Argonne NATIONAL LABORATORY

Dual readout energy correction HCAL for CLD / CLIC / ILC-like designs

S.Chekanov, S.Eno

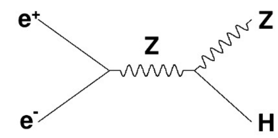
March 2, 2022

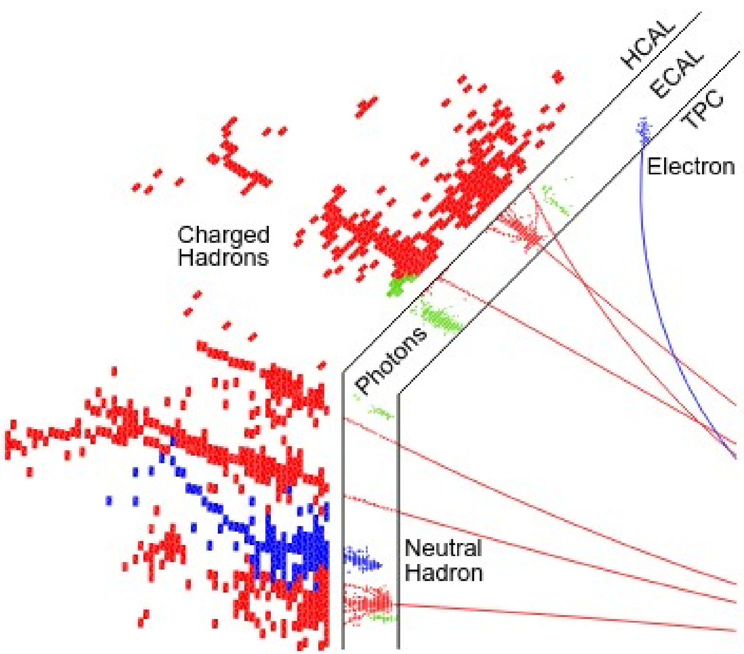
Detectors for Higgs Factories

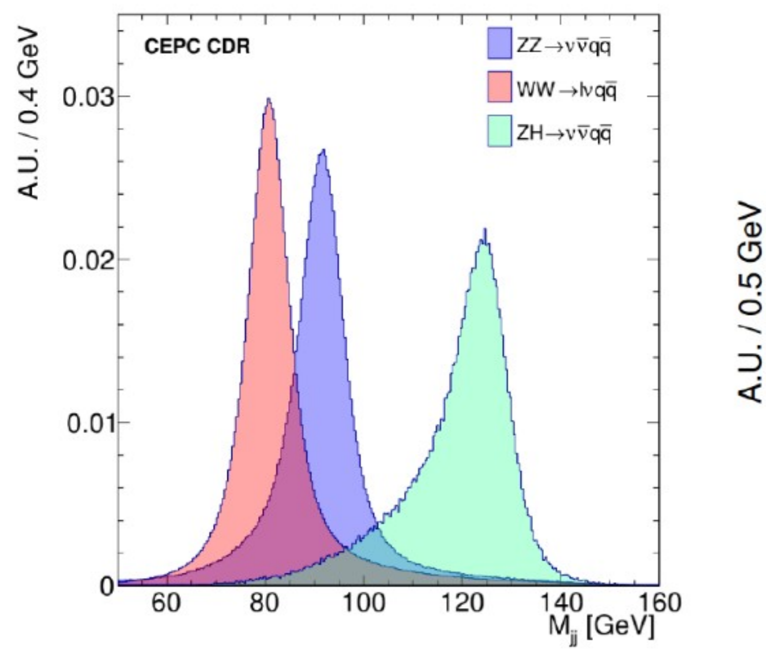
Detectors for circular e+e- Higgs factories, such as ILC, CLIC, FCC-ee and CEPC are expected to have **~50%** HAD and **~10%** EM stochastic terms for calorimeter measurements. PFA can reduce the stochastic term to **~30%** for jets

Dual readout calorimeters have the potential to decrease stochastic terms:

- **<30%/√ E for jets**
- **<10% /√ E for electrons/gamma**







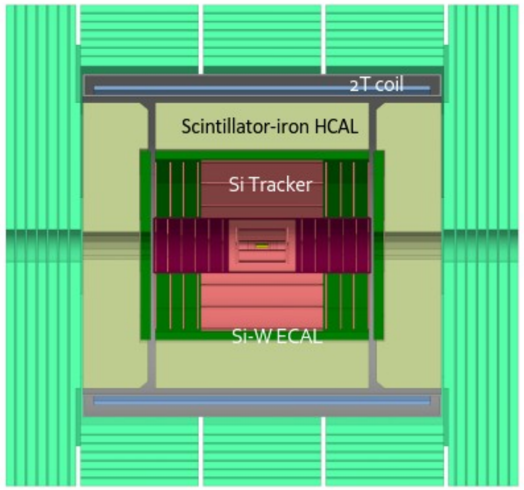
Credits to arXiv:1209.4039

Peizhu Lai & CEPC CDR

WW sample: using μvqq sample, Plot: the visible mass without the muon

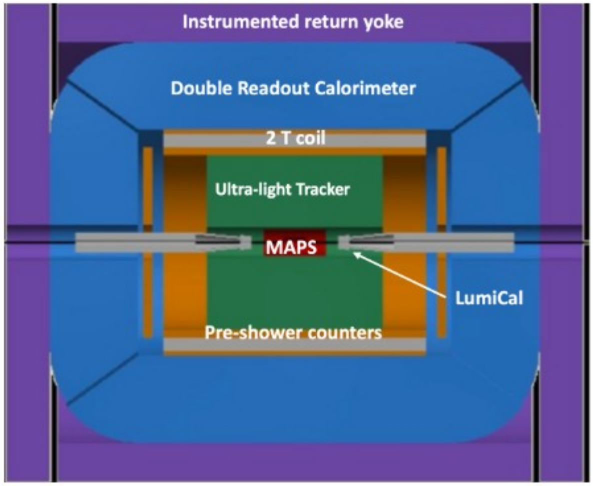
FCC-ee

Credits to Mogens Dam



CLD

- Consolidated option based on the detector design developed for CLIC
  - All silicon vertex detector and tracker
  - 3D-imaging highly-granular calorimeter system
  - Coil outside calorimeter system
- Proven concept, understood performance



IDEA

- New, innovative, possibly more cost-effective design
  - Silicon vertex detector
  - Short-drift, ultra-light wire chamber
  - Dual-readout calorimeter
  - Thin and light solenoid coil inside calorimeter system

~ similar to ILC, CLIC, CEPC

Implement dual readout for CLD and compare with the full suite of performance plots done in the last 15 year. Allow also comparisons with the IDEA

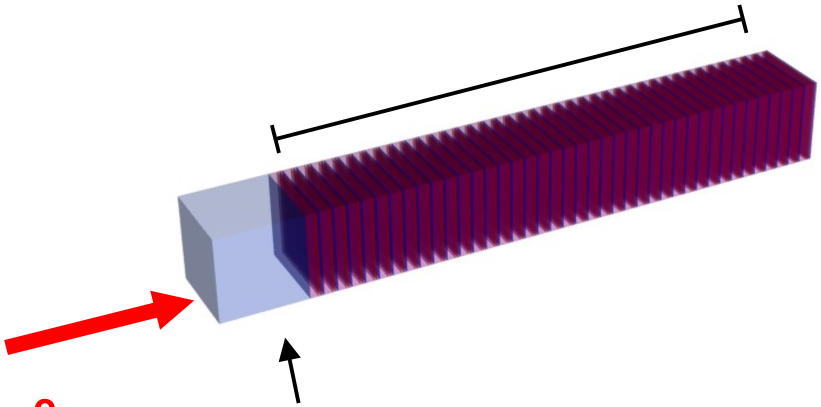
Goals for HCAL

- Most common for HCAL use Fe (absorber) + Scintillator (or RPC etc)
  - Example for CLIC: 60 Layers of 19 mm Fe absorber + scinitillator
- Simulation of Cherenkov light (or Scintillation light) is extremely time consuming inside simulations of full detector
- Instead, simulate optical photons using stand-alone simulation for a single tower and then “map” energy deposits with the the expected number of optical photons (Scintillation+Cherenkov)
- Associate optical photons with energy deposits with the reconstruction step

{Hits, MC ID} → {Cherenkov, Scintillation photon}

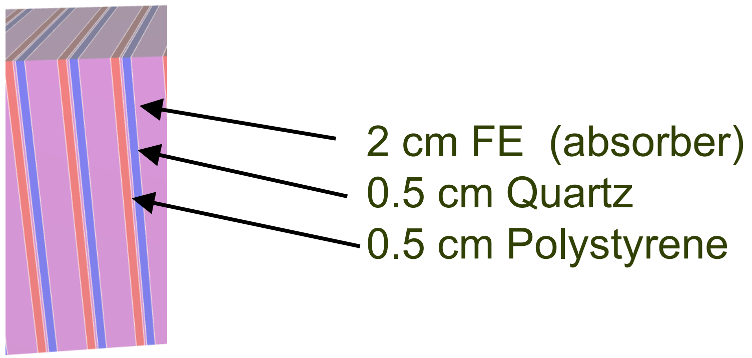
- The geometry of the tower (and its structure) should be similar to the currently used by the conventional simulations

HCAL tower with dual readout



20 cm x 20 cm ~ 21 X_0 ~ 1 λ_I

Simulate hits, N(scinitillation), N(cherenov) for particles of different types between 0.5 – 20 GeV



40 layers
→ 5.7 interaction lengths

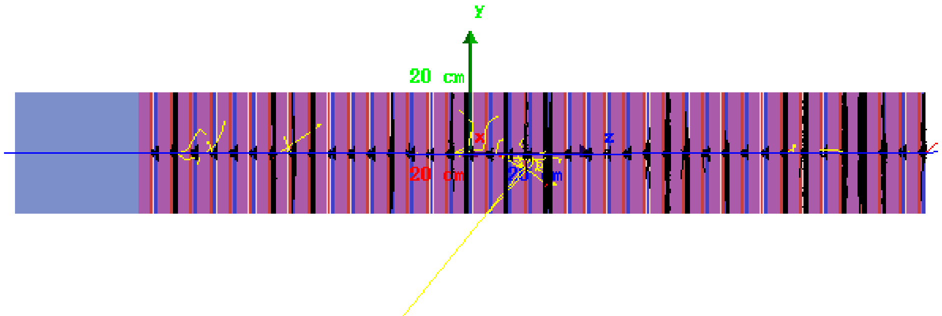
Each layer has

- *2 cm steel (red color)*
- *0.5 cm of Quartz*
- *0.5 cm Polystyrene*
- *Sampling fraction ~10%*

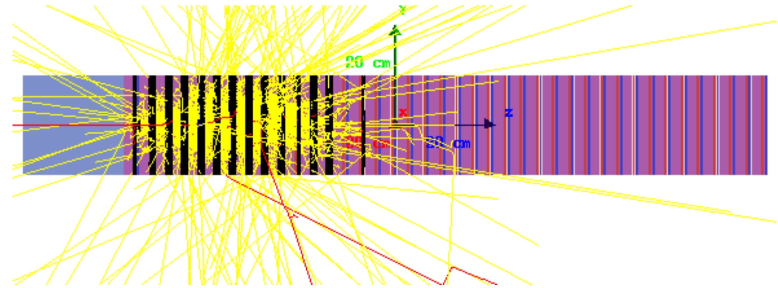
Geant4 simulations are challenging!
20 GeV particles produces 4 million photons (on average)

Simplified sampling HCAL: Examples

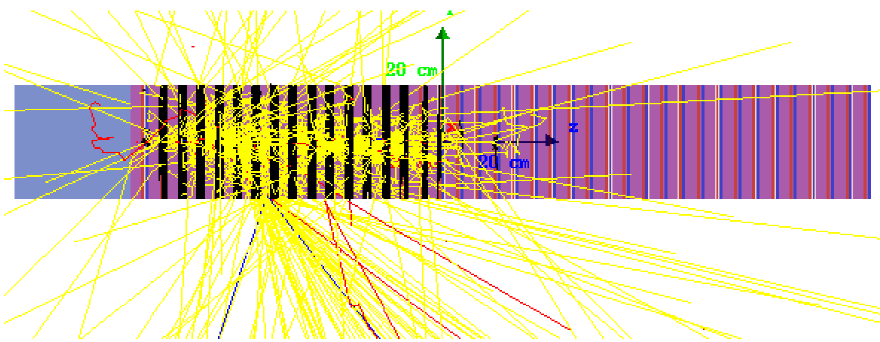
Muons 10 GeV



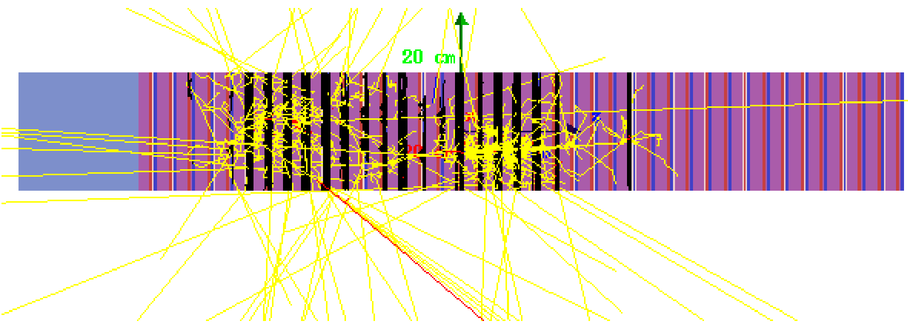
Electron 10 GeV



Pion 10 GeV



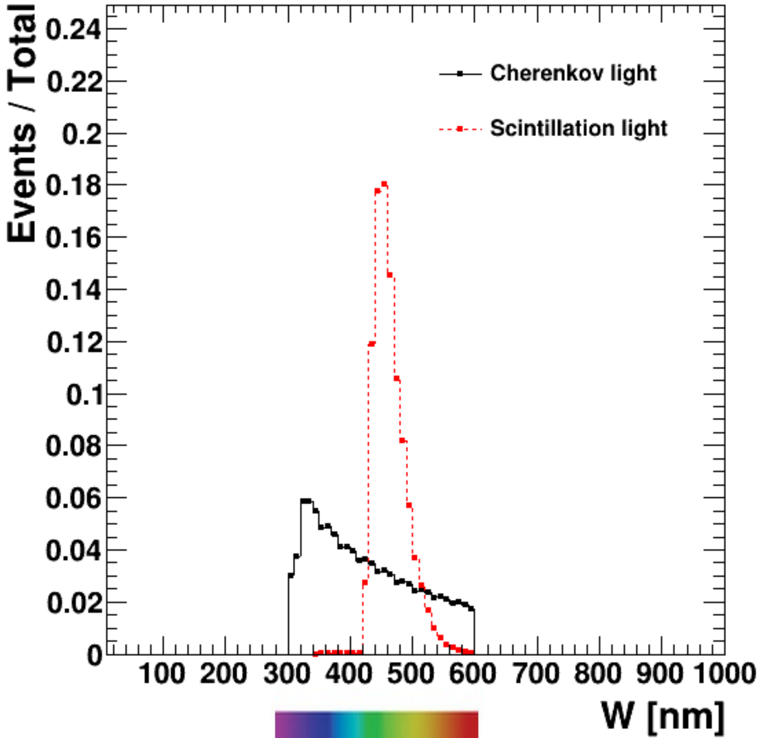
Neutron 10 GeV

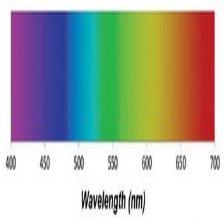


Optical photons are shown with black lines
(dark area – too many to show!)

Yellow: Photons

Wavelength for Cherenkov and Scintillation light





Scintillation light peak: ~460 nm

Counting of photons in [300-700] nm range

No any instrumental filter, efficiency of SiPMT etc.

"**Luminosity per MeV**" calculated as the average number of photons per MeV (for e-):

Scintillation light:
193 + -1 per MeV
Agrees with expectations for $PbWO_4$
see http://scintillator.lbl.gov/

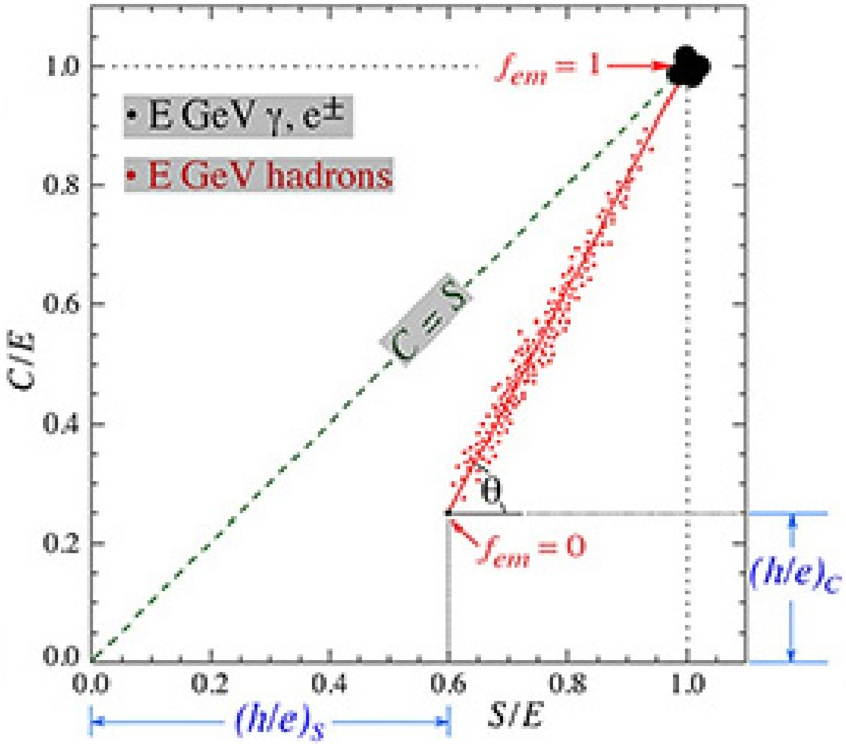
In simulation, scintillation light yield was reduced by 100 to speed up calculations

Calibrated Scintillation vs Cherenkov

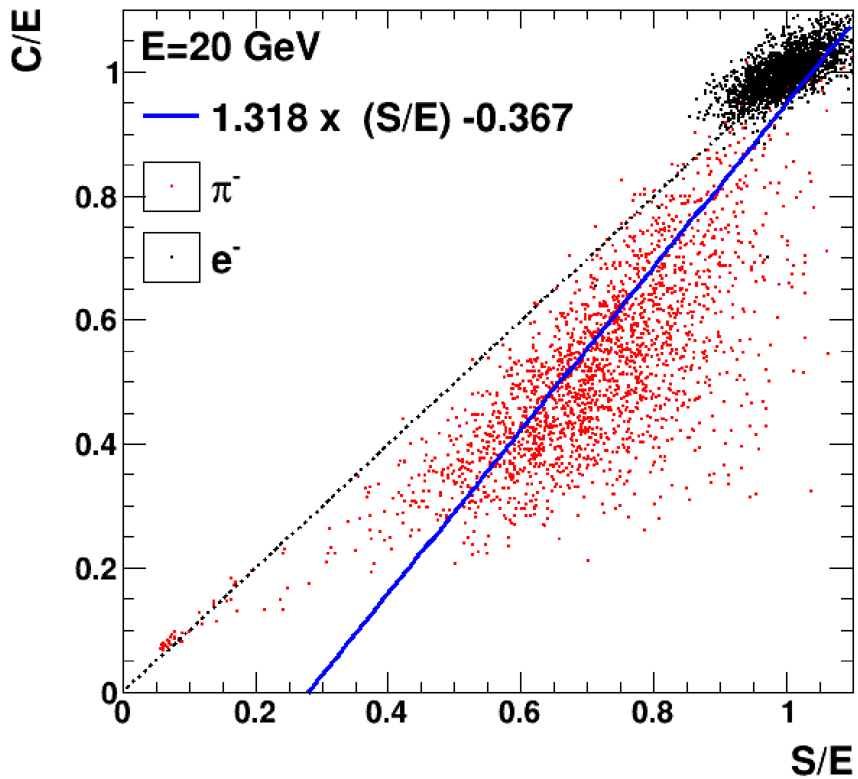
- Scintillation and Cherenkov light calibrated: N(optical photons)/E(beam) =1 using 20 GeV e-

1

DREAM: 200 GeV



20 GeV simulations

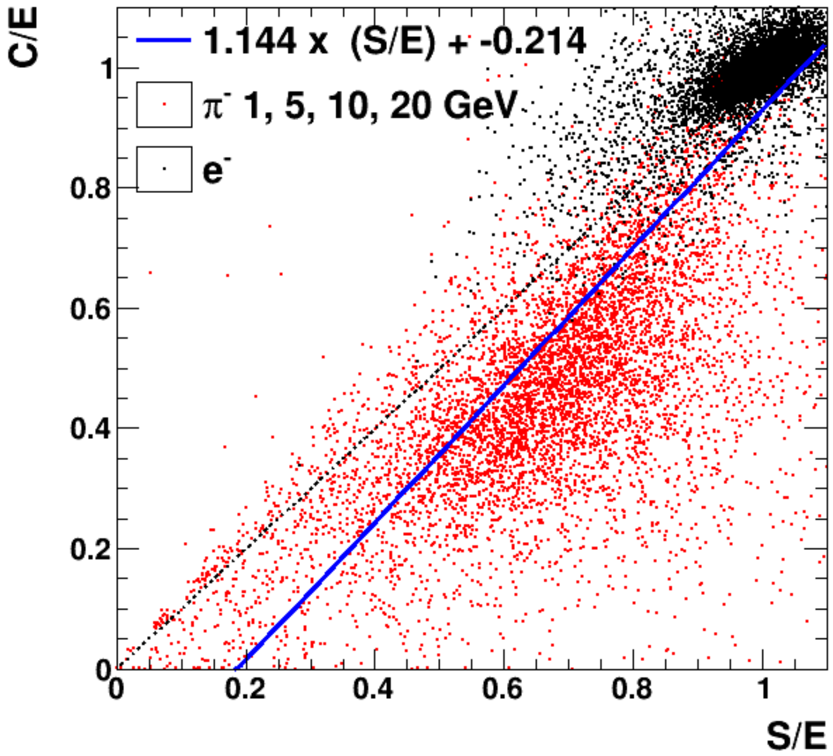


Dual-Readout Calorimetry
Sehwook Lee, Michele Livan, Richard Wigmans
Fig. 8: https://arxiv.org/pdf/1712.05494.pdf

Fit includes electrons to force the fit to cross (1,1)

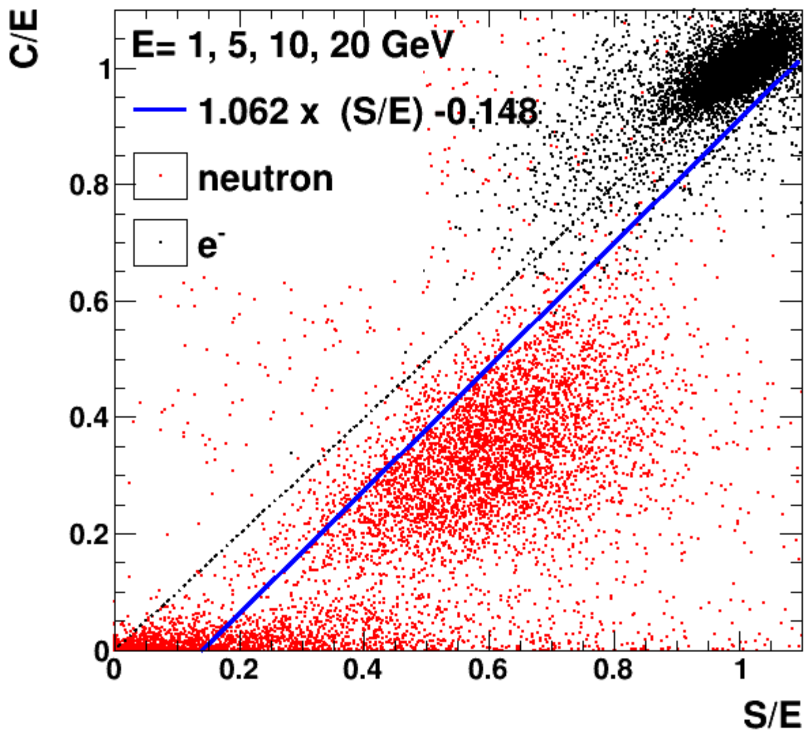
Calibrated Scintillation vs Cherenkov

Pions



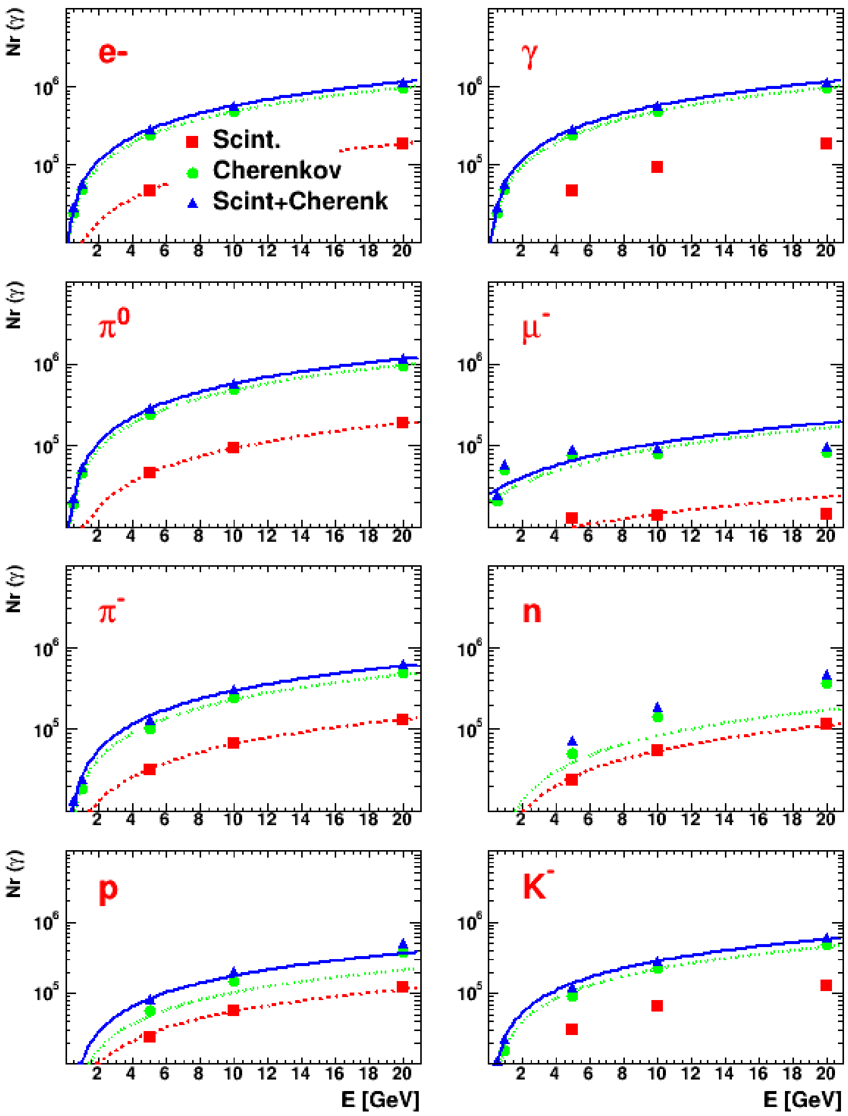
Neutrons

1



Cherenov/Scintillation light calibrated to electrons for each energy
Significant spread for neutrons

Rate of optical photons



Nr of photons fit with p1 function

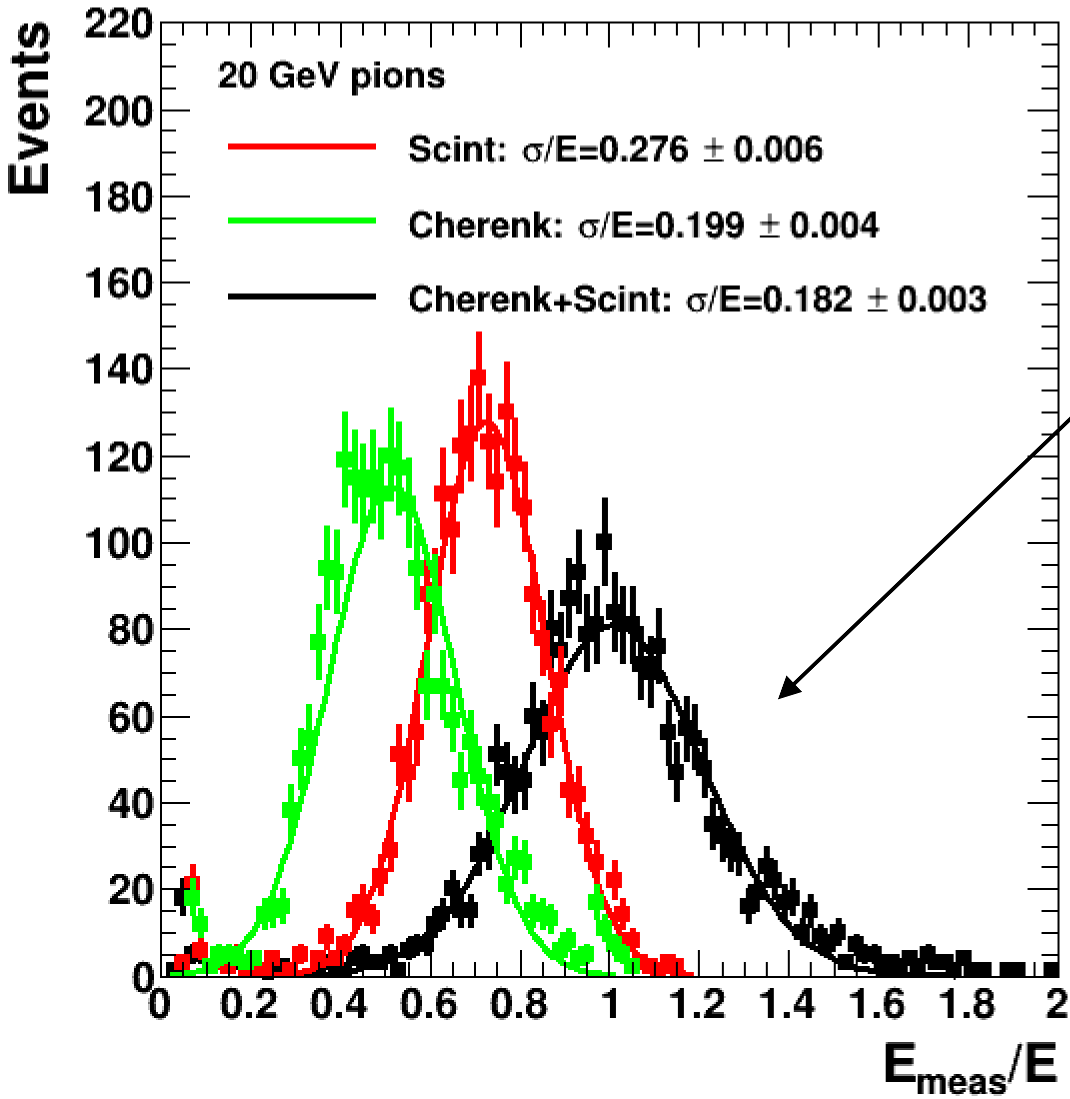
h/e = 0.71 for Scintillation light
h/e = 0.51 for Cherenkov light
(calculated using e- and **pi-** at 20 GeV)

$$\chi = \frac{1-\eta_S}{1-\eta_C} = 0.60$$

$$E = \frac{S - \chi C}{1-\chi}$$ ← correction formula

https://arxiv.org/pdf/1712.05494.pdf

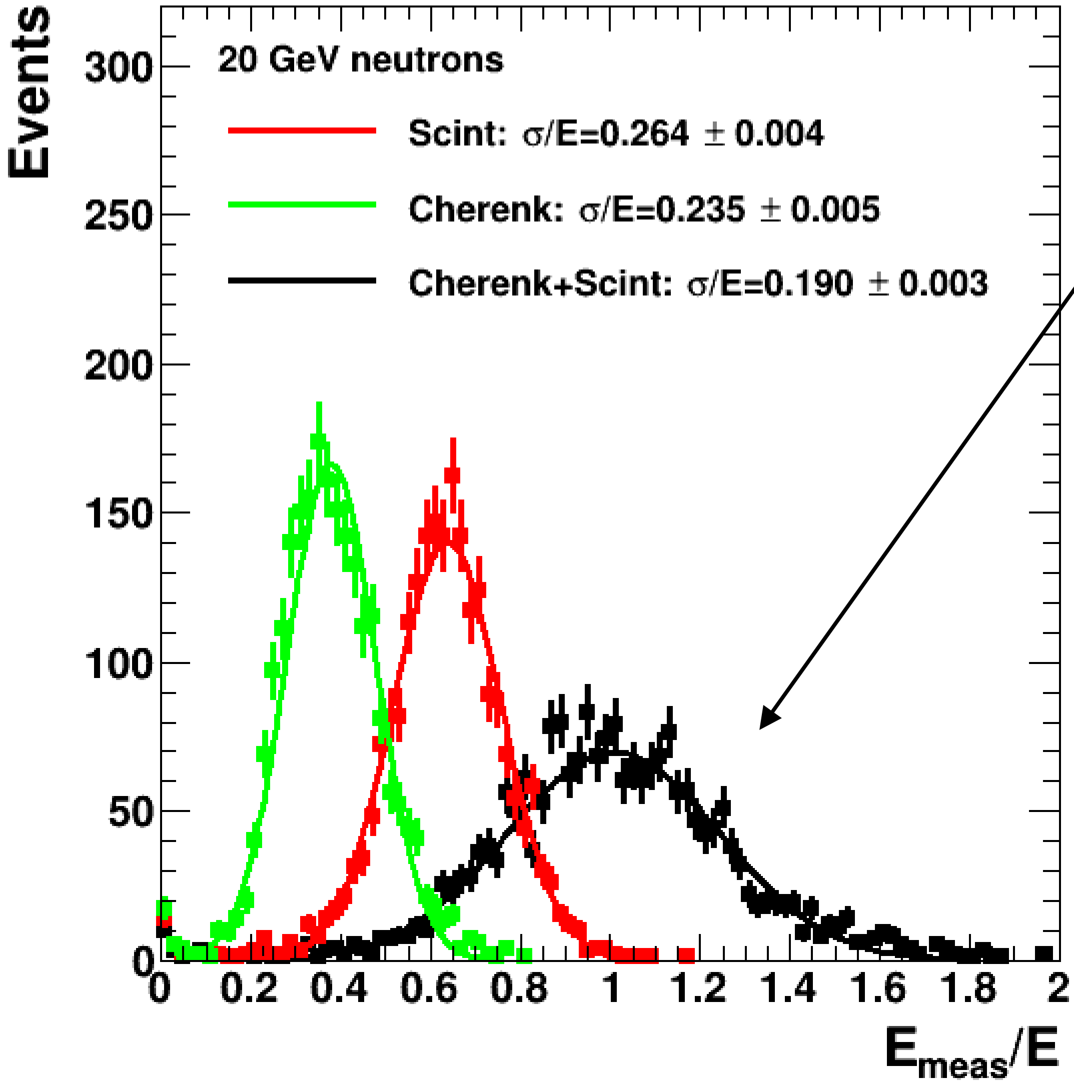
Resolution of Scintillation + Cherenkov photons



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

Cherenkov improves the resolution by ~34% compared to Scintillation (traditional calorimeter)

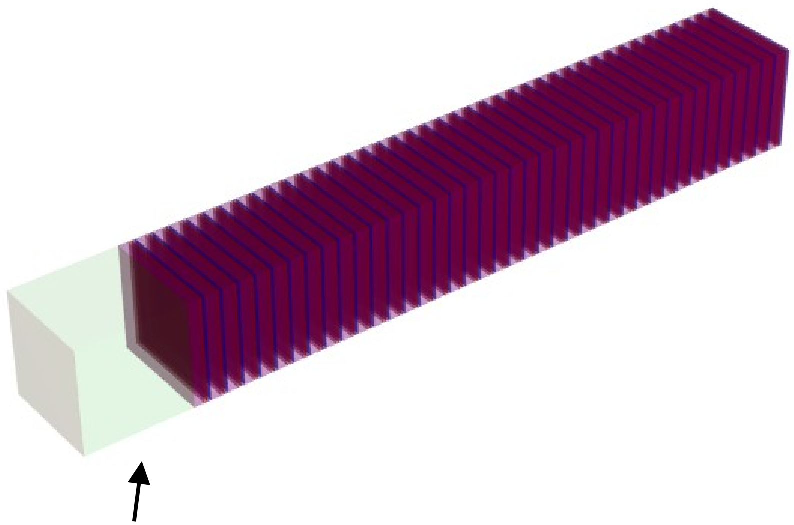
Resolution of Scintillation + Cherenkov photons



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

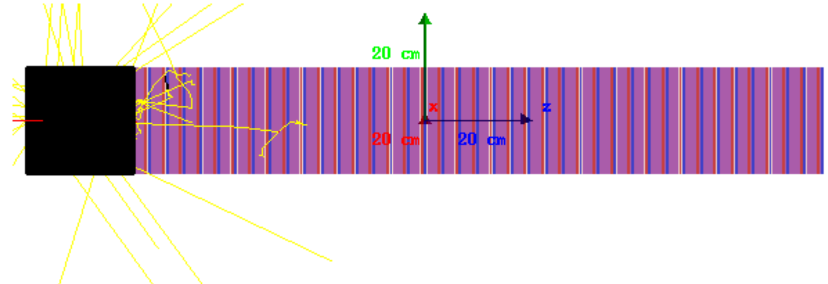
Cherenkov improves the resolution by ~28% compared to Scintillation (traditional calorimeter)

Full design with ECAL+HCAL simulation

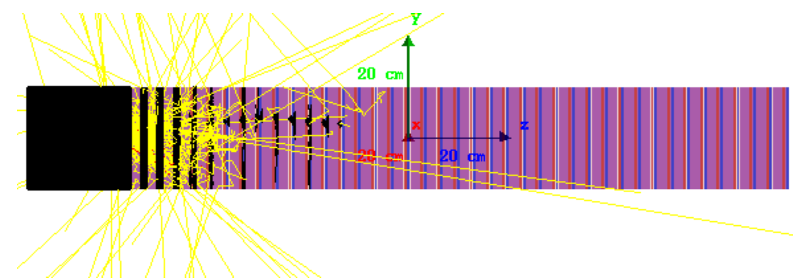


21 X0
20x20
$PbWO_4$

10 GeV e-



10 GeV pi-



- Simulations for single particles are available
- The correction process is complex! (in progress)
- Will start documenting everything on Overleaf