Simulations of single HCAL module

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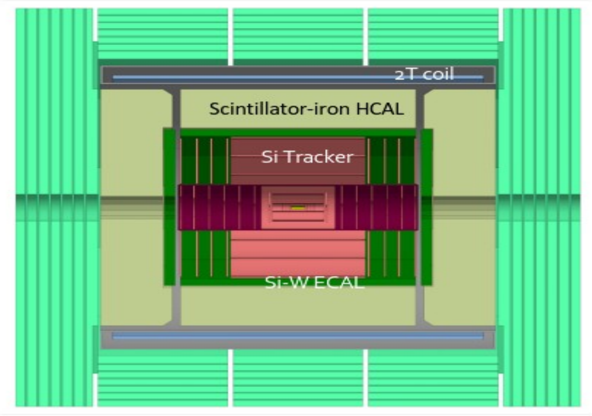
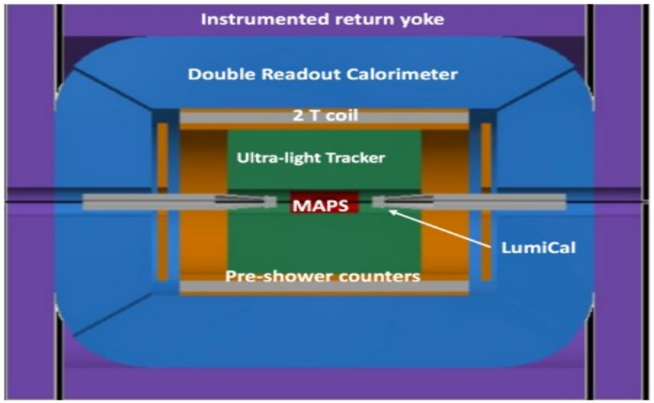
FCC-ee

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



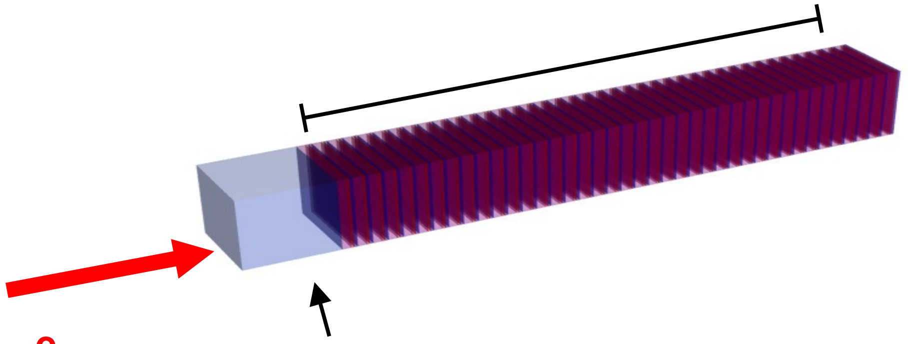
IDEA

- 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

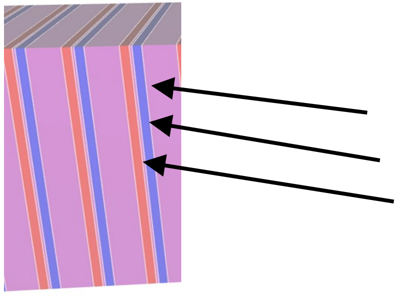
Implement dual readout for CLD and compare with the full suite of performance plots done in the last 15 year.
Allow also comparisons with the IDEA

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)

Goals for HCAL

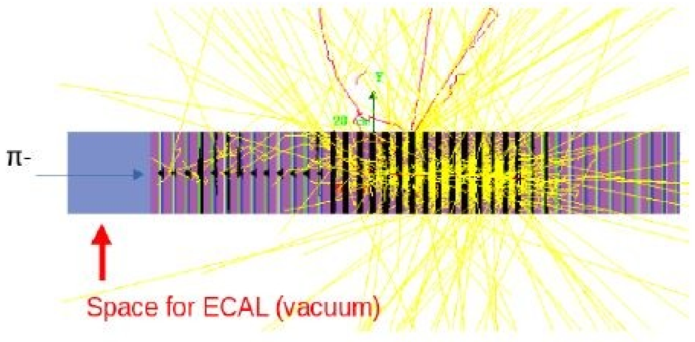
- Most common for HCAL use Fe (absorber) + Scintillator (or RPC etc)
  - Example for CLIC: 60 Layers of 19 mm Fe absorber + scinitillator
- Simulation of Cherenkov light (or Scintillation light) is extremely time consuming inside simulations of full detector
- Instead, simulate optical photons using 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

Sandwich-like HCAL with dual readout

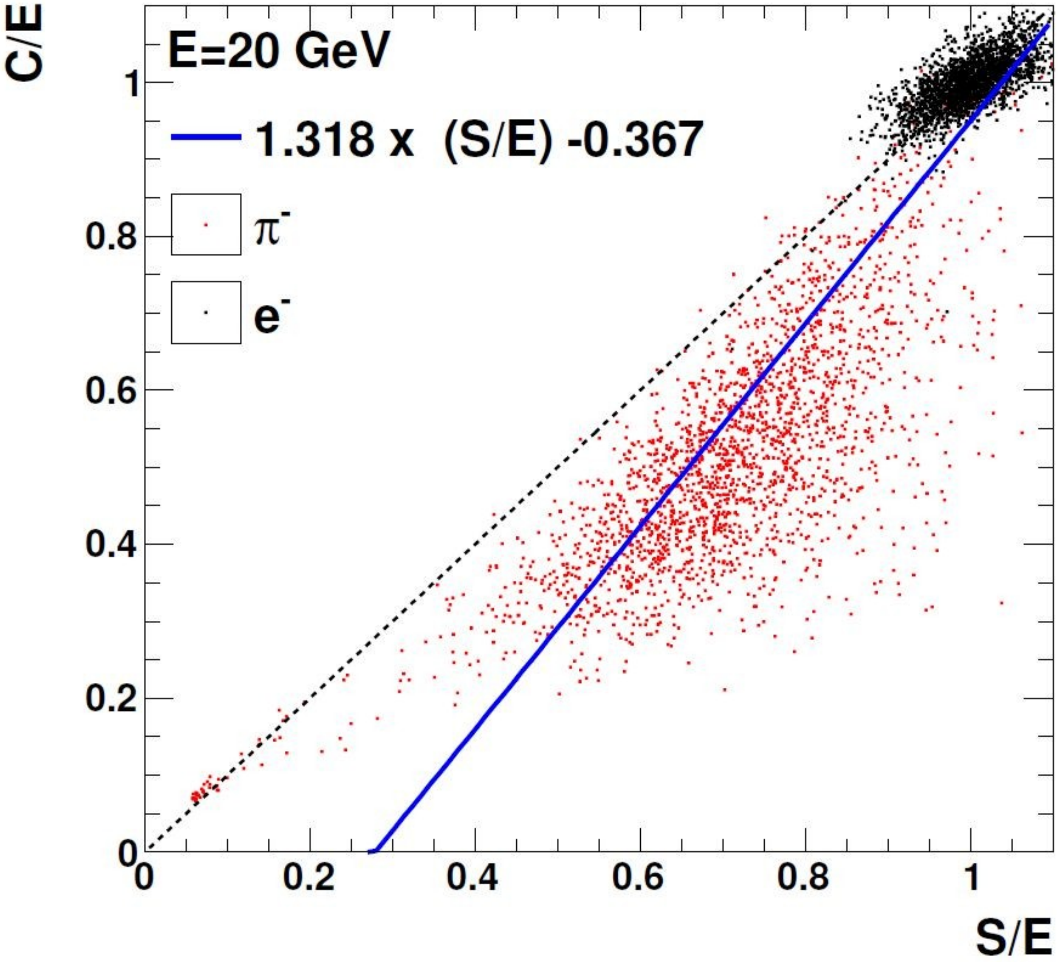
- Find numeric/analytic parameterizations of the scintillation and Cherenkov signals as a function of the energy deposits and particle types.
- Use these parameterizations to include dual readout at the reconstruction step of traditional sandwich HCAL (ILC/CLIC/CLD/etc)
- How to do this: Use Geant4 simulations of a single module with 3 k events for each particle type with energies from 1 to 20 GeV and find analytic shape of light yields



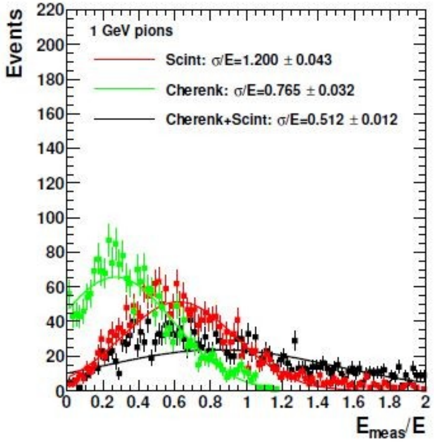
40 layers. Each layer:
- 2 cm steal (absorber)
- 0.5 cm polystyrene (for Scintillation)
- 0.5 cm quartz (for Cherenkov)

Calibrated light response

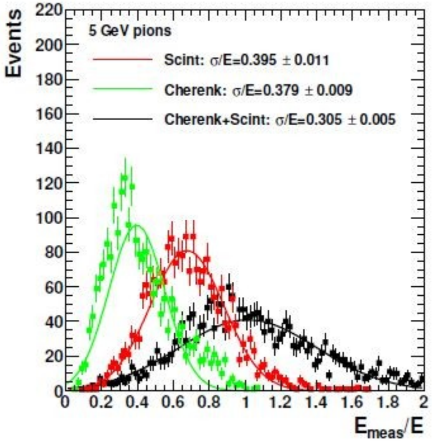
Simulations are based Sarah’s code for single crystals (+ modification)



Calibrated light response



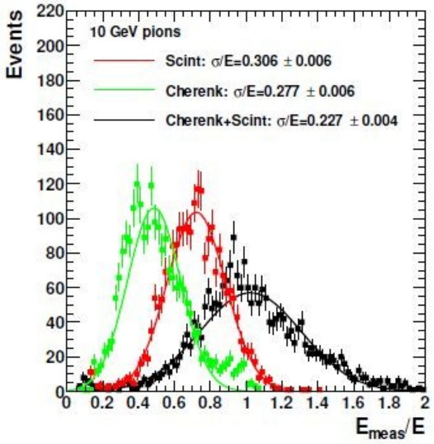
(a) 1 GeV



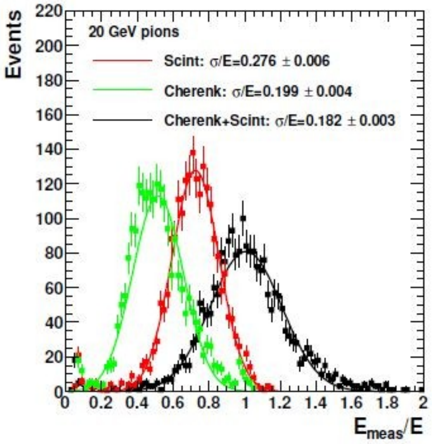
(b) 5 GeV

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

k ~ 0.6



(c) 10 GeV



(d) 20 GeV

Inclusion of Cherenkov signal improves resolution by 20-30%

Same for 5, 10, 20 TeV

Deriving parameterization

$$< Y_i >= F_i(h, E, T), \quad \sigma_{Y_i} = f_i(h, E, T), \quad i = S, C$$

<Y> - average light yields (Cherenkov or Schintillation)
h – hit energy
E – original energy of incoming particle
T – particle type (pi, K, p, n)

So far the most simple functional form found is:

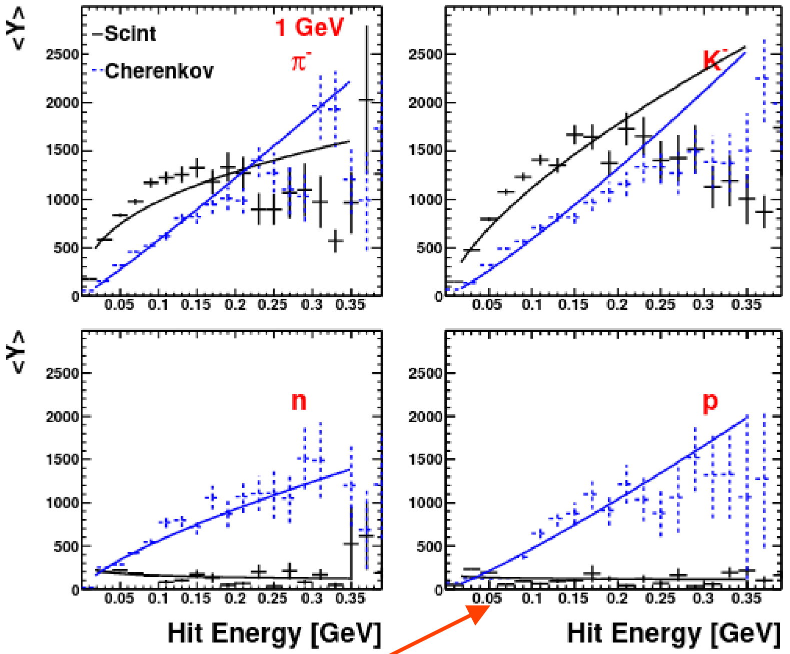
$$< Y >= A \cdot h^{B+C \cdot h}$$

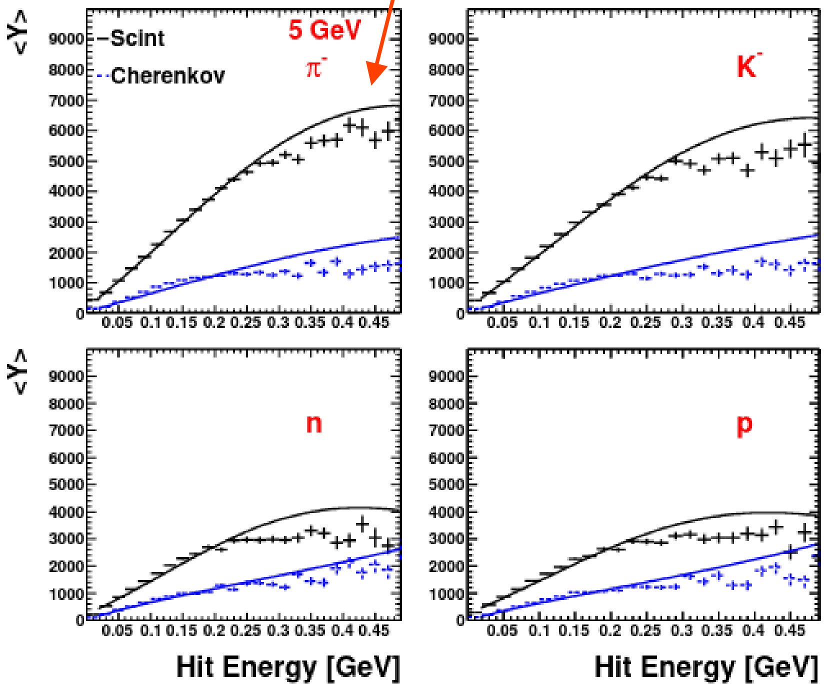
Where A, B, C are parameters that depend on E and T
(to be determined from fits of Geant4 data)

Another option: use machine learning to mimic density distributions
(but this would be too large overhead in actual implementation)

Birks effect ?

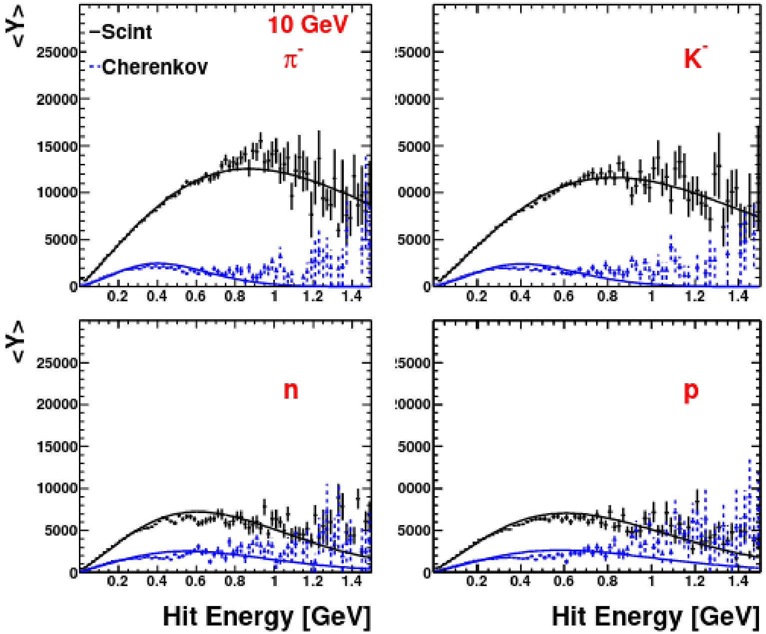
$$< Y > = A \cdot h^{B+C \cdot h}$$

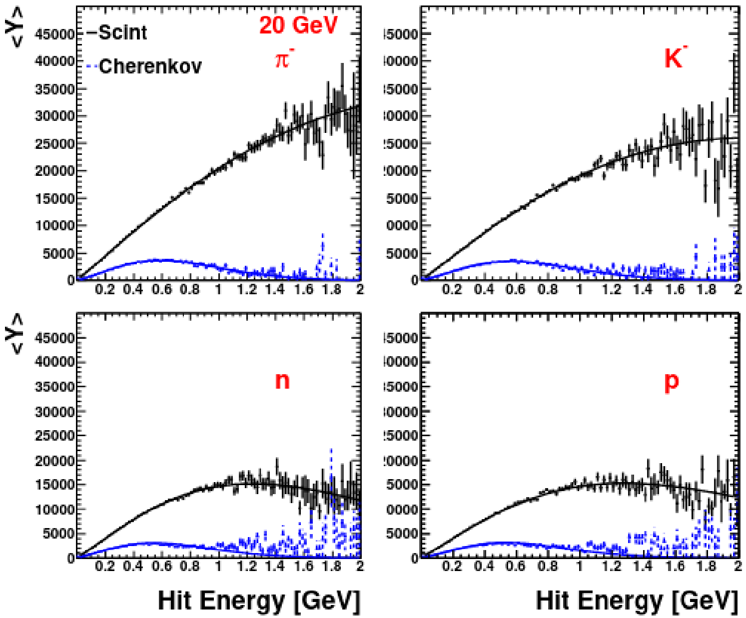




Bragg effect ?

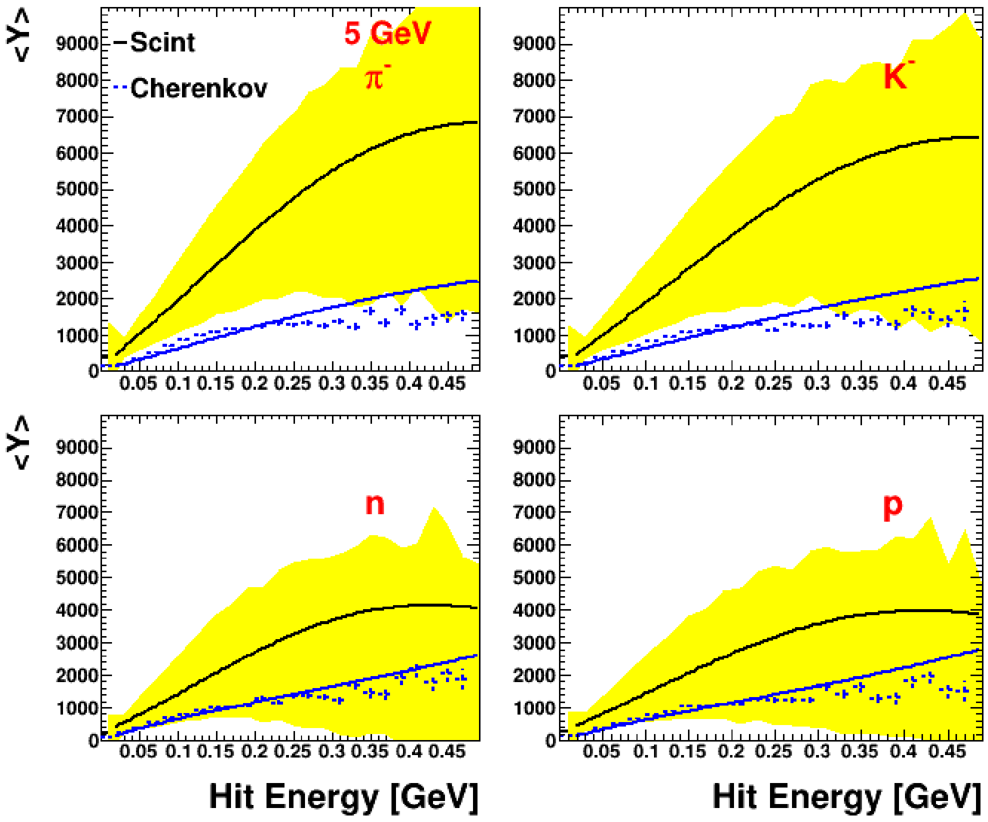
$$< Y > = A \cdot h^{B+C \cdot h}$$





From these fits one can determine energy and type dependence of A, B and C

Standard deviations for Y



Yellow area shows RMS on the Y (shown only for Scintillation light)

RMS ~ 50%. Perhaps no need to derive exact functional form

Introduce correlation between Cherenkov and Scintillation?

Still need to think about.