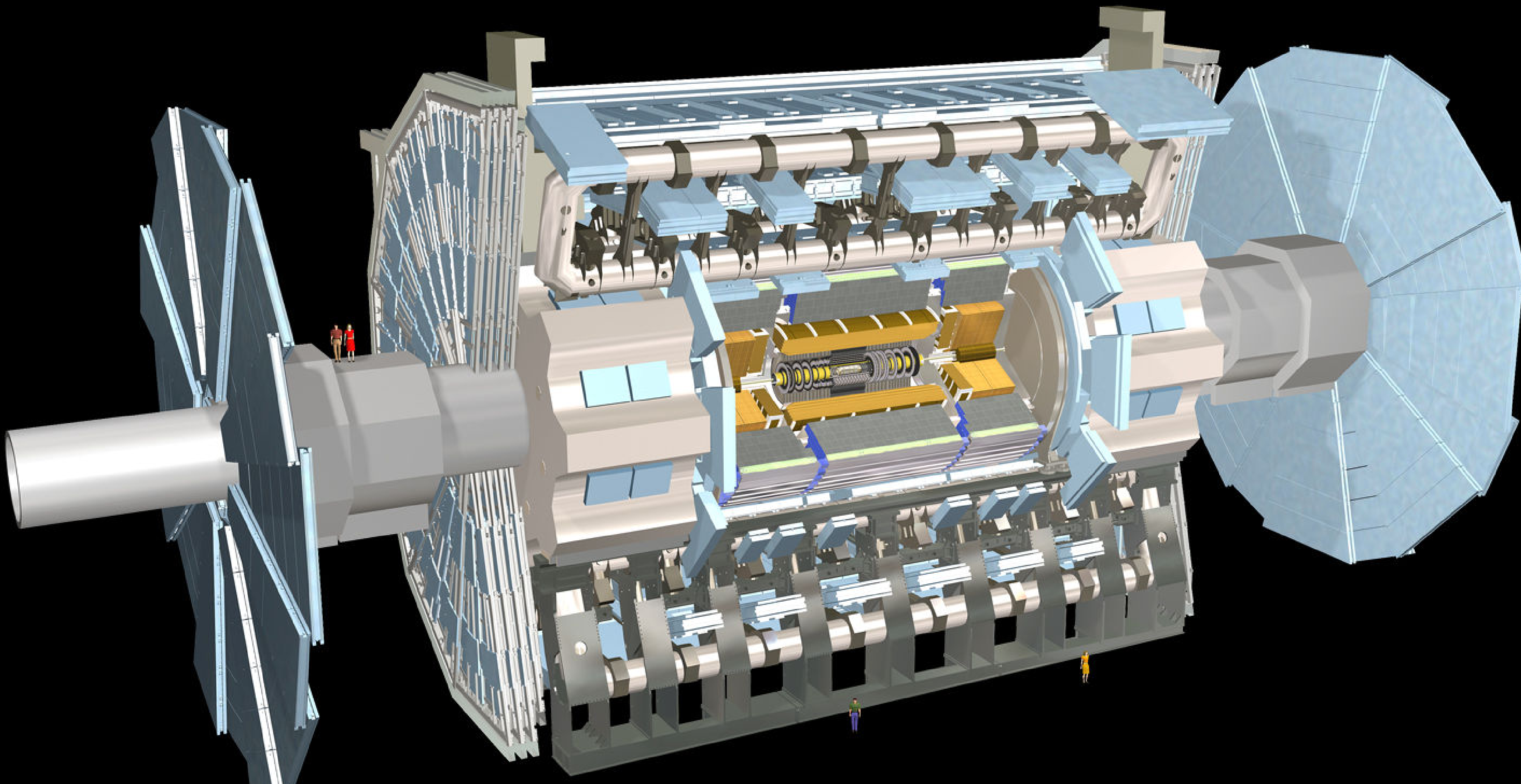
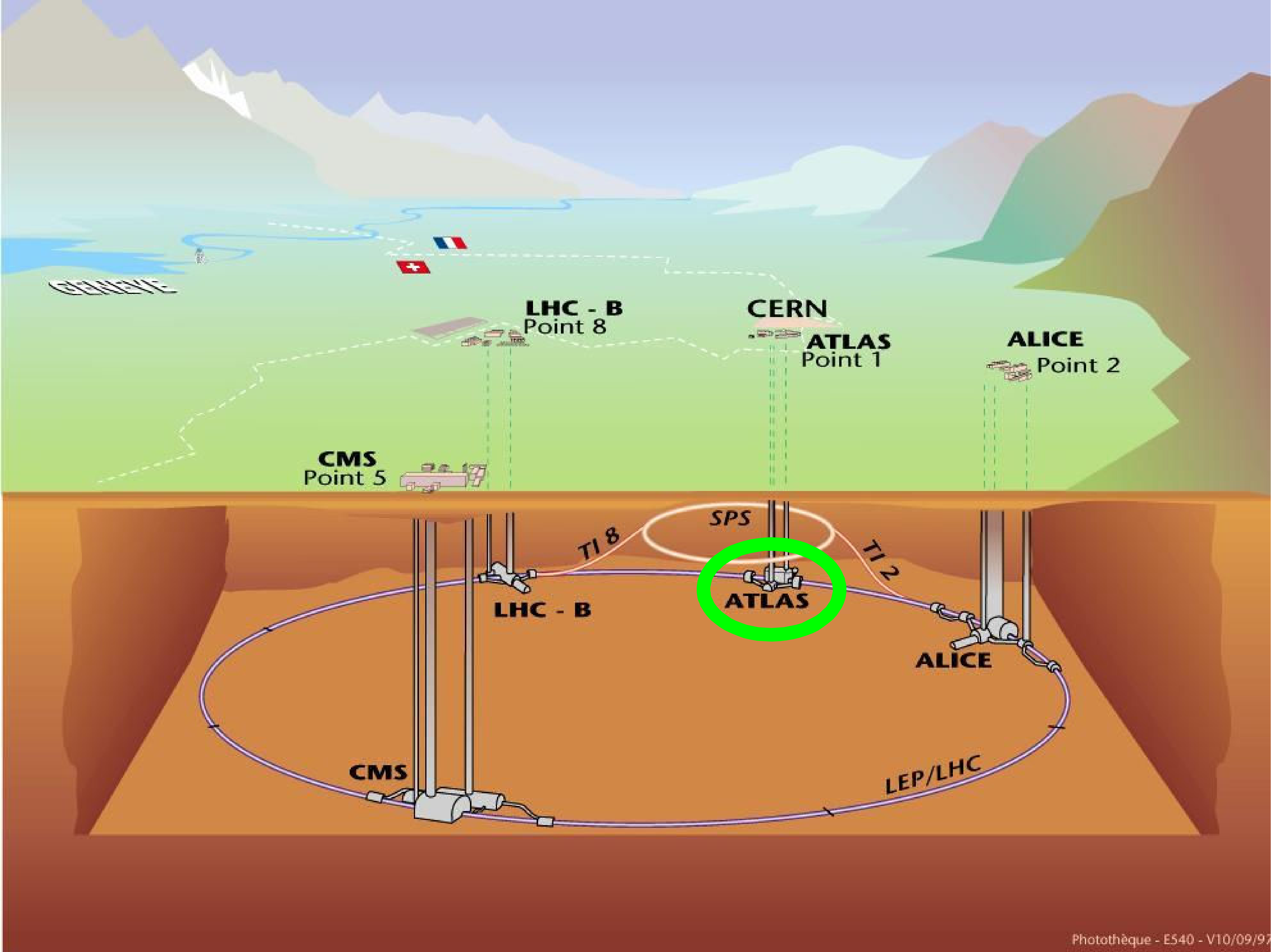
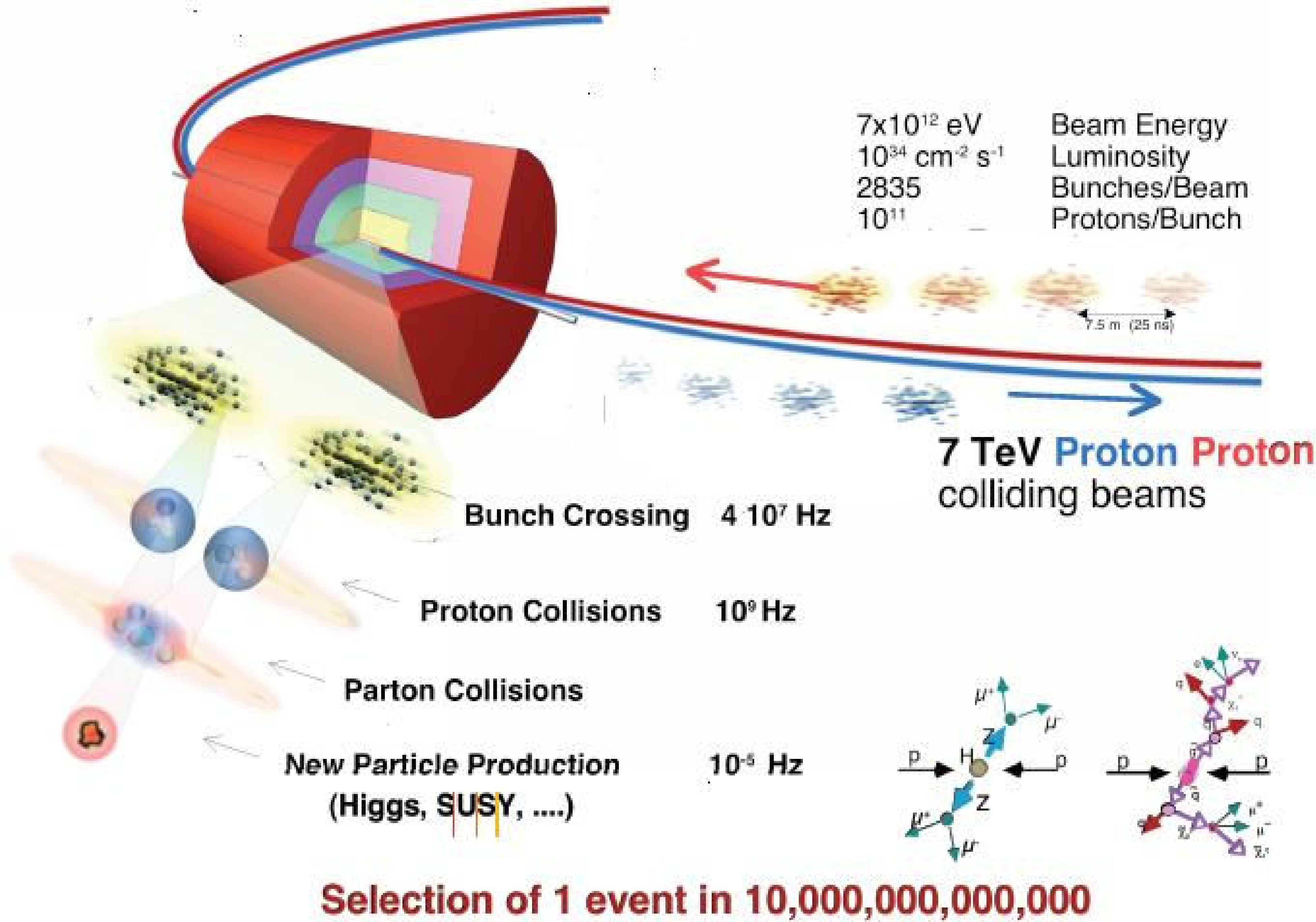
The ATLAS detector

(A Toroidal LHC ApparatuS)

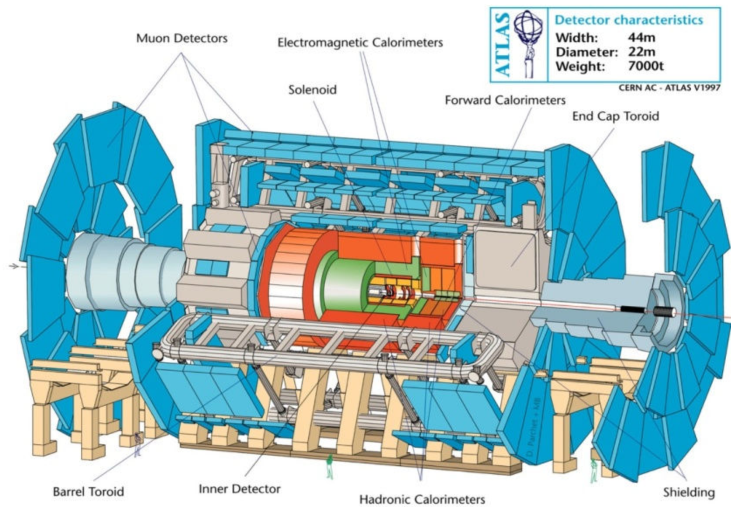



LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
ATLAS
LHC - B
ALICE
CMS
LEP/LHC
Photothèque - E540 - V10/09/97

LHC facts


7x10^12 eV Beam Energy
10^34 cm^-2 s^-1 Luminosity
2835 Bunches/Beam
10^11 Protons/Bunch
7.5 m (25 ns)
7 TeV Proton Proton
colliding beams
Bunch Crossing 4 10^7 Hz
Proton Collisions 10^9 Hz
Parton Collisions
New Particle Production 10^-5 Hz
(Higgs, SUSY, ...)
Selection of 1 event in 10,000,000,000,000

ATLAS numbers



- 44 m long
- 22 m tall
- 200 institutes
- 2500 scientists
- 40 countries
- Norway: Oslo, Bergen
  - 50 people

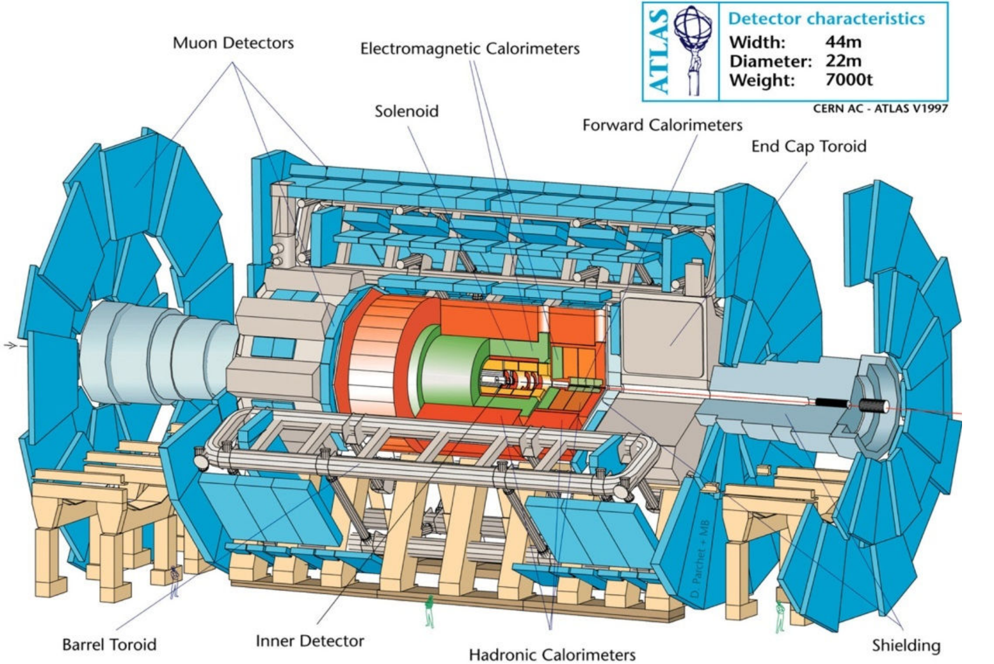
LHC – a discovery machine

- The high energy collisions allow production of high mass particles
  - Well known heavy particles as W, Z bosons for instance
  - But also anything else!
    - If supersymmetry exists: Supersymmetric particles
    - If other new symmetries exist: W' and Z'
    - If Higgs field exists: Higgs boson(s)!!
    - …. or extra dimensions, black holes, gravitons , fantasitons …
- The detectors must be able to register all these particles
  - But the particles are heavy and extremely unstable, decay immediately
    - How then to detect them?

A handfull of particles

- They all end up as a handfull of everyday particles
  - Electrons - elementary
  - Muons - elementary
  - Photons - elementary
  - Quarks and gluons
    - Manifested as jets of hadrons (p, π)
- The detector reconstructs what happened in the collision by tracking the charged particles, absorbing particles completely and measuring their deposited energy, and by measuring secondary vertices

ATLAS – a general purpose detector

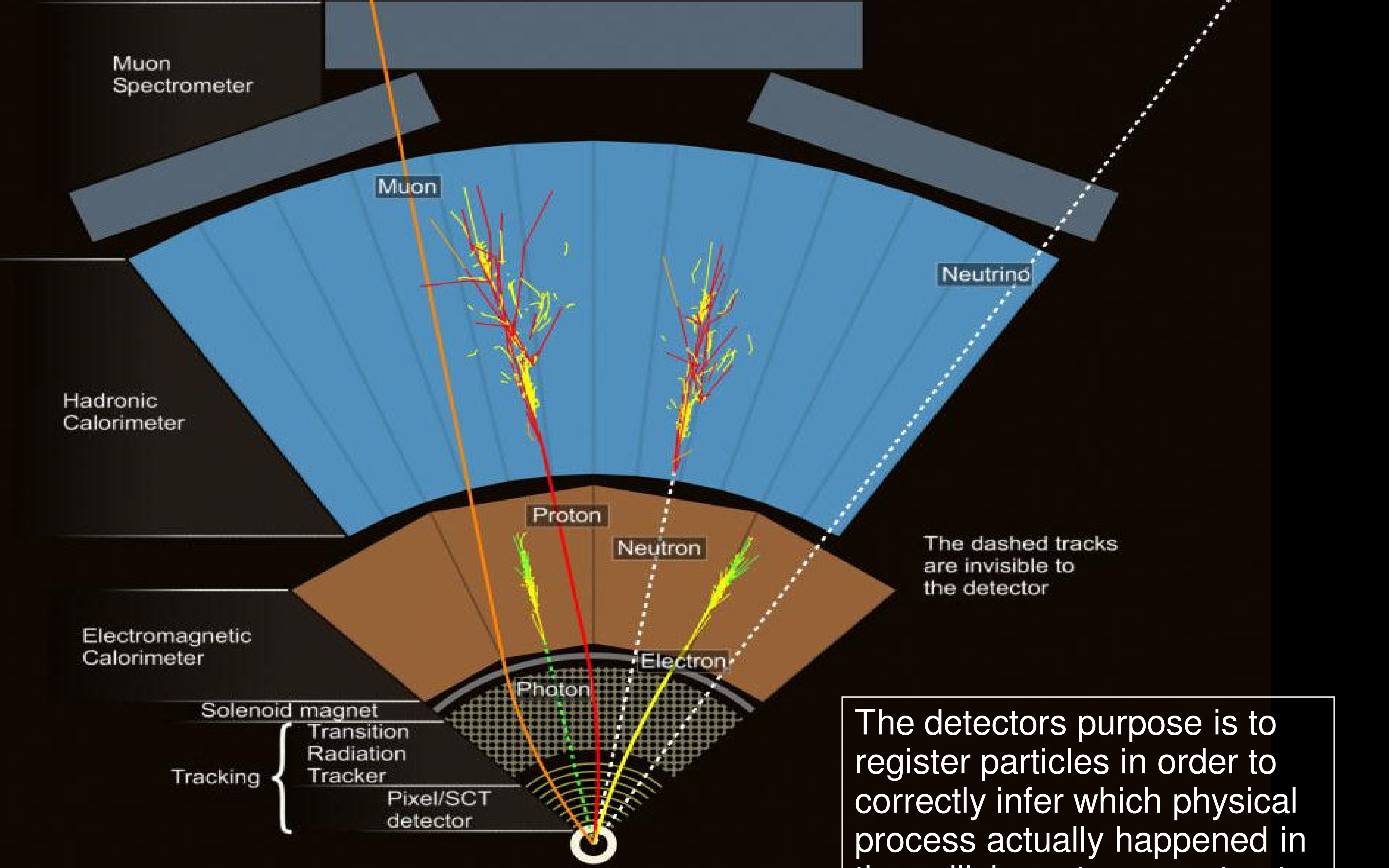


- Built to detect both new and and well known physics phenomena

- Design defined by ability to detect SM Higgs boson
  - Large range of production- and decay mechanisms
  - These have dictated the needed performance of its subdetectors

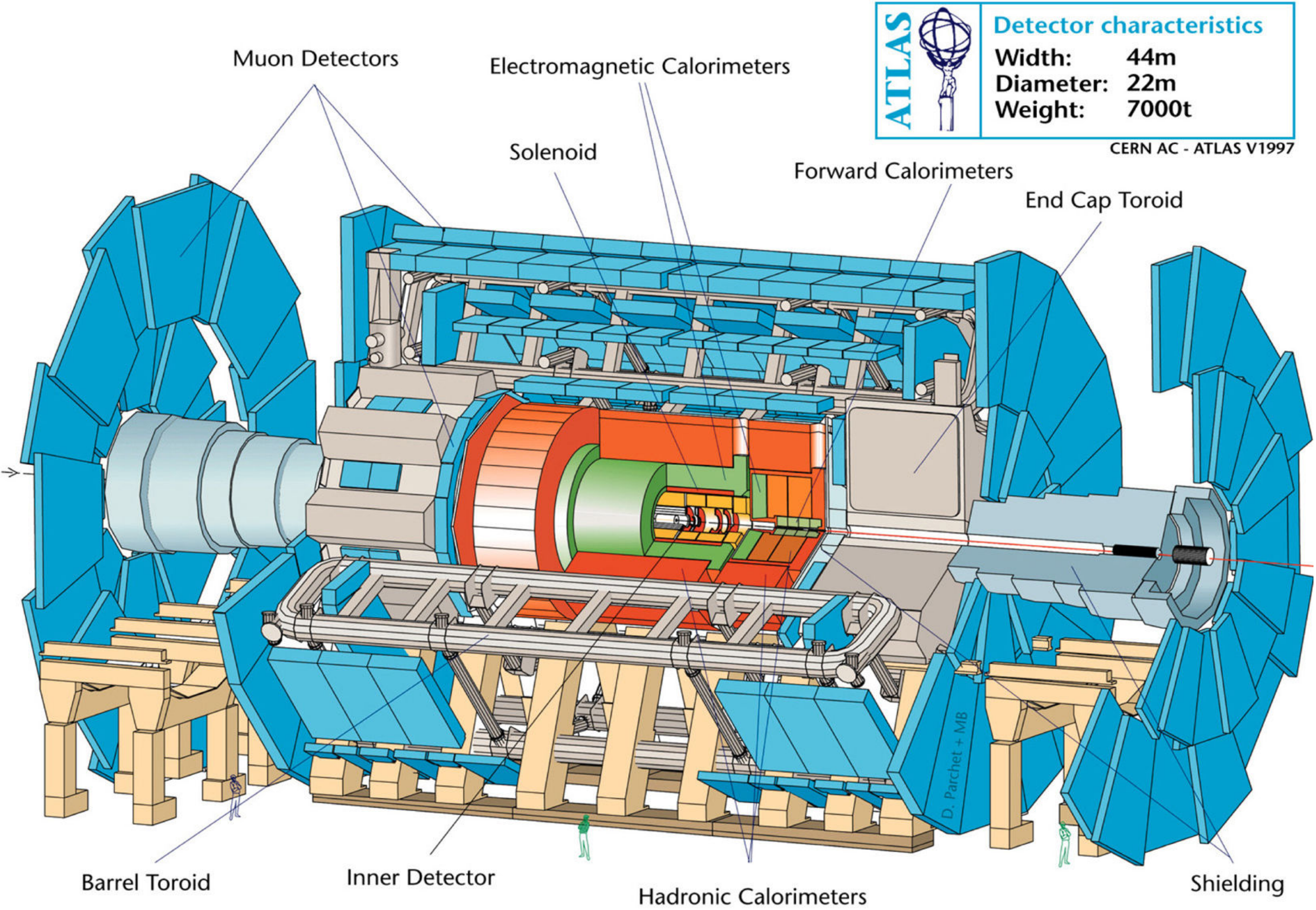
A detector needs to

Measure the **directions**, **momenta**, and **signs** of **charged particles**
Measure the energy carried by electrons and photons
Measure the **energy** carried by **hadrons** (protons, pions, neutrons, etc.)
Identify which charged particles from the collision, if any, are **electrons**
Identify which charged particles from the collision, if any, are **muons**
Identify secondary vertices: if some charged particles originate a few millimetres from the collision point
Infer (through momentum conservation) the presence of **undetectable neutral** particles such as neutrinos – weakly interacting
Be able to **process** the above information **fast enough** to permit flagging about 10-100 potentially interesting events per second out of the billion collisions per second that occur, and recording the measured information.
Be able to do this **reliably year after year** in a very hostile radiation environment.



The detectors purpose is to register particles in order to correctly infer which physical process actually happened in the collision – to reconstruct the collision

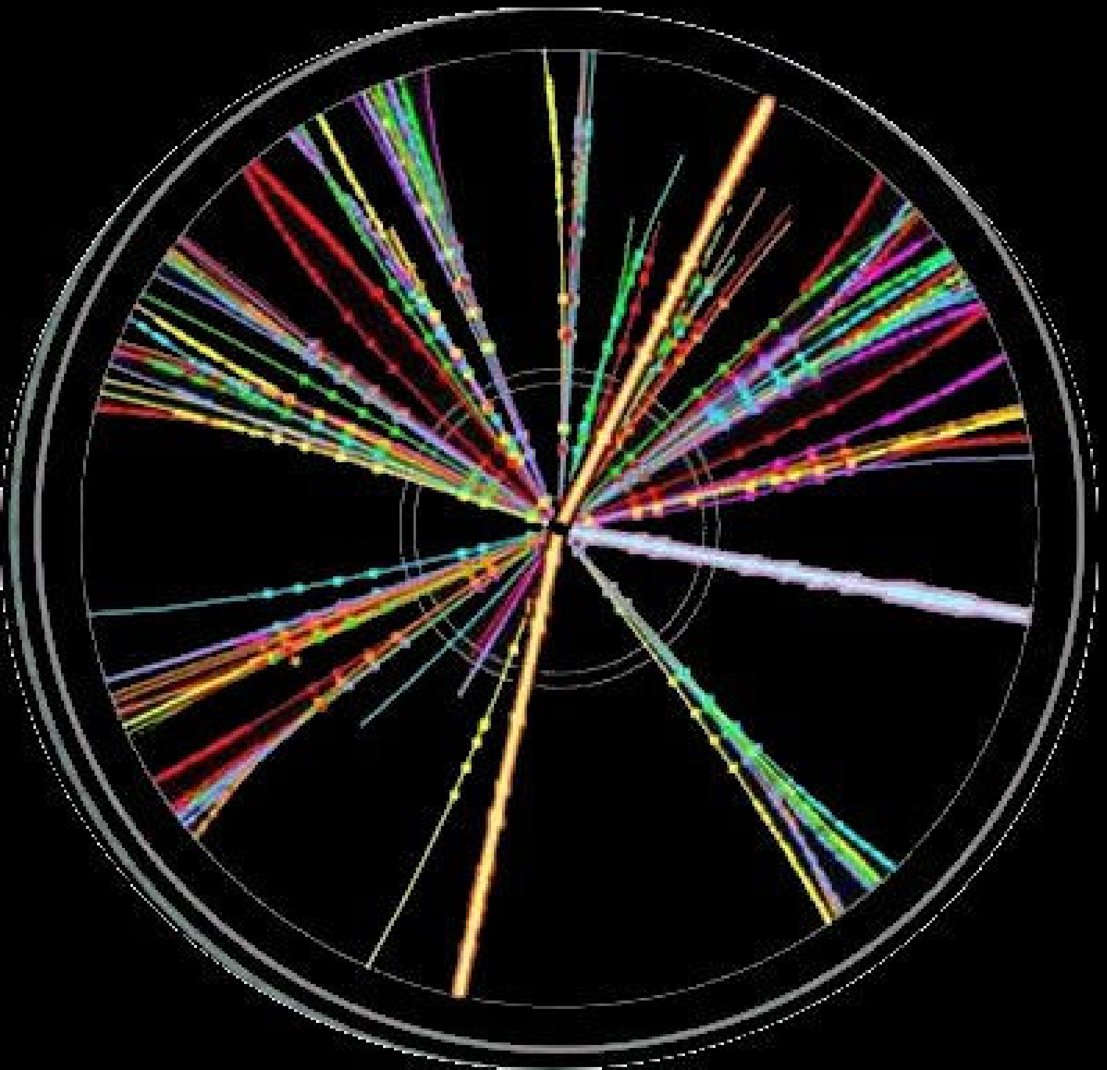
A detector is built to register and identify all possible (for the detector) stable particles that interact with the material of the detector



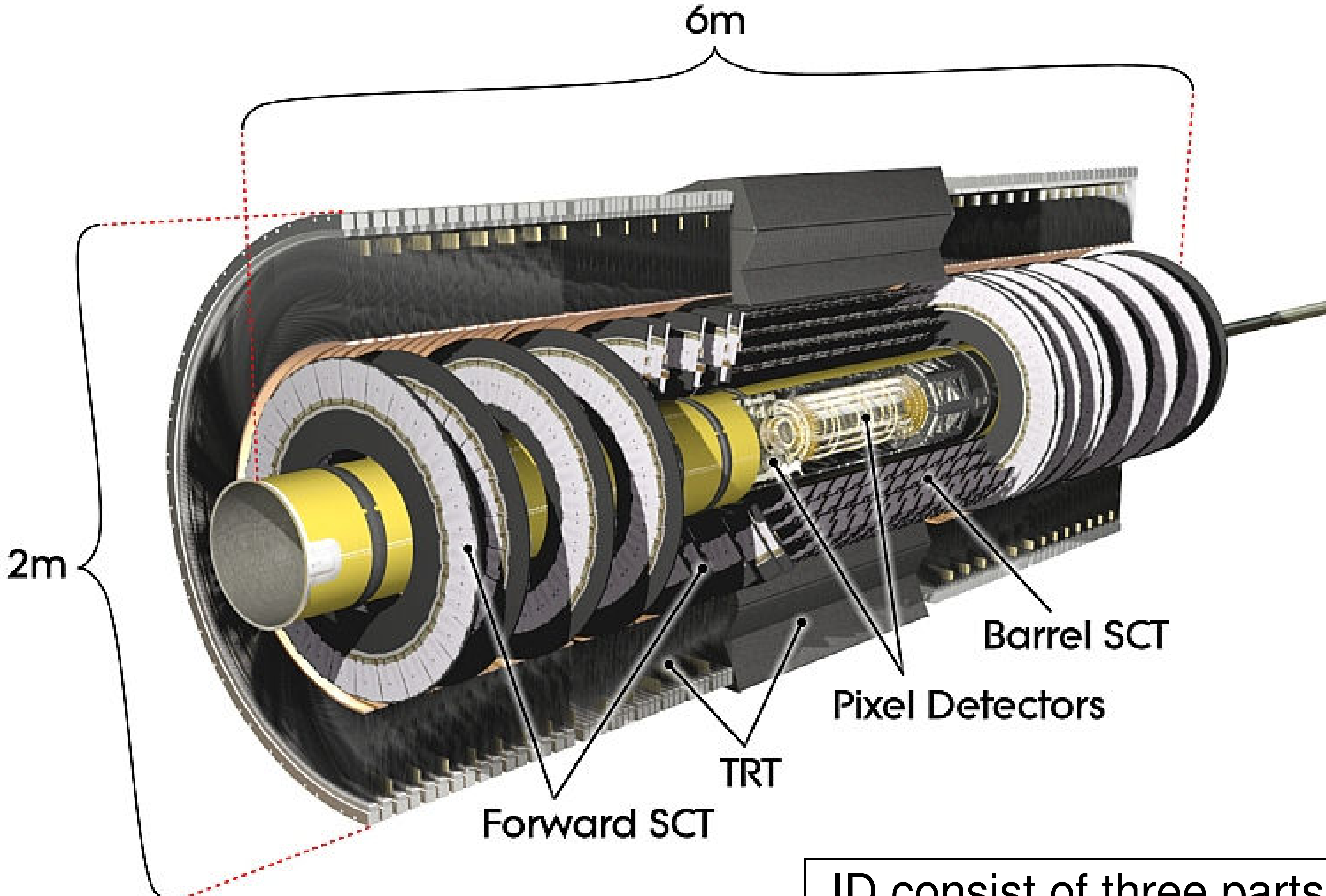
Detector characteristics
Width: 44m
Diameter: 22m
Weight: 7000t
ATLAS
CERN AC - ATLAS V1997
Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding
D. Parchet + MB

The Inner Detector (ID)

- detects charged particles as they travel through the detector
  - e.g electrons, muons, protons, quarks (jets) ...
- cannot detect neutral particles
  - e.g. photons, neutrons, neutrinos ...



- the whole ID is situated inside a manetic field (The Inner Solenoid)
  - Charged particles bend in this magnetic field
  - how much they bend reveals the particle's momenta
  - the direction of the curve reveals the charge (+/-)
- placed a few cm from the beampipe and extends to a radius of 1.2 m
- ca 5 meters long



ID consist of three parts

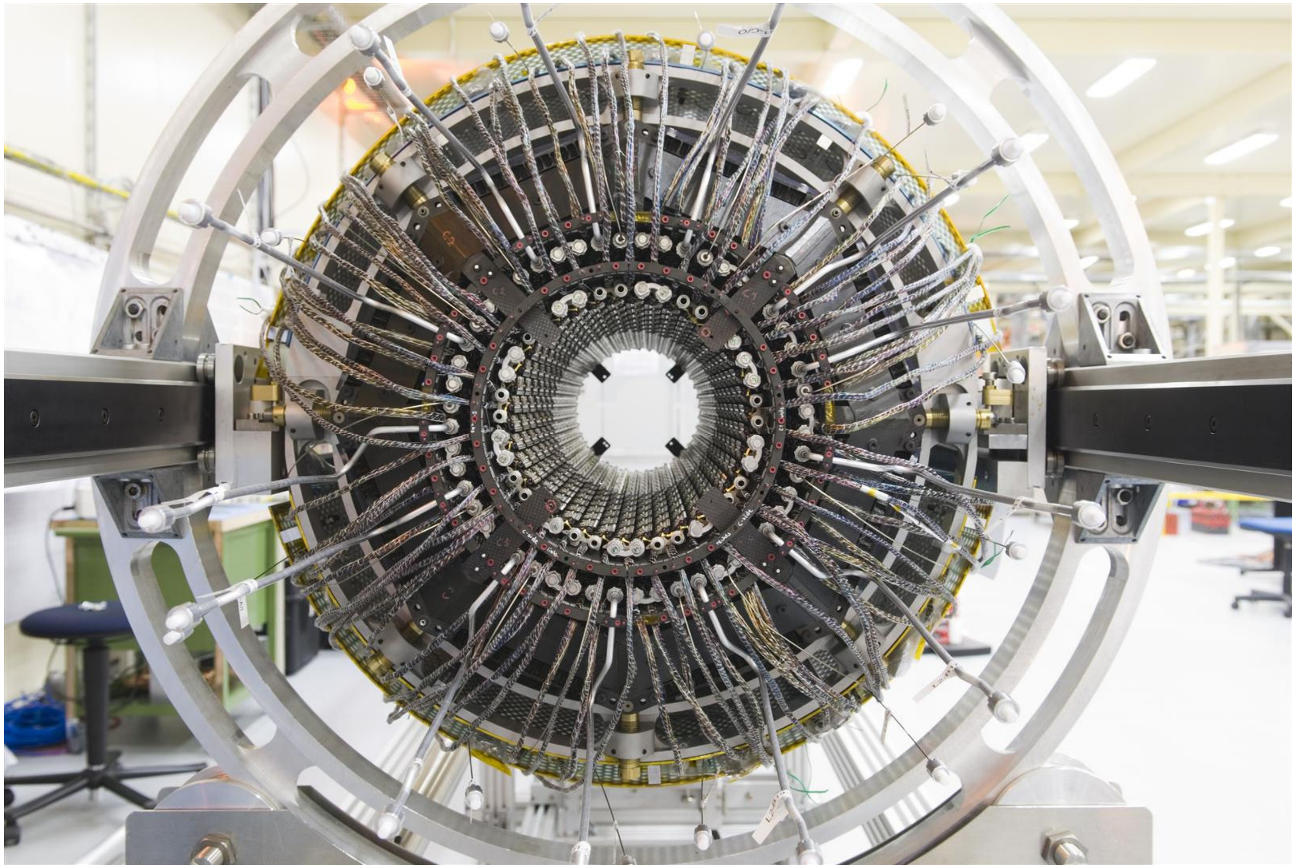
1) The Pixel Detector

2) The SemiConducting Tracker (SCT)

3) Transition RadiationTracker (TRT)

Pixel Detector – innermost

- contains 1744 modules in barrel and end-caps
  - each module is 2x6cm and consists of 47.000pixels each
- do extremly precise tracking very close to the interaction point
- accuracy of about 10μm in r-Φ and 115μm in z
- the innermost layer of the Pixel is called the b-layer (radius of 5cm from the interaction point)
- uses silicon as the detecting material
- 2D measurements

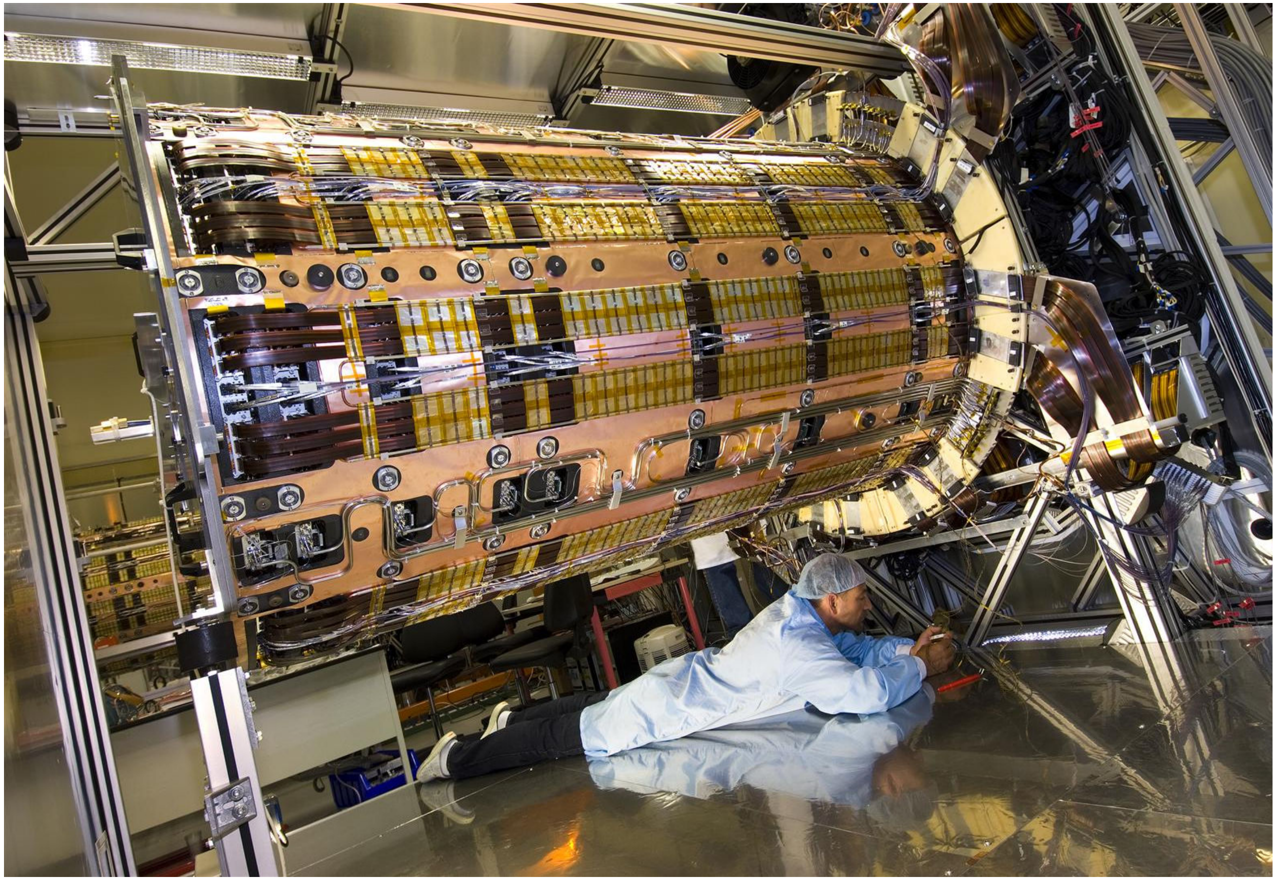


Main purpose

- provide precise trajectory information
- Measure interaction point and secondary vertices

The SemiConductor Tracker (SCT)

- The middle component of the Inner Detector
- more or less the same concept as the Pixel
  - but is made of long, narrow strips and covers a larger area than the Pixel
  - consists of 4088 modules in barrel + end-cap
- modules: single-sided micro-strip detectors glued back-to-back with a displacement of 40 mrad with respect to each other -> 2D information for each hit
- accuracy of about 16μm in r-Φ and 580μm in z
- cover a range of $|\eta| < 2.5$



Main purpose

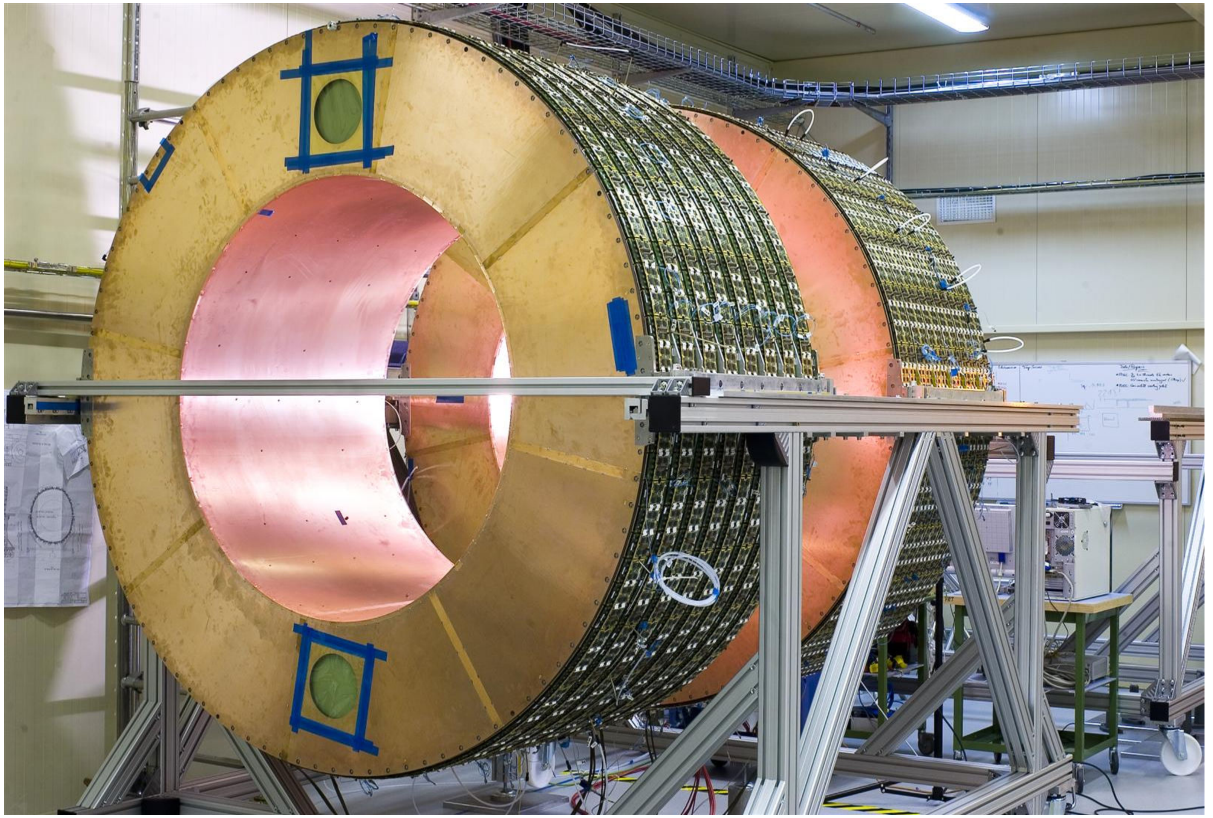
- Provide more track measurements
- Extends over a larger spacial area than pixel
- Not as precise as pixels but larger

Transition Radiation Tracker (TRT) -

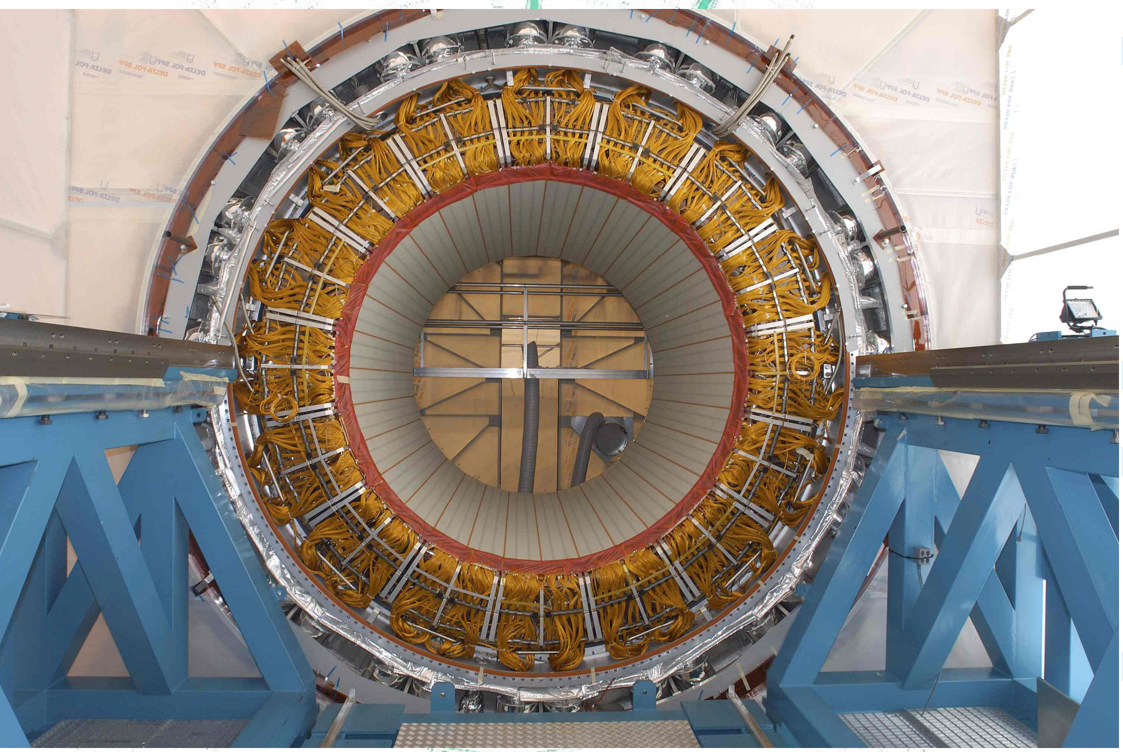
- a combination of a straw tracker and a transition radiation tracker
- contains 351.000 very small straws; 4mm in diameter and 144cm long
- covers a big volume and has a complemantary design in comparision with the Pixel and SCT
- between the straws there is material with varying refractive indices
  - ultra-relativistic charged particles produces transistion radiation
  - especially efficient for detecting electrons (because low mass)

Main purpose

- Large amount of measurements
- Distinguishes between electrons and other heavier particles, since electrons give off more transition radiation



Electromagnetic calorimeter



- detects all particles which interact electromagnetically
- e.g. electrons, photons, (muons)
- measures their energy and stops electrons and photons
- made of alternating layers of lead (to stop and provoke electromagnetic showers) and liquid argon (active material to sample the energy of the shower)
- situated outside the solenoidal magnet
- when these particles pass through or stop they deposit energy in the calorimeter which we can measure
- resolution is very good: 10%/sqrt(E) * 0.7%

Main purpose

- Measure energy of EM interacting particles
- Identify electrons and photons

Hadronic calorimeter

- detects particles which interact strongly
  - particles consisting of quarks (hadrons)
- resolution is 50%/sqrt(E) * 3% (worse than Ecal.)
- detector consist of 3 parts, with different design and material
  - Central barrel part made of steel as absorbing material and scintillators as active material
  - Forward and endcap calorimeter uses liquid argon as active material and copper or tungsten as absorbing material
- situated outside the solenoidal magnet

Main purpose

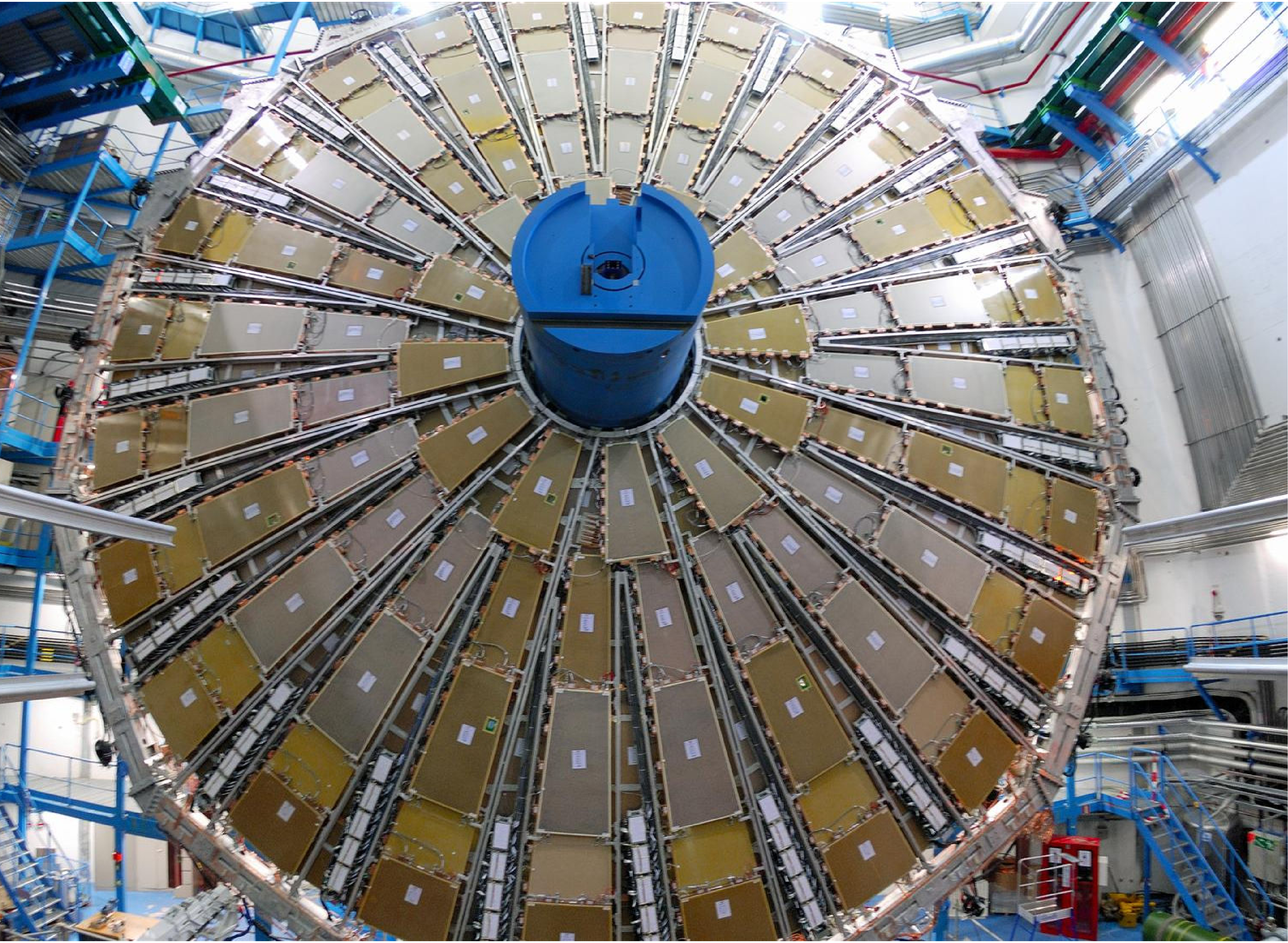
- Measure energy of strongly interacting particles
- Identify hadrons

Muon spectrometer

- **will only detect muons**
- **few particles will reach this part of the detector)**
- **is the outermost part of ATLAS (extending from a radius to 4.25m to 11m)**
  - **<u>barrel</u>: consists of 3 cylindrical shells**
  - **<u>end-caps</u>: 4 wheels on each side (7.4 - 21.5m from the interaction point)**
- **the outer toroidal magnetic field produces a non uniform field**
  - **the momenta and charge of the muons can be measured from the curvature**
- **roughly 1G of readout channels**

Main purpose

- Measure momentum and charge of muons

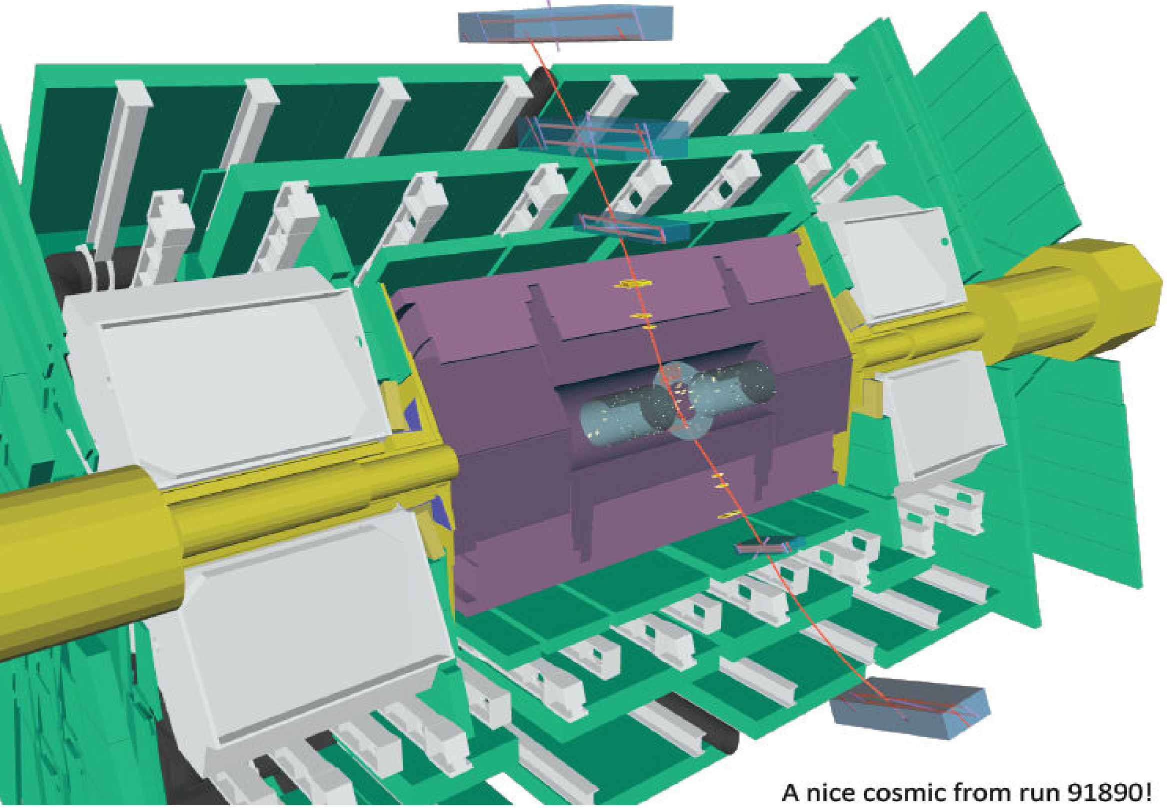


Last important components:Trigger and distribution on data

- will produce about 25Mb per. event
  - if no suppression of the data that correspond to ~1.6Mb per event
  - 40 million beam crossings per second gives 1petabyte per second of raw data
- trigger system is built to pick out the interesting events
  - three trigger systems (on on the detector, two on clusters close to the detector)
  - 1st trigger picks out ~10.000 events/sec.
  - after 2nd and 3rd trigger only a few hundred events remain
- ATLAS produces ~100Mb of data per sec.

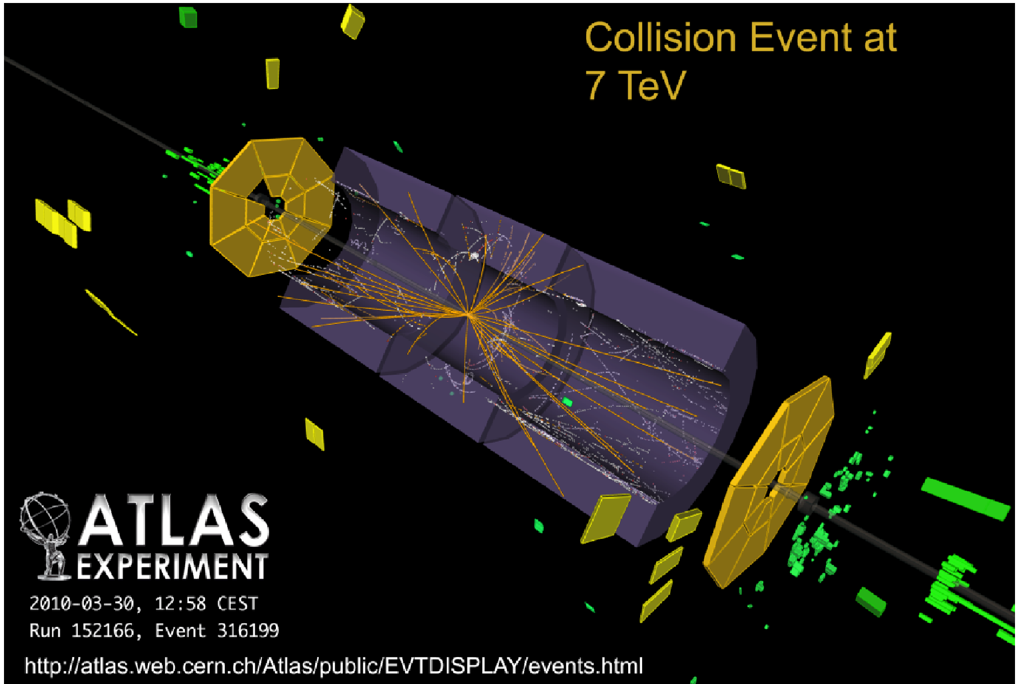
- This data is distributed through the world wide grid so physicists around the world can access it

ATLAS – at Work



- Collected millions of cosmic muons

- Collected 900 GeV, 2.36 TeV and 7 TeV collision data
- 7 TeV collisions ongoing, collecting data as we speak – first W-boson observed?

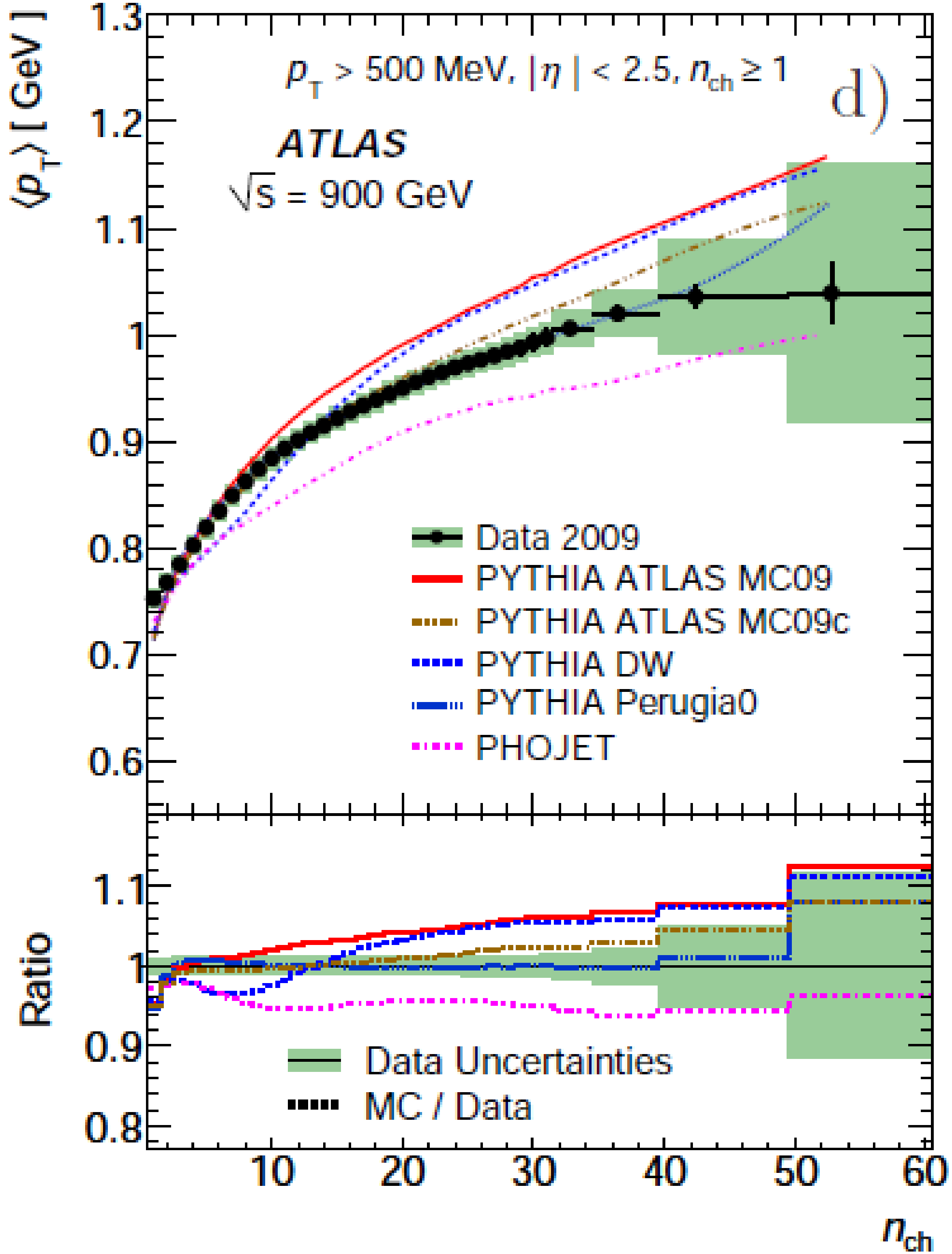


Understanding collisions

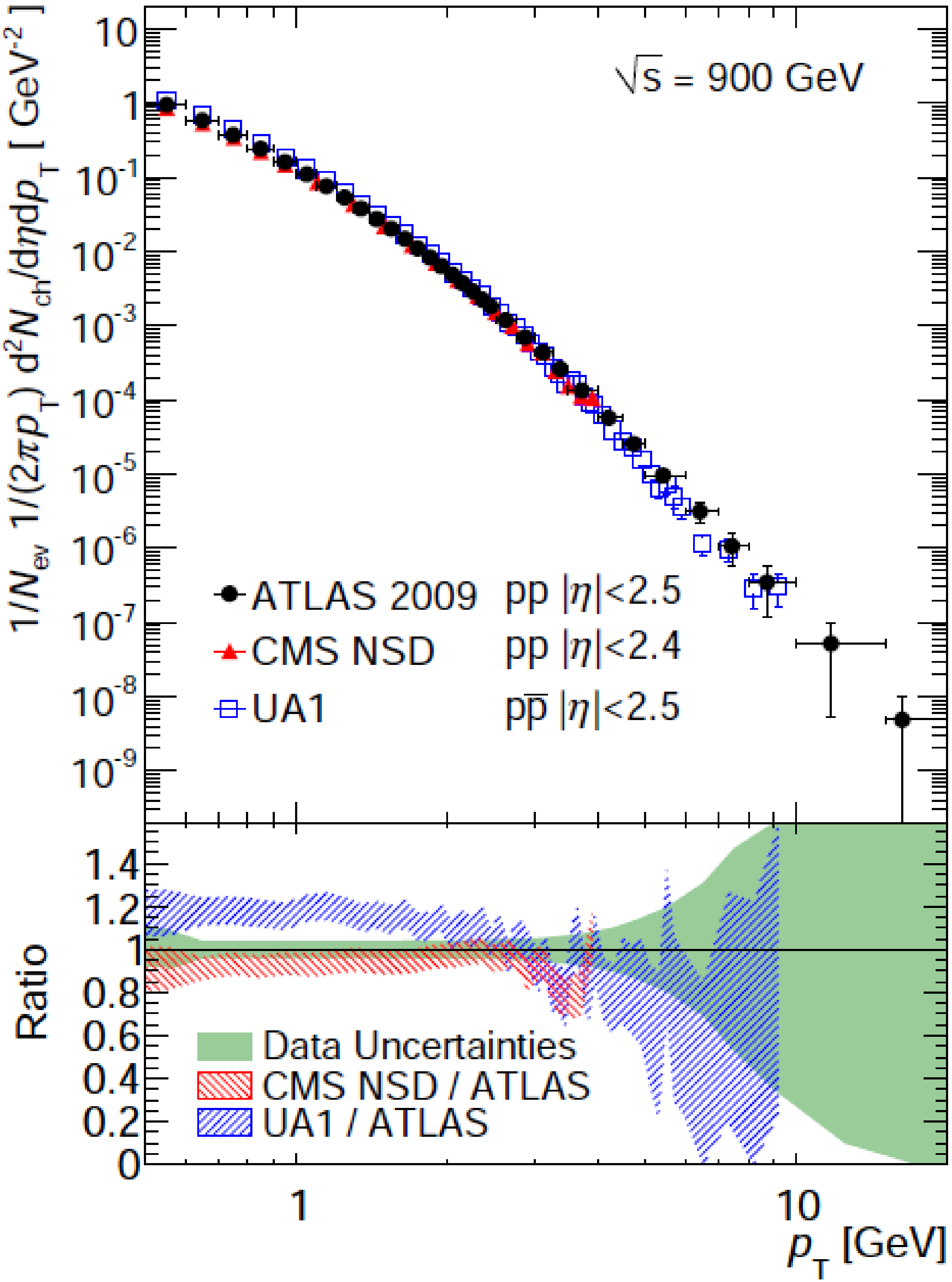
- What is a collision?
  - When the two meeting protons interact - scatter against each other
  - Elastic scattering
    - Protons continue forward in a small angle
    - Can get excited by the interaction and decay to a small shower of particles
  - Inelastic scattering
    - Exchange of SM or exotic particles
    - Energy in collision transforms to completely new particles
    - Large showers of particles in all directions

Understanding collisions cont.

- To be able to understand a typical collision we can start by
  - Counting number of charged particles in a collision
  - But we cannot really select a typical event – we need triggers
    - But we can be MINIMALLY BIASED (as unbiased as possible)
    - Have techniques for categorizing what type of collision we encounter
- We need to understand the basics before proceeding
- We need to know what to expect to be able to expect the unexpected!



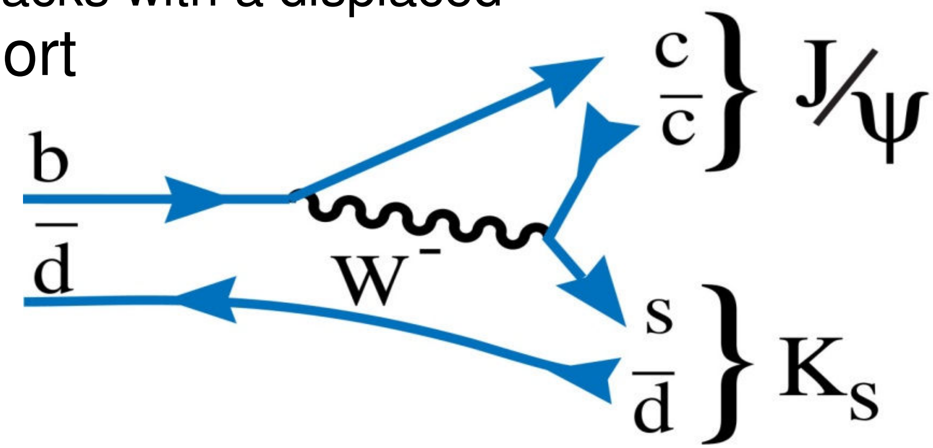
⟨p_T⟩ [GeV]
p_T > 500 MeV, |η| < 2.5, n_{ch} ≥ 1
d)
ATLAS
$\sqrt{s}$ = 900 GeV
Data 2009
PYTHIA ATLAS MC09
PYTHIA ATLAS MC09c
PYTHIA DW
PYTHIA Perugia0
PHOJET
Ratio
Data Uncertainties
MC / Data
n_{ch}
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.8
10
20
30
40
50
60



$\sqrt{s}$ = 900 GeV
ATLAS 2009 pp $|\eta|<2.5$
CMS NSD pp $|\eta|<2.4$
UA1 $p\bar{p}$ $|\eta|<2.5$
$1/N_{ev}\ 1/(2\pi p_T)\ d^2N_{ch}/d\eta dp_T$ [GeV^{-2}]
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
Ratio
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Data Uncertainties
CMS NSD / ATLAS
UA1 / ATLAS
1
10
p_T [GeV]

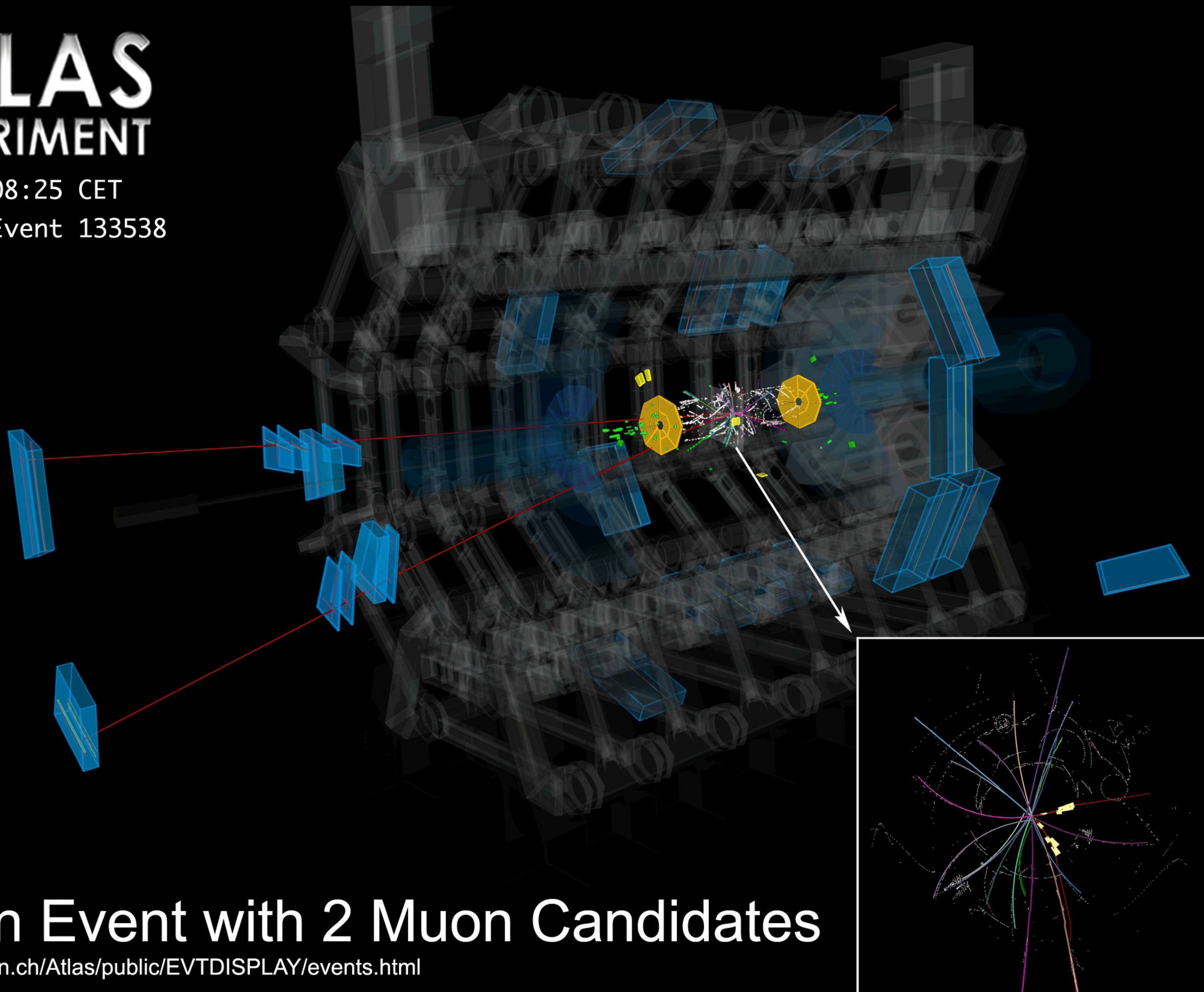
How to reconstruct what particles were created in the collision?

- Example the Kaon
  - K-short will live a short while in the detector before decaying
  - It lives sufficiently long to produce a secondary vertice inside the beampipe which the Inner detector can identify
  - It decays (70 % of times) to a pair of positive and negative pions
    - These are charged and leave tracks
    - By pairing two oppositely charged tracks with a displaced vertex we can search for the K-short



ATLAS EXPERIMENT

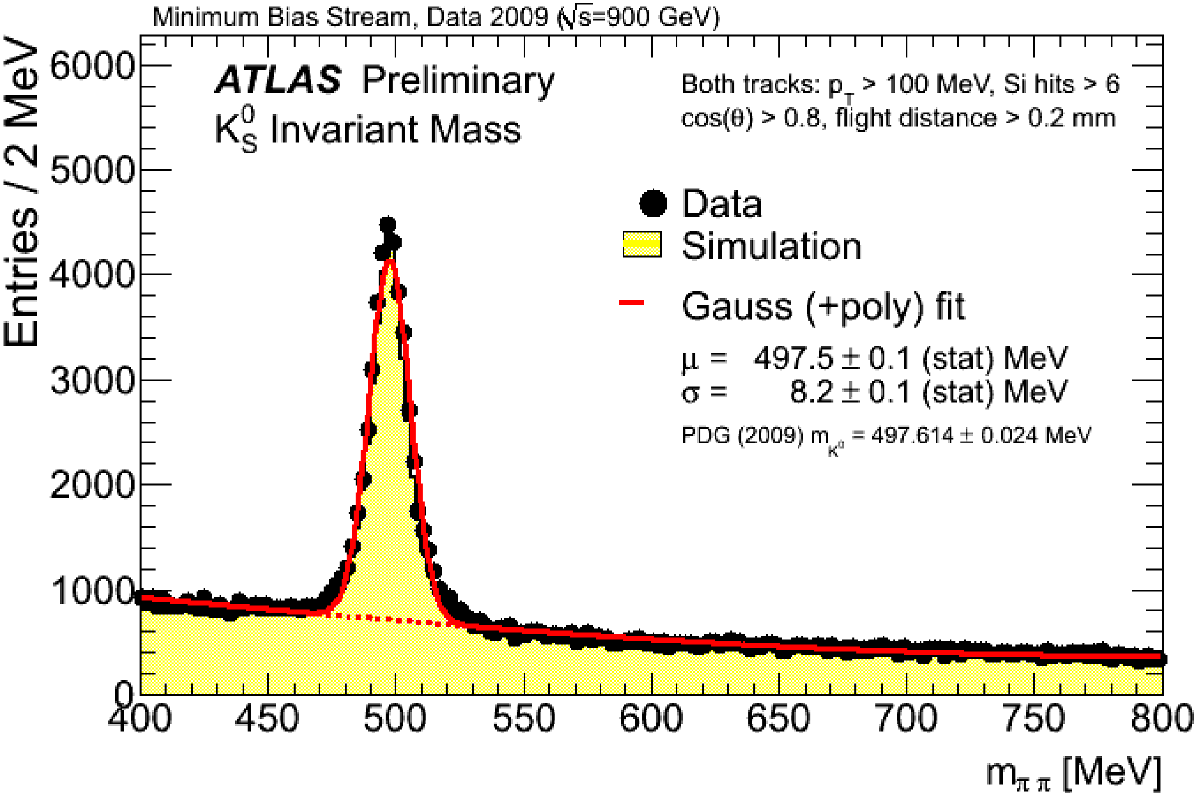
2009-12-06, 08:25 CET
Run 141749, Event 133538



J/Psi ??

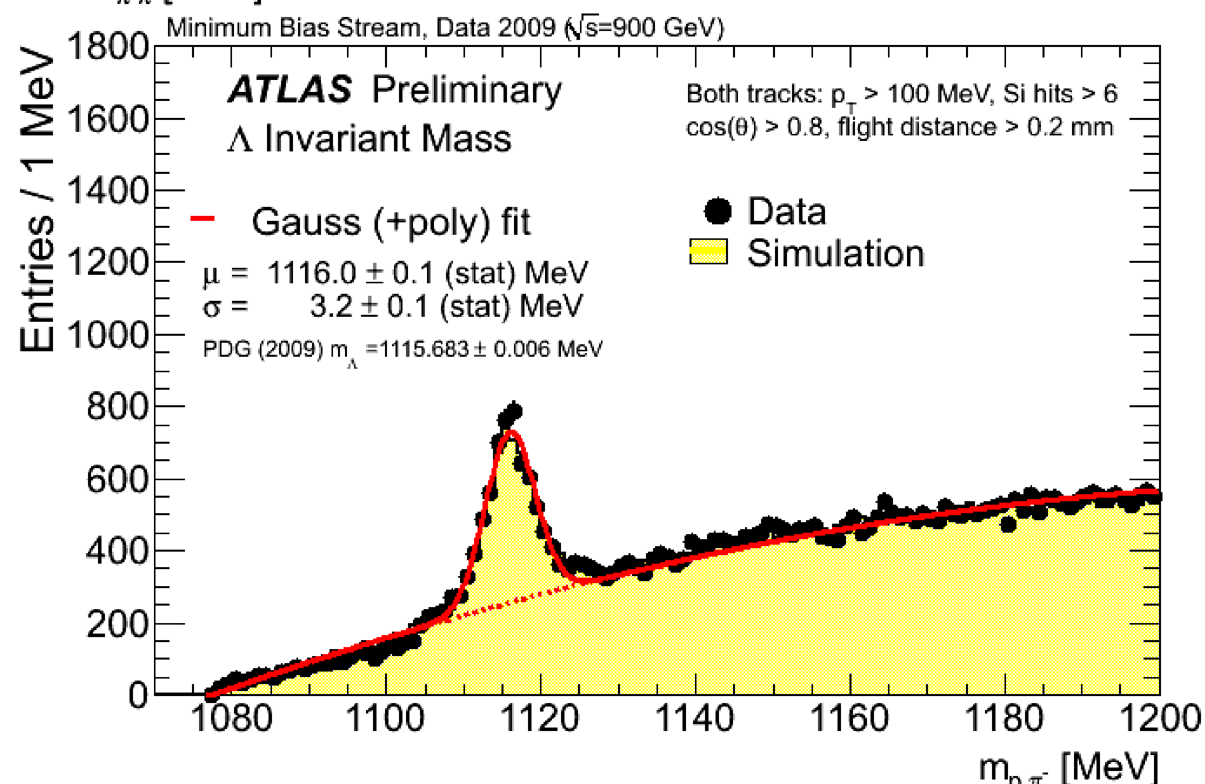
Collision Event with 2 Muon Candidates

http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html



K^0_s

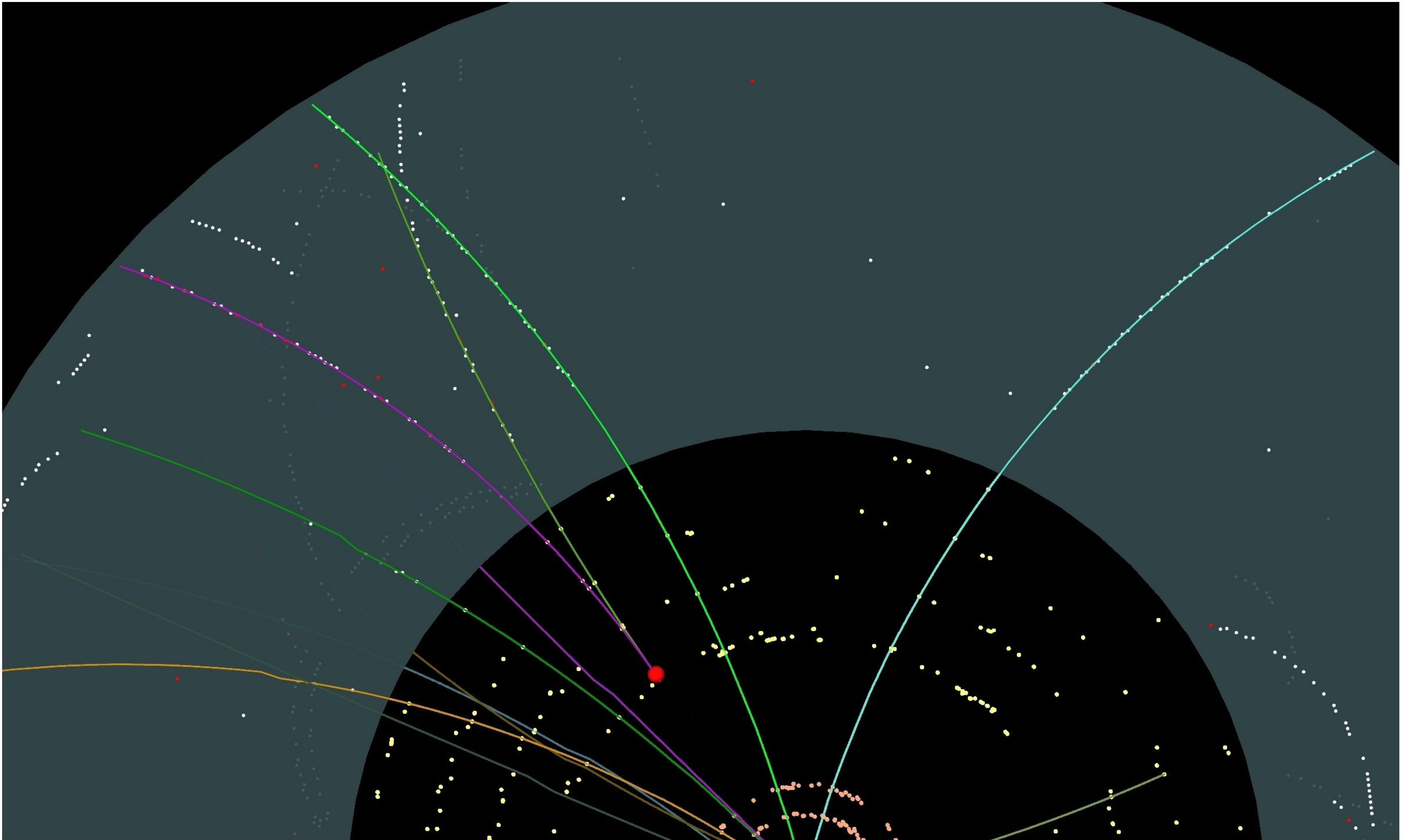
- Meson: s + d quarks
- Mass in PDG: 497.648 +- 0.022 MeV
- Mean lifetime: 8.9 *10-11 s
- Decay modes:
  - Ca 70 % pi+pi-
  - Ca 30 % pi0 pi0

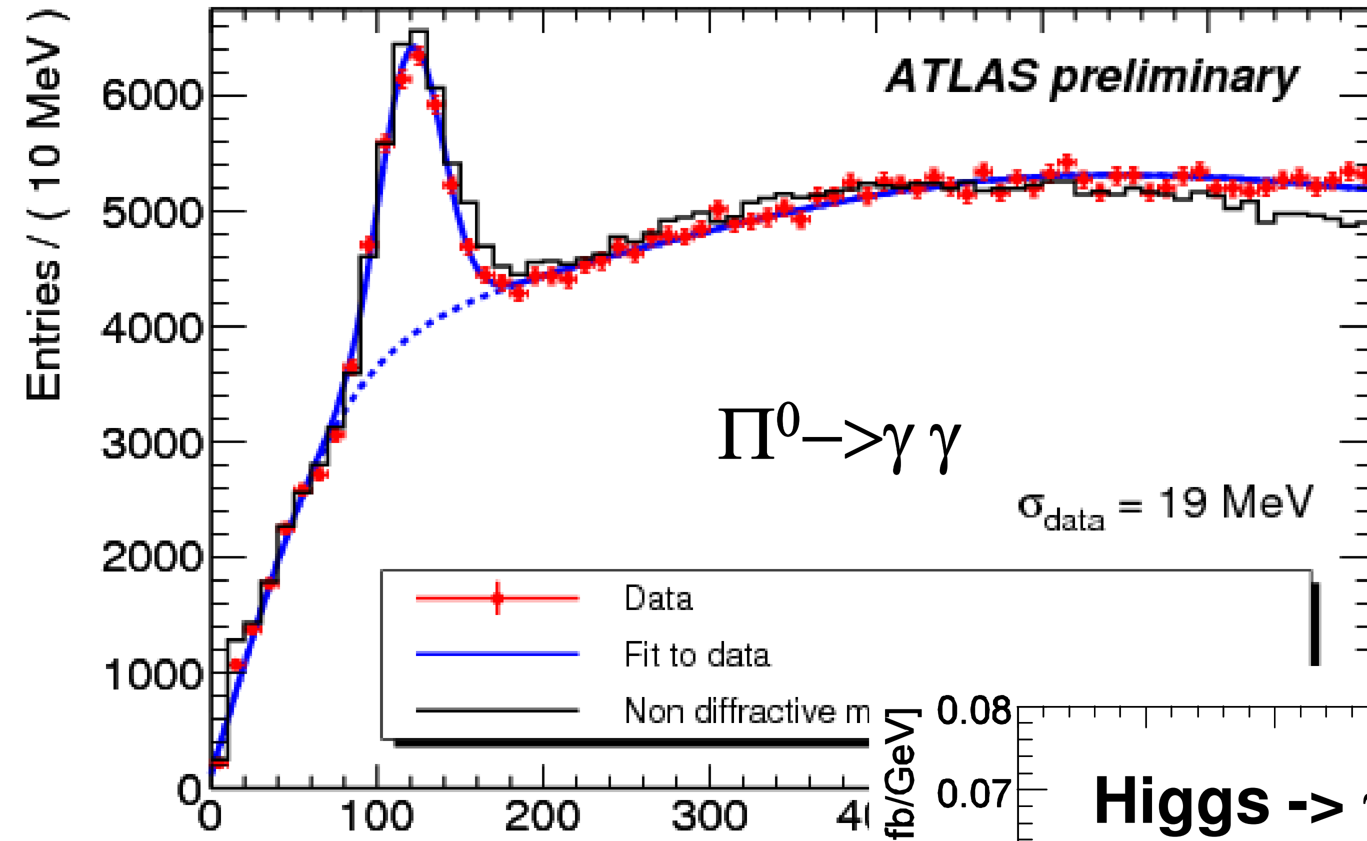


Λ^0

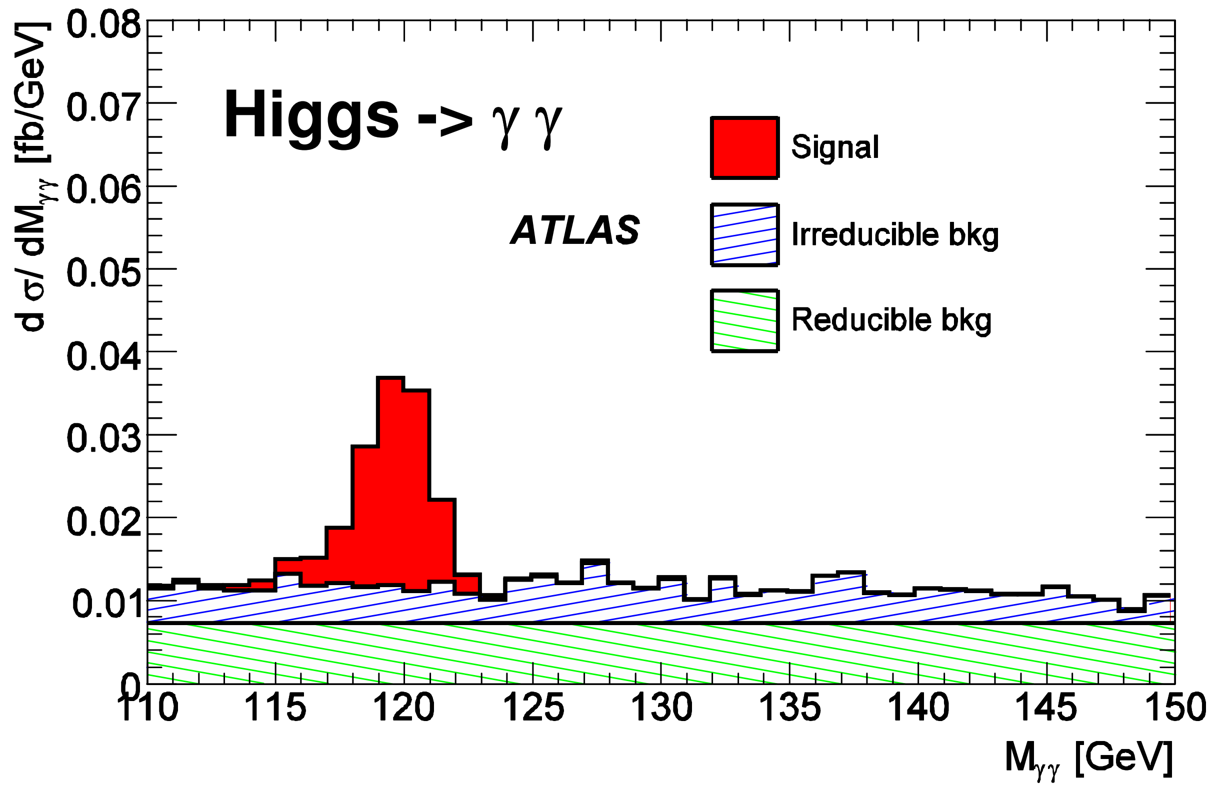
- Baryon: uds quarks
- Mass in PDG: 1115.683 +- 0.006 MeV
- Mean lifetime: 2.63 *10-10 s
- Decay modes:
  - Ca 64 % p pi-
  - Ca 36 % n pi0

Beautiful reconstruction of secondary vertex





Entries / (10 MeV)
ATLAS preliminary
Π0–>γ γ
σdata = 19 MeV
Data
Fit to data
Non diffractive m
6000
5000
4000
3000
2000
1000
0
0
100
200
300

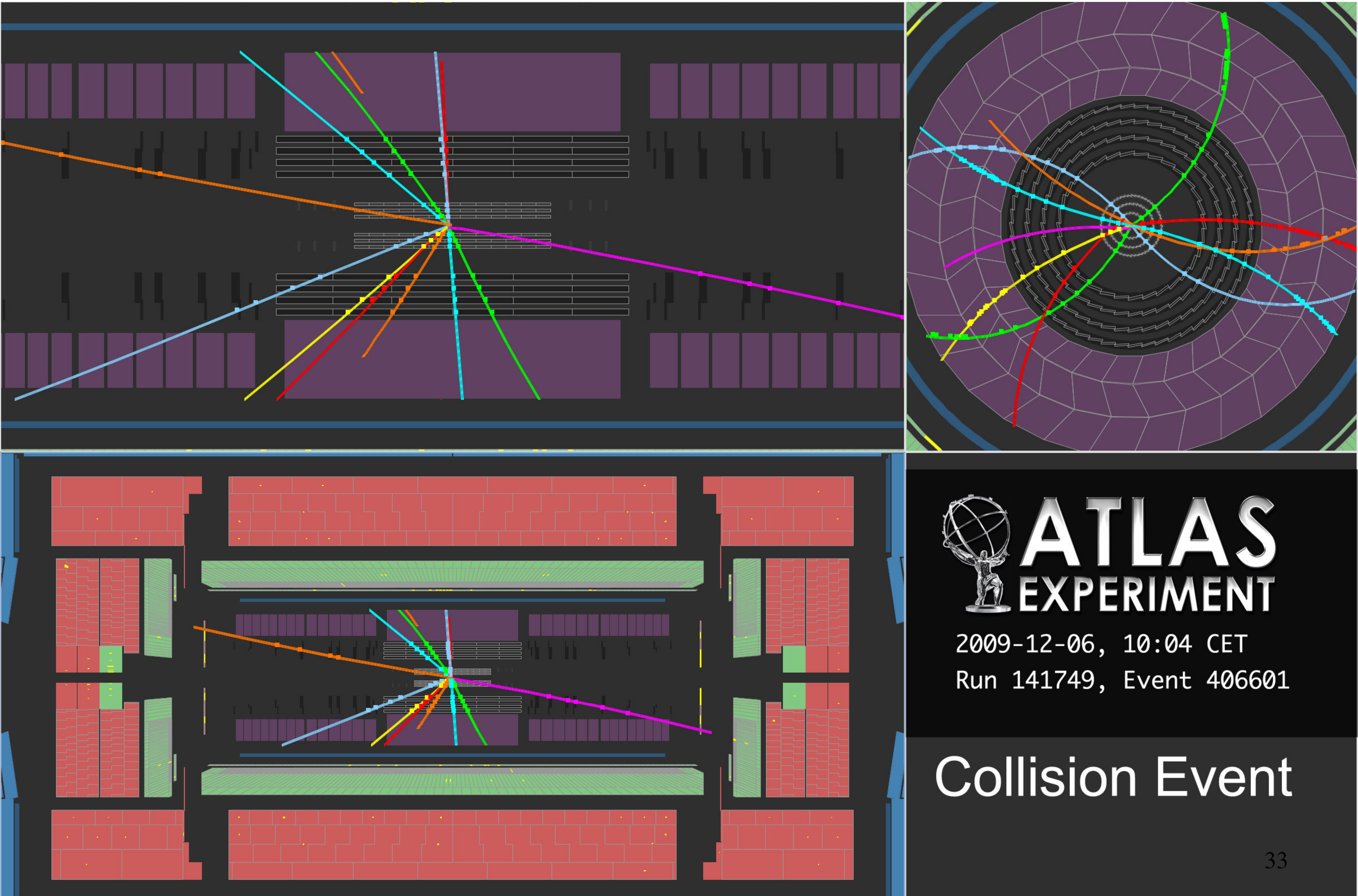


Higgs -> γ γ
ATLAS
Signal
Irreducible bkg
Reducible bkg
d σ/ dMγγ [fb/GeV]
Mγγ [GeV]
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
110
115
120
125
130
135
140
145
150

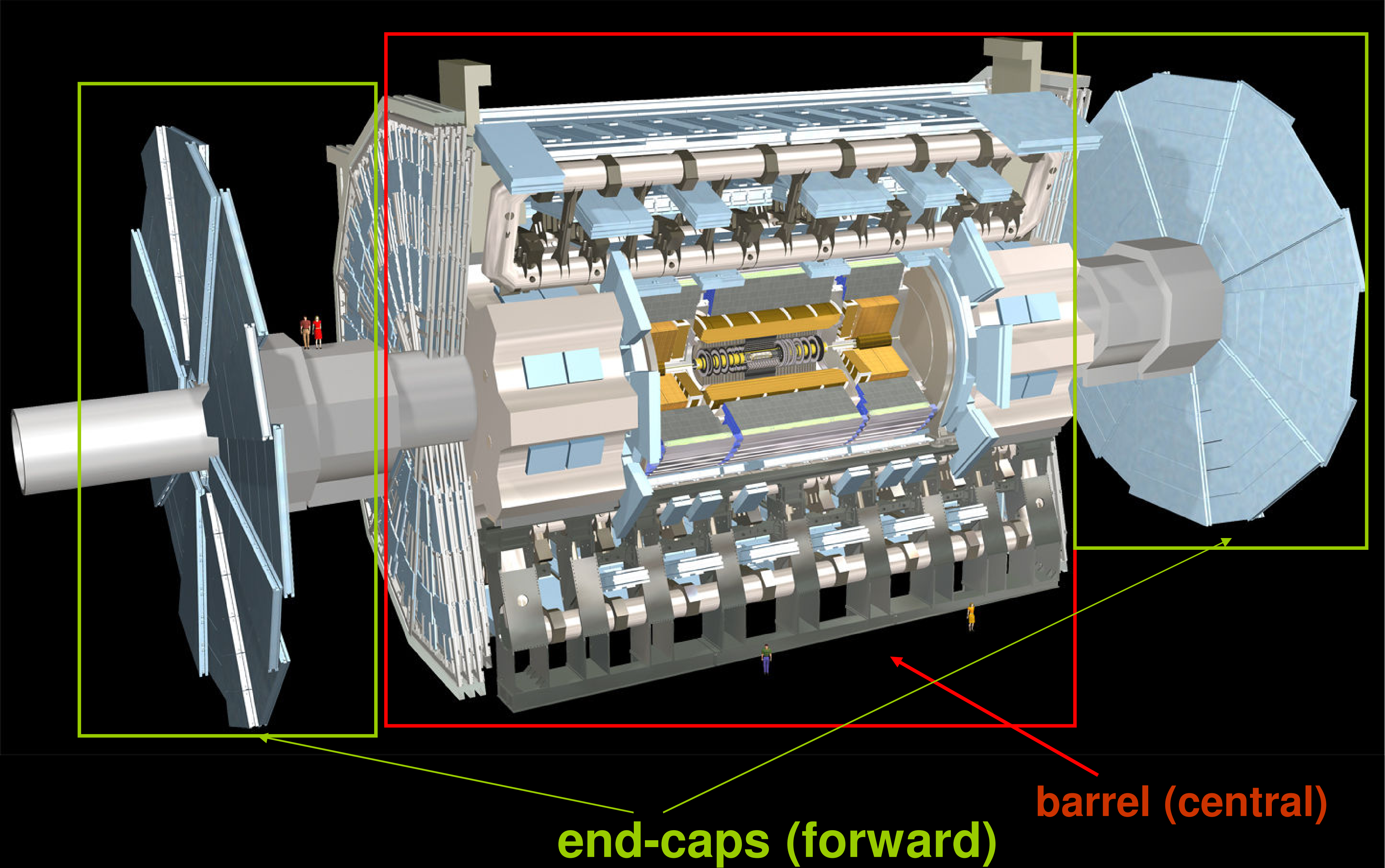
Conclusion

- Experiments have fully started – First 7 TeV collisions Tuesday 30 March 2010
- Collisions as we speak
- LHC will run continuously for about a year or more
- ATLAS is already perfoming beautifully
- Many interesting collisions to analyse
  - Already indications of first W boson seen
  - When will we see Supersymmetry? ☺ Higgs? ☺
- LCH built for 14 TeV collisions, this will happen after a shutdown of about a year
- THESE ARE REALLY EXITING TIMES!!!

The first collisons in ATLAS ever !



http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html



- we want to capture as many of the particles as possible produced in the collisions. Our detector is therefore as hermetically sealed around the collision point as possible.

Recapitulating: A detector needs to:

1) Measure the directions, momenta, and signs of charged particles. **(Inner Detector)**

2) Measure the energy carried by electrons and photons in each direction from the collision.
(Electromagnetic calorimeter)

3) Measure the energy carried by hadrons (protons, pions, neutrons, etc.) in each direction.
(Hadronic calorimeter)

4) Identify which charged particles from the collision, if any, are electrons.

5) Identify which charged particles from the collision, if any, are muons.
(Muon spectrometer)

6) Identify whether some of the charged particles originate at points a few millimeters from the collision point rather than at the collision point itself (signaling a particle's decay a few millimeters from the collision point).
(B-layer, Pixel)

7) Infer (through momentum conservation) the presence of undetectable neutral particles such as neutrinos.
(The whole detector)

8) Have the capability of processing the above information fast enough to permit flagging about 10-100 potentially interesting events per second out of the billion collisions per second that occur, and recording the measured information.
(Trigger)

9) The detector must also be capable of long and reliable operation in a very hostile radiation environment.
(We will ses if it manages :-))