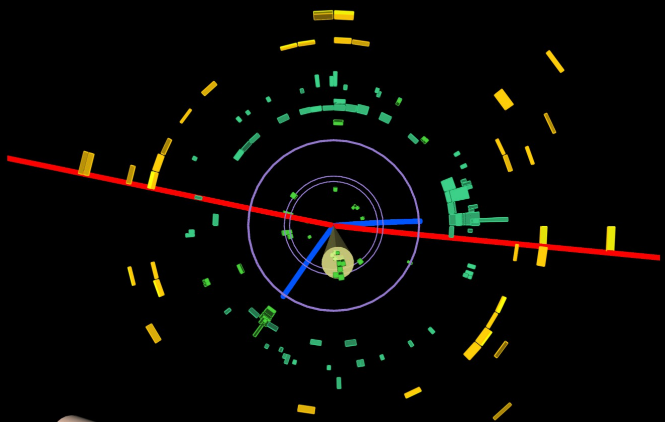
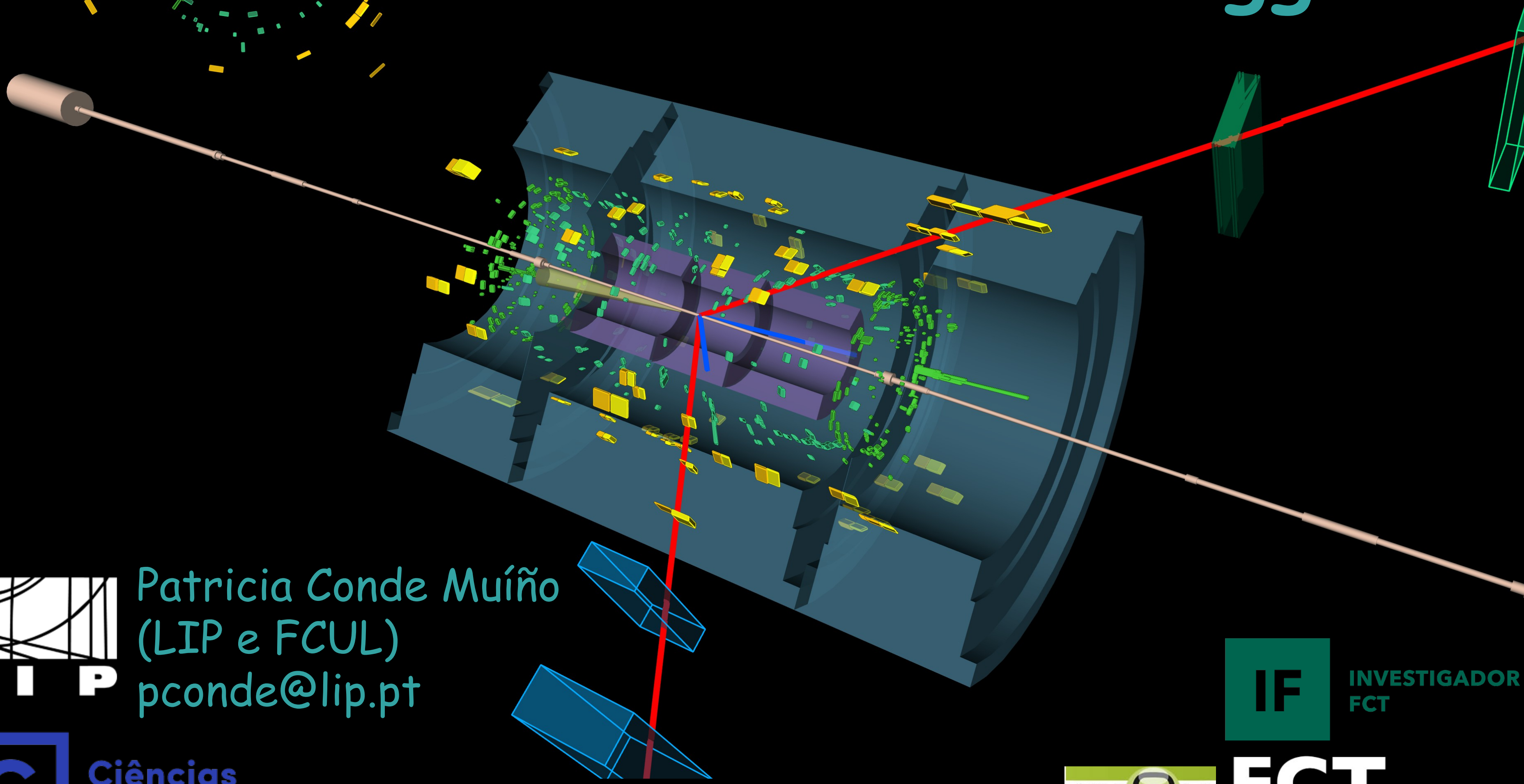


O bosão de Higgs



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LIP
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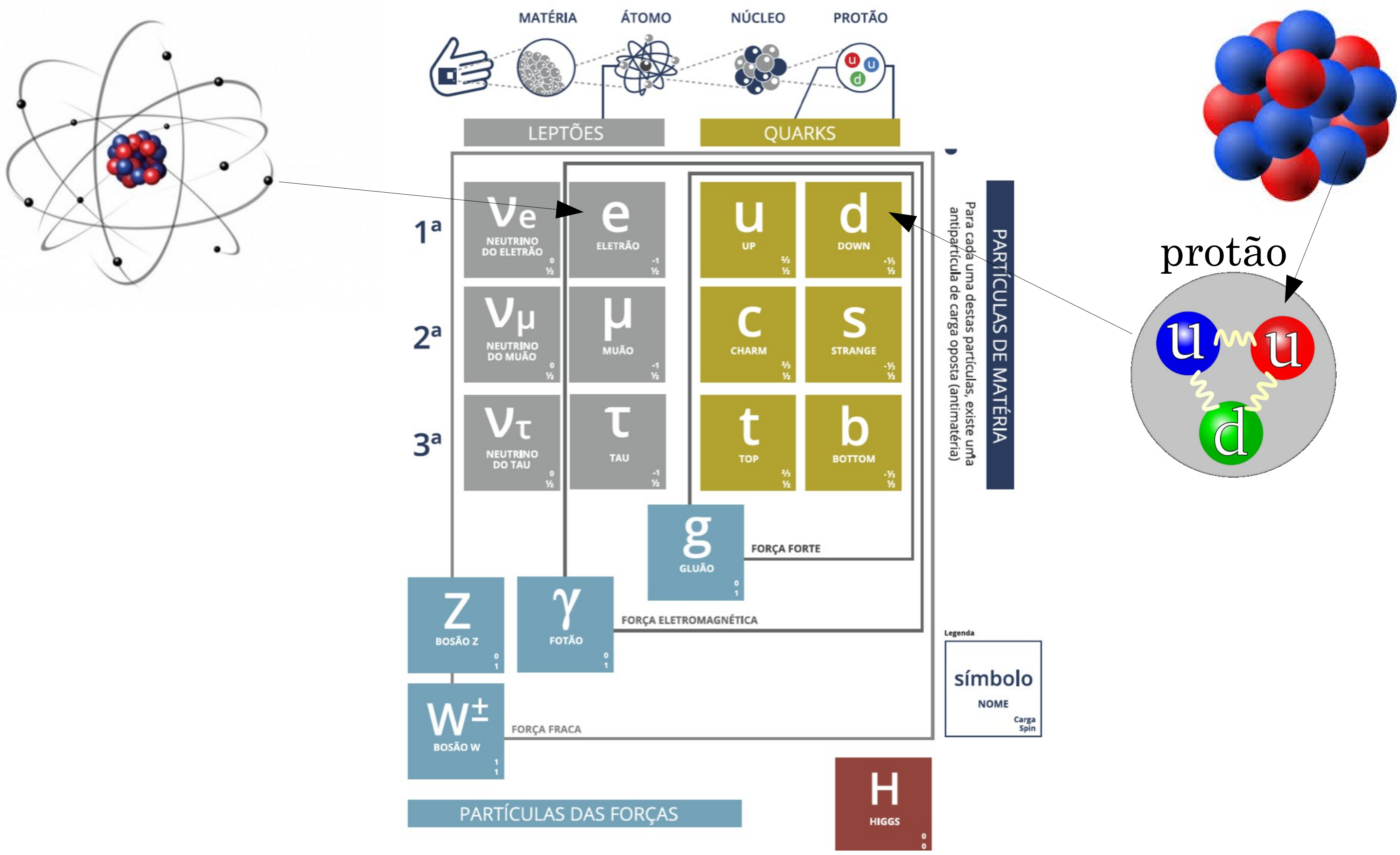
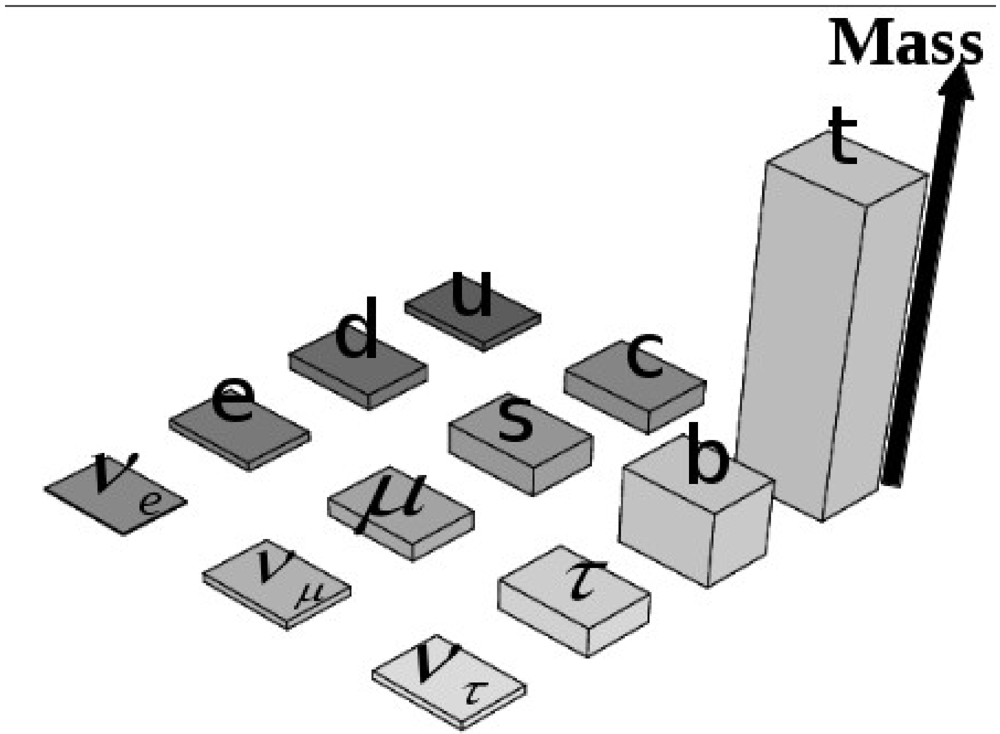
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

O Modelo Padrão da Física de Partículas



O problema da massa no Modelo Padrão

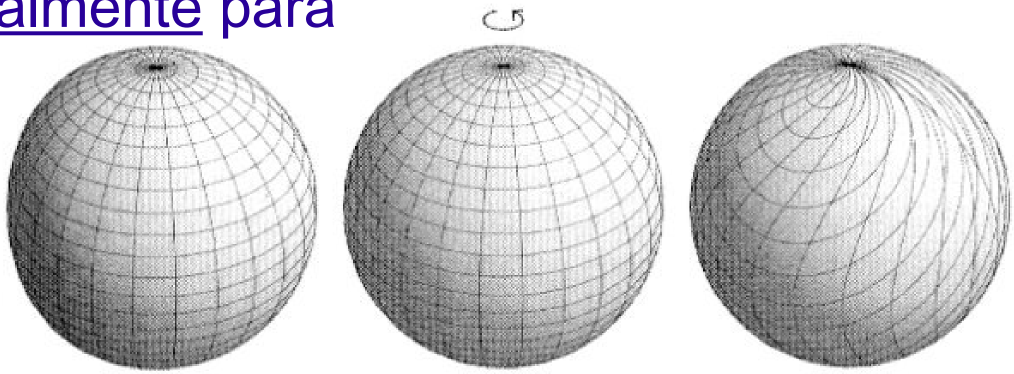
- Porque uma diferença tão grande nas massas das partículas fundamentais?



Simetrias na Teoria de Campo

- Simetrias → Interações!

  equações invariantes <u>localmente</u> para certas simetrias



aparecem novos campos, que descrevem as forças !!

Grupo de simetrias do Modelo Padrão

mudança de fase — rotações em 3D — generalização do SU(2)

U(1) x SU(2) x SU (3)

- U(1) → Fotão, Electromagnetismo
- SU(2) → Interacções fracas, Bosões W^+,W^-,Z
- SU (3) → Interação forte, Gluões

Interacções electrofracas

- Introduzidas no MP através de uma teoria gauge baseada na simetria $SU(2)_L x U(1)_Y$

Lagrangiano das partículas libres

$$\mathcal{L} = -\frac{1}{2} \mathbf{W}_{\mu\nu} \cdot \mathbf{W}^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}$$

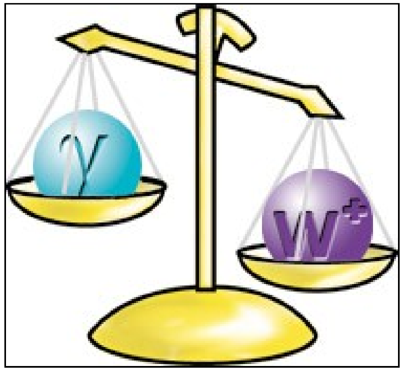
Termos cinéticos e de interacção dos campos W e B

$$+ \overline{\psi}_L \gamma^\mu \left(i\partial_\mu - g' \frac{Y}{2} B_\mu - g \frac{1}{2} \boldsymbol{\tau} \cdot \mathbf{W}_\mu \right) \psi_L$$

$$+ \overline{\psi}_R \gamma^\mu \left(i\partial_\mu - g' \frac{Y}{2} B_\mu \right) \psi_R$$

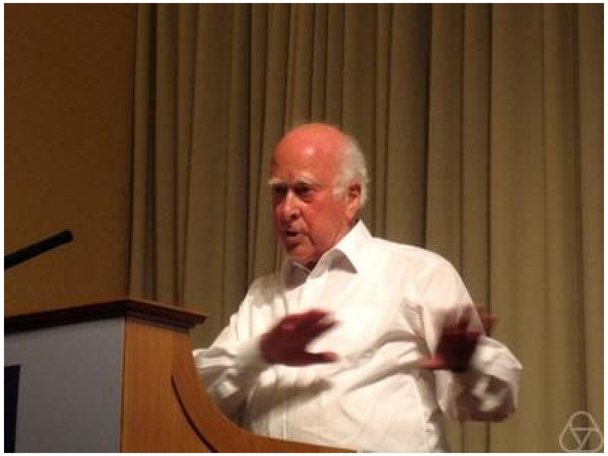
Interacções fermiónicas

- Os termos de massa violam a simetria!
- Como se resolve isto?



Solução

- Mecanismo de Higgs
  (ou Mecanismo de Higgs-Brout-Englert
  ou Mecanismo de Higgs-Brout-Englert-Guralnik-Hagen-Kibble)
- Proposto em 1964 por 3 grupos distintos



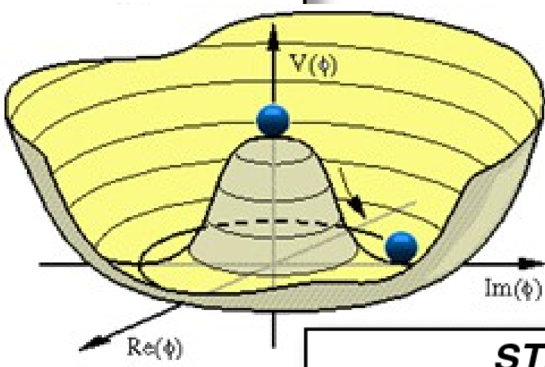
O mecanismo de Higgs

HIGGS FIELD

Complex weak isospin scalar doublet Φ with scalar potential $V[\Phi]$

$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \qquad V[\Phi] = \mu^2\Phi^\dagger\Phi + \lambda\,(\Phi^\dagger\Phi)^2$$

$$(\lambda > 0,\ \mu^2 < 0)$$



STANDARD MODEL

Yang-Mills $SU(2)_L \times U(1)_Y$

massless gauge bosons W_μ and B_μ

and *massless* fermions ψ

$$\mathscr{L} = -\frac{1}{2}W_{\mu\nu}\cdot W^{\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu}$$
$$+\left|\left(i\partial_\mu - g'\frac{Y}{2}B_\mu - g\frac{1}{2}\boldsymbol{\tau}\cdot W_\mu\right)\Phi\right|^2 - V(\Phi)$$
$$+\bar{\psi}_L\gamma^\mu\left(i\partial_\mu - g'\frac{Y}{2}B_\mu - g\frac{1}{2}\boldsymbol{\tau}\cdot W_\mu\right)\psi_L$$
$$+\bar{\psi}_R\gamma^\mu\left(i\partial_\mu - g'\frac{Y}{2}B_\mu\right)\psi_R$$

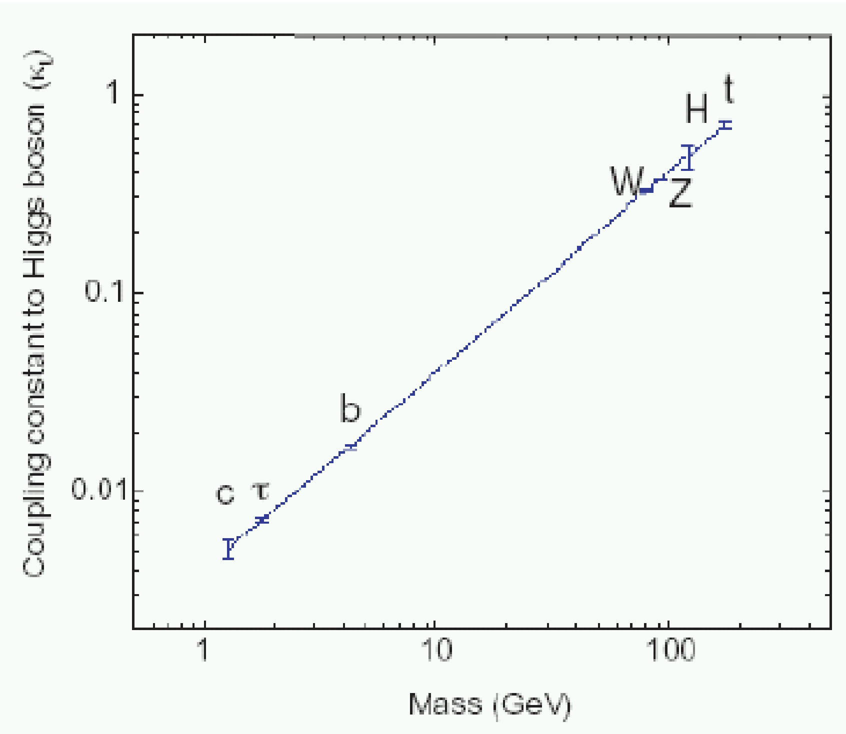
SPONTANEOUS SYMMETRY BREAKING

One component acquires non-zero vacuum expectation value

$$\langle 0|\Phi|0\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v \end{pmatrix} \longrightarrow \Phi(x) = \frac{1}{\sqrt{2}}\exp\left(i\frac{\xi\cdot\tau}{2v}\right)\begin{pmatrix} 0 \\ v + H(x) \end{pmatrix}$$

- Prevê uma nova partícula: o Bosão de Higgs!

As massas



- As massas das partículas sao proporcionais ao seu acoplamento ao bosão de Higgs
- Declive predito pela teoria:

  $v = 2M_W/g = 246$ GeV

- Acoplamentos aos fermiões determinados experimentalmente a través das medidas das massas

MASSIVE GAUGE BOSONS

$$W^{\pm}_{\mu} = \frac{1}{2}(W^1_{\mu} \mp iW^2_{\mu}) \qquad M_W = \frac{gv}{2}$$

$$Z_{\mu} = -B_{\mu}\sin\theta_W + W^3_{\mu}\cos\theta_W \qquad M_Z = \frac{M_W}{\cos\theta_W}$$

$$A_{\mu} = B_{\mu}\sin\theta_W + W^3_{\mu}\cos\theta_W \qquad M_{\gamma} = 0$$

MASSIVE FERMIONS

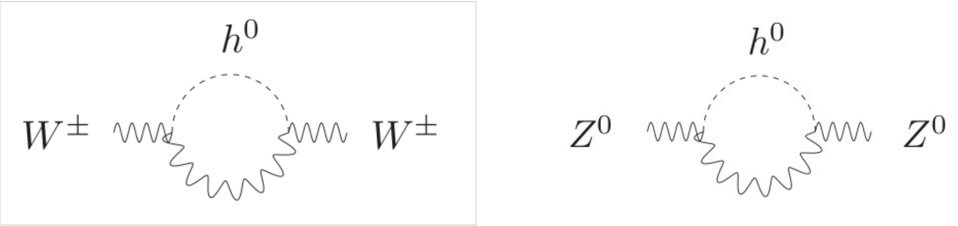
Yukawa couplings of Higgs to fermions

$$g_f\left[\bar{\psi}_L \Phi \psi_R + \bar{\psi}_R \Phi^{\dagger} \psi_L\right]$$

$$e.g.,\ m_e = \frac{g_e v}{\sqrt{2}}$$

Corrections to EW observables

- Electroweak observables are sensitive to masses of top quark and Higgs through radiative corrections



$$M_W^2 = \rho\, M_Z^2 \cos^2\theta_W$$

$$(\rho-1) \sim M_{top}^2$$

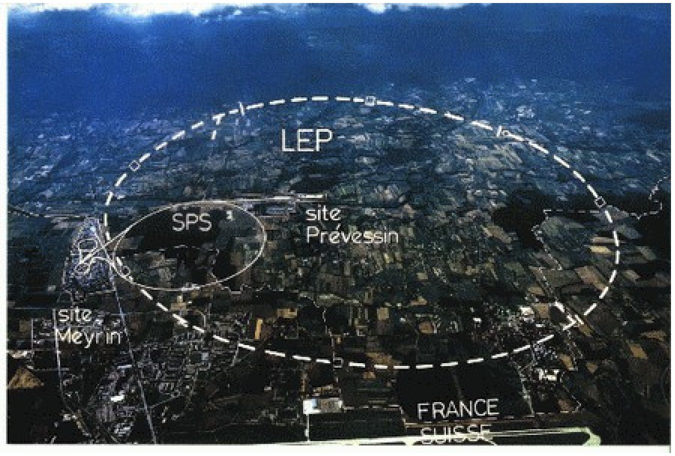
$$(\rho-1) \sim \ln M_H$$

- Precise measurements of electroweak observables can be used to constraint the Higgs boson mass

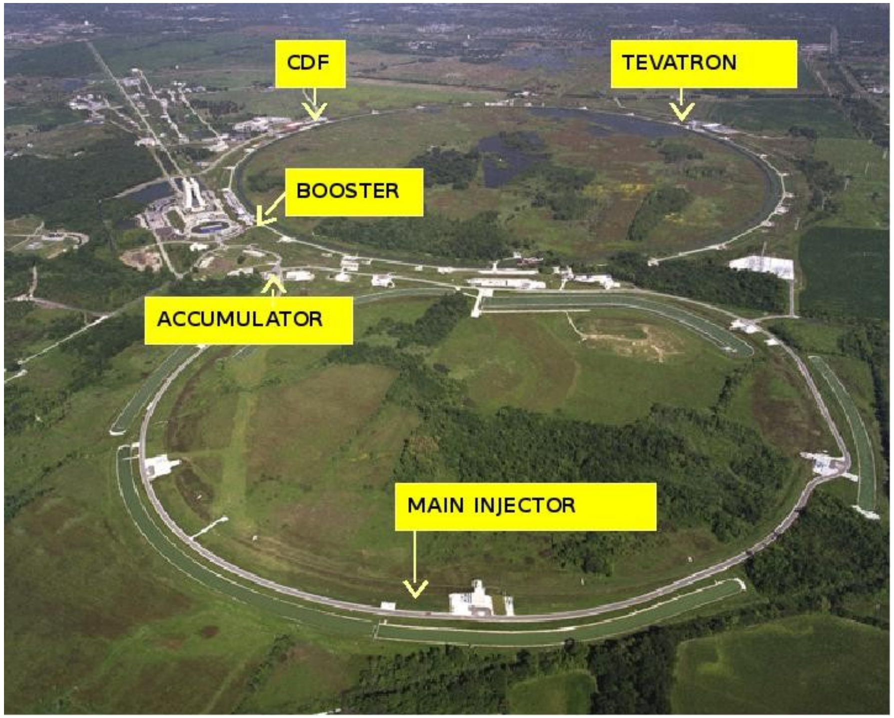
Sensitivity to Higgs mass is only logarithmic: Need ultra-precise measurements!

20 anos de procuras do Higgs antes do LHC

- LEP: $e^- - e^+$ (CERN)

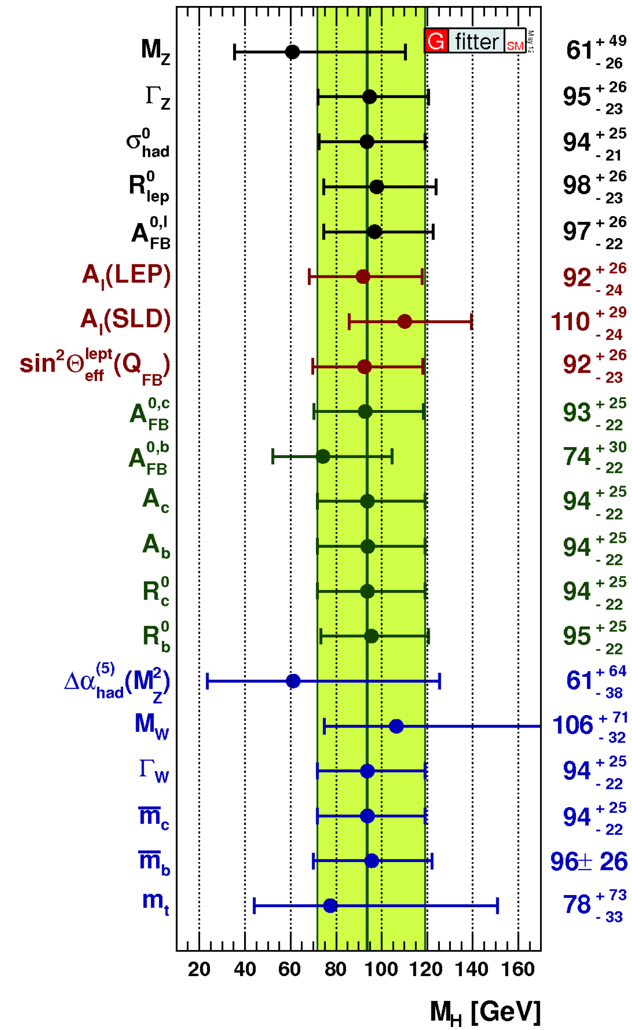


- Tevatron: p-anti p (Fermilab)



Só para impor limites na massa do Higgs...

- Large list of observables used in global fits to the electroweak precision data



Experimental constraints before the LHC

Fits to the EW observables predict:

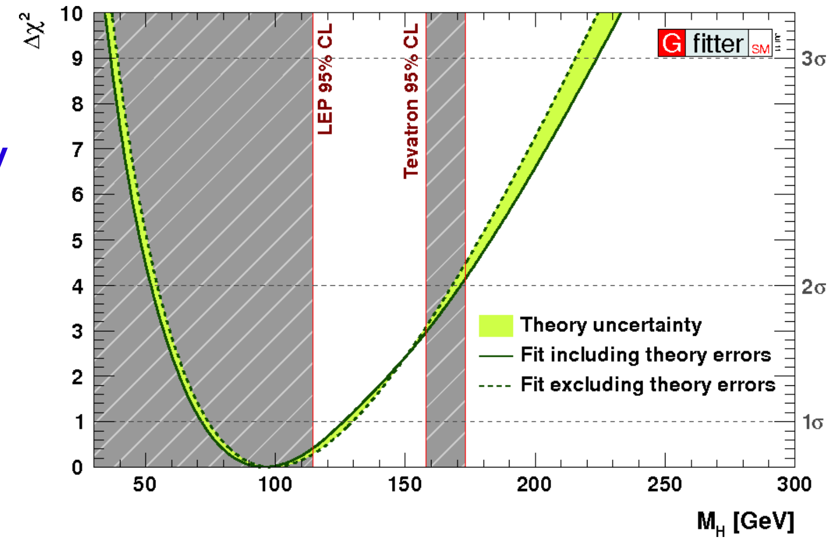
- Best Fit mass: $m_H = 94^{+25}_{-22}$ GeV
- Upper limit at 95% CL from fits:

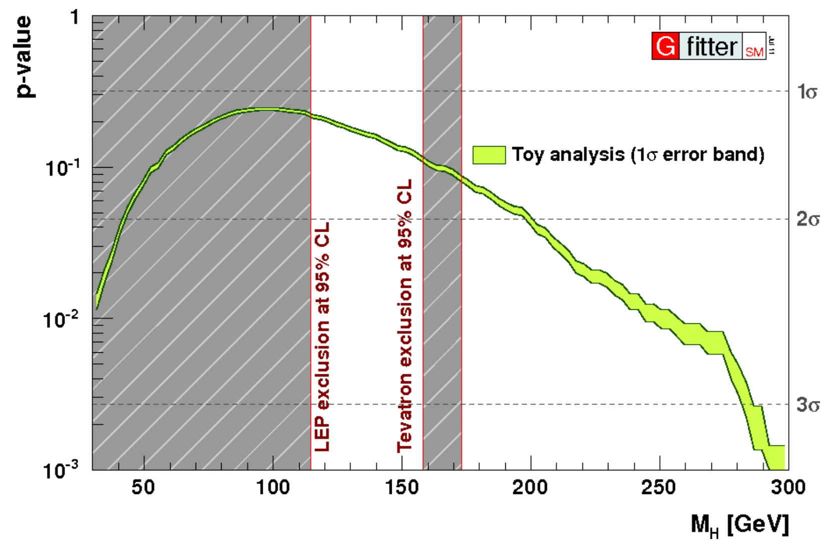
  $m_H < 169$ GeV

But the fit is not too bad for masses up to 200 GeV or so.

Direct searches excluded the regions at 95% CL:

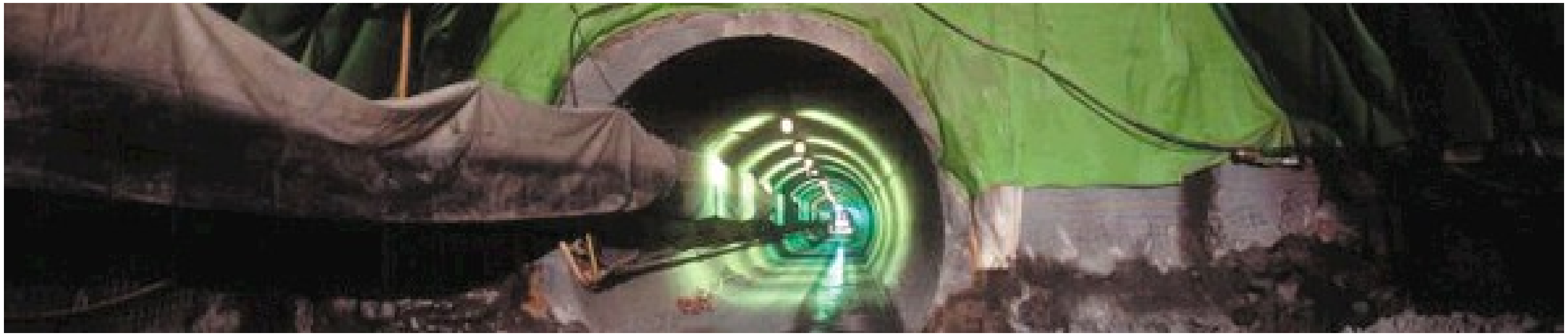
- LEP: $m_H < 114.5$ GeV
- Tevatron: $147 < m_H < 180$ GeV



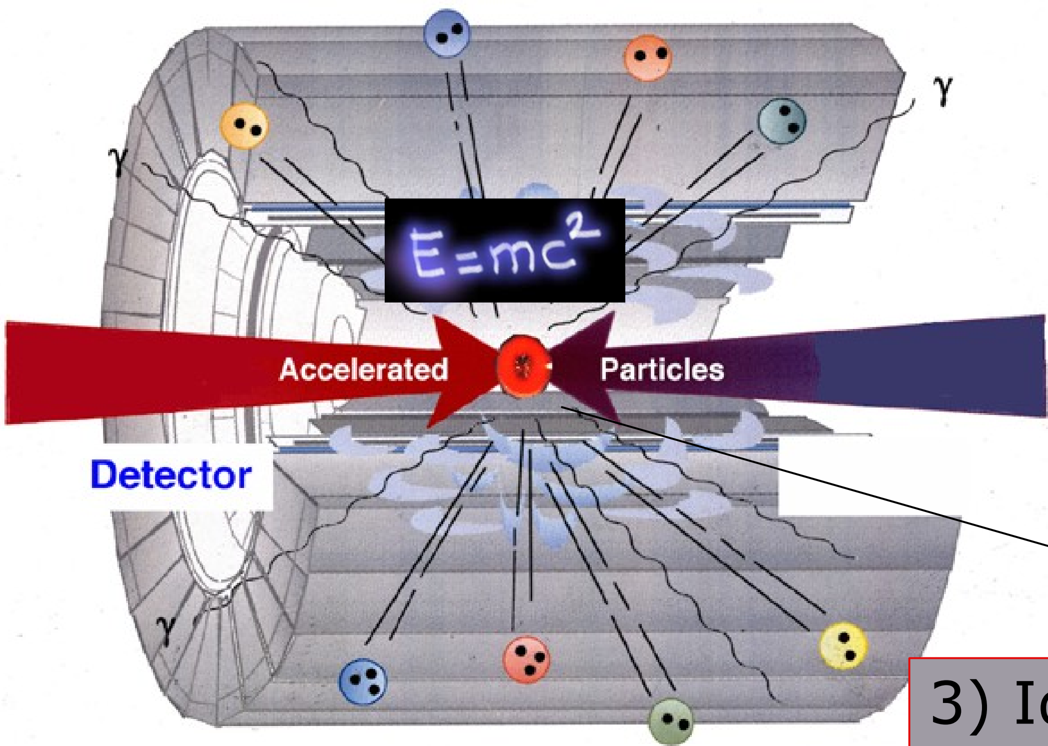


A procura do Higgs no LHC

Desvendando o mistério da massa...



Métodos experimentais

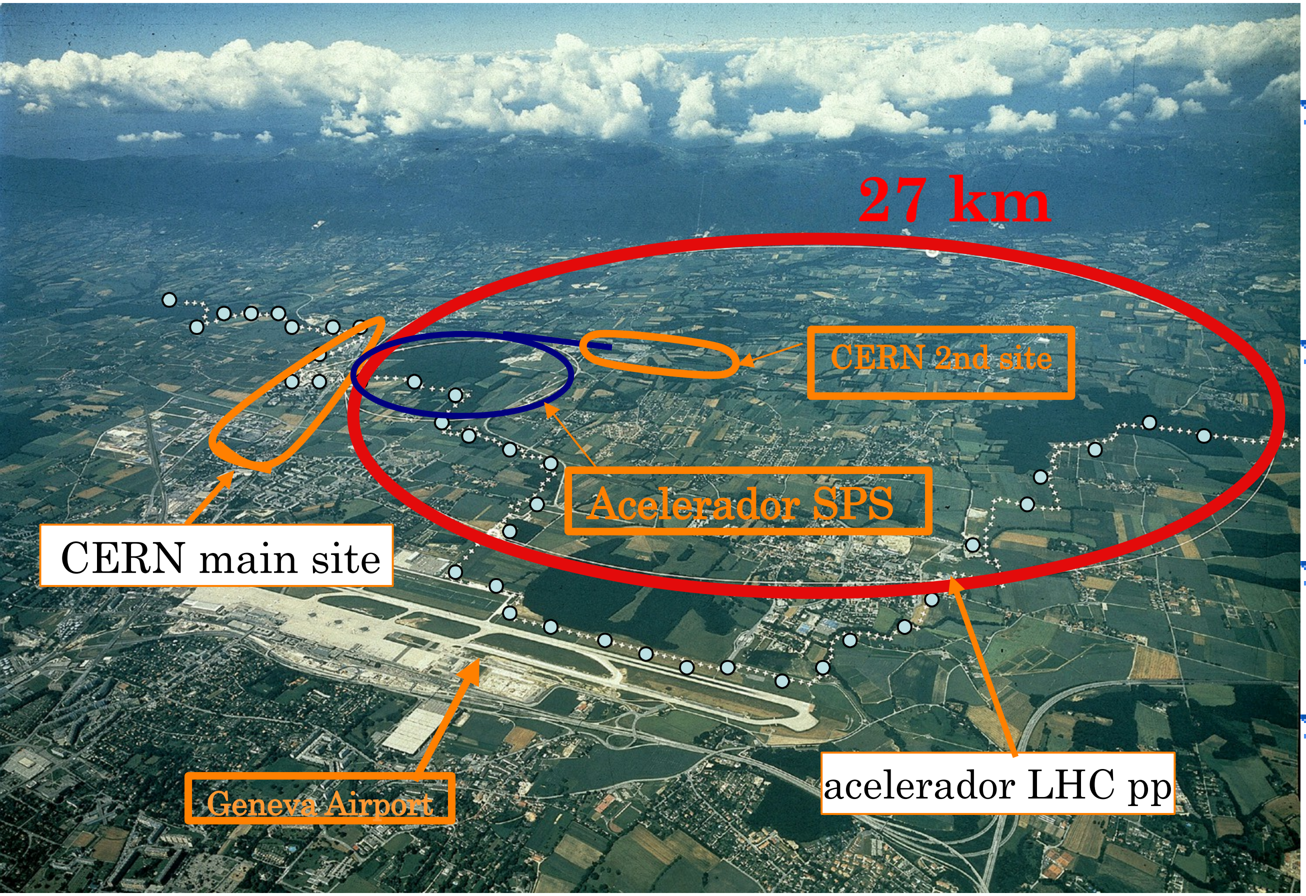


1) Concentrar a energia nas partículas (**acelerador**)

2) **Colidir** partículas

3) Identificar as partículas criadas com o **detector** (investigar novas propriedades)

O Large Hadron Collider (LHC)



- Colisões pp
  - 7 TeV em 2010/11
  - 8 TeV em 2012
- 40 milhões de cruzamentos dos feixes por segundo!
- Até 40 interações pp num cruzamento!
- 4 experiências
  - ATLAS, CMS, ALICE, LHCb

Energia do LHC

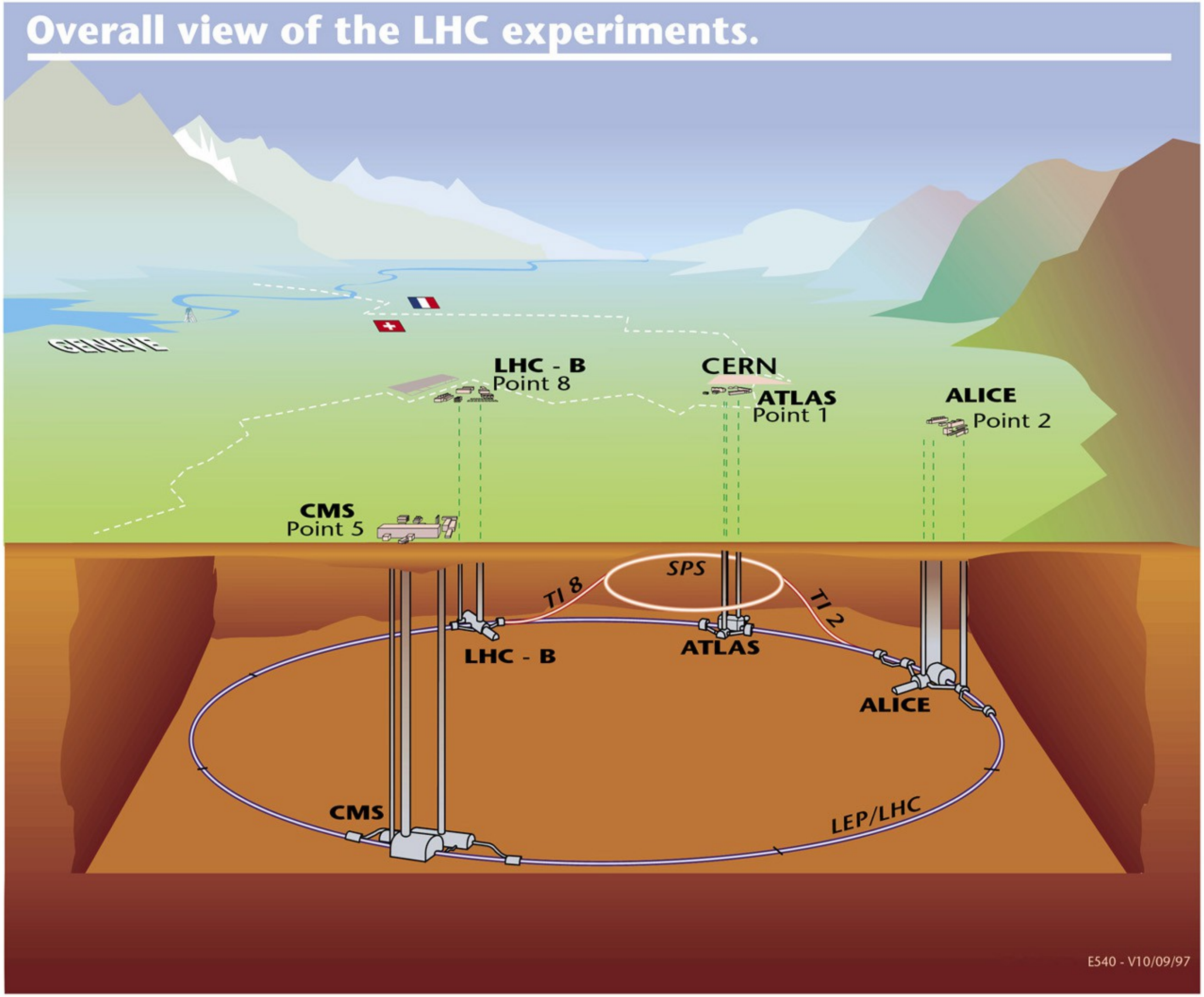
TeV: 10^{12} eV

x

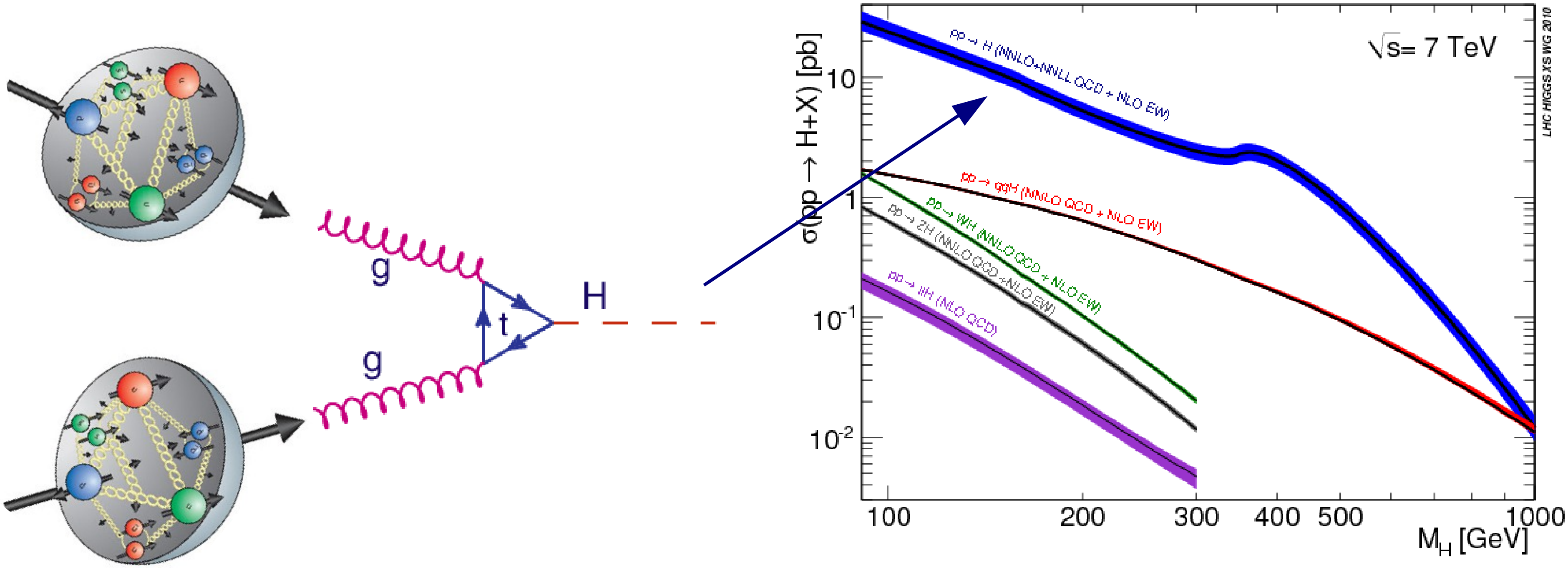
= 1 TeV

1 TeV é equivalente a 1 bateria por cada estrela da nossa galáxia

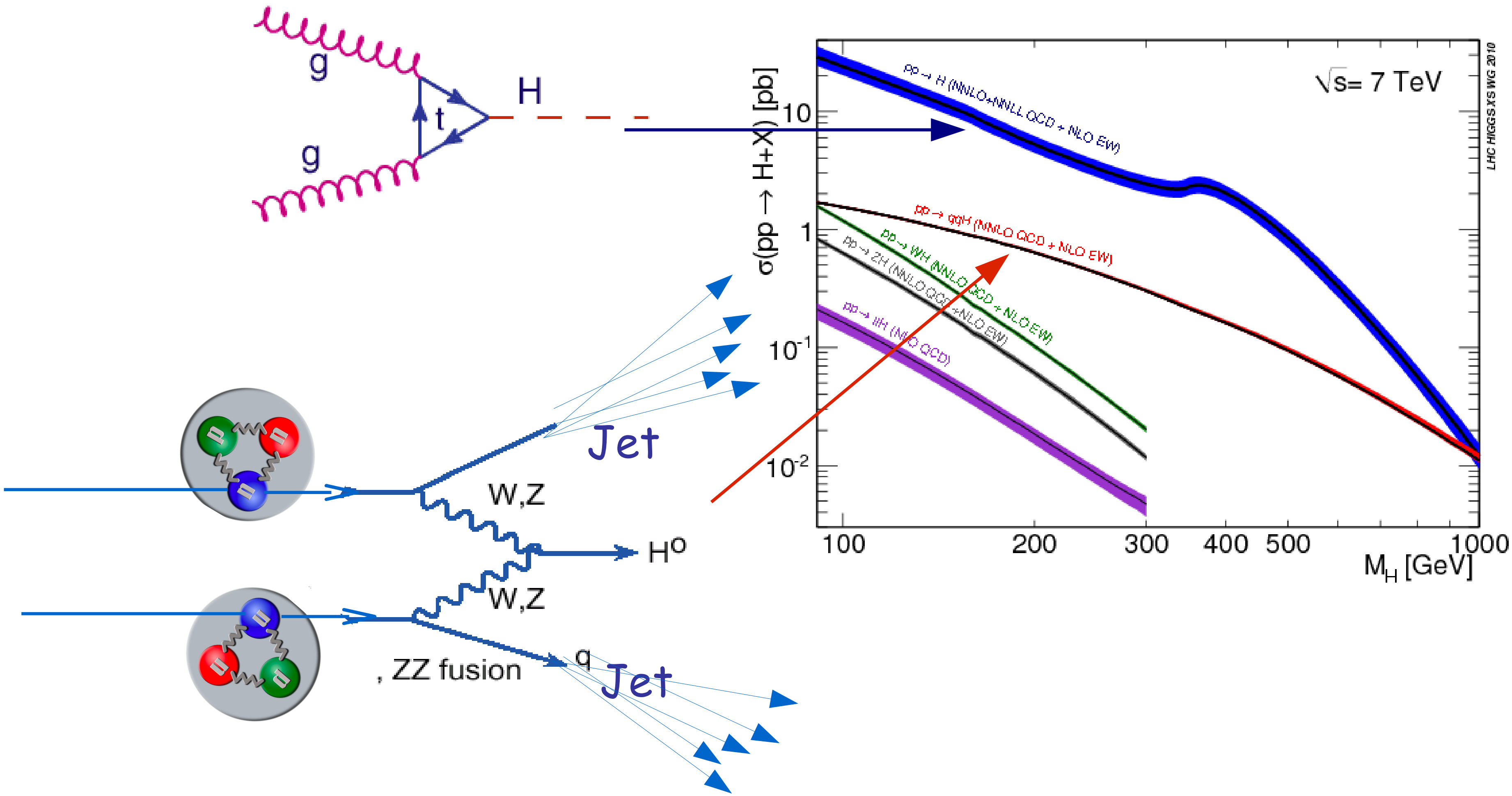
4 experiências no LHC



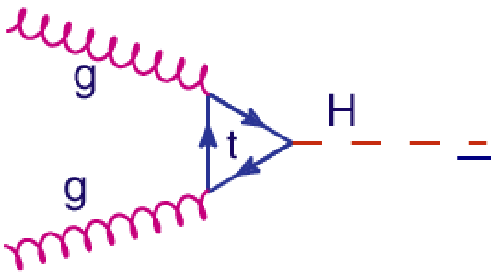
A produção do bosão de Higgs

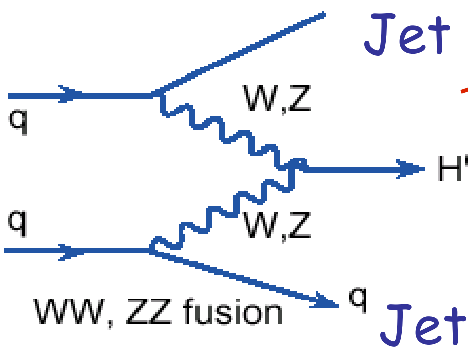


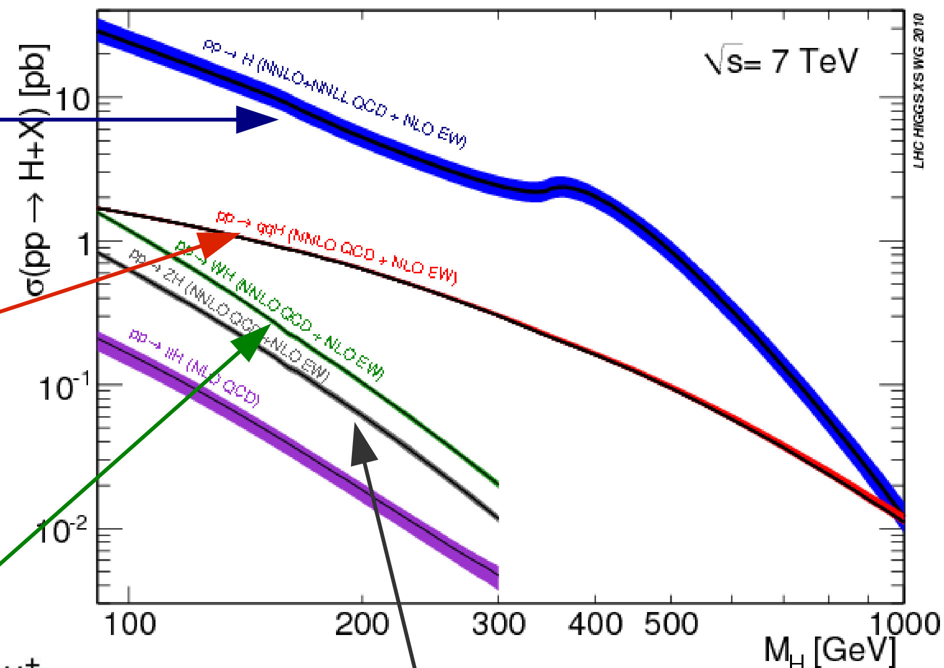
A produção do bosão de Higgs

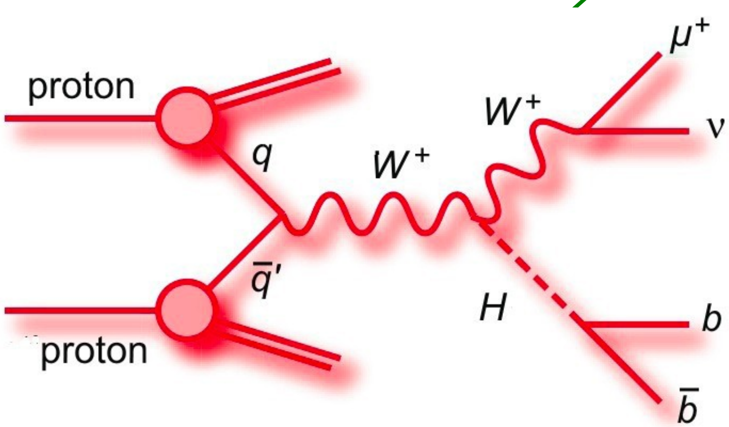


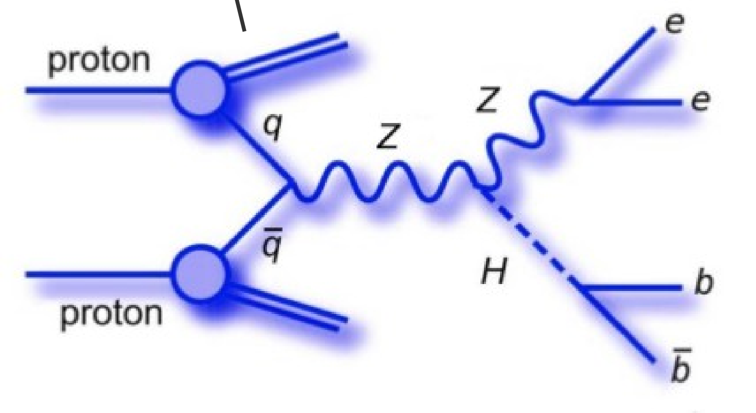
A produção do bosão de Higgs







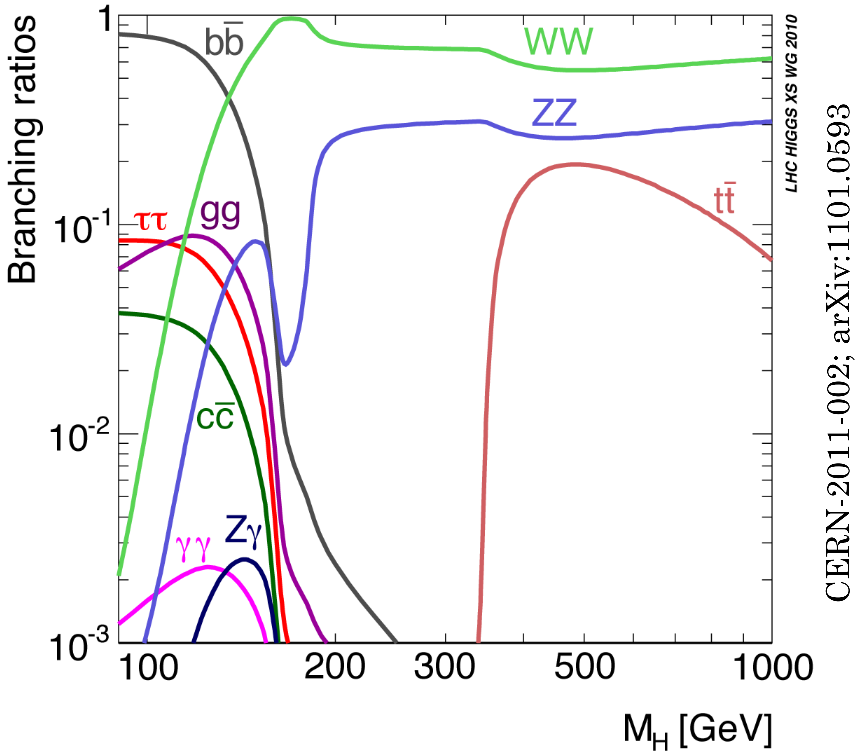




Modos de decaimento do Higgs no MP

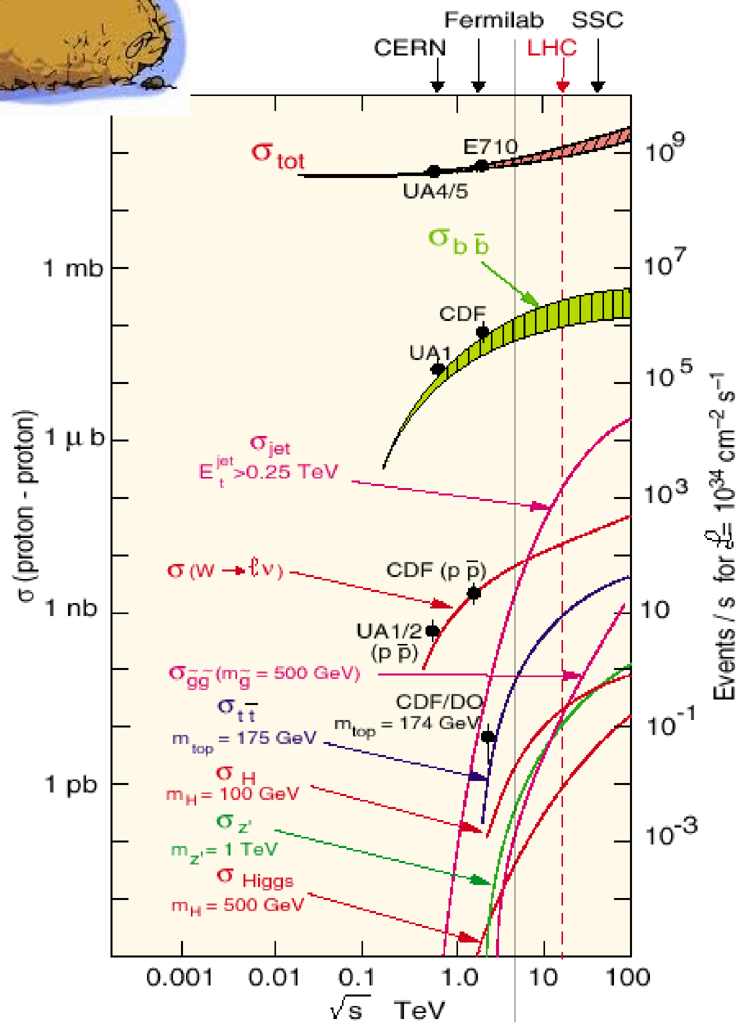
O bosão de Higgs decai imediatamente após ser produzido!

- Só podemos observar as partículas estáveis produzidas na sua desintegração
- As probabilidades de decaimento dependem da massa



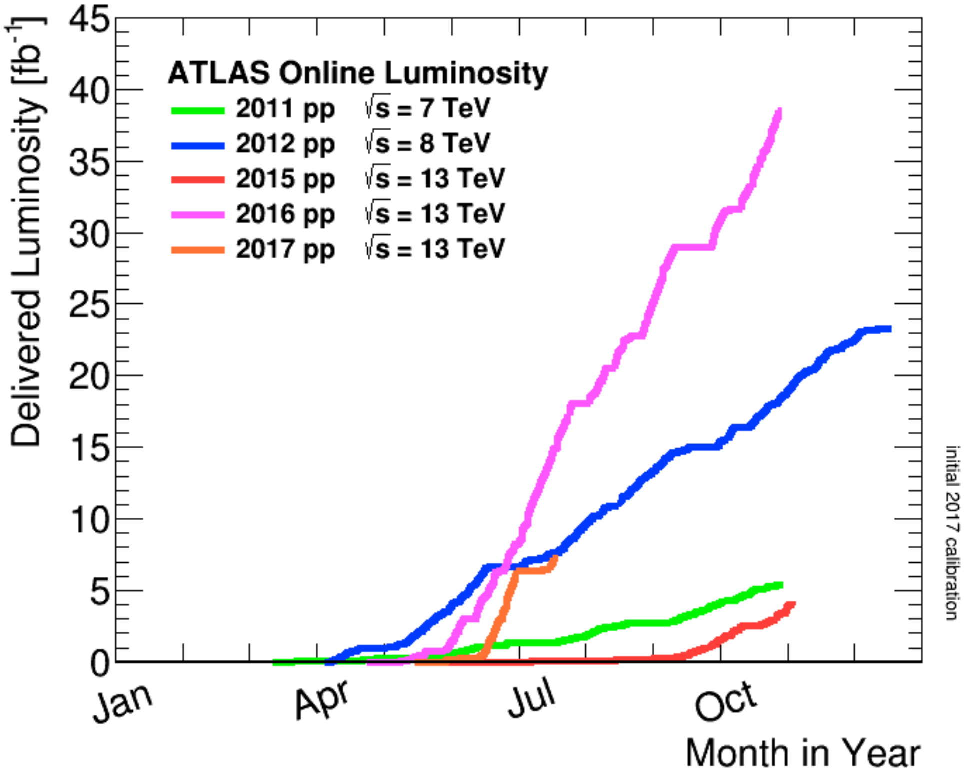
Canal de procura: modo de produção + modo de decaimento

Por que é tão difícil?

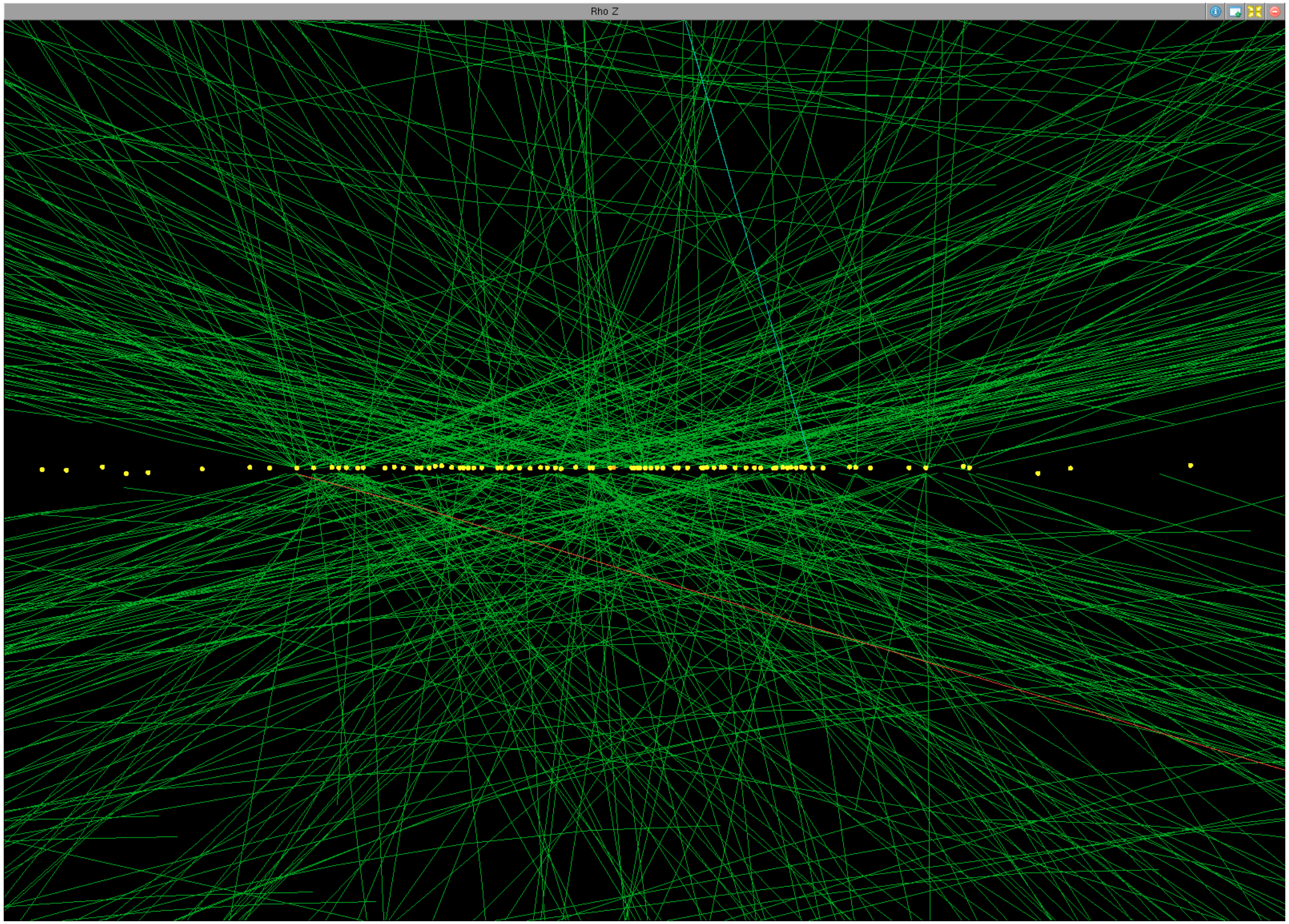


- Secção eficaz de produção de:
  - jatos ~ 100.000.000 vezes maior que a do Higgs
  - Jatos b ~10.000.000 vezes maior que a do Higgs
  - Bosões W: perto de 10000 vezes maior que a do Higgs
- Precisamos de modos de desintegração difíceis de confundir
  - $H \rightarrow \gamma\gamma$
  - H→ZZ→ll l'l'
  - H→WW→l l

LHC integrated luminosity

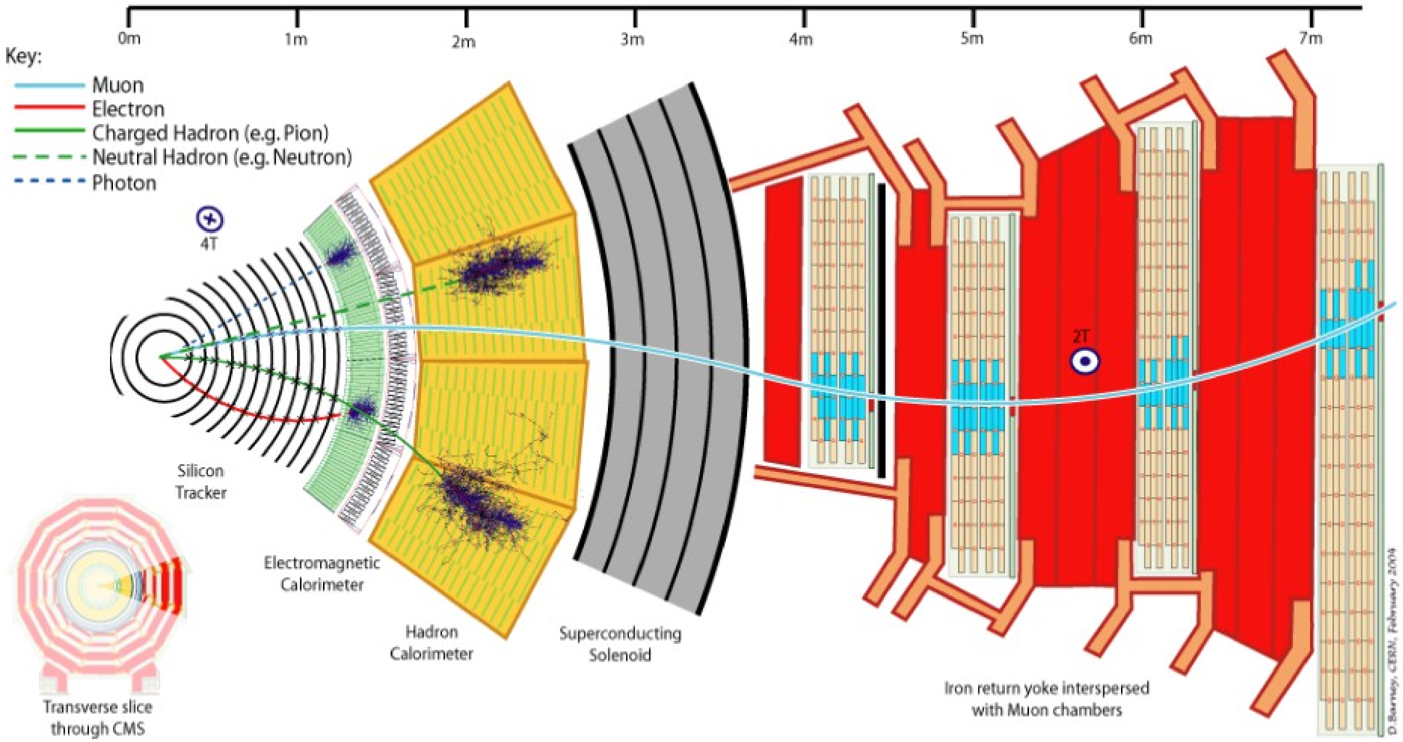


Pile-up



- CMS event
- 78 reconstructed vertices
- Extreme case up to now

Identificação das partículas no CMS

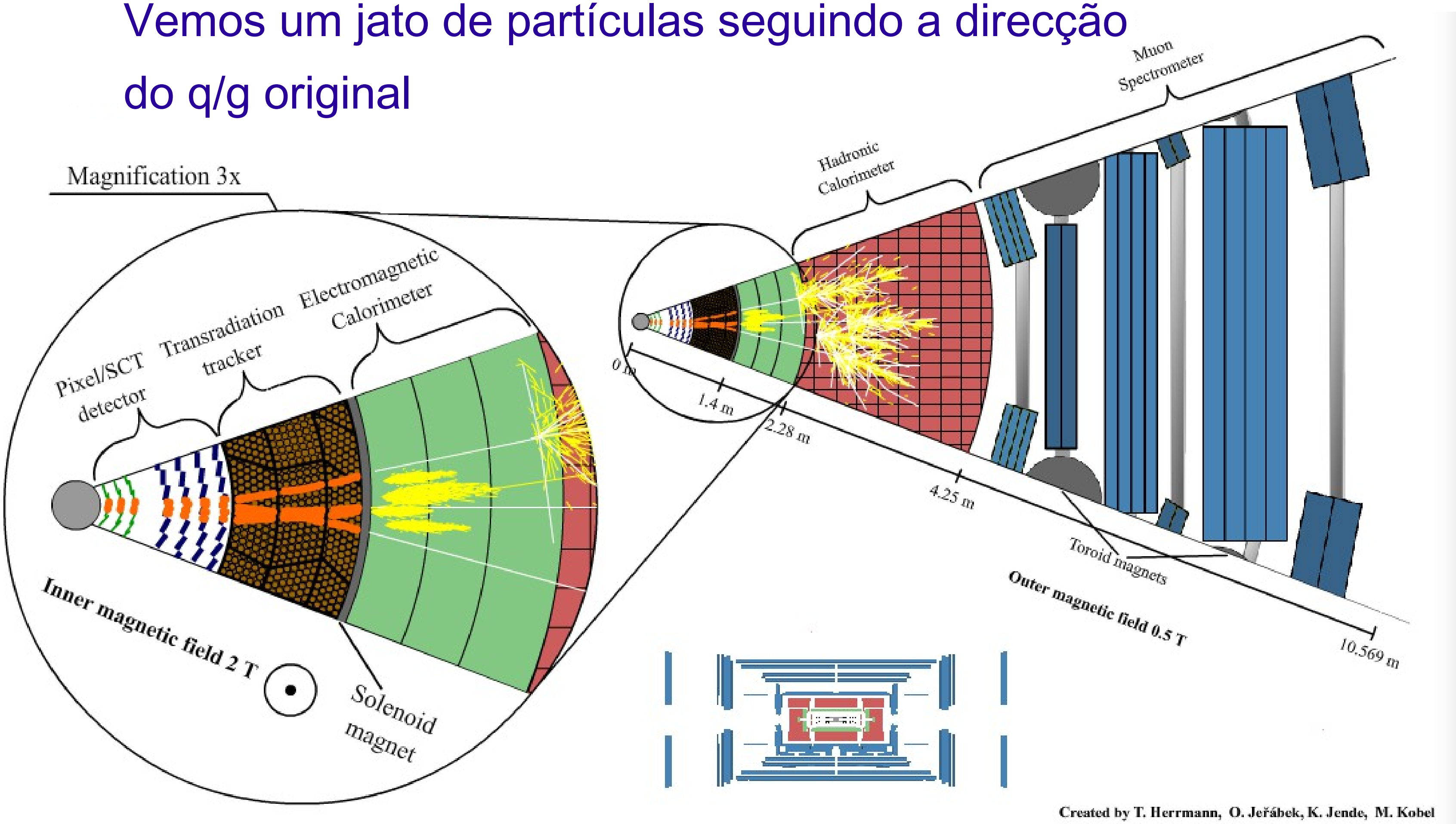


Princípios básicos do detector CMS: os mesmos que em ATLAS

Tecnologia, detalhes diferentes

Jatos

- Os quarks e gluões não existem em liberdade: hadronizam
  Vemos um jato de partículas seguindo a direcção do q/g original

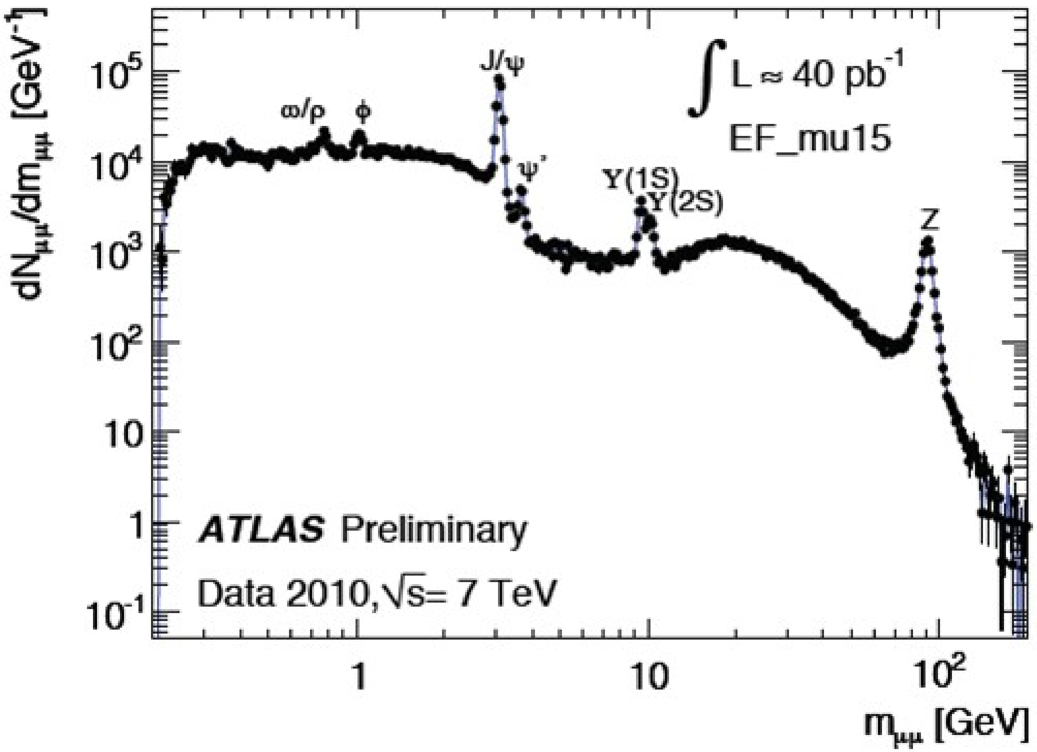


Reconstrução das partículas

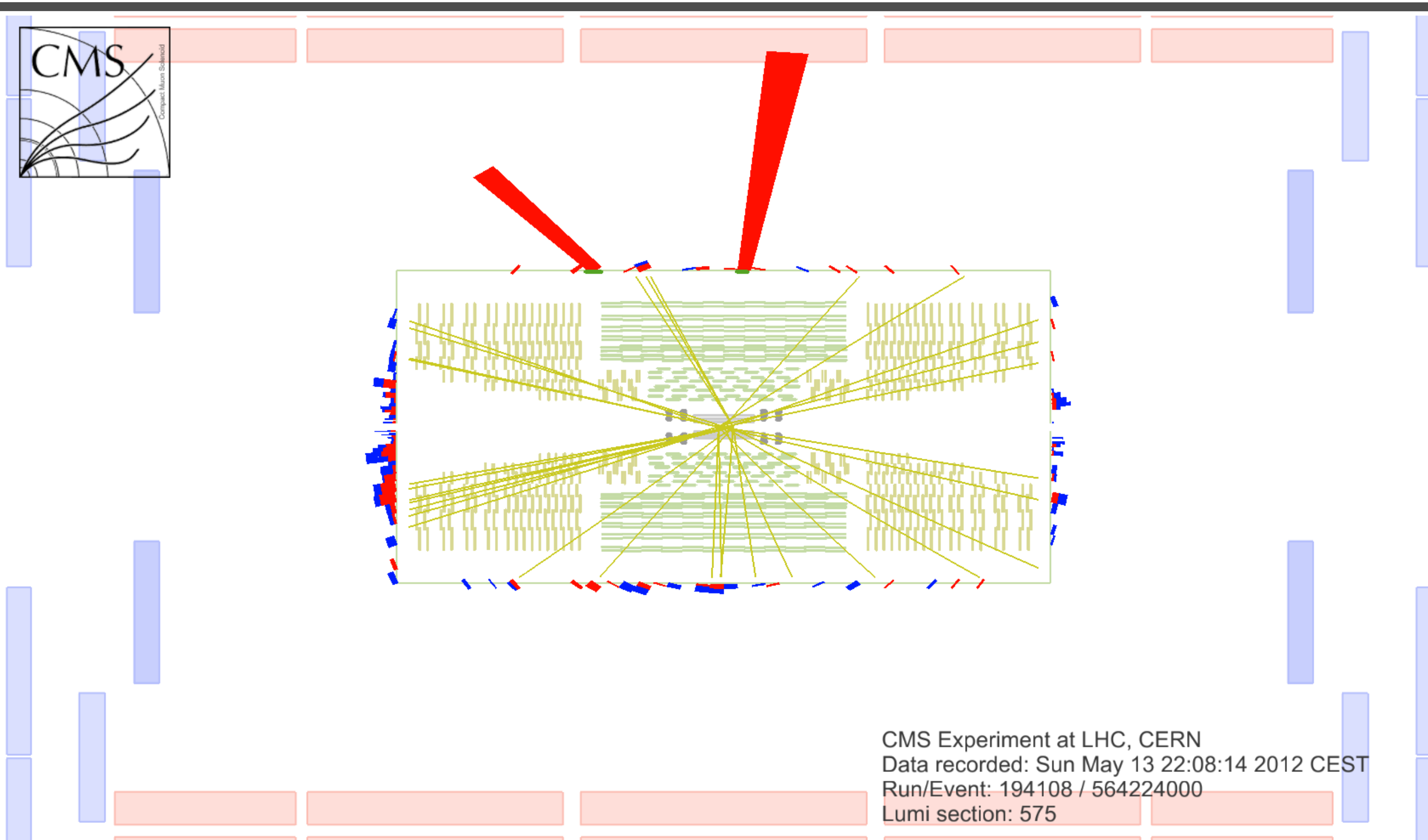
- A traves das propriedades das partículas produzidas na desintegração podemos inferir as propriedades do Higgs:

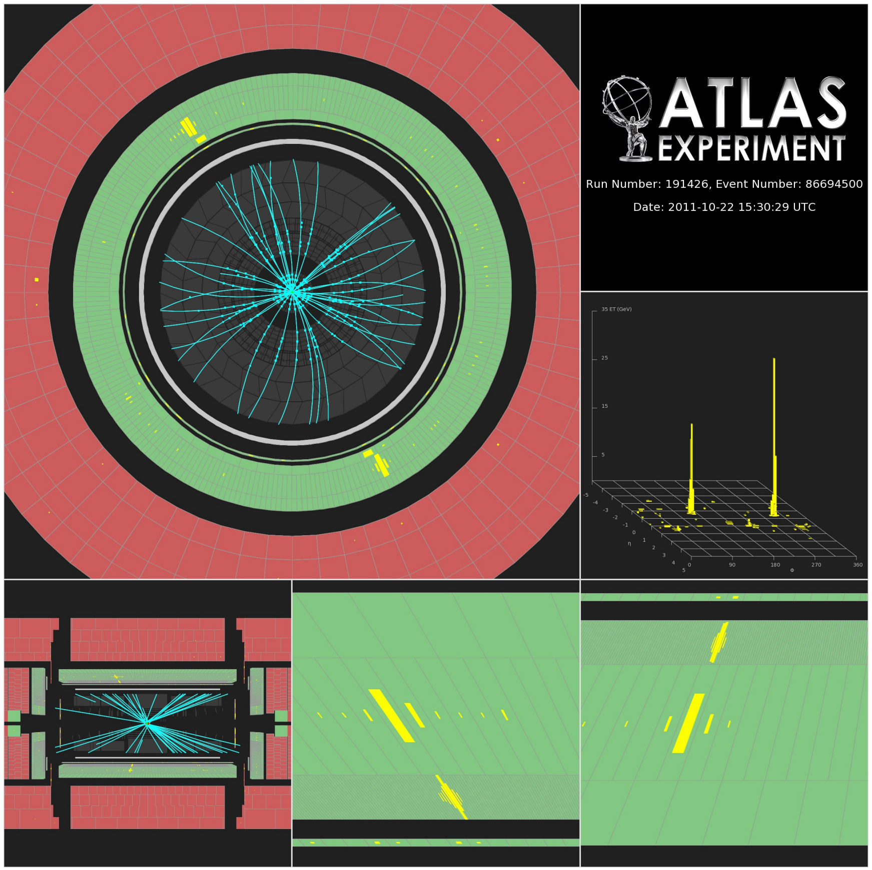
$$E^2 = (mc^2)^2 + (pc)^2$$

- 20 anos de física das partículas num só histograma



H→γγ


CMS
Compact Muon Solenoid
CMS Experiment at LHC, CERN
Data recorded: Sun May 13 22:08:14 2012 CEST
Run/Event: 194108 / 564224000
Lumi section: 575

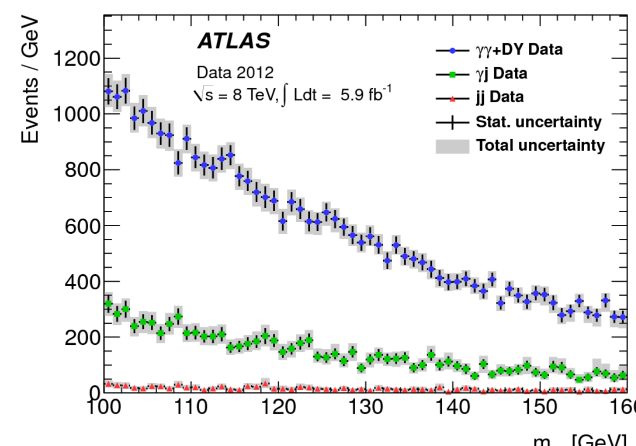


H→γγ candidate event

- Two isolated photons
- Search for a narrow peak on a large continuum

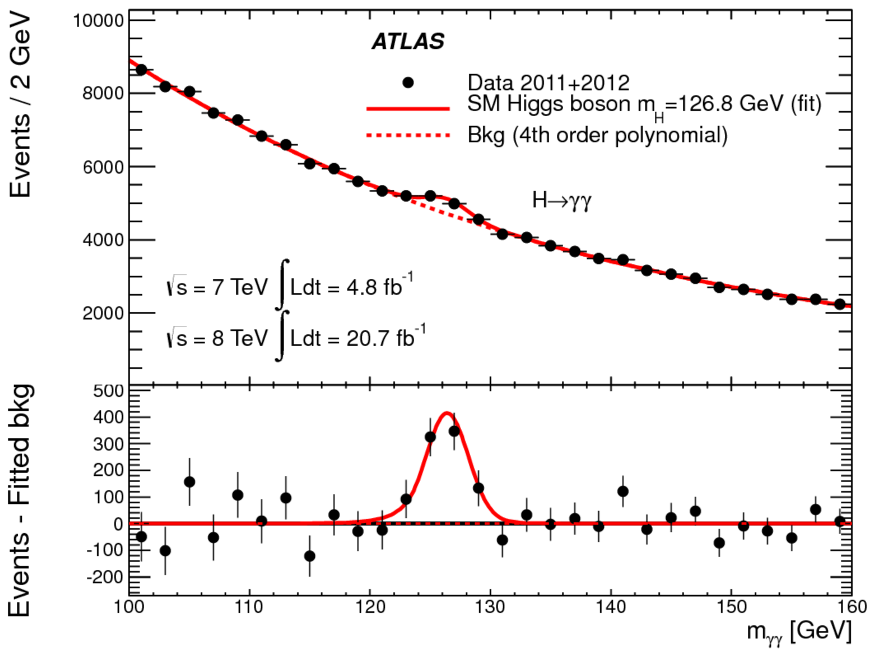
Main background:

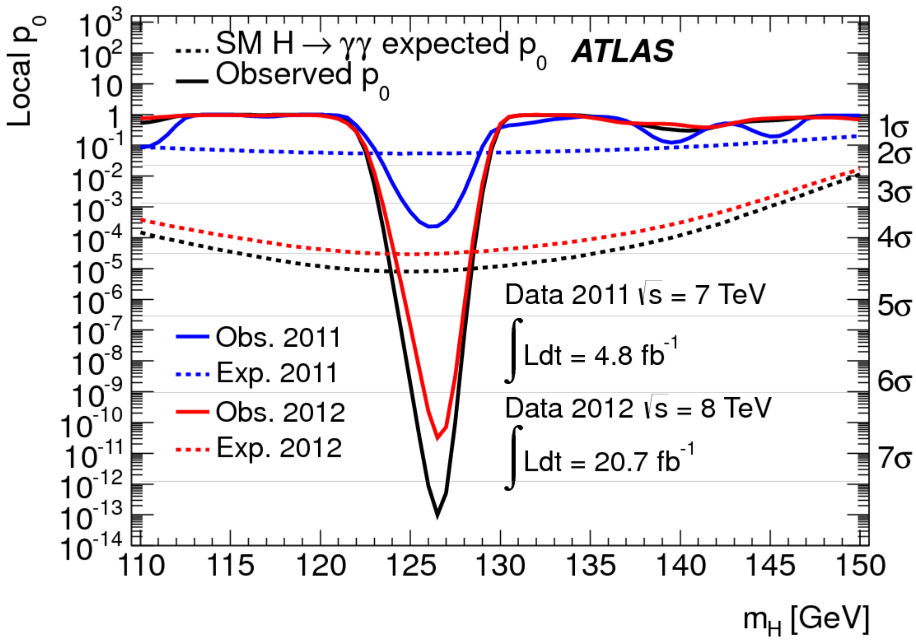
- Continuum γγ production
- γ+jet, jet+jet



H→γγ results

☆ Run 1 results

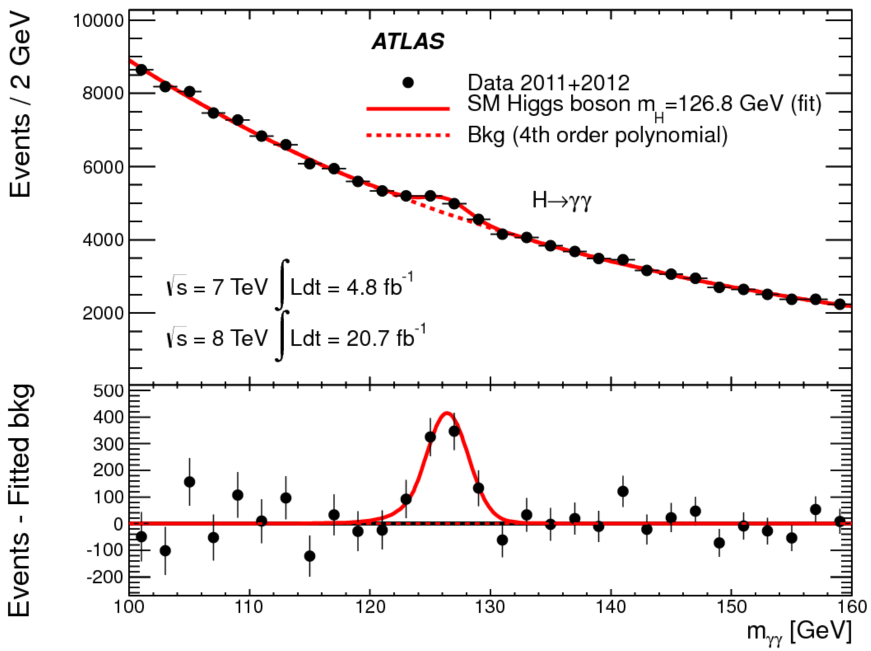




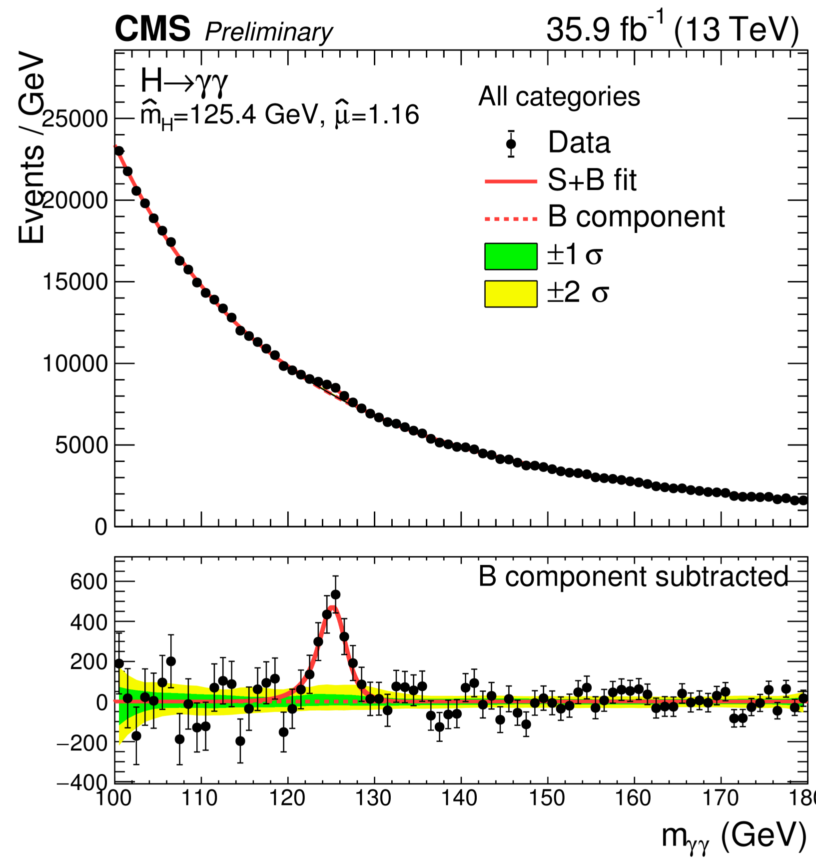
☆ Best signal strength at the time

$$\mu_H = (\sigma_{obs} \times BR_{obs}) / (\sigma_{SM} \times BR_{SM}) = 1.55^{+0.33}_{-0.28}$$

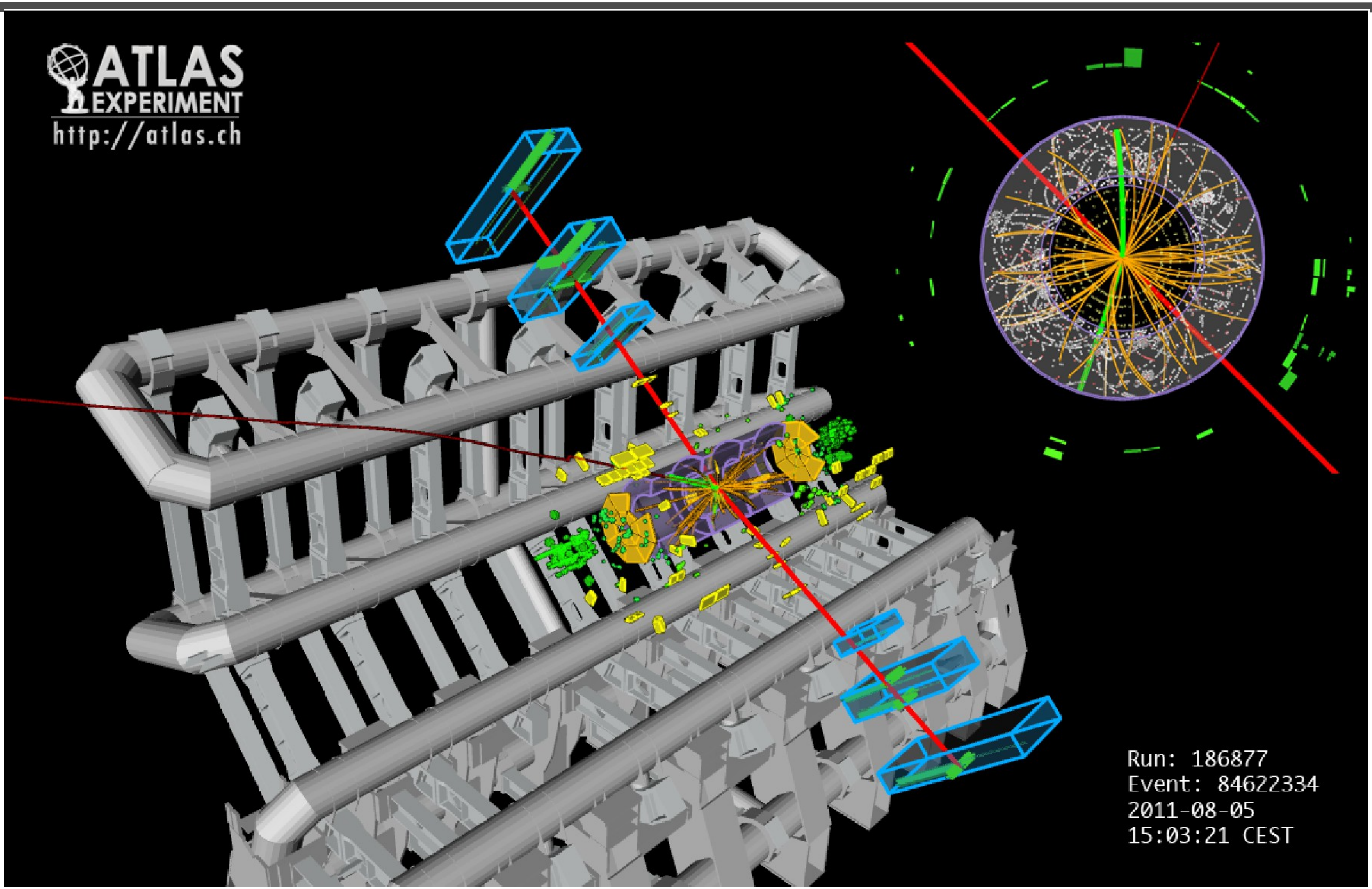
- Run 1 results



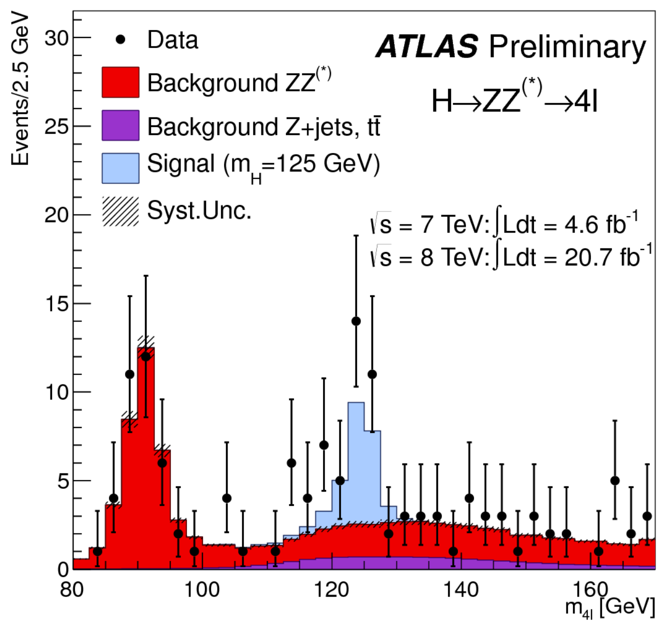
- Run 2 results!!



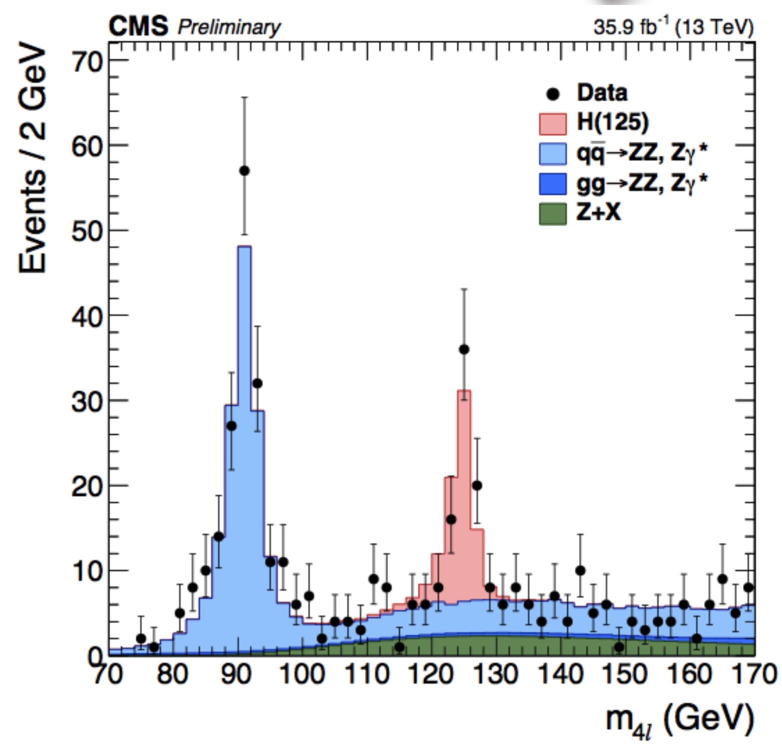
H→ZZ→4leptons



H→ZZ→4leptons results



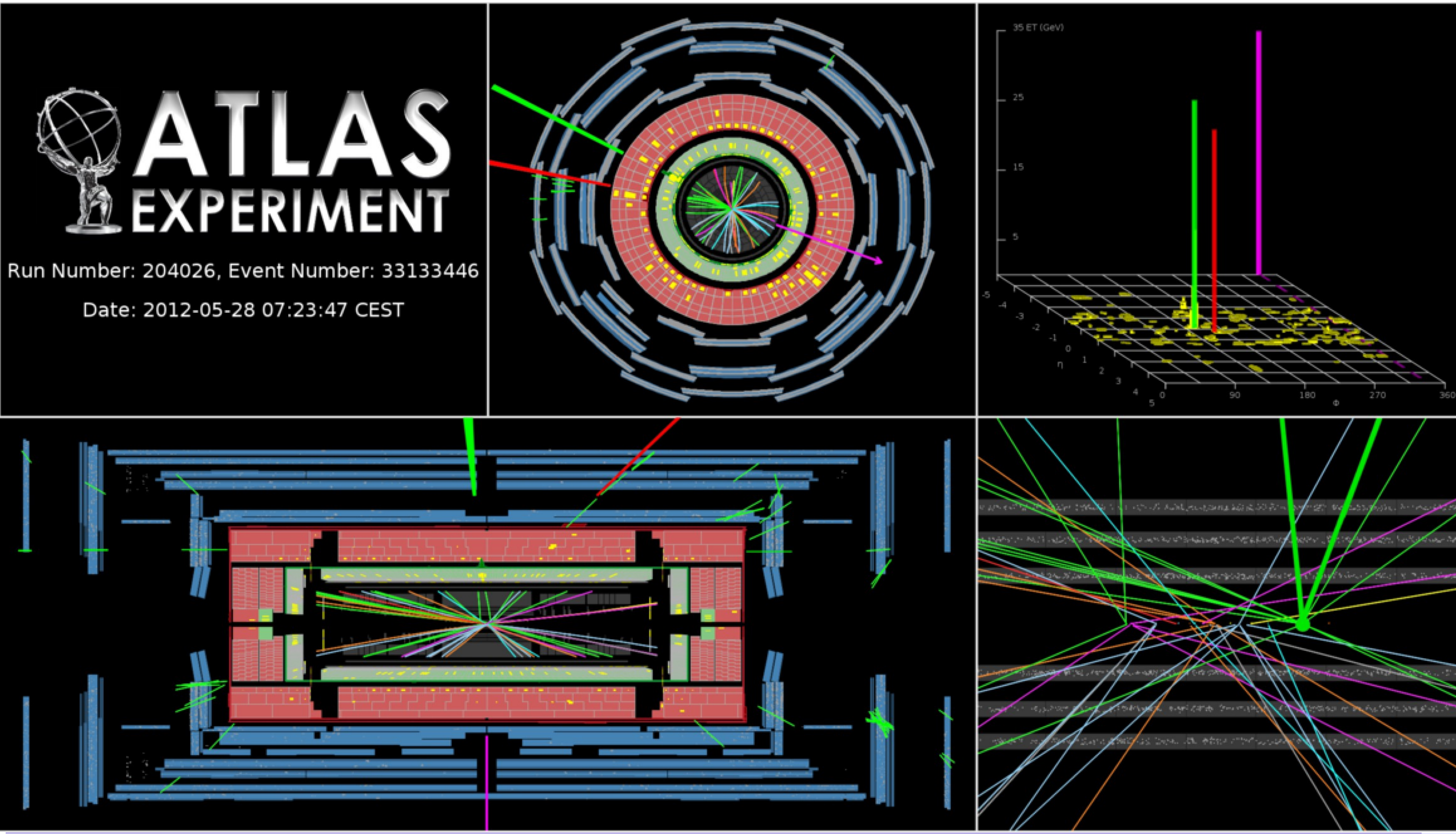
- Latest Run 2 results



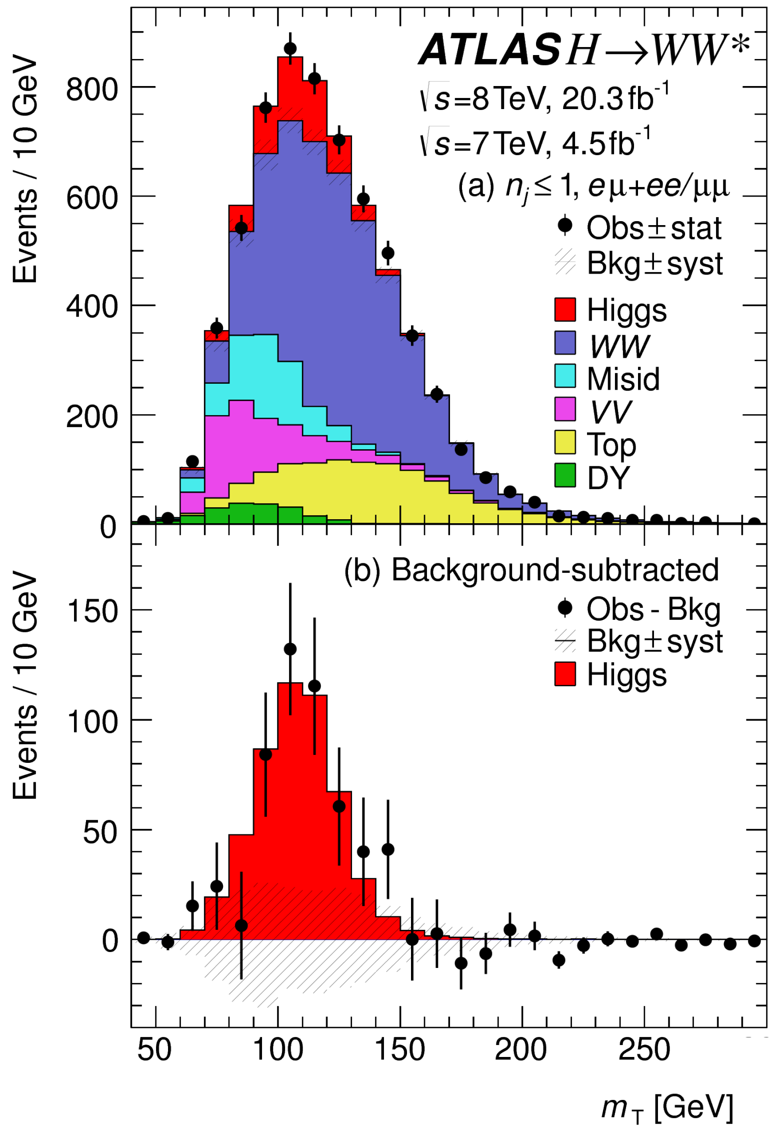
- ATLAS peak at 124.3 GeV

  Probabilidade de flutuação do fundo ~ 0.000000000001

H→WW→eν μν

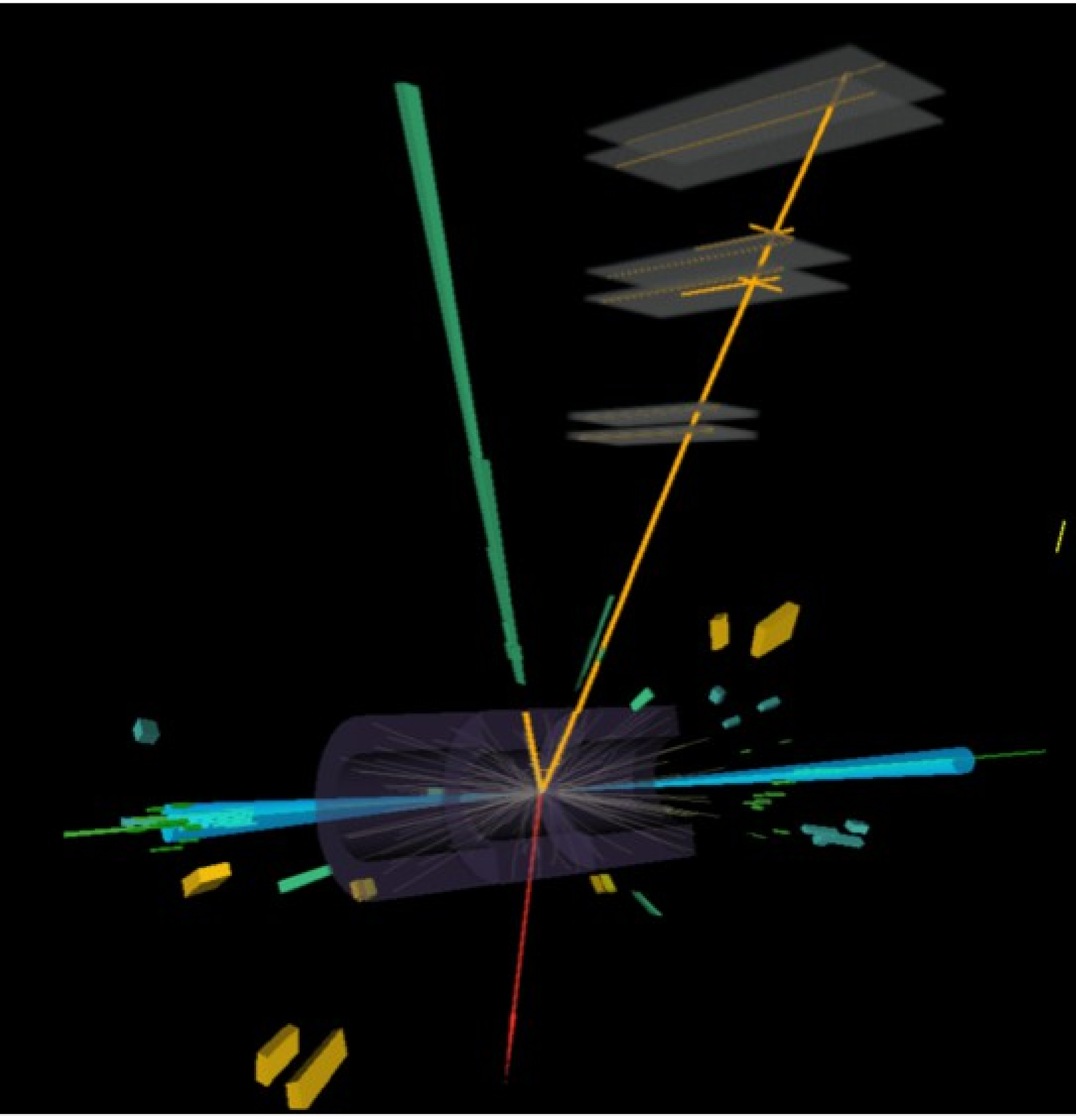

ATLAS EXPERIMENT
Run Number: 204026, Event Number: 33133446
Date: 2012-05-28 07:23:47 CEST

H→WW→lνlν

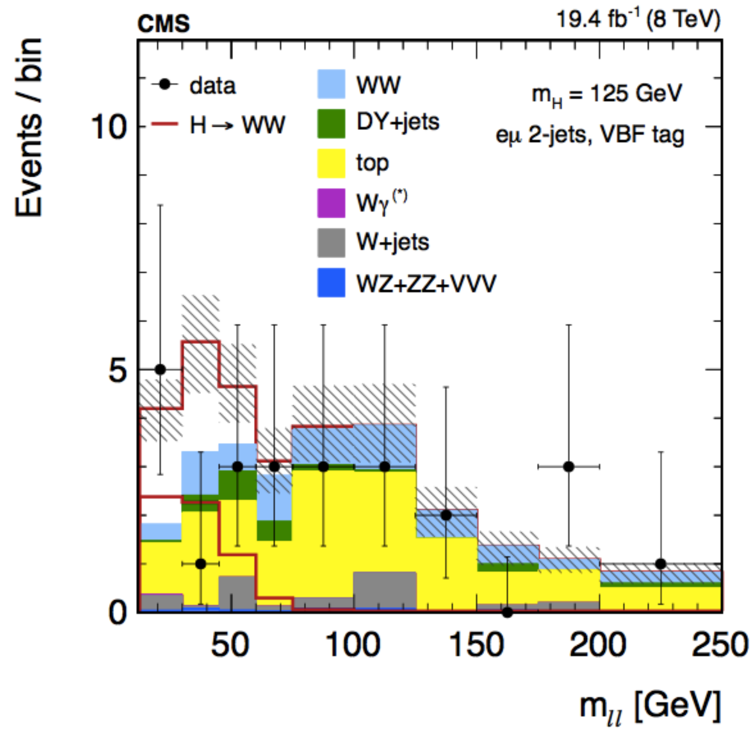


https://twiki.cern.ch/twiki/pub/AtlasPublic/HiggsPublicResults//WW-FixedScale.gif

Vector boson fusion $H\rightarrow WW$ production



- Dominated by VBF
- Large rapidity gap between jets



4 de Julho de 2012

Encontramos uma partícula nova! Mas… será o bosão de Higgs??

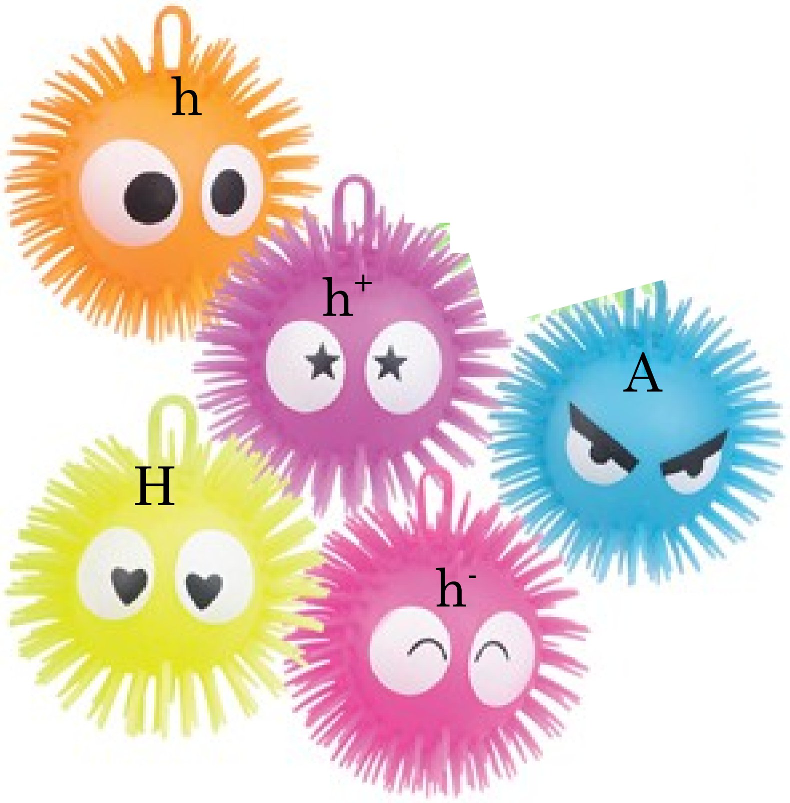
Descoberta: inicio de uma nova fase...

- Temos de medir as suas propriedades
  - Se produz com a probabilidade que esperamos?
  - Decai como é suposto?
  - Tem as propriedades que esperamos?

- O que já sabemos:
  - É um bosão, pela forma em como decai
  - Tem carga zero
  - Massa por volta de 125-126 GeV

Que outra coisa pode ser?

- Ter um bosão de Higgs é a opção mais simples no Modelo Padrão
- Poderia haver 5 Higgses!
  - A partícula descoberta agora poderia ser o Higgs mais ligeiro
- Super-Symmetry (SUSY)
  - Também há 5 bosões de Higgs
- Tecnicolor
  - O bosão de Higgs seria um estado ligado de tecniquarks
- ...



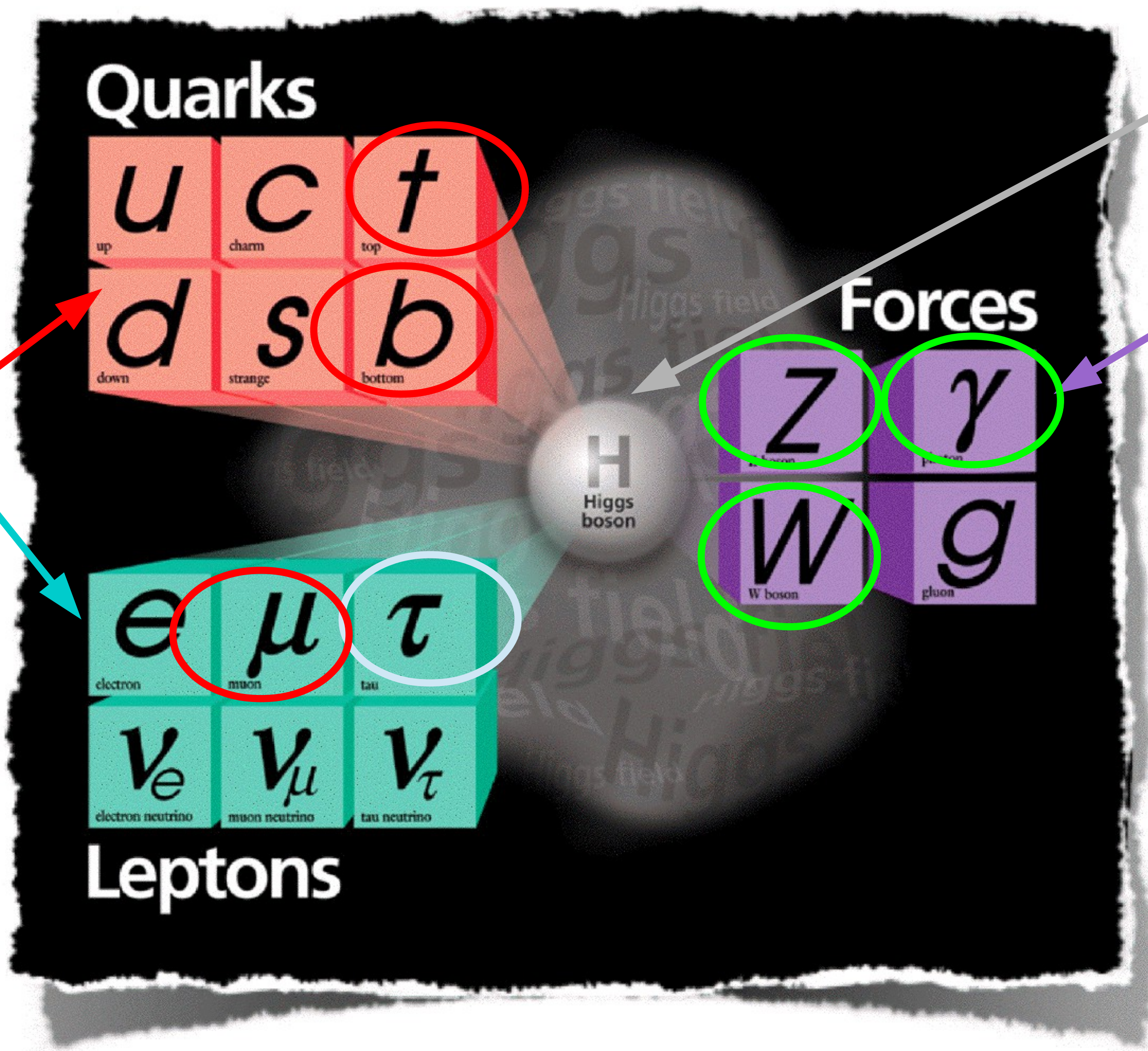
Previsões menos precisas que no caso do Higgs do MP

O Modelo Padrão da Física das Partículas

Spin 0

Spin 1

Spin 1/2



Mass

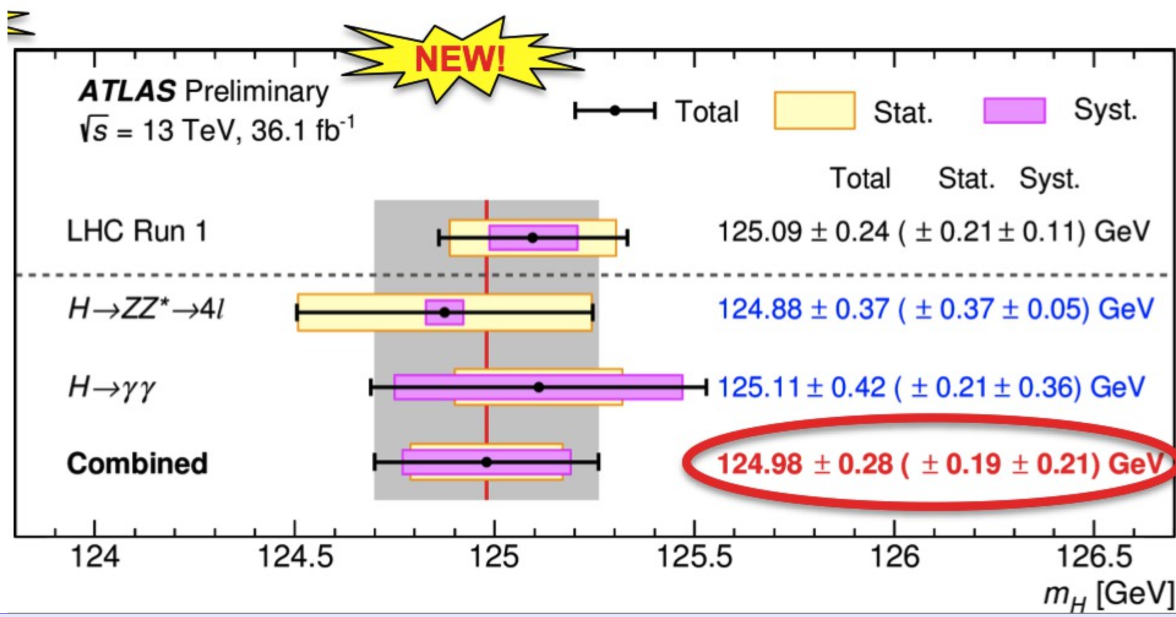
- CMS

Studied/measured via 3 production mechanisms (gluon fusion, VH, vector-boson fusion)

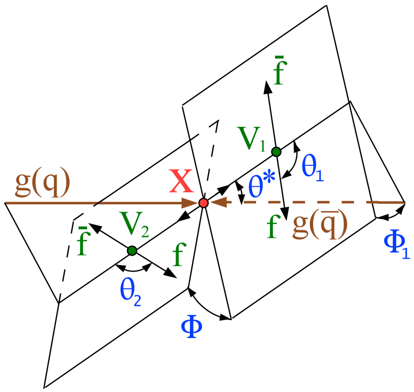
$$m_{\mathrm{H}} = 125.26 \pm 0.20(\mathrm{stat.}) \pm 0.08(\mathrm{sys.})\ \mathrm{GeV}$$

Submitted to JHEP: arXiv:1706.09936

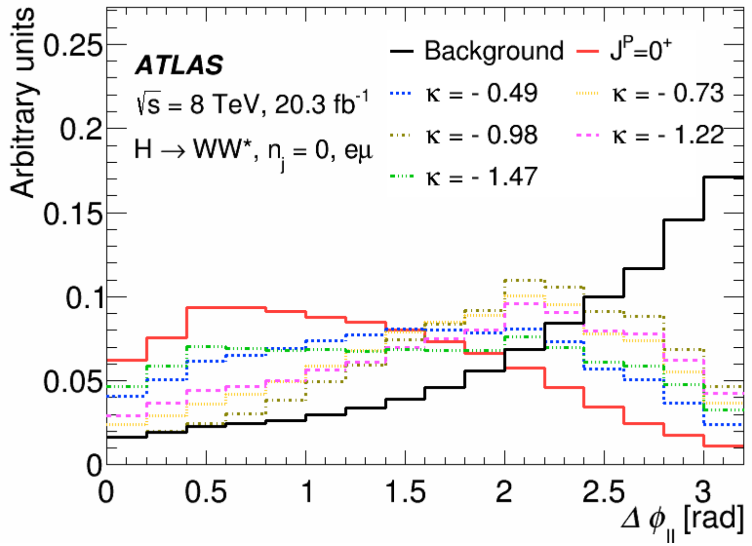
- ATLAS



- Can be determined looking at angular distributions of the decay products

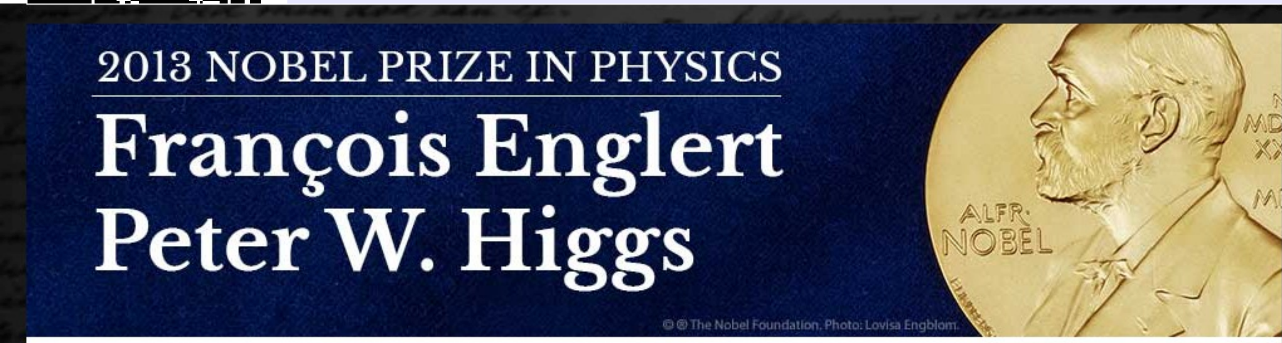


Example from H → WW analysis



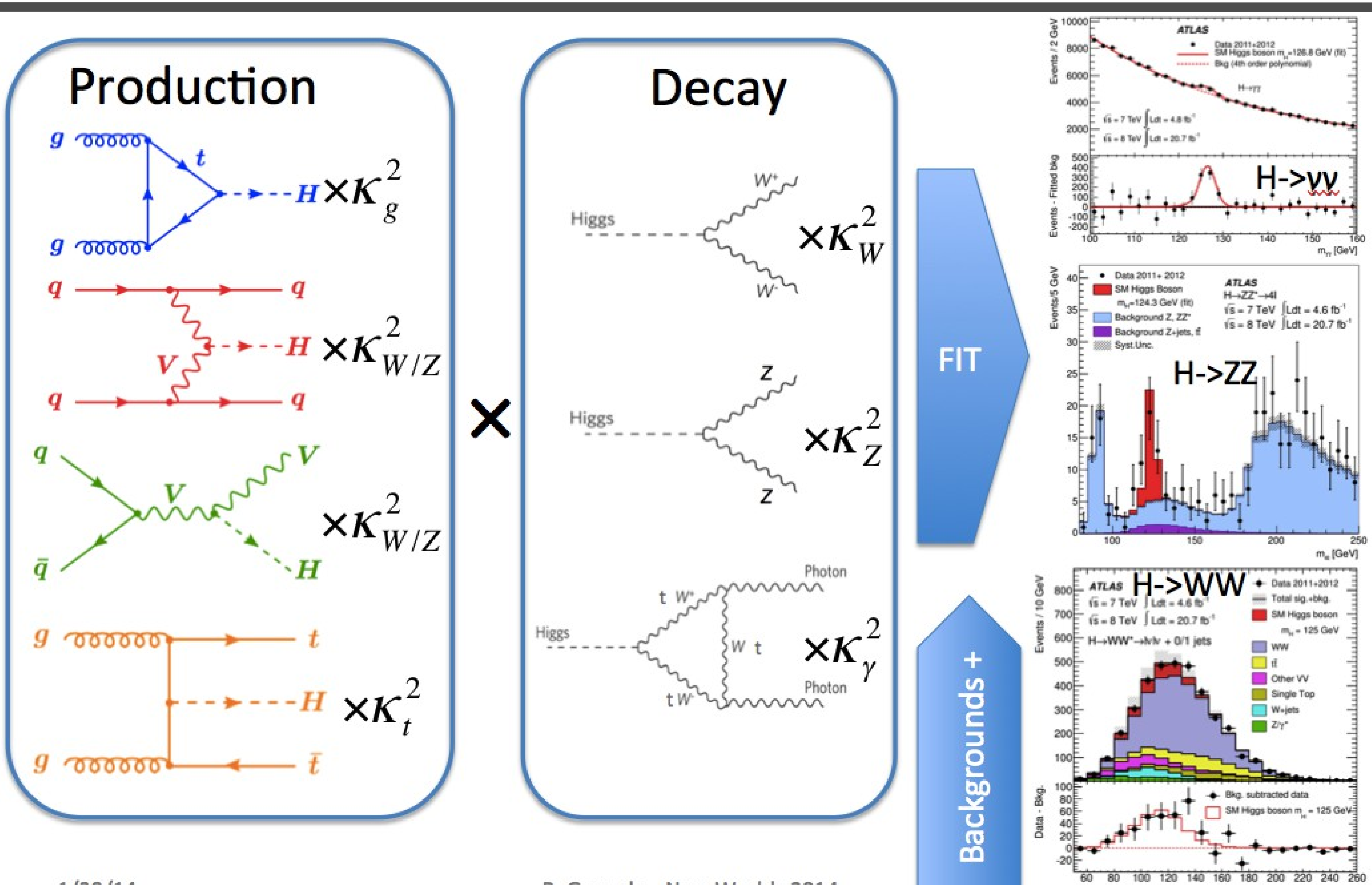
- Both ATLAS and CMS excluded alternative Spin and parity hypothesis at > 95% CL

  Combination of the three main bosonic channels



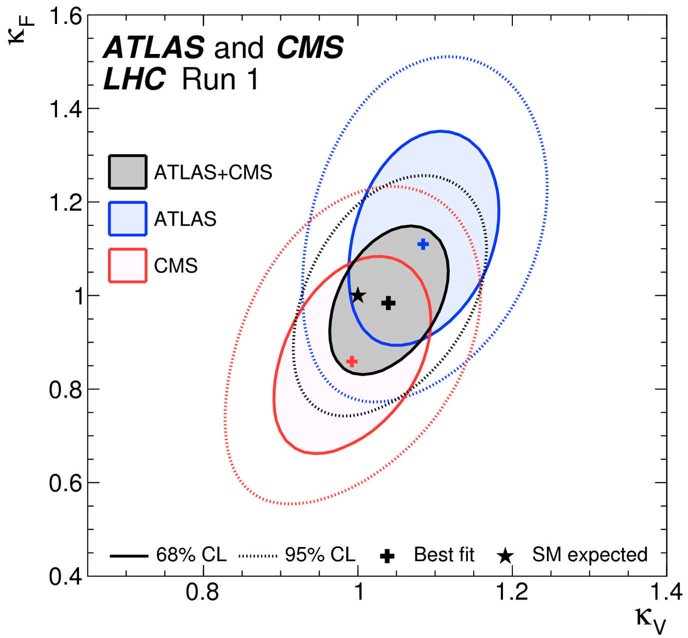
Prémio Príncipe de Asturias:

Couplingscombination

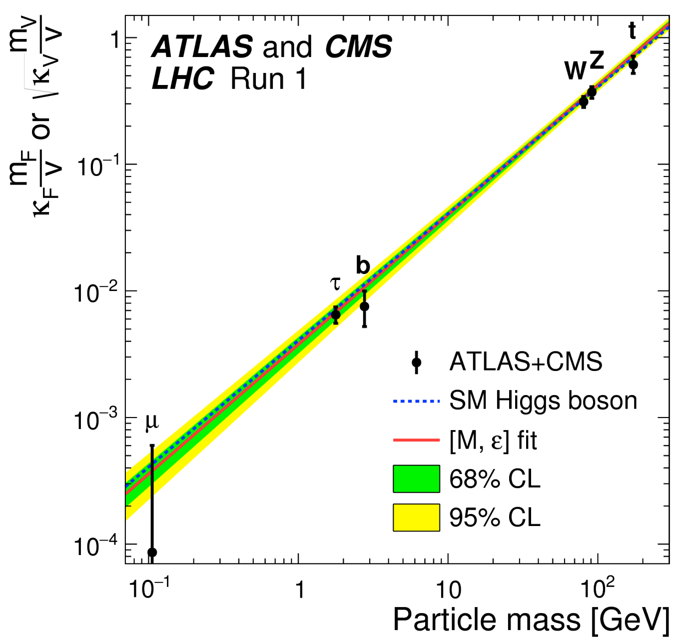


Combined ATLAS+CMS Run 1 results

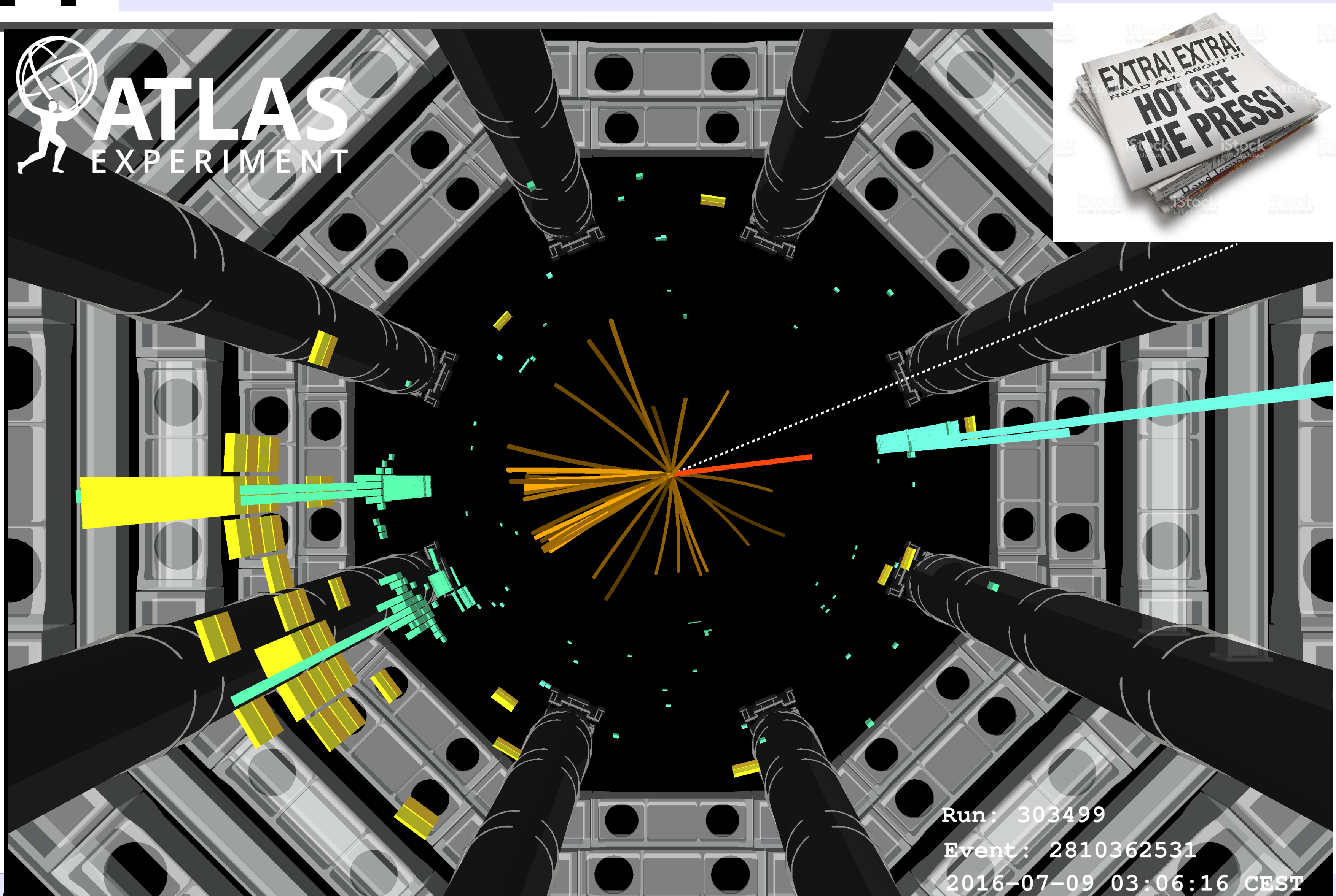
- Couplings to fermions and bosons



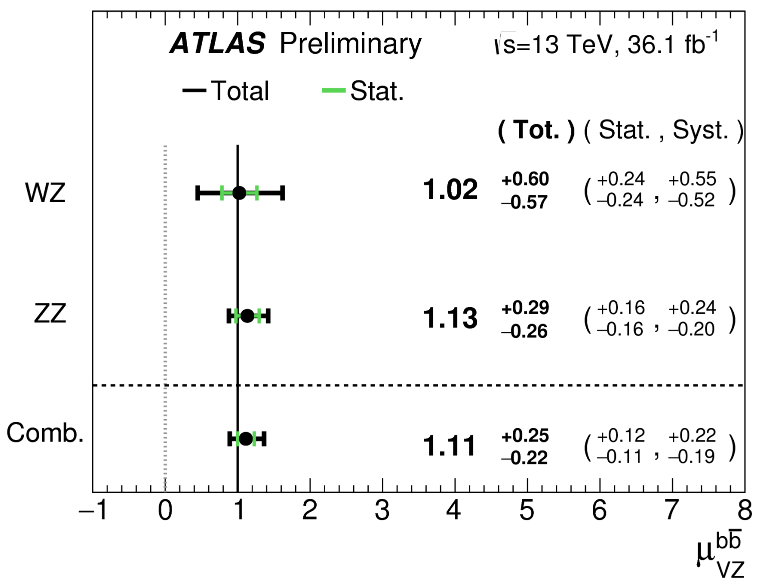
- Couplings to different particles

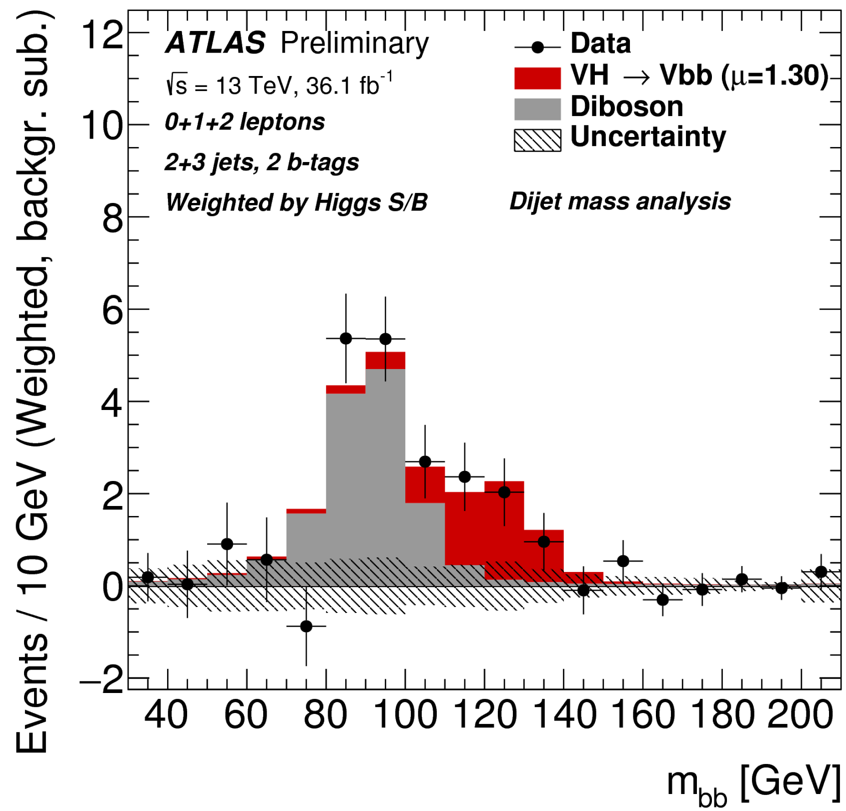


Evidence of Higgs decaying to b-quarks

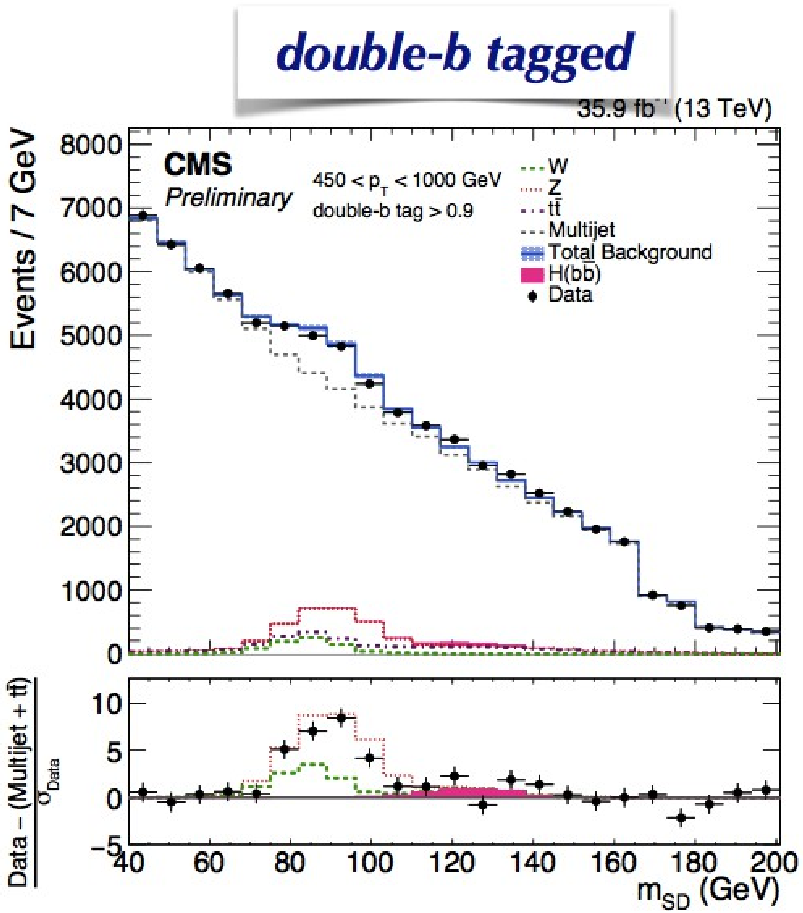


Evidence of Higgs decaying to b-quarks

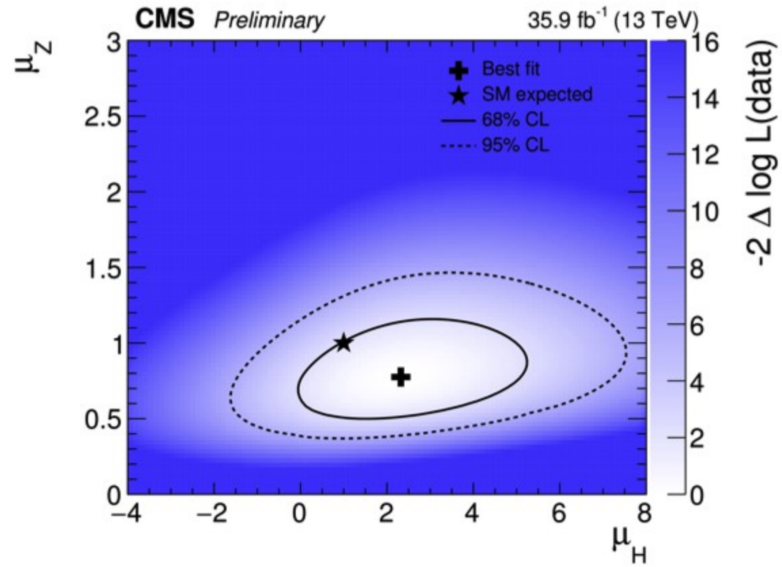




Inclusive H → bb search



- Simultaneous fit to search for $Z \to bb$ and $H \to bb$ signals

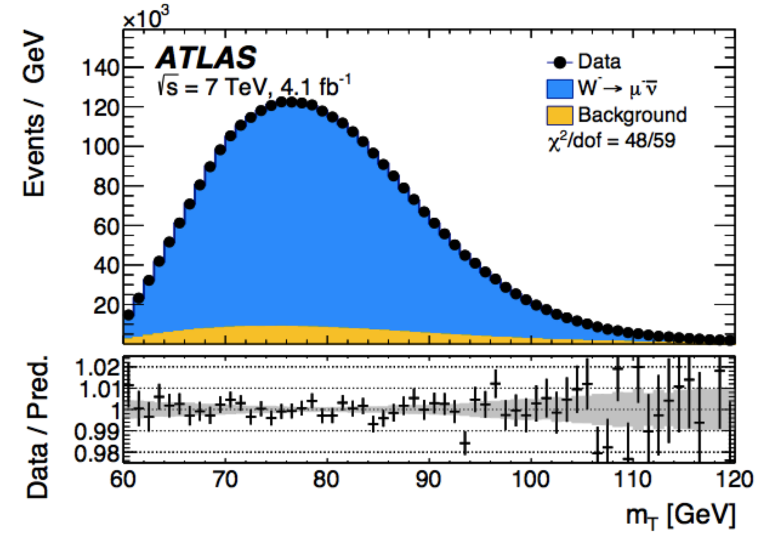


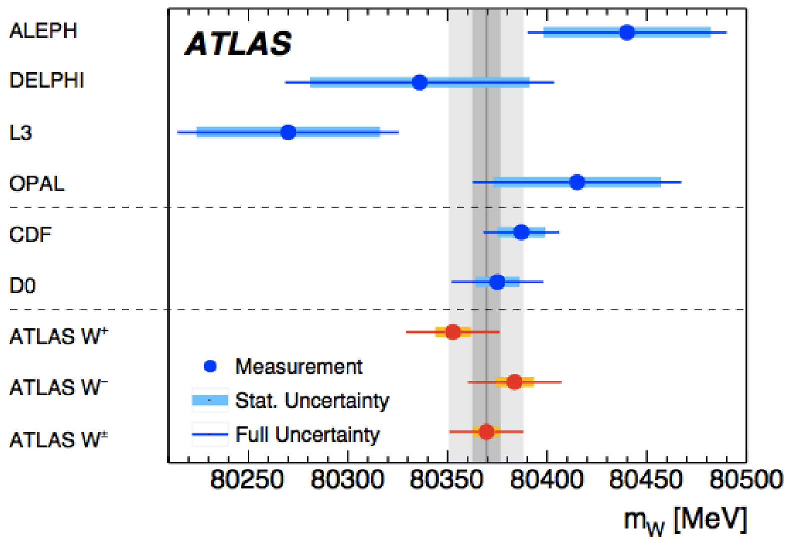
	H	Z
Observed best fit	$\mu_H = 2.3^{+1.8}_{-1.6}$	$\mu_Z = 0.78^{+0.23}_{-0.19}$
Expected significance	0.7σ ($\mu_H = 1$)	5.8σ ($\mu_Z = 1$)
Observed significance	1.5σ	5.1σ

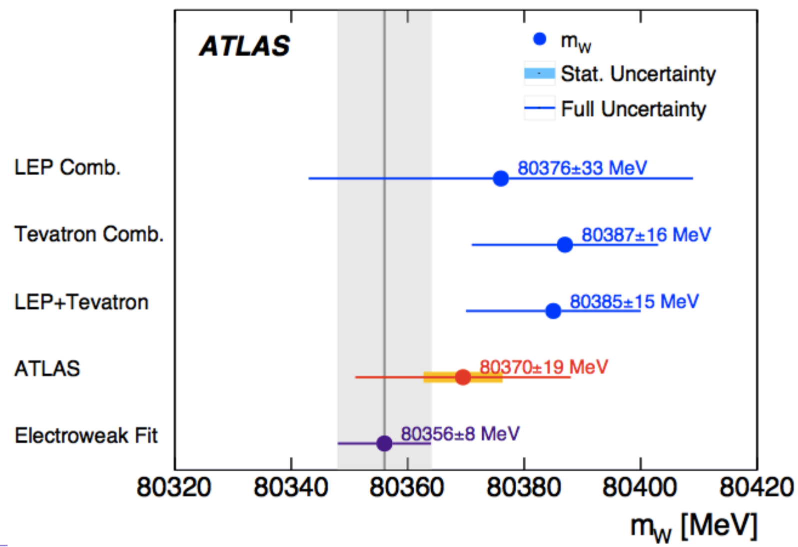
W boson mass measurement

- High precision measurement

  Data from 2011 only!
- Consistency test of the SM

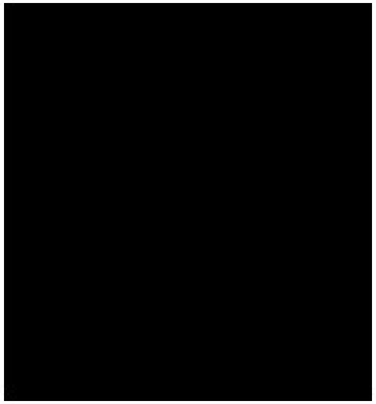




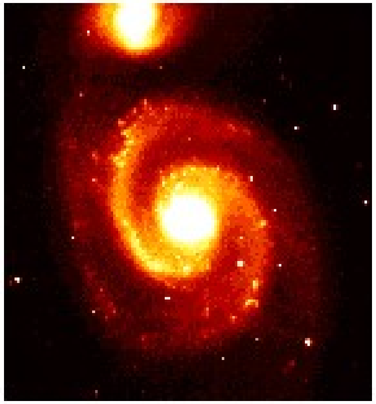


Matéria escura

- O Universo não é feito do mesmo tipo de matéria que a Terra
  - Efeitos gravitacionais: existe matéria escura
  - Existem evidencias de que não esta feita de p, e, n
  - 96% do universo é matéria/energia escura!
- De que esta feita a matéria escura?



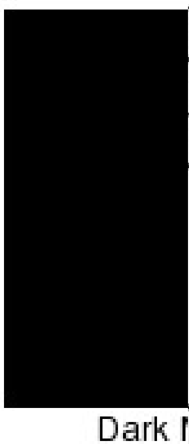
Dark Matter

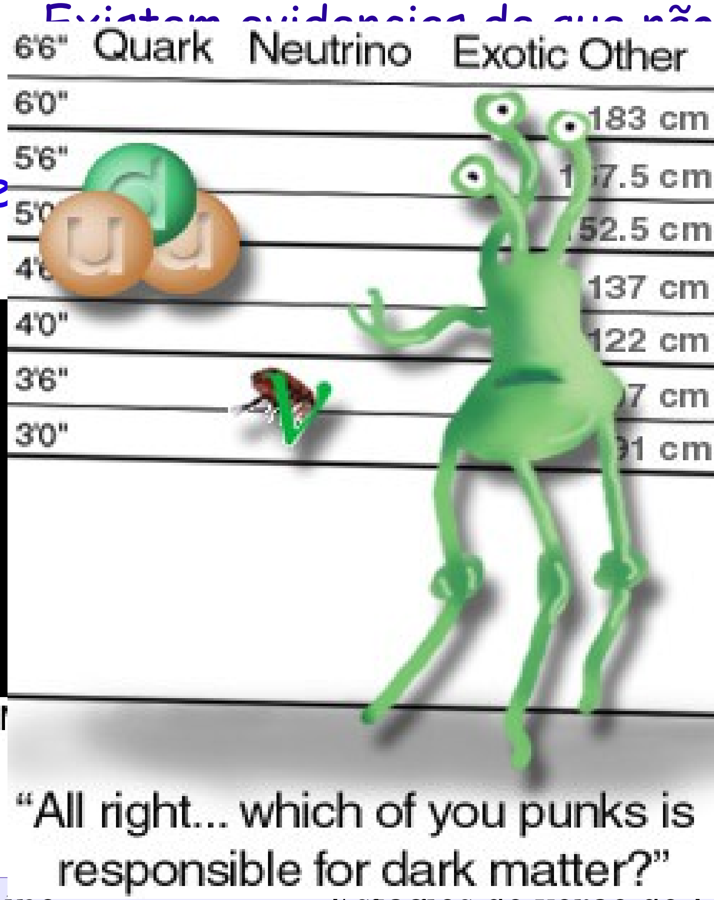


Not Dark Matter

Matéria escura

- O Universo não é feito do mesmo tipo de matéria que a Terra
  - Efeitos gravitacionais: existe matéria escura
  - … esta feita de p, e, n
  - … matéria/energia escura!
- De… …ura?



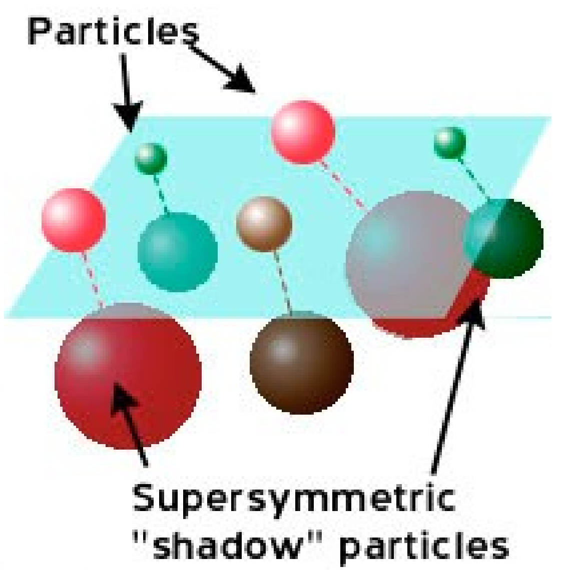


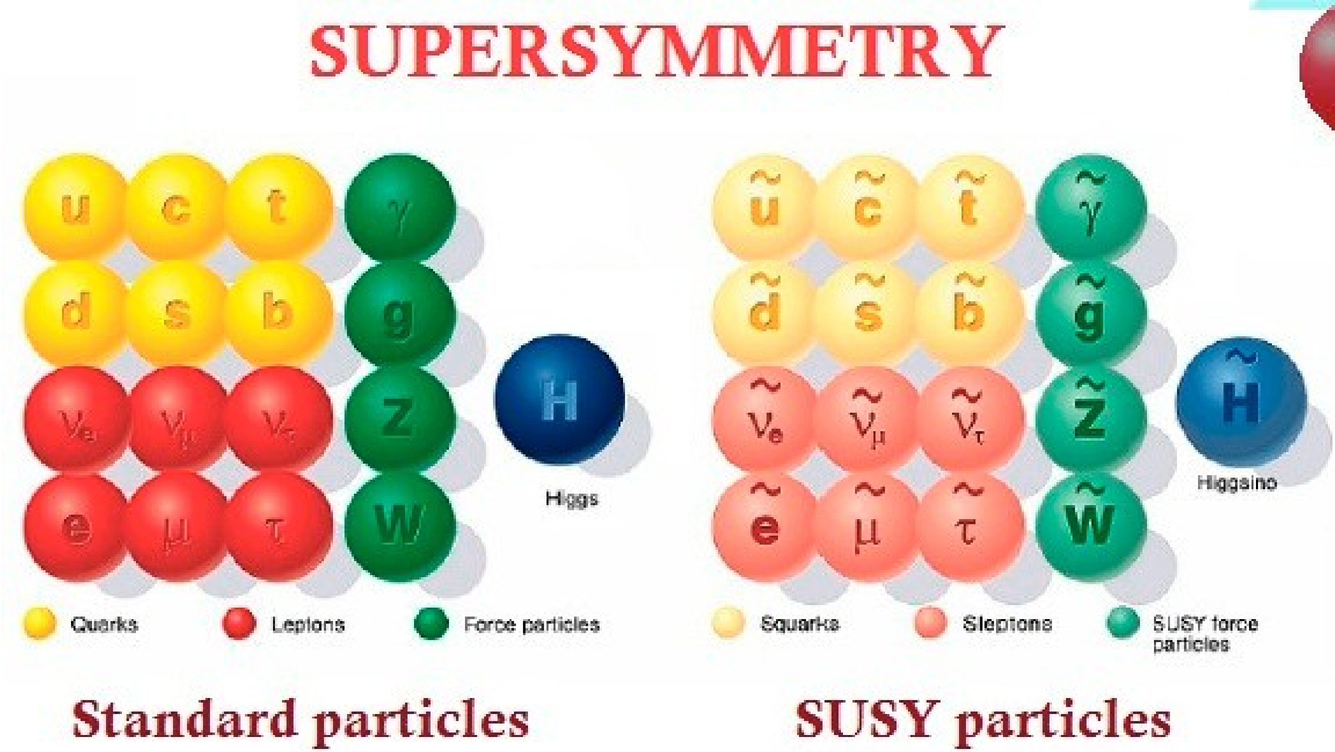
Supersimetria:

Propõe um candidato para a matéria escura do Universo: o fotino

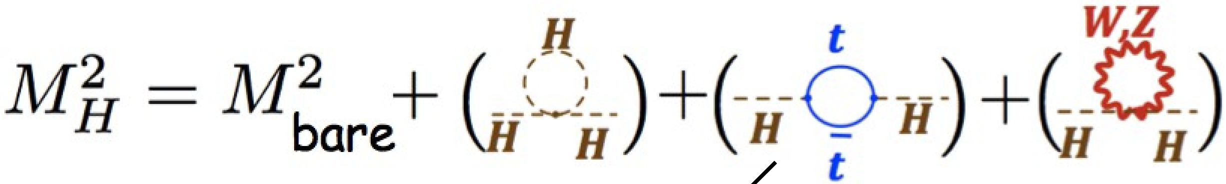
Supersimetria (SUSY)

- A supersimetria diz que para cada fermião na natureza existe um bosão e vice-versa.

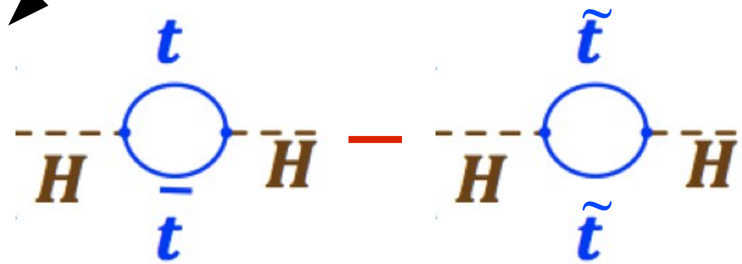




The stability of the Higgs mass



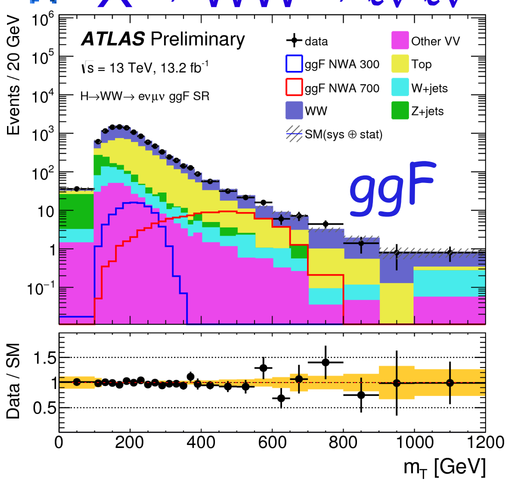
$\sim m_t^2 \Lambda^2$



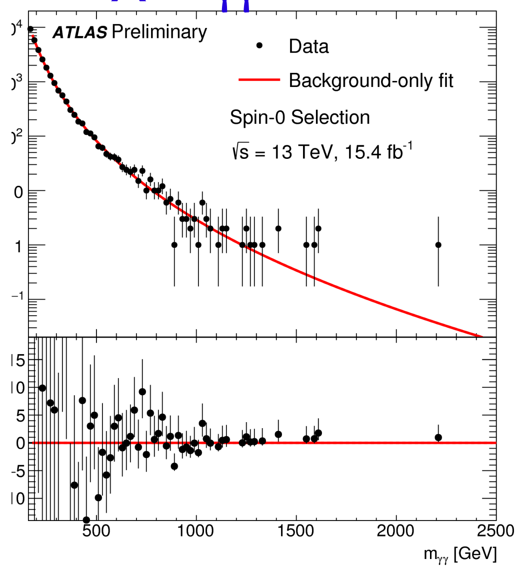
- Cancel out large terms:
  - Stop → SUSY
  - But... stop mass cannot be much larger than the top mass
    - Avoid fine tunning!
- Given the observed mass of the Higgs boson, the stop mass should not be much larger than 1-1.5 TeV
  - Accessible at the LHC?

À procura de outros bosões de Higgs

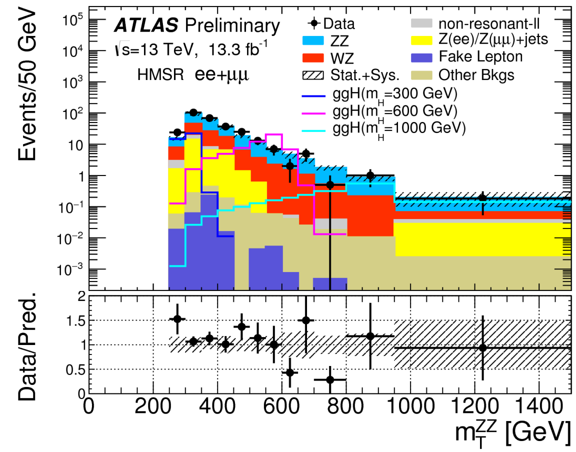
☆ $X \to WW \to \ell\nu\,\ell\nu$



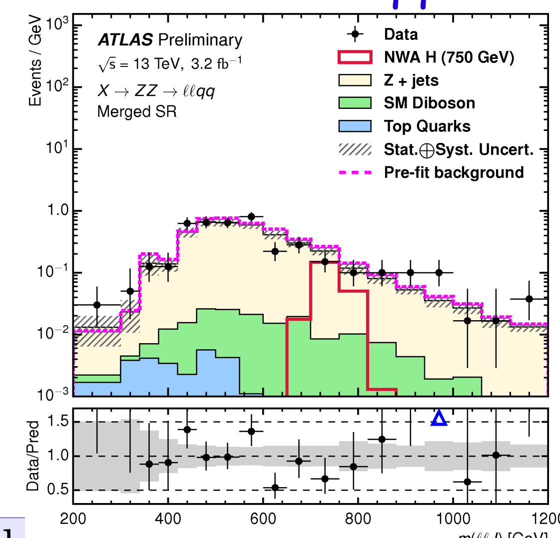
☆ $X \to \gamma\gamma$



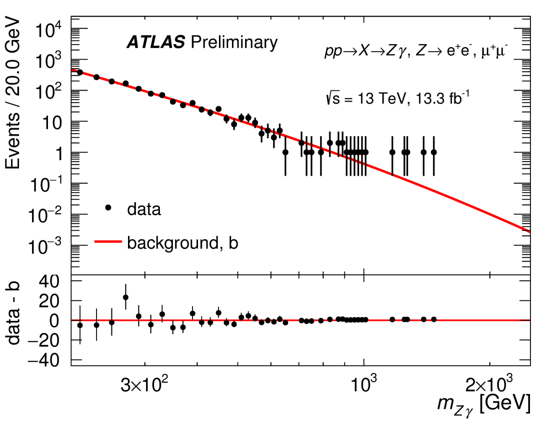
☆ $X \to ZZ \to \ell\ell\nu\nu$



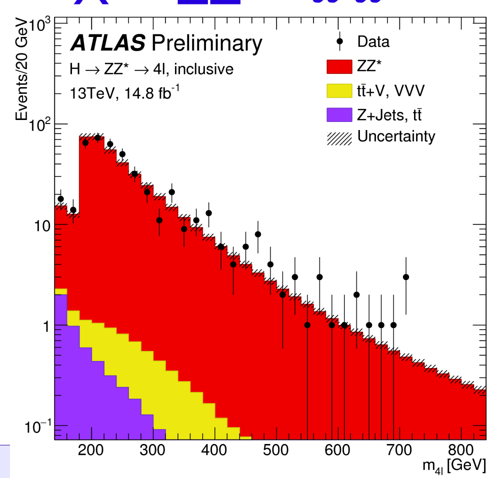
☆ $X \to ZZ \to \ell\ell qq$



☆ $X \to Z\gamma$

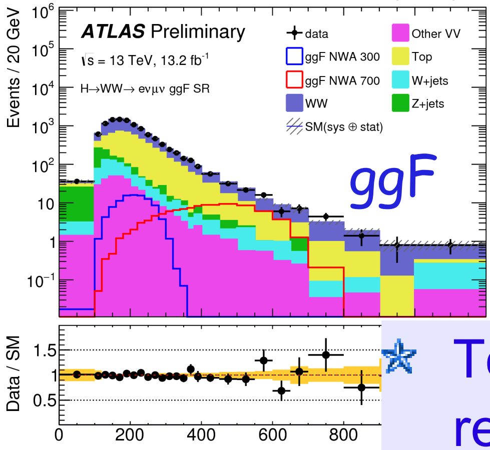


☆ $X \to ZZ \to \ell\ell\,\ell\ell$

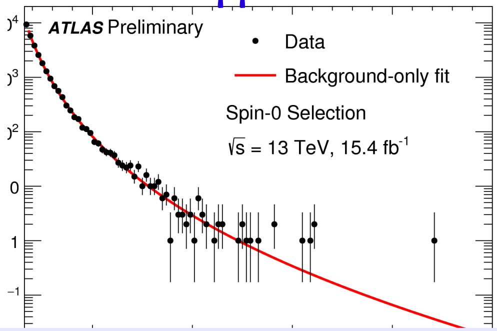


À procura de outros bosões de Higgs

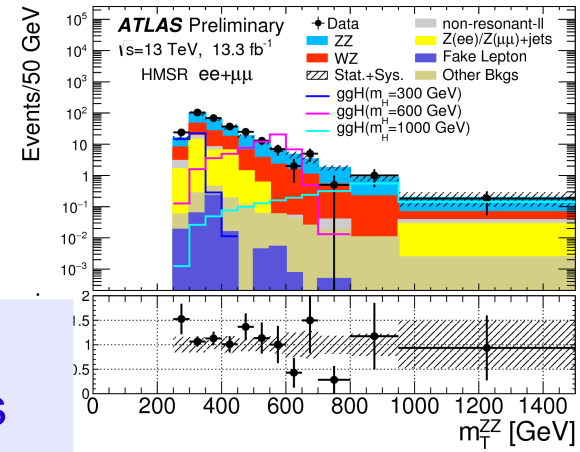
- $X \to WW \to \ell\nu\,\ell\nu$



- $X \to \gamma\gamma$

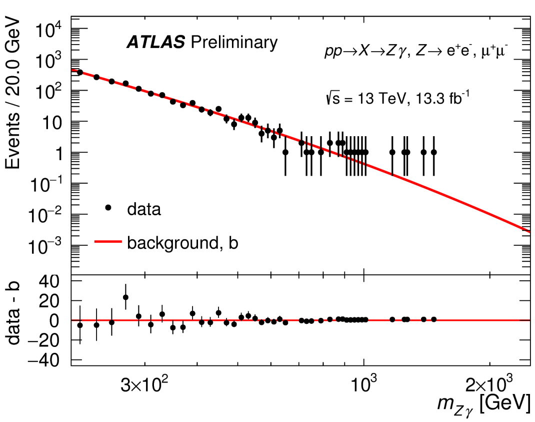


- $X \to ZZ \to \ell\ell\nu\nu$

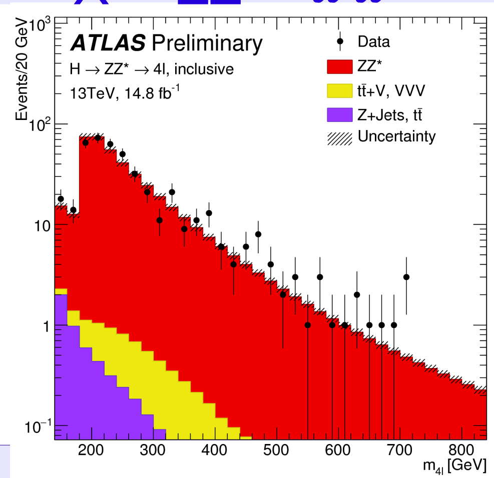


- Todas as procuras dão resultados compatíveis com os fundos esperados pelo Modelo Padrão

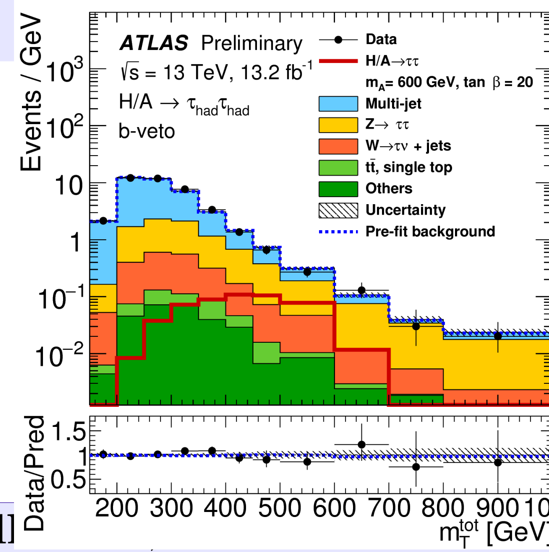
- $X \to Z\gamma$



- $X \to ZZ \to \ell\ell\,\ell\ell$



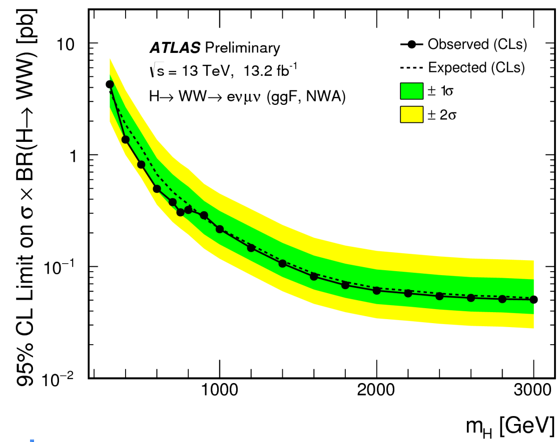
- $X \to \tau\tau$



À procura de outros bosões de Higgs

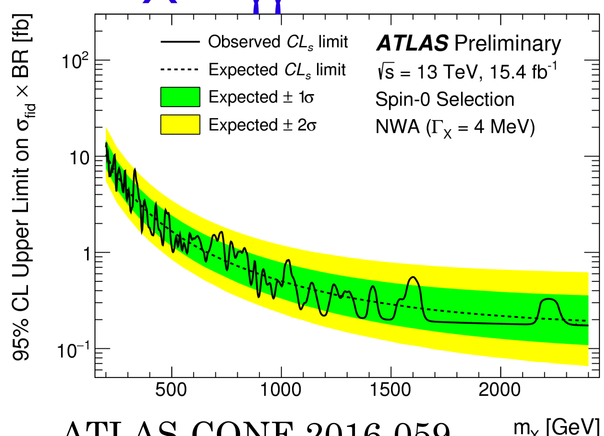
Limites...

X → WW → ℓν ℓν



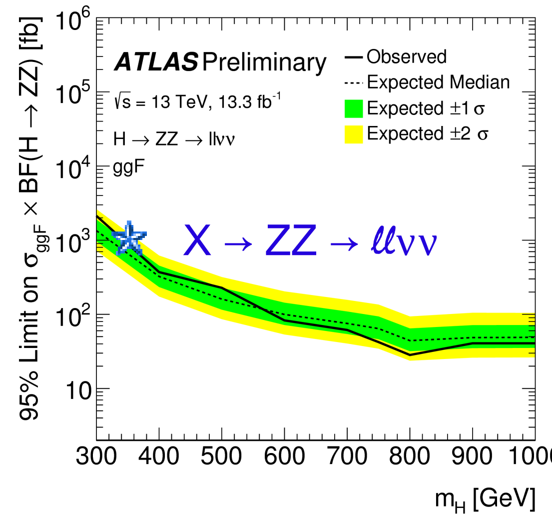
ATLAS-CONF-2016-074

X → γγ



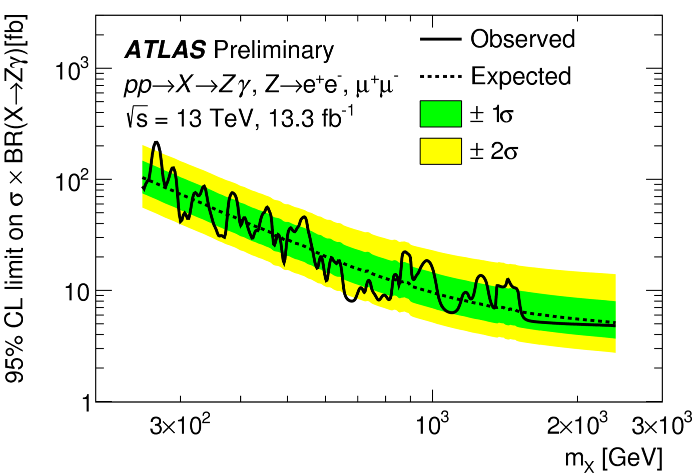
ATLAS-CONF-2016-059

X → ZZ → ℓℓνν



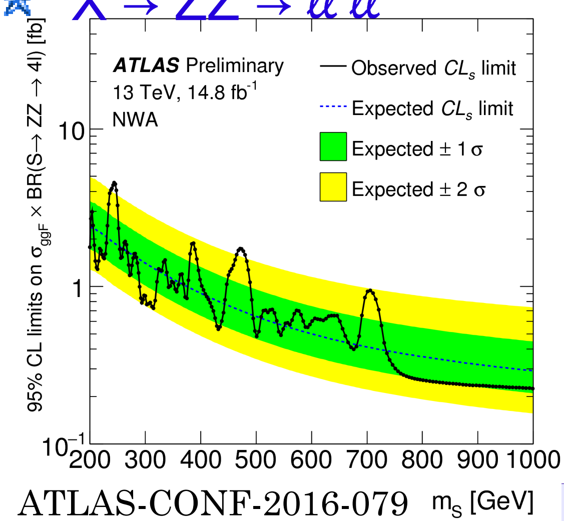
ATLAS-CONF-2016-056

X → Zγ



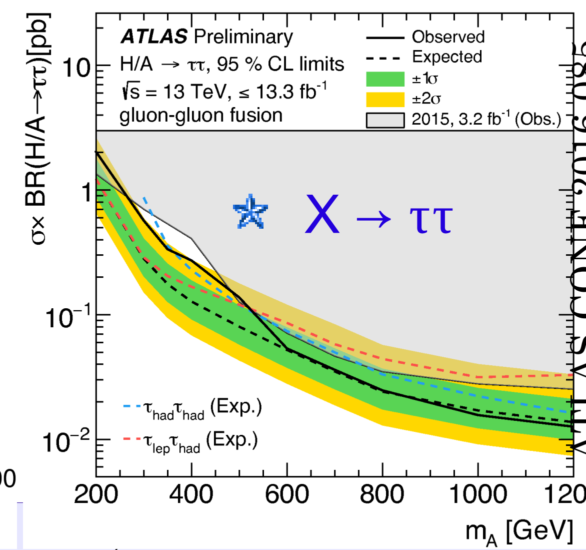
ATLAS-CONF-2016-044

X → ZZ → ℓℓ ℓℓ



ATLAS-CONF-2016-079

X → ττ



ATLAS-CONF-2016-085

[redacted]

ATLAS SUSY Searches* - 95% CL Lower Limits

May 2017

ATLAS Preliminary

$\sqrt{s}$ = 7, 8, 13 TeV

Legend: $\sqrt{s}$ = 7, 8 TeV (green) | $\sqrt{s}$ = 13 TeV (blue)

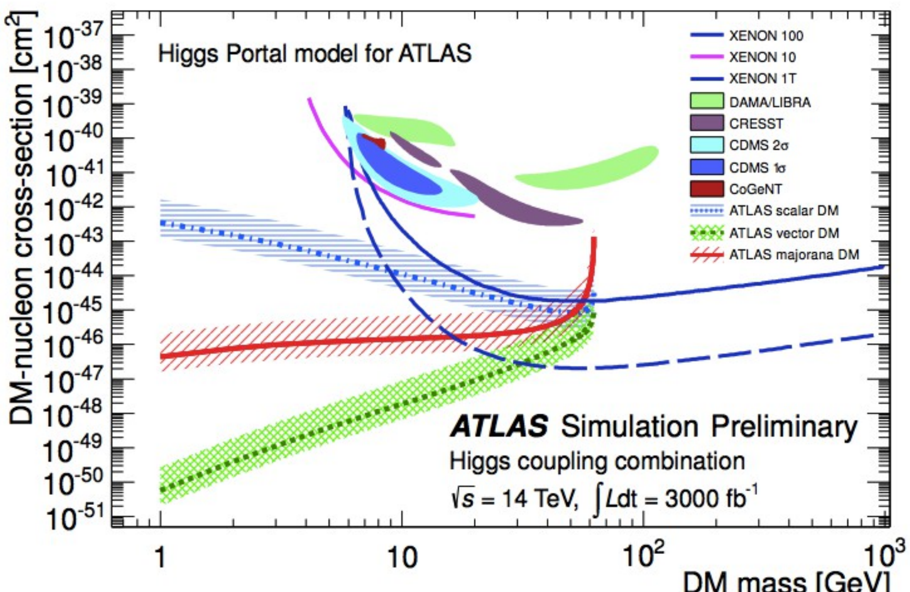
	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Mass limit	$\sqrt{s}$		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 1.85 TeV	7, 8 TeV	$m(\tilde{q})=m(\tilde{g})$	1507.05525
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{q}$ 1.57 TeV	13 TeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(1^{st}$ gen. $\tilde{q})=m(2^{nd}$ gen. $\tilde{q})$	ATLAS-CONF-2017-022
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	3.2	$\tilde{q}$ 608 GeV	13 TeV	$m(\tilde{q})-m(\tilde{\chi}_1^0)$<5 GeV	1604.07773
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{g}$ 2.02 TeV	13 TeV	$m(\tilde{\chi}_1^0)$<200 GeV	ATLAS-CONF-2017-022
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^{\pm}\to qqW^{\pm}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	$\tilde{g}$ 2.01 TeV	13 TeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}^{\pm})=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	ATLAS-CONF-2017-022
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e,μ	4 jets	-	36.1	$\tilde{g}$ 1.825 TeV	13 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	ATLAS-CONF-2017-030
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}_1^0$	0	7-11 jets	Yes	36.1	$\tilde{g}$ 1.8 TeV	13 TeV	$m(\tilde{\chi}_1^0)$ <400 GeV	ATLAS-CONF-2017-033
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	3.2	$\tilde{g}$ 2.0 TeV	13 TeV		1607.05979
	GGM (bino NLSP)	2 γ	-	Yes	3.2	$\tilde{g}$ 1.65 TeV	13 TeV	$c\tau$(NLSP)<0.1 mm	1606.09150
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$ 1.37 TeV	7, 8 TeV	$m(\tilde{\chi}_1^0)$<950 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	13.3	$\tilde{g}$ 1.8 TeV	13 TeV	$m(\tilde{\chi}_1^0)$>680 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	ATLAS-CONF-2016-066
	GGM (higgsino NLSP)	2 e,μ (Z)	2 jets	Yes	20.3	$\tilde{g}$ 900 GeV	7, 8 TeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 865 GeV	7, 8 TeV	$m(\tilde{G})>1.8\times10^{-4}$ eV, $m(\tilde{g})=m(\tilde{q})$=1.5 TeV	1502.01518
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	36.1	$\tilde{g}$ 1.92 TeV	13 TeV	$m(\tilde{\chi}_1^0)$<600 GeV	ATLAS-CONF-2017-021
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	36.1	$\tilde{g}$ 1.97 TeV	13 TeV	$m(\tilde{\chi}_1^0)$<200 GeV	ATLAS-CONF-2017-021
	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.37 TeV	7, 8 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	36.1	$\tilde{b}_1$ 950 GeV	13 TeV	$m(\tilde{\chi}_1^0)$<420 GeV	ATLAS-CONF-2017-038
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^{\pm}$	2 e,μ (SS)	1 b	Yes	36.1	$\tilde{b}_1$ 275-700 GeV	13 TeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_1^0)$+100 GeV	ATLAS-CONF-2017-030
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}_1^{\pm}$	0-2 e,μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$ 117-170 GeV; 200-720 GeV	7, 8 TeV; 13 TeV	$m(\tilde{\chi}_1^{\pm}) = 2m(\tilde{\chi}_1^0)$, $m(\tilde{\chi}_1^0)$=55 GeV	1209.2102, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	Yes	20.3/36.1	$\tilde{t}_1$ 90-198 GeV; 205-950 GeV	7, 8 TeV; 13 TeV	$m(\tilde{\chi}_1^0)$=1 GeV	1506.08616, ATLAS-CONF-2017-020
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet	Yes	3.2	$\tilde{t}_1$ 90-323 GeV	13 TeV	$m(\tilde{t}_1)-m(\tilde{\chi}_1^0)$=5 GeV	1604.07773
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-600 GeV	7, 8 TeV	$m(\tilde{\chi}_1^0)$>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	36.1	$\tilde{t}_2$ 290-790 GeV	13 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2017-019
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+h$	1-2 e,μ	4 b	Yes	36.1	$\tilde{t}_2$ 320-880 GeV	13 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2017-019
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	36.1	$\tilde{\ell}$ 90-440 GeV	13 TeV	$m(\tilde{\chi}_1^0)$=0	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	36.1	$\tilde{\chi}_1^{\pm}$ 710 GeV	13 TeV	$m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}/\tilde{\chi}_2^0$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$, $\tilde{\chi}_2^0\to\tilde{\tau}\tau(\nu\tilde{\nu})$	2 τ	-	Yes	36.1	$\tilde{\chi}_1^{\pm}$ 760 GeV	13 TeV	$m(\tilde{\chi}_1^0)$=0, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2017-035
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	36.1	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$ 1.16 TeV	13 TeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0Z\tilde{\chi}_1^0$	2-3 e,μ	0-2 jets	Yes	36.1	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$ 580 GeV	13 TeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $\tilde{\ell}$ decoupled	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$ 270 GeV	7, 8 TeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $\tilde{\ell}$ decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$ 635 GeV	7, 8 TeV	$m(\tilde{\chi}_2^0)=m(\tilde{\chi}_3^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_2^0)+m(\tilde{\chi}_1^0))$	1405.5086
	GGM (wino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	1 $e,\mu+\gamma$	-	Yes	20.3	$\tilde{W}$ 115-370 GeV	7, 8 TeV	$c\tau$<1 mm	1507.05493
	GGM (bino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	2 γ	-	Yes	20.3	$\tilde{W}$ 590 GeV	7, 8 TeV	$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet	Yes	36.1	$\tilde{\chi}_1^{\pm}$ 430 GeV	13 TeV	$m(\tilde{\chi}_1^{\pm})-m(\tilde{\chi}_1^0)$~160 MeV, $\tau(\tilde{\chi}_1^{\pm})$=0.2 ns	ATLAS-CONF-2017-017
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}_1^{\pm}$ 495 GeV	7, 8 TeV	$m(\tilde{\chi}_1^{\pm})-m(\tilde{\chi}_1^0)$~160 MeV, $\tau(\tilde{\chi}_1^{\pm})$<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 850 GeV	7, 8 TeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	3.2	$\tilde{g}$ 1.58 TeV	13 TeV		1606.05129
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{g}$ 1.57 TeV	13 TeV	$m(\tilde{\chi}_1^0)$=100 GeV, τ>10 ns	1604.04520
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$ 537 GeV	7, 8 TeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$ 440 GeV	7, 8 TeV	1<$\tau(\tilde{\chi}_1^0)$<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to eev/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}_1^0$ 1.0 TeV	7, 8 TeV	7 <$c\tau(\tilde{\chi}_1^0)$< 740 mm, $m(\tilde{g})$=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}_1^0$ 1.0 TeV	7, 8 TeV	6 <$c\tau(\tilde{\chi}_1^0)$< 480 mm, $m(\tilde{g})$=1.1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu$,$e\tau$,$\mu\tau$	-	-	3.2	$\tilde{\nu}_\tau$ 1.9 TeV	13 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 1.45 TeV	7, 8 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\nu, e\mu\nu, \mu\mu\nu$	4 e,μ	-	Yes	13.3	$\tilde{\chi}_1^{\pm}$ 1.14 TeV	13 TeV	$m(\tilde{\chi}_1^0)$>400GeV, $\lambda_{12k}\neq0$ (k = 1, 2)	ATLAS-CONF-2016-075
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\nu_e, e\tau\nu_\tau$	3 $e,\mu+\tau$	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 450 GeV	7, 8 TeV	$m(\tilde{\chi}_1^0)$>0.2×$m(\tilde{\chi}_1^{\pm})$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$ 1.08 TeV	13 TeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	0	4-5 large-R jets	-	14.8	$\tilde{g}$ 1.55 TeV	13 TeV	$m(\tilde{\chi}_1^0)$=800 GeV	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	1 e,μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$ 2.1 TeV	13 TeV	$m(\tilde{\chi}_1^0)$= 1 TeV, $\lambda_{112}\neq0$	ATLAS-CONF-2017-013
	$\tilde{g}\tilde{g}$, $\tilde{g}\to\tilde{t}_1t$, $\tilde{t}_1\to bs$	1 e,μ	8-10 jets/0-4 b	-	36.1	$\tilde{g}$ 1.65 TeV	13 TeV	$m(\tilde{t}_1)$= 1 TeV, $\lambda_{323}\neq0$	ATLAS-CONF-2017-013
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	15.4	$\tilde{t}_1$ 410 GeV; 450-510 GeV	13 TeV		ATLAS-CONF-2016-022, ATLAS-CONF-2016-084
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\ell$	2 e,μ	2 b	-	36.1	$\tilde{t}_1$ 0.4-1.45 TeV	13 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2017-036
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$ 510 GeV	7, 8 TeV	$m(\tilde{\chi}_1^0)$<200 GeV	1501.01325

10^{-1} — 1 — **Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

Higgs as a portal to dark matter

- WIMP: assumed to interact very weakly with visible matter, except for the Higgs boson
- Search for invisible Higgs decays
  - Assume couplings to other known particles as in SM
- Interpreted in terms of dark matter particles coupling only to Higgs sector
  - Exclusion limits depende
  - on WIMP spin
  - WIMP mass < $2m_H$



ATL-PHYS-PUB-2013-015

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 37.0)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 8,\ 13$ TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1 – 4 j	Yes	36.1	M_D 7.75 TeV	$n = 2$	ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	CERN-EP-2017-132
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n = 6$	1703.09217
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	CERN-EP-2017-132
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	1 e, μ	1 J	Yes	36.1	G_{KK} mass 1.75 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2017-051
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	KK mass 1.6 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	ATLAS-CONF-2016-104
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	36.1	Z' mass 4.5 TeV		ATLAS-CONF-2017-027
	SSM $Z' \to \tau\tau$	2 τ	–	–	36.1	Z' mass 2.4 TeV		ATLAS-CONF-2017-050
	Leptophobic $Z' \to bb$	–	2 b	–	3.2	Z' mass 1.5 TeV		1603.08791
	Leptophobic $Z' \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	3.2	Z' mass 2.0 TeV	$\Gamma/m = 3\%$	ATLAS-CONF-2016-014
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	36.1	W' mass 5.1 TeV		1706.04786
	HVT $V' \to WV \to qqqq$ model B	0 e, μ	2 J	–	36.7	V' mass 3.5 TeV	$g_V = 3$	CERN-EP-2017-147
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V = 3$	ATLAS-CONF-2017-055
	LRSM $W'_R \to tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	0 e, μ	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV η_{LL}^-		1703.09217
	CI $\ell\ell qq$	2 e, μ	–	–	36.1	Λ 40.1 TeV η_{LL}^-		ATLAS-CONF-2017-027
	CI $uutt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	20.3	Λ 4.9 TeV	$\lvert C_{RR}\rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	1 – 4 j	Yes	36.1	m_{med} 1.5 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 400$ GeV	ATLAS-CONF-2017-060
	Vector mediator (Dirac DM)	0 e, μ, 1 γ	≤ 1 j	Yes	36.1	m_{med} 1.2 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 480$ GeV	1704.03848
	$VV\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	≥1 b, ≥3 j	Yes	20.3	LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	0 or 1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	T mass 1.2 TeV	$\mathcal{B}(T \to Ht) = 1$	ATLAS-CONF-2016-104
	VLQ $TT \to Zt + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	36.1	T mass 1.16 TeV	$\mathcal{B}(T \to Zt) = 1$	1705.10751
	VLQ $TT \to Wb + X$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	T mass 1.35 TeV	$\mathcal{B}(T \to Wb) = 1$	CERN-EP-2017-094
	VLQ $BB \to Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	B mass 700 GeV	$\mathcal{B}(B \to Hb) = 1$	1505.04306
	VLQ $BB \to Zb + X$	2/≥3 e, μ	≥2/≥1 b	–	20.3	B mass 790 GeV	$\mathcal{B}(B \to Zb) = 1$	1409.5500
	VLQ $BB \to Wt + X$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	B mass 1.25 TeV	$\mathcal{B}(B \to Wt) = 1$	CERN-EP-2017-094
	VLQ $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	37.0	q^* mass 6.0 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1703.09127
	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	CERN-EP-2017-148
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	13.3	b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LRSM Majorana ν	2 e, μ	2 j	–	20.3	N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	ATLAS-CONF-2017-053
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g\rvert = 1 g_D$, spin 1/2	1509.08059

Limits at $\sqrt{s}$ = 8 TeV: LRSM $W'_R \to tb$ (both), CI $uutt$, Scalar LQ 3rd gen, VLQ $BB \to Hb + X$, VLQ $BB \to Zb + X$, VLQ $QQ \to WqWq$, Excited quark $b^* \to Wt$, Excited leptons ℓ^* and ν^*, and all entries under Other; all others at $\sqrt{s}$ = 13 TeV.

$\sqrt{s}$ = 8 TeV | $\sqrt{s}$ = 13 TeV

10^{-1} 1 10 **Mass scale [TeV]**

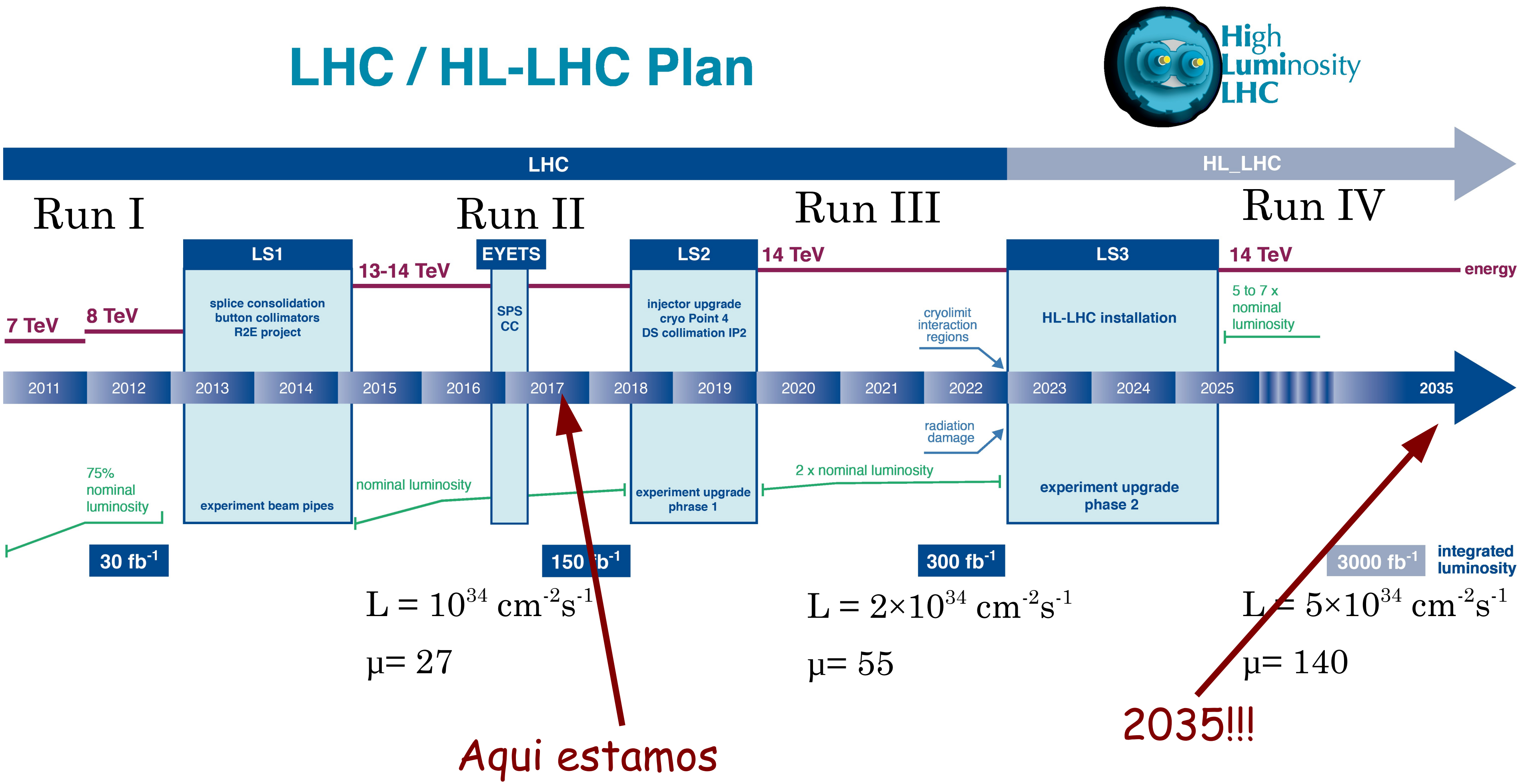
*Only a selection of the available mass limits on new states or phenomena is shown.

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

LHC reaching higher and higher luminosity...

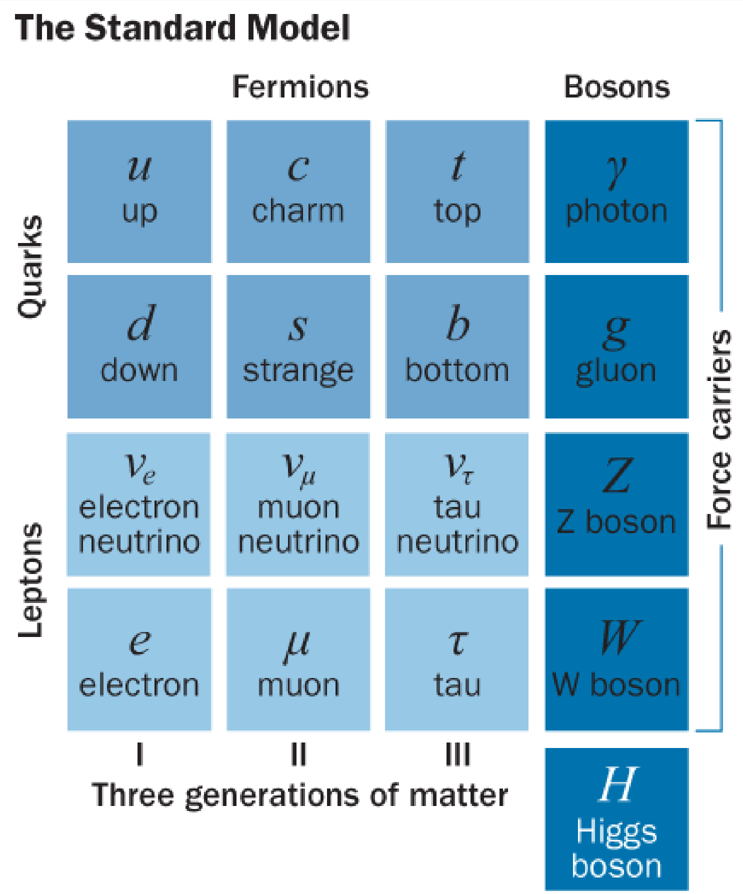
- Performance of the LHC surpassing expectations!
  - Higgs boson discovery and measurements
  - Reaching precision SM era!
- With higher luminosity discoveries might be around the corner...

Futuro do LHC e de ATLAS e CMS



Backup

O Modelo Padrão da Física das Partículas

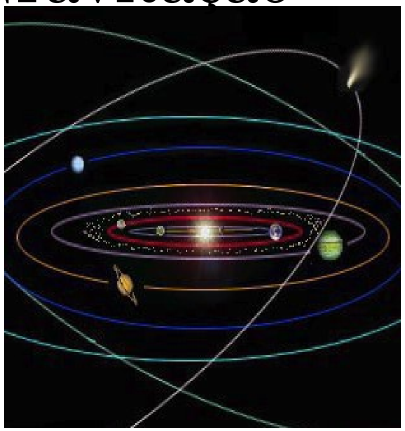


Quarks e **leptões**
spin = ½ (fermiões)

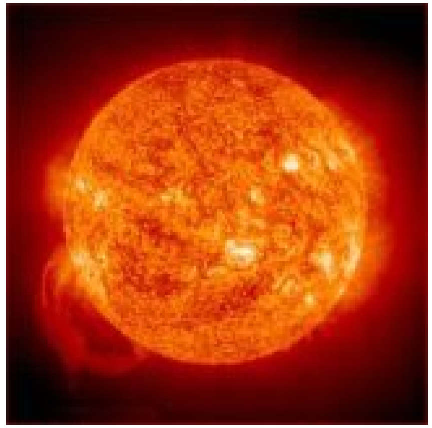
Mediadores das forças
spin inteiro (bosões)

As interações fundamentais

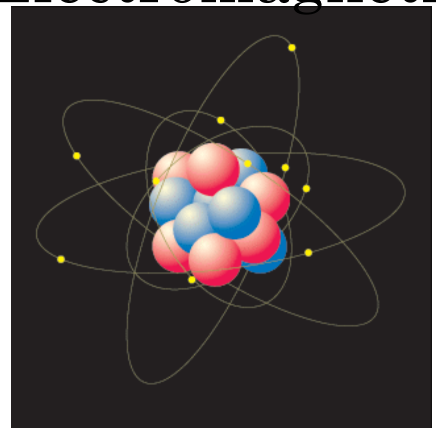
Gravitação



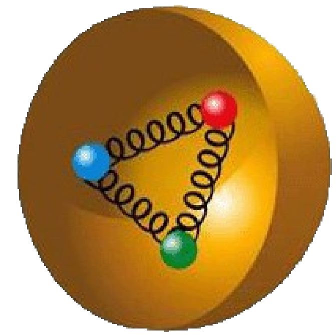
Fraca



Electromagnetismo



Forte



Interacção	Gravitação	Fraca	Electromagnética	Forte
Partícula	gravitão (?)	W^+, W^- e Z^0	fotão	gluão
Age sobre	massa	carga de "sabor"	carga eléctrica	"cor"
Força entre 2 protões no núcleo	10^{-36}	10^{-7}	1	20
Responsável por	Sistema solar galáxias	radioactividade beta fusão nuclear	luz, átomos, química, electrónica	hadrões núcleos

O que é a Supersimetria?

Dois tipos de partículas na natureza: fermiões e bosões

- Os fermiões têm spin semi-inteiro e tendem a ser tímidos e a manterem-se afastados uns dos outros (como num hotel onde as pessoas estão sempre em quartos individuais)

- Os bosões têm spin zero ou inteiro e tendem a estar todos juntos (como num hotel em que as pessoas ficam em dormitorios comuns)

Supersimetria

- A supersimetria diz que para cada fermião na natureza existe um bosão e vice-versa.
- Não se encontraram partículas supersimétricas (ainda) e portanto devem ser muito pesadas.

SPIN ½
FERMIONS

SPIN 0
BOSONS