Hadronic calorimeters

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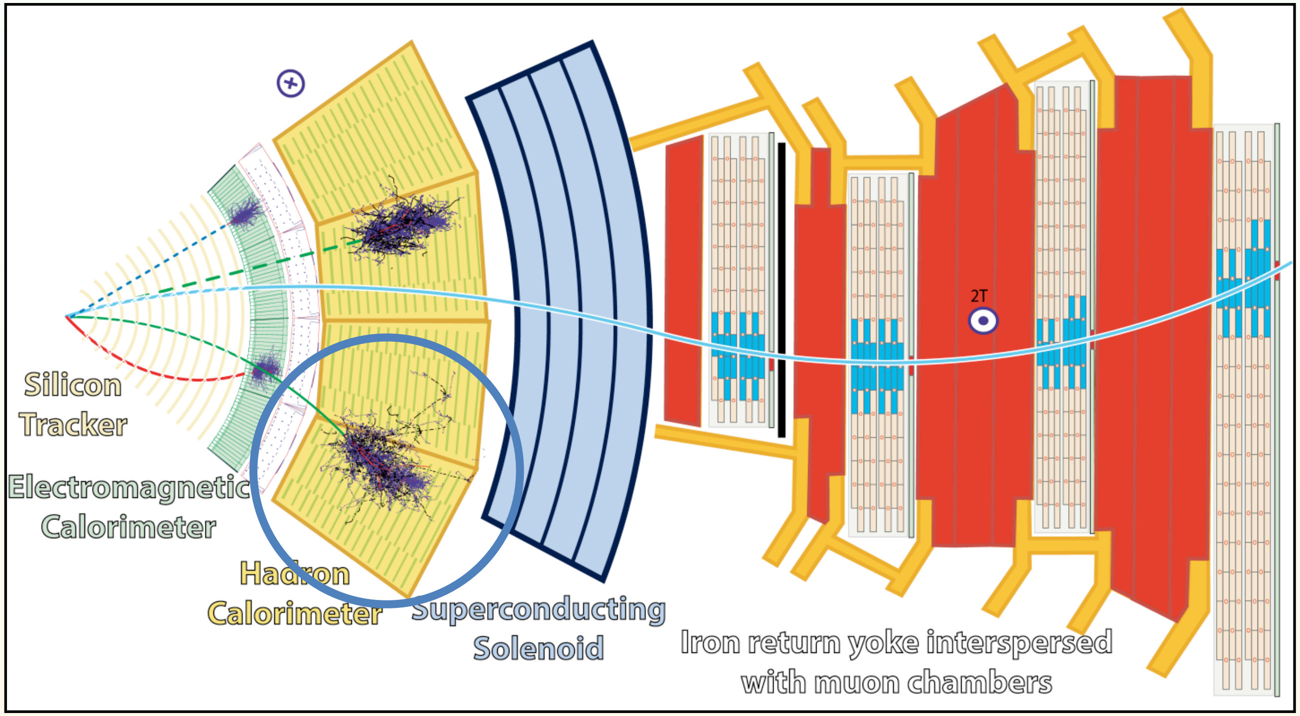
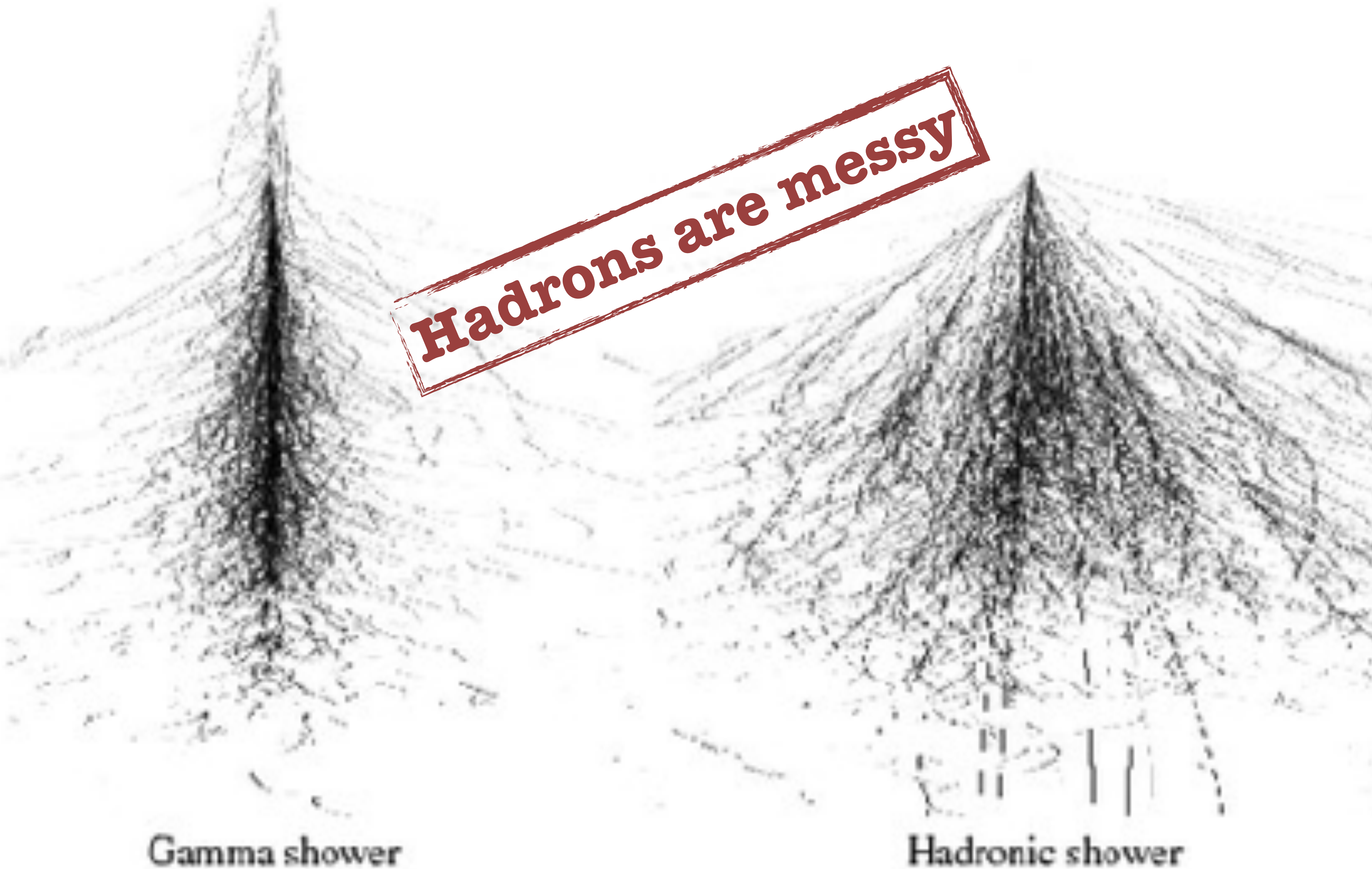
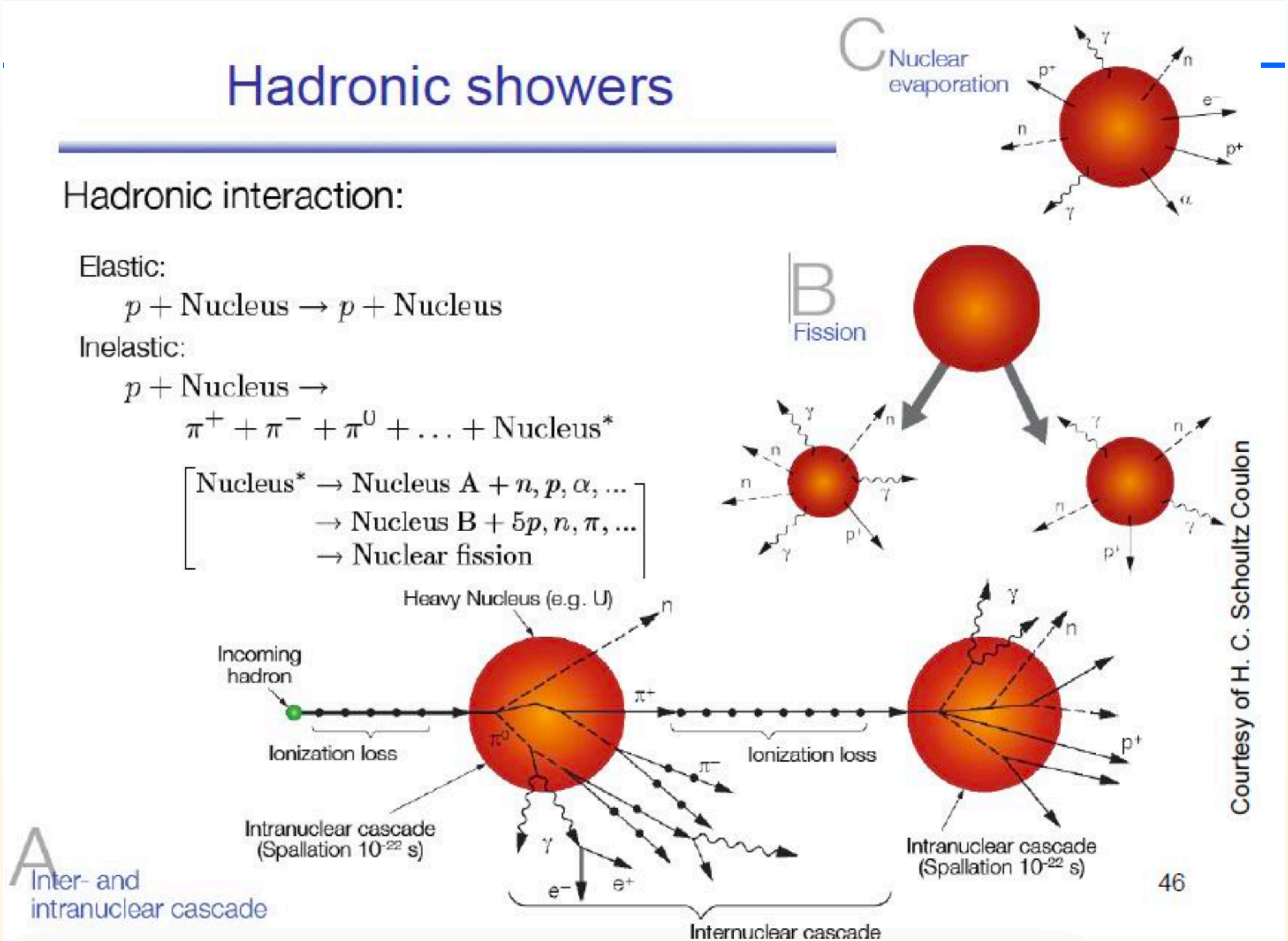
What is a calorimeter?



- Detection of particles and their properties through full absorption
- All energy of the particle is finally converted to heat (and more)
- Essential to detect neutral particles

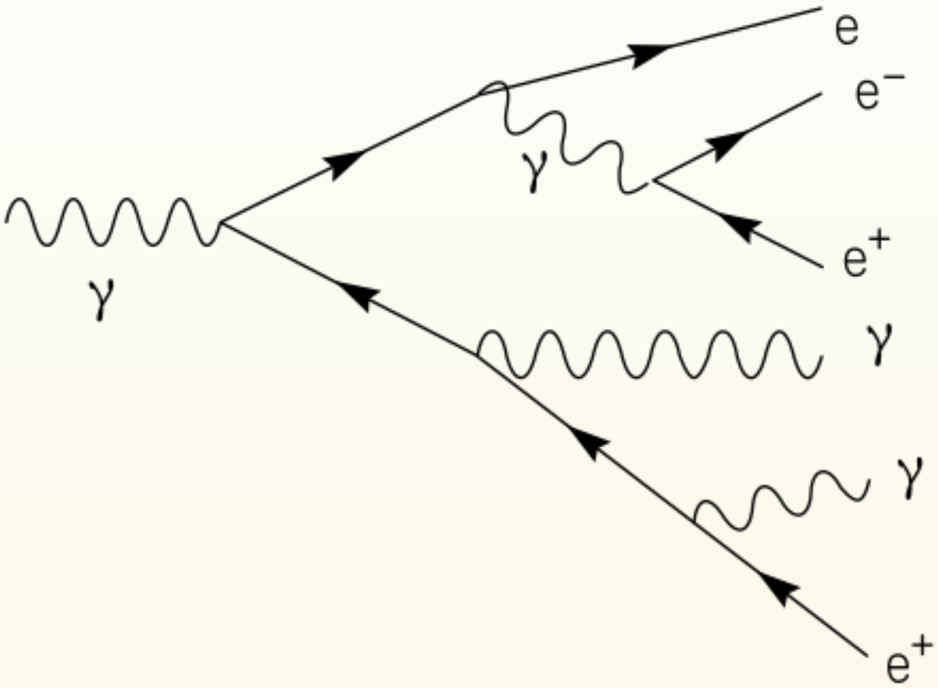

Hadrons are messy
Gamma shower
Hadronic shower

Why is that: hadronic interactions



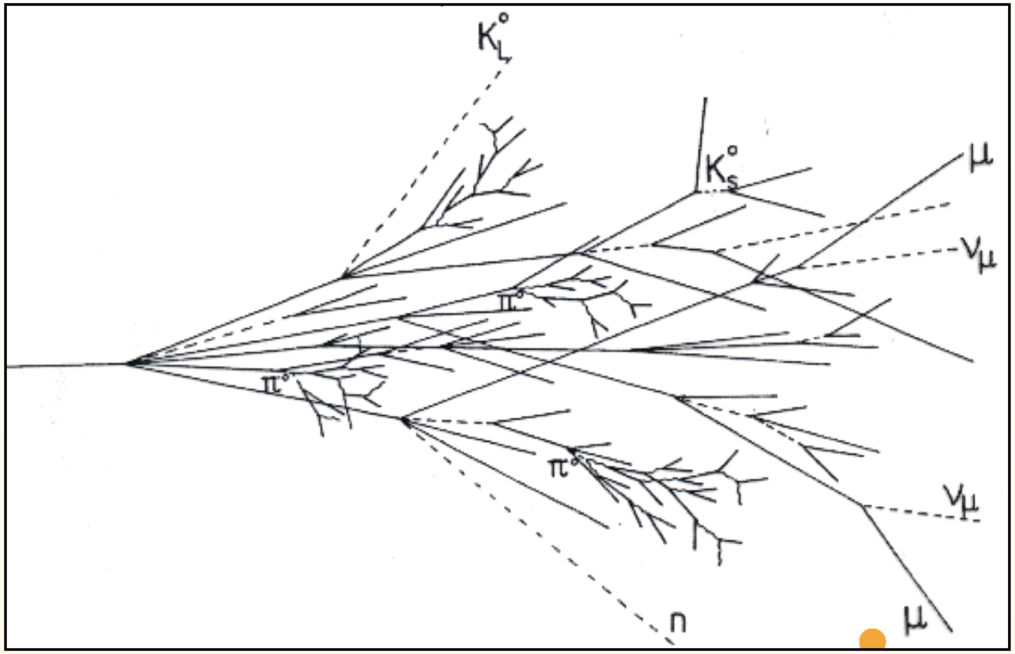
Recap: EM showers

- Very regular
- Only EM effects



- Dominated by pair production and bremsstrahlung

Hadronic showers



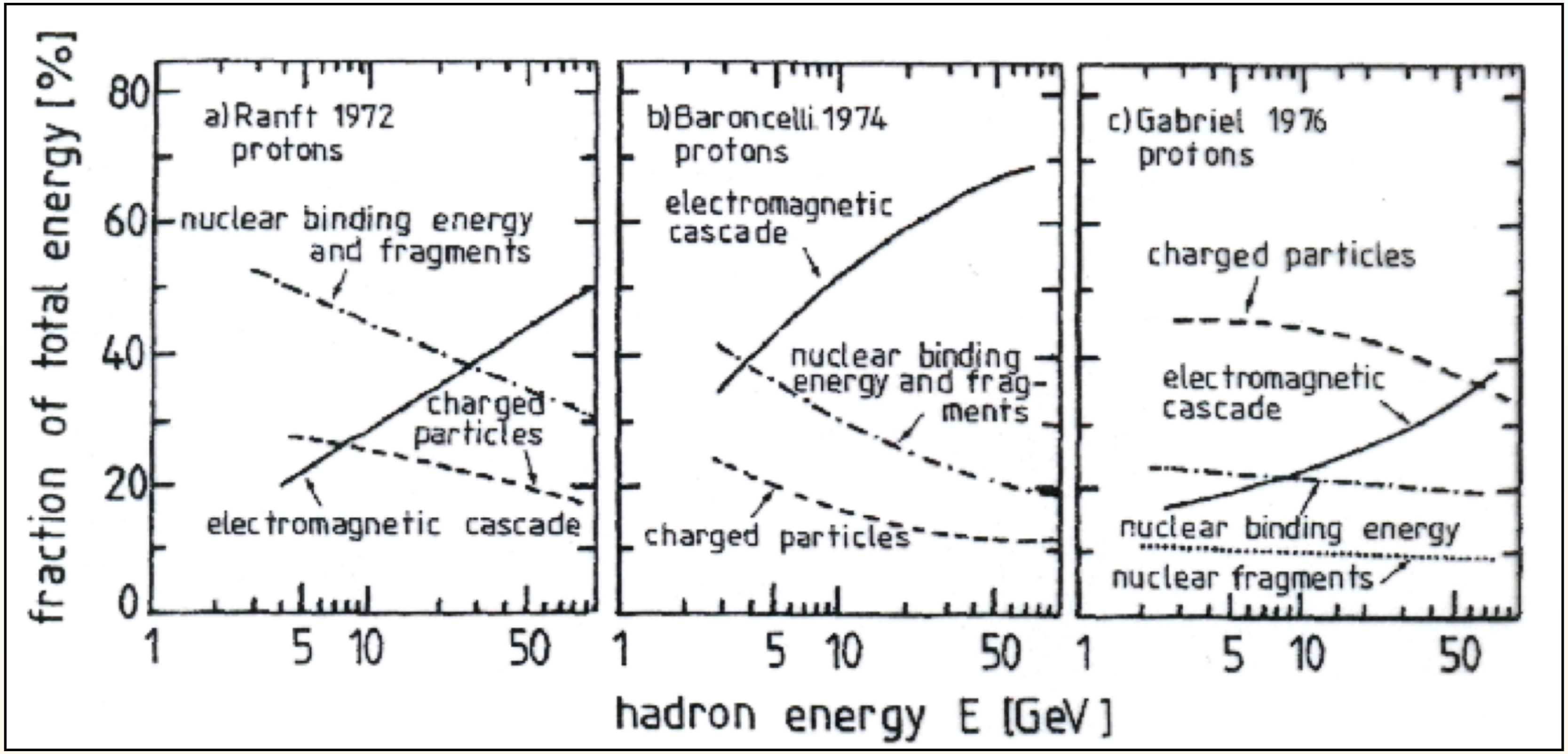
EM component

Hadronic component:
- Elastic
- Inelastic

Energy undetected:
- Binding energy
- Neutrinos

- Not possible to capture all energy
- Large fluctuations on a per-shower basis, also in time

The contributions



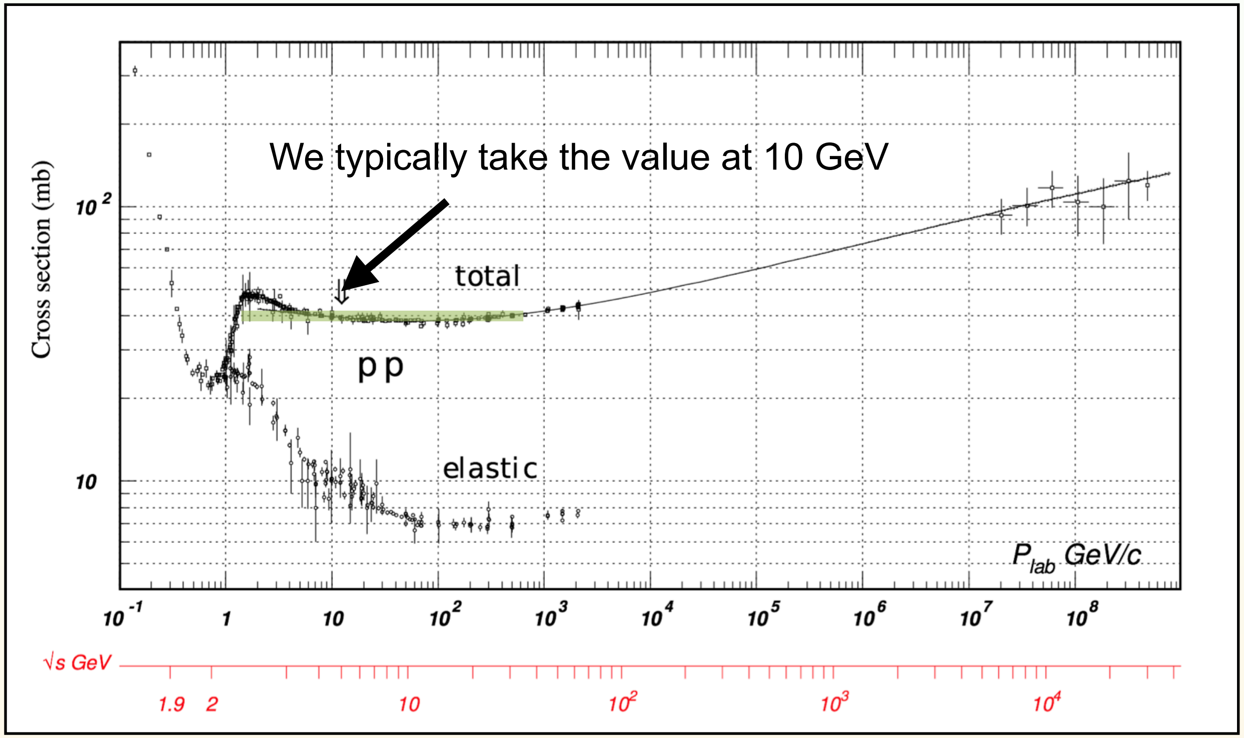
- Models differ significantly, but common features

More quantitatively

- Elastic and inelastic components

  $\sigma_{\text{el}} = \sigma_{\text{el}}(E)$

  $\sigma_{\text{inel}} \propto A^{2/3}$



- Inelastic dominates
- Nucleon-proton

  $\sigma_{\text{tot}} = \sigma_{pp}(10\,\text{GeV})\,A^{2/3}$

Define nuclear interaction length

For comparison: EM showers

$$\sigma_{pair} \approx \frac{7}{9}\left(4\alpha r_e^2 Z^2 \ln\frac{183}{Z^{1/3}}\right) = \frac{7}{9}\frac{A}{N_A X_0}$$

$$X_0 = \text{const.}\frac{A}{N_A \sigma_{\text{pair}}} \propto A/Z^2$$

- Define

$$\lambda_{\text{int}} = \frac{A}{N_A \rho \sigma_{\text{tot}}} \approx 35 \frac{\text{g}}{\text{cm}^2} A^{1/3}$$

- The nuclear interaction length is typically (much) larger than the radiation length for the same material

- The ratio of both is material dependent

Summary

- Hadronic showers are messy
- Important quantity: interaction length:material dependent
- EM fraction is important
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More tasks

Plot nuclear interaction length
and radiation length for as a function
of A and Z. Put markers for materials
in our material list for simulation

Adapt your EM calorimeter to also capture
Hadronic showers; what happens?
(Performance, cost, …)

Start by visualising the shower depth

How do energy sum and DNN regression relate?

Build an optimal hadronic calorimeter (no transversal granularity)
within for showers between 1 and 100 GeV and stay below 50kCHF