FCC-hh Detector Overview

FCC week Washington
23-27 March 2015

W. Riegler for the FCC-hh detector working group

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Physics at a 100 TeV Hadron 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 $\eta=2.5$.

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

FCC detectors must be 'general general' purpose detectors with very large η acceptance and extreme granularity.

Recent Workshops

Higgs and BSM at 100TeV, March 11-13, 2015
https://indico.cern.ch/event/352868/

Workshop on requirements for future detector technologies in view of FCC-hh, March 3-4, 2015
https://indico.cern.ch/event/358198/

Driving Requirements for an FCC-hh Detector

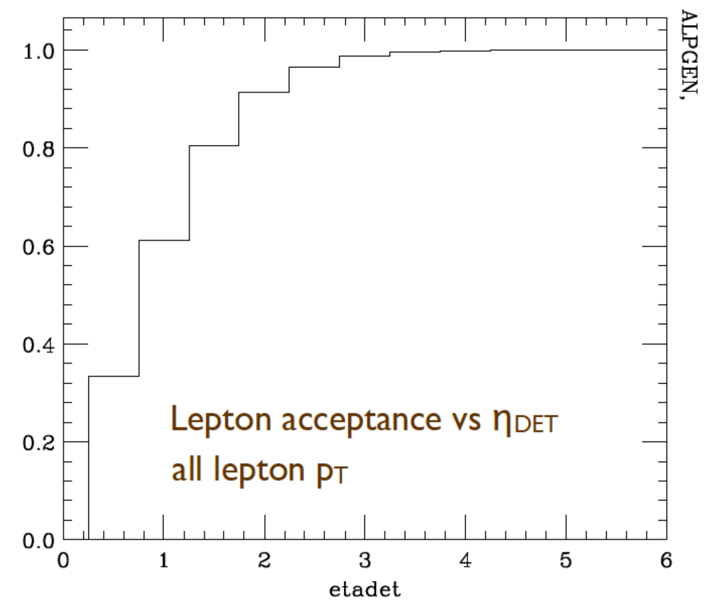
(1) Physics at the Lσ Limit

“Drell-Yan” limit m(Z’) ≈ 30TeV
Z’→□□: muon spectrometer spec.
Z’→ee: Emcal spec.

„QCD“ limit m(q*) ~ 50 TeV
q*→jets: Emcal+Hcal spec.
10 λ_{int} (LHC) → **12** λ_{int} (FCC)

SUSY
complex signatures E_{Tmiss}, jets, leptons, taus,…

Inclusive Z’ (M=20 TeV) production



Do we need to measure High Energy Muons well ?

Muons

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

'expensive', 10% at 15TeV difficult

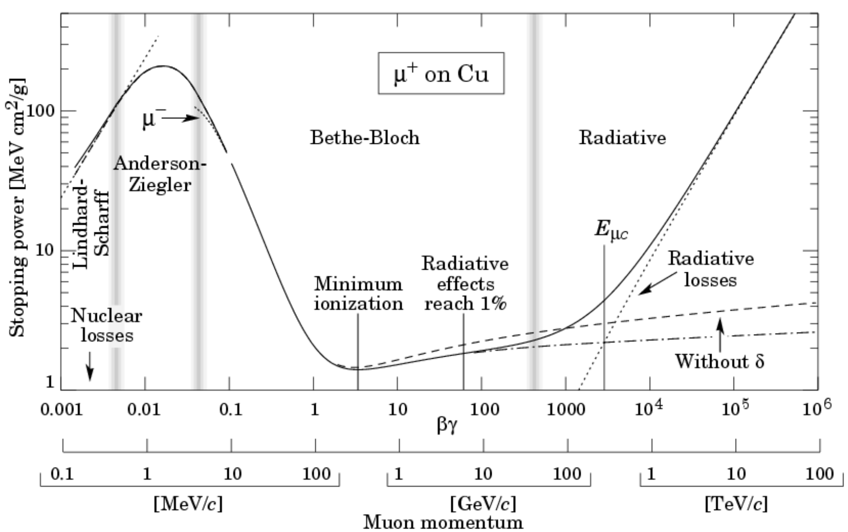
Jets → Ecal, Hcal → k

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

' cheap', 1% at 20TeV achievable ?, 2-3% needed

Careful !!

- **Calibration of jet energy scale at 20TeV is far from evident**
- **Muon systems are intrinsically linear ! Calibrate at low p_t – confidence at hight p_t**
- **Determination of charge for FB asymmetry essential**
- **For the enormous scale of the FCC-hh machine, detectors should not compromise !**



Also to be careful here: Critical Energy
E_c: Electrons 550MeV/Z, Muons ≈20TeV/Z

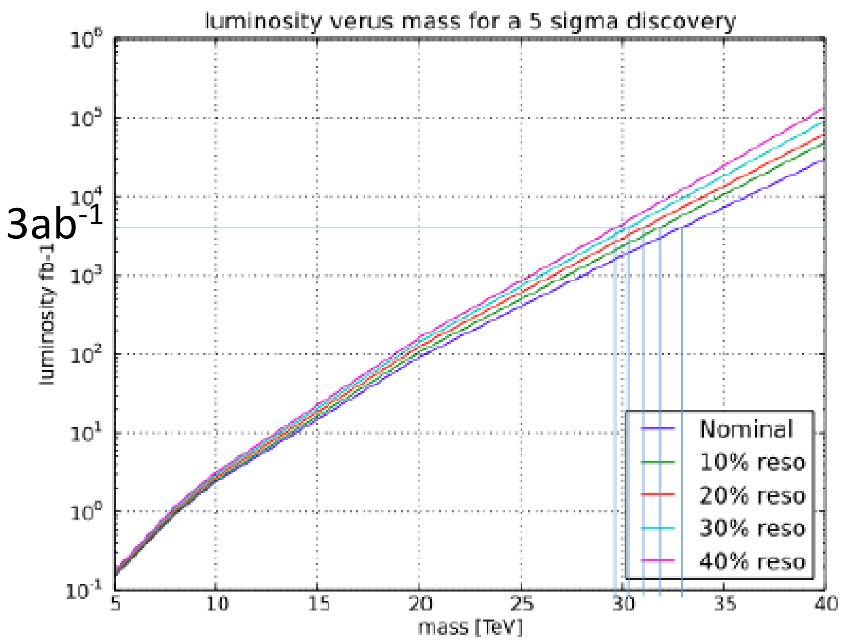
Muons in Iron ≈ 800GeV !

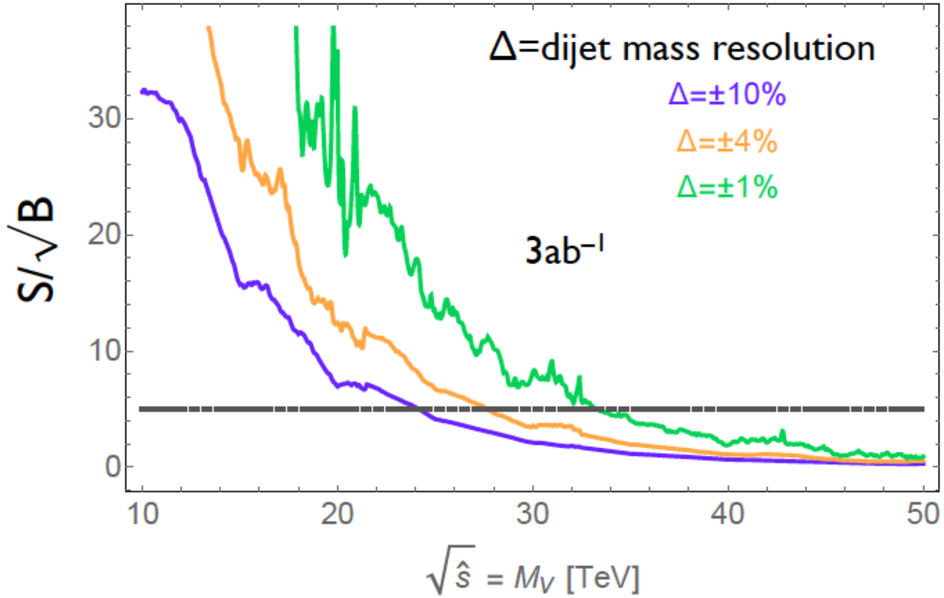
Energy loss due to radiative processes dominates !

How are muons doing behind 12 λ_{int} of Calo ?

Muons vs. Jets

C. Helsens, M. Mangano





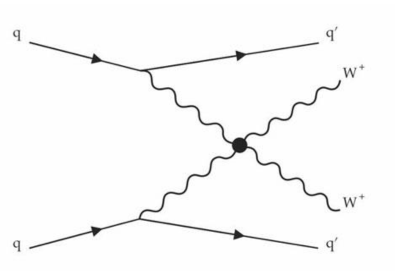
$$\frac{\Delta E}{E} \propto \frac{1}{\sqrt{E}} + k$$

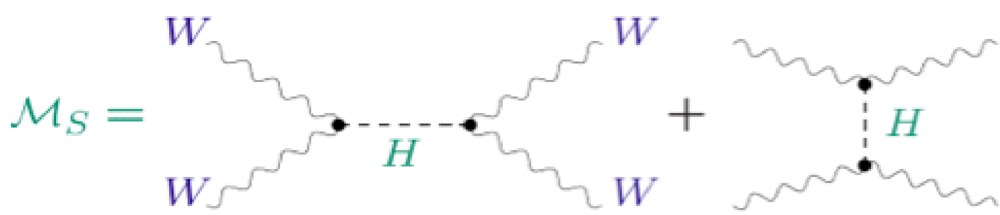
Muon resolution 15% at 10TeV ok ?

- → **Constant term dominates, 1-2% goal**
- → **full shower containment is mandatory !**
- → **A tail catcher behind 1.7m of coil will also not be very useful**
- → **Do not compromise on 12 lambda !**

(2) WW scattering by VBF Mechanism

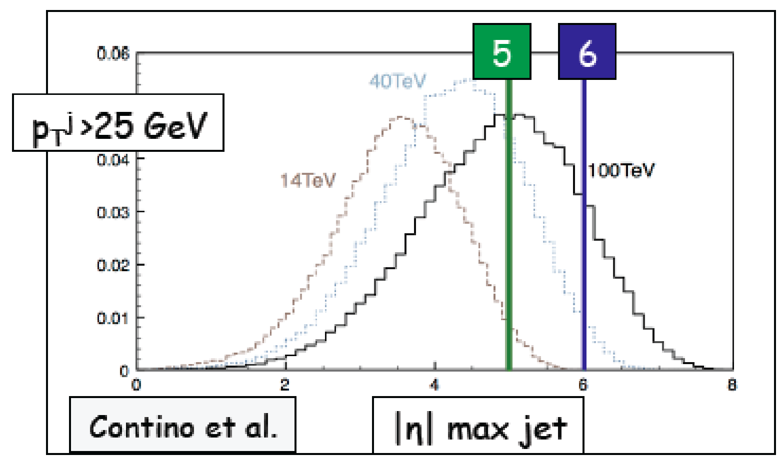
Is H playing it's role ? Unitarity at 1TeV ?
Are there high mass resonances WW, ZZ, HH, …



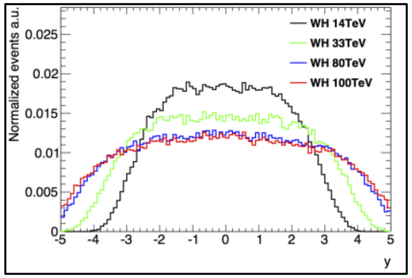


VBF jets between η~2 and η~6 need to be well measured and separated from pile-up

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



(3) Higgs Measurements



H→ 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

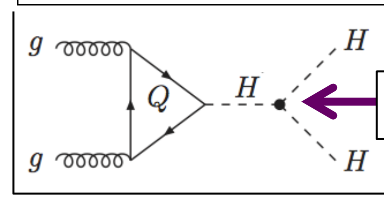
		|η| < 2.5	|η| < 4	|η| < 5
YY	100 TeV	0.74	0.95	0.99
	14 TeV	0.90	1	1

→ 30-50% acceptance loss for H→ 4l at 100 TeV wrt 14 TeV if tracking and precision EM calorimetry 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)

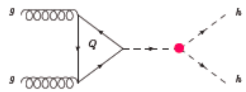


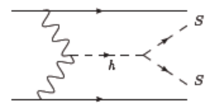
$g_{HHH} \sim \lambda v$

	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%

Electroweak Baryogenesis ?

Probing
Electroweak
Baryogenesis
at Future Colliders

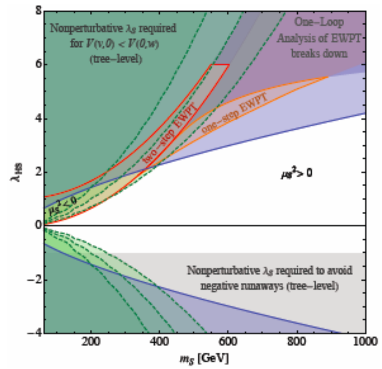




CERN FCC-Higgs Workshop
13 March 2015

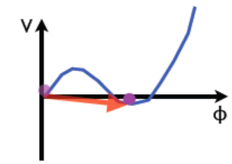
David Curtin
Maryland Center for Fundamental Physics
University of Maryland

Partially based on 1409.0005 (DC, Patrick Meade, Tien-Tien Yu)

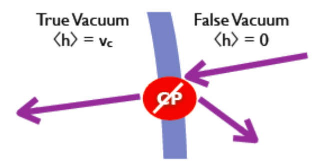


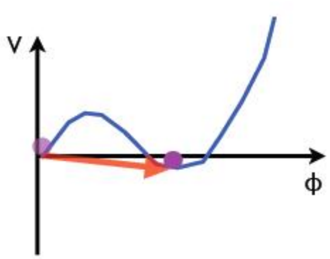
EWBG requires two BSM ingredients:

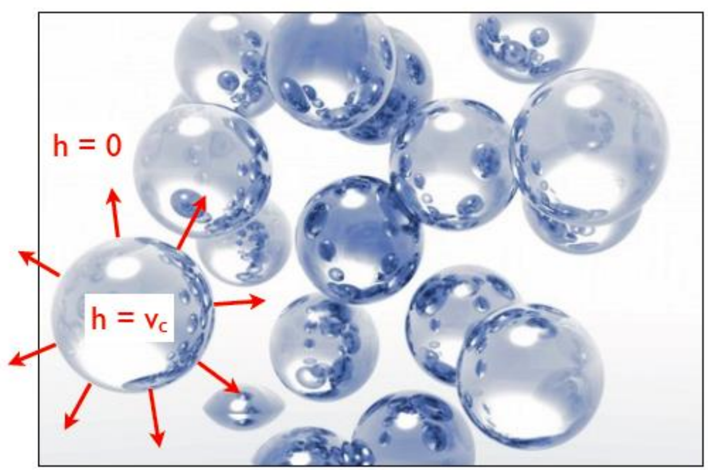
1. Modified higgs potential to make phase transition 1st order



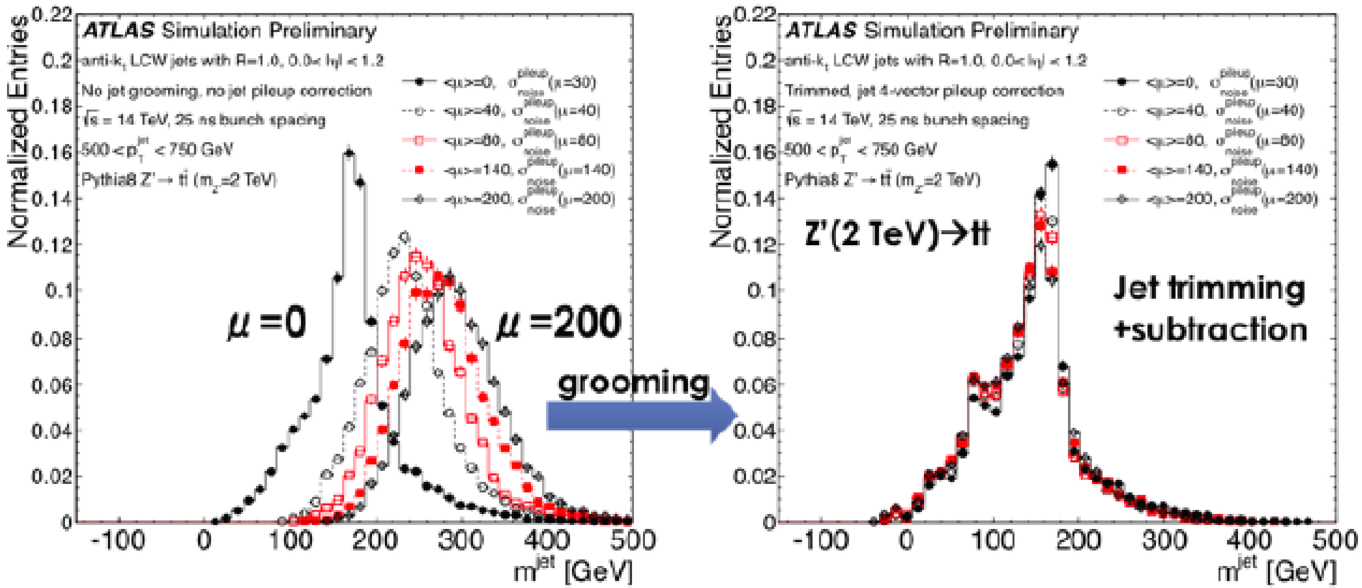
2. Sizable CPV coupling between higgs and another particle (BSM or SM) that is thermally active in the plasma ($M \lesssim T$)







(4) Pileup, Boosted Objects



topoclustering + grooming + area subtraction shows very good performance up to 200 PU

FCC Higgs & BSM Workshop
CERN, March 2015

Principles of tagging multi-TeV boosted objects

Gavin Salam (CERN)

What changes at FCC?

Much higher boost means decay opening angles ~ 0.02 instead of 0.2-0.3 relevant today

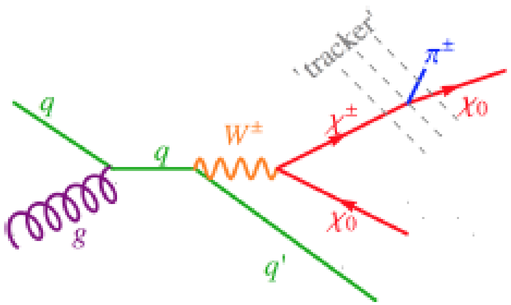
- Detector **granularity** becomes a critical issue
- W/Z/H become as collimated as τ leptons at LHC – can use similar "**isolation**" procedures (cut on radiation)
- top decay as collimated as b-decay at LHC – need to consider difference between **top quarks v. top jets**

(5) More Exotic

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

Filippo Sala

Approximate Overall Needs

Tracking: Momentum resolution Ħ15% at p_t=10TeV

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

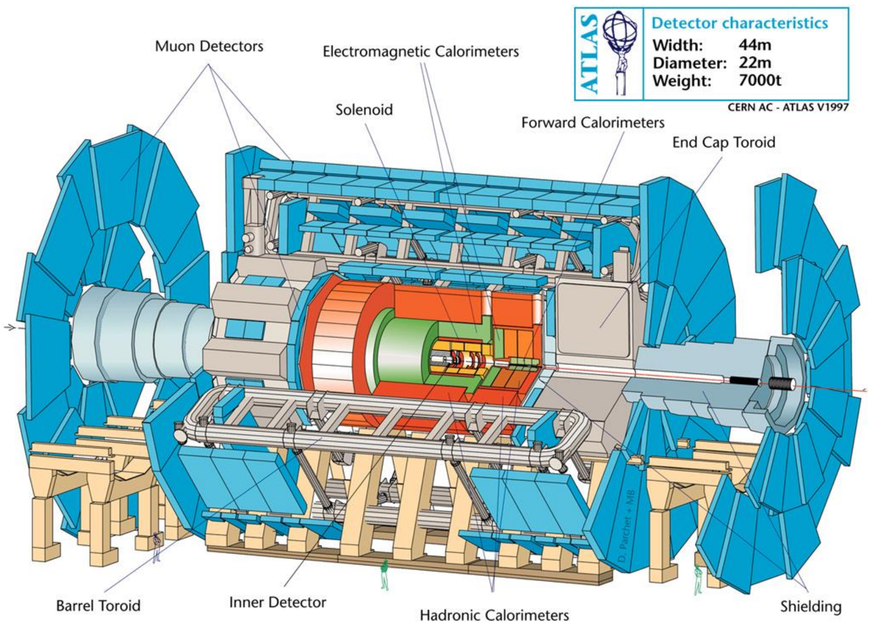
Tracking and Calo for jets up to η=6.

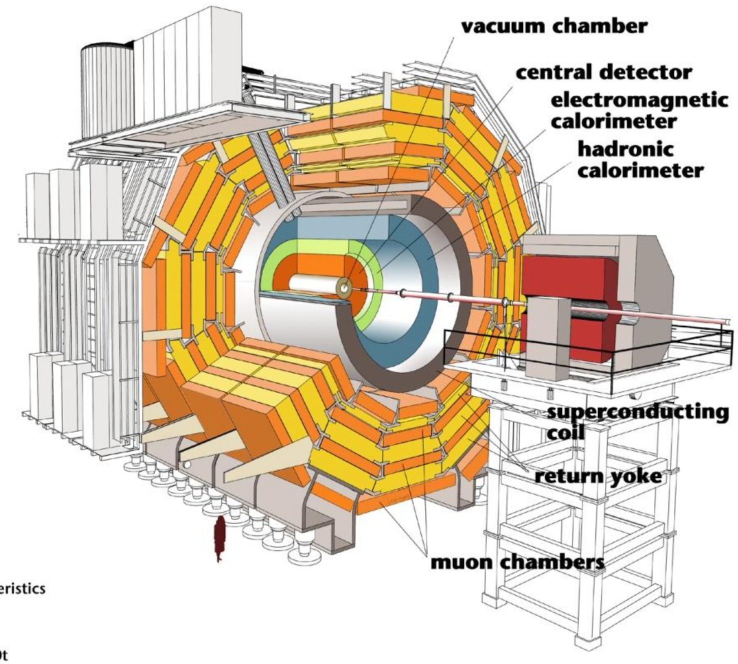
98% containing calorimetry of 12 λ_{in}, 1-2% constant term.

Calorimeter granularity to mitigate pileup and measure jet substructure and boosted objects.

B-tagging, timing for pileup rejection etc. …

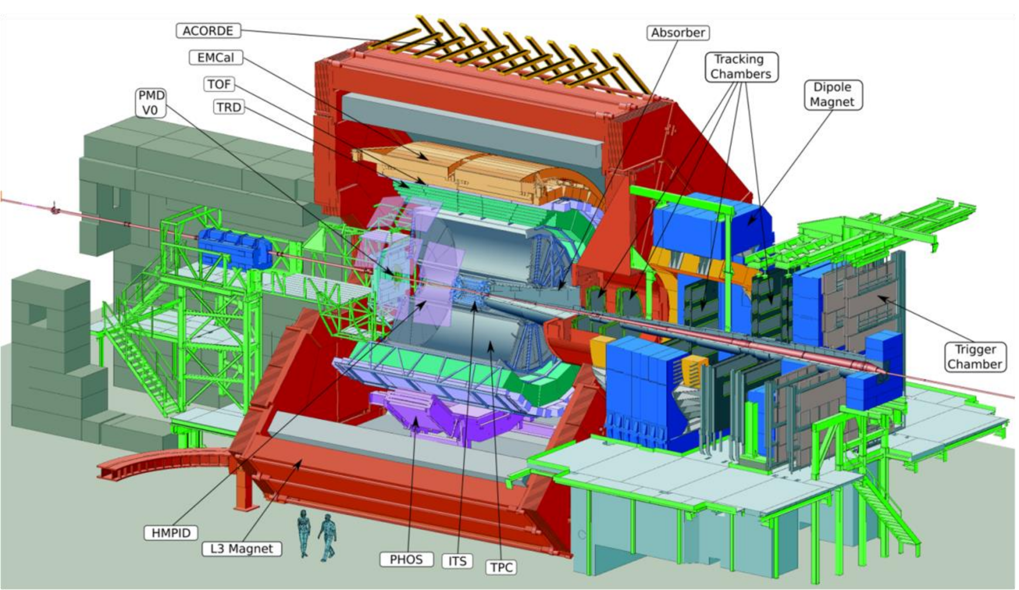
ATLAS, CMS, ALICE, LHCb

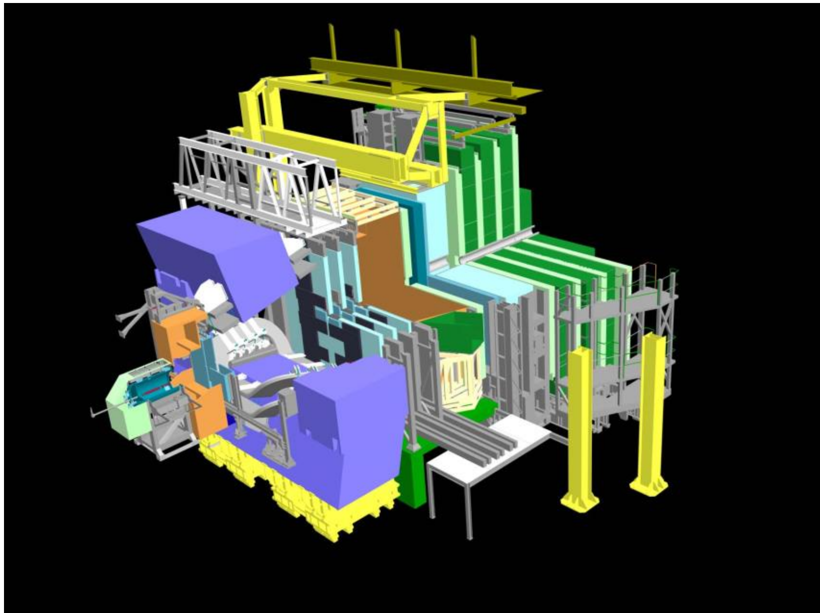


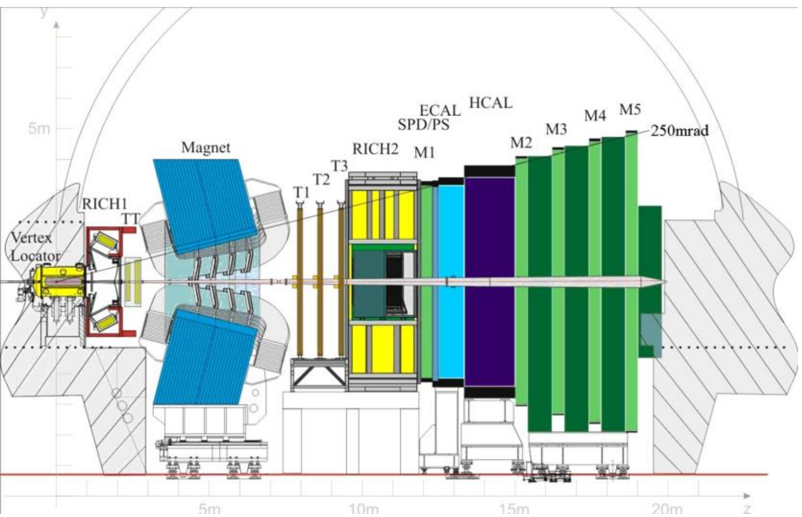


Detector characteristics

Width: 22m
Diameter: 15m
Weight: 14'500t



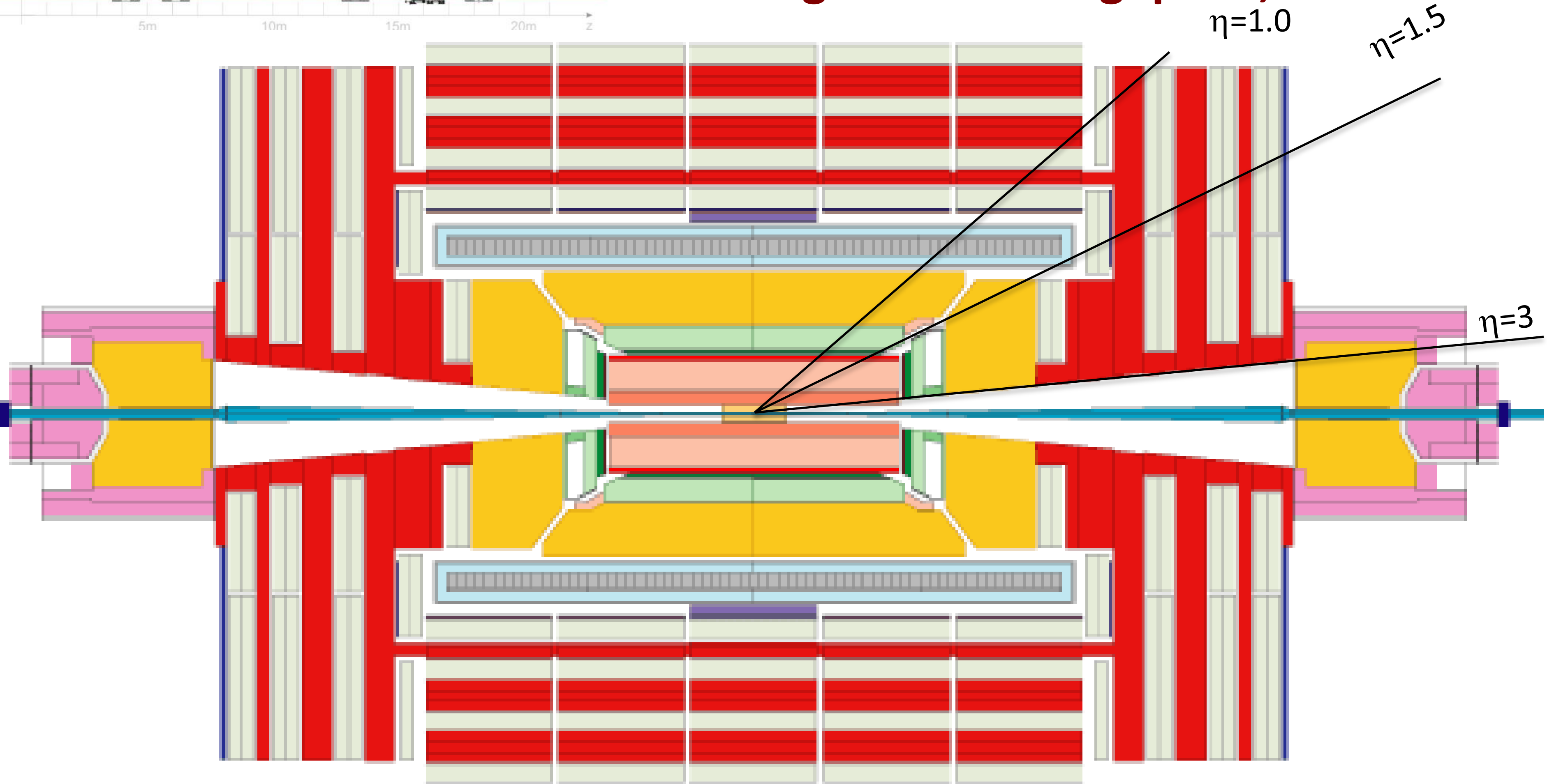




Tracking LHCb η = 2 - 5

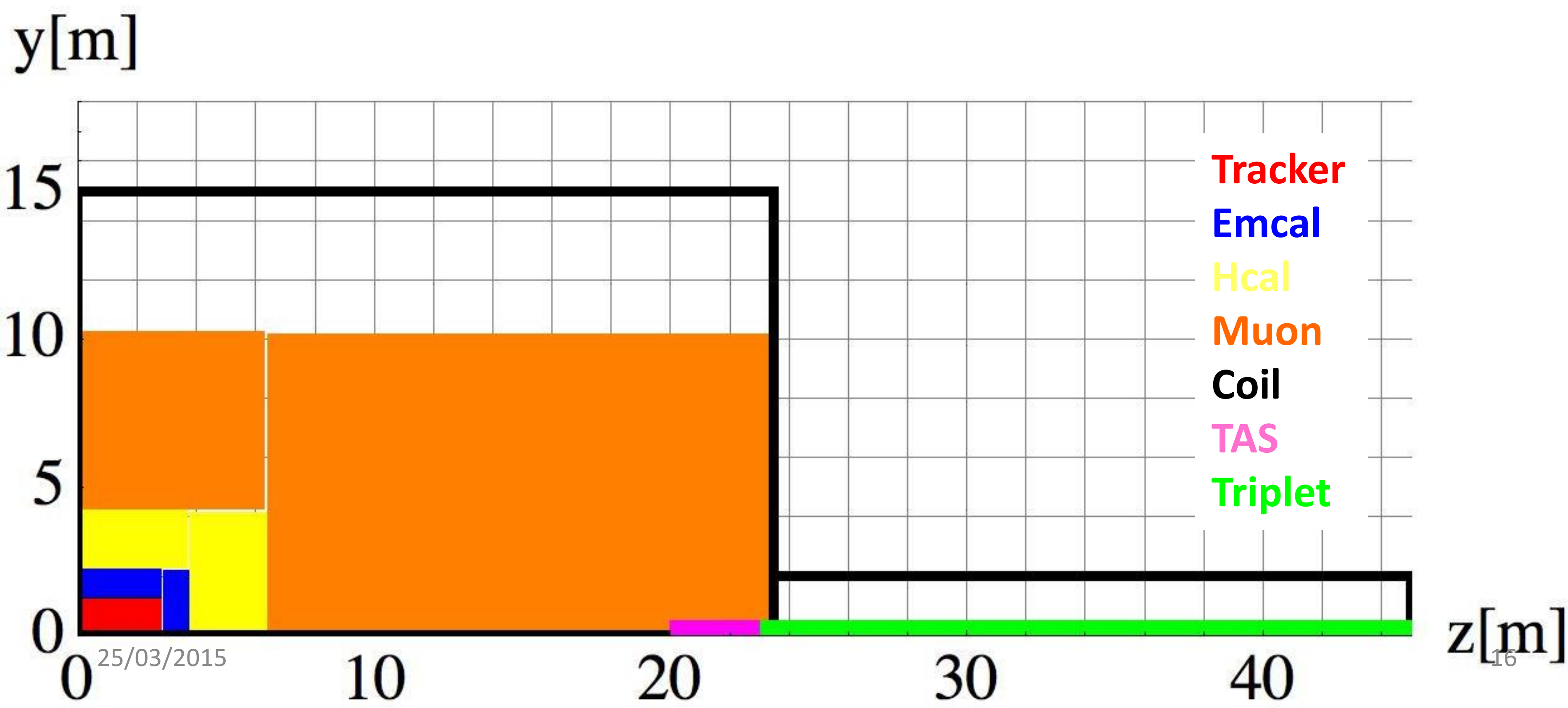
… all with impressive performance …

Tracking CMS tracking η -2.5,2.5



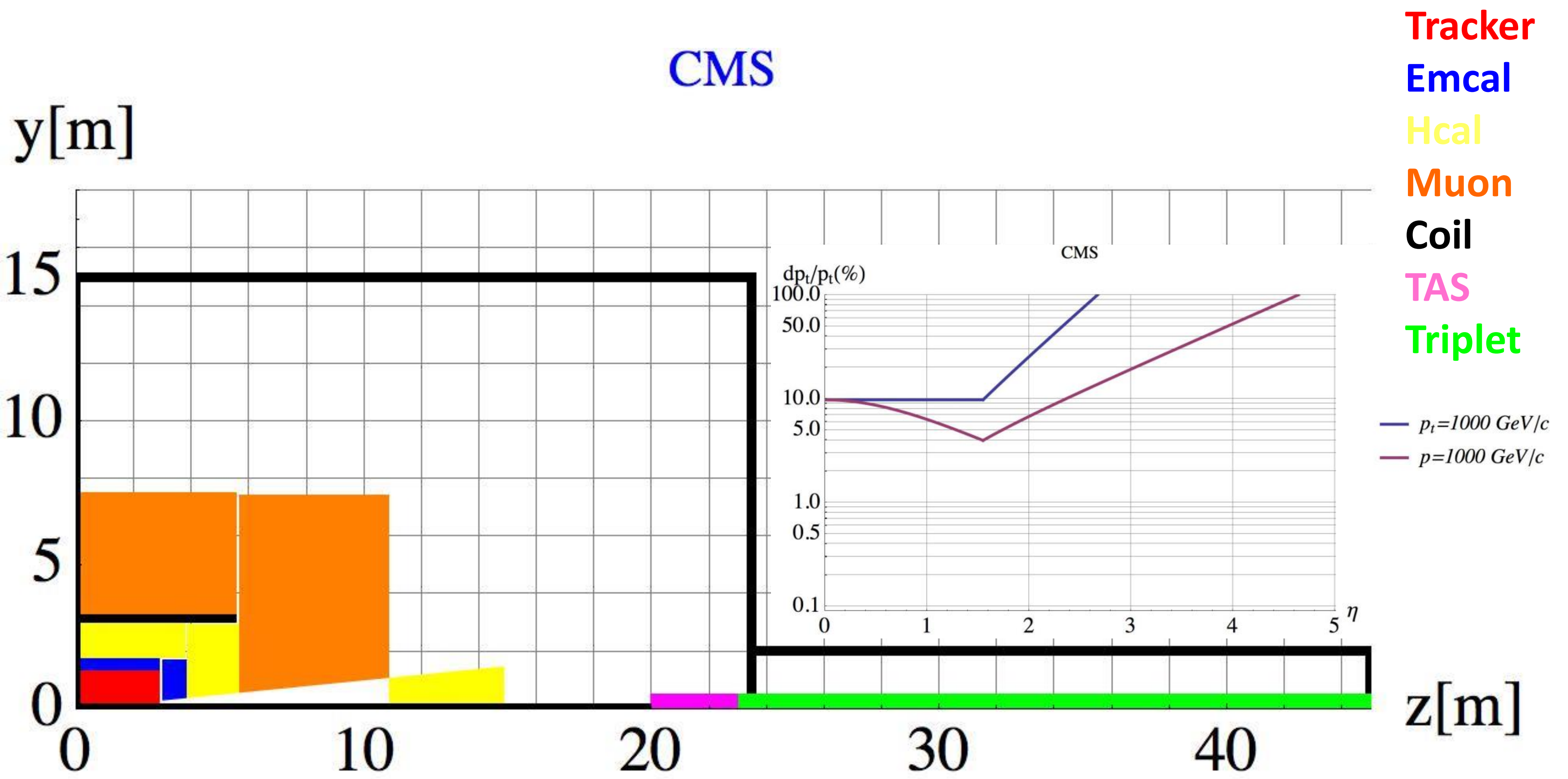
ATLAS

- LHC L*=23m, TAS inside the air core muon system, heavy shielding
- Tracker r=1m, B=2T thin coil in front of the calorimeters
- LArg ECAL, HCAL and 7.4 λ_{int} that returns the flux
- Large air core toroid, B=0.5T 'standalone muon system'

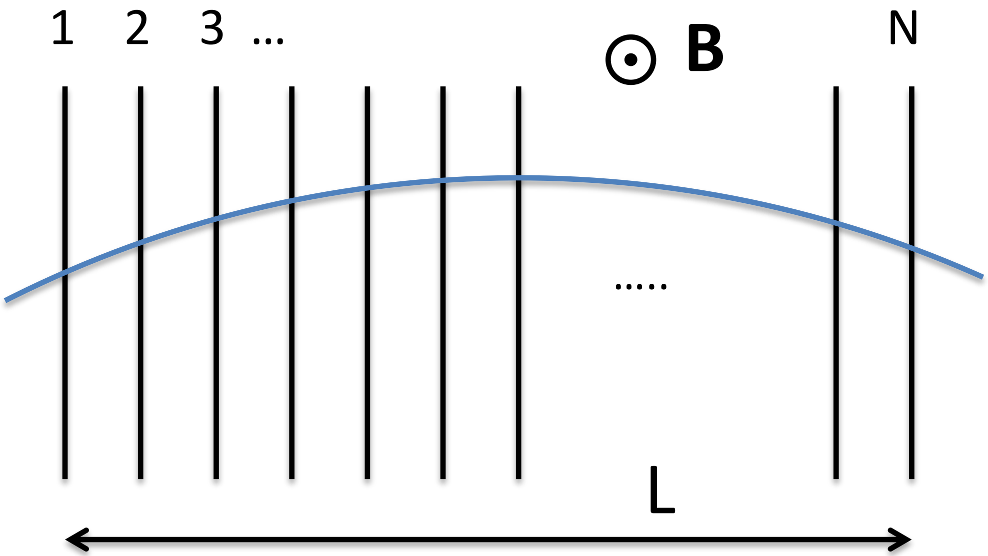


CMS

- LHC L*=23m, TAS shielding inside the cavern
- Tracker r=1.2m in B=3.8T
- Compact Crystal ECAL, 'short' HCAL of and 5.82 λ_{int}, cut at η = 3 to move FCAL away.
- Iron Yoke to return Flux, instrumented with muon chambers.
- CMS muons are relying on a properly working tracker.



Point Resolution and Multiple Scattering



σ … point resolution/plane

X_{tot}/X_0 … total material budget

Position Resolution

$$\frac{\Delta p_t}{p_t} = \frac{\sigma[m]\, p[\mathrm{GeV/c}]}{0.3\, B[T]\, L^2[m^2]} \sqrt{\frac{720\,(N-1)^3}{(N-2)\,N\,(N+1)\,(N+2)}}$$

$$\approx \frac{\sigma[m]\, p[\mathrm{GeV/c}]}{0.3\, B[T]\, L^2[m^2]} \sqrt{\frac{720}{N+4}}$$

Multiple Scattering

$$\frac{\Delta p_t}{p_t} = \frac{0.0136}{0.3\beta\, B[T]\, L[m]} \sqrt{\frac{X_{tot}}{X_0}} \sqrt{\frac{10}{7}\,\frac{12+(N-1)N^2(N+1)}{(N-2)N(N+1)(N+2)}}$$

$$\approx \frac{0.0136}{0.3\beta\, B[T]\, L[m]} \sqrt{\frac{X_{tot}}{X_0}} \sqrt{\frac{10}{7}}$$

$$\approx \frac{0.0542}{\beta\, B[T]\, L[m]} \sqrt{\frac{X_{tot}}{X_0}}$$

CMS

- LHC L*=23m, TAS shielding inside the cavern
- Tracker r=1.2m in B=3.8T
- Compact Crystal ECAL, 'short' HCAL of and 5.82 λ_{int}, cut at eta = 3 to move FCAL away.
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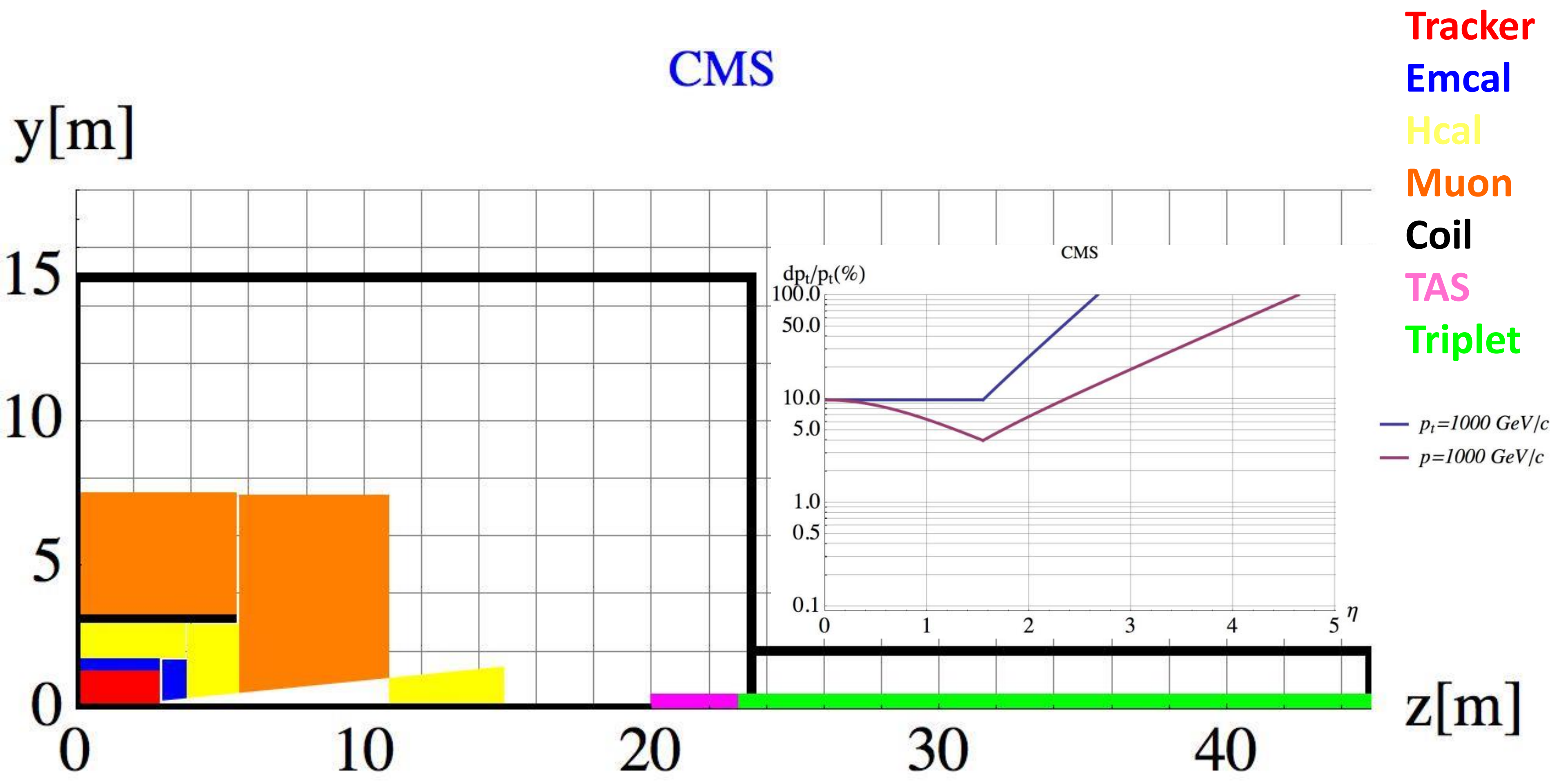
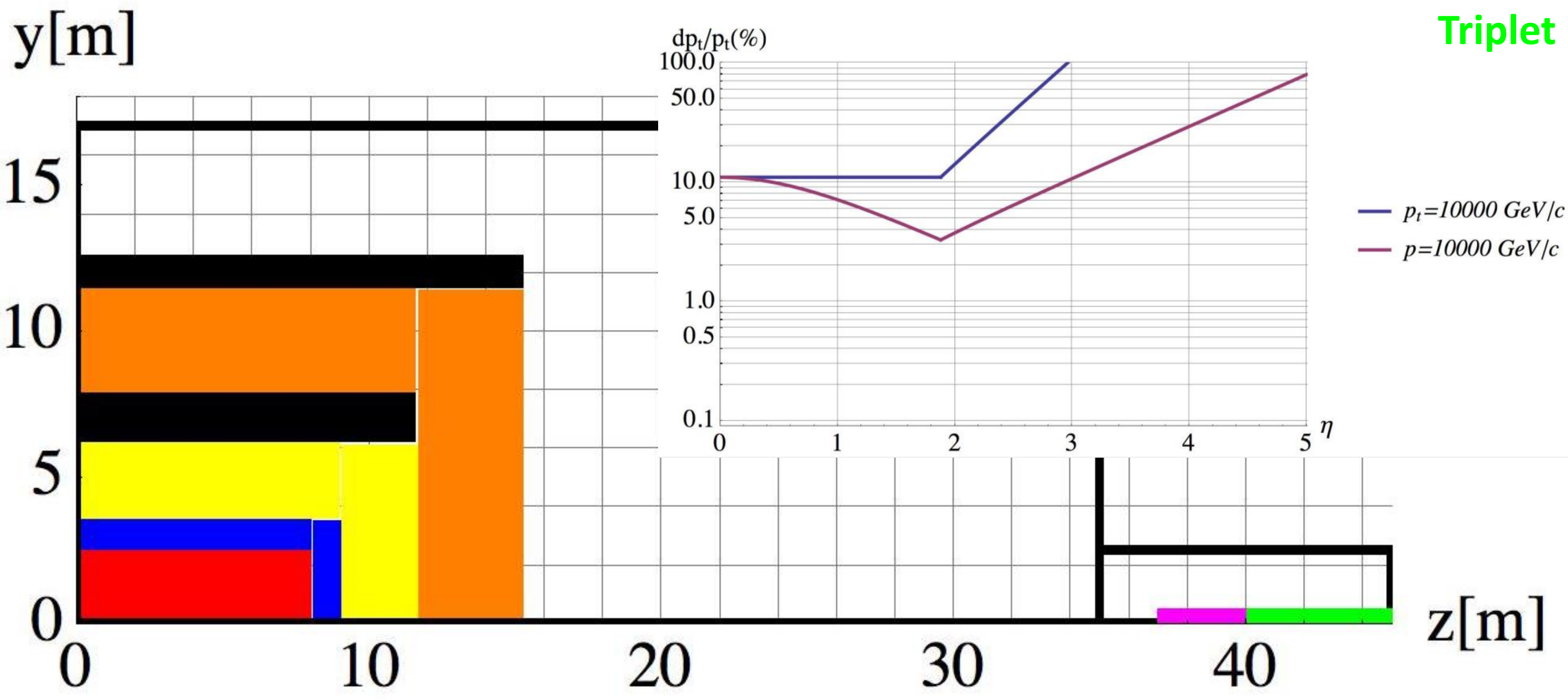


Twin Solenoid $7xBL^2$ scaling

- FCC L*=40m, hide inside tunnel
- Solenoid and shielding solenoid with B=6T in Tracker and B=3T in Muon System
- Tracker r=2.5m, L=16m, tracker resolution same as CMS detector
- ECAL+HCAL = 2.4m = 12 λ_{int}
- Momentum resolution gets marginal at η>3.

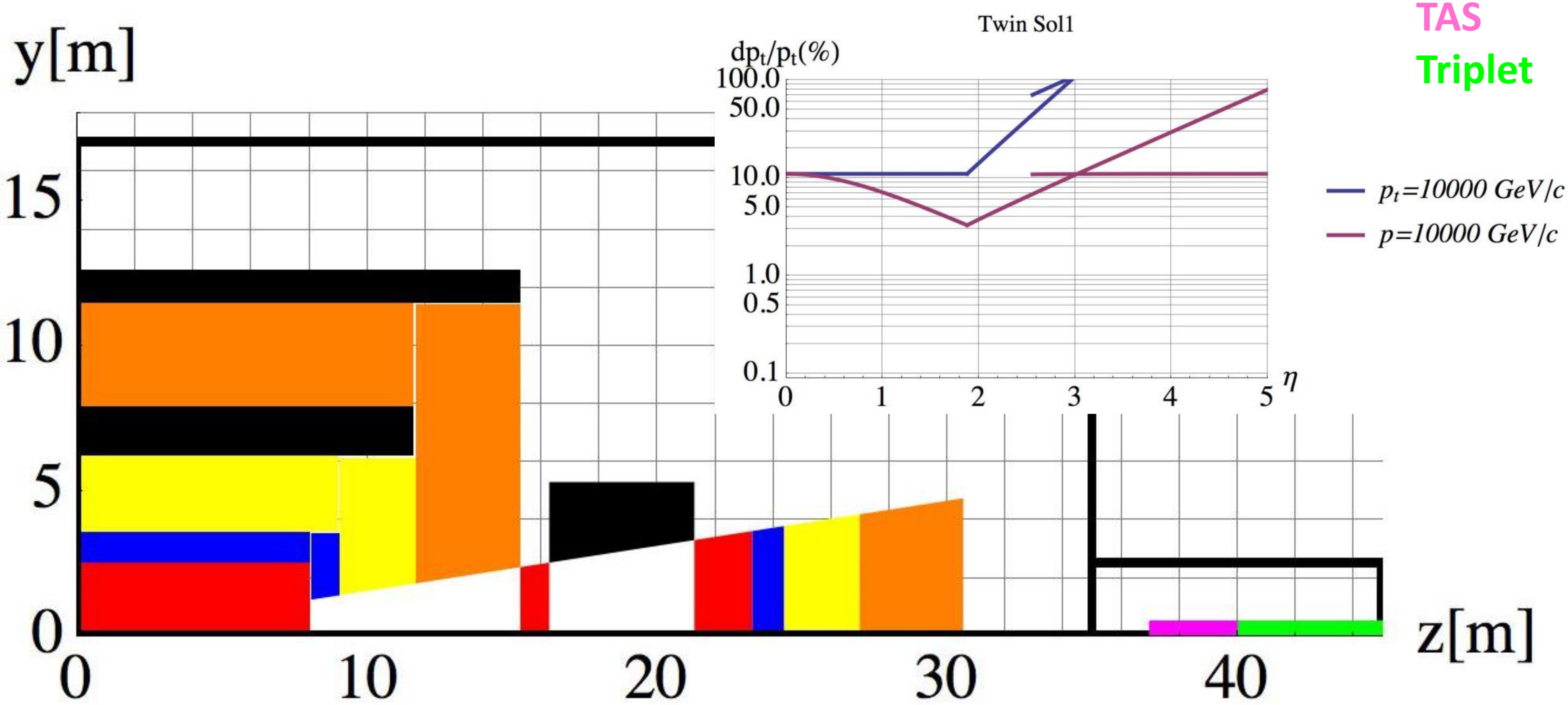
Tracker
Emcal
Hcal
Muon
Coil
TAS
Triplet



Twin Solenoid $7xBL^2$ scaling+Forward Dipole

- Opening at η = 2.5
- Adding a Dipole forward for momentum spectroscopy.
- Moving forward calorimeters to larger distance decreasing the particle densities and overlaps.
- Allows separate instrumentation and upgrade of forward detectors
- Integration and maintenance is a challenge

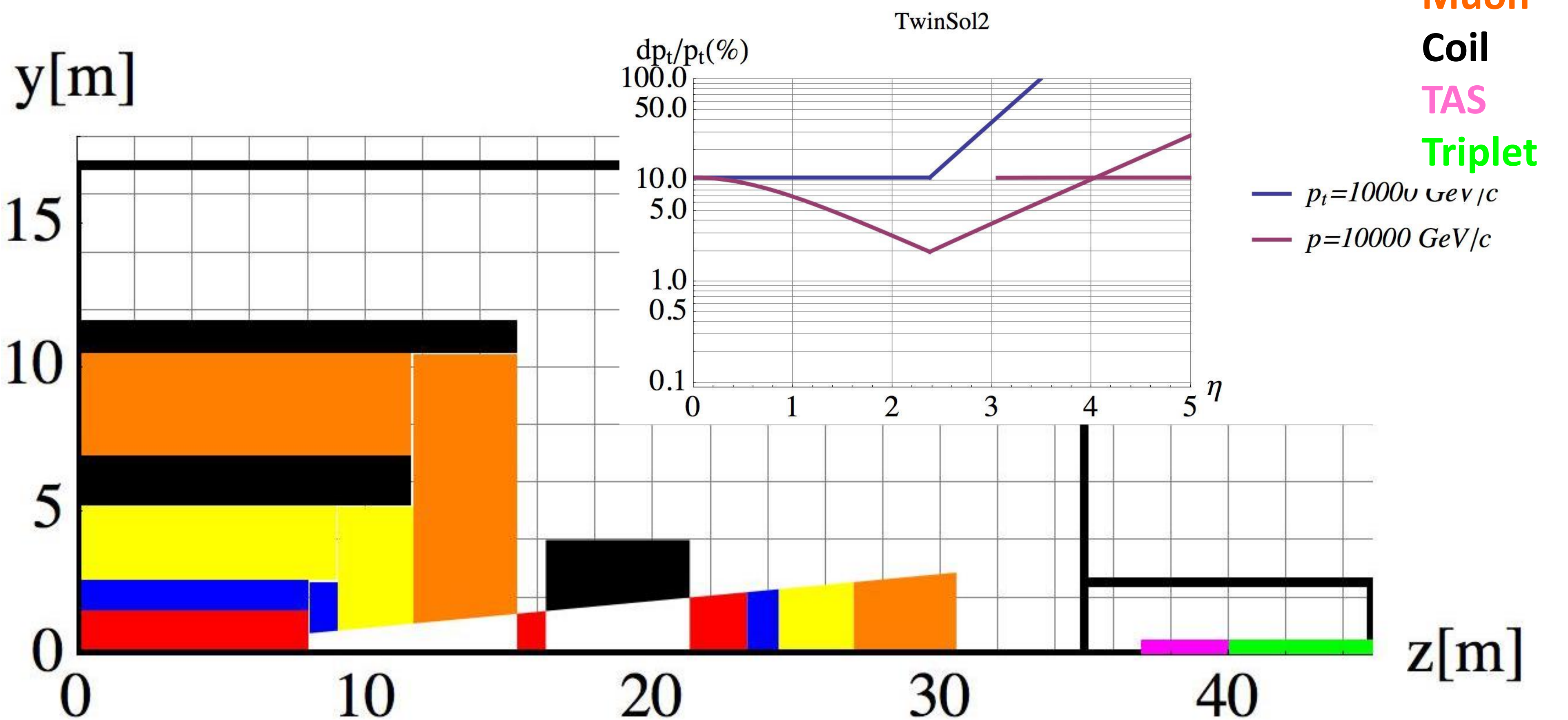
Tracker
Emcal
Hcal
Muon
Coil
TAS
Triplet



Twin Solenoid r=1.5m Tracker scaling+Forward Dipole

- Smaller tracker radius r=1.5m and improvement of resolution by factor 3 (7um, 15 layers) to keep same resolution
- Overall scale of solenoid stays the same if sower containment of 12 λ_{int} is required.
- Larger η acceptance for spectroscopy in central region
- Opening at eta η = 3.1 → smaller dipole needed

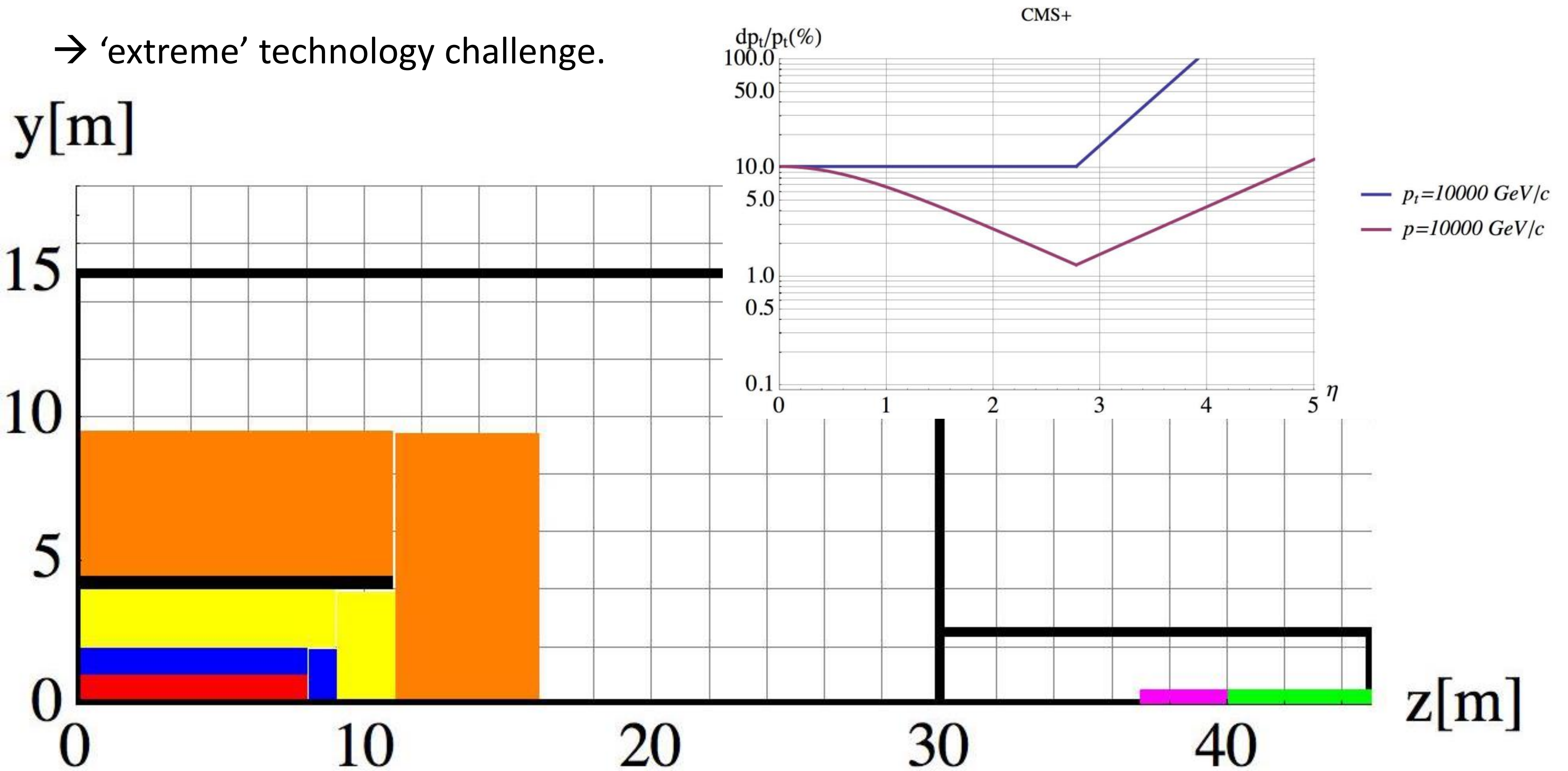
→ Push on tracker technology



CMS scaled detector with very long extreme resolution tracker

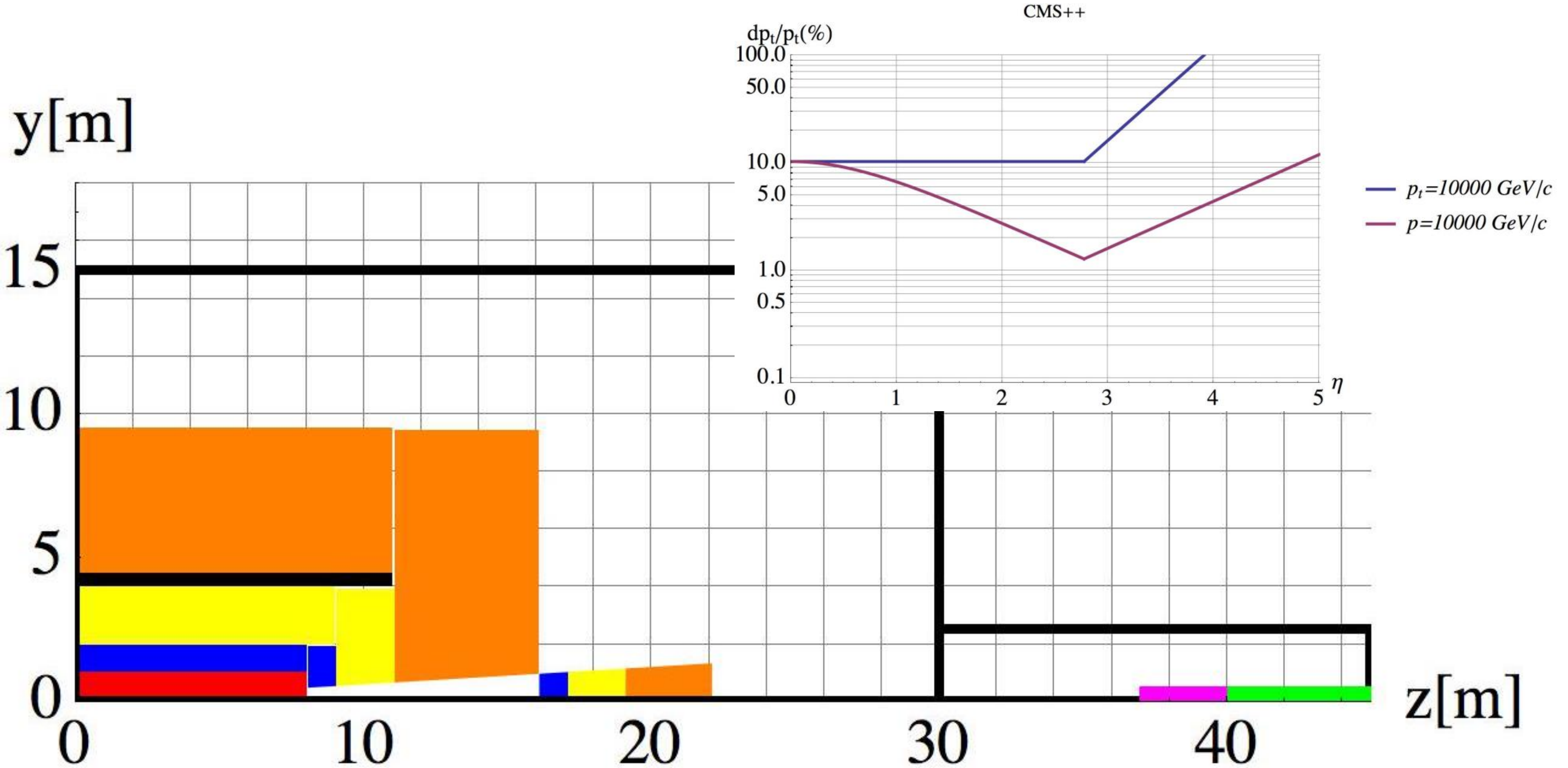
- Maximum coil producing 6T with affordable iron yoke (r=4m)
- Tracker radius 1m, resolution has to be improved factor 6 (15 layers, 3um resolution)
- 8m long tracker gives large η acceptance.
- 2.8m available for EMCAL+HCAL e.g. very compact W/Si particle flow calorimeters
- Very high granularity forward calorimeters needed
- Muon system a'la CMS

→ 'extreme' technology challenge.



CMS scaled detector, calorimetry moved to

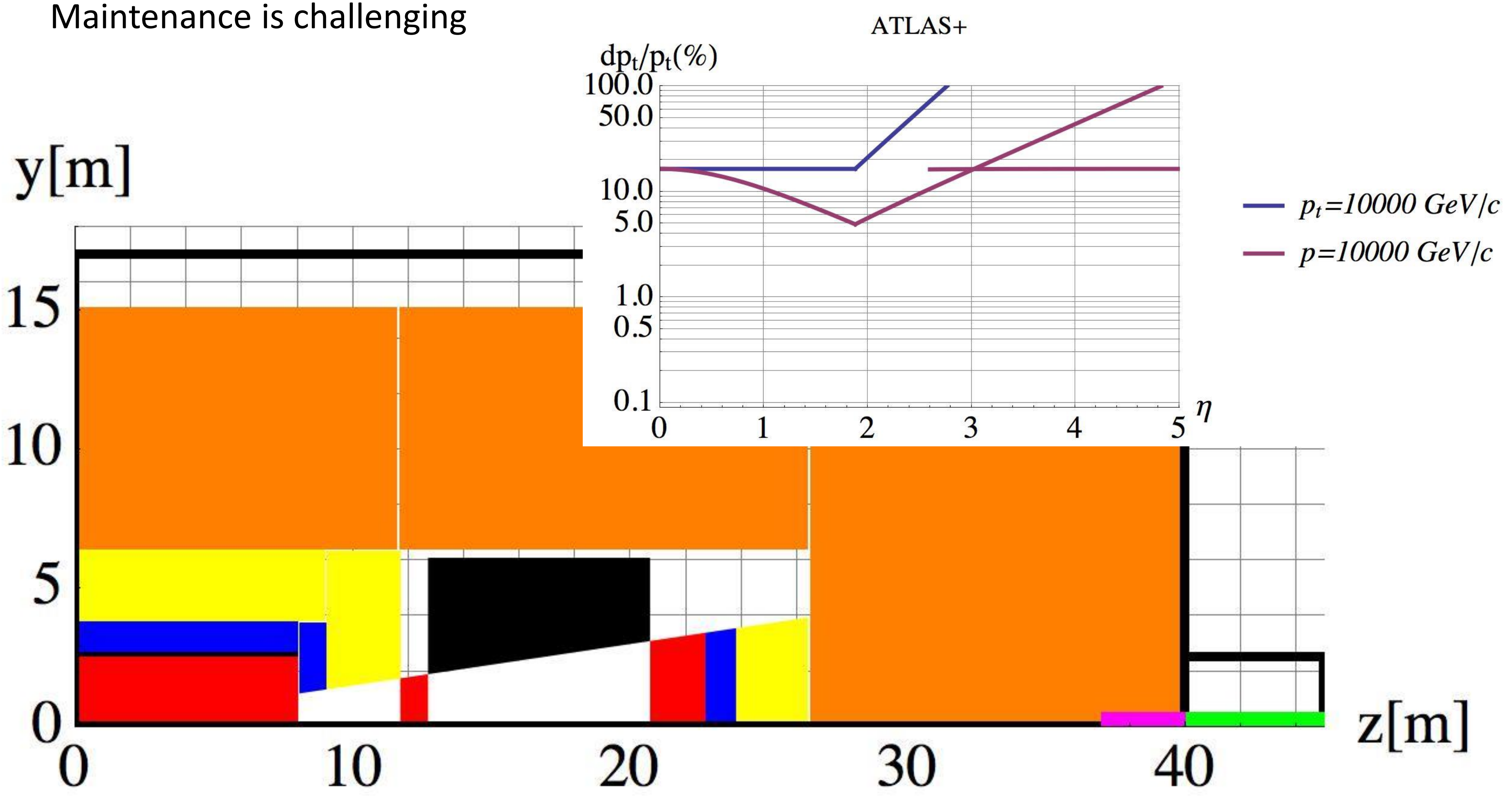
- Forward calorimetry moved to large distance from η = 3.5 for reduced occupancy and radiation load



Scaled ATLAS Detector 7xBL^2 with Integrated Dipole

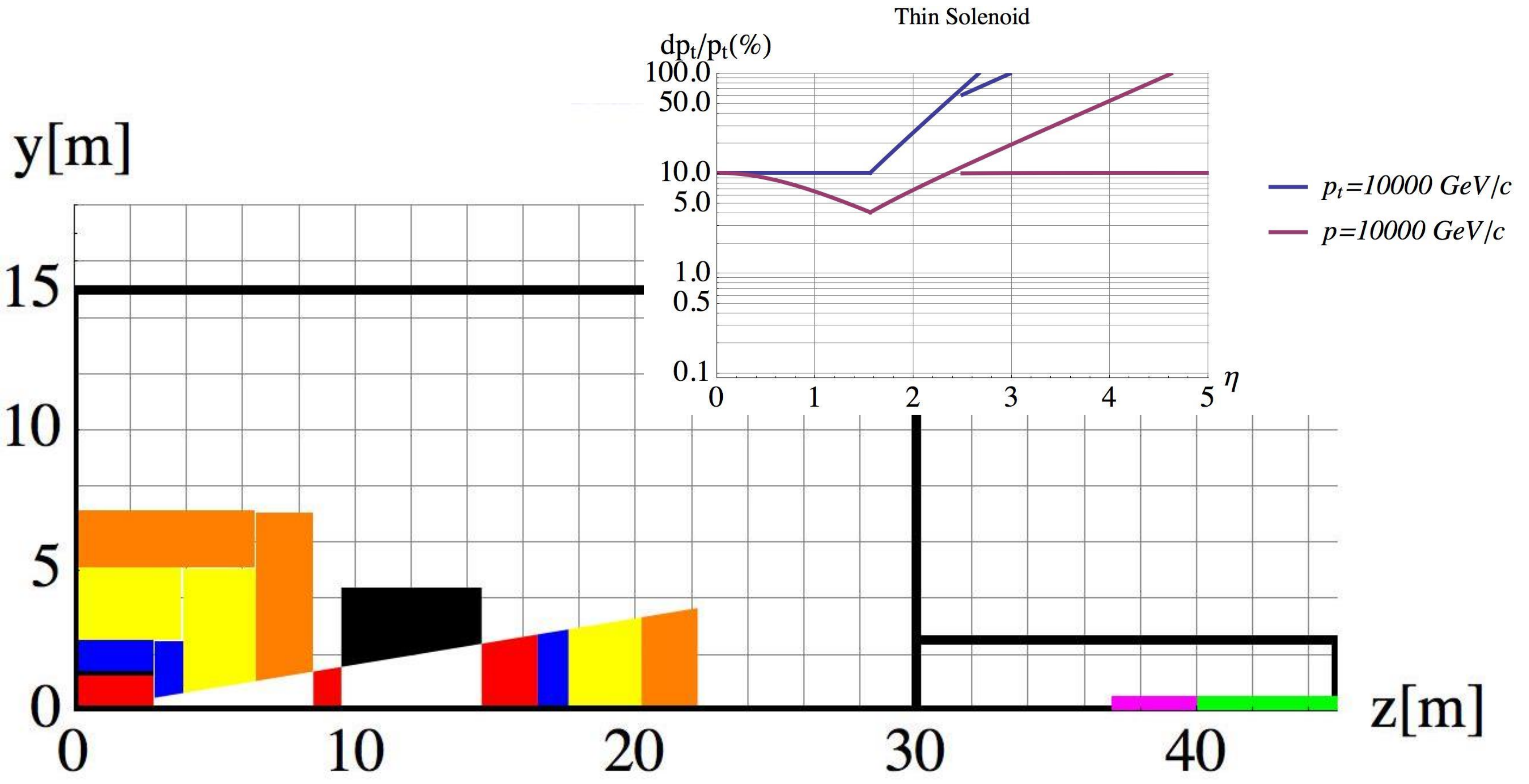
- 4T thin solenoid r=2.5m in front of ECAL
- Tracker r=2.5m, 16m long.
- Return flux through HCAL.
- Large Toroid for "standalon muon momentum spectroscopy" (needed ?)

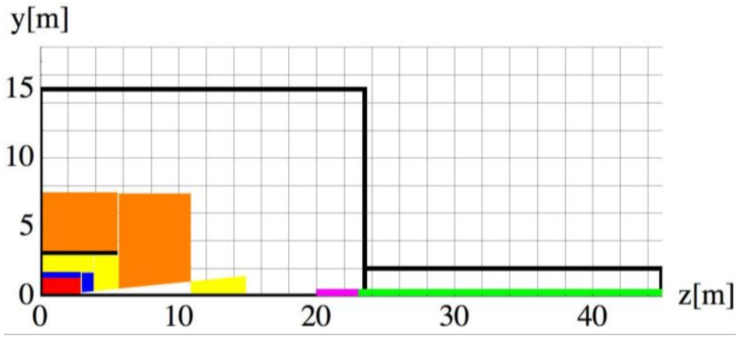
Maintenance is challenging



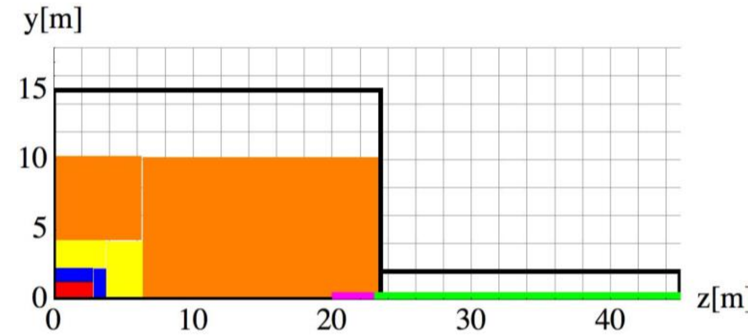
ATLAS type detector with muon tagging only

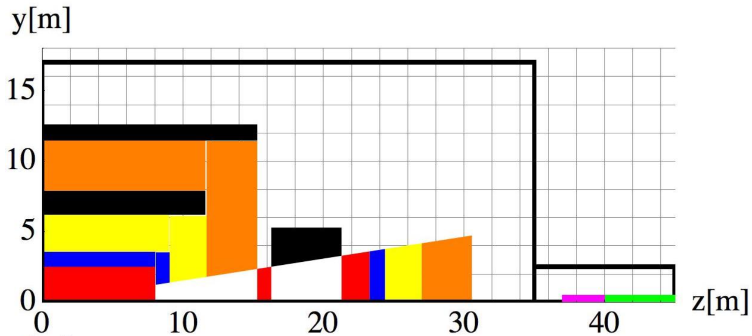
- Thin Coil B=4T of r=1.3m in front of ECAL
- Point resolution 3um in 15 layers
- Muon momentum measured on tracker, muon system only as Muon Indentifier





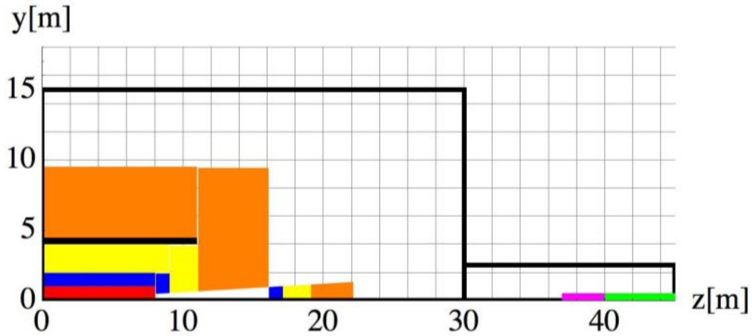
CMS & ATLAS



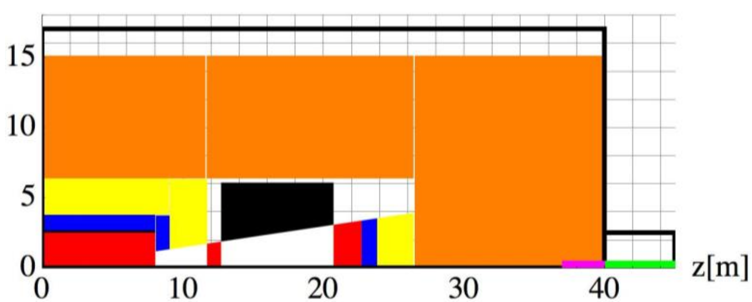


Twin Solenoid
+ Dipole

Popular at Present



CMS+



ATLAS+
+ Dipole

Key Point and Strategy

If the FCC hadron machine with 16T magnets, 5MW synchrotron radiation and a 100km tunnel can be realized, there is no doubt that a detector, that makes full use of the physics potential, can be built.

Much of detector technology is driven by silicon technology and computing power i.e. we can count on significant improvements.

Since the maximum energy an delivered luminosity are the key goals for the FCC-hh machine, the detector efforts should put minimal constraints at the machine efforts.

Conclusion on MDI Parameters

L* [25, 40]m or larger

Presently 60m is popular, we however stick to these numbers for now.

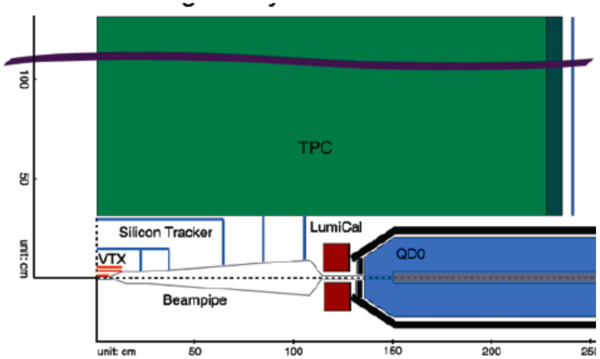
L_{peak} [$5x10^{34}$, $30x10^{34}$] $cm^{-2}s^{-1}$

→ N_{pileup} [170, 1020] at 25ns
→ N_{pileup} [34, 204] at 5ns

L_{int} [3, 30] ab^{-1}

Thes upper limits of L_{peak} and L_{int} should be read as Phase II assumptions for the MDI effort, and not as numbers specified for or promised by the machine !

FCC-ee, L* O(1.5m)
We don't envy them



14TeV → 100TeV:

Inelastic crossection 14 →100TeV changes from 80 → 108mb.

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.

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 $\langle N_{ch} \rangle$ 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 $\langle E_T \rangle$ 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 $\langle \Sigma p_T \rangle$ 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?

Integrated Luminosity

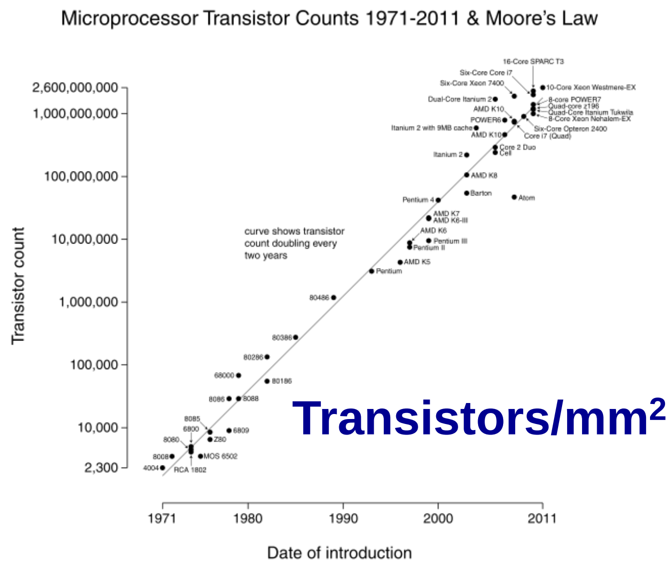
Estimate for radiation load of first Pixel Layer at r=3.7cm:

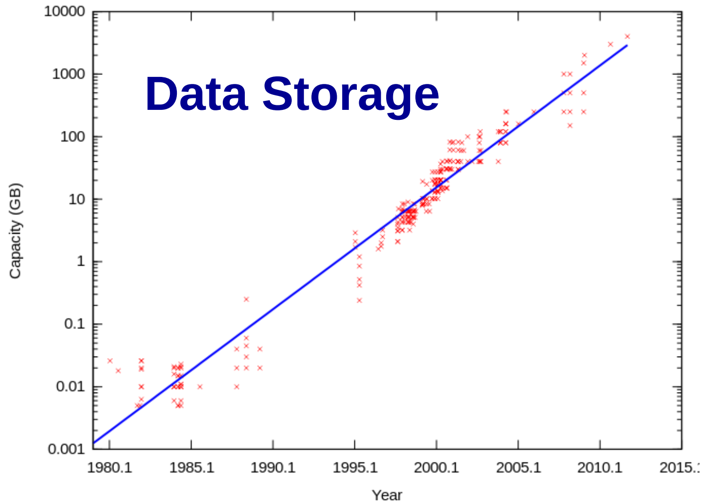
HL-LHC 3ab^{-1}
1MeVneq Fluence = 1.5x10^{16} cm^{-2}
Dose = 5MGy

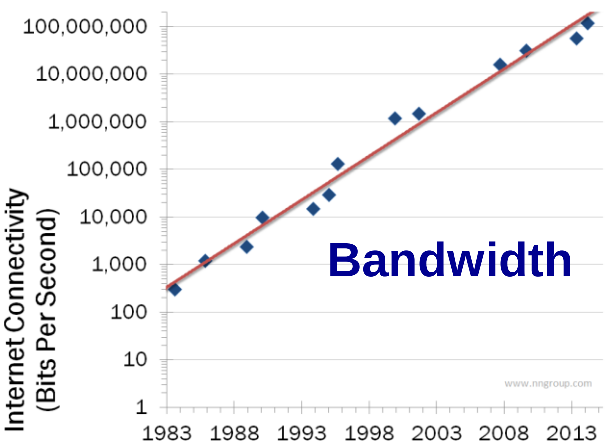
FCC 3ab^{-1}
1MeVneq Fluence = 3x10^{16} cm^{-2}
Dose = 10MGy

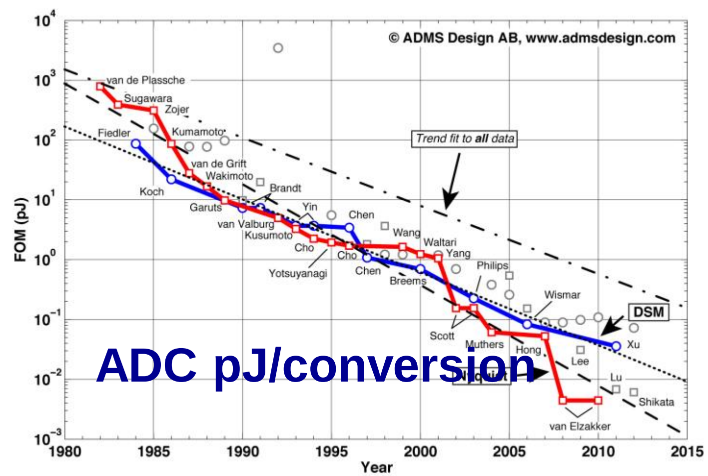
FCC 30ab^{-1}
1MeVneq Fluence = 3x10^{17} cm^{-2}
Dose = 100MGy

Prospects for ‚Microelectronics'









All these figures showed doubling times of < 2 years up to now ! Some scalings will stop, but different tricks might come in.

May dream about a factor 2^{10} = 1024 from 2014 – 2034 (of course optimistic)

This will allow major detector improvements !

Moore‘s Law

http://www.livescience.com/23074-future-computers.html

“If the doubling of computing power every two years continues to hold, then by 2030 whatever technology we're using will be sufficiently small that we can fit all the computing power that's in a human brain into a physical volume the size of a brain”,

explained Peter Denning, distinguished professor of computer science at the Naval Postgraduate School and an expert on innovation in computing.

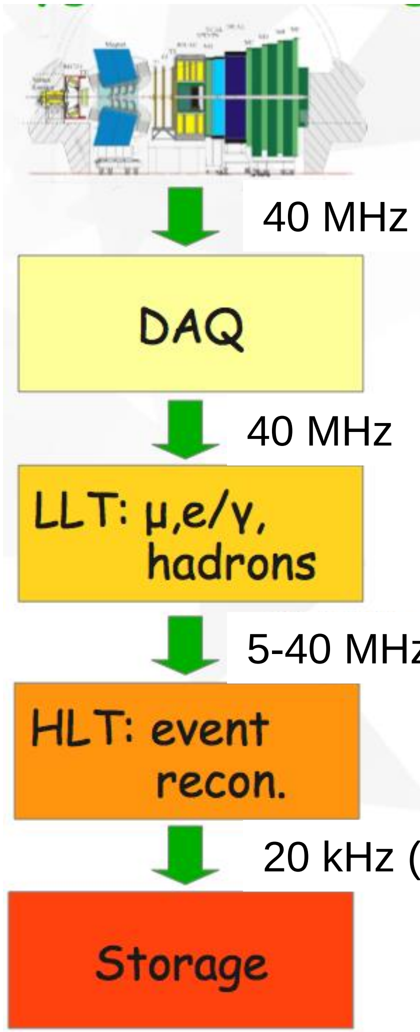
"Futurists believe that's what you need for artificial intelligence. At that point, the computer starts thinking for itself.“

→ **Computers will anyway by themselves figure out what to do with the data by 2035.**

Magnet systems and shielding will be rather conventional and can be worked out to some detail now.

For detector technology and computing power we are allowed to dream a bit.

LHCb & ALICE in 2018



40 MHz

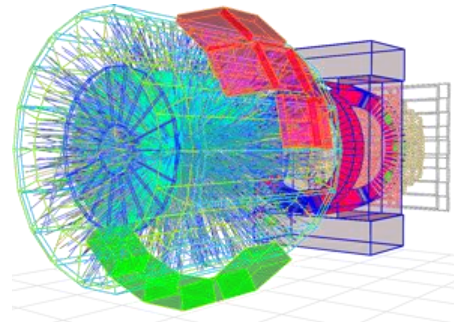
40 MHz

5-40 MHz

20 kHz (0.1 MB/event)

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

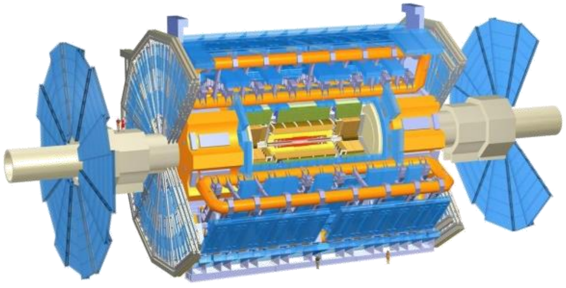
50 kHz (1.5 MB/event)

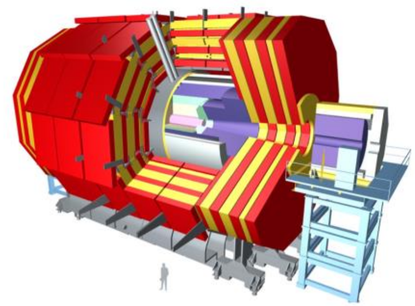
Storage

75 GB/s

← PEAK OUTPUT →

ATLAS & CMS @ Run 4





40 MHz

ATLAS		CMS
Level 1	0.5-1 MHz	Level 1
HLT	5-10 kHz (2MB/event)	HLT
Storage		10 kHz (4MB/event) Storage

5 TByte/s into PC farm for HLT selection.

Would be 200TByte/s without Level1

10-20 GB/s ← PEAK OUTPUT → 40 GB/s

Trigger ?

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

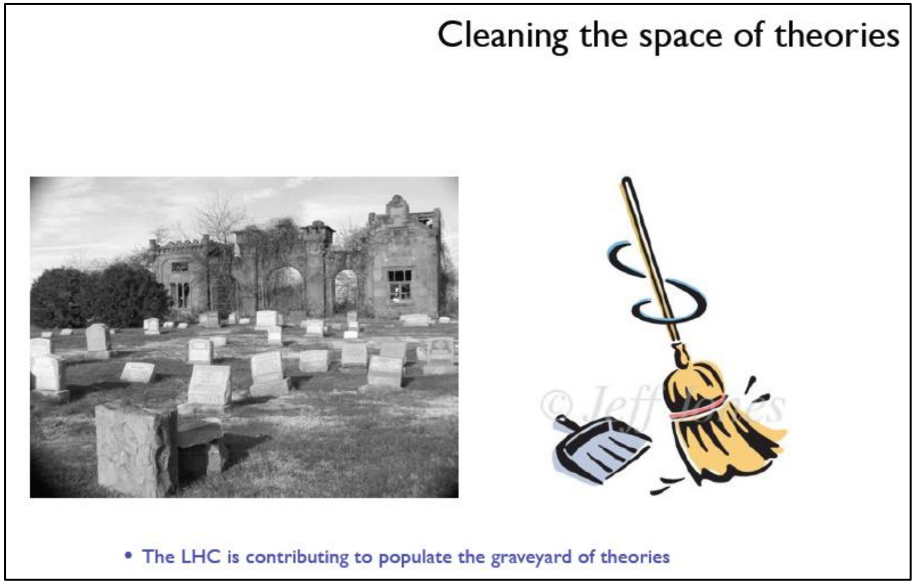
For 2022 this is considered too difficult.

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

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.

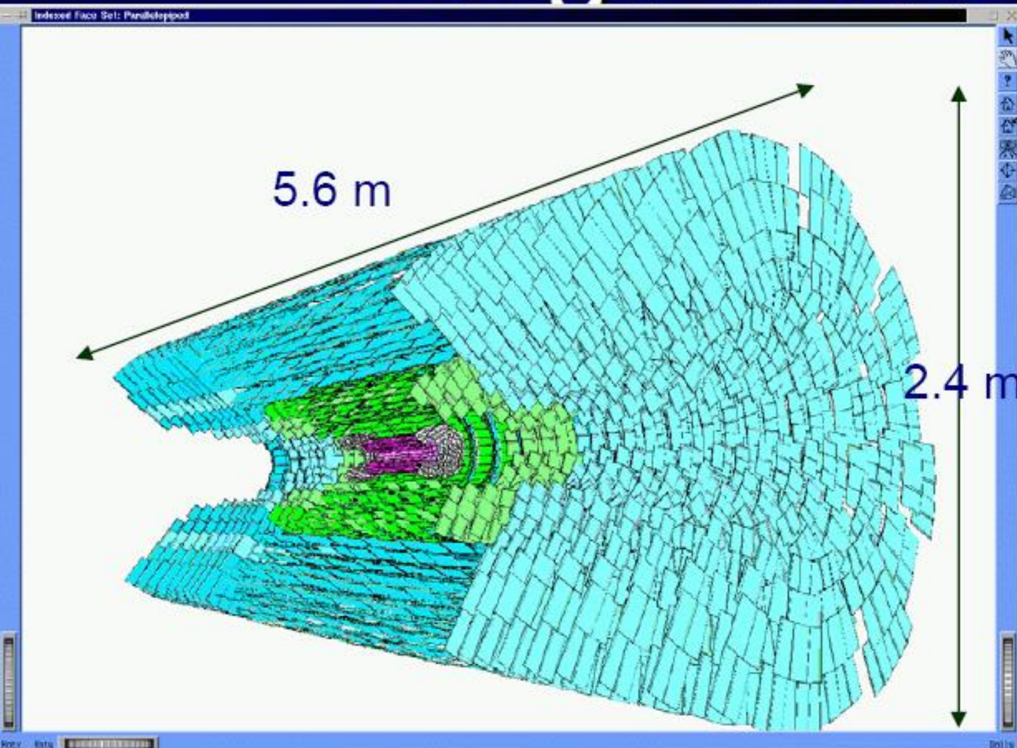
Detector Technologies

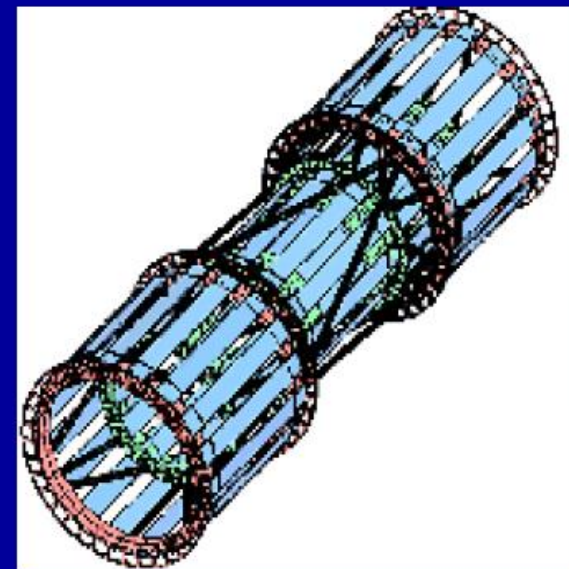


Luis Alvarez-Gaume

The graveyard of invented detectors that never made it to a successful large scale application is also significant !

Large Silicon Systems





CMS tracker (~2007)

12000 modules

~ 445 m^2 silicon area

~ 24,328 silicon wafers

~ 60 M readout channels

CDF SVX IIa (2001-)

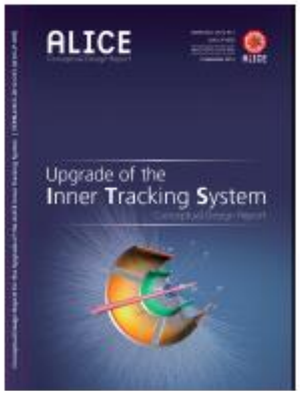
~ 11m^2 silicon area

~ 750 000 readout channels

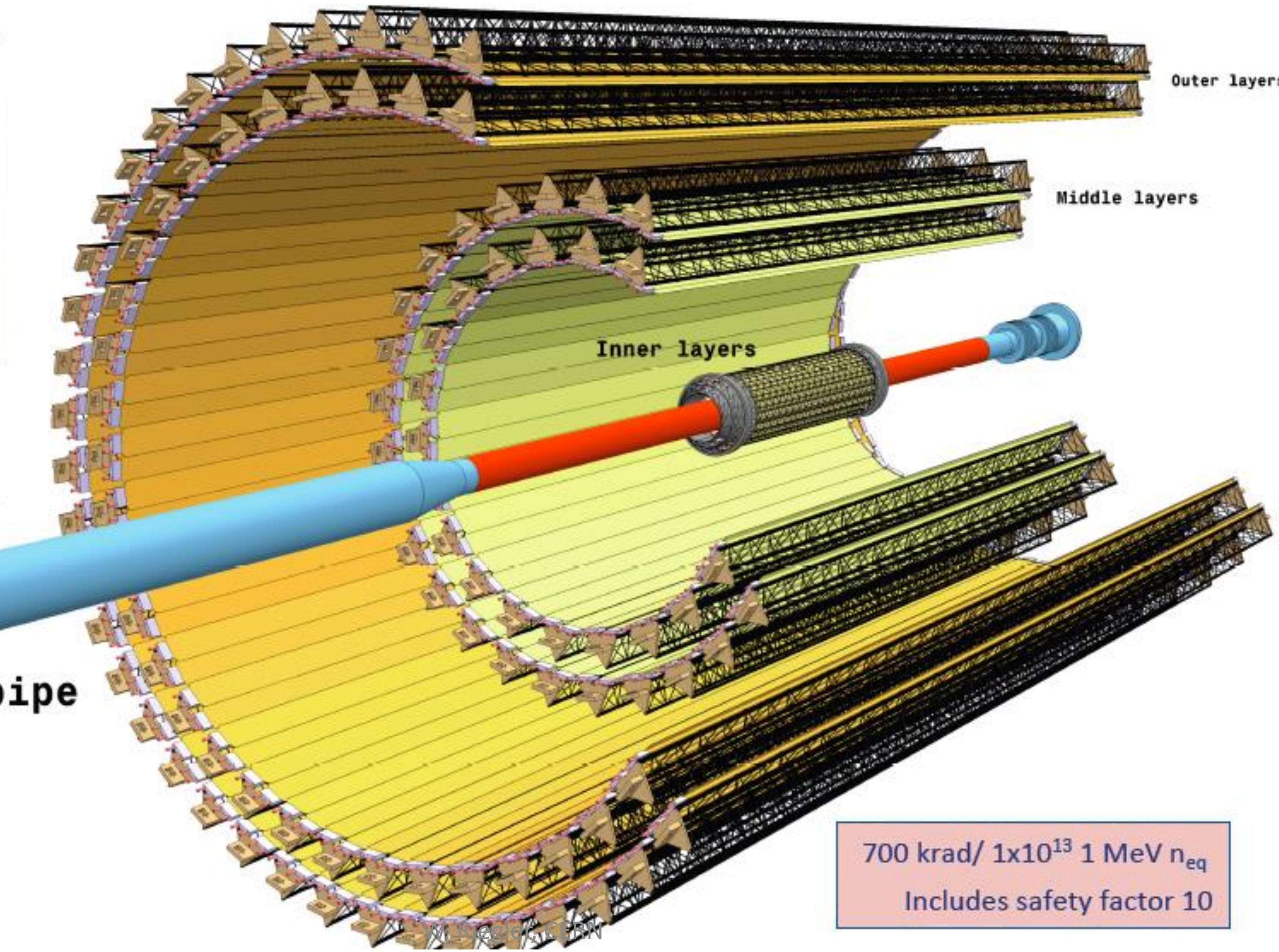
ALICE 2018 upgrade, 20x20um monolithic pixels

New ITS Layout

25 G-pixel camera
($10.3\ m^2$)



CERN-LHCC-2013-024



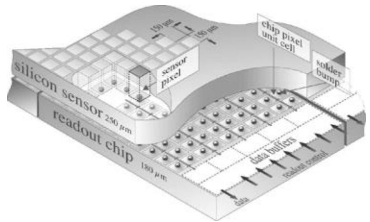
7 layers of MAPS

Radial coverage
22 – 406 mm

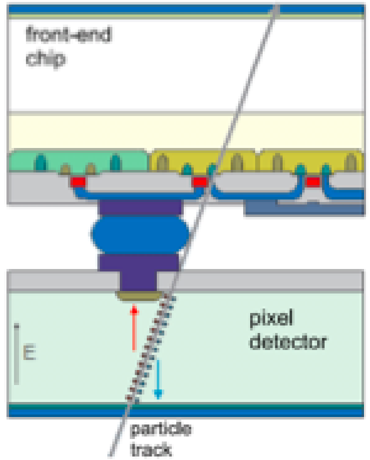
700 krad/ $1x10^{13}$ 1 MeV n_{eq}
Includes safety factor 10

CMOS Sensors

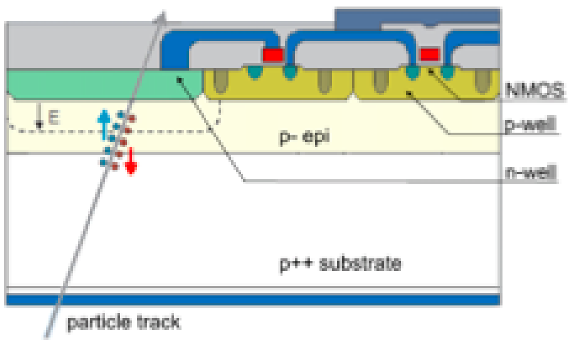
- CMOS sensors **contain sensor and electronics combined in one chip**
  - No interconnection between sensor and chip needed
- Standard CMOS processing
  - Wafer diameter (8")
  - Many foundries available
  - Lower cost per area
  - Small cell size – high granularity
  - Possibility of stitching (combining reticles to larger areas)
- Very low material budget
- CMOS sensors installed in STAR experiment
- Baseline for ALICE ITS upgrade (and MFT, LOI submitted to LHCC)



Hybrid Pixel Detector



CMOS (Pixel) Detector



Pixel Revolution Hybrid → Monolythic

Table 2.2: Chip design options.

Architecture (discriminator, read-out)	Pitch ($r\phi \times z$) (µm^2)	Integration time (µs)	Power consumption (mW cm^{-2})
MISTRAL (end-of-column, rolling-shutter)	22 × 33.3	30	200
ASTRAL (in-pixel, rolling-shutter)	24 × 31 36 × 31	20	85 60
CHERWELL (in-strixel[a], rolling-shutter)	20 × 20	30	90
ALPIDE (in-pixel, in-matrix sparsification)	28 × 28	4	< 50

[a] A strixel is a 128-pixel column over which the electronics are distributed.

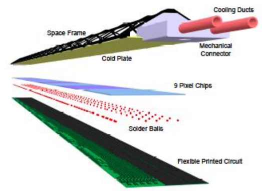
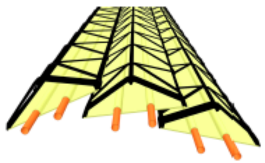
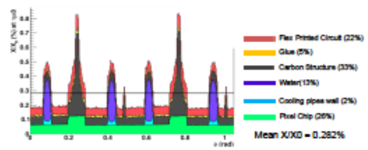
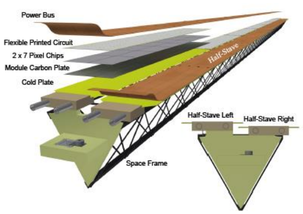
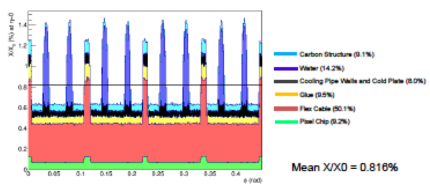


Figure 4.1: Schematic view of the Inner Barrel Stave.









→ **Technical design report for the upgrade of the ALICE inner tracking system** CERN-LHCC-2013-024

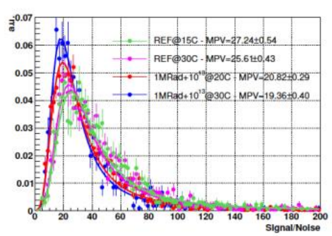


Figure 2.22: SNR of seed pixel measured with MIMOSA-32ter at the CERN-SPS, at two operating temperatures, before and after irradiation with the combined load of 1 Mrad and 10^{13} 1 MeV n_{eq}/cm^2.

Dramatic decrease in cost.

Very low power consumption, possibly <100mW/cm² i.e. simple water cooling

Ultra low material budget <0.3% for inner layers, <1% for outer layers.

Question of speed and radiation hardness:

At present,
integration time of 4µs (noise, electron diffusion)
radiation resistance up to few 10^{13} neq.

Development (next 20 years) towards larger (full) depletion will improve speed and radiation hardness significantly.

Also – in case one has a full pixel tracker one can use 1 or 2 layers with ‚fast' pixels to do the BCID (25ns or even 5ns) and then match the other hits.

With a full pixel tracker of 20x20um pixels one can pile up a fair amount of events before occupancy gets to large !!!

Top 10 IC Wafer Capacity Leaders* as of Dec-2013 (200mm-Equiv. Wafers per Month x1000)

2013 Rank	Company	Headquarters Region	Installed Capacity (K w/m)	% of Worldwide Total
1	Samsung	South Korea	1,867	12.6%
2	TSMC	Taiwan	1,475	10.0%
3	Micron**	Americas	1,380	9.3%
4	Toshiba/SanDisk	Japan	1,177	8.0%
5	SK Hynix	South Korea	1,035	7.0%
6	Intel	Americas	961	6.5%
7	ST	Europe	551	3.7%
8	UMC	Taiwan	520	3.5%
9	GlobalFoundries	Americas	482	3.3%
10	TI	Americas	441	3.0%
—	Total	—	9,889	66.8%

*Includes shares of capacity from joint ventures.

**Includes the former Elpida and Rexchip fabs.

Source: Companies, IC Insights

200mm wafer = $0.03 m^2$

10^6 wafers= 30 000 m^2

An FCC detector with $3000 m^2$ = 3 days

Simulation setup for FCC

- One framework for simulation/reconstruction

  - Gaudi framework chosen
- One single detector description source

  - for simulation, digitisation, fast simulation & reconstruction

  - xml-based DD4Hep chosen
- Main idea

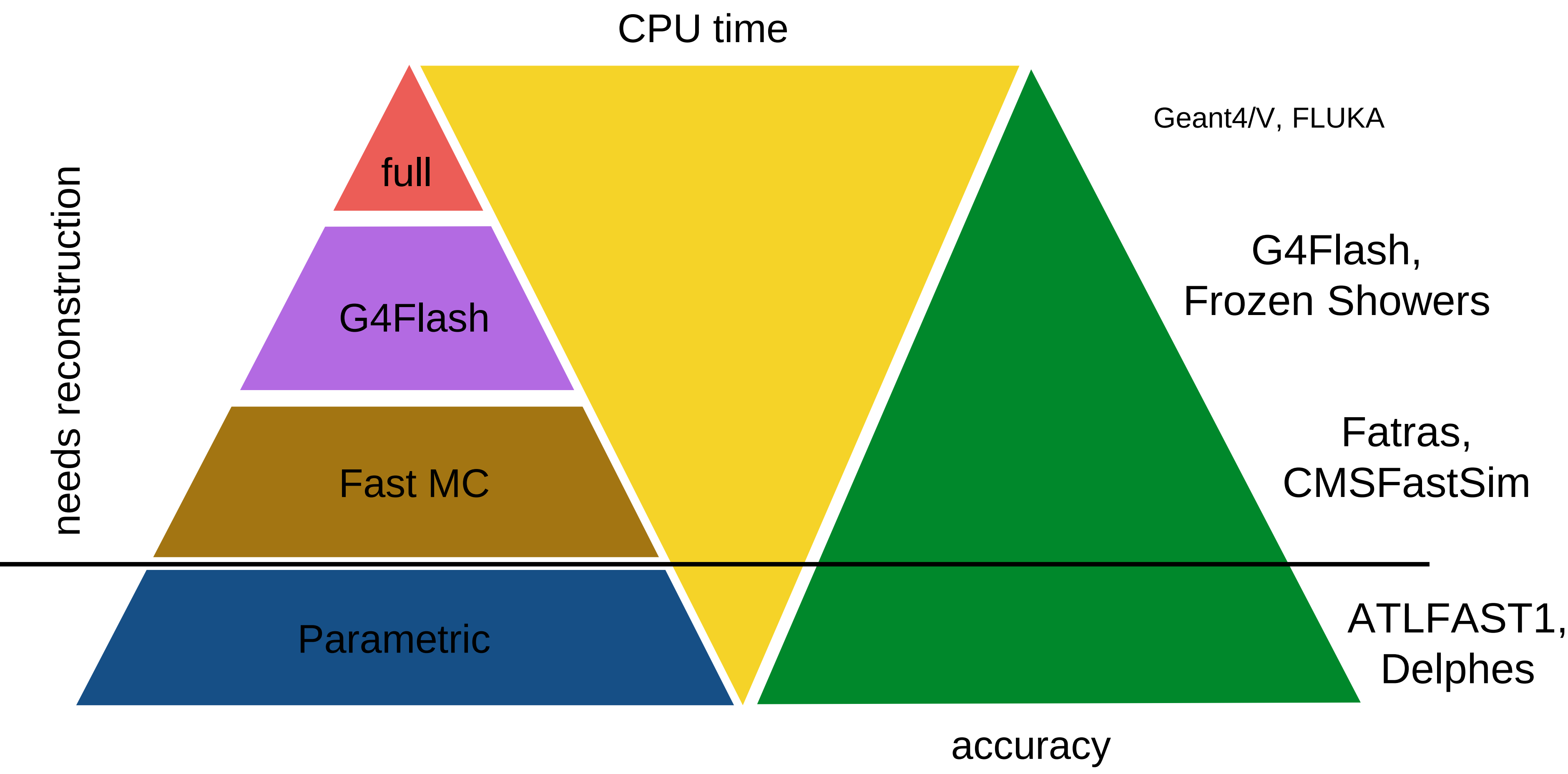
  - single simulation framework that allows layout prototyping in fast simulation

  - layouts can then be evolved towards full simulation in the same setup

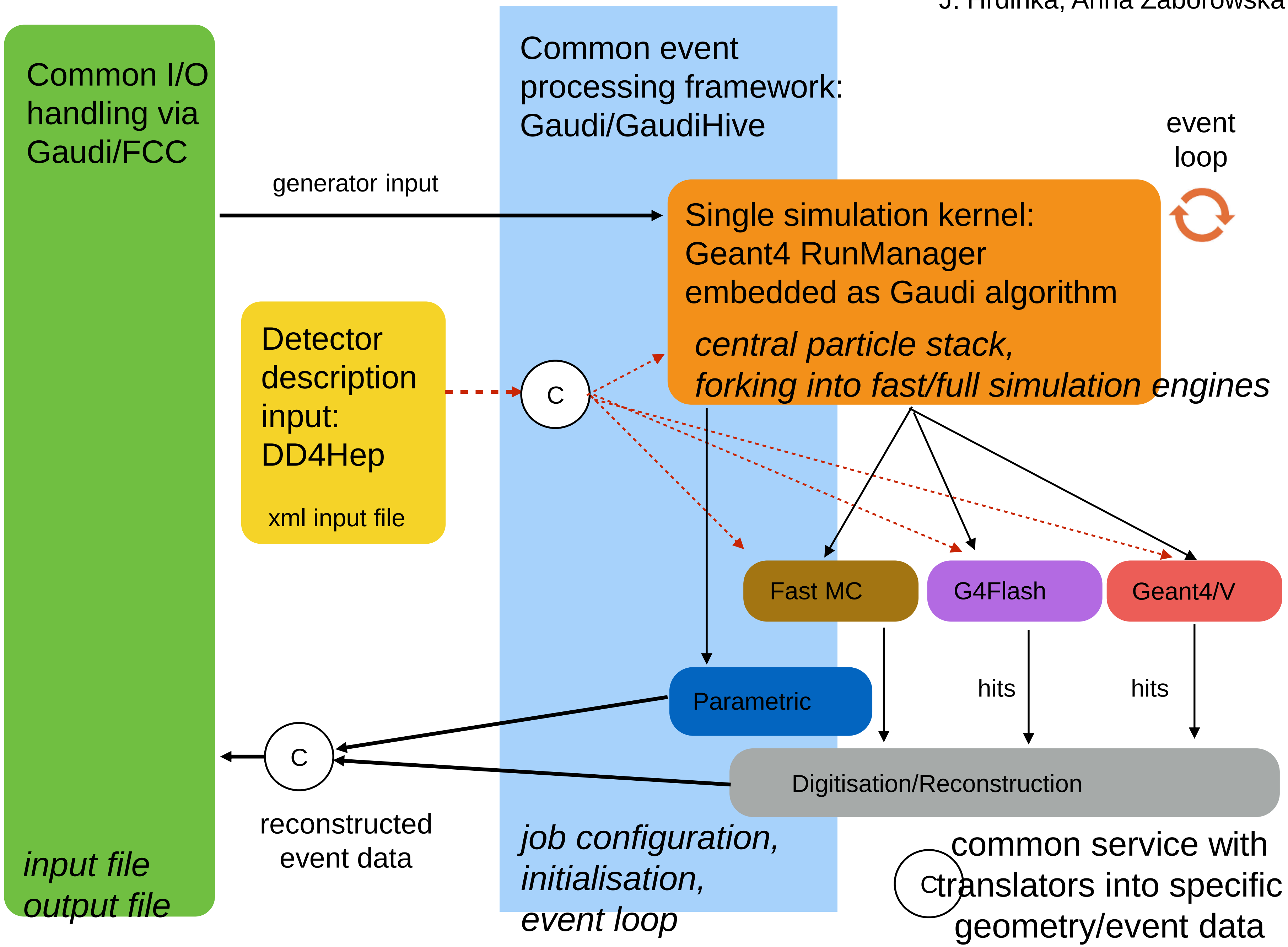
Several different MC exist in HEP

A. Salzburger, B. Hegner,
J. Hrdinka, Anna Zaborowska

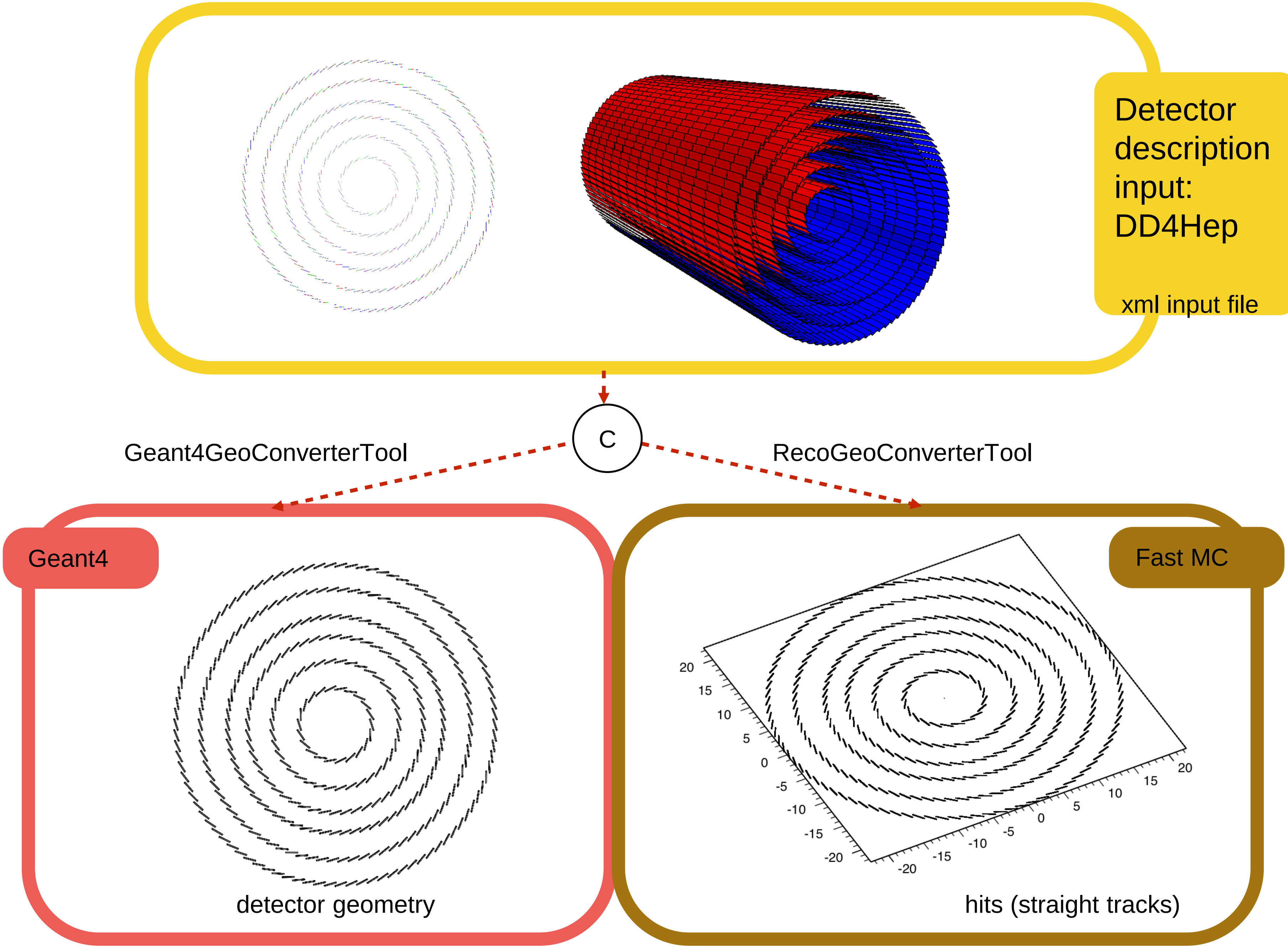
- Different speed with different accuracy



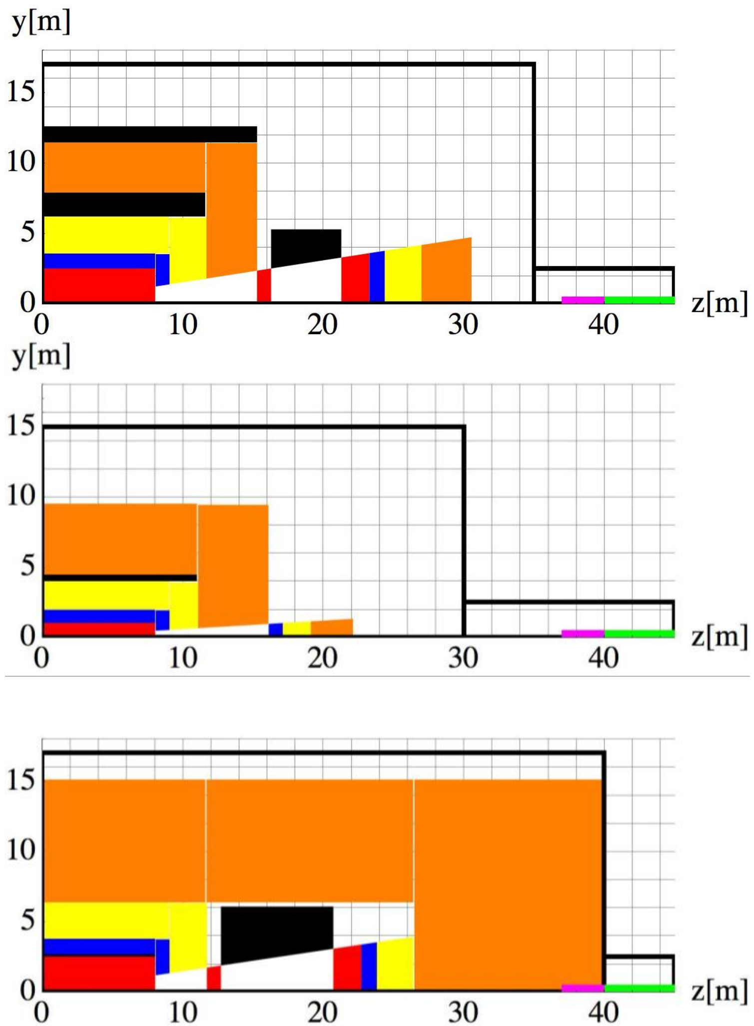
A. Salzburger, B. Hegner,
J. Hrdinka, Anna Zaborowska



J. Hrdinka


Detector description input: DD4Hep
xml input file
C
Geant4GeoConverterTool
RecoGeoConverterTool
Geant4
detector geometry
Fast MC
20
15
10
5
0
-5
-10
-15
-20
hits (straight tracks)

Conclusion



Next:

Define granularities and basic parametrization.

Simulation of benchmark channels with parametrized detector response.

Explore magnets, technologies.

Medium term:

Delevop strategy how do we push R&D in an effective way once the HL-LHC R&D is concluded.