# La competizione per la scoperta dei bosoni W-Z e i risultati fallimentari sul quark Top nei primi anni ‘80

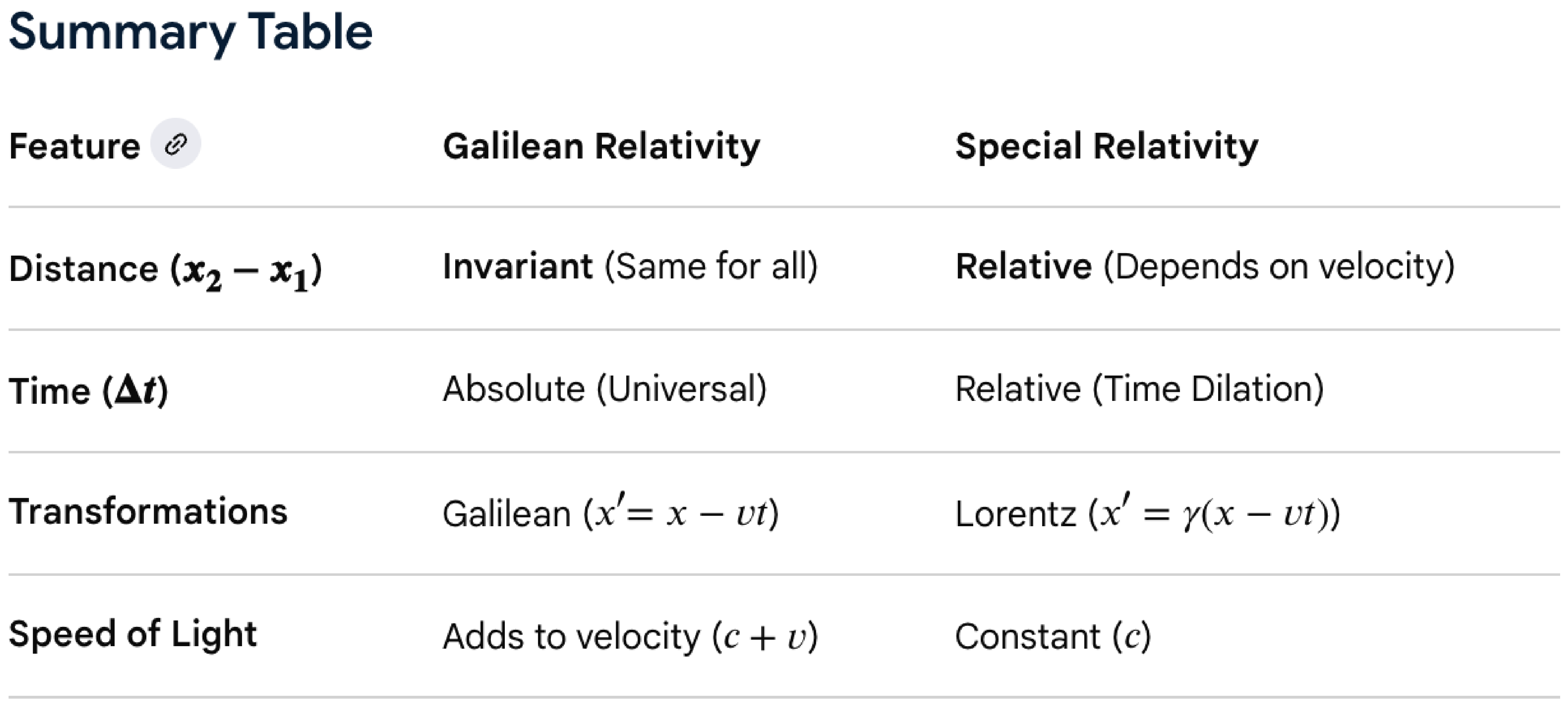
# Come cambia il modo di scoprire nuove particelle

- Fino agli anni ‘50 del secolo scorso si poteva ricostruire la massa di una nuova particella carica sia studiando la sua traccia in un campo magnetico che, in alternativa, studiando le particelle in cui decadeva
- A partire dagli anni ‘60 le nuove particelle sempre più spesso vivevano un tempo troppo breve per poterne osservare la traccia. Ci si doveva concentrare sullo studio delle tracce delle particelle figlie:
    - 1961 scoperta dei mesoni $\rho^+$, $\rho^-$, $\rho^0$, vita media $4.4\ 10^{-24}$ s
    - 1961 scoperta del mesone $\omega^0$, vita media $7.6\ 10^{-23}$ s
- In tempi così brevi era anche impossibile che le particelle arrivassero a fermarsi prima di decadere. Per questo motivo $\rho$ e $\omega^0$ furono le prime particelle per le quali si usò il metodo della **Massa Invariante**

# …Ma cosa è la massa invariante?

**Occorre un minimo di Relatività Speciale per poterlo capire…**

# Molte differenze tra relatività galileiana e speciale



## Summary Table

| **Feature** | **Galilean Relativity** | **Special Relativity** |
|---|---|---|
| **Distance ($x_2 - x_1$)** | **Invariant** (Same for all) | **Relative** (Depends on velocity) |
| **Time ($\Delta t$)** | Absolute (Universal) | Relative (Time Dilation) |
| **Transformations** | Galilean ($x' = x - vt$) | Lorentz ($x' = \gamma(x - vt)$) |
| **Speed of Light** | Adds to velocity ($c + v$) | Constant ($c$) |

# 4-vector notation

Lorentz Transformations

$$\begin{pmatrix} t' \\ x' \\ y' \\ z' \end{pmatrix} = \begin{bmatrix} \gamma & -\gamma\beta & 0 & 0 \\ -\gamma\beta & \gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} t \\ x \\ y \\ z \end{pmatrix}$$

$$\mathrm{x}' = \Lambda \mathrm{x}$$

*or*

$$(\mathrm{x}')^{\mu} = \sum_{\nu=0}^{3} \Lambda^{\mu}_{\nu} \mathrm{x}^{\nu}$$

*or*

$$(\mathrm{x}')^{\mu} = \Lambda^{\mu}_{\nu} \mathrm{x}^{\nu}$$

4-vector: "An object that transforms like $x^{\mu}$ between inertial frames"

E.g. $\textit{momentum}: \quad p \equiv (p^0, p^1, p^2, p^3) \equiv (E, p_x, p_y, p_z)$

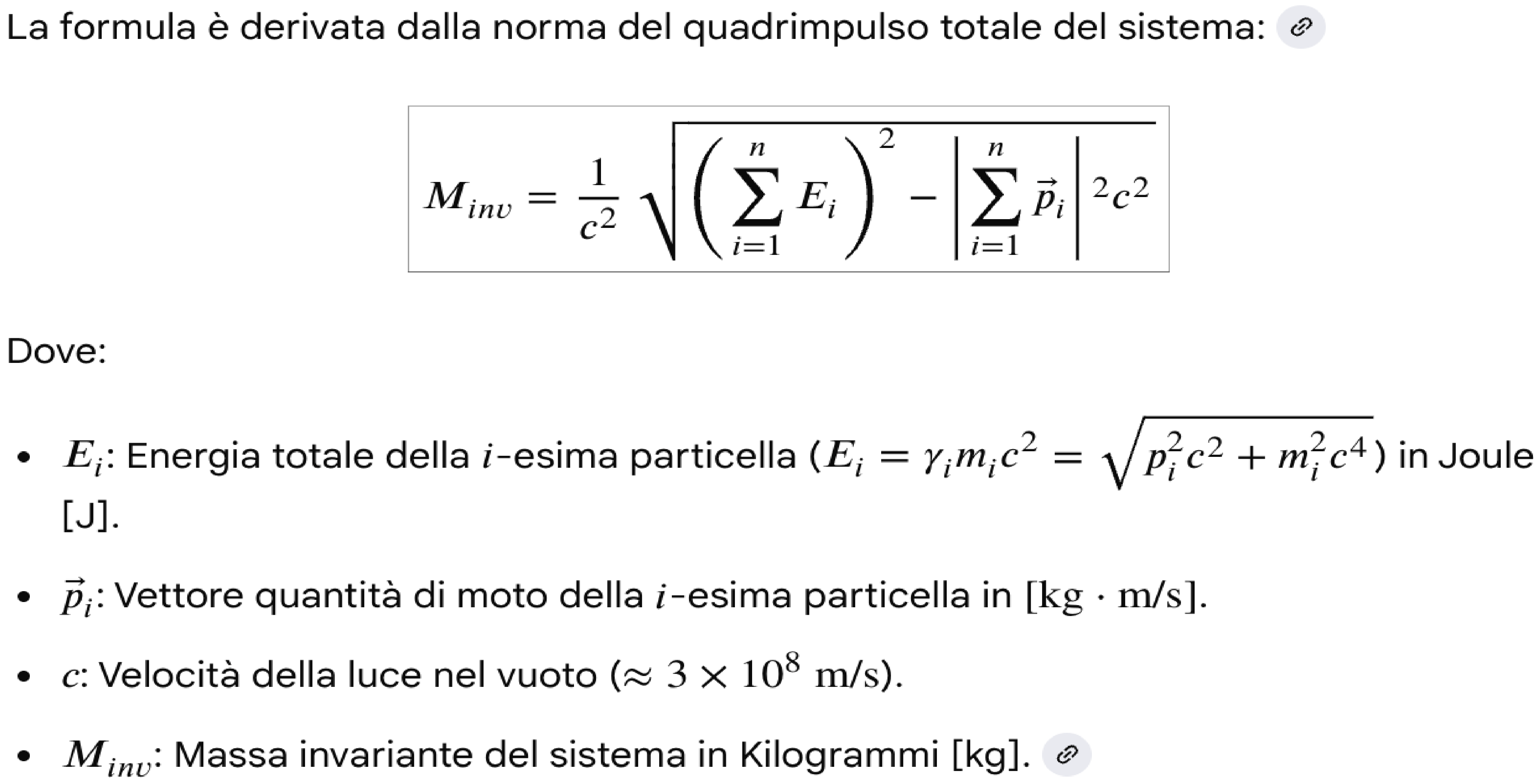
Invariant: "quantities unchanged in all inertial frames"

E.g.:

4-vector scalar product: $a \cdot b \equiv a^0 b^0 - a^1 b^1 - a^2 b^2 - a^3 b^3 = a^0 b^0 - \vec{\mathbf{a}} \cdot \vec{\mathbf{b}}$

4-vector length: $p^2 = p^0 p^0 - p^1 p^1 - p^2 p^2 - p^3 p^3 = E^2 - |\vec{\mathbf{p}}|^2 = \mathrm{m}^2$

# La massa invariante di un sistema di n particelle

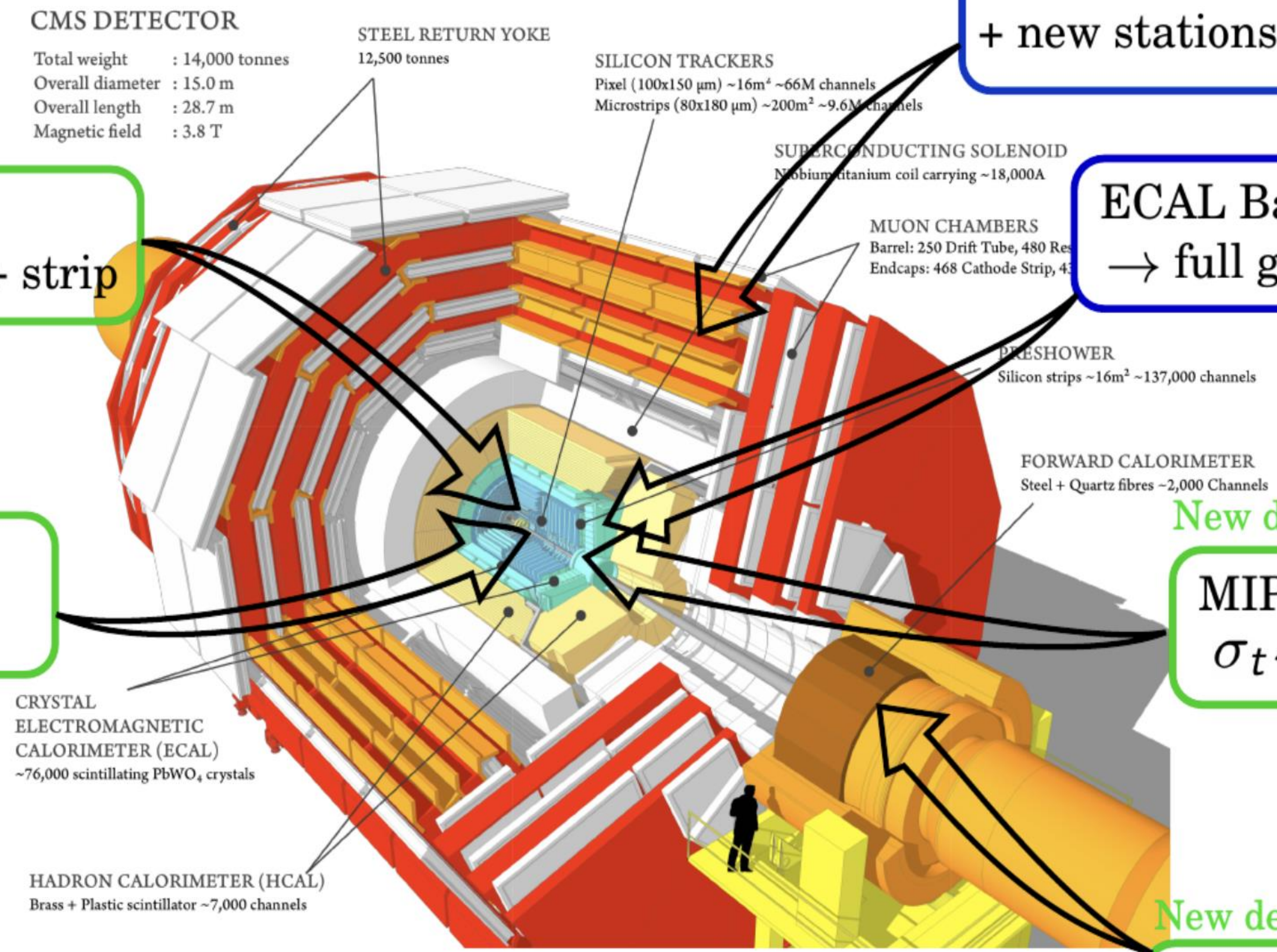


La formula è derivata dalla norma del quadrimpulso totale del sistema:

$$M_{inv} = \frac{1}{c^2} \sqrt{\left( \sum_{i=1}^{n} E_i \right)^2 - \left| \sum_{i=1}^{n} \vec{p}_i \right|^2 c^2}$$

Dove:

- $E_i$: Energia totale della $i$-esima particella ($E_i = \gamma_i m_i c^2 = \sqrt{p_i^2 c^2 + m_i^2 c^4}$) in Joule [J].
- $\vec{p}_i$: Vettore quantità di moto della $i$-esima particella in $[\mathrm{kg} \cdot \mathrm{m/s}]$.
- $c$: Velocità della luce nel vuoto ($\approx 3 \times 10^8\ \mathrm{m/s}$).
- $M_{inv}$: Massa invariante del sistema in Kilogrammi [kg].



New detector

Outer tracker
Si macro-pixel + strip

New detector

Inner tracker
Si Pixel

New readout for Muon system
+ new stations $1.6 < \eta < 2.4$

ECAL Barrel readout
→ full granularity @ 40MHz

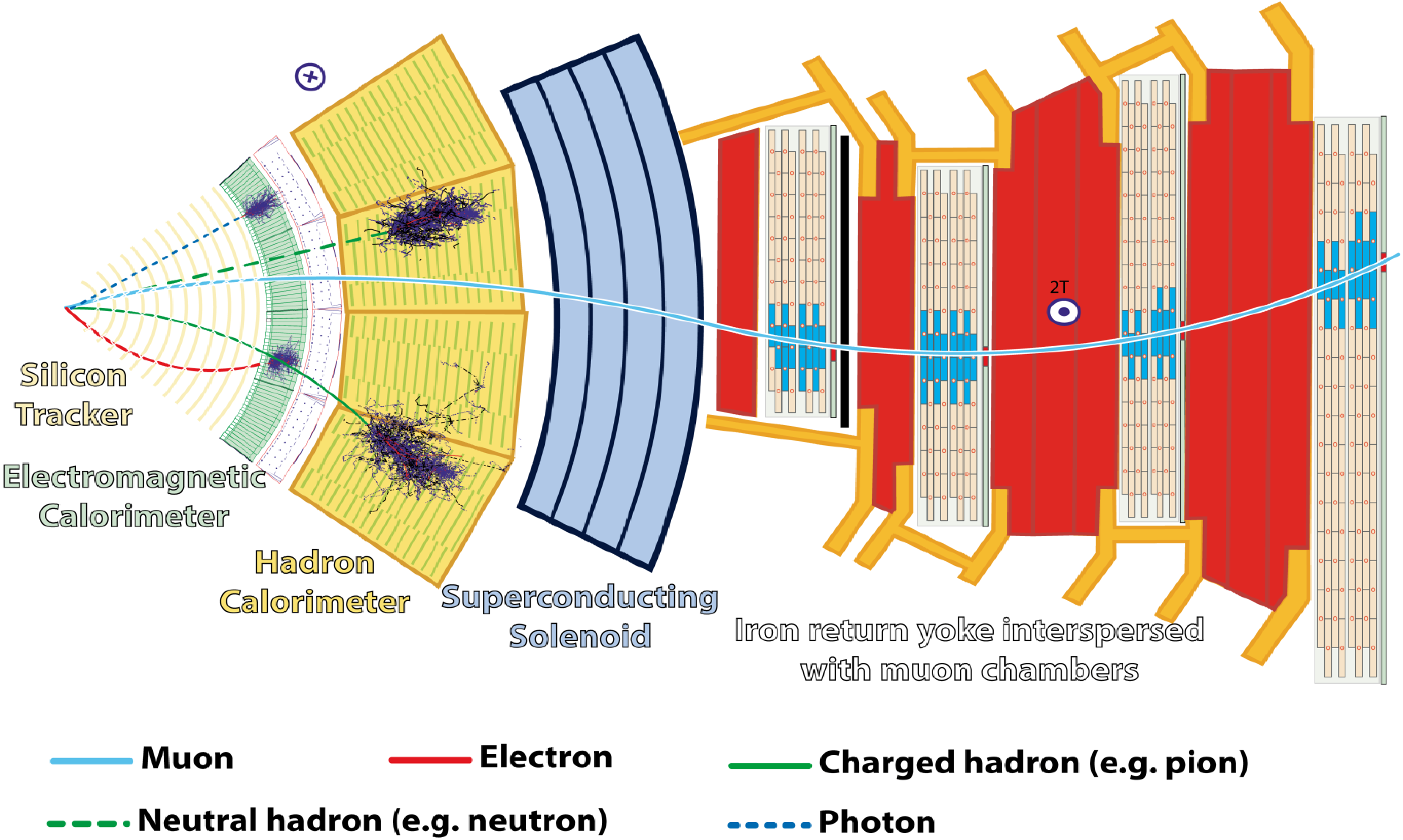
New detector

MIP timing
$\sigma_t \sim 30$ps

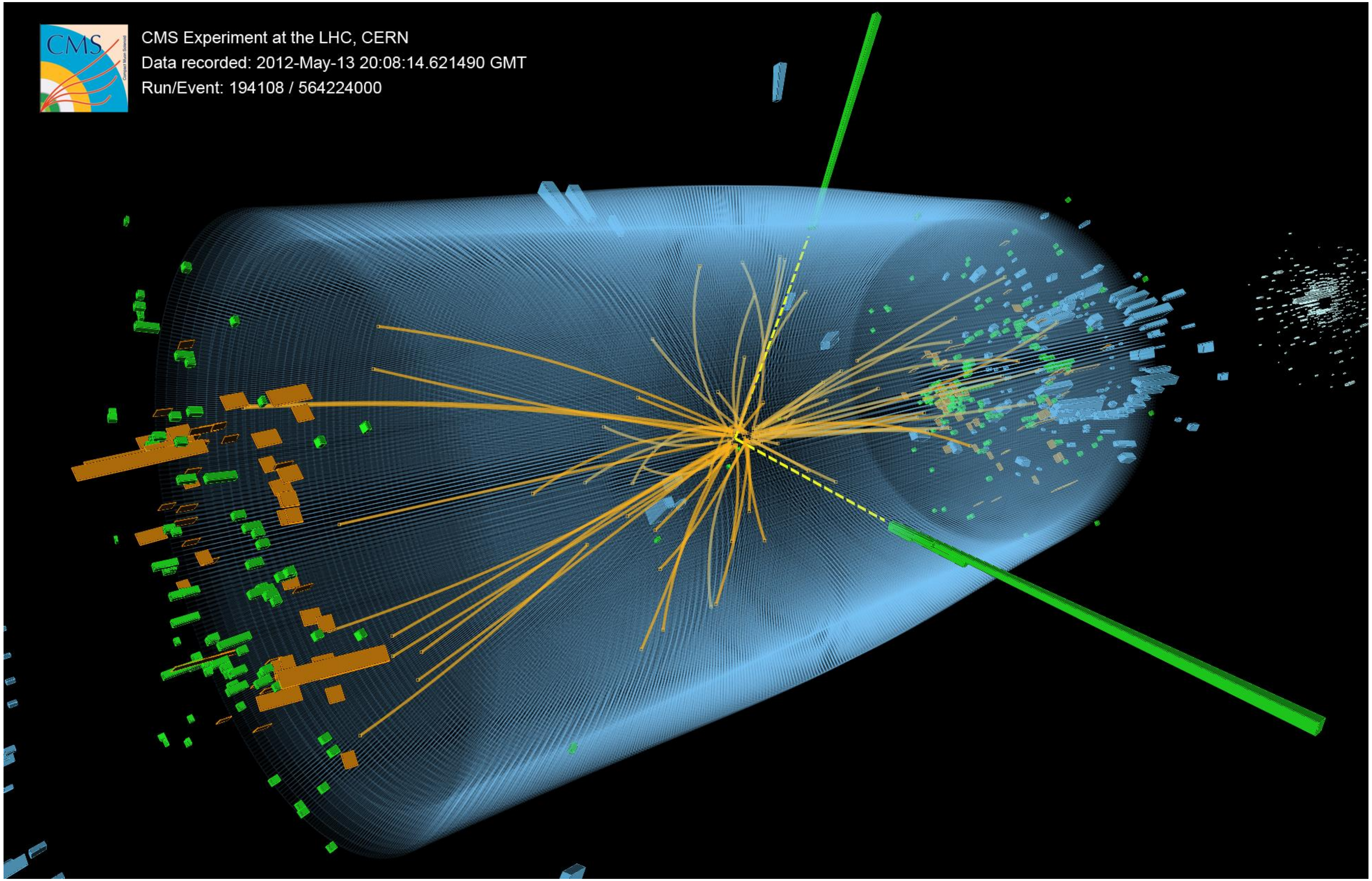
New detector

End-cap Calorimeter
4D showers, $\sigma_t \sim 20$ps

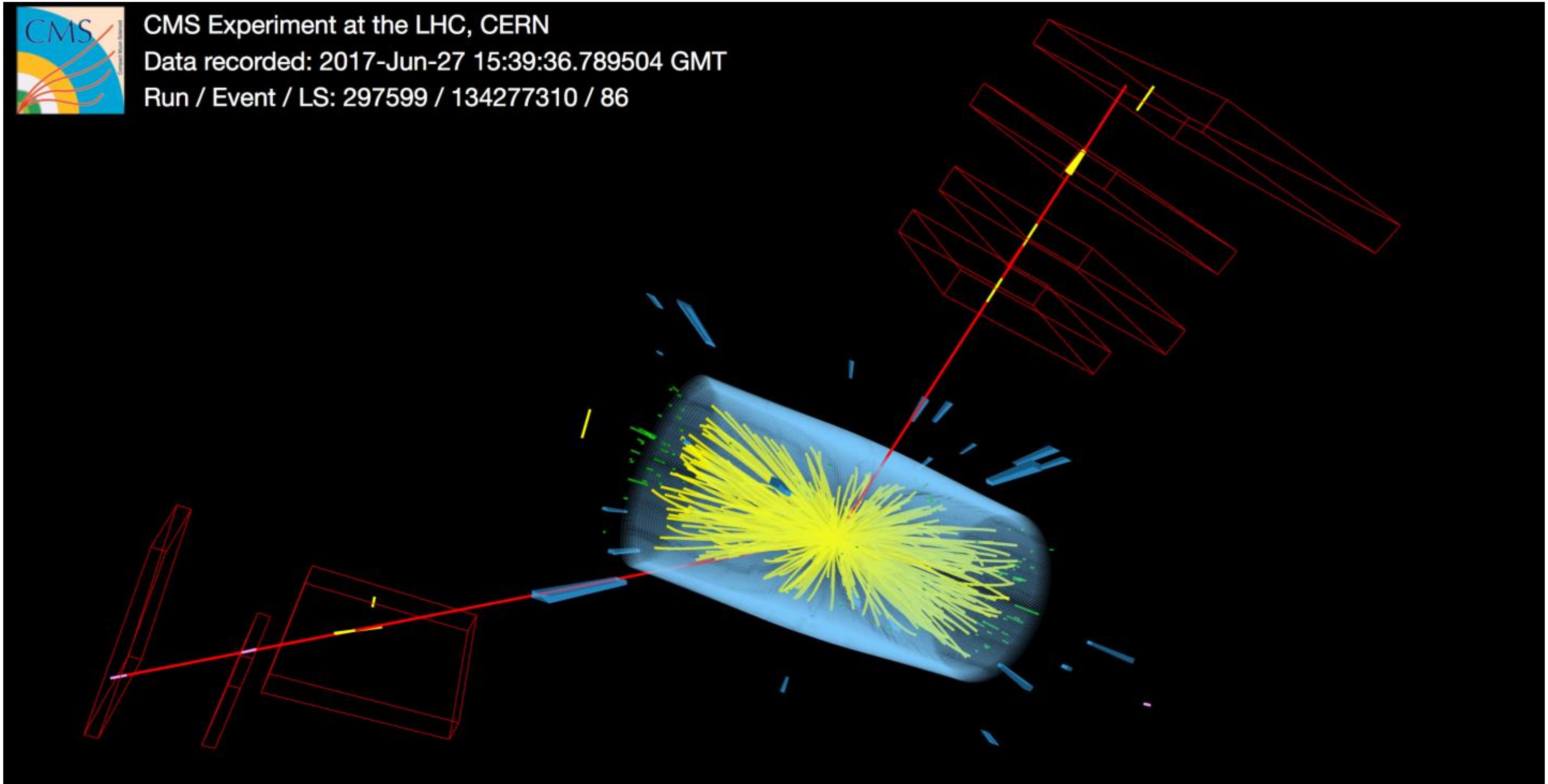
+ TDAQ modification to cope with modified detector
and higher lumi (including tracking in hardware)

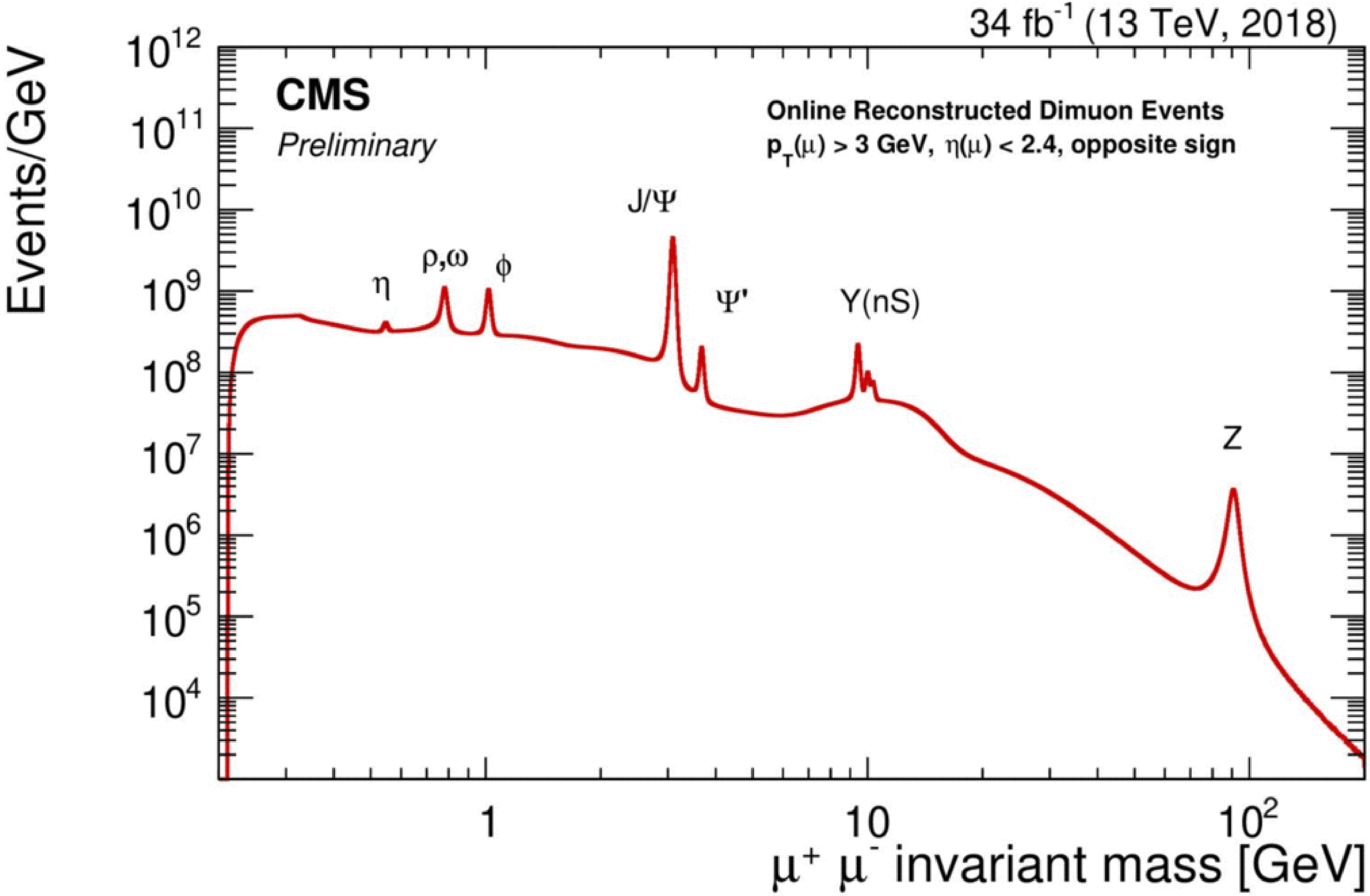

Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with muon chambers
2T
Muon
Electron
Charged hadron (e.g. pion)
Neutral hadron (e.g. neutron)
Photon

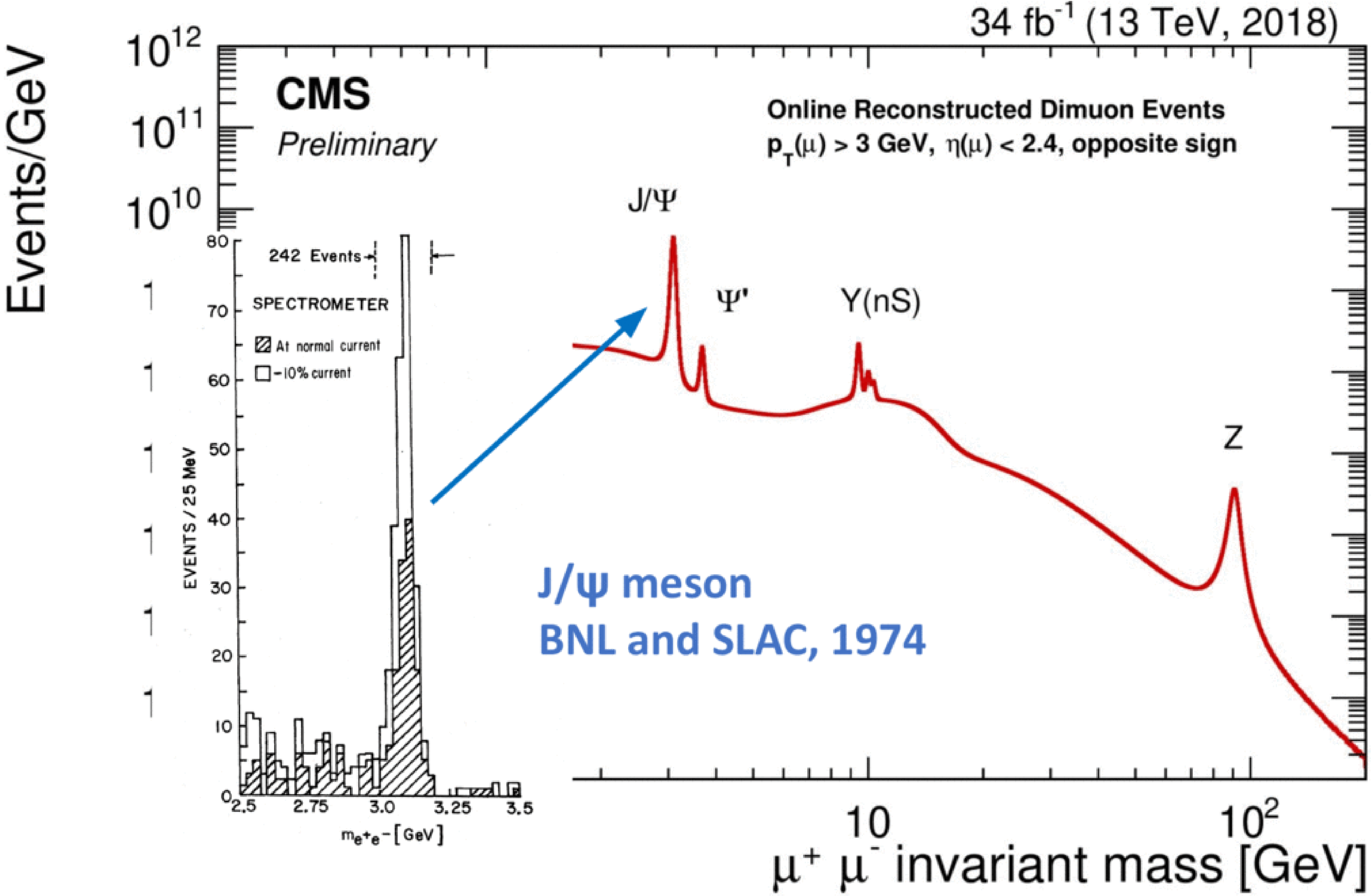
# Decadimento in 2 γ  di un bosone di Higgs



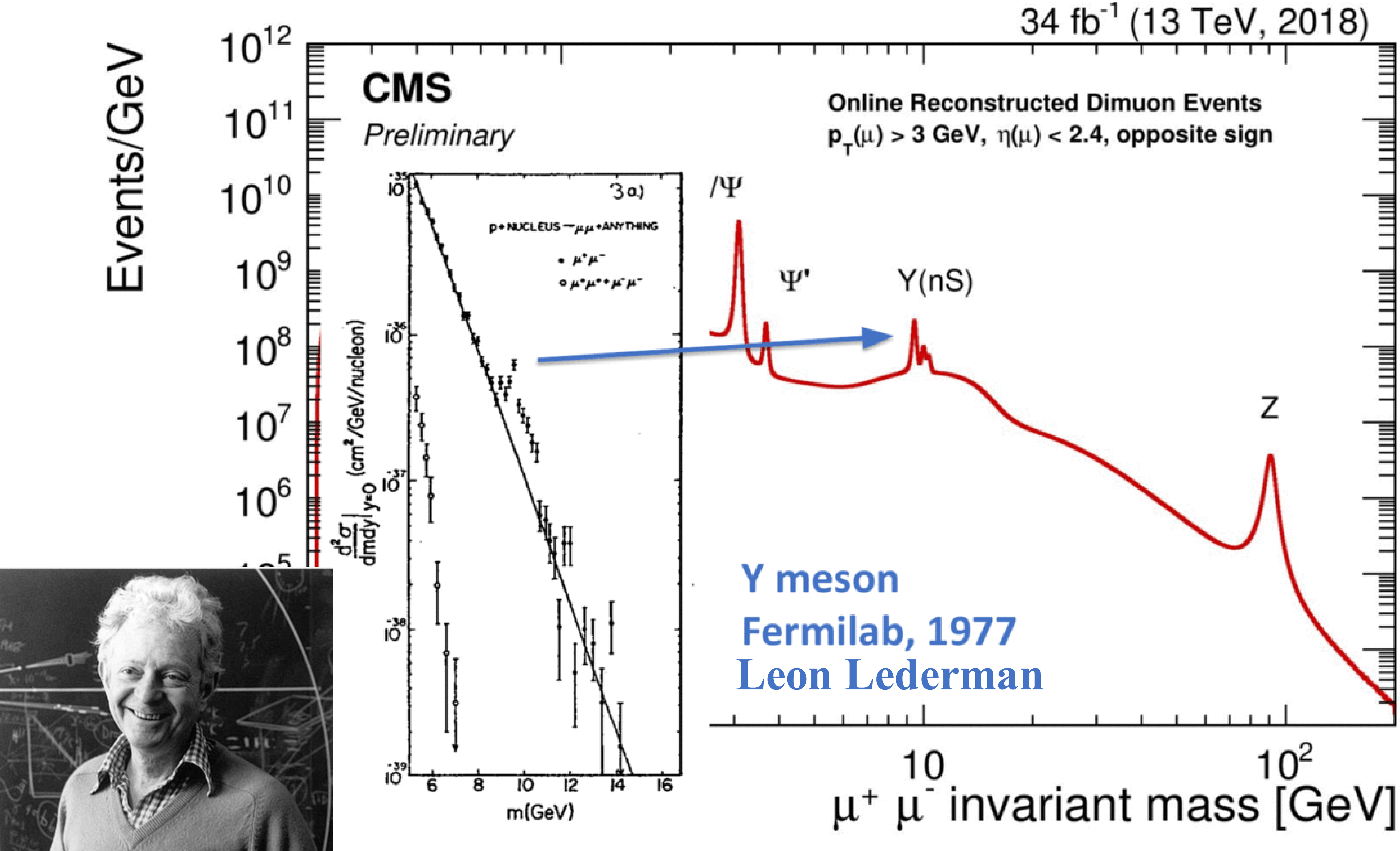
# Decadimento in 2 muoni di una particella neutra




34 fb-1 (13 TeV, 2018)
CMS
Preliminary
Online Reconstructed Dimuon Events
pT(μ) > 3 GeV, η(μ) < 2.4, opposite sign
Events/GeV
10^12
10^11
10^10
10^9
10^8
10^7
10^6
10^5
10^4
η
ρ,ω
ϕ
J/Ψ
Ψ'
Υ(nS)
Z
1
10
10^2
μ+ μ- invariant mass [GeV]



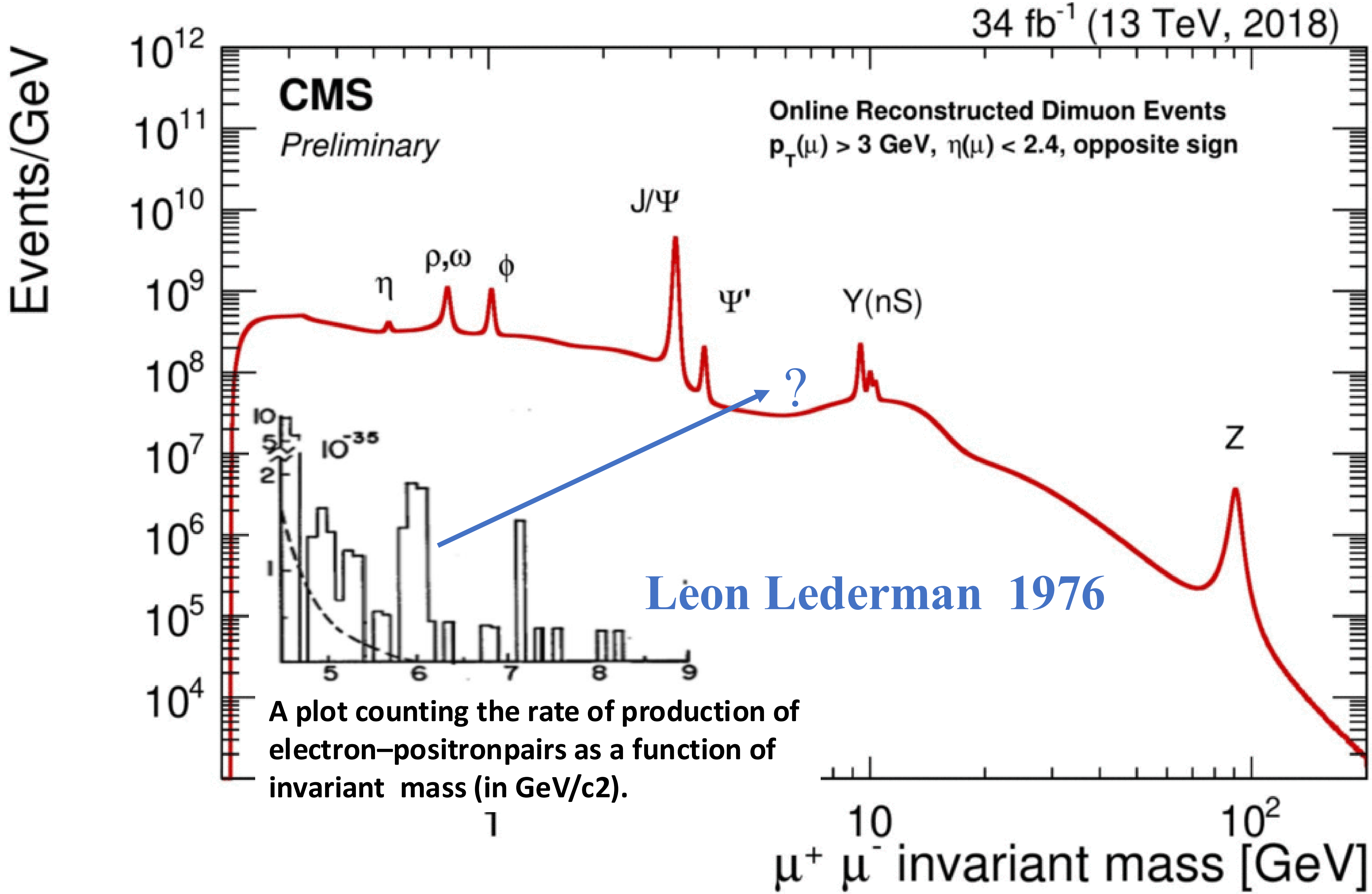
**J/ψ meson**
**BNL and SLAC, 1974**



**Υ meson**

**Fermilab, 1977**

**Leon Lederman**

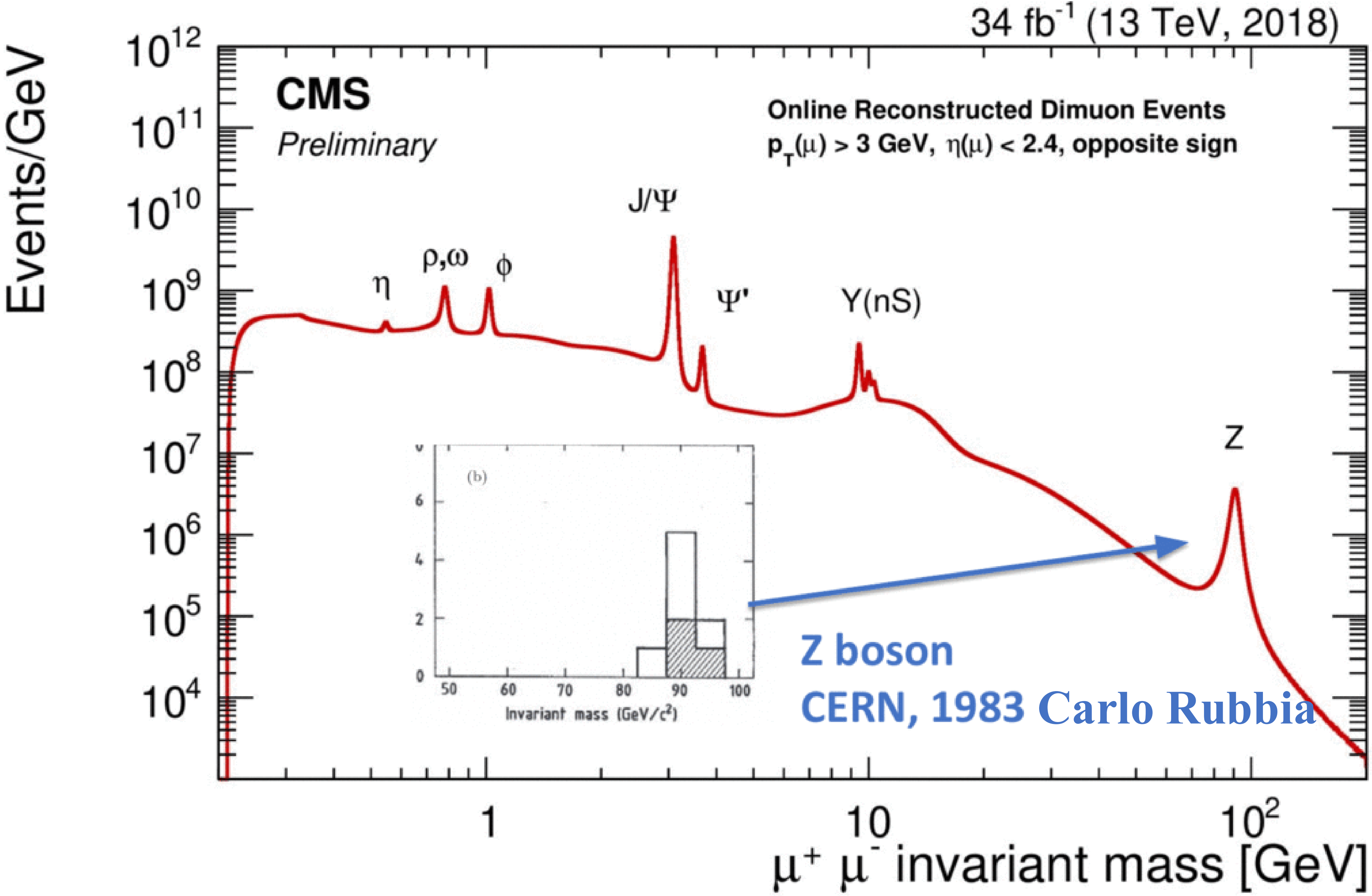


**Leon Lederman 1976**

A plot counting the rate of production of electron–positronpairs as a function of invariant mass (in GeV/c2).

# Oops-Leon

**Oops-Leon** is the name given by particle physicists to what was thought to be a new subatomic particle "discovered" at Fermilab in 1976. The E288 experiment team, a group of physicists led by Leon Lederman who worked on the E288 particle detector, announced that a particle with a mass of about 6.0 GeV/$c^2$, which decayed into an electron and a positron, was being produced by the Fermilab particle accelerator.[1] The particle's initial name was the Greek letter Upsilon ($\Upsilon$). After taking further data, the group discovered that this particle did not exist, and the "discovery" was named "Oops-Leon" as a pun on the original name and the first name of the E288 collaboration leader.[2]



**Z boson**

**CERN, 1983 Carlo Rubbia**

# La scoperta dei bosoni W

**Figure 3.** *The press conference in CERN's main auditorium at which the discovery of the W was announced on 25 January 1983. Seated, left to right: Carlo Rubbia, Simon van der Meer, Herwig Schopper, Erwin Gabathuler, and Pierre Darriulat. (Photo: Courtesy CERN.)*

- UA1 e UA2 avevano raggiunto risultat analoghi, ma UA2 aveva chiesto qualche settimana per verificare la correttezza delle proprie analisi, mentre UA1 era già perfettamente convinto della correttezza dei propri risultati.

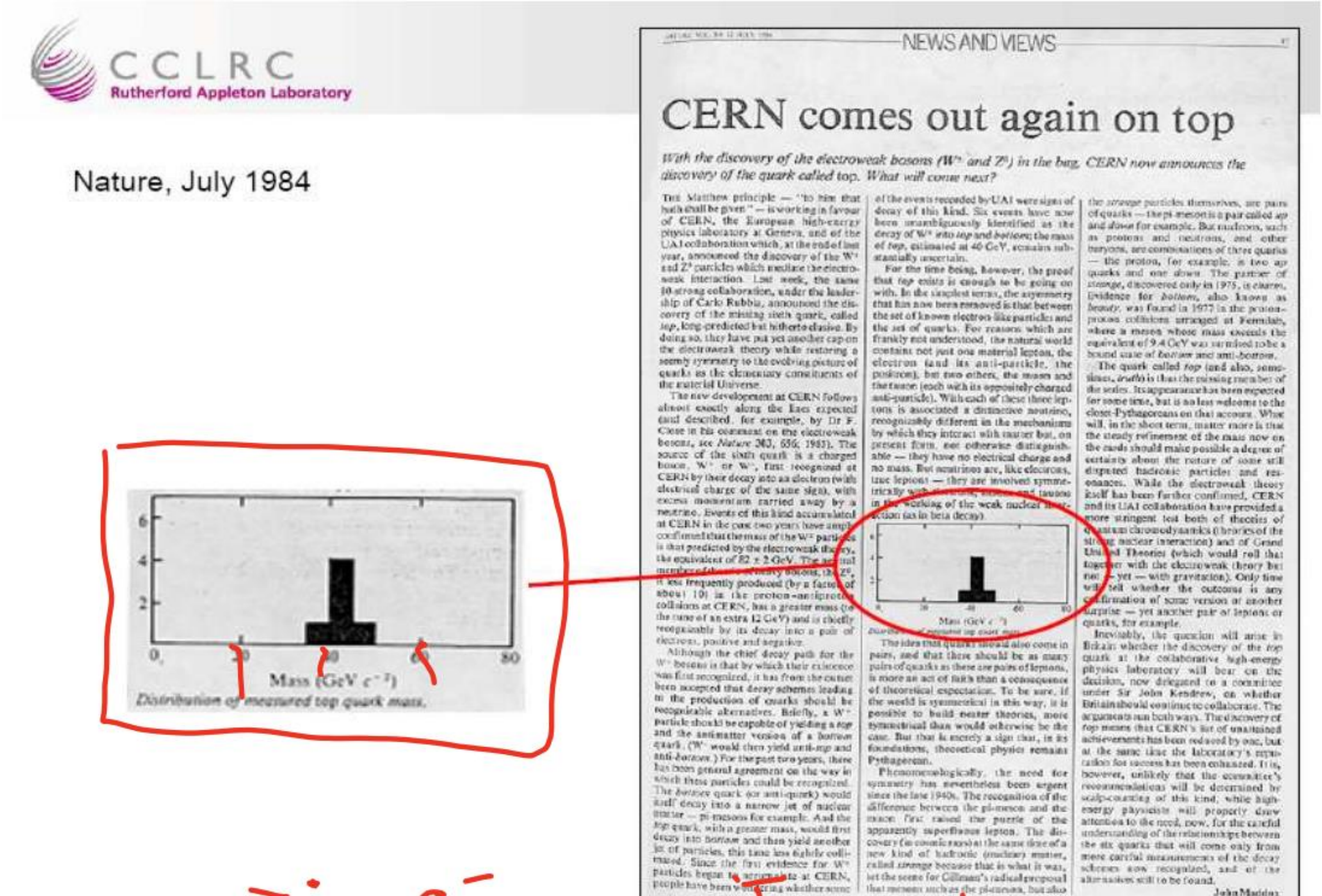
# La scoperta dei bosoni W e Z

**Figure 1.** *Carlo Rubbia and Simon van der Meer celebrate the announcement that they had won the 1984 Nobel Prize for physics. (Photo: Courtesy CERN.)*

**Carlo Rubbia e**
**Simon van der Meer**
**Vincitori del premio**
**Nobel 1984**

# La scoperta del quark top

- June-July 1984 Rubbia discovers Top!
  - Articles (*Nature*, *NY Times*) and press release
  - Mass peak between 30-50 GeV



CERN comes out again on top

*With the discovery of the electroweak bosons (W± and Z⁰) in the bag, CERN now announces the discovery of the quark called* top. *What will come next?*

**Carlo Rubbia nel 1984 Pubblica la scoperta del Quark top, ma questa Volta l'articolo viene Ritirato dopo poche Settimane, a causa di un Errore nella selezione dei Dati. Il quark Top verra' scoperto solo 10 dopo a Fermilab, a un valore di Massa di 172 GeV.**