FCC R&D

Agostinho Gomes (LIP and FCUL)
on behalf of Dlight and FCC portuguese team

4th Joint Workshop IGFAE/LIP – Lisbon - 13 April 2023

LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

COMPETE
QREN QUADRO DE REFERÊNCIA ESTRATÉGICO NACIONAL
UNIÃO EUROPEIA

A Tile Calorimeter in the framework of ECFA Roadmap

Patricia Conde Muíño, Geral Eigen, Jana Faltova, Luca Fiorini, Agostinho Gomes, Michaela Mlynarikova, Inês Ochoa, Rute Pedro, Beatriz Pereira, Ivo Polak, Gabriel Popeneciu, Oleg Solovyanov, Alberto Valero Biot, Henric Wilkens
CERN
CH1211 Geneva 23
(41) 075 411 3845

Scintillating Tile HCAL for future colliders with TileCal like geometry and SiPM photodetectors

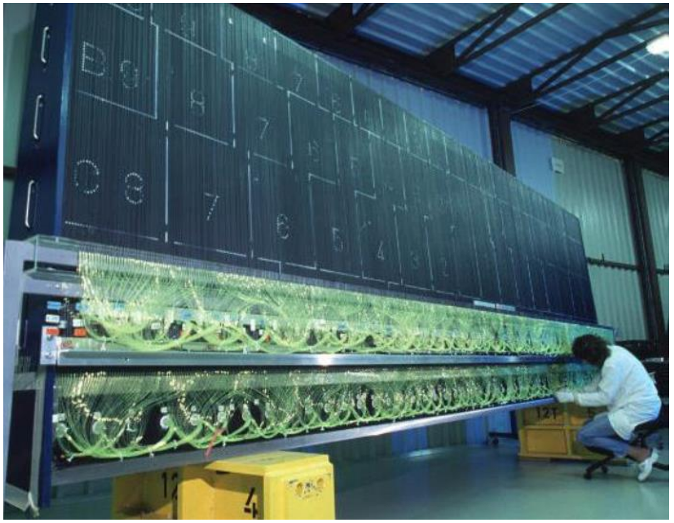
Within ECFA Detector R&D Roadmap (Calorimetry)

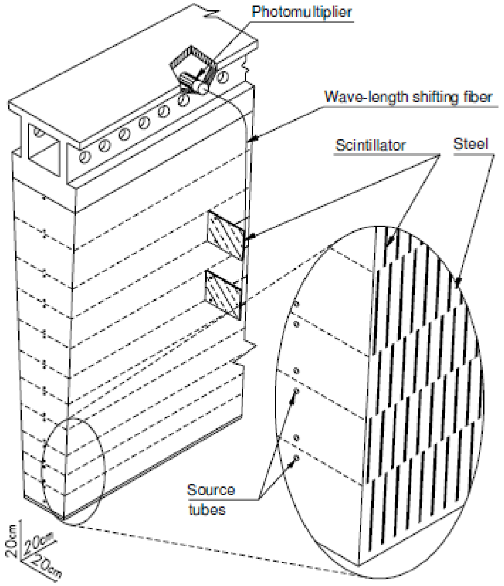
Team joining people from CERN, LIP, FZU and Charles University (Prague), IFIC(Valencia University), INCDTIM (Cluj) and University of Bergen

Hadronic calorimetry at FCC

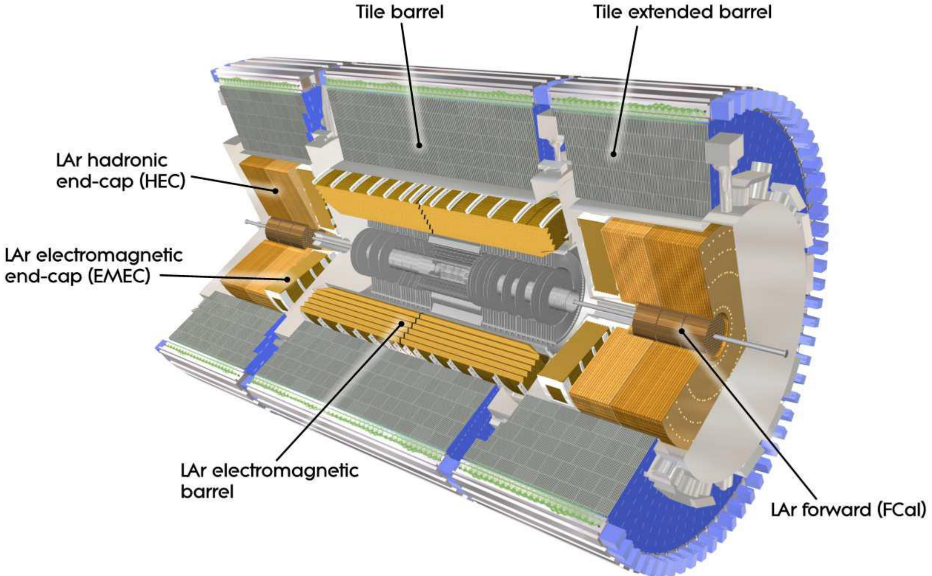
- Several types of hadronic calorimeters are being proposed for the future FCC experiments
- Hadron calorimeters with scintillating tiles readout by wavelength shifting fibres are well established
    - ATLAS Tile Calorimeter
    - CMS
    - LHCb
- Could ATLAS Tile calorimeter be used as a departing point?
    - Conceptually does not seems to be difficult for FCC-hh
    - FCC-ee is the first challenge

TileCal – ATLAS barrel hadronic calorimeter





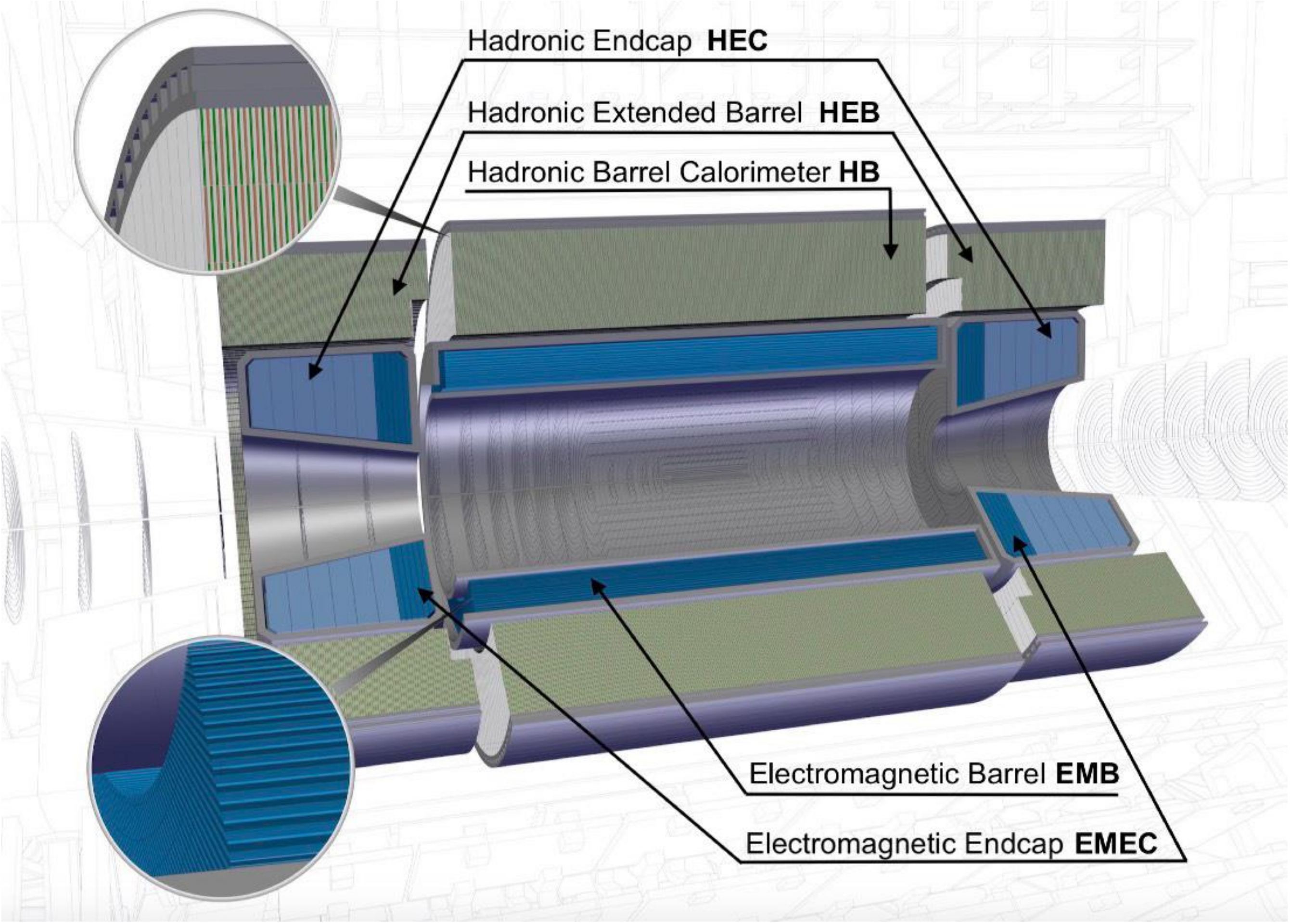
- Plastic scintillators (tiles) in a matrix of steel plates
- Light produced in tiles collected by WLS fibers
- Grouping of fibers in front of PMTs makes cell structure
- Each cell readout by 2 PMTs
- Dynamic range 10 MeV – 2 TeV per cell



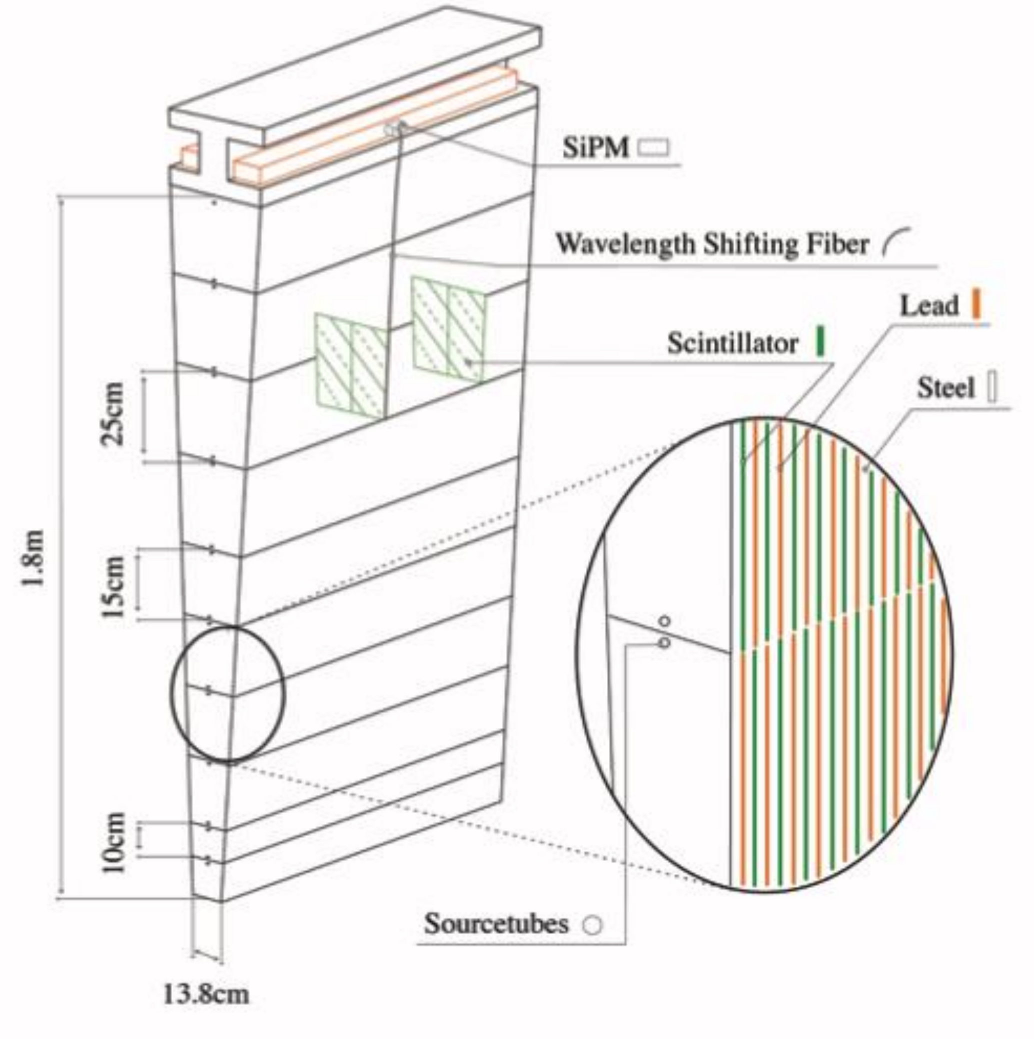
- 3 cylinders, covering $|\eta| < 1.0$ in central barrel and $0.8 < |\eta| < 1.7$ in the extended barrels
- ~5000 pseudo projective cells
- Calibration with ^{137}Cs and laser
- Current integration provides luminosity

Hadronic calorimetry at FCC-hh

- For FCC-hh a barrel hadron calorimeter Tilecal like in the central region is straight forward
- Better granularity and new photosensors are key to get better performance keeping a low cost
- Radiation hardness of the scintillators and WLS fibers are potential issues, improvement needed to cope with ~10 kGy



Hadronic calorimetry at FCC-hh



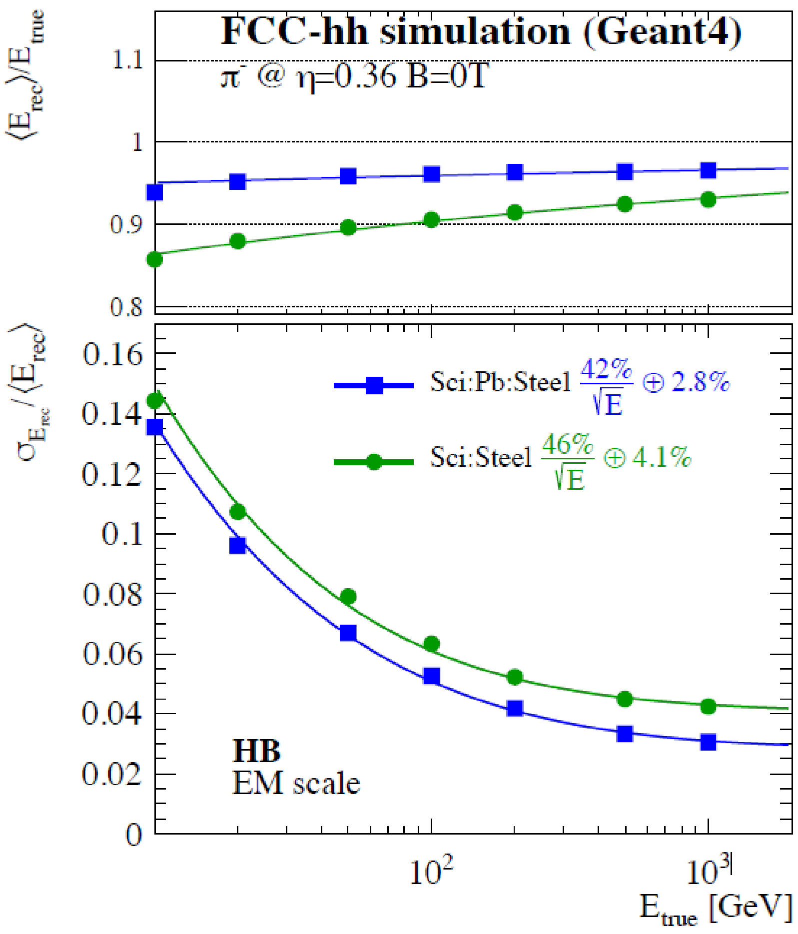
Structure:

- 5mm steel absorber plates, alternating with 3mm Scintillator and 4mm Pb tiles
- 128 modules in Φ, 2 tile/module
- 10 layers
- Δη=0.025 (grouping 3-4 tiles), ΔΦ=0.025

- 4 times more scintillators than in ATLAS
- 1 scintillator read by one fiber and one SiPM
- Scintillators and SiPM need to be radiation hard

Technology proven to work well, last point needs to be addressed

Hadronic calorimetry performance at FCC-hh



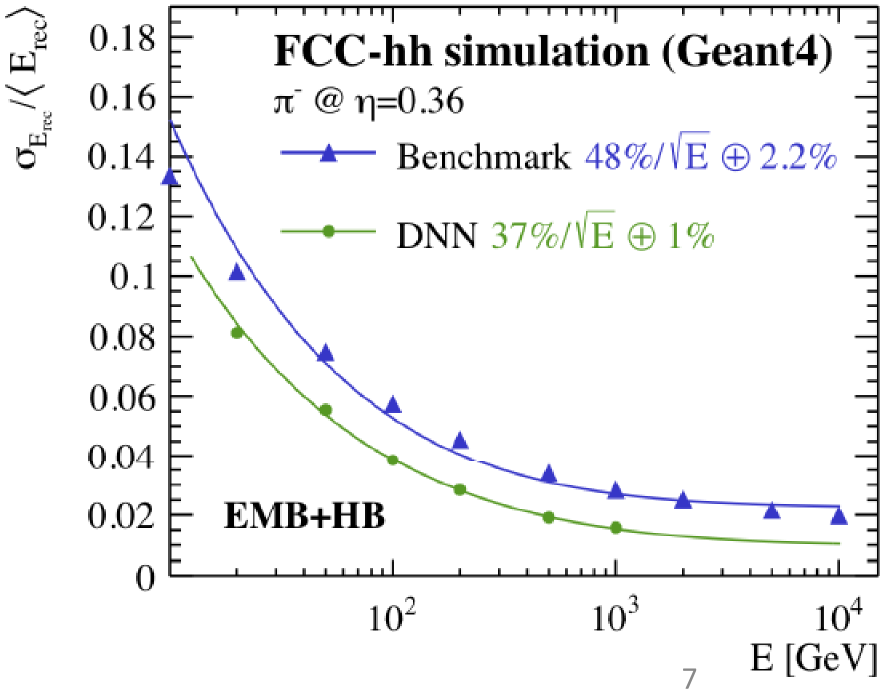
Addition of Pb tiles improves hadronic performance

- non-compensation decreased due to suppression of EM response

Pb: X_0 = 0.6 cm / Fe: X_0 = 1.8 cm

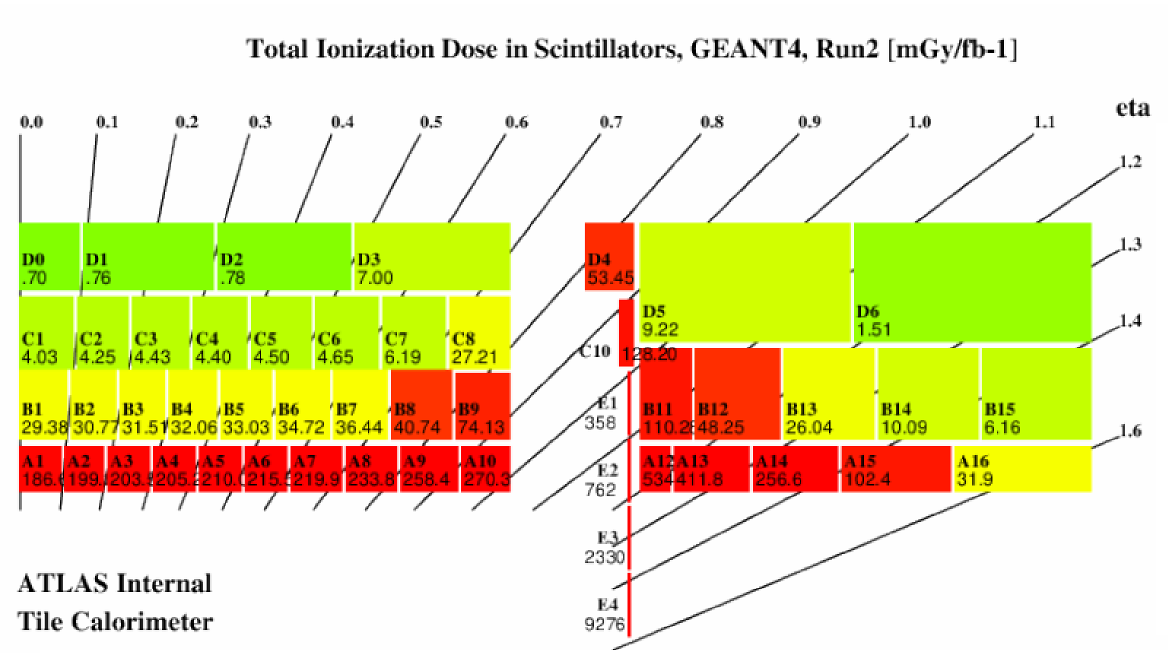
- improves stochastic and constant term, and e/h from 1.24 to 1.1

- 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

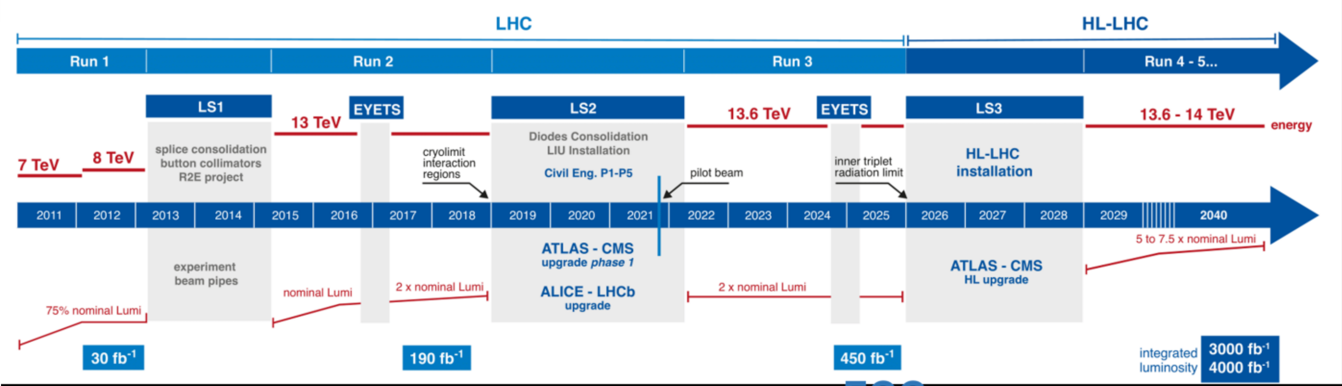


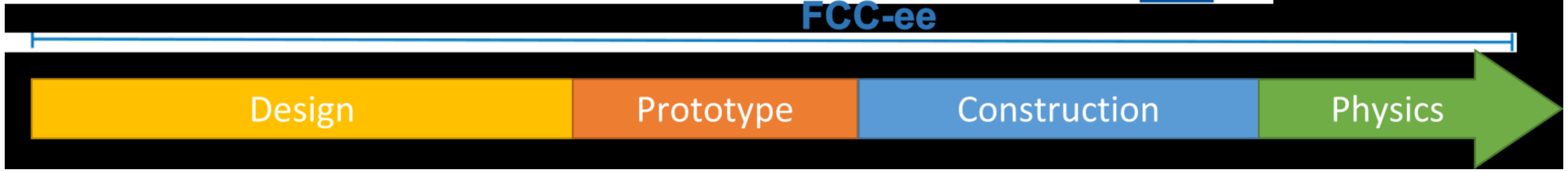
CERN work in note CERN-FCC-PHYS-2019-003

Input from ATLAS operation



- ATLAS Tile calorimeter is operating allowing to collect invaluable data
- Cells were exposed to different dose rates and total doses
- Scintillator damage is critical in E cells (gap/crack scintillators)

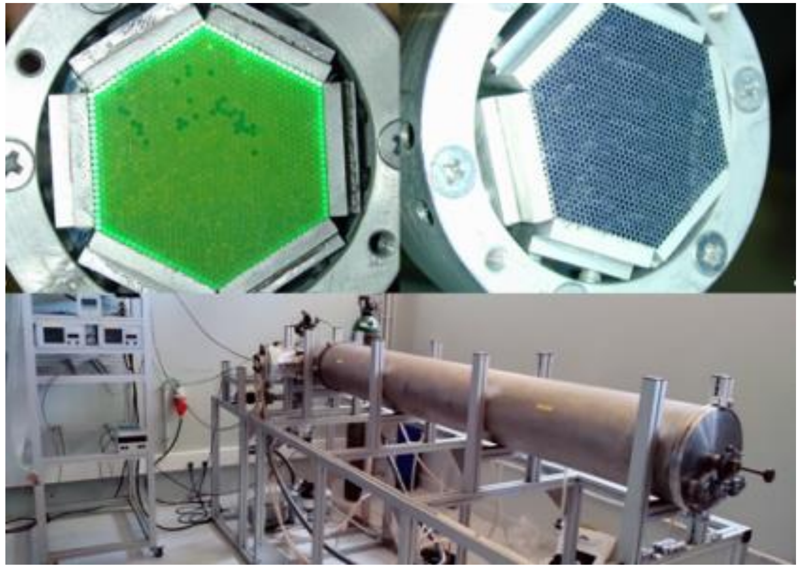




- Ongoing Run 3 will provide higher doses
- At the end of run, gap/crack scintillators will be replaced again

Scintillators replacement due to radiation damage

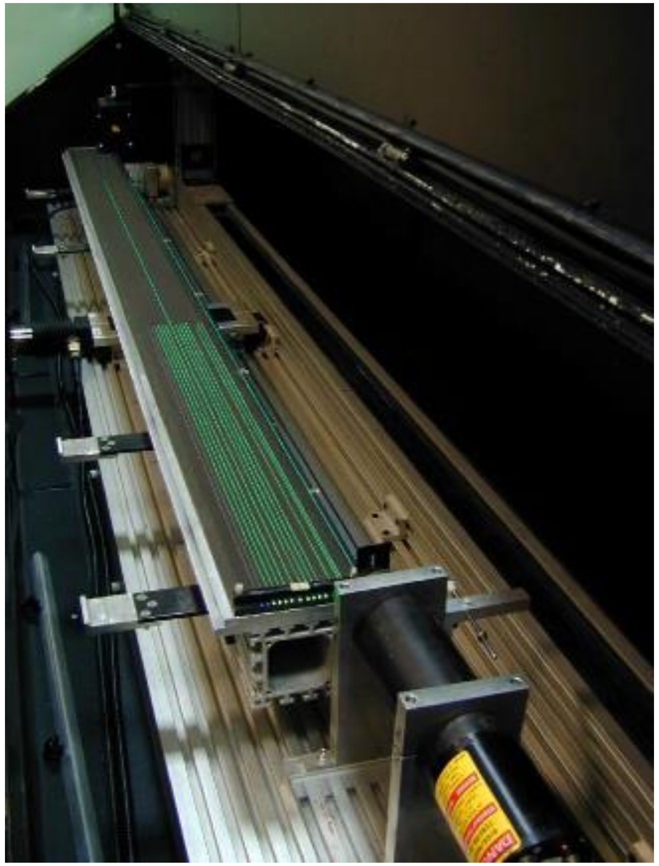
- ATLAS gap-crack scintillators are exposed to large doses
- Need to be replaced periodically, after a few years of operation
- Motivation for R&D on scintillators
- LIP participates in the replacement
- Preparation of sets of new WLS fibers



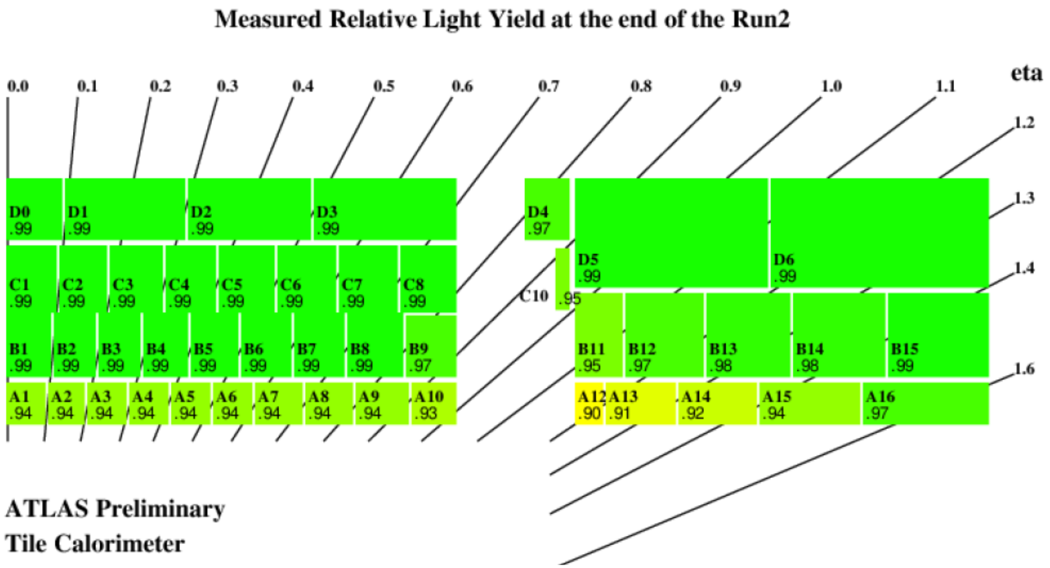
Polishing and aluminization of WLS fibers

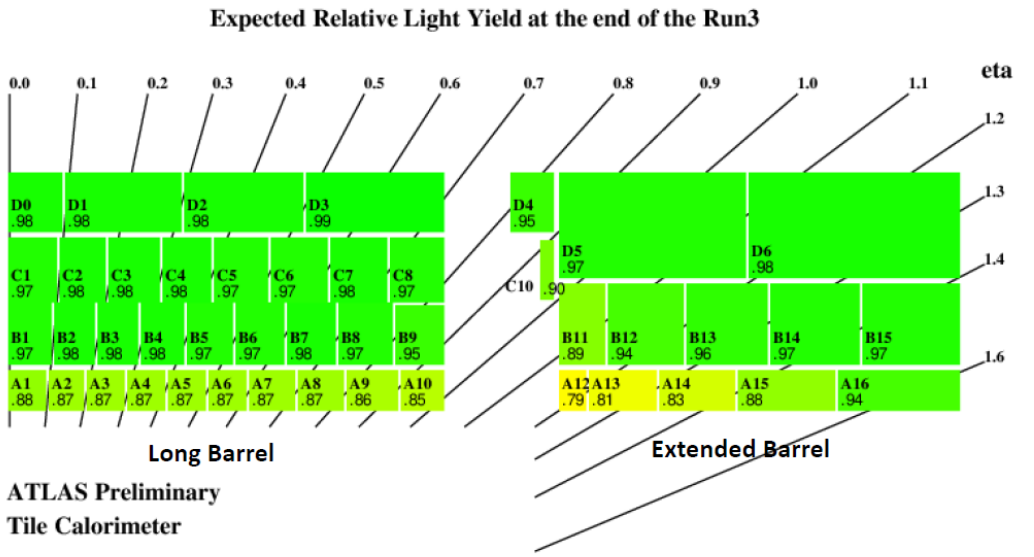
(at LIP LOMAC infrastructure)

Quality control of the WLS fibers at the fibermeter



Light loss at ATLAS Tile Calorimeter





- Study of the light loss of the Tile Calorimeter cells is part of a LIP - IST PhD thesis in progress
- Tile Calorimeter calibration systems are used
- Results can be used to foresee losses at the end of next LHC Runs
- Dose rates in the several cells have different values

But now first things first: FCC-ee

- FCC-ee is expected to be the first life of FCC, and only later FCC-hh will follow
- FCC-ee as a precision physics machine will be very demanding on detectors
- Different running conditions depending on beam energy may allow the production of
  - 5×10^{12} Z bosons
  - 10^8 WW pairs
  - 10^6 Higgs bosons
  - 10^6 top pairs

Physics requirements

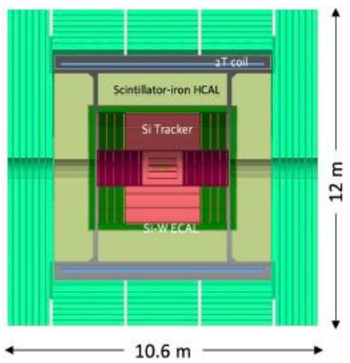
Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_T) \sim 2 \times 10^{-5}$
$H \to \mu^+\mu^-$	$\mathrm{BR}(H \to \mu^+\mu^-)$		$\oplus 1 \times 10^{-3}/(p_T \sin\theta)$
$H \to b\bar{b},\ c\bar{c},\ gg$	$\mathrm{BR}(H \to b\bar{b},\ c\bar{c},\ gg)$	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10/(p \sin^{3/2}\theta)\ \mu\mathrm{m}$
$H \to q\bar{q},\ VV$	$\mathrm{BR}(H \to q\bar{q},\ VV)$	ECAL, HCAL	$\sigma_E^{\mathrm{jet}}/E \sim 3-4\%$
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%$ (GeV)

- Very good momentum resolution.
- Very good vertex resolution.
- Excellent Hadronic calorimetry.
- Good, but not extreme, EM calorimetry
- Good tau identification capabilities and ability for polarisation measurements, very good PID.

Iacopo Vivarelli

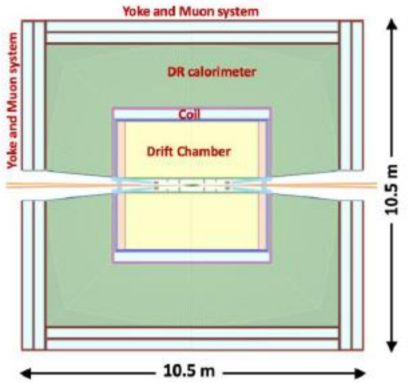
Design for FCC-ee central calorimeter system

CLD

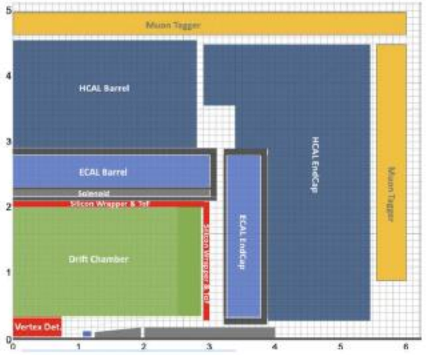


CDR

IDEA



Noble Liquid ECAL based



new

- Full Silicon vertex detector + tracker;
- Very high granularity, CALICE-like calorimetry;
- Muon system
- Large coil outside calorimeter system;

- Possible optimization for
  - Improved momentum and energy resolutions
  - PID capabilities

- Si vertex detector;
- Ultra light drift chamber w. powerfull PID;
- Monolitic dual readout calorimeter;
- Muon system;
- Compact, light coil inside calorimeter;

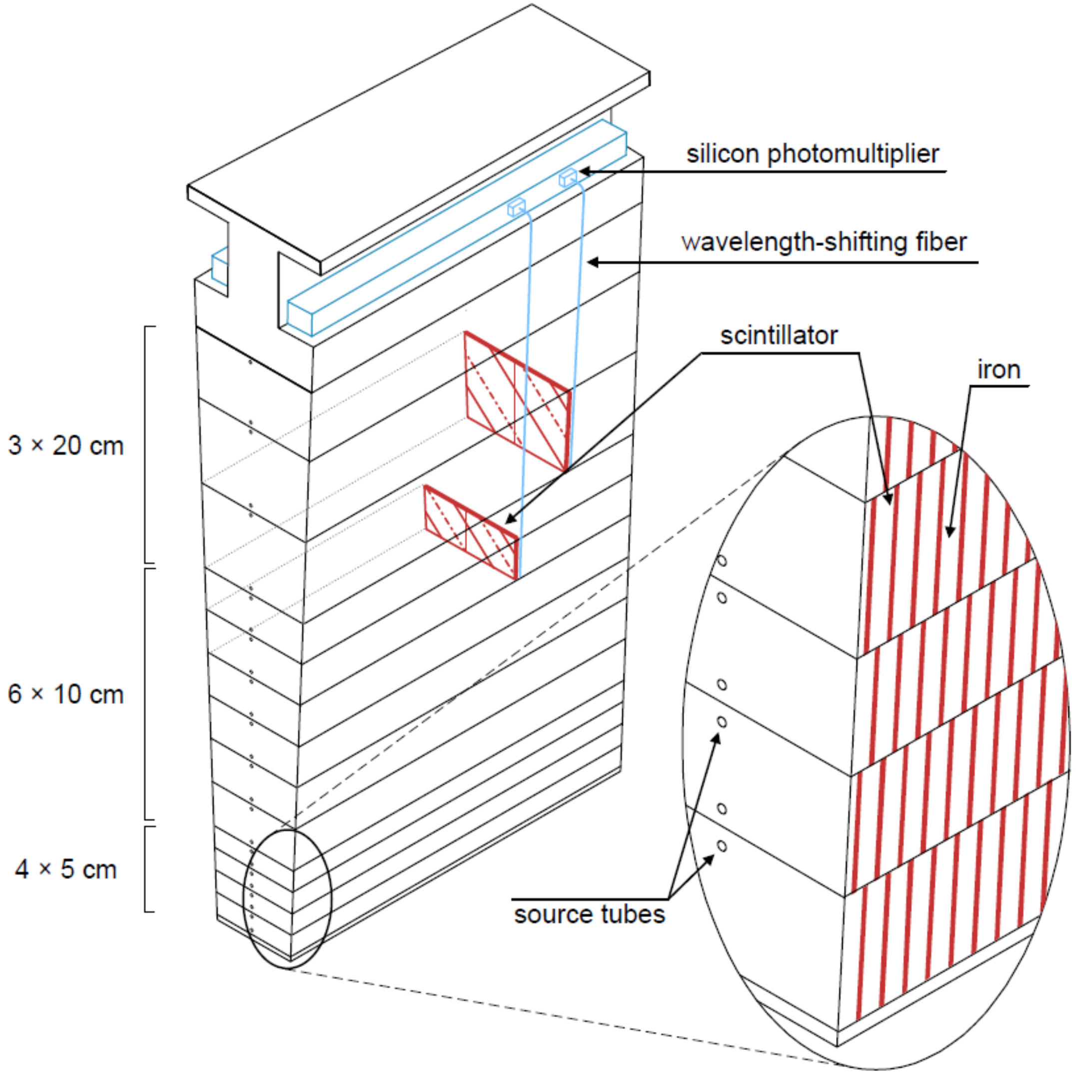
- Possibly augmented by crystal ECAL in front of coil;

- High granularity Noble Liquid ECAL as core;
  - PB+LAr (or denser W+LCr)
- Drift chamber (or Si) tracking;
- CALICE-like HCAL;
- Muon system;
- Coil inside same cryostat as LAr, possibly outside ECAL.

M. Aleksa et. al.

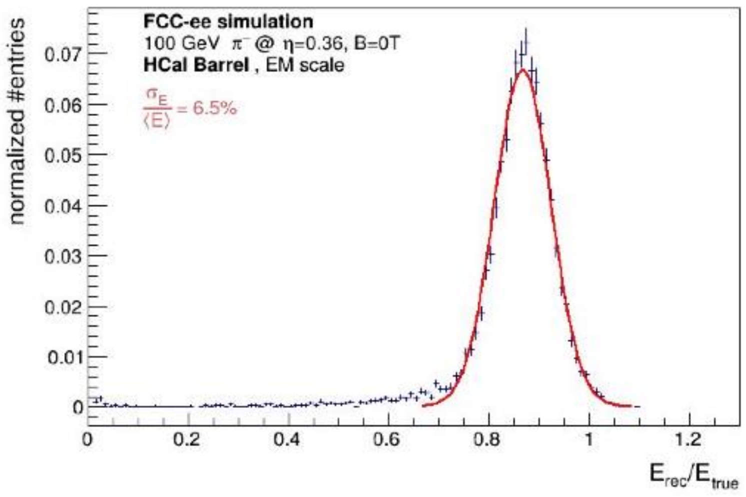
A new idea for a detector alternative to CLD and IDEA, using noble liquid ECAL. In the new idea, CALICE-like HCAL can also be replaced by a Tile barrel calorimeter. Performance studies starting.

Design for FCC-ee central calorimeter system



Base is the same as FCC-hh design, but
- Removed the Pb plates
- HCAL acts as return yoke for the central solenoid
- 13 layers in depth

Work on optimisation of segmentation and reconstruction starting



Towards a prototype for FCC-ee

Within ECFA Detectors R&D Roadmap, a team was formed for the development of a Tile hadronic calorimeter for FCC-ee

Tasks/goals are:

- production of small prototypes of the calorimeter (~1000 scintillators)
- mechanical design
- performance studies of a high granularity calorimeter for a future lepton collider including detector design optimisation using Machine Learning techniques
- exploration of PEN and PET based scintillating Tiles
- cost effective production of scintillators
- efficient coupling of the scintillating tiles to wavelength shifting fibers
- routing of the wavelength shifting fibers at the module edges
- coupling of the fibers to the SiPMs
- identify suitable and cost effective SiPM
- develop scalable readout systems
- setup a test beam facility

(LIP expects to contribute for tasks in red)

Scintillator development - Dlight project

DLight exploratory project, R. Pedro et al

Exploration of alternative scintillators based on PEN and PET

Get radiation hard and relatively cheap injection mould plastic scintillators

Collaboration of LIP and Institute for Polymers and Composites of U. Minho

- Characterisation of material.

- Develop PEN/PET granulate process by extrusion/injection moulding.

- Setup scalable manufacturing process.

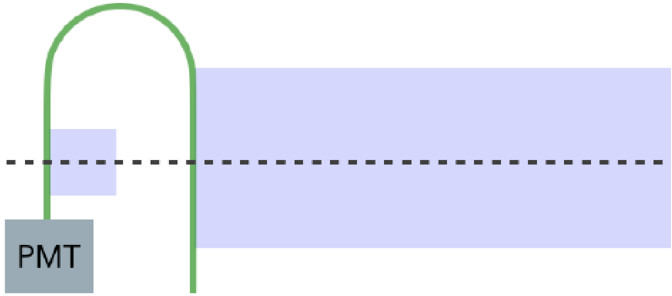
Dlight preliminary results

- Extrusion is used for preparation and mixture of the raw materials
- Mould injection for scintillator production
- Started by the production of small scintillators, 30 x 30 x 2 mm3

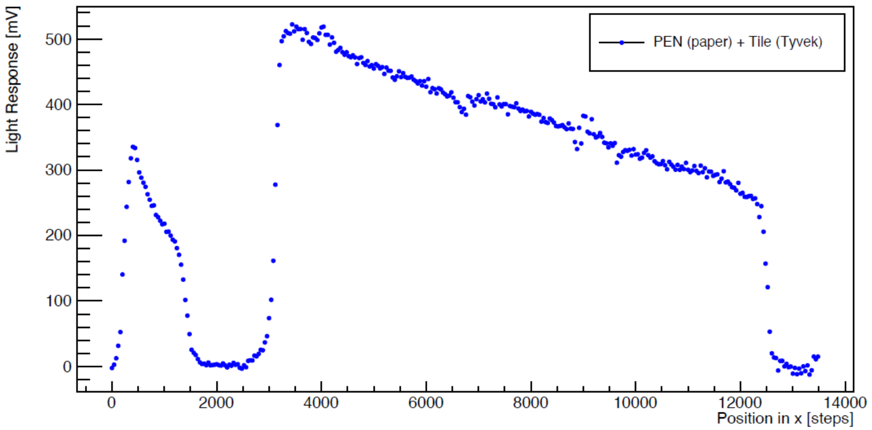
Setup used

^{90}Sr source scans along the central dashed line marked on the tiles

1 WLS green fiber and 1 PMT

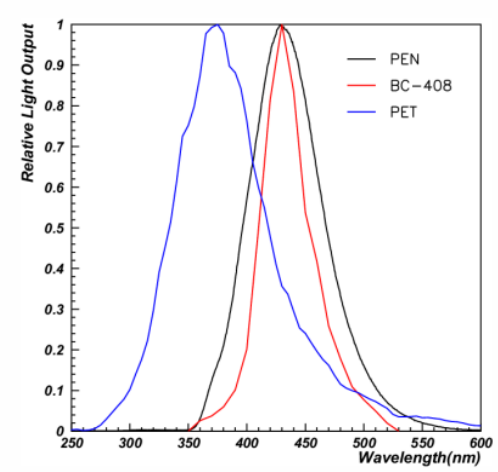


Light output as a function of distance compared with Tilecal scintillator

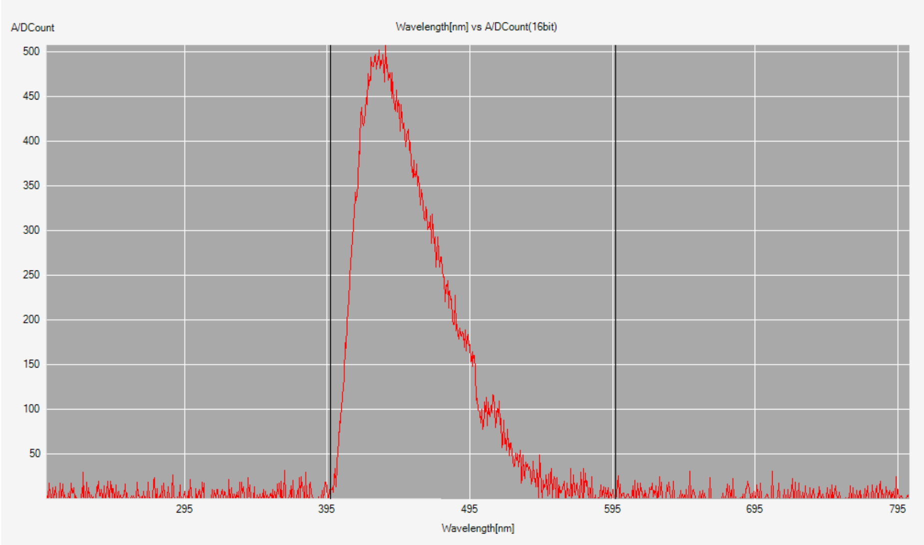


Dlight short term plans

- Produce 3mm thick scintillators with larger areas
- Setup UV LEDs to excite PET at lower wavelengths
- Use PET and PEN blends, later add suitable dopants
- Transparency and light yield of the scintillators need improvement



PET, PEN and BC-408 emission spectra



PEN emission spectrum measured at LIP LOMAC

Summary

FCC R&D is accelerating

Tile Calorimeter is a well established technology suited for FCC-hh

Input from ATLAS Tile calorimeter is a guideline

New design being prepared for FCC-ee

International collaboration being setup, following ECFA Roadmap

Performance studies needed

Production of prototypes to start

Developing new scintillators at LIP in collaboration with Institute for Polymers and Composites of U. Minho