



# LHC

What has been accomplished?  
What lies ahead?

Mike Flowerdew, MPP Munich

Science week, 04/12/13

# Some big questions

Extra dimensions?

Origin of mass?

Weakness of gravity?

Neutrino mass?

Where is the antimatter?

Are there new symmetries/interactions?

3 generations?

Dark matter?

SUSY,  
quantum  
black holes

Extra  
dimensions?

BEH  
mechanism  
& Higgs  
boson

Origin of  
mass?

Right-  
handed  
neutrinos?

Weakness  
of gravity?

KK towers,  
graviton  
production

Neutrino  
mass?

Flavour  
physics &  
new  
interactions

$SU(2)_R$ ,  $Z'/W'$ ,  
leptoquarks

Are there new  
symmetries/  
interactions?

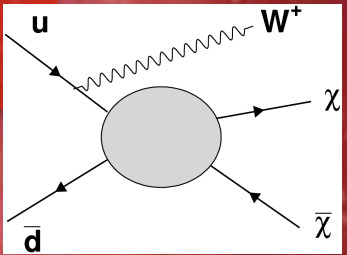
Where is  
the  
antimatter?

+ many more

Higgs  
coupling,  
searches

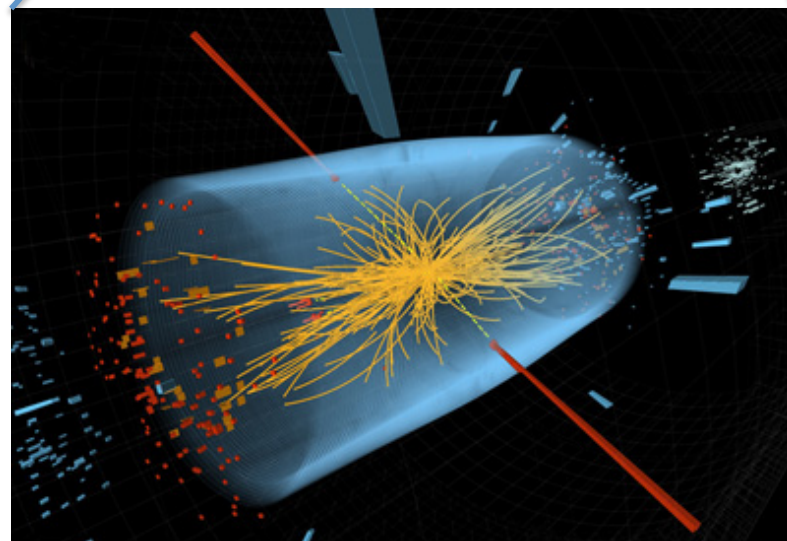
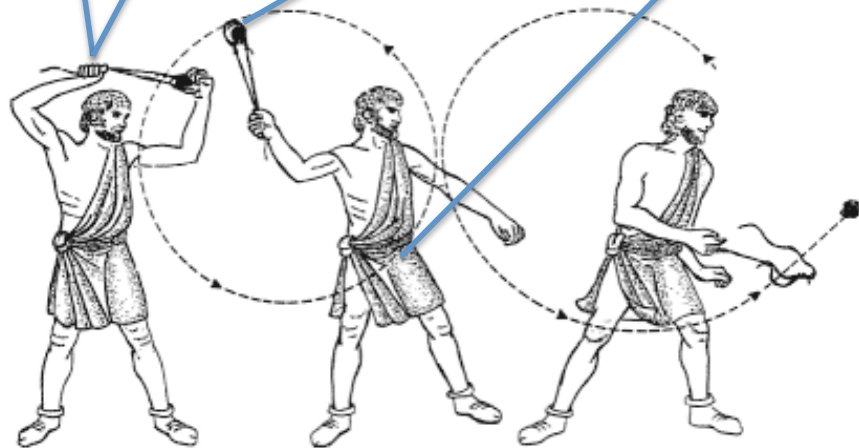
3 generations?

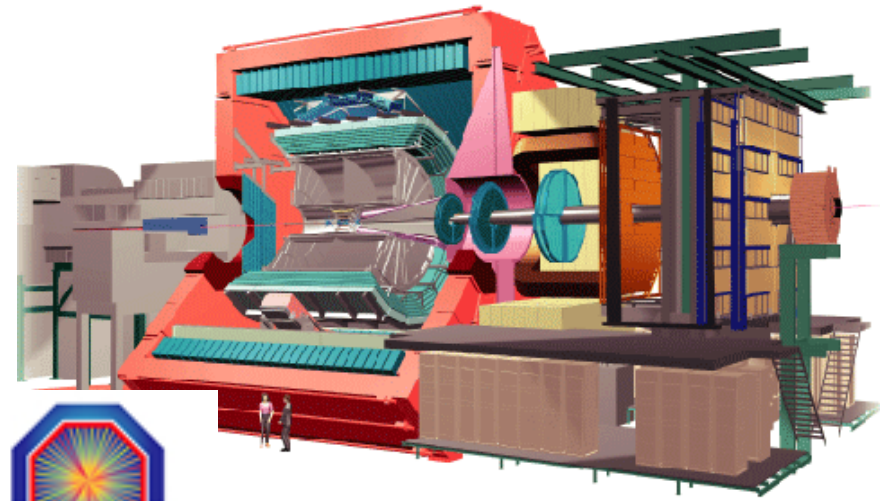
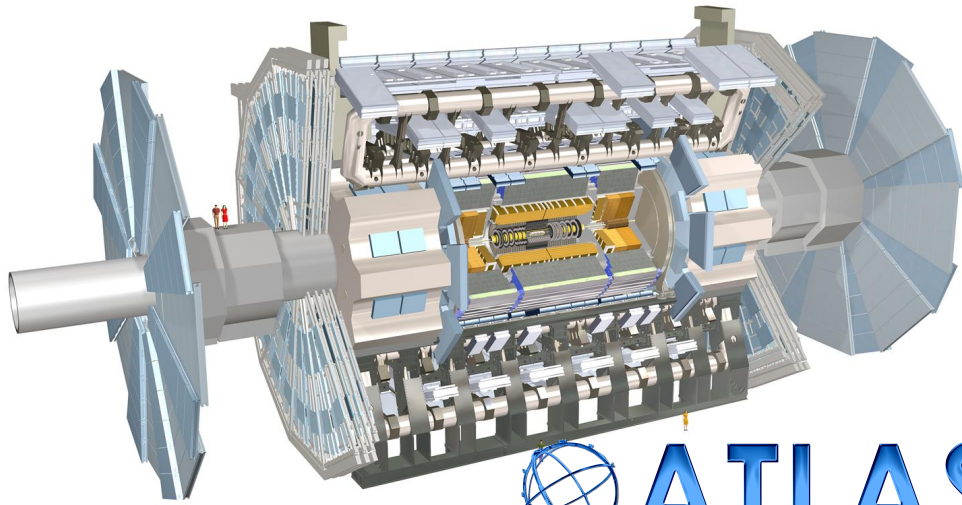
Dark matter?



arXiv:1309.4017  
[hep-ph]

# The Large Hadron Collider

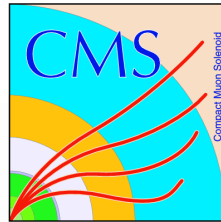




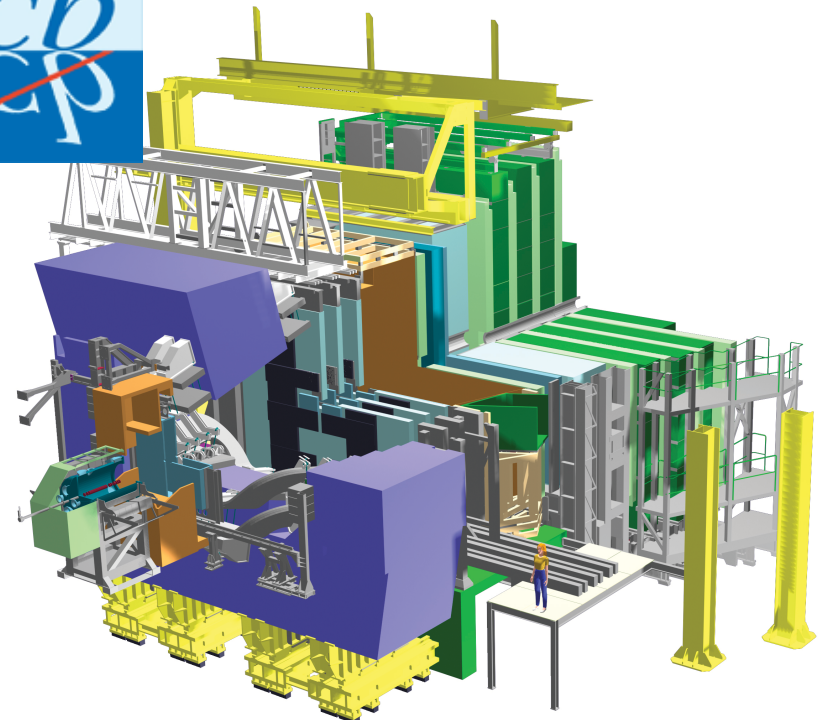
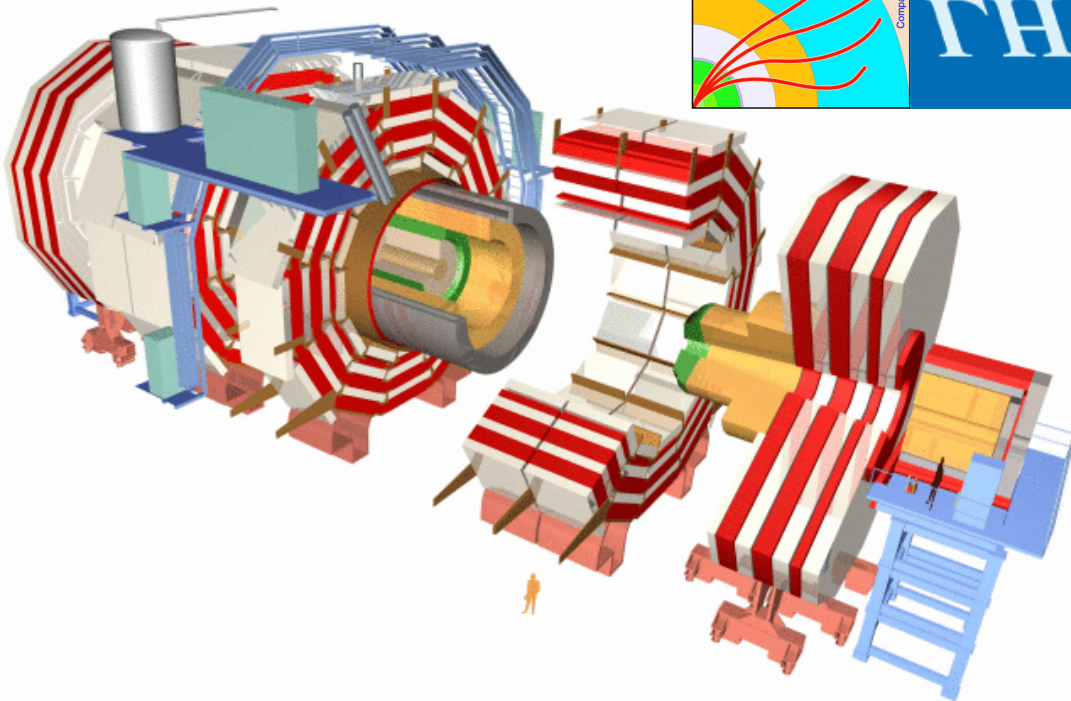
ATLAS  
EXPERIMENT



ALICE



LHCb  
THECP

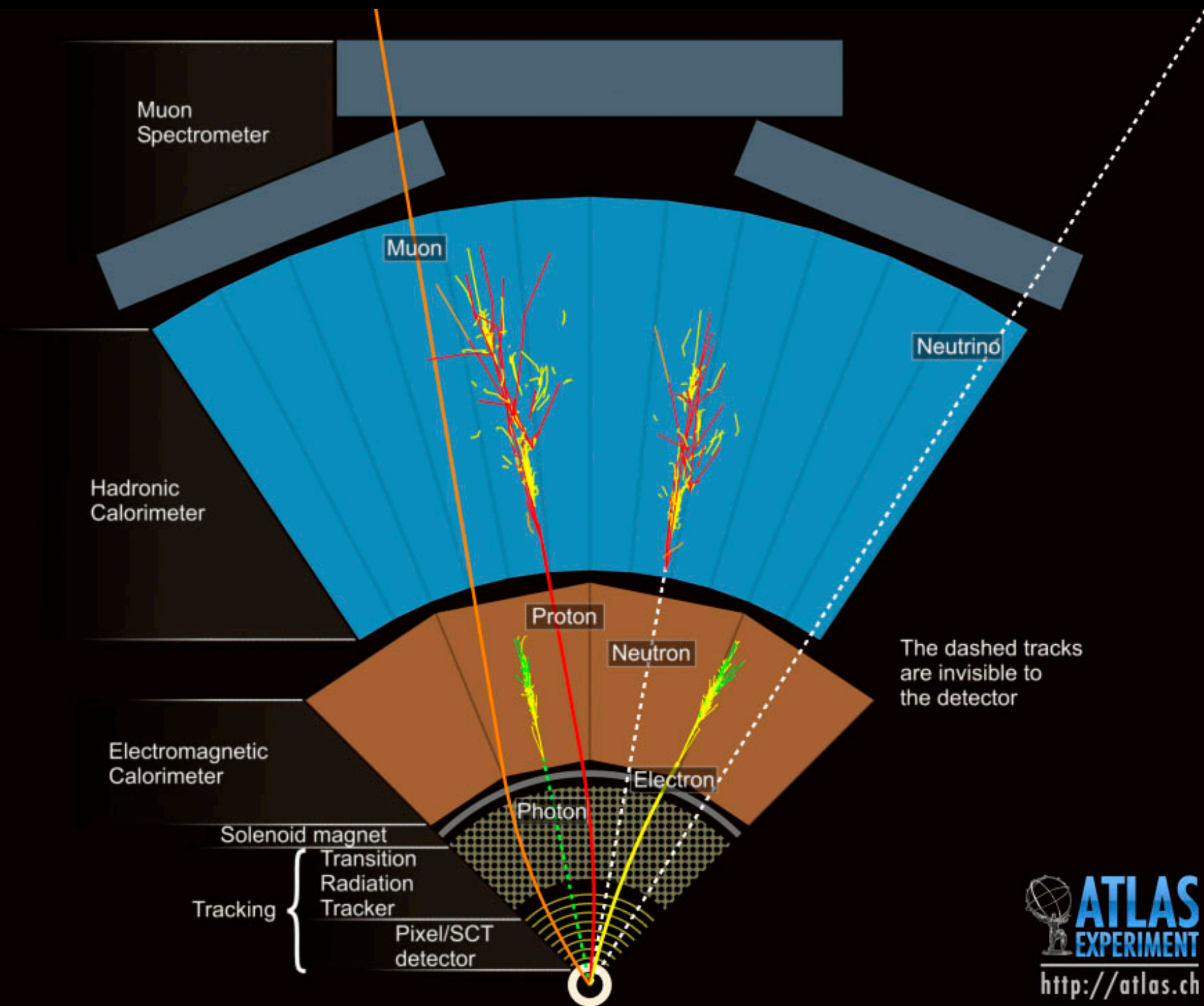


# THE STANDARD MODEL<sup>SM</sup>

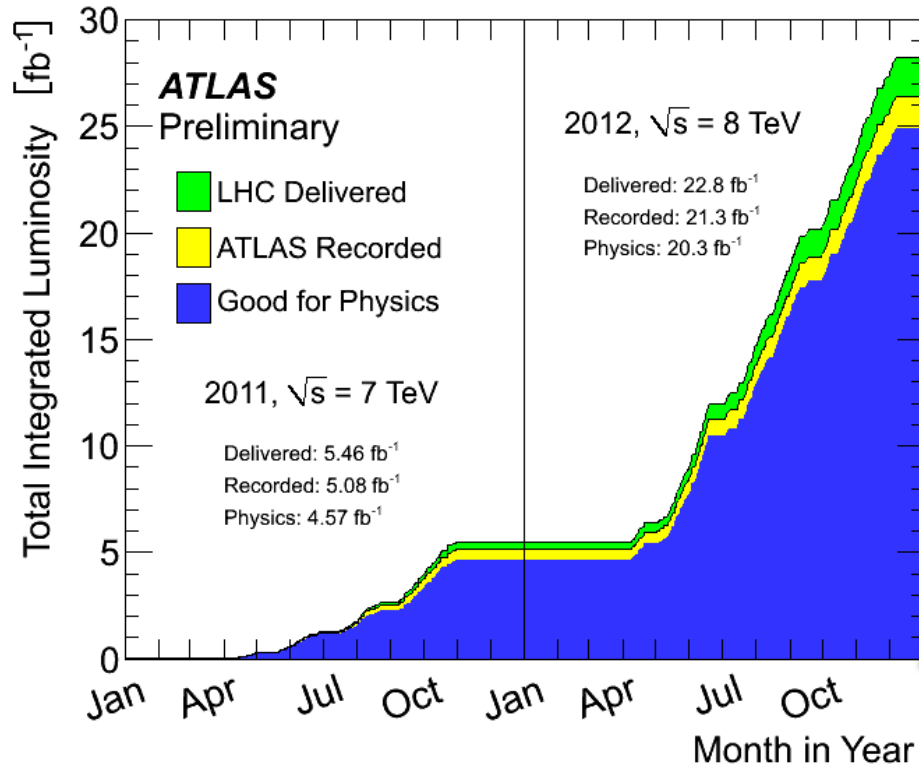
	Matter particles			Force carriers	
	Quarks			Gauge Bosons	Higgs Boson
Matter particles	$u$	$c$	$t$	$\gamma$	$h^0$
	$d$	$s$	$b$	$Z^0$	
More matter particles	Leptons			$W^\pm$	
	$e^\pm$	$\mu^\pm$	$\tau^\pm$	$g$	
	$\nu_e$	$\nu_\mu$	$\nu_\tau$		



All are *or should be* produced at the LHC



# Run I summary



## LUMINOSITY

We need data, and lots of it!

- 2,000,000,000,000,000** p-p collisions per experiment in 2 years
- Lots of chances to produce exceptionally rare processes
  - Only about **one in a million** events recorded

All achieved at reduced collision energy following 2008 incident

- **Full repairs now underway for Run II**

## ENERGY

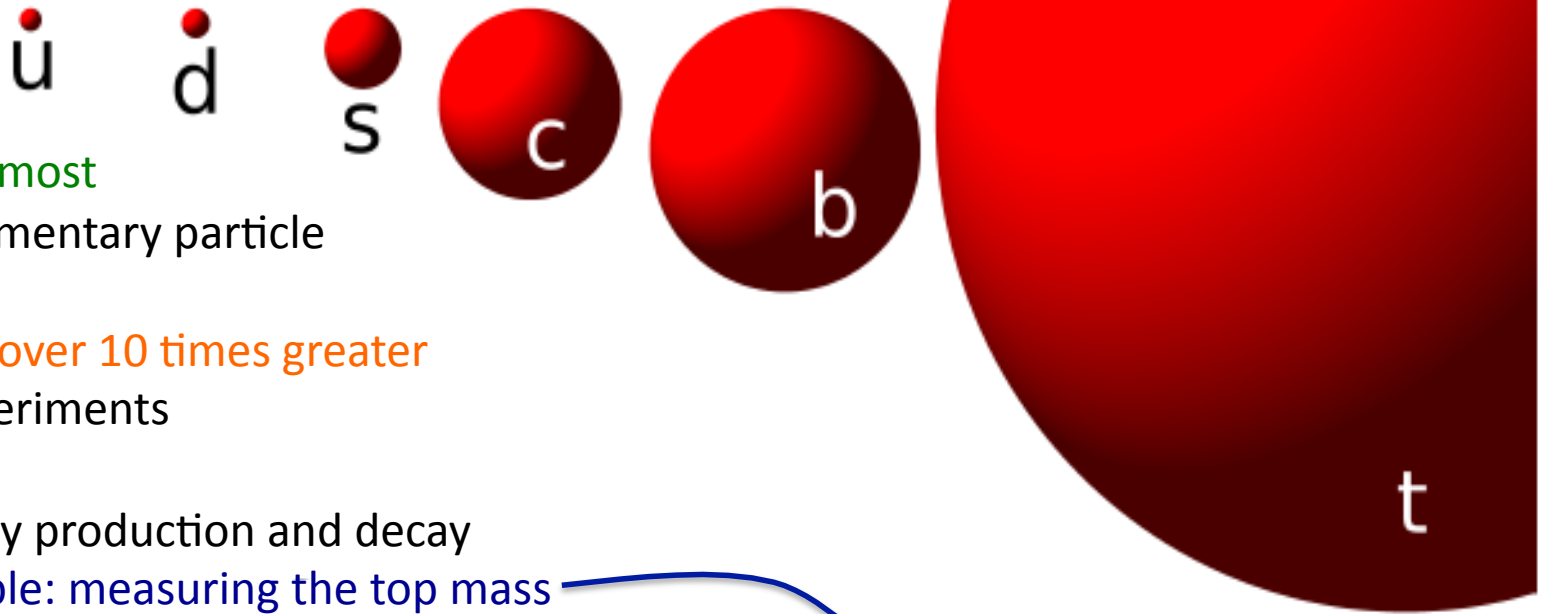
Year	Energy [TeV]
2009	0.9-2.36
2010-2011	7
2012	8
2015-?	13





# Precision measurements

~ 2.3 MeV    ~ 4.8 MeV    ~ 95 MeV    ~ 1.3 GeV    ~ 4.2 GeV    ~ 173 GeV

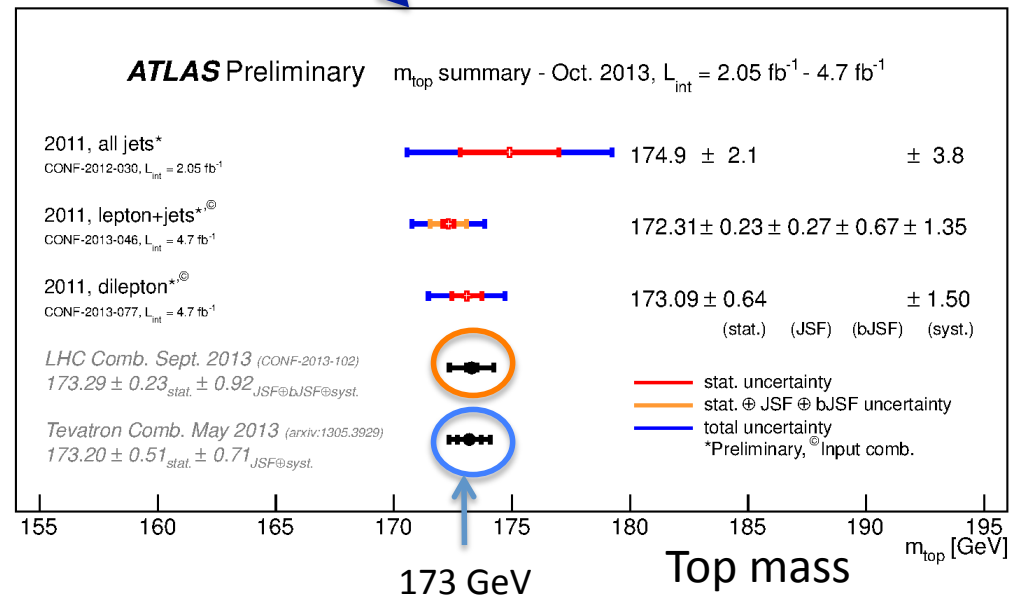
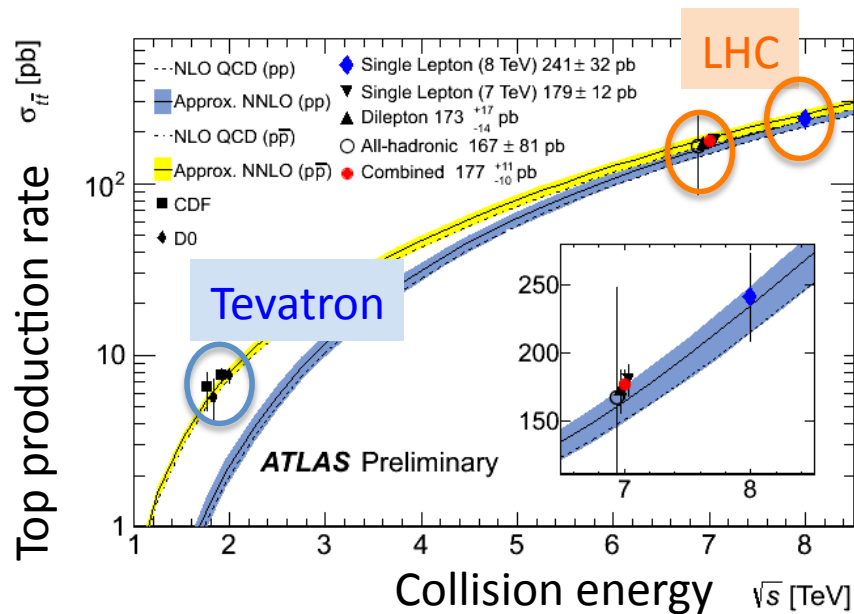


The top quark is the **most massive** (known) elementary particle

LHC production rate **over 10 times greater** than in previous experiments

Large sample to study production and decay

Example: measuring the top mass



# Observed particles (pre-LHC)



Particles with mass

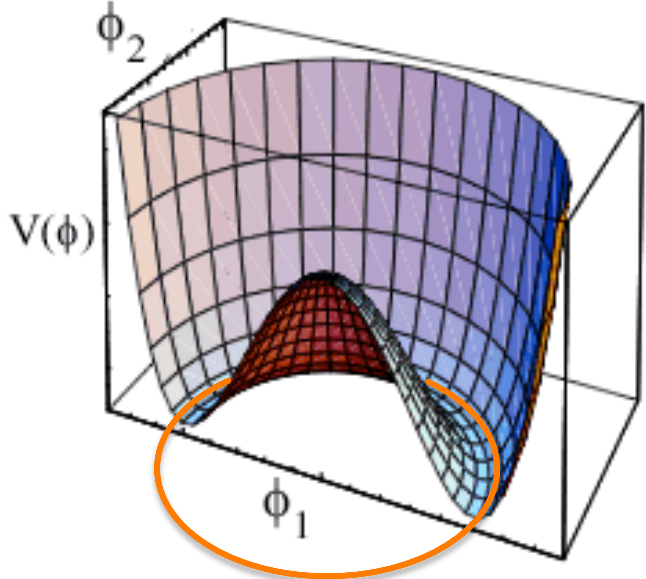
Forbidden  
by gauge  
symmetry

Another  
story

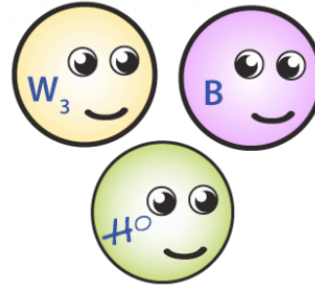
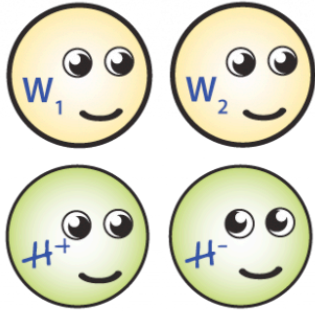
Quarks			Gauge Bosons
$u$	$c$	$t$	$\gamma$
$d$	$s$	$b$	$Z^0$
Leptons			$W^\pm$
$e^\pm$	$\mu^\pm$	$\tau^\pm$	$g$
$\nu_e$	$\nu_\mu$	$\nu_\tau$	

# The BEH mechanism

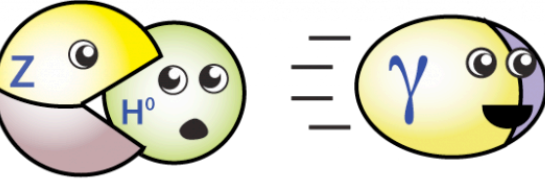
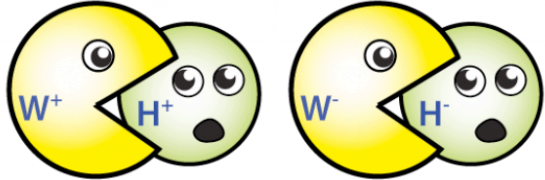
(Brout-Englert-Higgs)



BEH field:  $\phi_1, \phi_2$   
4 components overall  
Vacuum state breaks  
gauge symmetry



Massless bosons  
from SM  
symmetries



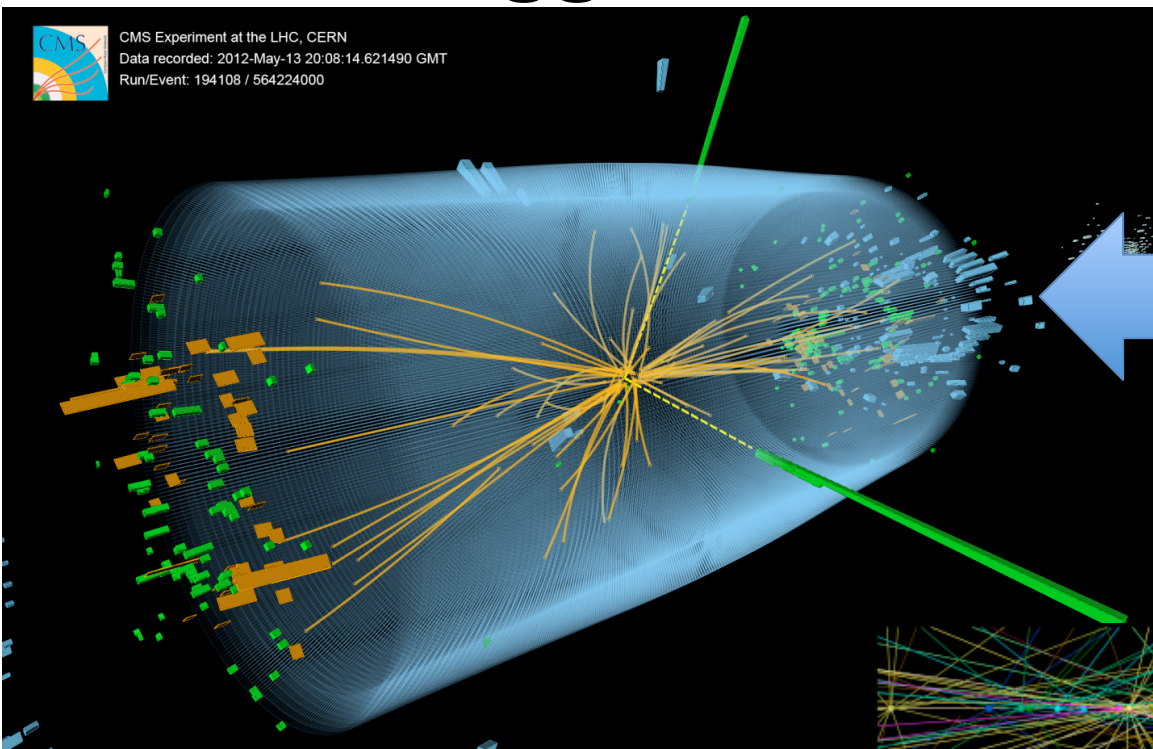
Physically observable  
bosons:  $W^\pm, Z, \gamma$

One field left over:

**The Higgs Boson**



# Higgs detection at the LHC



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

Precision channels  
(good mass resolution)

$$h \rightarrow \gamma\gamma$$

High rate, substantial background

$$h \rightarrow ZZ^* \rightarrow 4\ell$$

Low rate, but very pure

Other channels

(poor mass resolution)

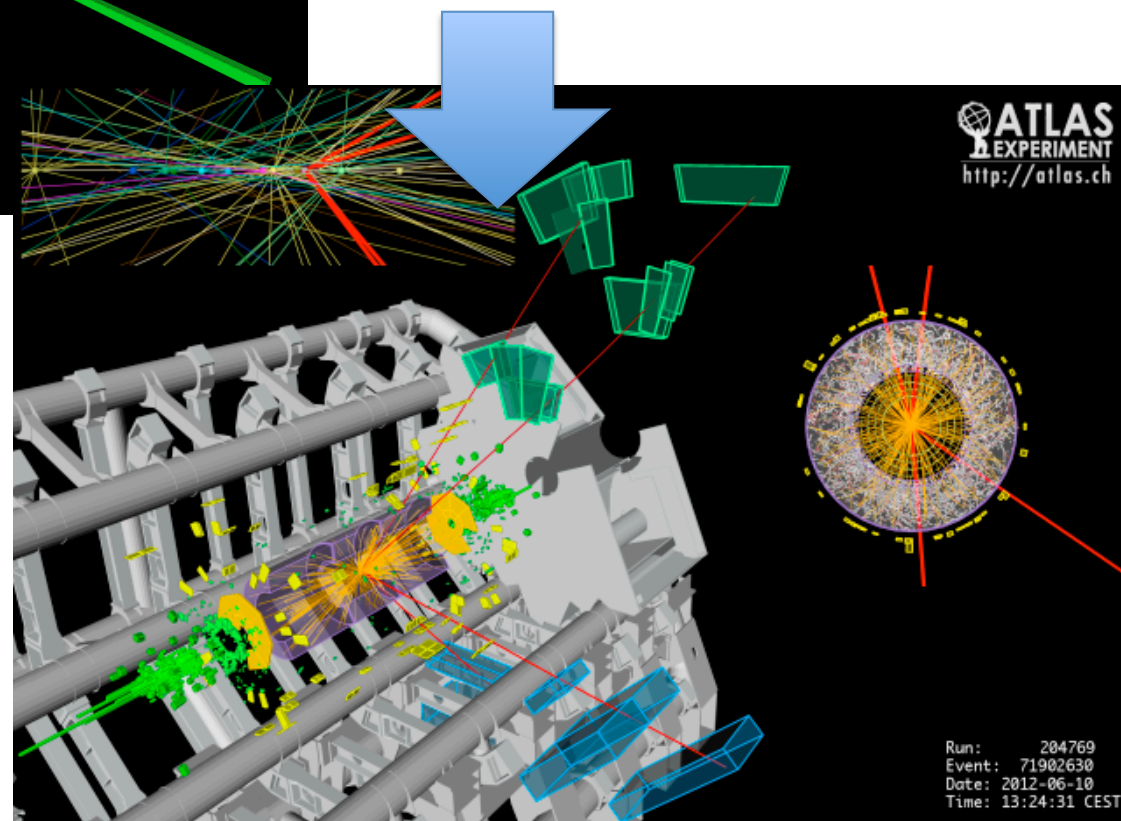
$$h \rightarrow WW^* \rightarrow 2\ell 2\nu$$

$$h \rightarrow \tau\tau$$

$$h \rightarrow b\bar{b}$$

$$h \rightarrow ZZ^* \rightarrow 2\ell 2\nu$$

and many more



ATLAS  
EXPERIMENT  
<http://atlas.ch>

Run: 204769  
Event: 71902630  
Date: 2012-06-10  
Time: 13:24:31 CEST

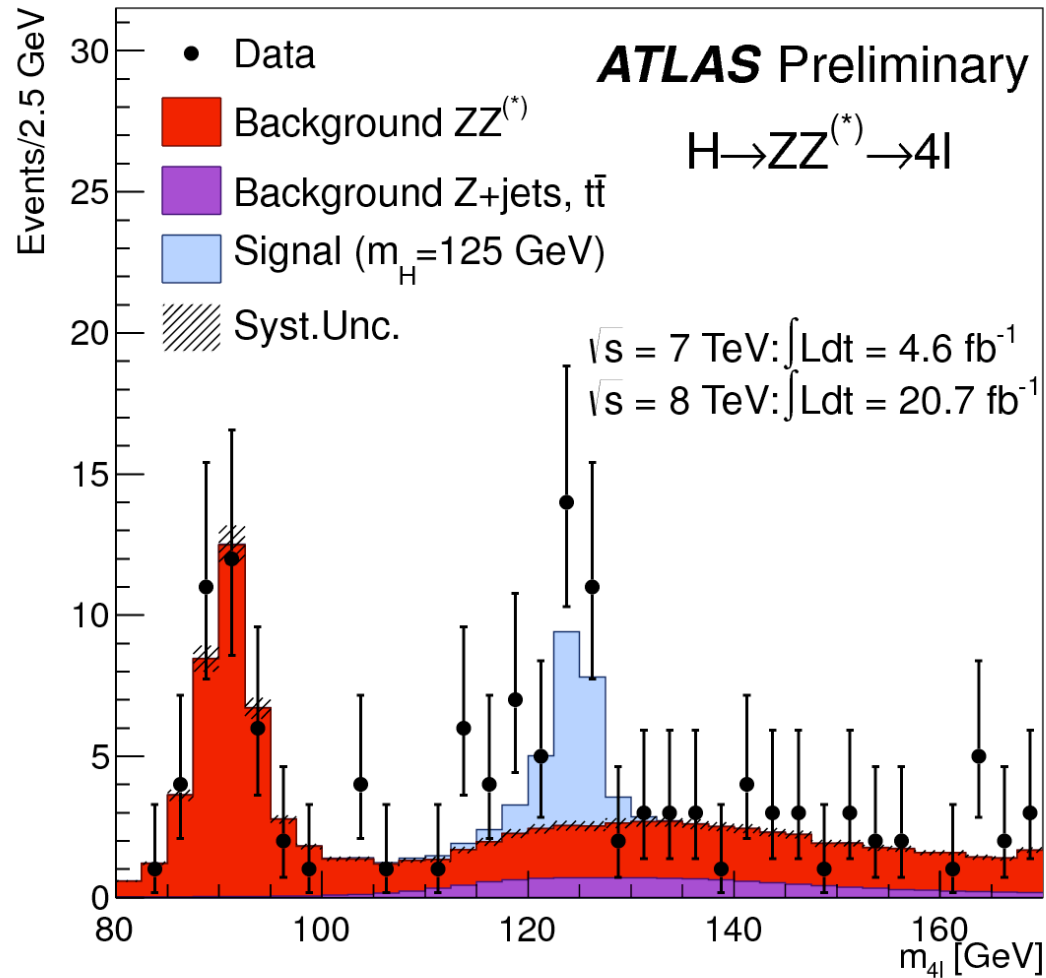
# How discoveries are made

$$h \rightarrow ZZ^* \rightarrow 4\ell$$

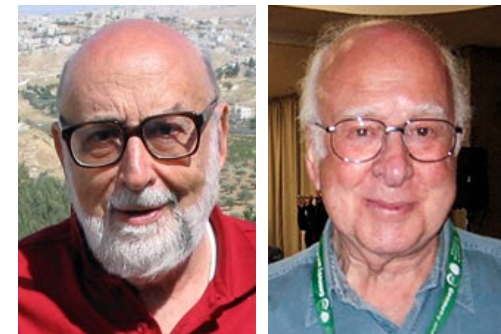
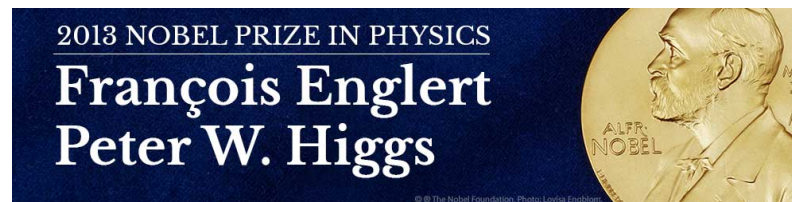
Ongoing measurements:

- Mass
- Couplings
- Spin/parity










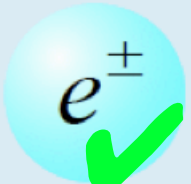

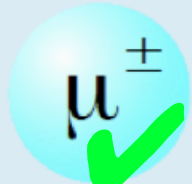
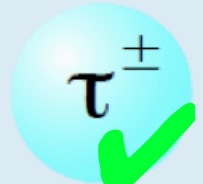




So far consistent with expectations



The 2013 Nobel prize honoured this successful prediction



# Revenge of the SM

Quarks	Gauge Bosons	Higgs Boson
 $u$ ✓	 $\gamma$ ✓	 $h^0$ ✓
 $c$ ✓		
 $t$ ✓		
 $d$ ✓	 $Z^0$ ✓	
 $s$ ✓		
 $b$ ✓		
Leptons		
 $e^\pm$ ✓	 $W^\pm$ ✓	
 $\mu^\pm$ ✓		
 $\tau^\pm$ ✓		
 $\nu_e$ ✓	 $g$ ✓	
 $\nu_\mu$ ✓		
 $\nu_\tau$ ✓		

**THE STANDARD MODEL WINS!**

# But is that it?

If SM parameters are random, how lucky are we?

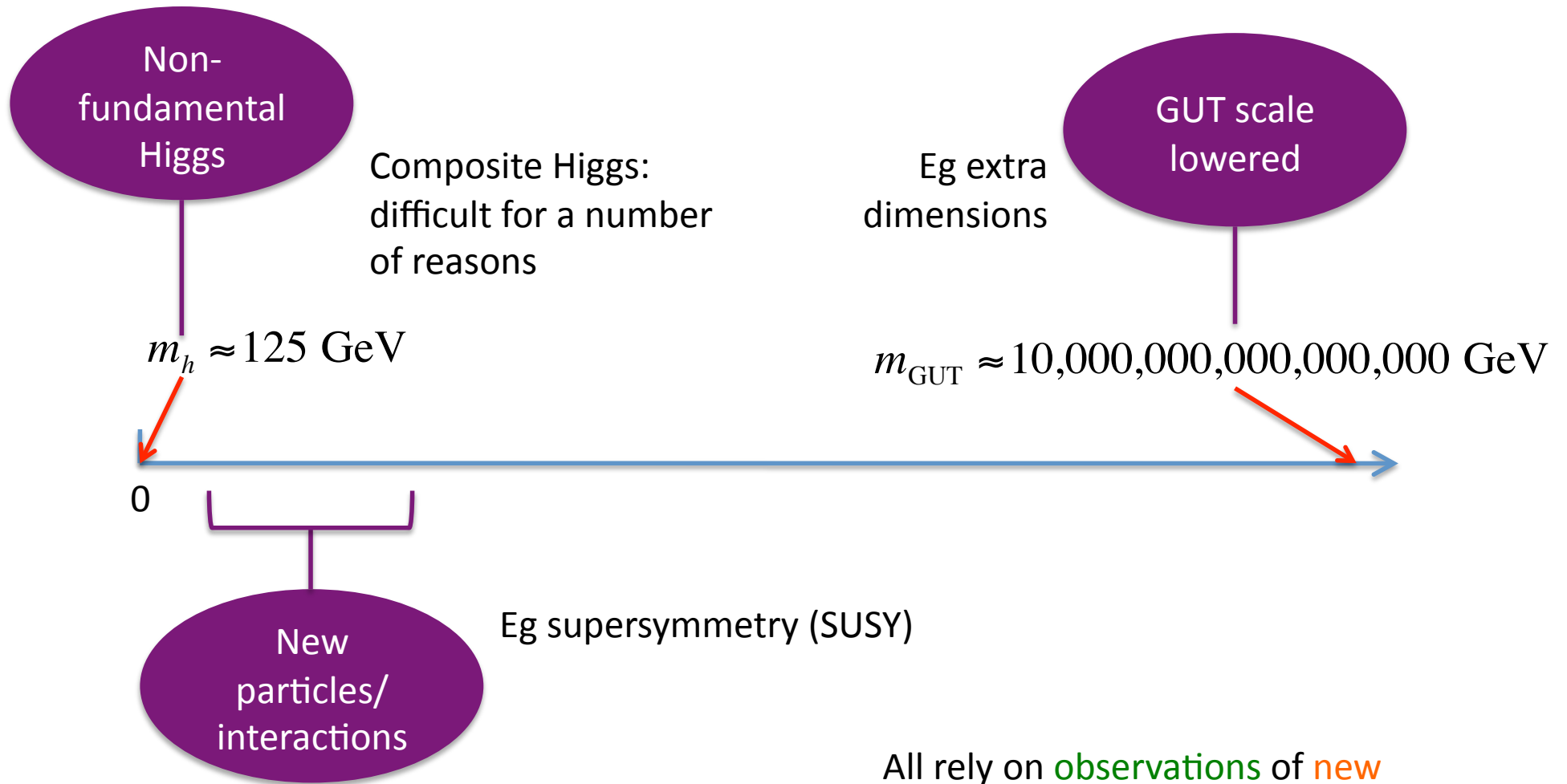


Good example: Higgs boson mass should be much, much **bigger**

It's like winning with odds of 1/**100,000,000,000,000**

What is more believable: **that this just happened** or **that the game is rigged?**

# Three solutions



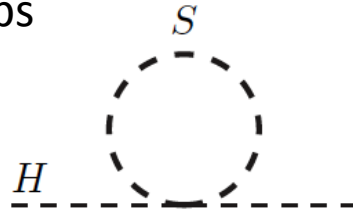
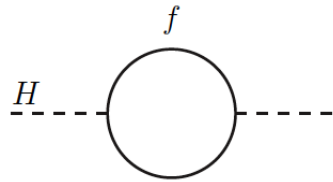
All rely on observations of new phenomena with mass near  $m_h$  ie at most  $\sim 1000 \text{ GeV} = 1 \text{ TeV}$



# Supersymmetry @ the LHC

Hypothesis: every SM particle gains a partner, different only by  $\frac{1}{2}$  a unit of spin

Solves hierarchy problem via (nearly) exact cancellation of Higgs mass loops



Bonus: potential **dark matter candidate** (or neutrino masses)

Guginos		Squarks		
$\tilde{\chi}_1^0$	$\tilde{\chi}_1^\pm$	$\tilde{u}$	$\tilde{c}$	$\tilde{t}$
$\tilde{\chi}_2^0$	$\tilde{\chi}_2^\pm$	$\tilde{d}$	$\tilde{s}$	$\tilde{b}$
$\tilde{\chi}_3^0$		Sleptons		
$\tilde{\chi}_4^0$	$\tilde{g}$	$\tilde{e}^\pm$	$\tilde{\mu}^\pm$	$\tilde{\tau}^\pm$
		$\tilde{\nu}_e$	$\tilde{\nu}_\mu$	$\tilde{\nu}_\tau$

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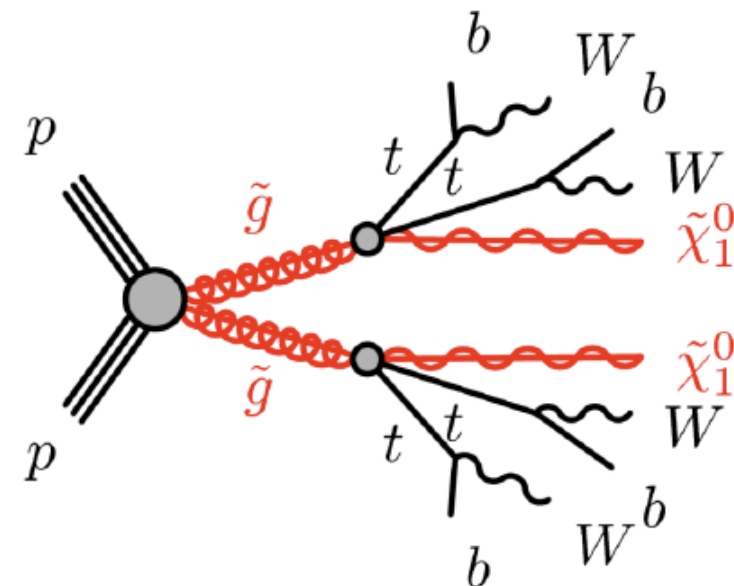
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What does it look like? There are many possibilities

1. **Squark/gluino production:** high rate, any SM particles possible in decays

Gauginos		Squarks		
$\tilde{\chi}_1^0$	$\tilde{\chi}_1^\pm$	$\tilde{u}$	$\tilde{c}$	$\tilde{t}$
$\tilde{\chi}_2^0$	$\tilde{\chi}_2^\pm$	$\tilde{d}$	$\tilde{s}$	$\tilde{b}$
$\tilde{\chi}_3^0$		Sleptons		
$\tilde{\chi}_4^0$	$\tilde{g}$	$\tilde{e}^\pm$	$\tilde{\mu}^\pm$	$\tilde{\tau}^\pm$
		$\tilde{\nu}_e$	$\tilde{\nu}_\mu$	$\tilde{\nu}_\tau$



# Supersymmetry @ the LHC

Hypothesis: every SM particle gains a partner, different only by  $\frac{1}{2}$  a unit of spin

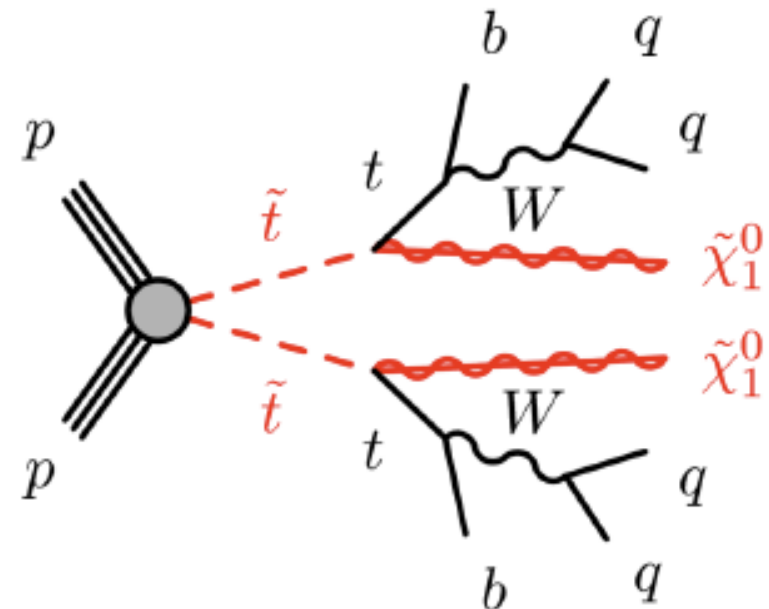
Solves hierarchy problem via (nearly) exact cancellation of Higgs mass loops



What does it look like? There are many possibilities

1. **Squark/gluino production:** high rate, any SM particles possible in decays
2. **Stop/sbottom production:** lower rate, must be light for naturalness

Gauginos		Squarks		
$\tilde{\chi}_1^0$	$\tilde{\chi}_1^\pm$	$\tilde{u}$	$\tilde{c}$	$\tilde{t}$
$\tilde{\chi}_2^0$	$\tilde{\chi}_2^\pm$	$\tilde{d}$	$\tilde{s}$	$\tilde{b}$
$\tilde{\chi}_3^0$		Sleptons		
$\tilde{\chi}_4^0$	$\tilde{g}$	$\tilde{e}^\pm$	$\tilde{\mu}^\pm$	$\tilde{\tau}^\pm$
		$\tilde{\nu}_e$	$\tilde{\nu}_\mu$	$\tilde{\nu}_\tau$



# Supersymmetry @ the LHC

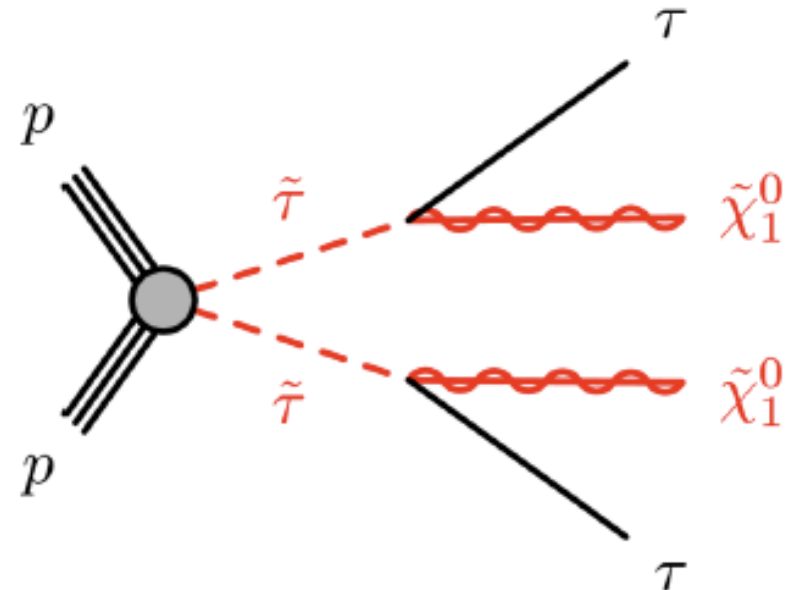
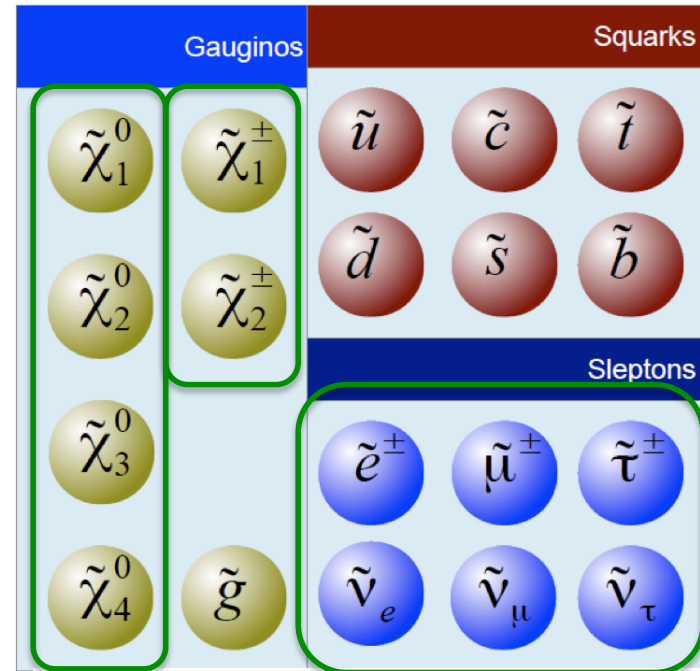
Hypothesis: every SM particle gains a partner, different only by  $\frac{1}{2}$  a unit of spin

Solves hierarchy problem via (nearly) exact cancellation of Higgs mass loops



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1. **Squark/gluino production:** high rate, any SM particles possible in decays
2. **Stop/sbottom production:** lower rate, must be light for naturalness
3. **Slepton/gaugino production:** could still be seen if squarks are very massive



# Supersymmetry @ the LHC

Hypothesis: every SM particle gains a partner, different only by  $\frac{1}{2}$  a unit of spin

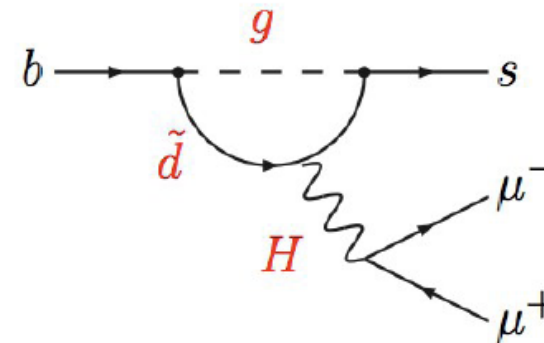
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What does it look like? There are many possibilities

1. **Squark/gluino production**: high rate, any SM particles possible in decays
2. **Stop/sbottom production**: lower rate, must be light for naturalness
3. **Slepton/gaugino production**: could still be seen if squarks are very massive
4. **Indirect effects**: usually in flavour physics

Gauginos		Squarks		
$\tilde{\chi}_1^0$	$\tilde{\chi}_1^\pm$	$\tilde{u}$	$\tilde{c}$	$\tilde{t}$
$\tilde{\chi}_2^0$	$\tilde{\chi}_2^\pm$	$\tilde{d}$	$\tilde{s}$	$\tilde{b}$
$\tilde{\chi}_3^0$		Sleptons		
$\tilde{\chi}_4^0$	$\tilde{g}$	$\tilde{e}^\pm$	$\tilde{\mu}^\pm$	$\tilde{\tau}^\pm$
		$\tilde{\nu}_e$	$\tilde{\nu}_\mu$	$\tilde{\nu}_\tau$



See Alexander Mann's talk yesterday for more

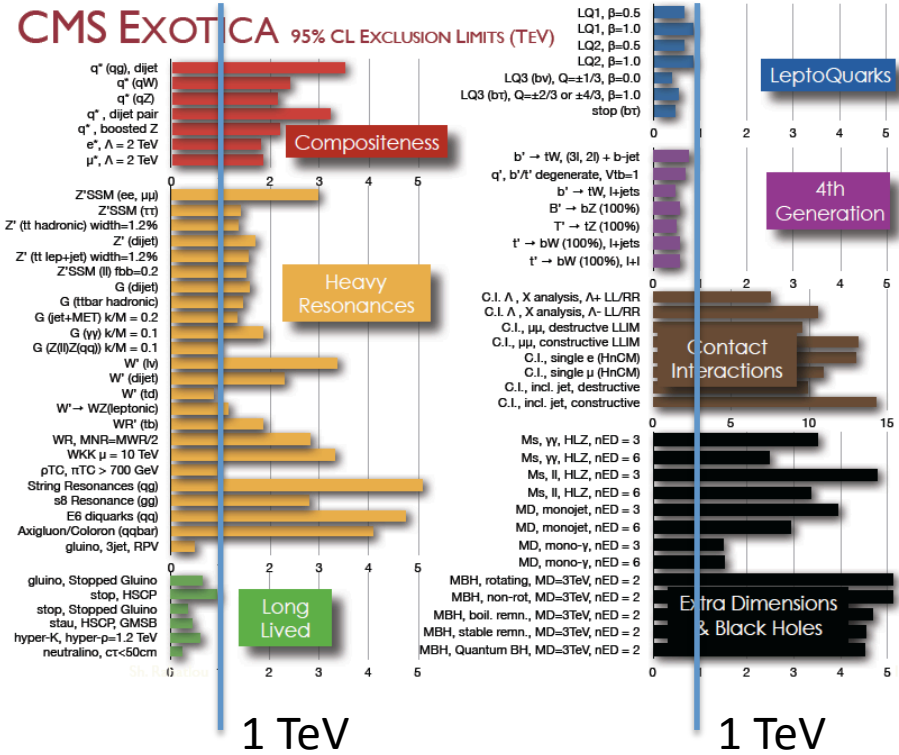
$B_s \rightarrow \mu^+ \mu^-$  now observed!  
 No enhancement over SM  
 LHCb-CONF-2013-012

**ATLAS SUSY Searches\* - 95% CL Lower Limits**  
Status: SUSY 2013

ATLAS Preliminary  
 $\int \mathcal{L} dt = (4.6 - 22.9) \text{ fb}^{-1}$   $\sqrt{s} = 7, 8 \text{ TeV}$

Model	$e, \mu, \tau, \gamma$	Jets	$E_{T}^{\text{miss}}$	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	Reference
<b>Inclusive Searches</b>						
MSUGRA/CMSSM	0	2,6 jets	Yes	20.3	1.7 TeV	m <sub>0</sub> =m <sub>1/2</sub>
MSUGRA/CMSSM	1 e, $\mu$	3,4 jets	Yes	20.3	1.2 TeV	any m <sub>0</sub>
MSUGRA/CMSSM	0	7,10 jets	Yes	20.3	1.1 TeV	m <sub>0</sub> =m <sub>1/2</sub>
$\tilde{g}, \tilde{q} \rightarrow q\tilde{q}^*$	0	2,6 jets	Yes	20.3	740 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow q\tilde{q}^* \tilde{g}$	0	2,6 jets	Yes	20.3	1 TeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow q\tilde{q}^* \tilde{g} \tilde{g}$	1 e, $\mu$	3,4 jets	Yes	20.3	1.16 TeV	m <sub>0</sub> =200 GeV, m <sub>1/2</sub> =0.5m <sub>0</sub> ( $\tilde{t}_1 \rightarrow m\tilde{t}_2$ )
GMSB (N LSP)	2 e, $\mu$	0,3 jets	Yes	20.3	1.12 TeV	m <sub>0</sub> =0 GeV
GMSB (N LSP)	2 e, $\mu$	2,4 jets	Yes	4.7	1.2 TeV	tan $\beta$ =15
GMSB (N LSP)	1 e, $\mu$	0,2 jets	Yes	4.7	1.2 TeV	tan $\beta$ =10
GGM (bino N LSP)	2 e, $\mu$	0,3 jets	Yes	4.8	1.07 TeV	m <sub>0</sub> =0 GeV
GGM (wino N LSP)	1 e, $\mu, \tau, \gamma$	-	Yes	4.8	619 GeV	m <sub>0</sub> =0 GeV
GGM (higgsino-bino N LSP)	1 e, $\mu, \tau, \gamma$	-	Yes	4.8	900 GeV	m <sub>0</sub> =0 GeV
GGM (higgsino N LSP)	2 e, $\mu$	0,3 jets	Yes	5.8	990 GeV	m <sub>0</sub> =0 GeV
Gravitino LSP	0	mono-jet	Yes	10.5	645 GeV	m <sub>0</sub> =10 <sup>-4</sup> eV
<b>g<math>\tilde{g}</math> pair squarks and gluinos</b>						
$\tilde{g}, \tilde{g} \rightarrow q\tilde{q}^* \tilde{g}$	0	3 b	Yes	20.1	1.2 TeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow t\tilde{t}^* \tilde{g}$	0	7,10 jets	Yes	20.3	1.1 TeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow b\tilde{b}^* \tilde{g}$	0.1 e, $\mu$	3 b	Yes	20.1	1.4 TeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow q\tilde{q}^* \tilde{g}$	0	2 b	Yes	20.1	100-620 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow t\tilde{t}^* \tilde{g}$	2 e, $\mu$ (SS)	0,3 b	Yes	20.7	275-430 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow b\tilde{b}^* \tilde{g}$	1.2 e, $\mu$	1,2 b	Yes	4.7	110-107 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow q\tilde{q}^* \tilde{g}$	2 e, $\mu$	0,2 jets	Yes	20.3	190-200 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow t\tilde{t}^* \tilde{g}$	2 e, $\mu$	2 jets	Yes	20.3	225-525 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow b\tilde{b}^* \tilde{g}$	0	2 b	Yes	20.1	150-580 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow q\tilde{q}^* \tilde{g}$	1 e, $\mu$	1 b	Yes	20.7	200-610 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow t\tilde{t}^* \tilde{g}$	0	2 b	Yes	20.5	320-660 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow q\tilde{q}^* \tilde{g}$	0	mono-jet+tag	Yes	20.3	90-200 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow t\tilde{t}^* \tilde{g}$	2 e, $\mu$ (Z)	1 b	Yes	20.7	300 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow b\tilde{b}^* \tilde{g}$	3 e, $\mu$ (Z)	1 b	Yes	20.7	271-320 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow q\tilde{q}^* \tilde{g}$	2 e, $\mu$	0	Yes	20.3	85-315 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow t\tilde{t}^* \tilde{g}$	2 e, $\mu$	0	Yes	20.3	125-450 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow b\tilde{b}^* \tilde{g}$	2 e, $\mu$	0	Yes	20.7	180-330 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow q\tilde{q}^* \tilde{g}$	3 e, $\mu$	0	Yes	20.7	315 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow t\tilde{t}^* \tilde{g}$	1 e, $\mu$	2 b	Yes	20.3	285 GeV	m <sub>0</sub> =0 GeV
<b>EW, direct</b>						
$\tilde{W}, \tilde{W} \rightarrow W\tilde{e}^* \tilde{e}$	2 e, $\mu$	0	Yes	20.3	180-330 GeV	m <sub>0</sub> =0 GeV
$\tilde{W}, \tilde{W} \rightarrow W\tilde{\mu}^* \tilde{\mu}$	2 e, $\mu$	0	Yes	20.3	180-330 GeV	m <sub>0</sub> =0 GeV
$\tilde{W}, \tilde{W} \rightarrow W\tilde{\tau}^* \tilde{\tau}$	2 e, $\mu$	0	Yes	20.3	180-330 GeV	m <sub>0</sub> =0 GeV
$\tilde{W}, \tilde{W} \rightarrow W\tilde{\nu}_\tau^* \tilde{\nu}_\tau$	3 e, $\mu$	0	Yes	20.7	315 GeV	m <sub>0</sub> =0 GeV
$\tilde{W}, \tilde{W} \rightarrow W\tilde{\nu}_\tau^* \tilde{\nu}_\tau$	1 e, $\mu$	2 b	Yes	20.3	285 GeV	m <sub>0</sub> =0 GeV
<b>Long lived particles</b>						
Direct $\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{g}$	Disapp. trk	1 jet	Yes	20.3	270 GeV	m <sub>0</sub> =0 GeV
Stable, stopped $\tilde{t}_1$ hadron	0	1-5 jets	Yes	22.9	1.5 TeV	m <sub>0</sub> =0 GeV
GMSB, $\tilde{t}_1 \rightarrow t\tilde{g}$	1.2 e, $\mu$	-	Yes	15.9	475 GeV	m <sub>0</sub> =0 GeV
GMSB, $\tilde{t}_1 \rightarrow t\tilde{g}$ , long-lived $\tilde{t}_1$	2 e, $\mu$	-	Yes	4.7	230 GeV	m <sub>0</sub> =0 GeV
$\tilde{g}, \tilde{g} \rightarrow q\tilde{q}^* \tilde{g}$	1 e, $\mu$ , displ. vtx	-	-	20.3	1.0 TeV	1.5 < c $\tau$ < 156 mm, BR( $\tilde{g} \rightarrow t$ )=1, m <sub>0</sub> ( $\tilde{t}_1$ )=108 GeV
<b>RPV</b>						
LFV $\tilde{g}, \tilde{g} \rightarrow X, \tilde{\nu}_i \rightarrow e + \mu$	2 e, $\mu$	-	-	4.6	1.01 TeV	$A_{11} = -0.1, A_{12} > 0.05$
LFV $\tilde{g}, \tilde{g} \rightarrow X, \tilde{\nu}_i \rightarrow e + \mu + \tau$	1 e, $\mu, \tau$	-	-	4.6	1.1 TeV	$A_{11} = -0.1, A_{12} > 0.05$
Bilinear RPV CMSSM	1 e, $\mu$	7 jets	Yes	20.7	1.2 TeV	m <sub>0</sub> =m <sub>1/2</sub> , $c_{\tilde{L}\tilde{L}} < 1 \text{ mm}$
$\tilde{t}_1, \tilde{t}_1 \rightarrow W\tilde{\nu}_\tau^* \tilde{\nu}_\tau$	4 e, $\mu$	-	Yes	20.7	760 GeV	m <sub>0</sub> =0 GeV, $A_{121} > 0$
$\tilde{t}_1, \tilde{t}_1 \rightarrow W\tilde{\nu}_\tau^* \tilde{\nu}_\tau$	3 e, $\mu, \tau$	-	Yes	20.7	350 GeV	m <sub>0</sub> =0 GeV, $A_{121} > 0$
$\tilde{t}_1, \tilde{t}_1 \rightarrow W\tilde{\nu}_\tau^* \tilde{\nu}_\tau$	0	6,7 jets	Yes	20.7	916 GeV	BR( $\tilde{t}_1 \rightarrow W\tilde{\nu}_\tau^* \tilde{\nu}_\tau$ )=0.95
$\tilde{t}_1, \tilde{t}_1 \rightarrow W\tilde{\nu}_\tau^* \tilde{\nu}_\tau$	2 e, $\mu$ (SS)	0,3 b	Yes	20.7	880 GeV	m <sub>0</sub> =0 GeV
<b>Other</b>						
Scalar gluon pair, gluino $\rightarrow q\tilde{g}$	0	4 jets	-	4.6	100-287 GeV	incl. limit from 1110.2693
Scalar gluon pair, gluino $\rightarrow t\tilde{t}$	2 e, $\mu$ (SS)	1 b	Yes	14.3	800 GeV	m <sub>0</sub> =0 GeV
WIMP-interaction (DS, Dirac $\chi$ )	0	mono-jet	Yes	10.5	708 GeV	m <sub>0</sub> =80 GeV, limit of $\tilde{g}\tilde{g}$ for DB

\*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1 $\sigma$  theoretical signal cross section uncertainty.



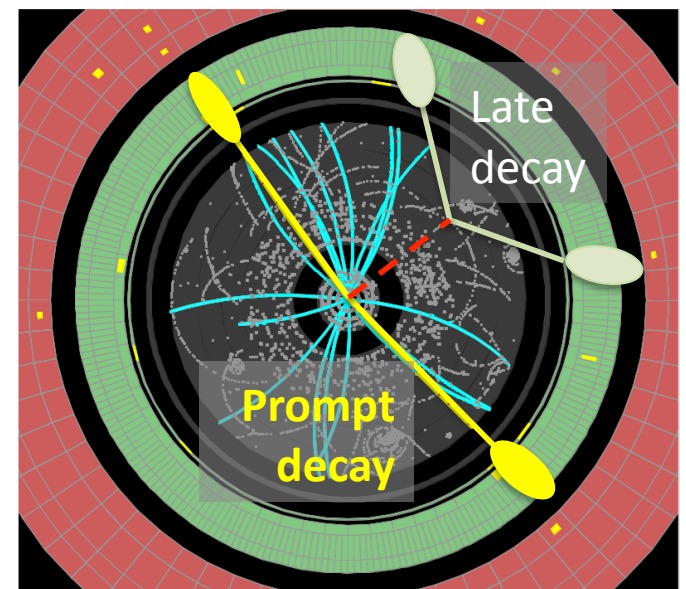
So far, **no significant deviation** from the Standard Model

No evidence for SUSY or other non-SM physics

Precision measurements in agreement with expectation

Caution: Many caveats and loopholes

Example: Limited sensitivity to **late-decaying particles**, surprises could still be lurking in the Run I data!



Extra  
dimensions?

Origin of  
mass?

Weakness  
of gravity?

Neutrino  
mass?

Some big  
answers?

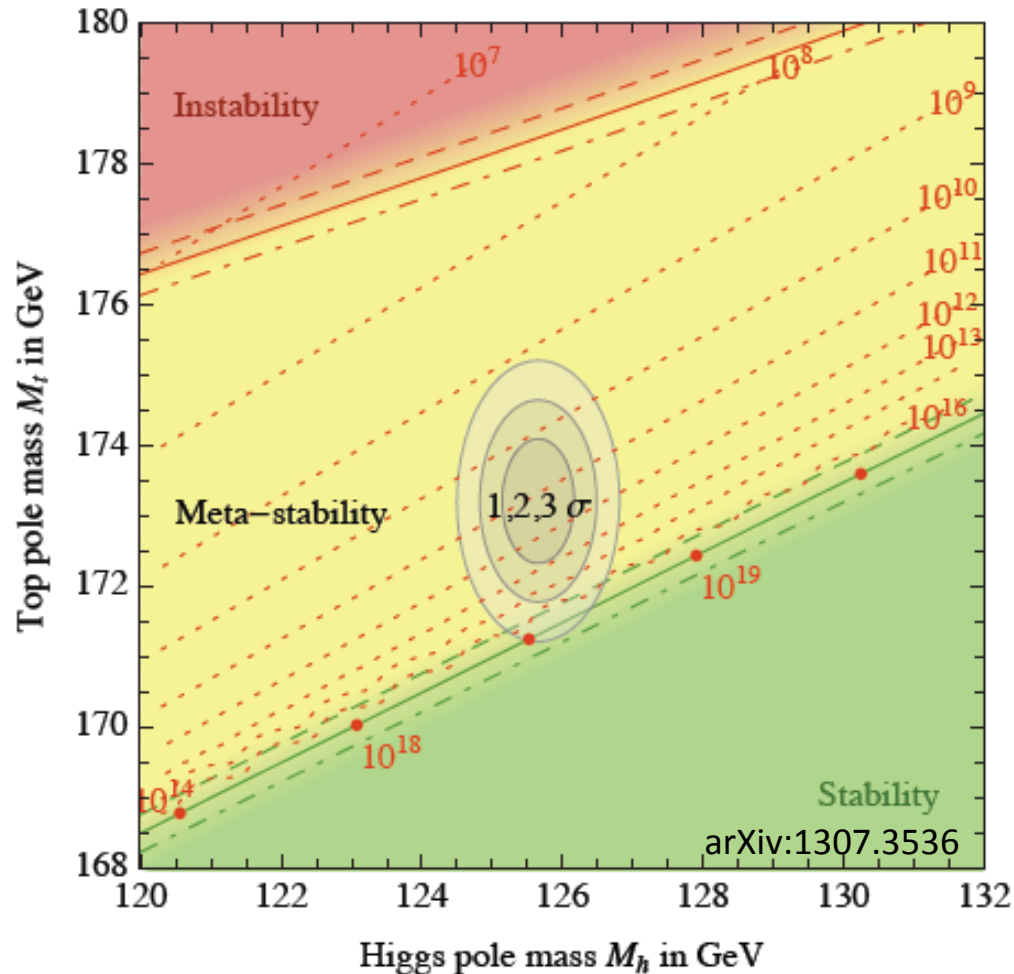
Are there new  
symmetries/  
interactions?

Where is  
the  
antimatter?

Dark matter?

3 generations?

# Is that it?



If the SM is all that is,  
the universe appears to be  
finely tuned and metastable

**Finely-tuned:** Apparently unlikely selection of fundamental constants  
**Metastable:** Our universe not the „best“ vacuum, but stable for current life of universe



How can this be?  
Are we in a multiverse?  
Do balancing pressures place us  
near the critical point?

Maybe



# The future

Warning: all simulation past this point!





# The main 2013-14 LHC consolidations

1695 Openings and final reclosures of the interconnections

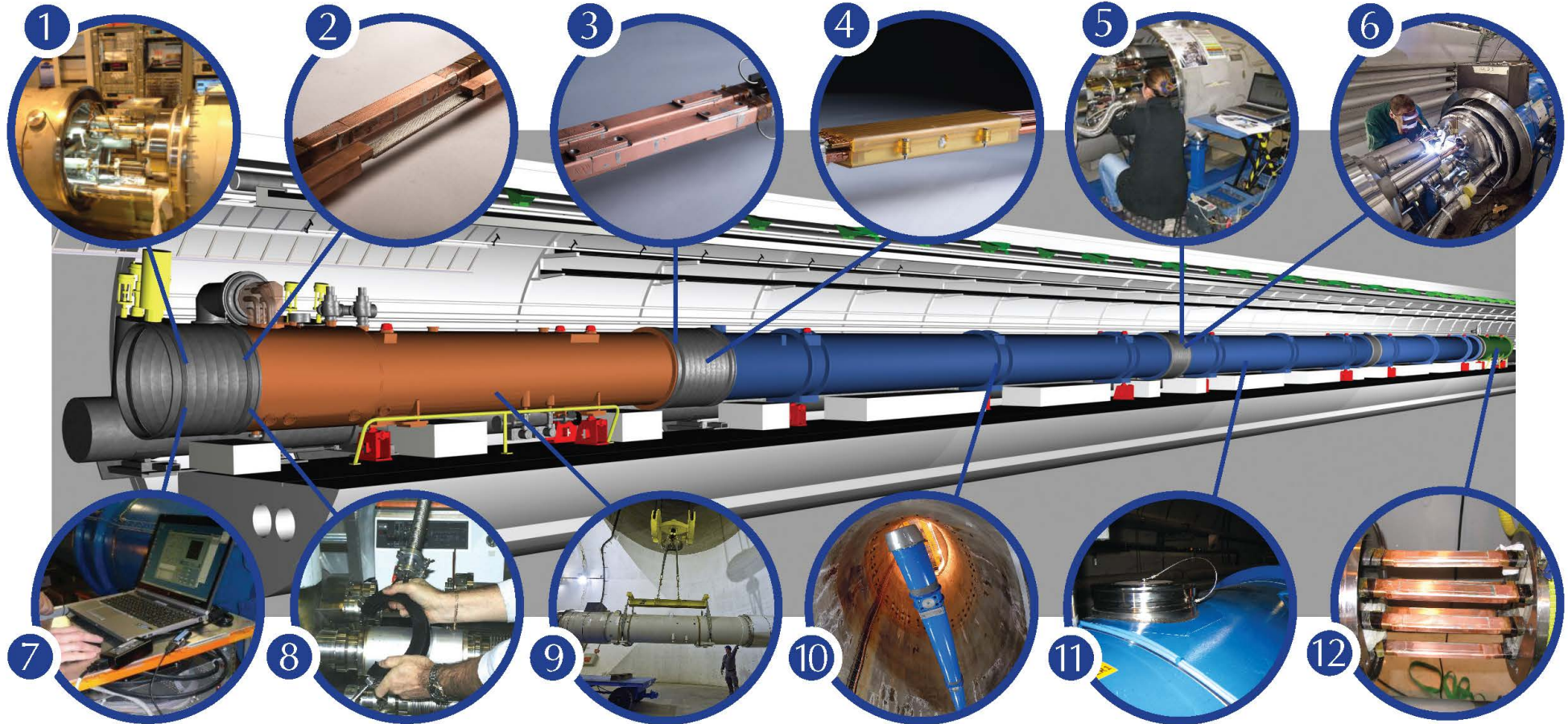
Complete reconstruction of 1500 of these splices

Consolidation of the 10170 13kA splices, installing 27 000 shunts

Installation of 5000 consolidated electrical insulation systems

300 000 electrical resistance measurements

10170 orbital welding of stainless steel lines



18 000 electrical Quality Assurance tests

10170 leak tightness tests

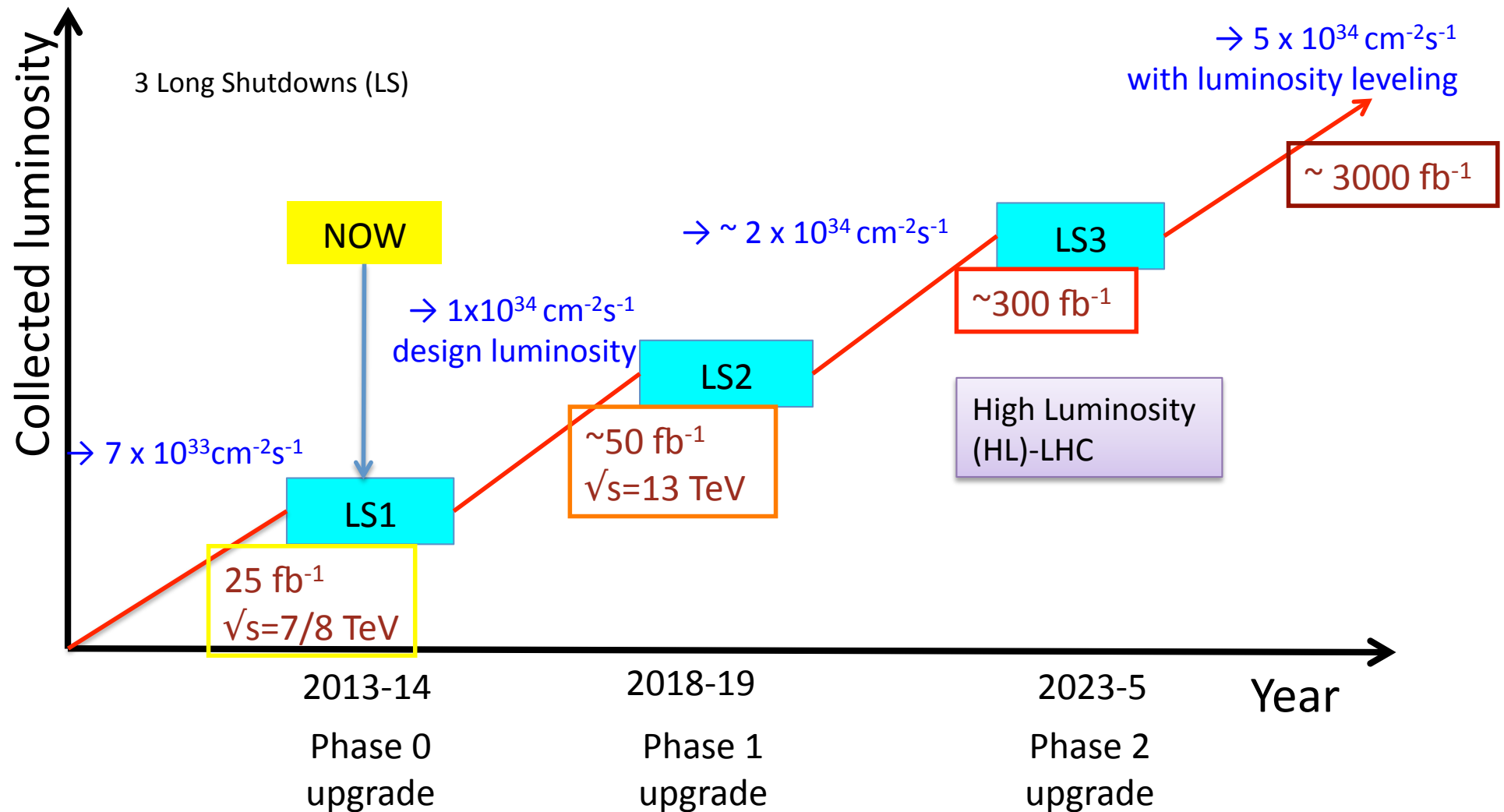
4 quadrupole magnets to be replaced

15 dipole magnets to be replaced

Installation of 612 pressure relief devices to bring the total to 1344

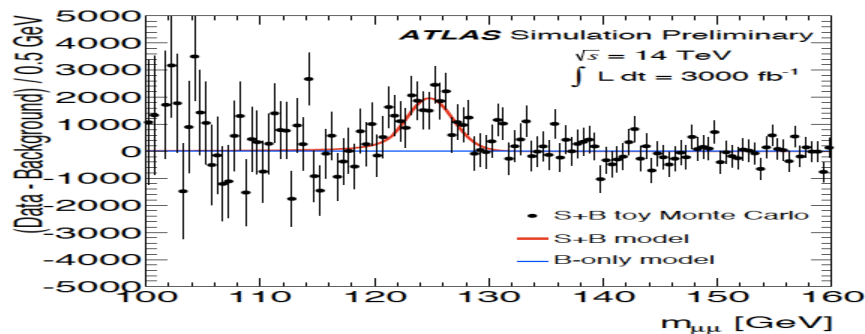
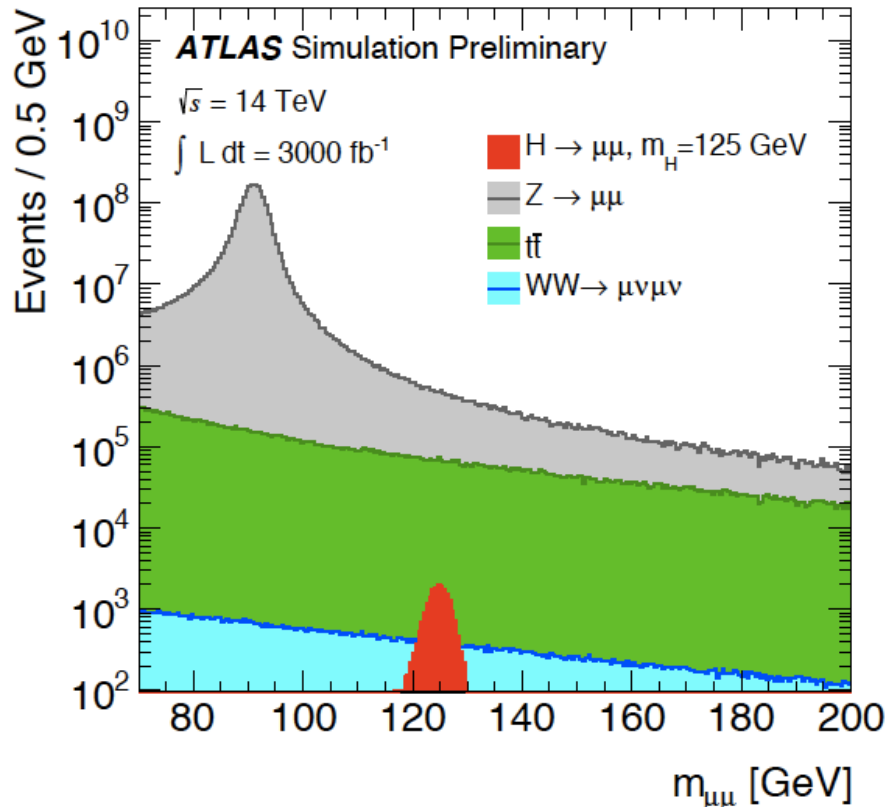
Consolidation of the 13 kA circuits in the 16 main electrical feed-boxes

# The LHC upgrade plan



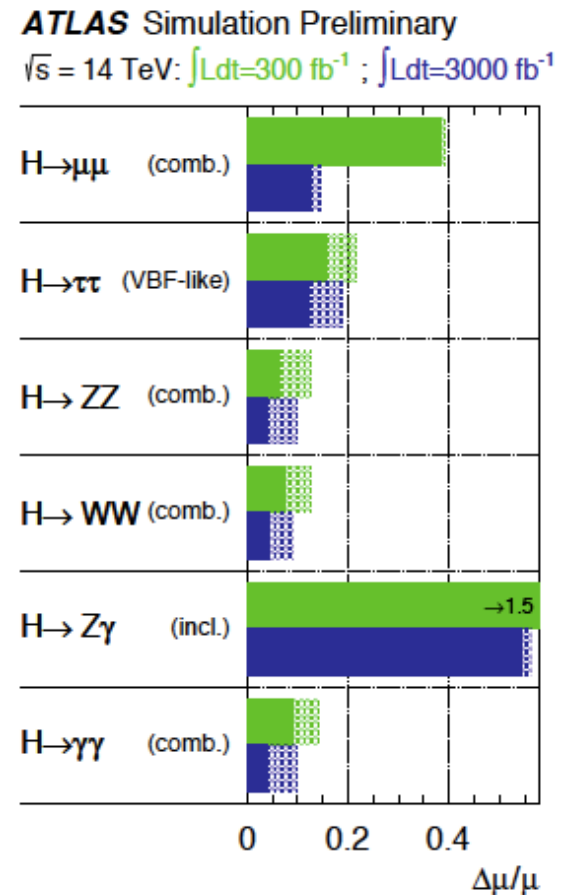
At each stage: beam improvements and detector repairs, upgrades  
Eventual target: >100 times today's dataset

# Future prospects: Higgs



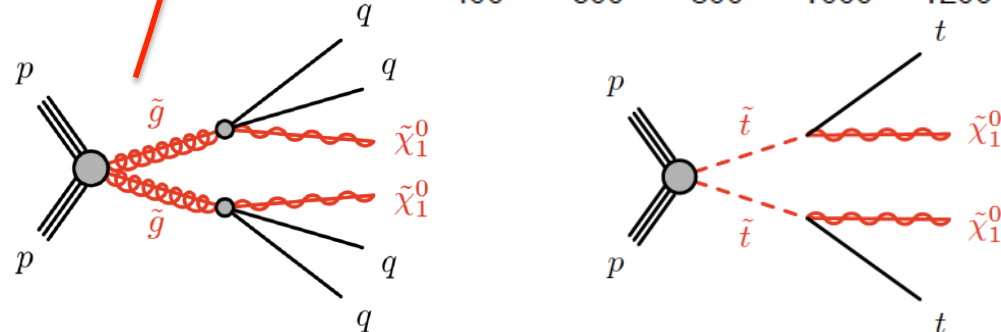
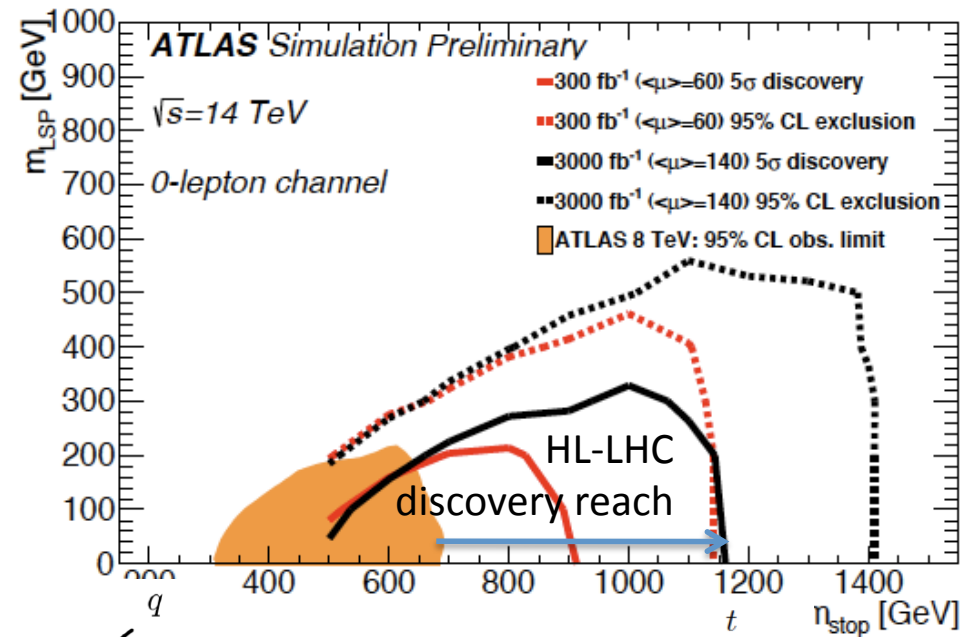
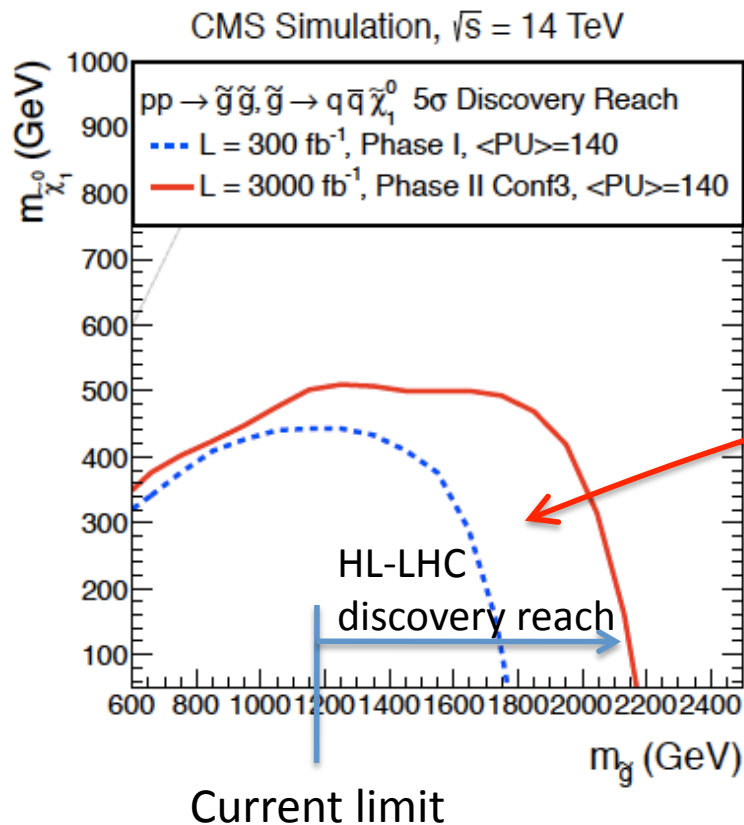
10-100x current dataset will allow rare events to be observed

- Eg  $h \rightarrow \mu\mu$ :  $\sim 1$  in 5000 decays
- Probe interaction strengths to  $O(5\%)$

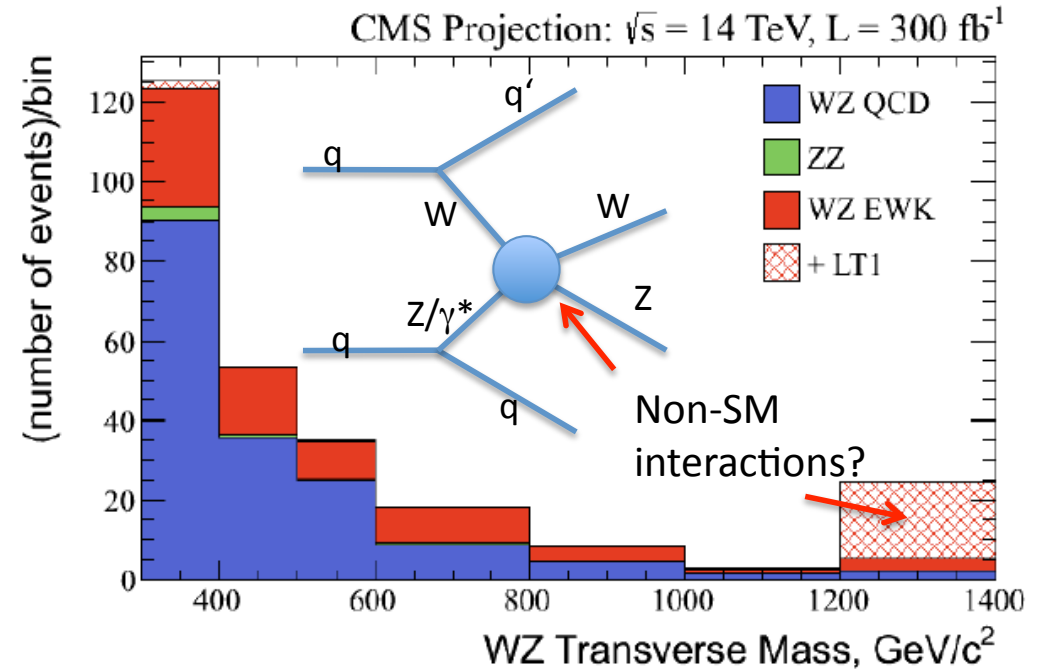
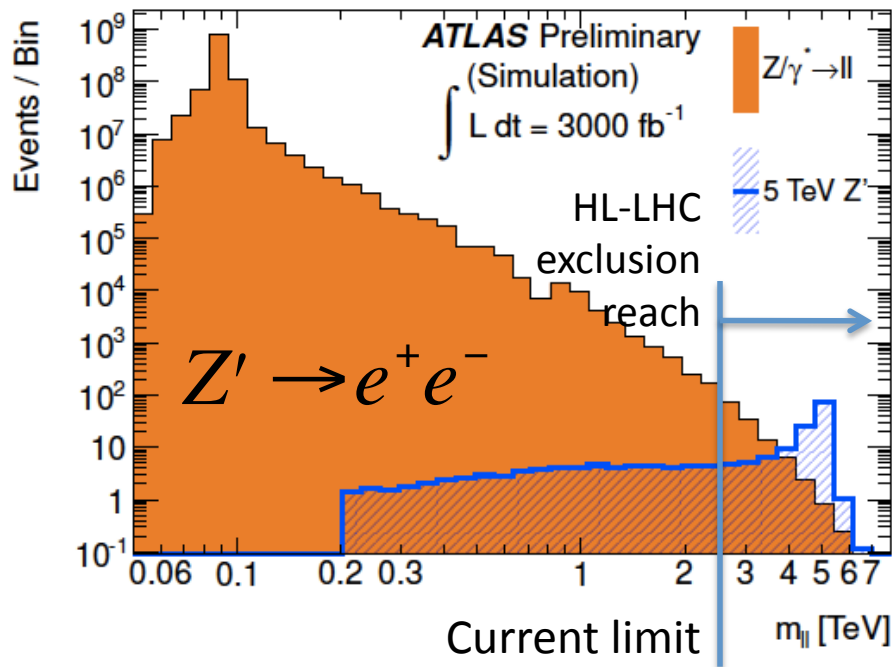


# Future prospects: SUSY

- Many searches statistically limited
  - More luminosity improves sensitivity to rarely produced particles
  - Higher energy increases production rate of massive particles
- Maintaining sensitivity to **all** scenarios challenging



# Future prospects: some other examples



New forces would emerge at the LHC through the production of new gauge bosons ( $Z'$ )

Exceptionally clean dilepton signatures are possible

Exclusion sensitivity could reach nearly 8 TeV

The LHC can collide gauge bosons too!

Rare, needs large luminosity to observe

Deviations in diboson kinematic distributions could hint at unexpected processes

# Conclusions

- In the **first three years** of high energy collisions, the LHC and its experiments have really delivered
- Brout-Englert-Higgs mechanism **confirmed** as the origin of mass
- **No sign of anything else**, so far, but questions about the Standard Model remain
- Higher energy LHC will help **probe even higher mass scales** to attempt answer these questions

