

# Résumé de l'épisode précédent

## Conception d'un détecteur

Episode IV

### A NEW HOPE

*It is a period of civil war.  
Rebel spaceships, striking  
from a hidden base, have won  
their first victory against  
the evil Galactic Empire.*

# Résumé → Episode IV A New Hope

## 1/ Introduction

- références, vocabulaire, unités

## 2/ Déetecter quoi ↔ pourquoi

- remarques liminaires
- modélisation
- déetecteur : ckoï ?

## 3/ Interaction particules matière

- rapide aperçu

## 4/ Généralités sur les détecteurs

## 5/ Exemples

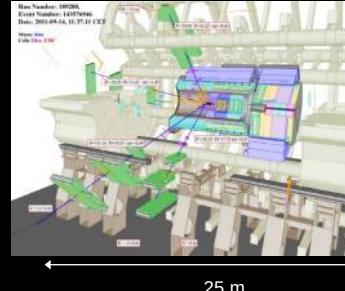
- D0 (Fermilab)
- ATLAS (CERN)



Particules

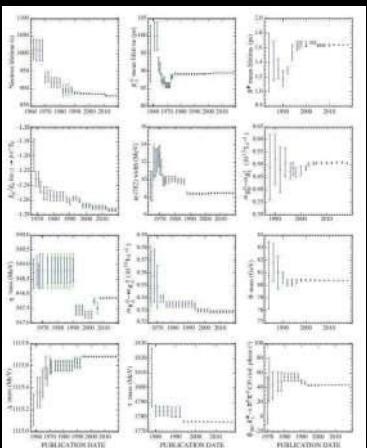
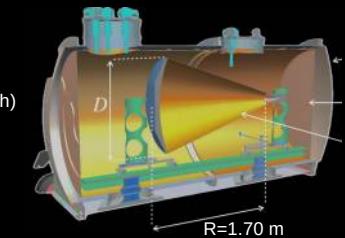
Delphi, D0, ATLAS...

Ondes



Champs

G-LEAD DAWA  
(Dark matter Axion Wide-band Approach)

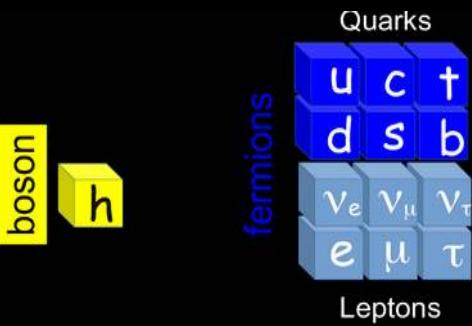


# Résumé → Episode IV A New Hope

Déterminer la bonne question → contexte scientifique

-ex: recherche du boson de Higgs

→ la plage d'énergie à étudier → 100 GeV à 1000 GeV



Théorie → conditions de production

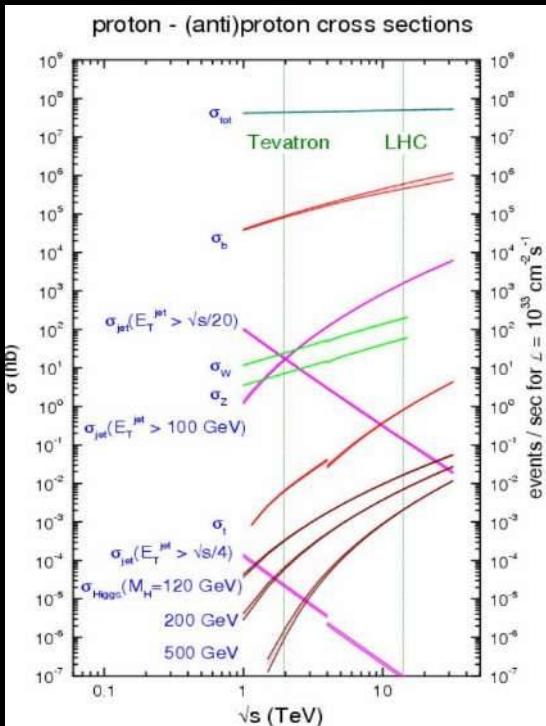
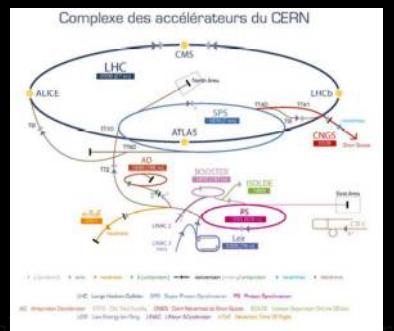
-paramètres théoriques sur 100 GeV à 1000 GeV

→ nombre de higgs , bruit de fond,...

Conditions des mesures : où

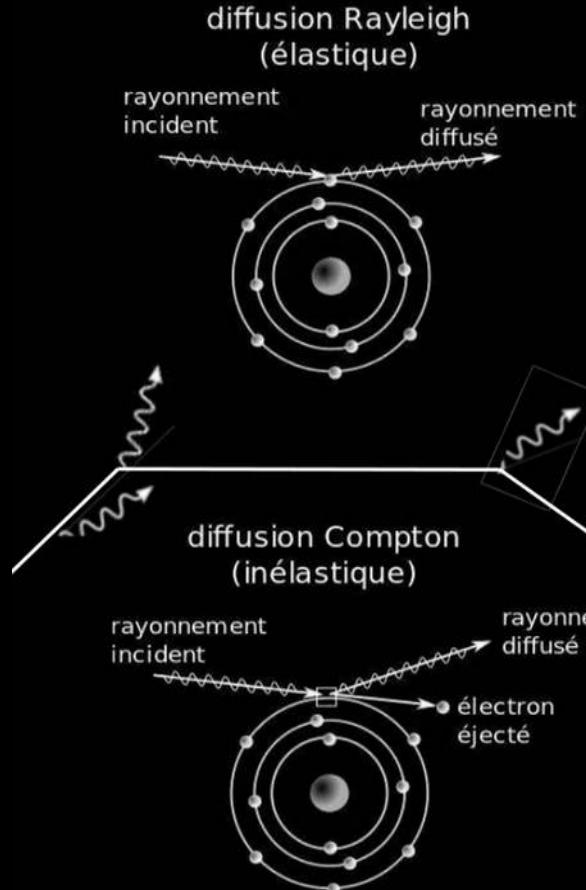
-CERN

→ 25ns → 40 MHz

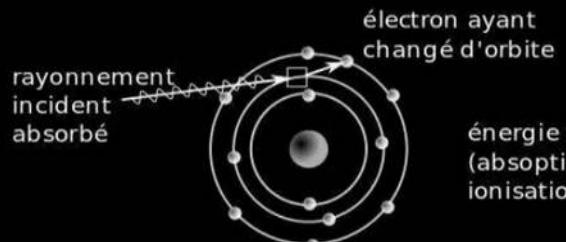


# Résumé → Episode IV A New Hope

## Mécanismes de détections

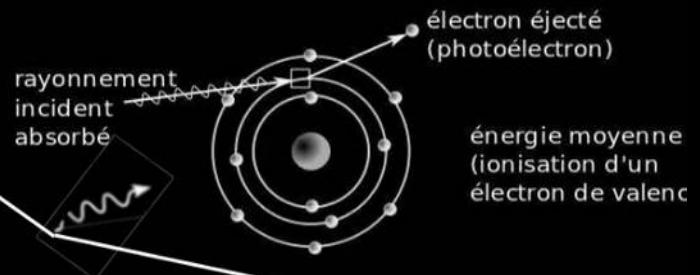


absorption simple

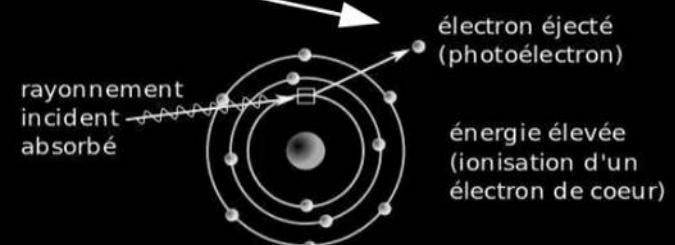


énergie faible (absorption sans ionisation)

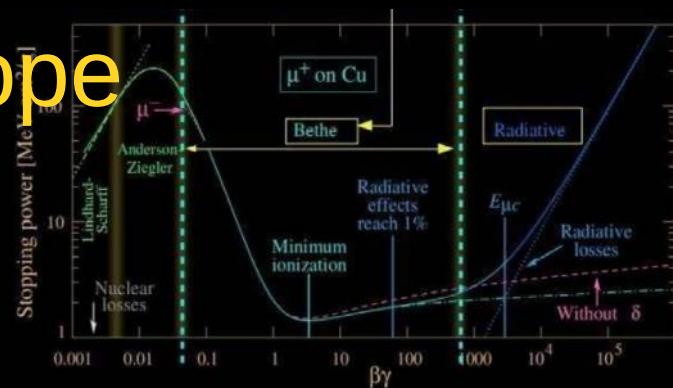
ionisation (effet photoélectrique, émission secondaire)



énergie moyenne (ionisation d'un électron de valence)



énergie élevée (ionisation d'un électron de cœur)



# Résumé → Episode IV A New Hope

# Détection

- traces chargées non destructif
  - mesures énergie totale absorption total

## Particules élémentaires



## États liés → hadrons

$p, \pi^\pm, K^\pm...$   
 $n, \pi^0, \lambda...$

10

Pions :  $u\bar{d}$ ,  $d\bar{u}$ ,  $(u\bar{u} - d\bar{d})$

## Contraintes sur le détecteur

- résolutions : impulsion=énergie, spatiale, temporelle Marco / Marco
  - couverture angulaire : acceptances ( $\eta$ ,  $\phi$ )
  - taux de comptage et tolérance au rayonnement Damien / Marco
  - contraintes mécaniques, thermiques et d'espace Julien

— STAR WARS —

# THE EMPIRE STRIKES BACK

— EPISODE V —

# Conception d'un détecteur

23-25 Novembre 2025, Roscoff

## 1/ Introduction

-références, vocabulaire, unités

Merci à  
Bertrand, Christina, Damien,  
Julien, Marco B., Marco D.,  
Raphaël

## 2/ Déetecter quoi ↔ pourquoi

-remarques liminaires  
-modélisation  
-détecteur : ckoï ?

Pas de Merci à  
Aline, je n'étais pas présent...

## 3/ Interaction particules matière

-rapide aperçu

## 4/ Généralités sur les détecteurs

## 5/ Exemples

-D0 (Fermilab)  
-ATLAS (CERN)

# 4/ Généralités sur les détecteurs

## Interactions particules-matière

Mesures partielles et/ou destructives (pour parties)

- Spécifiques à certaines particules (sous-détecteurs)

Séparation de charge : **champ magnétique**

- Mesure de l'impulsion pour les particules chargées
- +/- séparation / focalisation / nettoyage

Herméticité

- $W \rightarrow \mu\nu$  :  $\nu$  (neutrino), contrôle énergie manquante (Et\_miss)
- Moins vrai pour SK (mesure spécifique aux neutrinos)

# 4/ Généralités sur les détecteurs

champ magnétique

$$\mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

← force de Lorentz

$$\mathbf{F} = \frac{q}{m\gamma} \mathbf{p} \times \mathbf{B}$$

← partie magnétique

$$\mathbf{p}_{[\text{GeV}]} = 0.3q \mathbf{B}_{[\text{T}]} \mathbf{R}_{[\text{m}]}$$

← réécriture en unités qui vont bien

Intégrale de champ

→  $\int \mathbf{B} \cdot d\mathbf{l}$  → défini le système magnétique

→  $\int \mathbf{B} \cdot \mathbf{l} \cdot d\mathbf{l}$  → défini la résolution en impulsion du détecteur

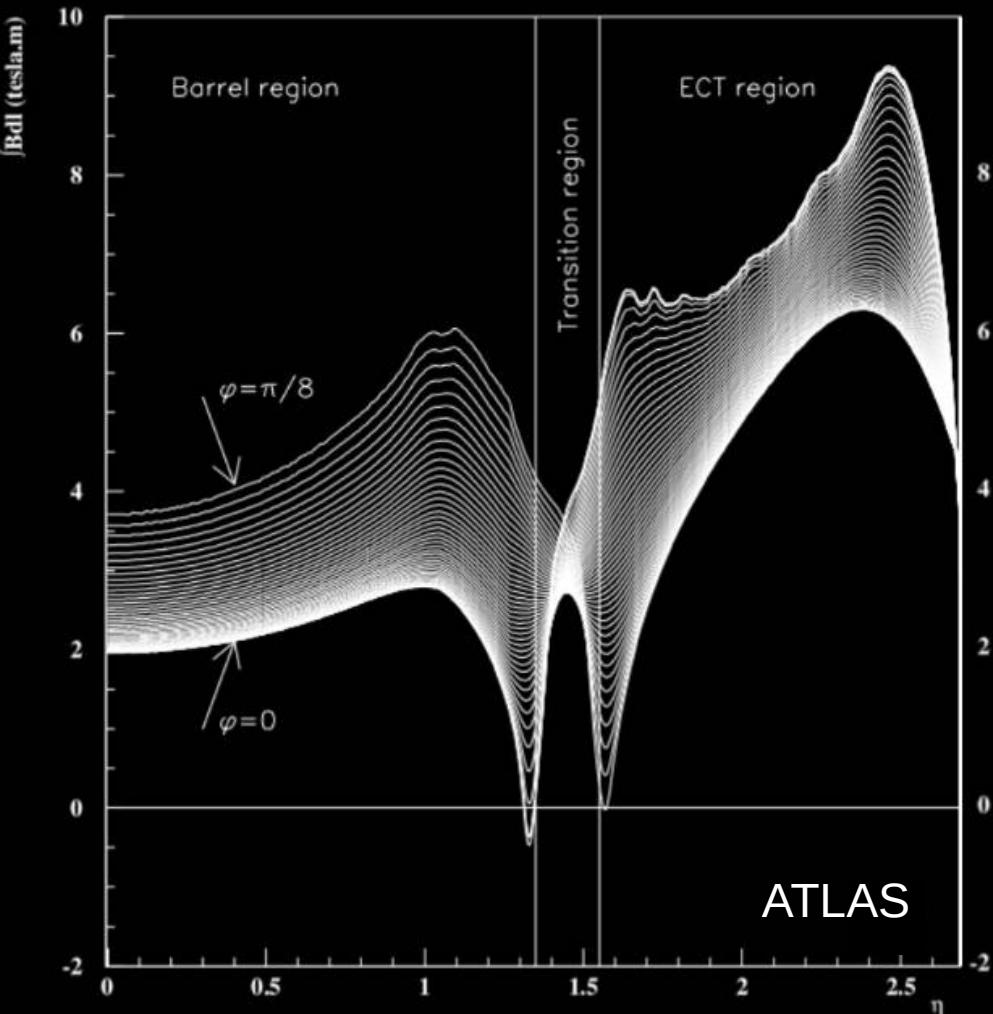
# 4/ Généralités sur les détecteurs

champ magnétique

Intégrale de champ

$$\rightarrow \int B \cdot dL$$

→ défini le système magnétique



# 4/ Généralités sur les détecteurs

champ magnétique

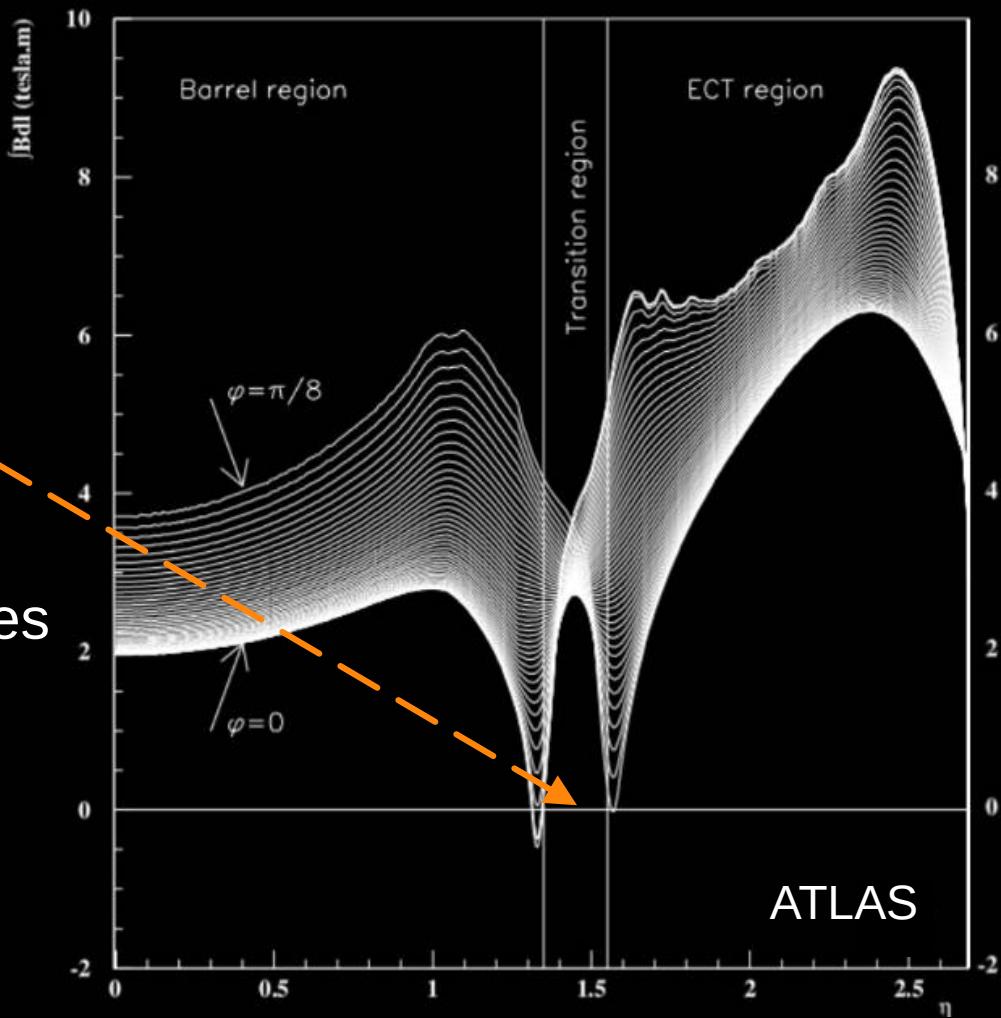
Intégrale de champ

$$\rightarrow \int B \cdot dl$$

→ défini le système magnétique

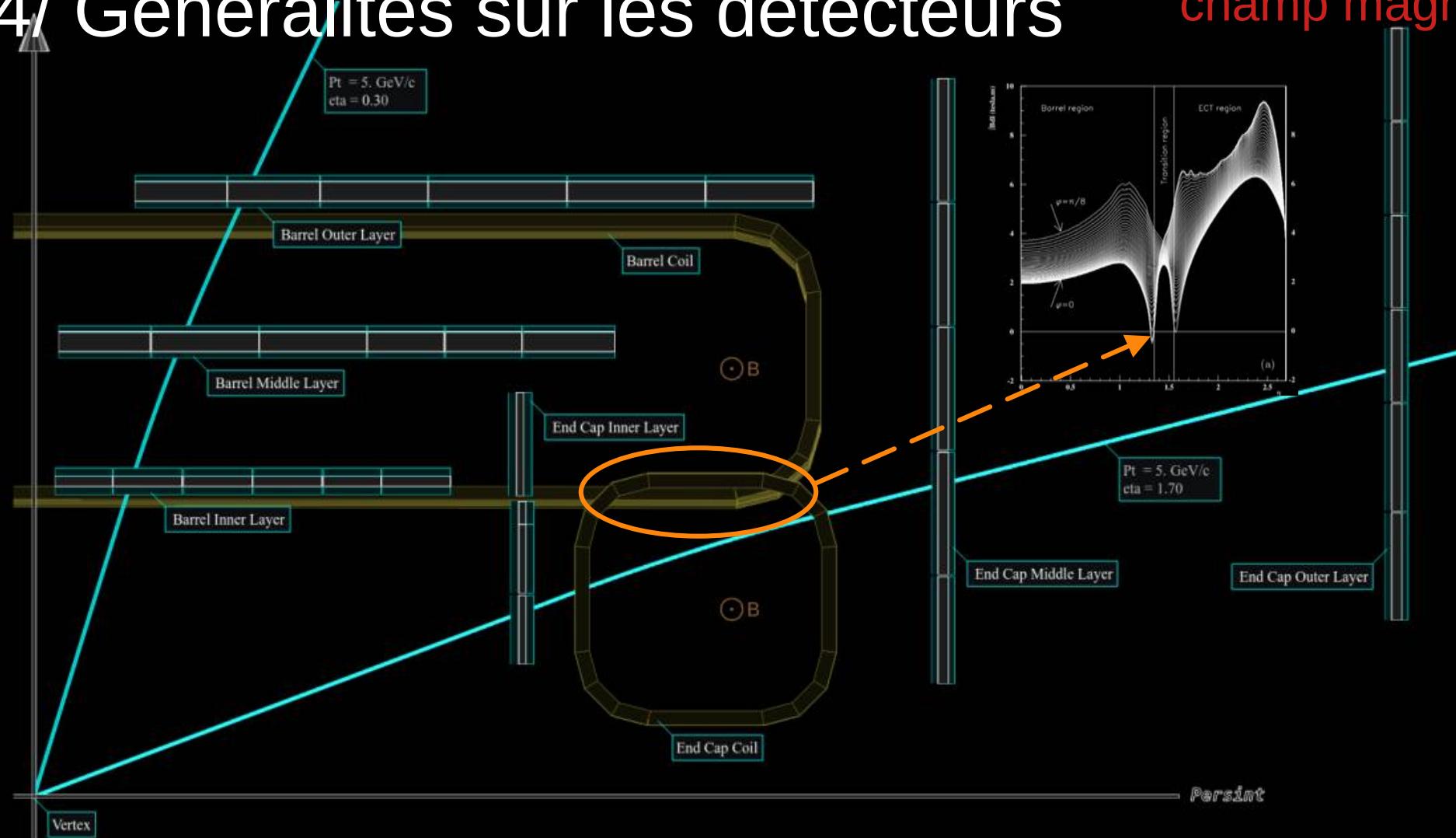
Et là, c'est le drame !

Julien,  
Je dois changer le cahier des charges



# 4/ Généralités sur les détecteurs

champ magnétique



### Solénoïdal

- Constant sur une grande partie de son volume
  - trajectographie « simplifiée »
- pp(bar): ok Plan transverse ( $R\phi$ ) (E beam mal connu!)
- impulsion donnée : courbure diminue qd rapproche de l'axe
- « Nettoyage » des traces chargées de faible impulsion

### Toroïdal

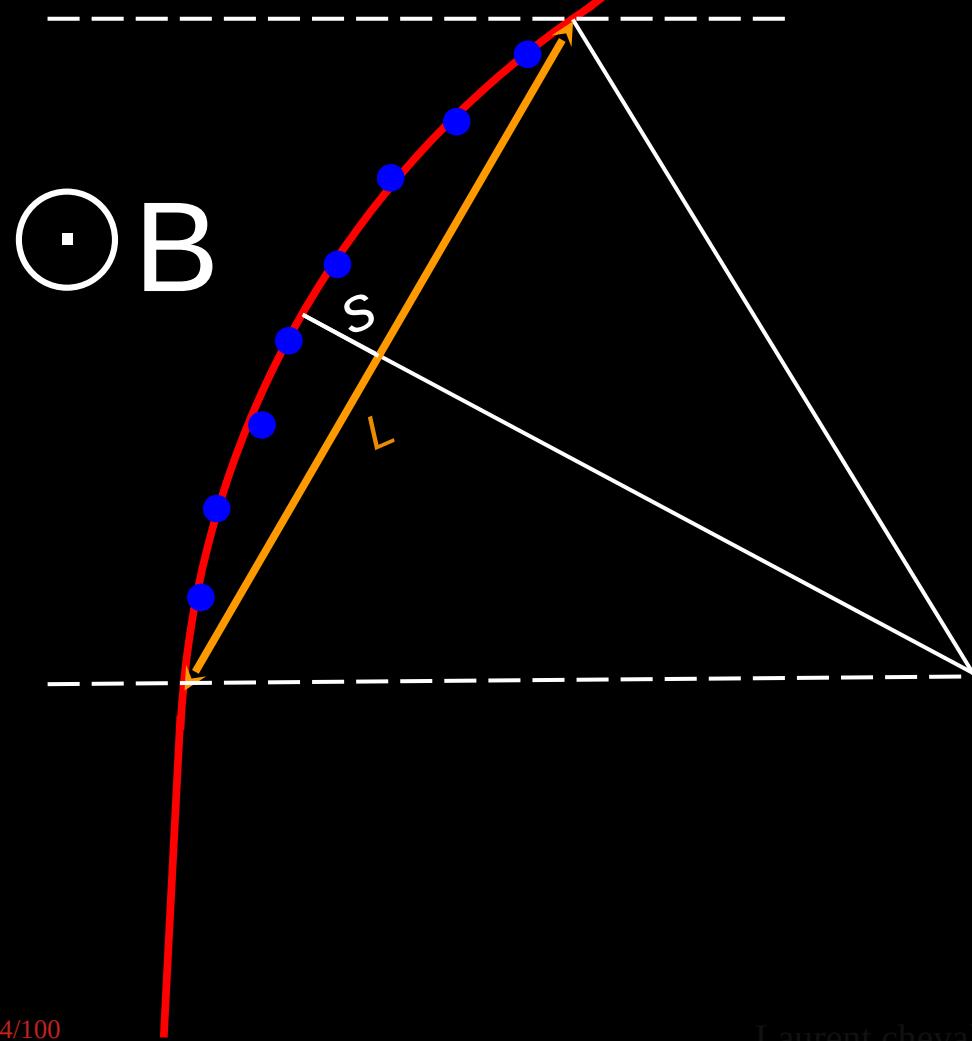
- Champ moins homogène
- Volume potentiel plus grand
- Intégral de champ +/- constant vers l'avant

| Magnetic field | OFF   | ON    |
|----------------|-------|-------|
| All Tracks     | 4.9 M | 2.7 M |
| SCT Tracks     | 1.2 M | 880 k |
| Pixel Tracks   | 230 k | 190 k |

ATLAS track statistics since Sep 2008

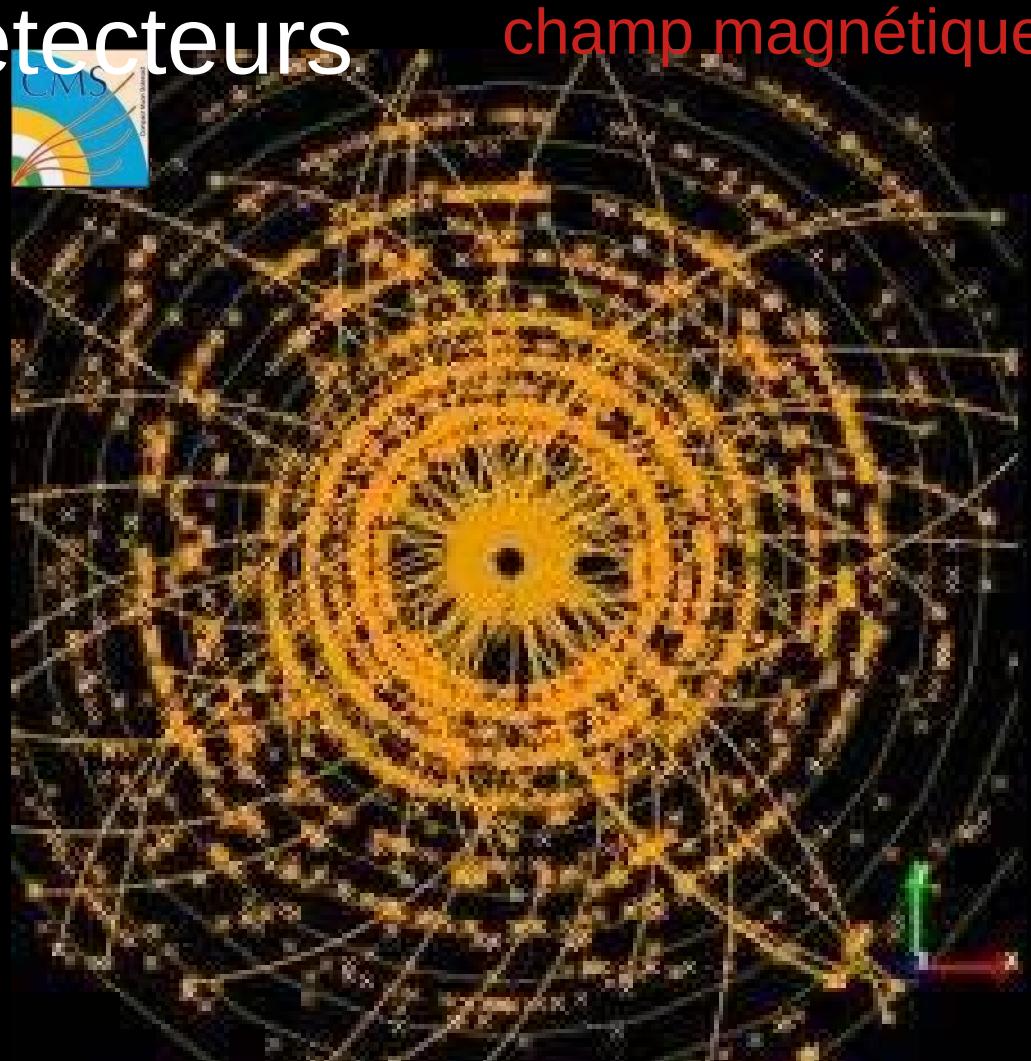
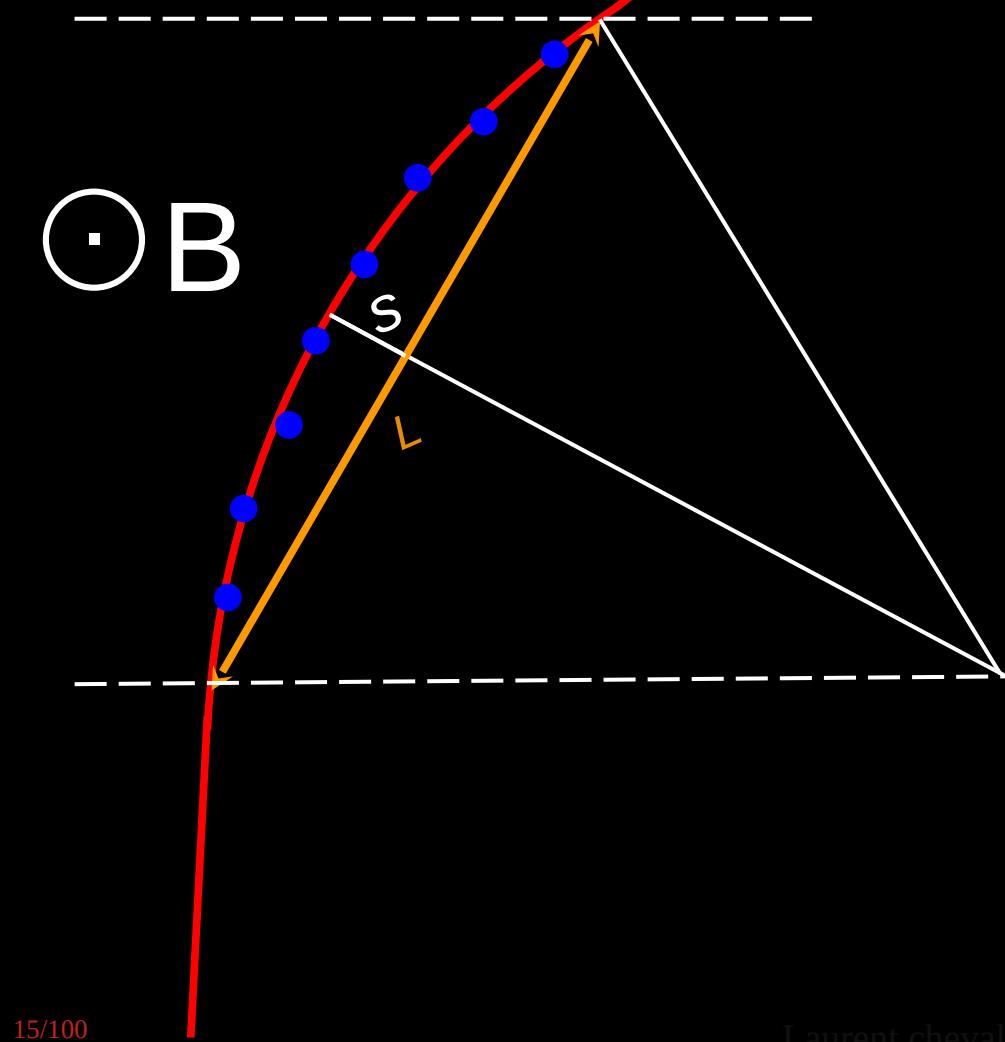
# 4/ Généralités sur les détecteurs

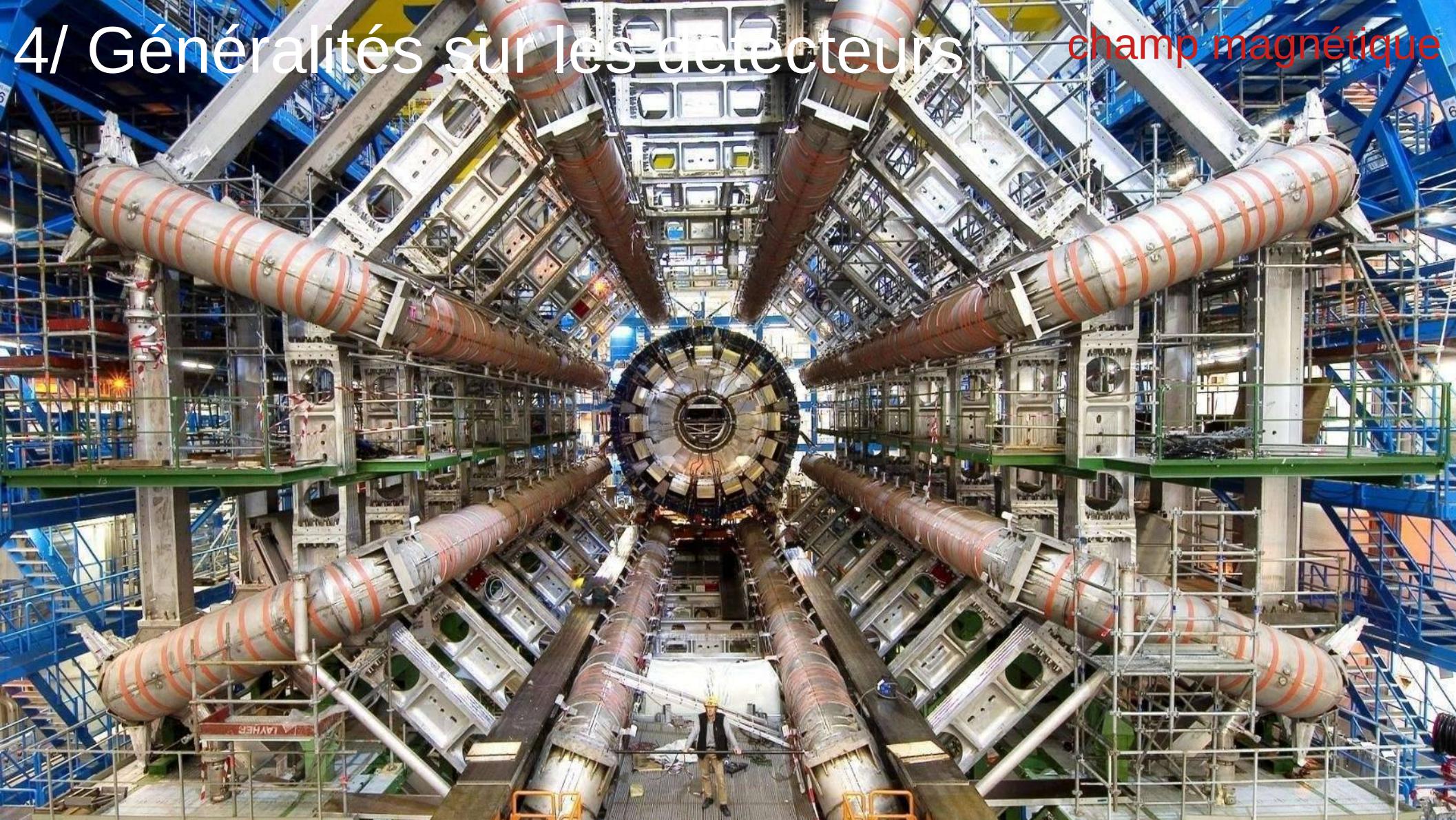
champ magnétique



# 4/ Généralités sur les détecteurs

champ magnétique



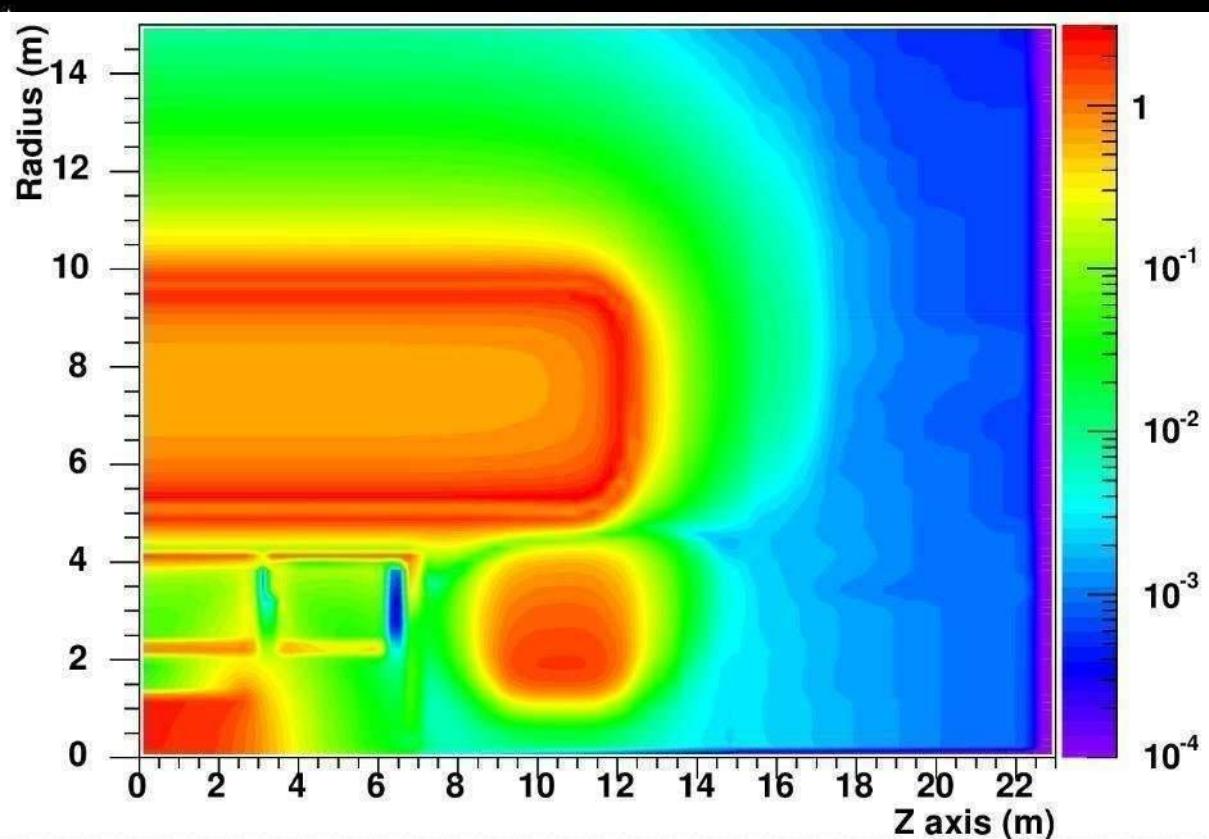
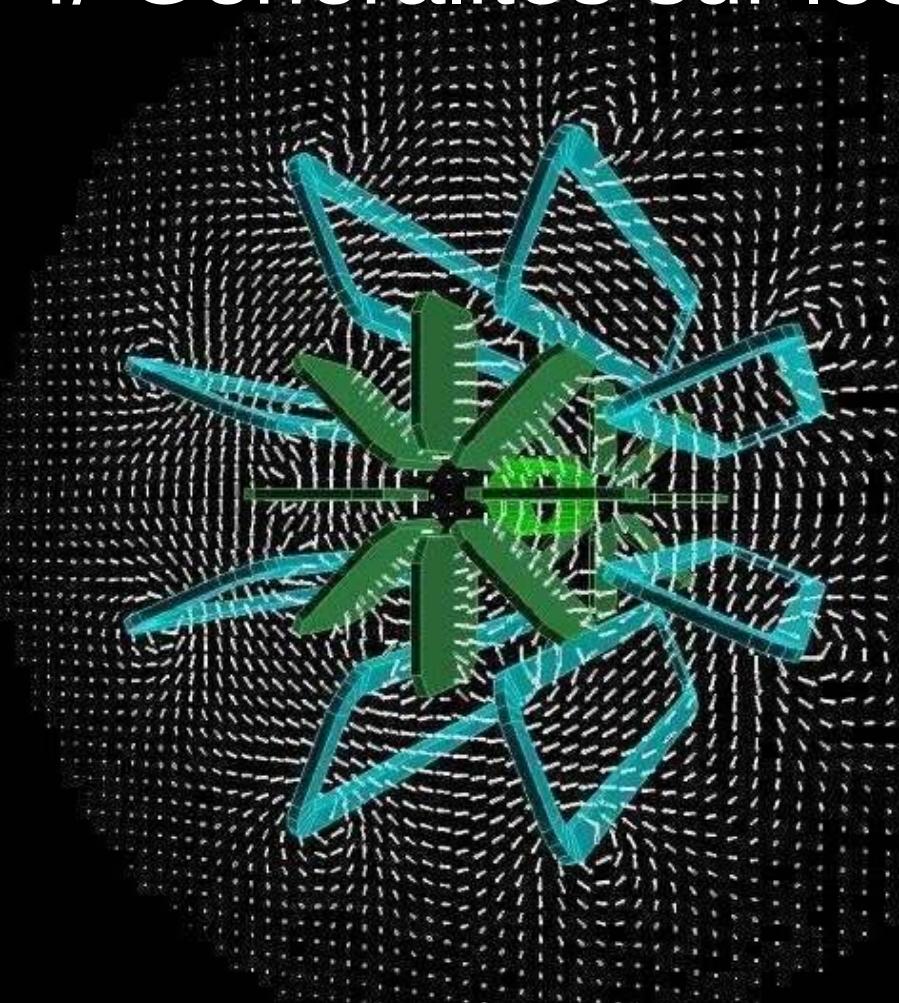


# 4/ Généralités sur les détecteurs

champ magnétique

# 4/ Généralités sur les détecteurs

champ magnétique



# 4/ Généralités sur les détecteurs

## Paramètres significatifs

Point d'interaction

Trajectographie

Cal électromagnétique

### Longueur de Radiation

- $X_0$  = Longueur caractéristique des pertes par radiation
  - Atténuation l'énergie par radiation :  $\exp(-x/X_0)$
  - Longueur sur laquelle un électron perd 1/e de son énergie par brem

Spectromètre à muons

### Longueur d'interaction

- $\lambda$  = Longueur caractéristique d'interaction nucléaire
- Libre parcours moyen d'un hadron entre 2 Interactions nucléaires

# 4/ Généralités sur les détecteurs

## Paramètres significatifs

Cal hadronique

### Longueur de Radiation

- $X_0$  = Longueur caractéristique des pertes par radiation
  - Atténuation l'énergie par radiation :  $\exp(-x/X_0)$
  - Longueur sur laquelle un électron perd 1/e de son énergie par brem

### Longueur d'interaction

- $\lambda$  = Longueur caractéristique d'interaction nucléaire
- Libre parcours moyen d'un hadron entre 2 Interactions nucléaires

# 4/ Généralités sur les détecteurs

## Trajectographie : détecteurs « Transparents »

- Mesure des particules chargées
  - mesure de la position du vertex (« peu » de perte d'énergie)
  - mesure de la trace et de l'impulsion (si champ magnétique)
  - identifier les particules :
    - $dE/dx$
    - rayonnement de transition
    - Cherenkov
    - temps de vol.

## Calorimètres : détecteurs « massifs » → absorption → mesure énergie

- mesure des électrons, photons, hadrons

Point d'interaction

Trajectographie

Cal électromagnétique

Cal hadronique

Spectromètre à muons

# 4/ Généralités sur les détecteurs

Point d'interaction

Trajectographie

Cal électromagnétique

Cal hadronique

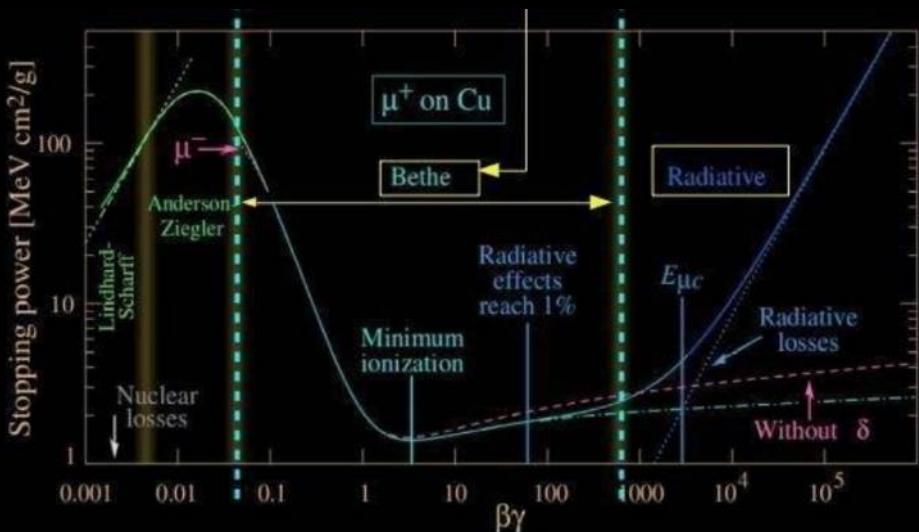
Spectromètre à muons

## Muons

- Identification des muons
  - connexion avec le trajectographe : Alignement relatif des sous-détecteurs
  - mesure de l'impulsion si champ magnétique

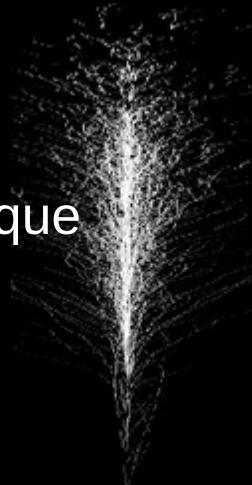
## Remarque:

- énergie manquante  $\rightarrow \nu$
- estimation de l'herméticité



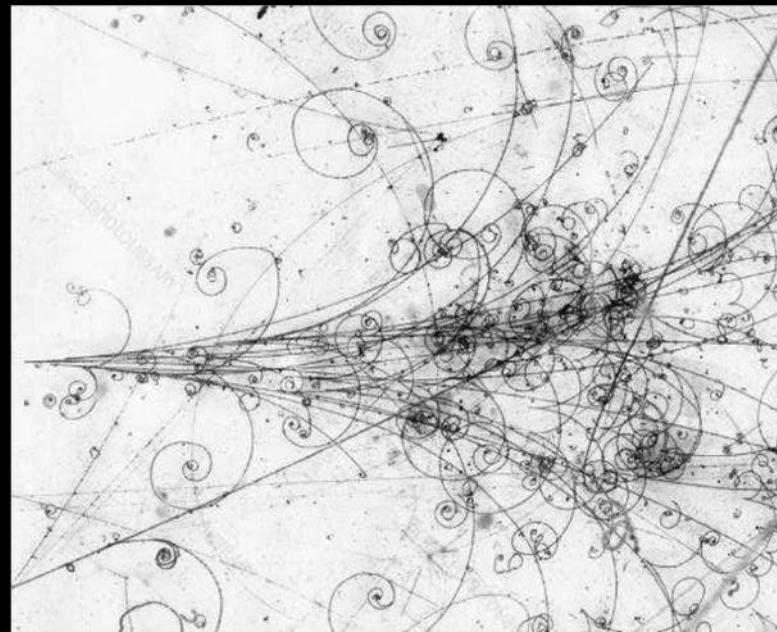
# 4/ Généralités sur les détecteurs

Réponse schématique



Gerbe :  
électromagnétique  
hadronique

Trace observée



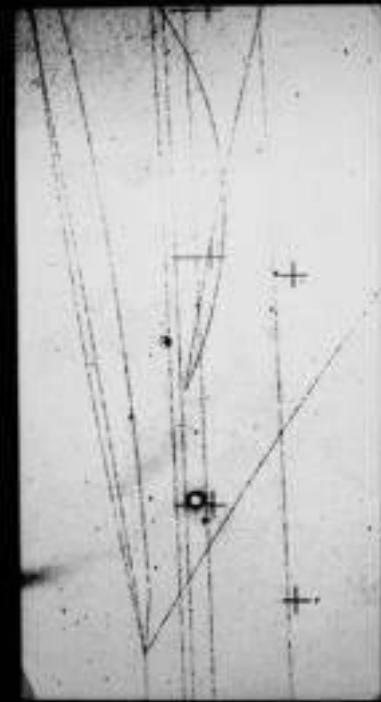
# 4/ Généralités sur les détecteurs

Réponse schématique

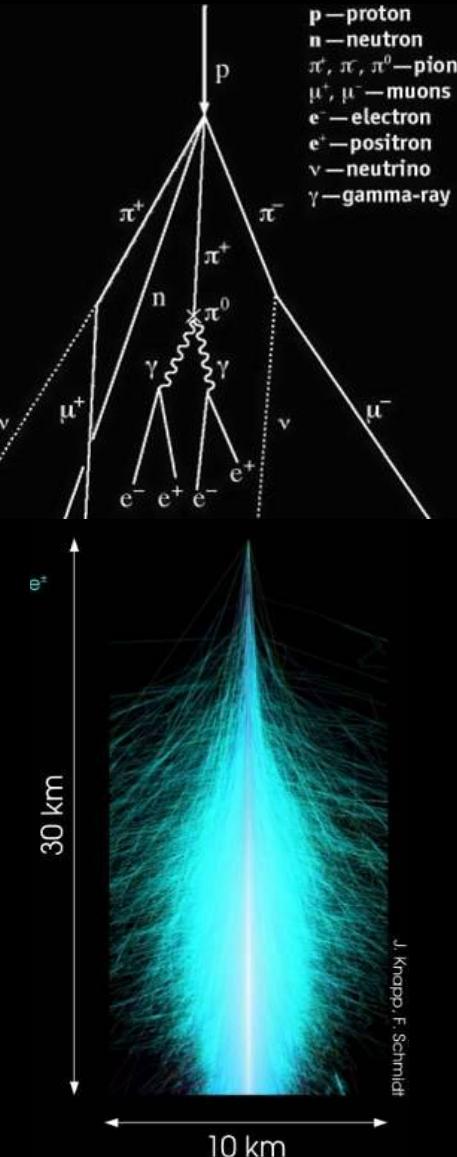
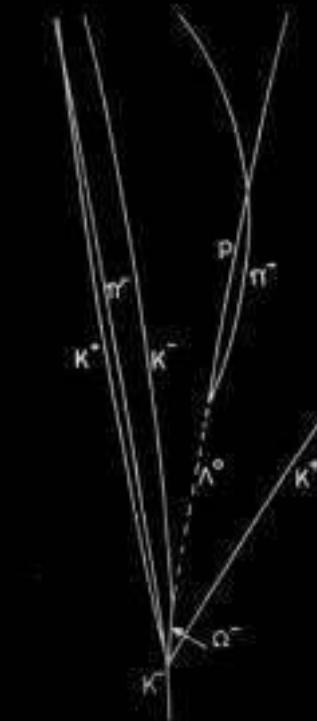
Gerbe :  
électromagnétique  
hadronique



Trace observée



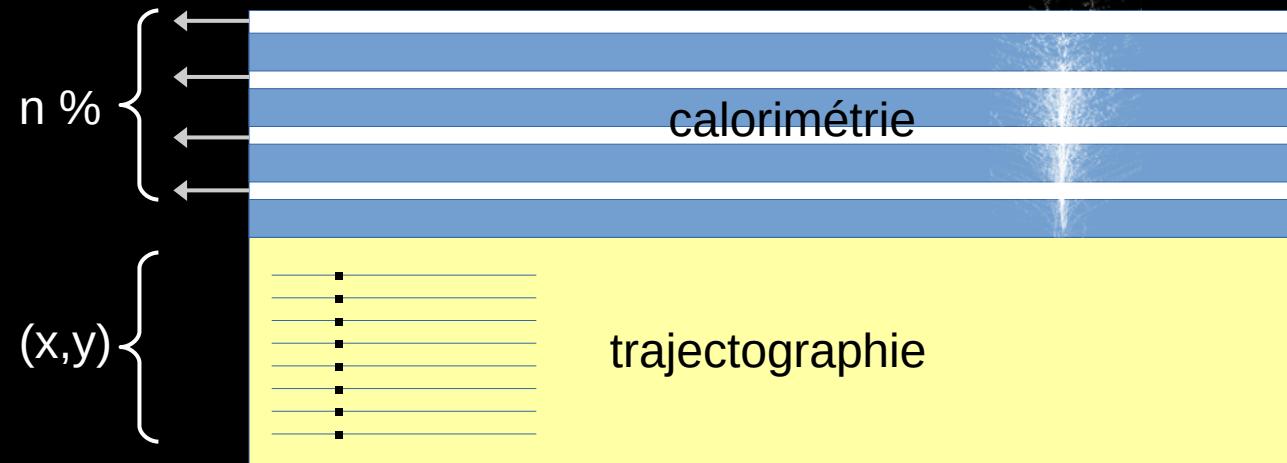
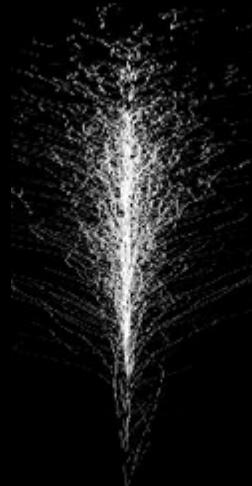
$K^- p \rightarrow \Omega^- K^+ K^+ \pi^-$   
 $\Omega^- \rightarrow \Lambda^0 K^-$   
 $\Lambda^0 \rightarrow p \pi^-$   
AT 10 GeV/c



# 4/ Généralités sur les détecteurs

## Réponse schématique

Gerbe :



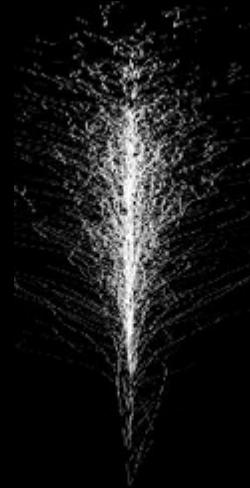
Trace observée:



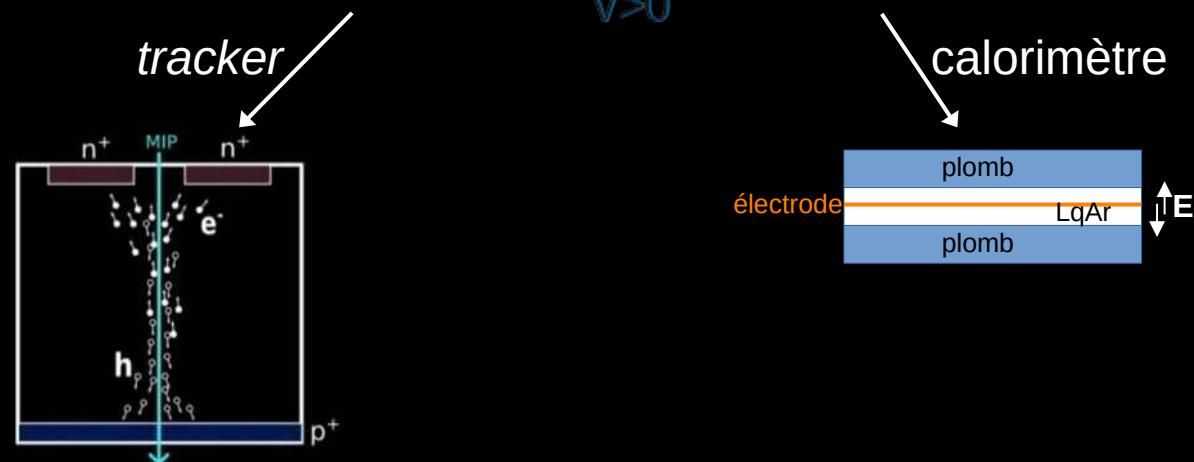
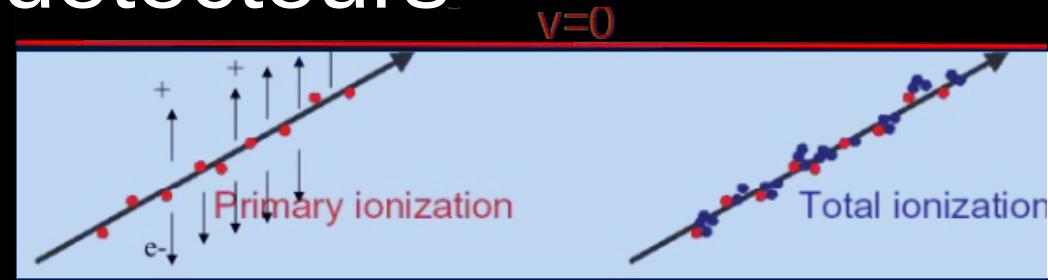
# 4/ Généralités sur les détecteurs

Réponse schématique

Gerbe :



Trace observée:

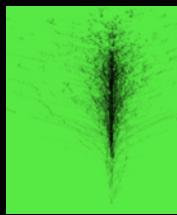


Particule interagie avec la matière du détecteur et produit quelques électrons qui seront multipliés

# 4/ Généralités sur les détecteurs

détecteur

Réponse schématique d'un détecteur  
mesures partielles & destructives



Gerbe :  
électromagnétique ou hadronique

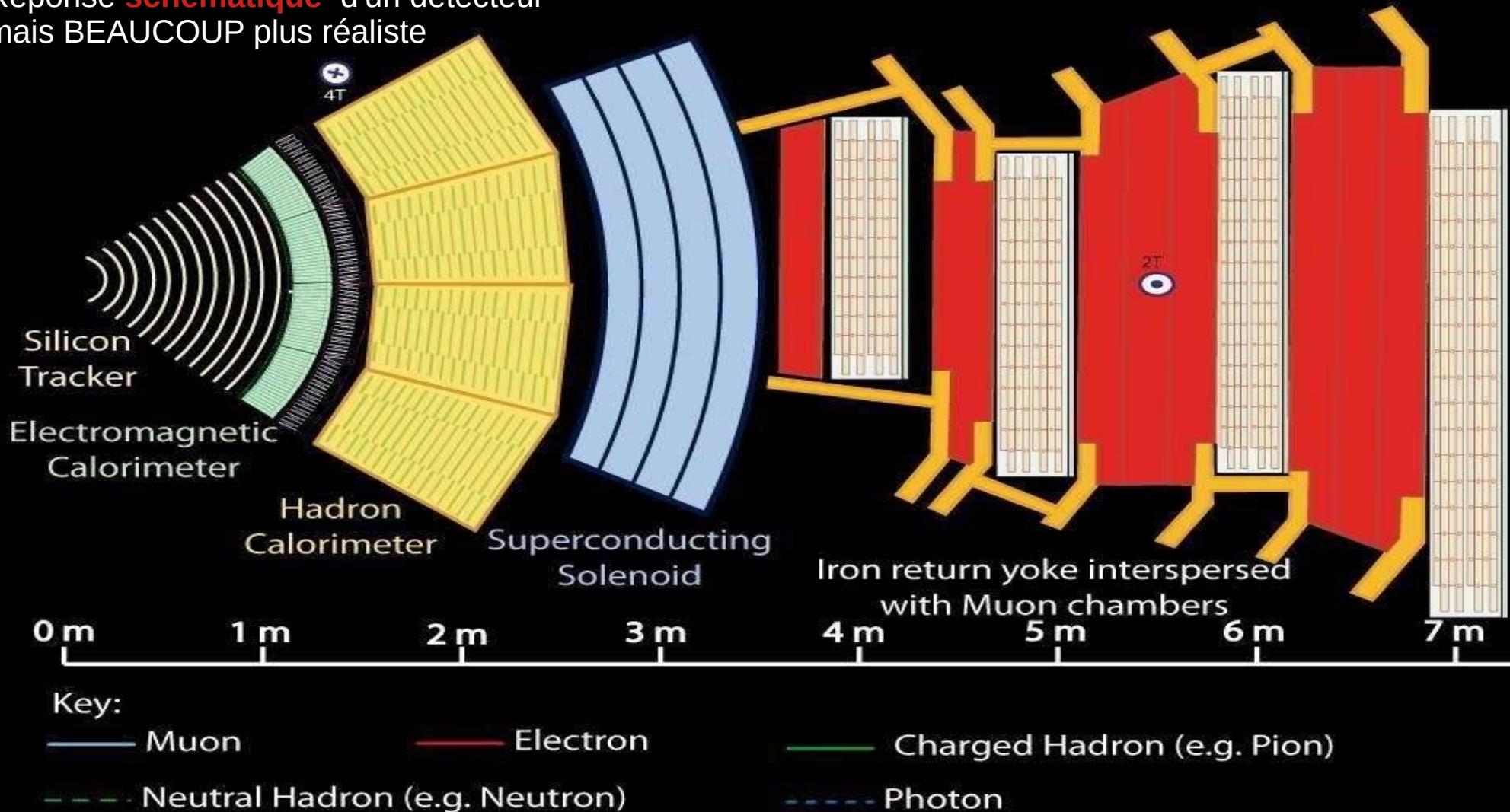


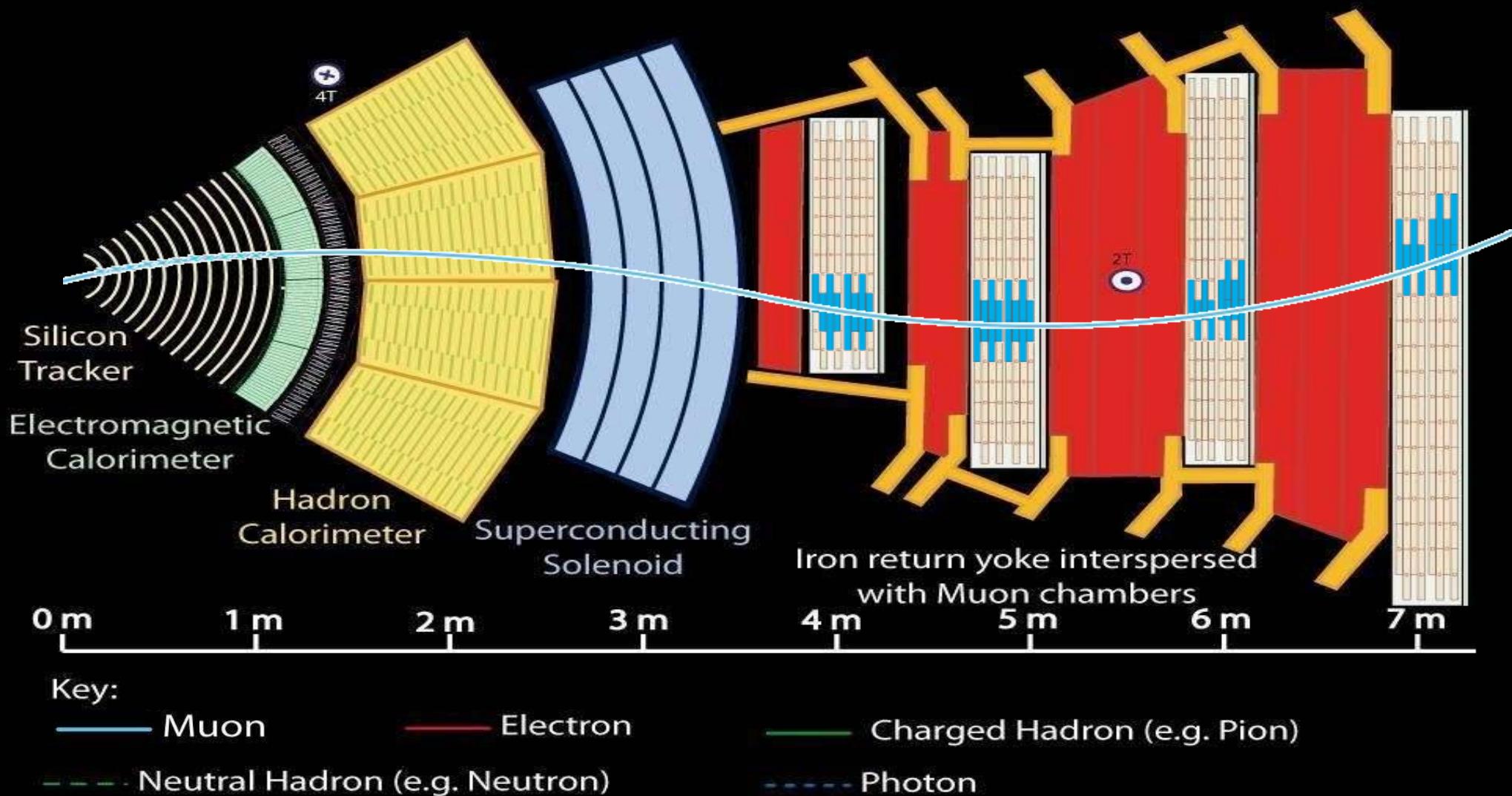
Trace chargée :  
mesurée par le détecteur

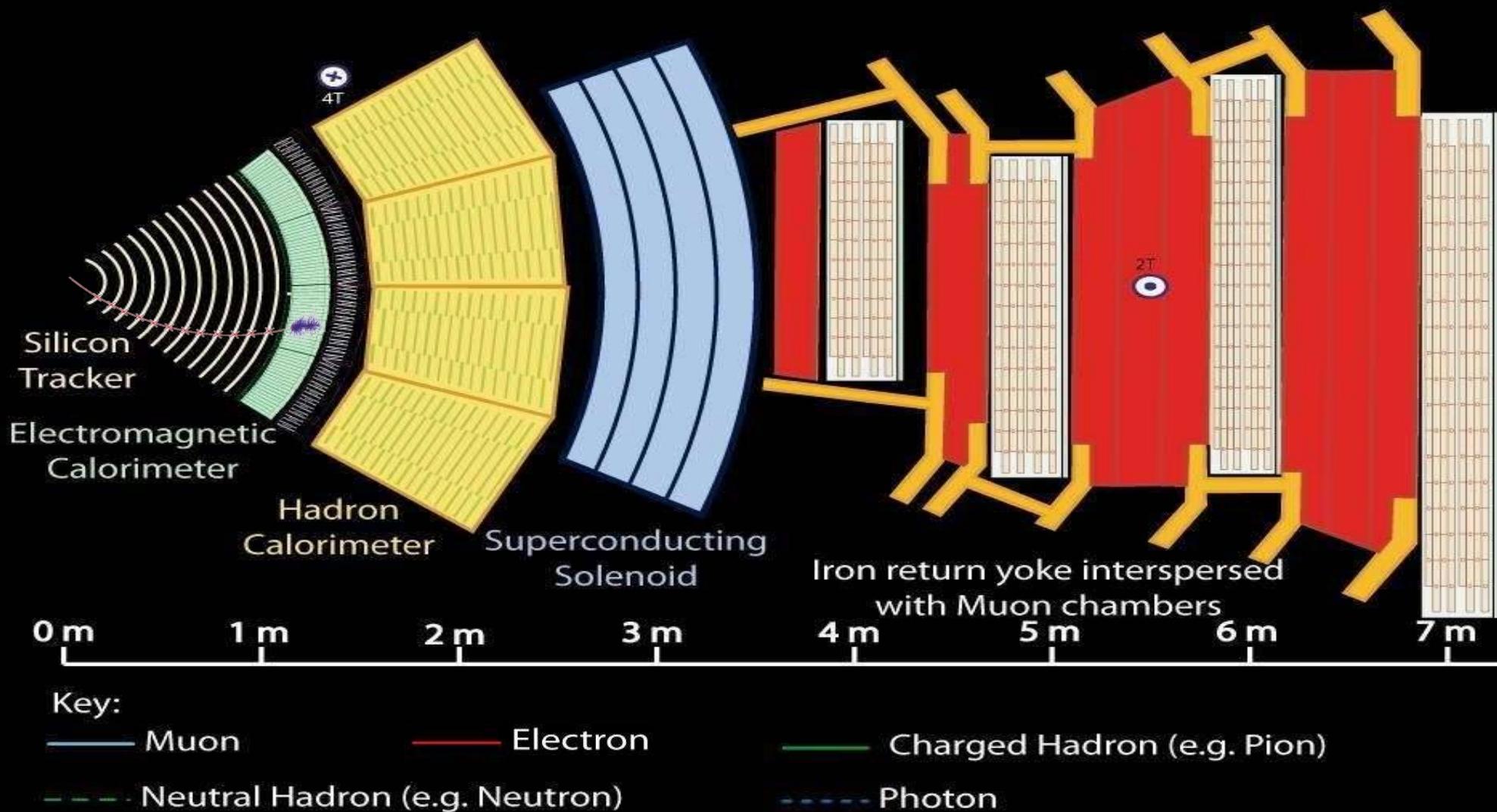
Point d'interaction

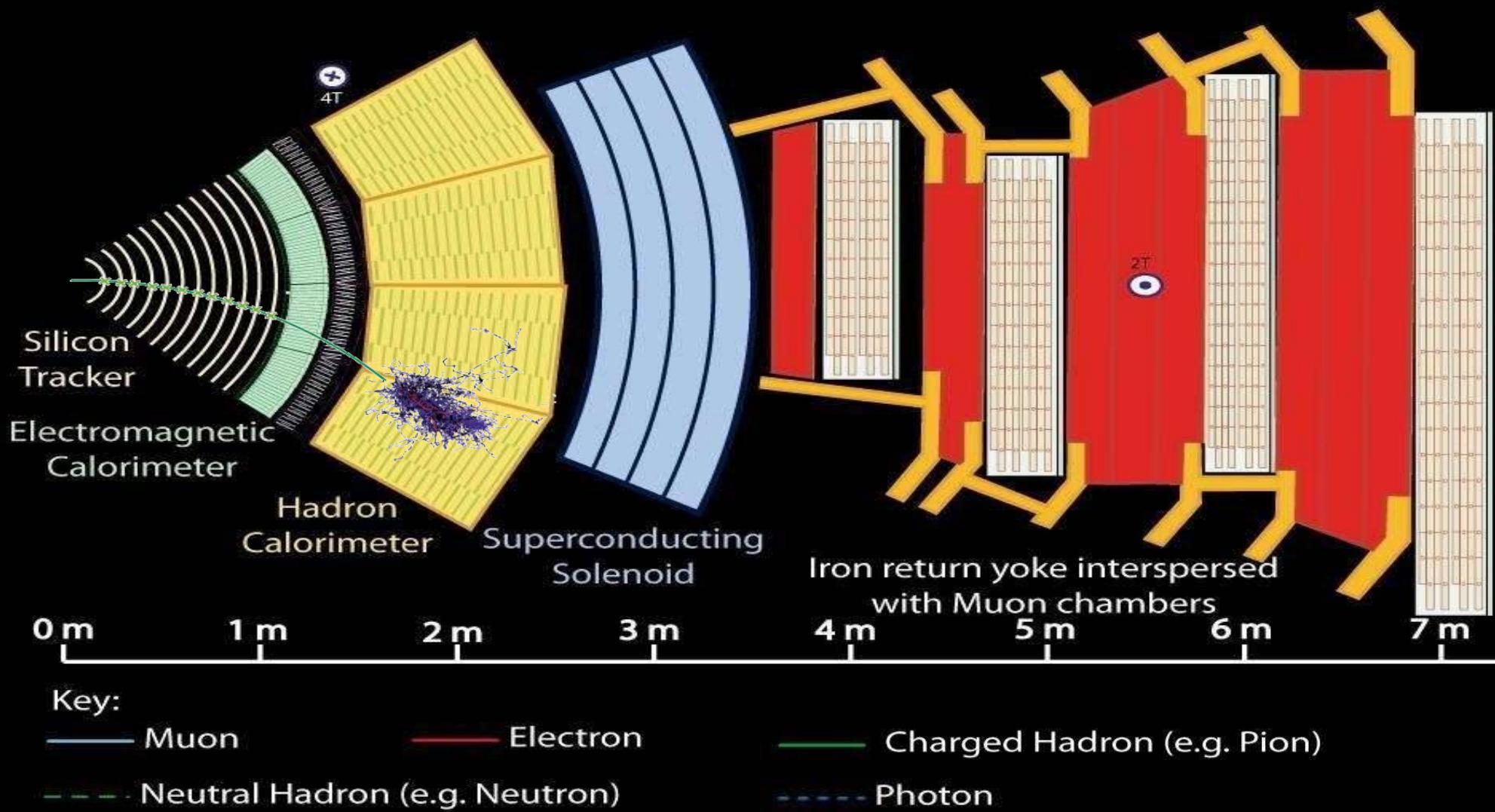


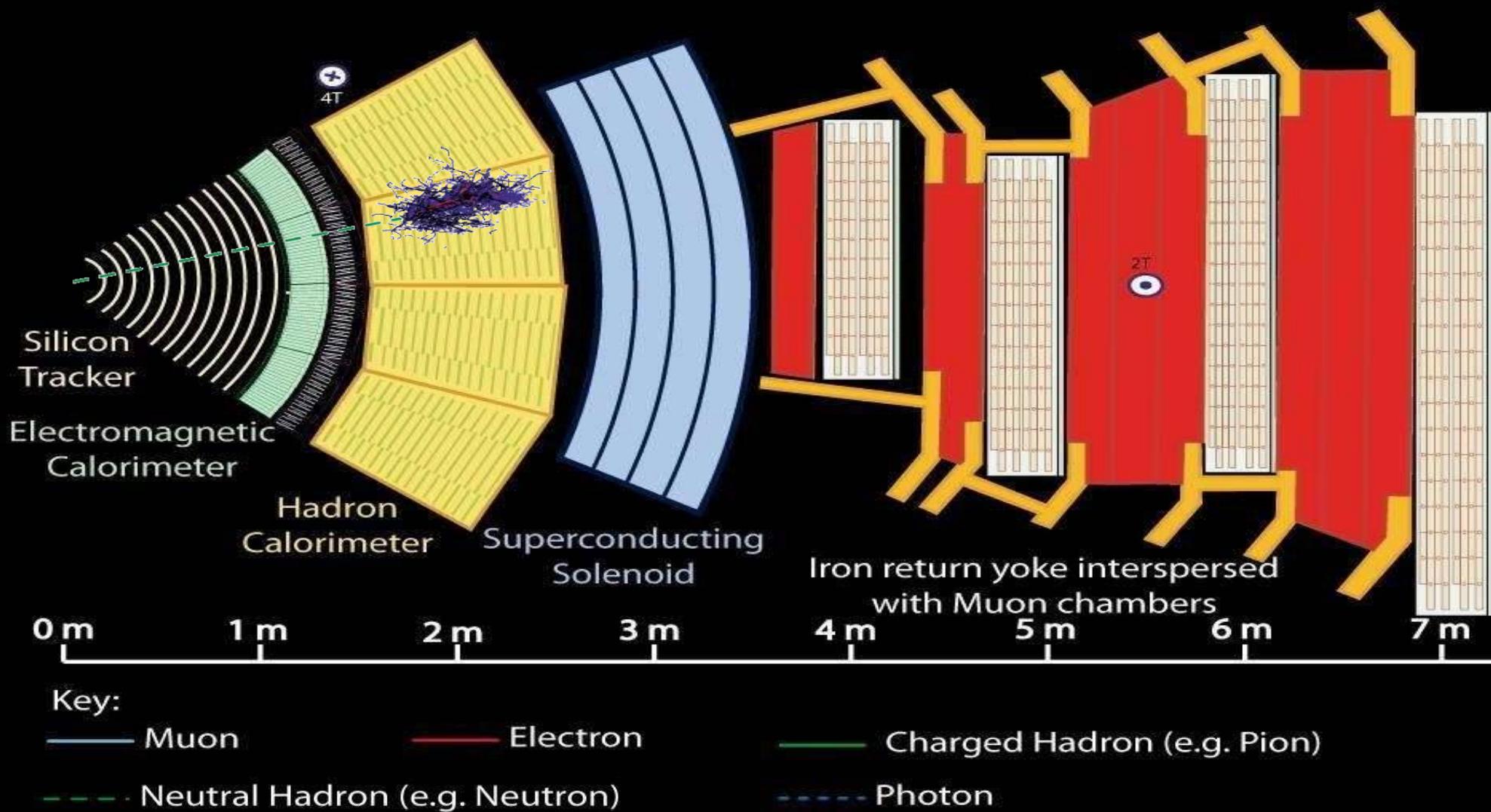
Réponse **schématique** d'un détecteur  
mais BEAUCOUP plus réaliste

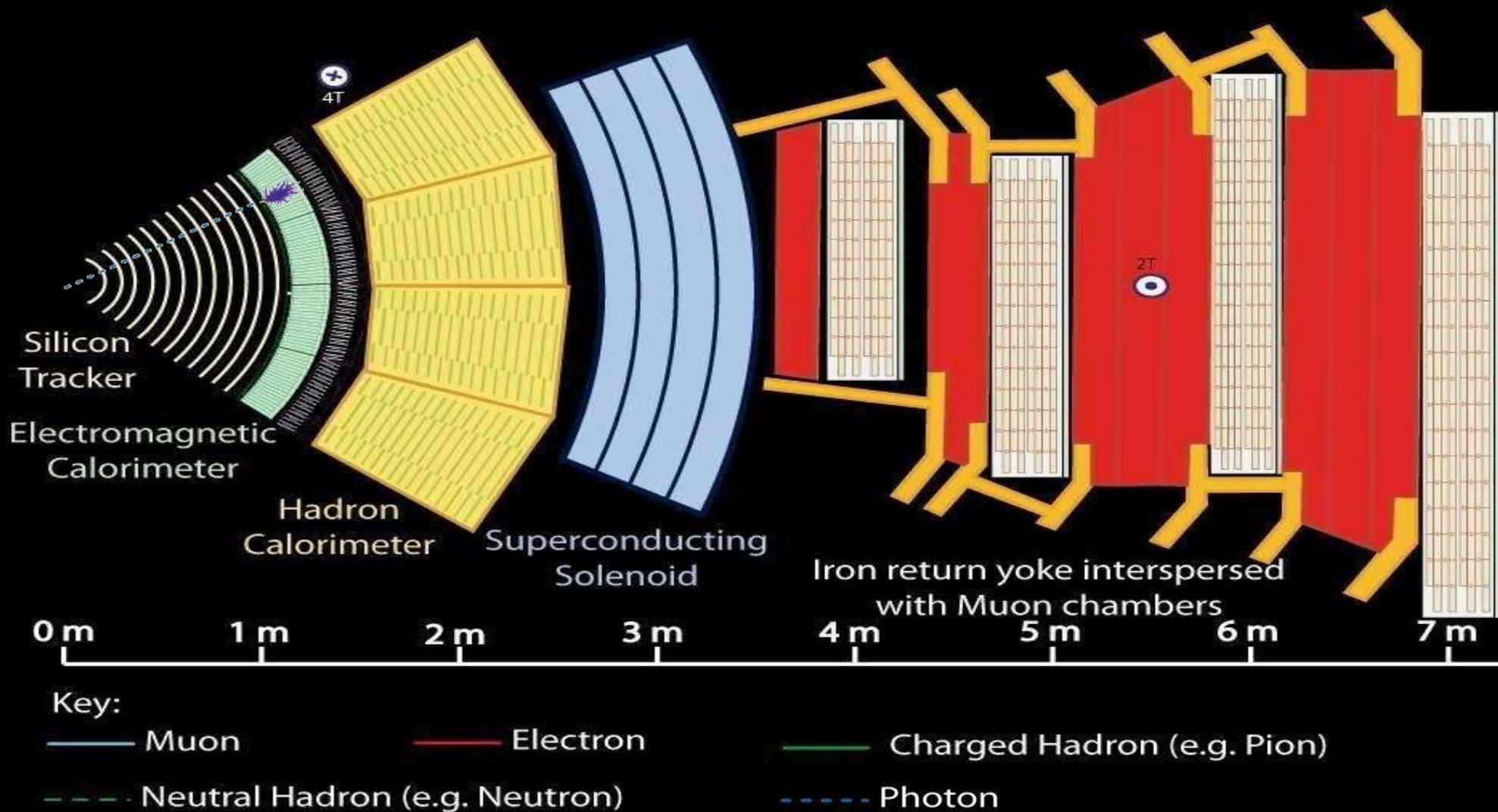












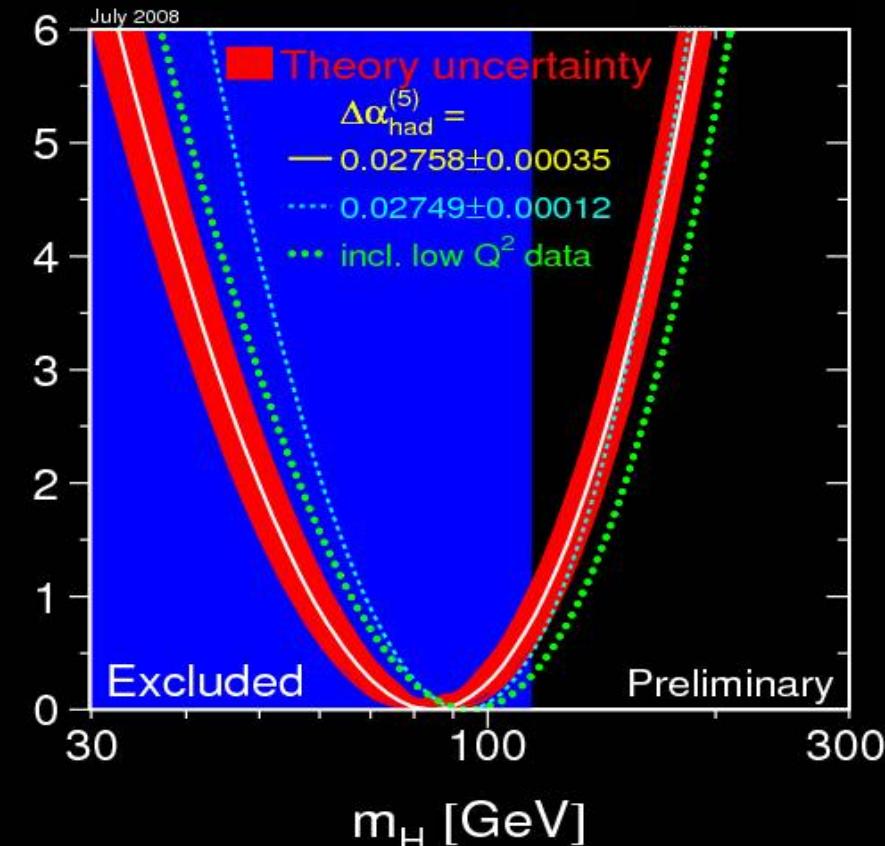
# 4/ Généralités sur les détecteurs

## Physique

- théorie (MS) → simulations
  - permet de concevoir le détecteur
  - contraintes précédentes

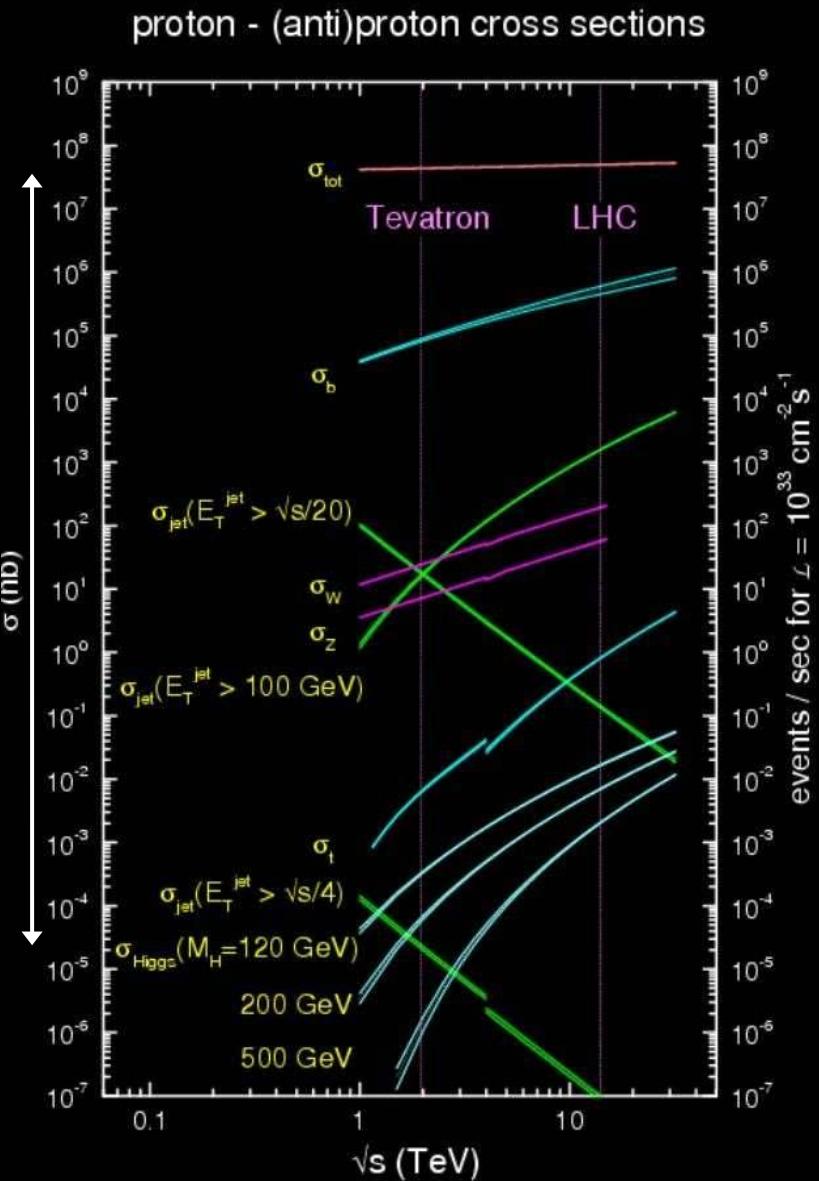
## Physique

- théorie (Maxwell) → simulations
  - détecteur ← GEANT4

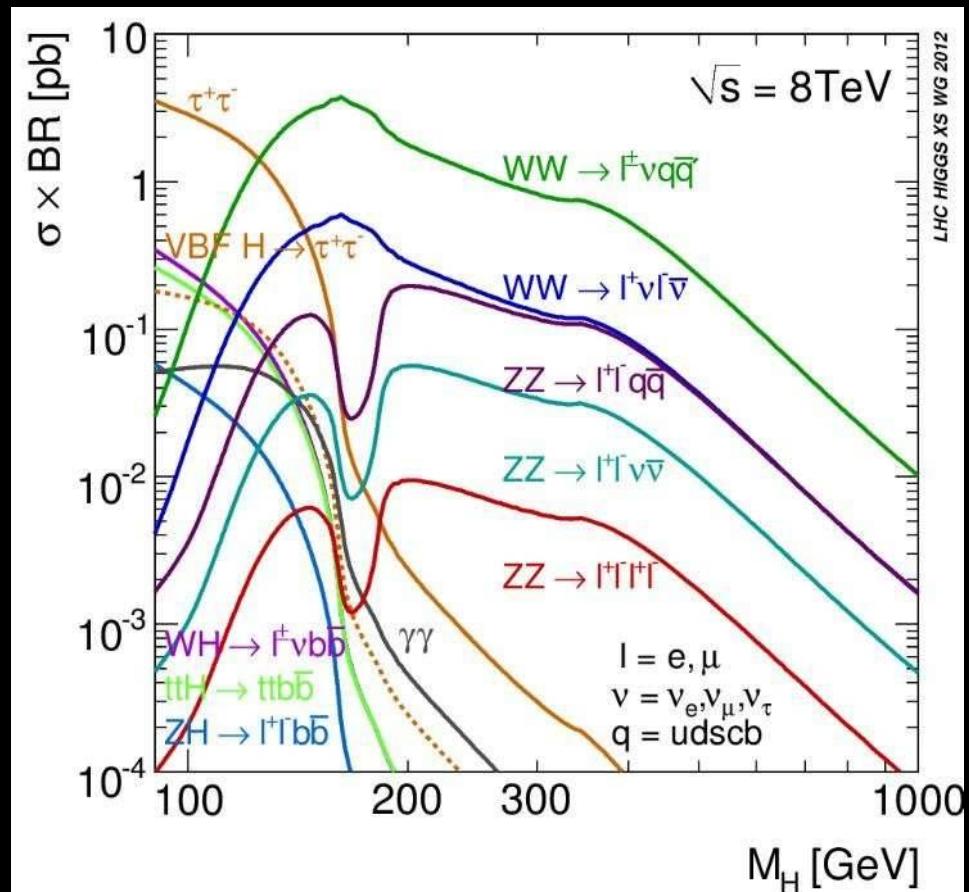
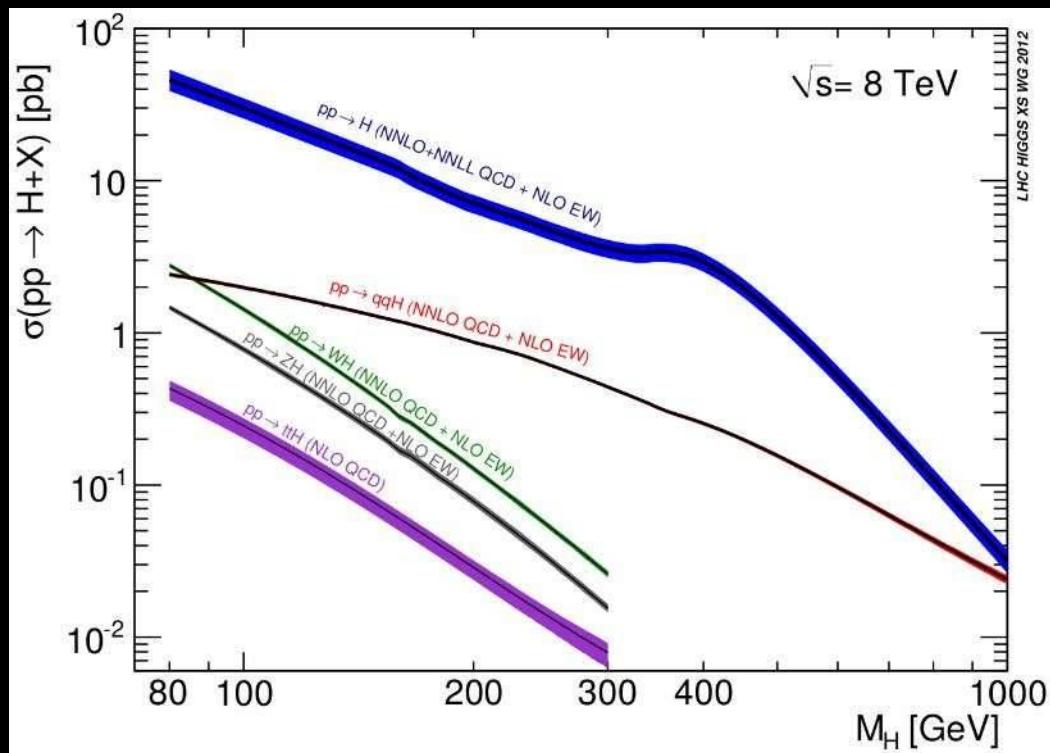


# Physique → théorie → simulations

ordre de grandeur  $\sim 10^{12}$   
de ce qu'on cherche



# Physique → théorie → simulations



# Physique → théorie → simulations



générateur

hard process

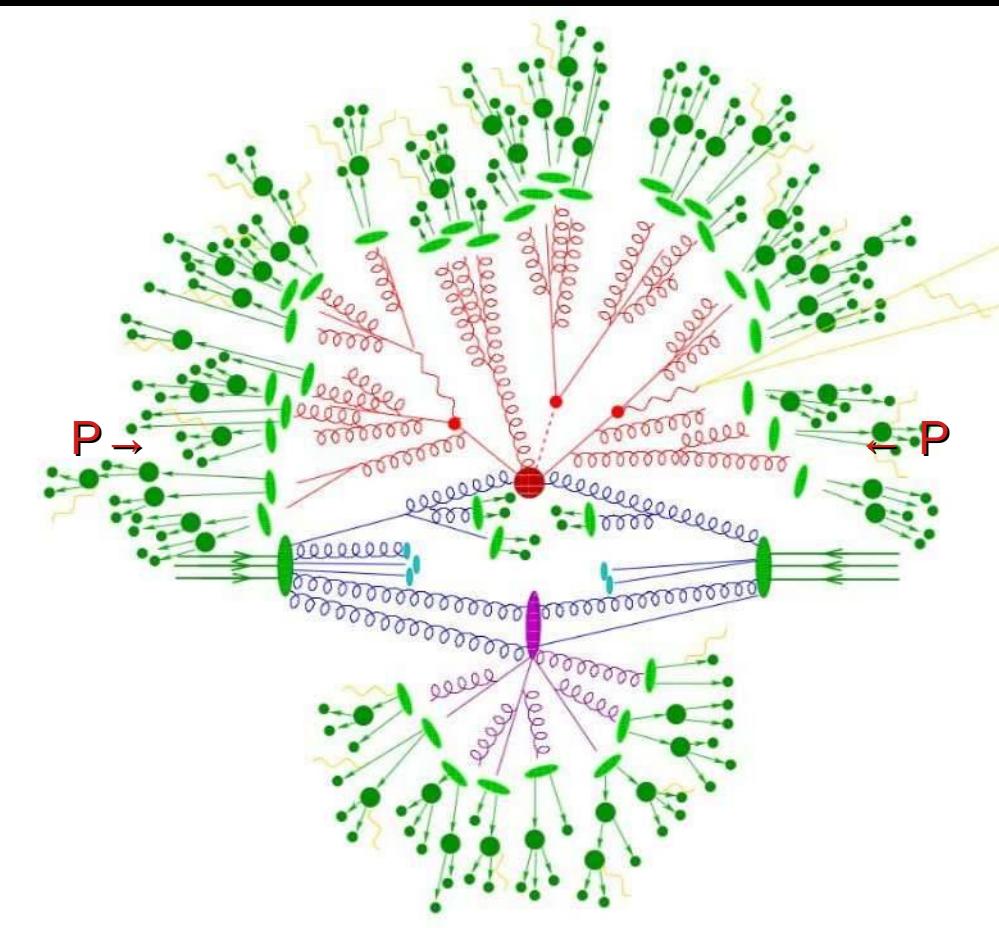
parton distribution function

underlying event

parton shower

hadronisation

pile-up



## Estimation du flux de données

25ns  $\rightarrow$  40 MHz  $\rightarrow$  100Hz  $\rightarrow$  400 Hz

1 Mbytes (10<sup>6</sup> octets)

1 année  $\rightarrow$  10<sup>7</sup>s

Par expérience LHC

$$\rightarrow 10^2 \times 10^6 \times 10^7 = 10^{15} \text{ octets} = 1 \text{ PBytes/an}$$

lexique usuel  $\sim$ 60000 mots  $\sim$ 10<sup>5</sup> octets

$\rightarrow$  1 PB  $\sim$ 1 milliards de lexiques/an

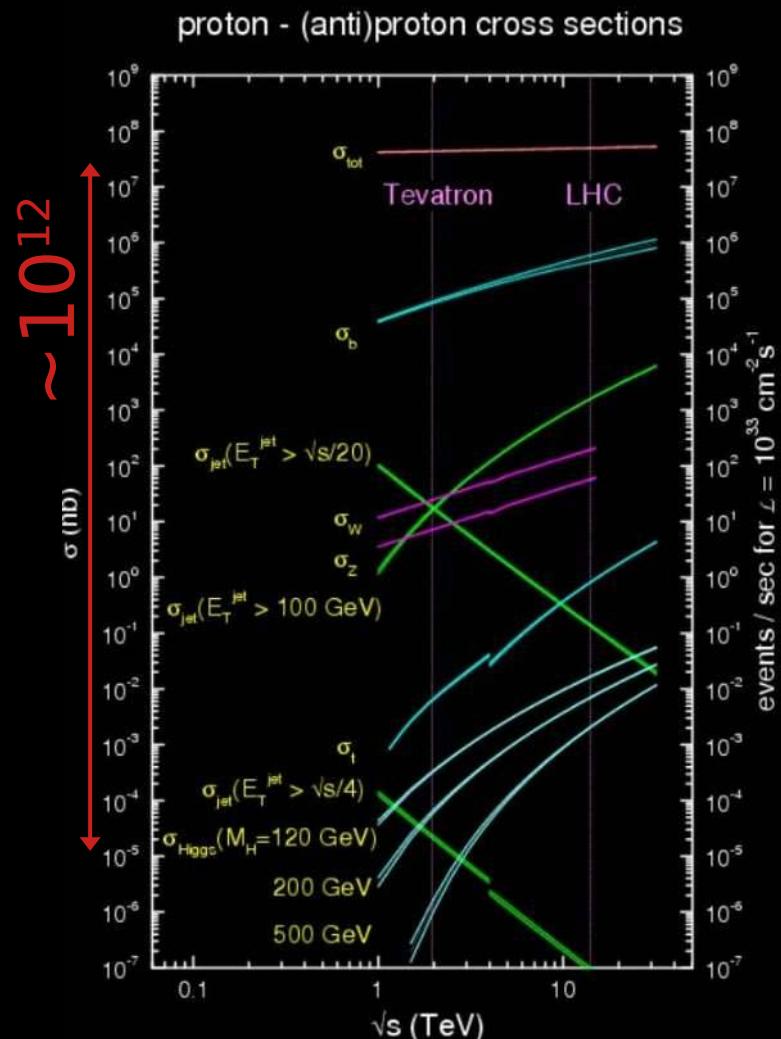
$\rightarrow$  1 million de DVD par an (pour un boomer)

Solution

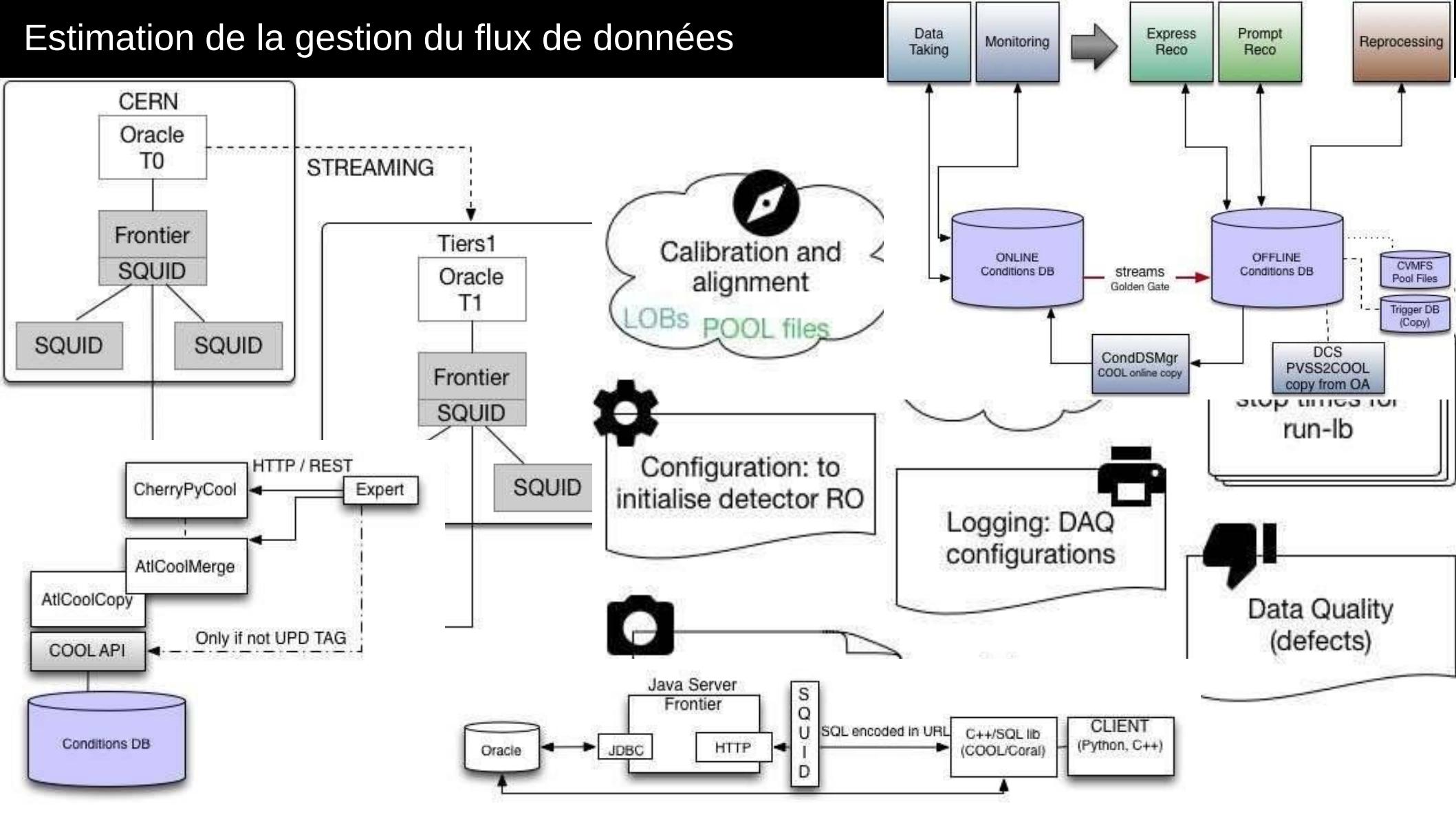
$\rightarrow$  calculs délocalisés

$\rightarrow$  Tier 0,1,2

$\rightarrow$  simulation...  $\rightarrow$   $\sim$ 10<sup>16</sup>B/an



# Estimation de la gestion du flux de données



# 4/ Généralités sur les détecteurs

## Physique

→ théorie (MS) → simulations

- permet de concevoir le détecteur

- contraintes précédentes

## Physique

→ théorie (Maxwell) → simulations

- détecteur ← GEANT4

# Physique → théorie → simulations

Pas de mesures raisonnables sans

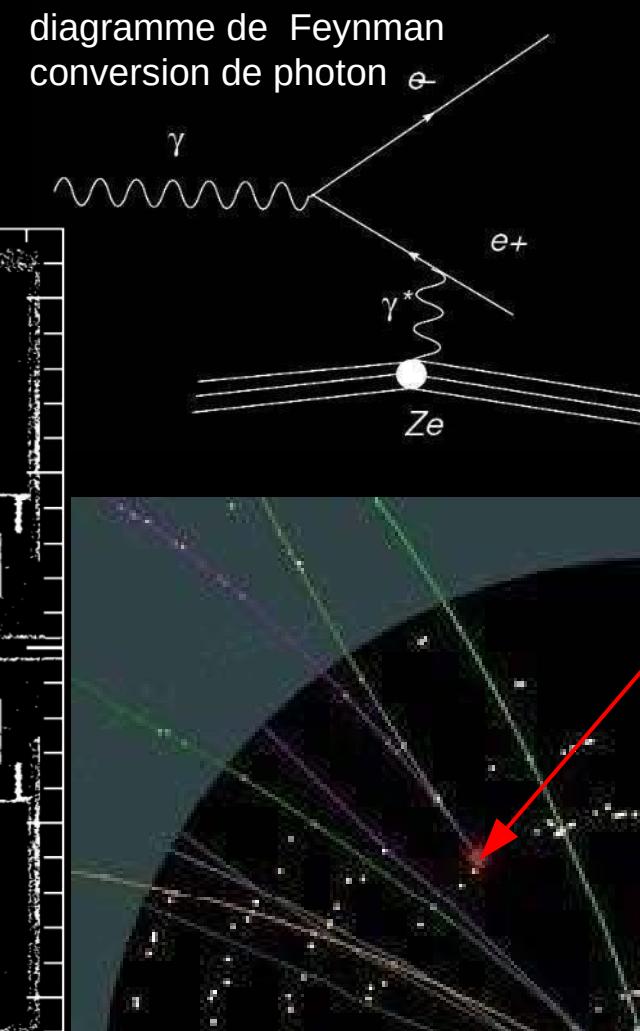
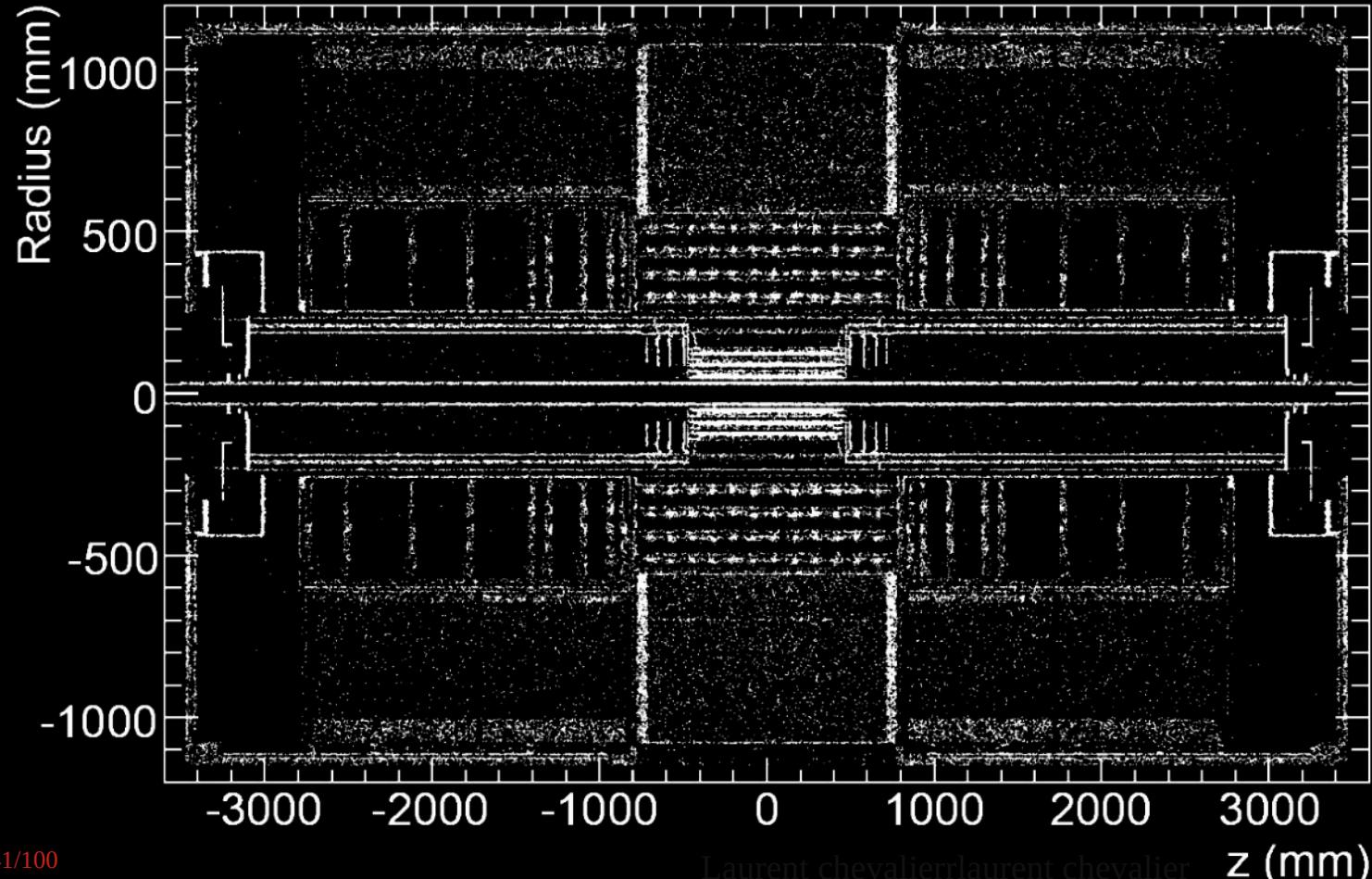
- détermination des erreurs de mesures
- comparaison data/simulation (Monte-Carlo)

La plupart des phénomènes mesurés peuvent provenir

- phénomènes physiques
  - Cherchés → ex : higgs
  - Autres → ex : pile-up
- de la mauvaise connaissance de l'appareil
- de problèmes électroniques
- du programme de reconstruction imparfait

# Interaction particules / matière

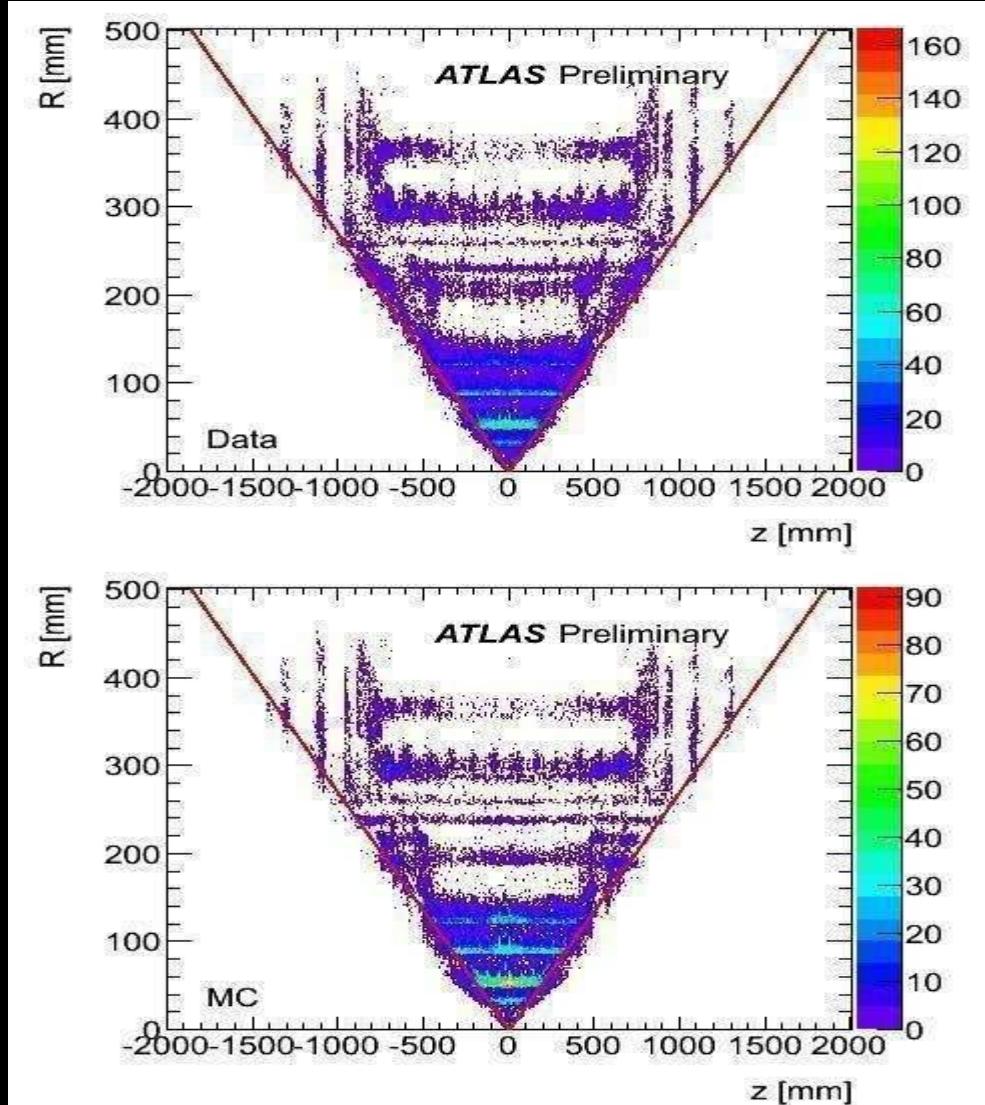
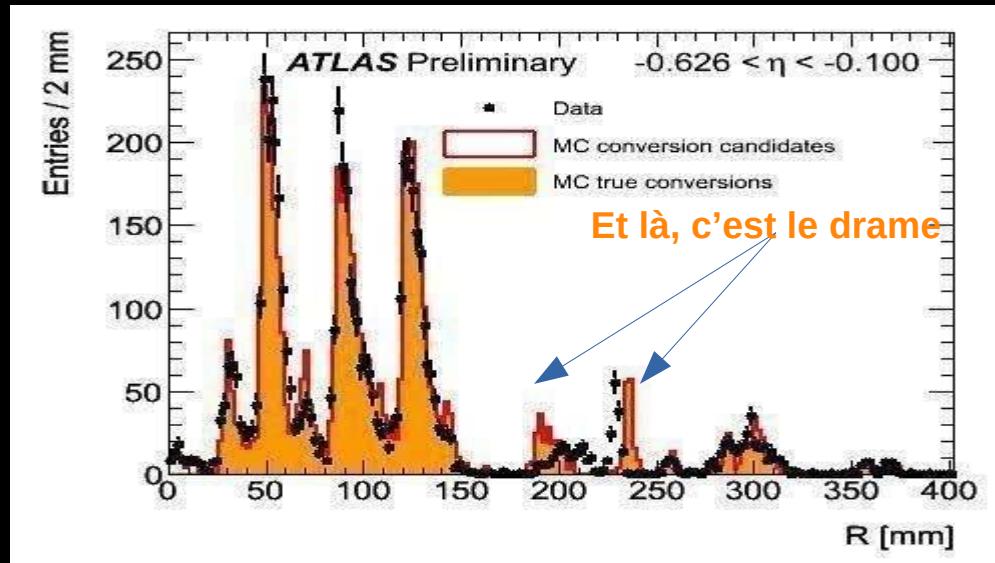
## Création de paires



# Simulation

## Data/MC

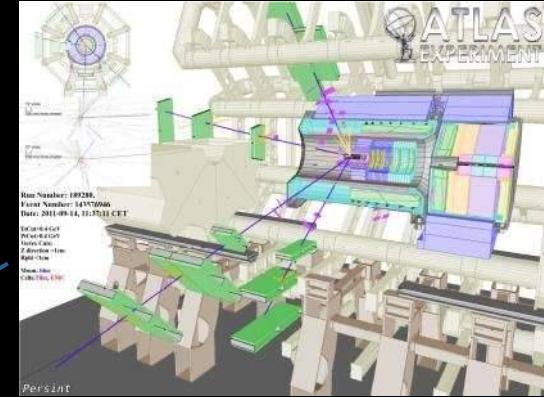
- Atlas : Pixels & SCT



# simulation



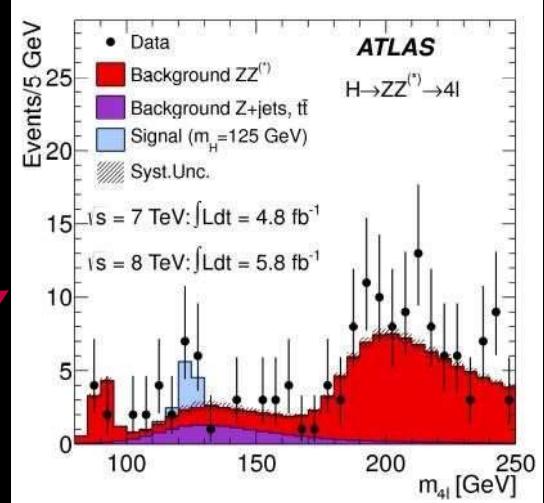
# données



## reconstruction



## analyses mesures



# Conception d'un détecteur

23-25 Novembre 2025, Roscoff

## 1/ Introduction

- références, vocabulaire, unités

## 2/ Déetecter quoi ↔ pourquoi

- remarques liminaires
- modélisation
- détecteur : ckoï ?

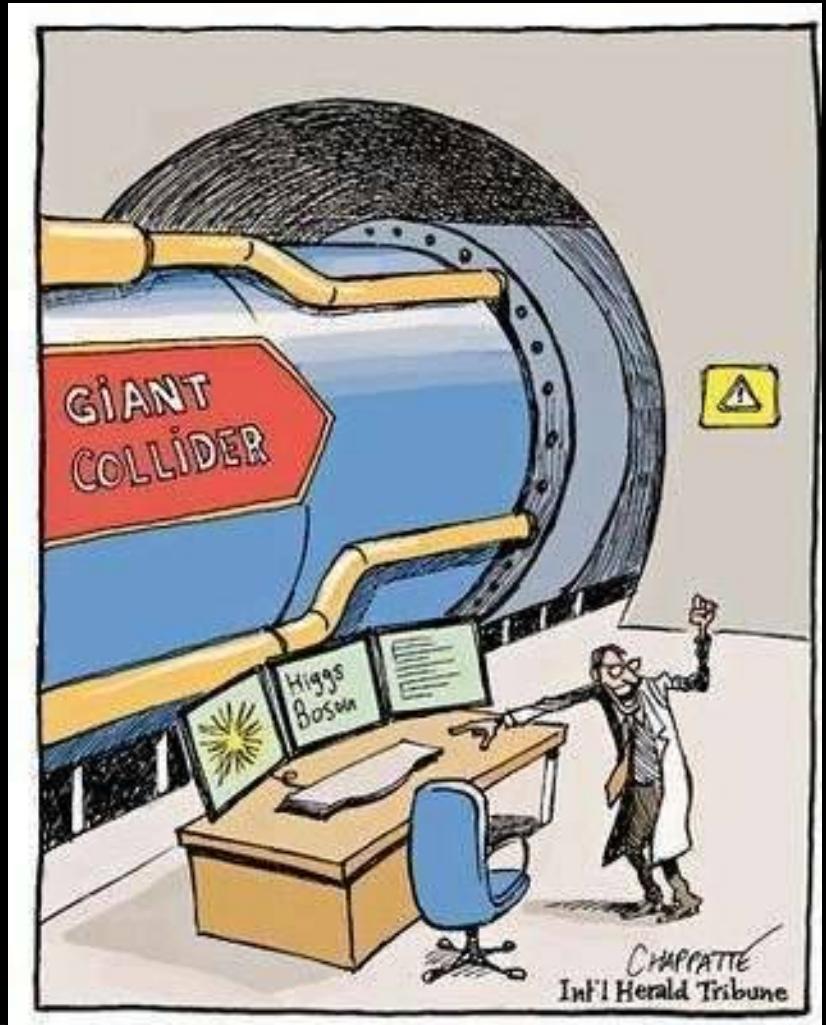
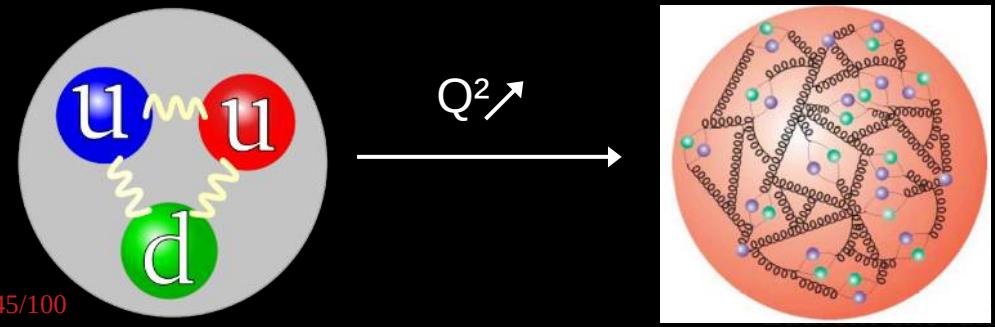
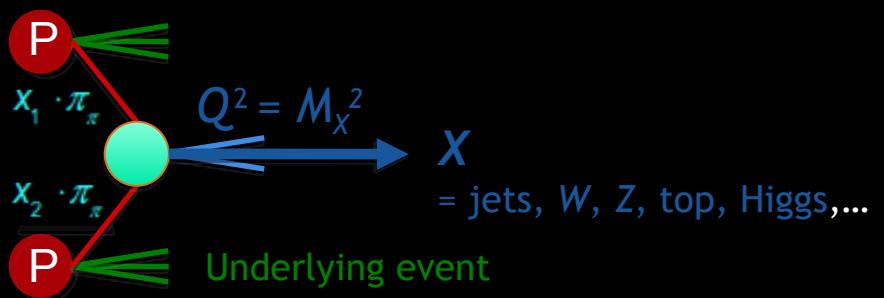
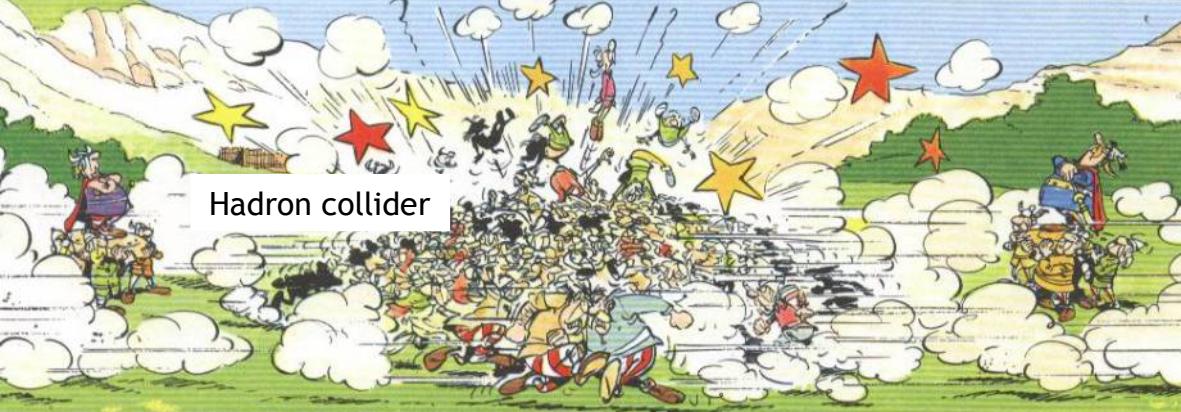
## 3/ Interaction particules matière

- rapide aperçu

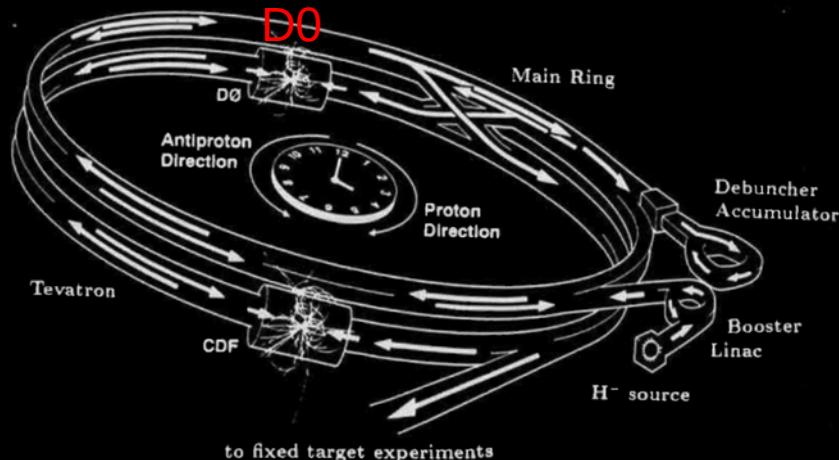
## 4/ Généralités sur les détecteurs

## 5/ Exemples

- D0 (Fermilab)
- ATLAS (CERN)



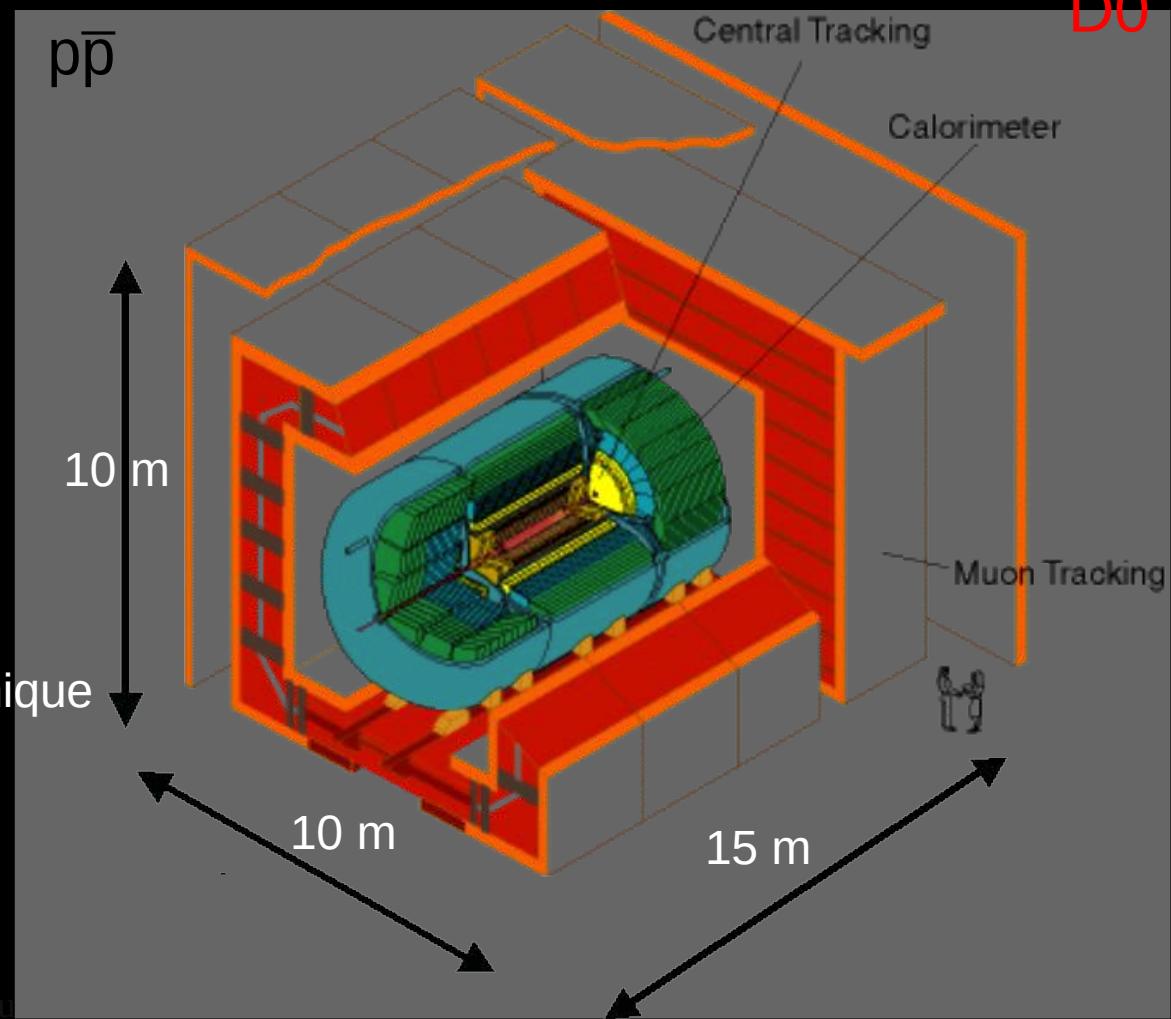
# Collisionneurs TeVatron



D0

- Trajectographie (détecteur à gaz)
- Détecteur à rayonnement de transition
- Calorimètre électromagnétique et hadronique
- Chambres à muons
- Toroïde à fer  $\sim 1.8$  T
- pas de solénoïde !**

FNAL (USA) Tevatron: 1.8 TeV  
Run I :1992-1995

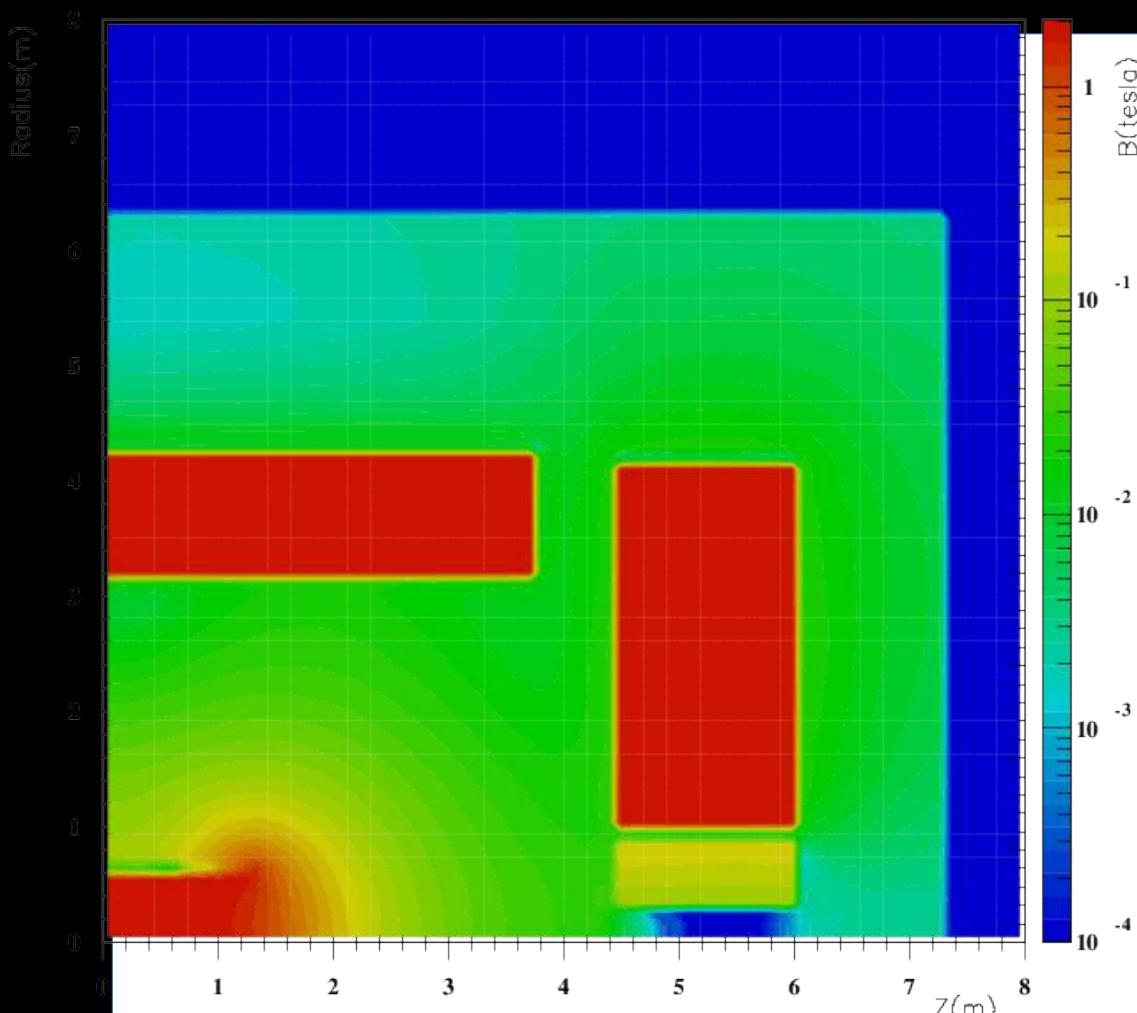


D0

# Champ magnétique

Run II :1998-2004

D0



D0

47/100

# D0

## D0

conception 1983

pas de simulation complète du détecteur avec GEANT

détection muons avec le plus grand angle solide

calorimètre à compensation uranium/argon **très compact**

trajectographie  $R \sim 1\text{m}$

**pas de solénoïde** suffisamment puissant pour la trajectographie

*Run I* 1992

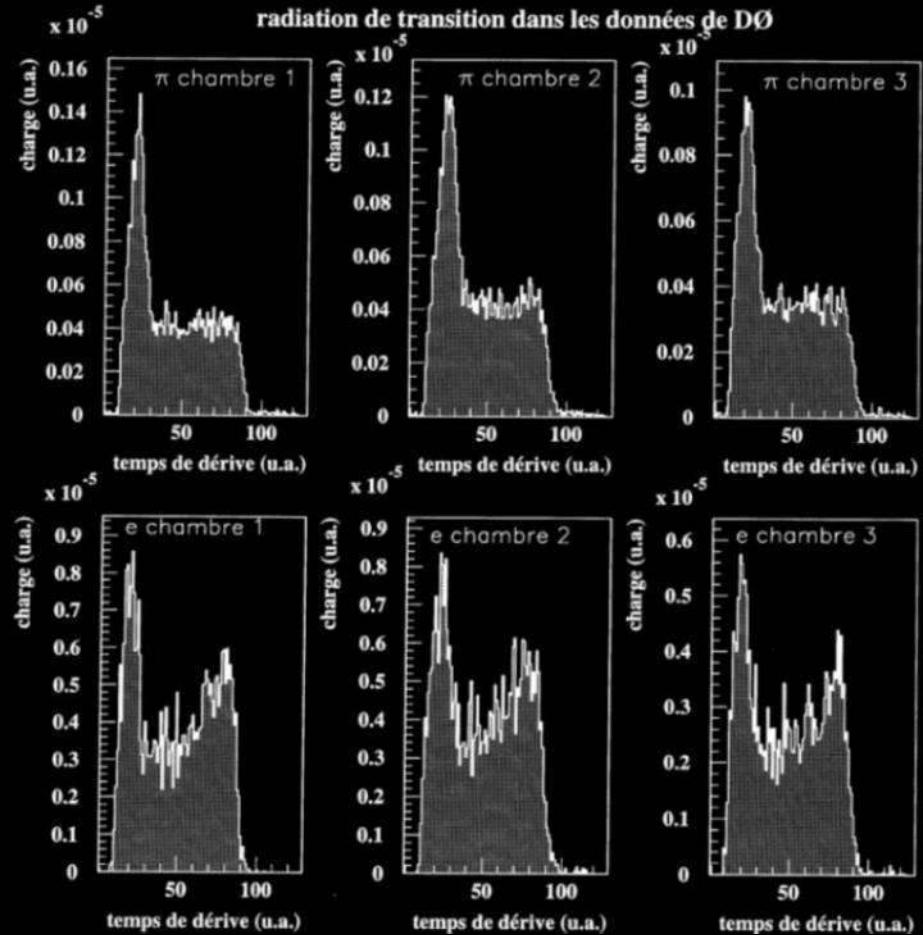
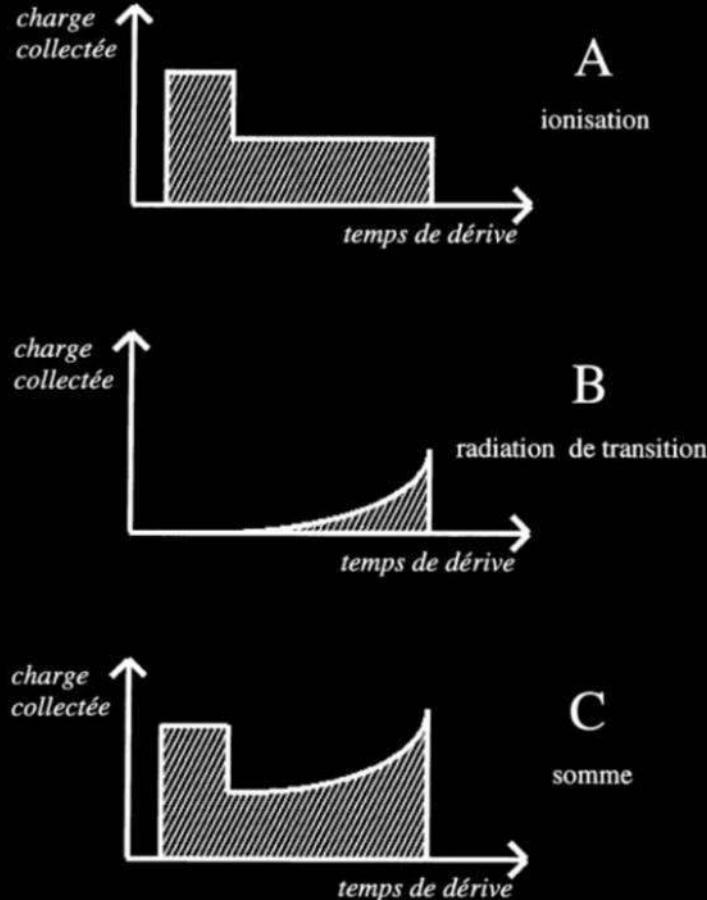
protons du main ring traversaient le détecteur DØ !!!

temps entre collision  $3.5\ \mu\text{s}$

masse du  $Z \rightarrow 60\ \text{GeV}$  ???

environ 500 signataires

# DéTECTEURS D0 → TRD

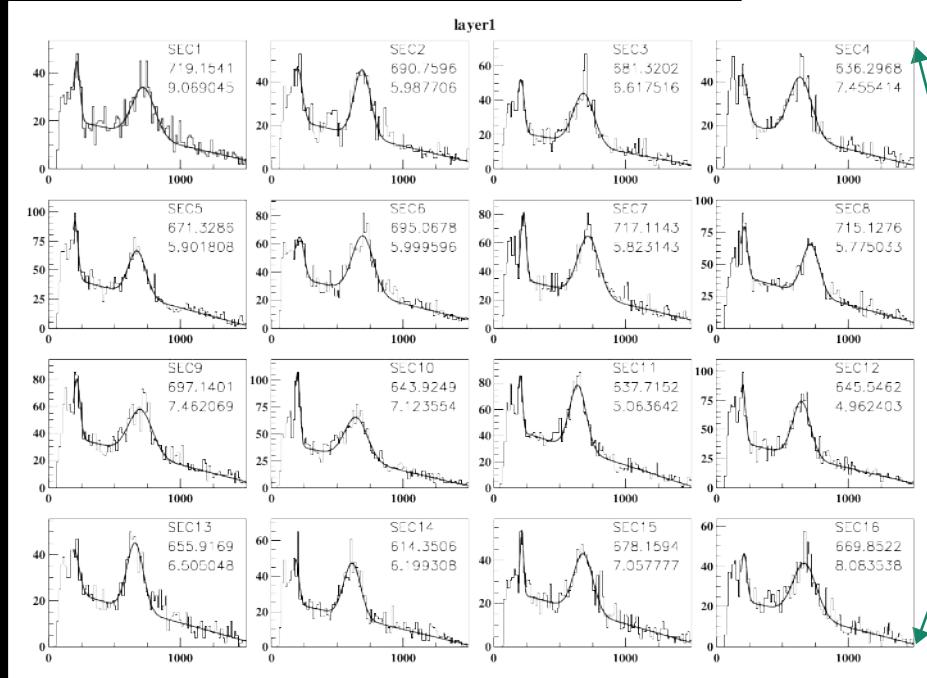
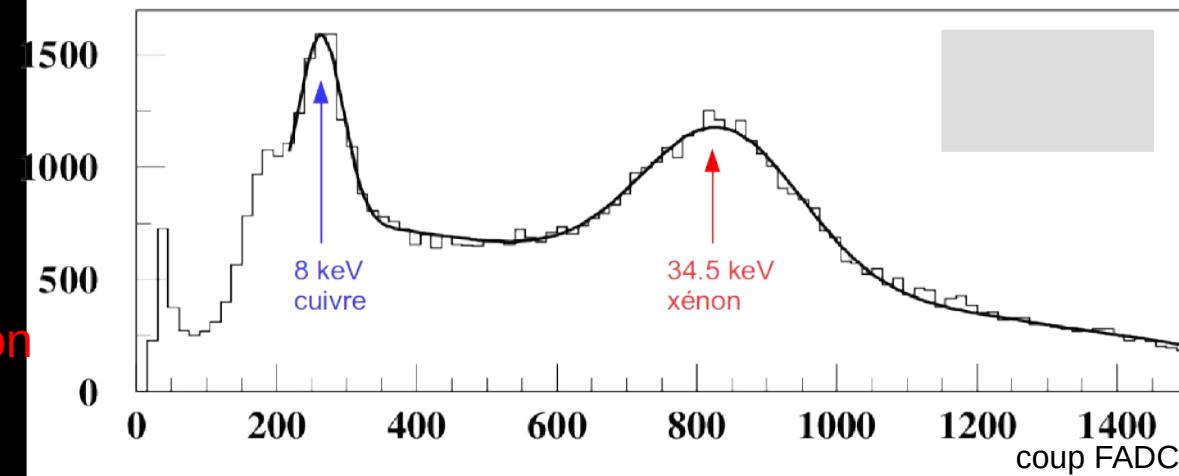


# DéTECTEURS D0

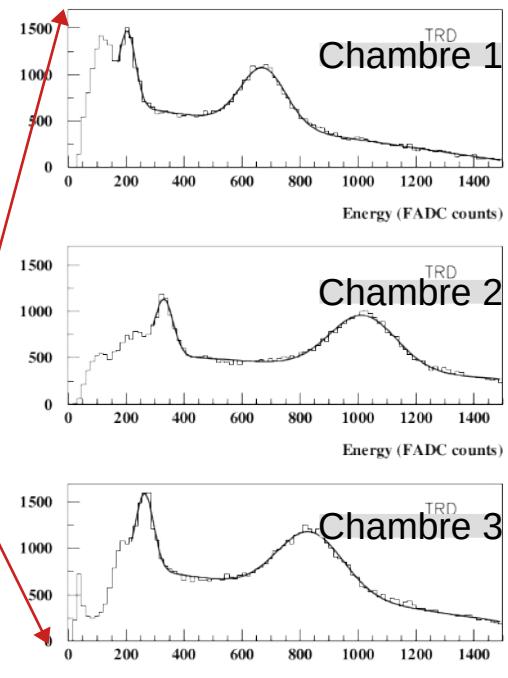
## Étalonnage TRD

Uranium (calorimètre)

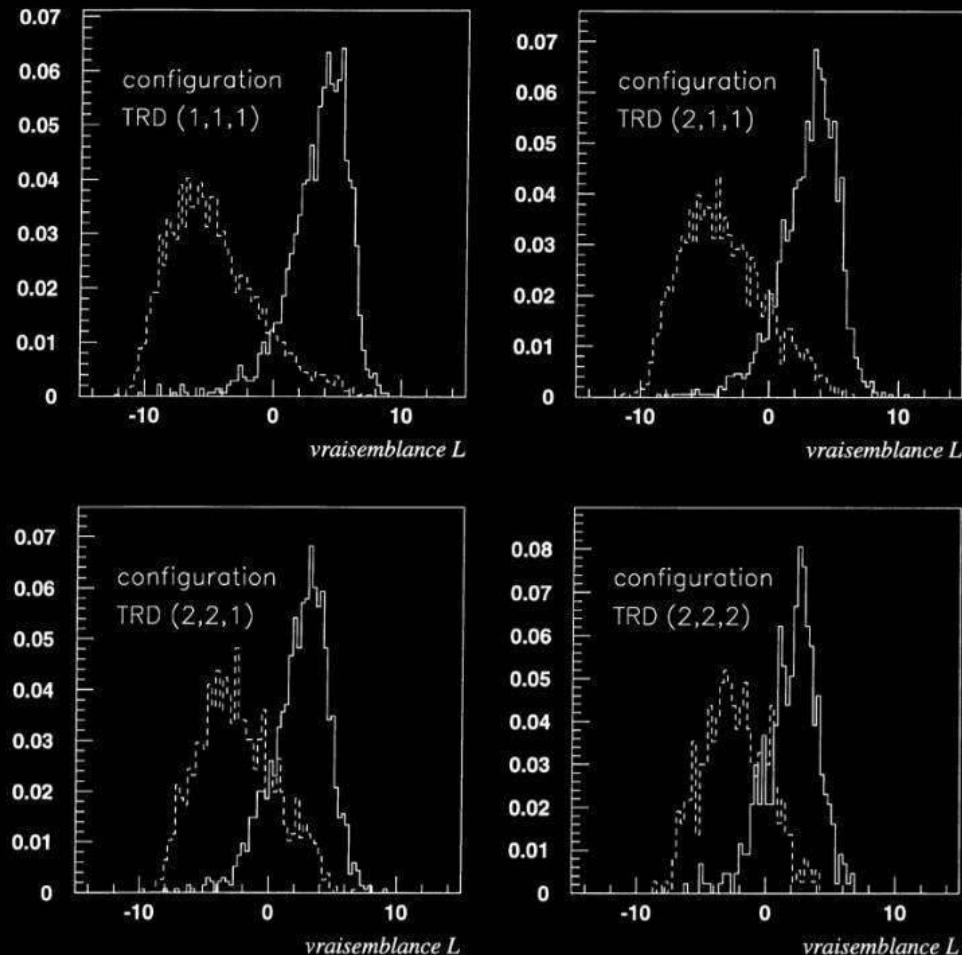
signal → cuivre & xénon



16 secteurs  
3 chambres

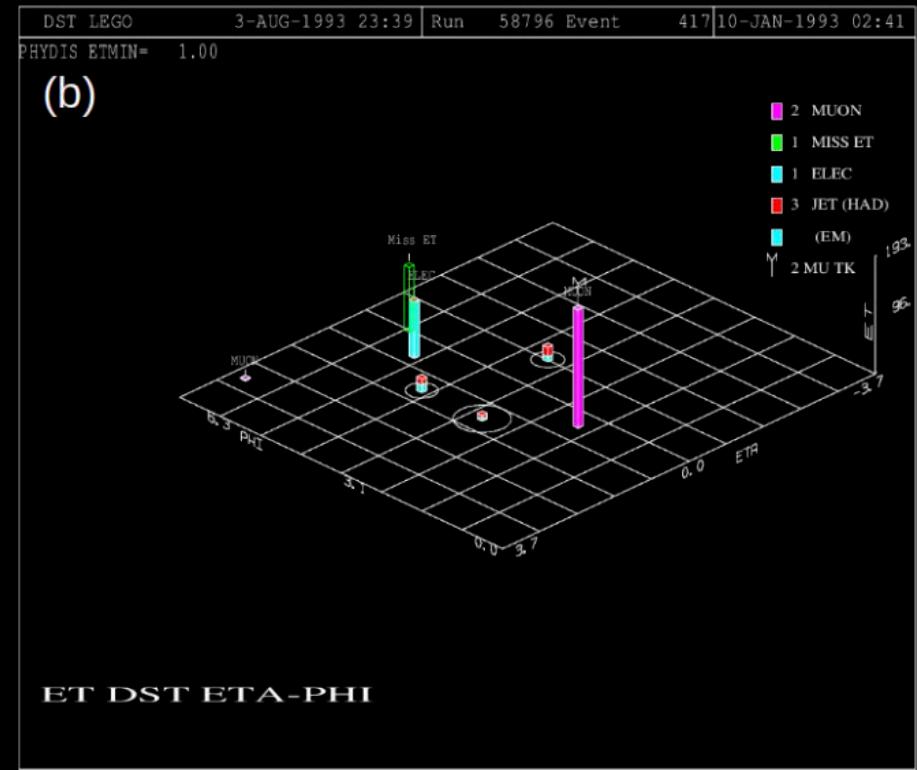
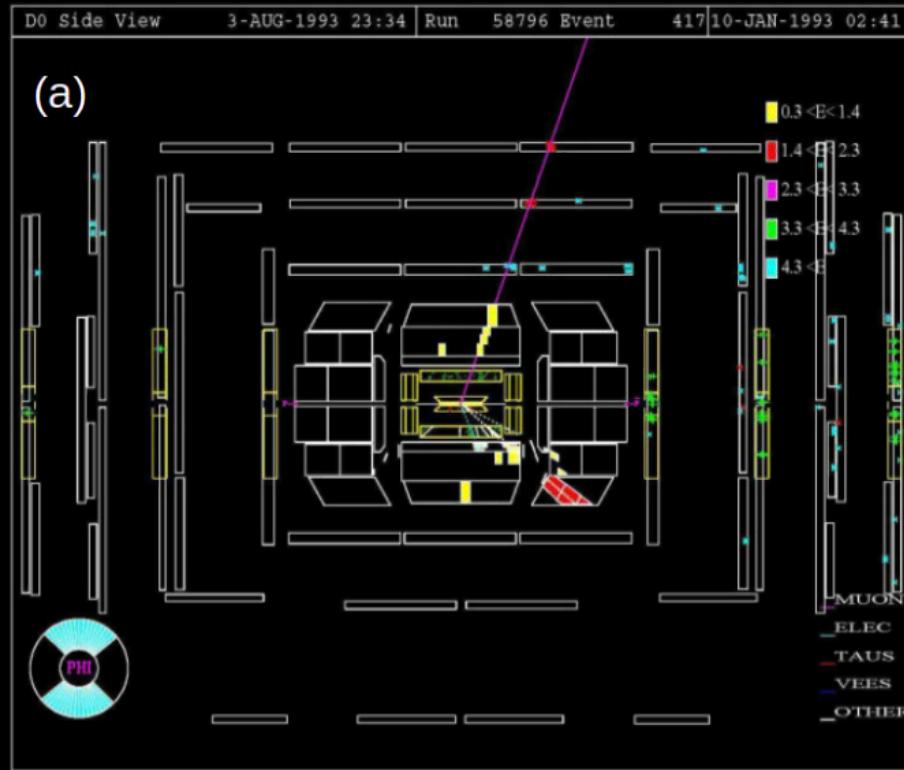


# DéTECTEURS D0



# D0

$t\bar{t} \rightarrow WbWb \rightarrow 2 \text{ leptons} + 2 \text{ jets} + \text{énergie manquante}$



D0 17 candidats : 7 avec 1 électron, 5 « confirmés » par le TRD

$t\bar{t} \rightarrow WbWb \rightarrow 2 \text{ leptons} + 2 \text{ jets} + \text{énergie manquante}$

Observation des premiers quarks top 1995

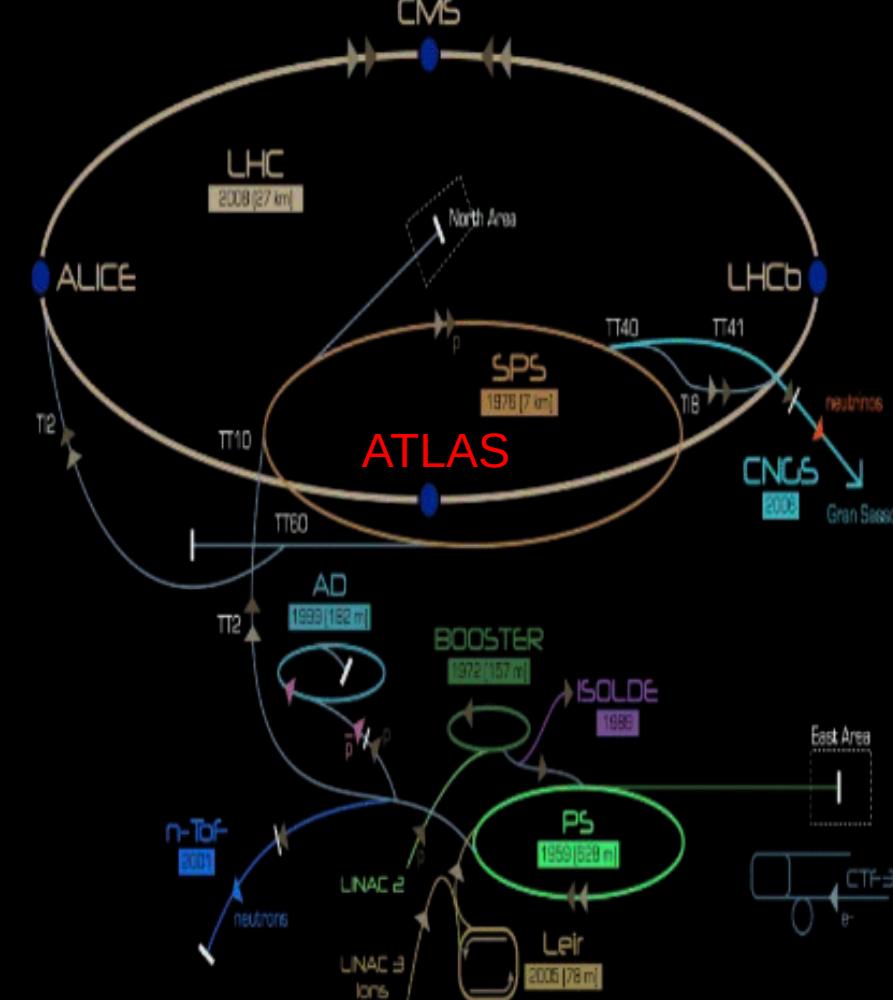
DØ  $\rightarrow m_{\text{top}} = 199^{+19}_{-21}(\text{stat}) \pm 22(\text{syst}) \text{ GeV/c}^2$

CDF  $\rightarrow m_{\text{top}} = 176 \pm 8(\text{stat}) \pm 10(\text{syst}) \text{ GeV/c}^2$

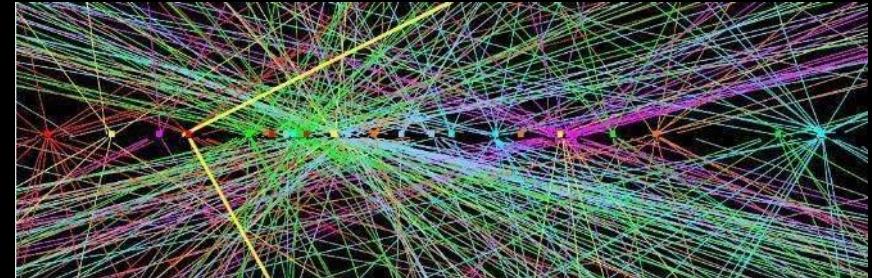
Remarque : prédiction 1992

LEP1  $\rightarrow m_{\text{top}} = 172.6^{+13.2}_{-10.2} \text{ GeV/c}^2$

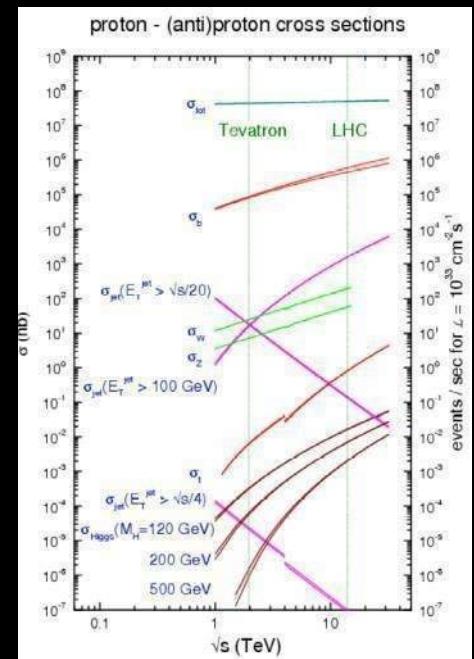
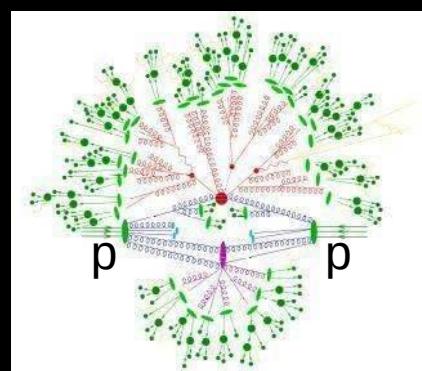
# Collisionneurs LHC



LHC PP: boom, 7, 8 et 14 TeV



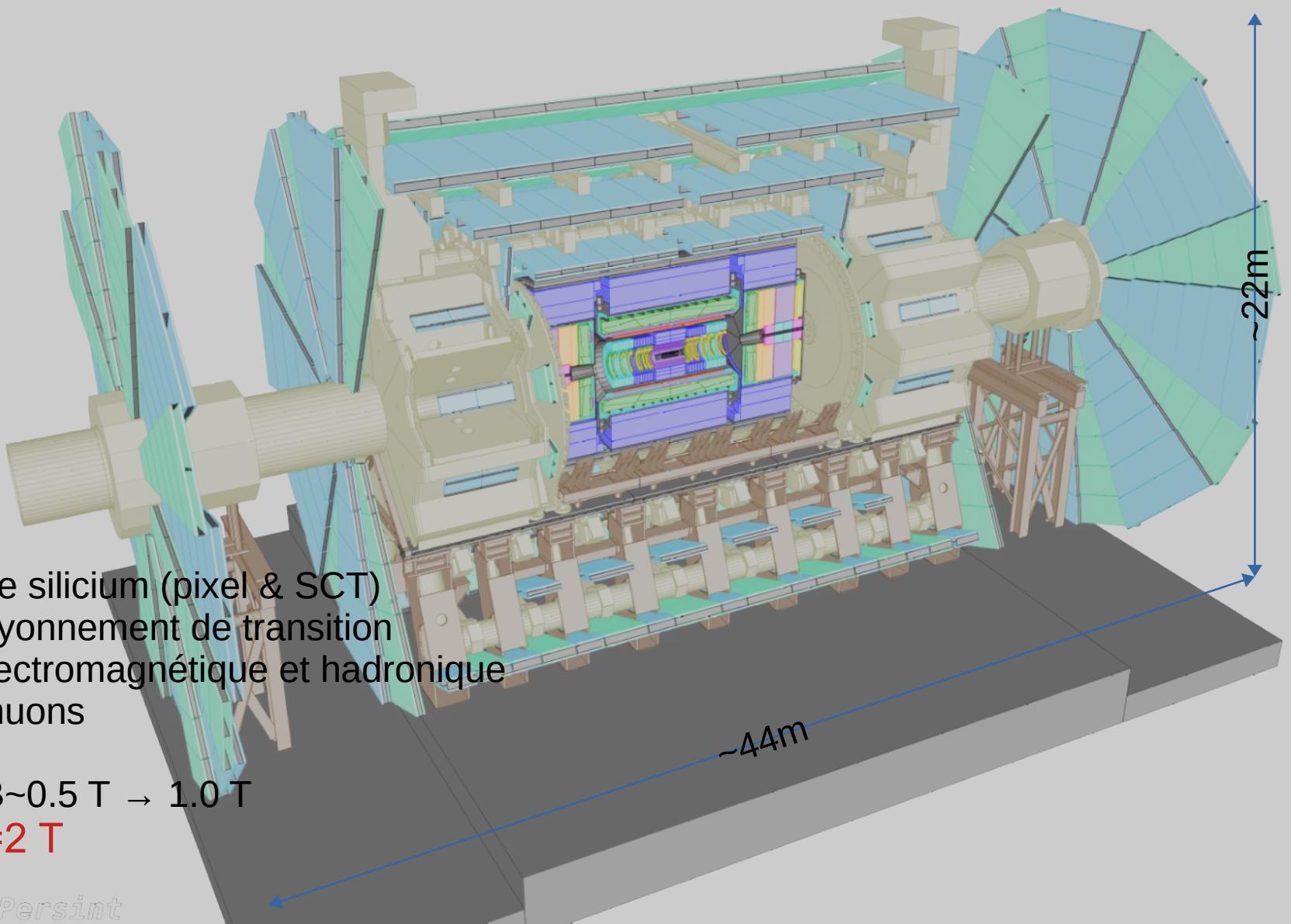
20 vertex ~5cm



# Détecteur

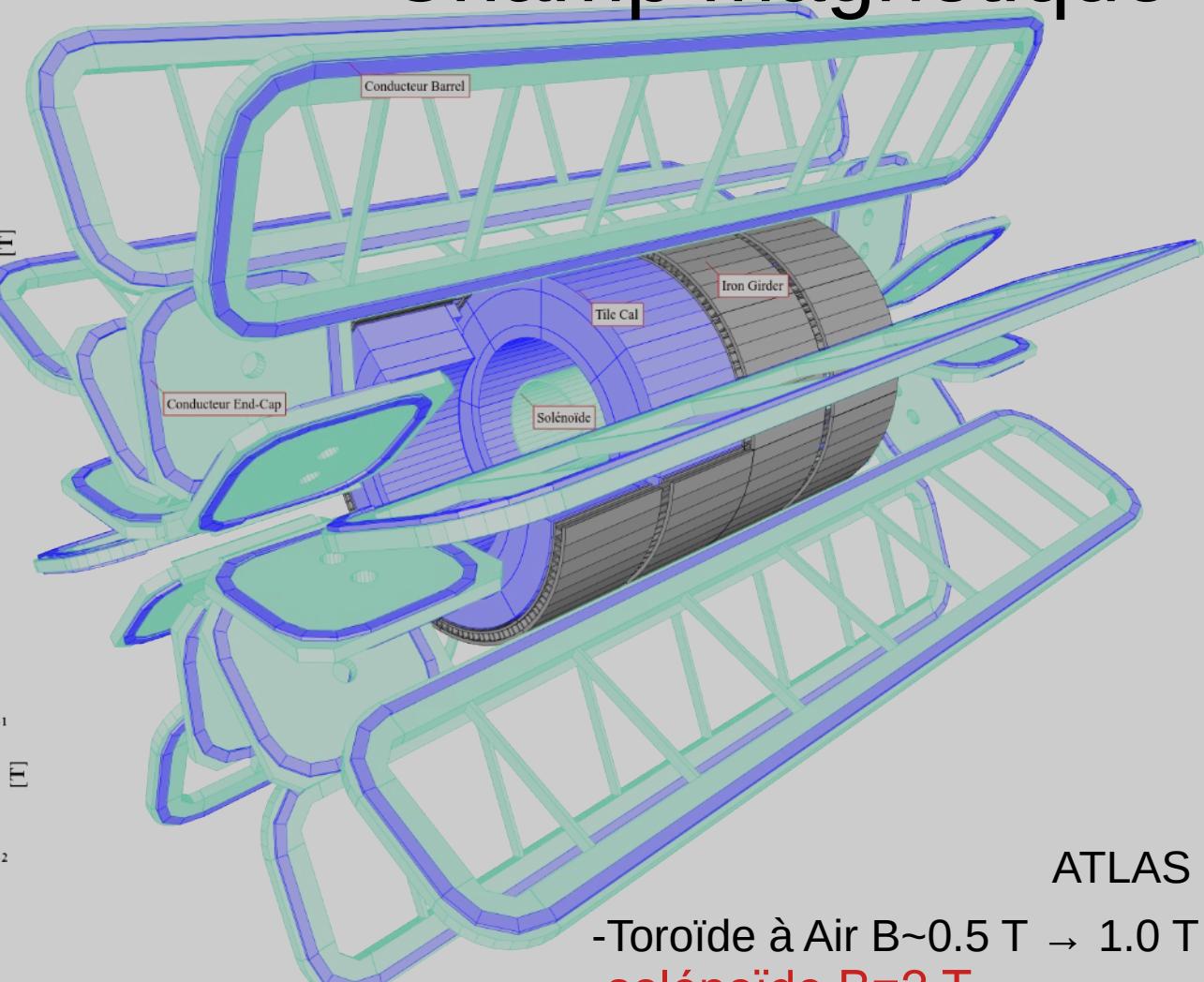
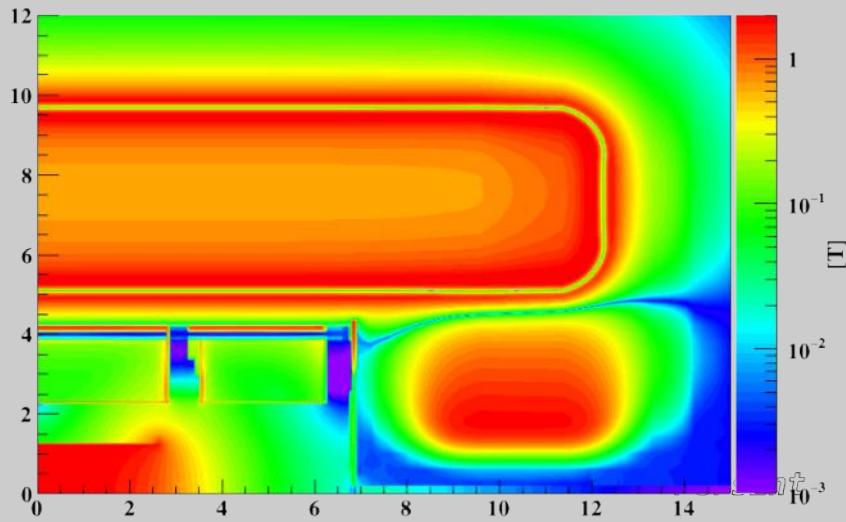
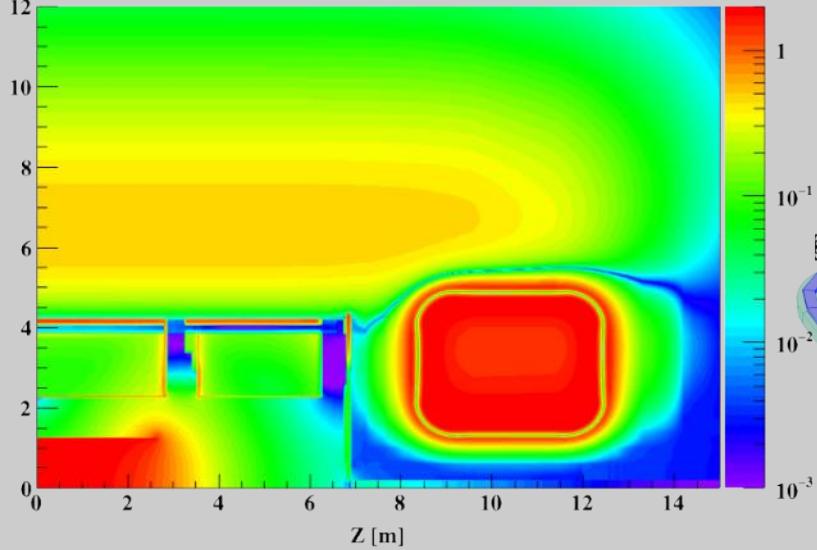
|                 | ATLAS (7 ktons)                                                                                                                                                                                                                                                                | CMS (12.5 ktons)                                                                                                                                                                                                                                              |
|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| INNER TRACKER   | <ul style="list-style-type: none"> <li>• Silicon pixels + strips</li> <li>• TRT with particle identification</li> <li>• <math>B = 2\text{T}</math></li> <li>• <math>\sigma(p_T) \sim 3.8\%</math> (at 100 GeV, <math>\eta = 0</math>)</li> </ul>                               | <ul style="list-style-type: none"> <li>• Silicon pixels + strips</li> <li>• No dedicated particle identification</li> <li>• <math>B = 4\text{T}</math></li> <li>• <math>\sigma(p_T) \sim 1.5\%</math> (at 100 GeV, <math>\eta = 0</math>)</li> </ul>          |
| MAGNETS         | <ul style="list-style-type: none"> <li>• 4 Magnets</li> <li>• Solenoid + Air-core muon toroids</li> <li>• Calorimeters outside solenoid field</li> </ul>                                                                                                                       | <ul style="list-style-type: none"> <li>• 1 Magnet</li> <li>• Solenoid</li> <li>• Calorimeters inside field</li> </ul>                                                                                                                                         |
| EM CALORIMETER  | <ul style="list-style-type: none"> <li>• Pb / Liquid Ar sampling accordion</li> <li>• <math>\sigma(E) \sim 10\text{--}12\% / \sqrt{E} \oplus 0.2\text{--}0.35\%</math></li> <li>• Longitudinal segmentation</li> <li>• Saturation at <math>\sim 3\text{ TeV}</math></li> </ul> | <ul style="list-style-type: none"> <li>• <math>\text{PbWO}_4</math> scintillation crystals</li> <li>• <math>\sigma(E) \sim 3\text{--}5.5\% / \sqrt{E} \oplus 0.5\%</math></li> <li>• No longitudinal segmentation</li> <li>• Saturation at 1.7 TeV</li> </ul> |
| HAD CALORIMETER | <ul style="list-style-type: none"> <li>• Fe / Scint. tiles (EC: Cu-liquid Ar)</li> <li>• <math>\sigma(E) \sim 45\% / \sqrt{E} \oplus 1.3\%</math> (Barrel)</li> </ul>                                                                                                          | <ul style="list-style-type: none"> <li>• Cu (EC: brass) / Scint. tiles</li> <li>• Tail catchers outside solenoid</li> <li>• <math>\sigma(E) \sim 100\% / \sqrt{E} \oplus 8\%</math> (Barrel)</li> </ul>                                                       |
| MUON            | <ul style="list-style-type: none"> <li>• Drift tubes &amp; CSC (fwd) + RPC/TGC</li> <li>• <math>\sigma(p_T) \sim 10.5\% / 10.4\%</math> (1 TeV, <math>\eta = 0</math>)</li> <li>(standalone / combined with tracker)</li> </ul>                                                | <ul style="list-style-type: none"> <li>• Drift tubes &amp; CSC (EC) + RPC</li> <li>• <math>\sigma(p_T) \sim 13\% / 4.5\%</math> (1 TeV, <math>\eta = 0</math>)</li> <li>(standalone / combined with tracker)</li> </ul>                                       |

# ATLAS

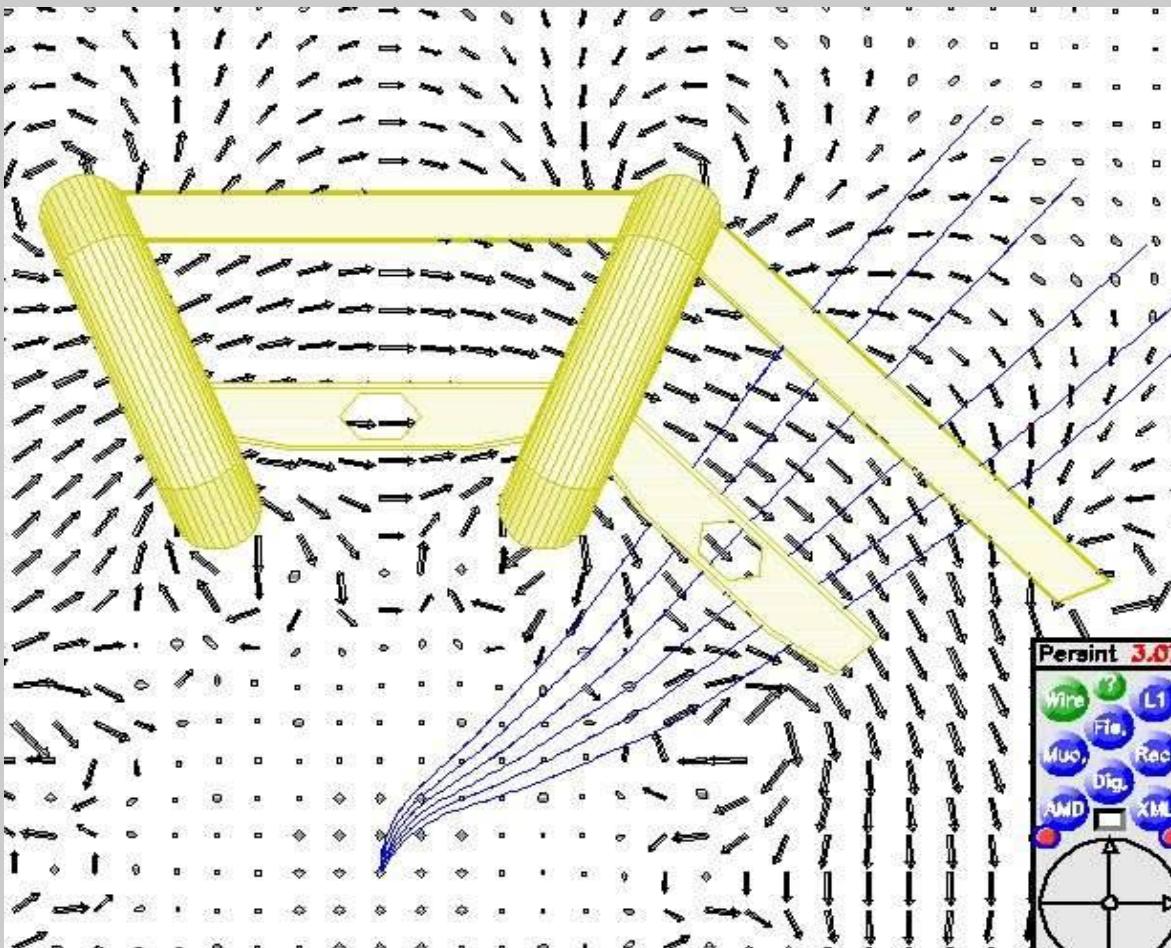


# ATLAS

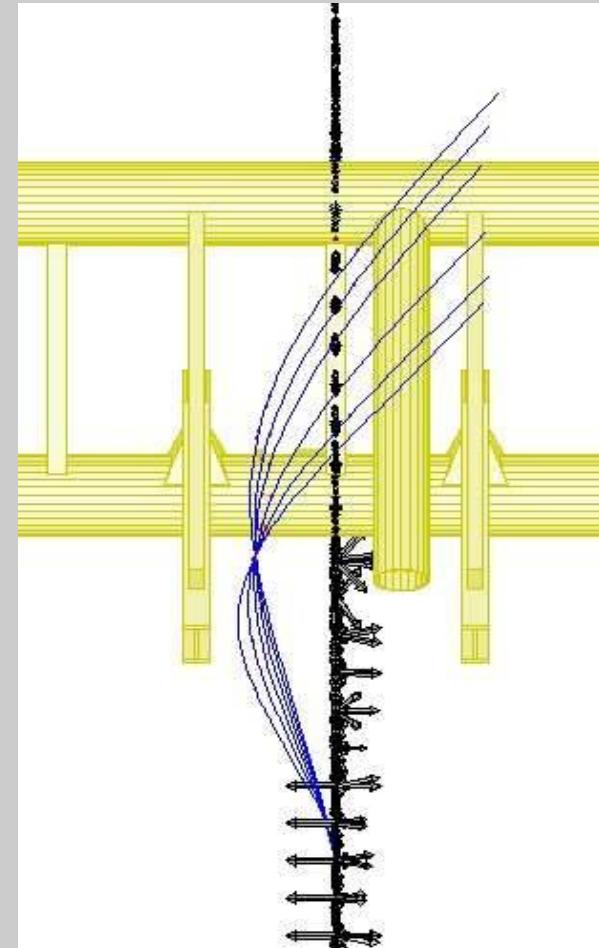
# Champ magnétique



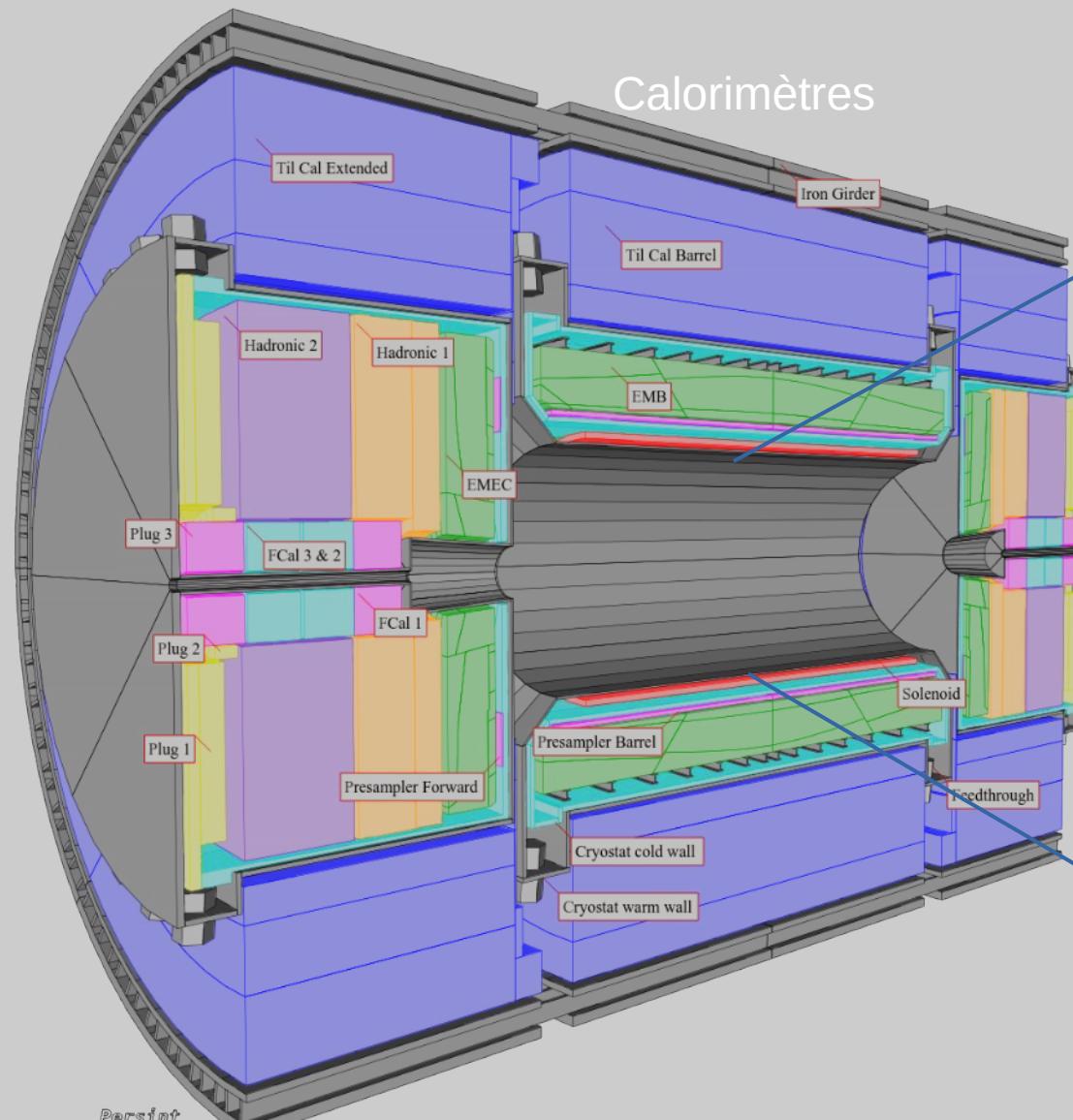
ATLAS  
-Toroïde à Air  $B \sim 0.5$  T  $\rightarrow 1.0$  T  
-solénoïde  $B=2$  T

R- $\phi$  projection

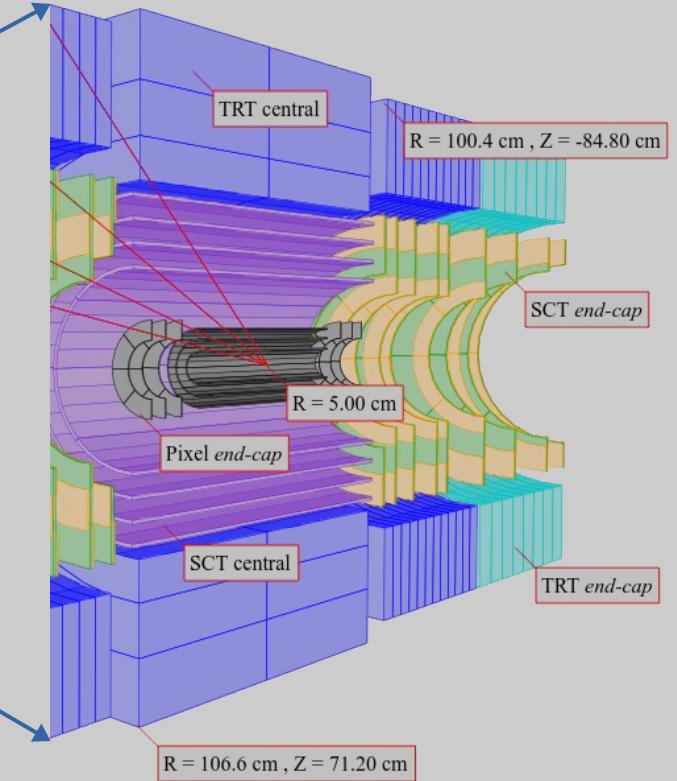
R-Z projection



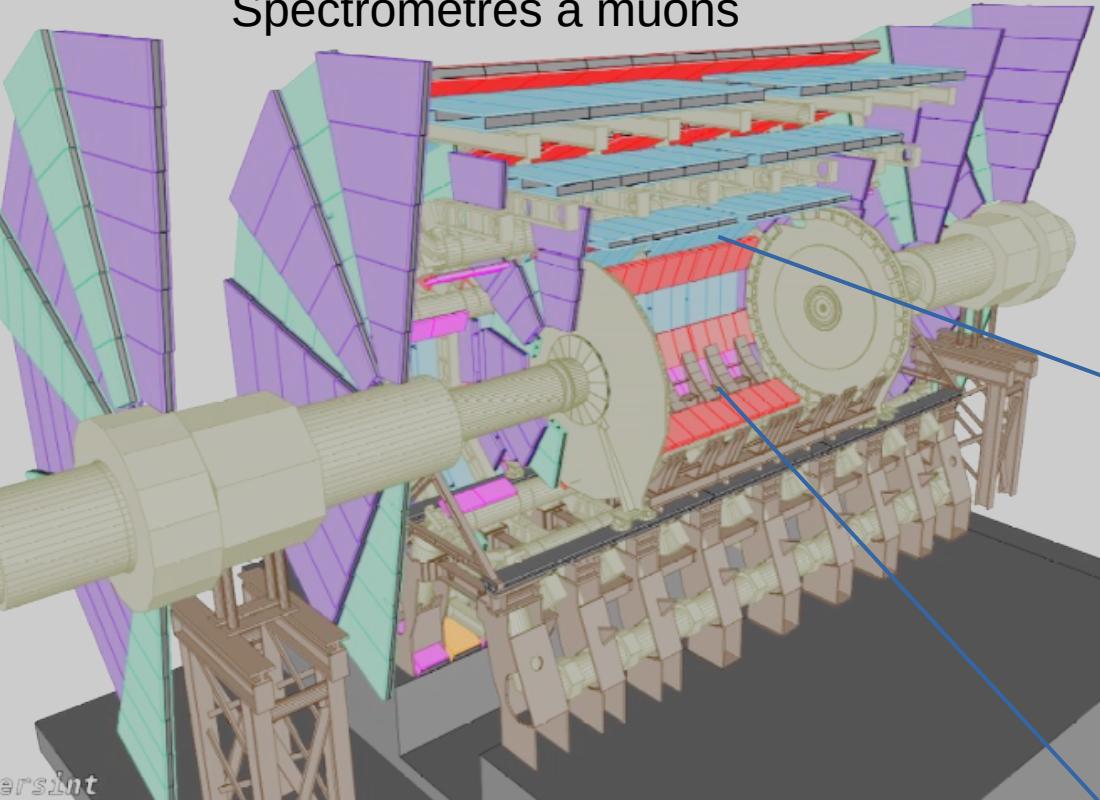
# Calorimètres



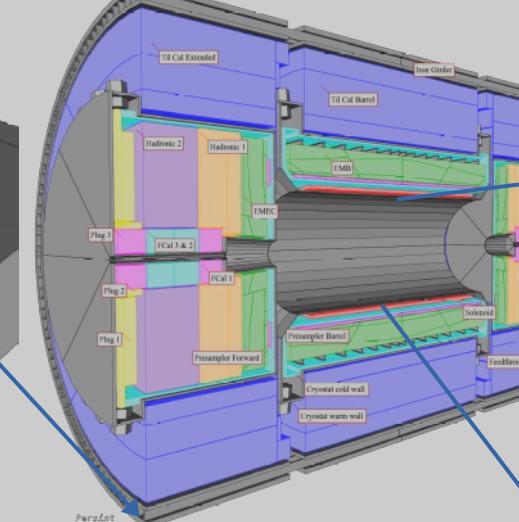
# Trajectographe interne



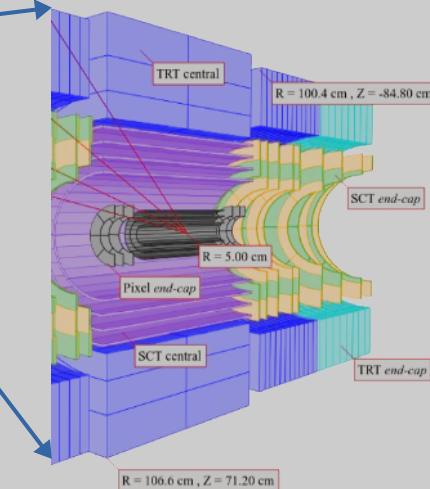
# Spectromètres à muons

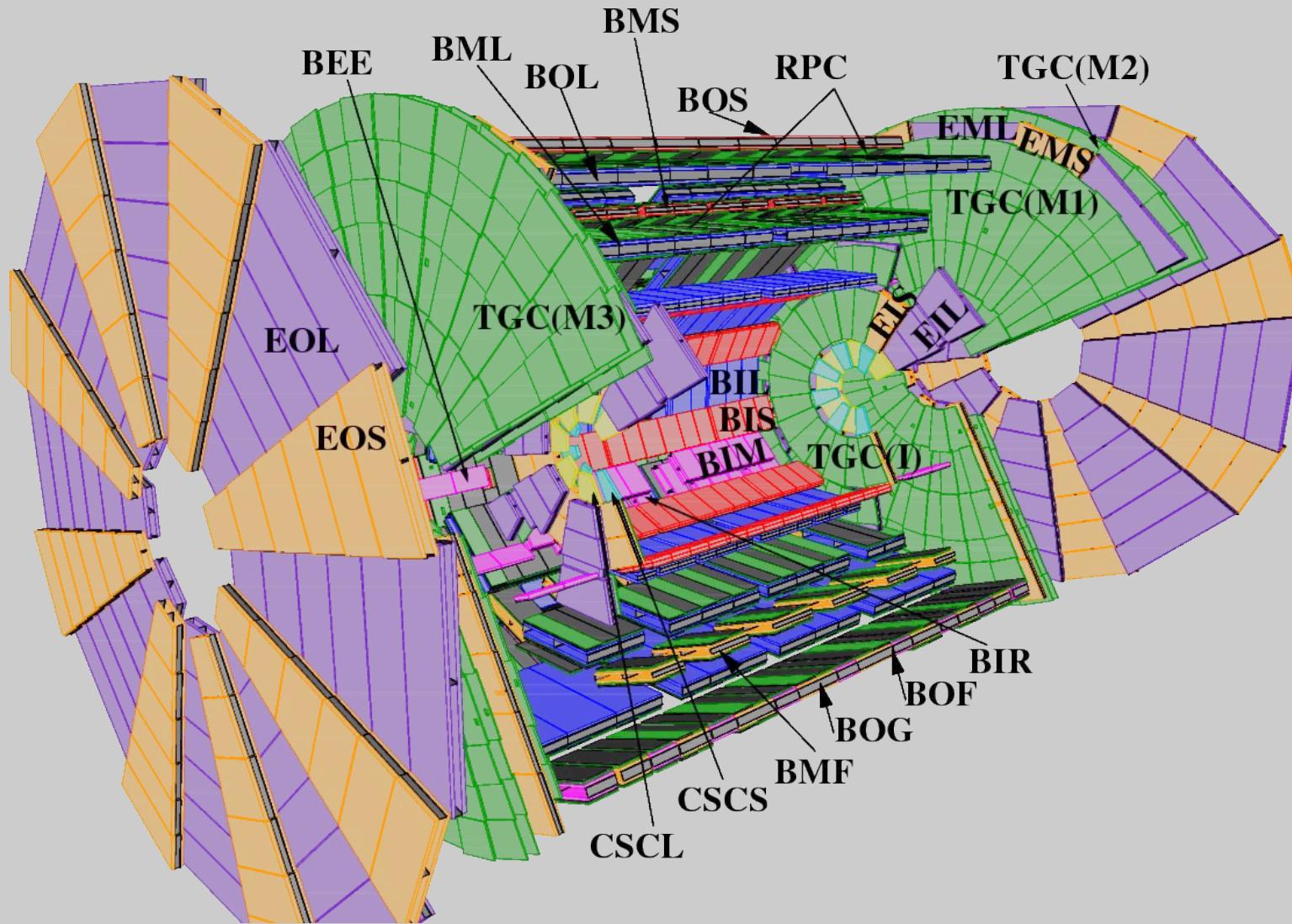


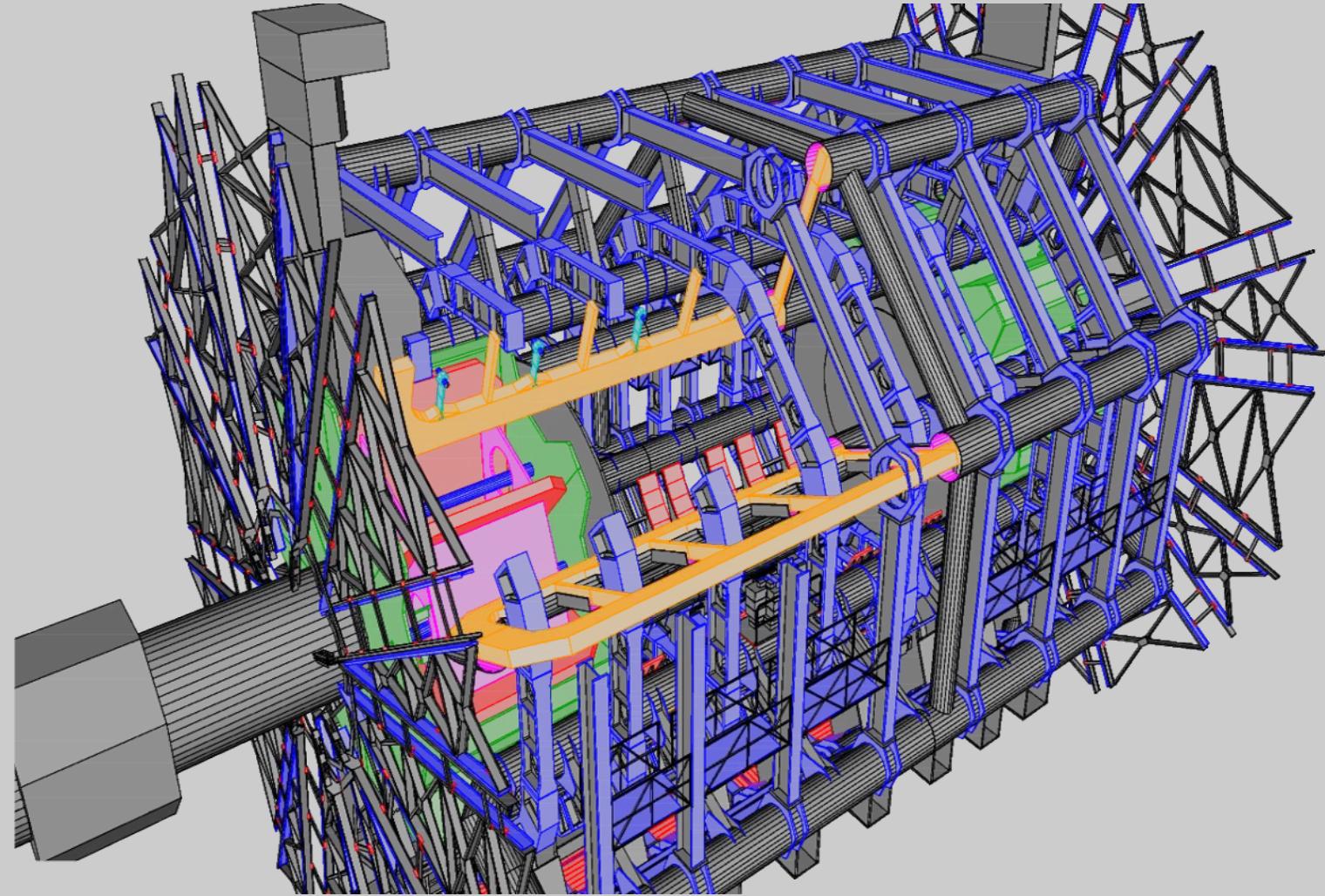
Calorimètres

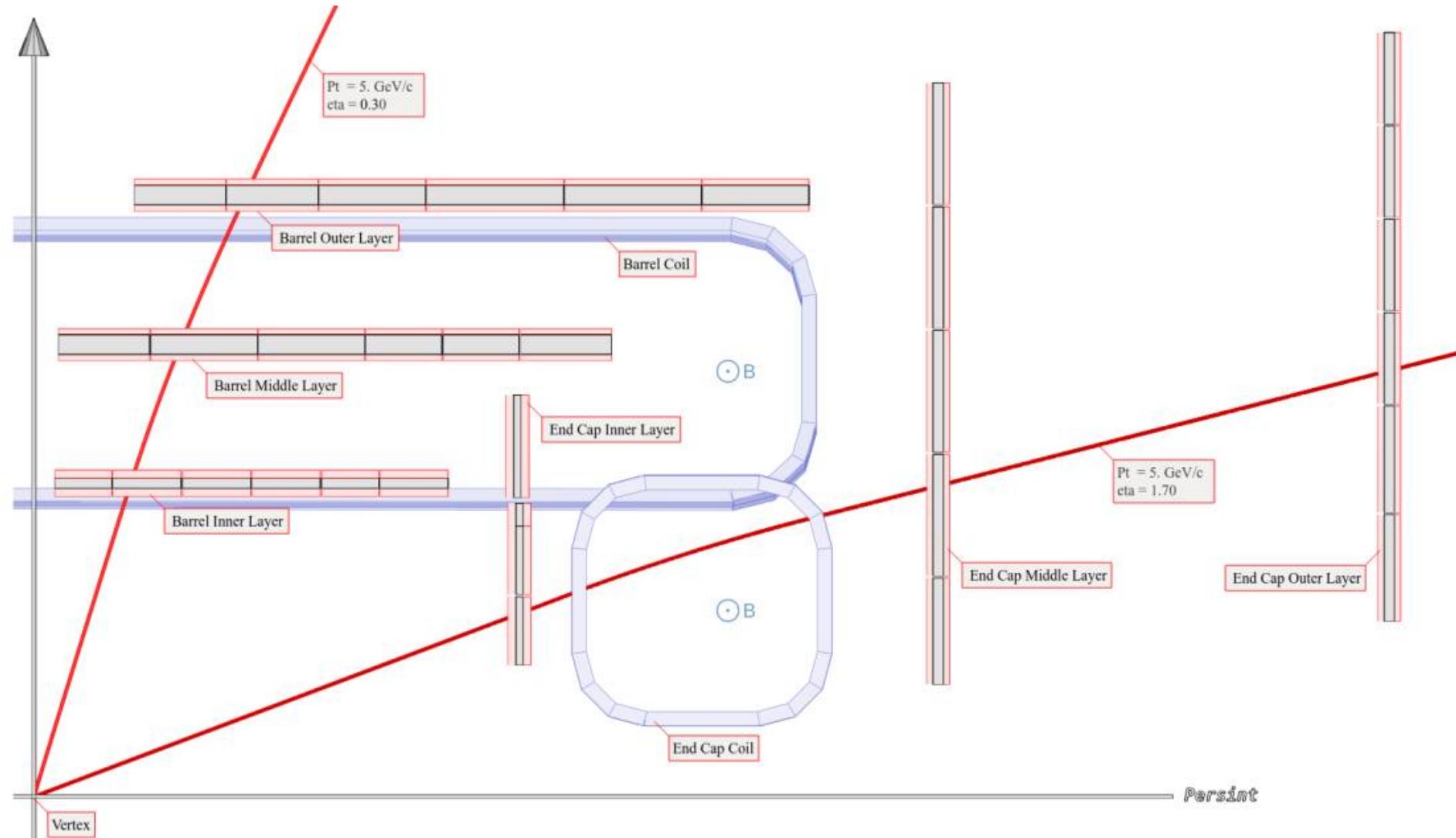


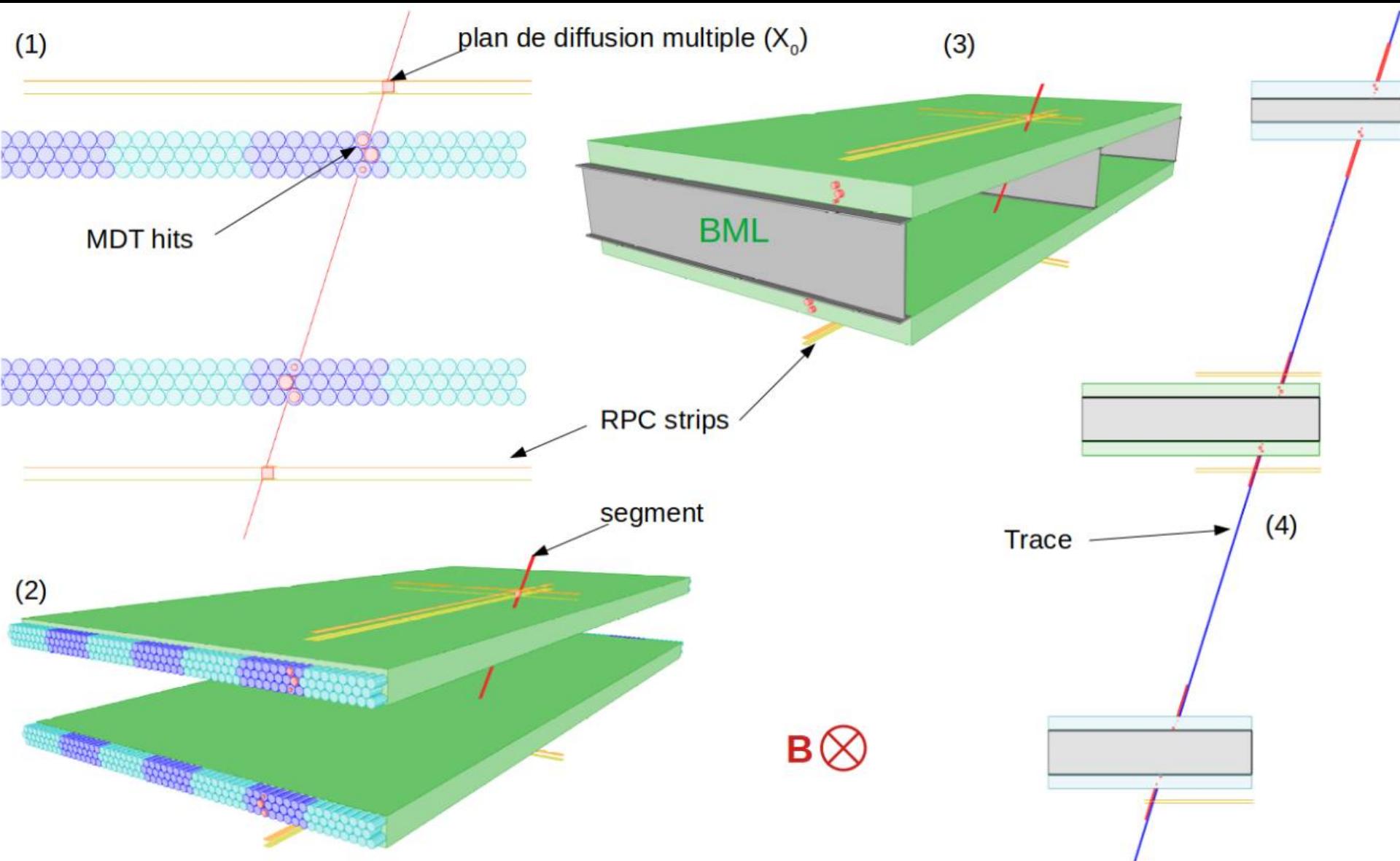
Trajectographie





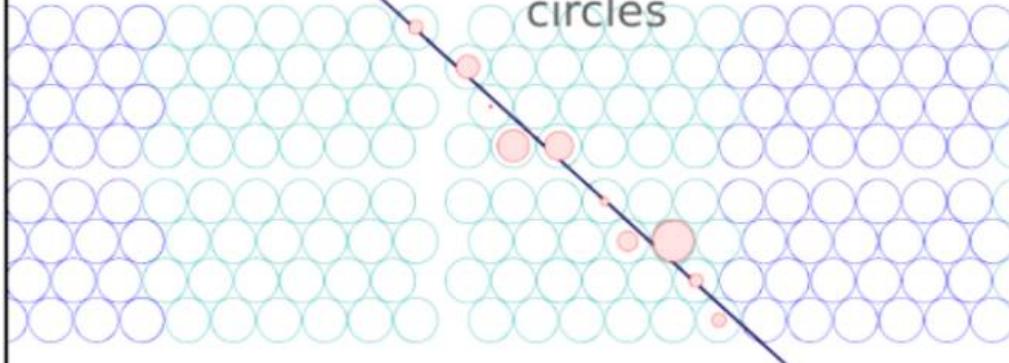






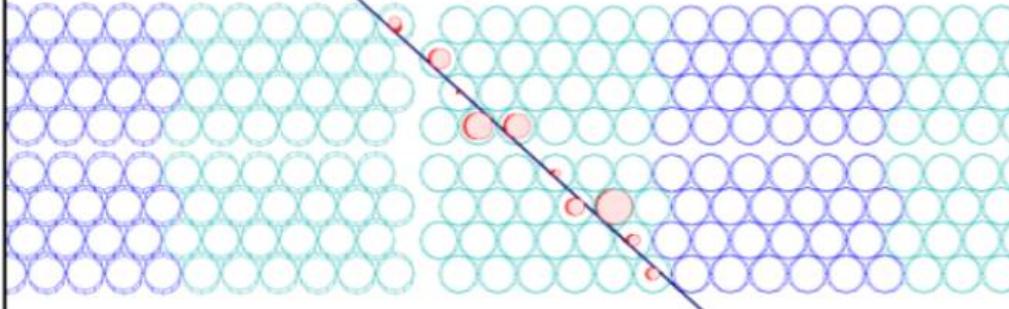
(a)

true track not  
aligned with drift  
circles



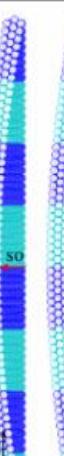
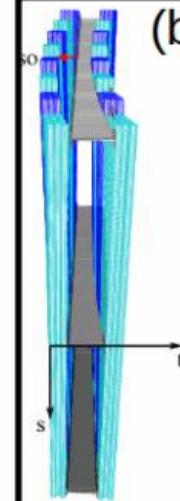
ABSORBENT

tubes slightly tilted

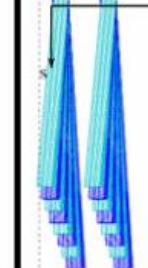


ABSORBENT

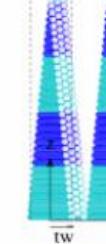
(b)



$2ltwl$



$2ltwl$

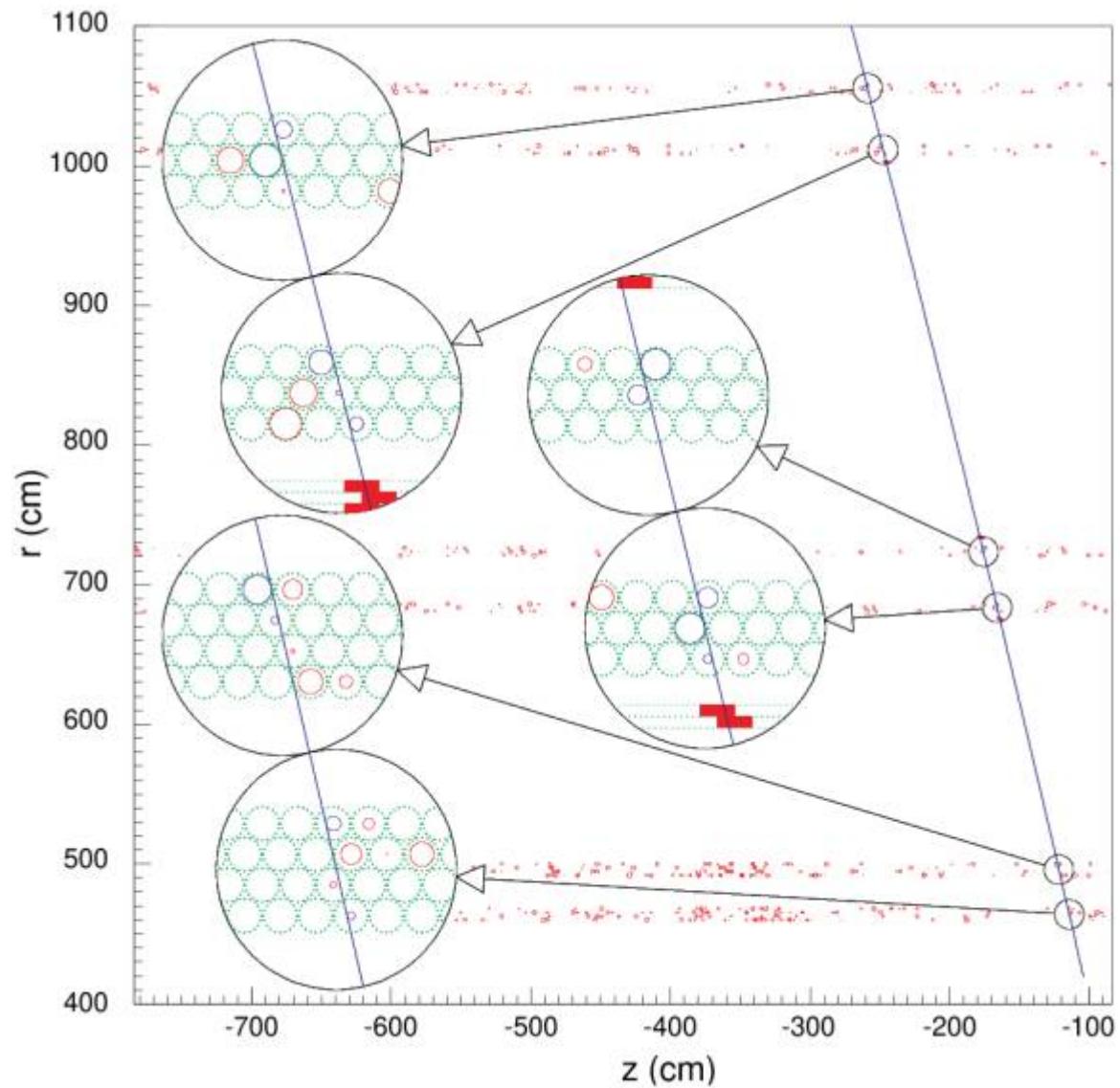


SO

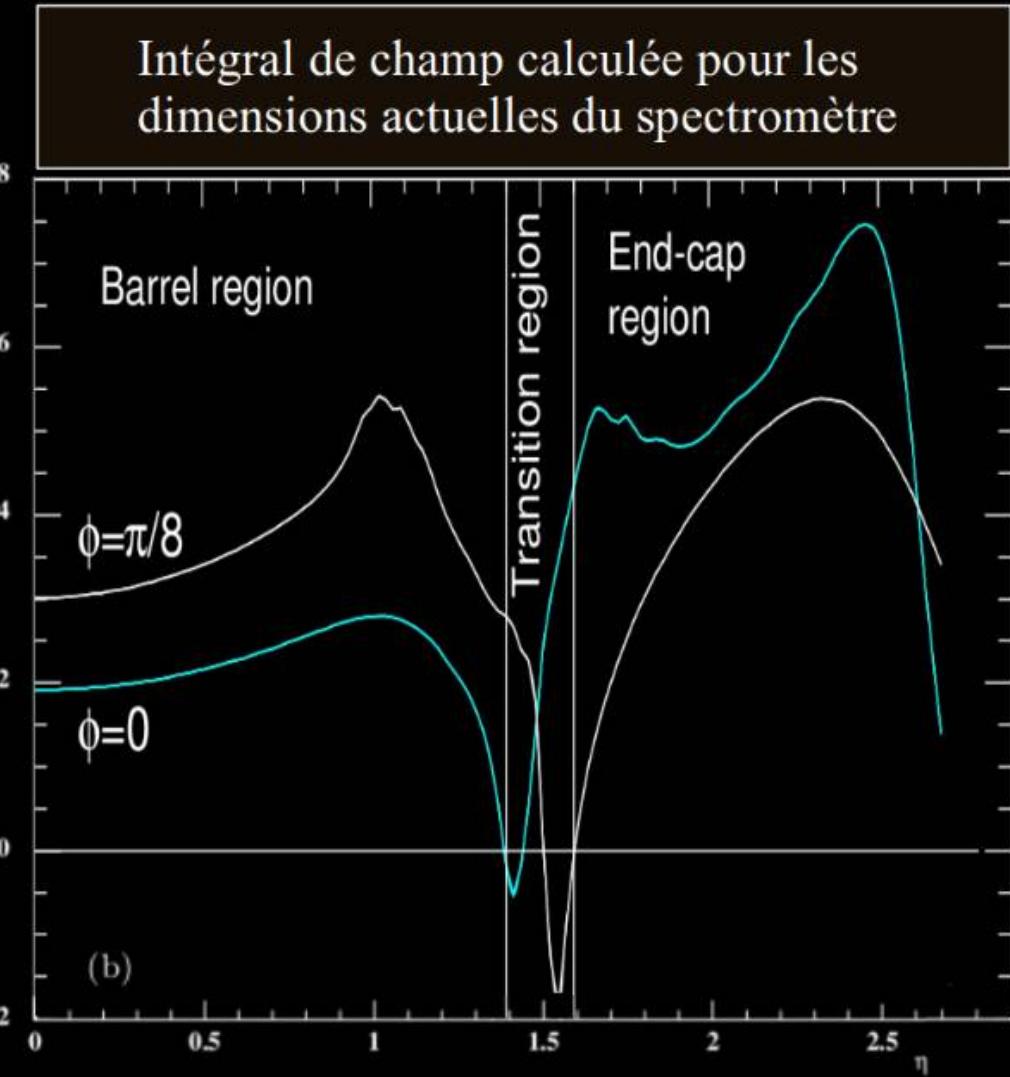
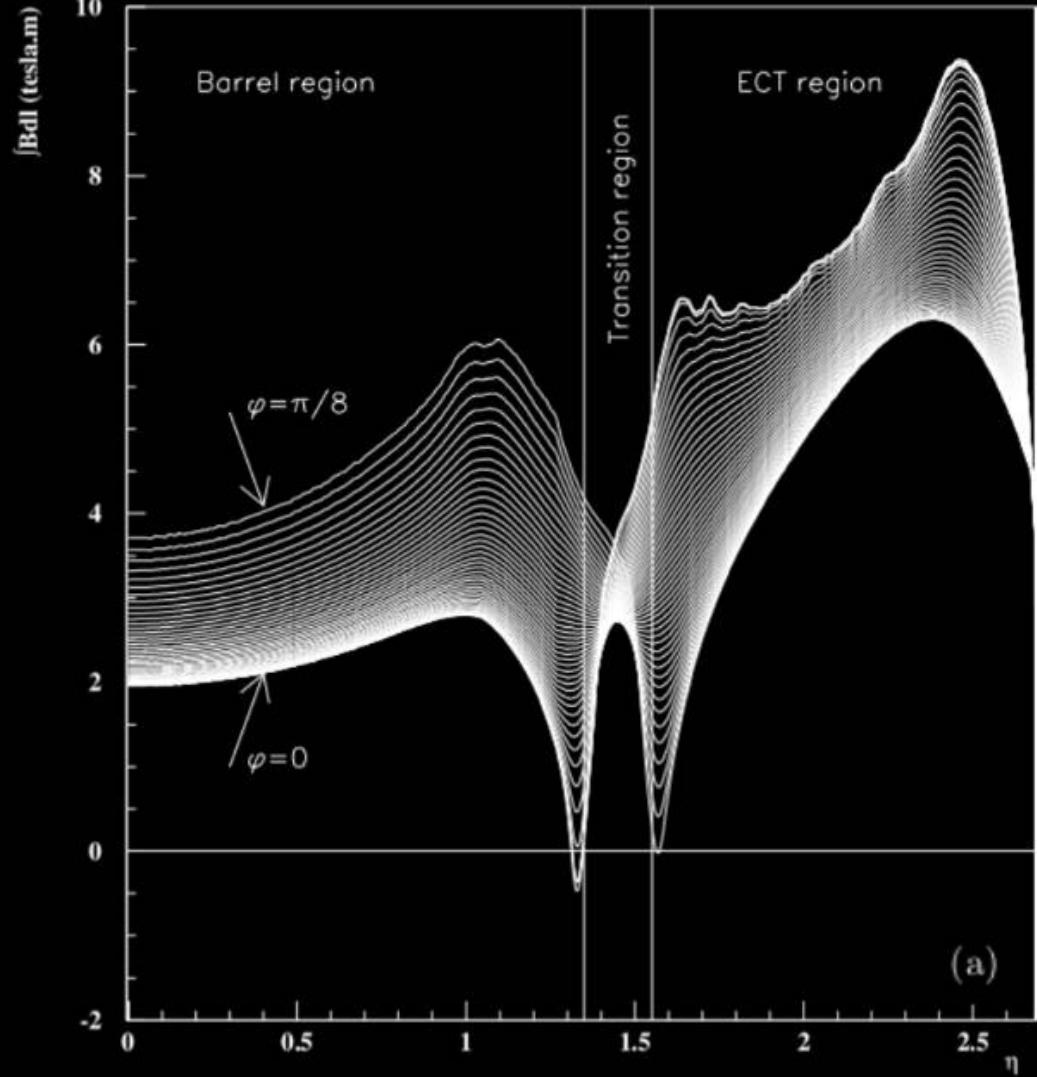


SO

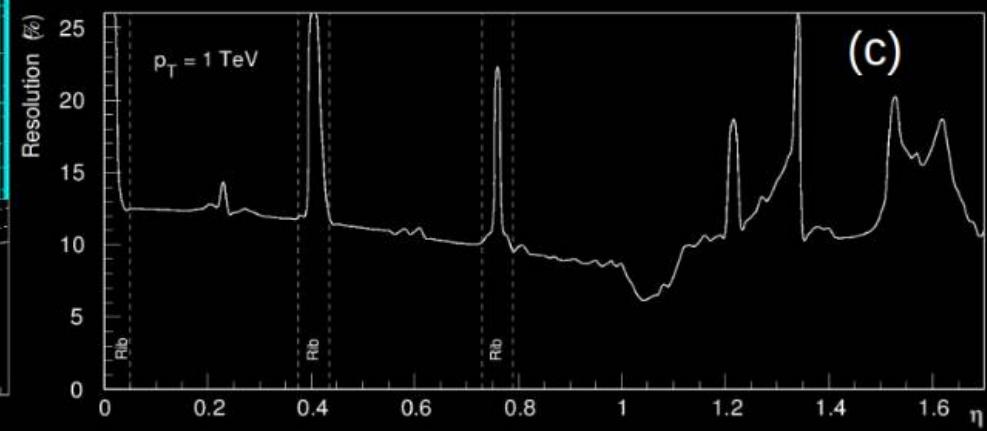
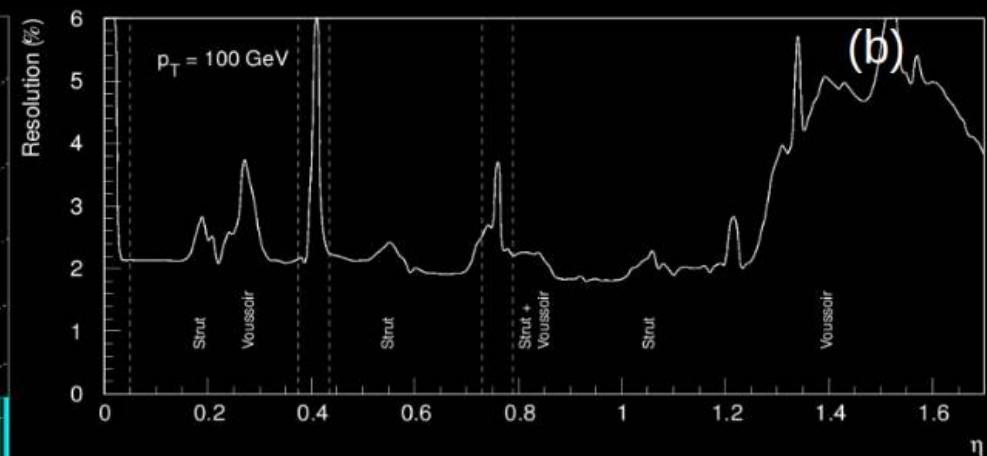
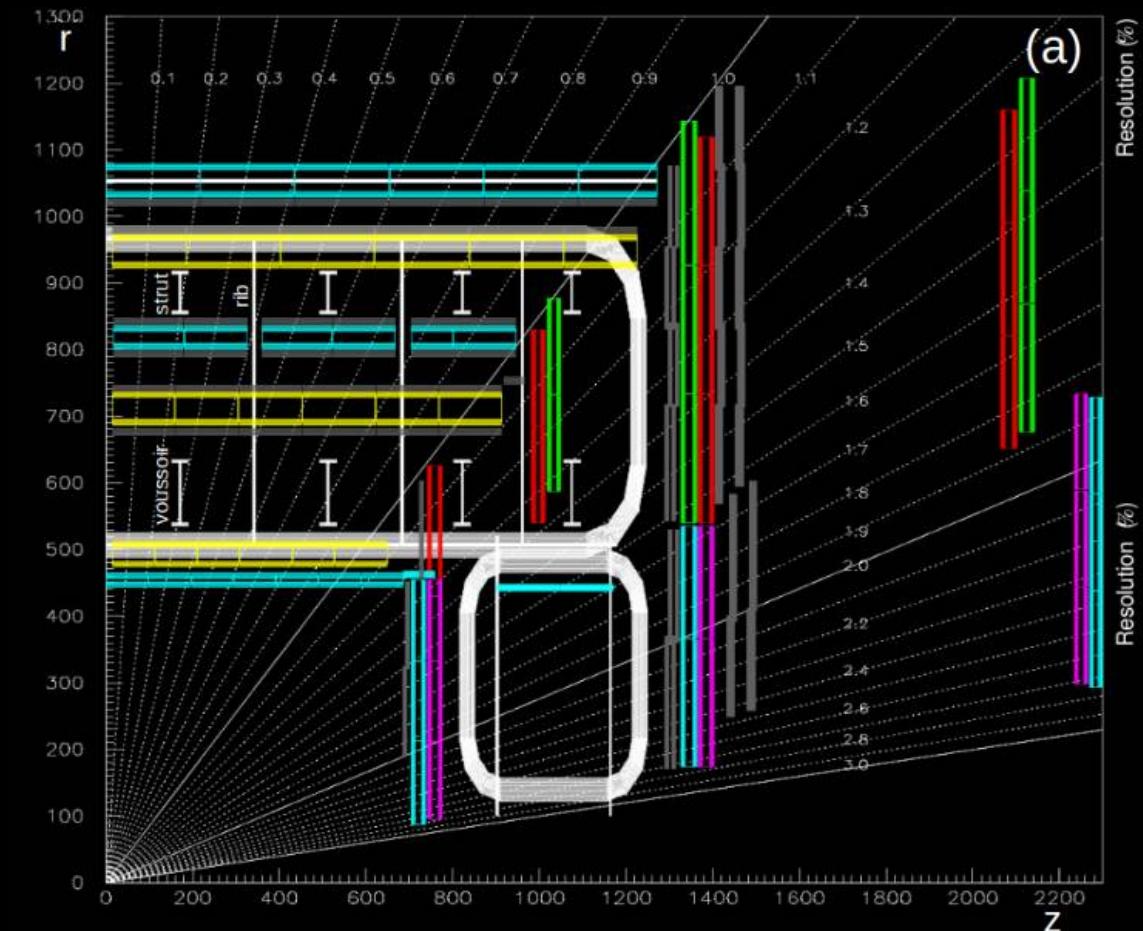


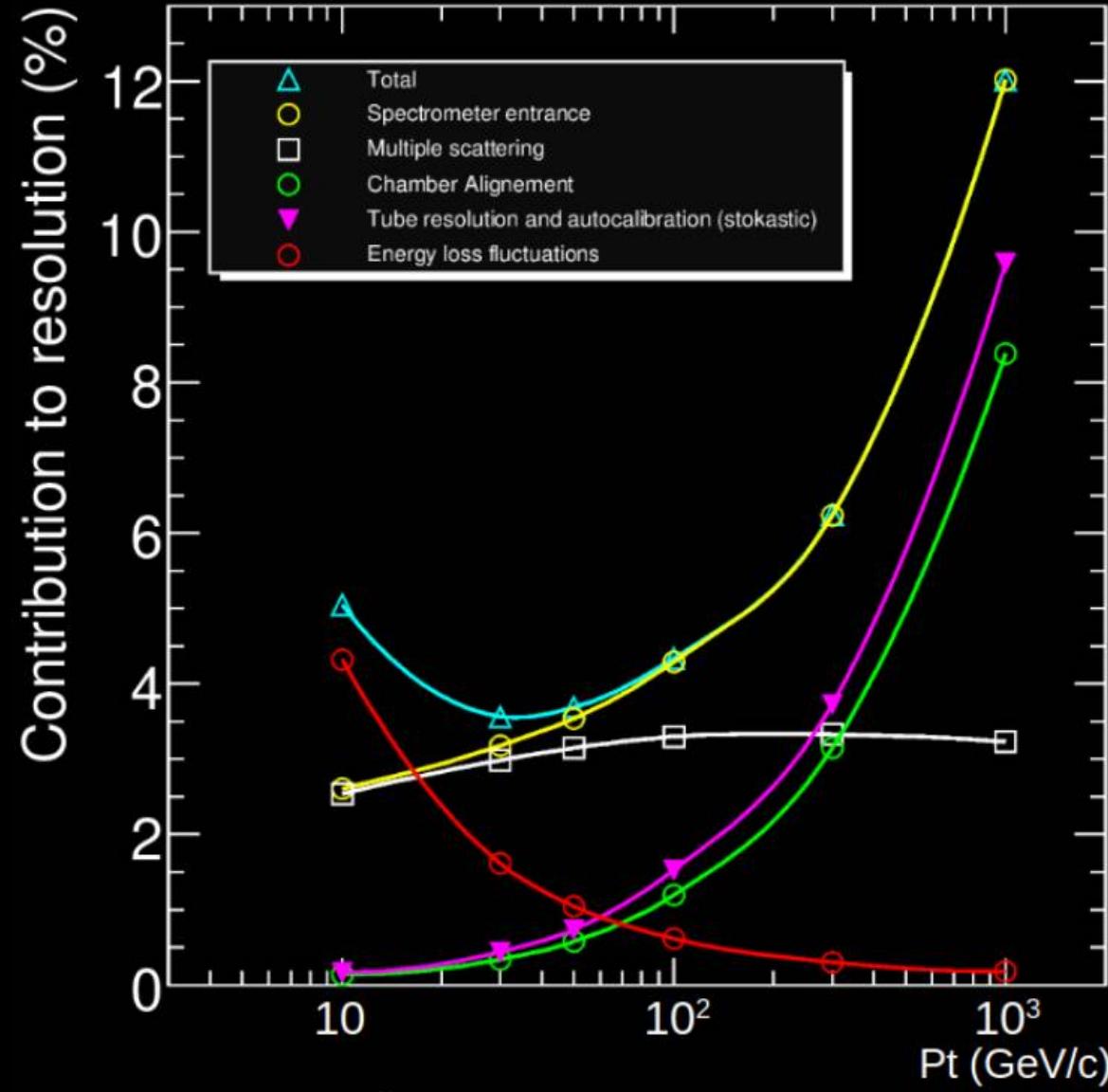


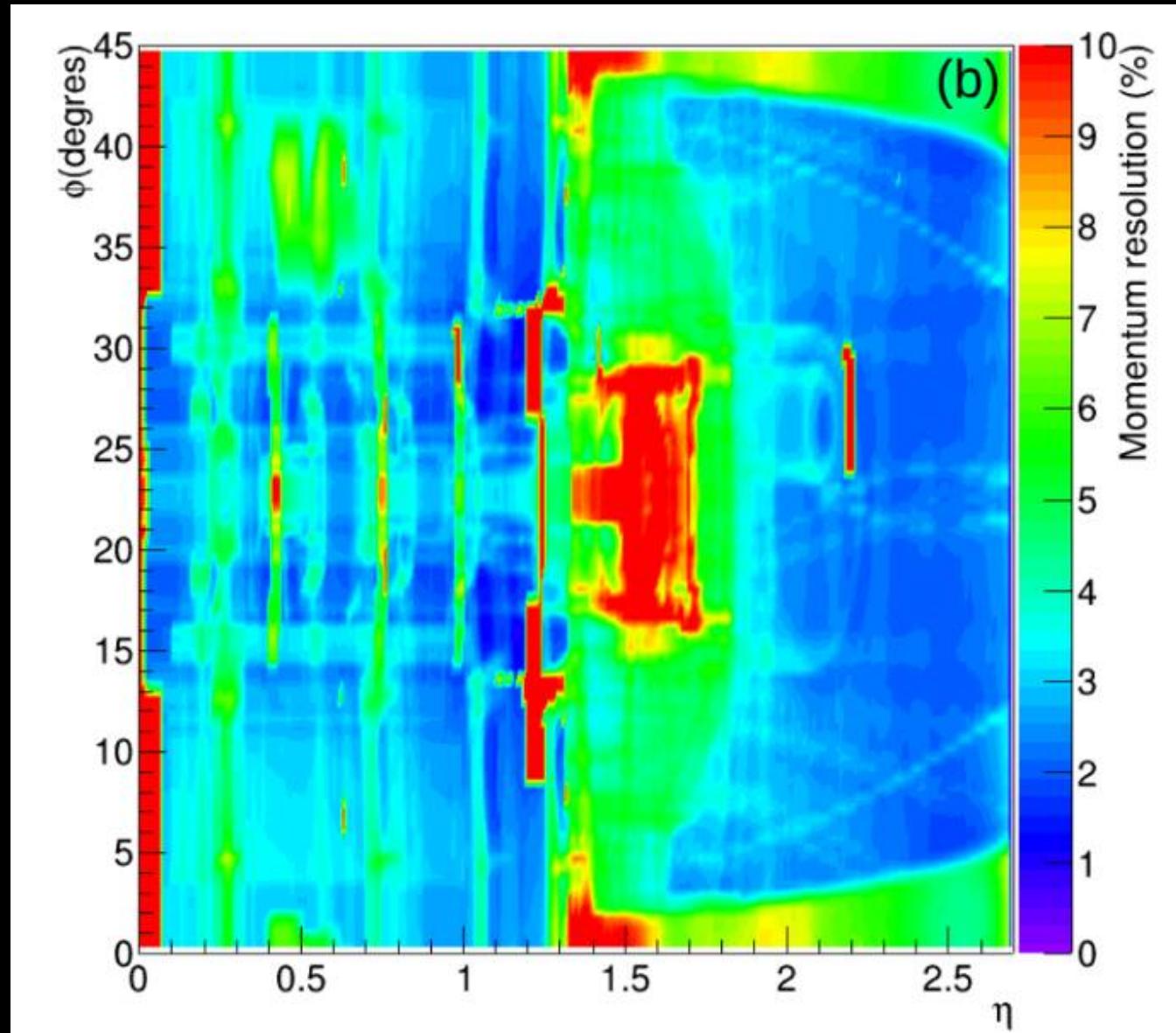
$$\int B \cdot d\mathbf{l} \rightarrow \text{défini le système magnétique}$$

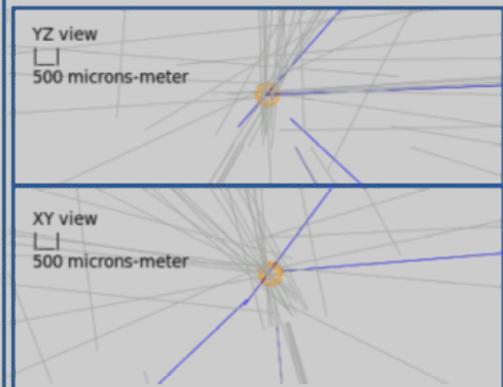
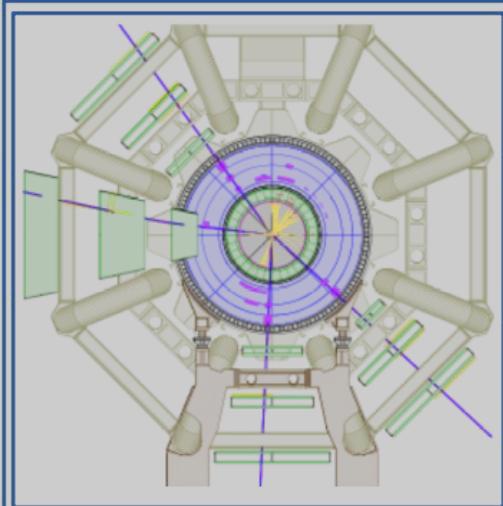


$\int B \cdot I \cdot dl \rightarrow$  défini la résolution en impulsion du détecteur







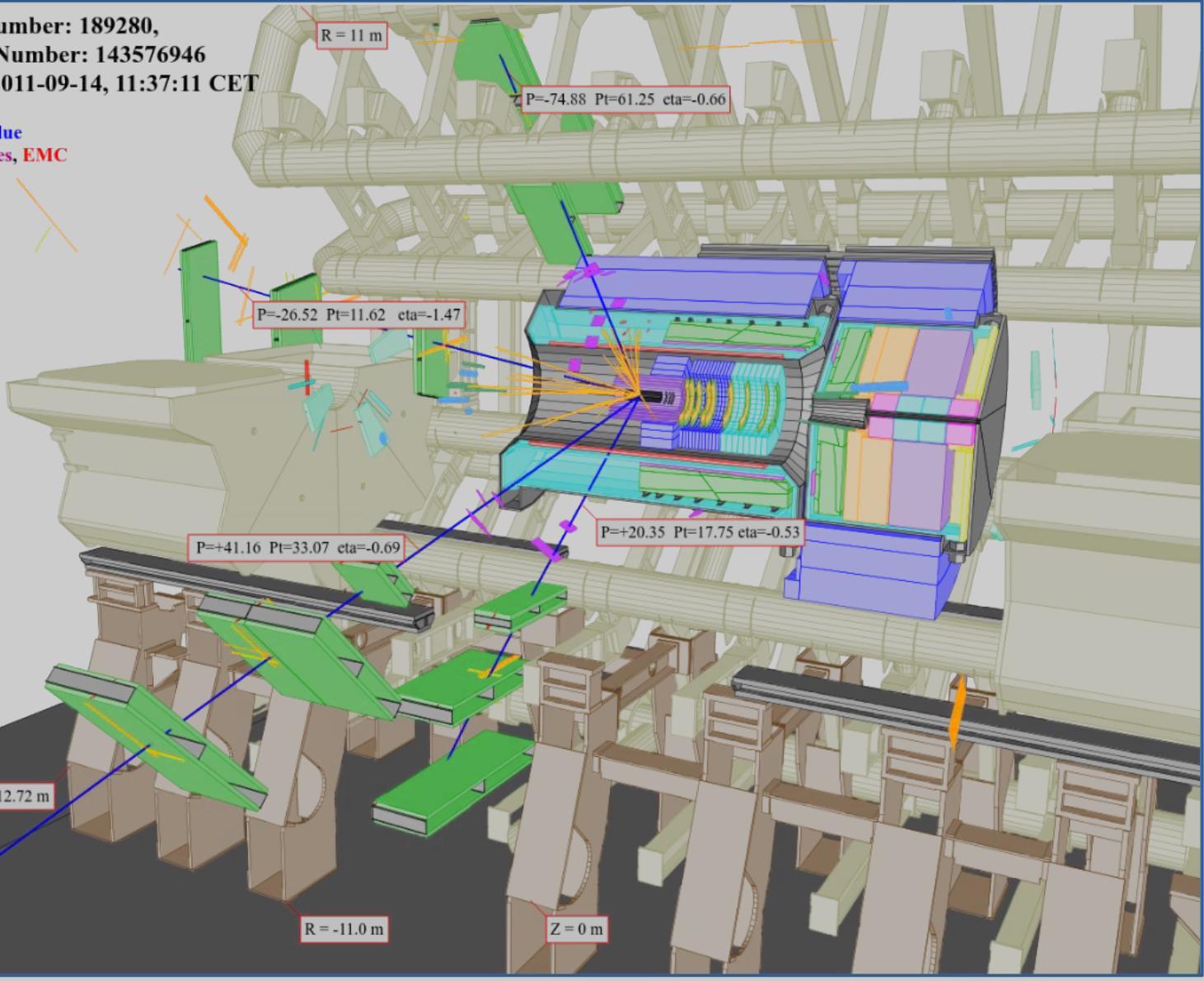


Invariant mass  
Invariant mass of tracks 155, 153, 156, 154 :  
 $124.6 \text{ GeV}/c^2$

Run Number: 189280,  
Event Number: 143576946  
Date: 2011-09-14, 11:37:11 CET

Muon: blue

Cells: Tiles, EMC



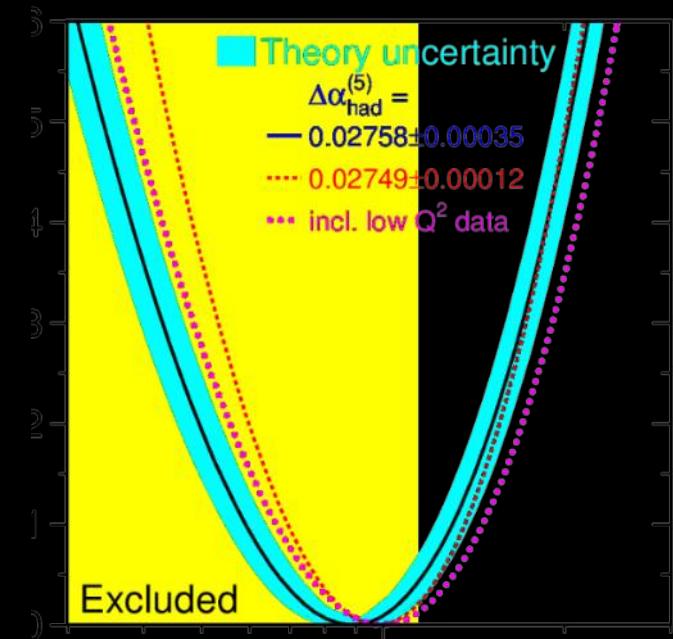
Observation des premiers bosons de Higgs 2012 ( $5 \text{ fb}^{-1}$ )

$$m_{4l} = 126.0 \pm 0.5 \text{ GeV}/c^2$$

$$m_{\gamma\gamma} = 124.5 \pm 0.5 \text{ GeV}/c^2$$

Remarque : prédiction 2006

$$\text{LEP2} \rightarrow m_H \sim 100 \pm 25 \text{ GeV}/c^2$$



**Spécial Festival d'Avignon**  
**La 66<sup>e</sup> fête du théâtre démarre le 7 juillet**  
**Supplément**

**Le Monde**

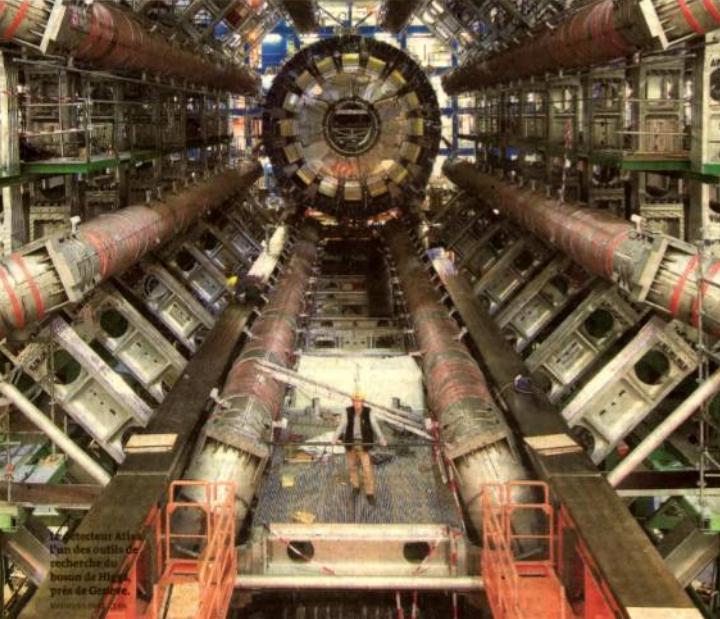
Jeudi 5 juillet 2012 - 68<sup>e</sup> année - N°20981 - 1,60 € - France métropolitaine - [www.lemonde.fr](http://www.lemonde.fr) -

**Le Monde des livres**  
**Les coups de cœur de la rédaction**  
**Supplément**

Fondateur : Hubert Beuve-Méry - Directeur : Erik Izraele

**Science : la matière dévoilée**

Le boson de Higgs, particule manquante pour expliquer l'Univers, vient d'être découvert  
 Les physiciens du CERN de Genève ont prouvé son existence à 99,9999 %



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# DéTECTEURS **ATLAS**

## **ATLAS**

conception 1990

simulation complète du détecteur avec GEANT 3 et 4

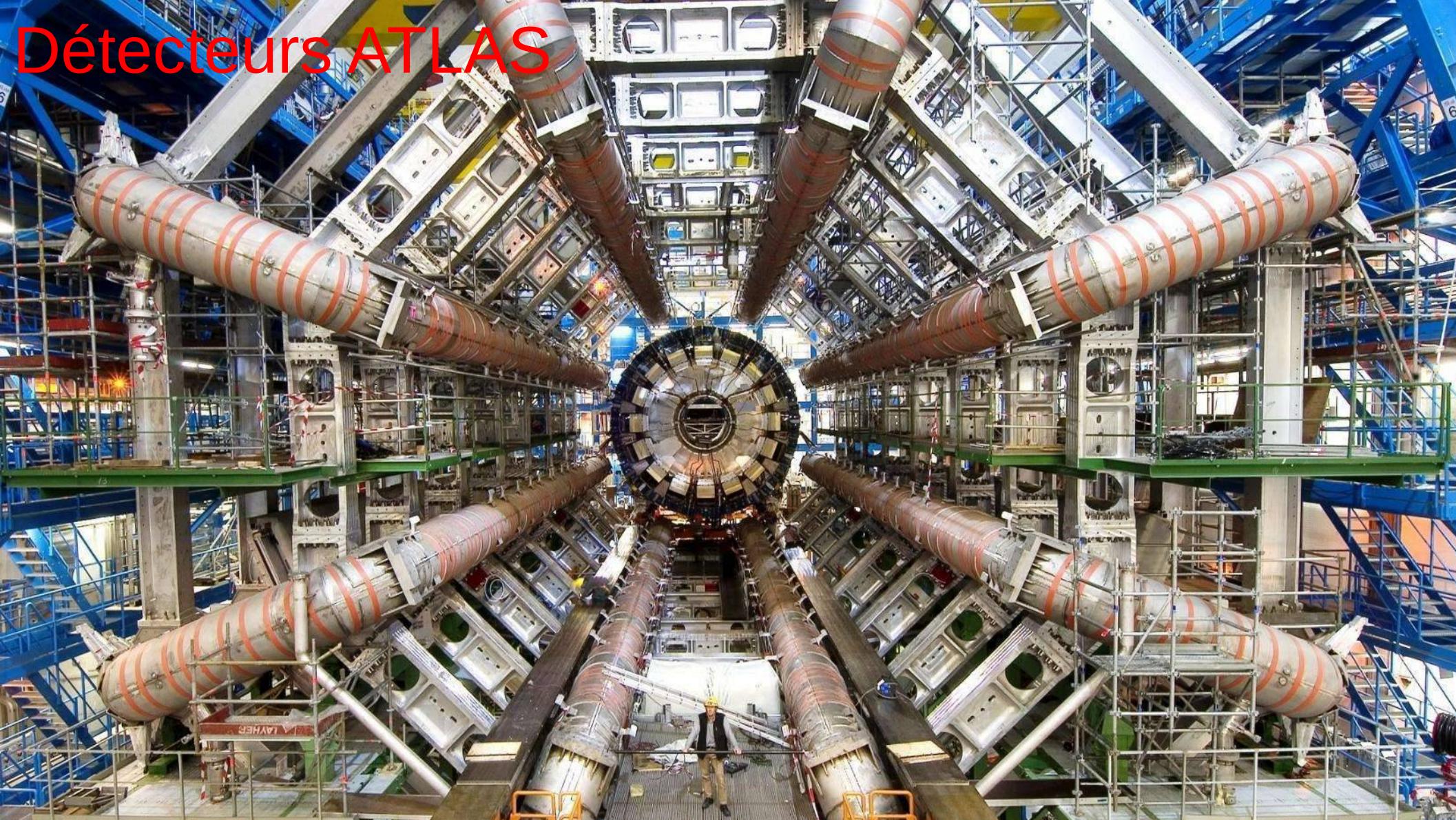
trajectographie  $R \sim 2m$

solénoïde 2 T et Toroïde

*Run I* 2009-2012

temps entre collision 25 ns

environ 3000 signataires



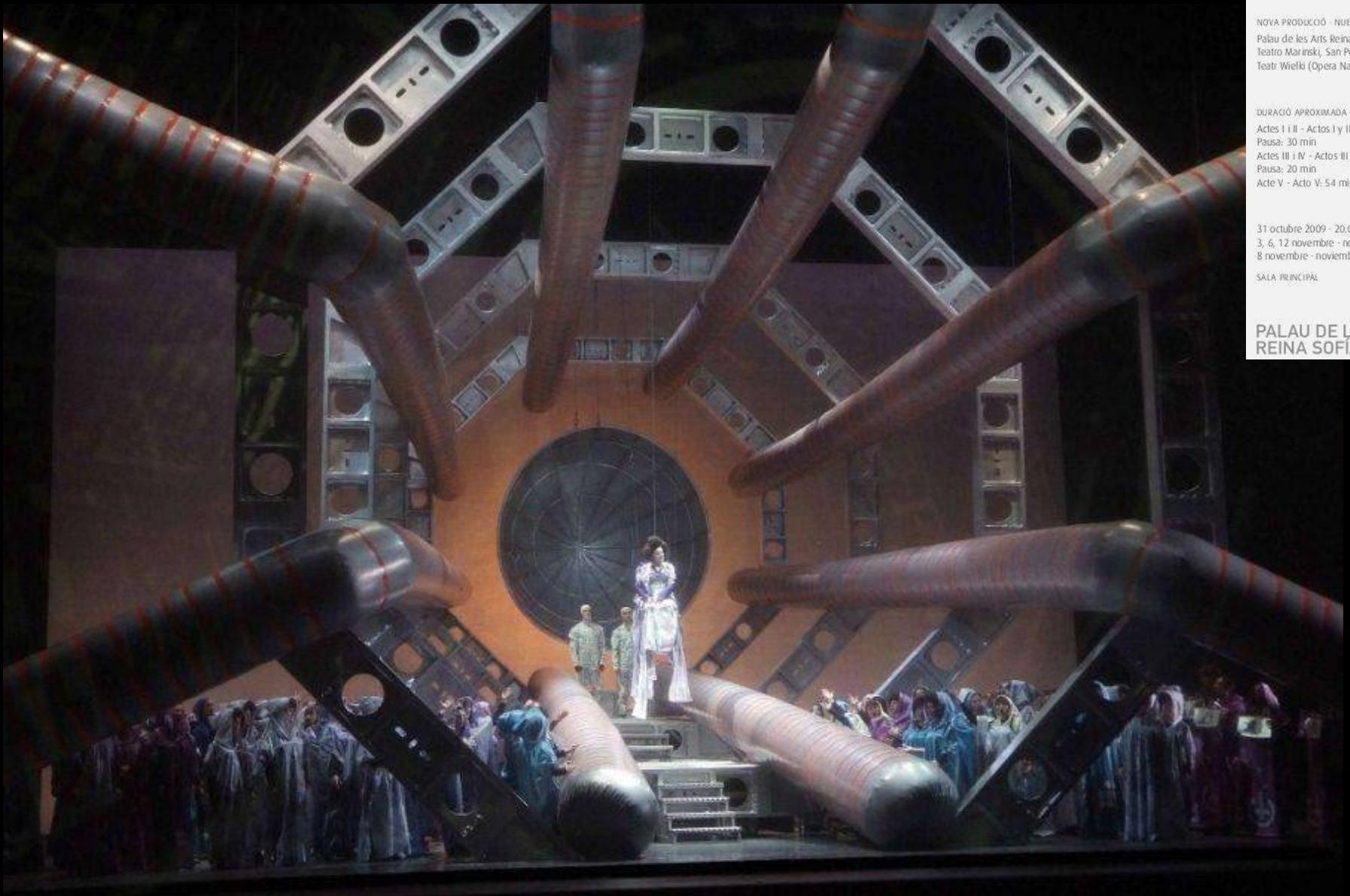
DéTECTEURS ATLAS

DURACIÓ APROXIMADA · DURACIÓN APROXIMADA  
Actes I i II - Actos I y II: 1 h 21 min  
Pausa: 30 min  
Actes III i IV - Actos III y IV: 1 h 42 min  
Pausa: 20 min  
Acte V - Acto V: 54 min

31 octubre 2009 - 20.00 h  
3, 6, 12 noviembre - noviembre 2009 - 20.00 h  
8 noviembre - noviembre 2009 - 19.00 h

SALA PRINCIPAL

PALAU DE LES ARTS  
REINA SOFÍA Temporada 2009/2010



# Détecteurs D0 vs ATLAS

Accélérateurs → LHC vs TeVatron

chaud / froid

1.8 TeV / 14 TeV

LHC( 1,9 K soit 271.3°C,  $10^{-13}$  atm,  $10^9$  collisions par seconde)

champ magnétique \* 10

intensité des faisceaux  $10^{30} \text{ cm}^{-2} \text{ s}^{-1}$  /  $2.10^{31} \text{ cm}^{-2} \text{ s}^{-1}$

Détecteurs ~10 ans d'écart

D0 : pas de solénoïde

→ pas de séparation de charge

→ pas de mesure d'impulsion !!!

ATLAS :

avancées énormes en électronique, informatique, détection

ATLAS et CMS au CERN

ont profité des avancées des précédents détecteurs Delphi, Aleph, L3 et opal

# Détecteurs D0 vs ATLAS

Accélérateurs → LHC vs TeVatron

chaud / froid

1.8 TeV / 14 TeV

LHC( 1,9 K soit 271.3°C,  $10^{-13}$  atm,  $10^9$  collisions par seconde)

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intensité des faisceaux  $10^{30} \text{ cm}^{-2} \text{ s}^{-1}$  /  $2.10^{31} \text{ cm}^{-2} \text{ s}^{-1}$

Détecteurs ~10 ans d'écart

avancées énormes en électronique, informatique, détection

ATLAS et CMS au CERN

ont profité des avancées des précédents détecteurs Delphi, Aleph, L3 et opal

# Conclusion

relire la présentation

# Backup

# Détecter pourquoi ? comprendre

|                                    |                                   |
|------------------------------------|-----------------------------------|
| 1.00794<br>H<br>Hydrogène<br>1     | 4.002602<br>He<br>Hélium<br>2     |
| 6.941<br>Li<br>Lithium<br>3        | 9.012182<br>Be<br>Béryllium<br>4  |
| 22.98976<br>Na<br>Sodium<br>11     | 24.3050<br>Mg<br>Magnéinium<br>12 |
| 39.0983<br>K<br>Potassium<br>19    | 40.078<br>Ca<br>Calcium<br>20     |
| 44.95591<br>Sc<br>Scandium<br>21   | 47.867<br>Ti<br>Titanium<br>22    |
| 50.9415<br>V<br>Vanadium<br>23     | 51.9962<br>Cr<br>Chromé<br>24     |
| 54.93804<br>Mn<br>Manganèse<br>25  | 55.845<br>Fe<br>Fer<br>26         |
| 58.93319<br>Co<br>Cobalt<br>27     | 58.6934<br>Ni<br>Nickel<br>28     |
| 63.545<br>Cu<br>Cupron<br>29       | 65.38<br>Zn<br>Zinc<br>30         |
| 69.723<br>Ga<br>Gallium<br>31      | 72.64<br>Ge<br>Gérasme<br>32      |
| 74.92160<br>As<br>Arsenic<br>33    | 78.96<br>Se<br>Sélénium<br>34     |
| 78.904<br>Br<br>Brome<br>35        | 83.798<br>Kr<br>Kryptan<br>36     |
| 85.4678<br>Rb<br>Rubidium<br>37    | 88.90585<br>Sr<br>Stroncium<br>38 |
| 91.224<br>Y<br>Yttrium<br>39       | 92.90635<br>Zr<br>Zirconium<br>40 |
| 95.96<br>Nb<br>Nobium<br>41        | 98.42<br>Mo<br>Molybde<br>42      |
| 101.07<br>Tc<br>Technetium<br>43   | 102.9055<br>Ru<br>Ruthénium<br>44 |
| 106.42<br>Rh<br>Rhodium<br>45      | 107.8862<br>Pd<br>Palladium<br>46 |
| 112.441<br>Ag<br>Argent<br>47      | 114.818<br>Cd<br>Cadmium<br>48    |
| 118.710<br>In<br>Indium<br>49      | 121.769<br>Sn<br>Sain<br>50       |
| 121.9044<br>Sb<br>Antimoine<br>51  | 127.80<br>Te<br>Tellure<br>52     |
| 131.293<br>I<br>Iode<br>53         | 136.9044<br>Xe<br>Xénon<br>54     |
| 132.9054<br>Cs<br>Césium<br>55     | 137.327<br>Ba<br>Baryum<br>56     |
| 174.9668<br>Lu<br>Lutérium<br>71   | 178.49<br>Hf<br>Hafnium<br>72     |
| 180.9478<br>Ta<br>Tantalum<br>73   | 183.84<br>W<br>Tungstène<br>74    |
| 186.207<br>Re<br>Rhenium<br>75     | 190.23<br>Os<br>Osmium<br>76      |
| 192.217<br>Ir<br>Iridium<br>77     | 195.08<br>Pt<br>Platine<br>78     |
| 198.9665<br>Au<br>Or<br>79         | 200.59<br>Hg<br>Mercure<br>80     |
| 204.3833<br>Tl<br>Thallium<br>81   | 207.2<br>Pb<br>Piombr<br>82       |
| 208.9804<br>Bi<br>Bismuth<br>83    | 210.0<br>Po<br>Polonium<br>84     |
| 210.0<br>At<br>Astato<br>85        | 210.0<br>Rn<br>Rosten<br>86       |
| (226)<br>Fr<br>Francium<br>87      | (242)<br>Ra<br>Radium<br>88       |
| (242)<br>Rf<br>Ruthénium<br>89     | (261)<br>Db<br>Dubrium<br>90      |
| (261)<br>Lr<br>Lanthanum<br>91     | (264)<br>Sg<br>Seathélium<br>92   |
| (264)<br>Bh<br>Bohrium<br>93       | (264)<br>Hs<br>Hassium<br>94      |
| (264)<br>Mt<br>Méradium<br>95      | (268)<br>Ds<br>Darmstadium<br>96  |
| (268)<br>Rg<br>Roentgenium<br>97   | (271)<br>Cn<br>Copernicium<br>98  |
| (271)<br>Uut<br>Ununtrium<br>99    | (272)<br>Fl<br>Filérovium<br>100  |
| (272)<br>Uup<br>Ununpentium<br>101 | (284)<br>Lv<br>Livermeium<br>116  |
| (284)<br>Uus<br>Ununseptium<br>117 | (292)<br>Uuo<br>Ununoctium<br>118 |

|                                   |                                  |                                      |                                |                                 |                                |                                 |                                  |                                 |                                   |                                 |                               |                                   |                                |
|-----------------------------------|----------------------------------|--------------------------------------|--------------------------------|---------------------------------|--------------------------------|---------------------------------|----------------------------------|---------------------------------|-----------------------------------|---------------------------------|-------------------------------|-----------------------------------|--------------------------------|
| 138.9054<br>La<br>Lanthanum<br>57 | 140.116<br>Ce<br>Cézium<br>58    | 140.9076<br>Pr<br>Praseodyme<br>59   | 144.242<br>Nd<br>Néodyme<br>60 | 145.0<br>Pm<br>Prométhium<br>61 | 150.36<br>Sm<br>Samarium<br>62 | 151.964<br>Eu<br>Europium<br>63 | 157.25<br>Gd<br>Gadolinium<br>64 | 158.9253<br>Tb<br>Terbium<br>65 | 162.500<br>Dy<br>Dysprosium<br>66 | 164.9303<br>Ho<br>Holmium<br>67 | 167.259<br>Er<br>Erbium<br>68 | 168.9342<br>Tm<br>Thulium<br>69   | 173.054<br>Yb<br>Yttrium<br>70 |
| (227)<br>Ac<br>Actinium<br>89     | 232.03890<br>Th<br>Thorium<br>90 | 231.0358<br>Pa<br>Protactinium<br>91 | 238.0289<br>U<br>Uranium<br>92 | (237)<br>Np<br>Neptunium<br>93  | (244)<br>Pu<br>Plutonium<br>94 | (243)<br>Am<br>Americium<br>95  | (247)<br>Cm<br>Curium<br>96      | (247)<br>Bk<br>Berkelium<br>97  | (251)<br>Cf<br>Californium<br>98  | (252)<br>Es<br>Eisenium<br>99   | (257)<br>Fm<br>Fermium<br>100 | (258)<br>Md<br>Mendelevium<br>101 | (259)<br>No<br>Nobelium<br>102 |

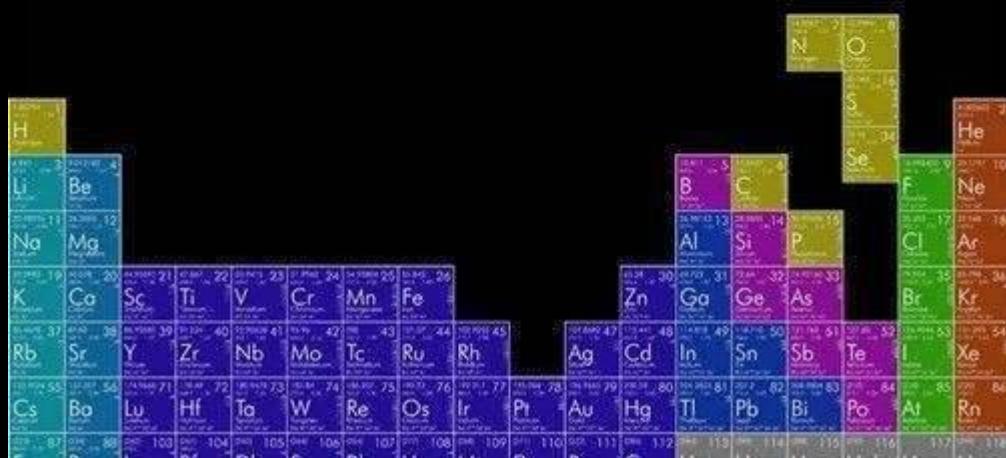
# Détecter pourquoi ? comprendre

Hydrogène = proton + e<sup>-</sup>



|                                    |                                    |                                   |
|------------------------------------|------------------------------------|-----------------------------------|
| 1.00794<br>1<br>H<br>Hydrogène     | 9.012182<br>4<br>Be<br>Béryllium   | 2.01360<br>10<br>Ne<br>Néon       |
| 6.941<br>3<br>Li<br>Lithium        | 24.3050<br>12<br>Mg<br>Magnéinium  | 4.002602<br>2<br>He<br>Hélium     |
| 22.98976<br>11<br>Na<br>Sodium     | 50.9415<br>23<br>Sc<br>Scandium    | 10.811<br>5<br>B<br>Bore          |
| 39.9983<br>19<br>K<br>Potassium    | 51.9962<br>24<br>Ti<br>Titanium    | 12.0107<br>6<br>C<br>Carbone      |
| 40.078<br>20<br>Ca<br>Calcium      | 54.93804<br>25<br>Cr<br>Chromé     | 14.0067<br>7<br>N<br>Azote        |
| 44.9591<br>21<br>Sc<br>Scandium    | 55.945<br>26<br>Mn<br>Manganèse    | 15.9994<br>8<br>O<br>Oxygène      |
| 49.9412<br>31<br>V<br>Vanadium     | 56.93319<br>27<br>Fe<br>Fer        | 18.998402<br>9<br>F<br>Fluor      |
| 54.93804<br>32<br>Cr<br>Chromé     | 58.6934<br>28<br>Co<br>Cobalt      | 20.1797<br>10<br>Ne<br>Néon       |
| 58.93115<br>33<br>Mn<br>Manganèse  | 58.93319<br>29<br>Ni<br>Nickel     | 26.98152<br>13<br>Al<br>Aluminium |
| 61.9412<br>34<br>Fe<br>Fer         | 63.545<br>30<br>Cu<br>Cupro        | 28.0855<br>14<br>Si<br>Silicium   |
| 69.723<br>31<br>Co<br>Cobalt       | 65.38<br>31<br>Zn<br>Zinc          | 30.97696<br>15<br>P<br>Phosphore  |
| 72.64<br>32<br>Ni<br>Nickel        | 69.723<br>31<br>Zn<br>Zinc         | 32.065<br>16<br>S<br>Sulfure      |
| 74.92160<br>33<br>Cu<br>Cupro      | 72.64<br>32<br>Ga<br>Gallium       | 35.453<br>17<br>Cl<br>Chlore      |
| 78.96<br>34<br>Zn<br>Zinc          | 72.64<br>32<br>Ge<br>Géermanium    | 39.948<br>18<br>Ar<br>Argon       |
| 79.904<br>35<br>Ga<br>Gallium      | 74.92160<br>33<br>As<br>Arsenic    | 83.798<br>36<br>Kr<br>Krypian     |
| 83.798<br>36<br>Ge<br>Géermanium   | 77.904<br>34<br>Se<br>Sélenium     | 131.293<br>53<br>Xe<br>Xénon      |
| 87.02<br>37<br>Rb<br>Rubidium      | 88.90585<br>39<br>Y<br>Yttrium     | 121.769<br>51<br>Te<br>Tellure    |
| 88.90585<br>39<br>Sr<br>Strontium  | 91.224<br>40<br>Zr<br>Zirconium    | 126.9044<br>52<br>Sn<br>Sain      |
| 91.224<br>40<br>Rb<br>Rubidium     | 92.90635<br>41<br>Nb<br>Nobium     | 127.80<br>54<br>I<br>Iode         |
| 95.96<br>42<br>Tc<br>Technetium    | 98.43<br>43<br>Ru<br>Rhodium       | 131.293<br>53<br>Xe<br>Xénon      |
| 101.07<br>44<br>Mo<br>Molybdo      | 102.9055<br>45<br>Rh<br>Rhodium    | 149.116<br>50<br>Cs<br>Césium     |
| 106.42<br>46<br>Ru<br>Rhodium      | 107.88682<br>47<br>Pd<br>Palladium | 174.96665<br>51<br>Ba<br>Baryum   |
| 112.441<br>48<br>Cd<br>Cadmium     | 112.441<br>48<br>Cd<br>Cadmium     | 178.49<br>72<br>Cs<br>Césium      |
| 114.818<br>49<br>In<br>Indium      | 118.710<br>50<br>Sn<br>Sain        | 180.9478<br>73<br>Lu<br>Lutetium  |
| 127.80<br>51<br>Te<br>Tellure      | 127.80<br>51<br>In<br>Indium       | 183.84<br>74<br>Hf<br>Hafnium     |
| 128.9044<br>52<br>I<br>Iode        | 128.9044<br>53<br>Te<br>Tellure    | 186.207<br>75<br>Ta<br>Tantale    |
| 131.293<br>53<br>Xe<br>Xénon       | 131.293<br>53<br>I<br>Iode         | 190.23<br>76<br>W<br>Tungstène    |
| 141.9054<br>55<br>Cs<br>Césium     | 195.08<br>78<br>Re<br>Rhenium      | 192.217<br>77<br>Os<br>Osmium     |
| 143.9054<br>57<br>La<br>Lanthan    | 196.99665<br>79<br>Ir<br>Iridium   | 198.9253<br>65<br>Pt<br>Platine   |
| 146.116<br>58<br>Ce<br>Cértium     | 204.9883<br>81<br>Au<br>Or         | 202.500<br>80<br>Hg<br>Mercure    |
| 149.9076<br>59<br>Pr<br>Praseodyme | 208.9804<br>83<br>Tl<br>Thallium   | 204.9303<br>67<br>Pb<br>Plomb     |
| 144.242<br>60<br>Nd<br>Néodyme     | 210.2<br>82<br>Bi<br>Bismuth       | 208.9804<br>83<br>Po<br>Polonium  |
| 145.61<br>61<br>Pm<br>Prométhium   | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>At<br>Astato       |
| 150.36<br>62<br>Sm<br>Samarium     | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>Rn<br>Rosten       |
| 151.964<br>63<br>Eu<br>Europium    | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 157.25<br>64<br>Gd<br>Gadolinium   | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 158.9253<br>65<br>Tb<br>Terbium    | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 162.500<br>66<br>Dy<br>Dysprosium  | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Rn<br>Rosten       |
| 164.9303<br>67<br>Ho<br>Holmium    | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>Rn<br>Rosten       |
| 167.259<br>68<br>Tm<br>Thulium     | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 168.9342<br>69<br>Yb<br>Yttrium    | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 173.054<br>70<br>Fr<br>Francium    | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 182.911<br>71<br>Ac<br>Actinium    | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 183.84<br>72<br>Ba<br>Baryum       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 186.207<br>73<br>Lu<br>Lutetium    | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 190.23<br>74<br>Hf<br>Hafnium      | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 192.217<br>75<br>Ta<br>Tantale     | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 195.08<br>76<br>W<br>Tungstène     | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 196.99665<br>77<br>Os<br>Osmium    | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 198.9253<br>78<br>Pt<br>Platine    | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 204.9883<br>79<br>Hg<br>Mercure    | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 208.9804<br>80<br>Pb<br>Plomb      | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 208.9804<br>81<br>Tl<br>Thallium   | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
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| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
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| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
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| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
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| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
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| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
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| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
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| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
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| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
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| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
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| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
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| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>86<br>Rn<br>Rosten       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>84<br>Po<br>Polonium     |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>85<br>At<br>Astato       |
| 210.2<br>82<br>Bi<br>Bismuth       | 210.2<br>82<br>Bi<br>Bismuth       | 210.2                             |

...and this is how, in 1869, Dmitri Mendeleev completed the first periodic table.

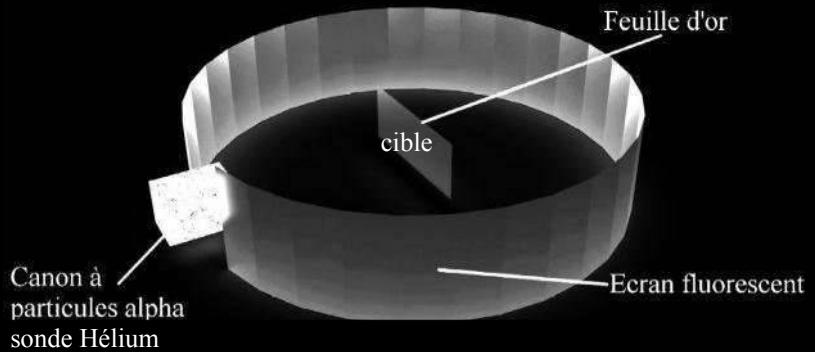


# Détecter pourquoi ? comprendre

|                                       |                                      |
|---------------------------------------|--------------------------------------|
| 1.00794<br>H<br>Hydrogène<br>1        | 4.002602<br>He<br>Hélium<br>2        |
| 6.941<br>Li<br>Lithium<br>3           | 9.012182<br>Be<br>Béryllium<br>4     |
| 22.98976<br>Na<br>Sodium<br>11        | 24.3050<br>Mg<br>Magnéinium<br>12    |
| 39.0983<br>K<br>Potassium<br>19       | 40.078<br>Ca<br>Calcium<br>20        |
| 44.95591<br>Sc<br>Scandium<br>21      | 47.867<br>Ti<br>Titanium<br>22       |
| 50.9415<br>V<br>Vanadium<br>23        | 51.9962<br>Cr<br>Chromé<br>24        |
| 54.93804<br>Mn<br>Manganèse<br>25     | 55.845<br>Fe<br>Fer<br>26            |
| 58.93319<br>Co<br>Cobalt<br>27        | 58.6934<br>Ni<br>Nickel<br>28        |
| 63.545<br>Cu<br>Cupron<br>29          | 65.38<br>Zn<br>Zinc<br>30            |
| 69.723<br>Ga<br>Gallium<br>31         | 72.64<br>Ge<br>Gérasme<br>32         |
| 74.92160<br>As<br>Arsenic<br>33       | 78.96<br>Se<br>Sélénium<br>34        |
| 78.904<br>Br<br>Brome<br>35           | 83.798<br>Kr<br>Kryptan<br>36        |
| 88.90585<br>Rb<br>Rubidium<br>37      | 89.91224<br>Sr<br>Stroncium<br>38    |
| 91.224<br>Y<br>Yttrium<br>39          | 92.90635<br>Zr<br>Zirconium<br>40    |
| 95.96<br>Nb<br>Nobium<br>41           | 98.42<br>Mo<br>Molybde<br>42         |
| 101.07<br>Tc<br>Technetium<br>43      | 102.9055<br>Ru<br>Ruthénium<br>44    |
| 106.42<br>Rh<br>Rhodium<br>45         | 107.8862<br>Pd<br>Palladium<br>46    |
| 112.441<br>Ag<br>Argent<br>47         | 114.818<br>Cd<br>Cadmium<br>48       |
| 118.710<br>In<br>Indium<br>49         | 121.769<br>Sn<br>Sain<br>50          |
| 121.769<br>Te<br>Tellure<br>51        | 126.9044<br>Sb<br>Antimoine<br>52    |
| 127.80<br>I<br>Iode<br>53             | 131.293<br>Xe<br>Xénon<br>54         |
| 137.3227<br>Cs<br>Césium<br>55        | 140.9668<br>Ba<br>Baryum<br>56       |
| 140.9668<br>Lu<br>Lutérium<br>71      | 141.974<br>Hf<br>Hafnium<br>72       |
| 143.9478<br>Ta<br>Tantalum<br>73      | 145.923<br>W<br>Tungstène<br>74      |
| 149.9665<br>Re<br>Rhenium<br>75       | 150.36<br>Os<br>Osmium<br>76         |
| 151.964<br>Ir<br>Iridium<br>77        | 157.25<br>Pt<br>Platine<br>78        |
| 158.9253<br>Au<br>Or<br>79            | 162.500<br>Hg<br>Mercure<br>80       |
| 164.9303<br>Tl<br>Thallium<br>81      | 167.259<br>Pb<br>Piombr<br>82        |
| 168.9342<br>Bi<br>Bismuth<br>83       | 170.000<br>Po<br>Polonium<br>84      |
| 173.054<br>At<br>Astato<br>85         | 172.000<br>Rn<br>Rosten<br>86        |
| 226.0261<br>Fr<br>Francium<br>87      | 226.0261<br>Ra<br>Radium<br>88       |
| 226.0261<br>Lr<br>Lanthanum<br>103    | 226.0261<br>Rf<br>Ruthénium<br>104   |
| 226.0261<br>Db<br>Dubrium<br>105      | 226.0261<br>Sg<br>Seathrium<br>106   |
| 226.0261<br>Bh<br>Bohrium<br>107      | 226.0261<br>Hs<br>Hassium<br>108     |
| 226.0261<br>Mt<br>Méradium<br>109     | 226.0261<br>Ds<br>Darmstadium<br>110 |
| 226.0261<br>Rg<br>Roentgenium<br>111  | 226.0261<br>Cn<br>Copernicium<br>112 |
| 226.0261<br>Uut<br>Ununtrium<br>113   | 226.0261<br>Fl<br>Filérovium<br>114  |
| 226.0261<br>Uup<br>Ununpentium<br>115 | 226.0261<br>Lv<br>Livermorium<br>116 |
| 226.0261<br>Uus<br>Ununseptium<br>117 | 226.0261<br>Uuo<br>Ununoctium<br>118 |

|                                 |                                  |                                      |                                |                                 |                                |                                 |                                  |                                 |                                   |                                 |                               |                                   |                                |
|---------------------------------|----------------------------------|--------------------------------------|--------------------------------|---------------------------------|--------------------------------|---------------------------------|----------------------------------|---------------------------------|-----------------------------------|---------------------------------|-------------------------------|-----------------------------------|--------------------------------|
| 138.9054<br>La<br>Lanthan<br>57 | 140.116<br>Ce<br>Cézium<br>58    | 140.9076<br>Pr<br>Praseodyme<br>59   | 144.242<br>Nd<br>Néodyme<br>60 | 145.0<br>Pm<br>Prométhium<br>61 | 150.36<br>Sm<br>Samarium<br>62 | 151.964<br>Eu<br>Europium<br>63 | 157.25<br>Gd<br>Gadolinium<br>64 | 158.9253<br>Tb<br>Terbium<br>65 | 162.500<br>Dy<br>Dysprosium<br>66 | 164.9303<br>Ho<br>Holmium<br>67 | 167.259<br>Er<br>Erbium<br>68 | 168.9342<br>Tm<br>Thulium<br>69   | 173.054<br>Yb<br>Yttrium<br>70 |
| (227)<br>Ac<br>Actinium<br>89   | 232.03890<br>Th<br>Thorium<br>90 | 231.0358<br>Pa<br>Protactinium<br>91 | 238.0289<br>U<br>Uranium<br>92 | (237)<br>Np<br>Neptunium<br>93  | (244)<br>Pu<br>Plutonium<br>94 | (243)<br>Am<br>Americium<br>95  | (247)<br>Cm<br>Curium<br>96      | (247)<br>Bk<br>Berkelium<br>97  | (251)<br>Cf<br>Californium<br>98  | (252)<br>Es<br>Eisenium<br>99   | (257)<br>Fm<br>Fermium<br>100 | (258)<br>Md<br>Mendelevium<br>101 | (259)<br>No<br>Nobelium<br>102 |

# Rutherford 1911



Canon à particules alpha sonde Hélium

|                                 |                                   |                                   |                                     |                                    |                                    |                                  |                                   |                                  |                                    |                                   |                                   |                                   |                                 |                                    |                                  |                                    |                                   |                              |                                   |                              |                                |                             |                               |
|---------------------------------|-----------------------------------|-----------------------------------|-------------------------------------|------------------------------------|------------------------------------|----------------------------------|-----------------------------------|----------------------------------|------------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|---------------------------------|------------------------------------|----------------------------------|------------------------------------|-----------------------------------|------------------------------|-----------------------------------|------------------------------|--------------------------------|-----------------------------|-------------------------------|
| 1.00704<br>1<br>H<br>Hydrogène  | 9.012182<br>4<br>Li<br>Lithium    | 12.010701<br>3<br>Be<br>Béryllium | 19.006976<br>11<br>Na<br>Sodium     | 24.03050<br>12<br>Mg<br>Magnéinium | 31.008932<br>13<br>Al<br>Aluminium | 39.0983<br>19<br>K<br>Potassium  | 40.078<br>20<br>Ca<br>Calcium     | 44.95591<br>21<br>Sc<br>Scandium | 47.867<br>22<br>Ti<br>Titanium     | 50.9415<br>23<br>V<br>Vanadium    | 51.9952<br>24<br>Cr<br>Chromé     | 54.93804<br>25<br>Mn<br>Manganèse | 55.945<br>26<br>Fe<br>Fer       | 58.93319<br>27<br>Co<br>Cobalt     | 63.545<br>28<br>Ni<br>Nickel     | 65.38<br>29<br>Cu<br>Cupron        | 69.723<br>30<br>Zn<br>Zinc        | 72.64<br>31<br>Ga<br>Gallium | 74.92160<br>33<br>Ge<br>Germanium | 78.96<br>34<br>As<br>Arsenic | 79.904<br>35<br>Se<br>Sélenium | 83.798<br>36<br>Br<br>Brome | 83.994<br>37<br>Kr<br>Kryptan |
| 6.941<br>3<br>Li<br>Lithium     | 9.012182<br>4<br>Be<br>Béryllium  | 12.010701<br>3<br>Be<br>Béryllium | 19.006976<br>11<br>Na<br>Sodium     | 24.03050<br>12<br>Mg<br>Magnéinium | 31.008932<br>13<br>Al<br>Aluminium | 39.0983<br>19<br>K<br>Potassium  | 40.078<br>20<br>Ca<br>Calcium     | 44.95591<br>21<br>Sc<br>Scandium | 47.867<br>22<br>Ti<br>Titanium     | 50.9415<br>23<br>V<br>Vanadium    | 51.9952<br>24<br>Cr<br>Chromé     | 54.93804<br>25<br>Mn<br>Manganèse | 55.945<br>26<br>Fe<br>Fer       | 58.93319<br>27<br>Co<br>Cobalt     | 63.545<br>28<br>Ni<br>Nickel     | 65.38<br>29<br>Cu<br>Cupron        | 69.723<br>30<br>Zn<br>Zinc        | 72.64<br>31<br>Ga<br>Gallium | 74.92160<br>33<br>Ge<br>Germanium | 78.96<br>34<br>As<br>Arsenic | 79.904<br>35<br>Se<br>Sélenium | 83.798<br>36<br>Br<br>Brome | 83.994<br>37<br>Kr<br>Kryptan |
| 85.4678<br>37<br>Rb<br>Rubidium | 88.90585<br>39<br>Sr<br>Strontium | 91.224<br>40<br>Y<br>Yttrium      | 92.90635<br>41<br>Zr<br>Zirconium   | 95.96<br>42<br>Nb<br>Nobium        | 98.42<br>43<br>Mo<br>Molybde       | 101.07<br>44<br>Tc<br>Technetium | 102.9055<br>45<br>Ru<br>Ruthénium | 106.42<br>46<br>Pd<br>Palladium  | 107.86862<br>47<br>Ag<br>Argent    | 112.441<br>48<br>Cd<br>Cadmium    | 114.818<br>49<br>In<br>Indium     | 118.710<br>50<br>Sn<br>Sain       | 121.769<br>51<br>Te<br>Tellure  | 127.80<br>52<br>I<br>Iode          | 126.9044<br>53<br>Xe<br>Xénon    | 131.293<br>54<br>Rn<br>Roton       |                                   |                              |                                   |                              |                                |                             |                               |
| 132.9054<br>55<br>Cs<br>Césium  | 137.3227<br>56<br>Ba<br>Baryum    | 174.9668<br>71<br>Lu<br>Lutérium  | 178.49<br>72<br>Hf<br>Hafnium       | 180.9478<br>73<br>Ta<br>Tantale    | 183.84<br>74<br>W<br>Tungstène     | 186.207<br>75<br>Re<br>Rhenium   | 190.23<br>76<br>Os<br>Osmium      | 192.217<br>77<br>Ir<br>Iridium   | 195.08<br>78<br>Pt<br>Platine      | 198.9665<br>79<br>Au<br>Or        | 200.59<br>80<br>Hg<br>Mercure     | 204.383<br>81<br>Tl<br>Thallium   | 207.2<br>82<br>Pb<br>Piombe     | 208.9804<br>83<br>Bi<br>Bismuth    | 210.2<br>84<br>Po<br>Polonium    | 210.2<br>85<br>At<br>Astato        | 210.2<br>86<br>Rn<br>Roton        |                              |                                   |                              |                                |                             |                               |
| (223)<br>87<br>Fr<br>Francium   | (226)<br>88<br>Ra<br>Radium       | (242)<br>103<br>Lr<br>Lanthanum   | (242)<br>104<br>Rf<br>Rutherfordium | (262)<br>105<br>Db<br>Dubium       | (264)<br>106<br>Sg<br>Seastrium    | (264)<br>107<br>Bh<br>Bohrium    | (268)<br>108<br>Hs<br>Hassium     | (271)<br>109<br>Mt<br>Méridium   | (272)<br>110<br>Ds<br>Darmstadtium | (273)<br>111<br>Rg<br>Roentgenium | (274)<br>112<br>Cn<br>Copernicium | (274)<br>113<br>Uut<br>Ununtrium  | (274)<br>114<br>Fl<br>Flérovium | (274)<br>115<br>Uup<br>Ununpentium | (274)<br>116<br>Lv<br>Livermeium | (274)<br>117<br>Uus<br>Ununseptium | (274)<br>118<br>Uuo<br>Ununoctium |                              |                                   |                              |                                |                             |                               |

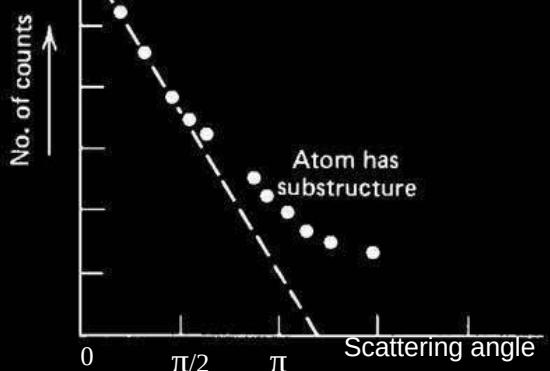
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|---------------------------------|---------------------------------|--------------------------------------|--------------------------------|--------------------------------|--------------------------------|---------------------------------|----------------------------------|---------------------------------|-----------------------------------|----------------------------------|-------------------------------|------------------------------------|--------------------------------|
| 138.9054<br>57<br>La<br>Lanthan | 140.116<br>58<br>Ce<br>Céritium | 140.9076<br>59<br>Pr<br>Praseodyme   | 144.242<br>60<br>Nd<br>Néodyme | 145<br>61<br>Pm<br>Prométhium  | 150.36<br>62<br>Sm<br>Samarium | 151.964<br>63<br>Eu<br>Europium | 157.25<br>64<br>Gd<br>Gadolinium | 158.9253<br>65<br>Tb<br>Terbium | 162.500<br>66<br>Dy<br>Dysprosium | 164.9303<br>67<br>Ho<br>Holmium  | 167.259<br>68<br>Er<br>Erbium | 168.9342<br>69<br>Tm<br>Thulium    | 173.054<br>70<br>Yb<br>Yttrium |
| (227)<br>89<br>Ac<br>Actinium   | 232.0389<br>90<br>Th<br>Thorium | 231.0358<br>91<br>Pa<br>Protactinium | 238.0289<br>92<br>U<br>Uranium | (237)<br>93<br>Np<br>Neptunium | (244)<br>94<br>Pu<br>Plutonium | (243)<br>95<br>Am<br>Americium  | (247)<br>96<br>Cm<br>Curium      | (247)<br>97<br>Bk<br>Berkelium  | (251)<br>98<br>Cf<br>Californium  | (252)<br>99<br>Es<br>Einsteinium | (255)<br>100<br>Fm<br>Fermium | (258)<br>101<br>Md<br>Mendeléovium | (259)<br>102<br>No<br>Nobelium |

comprendre

FAUX!

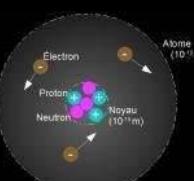


Au target *Phil. Mag. xx1, 669 (1911)*

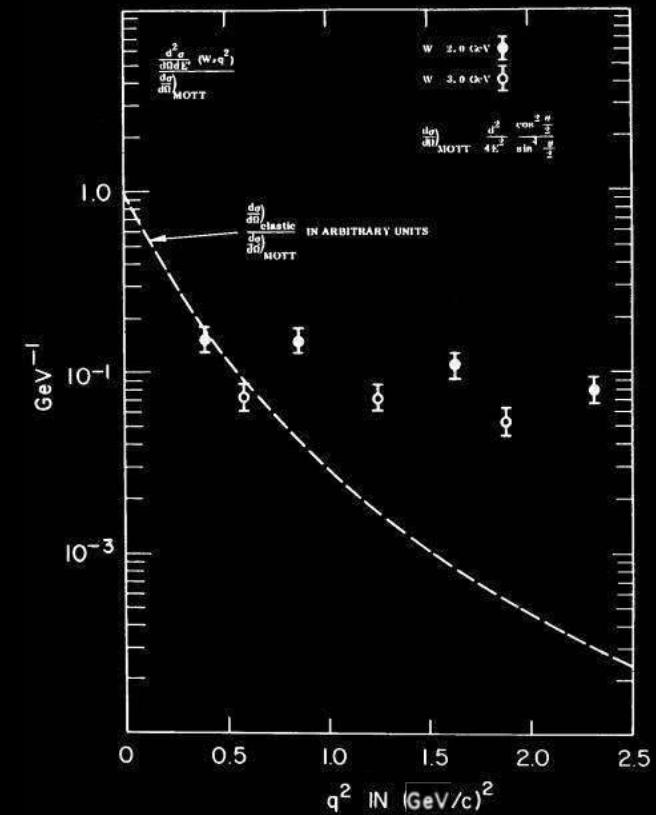
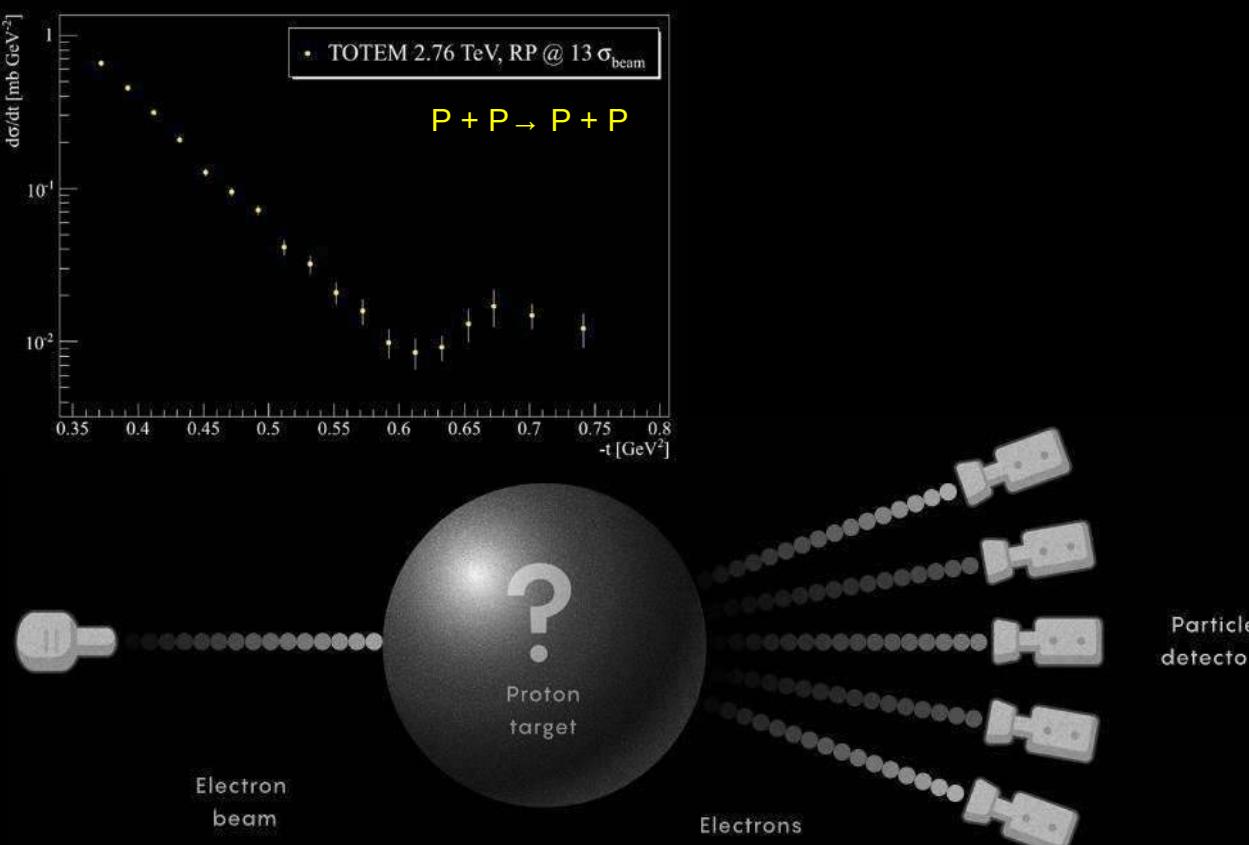


Hélium → Or

← mieux (?)

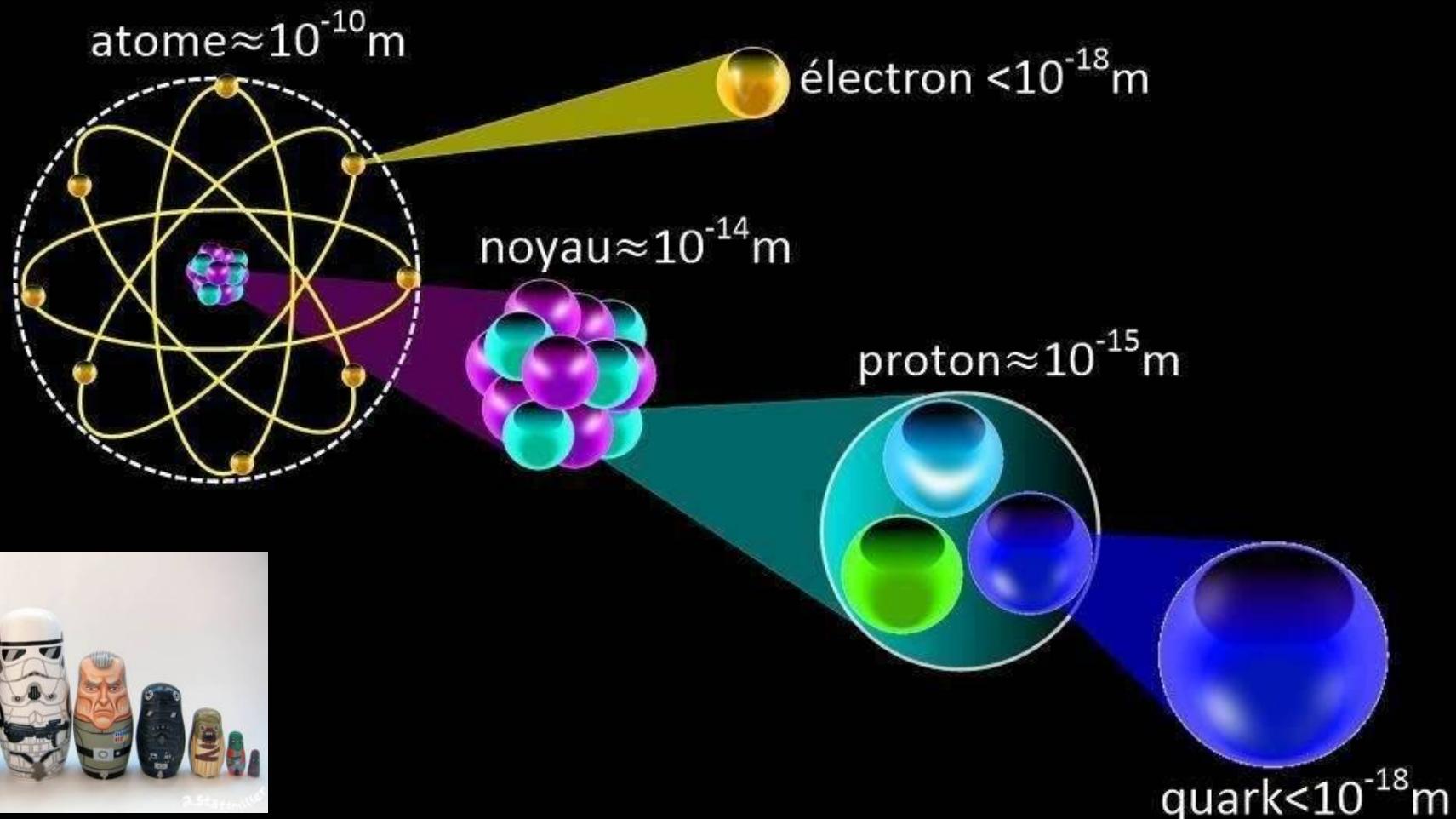


# comprendre

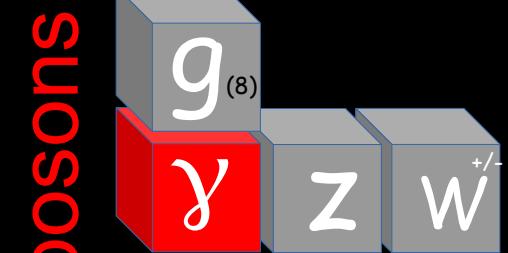
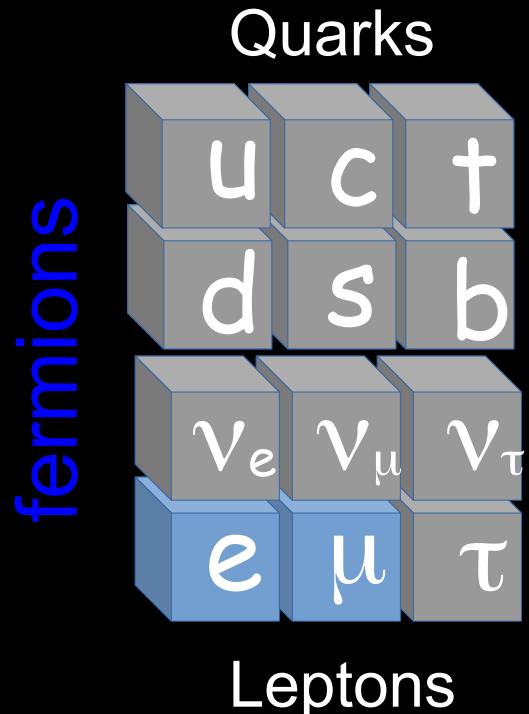
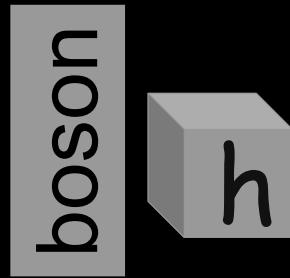


# Détecter pourquoi ?

# comprendre



# Détecter quoi ?



Spin 0

Spin 1/2

Spin 1