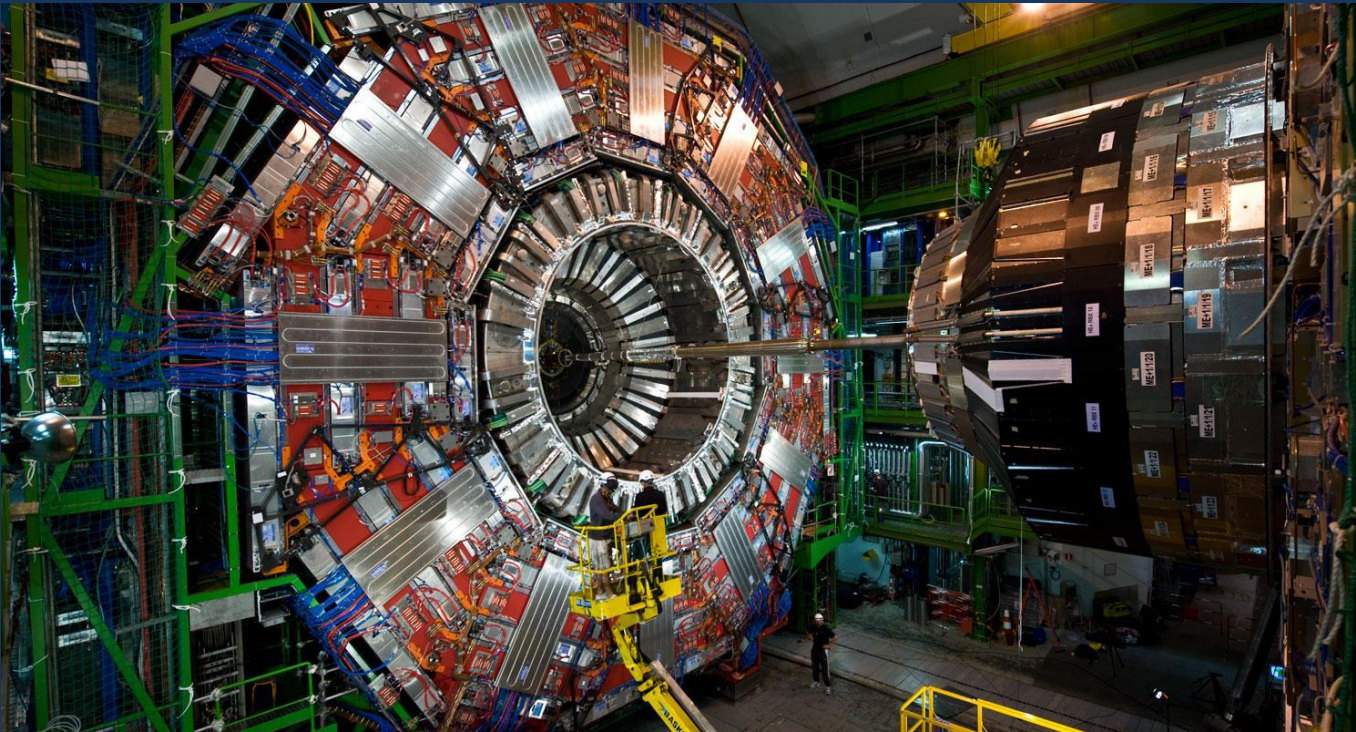


# Masterclass CMS

Curso para profesores CERN en español 2021

## Discusión resultados

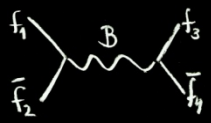


Jesús Puerta Pelayo /  
CIEMAT-FP



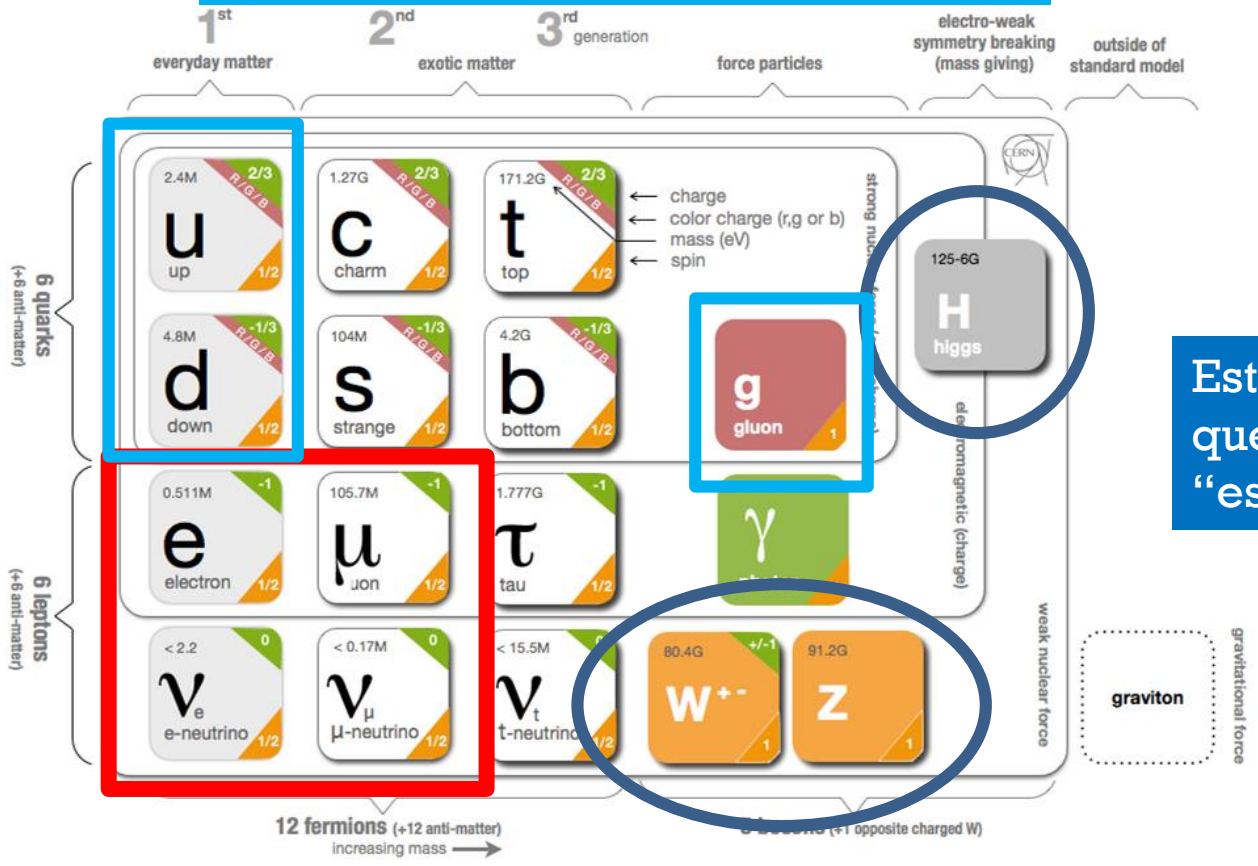
**Ciemat** Centro de Investigaciones  
Energéticas, Medioambientales  
y Tecnológicas





# El Modelo Estándar (ME)

Estas son las que han interactuado



Estas son las que habéis “visto”

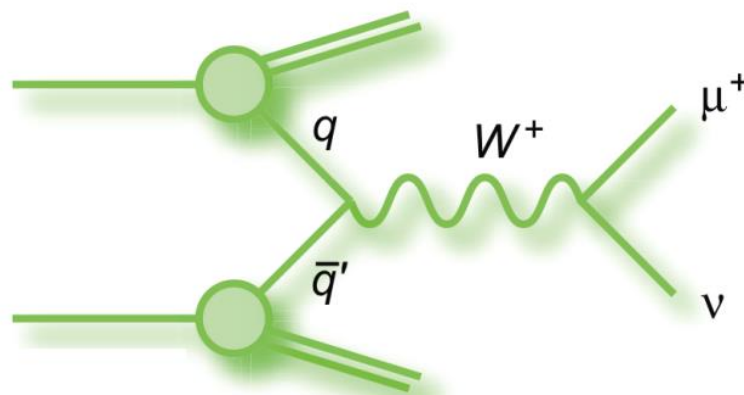
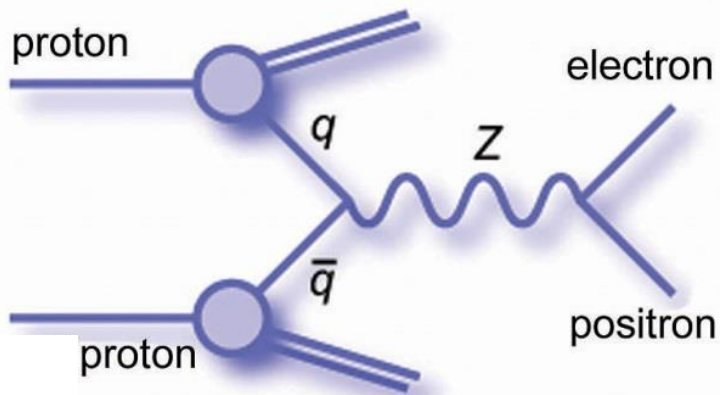
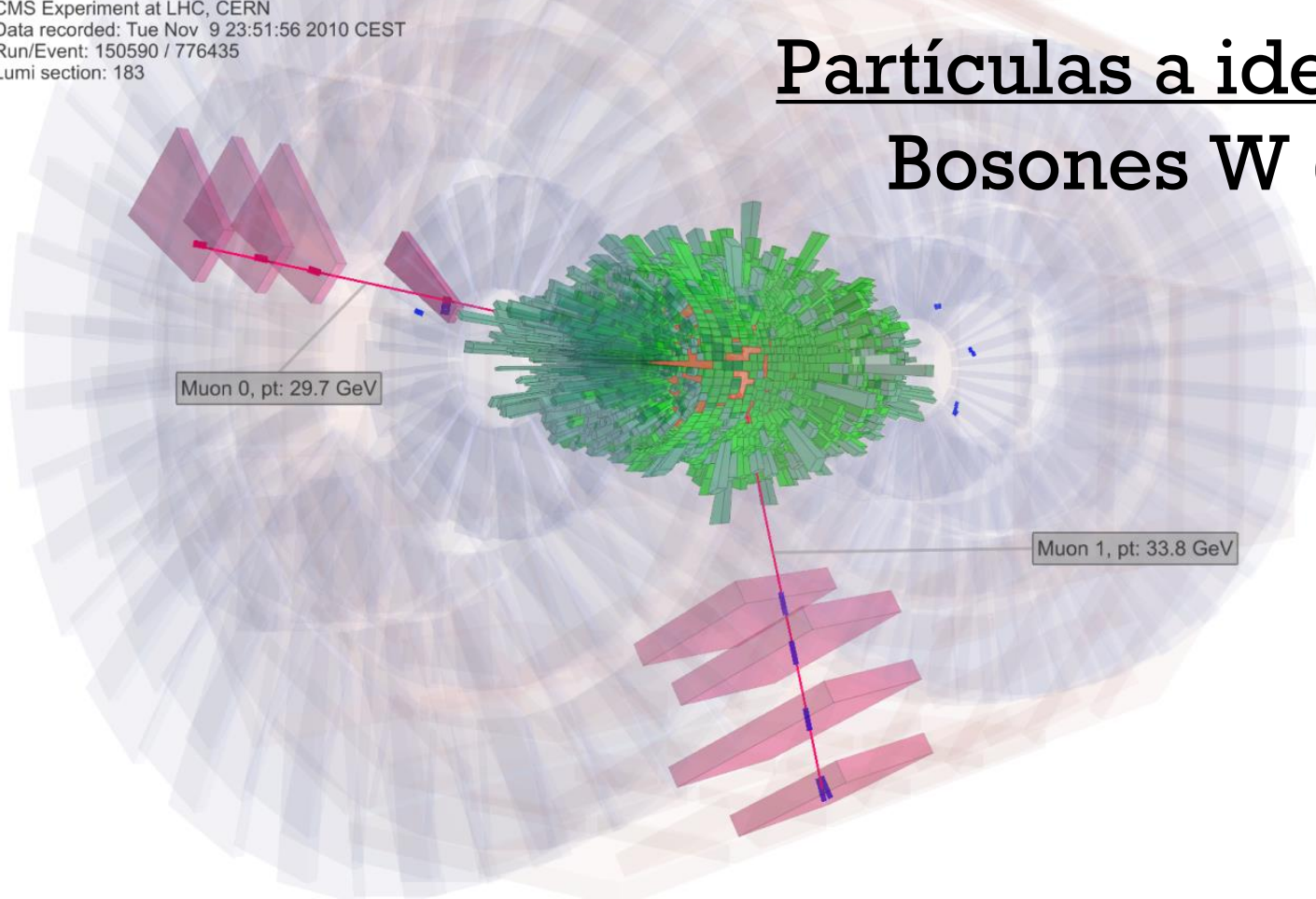
Estas son las que habéis “estudiado”

¡Y sus antipartículas también! ( $\mu^+$ , anti-u, anti-d,  $e^+$ ...)





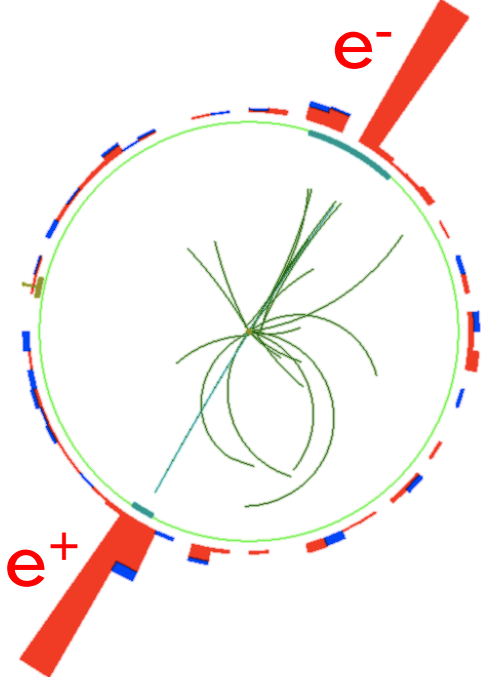
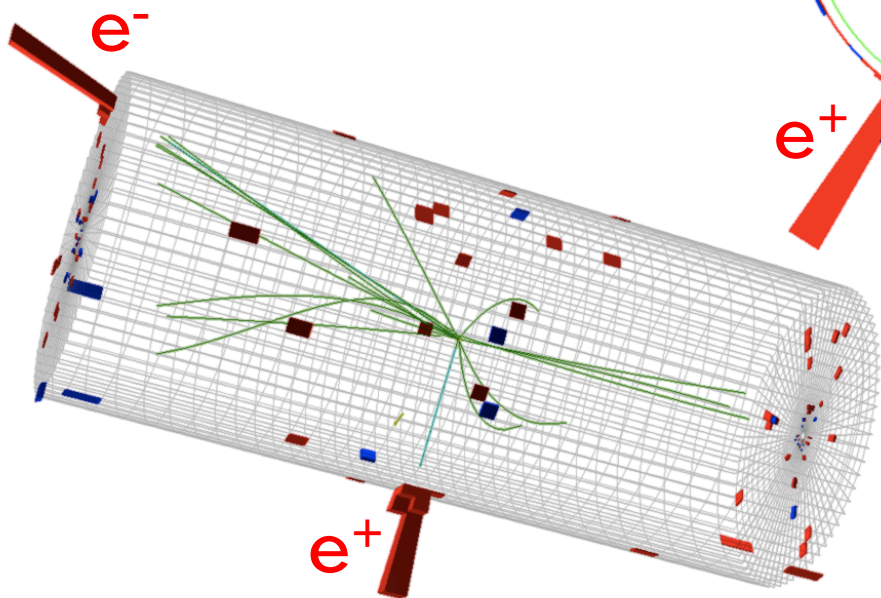
# Partículas a identificar: Bosones $W$ (+/-) y $Z$





CMS Experiment at LHC, CERN  
Run 133877, Event 28405693  
Lumi section: 387  
Sat Apr 24 2010, 14:00:54 CEST

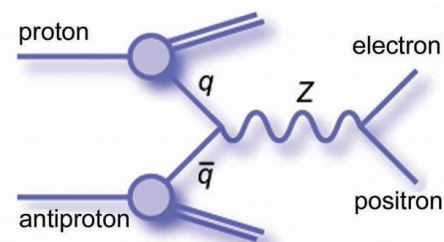
Electrons  $p_T = 34.0, 31.9$  GeV/c  
Inv. mass =  $91.2$  GeV/c<sup>2</sup>



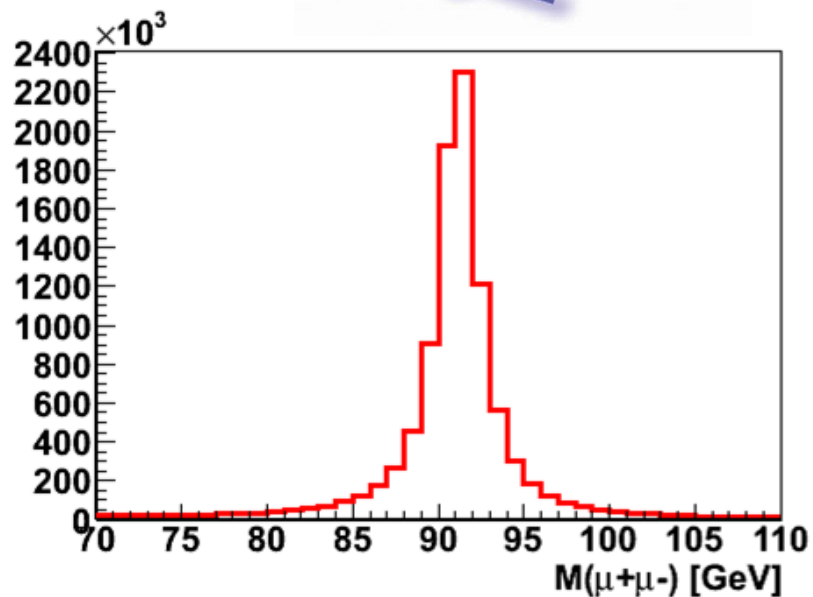
### Candidato a Z:

2 *leptones cargados* del mismo sabor ( $e, \mu$ ) y carga opuesta.

Balanceados en el plano transversal.



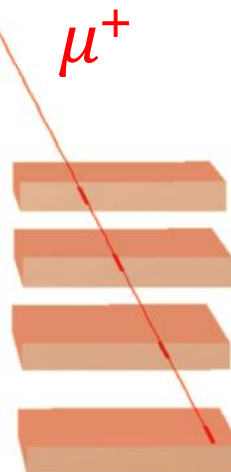
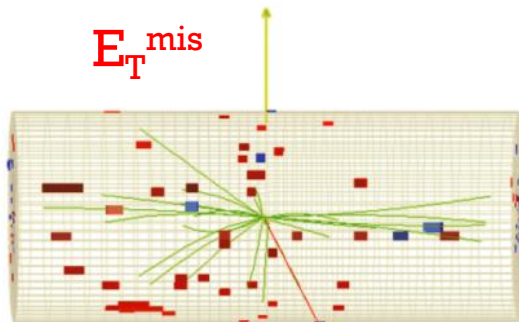
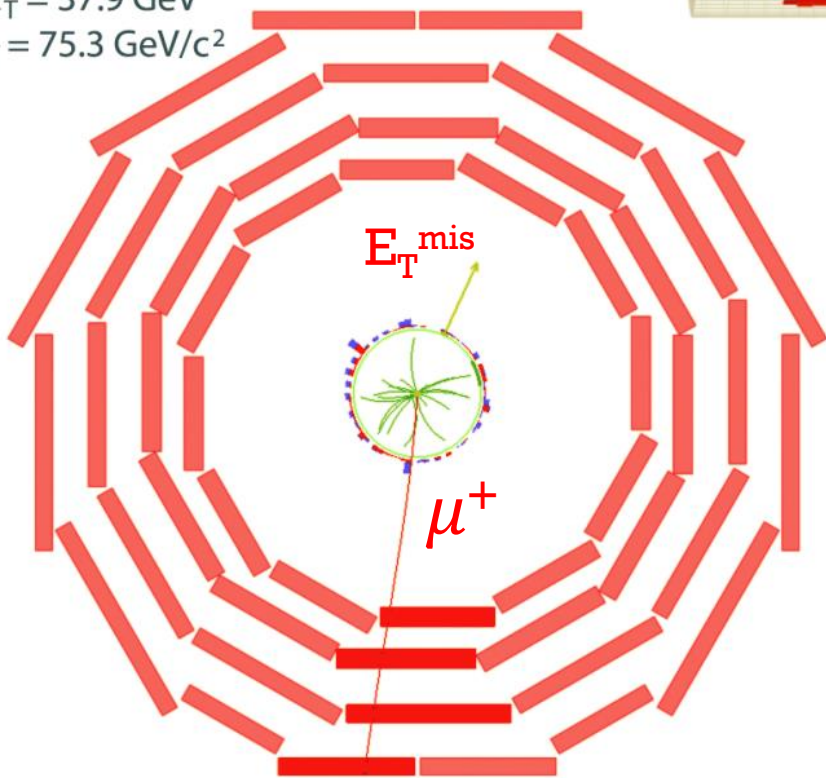
$$pp \rightarrow Z+X \rightarrow e^+e^-+X$$





CMS Experiment at LHC, CERN  
 Run 133875, Event 1228182  
 Lumi section: 16  
 Sat Apr 24 2010, 09:08:46 CEST

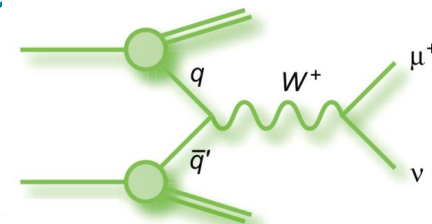
Muon  $p_T = 38.7 \text{ GeV}/c$   
 $ME_T = 37.9 \text{ GeV}$   
 $M_T = 75.3 \text{ GeV}/c^2$



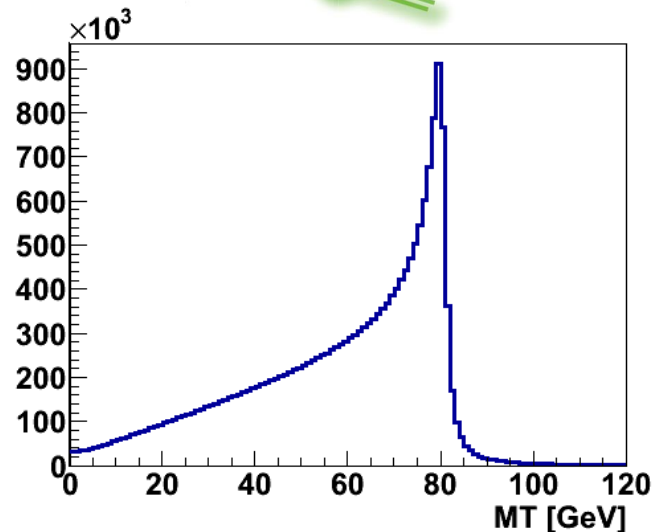
## Candidato a W:

1 **leptón cargado** ( $e$ ,  $\mu$ ) y un **neutrino** ( $E_T^{\text{mis}}$ ).

El neutrino se manifiesta por la *falta aparente de conservación de energía-momento*



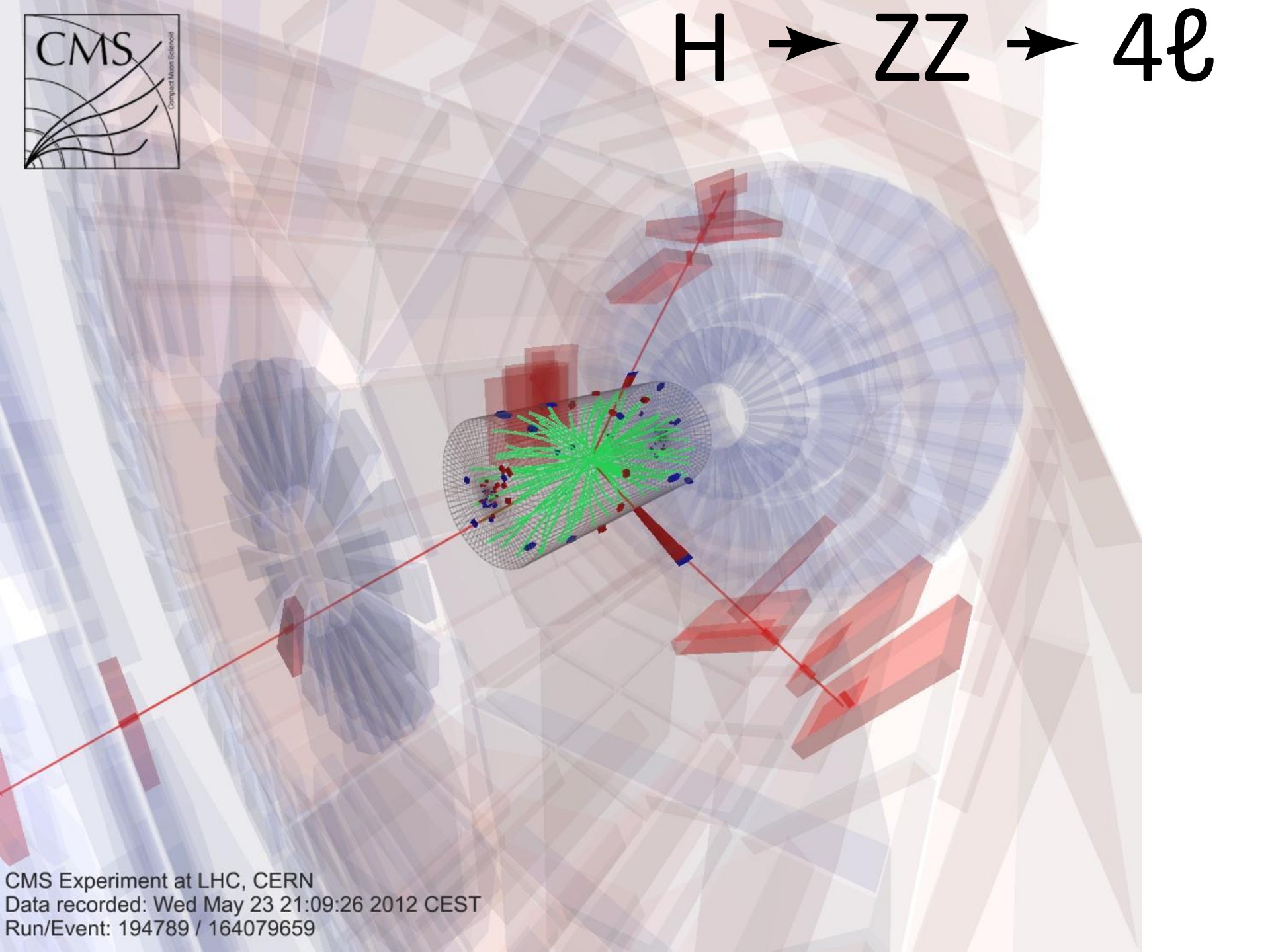
$$pp \rightarrow W+X \rightarrow \mu^+\nu+X$$



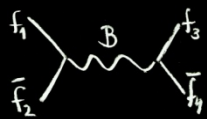




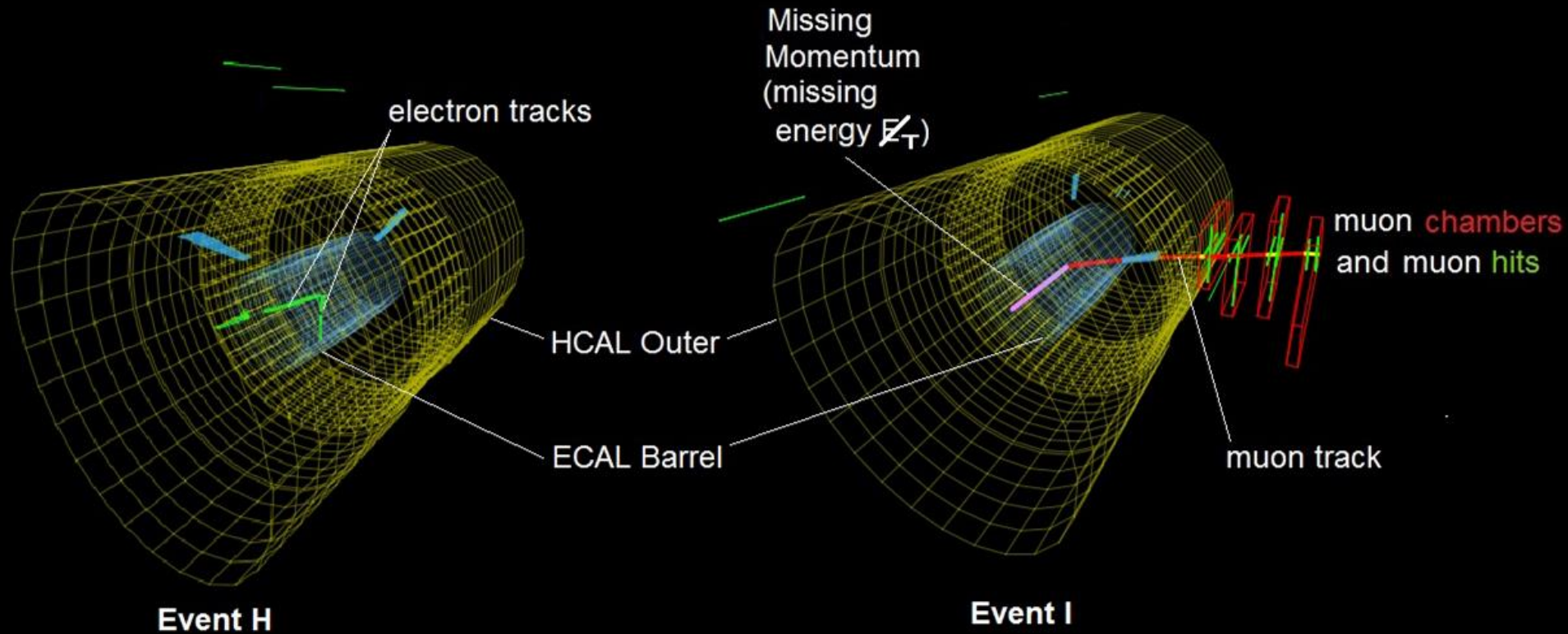
$H \rightarrow ZZ \rightarrow 4\ell$



CMS Experiment at LHC, CERN  
Data recorded: Wed May 23 21:09:26 2012 CEST  
Run/Event: 194789 / 164079659



# 1) Identificación de sucesos

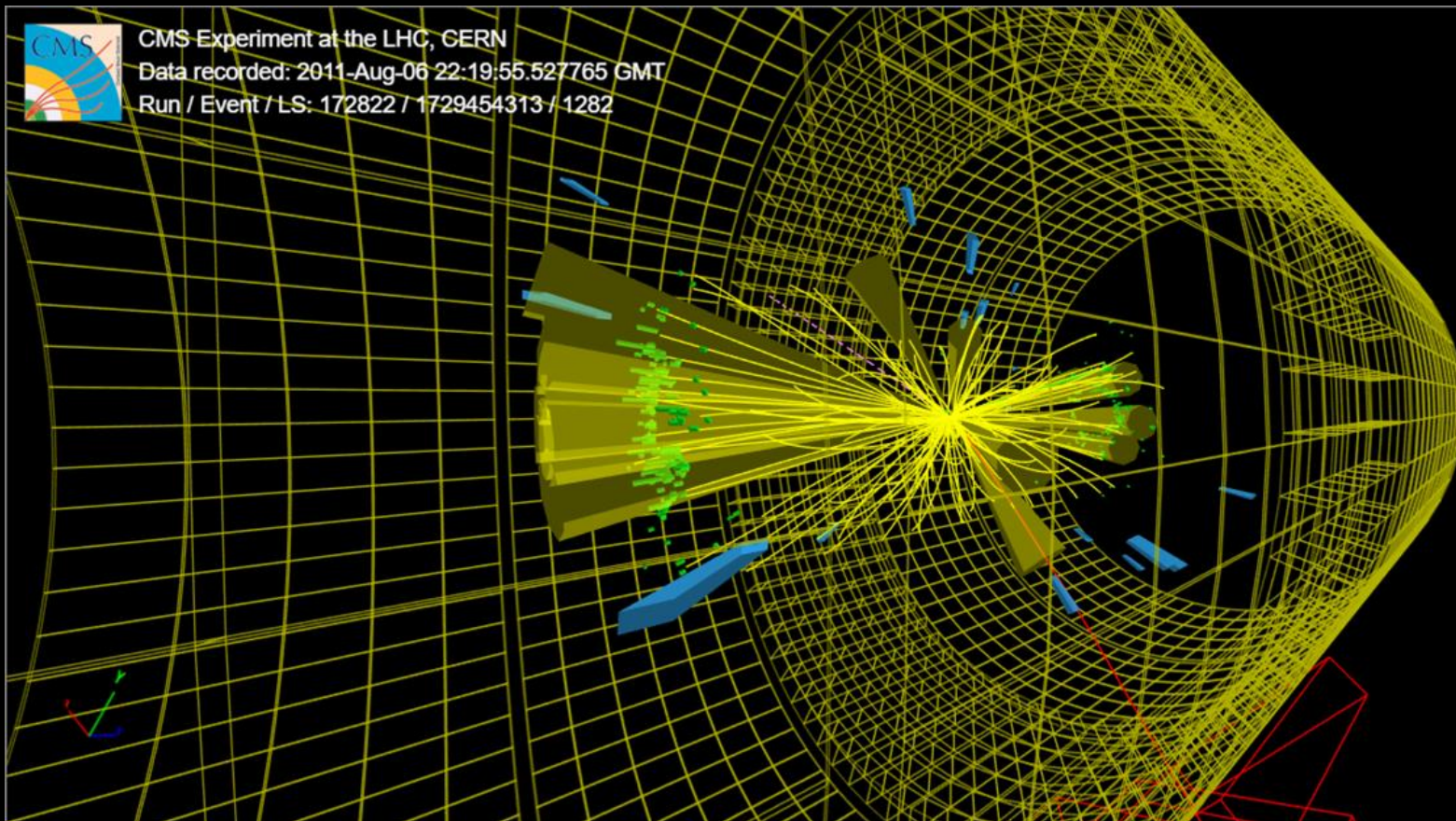


¿Problemas?

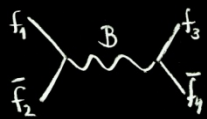


1. Manejo del visualizador
2. Identificar estados finales
3. ¿Por qué había eventos “zoo”?
4. ¿Por qué había otras partículas?

Requiere práctica...





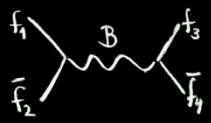


# Datos

## Datos de colisiones





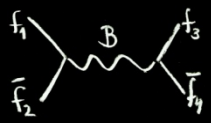


# Datos

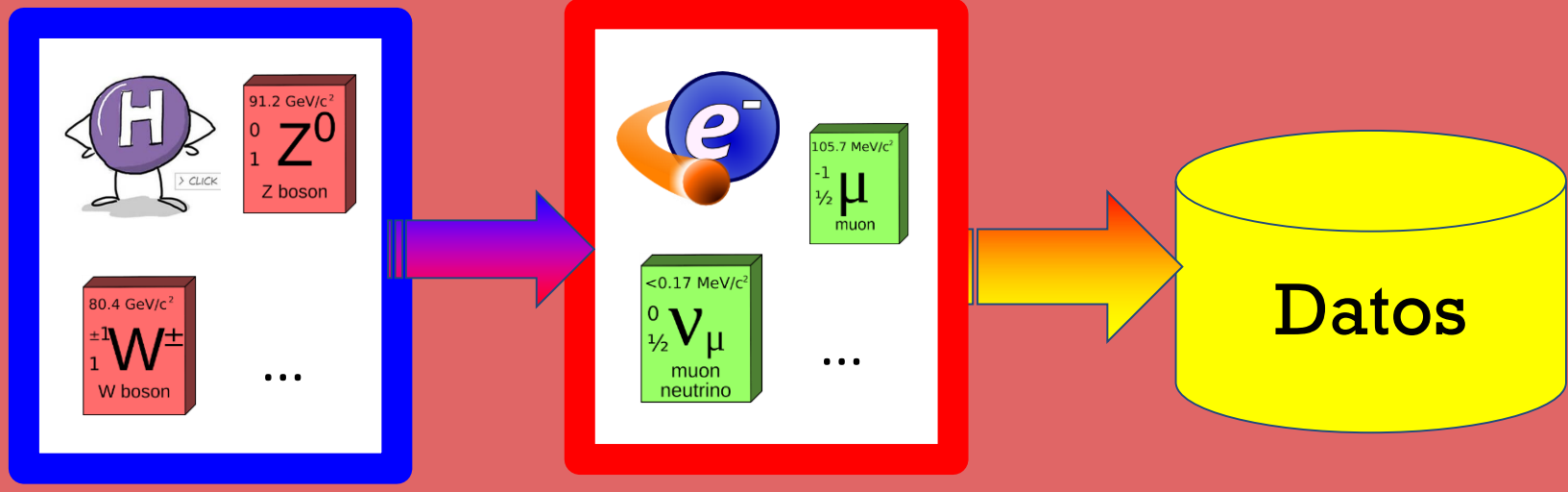


se transforman en

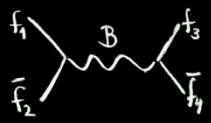




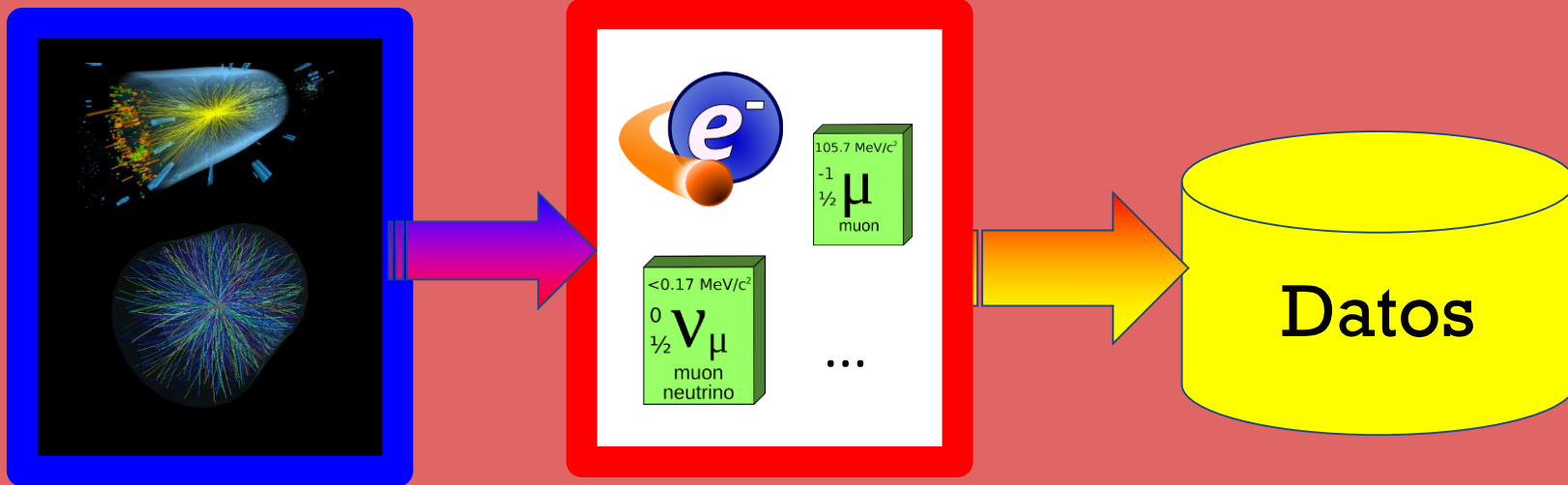
# Datos

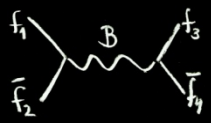




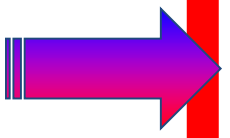


# Datos

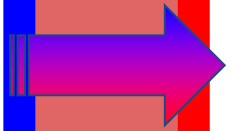
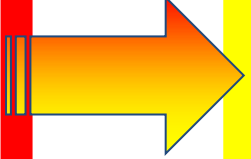




# Datos

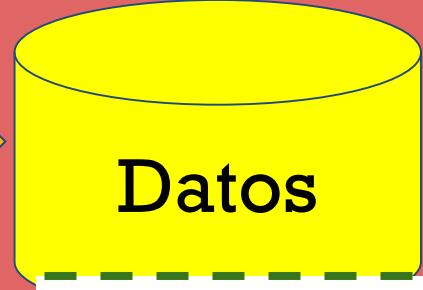
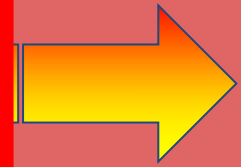


2 kg de Aluminio  
 3 m de cable  
 1 tapa de vidrio  
 ...

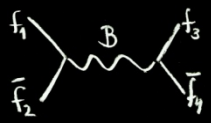


105.7 MeV/c <sup>2</sup> -1 1/2 μ muon	105.7 MeV/c <sup>2</sup> -1 1/2 μ muon	105.7 MeV/c <sup>2</sup> -1 1/2 μ muon	105.7 MeV/c <sup>2</sup> -1 1/2 μ muon
0.511 MeV/c <sup>2</sup> -1 1/2 e elektron	0.511 MeV/c <sup>2</sup> -1 1/2 e elektron	0.511 MeV/c <sup>2</sup> -1 1/2 e elektron	0.511 MeV/c <sup>2</sup> -1 1/2 e elektron
0.511 MeV/c <sup>2</sup> -1 1/2 e elektron	0.511 MeV/c <sup>2</sup> -1 1/2 e elektron	105.7 MeV/c <sup>2</sup> -1 1/2 μ muon	105.7 MeV/c <sup>2</sup> -1 1/2 μ muon

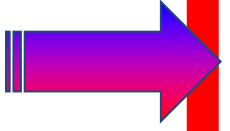
Energías > XX GeV  
 ...



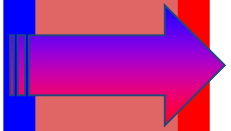
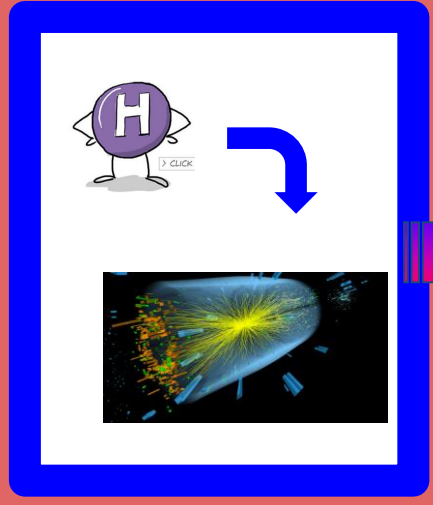
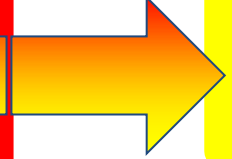
Sistema de discriminación (Trigger)  
 Selección de sucesos (Offline)



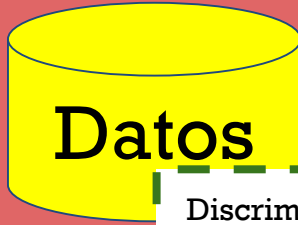
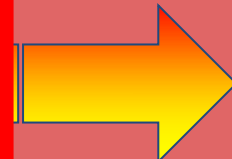
# Datos



- 2 kg de Aluminio
- 3 m de cable
- 1 tapa de vidrio
- ...
- +
- Cáscaras de naranja,**
- calcetines rotos, latas**
- de atún...**



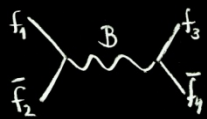
- |  |  |  |  |
|--|--|--|--|
| 105.7 MeV/c <sup>2</sup><br>-1<br>1/2<br>μ<br>muon     | 105.7 MeV/c <sup>2</sup><br>-1<br>1/2<br>μ<br>muon     | 105.7 MeV/c <sup>2</sup><br>-1<br>1/2<br>μ<br>muon     | 105.7 MeV/c <sup>2</sup><br>-1<br>1/2<br>μ<br>muon     |
| 0.511 MeV/c <sup>2</sup><br>-1<br>3/2<br>e<br>elektron | 0.511 MeV/c <sup>2</sup><br>-1<br>3/2<br>e<br>elektron | 0.511 MeV/c <sup>2</sup><br>-1<br>3/2<br>e<br>elektron | 0.511 MeV/c <sup>2</sup><br>-1<br>3/2<br>e<br>elektron |
| 0.511 MeV/c <sup>2</sup><br>-1<br>3/2<br>e<br>elektron | 0.511 MeV/c <sup>2</sup><br>-1<br>3/2<br>e<br>elektron | 105.7 MeV/c <sup>2</sup><br>-1<br>1/2<br>μ<br>muon     | 105.7 MeV/c <sup>2</sup><br>-1<br>1/2<br>μ<br>muon     |
- +
- muuuuuchas otras**
- partículas**



Discriminación /  
Selección





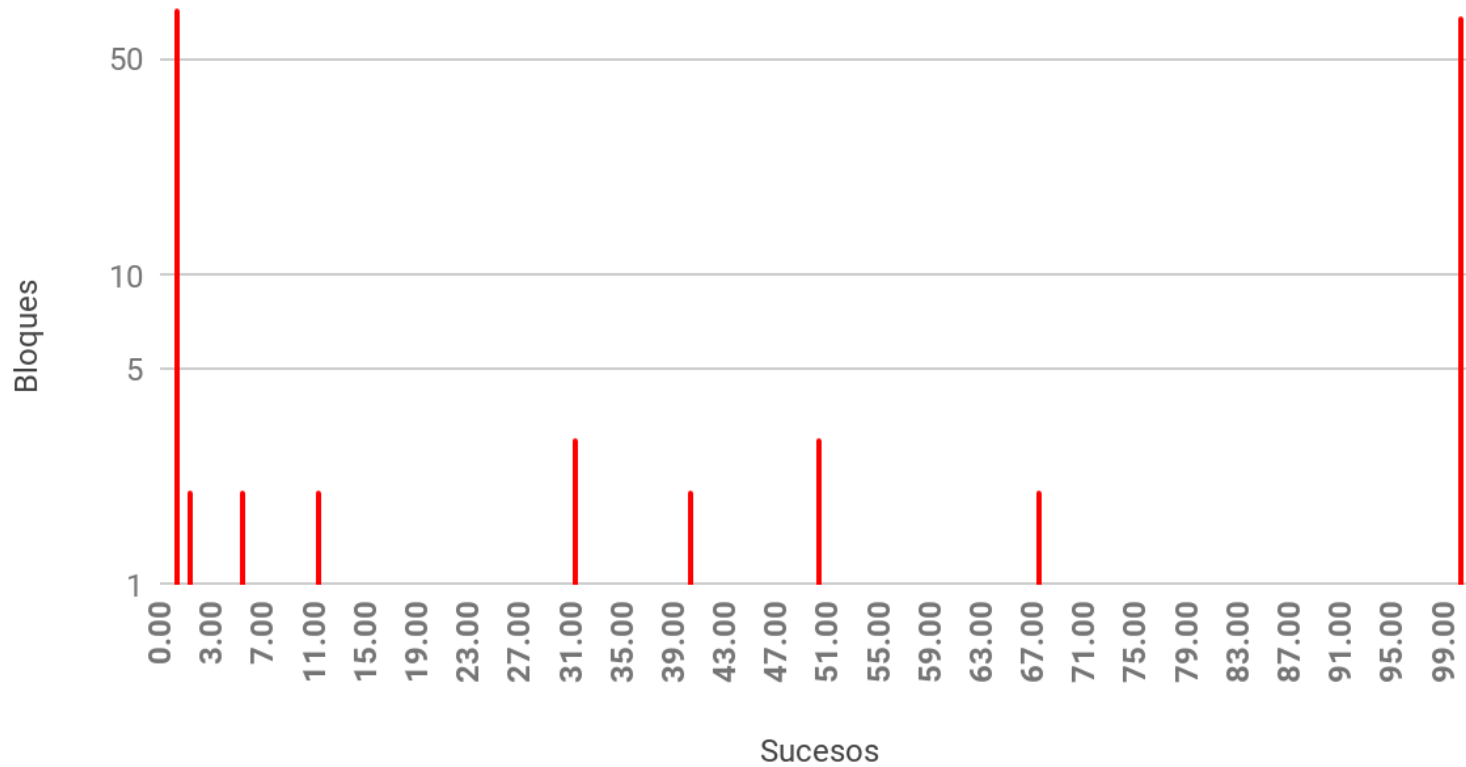


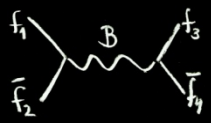
# Resultados

## Índice de pereza



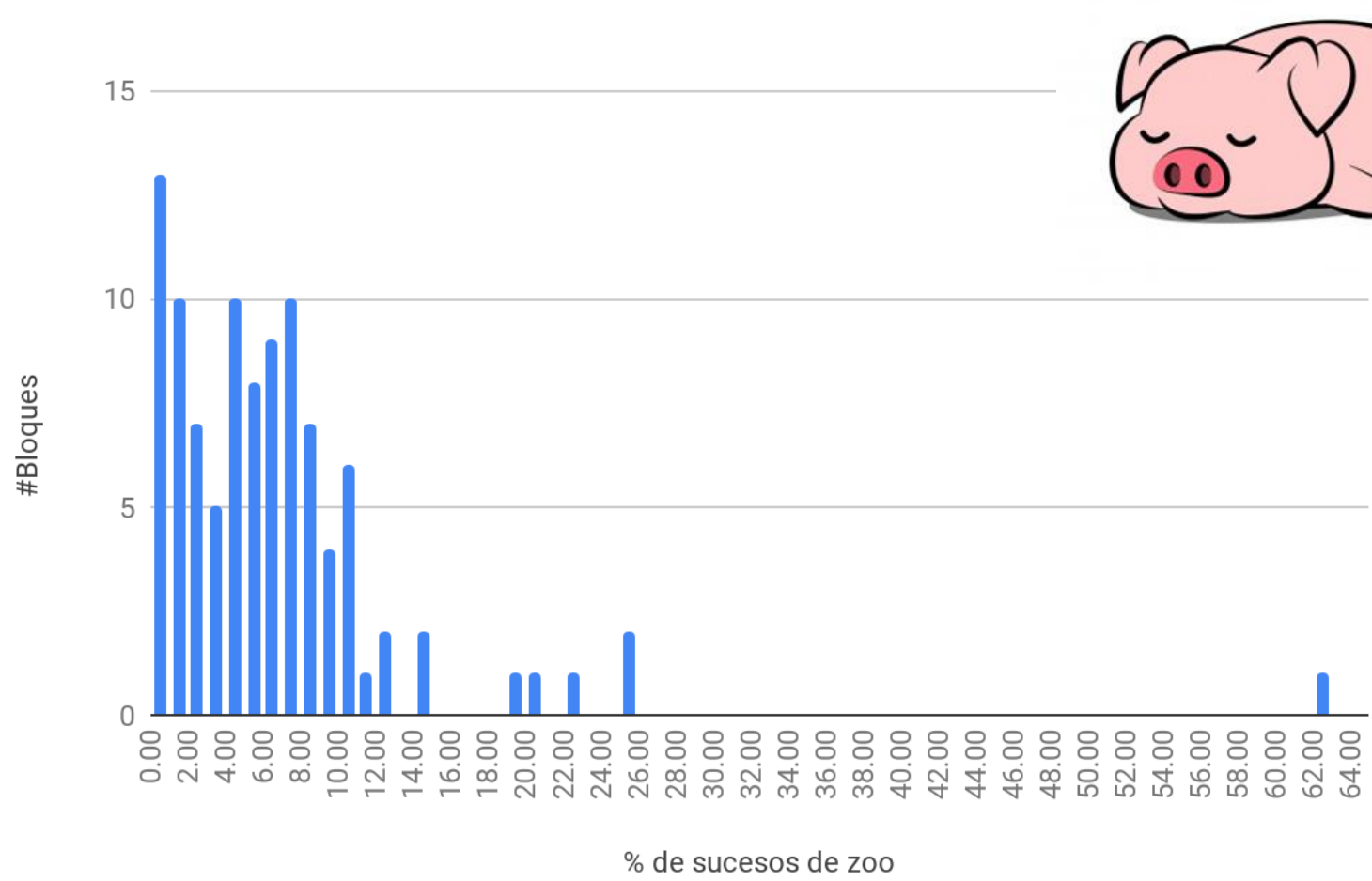
Eventos analizados

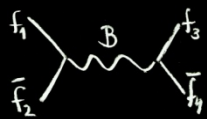




# Resultados

## Parámetro de dejadez





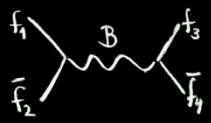
# Resultados

e	$\mu$	W+	W-	Wpm	NP	Zoo	Total
3886	4117	1858	1724	1027	2992	469	8070

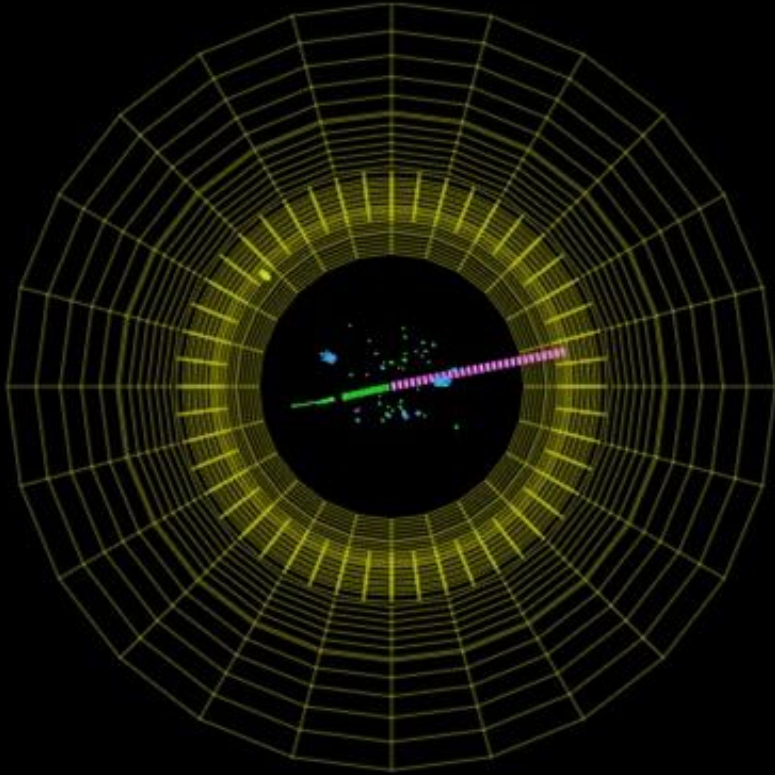
Bloques activos	100
Eventos totales	10000
% eventos analizados	80.70%



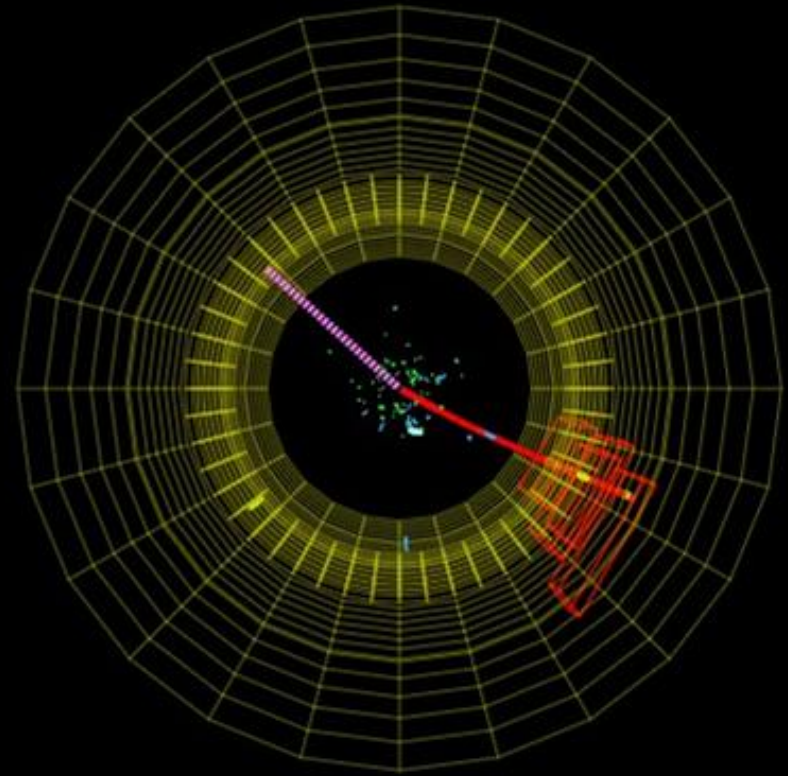




# Los bosones W

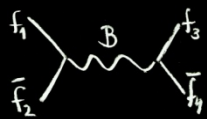


Event A



Event B

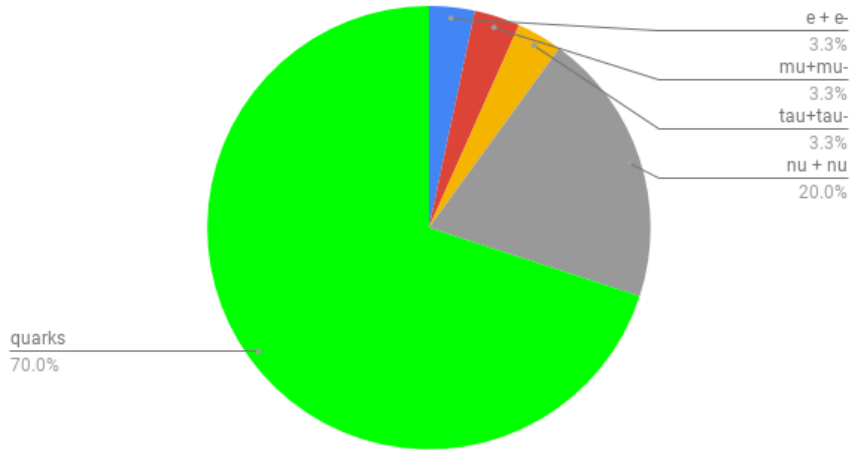
¿Problemas?



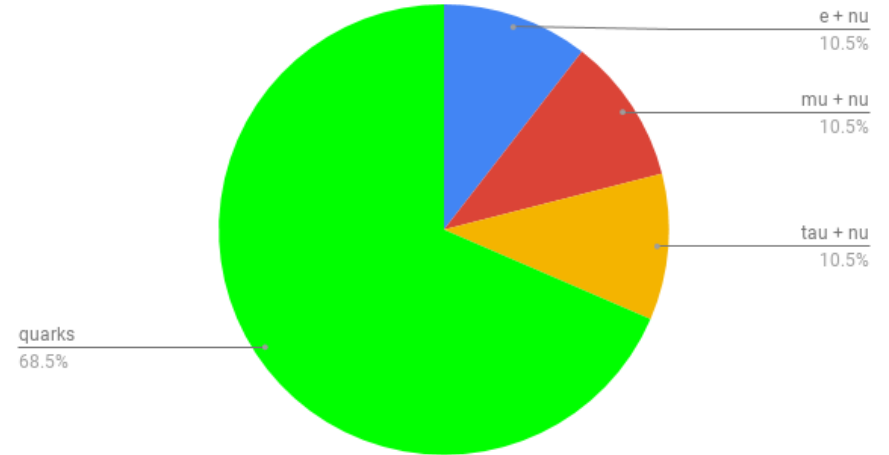
# Los bosones W

¿Podemos calcular la razón  $e/\mu$  en estados finales de W (igual para Z)?

Modos de desintegración del bosón Z



Modos de desintegración del bosón W

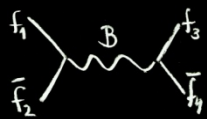


e	$\mu$	W+	W-	Wpm	NP	Zoo	Total
3886	4117						8070

Cocientes	e/ $\mu$	W+/W-
	0.94	

Teoría / medido en CMS :  $e/\mu = 1$





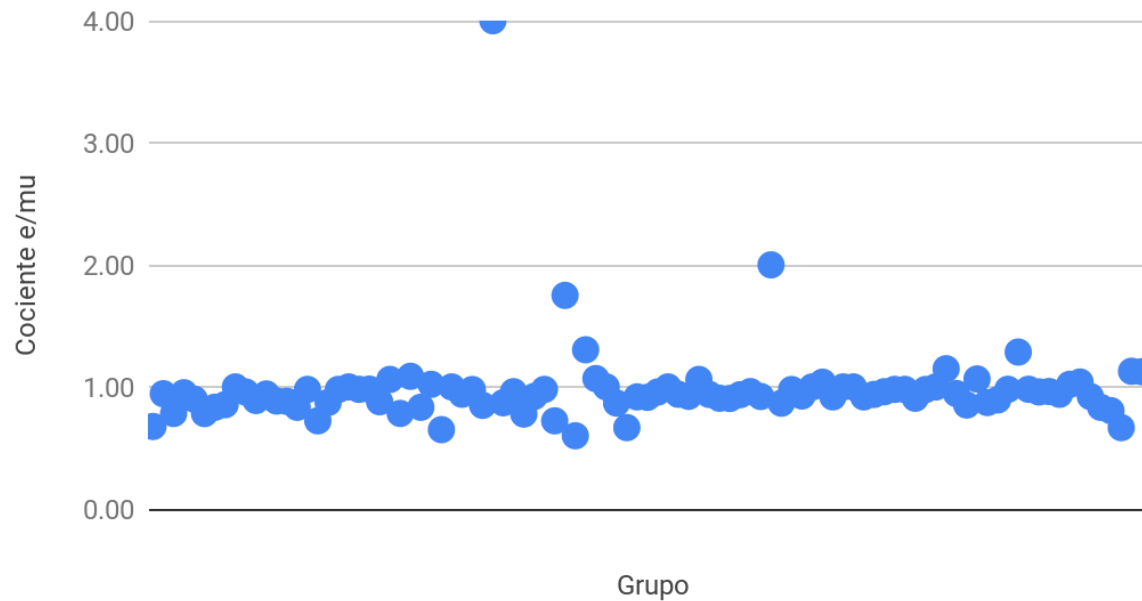
# Los bosones W

Por grupos

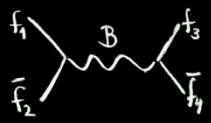
e	$\mu$	W+	W-	Wpm	NP	Zoo	Total
3886	4117						8070

Teoría / medido en CMS :  $e/\mu = 1$

Cociente e/mu por grupos

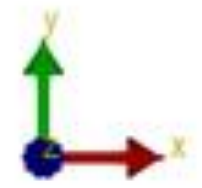
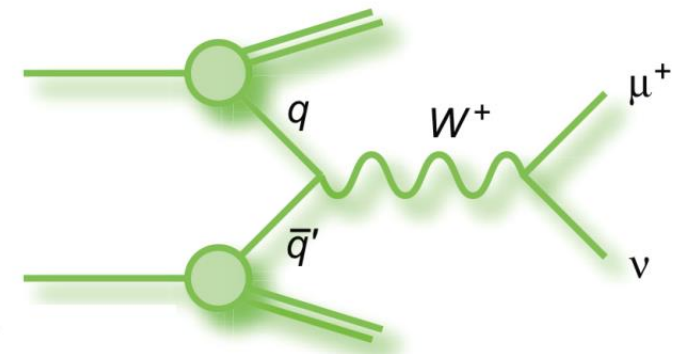
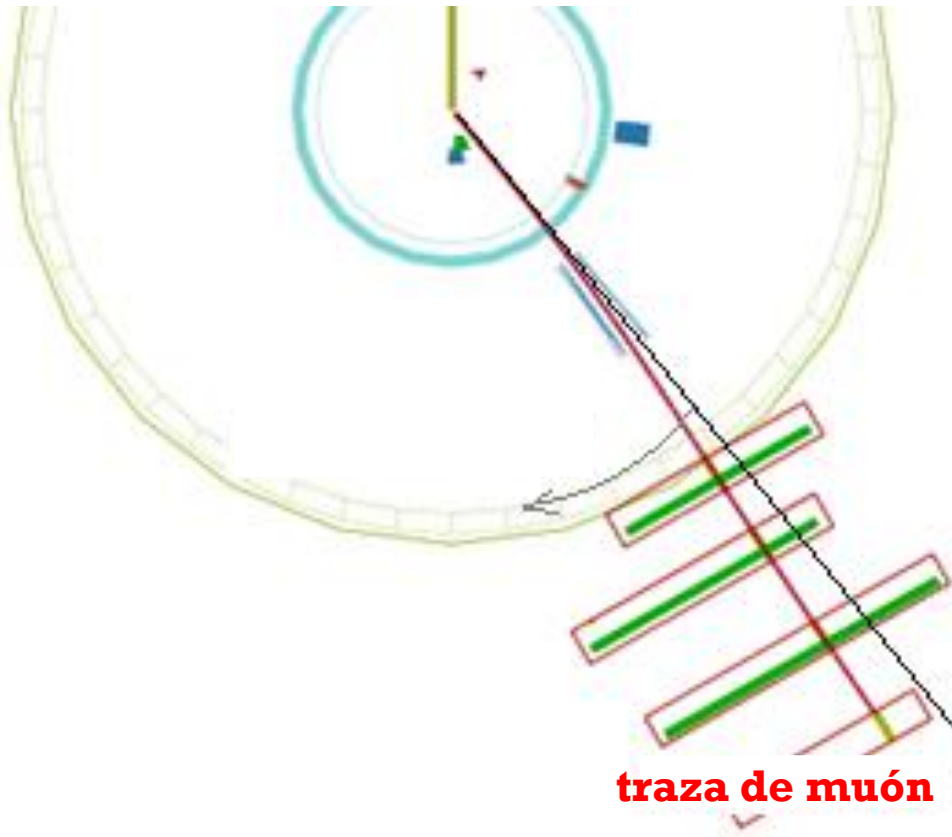


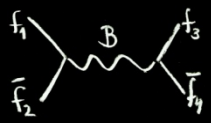




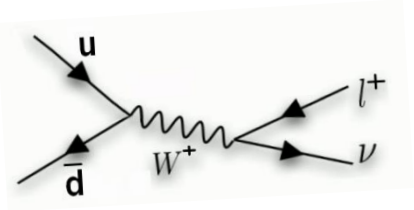
# Los bosones W

¿Podemos calcular la razón  $W^+/W^-$  para CMS?

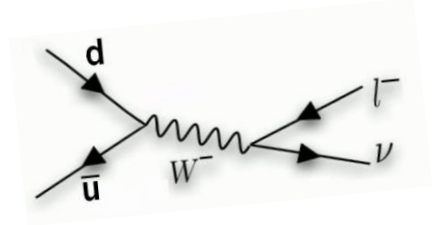




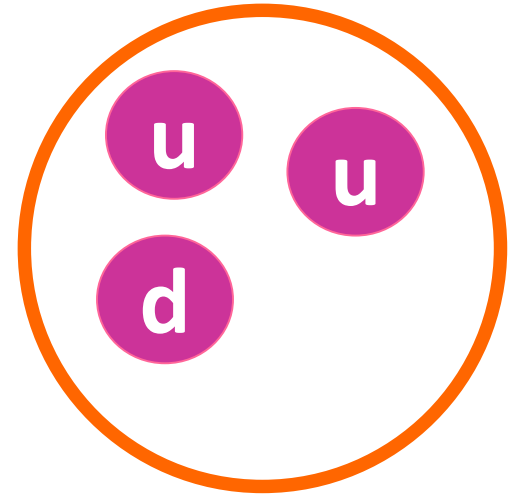
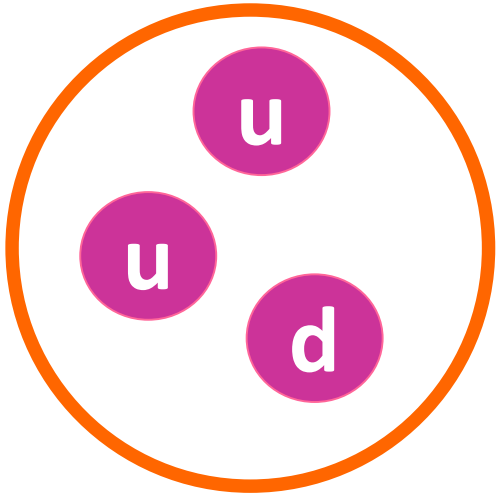
# Asimetría en la producción de W

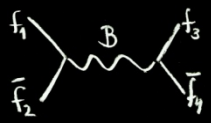


$$u\bar{d} \rightarrow W^+$$

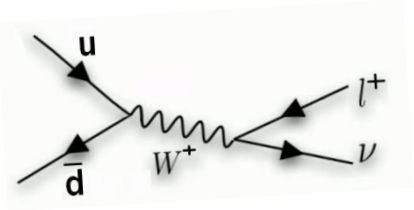


$$\bar{u}d \rightarrow W^-$$

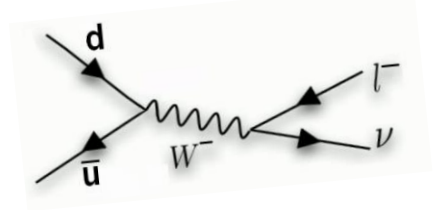




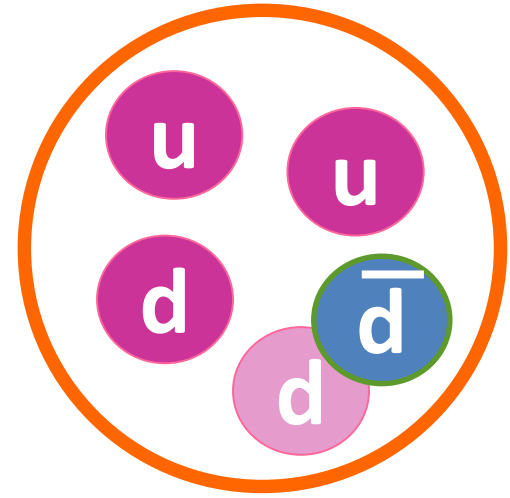
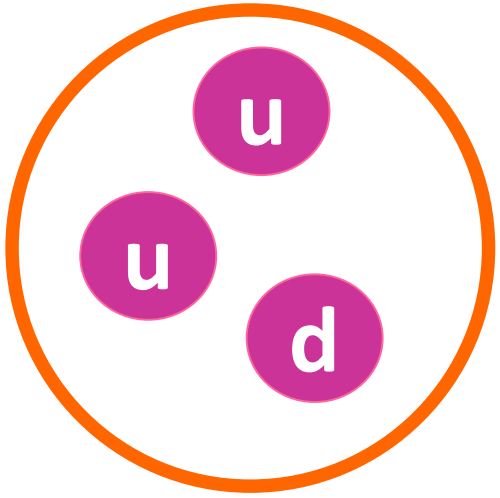
# Asimetría en la producción de W



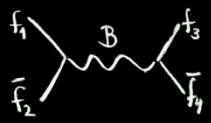
$$u\bar{d} \rightarrow W^+$$



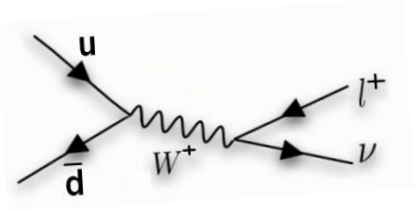
$$\bar{u}d \rightarrow W^-$$



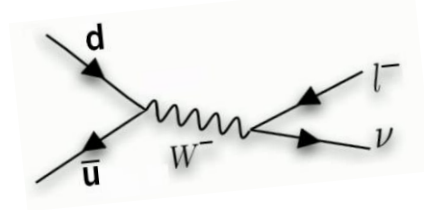




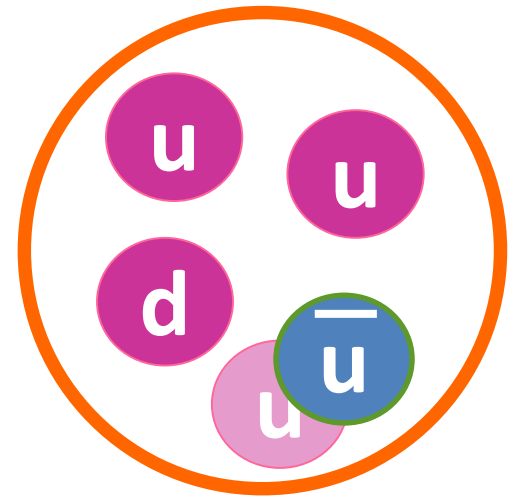
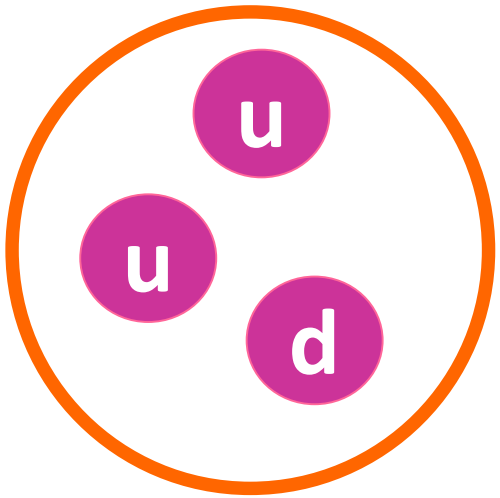
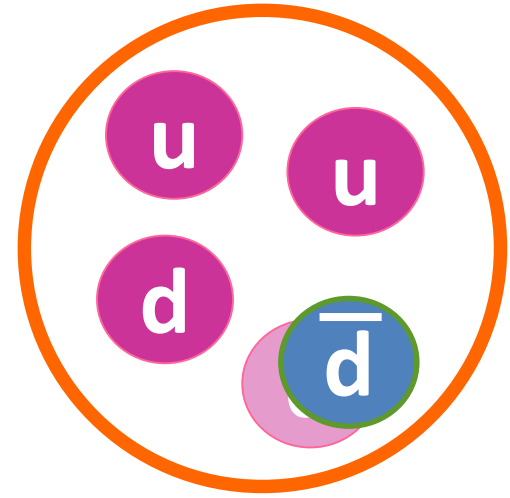
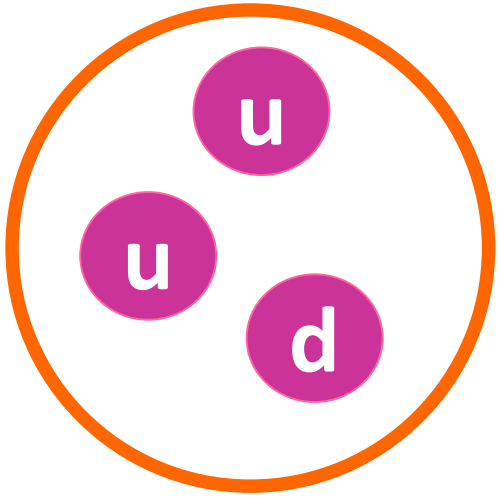
# Asimetría en la producción de W

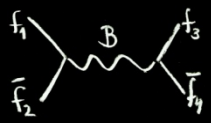


$$u\bar{d} \rightarrow W^+$$

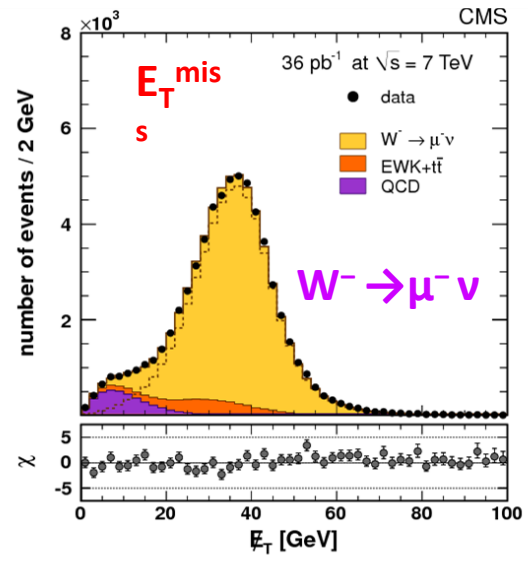
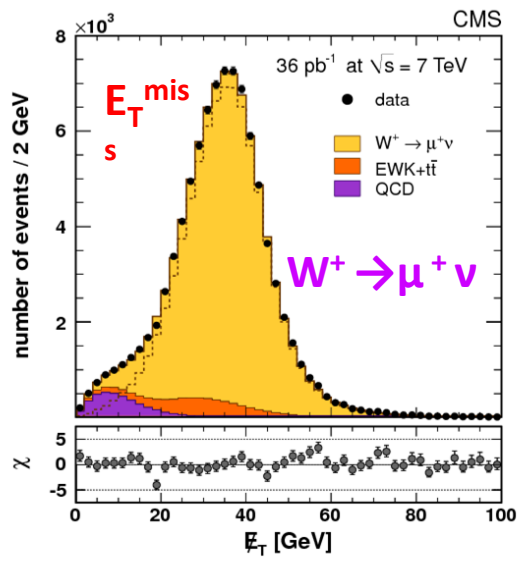
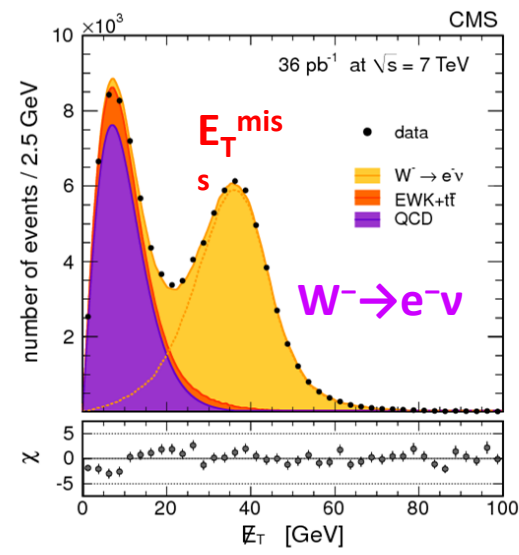
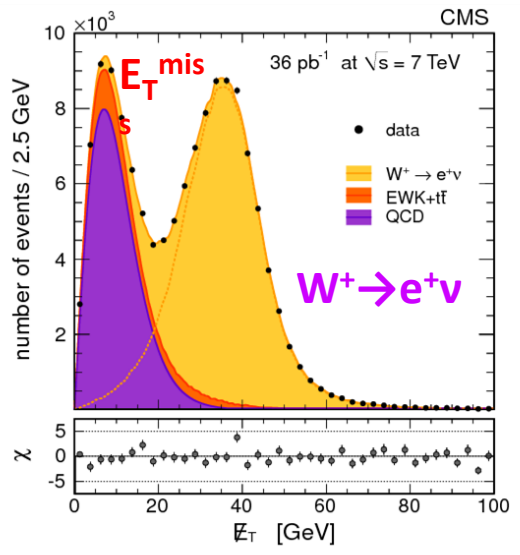


$$\bar{u}d \rightarrow W^-$$

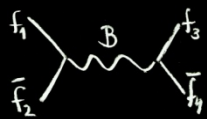




# Asimetría en la producción de W



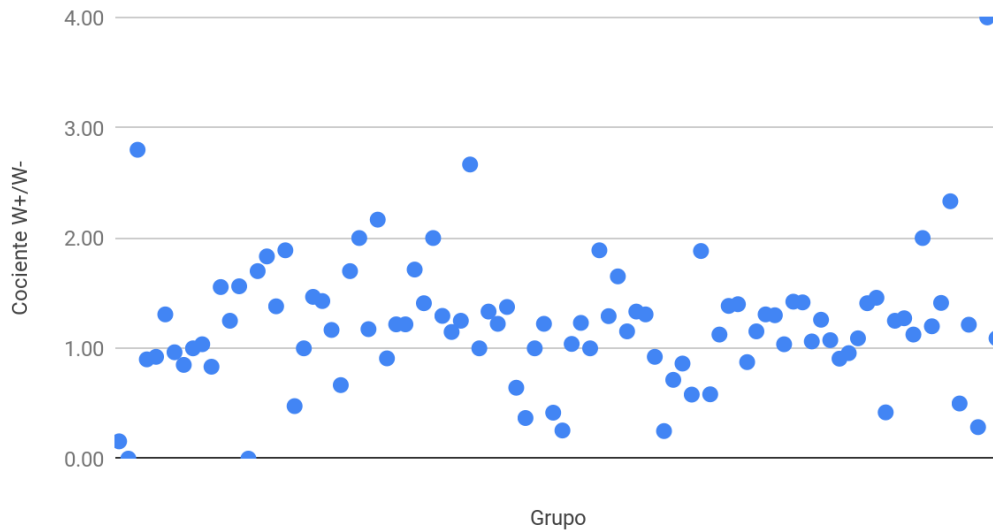
La asimetría depende de las PDFs de los quarks en el protón.



# 2) Los bosones W

¿Podemos calcular la razón  $W^+/W^-$  para CMS?

W+/W- por grupos



**CMS:  $W^+/W^- \approx 1.4$**

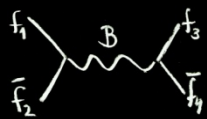
Cocientes	e/mu	W+/W-
	0.94	<b>1.08</b>



e	$\mu$	W+	W-	Wpm	NP	Zoo
3886	4117	1858	1724	<del>1027</del>		



Estimar la curvatura "a ojo" no es fiable...



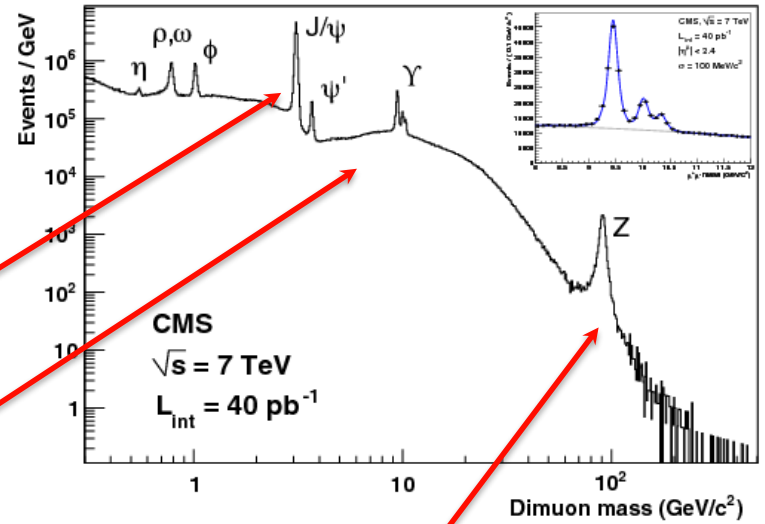
# Histograma de masas de partículas neutras





# Histograma masas

Masa  $J/\psi \sim 3 \text{ GeV}$   
Masa  $\Upsilon \sim 9.4 \text{ GeV}$

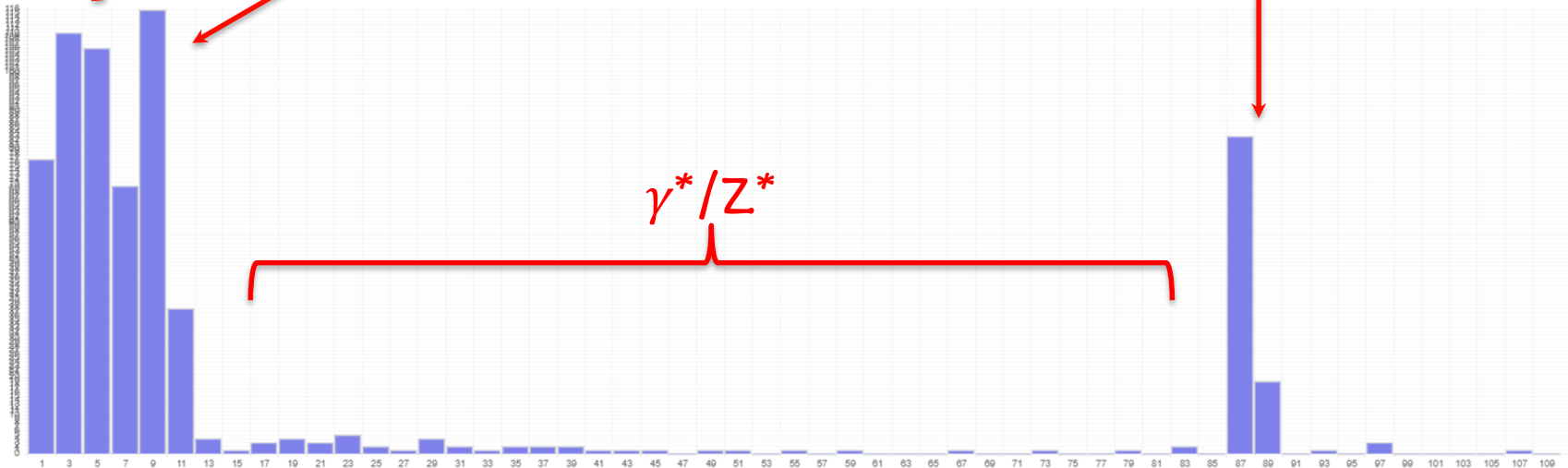


$J/\psi$  ( $c\bar{c}$ )

$\Upsilon$  ( $b\bar{b}$ )

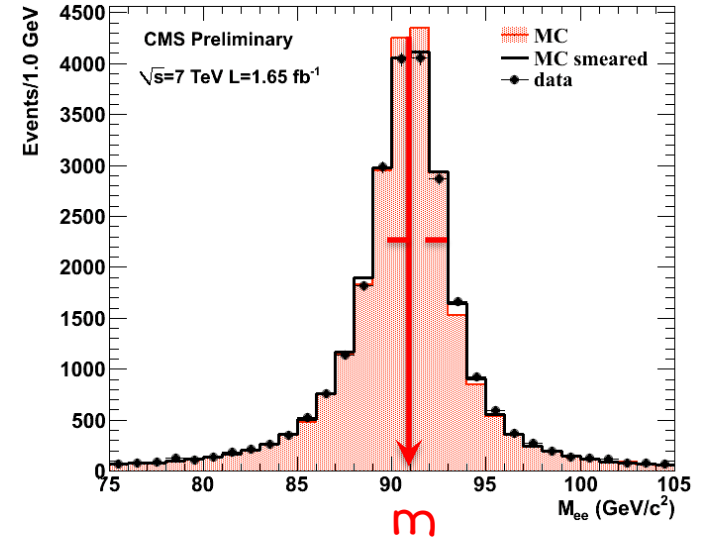
$Z$

$\gamma^*/Z^*$

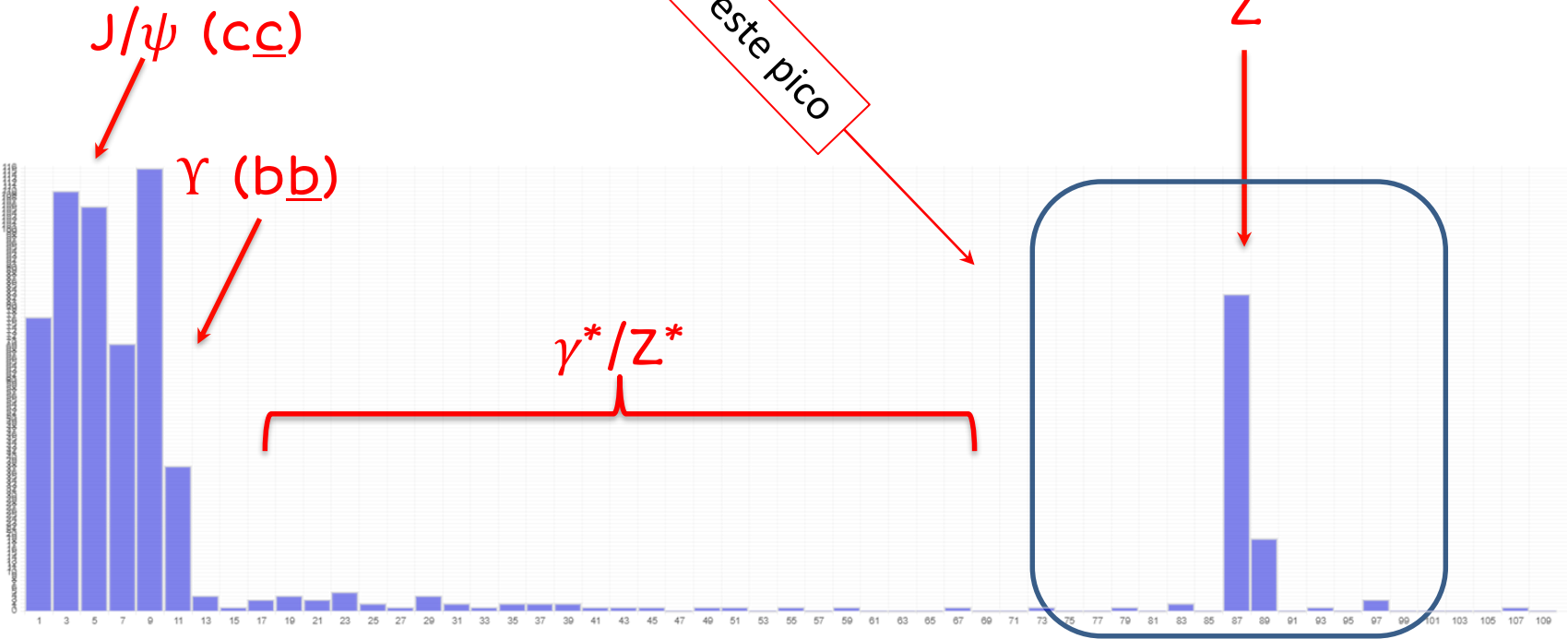


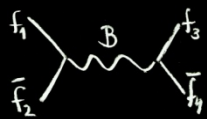
# Histograma masas

Masa Z ~ 91 GeV



~102 sucesos en este pico





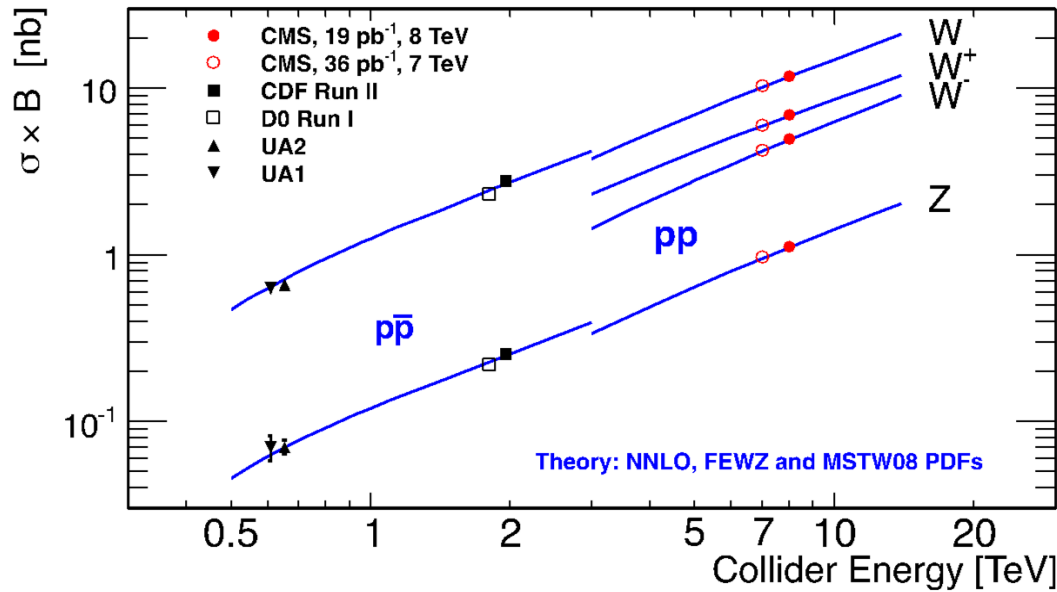
# ¿Hay más W o Z?

4592 sucesos W

e	$\mu$	W+	W-	Wpm	NP	Zoo	Total
3886	4117	1858	1724	1027	2992	469	8070



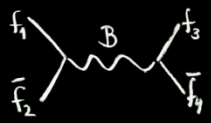
102 sucesos de Z entre estos



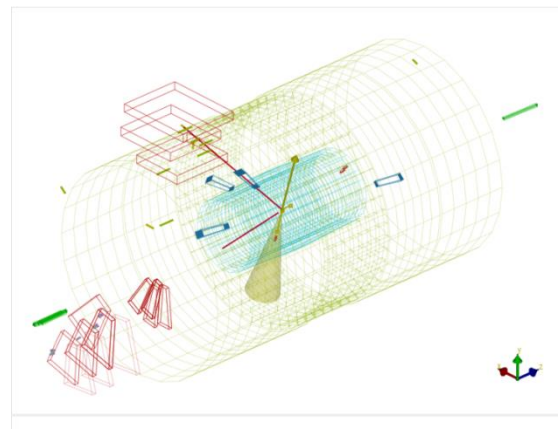
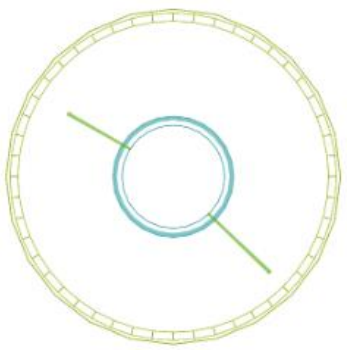
Medido:  $W/Z = 45$

CMS:  $W/Z \approx 12$

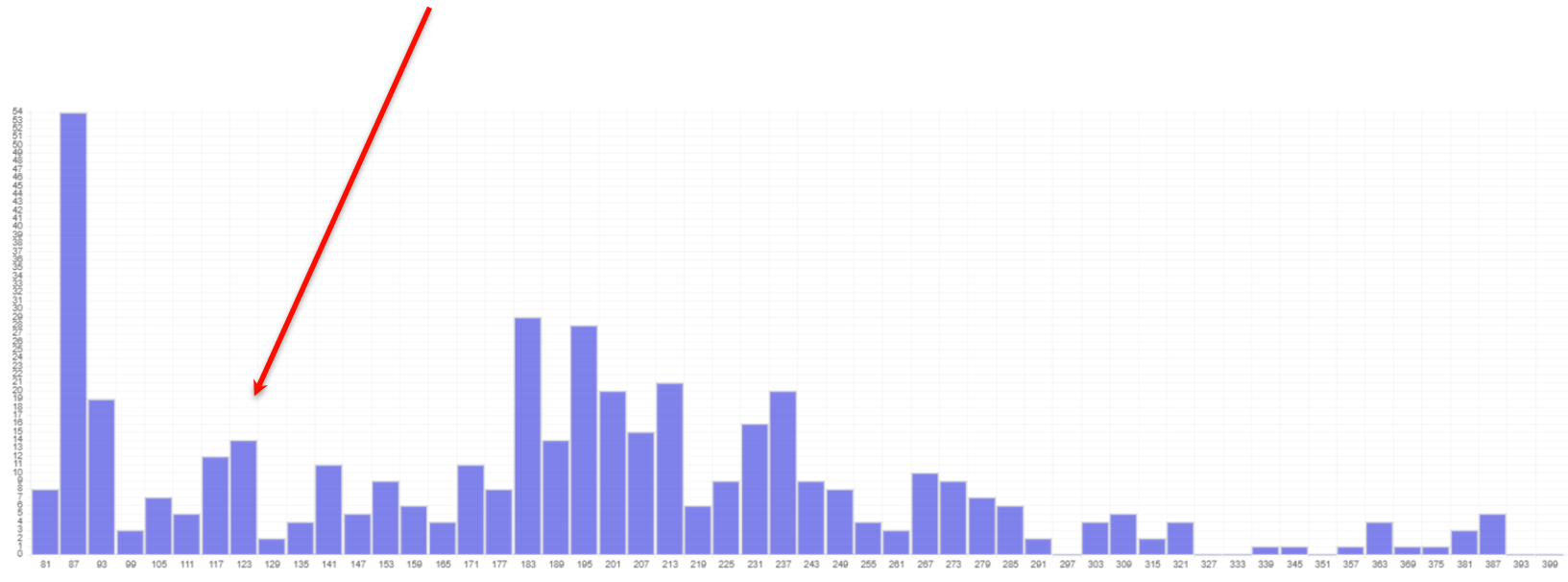
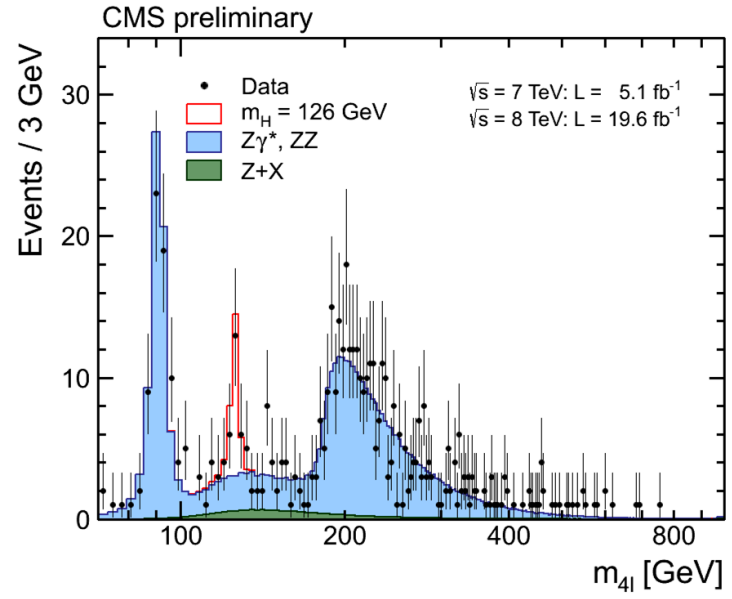




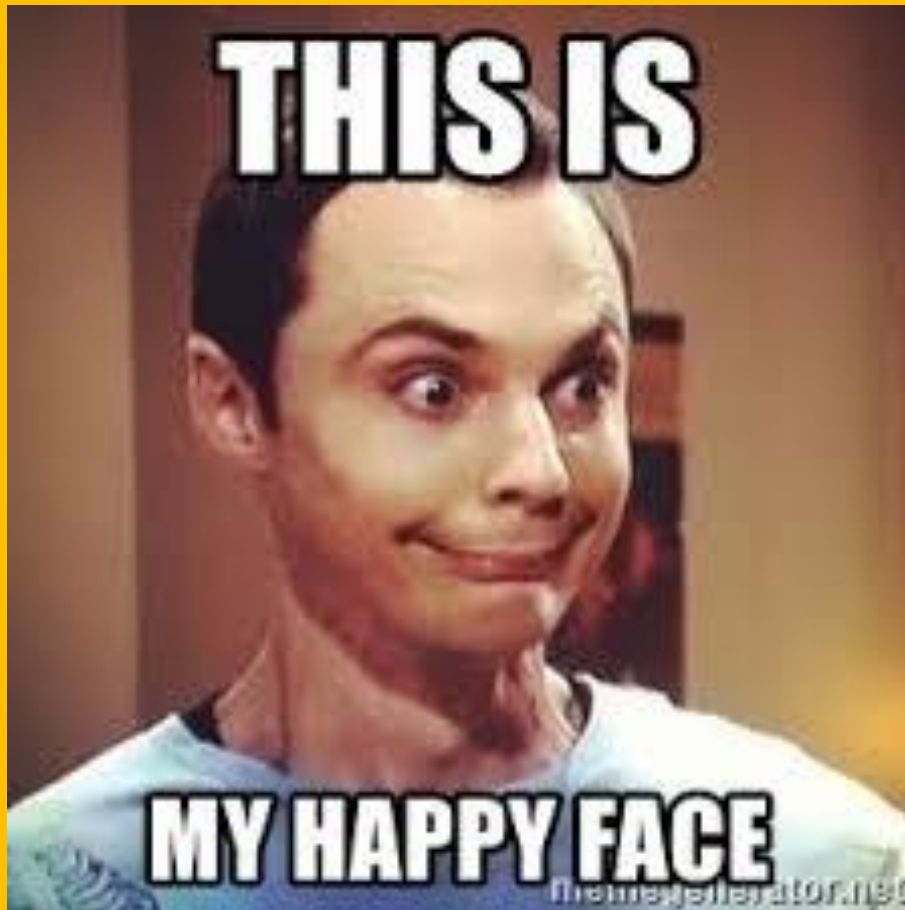
# ¿Bosones de Higgs?



**Masa H ~ 125 GeV**







**¡¡¡BUEN TRABAJO!!!**



cfp

CIEMAT

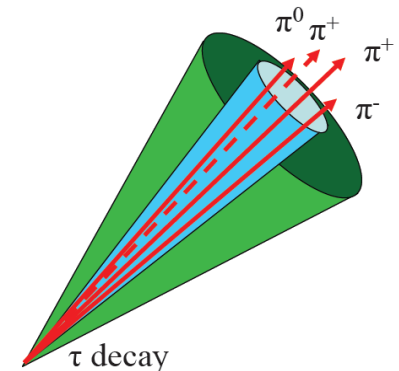
física de partículas

# Leptones tau: características

- $c\tau \approx 87 \mu\text{m}$ ,  $m_\tau = 1.78 \text{ GeV}/c^2$
- Desintegraciones leptónicas
  - $\tau \rightarrow e(\mu) \nu \nu : \sim 35.2 \%$ 
    - Identificados a través del leptón resultante
- Desintegraciones hadrónicas ( $\sim 65\%$ )
  - 1 rama
    - $\tau \rightarrow \nu_\tau + \pi^{+/-} + n(\pi^0) : 49.5 \%$
  - 3 ramas
    - $\tau \rightarrow \nu_\tau + 3\pi^{+/-} + n(\pi^0) : 15.2 \%$
  - Producción de “ **$\tau$ -jets**”

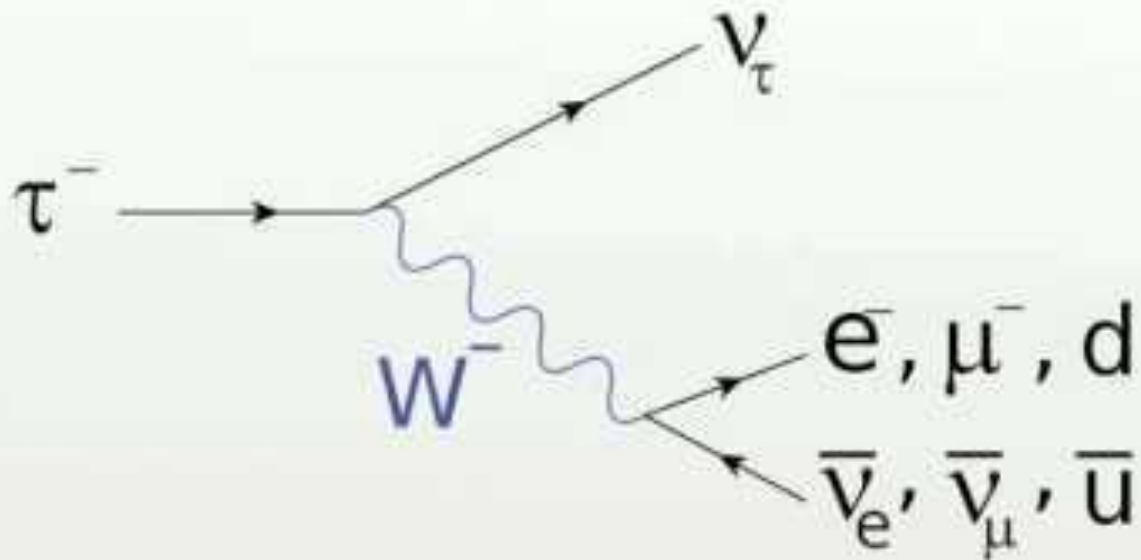
## Tau-jets en LHC:

- Muy colimados
  - 90% de la energía contenida en un cono de radio  $R=0.2$  alrededor de la dirección del jet para  $E_\tau > 50 \text{ GeV}$
- Baja multiplicidad de trayectorias
  - Una o tres ramas
- Depositos hadrónicos y EM
  - Piones cargados
  - Fotones de  $\pi^0$



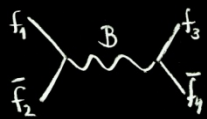
La vida media del tau ( $c\tau = 87 \text{ mm}$ ) permite reconstruir el vértice secundario

# Tau (particle)

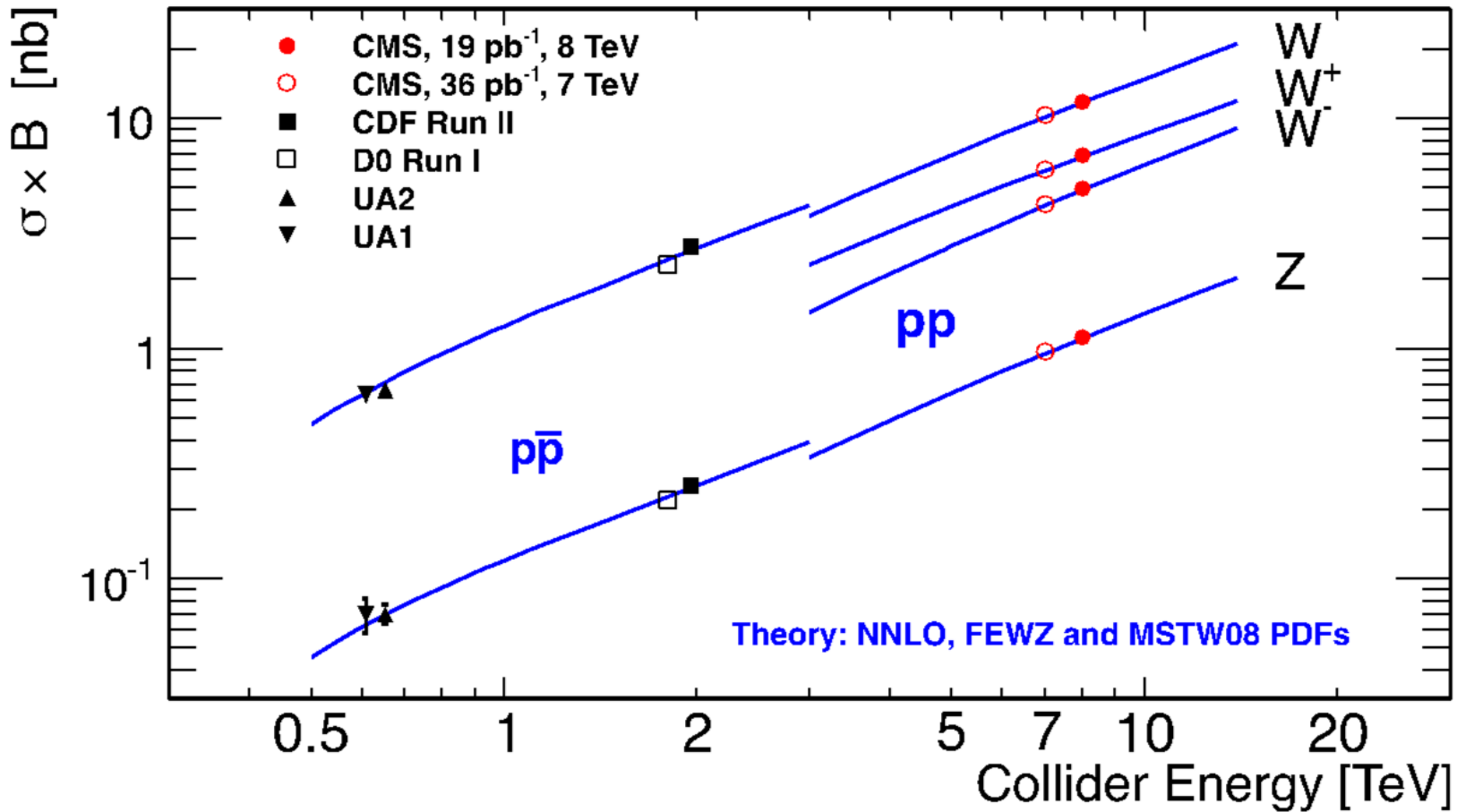


[https://en.wikipedia.org/wiki/File:Feynman\\_diagram\\_of\\_decay\\_of\\_tau\\_lepton.svg](https://en.wikipedia.org/wiki/File:Feynman_diagram_of_decay_of_tau_lepton.svg)



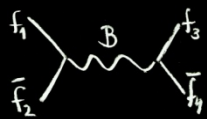


# Secciones eficaces de producción de W y Z



Las predicciones teóricas de la *evolución de la sección eficaz* con la energía están de acuerdo con las medidas experimentales.

Los *cocientes*  $W^+/W^-$  y  $W/Z$  se miden con *mayor precisión*.

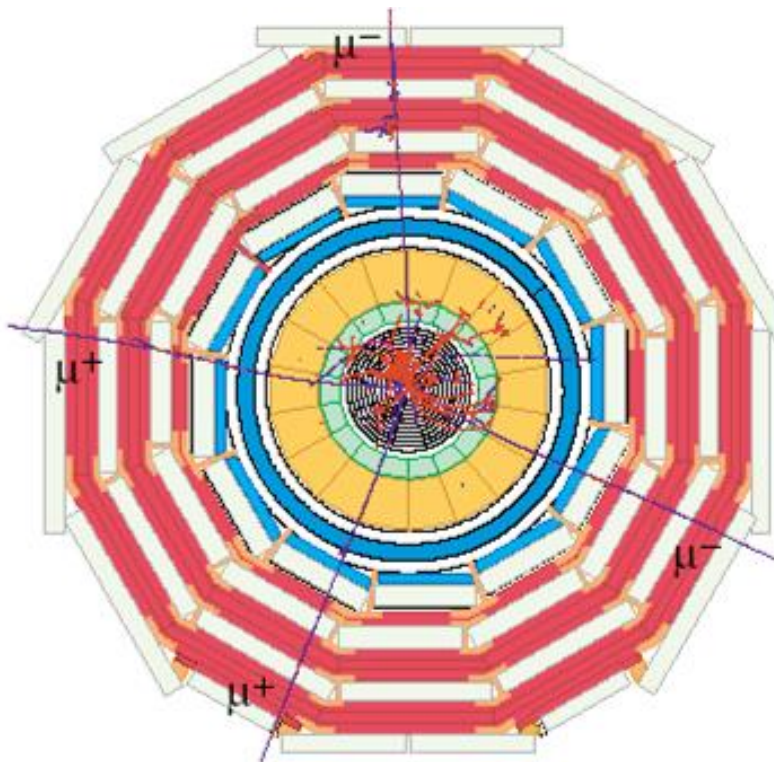


# Higgs -> 4 leptones

Otro modo de desintegración del Higgs es su desintegración en 2 bosones Z que a su vez se desintegran en pares de leptones.

Seleccionando sucesos con al menos 4 muones de alto momento se reconstruye la masa de la posible partícula que se desintegró en esos 4 cuerpos

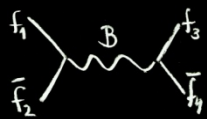
$$M_H^2 = (p_1 + p_2 + p_3 + p_4)^2$$



Al ser  $M(H)$  alta (125 GeV), los momentos de las partículas hijas serán altos

- Trayectorias “casi” rectas

$$p = 0.3 \cdot B \cdot R$$



# 2) Resultados

## Coeficiente de perrelación

