

LHC & ATLAS Introduction

Eric Torrence
University of Oregon

(Stephanie will describe some of the
physics later today)



Outline

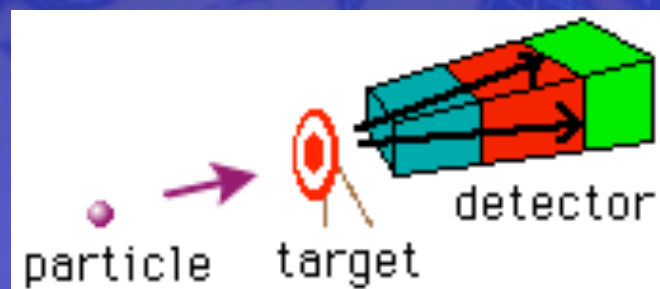
- Why Collide Particles?
- LHC Overview
- ATLAS Detector

Goal: What is the universe made of
and what holds it all together...

Particle Physics Experiments

- Source of High Energy Particles
- Target to collide with
- Detector to see the results

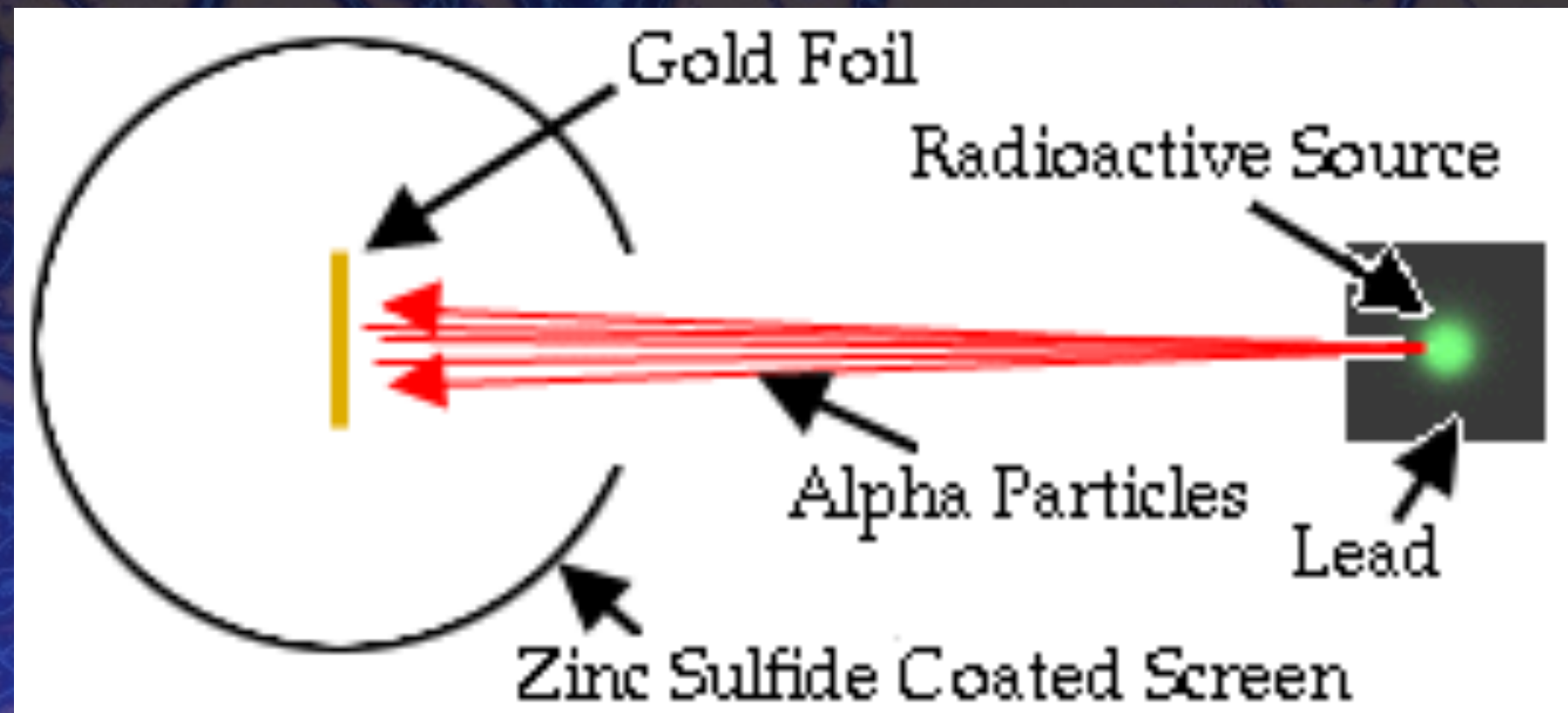
Fixed Target



Colliding Beam

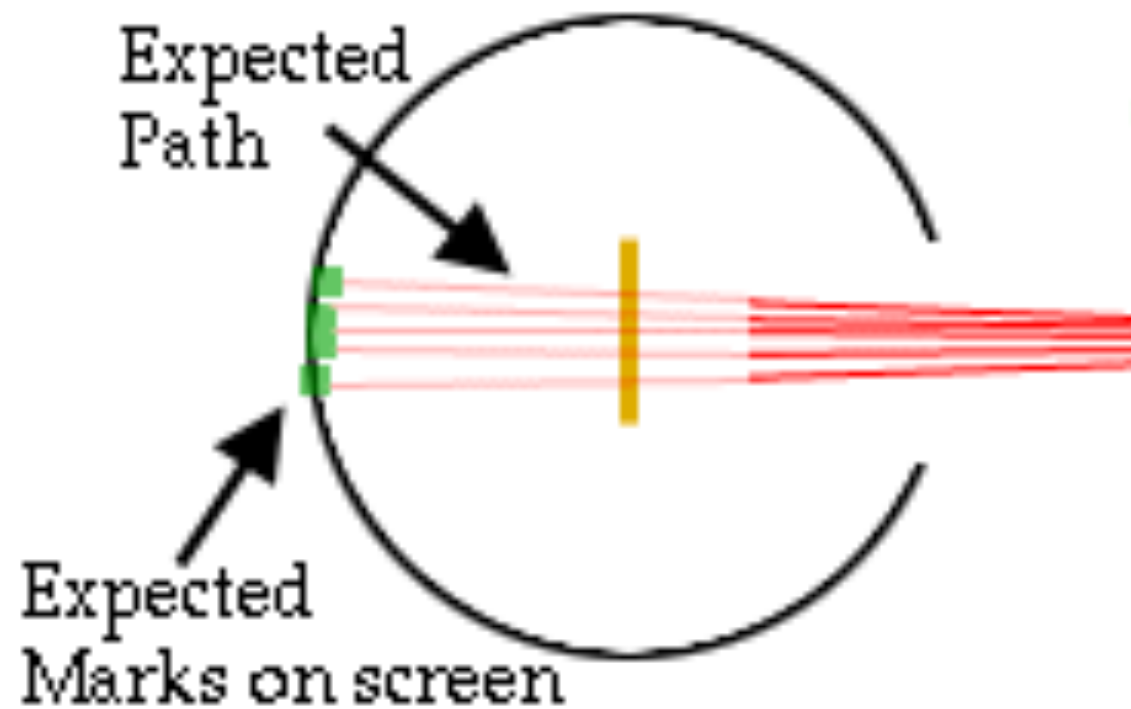


Rutherford's Scattering (1909)

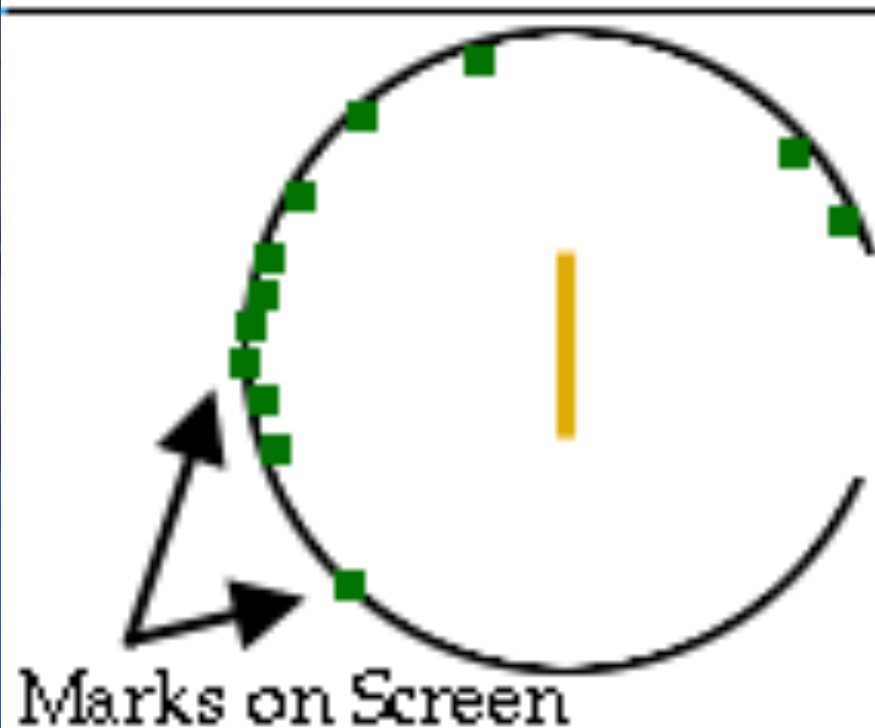


- Particle Beam
- Target
- Detector

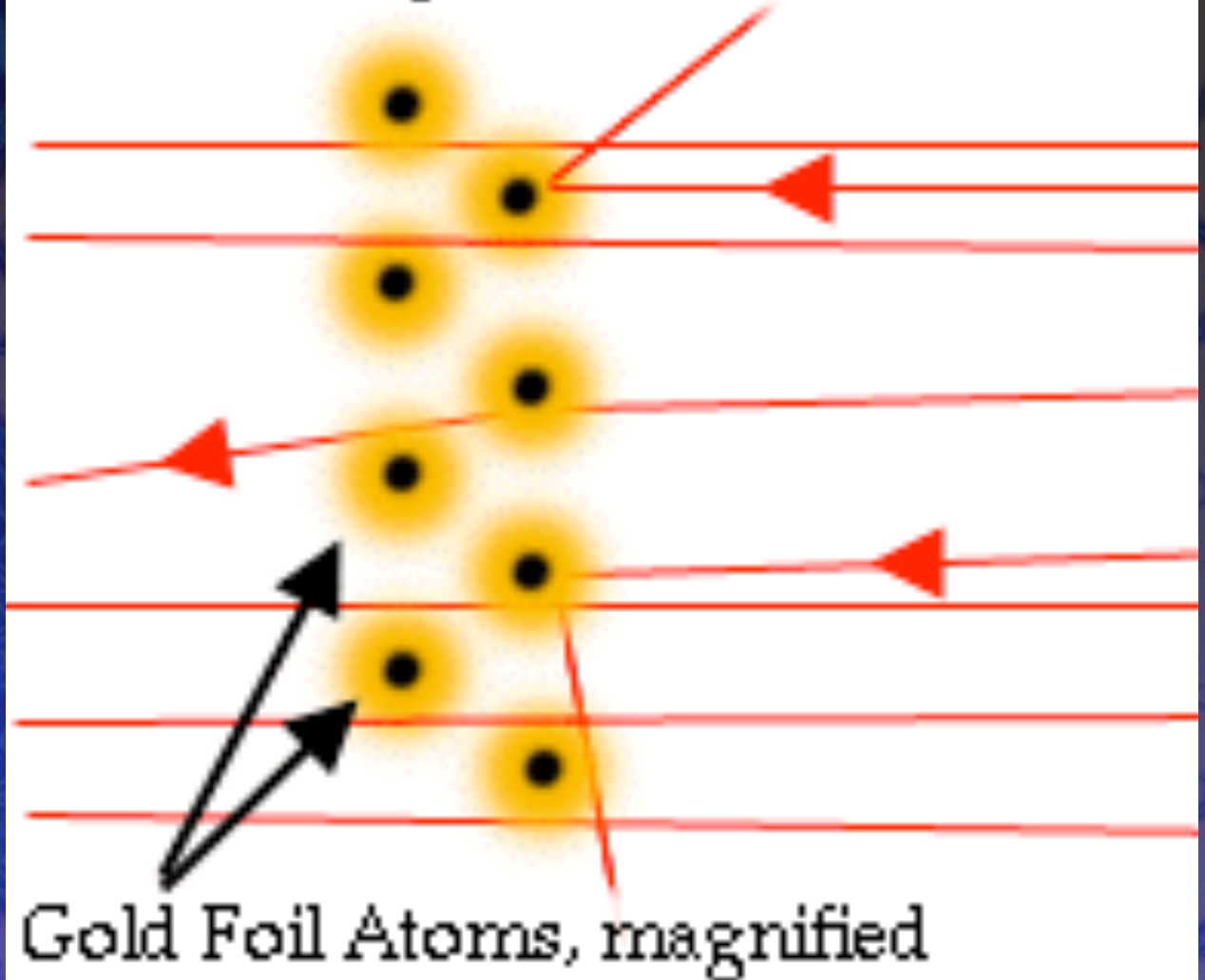
The Predicted Result:



The Result:



A Positive Nucleus Reflects Alpha Particles



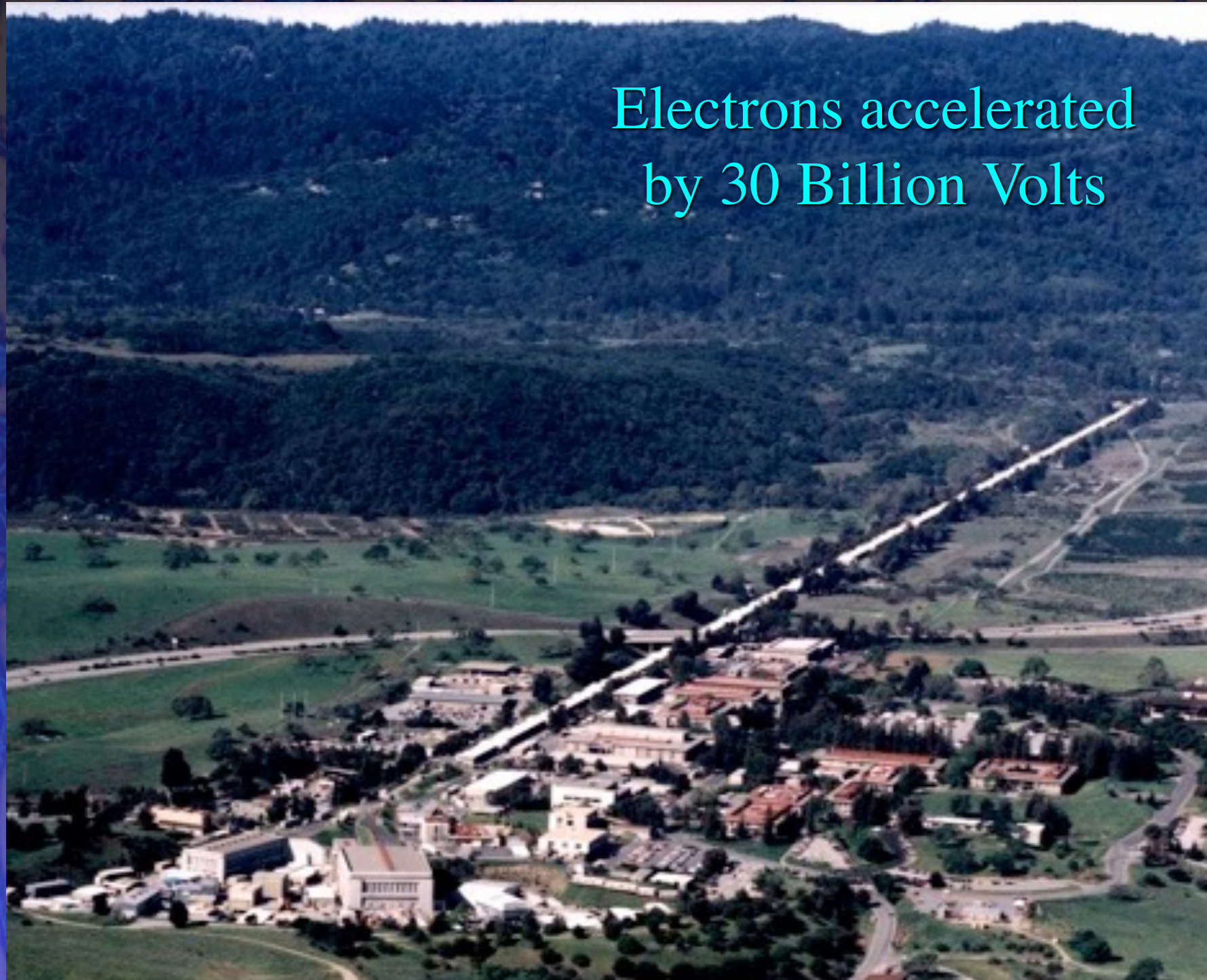
Nucleus $\sim 10^{-14}$ m

Deep Inelastic Scattering

Stanford Linear Accelerator Center (1968)



Electrons accelerated
by 30 Billion Volts



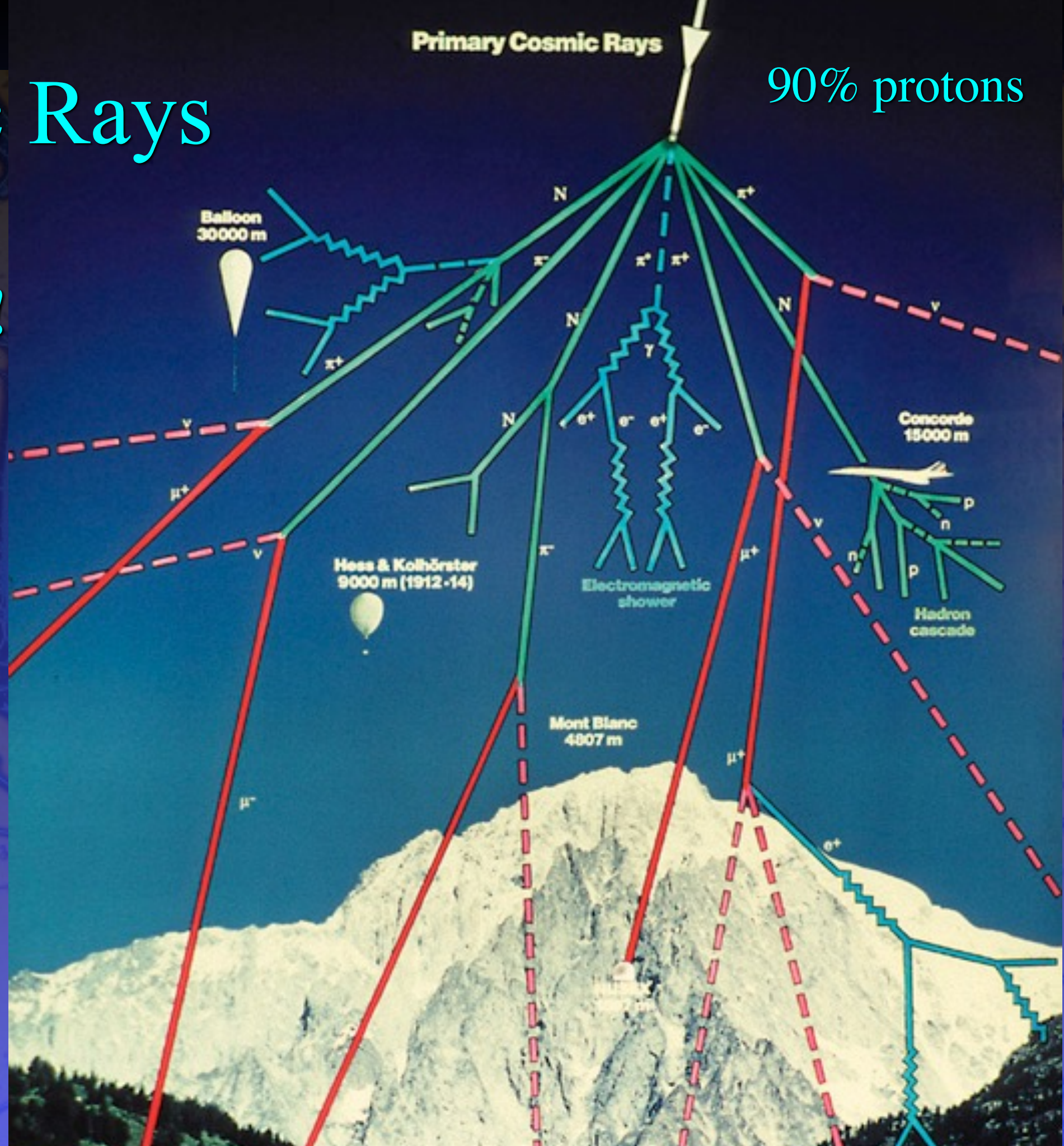
Cosmic Rays

p-p collisions!

Discovered 1912
by Victor Hess

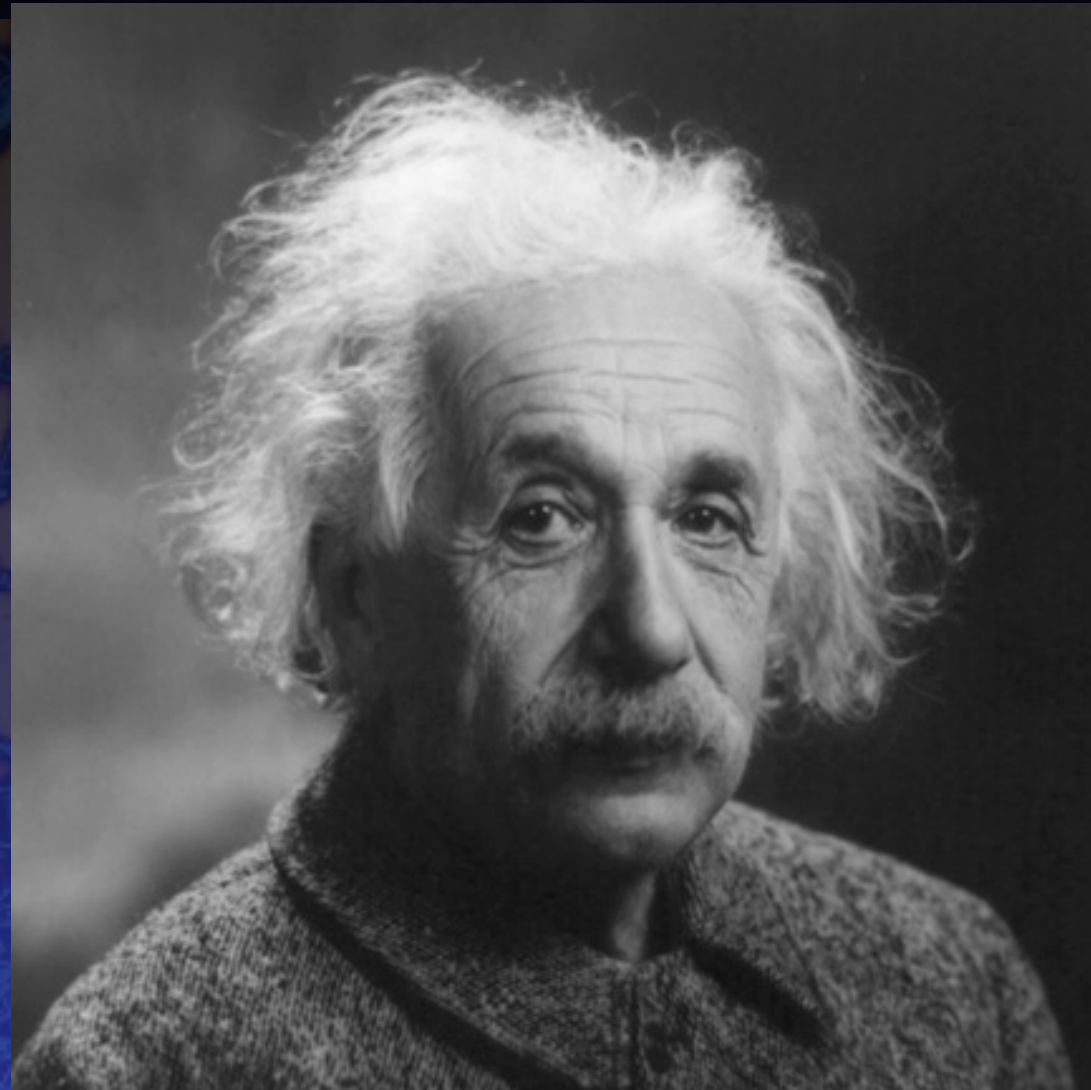
Mostly muons
at sea level (1936)

**LHC provides
more Energy
and Rate**



Why High Energy?

$$E = mc^2$$



High Energy



High Mass



Why High Rate?

- ‘Interesting’ events rare in p-p
- The higher the mass, the more rare it is



High Rate



High Mass

Standard Model

	1 st	2 nd	3 rd		
Quarks	1968 u up	1974 C charm	1995 t top	γ photon	Gauge Bosons
	d down	S strange	b beauty	1983 $W^{\pm}$ W boson	
Leptons	1897 e electron	1936 μ muon	1974 τ tau	Z^0 Z boson	
	ν_e neutrino electron	ν_{μ} neutrino muon	ν_{τ} neutrino tau	1979 g gluon	
				2012 H Higgs Boson	



The Large Hadron Collider

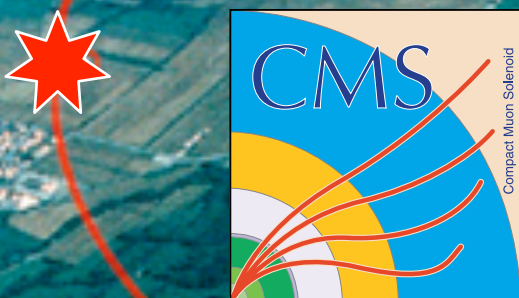
Conseil Européen pour la Recherche Nucléaire (CERN)

(European Laboratory for Particle Physics)

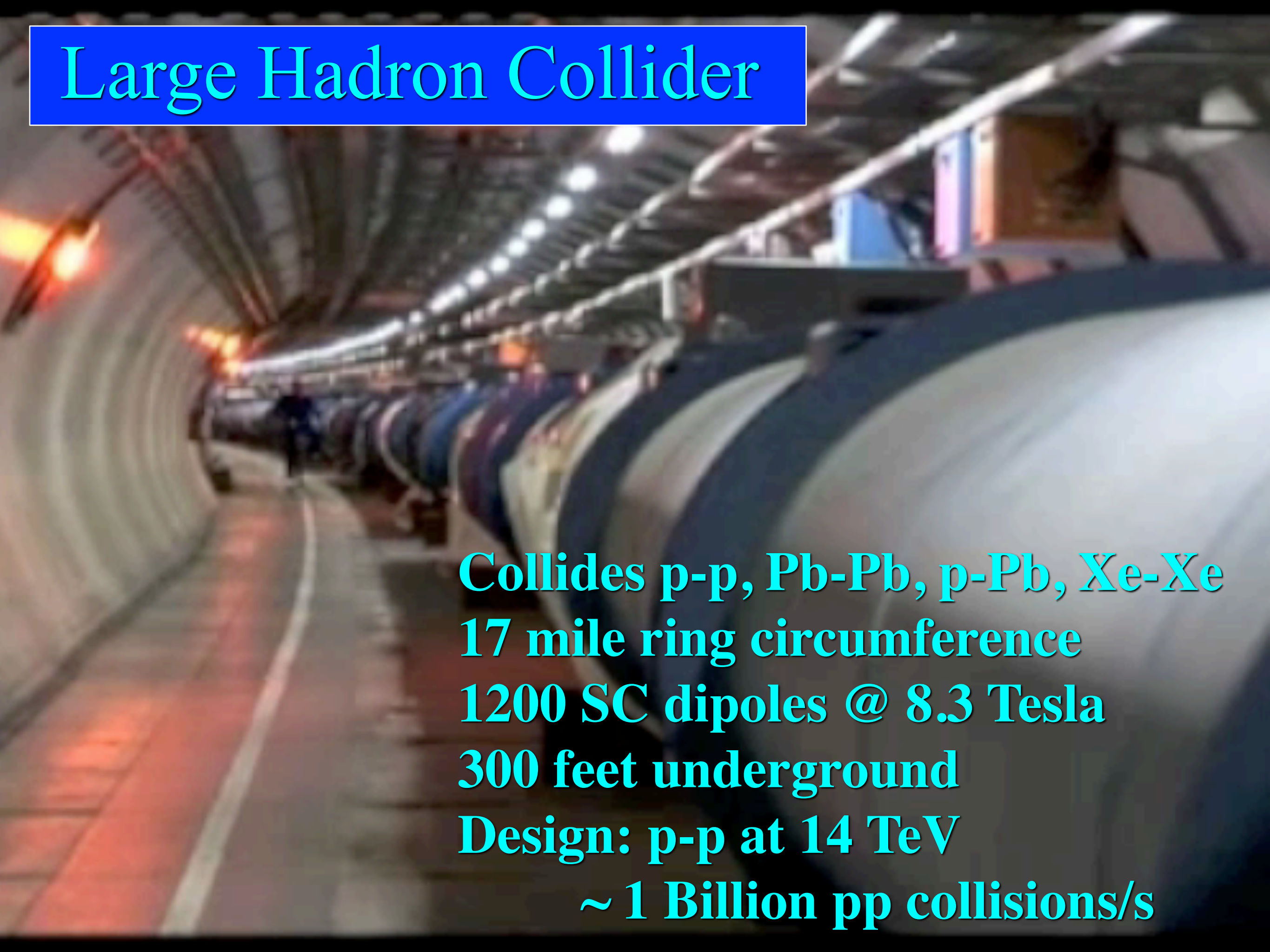


Large Hadron Collider

pp collisions
 $E_{\text{cm}} = 13 \text{ TeV}$

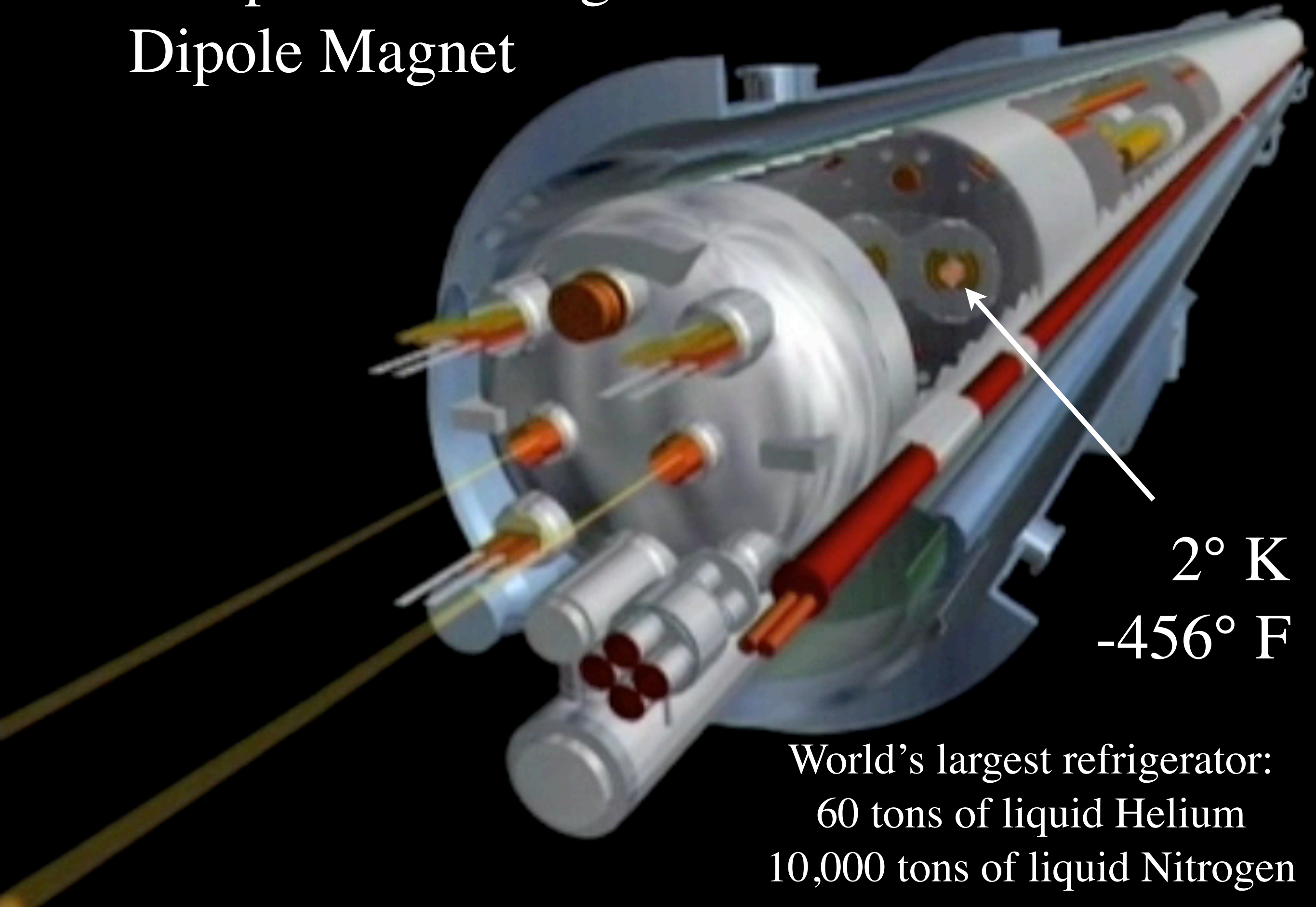


Large Hadron Collider

A photograph showing the interior of the Large Hadron Collider tunnel. The image captures a long, curved passage lined with large, cylindrical superconducting magnets. The floor is a reddish-brown color, and the walls are metallic. In the distance, a person can be seen walking, providing a sense of scale. The lighting is dim, with some bright spots from overhead fixtures.

Collides p-p, Pb-Pb, p-Pb, Xe-Xe
17 mile ring circumference
1200 SC dipoles @ 8.3 Tesla
300 feet underground
Design: p-p at 14 TeV
~ 1 Billion pp collisions/s

LHC Superconducting Dipole Magnet



2° K
 -456° F

World's largest refrigerator:
60 tons of liquid Helium
10,000 tons of liquid Nitrogen

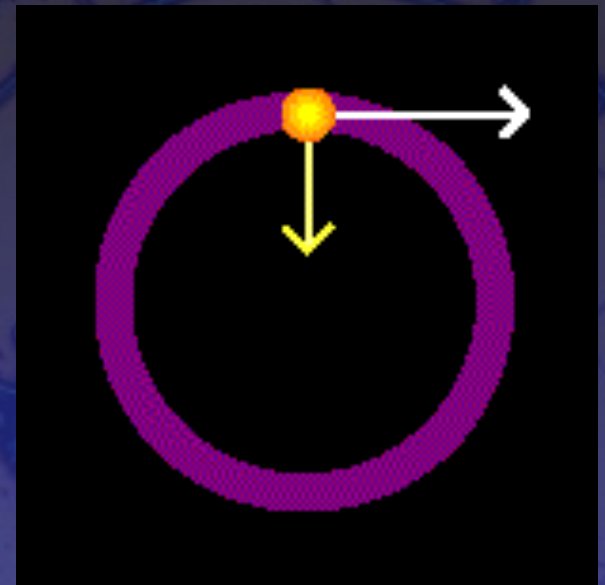
Accelerating Protons

Magnetic Fields
Superconducting
Dipoles

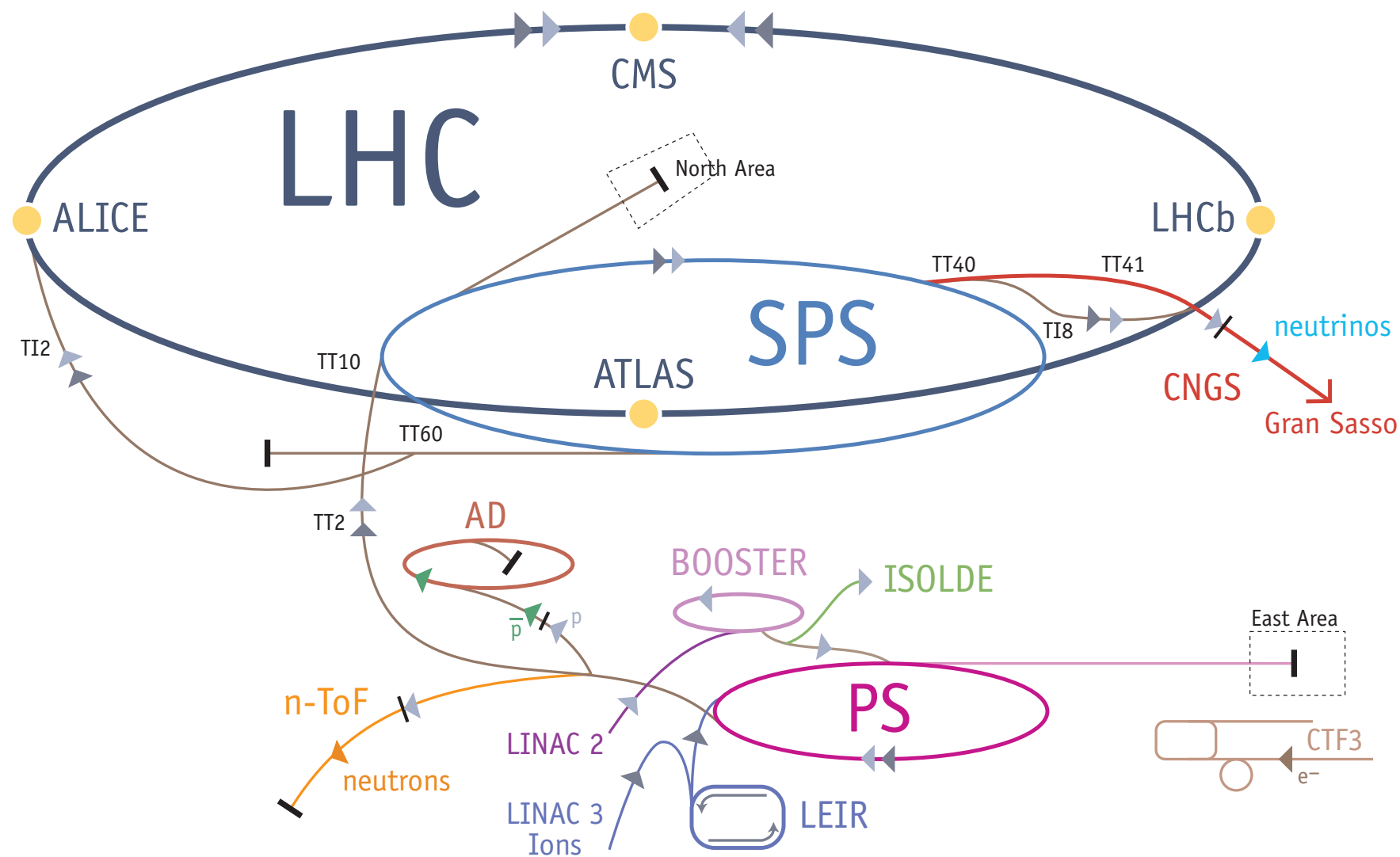
$$p = q B R$$

8.3 Tesla $\rightarrow$ 7 TeV/beam
(needs 12 kA current)

Peak energy really limited by magnet
technology - large field, large area



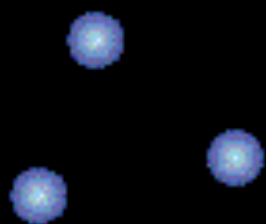
Accelerating Protons



Top Energy
per ring:
PS - 1.4 GeV
SPS - 450 GeV
LHC - 7 TeV

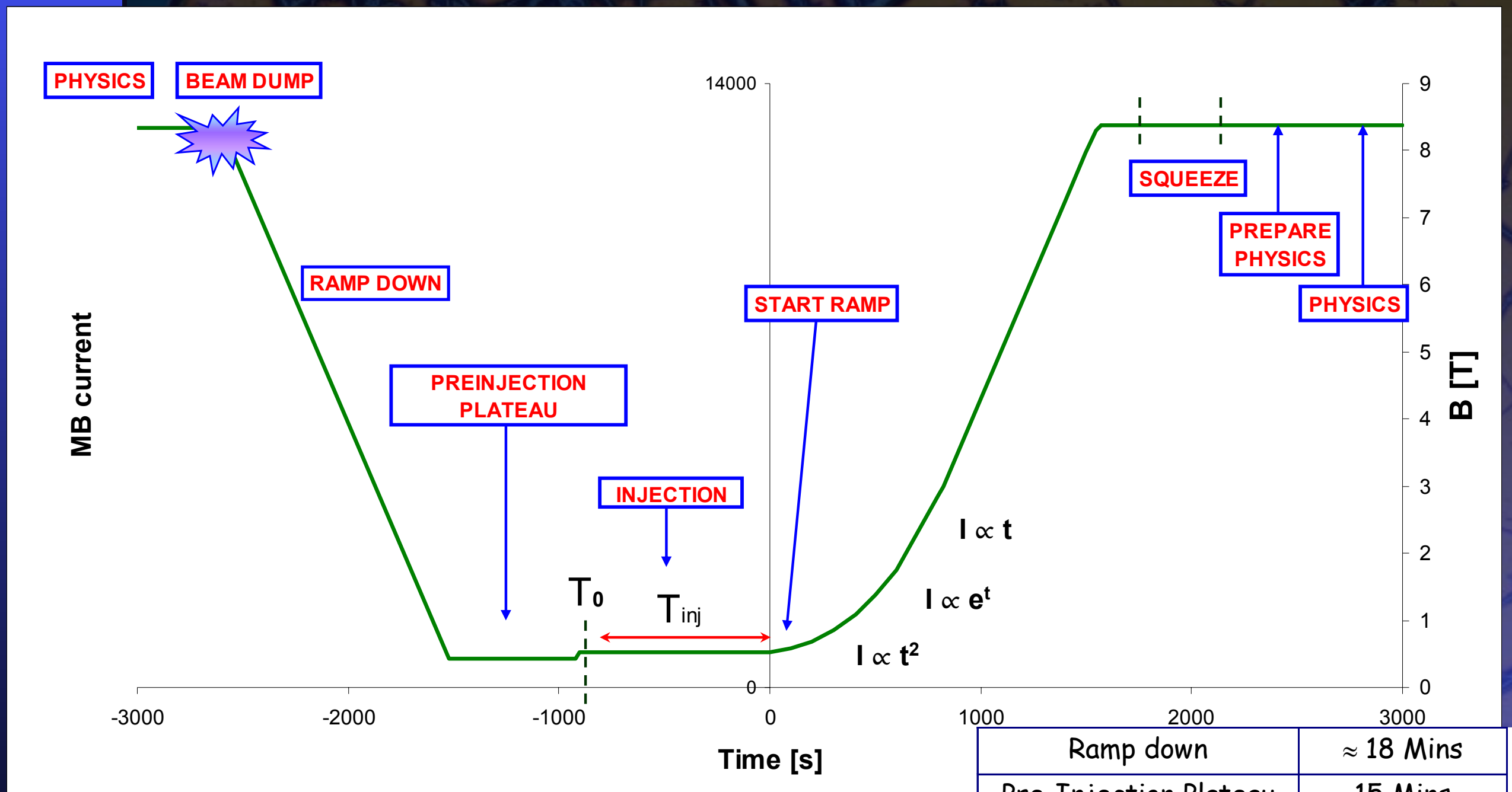
Electric Fields RF Cavities

1 Positive particles just sitting there



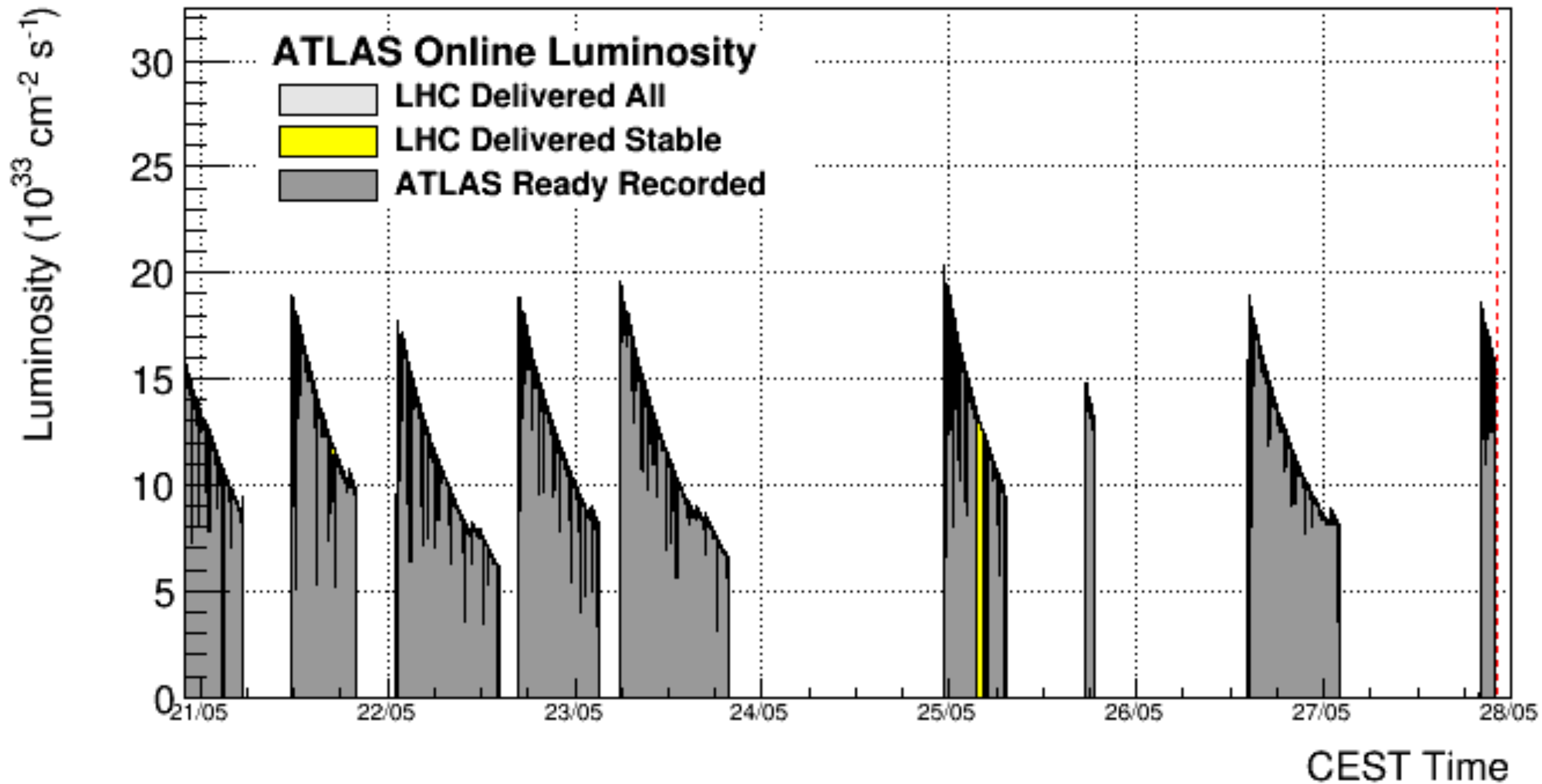
16 MV/beam/turn
(easy for protons)

LHC Fill Structure



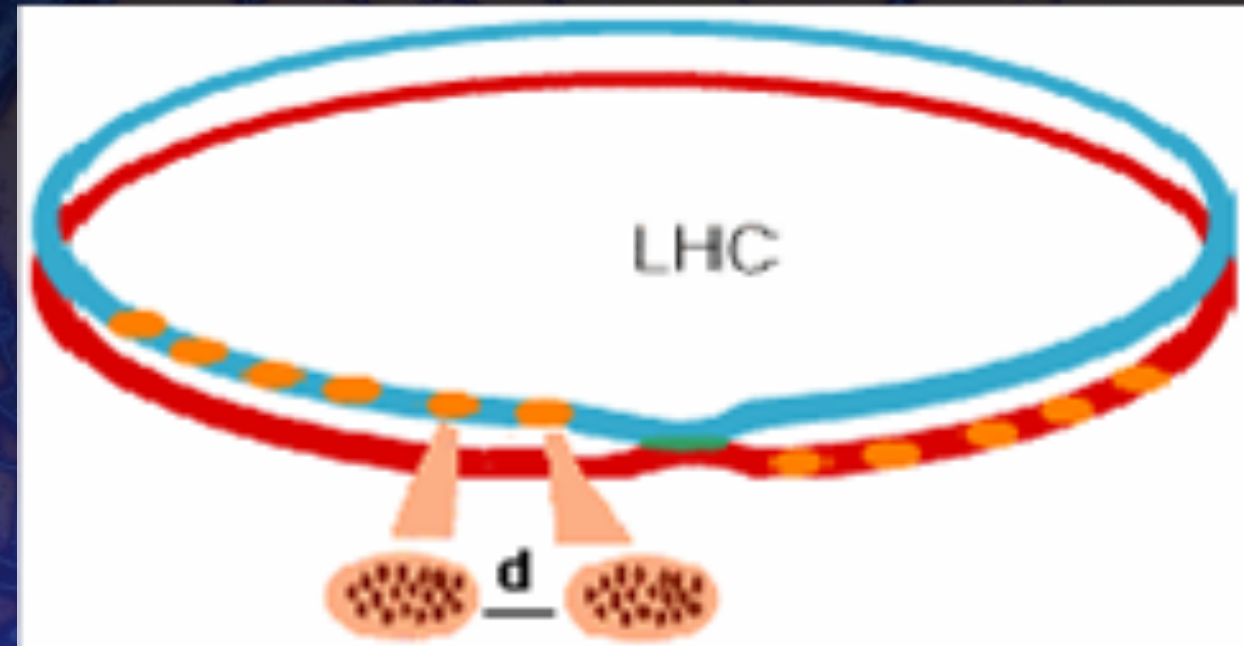
Ramp down	≈ 18 Mins
Pre-Injection Plateau	15 Mins
Injection	≈ 15 Mins
Ramp	≈ 28 Mins
Squeeze	< 5 Mins
Prepare Physics	≈ 10 Mins
Physics	10 - 20 Hrs

A Week at the LHC



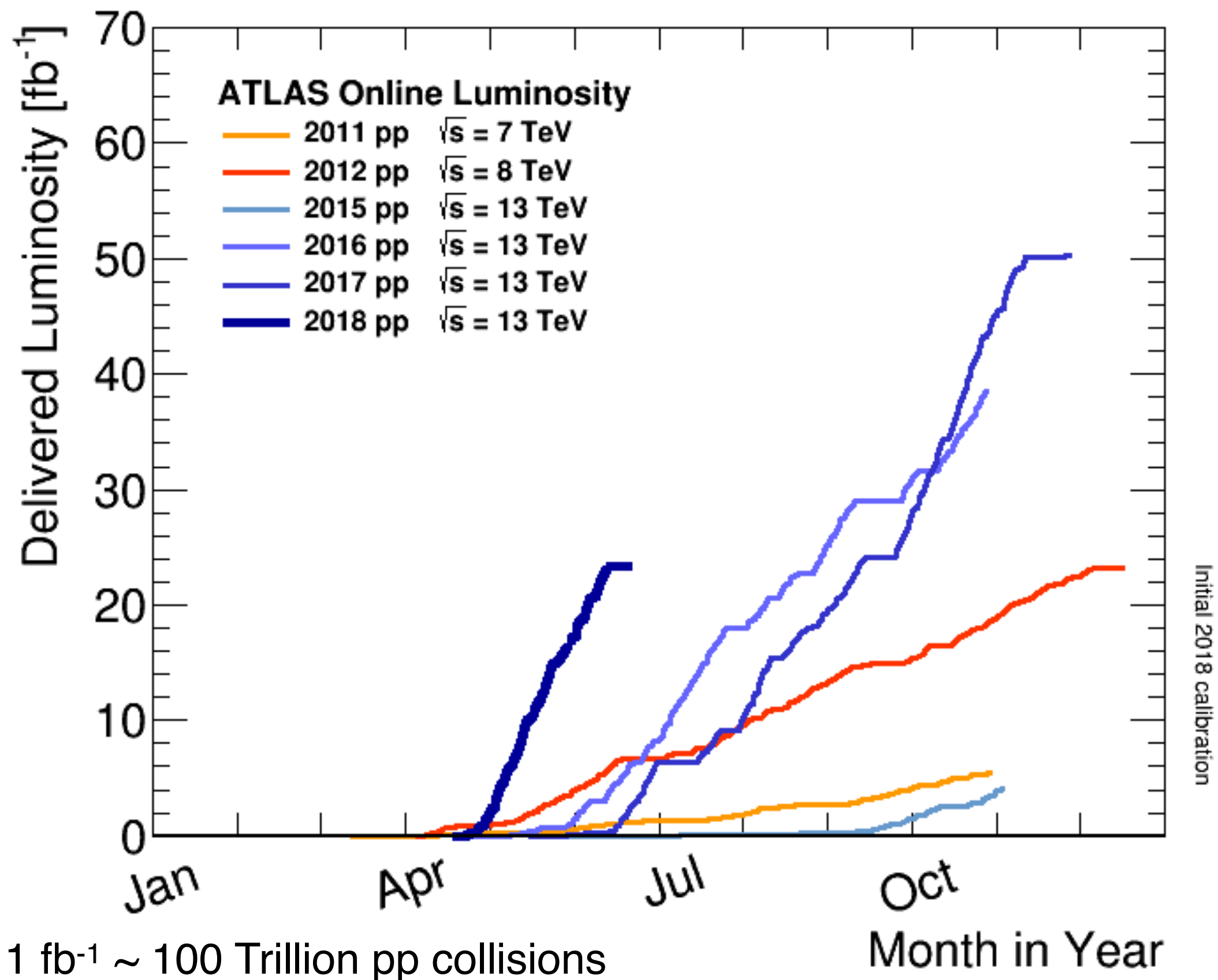
Road to Luminosity

$$L = f n \frac{N_1 N_2}{A}$$



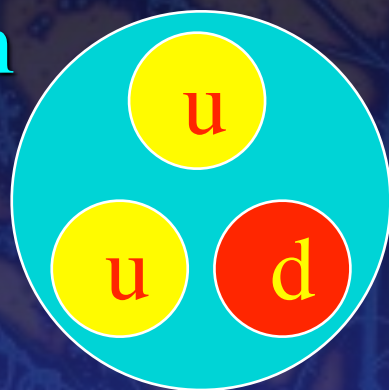
- f - revolution freq. - $c/(2\pi R) = 11.245$ kHz
- n - bunches per beam - up to ~ 2800
- N_i - protons per bunch - $\sim 10^{11}$
- A - cross-sectional beam area at collision currently $\sim (10 \mu\text{m})^2$
- Up to ~ 60 pp collisions per crossing (25 ns)

LHC Luminosity History



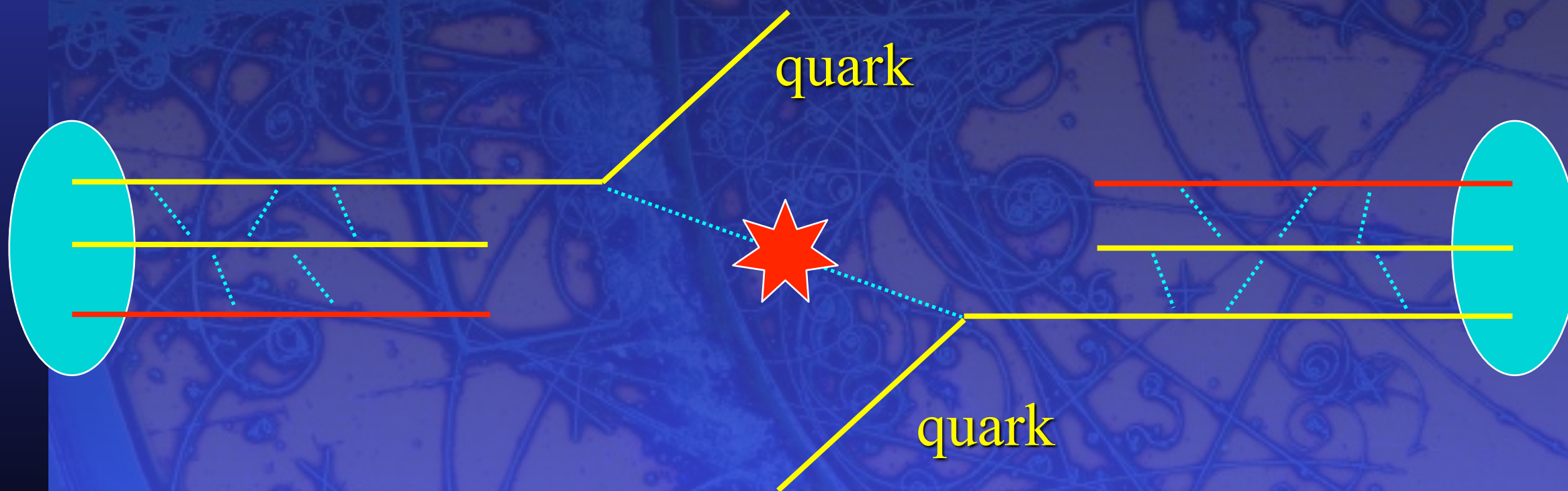
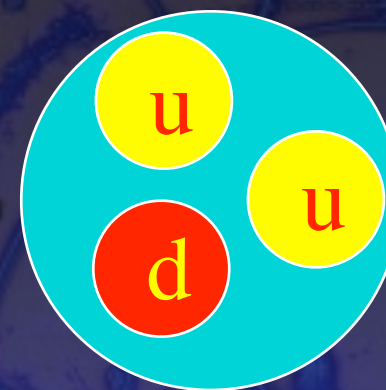
Quark/Gluon Collider!

6.5 TeV
proton



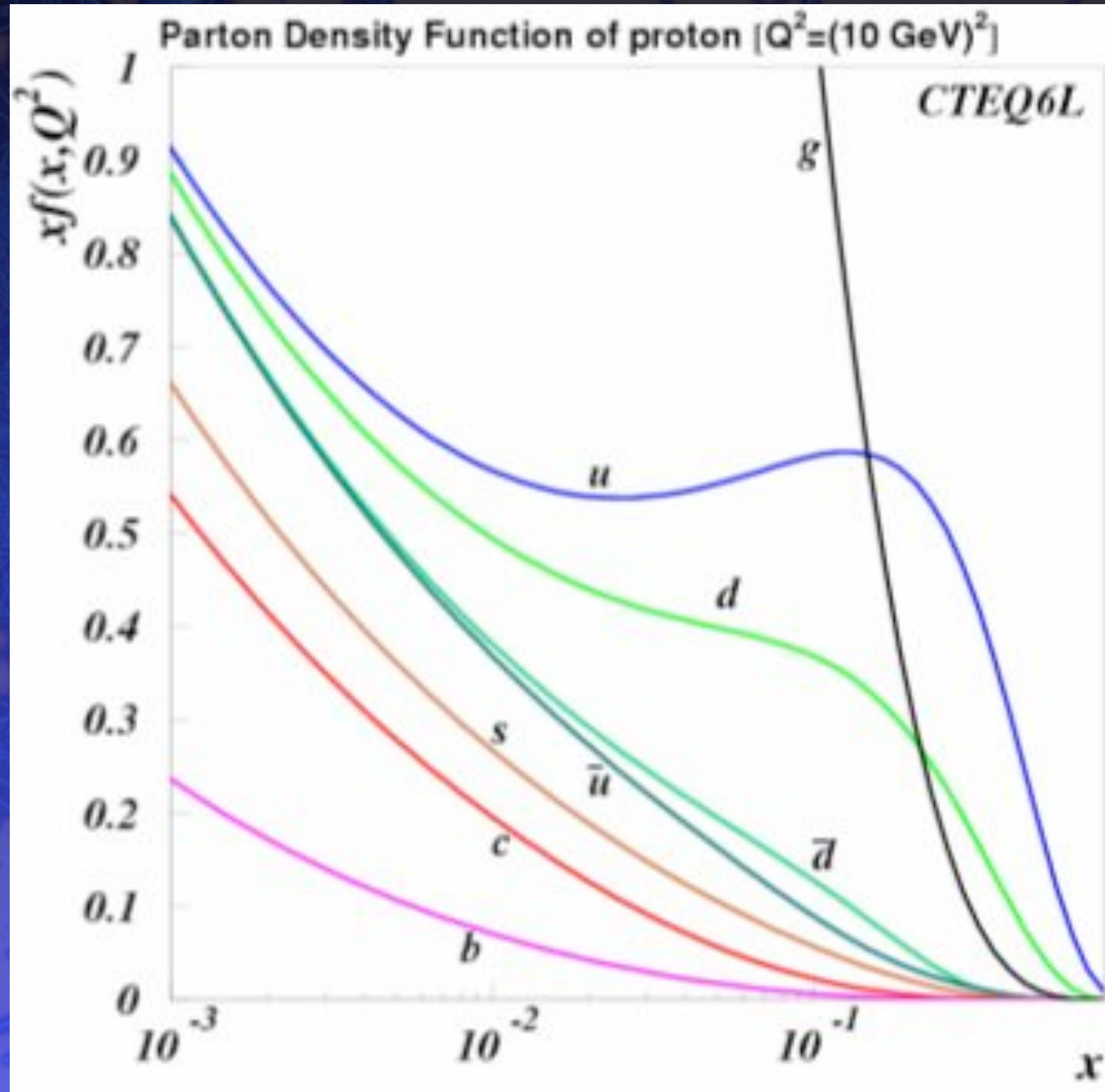
13 TeV

6.5 TeV
proton



What is in a proton?

- up & down quarks
- + gluons
- + anti-u and anti-d
- + s/c/b quarks
- PDF ~ probability of “finding” an object (parton) in the proton with given momentum fraction x

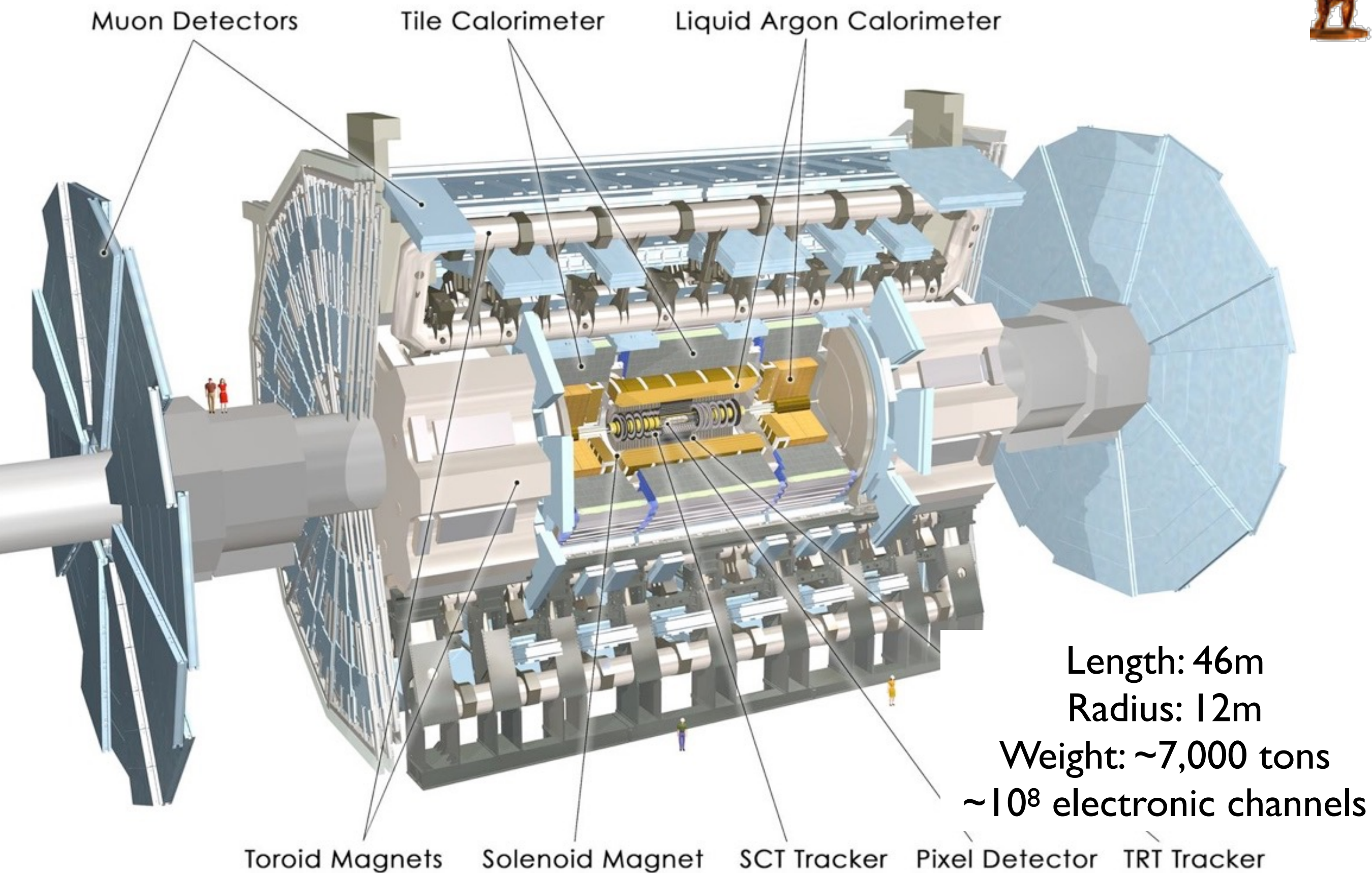




ATLAS Detector



ATLAS Detector Overview



Length: 46m

Radius: 12m

Weight: ~7,000 tons

~ 10^8 electronic channels

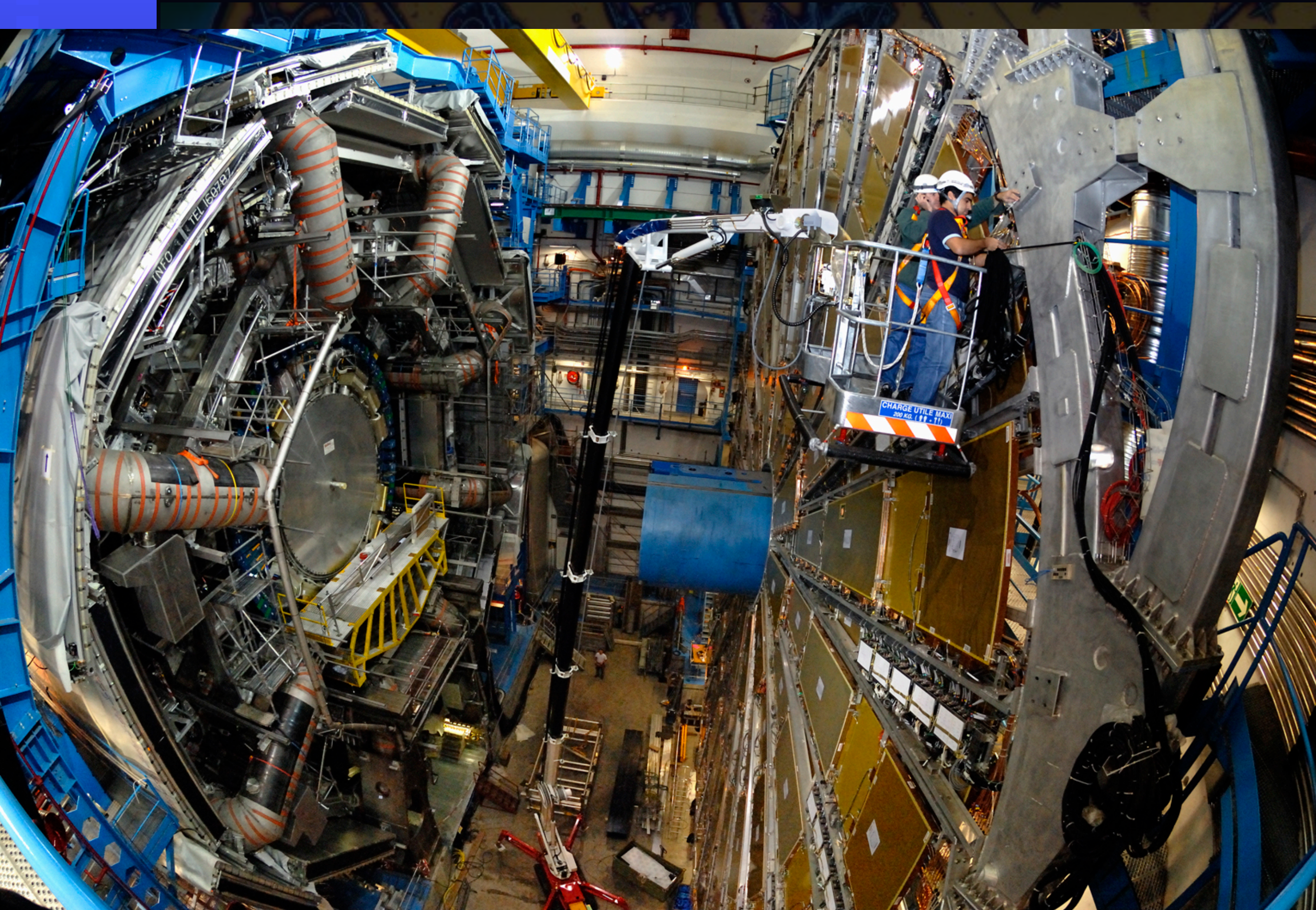
Toroid Magnets

Solenoid Magnet

SCT Tracker

Pixel Detector

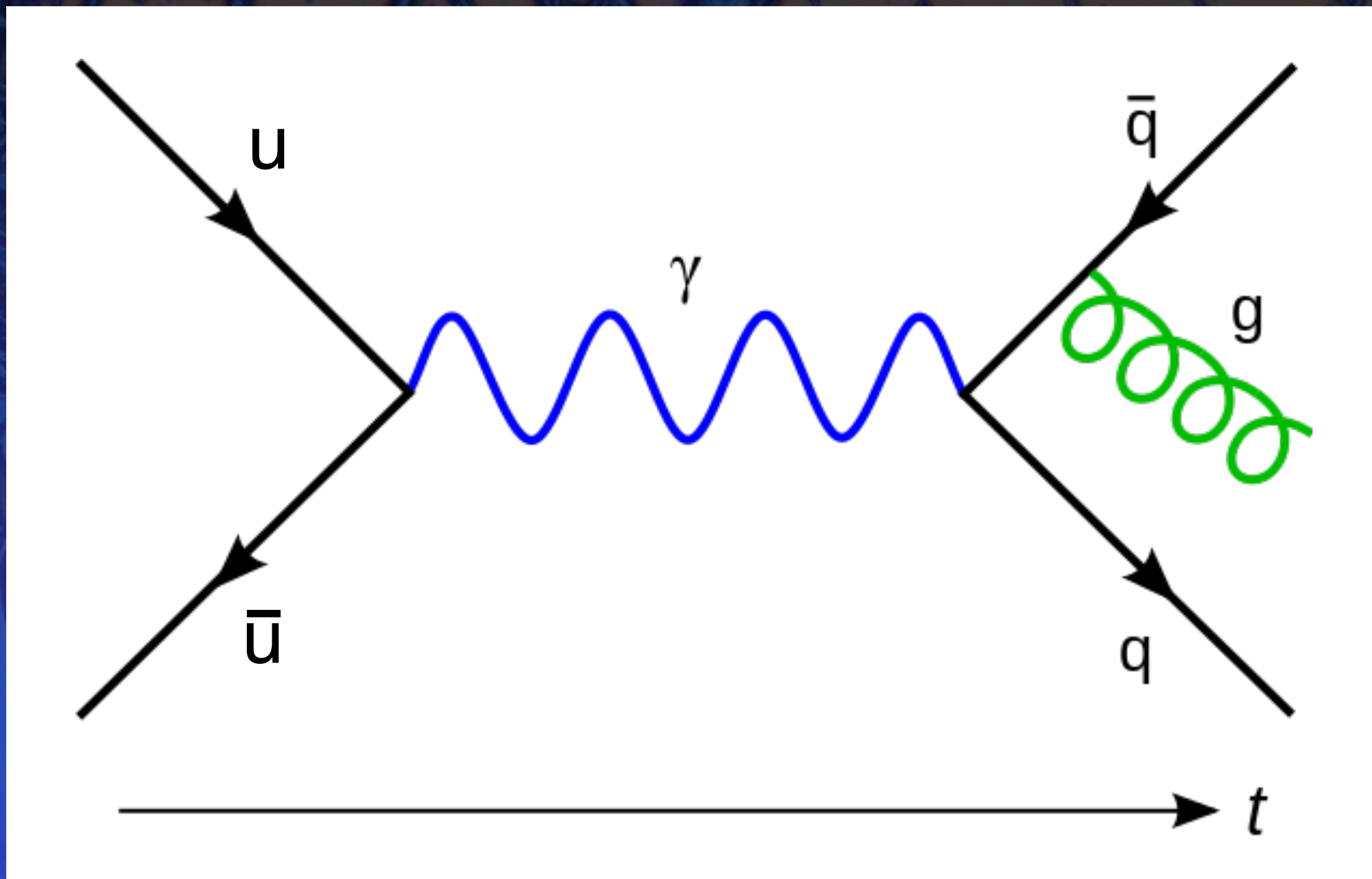
TRT Tracker



Feynman Diagrams



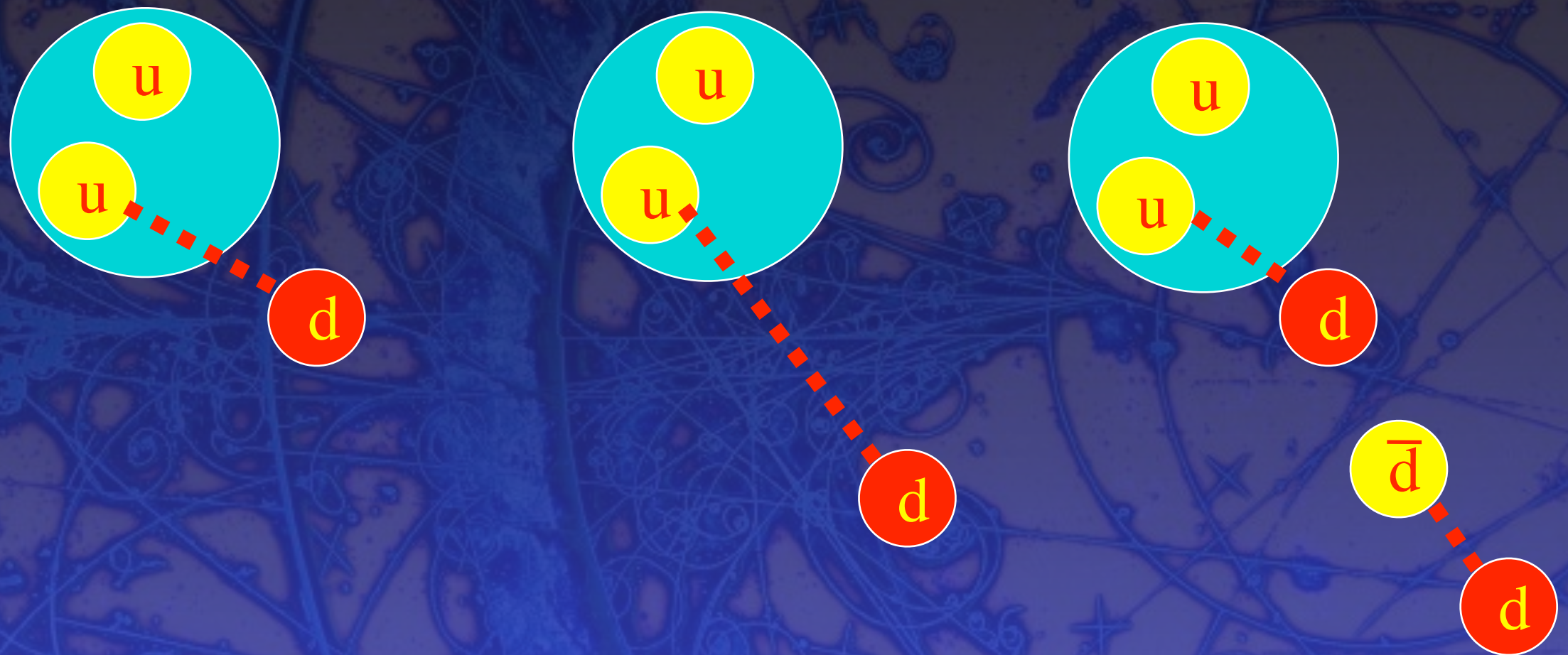
Feynman Diagrams



Initial
State

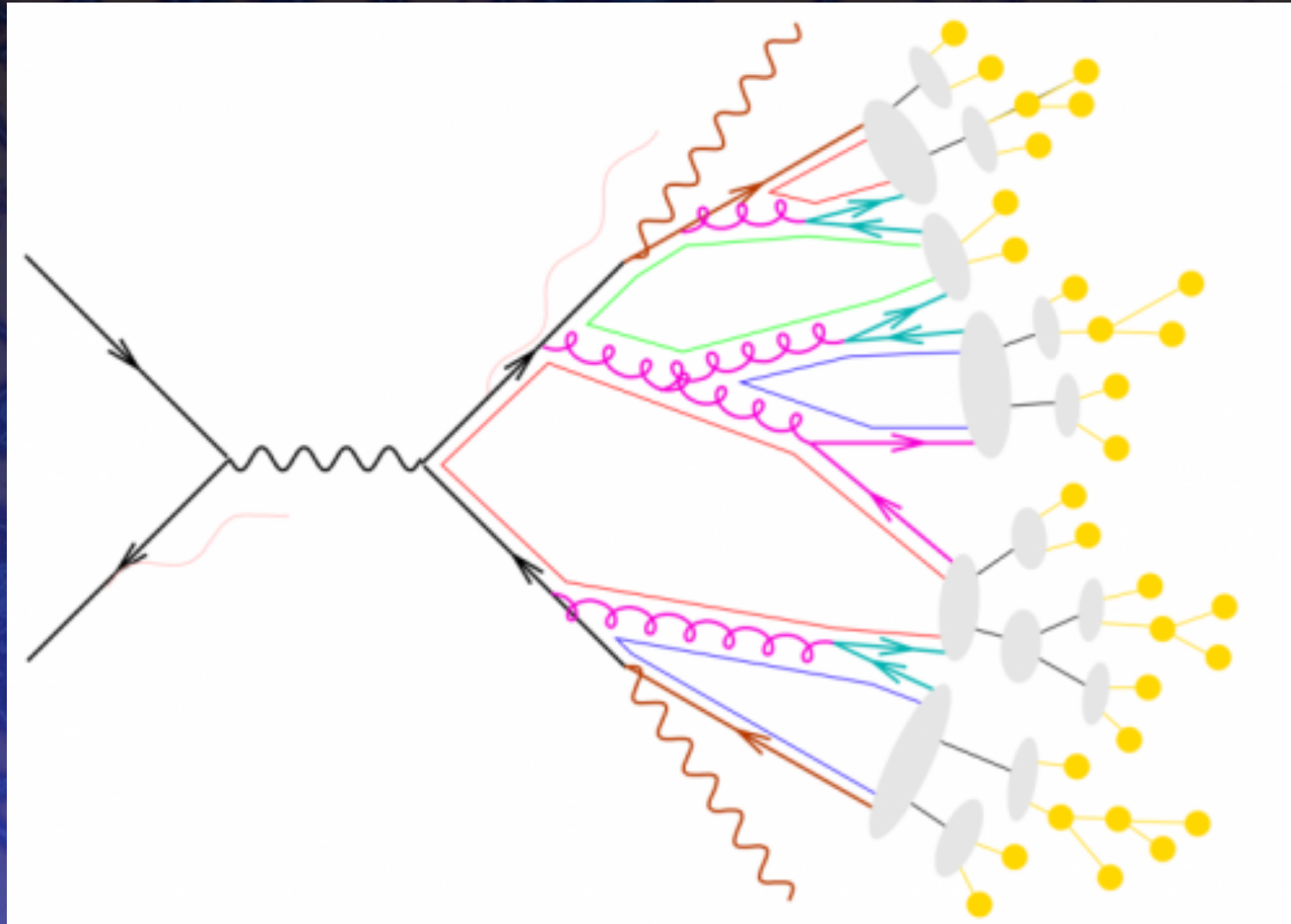
Final
State

No Bare Quarks



Strong force (carried by gluons) grows with distance
Energy increases (like a rubber band) as quark moves away
Eventually, there is enough energy to produce more particles

Hadronization



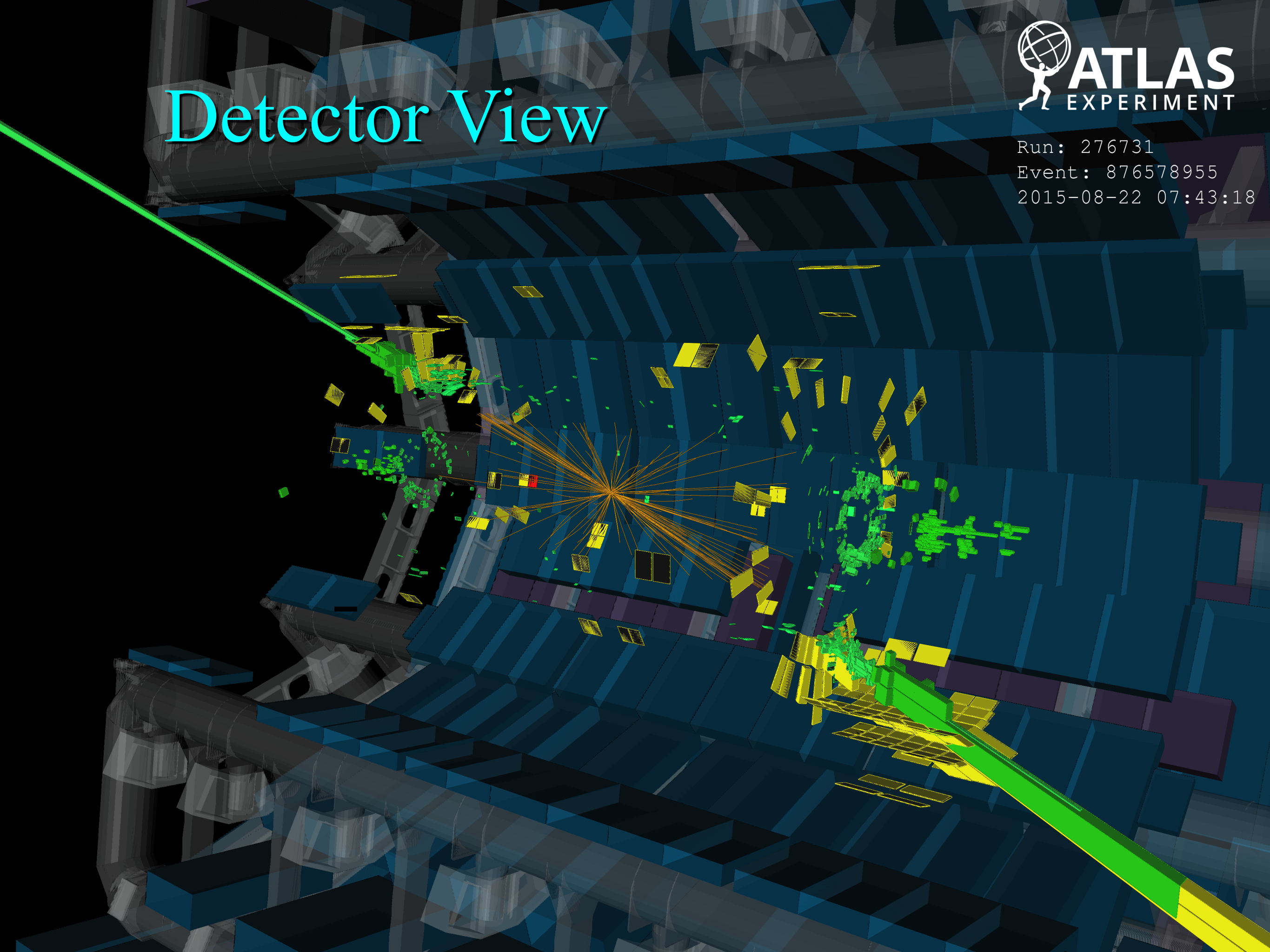
Process can repeat itself many times over
Single high momentum quark turns into 10s of $\sim$ pions
Not stable, but charged pions reach the detector
neutral turn into 2 photons
Momentum and Energy are conserved at each step

Detector View

Run: 276731

Event: 876578955

2015-08-22 07:43:18



Muon
Spectrometer

Muon
Detectors

Muon

Neutrino

Hadronic
Calorimeter

Calorimeter
(energy)

Proton

Neutron

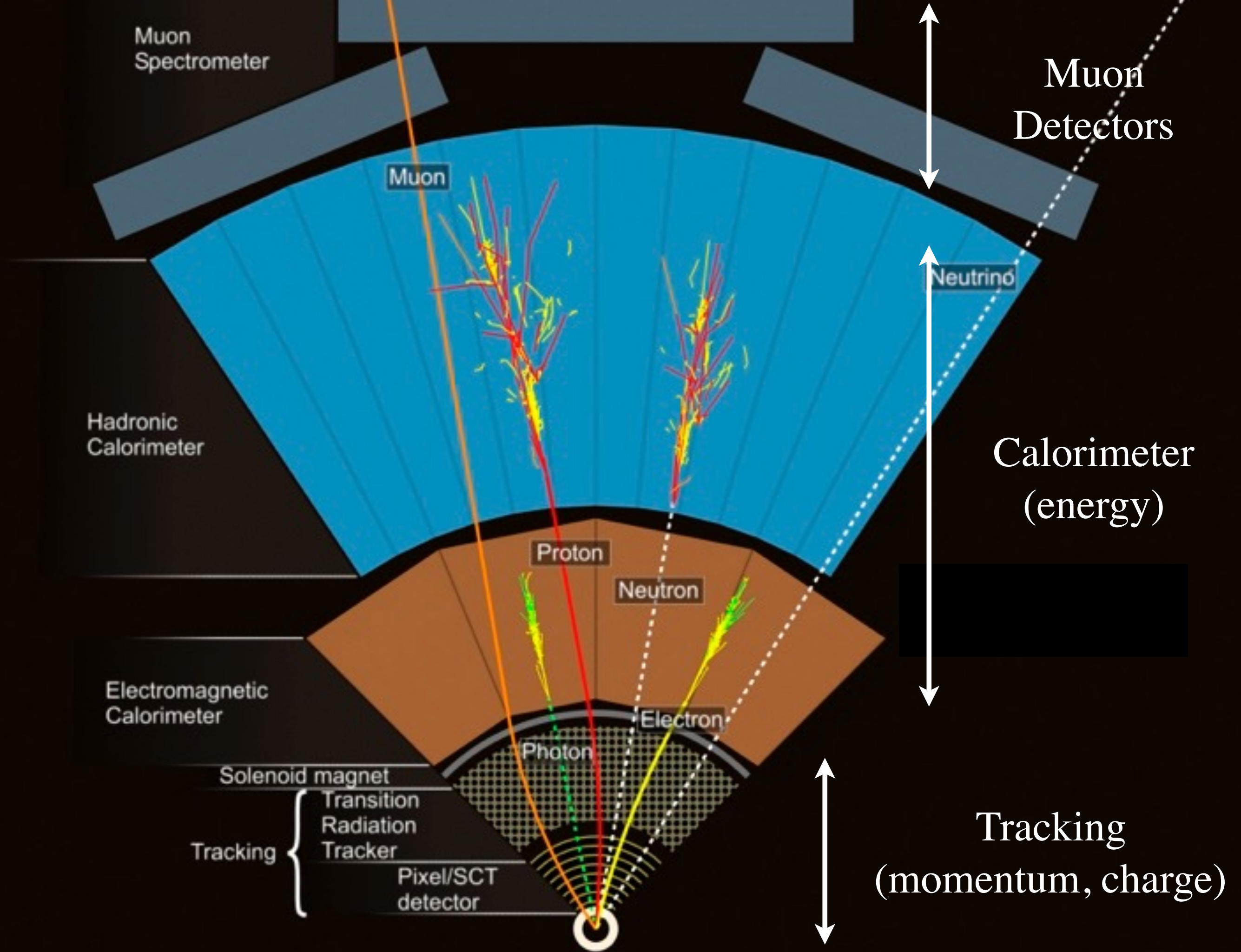
Electromagnetic
Calorimeter

Electron

Photon

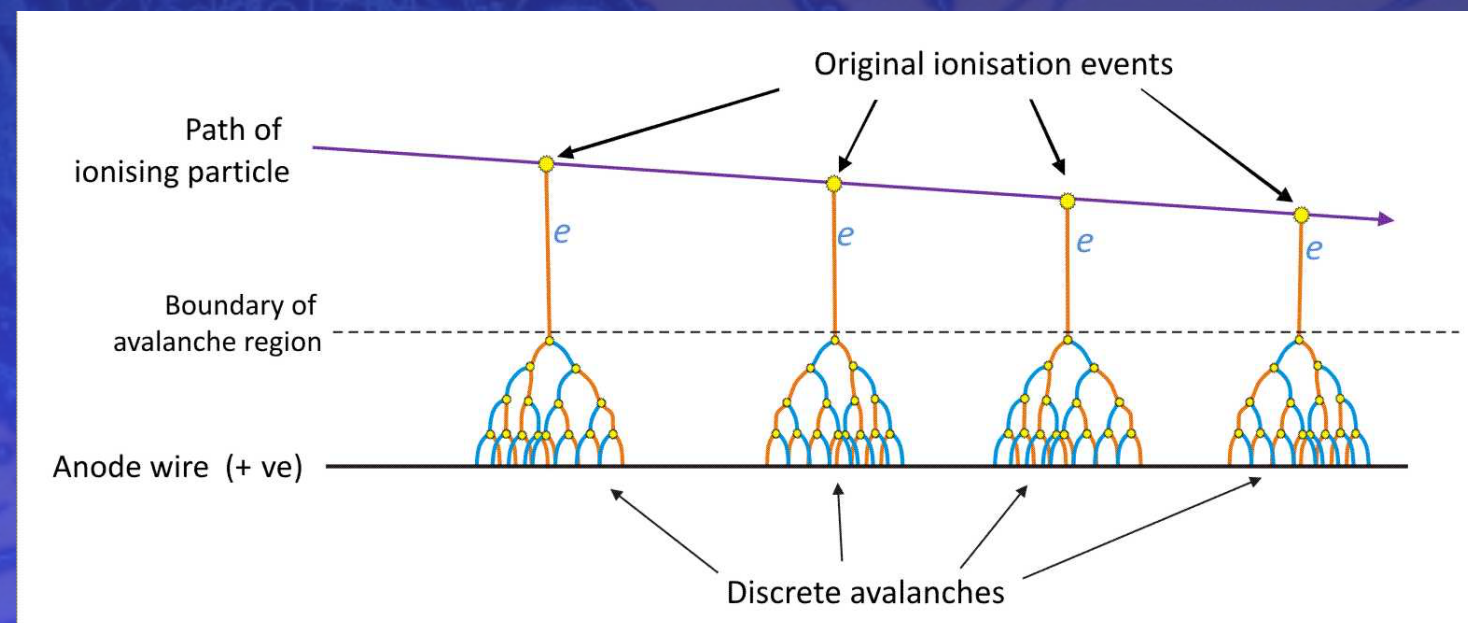
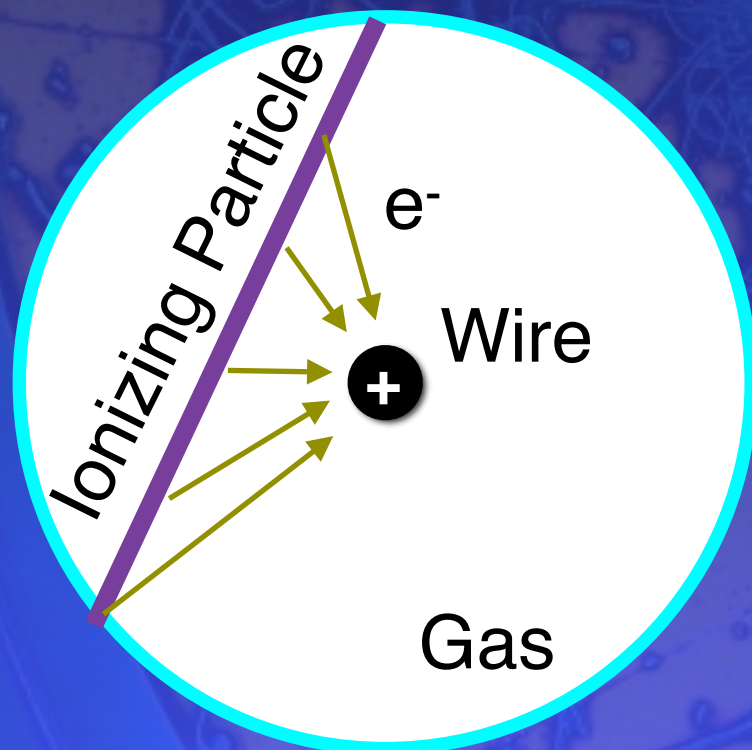
Tracking {
Solenoid magnet
Transition
Radiation
Tracker
Pixel/SCT
detector

Tracking
(momentum, charge)



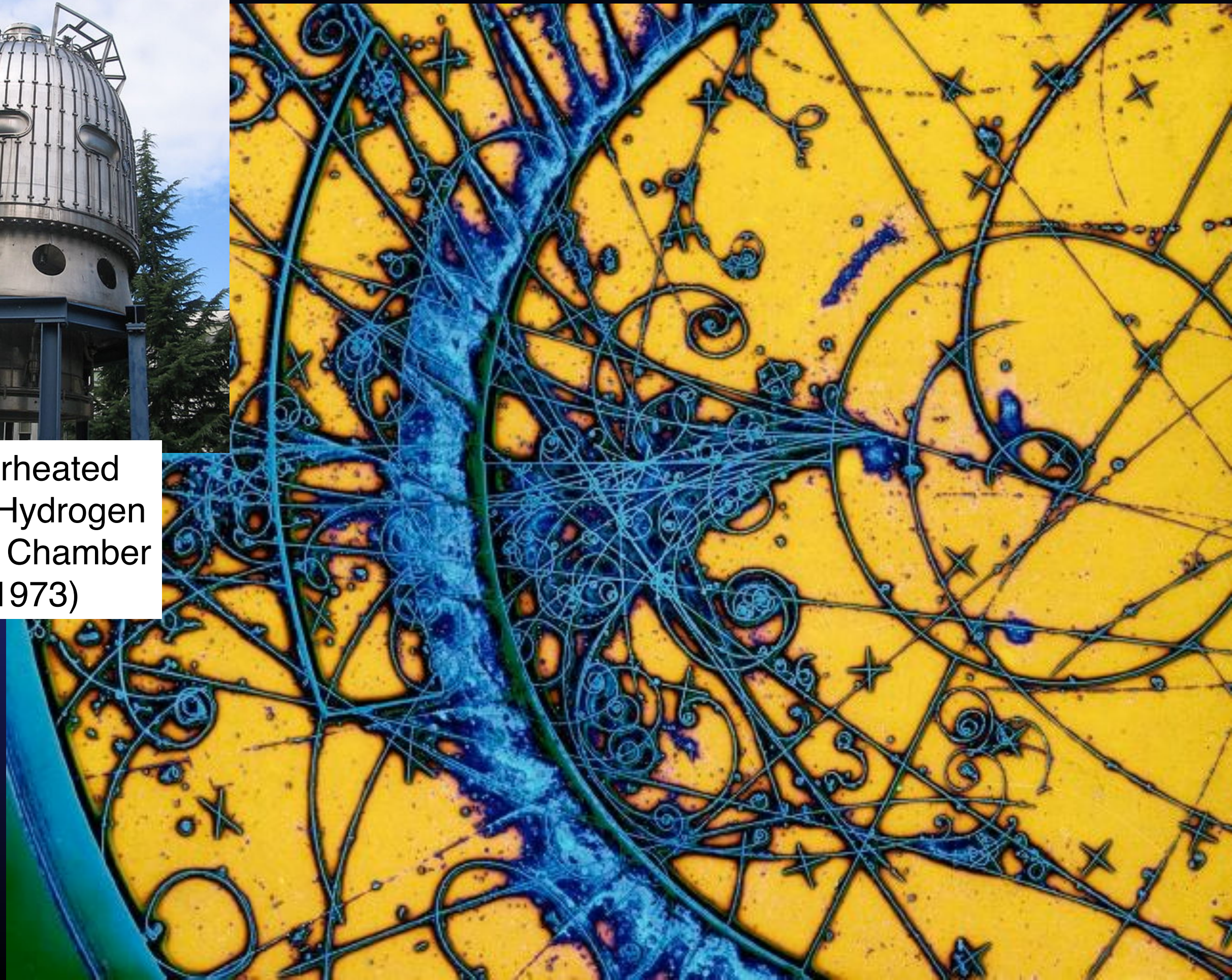
Detecting Particles

- Particle detectors often use ionization to observe the passage of particles
- Ionized electrons drift towards a wire where they are amplified and ultimately read out



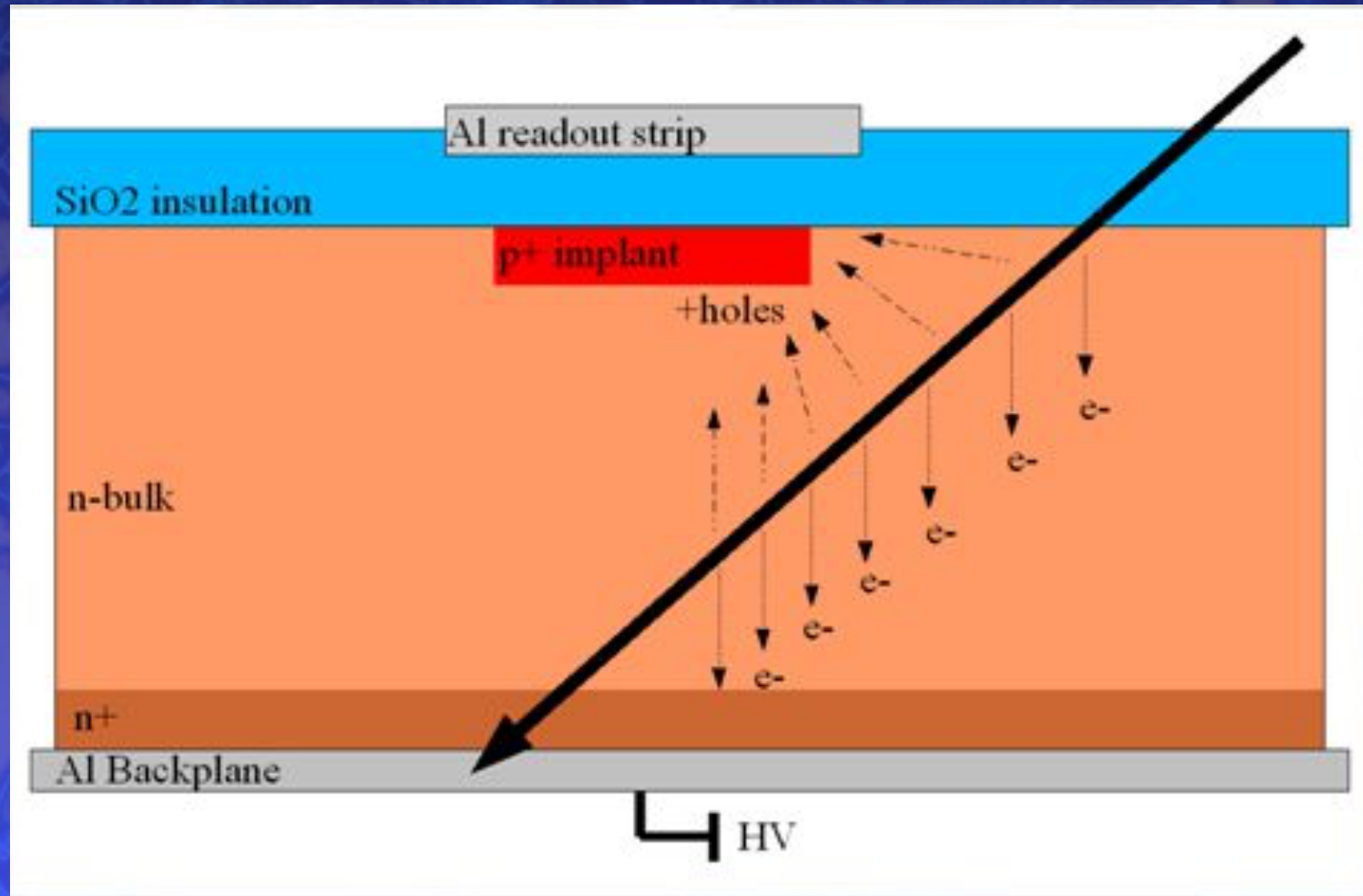


Superheated
Liquid Hydrogen
Bubble Chamber
(~1973)

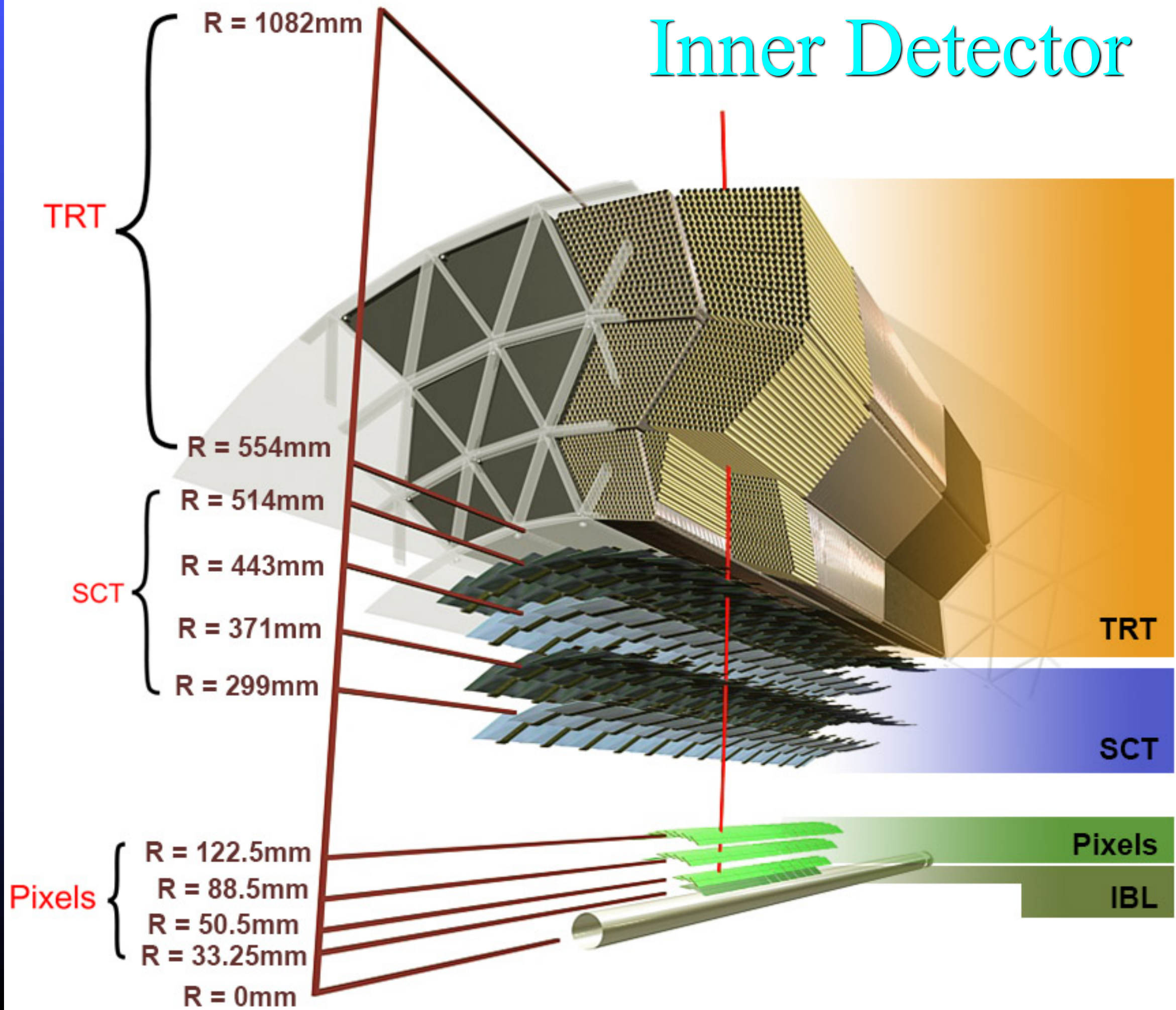


Detecting Particles

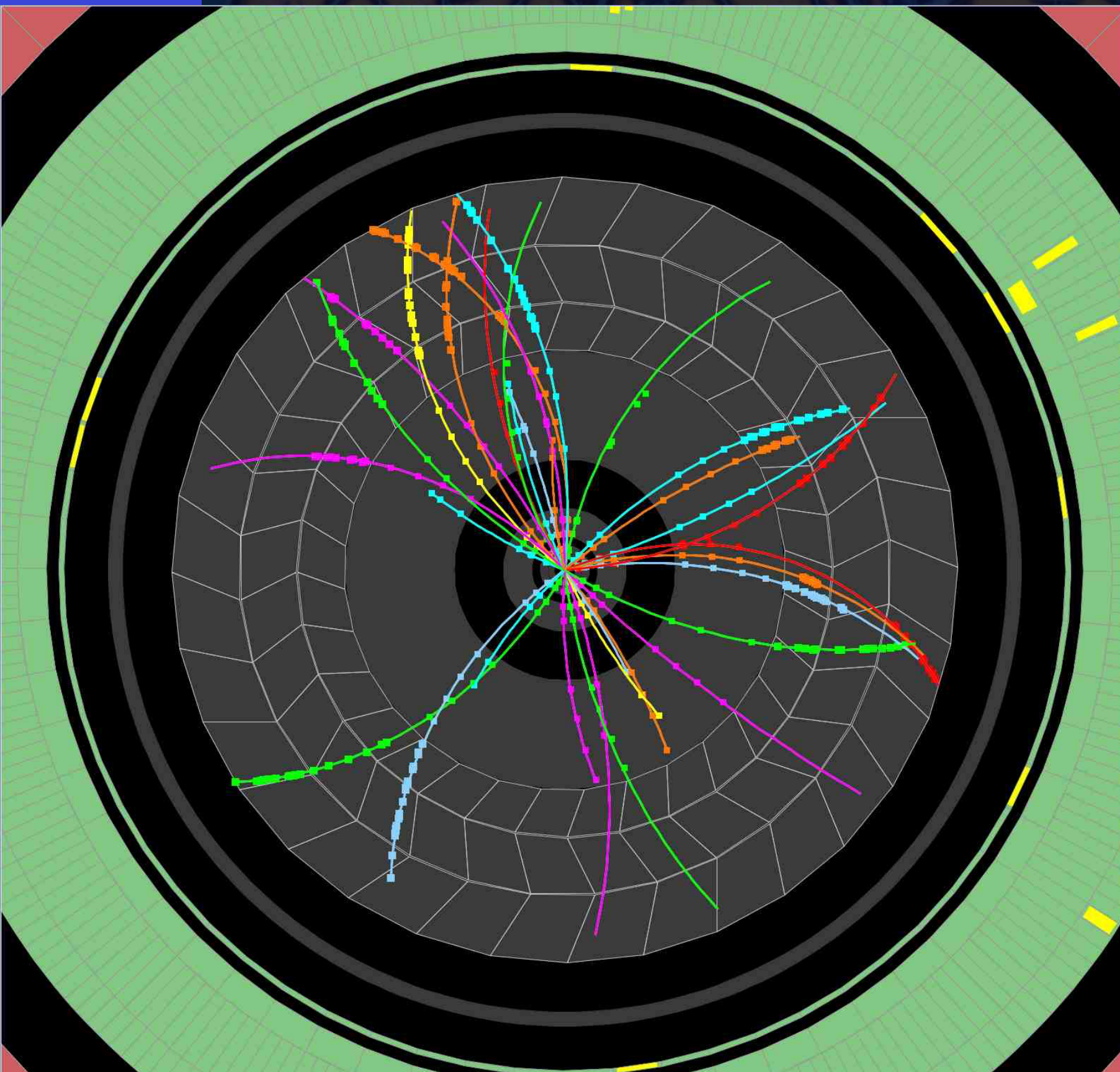
- Semiconductor trackers work similarly, although now the “ionization” energy creates electron-hole pairs



Inner Detector



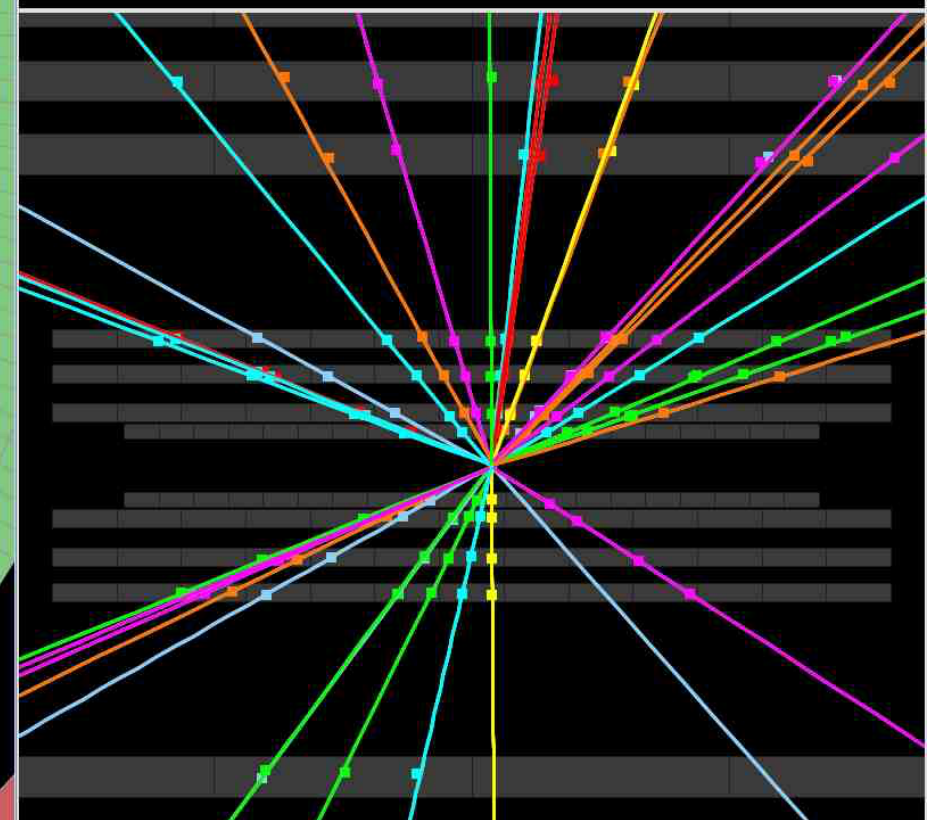
Tracking example



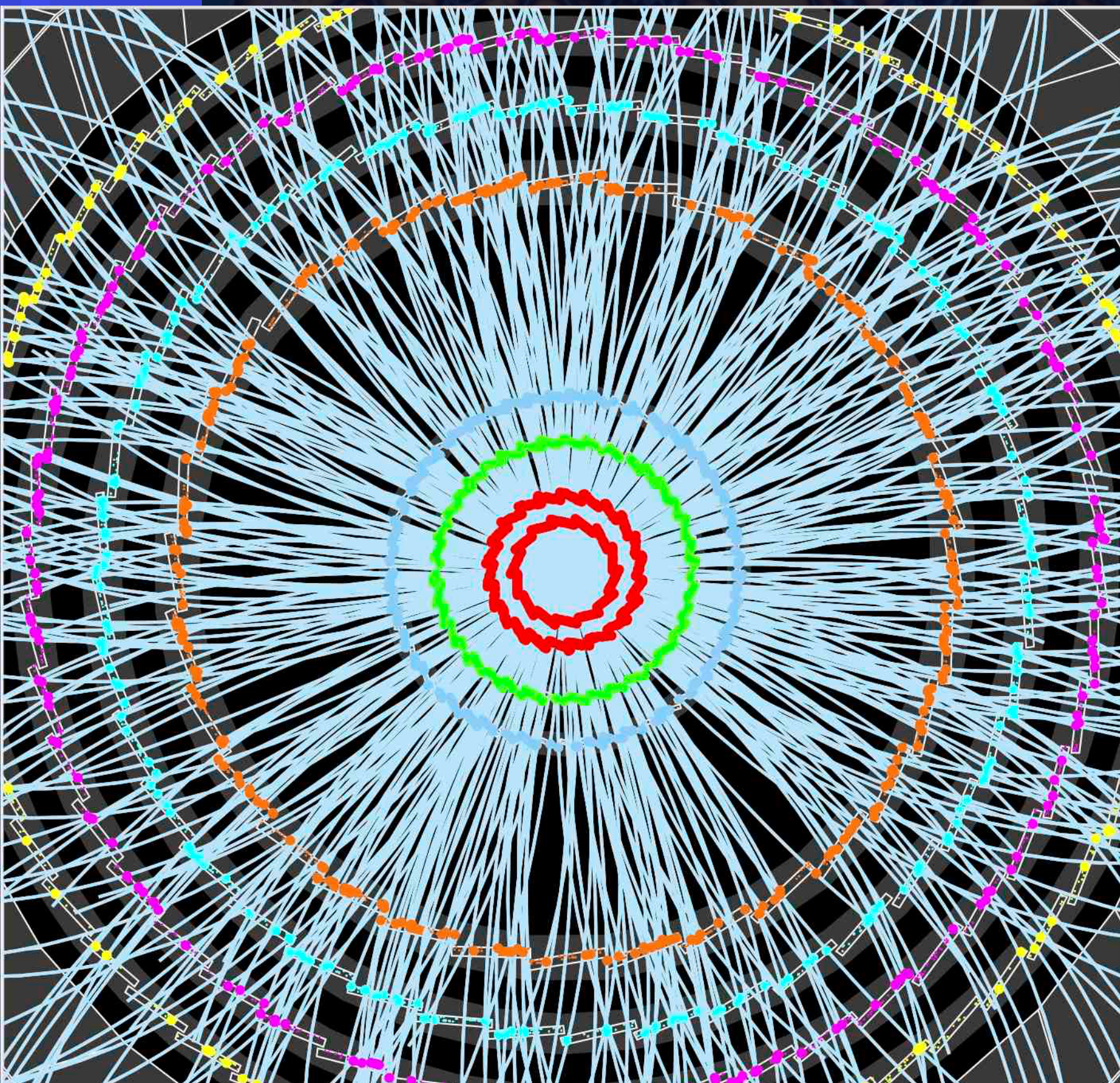
ATLAS
EXPERIMENT

Run Number: 264034, Event Number: 11475271

Date: 2015-05-06 22:53:45 CEST

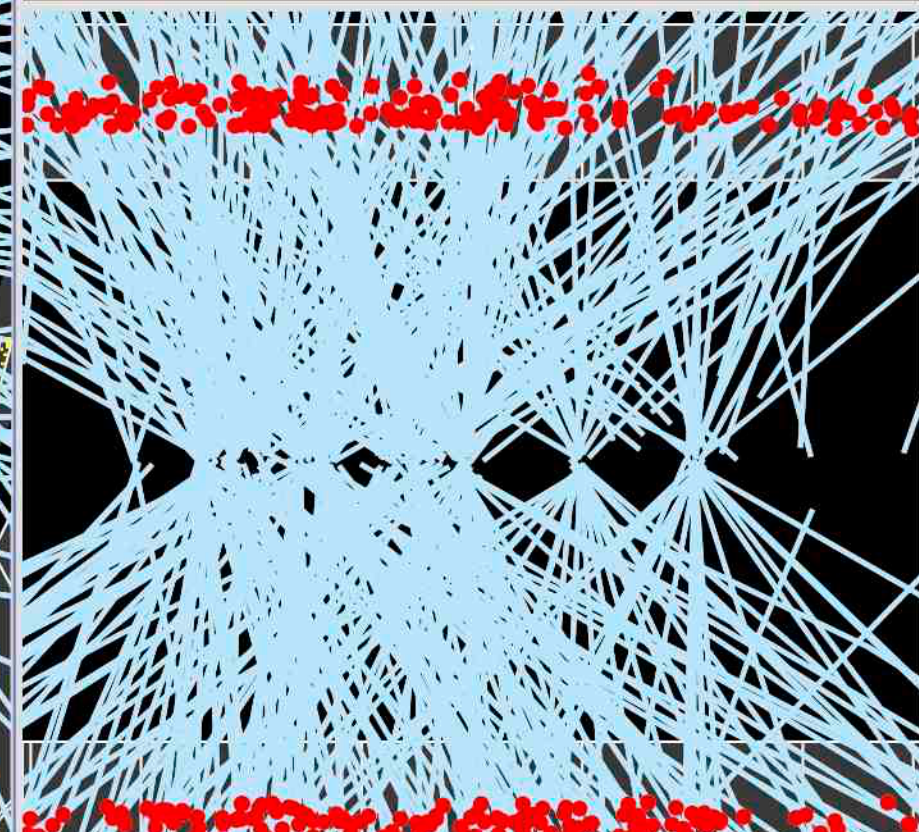


More realistic example



Run Number: 266904, Event Number: 25884805

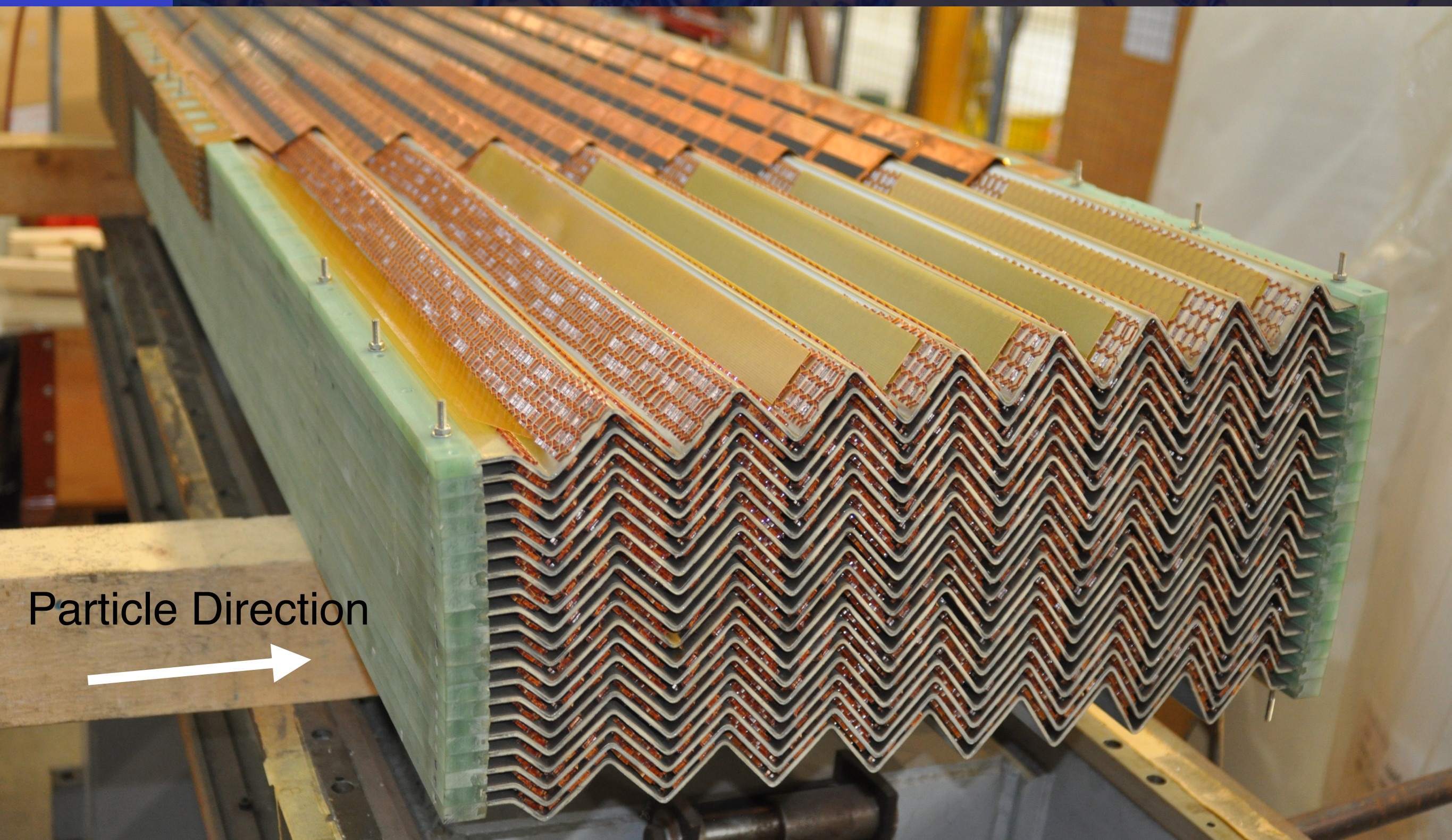
Date: 2015-06-03 13:41:54 CEST



Calorimeters

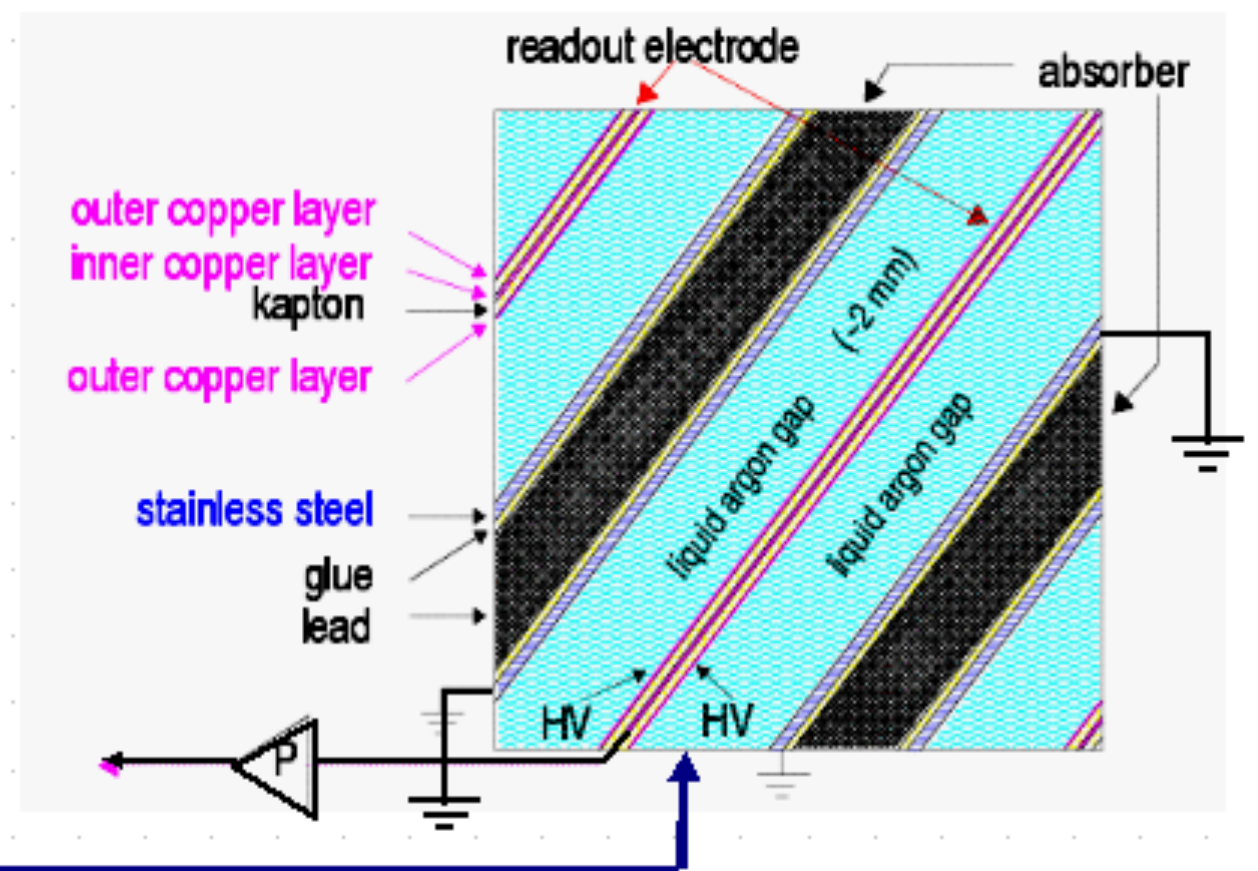
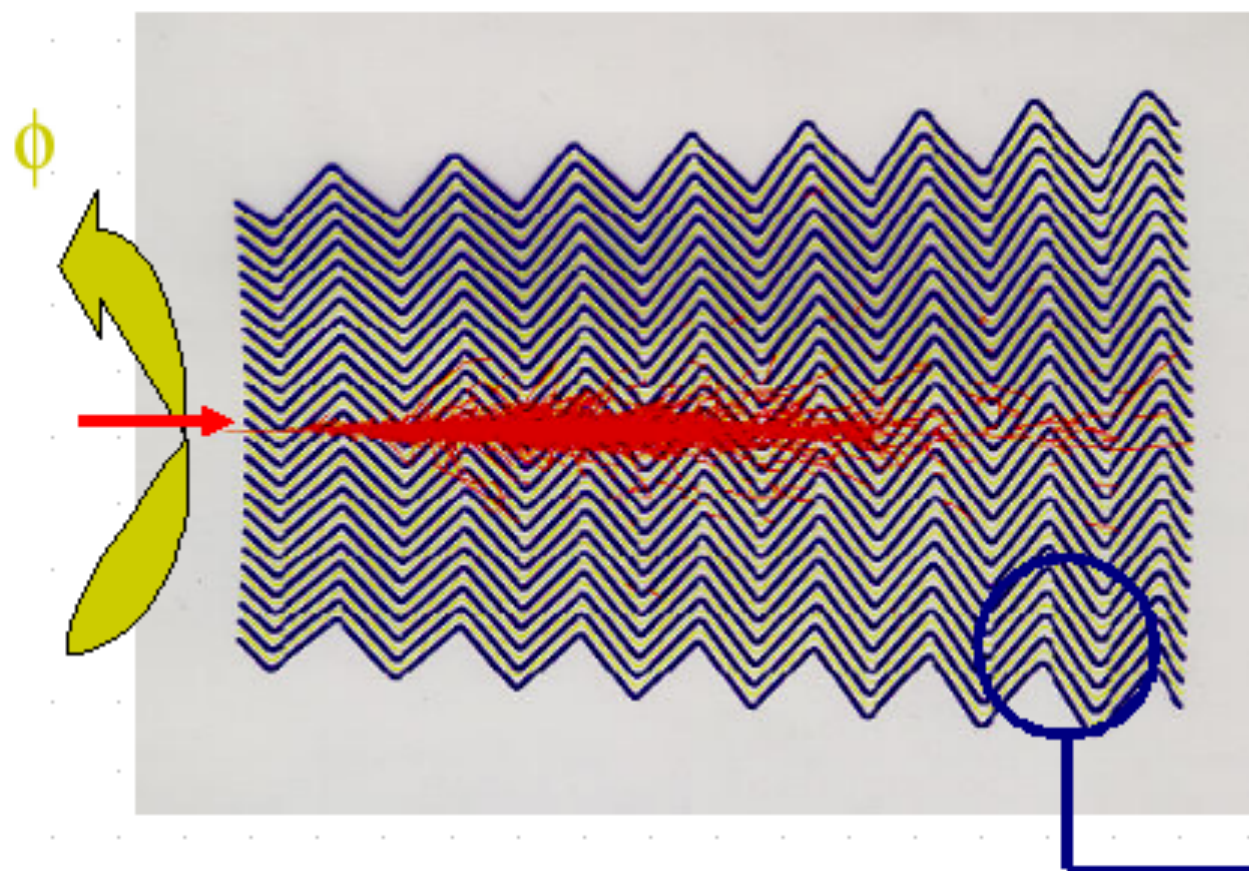
- Tracking detectors typically have low densities so that particles can pass through
- Calorimeters are designed to be dense enough to stop particles completely
- ATLAS uses sampling calorimeters, where much of the detector is inert (copper, lead) interleaved with “active” material (liquid Ar, plastic scintillators)

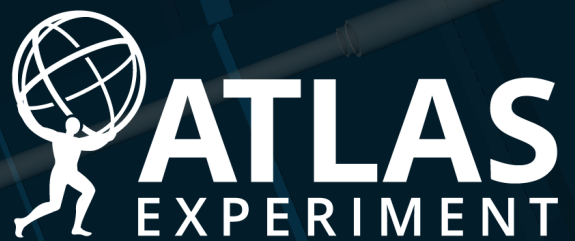
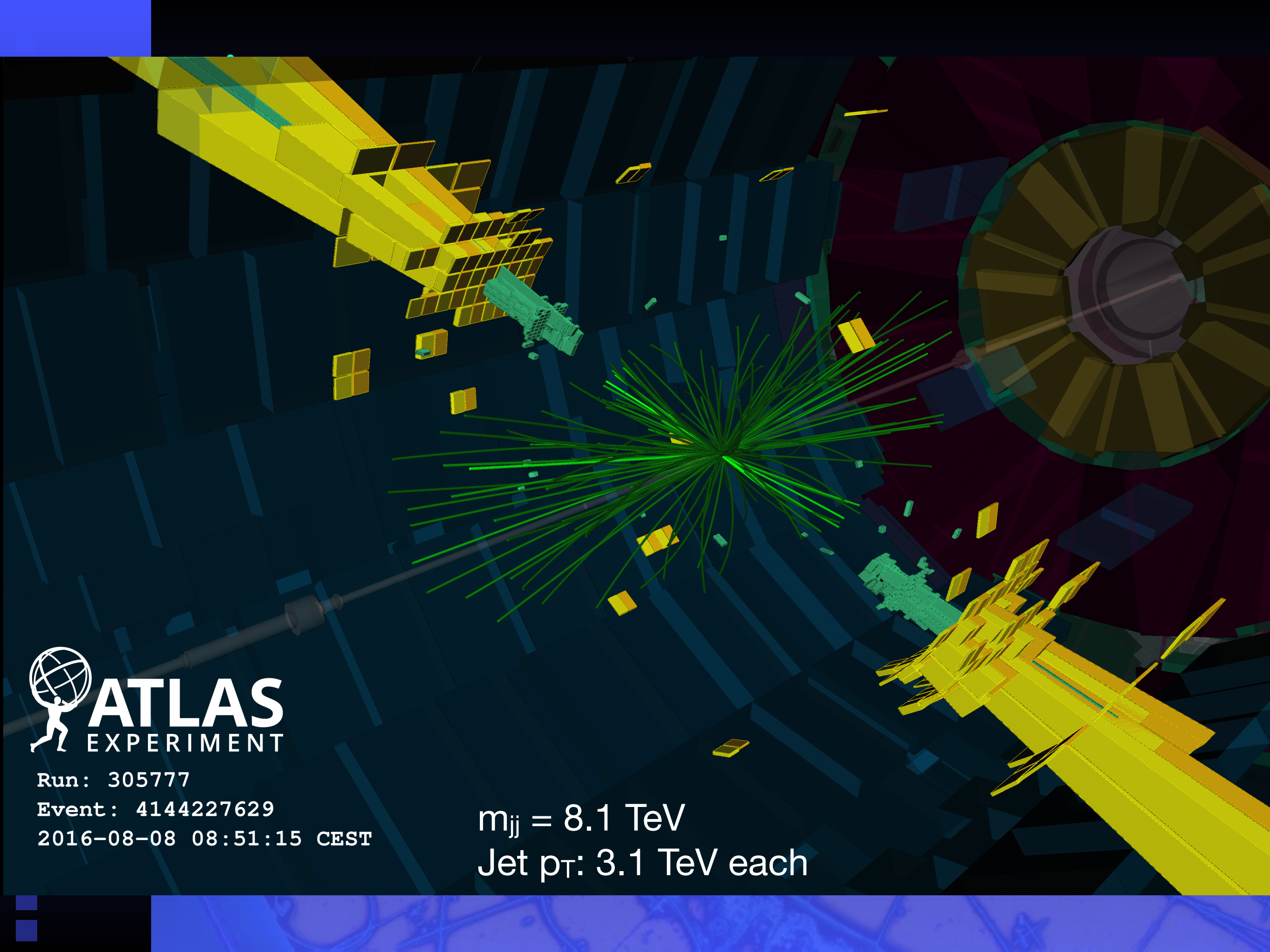
LAr Calorimeter



Calorimeters

- Particles interact with the dense material and produce secondary particles
- Leads to a cascade of particles, ionization energy of the secondaries is proportional to energy of incident particle





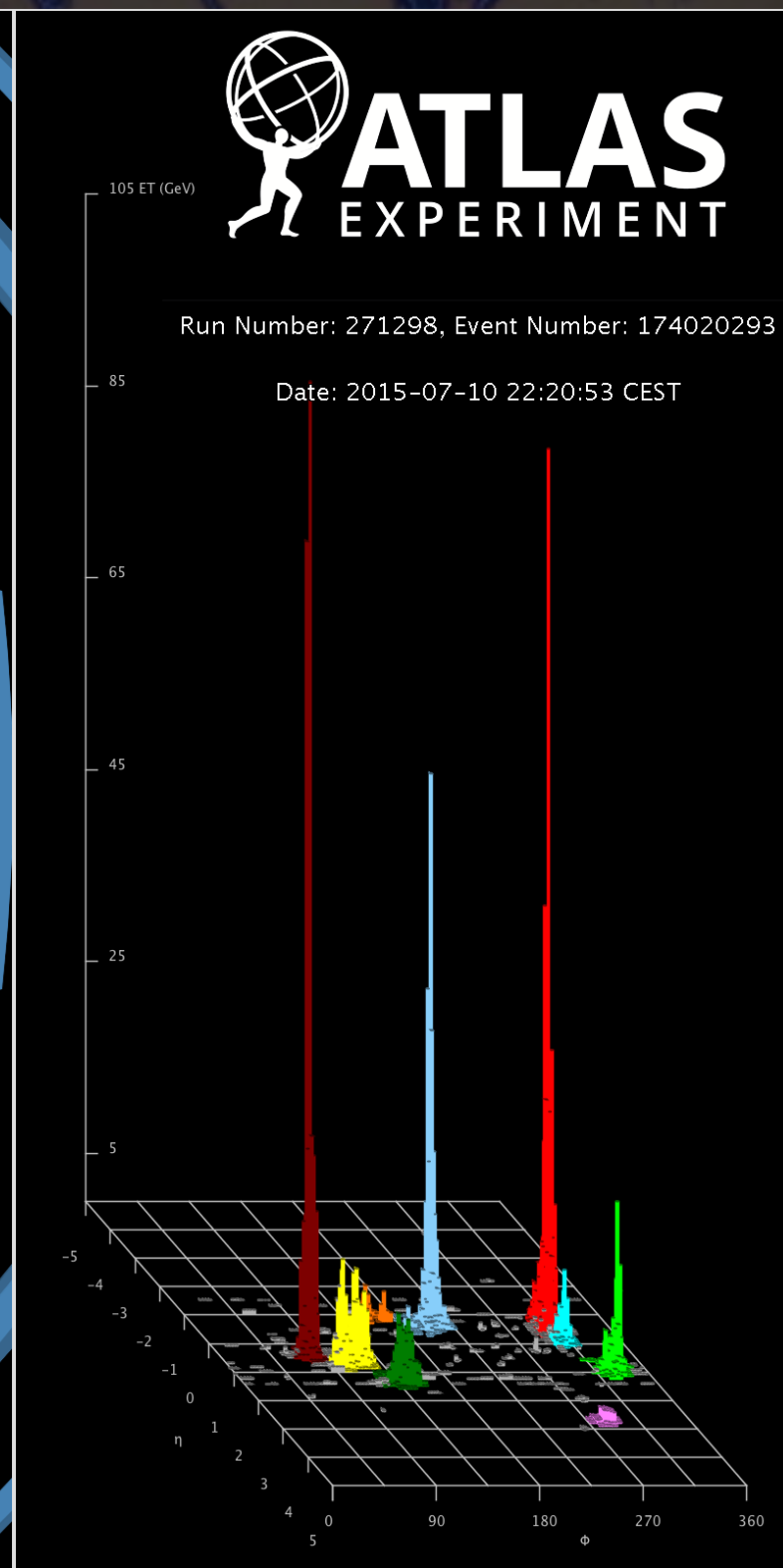
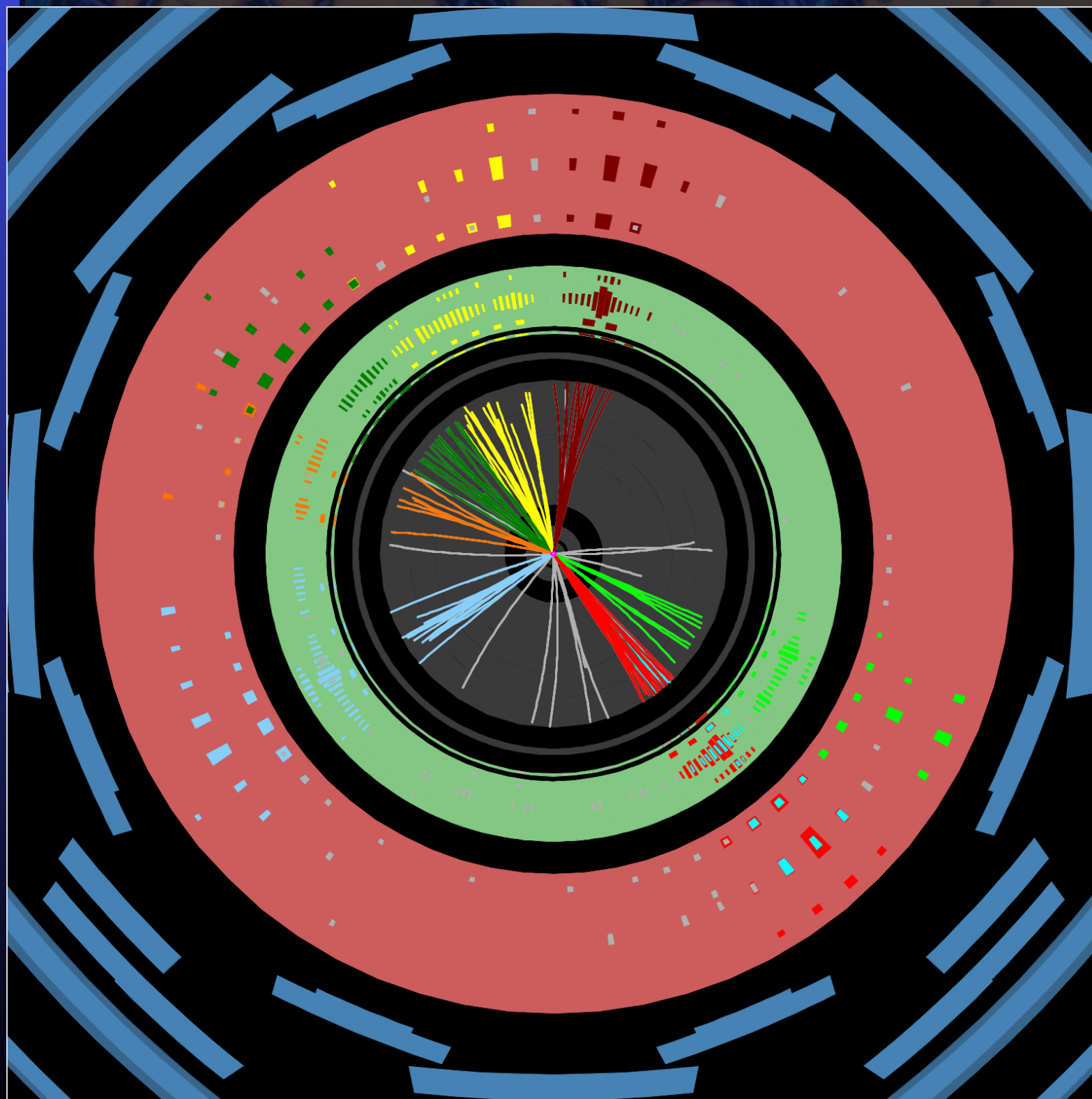
Run: 305777

Event: 4144227629

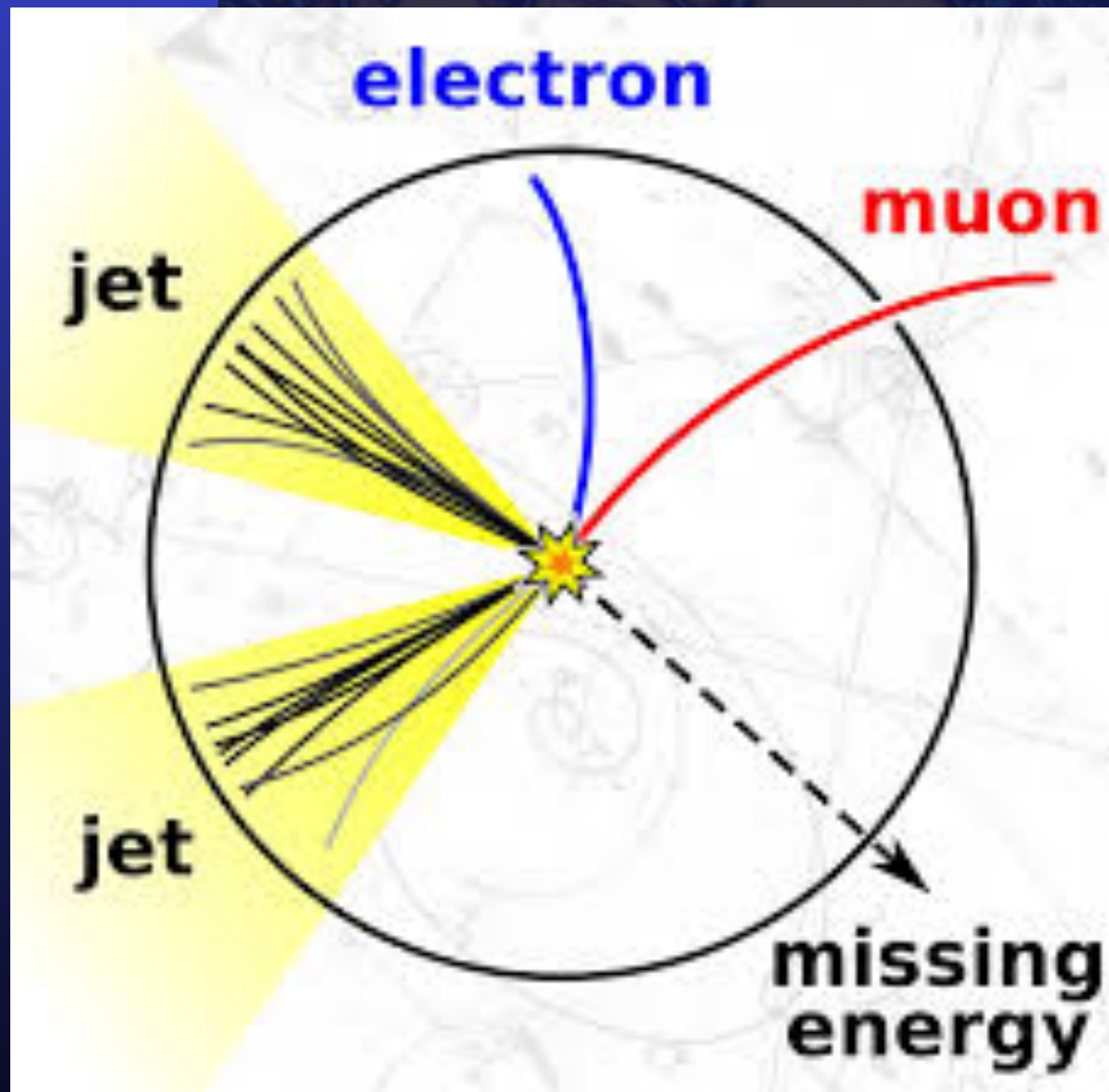
2016-08-08 08:51:15 CEST

$m_{jj} = 8.1 \text{ TeV}$
Jet p_T : 3.1 TeV each

Lego Plots



Physics Objects



- Typically observe e , μ , jets, and missing momentum
- Jets come from quarks or gluons
- Missing momentum most likely comes from neutrinos (or dark matter!)

Decay Chains

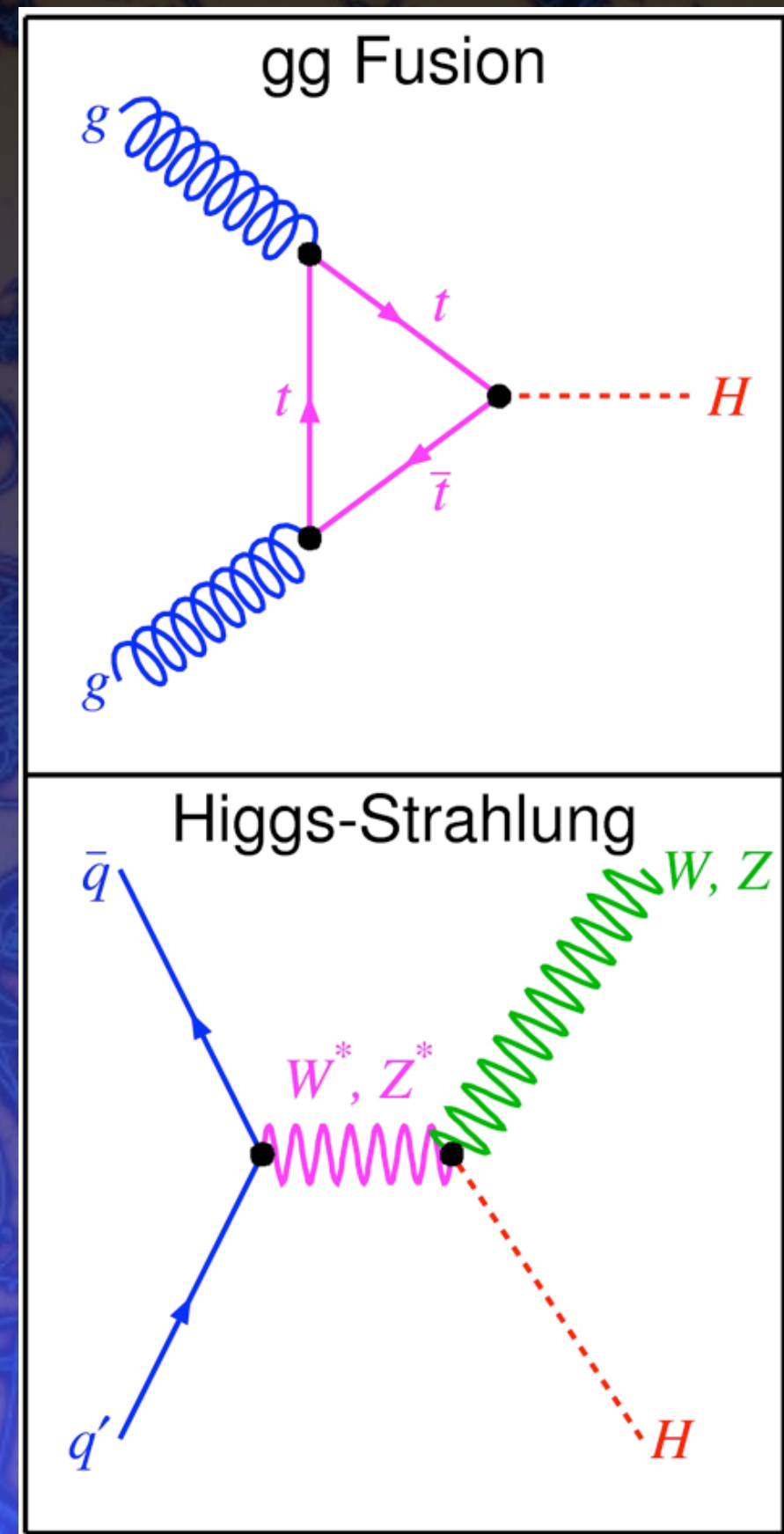
- Higgs Production

- H isn't stable

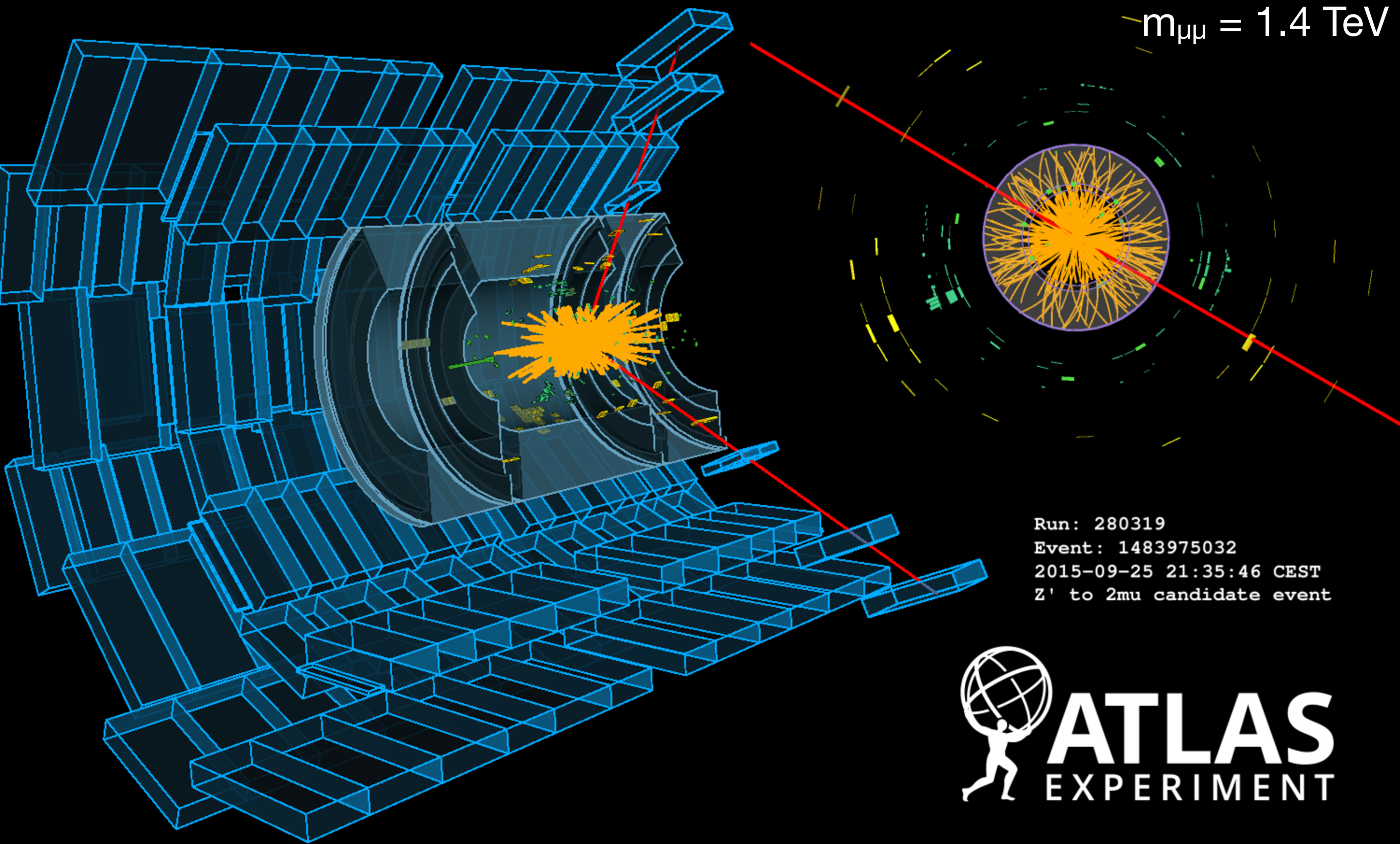
 - ◆ bb , WW , ZZ , $\tau\tau$, $t\bar{t}$

- None of these are stable either

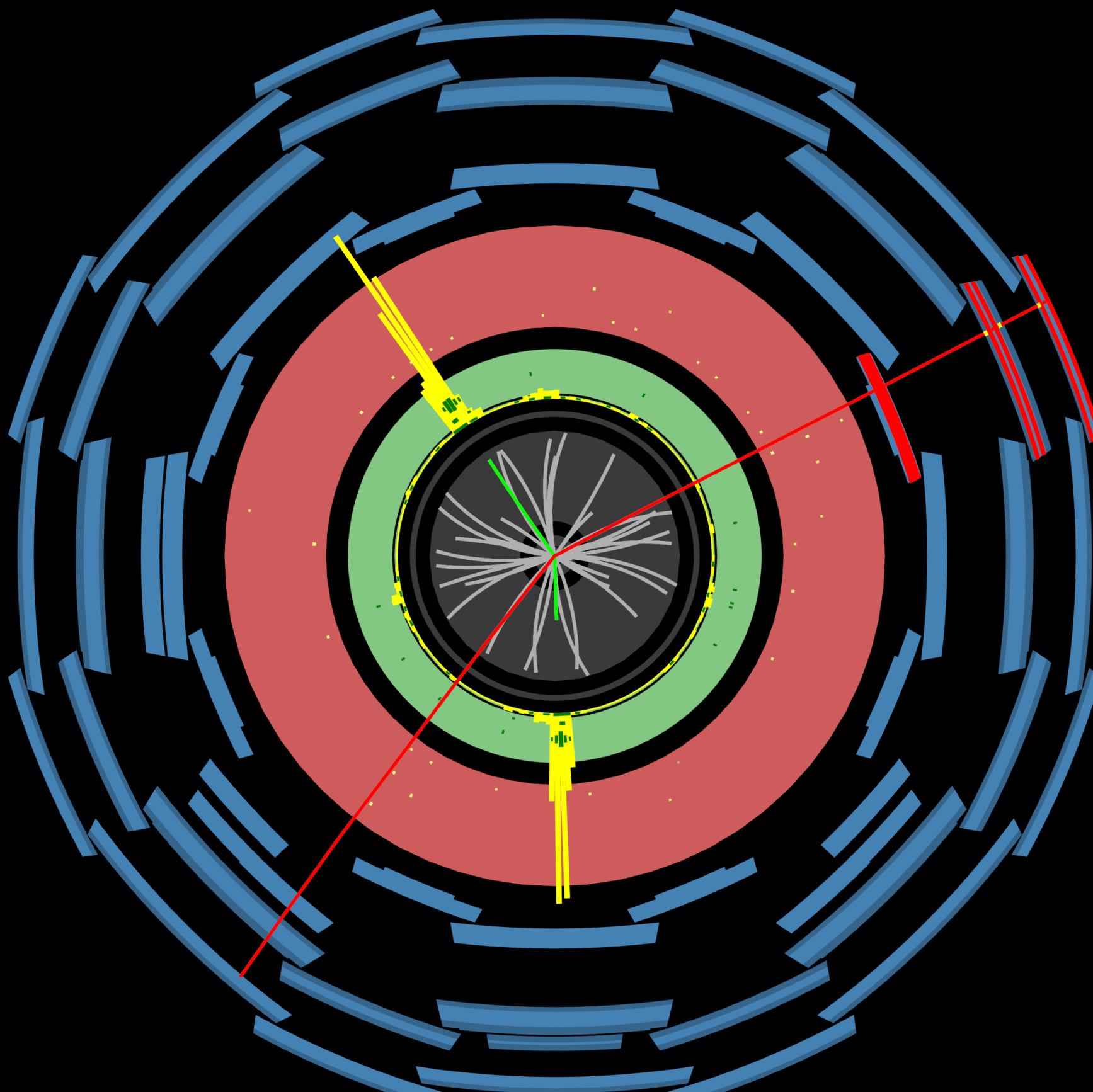
 - ◆ W can decay to leptons ($e\nu$, $\mu\nu$, $\tau\nu$) or qq



What do you see?



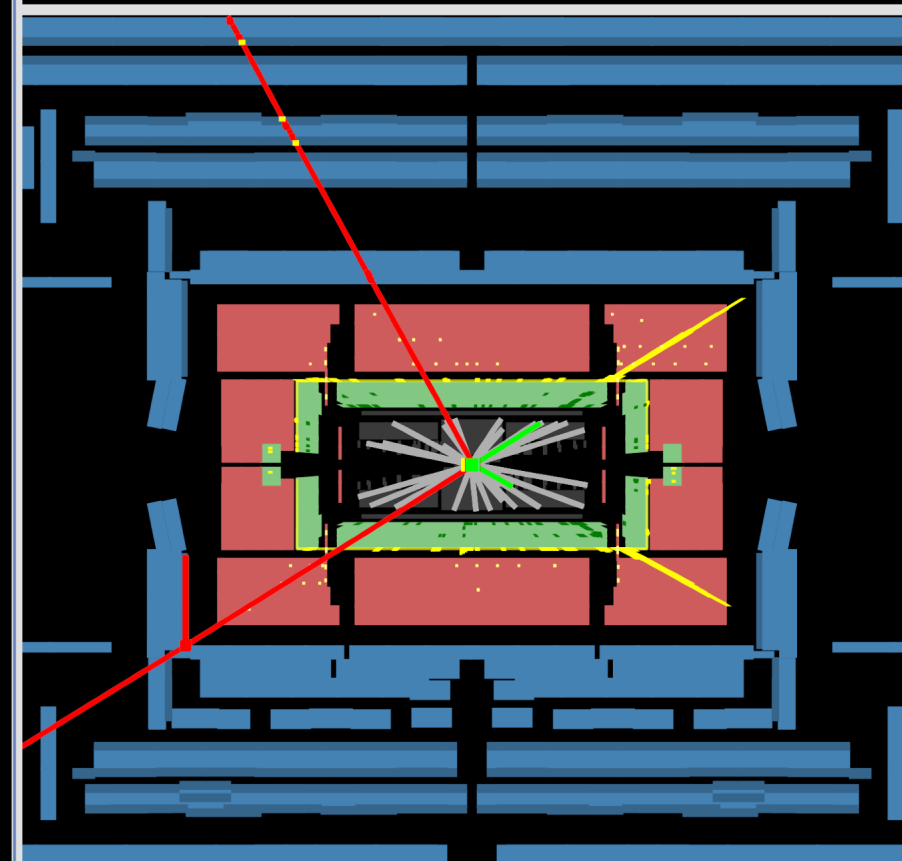
What do you see?



ATLAS
EXPERIMENT

Run Number: 271421, Event Number: 287349506

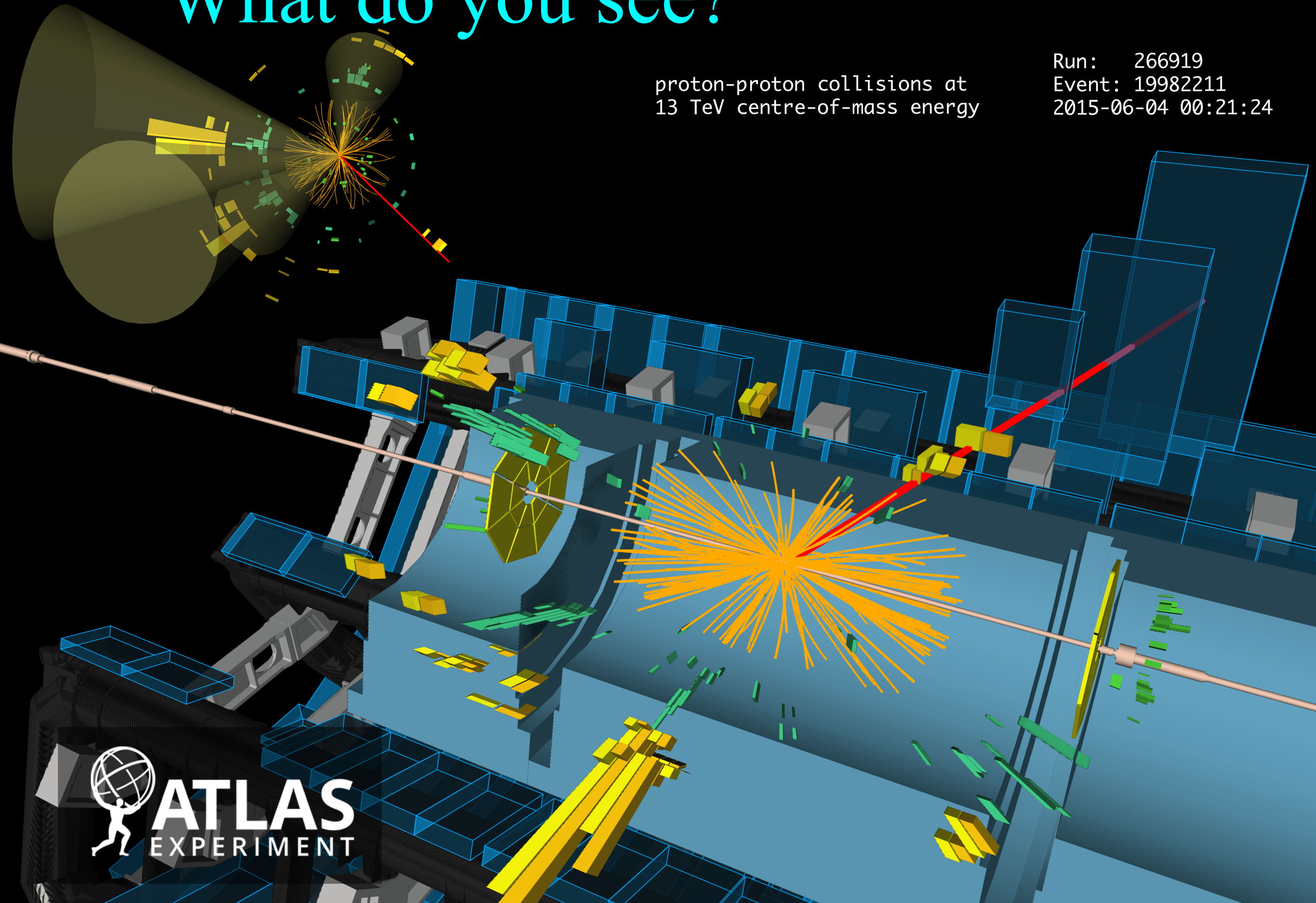
Date: 2015-07-12 09:53:46 CEST



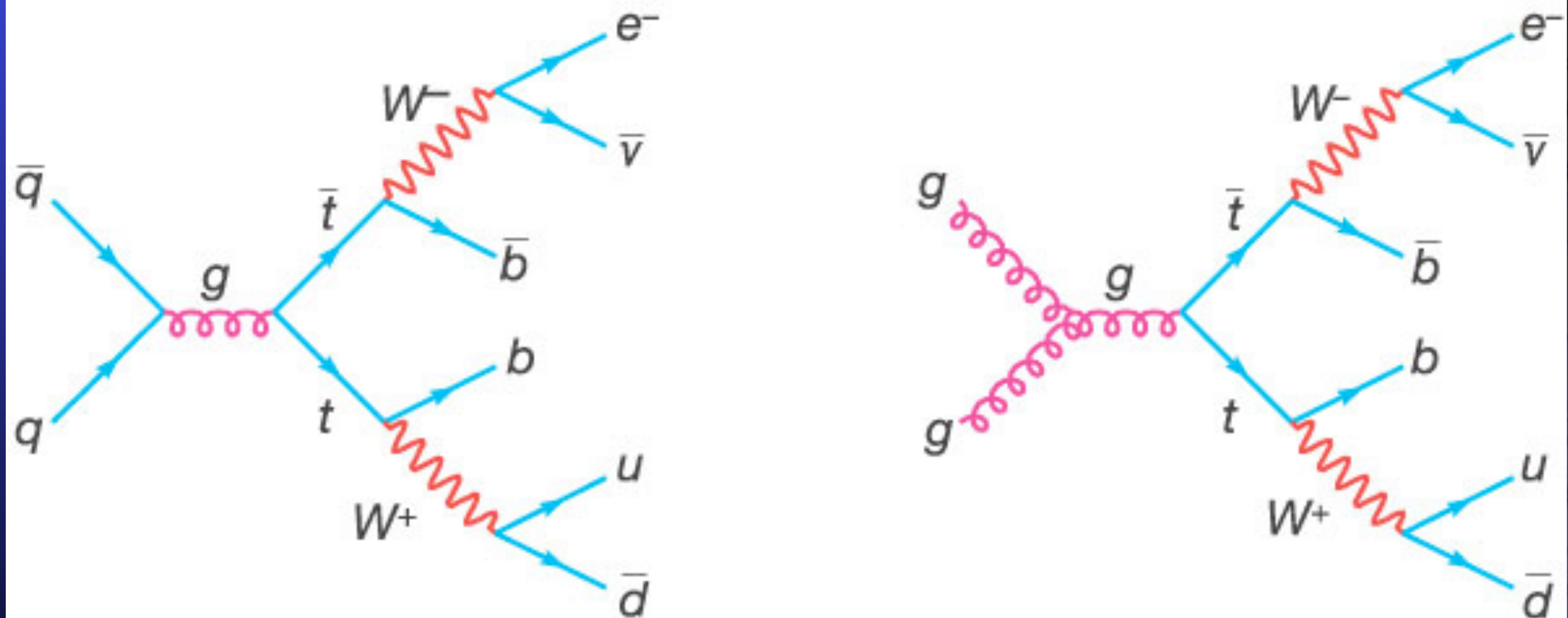
What do you see?

proton-proton collisions at
13 TeV centre-of-mass energy

Run: 266919
Event: 19982211
2015-06-04 00:21:24



top quarks



4 jets + lepton + MET
(could also have 2 leptons + MET, or 6 jets)
Analyses often classified by 'final state' observables