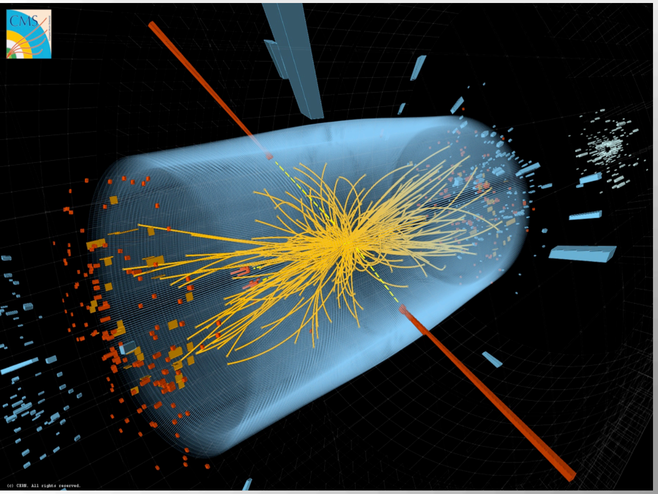
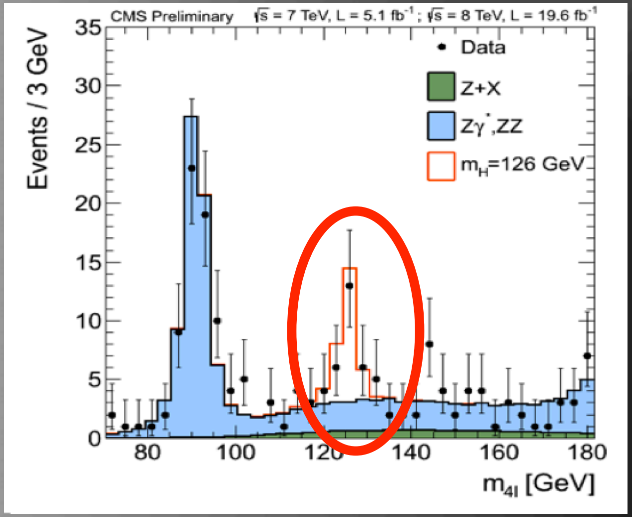


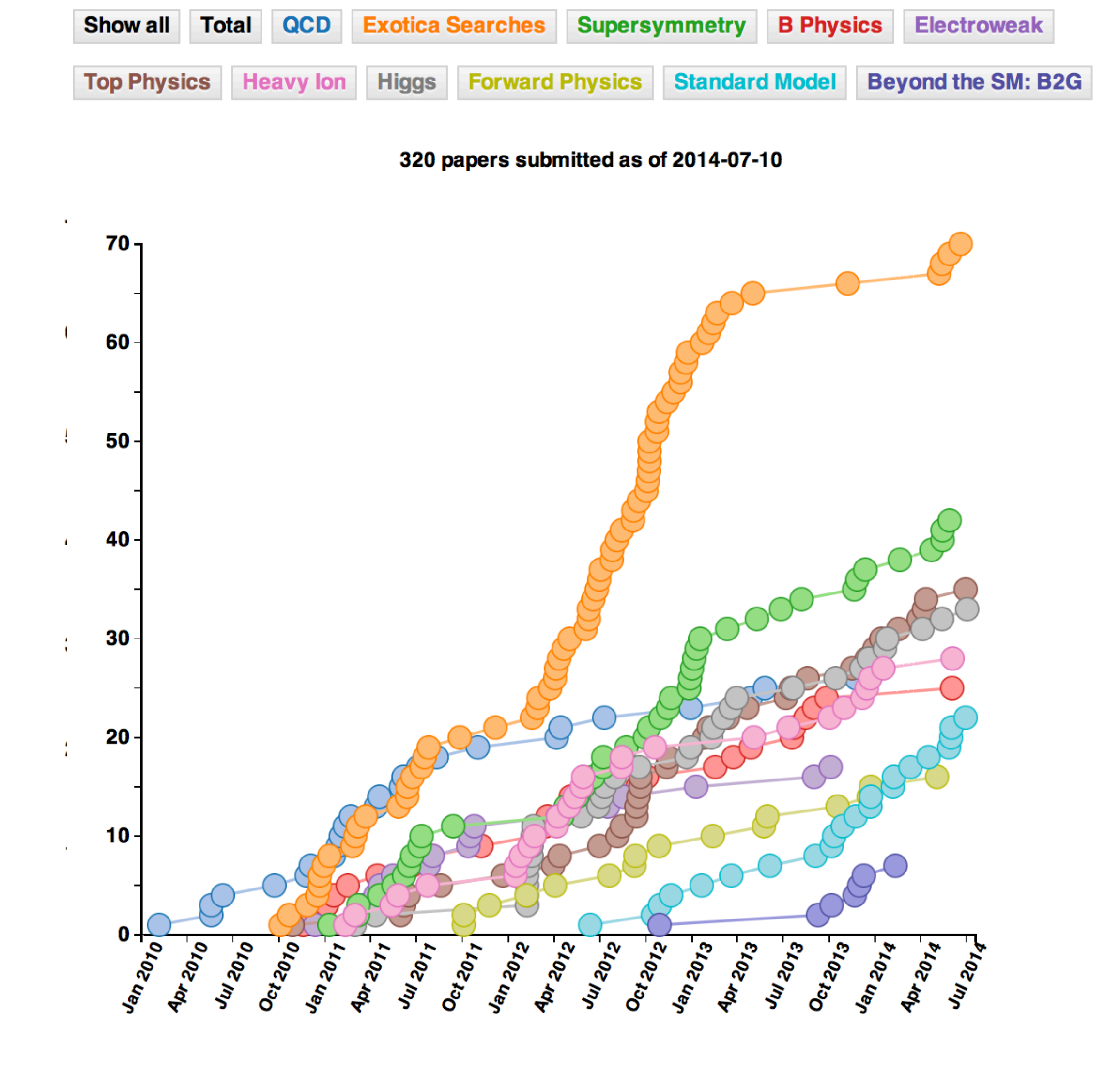
Outline

- Introduction: measurements and and searches.
- Some examples that history tell us
- Anomalies at the LHC?
- Outlook 2015+…



LHC: so far Delivered 25 fb^{-1}

Example: CMS publications



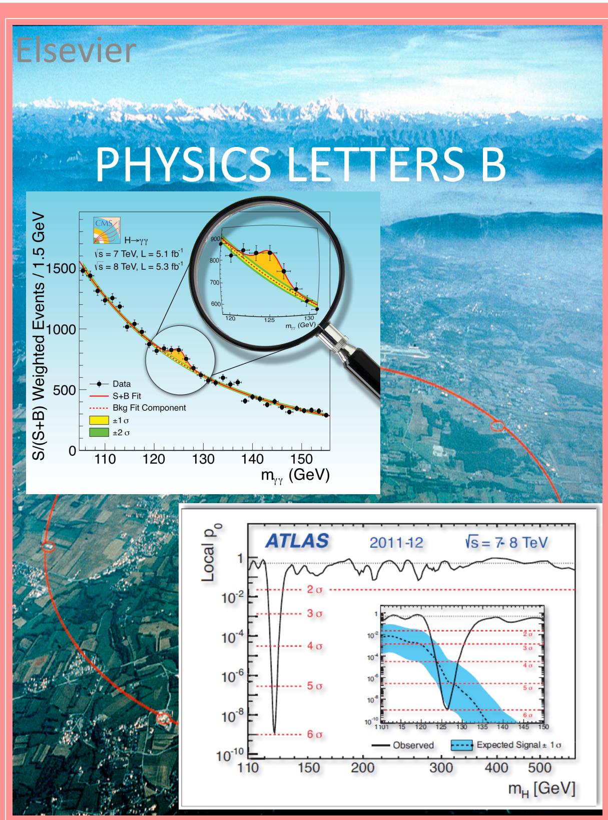
320 publications on pp (and pPb/PbPb) physics since January 2010 (19/7/2014)

Mostly on exotica searches and supersymmetry (>100 papers together)

Similar for ATLAS

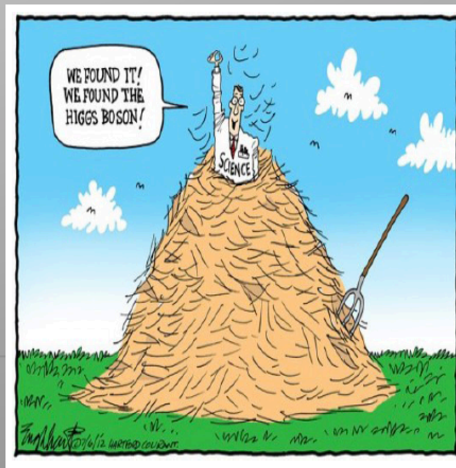
Most cited paper so far...

Special Physics Letters B edition with the ATLAS and CMS CMS papers on the Higgs Discovery



About ~3000 times cited so far…

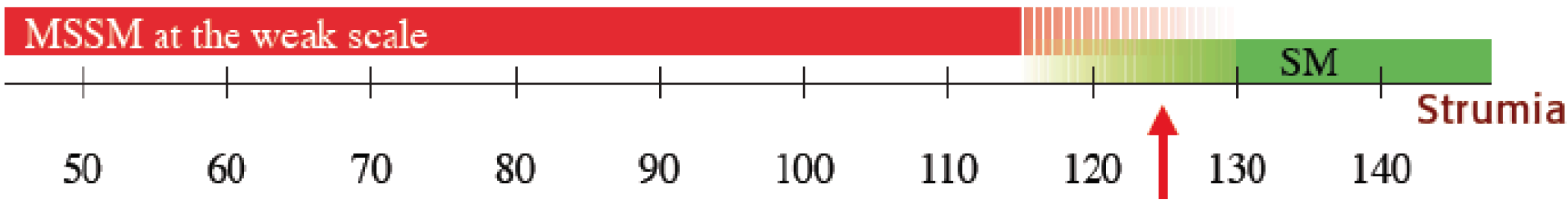
Also…



A Higgs…

A malicious choice!

$m_H = 125.6 \pm 0.4$ GeV



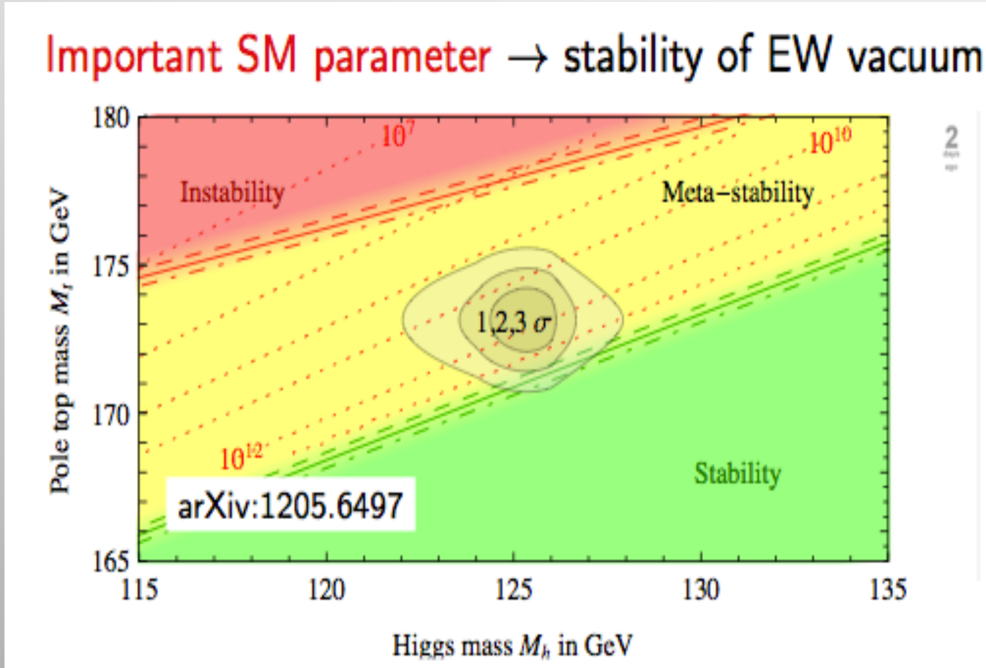
The Higgs:
so simple yet so unnatural

Guido Altarelli

Stockholm Nobel Symposium
May 2013

But there are still a lot of questions…

Consequences for our Universe?



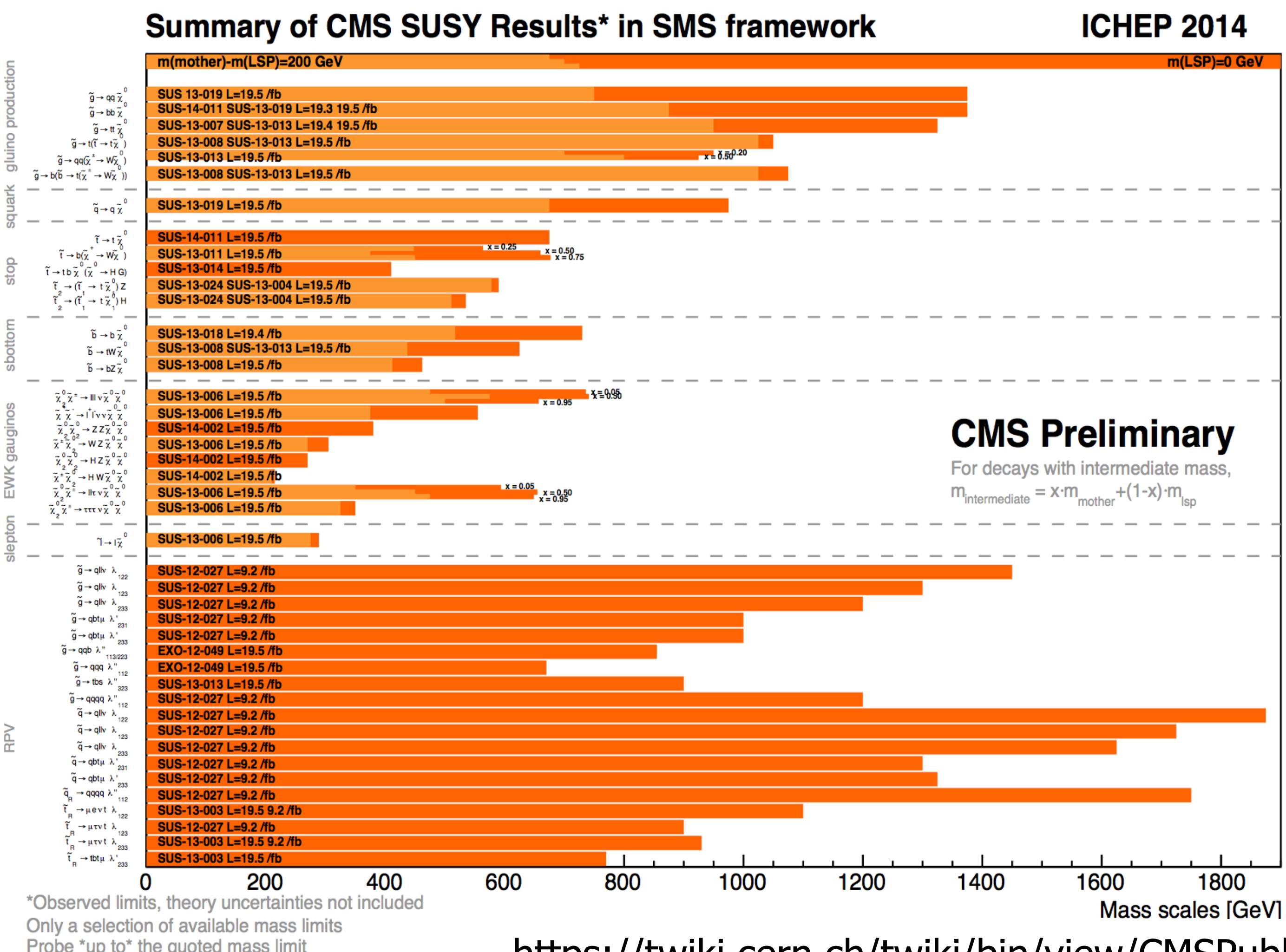
Precise measurements of the top quark and first measurements of the Higgs mass:

Our Universe meta-stable ? Will the Universe disappear in a Big Slurp? (NBCNEWS.com)

New Physics inevitable to stabelize the vacuum/Higgs field?
But at which scale or energy?

Summary of SUSY Searches

In short: no sign of SUSY with the data collected so far

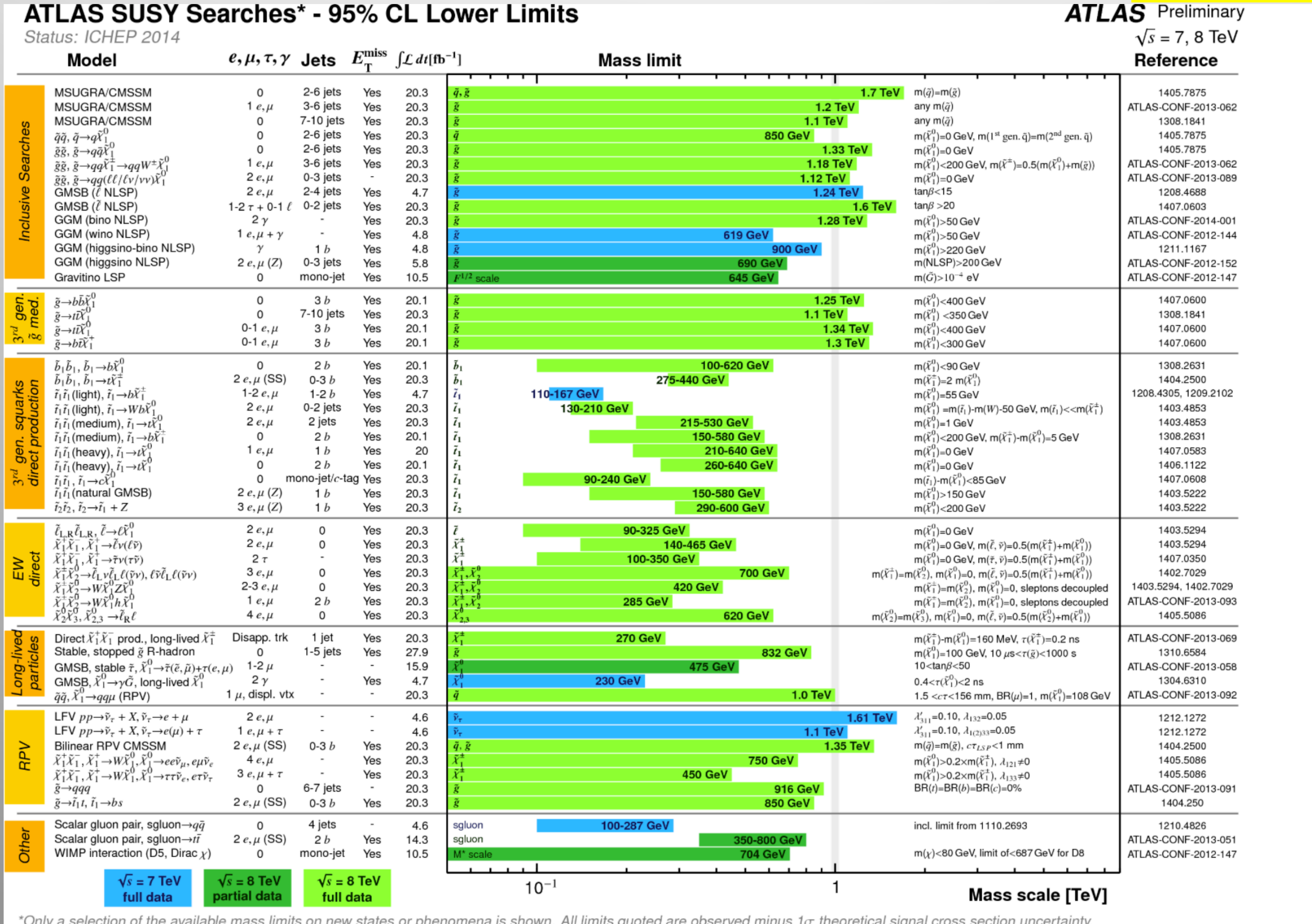


https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

New: compressed spectra, heavy stop (t_2) search, extended incl. searches…

Summary of SUSY Searches

ATLAS Results



Summary of Exotica Searches

ATLAS Exotics Searches* - 95% CL Exclusion

Status: ICHEP 2014

ATLAS Results

ATLAS Preliminary

$\int \mathcal{L}\, dt = (1.0 - 20.3)\ \text{fb}^{-1}$ $\sqrt{s} = 7, 8$ TeV

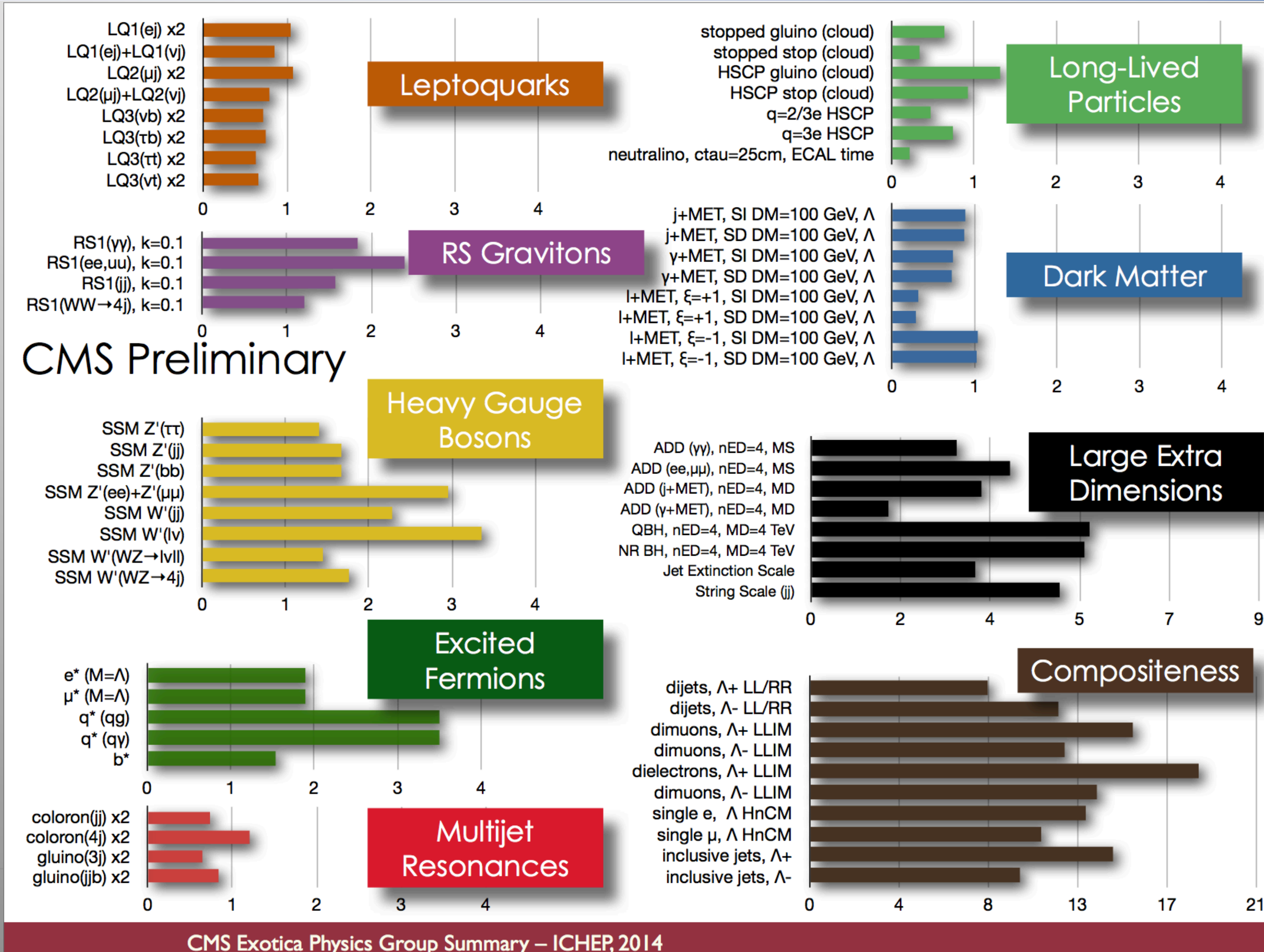
	Model	ℓ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt [fb^{-1}]$	Mass limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	1-2 j	Yes	4.7	M_D 4.37 TeV	$n = 2$	1210.4491
	ADD non-resonant $\ell\ell$	2e, μ	–	–	20.3	M_S 5.2 TeV	$n = 3$ HLZ	ATLAS-CONF-2014-030
	ADD QBH $\to \ell q$	1 e, μ	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	20.3	M_{th} 5.82 TeV	$n = 6$	to be submitted to PRD
	ADD BH high N_{trk}	2 μ (SS)	–	–	20.3	M_{th} 5.7 TeV	$n = 6$, $M_D = 1.5$ TeV, non-rot BH	1308.4075
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	20.3	M_{th} 6.2 TeV	$n = 6$, $M_D = 1.5$ TeV, non-rot BH	1405.4254
	RS1 $G_{KK} \to \ell\ell$	2 e, μ	–	–	20.3	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \to WW \to \ell\nu\ell\nu$	2 e, μ	–	Yes	4.7	G_{KK} mass 1.23 TeV	$k/\overline{M}_{Pl} = 0.1$	1208.2880
	Bulk RS $G_{KK} \to ZZ \to \ell\ell qq$	2 e, μ	2 j / 1 J	–	20.3	G_{KK} mass 730 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2014-039
	Bulk RS $G_{KK} \to HH \to b\bar{b}b\bar{b}$	–	4 b	–	19.5	G_{KK} mass 590-710 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2014-005
	Bulk RS $g_{KK} \to t\bar{t}$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	14.3	g_{KK} mass 2.0 TeV	BR = 0.925	ATLAS-CONF-2013-052
	S^1/Z_2 ED	2 e, μ	–	–	5.0	$M_{KK} \approx R^{-1}$ 4.71 TeV		1209.2535
	UED	2 γ	–	Yes	4.8	Compact. scale R^{-1} 1.41 TeV		ATLAS-CONF-2012-072
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	20.3	Z' mass 2.9 TeV		1405.4123
	SSM $Z' \to \tau\tau$	2 τ	–	–	19.5	Z' mass 1.9 TeV		ATLAS-CONF-2013-066
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	20.3	W' mass 3.28 TeV		ATLAS-CONF-2014-017
	EGM $W' \to WZ \to \ell\nu\ell'\ell'$	3 e, μ	–	Yes	20.3	W' mass 1.52 TeV		1406.4456
	EGM $W' \to WZ \to qq\ell\ell$	2 e, μ	2 j / 1 J	–	20.3	W' mass 1.59 TeV		ATLAS-CONF-2014-039
	LRSM $W'_R \to t\bar{b}$	1 e, μ	2 b, 0-1 j	Yes	14.3	W' mass 1.84 TeV		ATLAS-CONF-2013-050
	LRSM $W'_R \to t\bar{b}$	0 e, μ	≥ 1 b, 1 J	–	20.3	W' mass 1.77 TeV		to be submitted to EPJC
CI	CI $qqqq$	–	2 j	–	4.8	Λ 7.6 TeV	$\eta = +1$	1210.1718
	CI $qq\ell\ell$	2 e, μ	–	–	20.3	Λ 21.6 TeV	$\eta_{LL} = -1$	ATLAS-CONF-2014-030
	CI $uutt$	2 e, μ (SS)	≥ 1 b, ≥ 1 j	Yes	14.3	Λ 3.3 TeV	$\lvert C \rvert = 1$	ATLAS-CONF-2013-051
DM	EFT D5 operator (Dirac)	0 e, μ	1-2 j	Yes	10.5	M_* 731 GeV	at 90% CL for $m(\chi) < 80$ GeV	ATLAS-CONF-2012-147
	EFT D9 operator (Dirac)	0 e, μ	1 J, ≤ 1 j	Yes	20.3	M_* 2.4 TeV	at 90% CL for $m(\chi) < 100$ GeV	1309.4017
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	1.0	LQ mass 660 GeV	$\beta = 1$	1112.4828
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	1.0	LQ mass 685 GeV	$\beta = 1$	1203.3172
	Scalar LQ 3rd gen	1 e, μ, 1 τ	1 b, 1 j	–	4.7	LQ mass 534 GeV	$\beta = 1$	1303.0526
Heavy quarks	Vector-like quark $TT \to Ht + X$	1 e, μ	≥ 2 b, ≥ 4 j	Yes	14.3	T mass 790 GeV	T in (T,B) doublet	ATLAS-CONF-2013-018
	Vector-like quark $TT \to Wb + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	14.3	T mass 670 GeV	isospin singlet	ATLAS-CONF-2013-060
	Vector-like quark $TT \to Zt + X$	2/$\geq$3 e, μ	$\geq$2/$\geq$1 b	–	20.3	T mass 735 GeV	T in (T,B) doublet	ATLAS-CONF-2014-036
	Vector-like quark $BB \to Zb + X$	2/$\geq$3 e, μ	$\geq$2/$\geq$1 b	–	20.3	B mass 755 GeV	B in (B,Y) doublet	ATLAS-CONF-2014-036
	Vector-like quark $BB \to Wt + X$	2 e, μ (SS)	≥ 1 b, ≥ 1 j	Yes	14.3	B mass 720 GeV	B in (T,B) doublet	ATLAS-CONF-2013-051
Excited fermions	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	20.3	q^* mass 3.5 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1309.3230
	Excited quark $q^* \to qg$	–	2 j	–	20.3	q^* mass 4.09 TeV	only u^* and d^*, $\Lambda = m(q^*)$	to be submitted to PRD
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2 j or 1 j	Yes	4.7	b^* mass 870 GeV	left-handed coupling	1301.1583
	Excited lepton $\ell^* \to \ell\gamma$	2 e, μ, 1 γ	–	–	13.0	ℓ^* mass 2.2 TeV	$\Lambda = 2.2$ TeV	1308.1364
Other	LSTC $a_T \to W\gamma$	1 e, μ, 1 γ	–	Yes	20.3	a_T mass 960 GeV		to be submitted to PLB
	LRSM Majorana ν	2 e, μ	2 j	–	2.1	N^0 mass 1.5 TeV	$m(W_R) = 2$ TeV, no mixing	1203.5420
	Type III Seesaw	2 e, μ	–	–	5.8	$N^\pm$ mass 245 GeV	$\lvert V_e \rvert$=0.055, $\lvert V_\mu \rvert$=0.063, $\lvert V_\tau \rvert$=0	ATLAS-CONF-2013-019
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2 e, μ (SS)	–	–	4.7	$H^{\pm\pm}$ mass 409 GeV	DY production, BR($H^{\pm\pm} \to \ell\ell$)=1	1210.5070
	Multi-charged particles	–	–	–	4.4	multi-charged particle mass 490 GeV	DY production, $\lvert q \rvert = 4e$	1301.5272
	Magnetic monopoles	–	–	–	2.0	monopole mass 862 GeV	DY production, $\lvert g \rvert = 1 g_D$	1207.6411

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

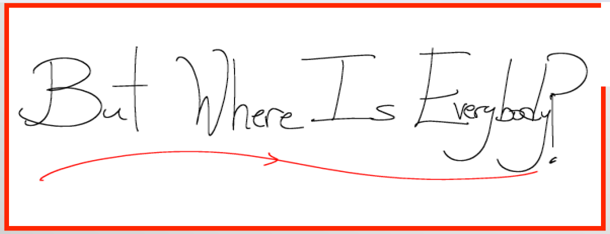
10^{-1} 1   10   Mass scale [TeV]

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

Summary of Exotica Searches



New Physics?



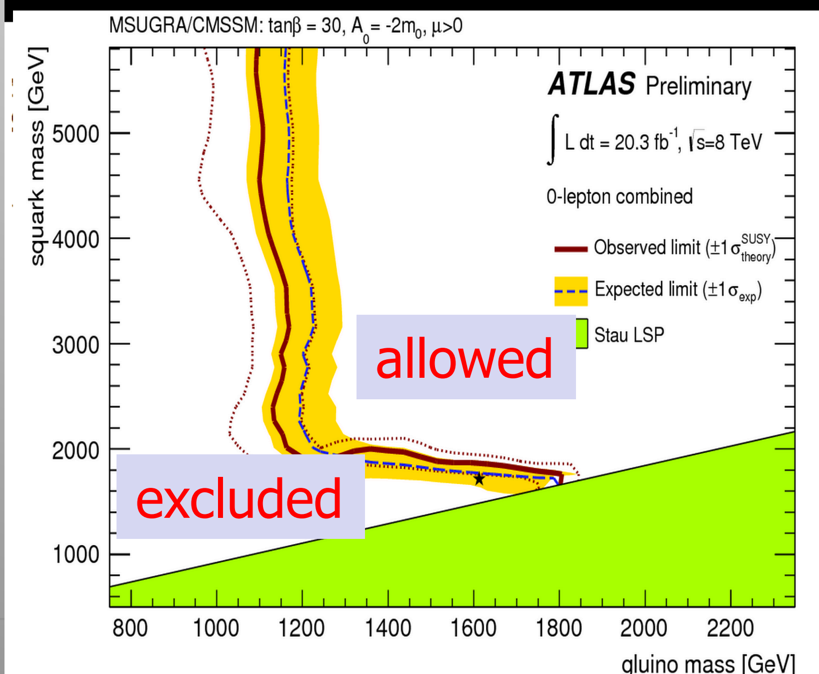
N. Arkani-Hamed

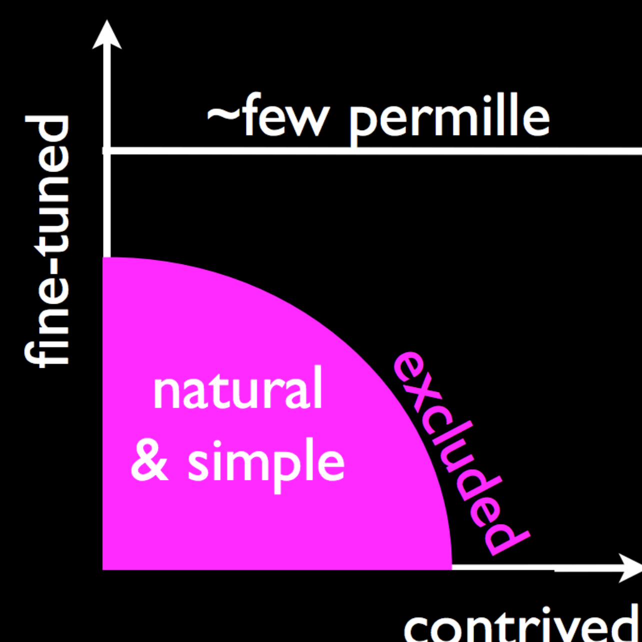
...The May Issue...

Supersymmetry and the Crisis in Physics

H. Murayama

no sign of new physics





Searches a the LHC

- LHC searches for NP right now: Nothing found at present!
- However most discoveries start with a hint i.e. less than 3 sigma (standard deviations), or evidence with more than 3 sigma before they become an observation or discovery (more that 5 sigma, like the Higgs)
- Any 2-3 sigma effects are of interest to follow up with additional data or check with other channels. They will either grow with luminosity (possible real signal) or get less significant (statistical fluctuation). But no excitement yet…
- Or there was a mistake or missing part in the analysis.. (Higgs discovery in 1984, SUSY discovery in 1985…)
- Or in the experiment had a problem (superluminal neutrinos).. Both to be avoided ☺ !!
- Some examples ➔

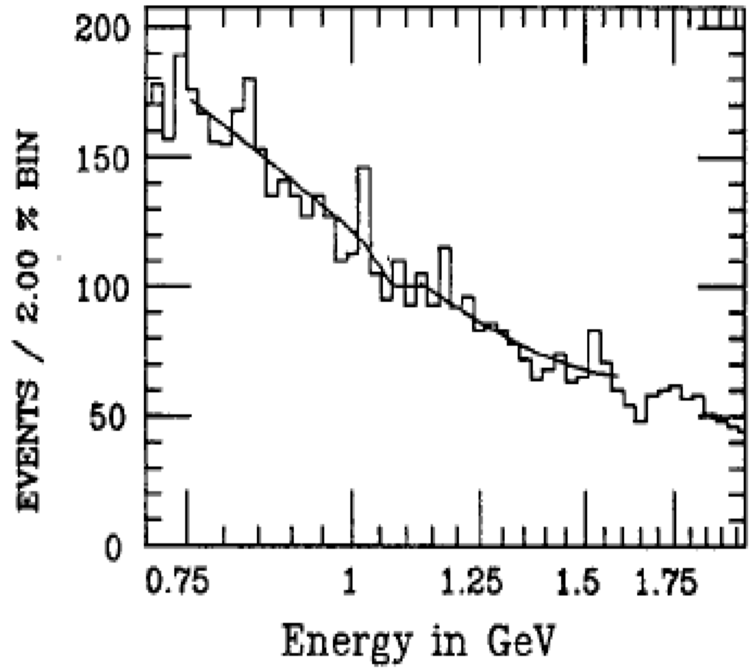
The Higgs? In 1984…

EVIDENCE FOR A MASSIVE STATE IN THE RADIATIVE DECAYS OF THE UPSILON

Crystal Ball Experiment, DESY, 1984

Υ(1S) ->photon+X (high multip.)

Is the X(8.31 GeV) the Higgs particle?
A lot of excitement summer 1984…
It was called the 'Zeta' particle



ICHEP'84

Made it to the NY Times!

In 1985 a new paper….

ABSTRACT

Results are presented from 22.1 pb^{-1} of $\Upsilon(1S)$ data, taken with the Crystal Ball detector at DORIS. These data were taken to further explore the $\varsigma(8.3)$ signal originally seen in 10.4 pb^{-1} of $\Upsilon(1S)$ data.[2] No evidence for the ς is observed in this new sample. Data quality checks and possible explanations are discussed.

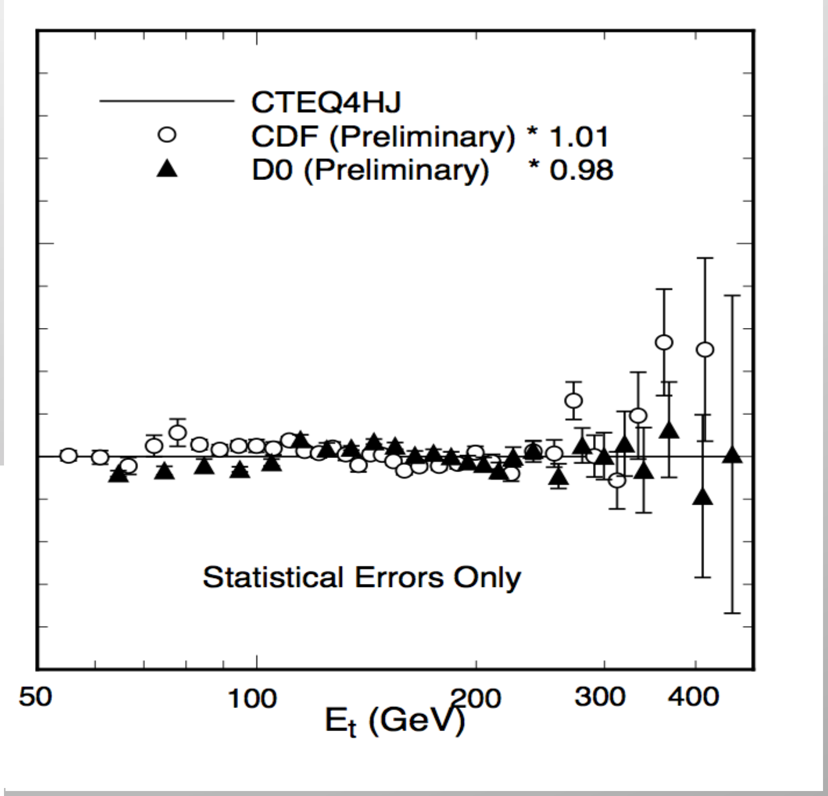
It was an error in the analysis!
Effect/peak went away…

Quark Substructure ? (1996)

Inclusive Jet Cross Section in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV

Phys. Rev. Lett. 77 438 (1996)

CDF Experiment: Inclusive jet analysis
It went into the New York Times



The New York Times **Archives**

Search All NYTimes.com

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Tiniest Nuclear Building Block May Not Be the Quark

By MALCOLM W. BROWNE
Published: February 8, 1996

EMAIL
PRINT

Scientists at Fermilab's huge particle accelerator 30 miles west of Chicago reported yesterday that the quark, long thought to be the simplest building block of nuclear matter, may turn out to contain still smaller building blocks and an internal structure.

If experiments using more powerful accelerators of the future should confirm suggestions of quark structure that scientists found in Fermilab's data, major revisions would be needed in the widely accepted theory of matter known as the "standard model." A whole new layer in the hierarchy of components that make up matter would lie exposed for exploration.

As some physicists express it, the onion of reality may have many deeper skins than scientists now know.

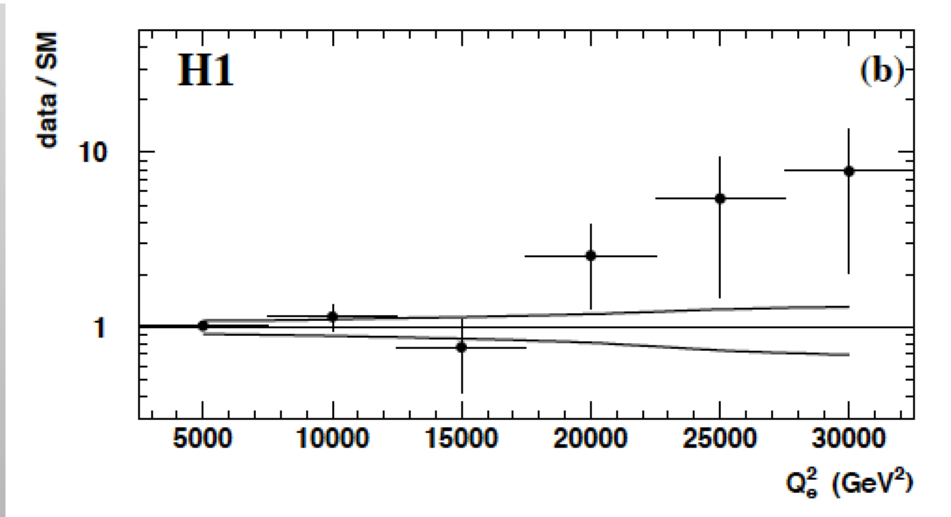
… it was parton distributions (& uncertainties)
→Good understanding of theory important!

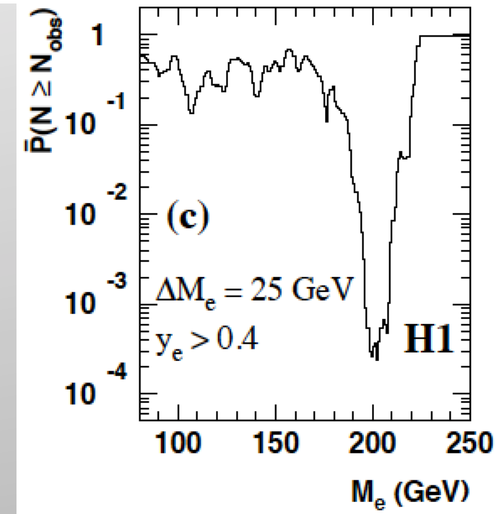
Leptoquarks or RPV SUSY? (1997)

Excess of events at high Q2 in ep DIS at HERA, mainly in H1

- 7 events found with an electron-quark mass of ~200 GeV, expected ~1 event
- 4 events found with expected 2 events in ZEUS

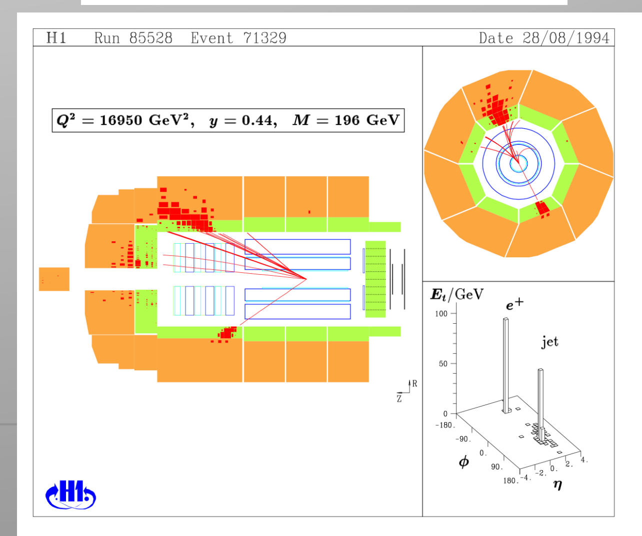
Z.Phys. C74 (1997) 191





More than 3σ local significance!

ΔM_e (GeV)	20	25	30	40
N_{obs}	5	7	7	7
N_{DIS}	0.63 ± 0.13	0.95 ± 0.18	1.10 ± 0.19	1.57 ± 0.28
$\bar{\mathcal{P}}(N \geq N_{obs})$	5.0×10^{-4}	2.6×10^{-4}	2.5×10^{-4}	1.6×10^{-3}



At the end it was a statistical fluctuation

The effect was totally gone with 10x statistics

Searches at the LHC

Many lessons from the past

- Independent cross checks of all important analyses
- Blinding of main search channels (eg for the Higgs)
- Backgrounds estimated from data (especially QCD ones, or backgrounds with many jets). Data driven efficiencies.
- Thorough studies on experimental effects eg for MET.
- Improved TH tools and calculations ((N)NLO+NLL, ME +PS, best PDFs…). Collaboration with Theorists!
- Be careful with statistical interpretation.
- Generally experiments tend to be (over-?)conservative for safety. But must ensure not to miss something…
- …But also MVAs, BDTs, more black box approaches…

In Short

- No real pending significant anomalies right now in the LHC (ATLAS+CMS data)
- Some heavy flavor issues in LHCb but will not discuss these here.
- Of course there are always a number of – statistically expected– 2 to 3 sigma effects
- No strong excitement in the experiments at this stage but some things to watch with new data --or when possible-- to study with different channels
- We have a look at some of these…

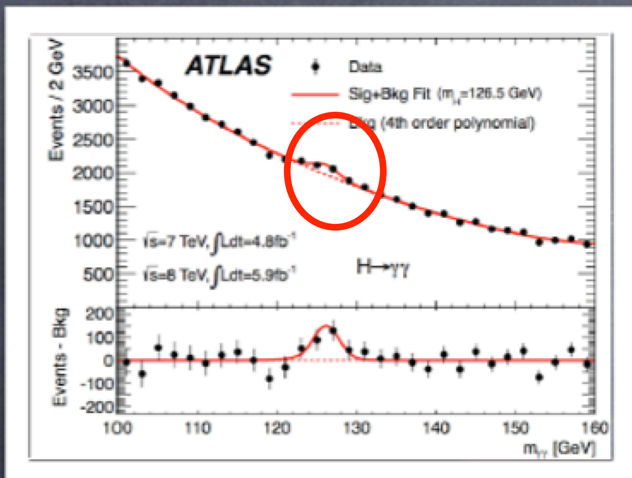
The Higgs Discovery

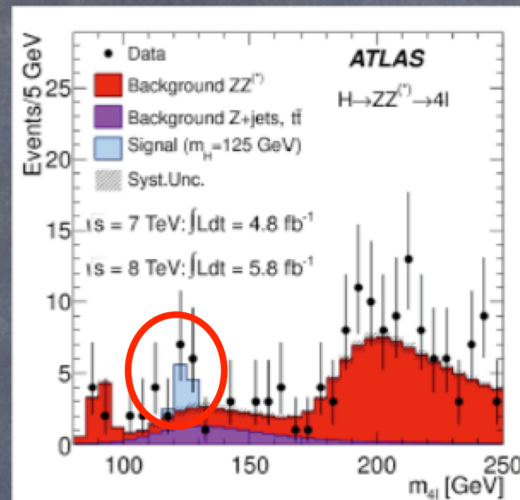
Higgs → 2 photons!!

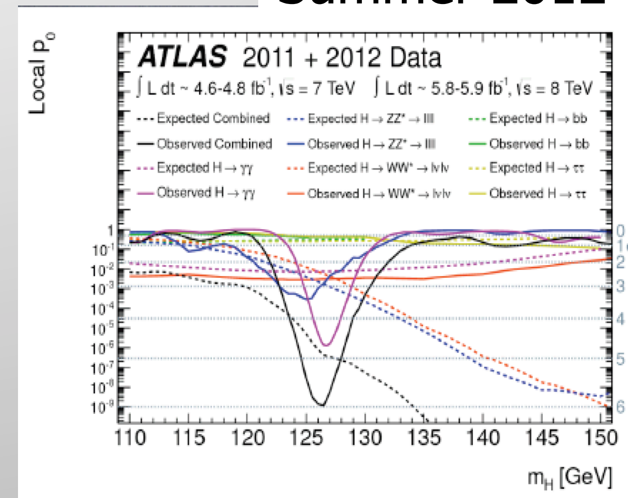
Higgs → 2Z → 4 leptons!!

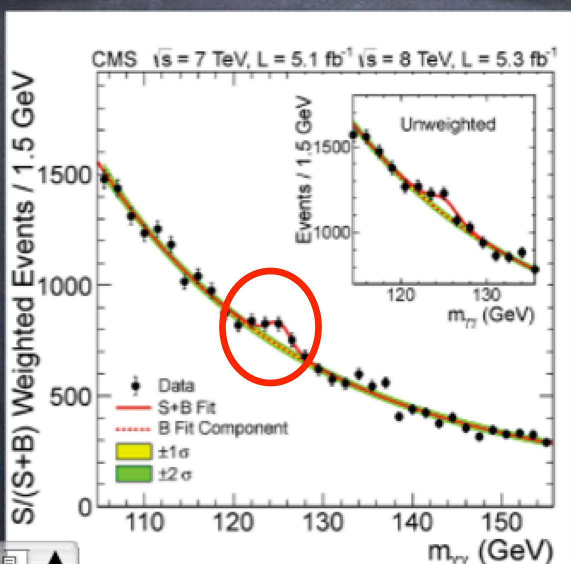
Channel combination

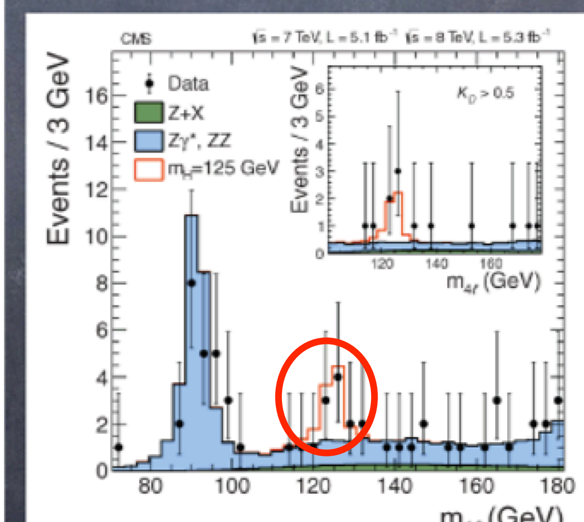
Summer 2012

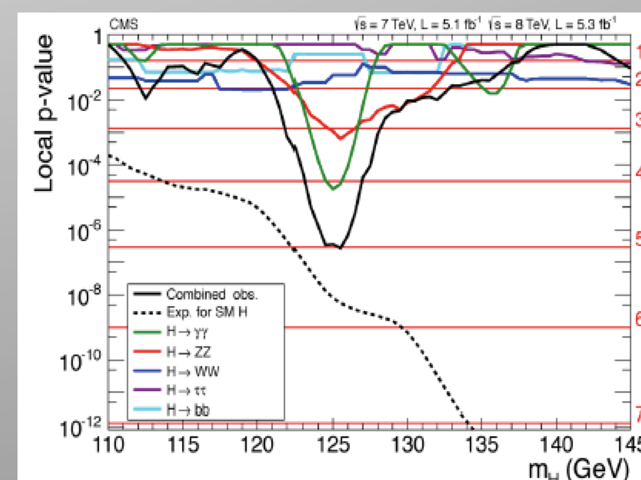






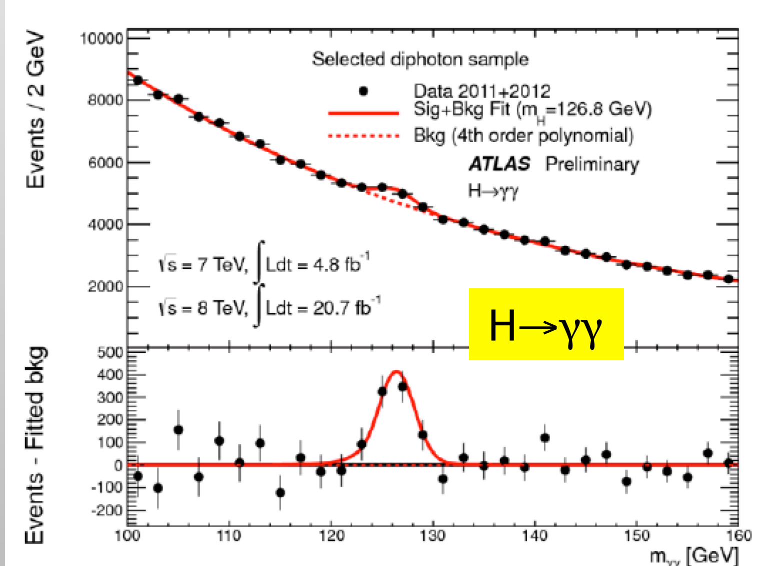


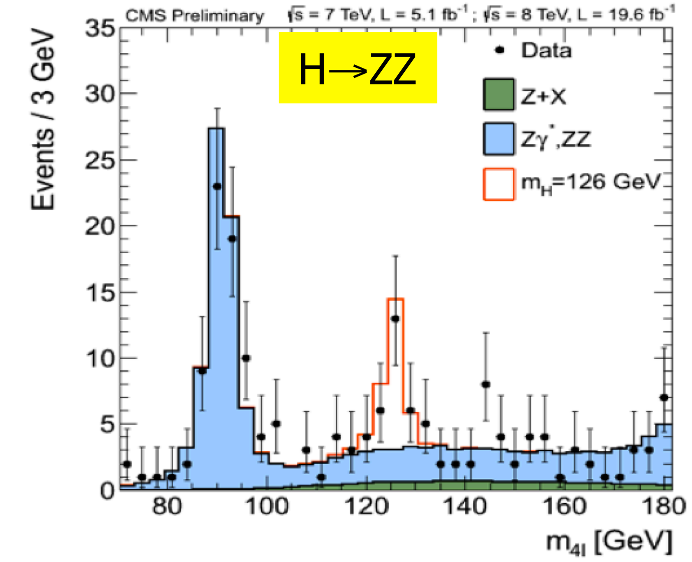




5σ in both experiments

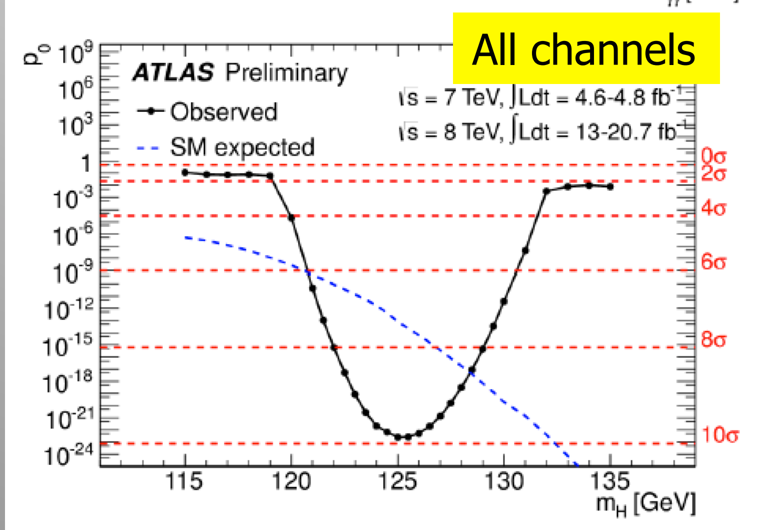
Update with the Full 2012 Data Sample

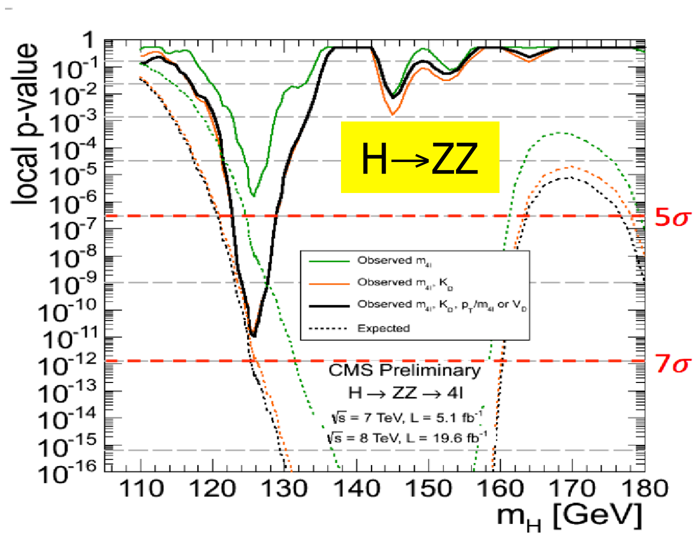




Spring 2013

Increased data sample with a factor of ~3

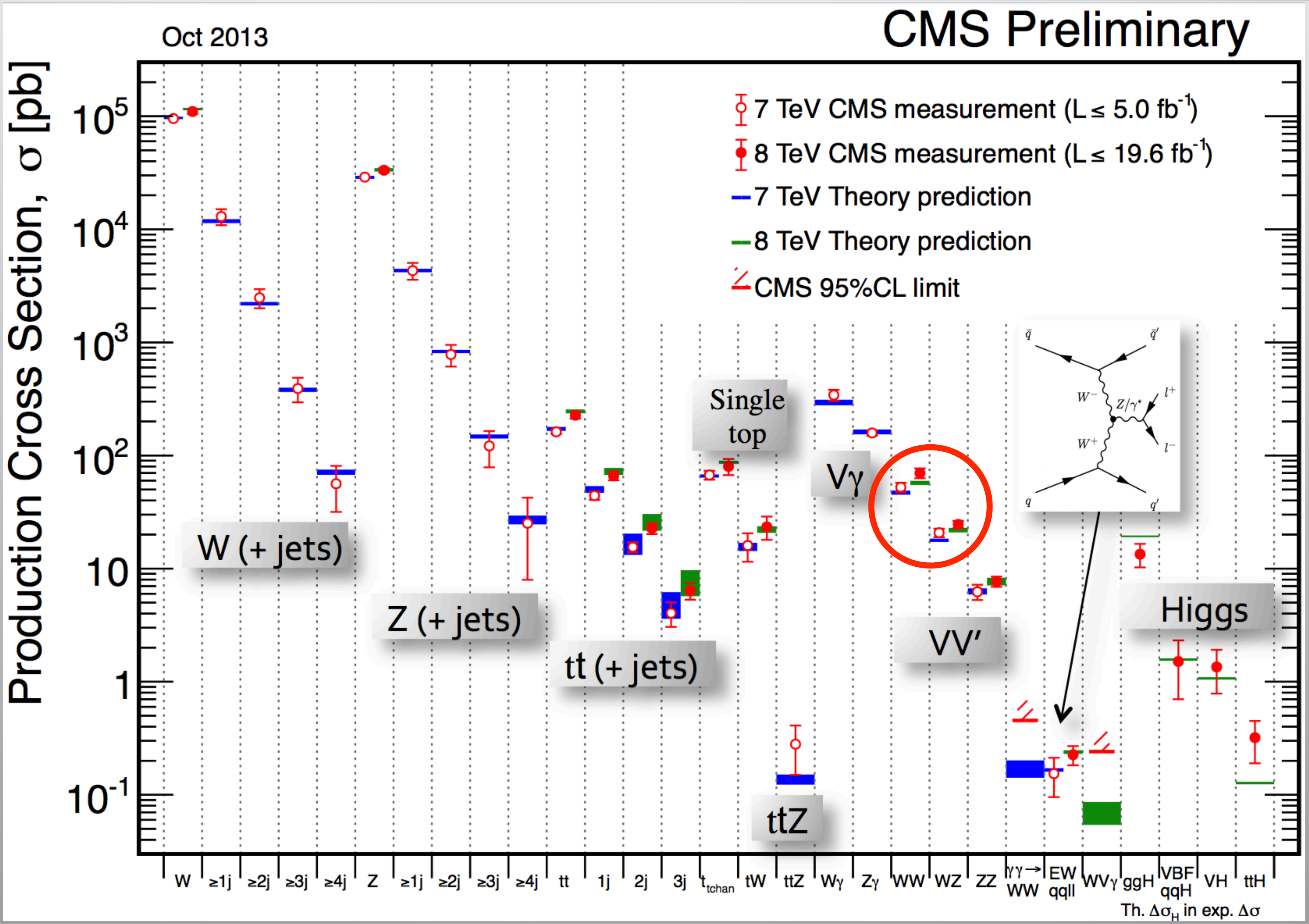




The particle is clearly still with us, now with a significance of >10σ !!

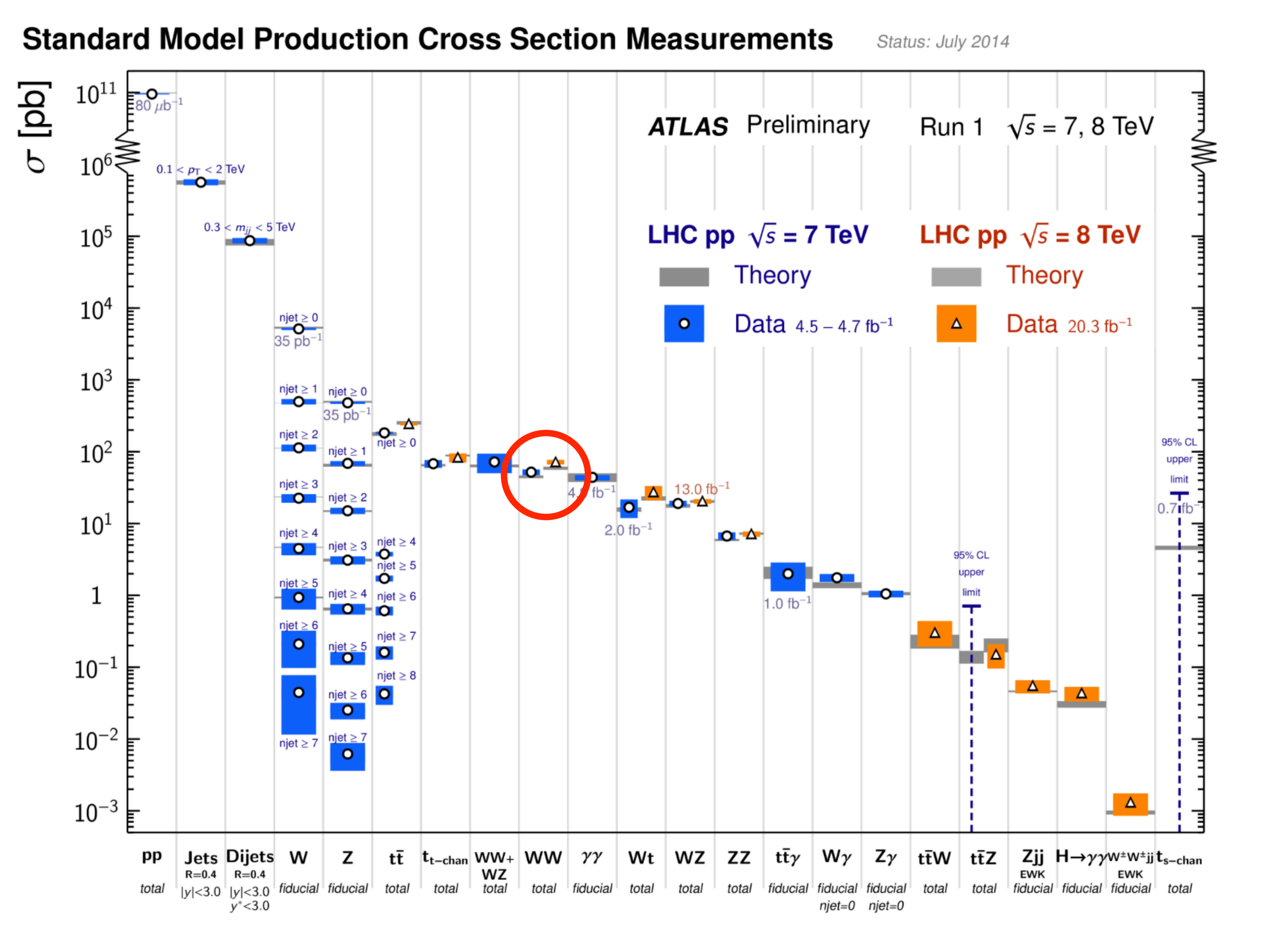
We now enter the phase of measuring the properties of the new particle

Summary: Cross Sections at 7/8 TeV



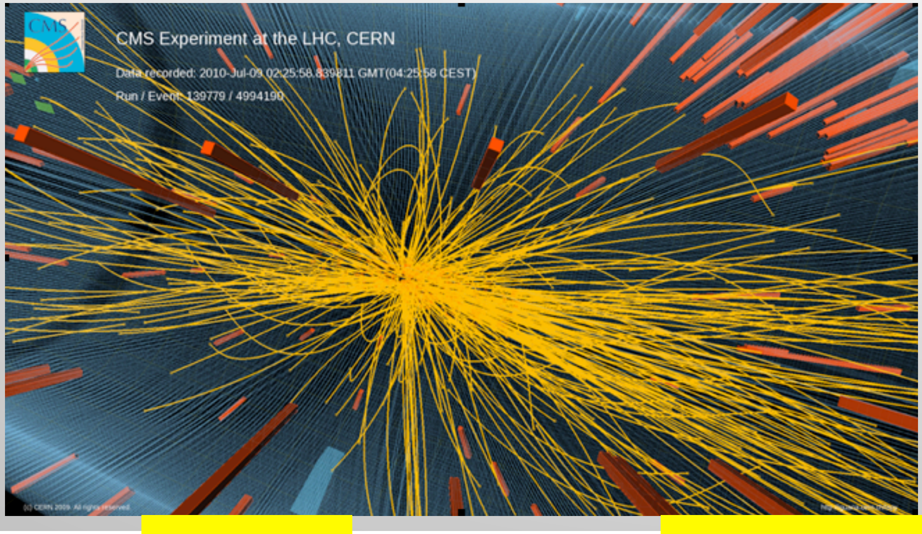
Measurements in good agreement with the Standard Model predictions

Summary: Cross Sections at 7/8 TeV



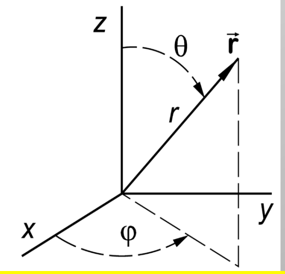
Measurements in good agreement with the Standard Model predictions
But this figure does not reveal 10-20% differences…

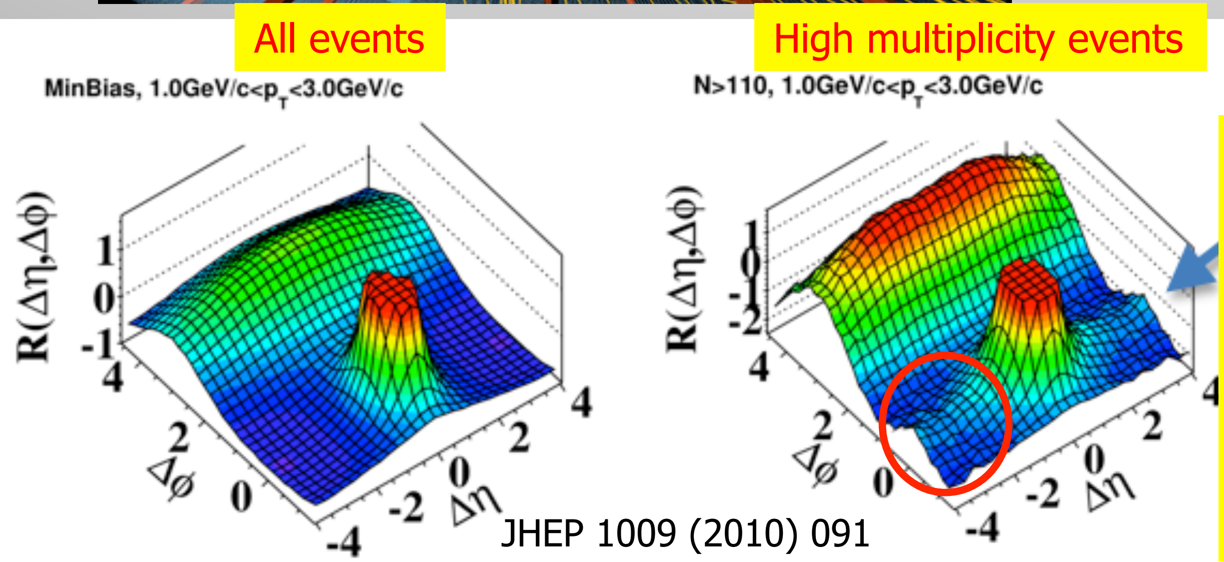
Correlations Between Produced Particles



- Select high multiplicity events
- Study the correlation between two charged particles in the angles φ (transverse): Δφ and θ (longitudinal): Δθ

η= -ln tanθ/2





A new phenomenon in the 'stronge force'?

- Multiple interactions?
- Glass condensates?
- Hydrodynamic models?

Still not quant. explained

This was the first (subtle) new effect, in 2010, studying the strong force…
Was first seen in AA, then pp (unexpected) and now also pA (~unexpected)

2011: Z' Boson to ee or μμ?

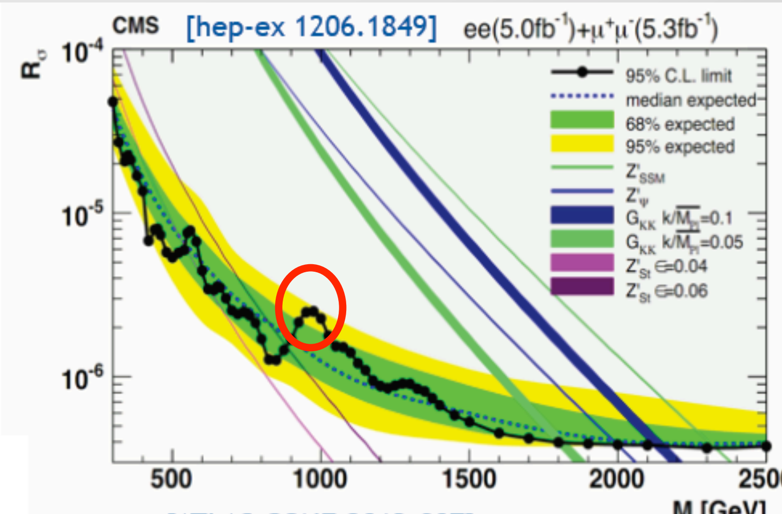
$SU(3)_C \times SU(2)_L \times U(1)_Y$

Extension of the symmetry?
New Gauge bosons?

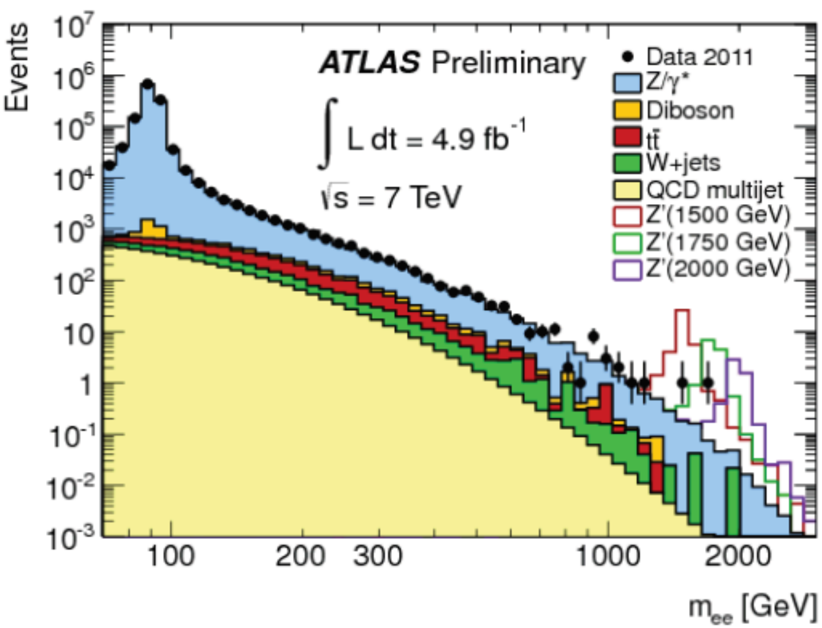
Early 2012

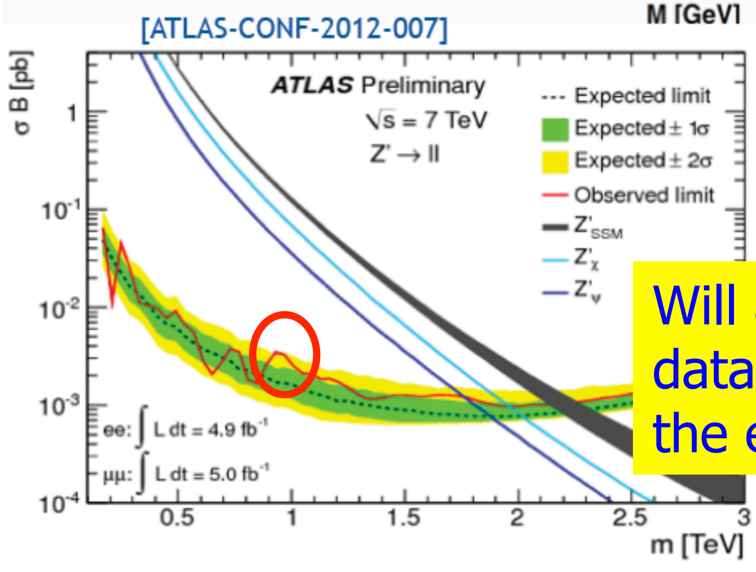
- Many new models have Z-like narrow resonances decaying to dileptons
- Interesting features in dilepton spectra
  - around 2σ each for CMS & ATLAS in e+μ
  - similar in scale to 2011 Higgs excess

Worth watching in 2012's 8 TeV data…



2011 data

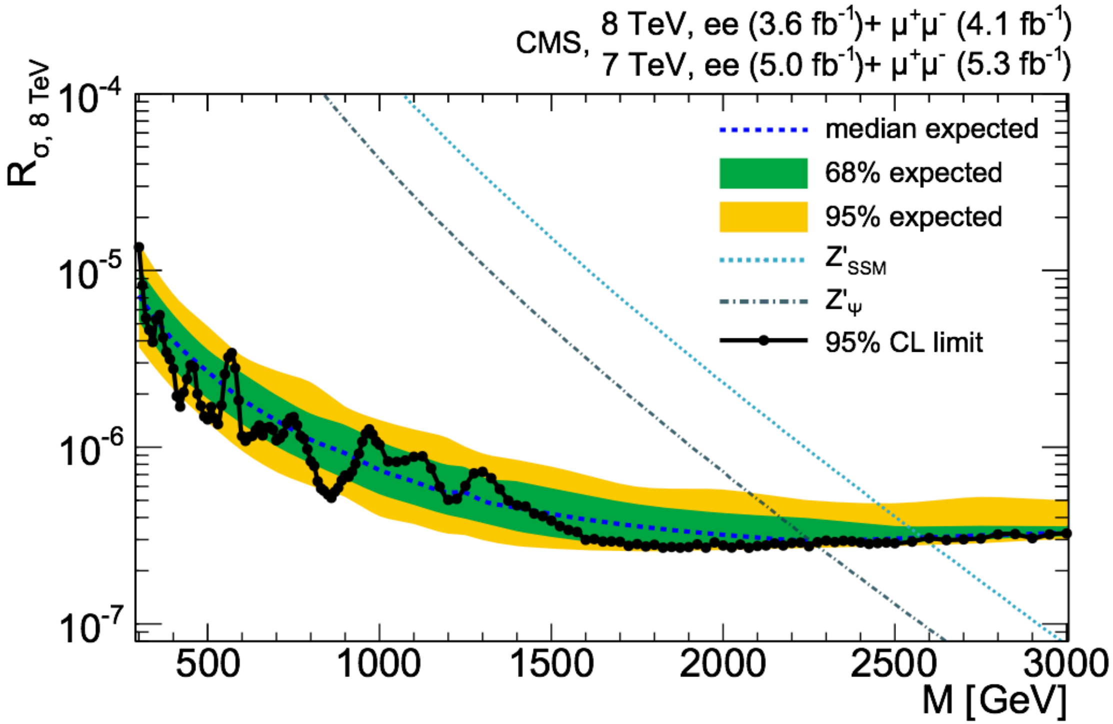




Will additional data confirm the excess??

Z' Combination of 7 & 8 TeV Data

[CMS EXO-12-015]



- Short time between data-taking and result

$$R_\sigma = \frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z + X \to \ell\ell + X)}$$

- Limits on the combined 7 TeV and 8 TeV data from 2011+2012
  - $M(Z'_{SSM})$ > 2950 GeV at 95% C.L.
  - $M(Z'_\psi)$ > 2600 GeV at 95% C.L.

Excess just below 1 TeV all but gone in CMS data

SUSY Searches: Example Analyses

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

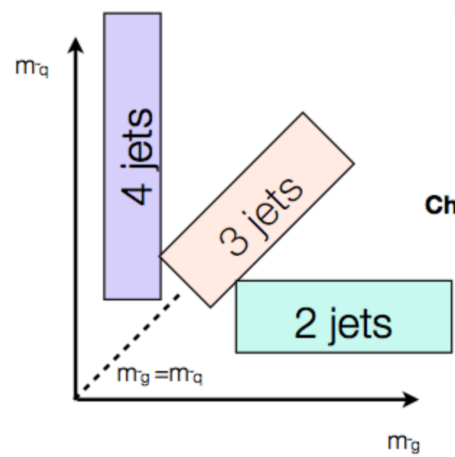
Large SM backgrounds **Low** →

← sensitivity to strongly produced SUSY

↔ sensitivity to gauge-mediated SUSY

All Analyses (CMS)

JETS+MET (ATLAS)



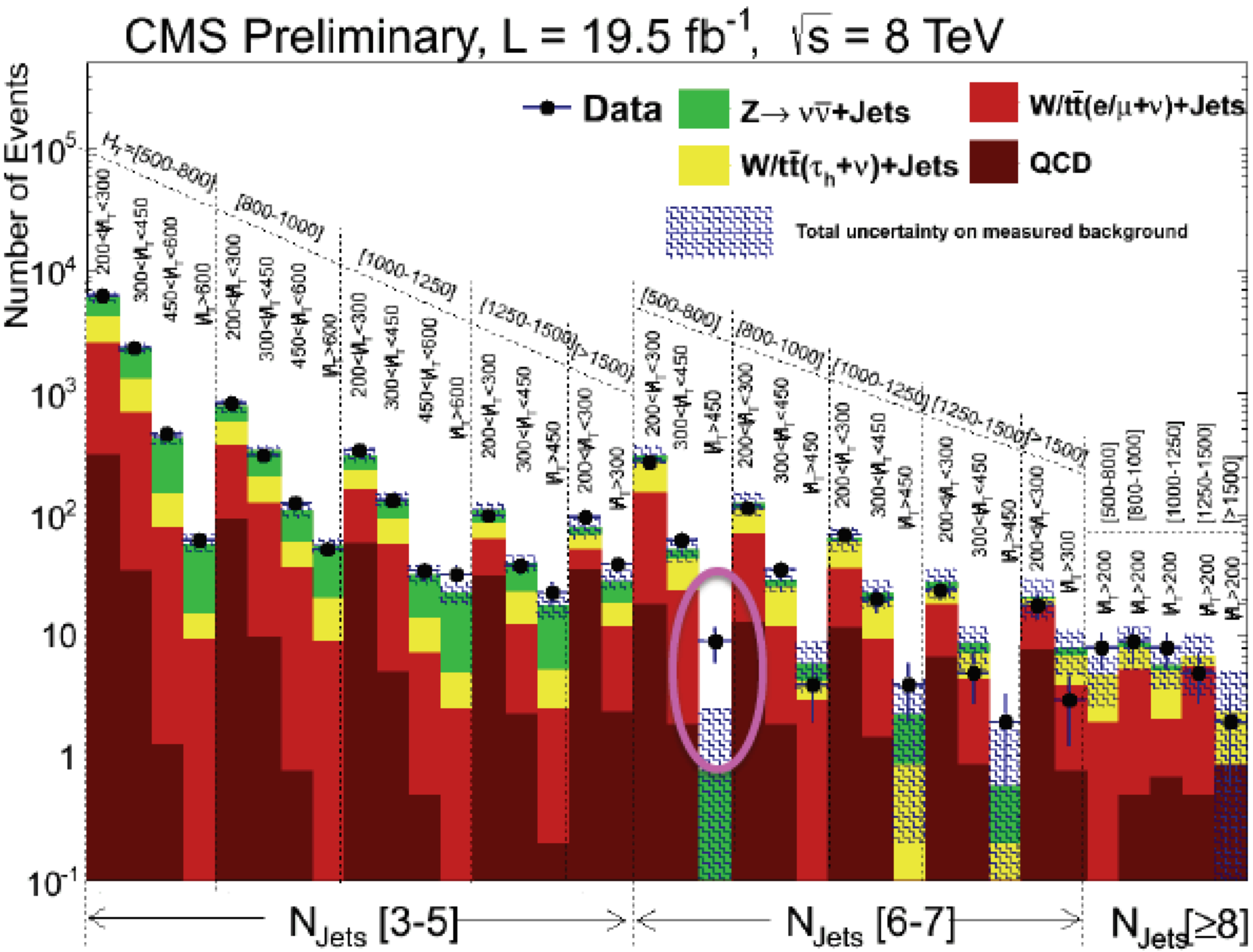
	Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets	High mass
Trigger requirements	E_T^{miss}	> 130	> 130	> 130	> 130
	Leading jet p_T	> 130	> 130	> 130	> 130
Channel definition	Second jet p_T	> 40	> 40	> 40	> 80
	Third jet p_T	–	> 40	> 40	> 80
	Fourth jet p_T	–	–	> 40	> 80
Reduce QCD	$\Delta\phi(\text{jet}, E_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
	E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
Enhance signal	m_{eff} [GeV]	> 1000	> 1000	> 500/1000	> 1100

$$m_{eff} = \sum_{i=1}^{n} |\vec{p}_T^{\,jet\ i}| + E_T^{miss}$$

Old Slide: now also searches for sbottom, stop, compressed spectra…

CMS SUSY: Jets + MET

Example: Checking many channels in a multi-jet +MET search



One bin shows an excess! Do we have to get exited?

N_{bg} = 0.7"±"1.8
N_{data} = 9

p (≥9|0.7"±"1.8) ~ 0.004
→ ~2.7 σ

To observe such (or a larger) fluctuation in any of the 36 bins:

p ~ 0.11 → ~1.2 σ

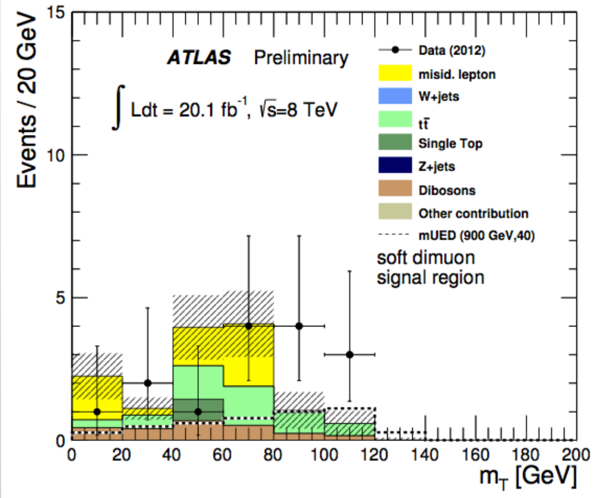
We do not get excited by it…!!

ATLAS SUSY: Lepton Channels

Study of single and double leptons + Jets + MET
- 19 channels studies
- One channel has 7 events with expectation 1.6±1.0. Significance is ~ 2.3σ

Two muons with $6<p_T<25$ GeV, 2 jets +MET

ATLAS-CONF-2013-062



	soft single-lepton 3-jet	5-jet	soft dimuon 2-jet
Observed events	7	9	7
Fitted background events	5.6 ± 1.6	14.8 ± 3.7	1.6 ± 1.0
Fitted $t\bar{t}$ events	1.3 ± 1.0	7.8 ± 3.3	1.2 ± 1.0
Fitted W+jets events	2.6 ± 0.7	2.1 ± 0.9	-
Fitted diboson events	0.6 ± 0.4	0.7 ± 0.4	0.4 ± 0.3
Fitted misidentified lepton events	$0.00^{+0.05}_{-0.00}$	3.3 ± 1.4	$0.0^{+0.3}_{-0.0}$
Fitted other background events	1.1 ± 0.5	0.9 ± 0.5	$0.01^{+0.06}_{-0.01}$

…Also used in the WW anomaly interpretation…

CMS SUSY: Lepton Channels

4 lepton analysis, with maximally one tau

arXiv:1404.5801

≥4 leptons $H_T < 200$ GeV	$m_{\ell^+\ell^-}$	E_T^{miss} (GeV)	$N_{\tau_h} = 0, N_b = 0$ Obs.	$N_{\tau_h} = 0, N_b = 0$ Exp.	$N_{\tau_h} = 1, N_b = 0$ Obs.	$N_{\tau_h} = 1, N_b = 0$ Exp.	$N_{\tau_h} = 0, N_b \geq 1$ Obs.	$N_{\tau_h} = 0, N_b \geq 1$ Exp.	$N_{\tau_h} = 1, N_b \geq 1$ Obs.	$N_{\tau_h} = 1, N_b \geq 1$ Exp.
OSSF0	—	$(100, \infty)$	0	0.11 ± 0.08	0	0.17 ± 0.10	0	$0.03^{+0.04}_{-0.03}$	0	0.04 ± 0.04
OSSF0	—	$(50, 100)$	0	$0.01^{+0.03}_{-0.01}$	2	0.70 ± 0.33	0	$0.00^{+0.02}_{-0.00}$	0	0.28 ± 0.16
OSSF0	—	$(0, 50)$	0	$0.01^{+0.02}_{-0.01}$	1	0.7 ± 0.3	0	$0.00^{+0.02}_{-0.00}$	0	0.13 ± 0.08
OSSF1	Off-Z	$(100, \infty)$	0	0.06 ± 0.04	3	0.60 ± 0.24	0	$0.02^{+0.04}_{-0.02}$	0	0.32 ± 0.20
OSSF1	On-Z	$(100, \infty)$	1	0.50 ± 0.18	2	2.5 ± 0.5	1	0.38 ± 0.20	0	0.21 ± 0.10
OSSF1	Off-Z	$(50, 100)$	0	0.18 ± 0.06	4	2.1 ± 0.5	0	0.16 ± 0.08	1	0.45 ± 0.24
OSSF1	On-Z	$(50, 100)$	2	1.2 ± 0.3	9	9.6 ± 1.6	2	0.42 ± 0.23	0	0.50 ± 0.16
OSSF1	Off-Z	$(0, 50)$	2	0.46 ± 0.18	15	7.5 ± 2.0	0	0.09 ± 0.06	0	0.70 ± 0.31
OSSF1	On-Z	$(0, 50)$	4	3.0 ± 0.8	41	40 ± 10	1	0.31 ± 0.15	2	1.50 ± 0.47
OSSF2	Off-Z	$(100, \infty)$	0	0.04 ± 0.03	—	—	0	0.05 ± 0.04	—	—
OSSF2	On-Z	$(100, \infty)$	0	0.34 ± 0.15	—	—	0	0.46 ± 0.25	—	—
OSSF2	Off-Z	$(50, 100)$	2	0.18 ± 0.13	—	—	0	$0.02^{+0.03}_{-0.02}$	—	—
OSSF2	On-Z	$(50, 100)$	4	3.9 ± 2.5	—	—	0	0.50 ± 0.21	—	—
OSSF2	Off-Z	$(0, 50)$	7	8.9 ± 2.4	—	—	1	0.23 ± 0.09	—	—
OSSF2	On-Z	$(0, 50)$	*156	160 ± 34	—	—	4	2.9 ± 0.8	—	—

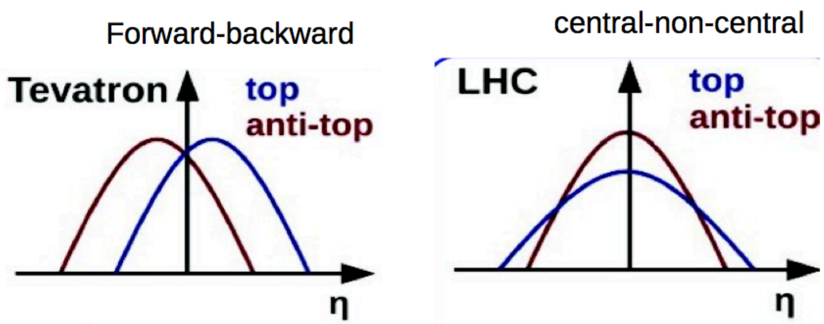
- 22 events seen and 10 expected in the opposite-sign/same flavor channel, outside the Z mass, in all E_{Tmiss} range…
- Significance is 2.6σ but > 30 channels studied
- Re-appears also as an excess in H→ hh search… (to appear)

Top Quark Charge Asymmetry?

Anomaly observed at the Tevatron. Any effect at the LHC?

T. Carli
ICHEP14

Charge asymmetry



$$A_{FB}^{t\bar{t}} = \frac{N(\Delta y_{t\bar{t}} > 0) - N(\Delta y_{t\bar{t}} > 0)}{N(\Delta y_{t\bar{t}} > 0) + N(\Delta y_{t\bar{t}} > 0)}$$

$$\Delta y_{t\bar{t}} = y_t - y_{\bar{t}}$$

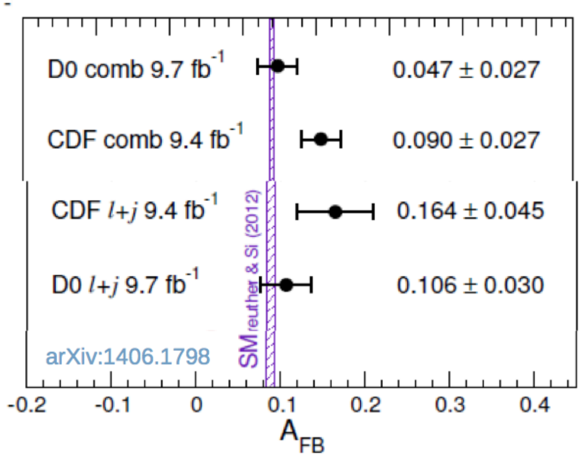
$$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| > 0)}{N(\Delta|y| > 0) + N(\Delta|y| > 0)}$$

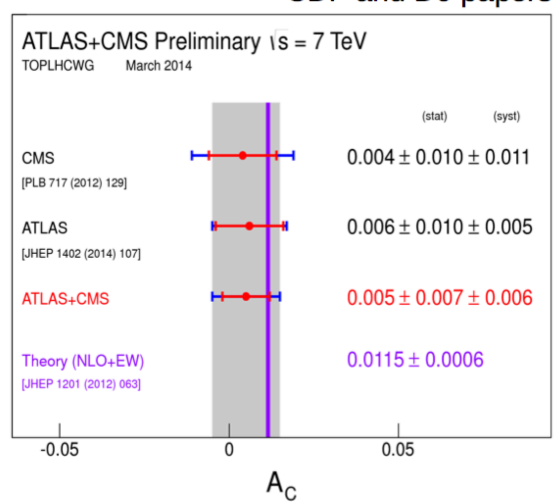
$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$

ATLAS JHEP02(2014)107
CMS JHEP 04 (2014) 191
Combination CMS PAS TOP-14-006
D0 arXiv:1403.1294
ATLAS-CONF-2014-012

Asymmetry (A) appears at NLO QCD as interference effect of terms to $O(\alpha_s^3)$
Only in qqbar final state
Forward-backward A_{FB} in ppbar
Top/anti-top A_C in pp

Large experimental and theory activity due to CDF and D0 papers in 2008



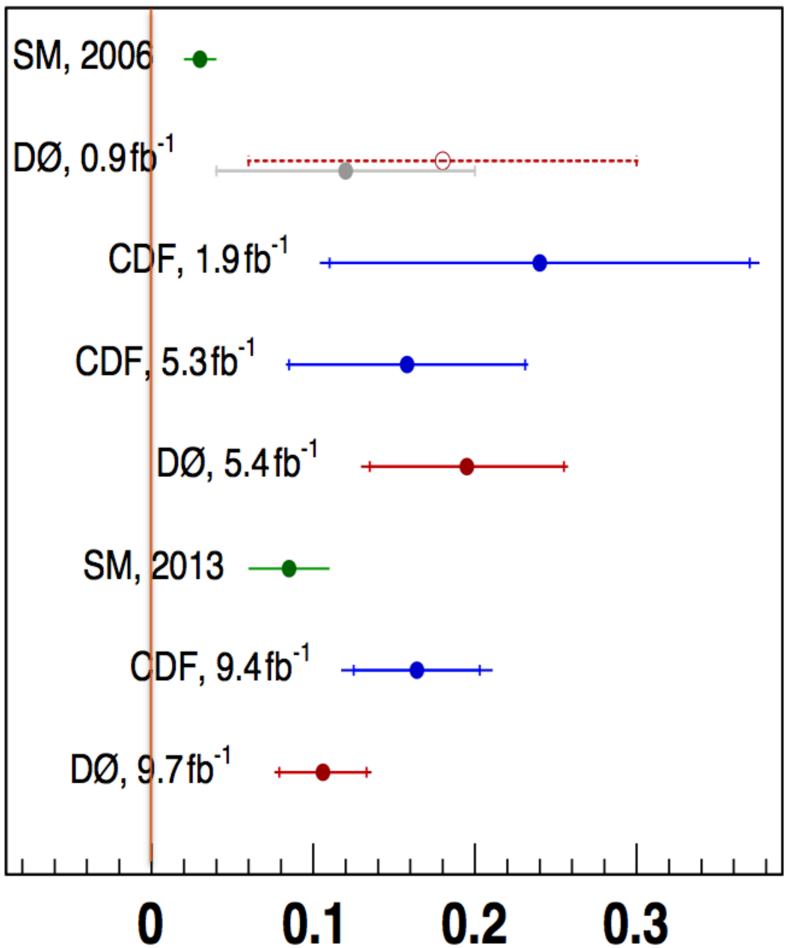


Effect may be going away at The Tevatron…
Latest D0 result agrees with SM

No observed effect at the LHC in any case

Top Quark Charge Asymmetry

Evolution of the "effect" at the Tevatron



D0 report

PRL100(2008)142002, 227 cit's

PRL101(2008)202001, 222 cit's

PRD83(2011)112003,409 cit's

PRD84(2011)112005, 292 cit's

Tevatron stopped taking data in Sep 2011

PRD87(2013)092002, 79 cit's

We achieved 3.0%

But the central value came down

Top Quark Charge Asymmetry

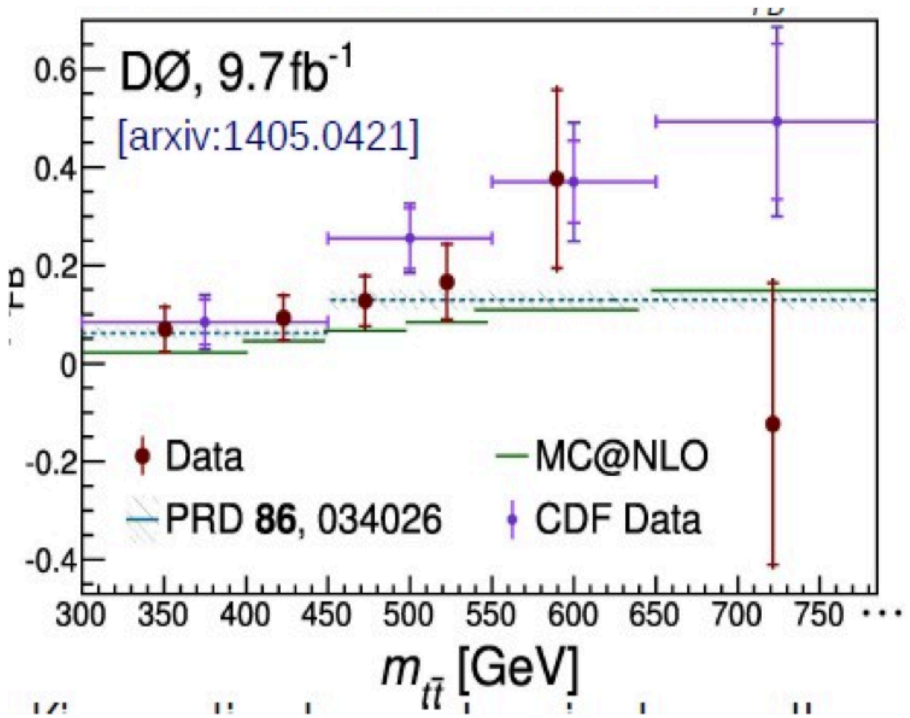
ATLAS JHEP02(2014)107

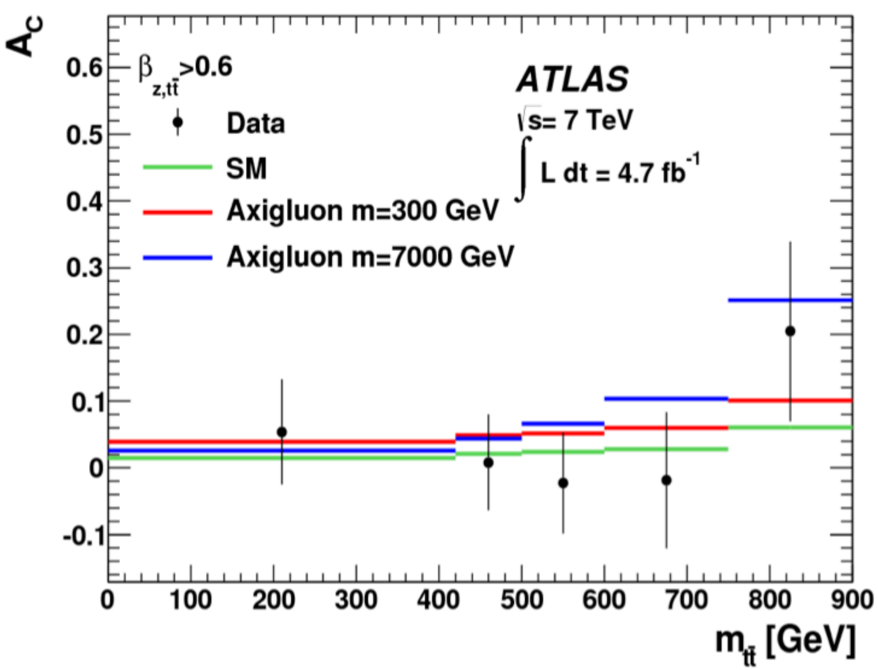
CMS JHEP 04 (2014) 191

Combination CMS PAS TOP-14-006

D0 arXiv:1403.1294

Differential asymmetry measurements





WW Production

Di-boson production: This should not be a problem for theory, no?

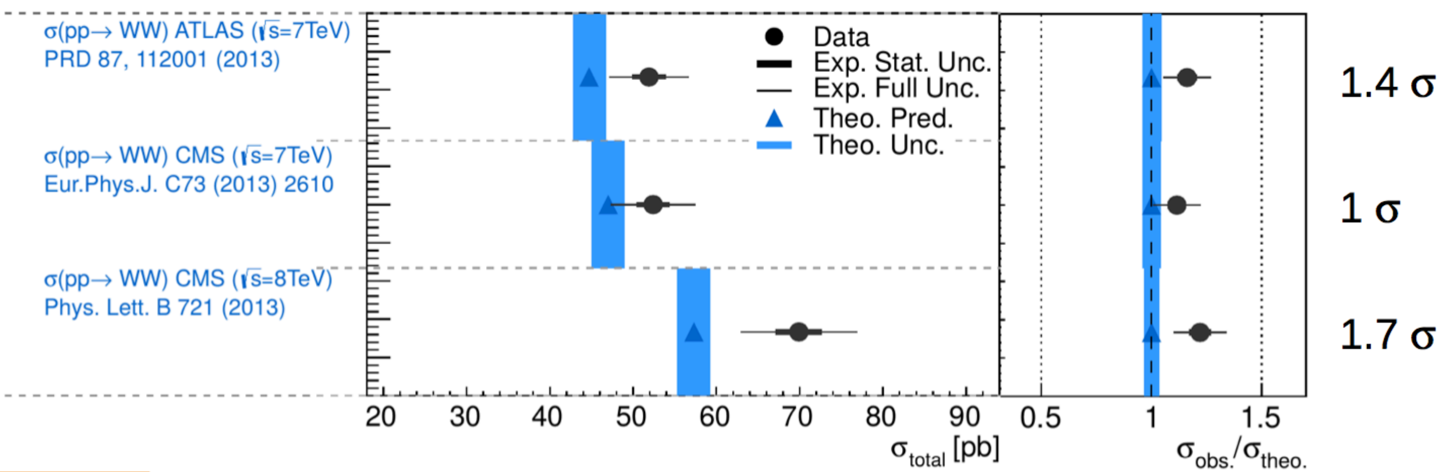
Standard Model prediction: $58.7^{+1.0}_{-1.1}$ (PDF) $^{+3.1}_{-2.7}$ (total) pb

Contributions neglected in this SM prediction

- $q\bar{q} \to WW$ (NLO → NNLO+NNLL k-factor) + 1.6 pb
- $gg \to WW$ (LO → NNLO+NNLL k-factor) + 1.4 up to +2.8 pb

- Electroweak corrections – 0.5 pb
- γγ-induced WW + 0.5 pb
- Vector boson scattering + 0.5 pb
- Double parton interaction + 0.04 pb

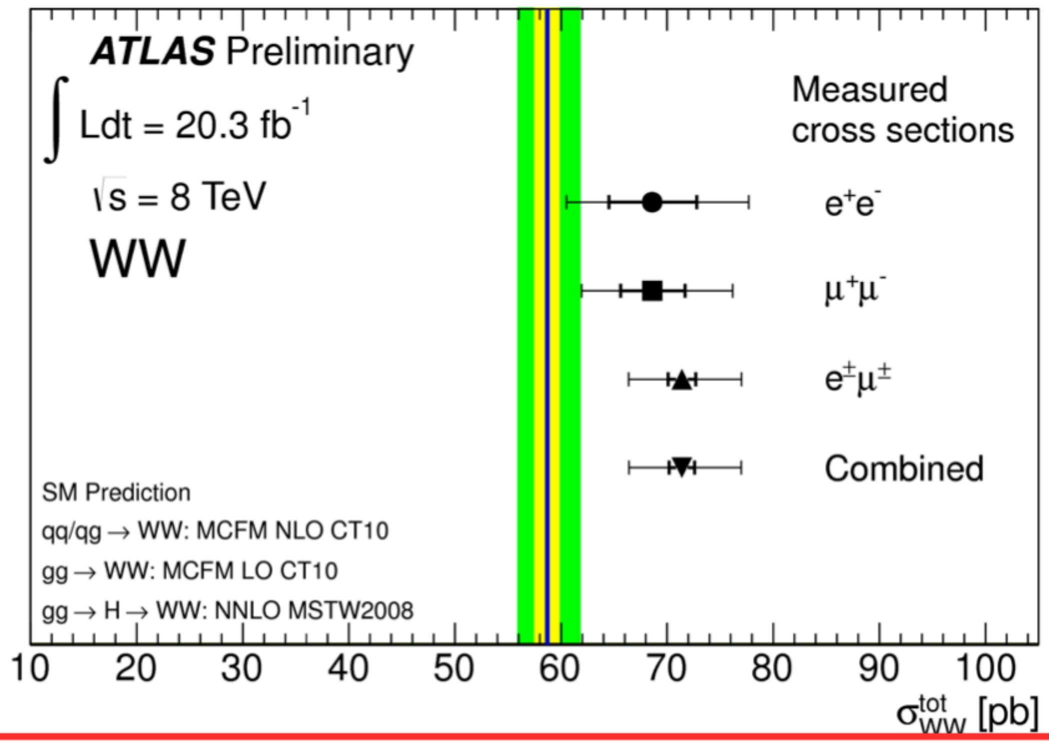
Total sum of:
+ 3.5 to 4.9 pb



Bizar: all measurements so far gave a systematically higher value!
Less the case for ZZ and WZ as far as we can see…

WW Production

What was missing until now was the ATLAS 8 TeV result



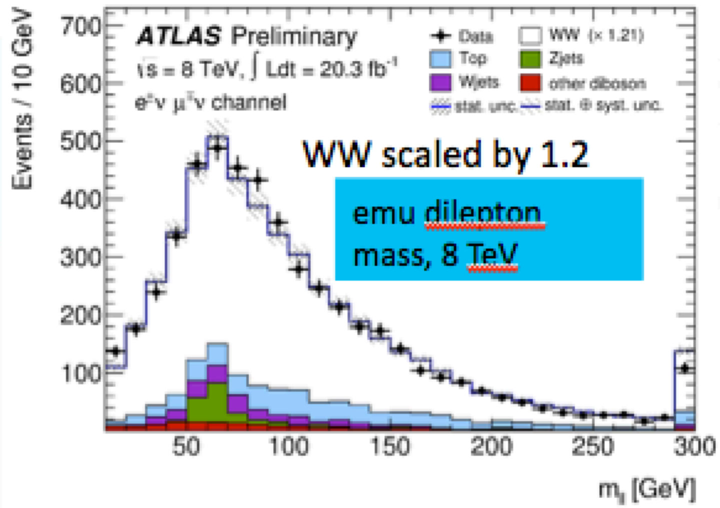
$$\sigma_{WW}^{tot} = 71.4\ ^{+1.2}_{-1.2}(\text{stat})\ ^{+5.0}_{-4.4}(\text{syst})\ ^{+2.2}_{-2.1}(\text{lumi})\ \text{pb}$$

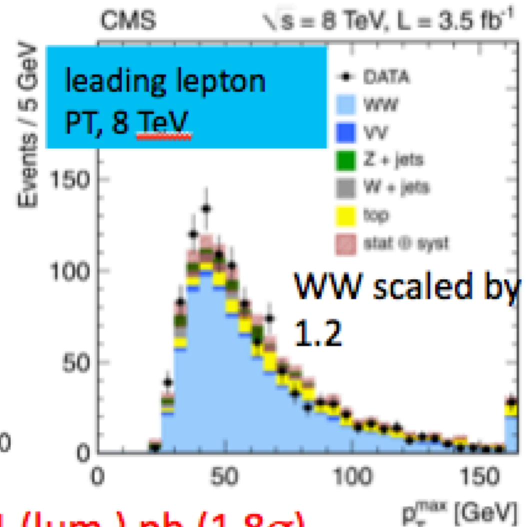
Standard Model prediction: $58.7^{+1.0}_{-1.1}$ (PDF) $^{+3.1}_{-2.7}$ (total) pb

Important: how well do we control the theory? Now NLO, Higgs included

WW Production

- Kinematic shapes agree with prediction, but cross section excess observed at 20% level in CMS and ATLAS
- ~5000 emu ATLAS candidates with 20/fb!
- Systematics from jet veto acceptance, background methods
- Not yet reporting: CMS lvlv 20/fb, WW→lvjj 20/fb
- Theory calculation being actively studied (jet vetoes, NNLO)





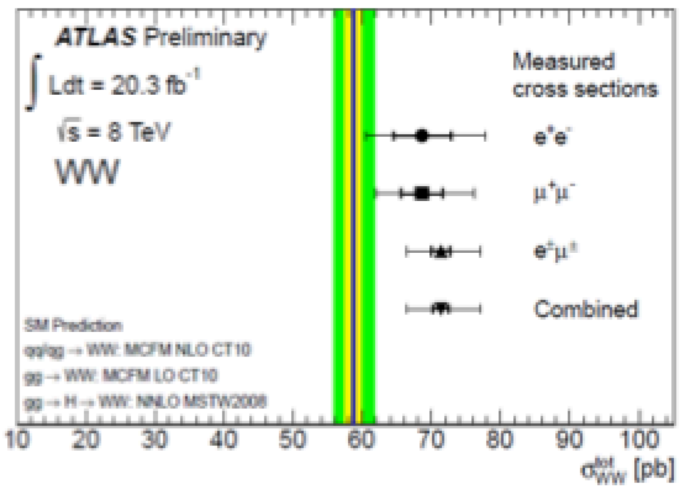
CMS 69.9±2.8 (stat.)±5.6 (syst.)±3.1 (lum.) pb (1.8σ)

ATLAS 71.4±1.2 (stat.)±5.0 (syst.)±2.2 (lum.) pb (2.1σ)

MCFM 58.7±3.0 (syst.) pb

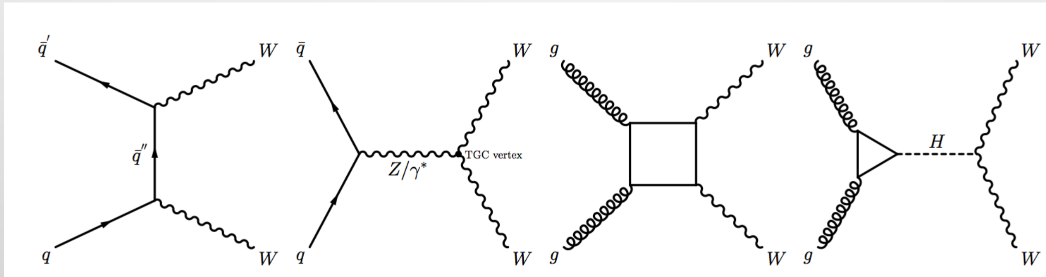
=qq,qg 53.2 MCFM NLO
+gg 1.4 MCFM LO
+HWW 4.1 NNLO+NNLL

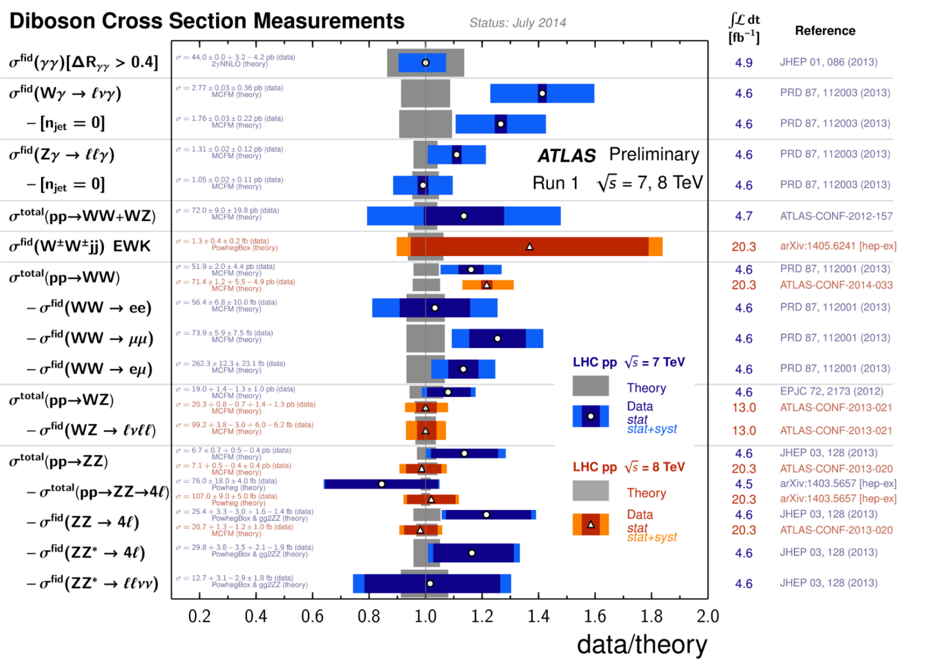
Higher order/other≈ +3-4pb?

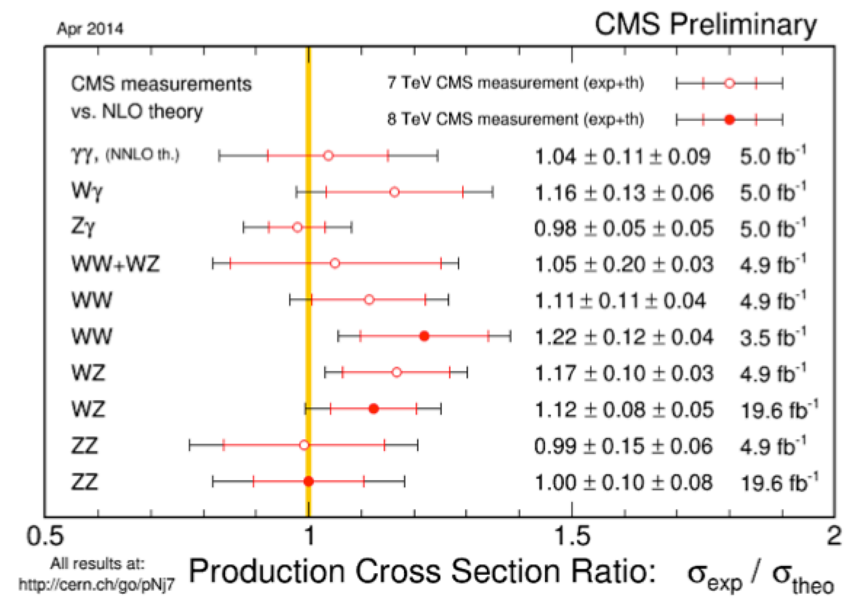


Full CMS 8 TeV still to come. Studies with/without jet vetoes, b-jets…

Di-boson Production @ LHC







WW data agreement with TH 'worst' and similarly in ATLAS and CMS
Less clear for the others. ZZ ok, WZ ok in CMS, W-photon on high side…

New Physics in WW Cross Sections?

Both these phenomenology papers appeared on June 3rd … → Next Talk!

'Stop' that ambulance! New physics at the LHC?

arXiv:1406.0858

Jong Soo Kim,[a] Krzysztof Rolbiecki,[a] Kazuki Sakurai,[b] and Jamie Tattersall[c]

Natural SUSY in Plain Sight

arXiv:1406.0848

David Curtin, Patrick Meade, Pin-Ju Tien

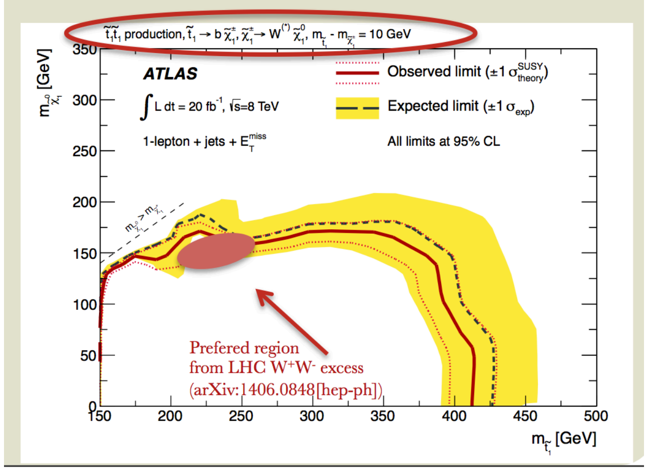
Interpretation in the two papers (Overall analyses of WW, and available SUSY searches):

→ Stop pair production -- with m_{stop} ~ 200 GeV– plus decay to chargino leading to the WW excess

$$\tilde{t}_1 \to \tilde{\chi}_1^{\pm}\, b \to \tilde{\chi}_1^0\, W^{\pm(*)}\, b \to \tilde{\chi}_1^0\, \ell^{\pm}\, \nu\, b$$

$$m_{\tilde{t}_1} = 212^{+35}_{-35}\ \mathrm{GeV},$$
$$m_{\tilde{\chi}_1^0} = 150^{+30}_{-20}\ \mathrm{GeV}.$$

- Tests in other channels?
  ATLAS already excluded this point?
- WW excess at 13 TeV?



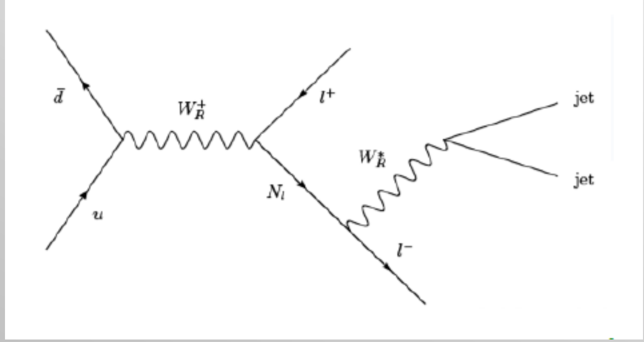
Da Costa ICHEP14

My take:

- Need to have a careful look at QCD corrections, effects of the jet veto…
- Need other measurements eg WW→lνjj, WW+0/1/2 jets…

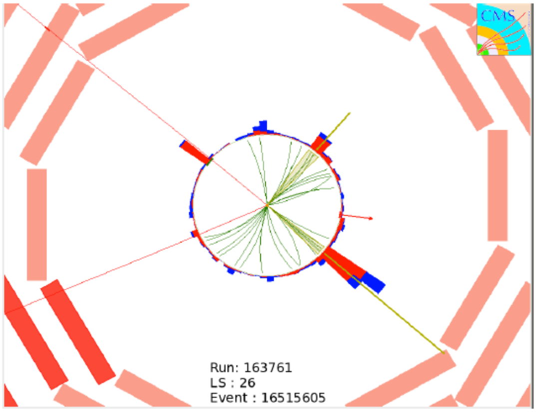
Search for Heavy Neutrinos and W_R

Left-right symmetric extension of the Standard Model

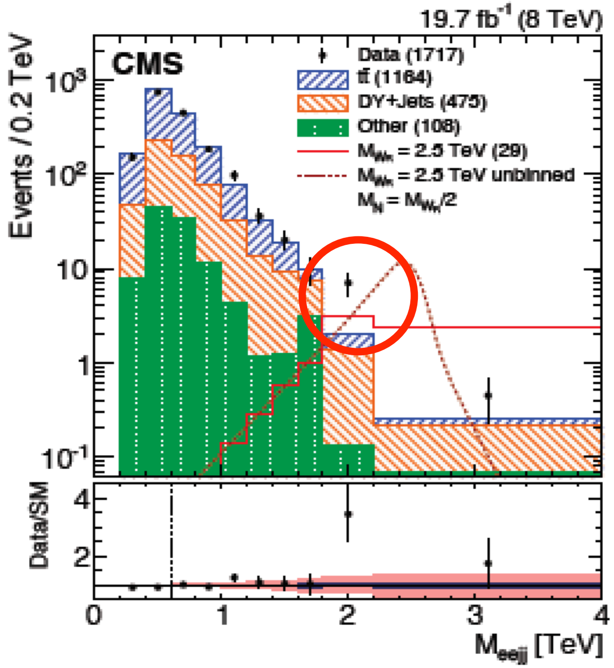


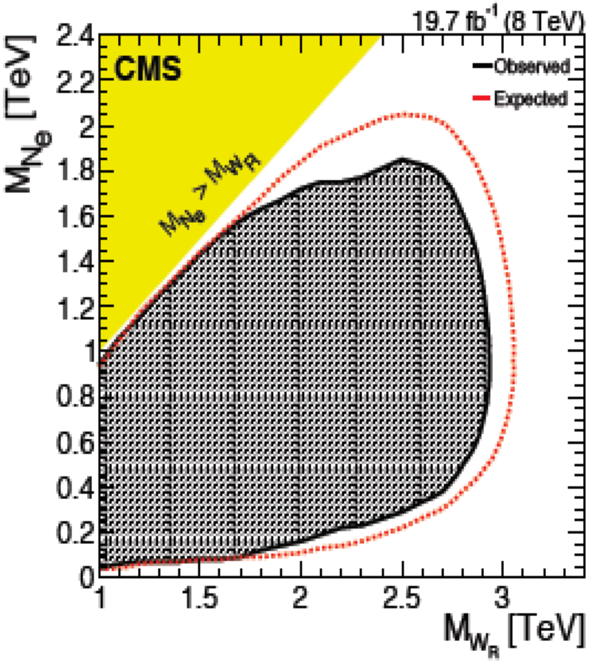
arXiv:1407.3683

Select events with 2 leptons and 2 jets



Muon channel: Event with $M_{\mu\mu}$ = 331 GeV, $M_{\mu\mu jj}$ = 881 GeV



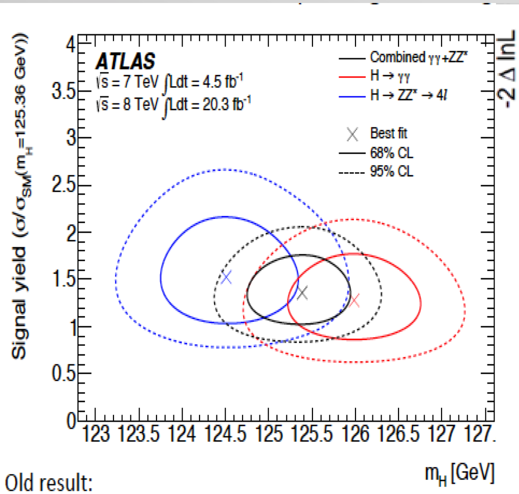


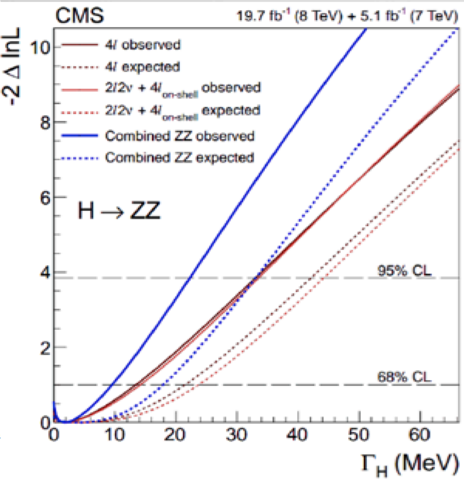
Large exclusion range in mass of the W_R and heavy neutrino

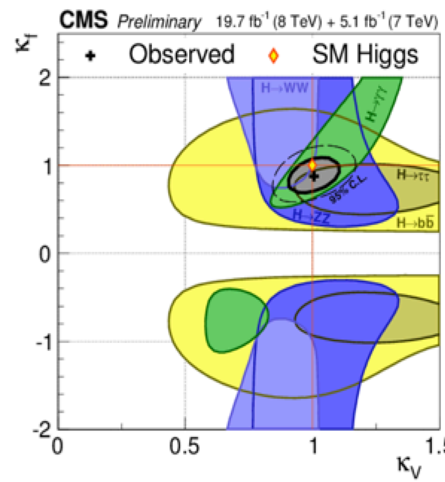
Observe a 2.8 sigma excess in the electron channel around 2 TeV W_R mass

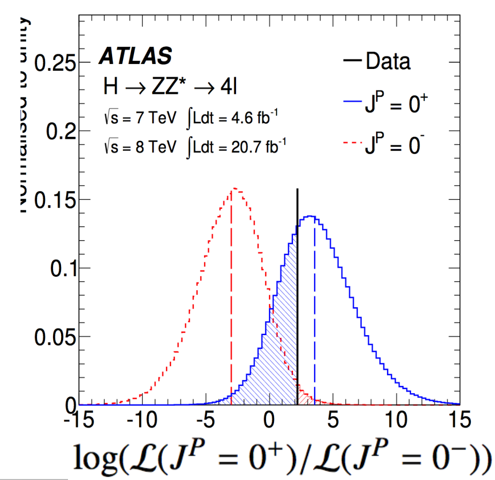
The Higgs… our New Tool!

We know already a lot on this Brand New Higgs Particle!!









Mass =
A: 125.4 ±0.4 GeV
C: 125.0 ±0.3 GeV

Width =
A: < 24 MeV
C: < 22 MeV
(95%CL)

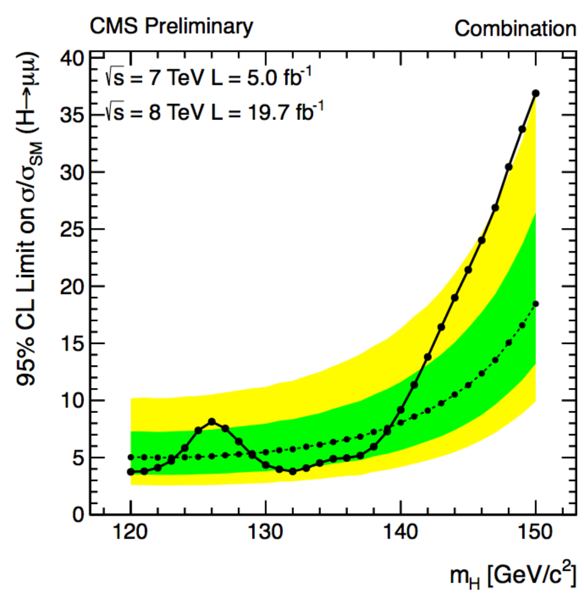
Couplings are within 20% of the SM values

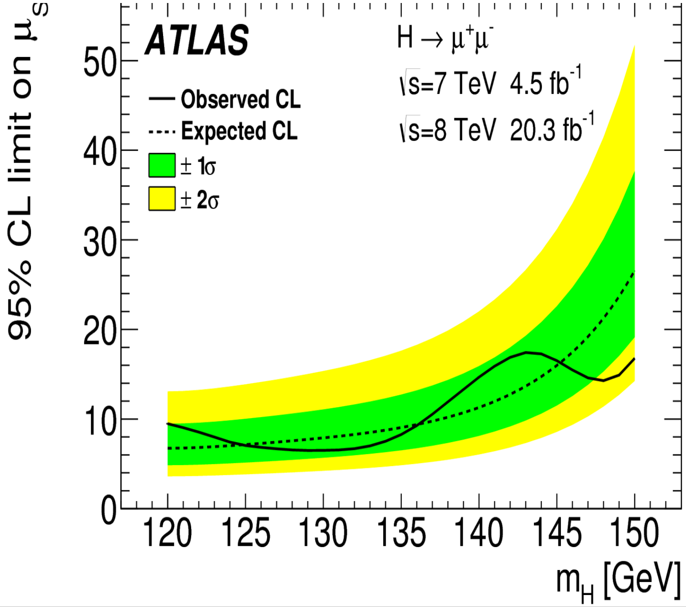
Spin =
0^+ preferred over 0^-,1,2

SM-like behaviour for most properties, but we look of course for anomalies, i.e. unexpected decay modes or couplings, multi-higgs production…

Higgs → μμ

This decay is not expected to be observed at the LHC yet

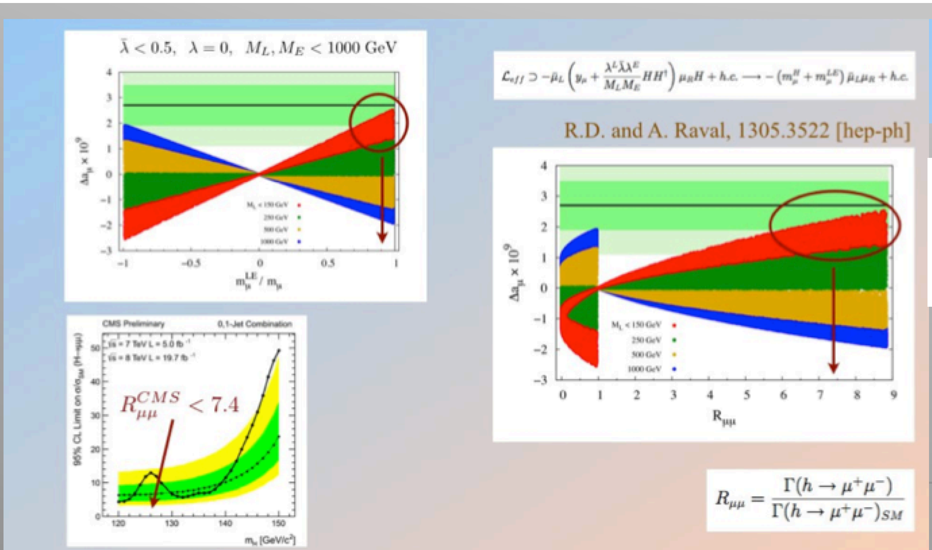




CMS-PAS-HIG-13-007
ATLAS: arXiv:1406.7663

ATLAS:
μ < 7.0 (7.2 exp.) @ 95% CL
CMS:
μ < 7.4 (5.1 exp.) @ 95% CL

Certainly NO claim from the experiments, but…



Extensions of the SM by complete vector-like families:

Explaining the g-2 anomaly with consequences for Higgs to μμ decays

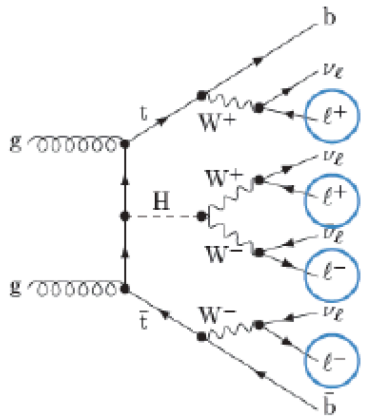
R. Dermisek et al.

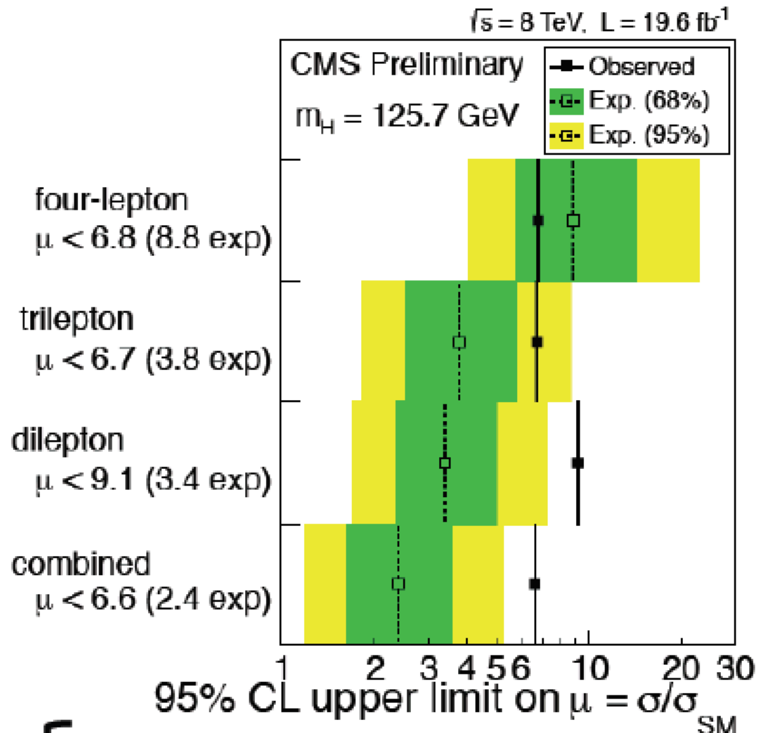
Desperately Searching New Physics ☺

Higgs: ttH production

- Expect to reach sensitivity for SM ttH process, using all H decay channels
- One channel shows an anomaly: the multi-lepton final state

Target ttH production in leptonic (e, μ) final states from $H \to \tau\tau$, ZZ^*, WW^*





4 leptons + b-jets (other than $H \to ZZ \to 4l$, no resonant $Z \to ll$)

3 leptons + b-jets (no resonant $Z \to ll$)

2 same-sign leptons (ee, eμ, μμ) + b-jets

95% CL limit on μ at m_H = 125 GeV

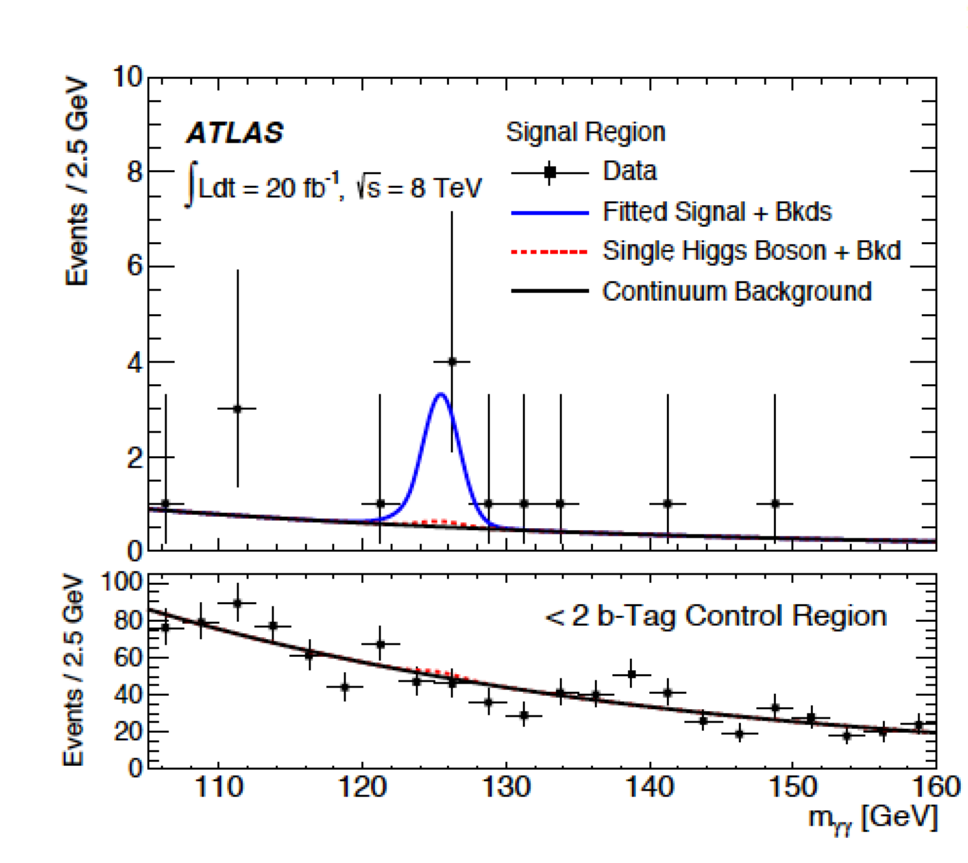
- **observed: 6.6**
- **expected: 2.4 (in absence of ttH signal)**
- **3.5 (with SM ttH production)**

Excess mainly comes from SS di-muon channel

Only in the same sign muon channel: most likely explanation is a fluctuation!!

ATLAS: hh → γγbb

- No signal expected with the present collected luminosity for this channel
- Select events with 2 b jets and 2 photons. (non-resonant channel)
- 5 events within bin of $M\gamma\gamma \pm 2\sigma_{M\gamma\gamma}$ and 1.5 expected which is about 2.4σ significance…

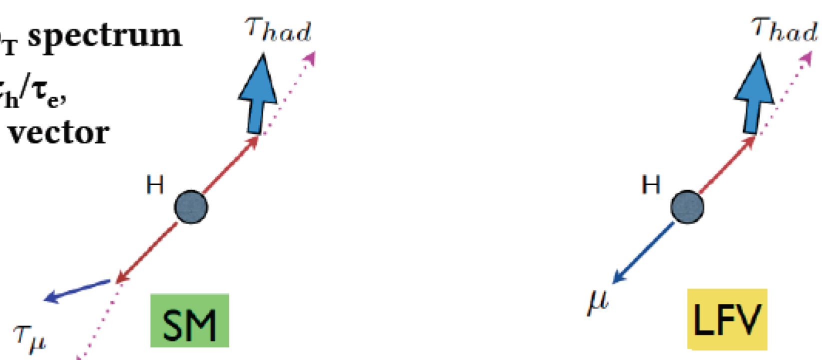


arXiv:1406.5053

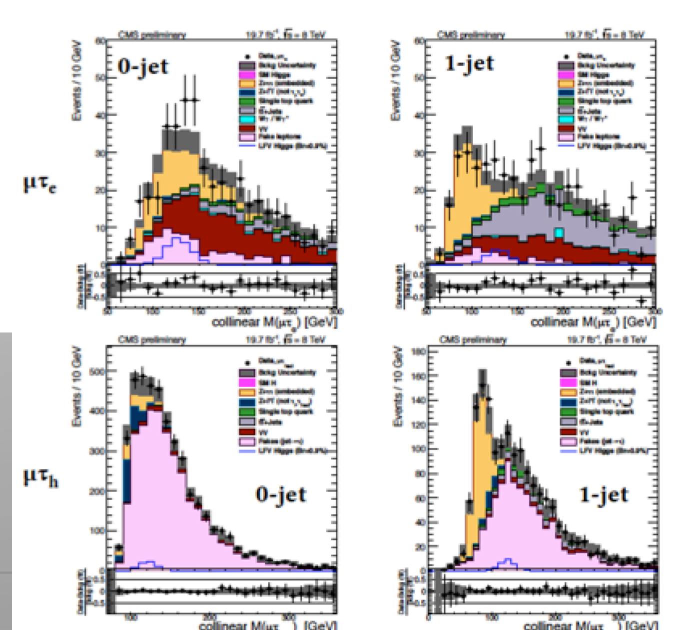
Search for LFV Decays: H $\rightarrow \mu\tau$

CMS-PAS-HIG-14-005

- Previous best limits on $B(H\rightarrow\mu\tau)$ <~ 10% from reinterpretation of LHC $H\rightarrow\tau\tau$ searches and from $\tau\rightarrow\mu\gamma$ arXiv:1209.1397
  - **Can do better with first dedicated search**
- Consider hadronic (τ_h) and electron (τ_e) tau decays
- Same basic event selection and jet categories as SM $H\rightarrow\tau\tau$ analysis (0-jet, 1-jet, VBF-tag)
- Differences in kinematics
  - **Harder muon p_T spectrum**
  - **$\Delta\phi$ between μ, τ_h/τ_e, missing energy vector**

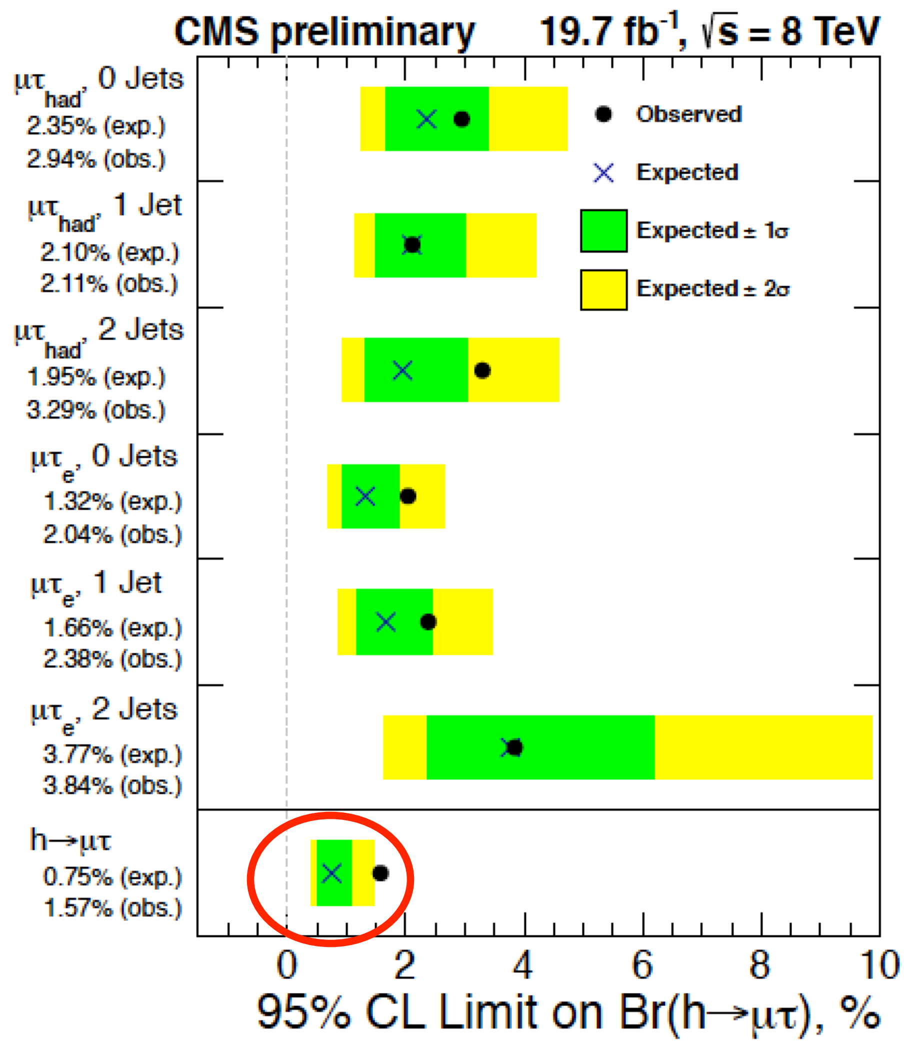


On public demand from our theory friends ☺



Search for LFV Decays: $H \rightarrow \mu\tau$

- Comparable sensitivity from all channels
- Observed limit 1.57% (exp. 0.75%)
- **Large improvement of previous limits**
- **Background-only p-value of 0.007 (2.46σ)**
  - Best-fit $B(H \rightarrow \mu\tau) = 0.89^{+0.40}_{-0.37}\%$

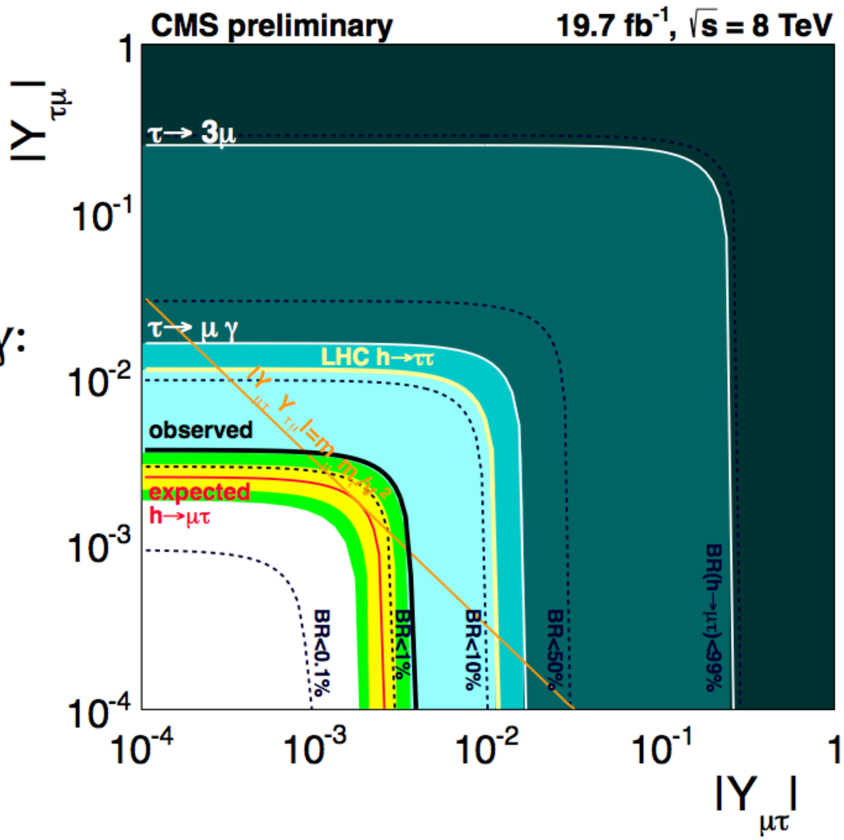


Mild excess giving a 2.5σ effect… To be watched!!!

Search for LFV Decays: H →μτ

Limits on Yukawa couplings

- Translate branching ratio limits to limits on Yukawa couplings
- Previous best limit from τ⟶μγ: $\sqrt{|Y_{\mu\tau}|^2+|Y_{\tau\mu}|^2} < 0.016$
- Observed limit: $\sqrt{|Y_{\mu\tau}|^2+|Y_{\tau\mu}|^2} < 0.0036$
- **Large improvement of previous limits**



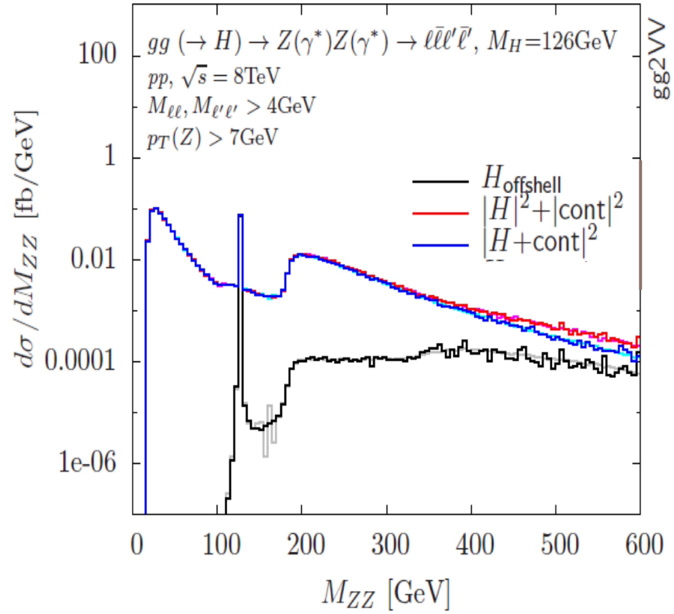
The Total Width of the Higgs

Recent History

arXiv:1405.3455

Direct width limits so far 3.4 GeV in ZZ and 6.9 GeV in two-photon decays (95% CL) from the resonance peak measurement
→Dominated by experimental resolution

- Until recently it seemed unlikely the LHC could measure the total Higgs width (~4.2 MeV in SM)
- In 2012 it was noted that 7.6% of the Higgs to ZZ cross section is above 180 GeV arXiv:1206.4803
- The off-shell contribution is independent of the total width!
- The ratio of on-shell to off-shell can thus provide information on the width
- Interference of the signal with ZZ continuum is important and must be taken into account



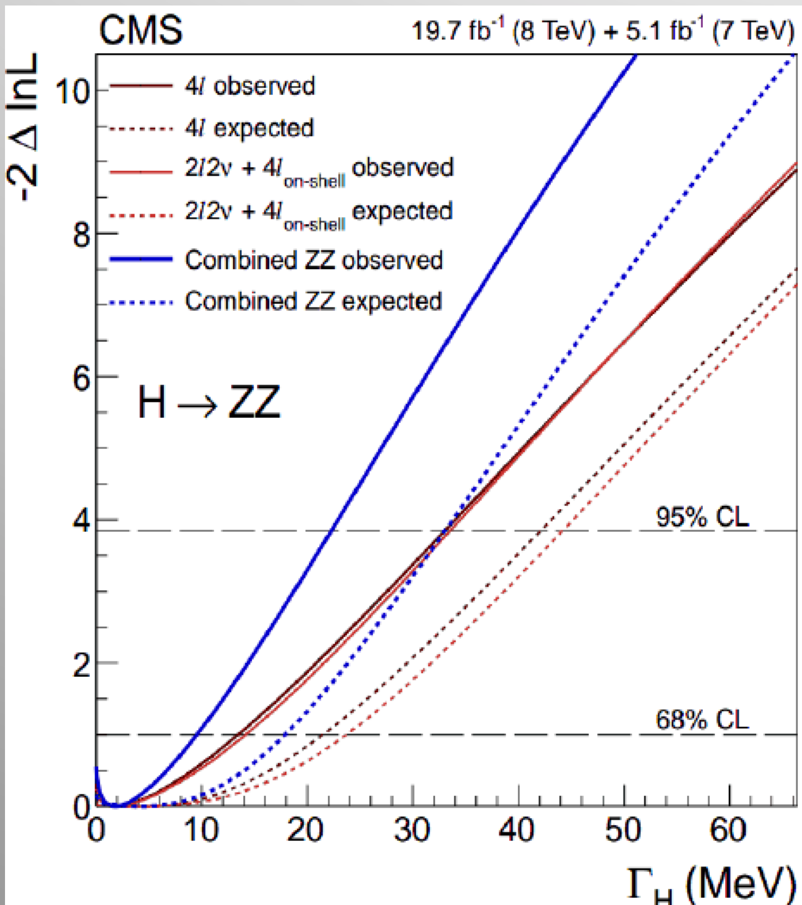
2012/13: Kauer, Passarino; Caola, Melnikov; Campbell, Ellis, Williams …

$$\sigma^{\text{on-peak}}_{gg\to H\to ZZ} \propto \frac{g^2_{ggH}g^2_{HZZ}}{\Gamma_H}, \qquad \sigma^{\text{off-peak}}_{gg\to H\to ZZ} \propto g^2_{ggH}g^2_{HZZ}.$$

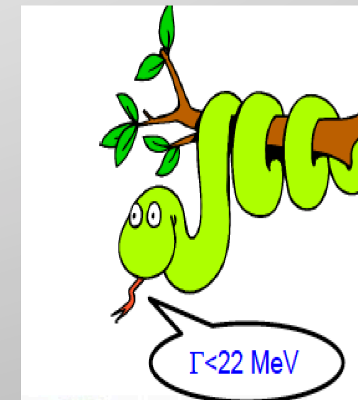
$$r = \Gamma_H/\Gamma_H^{SM}$$

The Total Width of the Higgs

- Study Higgs → ZZ in the 4 charged lepton and 2 charged lepton + 2ν decay
- Determine the total Higgs width in the two channels separately
- Use a kinematic discriminant and m_T distributions to reduce ZZ continuum



- **Reminder : SM predicts :**
  - $\Gamma_H = 4.2$MeV
- **95% C.L. Limits on Γ_H :**
  - Expected : 33MeV
  - Observed : 22MeV
- **Γ_H Measurement :**
  - Expected : $4.2^{+13.5}_{-4.2}$ MeV
  - Observed : $1.8^{+7.7}_{-1.8}$ MeV
- **Combination** improves the individual limits by ~20%
- Compatibility between the observed results and the SM hypothesis lead to a **p-value of 0.24**



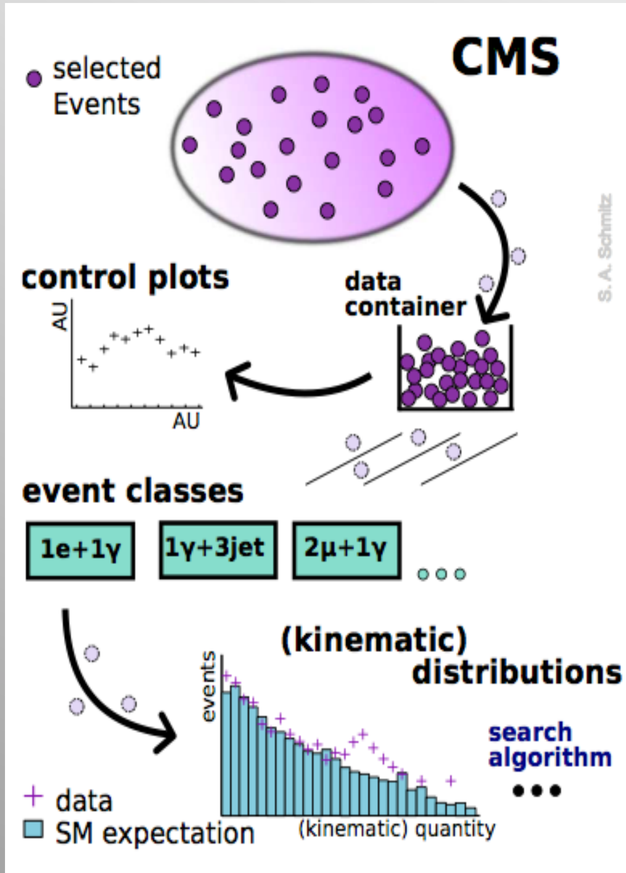
ICHEP: ATLAS!

Γ_H/Γ_{SM}	Observed	Expected μ =1
R_H^B=0.5	4.8	7.0
R_H^B=1	5.7	8.5
R_H^B=2	7.7	12.0

Issue with the Theory??

Finally: a Global View!

CMS-EXO-10-021



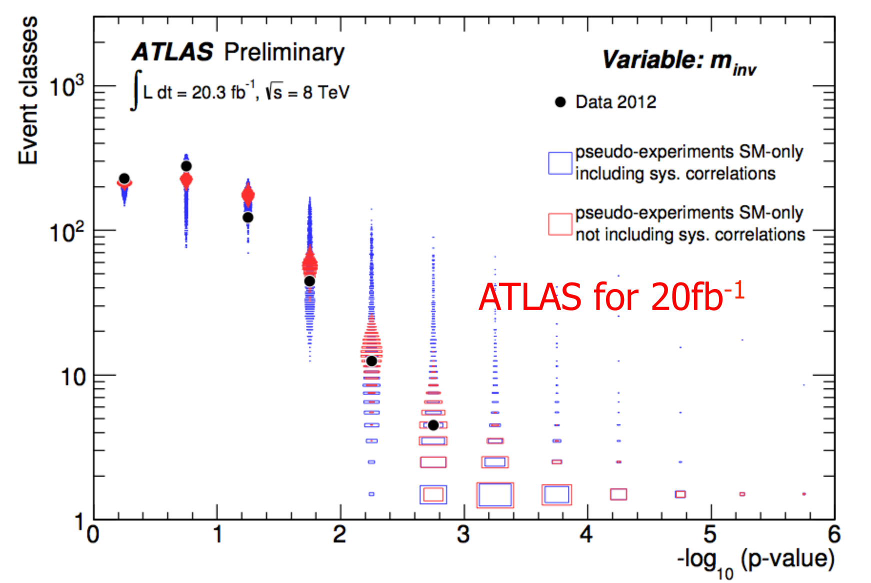
Model independent search

- Divide events into exclusive classes
- Study deviations from SM predictions in a statistical way

Distributions in each class

- $\sum p_T$ - Most general
- $M_{inv}^{(T)}$ - Good for resonances
- MET - Escaping particles

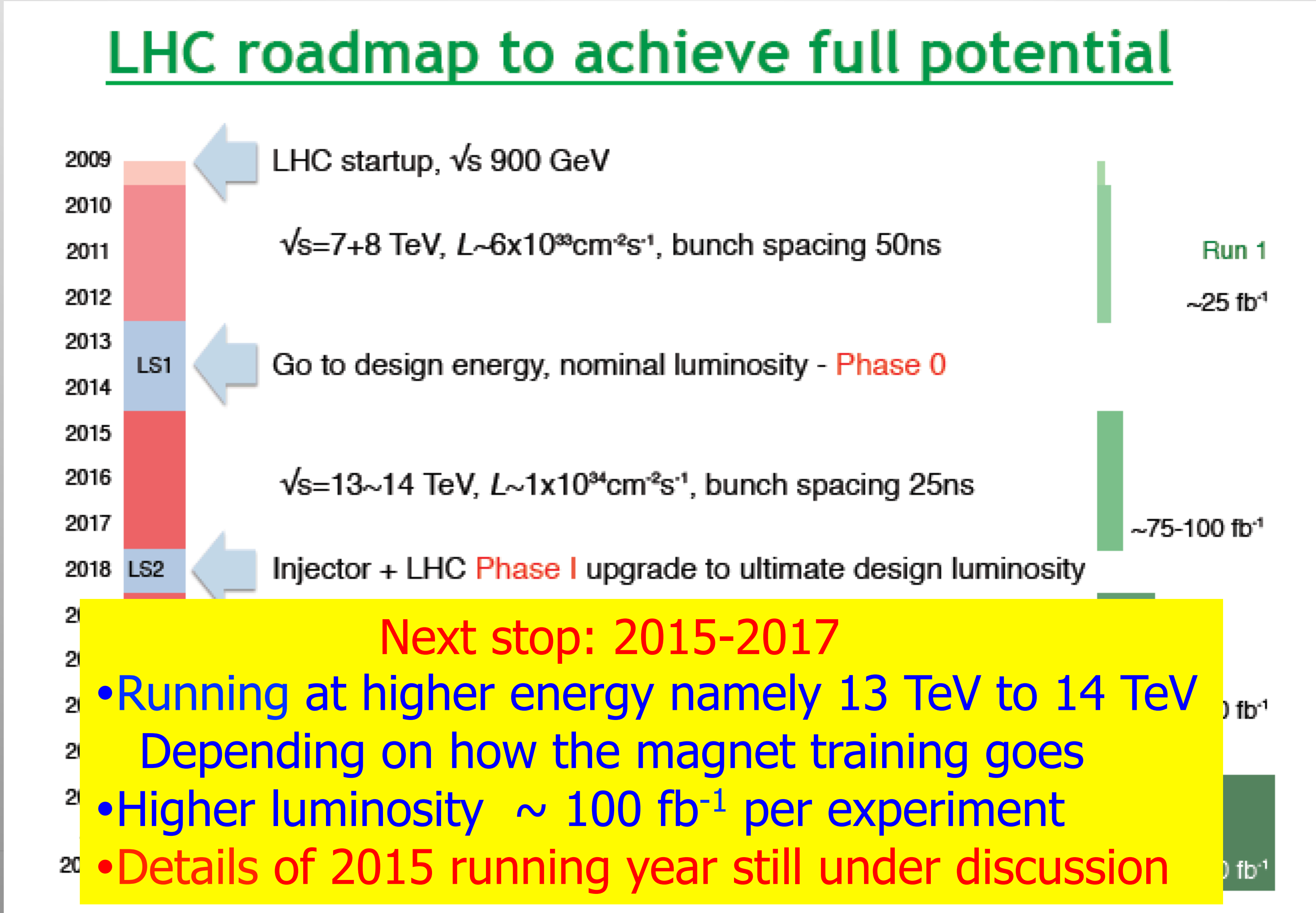
ATLAS-CONF-14-006



Probability distribution as expected for 35 pb^{-1} for CMS

→muons, electrons, photons, (b)jets, MET

The LHC schedule



Next stop: 2015-2017

- Running at higher energy namely 13 TeV to 14 TeV
  Depending on how the magnet training goes
- Higher luminosity ~ 100 fb^{-1} per experiment
- Details of 2015 running year still under discussion

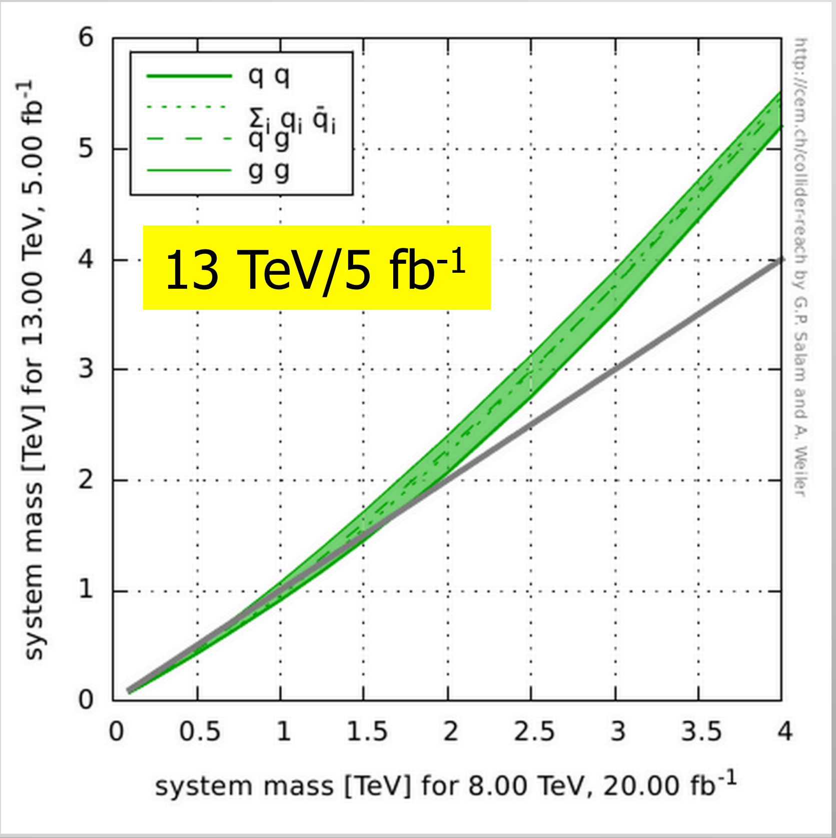
Reach at the Start of Run-II

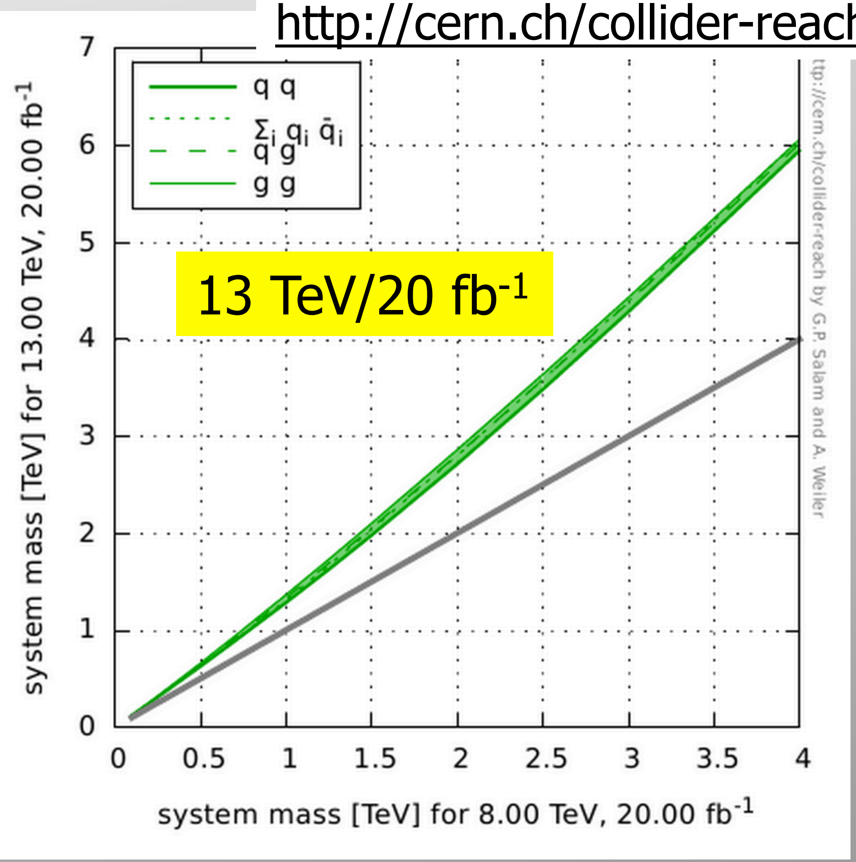
What can we expect in reach at 13 TeV with 5 or 20 fb^{-1}?

- Look at the parton luminosities to predict sensitivity
- Compare reach @8 TeV/20 fb^{-1} with future energy/luminosity

Salam & Weiler

http://cern.ch/collider-reach/

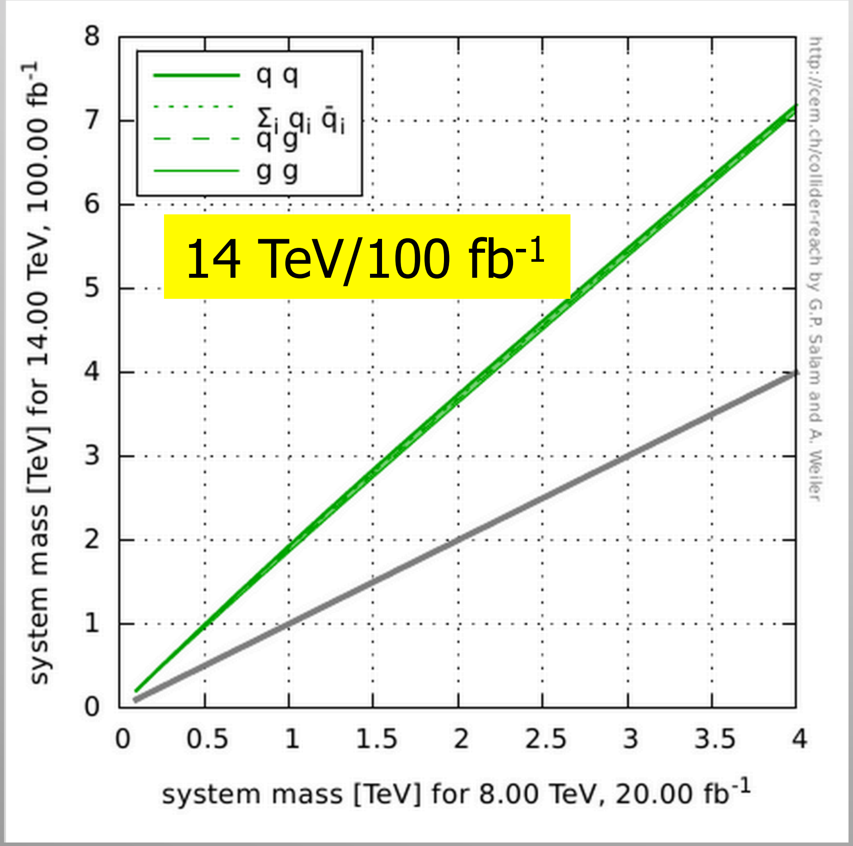


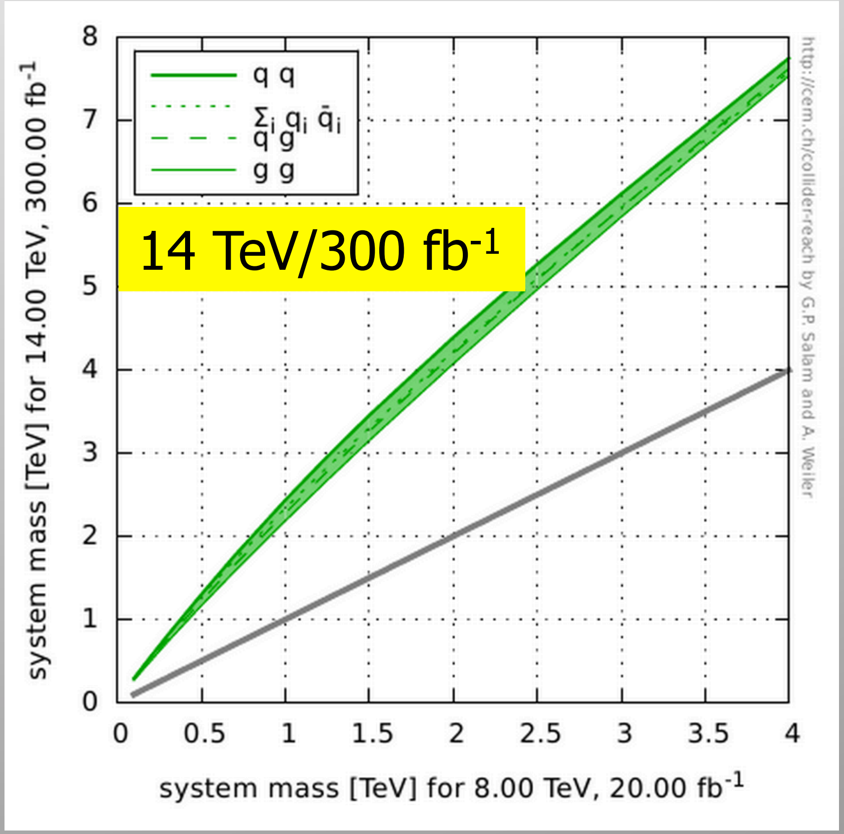


Expect about 20 fb^{-1} in 2015: Expect gain in reach of ~50% at high mass!!

Reach with Run-II

What can we expect in reach at 14 TeV with 100-300 fb^{-1}?
- Look at the parton luminosities to predict sensitivity
- Compare reach @8 TeV/20 fb^{-1} with future energy/luminosity





Phase-I LHC Expect gain in reach of a factor of two at high mass!!

Summary

- There are no striking anomalies in the present ATLAS and CMS data, as seen from the experiments from
  - Searches
  - Precision measurements
  - Higgs properties (so far)
- A number of -not unexpected- 2-3 sigma effects are seen, some of which may be of interest to follow up with the new data or channels: eg WW cross section, Higgs LFV decays…
- Careful theory assessment of the SM predictions very important, as always…
- Next stop: 13 TeV in 2015…   and maybe