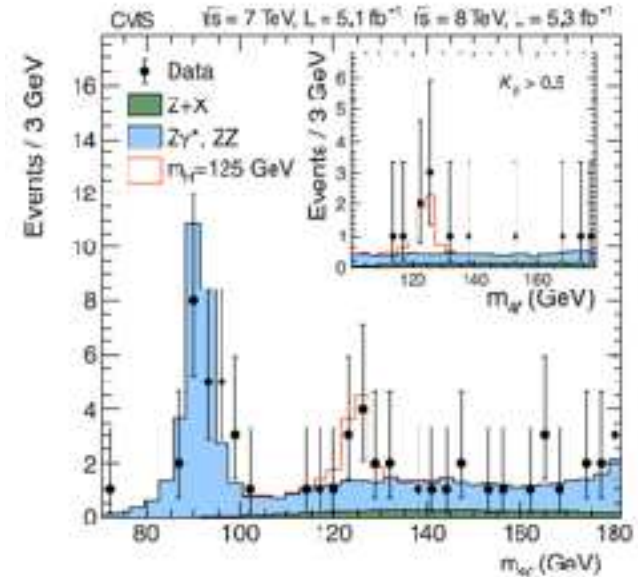


CMS Experiment at LHC - CERN  
Data recorded: Mon May 28 01:35:47 2012 CEST  
Run/Event: 195099 / 13740354  
Lumi section: 115



# Masterclass Χανιά 2019

## Ανάλυση γεγονότων CMS/LHC (ή βρες το μποζόνιο μόνος σου)

Γιώργος Αναγνώστου  
ΙΠΦΣ - Δημόκριτος



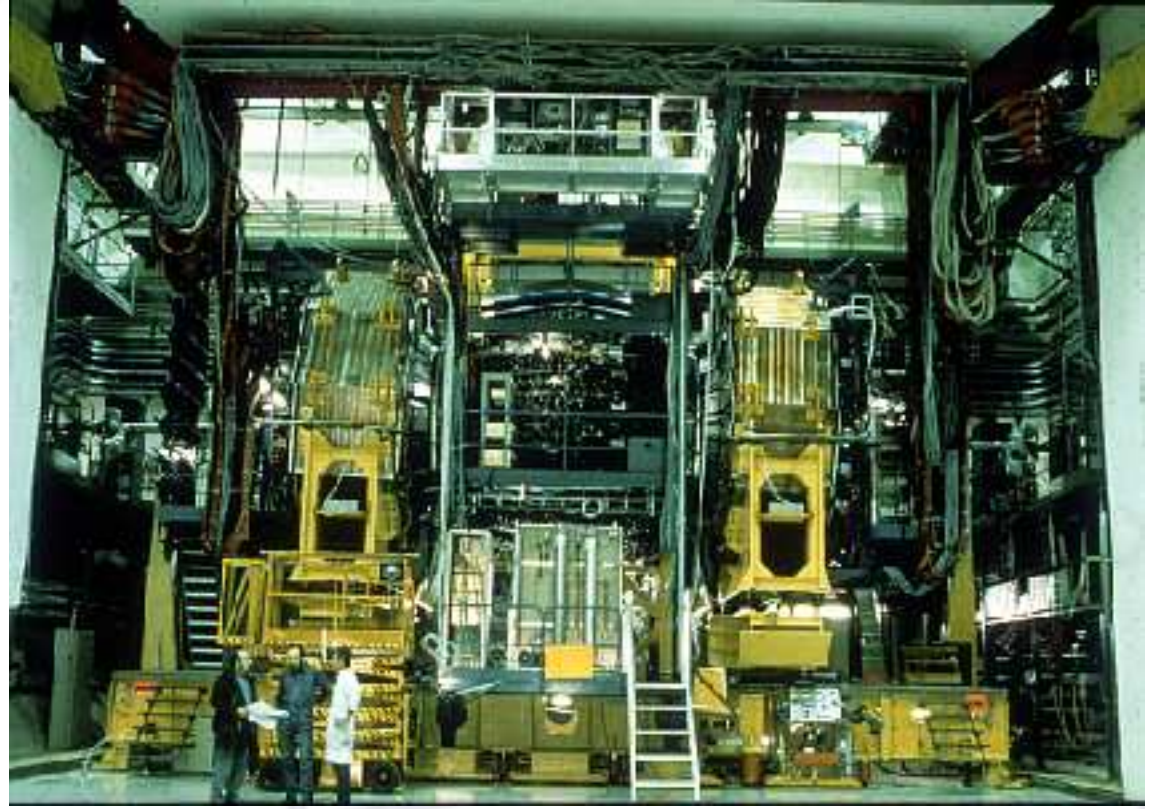
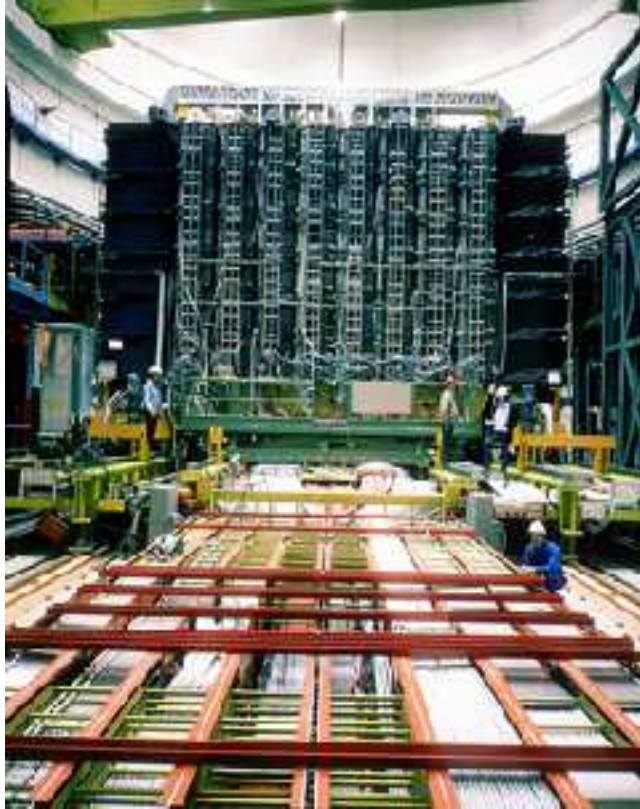
# Λίγη ιστορία



**Super Proton Synchrotron  
CERN, Geneva  
(6km circumference)**



# Τα πειράματα UA1 & UA2



## Underground Areas 1 and 2 (UA1 and UA2)

The discovery of the W particle in the UA1 detector from the October-December 1982 run of the proton-antiproton collider, producing a high transverse energy electron (arrowed). This particle is produced back-to-back with 'missing energy', indicative of the emission of an invisible neutrino.

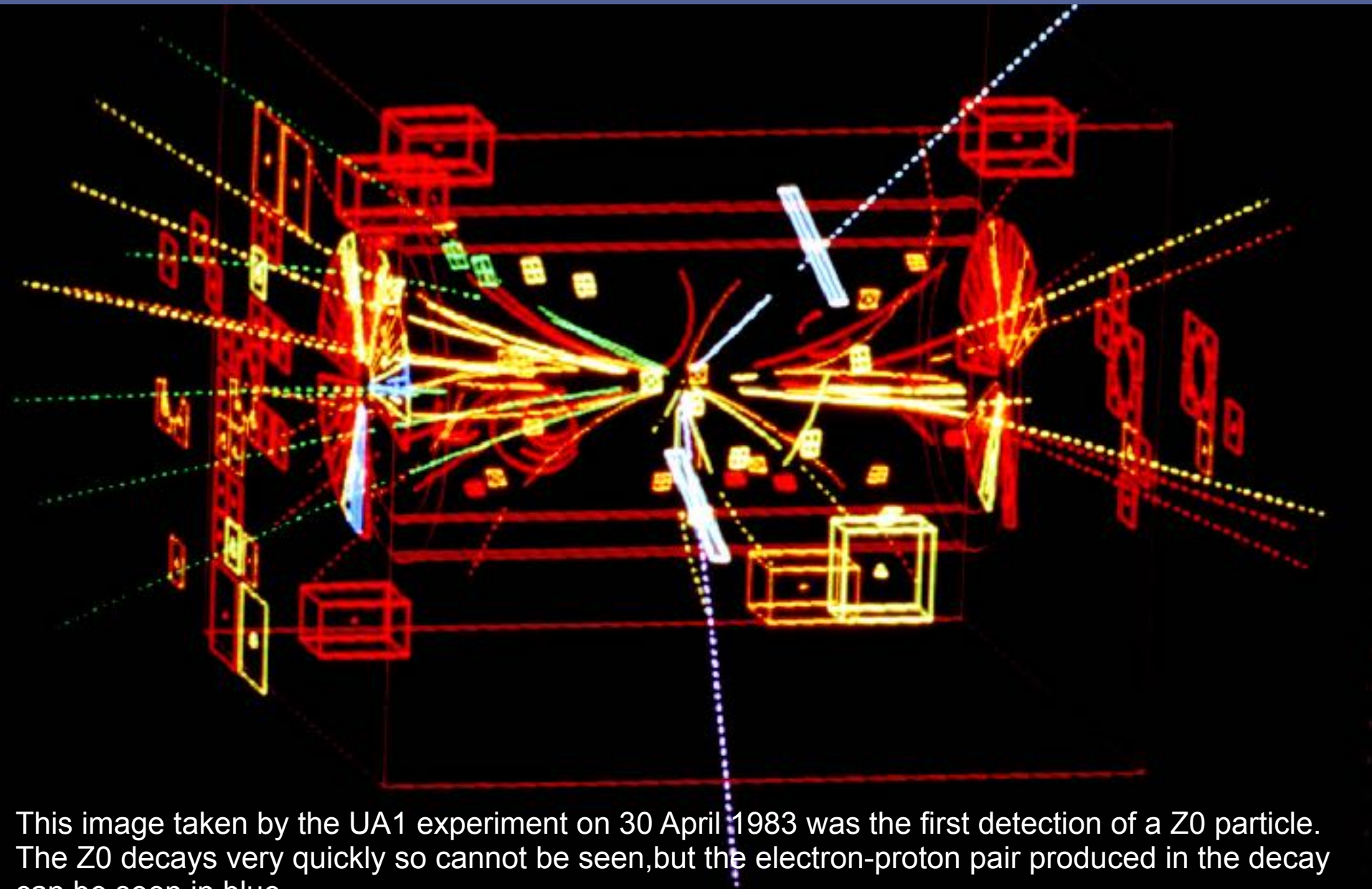
EVENT 2958. 1278.



Η ανακάλυψη του W boson



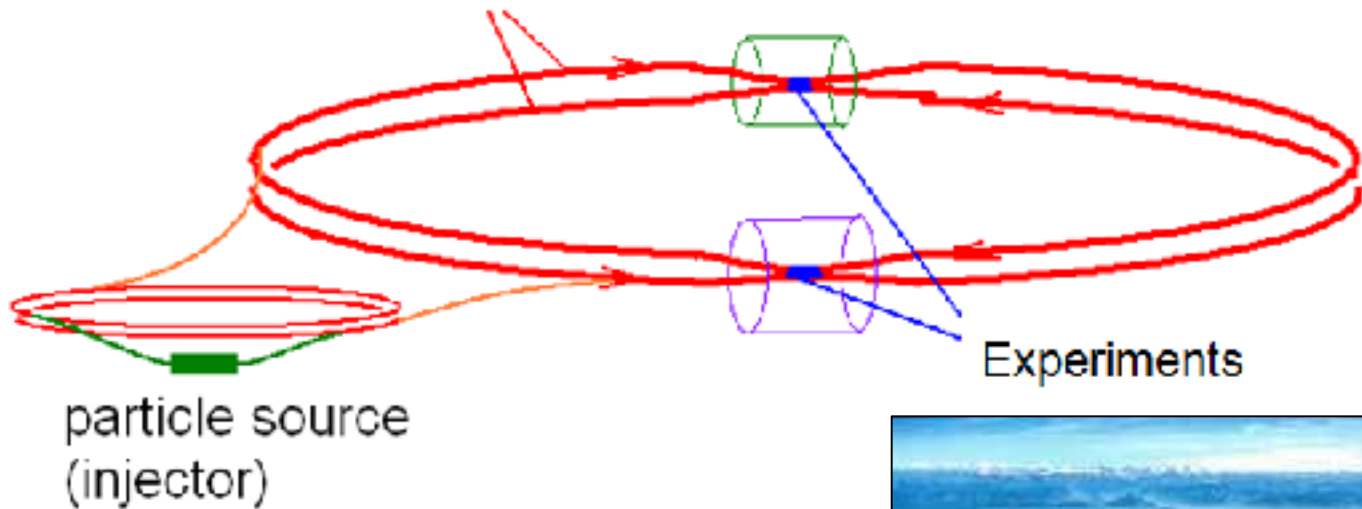
# Η ανακάλυψη του Z boson



This image taken by the UA1 experiment on 30 April 1983 was the first detection of a  $Z^0$  particle. The  $Z^0$  decays very quickly so cannot be seen, but the electron-proton pair produced in the decay can be seen in blue.

# Το πείραμα CMS/LHC

beams accelerated in large rings  
(27 km circumference at CERN)



# ΤΥΠΙΚΟΣ ΑΝΙΧΝΕΥΤΗΣ

Κυλινδρος γυρω απο το σημειο συγκρουσης των δεσμων

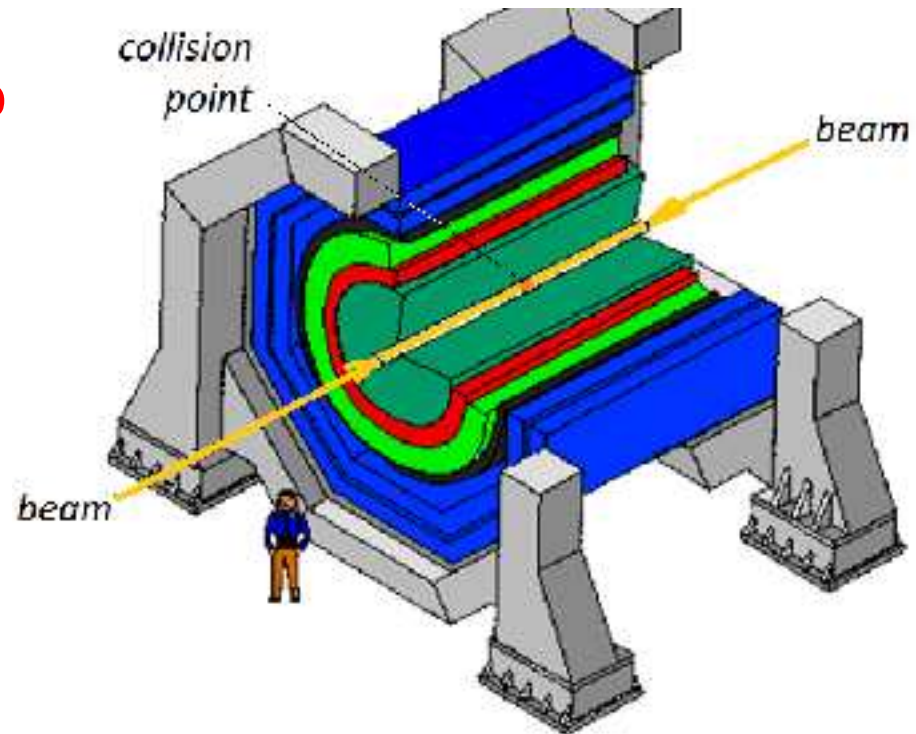
Ανιχνευτης τροχιων

Ηλεκτρομαγνητικο Θερμιδομετρο

Αδρονικο Θερμιδομετρο

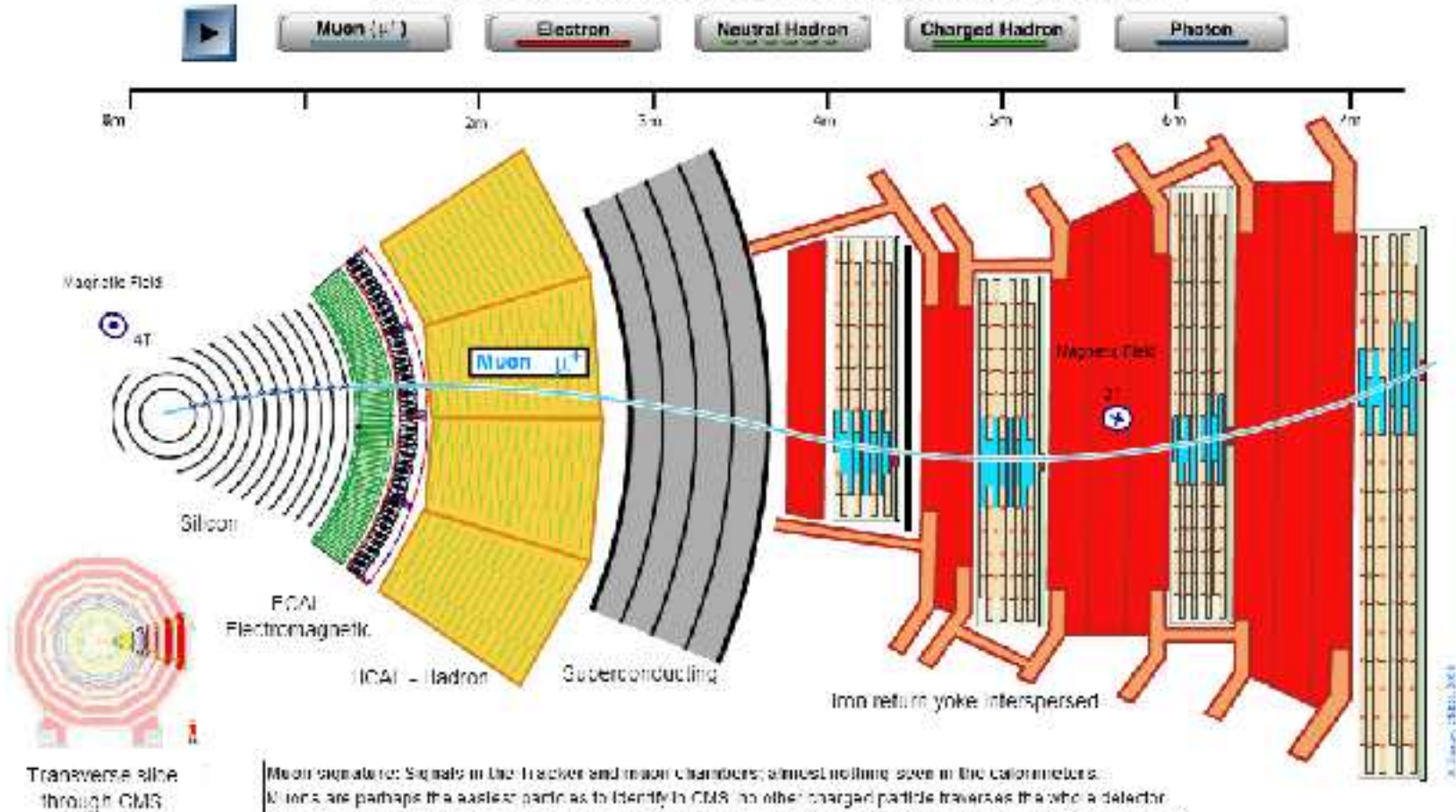
Μαγνητης\*

Ανιχνευτης τροχιων μιονιων



# Miovio

Transverse Slice of the Compact Muon Solenoid (CMS) Detector

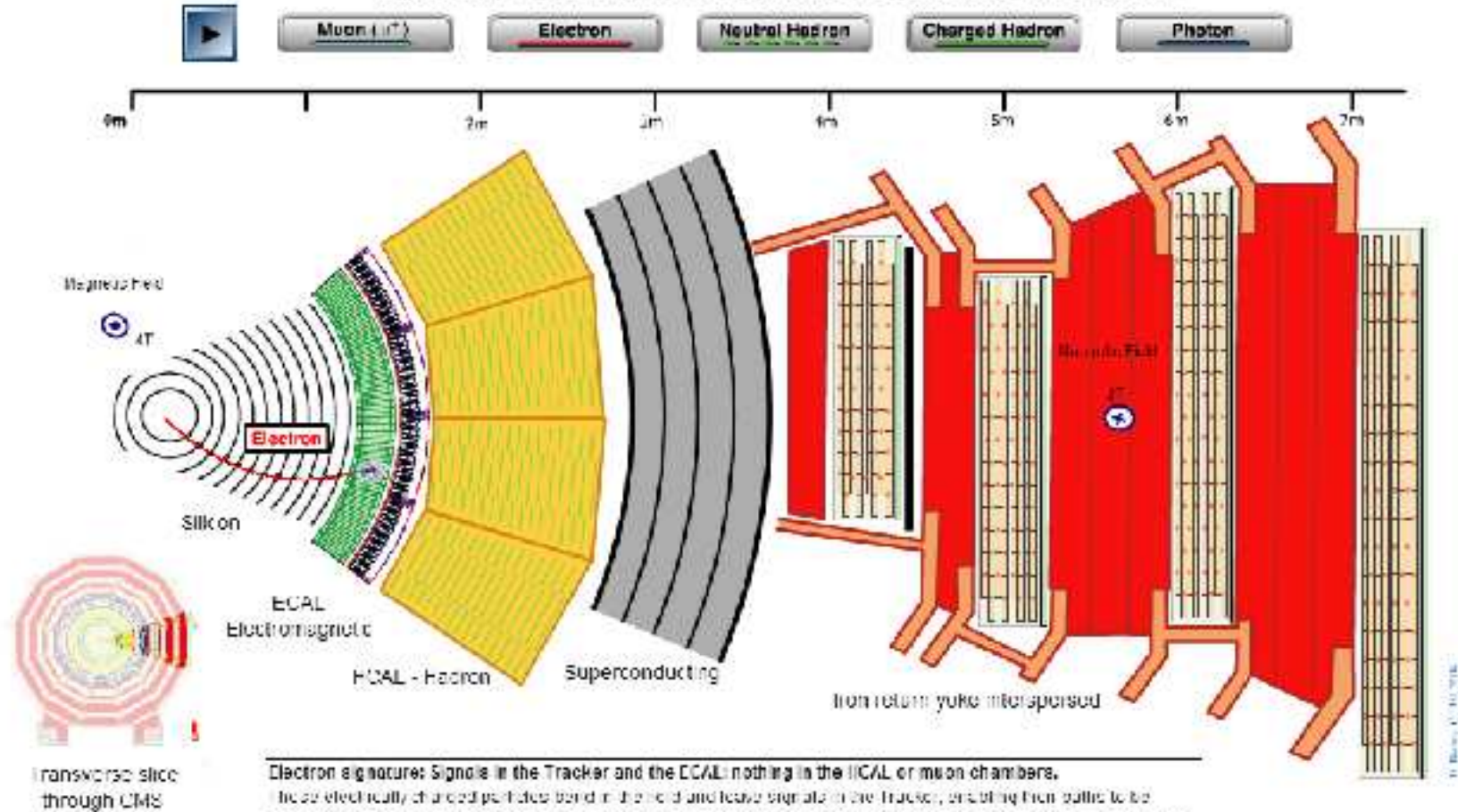


Downloaded from CMS Detector, or Slide from CERN



# Ηλεκτρονιο στο CMS

Transverse Slice of the Compact Muon Solenoid (CMS) Detector

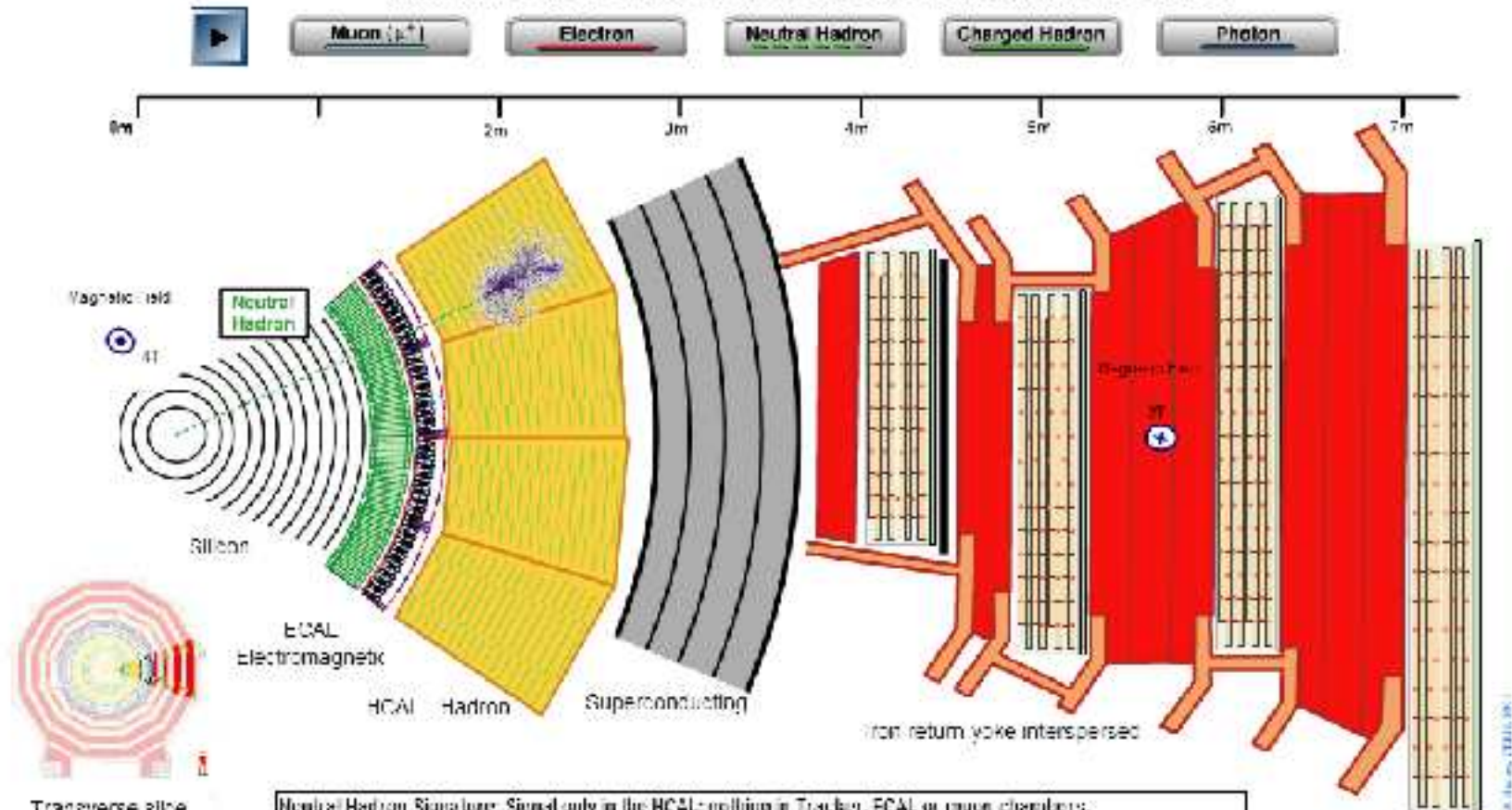


Electron signatures: signals in the Tracker and the ECAL; nothing in the HCAL or muon chambers.  
 Highly electrically charged particles bend in the field and leave signals in the Tracker, enabling their paths to be reconstructed. The amount of bend depends on the momentum they carry, with the radius of curvature,  $r$ , being given by the momentum,  $p$ , divided by  $0.3 \times B$ , where  $B$  is the magnetic field strength (3.8T in CMS). Electrons are slowed to a stop in the transparent lead tungstate crystals of the ECAL, producing a shower of electrons, photons and positrons along the way and depositing their energy in the form of light, which is detected. The amount of light is proportional to the electron energy.

Derived from CMS Detector Slice from CERN

# Ουδέτερο αδρόνιο στο CMS

Transverse Slice of the Compact Muon Solenoid (CMS) Detector



Transverse slice through CMS

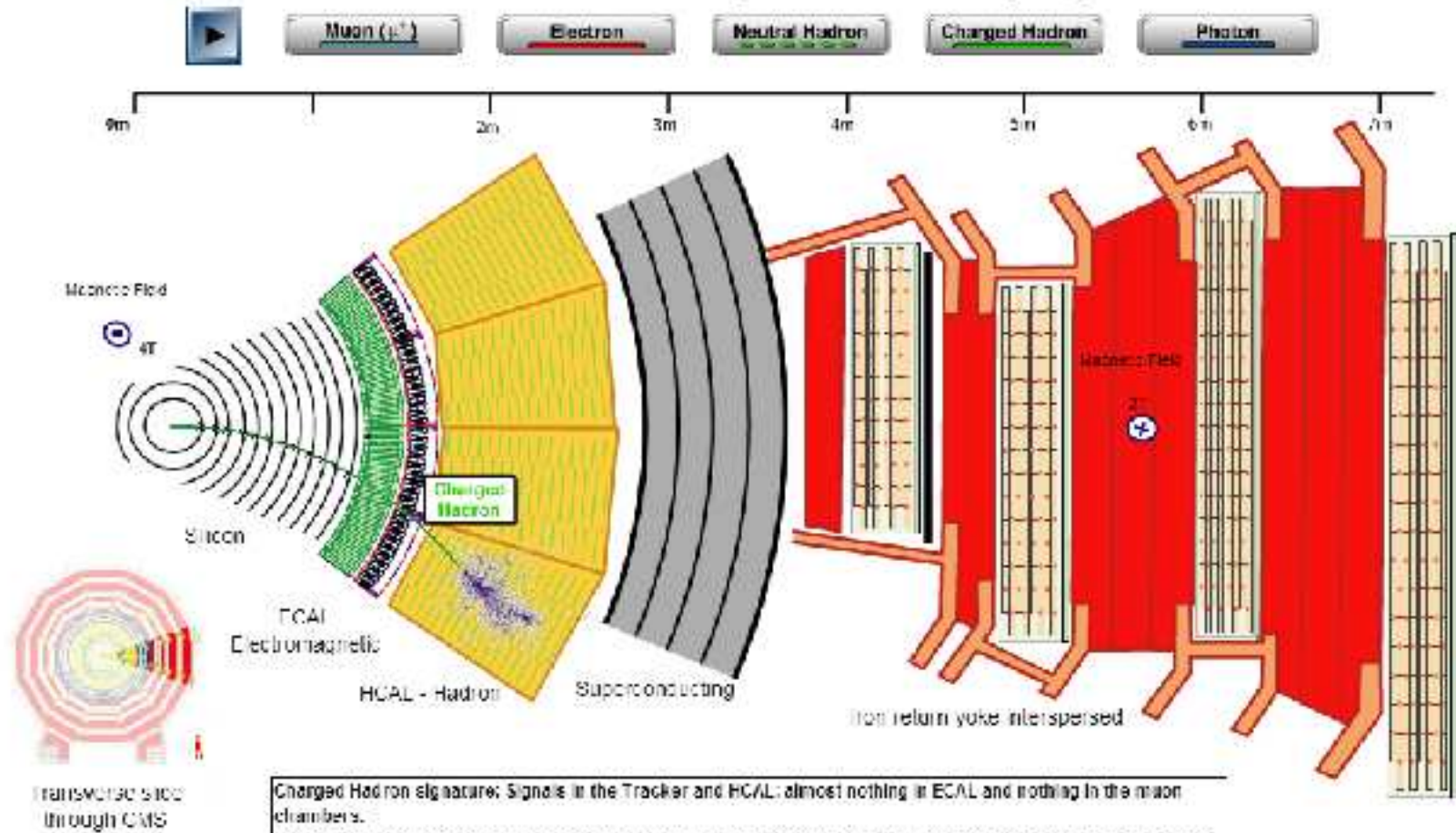
**Neutral Hadron Signature:** Signal only in the HCAL; nothing in Tracker, ECAL or muon chambers.  
 Neutral hadrons, such as neutrons, travel straight through the Tracker and ECAL, without being bent by the magnetic field or leaving any signals. Like charged hadrons, they are slowed to a stop in the HCAL, depositing their energy and leaving signals in the form of light in the plastic scintillators. The amount of light is proportional to the energy of the incoming hadron.

Derived from CMS Detector Simulation CHMS



# Φορτισμένο αδρόνιο στο CMS

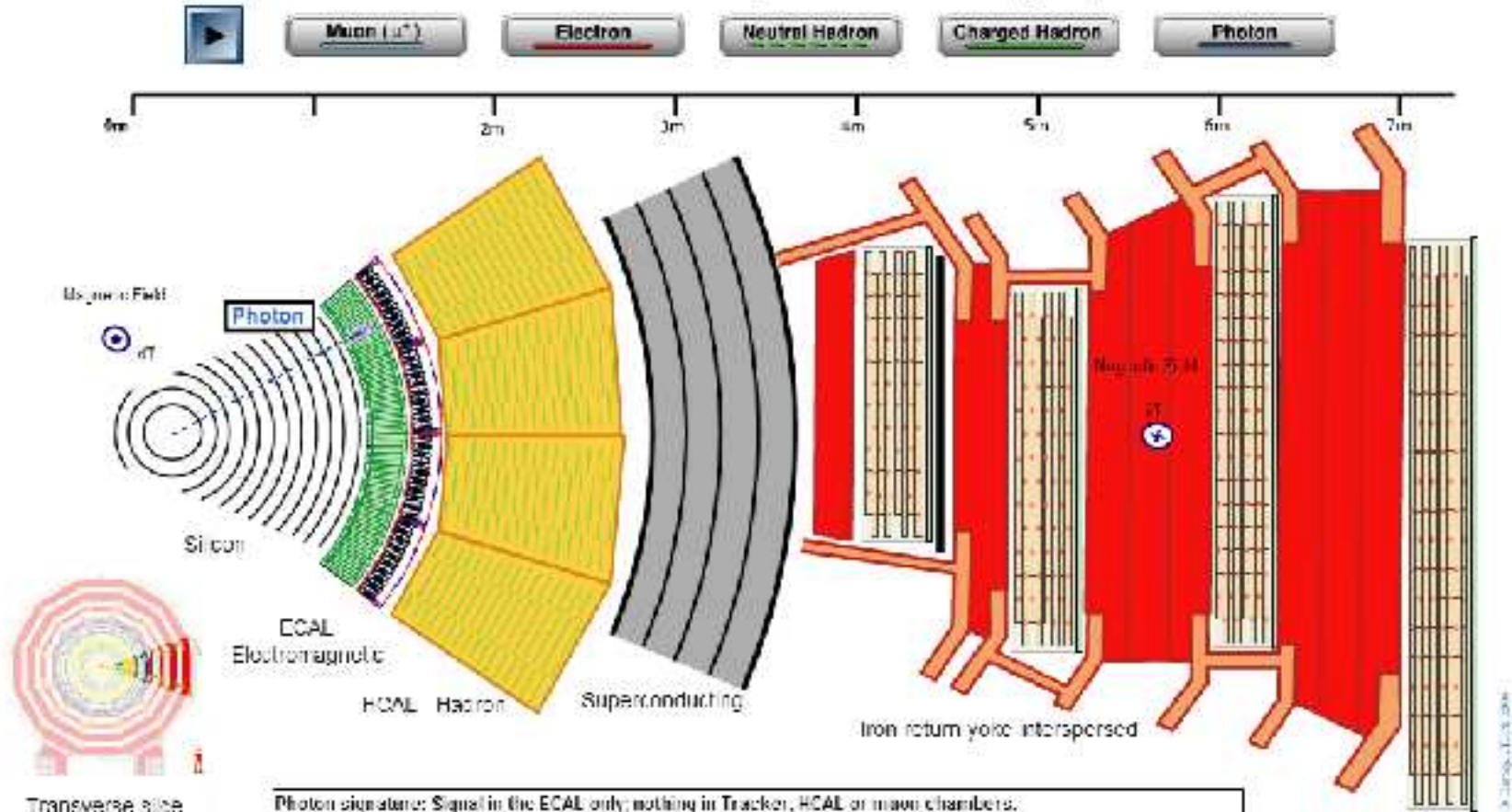
Transverse Slice of the Compact Muon Solenoid (CMS) Detector



Derived from CMS Detector Slice from CERN

# ΦΩΤΟΝΙΟ ΣΤΟ CMS

Transverse Slice of the Compact Muon Solenoid (CMS) Detector

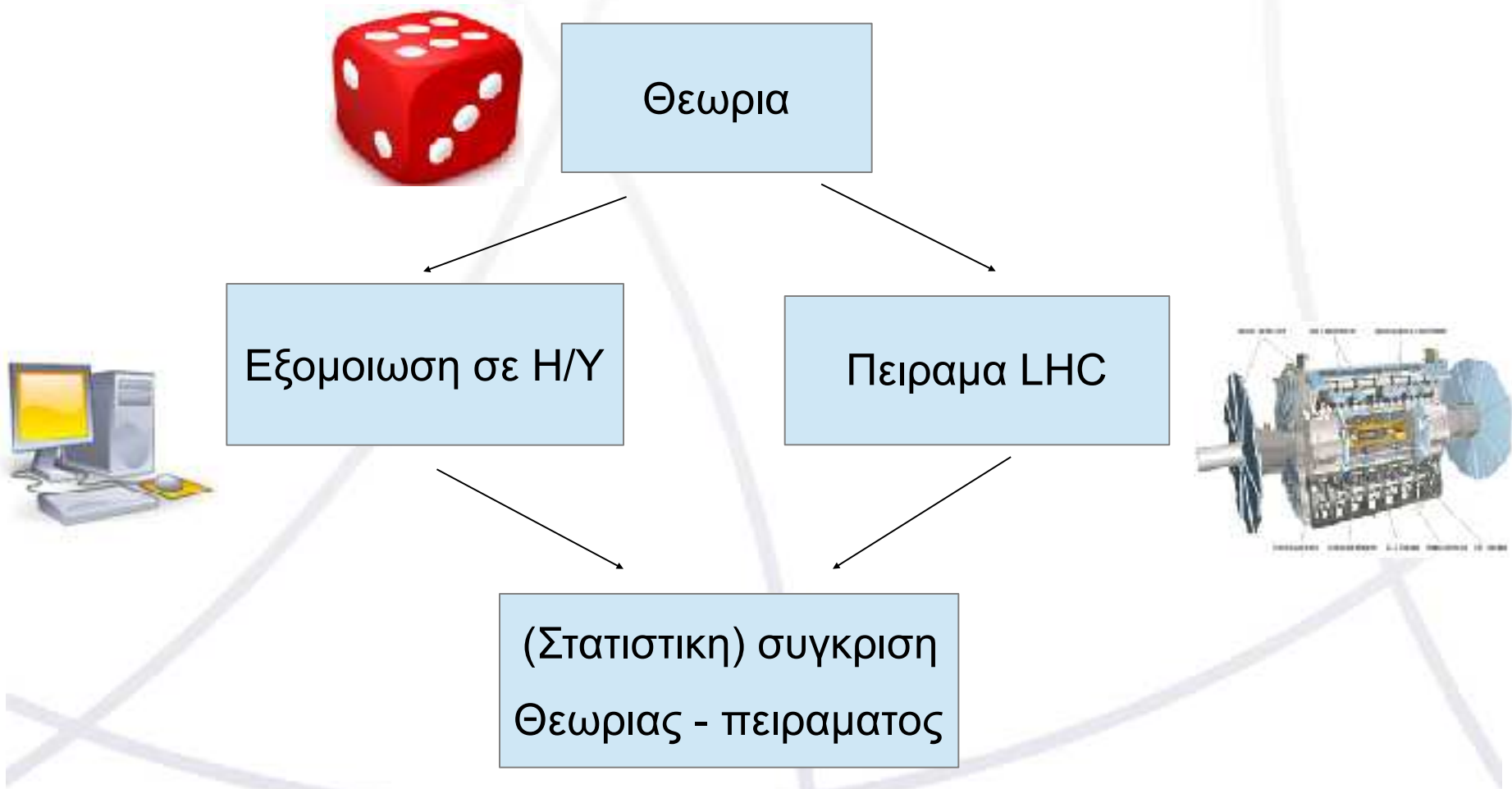


Photon signature: Signal in the ECAL only; nothing in Tracker, HCAL or muon chambers.  
 Being electrically neutral, photons pass through the Tracker undetected and not bent by the magnetic field. They interact in the ECAL in a similar way to electrons, producing electromagnetic showers that leave their energies in the form of light that is detected.

Derived from CMS Detector Slice from CERN



# Μεθοδολογία Σωματιδιακής Φυσικής (I)



# Μεθοδολογία Σωματιδιακής Φυσικής (I)

Θεωρία

Η κβαντομηχανική και η εξέλιξη της (κβαντική θεωρία πεδίου) μπορεί να μας δώσει την πιθανότητα να συμβεί ένα γεγονός π.χ η διάσπαση του Higgs σε 2 φωτόνια είναι  $\sim 1/3000$





# Μεθοδολογία Σωματιδιακής Φυσικής (I)

Εξομοίωση με Η/Υ



Μπορούμε να φτιαξουμε ένα προγραμμα που να “ριχνει ζαριες” με πιθανότητα  $1/6$  (γεννητρια τυχειων αριθμων).

Μπορούμε να το ρυθμισουμε ωστε τα “ζαρια” να ειναι ρυθμισμενα στις απαιτησεις μας (π.χ προβλεψεις της θεωριας που θελουμε να μελετησουμε + ανιχνευτης).

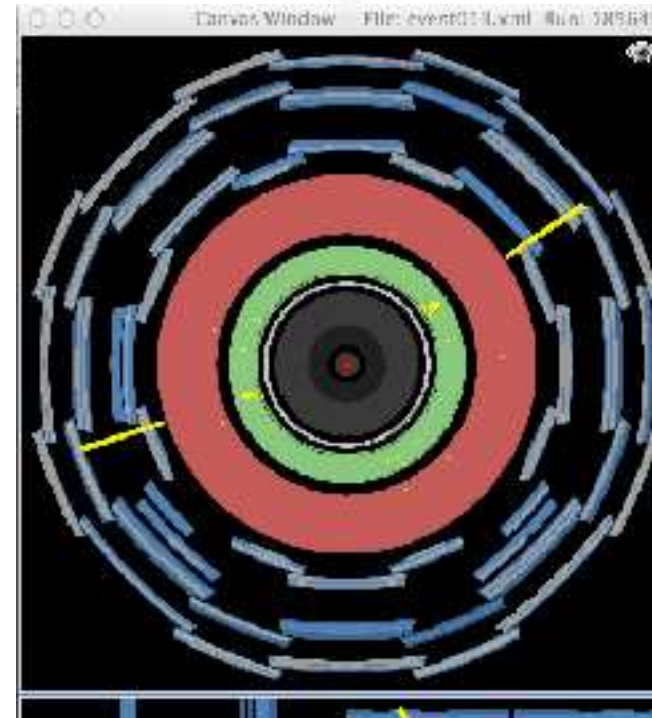
# Ψαχνοντας βελονα στα αχυρα

Ψαχνουμε (πολυ) σπανιες διασπασεις

Υπαρχουν και αλλες αντιδρασεις που δινουν παρομοιο πειρματικο αποτελεσμα (πχ 2 φωτονια)

Πρεπει να προσπαθησουμε να ξεχωρισουμε το σημα απο τις διαδικασιες υποβρθρου οσο καλυτερα γινεται

Π.χ μπορουμε να διαλεγουμε γεγονοτα με 2 φωτονια τα οποια εχουν μεγαλη ενεργεια και ειναι απομονωμενα.



# Στατιστική ανάλυση

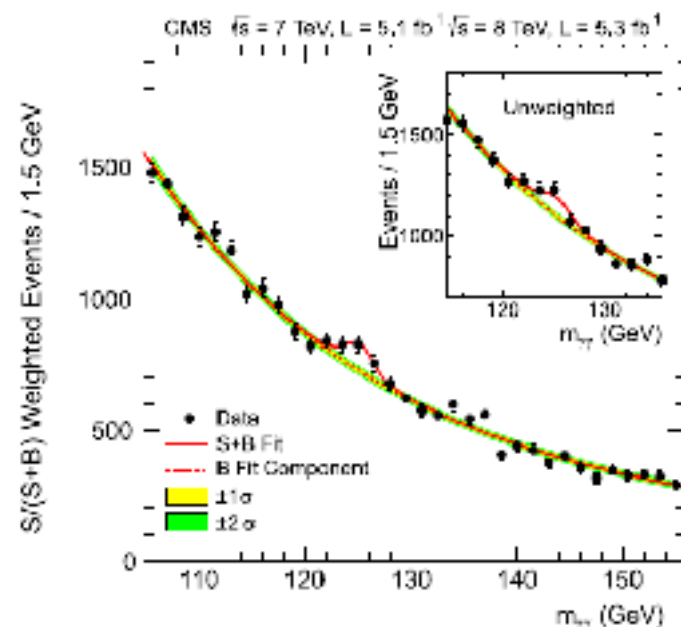
Μετράμε ποσα γεγονοτα παρατηρούμε  
με π.χ 2 φωτονια

Υπολογίζουμε την μαζα τους

Εξομοιώνουμε στον Η/Υ  
την διαδικασία παραγωγής  
σηματος & υποβαθρων.

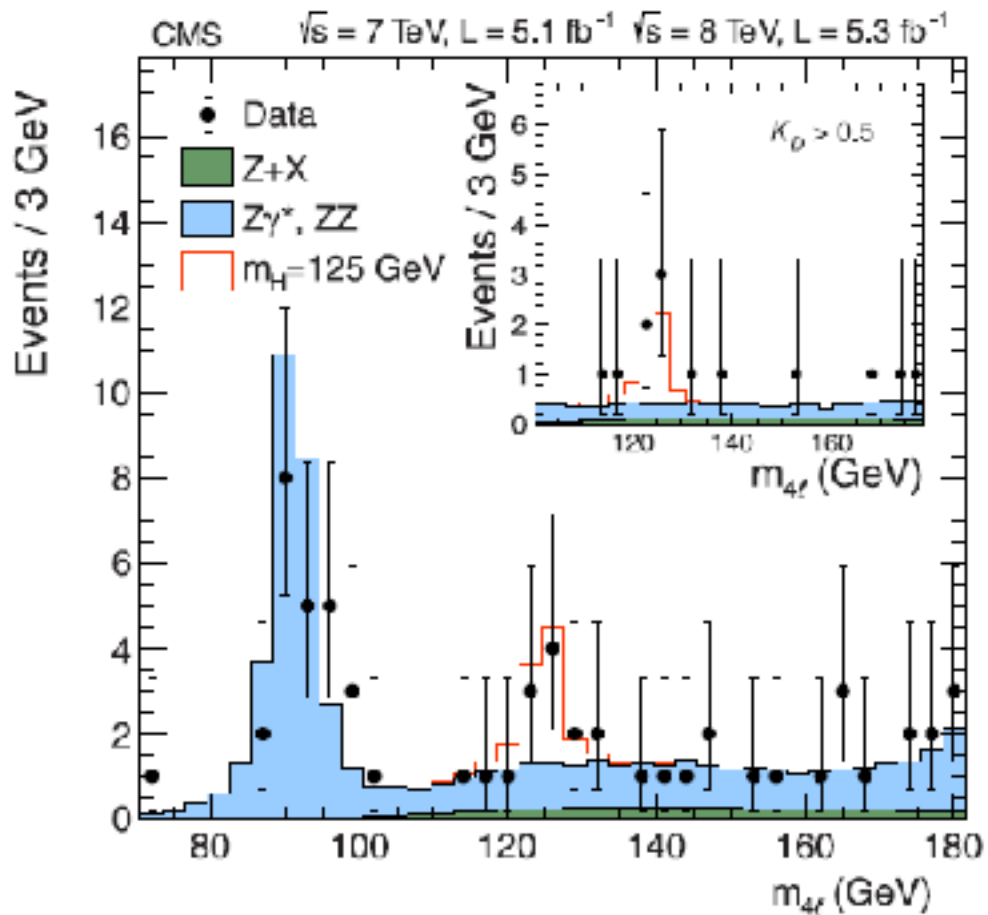
Για καθε εξομοιωμενο γεγονός κανουμε ακριβως το ιδιο με  
οτι κανουμε στα πραγματικα δεδομενα

Τα συγκρινουμε: ποσα γεγονοτα με μαζα 120-130 GeV  
παρατηρούμε;





# Στατιστική ανάλυση



# Μεθοδολογία Σωματιδιακής Φυσικής (I)

- Θεωρητικός υπολογισμός των όρων που περιγράφουν την φυσική διαδικασία (βάση κάποιου μοντέλου)
- Δημιουργία γεγονότων που προσομοιώνουν τις φυσικές διαδικασίες με την χρήση προγραμμάτων ηλεκτρονικών υπολογιστών
  - Γεννήτριες Γεγονότων ( Monte Carlo )
  - Στόχος η δημιουργία γεγονότων όμοιων με αυτά που παράγει η φύση
- Υπολογισμός της αλλοίωσης των γεγονότων λόγω της παρουσίας του ανιχνευτή

# Μεθοδολογία Σωματιδιακής Φυσικής (II)

- Εύρεση κατάλληλων χαρακτηριστικών που διαφοροποιούν τα προσομοιωμένα γεγονότα μεταξύ τους
- Βάση των χαρακτηριστικών διαφοροποίησης, διαχωρισμός των ενδιαφερόντων γεγονότων (σήμα) απο τα μη ενδιαφέροντα (υπόβαθρο).
- Μεγιστοποίηση αναλογίας σήματος / υποβάθρου
- Εκτίμηση αβεβαιοτήτων για όλα τα παραπάνω
- Σύγκριση πειραματικών και θεωρητικών αποτελεσμάτων



# Μεθοδολογία Σωματιδιακής Φυσικής (III)

- «**Άμεσα**» ανιχνεύσιμα σωματία (ηλεκτρόνια, φωτόνια, μιόνια)
  - Αλληλεπιδρούν με τον όγκο της ανιχνευτικής διάταξης
- «**Έμμεσα**» ανιχνεύσιμα σωματία (Z, W, νετρίνα)
  - Δεν αλληλεπιδρούν με τον ανιχνευτή
    - Σύντομου χρόνου ζωής ή μη ανιχνεύσιμα σωματία (νετρίνα)
- Τεχνική της «**αναλλοίωτης**» μάζας
  - Ανίχνευση σωματίου απο τα υπολείμματα της διάσπασης του.

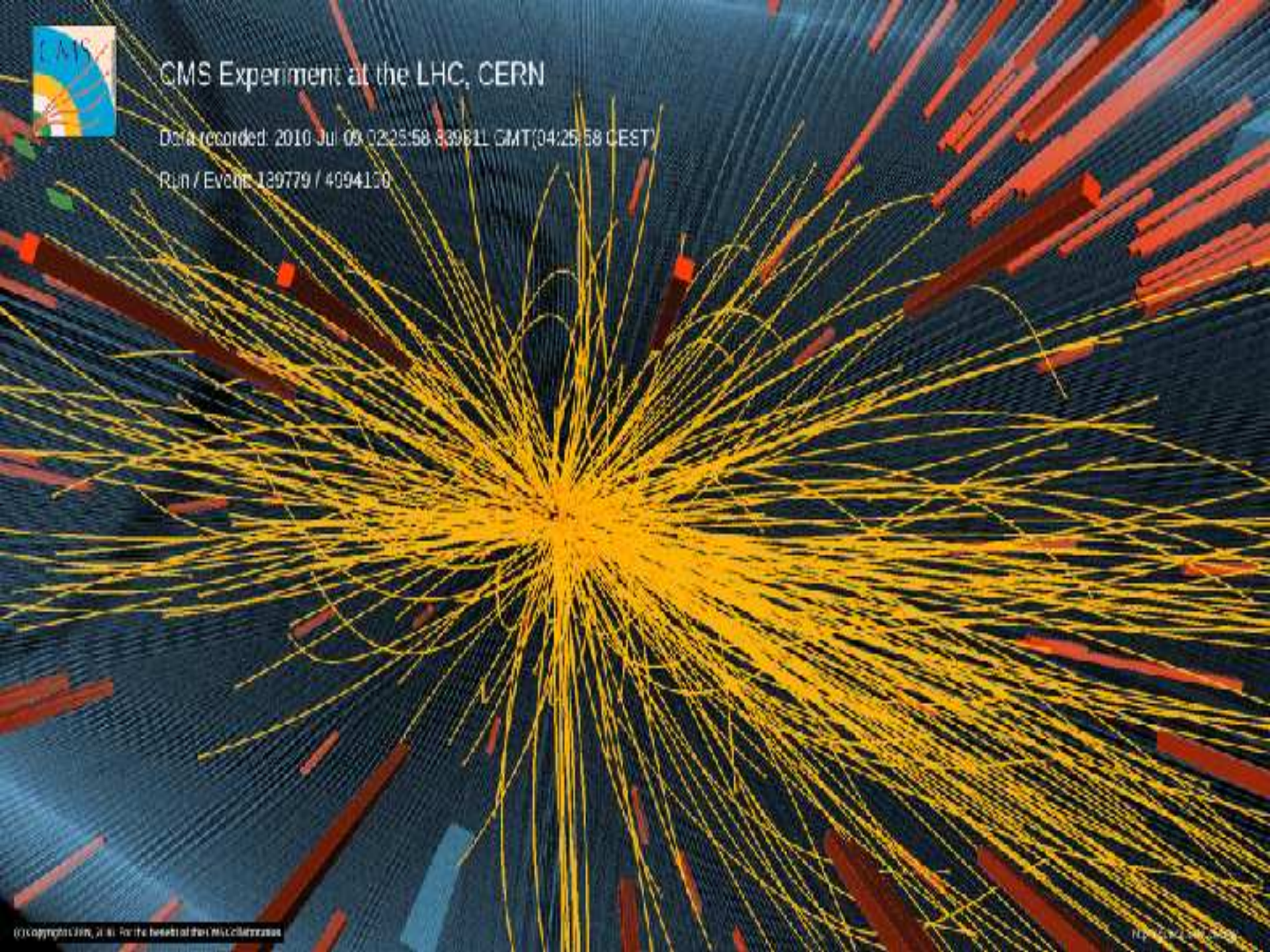




# CMS Experiment at the LHC, CERN

Data recorded: 2010 Jul 05 02:25:58.839811 GMT(04:25:58 CEST)

Run / Event: 129779 / 4094100

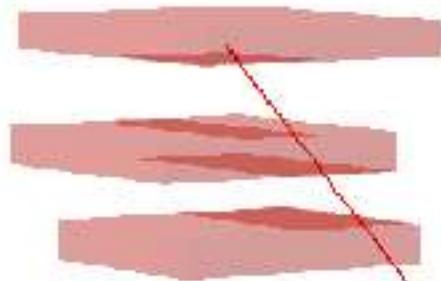




# Candidate of $H \rightarrow ZZ^* \rightarrow 4l$ (CMS)

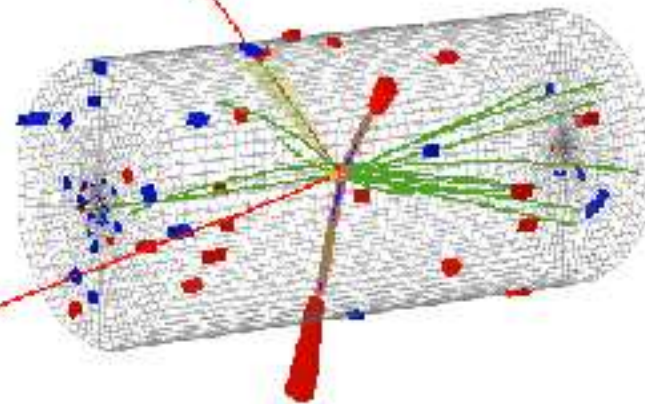


$M_{4l} = 126.9 \text{ GeV}$



$\mu^+(Z_1) p_T : 43 \text{ GeV}$

$e^-(Z_2) p_T : 10 \text{ GeV}$



$\mu^-(Z_1) p_T : 24 \text{ GeV}$



$e^+(Z_2) p_T : 21 \text{ GeV}$

CMS Experiment at LHC, CERN  
Data recorded: Mon May 28 01:35:47 2012 CEST  
Run/Event: 195099 / 137440354  
Lumi section: 115



# Observation of a New Particle !

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

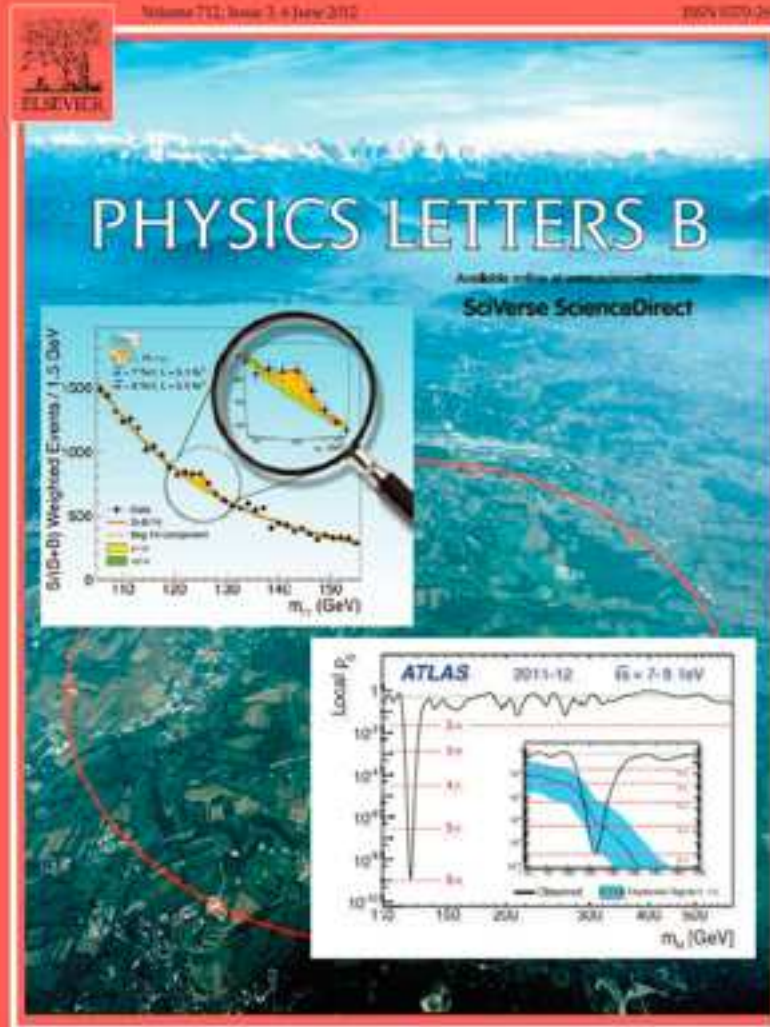
EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)



## Observation of a New Particle Model Higgs Boson with the ATLAS

The ATLAS

A search for the Standard Model Higgs boson at the LHC is presented. The datasets used are 36.1 fb<sup>-1</sup> collected at  $\sqrt{s} = 7$  TeV in 2011 and 5.8 fb<sup>-1</sup> collected at  $\sqrt{s} = 8$  TeV in 2012. Published results of searches for  $gg \rightarrow ZZ^{(0)} \rightarrow 4\ell$ ,  $gg \rightarrow \gamma\gamma$  and  $gg \rightarrow ZZ^{(0)} \rightarrow 4\ell$  are improved. An improved analysis of the  $gg \rightarrow ZZ^{(0)} \rightarrow 4\ell$  and  $gg \rightarrow ZZ^{(0)} \rightarrow 4\ell$  channels is presented. The production of a neutral boson with a measured mass of 125 GeV is observed. This observation, which has a significance of 5.0 standard deviations, is compatible with the Standard Model Higgs boson.



CERN-PH-EP-2012-092  
2012/08/01

new boson at a mass of 125 GeV with the ATLAS experiment at the LHC

by the CMS Collaboration\*

### Abstract

Searches for the standard model Higgs boson in proton-proton and lead-lead collisions at the LHC, using integrated luminosities of up to 5.1 fb<sup>-1</sup> at 7 TeV and 1.0 fb<sup>-1</sup> at 8 TeV, are presented. The search is performed in five decay modes:  $gg \rightarrow ZZ^{(0)} \rightarrow 4\ell$ ,  $gg \rightarrow \gamma\gamma$ ,  $gg \rightarrow ZZ^{(0)} \rightarrow 4\ell$ ,  $gg \rightarrow ZZ^{(0)} \rightarrow 4\ell$ , and  $gg \rightarrow ZZ^{(0)} \rightarrow 4\ell$ . A local signal is observed above the expected background, a local significance of 5.0 standard deviations, signalling the production and decay of a neutral boson with a measured mass of 125 GeV. This observation, which has a significance of 5.0 standard deviations, is compatible with the Standard Model Higgs boson.

the necessary of our colleagues who worked on CMS  
but have since passed away

any contributions to the achievement of this observation...

Submitted to Physics Letters B

arXiv:1207.7244v1 [hep-ex] 31 Jul 2012

Phys. Lett. B 716 (2012) 30–61

Phys. Lett. B 716 (2012) 30–61

# NEWS about the Higgs Boson (2012.7.4)

## The Higgs boson discovery is another giant leap for humankind

The Cern discovery of the Higgs particle is up there with putting man on the moon – something all humanity can be proud of

**Themis Bowcock**  
guardian.co.uk, Wednesday 4 July 2012 12:45:18  
[Jump to comments \( \)](#)

### Physicists Find Elusive Particle



Scientists at Cern on Wednesday applauded the discovery.  
By DENNIS OVERBYE  
Published July 4, 2012



Scientists gather at Cern. Formal confirmation of the Higgs boson discovery is expected to follow in the next few months. Photograph: Denis Hellerhouse/Reuters

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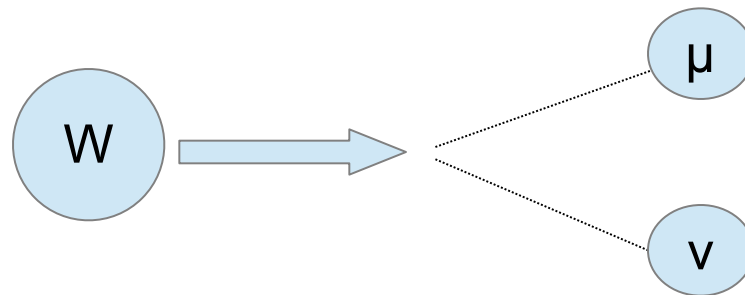
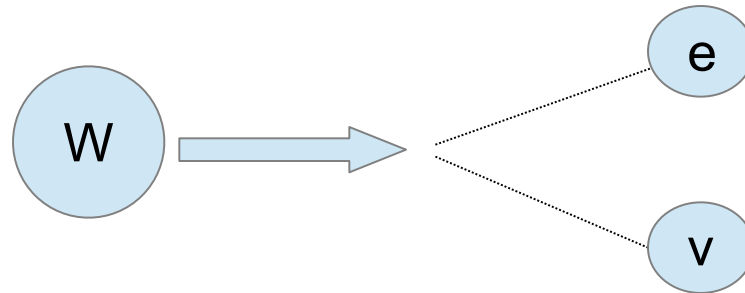
icle discovery



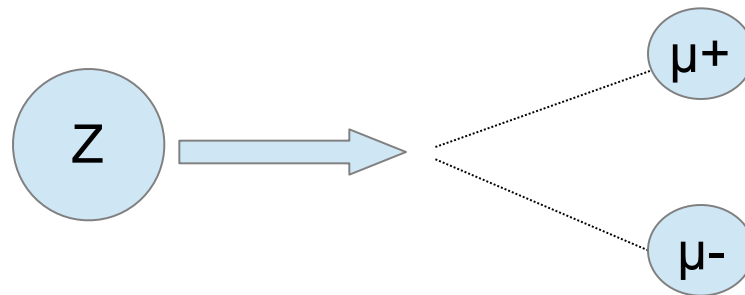
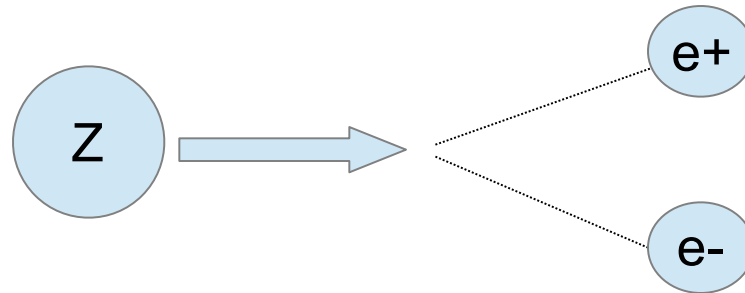
**iSpy - CIMA**



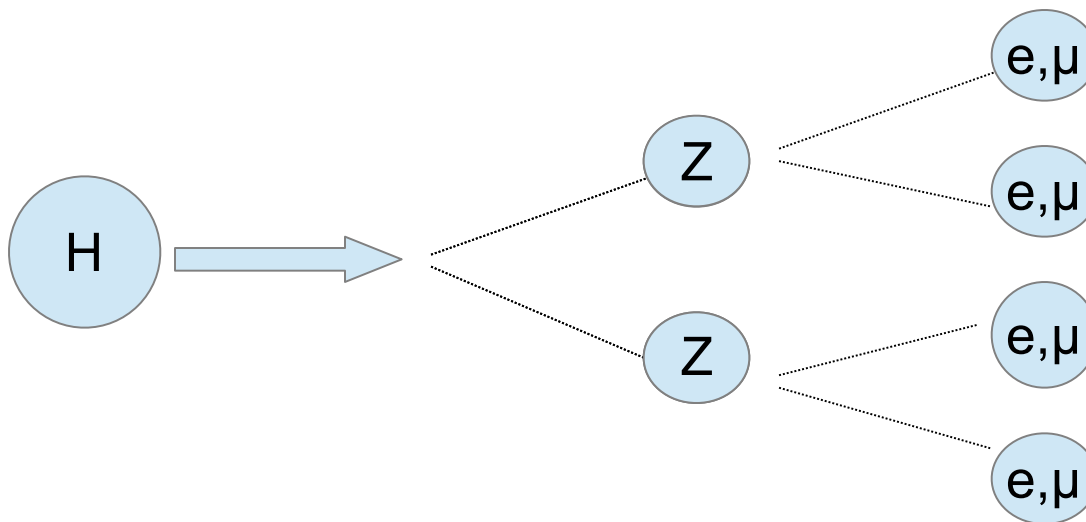
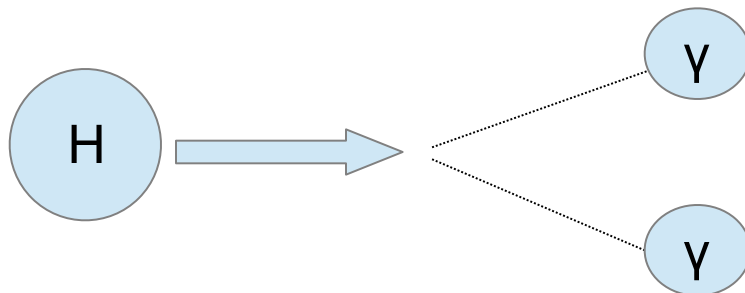
# (μερικες) Διασπασεις του W



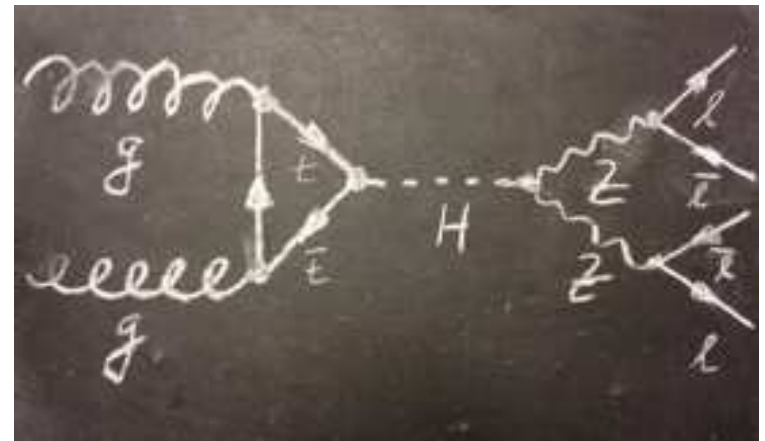
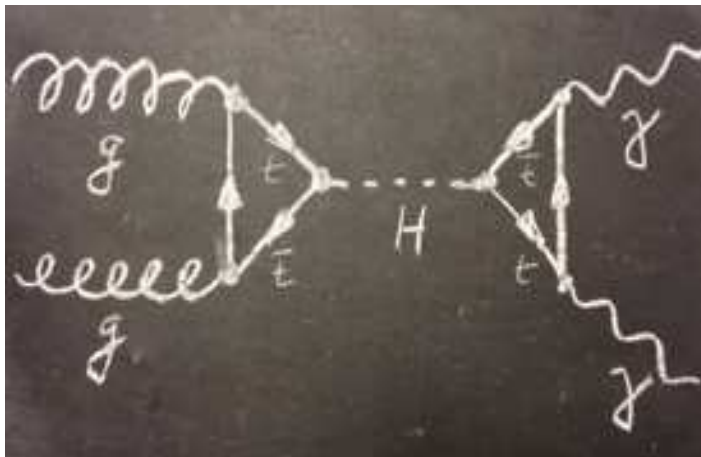
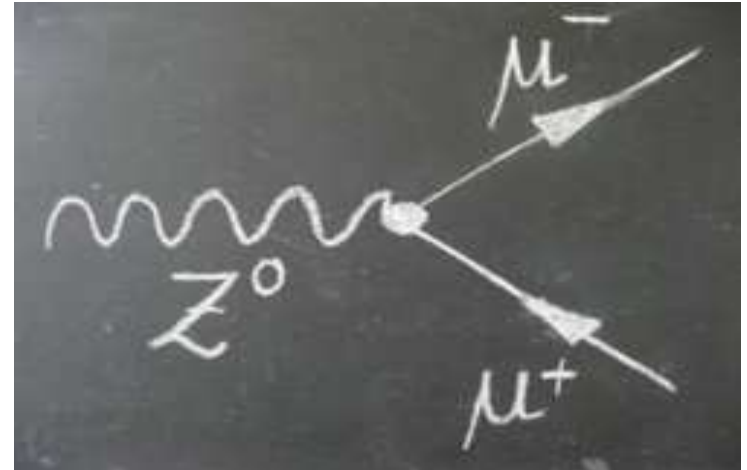
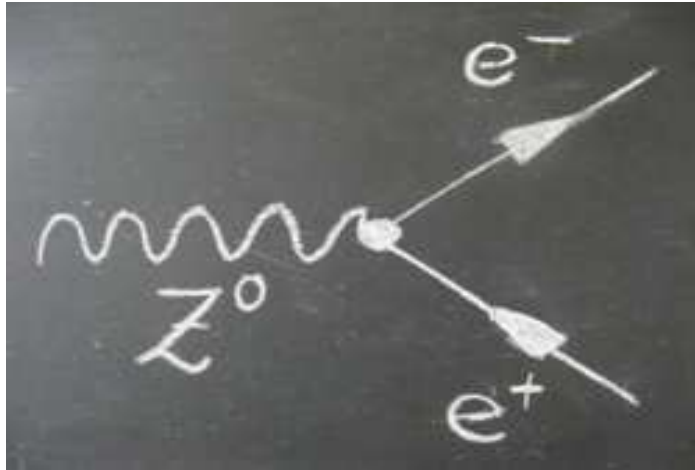
# Διασπασεις $Z \rightarrow 2$ λεπτονια (= ηλεκτρονια, μιονια)



# (μερικές απο τις) Διασπασεις του Higgs

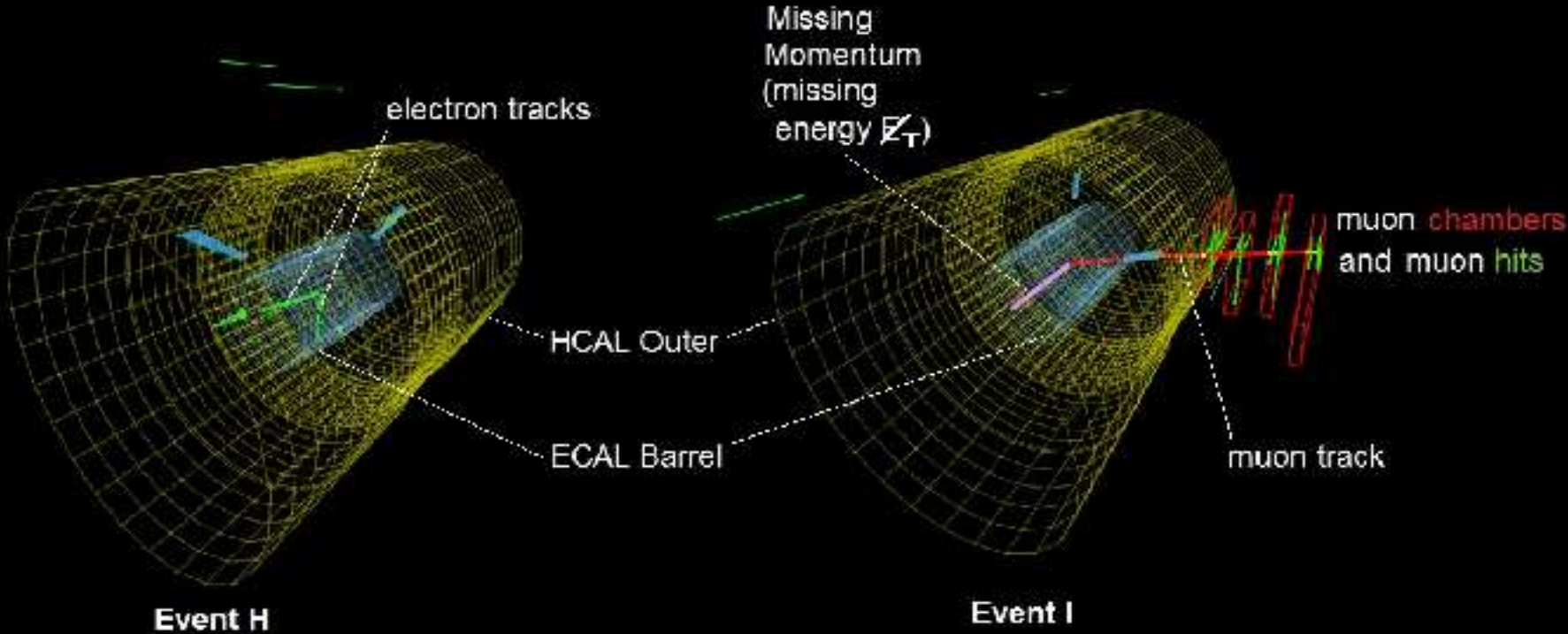


# Τελικές καταστασεις

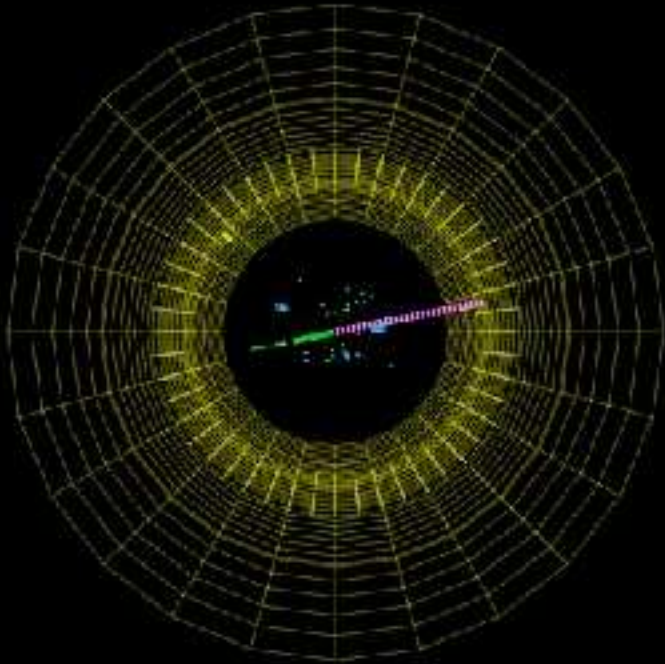




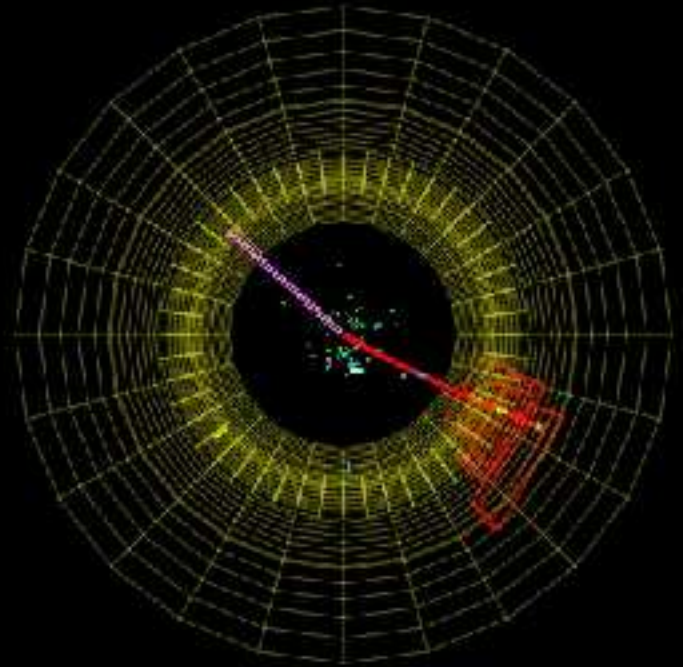
# iSpy-Webgl



# W boson candidate events

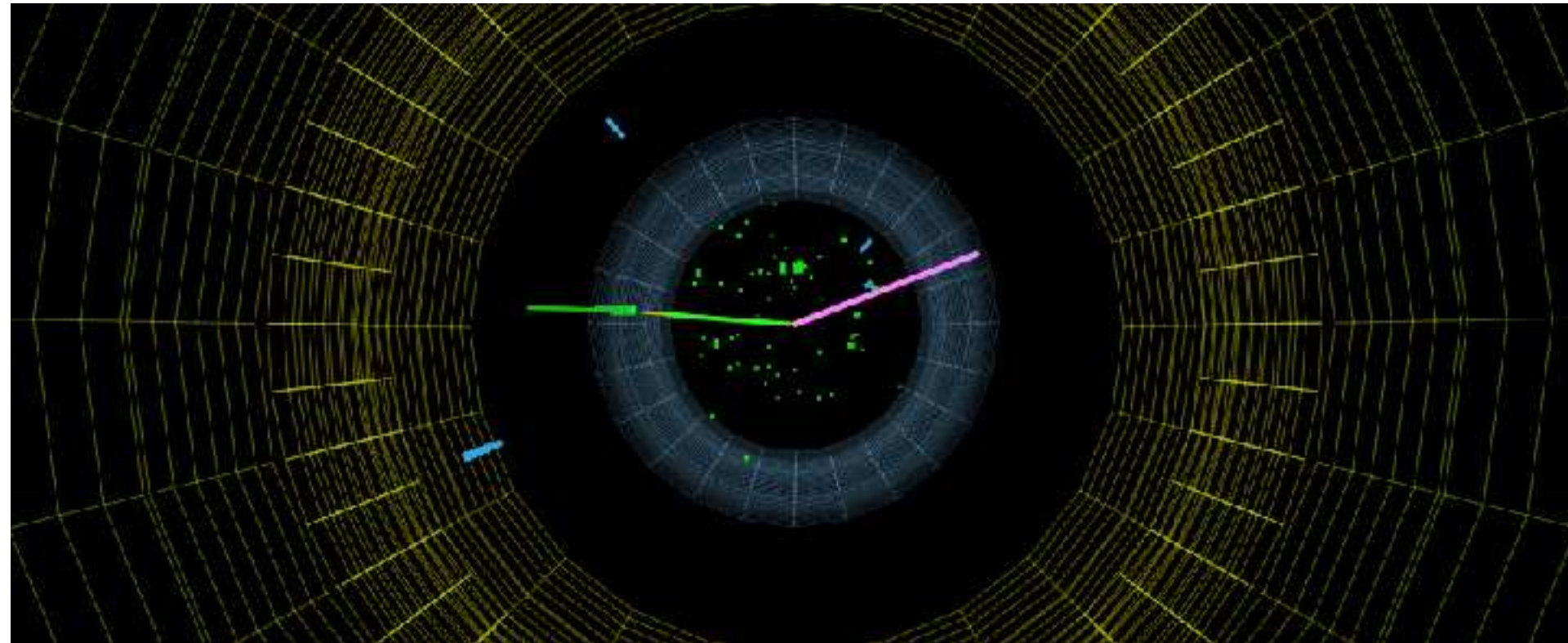


Event A



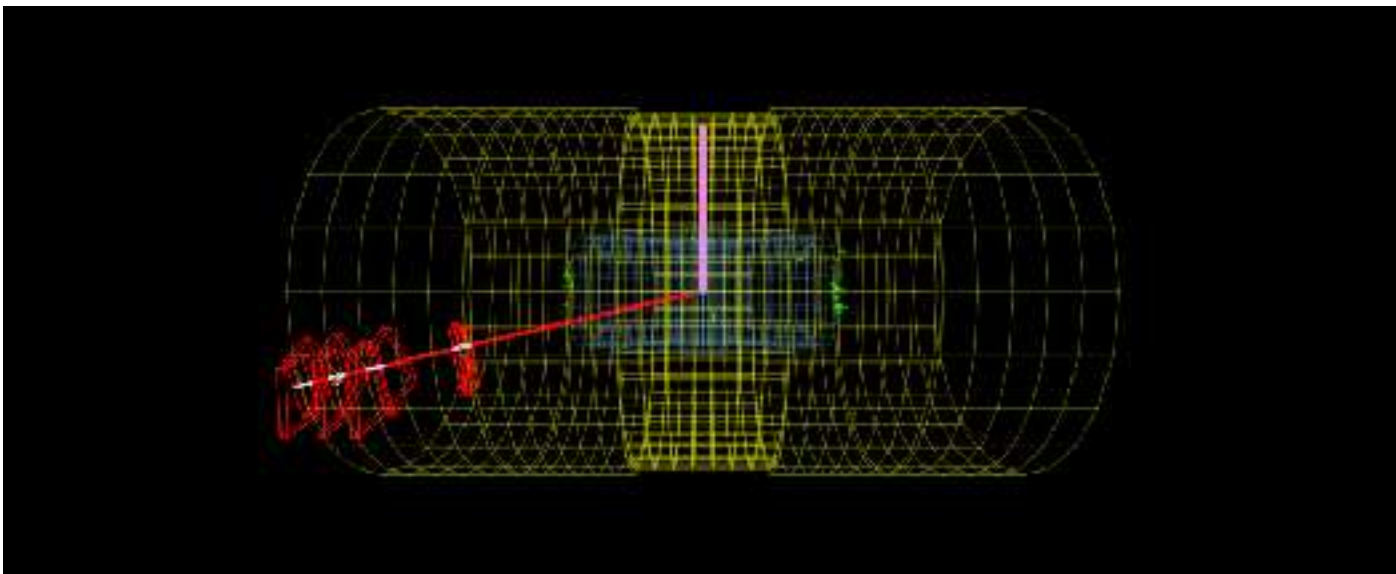
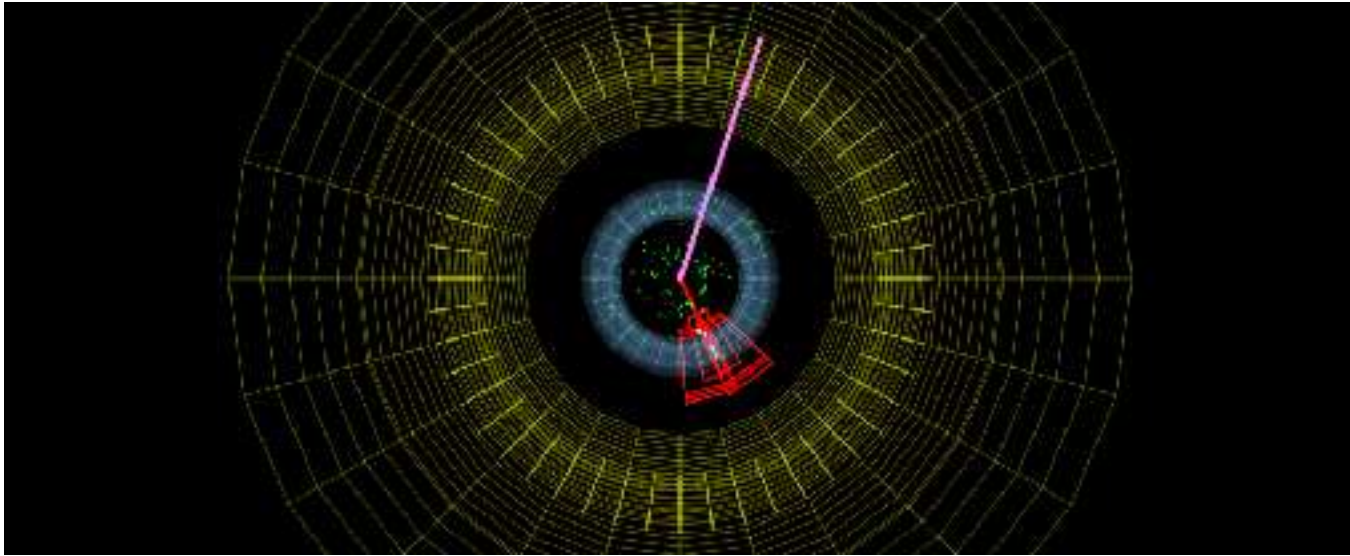
Event B

# W boson candidate events



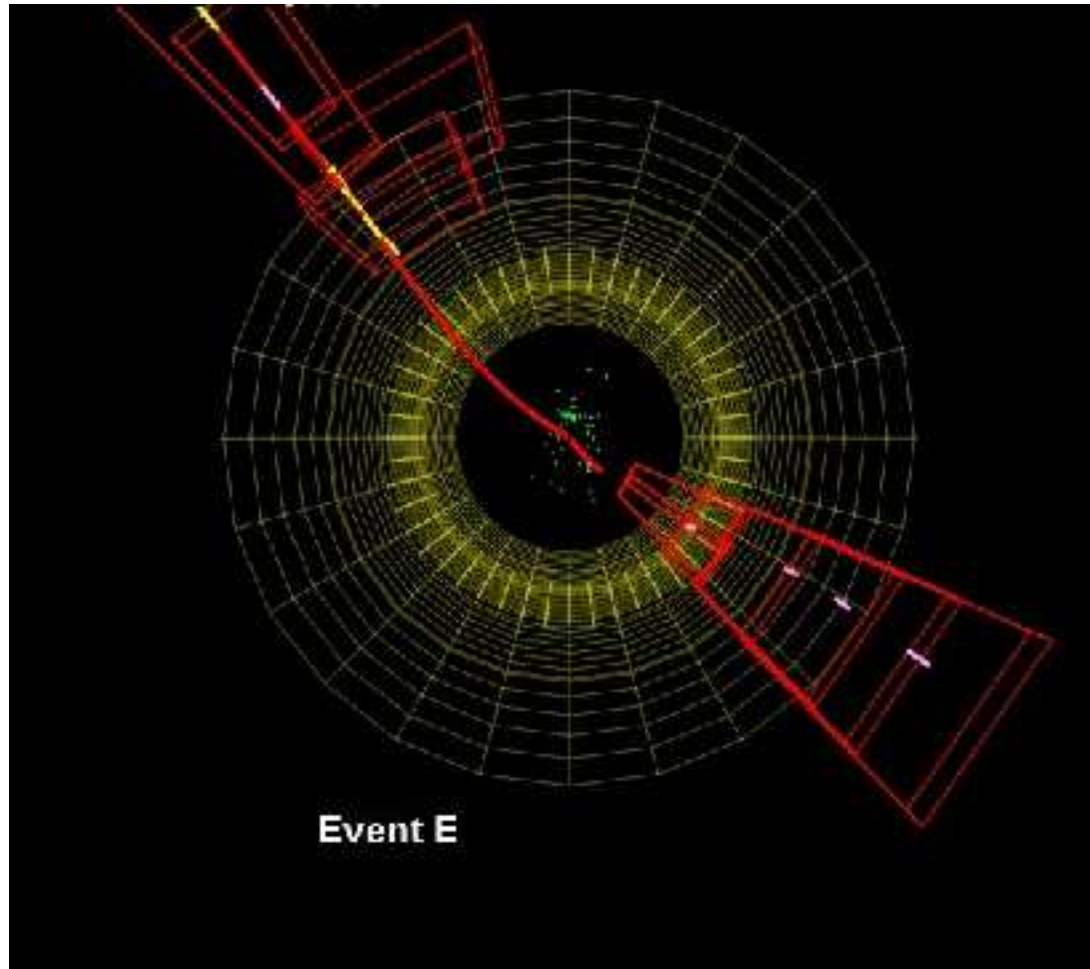


# W boson candidate events

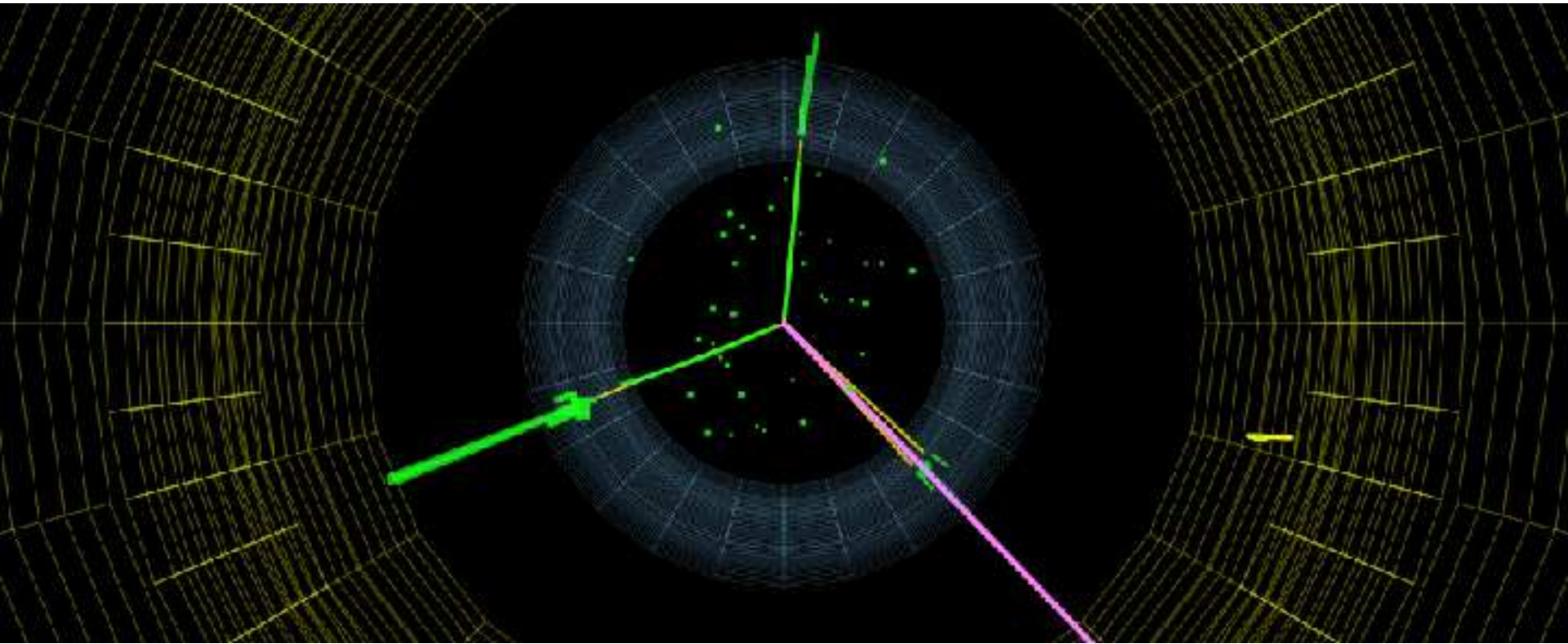




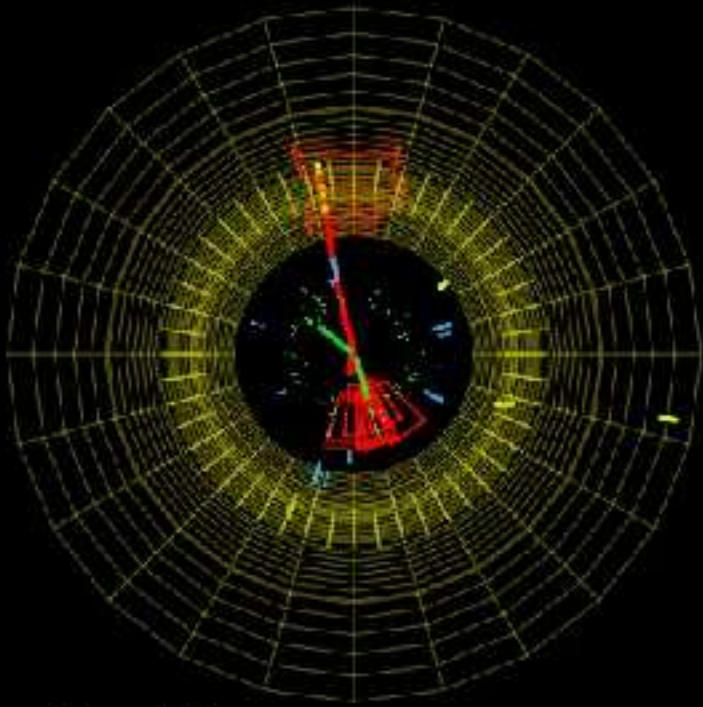
# Z boson candidate events



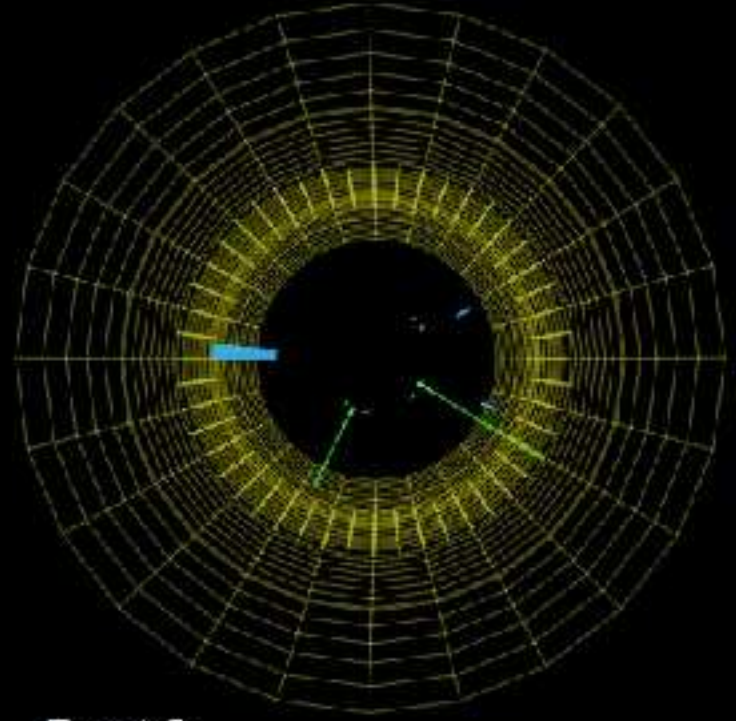
# Z boson candidate events



# Higgs boson candidate events

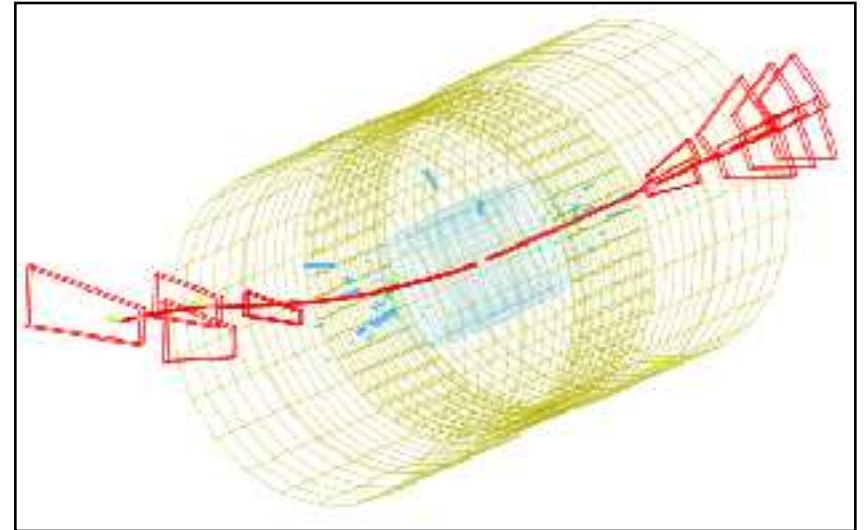
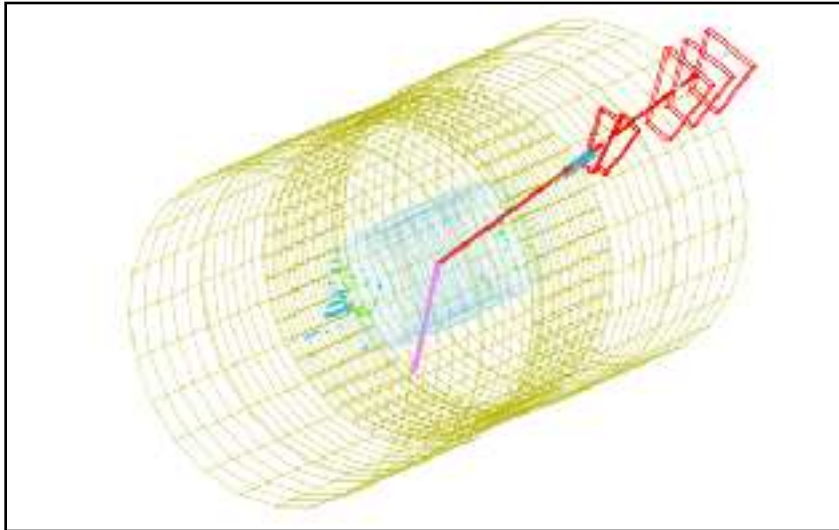


Event F



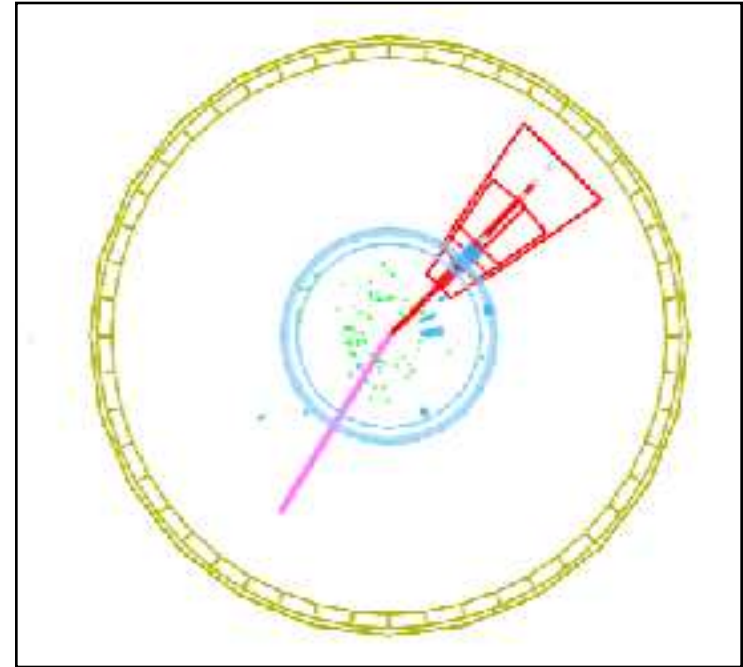
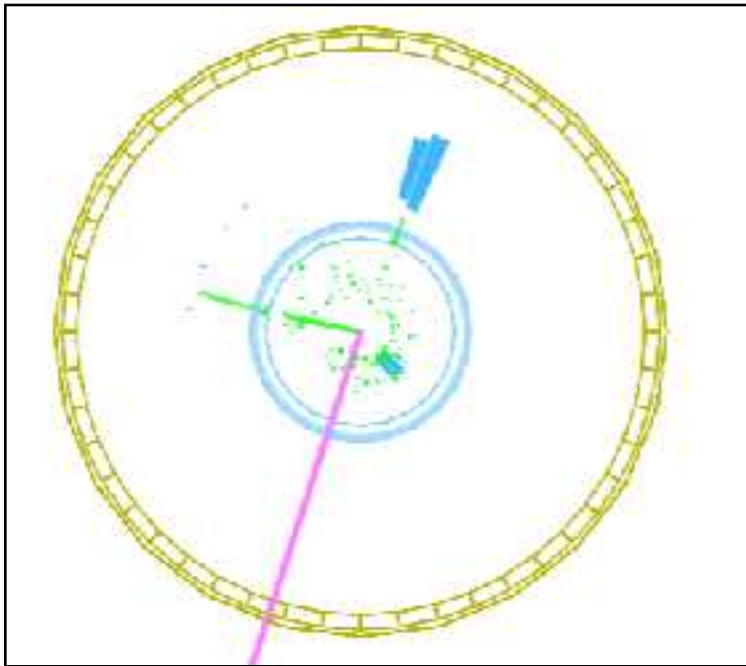
Event G

# Αρχίζουμε να ταυτοποιούμε

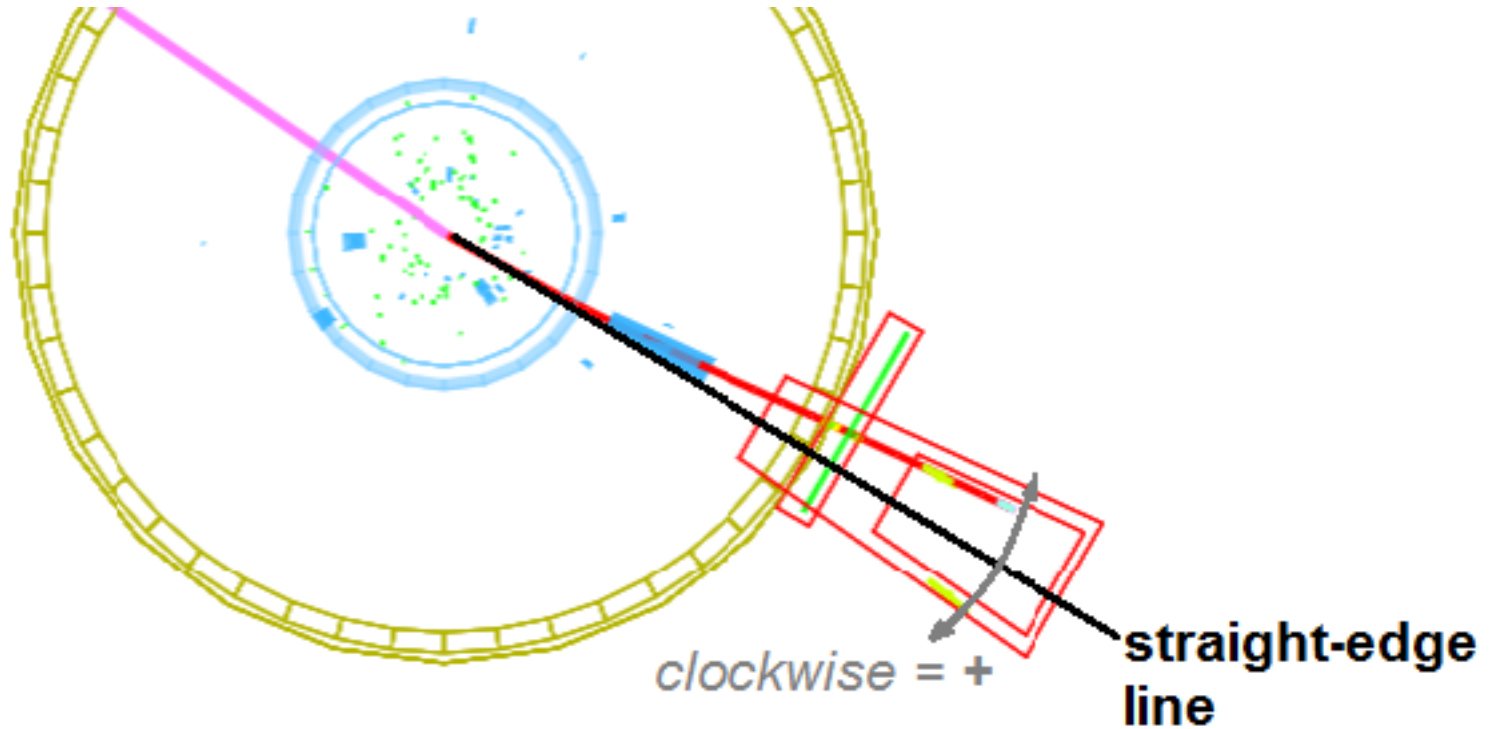




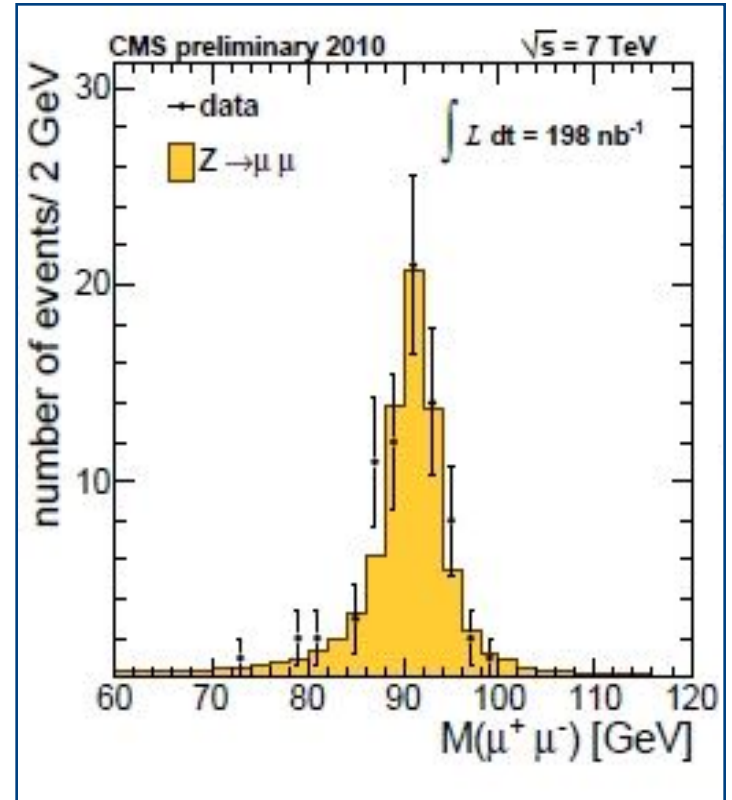
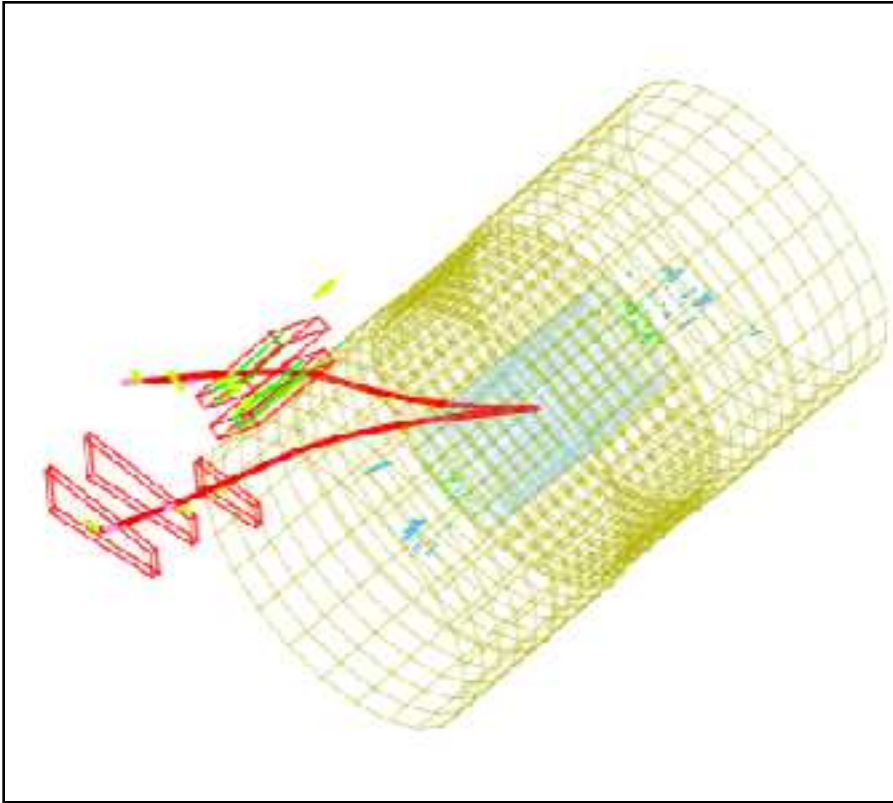
# Αρχίζουμε να ταυτοποιούμε



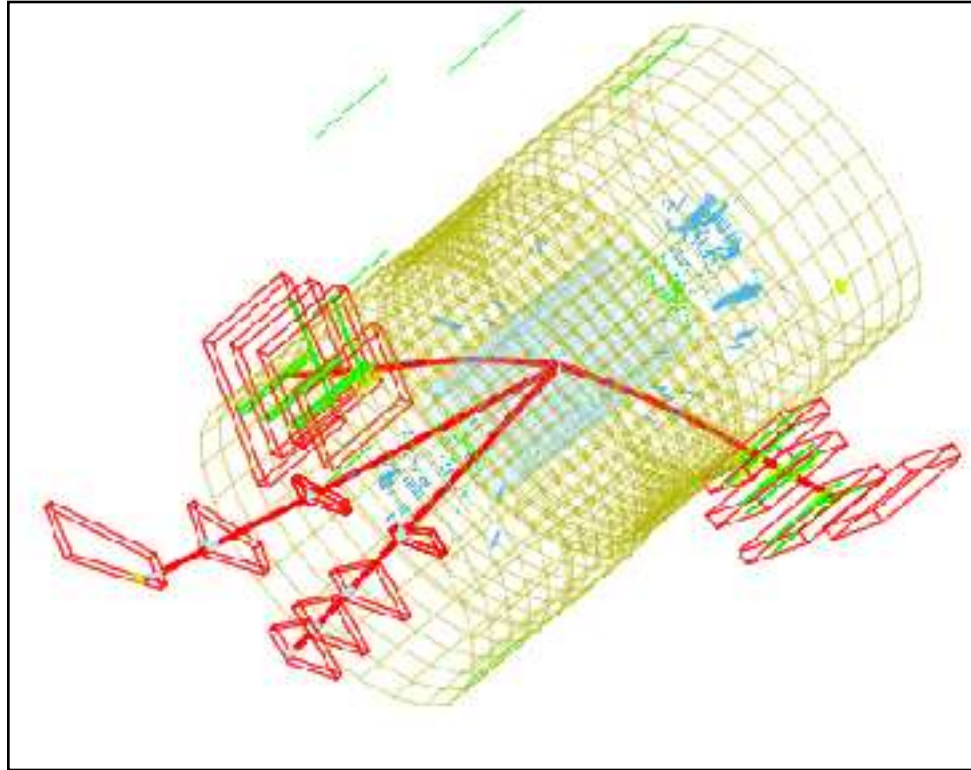
# Αρχίζουμε να ταυτοποιούμε



# Το ιστογράμμα των μαζών

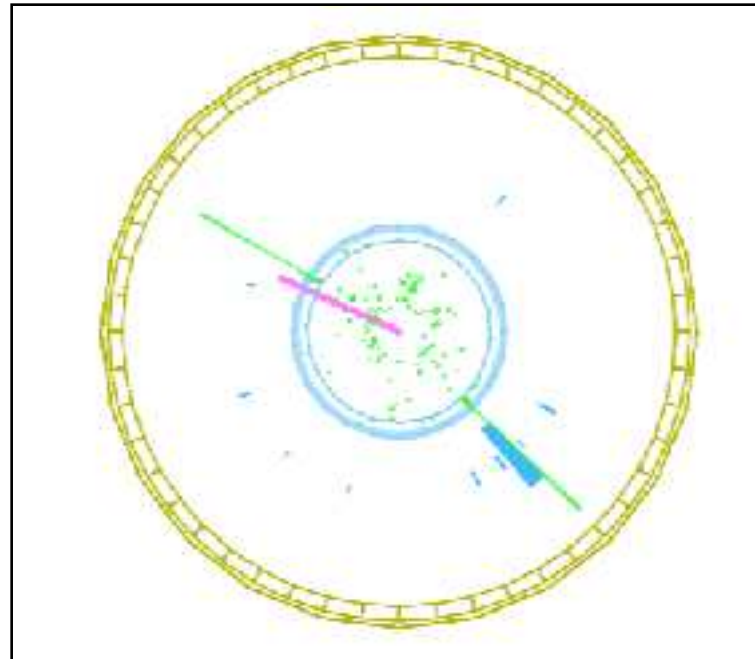


# Αρχίζουμε να ταυτοποιούμε

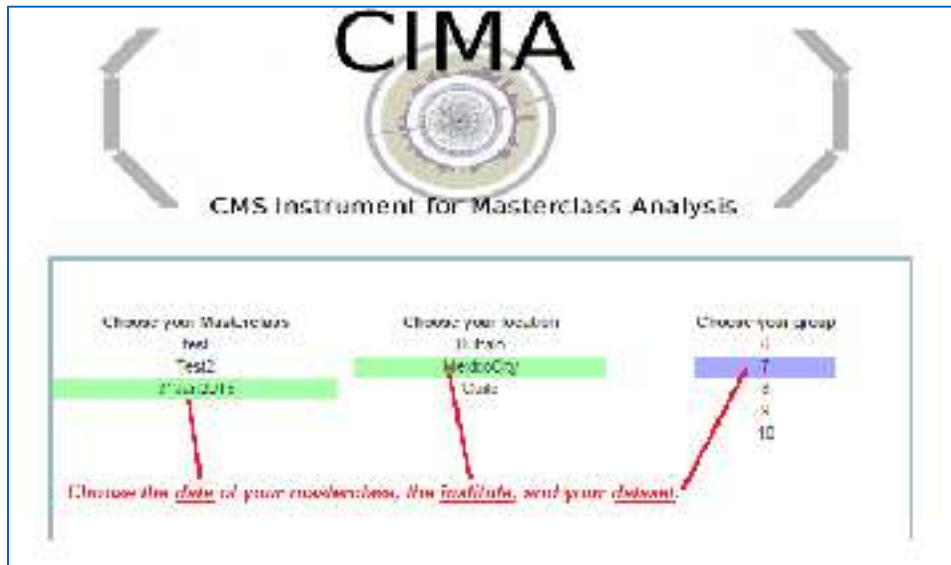




# Αρχίζουμε να ταυτοποιούμε



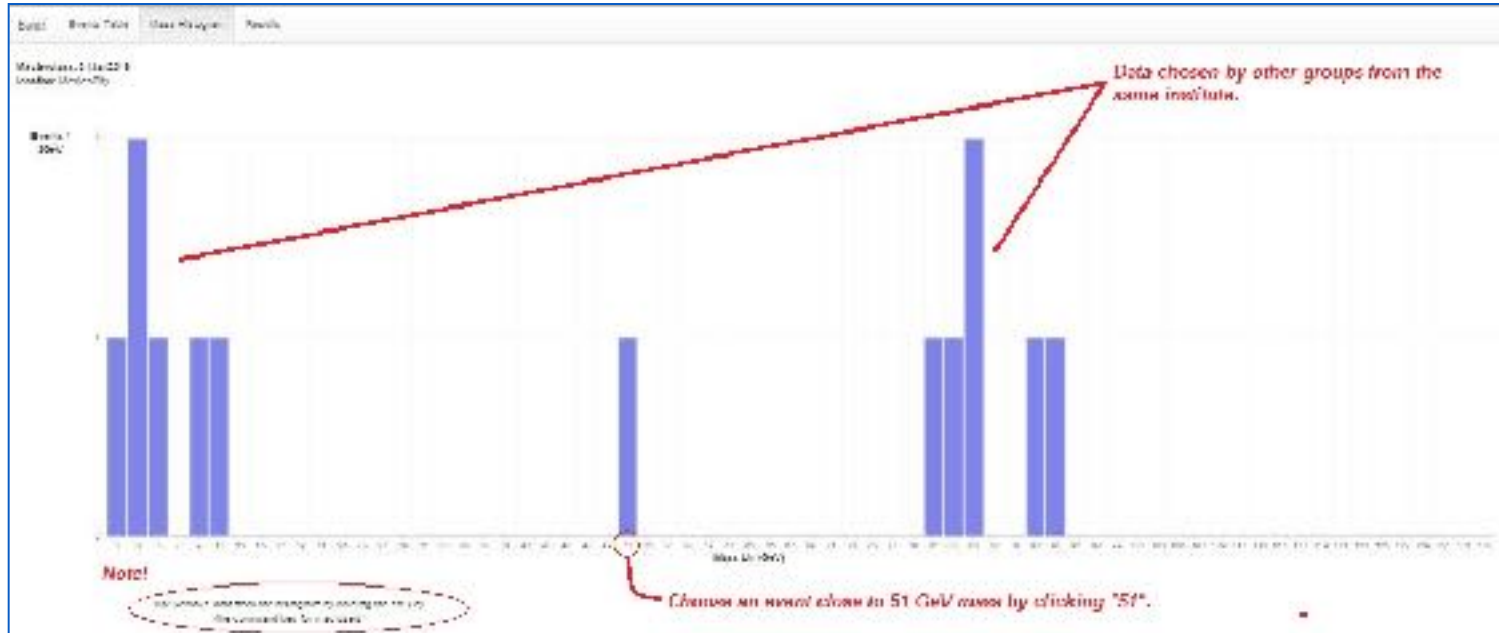
# CIMA – CMS Instrument for Masterclass Analysis



Βρες τα γεγονότα σου  
Ανάλυσε &  
κατέγραψε τις μάζες



# CIMA – CMS Instrument for Masterclass Analysis



## Ιστόγραμμα μαζών

# CIMA – CMS Instrument for Masterclass Analysis

Back System Status Orders Log Reports Summary

INSIDE THE SYSTEM  
Baseline Linearity

Order	Phase	Location	W	W+	W-	F	High	Low	W+	W-
1	C	0	0	0	0	C	0	C	0	0
2	C	11	11	11	11	C	11	C	11	11
3	C	0	0	0	0	C	0	C	0	0
4	C	11	11	11	11	C	11	C	11	11
5	C	0	0	0	0	C	0	C	0	0
6	C	11	11	11	11	C	11	C	11	11
7	C	0	0	0	0	C	0	C	0	0
8	C	11	11	11	11	C	11	C	11	11
9	C	0	0	0	0	C	0	C	0	0
10	C	11	11	11	11	C	11	C	11	11
11	C	0	0	0	0	C	0	C	0	0
12	C	11	11	11	11	C	11	C	11	11
13	C	0	0	0	0	C	0	C	0	0
14	C	11	11	11	11	C	11	C	11	11
15	C	0	0	0	0	C	0	C	0	0
16	C	11	11	11	11	C	11	C	11	11
17	C	0	0	0	0	C	0	C	0	0
18	C	11	11	11	11	C	11	C	11	11
19	C	0	0	0	0	C	0	C	0	0
20	C	11	11	11	11	C	11	C	11	11
21	C	0	0	0	0	C	0	C	0	0
22	C	11	11	11	11	C	11	C	11	11
23	C	0	0	0	0	C	0	C	0	0
24	C	11	11	11	11	C	11	C	11	11
25	C	0	0	0	0	C	0	C	0	0
26	C	11	11	11	11	C	11	C	11	11
27	C	0	0	0	0	C	0	C	0	0
28	C	11	11	11	11	C	11	C	11	11
29	C	0	0	0	0	C	0	C	0	0
30	C	11	11	11	11	C	11	C	11	11
31	C	0	0	0	0	C	0	C	0	0
32	C	11	11	11	11	C	11	C	11	11
33	C	0	0	0	0	C	0	C	0	0
34	C	11	11	11	11	C	11	C	11	11
35	C	0	0	0	0	C	0	C	0	0
36	C	11	11	11	11	C	11	C	11	11
37	C	0	0	0	0	C	0	C	0	0
38	C	11	11	11	11	C	11	C	11	11
39	C	0	0	0	0	C	0	C	0	0
40	C	11	11	11	11	C	11	C	11	11
41	C	0	0	0	0	C	0	C	0	0
42	C	11	11	11	11	C	11	C	11	11
43	C	0	0	0	0	C	0	C	0	0
44	C	11	11	11	11	C	11	C	11	11
45	C	0	0	0	0	C	0	C	0	0
46	C	11	11	11	11	C	11	C	11	11
47	C	0	0	0	0	C	0	C	0	0
48	C	11	11	11	11	C	11	C	11	11
49	C	0	0	0	0	C	0	C	0	0
50	C	11	11	11	11	C	11	C	11	11
51	C	0	0	0	0	C	0	C	0	0
52	C	11	11	11	11	C	11	C	11	11
53	C	0	0	0	0	C	0	C	0	0
54	C	11	11	11	11	C	11	C	11	11
55	C	0	0	0	0	C	0	C	0	0
56	C	11	11	11	11	C	11	C	11	11
57	C	0	0	0	0	C	0	C	0	0
58	C	11	11	11	11	C	11	C	11	11
59	C	0	0	0	0	C	0	C	0	0
60	C	11	11	11	11	C	11	C	11	11
61	C	0	0	0	0	C	0	C	0	0
62	C	11	11	11	11	C	11	C	11	11
63	C	0	0	0	0	C	0	C	0	0
64	C	11	11	11	11	C	11	C	11	11
65	C	0	0	0	0	C	0	C	0	0
66	C	11	11	11	11	C	11	C	11	11
67	C	0	0	0	0	C	0	C	0	0
68	C	11	11	11	11	C	11	C	11	11
69	C	0	0	0	0	C	0	C	0	0
70	C	11	11	11	11	C	11	C	11	11
71	C	0	0	0	0	C	0	C	0	0
72	C	11	11	11	11	C	11	C	11	11
73	C	0	0	0	0	C	0	C	0	0
74	C	11	11	11	11	C	11	C	11	11
75	C	0	0	0	0	C	0	C	0	0
76	C	11	11	11	11	C	11	C	11	11
77	C	0	0	0	0	C	0	C	0	0
78	C	11	11	11	11	C	11	C	11	11
79	C	0	0	0	0	C	0	C	0	0
80	C	11	11	11	11	C	11	C	11	11
81	C	0	0	0	0	C	0	C	0	0
82	C	11	11	11	11	C	11	C	11	11
83	C	0	0	0	0	C	0	C	0	0
84	C	11	11	11	11	C	11	C	11	11
85	C	0	0	0	0	C	0	C	0	0
86	C	11	11	11	11	C	11	C	11	11
87	C	0	0	0	0	C	0	C	0	0
88	C	11	11	11	11	C	11	C	11	11
89	C	0	0	0	0	C	0	C	0	0
90	C	11	11	11	11	C	11	C	11	11
91	C	0	0	0	0	C	0	C	0	0
92	C	11	11	11	11	C	11	C	11	11
93	C	0	0	0	0	C	0	C	0	0
94	C	11	11	11	11	C	11	C	11	11
95	C	0	0	0	0	C	0	C	0	0
96	C	11	11	11	11	C	11	C	11	11
97	C	0	0	0	0	C	0	C	0	0
98	C	11	11	11	11	C	11	C	11	11
99	C	0	0	0	0	C	0	C	0	0
100	C	11	11	11	11	C	11	C	11	11

Total

Mean	Median	W	W+	W-	F	High	Low	W+	W-
0	0	0	11	0	11	0	0	11	0

Σελίδα αποτελεσμάτων



# Και τώρα αναλυση!!

Είναι οι τροχιές των λεπτονίων, μίονια η ηλεκτρόνια;

Είναι  $W$  η  $Z$  η Higgs; Η μήπως είναι γεγονός zoo;

Είναι  $W^+$  η  $W^-$ ?

Εαν είναι  $Z$  η Higgs ποιά είναι η μάζα σε GeV;

# Και τώρα αναλυση!!

documentation

<https://quarknet.i2u2.org/page/cms-masterclass-2017-documentation>

Event display (ispy):

<https://www.i2u2.org/elab/cms/ispy-webgl>

Analysis of results with CIMA:

<https://www.i2u2.org/elab/cms/cima/index.php>

Video conference

<https://vidyoportal.cern.ch/join/3sGCerNrQV>

Τεστ

<https://vidyoportal.cern.ch/join/PNAG1VqJTW4n>

# Και τώρα αναλυση!!

Detector

Turn ON Ecal Barrel Detector

Physics objects

Turn OFF Tracking,

Turn ON Electrons (GSF), Muons, Photons, Missing Energy

Turn ON Ecal Rechits, Endcap Rechits

# Και τώρα αναλυση!!

WIFI network name : NCSR DEMOKRITOS

Password : **ncsrdemo**