PHYS 7363 - Experimental Particle Detection and Detectors I

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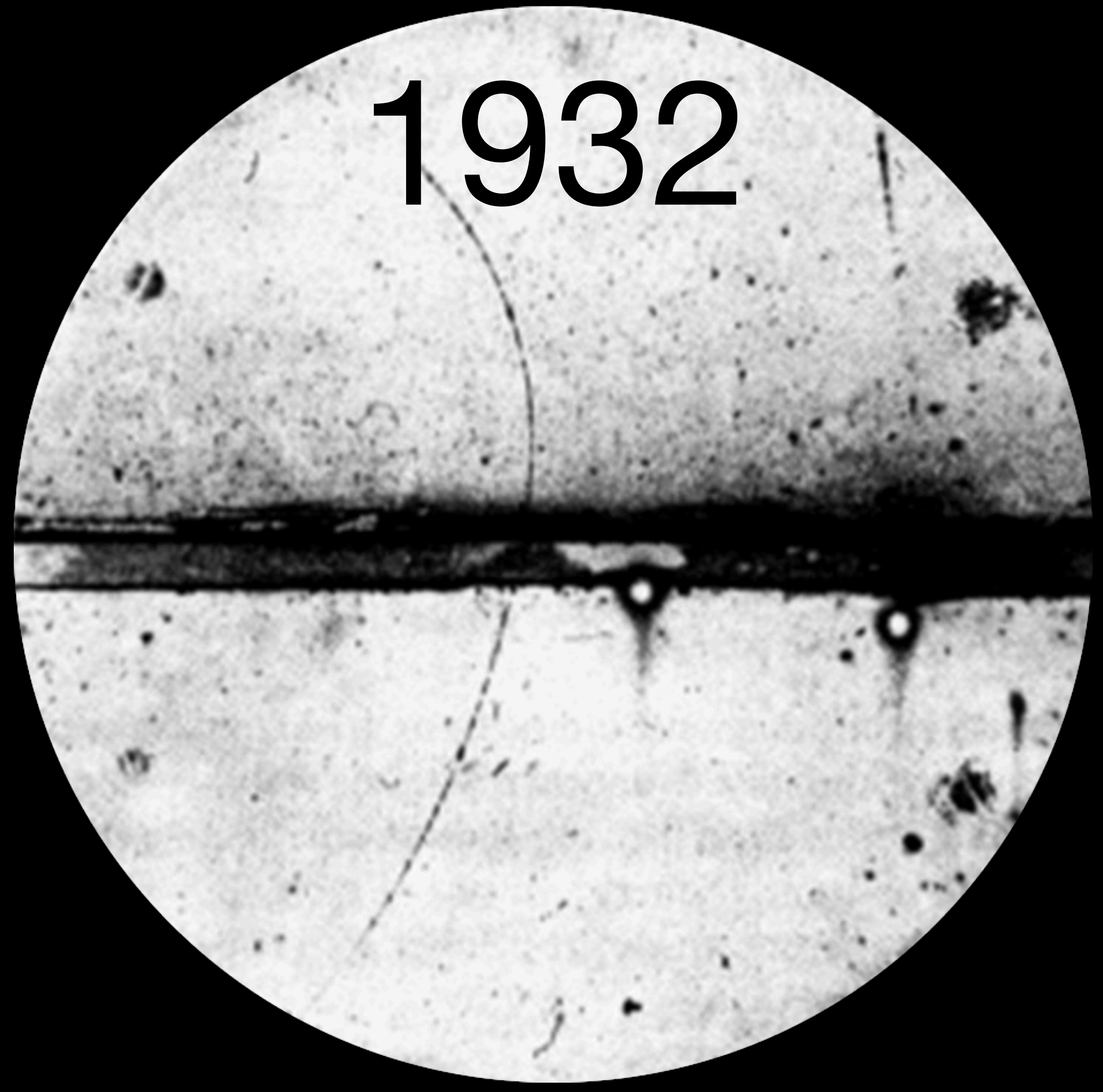
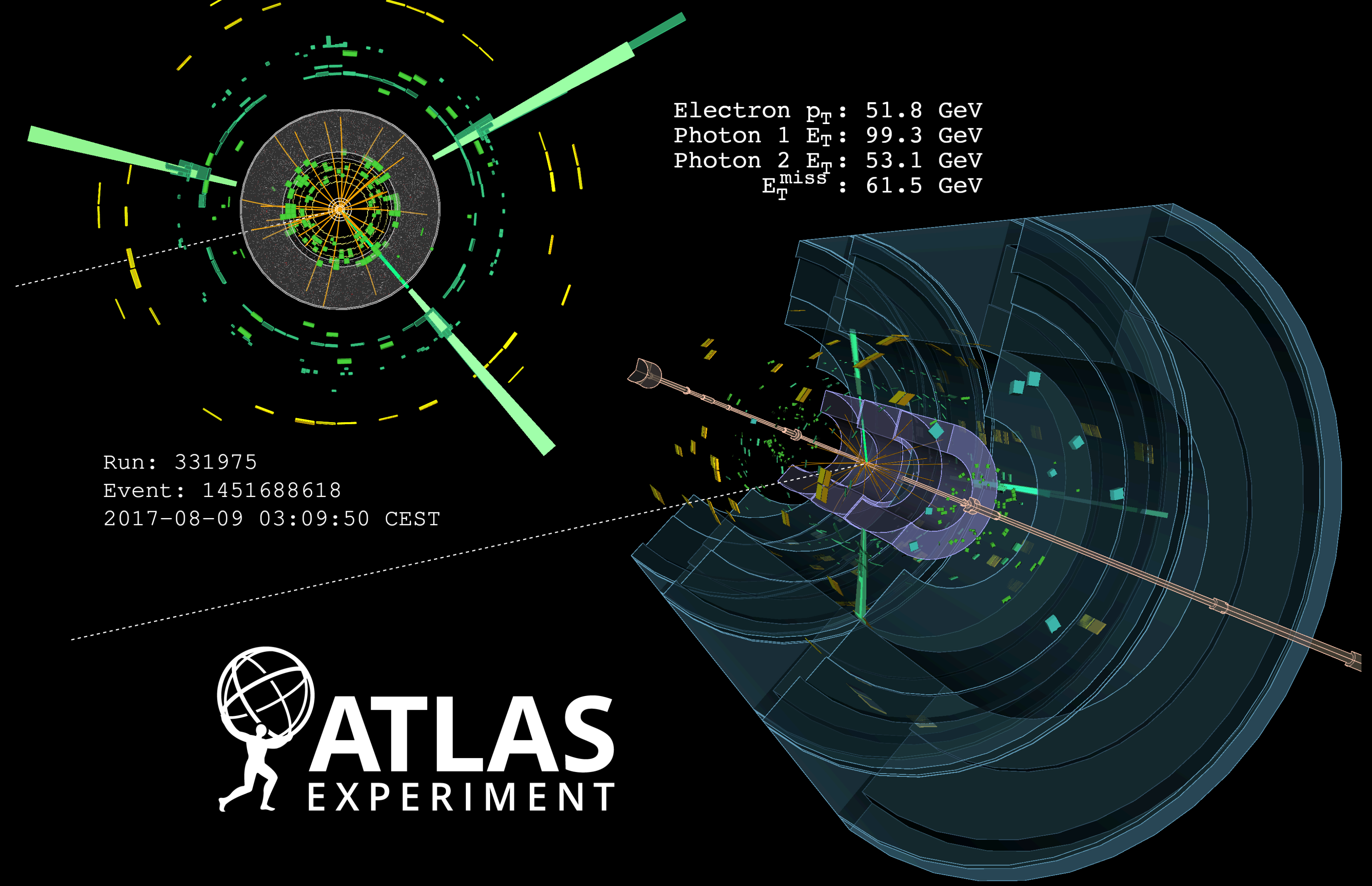
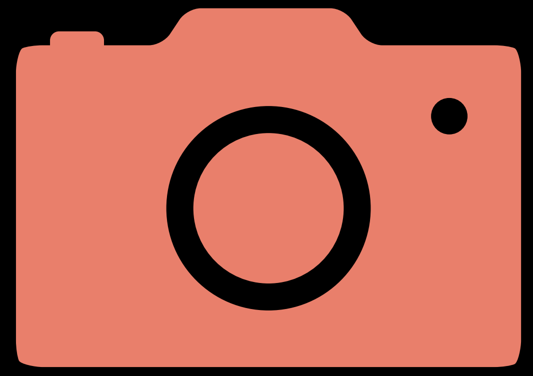


2017

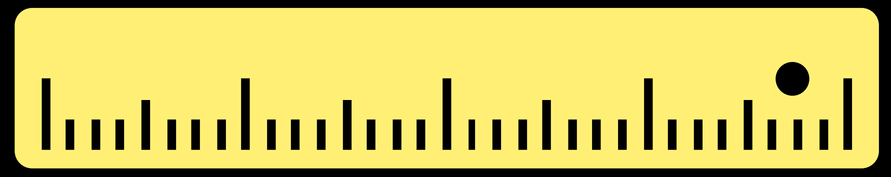


Particle detectors are the workhorses of experimental physics. In this course, we'll dive deep into their physics, exploring the incredible evolution of our experimental techniques over the past nine decades. You'll gain a solid understanding of *particle detection* and *identification*, examine the 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!



Detect

Identify



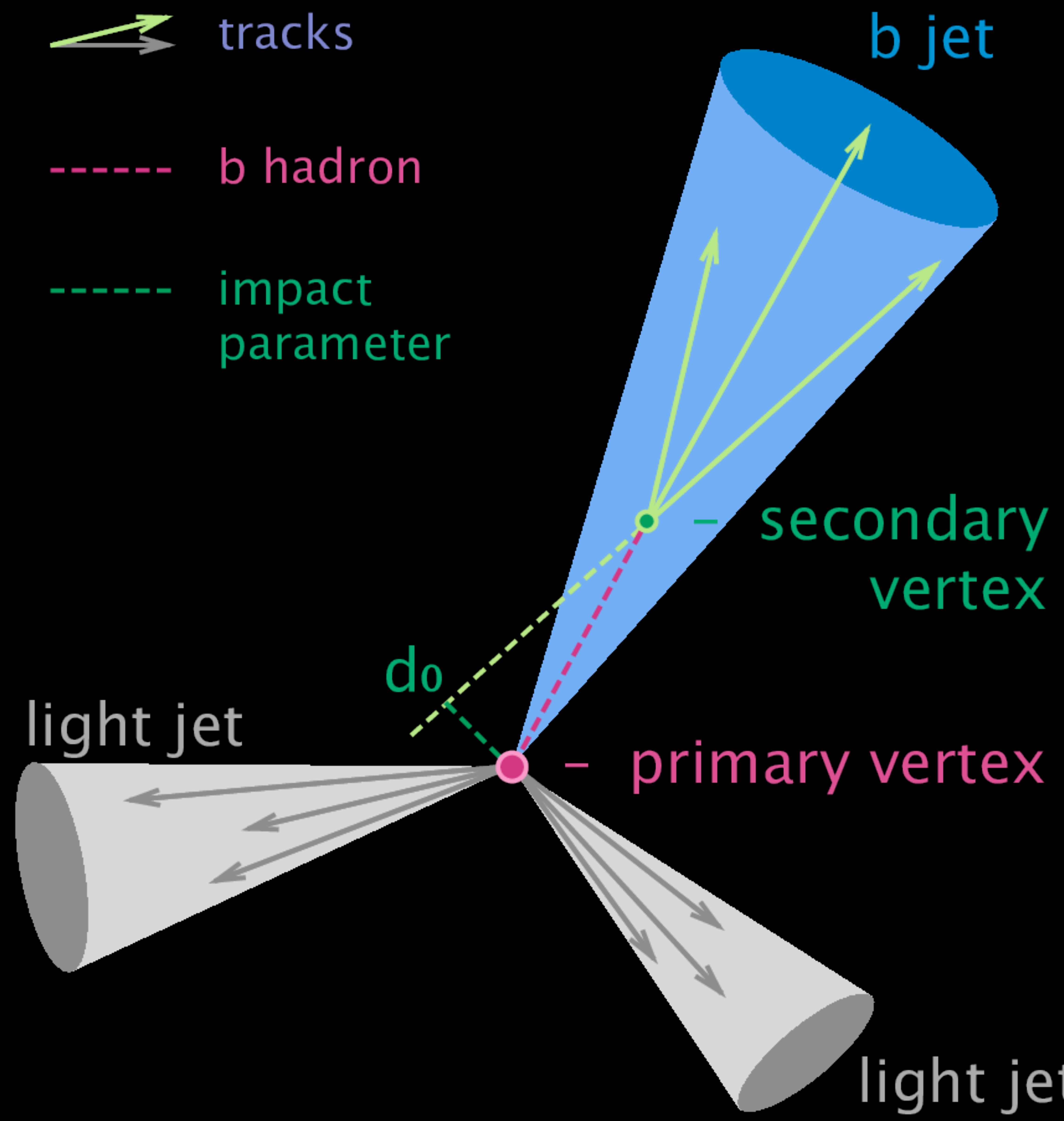
Measure

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

Schedule

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

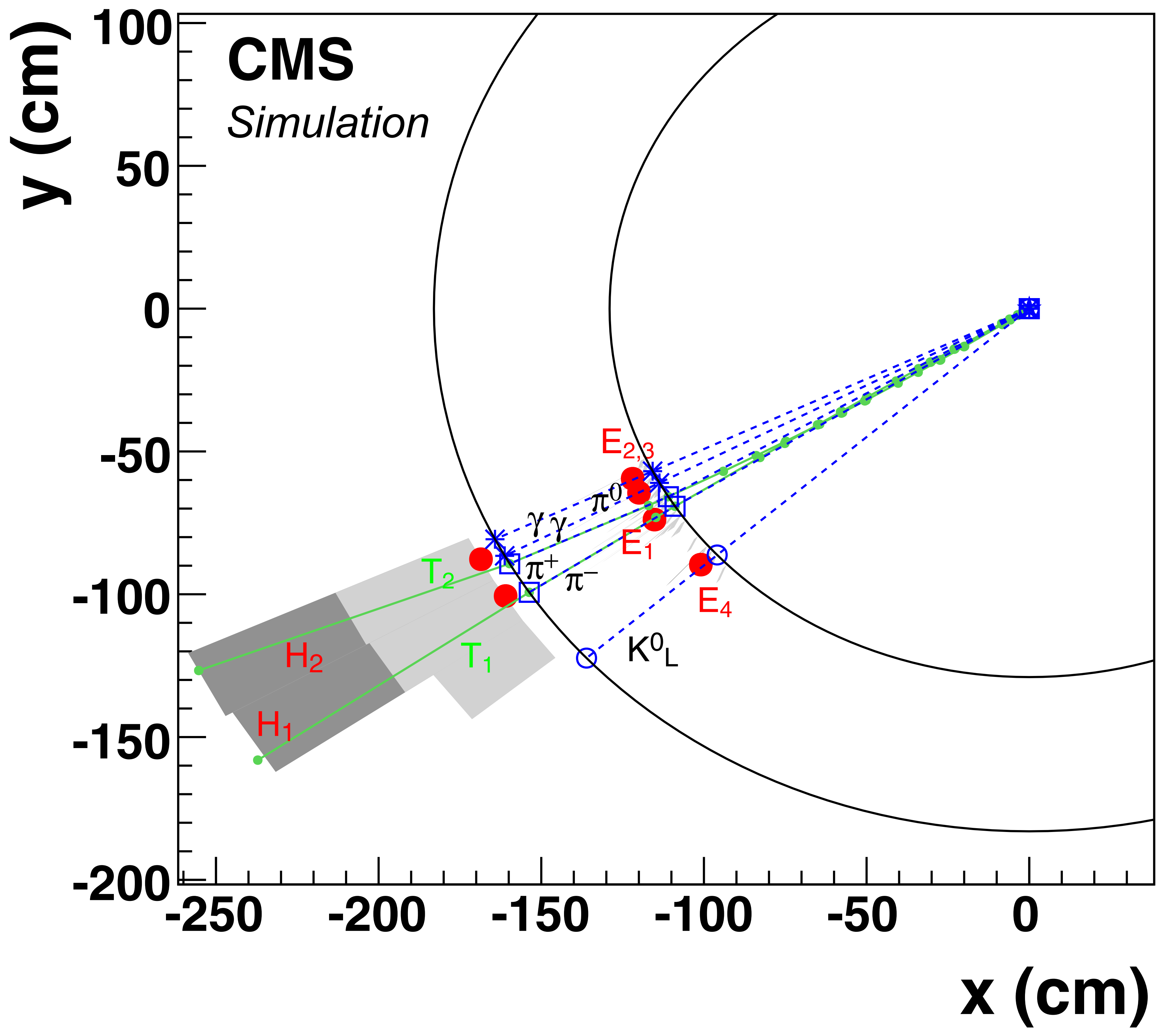
How do you identify b-jets



Which parts of the detectors are used?

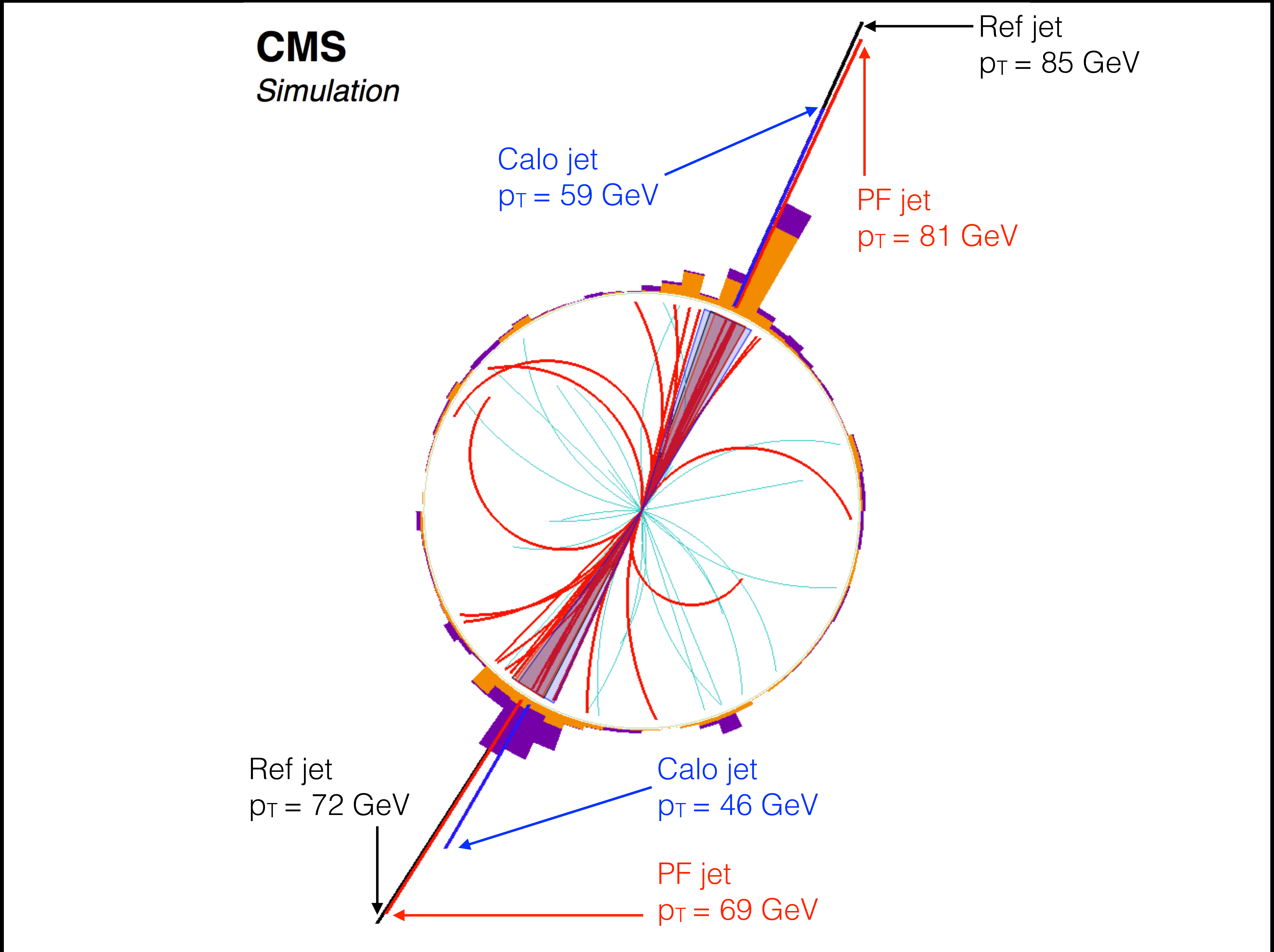
- Classroom participation

Particle Flow with CMS Open Data



- Event display of an illustrative jet made of five particles only in the (x, y) view
- The ECAL and HCAL surfaces are represented as circles centred around the interaction point
- The K_L^0 and the π^- and the two photons from the π^0 decay are detected as four well-separated ECAL clusters $(E_{1,2,3,4})$
- The π^+does not create a cluster in the ECAL
- The two charged pions are reconstructed as charged-particle tracks $T_{1,2}$ appearing as vertical solid lines in the (η, ϕ) views and the circular arcs in the (x, y) view
- These tracks point towards two HCAL clusters $H_{1,2}$

Particle Flow Jets



Particle Flow with CMS Open Data

- https://cms-opendata-workshop.github.io/workshop2023-lesson-advobjects/02-particleflow/index.html
- Particle flow paper: https://arxiv.org/abs/1706.04965
- Let's read parts of the paper:
  - Inputs: Pradip
  - Algorithm: Trevor and Dipesh
  - Performance: Isuru
- Take notes as slides or some other form and tell me what you have learned

Particle Flow in ATLAS

- Key difference in language: topoclusters for energy deposits in calorimeters: https://indico.physics.lbl.gov/event/2715/contributions/8548/attachments/4241/5725/Particle%20Flow%20and%20Jet%20Reconstruction.pdf
- ATLAS particle flow reconstruction of jets: https://arxiv.org/pdf/1703.10485

Particle Identification

- How is a particle's identify defined?
  - Mass
  - Lifetime
  - Quantum numbers: charge, spin, parity
- Methods of particle identification:
  - Charged particles:
    - Measuring momentum p and the velocity β, the mass can be deduced: $m = \dfrac{p}{\gamma\beta}$
      - The momentum can be measured in a magnetic filed and the Lorentz variables (β, γ or $\beta\gamma$) can be determined by measuring:
        - time of flight
        - specific energy loss by ionization (dE/dx)
        - Cherenkov radiation
        - transition radiation

Particle Identification

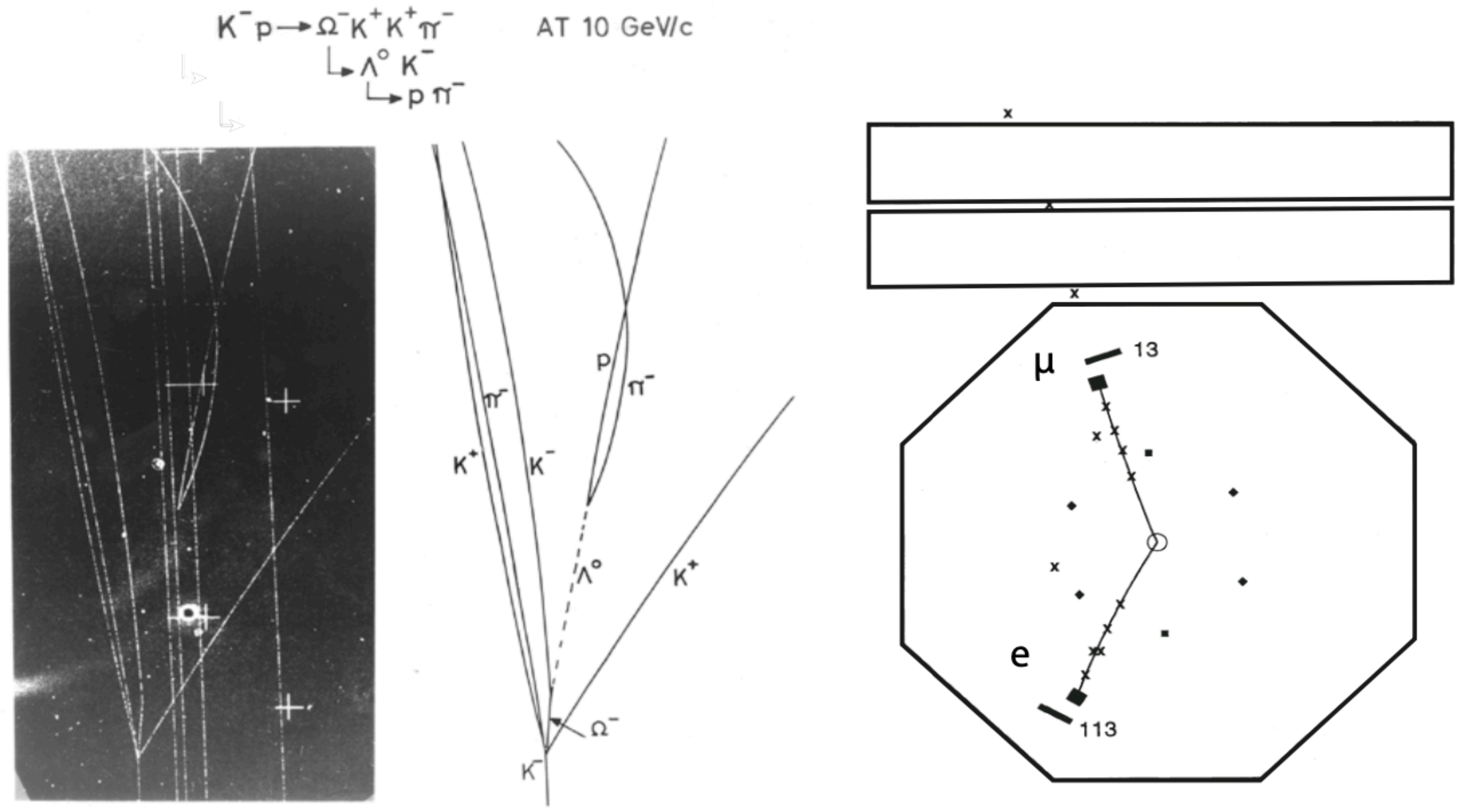


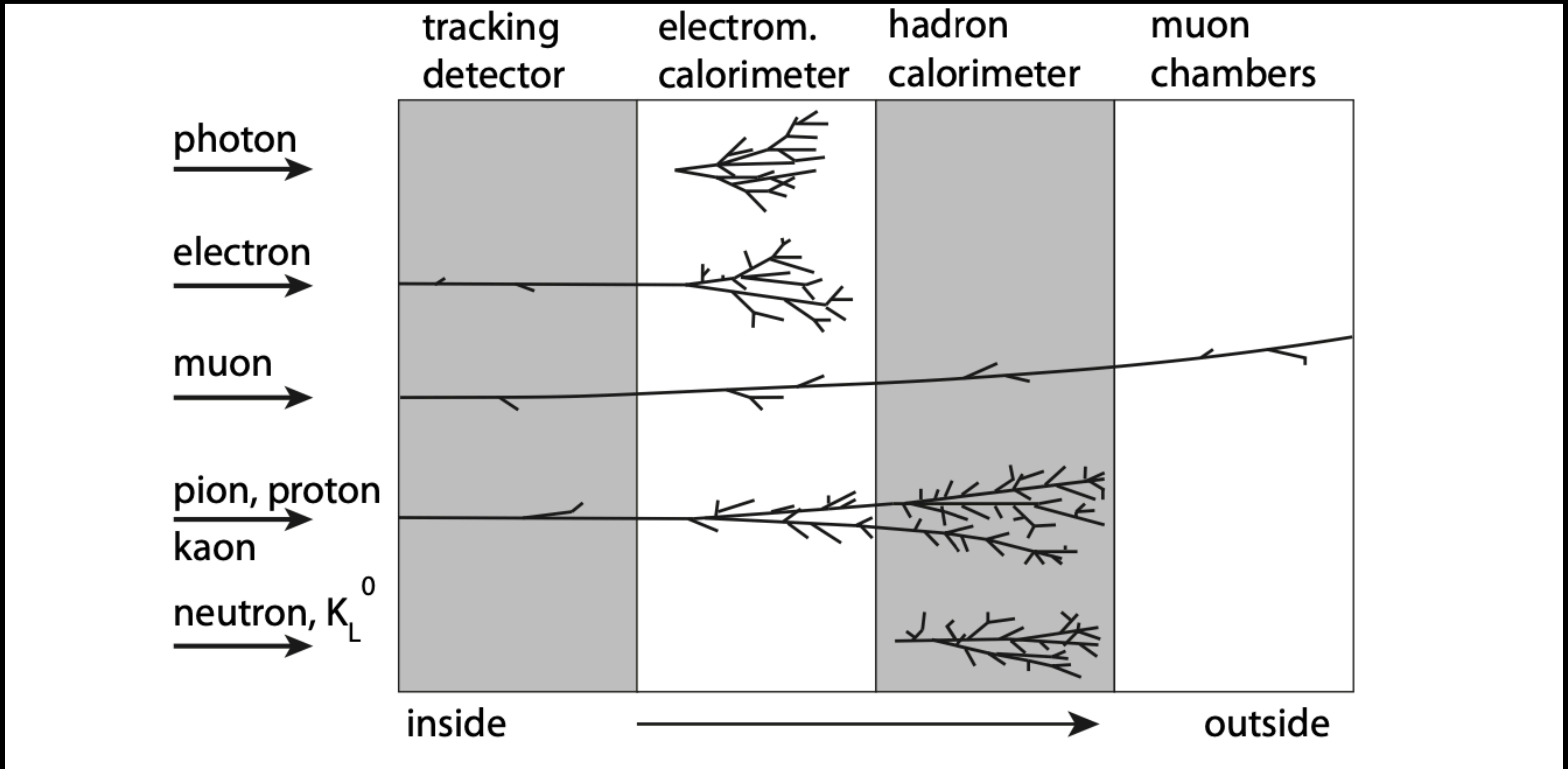
Fig. 14.1 Two historical examples for identification of a new particle. (a) The Ω^- baryon [156] is identified in a bubble chamber by its long lifetime, its kinematically reconstructed mass and associated strangeness production (source: CERN [284]). (b) τ-lepton pairs were first identified in e^+e^- collisions by observing a muon and an electron track in a cylindrical proportional chamber [774, 773]. The momenta of the tracks are unbalanced, indicating unidentified particles (neutrinos) taking part in the event. The upper track is identified as a muon since it traverses the iron yoke of the detector; the bottom track is an electron because 113 units of energy are deposited in the shower counter, to be compared to the muon energy of only 13 energy units. Taken from SLAC Report SLAC-PUB-5937 with kind permission by the SLAC National Accelerator Laboratory.

Particle Identification

- Masses (and sometimes also other quantum numbers) of decaying particles can be determined by kinematic reconstruction of the decay products:
- $m = \sqrt{\left(\sum_i p_i\right)^2}$, where p_i are the 4-momenta of the decay products
- Electrons and photons create electromagnetic showers. For electrons (and also for positrons), the measured shower energy E is about equal to the (magnetically determined) momentum p, such that $E/p \approx 1$

Particle Identification

- For muons, use their capability to penetrate thick absorber materials
- Hadrons can (at sufficiently high energies) be recognized via hadron showers
- Particles decaying on a time-scale of picoseconds can be identified by measuring the flight distance from production to decay by measuring traces of the decay products



Particle Identification

- The experimental techniques employed in particle identification change with the energy of the particles to be identified
- Methods, employed very successfully for low-energy particles, as for example time-of-flight or dE/dx methods are not suitable at high energies
- For detectors like LHCb and ALICE, which do not aim for full angle coverage, employ Cherenkov detectors for particle identification
- ATLAS and CMS restrict themselves to identifying:
  - Jets as signatures of quarks or gluons
  - Leptons (electrons, muons)
  - Photons
  - Secondary vertices as signatures of heavy quarks or heavy leptons

Long-lived particles

- The flight time of a particle between two detectors directly yields the velocity of the particle
- A particle with momentum p and mass m traverses two detectors positioned at a distance L from each other
  - One of the detectors generates the start and the other the stop signal
  - The time difference between the signal is digitized by a TDC (time to digital converter) with a resolution given by the TDC clock:
    - From the flight duration:
    - $\Delta t = \frac{L}{\beta c} = \frac{L}{c}\sqrt{\frac{p^2 + m^2}{p^2}}$
    - $\beta = \frac{L}{\Delta t c}$
    - $m^2_{TOF} = p^2 \left[\left(\frac{\Delta t c}{L} \right)^2 - 1 \right]$

Long-lived particles

- Difference in flight times of two particles of equal momenta but different masses ($m_2 > m_1$), one obtains ($p^2 \gg m^2$):
  - $$\frac{\Delta t_2 - \Delta t_1}{L} \approx \frac{1}{2cp^2}(m_2^2 - m_1^2)$$
- Mass resolution:
  - $$\frac{\sigma_m}{m} = \sigma_p p \oplus \gamma^2 \left(\frac{\sigma_{\Delta t}}{\Delta t} \oplus \frac{\sigma_L}{L} \right)$$
  - Mass resolution typically driven by the time measurement
    - $$\frac{\sigma_m}{m} \approx \gamma^2 \frac{\sqrt{2}\sigma_t}{\Delta t}$$

Time of flight for particle identification

- $n_\sigma(TOF) = \frac{m_2^2 - m_1^2}{\sigma_m^2} \approx \frac{\Delta t_2 - \Delta t_1}{\sigma_{\Delta t}} \approx \frac{L}{2\sqrt{2}cp^2\sigma_t}(m_2^2 - m_1^2)$