FCC-hh Experiments and Detectors Overview

FCC week, April 11-15, 2016, Rome

W. Riegler, CERN

Meetings

Following the FCC week in Washington we established regular meetings and made significant progress in some areas, that is being presented today.

FCC-hh Detectors: ≈ monthly meetings
https://indico.cern.ch/category/6069/
e-mail-list: fcc-experiments-hadron@cern.ch
→ Subscribe !

FCC-hh Detector Magnets
https://indico.cern.ch/category/6244/

FCC-hh machine detector interface
https://indico.cern.ch/category/5901/

Baseline Parameters for the FCC-hh Machine

From Michael's intro talk:

5 year long operation periods
- 3.5 years operation periods with
- 1.5 year shutdown

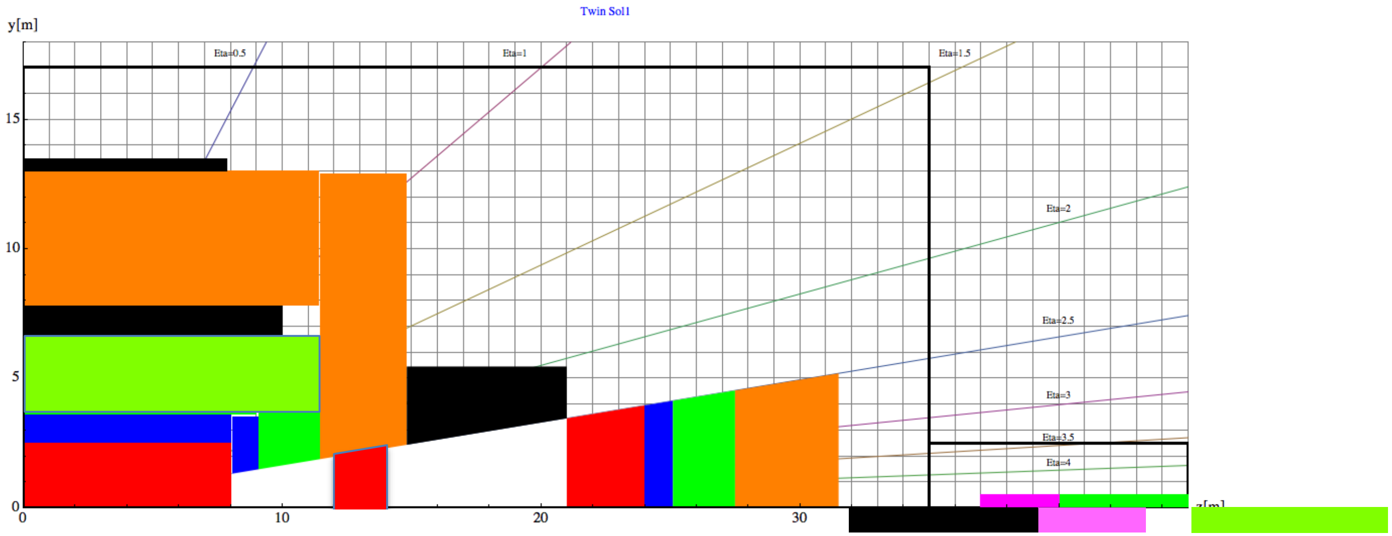
2 periods at baseline parameters (10 yrs) Phase1
- Peak luminosity $5x10^{34}cm^{-2}s^{-1}$, 25ns, pileup 170
- Total of $2.5ab^{-1}$ (per detector)

3 periods at ultimate parameters (15 yrs) Phase 2
- Peak luminosity <=$30x10^{34}cm^{-2}s^{-1}$, 25(5)ns, pileup 1020(204)
- $5ab^{-1}$ per period total of $15ab^{-1}$

→ Although some of us are confident about prospects of being able to deal with high pileup, the 5ns option should be considered 'at least with equal priority' as 25ns.

→ The transition from Phase1 to Phase2 luminosity is not related to major hardware changes in the accelerator, so it may be continuous. Important aspect for experiment strategy.

Baseline Geometry used up to now , Twin Solenoid, 6T, 12m bore, 10Tm dipole



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
Revision of outer radius is ongoing.

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

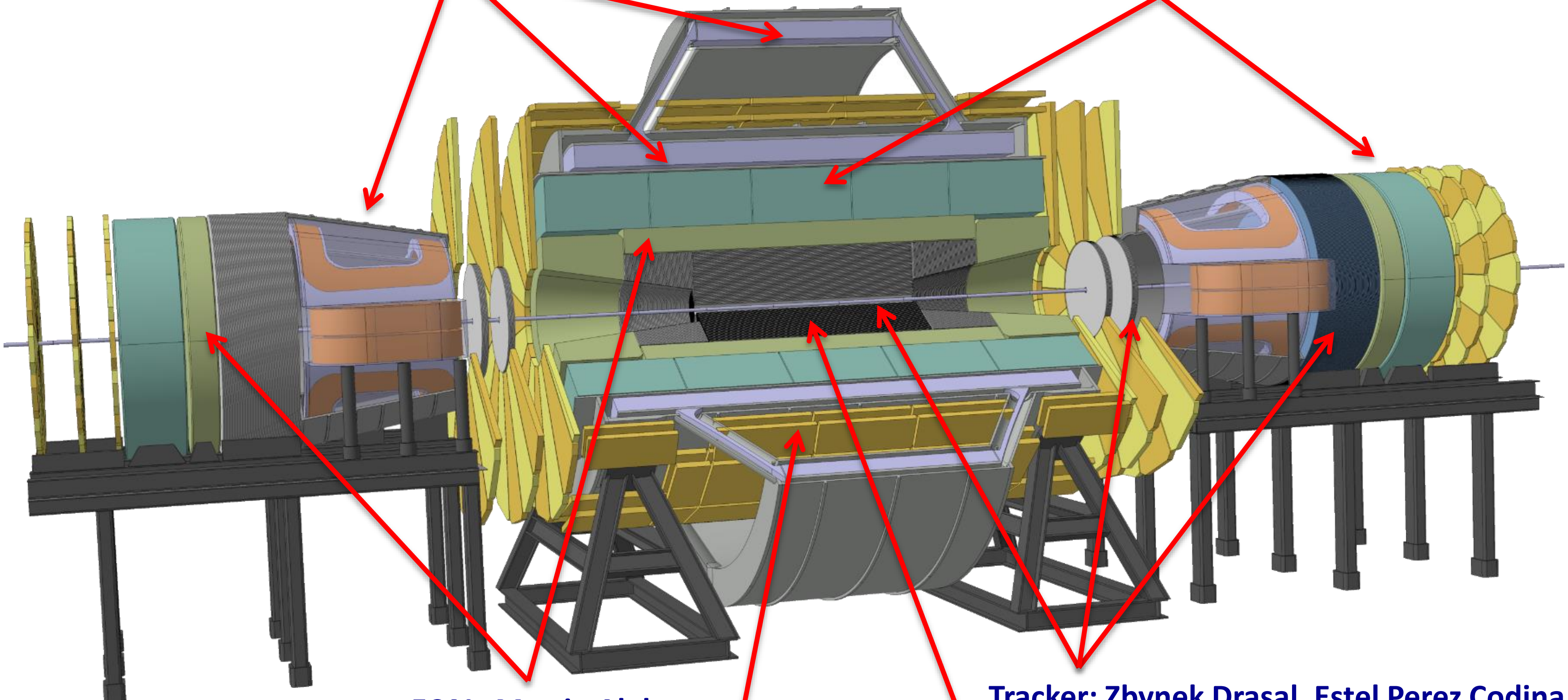
FTracker available space:
z=21m to R=24m, L=3m

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

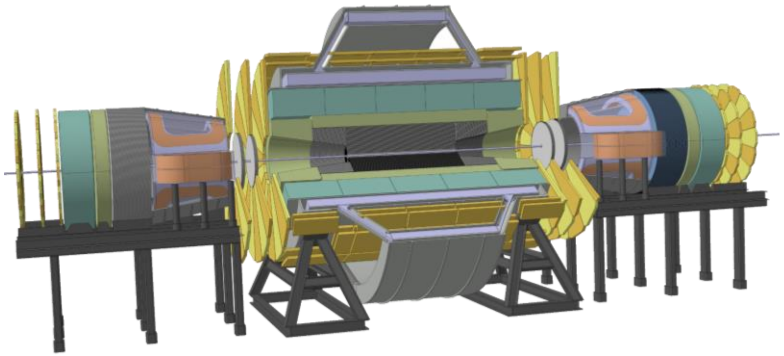
Presentations this Week



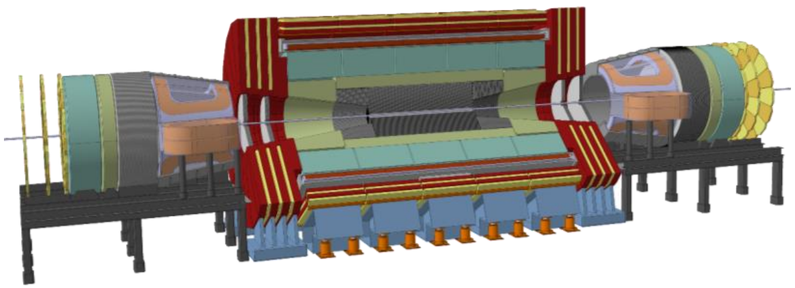
US activities: Ashutosh Kotwal, Ian Shipsey

Performance of this detector has been parametrized and formulated in DELPHES.

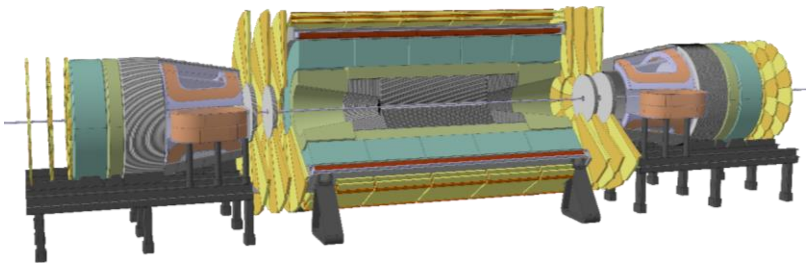
Magnet systems under consideration



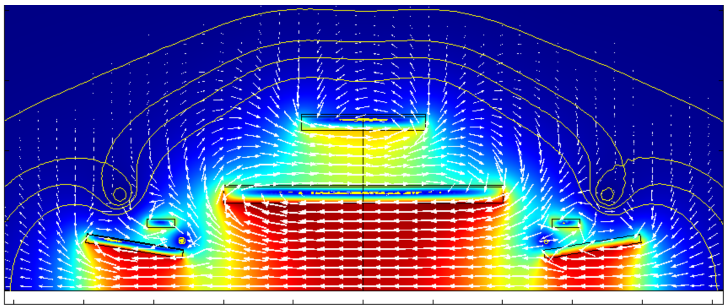
Twin solenoid with dipoles



Partially shielded solenoid with dipoles



Unshielded solenoid with dipoles



Twin solenoid with forward solenoid

Development of ‘Detector Baseline’

Considering that the experiment cost should be a reasonable fraction of the accelerator cost one could naively assume a very large budget for the detectors.

The magnet group studied the 6T, 12m bore, 10Tm dipole as engineering challenge.

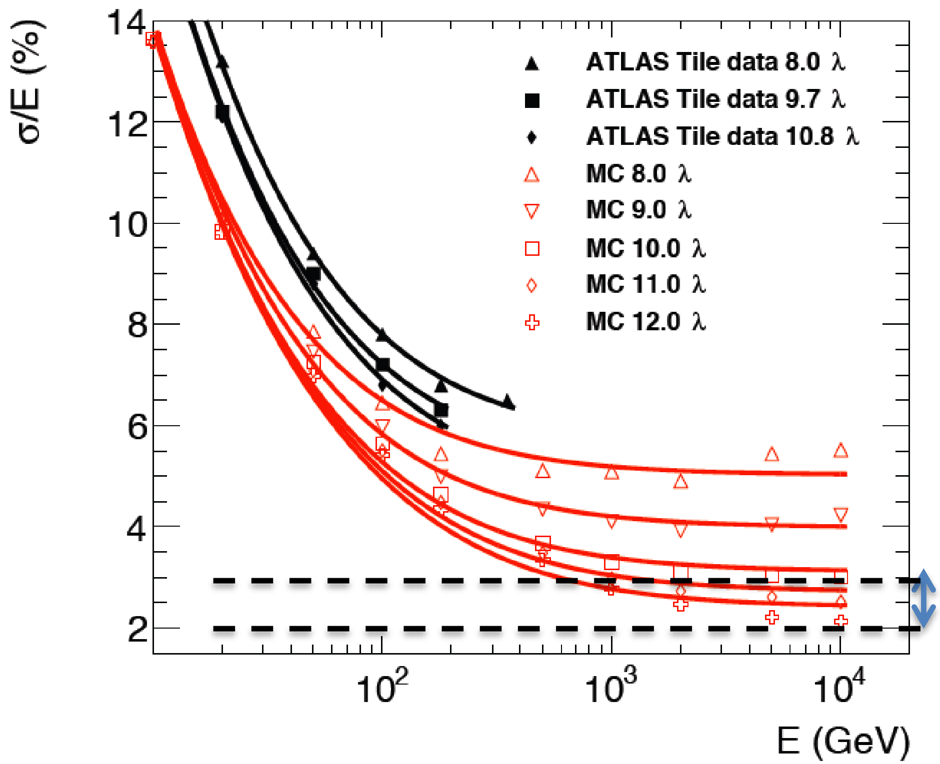
This geometry allows comfortably a 2.4m tracker cavity, 2.4m HCAL for 12 lambda.

Considering that such a magnet system costs on the order of 0.7-0.9 BEuros, and that for a reasonable balance the magnet system should represent between 20-30% of the detector cost, we are talking about a multi Billion cost for such a detector.

The ‘very comfortable’ space requirements are probably not really justified. Scaling down the magnet system to 4T/10m and 4Tm dipoles reduces the cost by about a factor 2 to 0.35 to 0.45 BEuros, which brings the detector cost closer towards the ‘one Billion’ range.

We should therefore think about a more realistic baseline for the 2018 report.

Calorimeter Depth



Containment and resolution of hadronic showers at the FCC

Tancredi Carli[a], Clement Helsens[a], Ana Henriques Correia[a], and Carlos Solans Sánchez[a]

[a]CERN

April 7, 2016

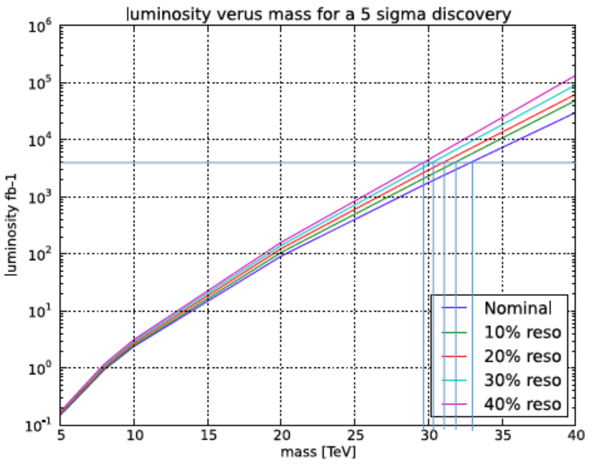
2% to 3%, for 10-12 lambda.

Difference is 42cm, which is significant.

arXiv:1604.01415v1 [physics.ins-det] 5 Apr 2016

The 10% at 10TeV resolution specification was originally motivated e.g. by Z' decaying to muons, however

C. Helsens



Conclusion

- For a 20TeV Z' where muons have peaks at p_T of 10TeV, the increase in luminosity needed to discover at 5sigma is:
  - 10% resolution -> 1.16 times more luminosity than nominal
  - 20% resolution -> 1.36 times more luminosity than nominal
  - 30% resolution -> 1.55 times more luminosity than nominal
  - 40% resolution -> 1.75 times more luminosity than nominal
- For 3ab^{-1} the discovery reach from 33TeV to 29.5 from nominal to 40% resolution at 10TeV:
- So it is indeed not well motivated to aim at 10% resolution at 10TeV only in terms of high di-muon narrow resonance discovery potential

Development of ‘Detector Baseline’

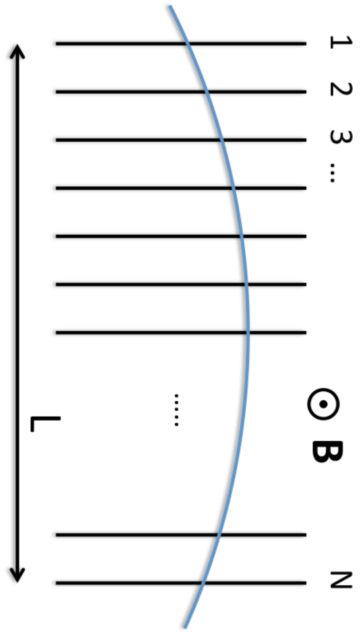
6T/12m bore:
Extreme magnet challenge, comfortable space for 2.4m tracker radius and 12 lambda of calorimeter.

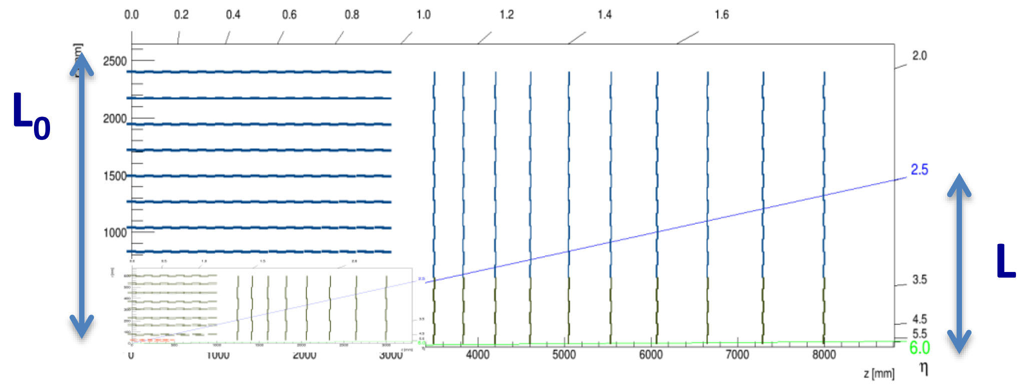
4T/8m bore:
Extreme detector technology challenge, 1m tracker radius, short calorimeter, possibly Tungsten.

4T/10m bore:
Probably a good middle ground from which we can explore the performance towards smaller and larger values.

For the forward spectrometer:
Pushing the detector resolution and relaxing the field integram form 10 to 4-5Tm seems appropriate.

Central Tracker





$$\frac{\Delta p_T}{p_T}\Big|_{reso.} = \frac{\sigma\, p_T}{0.3BL(\eta)^2}\sqrt{\frac{720}{N(\eta)+4}} \qquad \frac{\Delta p_T}{p_T}\Big|_{m.s.} = \frac{0.0136}{0.3\,BL(\eta)}\sqrt{\frac{x}{X_0}(\eta)}$$

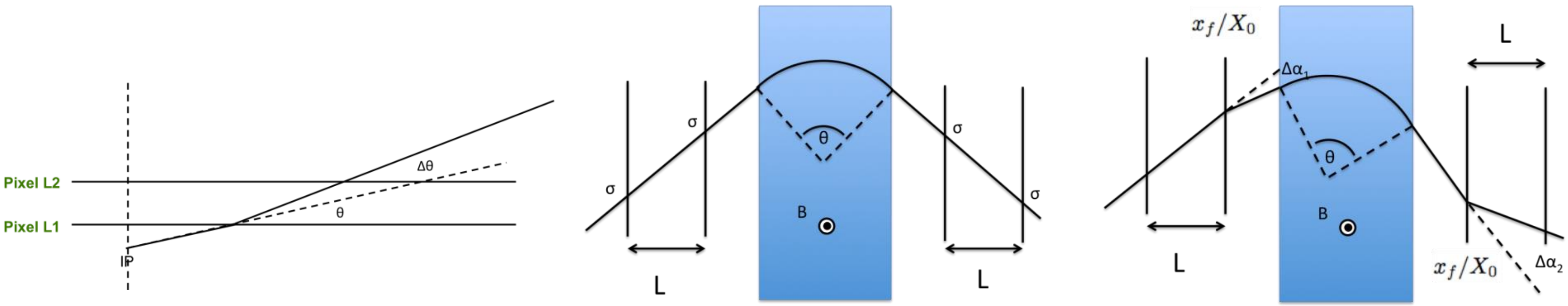
Large BL^2 needed for high momenta, but large BL also key to minimize multiple scattering contribution.

With BL 2.5 times larger than CMS, the multiple scattering contribution for the same amount of tracker material is a factor 2.5 smaller (reso: 0.8% → 0.32%).

How to scale the tracker and keep the performance constant ?

At constant B and 1/2 the tracker radius we need:
4 times the tracker resolution (20um → 5um) and
4 times less material budget (x/X_0=50% at eta=0 to x/X_0=12.5% at eta=0 i.e. 3% per Layer to 0.75% per layer)

Forward Tracker



$$\Delta\theta = \frac{0.0136}{p}\sqrt{\frac{x_t}{X_0}\frac{1}{\sin\theta}} = \frac{0.0136\,\sin\theta}{p_T}\sqrt{\frac{x_t}{X_0}\frac{1}{\sin\theta}}$$

$$\Delta\alpha_{res} = 2\sigma/L.$$

$$\Delta\alpha_{ms} = 0.0136/p_L\sqrt{2x_f/X_0}.$$

$$\left(\frac{\Delta p_T}{p_T}\right)^2 = \left(\frac{\Delta p_L}{p_L}\right)^2 + \left(\frac{1}{\sin\theta\cos\theta}\right)^2\Delta\theta^2$$

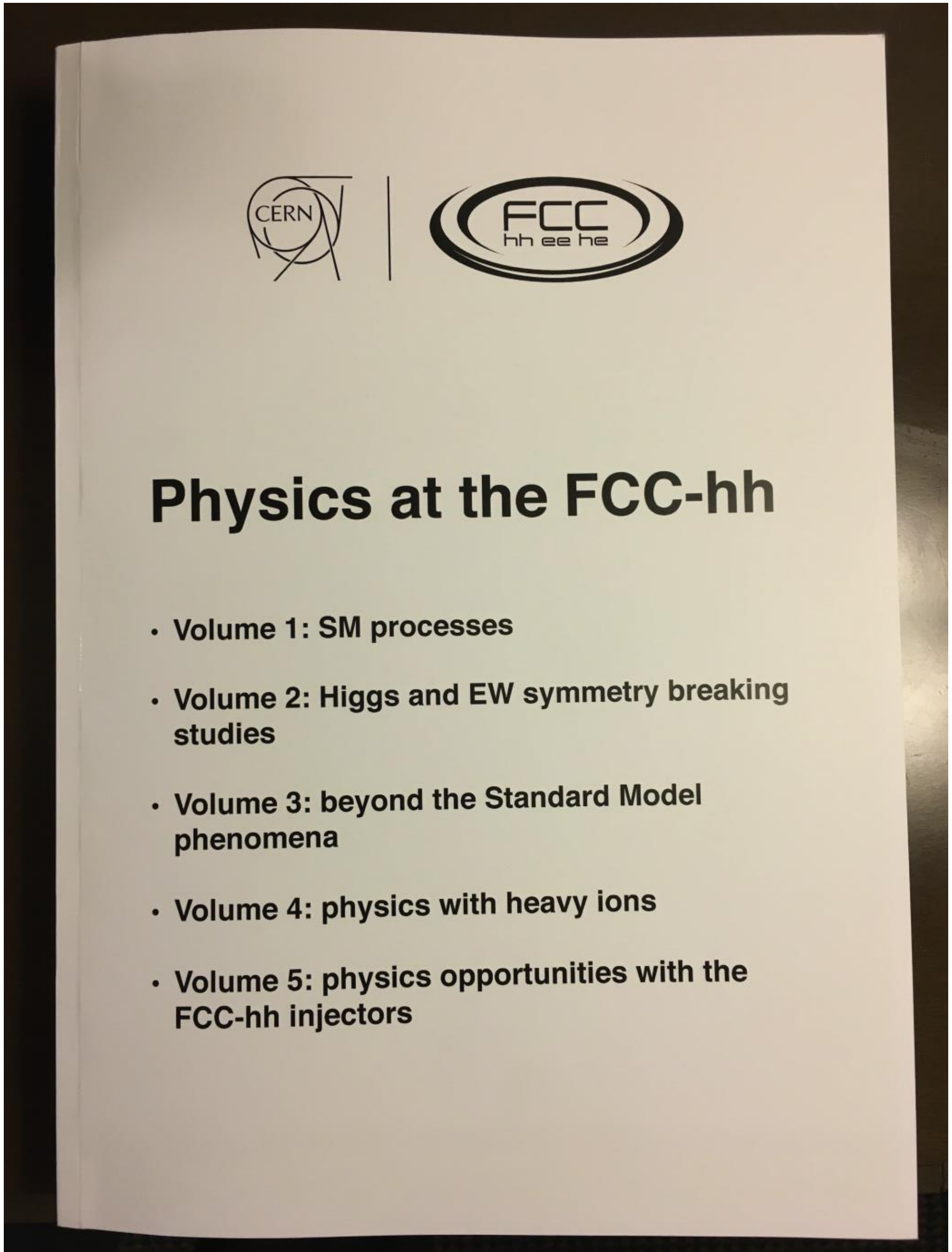
$$\left(\frac{\Delta p_L}{p_L}\right)^2 = \left(\frac{p_L}{0.3\int B_T dl}\right)^2(\Delta\alpha_{res}^2 + \Delta\alpha_{ms}^2)$$

Track angle to convert p_L to p_t

Position resolution

Multiple scattering

$$\left(\frac{\Delta p_T}{p_T}\right)^2 = \left(\frac{2\sigma\,p_T\,\sinh\eta}{0.3L\,\int B_T dl}\right)^2 + \left(\frac{0.0136}{0.3\int B_T dl}\sqrt{2\frac{x_f}{X_0}}\right)^2 + \left(\frac{0.0136\,\coth\eta}{p_T}\sqrt{\frac{x_t}{X_0}\cosh\eta}\right)^2$$

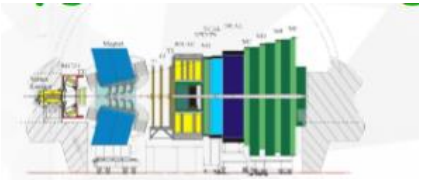


We have now a massive document that is detailing the physics opportunities and benchmarks.

The important next step are physics performance simulations in order to get a better idea of the required detector performance.

Software session (Thursday): Benedikt Hegner, Julia Hrdinka, Anna Zaborowska , Clement Helsens

LHCb & ALICE in 2018



40 MHz

DAQ

40 MHz

LLT: μ,e/γ, hadrons

5-40 MHz

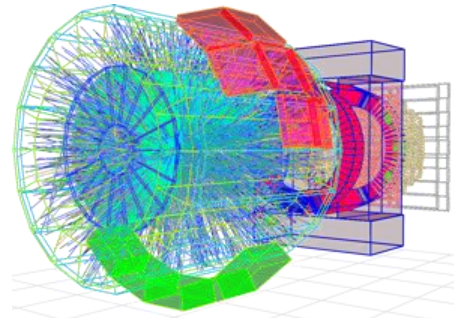
HLT: event recon.

20 kHz (0.1 MB/event)

Storage

2 GB/s

4 TByte/s into PC farm for HLT selection.



1 TByte/s into PC farm for data compression. All events to disc.

50 kHz

Reconstruction + Compression

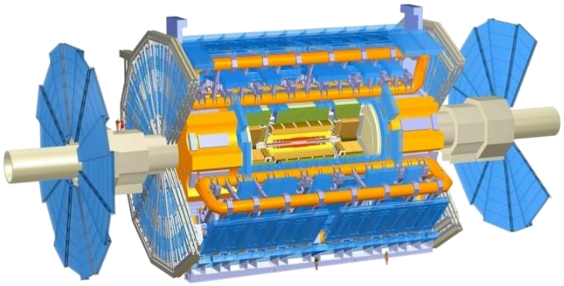
50 kHz (1.5 MB/event)

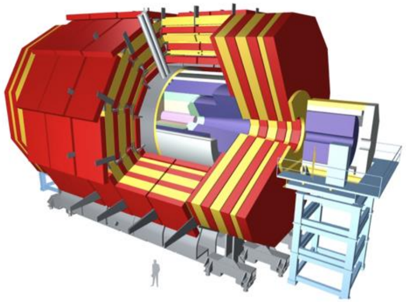
Storage

75 GB/s

← PEAK OUTPUT →

ATLAS & CMS in 2023





40 MHz

Level 1

0.5-1 MHz

HLT

5-10 kHz (2MB/event)

Storage

10-20 GB/s

Level 1

HLT

10 kHz (4MB/event)

Storage

40 GB/s

5 TByte/s into PC farm for HLT selection.

Would be 200TByte/s without Level1

← PEAK OUTPUT →

Hardware Trigger ?

CMS HL-LHC results in 200TByte/s into the online system for a triggerless readout.

An FCC tracker at $L=30\times10^{34}$ will produce >1000 TB/s of data rate.

Is it reasonable to assume that we can read all data into an online farm by 2035 ?

N.b. the techniques to get the data out of the detector with a small amount of material is a key question to be solved.

Even if one would afford to read all data to HLT for PhaseII, the amount of copper lines to get all the signals out of the silicon detector would destroy the tracker performance.

Common technology session (Thursday):
Walter Snoeys, Dave Newbold, Georg Viehhauser, Hans-Kristian Soltveit

Muons

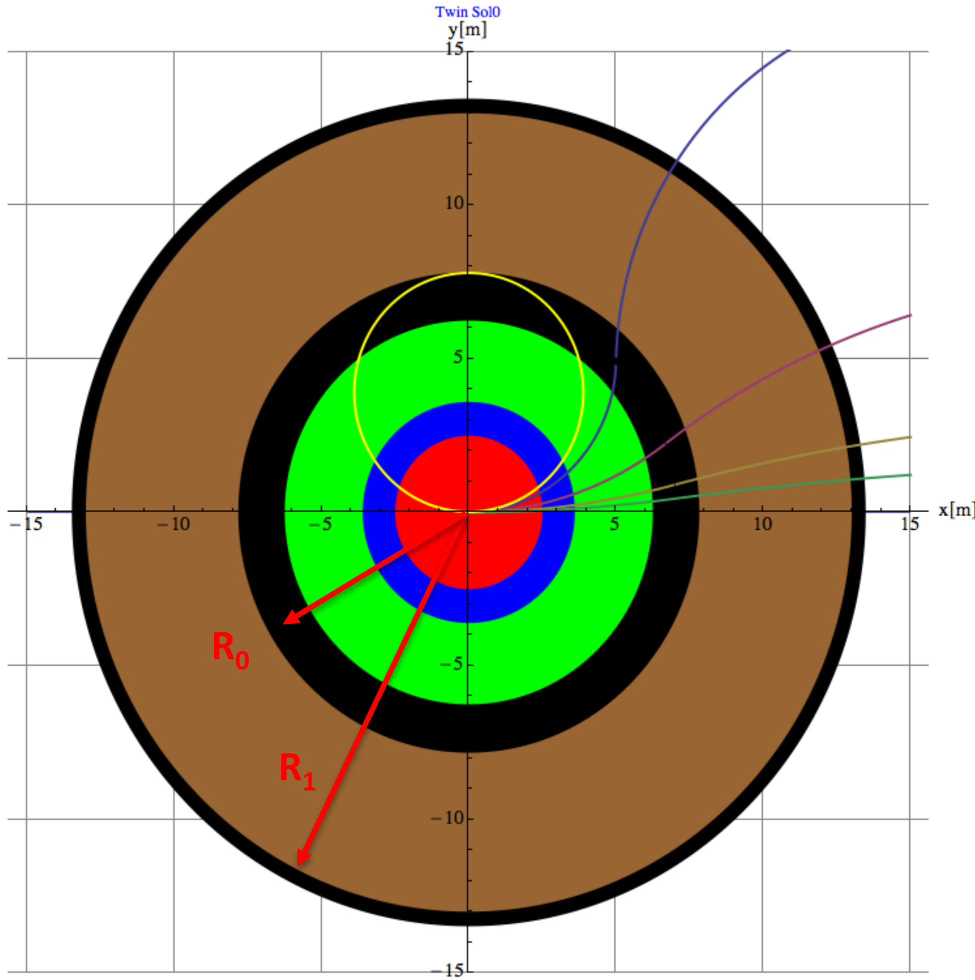
Muon Momentum can be measured by

1) The inner tracker

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

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

4) A sagitta measurement in the muon system



4) Muon measurement by 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

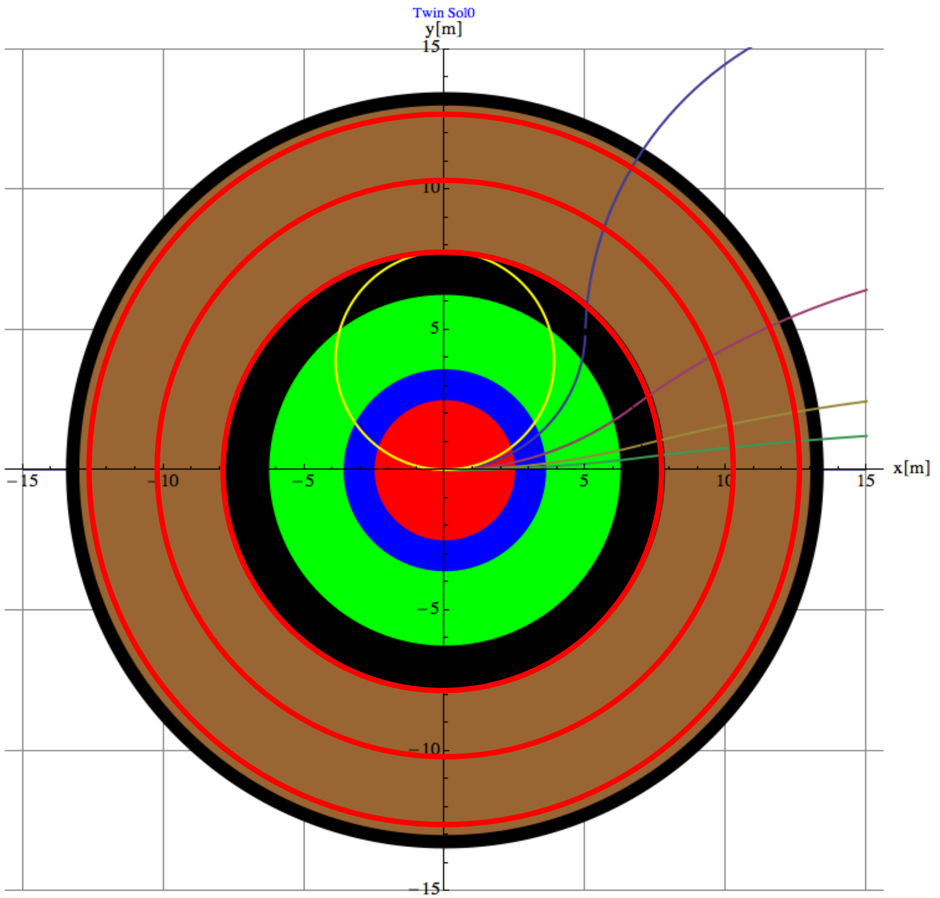
dp_T/p_T= sig*$p_T/(0.3*B*L^2)*8$
= 20% @ 10TeV

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

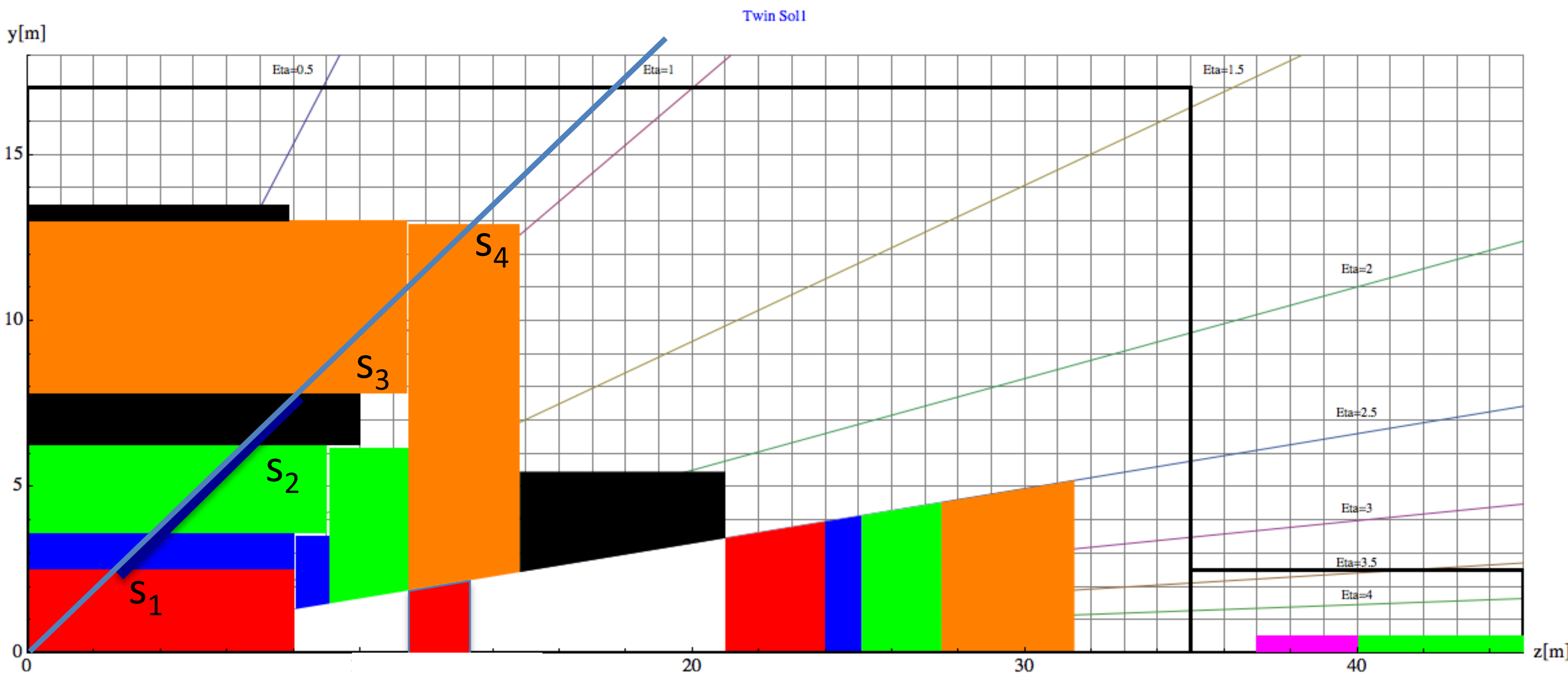
but very hard to beat the angular measurement at high p_T and the inner tracker at low p_T.

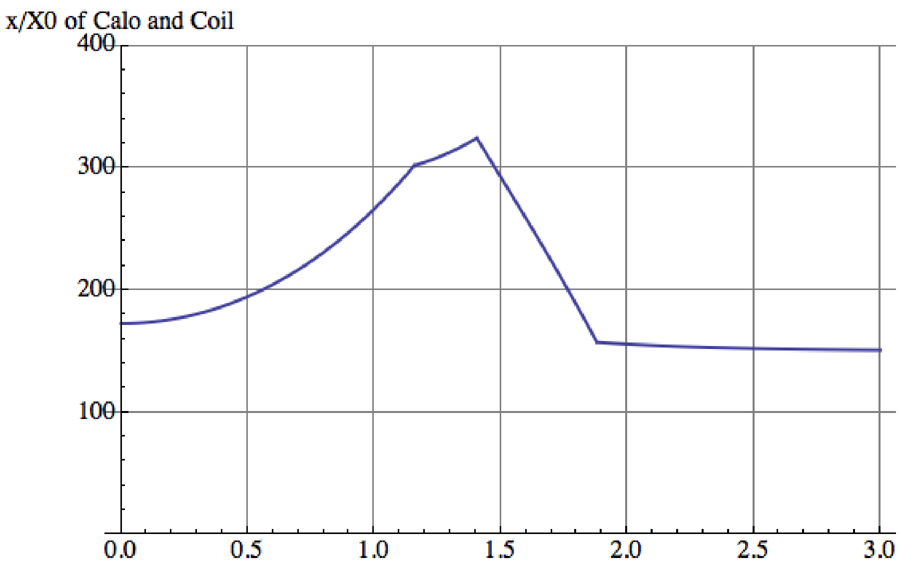
Surface > 5000 m^2

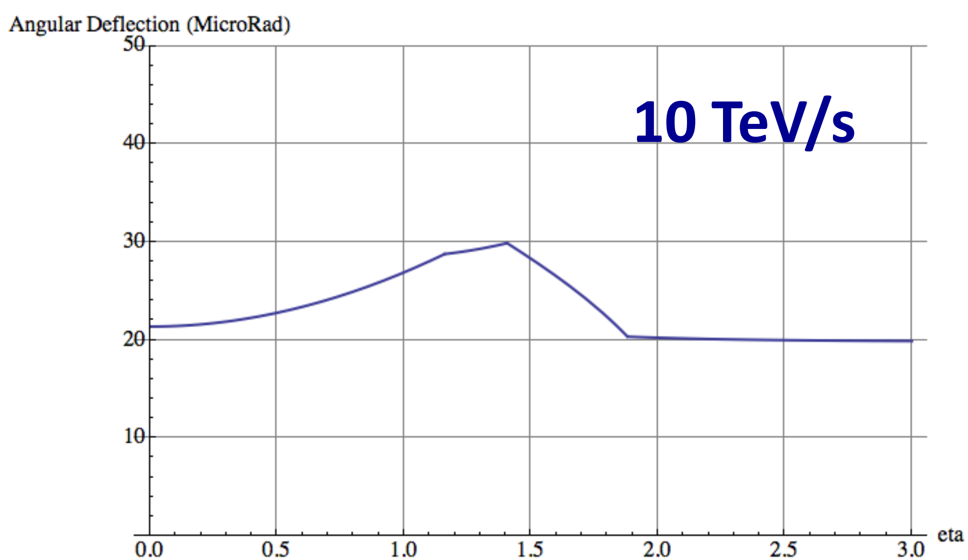
→ Seems not competitive



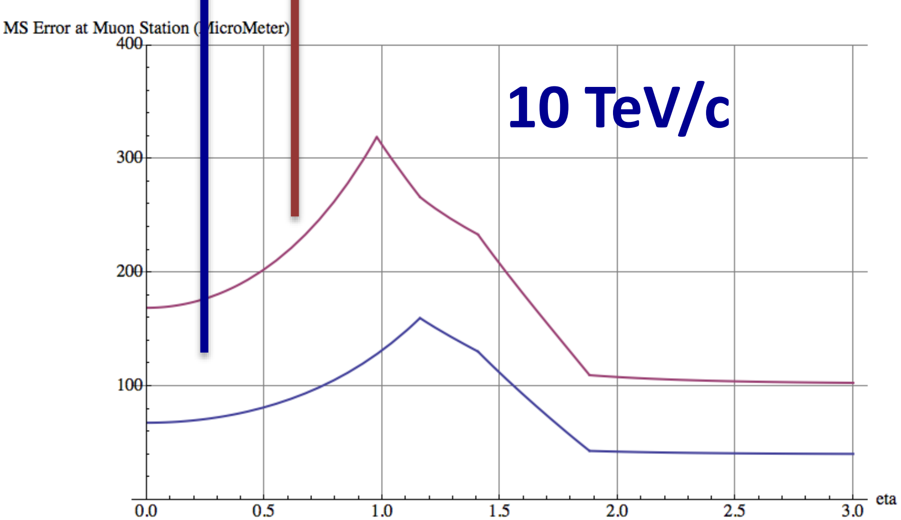
Radiation length and angular deflection of muons in calo+coil







Measurement error in the muon system due to multiple scattering



The r.m.s. (in plane) angular deflection θ_0 and spatial displacement σ_y of a particle passing through material of thickness x are given by

$$\theta_0 = \frac{0.0136}{\beta p[GeV/c]} \sqrt{\frac{x}{X_0}} \left(1 + 0.038 \log \frac{x}{X_0}\right) \tag{184}$$

$$\sigma_y = \frac{1}{\sqrt{3}} x \, \theta_0 \tag{185}$$

For the proper correlated M.C. generation of these two quantities, one uses two independent Gaussian random variables z_1, z_2 with mean of zero and sigma of one, and calculates

$$y = z_1 \, x \frac{\theta_0}{\sqrt{12}} + z_2 \, x \frac{\theta_0}{2} \tag{186}$$

$$\theta = z_2 \theta_0 \tag{187}$$

In case a muon passes the calorimeter of thickness L_1 and then propagates through the (material less) muons system of length L_2 the spatial deflection is given by

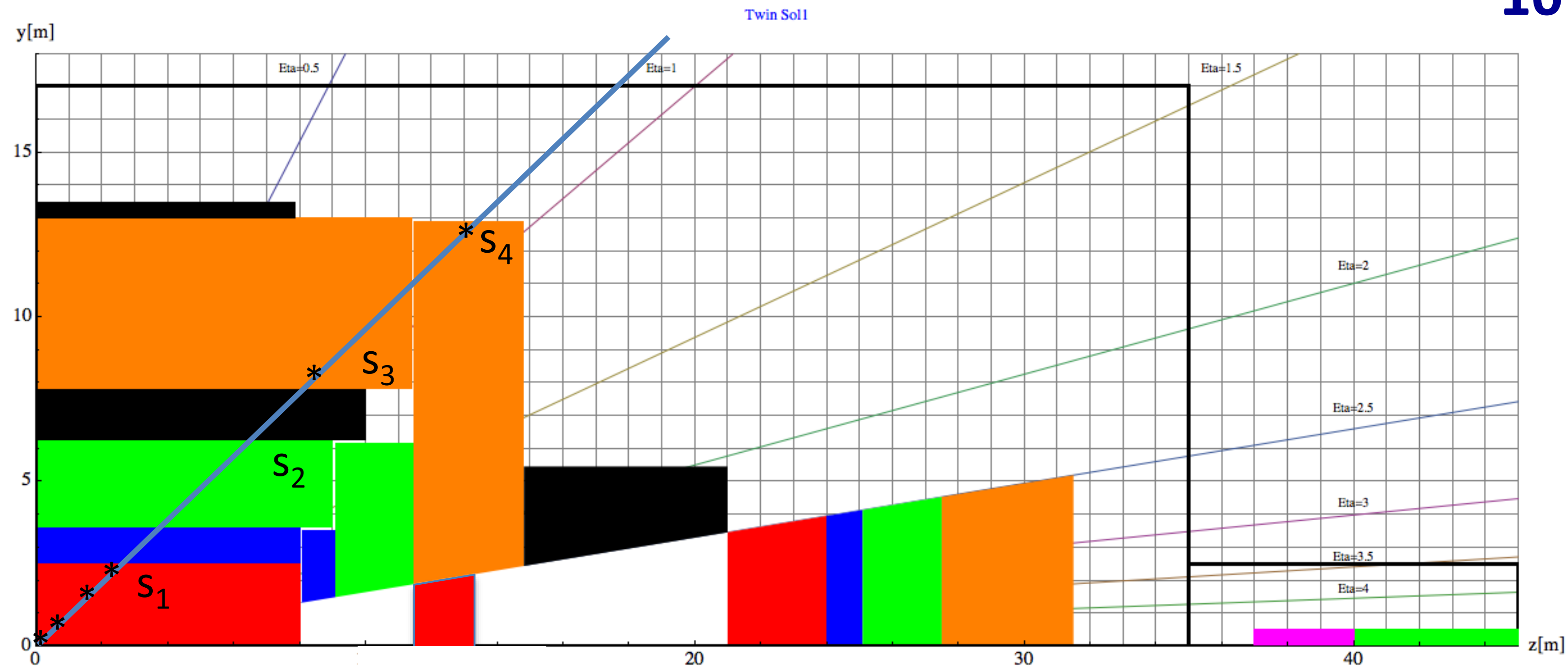
$$s = z_1 \, L_1 \frac{\theta_0}{\sqrt{12}} + z_2 \, L_1 \frac{\theta_0}{2} + z_2 \theta_0 L_2 \tag{188}$$

and therefore a position error of

$$\sigma_s^2 = \theta_0^2 \left[\frac{L_1^2}{12} + \left(\frac{L_1}{2} + L_2 \right)^2 \right] \tag{189}$$

Radiation length and angular deflection of muons in calo+coil

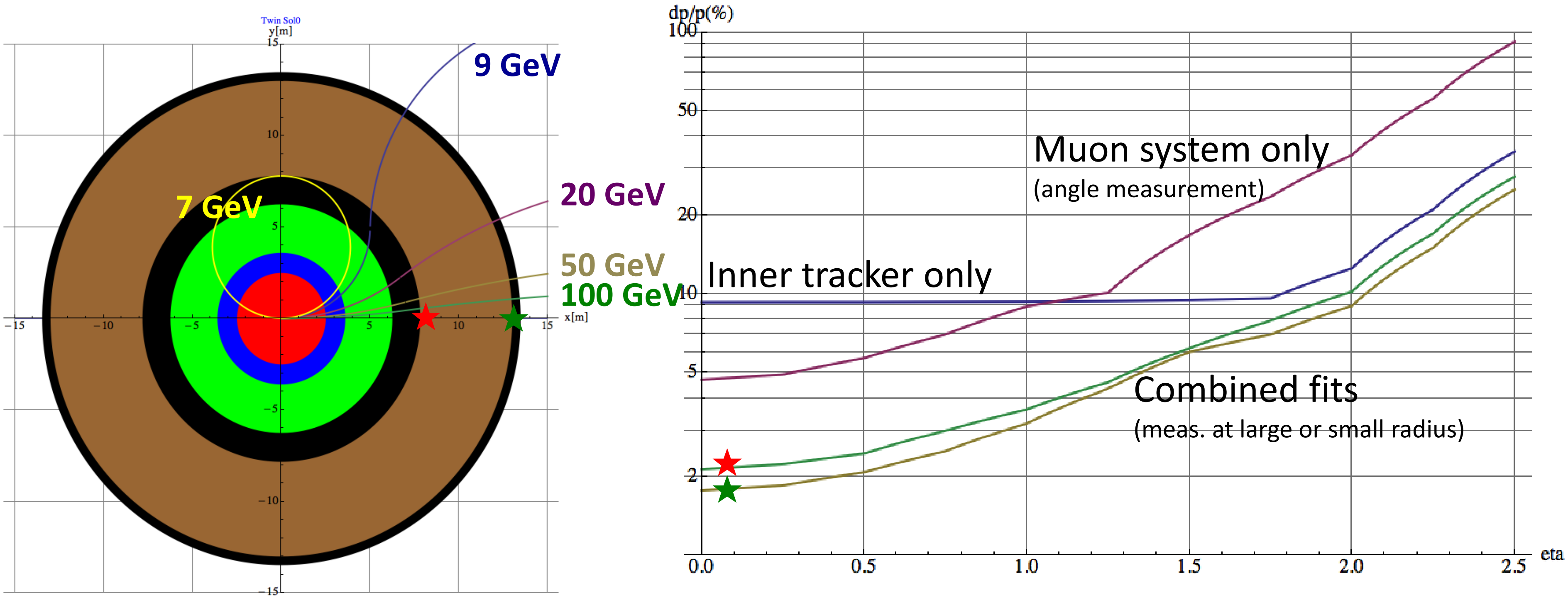
10 TeV/s



Fit of the template function to 14 measurement points of 23um in the inner tracker and 1 layer in the muon system with a resolution that is much better than the multiple scattering limit.

i.e. assuming the resolution at s4 to be better than 100um and at s3 to be better than 50um and the resolution of the angular measurement better than 20uRad.

Momentum Resolution for a 10 TeV/s Muon



Twin Solenoid assuming inner tracker with baseline resolution curves and multiple scattering limit in the muons system.

P_T=10TeV/c eta = 0: 5% muon standalone (angle)
10% inner tracker only
2% combined

P_T=10TeV/c eta=2.: 35% muon standalone (angle)
12.5% inner tracker only
8% combined

Compare to the CMS numbers:

P_T=1TeV/c, 0<eta < 0.8: 20% muon standalone (angle)
10% inner tracker only
5% combined

P_T=1TeV/c, eta 1.2<eta<2.4: 40% muon standalone (angle)
20% inner tracker only
10% combined

Summary

Significant progress on detector concepts has been made since the last FCC meeting.

Physics performance studies with parametrized detector performance are THE important next step.

Detector performance studies with fast/full simulations are needed as well.

We have to establish a credible 'baseline' detector in view of the 2018 report.