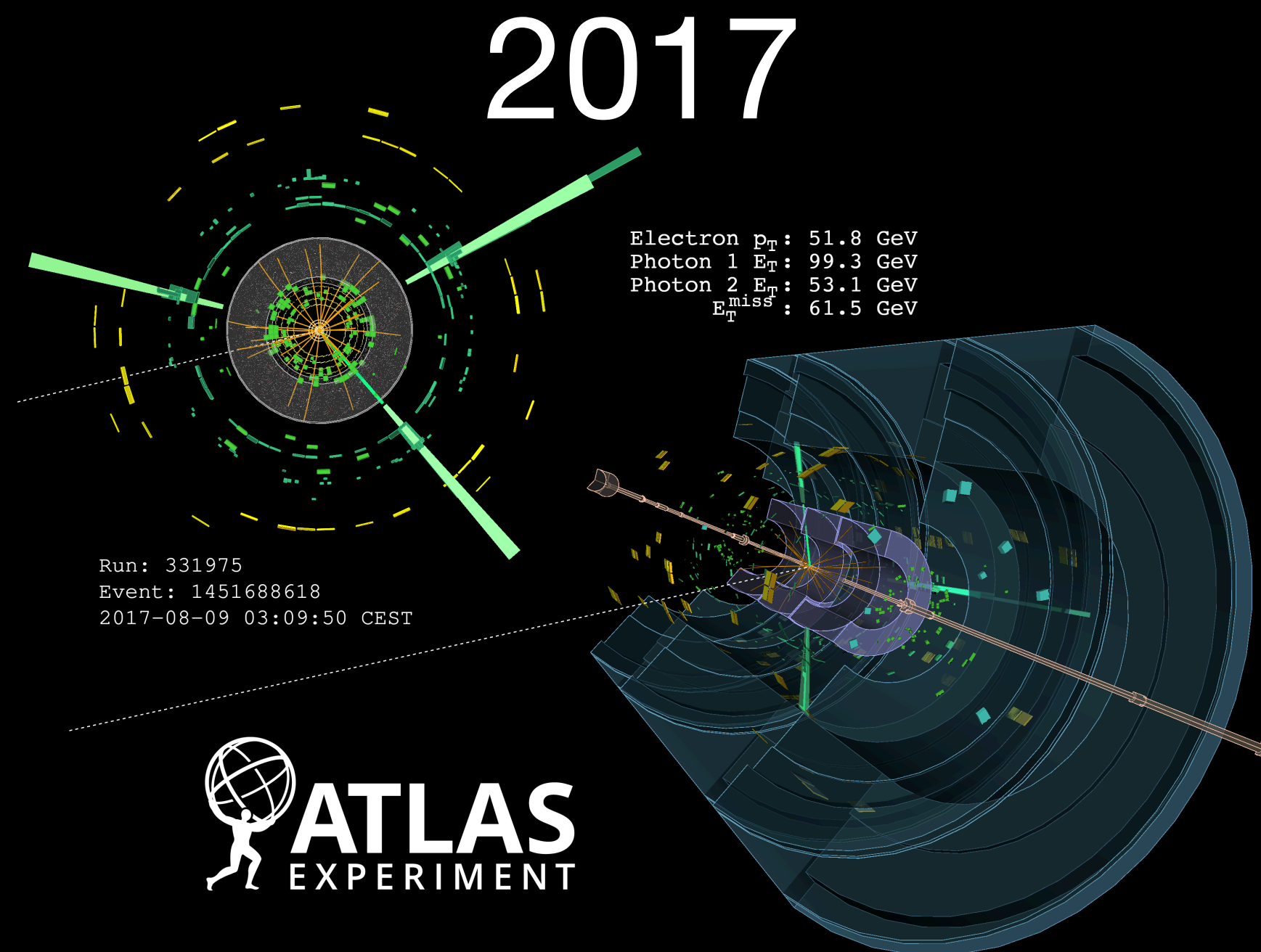


# PHYS 7363 - Experimental Particle Detection and Detectors I



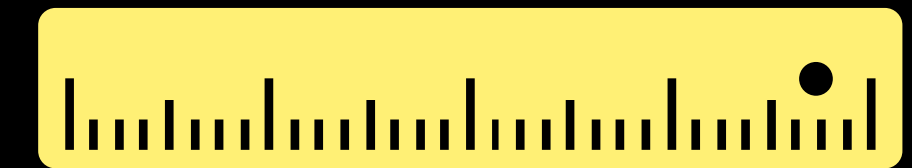
Particle detectors are the workhorses of experimental physics. In this course, we'll dive deep into their physics, exploring the incredible evolution of our experimental techniques over the past nine decades. You'll gain a solid understanding of *particle detection and identification*, examine the intricate 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](mailto:saptaparnab@smu.edu)



# Multiboson group at SMU



- I joined Southern Methodist University as an Assistant Professor in the fall of 2024
- My research interests lie in multiboson physics, polarization measurements and effective field theories
- I am interested in studying event generators on GPUs and contributing to ATLAS upgrades

# 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	9	10	11	12	13	14
	15	16	17	18	19	20	21
	22	23	24	25	26	27	28
	29	30	1	2	3	4	5
October	29	30	1	2	3	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

# Key dates

- Weeks 1-4: Particle interaction with matter
  - Interaction of charged and neutral particles
  - Particle showers
- Weeks 5-9: Detector technologies:
  - Tracking detectors (gaseous detectors, semiconductor detectors)
  - Particle detection with photons (scintillators, Cherenkov detectors)
  - Calorimetry (electromagnetic and hadronic calorimeters)
- Weeks 10-12: Large and small scale experiments:
  - Triggering and data acquisition
  - Tracking
  - Full reconstruction (particle flow)
- Week 13-15: Preparation for final project:
  - FCC-ee: [https://indico.fnal.gov/event/67484/contributions/314057/attachments/187076/257915/US%20FCC%20Tutorial\\_FullSim.pdf](https://indico.fnal.gov/event/67484/contributions/314057/attachments/187076/257915/US%20FCC%20Tutorial_FullSim.pdf)
  - Muon collider: <https://mcd-wiki.web.cern.ch/software/tutorials/fermilab2024/>

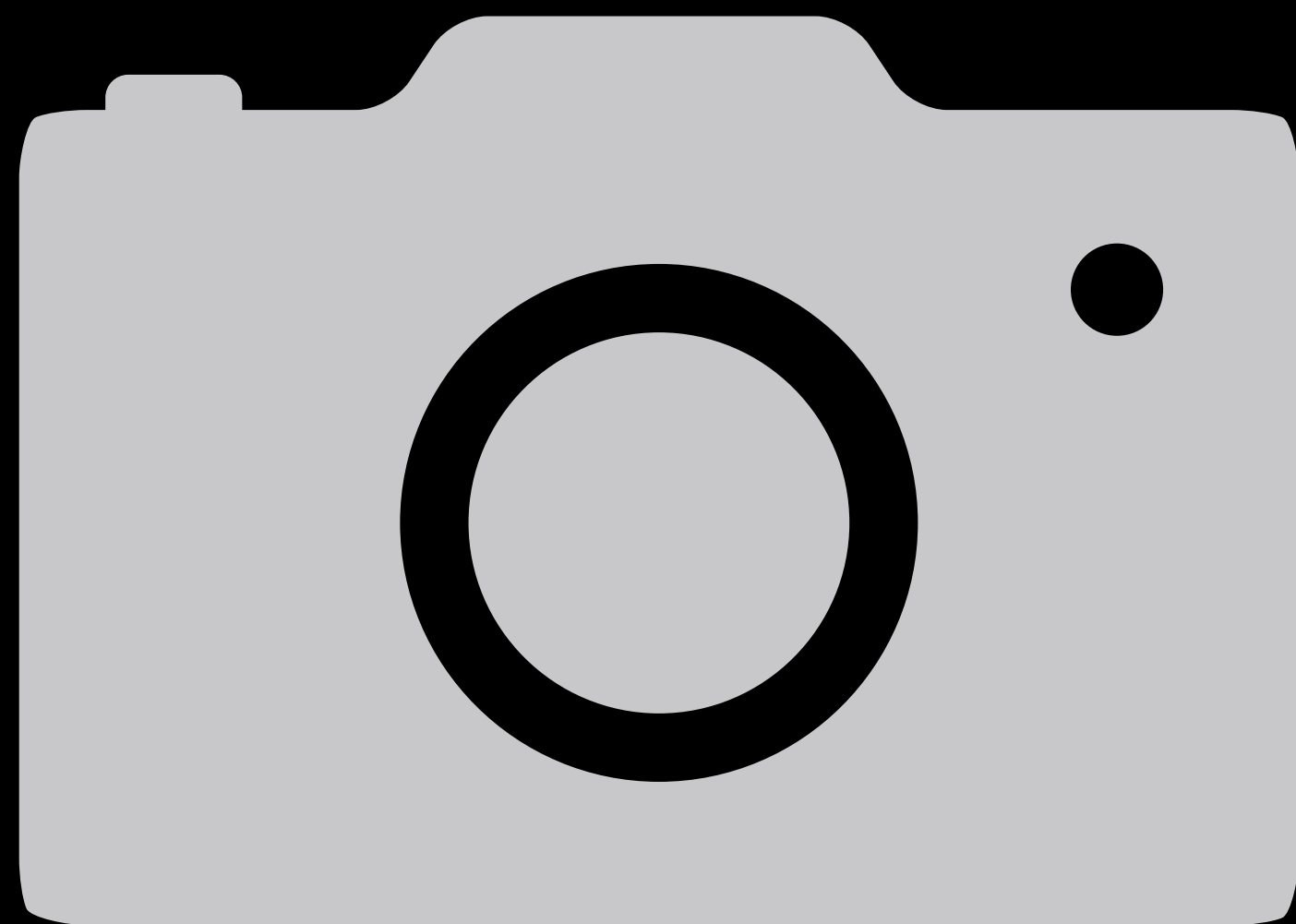
# Resources

- PDG review: Passage of particles through matter
  - <https://pdg.lbl.gov/2020/reviews/rpp2020-rev-passage-particles-matter.pdf>
- N. Wermes / H. Kolanoski, “Particle Detectors”, Oxford University Press, 2020
- C. Grupen / B. Schwartz, “Particle Detectors”, Cambridge University Press, 2011
- F. Hartmann, “Evolution of Silicon Sensor Technology in Particle Physics”
- A. Strandlie, R. Frühwirth, Pattern Recognition, Tracking and Vertex Reconstruction in Particle Detectors

- What do you know about detectors?
- Which sub detector are you working on?

# What are the requirements of a particle physics detector?

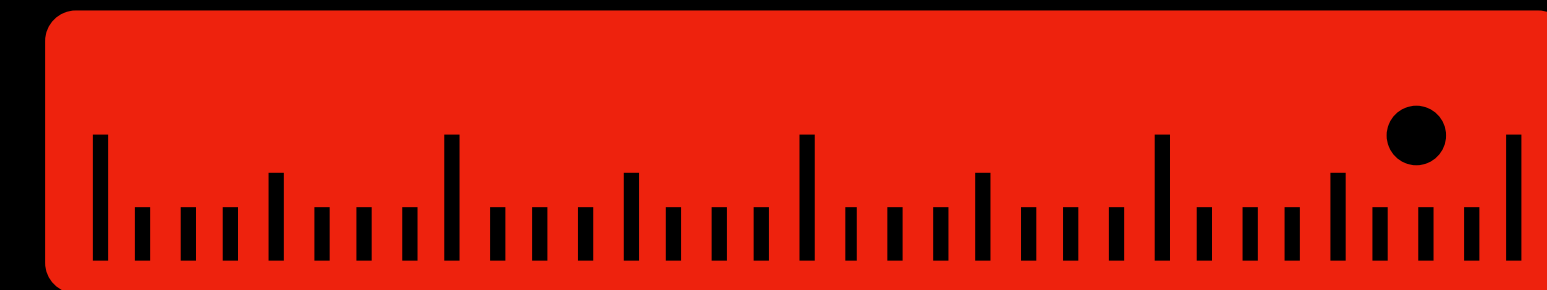
Detect



Identify



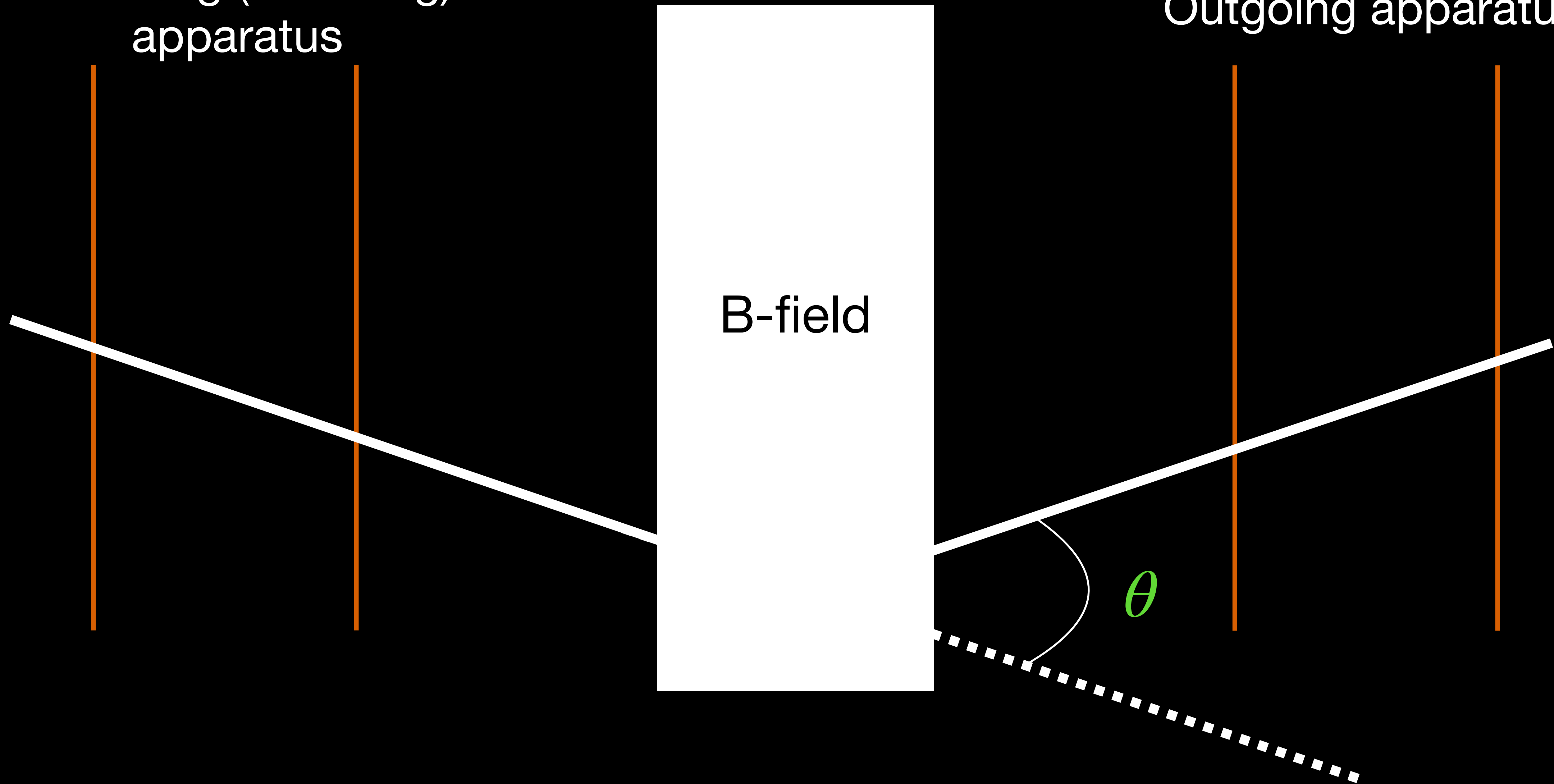
Measure



# A simple detector

Detecting (incoming)  
apparatus

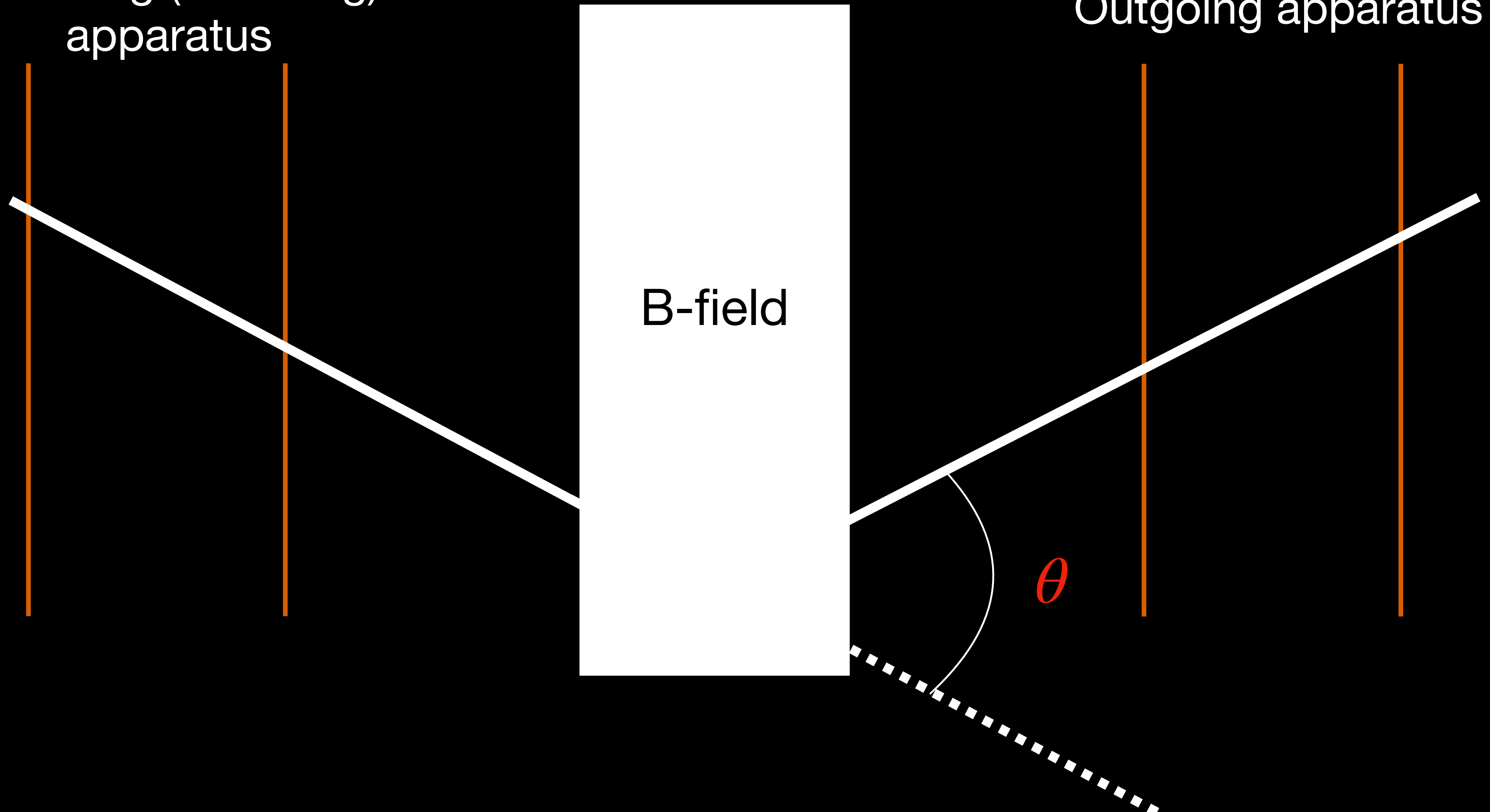
Outgoing apparatus



# A simple detector

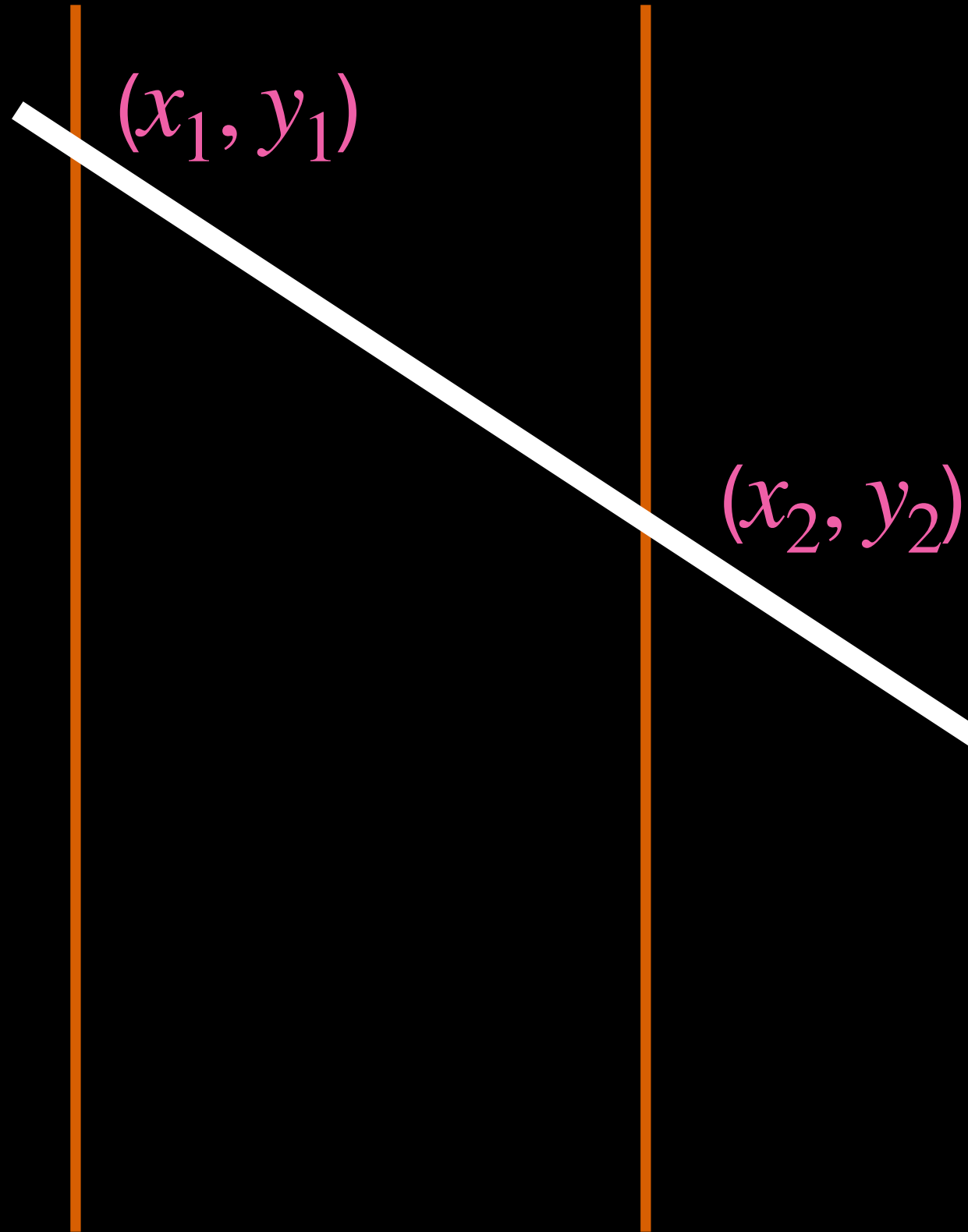
Detecting (incoming)  
apparatus

Outgoing apparatus

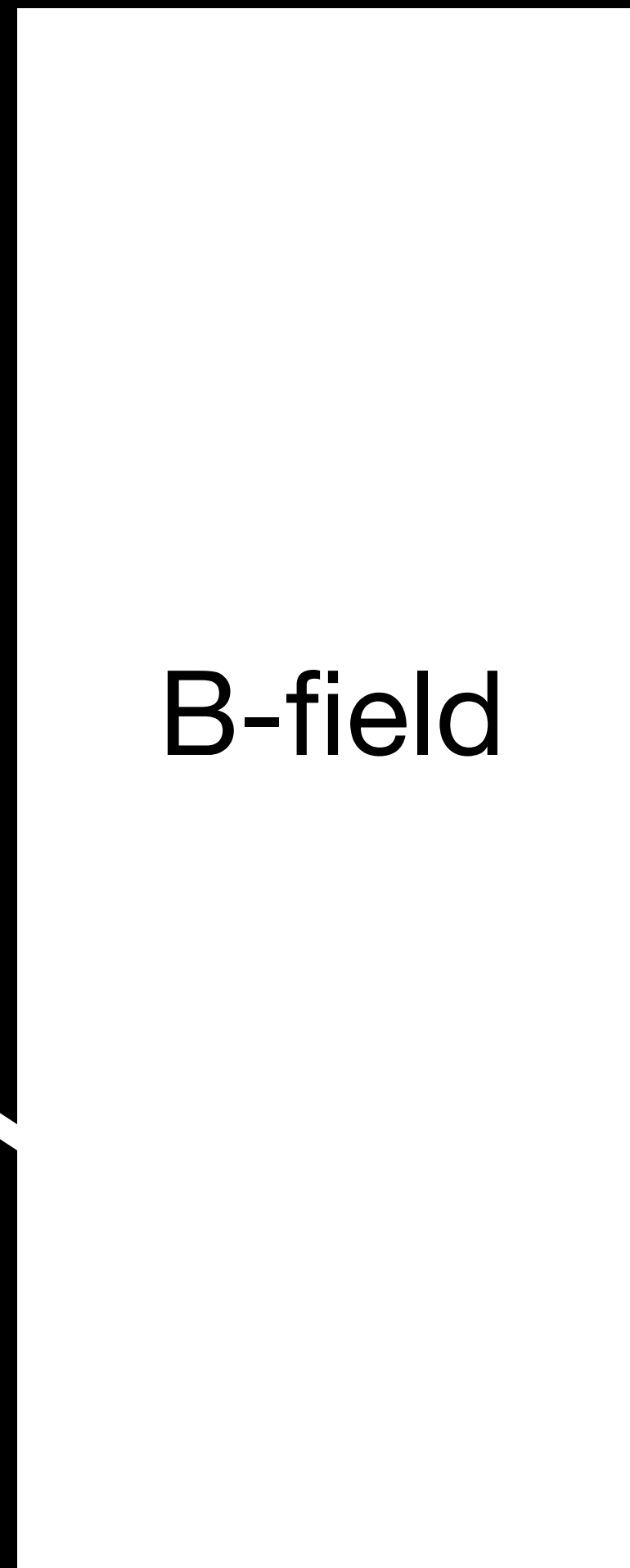


# A simple detector

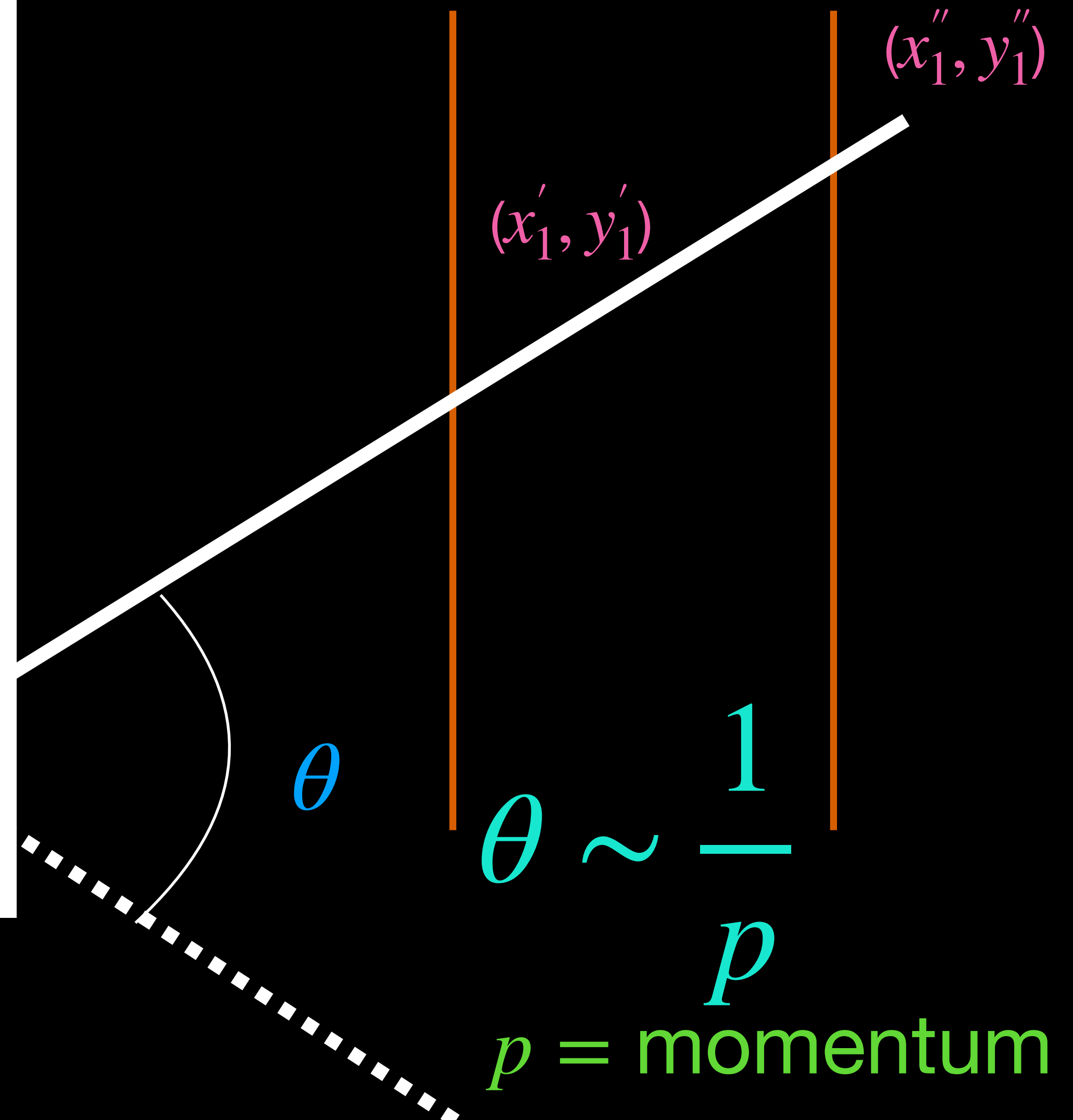
Detecting (incoming)  
apparatus



Use coordinates to construct  
straight line trajectory  $\rightarrow$  track



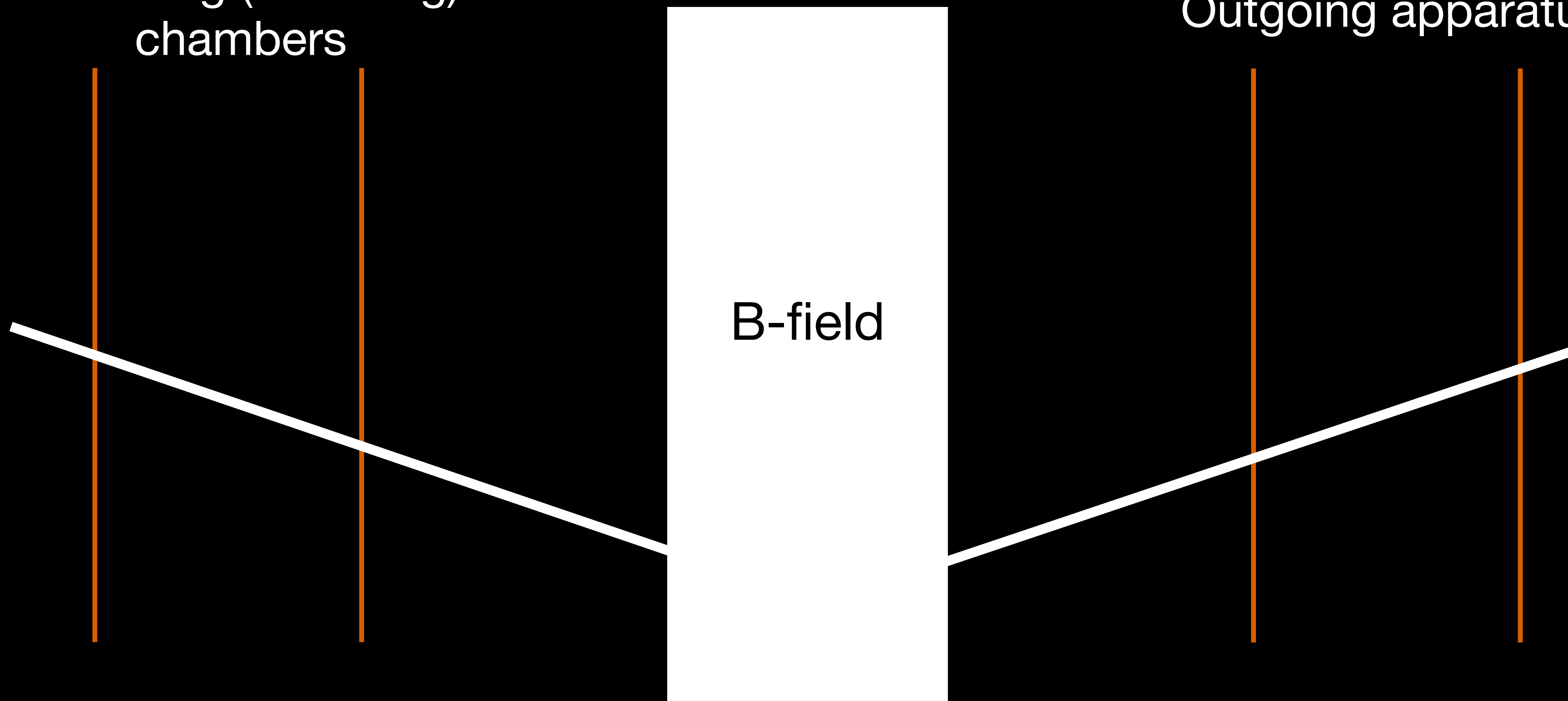
Outgoing chambers



# A simple detector

Detecting (incoming)  
chambers

Outgoing apparatus

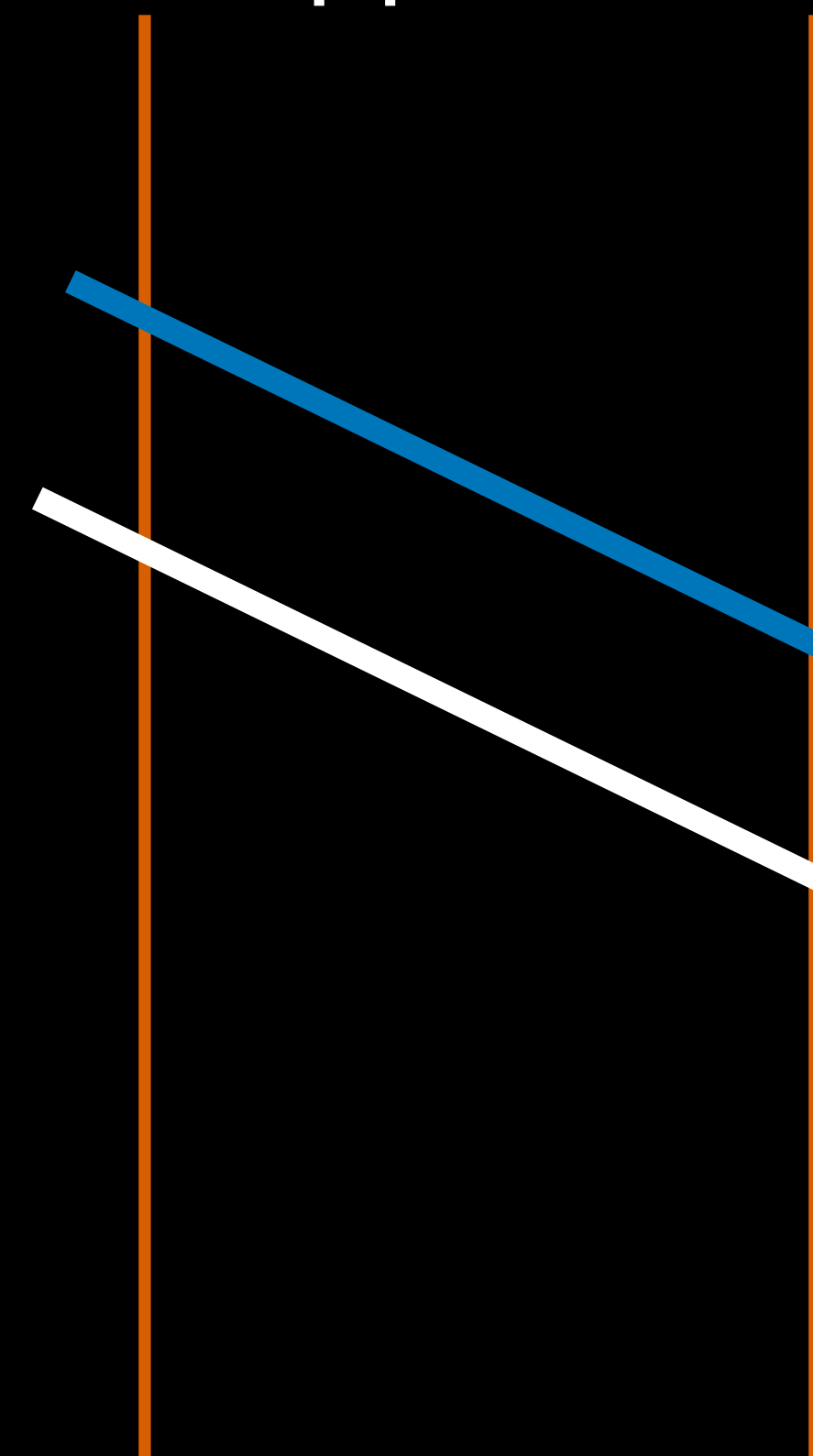


Same principle applies to  $e$  and  $\mu$

At LHC energies,  $p \sim E$

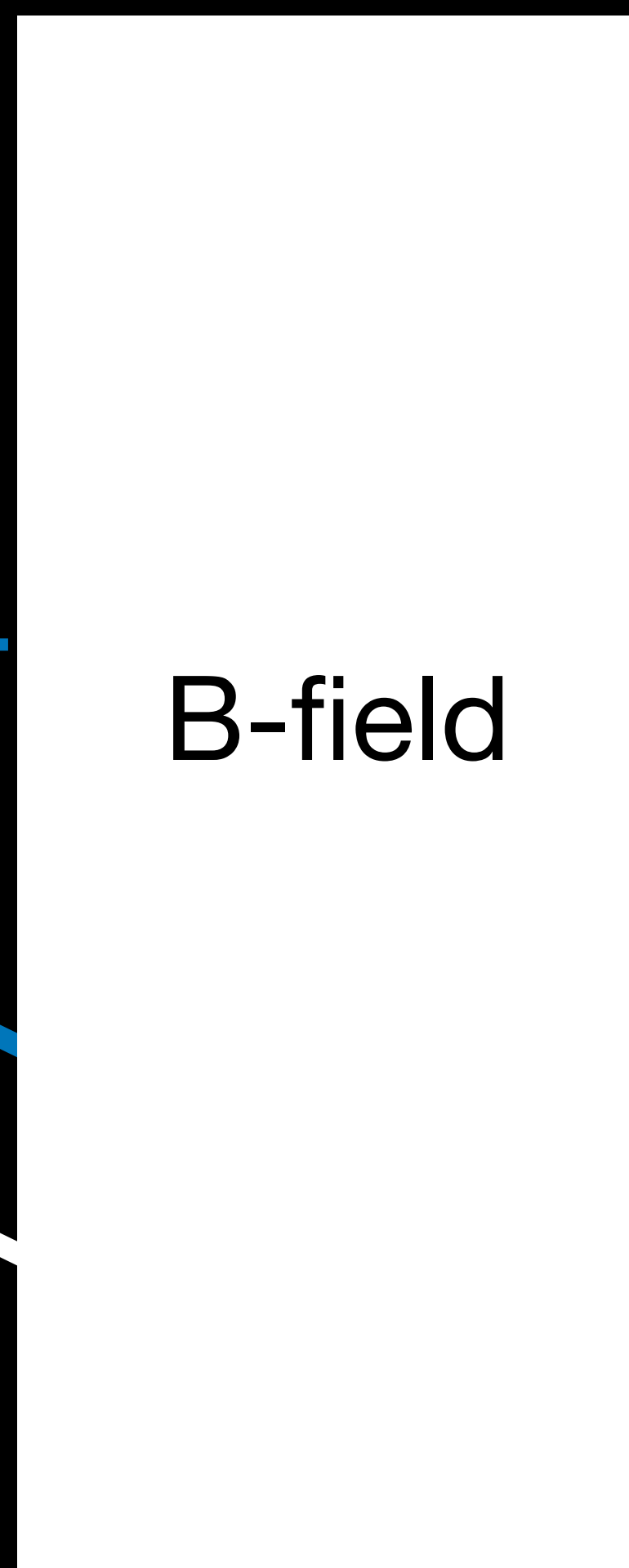
# A simple detector — for different types of particles

Detecting (incoming)  
apparatus

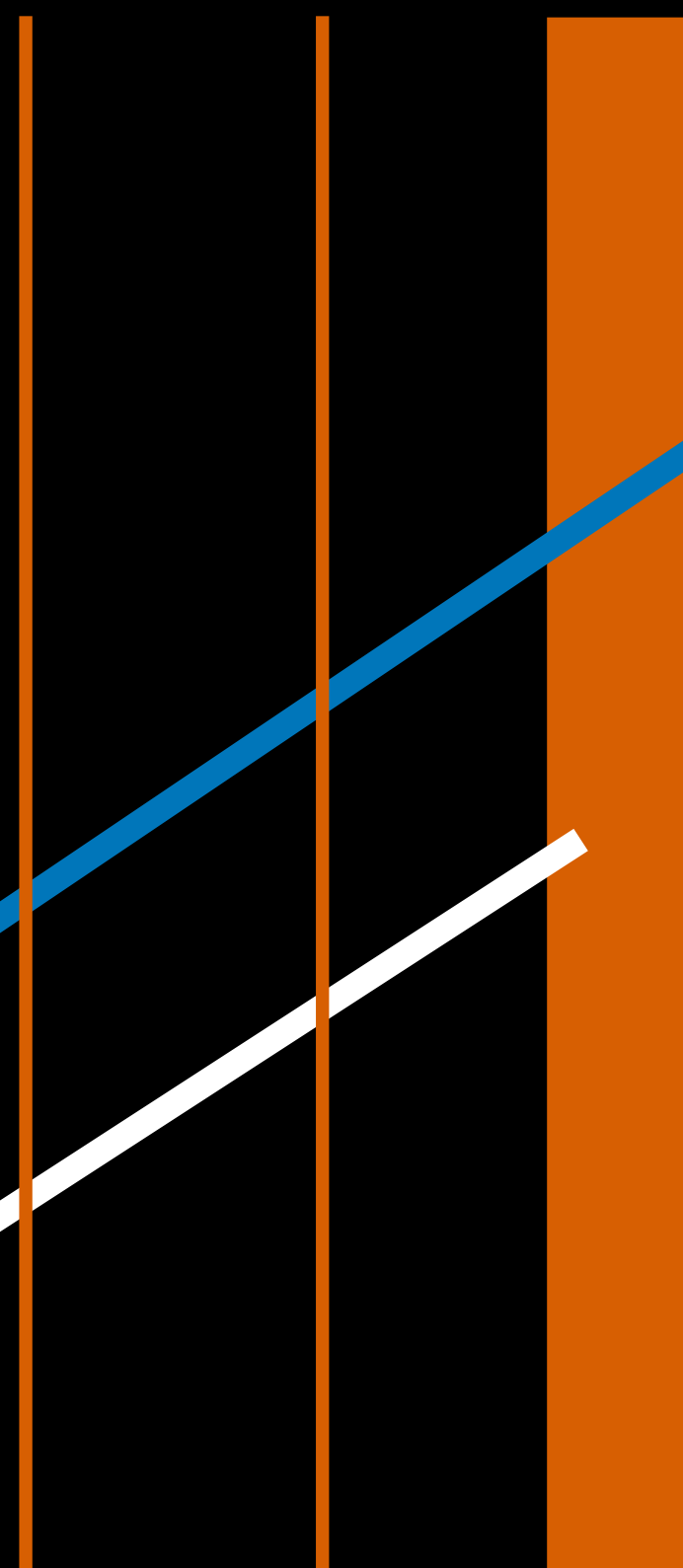


$\mu^+$

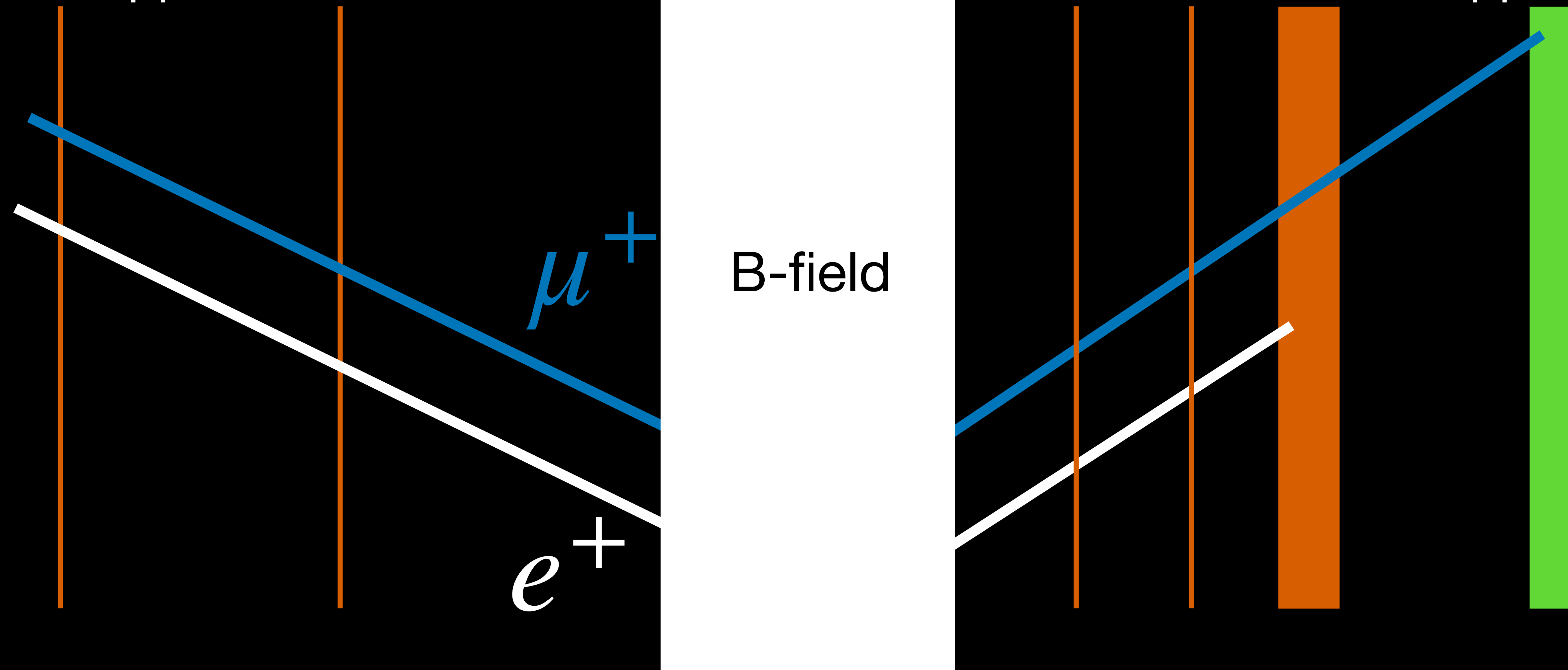
$e^+$



Absorber



Outgoing  
apparatus

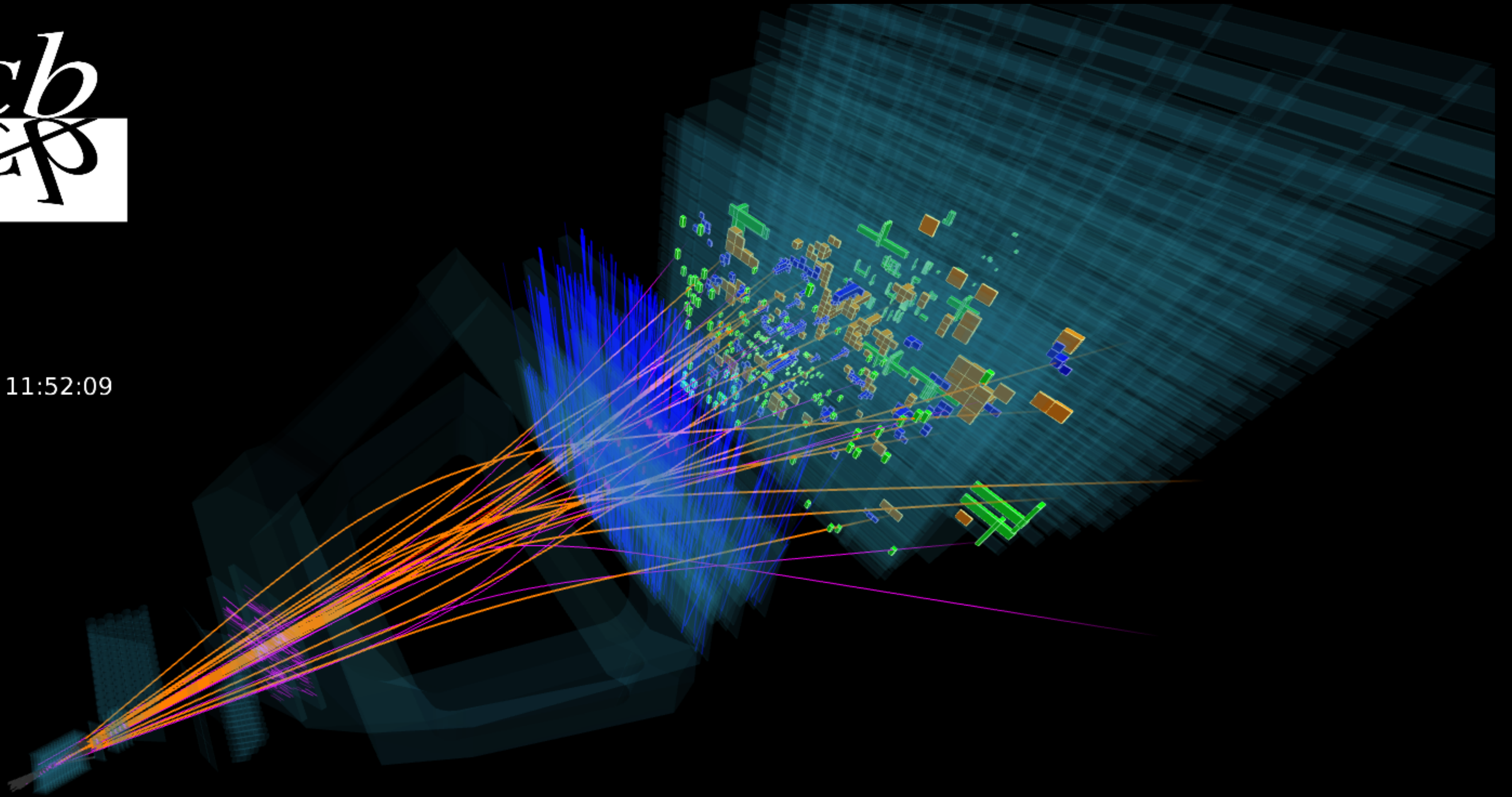




Event 41383468

Run 153460

Wed, 03 Jun 2015 11:52:09



An LHC experiment — based on elements of a simple detector

# What have we learned so far

- Charged particles can be detected through interaction with a detector
- Momenta can be measured from their trajectories → tracking

## Other means of measurement

Energy can be measured through interaction with matter → calorimetry

# Two types of interactions

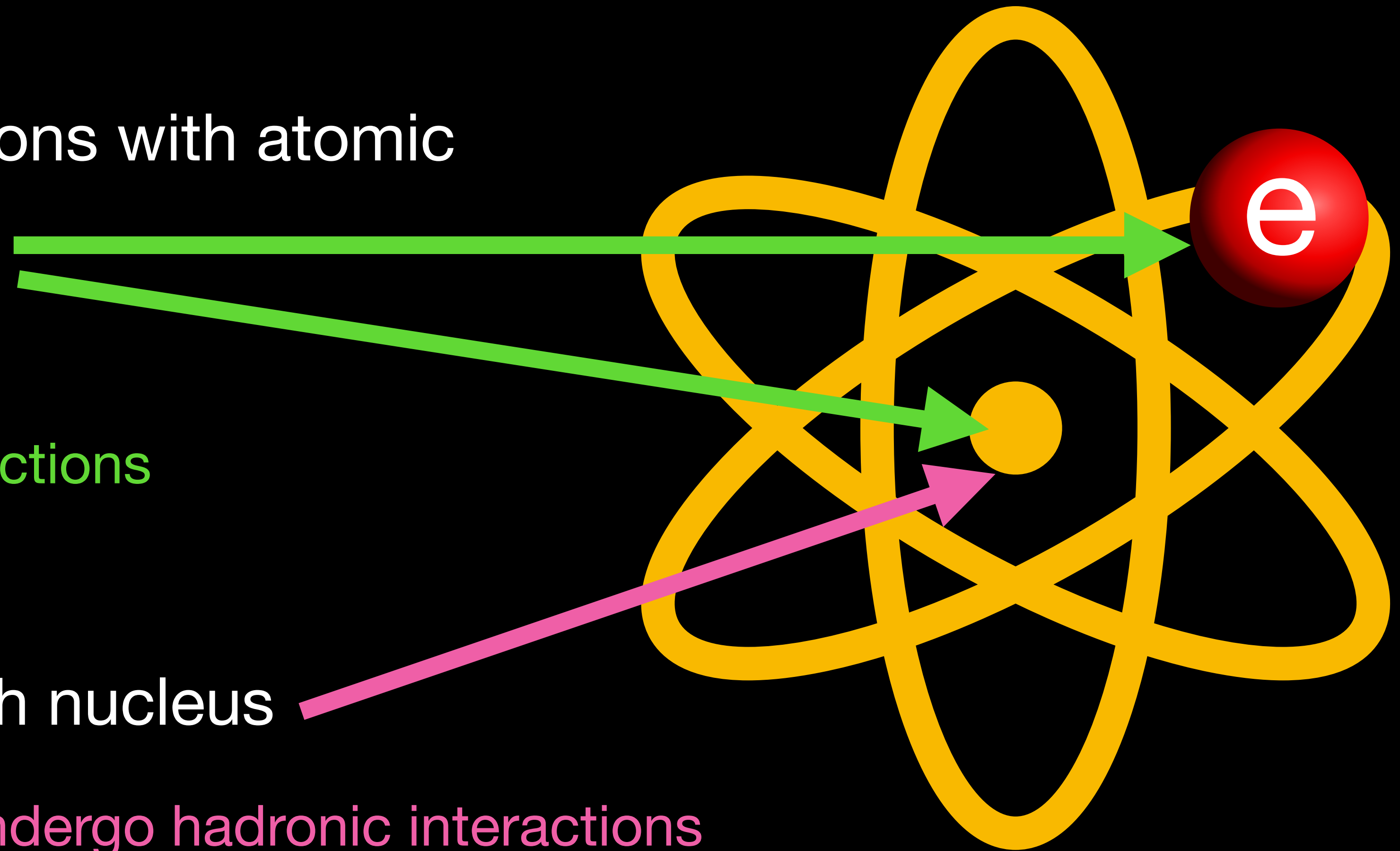
- Electromagnetic interactions with atomic electrons and nucleus

Photons, electrons and muons undergo electromagnetic interactions

- Hadronic interactions with nucleus

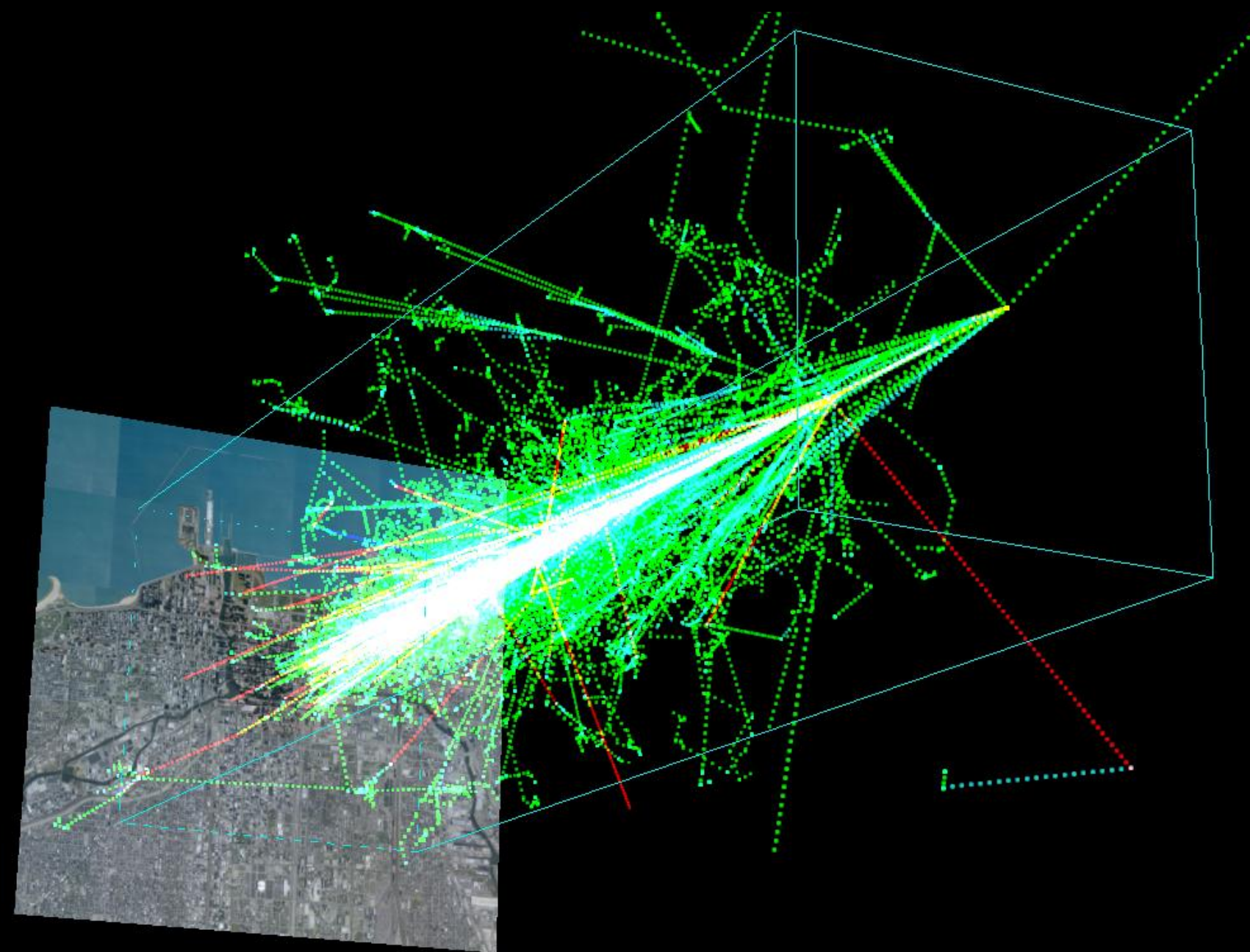
Protons, neutrons and pions undergo hadronic interactions

Hadronic interactions involve quarks and gluons and the strong force

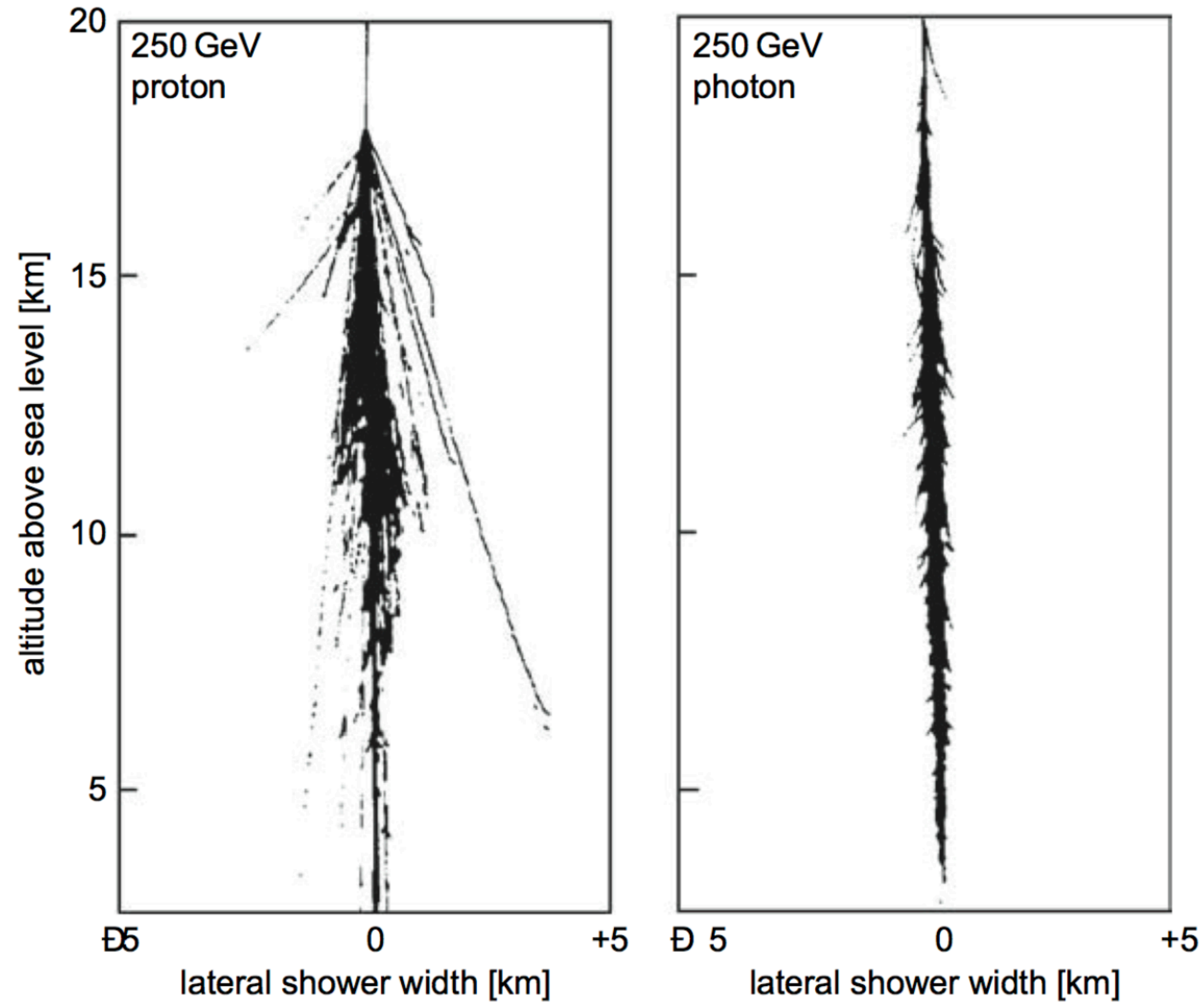


# Two types of showers

- Electromagnetic showers are short and dense and initiated immediately
- Hadronic showers are larger and diffused and initiated with some delay

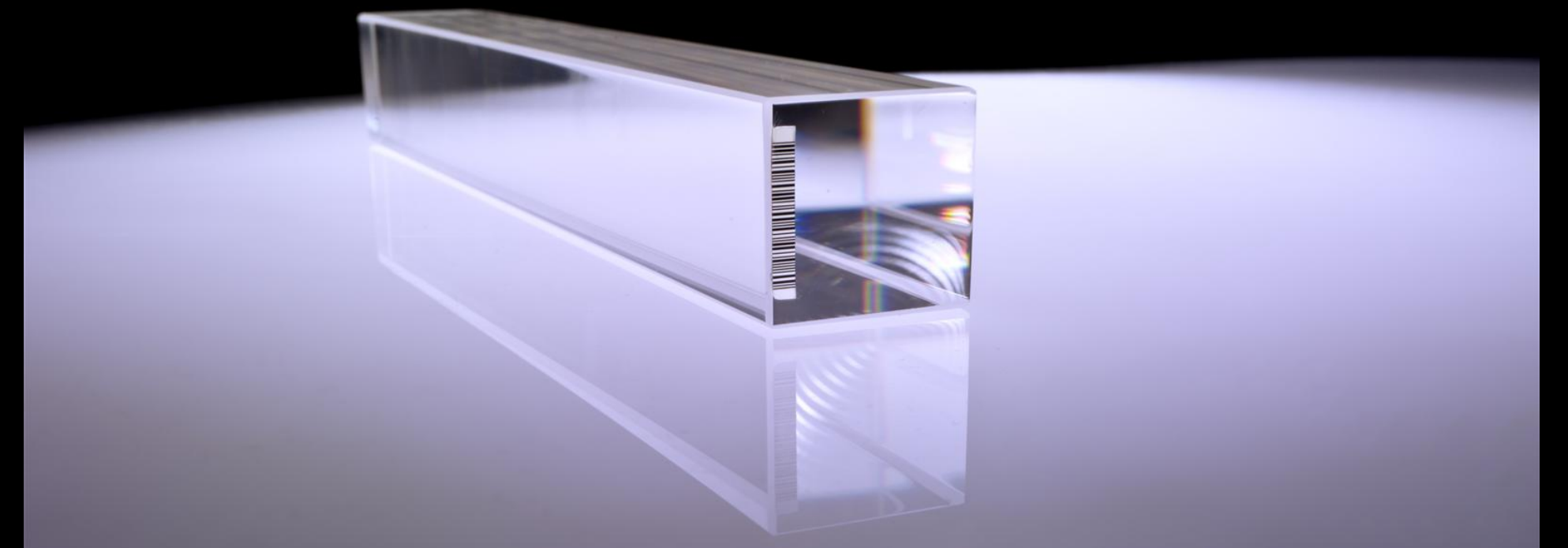


# Two types of showers



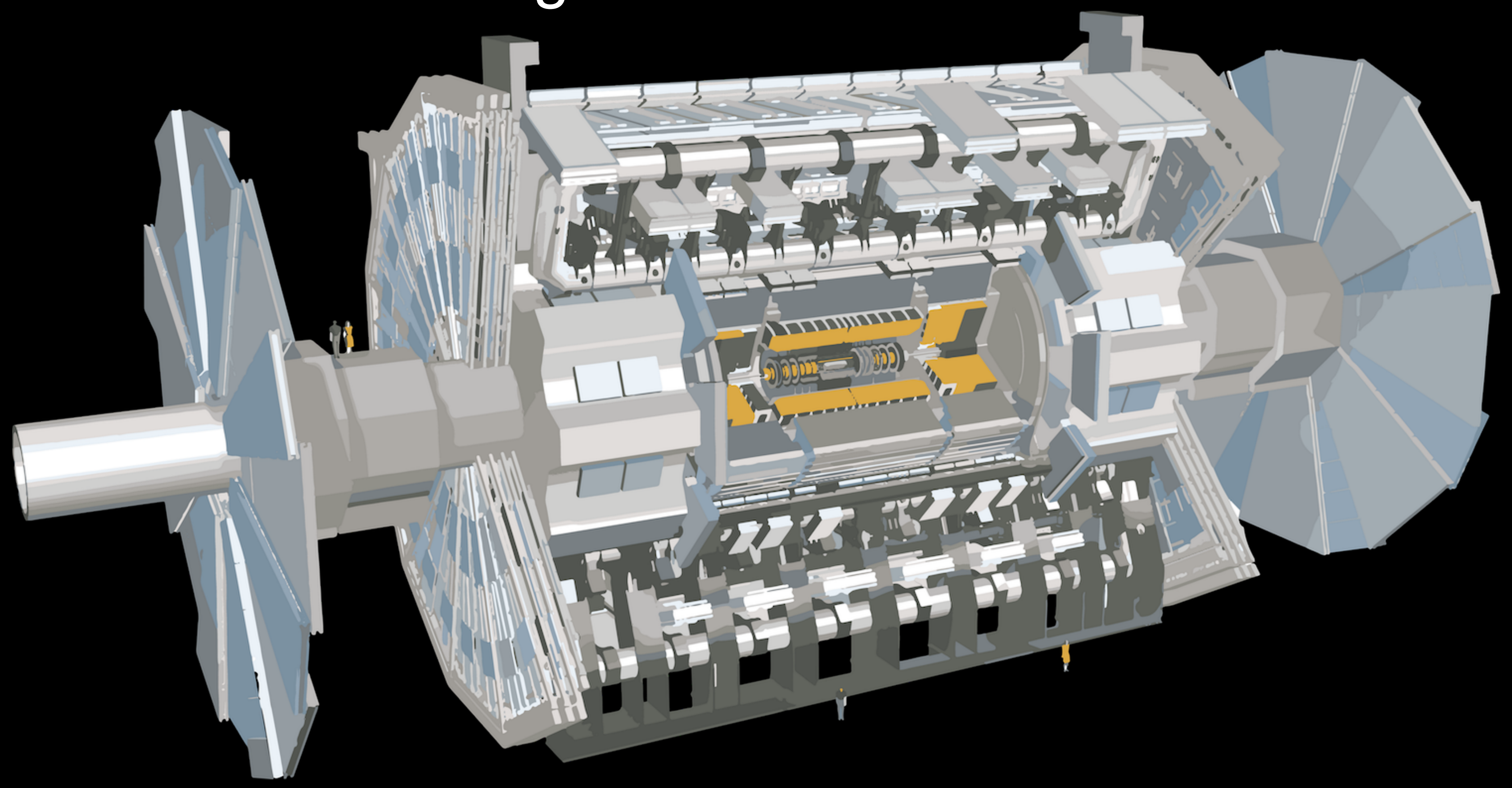
# Calorimeters

- The energy absorbed is proportional to the energy of incoming particle
- We can use this fact to build a detector that measures shower energies
- CMS uses special crystals to measure the energy of electromagnetic showers like those induced by a photon
- CMS also has a hadronic calorimeter, built using traditional techniques

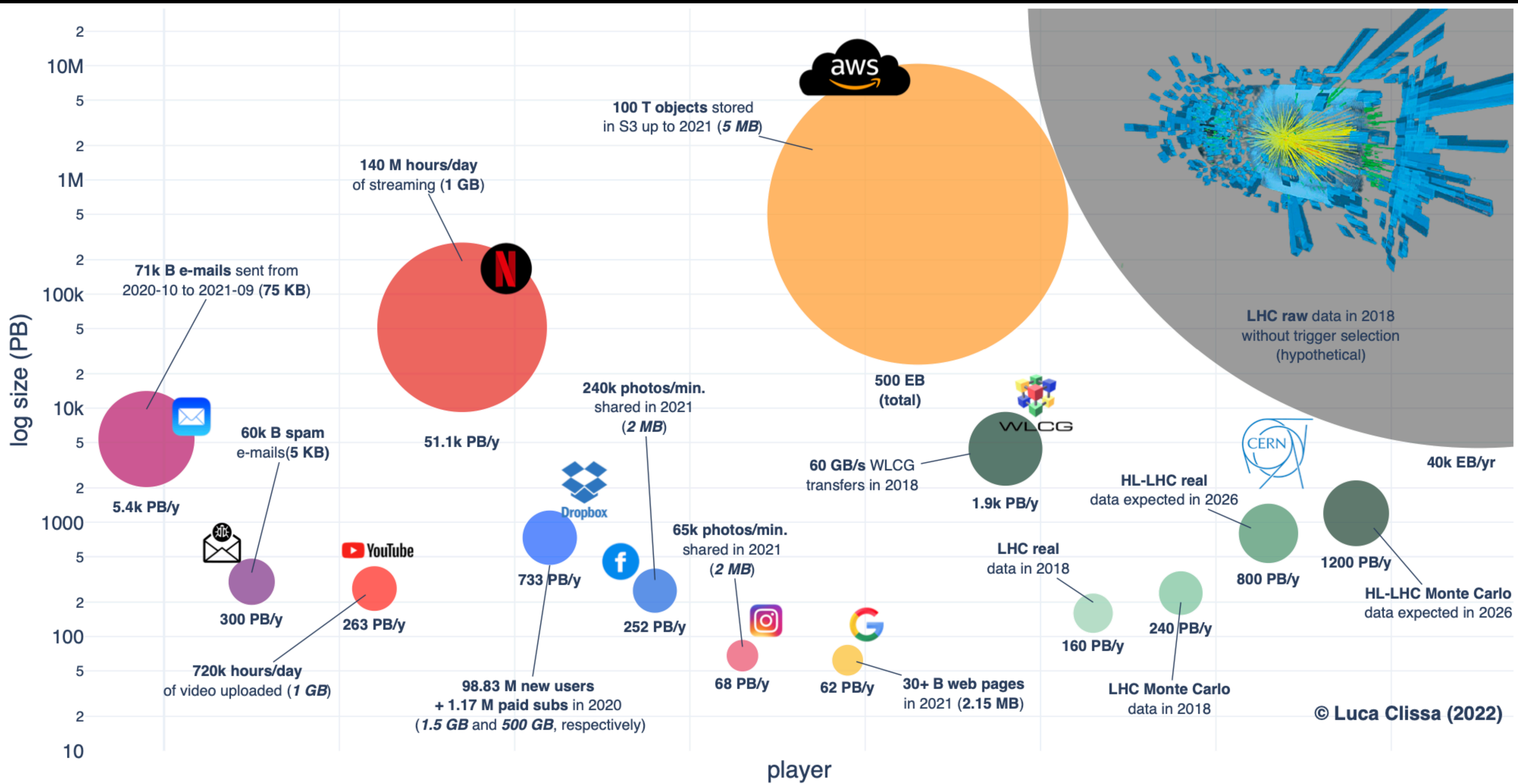


Electromagnetic calorimeter  
made with lead tungstate  
crystals

# Focusing on the ATLAS detector



# Data Collection



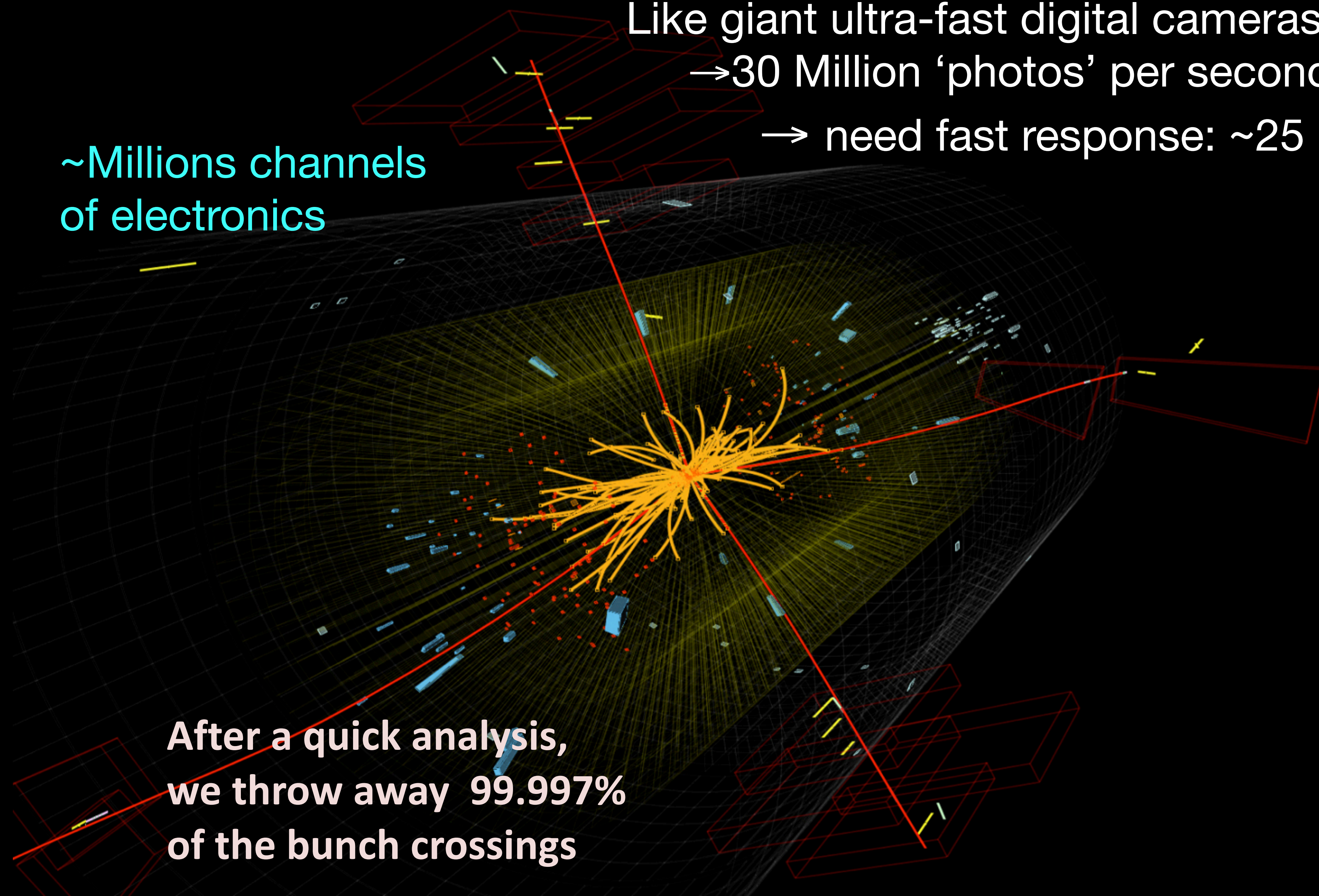
~Millions channels  
of electronics

Like giant ultra-fast digital cameras

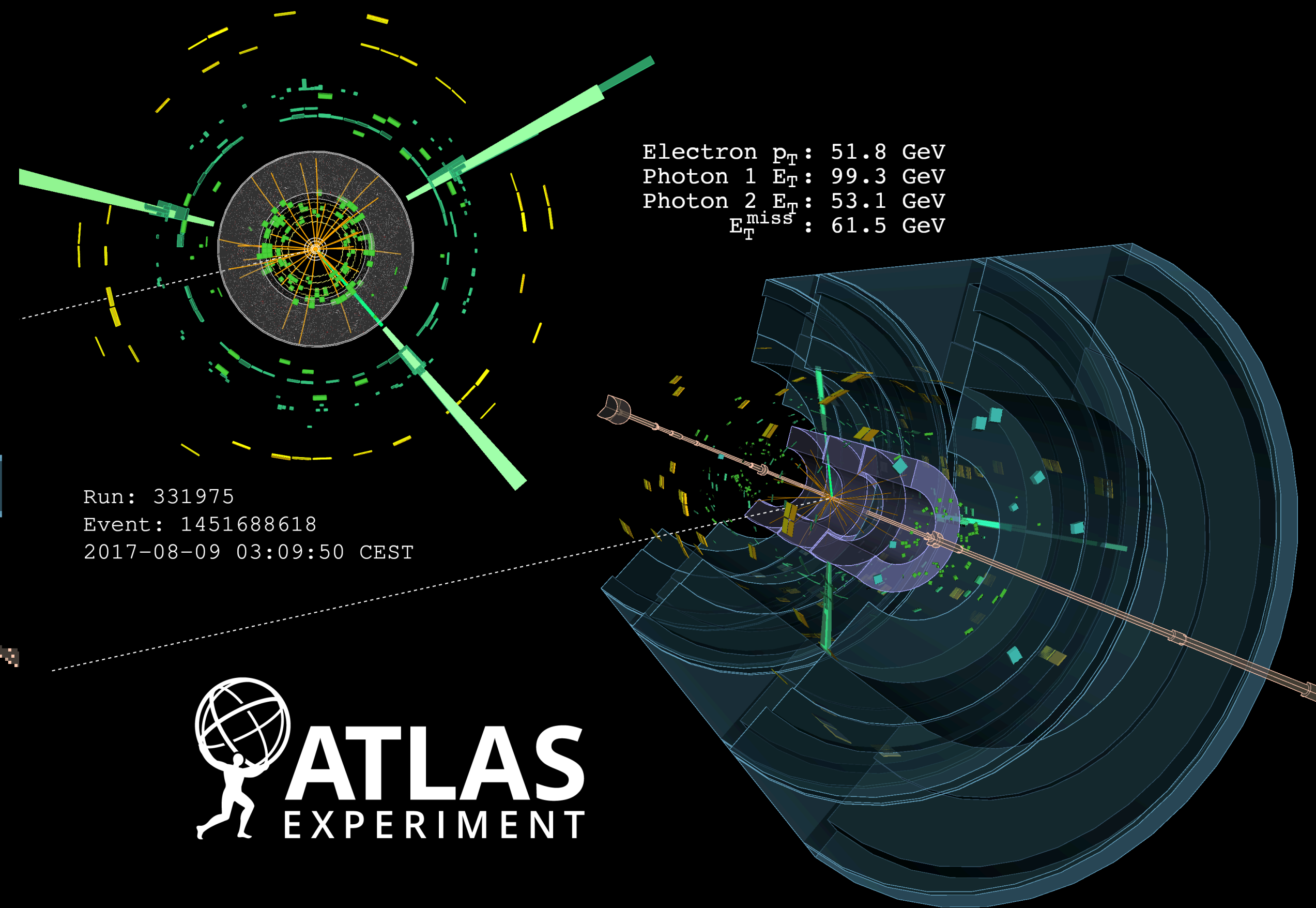
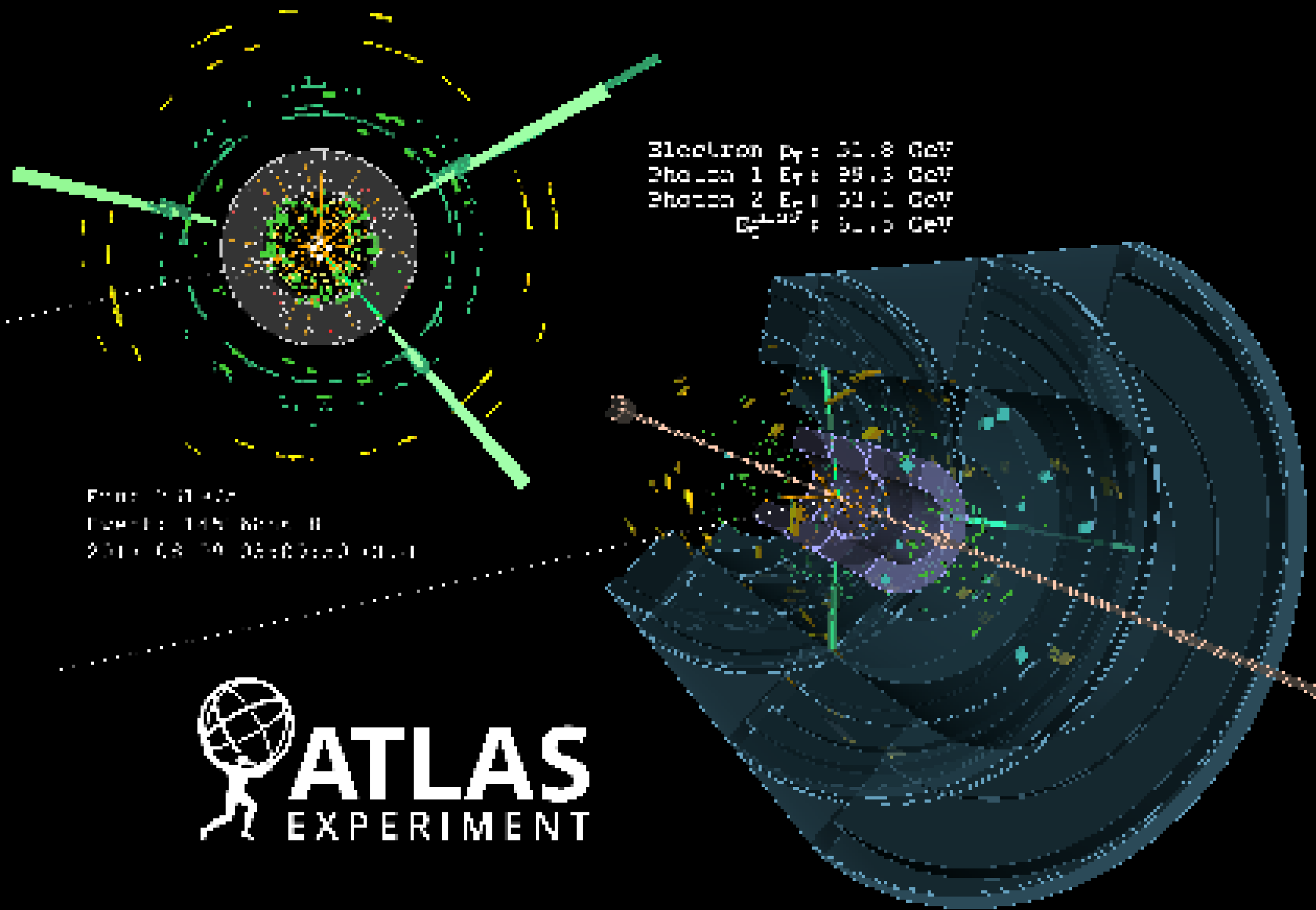
→ 30 Million 'photos' per second

→ need fast response: ~25 ns

After a quick analysis,  
we throw away 99.997%  
of the bunch crossings

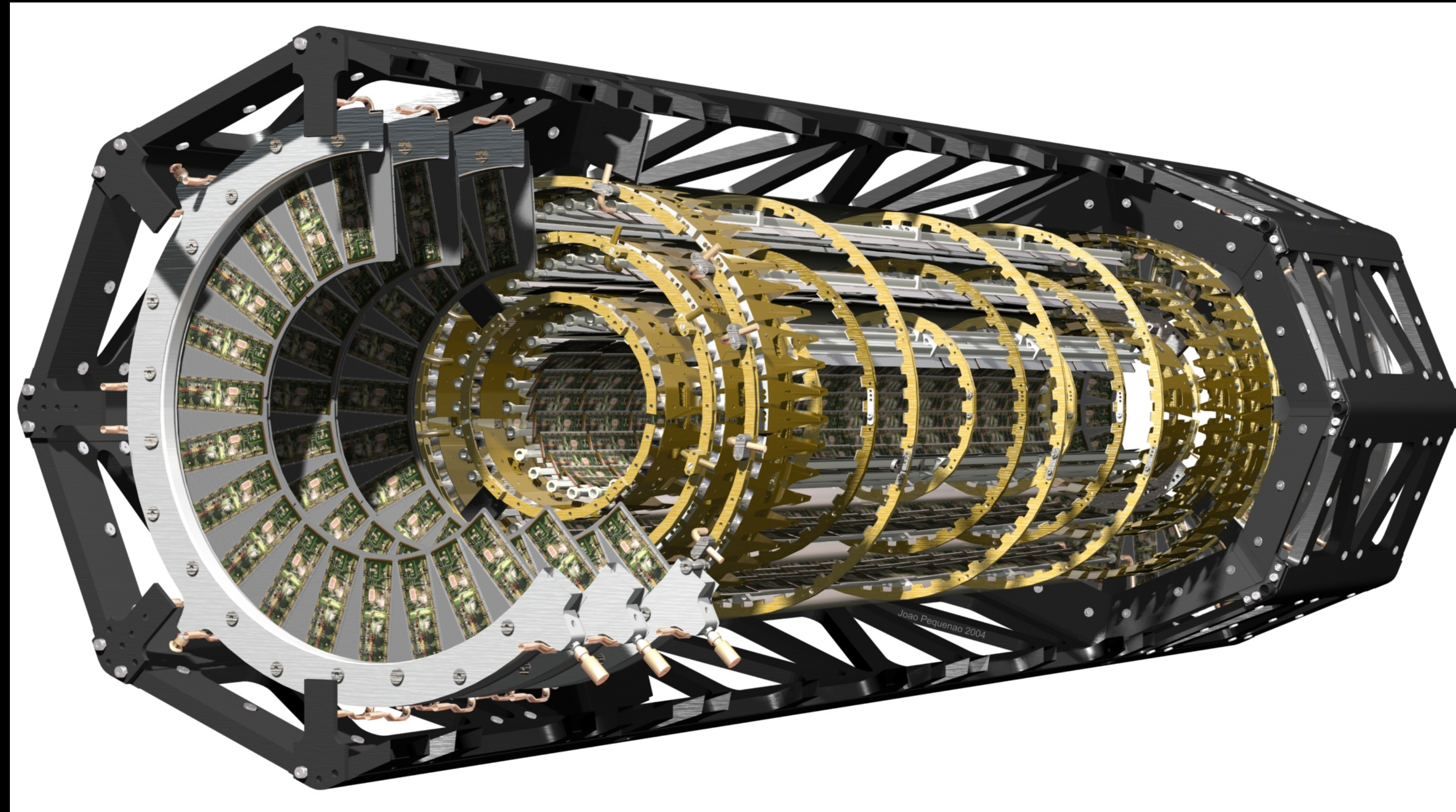


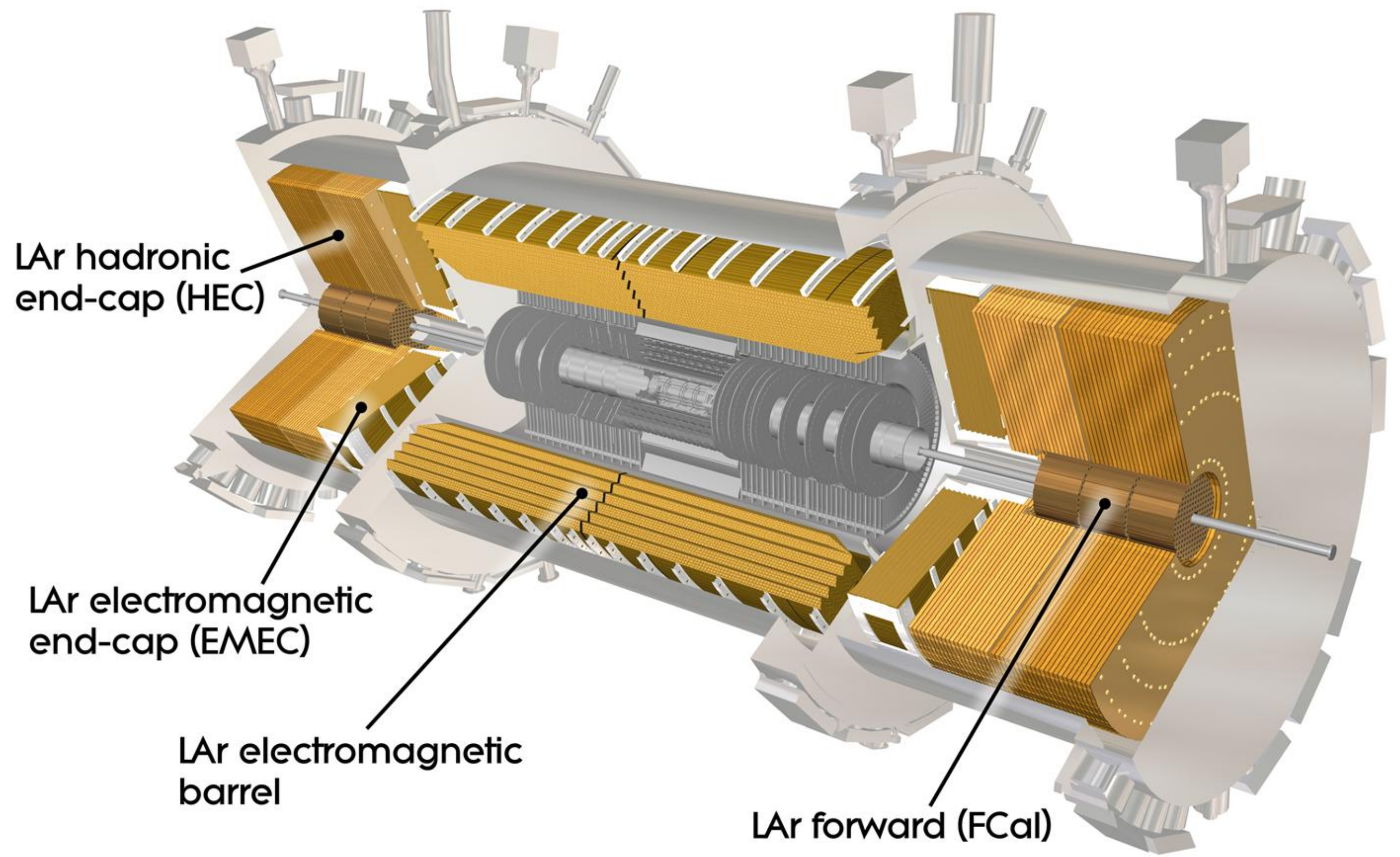
# Trigger





# Inner detector — the tracker





LAr hadronic end-cap (HEC)

LAr electromagnetic end-cap (EMEC)

LAr electromagnetic barrel

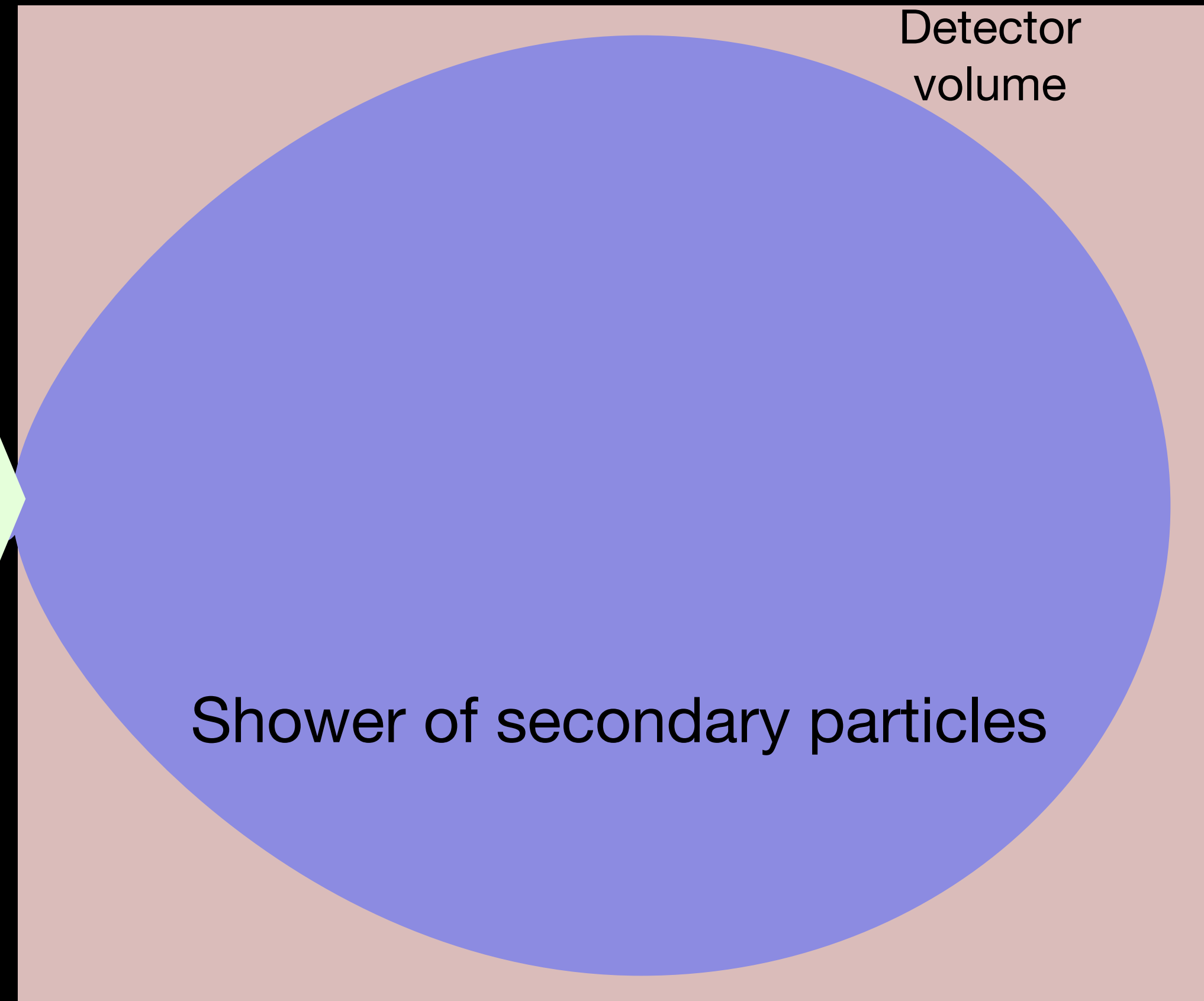
LAr forward (FCal)

# Homogeneous calorimeter

Convert energy  $E$  of incident particles to detector response

$$S \propto E$$

Incoming particle



This is a homogenous calorimeter — think of lead tungstate ECAL in CMS

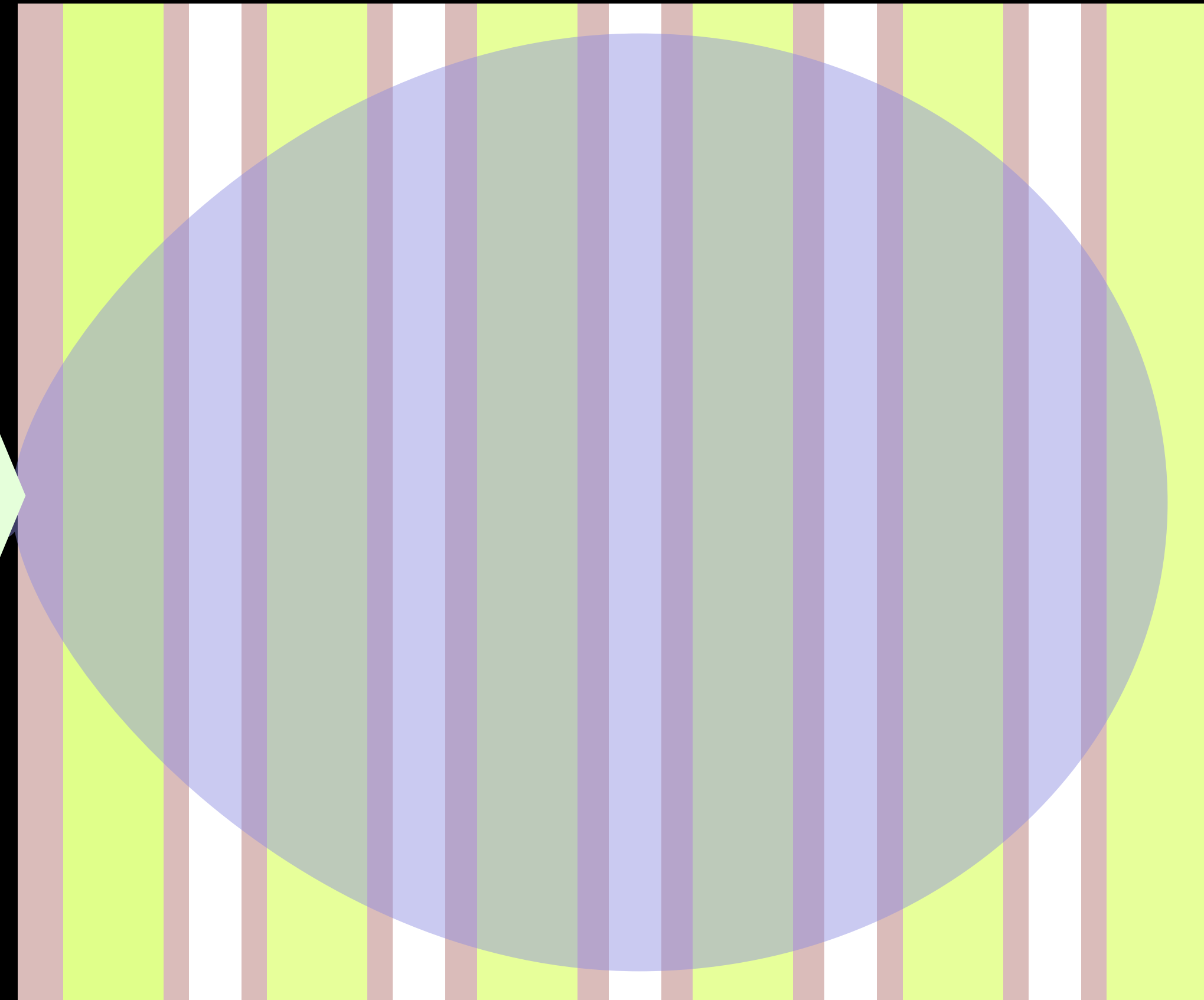
# Sampling calorimeter

Convert energy  $E$  of incident particles to detector response

$$S \propto E$$

Incoming particle

Detector volume



Interleaved with passive absorber material and active detectors

This is a sampling calorimeter — think Shower of secondary particles of HighGranularity Calorimeter in CMS