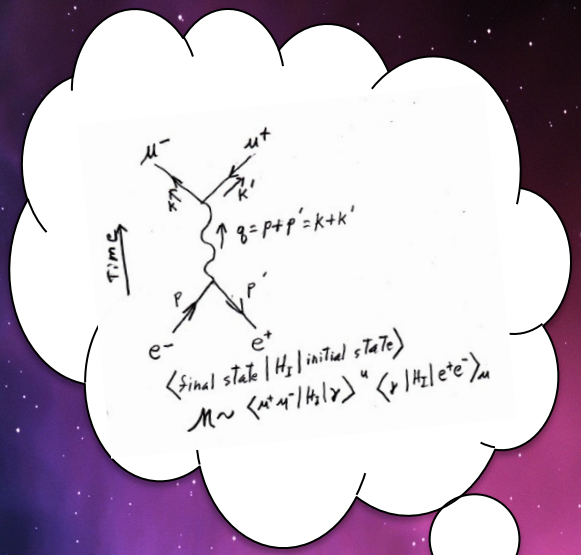
Tornar visível o invisível

Ricardo Gonçalo, Laboratório de Instrumentação e Física Experimental de Partículas (LIP)
Com muitos slides de colegas e amigos… obrigado!

Cofinanciado por:

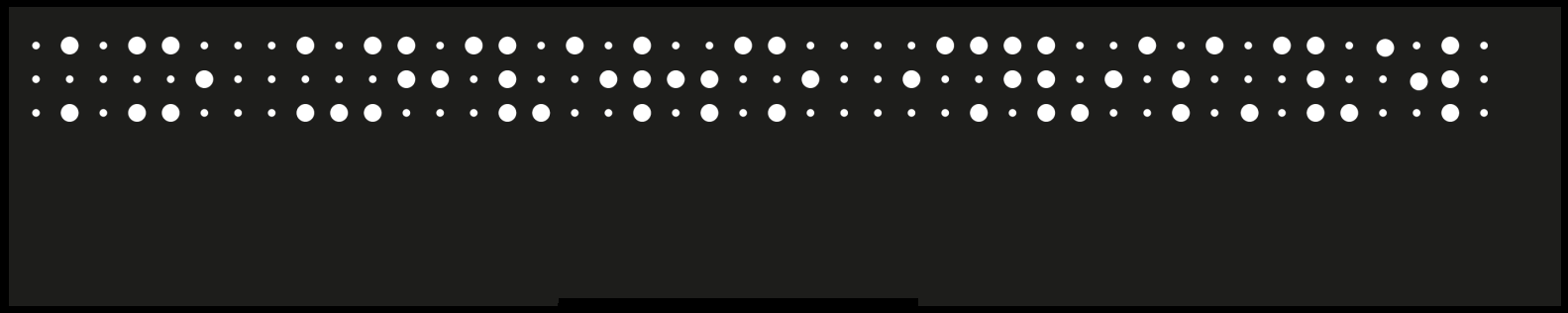


Sumário

- Introdução – ver o invisível
- Os aceleradores de partículas
- Os detetores de partículas
- O CERN
- O LHC e as suas experiências
- O bosão Z
- O exercício de hoje

(Sol em) neutrinos

Raios Cósmicos de Energia Extrema



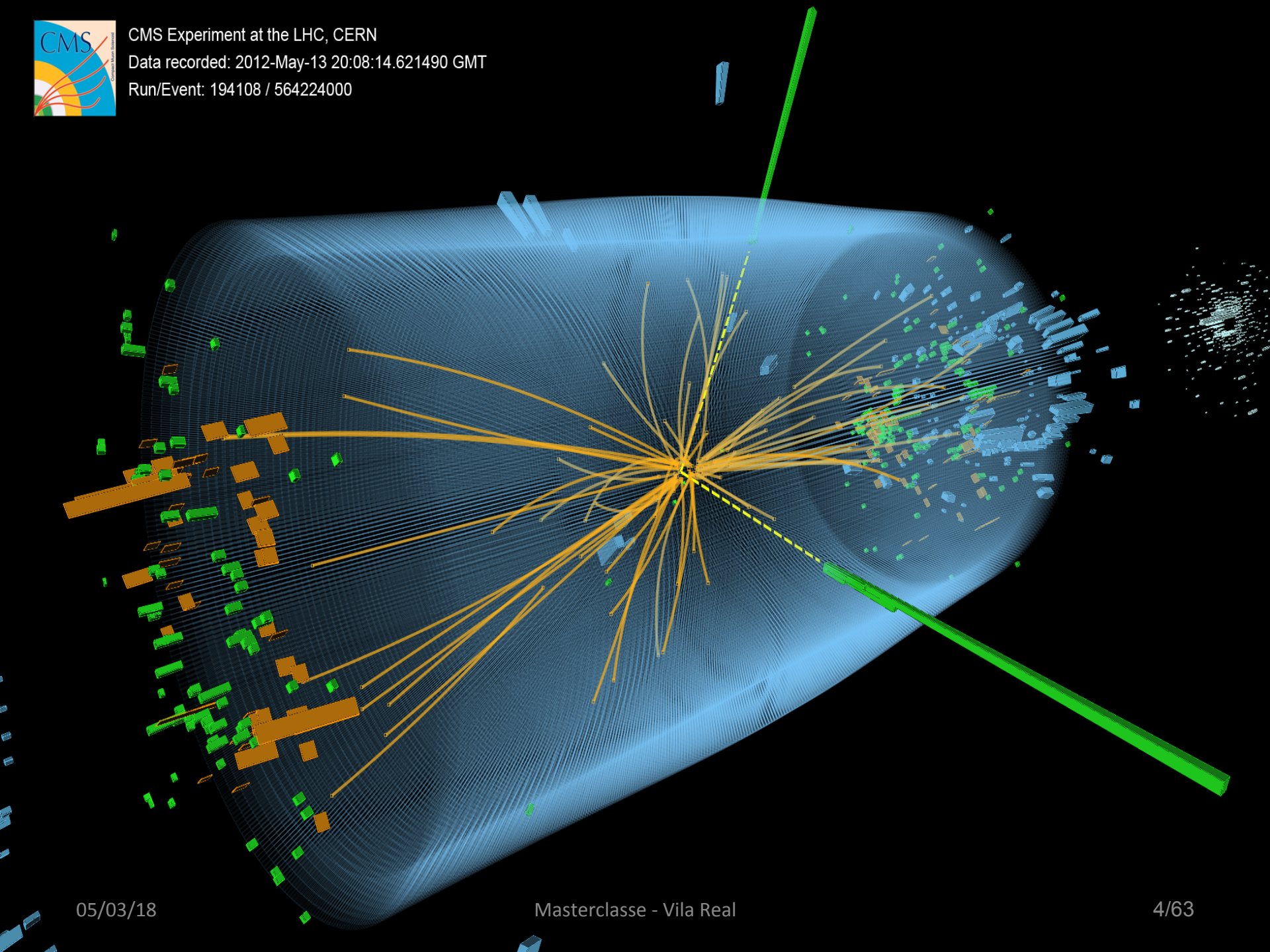
Ótico

InfraVerm.

UltraVioleta

Raios-X

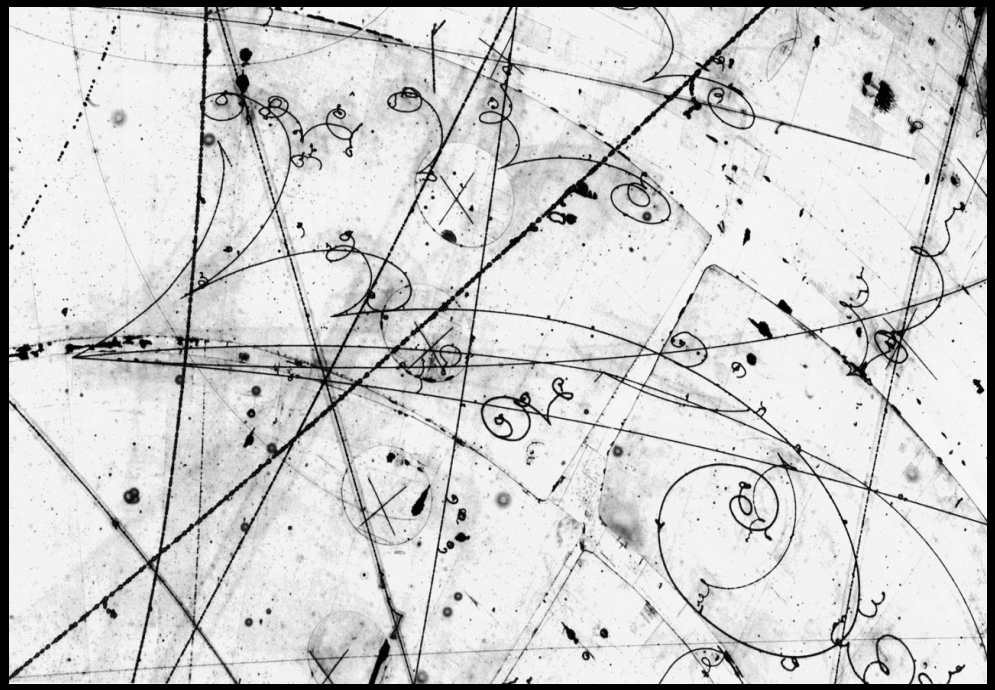
Ondas Rádio


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000

Experiências de Física de Partículas

A idade heroica


Observação de raios cósmicos, Plaza de Mulas Argentina, 1950

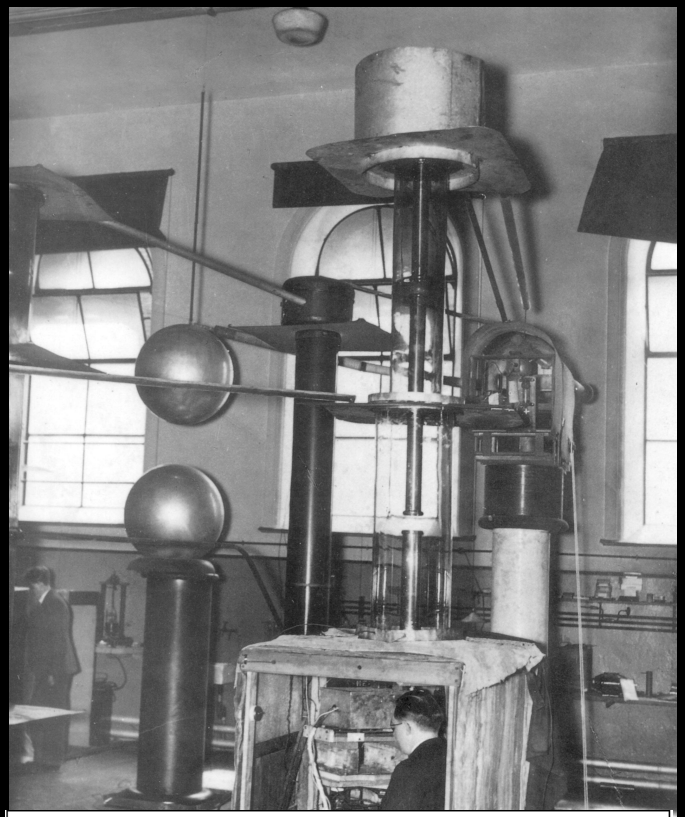


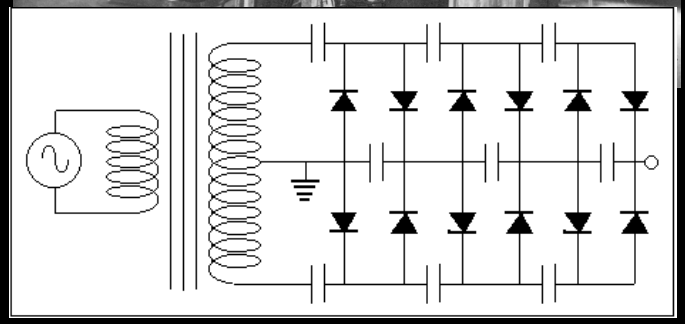

Victor Hess em 1911/1912


Acelerador de Van de Graaff

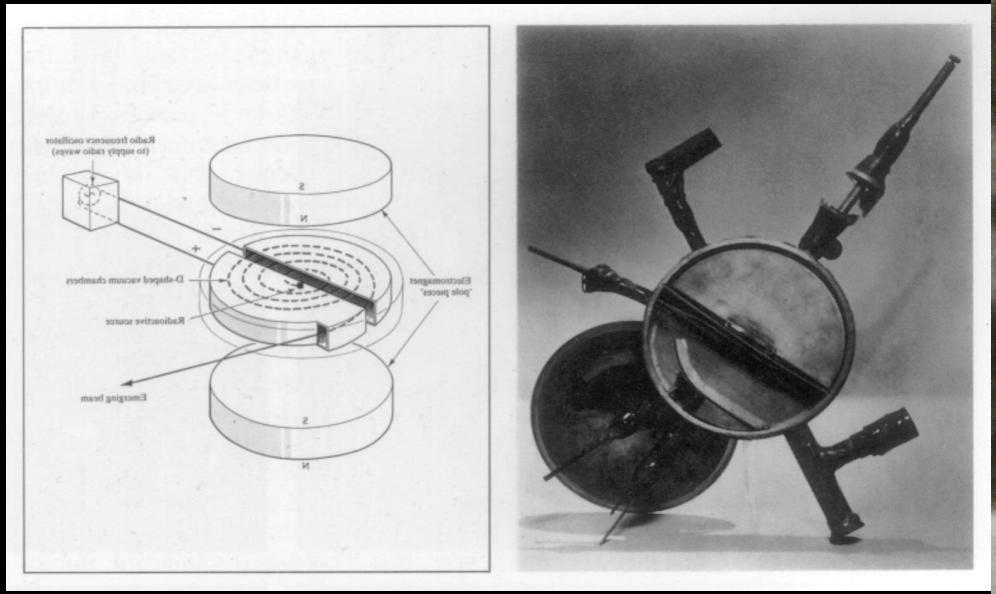

Um ciclotrão, cerca de 1950

Os primeiros aceleradores

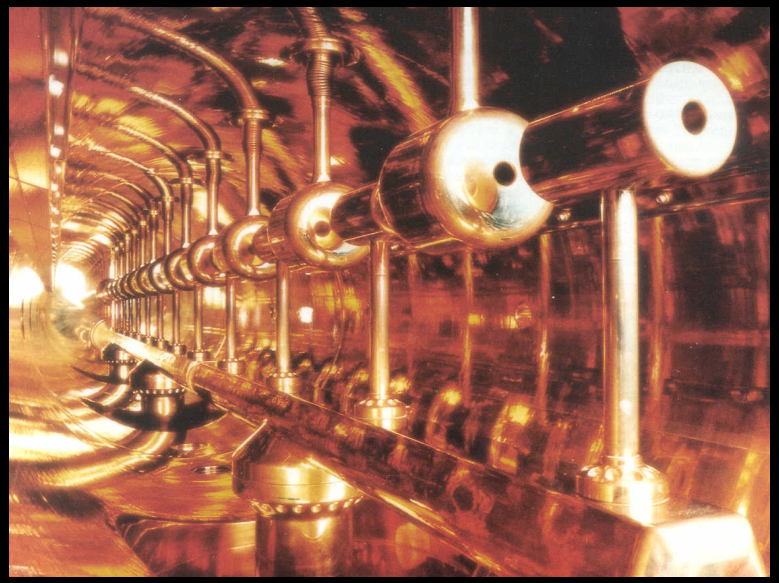


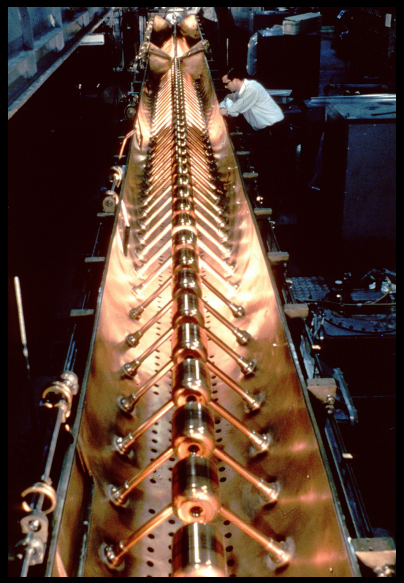


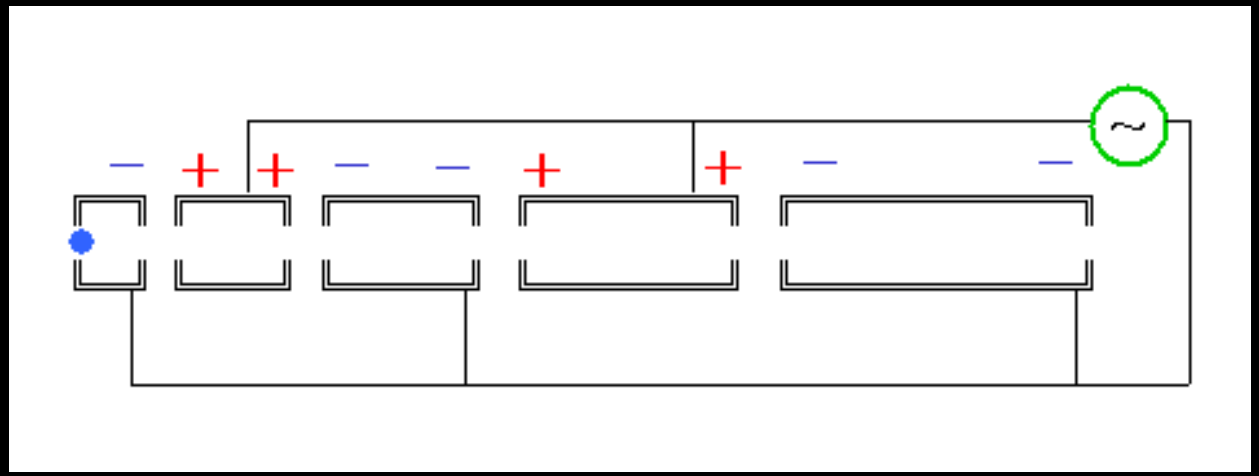
O ciclotrão


Radio frequency oscillator
(to supply radio waves)
S
N
+
−
D-shaped vacuum chamber
Electromagnet
'pole pieces'
Radioactive source
Emerging beam
S
N

O acelerador linear

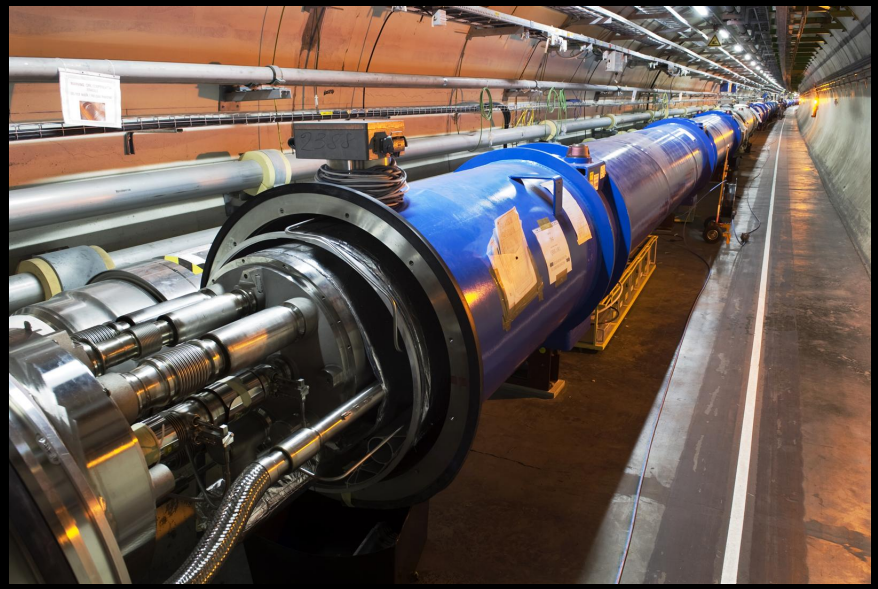


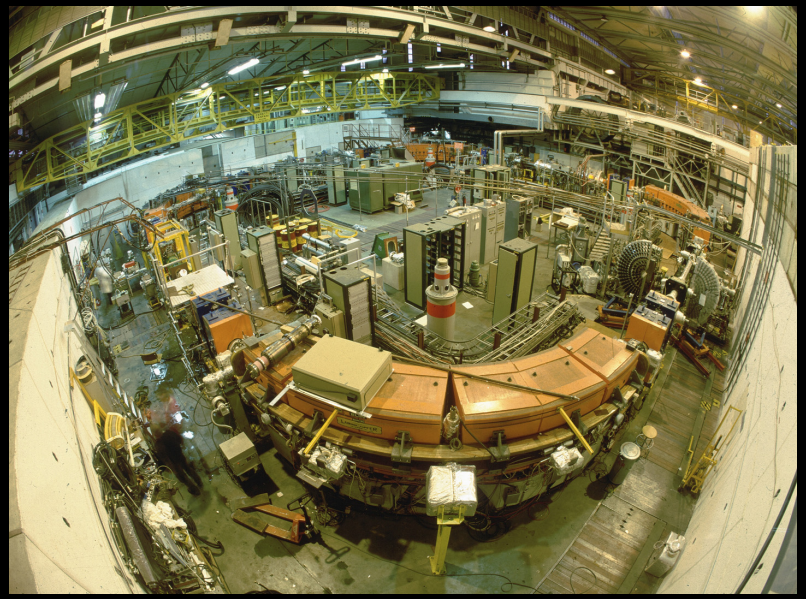




O Sincrotrão

Acelera





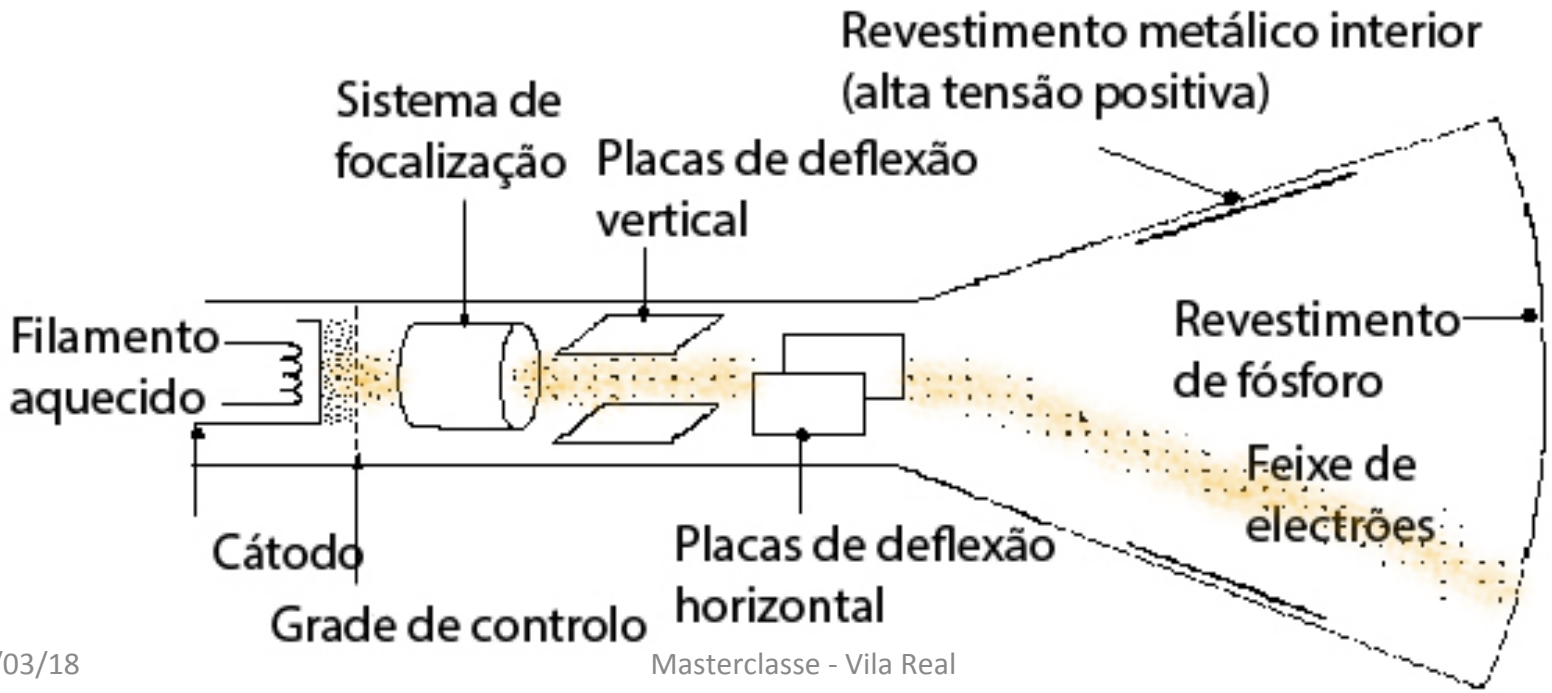
Exemplo de um acelerador...

Tubo de raios catódicos

- **fonte de partículas**
- **campos electromagnéticos**

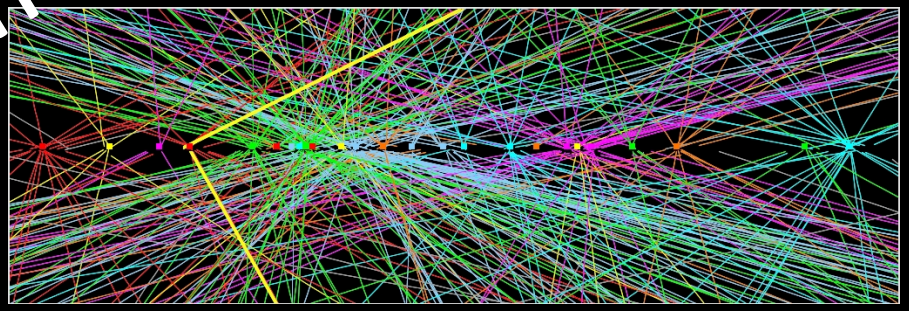
para as acelerar e guiar

- **meio de detecção (detector)**

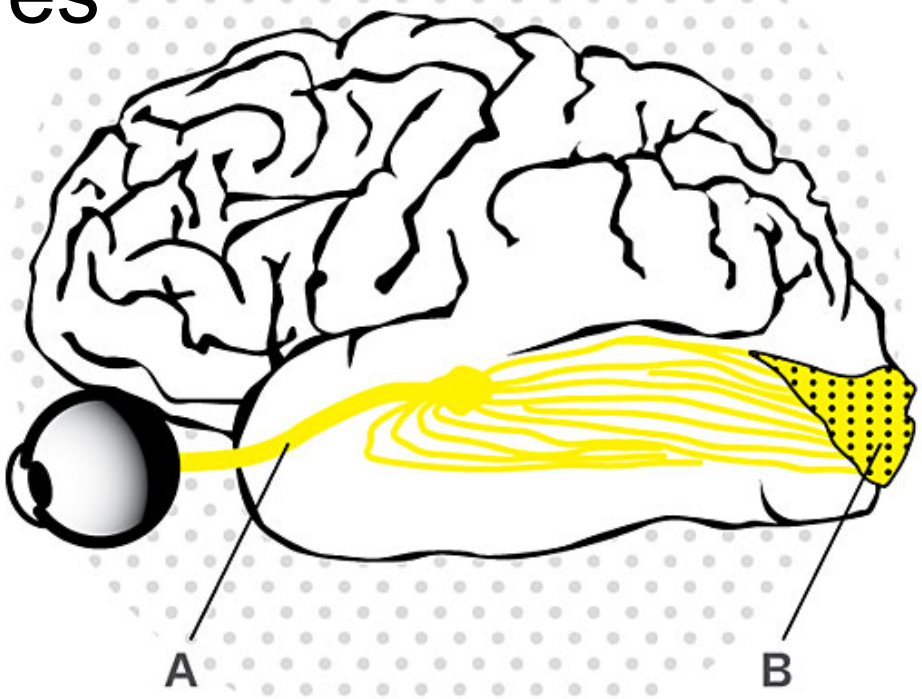


Para que precisamos de aceleradores?

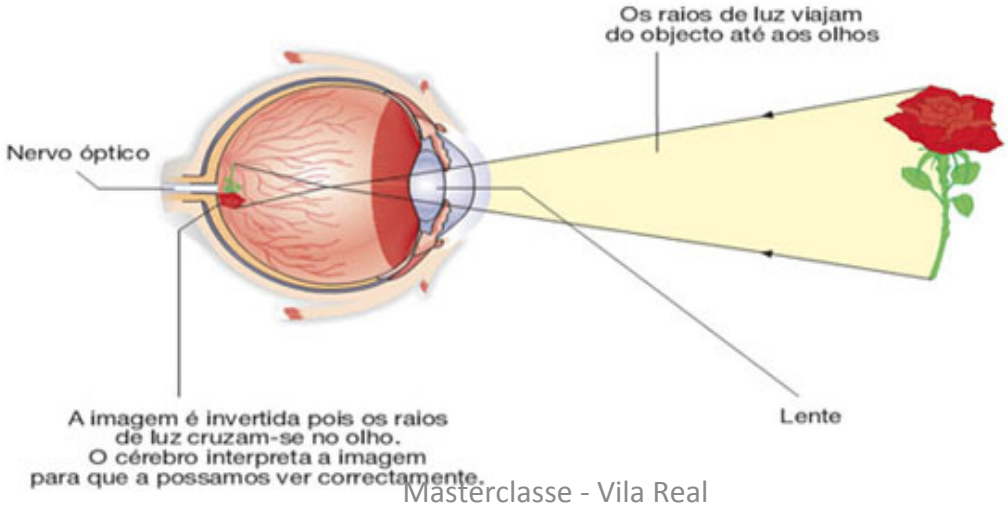
$E = mc^2$



Detectores

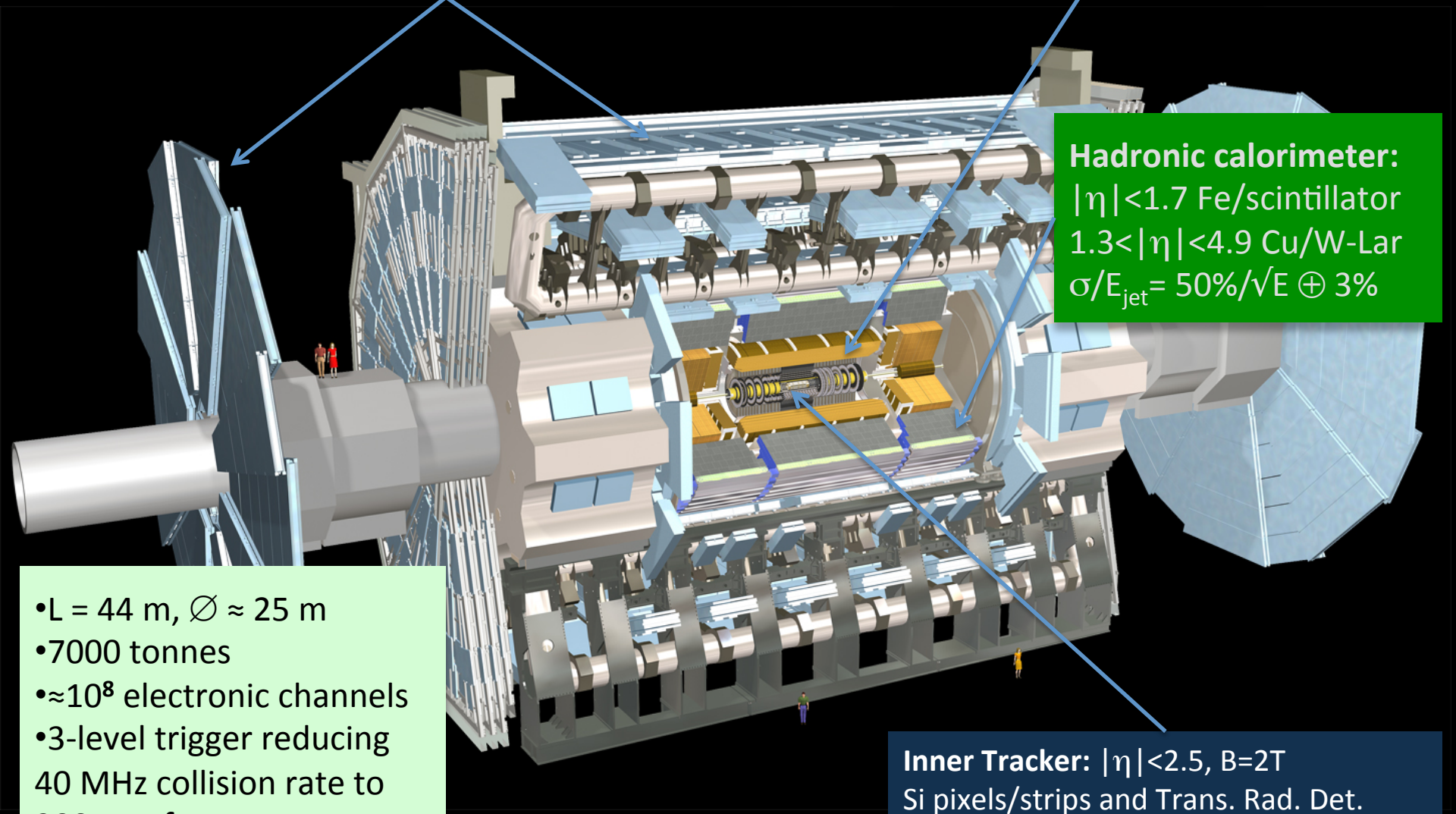


Impulsos Eléctricos



Muon Spectrometer: $|\eta|<2.7$
Air-core toroids and gas-based muon chambers
σ/p_T = 2% @ 50GeV to 10% @ 1TeV (ID+MS)

EM calorimeter: $|\eta|<3.2$
Pb-LAr Accordion
$\sigma/E = 10\%/\sqrt{E} \oplus 0.7\%$

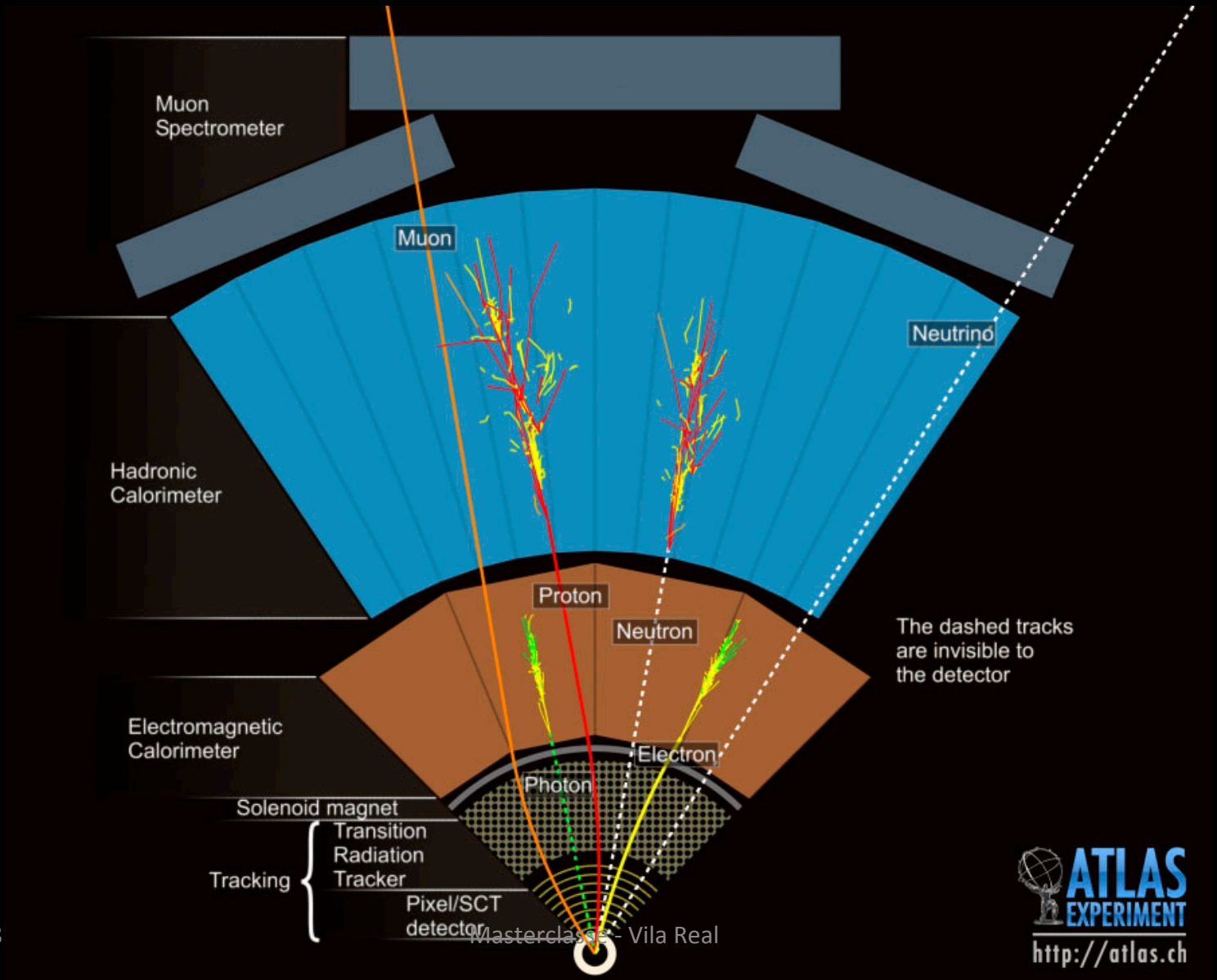


Hadronic calorimeter:
$|\eta|<1.7$ Fe/scintillator
$1.3<|\eta|<4.9$ Cu/W-Lar
$\sigma/E_{jet} = 50\%/\sqrt{E} \oplus 3\%$

- L = 44 m, ∅ ≈ 25 m
- 7000 tonnes
- $\approx 10^8$ electronic channels
- 3-level trigger reducing 40 MHz collision rate to 200 Hz of events to tape

Inner Tracker: $|\eta|<2.5$, B=2T
Si pixels/strips and Trans. Rad. Det.
$\sigma/p_T = 0.05\%\ p_T\,(\text{GeV}) \oplus 1\%$

Particle identification



CERN

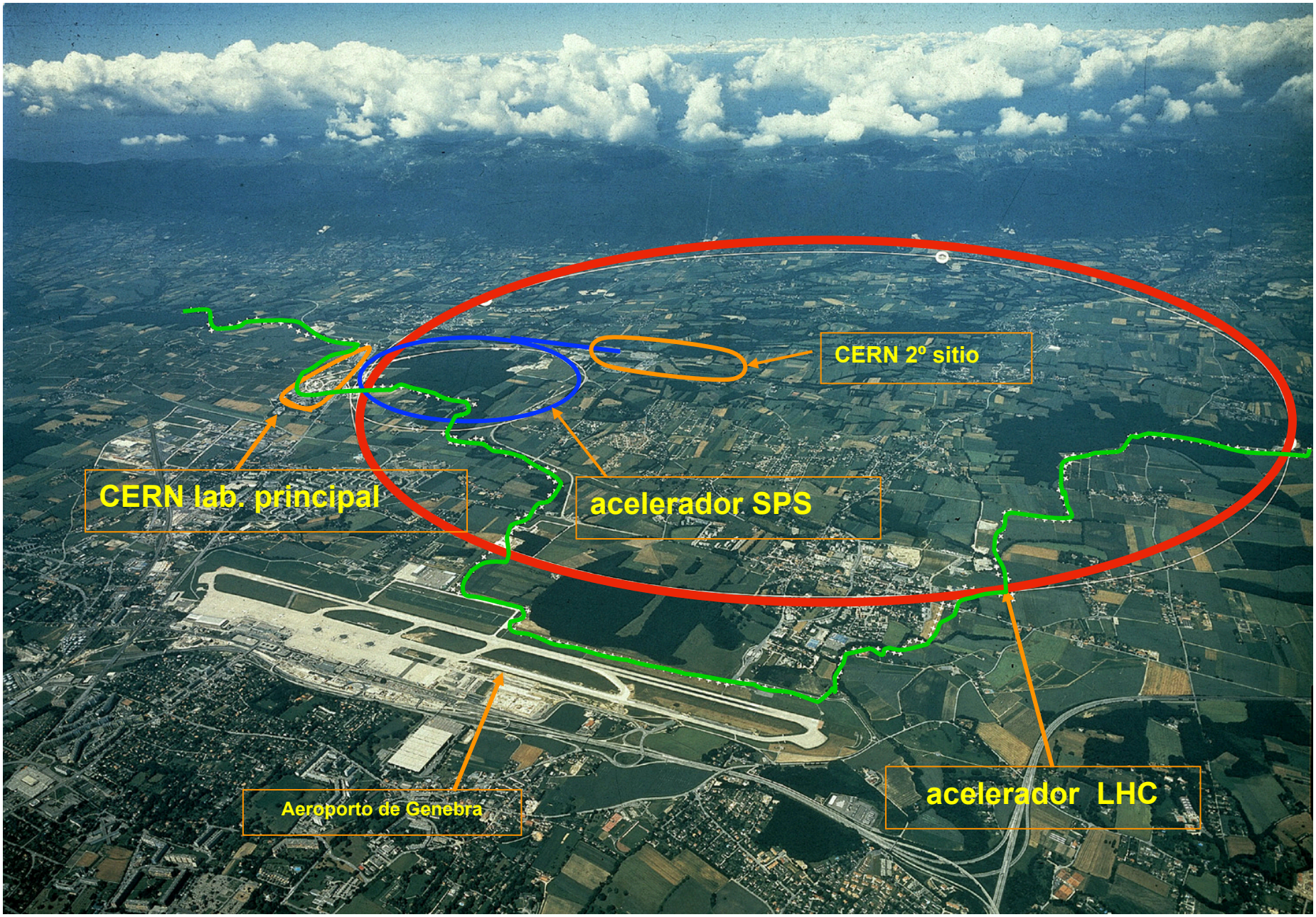
European Organization for Nuclear Research

Fundado em 1954 por 12 países

Actualmente: 22 estados membros (1986-Portugal)

2500 Engenheiros, Físicos, Técnicos, Administrativos

Mais de 13000 utilizadores de todas as partes do mundo ~1100 M€ / orçamento anual


CERN 2º sitio
CERN lab. principal
acelerador SPS
Aeroporto de Genebra
acelerador LHC

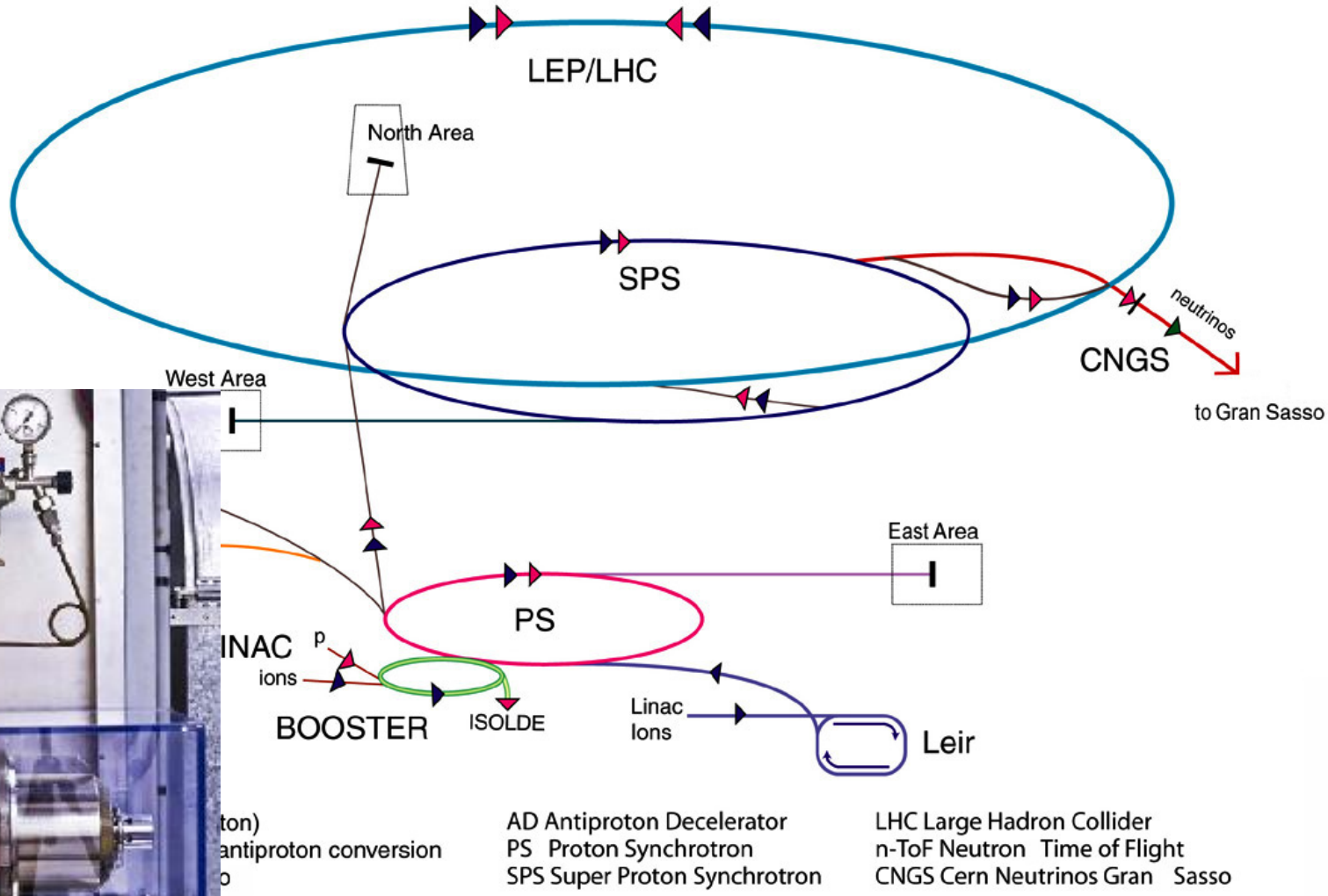
LINAC2 → **50 MeV**

Booster → **1.4 GeV**

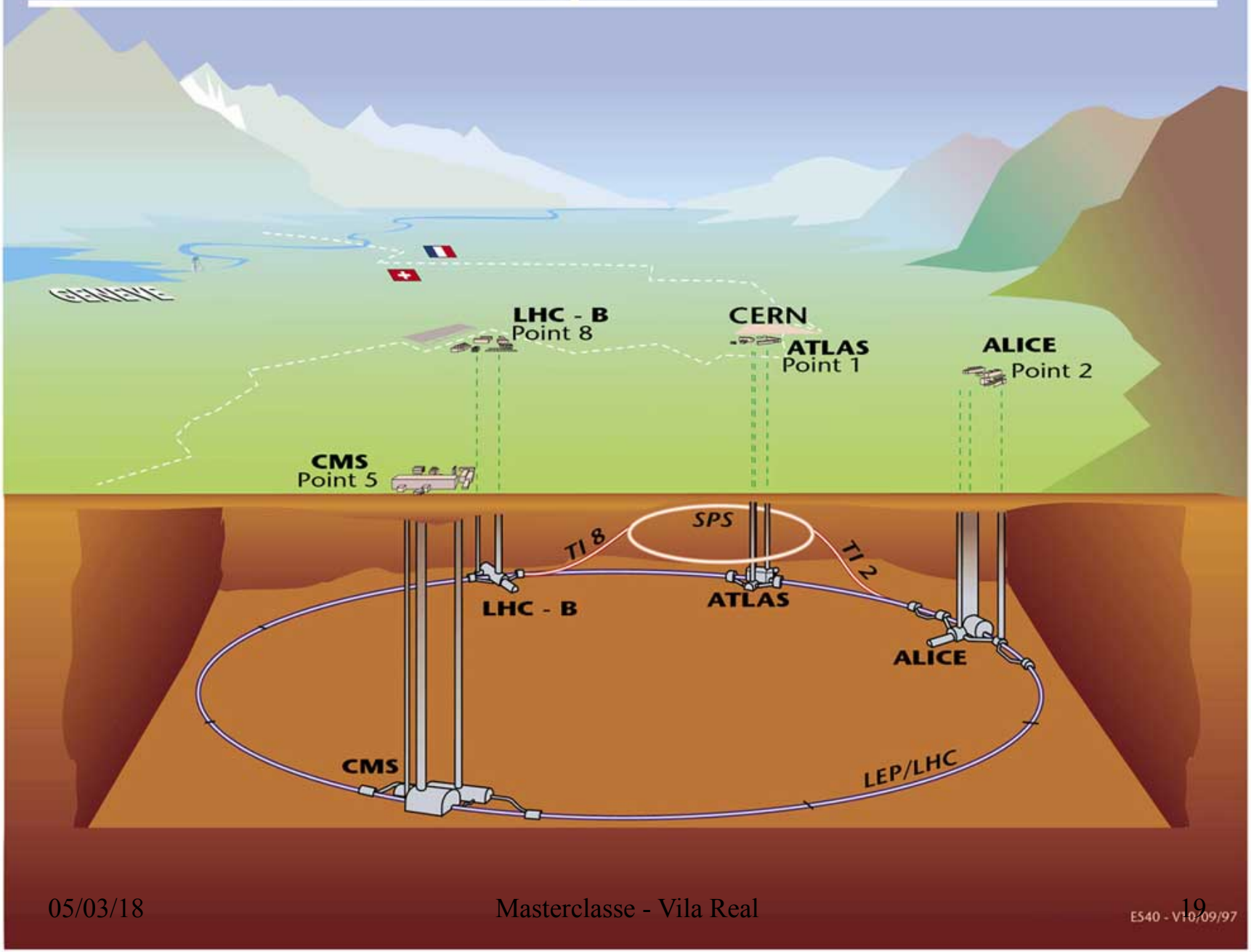
Proton Synchroton (PS) → **25 GeV**

Super Proton Synchrotron (SPS) → **450 GeV**

Large Hadron Collider (LHC)→ **7 TeV**



Overall view of the LHC experiments.



Portugal no CERN

O LIP é a referência para a Física de Partículas experimental em Portugal

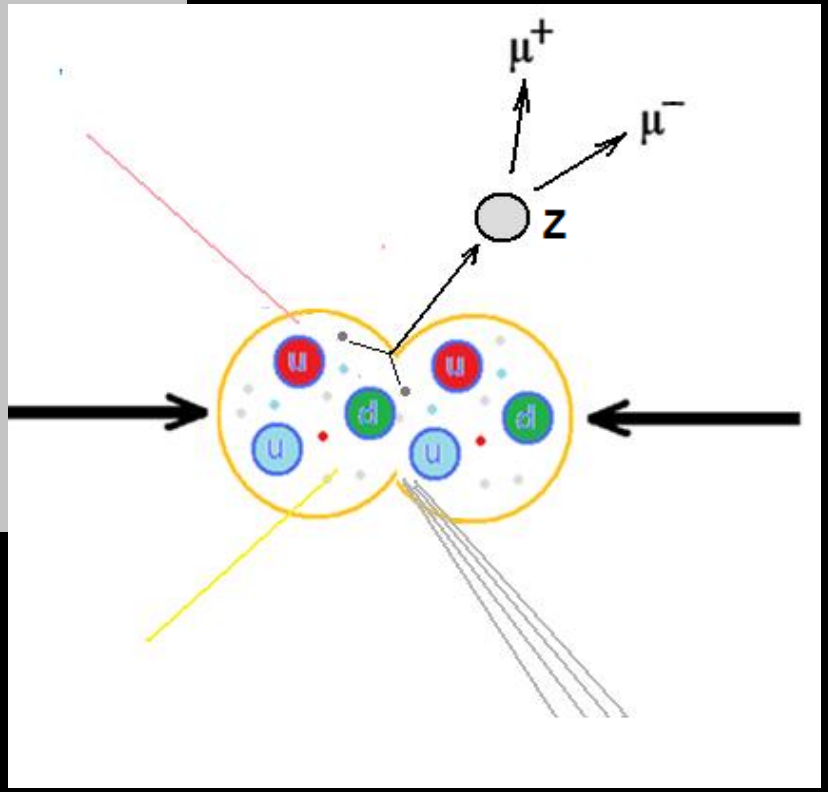
- Delegações do LIP em Lisboa, Coimbra, e Minho
- Trabalhamos no CERN mas também com outras organizações internacionais
  - ESA, ESO, Snolab (Canadá), observatório Pierre Auger (Argentina), etc

Então e o trabalho de hoje?

Decaimentos de Partículas

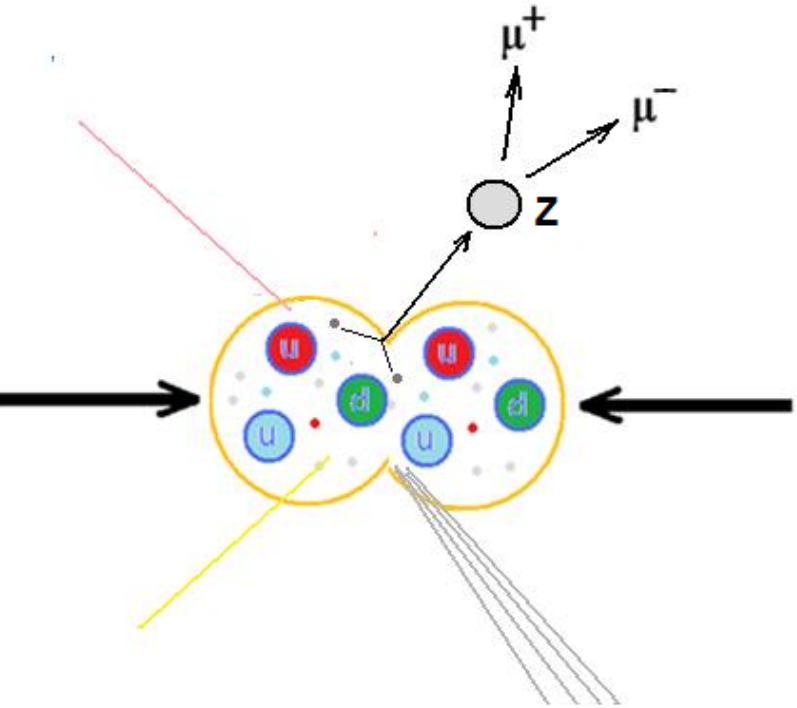
Estamos **à procura do** bosão **Z**, uma partícula **sem carga eléctrica** que decai num **par muão-antimuão** ou num **par electrão-positrão***.

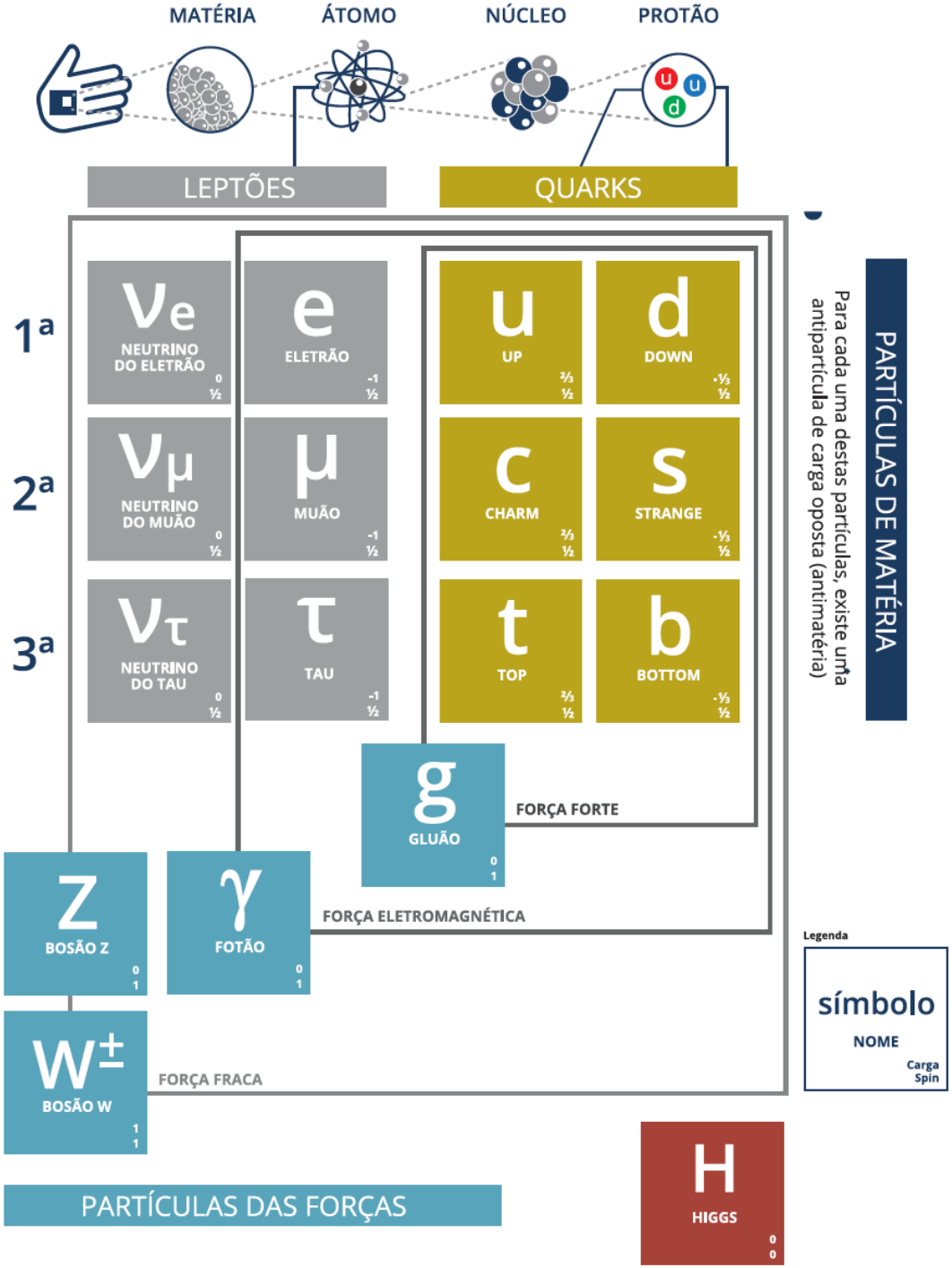
O que sabemos das cargas eléctricas dos pares?
Qual a carga eléctrica do Z?



**O bosão Z tem outros decaimentos… mas não estamos interessados nesses.*

O Modelo Padrão da Física de Partículas



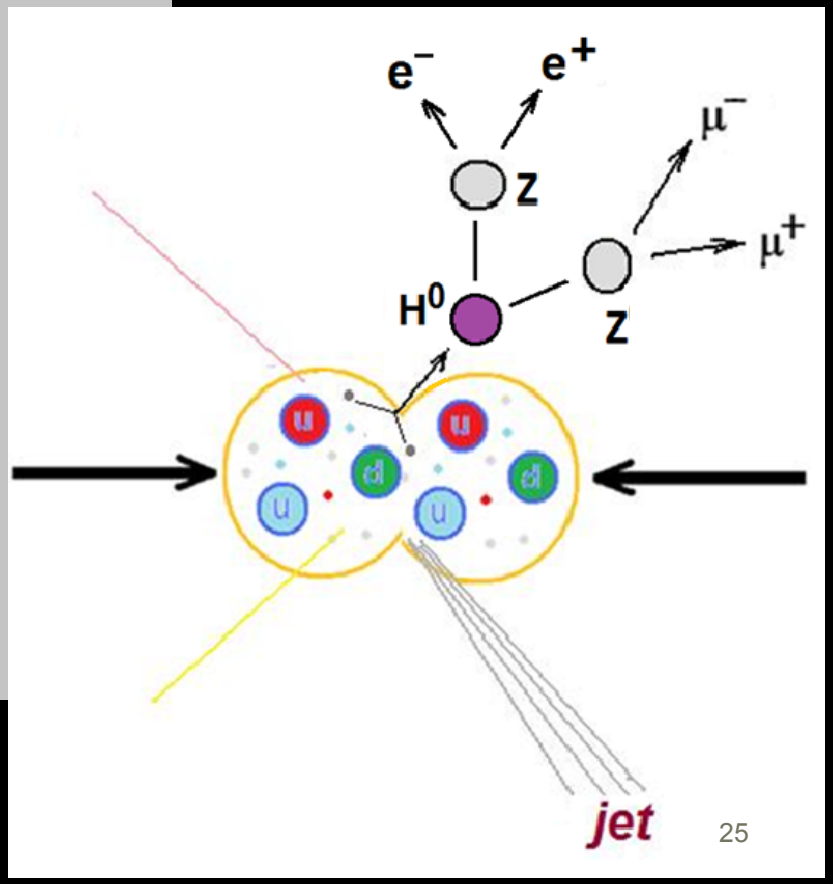


Produção e Decaimento de Partículas

O **bosão de Higgs** (**H**) foi encontrado nas experiências ATLAS e CMS no LHC do CERN em 2012.

Podemos ter acontecimentos candidatos a bosões de Higgs nos decaimentos

- **H -> ZZ -> 4 leptões**
- **H -> $\gamma\gamma$ (2 fotões)**

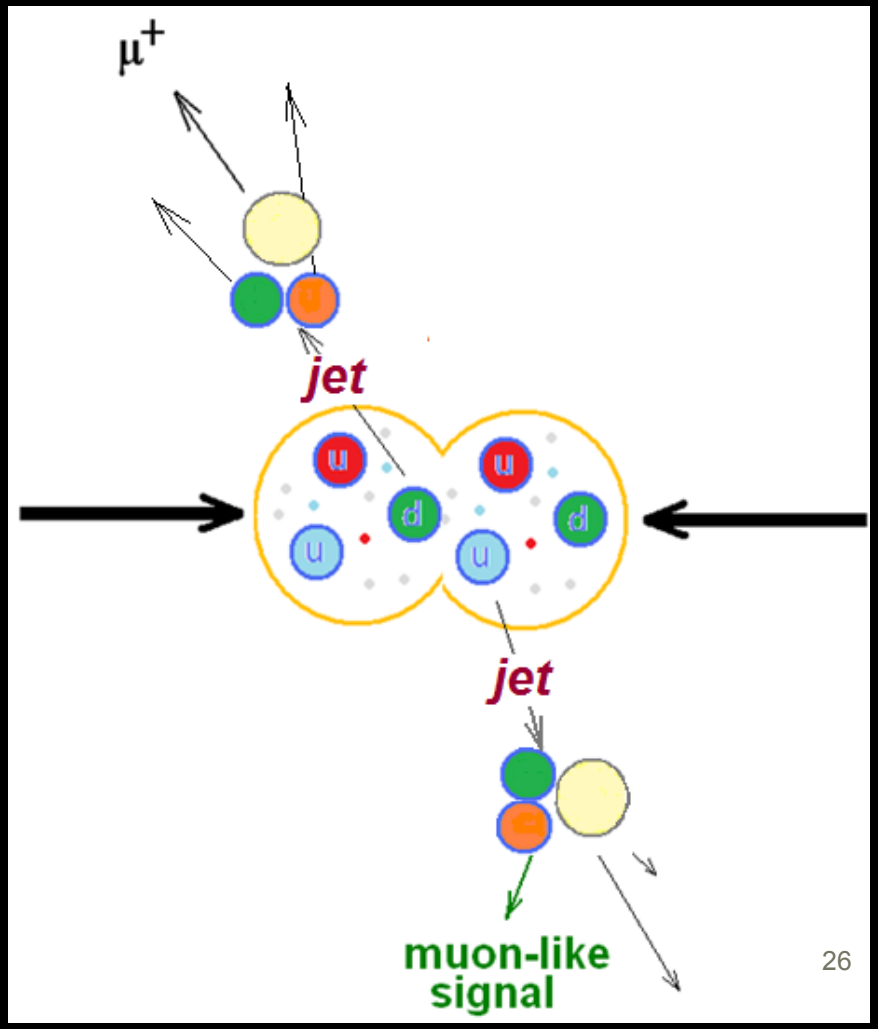


Decaimentos de Partículas

Frequentemente quarks são dispersados em colisões.

Estes quarks dão origem a jatos de partículas. Electrões e muões de baixa energia podem ser produzidos nos jatos.

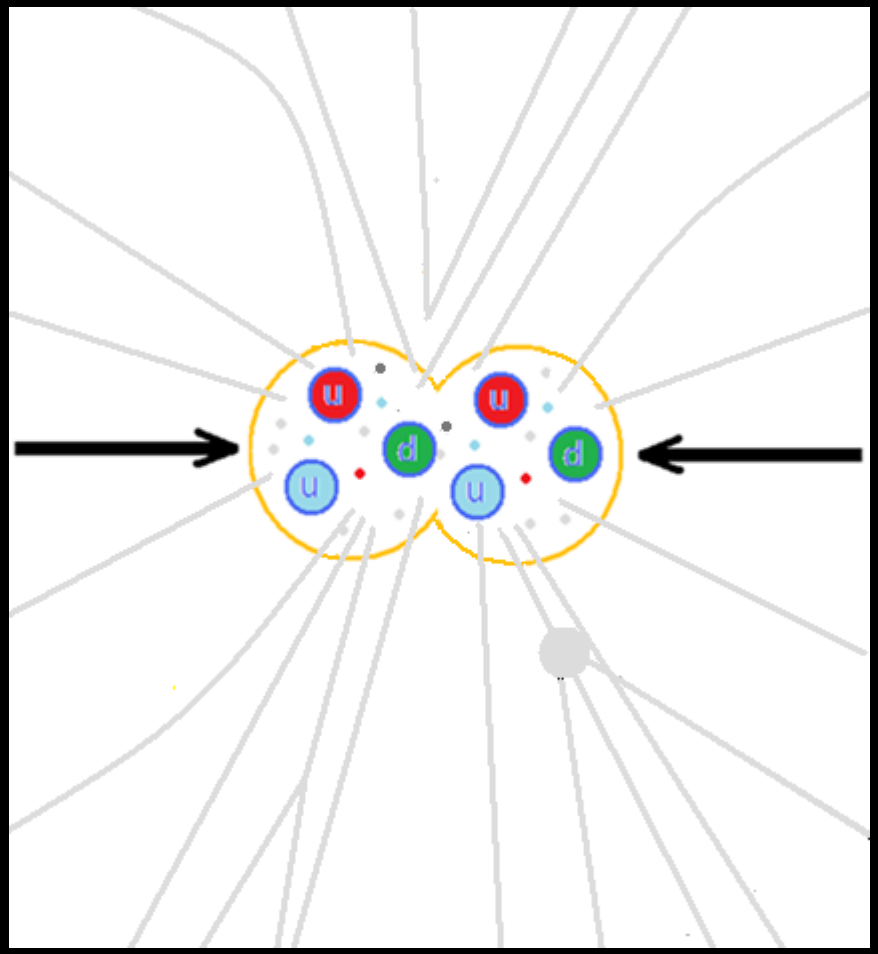
Não são o que estamos à procura!



Decaimentos de Partículas

Um acontecimento “di-muão” ou “di-electrão” ***pode*** ser o decaimento da partícula em que estamos interessados.

Pode ser difícil reconhecer os traços que queremos, se não eliminarmos os traços de baixo momento transverso.

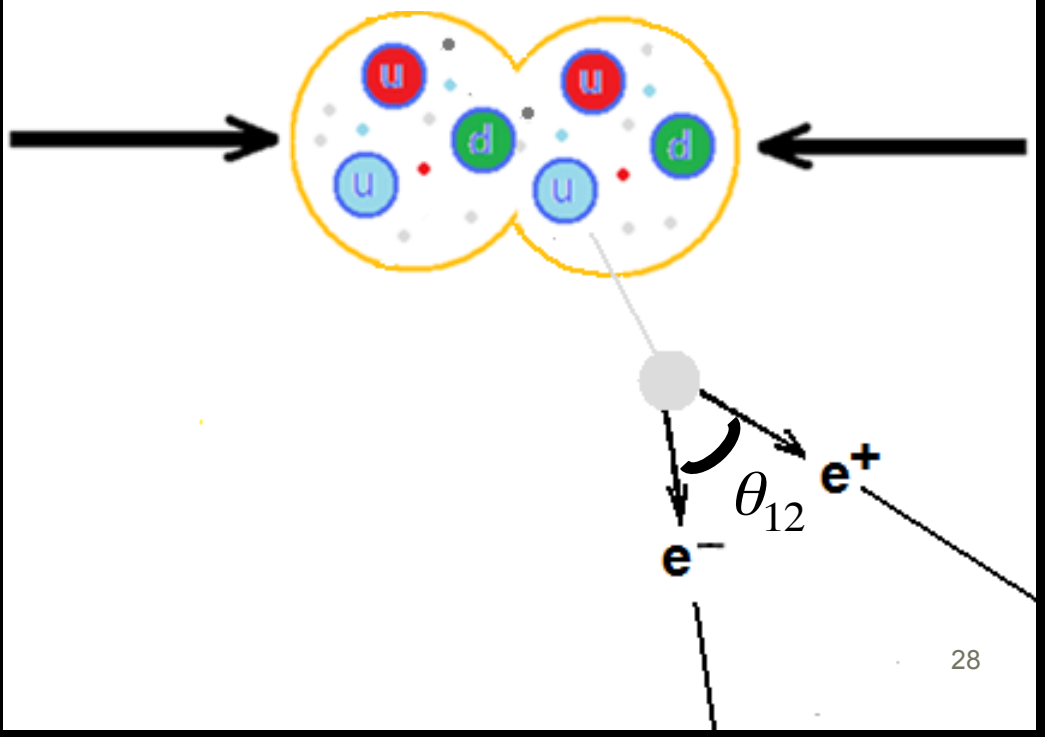


Decaimentos de Partículas

Se selecionarmos só os traços com momento transverso superior a 10 GeV, ficamos com uma imagem mais nítida.

Hoje iremos seleccionar vários acontecimentos $Z \rightarrow e^+e^-$ e $Z \rightarrow \mu^+\mu^-$ e usar a informação de massa [invariante] m $[.c^2]$ para saber se descobrimos o bosão Z ou outras partículas.

$$
\begin{aligned}
E &= mc^2 \rightarrow E^2 = m^2c^4 + p^2c^4 \\
E &= E_1 + E_2 \\
p &= |\vec{p}| = |\vec{p}_1 + \vec{p}_2| \\
m &= \frac{\sqrt{(E_1 + E_2)^2 + c^2(\vec{p}_1 + \vec{p}_2)^2}}{c^2}
\end{aligned}
$$



Visualizador de Acontecimentos HYPATIA

=> cuts: Pt > 5.0-10.0 GeV

Hybrid pupils' analysis tool for interactions in ATLAS - version 6.0 - Invariant Mass Window

File View Histograms Preferences Help

File Name	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	φ	η	M(2l) [GeV]	M(4l) [GeV]	e/μ
00036_JiveXML_166964_987982.xml	19.626	Tracks 3	112.6	+	49.4	1.441	-1.464	95.325		μ
		Tracks 69	96.8	-	45.9	-1.720	-1.378			μ

Canvas Window - File: 00036_JiveXML_166964_987982.xml Run: 166964 Event: ...

ATLAS 2010-10-18 04:39:34 CEST run:166964 ev:987982 HYPATIA

Y (m) X (m) ρ (m)

HYPATIA - Track Momenta Window

File Previous Event Next Event Insert Electron Insert Muon Delete Track Reset Canvas

ETMis: 20.808 GeV φ: -2.415 rad Collection: MET_RefFinal

C:\installers\HYPATIA\groupA\00036_JiveXML_166964_987982.xml

Reconstructed Tracks

Track	+/-	P [GeV]	Pt [GeV]	φ	θ
Tracks 3	+	112.57	49.42	1.441	2.687
Tracks 69	-	96.83	45.88	-1.720	2.648
Tracks 127	-	37.93	30.81	1.803	0.948
Tracks 128	+	25.73	12.70	0.303	2.625
Tracks 134	+	121.30	89.22	-0.597	2.315
Tracks 136	-	34.18	8.63	-3.123	0.255
Tracks 154	+	14.19	8.35	-2.346	2.513
Tracks 176	-	13.53	12.74	0.259	1.915

HYPATIA - Control Window

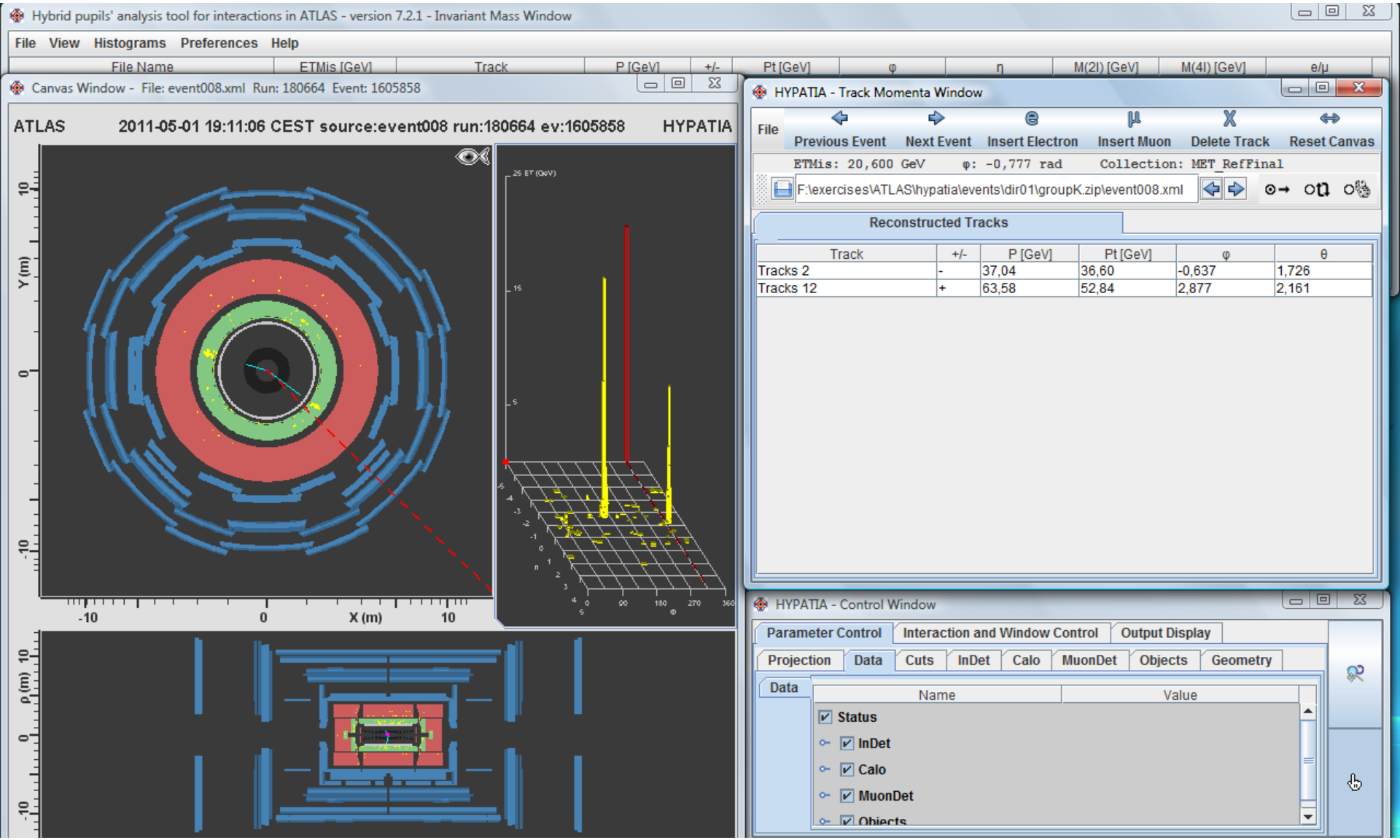
Parameter Control | Interaction and Window Control | Output Display

Projection | Data | Cuts | InDet | Calo | MuonDet | Objects | Geometry

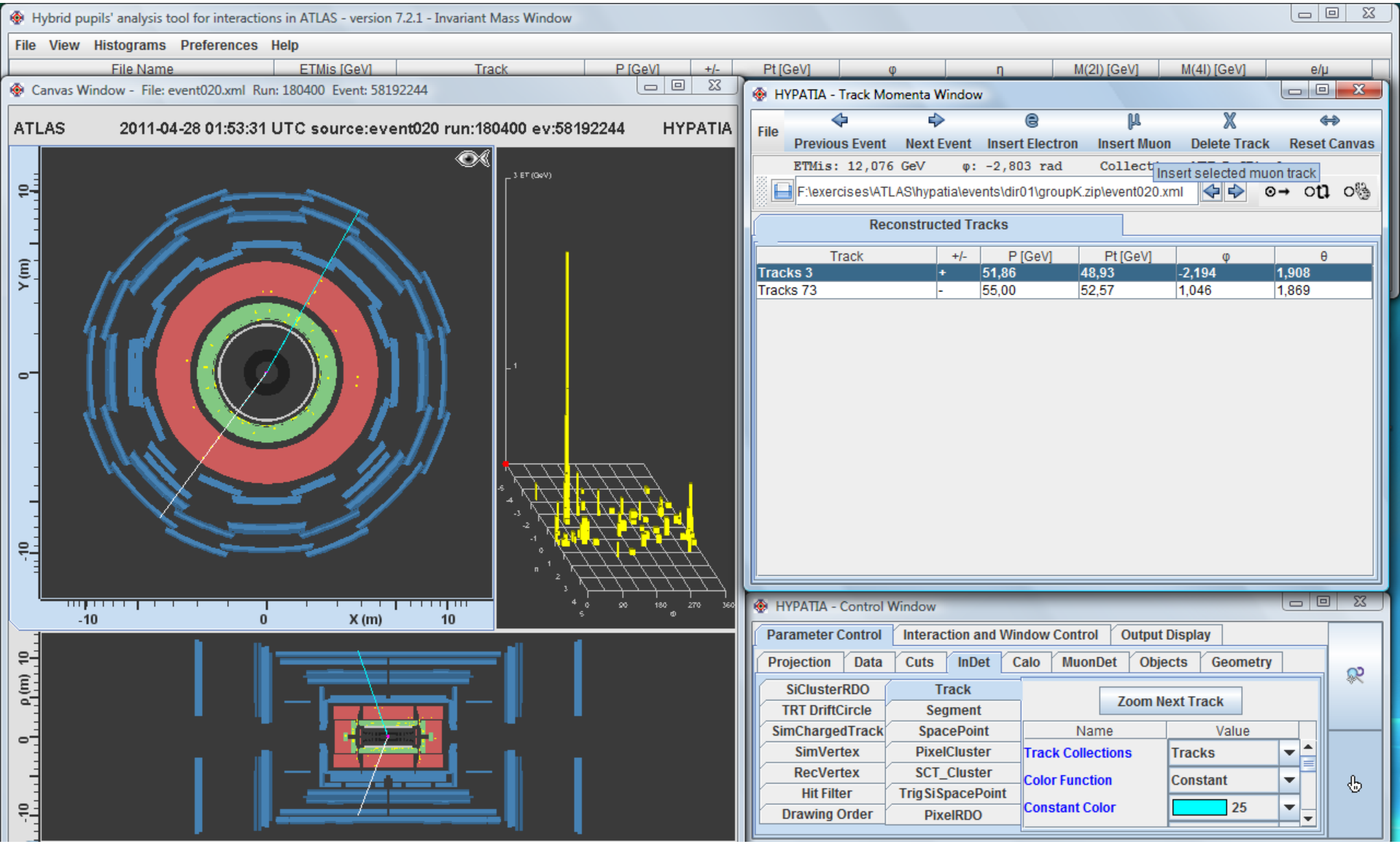
InDet | Calo | MuonDet | Objects | ATLAS

Name		Value
☑ |Pt|	>	5.0 GeV
☐ |d0|	<	2.5 mm
☐ |z0|	<	20.0 cm
☐ |d0 Loose|	<	2.0 cm
☐ |z0-zVtx|	<	2.5 mm

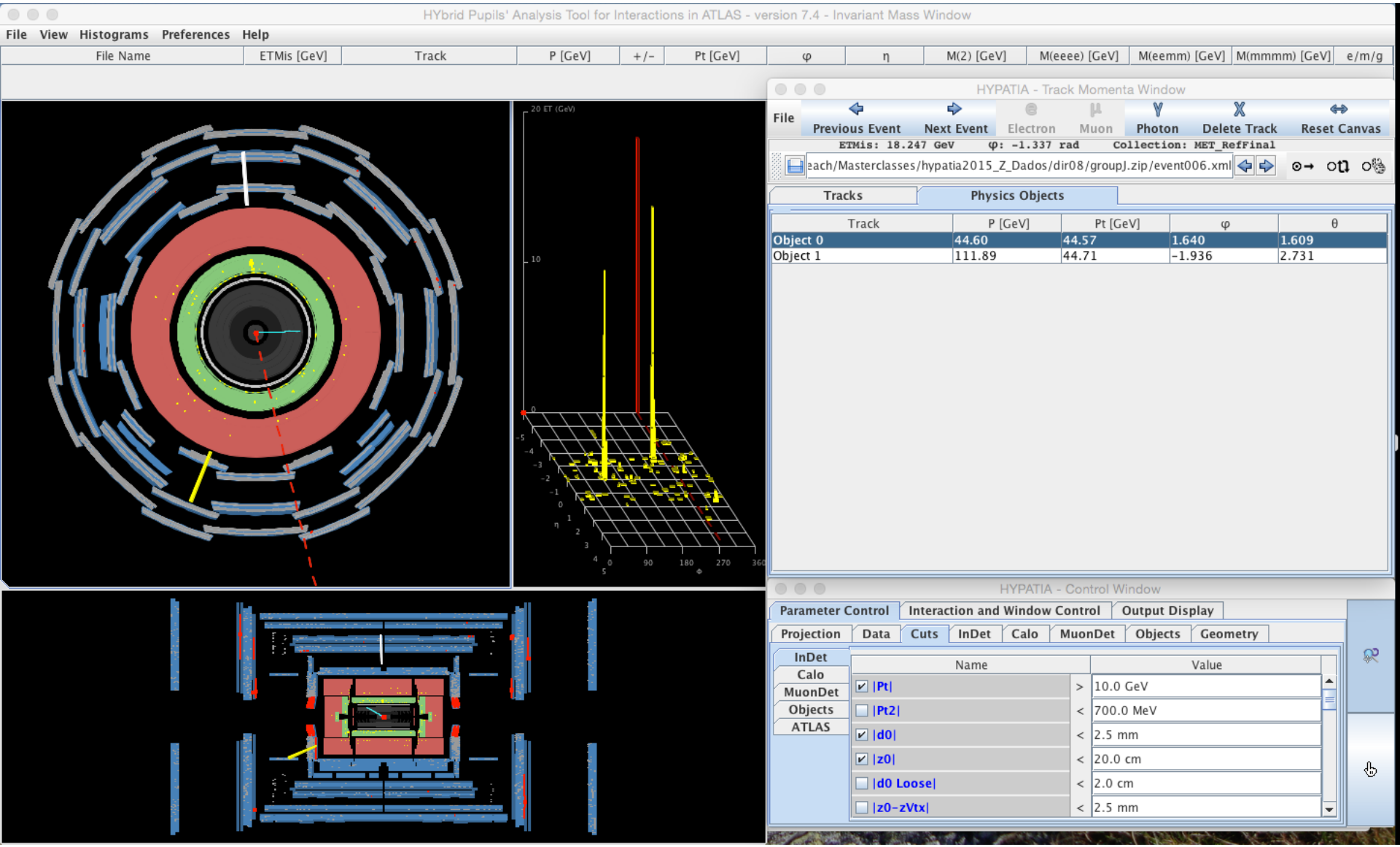
HYPATIA: $Z \rightarrow e^+ e^-$



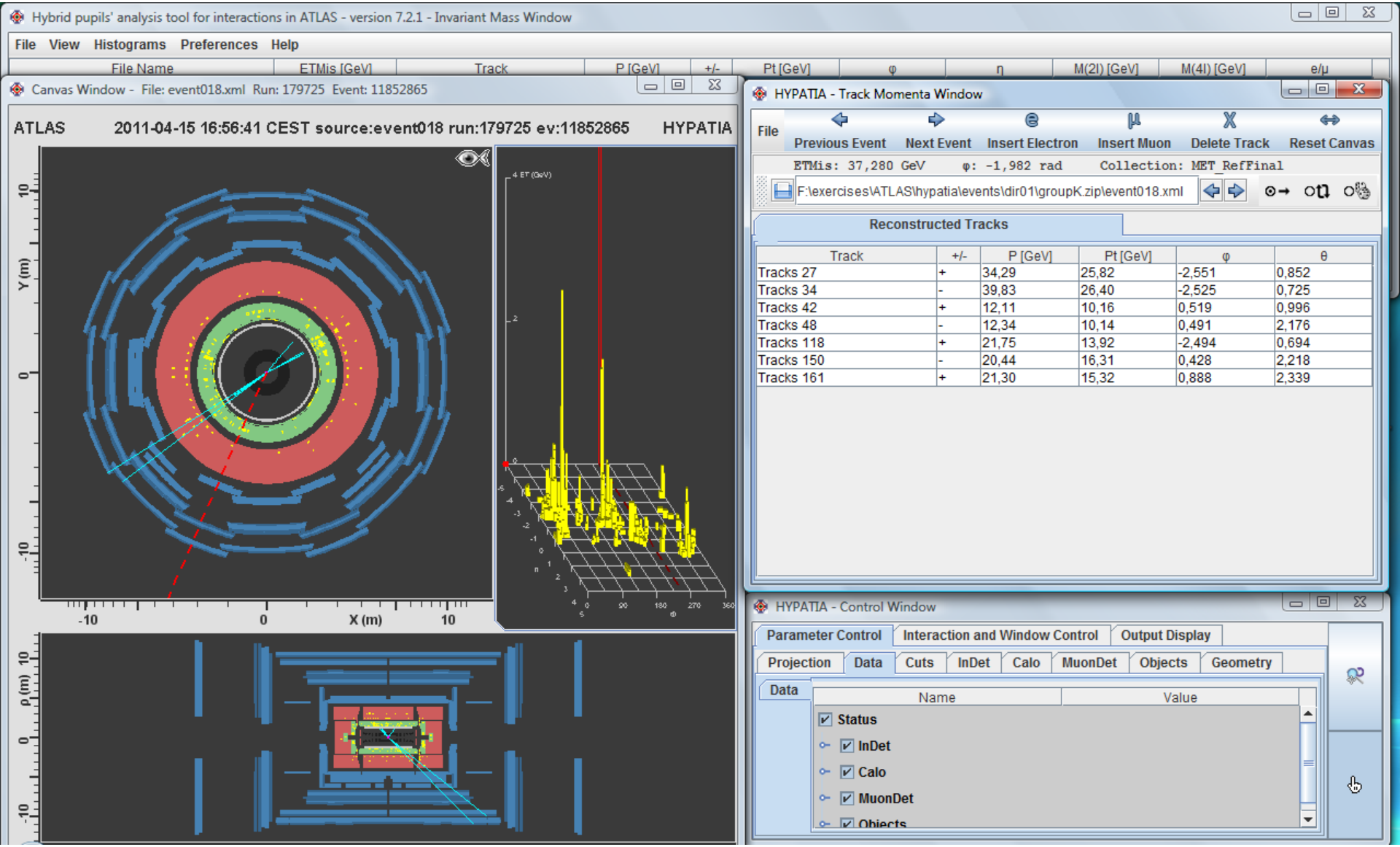
HYPATIA: $Z \rightarrow \mu^+ \mu^-$



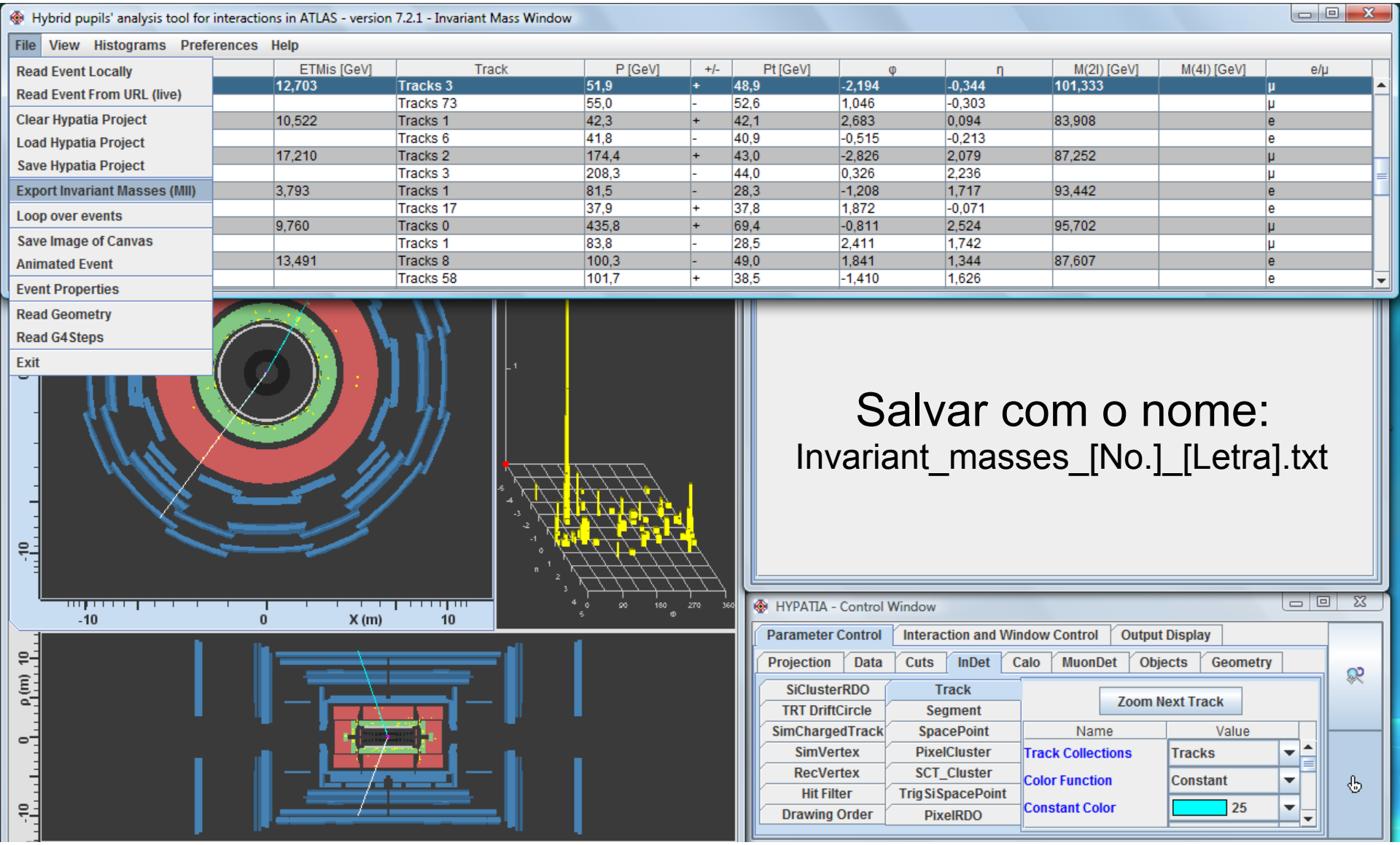
HYPATIA: H → γγ


HYbrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window
File View Histograms Preferences Help
File Name | ETMis [GeV] | Track | P [GeV] | +/- | Pt [GeV] | φ | η | M(2) [GeV] | M(eeee) [GeV] | M(eemm) [GeV] | M(mmmm) [GeV] | e/m/g
HYPATIA - Track Momenta Window
File
Previous Event
Next Event
Electron
Muon
Photon
Delete Track
Reset Canvas
ETMis: 18.247 GeV φ: -1.337 rad Collection: MET_RefFinal
each/Masterclasses/hypatia2015_Z_Dados/dir08/groupJ.zip/event006.xml
Tracks
Physics Objects
Track | P [GeV] | Pt [GeV] | φ | θ
Object 0 | 44.60 | 44.57 | 1.640 | 1.609
Object 1 | 111.89 | 44.71 | -1.936 | 2.731
HYPATIA - Control Window
Parameter Control
Interaction and Window Control
Output Display
Projection
Data
Cuts
InDet
Calo
MuonDet
Objects
Geometry
InDet
Calo
MuonDet
Objects
ATLAS
Name | Value
|Pt| > 10.0 GeV
|Pt2| < 700.0 MeV
|d0| < 2.5 mm
|z0| < 20.0 cm
|d0 Loose| < 2.0 cm
|z0-zVtx| < 2.5 mm

HYPATIA: Z → jatos (fundo)



HYPATIA: Salvar os dados!!!



Salvar com o nome:
Invariant_masses_[No.]_[Letra].txt

UPLOAD para: **http://cernmasterclass.uio.no/OPloT/**

Procuramos picos que correspondem à massa das partículas

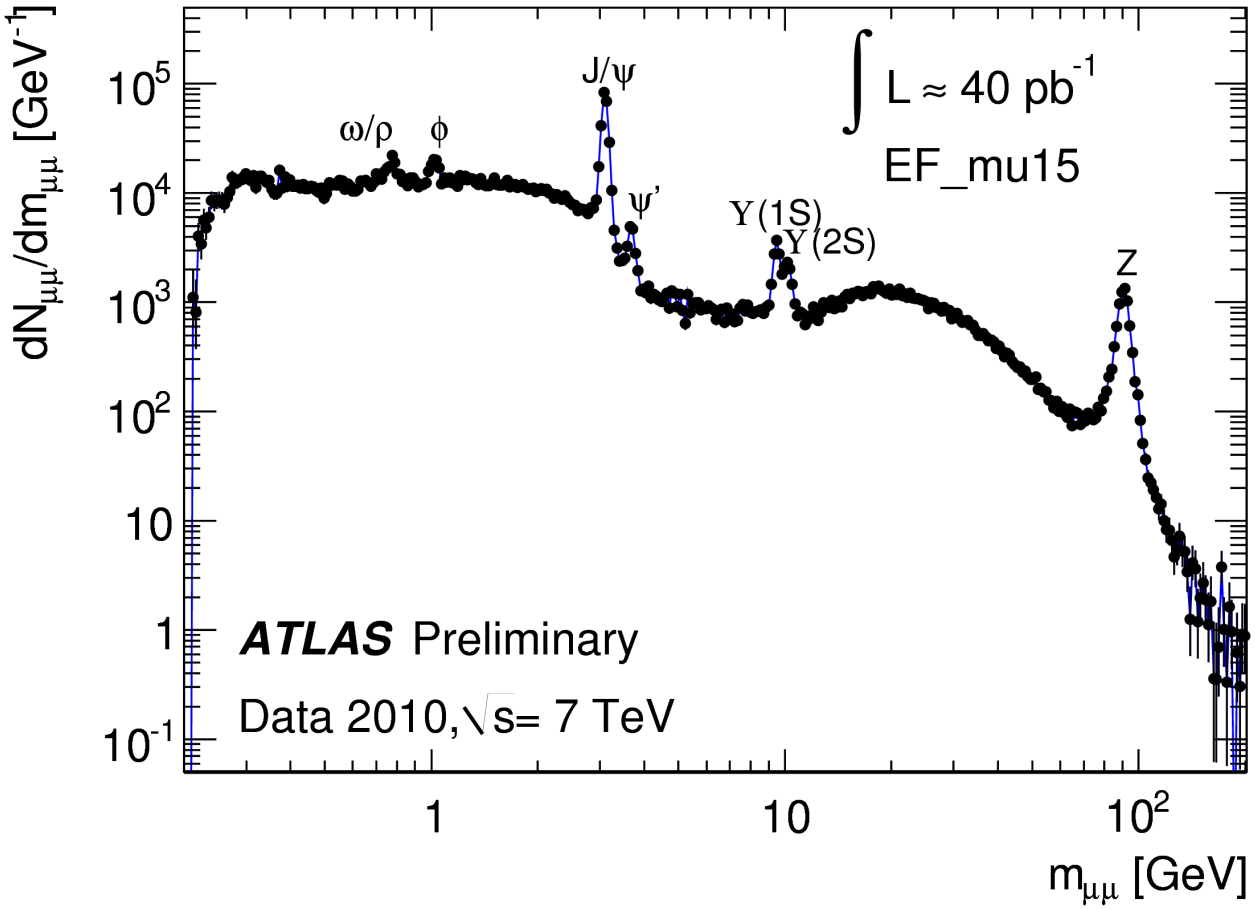
Algumas partículas conhecidas:

$m_{J/\psi}$ = 3.1 GeV

m_{Υ} = 9.5 GeV

m_Z = 91.2 GeV

m_H = 125.1 GeV



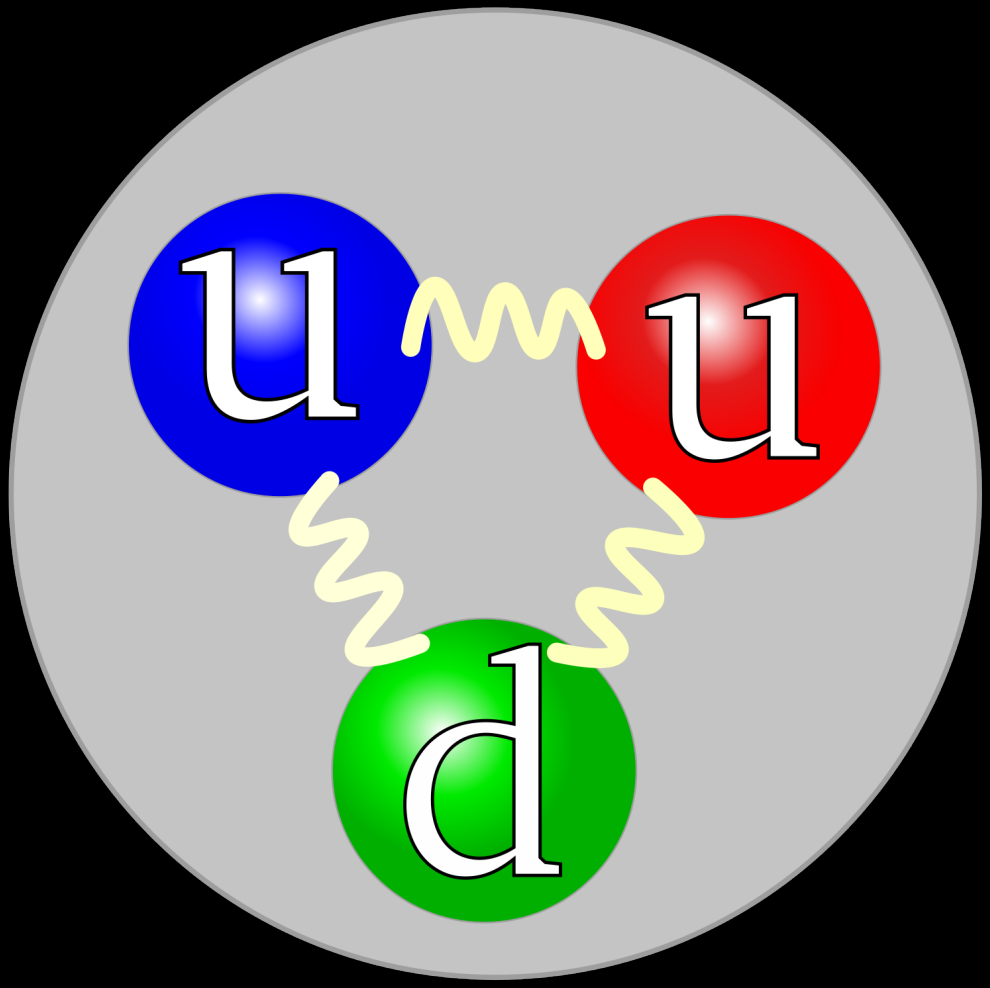
Perguntas?


QUI A PEUR
DU
TROU NOIR

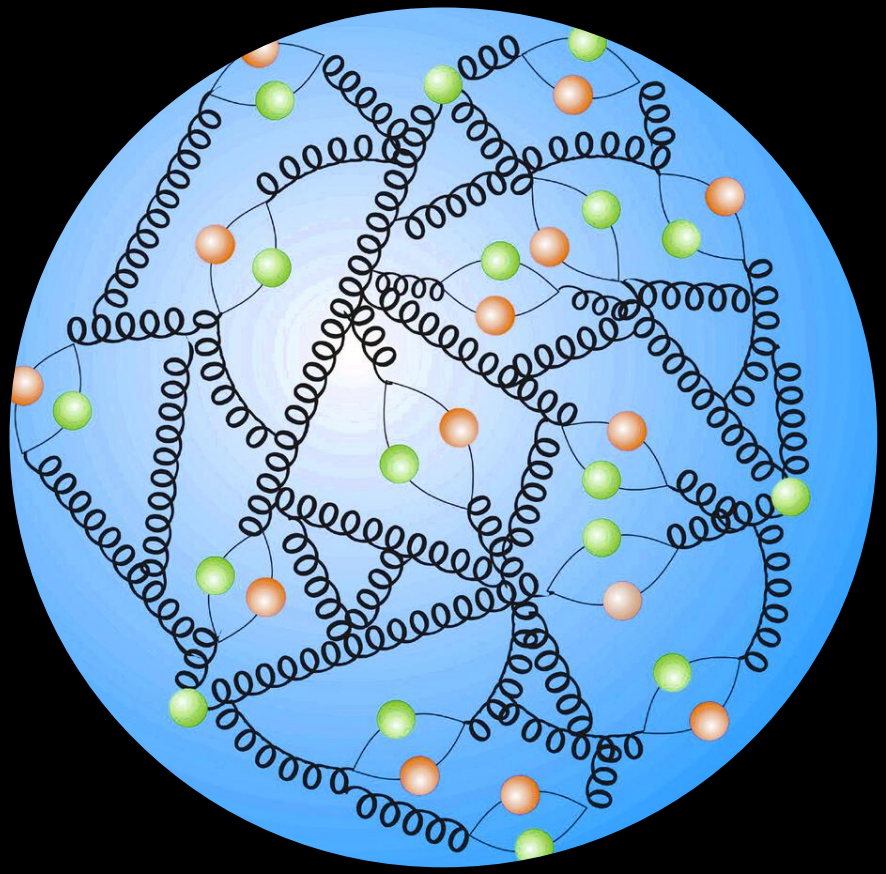

13.8 BILLION YEARS AGO, A FEW SECONDS BEFORE THE CREATION OF OUR UNIVERSE...
All set. Let's fire up this Large Hadron Particle Collider and see what happens!
MOEU

O Protão revisitado

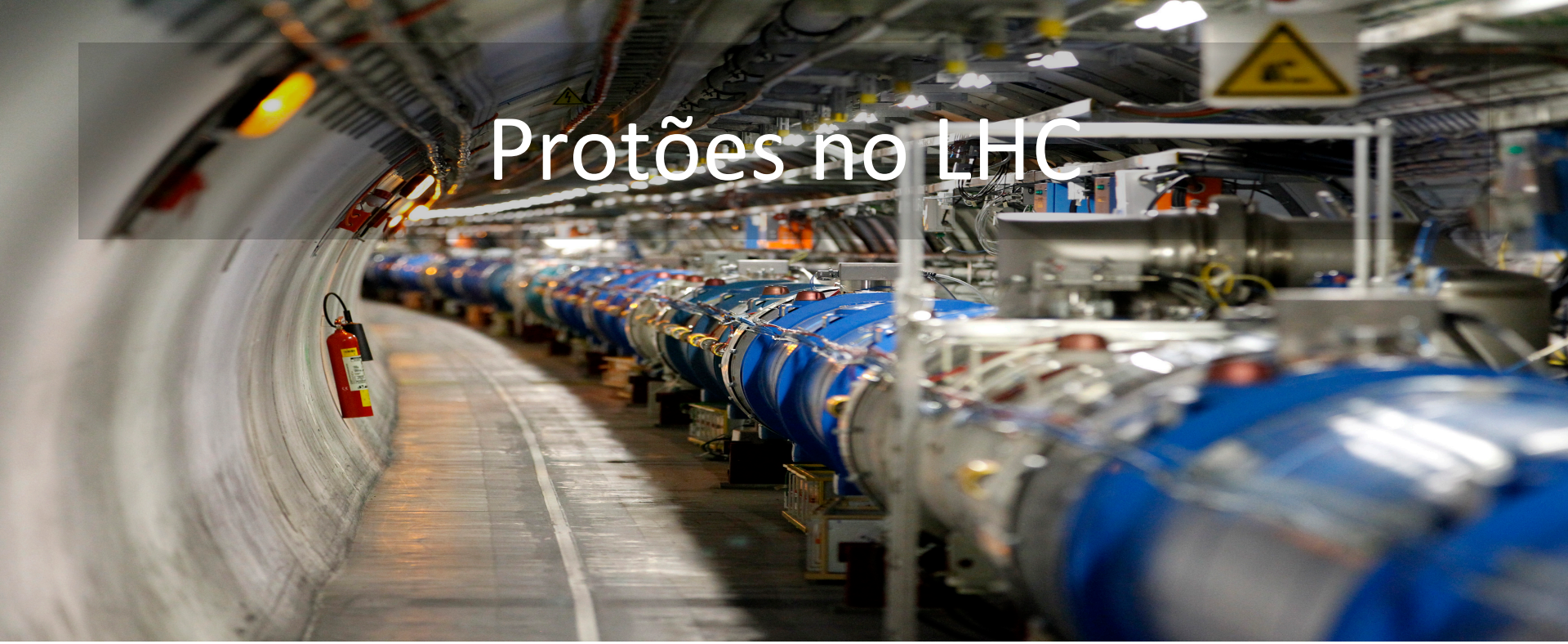
O protão no modelo dos quarks

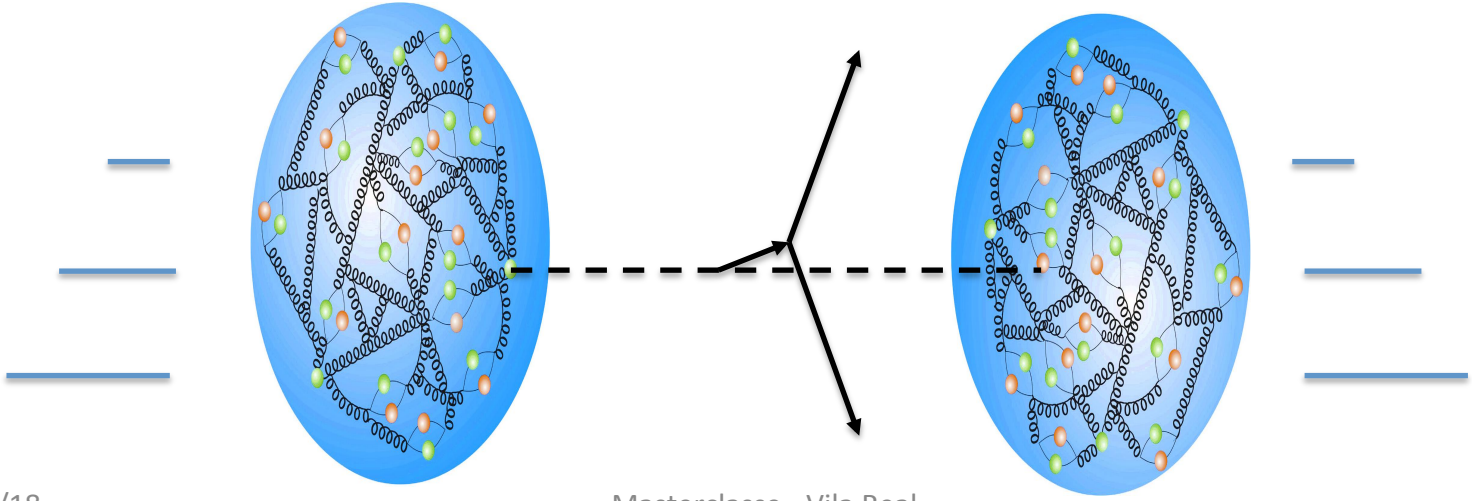


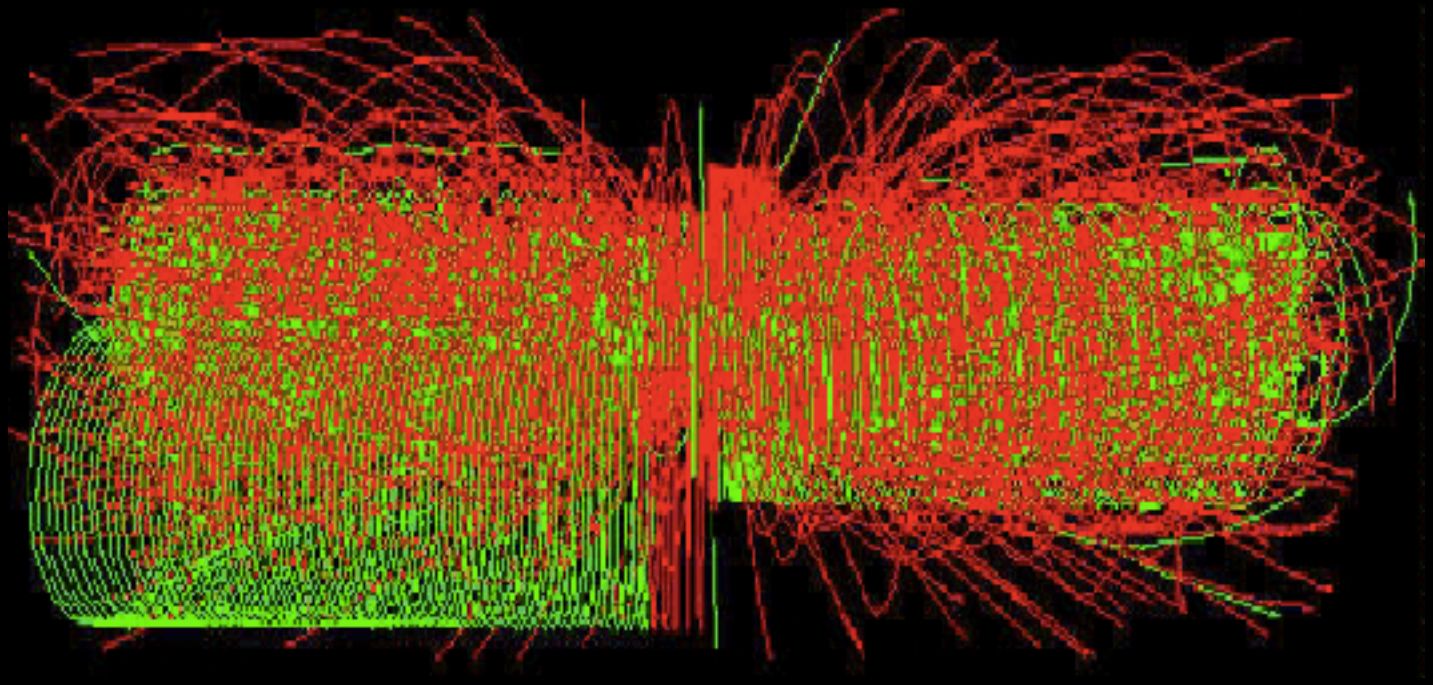
O protão tal como o conhecemos hoje



Protões no LHC

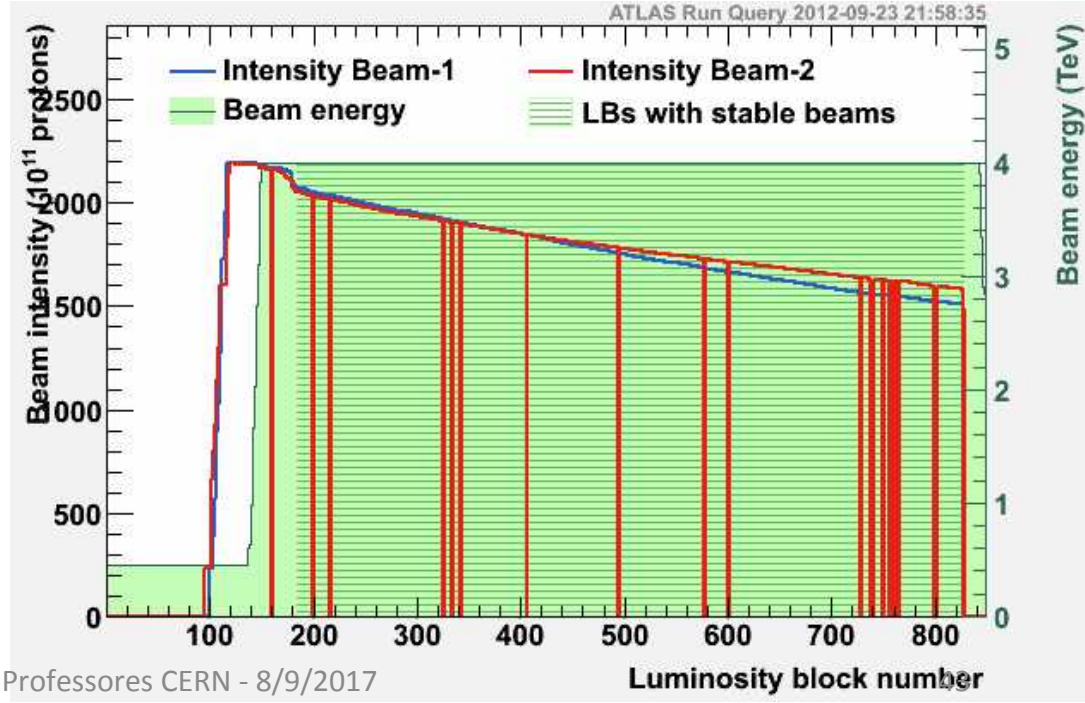


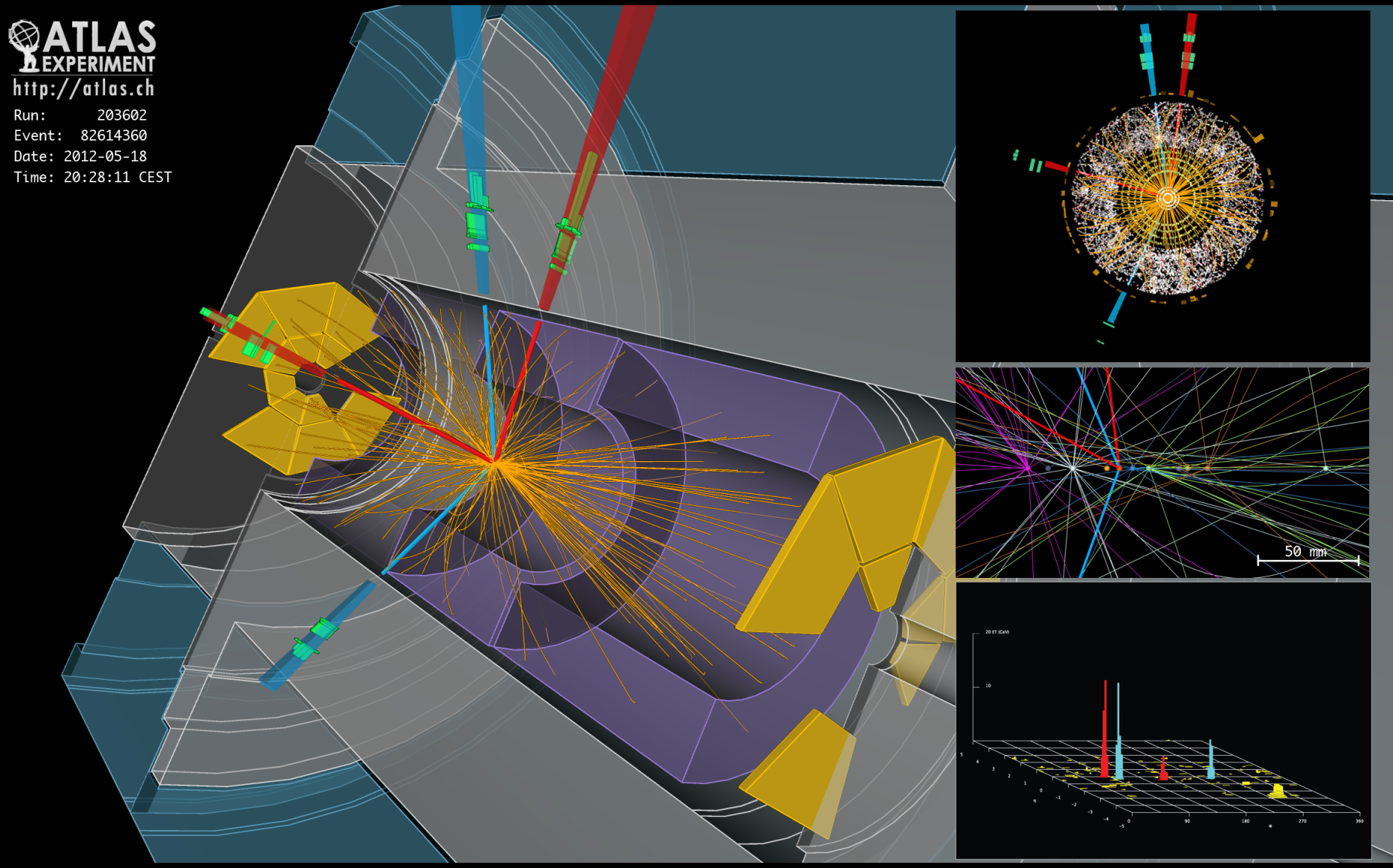




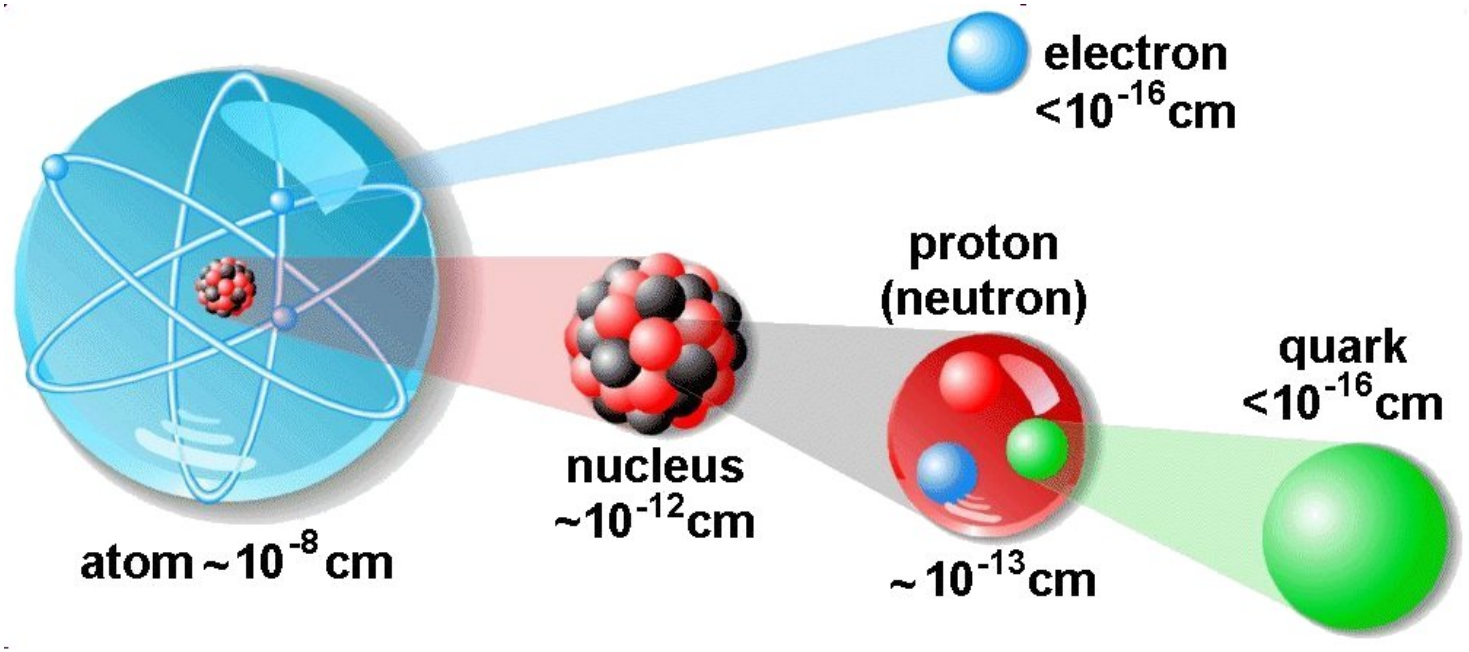
- Energia do feixe:
- 2802 bunches de 1.15×10^{11} protões
- 7TeV / protão (2015) = $7 \times 10^{12} \times 1.602 \times 10^{-19}$ J
- Dá 362 MJ por feixe…
- Igual à energia cinética de um porta-aviões de 20,000t a viajar a 11,7 nós (21.7 km/h)

- Tudo contido num feixe de ≈16µm
- Runs típicos duram cerca de 8 horas
- Intensidade diminui devido a perdas
- Depois voltamos a injectar novos feixes



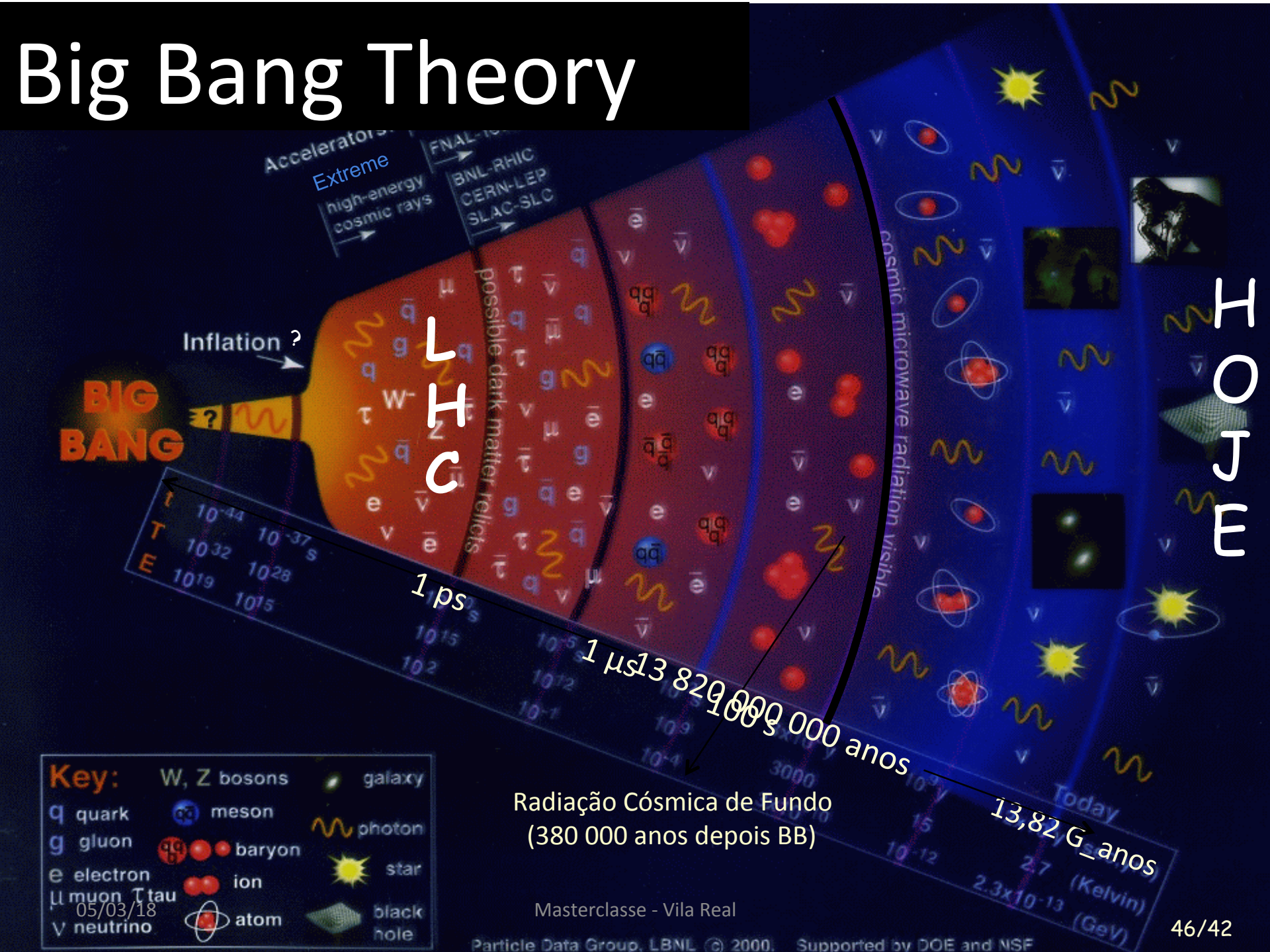

ATLAS
EXPERIMENT
http://atlas.ch
Run: 203602
Event: 82614360
Date: 2012-05-18
Time: 20:28:11 CEST
50 mm

Do átomo às partículas fundamentais



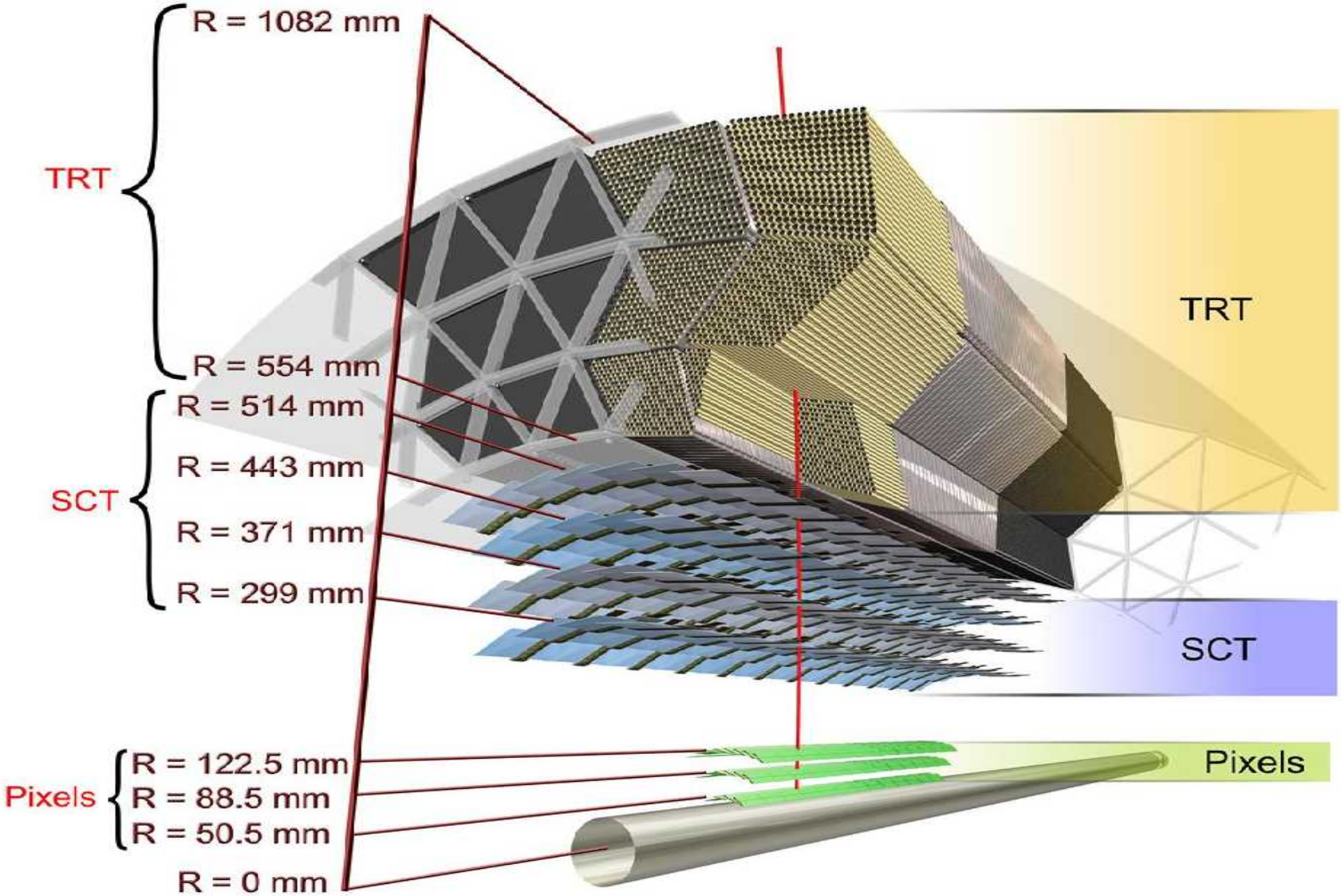
(1909/1914)

Big Bang Theory

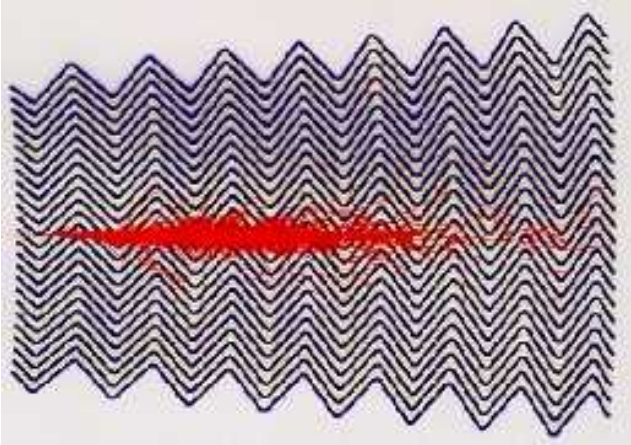


Radiação Cósmica de Fundo
(380 000 anos depois BB)

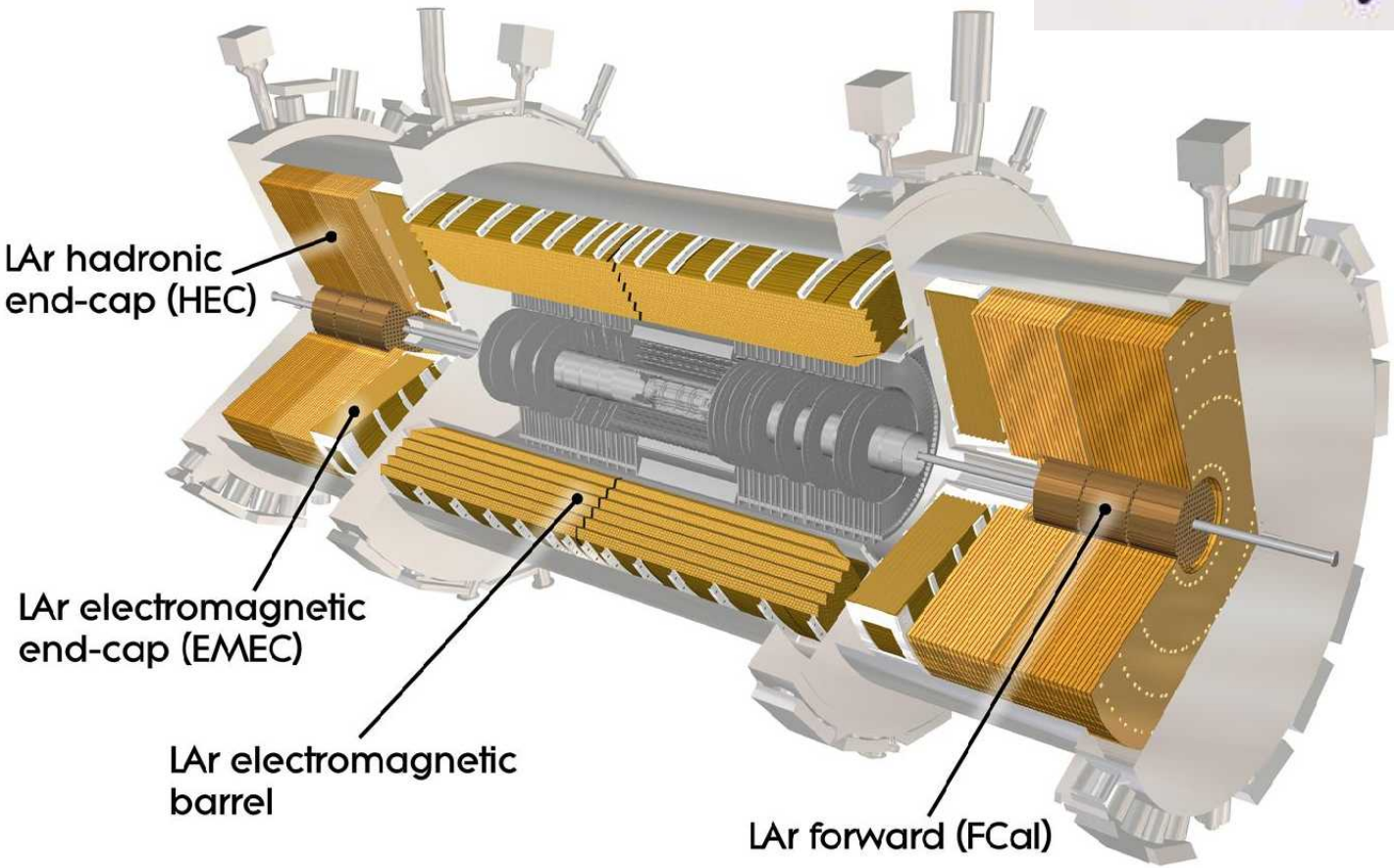
Detetores de traços



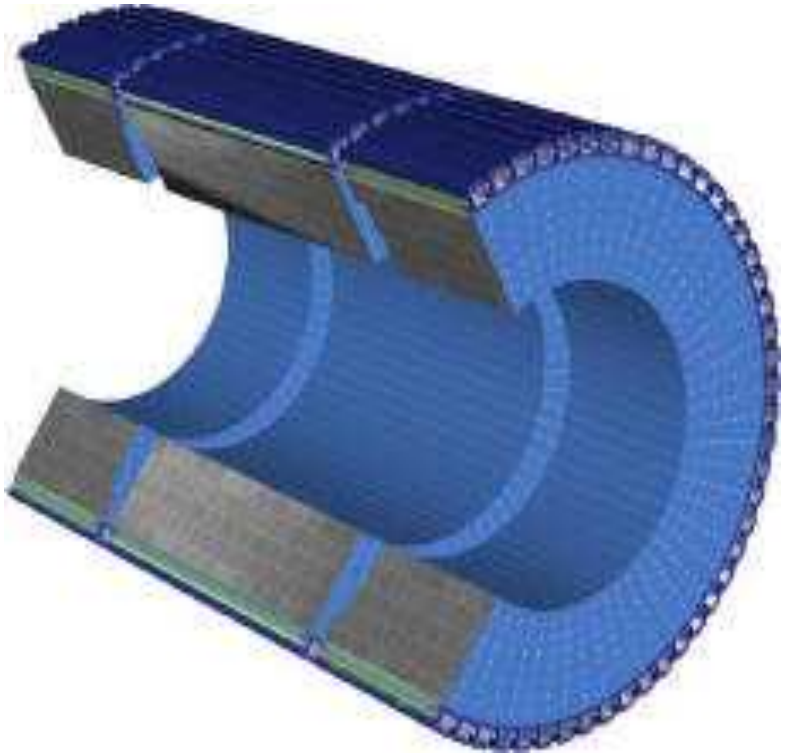
Calorímetros de Árgon Líquido



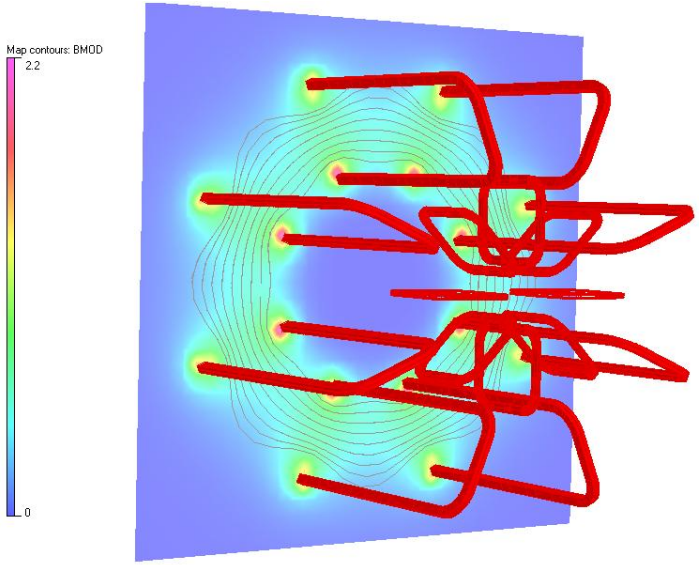
EM calorimeter: $|\eta|<3.2$
Pb-LAr Accordion
$\sigma/E = 10\%/\sqrt{E} \oplus 0.7\%$

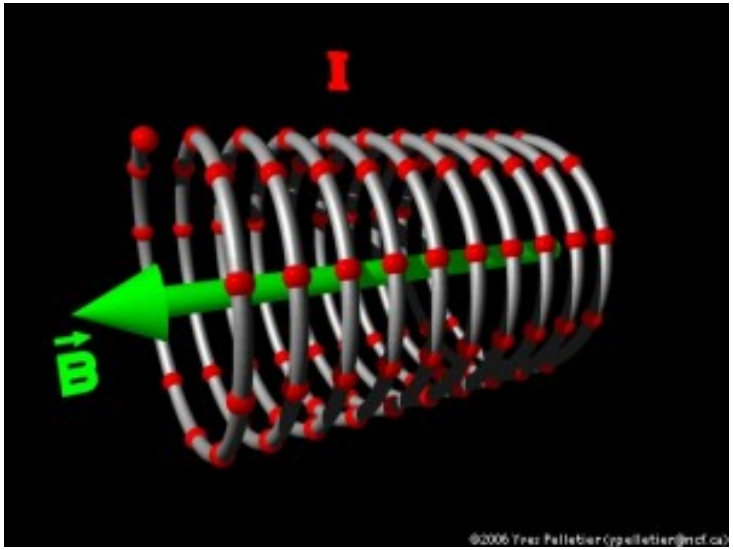


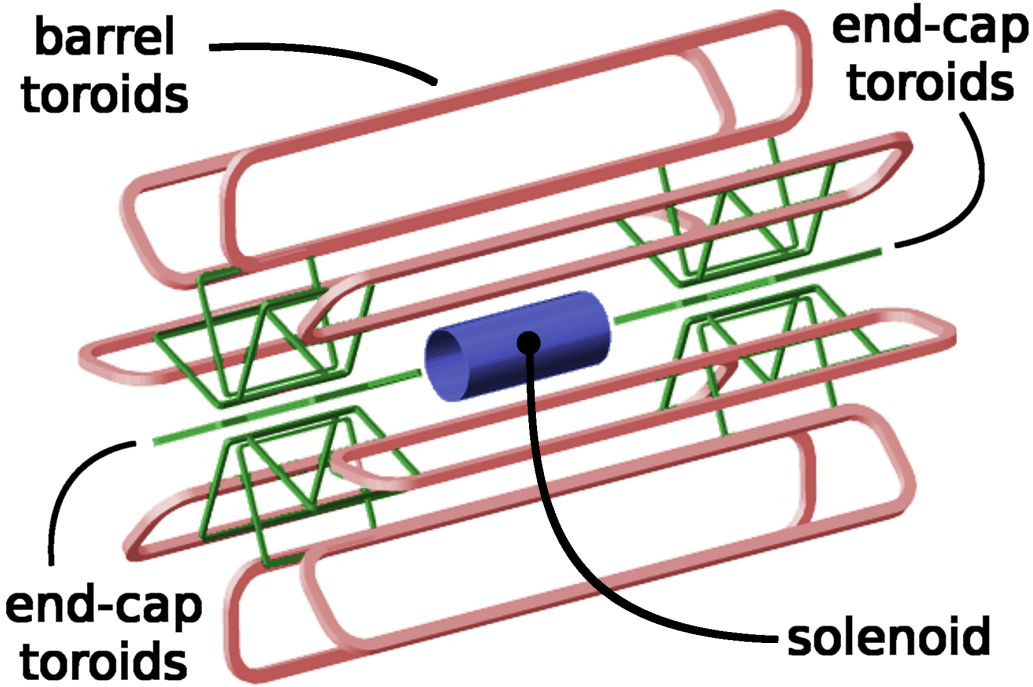
O calorímetro de telhas (TileCal)



Sistema de ímanes de ATLAS



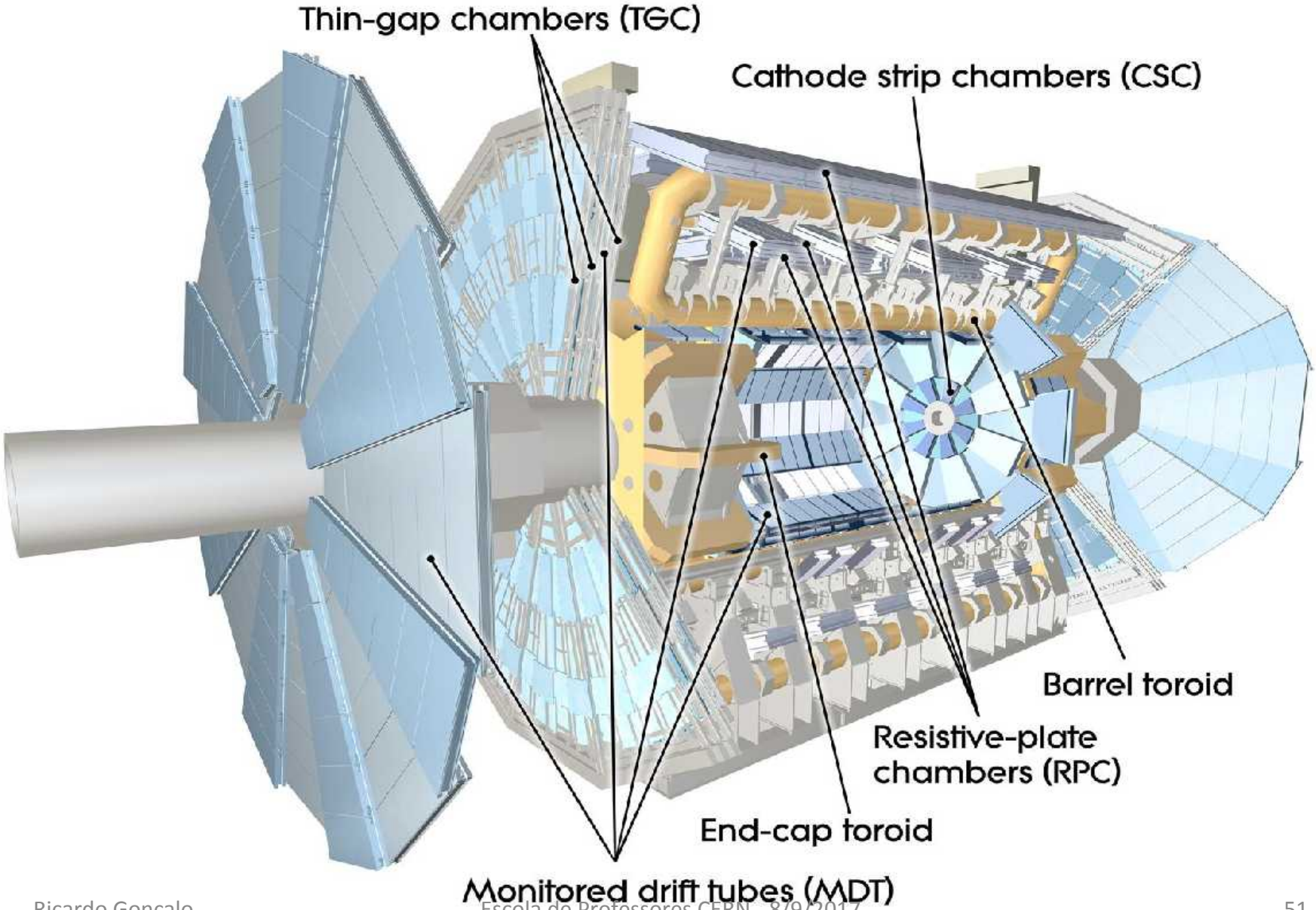




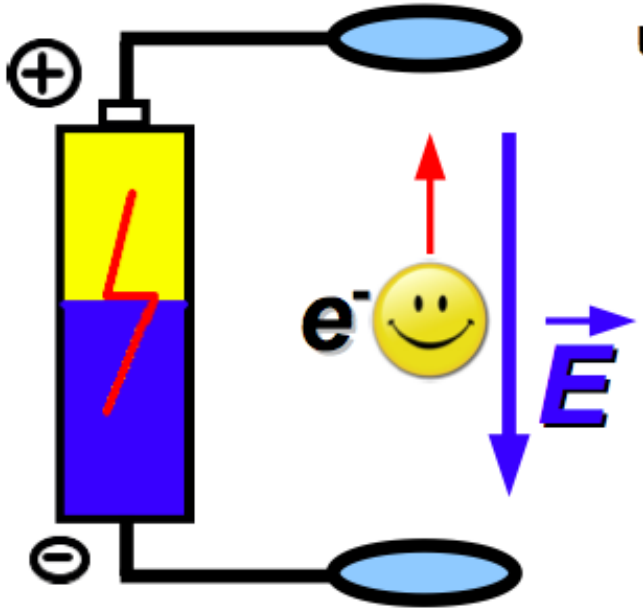
- Campos magnéticos muito intensos (2T, 4T max) gerados por ímanes supercondutores
- Curvam as partículas carregadas através da força de Lorenz:

$$\mathbf{F} = \mathbf{v} \times \mathbf{B}$$

Detetores de muões



Unidades...



- **1 electrão-volt (eV) = energia adquirida por um electrão sujeito a uma d.d.p. de 1 volt**

1 eV = 1,602 x 10^{-19} joule

Múltiplos mais comuns:

1 keV = 10^3 eV = 1000 eV

1 MeV = 10^6 eV = 1000000 eV

1 GeV = 10^9 eV = 1000000000 eV

1 TeV = 10^{12} eV = 1000000000000 eV

Massa: $E_c = ½ mv^2$ => massa em unidades de energia/(velocidade)^2

Momento linear: $\vec{p} = m\vec{v}$ => momento em unidades de energia/velocidade