



Manipulando dados com o ROOT - Parte I

Introdução à análise de dados em FAE e tecnologias associadas



objetivos

- Realizar uma análise de dados simples
 - visualizar dados
 - manipular ntuple (TTree) de dados
 - produzir, processar e exibir histogramas de dados
 - selecionar sinal de física
 - plotar distribuições cinemáticas
 - critérios de seleção
 - extrair parâmetros físicos dos dados
 - medir os yields do sinal realizando um ajuste de probabilidade (likelihood fit) aos dados
 - incertezas estatísticas e sistemáticas



Detecção, Reconstrução e Visualização de Eventos

Solenoide Compacto de Múons (CMS)

CMS DETECTOR

Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel ($100 \times 150 \mu\text{m}$) $\sim 16\text{m}^2$ $\sim 66\text{M}$ channels
Microstrips ($80 \times 180 \mu\text{m}$) $\sim 200\text{m}^2$ $\sim 9.6\text{M}$ channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying $\sim 18,000\text{A}$

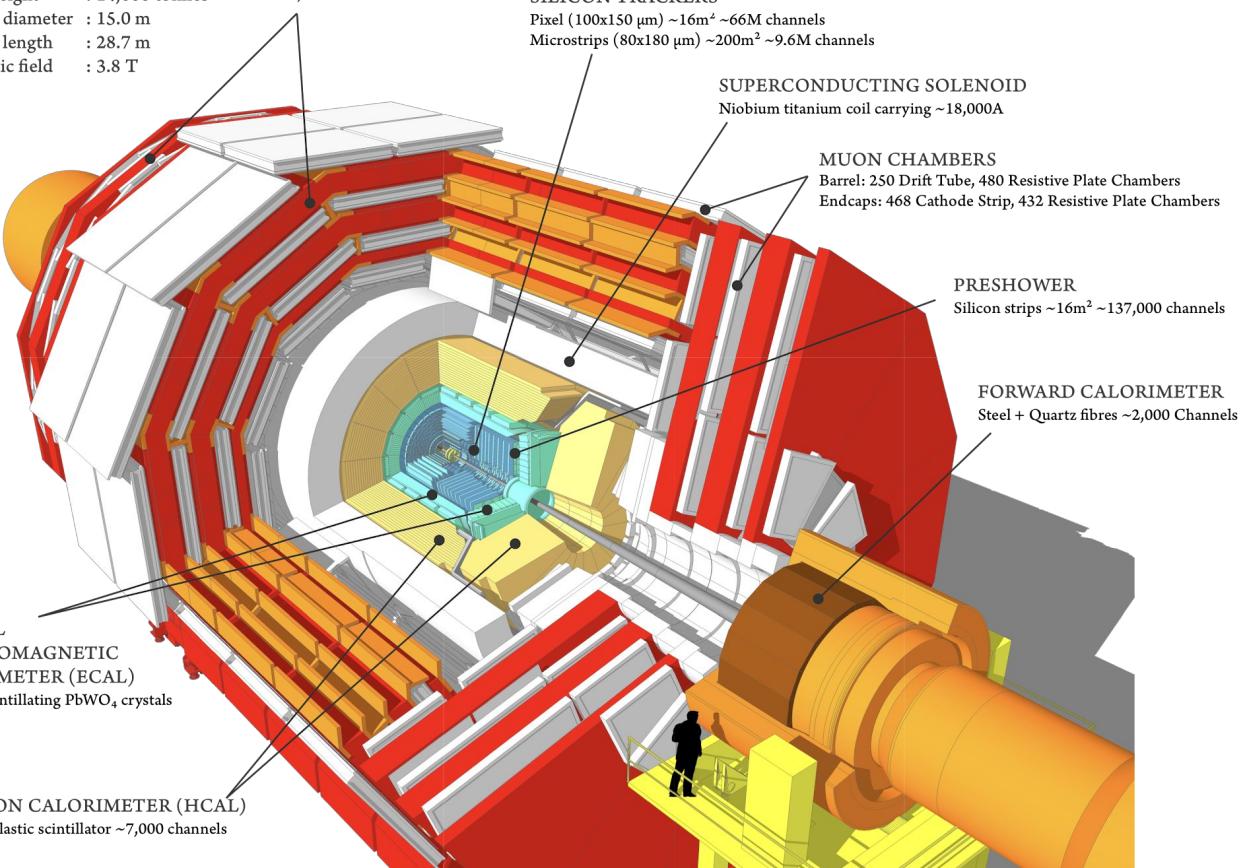
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
Silicon strips $\sim 16\text{m}^2$ $\sim 137,000$ channels

FORWARD CALORIMETER
Steel + Quartz fibres $\sim 2,000$ Channels

CRYSTAL
ELECTROMAGNETIC
CALORIMETER (ECAL)
 $\sim 76,000$ scintillating PbWO₄ crystals

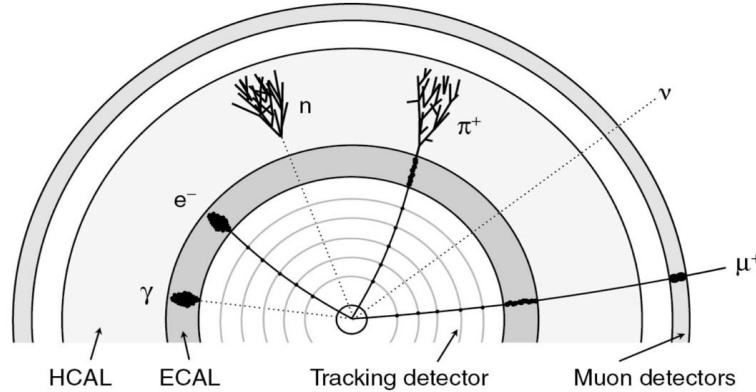
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator $\sim 7,000$ channels



identificação de partículas

Os objetos são reconstruídos usando as informações dos diferentes subsistemas do detector, combinado com o algoritmo “Particle Flow”.

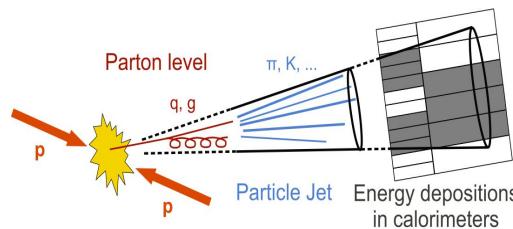
- Elétrons irradiam via freamento (Bremsstrahlung) ;
- Fótons convertem-se em pares e+e- no tracker;
- A energia dos jatos de partículas é formada de hadrons carregados/neutros (65%/10%) e fótons(25%): a informação é explorada no calorímetro e no tracker;
- A energia transversa faltante(missing E_T) requer a reconstrução total do evento.



calorímetros:
mede a energia das partículas absorvendo-as

trackers:
detecta a trajetória das partículas carregadas

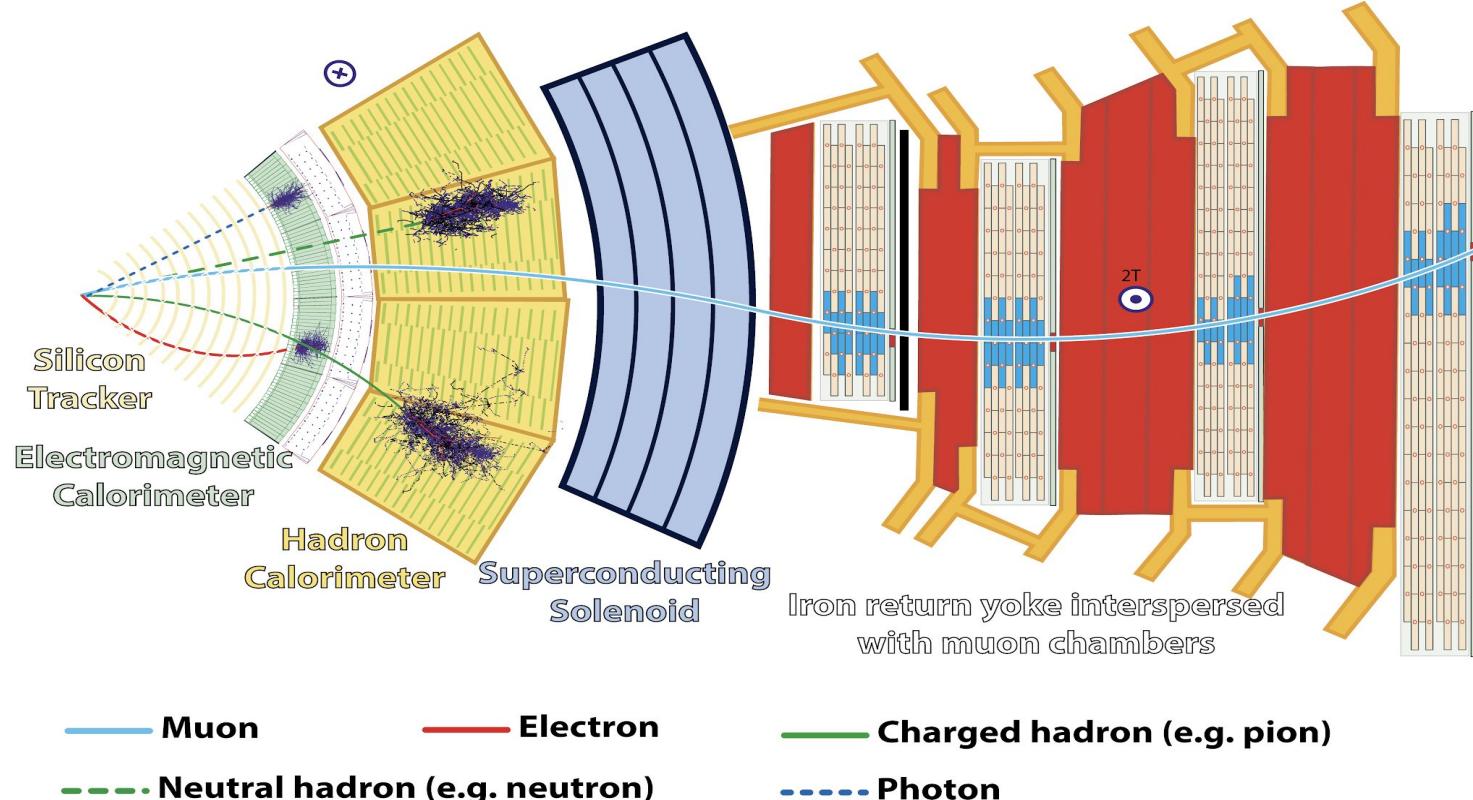
múons:
detectados em camadas mais externas do detector

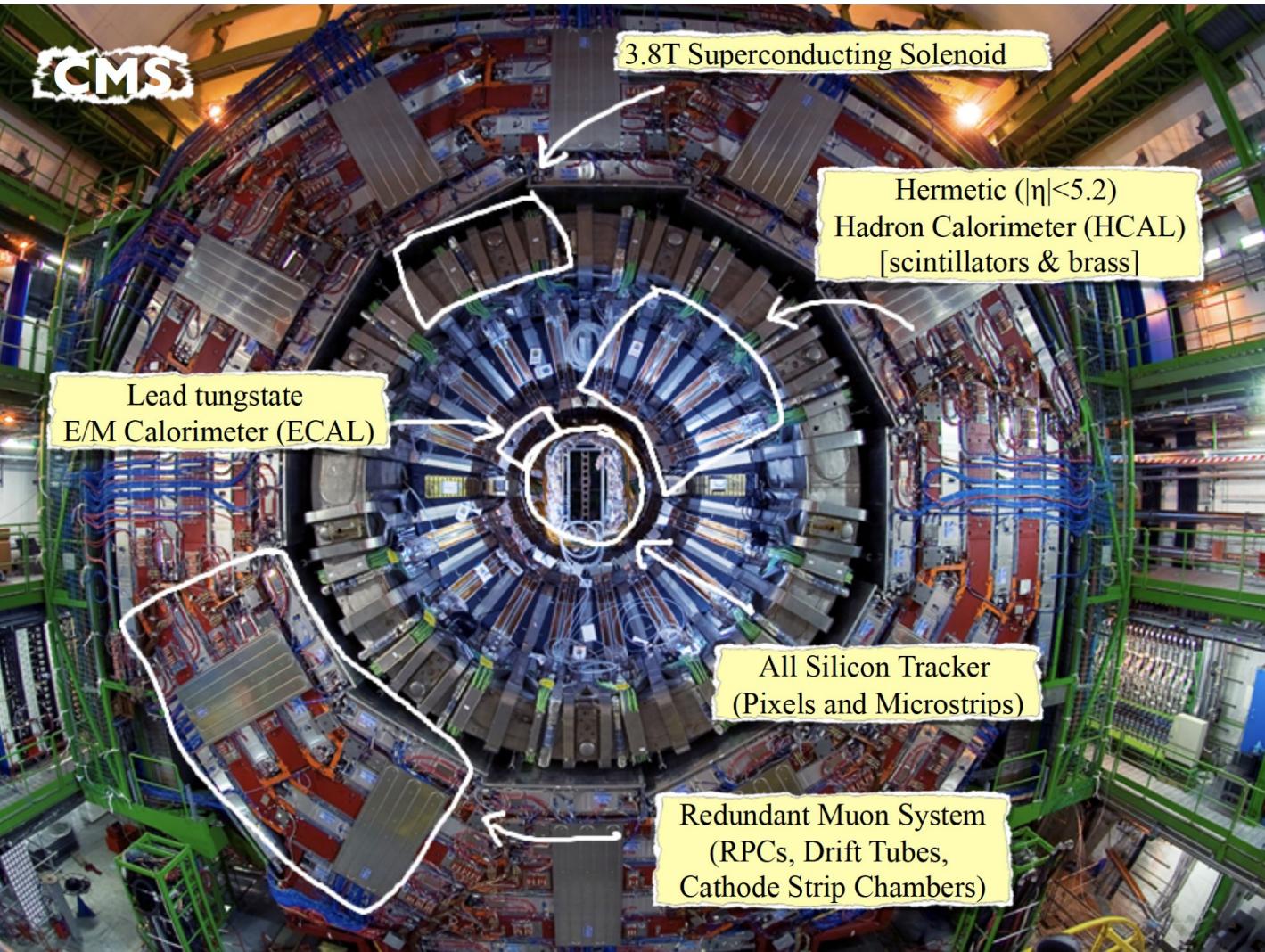


$$\rho = \frac{p}{ZeB}$$

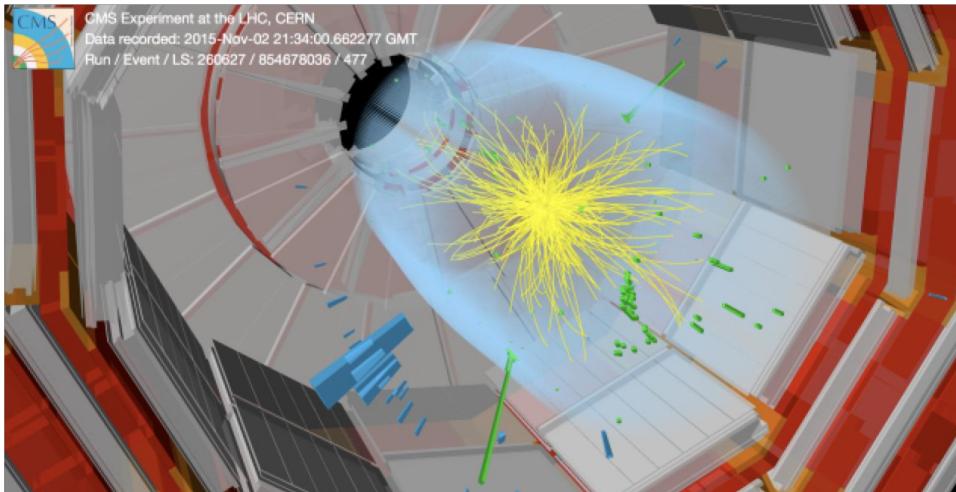
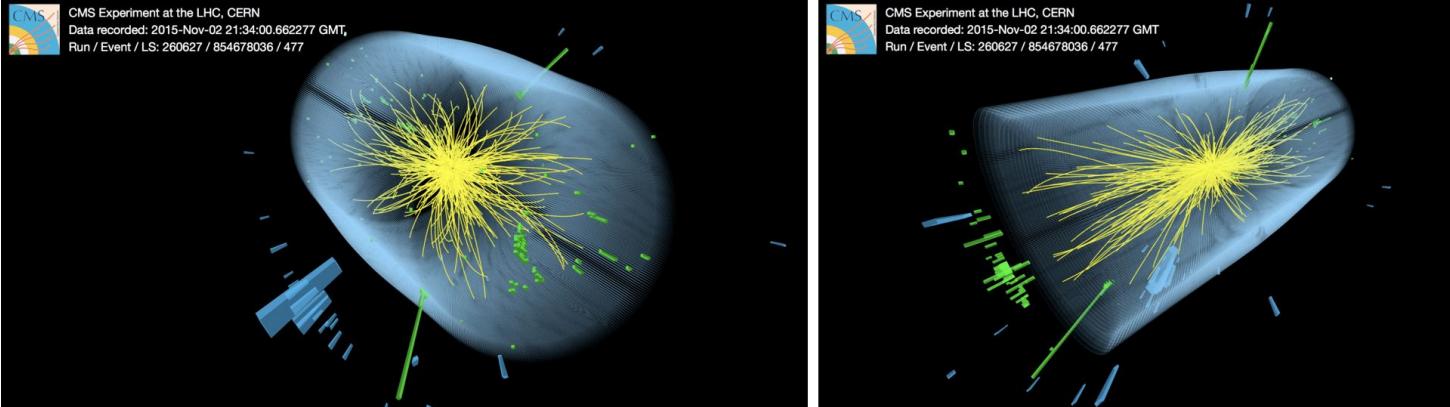
$$\rho \quad \odot B$$

A diferença em massa, carga e interação é a chave da identificação.



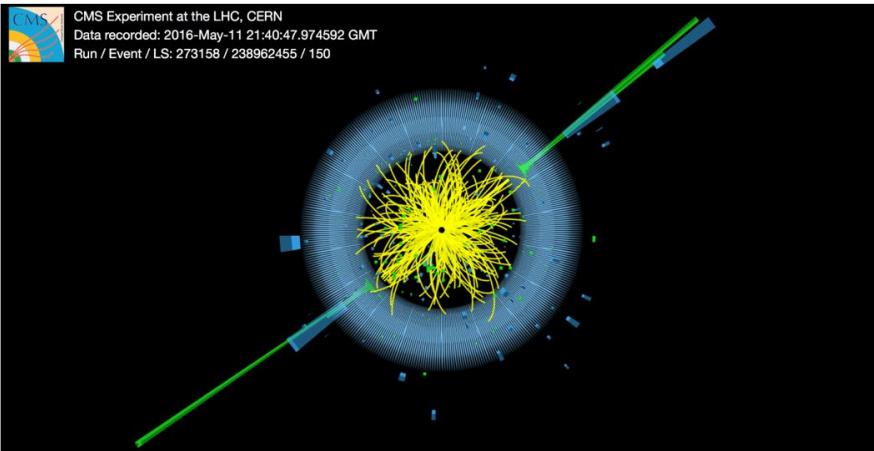
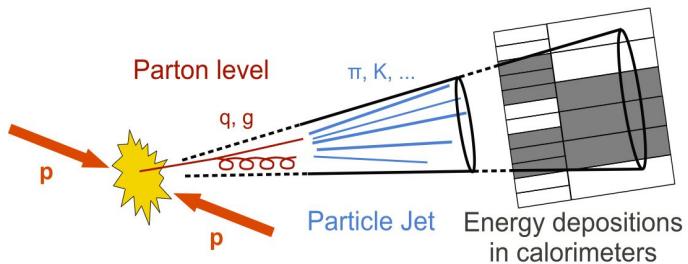
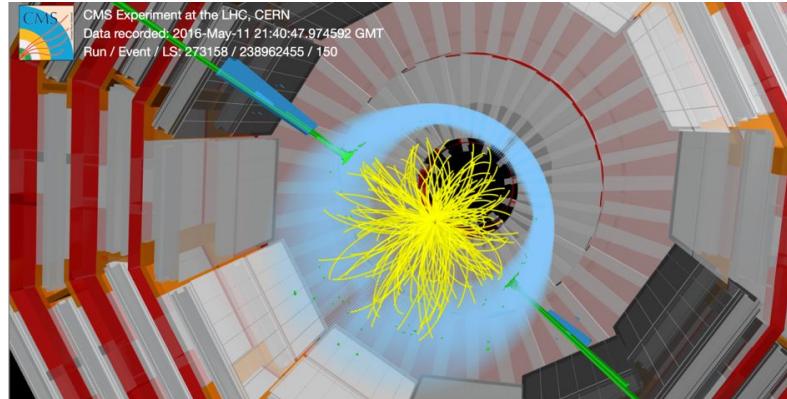
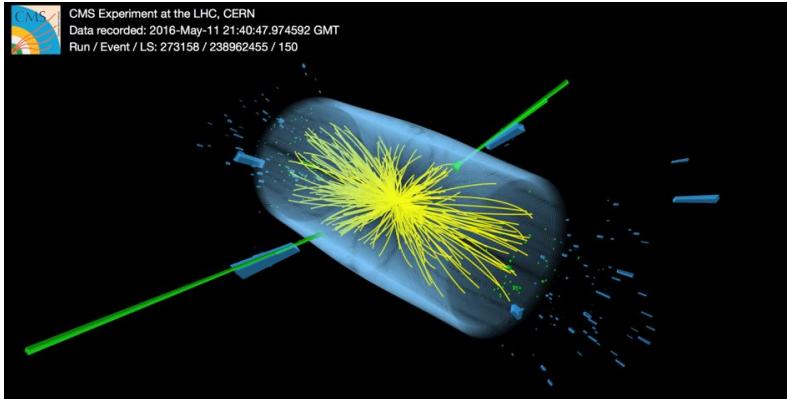


eventos de difótons ($X \rightarrow \gamma\gamma$)

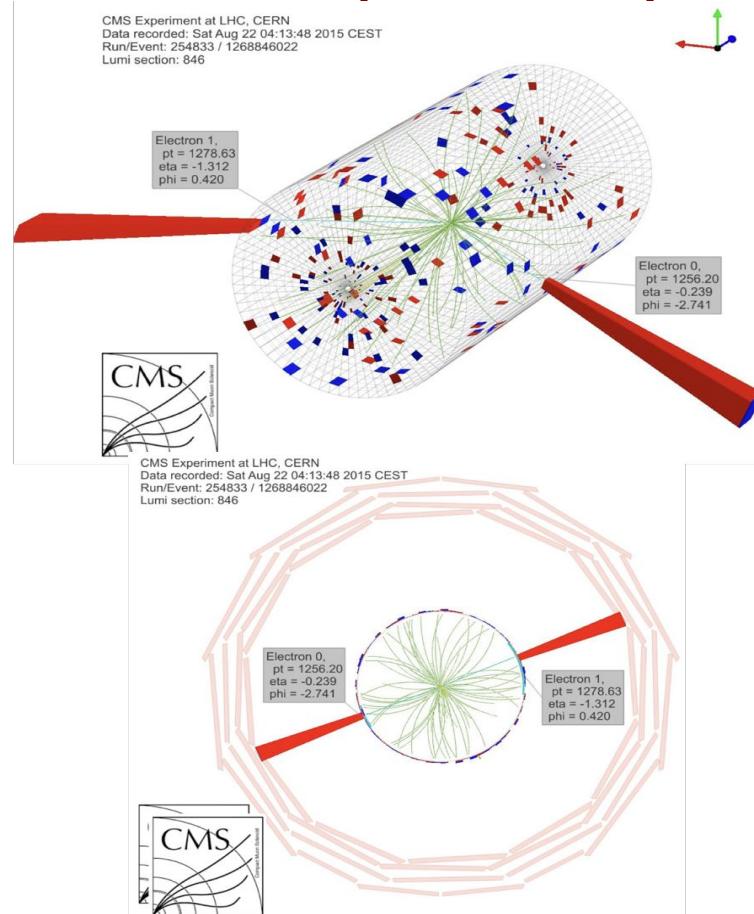
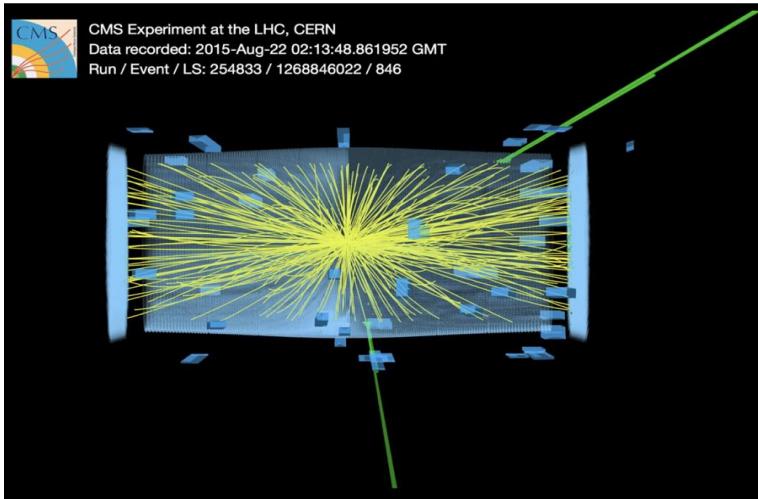


[OpenData](#)
[iSpy WebGL](#)

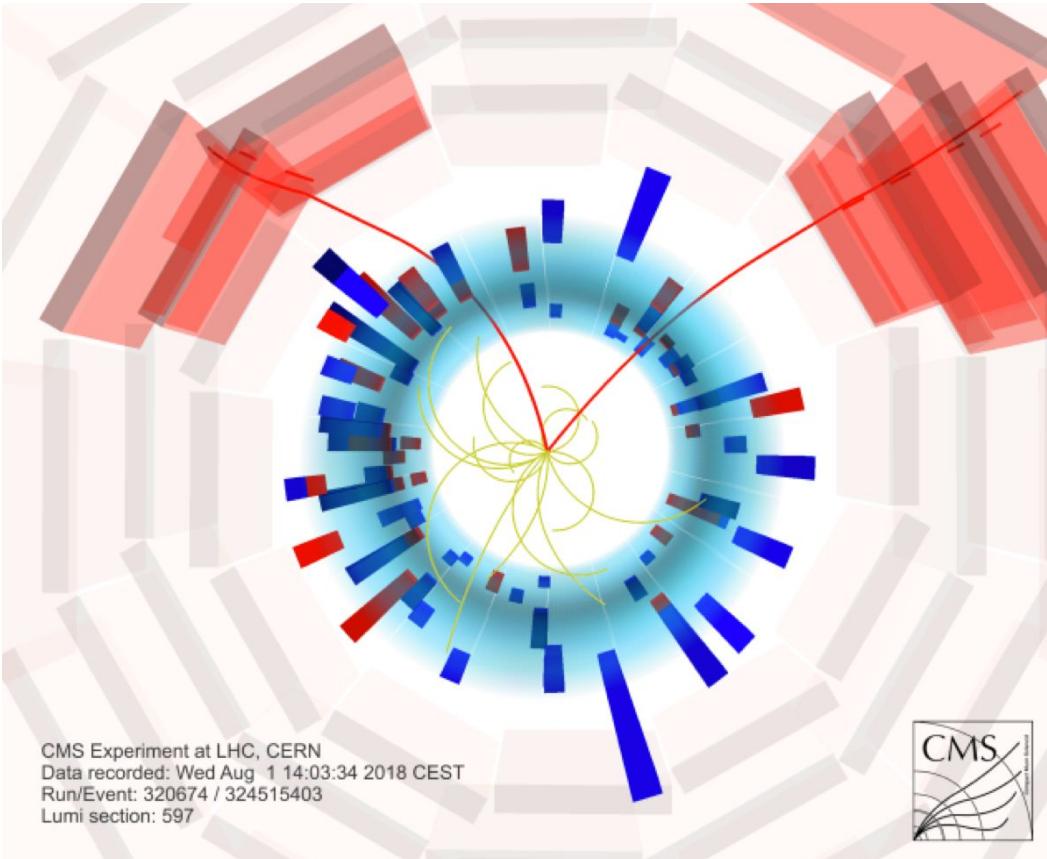
eventos de dijetos ($x \rightarrow jj$)



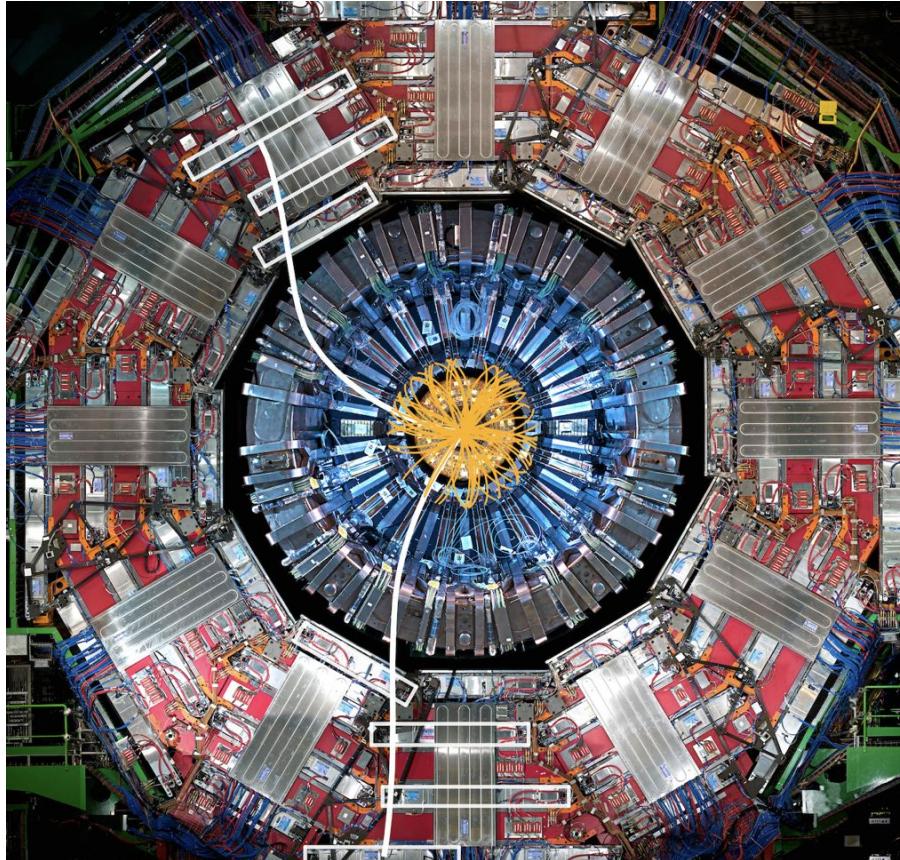
eventos de di-elétrons ($\chi \rightarrow ee$)



eventos de dimúons ($x \rightarrow \mu\mu$)

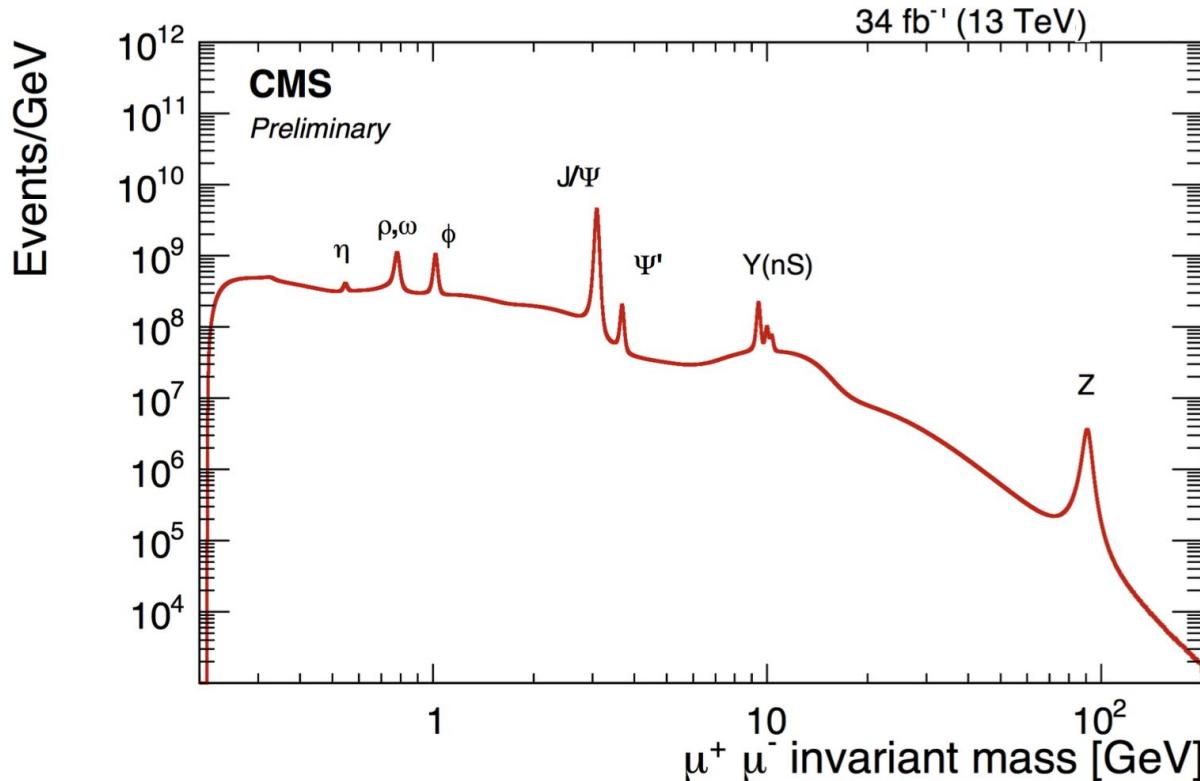


Análise de eventos de dimúons

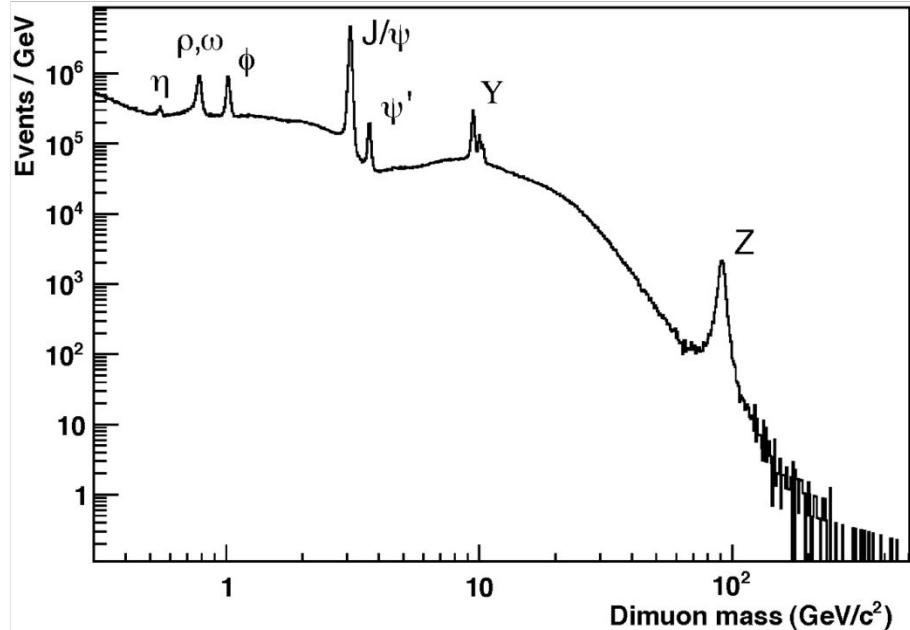
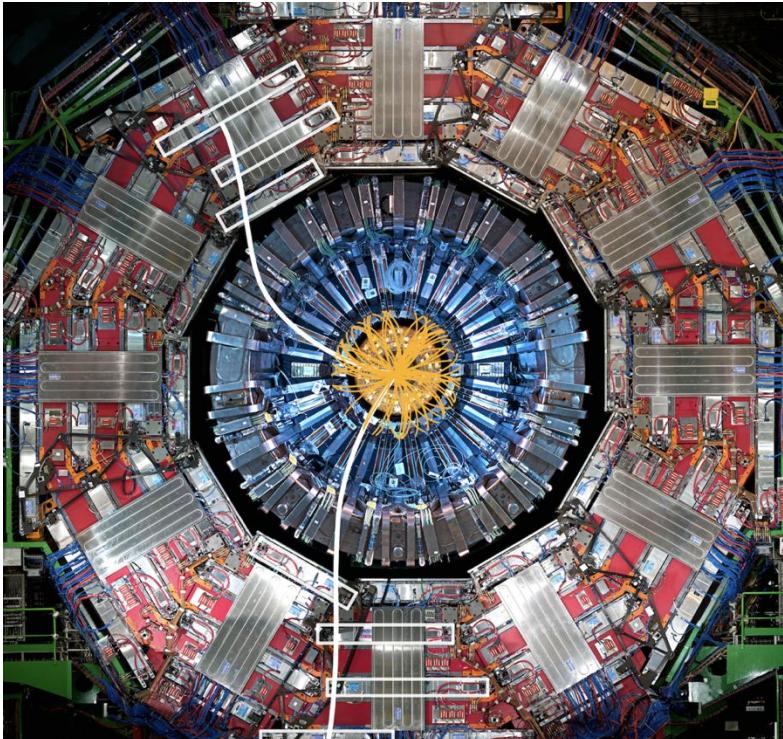


o espetro de dimuon ($\chi \rightarrow \mu^+ \mu^-$)

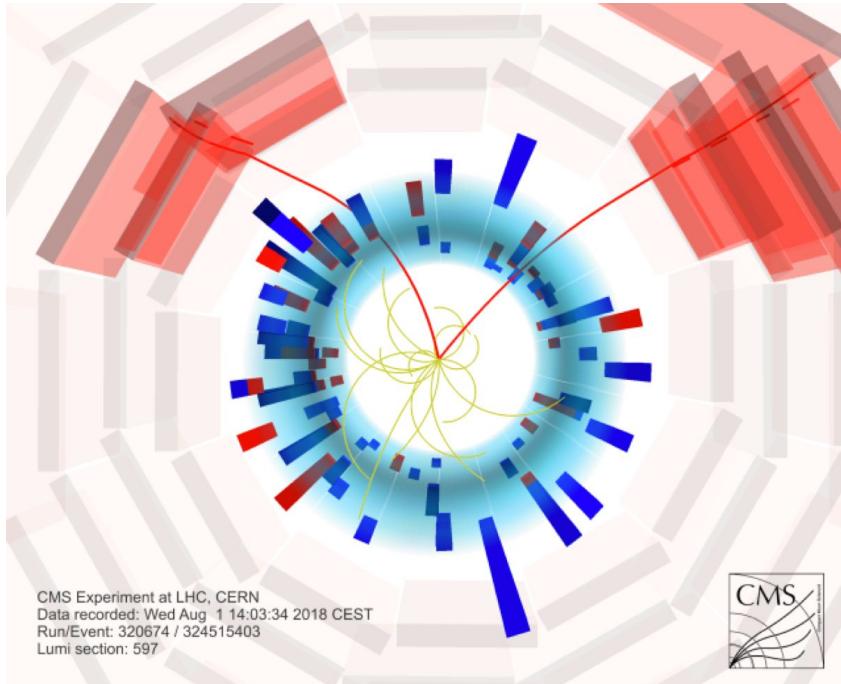
Décadas de descobertas em física de partículas... em um único gráfico!



como saímos do detector para a física ...



massa invariante de dimúons



identificação de partículas

- sinal nas câmaras de múons
→ é um múon!
- ⇒ $m = m(\mu) \sim 106 \text{ MeV}/c^2$

trajetória da partícula

- câmaras de múons, mas especialmente o silicon tracker
- ⇒ momentum linear , $\vec{p} = (p_x, p_y, p_z)$

⇒ 4-momentum de cada múon: $\vec{P} =$

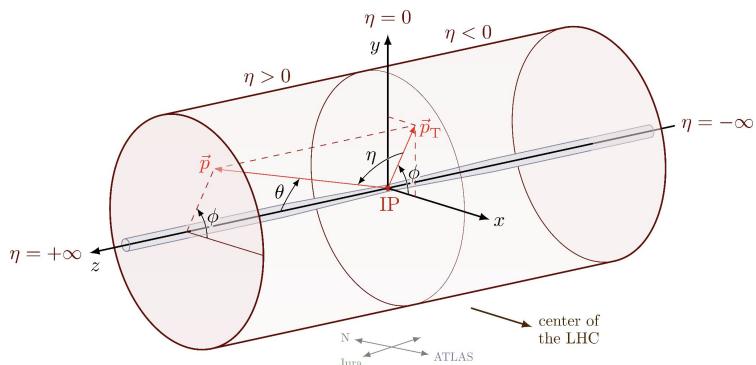
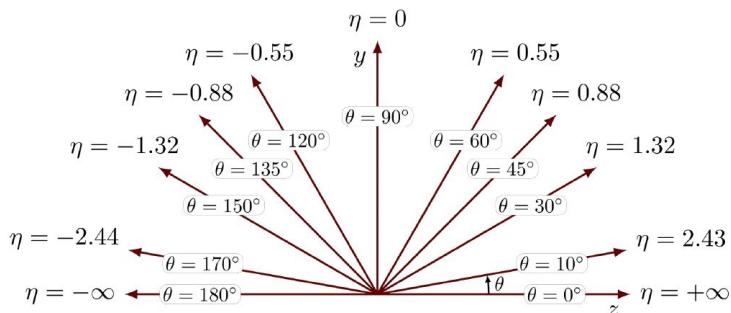
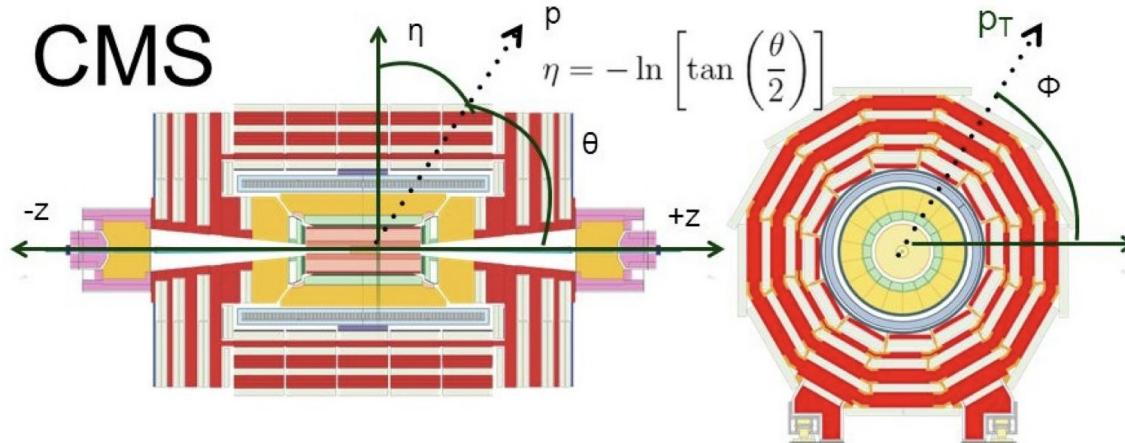
(E, p_x, p_y, p_z) ou $\vec{P} = (p_T, \eta, \phi, M)$ para $E \gg m$

⇒ para o par de dimuon: $\vec{P}_{\mu\mu} = \vec{P}_{\mu_1} + \vec{P}_{\mu_2}$

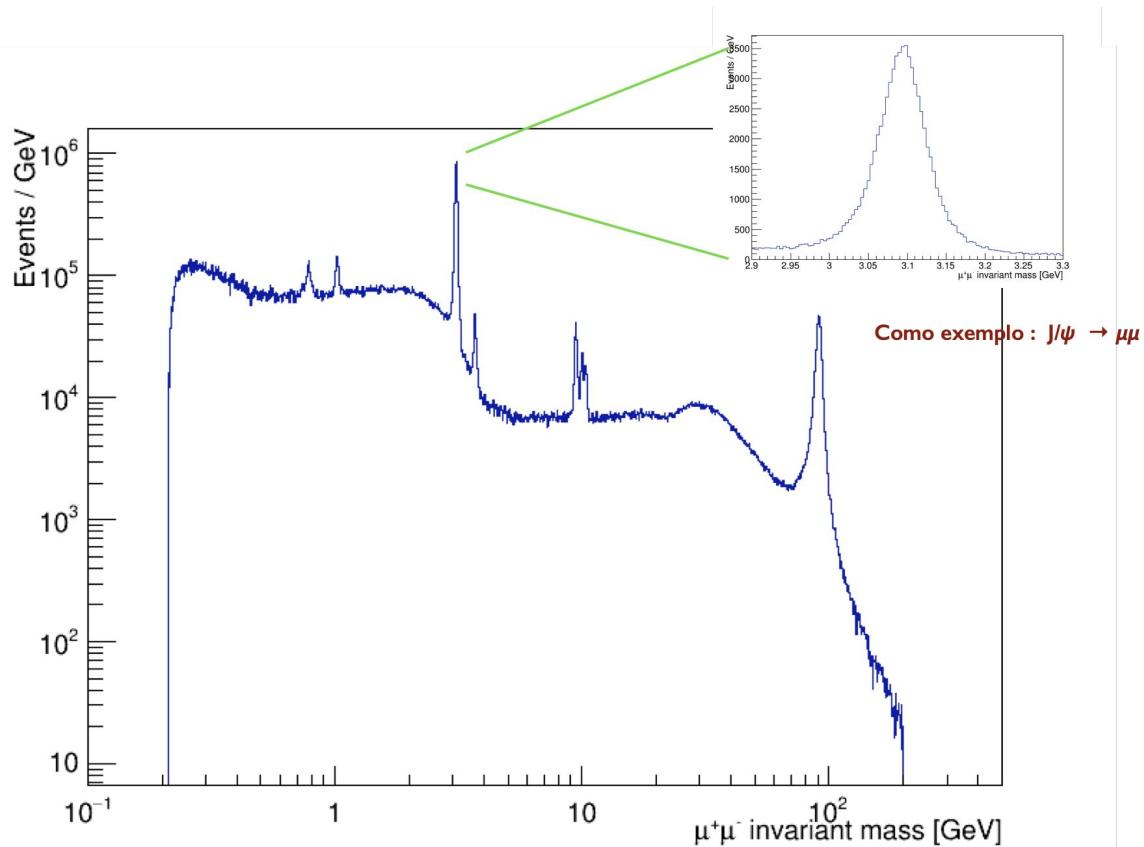
⇒ massa invariante: $M_{\mu\mu} = (\vec{P}_{\mu_1} + \vec{P}_{\mu_2})^2$

outras variáveis

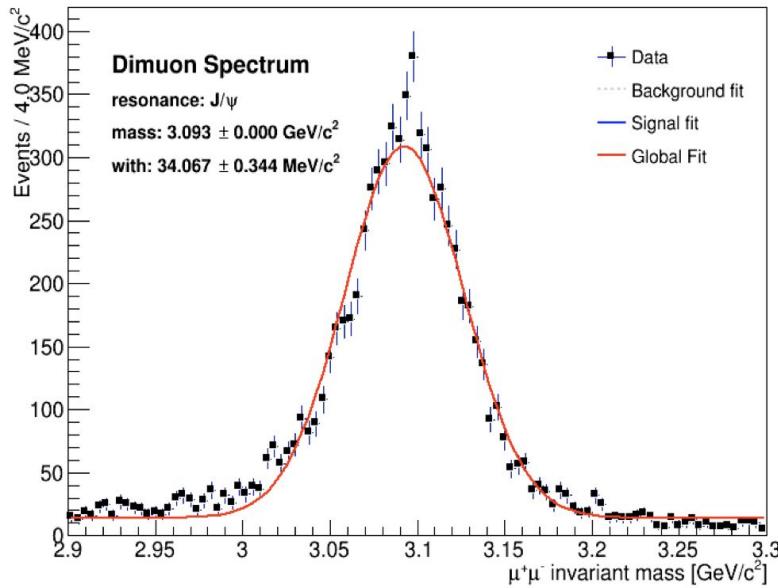
CMS



o espectro do dimuon reconstruído



ajuste aos dados



Inspeção da qualidade do ajuste
o ajuste pode ser melhorado?
dica: a radiação do estado final
($\mu \rightarrow \mu\gamma$) pode distorcer a forma.

Passos:

Estabelecer um modelo de ajuste

sinal: gaussiana

fundo: polinomial

Extrair parâmetros do sinal

yields ($N \pm \sigma_N$), massa ($m \pm \sigma_m$)

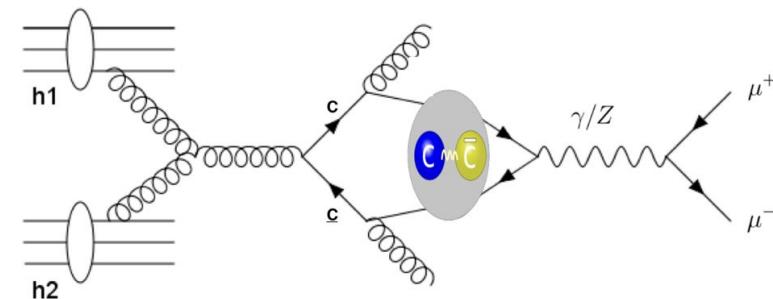
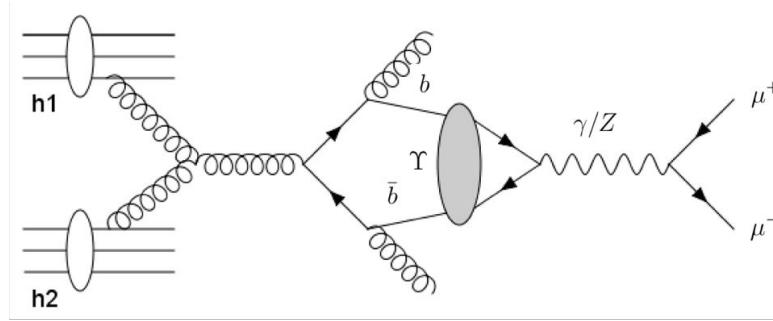
Estimar as incertezas sistemáticos

a escolha do modelo afeta os resultados
medidos?

quantificar as variações sistemáticas
empregando diferentes modelos

Apresentar as medidas finais ($N \pm \sigma_{\text{esta}} \pm \sigma_{\text{sis}}$)

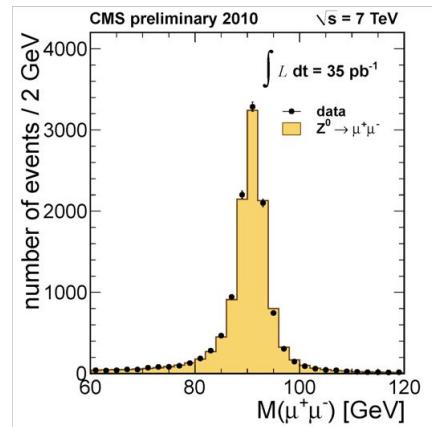
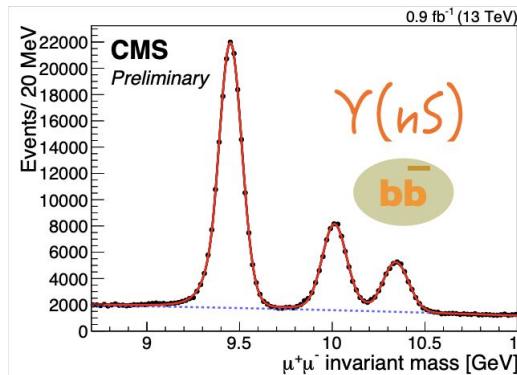
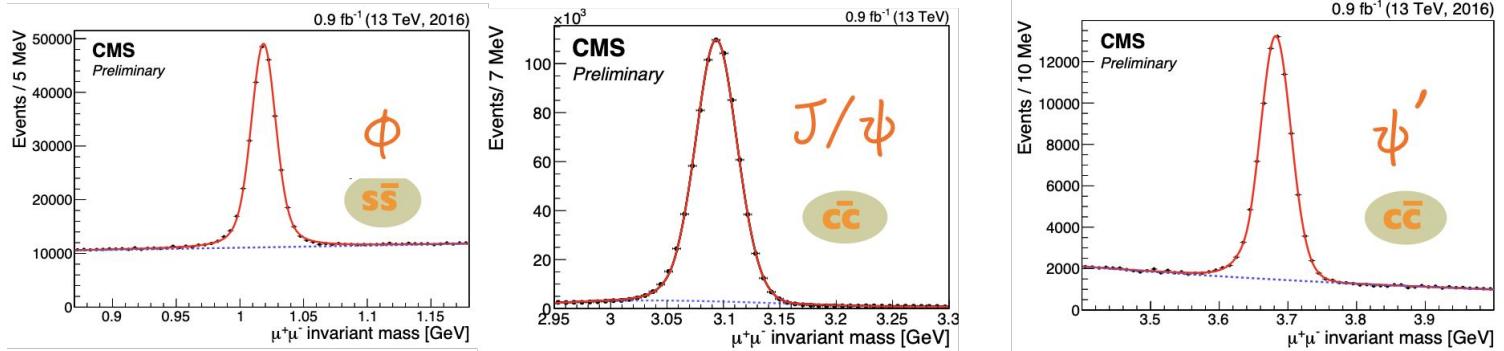
qual é o processo físico?



production: strong force

decay: electroweak force

o que são os picos?



suas propriedades podem ser consultadas aqui: <https://pdglive.lbl.gov/Viewer.action>

informações no pdg

Z $J=1$

See related reviews:

- Z Boson
- Anomalous ZZ γ , Z $\gamma\gamma$, and ZZV Couplings
- Anomalous W/Z Quartic Couplings (QGCs)

► Expand all sections

Z MASS	91.1876 ± 0.0021 GeV
Z WIDTH	2.4955 ± 0.0023 GeV
► AVERAGE PARTICLE MULTIPICITIES IN HADRONIC Z DECAY	
Z HADRONIC POLE CROSS SECTION	41.4802 ± 0.0325 nb

1

55. Z Boson

55. Z Boson

Revised August 2018 by M. Grünwald (University Coll. Dublin) and A. Gurtu (CERN; TIFR Mumbai).

Precision measurements at the Z-boson resonance using electron–positron colliding beams began in 1989 at the SLC and at LEP. During 1989–95, the four LEP experiments (ALEPH, DELPHI, L3, OPAL) made high-statistics studies of the production and decay properties of the Z. Although the SLD experiment at the SLC collected much lower statistics, it was able to match the precision of LEP experiments in determining the effective electroweak mixing angle $\sin^2\theta_W$ and the rates of Z decay to b- and c-quarks, owing to availability of polarized electron beams, small beam size, and stable beam spot.

The Z-boson properties reported in this section may broadly be categorized as:

- The standard ‘lineshape’ parameters of the Z consisting of its mass, M_Z , its total width, Γ_Z , and its partial decay widths, $\Gamma(\text{hadrons})$, and $\Gamma(\ell\ell)$ where $\ell = e, \mu, \tau, \nu$;
- Z asymmetries in leptonic decays and extraction of Z couplings to charged and neutral leptons;
- The b- and c-quark-related partial widths and charge asymmetries which require special techniques;
- Determination of Z decay modes and the search for modes that violate known conservation laws;
- Average particle multiplicities in hadronic Z decay;
- Z anomalous couplings.

**c \bar{c} MESONS
(including possibly non- q \bar{q} states)**

PDGID:M071 JSON (beta) INSPIRE Q

$\psi(2S)$ $I^G(J^{PC}) = 0^-(1^{--})$

See the Review on “ $\psi(2S)$ and χ_c branching ratios” before the $\chi_{c0}(1P)$ Listings.

► Expand all sections

$\psi(2S)$ MASS	3686.10 ± 0.06 MeV (S = 5.9)
$m_{\psi(2S)} - m_{J/\psi(1S)}$	589.188 ± 0.028 MeV
$\psi(2S)$ WIDTH	294 ± 8 keV

► MULTIPOLE AMPLITUDE RATIOS IN RADIATIVE DECAYS $\psi(2S) \rightarrow \gamma \chi_{cJ}(1P)$ and $\chi_{cJ} \rightarrow \gamma J/\psi(1S)$

**c \bar{c} MESONS
(including possibly non- q \bar{q} states)**

PDGID:M070 JSON (beta) INSPIRE Q

$J/\psi(1S)$ $I^G(J^{PC}) = 0^-(1^{--})$

$J/\psi(1S)$ MASS 3096.900 ± 0.006 MeV

$J/\psi(1S)$ WIDTH 92.6 ± 1.7 keV (S = 1.1)

► Collapse all decays

$J/\psi(1S)$ DECAY MODES

Mode	Fraction (Γ_i / Γ)	Scale Factor/ Conf. Level	P(MeV/c)
Γ_1 hadrons	(87.7 ± 0.5)%		
Γ_2 virtual $\gamma \rightarrow$ hadrons	(13.50 ± 0.30)%		
Γ_3 ggg	(64.1 ± 1.0)%		
Γ_4 γgg	(8.8 ± 1.1)%		
Γ_5 $e^+ e^-$	(5.971 ± 0.032)%		1548
Γ_6 $e^+ e^- \gamma$	(8.8 ± 1.4) × 10 ⁻³		1548

a seção de choque

A área efetiva de interação
unidade: barn, $1b = 10^{-28} m^2 = 100 fm^2$

$$\frac{d^2\sigma(q\bar{q})}{dp_T dy} \mathcal{B}(q\bar{q} \rightarrow \mu^+ \mu^-) = \frac{N_{fit}(q\bar{q})}{\mathcal{L} \cdot \mathcal{A} \cdot \epsilon \cdot \Delta p_T \cdot \Delta y}$$

- N : yield do sinal ajustado
- A : aceitação do detector obtida por simulação
- ϵ : eficiências de reconstrução e trigger do detector (simulação ou baseada em dados)
- L : luminosidade integrada da amostra

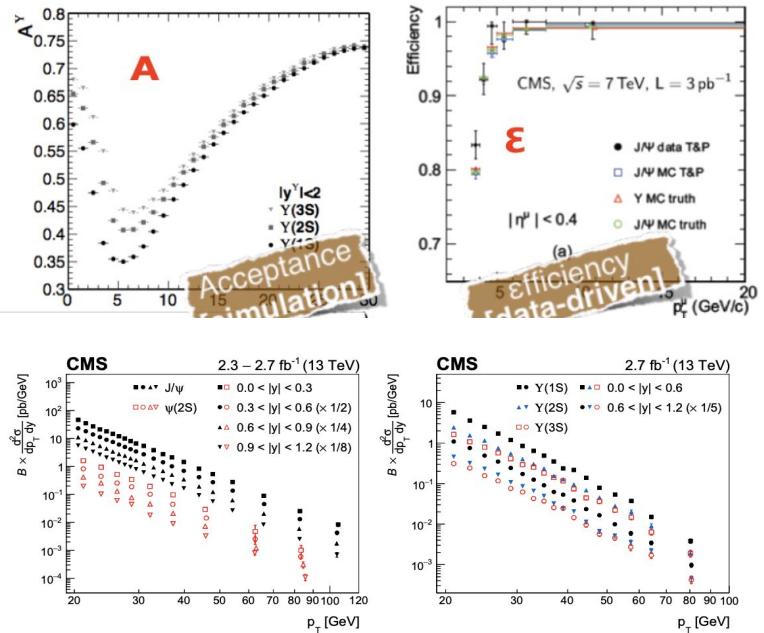
$$N = L \cdot \sigma$$

$$L = \frac{k N^2 f \gamma}{4\pi \beta^* \epsilon} \cdot F$$

N..... No. particles per bunch
 k..... No. bunches
 f..... revolution freq.
 g..... rel. gamma
 β^* beta-function at IPs
 ϵ norm. trans. emit

$$\sigma = \frac{N}{L}$$

A equação expressa a seção de choque diferencial em termos da quantidade de eventos observados, ajustados pela luminosidade, aceitação do detector, eficiência de detecção e os intervalos de espaço de fase considerados.



Exemplo





configurações

Inicie o ROOT:

```
$root -l  
$root[ ]
```

Verifique e carregue (relembrando das aulas sobre o ROOT):

```
root [ ] .!pwd  
/Users/eliza/Analise-Dados-FAE/2024_02/analise-dados-partel  
root [ ] .!ls  
DataSkim4.root anadimuon.h      anadimuons.C  
root [ ] .!mkdir plots  
root [ ] .!ls  
DataSkim4.root anadimuon.h      anadimuons.C plots
```

inspeção do conjunto de dados

```

root [0] TFile f("DataSkim4.root")
(TFile &) Name: DataSkim4.root Title:
root [4] gDirectory->ls()
TFile**      DataSkim4.root
TFile*       DataSkim4.root
KEY:TTree   oniaTree;      Tree of Onia2MuMu
root [6] oniaTree->Show(0)
=====> EVENT:0
event        = 32559317
dimuon_p4    = (TLorentzVector*)0x7f83e81f9c50
muonP_p4     = (TLorentzVector*)0x7f83e81f9f60
muonN_p4     = (TLorentzVector*)0x7f83e81fafb0

```

esses são os 4-momenta \mathbf{P} das partículas

```

root [7] oniaTree->Draw("dimuon_p4.M()")
Info in <TCanvas::MakeDefCanvas>: created default TCanvas with name c1

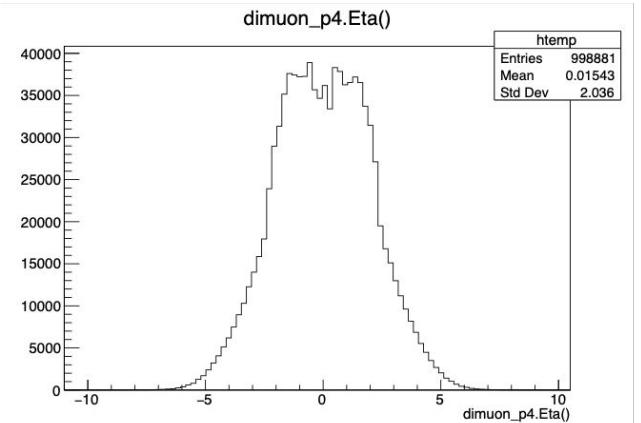
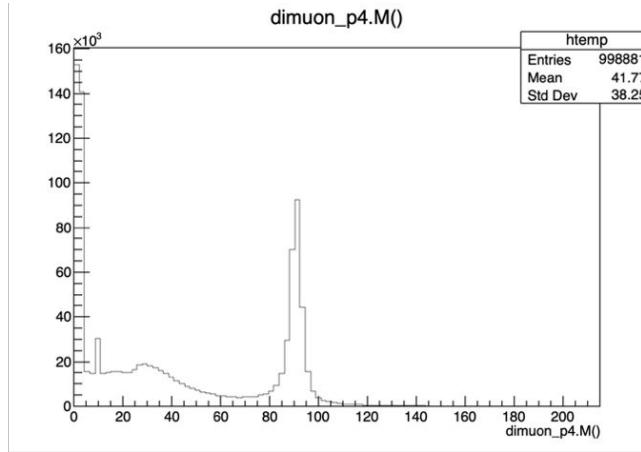
```

massa invariante: dimuon_p4.M()

```

root [2] oniaTree->Draw("dimuon_p4.Eta()")
Info in <TCanvas::MakeDefCanvas>: created default TCanvas with name c1

```



distribuições cinemáticas

```
root [] oniaTree->Draw("dimuon_p4.Pt()")
```

```
root [] oniaTree->Draw("dimuon_p4.Pt()>>hptz(500,0,100)","dimuon_p4.M()>70")
```

```
root [] oniaTree->Draw("dimuon_p4.Pt()>>hptj","dimuon_p4.M()>3.0&&dimuon_p4.M()<3.2")
```

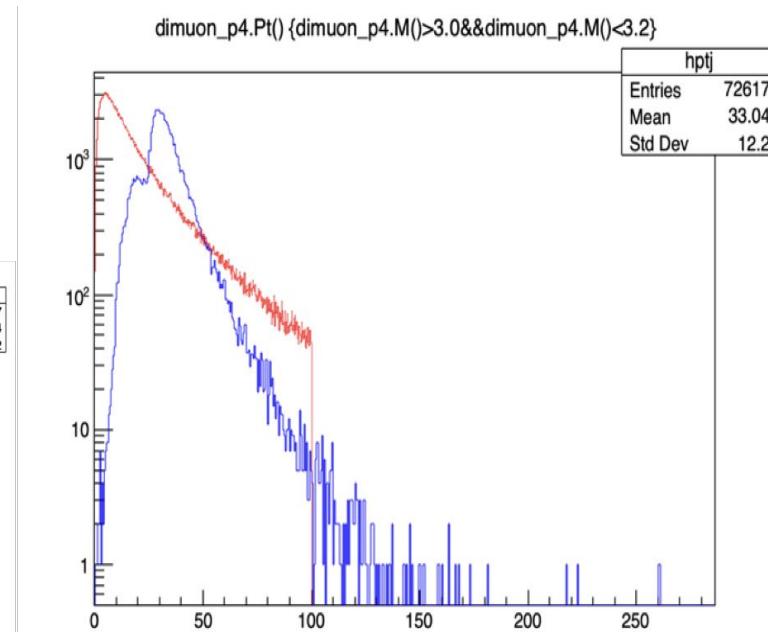
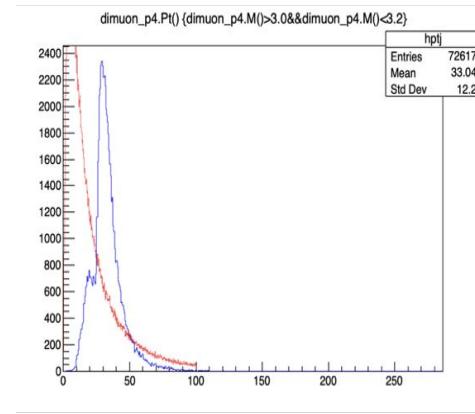
```
root [] hptz->SetLineColor(kRed)
```

```
root [] hptj->SetLineColor(kBlue)
```

```
root [] hptz->Draw("same")
```

```
root [] hptj->Draw("same")
```

```
root [] .q
```





o código

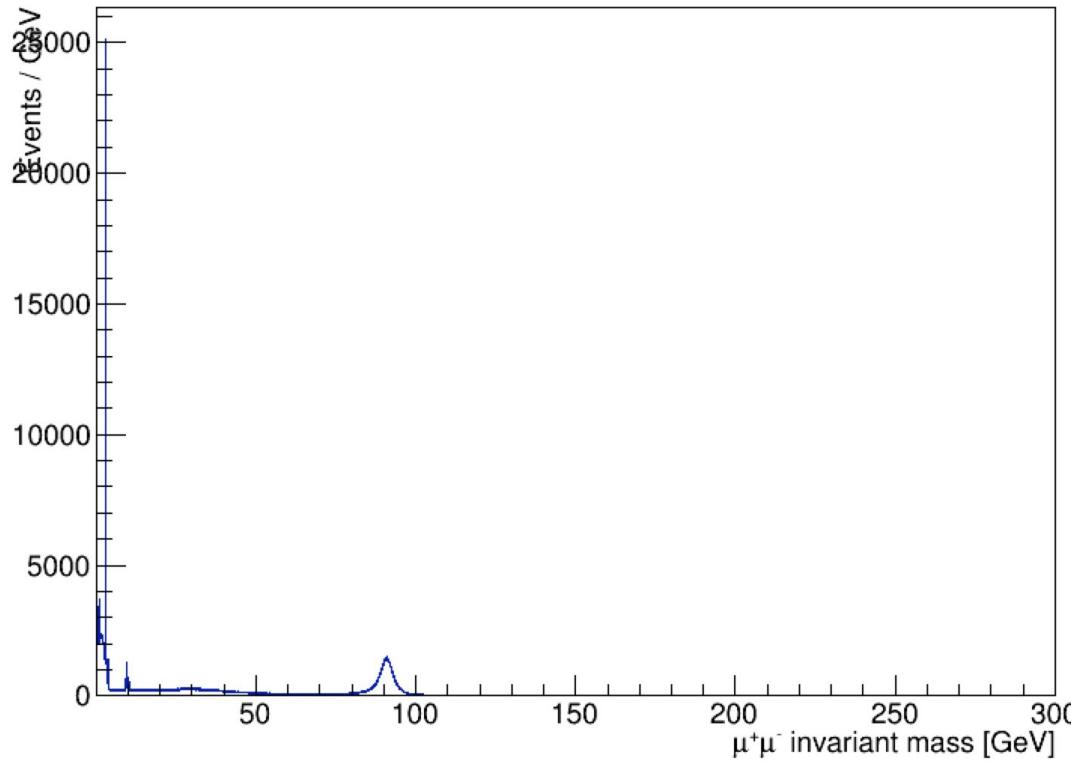
Métodos principais:

- **GetSpectrum()**: cria o espectro de massa de dimuon a partir do conjunto de dados brutos
- **Cut()**: permite aplicar cortes de seleção
- **SelectPeak()**: permite selecionar um dos sinais do espectro
- **FitPeakRoofit()**: ajusta os dados e extrai os parâmetros do sinal

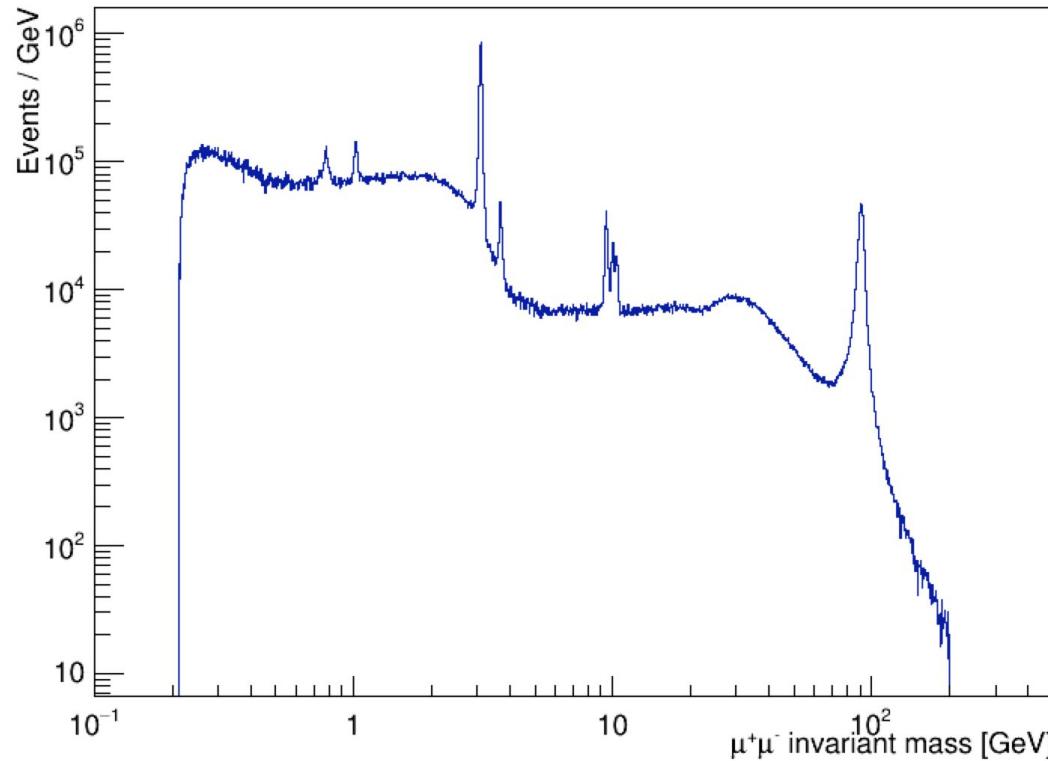
```
$root -l -b -q anadimuons.C++
```

```
$ls plots
```

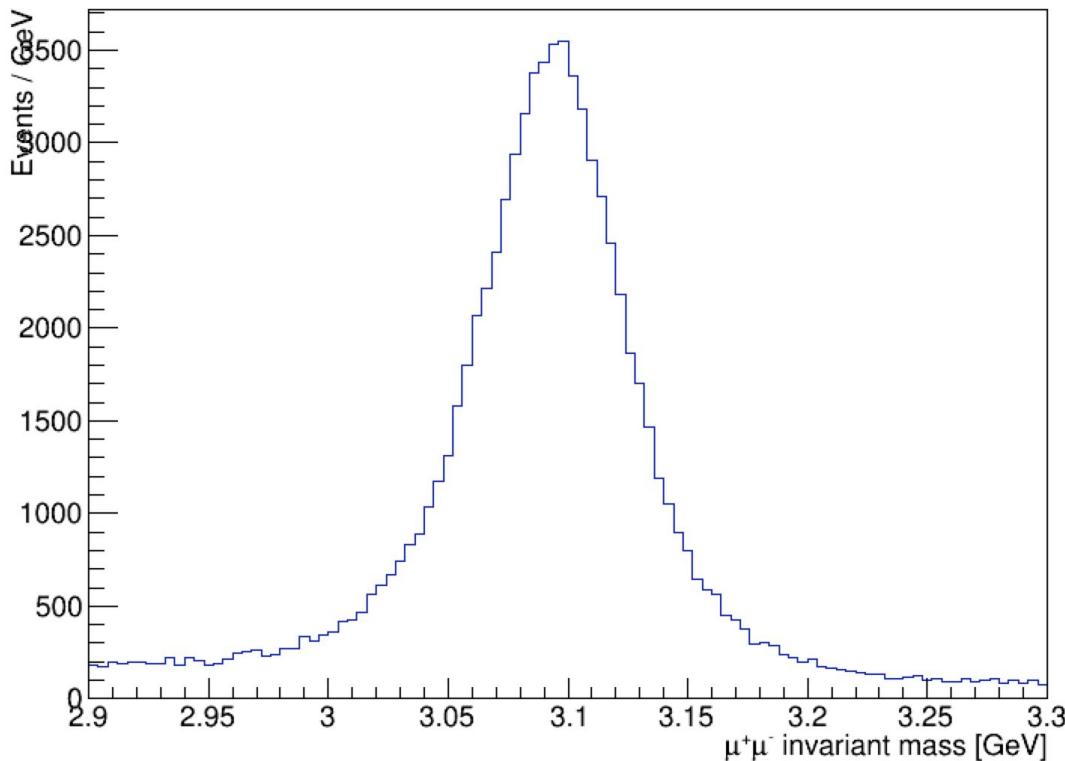
o espectro bruto ou cru



o espectro “correto”

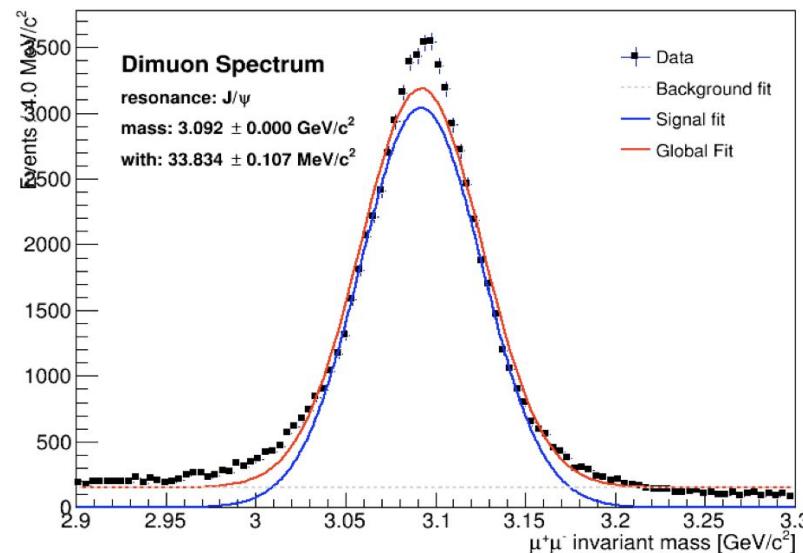
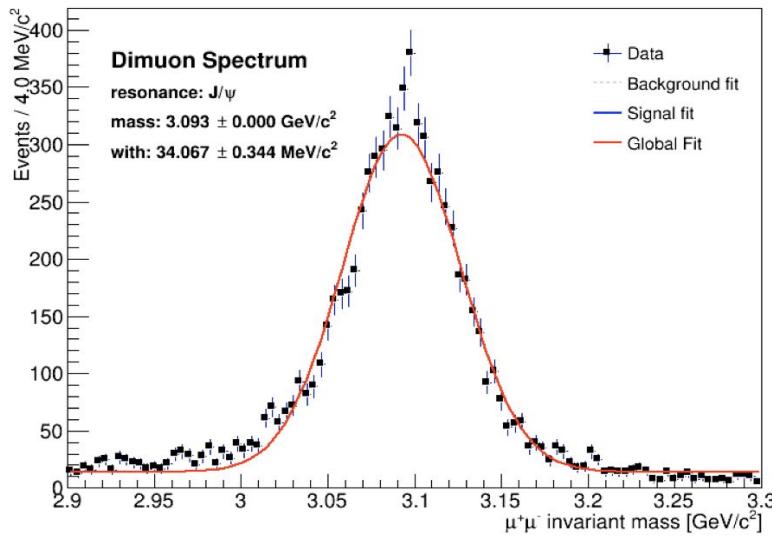


zoom... e selecione um sinal



ajuste aos dados

Modelo simplificado: Gaussiana (sinal) + polinomial (bckg)



Como poderíamos melhorar?
dica: final-state radiation

e essa distribuição com yield alto,
não está bem descrita, por quê?

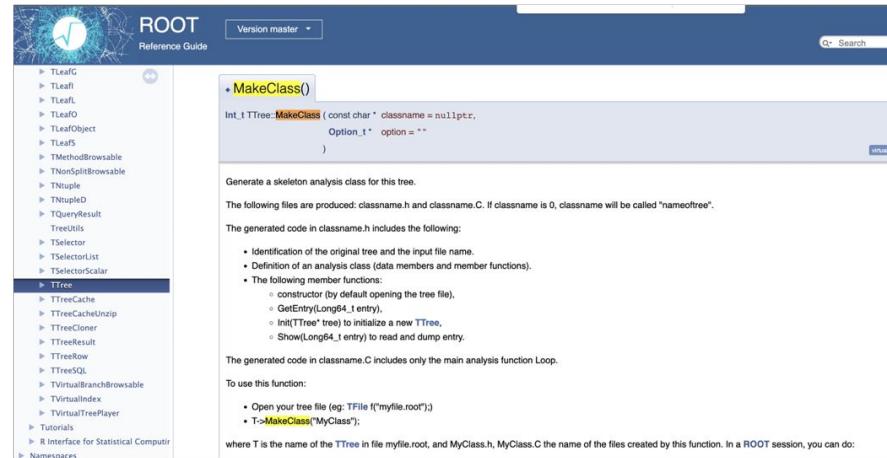
pode criar seu próprio código

<https://root.cern.ch/doc/master/classTTree.html>

Tree->MakeClass()

```
[Elizas-MacBook-Pro:analise-dados-parteI eliza$ root -l
[root [0] TFile f("DataSkim4.root")
(TFile &) Name: DataSkim4.root Title:
[root [1] .!ls
DataSkim4.root anadimuon.h      anadimuons.C    plots
[root [2] oniaTree->MakeClass("MyClass")
Info in <TTreePlayer::MakeClass>: Files: MyClass.h and MyClass.C generated from TTree: oniaTree
(int) 0
[root [3] .!ls
DataSkim4.root MyClass.C        MyClass.h       anadimuon.h      anadimuons.C    plots
```

```
Elizas-MacBook-Pro:analise-dados-parteI eliza$ root -l
root [0] .L MyClass.C
root [1] MyClass t
(MyClass &) @0x113b43c88
root [2] t.GetEntry(12);
root [3] t.Show();
=====> EVENT:12
event          = 32826671
dimuon_p4      = (TLorentzVector*)0x7f9f41e11ca0
muonP_p4       = (TLorentzVector*)0x7f9f41d67c80
muonN_p4       = (TLorentzVector*)0x7f9f41d9a450
root [4] t.Show(16);
=====> EVENT:16
event          = 32593775
dimuon_p4      = (TLorentzVector*)0x7f9f41e11ca0
muonP_p4       = (TLorentzVector*)0x7f9f41d67c80
muonN_p4       = (TLorentzVector*)0x7f9f41d9a450
root [5]
```



The screenshot shows the ROOT Reference Guide interface. The main content area displays the documentation for the `Int_t TTree::MakeClass` function. The function signature is shown as:

```
Int_t TTree::MakeClass (const char * classname = nullptr,
                      Option_t * option = "")
```

Below the signature, it says "Generate a skeleton analysis class for this tree." and "The following files are produced: classname.h and classname.C. If classname is 0, classname will be called "nameoftree"."

The generated code in `classname.h` includes the following:

- Identification of the original tree and the input file name.
- Definition of an analysis class (data members and member functions).
- The following member functions:
 - constructor (by default opening the tree file),
 - `GetEntry(Long64_t entry)`,
 - `Init(TTree* tree)` to initialize a new `TTree`,
 - `Show(Long64_t entry)` to read and dump entry.

The generated code in `classname.C` includes only the main analysis function `Loop`.

To use this function:

- Open your tree file (eg: `TFile f("myfile.root")`)
- `T->MakeClass("MyClass");`

where `T` is the name of the `TTree` in file `myfile.root`, and `MyClass.h`, `MyClass.C` the name of the files created by this function. In a ROOT session, you can do:

Reveja a aula sobre ROOT do prof. Mauricio

exercício

Usando a idéia inicial do exercício da aula anterior que você calculou a M com a amostra do seu grupo:

1. Aplique cortes de seleção antes de plotar a massa, vamos exigir um limiar de pT e η em cada objeto e depois salvar a figura da M no formato png.

O número de eventos é afetado? Explique o limiar que você escolheu para pT e η . Adicione as figuras e o código no git.

2. Extraia o resultado do ajuste :

massa do sinal;

incertezas estatísticas incluídas.

3.(extra): Efeitos sistemáticos

implemente diferentes modelos para sinal e fundo;

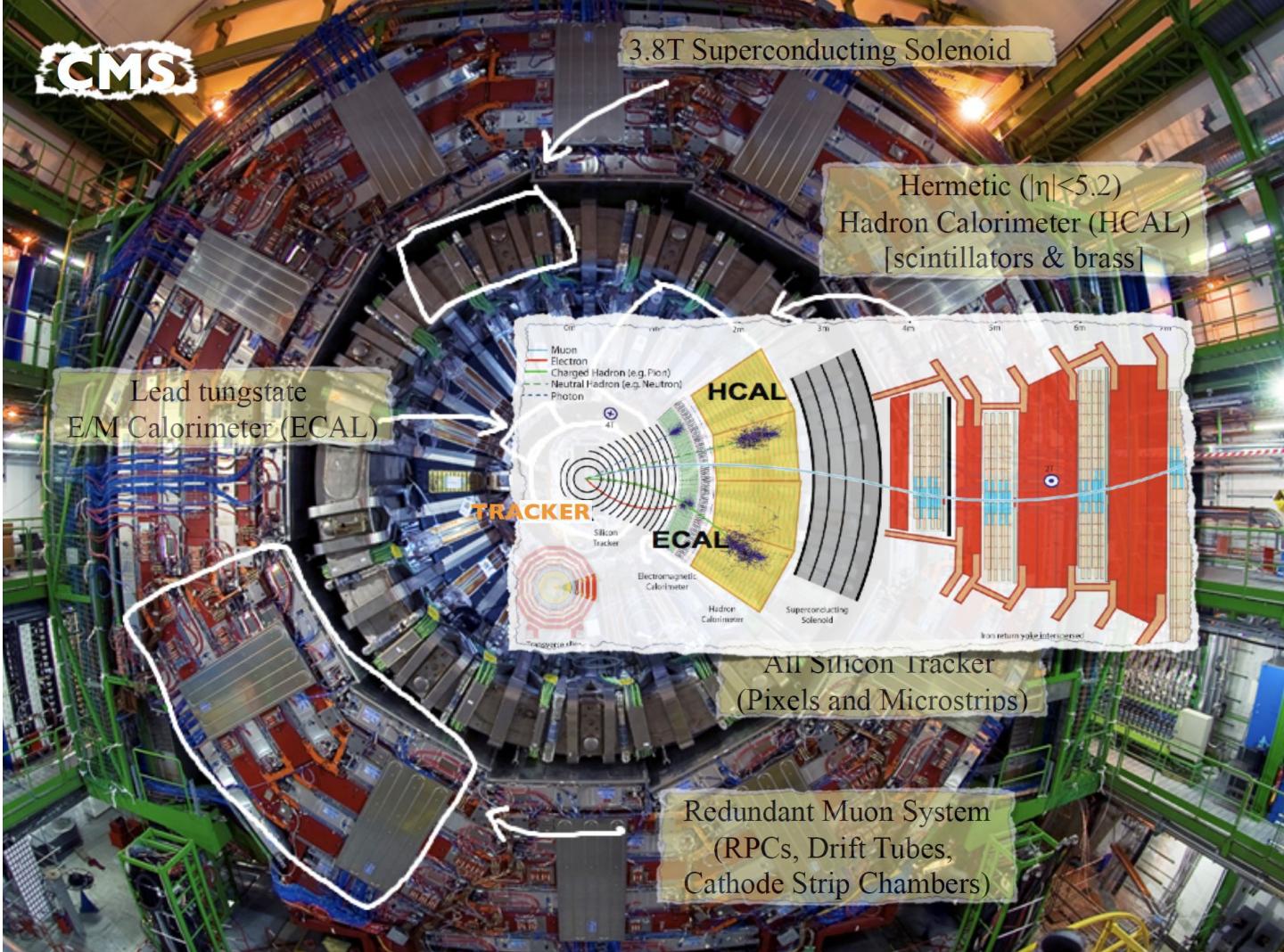
repita o ajuste e extraia as incertezas sistemáticas.



Referências

- N. Leonardo
- 16th Portuguese Language Teacher Programme
- Particle physics with the computer

Backup



Campo magnético: no coração de uma experiência

Cargas elétricas em movimento são sensíveis aos campos magnéticos

A partir da trajectória de uma partícula sujeita a \mathbf{B} :

- *direcção*
⇒ medição da carga eléctrica
- *raio de curvatura*
⇒ medida de momento (conhecida a massa)
⇒ medida de massa (conhecida a velocidade)

$$p \cos \lambda = 0.3 z B R$$

momento linear [GeV/c] ângulo de inclinação carga eléctrica [e] intensidade de campo magnético [T] Raio de curvatura [L]

