Some thoughts about homogeneous dual-readout calorimeters

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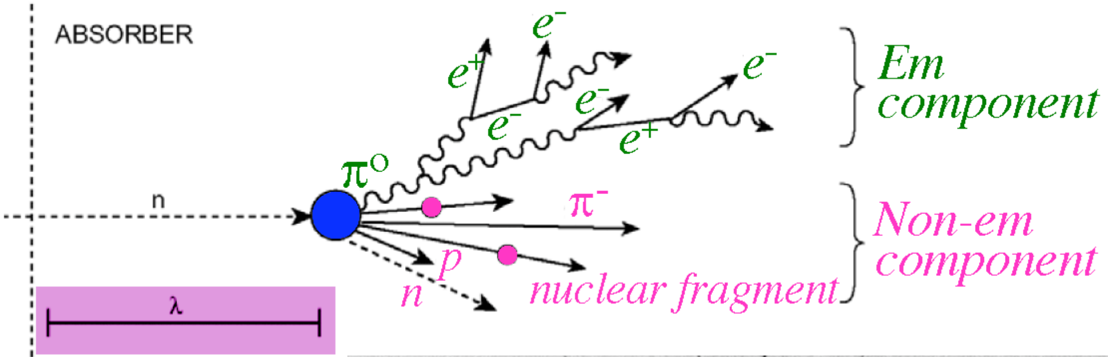
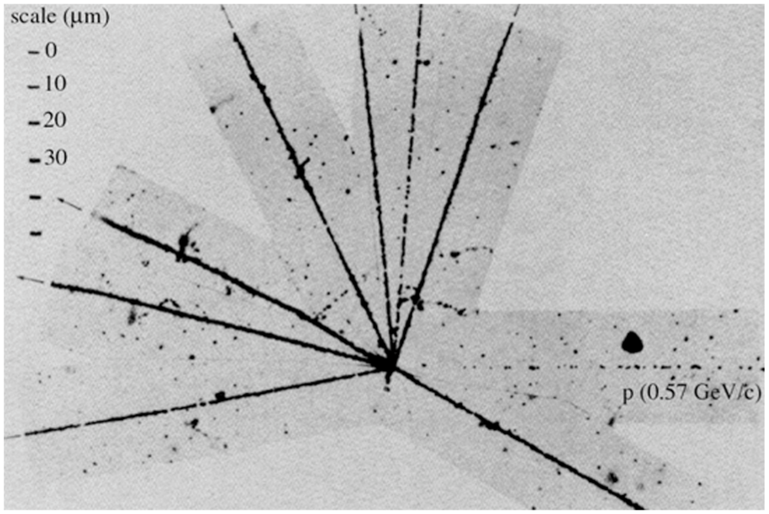
The physics of hadronic shower development

- *A hadronic shower consists of two components*



- *Electromagnetic component*
  - electrons, photons
  - neutral pions → 2 γ
- *Hadronic (non-em) component*
  - charged hadrons $\pi^\pm$,$K^\pm$ (20%)
  - nuclear fragments, p (25%)
  - neutrons, soft γ's (15%)
  - break-up of nuclei *("invisible")* (40%)



- *Important characteristics for hadron calorimetry:*
  - *Large, non-Gaussian fluctuations in energy sharing em/non-em*
  - *Large, non-Gaussian fluctuations in "invisible" energy losses*

About the contribution of relativistic hadrons to the signals

D. Groom: $< f_{em} > = 1 - \left[\frac{E}{E_0}\right]^{(k-1)}$

with E_0 = average shower energy needed for production of 1 secondary π
varies from 0.7 GeV (Fe) - 1.3 GeV (Pb)

$k \sim 0.8$ related to average multiplicity

Example: High-energy hadron on Pb, 100 GeV non-em energy deposit
→ 100/1.3 = 77 secondairy/tertiary shower pions, kaons

- mips in Pb lose 218 MeV per λ_{int} through ionization
  → 77 mips lose in total 16.8 GeV
- π,K may lose a bit more, since λ_{int} defined for protons
- On the other hand, many soft π's cause Δ resonance production, with cross sections much larger than the asymptotic one used for calculating λ_{int} (e.g. $\pi^+ n \longrightarrow p\pi^o$)

→ ionization loss π,K may account for ~20% of non-em E

Naive expectations for hadron calorimeters

Average composition of non-em shower component:

- Pions, kaons,....	20%	(relativistic)
- Protons	25%	
- Neutrons	15%	
- Invisible	40%	

		Exp. value
Cherenkov calorimeter:	$e/h = 1/0.2$	~ 5
Crystal calorimeter:	$e/h = 1/(0.2 + f_1 \,.\, 0.25)$ with $f_1 < 1$	> 2
LAr calorimeter:	$e/h = \frac{e}{mip}/(0.2 + f_1 \,.\, 0.25)$, $0.6 < \frac{e}{mip} < 1$	$1.3 - 1.8^{*}$
Plastic-scint. calorimeter	$e/h = \frac{e}{mip}/(0.2 + f_1 \,.\, 0.25 + f_2 \,.\, 0.15)$ with $f_2 > 1$	< 1.5

Efficient neutron detection is very important for hadronic energy resolution because kinetic energy neutrons correlated with invisible energy

Compare intrinsic limits SPACAL, ZEUS, D0

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* Except for uranium absorbers (fission energy)

Pros & Cons of Compensating Calorimeters

Pros

- Same *energy scale* for electrons, hadrons and jets. No ifs, ands or buts.
- *Calibrate* with electrons and you are done.
- Excellent hadronic *energy resolution* (SPACAL: 30%/$\sqrt{E}$).
- *Linearity,* Gaussian *response function* and all that good stuff.
- Compensation fully understood.
  We know how to build these things, even though GEANT doesn't

Cons

- Small sampling fraction (2.4% in Pb/plastic)
  ⟶ *em energy resolution limited* (SPACAL: 13%/$\sqrt{E}$, ZEUS: 18%/$\sqrt{E}$)
- Compensation relies on detecting neutrons
  ⟶ Large *integration volume*
  ⟶ Long *integration time* (~50 ns)

The DREAM project was started with the goal

to IMPROVE these results!

i.e.

- *Better em energy resolution*
- *Smaller integration volume*
- *Faster charge collection*

- *All this while maintaining (or further improving) the excellent hadronic performance*

The Dual-Readout Approach to Hadron Calorimetry

Elements needed to improve the excellent ZEUS/SPACAL performance:

1) *Eliminate/reduce effects of fluctuations in "invisible energy"*
   → *calorimeter needs to be efficient in detecting the "nuclear" fraction of the non-em shower component*

2) *Efficient neutron detection is an excellent tool in that respect*
   but one should not depend on detecting all interactions by all neutrons
   (integration cone, time!)

3) *Reduce the contribution of sampling fluctuations to energy resolution*
   (THE limiting factor in SPACAL/ZEUS)

4) *Eliminate the effects of fluctuations in the em shower fraction,* f_{em}
   in a way that does NOT prevent 2), 3)

→ *Dual-Readout Calorimetry*

Advantages / disadvantages HHCAL concept

Advantages:

- *No sampling fluctuations*
- *Some calibration problems characteristic for sampling calorimeters don't play a role*

Disadvantages:

- *No sensitivity to neutrons, and thus to invisible energy fluctuations*
- *Light attenuation*
- *Readout*
- *COST*

(My personal) Conclusions

Advances in hadron calorimetry have always been the result of experimental R&D.

Don't take MC simulations too seriously.
Their predictive value has been unimpressive

If you can find the money, go for it. It can't be worse than PFA

I am personally not betting any money on this effort