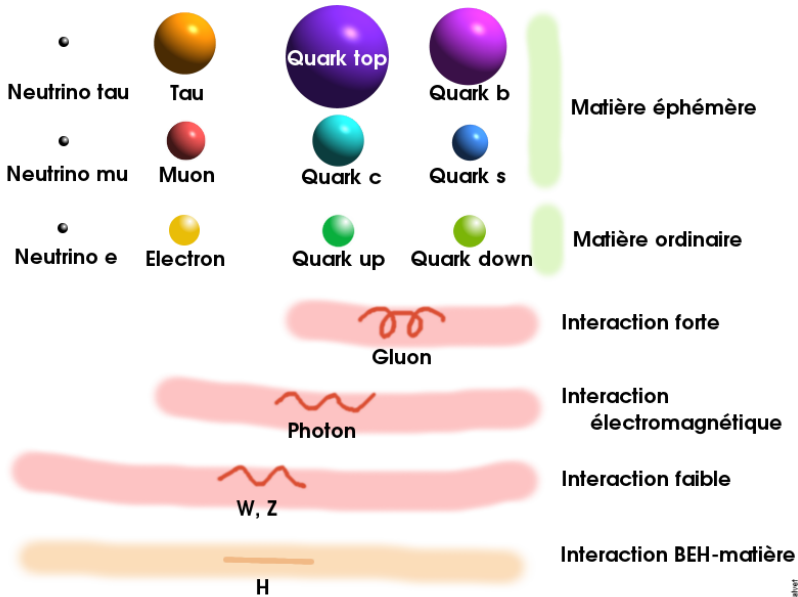


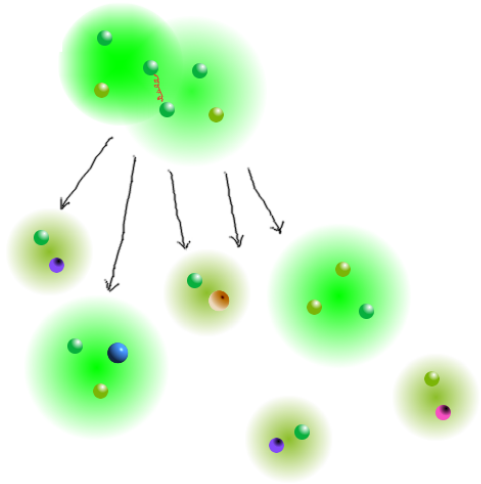
# ACCÉLÉRATEURS ET DÉTECTEURS

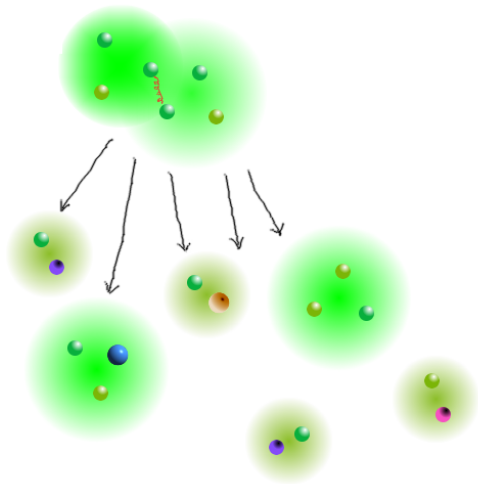
David Calvet



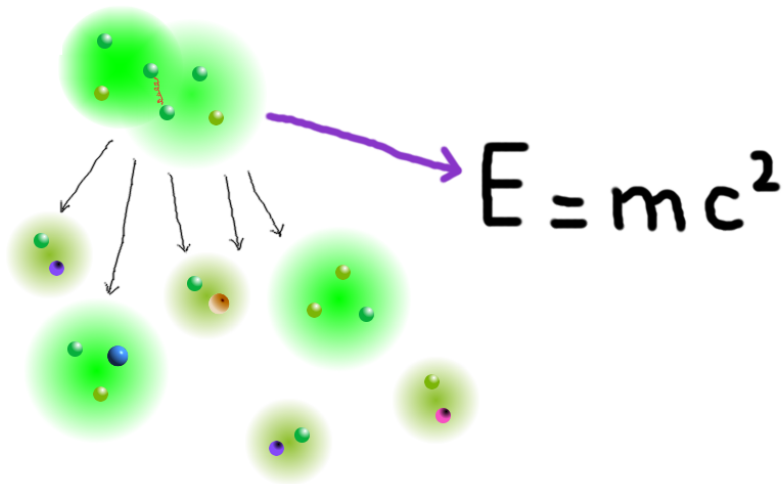
MasterClass@Clermont 2019

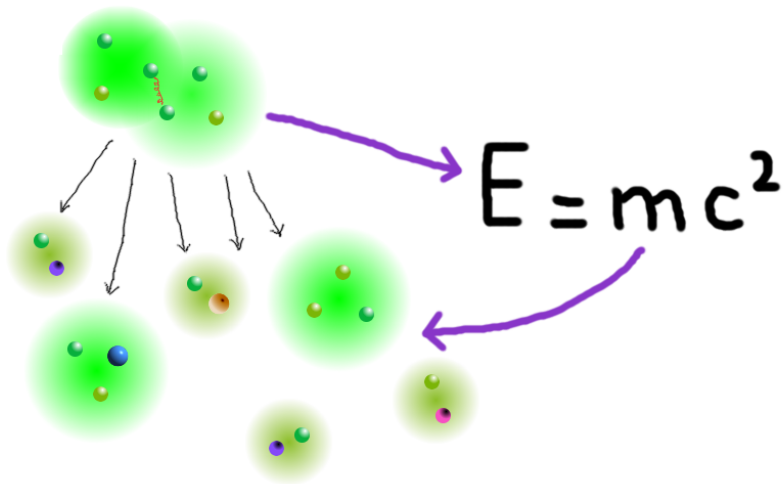


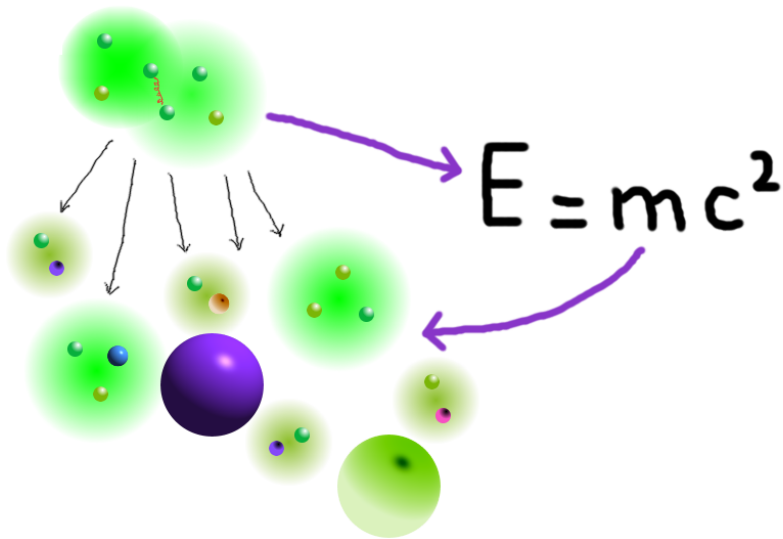




$$E = mc^2$$









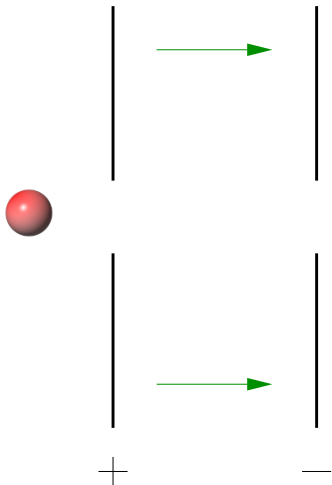


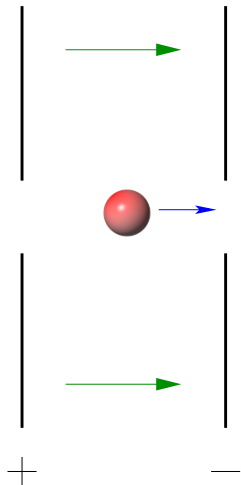


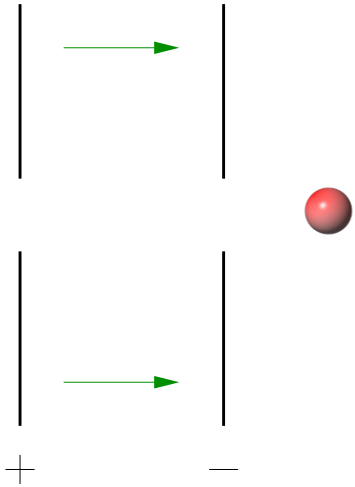
# Etudier des collisions de particules

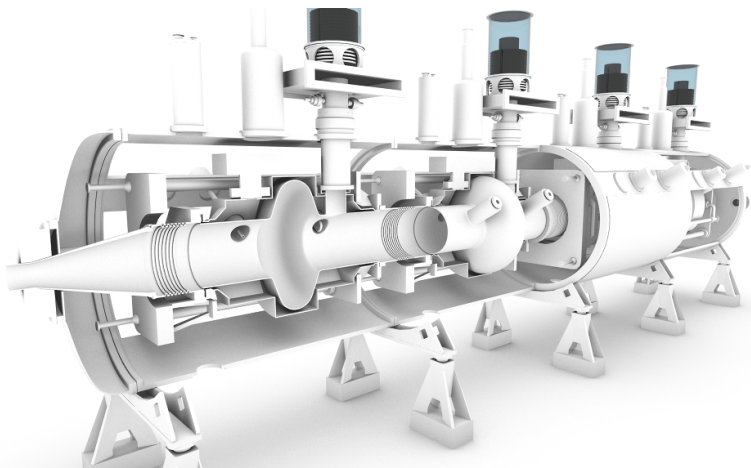
- 1 Accélérer les particules
- 2 Provoquer des collisions
- 3 Détecter les “débris”

Comment accélérer des particules ?









CERN

8 cavités par faisceau, 2 MV chacune  $\Rightarrow$  +16 MeV

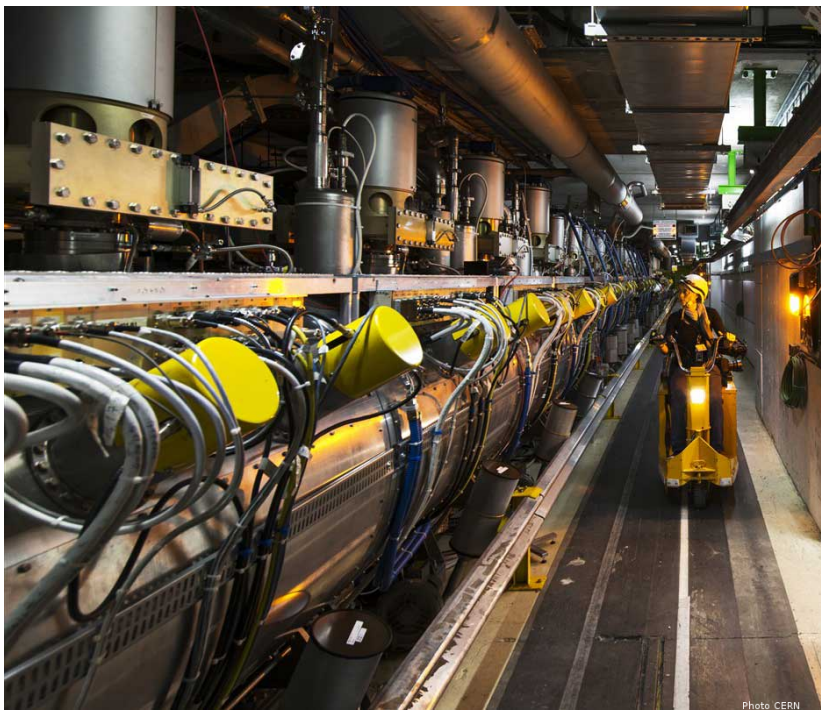


Photo CERN





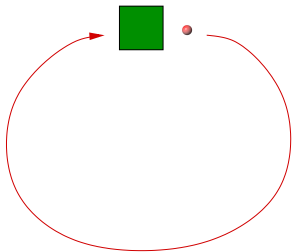


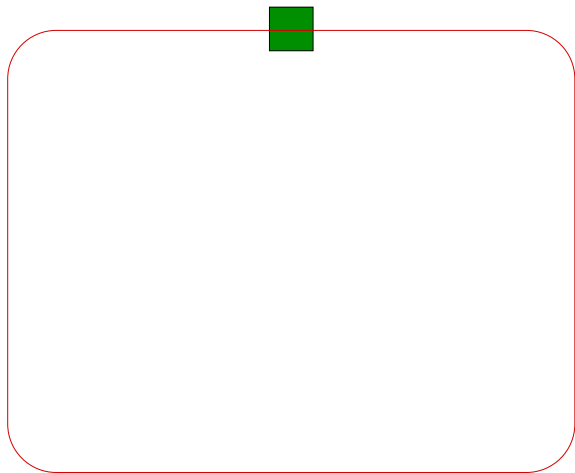


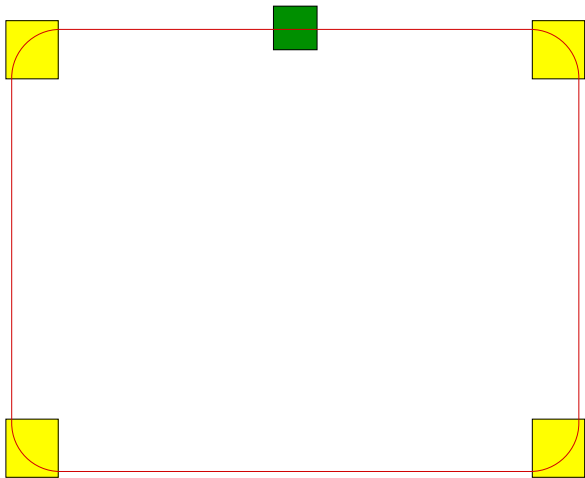




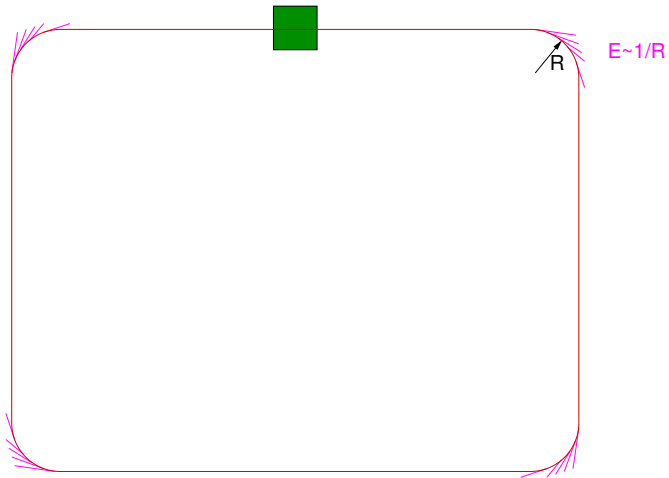


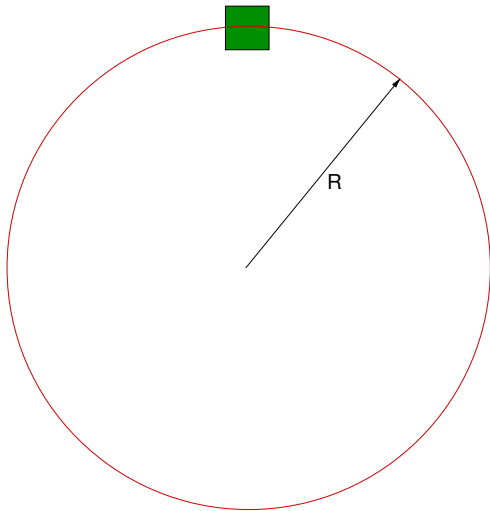




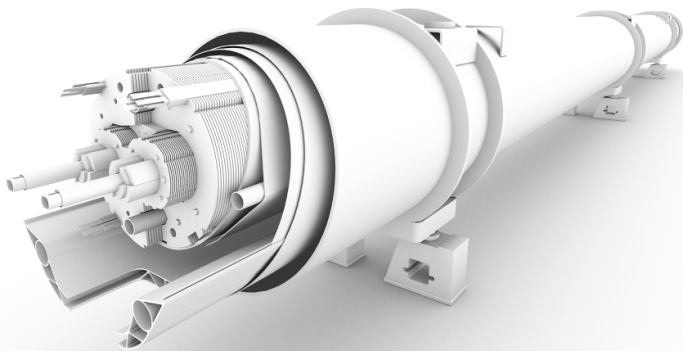






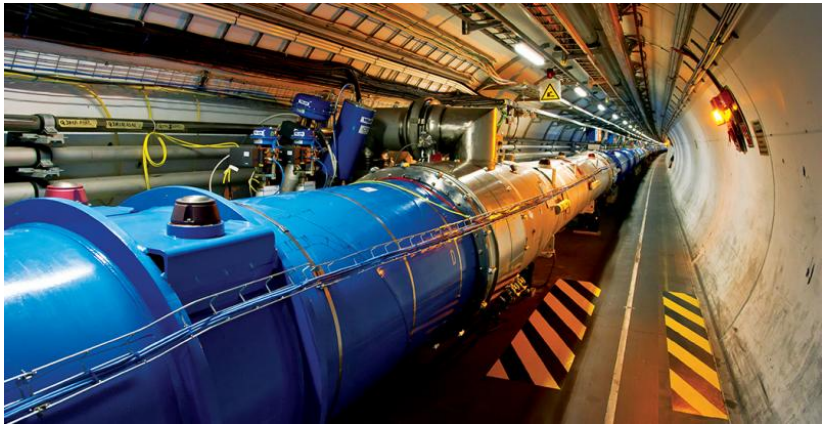


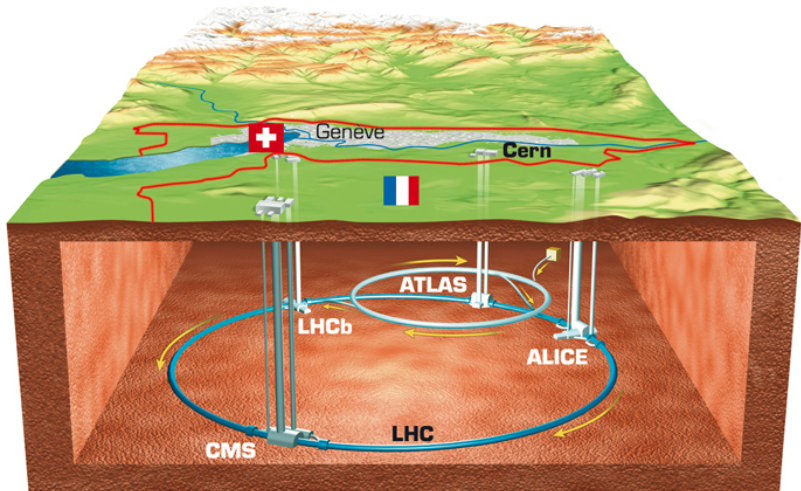
1232 dipôles  $\times$  14 m / 35 t

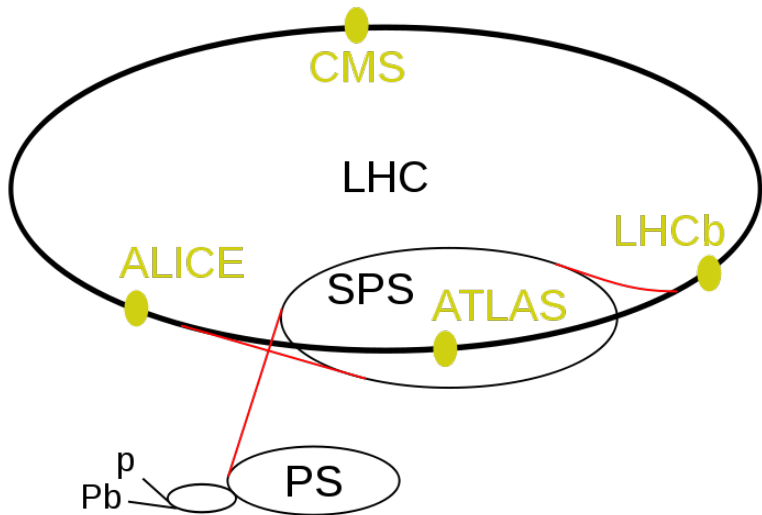


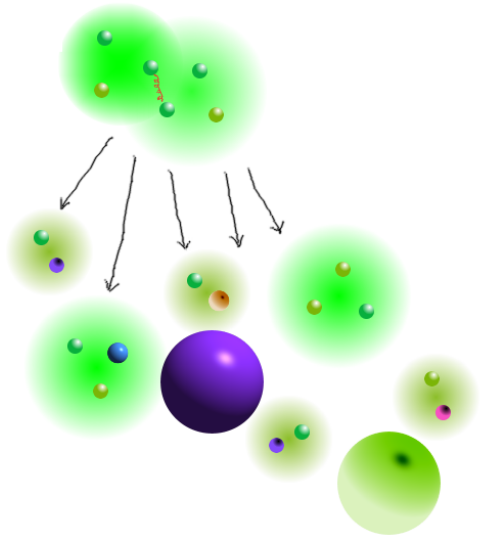
CERN

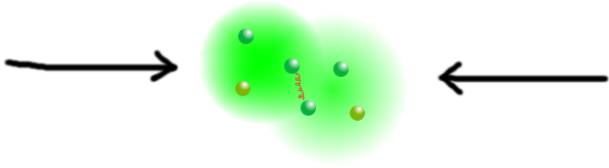
11 850 A  $\Rightarrow$  B=8 T=177 000 B<sub>Terre</sub>



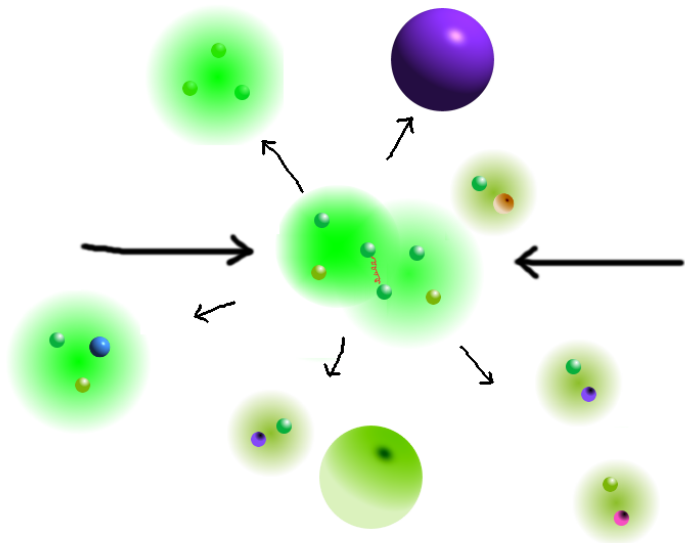


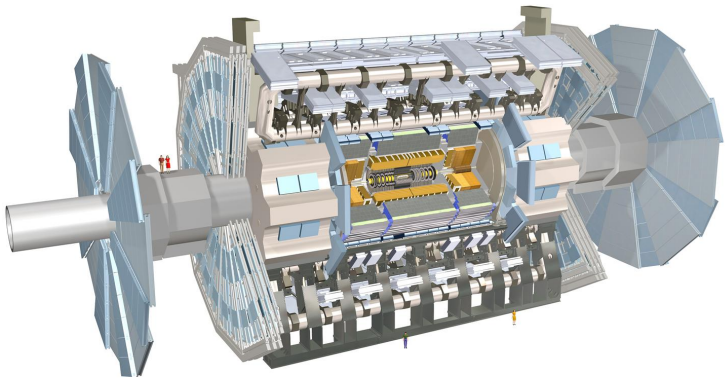


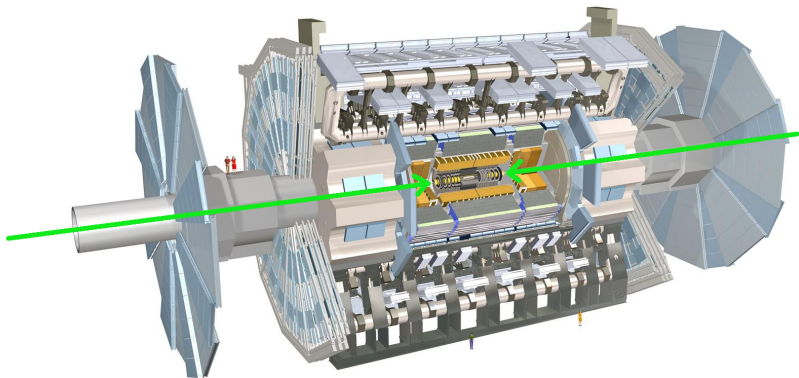


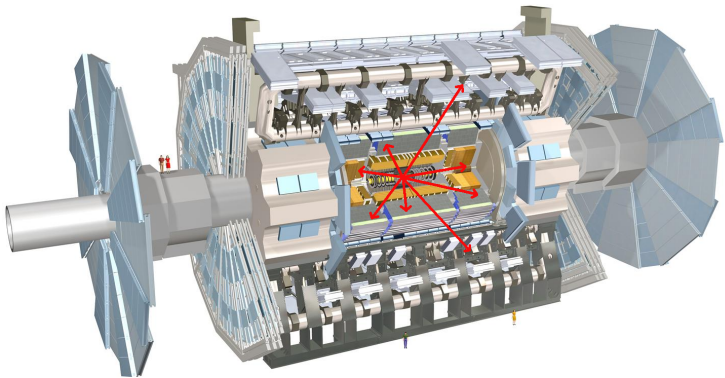


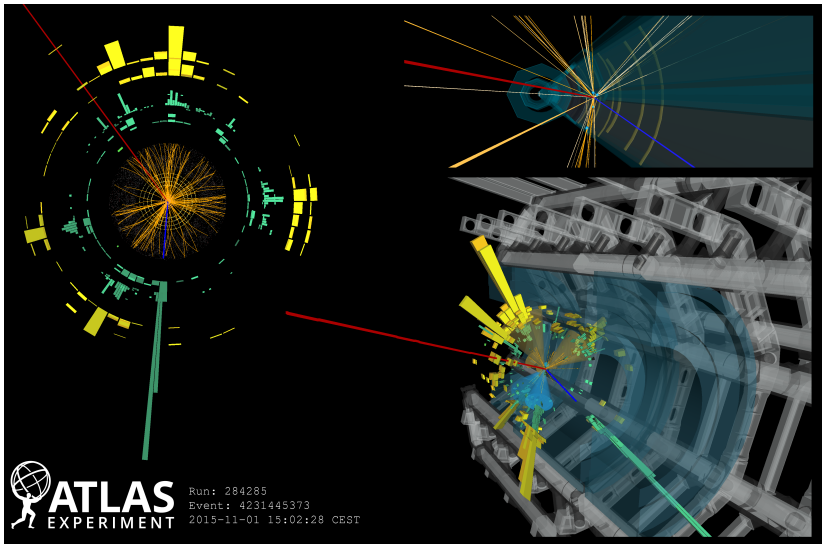






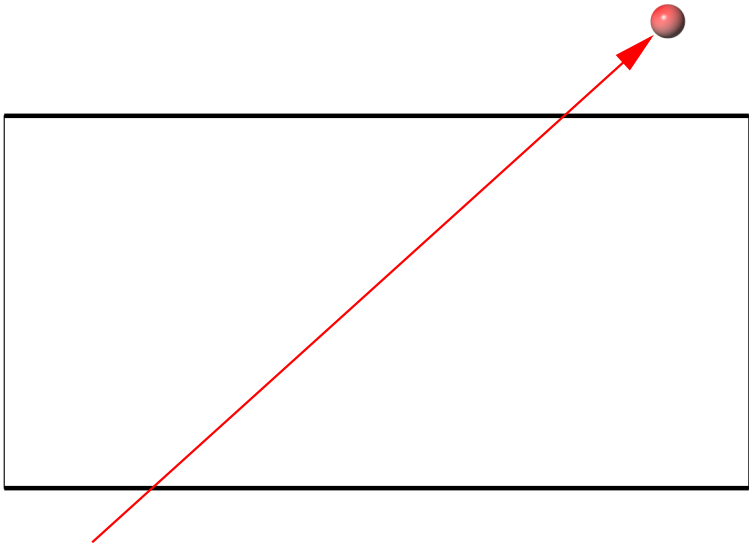




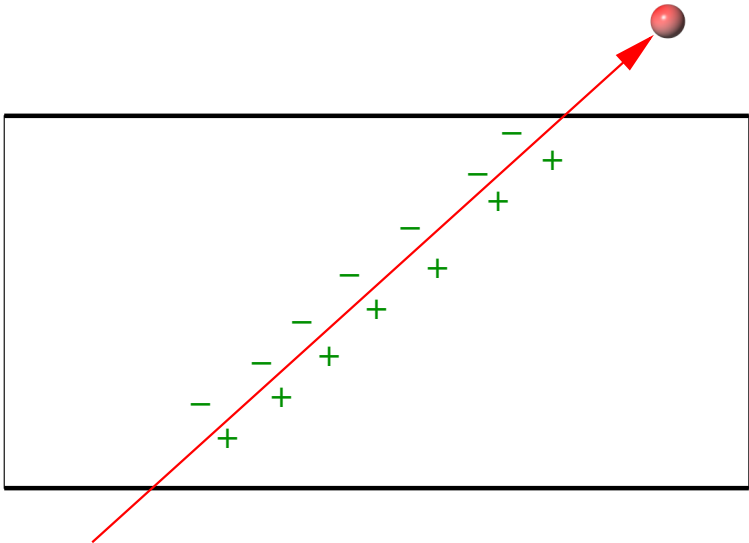


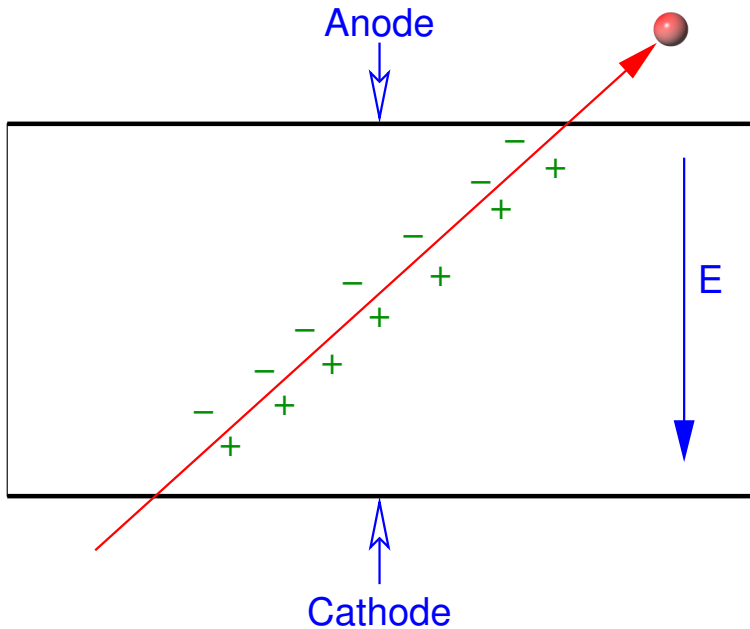
Comment fonctionne un détecteur de particules ?

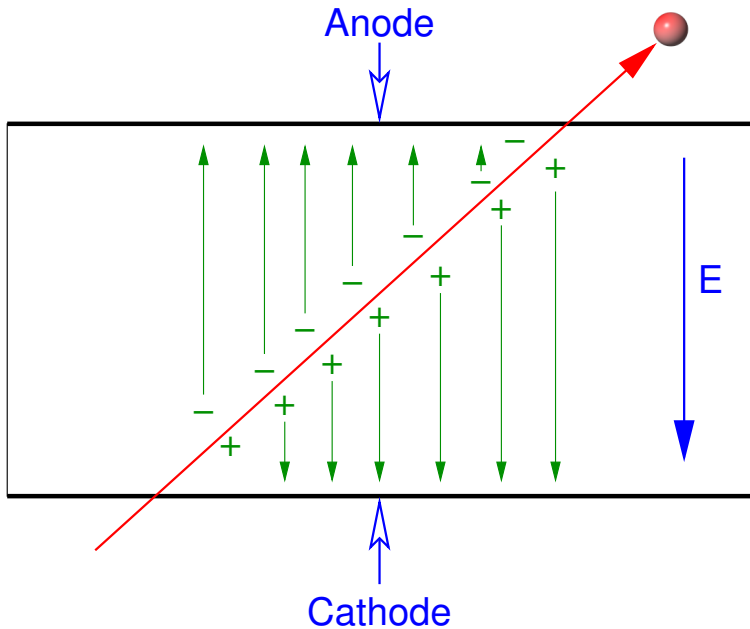


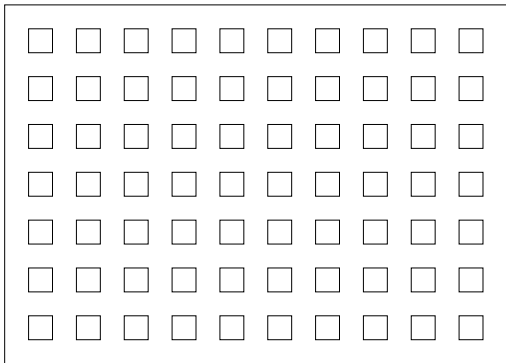


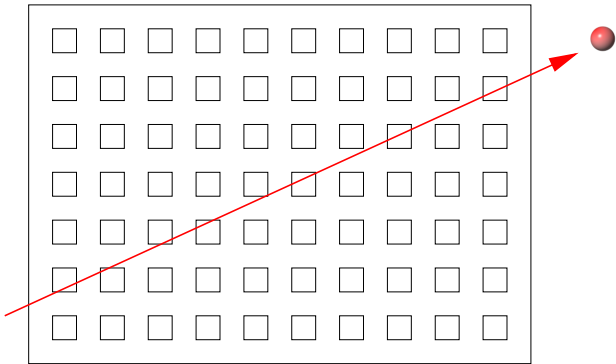


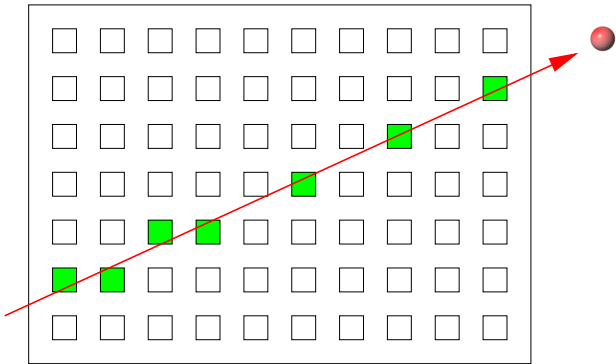


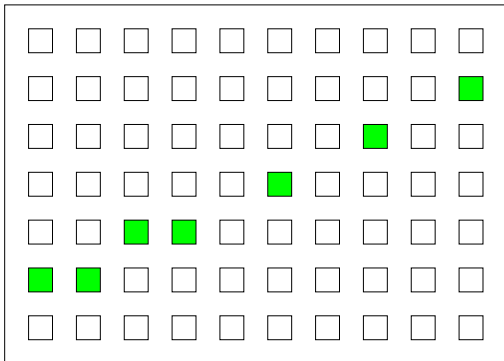




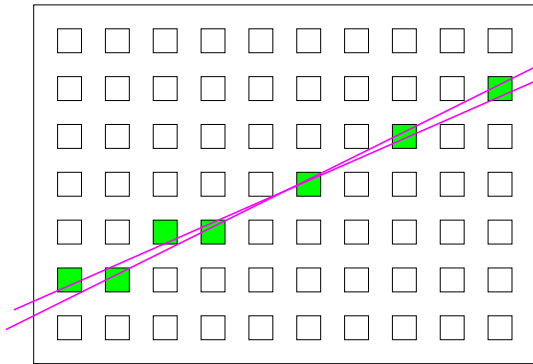






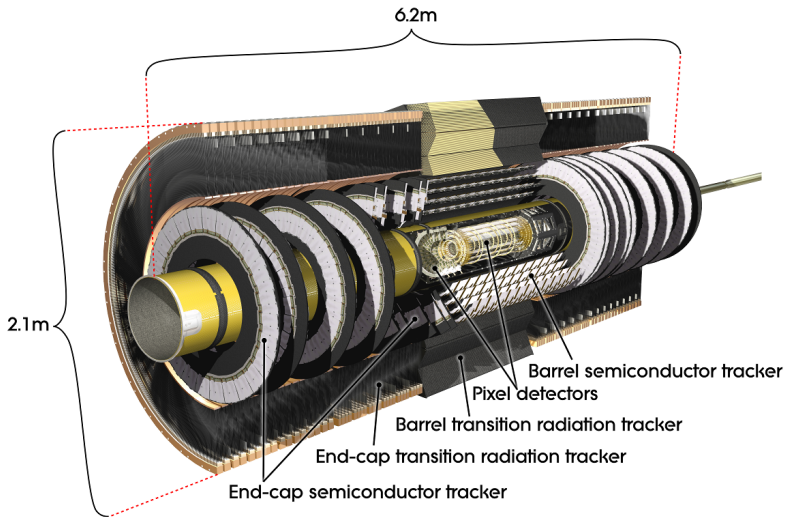


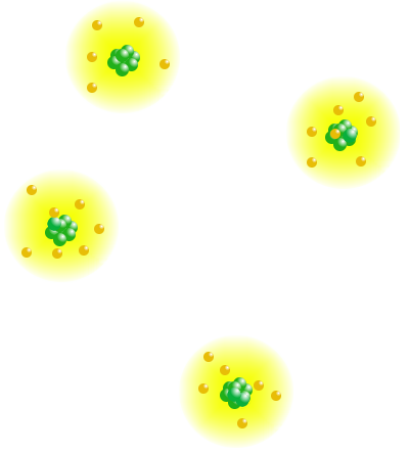
"Image"  
enregistrée

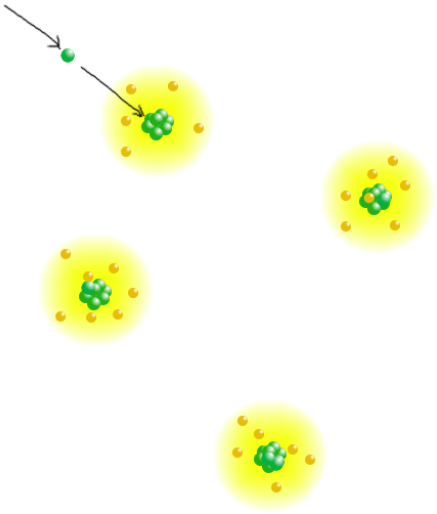


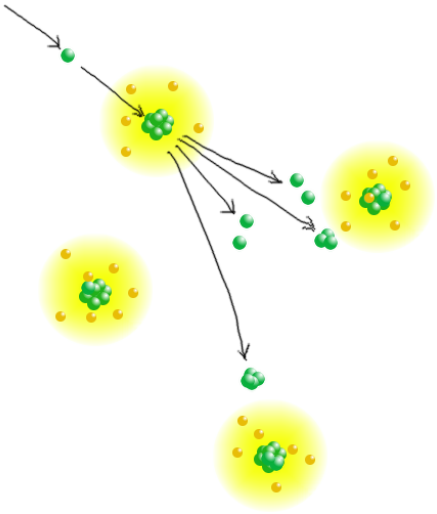
Trajectoires  
possibles

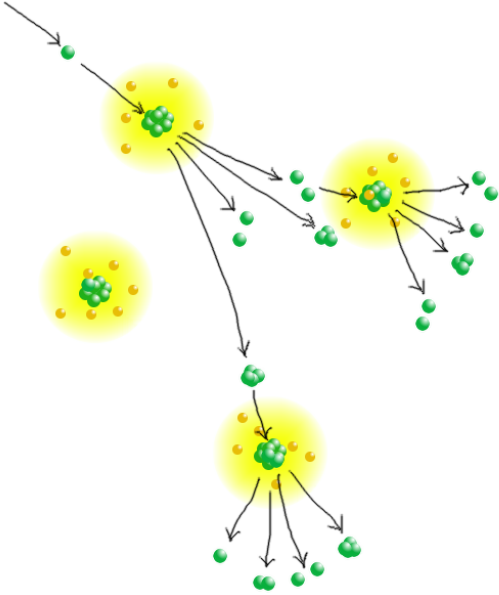


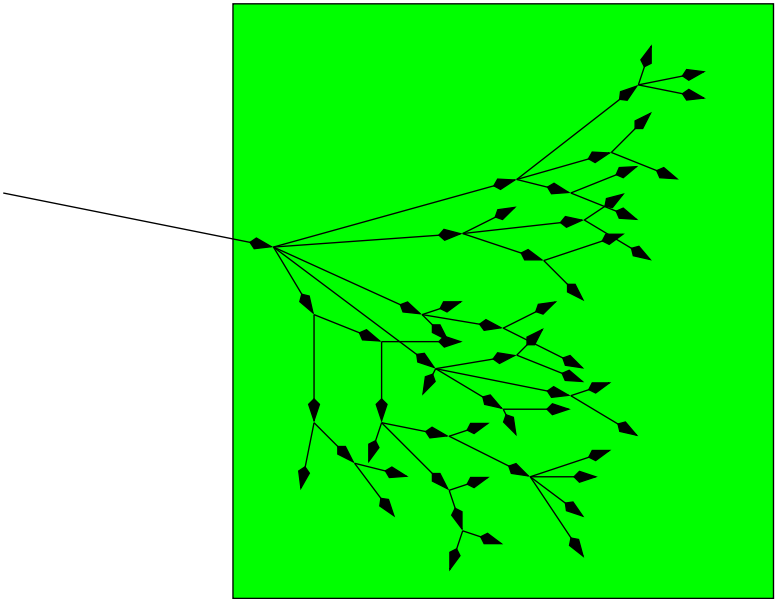


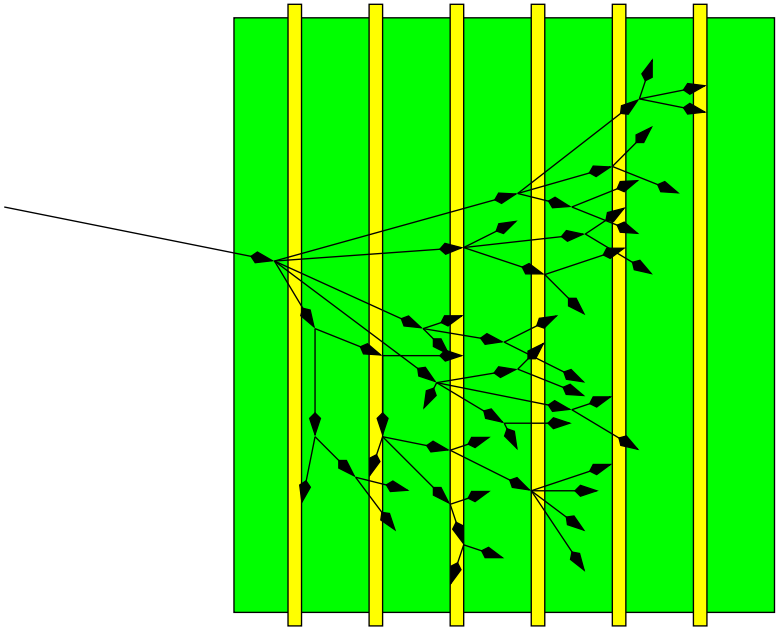


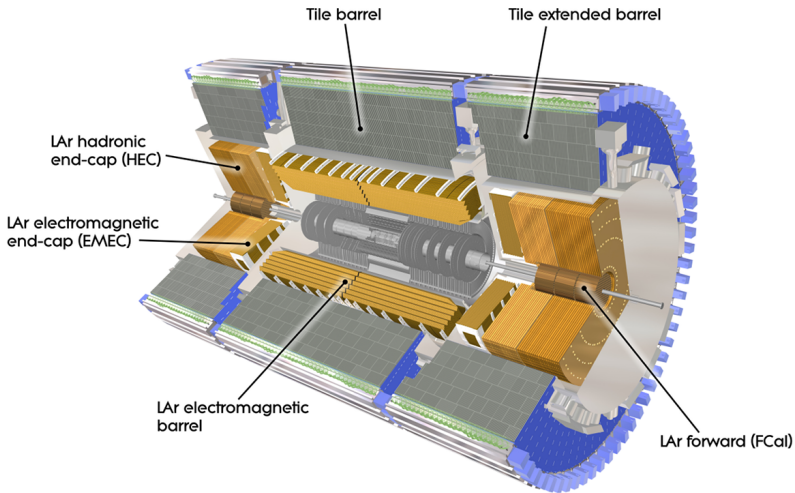






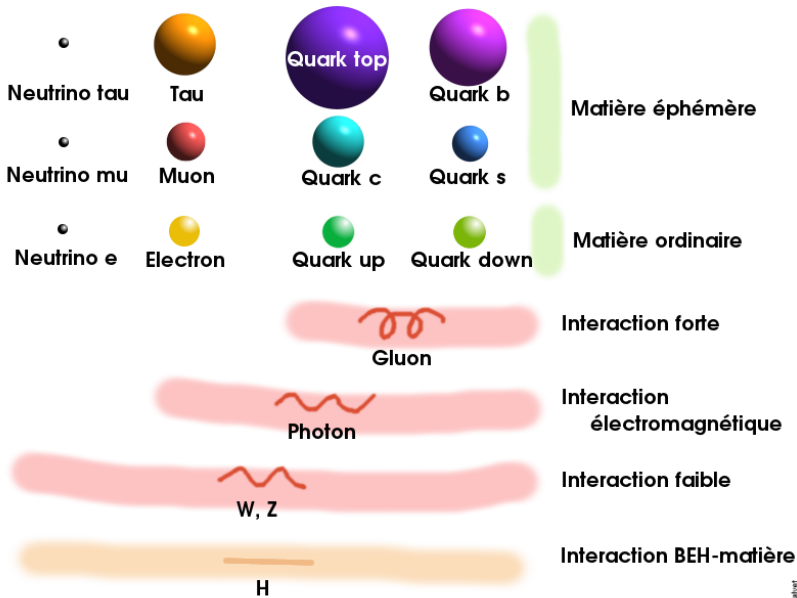


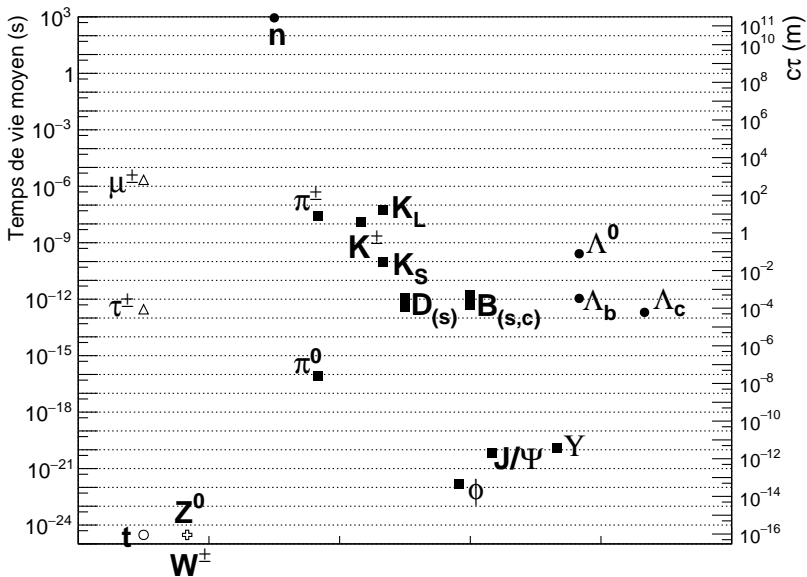


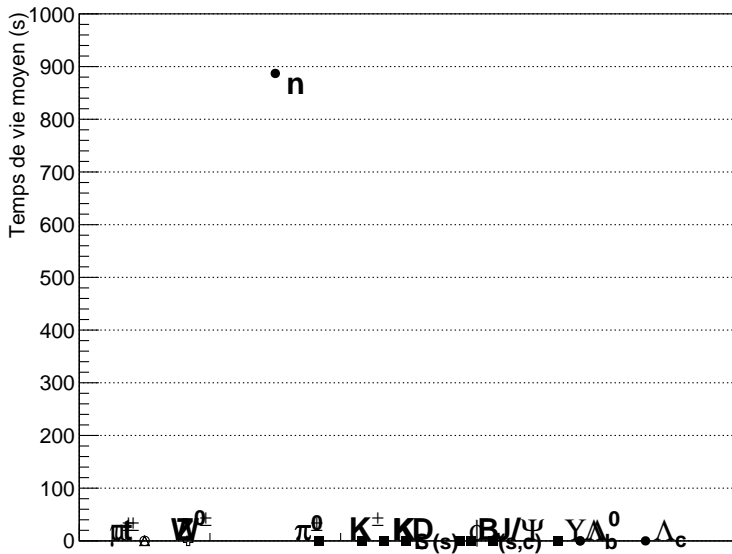




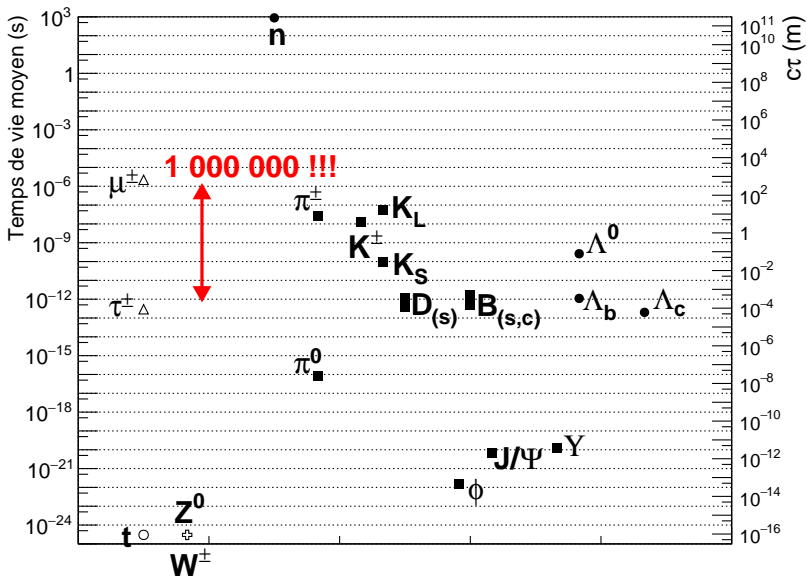
Quelles sont les particules visibles dans le détecteur ?



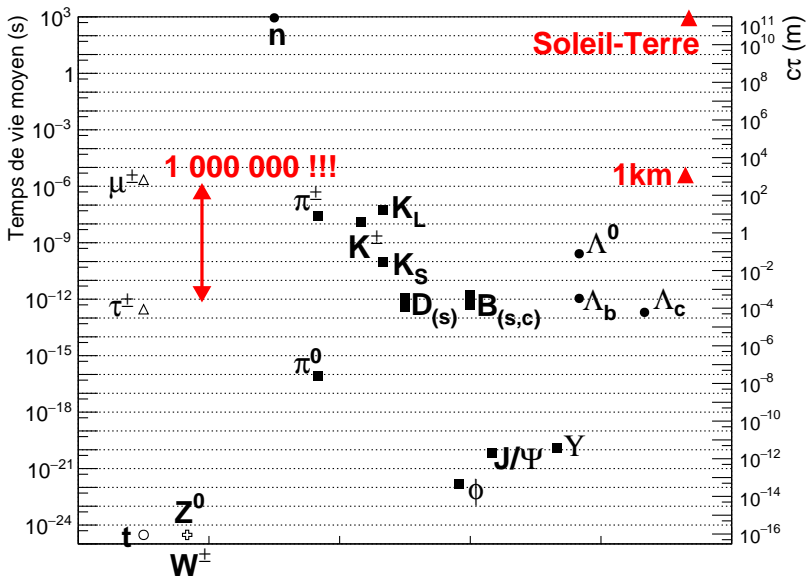




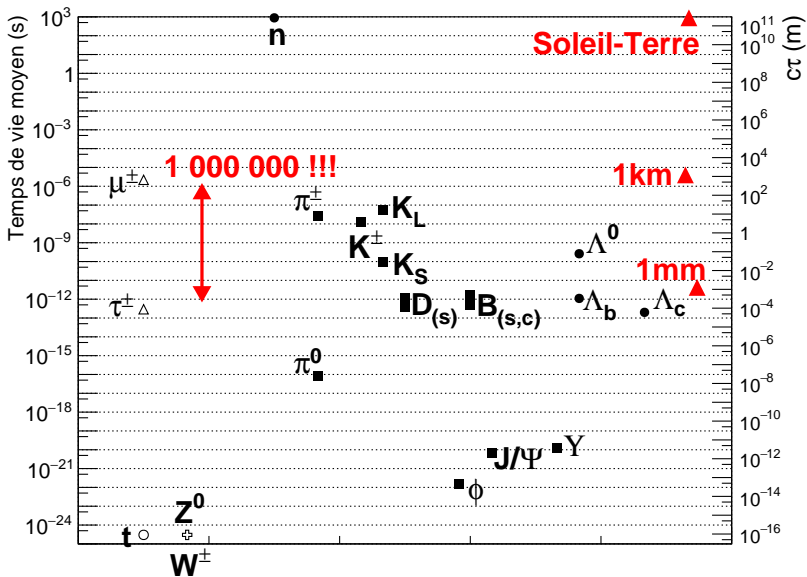


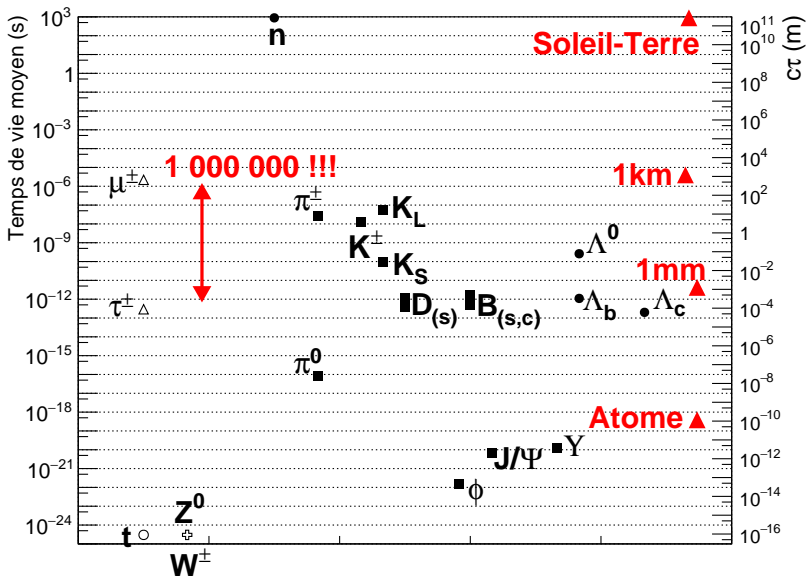


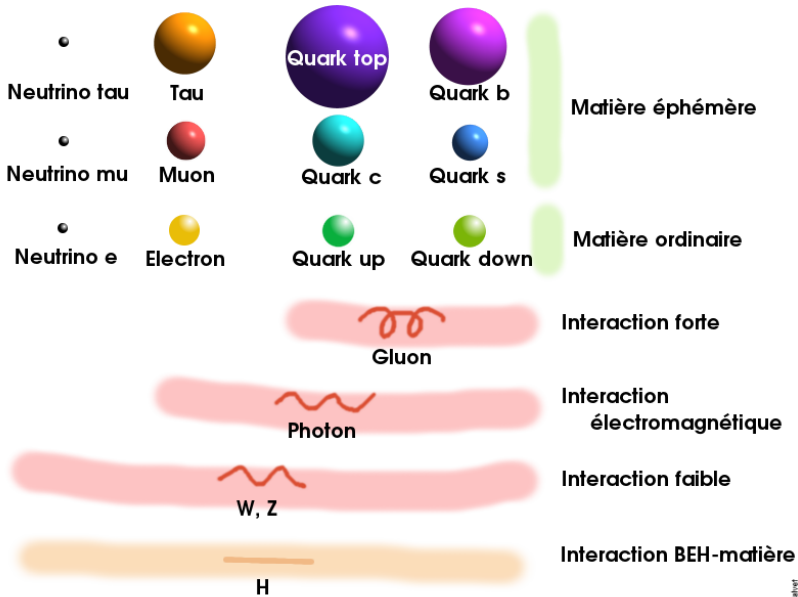


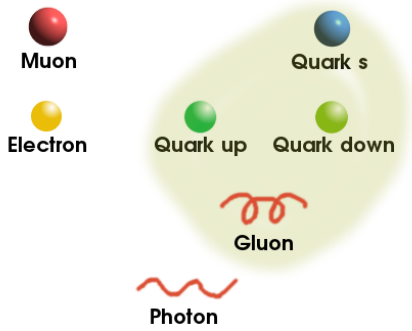


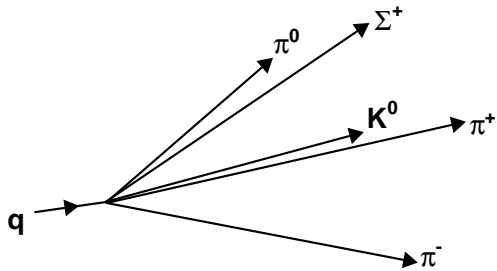


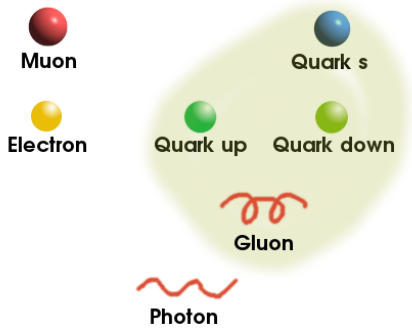


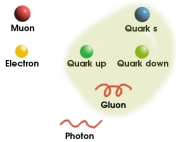


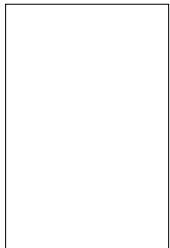
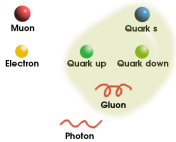






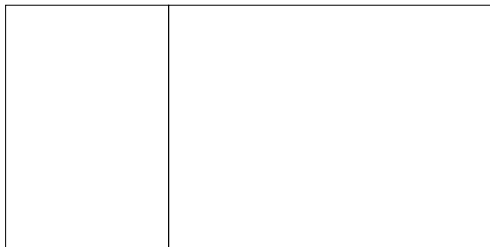






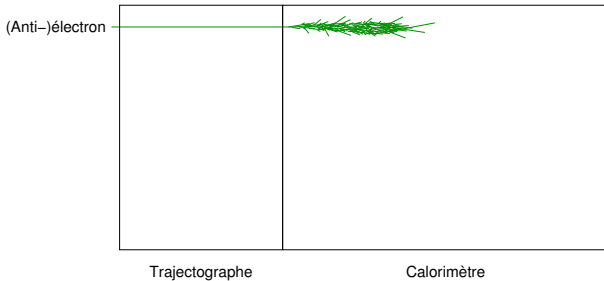
Trajectographe

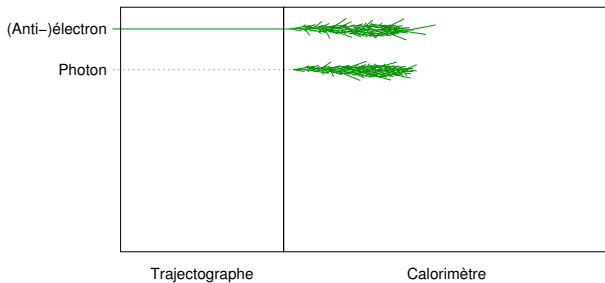
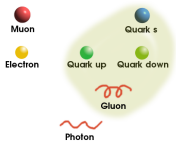


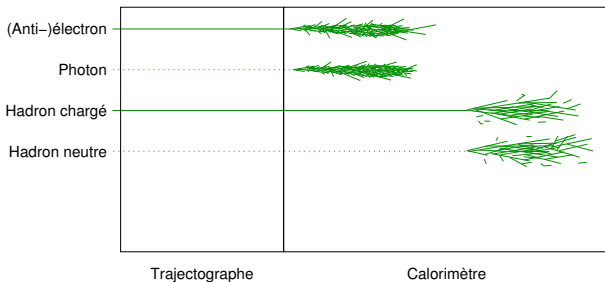


Trajectographe

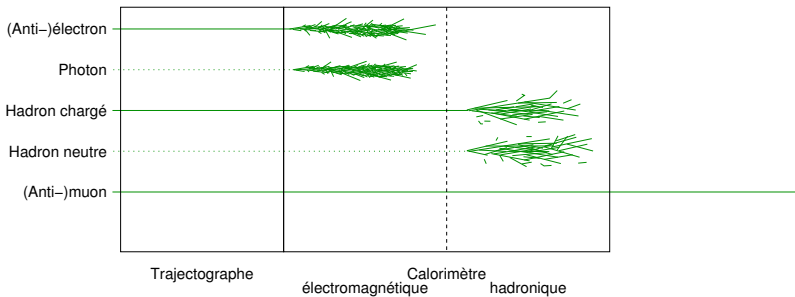
Calorimètre

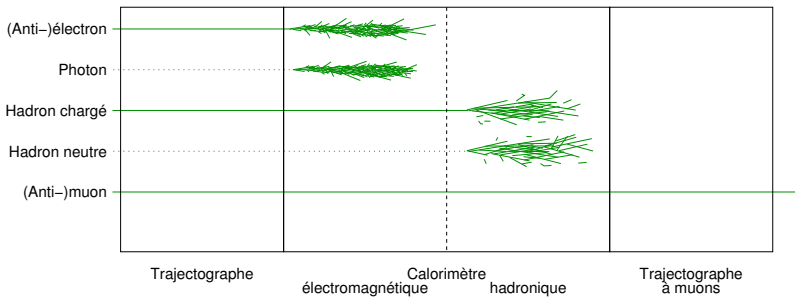
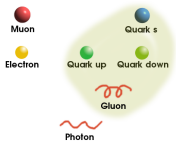


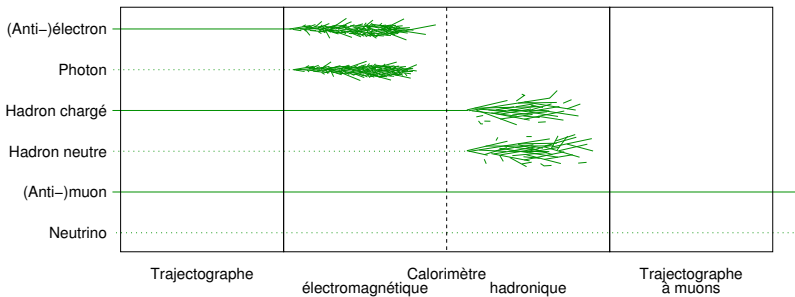




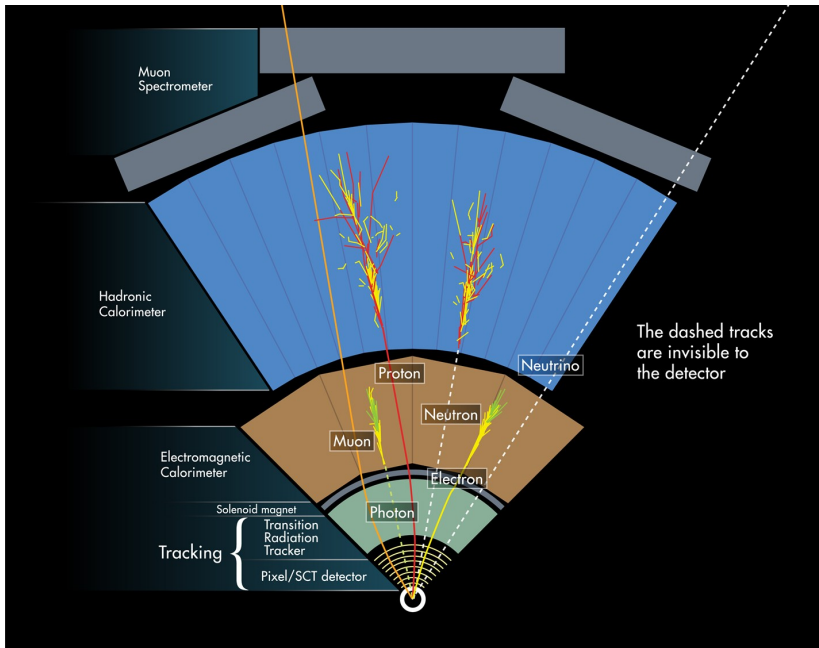


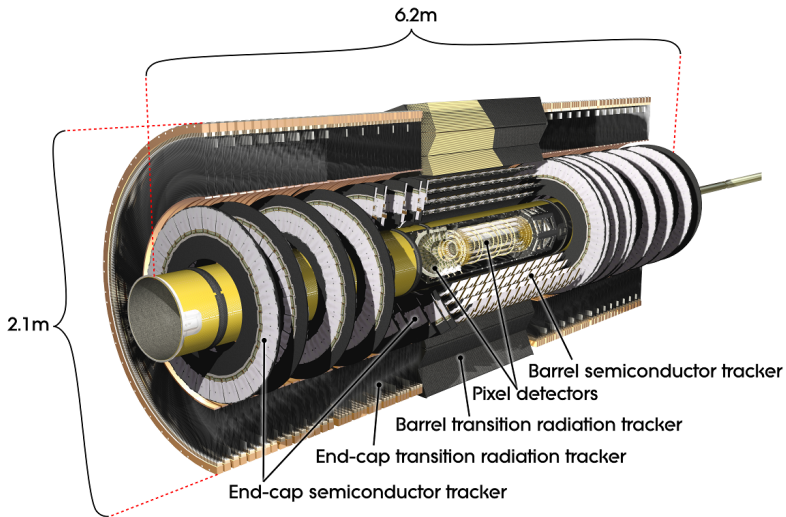


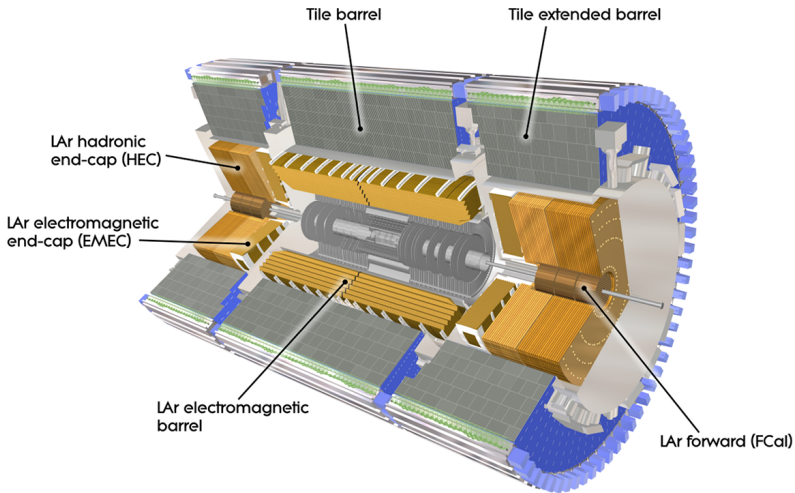


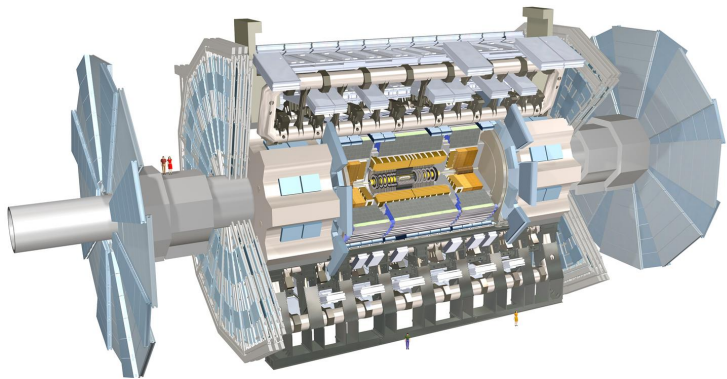


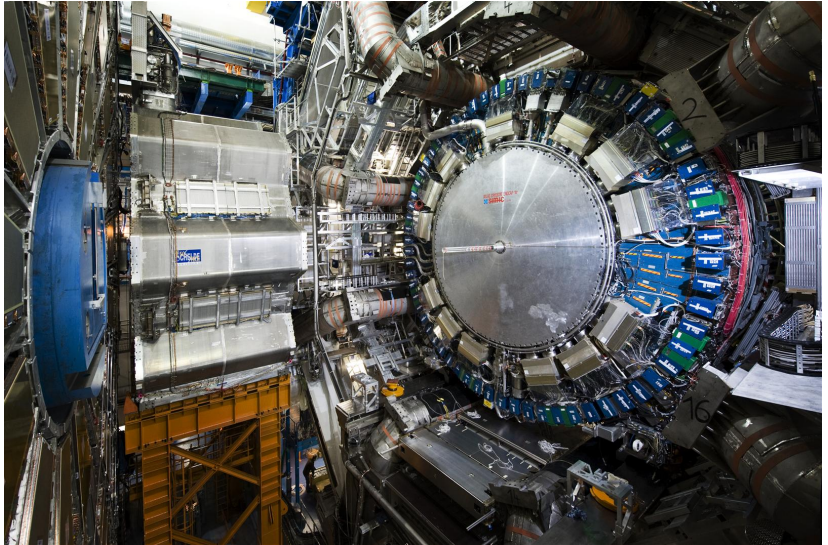


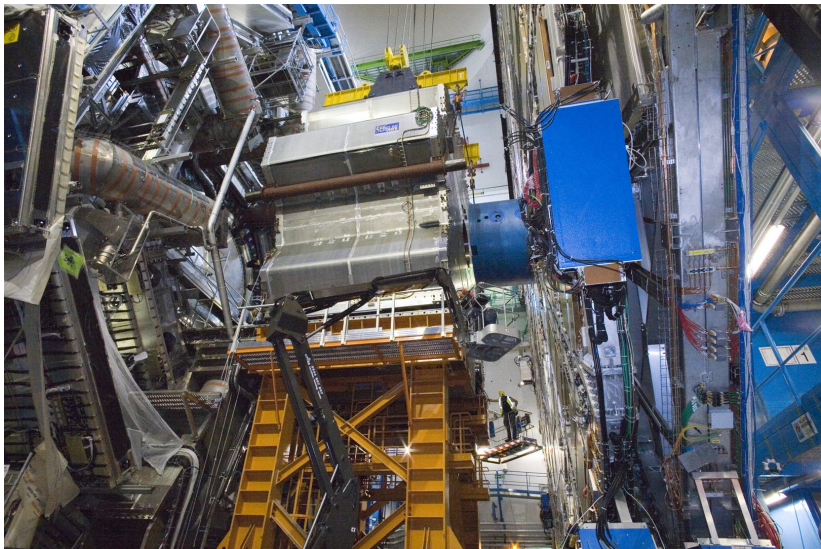


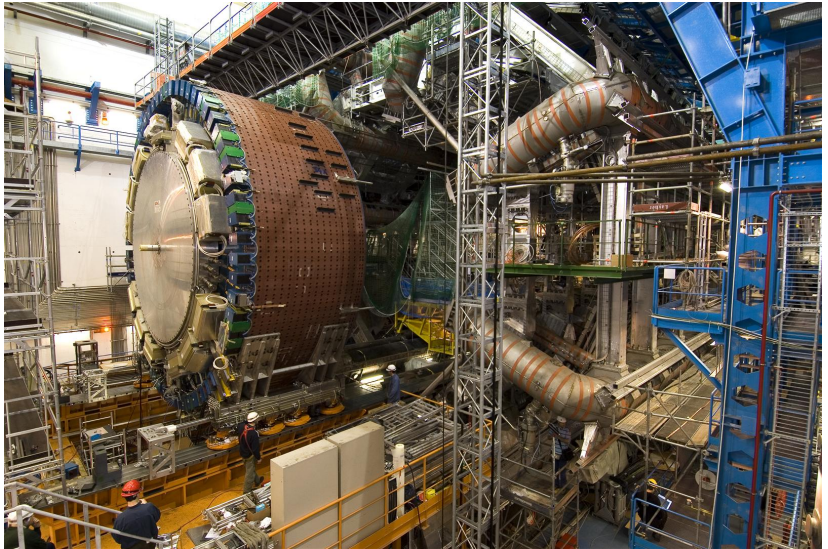


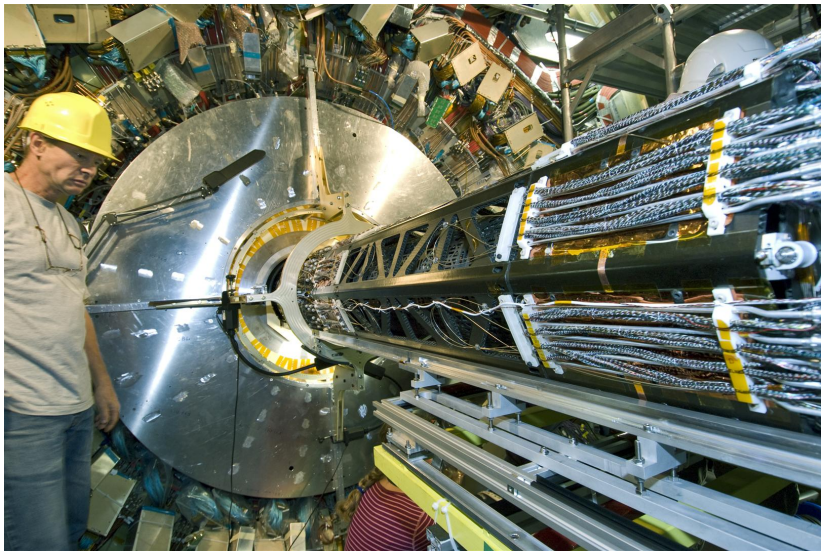




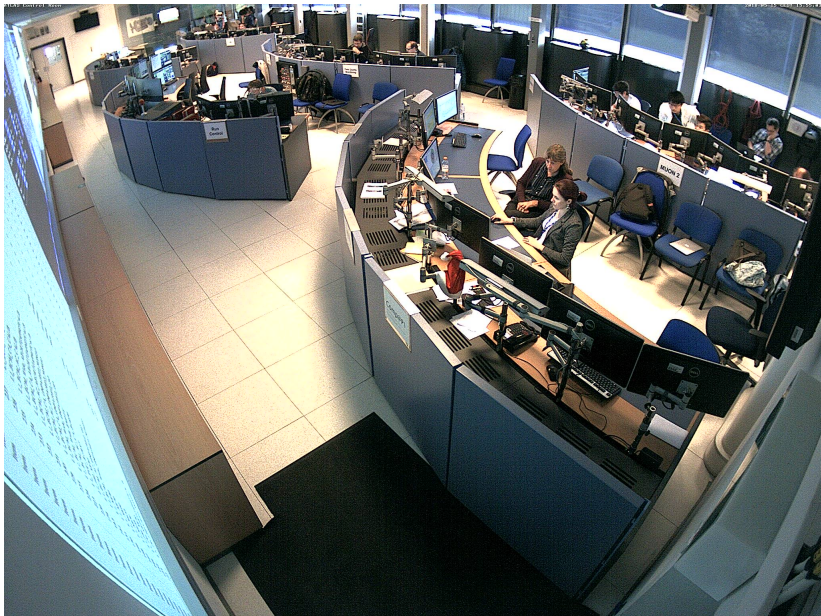


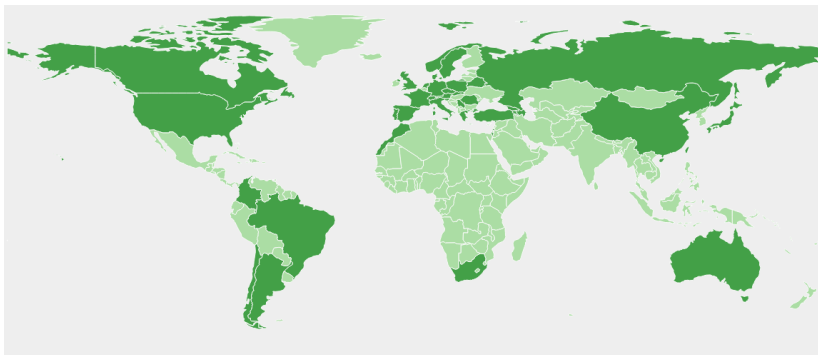




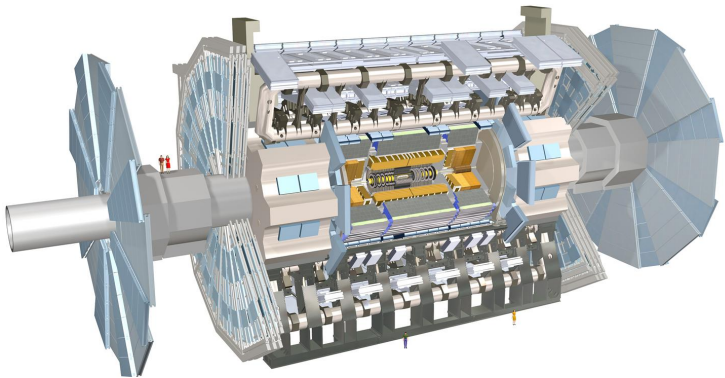




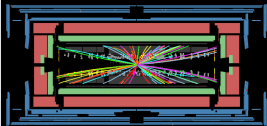
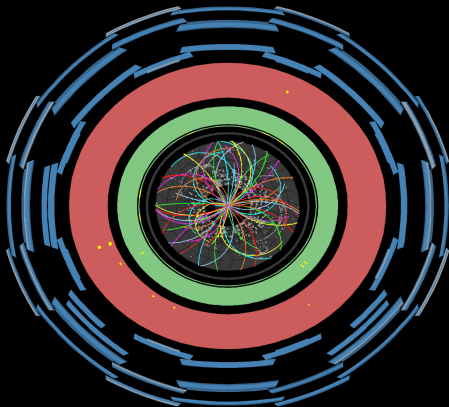




■  $\approx 3000$  physicien(ne)s



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

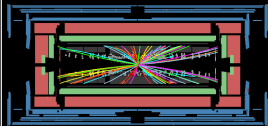
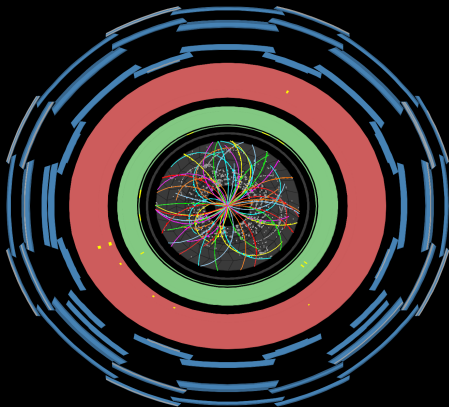


**ATLAS**  
**EXPERIMENT**

Run Number: 152166, Event Number: 316199

Date: 2010-03-30 12:58:23 CEST

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



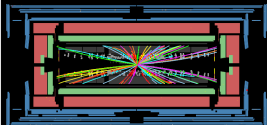
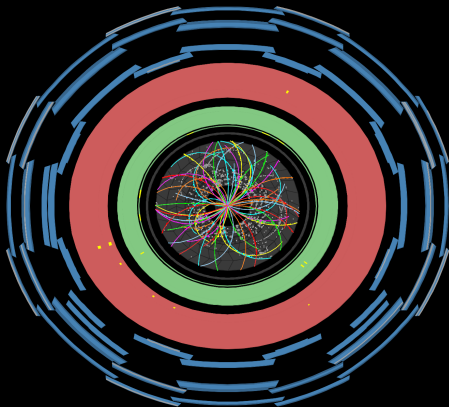
 **ATLAS**  
EXPERIMENT

Run Number: 152166, Event Number: 316199

Date: 2010-03-30 12:58:23 CEST

■ “Caméra” 3D de  $\approx 100$  Mpixels

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



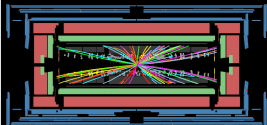
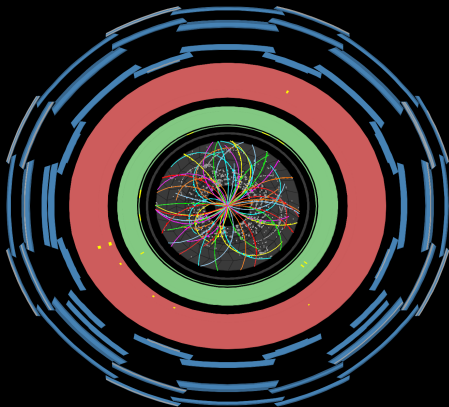
**ATLAS**  
**EXPERIMENT**

Run Number: 152166, Event Number: 316199

Date: 2010-03-30 12:58:23 CEST

- “Caméra” 3D de  $\approx 100$  Mpixels
- Traitement de 40 080 000 images/seconde

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



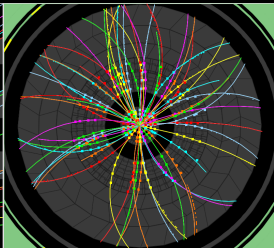
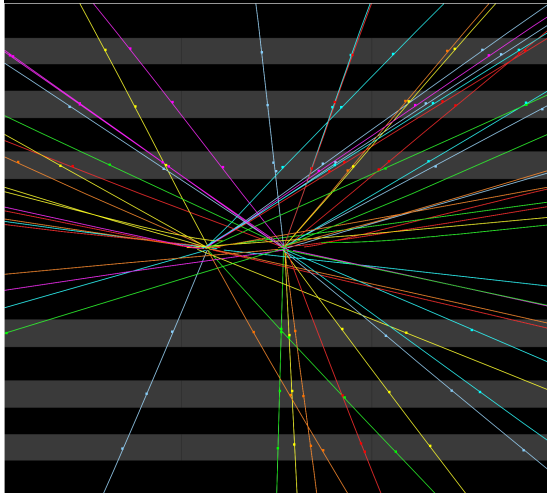
**ATLAS**  
**EXPERIMENT**

Run Number: 152166, Event Number: 316199

Date: 2010-03-30 12:58:23 CEST

- “Caméra” 3D de  $\approx 100$  Mpixels
- Traitement de 40 080 000 images/seconde
- ⇒ Enregistrement de  $\approx 1000$  images/seconde

# Collision Event at 7 TeV with 2 Pile Up Vertices



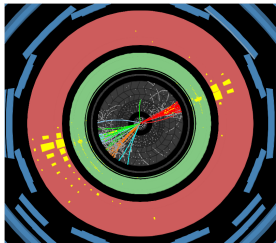
**ATLAS**  
EXPERIMENT

Run Number: 152166, Event Number: 467774

Date: 2010-03-30 13:31:46 CEST

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



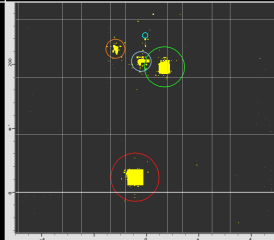
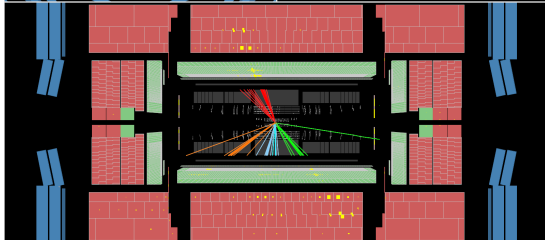
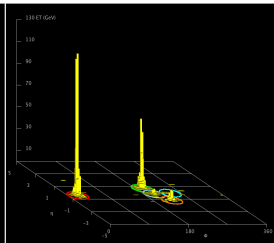


 **ATLAS  
EXPERIMENT**

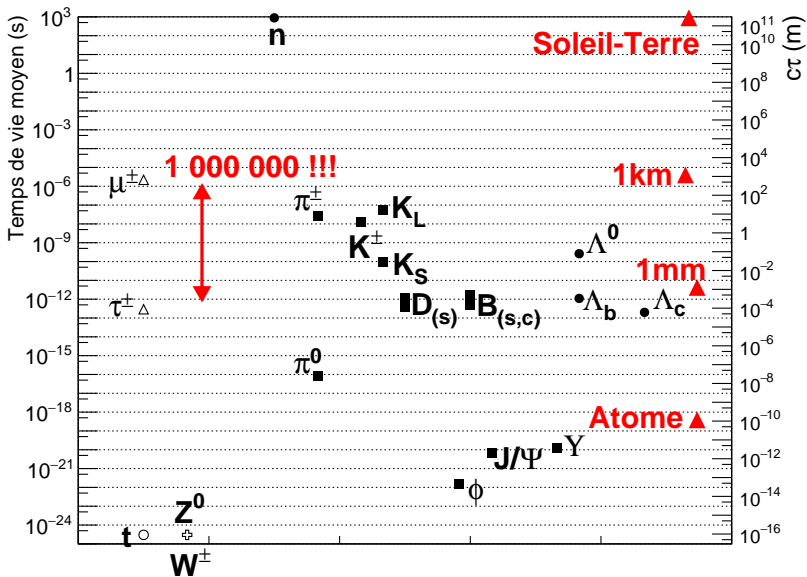
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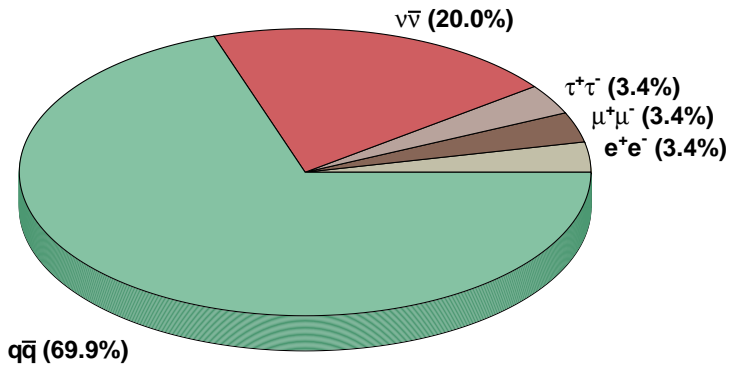
Date: 2010-07-04 06:46:45 CEST

**Multijet Event in  
7 TeV Collisions**



Et pour les particules qui ne sont pas directement observables ?





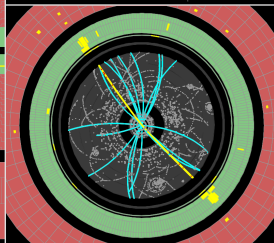
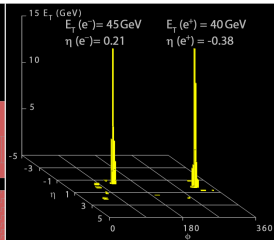
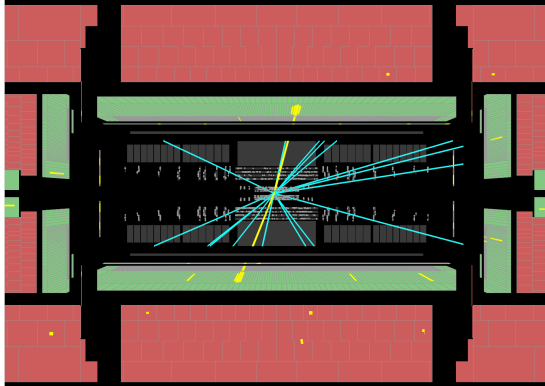


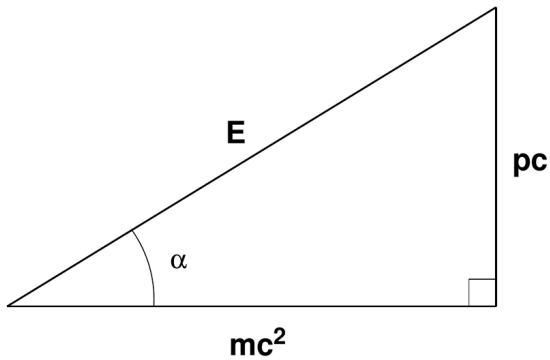
Run Number: 154817, Event Number: 968871

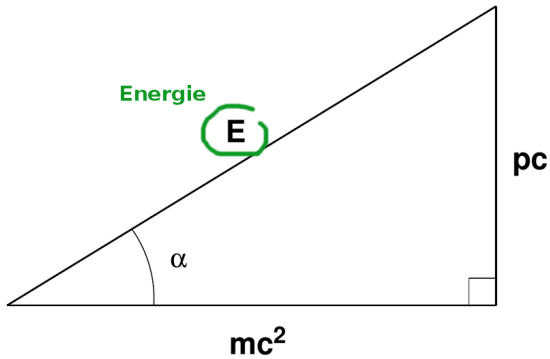
Date: 2010-05-09 09:41:40 CEST

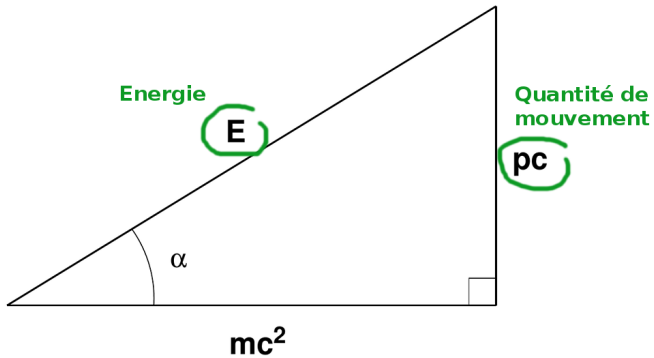
$M_{ee} = 89 \text{ GeV}$

Z-ee candidate in 7 TeV collisions

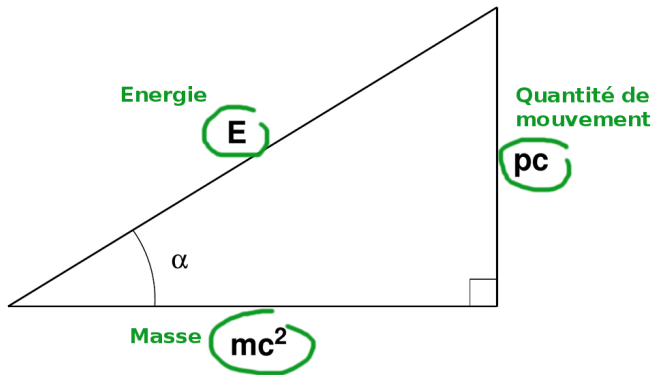


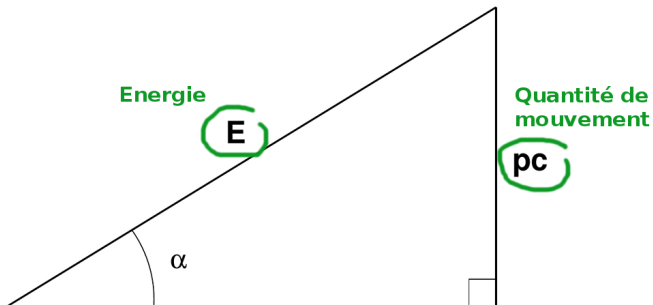




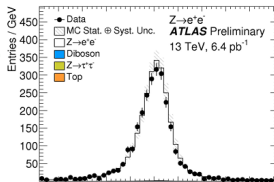




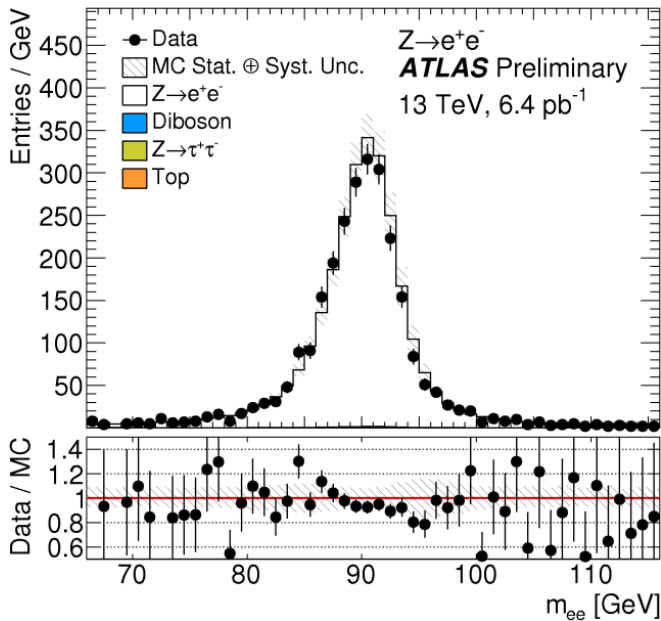


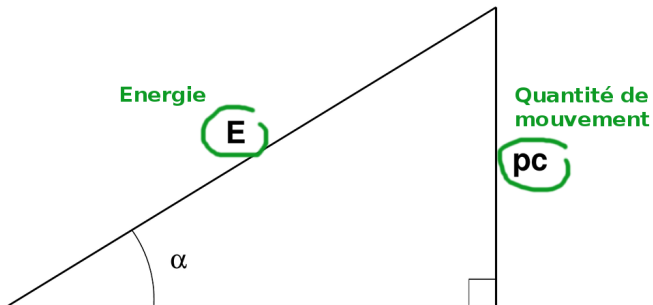


$mc^2$

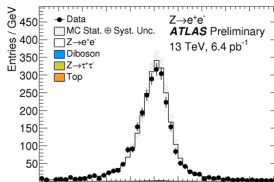


Histogramme de masse

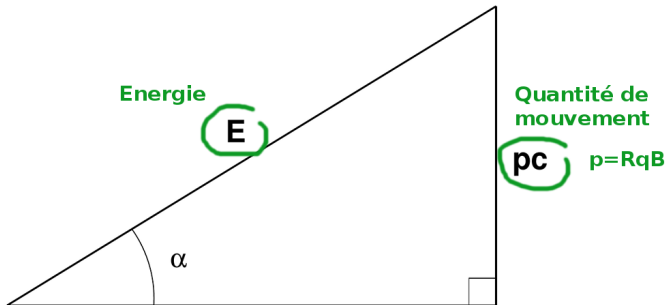




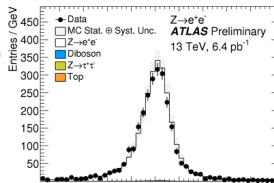
$mc^2$



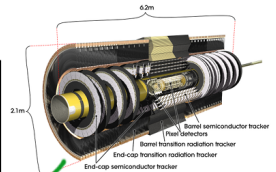
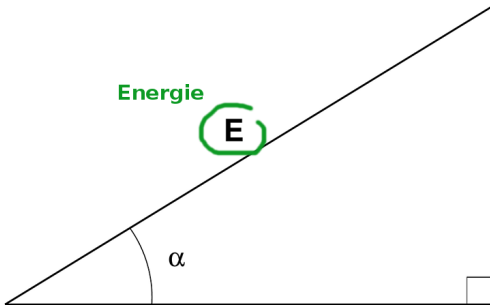
Histogramme de masse



$mc^2$

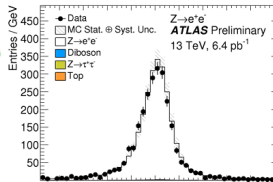


Histogramme de masse

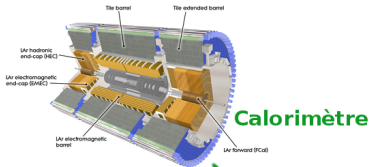


**Spectromètre =  
trajectographe  
+ aimant**

**$mc^2$**

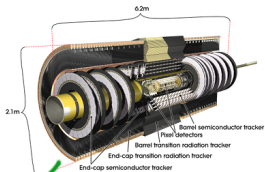


**Histogramme  
de masse**



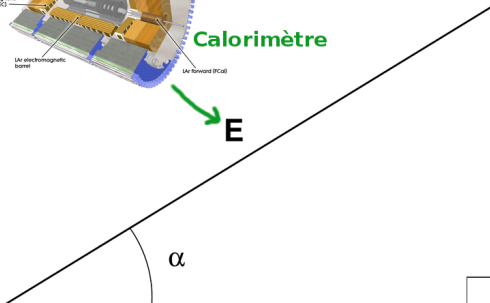
**Calorimètre**

**E**

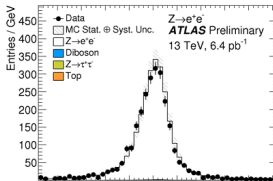


**Spectromètre =  
trajectographe  
+ aimant**

**pc**



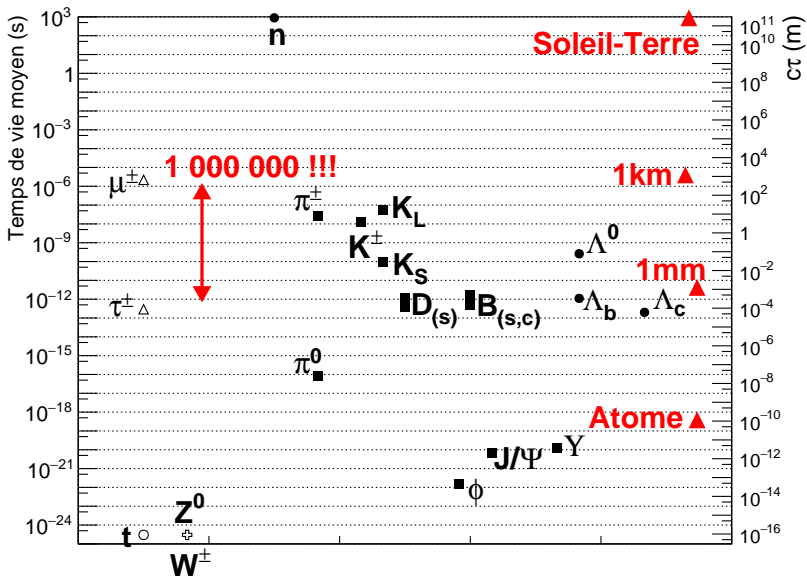
**mc<sup>2</sup>**

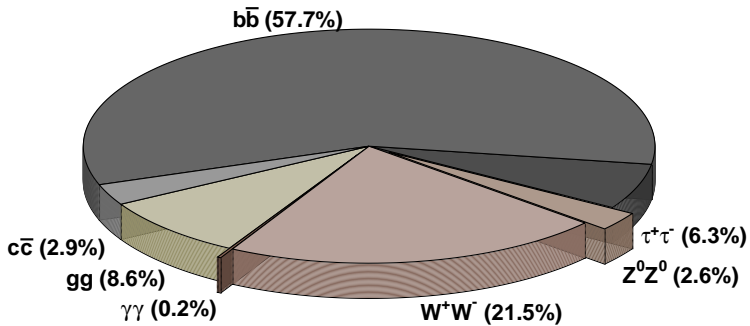


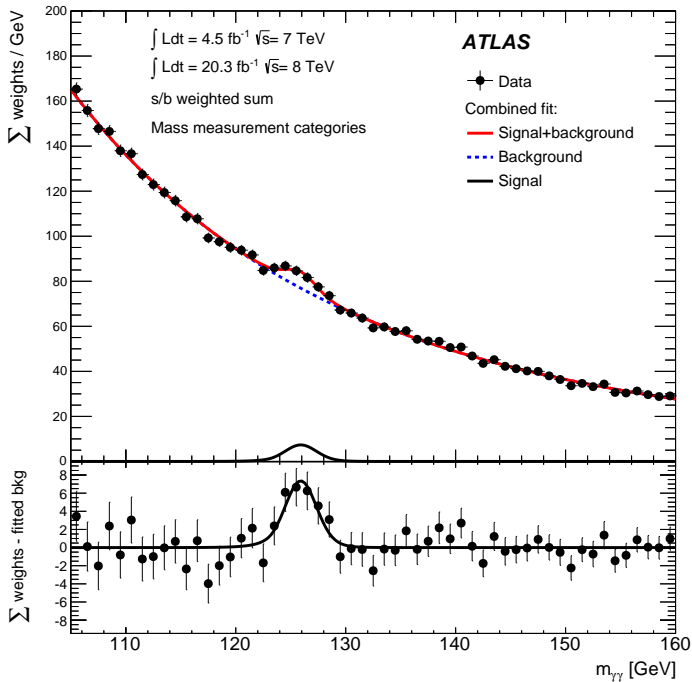
**Histogramme  
de masse**

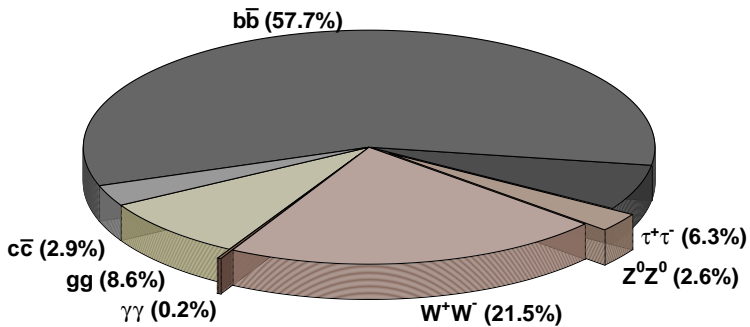
Comment a-t-on observé le boson de Higgs ?

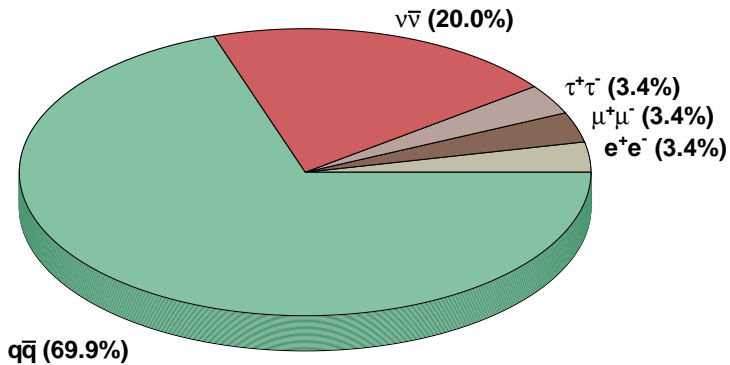


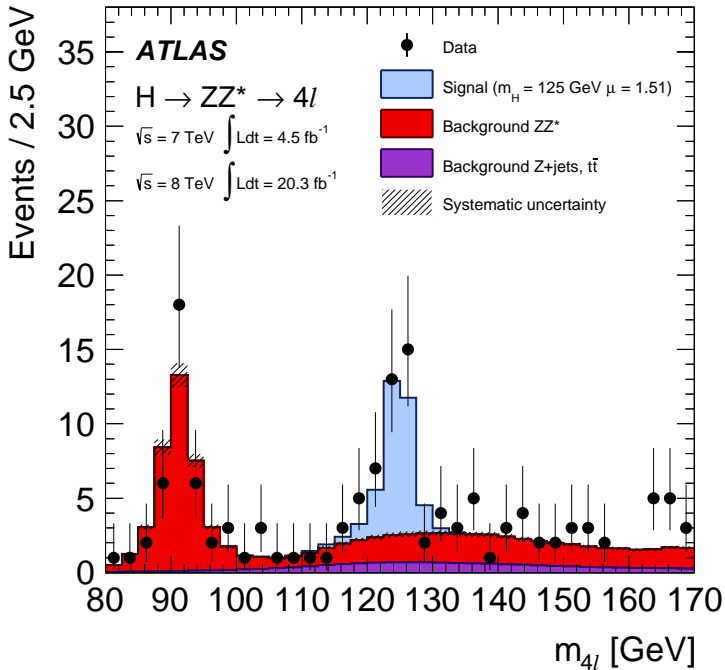


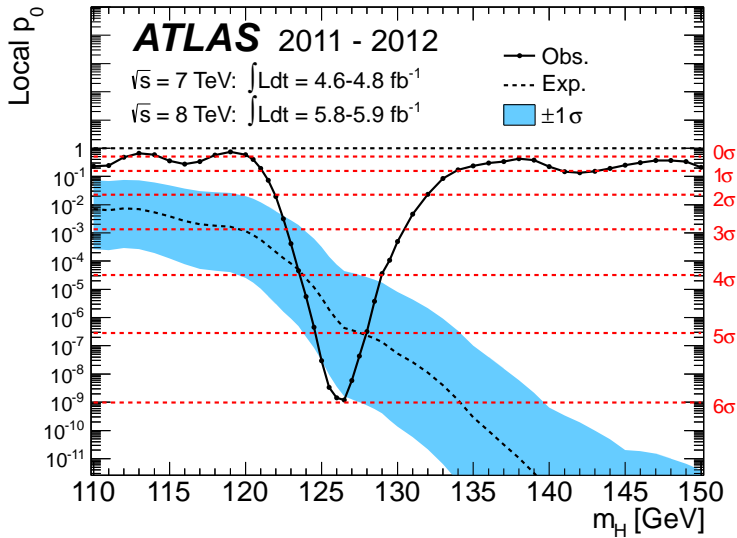














## Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC<sup>☆</sup>

ATLAS Collaboration<sup>\*</sup>

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

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### ABSTRACT

A search for the Standard Model Higgs boson in proton–proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb<sup>-1</sup> collected at  $\sqrt{s}=7$  TeV in 2011 and 5.8 fb<sup>-1</sup> at  $\sqrt{s}=8$  TeV in 2012. Individual searches in the channels  $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ ,  $H \rightarrow \gamma\gamma$  and  $H \rightarrow WW^{(*)} \rightarrow e\nu\mu\nu$  in the 8 TeV data are combined with previously published results of searches for  $H \rightarrow ZZ^{(*)}$ ,  $WW^{(*)}$ ,  $b\bar{b}$  and  $\tau^+\tau^-$  in the 7 TeV data and results from improved analyses of the  $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$  and  $H \rightarrow \gamma\gamma$  channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of  $126.0 \pm 0.4$  (stat)  $\pm 0.4$  (sys) GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of  $1.7 \times 10^{-9}$ , is compatible with the production and decay of the Standard Model Higgs boson.

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### 1. Introduction

The Standard Model (SM) of particle physics [1–4] has been tested by many experiments over the last four decades and has been shown to successfully describe high energy particle interactions. However, the mechanism that breaks electroweak symmetry in the SM has not been verified experimentally. This mechanism [5–10], which gives mass to massive elementary particles, implies the existence of a scalar particle, the SM Higgs boson. The search for the Higgs boson, the only elementary particle in the SM that has not yet been observed, is one of the highlights of the Large Hadron Collider [11] (LHC) physics programme.

Indirect limits on the SM Higgs boson mass of  $m_H < 158$  GeV at 95% confidence level (CL) have been set using global fits to precision electroweak results [12]. Direct searches at LEP [13], the Tevatron [14–16] and the LHC [17,18] have previously excluded, at 95% CL, a SM Higgs boson with mass below 600 GeV, apart from some mass regions between 116 GeV and 127 GeV.

Both the ATLAS and CMS Collaborations reported excesses of events in their 2011 datasets of proton–proton (pp) collisions at centre-of-mass energy  $\sqrt{s}=7$  TeV at the LHC, which were compatible with SM Higgs boson production and decay in the mass region 124–126 GeV, with significances of 2.9 and 3.1 standard deviations ( $\sigma$ ), respectively [17,18]. The CDF and DØ experiments at the Tevatron have also recently reported a broad excess in the mass region

120–135 GeV; using the existing LHC constraints, the observed local significances for  $m_H = 125$  GeV are 2.7 $\sigma$  for CDF [14], 1.1 $\sigma$  for DØ [15] and 2.8 $\sigma$  for their combination [16].

The previous ATLAS searches in 4.6–4.8 fb<sup>-1</sup> of data at  $\sqrt{s}=7$  TeV are combined here with new searches for  $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ ,<sup>1</sup>  $H \rightarrow \gamma\gamma$  and  $H \rightarrow WW^{(*)} \rightarrow e\nu\mu\nu$  in the 5.8–5.9 fb<sup>-1</sup> of pp collision data taken at  $\sqrt{s}=8$  TeV between April and June 2012.

The data were recorded with instantaneous luminosities up to  $6.8 \times 10^{33}$  cm<sup>-2</sup>s<sup>-1</sup>; they are therefore affected by multiple pp collisions occurring in the same or neighbouring bunch crossings (pile-up). In the 7 TeV data, the average number of interactions per bunch crossing was approximately 10; the average increased to approximately 20 in the 8 TeV data. The reconstruction, identification and isolation criteria used for electrons and photons in the 8 TeV data are improved, making the  $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$  and  $H \rightarrow \gamma\gamma$  searches more robust against the increased pile-up. These analyses were re-optimised with simulation and frozen before looking at the 8 TeV data.

In the  $H \rightarrow WW^{(*)} \rightarrow e\nu\mu\nu$  channel, the increased pile-up deteriorates the event missing transverse momentum,  $E_{\text{miss}}^{\text{reco}}$ , resolution, which results in significantly larger Drell–Yan background in the same-flavour final states. Since the  $e\mu$  channel provides most of the sensitivity of the search, only this final state is used in the analysis of the 8 TeV data. The kinematic region in which a SM Higgs boson with a mass between 110 GeV and 140 GeV is

<sup>☆</sup> © CERN for the benefit of the ATLAS Collaboration.

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<sup>1</sup> The symbol  $\ell$  stands for electron or muon.