# ECCE Forward Calorimeter Design

**April 27, 2022**


**Friederike Bock**
**for the ORNL Relativistic Nuclear Physics Group**

**F. Bock, M. Demarteau, M. Fasel, E. Glimos, O. Hartbrich, H. Hassan,**
**F. Jonas, C. Loizides, J. Osborn, M. Poghosyan, K. Read, A. Russu, J. Schambach, N. Schmidt**

# Main Physics Objectives

## Full jet physics in forward region and their substructure

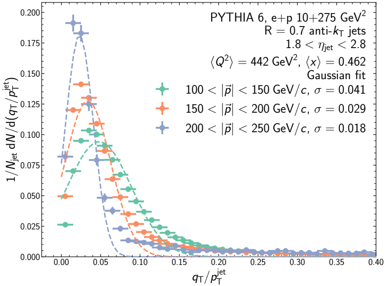
- consistent with YR specifications[1] and constraints [YR]
  **ECal:** $2\%/E \oplus (4-12)\%/\sqrt{E} \oplus 2\%$
  **HCal:** $50\%/\sqrt{E} + 10\%$
- reconstruction via particle flow as final goal
- single particle track to cluster association
- complementing tracking at high $\eta$

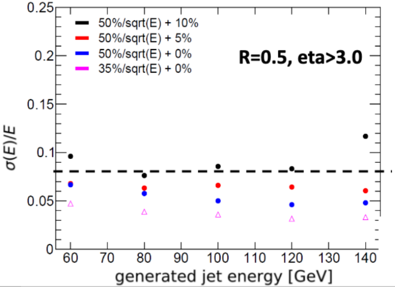
→ **Specific Example: Sivers asymmetry measurement[2]**

- binned in $q_T = |\vec{p}_{T,e} - \vec{p}_{T,jet}|$
- intrinsic width of $q_T/p_T \sim$ 1-5%, depending on jet $R$
- precision driven by jet resolution
- aims for high $x \rightarrow$ high jet $p$, $p_T$
- constant term of $< 10\%$ for FHCAL desired

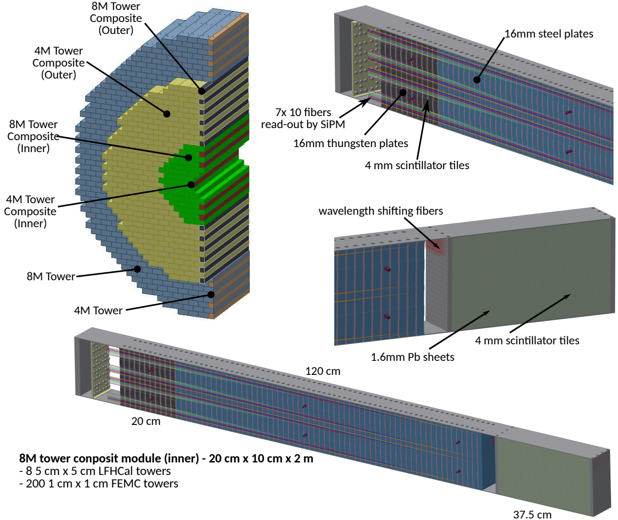
[A. Bazilevsky, YR summary] [M. Arratia, jets]

[1] T. Horn, Detector Matrix - Forward HCAL resolution
[2] M. Arratia, *et al.*, Jet-based measurements of Sivers and Collins asymmetries at the future Electron-Ion Collider



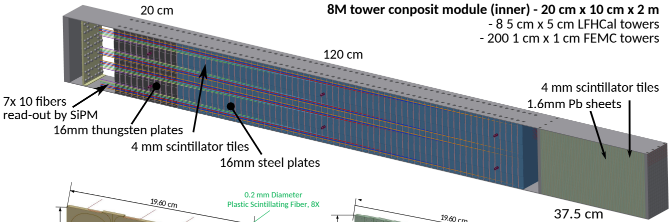
# The General Idea

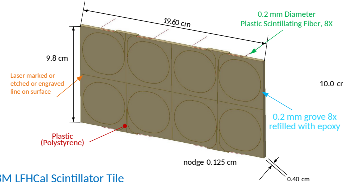



- Combined module design for ECal & HCAL
- **ECal:**
  66 layers of Pb (16 mm)-Sci plates (4mm)
- **HCal**
  60 layers of Steel (160 mm)-Sci plates (4mm) +
  10 layers of W (160 mm)-Sci plates (4mm)
- Multiple towers combined in one module to reduce dead areas, increase granularity
- Read-out:
  - ECal: 1 signal per tower
    readout position: between ECal & HCal
  - HCal: 7 signals per tower (signals combined from 10 Sci-plates) readout position: after full HCal
- Modules of different sizes (8M, 4M, 2M, 1M) to maximize coverage & assembly efficiency

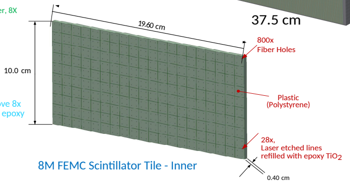
# Calorimeters in Numbers

| | parameter | value |
|---|---|---|
| **FEMC** | inner radius (envelope) | 17 cm |
| | outer radius (envelope) | 170 cm |
| | $\eta$ acceptance | $1.3 < \eta < 3.5$ |
| tower information | | |
| | x, y ($R < 0.8$ m / $R > 0.8$ m) | 1 cm/ 1.65 cm |
| | z (active depth) | 37.5 cm |
| | z read-out | 5 cm |
| | # scintillor plates (0.4 cm) | 66 |
| | # Pb sheets (0.16 cm) | 66 |
| | weight | $\sim$ 6.4 kg |
| | # towers (inner/outer) | 19 200 / 34 416 |
| | # read-out channels/ SiPM | 53 616 |
| | radiation lengths $X/X_0$ | 18.5 |
| | Molière radius $R_M$ | 5.2 cm |
| | Sampling fraction $f$ | 0.220 |
| **LFHCAL** | inner radius (envelope) | 17 cm |
| | outer radius (envelope) | 270 cm |
| | $\eta$ acceptance | $1.2 < \eta < 3.5$ |
| tower information | | |
| | x, y | 5 cm |
| | z (active depth) | 140 cm |
| | z readout | 20 cm |
| | # scintillor plates (0.4 cm) | 70 |
| | # steel plates (1.6 cm) | 60 |
| | # thungsten plates (1.6 cm) | 10 |
| | weight | $\sim$ 30.6 kg |
| | # towers | 9040 |
| | # read-out channels/ SiPM | 7 x 9040 = 63 280 |
| | interaction lengths $\lambda/\lambda_0$ | 6.9 |
| | Molière radius $R_M$ for $\pi^{\pm}$ | 21.1 cm |
| | Sampling fraction $f$ | 0.040 |
| **Assembly Modules** | | |
| 8 LFHCAL towers (8M) | total | 1091 |
| no FEMC towers | LFHCAL only | 538 |
| 200 FEMC towers | LFHCAL+FEMC (inner) | 87 |
| 72 FEMC towers | LFHCAL+FEMC (outer) | 466 |
| 4 LFHCAL towers (4M) | total | 76 |
| no FEMC towers | LFHCAL only | 36 |
| 100 FEMC towers | LFHCAL+FEMC (inner) | 16 |
| 36 FEMC towers | LFHCAL+FEMC (outer) | 24 |
| 2 LFHCAL/ 50 FEMC towers (2M) | LFHCAL+FEMC (inner) | 2 |
| 1 LFHCAL/ 25 FEMC towers (1M) | LFHCAL+FEMC (inner) | 4 |



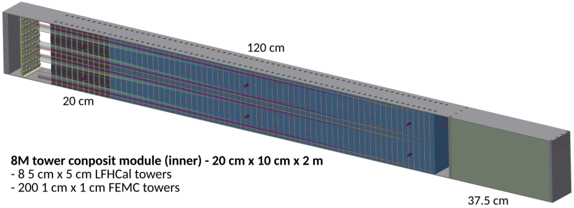

8M LFHCal Scintillator Tile

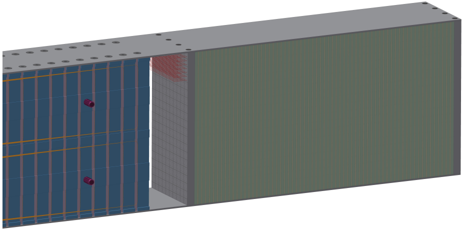


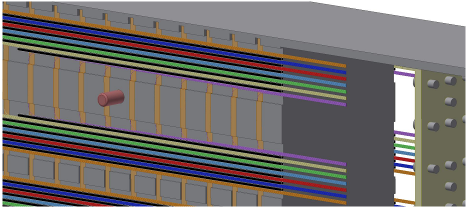

8M FEMC Scintillator Tile - Inner

- **ECal:** $X/X_0 = 18.5$, **HCal:** $\lambda/\lambda_0 = 6.9$
- Single Towers smaller than $R_M$, use shower maxima to separate close particles
- Modules optimized for easy assembly with dedicated tooling
- Interested Institutes: ORNL, ISU, Ohio U., EIC Japan, EIC Korea, EIC China, BNL

# 8M modules

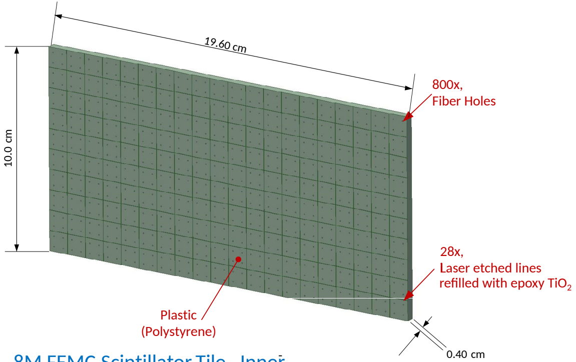


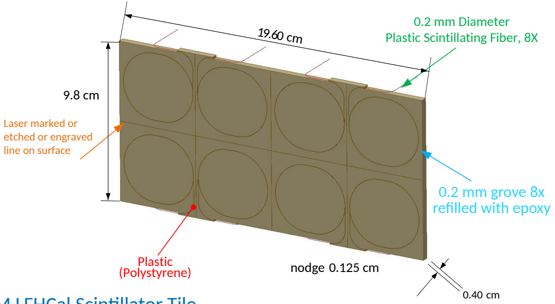


- **outer 8M module** contains (100x200 mm):
  8 HCal (50x50 mm ) + 72 ECal (16.5x16.5 mm) towers
- **inner 8M module** contains (100x200 mm):
  8 HCal (50x50 mm) + 200 ECal (10x10 mm) towers
- separation of towers in each scintillator layer using Epoxy-$TiO_2$
- **ECal:** Classical Shashlik design (fibers run through Pb & Scintillator) - 4 fibers per tower readout by 1 SiPM
- **HCal:** 1 fiber per tower tile, running on side 1 of tower - 10 fibers combined for readout with 1 SiPM

# Current 8M Scintillator Plate Design



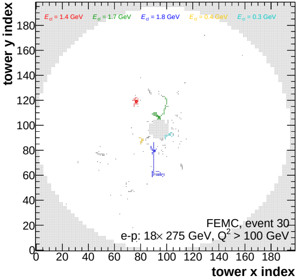

8M FEMC Scintillator Tile - Inner

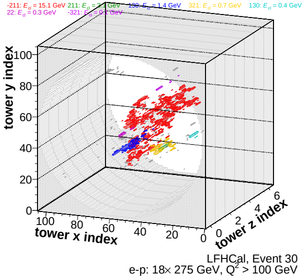



8M LFHCal Scintillator Tile

- Scintillator plates produced as 1 unit of 100x200mm plates
- Separation of tiles edged into the plate (95%) through, refilled with Epoxy-$TiO_2$ mix
- Wrapped in Tyvek paper and Kapton tape

# Read-out 8M module

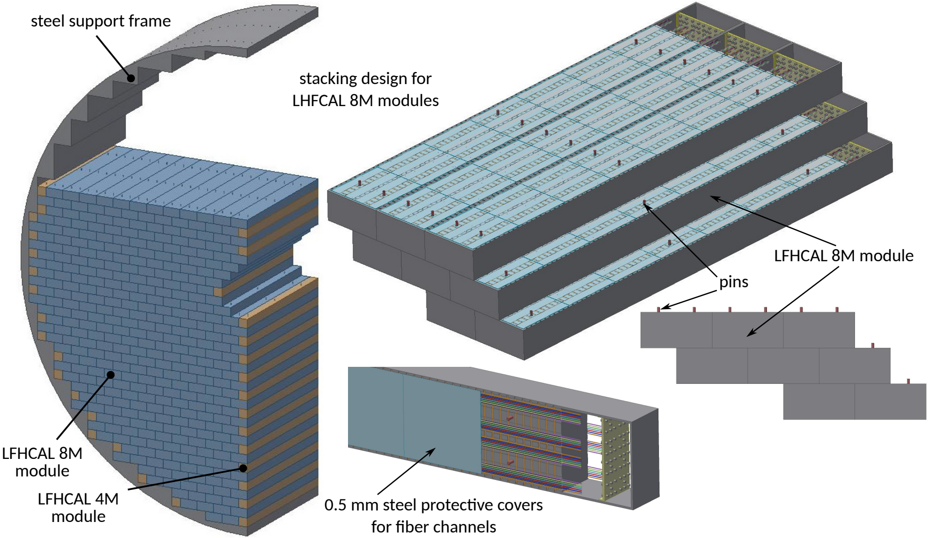


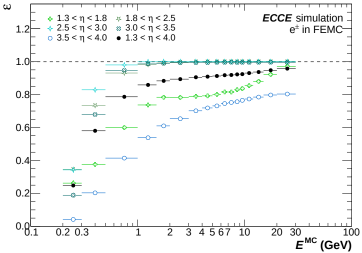

- High granularity needed to try to distinguish shower maxima close to beam pipe
- **ECal**: desireable min measurable tower energy 1-3 MeV, max 20-30 GeV in single tower
- **HCal**:
  read out in 7 layers longitudinally
  desireable min measurable tower energy 3-5 MeV, max 20-30 GeV in single tower segment

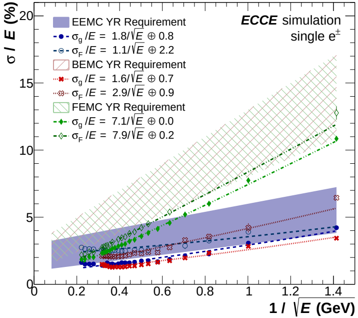
- FEMC 1 SiPM per tower (4-5 fibers), LFHCal 1 SiPM per 10 fibers (7 per tower) -i.e Hamamatsu S14160-3050HS
- readout of ECal directly after ECal segment in module, HCal readout at end of module
- Small light collection prisms might be needed infront of SiPM
- Idea use each 1 SiPM HGCROC for readout of ECal and HCal

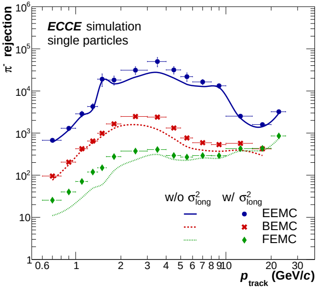
# Assembly of Calorimeter

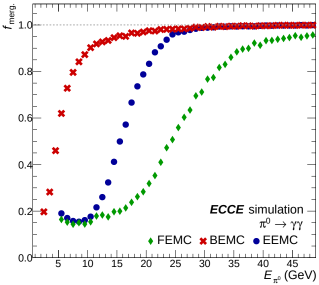


# FEMC Performance



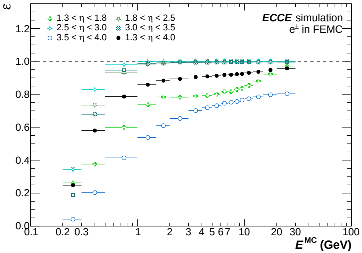



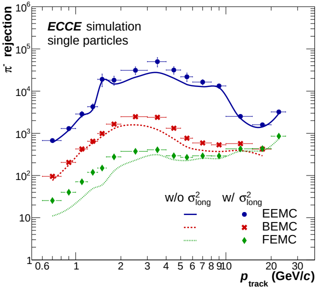



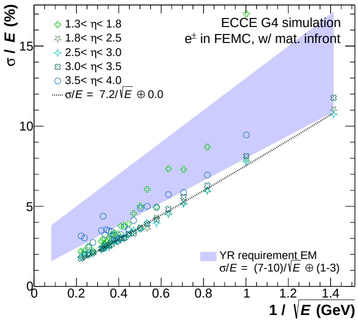



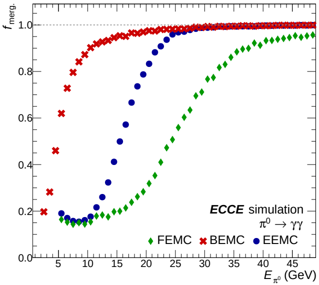

- Cluster finding efficiencies very good in center of FEMC, losses towards edges
- Meeting YR energy resolution requirements even without ML based clusterizer optimization
- First pion rejection & $\pi^0$ separation studies encouraging
- small $\eta$ dependence for energy resolution
- studies to improve clusterization further using ML started

# FEMC Performance



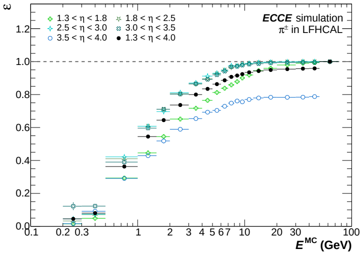



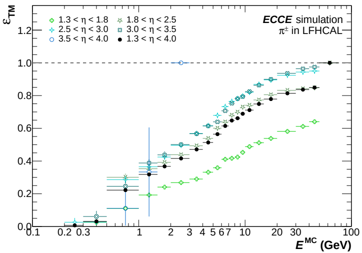



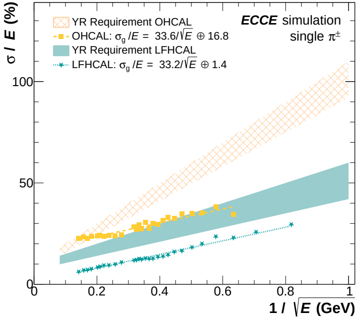



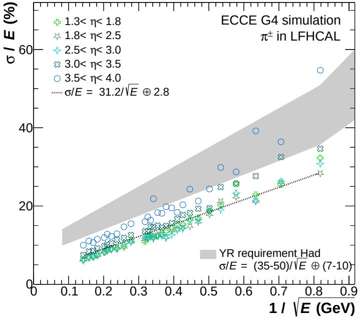

- Cluster finding efficiencies very good in center of FEMC, losses towards edges
- Meeting YR energy resolution requirements even without ML based clusterizer optimization
- First pion rejection & $\pi^0$ separation studies encouraging
- small $\eta$ dependence for energy resolution
- studies to improve clusterization further using ML started

# LFHCAL Performance




- Cluster finding and track matching efficiencies good in center of LFHCAL, losses towards edges
- Meeting YR energy resolution requirements even without ML based clusterizer optimization
- Small $\eta$ dependence for energy resolution
- Studies to improve clusterization further using ML started

# Thanks!