Very first look at Hadronic Calorimetry requirements for FHC

FCC-hh workshop

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Outline

1. Reminder of SSC study (pp $\sqrt{s}$ = 40TeV)
2. Jet truth level study
3. FCC Hadronic calorimeter performance consideration
4. Next steps

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SSC calorimeter requirements reminder

- SSC parameters: (http://lss.fnal.gov/conf/C860623/p355.pdf)
  - Good jet resolution for a wide range of jet p_T with 35-60%/√E ⊕ 3%
  - Small punch-through (MET) -> contain hadronic showers to avoid punch-through (fake MET, JER degradation)-> 12λ HCAL
  - Good transverse and longitudinal granularity

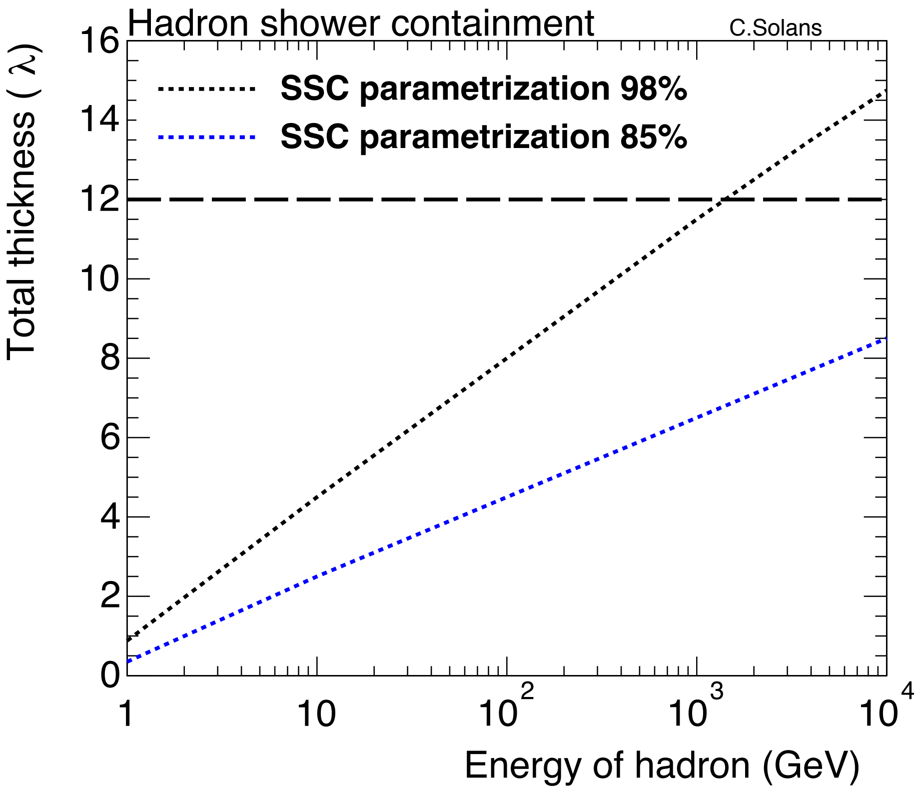
- Comparison with ATLAS: (http://cds.cern.ch/record/1125884?ln=fr)
  - Similar jet resolution
  - Similar longitudinal granularity
  - ATLAS has ~ 2 times worse transversal granularity (dηxdϕ=0.1x0.1)

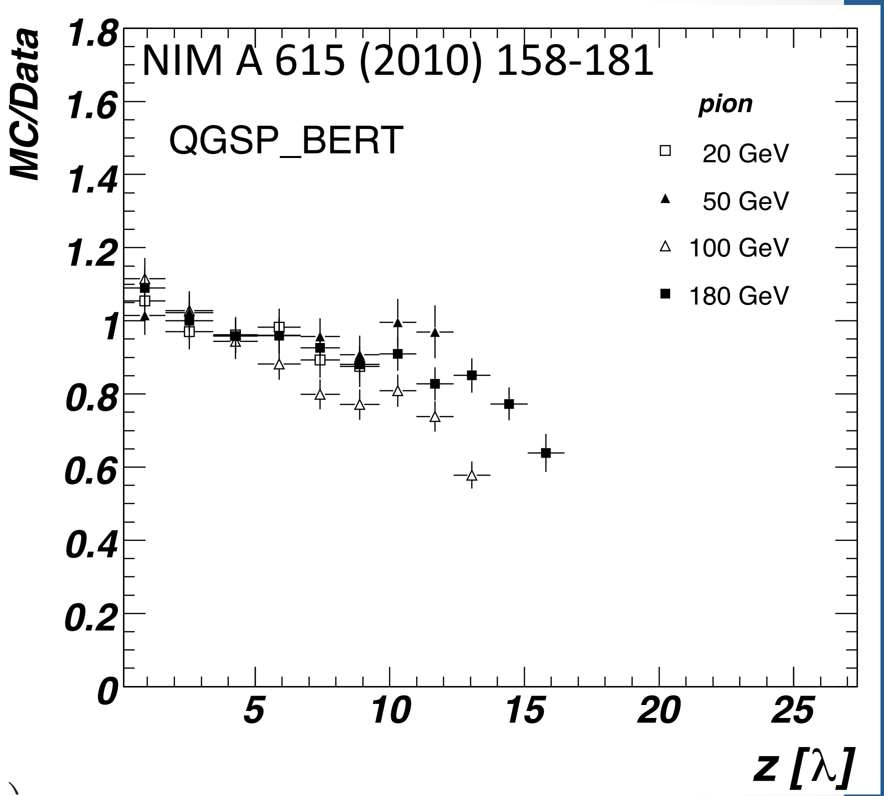
SSC calorimetry

http://lss.fnal.gov/conf/C860623/p355.pdf

Electromagnetic thickness	$25\ X_0$,	~1λ
Precision Hadronic	5λ	
Total Precision EM + Hadr.	6λ	
Hadronic tail catcher	6λ	
Total	12λ	
Transverse Segmentation		
EM Δy x Δϕ	.03 x .03	
Hadronic Δy x Δϕ	.06 x .06	
Tail Catcher Δy x Δϕ	.06 x .06	
Longtitudional Segmentation		
EM	3	
Hadronic	2	
Tail Catcher	2	

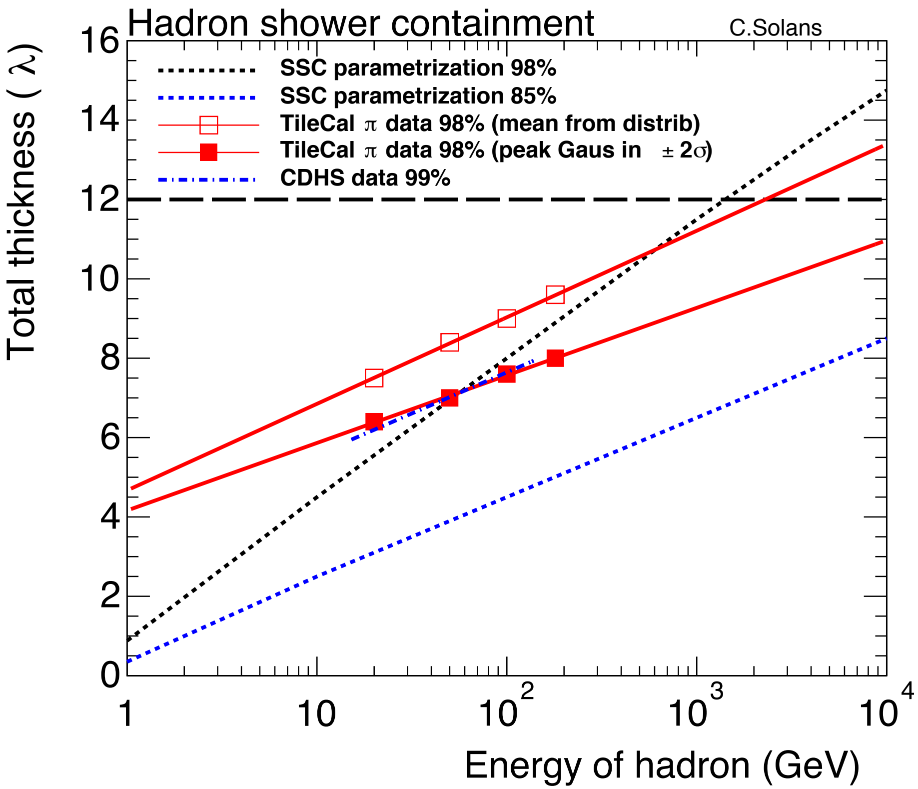
Single hadron (π) containment vs. depth

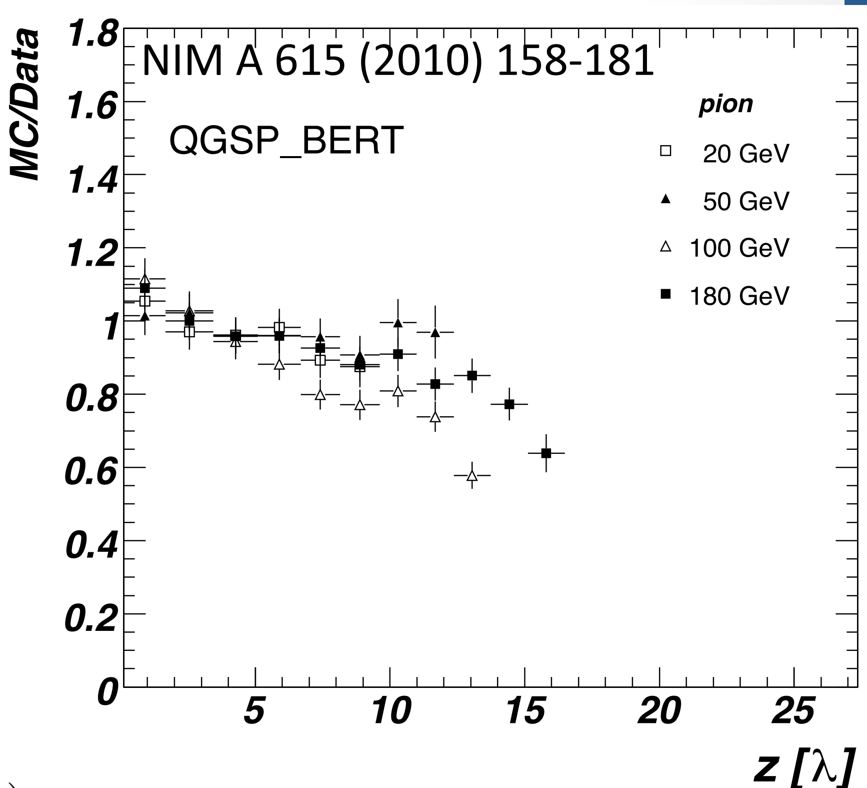




- ~ 12λ to contain 98% of 1TeV hadron showers
- Data has longer hadronic showers than Geant4 simulation…
- Longitudinal leakage and calibration will dominate high PT jets (constant term)
- Multi- 10TeV jets contains several multi-TeV hadron. See next slides

Single hadron (π) containment vs. depth





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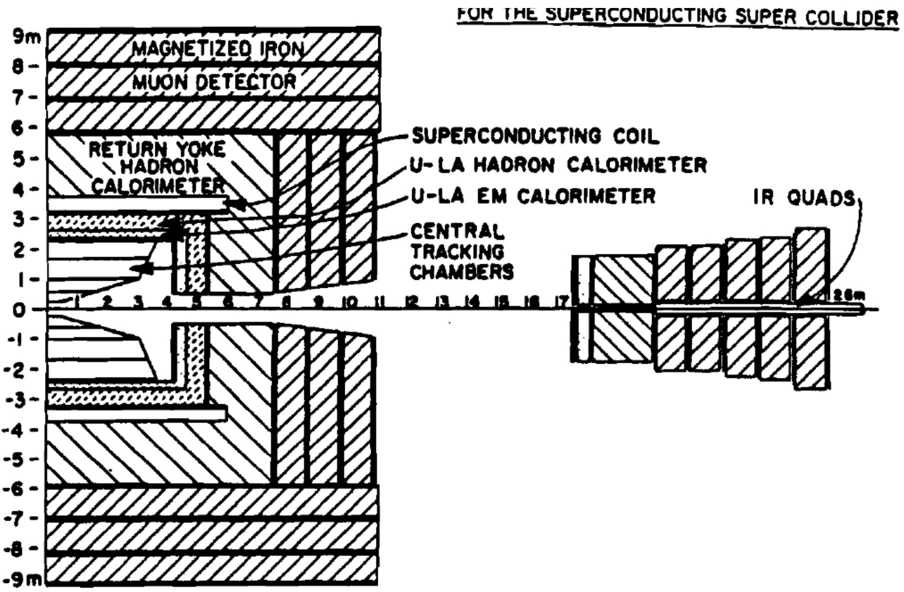
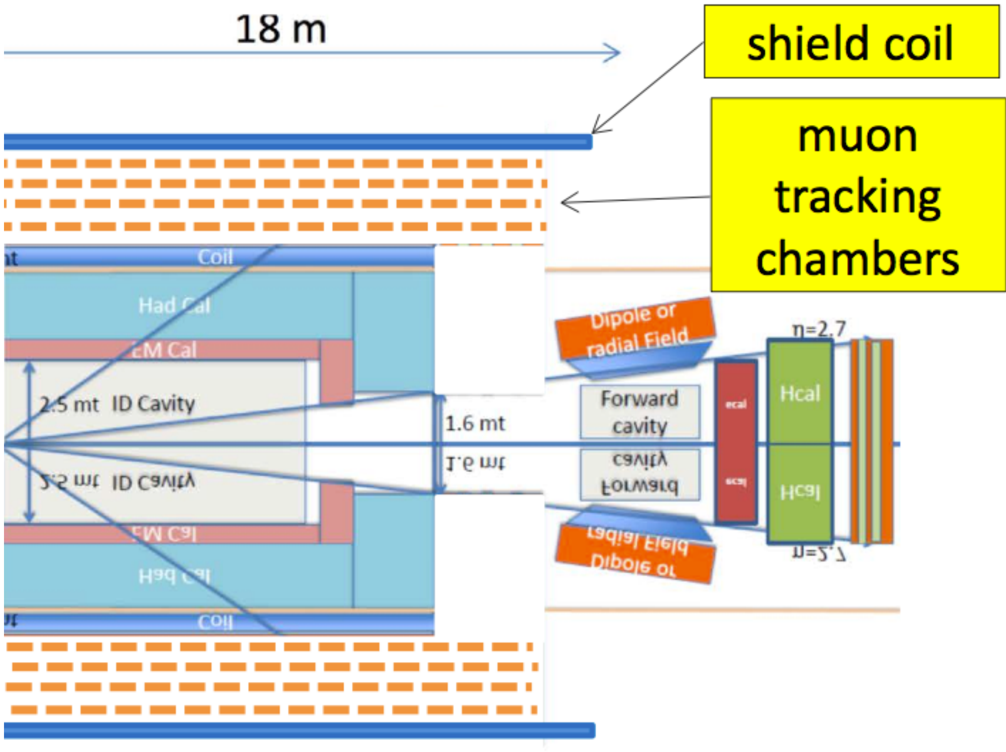
FCC twin solenoid option

SSC layout

D. Fournier, A. Henriques, F. Gianotti and al





FCC-hh similar to SSC layout: 2.5 m Radius ID cavity
Forward detectors for a large eta coverage, forward b tagging

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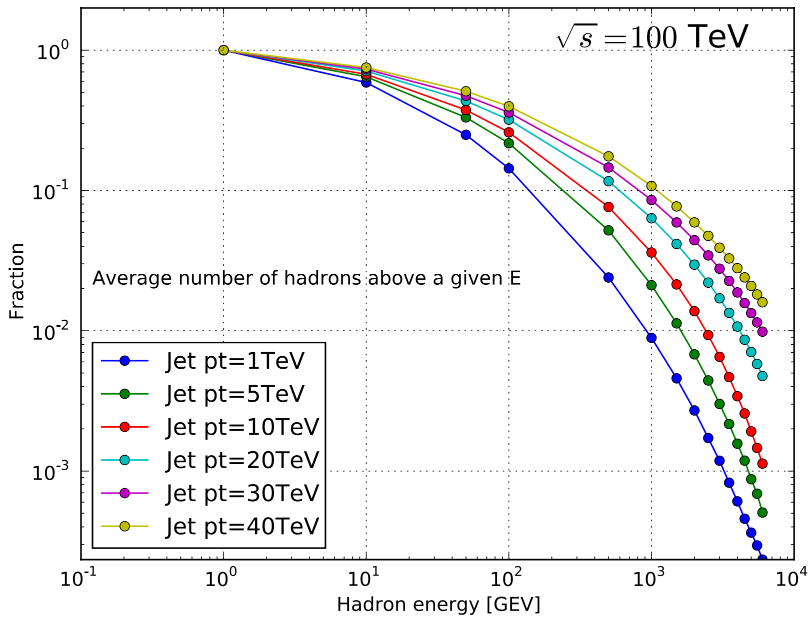
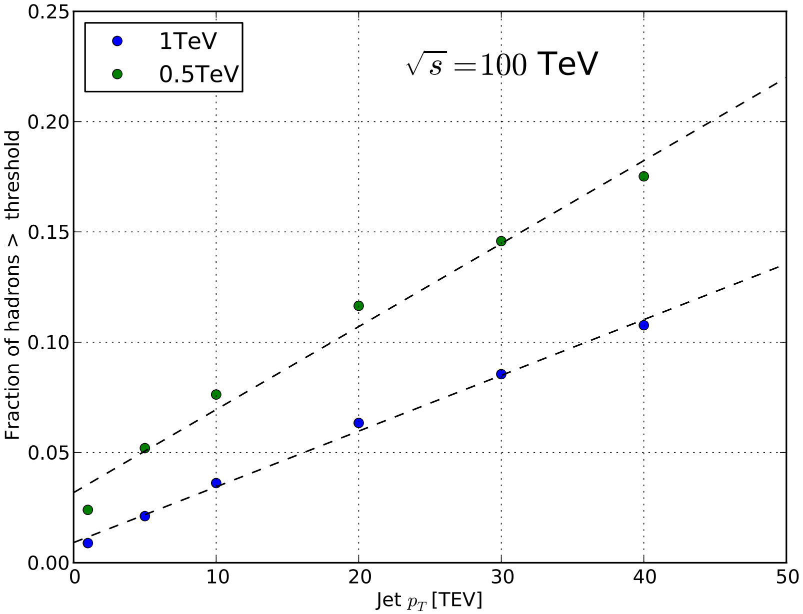
Jet truth level study

- Use Madgraph5 aMC@NLO and Pythia6 to generate di-jet events
  - pp -> jj
  - 50 TeV beam energy so $\sqrt{s}$ = 100 TeV
  - 1, 5, 10, 20, 30, 40 TeV p_T cut on leading and sub-leading jet
- Use Delphes to reconstruct truth jets
  - Antikt-0.5 jet algorithm and cone used
- From the truth jet collection
  - select jets with p_T within 20% of [1, 2, 10, 20, 30, 40] TeV
- Look at the jets constituents
  - everything except photons

Single hadron content inside jets

C. Helsens





- In a 30TeV jet, ~8(15%) of hadrons with an energy above 1(0.5)TeV
- ~Linear behavior versus jet p_T

Single hadron content inside jets

- Average number of hadrons above a threshold for various jet p_T

Jet p_T [TeV]	All	>50GeV	>500GeV	>1TeV	>2TeV	>5TeV
1	34	8.5	4.9	0.8	0.16	0.01
5	52	17.3	11.3	2.7	0.6	0.05
10	59	22.1	15.3	4.5	1.3	0.11
20	62	27	19.8	7.2	2.6	0.44
30	62	29.5	22.4	9.1	3.7	0.83
40	60	30.5	23.8	10.5	4.6	1.24

- Dijet cross-section (from madgraph 5 aMC@NLO)

C. Helsens

Jets p_T [TeV]	1	5	10	20	30	40
Cross section [pb]	3453	0.974	0.0108	$1.84e^{-5}$	$3e^{-8}$	$3.4e^{-12}$

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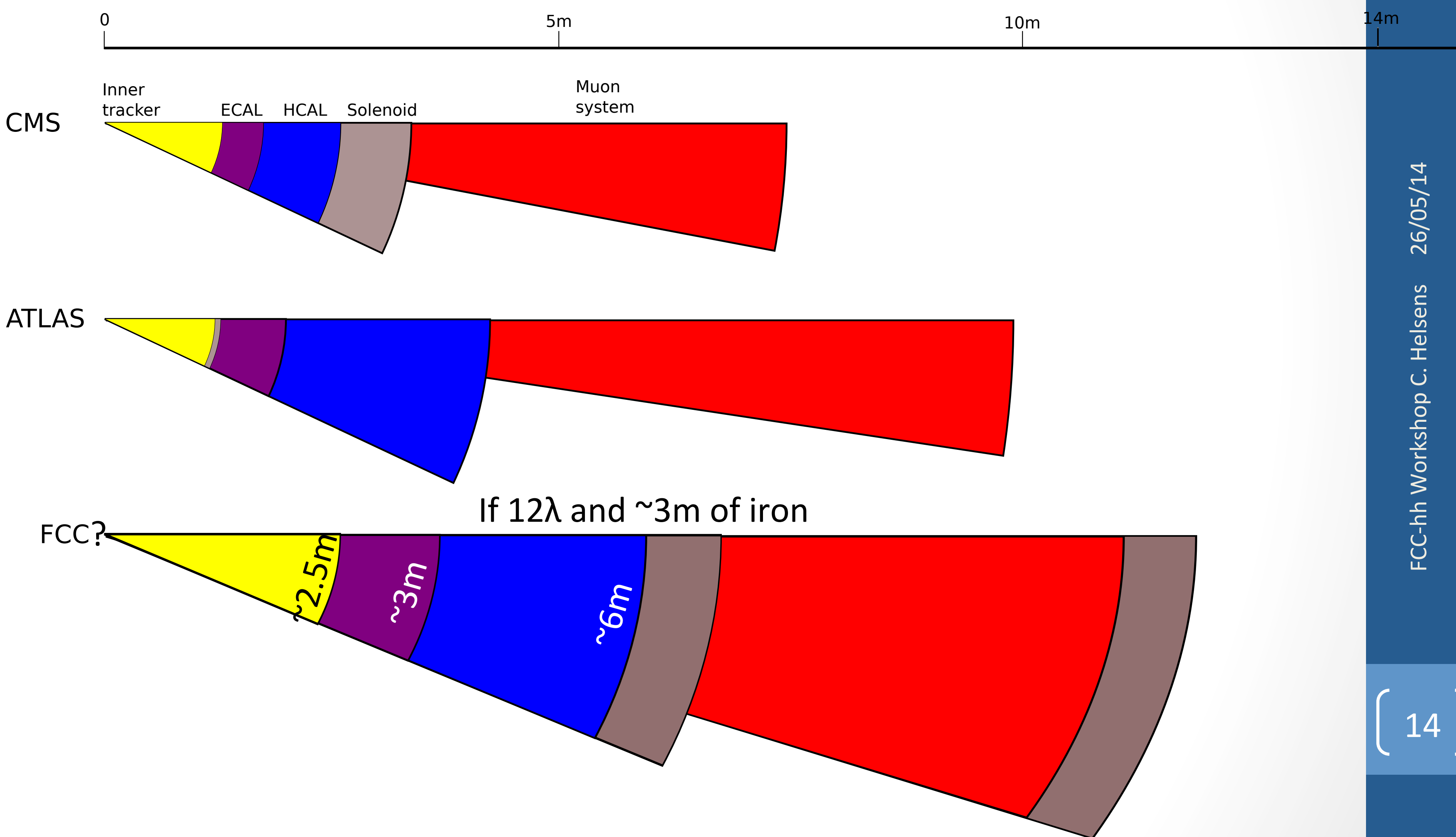
Scenarios for 12λ calorimeter (incl. ~1.5 λ EM)

- 1) Full iron absorbers in hadron calorimeter:
  - Dimension:
    - → had. calorimeter thickness of ~2.5 -3 m depth (incl. Scint or equivalent)
    - → Outer radius ~ 6m => big solenoid
  - Performance:
    - Fast showers
    - Low muon energy loss
- 2) Full tungsten absorber in hadron calorimeter:
  - Dimension:
    - → shorter calorimeter $\lambda(Fe)/\lambda(W) \sim 1.7$; $X_0(Fe)/X_0(W) \sim 5$.
    - But way more expensive!!
  - Performance:
    - More neutrons
    - Slower showers
    - More muon energy loss
- 3) Different absorbers versus depth
- 4) Instrument the solenoid and before the first layer of the muon spectrometer with tail catcher calorimeter (a la SSC)

All scenarios to be studied in terms of performance, cost, impact on the overall detector layout,…. (see my talk this afternoon about simulation)

Detector dimensions



Thanks to C. Bernet for the source

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Next steps

- Need detailed simulations to address hadron calorimeter performance:
  - Depth/Containment
  - Transversal and longitudinal granularity
  - Resolution
  - Absorber, active material choices as a function of eta (taking into account radiation, speed, price considerations, overall detector optimization)
  - Degradation of the di-jet mass spectrum resolution and tails in more basic inclusive jet searches, and other physics benchmarks
  - ….
- The simulation tools are progressing well. Parameterized simulations are already available (DELPHES) and few of us involved (see simulation session), hopefully results will be available soon
- Need to get more organized, close collaboration with other parts of the detectors (in particular with the EM calorimeter) and physics studies , start meeting more regularly, build twikipages, …
- Everybody is well to join!!!
  - https://e-groups.cern.ch/e-groups/EgroupsSubscription.do?egroupName=fcc-experiments-hadron-ecal

Backup

ATLAS depth and punch-through probability

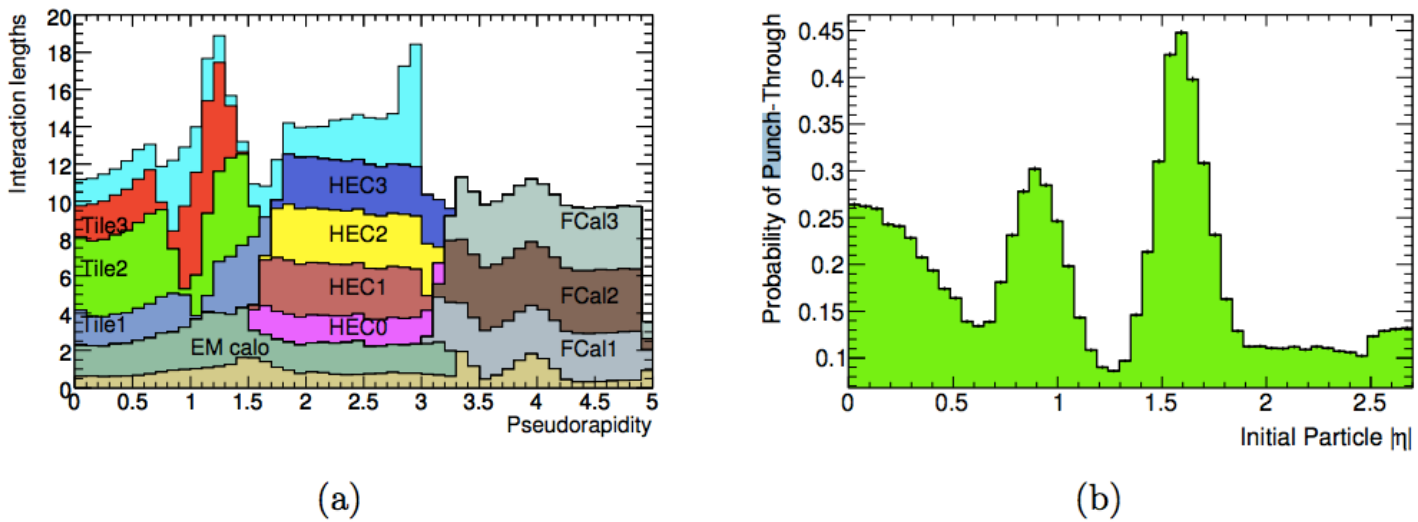
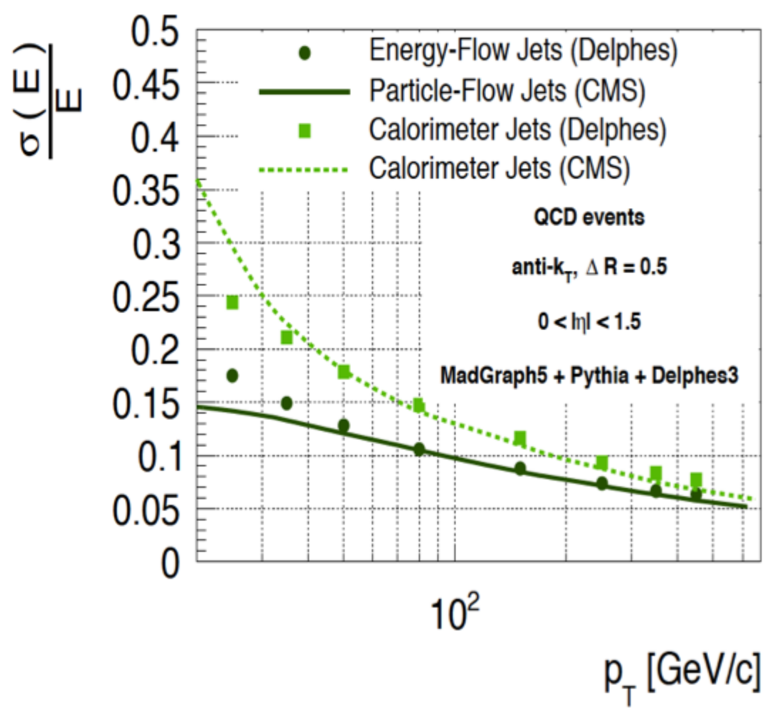
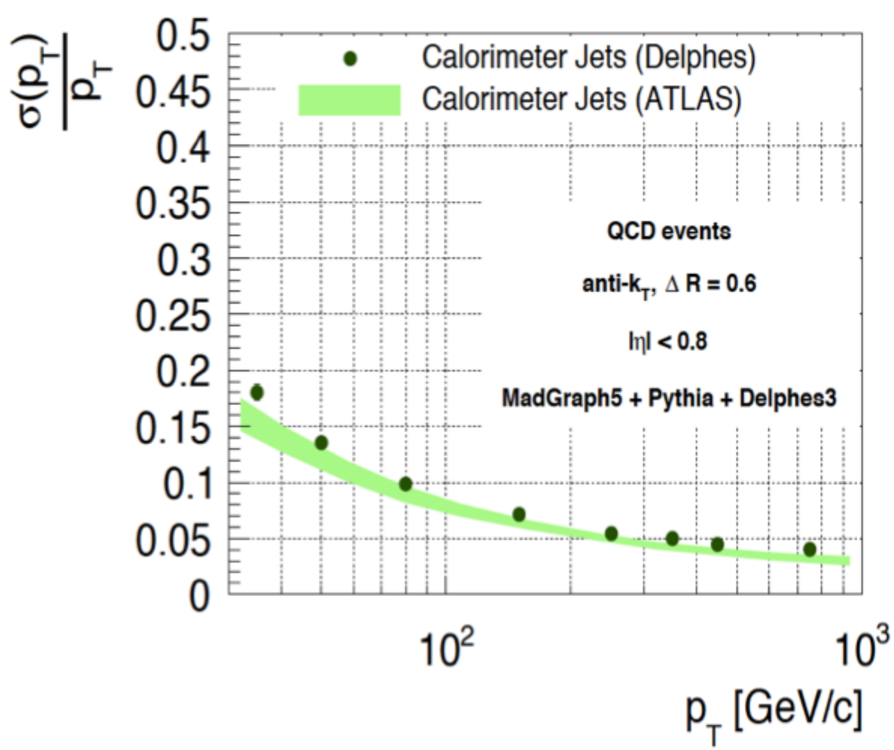


Figure 4.6: (a) Calorimeter material budget (in units of interaction length x_0) versus pseudorapidity $|\eta|$ [3]. (b) Probability to find one or more relevant punch-through particles in a single event vs. the initial particle's $|\eta|$.

Jet resolution (LHC detectors)

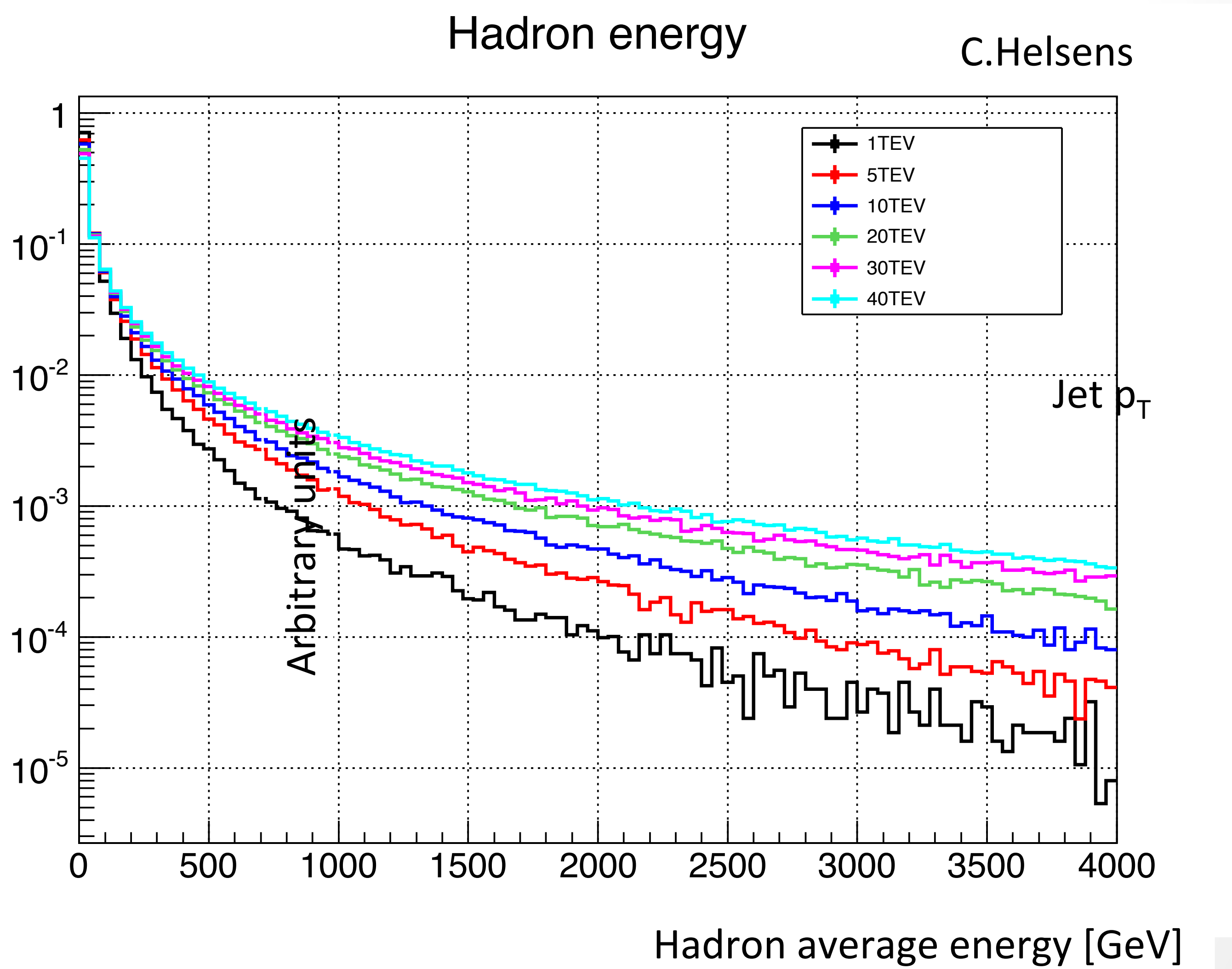
- At high p_T calorimeter and particle flow jets are very close in CMS
- With a larger tracker and stronger magnetic field this will improve but will also look at much high PT regime.
- Longitudinal leakage and calibration determine the high PT resolution (constant term)





Hadron Energy

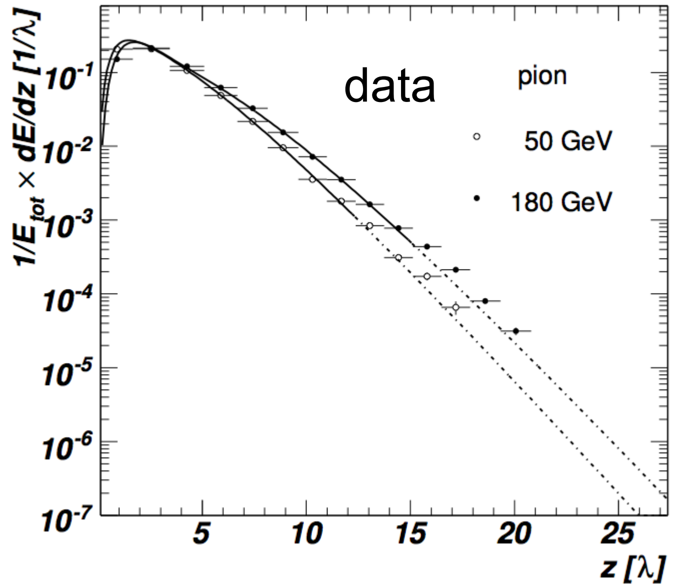
- Hadron average energy inside jets



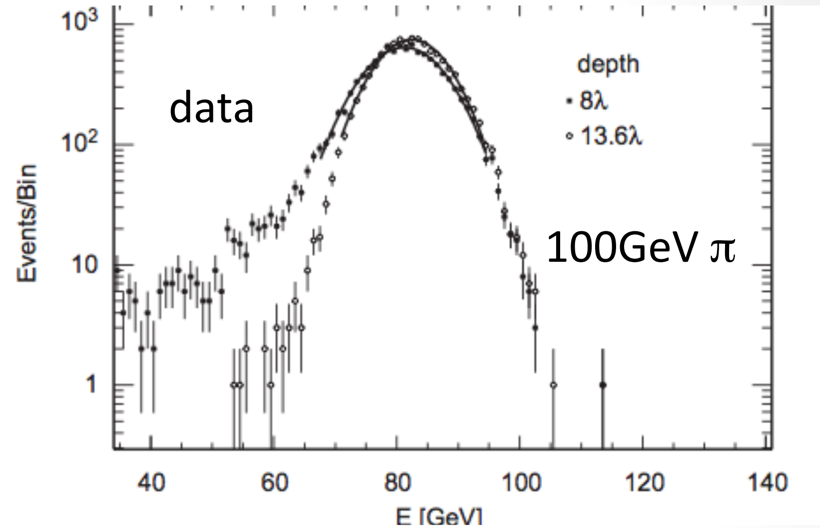
Pion longitudinal shower profiles in Tilecal up to ~20 λ

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

showers grow with log E



Leakage/low tails visible in 8λ 100Gev π



MC/data within 20% up to10λ, MC showers shorter.