



Universidade do Minho
Escola de Ciências



LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

[a experiência ATLAS]

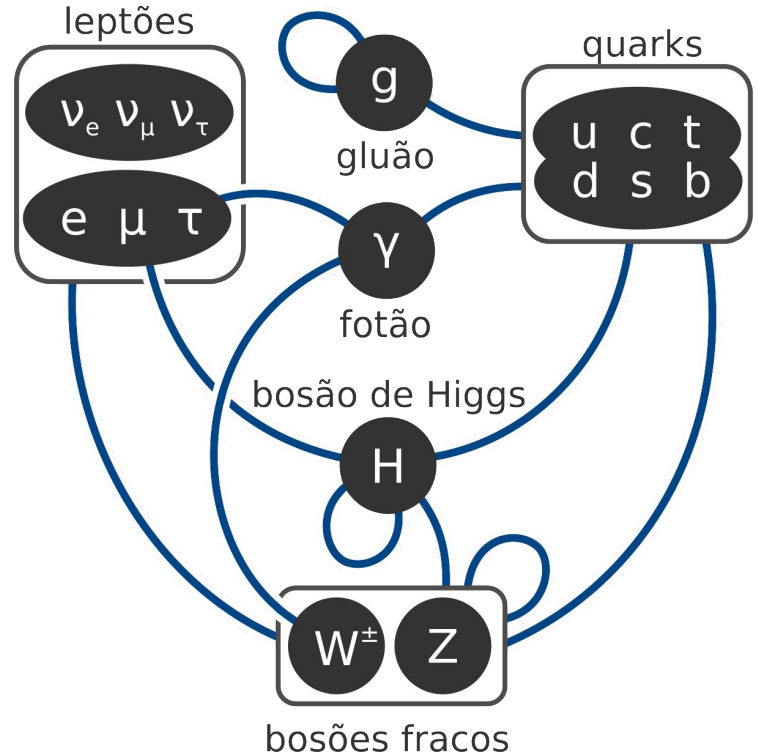
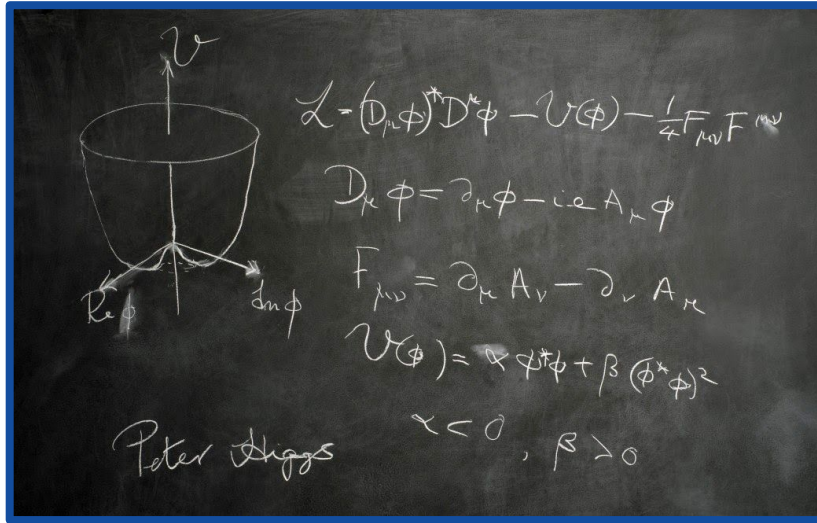
12^a Escola de Professores no CERN em Língua Portuguesa

CERN, 6 de setembro de 2018

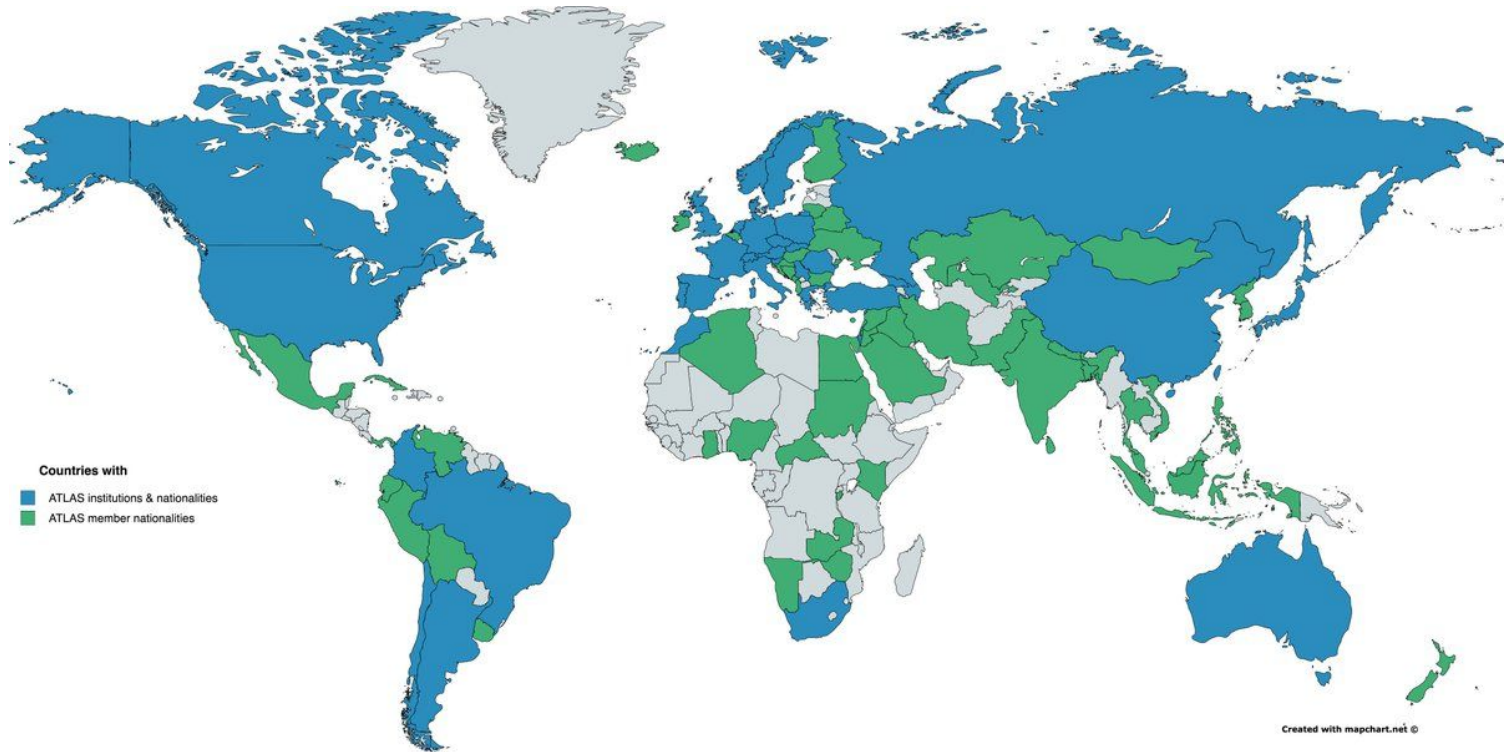
Nuno Castro

nfcastro@lip.pt

(provavelmente desnecessárias) revisões - o Modelo Padrão



ATLAS: *A Toroidal LHC Apparatus* uma colaboração mundial



ATLAS: *A Toroidal LHC Apparatus* uma colaboração mundial

3000 cientistas
(1000 estudantes)
33 países
177 universidades
e laboratórios



ATLAS: *A Toroidal LHC Apparatus* investigação em língua portuguesa

Portugal:

~20 investigadores, ~10 – 15 estudantes

LIP – Coimbra, Minho, Lisboa

FCUL, FCTUC, UM, CEFITEC/UNL, INESC, CFMC

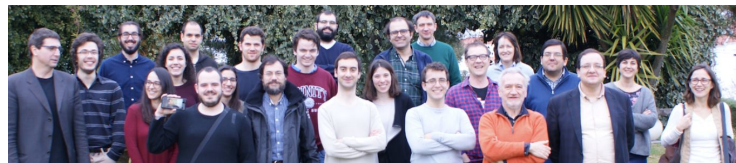
Programa de treino de engenheiros no CERN

Brasil:

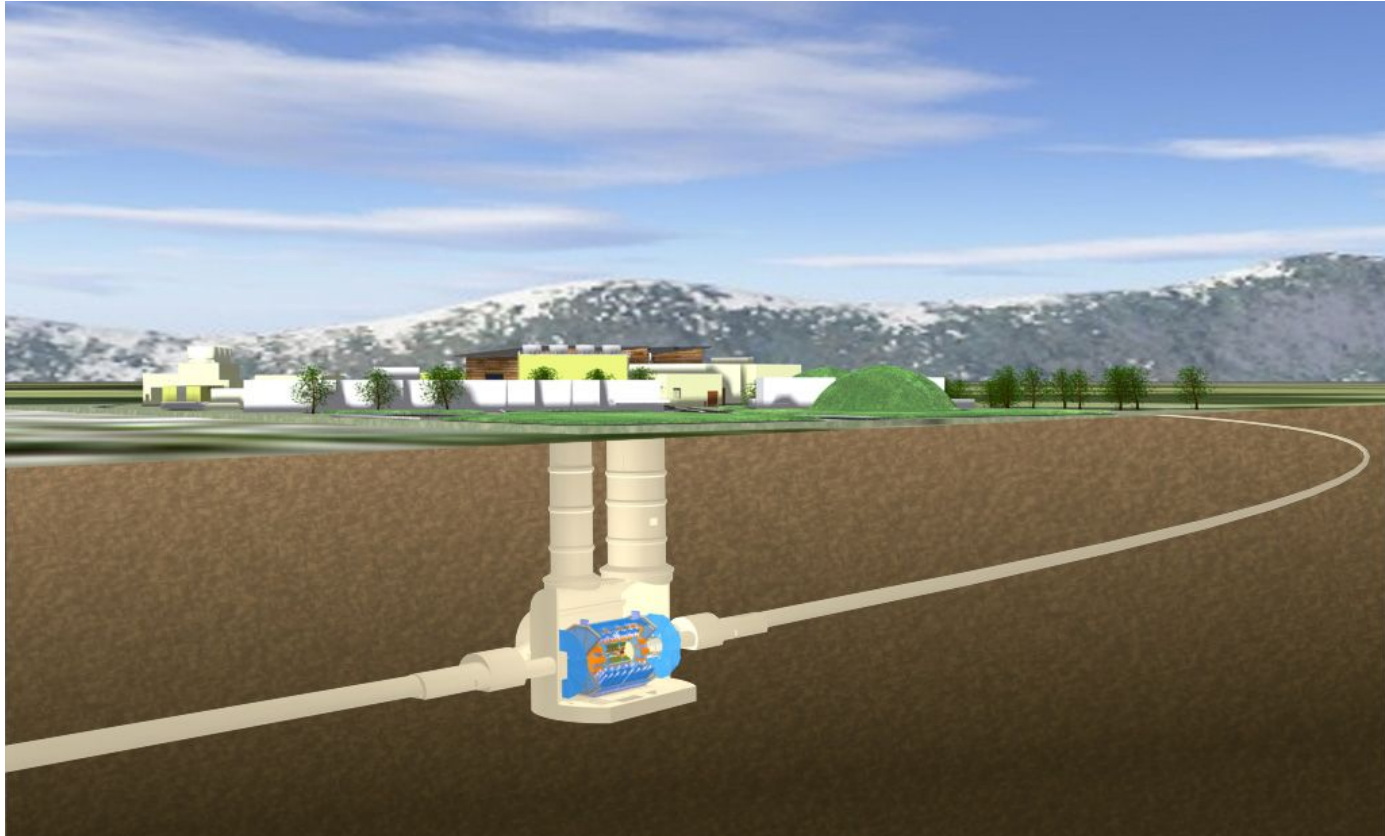
Cerca de 30 colegas de várias instituições

UFRJ-COPPE, UFJF, USP, UFSJ

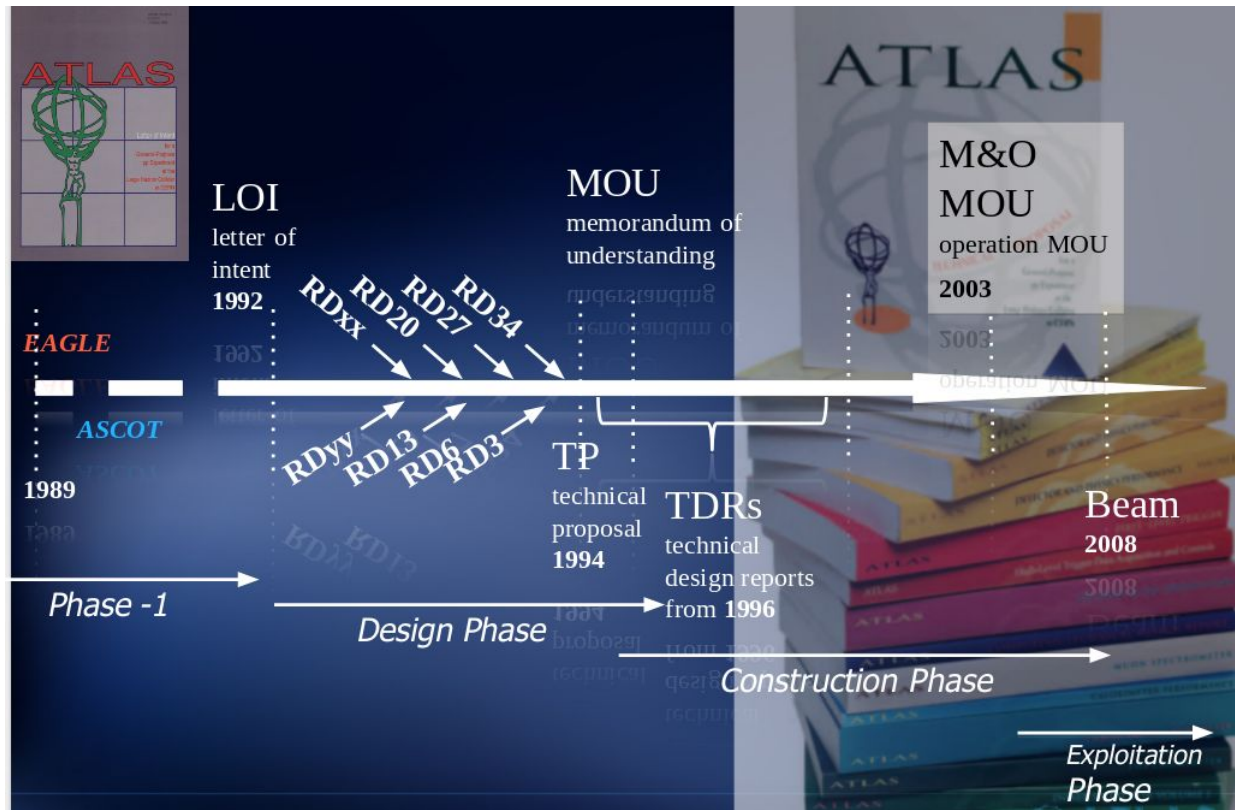
(UFBA, CEFET-RJ, UFF)



ATLAS: A Toroidal LHC Apparatus



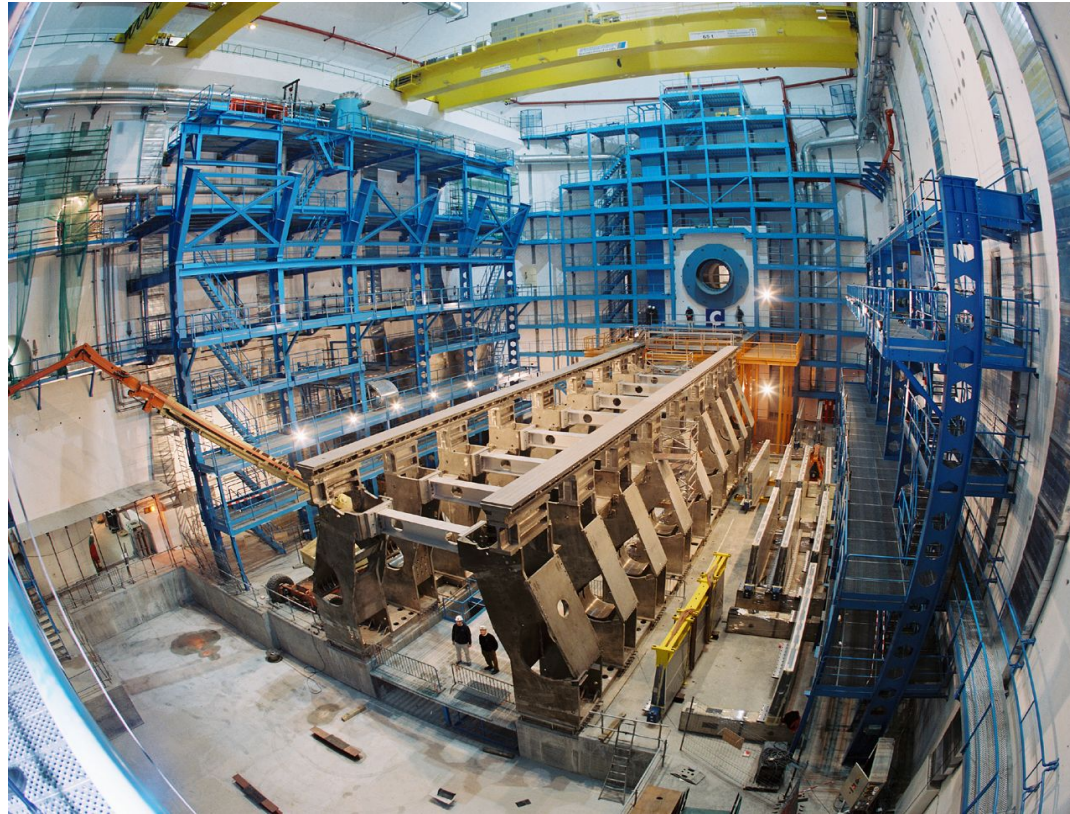
ATLAS: uma longa história



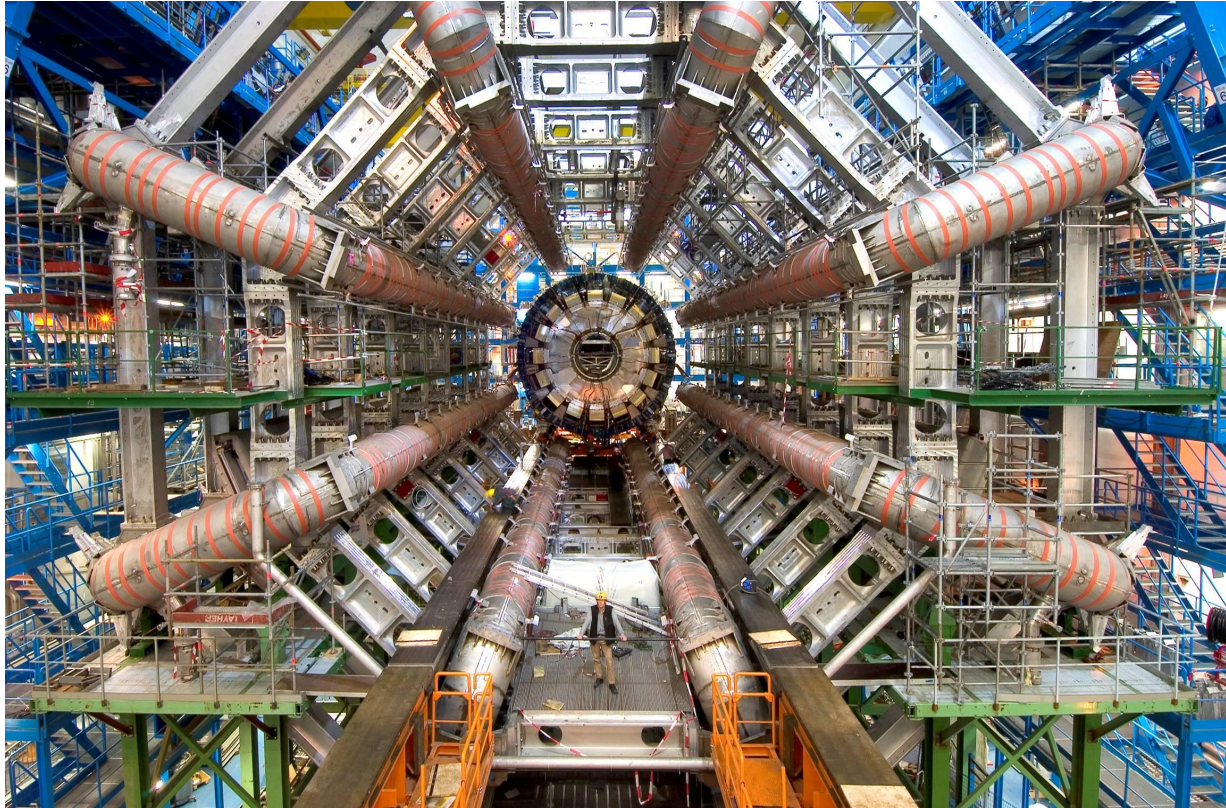
ATLAS: uma longa história



ATLAS: uma longa história



ATLAS: uma longa história



ATLAS

exemplo: o TileCal (1993-2009)



1993-1995 R&D-protótipos



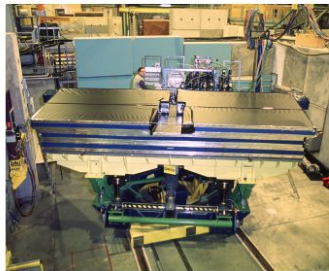
1996-2002: construção



1999-2002 Instrumentação



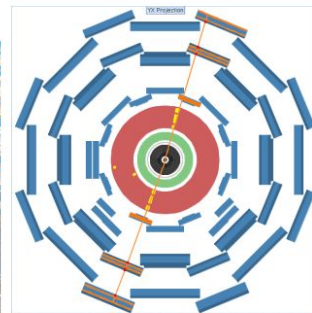
1999-2004: Electrónica



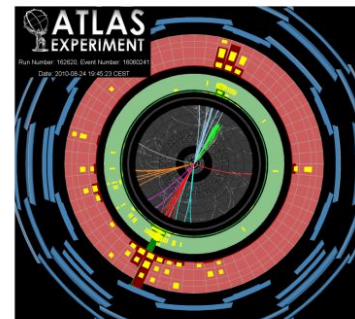
2002-2004: calibrações



2004-2006 Instalação



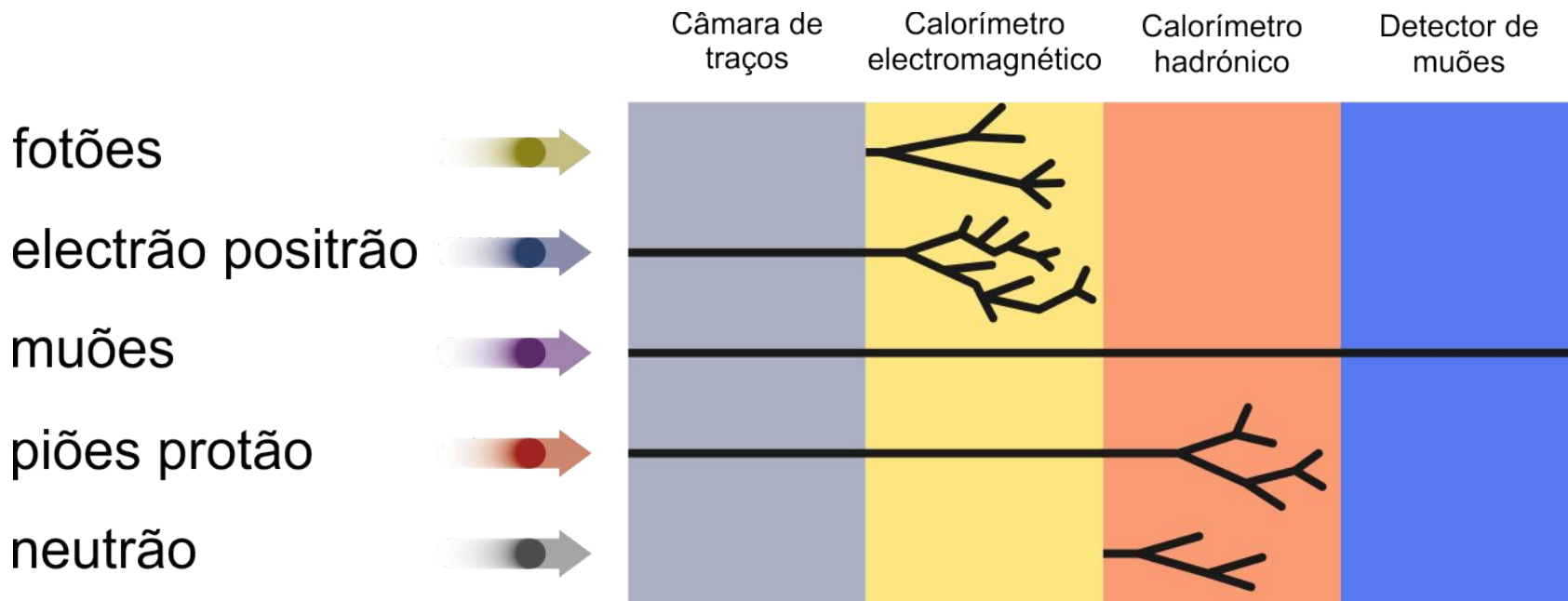
2007-2009 certificação
(raios cósmicos)



2009: aquisição/análise
dados LHC

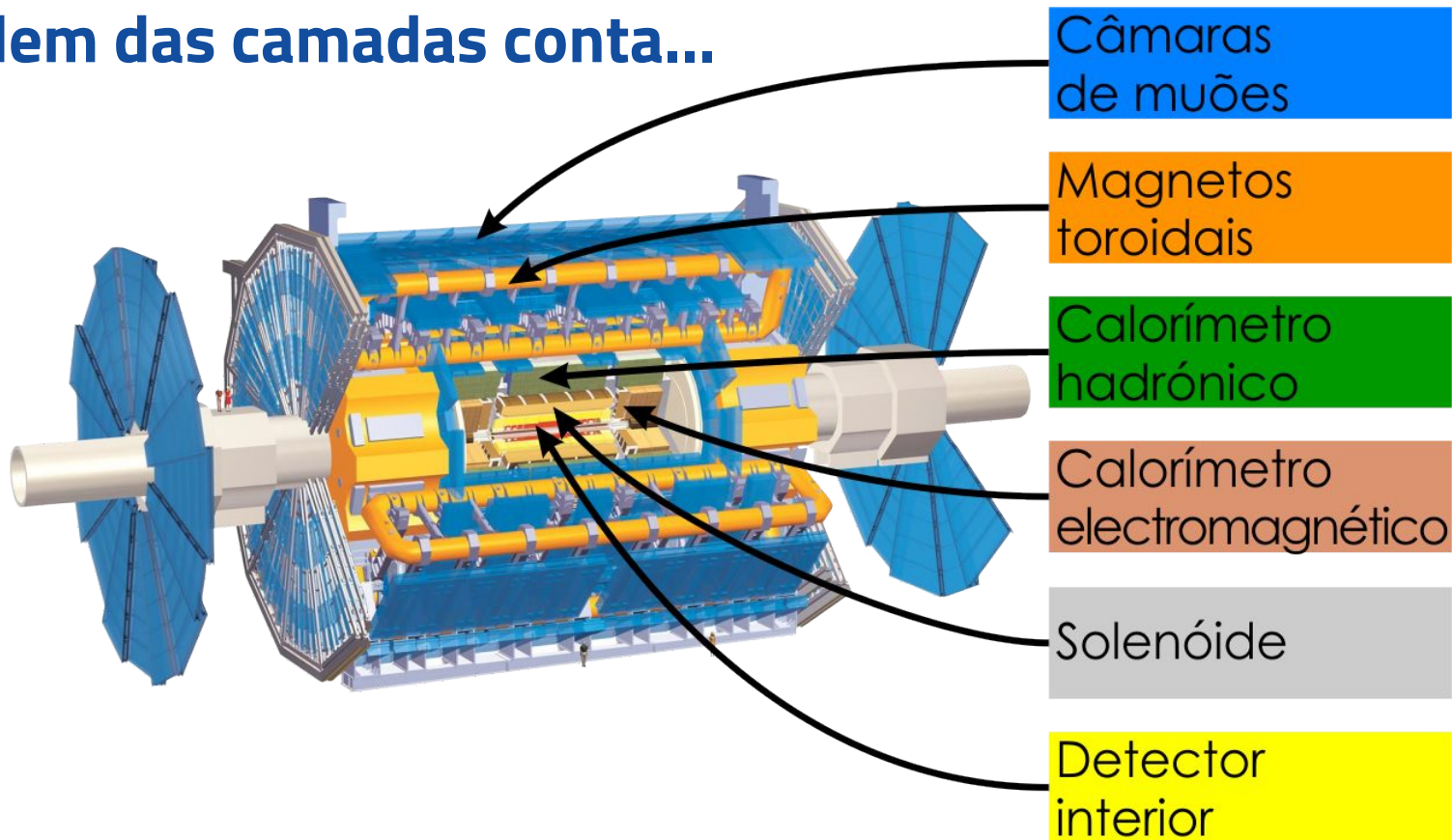
ATLAS

revisão: como funciona um detector



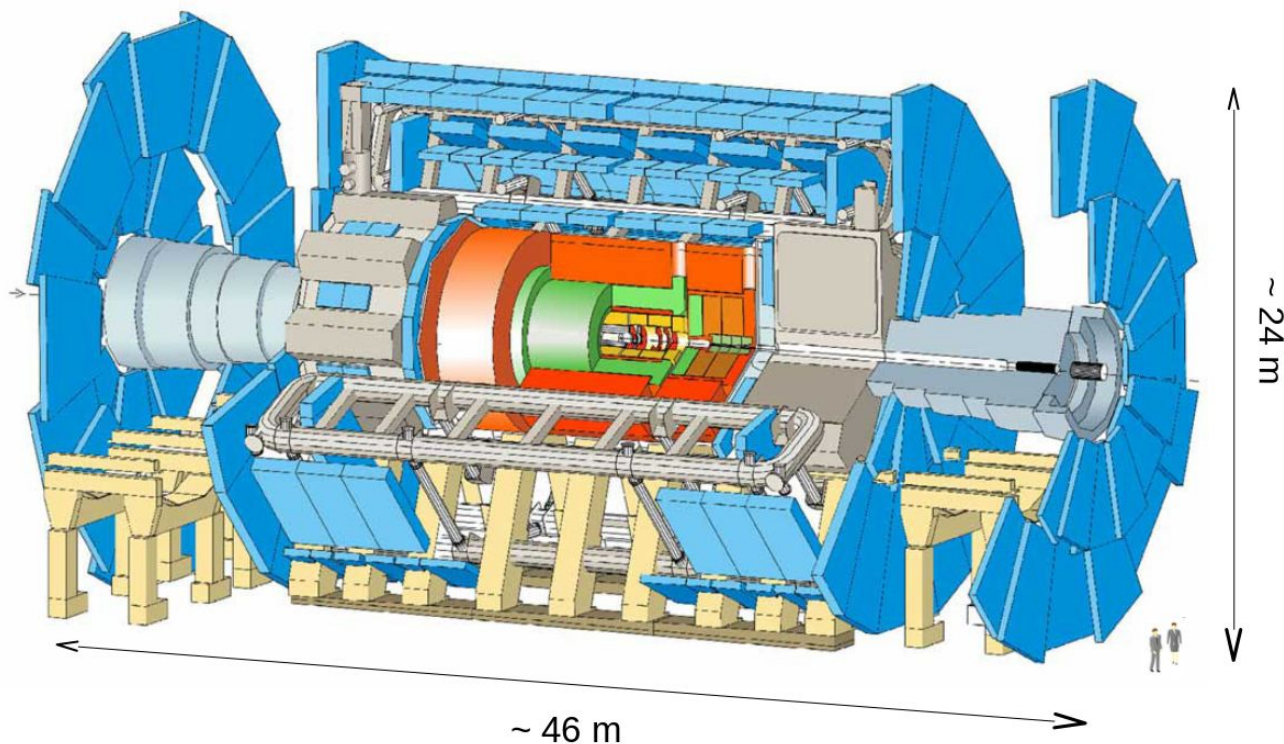
ATLAS

a ordem das camadas conta...

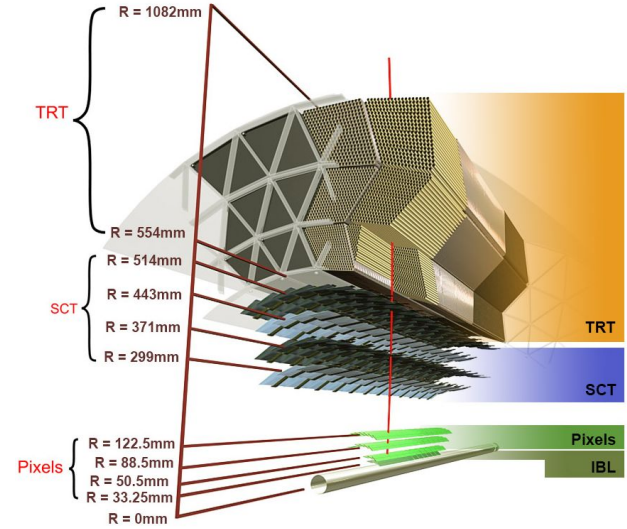
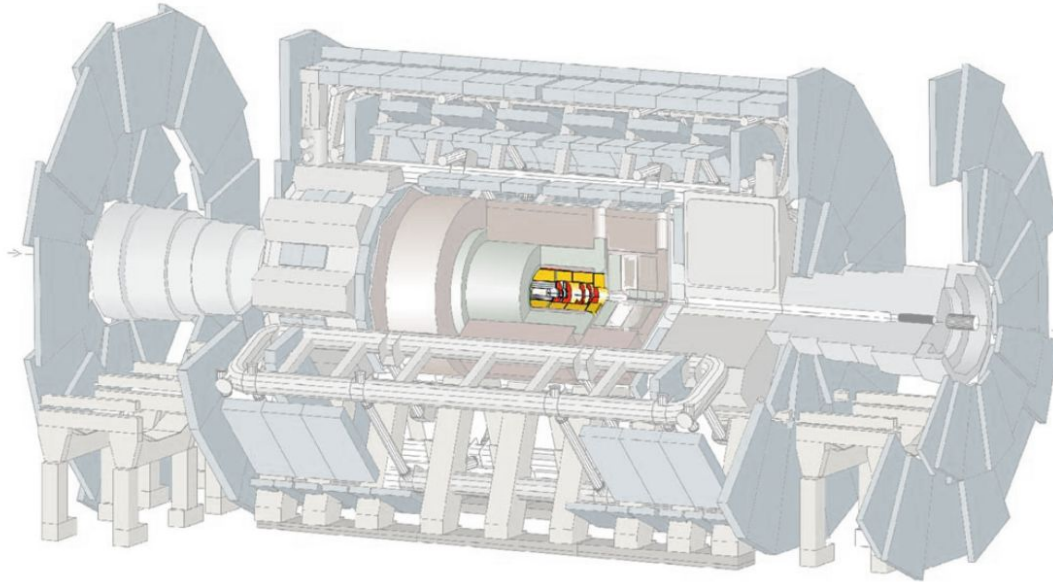


o detector ATLAS

Peso: ~ 7000 t
~ 10^8 canais leitura
~ 3000 km de cabos
~ 40×10^6 colisões / s
~ 320 MB de dados / s



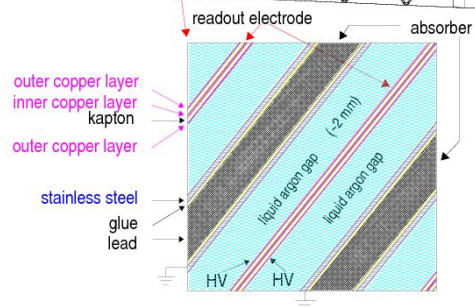
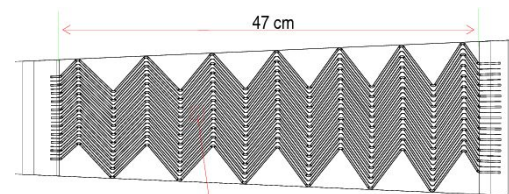
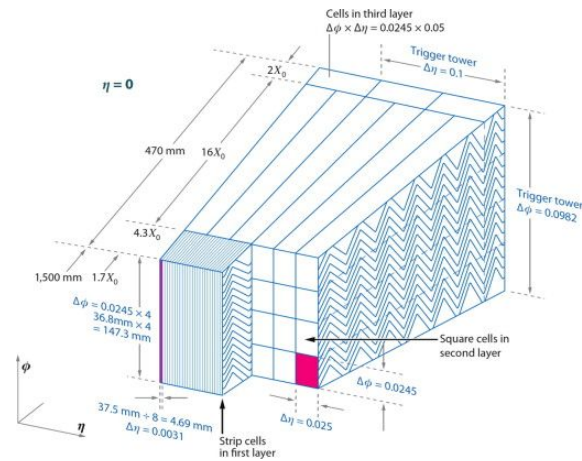
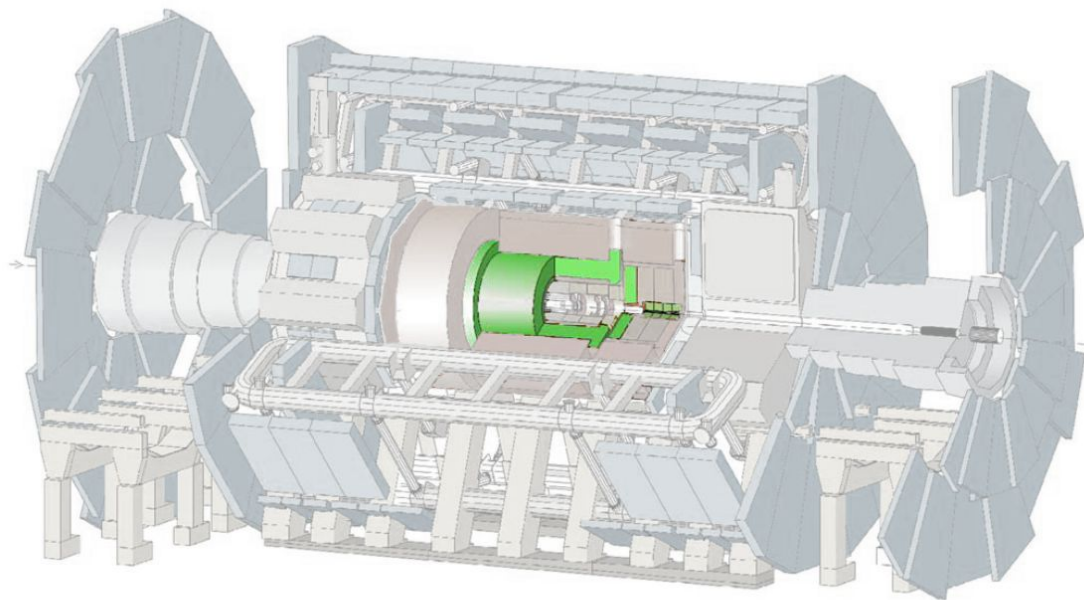
ATLAS detector interior



$$\sigma/p_T \sim 3.8 \times 10^{-4} p_T \text{ (GeV)} \oplus 0.015$$

i.e. $\sigma/p_T < 2\%$ for $p_T < 35 \text{ GeV}$

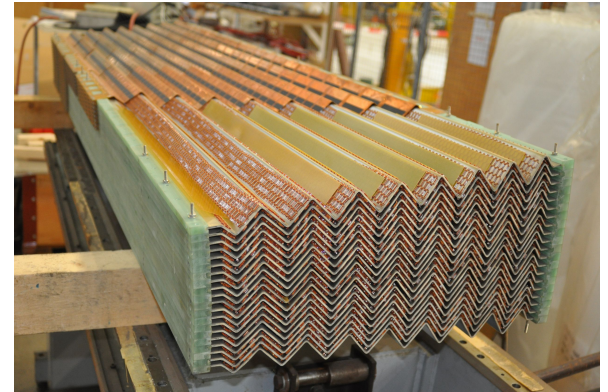
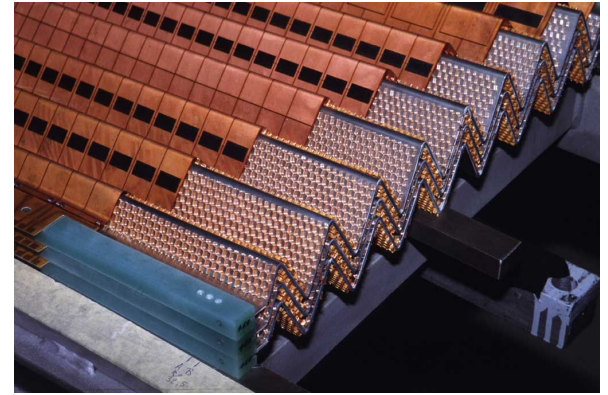
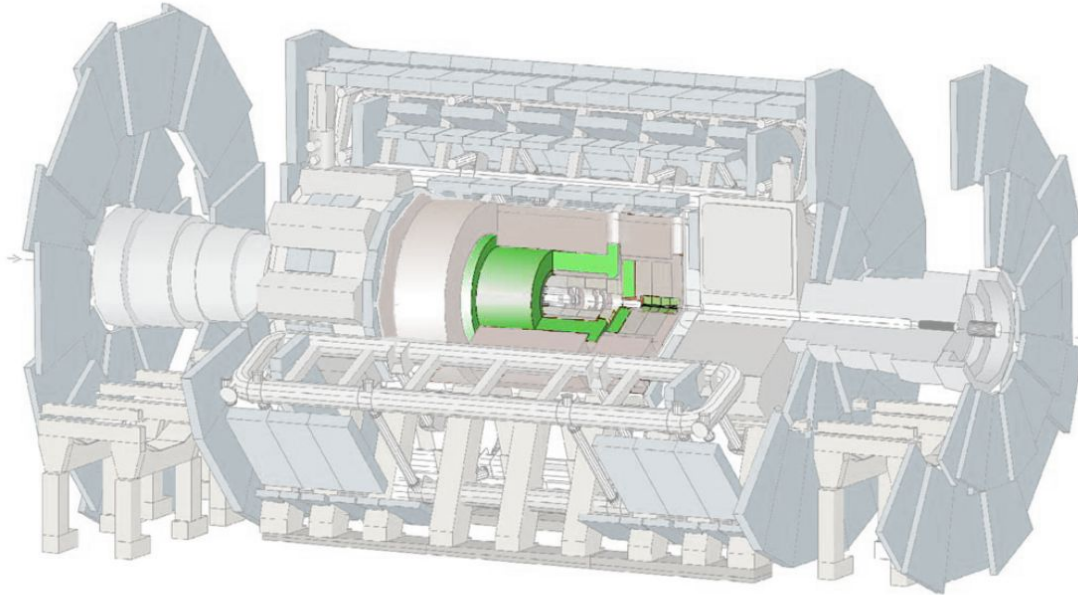
ATLAS calorímetro electromagnético



$$\sigma/E \sim 10\%/\sqrt{E}$$

ATLAS

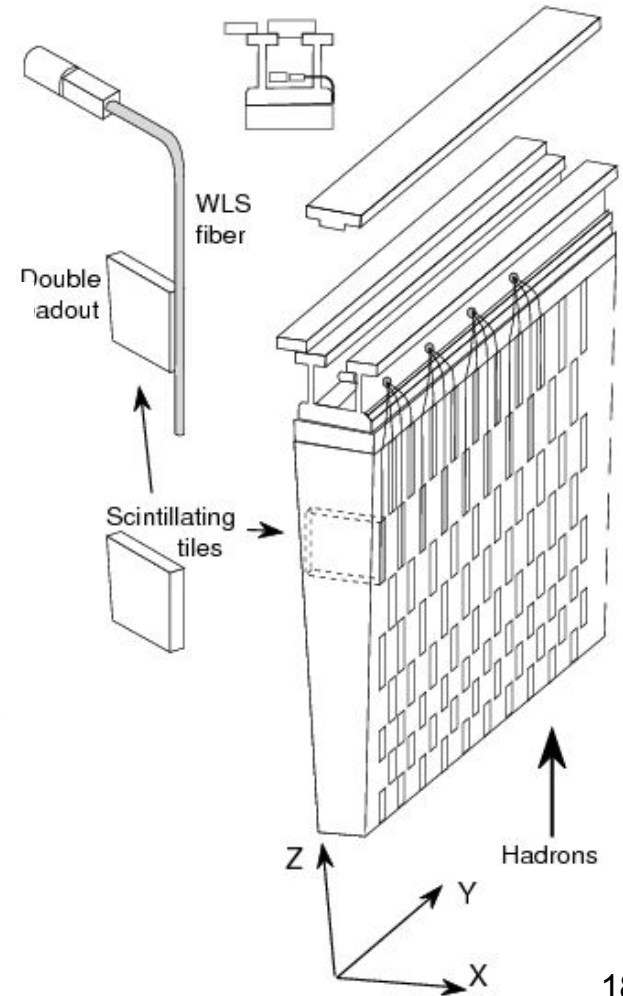
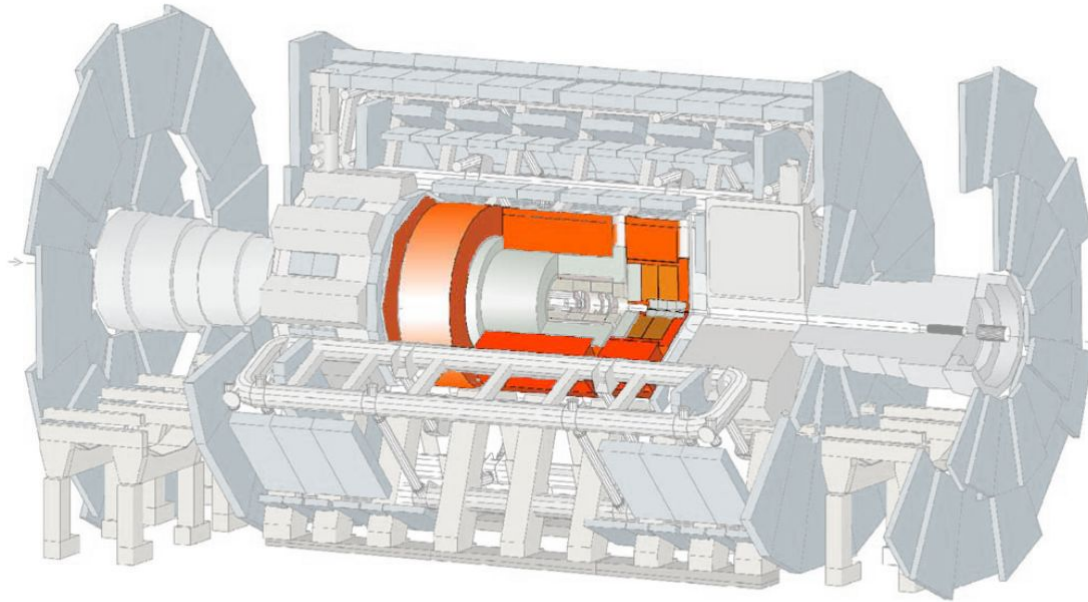
calorímetro electromagnético



$$\sigma/E \sim 10\%/\sqrt{E}$$

ATLAS

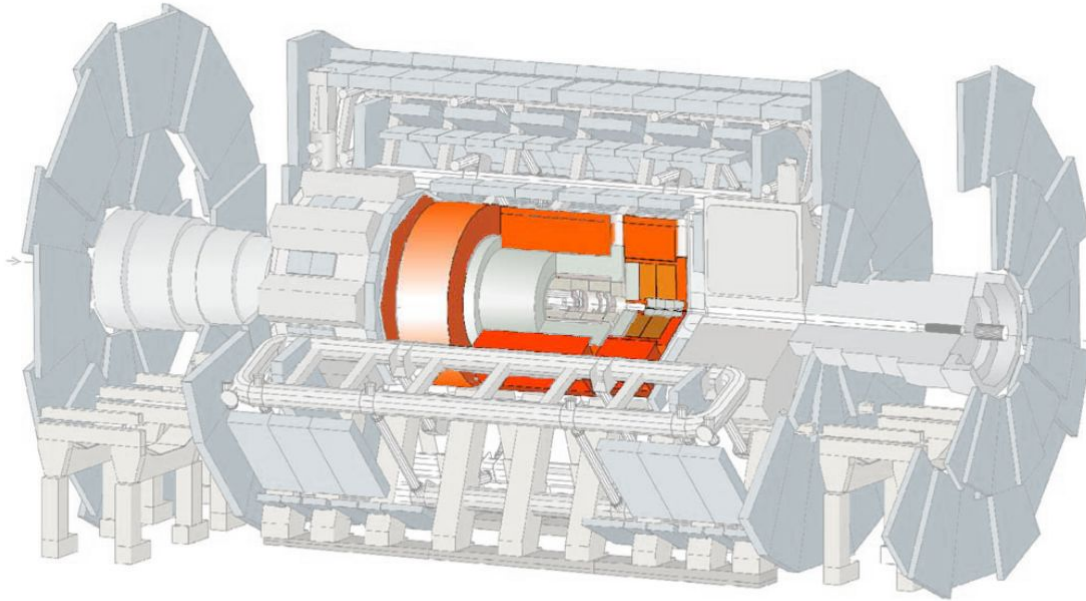
calorímetro hadrónico



$$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$$

ATLAS

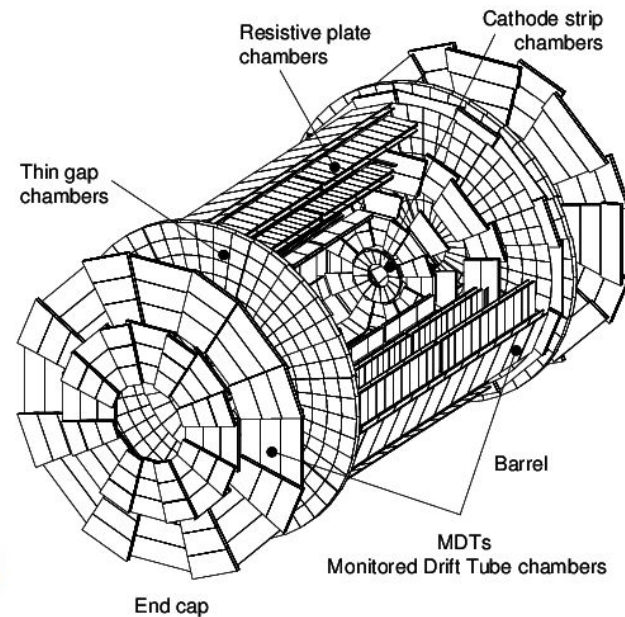
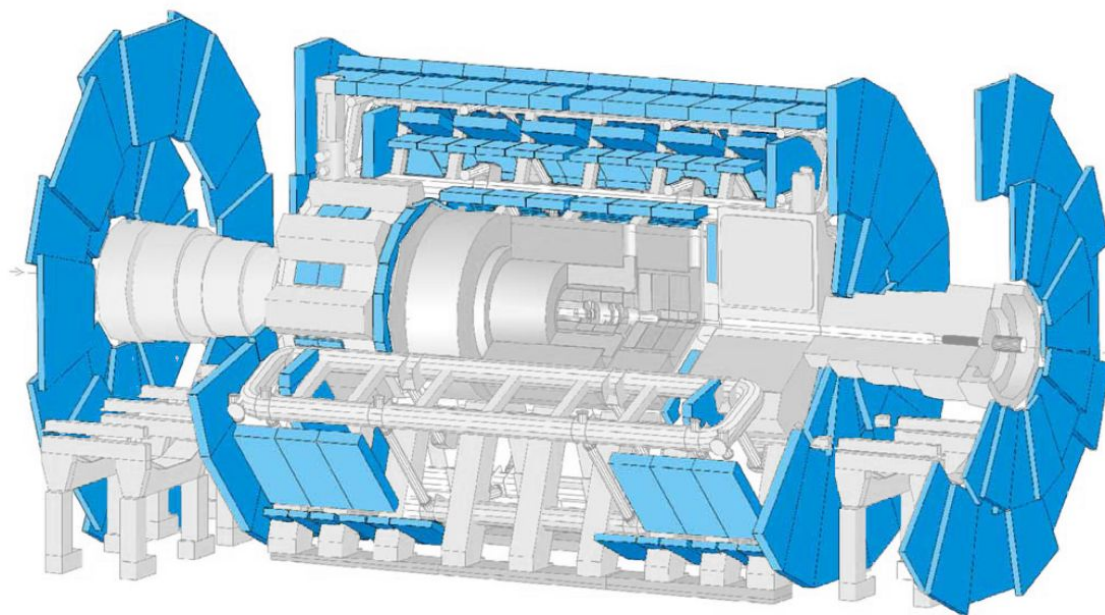
calorímetro hadrónico



$$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$$

ATLAS

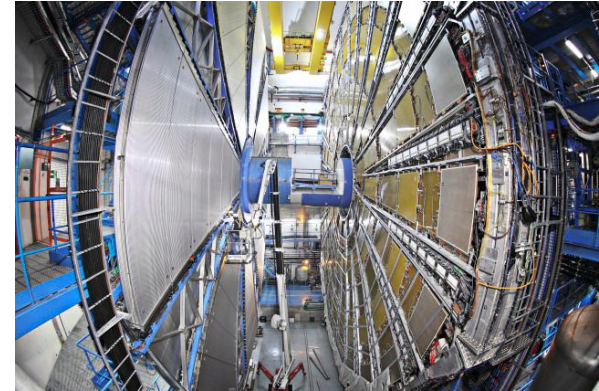
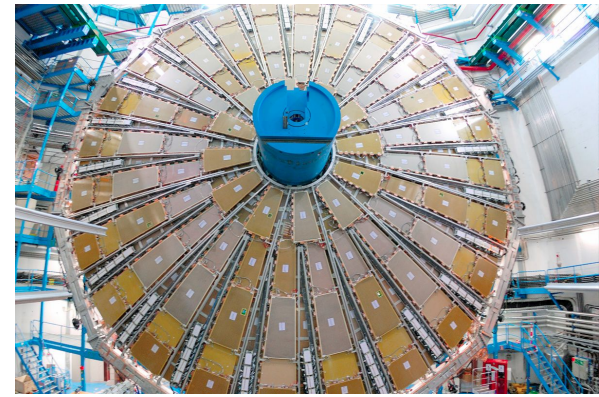
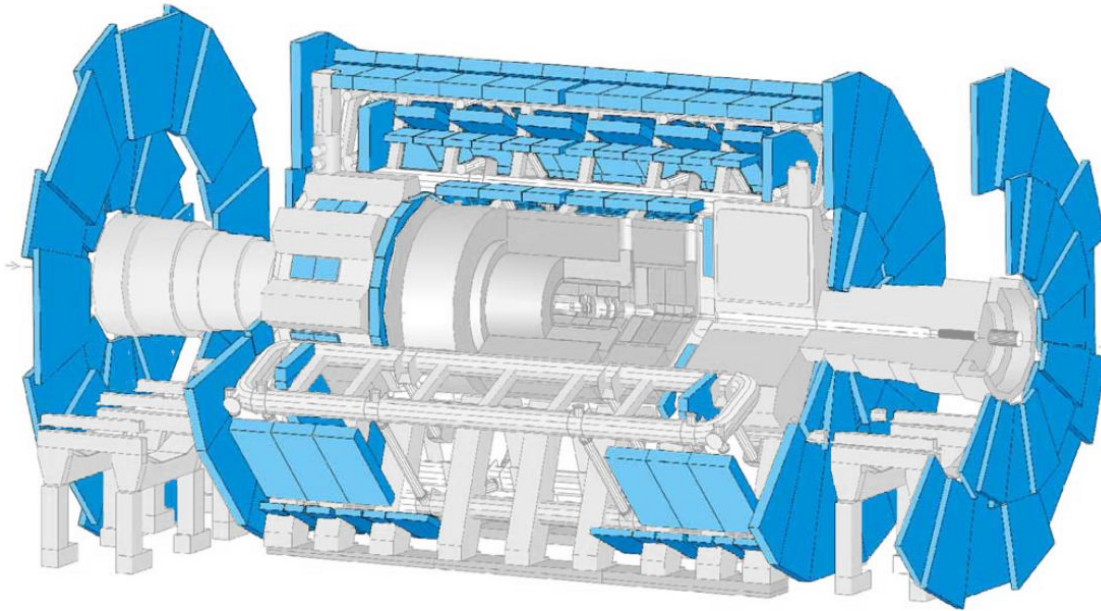
câmaras de muões



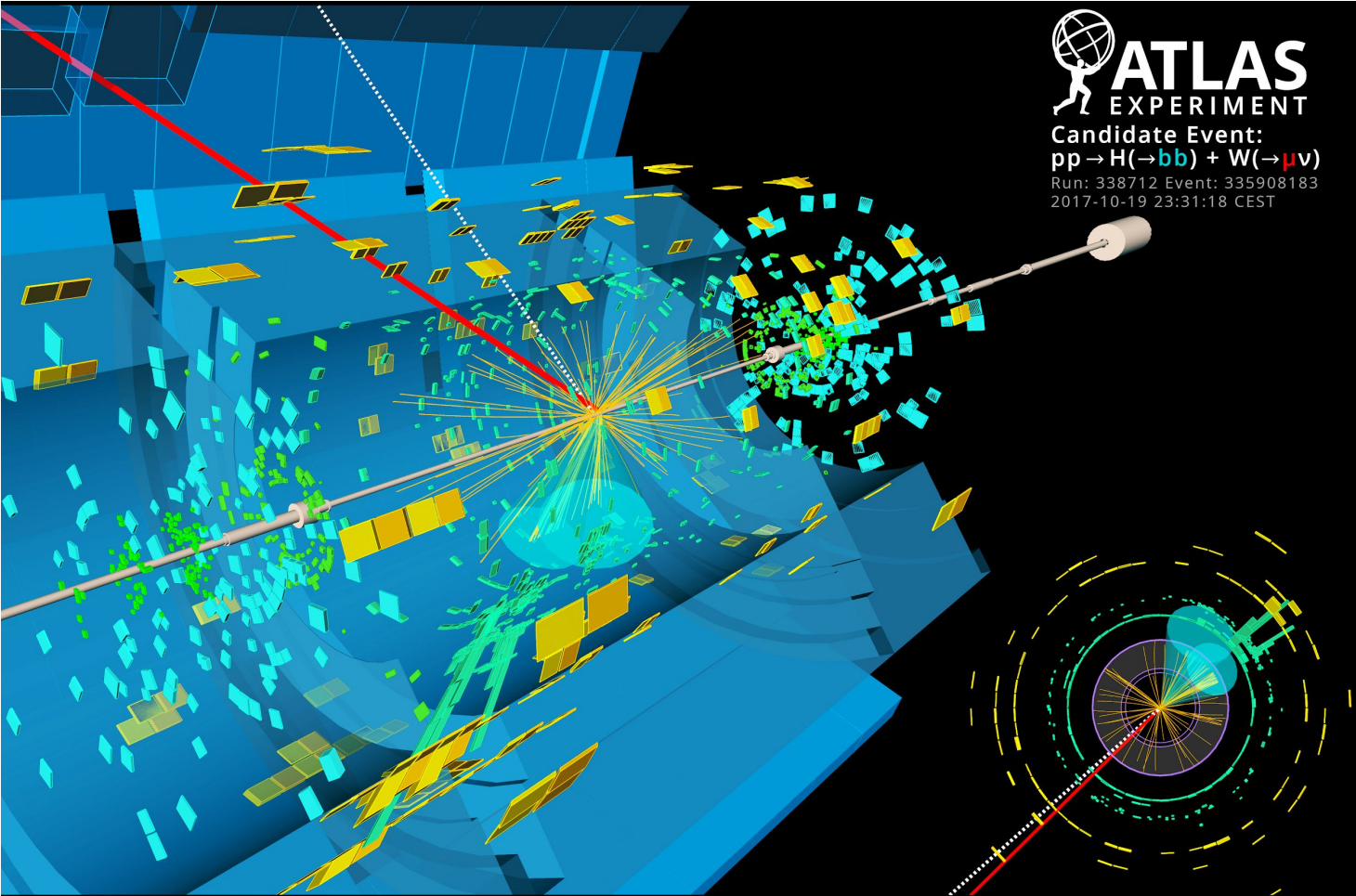
< 10% up to $E_{\mu} \sim 1 \text{ TeV}$

ATLAS

câmaras de muões

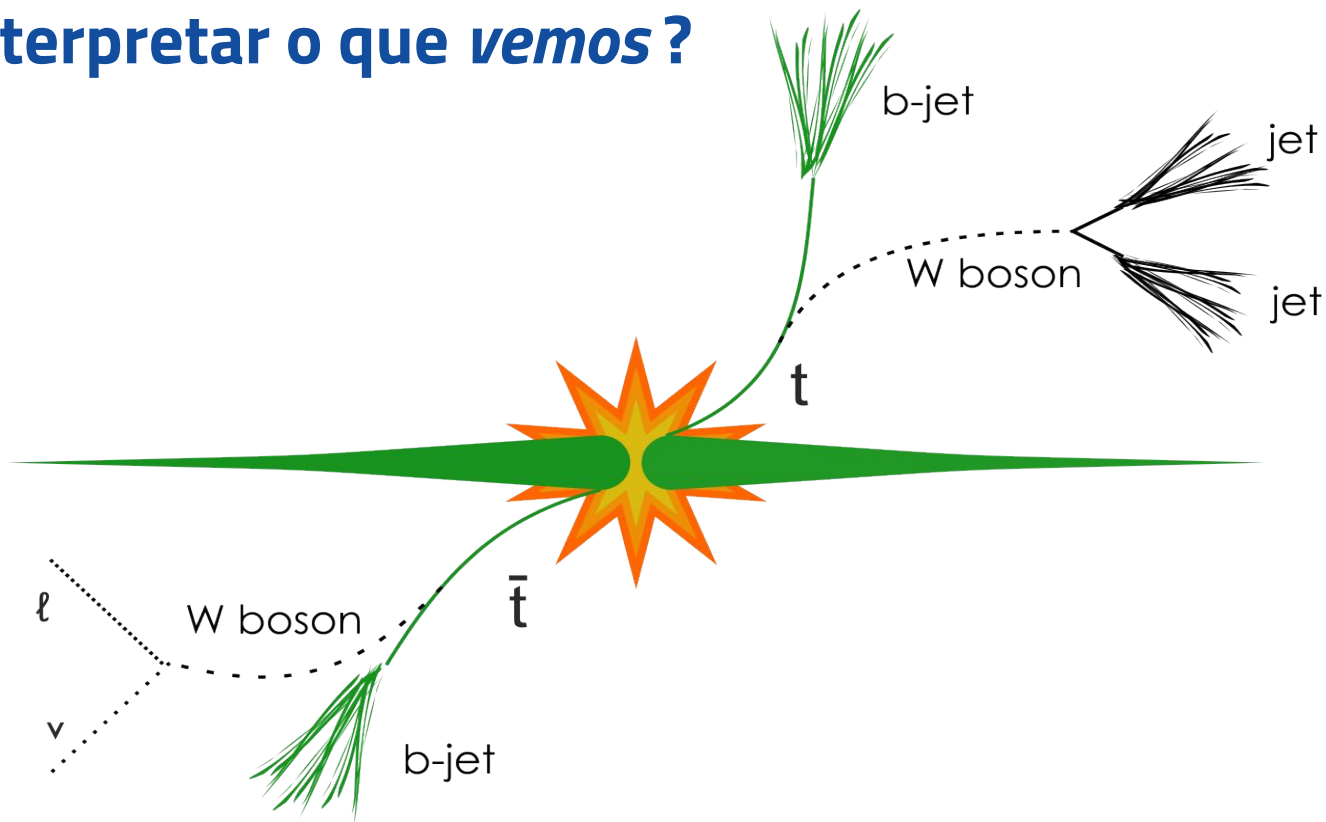


< 10% up to $E_{\mu} \sim 1 \text{ TeV}$



ATLAS

como interpretar o que *vemos*?



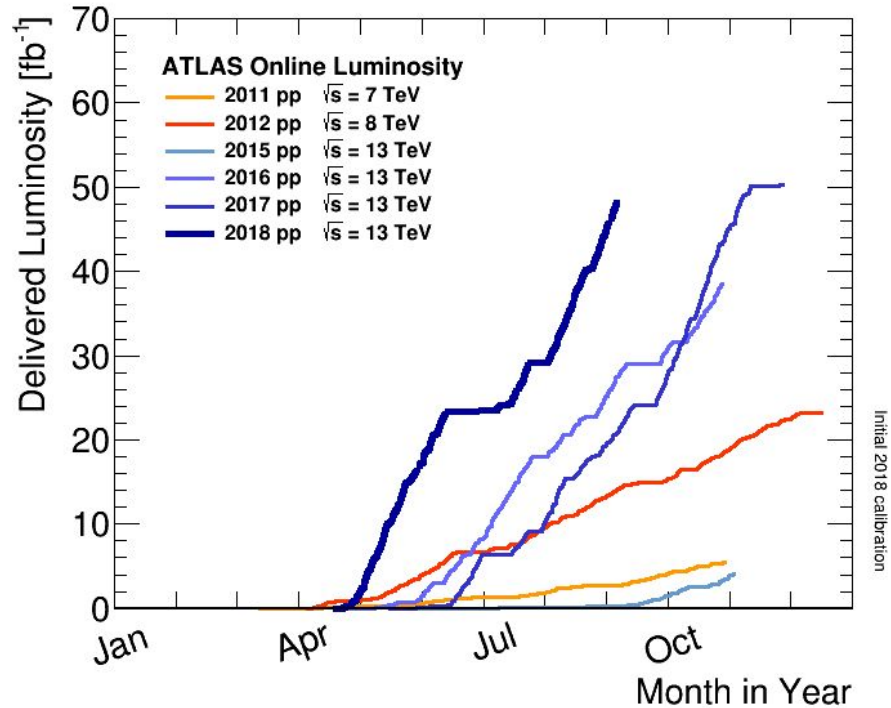
ATLAS

como interpretar o que *vemos*?



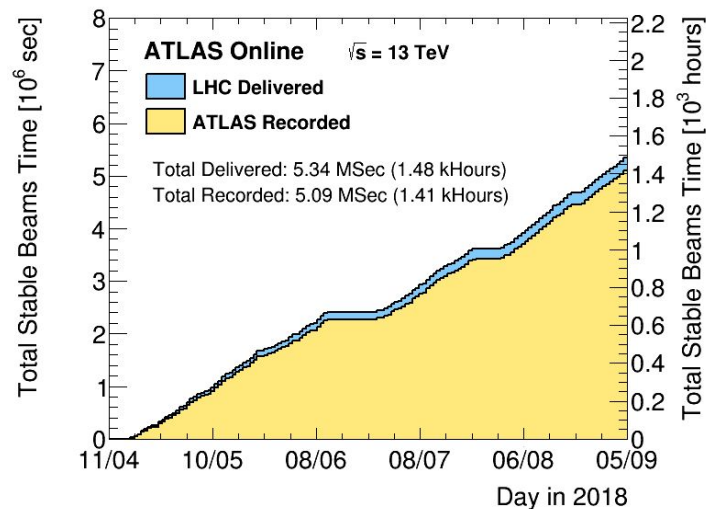
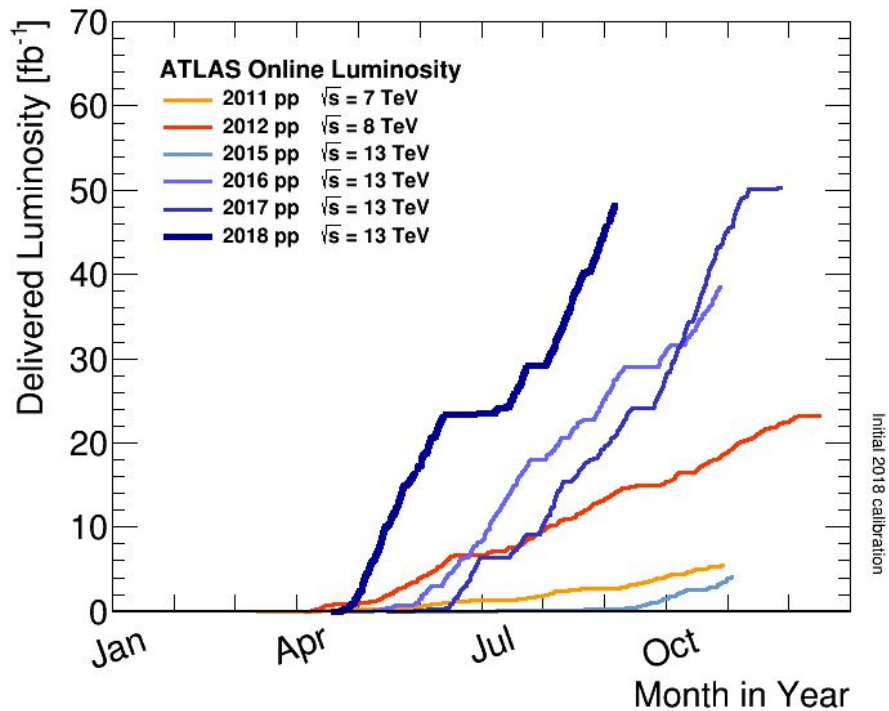
Dados adquiridos

ATLAS

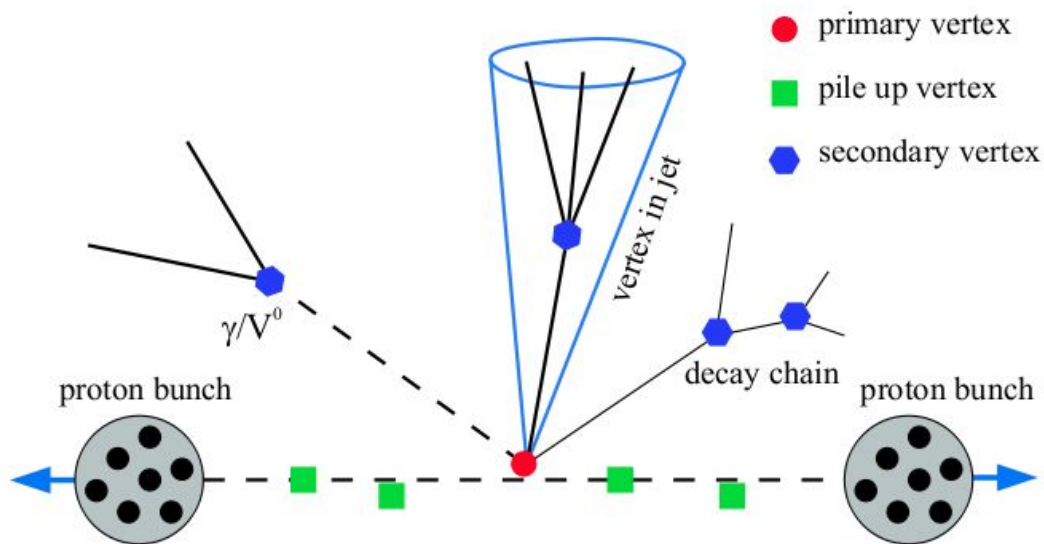


Dados adquiridos

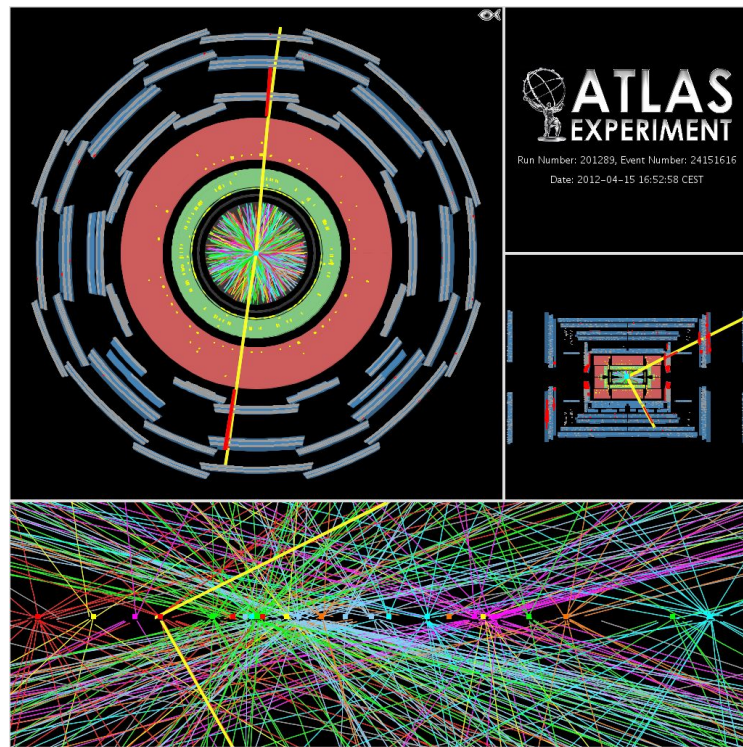
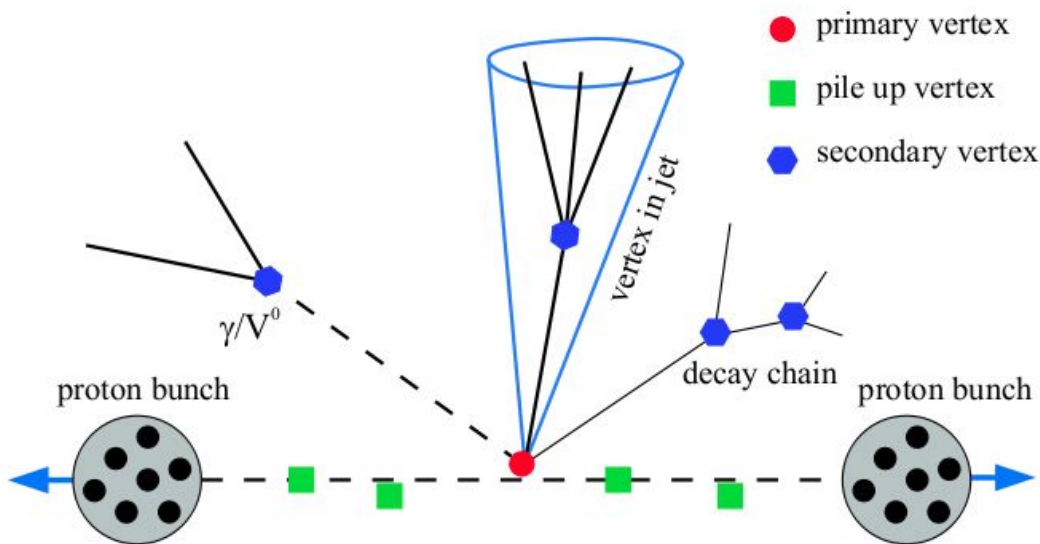
ATLAS



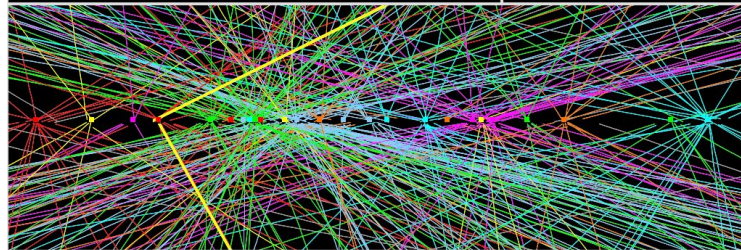
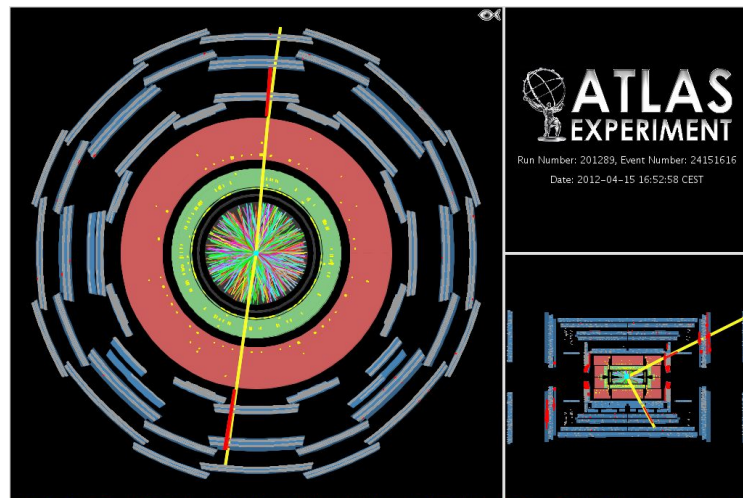
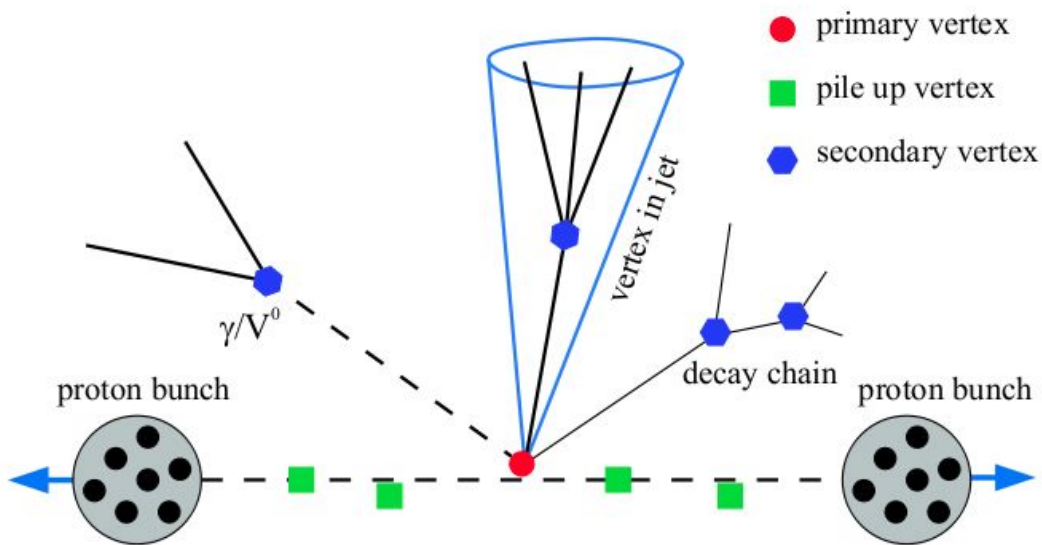
Dados adquiridos o outro lado da moeda



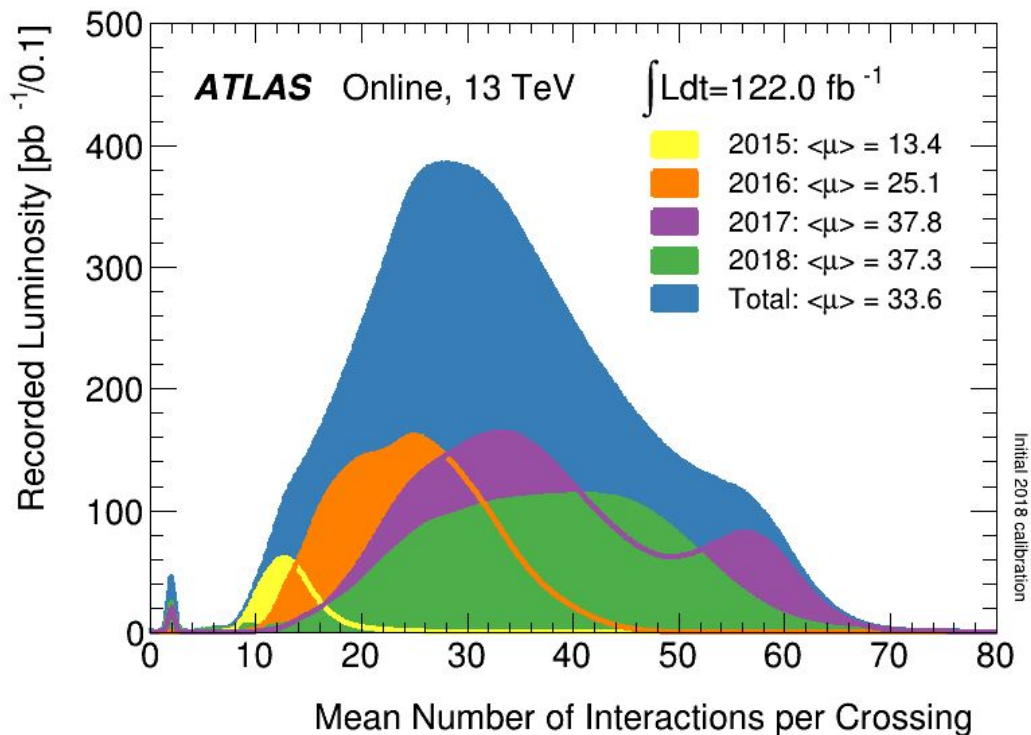
Dados adquiridos o outro lado da moeda



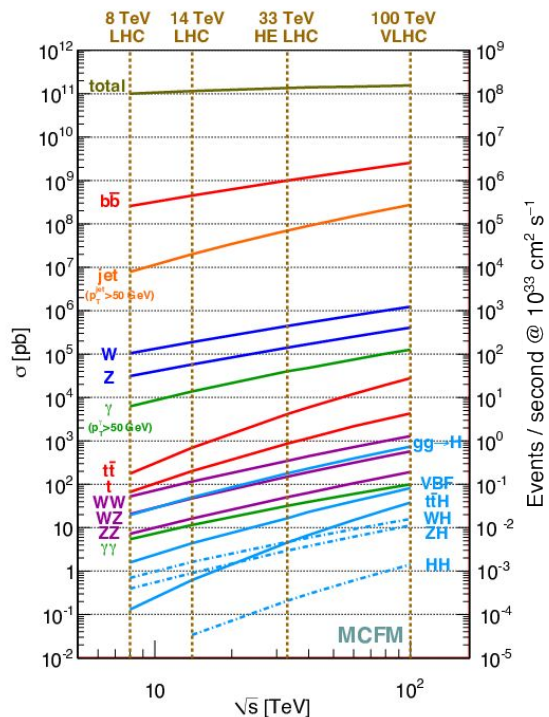
Dados adquiridos o outro lado da moeda



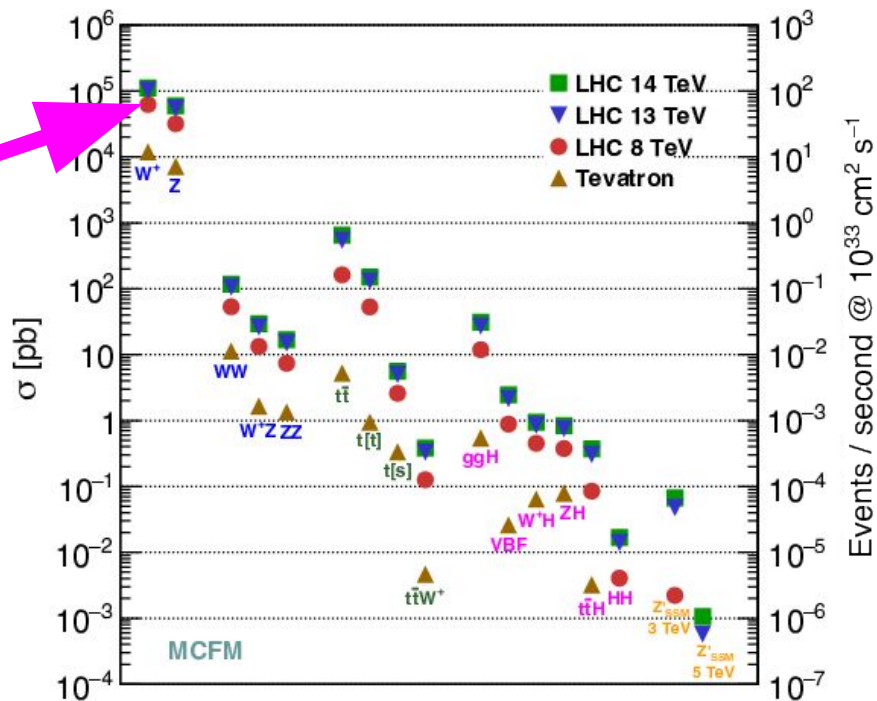
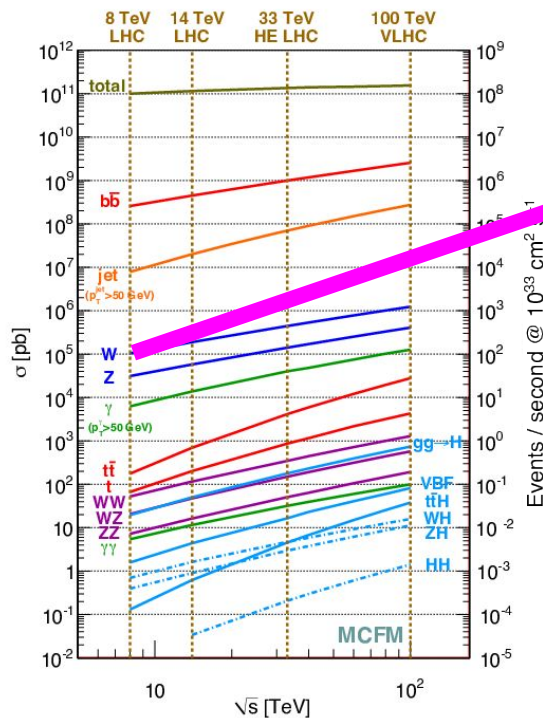
Dados adquiridos o outro lado da moeda



O desafio de escolher os acontecimentos interessantes as probabilidades estão contra nós...



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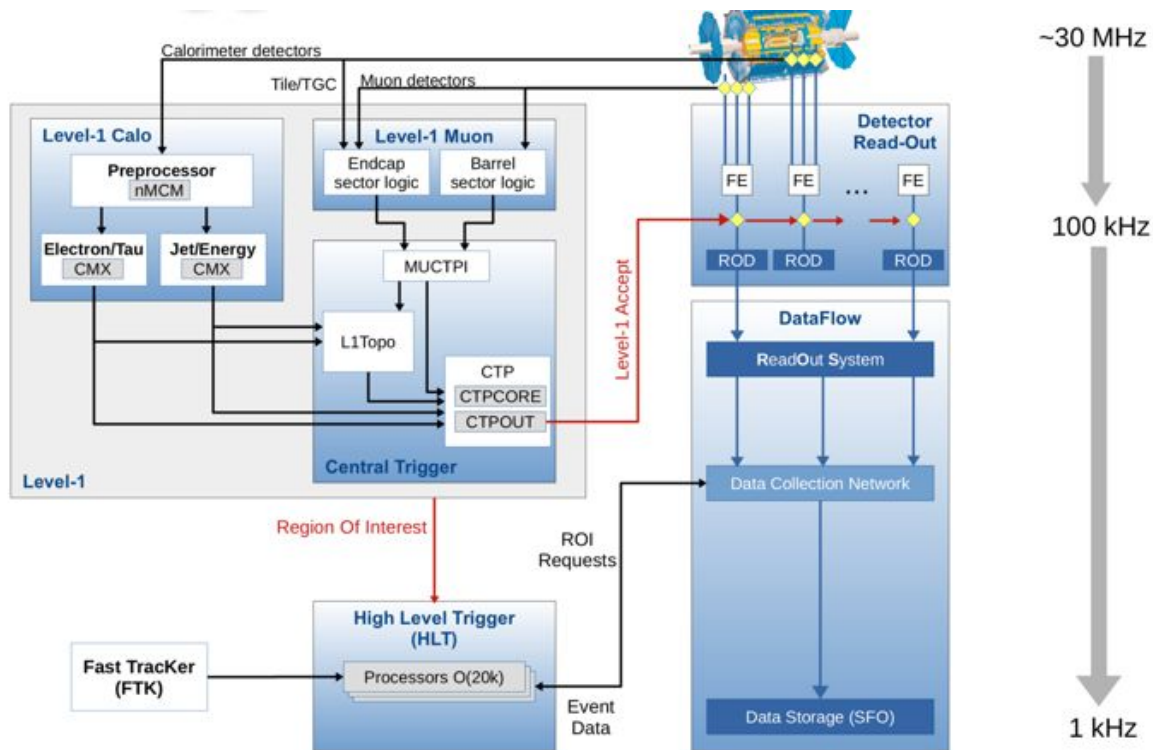
O desafio de escolher os acontecimentos interessantes as probabilidades estão contra nós...

- por limitações técnicas não podemos guardar todos os dados
 - temos de fazer escolhas...
 - com ~ 10 ordens de grandeza de diferença entre a secção eficaz total do LHC e as dos processos em que estamos interessados, não podemos deixar esta escolha ao acaso...



O desafio de escolher os acontecimentos interessantes

sistema de *trigger*

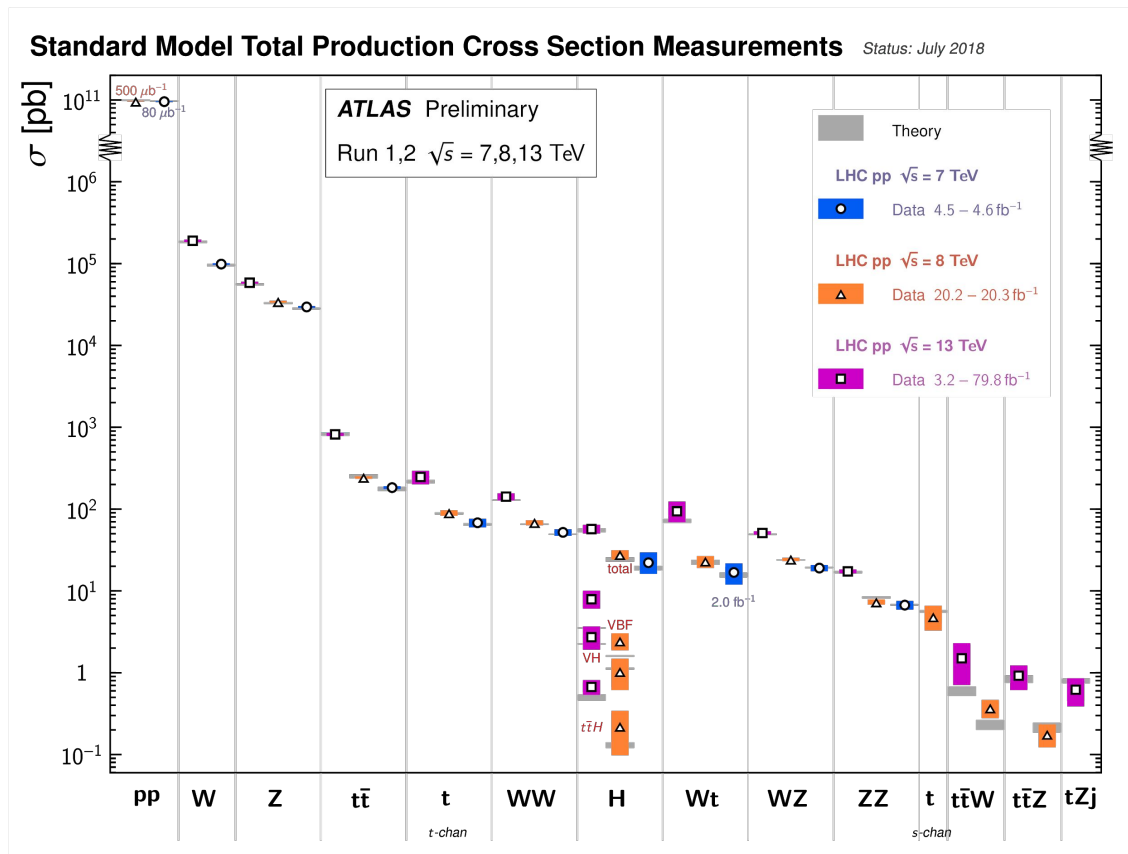


E o que queremos fazer com todos estes dados?

testar o Modelo Padrão !

- Comparação com as previsões teóricas

o acordo é excelente

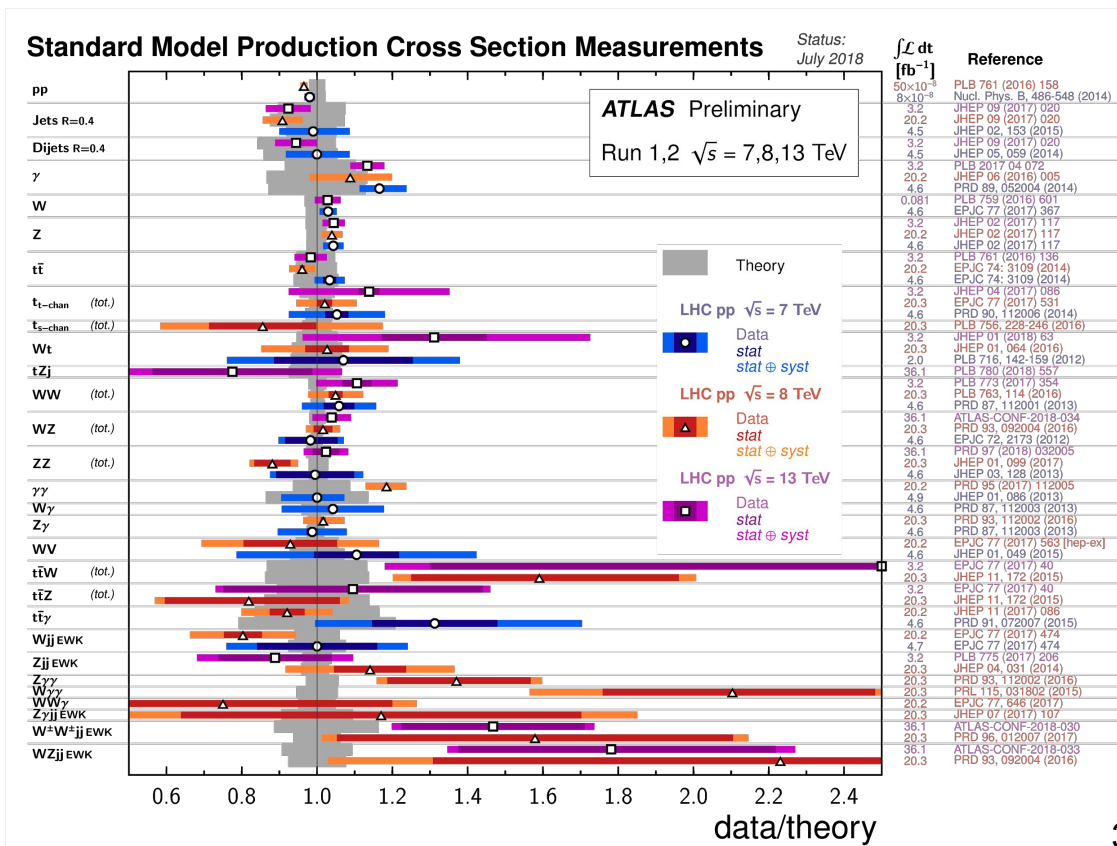


E o que queremos fazer com todos estes dados?

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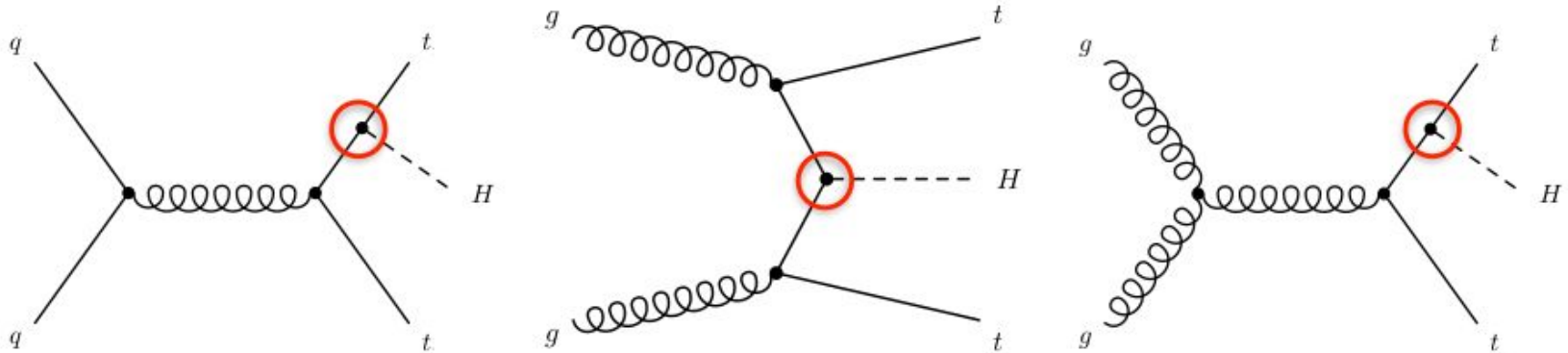
- Comparação com as previsões teóricas

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E o que queremos fazer com todos estes dados?

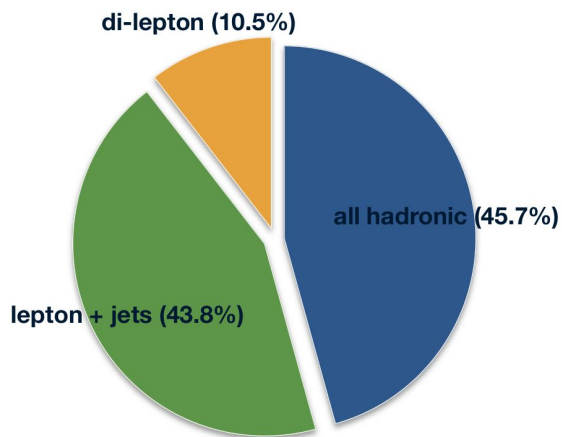
testar o Modelo Padrão - propriedades do bóson de Higgs



E o que queremos fazer com todos estes dados?

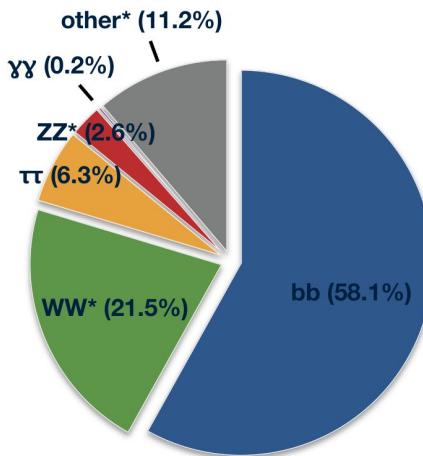
testar o Modelo Padrão - propriedades do bóson de Higgs

ttbar decay BRs



- all hadronic (45.7%)
- lepton + jets (43.8%)
- di-lepton (10.5%)

Higgs decay BRs

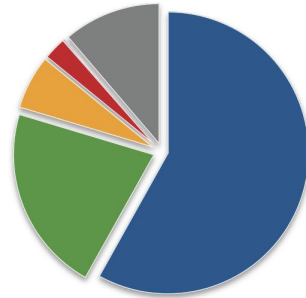


- bb (58.1%)
- WW* (21.5%)
- $\tau\tau$ (6.3%)
- ZZ* (2.6%)
- $\gamma\gamma$ (0.2%)
- other* (11.2%)

smaller BR,
higher purity
(generally)

E o que queremos fazer com todos estes dados?

testar o Modelo Padrão - propriedades do bóson de Higgs



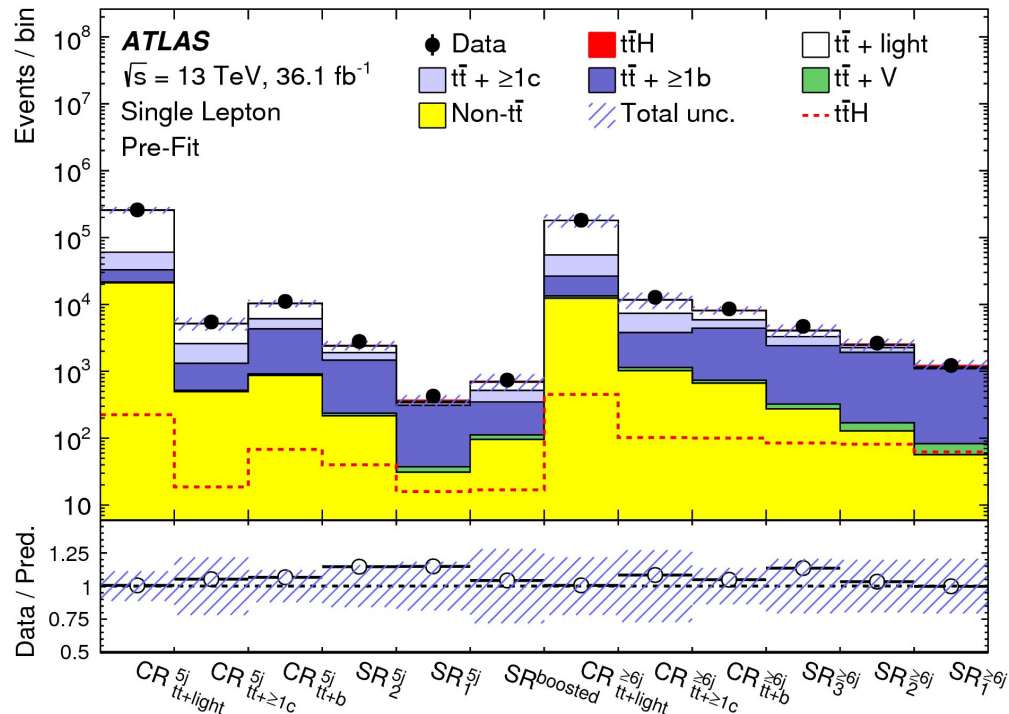
- bb (58.1%)
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smaller BR,
higher purity
(generally)

Channel	Dataset	Reference
ttH(bb)	36.1 fb ⁻¹ , 13 TeV	Phys. Rev. D 97, 072016
ttH multi-lepton (mostly H→WW* and H→ττ)	36.1 fb ⁻¹ , 13 TeV	Phys. Rev. D 97, 072003
ttH(ZZ*→4l)	79.8 fb ⁻¹ , 13 TeV	CERN-EP-2018-138 submitted to PLB
ttH(γγ)	79.8 fb ⁻¹ , 13 TeV	
ttH combination	36.1 - 79.8 fb ⁻¹ , 13 TeV	

E o que queremos fazer com todos estes dados?

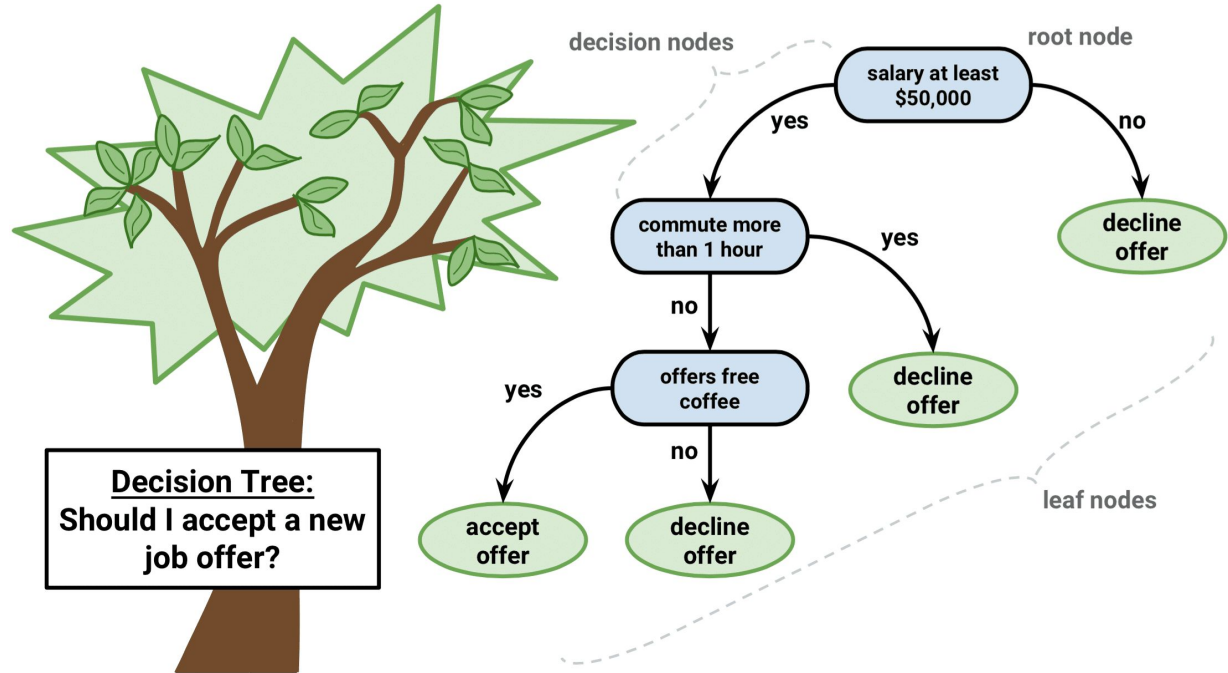
testar o Modelo Padrão - propriedades do bóson de Higgs



E o que queremos fazer com todos estes dados?

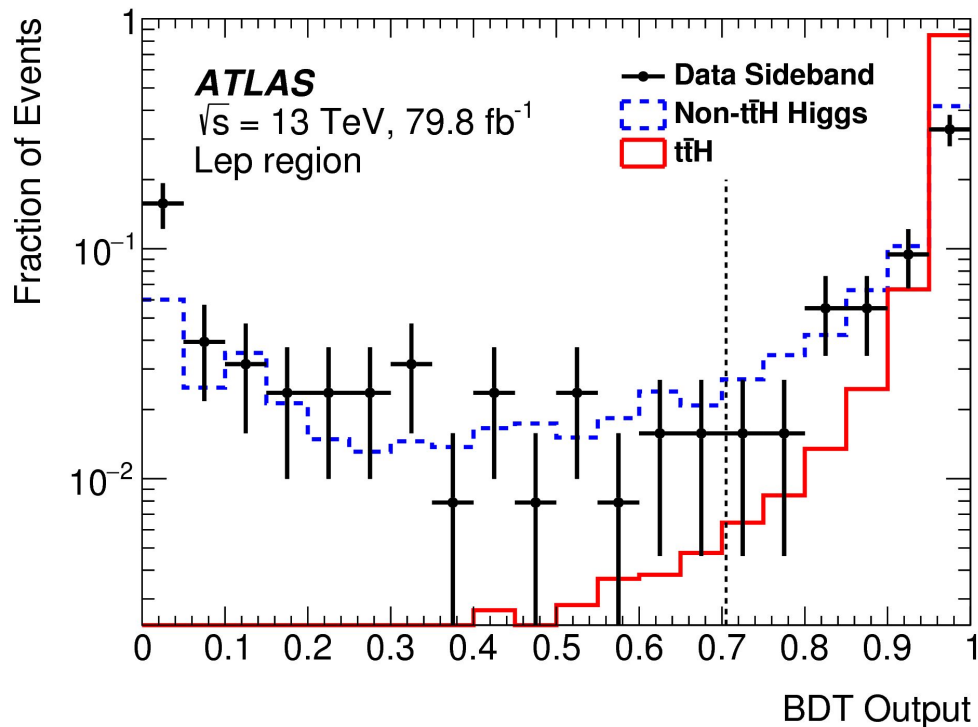
testar o Modelo Padrão - propriedades do bóson de Higgs

machine learning:
decision trees



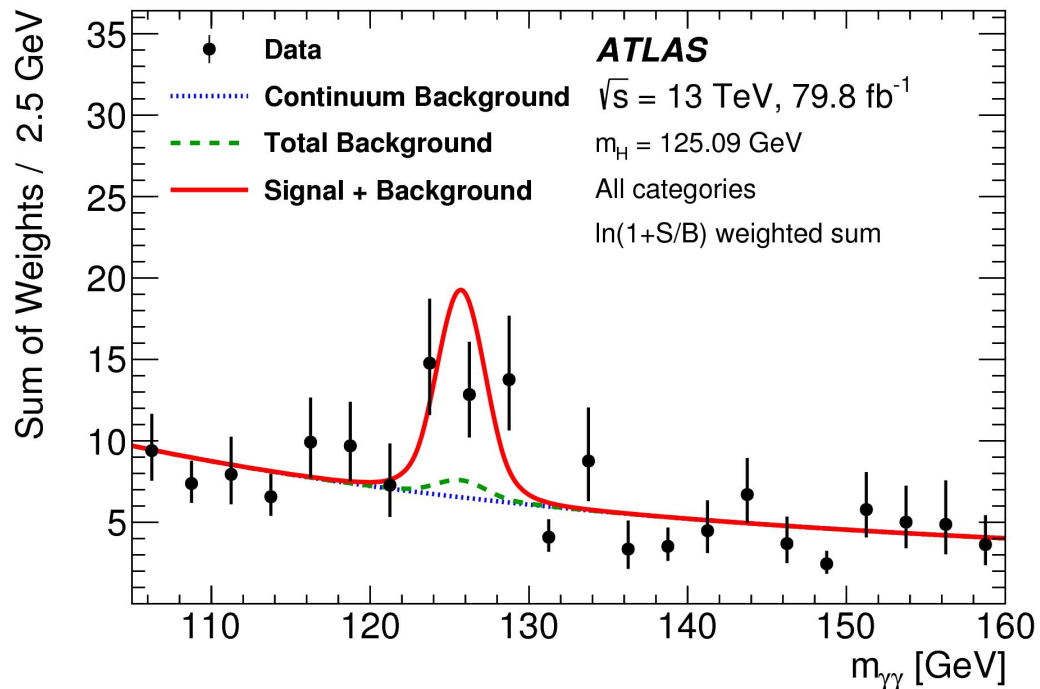
E o que queremos fazer com todos estes dados?

testar o Modelo Padrão - propriedades do bóson de Higgs



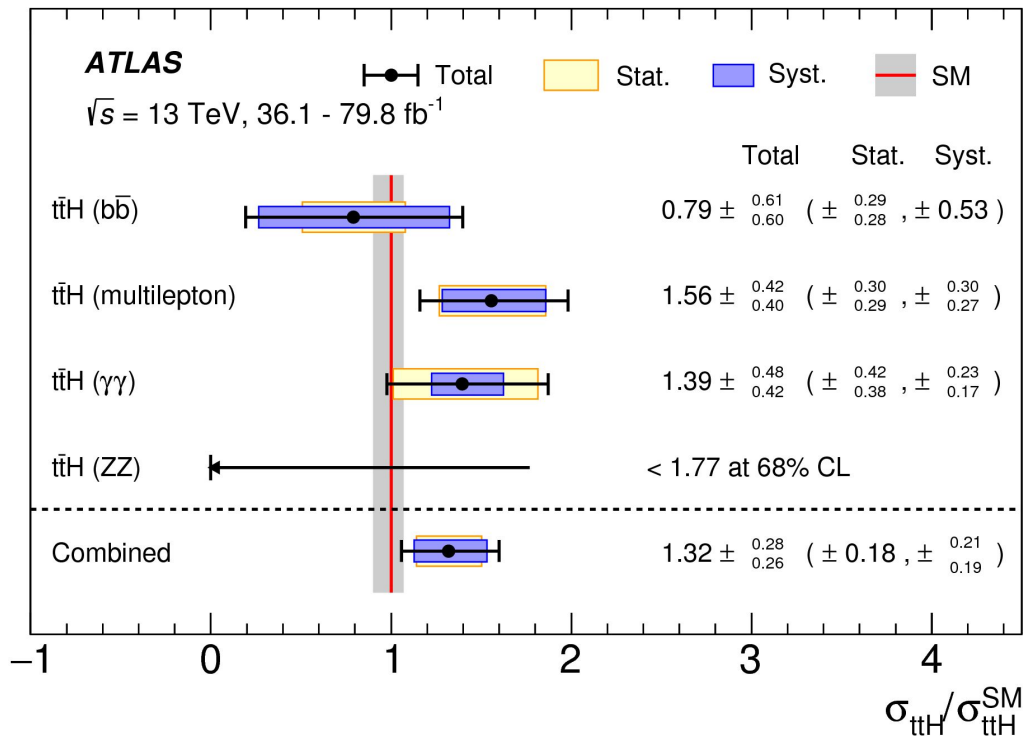
E o que queremos fazer com todos estes dados?

testar o Modelo Padrão - propriedades do bóson de Higgs



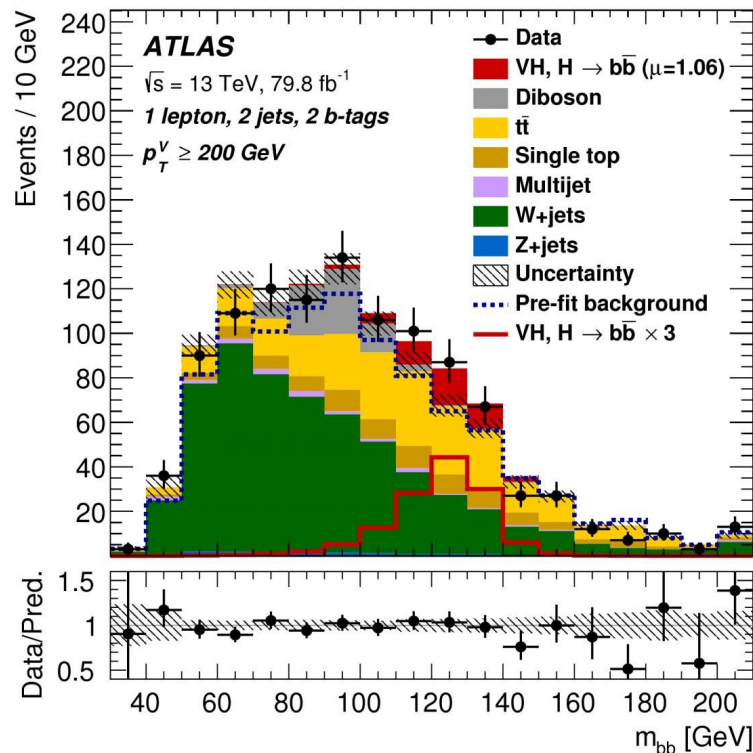
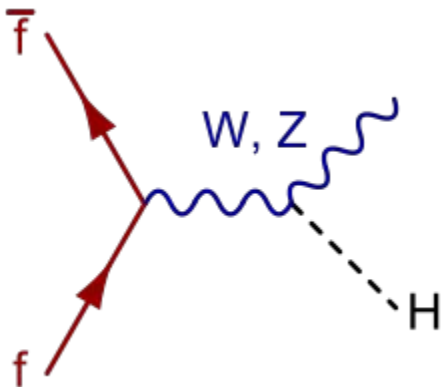
E o que queremos fazer com todos estes dados?

testar o Modelo Padrão - propriedades do bóson de Higgs



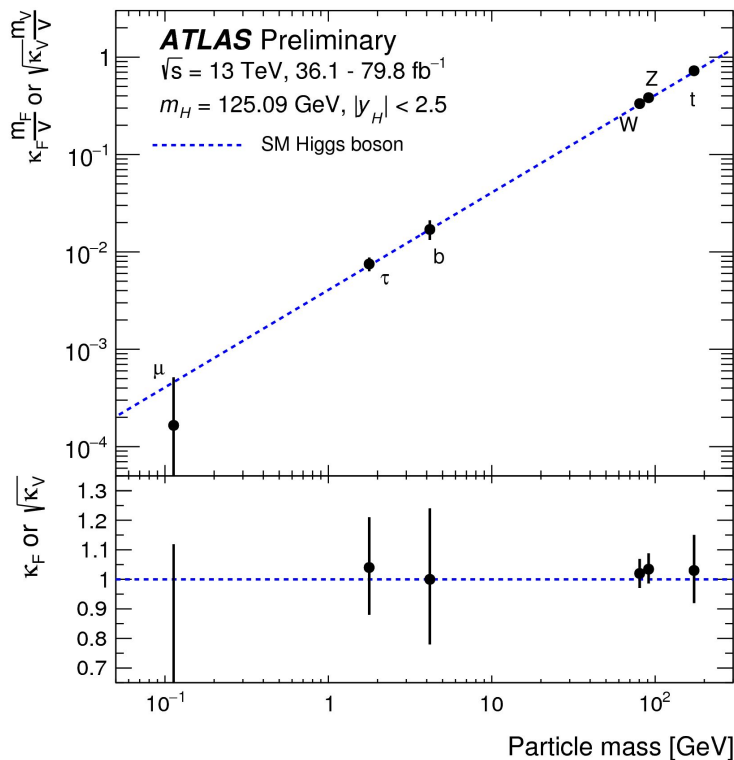
E o que queremos fazer com todos estes dados?

testar o Modelo Padrão - propriedades do bóson de Higgs



E o que queremos fazer com todos estes dados?

testar o Modelo Padrão - propriedades do bóson de Higgs



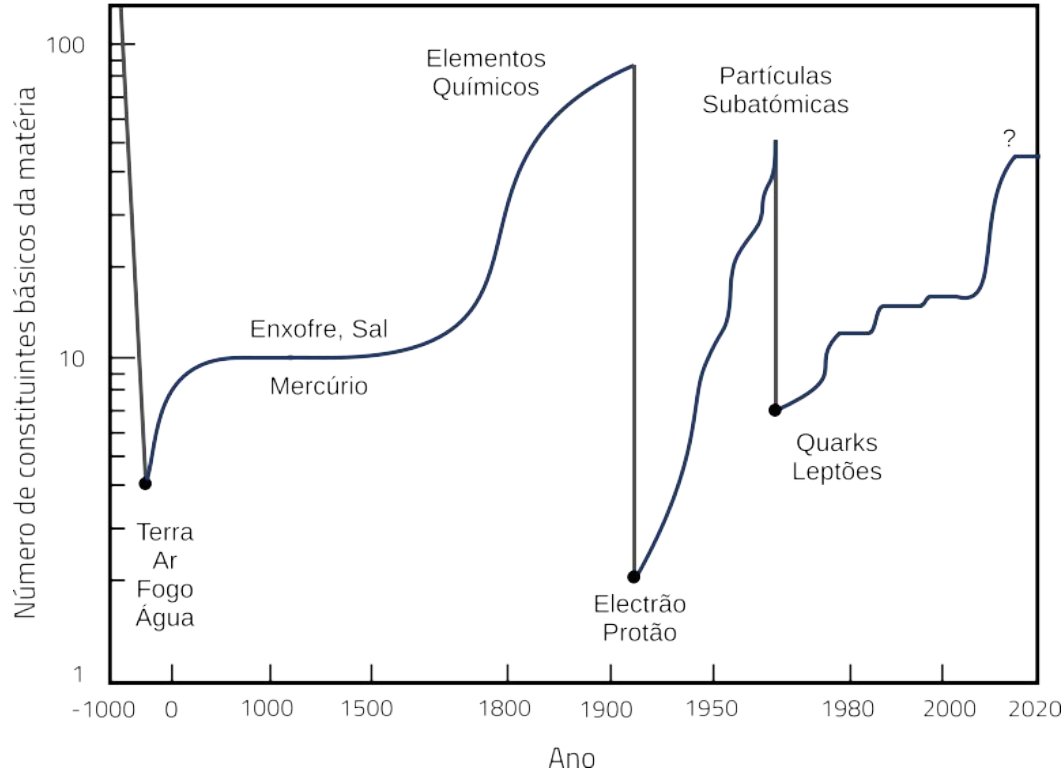
E o que queremos fazer com todos estes dados?

testar o Modelo Padrão (e o que mais houver)!

- Mas porquê procurar indícios de fenómenos para além do Modelo Padrão?
 - porque é uma obrigação científica dos experimentalistas ...
 - ... mas também porque há boas motivações para tal:
 - hierarquia de massa dos fermiões (e seu número)
 - assimetria matéria/anti-matéria
 - origem da matéria escura
 - ...

E o que queremos fazer com todos estes dados?

testar o Modelo Padrão (e o que mais houver)!



E o que queremos fazer com todos estes dados?

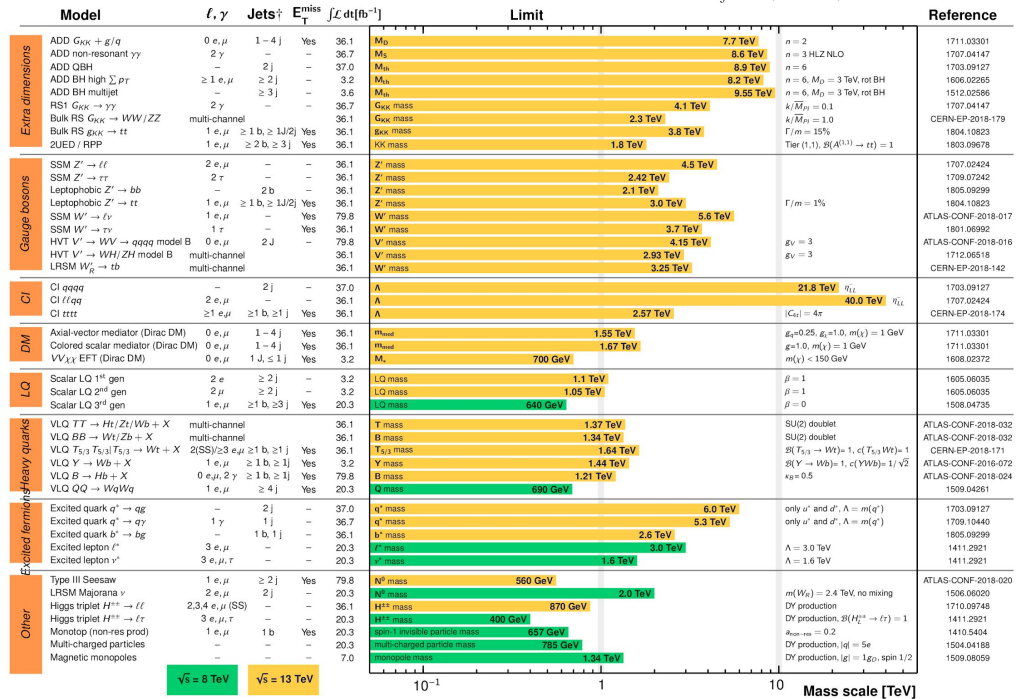
testar o Modelo Padrão (e o que mais houver)!

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2018

ATLAS Preliminary

$\int \mathcal{L} dt = (3.2 - 79.8) \text{ fb}^{-1}$ $\sqrt{s} = 8, 13 \text{ TeV}$



*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).

à procura do desconhecido

um exemplo: o problema da hierarquia

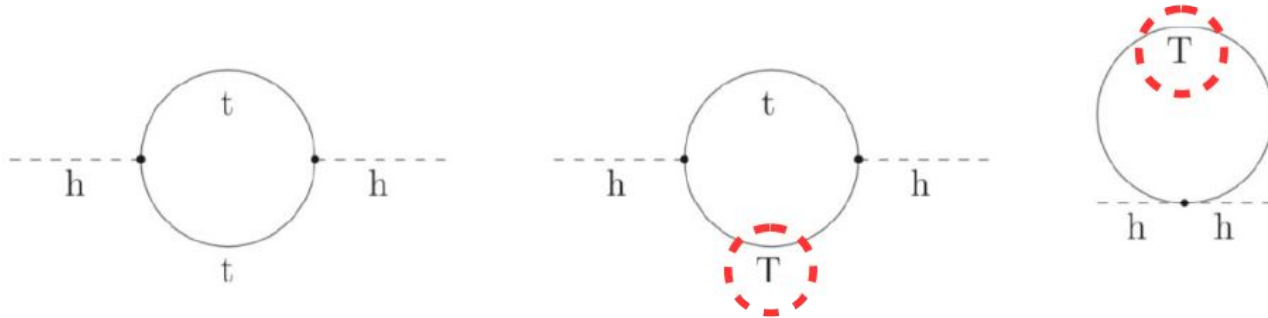
- Se assumirmos que tem de haver nova física a uma escala muito mais elevada do que a que nos é acessível agora (escala de unificação):
 - a massa do Higgs deixa de ser um parâmetro livre, sendo calculável:

$$M_H^2 = \begin{array}{r} \text{"bare mass"} \\ 3.2734594296342905438674964732159643 \\ -3.2734594296342905438674964732159645 \\ \hline = 10^{-32} \end{array} \quad \begin{array}{l} \text{(in planck units)} \\ \text{quantum} \\ \text{corrections, e.g.} \end{array} \quad \text{---} \bigcirc \text{---}$$

à procura do desconhecido

um exemplo: o problema da hierarquia

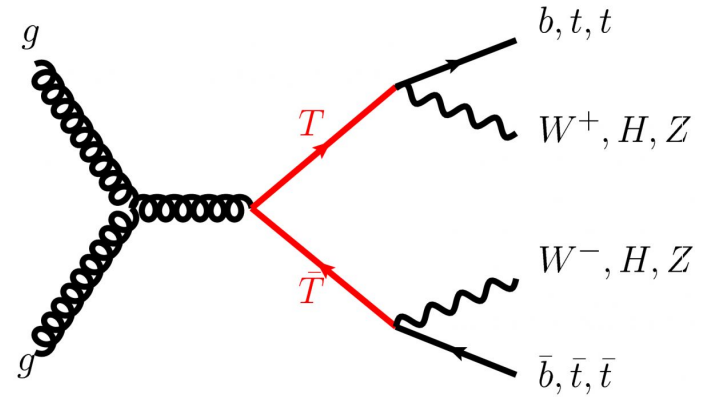
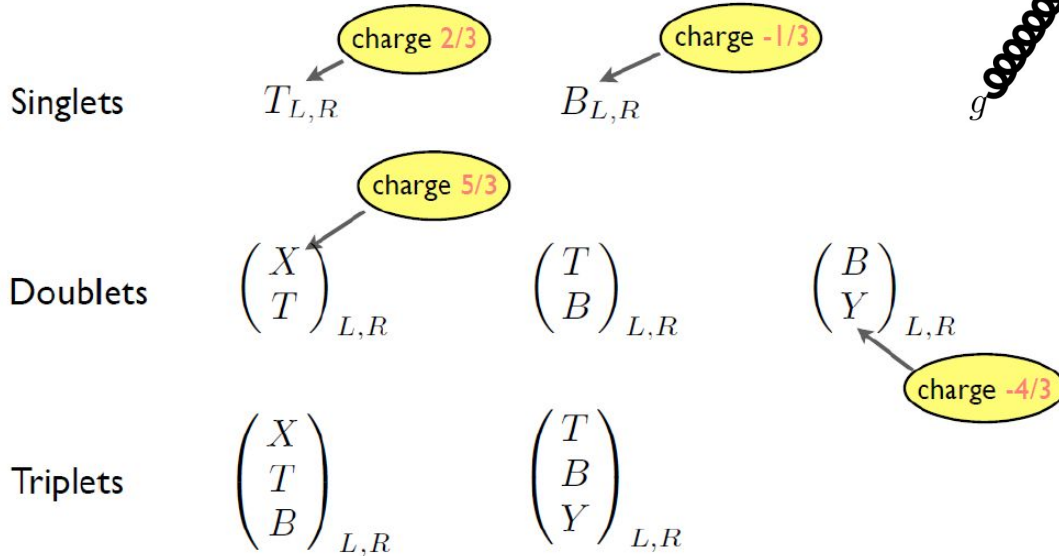
- A solução “natural” para fazer este balanceamento sem ajustes finos é ter novas partículas de massa elevada (parceiros do top)



$$M_H^2 \sim 10 - 9 = 1 \text{ (in units of } \sim 100 \text{ GeV squared)}$$

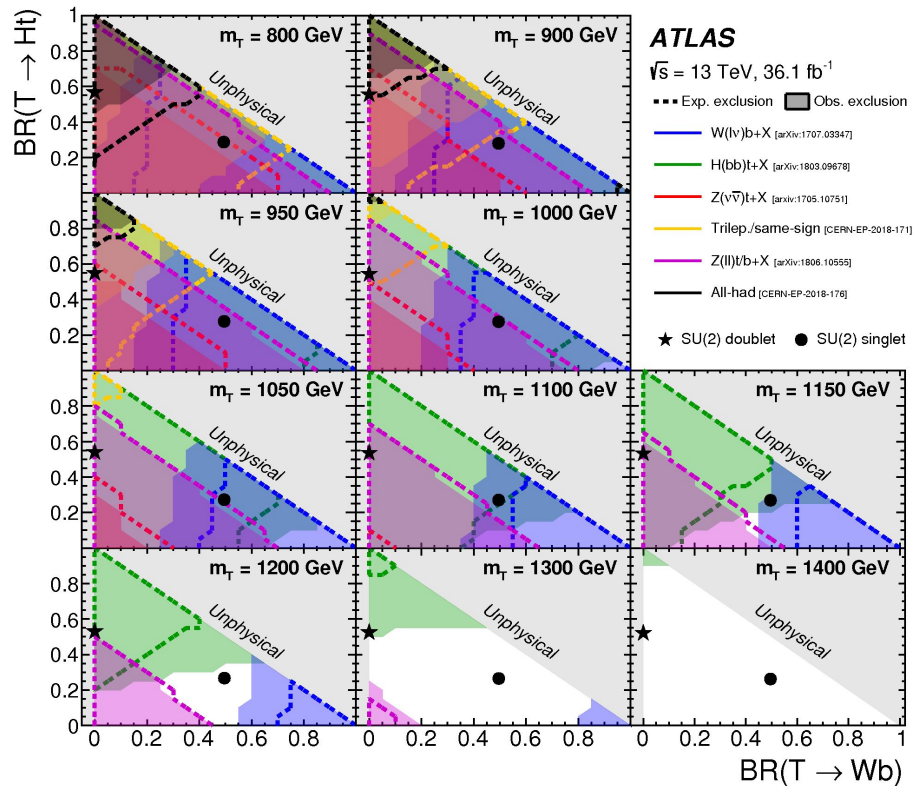
à procura do desconhecido

um exemplo: novos quarks (vectoriais)



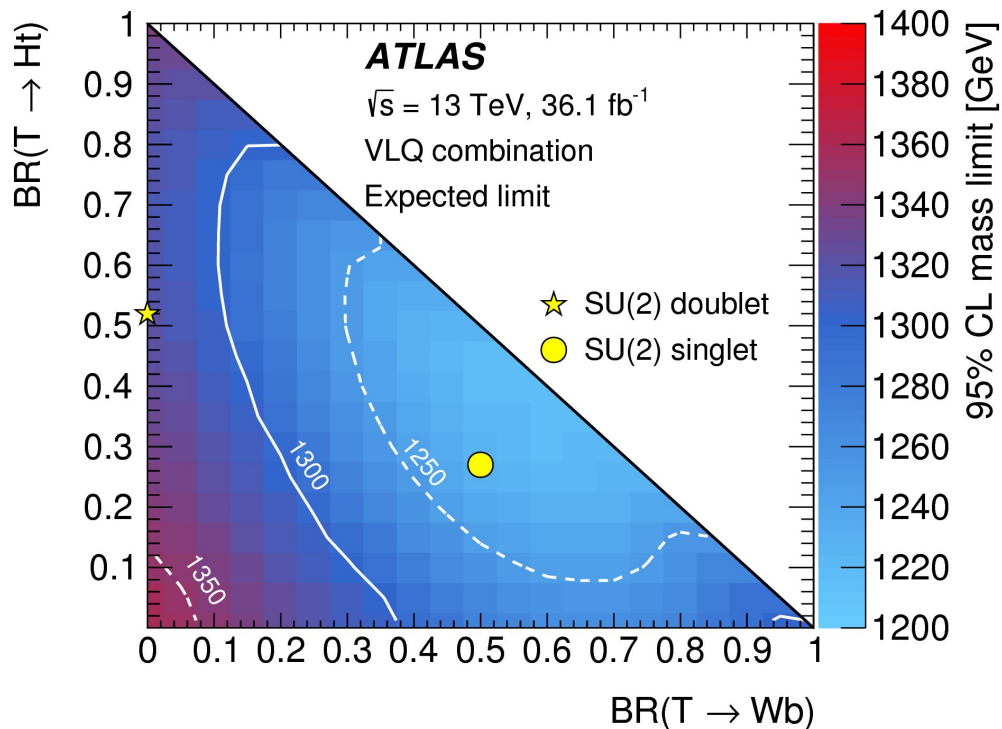
à procura do desconhecido

um exemplo: novos quarks (vectoriais)



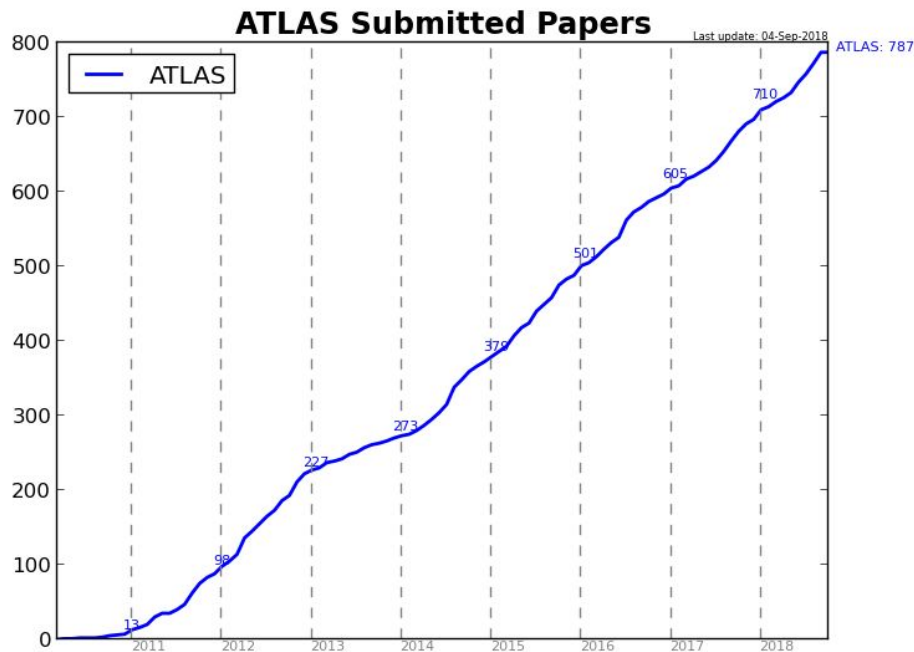
à procura do desconhecido

um exemplo: novos quarks (vectoriais)



Resumo dos resultados de ATLAS

missão impossível (nem sequer tentada aqui...)



Resumo dos resultados de ATLAS

physics briefings

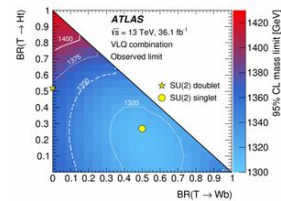
<https://atlas.cern/updates/briefing>

Physics Briefing

Could a new type of quark fix the “unnaturalness” of the Standard Model?

While the discovery of the Higgs boson at the Large Hadron Collider (LHC) in 2012 confirmed many Standard Model predictions, it has raised as many questions as it has answered. For example, interactions at the quantum level between the Higgs boson and the top quark ought to lead to a huge Higgs boson mass, possibly as large as the Planck mass ($>10^{18}$ GeV). So why is it only 125 GeV? Is there a mechanism at play to cancel these large quantum corrections caused by the top quark (t)? Finding a way to explain the lightness of the Higgs boson is one of the top (no pun intended) questions in particle physics.

[Read more →](#)

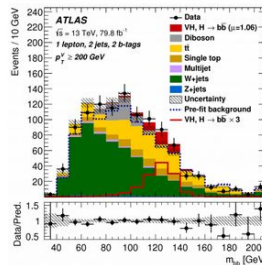


Physics Briefing

Higgs boson observed decaying to b quarks – at last!

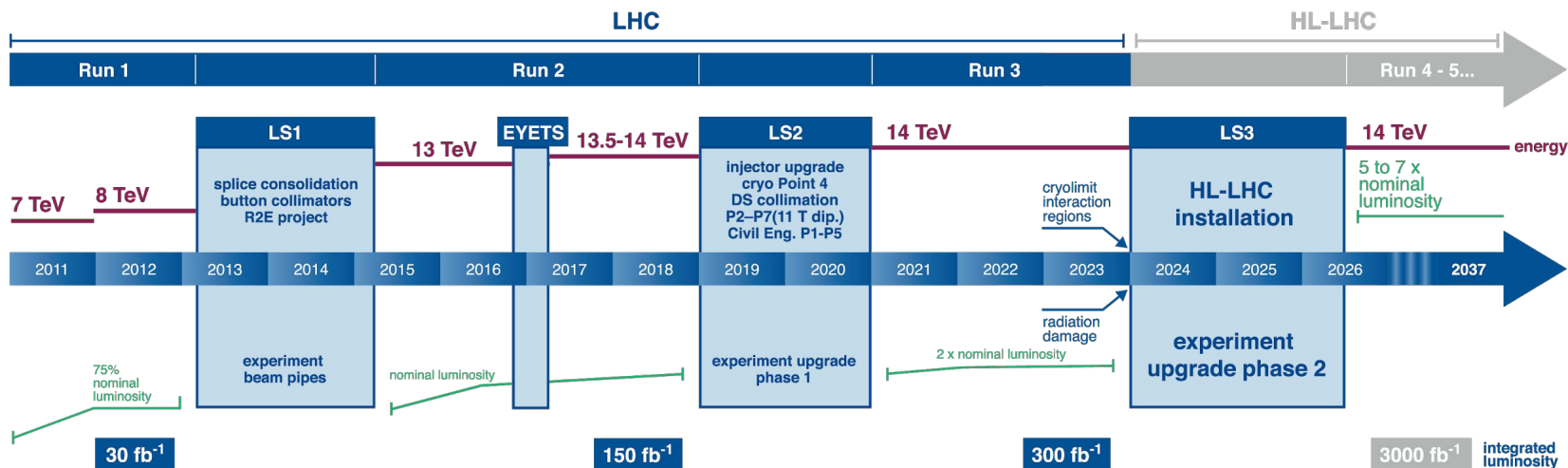
Today, at the 2018 International Conference on High Energy Physics in Seoul, the ATLAS experiment reported a preliminary result establishing the observation of the Higgs boson decaying into pairs of b quarks, furthermore at a rate consistent with the Standard Model prediction.

[Read more →](#)



O futuro ATLAS e LHC

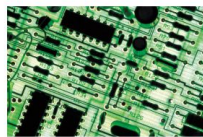
LHC / HL-LHC Plan



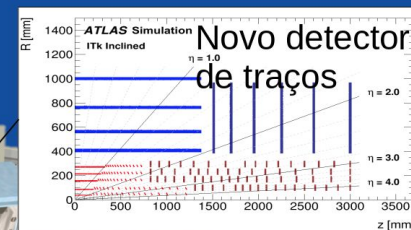
O futuro ATLAS e LHC



Nova eletrônica, fontes de alta tensão e cintiladores do calorímetro



Hardware para reconstruir traços carregados (trigger)



Novo detector de muões "Small Wheel"

High Granularity Timing Detector (30ps/traço)

Obrigado pela atenção

Perguntas?

podem sempre contactar-me via nfcastro@lip.pt
e estarei por cá até ao fim da semana - tenho todo o prazer em
discutir quaisquer pontos que queiram

And now
for something
completely different...





O programa HYPATIA

Canvas Window - File: jiveXML_165632_82716614.xml Run: 165632 Event: 82716614
ATLAS 2010-09-24 07:01:05 CEST source:jiveXML_165632_82716614 HYPATIA

Y (m)

X (m)

Bottom-left plot: ATLAS detector cross-section in the X-Z plane. The detector is shown as concentric rings of blue and orange segments. A central event is shown with tracks in cyan and green. The axes range from -20 to 20 meters.

Z (m)

Top-right window: HYPATIA - Track Momenta Window

Previous Event Next Event Insert Electron Insert Muon Delete
ETRLs: 7.384 GeV ϕ : 2.227 rad Collection: MET RefFinal
MasterClass/zpath/Els/jiveXML_165632_82716614.xml

Reconstructed Tracks

Track	±	P [GeV]	Pt [GeV]	η	θ
Tracks 15	+	1.32	1.19	0.728	1.126
Tracks 23	+	1.81	1.81	-3.046	1.513
Tracks 24	+	1.64	1.63	-1.903	1.695
Tracks 26	+	5.08	1.53	-0.616	2.835
Tracks 30	+	2.19	1.27	-2.001	2.526
Tracks 31	+	6.86	1.21	2.569	0.177
Tracks 32	+	1.58	1.55	1.978	1.766
Tracks 34	-	5.41	1.81	-3.037	2.801
Tracks 36	-	10.23	2.05	1.480	2.940
Tracks 40	+	4.73	1.45	-2.665	2.830
Tracks 54	-	60.96	33.55	2.296	2.559

Bottom-right window: HYPATIA - Control Window

Interaction and Window Control Output Display

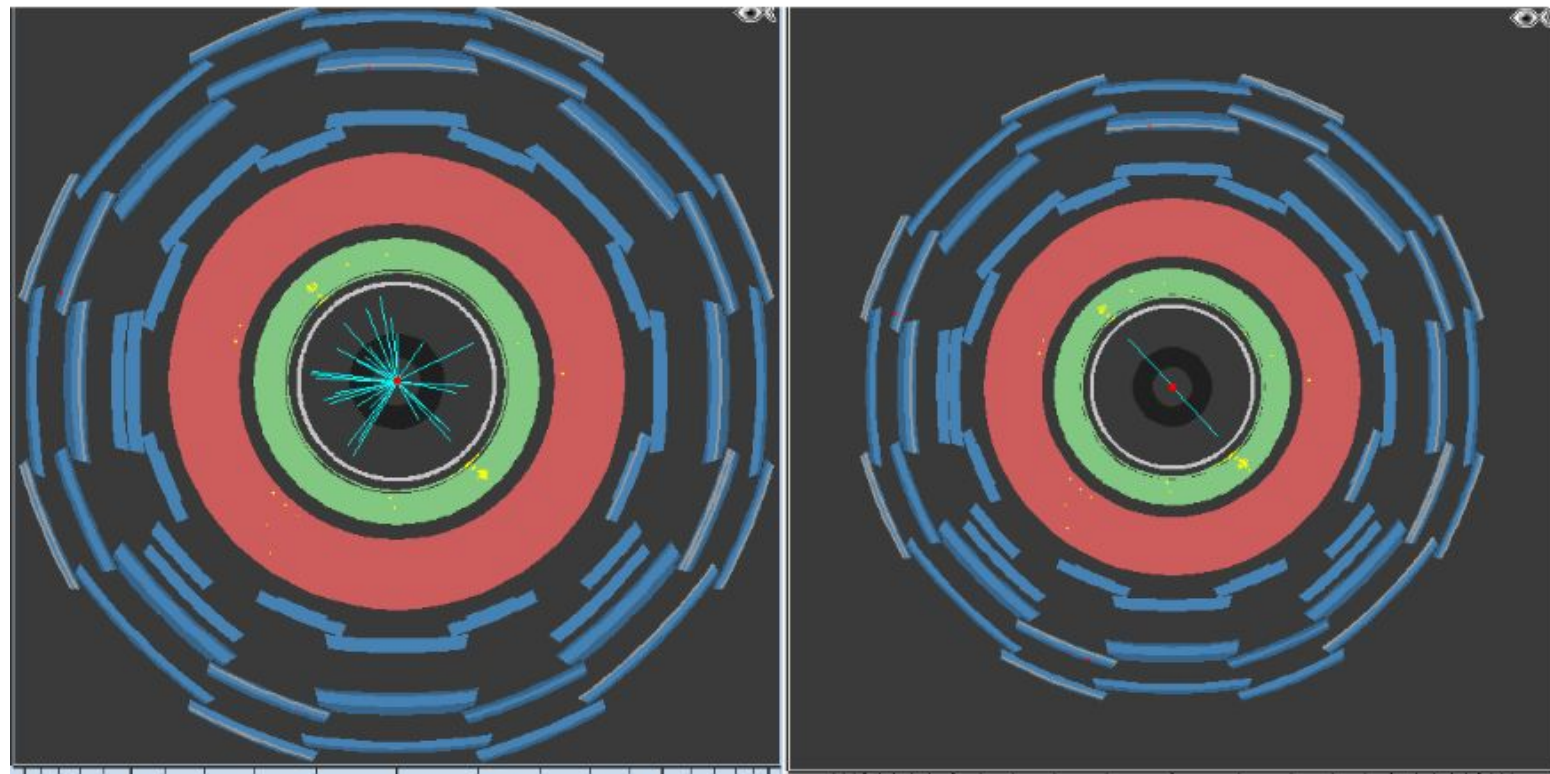
Parameter Control

InDet Calo MuonDet Objects Geometry

Projection Data Cuts

InDet	Name	Value
Calo	<input checked="" type="checkbox"/> PT	> 1.0 GeV
MuonDet	<input checked="" type="checkbox"/> d0	< 6.5 mm
Objects	<input checked="" type="checkbox"/> z0	< 25.0 cm
ATLAS	<input type="checkbox"/> d0 Loose	< 2.0 cm
	<input type="checkbox"/> z0-zVtx	< 2.5 mm
	<input type="checkbox"/> Layer	> 0
	<input type="checkbox"/> Number Pixel Hits	>= 2
	<input type="checkbox"/> Number SCT Hits	>= 7
	<input type="checkbox"/> Number TRT Hits	>= 30
	<input type="checkbox"/> Sim. Particle PDG-ID	< 40
	<input type="checkbox"/> Sim. Particle Barcode	= 0

cortes: ver apenas traços com $PT > 25\text{GeV}$



$Z \rightarrow e^+e^-$

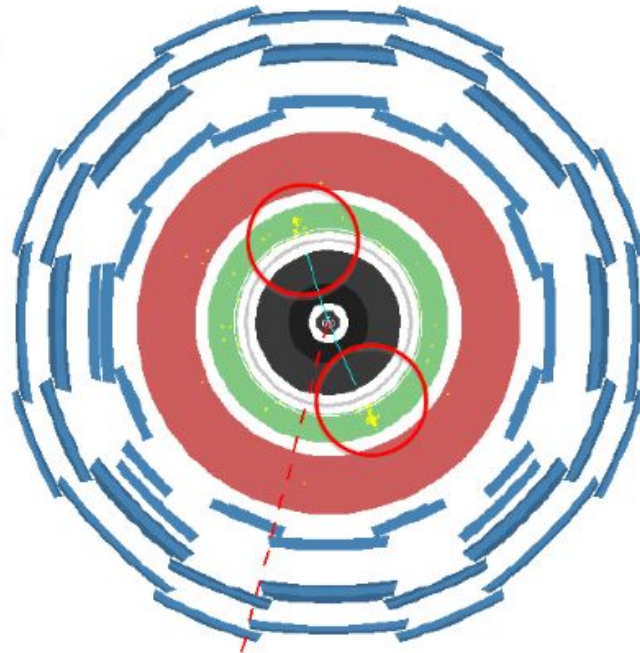
Previous Event Next Event Insert Electron Insert Muon Delete Track

ETMis: 16.510 GeV ϕ : -1.826 rad Collection: MET_Refin

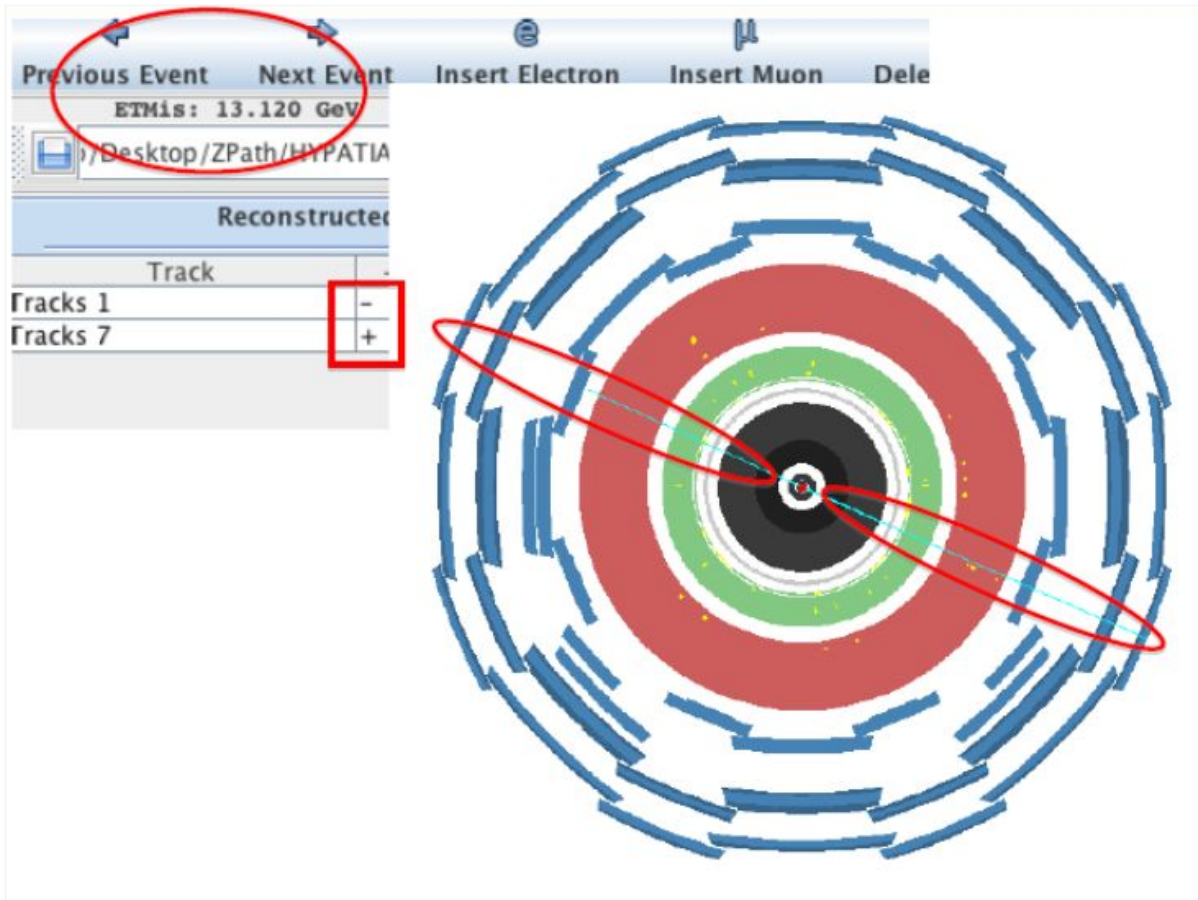
/Desktop/ZPath/HYPATIA/HYPATIA/events/groupA.zip/event005.xml

Reconstructed

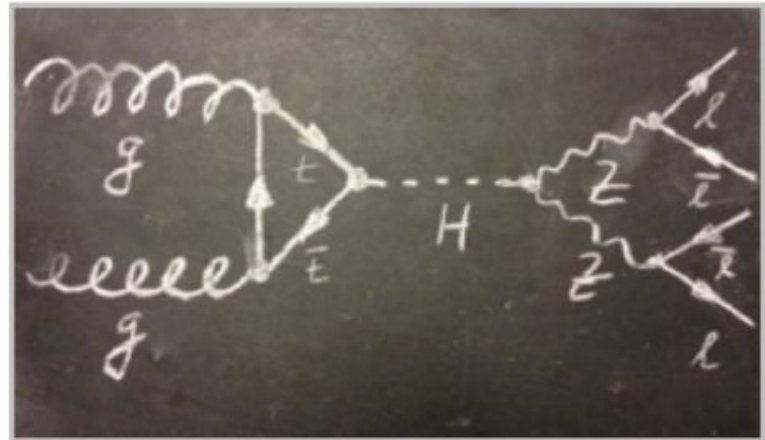
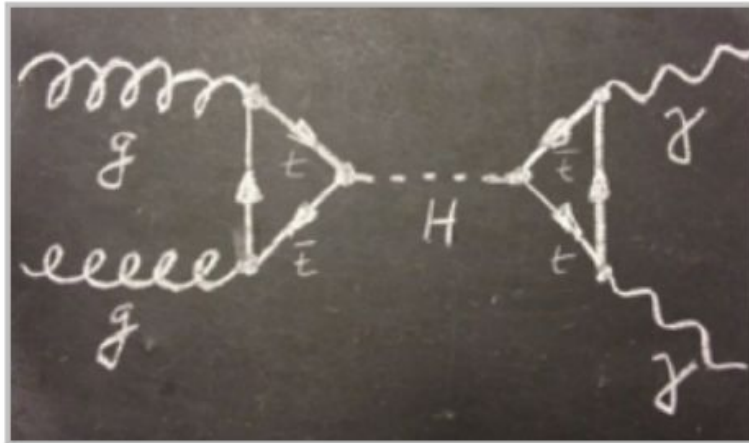
Track	
Tracks 3	+
Tracks 65	-



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

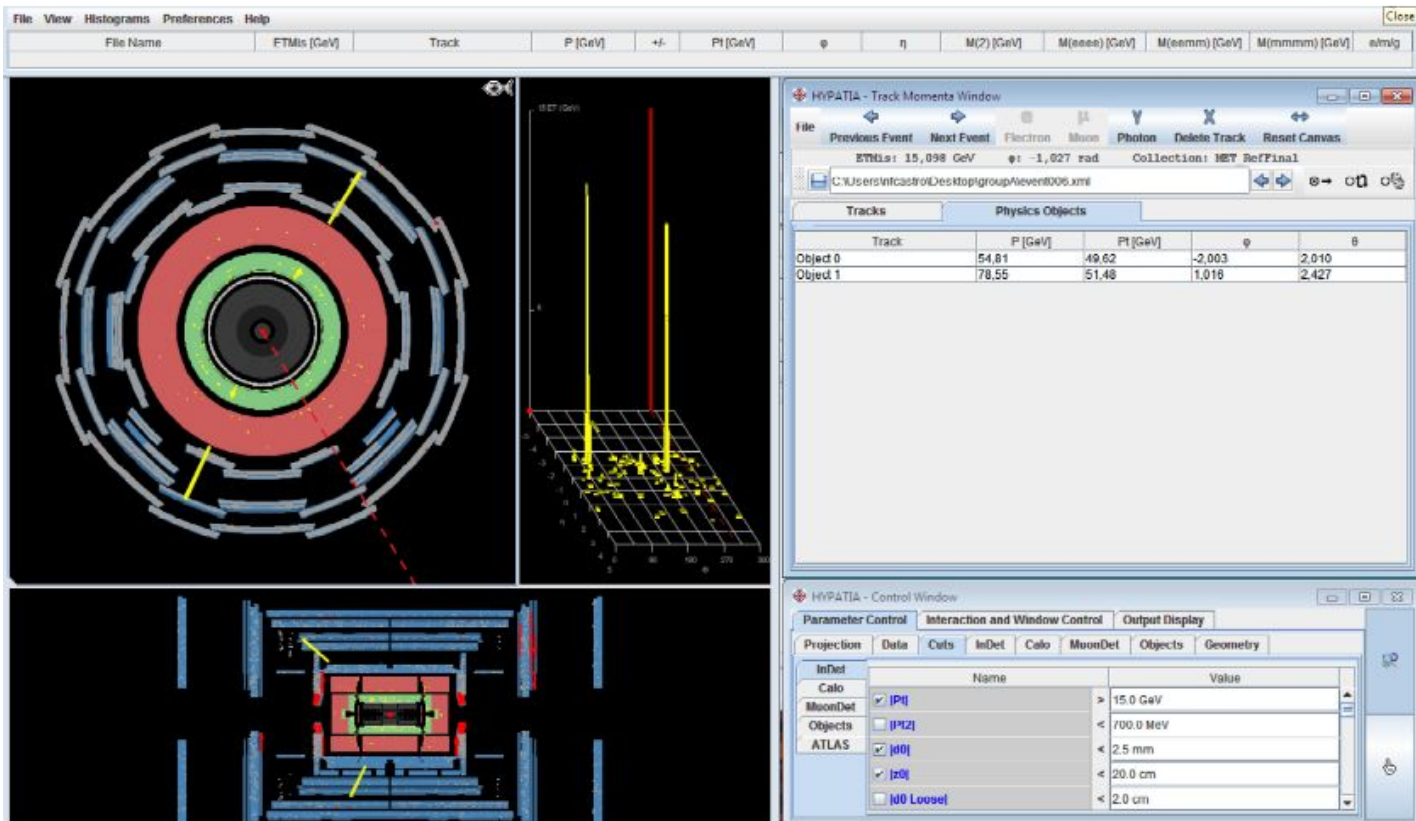


O Bosão de Higgs



O Bosão de Higgs

$$H \rightarrow \gamma\gamma$$







<http://opendata.atlas.cern>

