Dual-Readout Calorimetry with Homogenous Crystals at FCC-ee

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CalVision Collaboration

FUTURE CIRCULAR COLLIDER

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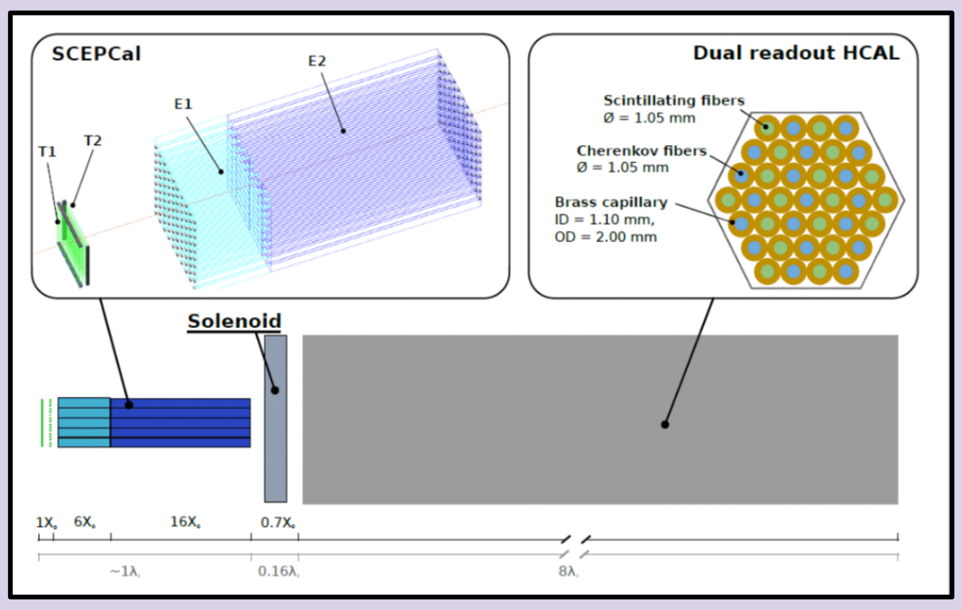
Segmented DRO: Crystal ECAL + Fiber HCAL

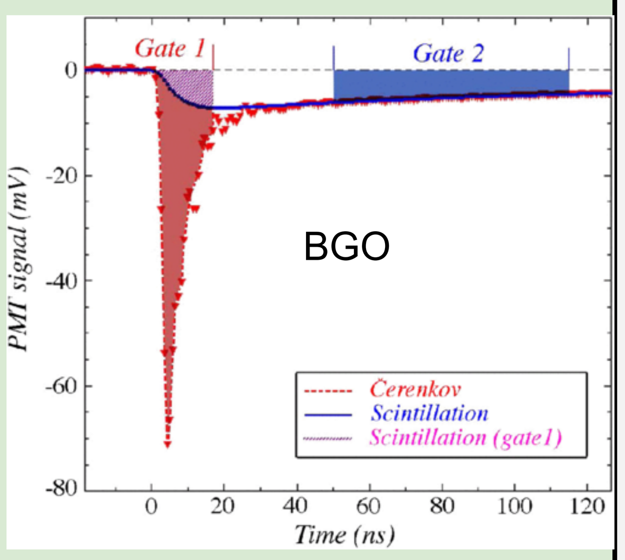


GEANT simulation, reference: arXiv:2008.00338

- ❖ Timing layer
- ❖ SCEPCal: Segmented Crystal Electromagnetic Precision Calorimeter
- ❖ Thin Solenoid
- ❖ DREAM/RD52 Style HCAL
- ❖ Enhance with precision ECAL + IDEA concept fiber HCAL

Scintillation vs Cerenkov Light

- ❖ Different crystal types: PWO, BGO, PbF2 + heavy glasses
- ❖ Scintillation and Cerenkov separation using timing and wavelength
- ❖ Scintillation optical spectrum is narrower than → use filter to distinguish C vs S
- ❖ Cerenkov light propagate faster than scintillation light



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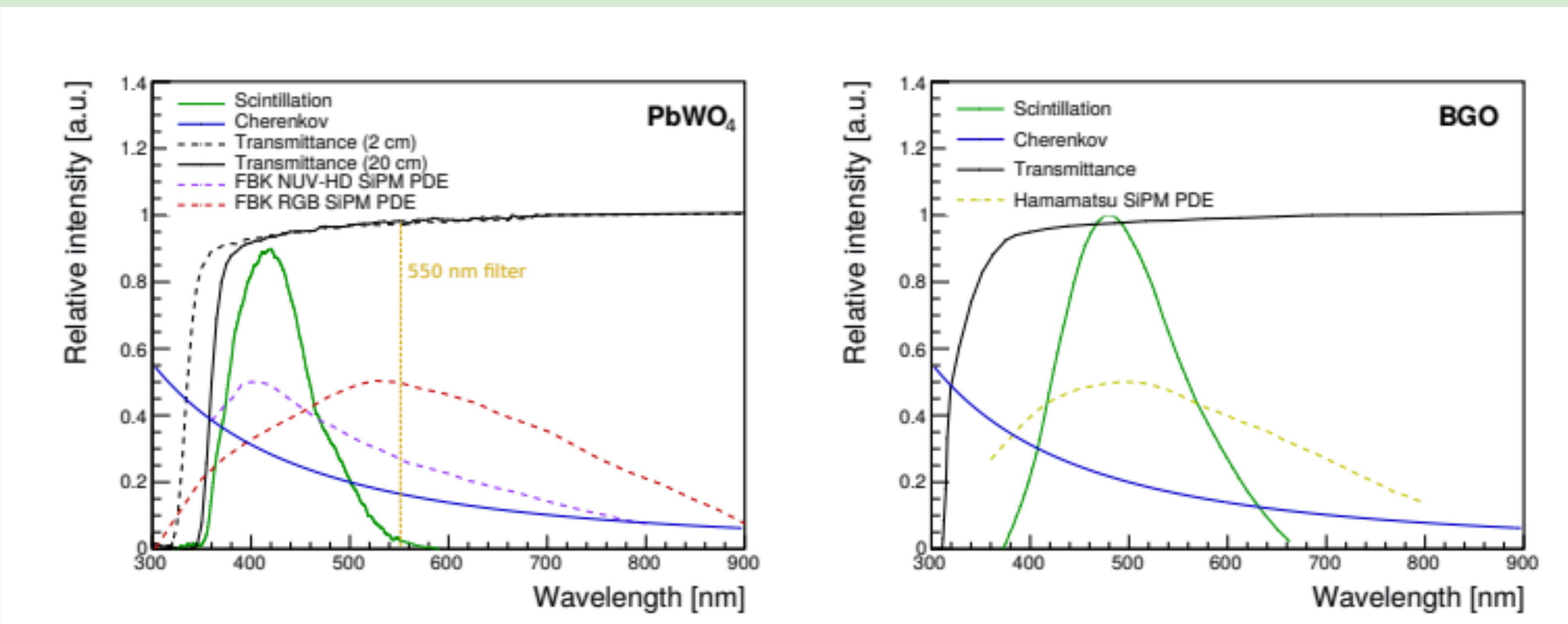
- ❖ Crystal transparency where Cerenkov light is most intense (near NUV) is poor → using filter beyond scintillation spectrum ($\lambda > 550\ nm$)



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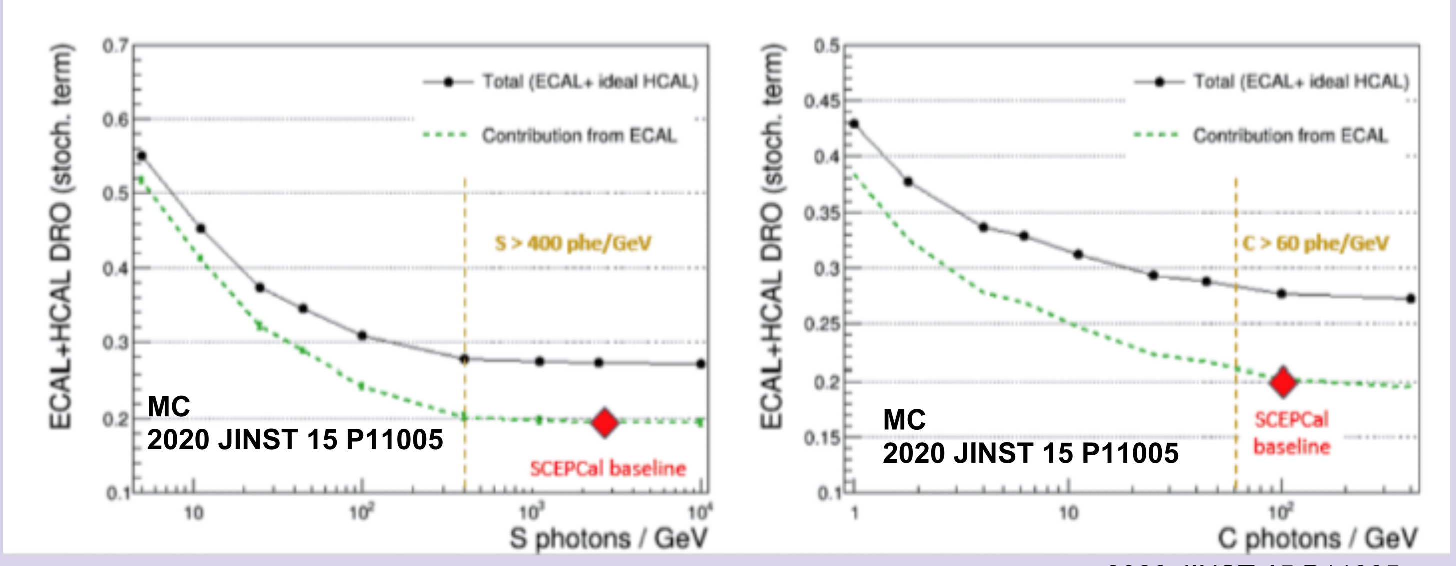
Test Beams Purpose

- ❖ Focus: understanding photon collection in PbWO4, PbF2, BGO and BSO single crystals
- ❖ Goals: Acquire enough sampling statistics for Cerenkov (~60/GeV) and scintillation photons (~400/GeV) to attain better resolution



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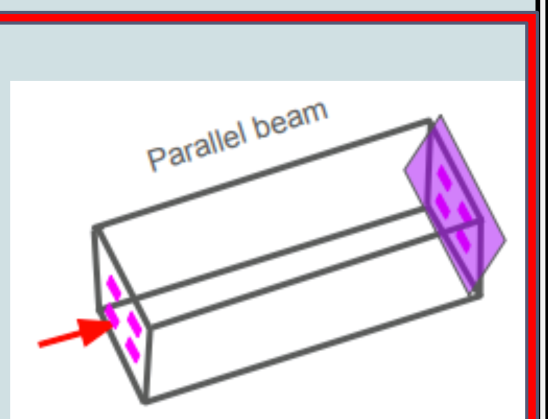
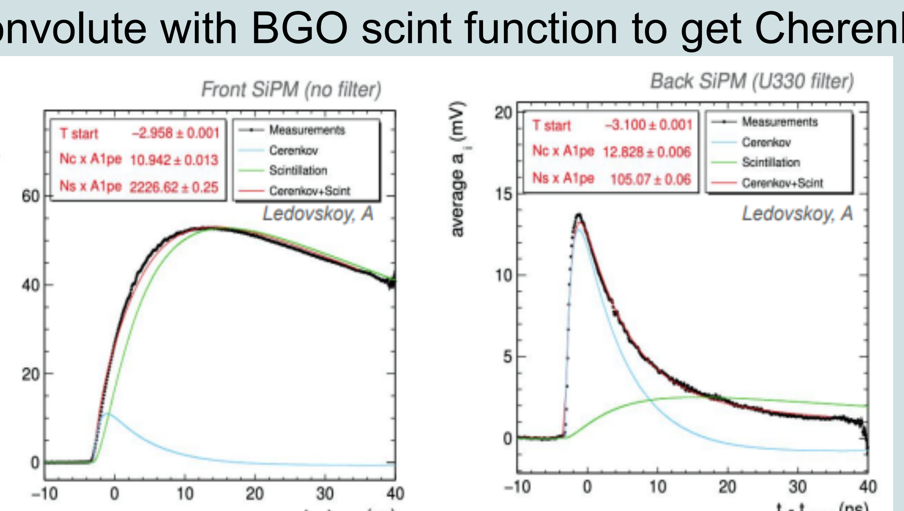
Single Crystal DRO: Test Beams

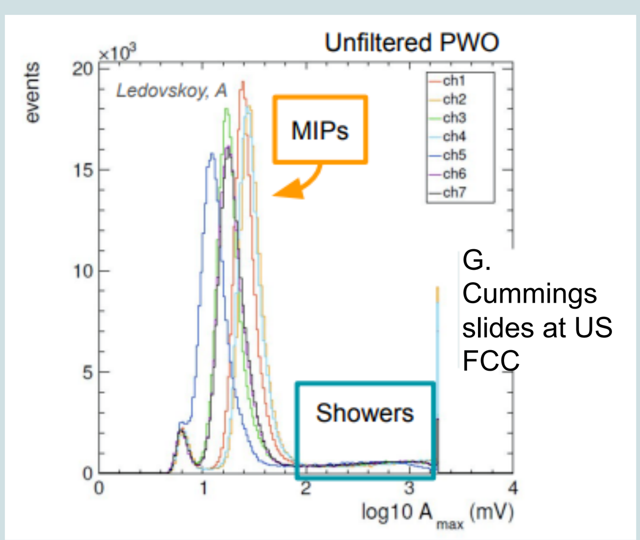
❖ FNAL facility with 120 (GeV) proton test beam(s):

- ➢ PWO4/BGO short crystals
- ➢ Material, angle and absorption filter scans
- ➢ Study: MIP + shower, angular dependence of light collection and S,Ĉ components, timing
- ➢ take Scintillation shape from unfiltered channels
- ➢ deconvolute with BGO scint function to get Cherenkov



Central MIP signals





G. Cummings slides at US FCC

G. Cummings slides at US FCC Workshop

FNAL test beam conclusions:

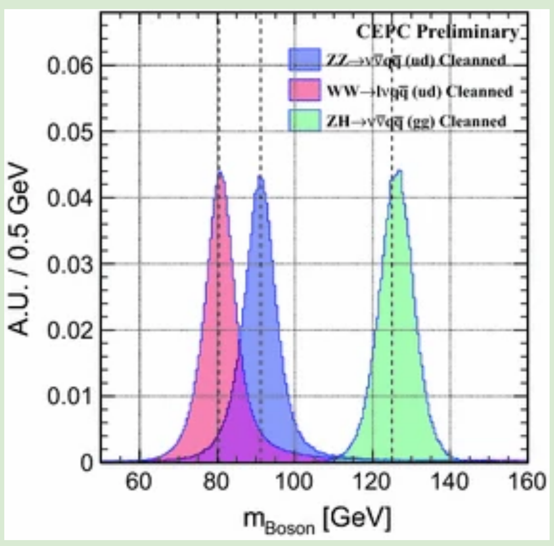
- Need larger crystal to improvement tracks with photo-statistics
- Separation Promising for BGO, PWO4 separation is harder since scintillation light is faster → needs to use better filters

❖ DESY test beam with 2 to 4 (GeV) electron beam:

- ➢ PWO4/BGO/BSO/PbF2 long crystals
- ➢ Material, angle, and filter scan
- ➢ Faster electronics

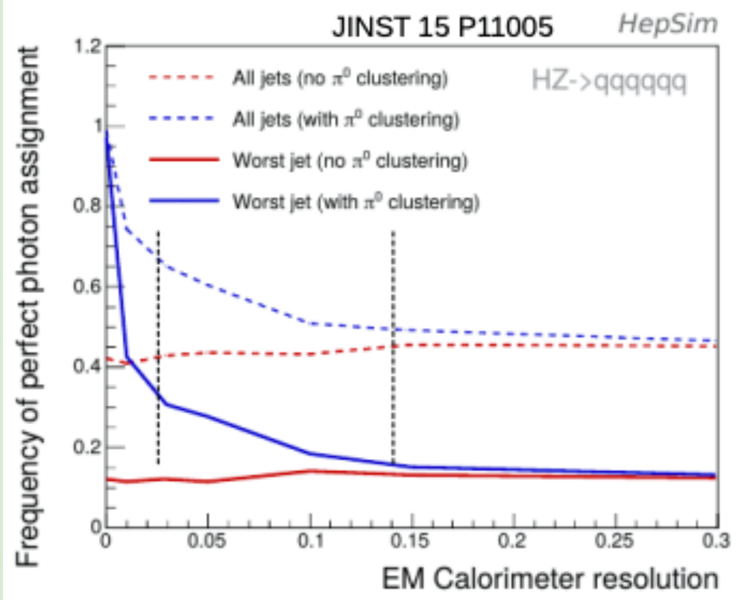
Physics Goal at FCC-ee Calorimetry

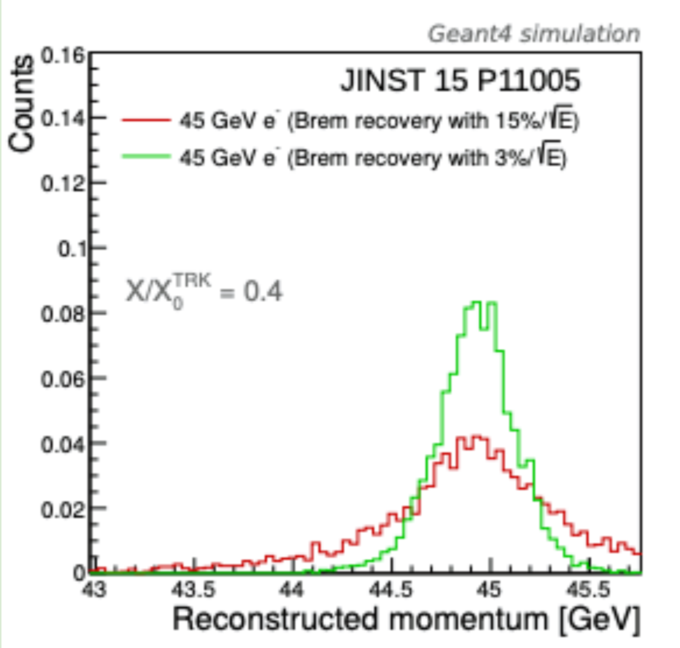
- ❖ Distinguish hadronic decay of W,Z,H with Jet energy resolution of ~3% for clean W/Z separation (hard with traditional calorimetry with σ_{HCAL} >~50%/√E)
- ❖ Precision reconstruction of exclusive b and tau final state to reduce backgrounds



EPJC (2018) 78:426

- ❖ Reduce effect of bremsstrahlung on electron energy resolution



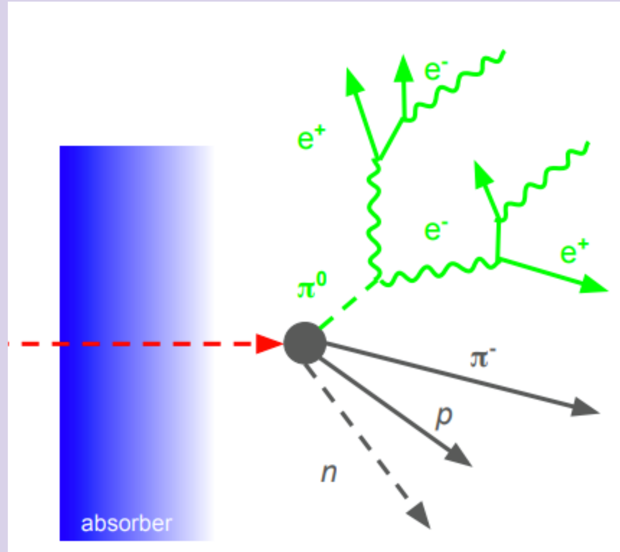


- ❖ π^0 reconstruction and jet matching, e.g. photon matching in 6 jet event

Challenges of Hadron Calorimeter

Hadronic jets components:

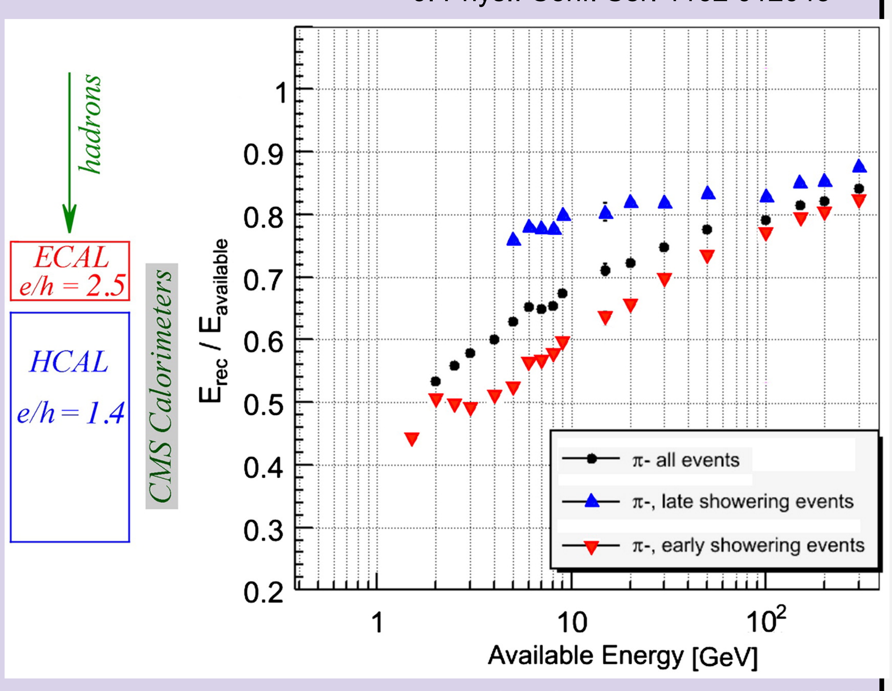
- ❖ EM fraction: relativistic and charged
- ❖ Hadronic fraction: slower compared to EM fraction; invisible nuclear binding
- ❖ EM to hadronic ratio fluctuates events by events
- ❖ Detector response to EM energy deposition differs from hadronic energy deposition



J. Phys.: Conf. Ser. 1162 012043

Benefits of using DR in crystal ECAL:

- ❖ EM/had ratio can be inferred from ratio of Cerenkov to scintillation light
- ❖ To compensate for less hadron energy degradation



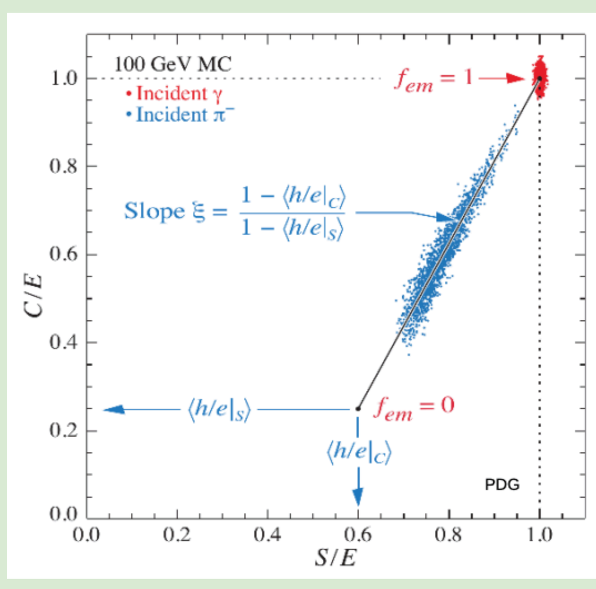
Nuclear Intr. and Meth. A666(80)

Homogenous DR Crystals

- ❖ Overcome the fluctuations in the number of nuclear breakups by comparing scintillator (sensitive to all charge particles) to Cherenkov light (mostly e+e-)
- ❖ e/h ratio can be inferred from ratio of Cerenkov to scintillation light → proxy to correct for nuclear (invisible) binding energy

$$\xi = \frac{1 - \left\langle \frac{h}{e} \right\rangle_C}{1 - \left\langle \frac{h}{e} \right\rangle_S}$$

$$E = \frac{\xi S - C}{\xi - 1}$$



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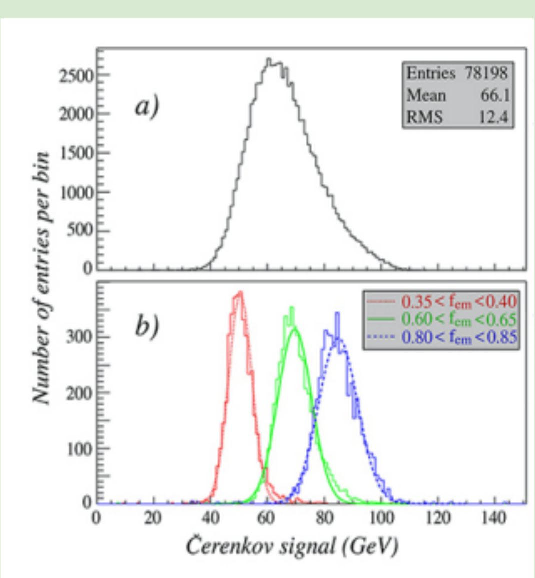

arXiv:1807.03853

Outlook & References

Started to analyse/understand data from April 2024 DESY test beam with:

- ❖ Larger crystal to improve tracks photo-statistics
- ❖ Faster electronics
- ❖ Wider range of filters

References:

- arXiv:2008.00338
- arXiv:1807.03853
- 2020 JINST **15** P11005
- RevModPhys.90.025002
- Nuclear Intr. and Meth. A666(80)
- J. Phys.: Conf. Ser. 1162 012043
- EPJC (2018) 78:426
- G. Cummings presentation at US FCC
- B. Hirosky presentation at CALOR 2024