The Future Circular Collider (FCC-hh) project
Detector concept
The hadron central calorimeter

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LIP seminar 24 April 2015

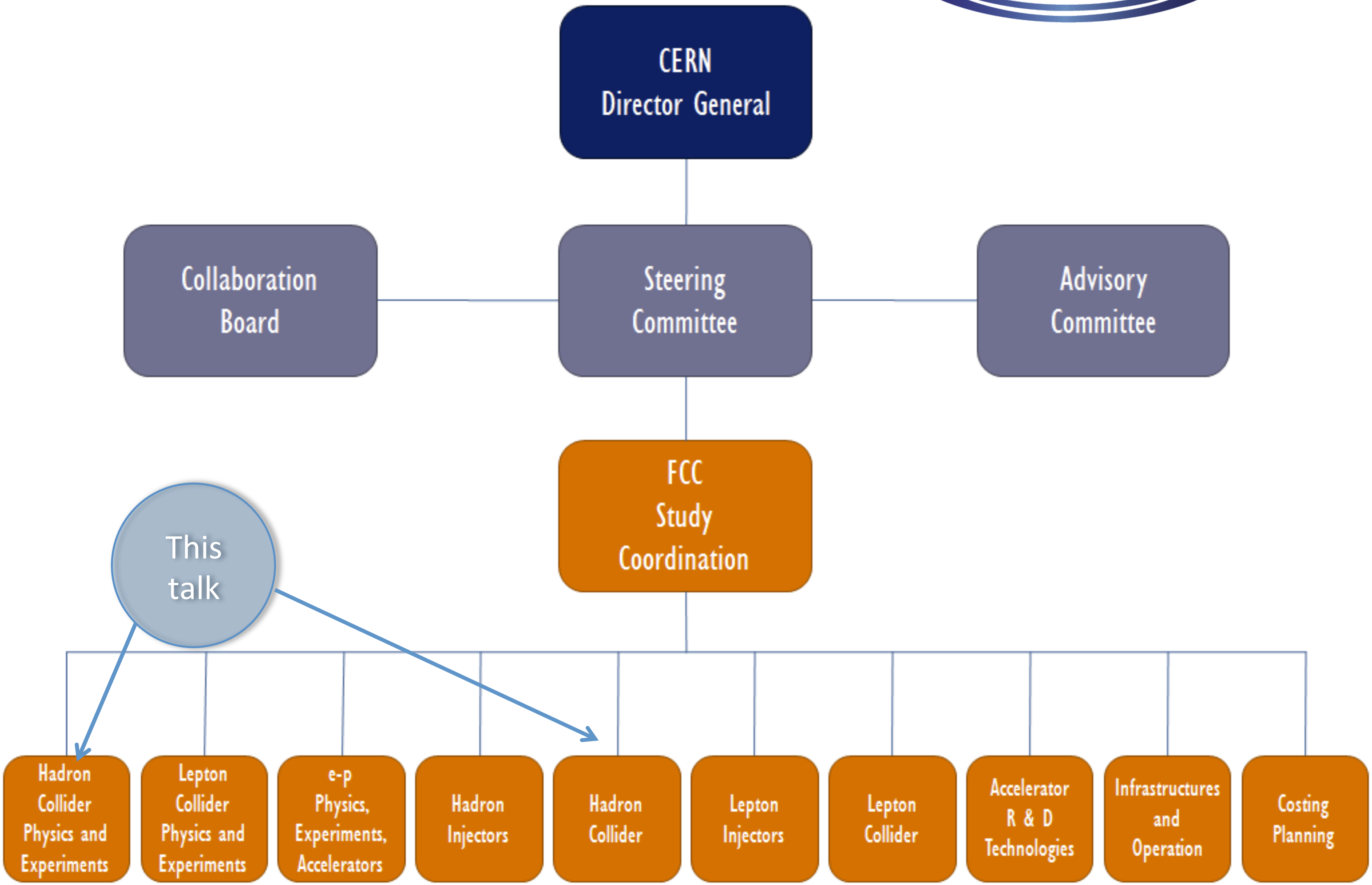
Layout

- The machine
- Detector concept
- Hadronic calorimeter requirements
- The potential of the ATLAS Tile calorimeter concept with higher granularity readout (si-PMTs) for the central HCAL

FCC (ee, hh, eh) Project targets

- Following the 2013 European Strategy report CERN Management set up the FCC Study project, with the goal of preparing a Conceptual Design Report by 2018
- Establish the physics capabilities of the FCCs (ee, hh, eh)
- Document the potential for (new) physics discovery
- Understand the detector performance requirements
- Study the machine-detector interface & experimental environment issues

Organization



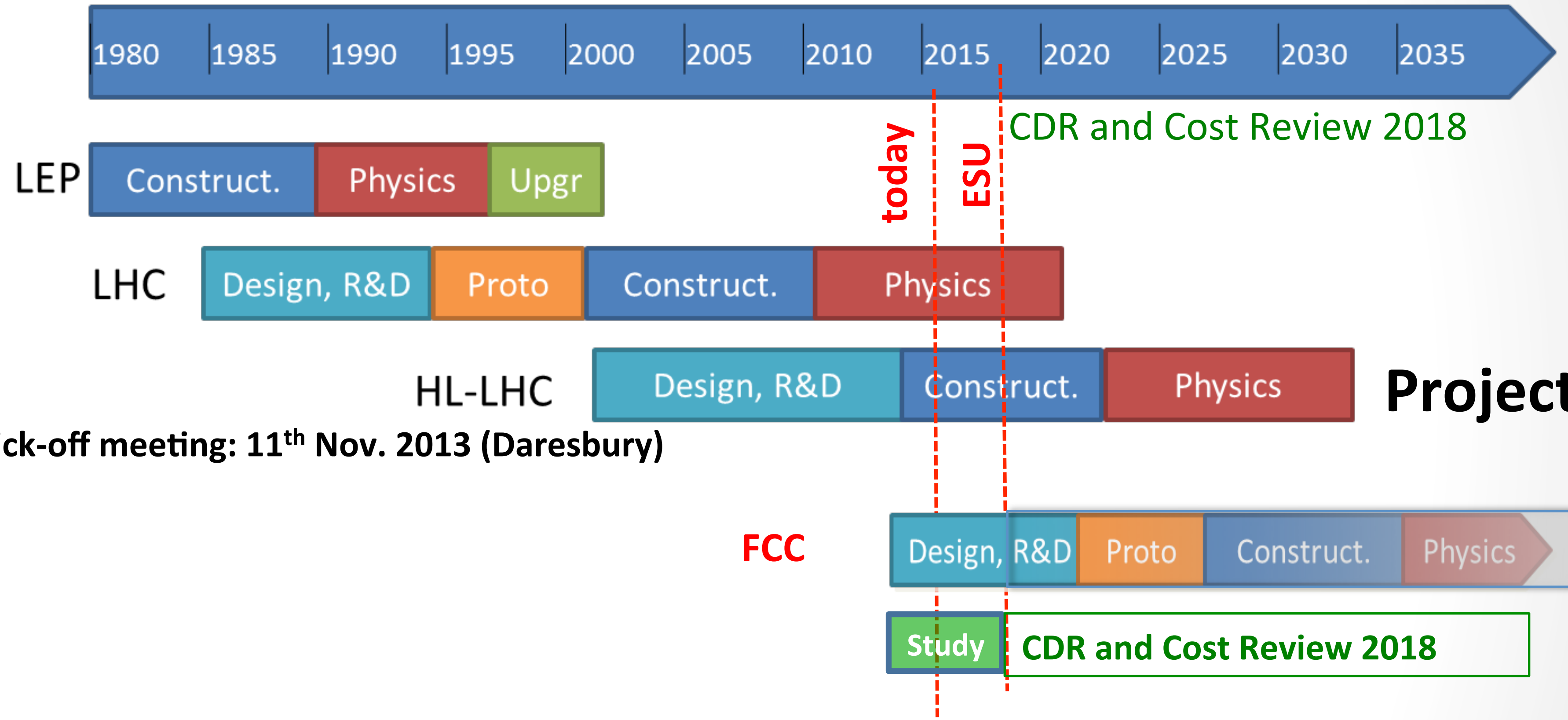
FCC-hh : Working groups

- Physics studies
  - Higgs and EW symmetry breaking
  - Beyond the Standard Model
  - Standard Model
  - Physics of heavy ion collisions
  - Experiments with the injectors

- Experiment studies at 100 TeV
  - Detectors
  - Detector magnets
  - Machine-detector interface

- Overall twiki page
  - *https://twiki.cern.ch/twiki/bin/view/LHCPhysics/FutureHadroncollider*
- Mailing list for general announcements: *fcc-experiments-hadron@cern.ch*
  - To subscribe: http://cern.ch/simba3/SelfSubscription.aspx?groupName=fcc-experiments-hadron
- Agenda for WG meetings and workshops
  http://indico.cern.ch/category/5258/

Timeline



- LHC and HL-LHC operation until ~2035
- Must start now developing FCC concepts to be ready in time

Main FCC-hh or FCC joined events

- **FCC Kick-off meeting February 2014, Geneva:**
  - http://indico.cern.ch/event/282344/
- Physics at a 100TeV collider, 04/2014, SLAC:
  - https://indico.fnal.gov/conferenceDisplay.py?confId=7633
- First FCC-hh workshop 05/2014, CERN:
  - http://indico.cern.ch/event/304759/
- Next steps in energy Frontier 08/2014, FNAL:
  - https://indico.fnal.gov/conferenceDisplay.py?confId=7864
- The Future of High Energy Physics 01/2015, Honk-Hong:
  - http://iasprogram.ust.hk/201501fhep/conf.html
- **FCC- hh detector WS February 2015 CERN**
- https://indico.cern.ch/event/358198/
- **FCC Week 2015, March 2015, Washington**:
  - https://indico.cern.ch/event/340703/

~1year

FCC-hh accelerator

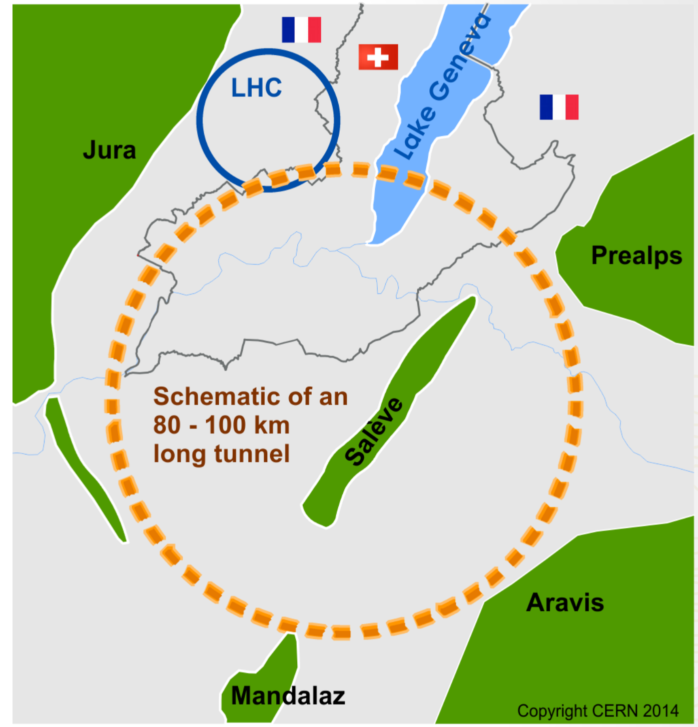
FCC where and ultimate goals?

- Possible to host FCC-hh in Geneva area
- Centre mass E = 100TeV (x7 LHC)
- 83-100 Km tunnel (x 3-4 LHC)

(If NiTi 8.3 Tesla (LHC dipoles) ⇒ √s=42 TeV in 100km ...)=>

  - **~16 T dipoles ($NbSn_3$) ⇒ 100 TeV *pp* in 100 km**
  - **~20 T (HST) ⇒ 100 TeV *pp* in 83 km**

- Use LHC as injector
- Strong support from CERN



- e^+e^- collider (*FCC-ee*) as potential intermediate step
- *p-e* (*FCC-he*) option
- China also interested to host the project

FCC-hh	Phase 1	Phase 2
C.M Energy	100TeV	100TeV
Luminosity	5×10^{34} $cm^{-2}s^{-1}$	$3 \times 10^{35} cm^{-2} s^{-1}$ *
Integrated Lumi	3 ab^{-1}	30 ab^{-1} *
Bunch spacing	25ns → 5ns	5ns

* NB upper values used for detector R & D + radiation studies

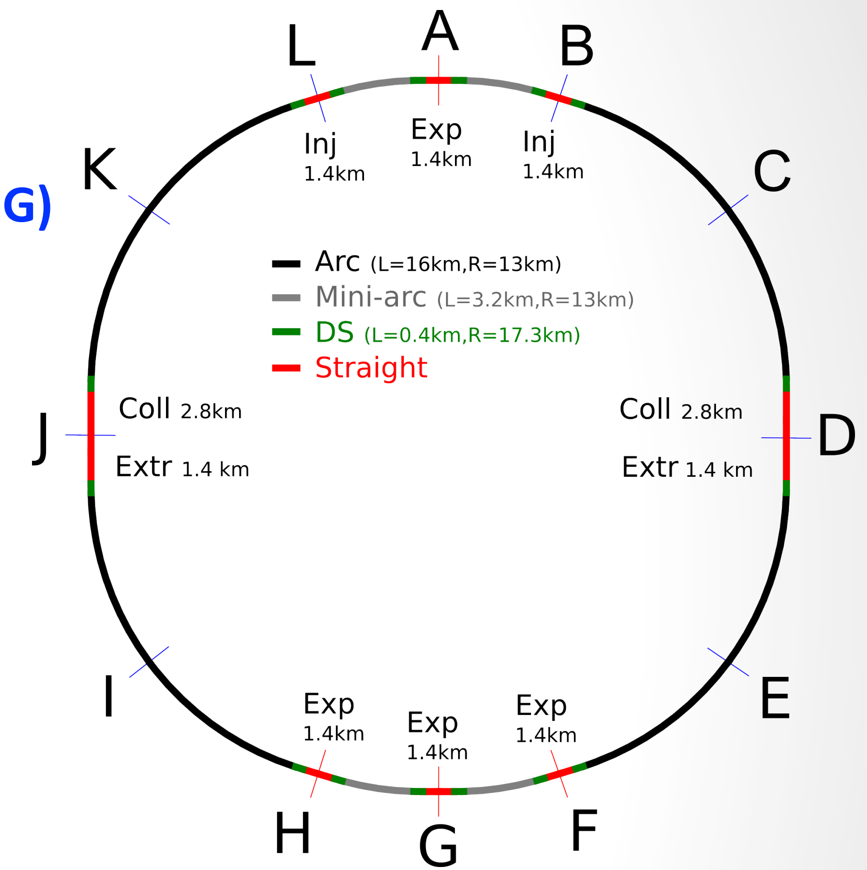
Machine parameters

parameter	LHC	HL-LHC	FCC-hh
c.m. energy [TeV]	14		100
dipole magnet field [T]	8.33		16 (20)
circumference [km]	26.7		100 (83)
luminosity [10^{34} $cm^{-2}s^{-1}$]	1	5	5 [→20?] (*)
bunch spacing [ns]	25		25 {5}
events / bunch crossing	**27**	**135**	**170 {34}**
bunch population [10^{11}]	1.15	2.2	1 {0.2}
norm. transverse emitt. [μm]	3.75	2.5	2.2 {0.44}
IP beta-function [m]	0.55	0.15	1.1
IP beam size [μm]	16.7	7.1	6.8 {3}
synchrotron rad. [W/m/aperture]	0.17	0.33	28 (44)
critical energy [keV]	0.044		4.3 (5.5)
total syn.rad. power [MW]	**0.0072**	**0.0146**	**4.8 (5.8)**
longitudinal damping time [h]	**12.9**		**0.54 (0.32)**

(*) Inst. Luminosity $5x10^{34}$ → ~20-30 $x10^{34}$ $cm^{-2}s^{-1}$ in a second phase

A Preliminary Layout of the accelerator

- **Two high-luminosity experiments (A and G)**
- Two other experiments (F and H)
- Two collimation lines
- Two injection and two extraction lines



- Arc dipoles are the main cost and parameter driver
- **Baseline is Nb_3Sn at 16T** (enough for the 100km tunnel)
- **HTS at 20T also studied as alternative** (needed if 80 km tunnel)

FCC-hh Detector
and
Physics Benchmarks

FCC-hh Luminosity increase -> consequences for detectors

- Phase 1 $L=5x10^{34}cm^{-2}s^{-1}$ (= HL-LHC) & pile-up =170 for 25ns Bunch Crossing
- Phase 2 $L=20\text{-}30\ x10^{34}cm^{-2}s^{-1}$ (=> up to 6 time more pile-up…)
- Reduce Pile-up by decreasing the bunch spacing (option to go 25ns -> 5 ns)
- Maximize integrated Luminosity for heavy physics

- Very radiation hard and fast detectors with sub ns time resolution (in particular in the forward region...)
- Design detectors for the Very high Luminosity option (+safety factors), already at first design level, to bear the higher requirements.
- At LHC now we are forced to rebuild many detectors because they were meant to work for 10 years at $L=1x10^{34}$ and not for other 10 year at L= $5x10^{34}cm^{-2}s^{-1}$....

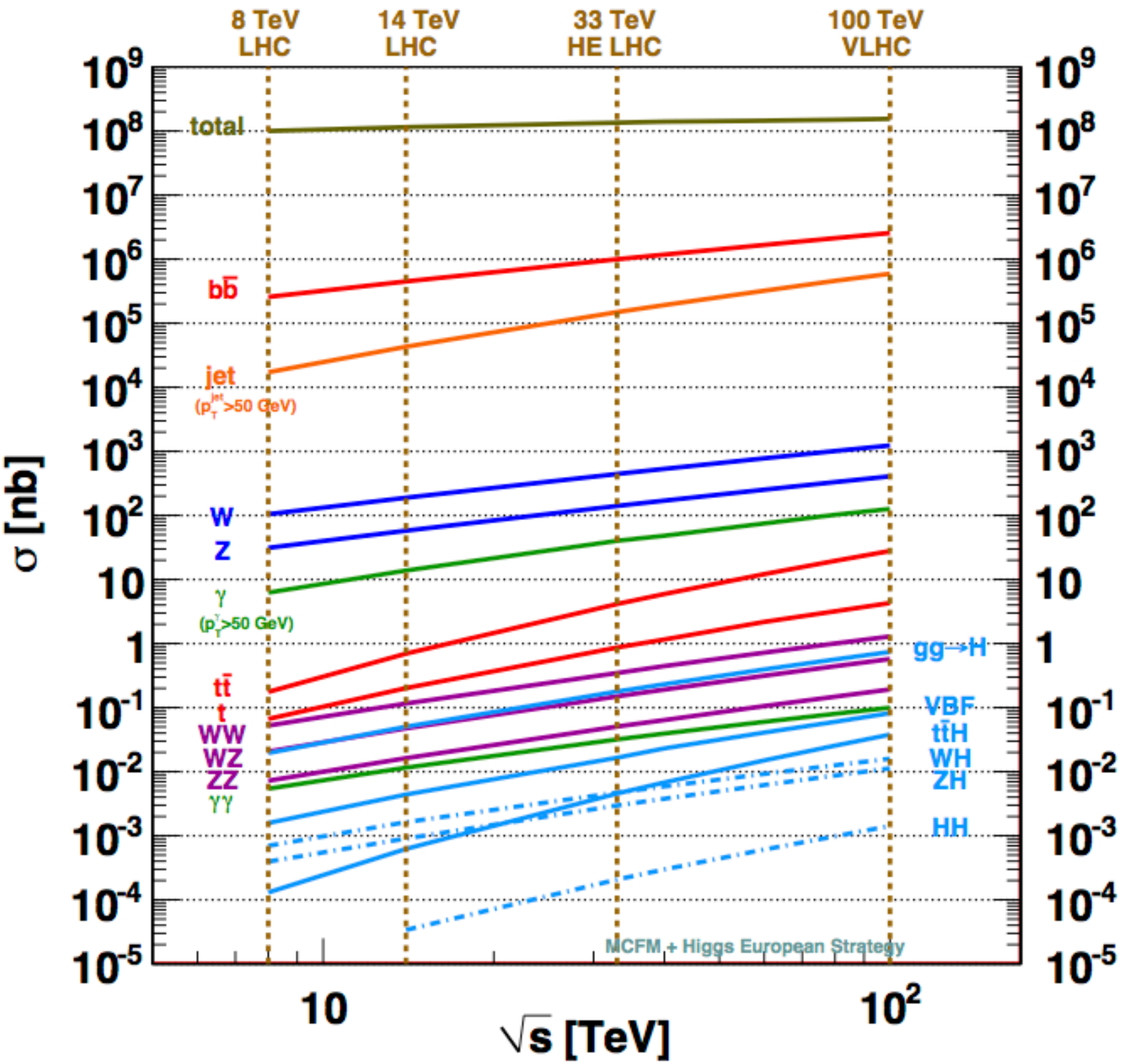
Physics Benchmarks

- **Standard Model (SM) :**
  - Higgs Self Coupling
  - WW scattering
  - Top studies
- **Behind the Standard Model (BSM):**
  - Dark Matter
  - Exotic searches (W',Z', Compositness,Top resonances)

    - Extend mass reach by large factor
  - SUSY
    - Extend mass reach by large factor
  - ?....

Physics benchmarks may point to different detector requirements….

Cross sections vs Centre of mass energy

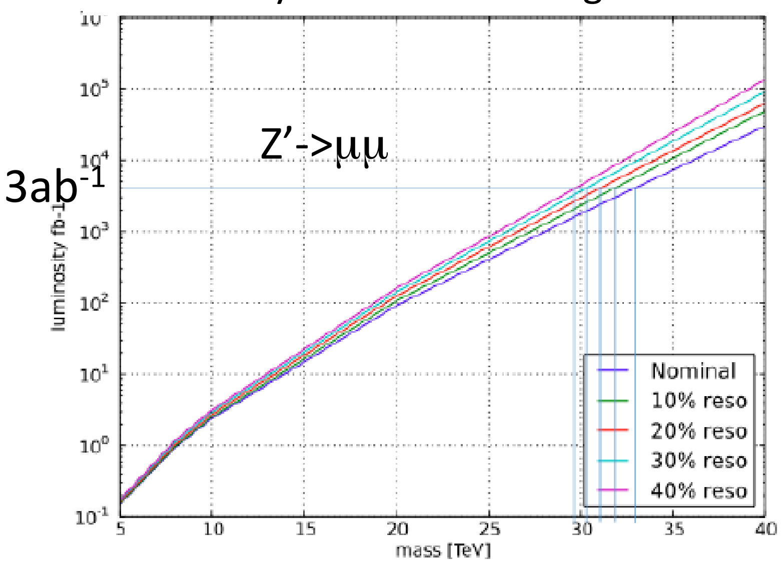


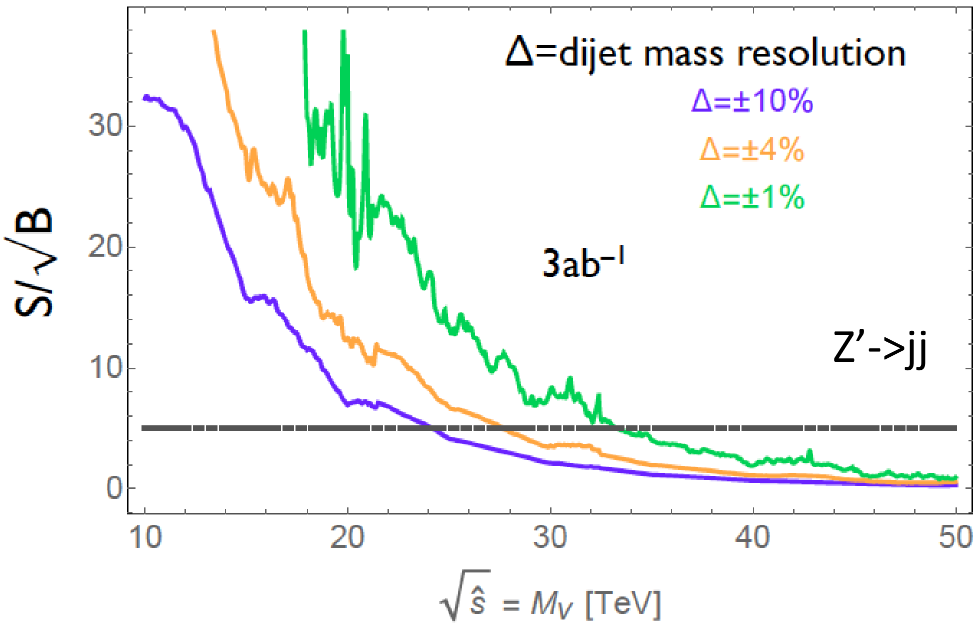
Process	σ (100 TeV)/σ (14 TeV)
Total pp	1.25
W	~7
Z	~7
WW	~10
ZZ	~10
tt	~30
H	~15 (ttH ~60)
HH	~40
stop (m=1 TeV)	$\sim 10^3$

Energy and momentum resolution requirements

- At multi-TeV, dijets resonances may provide comparable discovery reach as lepton channels, if jet resolution <=3% (=> reduced HCAL resol. constant term).
- Moderate momentum resolution is required (~15% at 10 TeV muons)

Luminosity vs Z'mass for 5sigma discovery





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

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

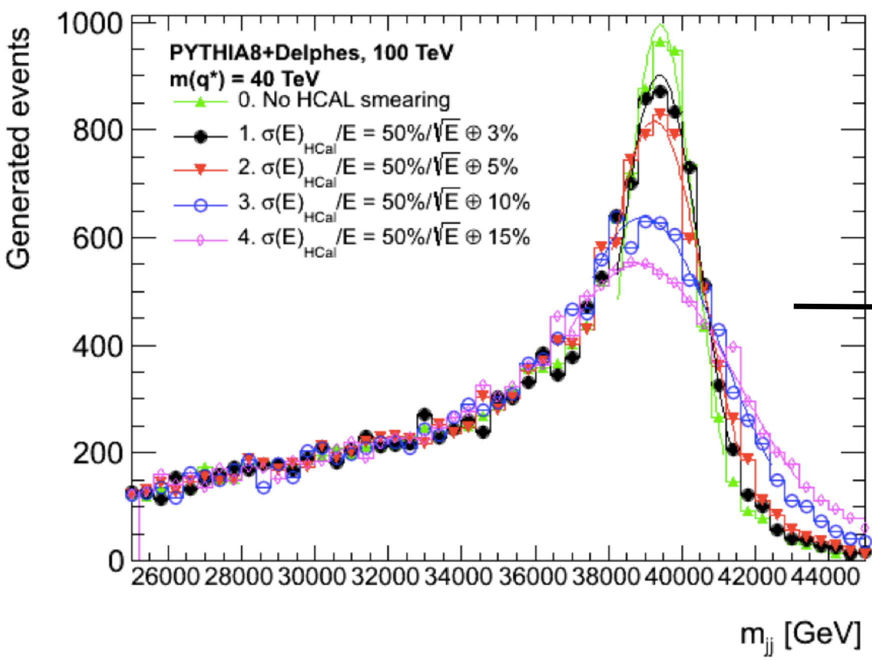
Muon momentum resolution O(15%) at 10TeV.

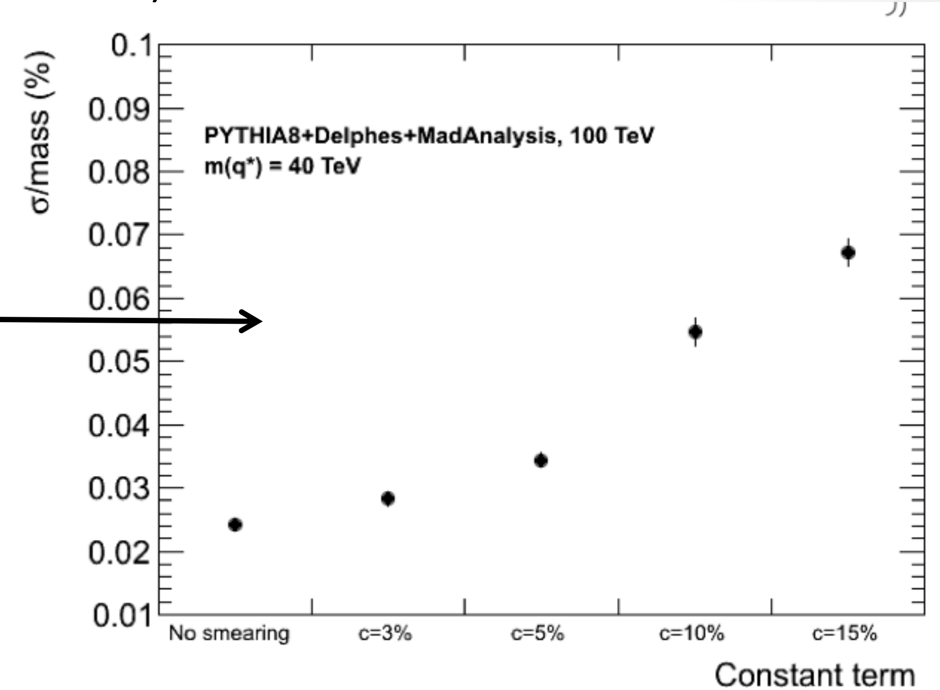
→ **Constant term dominates** Goal 3% or better

Effect of calorimeter jet resolution on dijet resonances

Jet resolution ~3% needed for 40 TeV q* ->jj

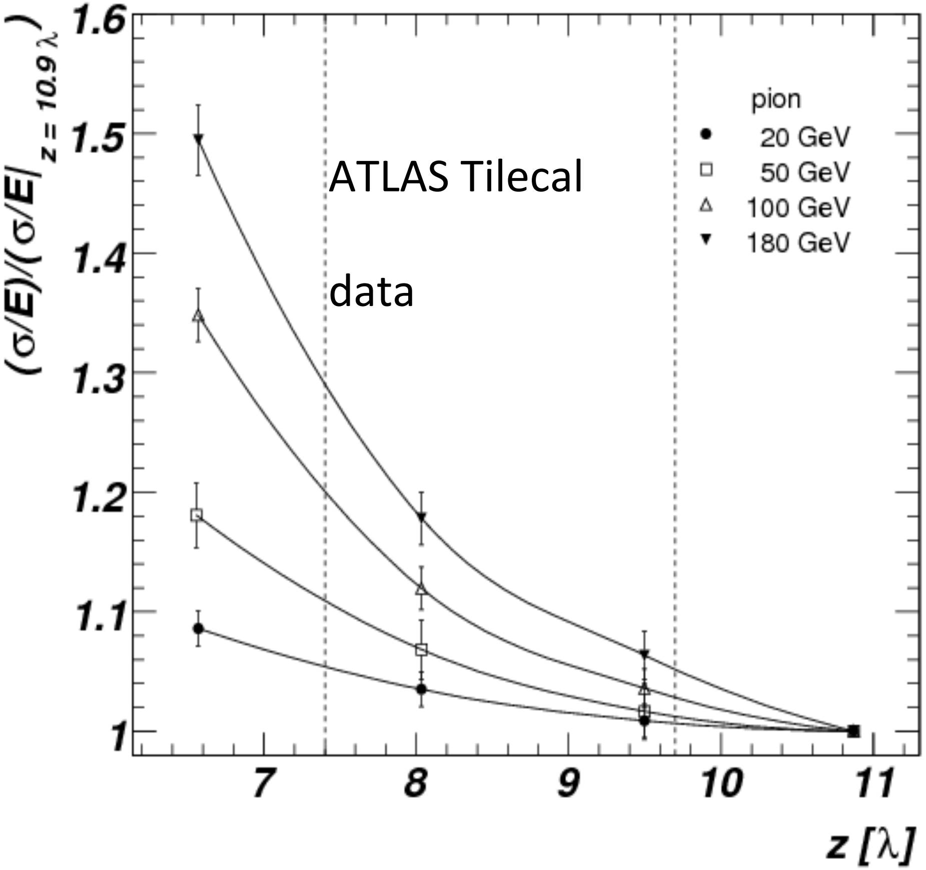
40 Tev q* ($\sigma_E/E \sim 50\%/\sqrt{E} \oplus C$ (C=0-15%)

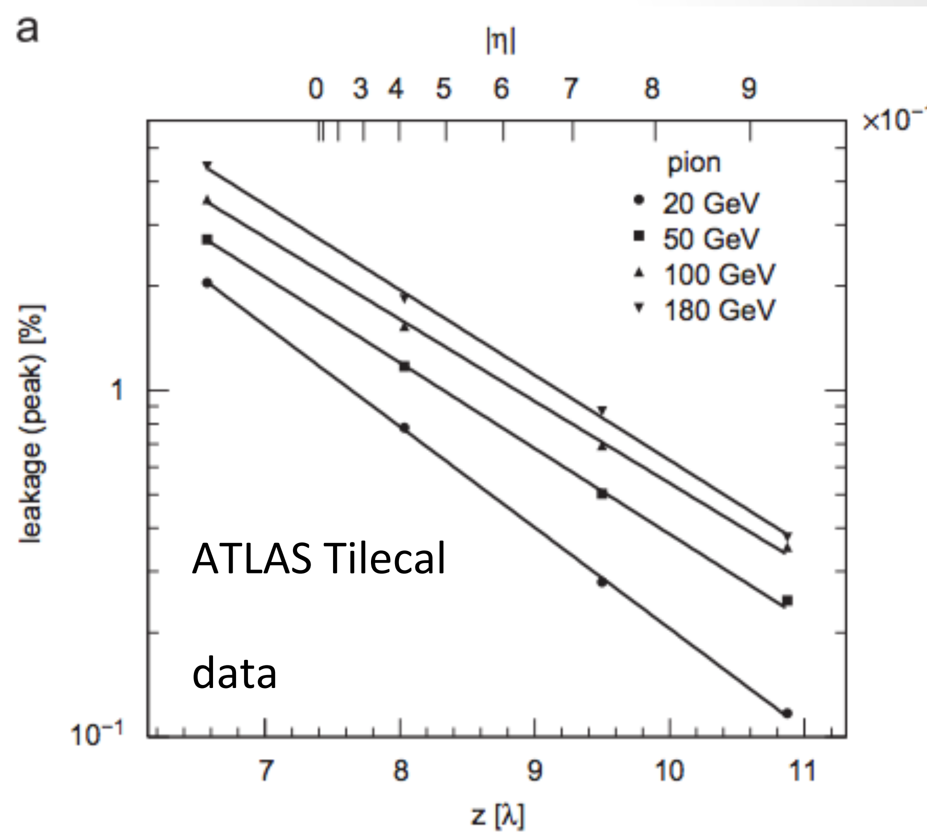




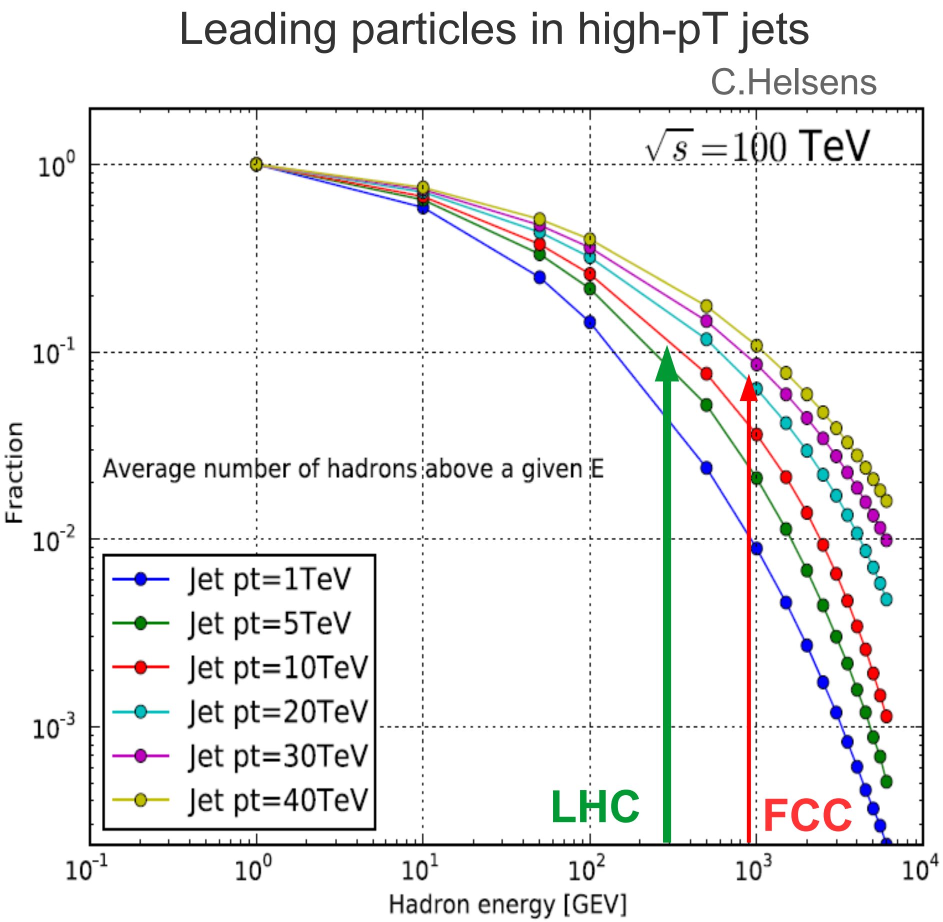
Longitudinal leakage increase hadron resolution constant term =>
keep hadronic shower containment >98% (also important for Etmiss)

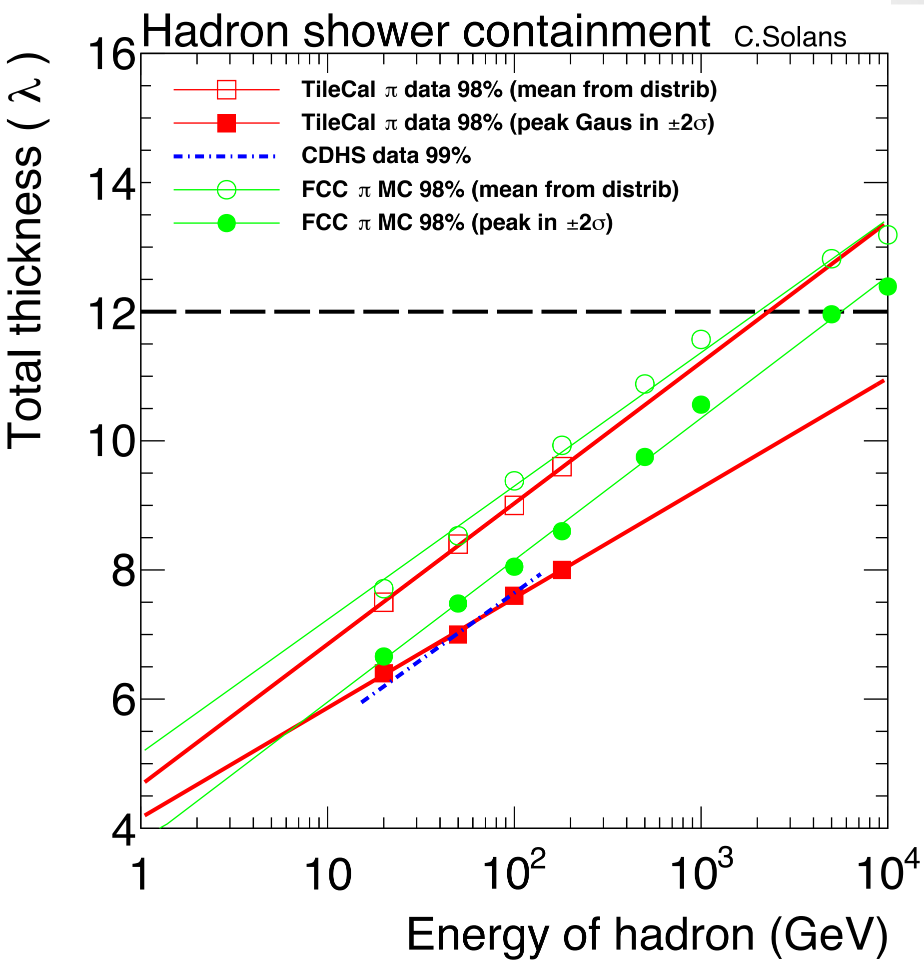
http://dx.doi.org/10.1016/j.nima.2010.01.037





FCC HCAL depths requeriments →12 λ



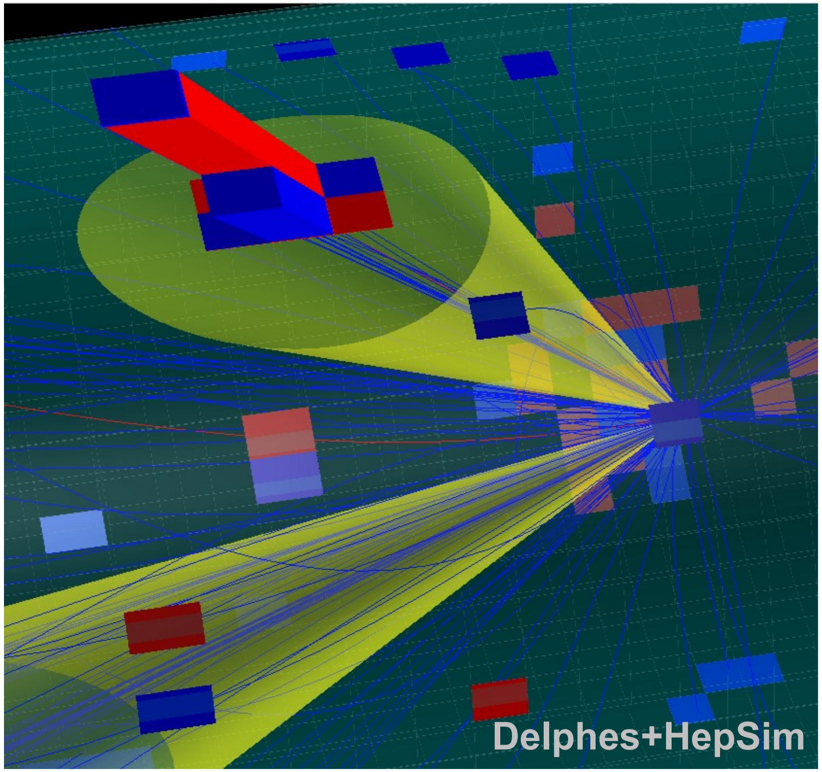


pT(jet)>30 TeV: ~10% will be carried by 1 TeV hadrons (~9 hadrons/jet)
12 λ is needed to contain 98% of energy of a 1 TeV hadron

Effect of Calorimeter Transverse granularity

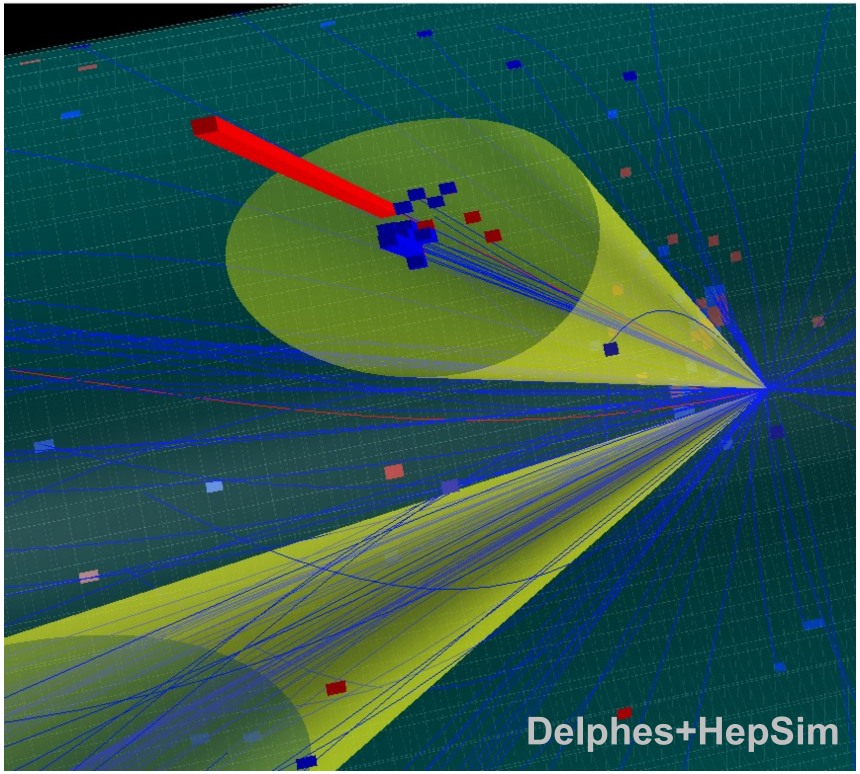
Example: Z'(10 TeV) → $t\bar{t}$ → 2 antiKT05 jets (pT(top)> 3 TeV)

Snowmass-like CAL geometry 'ATLAS'-like



~ 5 deg :
Phi ~ 5 deg, Eta ~ 0.1

x4 smaller CAL cells



~ 1.25 deg :
Phi ~ 1.25 deg, Eta ~ 0.025

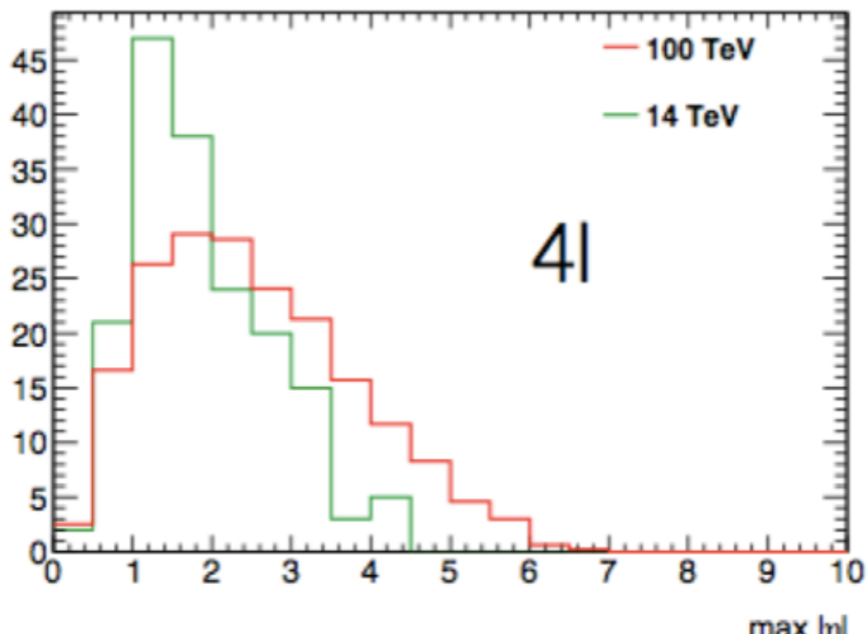
x 4 better segmentation

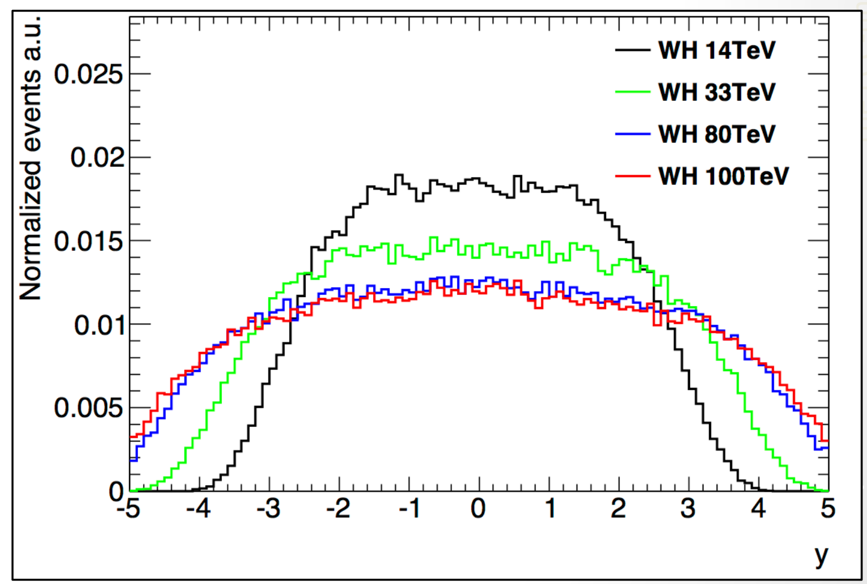
At least 2-4 times better transversal granularity than ATLAS/CMS $\Delta\eta x \Delta\phi$=0.1x0.1-> 0.25x0.25

Eta coverage requeriments

- Coverage up to η~6 for calorimeter and tracking (vector boson fusion (VBF) production and WW scattering).

H production in gluon gluon fusion (ggF)





Summary requirements for the FCC-hh HCAL

- Good energy resolution at medium (GeV) and high (TeV) energies
  - ~50-60%/$\sqrt{E}$ (di-Higgs production, …)
  - + C~3% or below (di-jet resonances (Z', q*, ….)=>
- 12 λ in depth (containment > 98%)
- Transverse granularity $\Delta\eta x \Delta\phi$ =0.25x0.25 or better ? (highly boosted objects, jet substructure) how much exactly still no conclusion
- Extend coverage to η~6.

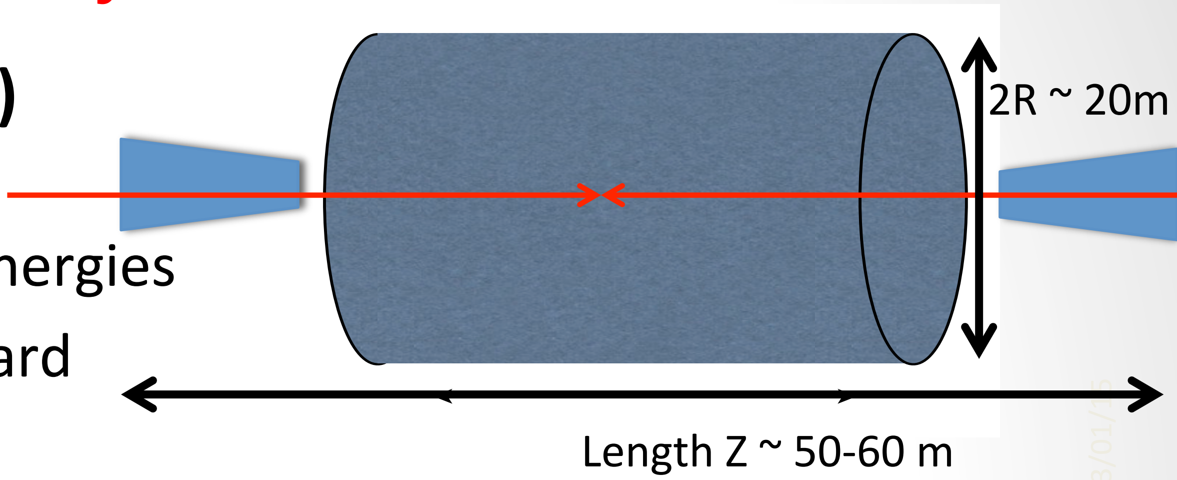
+

- Good Etmiss resolution (minimize cracks , good containment)
- Fast response and time resolution (for pile-up rejection)
- Radiation resistance, including safety factors for probable increase in Luminosity, unknowns…..

More info: http://indico.cern.ch/event/340703/session/101/contribution/200/material/slides/0.pdf)

Detector: towards a layout

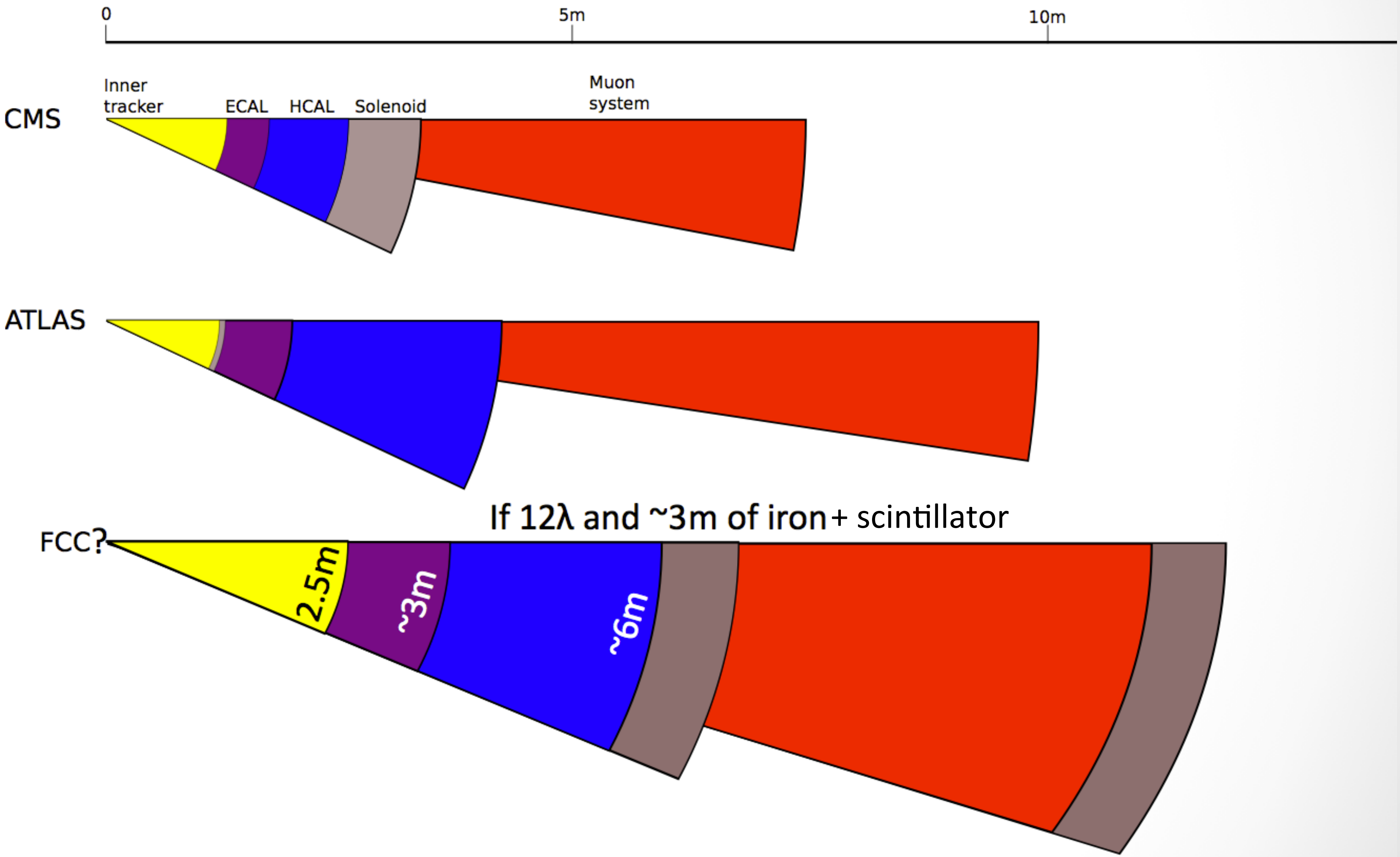
With higher E_{cm}: (x7 LHC)



- Particles with higher energies
- More particles in forward

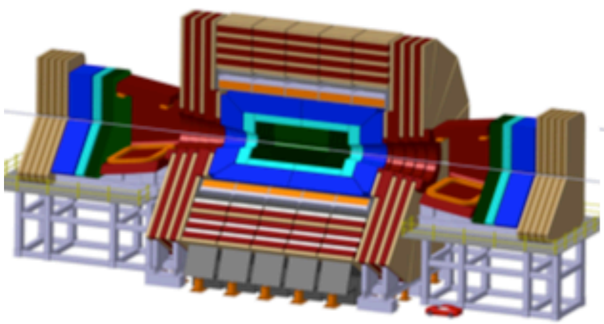
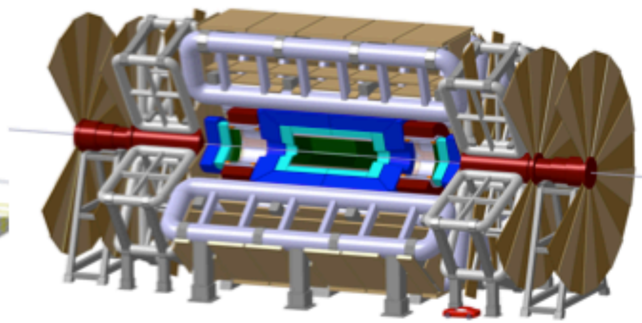
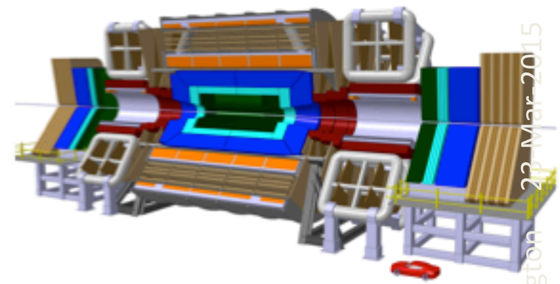
- Larger detector radius (deeper calorimeter, Tracker)
  - Calorimetry: ≥ 12 λ for hadronic showers containment
  - BR^2 ~7xATLAS/CMS to achieve muon σp_T~ 10% at 10-20 TeV
    - Field ~ 6.0T
    - Tracker Radius~ 2.5m (decrease if better point resolution)
- Longer detector in Z
  - η=5 -->η=6, for a fixed Radius => move detector x 2.7 further away from the IP
  - Forward dipole à la LHCb: B~10 Tm

Dimensions



0
5m
10m
CMS
Inner tracker
ECAL
HCAL
Solenoid
Muon system
ATLAS
If 12λ and ~3m of iron + scintillator
FCC?
2.5m
~3m
~6m

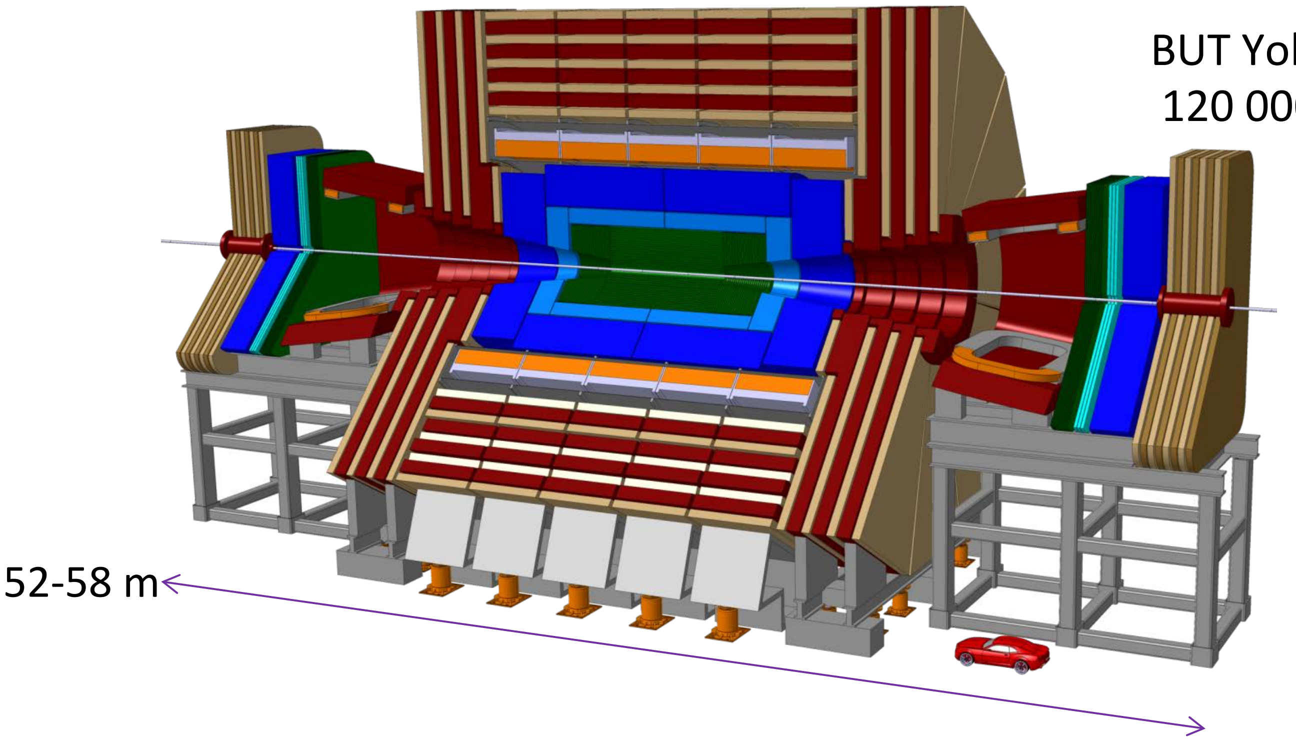
FCC-hh : Magnet options

long solenoid	thin solenoid + toroid	twin solenoid
		
CMS-like -possible reduced yoke (accepting fringe field)	ATLAS-like	no return yoke

More details :

http://indico.cern.ch/event/340703/session/24/contribution/165/material/slides/0.pdf

2. Option 1: Solenoid-Yoke + Dipoles (CMS+)

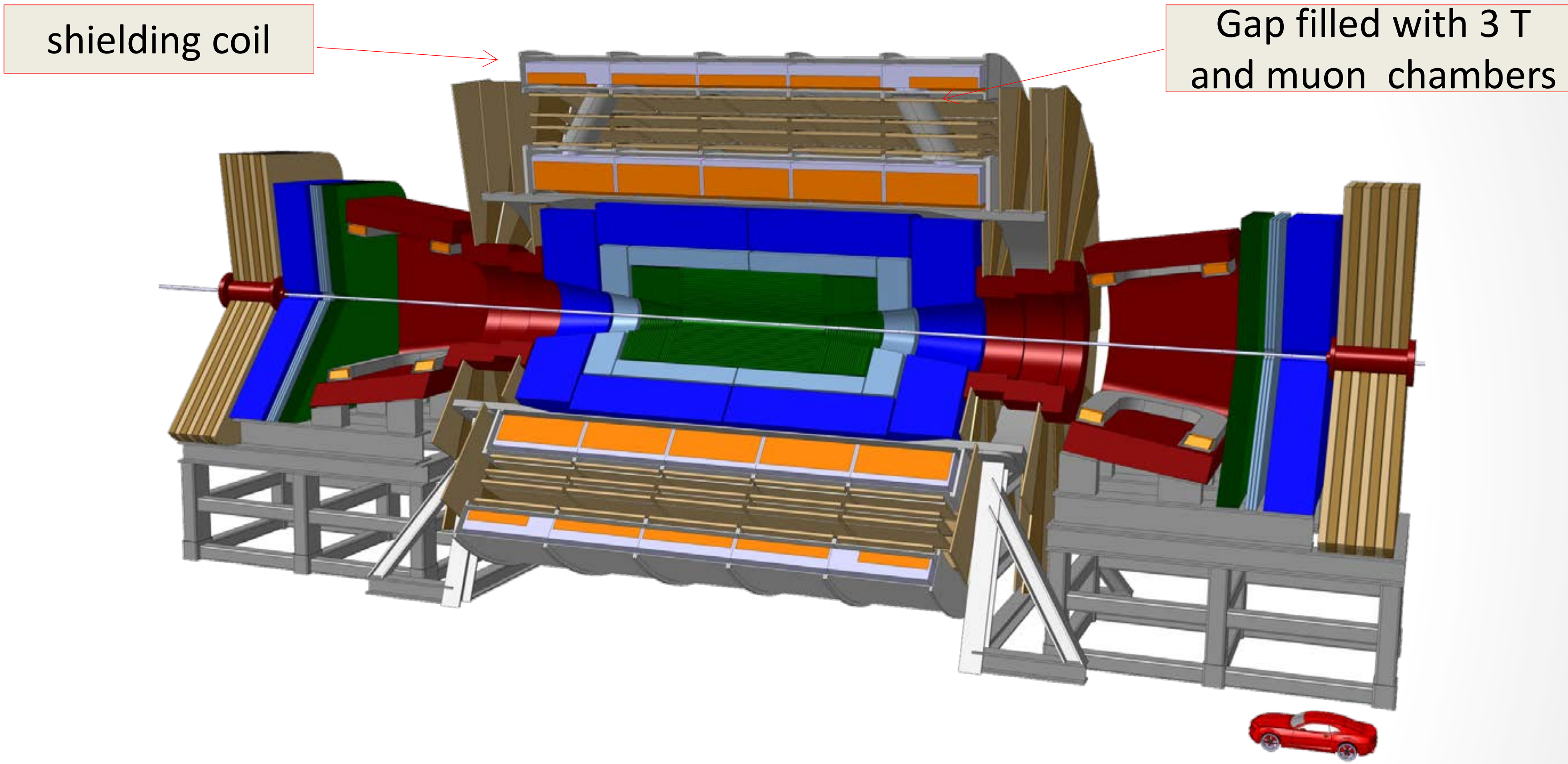


BUT Yoke 6.3 m thick…
120 000 tons (>250MEuros
just for Iron…

- **Solenoid:** 10-12 m diameter, 19-23 m long, respectively, and 5-6 T + iron yoke for flux shielding and muon tracking.

- **Dipoles:** 10 Tm with return yoke placed at z≈18 m.
  Practically no coupling between dipoles and solenoid.
  They can be designed independently at first.

2. Option 2: Twin Solenoid + Dipoles

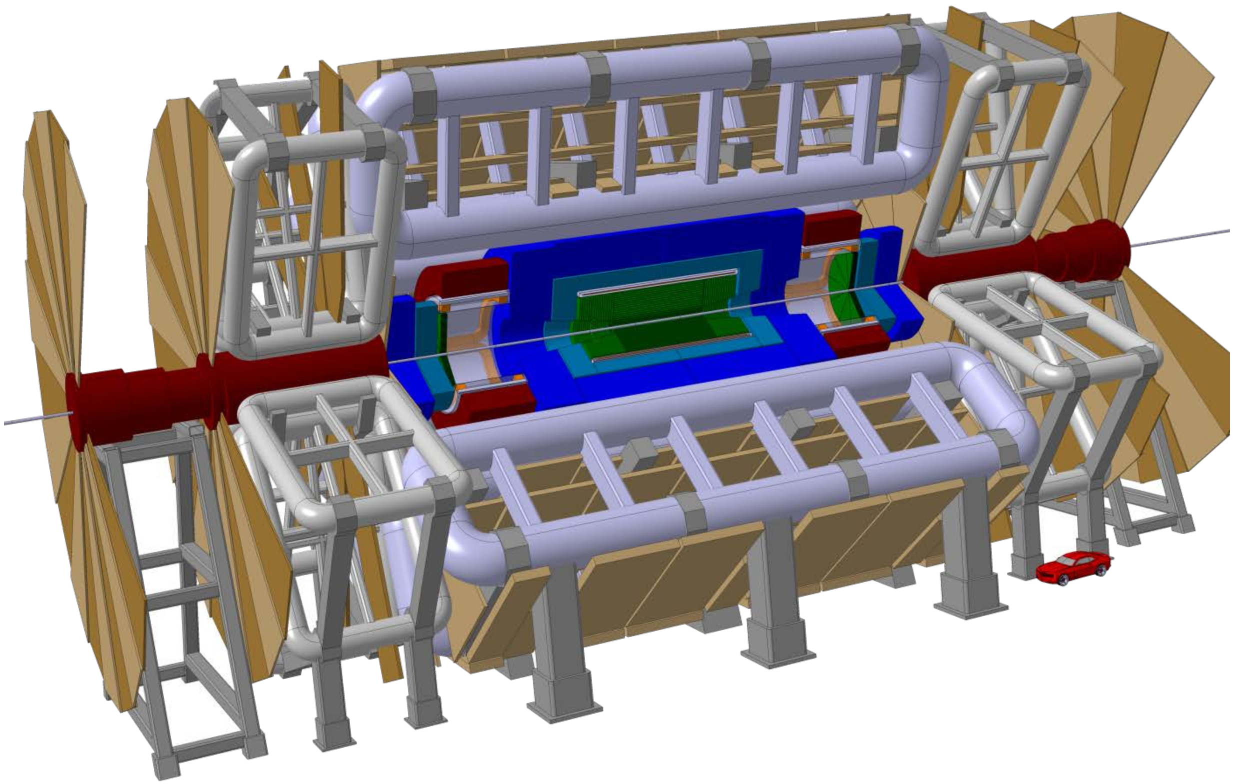


Twin Solenoid: 6 T, 12 m dia, 23 m long main solenoid + shielding coil

Important advantages:

- **Nice muon tracking space:** gap with ≈2-3 T for muon tracking in 4-5 layers.
- **Light:** shielding coil + structure ≈ 8 kt, much lighter than the iron yoke!

2. Option 3: Toroids + Solenoid + Dipoles (ATLAS+)



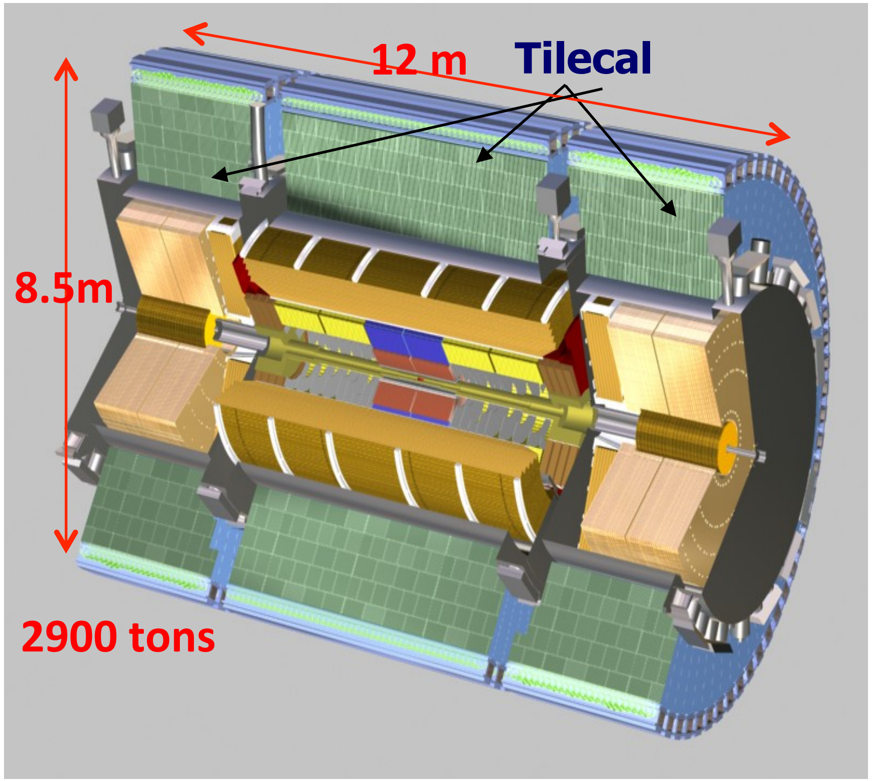
Stored energy	40 GJ (34 GJ BT + 2x 3 GJ ECT)
Conductor mass	3.3 kt (10x 280 t BT modules + 20x 25 t ECT modules)
Length BT [m]	36
Inner radius BT [m]	7
Outer radius BT [m]	15
Length ECT [m]	8
Inner radius ECT [m]	2.5
Outer radius ECT [m]	15

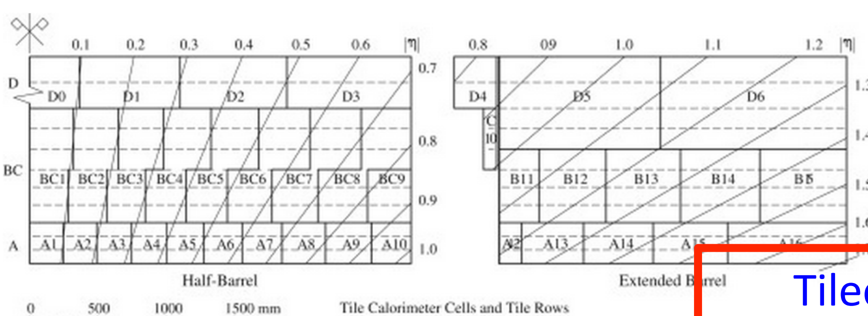
Variant with shorter Barrel Toroid and full diameter End Cap Toroids, both in open structure. Advantages:

- Shorter coils, easier to handle
- Open end cap toroids allowing muon chambers inside
- Improved coverage in overlap sections

The potential of the ATLAS Tile hadronic calorimeter concept with higher granular readout (siPMTs) for the central FCC-hh detector

ATLAS Tile hadron calorimeter (|η|<1.7)



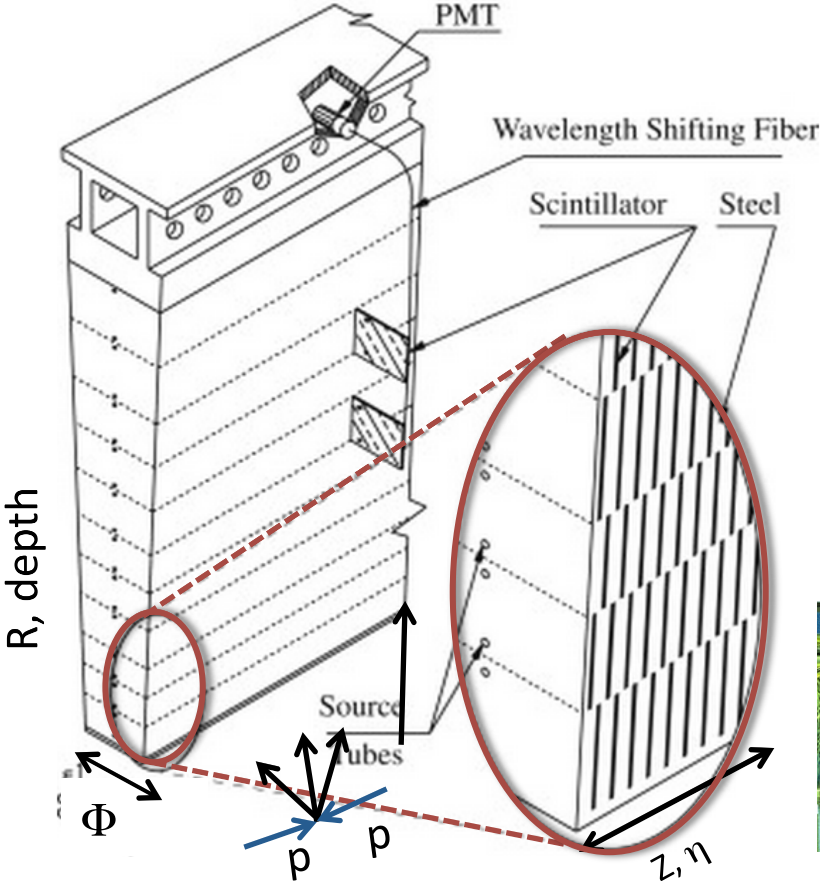


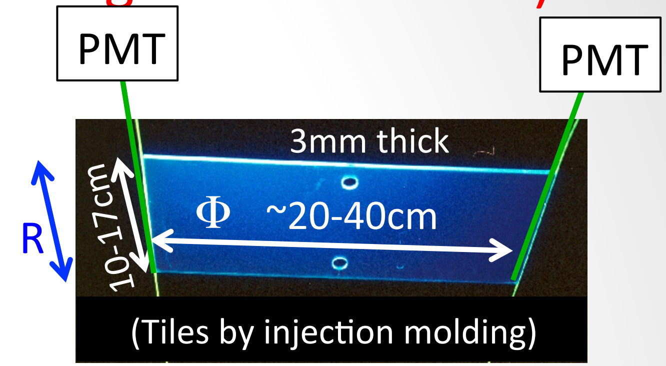
- Scint. Tiles; fibres // to incoming particles at η=0
- Steel/Tiles: = 4.7 : 1 (λ = 20.7 cm)
- Active cells volume: ~ 372m3
- ~ 620k fibres ; 40k Tiles
- 10 k channels
- 7.7 λ at |η|=0 ; (9.7 λ with the em LAr calo)
- Transversal granularity $\Delta\eta\times\Delta\phi=0.1\times0.1$
- Longitudinal segmentation: 3 layers
- e/h = 1.33
- Pion resolution (test beam):
  - $\sigma_E/E \sim 52\%/\sqrt{E} \oplus 5.7\ \%$ (7.9 λ)
  - $\sigma_E/E \sim 45\%/\sqrt{E} \oplus 2\ \%$ (9.2 λ)
- target (with e.m. LAR) at ATLAS/LHC:
  - Jet $\sigma_E/E \sim 50\text{-}60\%/\sqrt{E} \oplus 3\%$
  - Containment ~ 98% TeV hadrons, jets

Tilecal MoU Core Cost (1998):

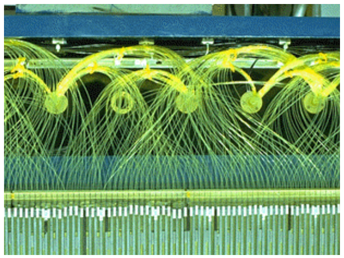
- 17 MCHF (46% mechanics ; 11% optics ; 43% electronics).
- Readout elect. determine cost: ~730 CHF/channel
- 3.6% cost of the ATLAS detector

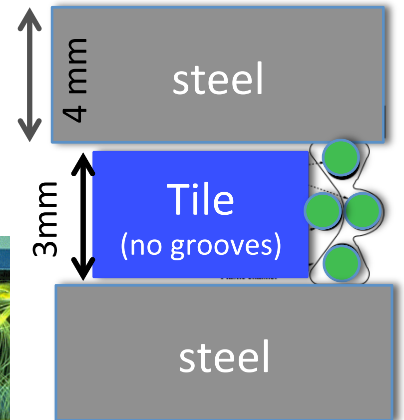
Today's ATLAS Tilecal optics granularity (but merged at readout…)





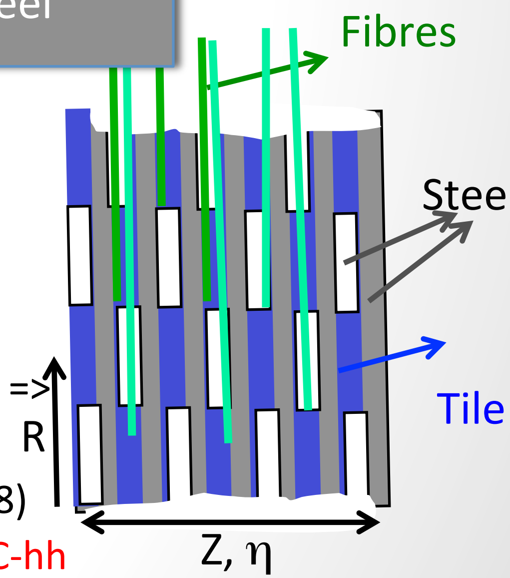
Fibre bundles (at outer radius)





Fibres start at different R and go radially out =>

- No ϕ cracks
- R segmentation
- PMTS out Radius



$\Delta\eta$: 3mm tiles every 9-18mm in Z-> $\Delta\eta<0.008$

ΔR: 11 tiles and 8 fibres in R -> 8-11 layers with $1\lambda<\Delta R<0.5\ \lambda$

$\Delta\Phi$: 20 cm tiles-> $\Delta\phi=0.1$ (with dual fibre readout)

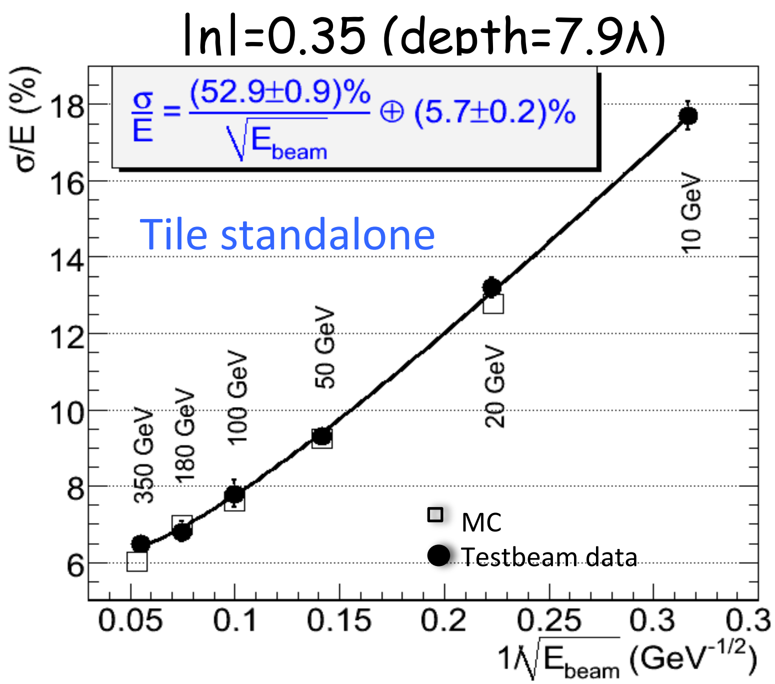
In total ~ 620k fibres and 40k tiles ; but ~80-300 Tile-fibres couplings in 1PMT =>

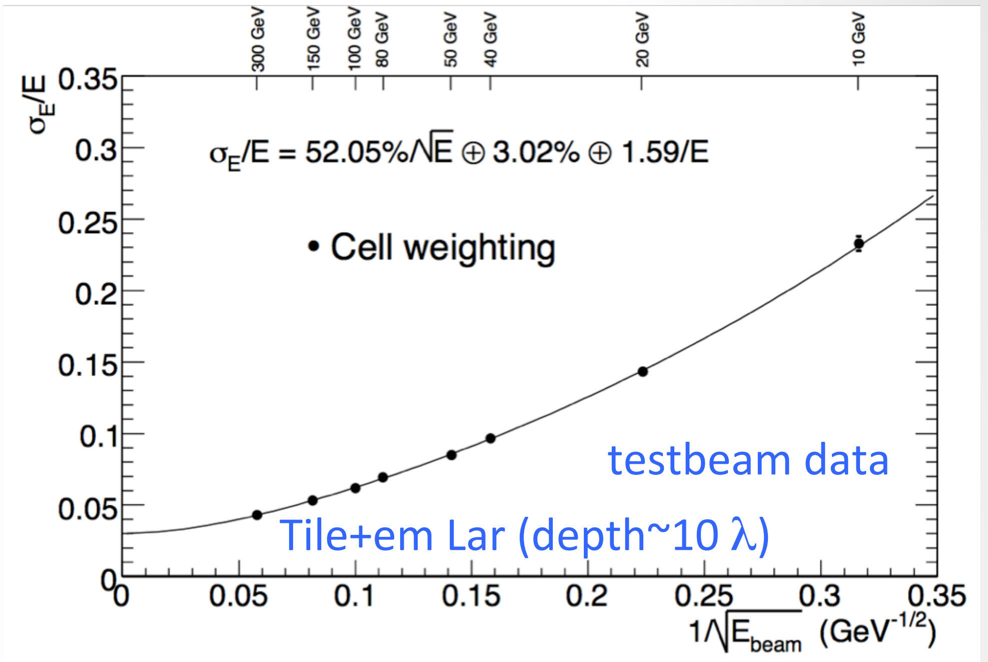
10 k channels ; $\Delta\eta \times \Delta\phi=0.1\times0.1$; 3 longitudinal layers in LHC

Cost/performance compromise in electronics costs (~730CHF/channel in 1998)

Minimal changes needed in optics/mechanics to exploit full granularity at FCC-hh

π resolution in testbeams ->jet resolution in ATLAS

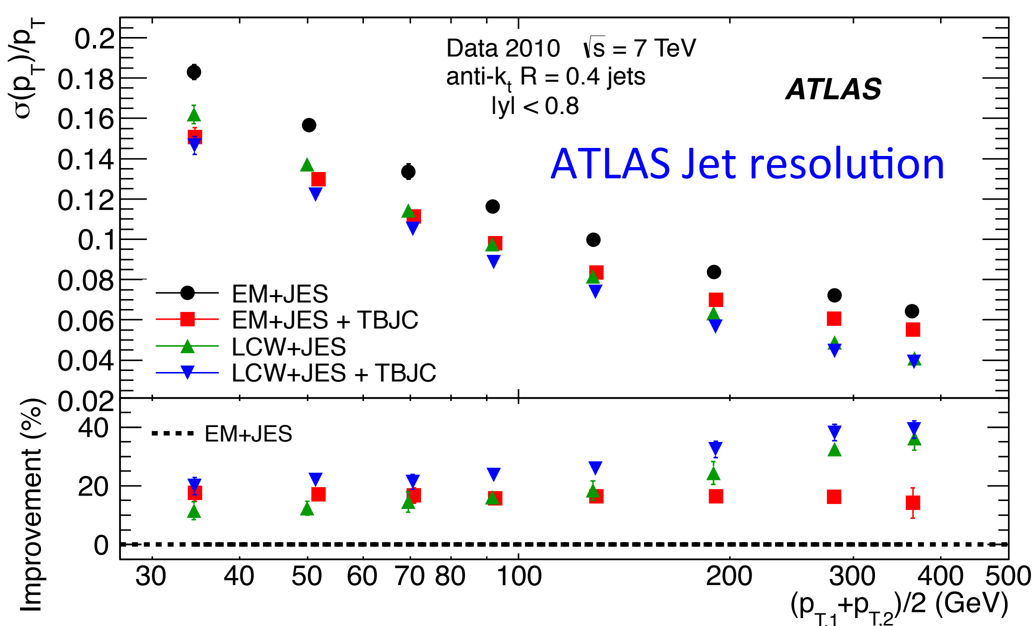




Good performance thanks to >10 years R&D, test-beams, MC tuning, cosmics

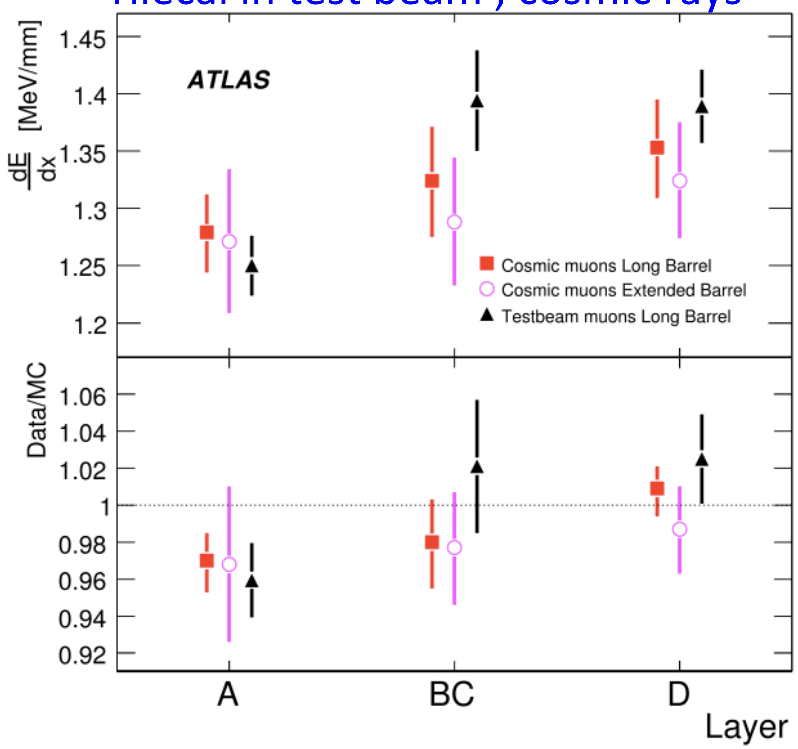
Jet resolution close to design:

- constant term ~3%
- Pile-up worsen low p_t resolution
- Improvements after pile-up corrections for in-time/out-time bunches/noise threshold tuning, etc.

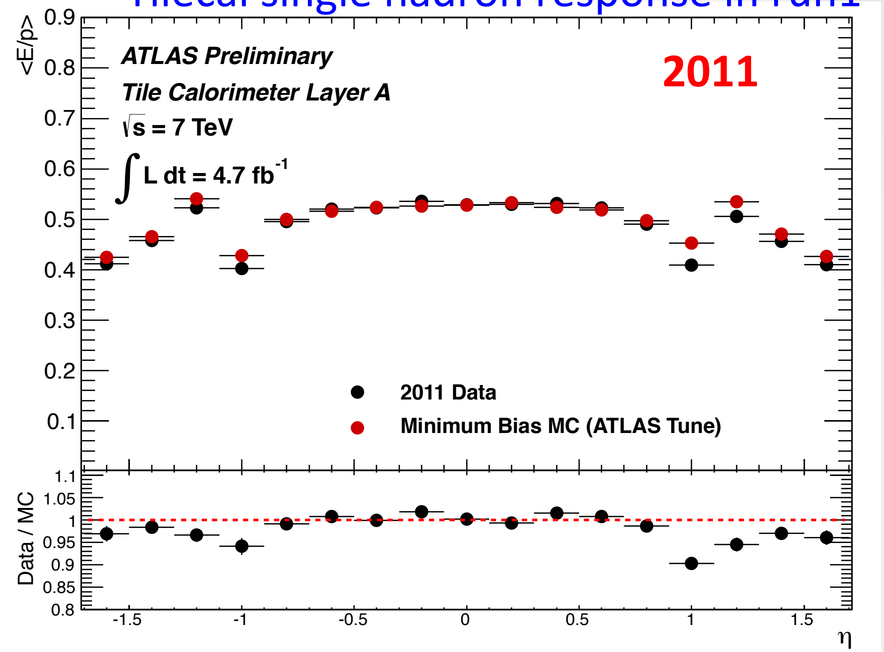


Jet energy scale precision (ΔJES) in run 1

Tilecal in test beam ; cosmic rays

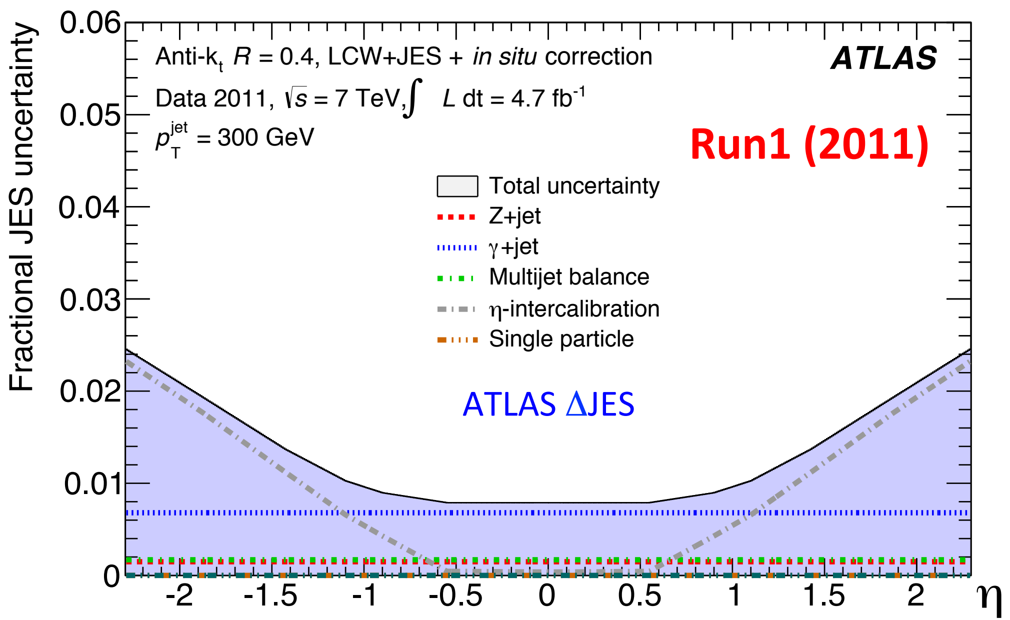


Tilecal single hadron response in run1



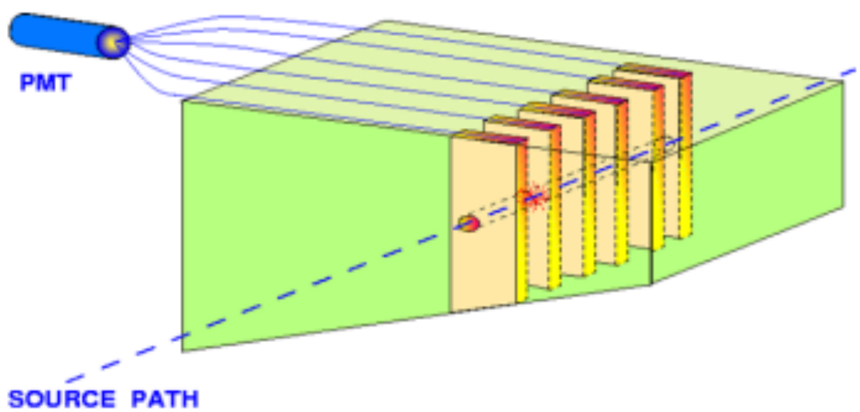
Tilecal electromagnetic scale:

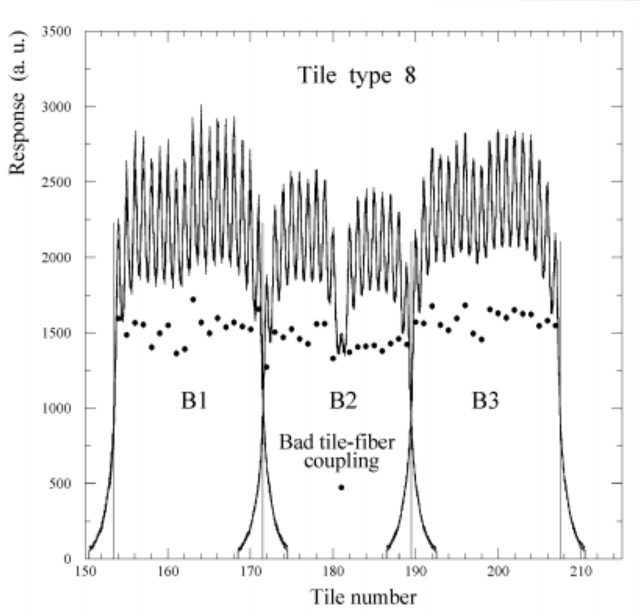
- from test beam (e, μ) in 11% of modules
- error ~3% (from test beam, cosmic rays)
- monitored after re-calibrations with μs from collisions, e/p, cosmic rays



ATLAS ΔJES is the main uncertainty in many physics channels. Achieved < 1% error in central region and medium p_t

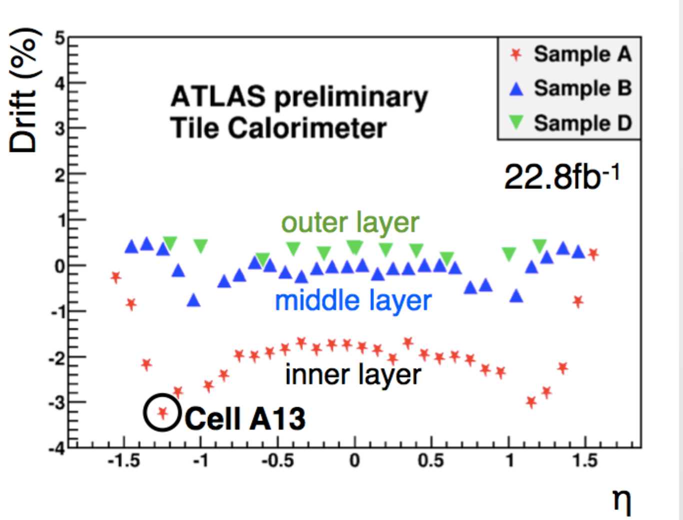
ATLAS-Tile cesium calibration system





- 137 Cs ~ 1/month monitor optics + electronics (~ 0.3% precision in 10 000 channels)
- Laser ~ 2-3/week monitor PMTS gain (the main source of cells drifts)

- Cs constants: average of all Tile/fibre peaks in a cell
- => same system well adapted to a Tilecal concept with bigger/full readout granularity for FCC-hh

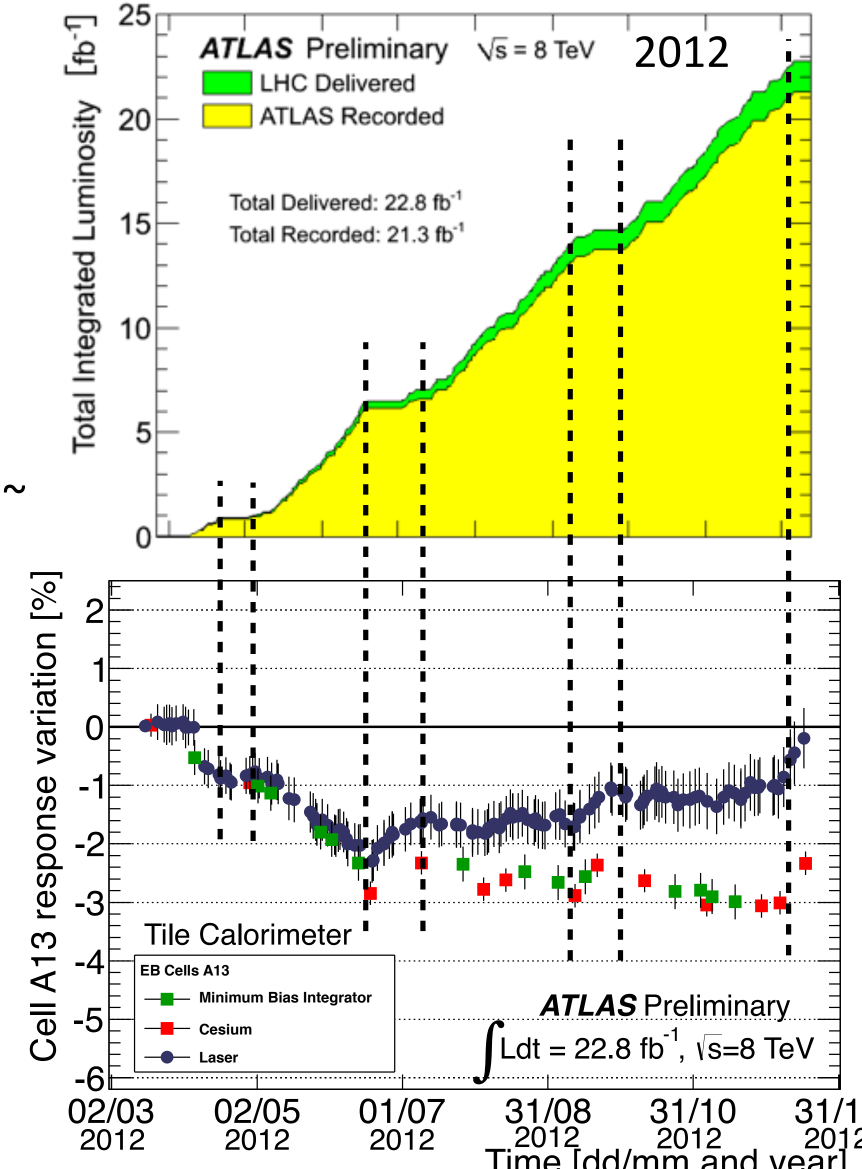


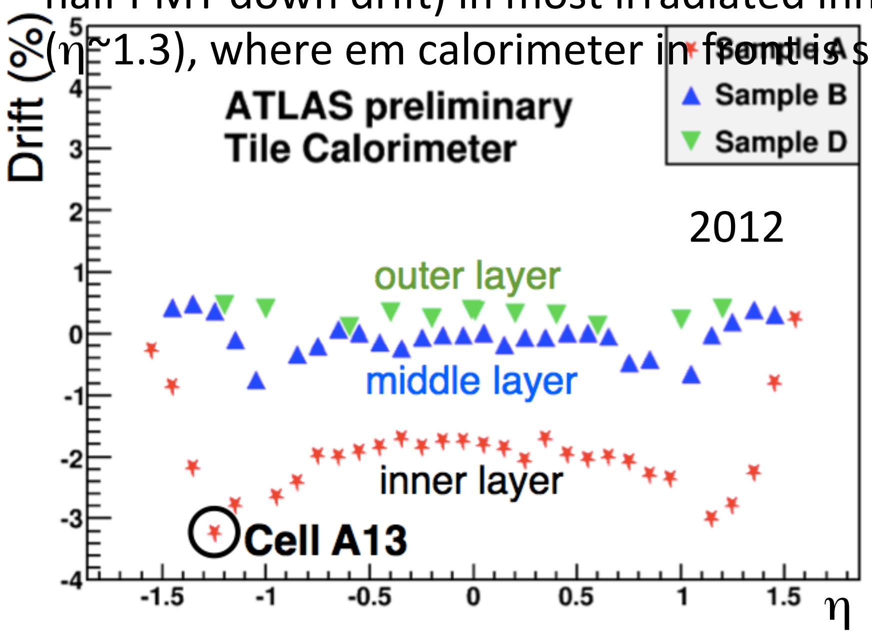
ATLAS Tilecal Calibrations

- ^{137}Cs:
- correct for optics +PMT+ electronics variations.
- Used in test beams to bring em scale to ATLAS + inter-calibrate all 10k channels.
- In run1 used ~1/month
- Laser: ~ 2/week monitor PMT gain + electronics
- Charge injection: ~ 2/week monitor electronics

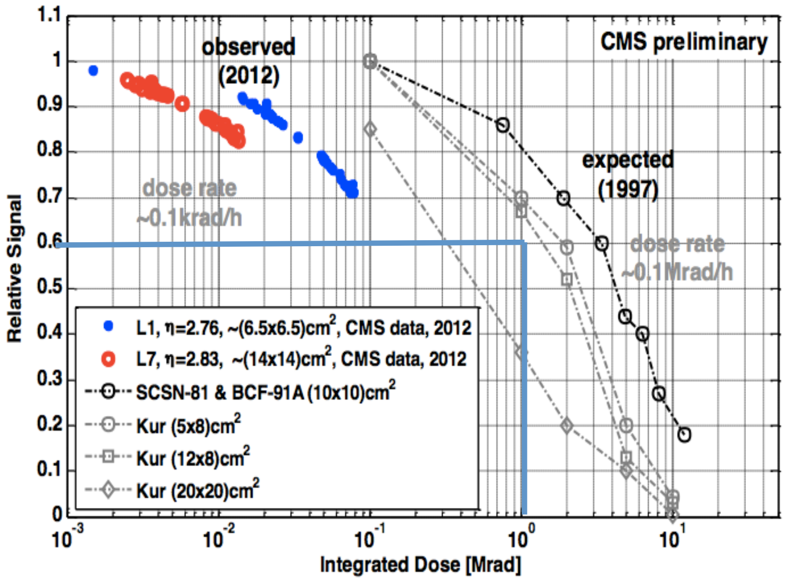
In run 1:

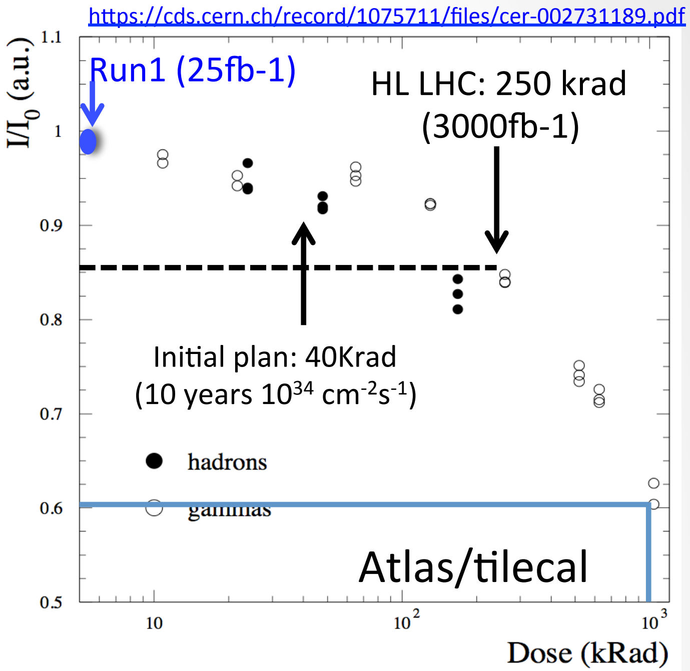
- Calibrations systems precision < 1%
- Short time scale drifts dominated by PMT ΔGain
- ~ -3.5% tot max. loss (~ half is optics irradiation; ~ half PMT down drift) in most irradiated inner cell (η~1.3), where em calorimeter in front is shorter





Effects of radiation in ATLAS/CMS **optics** at run1 and consequences for HL-LHC



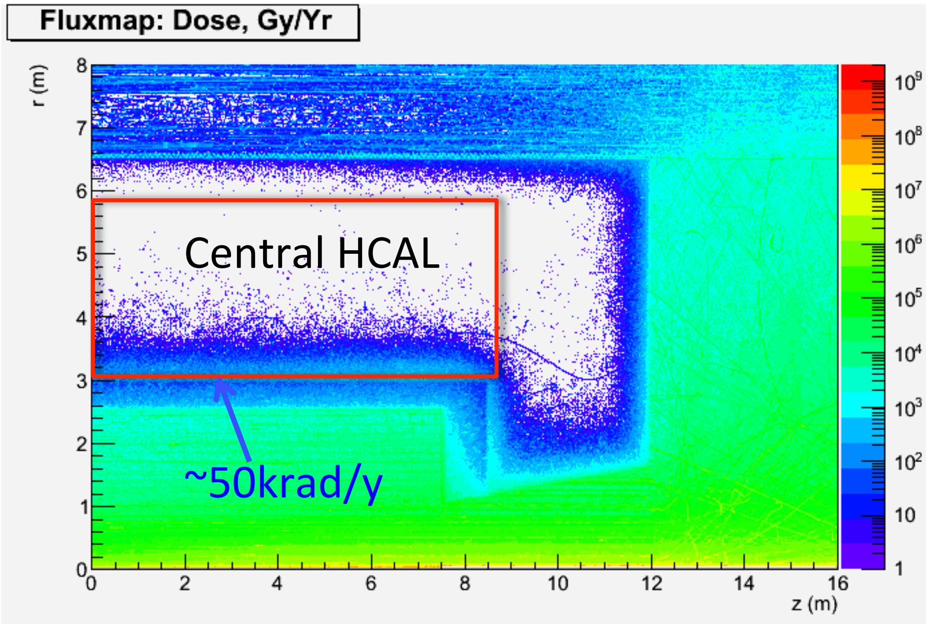


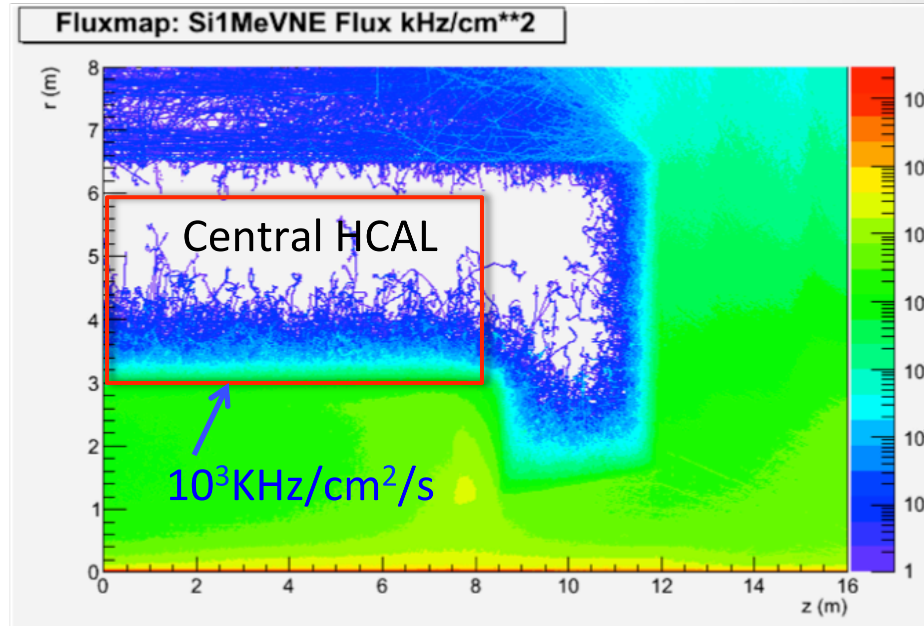
- CMS/ATLAS 1997 data w/ similar results <u>(1 Mrad-> -40%)</u>
- In LHC CMS x 100 dose than ATLAS because:
  - CMS R_{min}= 0.4 m in endcap $|\eta|<2.8$
  - ATLAS R_{min}=2.2m ; $|\eta|<1.7$
- In run1 (25 fb^{-1}) maximum damage:
  - ATLAS: -2% for 2.2Krad within expectations (in few inner cells w/ shorter em calo in front at η~1.3)
  - CMS end-cap: -30% for 0.2Mrad (losses 2-3 larger than expected, dose rate effects?).
  - CMS barrel: -5% for 3Krad
- Expectations at HL-LHC (3000 fb^{-1}):
  - ATLAS: 0.3 Mrad max.=> -15% in few inner cells at η~1.3 => no impact in jet performance
  - CMS: 25 Mrad max=> replace end-caps in phase 2, get longitudinal segmentation in phase 1

Important to get enough safety factors in planning new detectors for future FCC-hh

Expected doses in FCC-hh if L=10^{36}cm^{2}s^{-1} (FCC-hh phase 1 L=5x10^{34}cm^{-2}s^{-1} ; ph 2 L=3x10^{35}cm^{-2}s^{-1})

(assuming radial dimensions: tracker=2.5m ; 2.5m<ECAL <3m ; 3m<HCAL<6m and Zbarrel=+-8.5m)





- In central HCAL Dose ~ constant vs. Z/eta ; shielded by ECAL ; lower for bigger radius
- Max. annual dose in central HCAL at L= 10^{36}cm^{-2}s^{-1} :
  - ~5x10^2Gy/y = 50krad/y max. **=>**
  - **=> 0.5 Mrad after 10 years at L=10^{36}cm^{2}s^{-1} (=> -15% total based on atlas-tilecal scintillators)**
  - 10^3KHz/cm^2/s (1 MeV n eq.) => 10^{13} n/cm^2/year. In the electronics/outer radius flux much smaller)

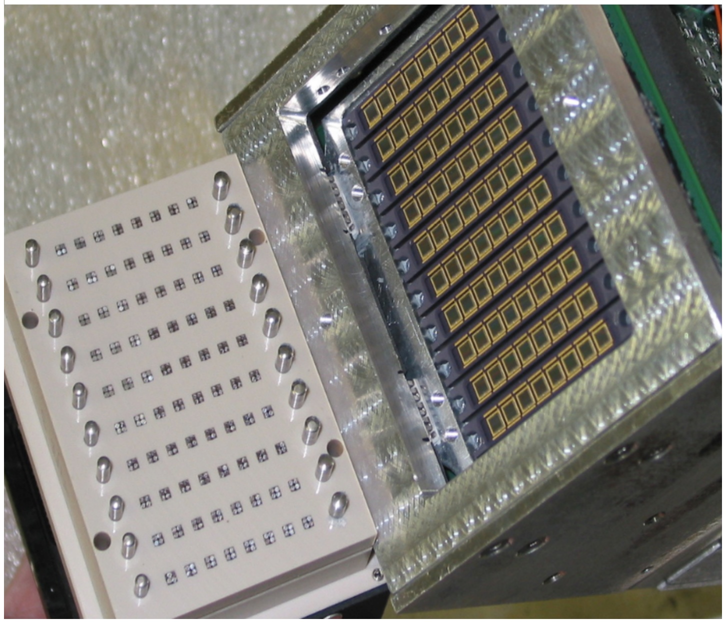
- Today's commercial scintillators (BC408 ; EJ 200) ~ 1.5-2 more radiation resistance than the scintillators used in ATLAS-Tilecal
- Active R&D on-going on radiation hard scintillators (CMS calo upgrades, …)
- **The use of organic scintillators in the central HCAL ($\eta \lesssim 1.5$) seems to be a safe option.**

Main R&D/improvements needed for an "ATLAS-Tile layout using Si-PMTS" in the central HCAL FCC-hh detector ($\eta \lesssim 1.5$)

- Electronics:
  - Si-PMTs very promising in performance and cost. Used for CMS upgrades, CALICE,....(details T. Tabarelli talk and back-up slides):
    - Allows to increase lateral and longitudinal readout granularity, profiting from the existing/or better optics granularity.
    - Insensitive to magnetic field
    - Faster time response than PMTs
    - Read single 1mm fibres or grouped fibres
    - Better quantum efficiency than PMTS (QE ~ 35% in CMS, still improving)
    - Dynamic range ~ 10^5 adequate (smaller cells).
    - Radiation resistance to ~ 10^{12}n/cm^2/y (Si-PMTS at outer radius like in CMS). R&D on-going to improve with reduced pixel size (15μm-> 5μm).
    - Cost per readout channel is promising (~ 50CHF/ for CMS upgrades) . But still (too much ?) if we wanted to exploit the full potential of ATLAS-Tile concept in eta and depth....
  - Readout electronics/cooling: developments for upgraded CMS calorimeters (and others experiments) very useful and with potential synergies.
  - .....

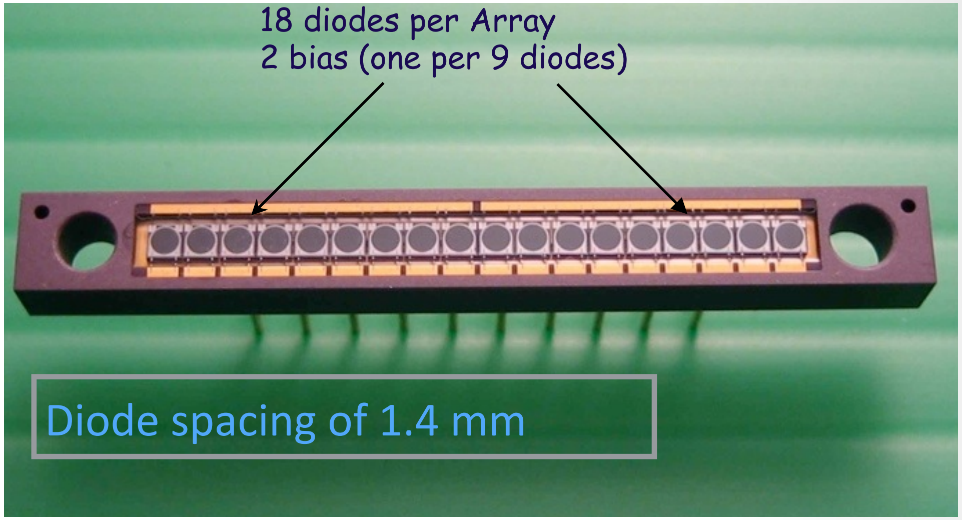
Si-PMTS under study for CMS calorimeter upgrades

8 ch Array package w/ 4 fiber/ch readout

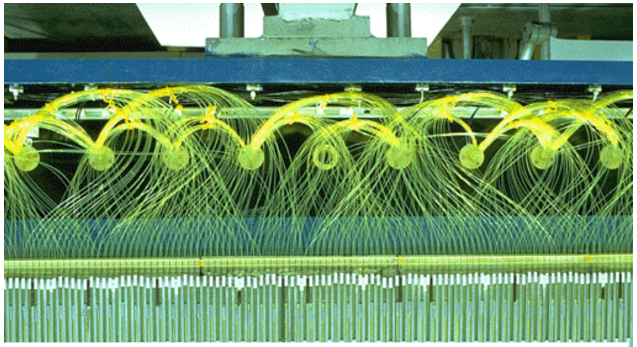


P. De Barbaro; P. Rumerio; A. Heering, T. Tabarelli

18 ch Array package for single fiber readout



Si-PMts insensitivity to B field and more granular readout should minimize space at outer radius for fibre bundles (if any) and electronics



~ 30cm (~ 1.5 λ)

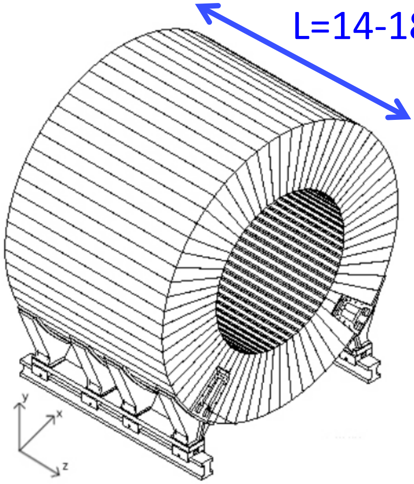
Fibre bundles in ATLAS Tilecal

Main R&D/improvements needed for an "ATLAS-Tile layout using si-PMTS" in the central HCAL FCC-hh detector (η~<1.5) (cont.)

Mechanics :

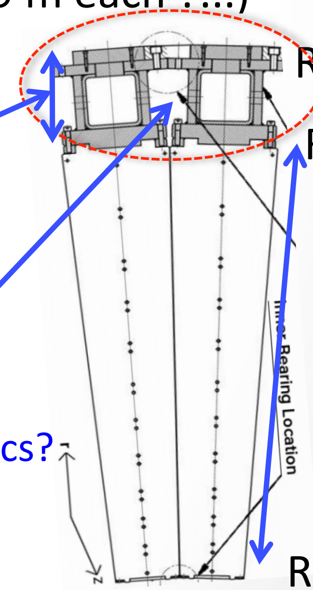
- Optimize choice of absorber (non-magnetic for solenoid options) .
- Steel, brass, Cu, W… Steel: cheapest and best performance (shower speed, μ tails,….
- Increase active cells thickness to 10-11λ (2-2.2m) ($\lambda_{Tilecal}$=20.7cm). Could reduce λ_{ef} using part of absorber plates (spacers) with W, see impact in performance…)
- Redesign outer radius girder to reduce "dead" calo thickness (ATLAS ~30 cm; 1.5λ):
    - Optimize fibres to Si-Pmts coupling (need little/absent fibre bundles)
    - Optimize electronics location/space (no need to shield Si-PMT)
- Minimize cracks in the Z at η=0 if barrel made in 2 halfs of ~7-9 m each ?...)
- Optimize supports with ~ x2 volume/weight than ATLAS
- …..

L=14-18m in 2 half?



Redesign support,
(Reduced Rout'-Rout)

New place for electronics?



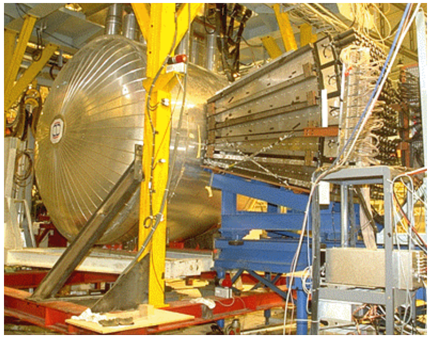
Main R&D/improvements needed for an "ATLAS-Tile layout using si-PMTS" in the central HCAL FCC-hh detector (η~<1.5) (cont.)

Optics:

- R&D on more radiation hard scintillators/fibres (> safety factors)
- Improve ϕ granularity. Possible cumulative actions

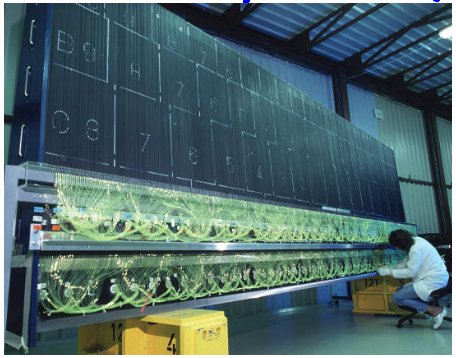
  Example $\Delta\phi$ =0.1-> 0.025:
  - Move outer radius; R_{min} =2.2 m (ATLAS-tilecal) -> 3.0m => $\Delta\phi$ =0.1 -> 0.07 (64 ->87 modules in cylinder).
  - Half trapezoidal tiles read by fibres in 1 side ($\Delta\phi$ =0.07-> 0.035) ; 87 modules; loose light and uniformity
  - Modules/tiles with smaller ϕ dimensions ($\Delta\phi$ =0.035 -> 0.025 (87 -> 122 modules/cylinder)
- Optimize depth granularity with the best match tiles-fibres and Tile depth dimensions (depends on real needs)
- ....

Tilecal from R&D->first collisions ~15 years (1993-2009)

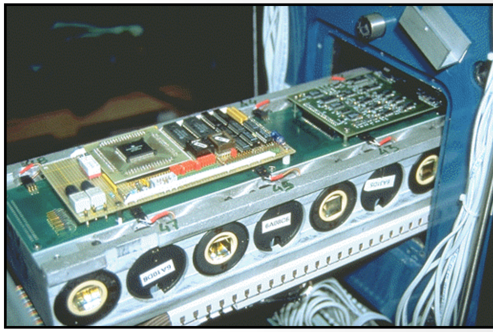


1993-1995 R&D

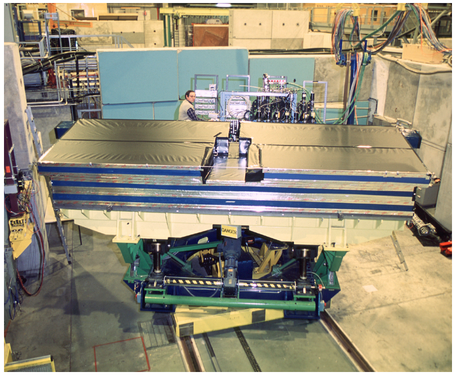
1996-2002:construction)



1999-2002 Instrumentation

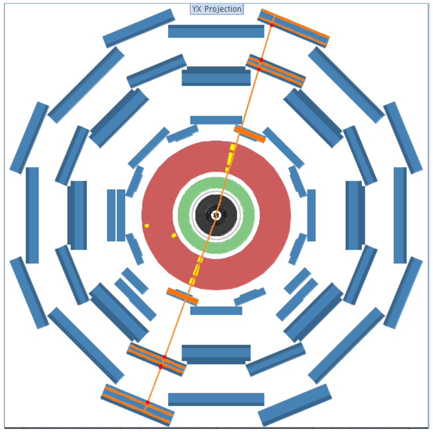


1999-2004: Electronics



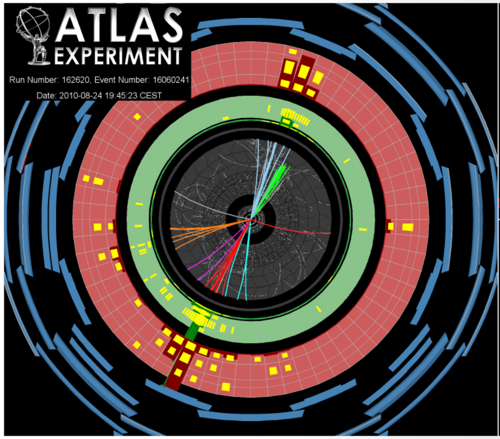
2002-2004: calibrations

2004-2006 Installation



2007-2009 commissioning

(Mostly with cosmics)



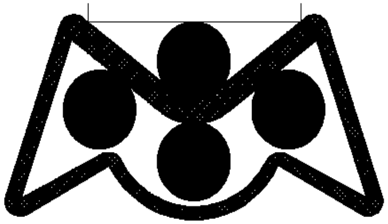
2009-->: LHC data taking

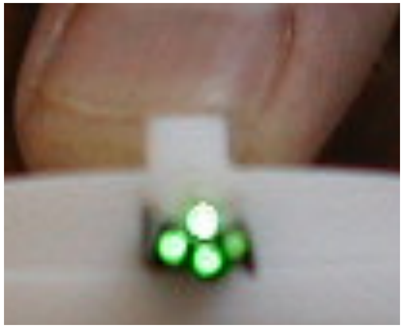
(Highest dijet M_{jj} ~ 3.1 TeV)

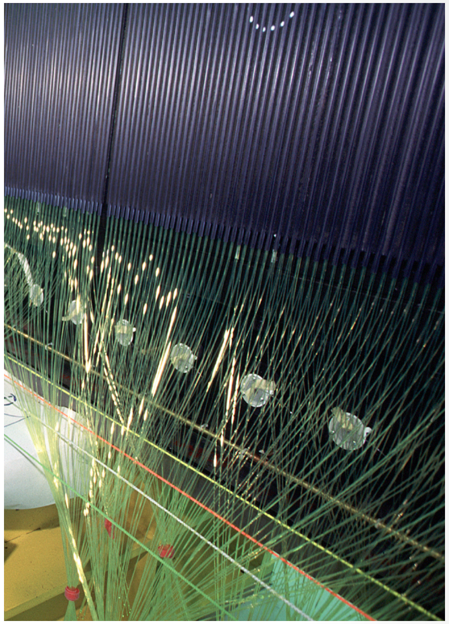
A long way to arrive to the excellent performance of Tilecal in ATLAS/LHC
With a crucial contribution from LIP (Amelia Maio team) since the very beginning!)

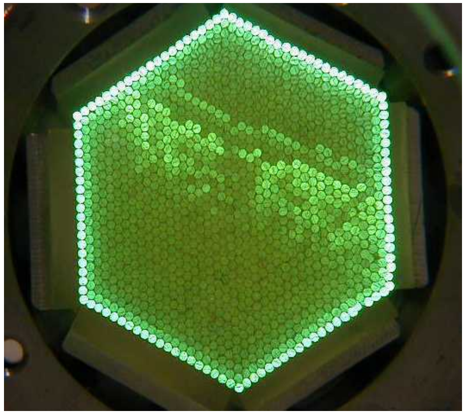
Algumas das actividades do grupo Português na construção do Tilecal

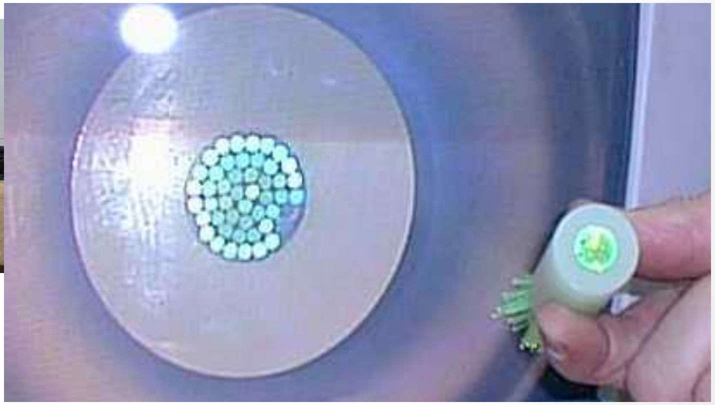
(Laboratório de Instrumentação e Física Experimental de Partículas , Universidade de Lisboa, Universidade de Coimbra, Universidade Católica-Figueira da Foz, Universidade Nova de Lisboa, Instituto Superior Técnico e Industrias Portuguesas)











E também actividades relacionadas com: analise de dados do feixe teste, simulação de Física, aquisição de dados, software,…… (5 teses de mestrado e 2 teses de doutoramento em curso)

Conclusions

- FCC-hh is a discovery machine and an exciting project for the High Energy Physics community and CERN future
- A lot to be done to mature the physics discovery potential, the accelerator and detectors design/feasibility.
- ATLAS-Tilecal concept with si-PMTs is a promising technique for the central HCAL detector, with excellent performance and cost.
- Many similar steps to the LHC project 25 years ago, hopefully LIP will be involved!

Mailing list: *fcc-experiments-hadron@cern.ch*

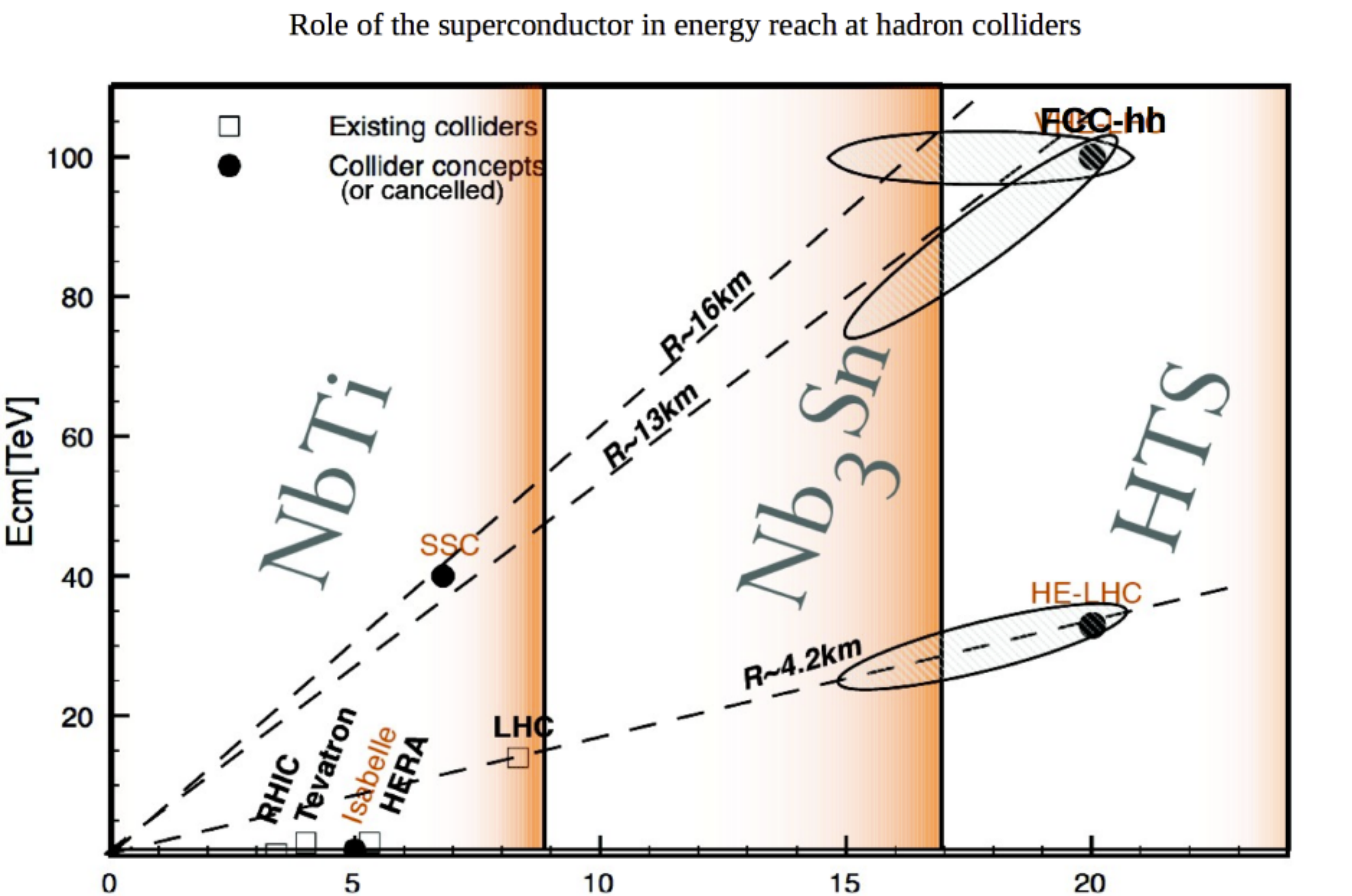
To subscribe: http://cern.ch/simba3/SelfSubscription.aspx?groupName=fcc-experiments-hadron

Obrigada Zé Mariano pelo teu constante apoio na Ciência, ao LIP , ao CERN mesmo nos momentos mais difíceis…..

Longa vida ao LIP, cheia de sucesso !

Back-up

E_{cm}[TeV] versus B [Tesla]



Field (T)

parameter	LEP2	FCC-ee				
		Z	Z (c.w.)	W	H	t
E_{beam} [GeV]	104	45	45	80	120	175
circumference [km]	26.7	100	100	100	100	100
current [mA]	3.0	1450	1431	152	30	6.6
$P_{SR,tot}$ [MW]	22	100	100	100	100	100
no. bunches	4	16700	29791	4490	1360	98
N_b [10^{11}]	4.2	1.8	1.0	0.7	0.46	1.4
ε_x [nm]	22	29	0.14	3.3	0.94	2
ε_y [pm]	250	60	1	1	2	2
β^*_x [m]	1.2	0.5	0.5	0.5	0.5	1.0
β^*_y [mm]	50	1	1	1	1	1
σ^*_y [nm]	3500	250	32	84	44	45
$\sigma_{z,SR}$ [mm]	11.5	1.64	2.7	1.01	0.81	1.16
$\sigma_{z,tot}$ [mm] (w beamstr.)	11.5	2.56	5.9	1.49	1.17	1.49
hourglass factor F_{hg}	0.99	0.64	0.94	0.79	0.80	0.73
L/IP [10^{34} cm^{-2}s^{-1}]	0.01	28	212	12	6	1.7
τ_{beam} [min]	434	298	39	73	29	21

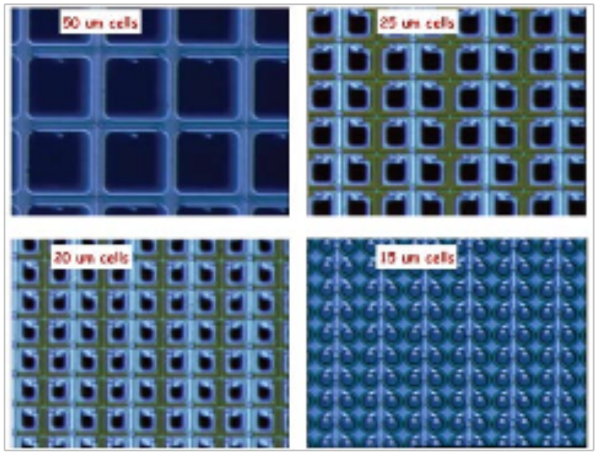
Synchrotron radiation

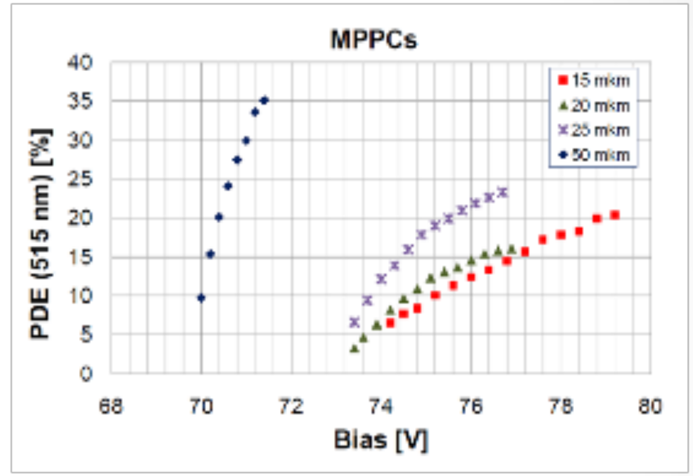
	LHC	HL-LHC	HE-LHC	FCC-hh
Dipole field [T]	8.33	8.33	20	16 (20)
Synchr. Rad. in arcs [W/m/aperture]	0.17	0.33	4.35	28 (44)
Eng. Loss p. turn [MeV]	0.007		0.2	4.6 (5.9)
Crit. eng. [keV]	0.044		0.575	4.3 (5.5)
Total synr. Power [MW]	0.0072	0.0146	0.2	4.8 (5.8)
Long. Damp. Time [h]	12.9		1.0	0.54 (0.32)
Transv. Damp. Time [h]	25.8		2.0	1.08 (0.64)

- Values in brackets for 20T magnet field
- Radiation given by beam energy and dipole field
- Equivalent to 30W/m /beam in the arcs
- LHC <0.2W/m, total heat load 1W/m

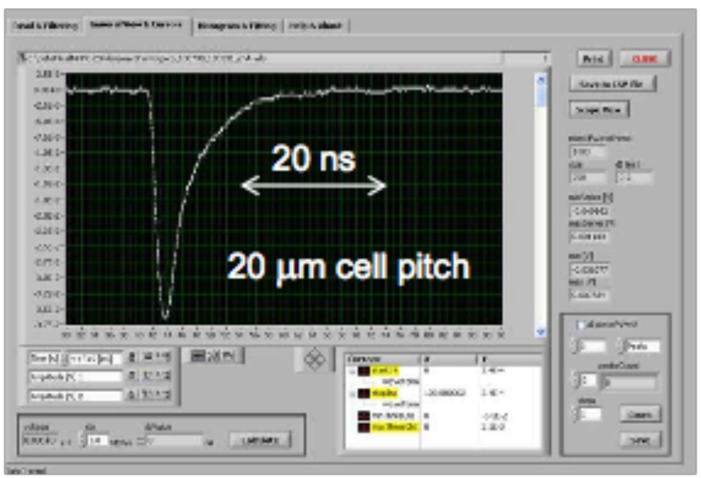
P. De Barbaro; A. Heering

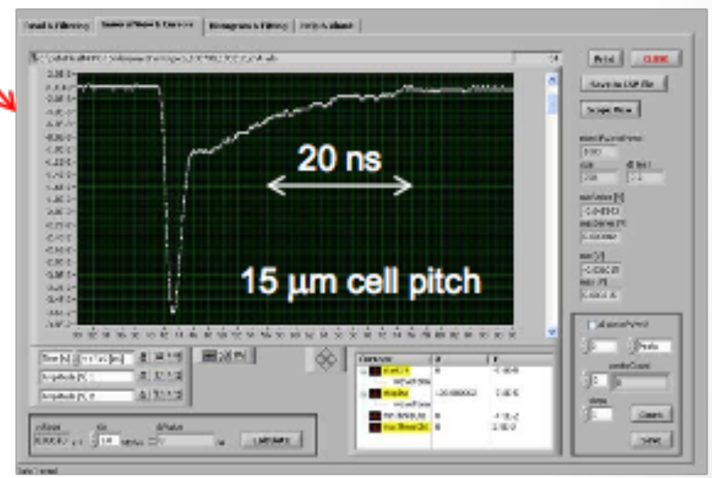
SiPM Pulse shape vs cell size





MPPC responses to a fast (35 psec FWHM) laser pulse

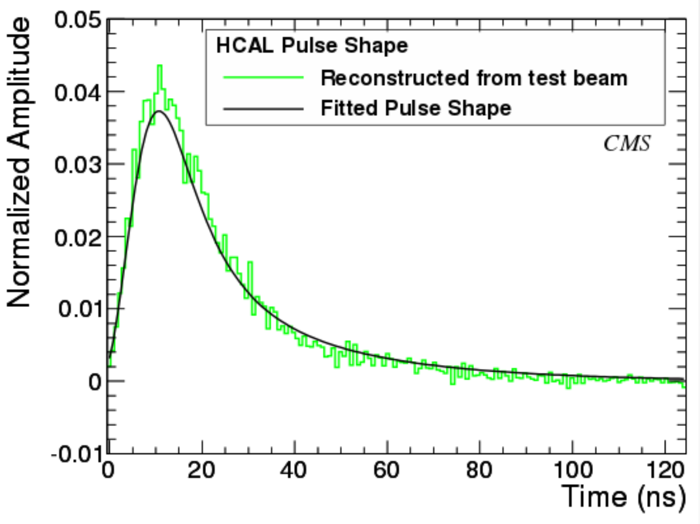


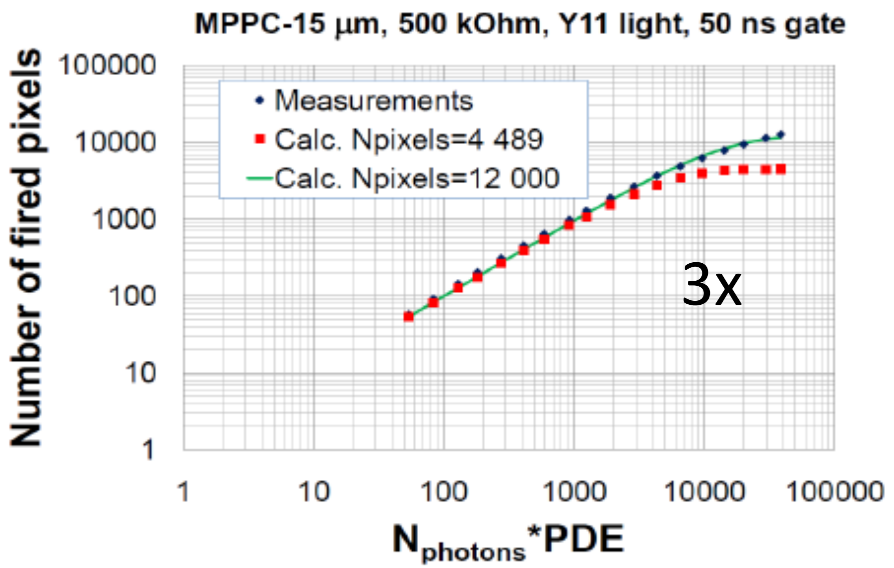


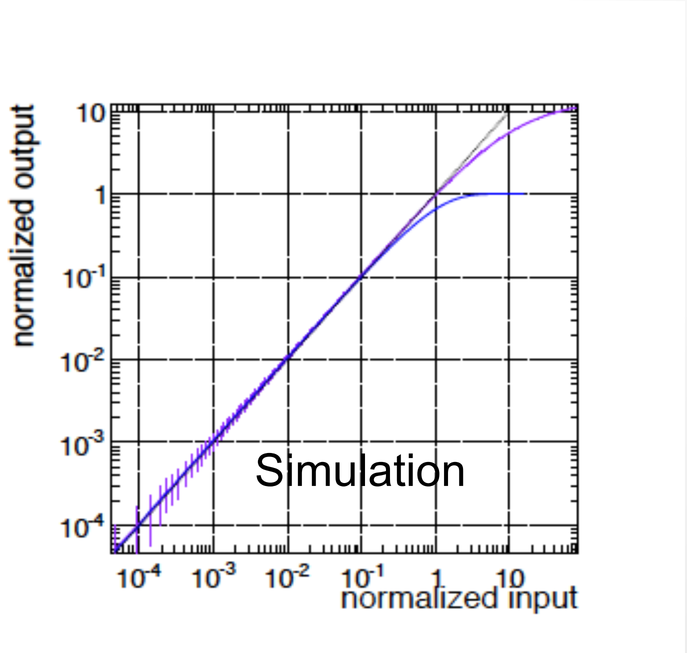
P. De Barbaro; A. Heering

Recovery Time vs Linear range (State of the Art)

- Because of the long Y-11 pulse shape, a very fast SiPM (able to reset its pixels within a few ns) can fire multiple times within the pulse: effective increase in dynamic range
- Validated in simulation and on the bench with real SiPMs
- State of the Art of even smaller SiPMs with smaller 10 and 5 micron can give **>> 100 k cells/mm2** effective pixels

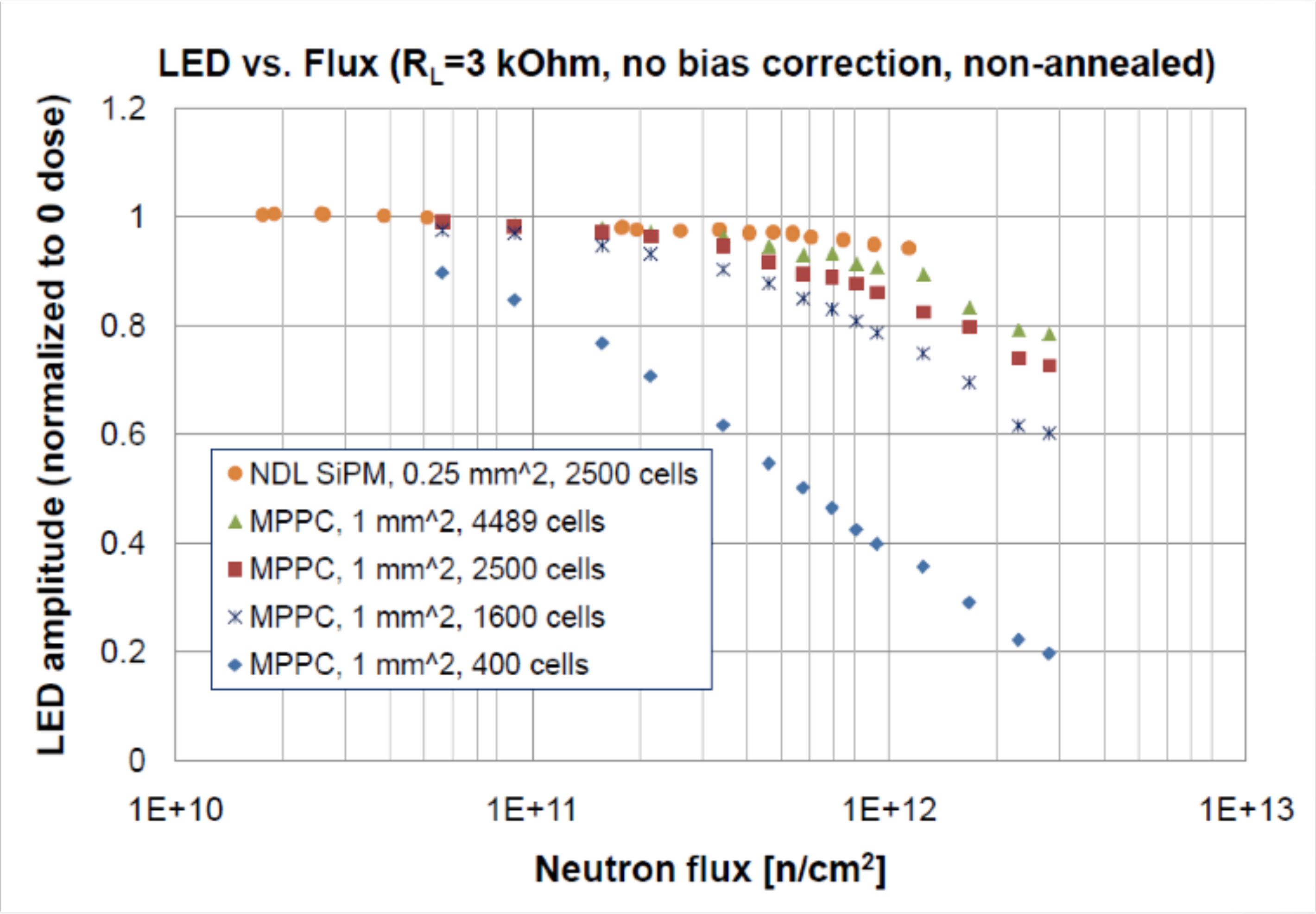






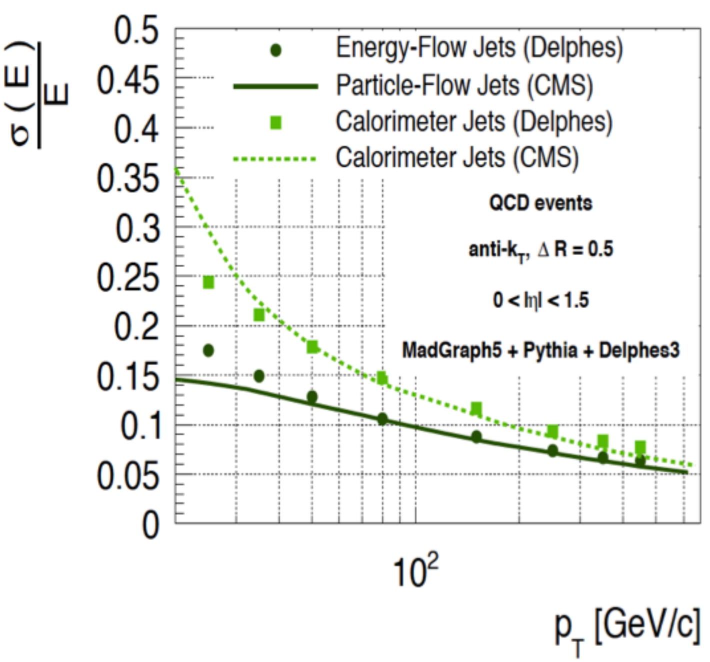
P. De Barbaro; A. Heering

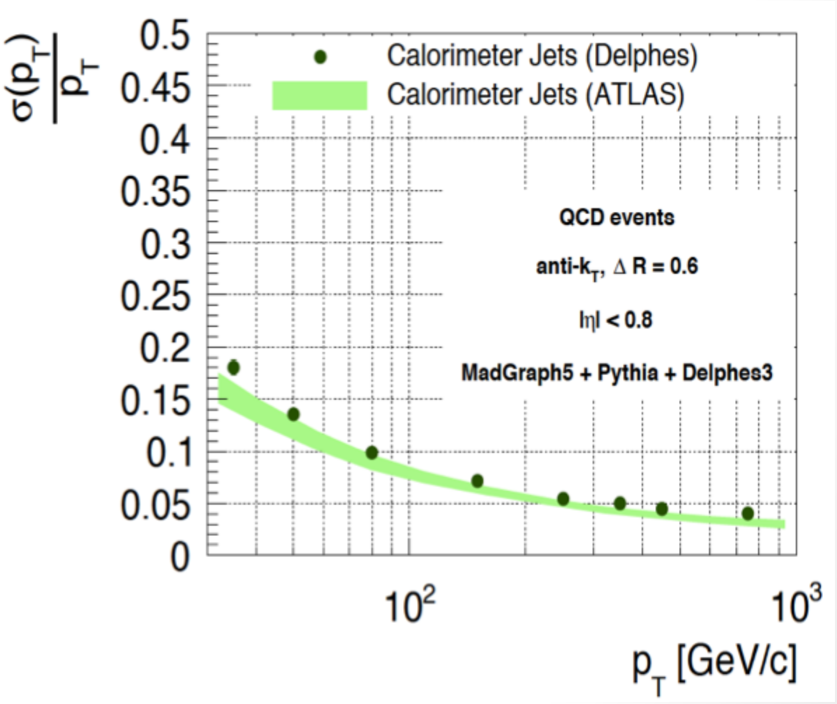
SiPM Cell size vs Radiation Damage



Jet resolution (LHC detectors)

- At high p_T calorimeter and particle flow jets are very close in CMS
- With a larger tracker and stronger magnetic field this will improve but will also look at much high PT regime.
- Longitudinal leakage and calibration determine the high PT resolution (constant term)





ATLAS depth and punch-through probability

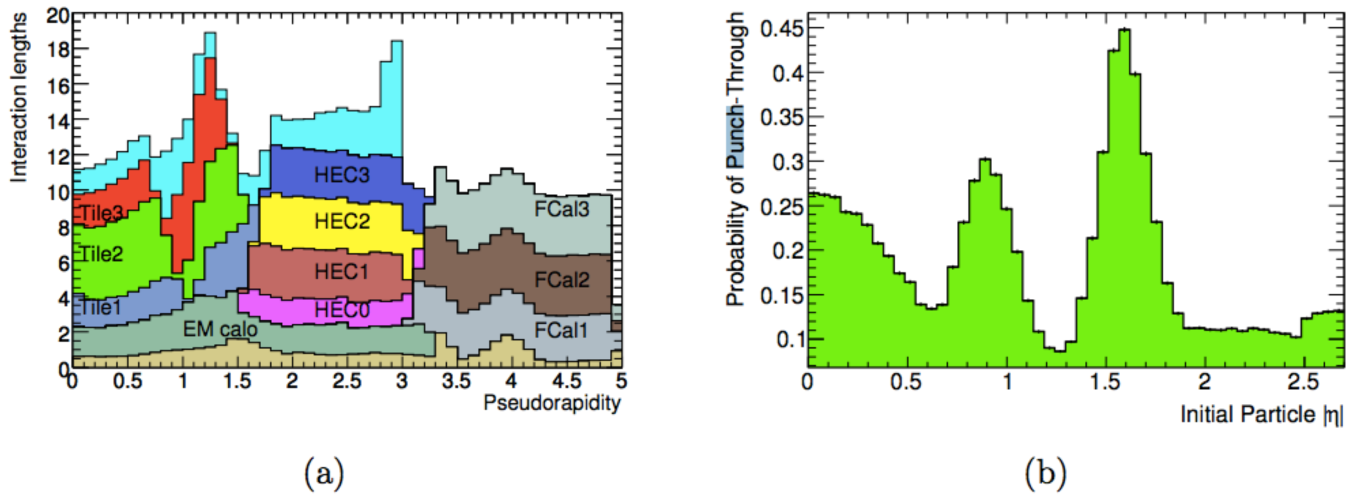


Figure 4.6: (a) Calorimeter material budget (in units of interaction length x_0) versus pseudorapidity $|\eta|$ [3]. (b) Probability to find one or more relevant punch-through particles in a single event vs. the initial particle's $|\eta|$.

ATLAS Tile calorimeter characteristics

Characteristics	ATLAS $\|\eta\|<1.7$
Absorber Absorber/scintillator ratio Geometry Tiles-Fe periodicity in Z	Steel 4.7:1 Tiles & fibres ⊥ to pp beam axis 18 mm (3mm Tiles+14mm Fe)
Tiles characteristics: - Tile dimensions (ηxϕxR): - Inner radius - Outer radius - WLS Fibres	Polystyrene+1.5%PTP+0.04%POPOP by injection molding, no grooves ; ~ 70 tons 11 trapezoidal sizes in depth/R ; ~ 40105 tiles 3 mm x ~22 cm x ~10 cm ; 3 mm x ~35 cm x ~19 cm Kurary Y11 ; 1mm diameter ; ~1062 Km ; ~620 000 fibres
3 cylinders (Barrel+2 Ext B): Length in Z Outer radius(w/supports+elect.) Outer active radius Inner active radius Active depth ΔR at η=0 Volume (inner-outer active R) Weight	 12m 4.2 m 3.9 m 2.3 m 1.6m; 7.7 λ 372m3 2900 T
Longitudinal Segmentation	3 layers
Transversal granularity ($\Delta\eta$x$\Delta\phi$)	0.1x0.1 inner and middle layers ; 0.2x0.1 outer layer
# channels/PMTs	10 000 channels
Gain-dynamic range	10^5 ; 2 gain 10 bits ADCs
Xo ; λ_p ; Moliere Radius	22.4 mm ; 20.7 cm ; 20.5 mm

ATLAS Tile calorimeter Performance

Characteristics	ATLAS $|\eta|<1.7$
Light yield	70 phe/GeV
σ_E/E (tbeam standalone)	52%/√E+ 5.7% (7.7 λ) 45%/√E+2 % (if 9.2 λ)
Jet resolution target	~50-60%/VE ⊕ 3%
e/h	1.33
em sampling fraction	3%
Max dose at HL LHC (3000 fb-1) Max light reduction due to irradiation in run1 Max. light reduction expected at HL LHC	0.2Mard -2% -15%

Three main outcomes from LHC Run 1

F. Gianotti

We have consolidated the SM with detailed studies at √s = 7-8 TeV
(including measurement of the rare, and very sensitive to New Physics, $B_s \rightarrow \mu\mu$ decay)
→ it works BEAUTIFULLY …

We have completed the Standard Model: Higgs boson discovery
(almost 100 years of theoretical and experimental efforts !)

We have NO evidence of new physics (yet …)

Note: the last point implies that, if new physics exists at the TeV scale and is discovered at √s ~ 14 TeV in 2015++, its mass spectrum is quite heavy
→ it will likely require a lot of luminosity and energy to study it fully and in detail
→ implications on energy of future machines

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Full exploitation of the LHC → HL-LHC ($\sqrt{s}$ ~ 14 TeV, up to 3000 fb^{-1}) is a MUST
Europe's top priority, according to the European Strategy

HL-LHC potential in a nutshell

- Higgs couplings (assuming SM Γ_H):
  - -- 2-5% in most cases, 10% for rare processes ($H \rightarrow \mu\mu$, $ttH \rightarrow tt\gamma\gamma$)
  - -- access for first time to 2^{nd} generation fermions through (rare) $H \rightarrow \mu\mu$ decay
  - -- direct access for first time to top Yukawa coupling through (rare) $ttH \rightarrow tt\gamma\gamma$
  - -- may measure Higgs self couplings to 30% ?
- Extend reach for stop quarks (naturalness !) up to m ~ 1.5 TeV
- Extend mass reach for singly-produced particles by 1-2 TeV compared to design LHC (300 fb^{-1}) → push energy frontier close to ~10 TeV

→ significant step forward in the knowledge of the Higgs boson
(though not competitive with ultimate reach of FCC-ee, ILC, CLIC)
→ detailed exploration of the TeV scale

Physics case: two scenarios

One of the main goals of
the Conceptual Design Report (~ 2018)
→ will be studied in detail in the years to come …

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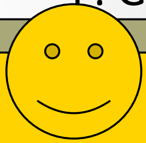

- LHC and/or HL-LHC find new physics:
  the heavier part of the spectrum may not be fully accessible at √s ~ 14 TeV
  → strong case for a 100 TeV pp collider: complete the spectrum and measure it in some detail
- LHC and/or HL-LHC find indications for the scale of new physics being in the
  10-50 TeV region (e.g. from dijet angular distributions → Λ Compositeness)
  → strong case for a 100 TeV pp collider: directly probe the scale of new physics

LHC and HL-LHC find NO new physics nor indications of the next E scale:

- several Higgs-related questions (naturalness, HH production, $V_L V_L$ scattering) may require high-E machines (higher than 1 TeV ILC); access unbroken regime of EW symmetry; baryon asymmetry from EW phase transition ?
- a significant step in energy, made possible by strong technology progress (from which society also benefits), is the only way to look directly for the scale of new physics

Although there is no theoretical/experimental preference today for new physics in the 10-50 TeV region, the outstanding questions are major and crucial, and we must address them. This requires concerted efforts of all possible approaches: intensity-frontier precision experiments, astroparticle experiments, dedicated searches, neutrino physics, high-E colliders, …

Among the main targets for the coming months: identify experimental challenges, in particular those requiring new concepts and detector R&D

F. Gianotti

The two main goals

- ❑ Higgs boson measurements beyond HL-LHC (and any e^+e^- collider)
- ❑ exploration of energy frontier

are quite different in terms of machine and detector requirements

Exploration of E-frontier → look for heavy objects up to m ~30-50 TeV, including high-mass $V_L V_L$ scattering:

- ❑ requires as much integrated luminosity as possible (cross-section goes like 1/s)
- → may require operating at higher pile-up than HL-LHC (~140 events/x-ing)
- ❑ events are mainly central → "ATLAS/CMS-like" geometry is ok
- ❑ main experimental challenges: good muon momentum resolution up to ~ 50 TeV; size of detector to contain up to ~ 50 TeV showers; forward jet tagging; pile-up

Precise measurements of Higgs boson:

- ❑ would benefit from moderate pile-up
- ❑ light object → production becomes flatter in rapidity with increasing √s
- ❑ main experimental challenges: larger acceptance for precision physics than ATLAS/CMS
- → tracking/B-field and good EM granularity down to |η|~4-5; forward jet tagging; pile-up