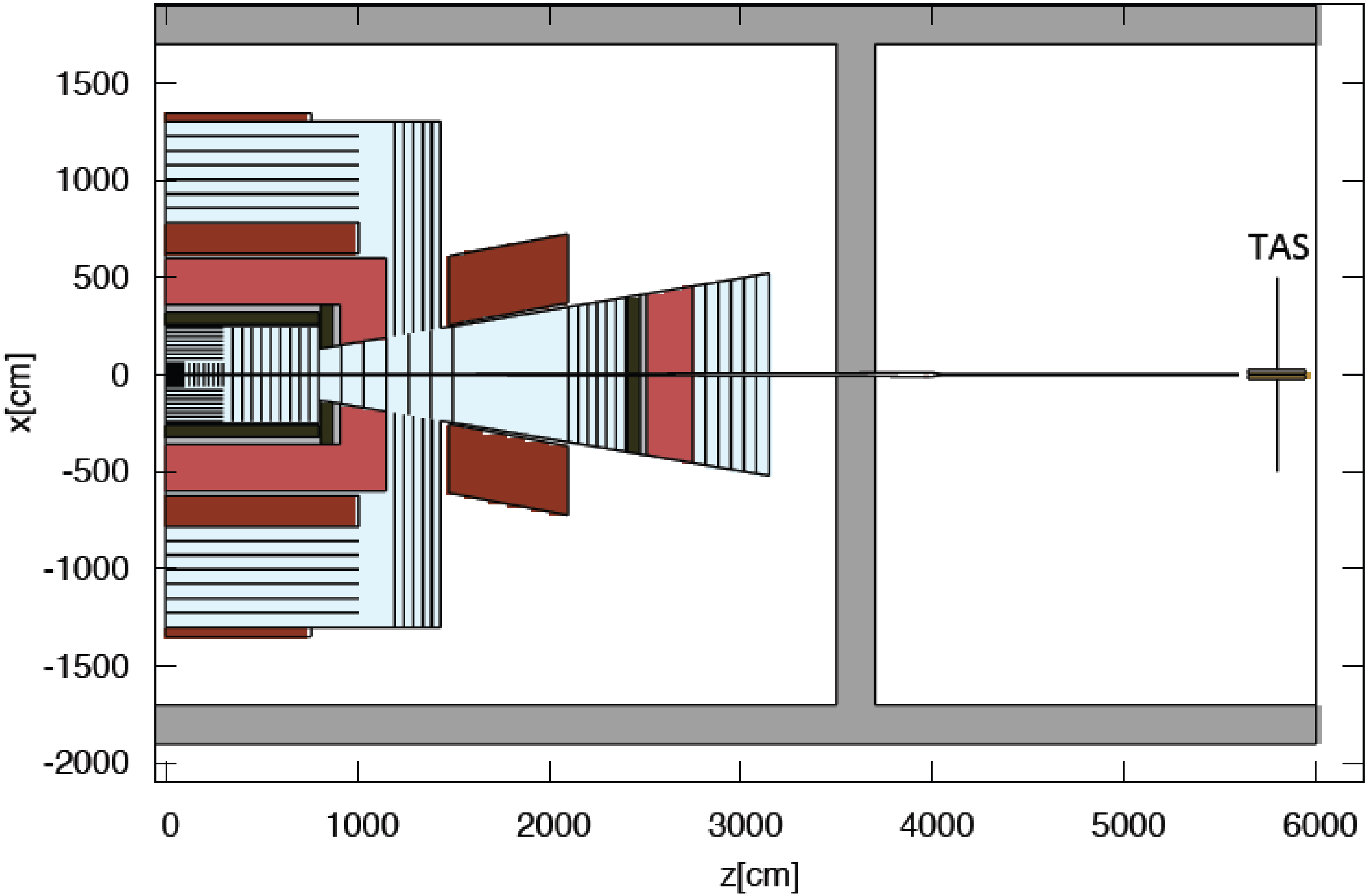
FCC 30ab^{-1}
1MeVneq Fluence = 3×10^{17} cm^{-2}
Dose = 100MGy

Estimate for radiation load of first Pixel Layer at r=2.5cm:

FCC 30ab^{-1}
1MeVneq Fluence = 7×10^{17} cm^{-2}
Dose = 220MGy

→ With safety factors we go into the 10^{18}/cm^2 and GGy range !

Layout


1500
1000
500
0
-500
-1000
-1500
-2000
x[cm]
TAS
0
1000
2000
3000
4000
5000
6000
z[cm]

The approximate detector performance has been parametrized and included in a DELPHES description that is embedded in the FCC software.

Physics simulations can start.

Efforts of embedding the FCC studies in the activities and groups working on LHC & HL-LHC preparation are ongoing.

It is crucial that the community takes 'ownership' of this project and all thoughts about LHC physics at 14 TeV are also investigated for 100TeV.

Presently the group consists of 10-15 part time contributors
More people to join Welcome!! (contact W. Riegler)

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