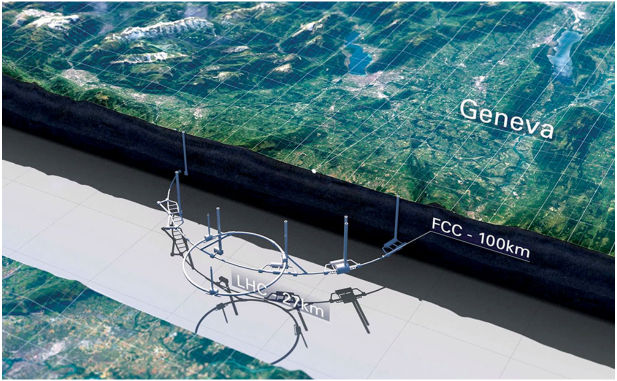


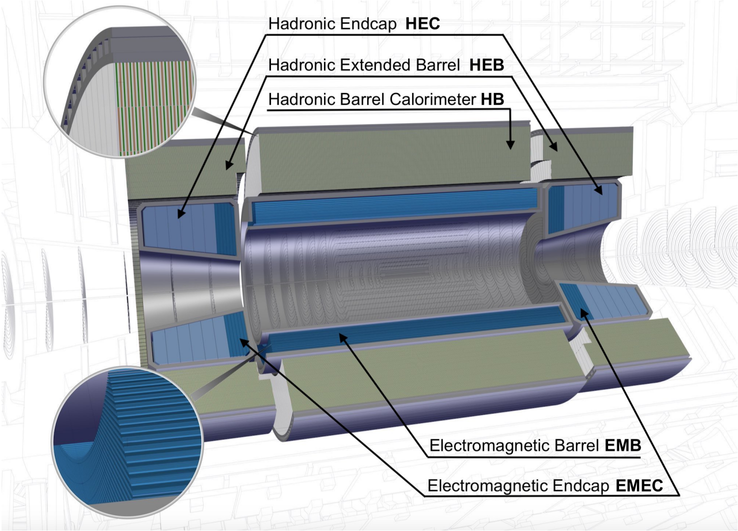
ATLAS TileCal-like Hadron Calorimeter for FCC-hh

Coralie Neubüser, on behalf of the FCC-hh Detector group

EP R&D Day
24.10.19

FCC-hh central calorimeter system

total length ∼47 m, height ∼18 m
calo system: 2 (+1.1/0.2) M channel in barrel (+endcap/forward)

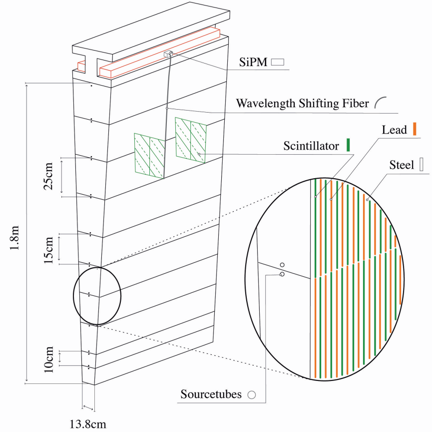


FCC-hh Barrel HCal – Sci/Pb/Steel

Specs:

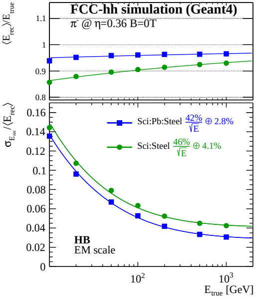
5 mm steel absorber plates,
alternate w/ 3 mm Sci and 4 mm Pb tiles
128 modules in ϕ, two tiles/module
10 longitudinal layers
$\Delta\eta(>0.006) = 0.025$, $\Delta\phi = 0.025$

- 4× granularity of ATLAS TileCal, single tile readout
- SiPM readout at outer radius ($\sim 10^{11}$ neq) → single channel readout, timing
- current ongoing R&D on scintillator material and SiPM technology fulfil requirements (8 kGy)



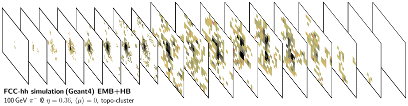
→ mechanical structure feasible, assembly study done
→ **first tests of Sci tiles+WLS fibre+SiPM readout started**

Standalone FCC TileCal and combined LAr+Tile performance

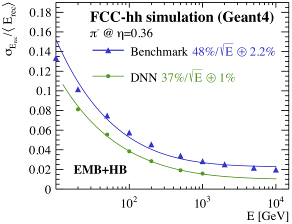


Optimised absorbers for hadronic performance

- decreasing non-compensation by suppression of EM response
  Pb: $X_0 = 0.6\,\mathrm{cm}$ / Fe: $X_0 = 1.8\,\mathrm{cm}$
- improves stochastic and constant term, and e/h from 1.24 to 1.1



- 8 layer LAr + 10 layer TileCal achieves desired performance
- high granularity allows for machine learning technique: Deep Neural Nets (DNNs)
- granularity achieved in the HB through SiPM readout



→ currently preparing a comprehensive report on FCC-hh calorimetry.

First lab measurements of FCC-hh type Sci tiles

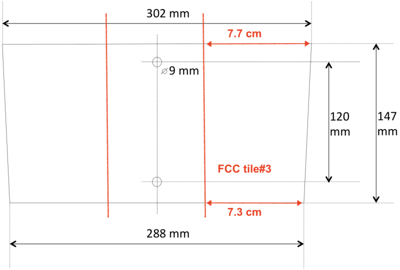
+ PMT readout at LIP Lisbon: J. Gentil, R. Goncalo
+ SiPM readout at CERN (building 175): M. Centis Vignali, A. Henriques, A. Karioukhine, C. Neubüser, J. Schliwinski, O. Solovyanov

Scintillating tiles in FCC sizes

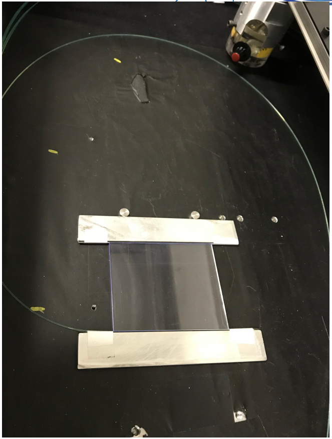
cut ATLAS tiles #2,7,8 (two of each):

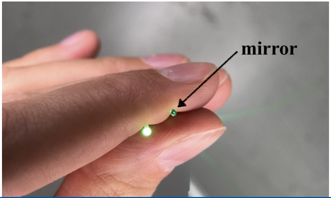
4× FCC tile#1: (6.9/7.2) cm × 10 cm
4× FCC tile#3: (7.3/7.7) cm × 15 cm
4× FCC tile#10: (10.7/11.3) cm × 25 cm

ATLAS tile#7



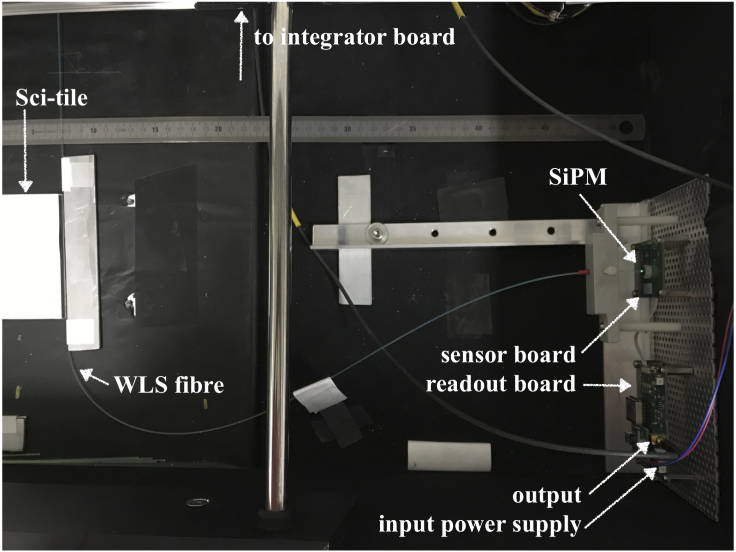
FCC tile#1





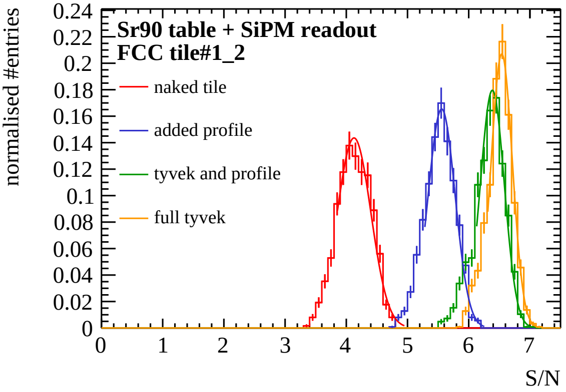
ATLAS TileCal Sr90 source table

the black box



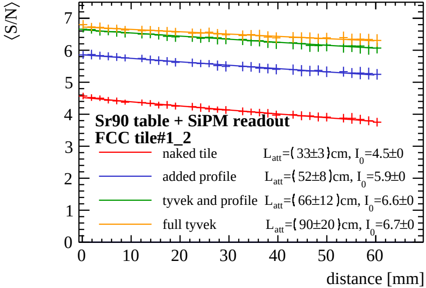
Response uniformity in Sr^{90} source scan

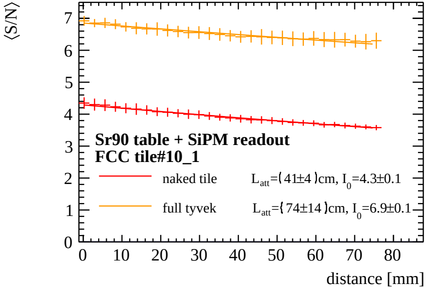
spread smaller 5 %



	FCC tile #1				FCC tile #10			
	rms/mean	σ/μ	L_{att}	I_0	rms/mean	σ/μ	L_{att}	I_0
unit	%	%	cm		%	%	cm	
naked tile	6.5	6.7	33	4.5	7.6	6.3	41	4.3
full tyvek	3.2	2.7	90	6.7	4.4	3.8	74	6.9

Attenuation length





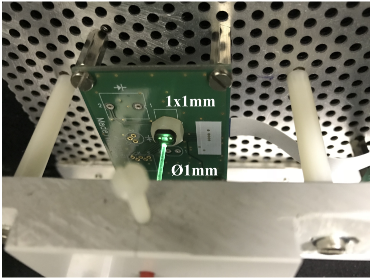
$$\langle S/N \rangle = I_0 \cdot e^{-\frac{d}{L_{att}}}$$

FCC layer 1 and 10 tiles show very similar light responses.

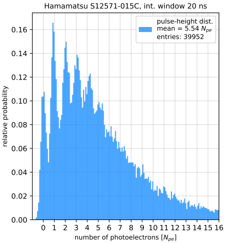
- increase of 50 % in response from naked to fully wrapped tile
- attenuation length > 70 cm

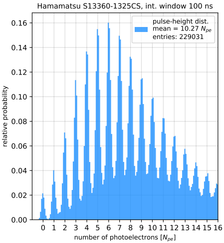
Silicon Photomultipliers (SiPMs)

matrix of single photon avalanche diodes (SPADs) in Geiger mode operated above break down voltage



	S13360-1325CS	S12571-015C
area [mm^2]	1.3×1.3	1×1
pixel pitch	25 μm	15 μm
pixels	2,668	4,489
fill factor	47 %	53 %
gain	7×10^5	2.3×10^5
PDE	25 %	25 %
dark count	70 kHz	100 kHz



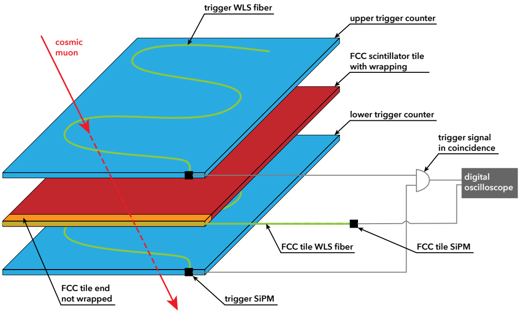


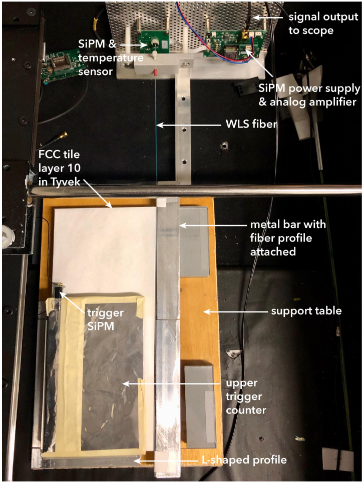
tested two SiPM types from Hamamatsu

- different pixel pitch
  → dynamic range
  → smaller gain
  → in this case higher cross talk
- different integration windows

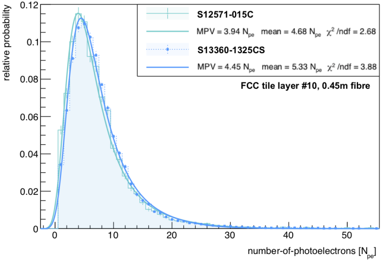
Cosmics setup

- trigger scintillators for cosmic muon detection by coincidence **cosmicπ**





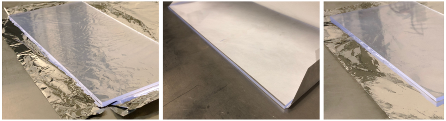
Number of photo-electrons per MIP

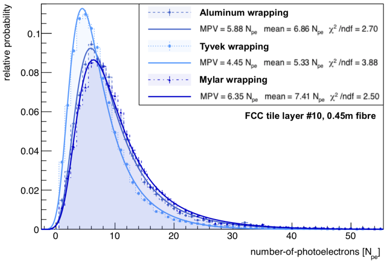


test of SiPMs:

- comparable results $\rightarrow$ validation of gain calibration

Number of photo-electrons per MIP





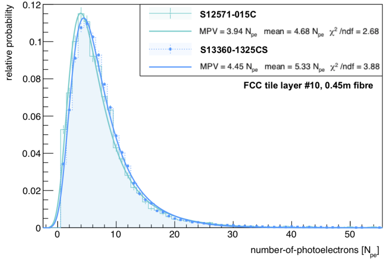
test of SiPMs:

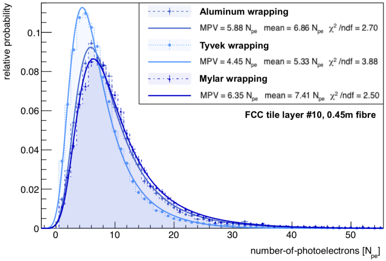
- comparable results → validation of gain calibration

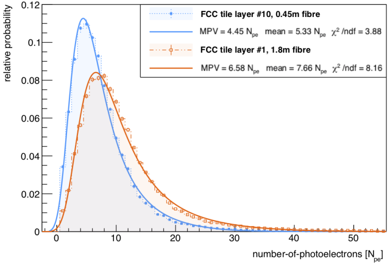
test of wrapping materials:

- Mylar wrapping increases response by 10 %

Number of photo-electrons per MIP







test of SiPMs:

- comparable results → validation of gain calibration

test of wrapping materials:

- Mylar wrapping increases response by 10 %

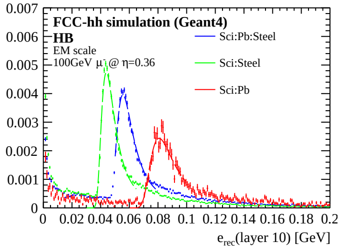
test of tile size and fibre length:

- smallest FCC tile layer #1 sees 7 p.e/MIP
- largest FCC tile layer #10 sees 5 p.e/MIP

Dynamic range

example calculation for layer #10 type tiles

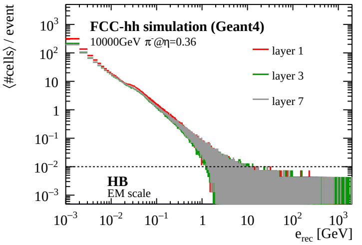
from muons in full-simulation:
→ 56 MeV (EM scale)
lab measurements:
→ 5 p.e/MIP



needed dynamic range:
→ up to 10 GeV for 10 TeV π shower

$$\frac{10\text{ GeV}}{56\text{ MeV/MIP}} \times 5\text{ p.e./MIP} = 893\#\text{ p.e.}$$

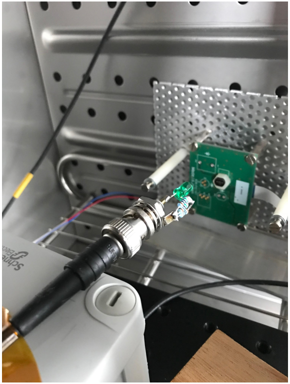
→ well below the # pixel per SiPM (2.6 and 4.5 k pixel)



Measurements in a climate chamber

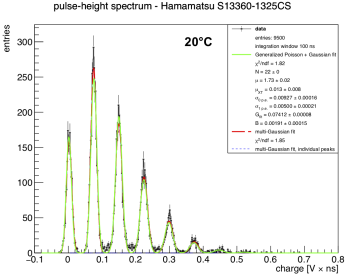
test temperature dependence of SiPM

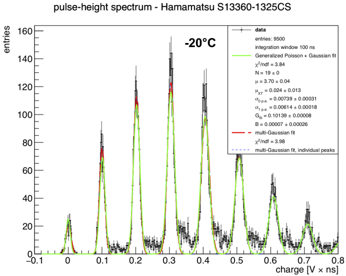
courtesy of SSD group (EP-DT-DD)



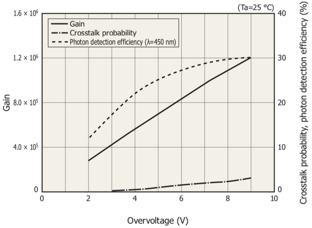
Temperature dependence of gain

$V_{BD} = 57.5\,\text{V}$, 5 V over breakdown at 25°C



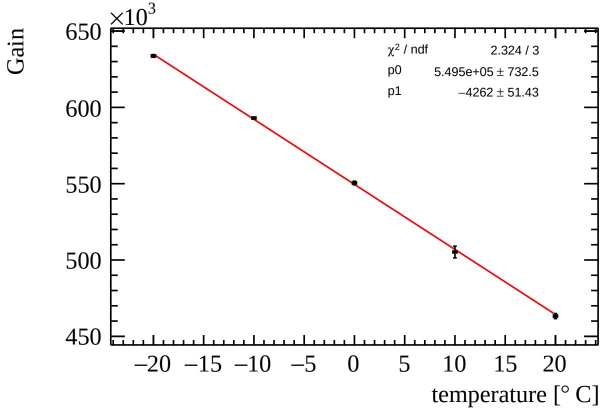


- breakdown voltage decreases with decreasing temperature
  → effectively higher over-voltage
- observation higher efficiency due to increased PDE



- Generalised Poisson fit to extract gain for calibration to #p.e.

Determination of temperature coefficient

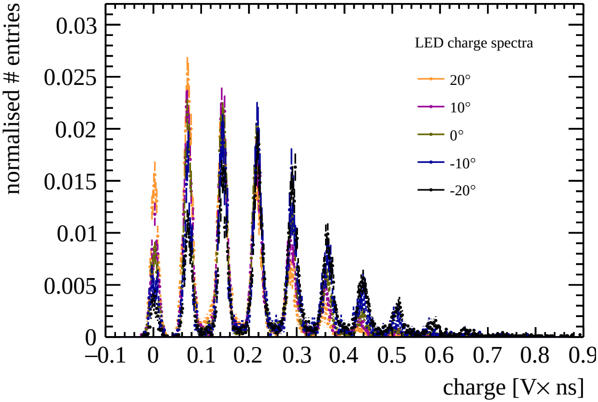


Test of gain stability

using the on-board temperature sensor and applied operating voltage correction

$$V_{op} = V_{BD} + \Delta V \cdot T + 5\,V \qquad (1)$$

$\Delta V = 54\,\mathrm{mV}/^{\circ}\mathrm{C}$, $V_{BD} = 57.5\,\mathrm{V}$ provided by Hamamatsu



Conclusions

ATLAS TileCal for FCC-hh ...

- was optimised for e/h closer to 1, full shower containment up to multiple TeV
- combined LAr+Tile system shows promising results in full-simulation studies
- high granularity through single tile readout via SiPMs

→ FCC note summarising all simulation studies will be published soon.

First lab measurements ..

- proven good uniformity over full tile $< 5\,\%$ spread in response
- even with 30 year old TileCal tiles, necessary MIP sensitivity achieved
- MIP sensitivity and dynamic range fulfils requirements

→ paper on these studies in preparation.

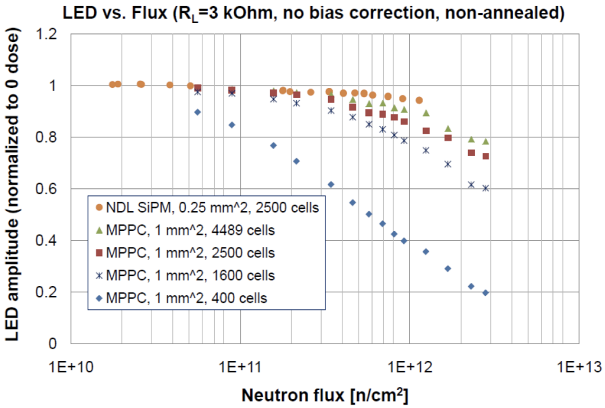
Next steps within EP R&D program

- development of multi-channel readout
- equipment of an absorbers stack
- *0.5 Fellow starting 2021 → supervisor: Ana Henriques*

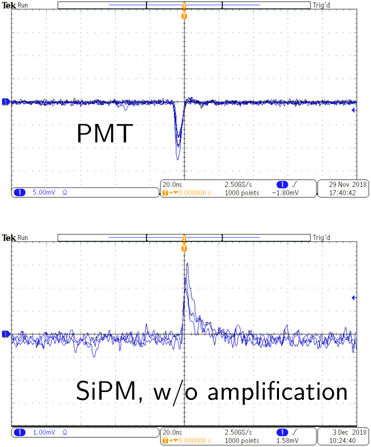
www.cern.ch

Radiation tolerance

tests for CMS HCAL phase I upgrade
–> small pitch



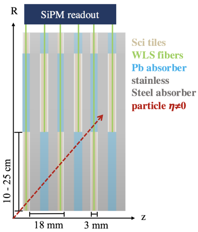
SiPM versus PMT response

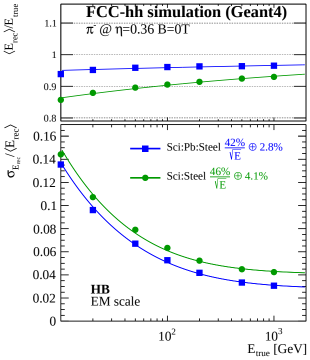


Optimisations of Barrel Tile HCal

included Pb absorbers as 'spacers'
→ Scintillator/Pb/Steel (1:1.3:3.3)

- decreasing non-compensation by suppression of EM response
  Pb: $X_0 = 0.6\,\mathrm{cm}$,
  $\lambda_n = 17.6\,\mathrm{cm}$
  Fe: $X_0 = 1.8\,\mathrm{cm}$,
  $\lambda_n = 16.8\,\mathrm{cm}$
- reduces total depth $[\lambda_n]$ from 8.9 (full Steel) to 8.5





	stochastic term	constant term	e/h
Sci:Steel (1:4.7)	46% $\mathrm{GeV}^{1/2}$	4.1%	1.24
Sci:Pb:Steel (1:1.3:3.3)	42% $\mathrm{GeV}^{1/2}$	2.8%	1.1