Preliminary considerations about general purpose….

Detectors for ~100 TeV p-p collisions

F.Gianotti, A.Henriques, H.TenKate,
L.Pontecorvo, DF
and informally many other colleagues

Presented by D.Fournier, LAL-Université Paris-Sud & CNRS

Driving requirements

(1) Discovery of « high-mass » phenomena at the « Lσ »limit

- From « Drell-Yan » Limit m(Z') ~ 30 TeV

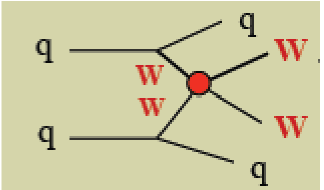
Z'→$\mu\mu$: muon spectrometer (resolution,acceptance)

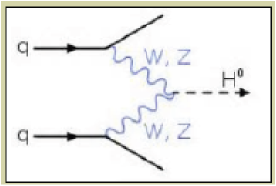
Z'→ee : EMcal (thickness, resolution-constant term- ,dynamic range,..)

- From QCD: q* Limit m(q*) ~ 50 TeV
  - -jet resolution, linearity
- -SUSY
  - -complex signatures ETmiss, jets, leptons, taus,...
- -Many other scenarios (monopoles,...) not to be forgotten

(2) Study of VV scattering by « VBF mechanism »

- **Is H playing its role?**





- **Are there « high mass » resonances in 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 pT
need to be triggered, identified, precisely measured
- Boosted jets ? To supply leptonic final states

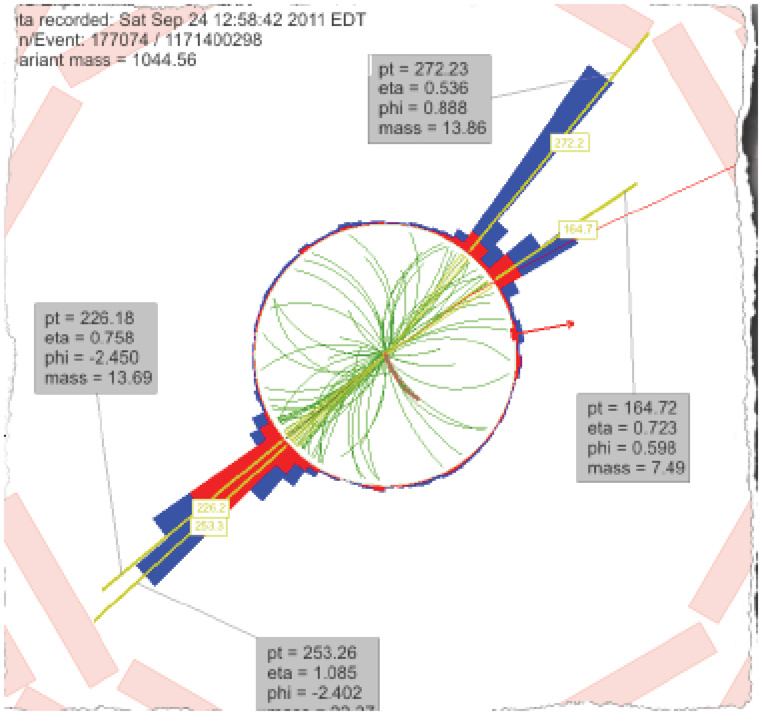
(3) Boosted Jets (M.Pierini –see talk on friday)

- Recognizing if a high-PT jet is a QCD jet (quark,gluon) or a W or a Z or a H would greatly enhance the physics potential (WW-scat, New resonances,.)
- With PT of ~1 TeV pileup should not be the isssue…
- Part of ILC/CLIC program ; some trials in CMS : JME 13-006, EXO-12-021,..

For FCC-100 TeV

- Simulated RS->VV
- Jet pruning
- Discriminating variables:
  - -jet mass
  - -SubJettiness
- Very preliminary results,..Ongoing effort

Detector Aspects:
-is the « track-only » sub-structure good-enough?
-Can Particle-Flow work (at and above ~1 TeV)?
(require high granularity calorimeter)



CMS VV_jet candidate

(4) More on the Higgs Boson(s)

- As many decay modes as possible

  -γγ, Zγ : EMcal resolution & acceptance

  -ZZ* →4l : acceptance , particle ID

  -WW→llνν :acceptance, ETmiss

  -ττ , bb :high performance tracking, secondary vertices

  -μμ :luminosity, acceptance

- As many production modes as possible

  ggF,

  WH,ZH :large boost,

  VBF : forward jet tagging (again)

  ttH : complex final state

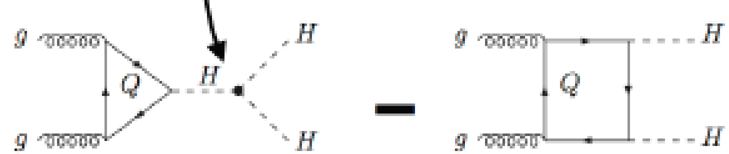
Examples:
ttH : x 60 (from LHC 14)
HH : x 42

- Di-Higgs production: HE machines like 100TeV pp are « the places» where to measure λ

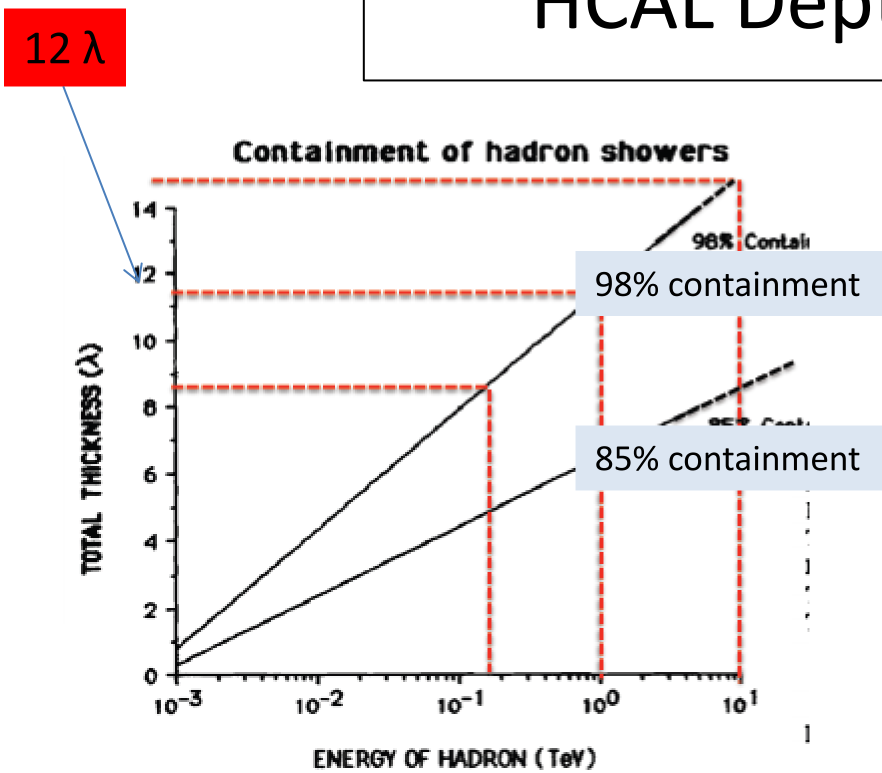
  promising final states: bbγγ , bbττ,.

$$M_H^2 = \lambda v^2$$

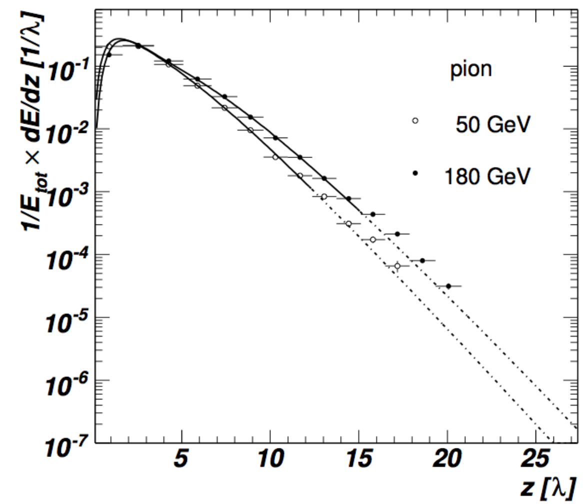
$$g_{hhh} \equiv 3\lambda v = \frac{3M_H^2}{v}$$



HCAL Depth and Material



Data “Tile cal” 90 deg/beam)



- SSC study confirmed by TileCal measurements (up to 20λ)
  - -A 20TeV jet has 1→several 1 TeV hadrons
  - -require ~98% containment of 1 TeV hadrons

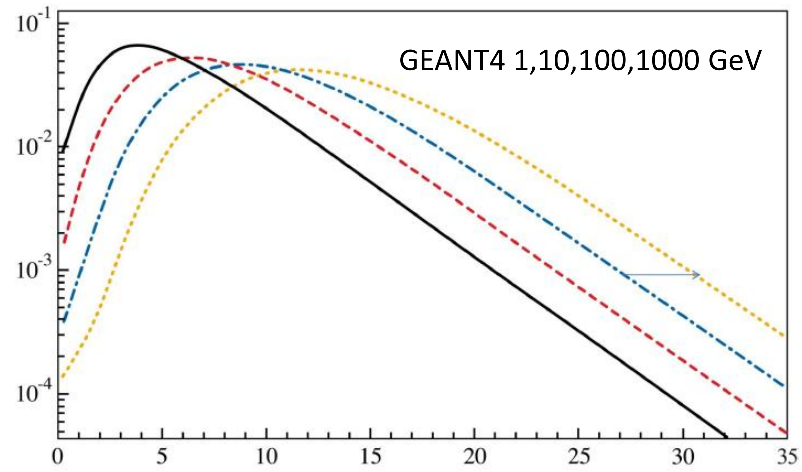
“Common understanding”
10 λ at LHC→12λ at 100 TeV
(including ~1λ EM in front)

<u>Material: </u>high Z better for “ compensation”, and takes less space (W in particular)

- requires integrating “slow neutrons” over ~50ns → not practical for Had machine
- Higher Eloss per λ for muons
- > 12 λ (iron) → calorimeter thickness of ~300 cm (incl. Scint or equivalent)

ECAL

- Depth: + ~$3X_0$ for x 10 in energy
  -CMS   crystals: 25 X_0
  -ATLAS LAr (segmented in depth) 23-29 X_0



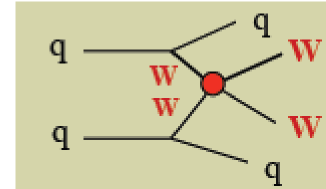
- Dynamical range
  -16 bits at LHC→19 bits
  (can be mitigated by high segmentation)
  (max electron energy 3 TeV→~20 TeV)

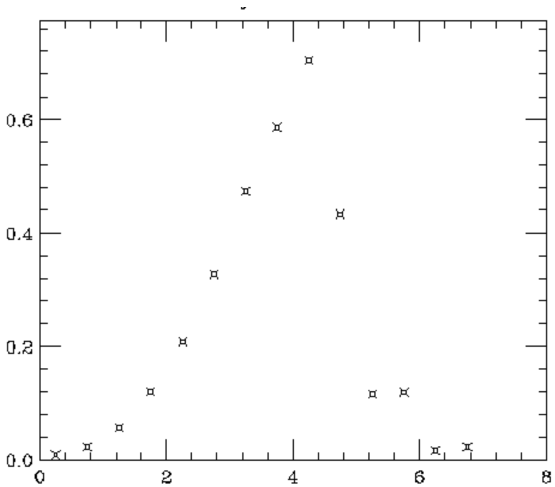
- Resolution
  -measuring H→γγ will remain an essential requirement
  -in the ~60 GeV ET range need to be as good as ATLAS/CMS

- Speed of response
  -25ns bc → Crystals, LAr OK
  -5 ns ??

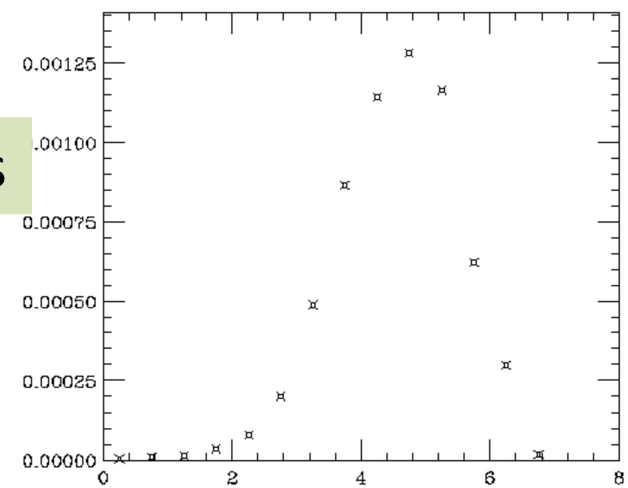
- Particle flow? High segmentation desirable
  In general not so good for constant term…

VBF jets acceptance





Max η of forward jets



WW by VBF M_{WW}>1 TeV

HH by VBF M_{HH} > 1 TeV

VBF measurement up to eta=6 desirable (means coverage beyond 6…)

ETmiss ?? No investigation so far

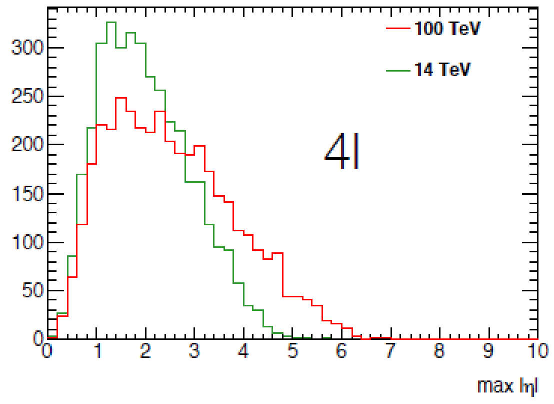
To gain 1 η unit, an EC calo of fixed Inner Radius needs to be moved 2.7 times further away from the collision point (from ~5m in present expts to ~15m)

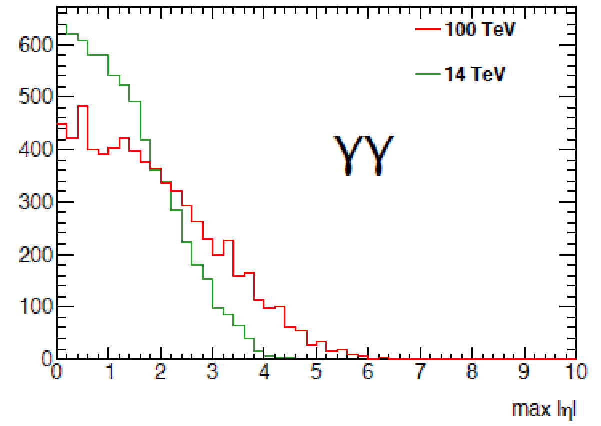
High density(W) desirable –inner part at least- to limit transverse size of particle showers

Fast response mandatory. 5ns bc would be an asset if detector speed can follow…

Lepton/photon acceptance from Higgs decay (H.M.Gray)

ggF





		|η| < 2.5	|η| < 4	|η| < 5
ll	100 TeV	0.56	0.88	0.97
	14 TeV	0.74	0.99	0.99
YY	100 TeV	0.74	0.95	0.99
	14 TeV	0.90	1	1

η=2.5
↓
η>4

4lep

	Inclusive		Higgs p_T > 100 GeV		Higgs p_T > 150 GeV	
	2.5	4	2.5	4	2.5	4
ggF	0.56	0.88	0.64	0.93	0.70	0.95
WH	0.45	0.77	0.53	0.84	0.54	0.87
ZH	0.48	0.81	0.53	0.85	0.58	0.88
ttH	0.56	0.90	0.59	0.92	0.63	0.95
VBF	0.55	0.87	0.61	0.93	0.67	0.95

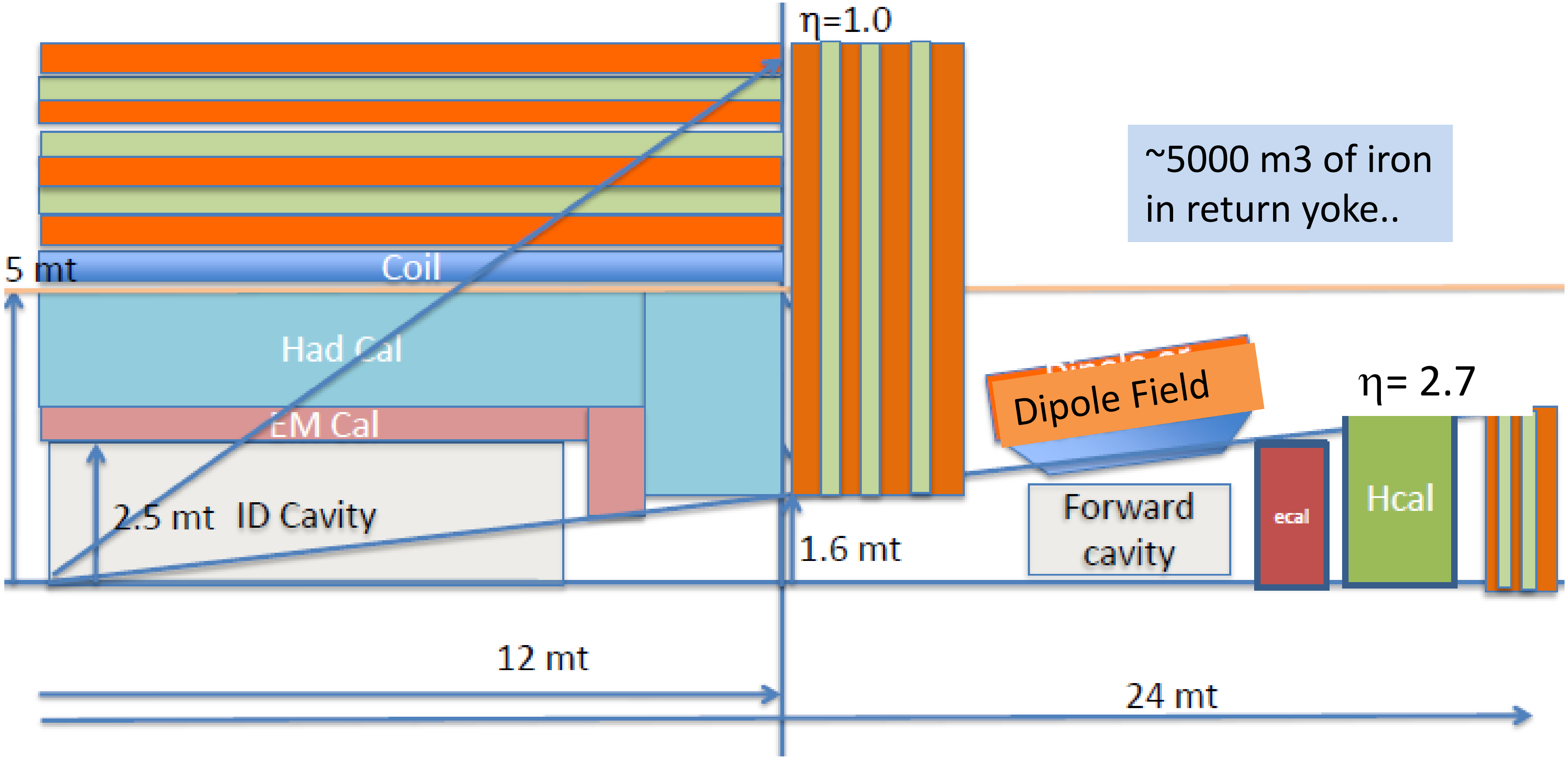
Detector « geometries/Magnets »

Very preliminary sketches, to stimulate discussions…

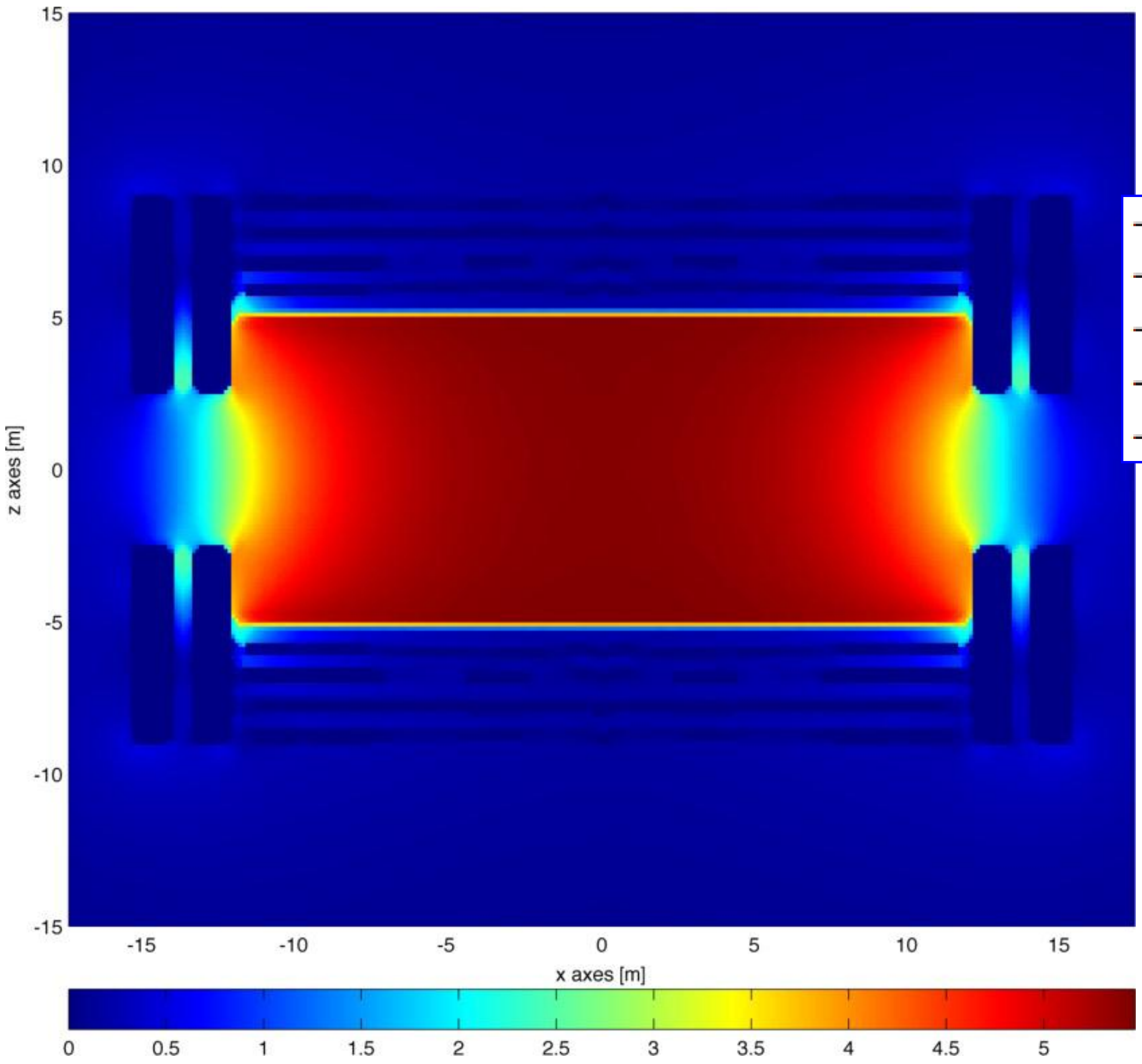
- Increase central bending power (muons)
- Extend coverage of tracking in B–field (up to ~η=5?)
- Increase thickness of calorimeters
- Move EC calorimeters away from collision point

LARGE SOLENOID :
coil : 24 m long and 5 m radius

ALTERNATIVES:
- increase R_coil up to 6m (to accomodate >12 λ calorimeter depending on absorber choice)
- Replace Iron return by large SC coil (~10 m radius) and « low »field

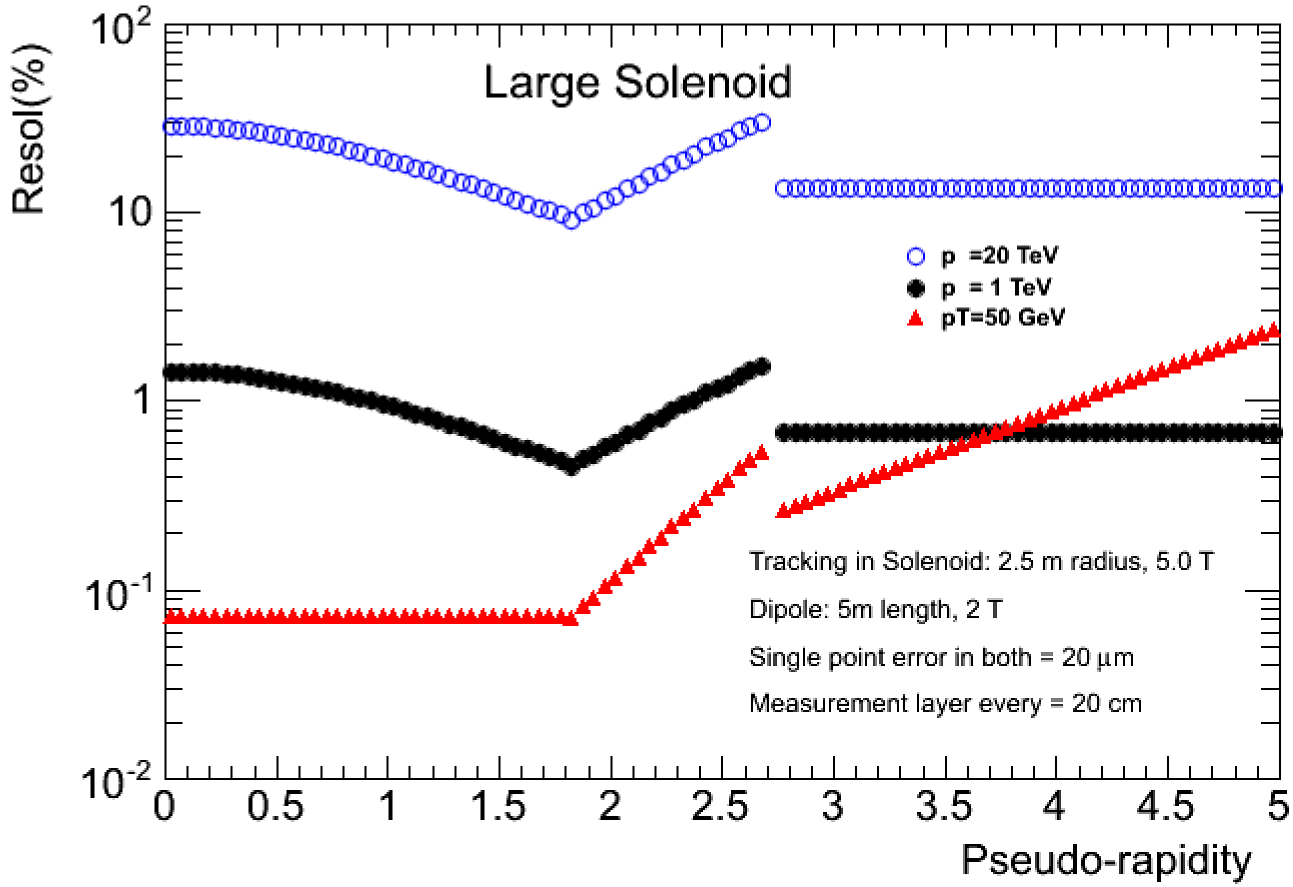


First magnetic calculations (H.TenKate, J.VanNugteren)

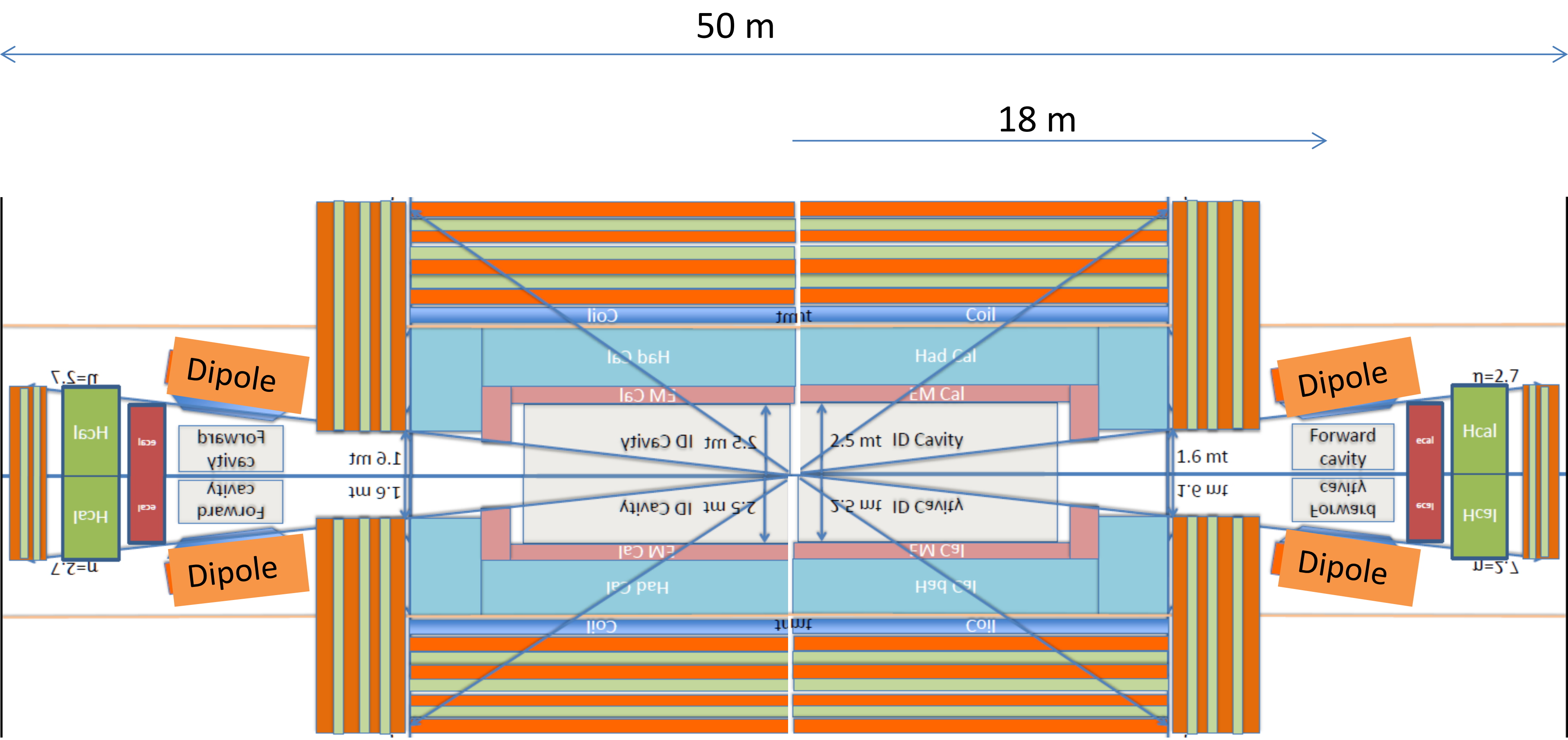


- 5m radius 0.5 m thick
- 10 A/mm² in conductor block
- 5.5 T peak field on conductor
- 20 GJ stored energy (without iron)
- 5 T central bending field

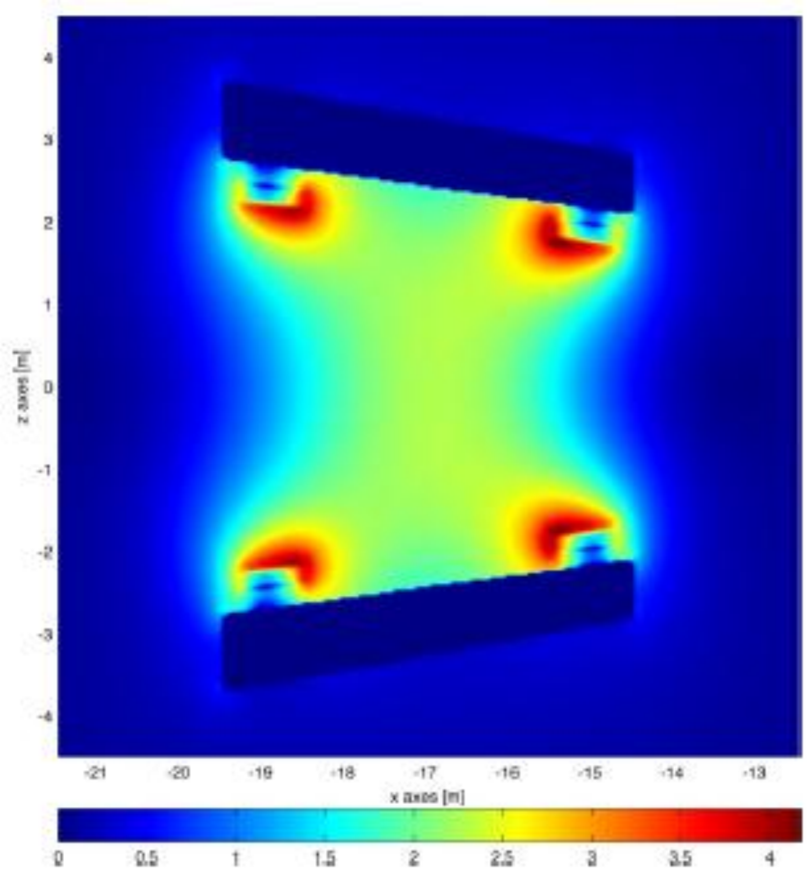
“Ideal resolution “
(no mult scatt, perfect alignment,…)



CMS:
12% at 1 TeV

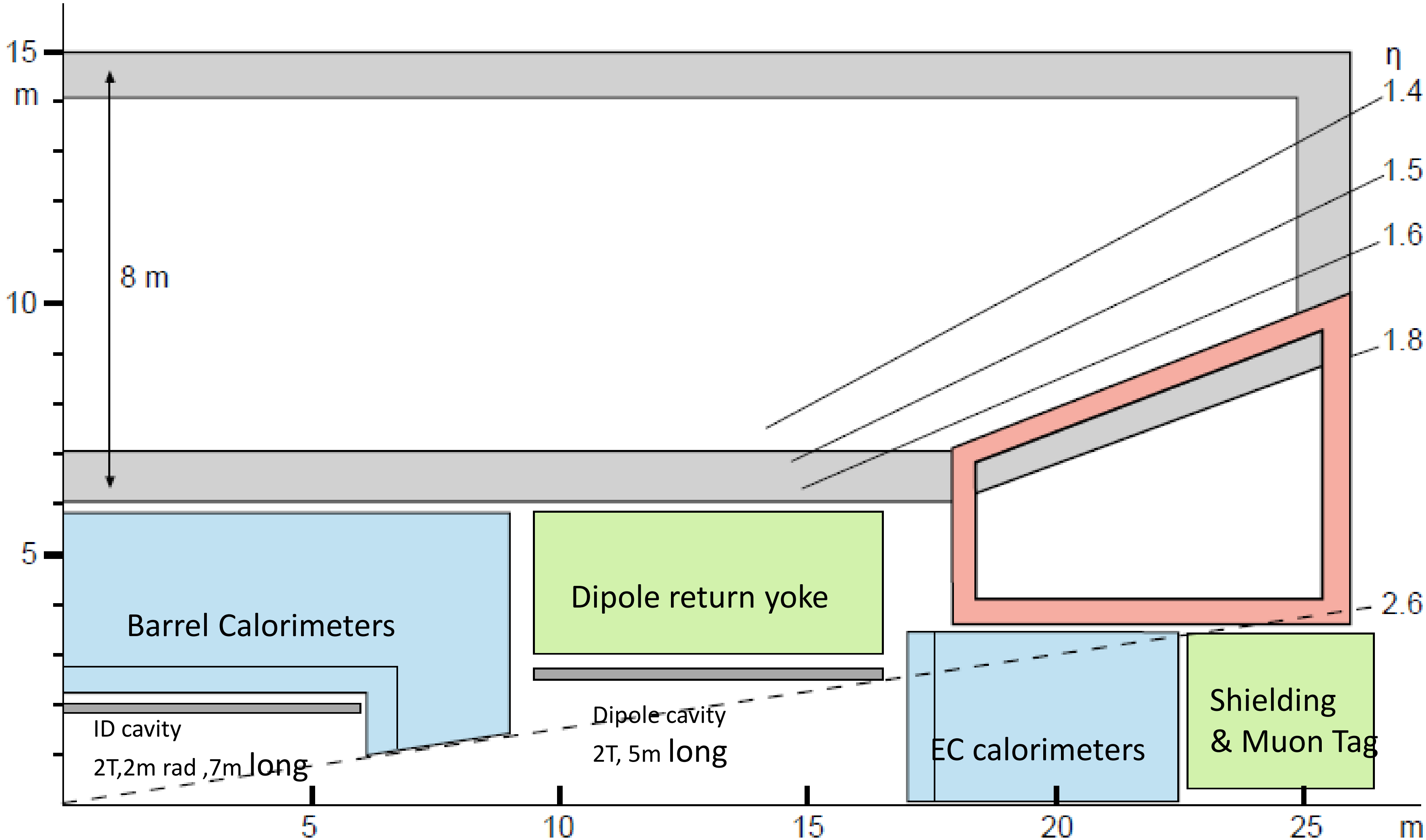

50 m
18 m
Coil
Had Cal
EM Cal
2.5 mt ID Cavity
1.6 mt
Forward cavity
ecal
Hcal
η=2.7
Dipole
Dipole
Dipole
Dipole

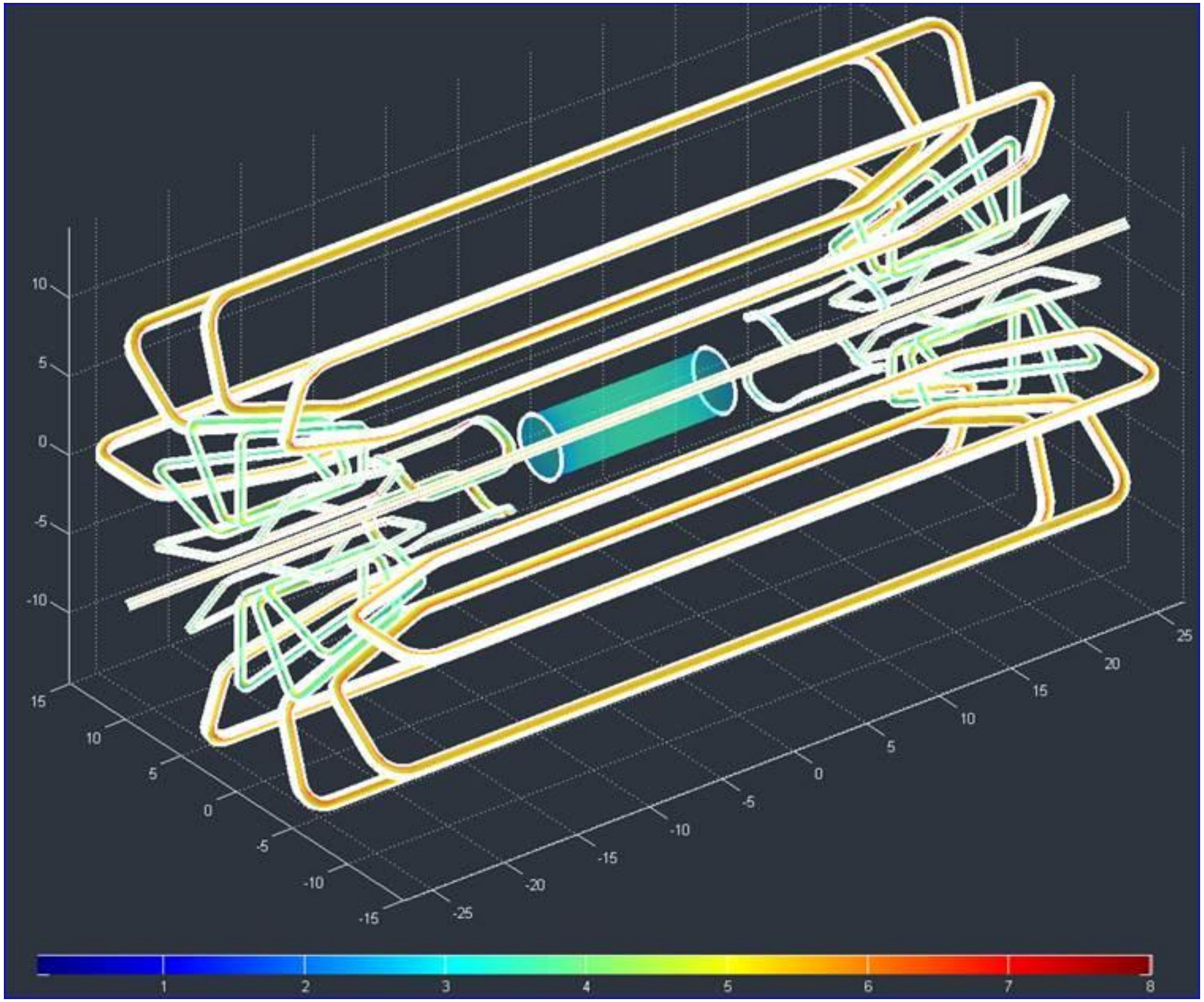
Dipole magnet: wedge option



- 2 Decks with each 0.08 m^2 cross section
- 30 A/mm^2 current Density in conductor block
- 5.6 T peak field on conductor
- 0.2 GJ stored energy (without iron)
- 2.2 T central bending field

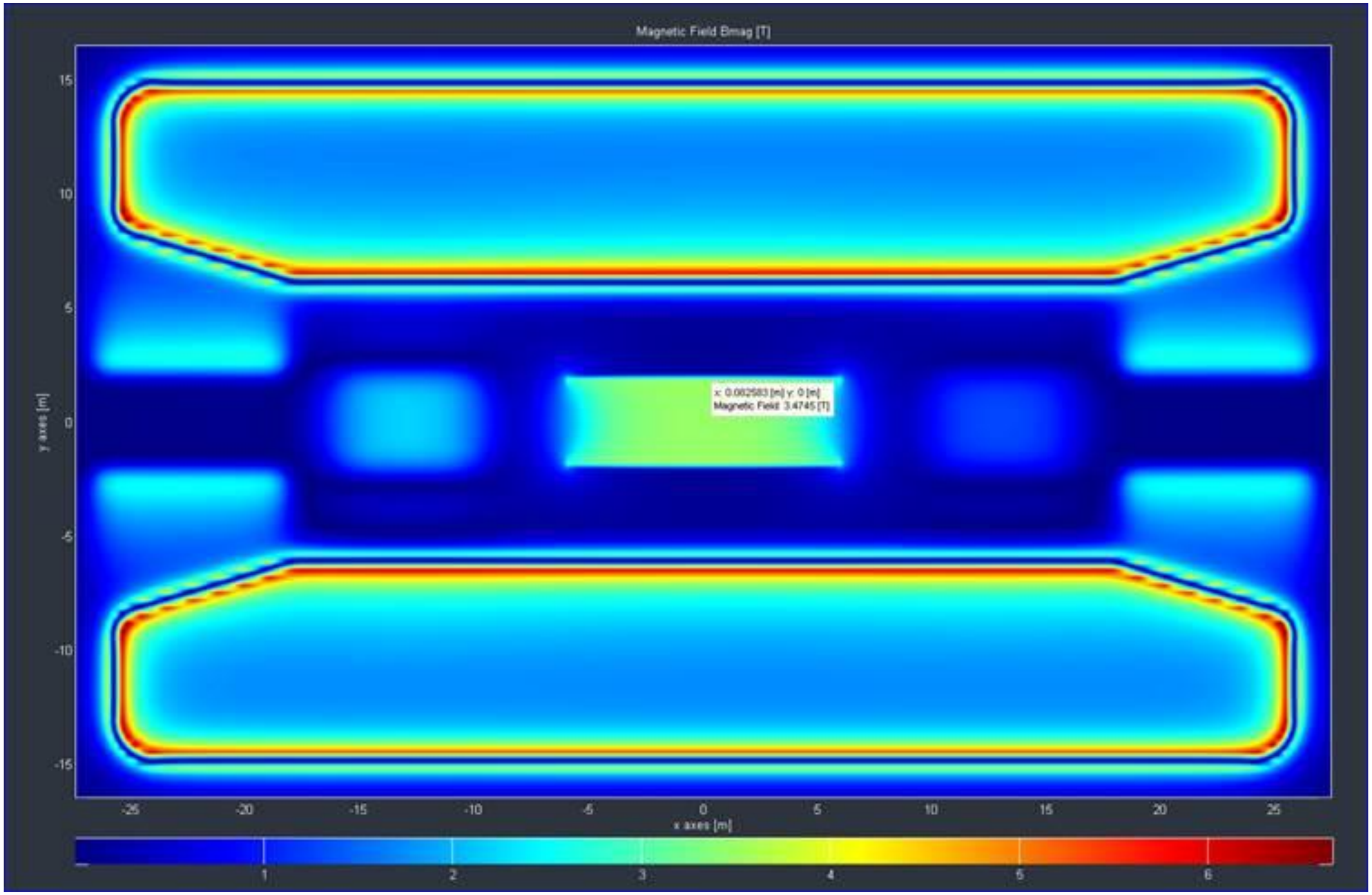
Large Toroid option



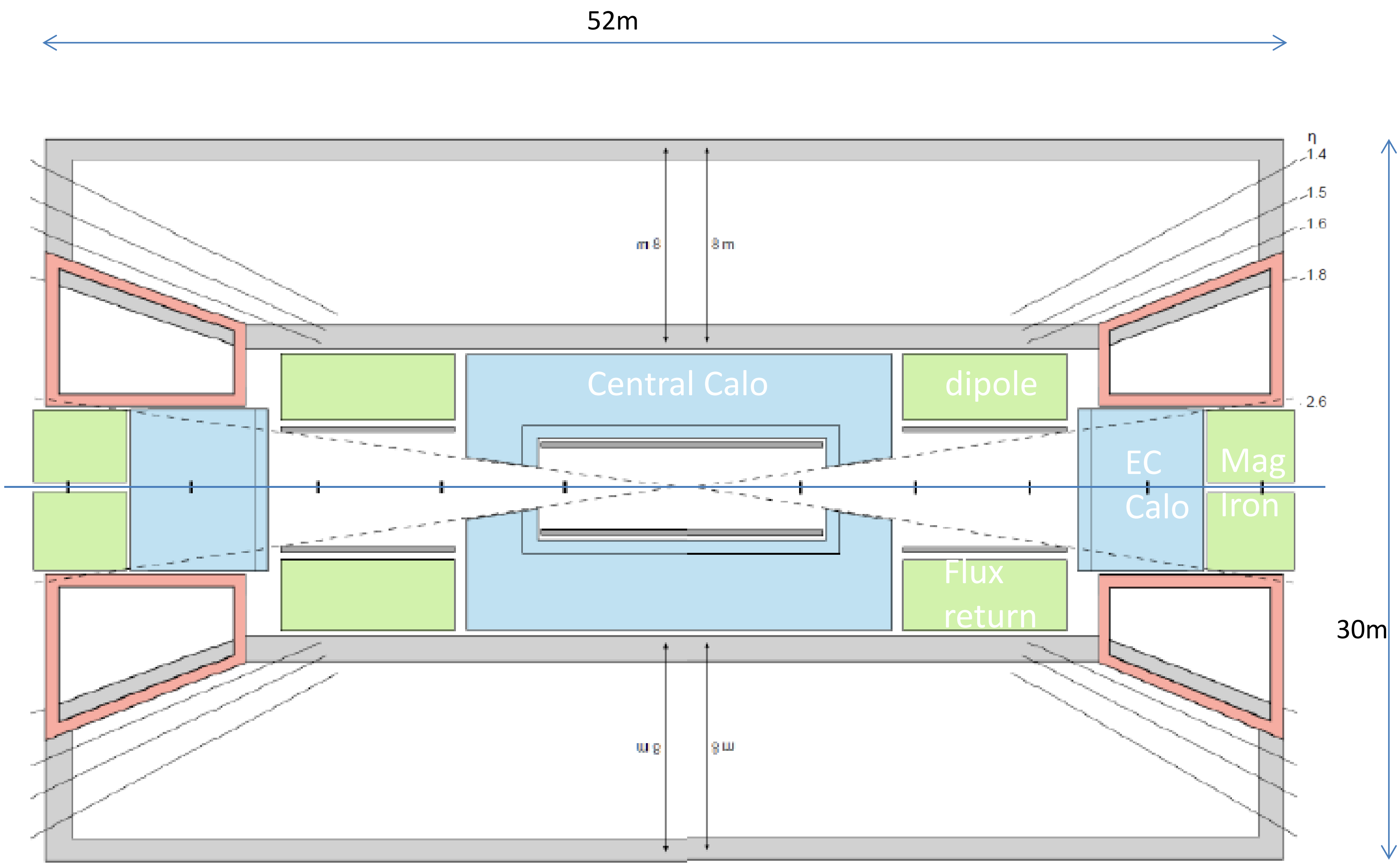


Radially: ~20Tm against 2.4 in ATLAS

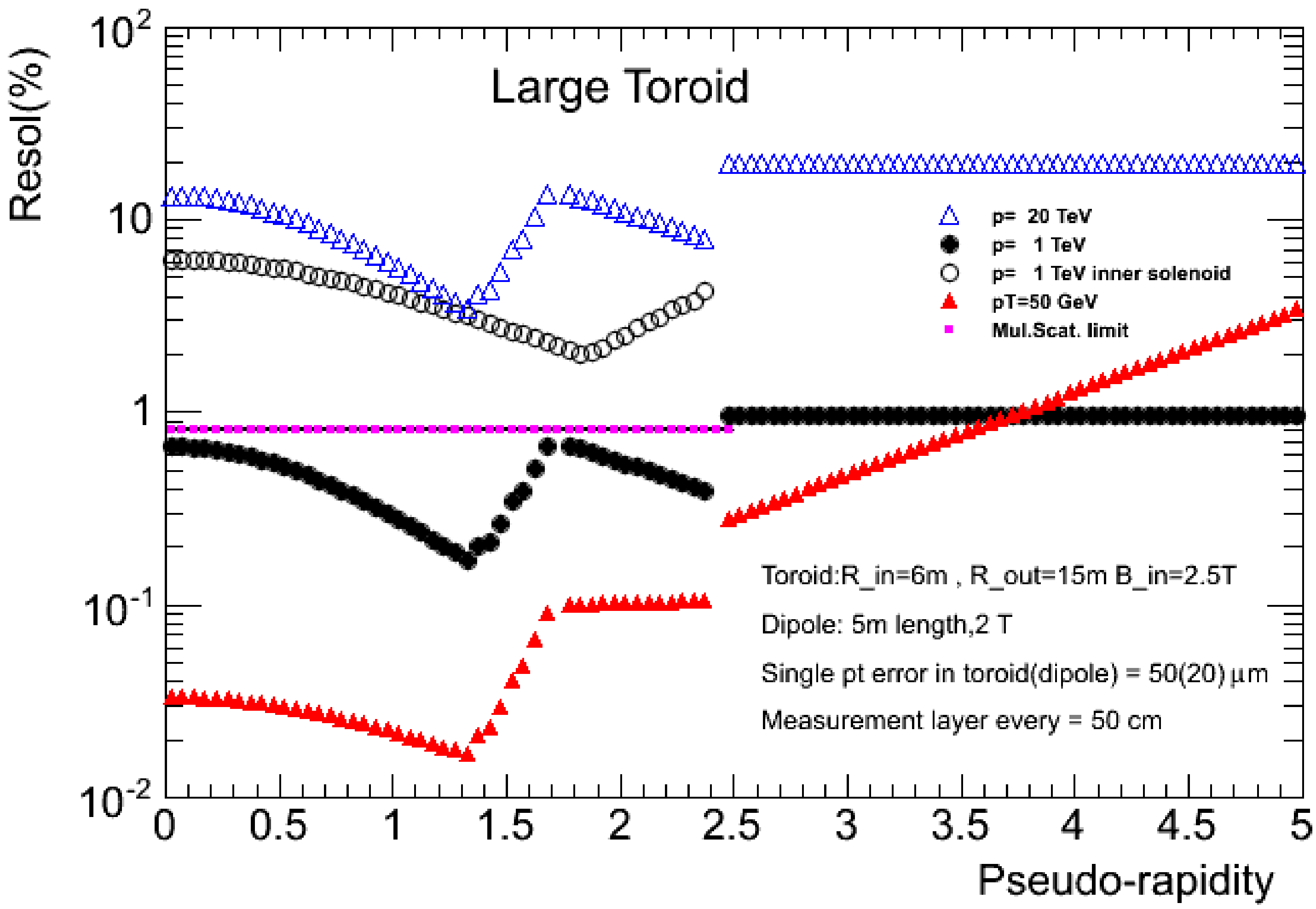
- Peak field on conductor up to ~8 T (to be minimized)
- Stored energy > 50 GJ



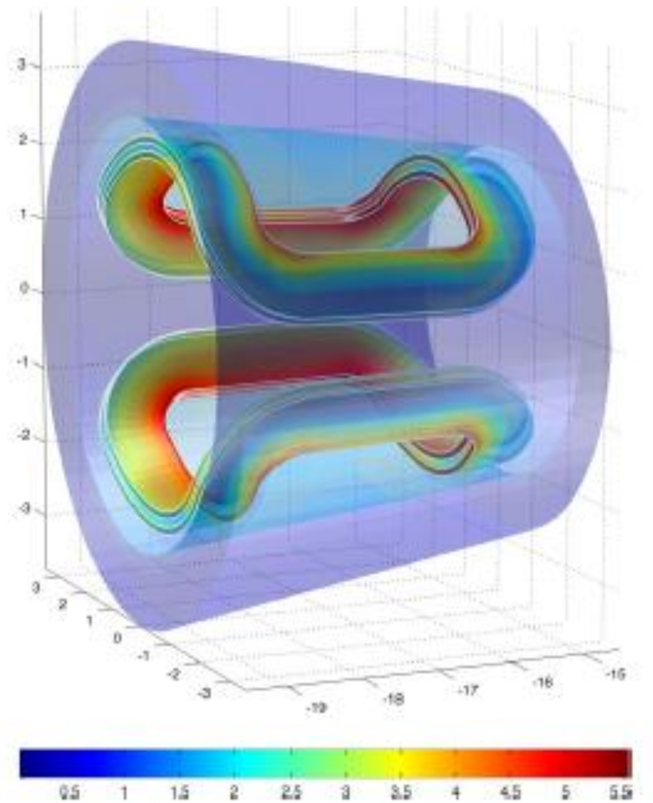
Magnetic Field Bmag [T]
x: 0.082583 [m] y: 0 [m]
Magnetic Field: 3.4745 [T]
y axes [m]
15
10
5
0
-5
-10
-15
-25
-20
-15
-10
-5
0
5
10
15
20
25
x axes [m]
1
2
3
4
5
6


52m
30m
η
1.4
1.5
1.6
1.8
2.6
8m
8m
Central Calo
dipole
EC
Calo
Mag
Iron
Flux
return

Large Toroid: ideal resolution



Cylindrical dipole for " large toroid" option



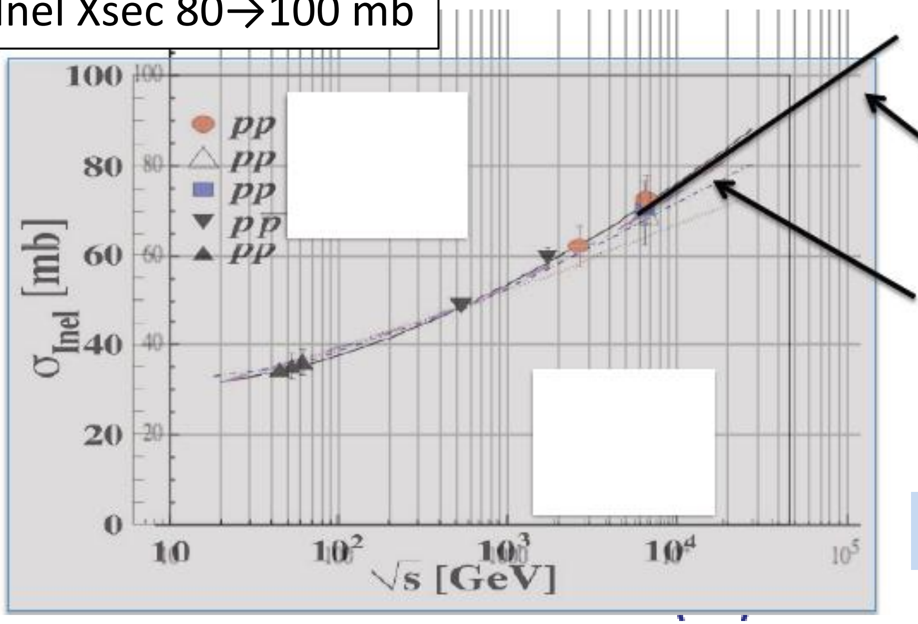
1st sketch of the 10Tm cylindrical dipole with iron

Detector Technologies

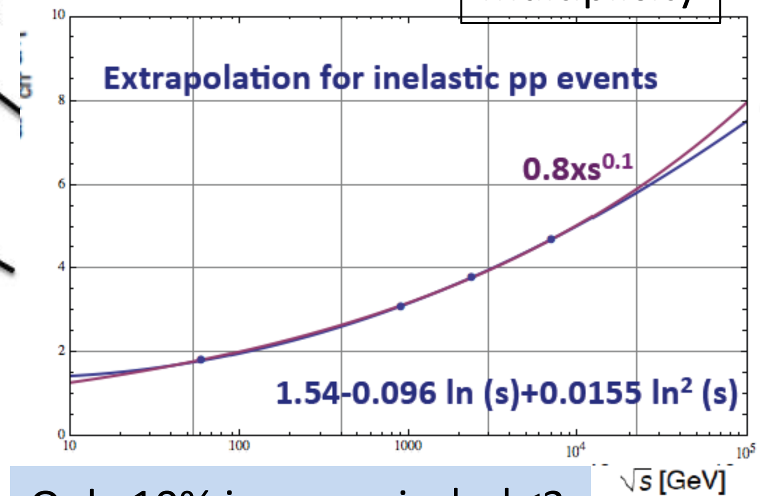
- Radiation
- 5ns option
- Ultrafast Si
- Triggerless readout

Radiation level (W.Riegler/ talk on friday)

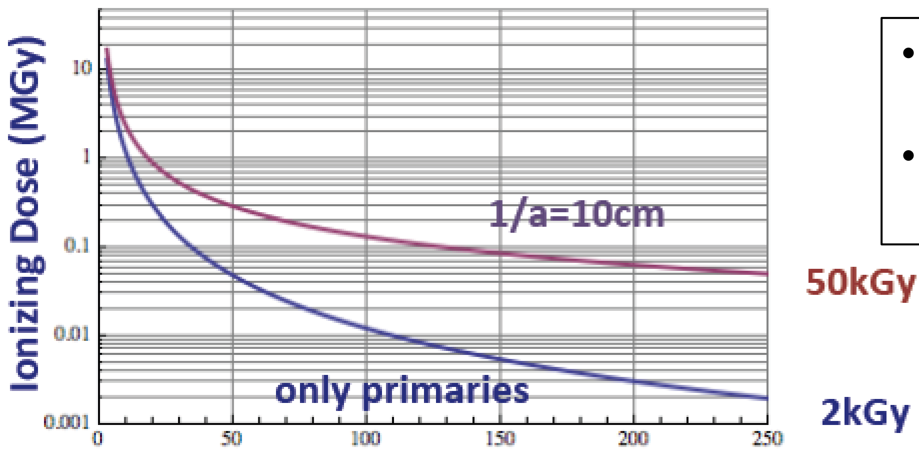
Inel Xsec 80→100 mb



multiplicity



Only 10% increase in $|\eta|\leq3$



- Rather accurate prediction for « primaries only » (factor ~2 /HL-LHC for the same int lumi-3 ab-1)
- More uncertain for neutrons at large distance fom beam pipe

5ns option (B.Gorini/talk on friday, F.Lanni)

- For the same lumi:pile-up /5 (assuming detectors can follow)
- Require more current in the machine or lower ε,β or a mix
- Beam lifetime possibly increased

Detectors:

- RPC for muon trigger most likely OK
- Si-Tracking (see below) most likely OK
- Calorimeters :
  - -not obvious with present technologies (LAr,crystals)
  - -Si ? Probably OK…but constant term? Sampling term?
- EC/Forward calorimeters?
  - -need to be dense … Ultra-thin Lar gaps (100μm??)
- DAQ: can be clocked at 40 MHz with time stamping/5ns

Ultra fast Si

(to take specific examples of tracking developments)

- NA 62 « Gigatracker » Si-pixels+ TDCpix
  - 3 stations of 18000 300 μm x 300 μm hybrid pixels (0.1% of ATLAS or CMS pixels)
  - -100ps TDC for ≤200ps timing accuracy (for charged kaons ~ mips)
  - -first prototype TDC chip (130nm) produced and tested with sensor in beam .
  - -timing accuracy improves with HV ; 175 ps for 400 Volts bias
- RD50 & arXiv 1312.1080
  - Si sensor with internal gain ~50 by LGAD
  - Shaping time ~ 4ns & LGAD gain ~50 (simulations)→down to 20ps (eq to 6mm path !) for 300 x 300 μm pixels 200 μm thick, and even better for smaller ones

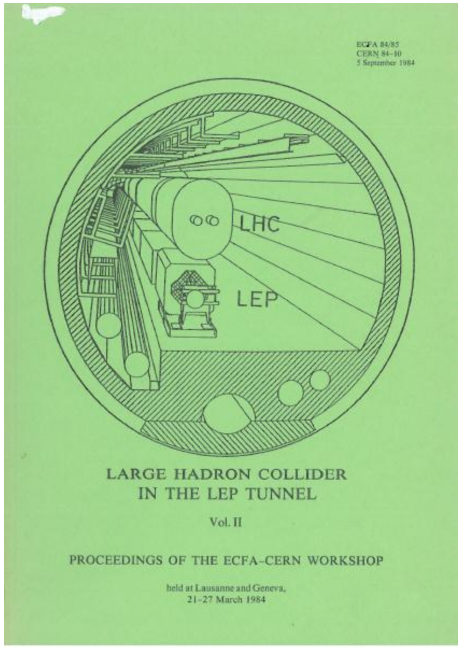
<u>If feasible</u>....Many interesting possibilities (vertex along z)

Raise the question of amount of information to be transferred to DAQ

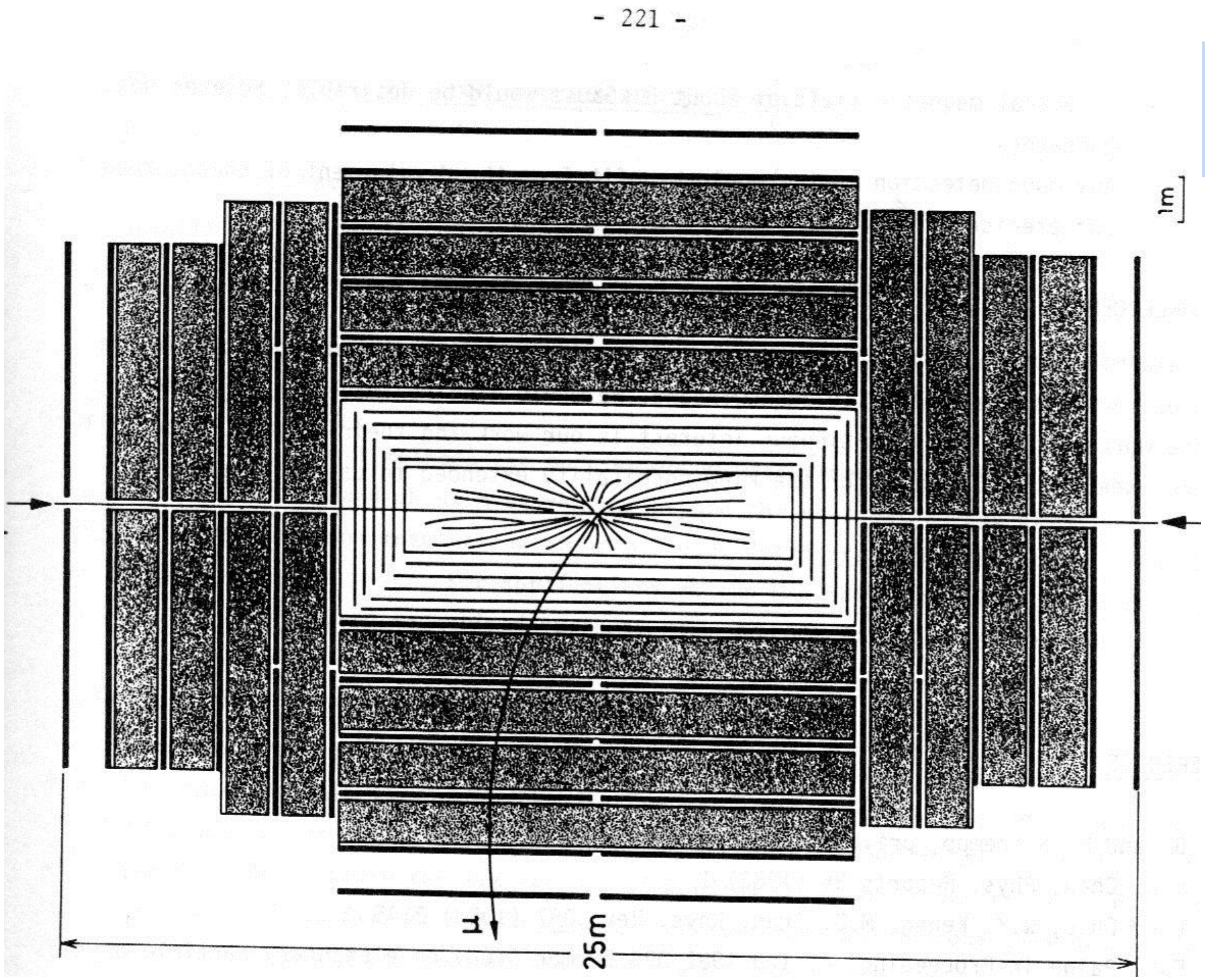
Room for many challenging
detector developments
Coupled to developments of the
Physics program

A reminder: Lausanne(1984)
-10 years up to LHC approval (tunnel existed..)
-12 years up to Detector TDR presentation (1996+)

- « generic » detector R&D up to ~1994
  (controlled by DRDC, financed by Labs)
- LoI 1992 : Physics and basic technologies
- 1992-2000 :« Shout-out » between technologies
  :Formation of « sub-detector communities »
  :Prototypes
- 2000-2008 :Construction
- 2004-2009 :Installation, commissioning, cosmic runs,…
- 2010-20XX :Exploitation,….
  : 2012: Higgs boson discovery….
  : ???

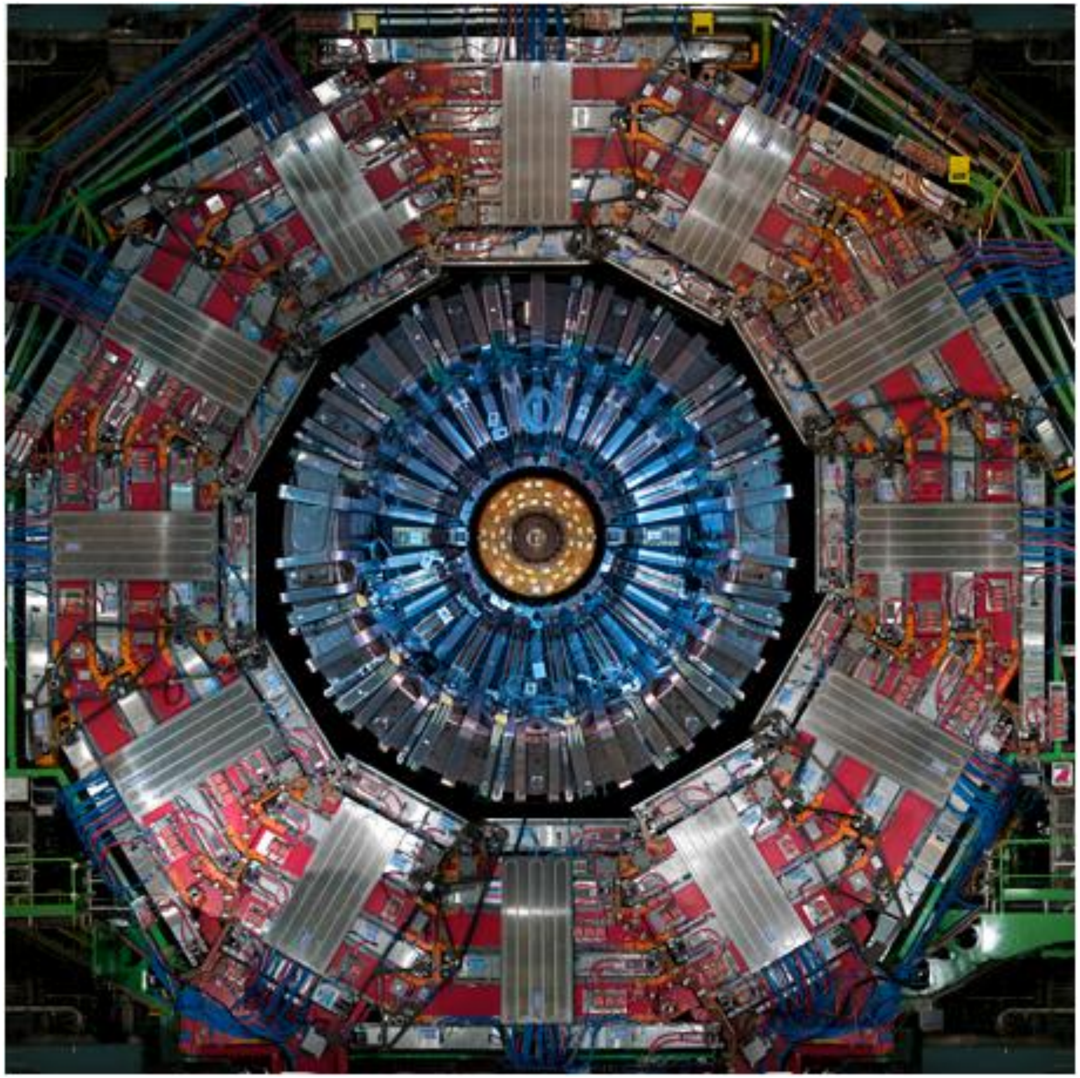


Detectors discussed at Lausanne



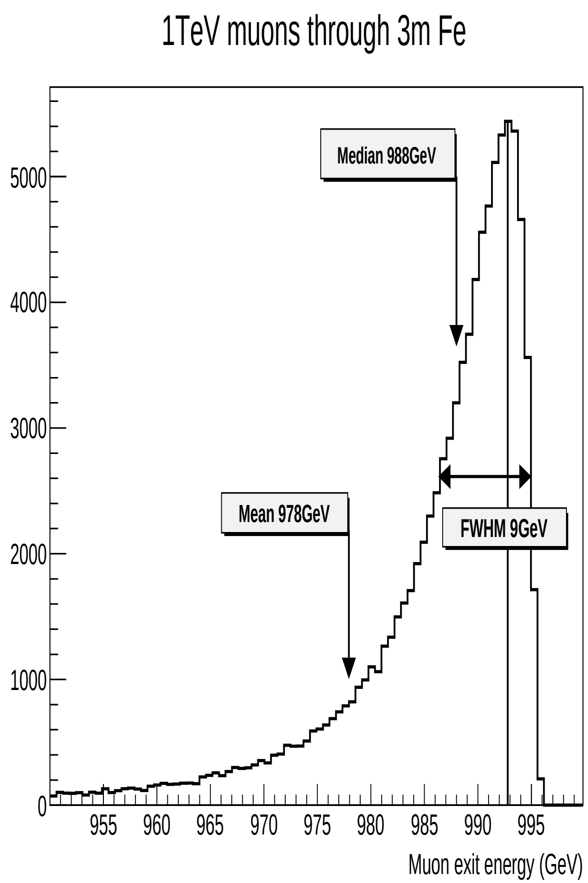
- Magnetized Iron ball
- Tracking a la « UA1 »

Had little to do with what they actually are



Back-up

Eloss by muons in calorimeters (S.Vlachos)
(one limitation to spectrometer performance)



- 1 TeV muon in 3m iron

  →median loss=13 GeV
  most probable loss= 8 GeV
  fwhm = 9 GeV
  dominated by radiation (~3 GeV/dEdx)

(Eloss linear with Emuon; rms /Eloss improves by ~factor 2 between 1 and 10 TeV)

- Not a strong limitation to precision of measurement behind the calorimeter: ~0.3% at 1 TeV
- Worse with higher Z material (W,Pb)
- (U a factor 2 worse/Fe in <Eloss>/gm/cm2

Tails due to "Catastrophic losses"

- X(Y)% of muons with >5% loss at 1(10) TeV
- Mitigated by "muon by muon" correction (ATLAS: tail below 8% reduced from 1.8% to 0.3 % at 300 GeV)

DAQ challenges (W.Riegler)

Data Volume from tracker in a <u>triggerless mode</u>:

- $L=5x10^{34}$ at 100TeV → $5x10^{9}$ pp collisions/second
- $dN/d\eta = 8$ i.e. 80 tracks inside $\eta \pm 5$
- Each track crosses 15 tracking stations
- In each station 5 pixels are fired.
- Each hit is encoded in 5 Bytes
- Factor 5 for background + curling etc.

→750 TByte/second into online system

~500000 « 10Gbit links of today »
not totally ridiculous if Moore's law still apply for the next 20 years

ATLAS-muons

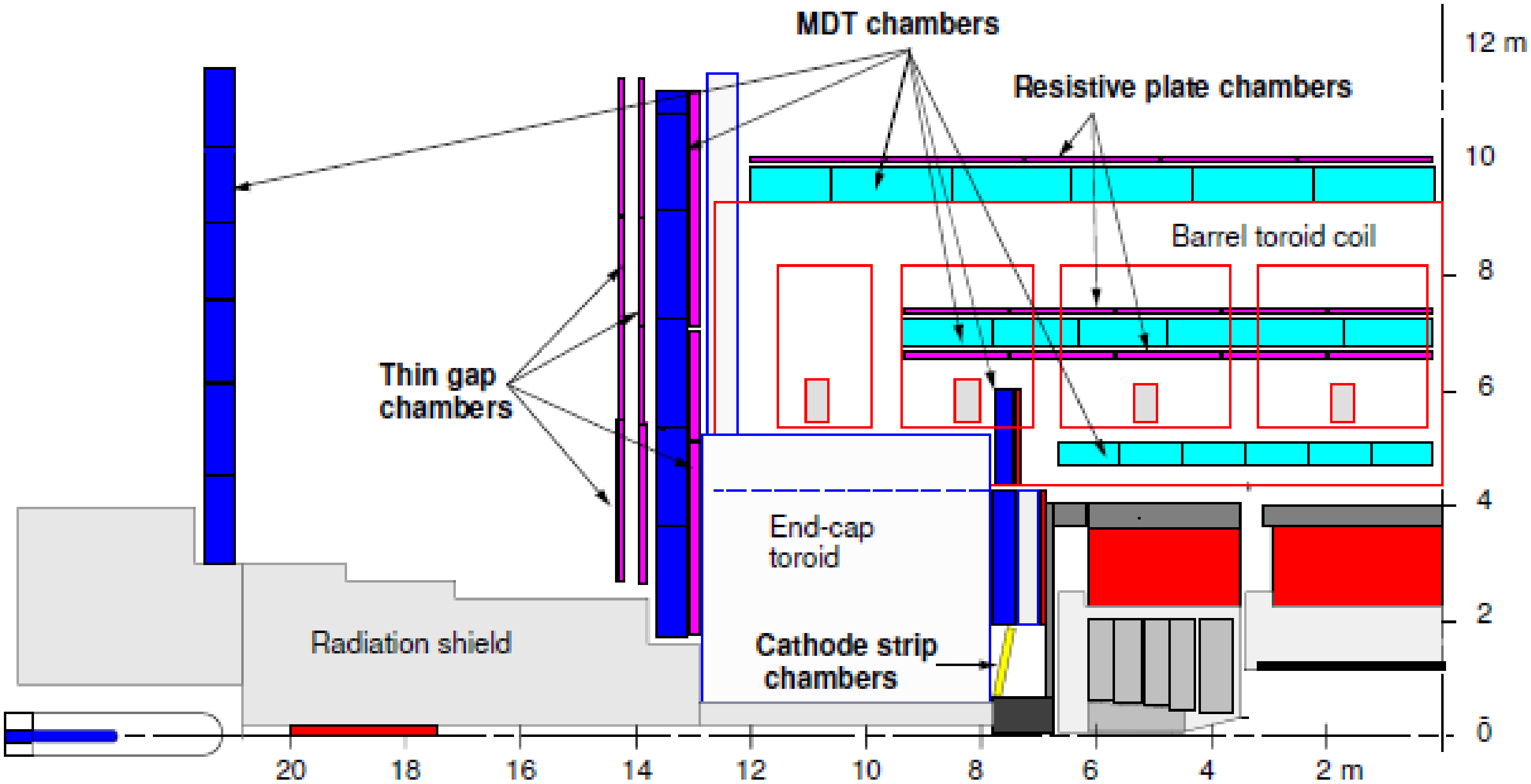
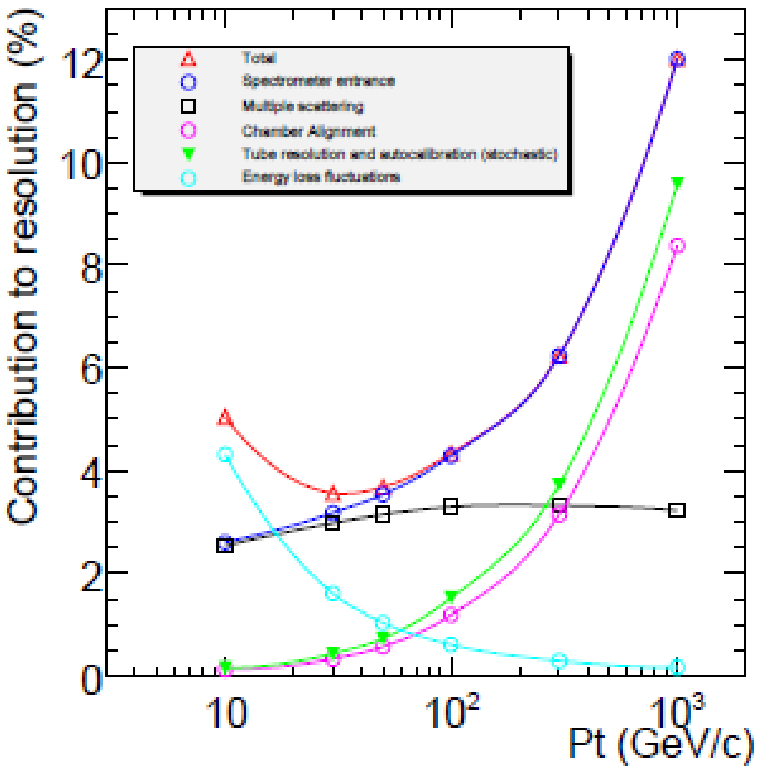


Figure 1: The ATLAS muon spectrometer.


Total
Spectrometer entrance
Multiple scattering
Chamber Alignment
Tube resolution and autocalibration (stochastic)
Energy loss fluctuations
Contribution to resolution (%)
0
2
4
6
8
10
12
10
10^2
10^3
Pt (GeV/c)