FCC-hh Detector Studies

Albert De Roeck, CERN
On behalf of the FCC-hh Detector Study Group

IAS Meeting Hong Kong
18-21 January 2016

Based on material from W. Riegler

IAS Program on
High Energy Physics
4-29 Jan 2016 Conference: 18-21 Jan 2016

FCC
hh ee he

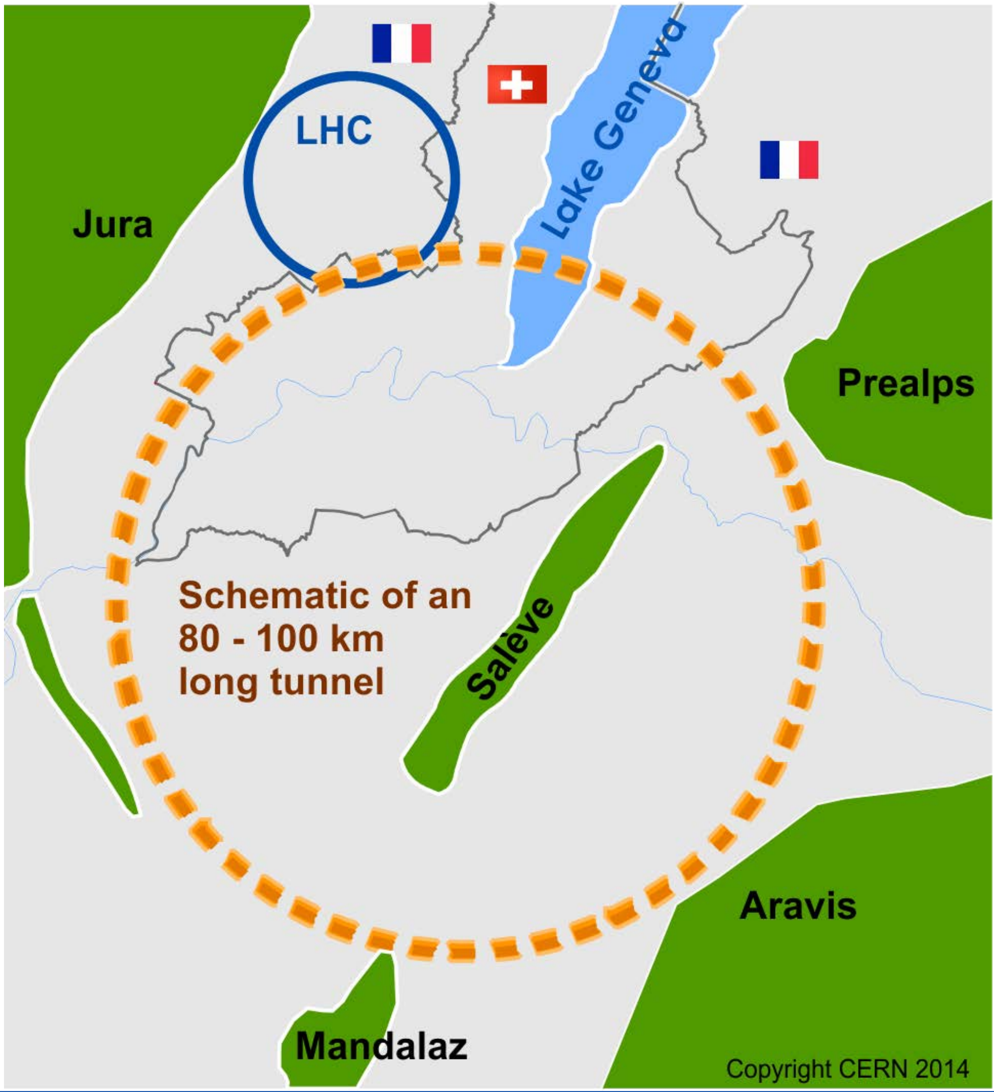
Future Circular Collider Study

International FCC collaboration (CERN as host lab) to study:

- ***pp*-collider (*FCC-hh*)**
  → main emphasis, defining infrastructure requirements

~16 T ⇒ 100 TeV *pp* in 100 km

- **80-100 km infrastructure** in Geneva area
- ***e⁺e⁻* collider (*FCC-ee*)** as potential intermediate step
- ***p-e* (FCC-he) option**
- **HE-LHC** with FCC-hh technology



LUMINOSITY GOALS FOR A 100-TEV PP COLLIDER

Ian Hinchliffe[a*], Ashutosh Kotwal[b†], Michelangelo L. Mangano[c‡], Chris Quigg[d§], Lian-Tao Wang[e¶]

[a] Phyiscs Division, Lawrence Berkeley National Laboratory, Berkeley CA 94720, USA

[b] Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA
Duke University, Durham, North Carolina 27708, USA

[c] PH Department, TH Unit, CERN, CH-1211 Geneva 23, Switzerland

[d] Theoretical Physics Department, Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510 USA
Institut de Physique Théorique Philippe Meyer, École Normale Supérieure
24 rue Lhomond, 75231 Paris Cedex 05, France

[e] Department of Physics and Enrico Fermi Institute, University of Chicago, Chicago, IL 60637 USA

April 24, 2015

arXiv:1504.06108v1 [hep-ph] 23 Apr 2015

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

Last year here @ HKUST.....

Luminosity for a Hadron Machine

The present working hypothesis is:

- peak luminosity baseline: $5x10^{34}$
- peak luminosity ultimate: ≤ $30x10^{34}$

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

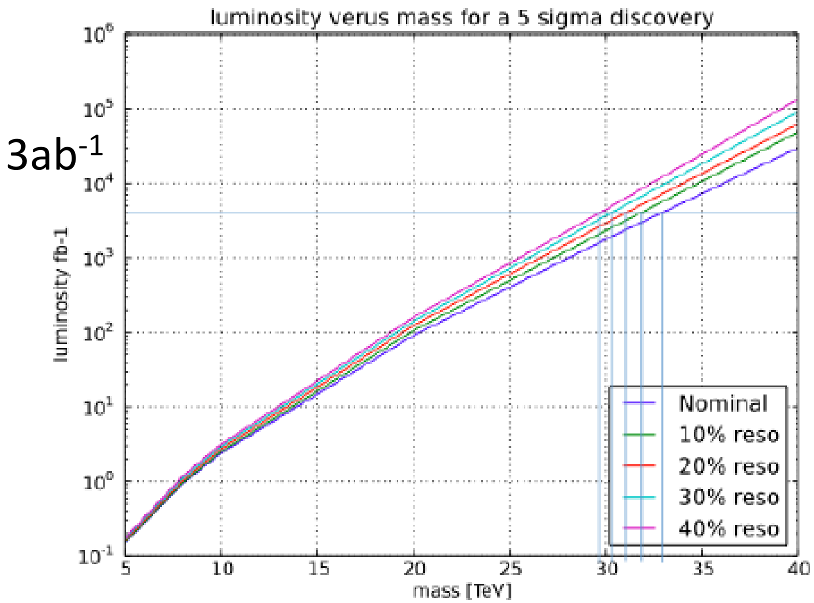
An operation scenario with:

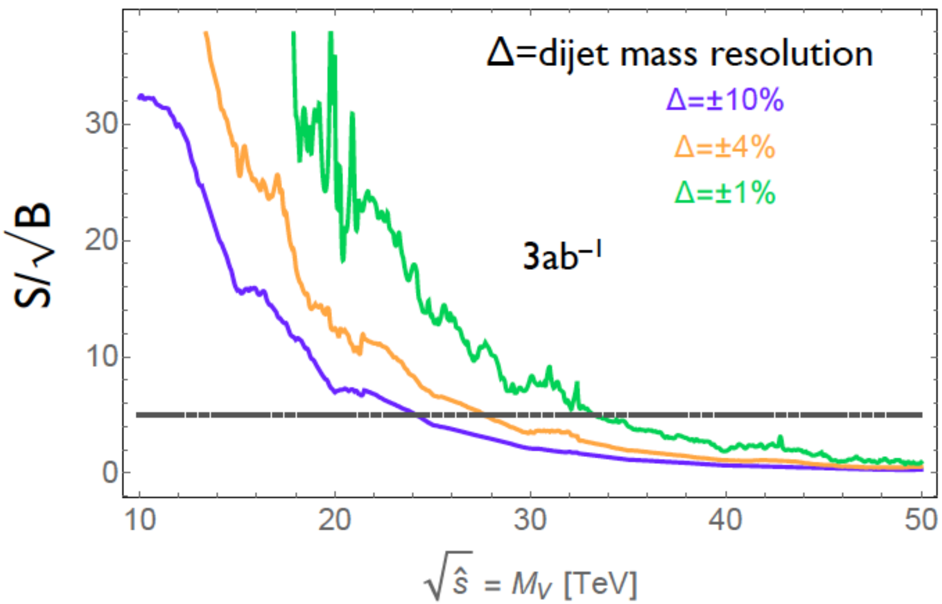
- 10 years baseline, leading to 2.5 ab^{-1}
- 15 years ultimate, leading to 15 ab^{-1}

would result in a total of O(20) ab^{-1} over 25 years of operation.

Physics at a Hadron Machine

C. Helsens, M. Mangano





$$\frac{\Delta p}{p} \propto \frac{p}{BL^2}$$

$$\frac{\Delta E}{E} \propto \frac{1}{\sqrt{E}} + k$$

Muon momentum resolution O(15%) at 10TeV.

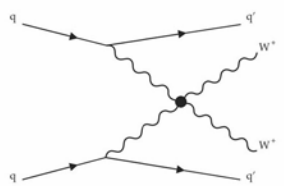
→ **Constant term dominates, 1-2% goal**

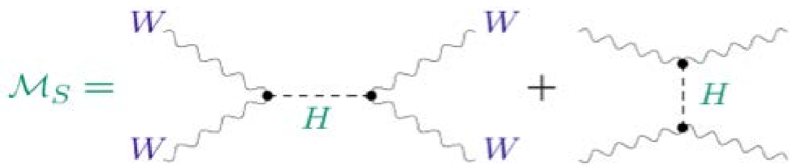
→ **full shower containment is mandatory !**

→ **Do not compromise on 12 lambda !**

VBF / WW Scattering

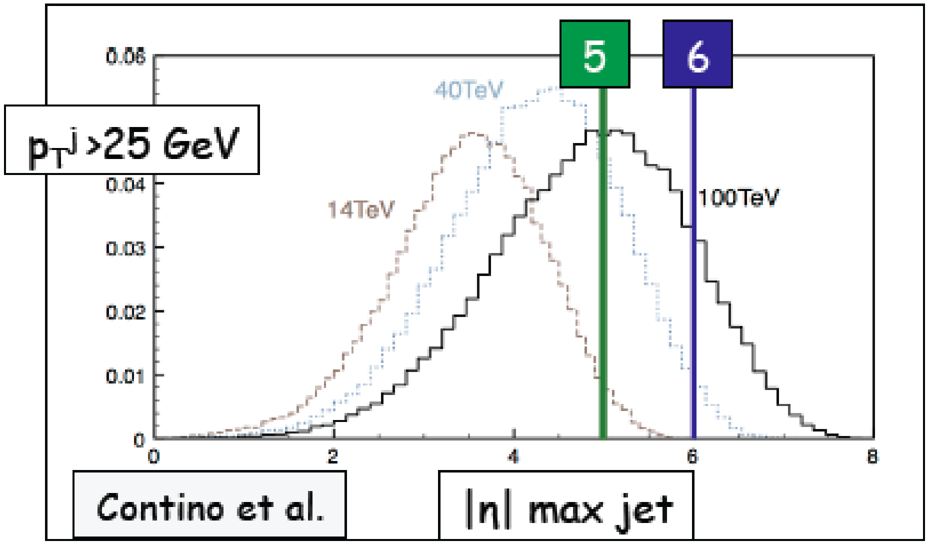
Is H playing it's role ? Unitarity at 1TeV ? Are there high mass resonances WW, ZZ, HH, …



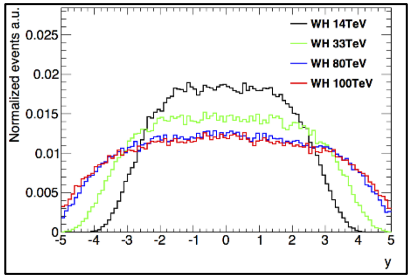


VBF jets between η~2 and η~6 need to be well measured and separated from pile-up

Muons (and electrons) around ~1 TeV p_T need to be triggered, identified, precisely measured



Higgs Measurements



$H \rightarrow 4l$ acceptance vs η coverage (l p_T cuts applied)

	14 TeV		100 TeV	
	2.5	4	2.5	4
ggF	0.74	0.99	**0.56**	0.88
WH	0.66	0.97	**0.45**	0.77
ZH	0.69	0.98	**0.48**	0.80
ttH	0.84	1	**0.56**	0.90
VBF	0.75	0.98	**0.55**	0.87

H. Gray, C. Helsens

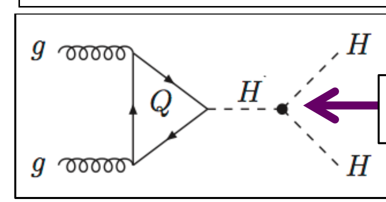
		|η| < 2.5	|η| < 4	|η| < 5
YY	100 TeV	0.74	0.95	0.99
	14 TeV	0.90	1	1

→ 30-50% acceptance loss for H→ 4l at 100 TeV wrt 14 TeV if tracking and precision EMcalorimetry limited to |η|<2.5 (as ATLAS and CMS)

→ can be recovered by extending to |η|~ 4

Examples:
ttH : x 60 (from LHC 14)
HH : x 42

"Heavy" final states require high √s, e.g.:
HH production (including measurements of self-couplings λ) ttH (note: ttH→ ttμμ, ttZZ "rare" and particularly clean)



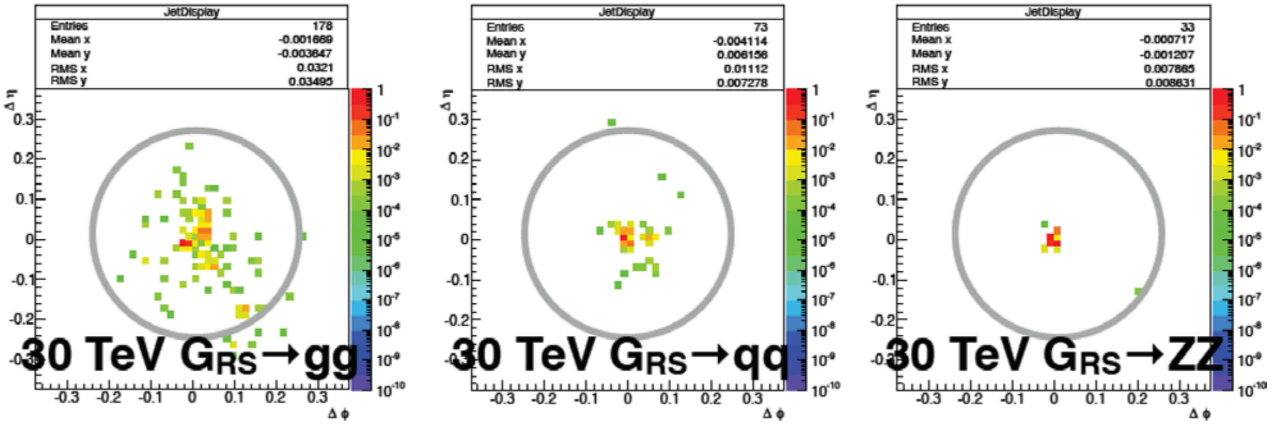
$g_{HHH} \sim \lambda v$

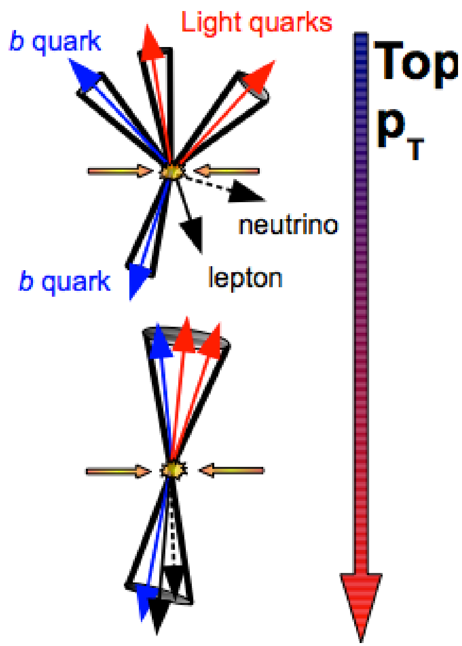
	HL-LHC	ILC500	ILC500-up	ILC1000	ILC1000-up	CLIC1400	CLIC3000	HE-LHC	VLHC
$\sqrt{s}$ (GeV)	14000	500	500	500/1000	500/1000	1400	3000	33,000	100,000
$\int \mathcal{L}dt$ (fb^{-1})	3000	500	1600‡	500/1000	1600/2500‡	1500	+2000	3000	3000
λ	[redacted]	83%	46%	21%	13%	21%	10%	20%	8%

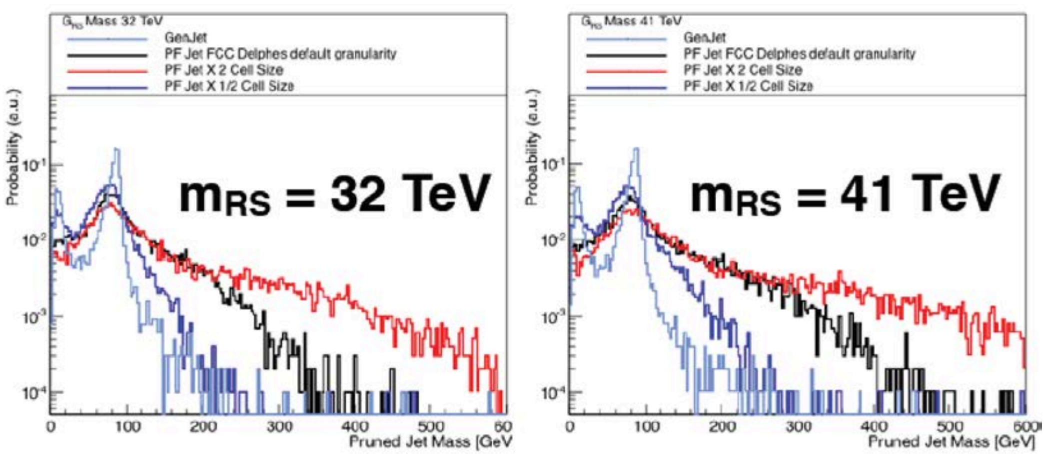
Boosted Objects

Already important at the LHC now!
Will be even more so at a 100 TeV machine !

M.Pierini







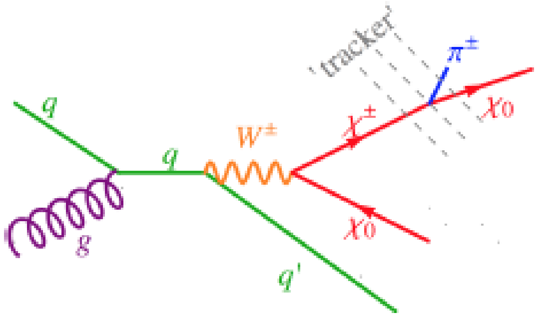
Calorimeter granularity important in optimization for boosted objects

Exotic Particles

Disappearing Tracks - Introduction

$M_{\chi^\pm} - M_{\chi_0} = 165$ MeV $> m_\pi \quad \Rightarrow \quad$ lifetime $\tau \simeq 6\,\mathrm{cm} \simeq 0.2\,\mathrm{ns}$

Almost all $\chi^\pm$s decay to χ_0 + soft pions before reaching detectors



Feng Strassler 1994

Feng Moroi Randall Strassler Su 1999

...

Low Wang 1404.0682

F. Sala

Detector should be ready for exotic particles, eg heavy stable particles, displaced vertices, displaced photons, disappearing tracks, large dE/dx… Use precise timing techniques?

Physics at a 100 TeV Collider

Exploration + Higgs as a tool for discovery

Numerous physics opportunities with a large number of possible measurements. How to specify detectors for such a machine ?

ATLAS and CMS are general purpose detectors that were benchmarked with the 'hypothetical' Higgs in different mass regions with tracking up to η=2.5.

The Higgs is also key benchmark for the FCC detectors, with highly forward boosted features (100TeV, 125GeV Higgs)

As a start consider that FCC detectors must be 'general general' purpose detectors with very large η acceptance and extreme granularity. But keep an eye on more specialized experiments in future.

Overall Approximate Needs

Tracking: Momentum resolution <15% at p_t=10TeV

Precision tracking (momentum spectroscopy) and Ecal up to η=4

Tracking and calorimetry for jets up to η=6.

12 λ_{in} calorimetry, 1-2% constant term.

Calorimeter granularity of 0.05x0.05 or 0.025x0.025 to mitigate pileup and measure jet substructure and boosted objects.

B-tagging, timing for pileup rejection etc. …

Much of detector technology is driven by silicon technology and computing power -> count on significant improvements.
Since the maximum energy and delivered luminosity are the key goals for the FCC-hh machine, the detector efforts should put minimal constraints at the machine efforts.

What do MB events at 100 TeV look like?

14TeV → 100TeV Minimum Bias Events:

Inelastic crossection 14 →100TeV changes from 80 → 105mb.

Multiplicity 14 →100TeV changes from 5.4 → 8 charged particles per rapidity unit.

Average p_T of charged particles 14 → 100 TeV 0.6 →0.8 GeV/c, i.e. bending radius in 4T magnetic field is 50 → 67cm.

Transverse energy increase by about a factor of 2.

→The Min. Bias events at FCC are quite similar to the Min. Bias events at LHC

→Pile up ~ 170 Events/BX in phase 1 ie similar to HL-LHC conditions
→Pile up ~ 1000 Events/BX in phase 2 OR stay at ~170 events for 5 ns bunch spacing

Peter Skands:

See more control plots at http://mcplots.cern.ch

If you don't require precision better than 10%

And if you don't look at very exclusive event details (such as isolating specific regions of phase space or looking at specific identified particles)

Then I believe these guesses are reasonable

σ_{INEL}	σ_{EL}	
~ 80 mb	~ 22 mb	@ 13 TeV
~ 90 mb	~ 25 mb	@ 30 TeV
~ 105 mb	~ 32 mb	@ 100 TeV

Central <N_{ch}> density (INEL>0)
- ~ 1.1 ± 0.1 / $\Delta\eta\Delta\varphi$ @ 13 TeV
- ~ 1.33 ± 0.14 / $\Delta\eta\Delta\varphi$ @ 30 TeV
- ~ 1.8 ± 0.4 / $\Delta\eta\Delta\varphi$ @ 100 TeV

Central <E_T> density (INEL)
- ~ 1.0 ± 0.15 GeV / $\Delta\eta\Delta\varphi$ @ 13 TeV
- ~ 1.3 ± 0.2 GeV / $\Delta\eta\Delta\varphi$ @ 30 TeV
- ~ 2.0 ± 0.4 GeV / $\Delta\eta\Delta\varphi$ @ 100 TeV

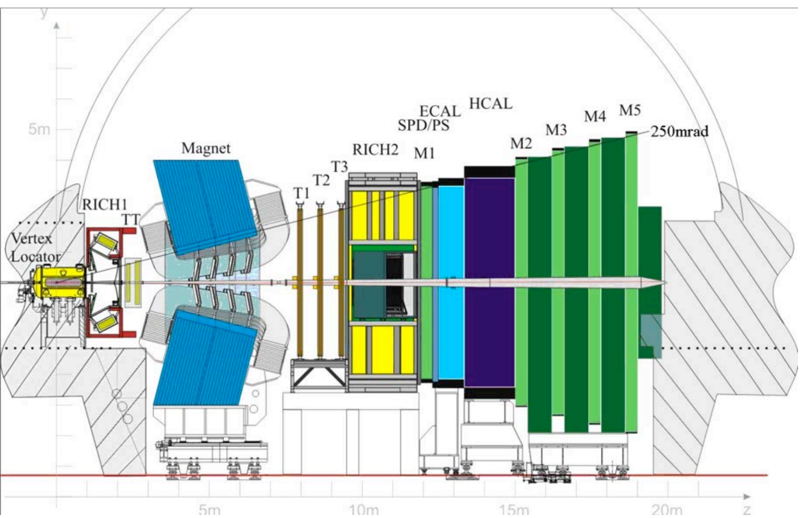
UE TRNS <Σp_T> density (j100)
- ~ 3.3 ± 0.2 / $\Delta\eta\Delta\varphi$ @ 13 TeV
- ~ 3.65 ± 0.25 / $\Delta\eta\Delta\varphi$ @ 30 TeV
- ~ 4.4 ± 0.45 / $\Delta\eta\Delta\varphi$ @ 100 TeV

For tuning, Perugia 2012 (PY6) → Monash 2013 (PY8)

Diffraction could still use more dedicated pheno / tuning studies

Baryon and strangeness spectra in pp still not well understood → color reconnections?

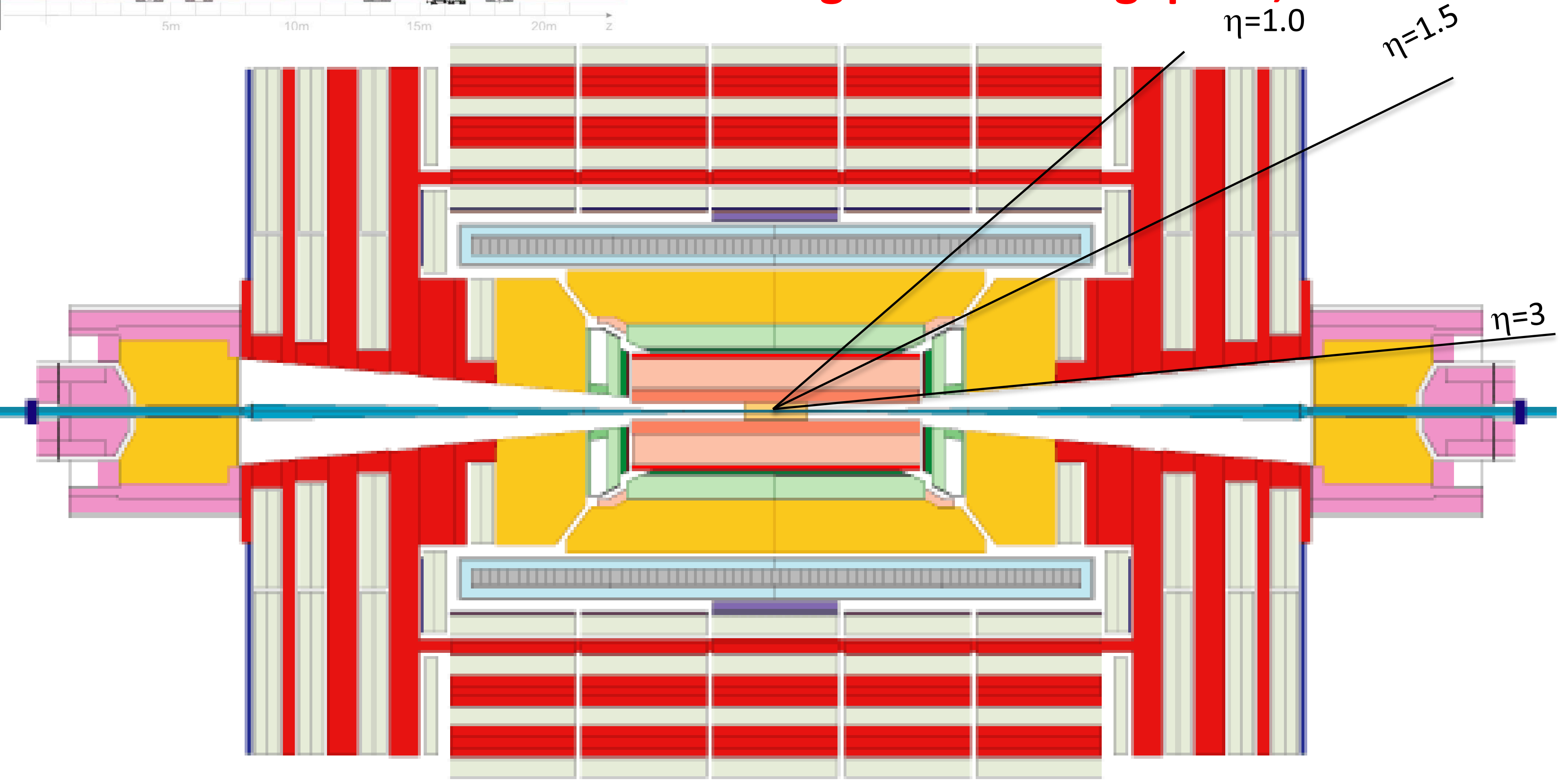
Forward region highly sensitive to PDF choice → what do low-x PDFs mean?



Tracking LHCb η = 2 - 5

… all with impressive performance …

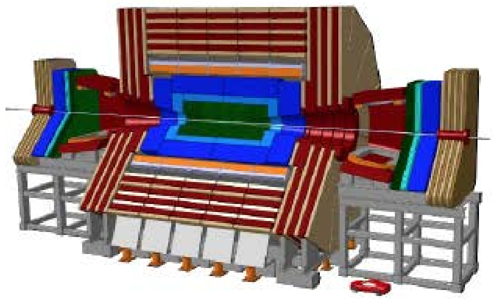
Tracking CMS tracking η -2.5,2.5



Detector Concepts Studied

Added dipoles in the forward region for measurements over a large eta range.

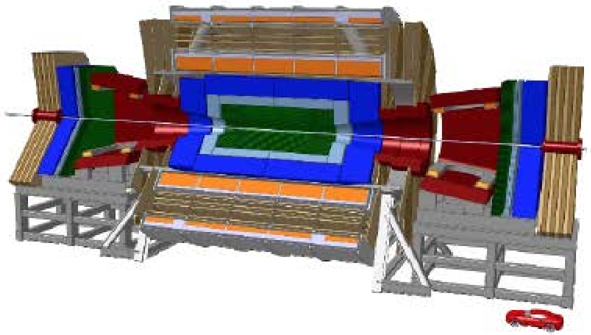
H. Ten Kate et al.



(1) Solenoid with light yoke + Forward Dipoles
"Classic, heavy, low shielding"

Huge mass,
Iron very expensive

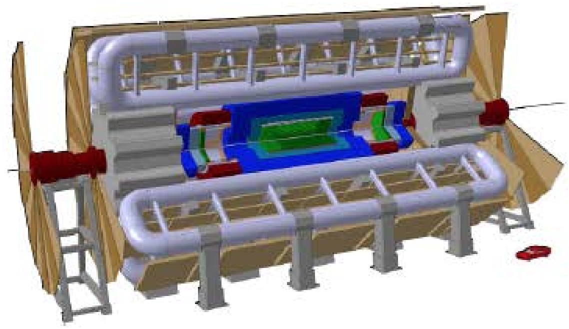
→ Seems not feasible



(2) Twin Solenoid, no yoke + Forward Dipoles
"Innovative, light, good shielding"

Shielding Solenoid, very large system

→ Used as baseline



(3) Solenoid + three toroids + internal Forward Dipoles
"No request for this μ-system"

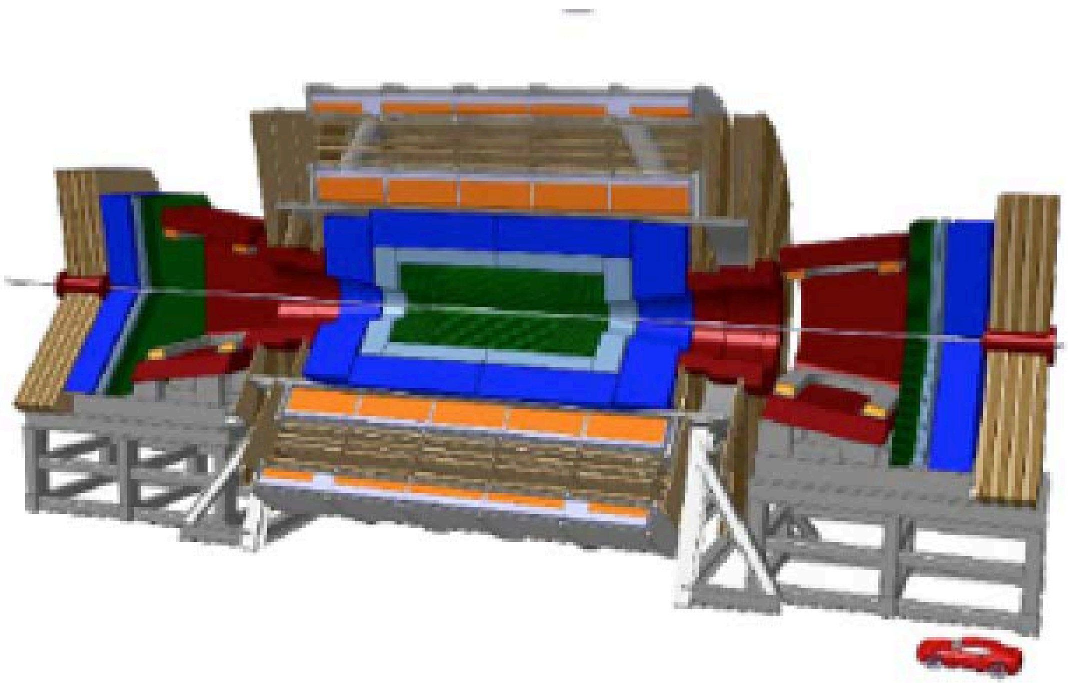
The ATLAS 'standalone' Muon Toroid was motivated by

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

- **→ No real motivation**

Complementary dedicated experiments, eg for flavour, low pT etc) ? To be studies

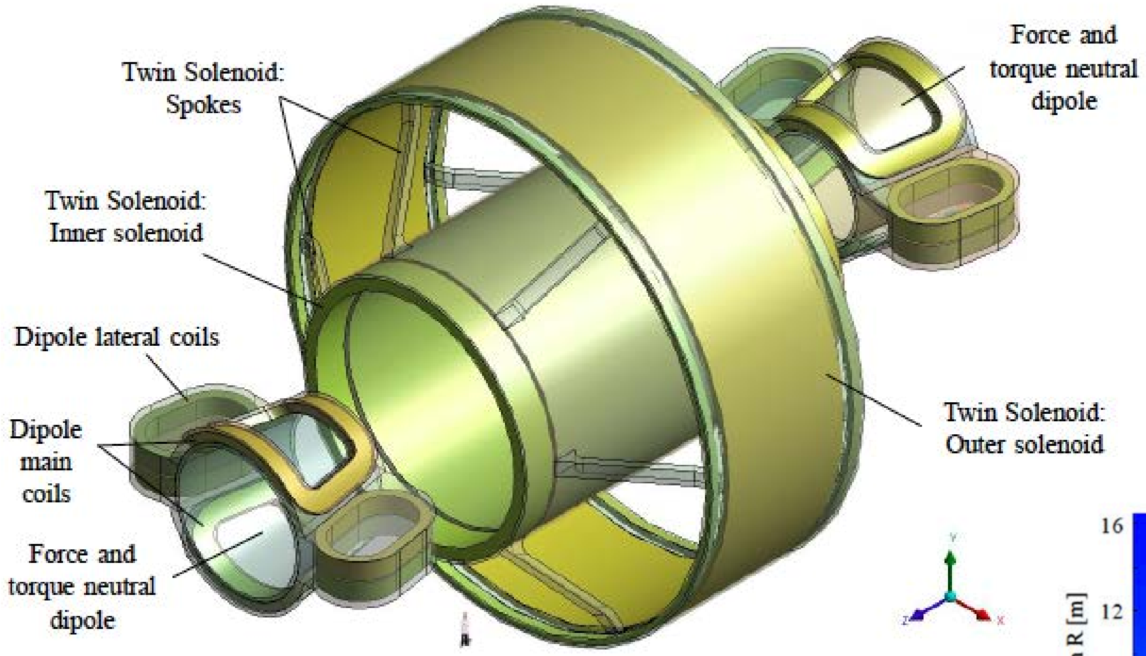
Dimensions…

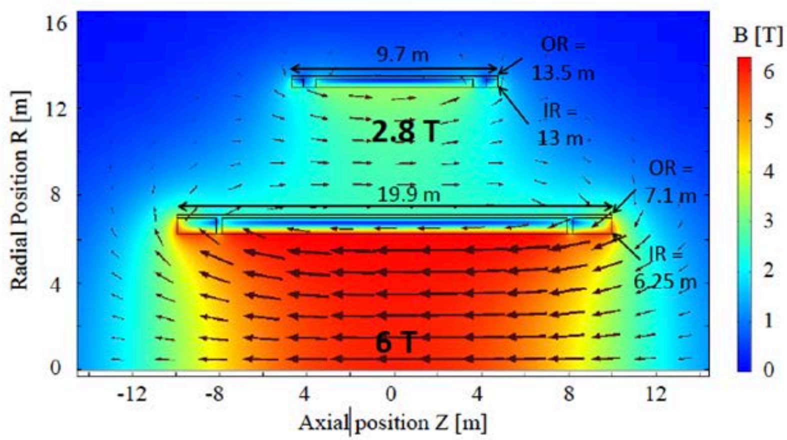


- FCC-hh experiment diameter ~ 1.4 times ATLAS diameter
- FCC-hh experiment height ~ same as the building you are in
- FCC-hh inner solenoid diameter = same inner circle in atrium here! (12m)

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

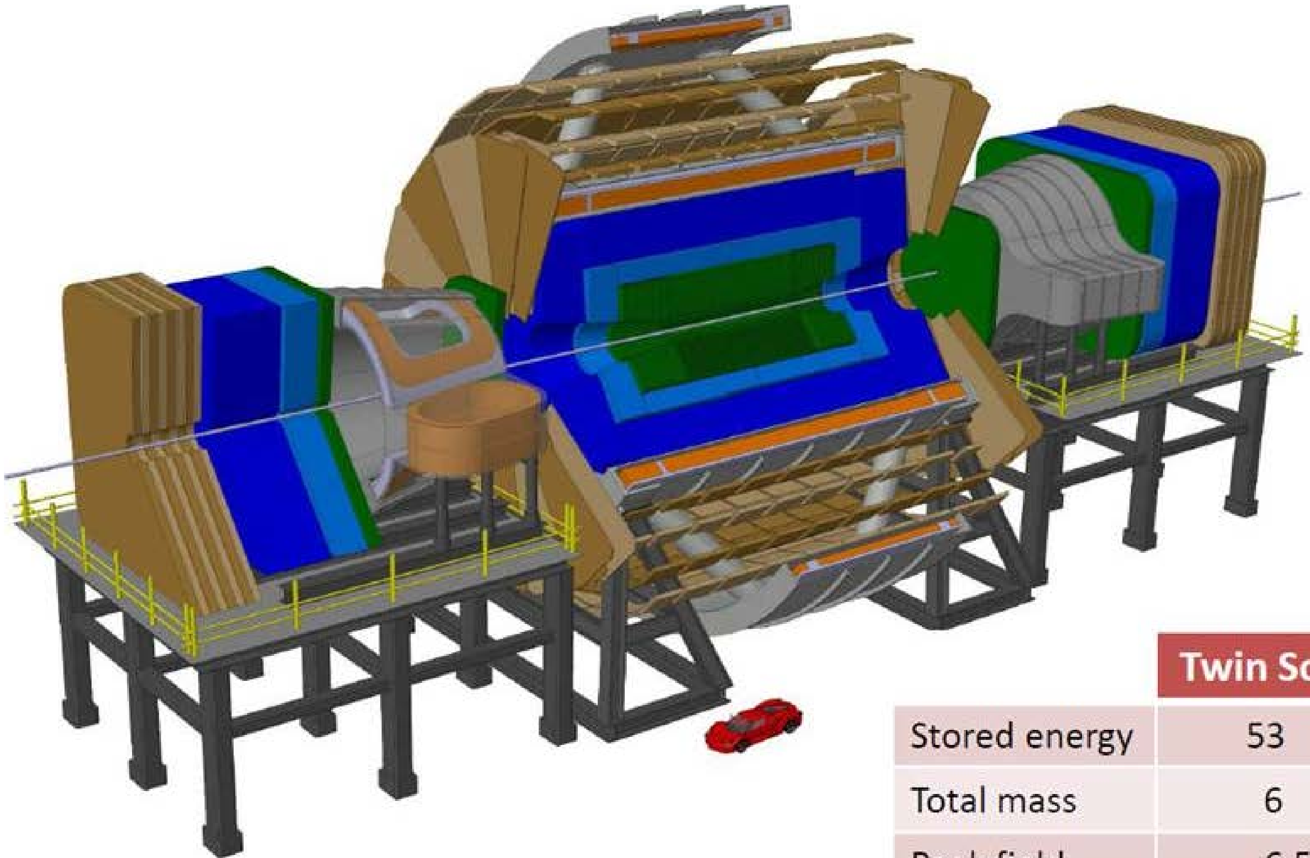




Twin solenoid + Dipole is being engineered in detail.
The two solenoids are connected in series, ie to be considered as a single magnet

Baseline Twin Solenoid + Dipoles

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

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].

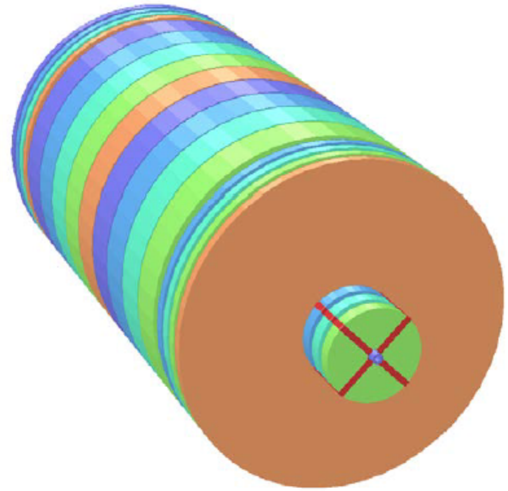
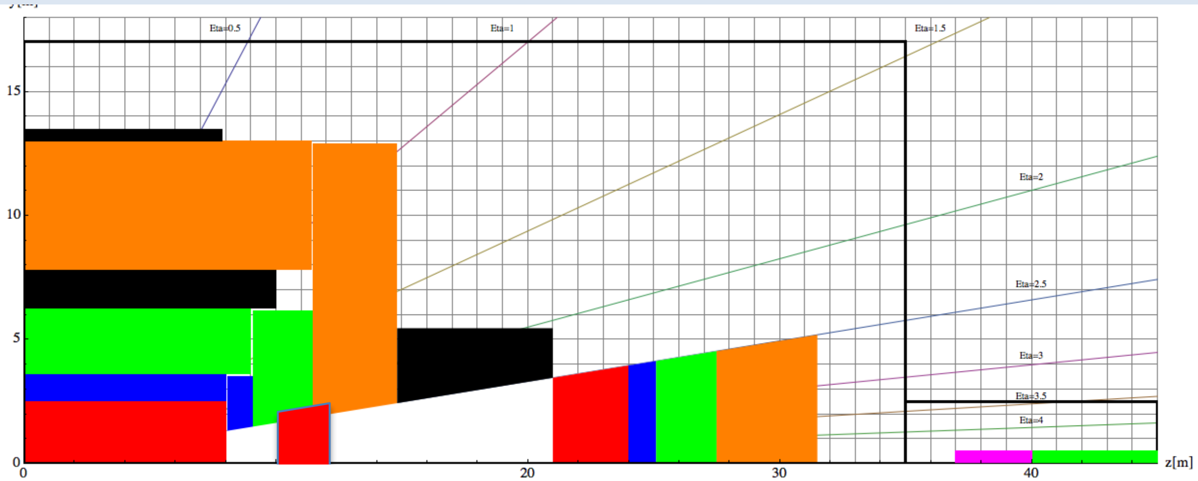


Fig. 1. 3-D model of the FCC-hh detector magnetic system.

Alternative magnet systems with partial passive shielding are being investigated.

Baseline Geometry for 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:

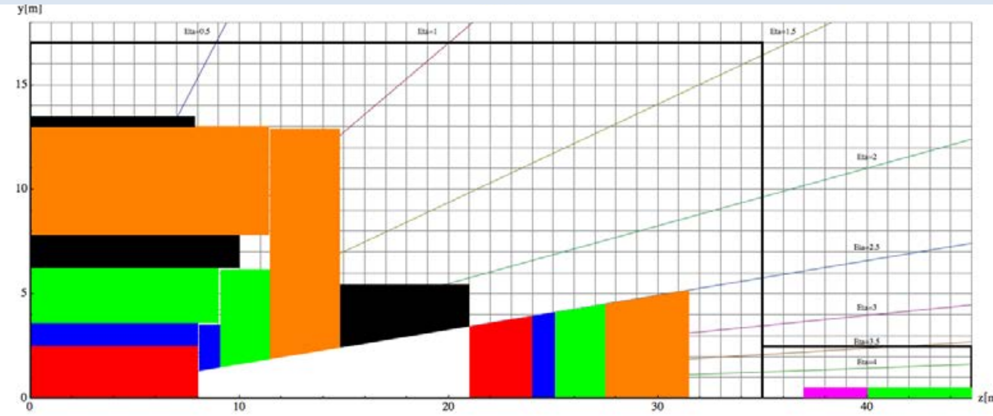
- **EMCAL available space:**
  z=8m to z= 9.1m
  → dz= 1.1m
- **HCAL available space:**
  z= 9.1m to z=11.5m
  → dz=2.4m
- **Muon available space:**
  z= 11.5m to z= 14.8m
  → dz = 3.3m

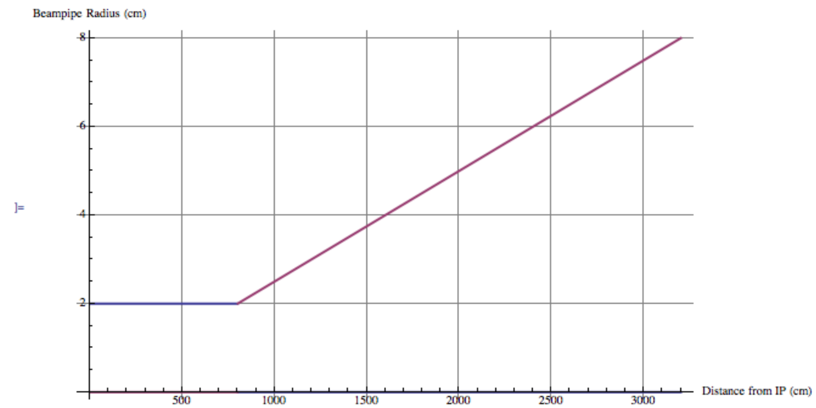
Forward:

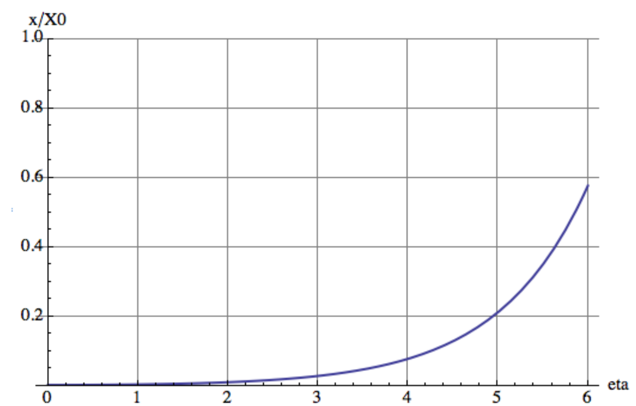
- **Dipole:**
  z= 14.8m to z= 21m → dz=6.2m
- **FTracker available space:**
  z=21m to R=24m, L=3m
- **FEMCAL available space:**
  Z=24m to z= 25.1m → dz= 1.1m
- **FHCAL available space:**
  z= 25.1m to z=27.5m → dz=2.4m
- **FMuon available space:**
  z= 27.5m to z=31.5m → dz=4m

Beampipe

- **Central beampipe: Cylinder**
  Beryllium R_{in} =2cm, R_{out}=2.1cm
  From z=0 to z=800cm
- **Forward beampipe: Cone**
  Beryllium 1mm wall thickness
  Projective cone (inner envelope) along 2.5mRad
  From z=800cm to z=32000cm
  Radius at 32m: 8cm
- **From z=3200 to 3230cm – cone to go from R=8cm to R=1cm-2cm (matching TAS), Aluminum**
  Between 3230cm and TAS – keep cylindrical beampipe, Aluminum
- **Cylindrical shield around this beampipe will be necessary.**
  Still to be checked with FCC aperture requirements !!



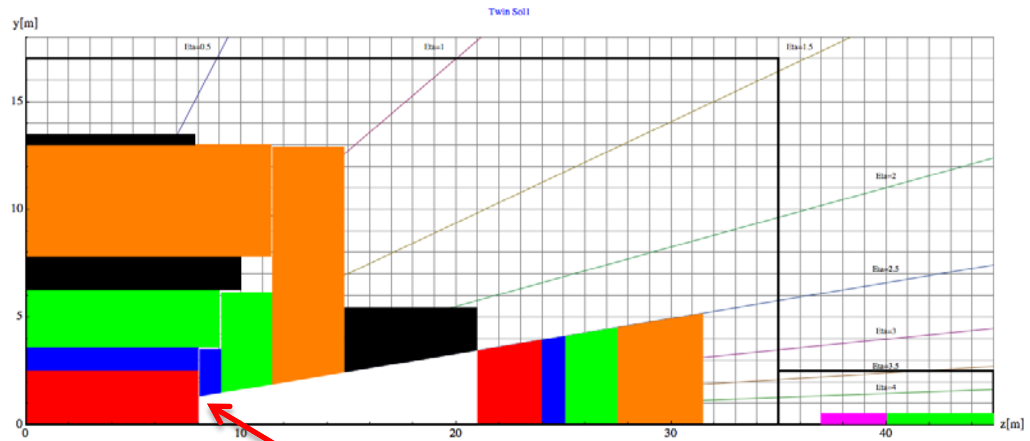




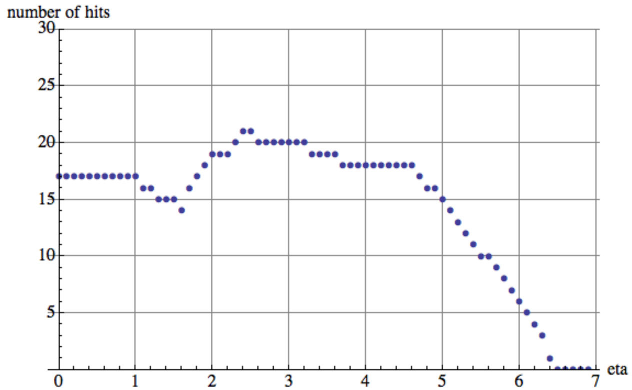
Central Tracker

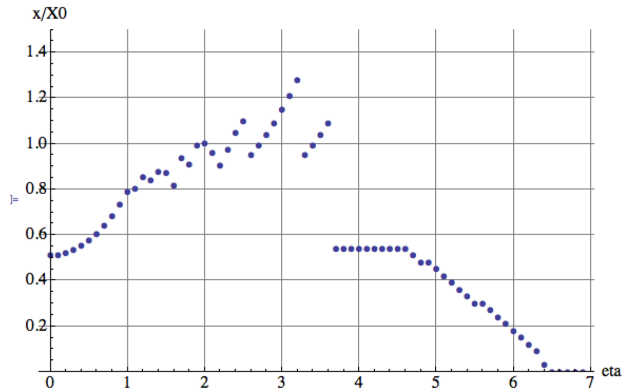
Material composition in Volume (%):
Si 20%, C 42%, Cu 2%, Al 6%, Plastic 30%
X_0 of this mix: 14.37cm

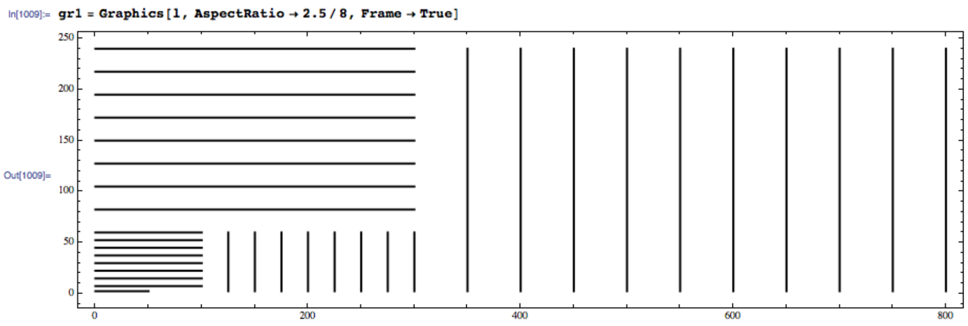
We assume 3% of radiation length per layer, i.e. each layer has a thickness of 0.43cm.



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

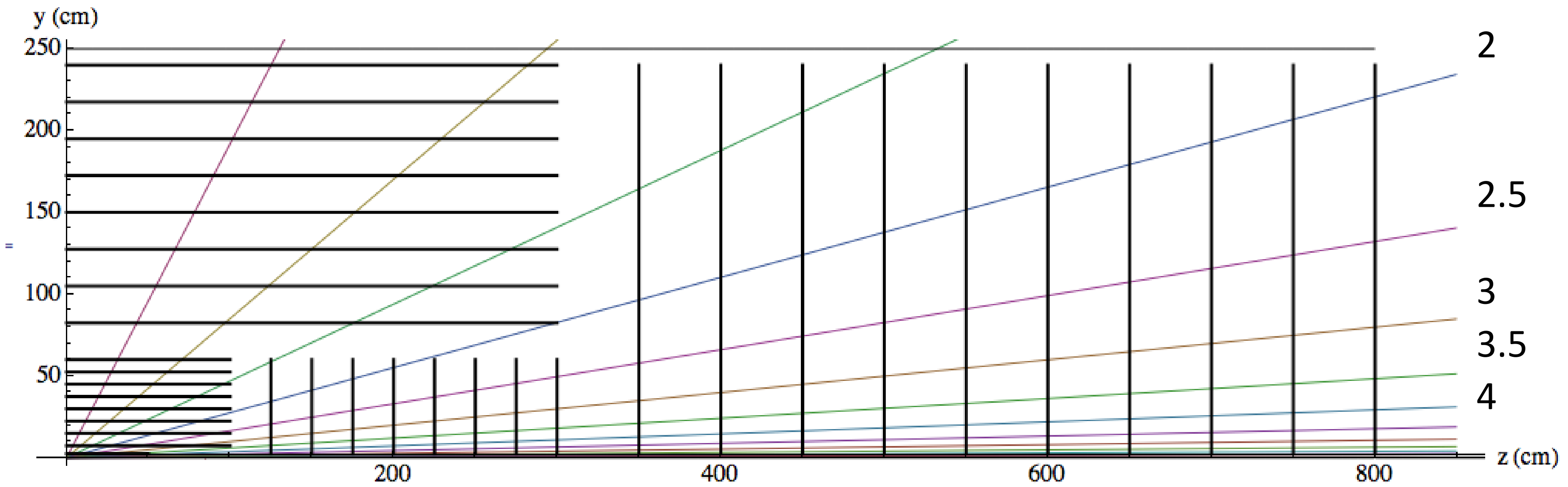




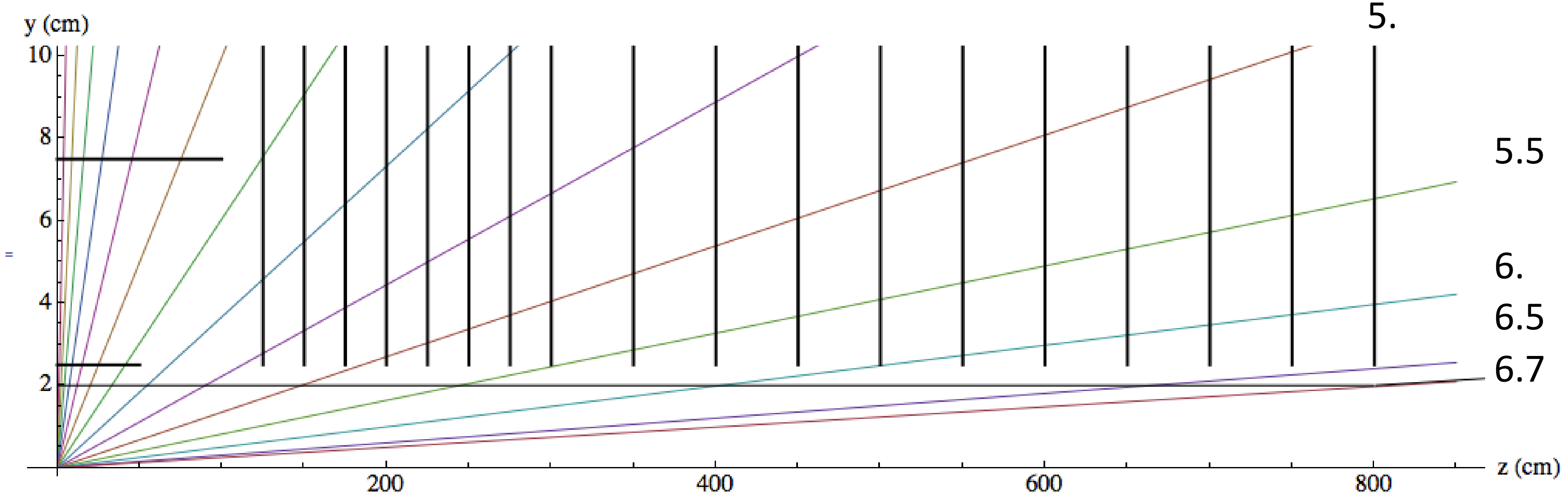


Silicon tracker inspired by the CMS upgrade studies
Details see http://fcc-tklayout.web.cern.ch/fcc-tklayout/index4.html

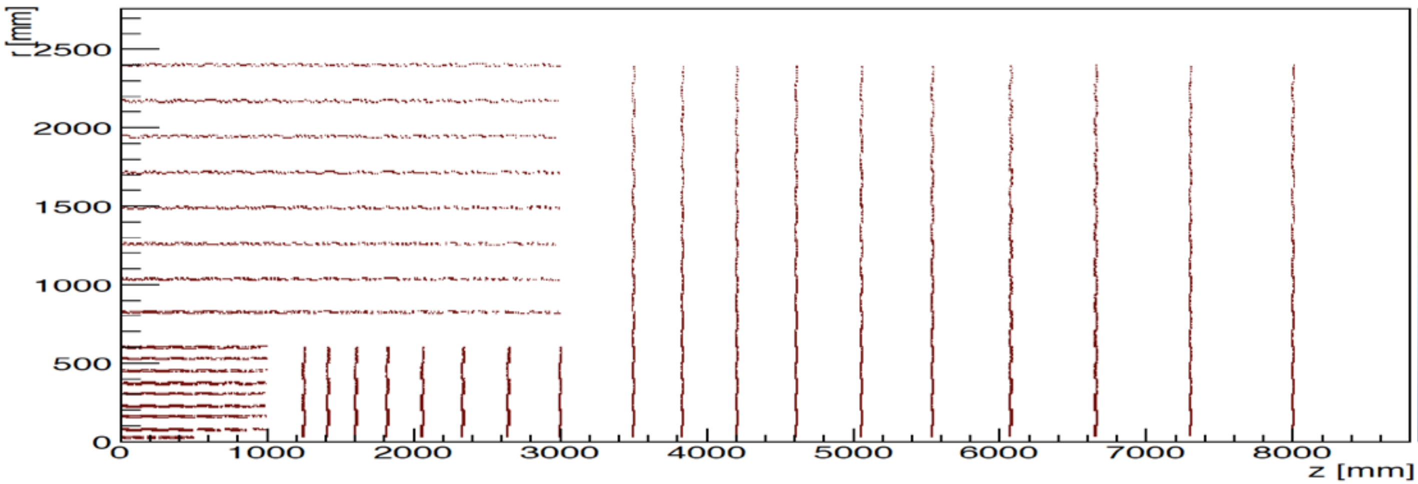
Central Tracker Geometry

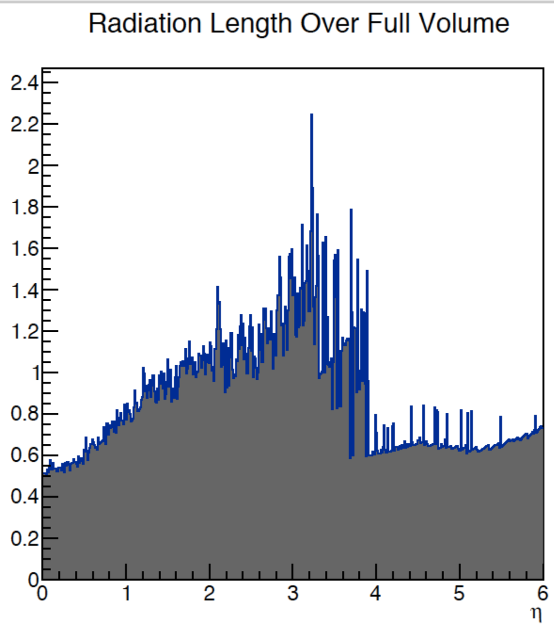


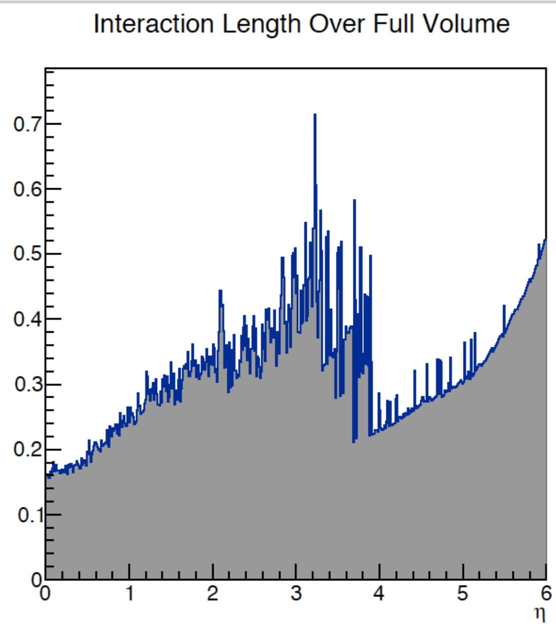

```
Show[pl1, gr1, pl0, plbeampipe, PlotRange → {{0, 850}, {0, 10}}, AspectRatio → 250 / 850]
```



Central Tracker







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

Lots of room for future optimization, technology studies etc

Design: careful with the services

http://fcc-tklayout.web.cern.ch/fcc-tklayout/FCChh_Option2/errorsTRK.html

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%).

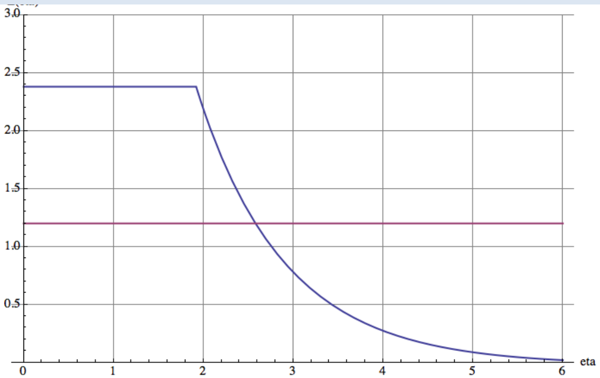
How to scale the system and keep the performance constant ?

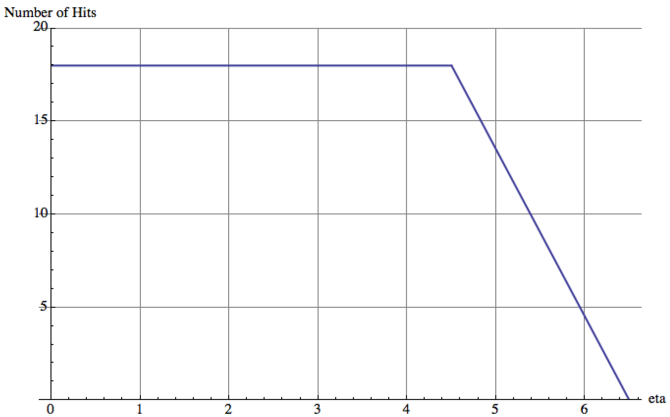
At constant B and 1/2 the tracker radius we need:
4 times the tracker resolution (20um → 5um) and
4 times less material budget (x/X_0=50% at eta=0 to x/X_0=12.5% at eta=0 i.e. 3% →0.75% per layer)

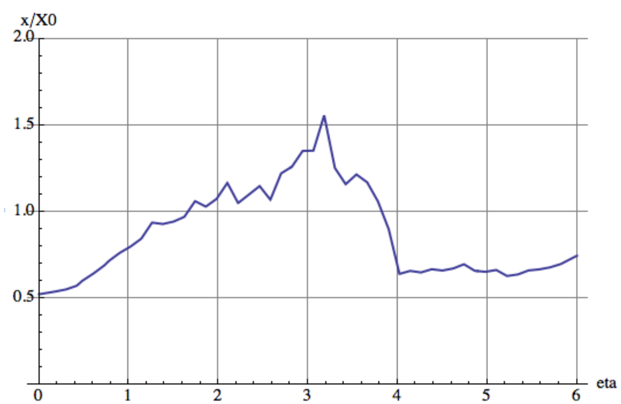
These values are challenging but not out of reach.
Tracker instead of diam=4.8m & length=16m reduced to half of that !

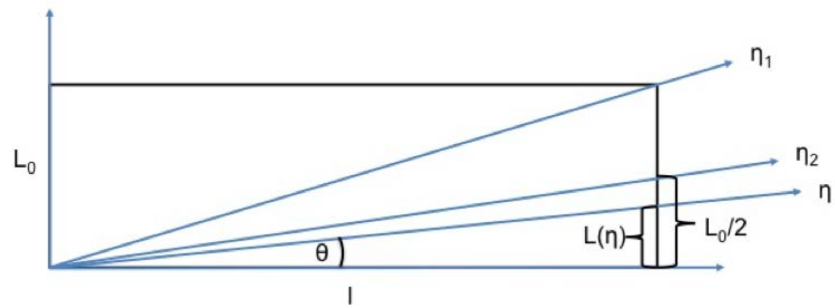
→ A final choice is part of an optimization that depends on future technologies
→ We will have to show 'cost scaling' models in the 2018 report.

Track resolution Simplified Formulae









$$\eta_1 = -\ln\tan\left(\frac{1}{2}\arctan\frac{L_0}{l}\right) \qquad \eta_2 = -\ln\tan\left(\frac{1}{2}\arctan\frac{L_0}{2l}\right)$$

For a geometry with $L_0 = 2.4m$ and $l = 8m$ we have $\eta_1 = 1.9$ and $\eta_2 = 2.6$

$$L(\eta) = L_0 \quad \eta < \eta_1 \qquad\qquad L(\eta) = L_0\frac{\sinh\eta_1}{\sinh\eta} \quad \eta > \eta_1$$

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

$$\frac{\Delta p_T}{p_T} = \sqrt{\left(\frac{\Delta p_T}{p_T}\Big|_{reso.}\right)^2 + \left(\frac{\Delta p_T}{p_T}\Big|_{m.s.}\right)^2}$$

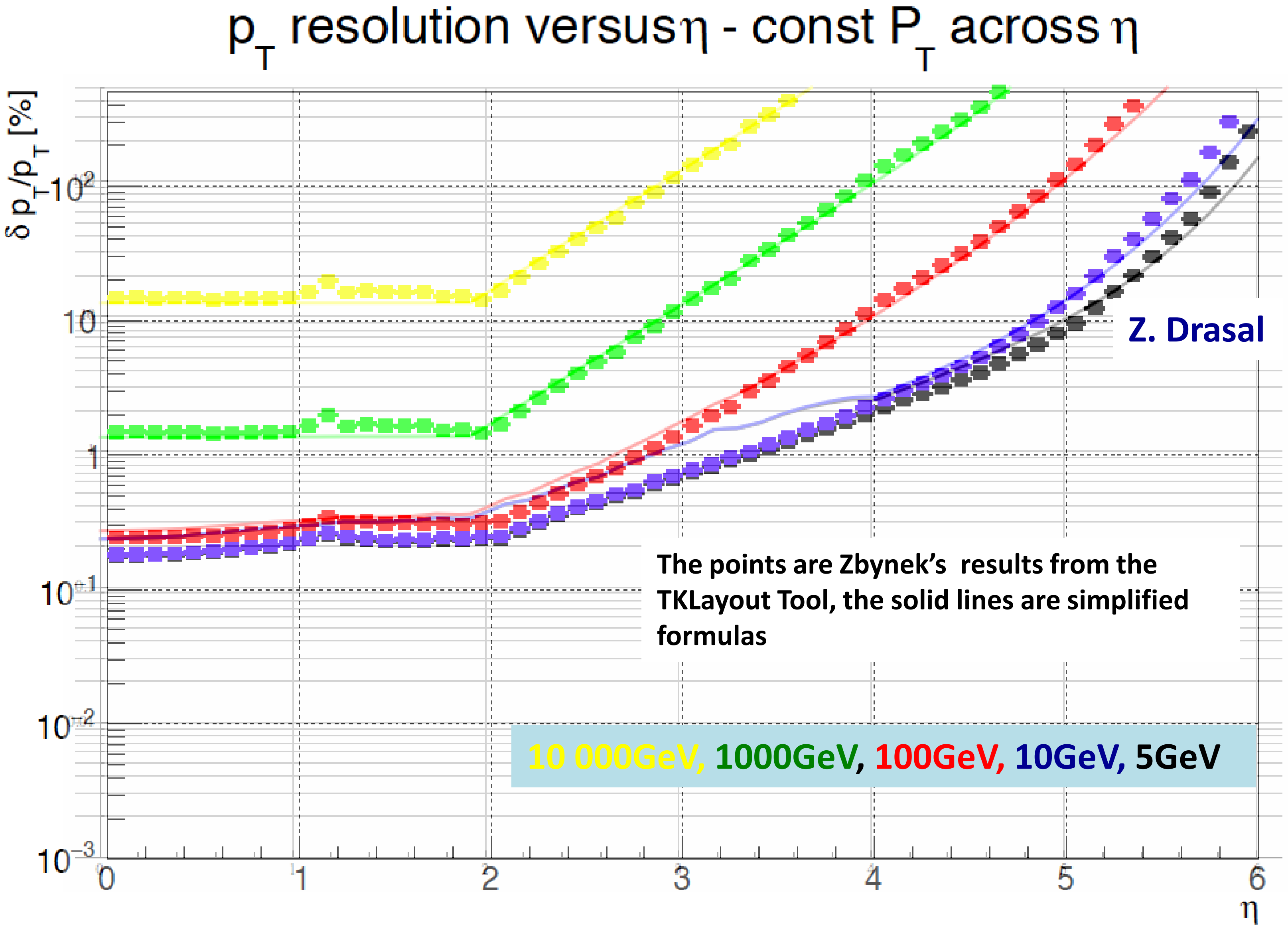
```
In[60]:= L0 = 2.4;

In[61]:= l = 8;

In[62]:= B = 6;

In[63]:= sig = 23 * 10 ^ (-6);
```

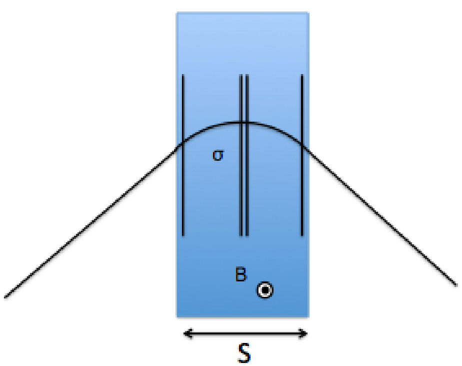
Track Resolution

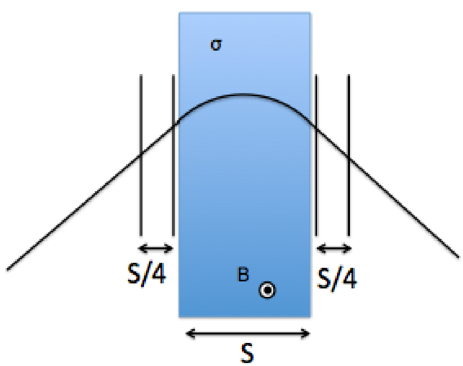


Note: 10% at 10TeV from large BL^2 and 0.3% at low momenta due to large BL !!

Forwards Tracking

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 Tracking Resolution

$$\left(\frac{\Delta p_T}{p_T}\right)^2 = \left(\frac{2\sigma\, p_T}{\tan\theta 0.3L\ \int B_T dl}\right)^2 + \left(\frac{0.0136}{0.3\int B_T dl}\sqrt{2\frac{x_f}{X_0}}\right)^2 + \left(\frac{0.0136}{p_T\cos\theta}\sqrt{\frac{x_t}{X_0}\frac{1}{\sin\theta}}\right)^2$$

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

σ=30μm
Int Bdl=10 Tm
L=2m

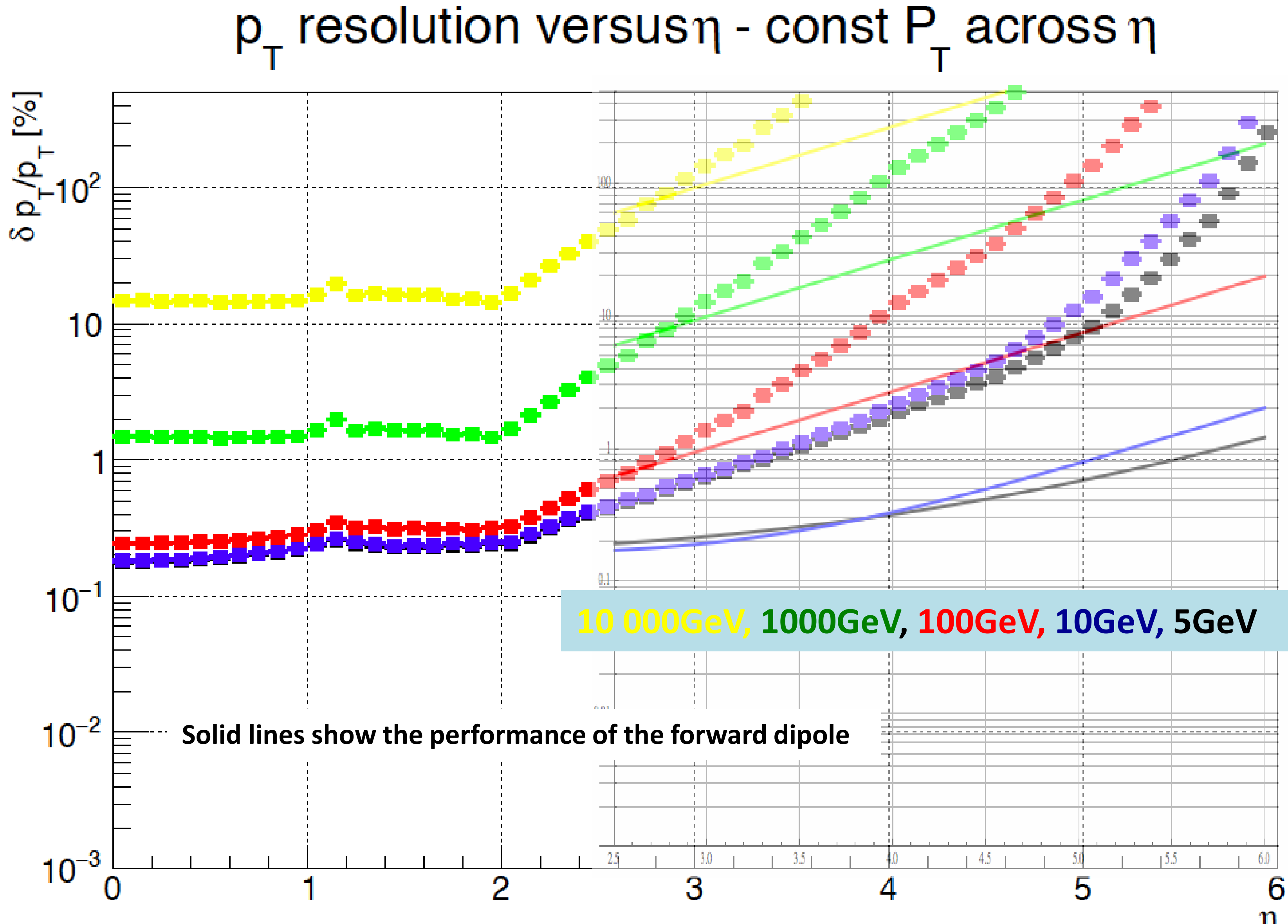
X_f/X_0=0.06
Int Bdl=10 Tm

X_t/X_0=0.03

Using $L = 2\,\mathrm{m}$, $\sigma = 30\,\mu\mathrm{m}$, $x_f/X_0 = 0.06$, $x_t/X_0 = 0.03$

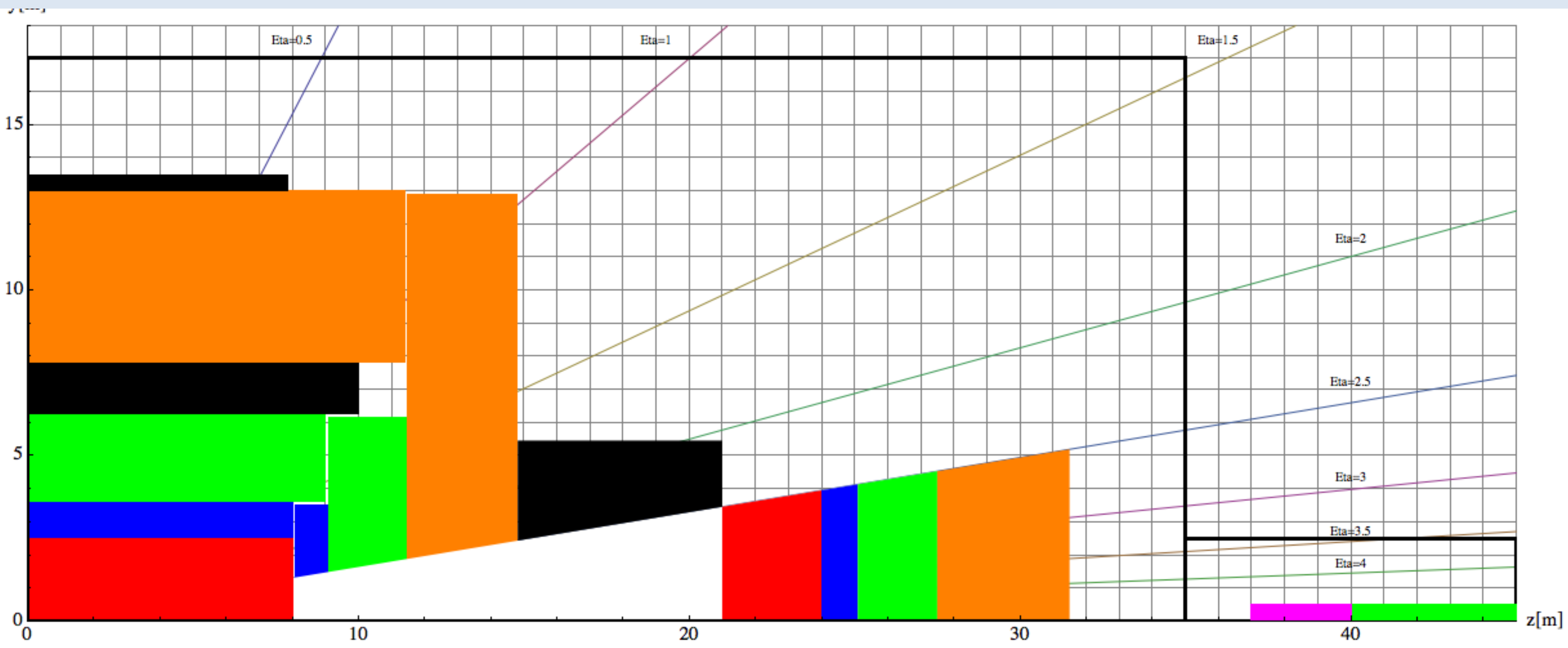
$$\frac{\Delta p_T}{p_T} = 10^{-3}\sqrt{1.5^2 + (10^{-2} p_T \sinh\eta)^2 + \left(2.4\frac{\coth\eta}{p_T}\sqrt{\cosh\eta}\right)^2}$$

Forward Tracker Resolution



The spectrometer performance of the dipole takes over at eta=2.5-3, exactly where the acceptance starts

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

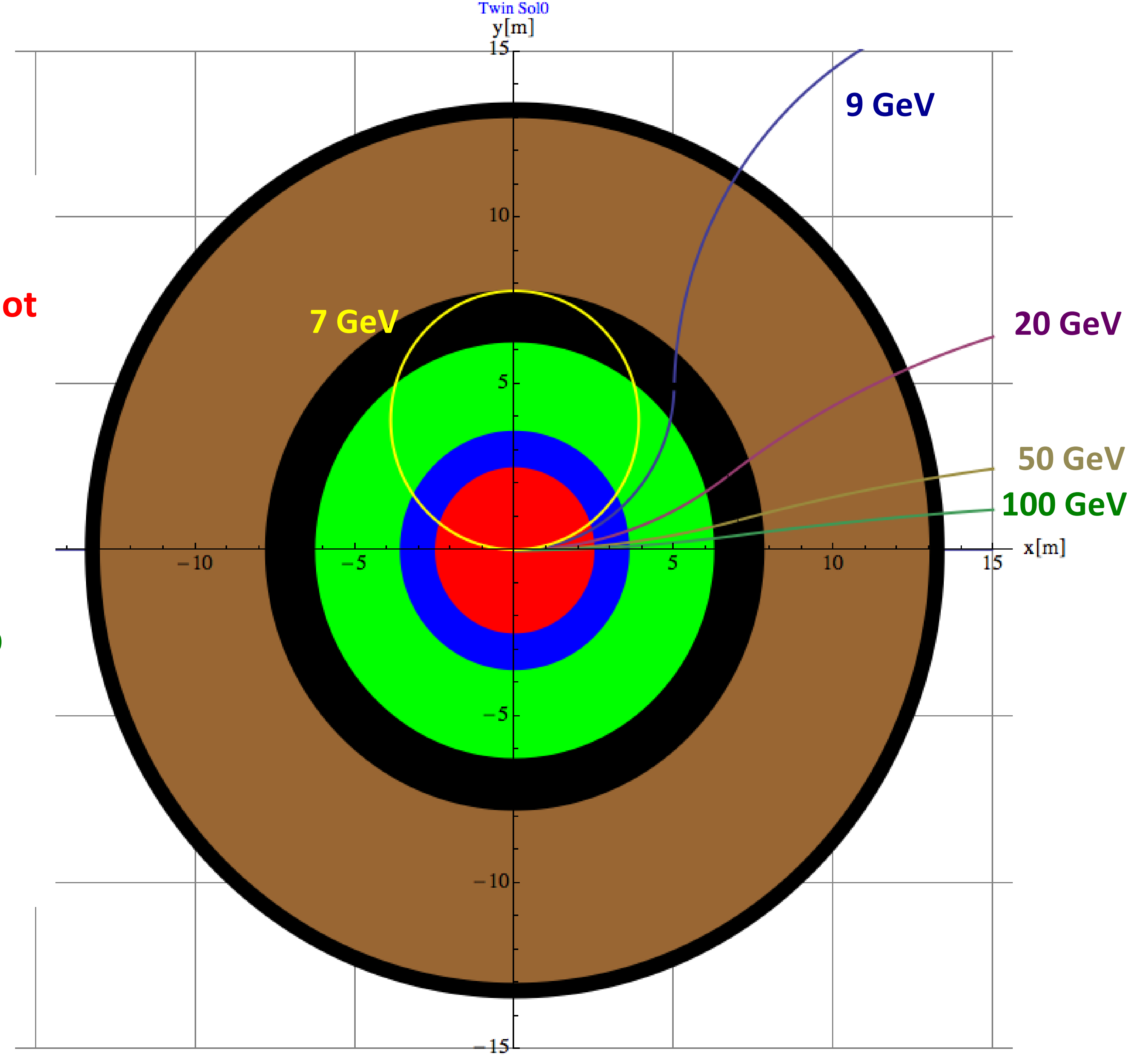
Energy resolutions are ~ ATLAS ones

HCAL simulation studies have been made
ECAL simulation studies starting
Much room for new ideas!

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 a high granularity calorimeter.



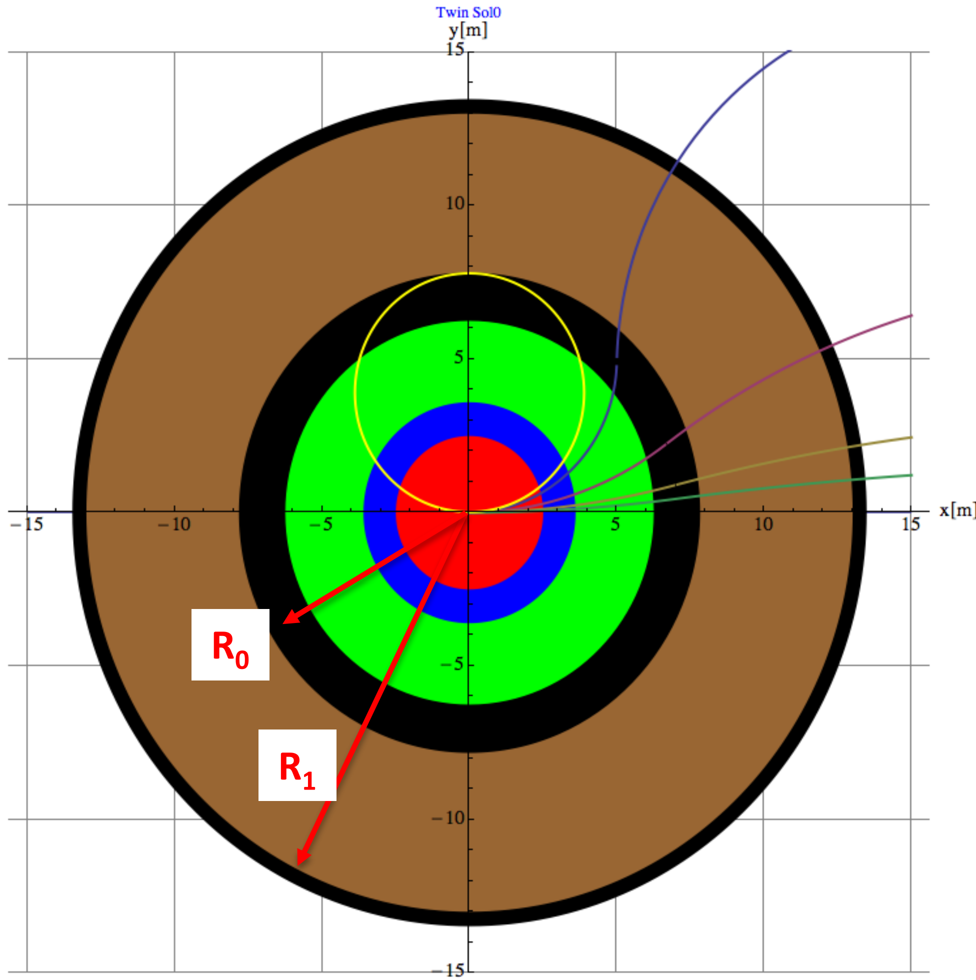
Muon Momentum can be measured by

1) The inner tracker → resolution plots from before

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

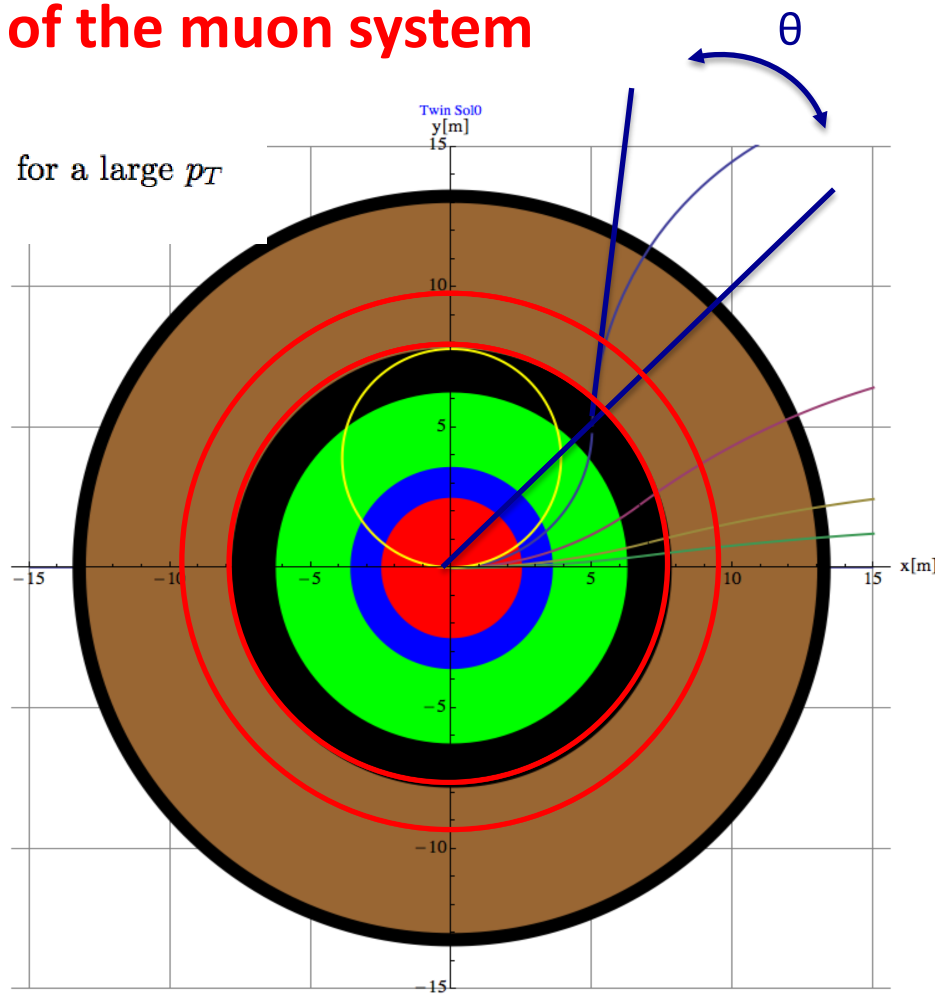
3) A sagitta measurement in the muon system (no iron → precise !)

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



2) Track angle at the entrance of the muon system

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



10% at 10TeV, B_0=6T, R_0=6m
$\Delta\theta$=50µRad
→ 2 stations at 1.5m distance with 50um position resolution

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

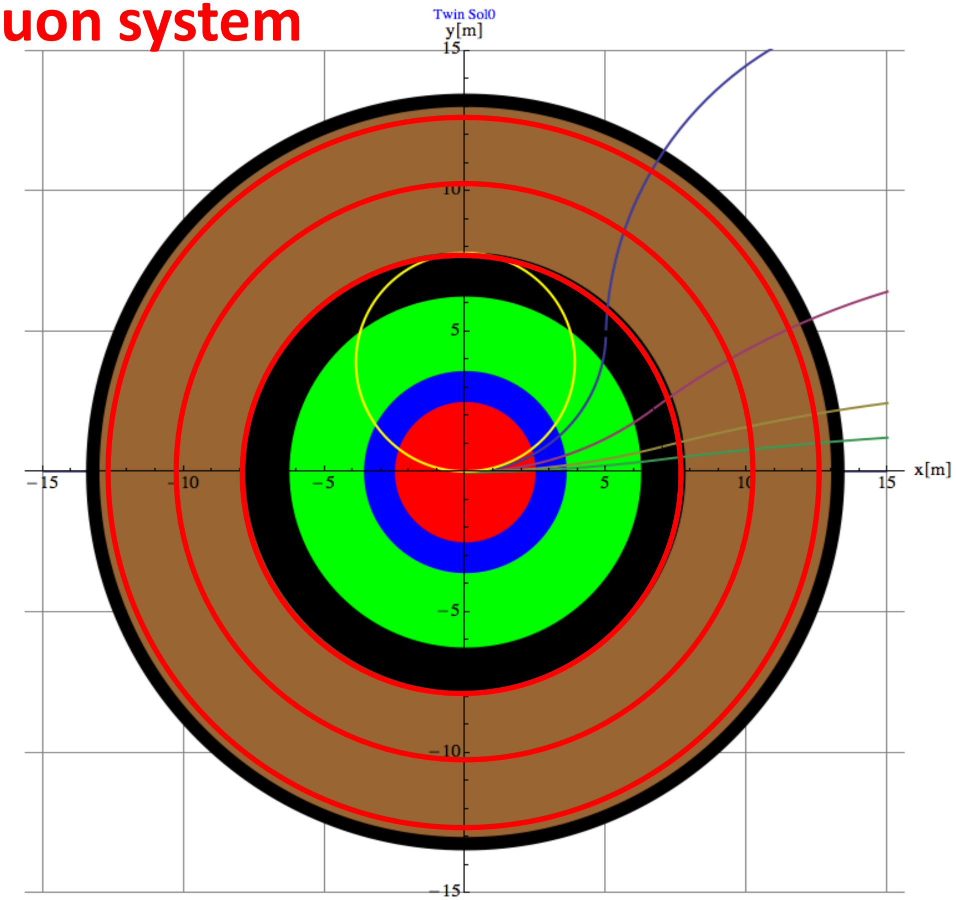
Calorimeter+Cryostat: 35X_0
HCAL: 110X_0Coil: 5X_0→ x_{tot}/X_0 ≈150

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

B_0=6T, R_0=6m →dp/p=3% !!!
(CMS 9% because B_0R_0=1/3)

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.

Combined Measurement

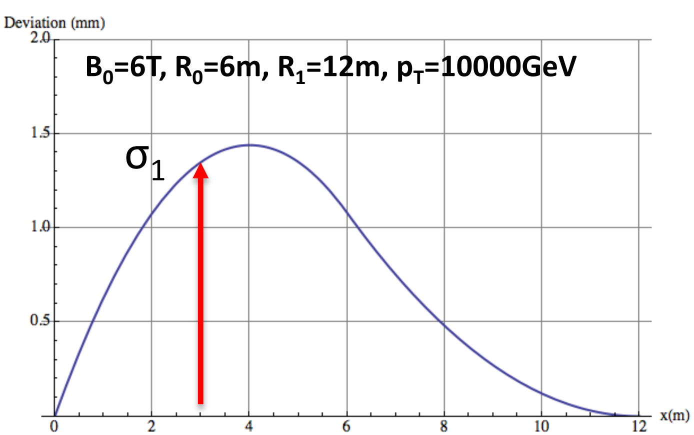
If the full flux is returned trough the muon system, the muon trajectory at the exit of the system points exactly to the IP !

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

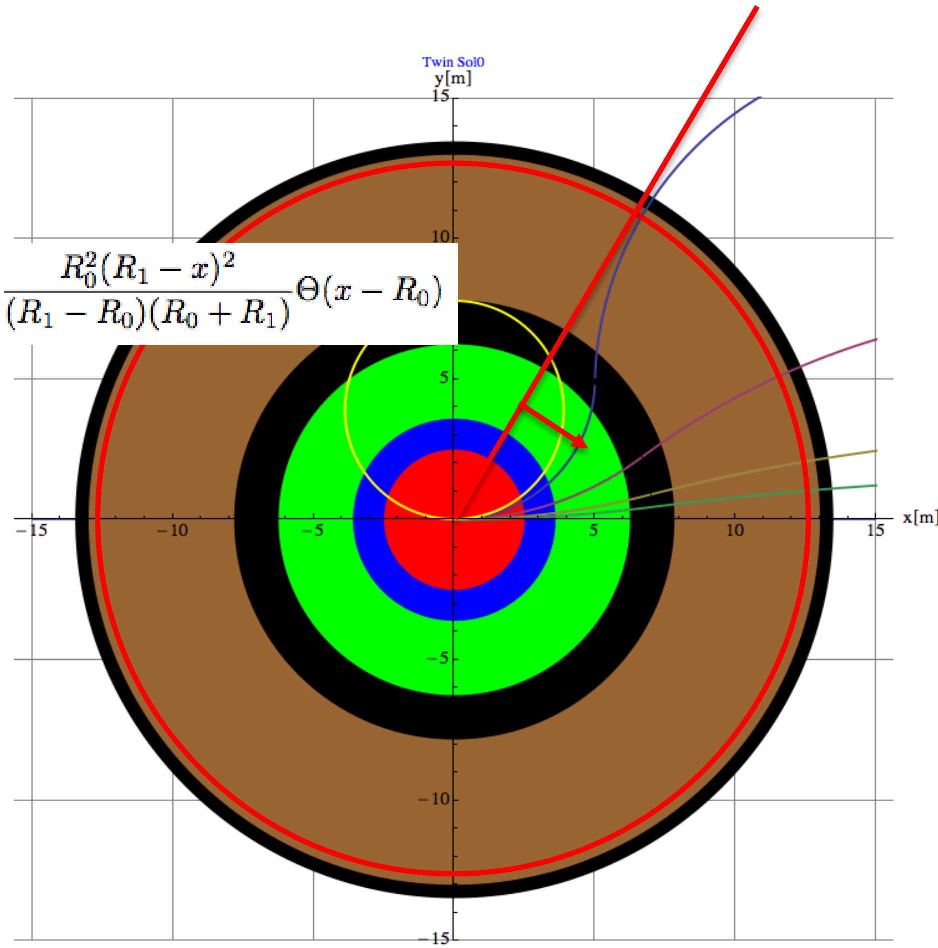
The maximum excursion $y_t(x_0)$ is always at

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

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 !



σ2



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

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).

Hardware Trigger ?

CMS HL-LHC results in 200TByte/s into the online system for a “triggerless readout”. For 2022 this is considered too difficult.

Assuming that the total track rate for 100TeV pp collisions (Phase I) is only a factor 2 larger, one could anticipate that by 2035 and FCC-hh detector can be read out in a triggerless fashion.

IE in 2035 maybe no hardware trigger necessary ! All data to the online system, synchronous or asynchronous, where a sophisticated selection and compression can be done.

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 Phase-II, the amount of copper lines to get all the signals out of the silicon detector would destroy the tracker performance.

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

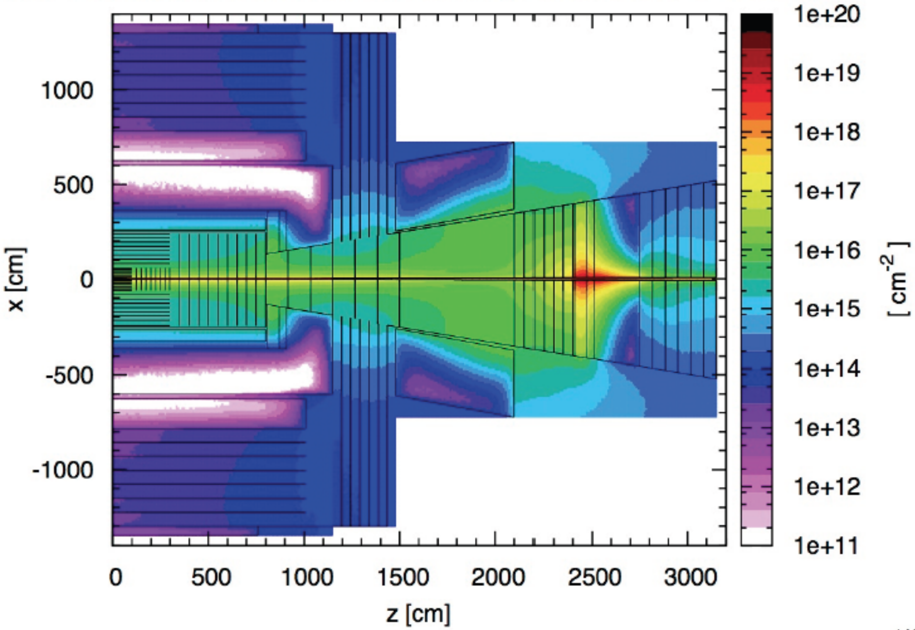
Estimate for radiation load of first Pixel Layer at r=2.5cm:

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

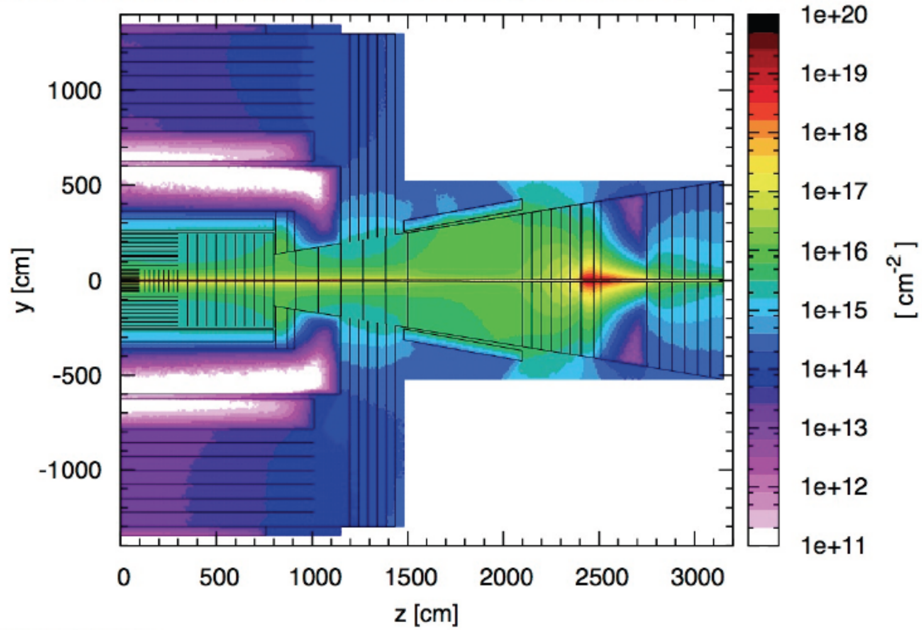
→ With safety factors we go into the 10^{18}/cm^2 and GGy range !

1 MeV Neutron Equivalent Fluence

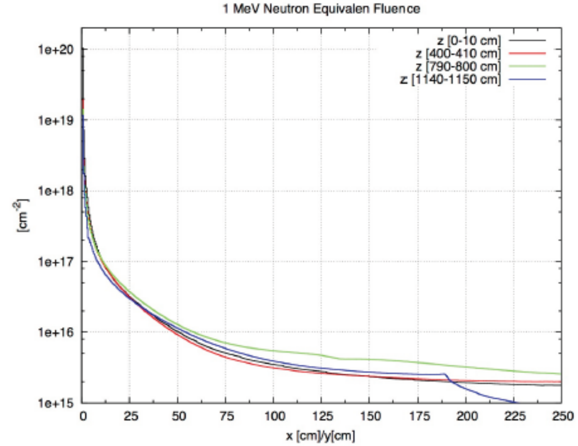
1 MeV Neutron Equivalent Fluence after an integrated luminosity of 30 ab^{-1}, y=0



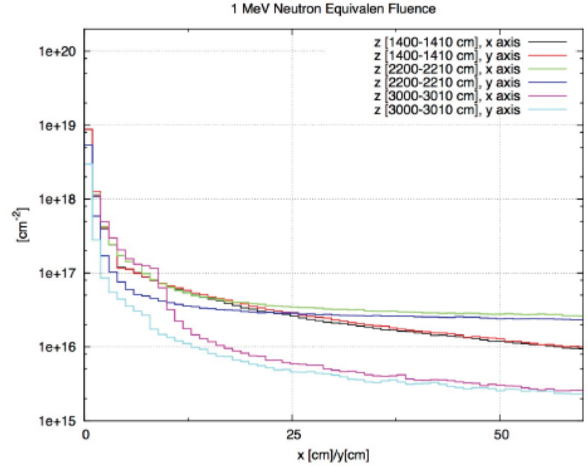
1 MeV Neutron Equivalent Fluence after an integrated luminosity of 30 ab^{-1}, x=0



1 MeV Neutron Equivalen Fluence

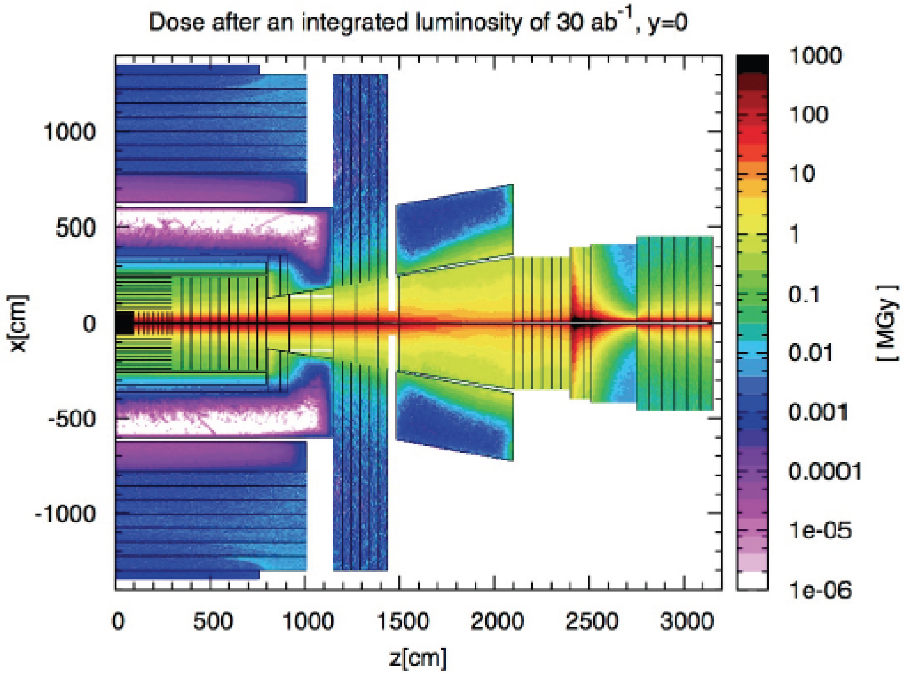


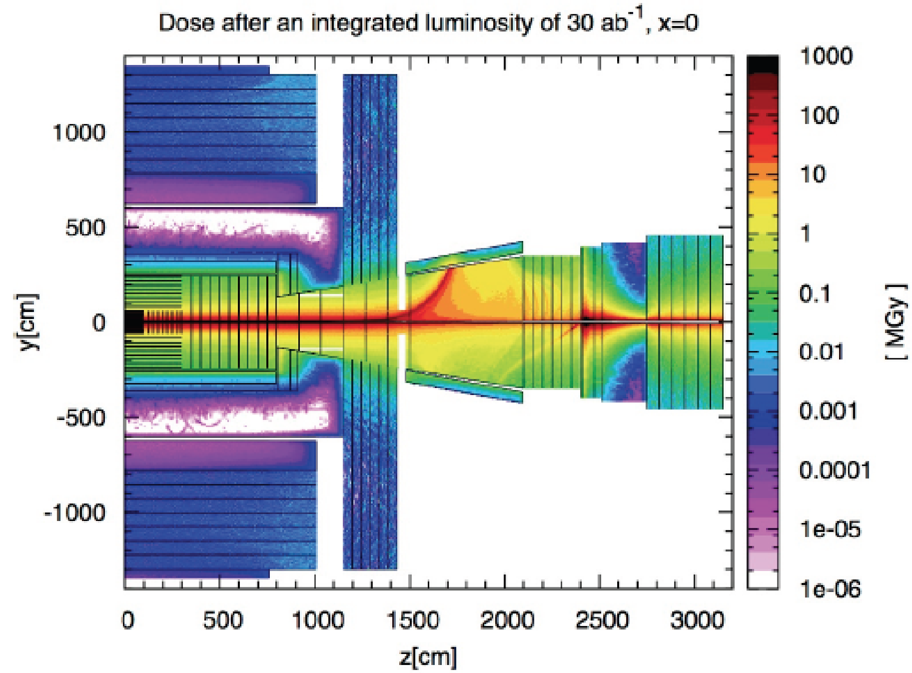
1 MeV Neutron Equivalen Fluence

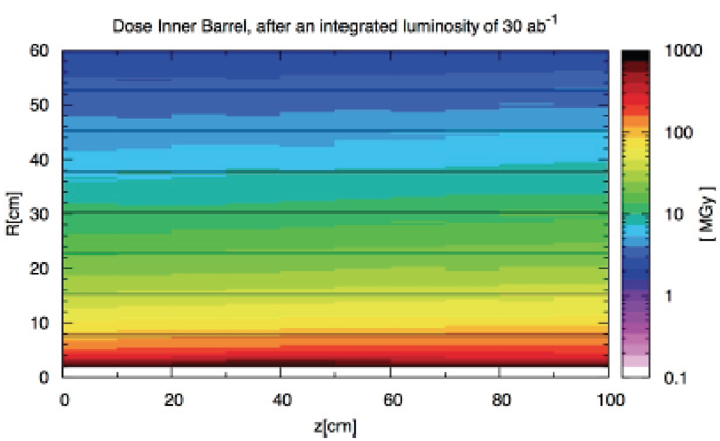


Different radial binning!

Dose







	Dose [MGy]
First layer of the IB (R =2.5 cm)	600
max in forward detector	10^4
max in barrel muon chambers	10^{-2}
max in end-cap muon chambers	10^{-1}

Summary

Studies of detectors for the FCC-hh new energy frontier in full swing.

A conceptual design report is planned for 2018.

Basic concepts for detectors at these future colliders are being worked on. A baseline detector has been defined and included in fast simulation DELPHES: Benchmark process studies starting!

Silicon sensors will play a key role in these future detectors, for tracking and probably also for High Granularity Calorimetry.

Areas of needed detector R&D emerging (eg radhard thin silicon)

Brand new tracker & calorimeter concepts ?! Precise timing (4D)?

Lots of room for blue sky thinking!

FCC-hh Meetings

FCC hadron detector meetings, leading up to the next FCC week in Rome (April 11-15, 2016).

Jan. 21, 2016
Mar. 03, 2016
Apr. 06, 2016

Thursday, 21 January 2016	
14:00 - 14:30	FCC week organization, detector geometry update *30'* Speaker: Werner Riegler (CERN)
14:30 - 15:00	Software status and next steps *30'* Speakers: Clement Helsens (CERN), Benedikt Hegner (CERN)
15:00 - 15:20	Integration of tracking software *20'* Speaker: Julia Hrdinka (Vienna University of Technology (AT))
15:20 - 15:40	Tracker data rates *20'* Speaker: Zbynek Drasal (CERN)
15:40 - 16:00	Update on radiation studies *20'* Speaker: Maria Ilaria Besana (CERN)

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

e-mail-list:
fcc-experiments-hadron@cern.ch

→Join, subscribe and follow !

→Contact Werner Riegler (Werner.Riegler@cern.ch)

Backup