Hadron calorimetry at the FCC-hh experiment

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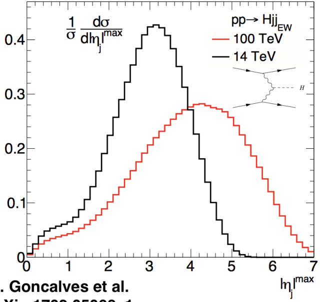
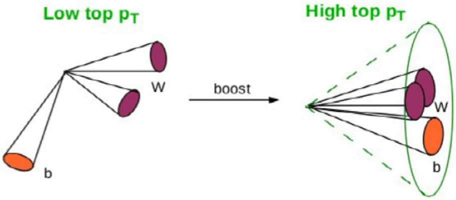
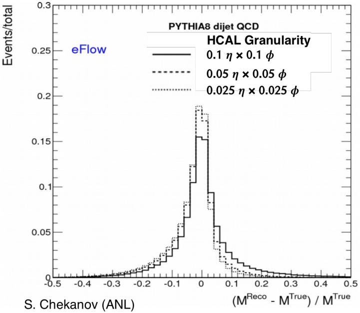
FCC-hh Hadron Calorimeter – physics requirements



D. Goncalves et al.
arXiv:1702.05098v1





S. Chekanov (ANL)

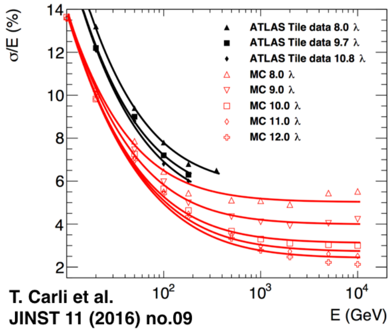
- Jet rapidity of WBF
  –> η **coverage up to 6**
- Highly collimated final states (boosted decay products of heavy objects)
  –> **High granularity** to resolve jet sub-structure and background rejection (e.g. pile-up jets, π^0)
- High p_T jets at $\eta = 0$
  –> **containment** $\geq 11\ \lambda$

FCC-hh Hadronic Calorimeter – Scintillator/Steel I

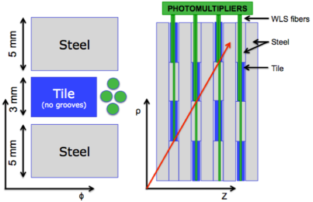
1. Current reference for FCC-hh

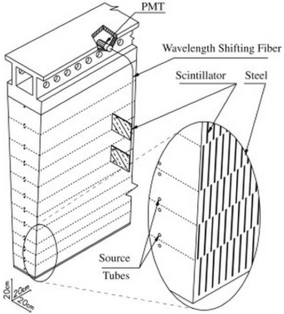
ATLAS type Scintillator tile - Steel
in Barrel and Extended Barrel

- 4 times higher granularity $\Delta\phi \times \Delta\eta = 0.025 \times 0.025$
- 10 instead of 3 longitudinal layers
- Steel –> stainless Steel absorber (Calos in magnetic field)
- SiPM readout –> faster, less noise, less space



T. Carli et al.
JINST 11 (2016) no.09

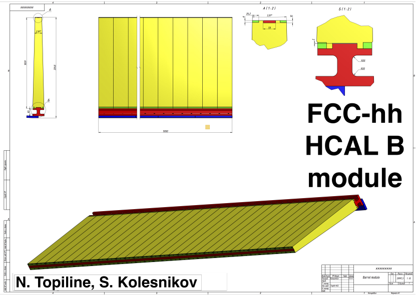




$\sim 11\,\lambda$ FCC-hh HCAL, pion resolution:

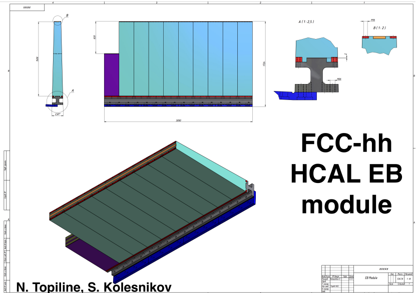
$\sigma_E/E = 43\,\%/\sqrt{E} \oplus 2.7\%$

FCC-hh Hadronic Calorimeter – mechanics



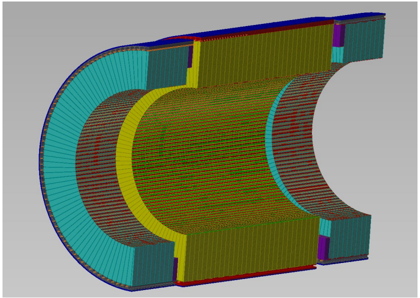
FCC-hh HCAL B module

N. Topiline, S. Kolesnikov



FCC-hh HCAL EB module

N. Topiline, S. Kolesnikov



128 modules in 2ϕ feasible

mechanical structure fits within foreseen space

85×85 mm in $dz = 9(2 \times 3)$ m space within mechanical support for SiPMs and electronics

FCC-hh Hadronic Calorimeter – Scintillator/Steel II

2. High Granularity (HGCAL) option

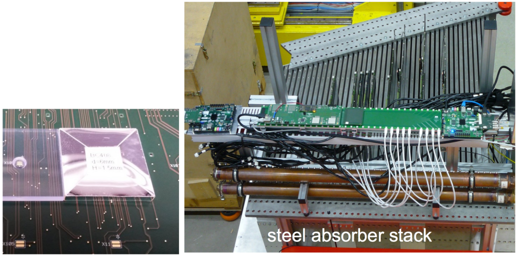
CALICE type, Scintillator tile - Steel/Brass

- Phase II upgrade of CMS Endcaps
- $3 \times 3\,\mathrm{cm}^2$ Sci tiles
- integrated SiPM readout
- active prototyping within CALICE collaboration

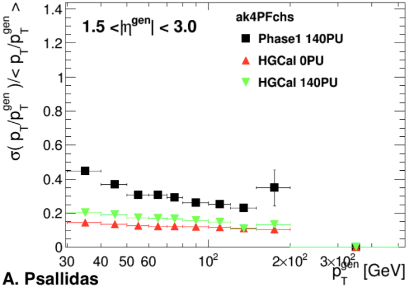
Plans for FCC-hh:

- combined with Silicon - Lead ECAL
- granularity used for pile-up rejection

–> Sergej will show jet reconstruction using this High Granularity HCAL



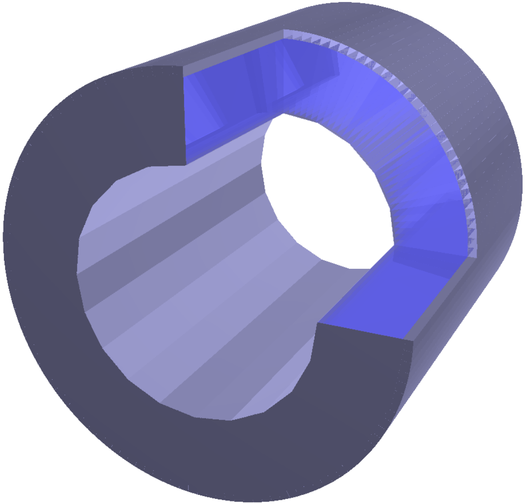
Wrapped Sci Tile of CALICE AHCAL
Testbeam setup in ILD stack



HGCAL simulations, jet p_T resolution w/wo pile-up

FCC-hh full detector simulations

of the Sci-tile/stainless Steel HCAL



HCAL B

10 longitudinal layers

$2 \times 10\,\mathrm{cm}$

$+\ 4 \times 15\,\mathrm{cm}$

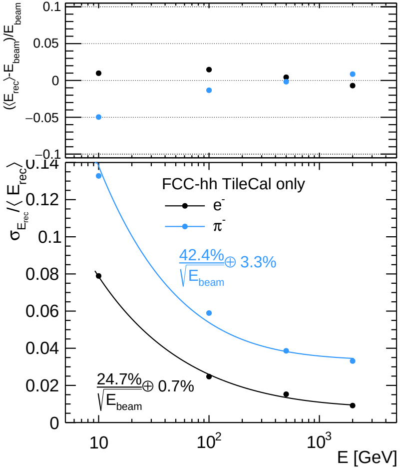
$+\ 4 \times 25\,\mathrm{cm}$

$\Delta\eta \times \Delta\Phi$

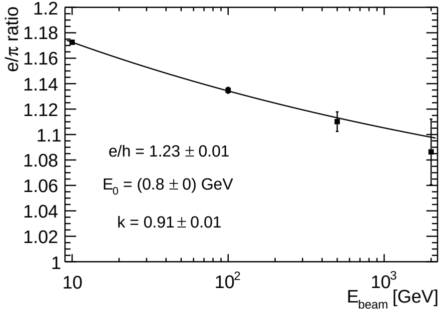
0.025×0.025

HCAL B performance for e^- and π^-

10,000 events per energy,
FTFP_BERT physics list,
$\eta = 0.36$ –> 9.3 $\#\lambda$



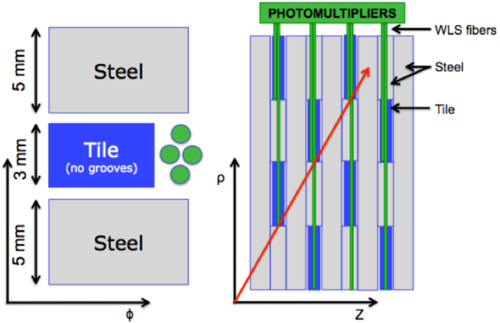
$$e/\pi = \frac{e/h}{1 - \left[1 - \left(\frac{E_{beam}}{E_0}\right)^{1-k}\right](1 - e/h)} \qquad (1)$$



- E_0, k energy threshold/ multiplicity of π^0 production
- increasing EM fraction with increasing energy

How can we achieve compensation?

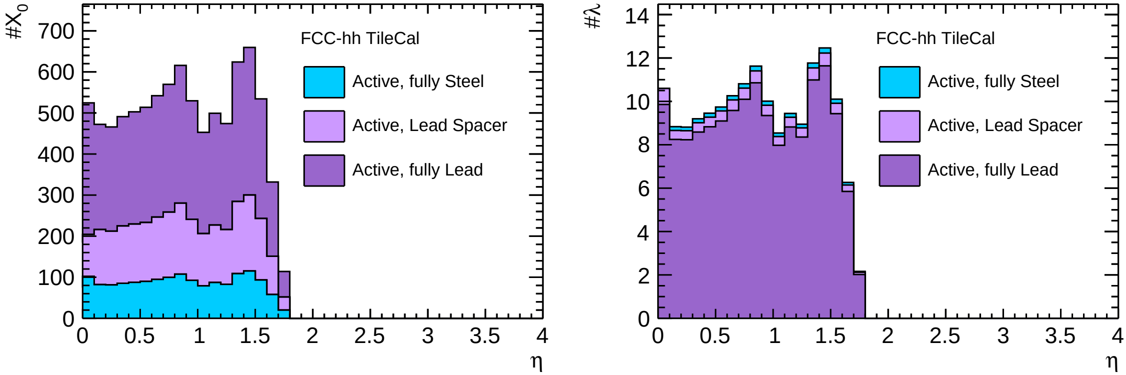
1. Increase response to neutrons
   by increased fraction of hydrogen in Scintillator
2. Suppression of EM response
   by higher Z absorber
   –> spacer of HCAL in Pb: X_0=0.6 cm, λ=17.59 cm (Fe: X_0=1.8 cm, λ=16.77 cm)
   –> λ_{eff} of HCAL Barrel increases to 20.87 from 20.59 cm ($\eta = 0.36$)



Expected compensation

- Fe:Sci ≈ 20:1
- Pb:Sci ≈ 4-5:1

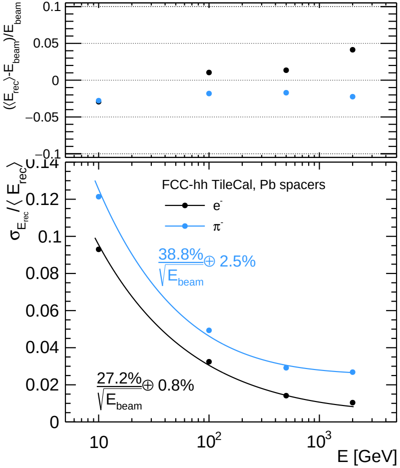
Material budget of the HCAL B + EB



Pb spacers:	X_0 increases by $\sim$ 50%, minor decrease in $\#\lambda$
full Pb HCAL:	X_0 increases by $\sim$ 150%, still little change in $\#\lambda$

HCAL B performance with Pb spacers for e^- and π^-

10,000 events per energy,
FTFP_BERT physics list,
$\eta = 0.36$ –> 9.1 $\#\lambda$



$$E_{reco} = \sum_{i=1}^{hits} E_i/a \qquad (2)$$

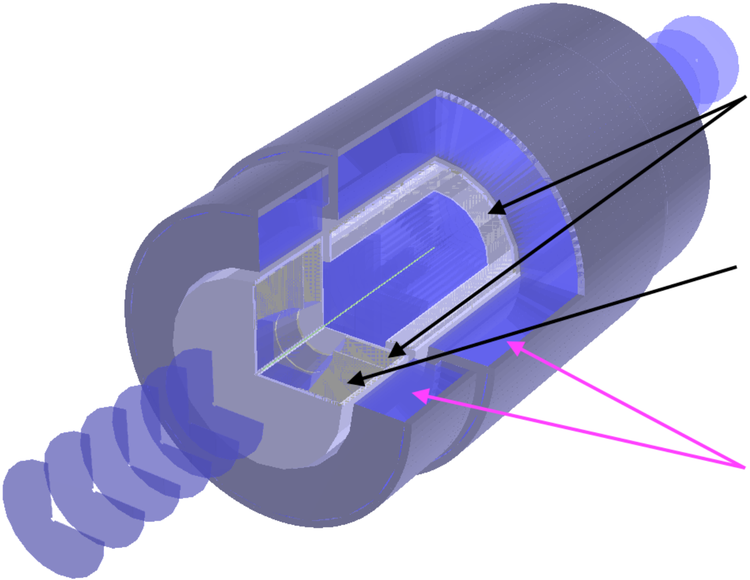
- $a_{EM,hadron} = 3.2\,\%, 2.7\,\%$
- $e/h = 1.1$
- constant term decreased from 3.3 to 2.5 %

–> need test performance in combined system

Arguments pro Pb

- Pb structures constructible!
- higher Z material not an issue for timing (50 ns in SPACAL)
- steel structure not needed as return yoke

FCC-hh full detector simulations

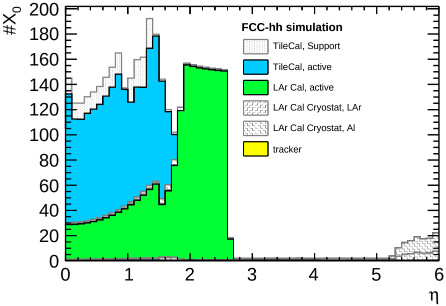


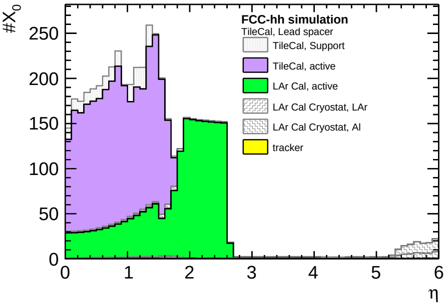
ECAL B, EC
LAr/Pb
3(-5.6)mm/2mm
8, 6 layers
$\Delta\eta \times \Delta\Phi$
0.01×0.01

HCAL EC
LAr/Cu
3mm/2cm
6 layers
$\Delta\eta \times \Delta\Phi$
0.025×0.025

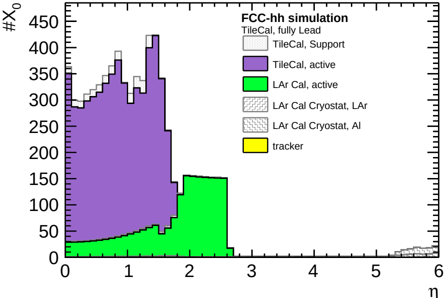
HCAL B, EB
Sci-tile/stainless Steel
1/4.7
10, 8 layers
$\Delta\eta \times \Delta\Phi$
0.025×0.025

Material budget of FCC-hh **full B+EB+EC**



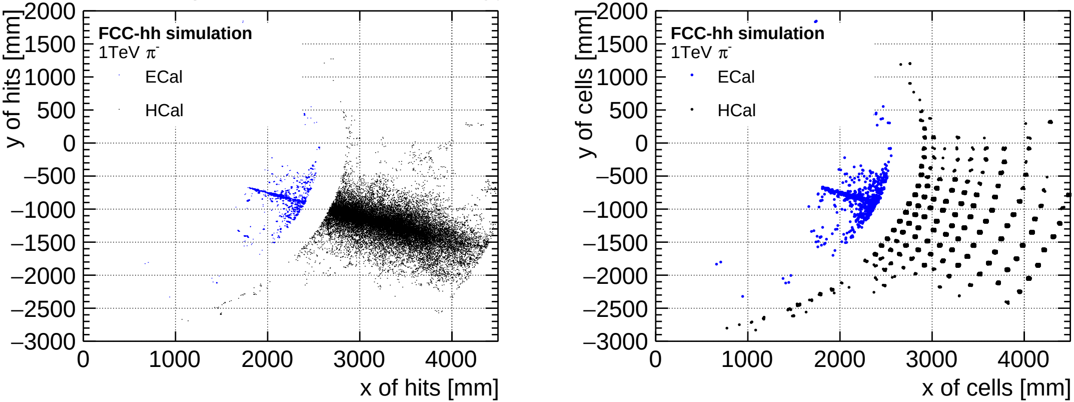


- ECAL thickness: 30 $\#X_0$
- E+HCAL thickness:
  115 – 150 – 300 $\#X_0$
  –> needs study of muons
- E+HCAL thickness: $\sim$ 11 $\#\lambda$
  – for all Pb options
- approx. 1.5 $\#X_0$ in front of ECal
- good η coverage, dip in $\#\lambda$ at $\eta = 1.7$ requires optimisation (longer HCAL EB?)



LAr ECal + TileCal simulations

from Geant4 depositions (hits) to energy in Calorimeter cells



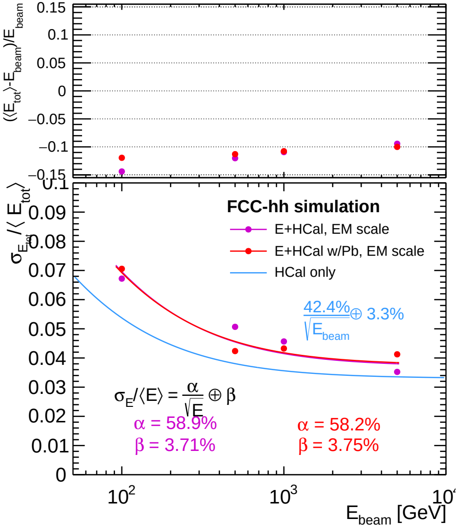
EM showers are contained in ECAL (30 $\# X_0$)

Not included in the simulation yet:

- electronics noise
- pile-up noise

E+HCal Resolution and Linearity

10,000 π^- events per energy,
FTFP_BERT, $\eta = 0.36$ –> 11 $\#\lambda$



- degraded resolution compared to HCAL only: impact different sampling, EM scale ($e/h \neq 1$)
- 0.25 $\#\lambda$ / 1.5 $\#X_0$ passive material between E and HCal
- comparable to ATLAS results: $\alpha = 52.1 \pm 5.5\%$, $\beta = 1.9 \pm 0.3\%$
- Pb spacers no effect on resolution, but linearity improves

Next steps:

1. Correction for lost energy needed
2. Clustering algorithm for jet reconstruction

Summary & Outlook

FCC-hh hadron calorimeters have to

- survive harsh radiation environment $\sim 5 \times 10^{14}$ neq
- perform precise jet reconstruction of boosted objects

First (reference) calorimeter system tested in simulations

- containment of 10 TeV hadron showers ensured
- combined hadron reconstruction need further corrections

Next steps

- implementation of other calorimeter options in FCCSW
- tests including pile-up
- jet reconstruction with particle flow algorithms

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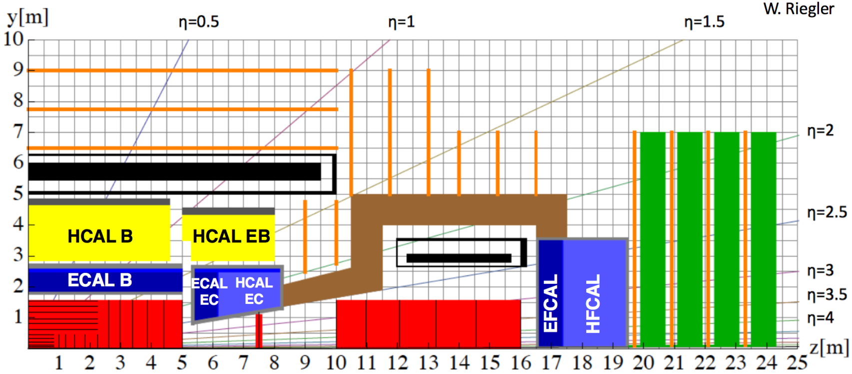
Thank You!

Backup!

FCC-hh detector

baseline FCC week Berlin May 2017

total length ∼47 m, height ∼18 m



W. Riegler

NAME	Technology	*η* coverage	# long.layers	*Δη x Δφ*	# channels (x10^6)
ECAL B	LAr / Pb	< 1.7	8	0.01 x 0.012	1.3
ECAL EC	LAr / Pb	1.5 – 2.5	6	0.01 x 0.012	0.6
HCAL EC	LAr / Cu	1.7 – 2.5	6	0.025 x 0.025	0.1
EFCAL	LAr / Pb	2.3 – 6.0	6	0.025 x 0.025	0.5
HFCAL	LAr / Cu	2.3 – 6.0	6	0.05 x 0.05	0.1