

LHC News & Highlights



UCSB/CERN

J. Incandela

Durham, UK

Invisibles13 Workshop

July 15, 2013

Invisibles13 Workshop
Durham, UK

July 15, 2013

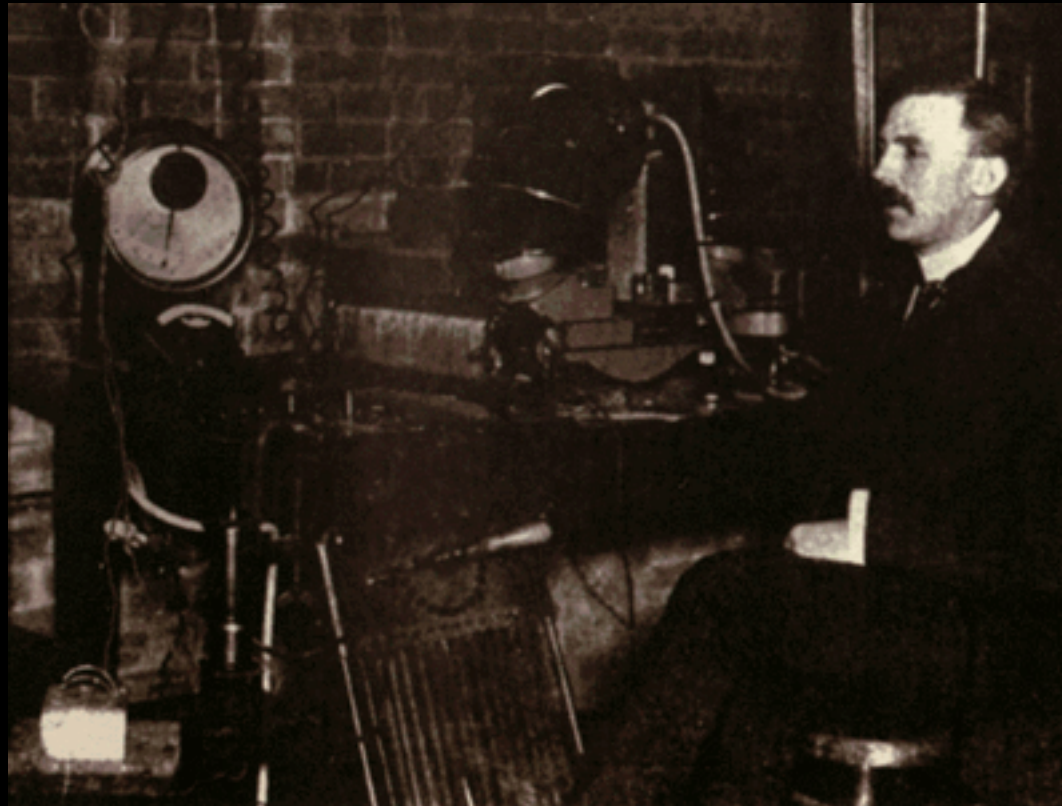
Joe Incandela
Santa Barbara/CERN

June 2013 - photo by
Michael.Hoch@CERN.ch

Major challenges on 5 different fronts

- **Between now and first physics results ca. 2015**
 1. Harvesting full 2011-12 dataset for physics
 2. Lessons learned and Run 2 preparations
 3. LS1 consolidation, early upgrades
 4. Phase 1 Upgrades 2016-19
 5. Phase 2 Upgrades 2022?

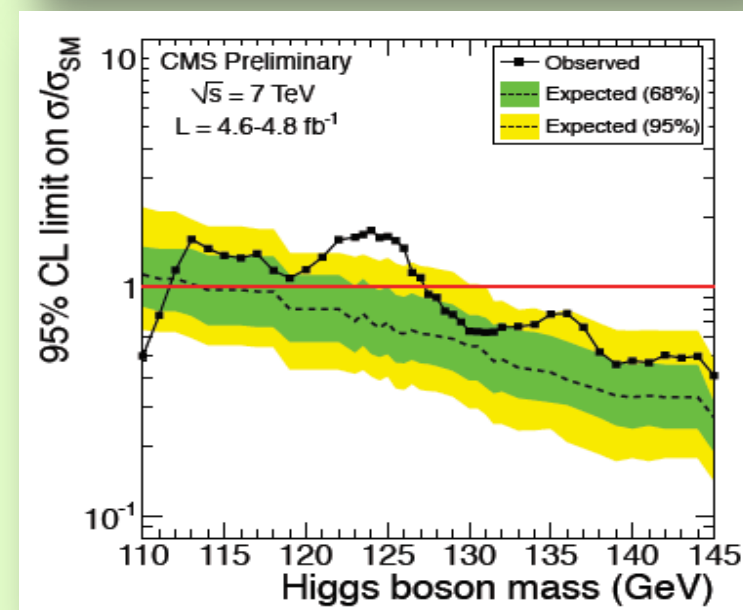
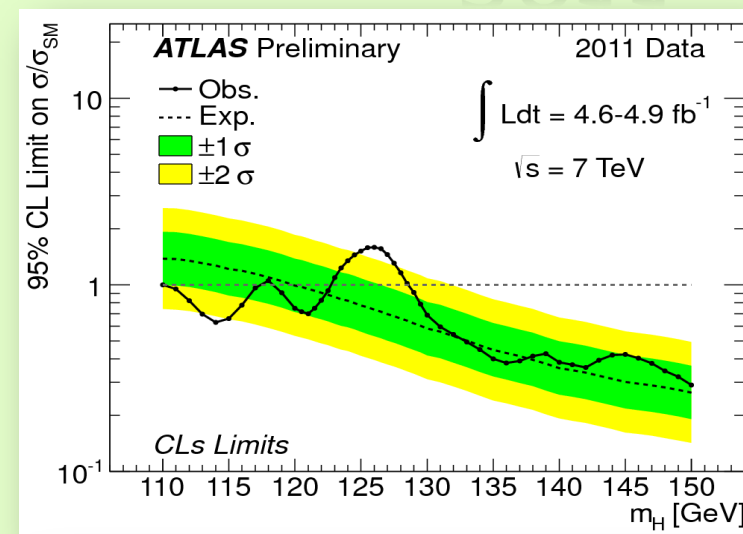
A bit of history...



E. Rutherford ~110 years ago

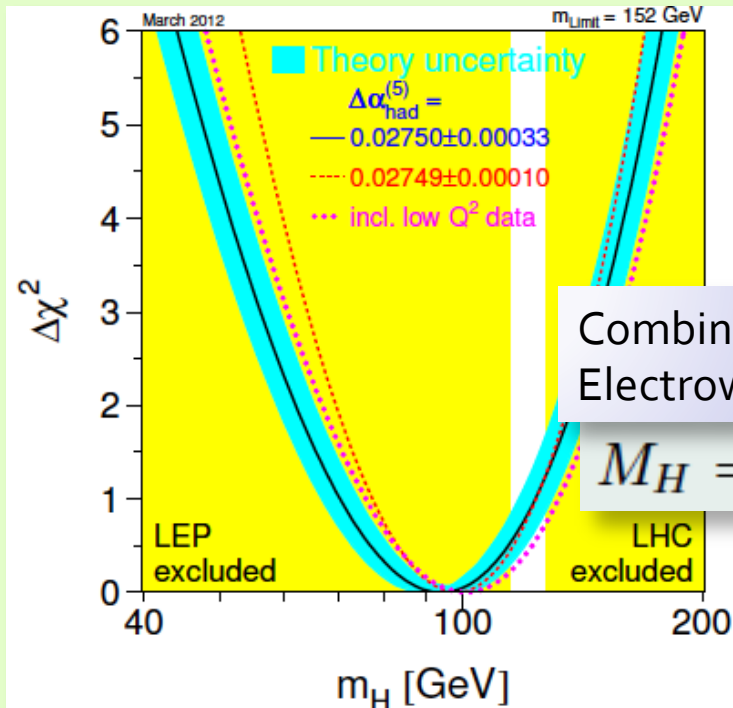
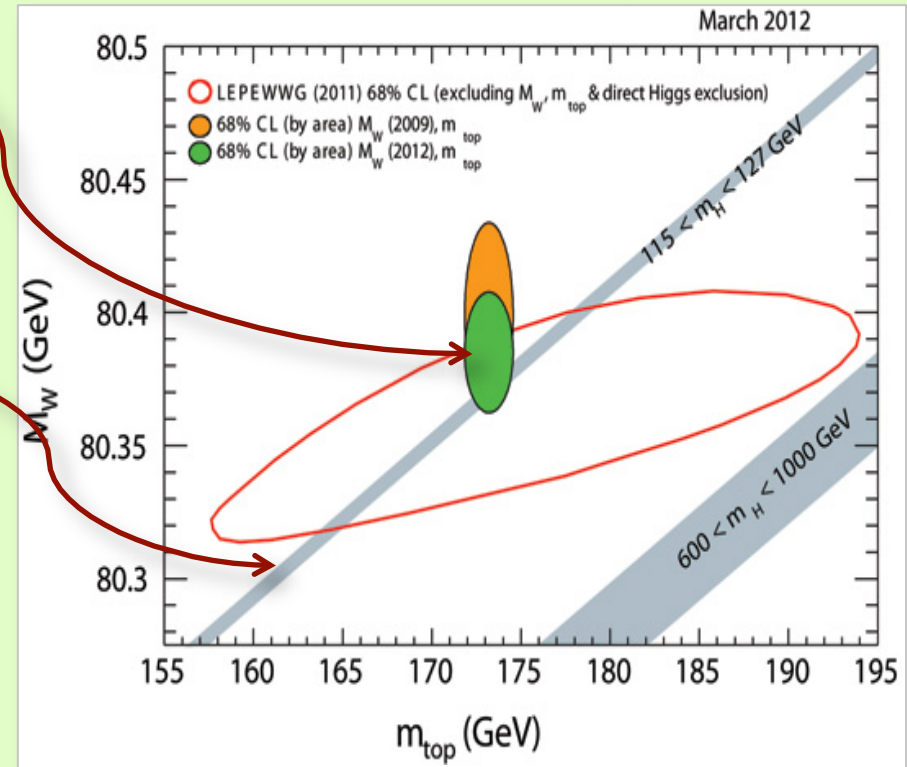
Well, maybe not quite this far back...

- Small excesses at 125 GeV
- Could not celebrate yet...
 - Not unprecedented to have coincidences at low significance
 - $\gamma\gamma$ channel the main contributor
- Critically important steps taken for the 2012 hunt
 - Luminosity increased and collision energy increased (3.5 TeV to 4 TeV)
 - Sensitivity to 110 GeV
 - Extended run by ~2.5 months
 - To characterize it if we found it...
 - 'Blinding' of 2012 data



Based on slide ca.
 May 2012

1. M_{top} vs. M_W
 - Tevatron M_W *Tour de Force!!*
 - $m_W = 80385 \pm 15$ MeV
(World Ave – Mar 2012)
2. Colliders leave little space



This is the main story of 2011

We eliminated >450 GeV of Higgs mass range.



40 reconstructed vertices

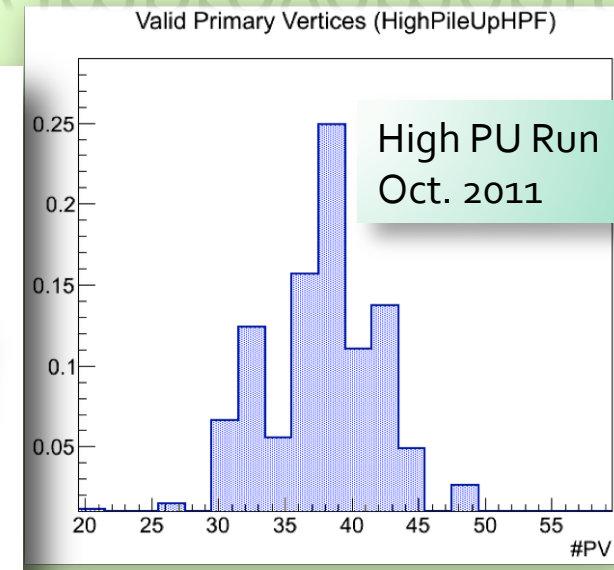
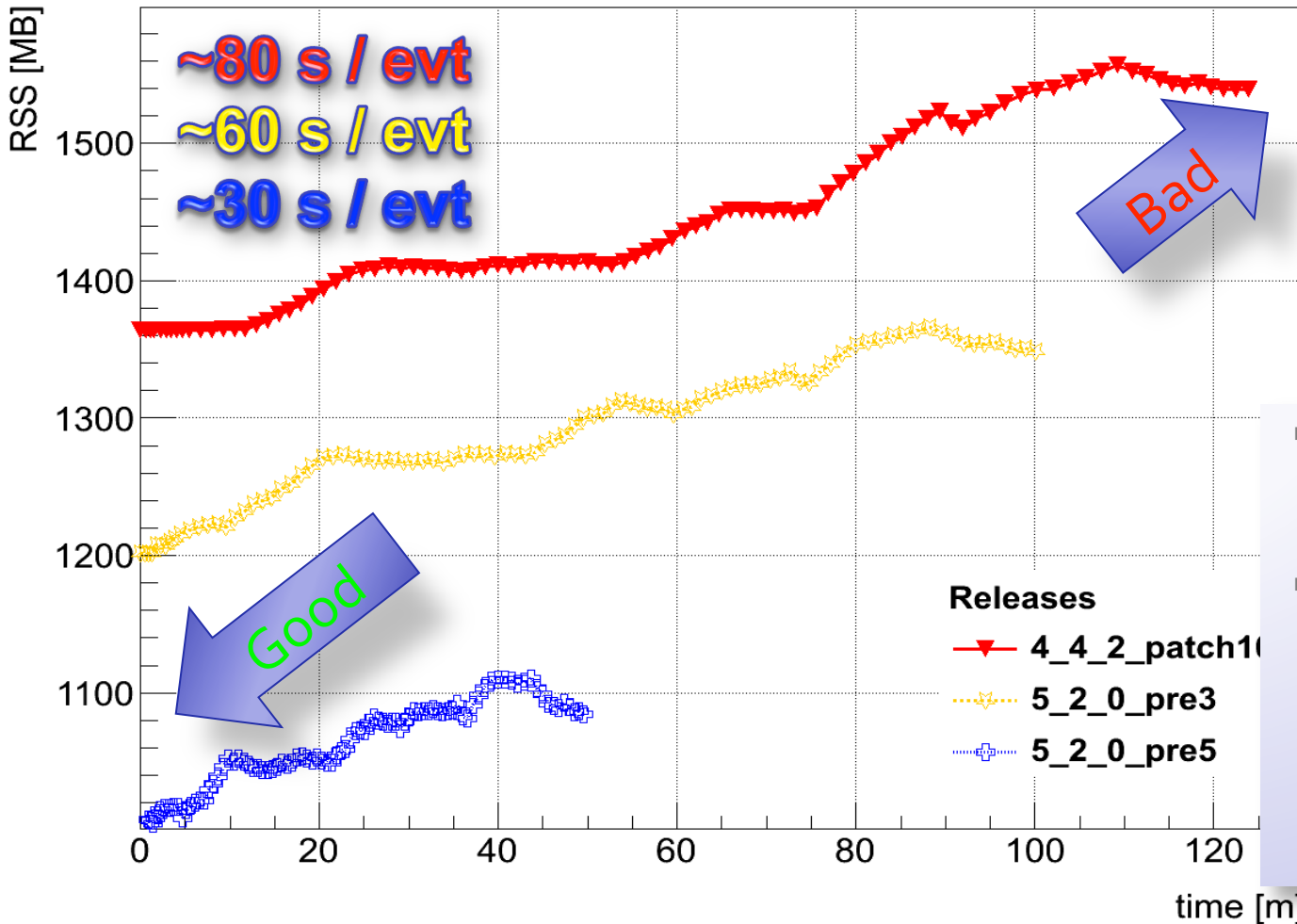
High PU run October 25, 2011

By November we knew that our software would not be able to cope with the luminosities planned for 2012!



Reconstruction Speed/Memory Improvements

Reconstruction: CPU perf - Memory Curves (HighPileUpHPF 100 Evts)



- Technical Improvements
 - Compiler, ROOT, JEMalloc
 - Vectorization, Devirtualization
- Algorithmic (mainly tracking)
 - Seed filtering (extended to pairs) and seed combinations, Merging strategies, Loopers identification, Strip Template & cluster splitting, K2Tree template class

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Losing control: pileup studies Feb 2012

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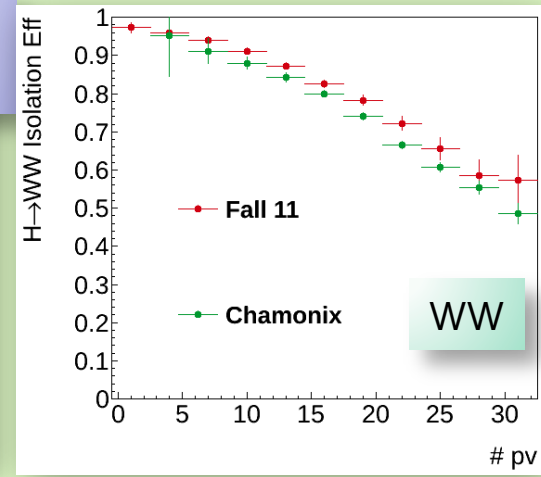
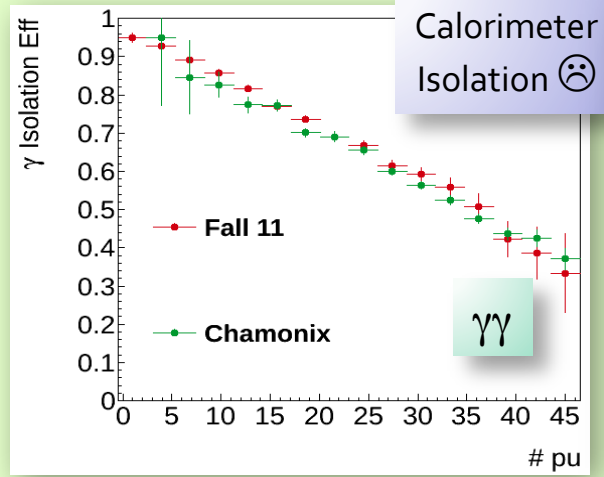
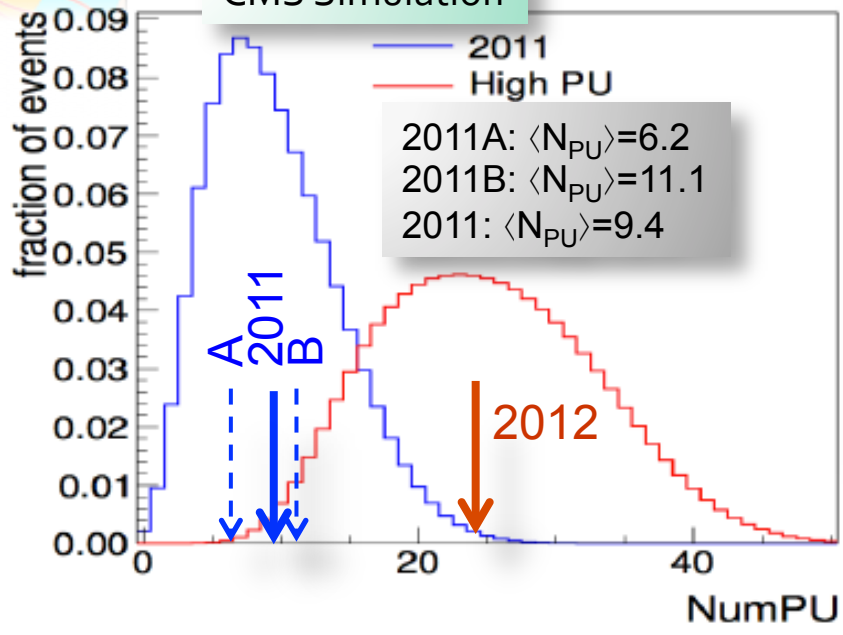
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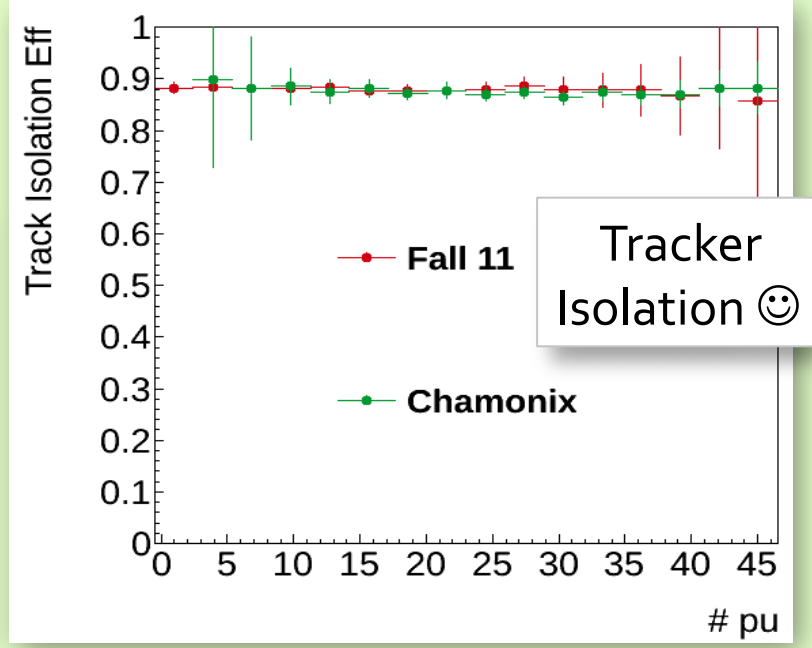
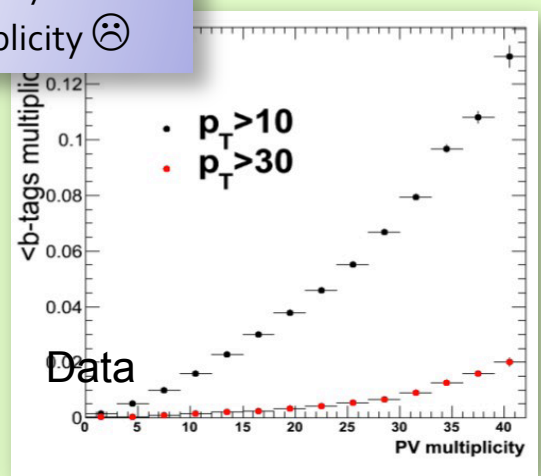
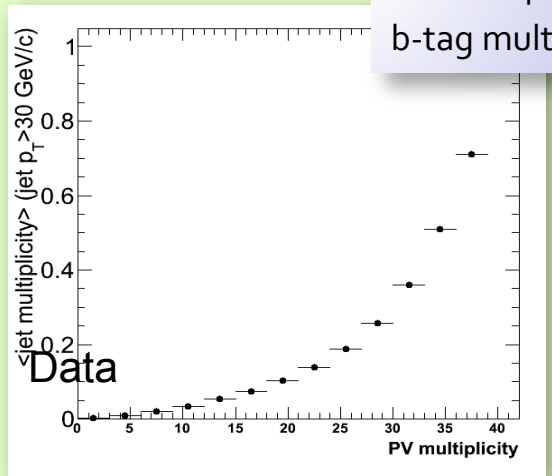
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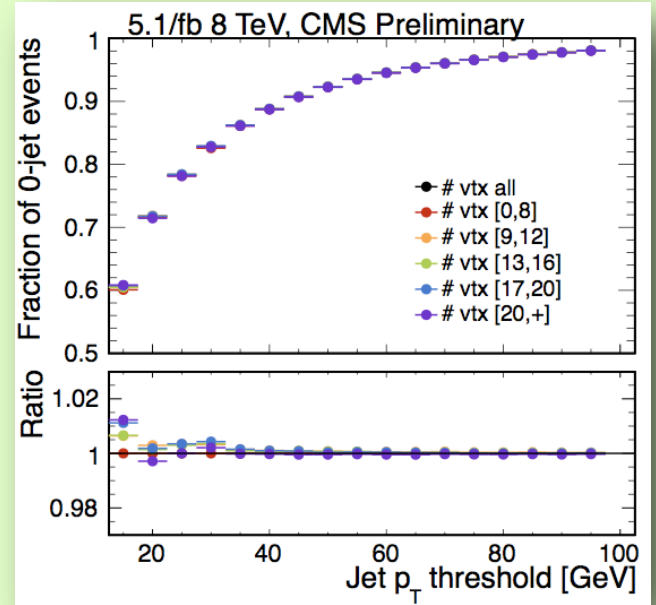
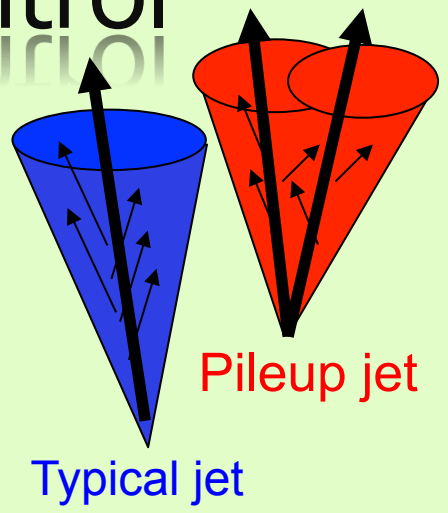
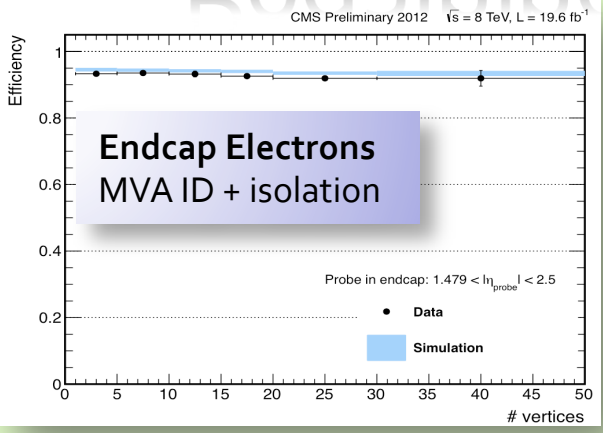
CMS Simulation



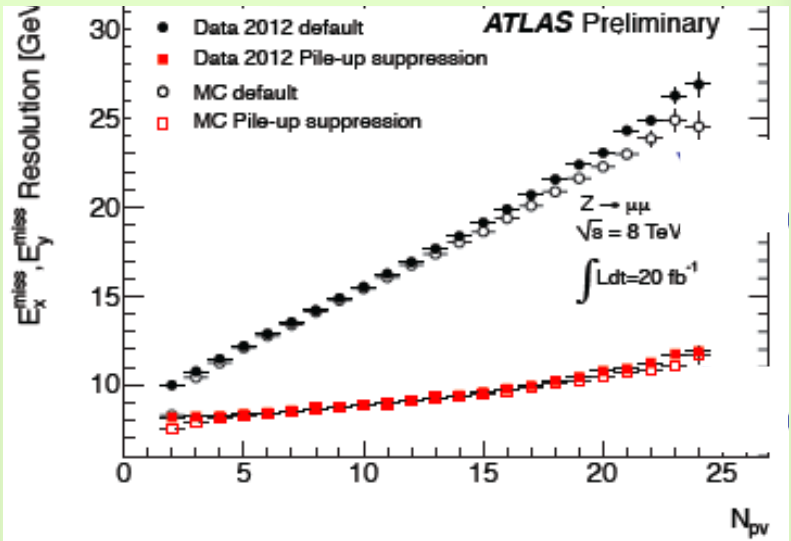
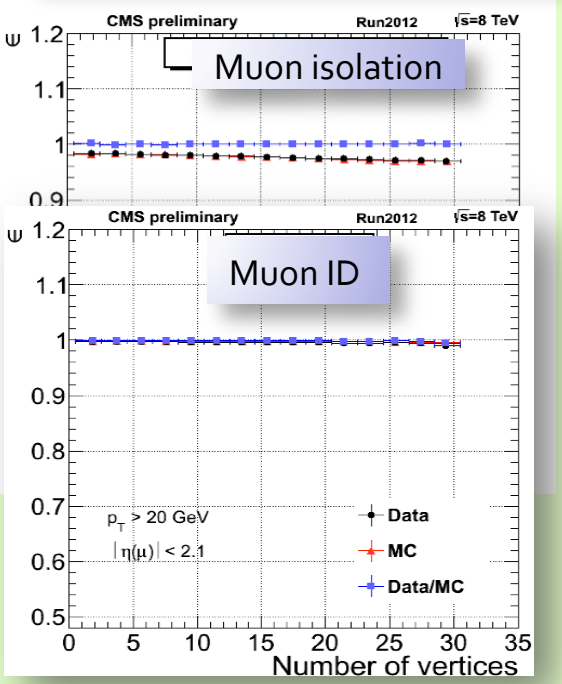
Jet multiplicity
b-tag multiplicity ☹️



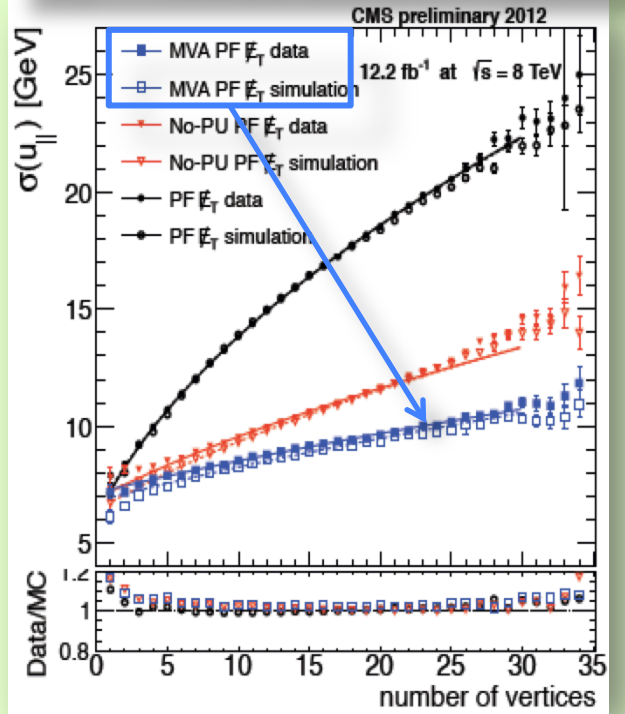
Regaining control



Particle flow, improved ID...



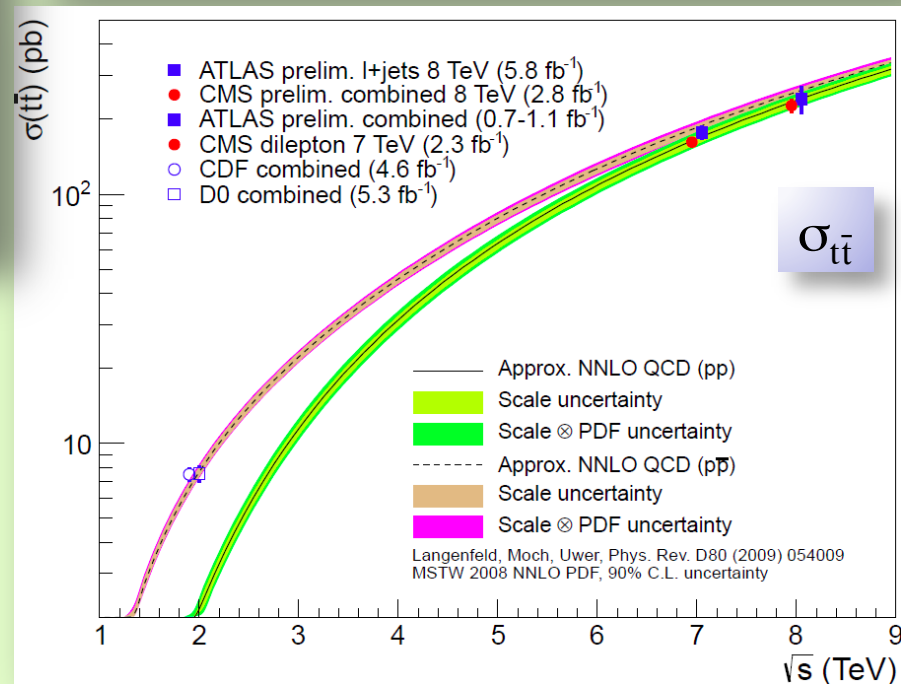
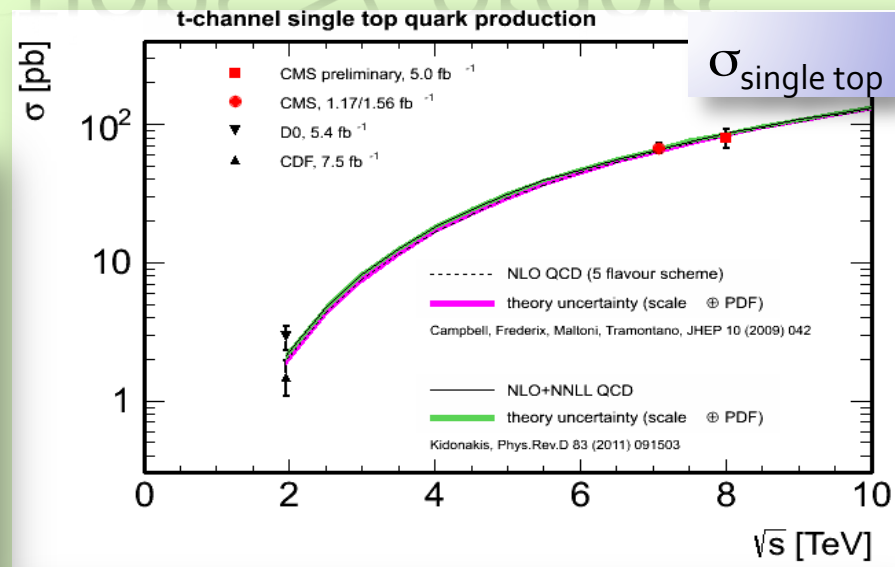
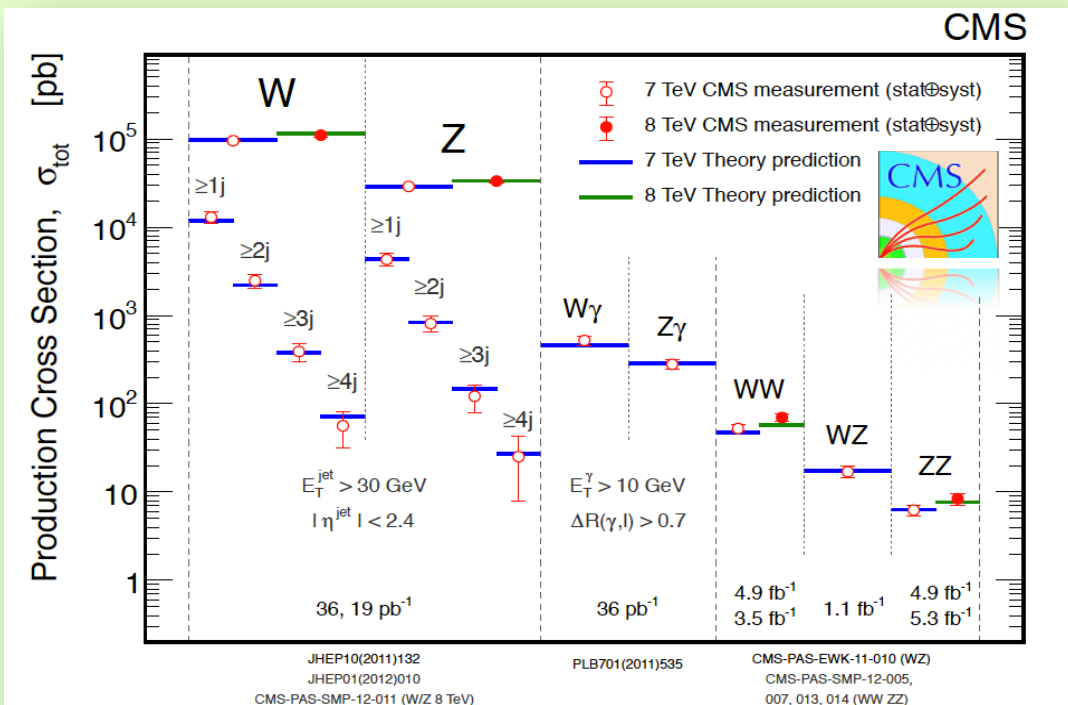
E_T^{miss} : PFlow and MVA regression



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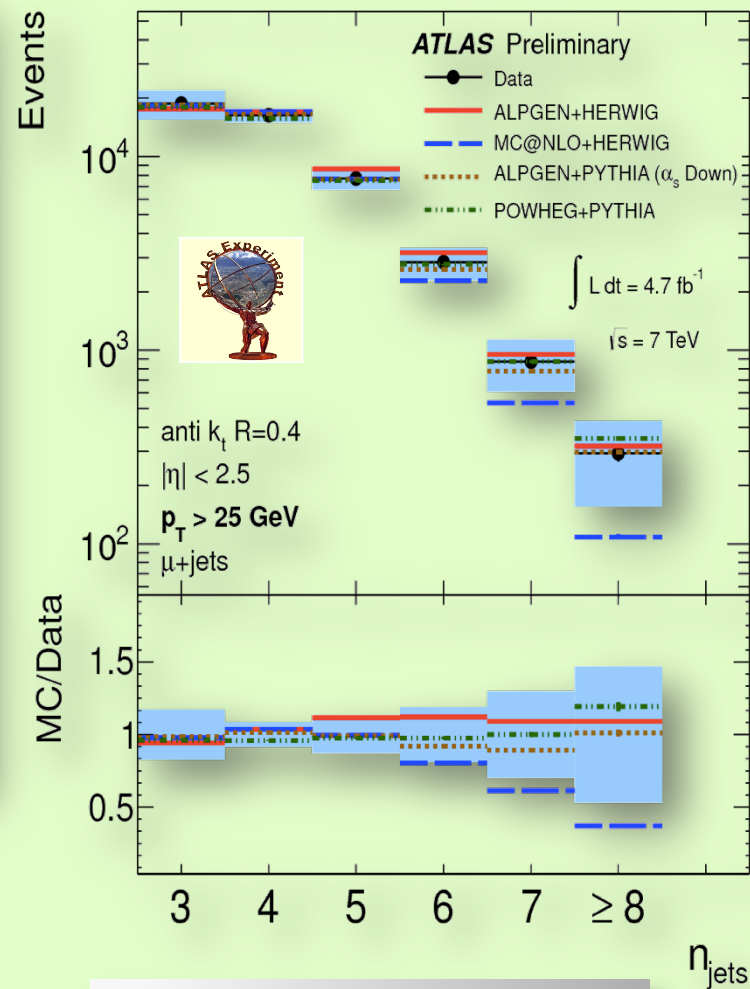
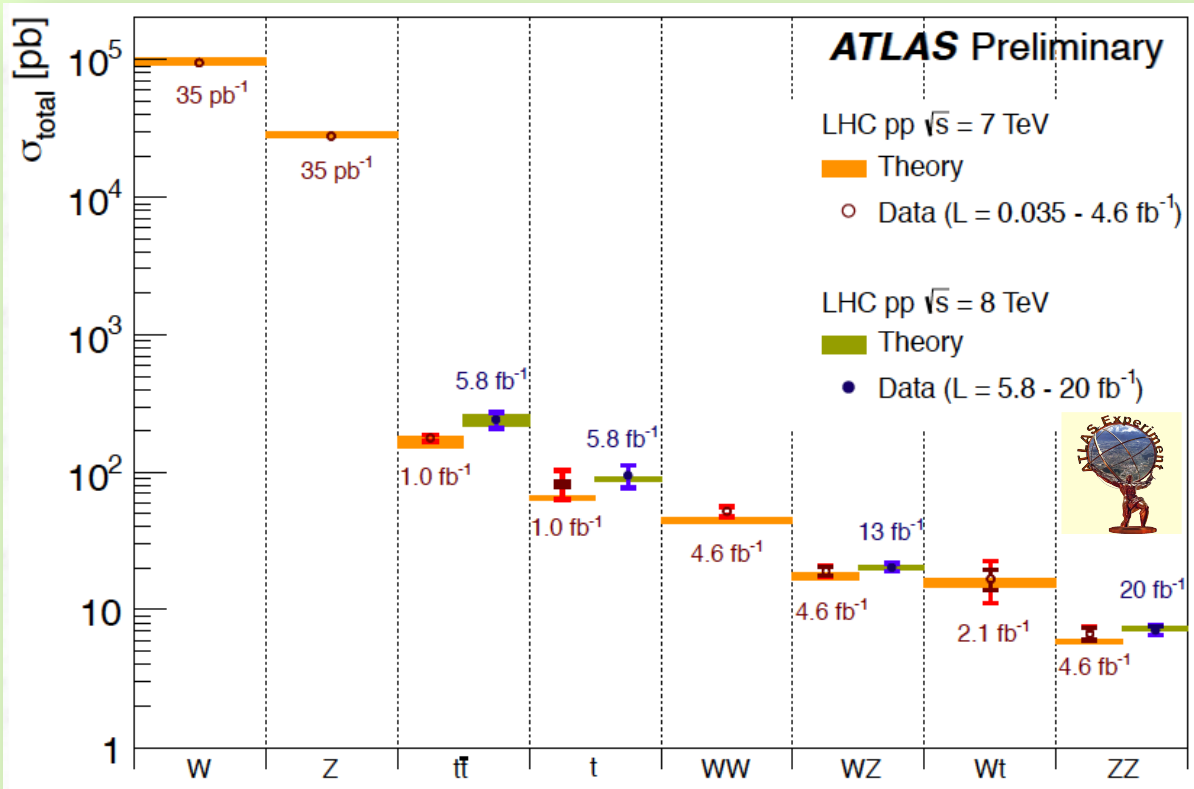
EWK and Top cross sections >4 orders

Electroweak Measurements



Good understanding of the detector
+ accurate theory predictions
→ Precision SM measurements
→ Excellent control of backgrounds

Differential cross sections, precision measurements



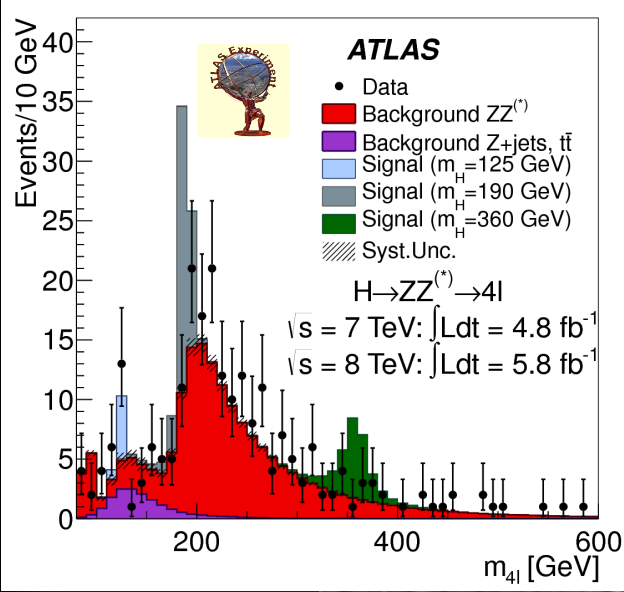
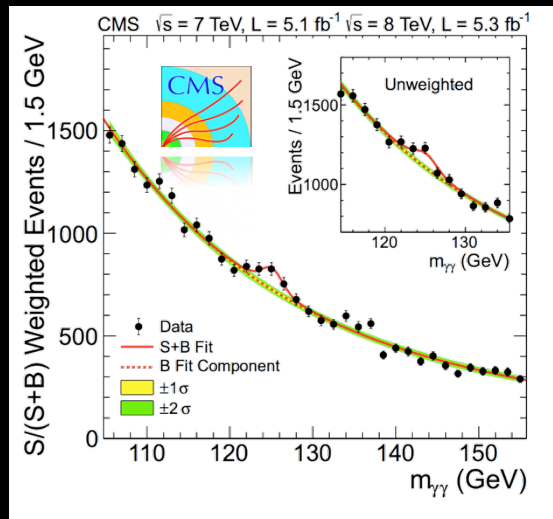
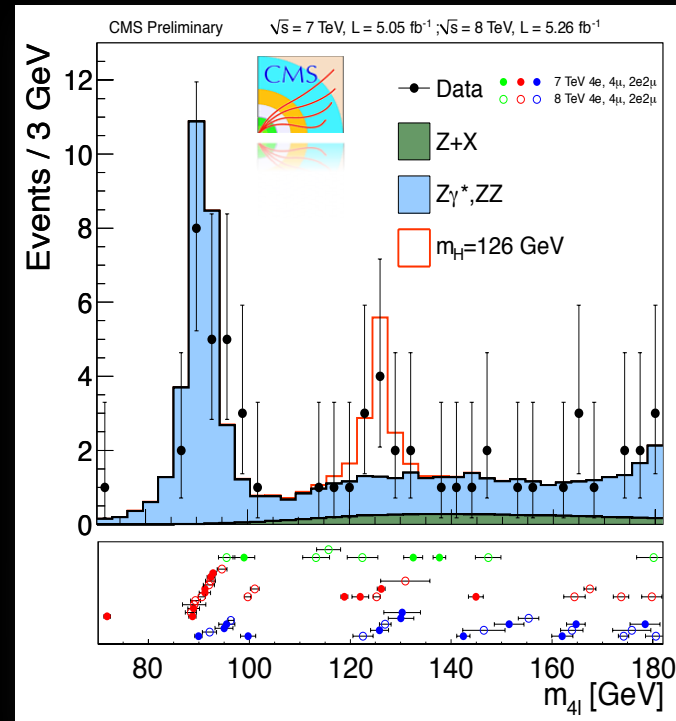
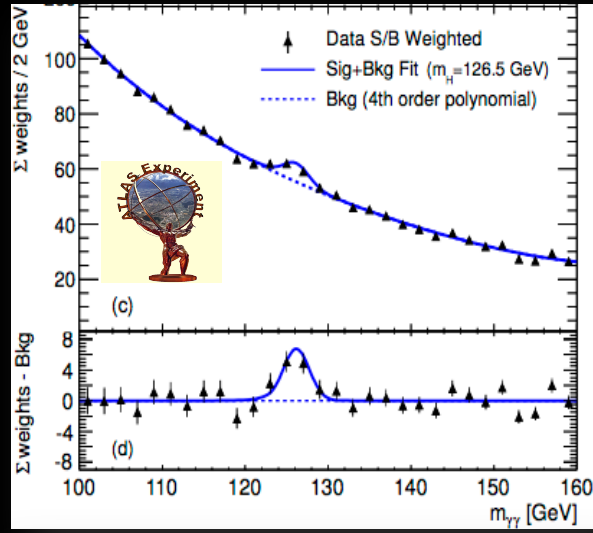
Constrain/tune/test generators and shower matching MCs

Top Mass Measurements

Tevatron Combo	173.2 ± 0.87
CMS Combo (2011)	$173.2 \pm 0.6 \pm 0.8$
ATLAS L+jets (2011)	$172.31 \pm 0.23 \pm 0.27$ (JES) ± 0.67 (bJES) ± 1.35

→ July 4th 2012

'Higgs-like' particle found



The
Economist

JULY 7TH-13TH 2012

Economist.com

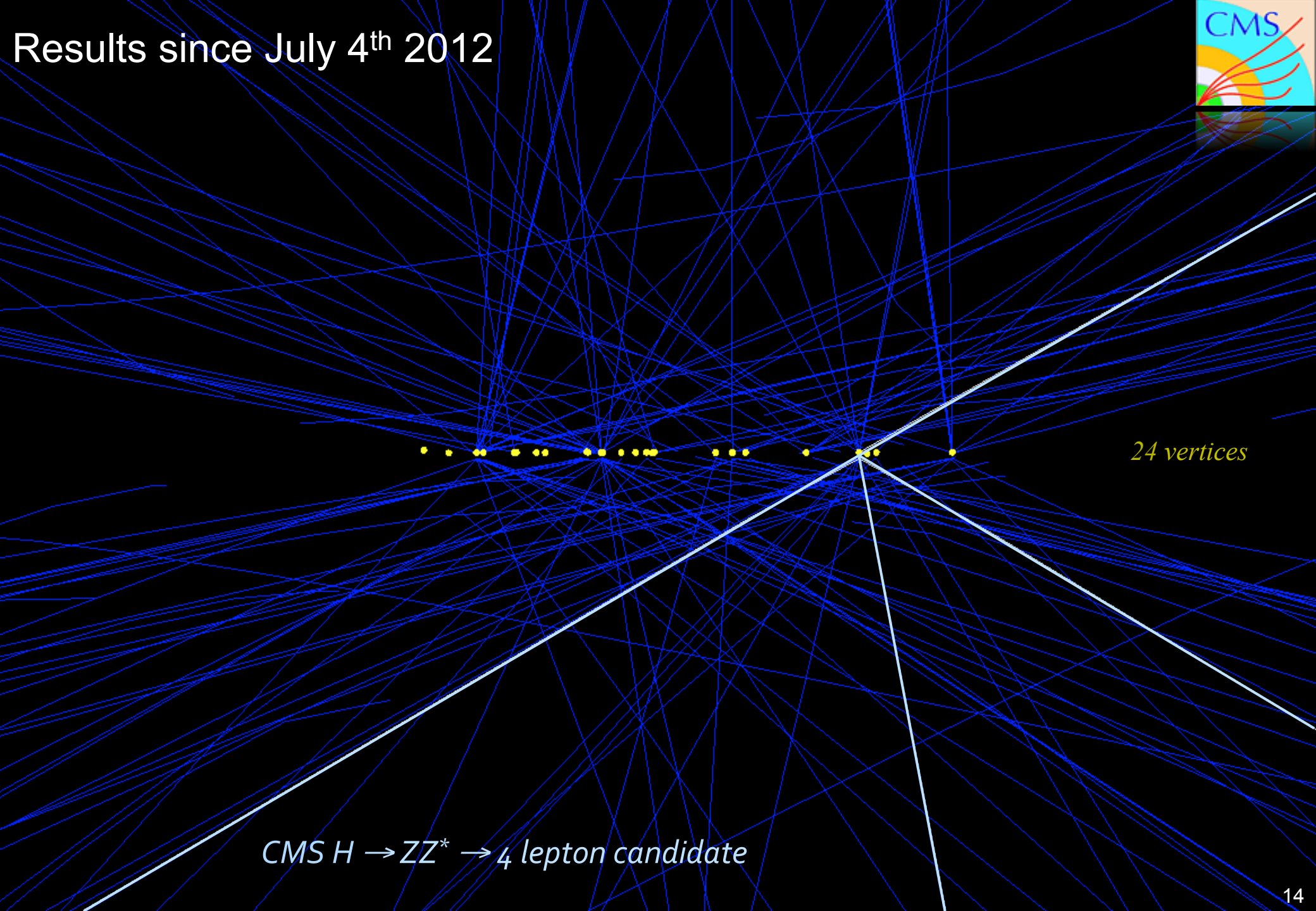
In praise of charter schools
Britain's banking scandal spreads
Volkswagen overtakes the rest
A power struggle at the Vatican
When Lonesome George met Nora

A giant leap for science

Finding the Higgs boson



Results since July 4th 2012

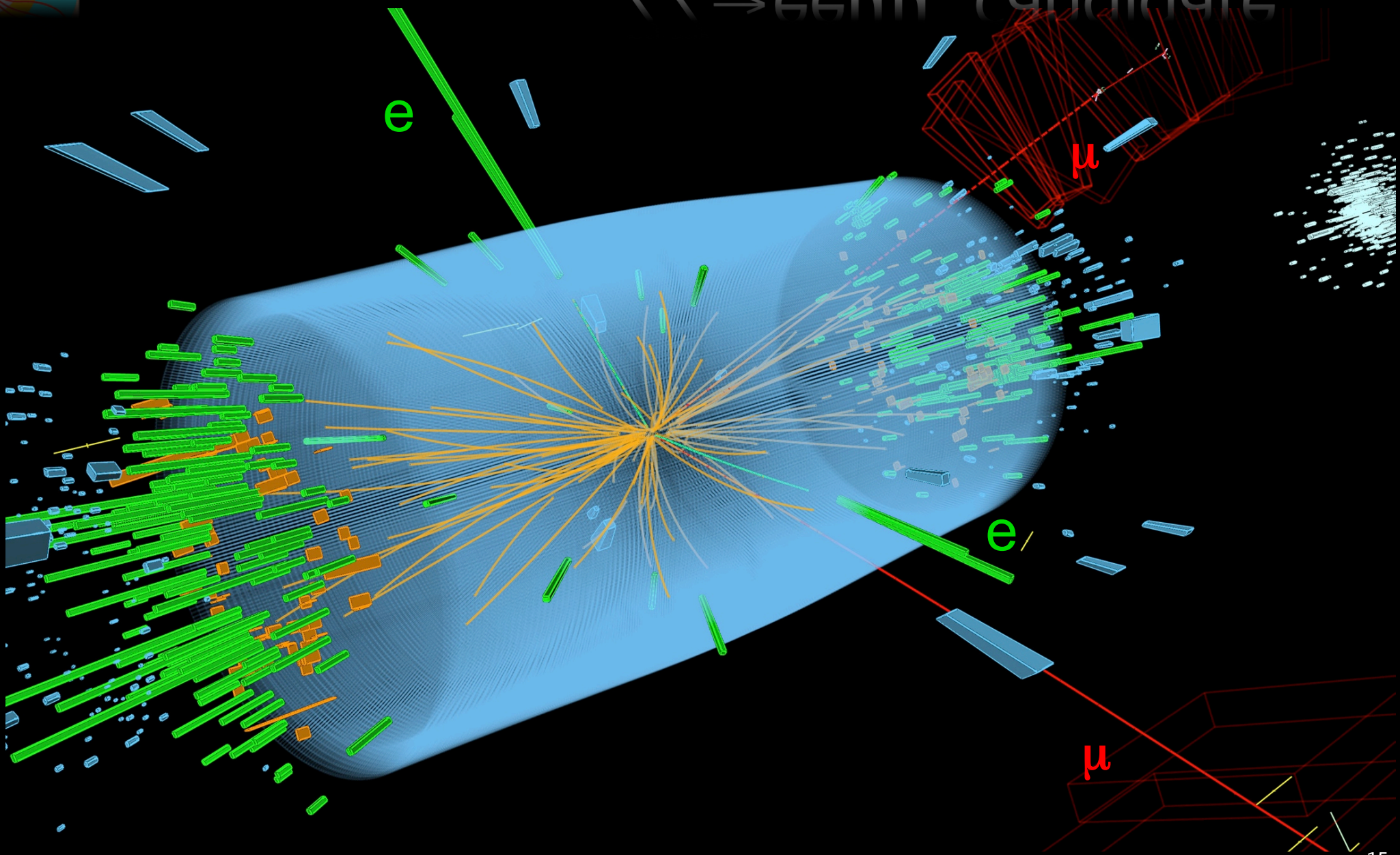


24 vertices

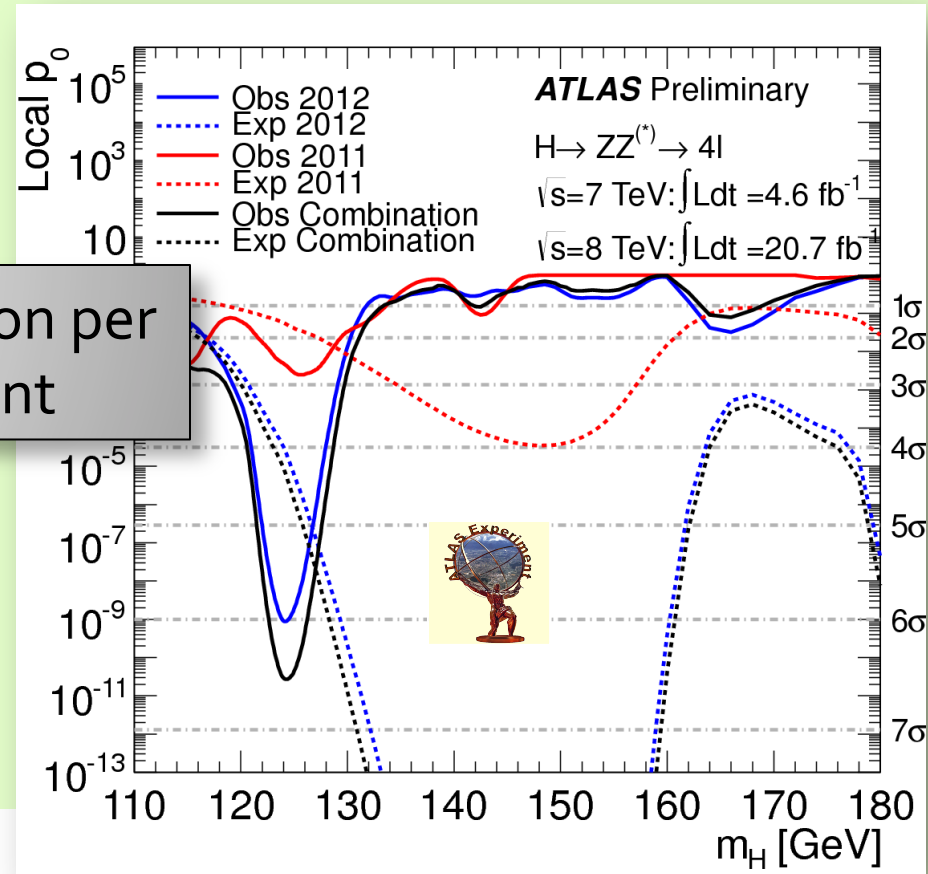
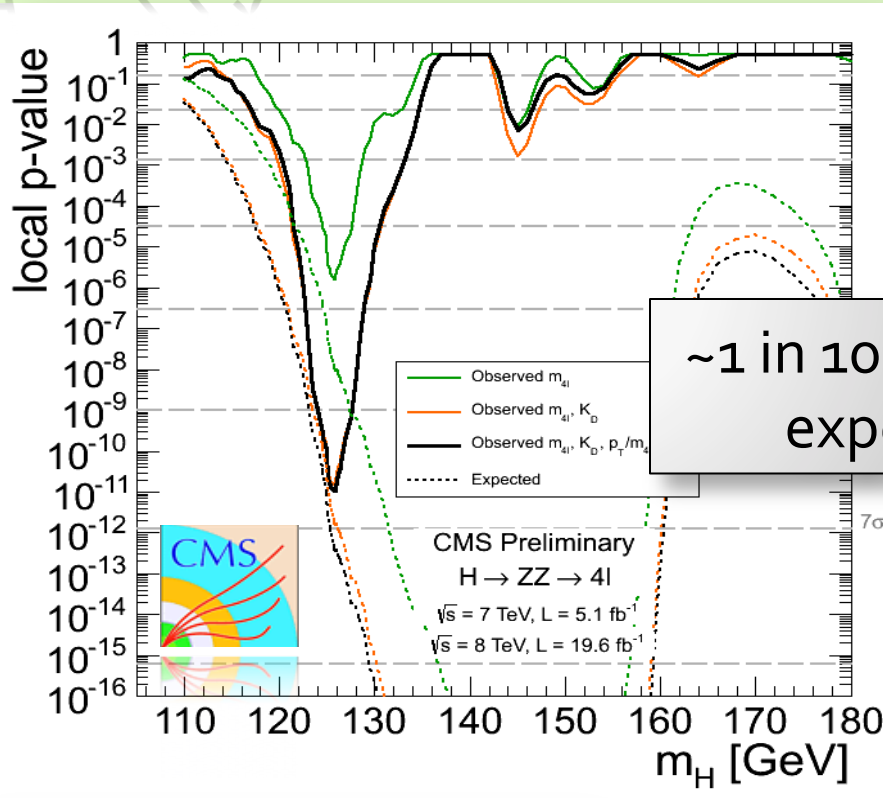
CMS $H \rightarrow ZZ^ \rightarrow 4$ lepton candidate*



$ZZ \rightarrow ee\mu\mu$ candidate



$H \rightarrow ZZ^* \rightarrow 4 \text{ leptons}$



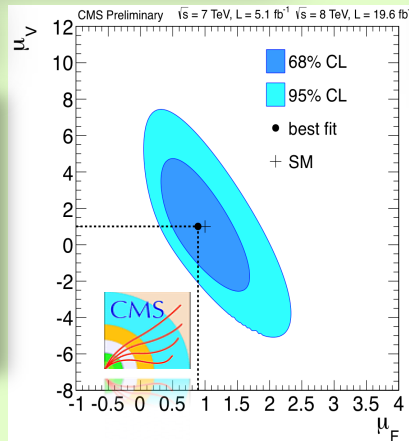
$125.8 \pm 0.5(\text{stat.}) \pm 0.2(\text{syst.})$

6.7σ (7.1σ expected)

Signal strength relative to the Standard Model:

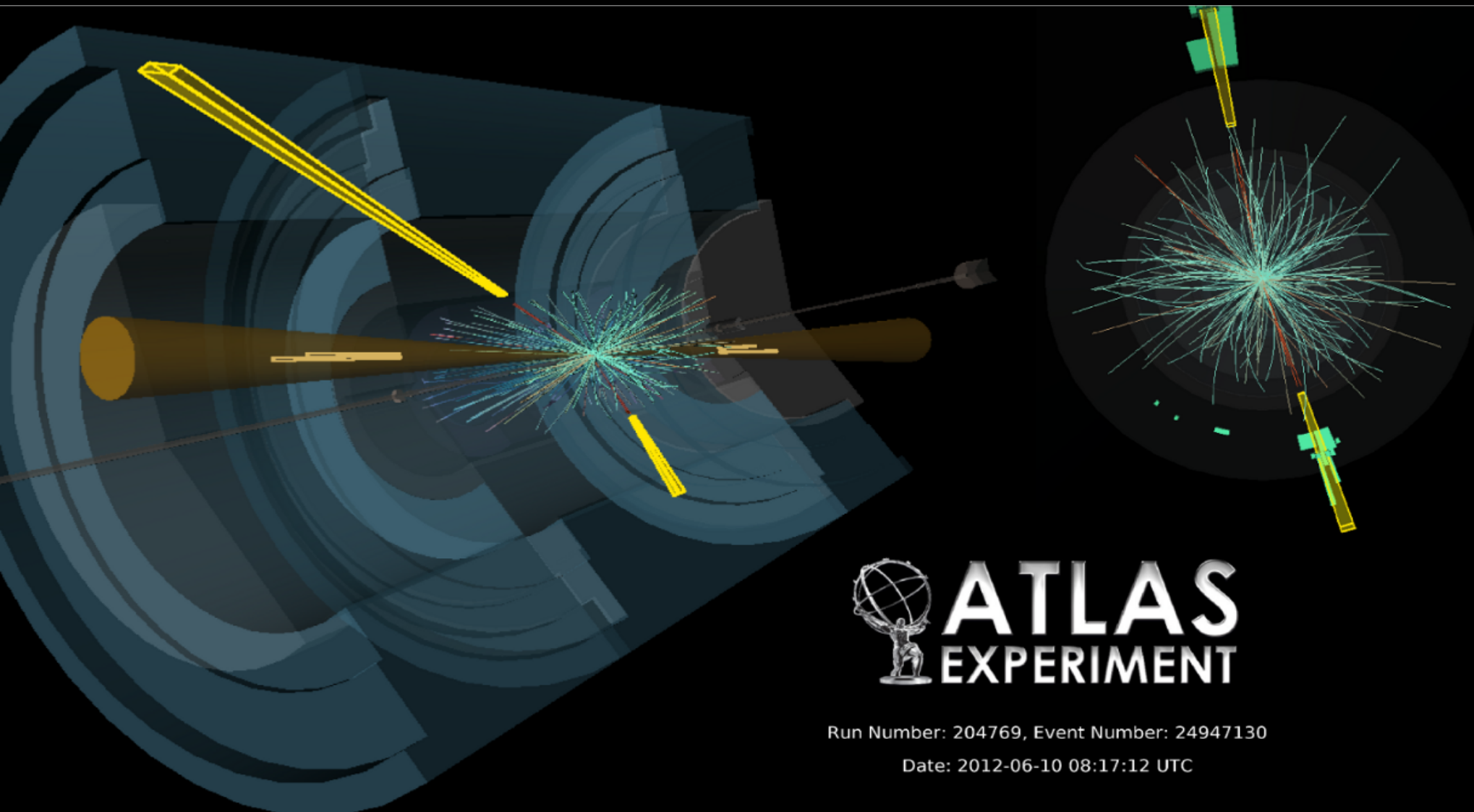
$\mu = 0.92 \pm 0.28$

[CMS HIG-13-002](#)



6.6σ at 124.3 GeV (expect 4.4σ)
 $m_H = 124.3 \pm 0.6 \pm 0.5 \pm 0.3 \text{ GeV}$
 $\mu = 1.7 \pm 0.5 \pm 0.4$

ATLAS-CONF-2013-013

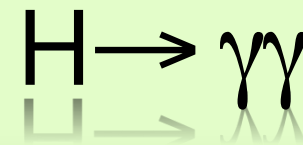


 **ATLAS**
EXPERIMENT

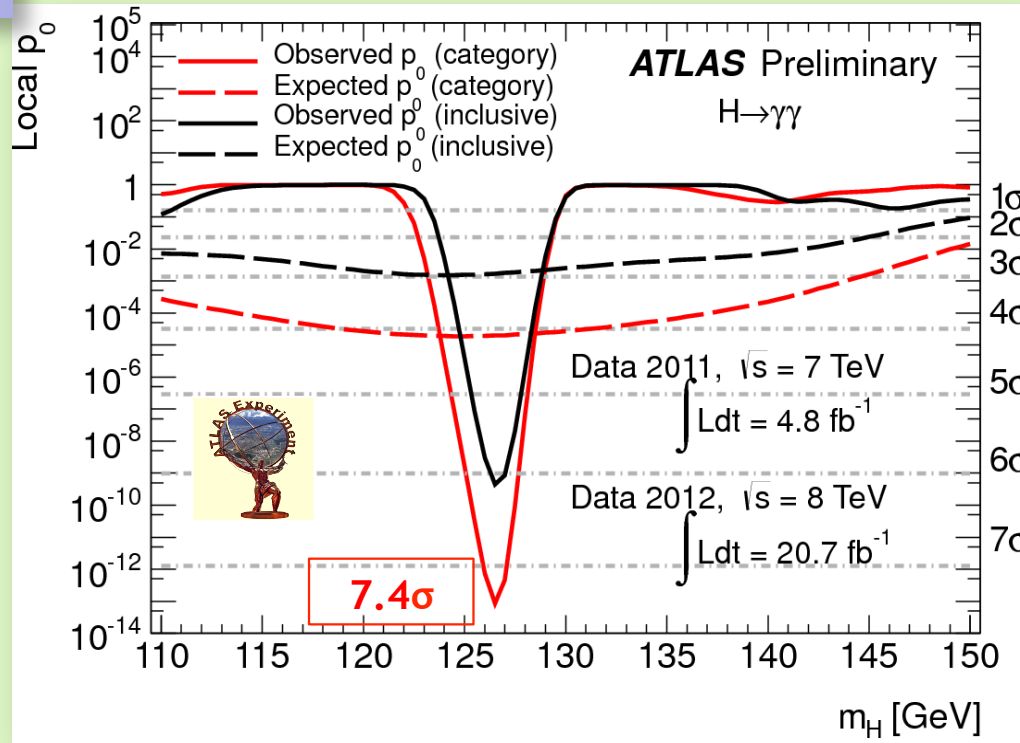
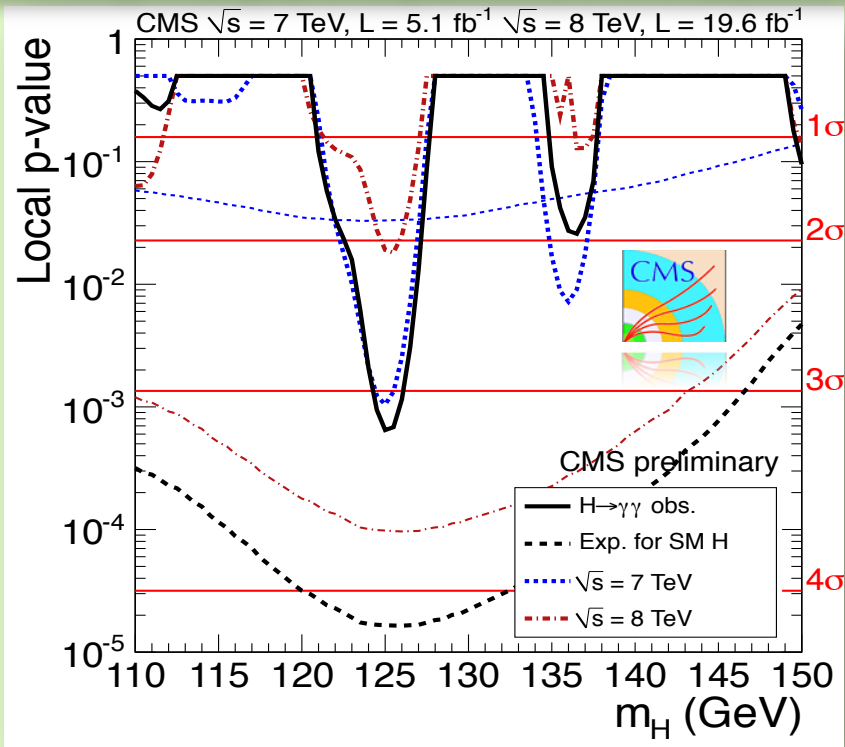
Run Number: 204769, Event Number: 24947130

Date: 2012-06-10 08:17:12 UTC

**$H \rightarrow \gamma\gamma$ candidate: Vector Boson Fusion (VBF) category
(2 jets in forward-backward regions)**



CMS 3.2σ (expect 4.2σ)
 $m_H = 125.4 \pm 0.5$ (stat.) ± 0.6 (syst.)



With additional data, the significance decreased relative to 4th of July!!

$m_H = 125.4 \pm 0.5$ (stat.) ± 0.6 (syst.)

CMS HIG-13-001

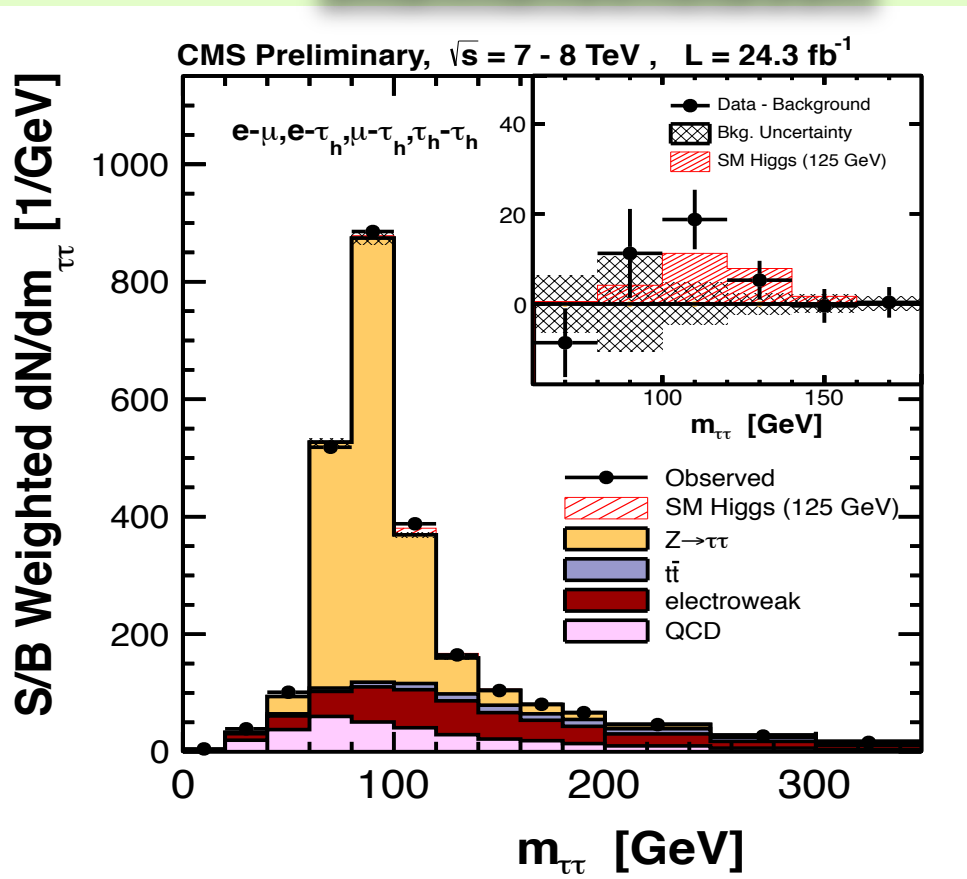
7.4σ (expect 4.1σ) 2.3σ from $\mu=1$
 $m_H = 126.8 \pm 0.2$ (stat) ± 0.7 (syst) GeV
 $\mu = 1.65 \pm 0.24$ (stat) $\pm^{0.25}_{0.18}$ (syst)

ATLAS-CONF-2013-021

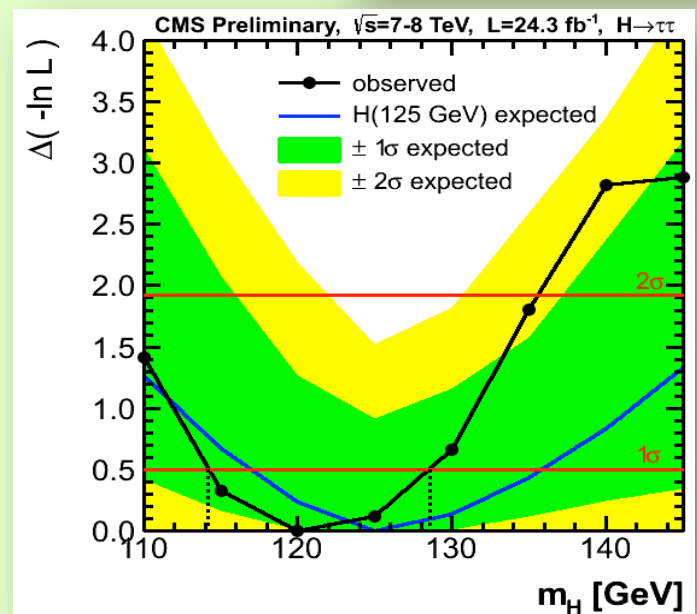
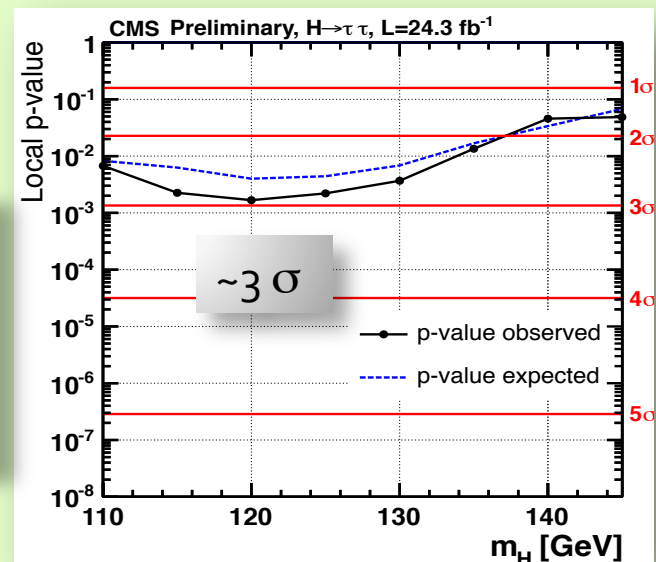
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$$H \rightarrow \tau\tau$$

$\mu\tau_{hr}, e\tau_{hr}, e\mu, \tau_h\tau_{hr}, \mu\mu$



First strong indication of decay to spin $1/2$ particles



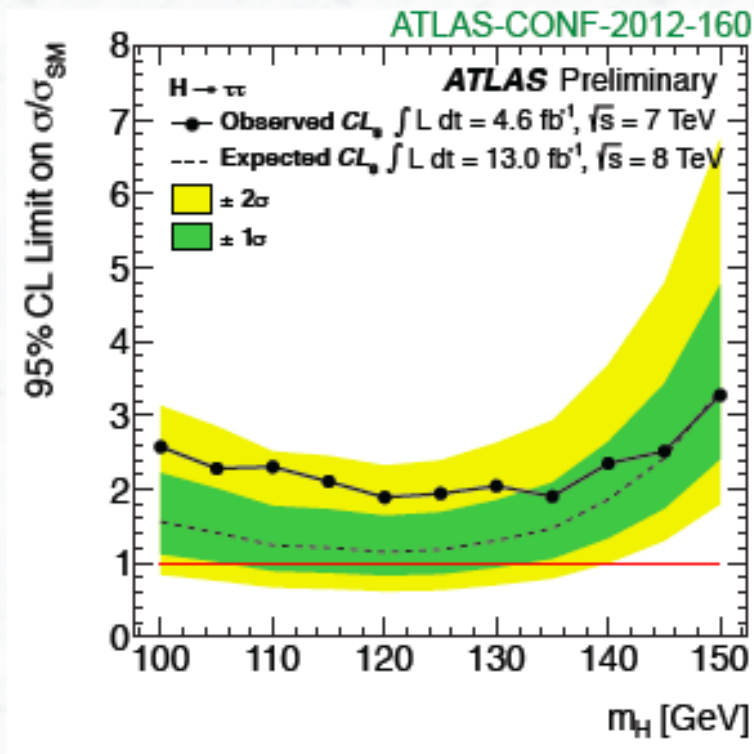
[CMS HIG-13-004](#)

$m = 120^{+9}_{-7} \text{ (stat+syst) GeV}$



Results on the search for $H \rightarrow \tau\tau$ decays

- Discovery sensitivity for a signal not yet reached
- \rightarrow 95% C.L. limits on cross section (normalized to SM cross sections)



$m_H = 125 \text{ GeV}$:

Observed 95% CL: $1.9 \sigma_{SM}$
Expected (no Higgs): $1.2 \sigma_{SM}$

Fitted signal strength
(all sub-channels):

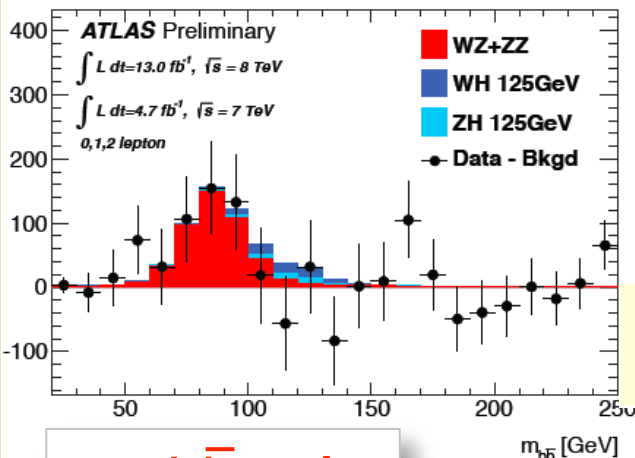
$$\mu = 0.7 \pm 0.7$$

Updated analysis, including the full data sample, expected soon

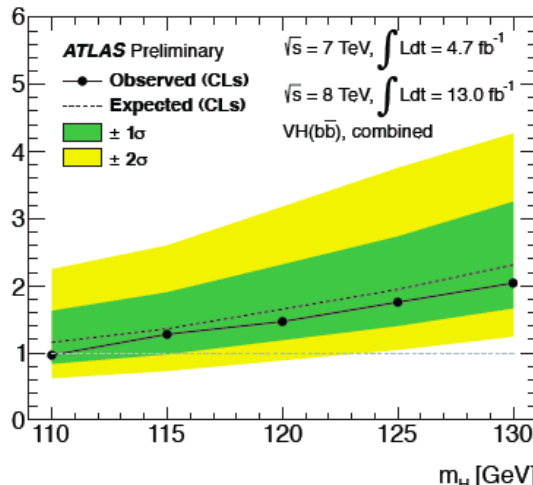
ATLAS: $\mu_H = -0.4 \pm 0.7$ (stat) ± 0.8 (sys)

$H \rightarrow b\bar{b}$

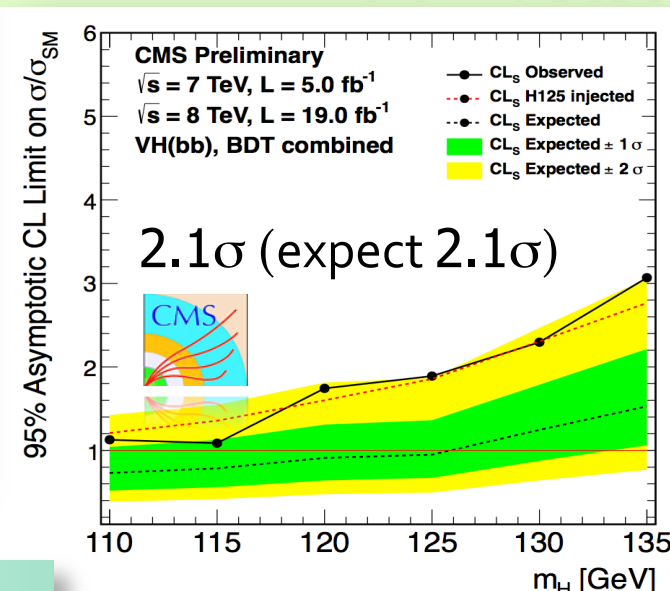
combination: data - background



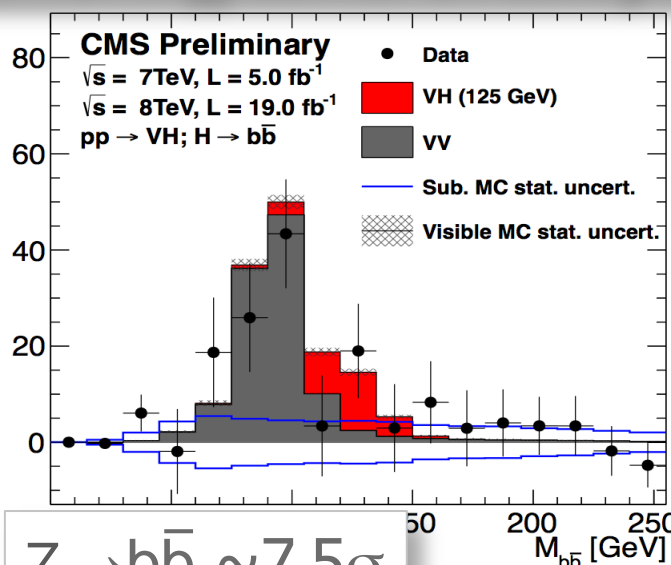
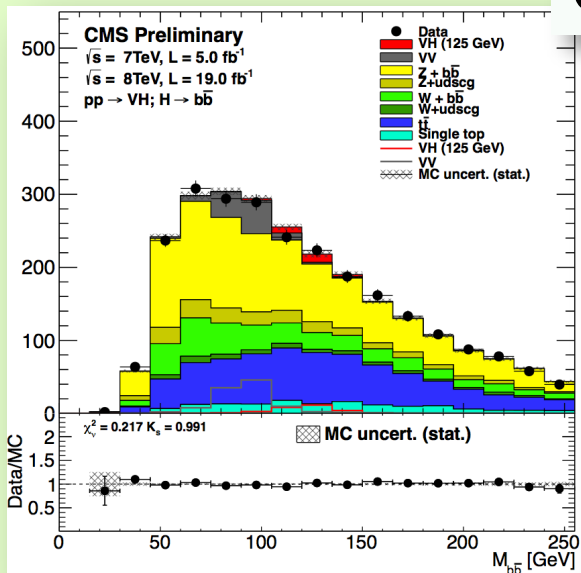
95% C. L. limit on σ/σ_{SM}



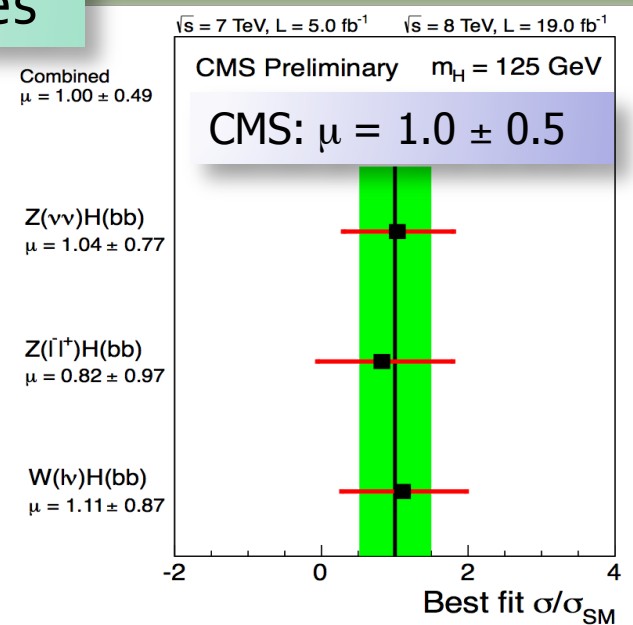
$Z \rightarrow b\bar{b} \sim 4\sigma$



CMS: $M_{b\bar{b}}$ comb. all categories



$Z \rightarrow b\bar{b} \sim 7.5\sigma$

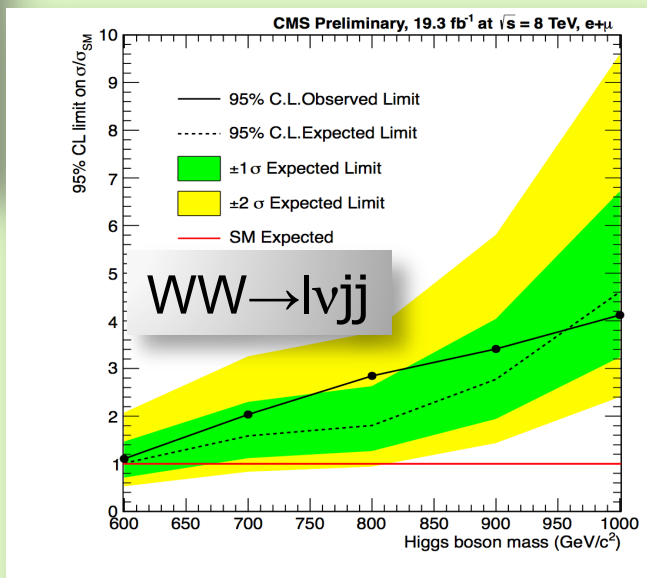
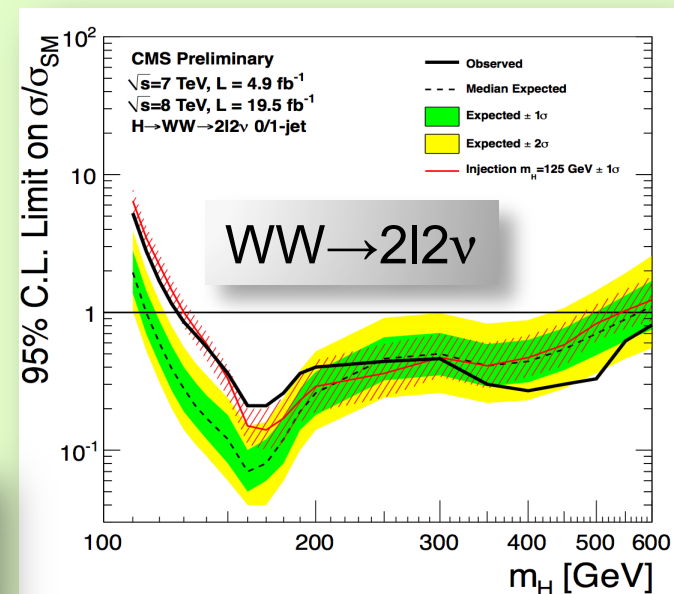
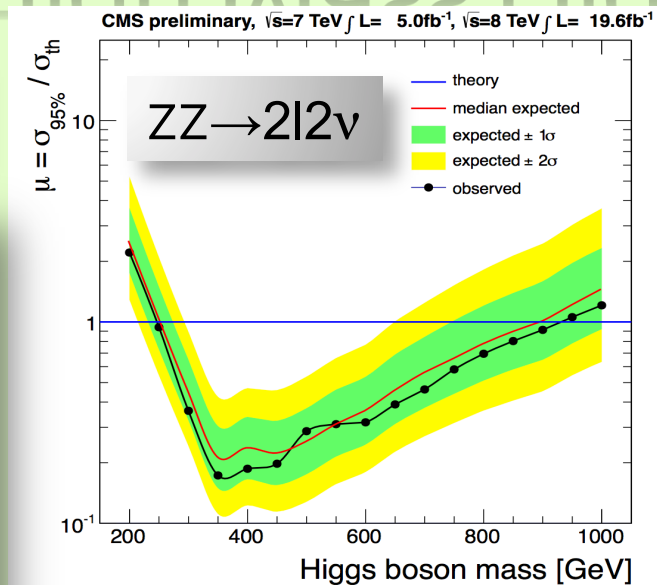
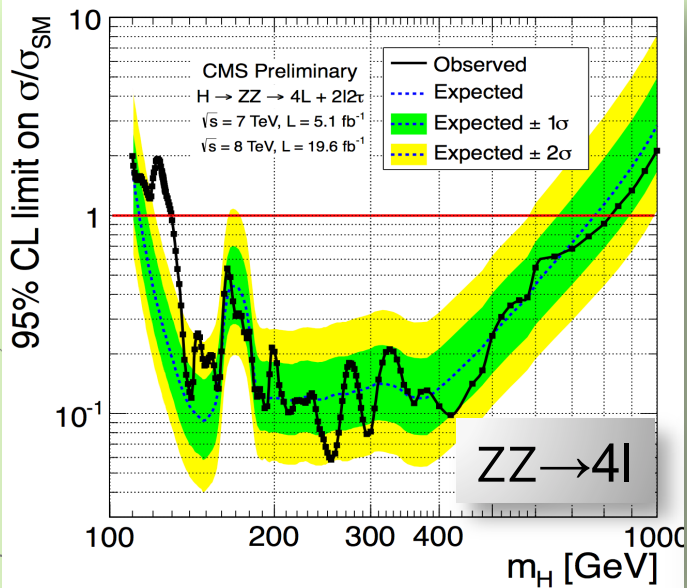


CMS: $\mu = 1.0 \pm 0.5$



High Mass Higgs Searches

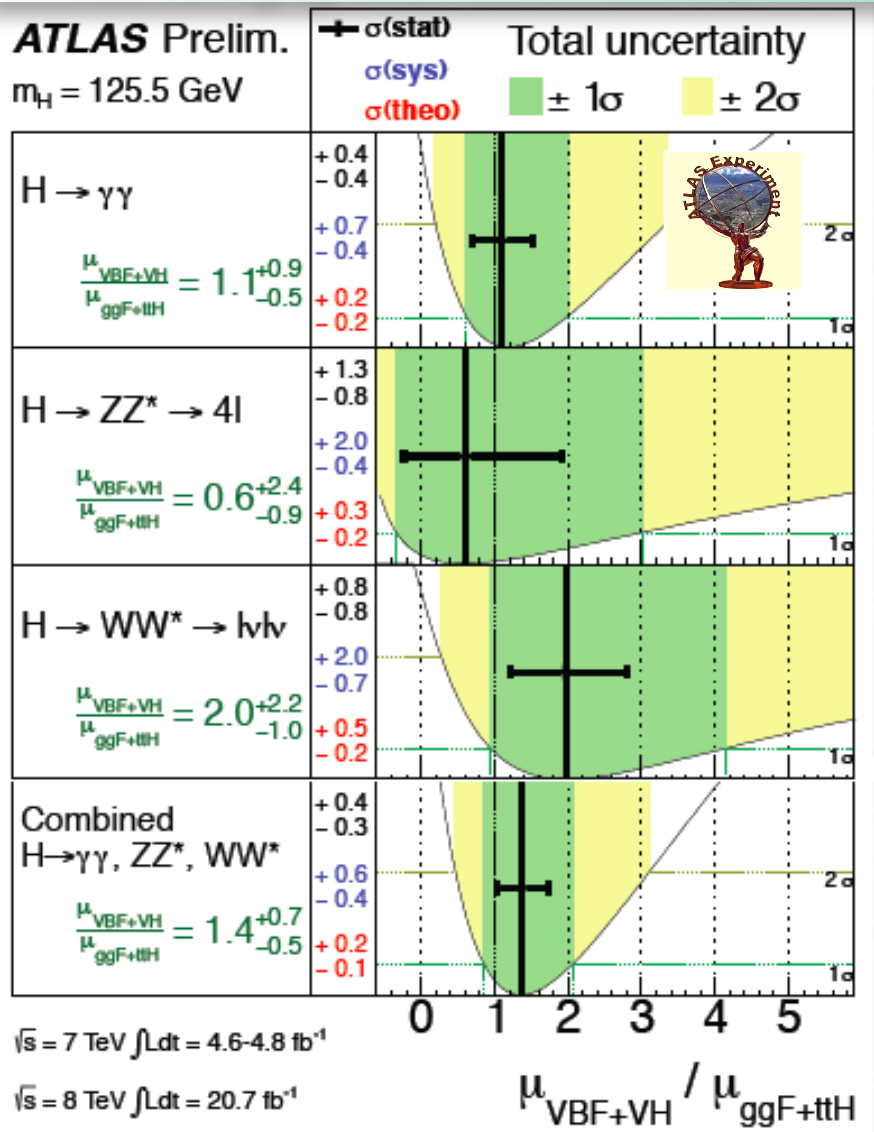
Sensitivity to ~ 1 TeV



Interpretation of data in EW-singlet models and LHC XS WG benchmark models:
 CMS-PAS-HIG-13-008
 CMS-PAS-HIG-13-014

ATLAS: 3.3σ Evidence for VBF

More ...



CMS: 3.4σ Evidence for $H \rightarrow f\bar{f}$

Decay	Expected	Observed
ZZ	7.1 σ	6.7 σ
γγ	3.9 σ	3.2 σ
WW	5.3 σ	3.9 σ
bb	2.2 σ	2.1 σ
ττ	2.6 σ	2.8 σ

$m_H = 125.7$

Summary: 3.4σ evidence for $H \rightarrow f\bar{f}$

$b\bar{b}$: $VH \oplus VBF$
 WW: $ggF \oplus VH \oplus VBF$

CMS-PAS-HIG-13-005

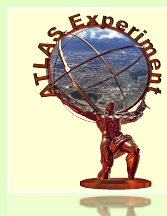
$$\mu_{\text{VBF}} / \mu_{\text{ggF+ttH}} = 1.4^{+0.4}_{-0.3} (\text{stat})^{+0.6}_{-0.4} (\text{sys})$$

[arXiv:1307.1427](https://arxiv.org/abs/1307.1427)

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σ/σ_{SM} and Mass ($\gamma\gamma \oplus ZZ$)

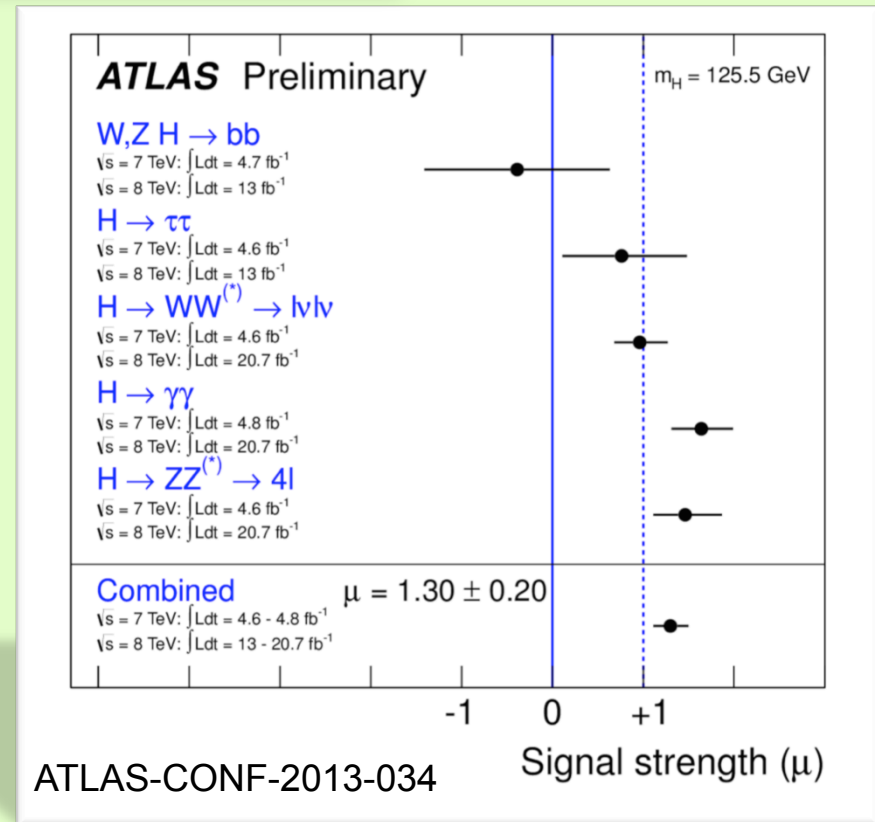
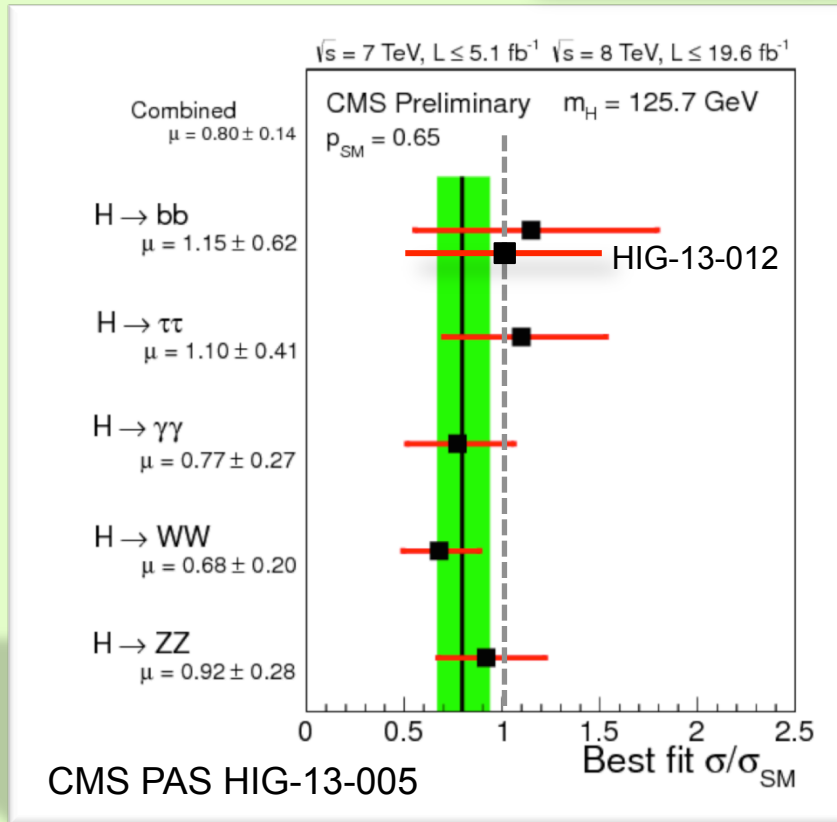


CERN April 15, 2013

$$\mu = 0.80 \pm 0.14$$

Spin tests, couplings also show consistency with Standard Model

$$\mu = 1.30 \pm 0.20$$



$$m = 125.7 \pm 0.3^{(stat)} \pm 0.3^{(syst)} \text{ GeV}$$

$$m = 125.5 \pm 0.2^{+0.5}_{-0.6} \text{ GeV}$$

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All tests favor 0^{++}

- Both ATLAS and CMS strongly prefer $J^{PC} = 0^{++}$ over the alternatives
 - Pseudoscalar 0^{-+} and tensor 2^{++} hypotheses have been excluded at $>3\sigma$ level by each experiment

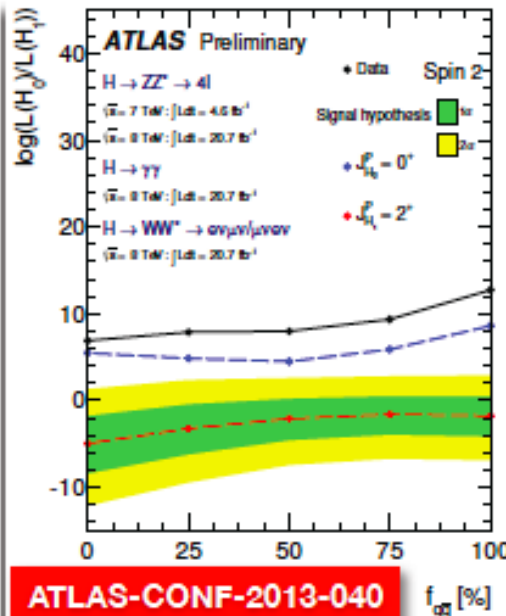
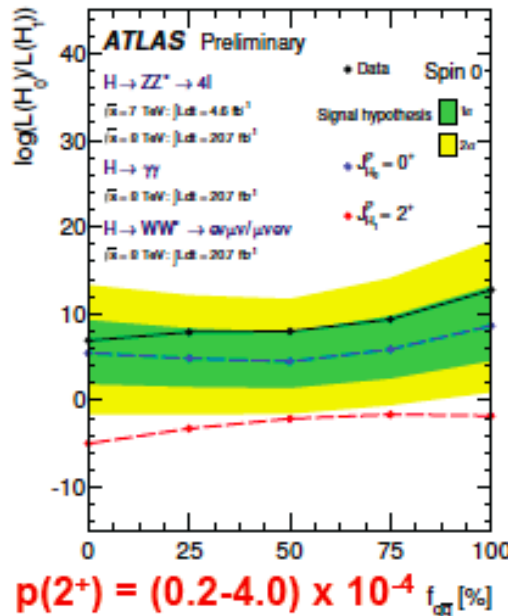
ATLAS-CONF-2013-013

		BDT analysis			CL_s
		tested J^P for an assumed 0^+		tested 0^+ for an assumed J^P	
		expected	observed	observed*	
0^-	p_0	0.0037	0.015	0.31	0.022
1^+	p_0	0.0016	0.001	0.55	0.002
1^-	p_0	0.0038	0.051	0.15	0.060
2^+_{gg}	p_0	0.092	0.079	0.53	0.168
2^-	p_0	0.0053	0.25	0.034	0.258

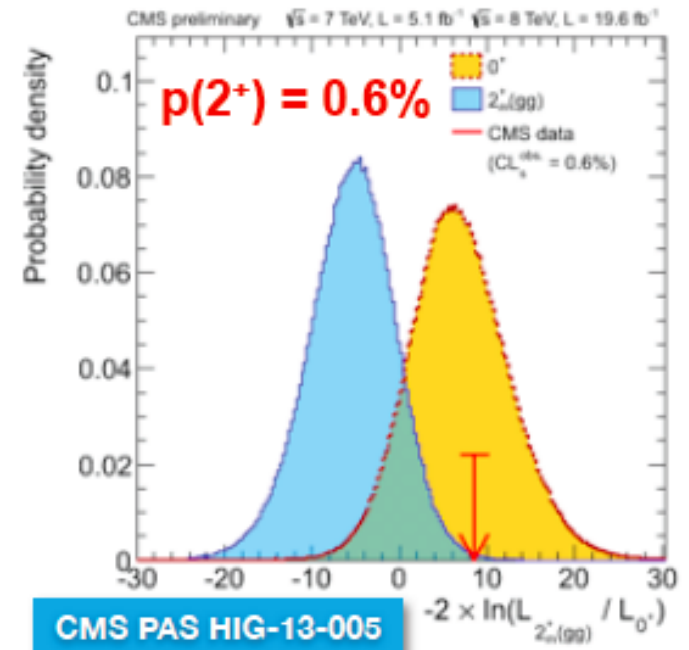
H(ZZ) alone

CMS PAS HIG-13-002

J^P	production	comment	expect ($\mu=1$)	obs. 0^+	obs. J^P	CL_s
0^-	$gg \rightarrow X$	pseudoscalar	2.6σ (2.8σ)	0.5σ	3.3σ	0.16%
$0^+_{h,h}$	$gg \rightarrow X$	higher dim operators	1.7σ (1.8σ)	0.0σ	1.7σ	8.1%
$2^+_{m,gg}$	$gg \rightarrow X$	minimal couplings	1.8σ (1.9σ)	0.8σ	2.7σ	1.5%
$2^+_{m,q\bar{q}}$	$q\bar{q} \rightarrow X$	minimal couplings	1.7σ (1.9σ)	1.8σ	4.0σ	<0.1%
1^-	$q\bar{q} \rightarrow X$	exotic vector	2.8σ (3.1σ)	1.4σ	$>4.0\sigma$	<0.1%
1^+	$q\bar{q} \rightarrow X$	exotic pseudovector	2.3σ (2.6σ)	1.7σ	$>4.0\sigma$	<0.1%



Combination



A big news week!

HollywoodLife.com

BREAKING NEWS!

SIMON FRASER UNIVERSITY
PUBLIC AFFAIRS AND MEDIA RELATIONS

Burnaby | Surrey | Vancouver

SFU Online

ISSUES AND EXPERTS

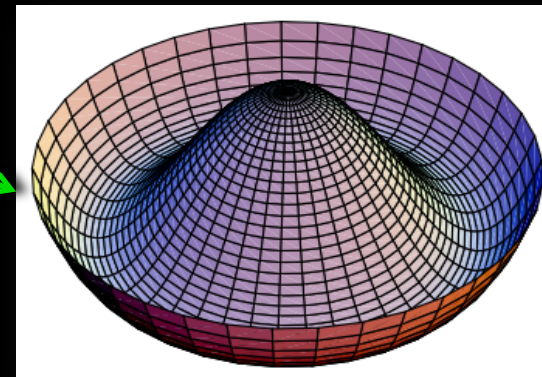
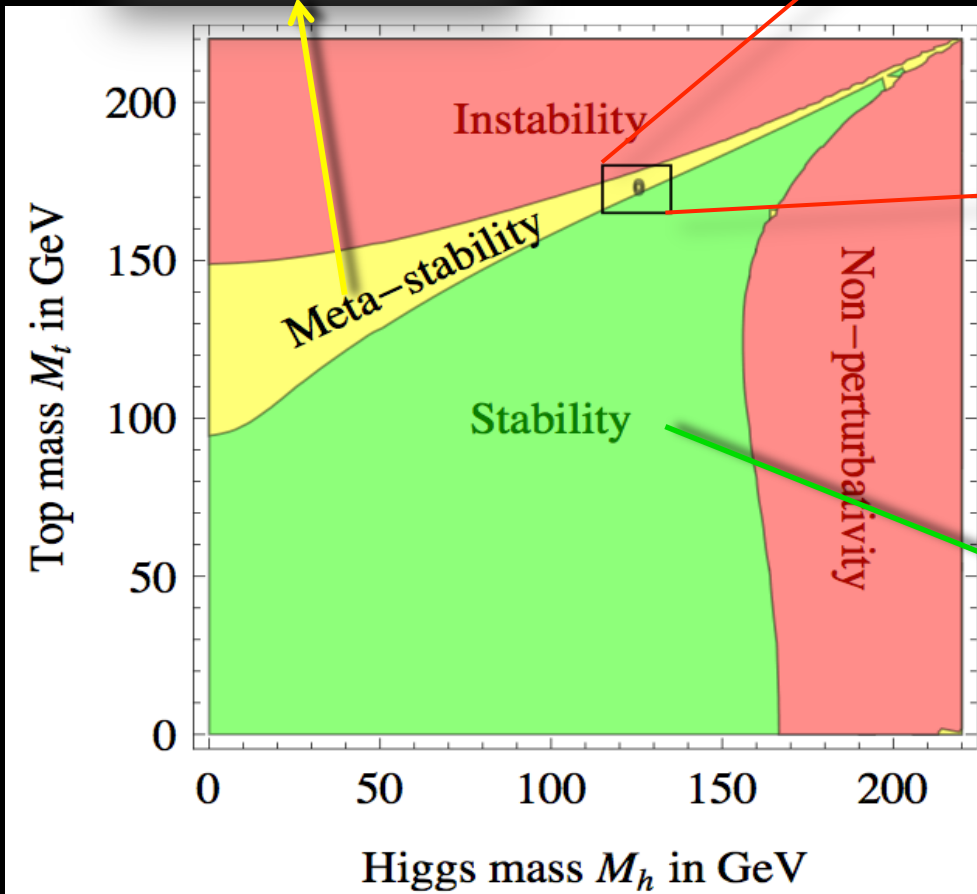
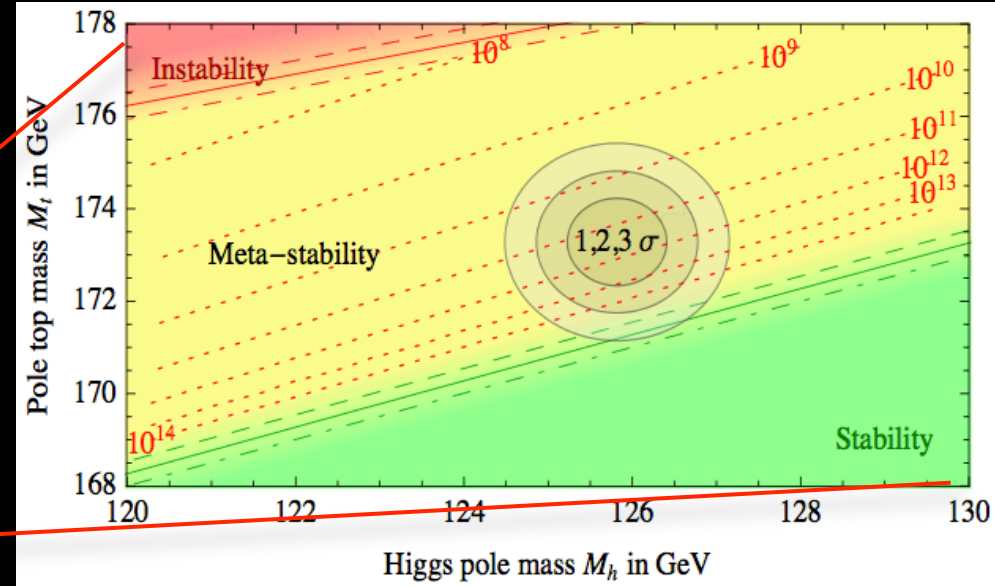
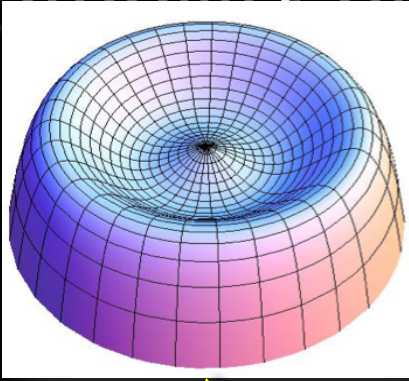
Higgs boson and new pope confirmed

March 14, 2013

White smoke rises from the chimney on the roof of the Sistine Chapel meaning that cardinals elected a new pope on March 13, 2013.

pa

Stability of the universe in the Standard Model



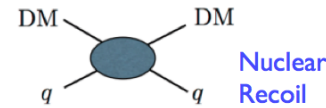
Other searches



Dark matter

- Using monojets and mono-photons
 - Stringent DM limits for heavy mediators

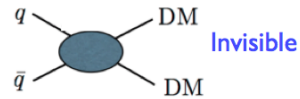
Elastic Scattering (t-channel)



Nuclear Recoil

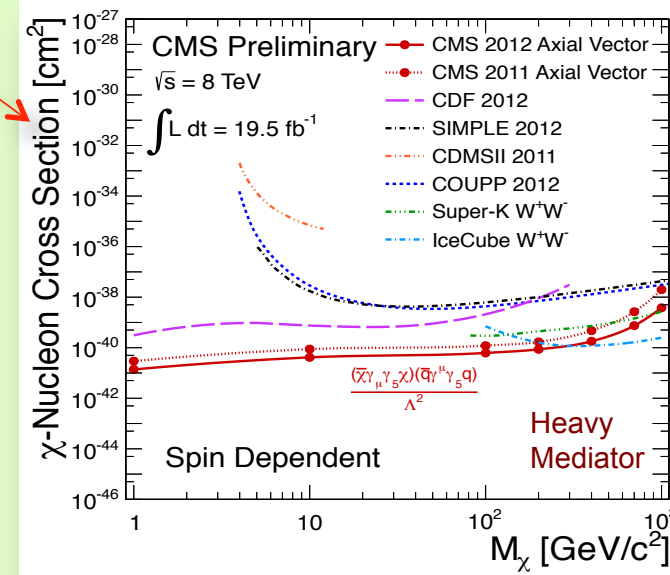
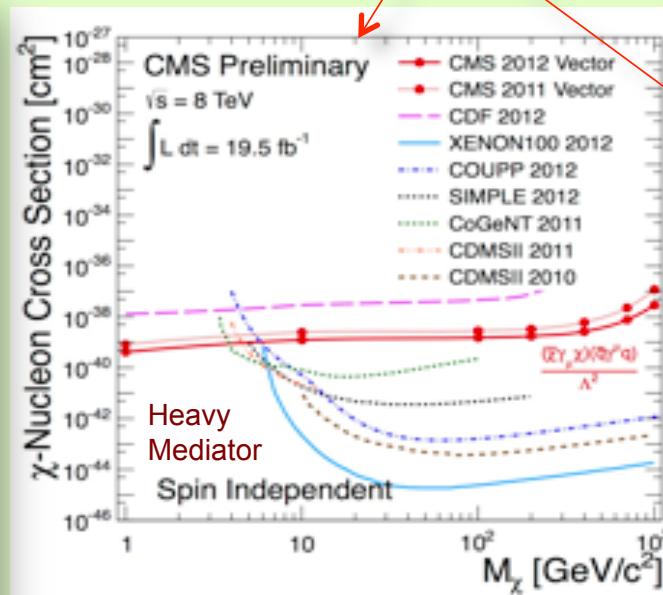
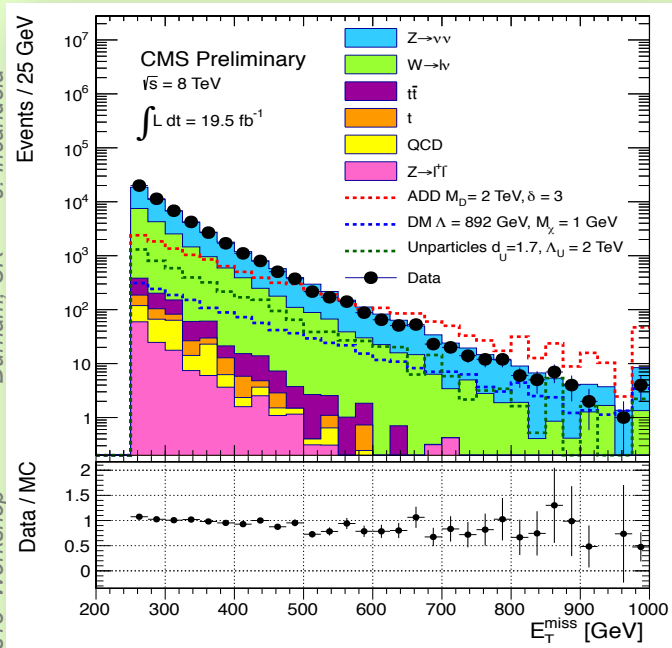
Direct Searches

Pair Production (s-channel)



Invisible

Collider Searches



CMS-PAS-EXO-12-048

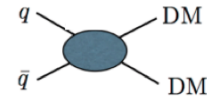
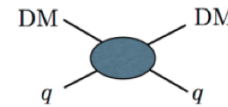


Dark matter

- Using monojets and mono-photons
 - Stringent DM limits for heavy mediators

Elastic Scattering (t-channel)

Pair Production (s-channel)

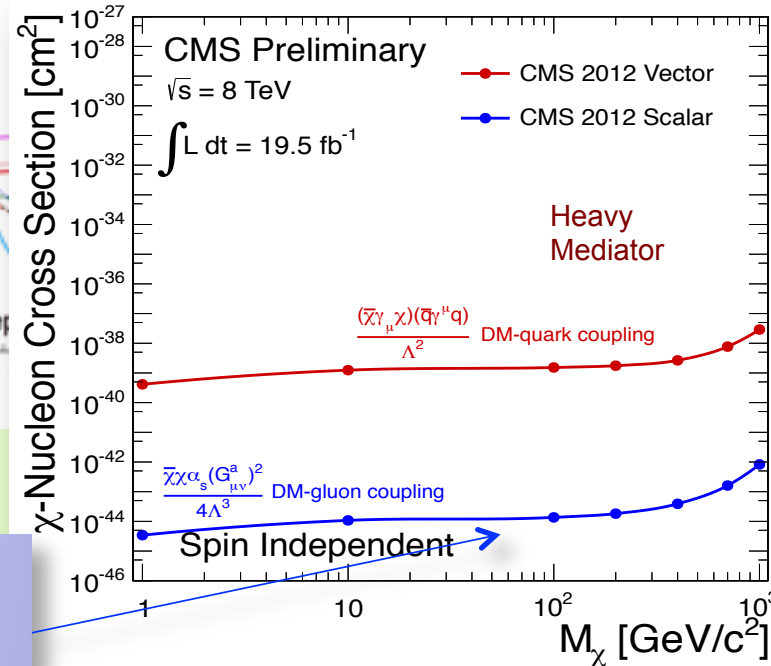
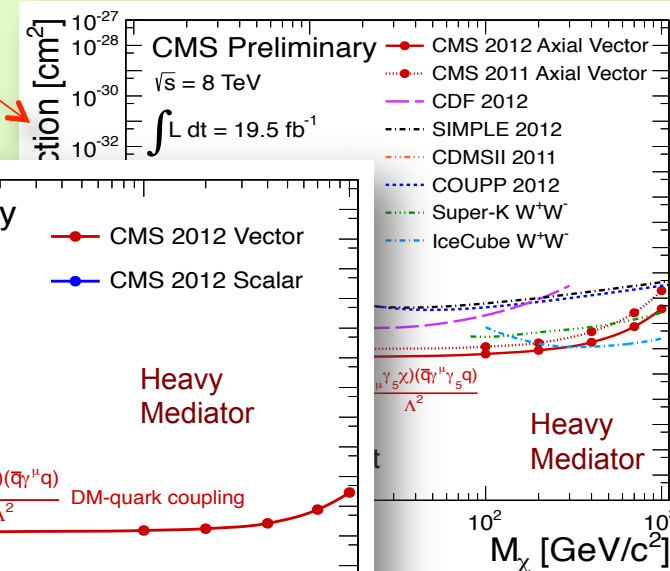
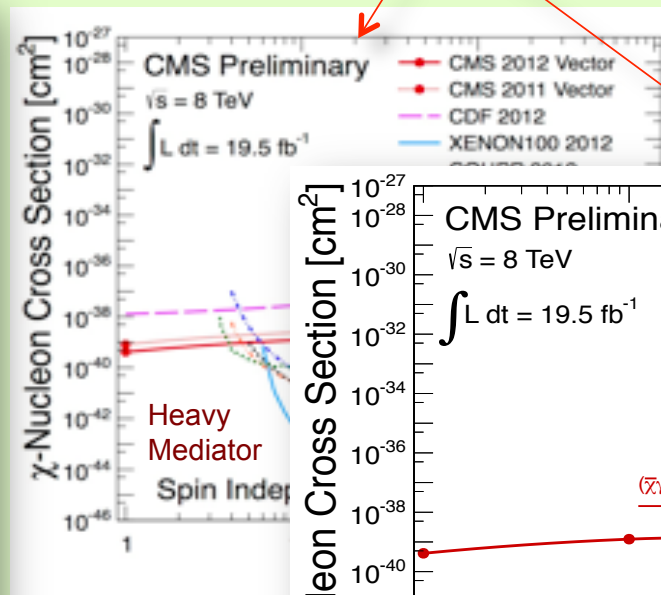
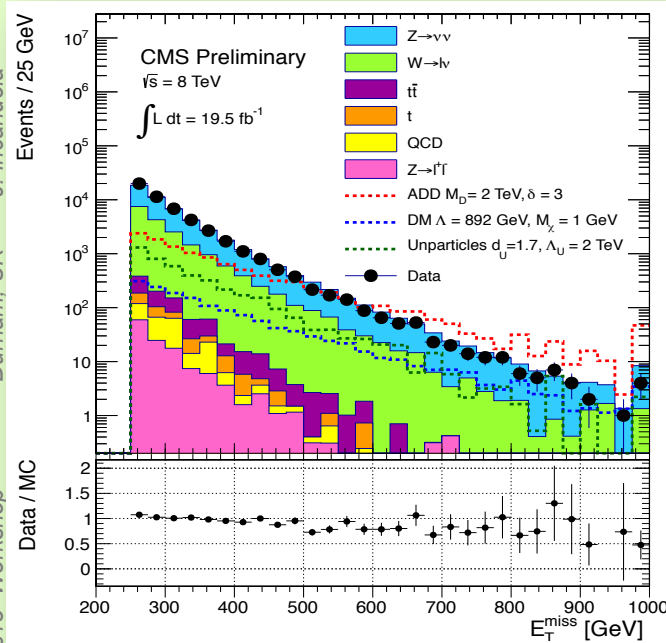


Nuclear Recoil

Invisible

Direct Searches

Collider Searches



Also sensitive to DM-gluon couplings

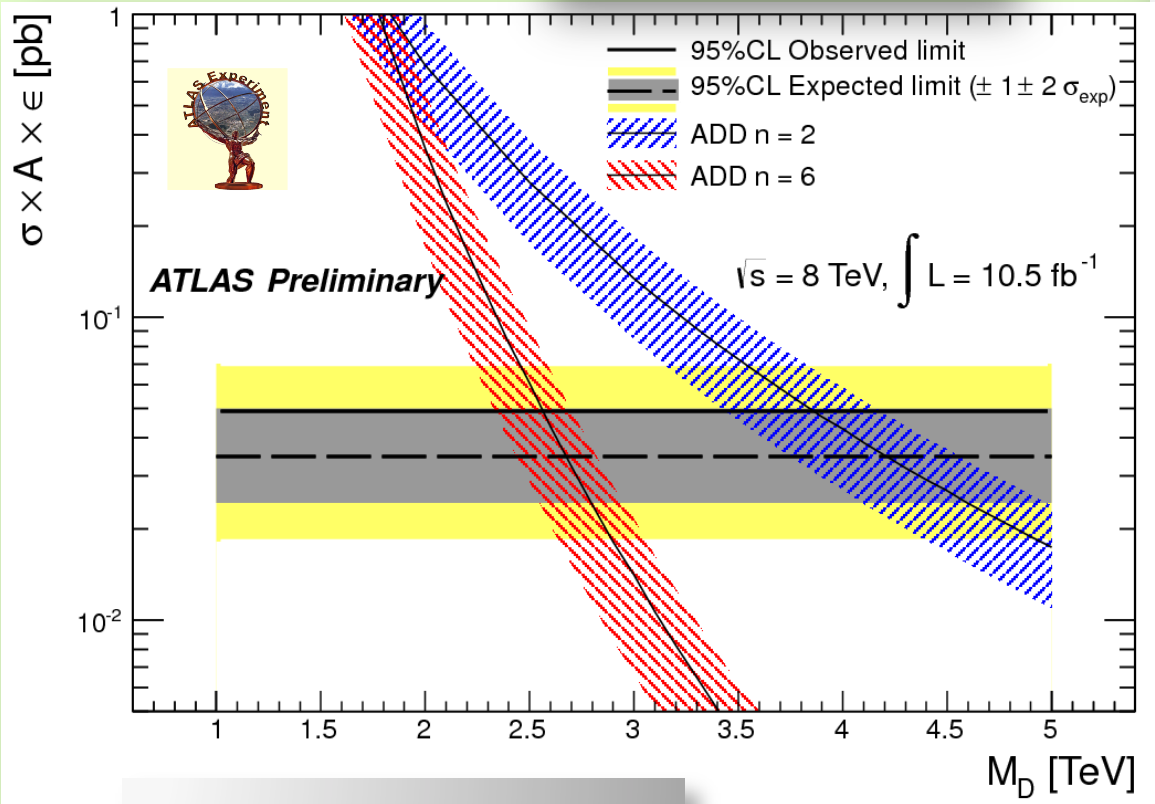
CMS-PAS-EXO-12-048

UCSB/CERN
 J. Incandela
 Durham, UK
 Invisibles13 Workshop
 July 15, 2013

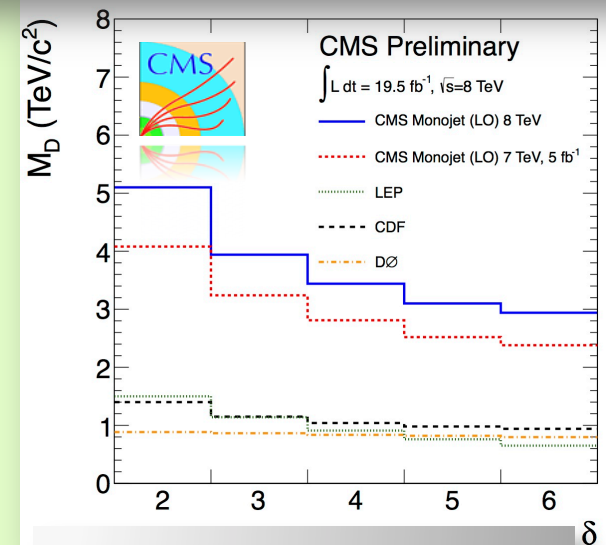
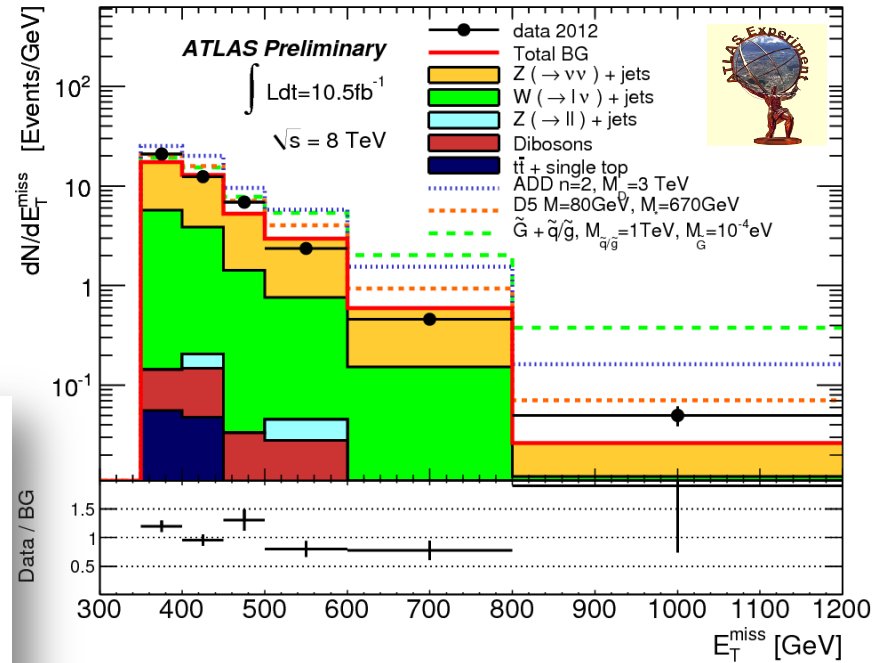
Extra dimensions

- Using monojets and mono-photons
 - Look for evidence of KK Gravitons
 - ADD Extra Dimensions

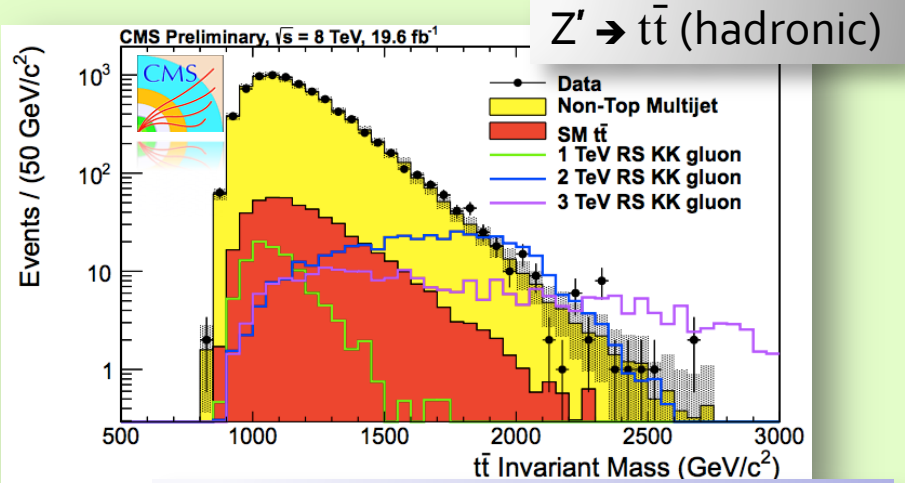
$$M_{Pl}^2 \sim M_D^{2+n} R^n$$



ATLAS-CONF-2012-147

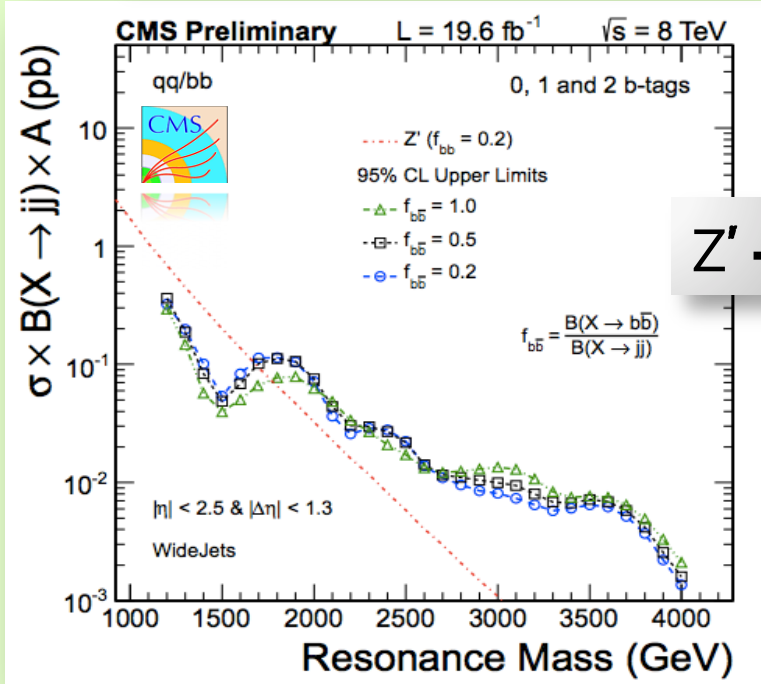
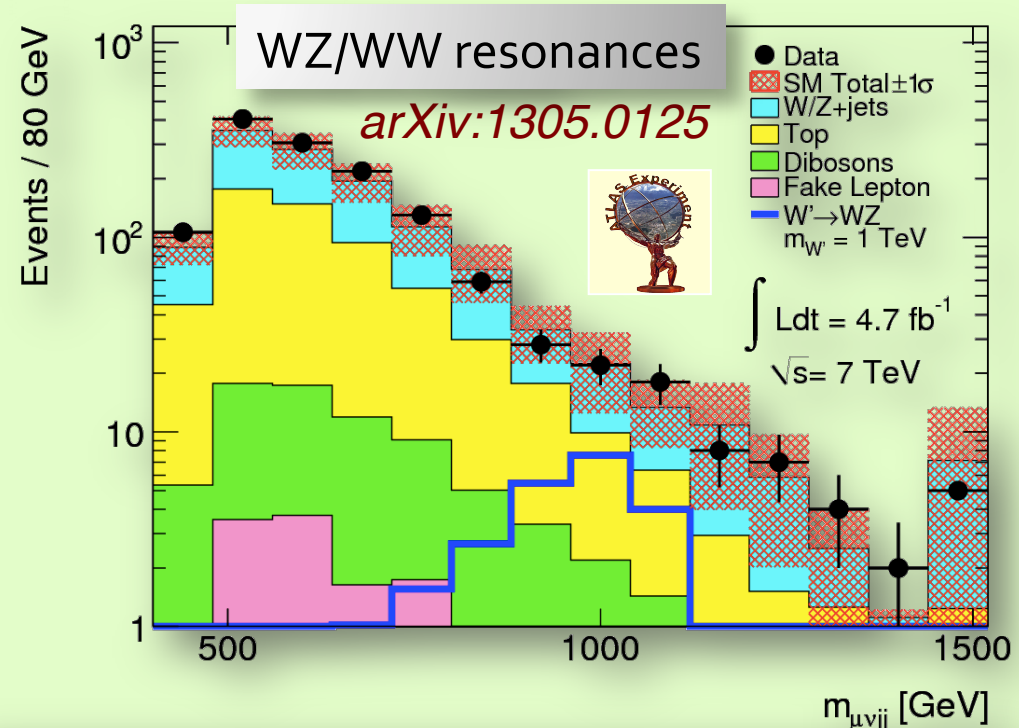


CMS-PAS-EXO-12-048

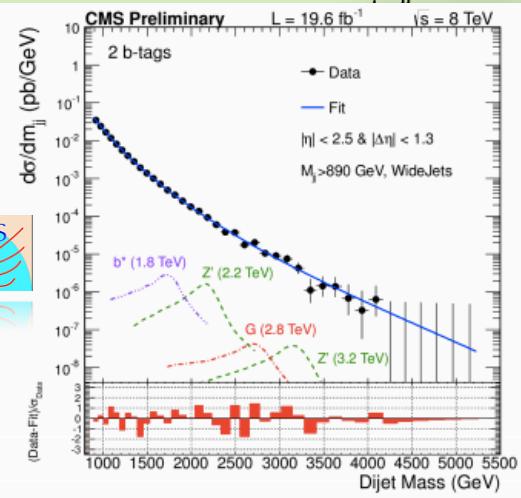
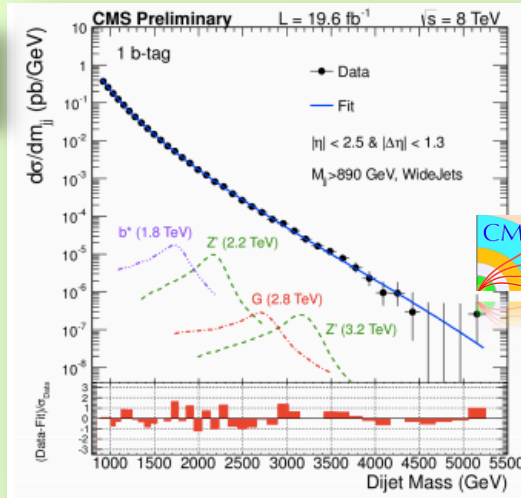


2 fat jets $140 < M < 250$
 $M_{Z'} > 1.6$ (2.3) TeV for 1.2 (10) % width
 $M_{g(KK)} > 1.8 \text{ TeV}$

Heavy Resonances

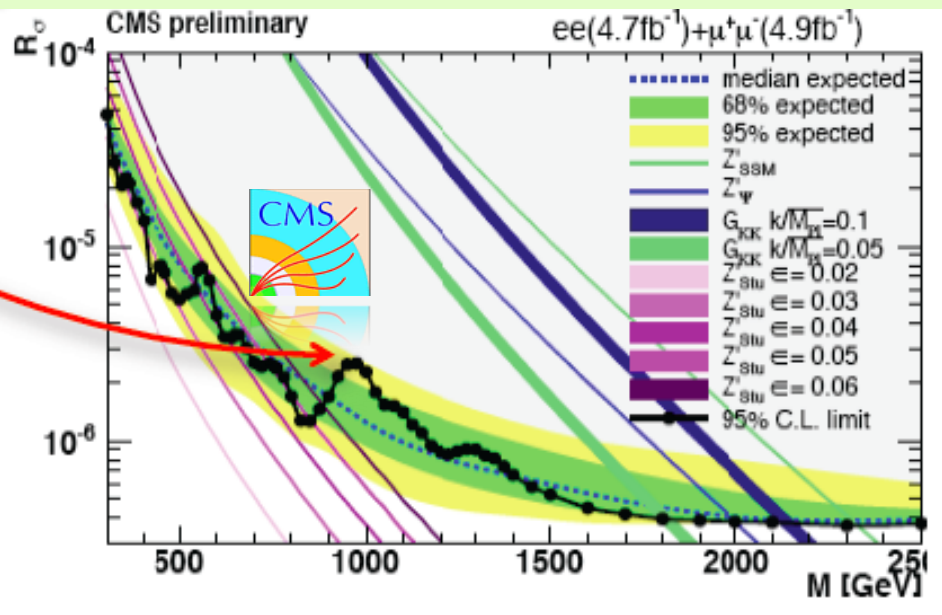
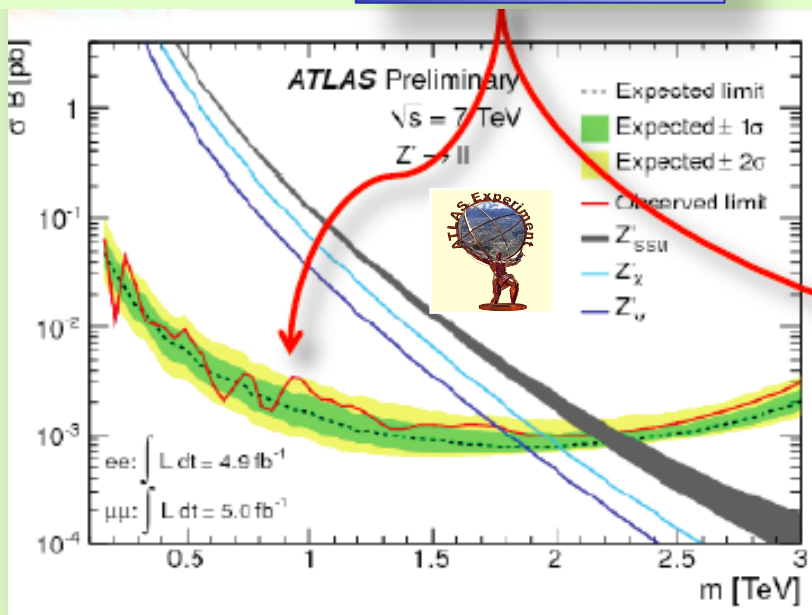


$Z' \rightarrow b\bar{b}$



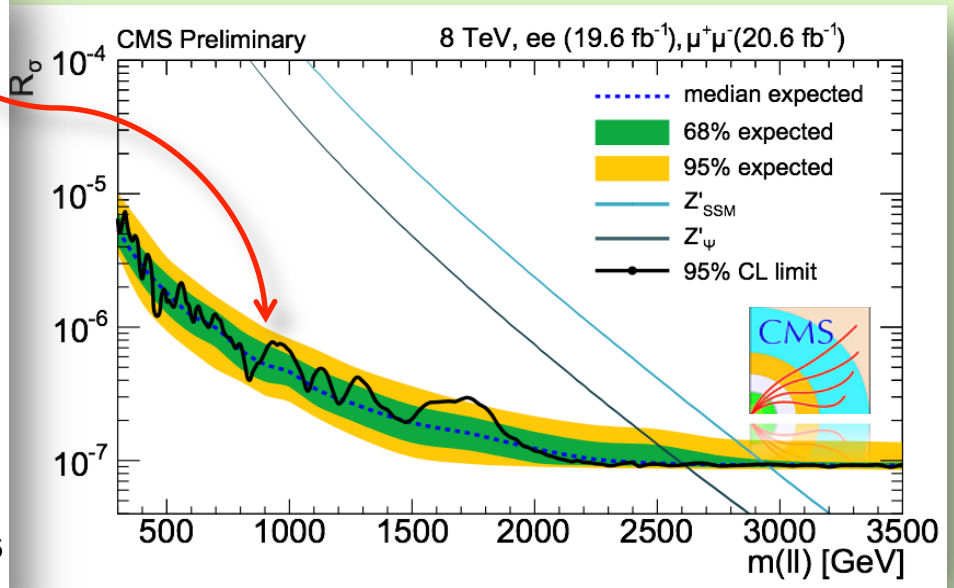
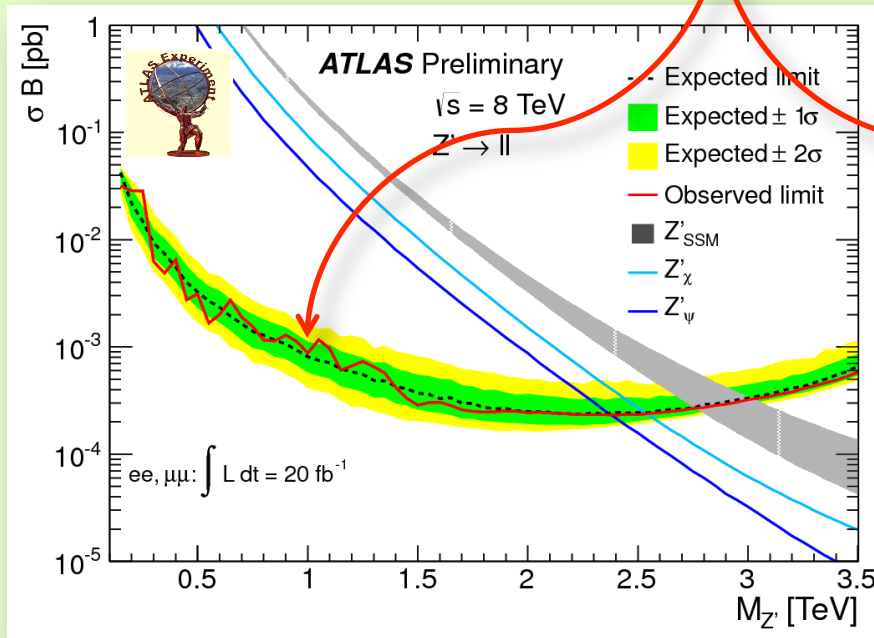
$Z' \rightarrow ll$: ca. Moriond 2012

Going, going...



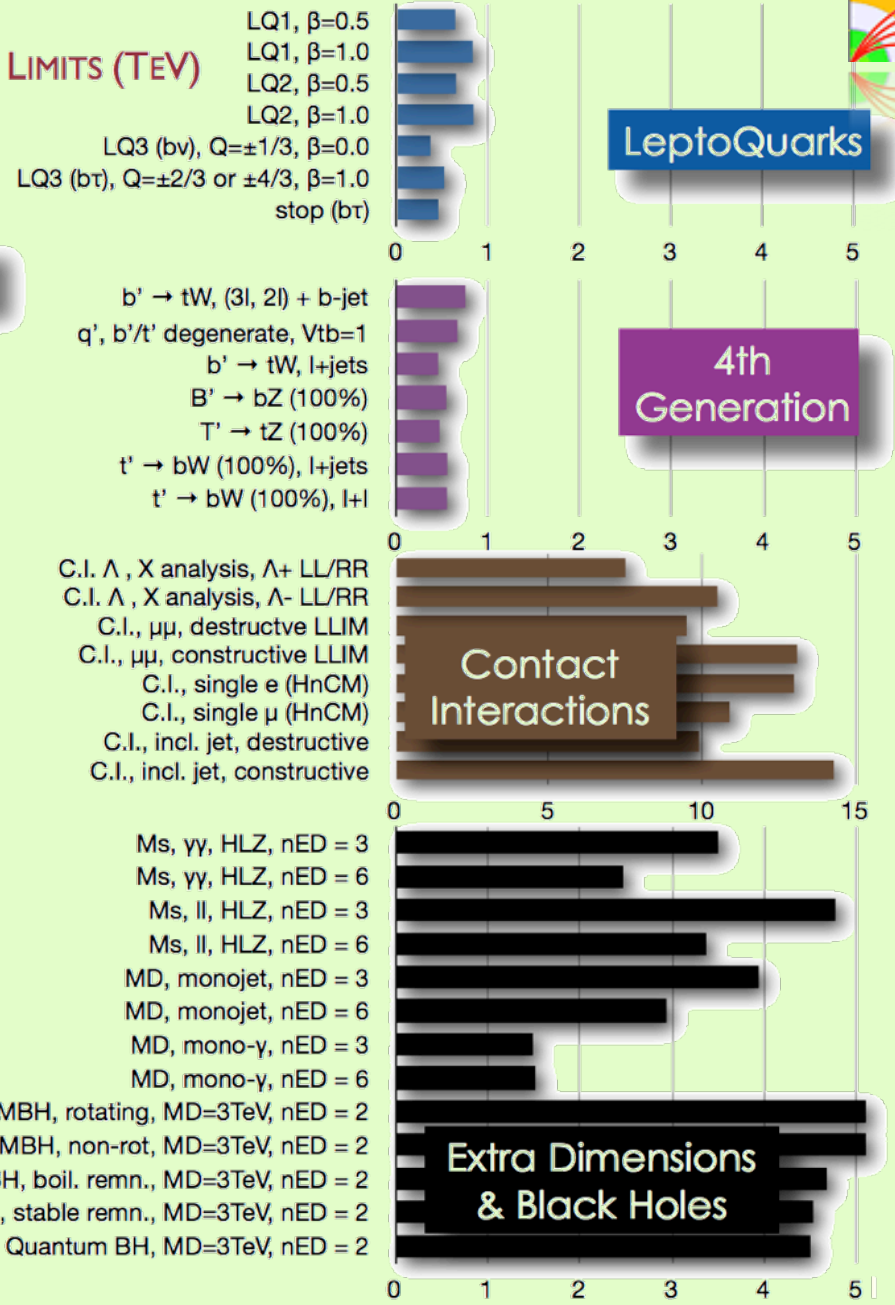
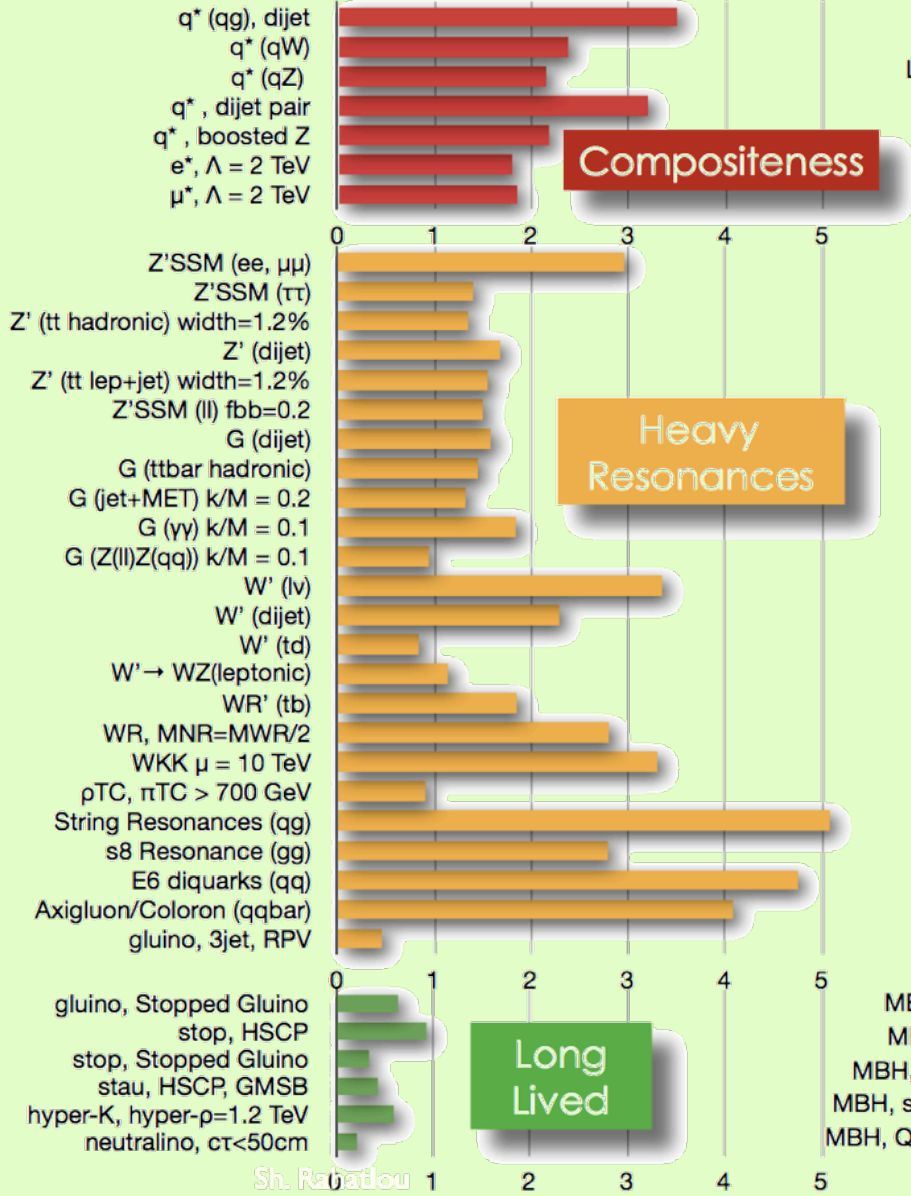
$Z' \rightarrow ll$: ca. Moriond 2013

gone





CMS EXOTICA 95% CL EXCLUSION LIMITS (TeV)



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Durham, UK
Invisibles13 Workshop
July 15, 2013

Sh. Rattou



UCSB/CERN

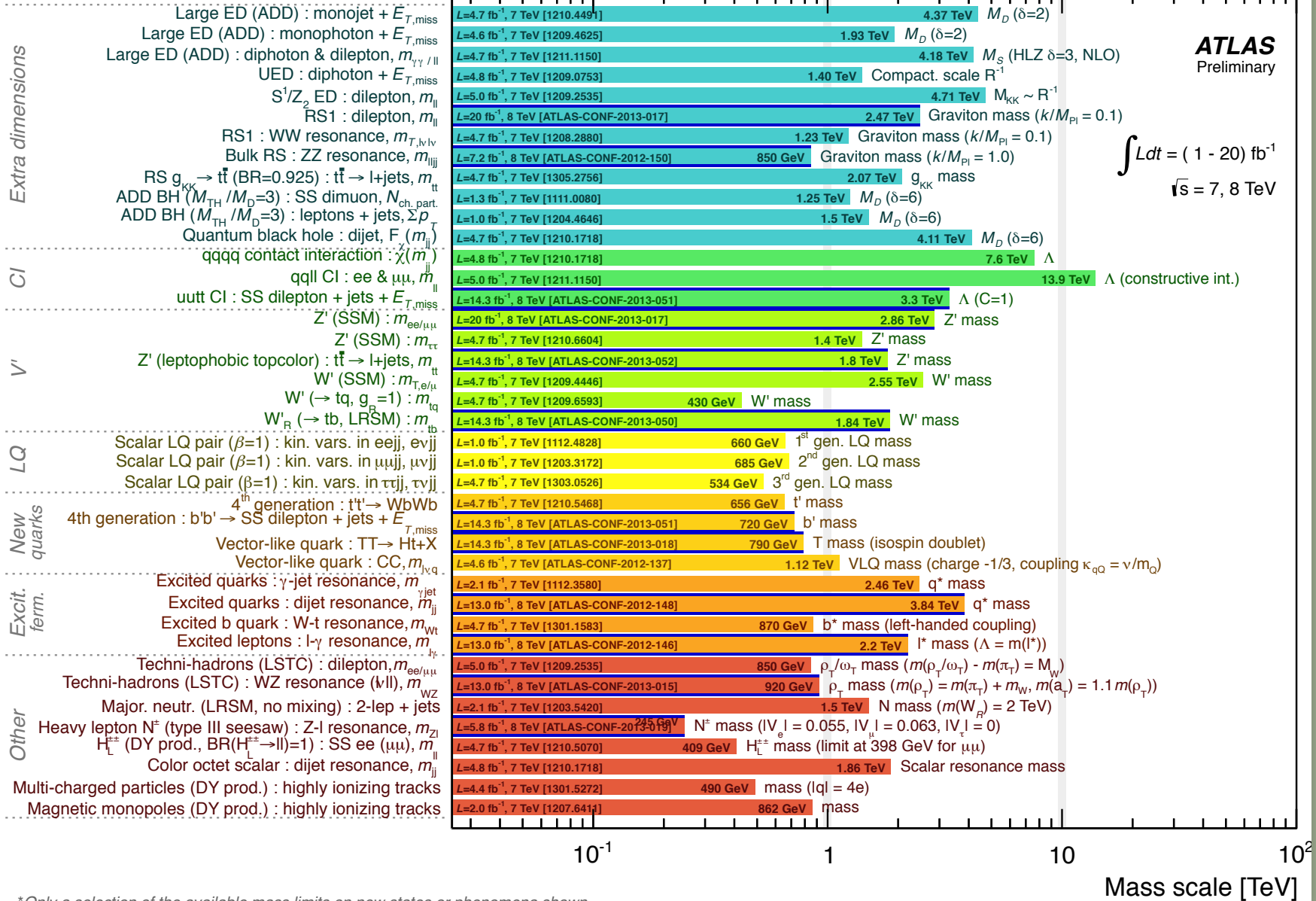
J. Incandela

Durham, UK

Invisibles13 Workshop

July 15, 2013

ATLAS Exotics Searches* - 95% CL Lower Limits (Status: May 2013)

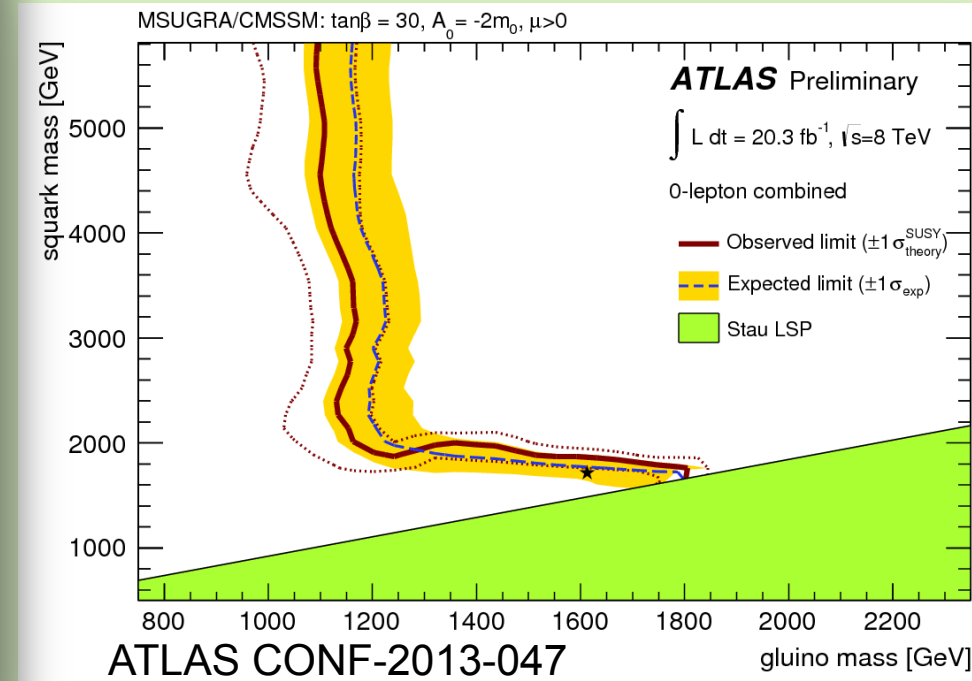
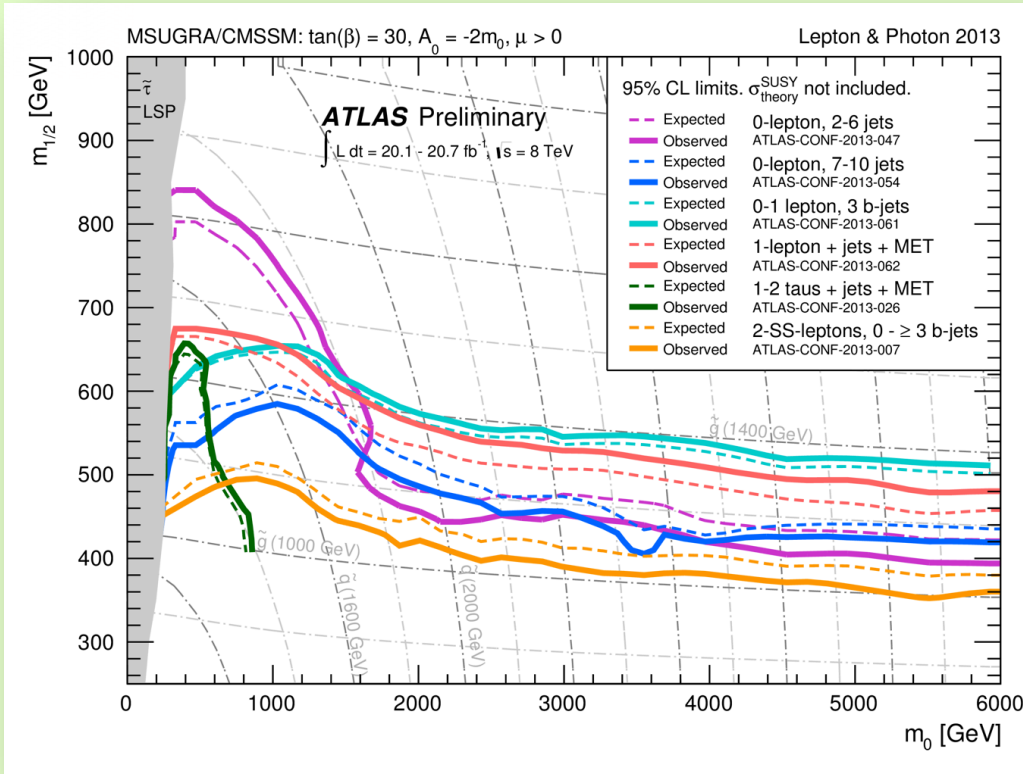


*Only a selection of the available mass limits on new states or phenomena shown



MSUGRA/CMSSM

UCSB/CERN
 J. Incandela
 Durham, UK
 Invisibles13 Workshop
 July 15, 2013



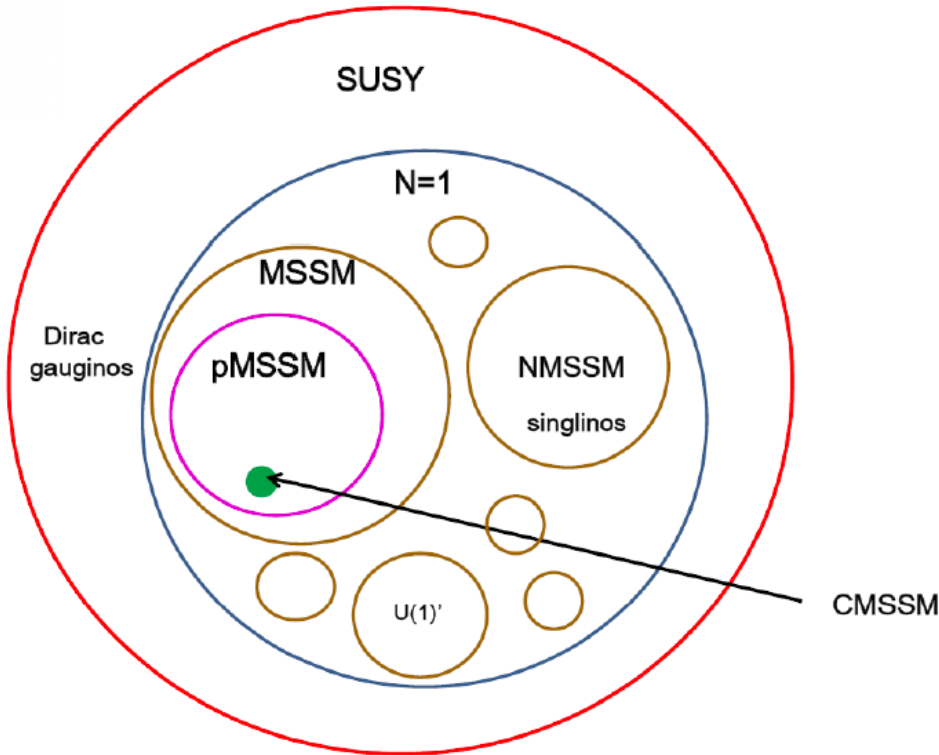
■ MSUGRA/CMSSM

- Exclude squarks and gluinos $> 1 \text{ TeV}$ and $> 1.8 \text{ TeV}$ respectively



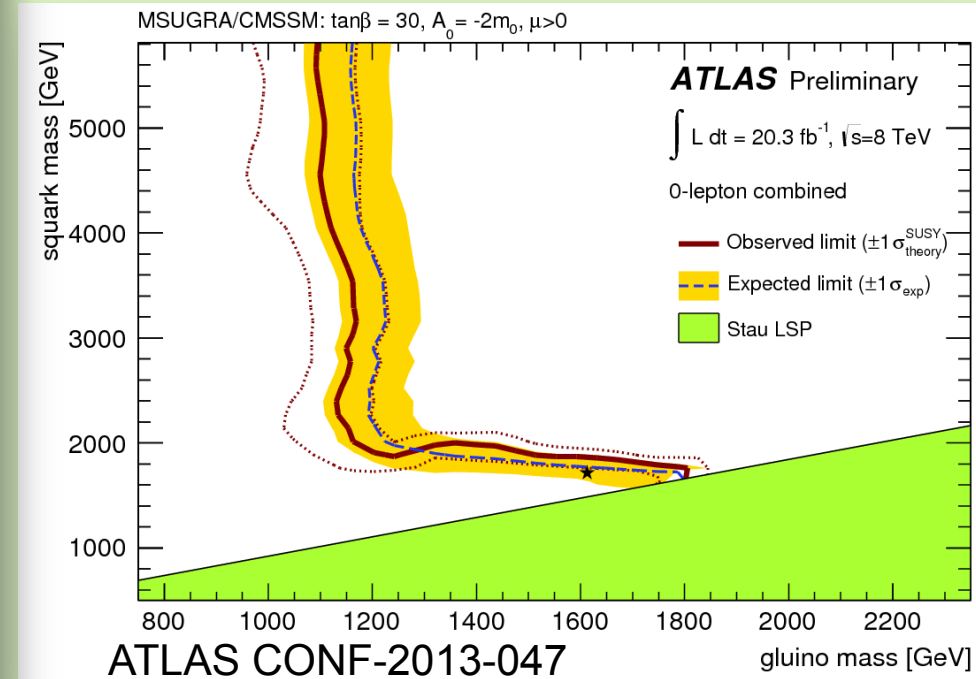
MSUGRA/CMSSM

SUSY Theory phase space

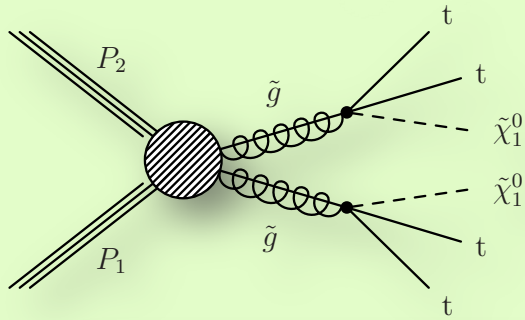


T. Rizzo (SLAC Summer Institute, 01-Aug-12)

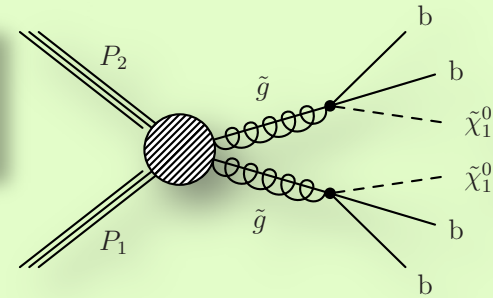
- MSUGRA/CMSSM
 - Exclude squarks and gluinos > 1 TeV and > 1.8 TeV respectively
- But, only really probing a tiny part of a very large parameter SUSY space



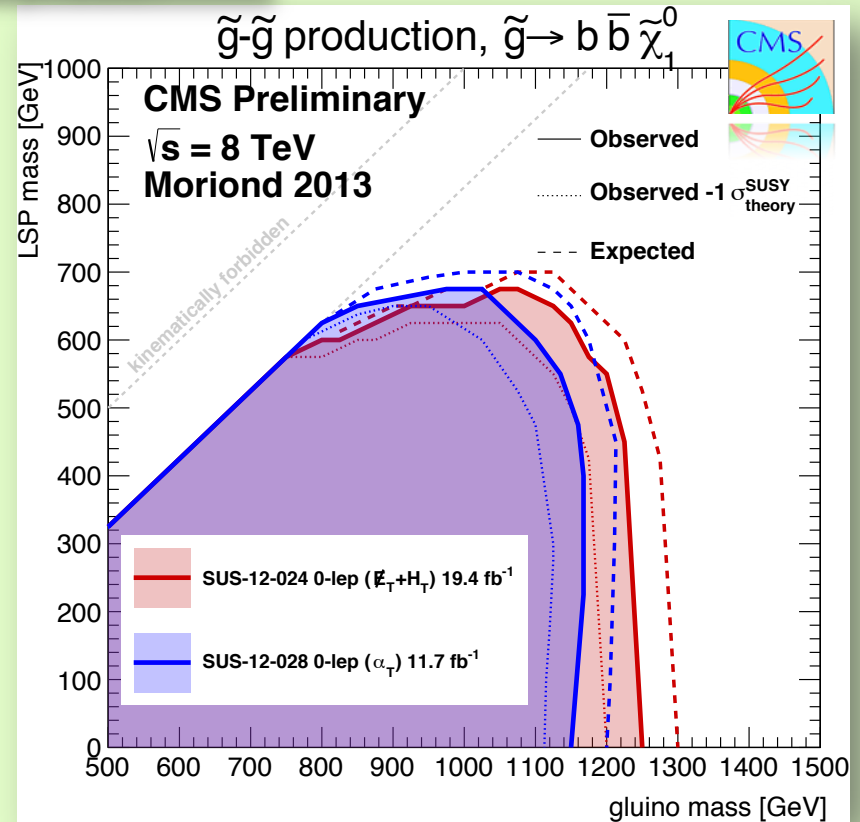
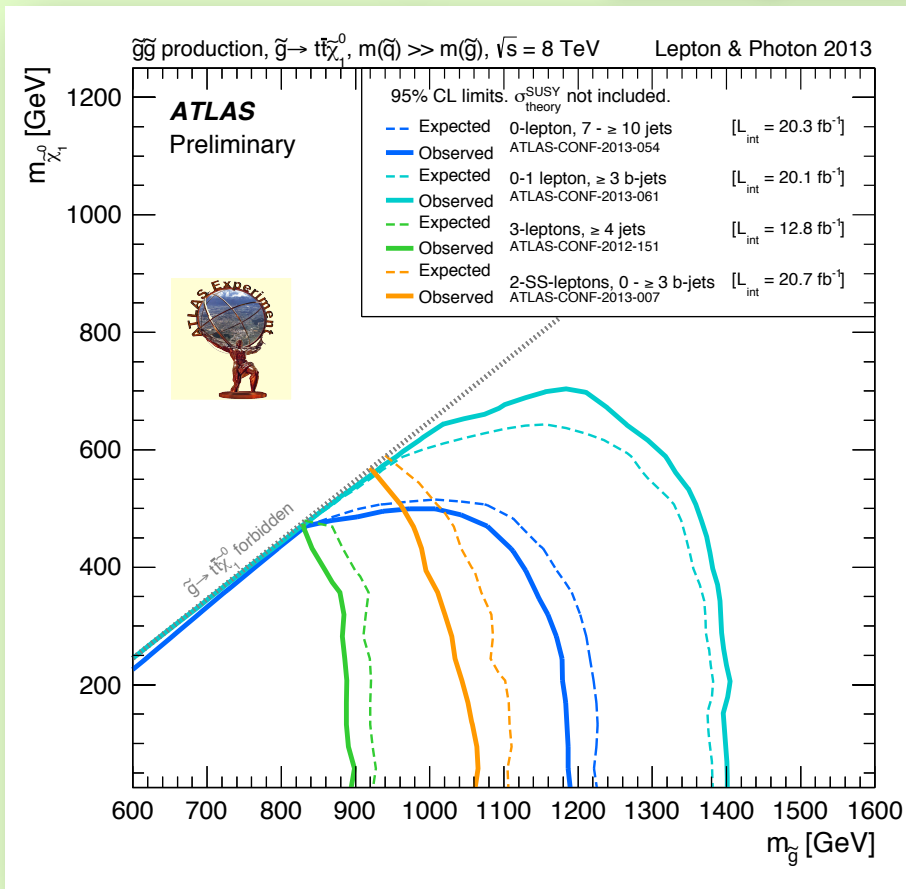
Onto more general SUSY searches



Gluginos decaying to stop or sbottom
decaying to top or bottom + neutralino



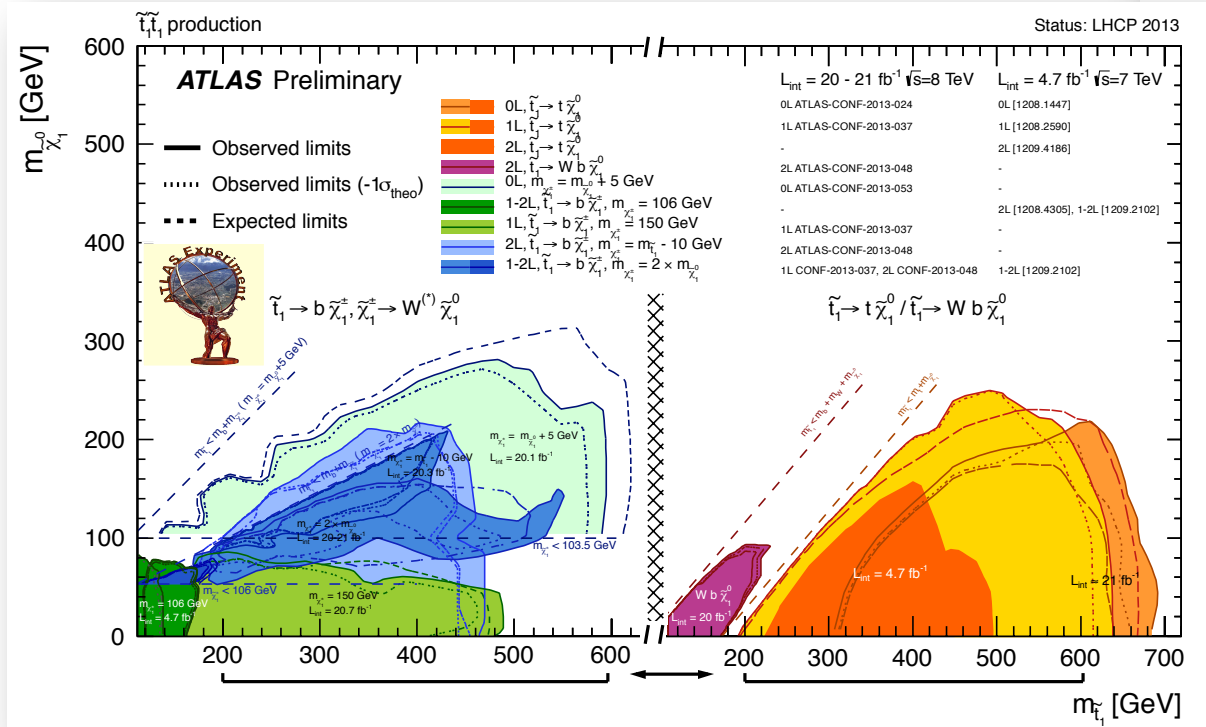
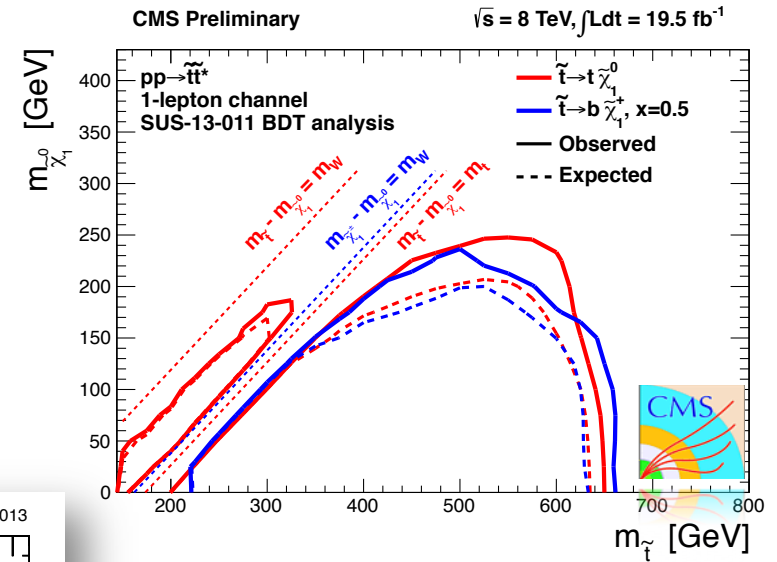
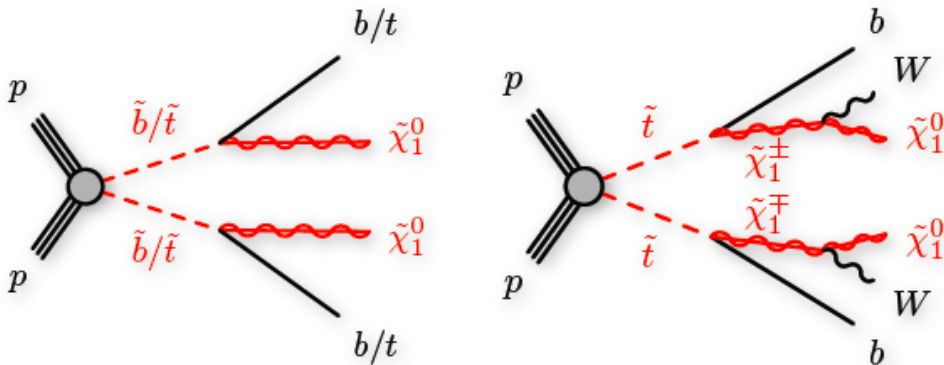
Eliminating essentially all of
the regions we can probe:



CMS SUS-12-024, SUS-12-028

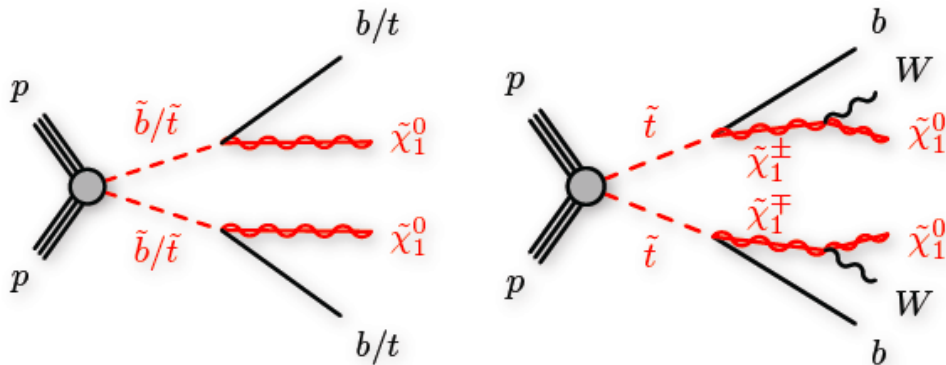
Direct 3rd generation production

Direct \tilde{b}/\tilde{t} pair production

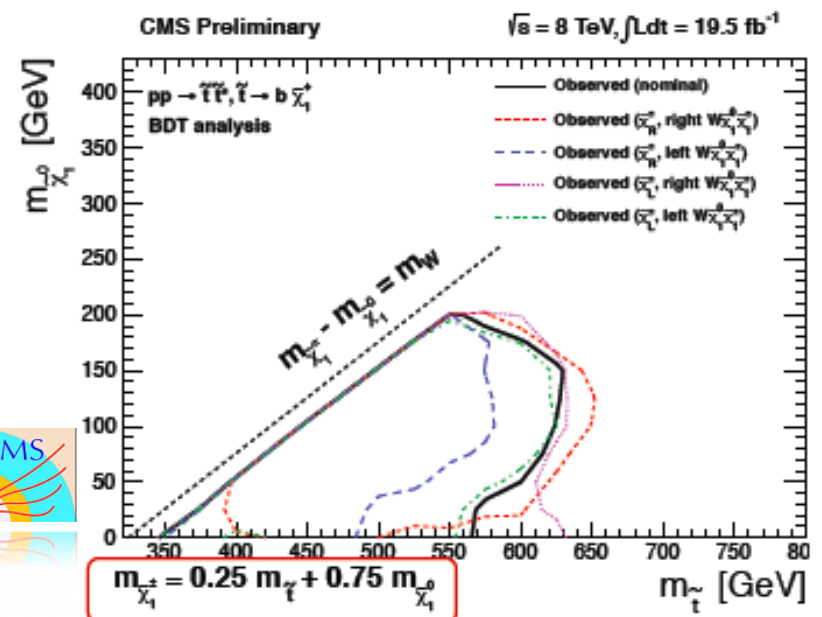
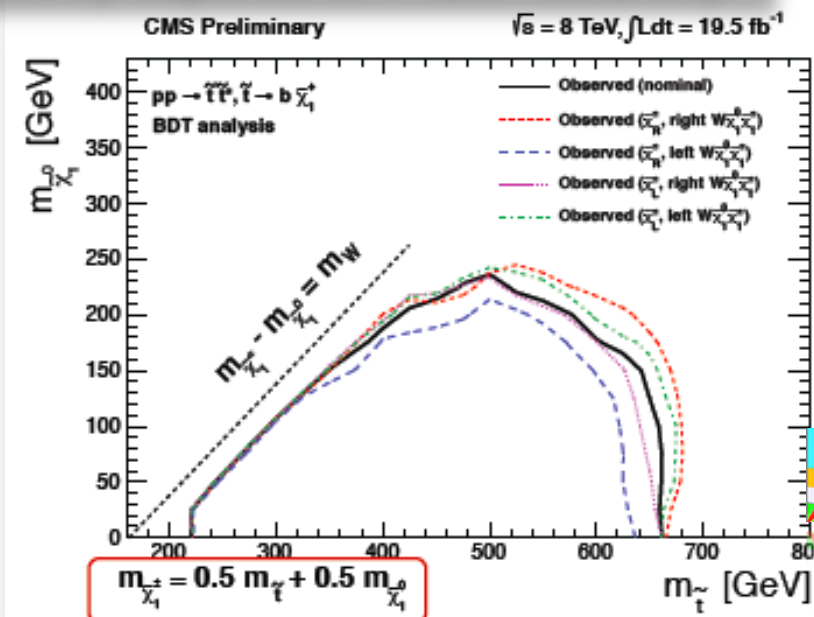
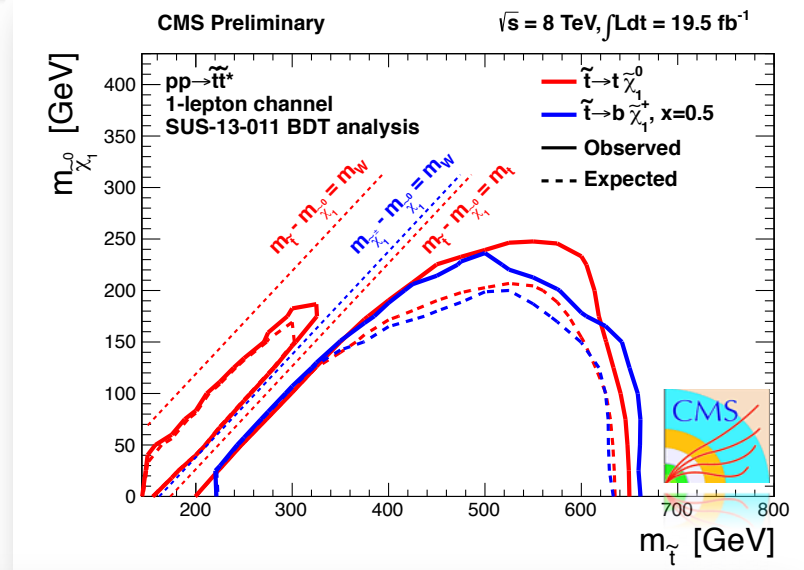


Direct 3rd generation production

Direct \tilde{b}/\tilde{t} pair production



Sensitivity depends on mass hierarchy



CMS: PAS-SUS-13-011



SUSY no show tables

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: LP 2013

ATLAS Preliminary

$\int \mathcal{L} dt = (4.4 - 22.9) \text{ fb}^{-1}$ $\sqrt{s} = 7, 8 \text{ TeV}$

Model	e, μ, τ, γ Jets	E_T^{miss} [$\mathcal{L} dt [\text{fb}^{-1}]$]	Mass limit	Reference			
Inclusive Searches	MSUGRA/CMSSM	1 e, μ 3-6 jets	Yes 20.3	\tilde{g} 1.2 TeV	any $m(\tilde{g})$	ATLAS-COIN-2013-002	
	MSUGRA/CMSSM	0 7-10 jets	Yes 20.3	\tilde{g} 1.1 TeV	any $m(\tilde{g})$	ATLAS-COIN-2013-004	
	$q\bar{q} \rightarrow q\bar{q} + \tilde{g}^2$	0 2-6 jets	Yes 20.3	\tilde{q} 740 GeV	$m(\tilde{q}) \geq 0 \text{ GeV}$	ATLAS-COIN-2013-047	
	$g\bar{g} \rightarrow g\bar{g} + \tilde{g}^2$	0 2-6 jets	Yes 20.3	\tilde{g} 1.3 TeV	$m(\tilde{q}) \geq 0 \text{ GeV}$	ATLAS-COIN-2013-047	
	$g\bar{g} \rightarrow q\bar{q} + \tilde{g}^2$	1 e, μ 3-6 jets	Yes 20.3	\tilde{g} 1.18 TeV	$m(\tilde{q}) \geq 200 \text{ GeV}, m(\tilde{g}) \geq 0.5 m(\tilde{q}) + m(\tilde{g})$	ATLAS-COIN-2013-002	
	$g\bar{g} \rightarrow q\bar{q} + \tilde{g}^2$	2 e, μ (BS) 3 jets	Yes 20.7	\tilde{g} 1.1 TeV	$m(\tilde{q}) \geq 80 \text{ GeV}$	ATLAS-COIN-2013-007	
	GMSS (Z NLSP)	2 e, μ 2-4 jets	Yes 4.7	\tilde{g} 1.24 TeV	$\tan\beta < 15$	1205.4655	
	GMSS (Z NLSP)	1-2 τ 0-2 jets	Yes 20.7	\tilde{g} 1.4 TeV	$\tan\beta > 15$	ATLAS-COIN-2013-028	
	GGM (bino NLSP)	2 γ 0	Yes 4.8	\tilde{g} 1.07 TeV	$m(\tilde{q}) \geq 50 \text{ GeV}$	1209.0753	
	GGM (wino NLSP)	1 $e, \mu + \gamma$ 0	Yes 4.8	\tilde{g} 619 GeV	$m(\tilde{q}) \geq 50 \text{ GeV}$	ATLAS-COIN-2013-144	
	GGM (higgsino-bino NLSP)	γ 1 b	Yes 4.8	\tilde{g} 800 GeV	$m(\tilde{q}) \geq 230 \text{ GeV}$	1211.1167	
	GGM (higgsino NLSP)	2 e, μ (Z) 0-3 jets	Yes 5.8	\tilde{g} 890 GeV	$m(\tilde{q}) \geq 200 \text{ GeV}$	ATLAS-COIN-2012-152	
	Gravitino LSP	0 mono-jet	Yes 10.5	\tilde{g} 645 GeV	$m(\tilde{g}) \geq 10^{-4} \text{ eV}$	ATLAS-COIN-2012-147	
	3^{rd} gen. \tilde{g} med.	$q\bar{q} \rightarrow b\bar{b} + \tilde{g}^2$	0 3 b	Yes 20.1	\tilde{g} 1.2 TeV	$m(\tilde{q}) < 800 \text{ GeV}$	ATLAS-COIN-2013-001
		$q\bar{q} \rightarrow t\bar{t} + \tilde{g}^2$	0 7-10 jets	Yes 20.3	\tilde{g} 1.14 TeV	$m(\tilde{q}) < 800 \text{ GeV}$	ATLAS-COIN-2013-004
$q\bar{q} \rightarrow t\bar{t} + \tilde{g}^2$		0-1 e, μ 3 b	Yes 20.1	\tilde{g} 1.34 TeV	$m(\tilde{q}) < 400 \text{ GeV}$	ATLAS-COIN-2013-001	
$q\bar{q} \rightarrow b\bar{b} + \tilde{g}^2$		0-1 e, μ 3 b	Yes 20.1	\tilde{g} 1.3 TeV	$m(\tilde{q}) < 300 \text{ GeV}$	ATLAS-COIN-2013-001	
3^{rd} gen. squarks direct production	$\tilde{t}_1 \tilde{t}_1^* \rightarrow b\bar{b} + \tilde{g}^2$	0 2 b	Yes 20.1	\tilde{t}_1 100-630 GeV	$m(\tilde{q}) < 100 \text{ GeV}$	ATLAS-COIN-2013-003	
	$\tilde{b}_1 \tilde{b}_1^* \rightarrow q\bar{q} + \tilde{g}^2$	2 e, μ (BS) 0-3 b	Yes 20.7	\tilde{t}_1 430 GeV	$m(\tilde{q}) \geq 2 m(\tilde{q})$	ATLAS-COIN-2013-007	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow t\bar{t} + \tilde{g}^2$	1-2 e, μ 1-2 b	Yes 4.7	\tilde{t}_1 167 GeV	$m(\tilde{q}) \geq 50 \text{ GeV}$	1205.4905, 1209.2102	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow t\bar{t} + W\tilde{g}$	2 e, μ 0-2 jets	Yes 20.3	\tilde{t}_1 220 GeV	$m(\tilde{q}) \geq m(\tilde{g}) - m(W) - 50 \text{ GeV}, m(\tilde{t}_1) < m(\tilde{q})$	ATLAS-COIN-2013-048	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow t\bar{t} + \tilde{g}^2$	2 e, μ 0-2 jets	Yes 20.3	\tilde{t}_1 150-440 GeV	$m(\tilde{q}) \geq 0 \text{ GeV}, m(\tilde{t}_1) \geq m(\tilde{q}) - 10 \text{ GeV}$	ATLAS-COIN-2013-048	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow t\bar{t} + \tilde{g}^2$	0 2 b	Yes 20.1	\tilde{t}_1 150-590 GeV	$m(\tilde{q}) < 200 \text{ GeV}, m(\tilde{q}) \geq m(\tilde{q}) - 5 \text{ GeV}$	ATLAS-COIN-2013-003	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow t\bar{t} + \tilde{g}^2$	1 e, μ 1 b	Yes 20.7	\tilde{t}_1 200-610 GeV	$m(\tilde{q}) \geq 0 \text{ GeV}$	ATLAS-COIN-2013-037	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow t\bar{t} + \tilde{g}^2$	0 2 b	Yes 20.5	\tilde{t}_1 320-660 GeV	$m(\tilde{q}) \geq 0 \text{ GeV}$	ATLAS-COIN-2013-024	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow t\bar{t} + Z$	2 e, μ (Z) 1 b	Yes 20.7	\tilde{t}_1 500 GeV	$m(\tilde{q}) \geq 150 \text{ GeV}$	ATLAS-COIN-2013-025	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow t\bar{t} + Z$	3 e, μ (Z) 1 b	Yes 20.7	\tilde{t}_1 520 GeV	$m(\tilde{q}) \geq m(\tilde{q}) + 150 \text{ GeV}$	ATLAS-COIN-2013-025	
	EW direct	$\tilde{t}_1 \tilde{t}_1^* \rightarrow e^+e^- + \tilde{g}^2$	2 e, μ 0	Yes 20.3	\tilde{t}_1 85-315 GeV	$m(\tilde{q}) \geq 0 \text{ GeV}$	ATLAS-COIN-2013-049
		$\tilde{t}_1 \tilde{t}_1^* \rightarrow \mu^+\mu^- + \tilde{g}^2$	2 e, μ 0	Yes 20.3	\tilde{t}_1 125-450 GeV	$m(\tilde{q}) \geq 0 \text{ GeV}, m(\tilde{t}_1) \geq 0.5 m(\tilde{q}) + m(\tilde{q})$	ATLAS-COIN-2013-049
$\tilde{t}_1 \tilde{t}_1^* \rightarrow \tau^+\tau^- + \tilde{g}^2$		2 τ 0	Yes 20.7	\tilde{t}_1 180-330 GeV	$m(\tilde{q}) \geq 0 \text{ GeV}, m(\tilde{t}_1) \geq 0.5 m(\tilde{q}) + m(\tilde{q})$	ATLAS-COIN-2013-028	
$\tilde{t}_1 \tilde{t}_1^* \rightarrow \tilde{t}_1 \tilde{t}_1^* + \tilde{g}^2$		3 e, μ 0	Yes 20.7	\tilde{t}_1 600 GeV	$m(\tilde{q}) \geq m(\tilde{q}), m(\tilde{t}_1) \geq 0, m(\tilde{t}_1) \geq 0.5 m(\tilde{q}) + m(\tilde{q})$	ATLAS-COIN-2013-035	
$\tilde{t}_1 \tilde{t}_1^* \rightarrow W\tilde{g} + \tilde{g}^2$		3 e, μ 0	Yes 20.7	\tilde{t}_1 315 GeV	$m(\tilde{q}) \geq m(\tilde{q}), m(\tilde{t}_1) \geq 0, \text{ sleptons decoupled}$	ATLAS-COIN-2013-035	
Long-lived particles		Direct $\tilde{t}_1 \tilde{t}_1^*$ prod., long-lived \tilde{t}_1^*	0 1 jet	Yes 4.7	\tilde{t}_1 220 GeV	$1 - \tau(\tilde{t}_1) < 10 \text{ ns}$	1210.2852
	Stable, stopped \tilde{g} R-hadron	0 1-5 jets	Yes 22.0	\tilde{g} 657 GeV	$m(\tilde{q}) \geq 100 \text{ GeV}, 10 \mu\text{s} < \tau(\tilde{g}) < 100 \mu\text{s}$	ATLAS-COIN-2013-057	
	GMSS, stable \tilde{t}	1-2 μ 0	- 15.0	\tilde{t} 395 GeV	$5 - \text{cl}(\tau) < 50$	ATLAS-COIN-2013-058	
	Direct $\tilde{t}\tilde{t}^*$ prod., stable \tilde{t} or \tilde{t}^*	1-2 μ 0	- 15.0	\tilde{t} 395 GeV	$m(\tilde{t}) = m(\tilde{t}^*)$	ATLAS-COIN-2013-058	
	GMSS, $\tilde{t}_1 \rightarrow \tilde{t}_1^* + \tilde{g}$, long-lived \tilde{t}_1^*	2 γ 0	Yes 4.7	\tilde{t}_1 230 GeV	$0.4 - \text{cl}(\tilde{t}_1^*) < 2 \text{ ns}$	1204.8310	
RPV	$\tilde{t}_1 \rightarrow q\bar{q} + \tilde{g}$ (RPV)	1 μ 0	Yes 4.4	\tilde{t}_1 700 GeV	$1 - \text{res} < \text{cl}(\tilde{t}_1, \tilde{g}) \text{ decoupled}$	1210.7451	
	LPV $p\bar{p} \rightarrow \tilde{t}_1 + X, \tilde{t}_1 \rightarrow e + \mu$	2 e, μ 0	- 4.6	\tilde{t}_1 1.61 TeV	$A_{211} = 0.10, A_{222} = 0.05$	1212.1272	
	LPV $p\bar{p} \rightarrow \tilde{t}_1 + X, \tilde{t}_1 \rightarrow e(\mu) + \tau$	1 $e, \mu + \tau$ 0	- 4.6	\tilde{t}_1 1.1 TeV	$A_{211} = 0.10, A_{222} = 0.05$	1212.1272	
	Bilinear RPV CMSSM	1 e, μ 7 jets	Yes 4.7	\tilde{q}, \tilde{g} 1.2 TeV	$m(\tilde{q}) = m(\tilde{g}), c_{0,1,2} < 1 \text{ mm}$	ATLAS-COIN-2012-140	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow W\tilde{g} + \tilde{g}^2$	4 e, μ 0	Yes 20.7	\tilde{t}_1 760 GeV	$m(\tilde{q}) \geq 300 \text{ GeV}, A_{222} > 0$	ATLAS-COIN-2013-036	
	$\tilde{t}_1 \tilde{t}_1^* \rightarrow W\tilde{g} + \tilde{g}^2$	3 $e, \mu + \tau$ 0	Yes 20.7	\tilde{t}_1 350 GeV	$m(\tilde{q}) \geq 50 \text{ GeV}, A_{222} > 0$	ATLAS-COIN-2013-036	
Other	Scalar gluon	0 4 jets	- 4.6	\tilde{g} 100-287 GeV	incl. limit from 1110.2893	1210.4828	
	WMP interaction (D5, Dirac χ)	0 mono-jet	Yes 10.5	\tilde{M} scale 704 GeV	$m(\tilde{q}) < 80 \text{ GeV}, \text{ limit on } \tilde{M} \text{ GeV for D5}$	ATLAS-COIN-2012-147	

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

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Extended
MSSM
LLP + RPV
Natural SUSY
Incl. searches

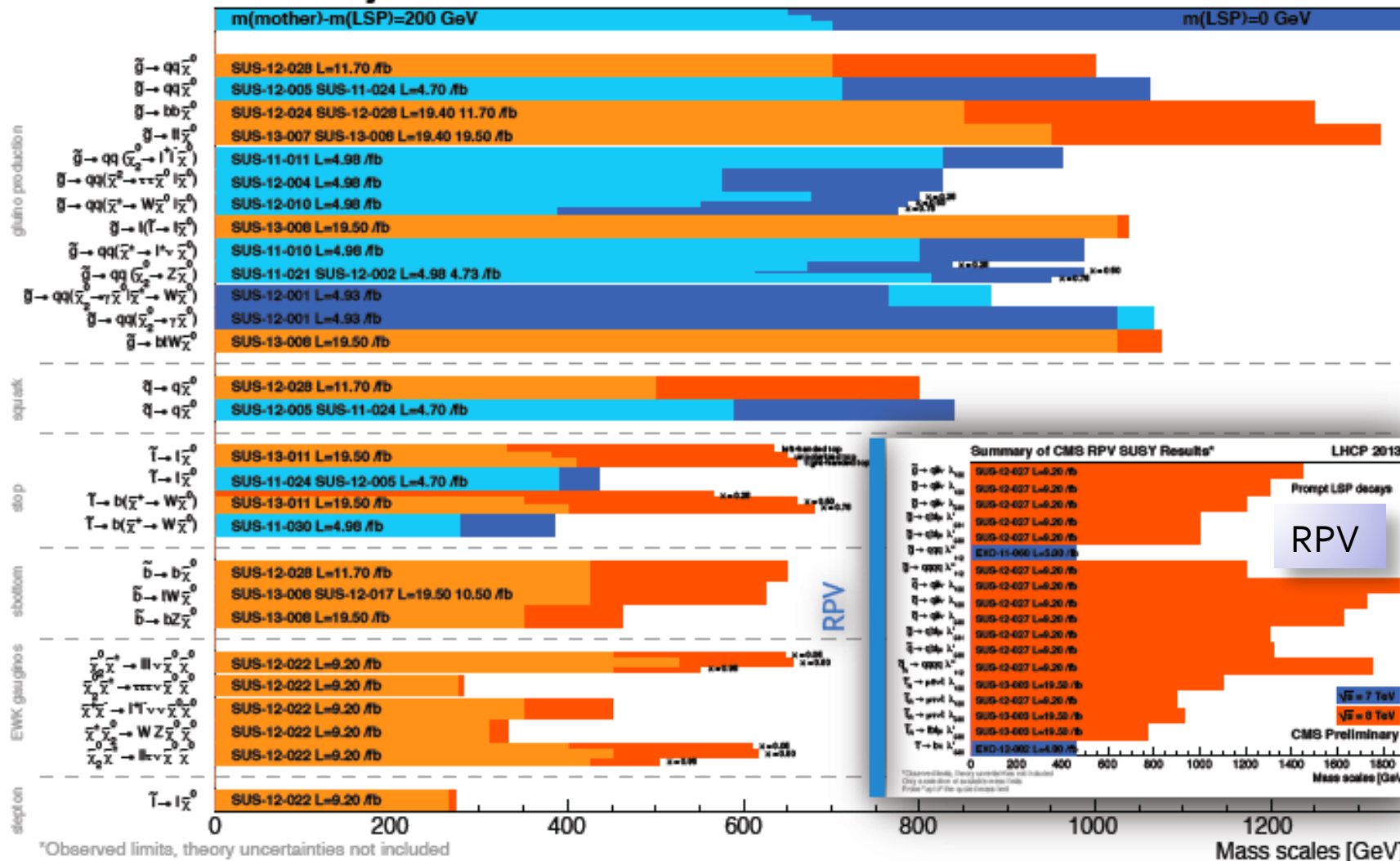
SUSY no show tables

Incl. searches

Natural SUSY

Summary of CMS SUSY Results* in SMS framework

LHCP 2013

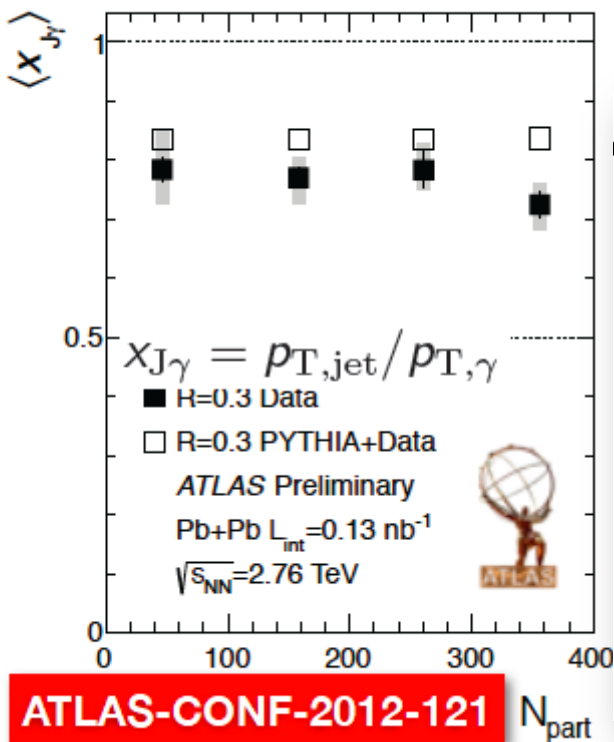


*Observed limits, theory uncertainties not included
 Only a selection of available mass limits
 Probe "up to" the quoted mass limit

Heavy Ions at LHC

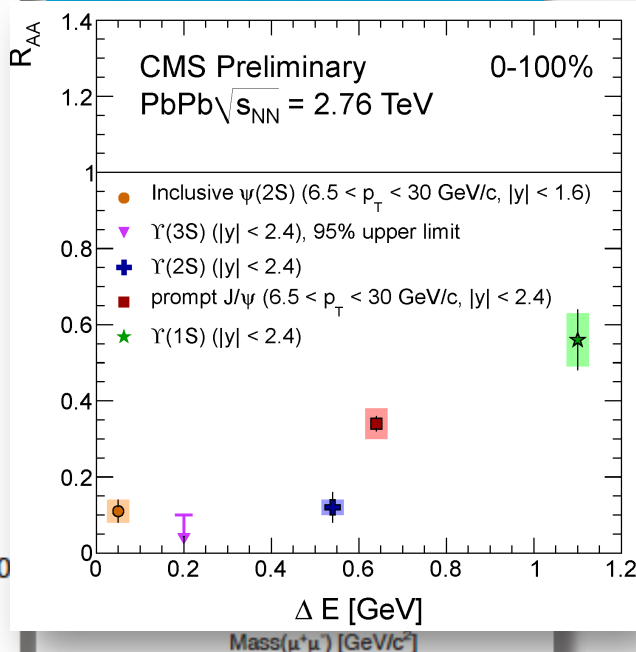
- ◆ Some of the many heavy-ion highlights from the LHC
- ◆ Plus many more results with exclusive strange and charm hadron identification, as well as beauty tagging, completely unique to the LHC experiments

$j+\gamma$ nuclear modification factor

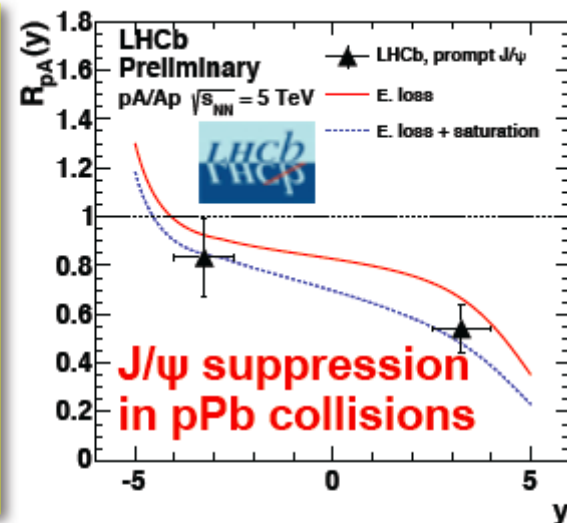


Suppression ordered by binding energy

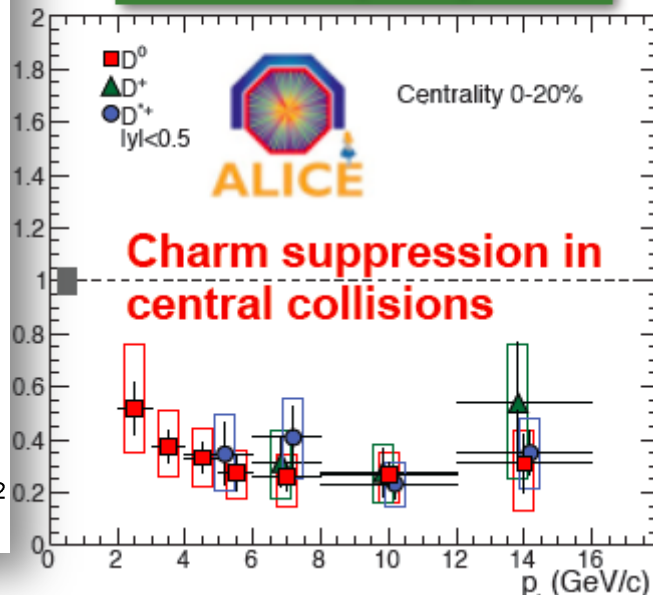
CMS Collaboration



LHCb-PAPER-2013-008



ALICE Collaboration
JHEP 09 (2012) 112

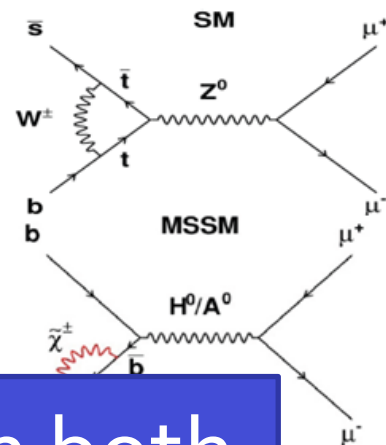


The search for $B_{s(d)} \rightarrow \mu \mu$

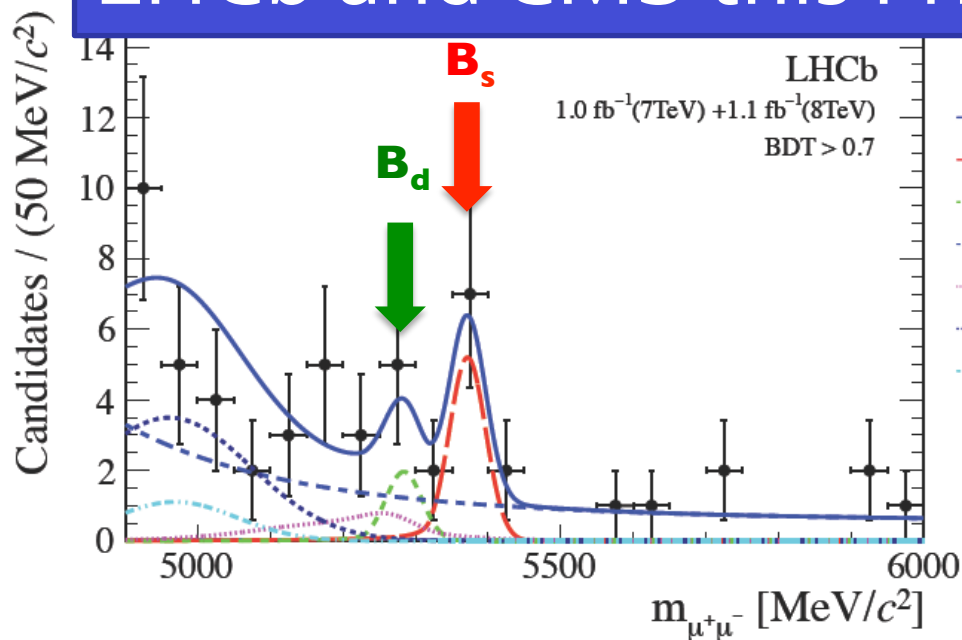
Predicted to be very rare in SM due to GIM & helicity suppression:

Precise predictions in SM:

- $\mathcal{B}(B_s \rightarrow \mu \mu) = 3.5 \pm 0.2 \cdot 10^{-9}$
- $\mathcal{B}(B_d \rightarrow \mu \mu) = 1.1 \pm 0.2 \cdot 10^{-10}$



New results with full dataset from both LHCb and CMS this Friday at EPS !!



the first evidence of $B_s \rightarrow \mu \mu$ decay at $\sim 3.5 \sigma$

$$\mathcal{B}(B^0_s \rightarrow \mu^+ \mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$$

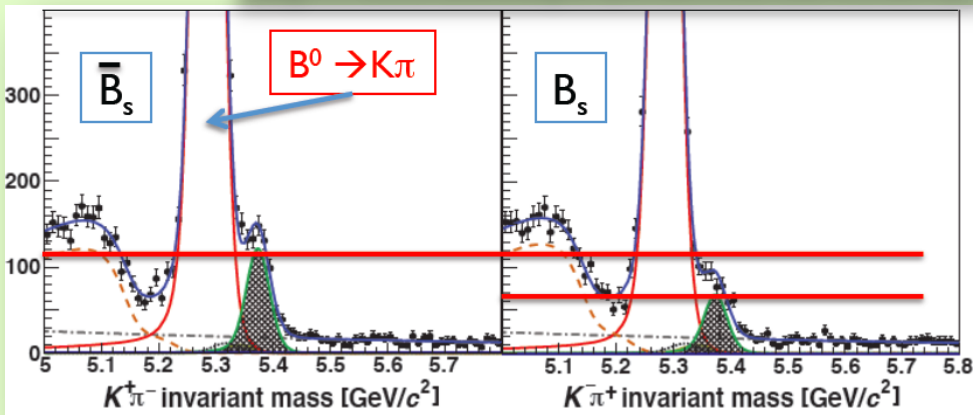
in agreement with SM
 “Background only” p value $\sim 5 \cdot 10^{-4}$

Also best limit on $B_d \rightarrow \mu \mu$

$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) < 9.4 \times 10^{-10} \text{ at 95\% CL}$$

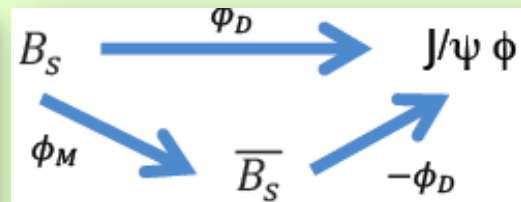
First 5σ observation of CPV in $B_s \rightarrow K\pi$ decays (thanks to RICH)

CPV



CP violating phase $\phi_s = \phi_M - 2\phi_D$

If $\phi_s \neq 0$, New Physics in B_s oscillations?

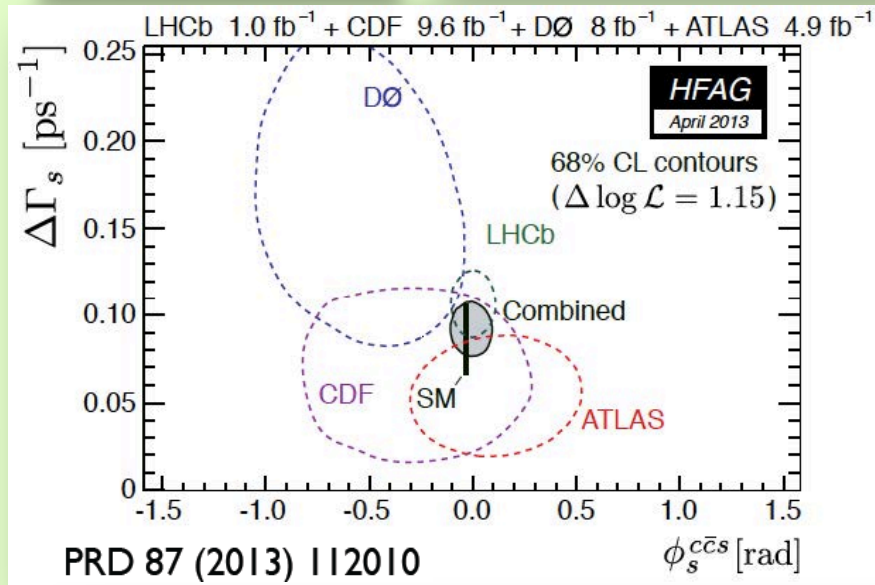


Raw asymmetry is corrected for production and detector asymmetries (small: $\sim 1\%$)

$ACP = 0.27 \pm 0.04 \pm 0.01$ (1 fb^{-1})

4th particle exhibiting CP violation (K^0 [1964], B^0 [2000], B^\pm [2012])

Previous evidence for CPV in charm $D \rightarrow \pi\pi$, KK decays is not confirmed either



$\Phi_s = 0.01 \pm 0.07 \pm 0.01$ rad
 $\Delta\Gamma_s = 0.106 \pm 0.011 \pm 0.007$ ps^{-1}

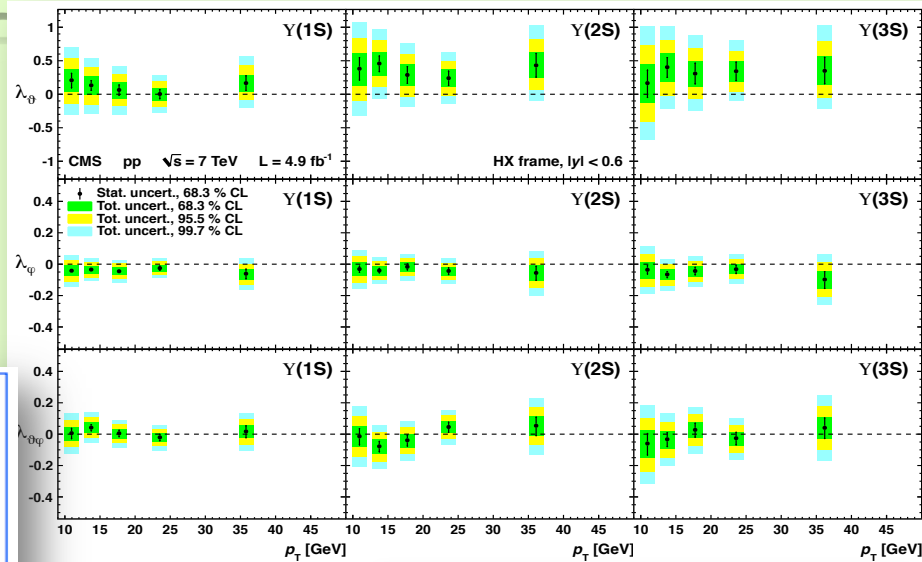
LHCb: $\sigma_t \sim 44$ fs – tagging $\epsilon D^2 \sim 3.5\%$



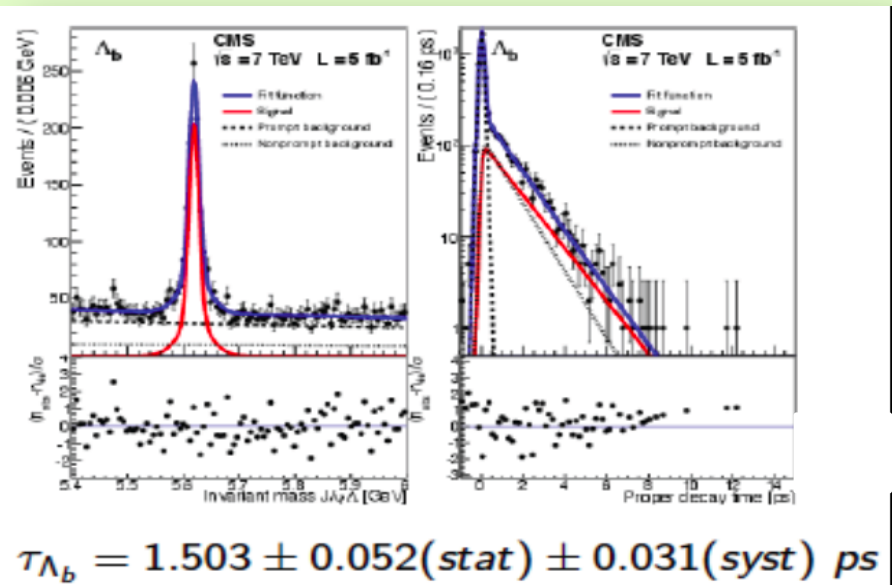
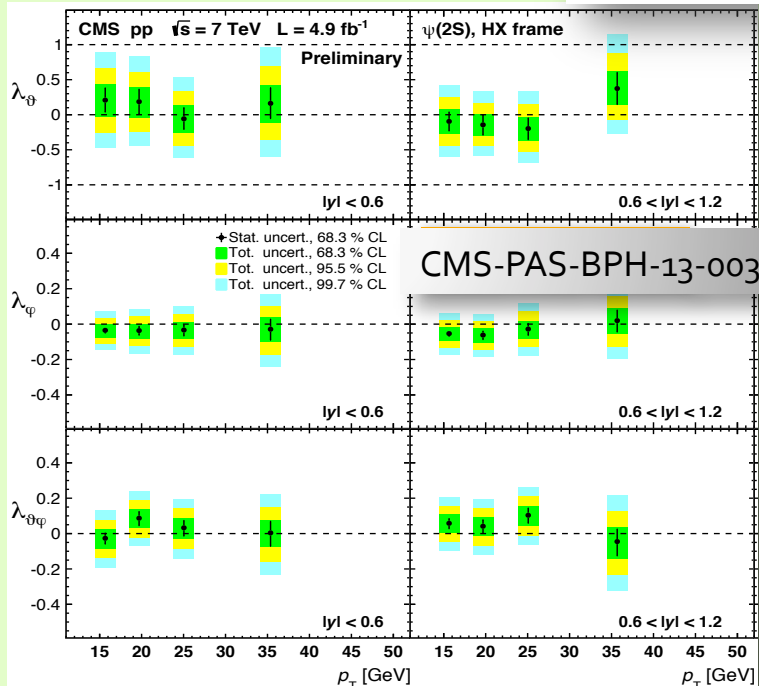
Ψ/Υ Polarization, Λ_b lifetime

- 1st meas. of $\Upsilon(nS)$ polarization at the LHC
 - Now extended to $\Psi(2S)$ polarization measurement
- No evidence for large polarizations
 - An issue for NRQCD that needs to be resolved!

$$\frac{dN}{d\Omega} \propto 1 + \lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos \phi$$



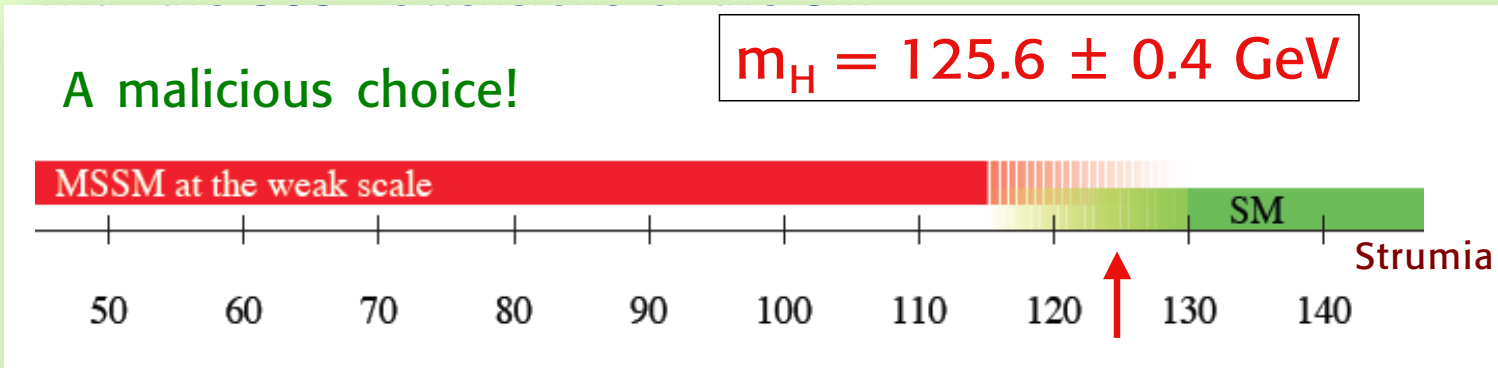
PRL 110 (2013) 081802



Where do we stand now?

The Higgs:
so simple yet so unnatural

Guido Altarelli



*G. Altarelli: <https://indico.cern.ch/conferenceDisplay.py?confId=239571>

UCSB/CERN
J. Incandela
Durham, UK
Invisibles13 Workshop
July 15, 2013

Implications

- 126 GeV Higgs boson
 - Important constraint on “simple” SUSY models
 - Especially if we require “naturalness” values of superpartner masses
 - i.e. avoiding non-fine-tuned solution to the hierarchy problem

*“If not, we would be giving up at least one of the three SUSY ‘miracles’ ” –
Greg Landsberg (CMS Physics Coordinator)*

- If 15% higher, we might have stopped considering MSSM scenarios...
- An interesting situation also in regard to SM
 - Vacuum stability \Rightarrow new physics must come in at $\sim 10^{11}$ GeV
 - $\sim 15\%$ higher, the SM would be fine to the Planck scale

SUSY still fills an obvious gap!

Belief in Principles Paid Off

0, $\frac{1}{2}$, 1, $\frac{3}{2}$, 2



Higgs is first "really new" particle we've seen

An Obvious Gap!

{0, $\frac{1}{2}$, 1, $\frac{3}{2}$, 2}

↑ POSSIBLE, VERY SPECIAL!

SUPERSYMMETRY

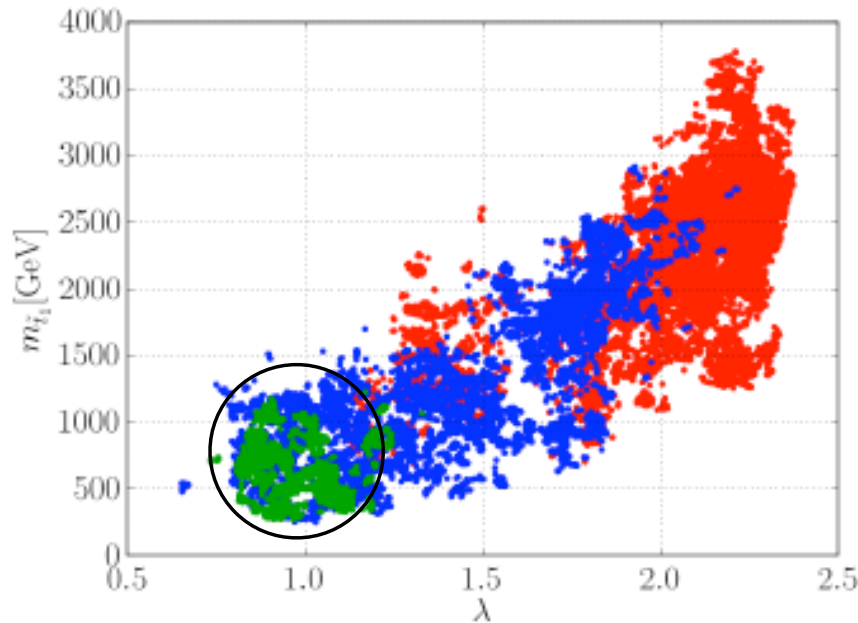
What seems “so simple” may just be more complicated...

Fayet 1975

Two independent reasons to consider it:

1. Add an extra contribution to $m_{hh}^2 = m_Z^2 c_{2\beta}^2 + \Delta_t^2 + \lambda^2 v^2 s_{2\beta}^2$ thus allowing for lighter stops
2. Alleviates fine tuning in v for $\lambda \gtrsim 1$ and moderate $\tan \beta$

$$\left. \frac{dv^2}{dm_{H_u}^2} \right|_{NMSSM} \approx \frac{\kappa}{\lambda^3} \cot 2\beta \quad \text{versus} \quad \left. \frac{dv^2}{dm_{H_u}^2} \right|_{MSSM} \approx \frac{4}{g^2}$$



green points have better than 5% “combined” fine-tuning and $\Lambda_{mess} = 20 \text{ TeV}$ in the scale invariant NMSSM

$$m_{\tilde{t}_1} < 1.2 \text{ TeV}$$

$$m_{\tilde{g}} < 3 \text{ TeV}$$

Gherghetta et al 2012

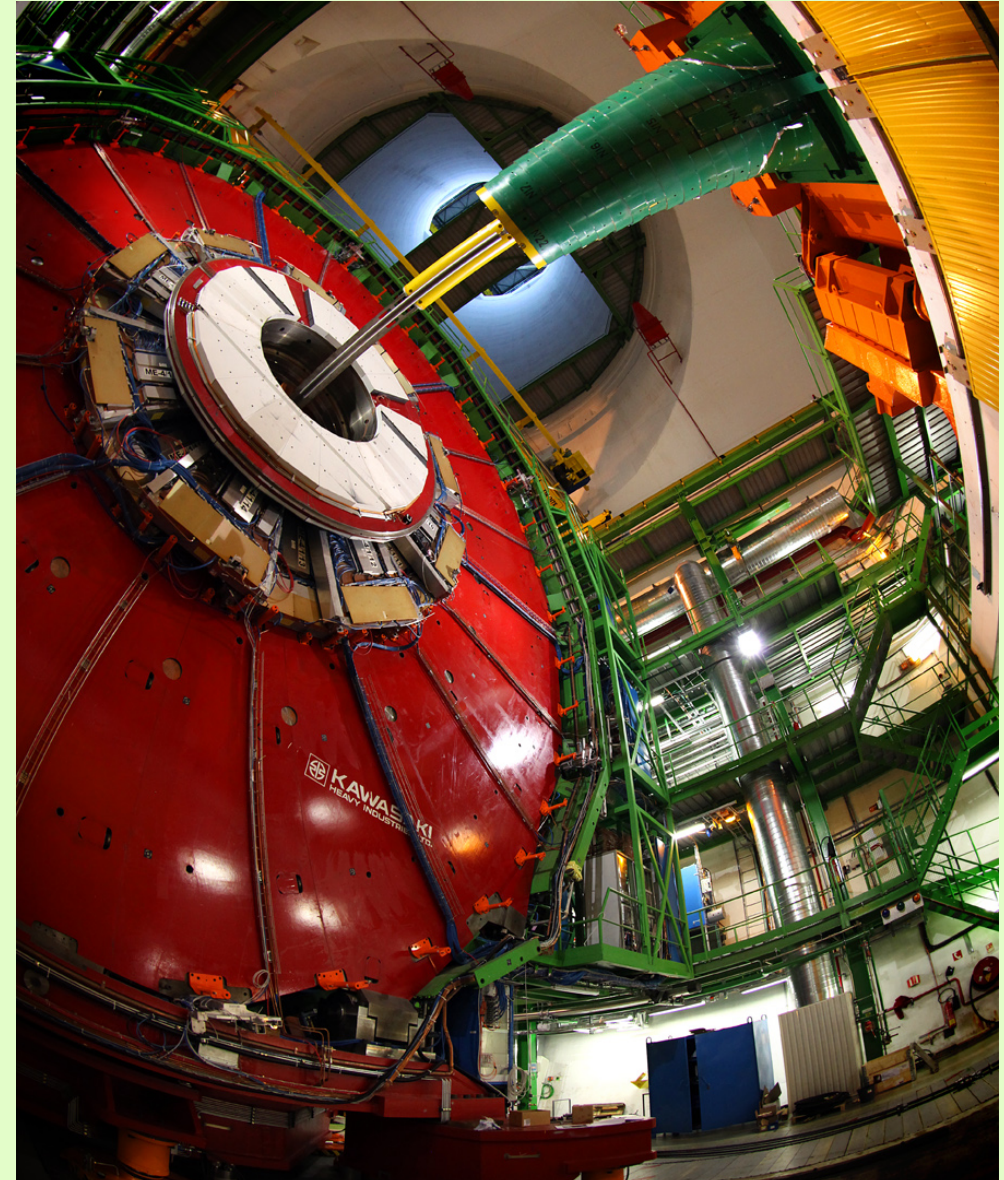
NMSSM as an example

(Talk by R. Barbieri*)

*R. Barbieri: <https://indico.cern.ch/conferenceDisplay.py?confId=239571>

What next?

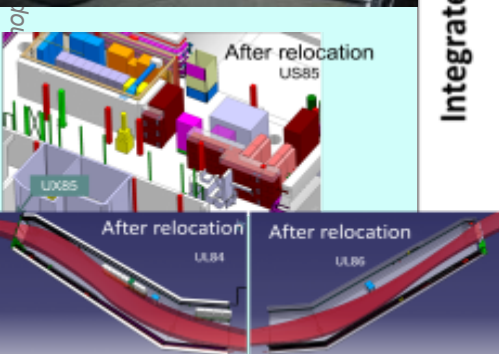
- Run 1 has been a success
 - But the LHC is in its childhood
- Run 2 and beyond
 - Extend searches, precision measurements - significantly
 - For the next 15+ years the LHC is the only Higgs (and top, W, Z ...) factory we have!



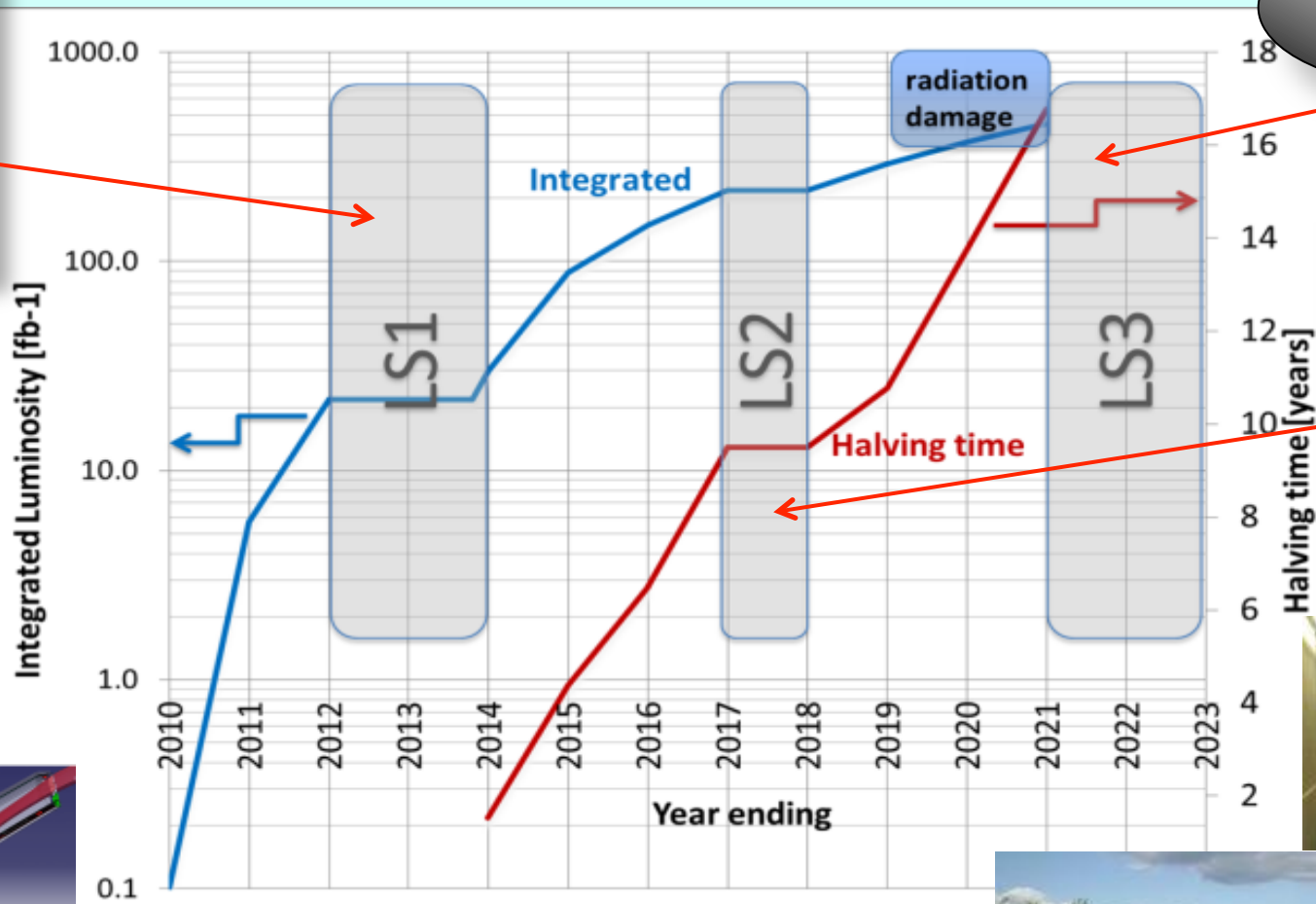
CERN Plan for the next 10 years

RN

Shut down to fix interconnects and overcome energy limitation (LHC incident of Sept 2008) and R2E



July 15, 20



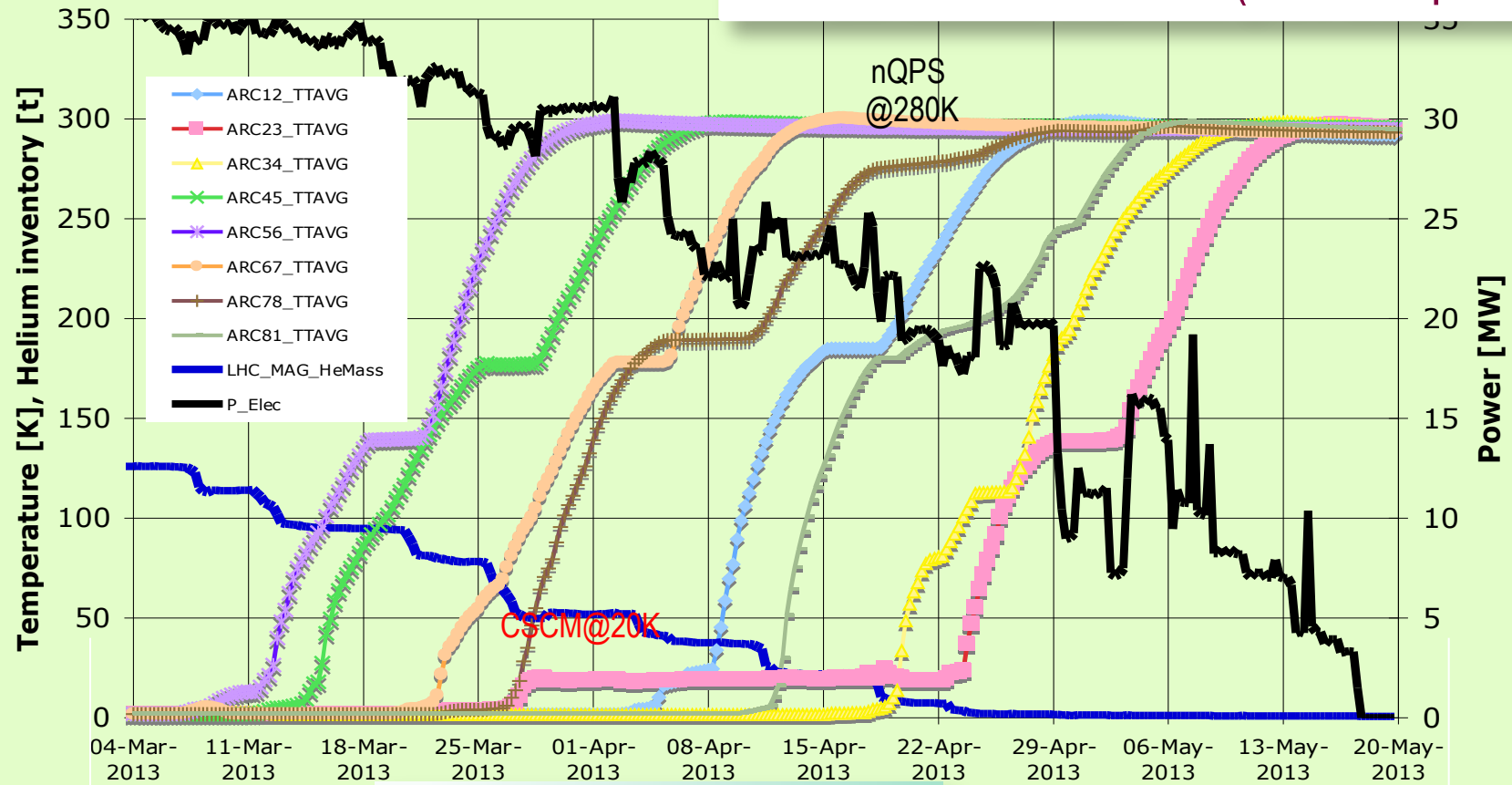
HiLumi LHC

Shut down to overcome beam intensity limitation (Injectors, collimation and more...)



LHC Warm-UP 2013

Few perturbations (EL, CV, controls),
Few issues with HW (HX-Comp-Tu)



Done in 10 weeks !!!

- Physics
- Beam commissioning
- ShutdownTests

LS1

16th Feb. 2013 – Dec. 2014

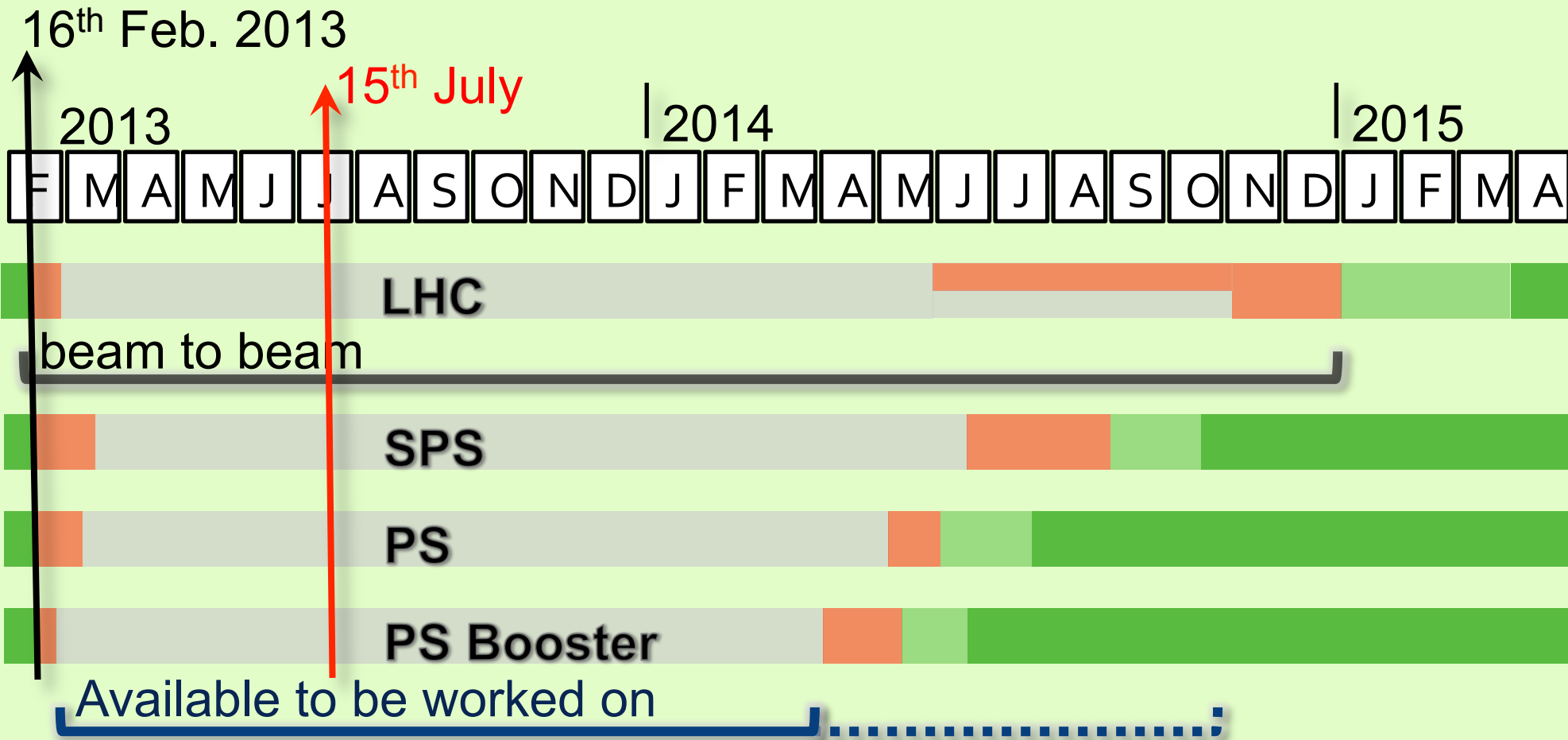
UCSB/CERN

J. Incandela

Durham, UK

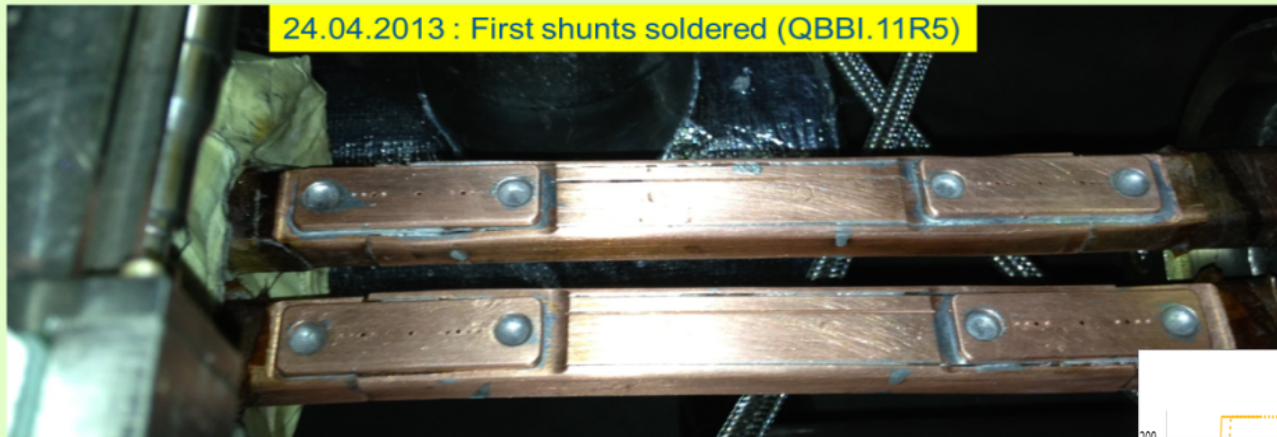
Invisibles13 Workshop

July 15, 2013

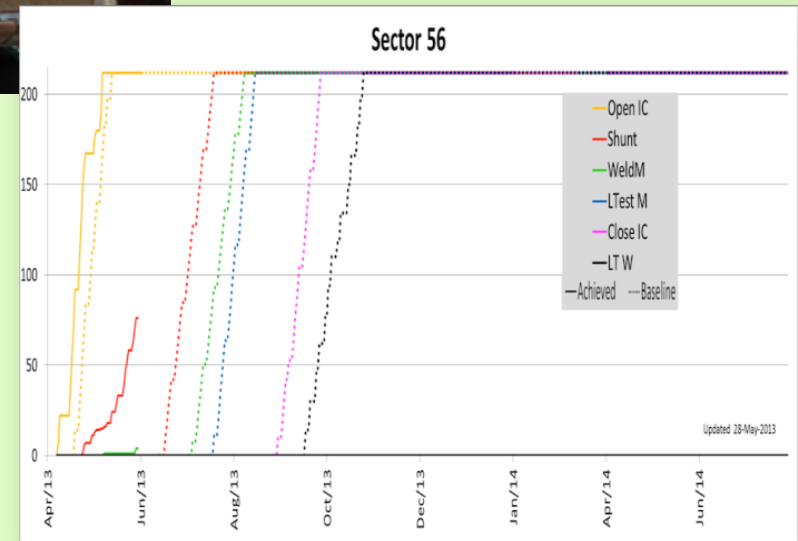


SMACC: Installation of shunts

- >160 IC in sector 56 (75% of one sector) are now equipped with shunts (almost 10% of the LHC, 2560 shunts)
- Started ahead of schedule, learning for critical activity



First shunt soldered on 24.04.2013





Run 2: ca. 2015-2018

*Illustrate for CMS,
same generally
applies to ATLAS*

Basically, life will not be easy...

Pileup ~ 50 at 25 ns and $L = 2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$

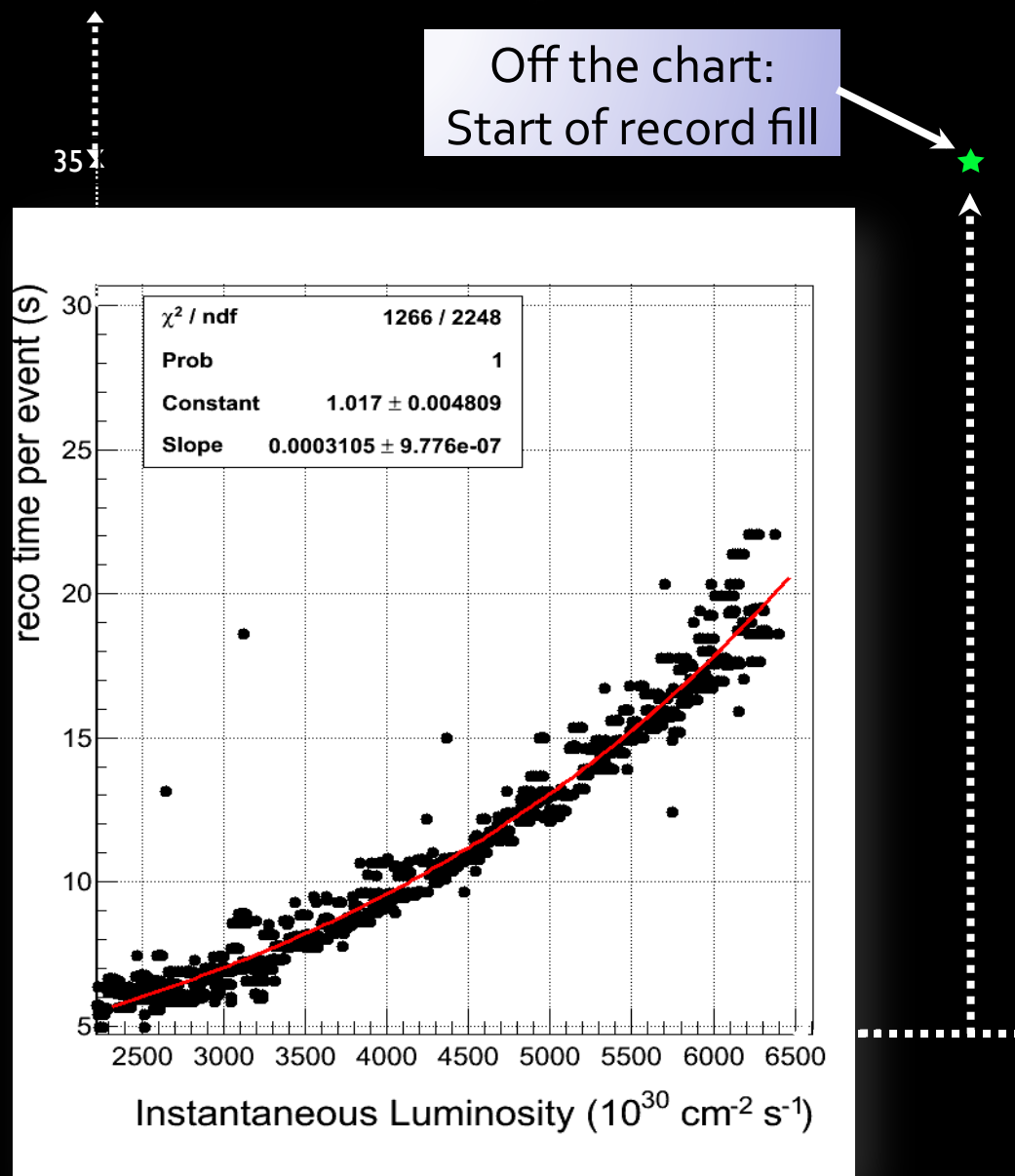


Looking Ahead to Run 2: Summary of Challenges

- CPU for 2015 (25 ns bunch spacing, $L = 1.5E34 \text{ cm}^{-2}\text{s}^{-1}$):
 - x10 CPU required in 2015.
 - x2 or more from trigger rate;*
 - x2.5 from in-time pile up;*
 - x2 from out of time pileup at 25 ns (worse for luminosity leveling at 50 ns)*

- Improvements are *crucial*
 - Faster algorithms needed:
 - *A first example; increase tracking cluster charge thresholds*

- A real challenge
 - Requires a lot of expertise.
 - *Work for next 2 years will be very challenging*

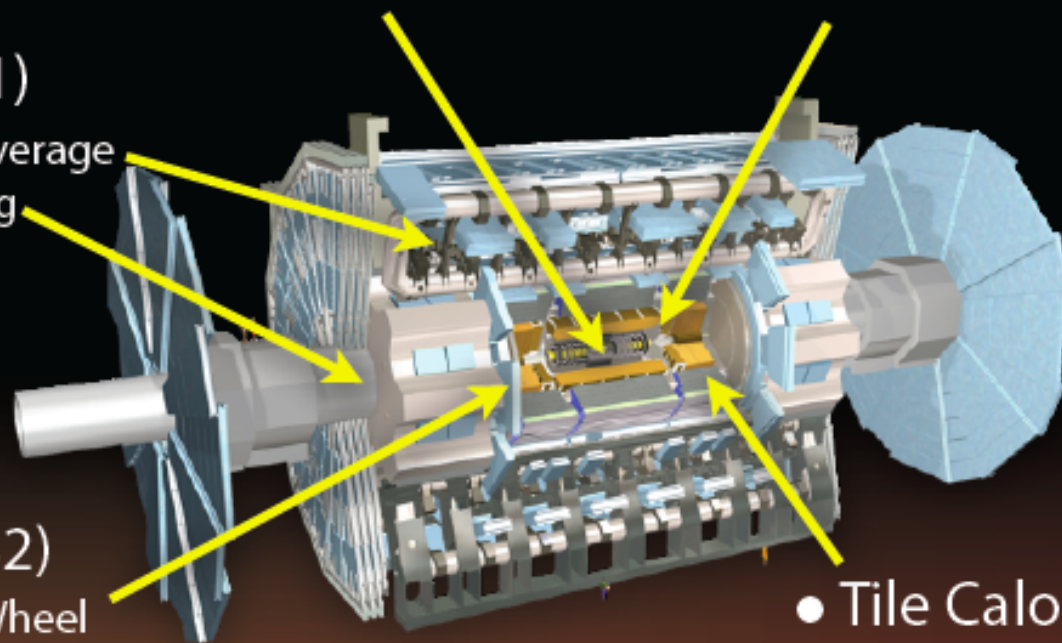


ATLAS Upgrades up to Phase-1



- Insetable B-Layer (LS1)
 - ➔ and new services for Pixels
- LAr Calorimeter (LS2)
 - ➔ fine granularity readout for Level-1

- Muons (LS1)
 - ➔ complete coverage
 - ➔ new shielding



- Level-1 Trigger
 - ➔ new electronics
 - ➔ topological trigger (phased in before LS2)

- Muons (LS2)
 - ➔ New Small Wheel

- High Level Trigger farm (phased in before LS2)

- Tile Calorimeter (LS2)
 - ➔ new gap scintillators
 - ➔ new trigger electronics

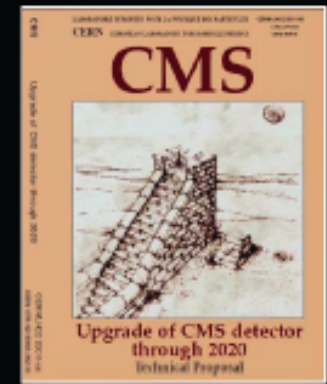
- ATLAS Forward Physics AFP
 - ➔ 210m downstream from P1 (before LS2)

- Fast Track Trigger FTK (LS2)
 - ➔ HW tracking input to Level-2



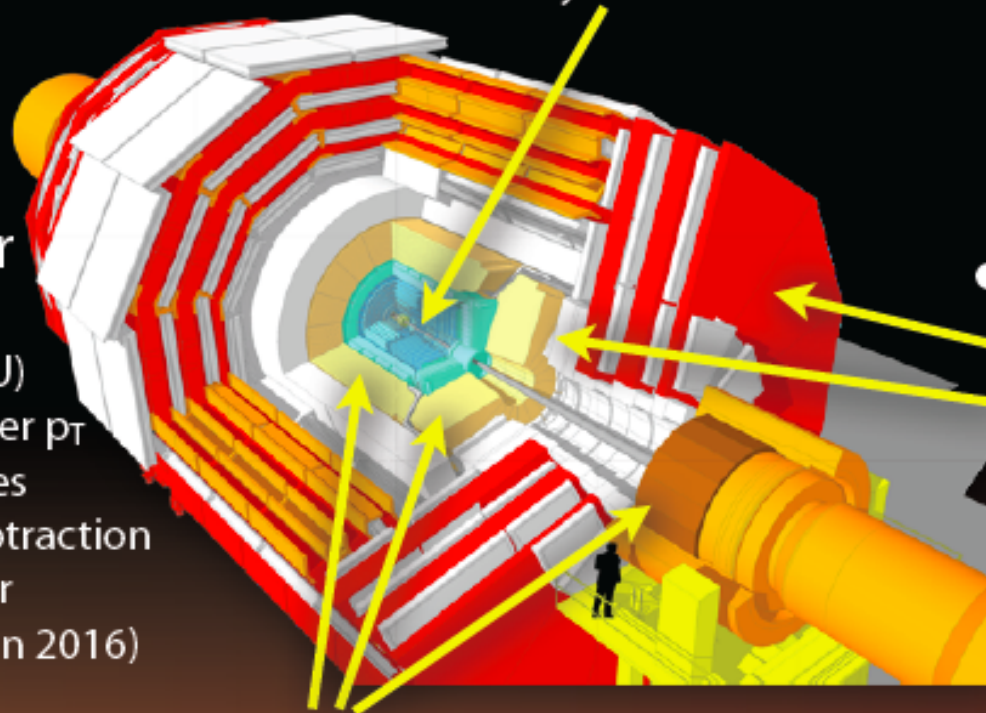
CMS Upgrades up to Phase-1

- new Pixel detector
 - ➔ installation in 2016/17 in end of year shutdown



- Level-1 Trigger

- ➔ new electronics
 - e, γ isolation (PU)
 - μ isolation, better p_T
 - narrower τ -cones
 - jets with PU subtraction
- ➔ topological trigger (ready for operation in 2016)



- Muons (LS1)

- ➔ complete coverage
- ➔ increase CSC readout granularity

- Hadron Calorimeters (LS2)

- ➔ new photodetectors, higher Level-1 granularity
 - better background rejection using timing
- ➔ longitudinal segmentation (5 HB and 3 HE segments)

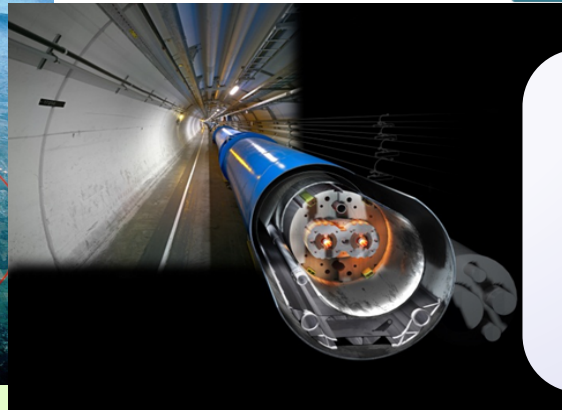
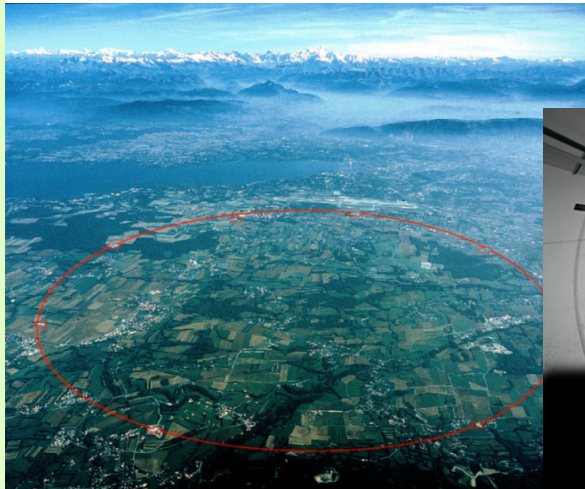
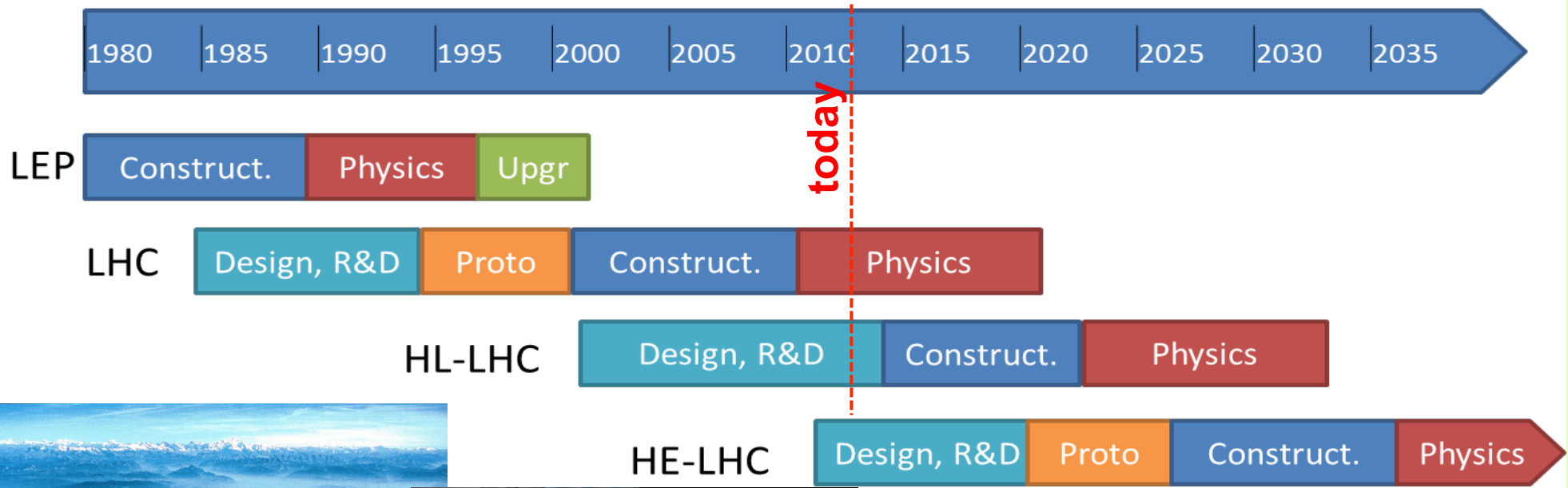


High Luminosity LHC (HL-LHC) and beyond

Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030

- European strategy update document: Approved by CERN Council in May

Injectors, LEP/LHC tunnel, infrastructures



2000 large magnets of 15-20 T
1500 tons of HEP grade Nb₃Sn
500 tons of HTS for magnets
100 tons of SC for Sc links

Courtesy L. Rossi



New CMS Higgs projections for 300(o) fb⁻¹

UCSB/CERN

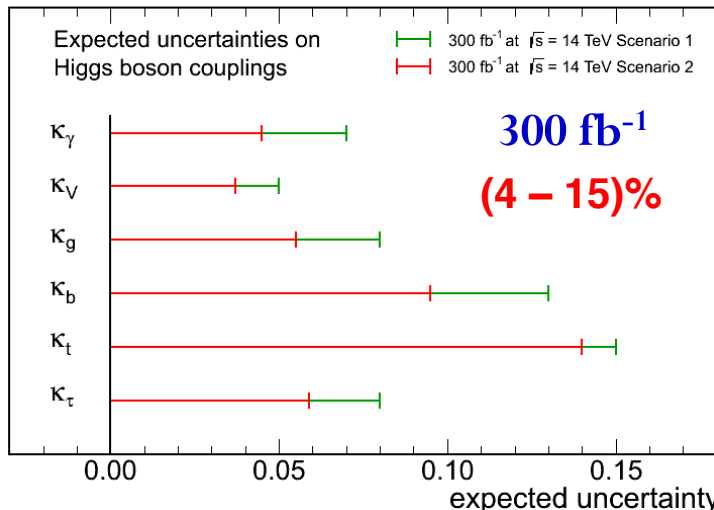
J. Incandela

Durham, UK

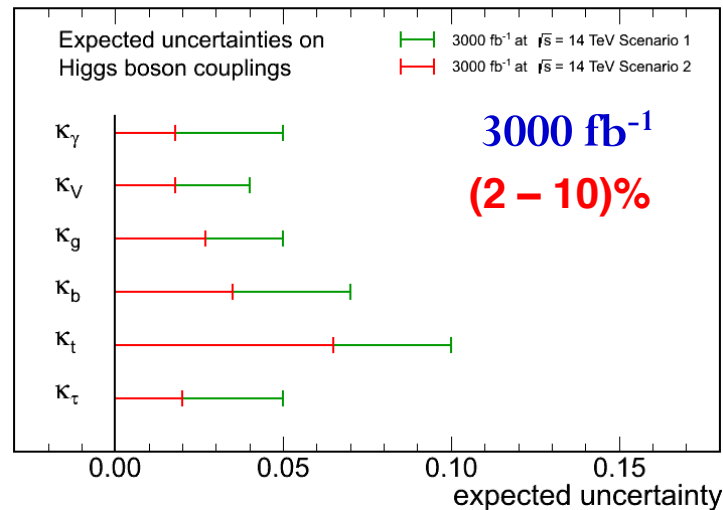
Invisibles13 Workshop

July 15, 2013

CMS Projection (Prelim.)



CMS Projection (Prelim.)



Numbers in brackets are % uncertainties on coupling deviations for [scenario 2, scenario 1]

L (fb ⁻¹)	κ_γ	κ_V	κ_g	κ_b	κ_t	κ_τ
300	[5, 7]	[4, 5]	[6, 8]	[10, 13]	[14, 15]	[6, 8]
3000	[2, 5]	[2, 3]	[3, 5]	[4, 7]	[7, 10]	[2, 5]

Goal: ultimate precision of ~5% or better

July 1, 2013

J. Olsen – Snowmass Energy Frontier Workshop

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Bracket precision estimates

1. Systematics unchanged
2. Theory uncertainties reduced 1/2, all other systematics $\sim 1/\sqrt{(fLdt)}$

Upgrades target precision Higgs measurements with pileup ~ 140 !!
 (25 ns and $L = 5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$)

CMS Phase-2 Upgrades

• Muons

- ➔ complete RPCs in forward region with new technology, GEM or GRPCs
- ➔ extend η coverage ?

• new Inner Tracker

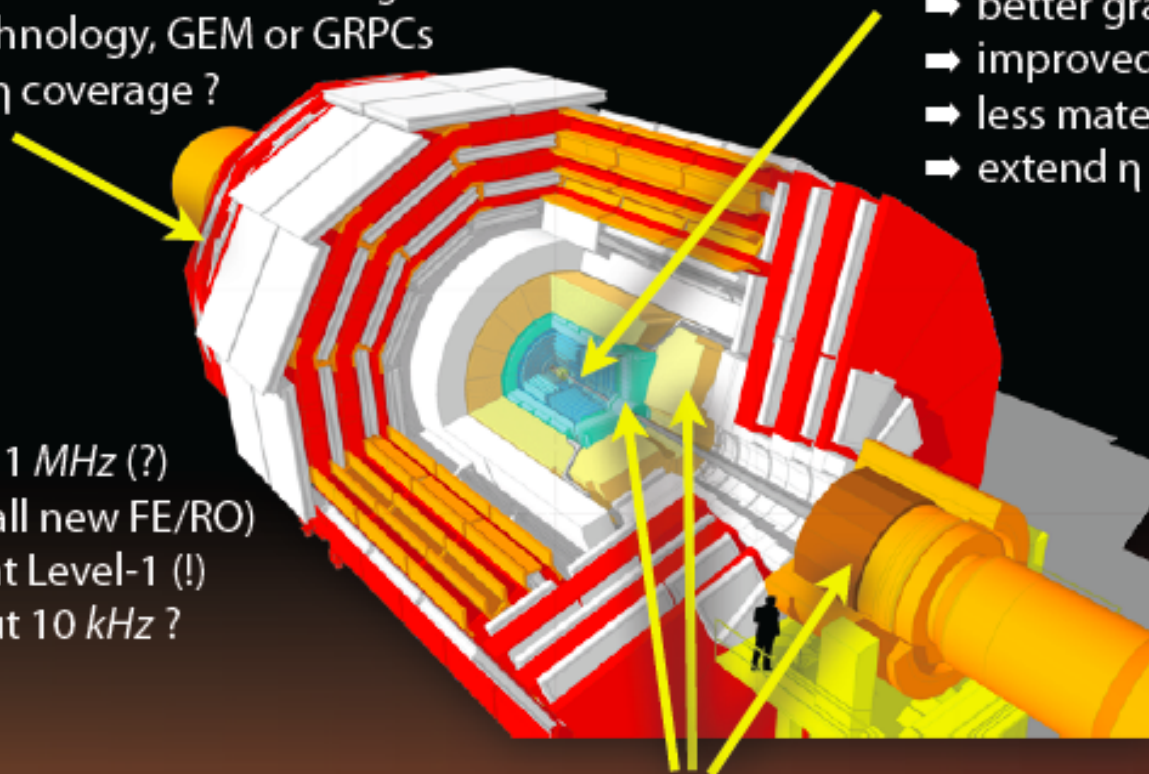
- ➔ radiation hardness
- ➔ better granularity and faster links
- ➔ improved precision
- ➔ less material
- ➔ extend η coverage ?

• T/DAQ

- ➔ Level-1 at 1 MHz (?)
(requires all new FE/RO)
- ➔ Tracking at Level-1 (!)
- ➔ HLT output 10 kHz ?

• upgrade/replace Forward Calorimeters

- ➔ extend η coverage ?
- ➔ mitigate pileup effects with tracking and precise timing

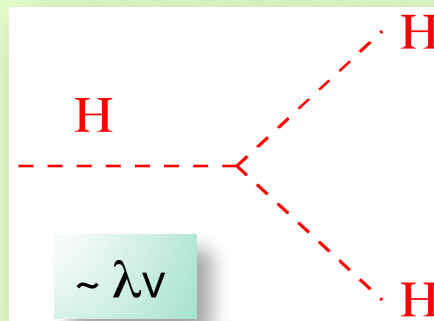
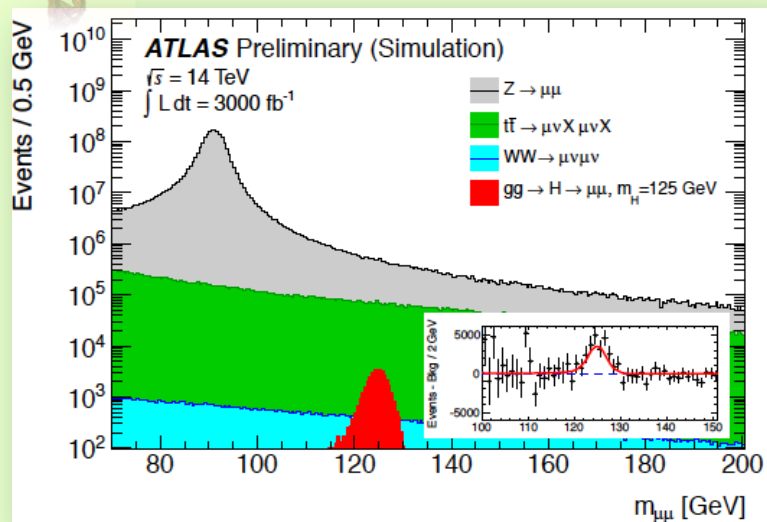


Technical
Proposal
in 2014

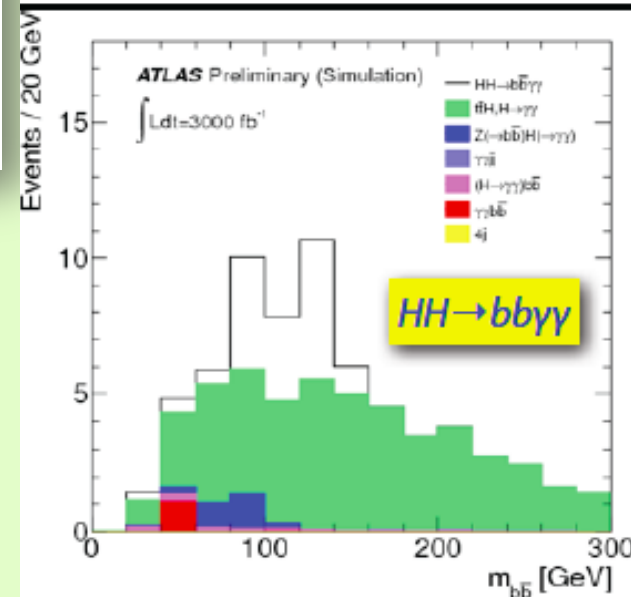
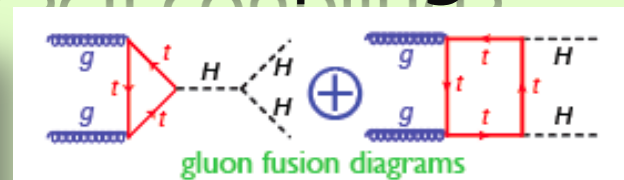




ATLAS Projections: rare decays, self couplings



$$m_H^2 = 2 \lambda v^2$$



Atlas-PHYS-PUB-2013-01

- $H \rightarrow \mu\mu$
 - Low rate and S/B only 0.2%
 $> 6\sigma$ with 3000 fb^{-1}
- $t\bar{t}H, H \rightarrow \mu\mu$
 - ~ 30 events at 3000 fb^{-1}
 \Rightarrow top- and μ -Yukawa couplings with a precision on total signal strength of 25%

- Higgs self-couplings: $\sim 3\sigma$ from
 - $HH \rightarrow bb\gamma\gamma$ channel with 3000 fb^{-1}
 - $HH \rightarrow bb\tau\tau$ also promising $\pm 30\%$ on $\lambda/\lambda_{\text{SM}}$ may be achieved

ATLAS Phase-2 Upgrades

- new Inner Tracker

- ➔ radiation hardness
- ➔ better granularity and faster links
- ➔ improved precision
- ➔ less material
- ➔ extend η coverage ?

- LAr and Tile Calorimeter

- ➔ new FE and BE electronics

- T/DAQ

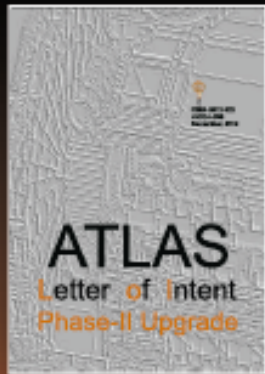
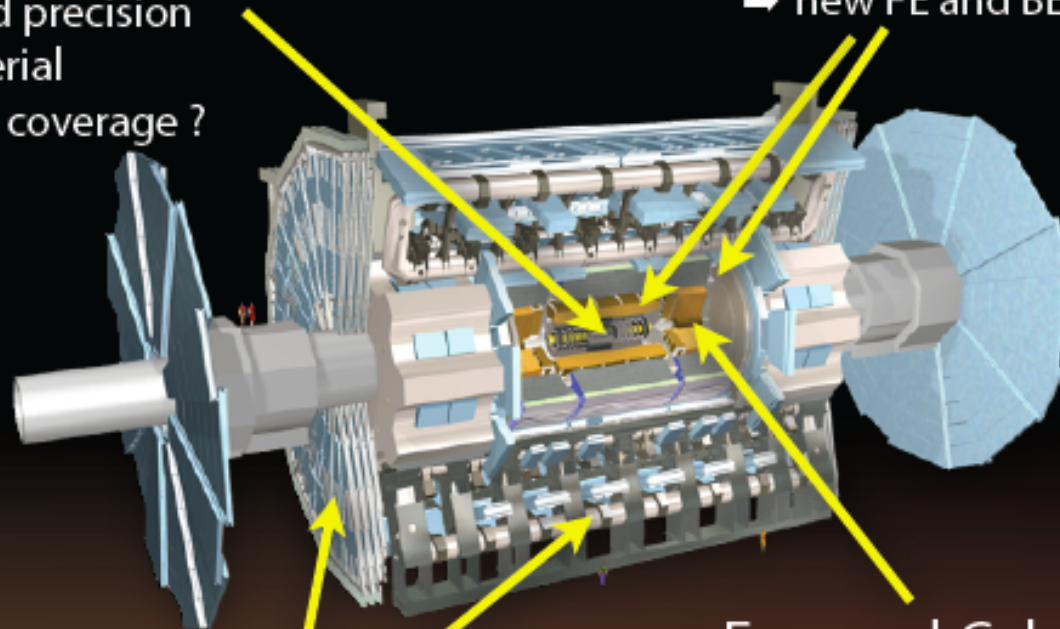
- ➔ Level-0 at 500 kHz
- ➔ Tracks at Level-1
- ➔ 200 kHz input to HLT
- ➔ output 5 kHz ?

- Forward Calorimeters

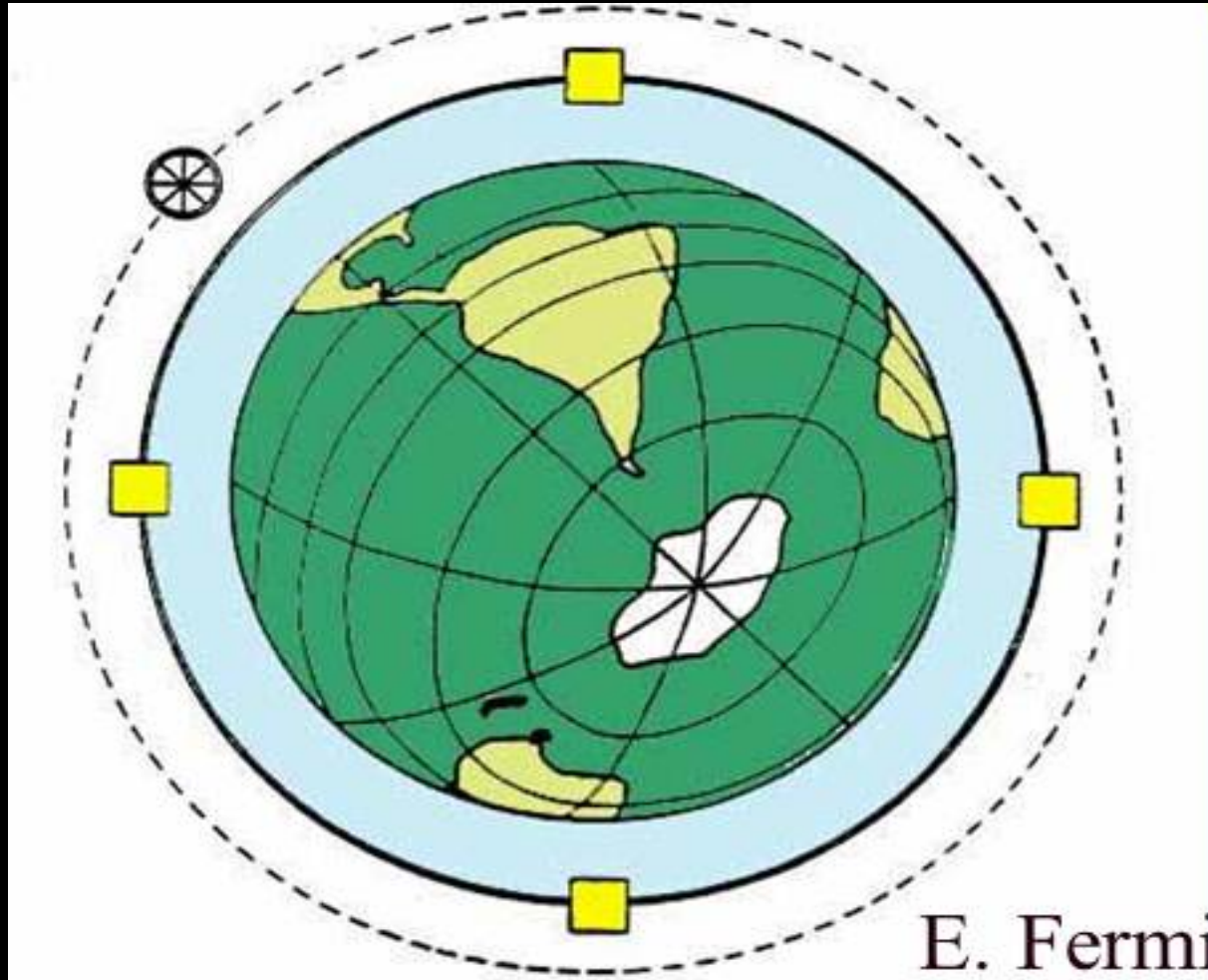
- ➔ replace FCal ?
- ➔ replace HEC cold electronics ?

- Muons

- ➔ new FE electronics
- ➔ improved resolution

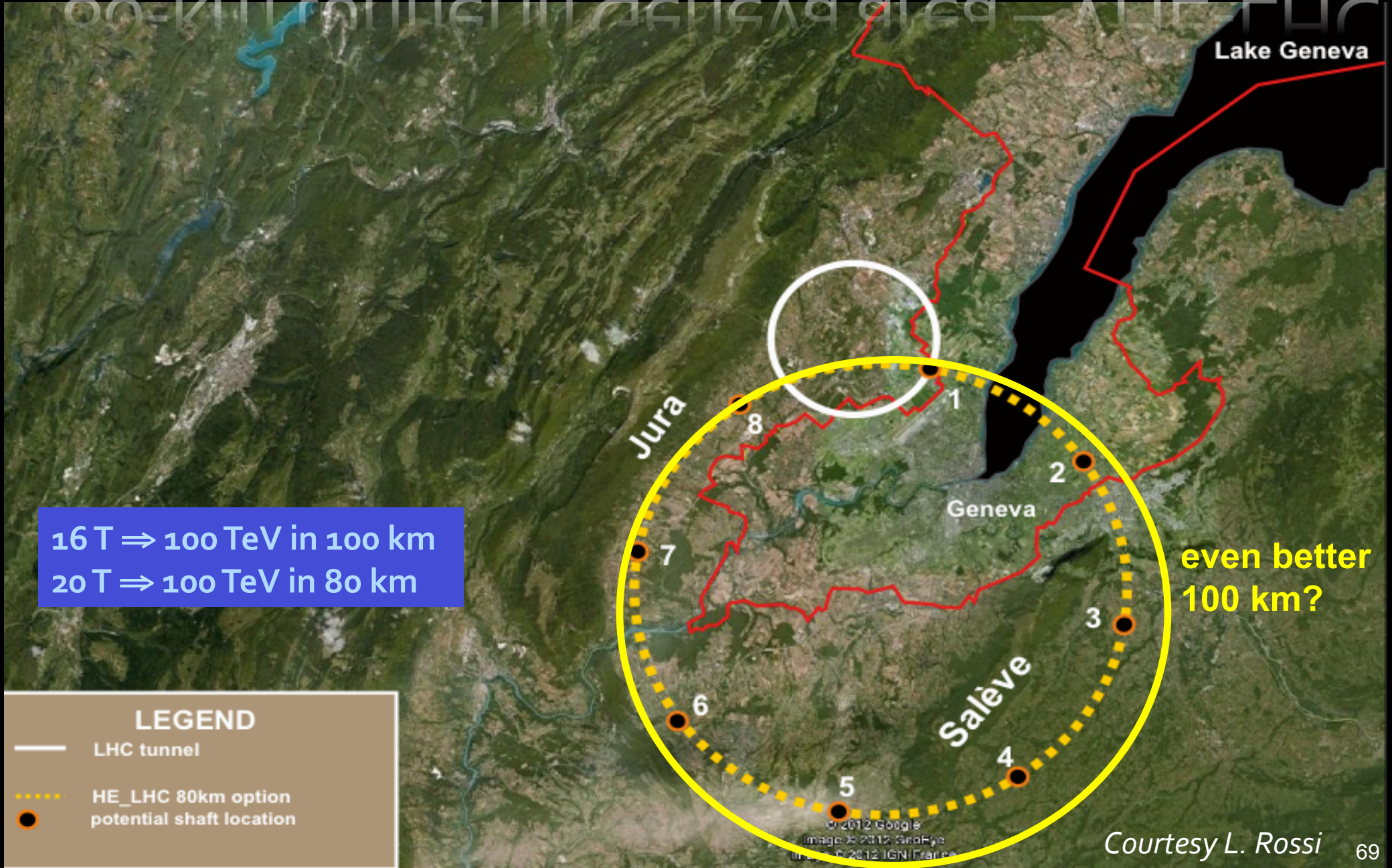


Further into the Future...



Well, maybe not quite this far forward...

80-km tunnel in Geneva area – VHE-LHC



Advancing on 5 fronts

1. *Run 1 Physics*
2. *LS1 consolidation*
3. *Phase 1 Upgrades*
4. *Run 2 preparation of detector, operations, computing, offline, trigger and simulations for physics*
5. *Phase 2 simulation studies to converge on cost, scope, possible baseline scenario(s) plus (staged) options*