

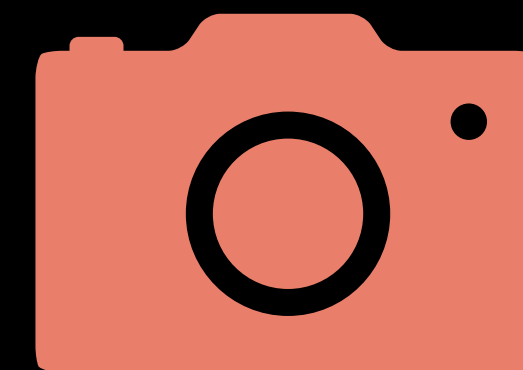
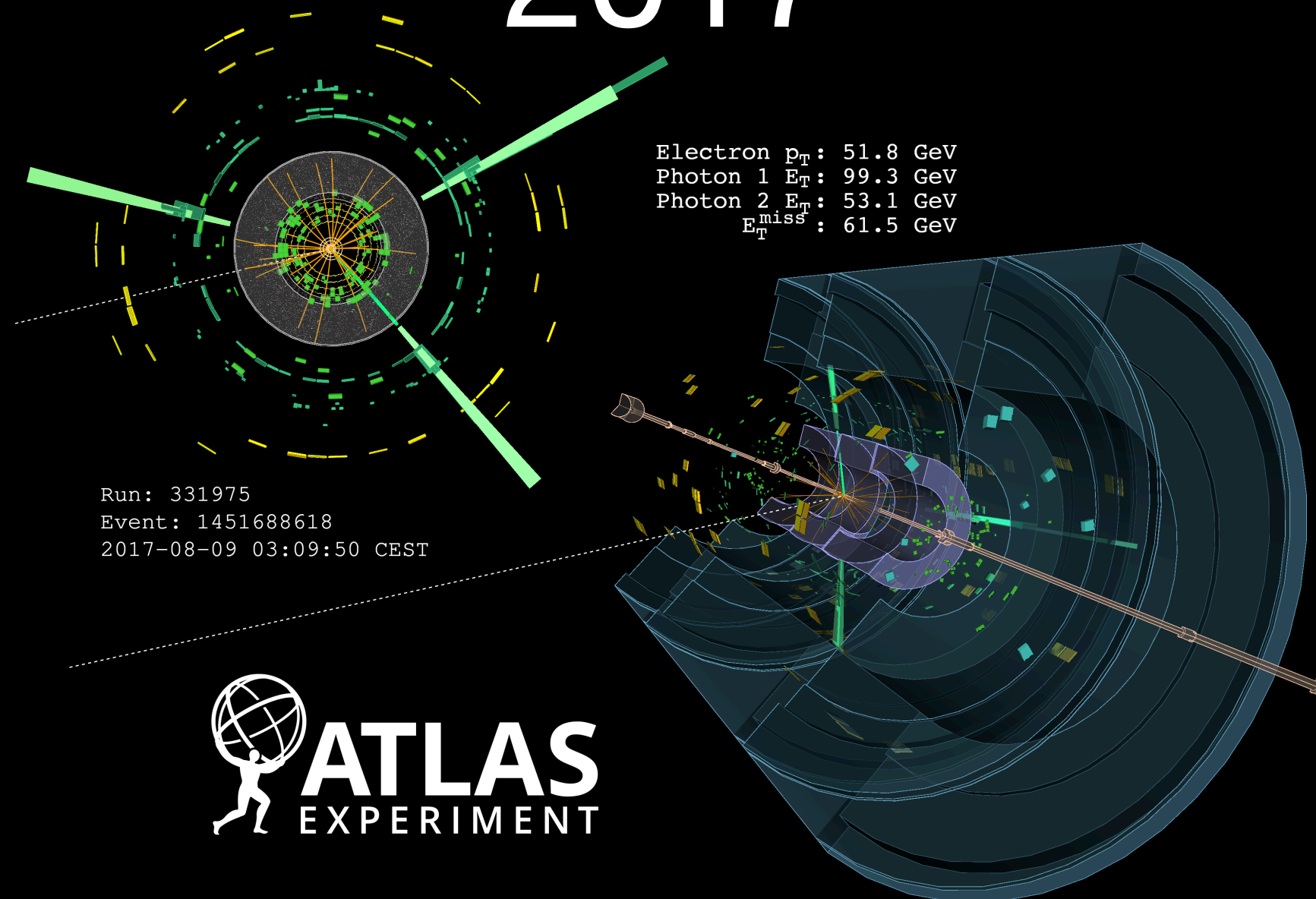
# PHYS 7363 - Experimental Particle Detection and Detectors I



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Particle detectors are the workhorses of experimental physics. In this course, we'll dive deep into their physics, exploring the incredible evolution of our experimental techniques over the past nine decades. You'll gain a solid understanding of *particle detection and identification*, examine the intricate designs of modern detectors, and learn how machine learning is being harnessed to push the boundaries of detector design. If you're intrigued by how we “see” subatomic particles, this course is for you!

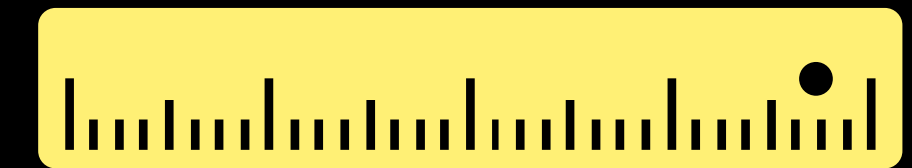
2017



Detect



Identify



Measure

To discuss prerequisites (and any questions on the content of the course), please contact me: [saptaparnab@smu.edu](mailto:saptaparnab@smu.edu)



# Schedule

Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
August	18	19	20	21	22	23	24
	25 ✓	26	27	28	29 ✓	30	31
September	1	2	3 ✓	4	5 ✓	6	7
	8 ✓ ← 1.5 hours →	9	10	11	12	13	14
	15 ✓ 1.5 hours	16	17 ✓ 1.5 hours	18	19 ✓ 1.5 hours	20	21
	22 ✓ 1.5 hours	23	24 ✓ 1.5 hours	25	26 ✓ 1.5 hours	27	28
	29 ✓ 1.5 hours	30	1 ✓ 1.5 hours	2	3 ✓ 1.5 hours	4	5

# Schedule

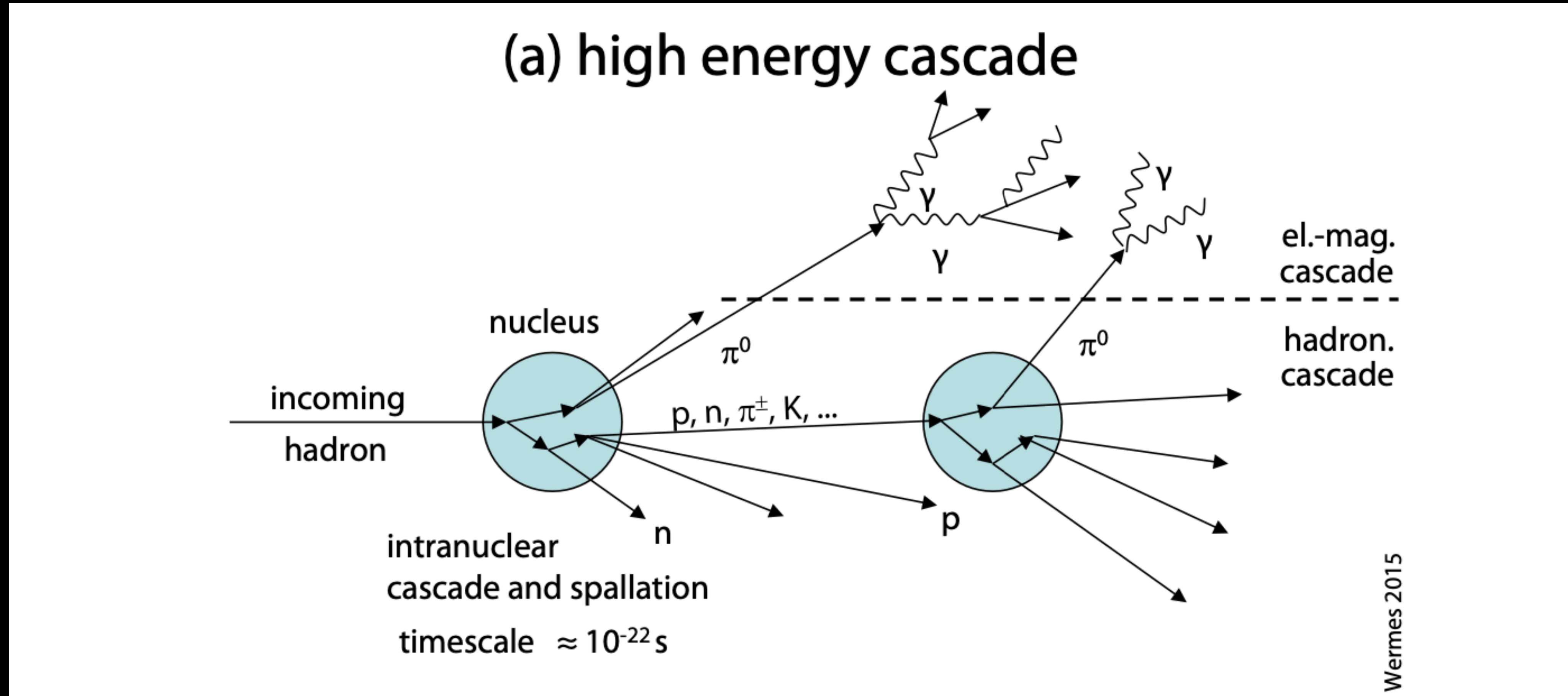
Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
October	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
	27	28	29	30	31	1	2
November	3	4	5	6	7	8	9
	10	11	12	13	14	15	16
	17	18	19	20	21	22	23
	24	25	26	27	28	29	30
December	1	2	3	4	5	6	7
	8	9	10	11	12	13	14

# Schedule

- Midterm on October 27th
- We decided on continue with this 80 min long lectures thrice a week
  - We will continue with this schedule unless I think that we don't need to meet for that long a time frame
  - Next week, I am away at a conference, so we will meet on Monday as planned in person, Wednesday would be a zoom lecture and no lecture on Friday

# Hadron Showers

- High energy hadrons form particle showers when passing through dense material

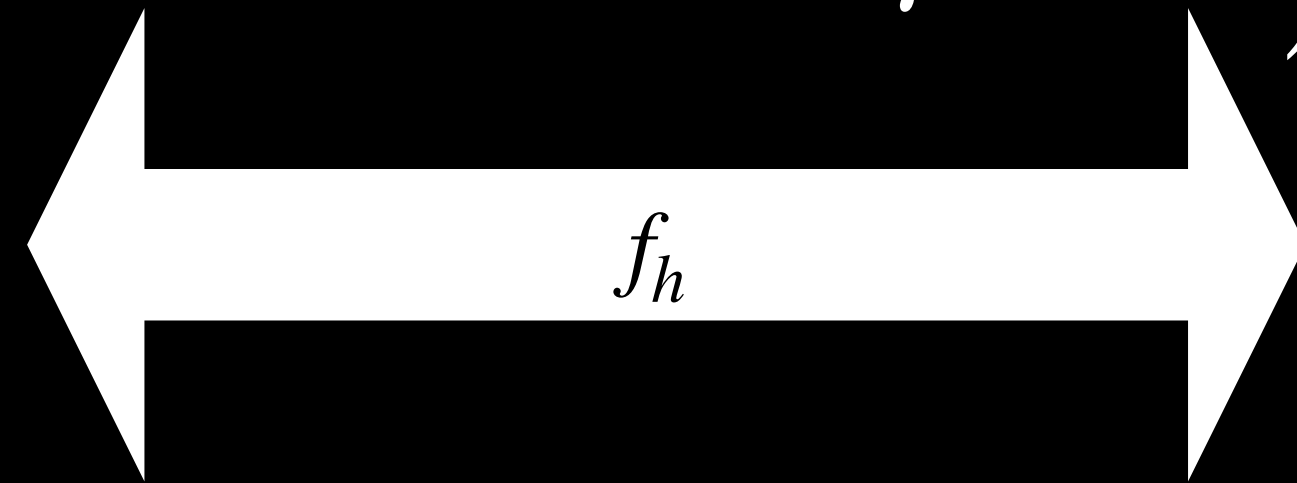


Spallation: The excited nucleus releases its energy through emission of nucleons

# Shower components and shower fluctuations

- Shower fluctuations are much stronger in hadronic than electromagnetic showers
- Caused by the splitting of the shower in different components for which the fractions  $f_i$  of the total deposited energy strongly fluctuate
- The energy deposited in a block of matter consists of the following components:

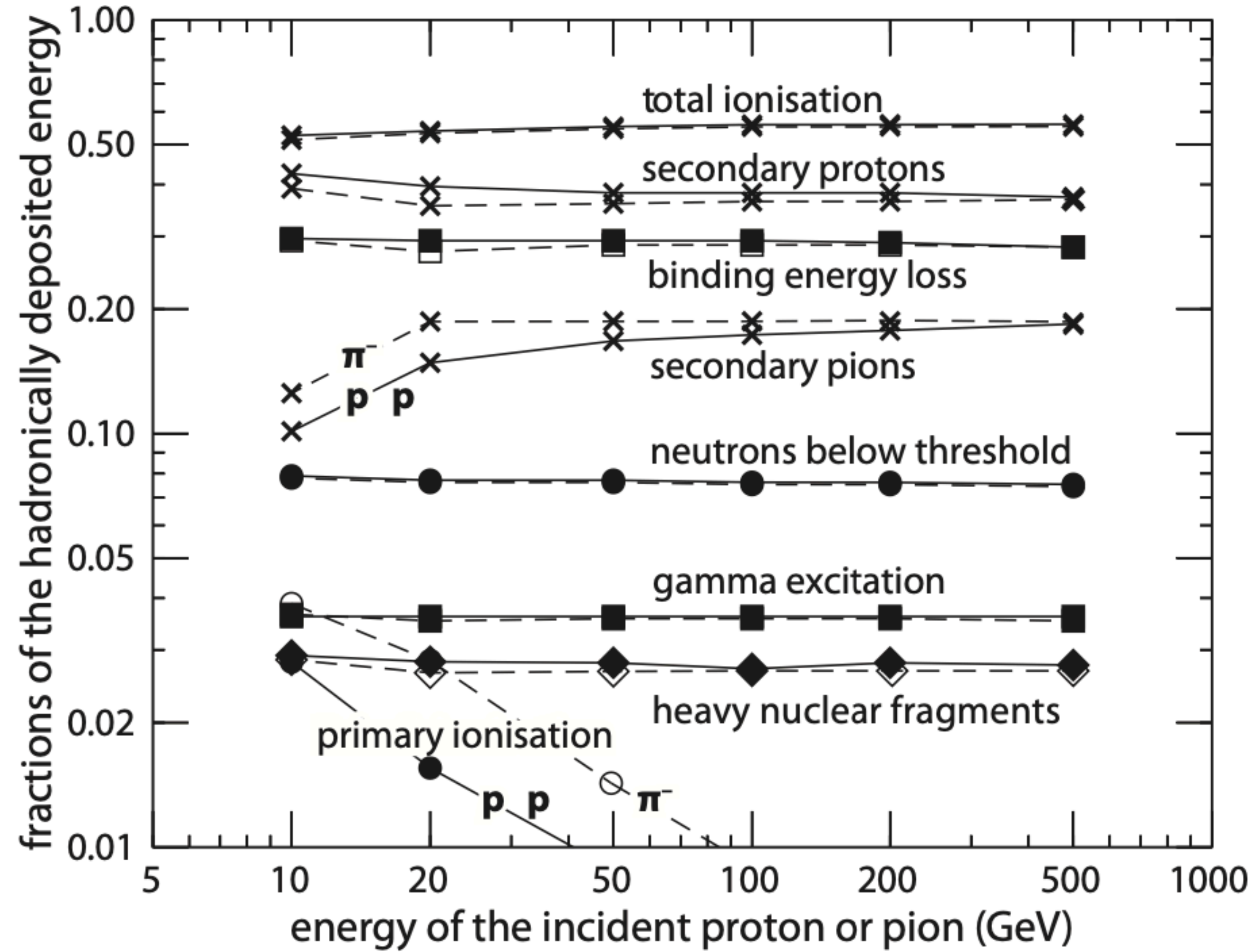
- $$E_{dep} = \left( f_{em} + f_{ion} + f_n + f_\gamma + f_B \right) E$$



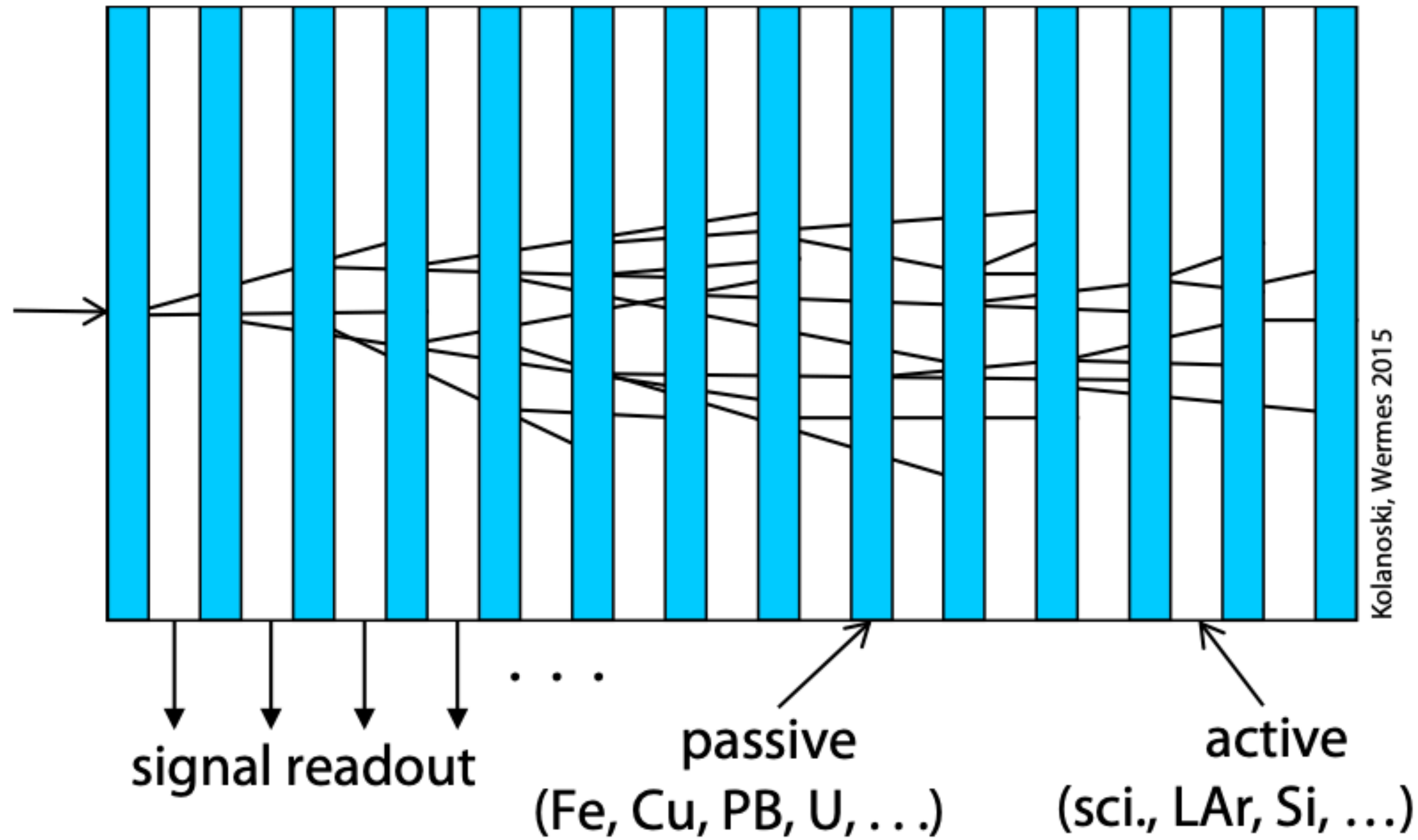
# Shower components and shower fluctuations

- The hadronic fraction is divided into contributions which differ in the way they are detected:
  - $f_{ion}$ : Charged particles transfer energy to the medium through ionization
  - $f_n$ : Neutrons transfer the energy through elastic collision or nuclear reactions
  - $f_\gamma$ : The photons from nuclear reactions are allocated to the 'hadronic' part of the energy because they arise from nuclear reactions and are strongly correlated with other hadronic energies
  - $f_B$ : The energy which is needed to break up a nucleus, corresponding to its binding energy

# Fractions of hadronically deposited energy

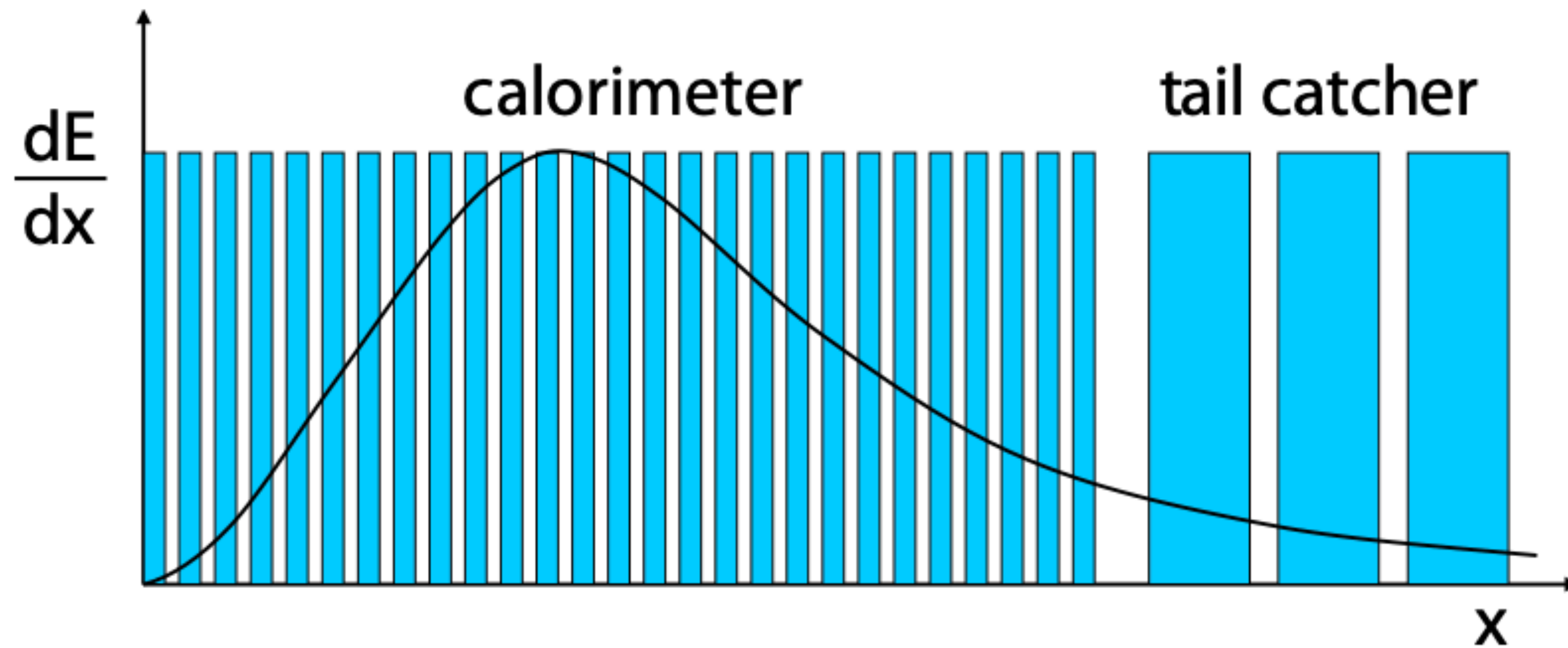


# General Principles of Calorimetry



**Fig. 15.15** Schematic of a sampling calorimeter, here in a sandwich arrangement.

# General Principles of Calorimetry



Kolanoski, Wermes 2015

**Fig. 15.19** Measurement of the shower loss by means of a subsequent coarser detector (*tail catcher*).

# Longitudinal Structure

- Longitudinal segmentation: In electromagnetic calorimeters, a longitudinal segmentation of the signal readout can substantially improve the hadron-electron separation
- Tail catcher: If shower losses cannot be avoided even a quite rough measurement of the loss by a so-called *tail catcher* can cause a distinct improvement of the energy
- Presampler: In front of the calorimeters detectors for tracking and possibly particle identification are often installed. Made of as little material as possible. Actual radiation length in front of the calorimeter can degrade energy resolution. Determines if the shower has started

# Energy Resolution

- In most calorimeters the energy resolution is determined by the stochastic fluctuations of the number of charged particles contributing to the signal
- If their number  $N_S$  is proportional to the primary energy ( $N_S \propto E$ ), with a standard deviation ( $\sqrt{N_S}$ ) according to Poisson statistics, then the resolution is:

- $$\frac{\sigma_E}{E} \propto \frac{\sqrt{N_S}}{N_S} = \frac{1}{\sqrt{N_S}} \propto \frac{1}{\sqrt{E}}$$

- Energy resolution calculated as:

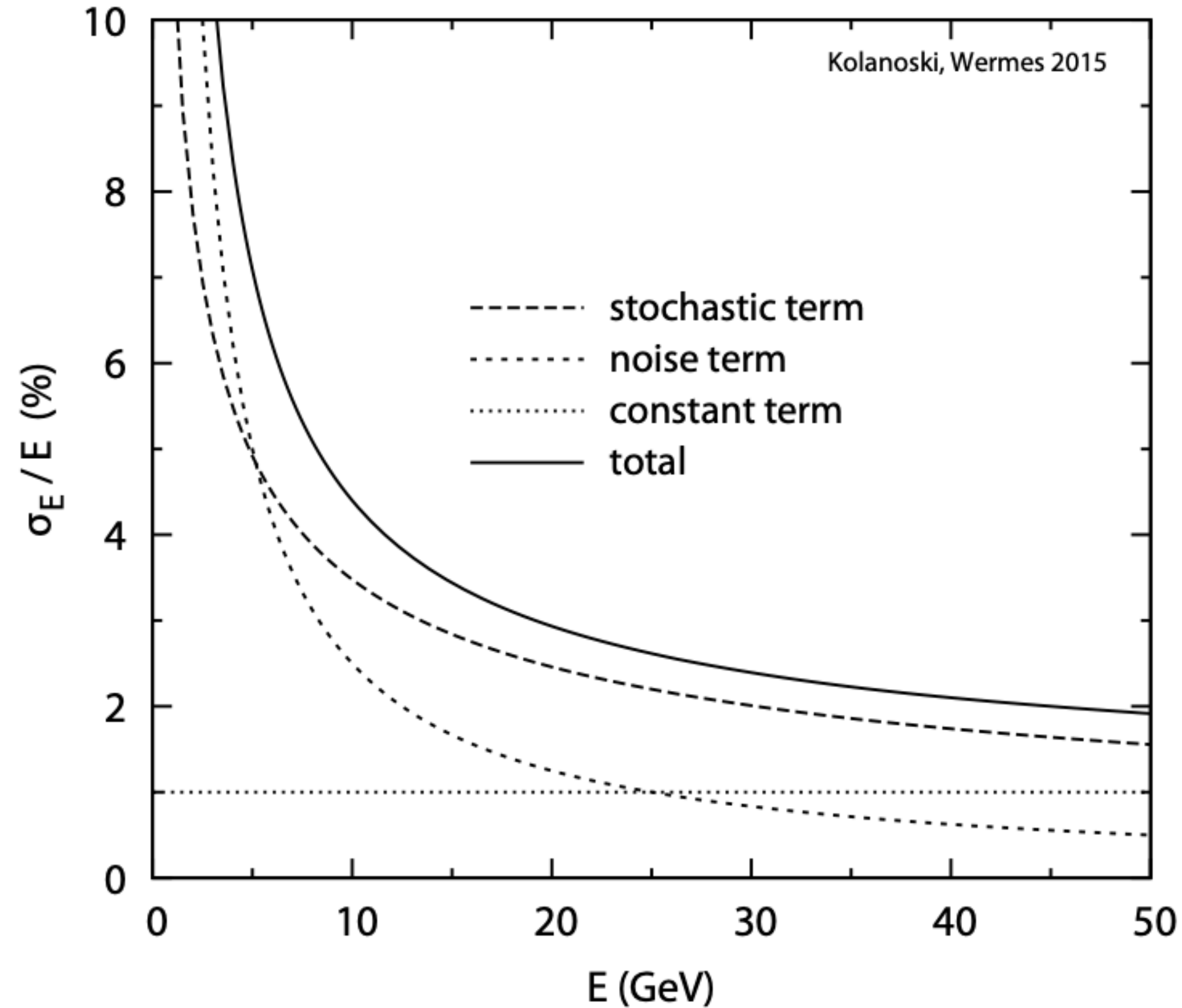
- $$\frac{\sigma_E}{E} = \sqrt{\frac{a^2}{E} + \frac{b^2}{E^2} + c^2}$$

# Energy Resolution

- $$\frac{\sigma_E}{E} = \sqrt{\frac{a^2}{E} + \frac{b^2}{E^2} + c^2}$$

- $a$ : stochastic fluctuations of the shower development being particularly strong for sampling calorimeters due to incomplete sampling
- $b$ : electronic noise which contributes  $\frac{1}{E}$  term to the relative resolution because the absolute fluctuations are energy independent
- $c$ : mechanical and electronic imperfections, fluctuations in the leakage losses, inter-calibration errors and others with absolute contributions which rise with energy

# Energy Resolution



**Fig. 15.20** Example for the energy dependence of the energy resolution of a calorimeter with the individual contributions of the resolution terms as given in (15.33), with  $a = 0.11/\sqrt{\text{GeV}}$ ,  $b = 250 \text{ MeV}$ ,  $c = 0.01$ .