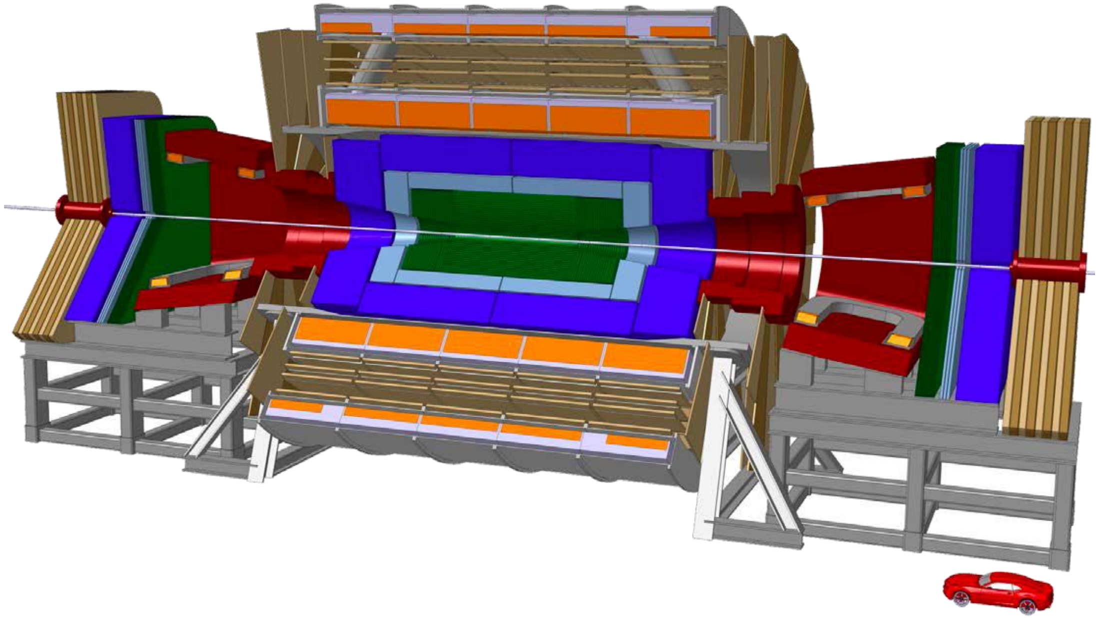
Impressions from the recent FCC workshop in Washington

http://indico.cern.ch/event/340703/overview



Lucie Linssen, CERN

Slides taken from: Patrizia Azzi, Michael Benedikt, Benedikt Hegner, Werner Riegler, Daniel Schulte, Herman Ten Kate, Frank Zimmermann

Key Parameters FCC-hh

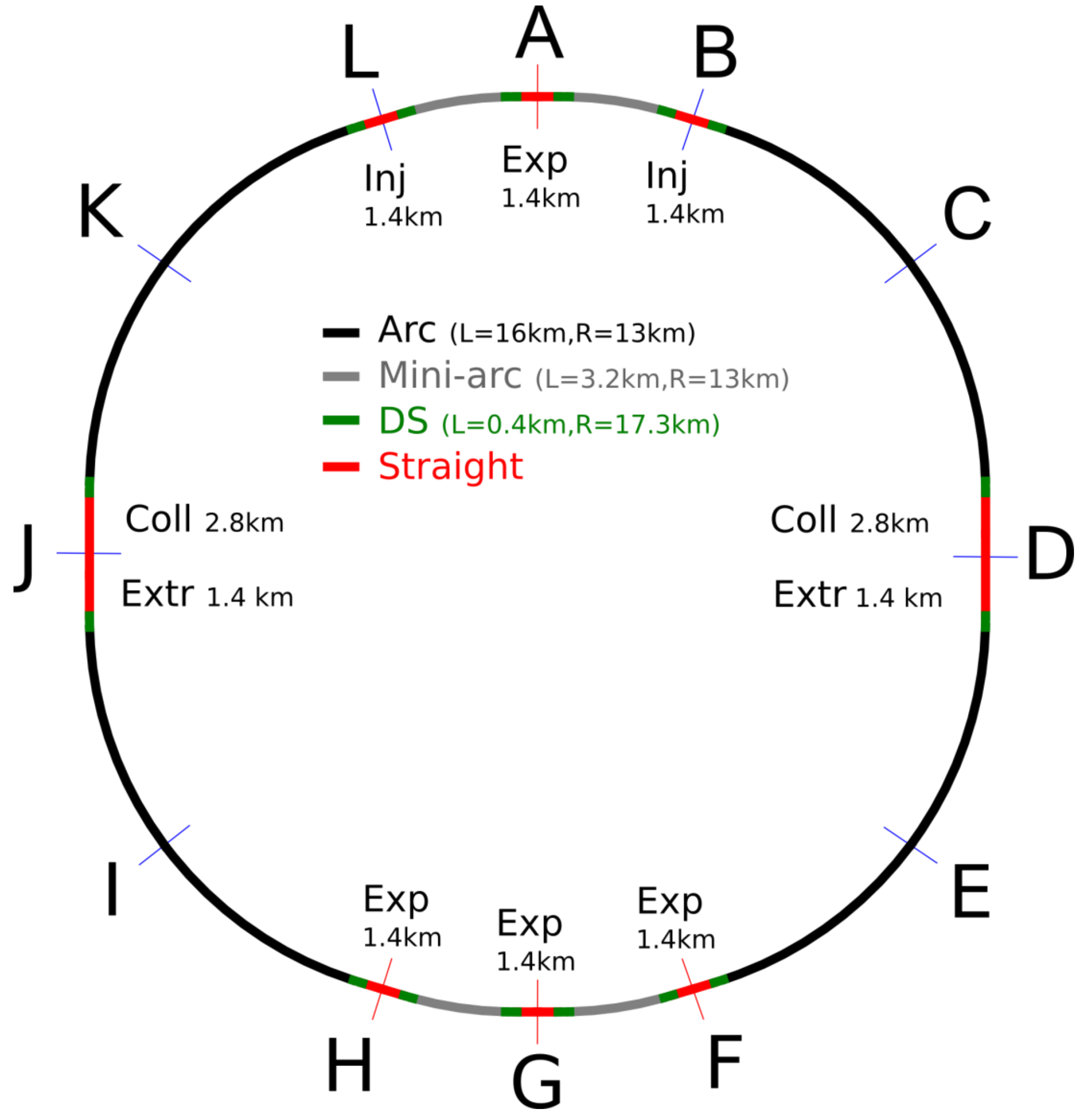
Parameter	FCC-hh	LHC
Energy [TeV]	100 c.m.	14 c.m.
Dipole field [T]	16	8.33
# IP	2 main, +2	4
Luminosity/IP$_{main}$ [cm^{-2}s^{-1}]	5 - 25 x 10^{34}	1 x 10^{34}
Stored energy/beam [GJ]	8.4	0.39
Synchrotron rad. [W/m/aperture]	28.4	0.17
Bunch spacing [ns]	25 (5)	25

Michael Benedikt

Preliminary Layout

First layout developed

- Two high-luminosity experiments (A and G)
- Two other experiments (F and H)
- Two collimation lines
- Two injection and two extraction lines
- Insertion lengths are based on first order estimates, will be reviewed as optics designs are made



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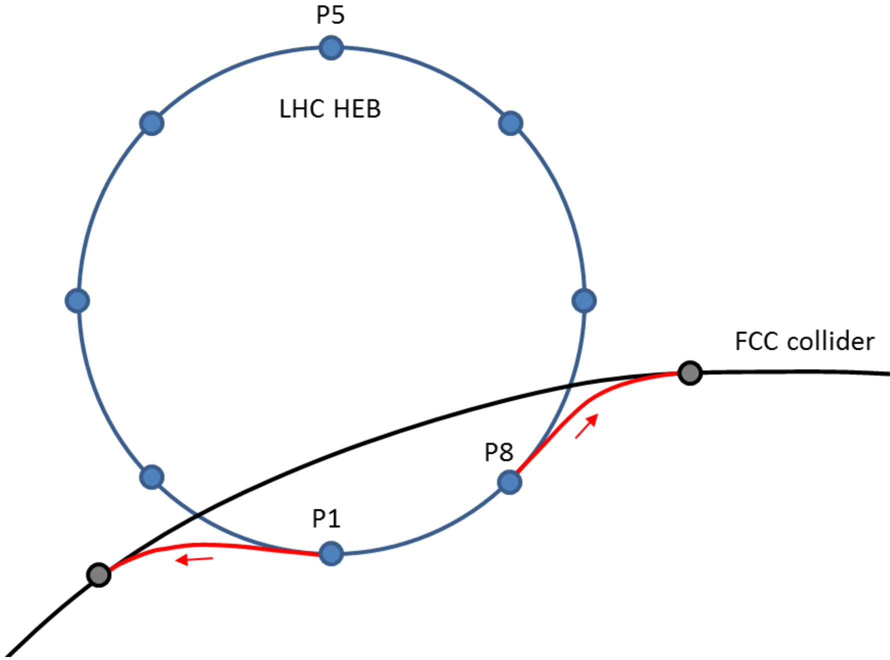
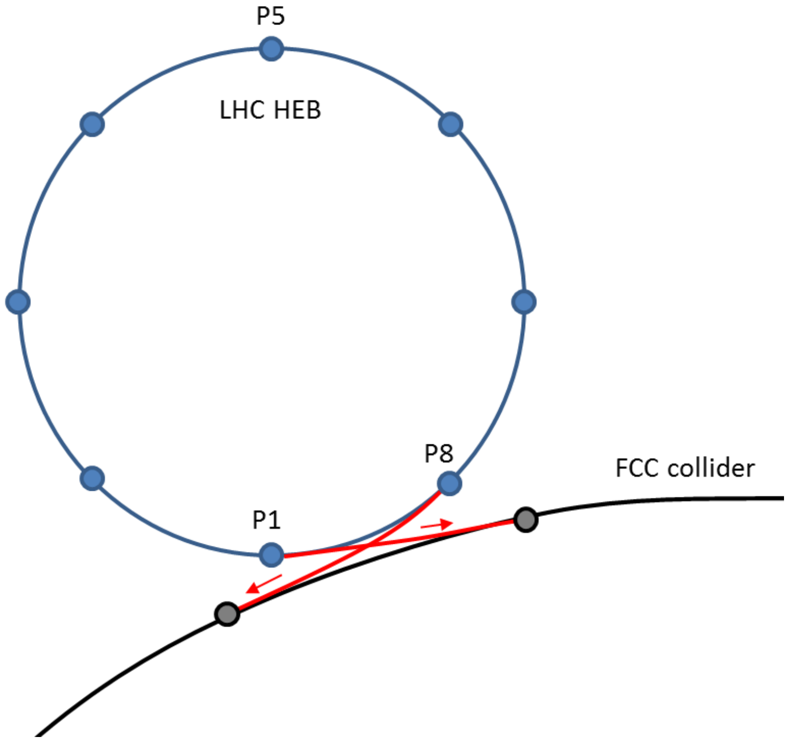
Injection and Site Study

SPS, LHC or injector in collider tunnel considered as injectors

Injection energy 3.3TeV (could be increased a bit if LHC is used)





Preliminary conclusions:

- 93km seems to fit the site really well, likely better than smaller ring
- 100km tunnel appears possible
- The LHC could be used as an injector

FCC-hh experiment environment (1)

Some basic assumptions:

- pp centre-of-mass energy: 100 TeV
- Luminosity: 5×10^{34} $cm^{-2}s^{-1}$ in the 1st phase
  30×10^{34} $cm^{-2}s^{-1}$ in a 2nd phase
- Pile-up: [170, then 1020] events at 25 ns spacing
  [34, then 204] events at 5 ns spacing
- Average/maximum occupancy: ~50% higher than at 14 TeV
- Integrated luminosity: 3 ab^{-1} for the 1st phase
  30 ab^{-1} for a 2nd phase
- Expected radiation level: $3x10^{16}$ cm^{-2} 1MeVneq fluence (1st phase)
  10MGy Dose (1st phase)
- η coverage: up to η= 4 (~2 degrees) or η= 6 (~0.3 degrees)

Daniel Schulte

FCC-hh experiment environment (2)

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.

Werner Riegler

Approximate FCC-hh Overall Needs

Tracking: Momentum resolution H15% 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.

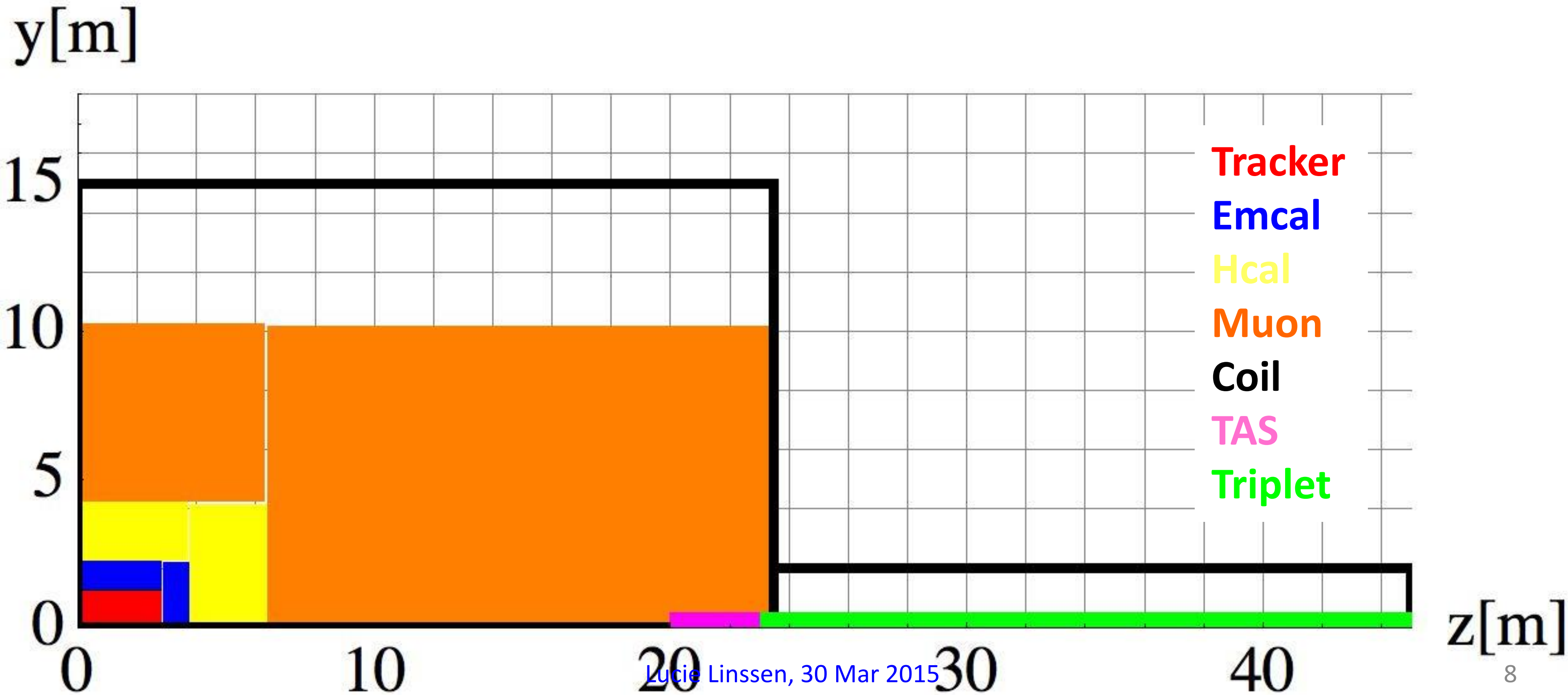
B-tagging, timing for pileup rejection etc. …

Werner Riegler

Werner Riegler

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'



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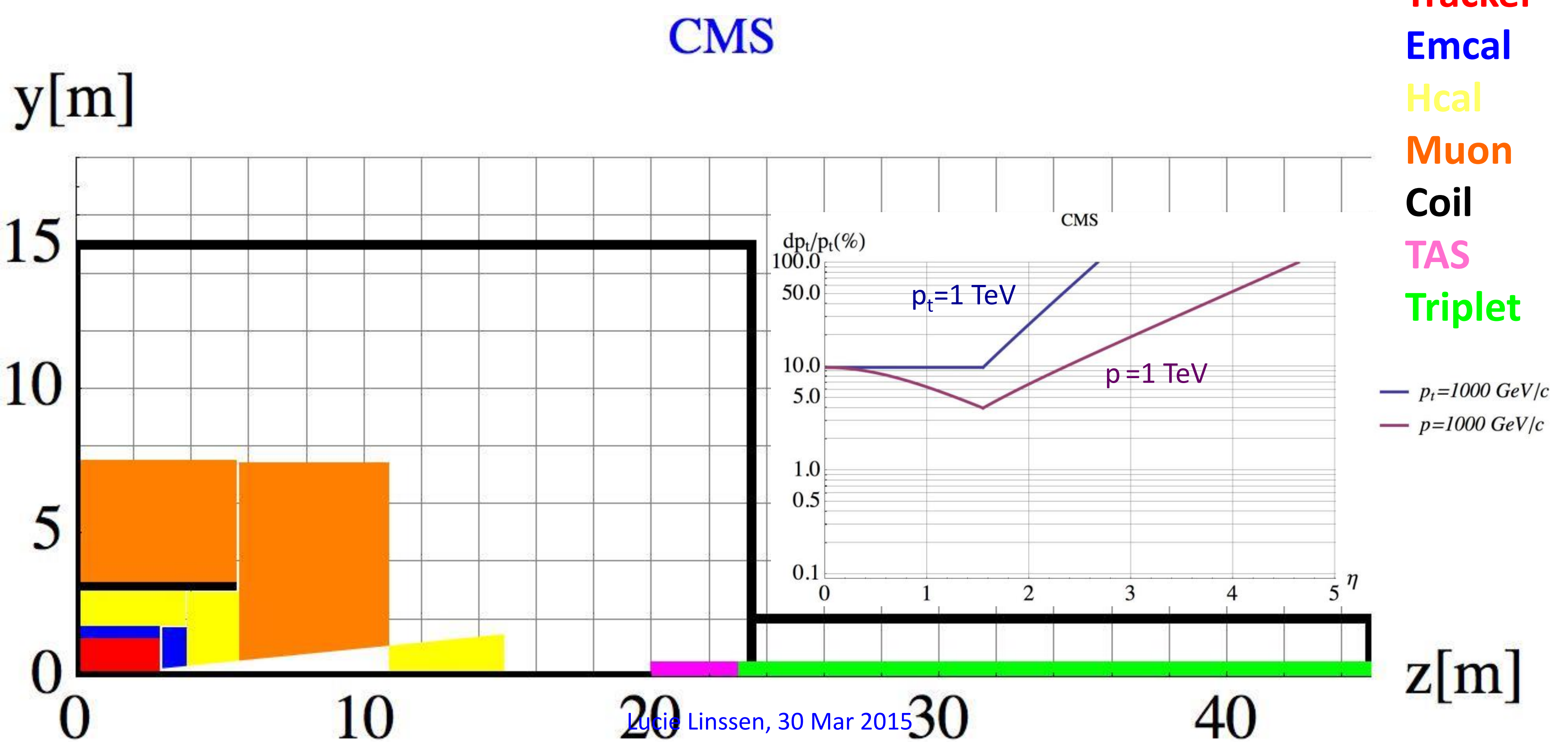
CMS

- 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.
- Iron Yoke to return Flux, instrumented with muon chambers.
- CMS muons are relying on a properly working tracker.



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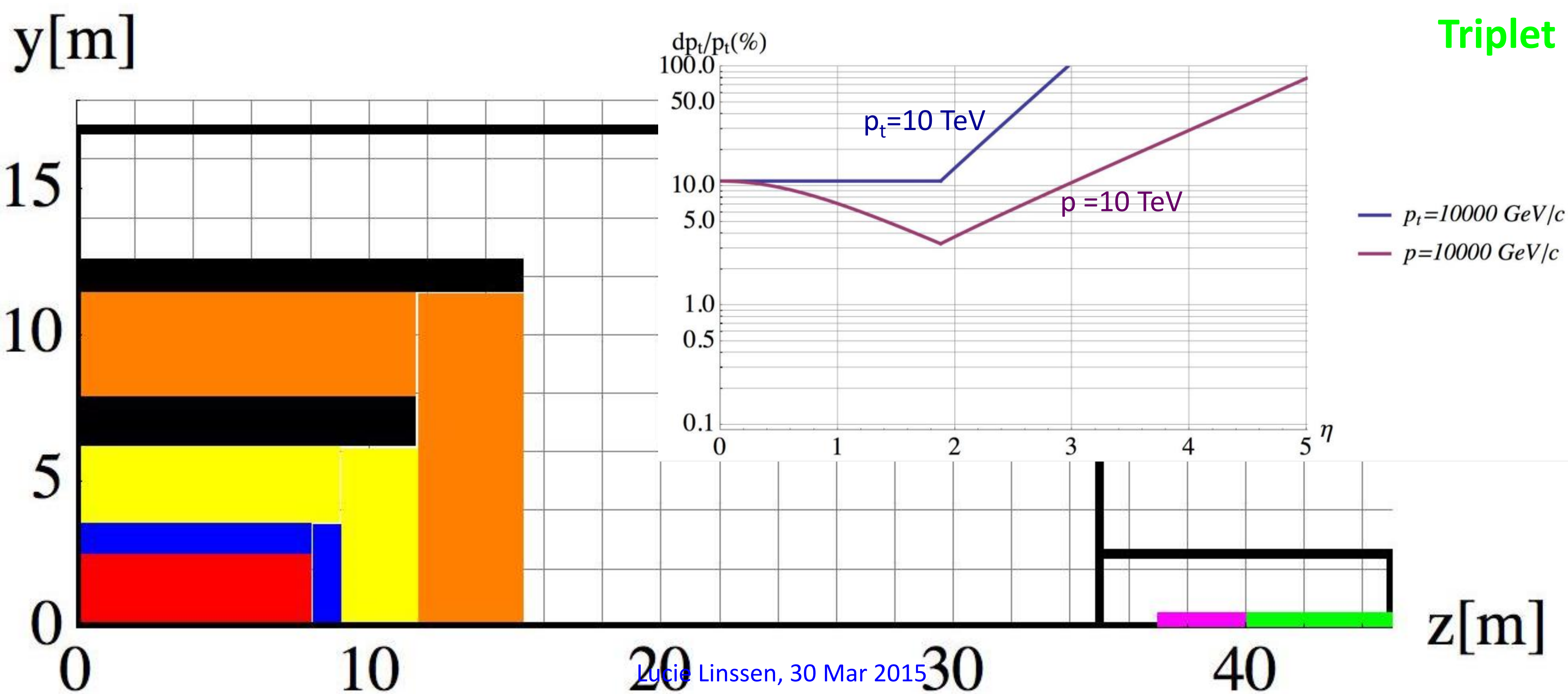
Twin Solenoid 7xBL^2 scaling

- 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



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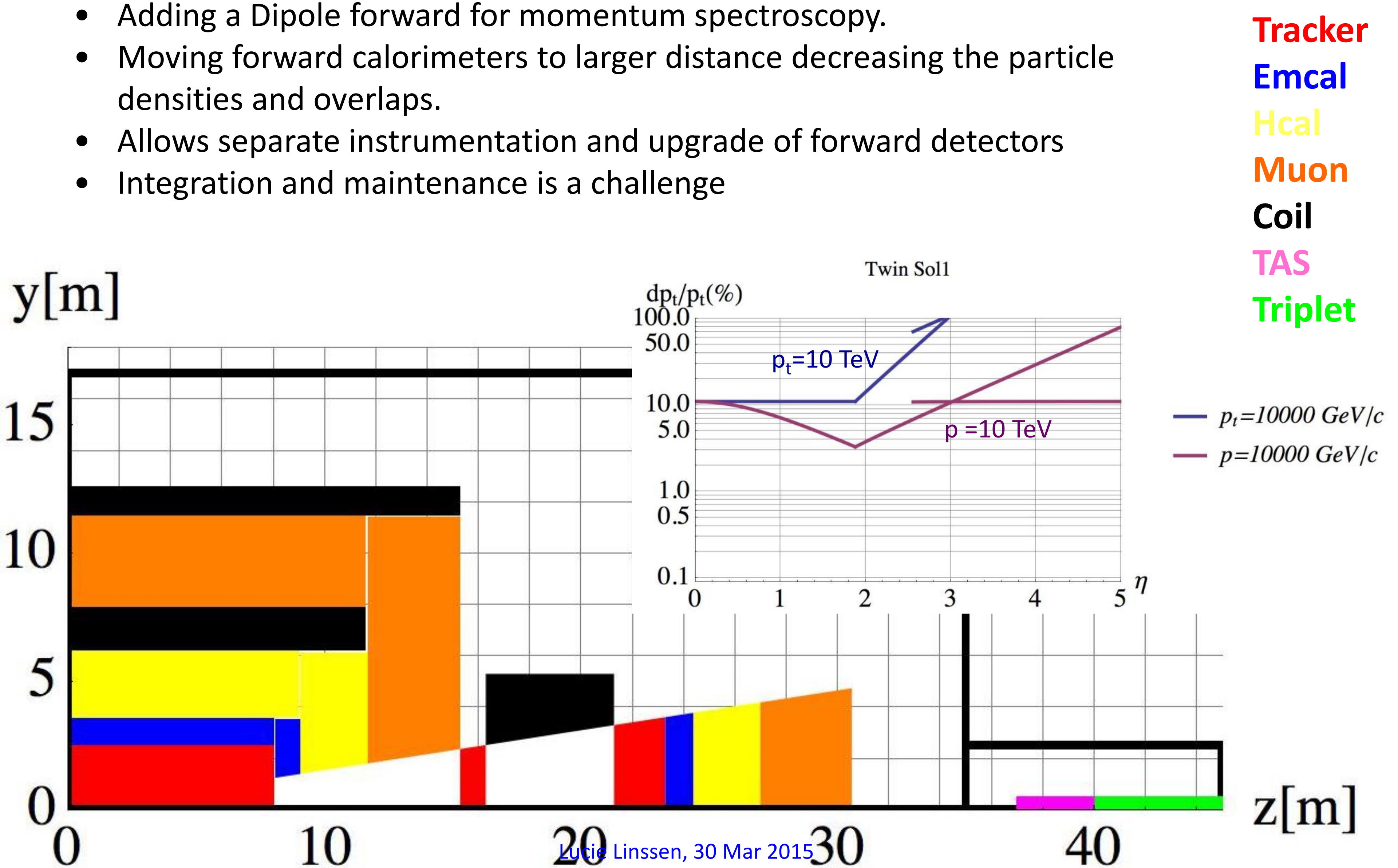
Twin Solenoid 7xBL^2 scaling+Forward Dipole

- 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



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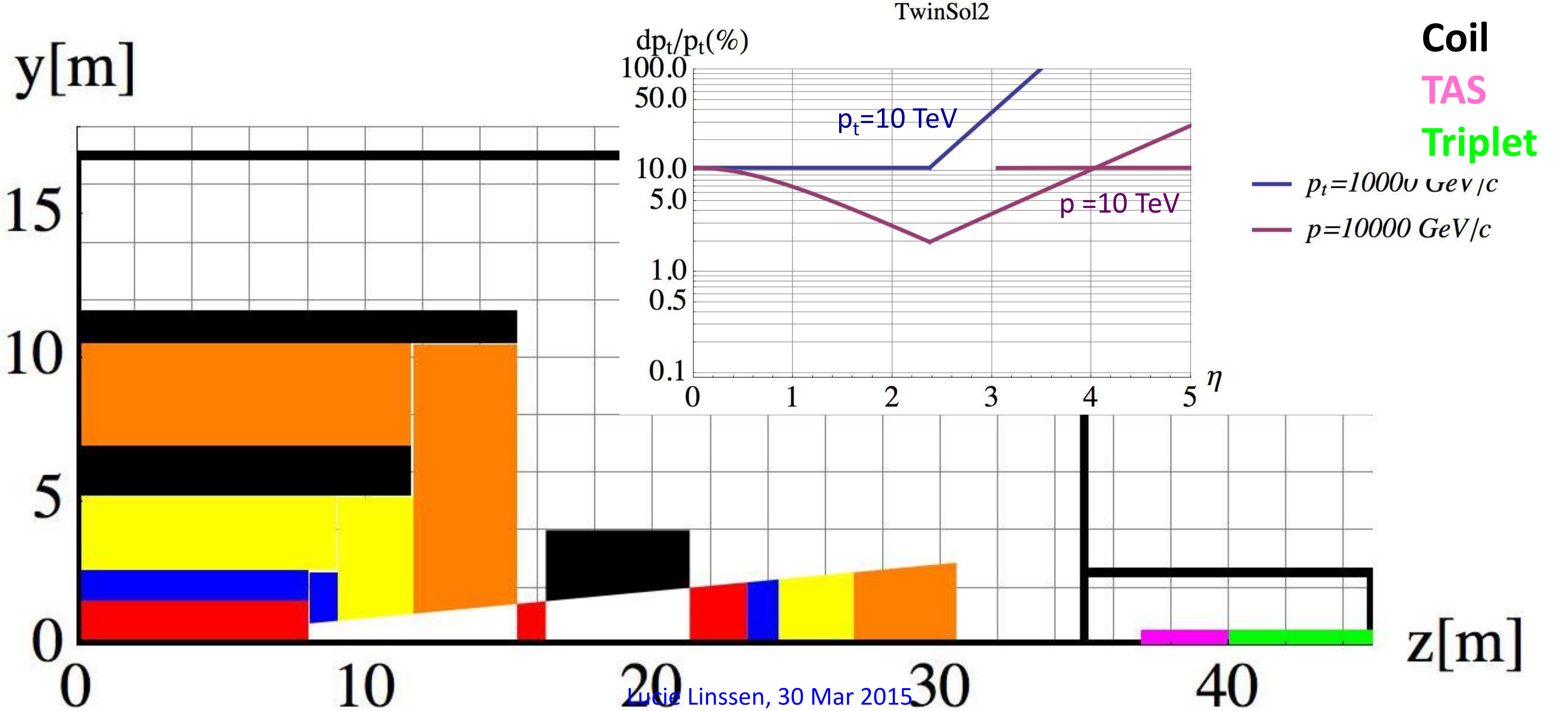
Twin Solenoid r=1.5m Tracker scaling+Forward Dipole

- 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

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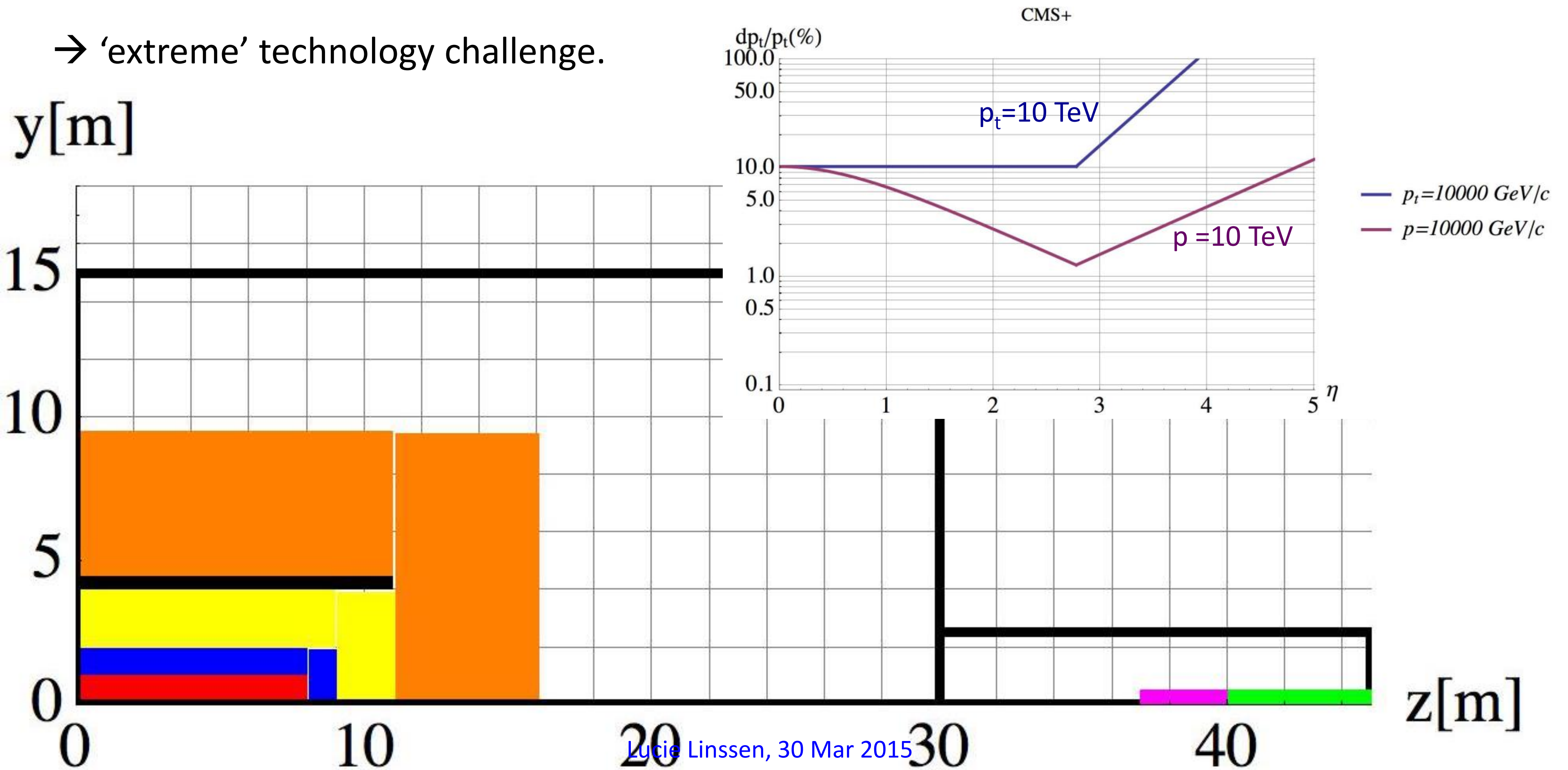
→ 'extreme' technology challenge.



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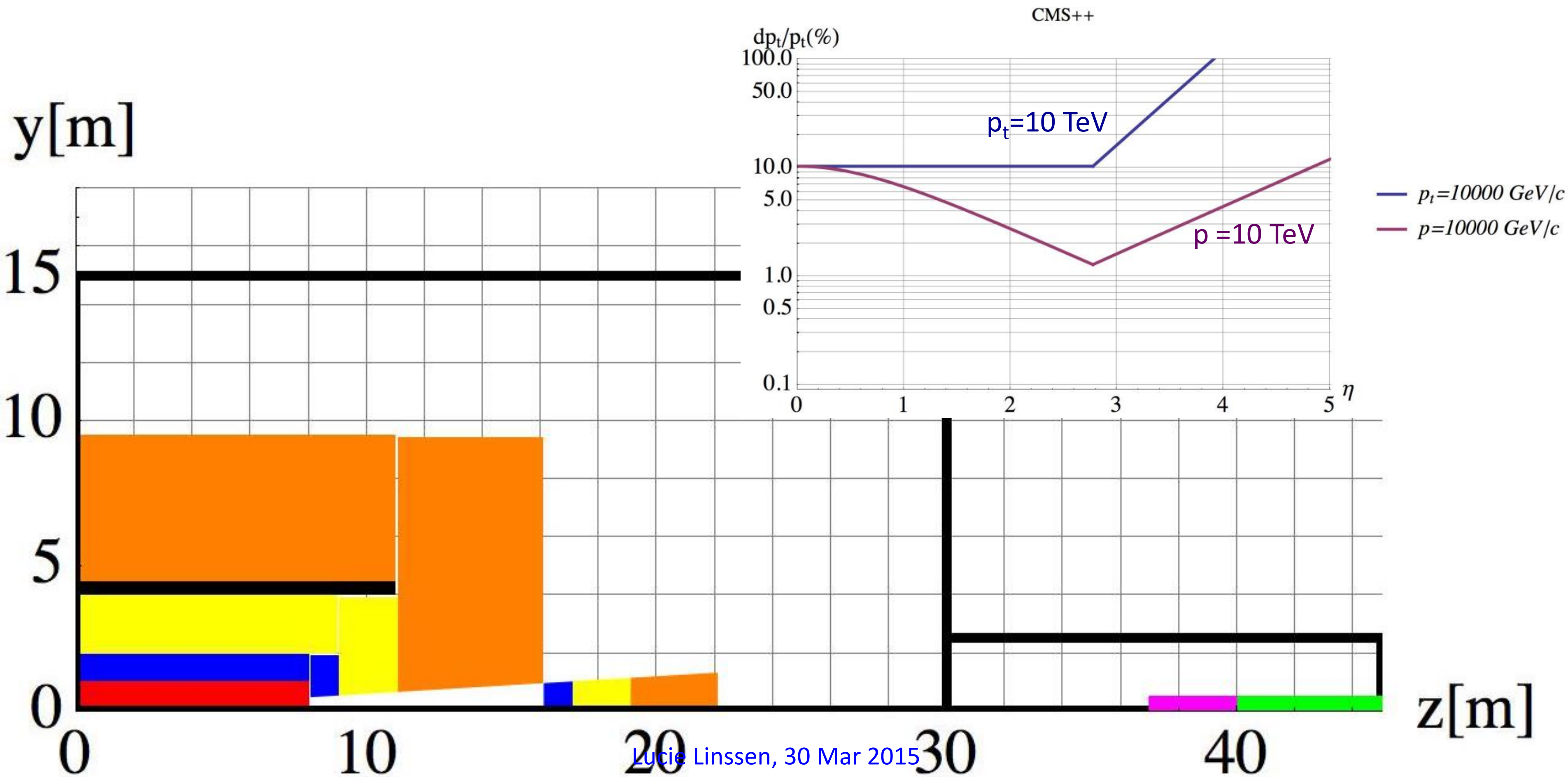
caled detector, calorimetry at high-η moved forward

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



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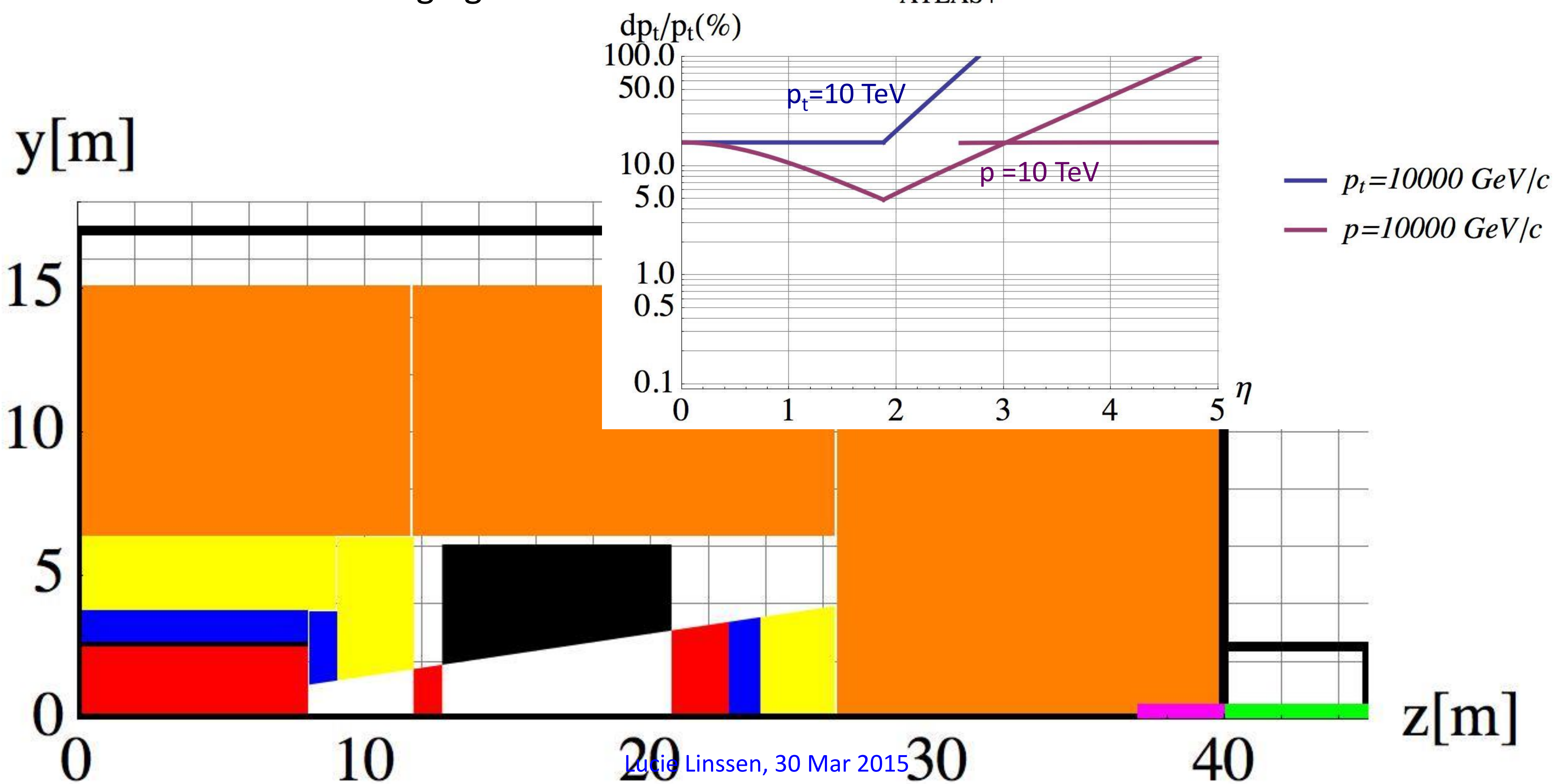
Scaled ATLAS Detector $7xBL^2$ with Integrated Dipole

- 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



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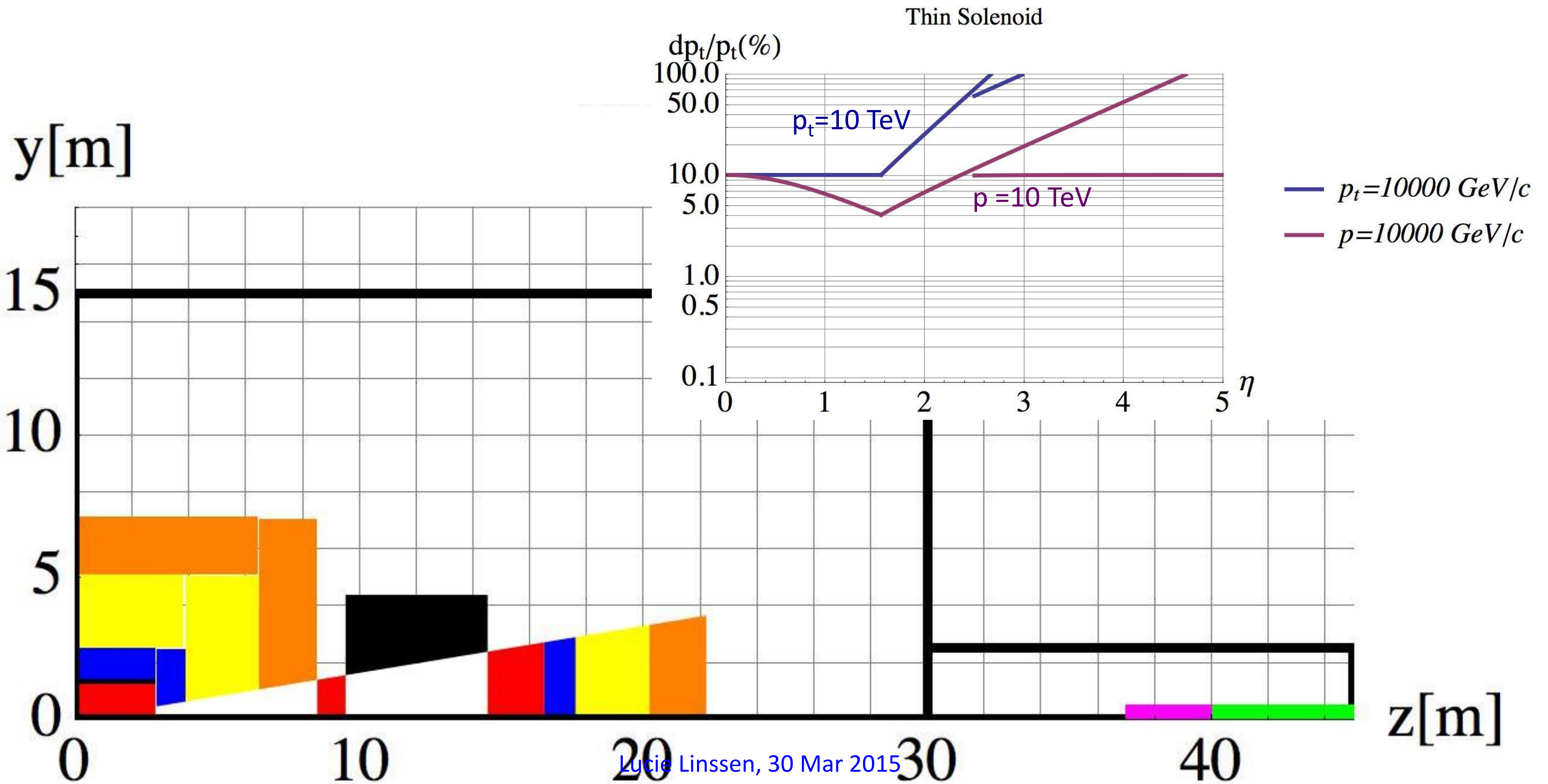
ATLAS type detector with muon tagging only

- 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



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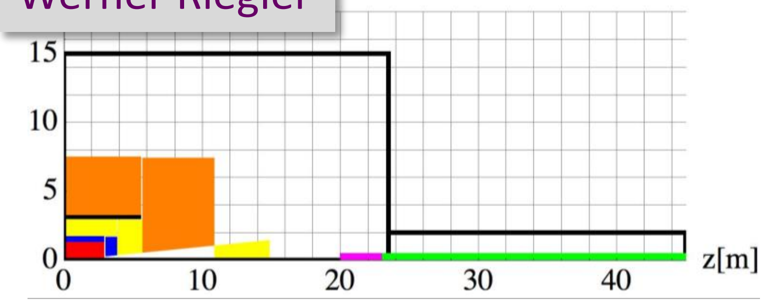
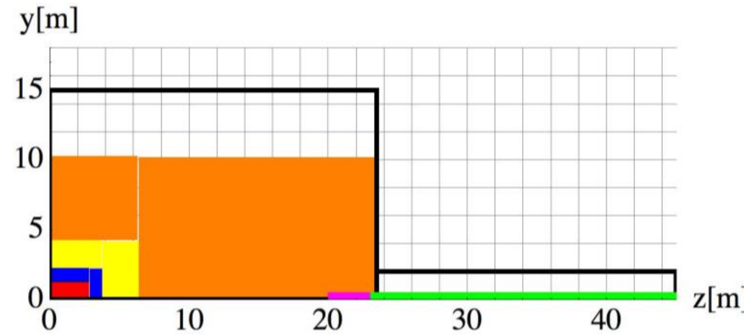
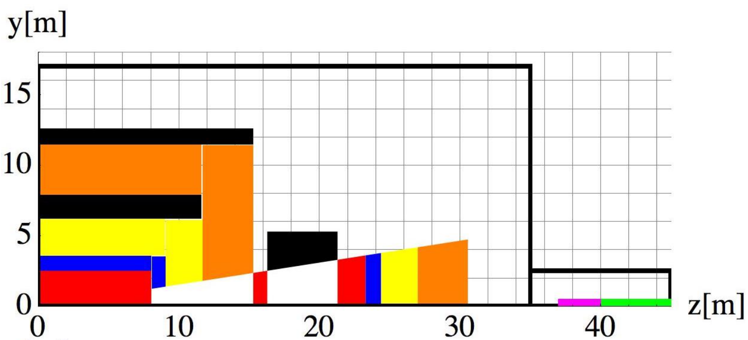


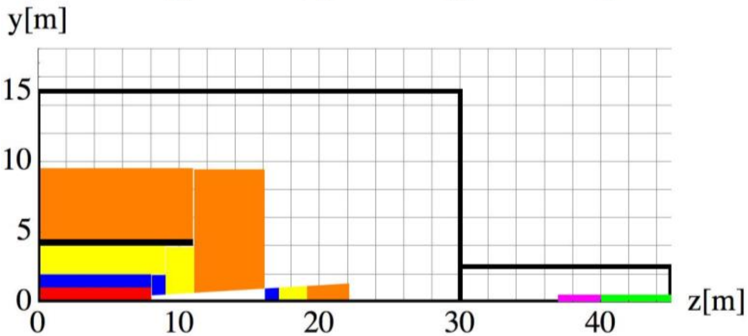
CMS & ATLAS



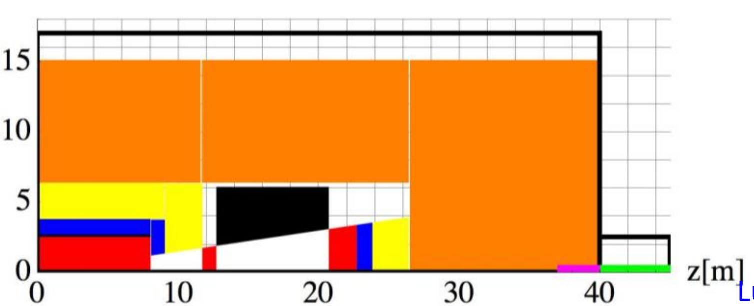


Twin Solenoid
+ Dipole

Popular at Present



CMS+



ATLAS+
+ Dipole

Physics at FCC-ee

- *beam energy range from 45 GeV to 175 GeV*
- main physics programs / energies:
  - *Z (45.5 GeV): Z pole, 'TeraZ' and high precision M_Z & Γ_Z,*
  - *W (80 GeV): W pair production threshold, high precision M_W*
  - *H (120 GeV): ZH production (maximum rate of H's),*
  - *t (175 GeV): $t\bar{t}$ threshold*
- some polarization up to ≥80 GeV for beam energy calibration
- optimized for operation at 120 GeV?! (2nd priority "*Tera-Z*")

Fank Zimmermann

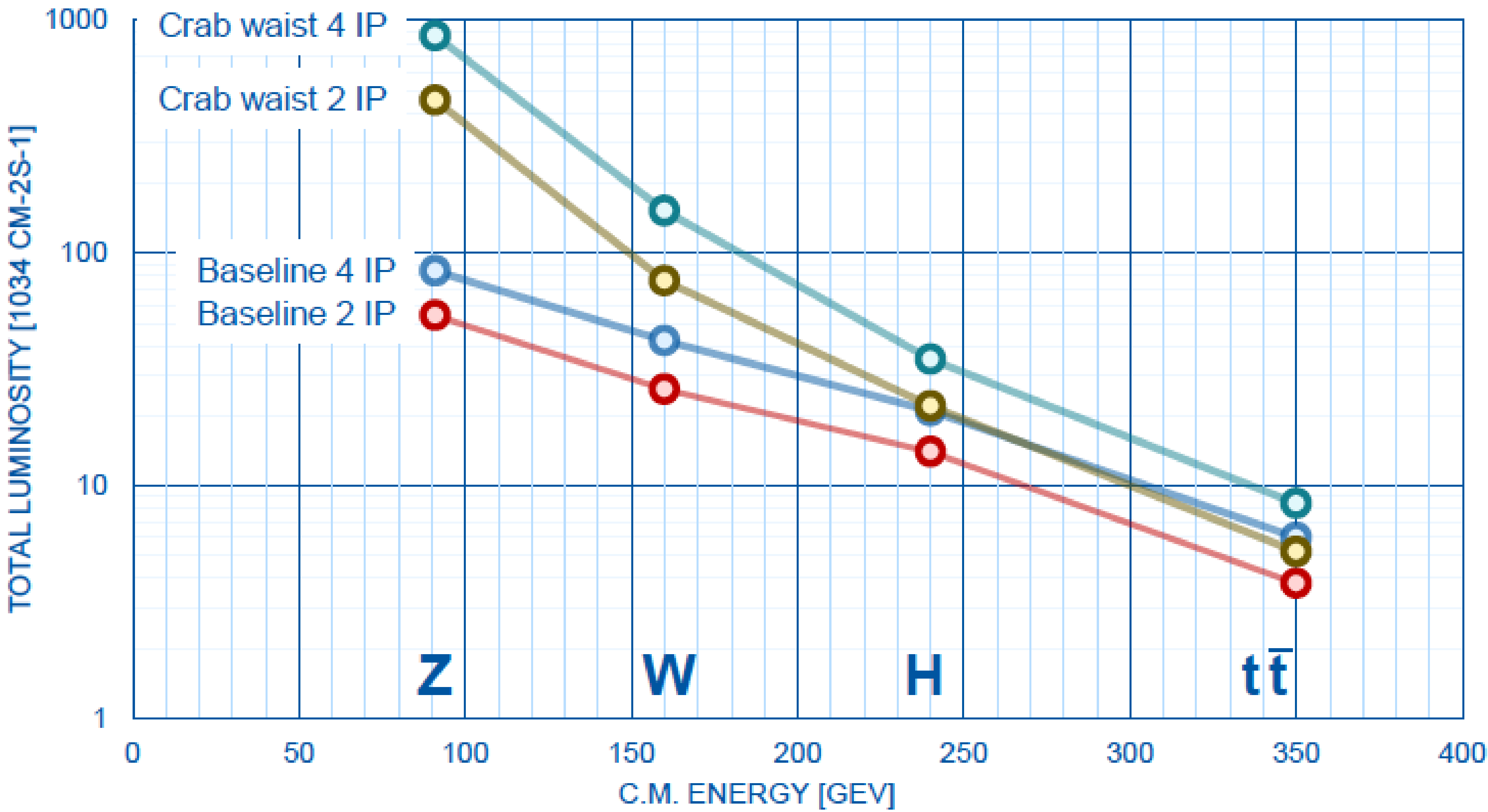
Key Parameters FCC-ee

Parameter	FCC-ee			LEP2
Energy/beam [GeV]	45	120	175	105
Bunches/beam	13000-60000	500-1400	51- 98	4
Beam current [mA]	1450	30	6.6	3
Luminosity/IP x 10^{34} $cm^{-2}s^{-1}$	**21 - 280**	**5 - 11**	**1.5 - 2.6**	0.0012
Energy loss/turn [GeV]	0.03	1.67	7.55	3.34
Synchrotron Power [MW]	100			22
RF Voltage [GV]	0.3-2.5	3.6-5.5	11	3.5

Dependency: crab-waist vs. baseline optics and 2 vs. 4 IPs

Michael Benedikt

FCC-ee: Luminosity vs. Energy

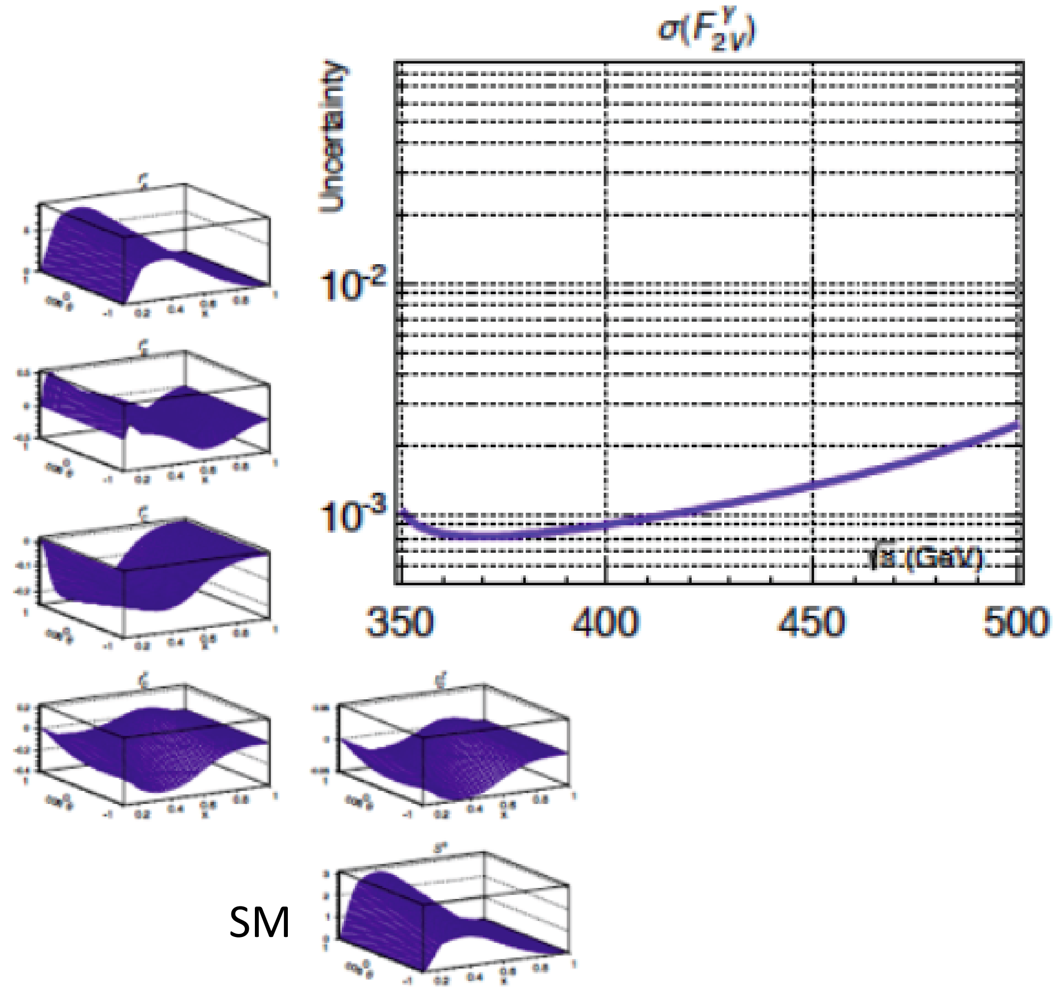


Note: here luminosity is scaled with the number of IP's

Michael Benedikt

γt and Zt couplings from measurement of in top decay productspolarisation

- It is known that the top polarization information is maximally transferred to its final state particles via the weak decay
  - the lack of beam polarization is compensated by the final state polarization and by a larger statistics
- In particular some optimal observable can be defined. In the case of tt->l+jets: the lepton polar angle and its reduced energy.
- main systematic comes from predicted event rate
- More final state variables can be considered: this is first look a more complete study is in progress



Patrizia Azzi - FCC Week @Washington March 2015

P. Janot. arXiv:1503.01325v2

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Patrizia Azzi, Patrick Janot

Further comments on FCC-ee

How come the luminosities at FCC-ee are so much higher than at LEP?

Experience with flavour factories:

⇒ Can meanwhile produce beams with much lower emittances (factor ~10) and with small beta-function at the IP (large factor);

⇒ Can inject many more bunches in the machine (large factor), however this requires **2 rings** for FCC-ee (e.g. LEP had both beams in 1 ring, KEKB has 2 rings);

⇒ Continuous beam top-up, required at FCC-ee given the large synchrotron radiation (2×50 MW).

Other remarks:

⇒ 4 physics operation energies => each time quite a different machine (currently with different machine cell lengths);

⇒ Large synchrotron radiation load on the interaction point (2 MW), under study;

⇒ Beamstrahlung is sizeable and is being addressed (limits beam lifetime and imposes enlarged momentum acceptance>1.5%).

Software

- Adapt existing solutions from LHC
  - Gaudi as underlying framework
  - ROOT for I/O
  - Geant4 for simulation
  - C++ and Python for user analysis
- Adapt software developments from ILC/CLIC
  - DD4Hep for detector description
- Invest in **better fast vs. full sim integration**
  - Geant4 fastsim, Atlfast (ATLAS)
- Invest in **proper future-proof data model**
  - The LHC experiments' ones are over-engineered
  - The ILC/CLIC model (LCIO) was designed before power and memory wall

Benedikt Hegner

Software

- FCC Software needs to support the studies of multiple detectors
- At different stages different level of detail required
  - Smearing vs. fast sim vs. full sim
- FCC choices are
  - Delphes (*) and HepSim (**)
  - Fast simulation in Python
  - Integrated fast/full simulation with Geant4
- Should all be accessible from within the same framework

(*) http://delphes.hepforge.org
(**) http://atlaswww.hep.anl.gov/hepsim/

Possible areas for collaboration with FCC?

Software development

- Some synergies are already being exploited

FCC-ee experiment layout

- FCC-ee will be using a CLIC-like experiment layout, based on elements of our new optimised CLIC detector (parametrised version for physics simulation with Delphes).

FCC-hh

- Possibility for common developments of tracking and vertex detector technologies:
  - Hybrid detectors with very small pixel pitches
  - HV-CMOS detector development towards full depletion and very small pitches
- Fine-grained calorimetry and PFA
  - Tagging of multi-TeV boosted objects (jet sub-structures)

Physics

- Ongoing exchanges of information. Realistic to exploit further?

thank you

FCC-hh target beam parameters

	LHC	HL-LHC	Baseline	Ultimate
Luminosity [$10^{34}cm^{-2}s^{-1}$]	1	5	5	20
Bunch distance [ns]	25	25	25 (5)	25 (5)
Background events/bx	27	135	170 (34)	680 (136)
Bunch charge [10^{11}]	1.15	2.2	1 (0.2)	1 (0.2)
Norm. emitt. [μm]	3.75	2.5	2.2(0.44)	2.2(0.44)
IP beta-function [m]	0.55	0.15	1.1	0.3
IP beam size [μm]	16.7	7.1	6.8 (3)	3.5 (1.6)
RMS bunch length [cm]	7.55	7.55	8	8
Turn-around time [h]			5	4
Crossing angle [σ□]			12	Crab. Cav.

Values in brackets for 5ns spacing, would be good for background

Daniel Schulte

FCC-ee baseline

parameter	FCC-ee baseline (2 IPs)			
	Z	W	H	t
RF frequency [MHz]	400	400	400	400
RF voltage [GV]	2.5	4	5.5	11
circumference [km]	100	100	100	100
momentum compaction [10^{-5}]	18	2	0.5	0.5
synchrotron tune	0.458	0.145	0.068	0.070
$\sigma_{z,SR}$ [mm]	3.29	2.02	1.62	2.31
$\sigma_{z,tot}$ [mm] (w beamstr.)	3.84	2.29	1.81	2.46
$\sigma_{\delta,SR}$ [%]	0.052	0.092	0.139	0.202
$\sigma_{\delta,tot}$ [%] (w beamstr.)	0.061	0.105	0.155	0.216
hourglass factor F_{hg}	0.53	0.67	0.73	0.65
beam-beam par. ξ_y/IP (2IPs)	0.040,0.070	0.077	0.121	0.118
L/IP [10^{34} cm^{-2}s^{-1}] (2 Ips)	27	13	7.0	1.9
τ_{beam} [min] (2 IPs)	620	130	50	39

Frank Zimmermann

FCC-ee parameters (with crab waist)

parameter	FCC-ee crab waist (2 IPs)			
	Z	W	H	t
RF frequency [MHz]	400	400	400	400
RF voltage [GV]	0.3	1.0	3.6	11
circumference [km]	100	100	100	100
momentum compaction [10^{-5}]	0.5	0.5	0.5	0.5
synchrotron tune	0.030	0.035	0.053	0.070
$\sigma_{z,SR}$ [mm]	0.97	2.08	2.08	2.31
$\sigma_{z,tot}$ [mm] (w beamstr.)	3.33	3.12	2.61	2.83
$\sigma_{\delta,SR}$ [%]	0.037	0.092	0.139	0.202
$\sigma_{\delta,tot}$ [%] (w beamstr.)	0.127	0.139	0.174	0.248
hourglass factor F_{hg}	0.94	0.87	0.81	0.75
beam-beam par. ξ_y/IP (2 IPs)	0.06,0.21	0.04,0.16	0.03,.124	0.04,0.118
L/IP [10^{34} cm^{-2}s^{-1}] (2 IPs)	277	38	11.0	2.6
τ_{beam} [min] (2 IPs)	60	41	31	28

Frank Zimmermann

Collaboration Status

- 51 institutes
- 19 countries
- EC participation

Michael Benedikt

News from FCC workshop

51 FCC collaboration members & CERN as host institute, 22 March 2015

ALBA/CELLS, Spain
Ankara U., Turkey
U Bern, Switzerland
BINP, Russia
CASE (SUNY/BNL), USA
CBPF, Brazil
CEA Grenoble, France
CEA Saclay, France
CIEMAT, Spain
CNRS, France
Cockcroft Institute, UK
U Colima, Mexico
CSIC/IFIC, Spain
TU Darmstadt, Germany
DESY, Germany
TU Dresden, Germany
Duke U, USA
EPFL, Switzerland
GWNU, Korea
U Geneva, Switzerland
Goethe U Frankfurt, Germany
GSI, Germany
Hellenic Open U, Greece
HEPHY, Austria
IFJ PAN Krakow, Poland
INFN, Italy
INP Minsk, Belarus
U Iowa, USA
IPM, Iran
UC Irvine, USA
Istanbul Aydin U., Turkey
JAI/Oxford, UK
JINR Dubna, Russia
FZ Jülich, Germany
KAIST, Korea
KEK, Japan
KIAS, Korea
King's College London, UK
KIT Karlsruhe, Germany
Korea U Sejong, Korea
MEPhI, Russia
MIT, USA
NBI, Denmark
Northern Illinois U., USA
NC PHEP Minsk, Belarus
U. Liverpool, UK
PSI, Switzerland
Sapienza/Roma, Italy
UC Santa Barbara, USA
U Silesia, Poland
TU Tampere, Finland

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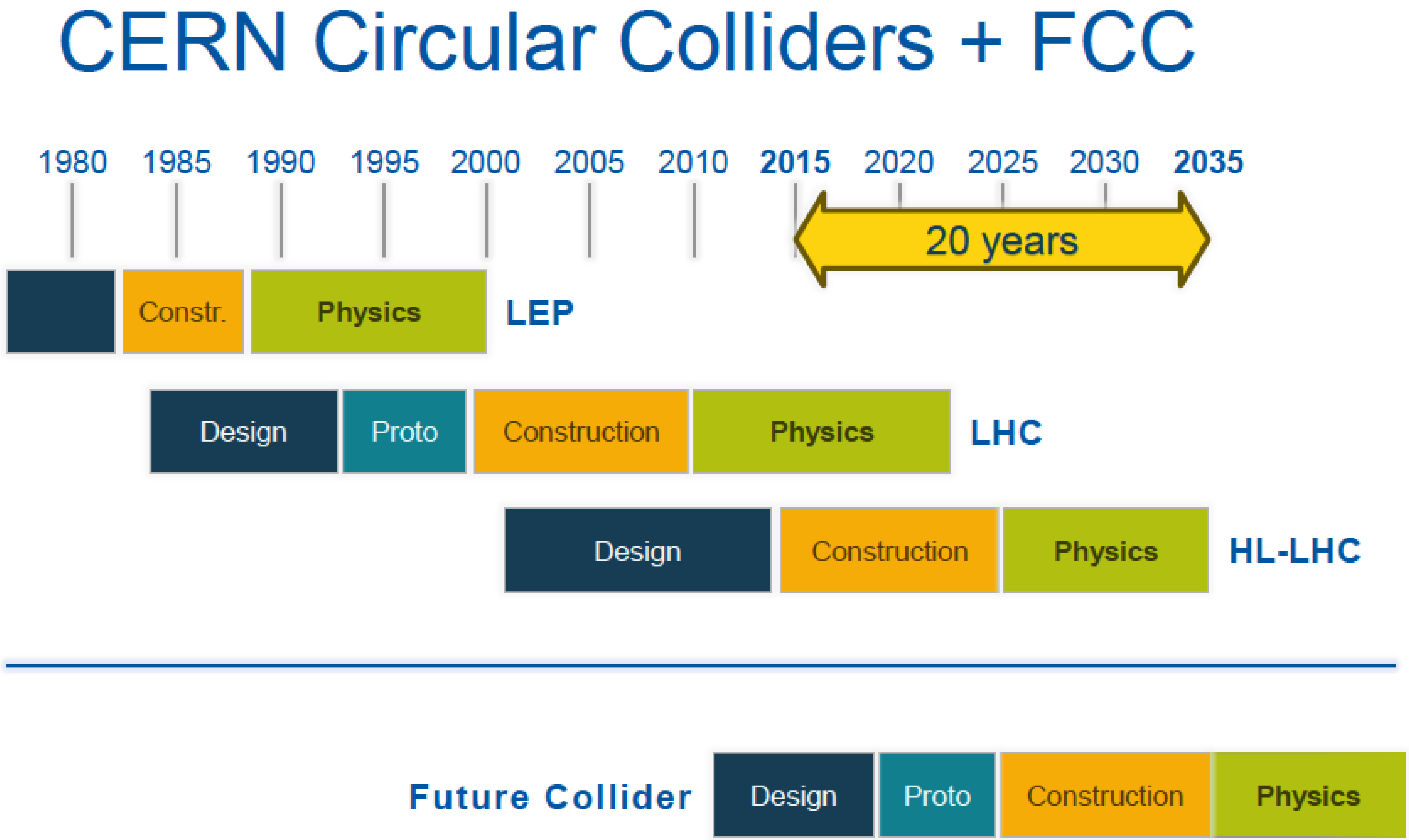
News from FCC workshop



Michael Benedikt