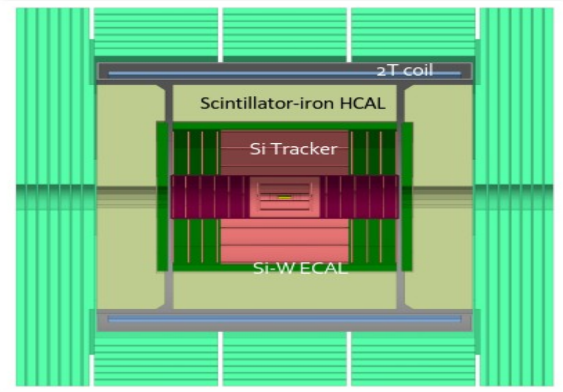
Geant4 simulations of a sampling hadronic calorimeter with dual readout for future colliders

S.Chekanov, S.Eno, S.Magill

(paper in preparation)

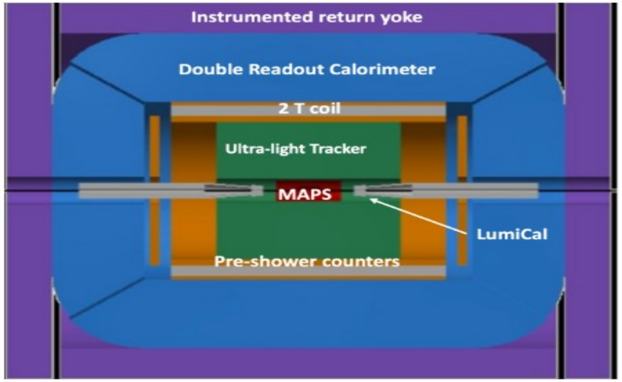
Motivation: FCC-ee conceptual designs

Credits to Mogens Dam



CLD ~ ILC, CLIC, CEPC

- 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



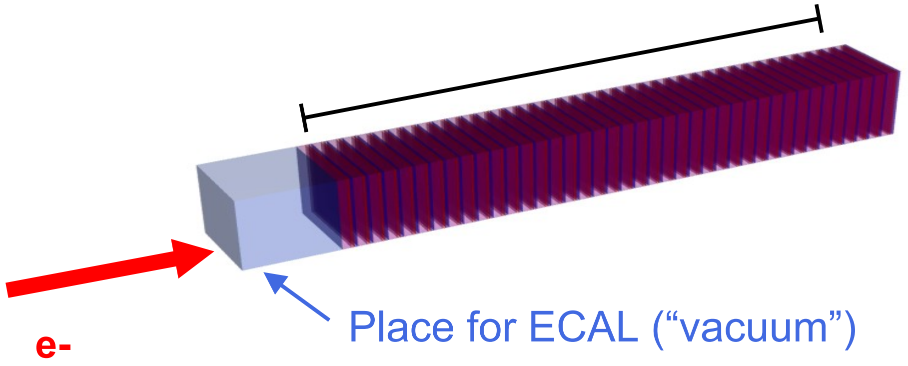
IDEA

- 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

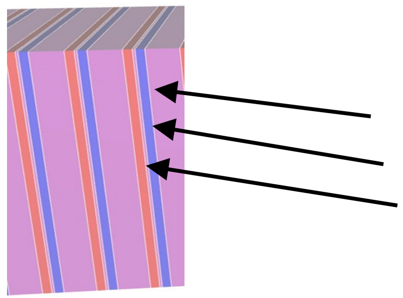
Long term: Implement dual readout for CLD and compare with the full suite of performance plots done in the last 15 years. Allow also comparisons with the IDEA

Short term: Implement dual readout for a single module of a sandwich-style HCAL and perform Geant4 simulations

HCAL tower with dual readout (40L-PFQ)



Transverse size: 20 cm x 20 cm ~ 21 X_0 ~ 1 λ_I



40 layers
→ 5.7 interaction lengths

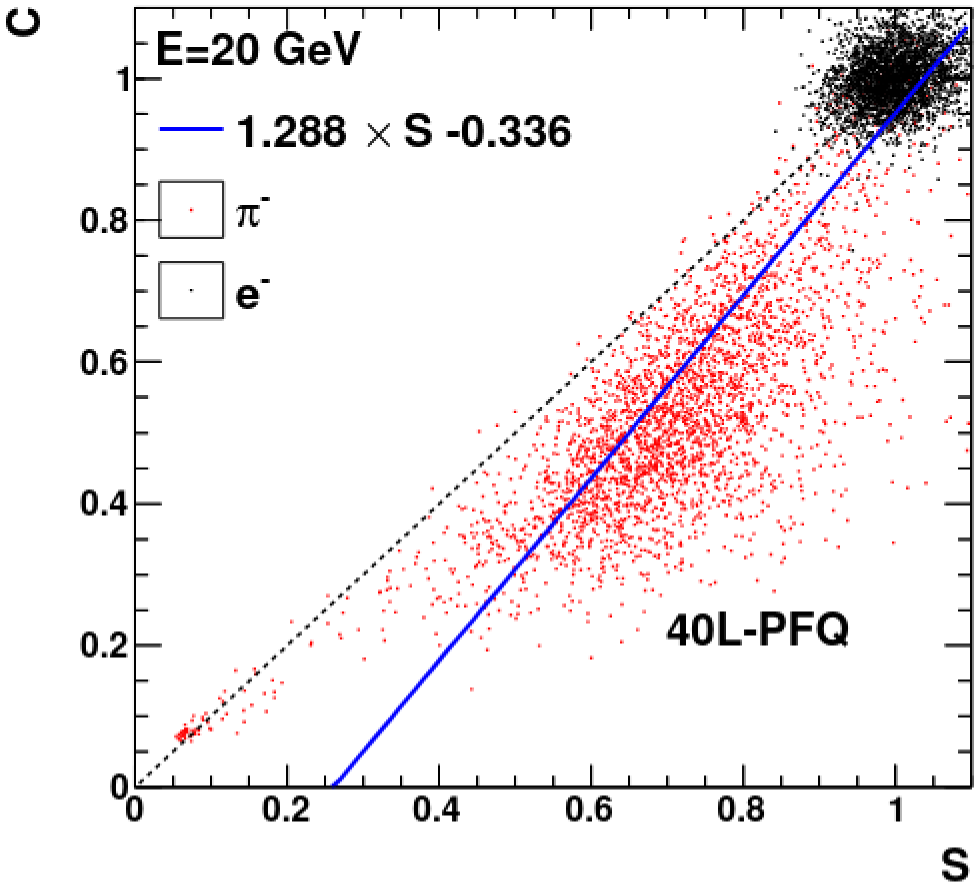
Each layer has

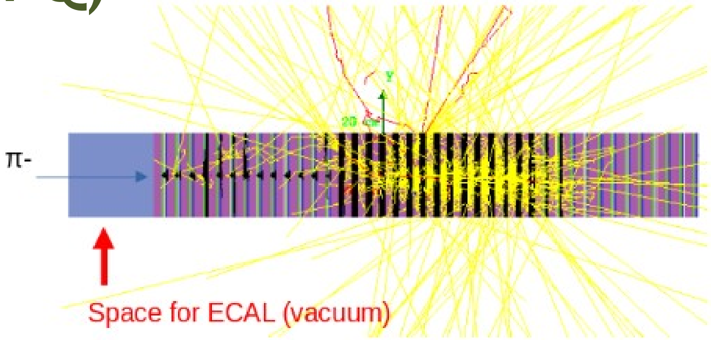
- *2 cm steel (red color)*
- *0.5 cm of Quartz*
- *0.5 cm Polystyrene*
- *Sampling fraction ~10%*

Simulate hits, N(scinitillation), N(cherenov) for particles of different types between 0.5 – 40 GeV

Simulations are done without any approximation (grouping photons, "killing" photons etc)
→ **single-photon precision Gean4 simulations**

Calibrated light response for (40L-PFQ)

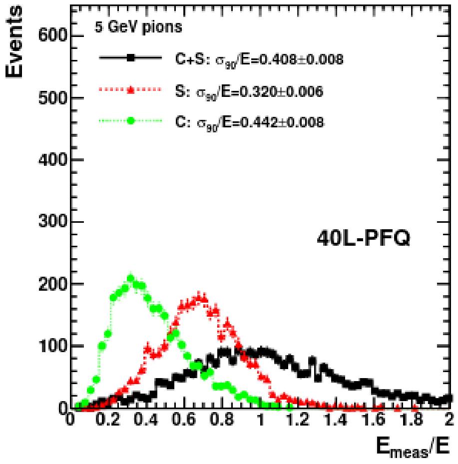




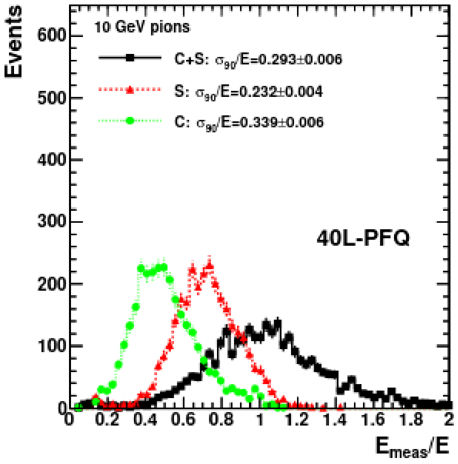
Scintillation ("S") and Cherenkov ("C") photons are calibrated to electrons at the same energy as pions

<S>= <C> = 1 for electrons

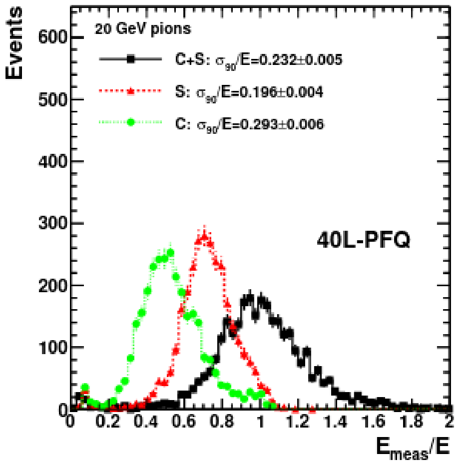
Resolution studies (40L-PFQ)



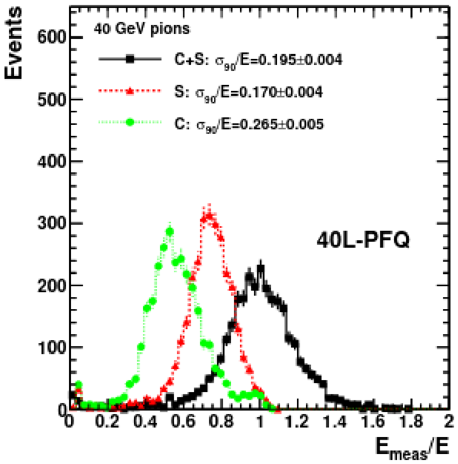
(a) 5 GeV



(b) 10 GeV



(c) 20 GeV



(d) 40 GeV

$$E = \frac{S - \kappa \cdot C}{1 - \kappa}$$

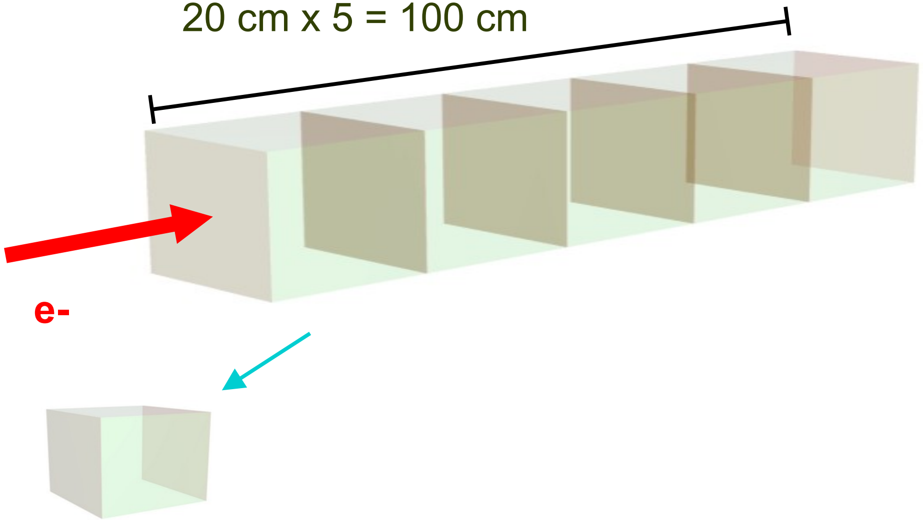
$$\kappa \equiv (1-(h/e)_S)/(1-(h/e)_C) = 0.6$$

$(h/e)_S$ =0.7 and $(h/e)_C$ =0.52

obtained from Geant4 simulations by measuring the ratio of the average Nr of photons for pions and electrons

Inclusion of C photons does not improve resolution for S+C

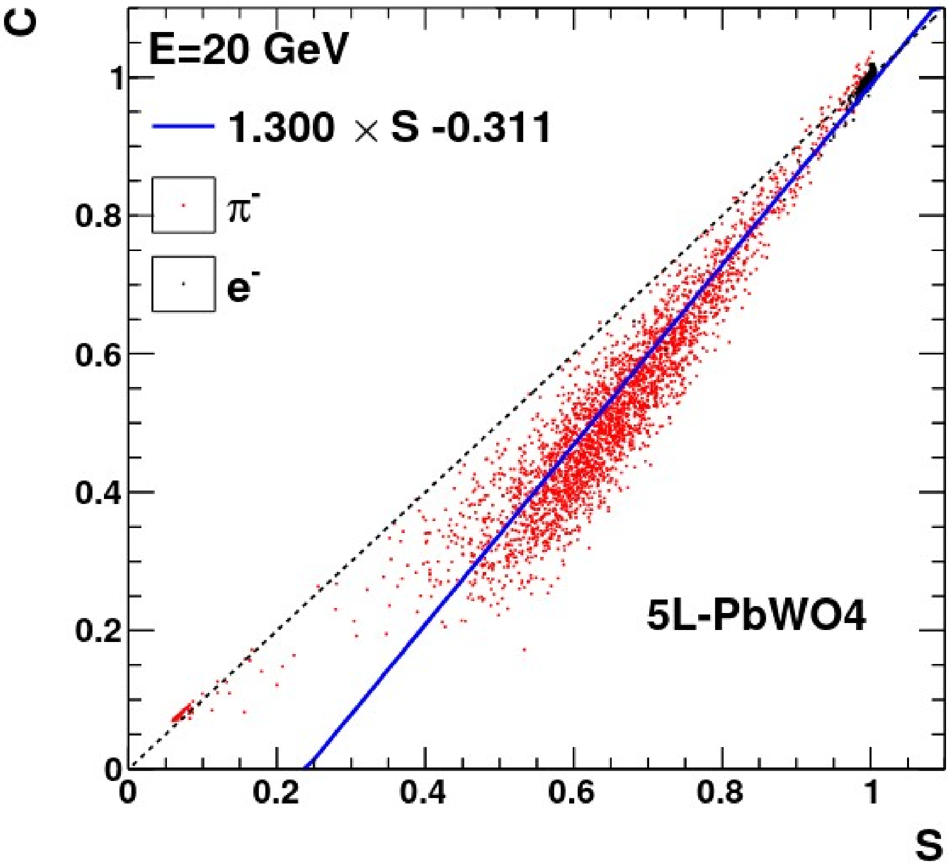
Simulation of HCAL tower using PbWO4 (5L-PbWO4)



20 cm x 20 cm ~ 21 X_0 ~ 1 λ_I

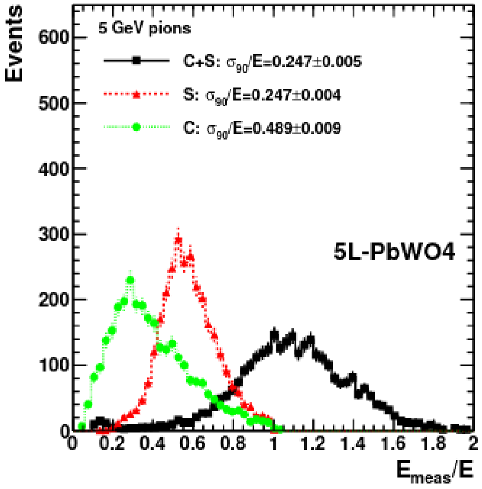
5 layers of PbWO4
→ 5.7 interaction lengths in Z
→ 1 interaction length in X-Y

Calibrated light response (5L-PbWO4)

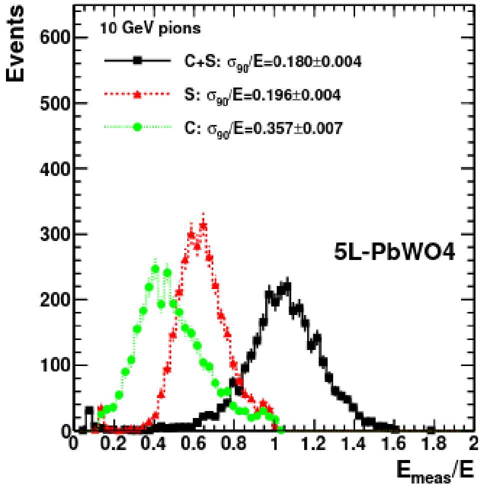


Significantly smaller spread of S and C photons for electrons and pions (compared to 40L-PFQ sandwich design)

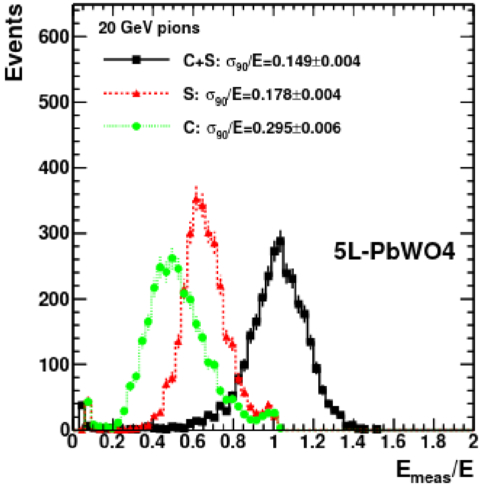
Resolution studies (5L-PbWO4)



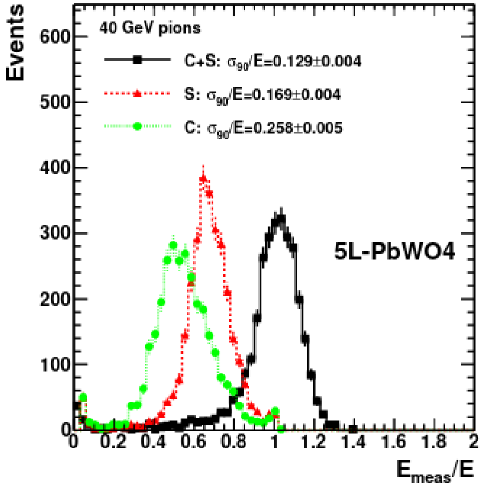
(a) 5 GeV



(b) 10 GeV



(c) 20 GeV



(d) 40 GeV

$$E = \frac{S - \kappa \cdot C}{1 - \kappa}$$

k ~ 0.6

Inclusion of C photons improves resolution by ~30% at 40 GeV

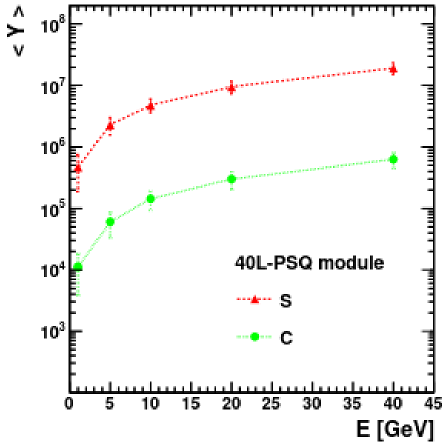
Other variations of the sandwich-style designs

All designs have ~5 interaction lengths in Z and 1 interaction length in X-Y

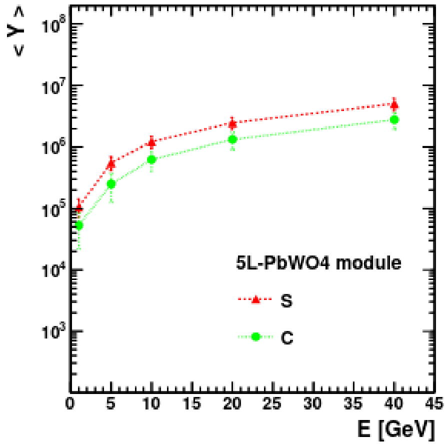
- **250L-PQ**
  - 250 layers
  - Each layer: Polystyrene (0.5 cm) + Foil (0.5mm)+Quartz (0.5 cm)
  - Quartz is both active media and absorber
  - Length: ~3 m to maintain 5 lambda interaction length
- **200-PFQ**
  - 200 layers
  - Each layer: Polystyrene (0.3cm)+ Fe (0.3 cm, passive)+ Quartz (0.3cm)

Such modules will not ft into the CLD HCAL envelop→ only used for comparisons

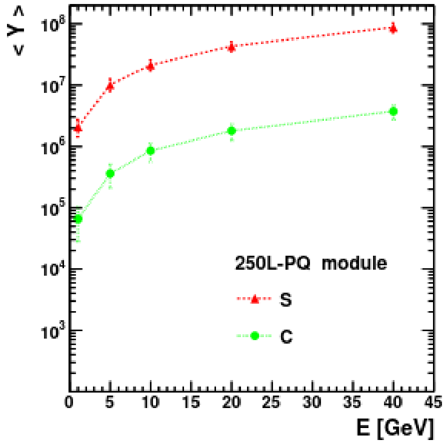
Average number of photons for each design



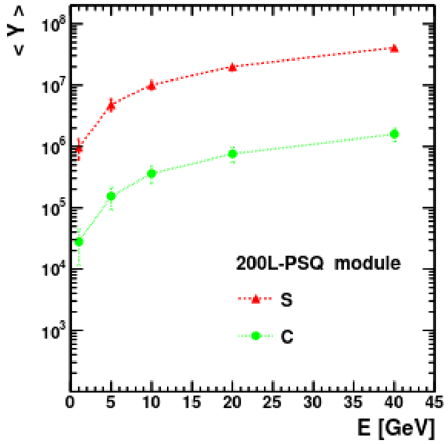
(a) 40L-PFQ



(b) 5L-PbWO4



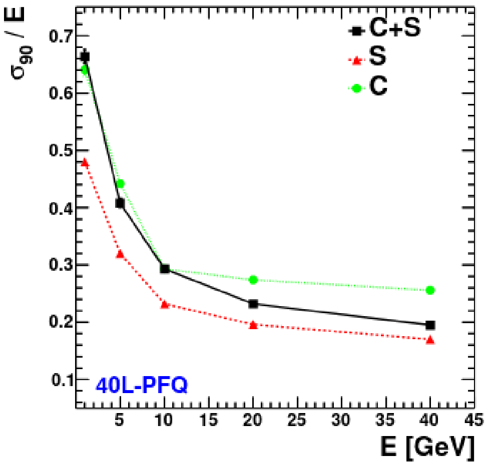
(c) 250L-PQ



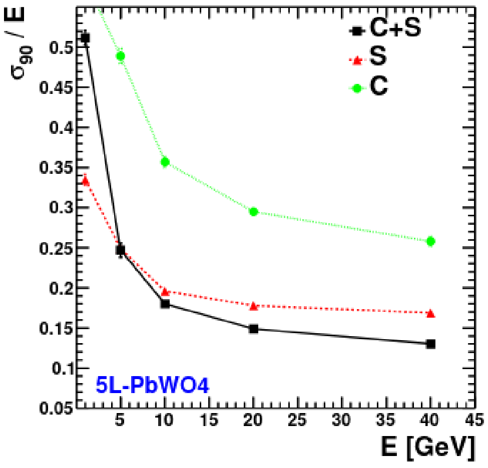
(d) 200L-PFL

- Simulations with single-photon precision are CPU intensive (~40 min per event).
  - ~40 GeV pions create 10^7 photons
  - Impractical for full calorimeter simulations, or for modules with high-granularity in the transverse direction, or fiber-style calorimeters
  - Various simplifications (grouping photons, rejecting photons etc) will require additional studies since such techniques influence S/C ratios and thus the effect on dual readout corrections

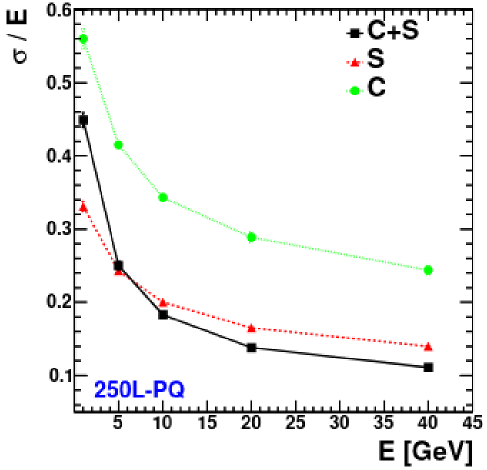
Summary of resolutions studies



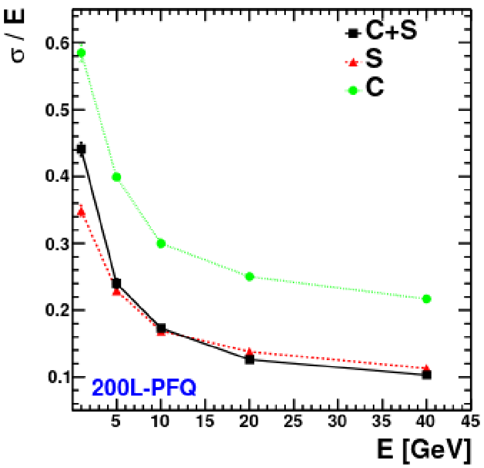
(a) 40L-PFQ



(b) 5L-PbWO4



(c) 250L-PQ



(d) 200L-PFL

- ➔ 10-26% improvements for calorimeters with >200 layers for 5-40 GeV pions
- ➔ Largest improvement (~30%) in resolution from C photons for homogeneous calorimeters (5L-PbWO4) for 40 GeV pions
- ➔ Final resolution for S+C sandwich modules is very similar to RD52 lead-fiber calorimeter

Summary

- ➔ No advantage in using quartz as additional layer for dual readout to improve resolution for CLD/CLIC/SID sandwich calorimeters with 40 layers
- ➔ 10-26% improvements are seen for calorimeters with >200 layers for 5-40 GeV pions
- ➔ Largest improvement (~30%) for homogeneous calorimeters (5L-PbWO4)
- ➔ Resolution for S+C sandwich modules is similar to RD52 lead-fiber calorimeter
- ➔ Simulations with single-photon precision are very CPU intensive (~40 min per event).
  - ✔ Impractical for full calorimeter simulations, or for modules with high-granularity in the transverse direction, or fiber-style calorimeters
  - ✔ Various simplifications (grouping photons, rejecting photons etc) require additional studies since such techniques influence S/C ratios and thus the effect on dual readout corrections