The LHC Start-up and Run-II & III Prospects

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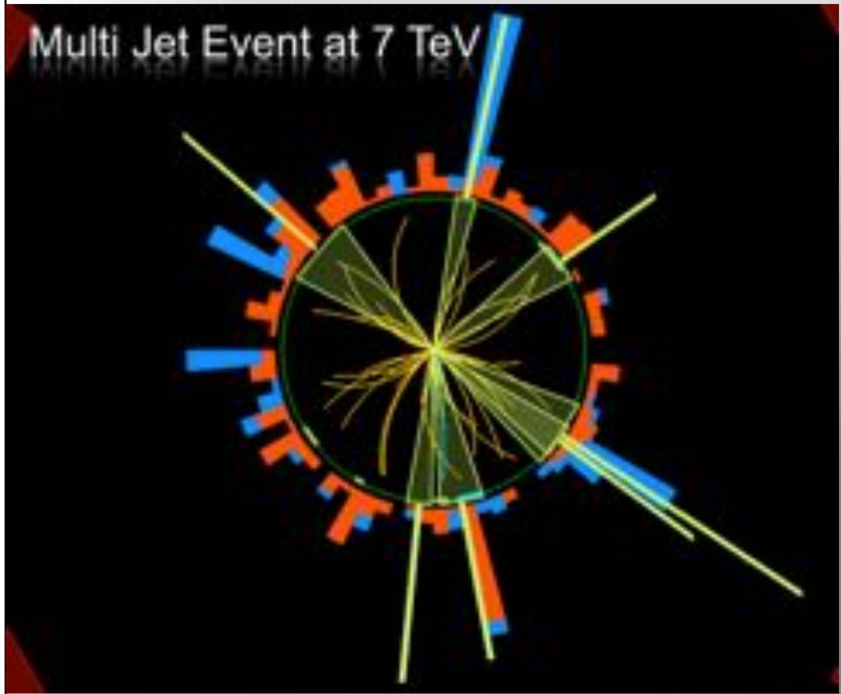
Antwerp University Belgium
UC-Davis California USA
IPPP, Durham UK
BUE, Cairo, Egypt
NTU, Singapore

UCDavis California
5th May 2015



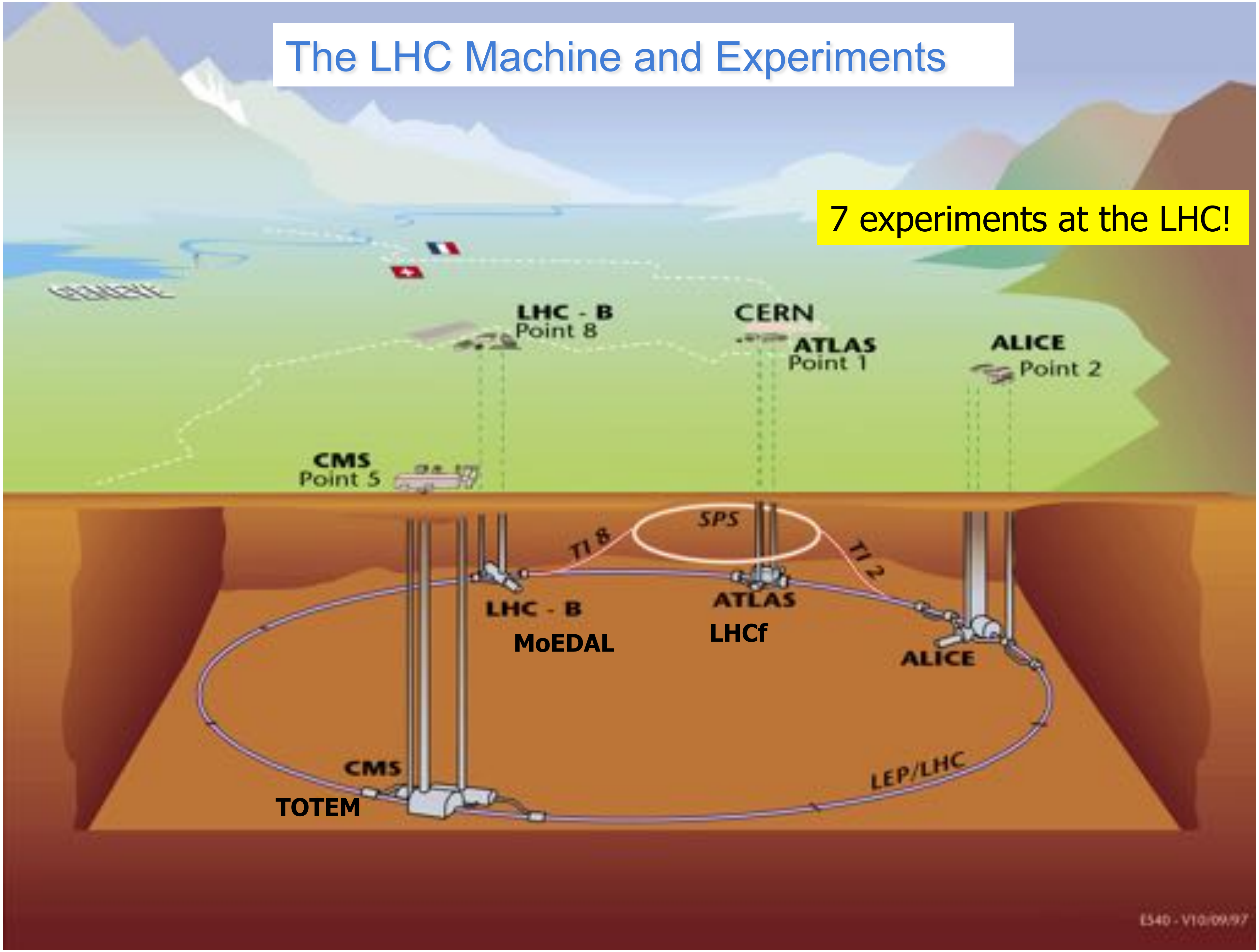
Outline

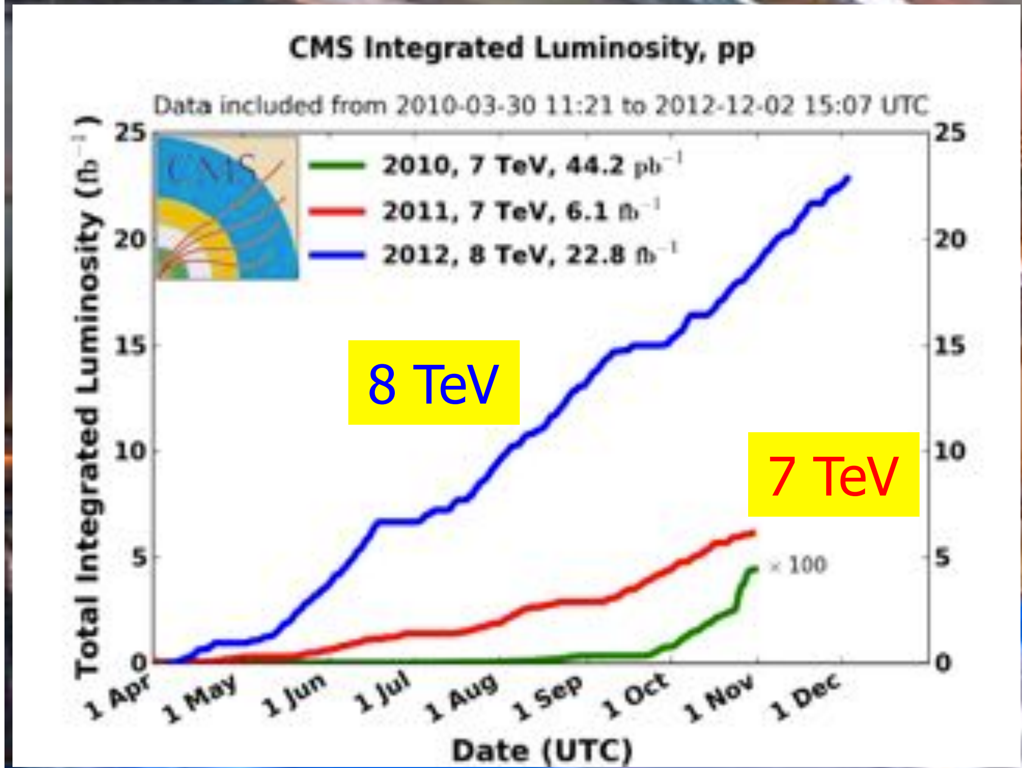
- The LHC today and the near future
- Start-up physics in 2015
- Status of the Higgs search and expectations for run II and run III
- Moment of truth: Desperately seeking New Physics in run II/III?
- Summary

The LHC: Past and Future

The LHC Machine and Experiments

7 experiments at the LHC!





LHC did very well in 2011/2012

2011: luminosity $3 \cdot 10^{33}$ cm^{-2} s^{-1} $\Rightarrow$ 5 fb^{-1} collected in total

2012: luminosity $7.8 \cdot 10^{33}$ cm^{-2} s^{-1} $\Rightarrow$ 20 fb^{-1} collected in total

LHC: Coming Back Alive

Circuit	Status	#M Firm 1	#M Firm 2	#M Firm 3	#MQ Firm 1	#MQ Firm 2	#MQ Firm 3	#MQ total	#CQ total
RB.A12	11080 A reached	50	96	9	2	1	4	7	7
RB.A23	11080 A reached	56	58	40	0	2	15	17	17
RB.A34	11080 A reached	44	61	29	1	7	8	16	16
RB.A45	11080 A reached	48	44	62	-	3	48	51	49
RB.A56	11080 A reached	28	42	84	0	0	18	18	17
RB.A67	11080 A reached	57	36	61	0	1	21	22	21
RB.A78	11080 A reached	53	40	61	2	10	7	19	19
RB.A81	11080 A reached	64	24	66	0	3	26	29	26

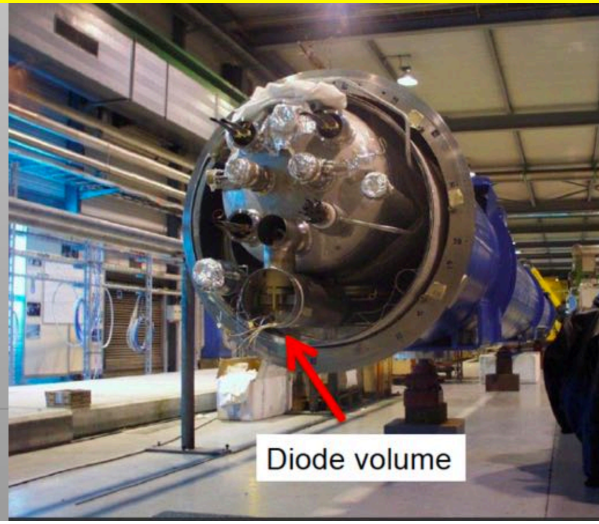
Still a lot of validation/commissioning to be done with beam in the next 4 weeks…

End of March:

Sector 3-4 showed a fault to ground in the last steps!!

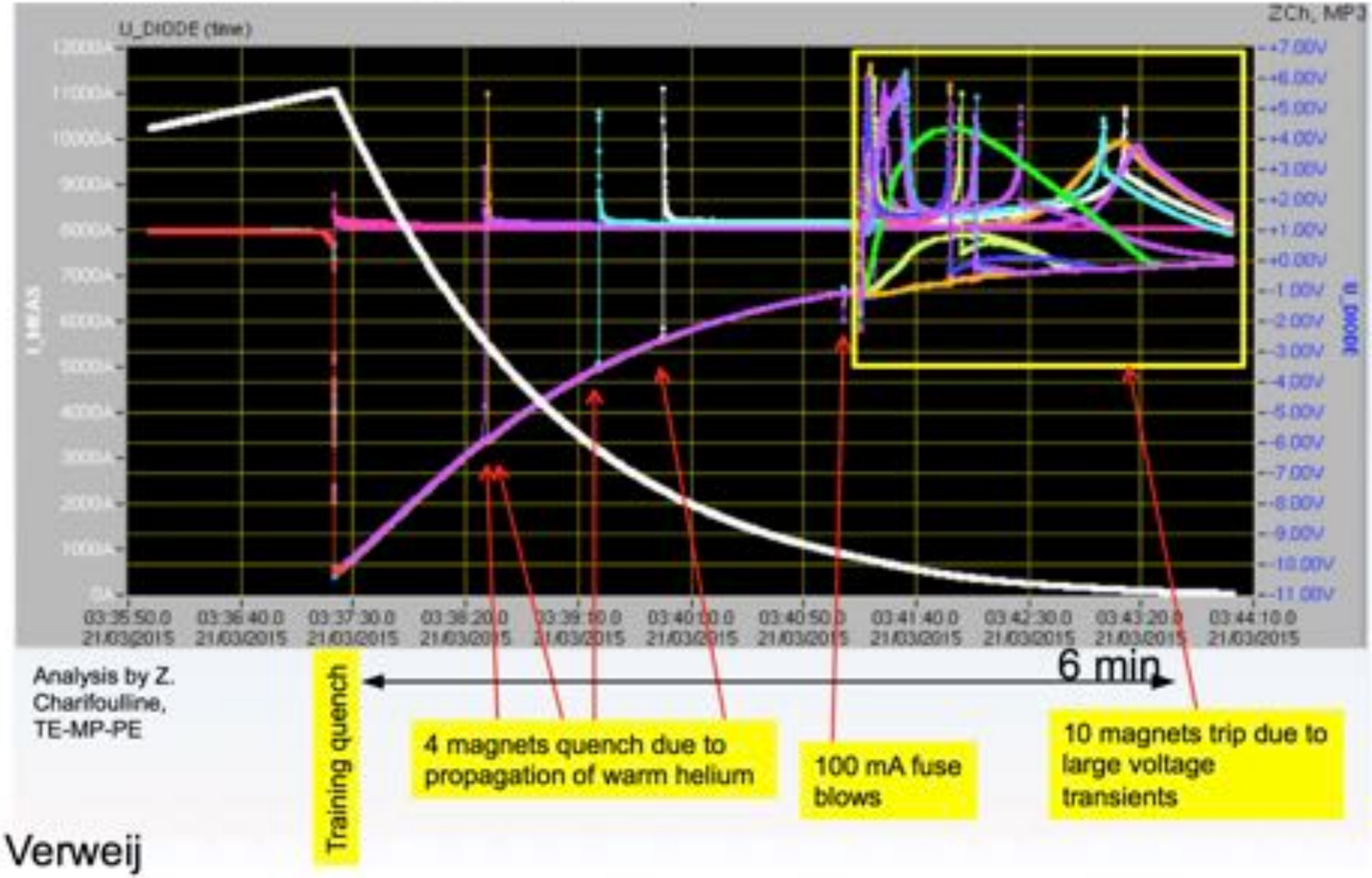
The short could be burnt away in the week before Easter. Oufff!

Delay~ 2 weeks



Earth fault in S34

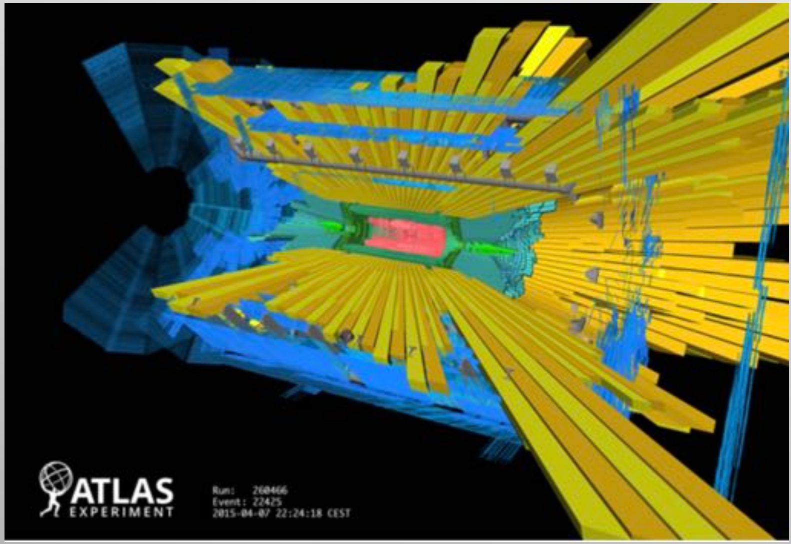
A spectacular Quench while training S34:
14 magnets quenched within 6min

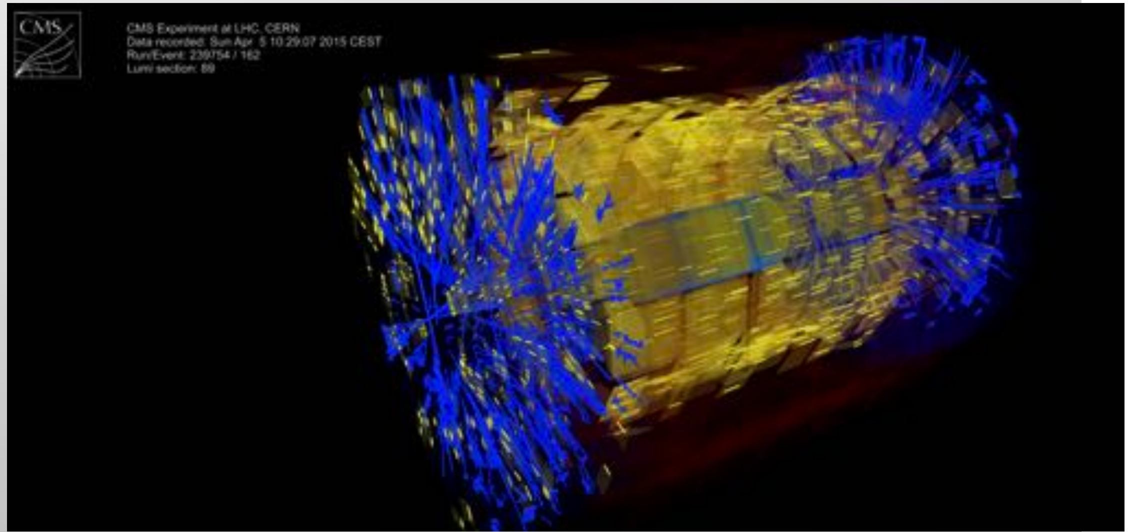


A. Verweij

LHC: First Splashes and Ramps to 6.5 TeV

The beam is back!!





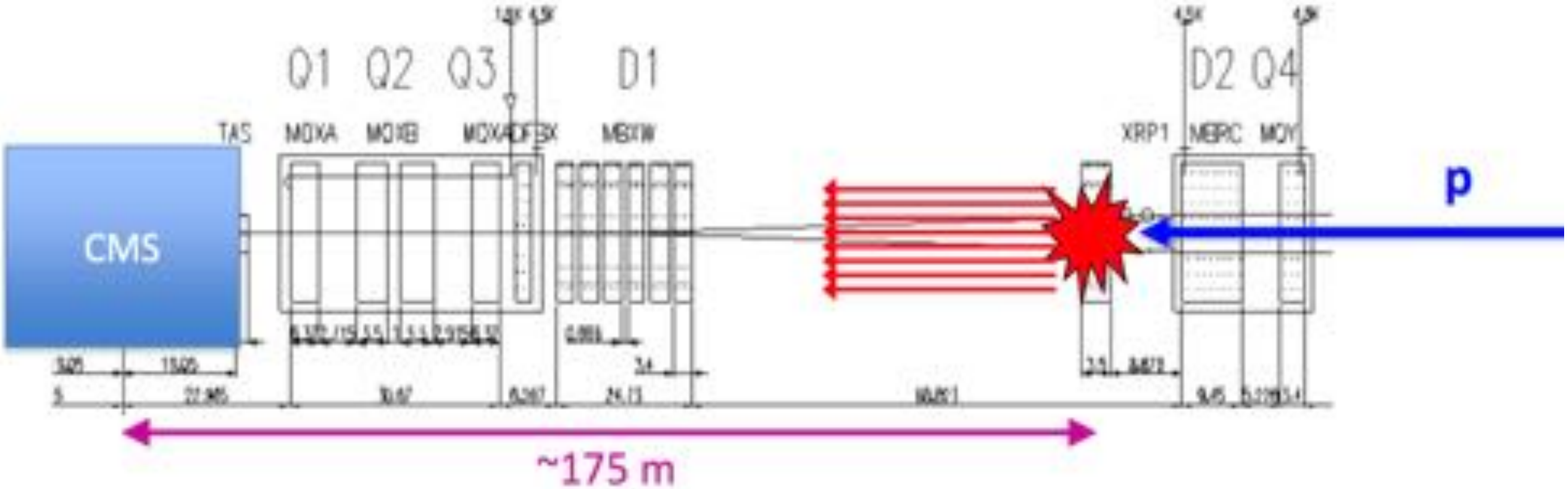
5^{th} April (Easter Sunday, Christ resurrection day) splashes at injection energy of 450 GeV/beam, by beam dump just in front of the experiment

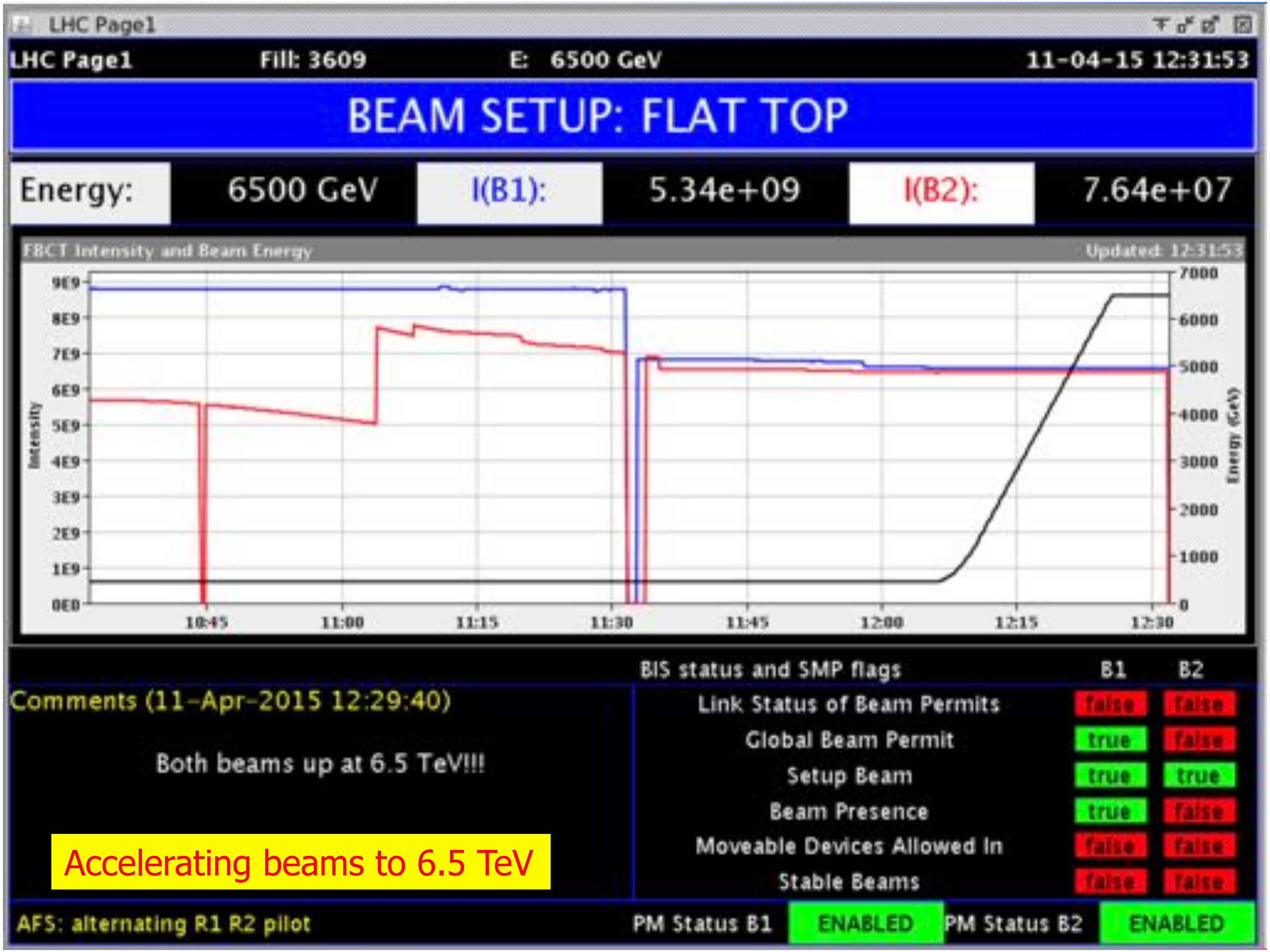
Two weeks ago: Ramp of both beams to an energy at 6.5 GeV
The machine works! (with low intensities so far)

"Beam Splash"

~3 – 4 x 10^9 protons at 450 GeV/c hit TCT collimators
~175m upstream of CMS

(Sunday ~10^{5-6} protons)




LHC Page1
LHC Page1
Fill: 3609
E: 6500 GeV
11-04-15 12:31:53
BEAM SETUP: FLAT TOP
Energy:
6500 GeV
I(B1):
5.34e+09
I(B2):
7.64e+07
FBCT Intensity and Beam Energy
Updated: 12:31:53
Intensity
Energy (GeV)
9E9
8E9
7E9
6E9
5E9
4E9
3E9
2E9
1E9
0E0
7000
6000
5000
4000
3000
2000
1000
0
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
BIS status and SMP flags
B1
B2
Comments (11-Apr-2015 12:29:40)
Both beams up at 6.5 TeV!!!
Link Status of Beam Permits false false
Global Beam Permit true false
Setup Beam true true
Beam Presence true false
Moveable Devices Allowed In false false
Stable Beams false false
AFS: alternating R1 R2 pilot
PM Status B1 ENABLED
PM Status B2 ENABLED
Accelerating beams to 6.5 TeV

The 2015 Schedule

As we know it today. Still ‘dynamic’…

The Plan

Includes the present delay of 2 weeks. Still intense Commissioning ongoing

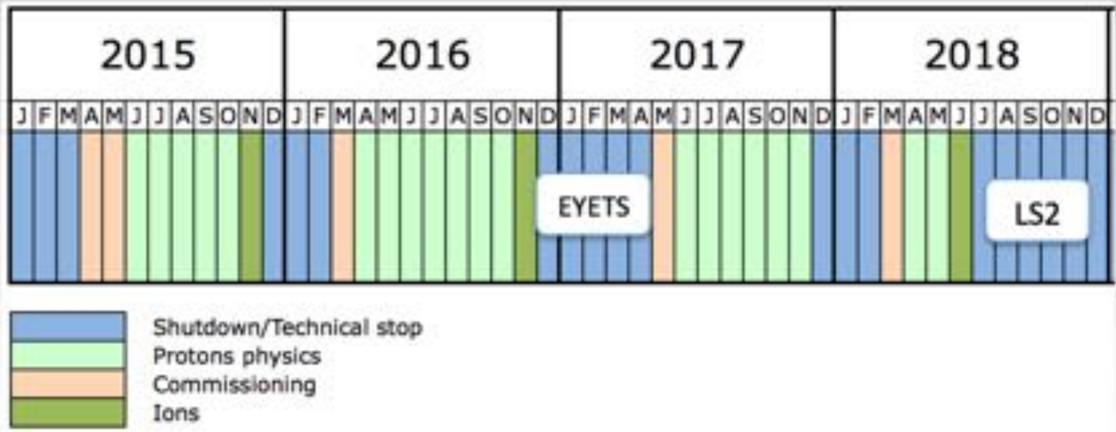
The beam energy will not be changed in 2015

Bunch spacing will be changed from 50ns to 25ns (less pile-up) in summer

Total integrated lumi for 2015: O(10) fb^{-1}

Run II Expectation

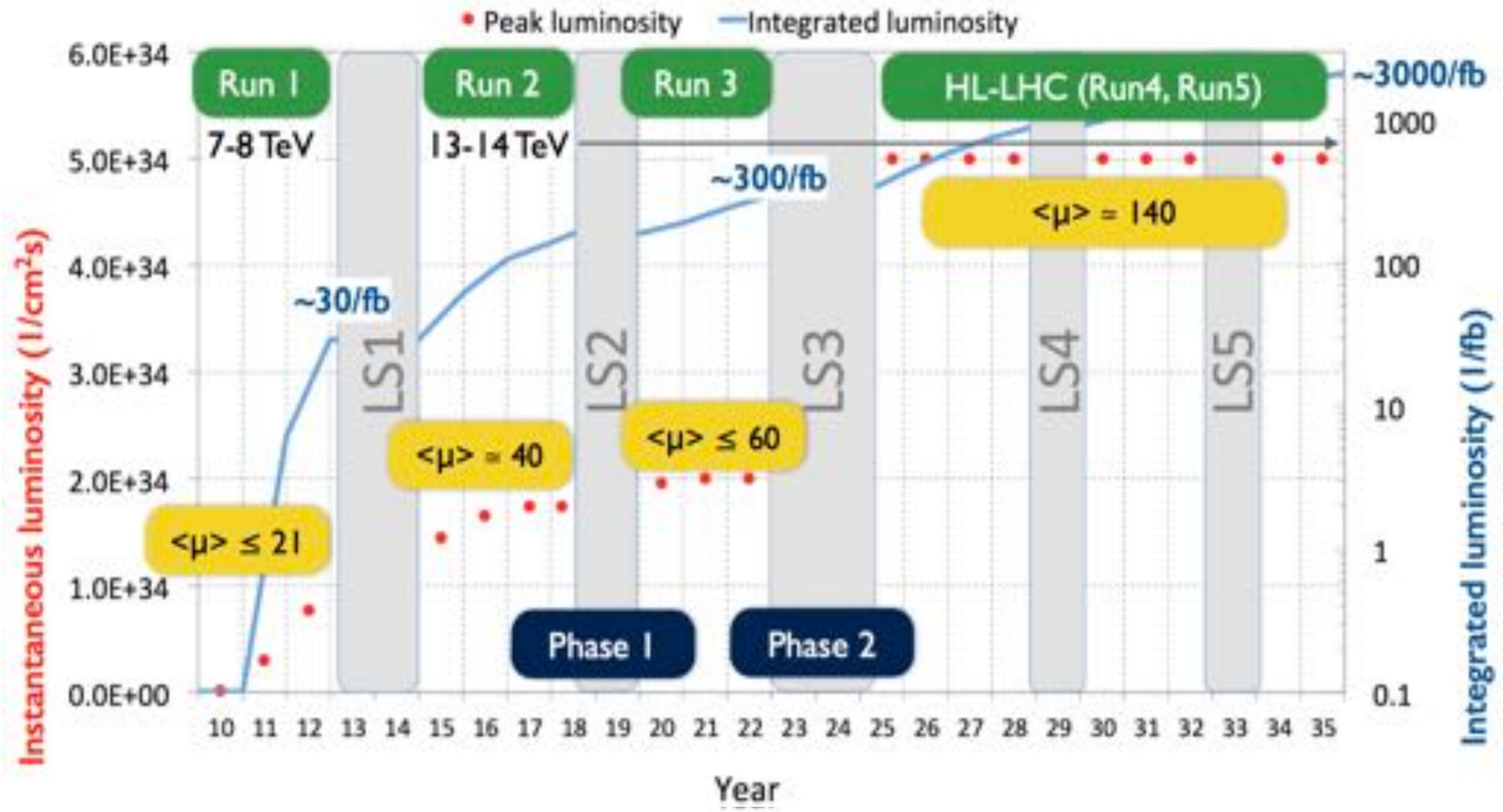
Run 2



	Peak lumi E34 $cm^{-2}s^{-1}$	Days proton physics	Approx. int lumi [fb^{-1}]
2015	1.3	100	10
2016	1.5	160	35
2017	1.7	160	45
2018	1.7	40	10

CSM Energy	Inter BX	No bunches	Bunch Intensity	Emitt.	Peak Lumi	Max Pileup	Int. Lumi 2015
6.5 TeV	25ns	2590	1.15×10^{11}	1.9 um	1.7e34	49	O(10/fb)

Long Term Schedule



F. Bordry at the FCC Workshop at Washington DC March 2015

Latest News

- Good news:
  - beams routinely ramped at 6.5 Tev (in one case they kept the few bunches for more than 4 hours)
  - Injected nominal intensity bunches
- Of some concern…
  - Repeated UFO events in one sector (15R8) traced to a ULO (Unidentified Lying Object) which is located within one specific magnet. One hypothesis is that it might be a piece of insulation material which can be kicked around when charged electrostatically and intercept the tail of the beam... They are still trying to fully explore what can be done to mitigate this

Any Journalists in the Room???

1st proton collisions at the world's largest science experiment expected to start the first or second week of June

DIS2015 Conference at SMU

Posted on April 28, 2015

"No significant signs of new physics with the present data yet but it takes only one significant deviation in the data to change everything." — Albert De Roeck, CERN

First collisions of protons at the world's largest science experiment are expected to start the first or second week of June, according to a senior research scientist with CERN's Large Hadron Collider in Geneva.

"It will be about another six weeks to commission the machine, and many things can still happen on the way," said physicist Albert De Roeck, a staff member at CERN and a professor at the University of Antwerp, Belgium and UC Davis, California. De Roeck is a leading scientist on CMS, one of the Large Hadron Collider's key experiments.

"Unidentified Lying Object" not a problem — remains stable

But work remains to be done. One issue the accelerator physicists remain cautiously aware of, he said, is an "Unidentified Lying Object" in the beam pipe of the LHC's 17-mile underground tunnel, a vacuum tube where proton beams collide and scatter particles that scientists then analyze for keys to unlock the mysteries of the Big Bang and the cosmos.

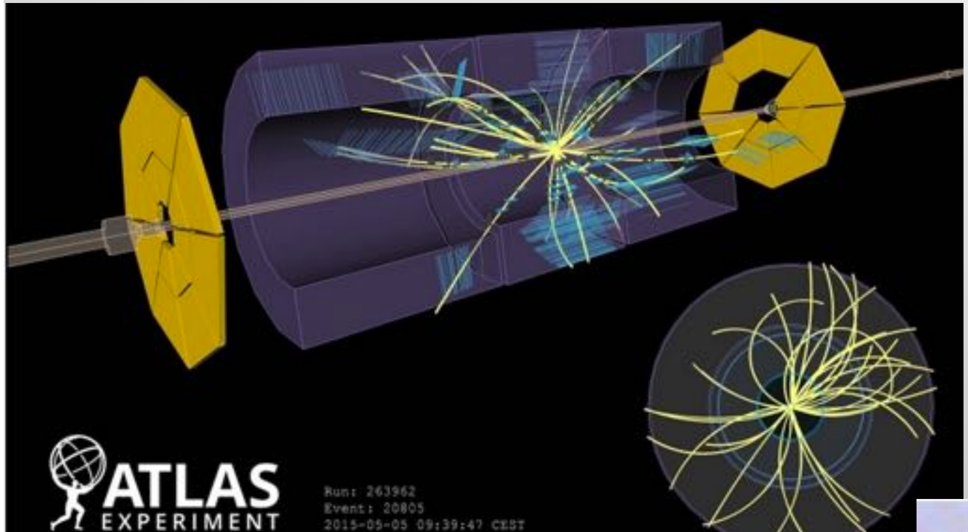
Because the proton beam is sensitive to the geometry of the environment and can be easily blocked, the beam pipe must be free of even the tiniest amount of debris. Even something as large as a nitrogen particle could disrupt the beam. Because the beam pipe is a sealed vacuum it's impossible to know what the "object" is.

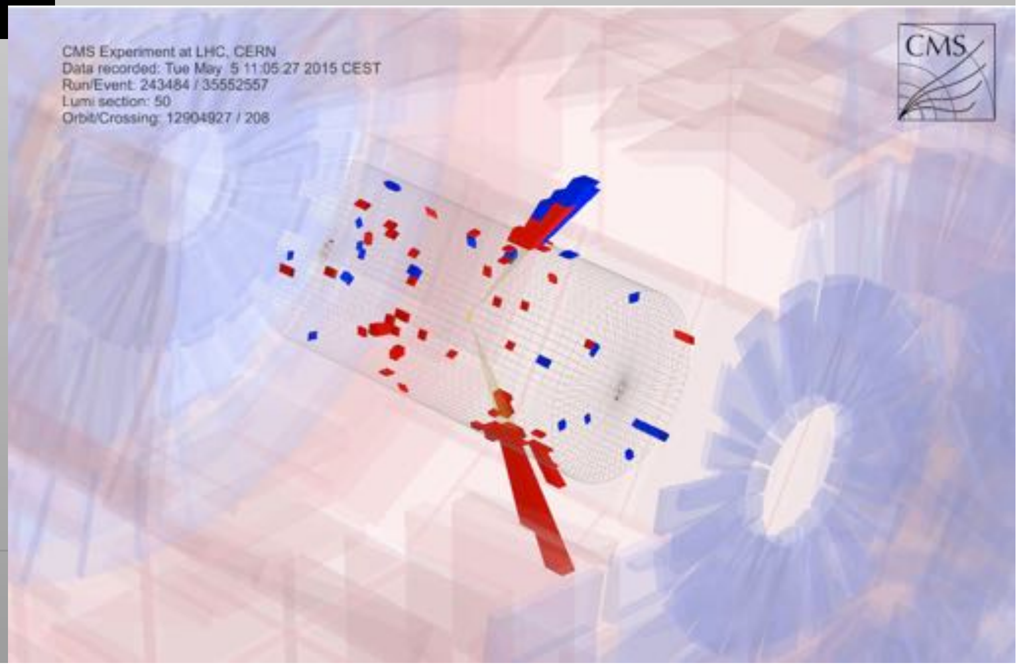
"The unidentified lying object turns out not to be a problem for the operation, it's just something to keep an eye on," De Roeck said. "It's in the vacuum tube and it's not a problem if it doesn't move and remains stable."

SMU University News + many blogs (incl. Science, DOE…)

Latest News

First test collisions at 900 GeV today 5/5/2015. Higher energy soon





The Experiments

- …are ready for the new data. Experiments are taking regularly cosmic rays now.
- Many changes with respect to the detectors in 2010-2012, i.e. ‘repairs’ or replacements/upgrades. Eg new beampipes, DAQ, trigger components and HLT, new calibration systems, reconstruction software…
- The experiments have to be commissioned as ‘new detectors’
- ATLAS: new Insertable pixel B-Layer (IBL), diamond beam monitor, new MDTs , RPCs and TGCs installed (muon system).
- CMS: pixel lumi telescope, SiPMs and PMTs in part of the calorimeter, 4th muon station installed (CSCs, RPCs)

CMS Pixel Detector

Tracker – Pixel

- March 2015
  - Lessons learned for Phase I
- Pixel detector installed before Christmas
  - Shimming → detector now centered 0:0
  - Very dry environment
  - Including 8 modules with Phase I components – Pilot Blade
- 99.2% of the detector is alive: **better than during Run I (96.3%)**
- Pixel calibration at T = -10°C completed

Happily taking cosmics,
first alignment efforts OK

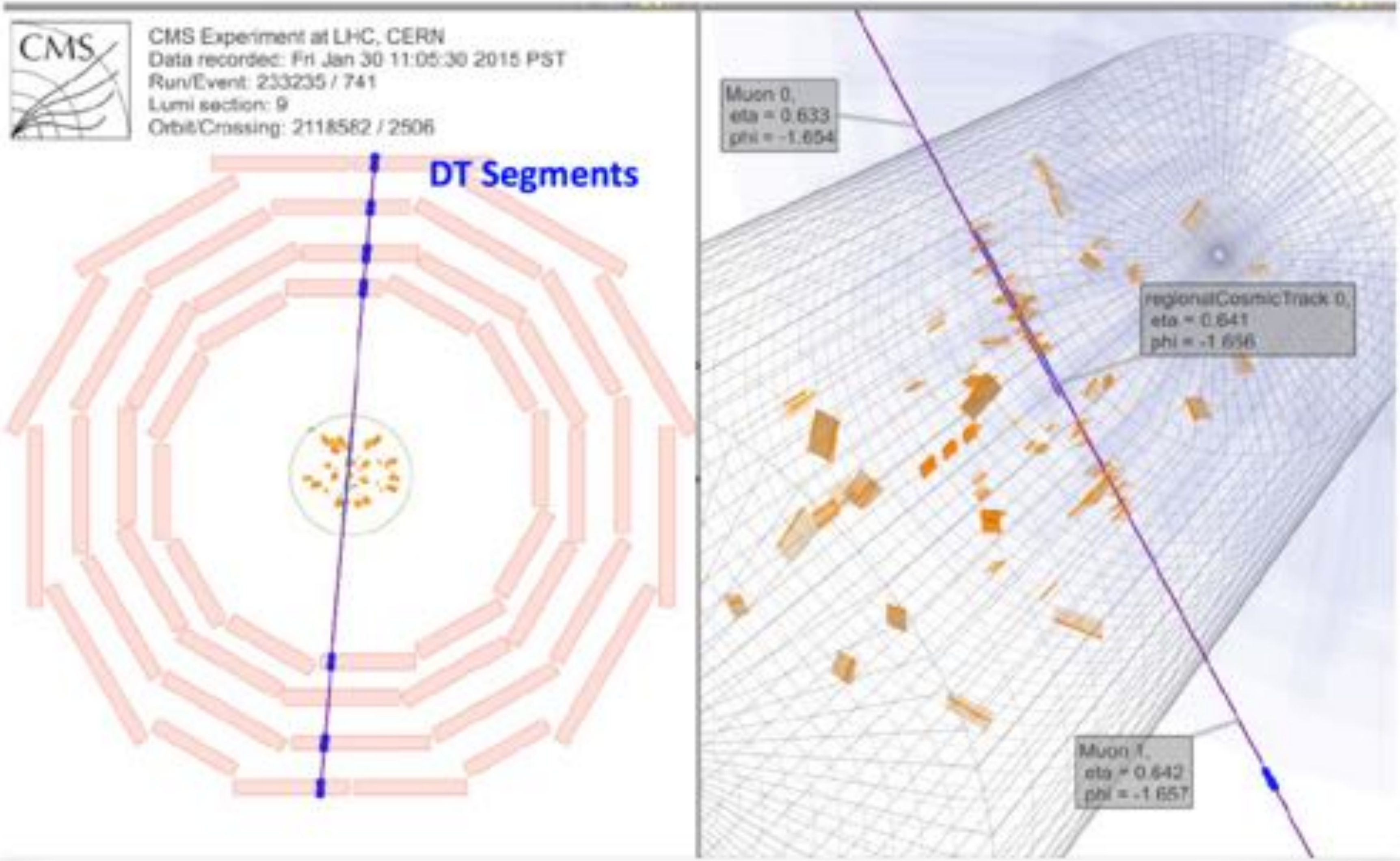
Jim Olsen - LHCC Open Session

CMS Muon System

- CMS Muon System has three sub-systems: Drift Tubes (DT), Cathode Strip Chambers (CSC), Resistive Plate Chambers (RPC)
- Removal, revision, re-installation of ME1/1 chambers
- 4th muon station added: 72 (144) new CSC (RPC) chambers

Jim Olsen - LHCC Open Session

Example Cosmic Ray: Jan 30, 2015



Extensive use of cosmic rays to commission CMS in LS1

Getting Ready for RUN-II Physics

Standard Model Studies

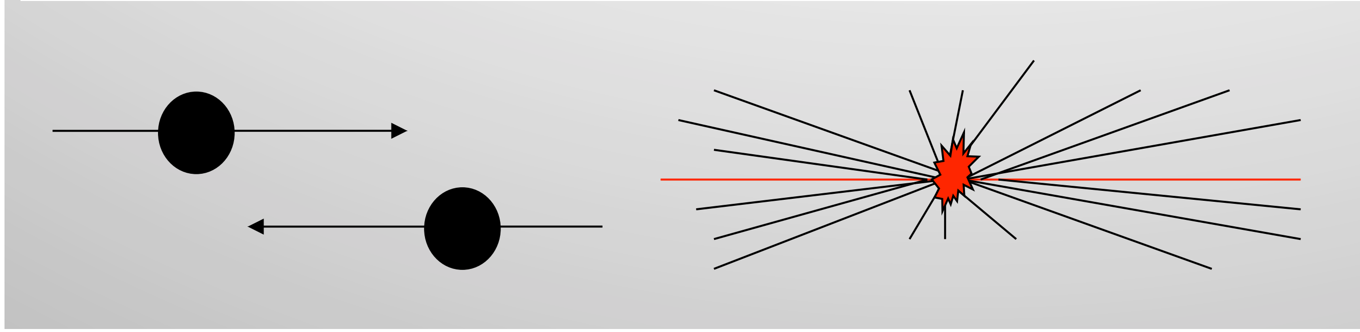
The study of the Standard Model at 13/14 TeV will be one of the first points to tackle at the new energy.
The first QCD and Electroweak Studies can be done with << fb^{-1}

LHC is likely to make a careful start with low luminosity for some time, and plans a stop after the first 1 fb^{-1} (to go to 25 ns)

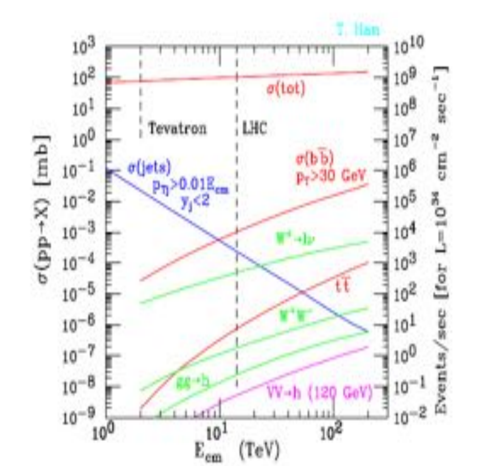
Note: this plan can still change

Understanding Soft Collisions

Most collisions at the LHC do not involve a hard scattering scale: these are so called soft collisions. They make up most of a “minimum bias” event sample

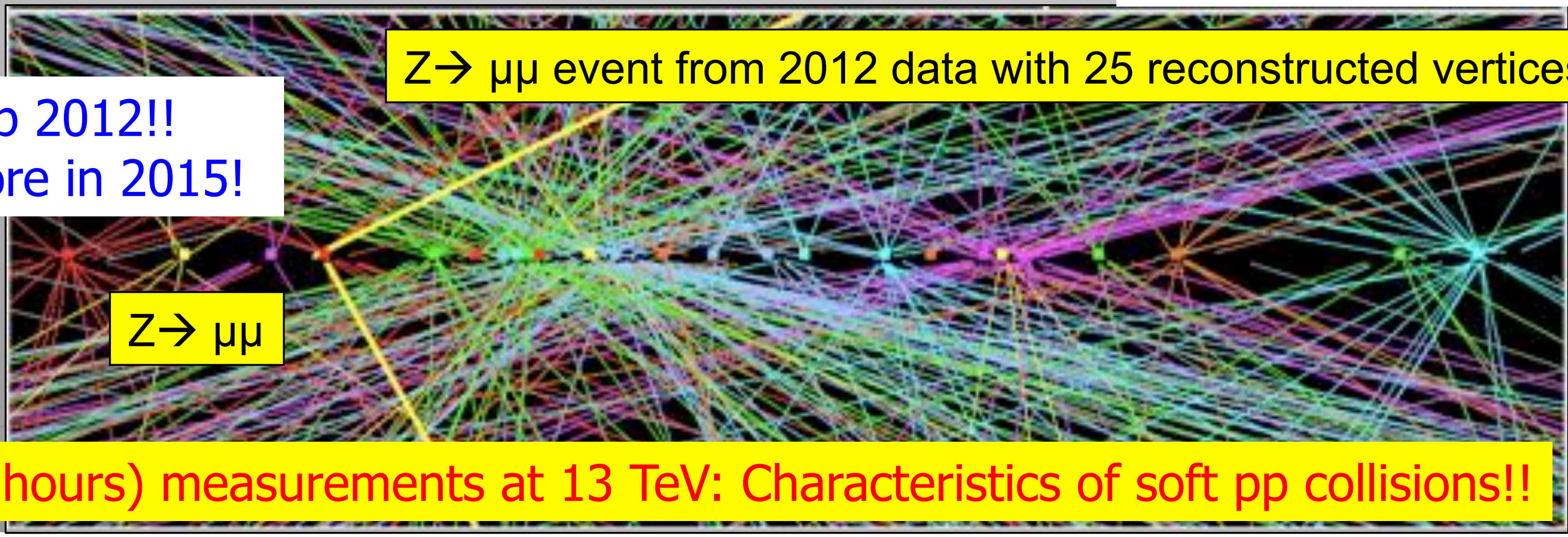


Scattering cross sections for various SM processes:



- Detailed studies of multi-particle production in pp
- Monte Carlos tunes, eg for describing the pile-up

Pile-up 2012!!
2x more in 2015!

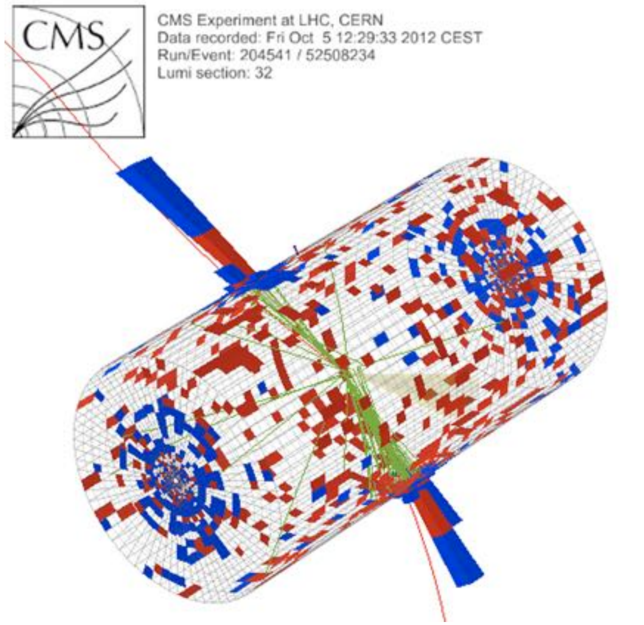


Z→ μμ event from 2012 data with 25 reconstructed vertices

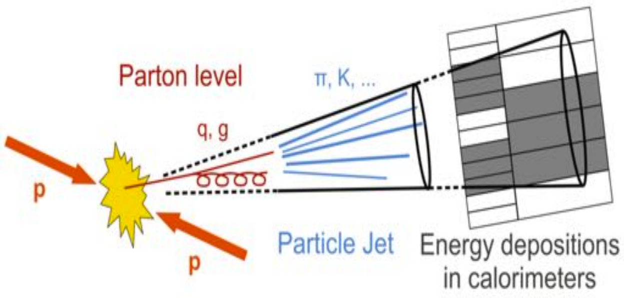
Z→ μμ

First (hours) measurements at 13 TeV: Characteristics of soft pp collisions!!

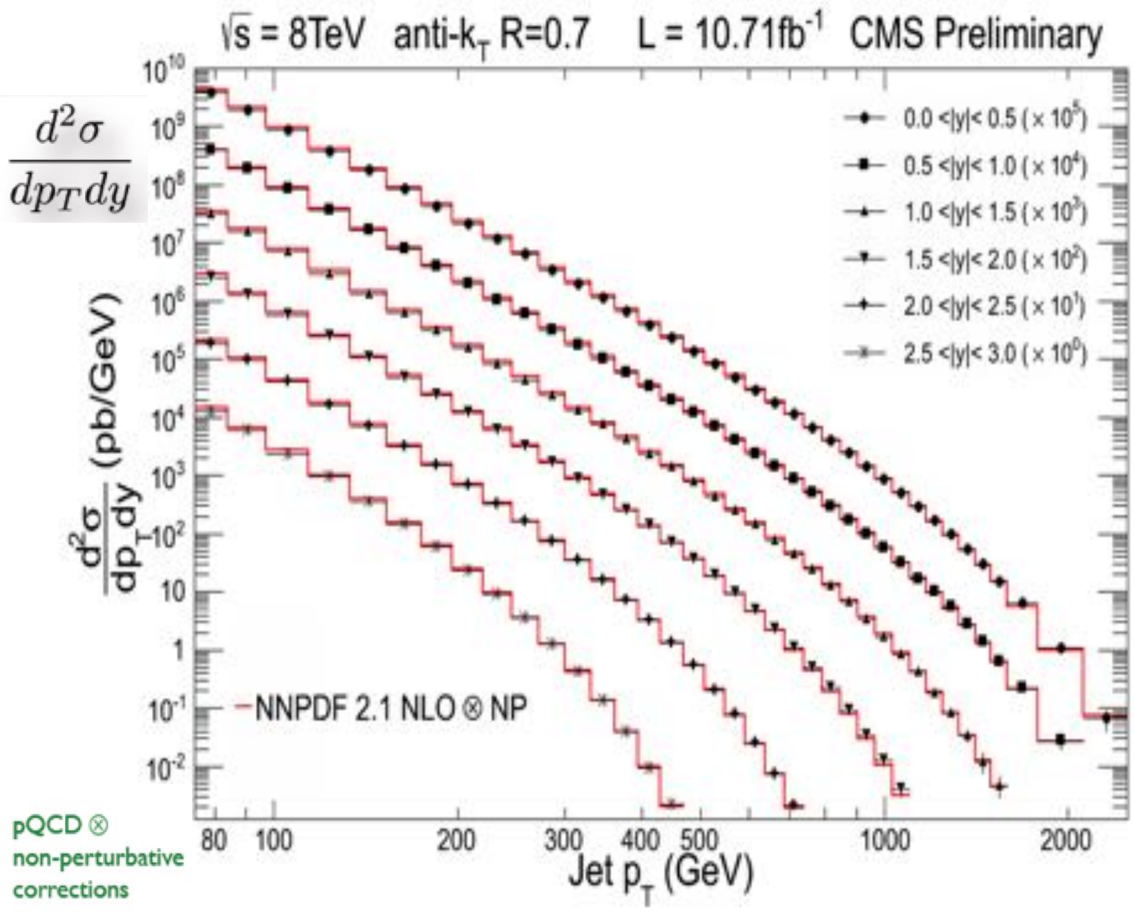
Inclusive Jet Production (8 TeV)



Di-jet invariant mass = 5.15 TeV (R=1.1 jets)

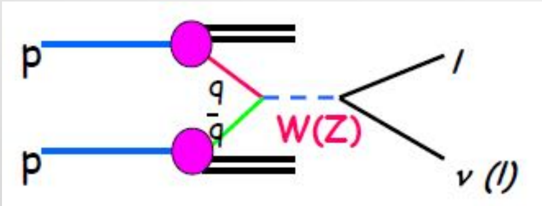


CMS-PAS-SMP-12-012

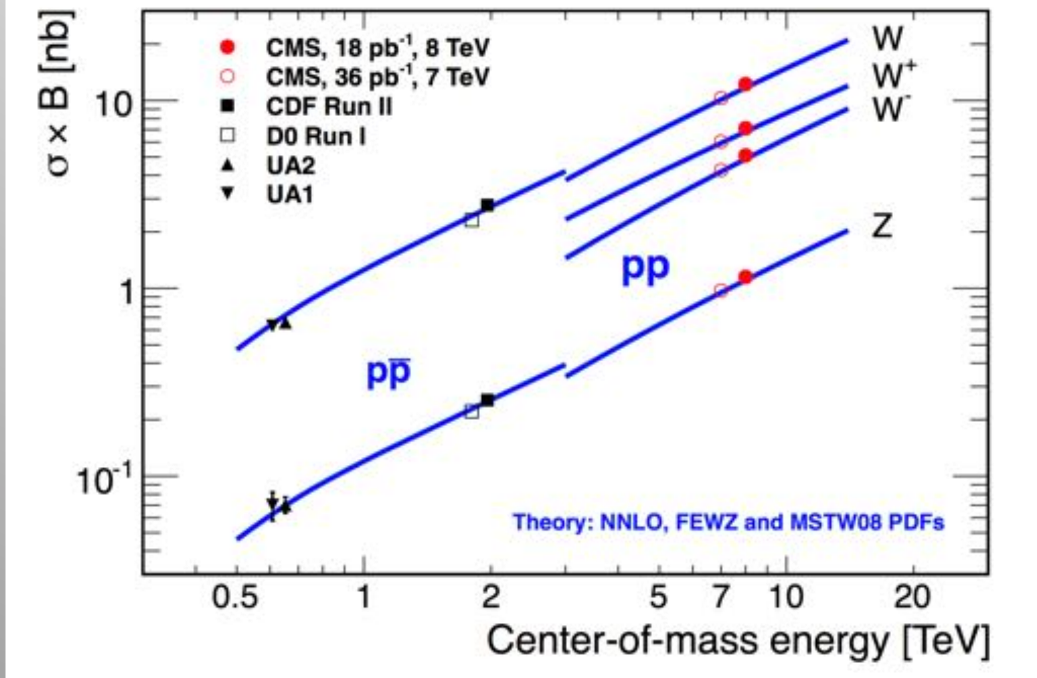


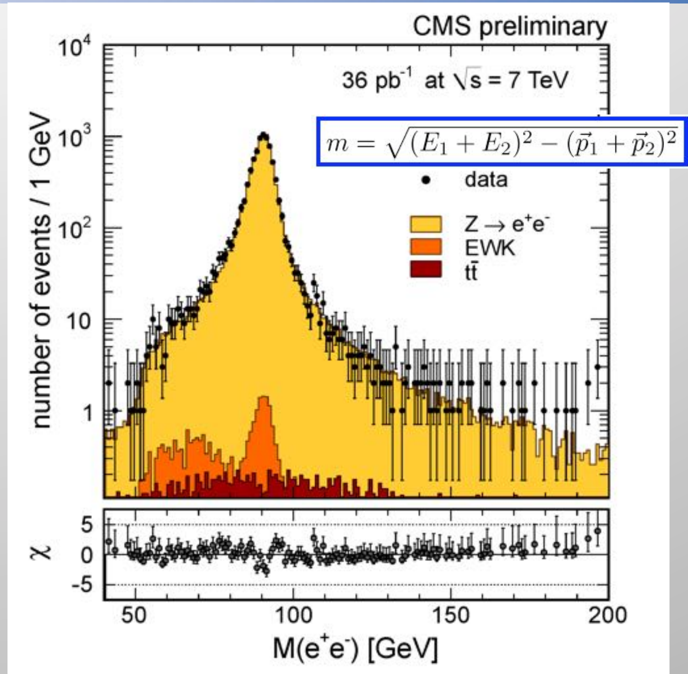
Agreement with NLO calculations over the full range, up to and beyond 2 TeV p_T jets… Hard scattering via the strong force works well…so far…

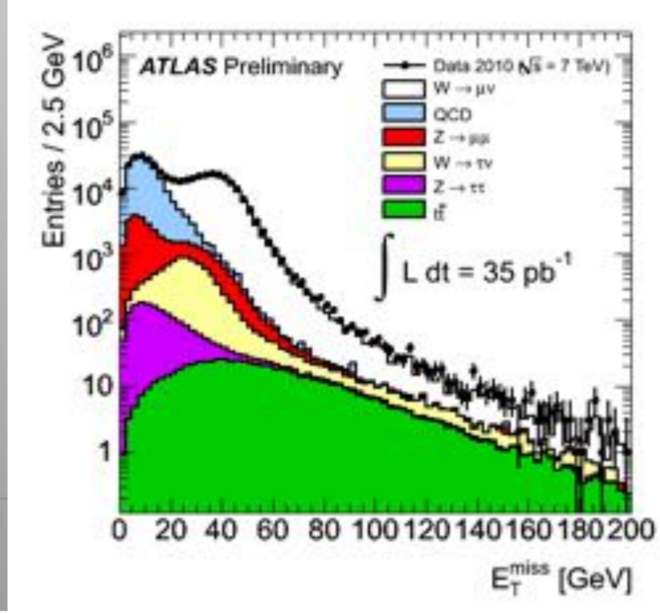
W and Z Boson Production



arXiv:1107.4789[hep-ex]





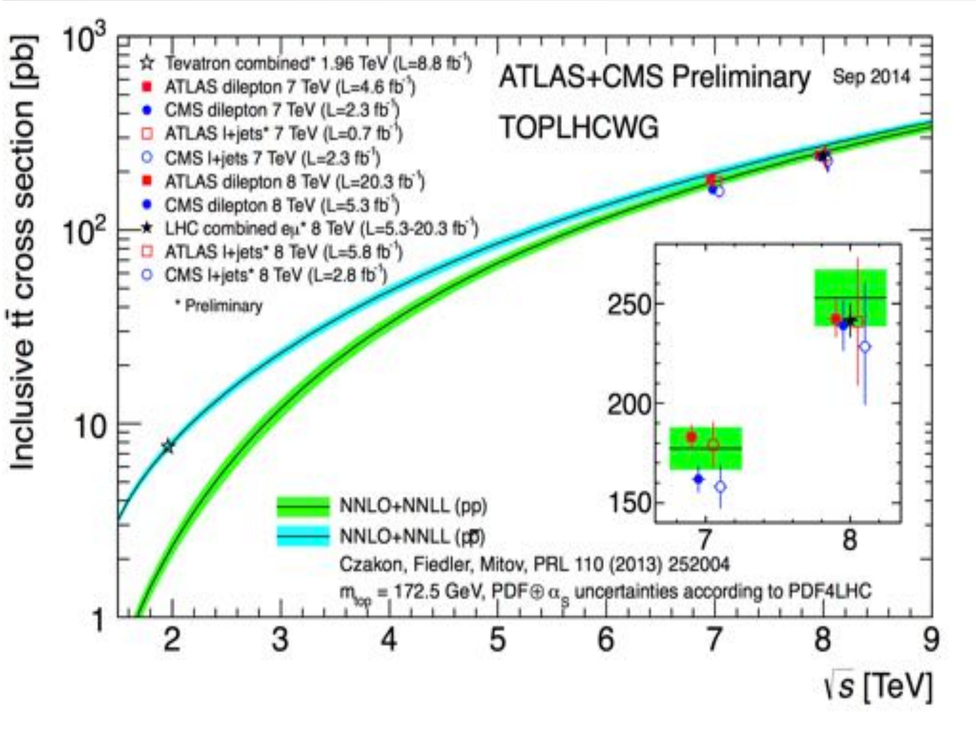


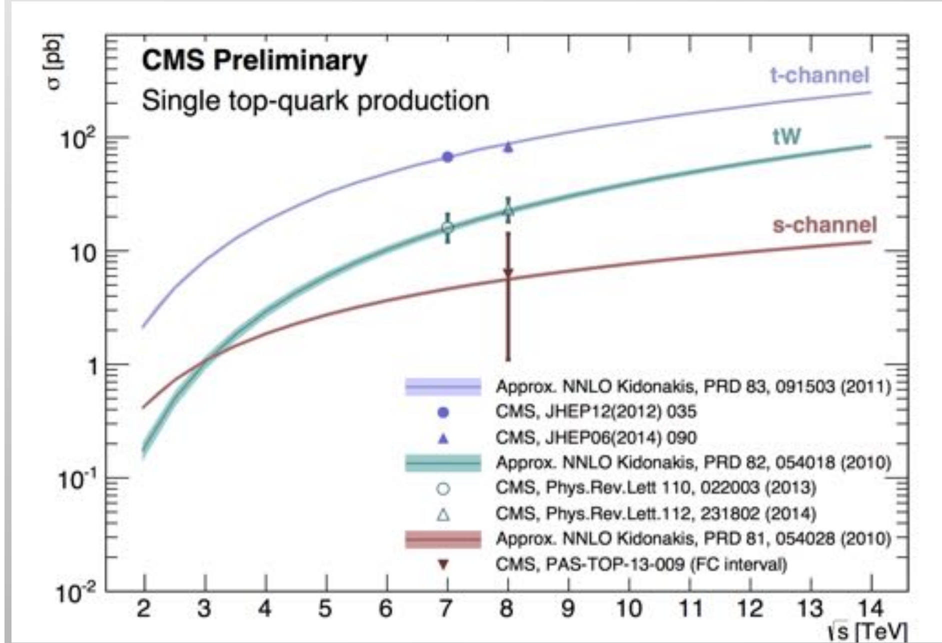
Precise measurements can already be made with ~ 10 pb^{-1}

Top Quark Production at 7/8 TeV

QCD production of tt-bar pair

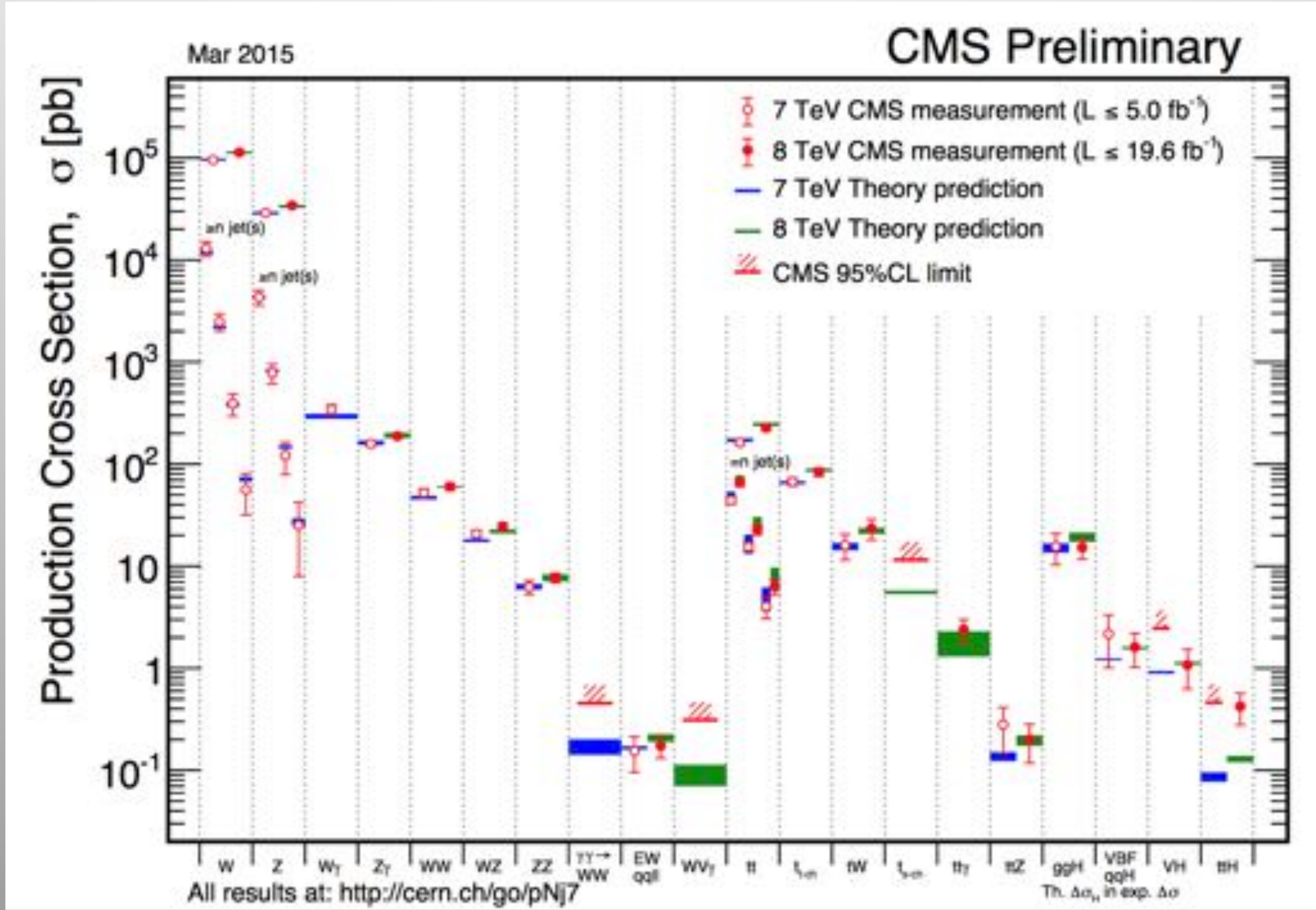
EWK production of single-top





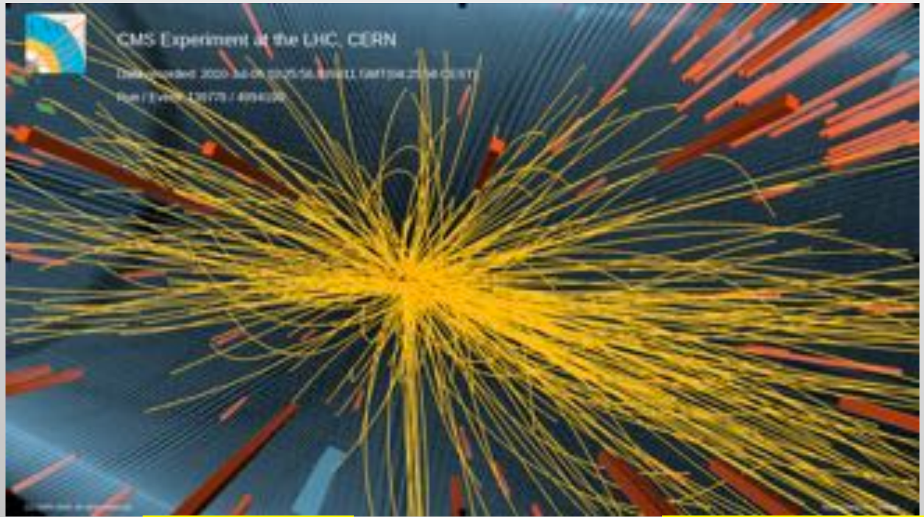
Measurements at 7/8 TeV in agreement with NLO QCD expectations. Present precision 4%

Summary: Cross Sections at 7/8 TeV



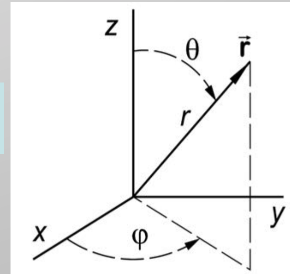
Measurements in good agreement with the Standard Model predictions

Correlations Between Produced Particles



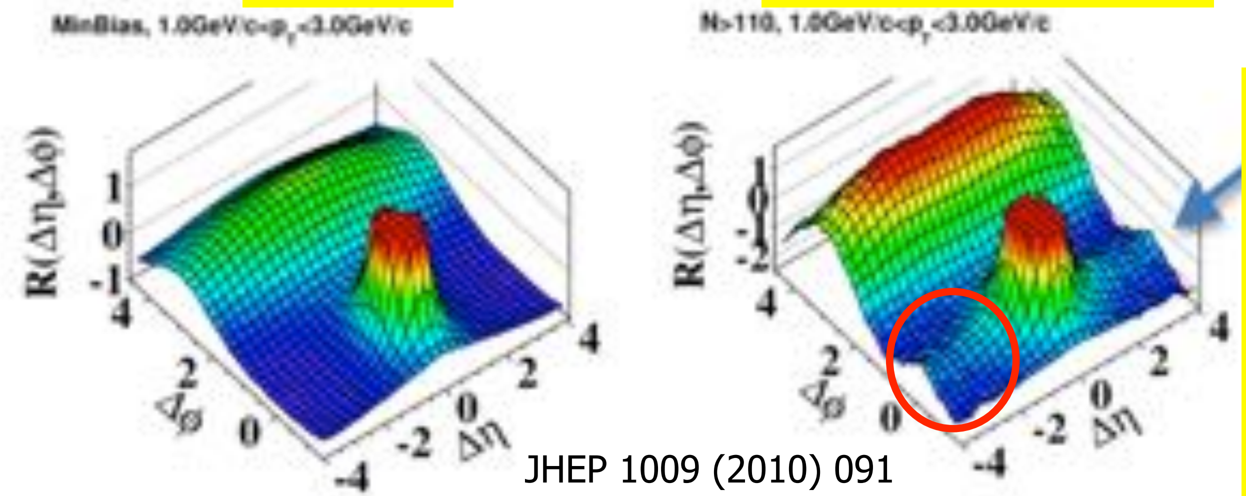
- Select high multiplicity events
- Study the correlation between two charged particles in the angles φ (transverse): Δφ and θ (longitudinal): Δθ

η= -ln tanθ/2



All events

High multiplicity events



JHEP 1009 (2010) 091

A new phenomenon in the ‘stronge force’?

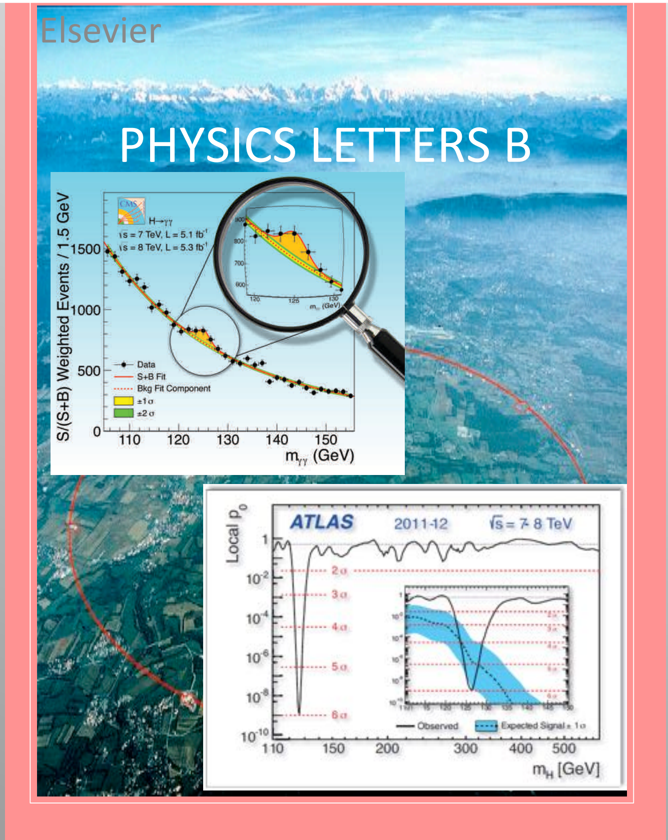
- Multiple interactions?
- Glass condensates?
- Hydrodynamic models?

…

- Understanding the “Ridge” in pp collisions? New measurements at 13 TeV!
- Was first seen in AA, then pp (unexpected) and now also pA (~unexpected)

2012: The year of the Higgs!

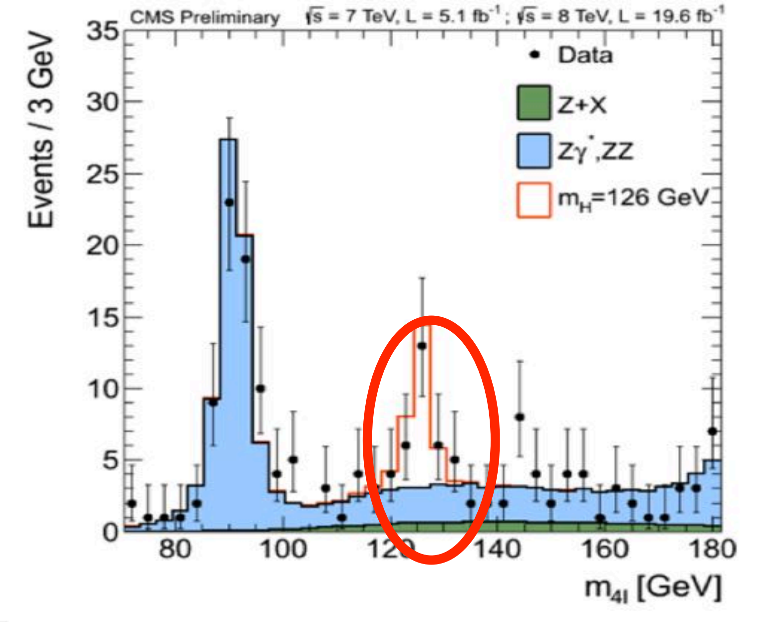
Special Physics Letters B edition with the ATLAS and CMS papers (> 4200 citations so far)

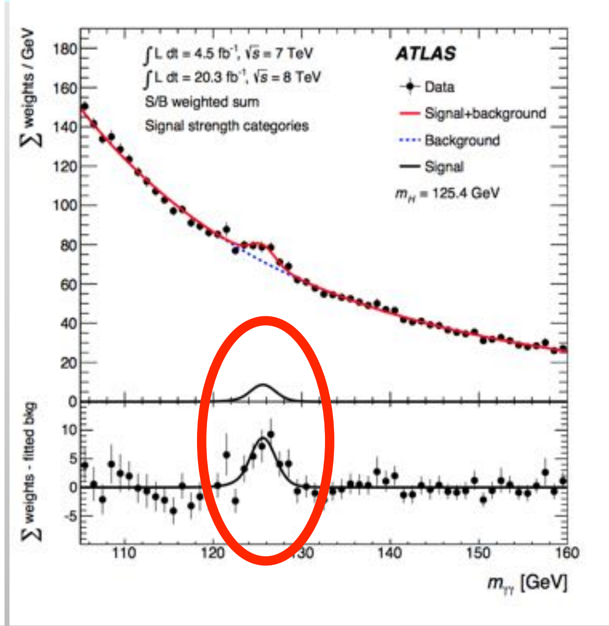


Also…

The Higgs Boson

Observation of a Higgs Particle at the LHC, after about 40 years of experimental searches to find it





2013

2015: Higgs Boson well established.

All accessible channels studied

	untagged	VBF	VH	ttH
H-> gamgam	Results released	Results released	Results released	Results released
H-> ZZ	Results released	Results released	Results released	Results released
H->WW	Results released	Results released	Results released	Results released
H-> bb		In progress	Results released	Results released
H-> tau tau	Results released	Results released	Results released	Results released
H-> Zgamma	Results released	Results released		
H-> mumu	Results released	Results released	Results released	
H-> invisible	In progress	Results released	Results released	In progress

Results released (green)

In progress (yellow)

Essentially all channels still statistically limited

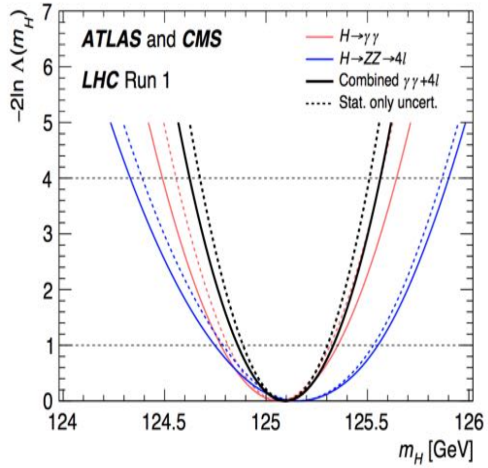
Results Summary @ 125 GeV

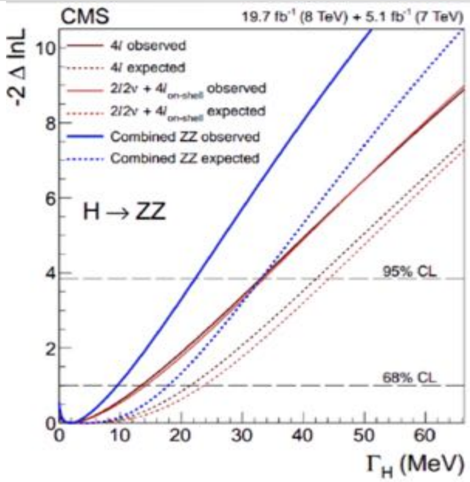
Run-I Legacy papers

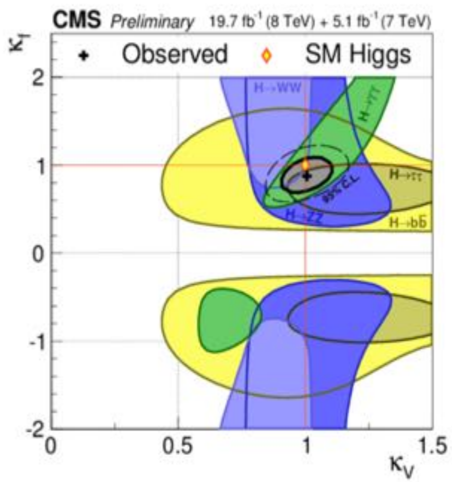
Channel	ATLAS Lumi [fb-1]	CMS Lumi [fb-1]	Specialty	σ Obs. (exp.)	Mass [GeV]	Signal strength μ	$J^P = 0^+$
H→γγ	4.8+20.7	5.1+19.6	mass, discovery, couplings	5.2 (4.6)	126.	1.17±0.27	✔
				5.7 (5.3)	124.7	1.14+ 0.26-0.23	✔
H→ZZ→4l	4.6+20.7	5.1+19.7	mass, discovery, couplings	8.1 (6.0)	124.7	1.44 ± 0.4	✔
				6.8 (6.7)	125.6	0.93 +0.29-0.25	✔
H→WW→2l2ν	4.6+20.7	4.9+19.4	cross section, couplings	6.1 (5.8)	Compatible with 125GeV	1.09 +023-0.21	✔
				4.3 (5.8)	125.5+3.6–3.8 (μ = 1)	0.72 +0.20-0.18	✔
H→bb	4.5+20.3	5.1+18.9	couplings to fermions	1.4 (2.6)	--	0.52 +0.40- 0.27	--
				2.1 (2.1)	Compatible with 125GeV	1.0 ± 0.5	--
H→ττ	20.3	4.9+19.4	couplings to fermions	4.5 (3.4)	Compatible with 125GeV	1.43 +0.43–0.37	--
				3.2 (3.7)	122 ±7 GeV	0.78 ± 0.27	--

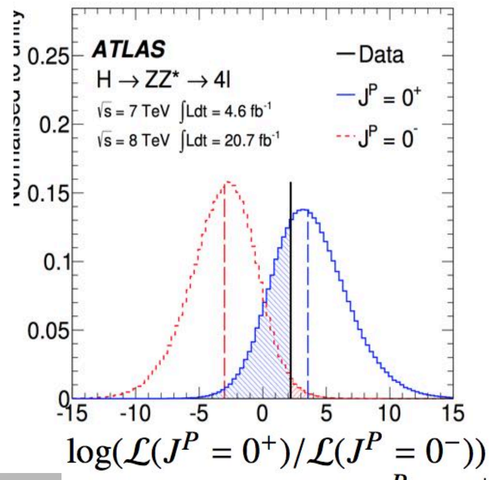
Brief Higgs Summary

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









Mass = CMS+ATLAS
125.09 ±0.21(stat)
±0.11(syst) GeV

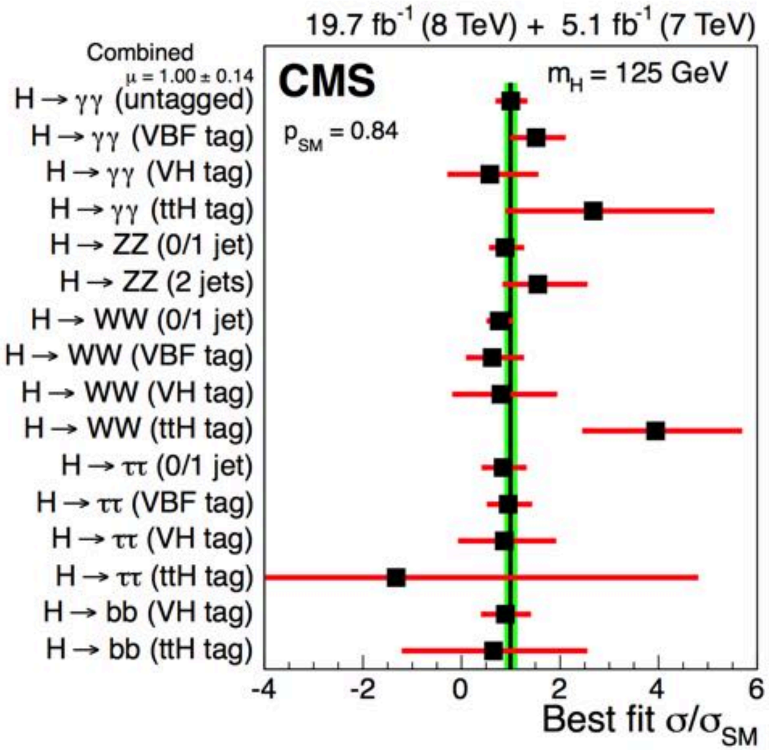
Width =
A: < 24 MeV
C: < 22 MeV
(95%CL)

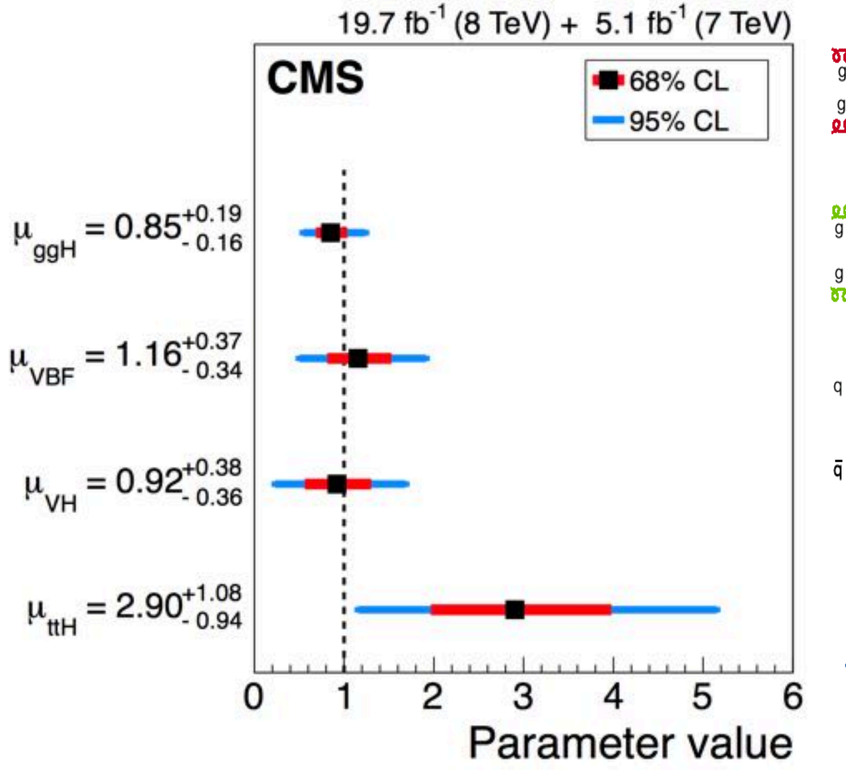
Couplings are within 20% of the SM values

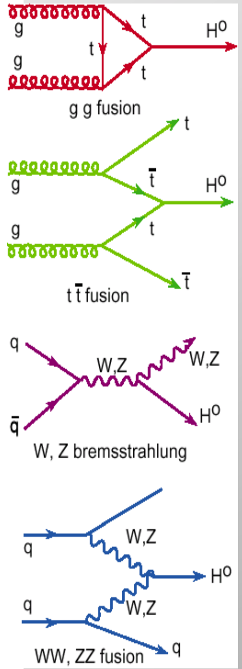
Spin =
$0^{+(+)}$ preferred over 0^-,1,2

SM-like behaviour for most properties, but continue to look for anomalies, i.e. unexpected decay modes or couplings, multi-Higgs production…

Combination of the Higgs Data







Overall consistency with the Standard Model

Simultaneous fit of the four production cross sections, normalized to the SM
The decay BR's are assumed to be the SM ones

$$1.00 \pm 0.09\,(\text{stat})\ ^{+0.08}_{-0.07}\,(\text{theo}) \pm 0.07$$

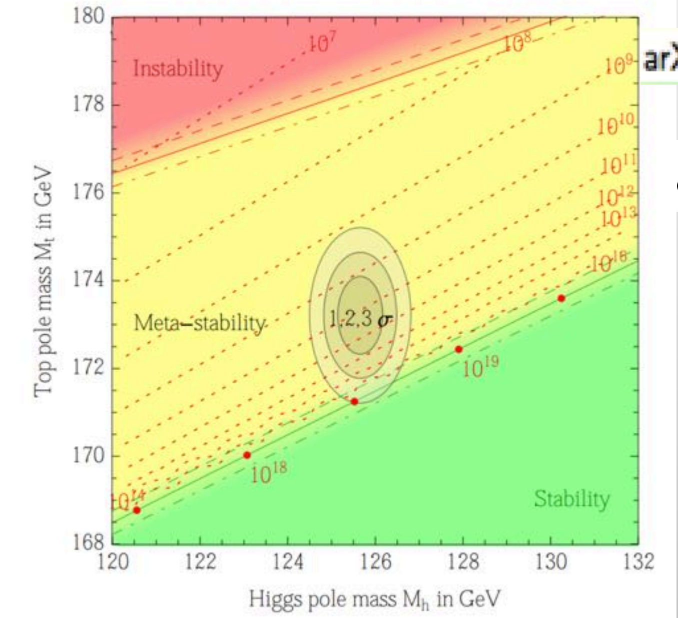
CMS arXiv:1412.8662

$$1.18 \pm 0.10 \pm 0.07^{+0.08}_{-0.07}$$

ATLAS-CONF-2015-007

Consequences for our Universe?

Important SM parameter → stability of EW vacuum

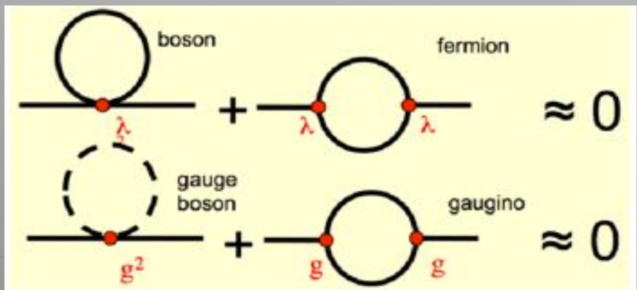


arXiv:1205.6497

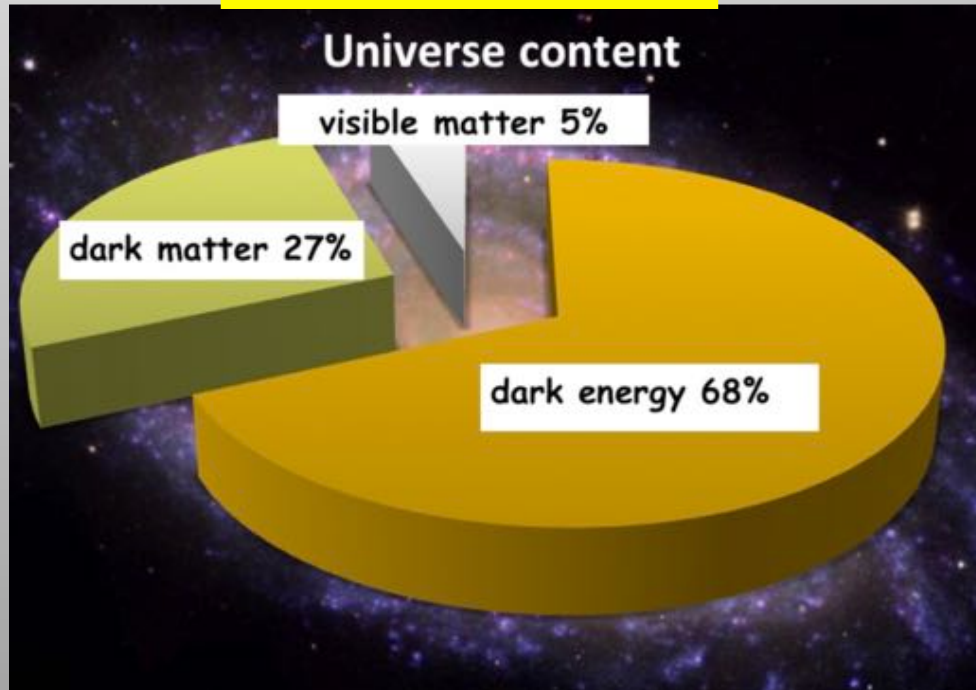
arXiv:1403.6535

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

New Physics inevitable?
But at which scale/energy?



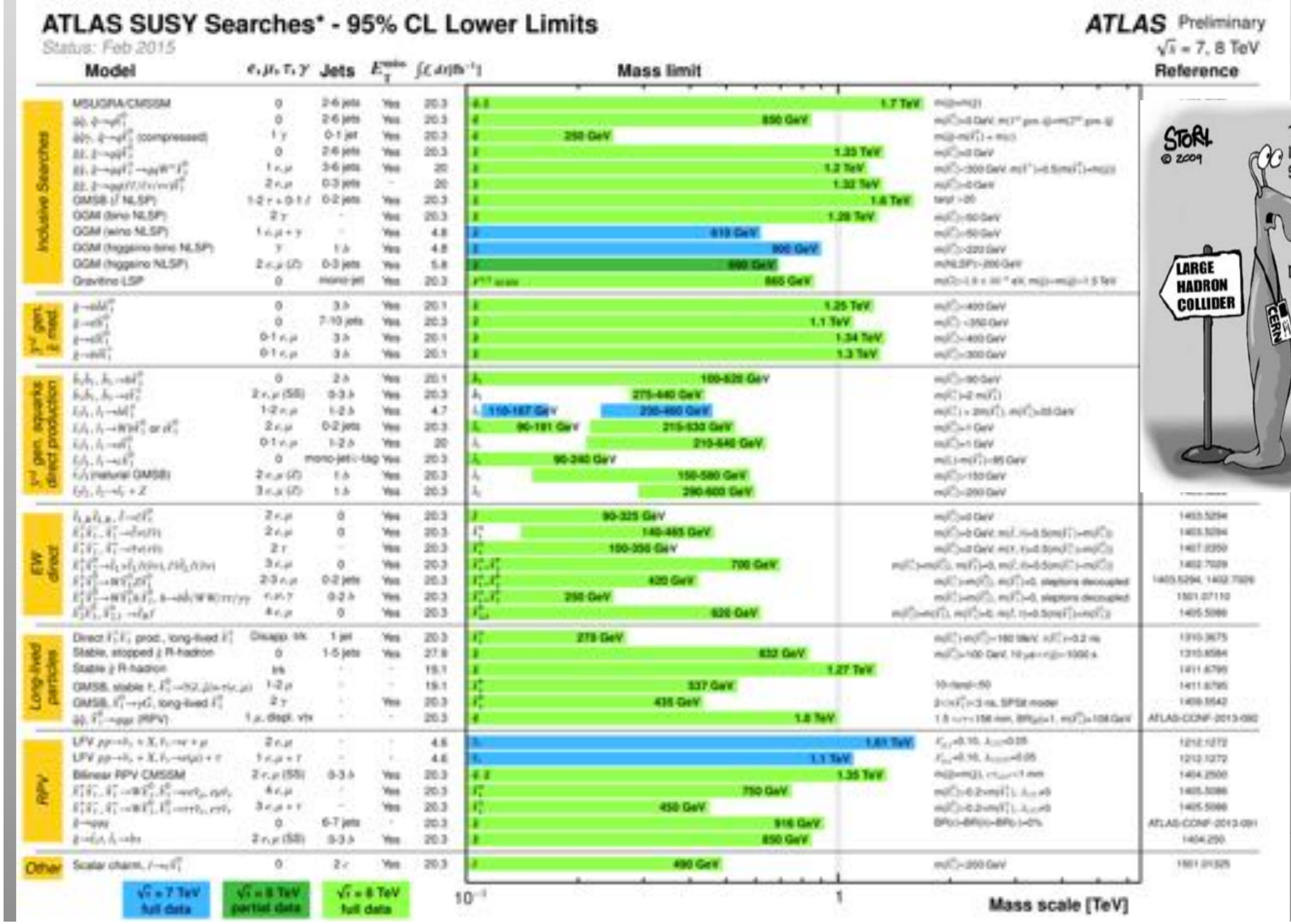
We also know that:



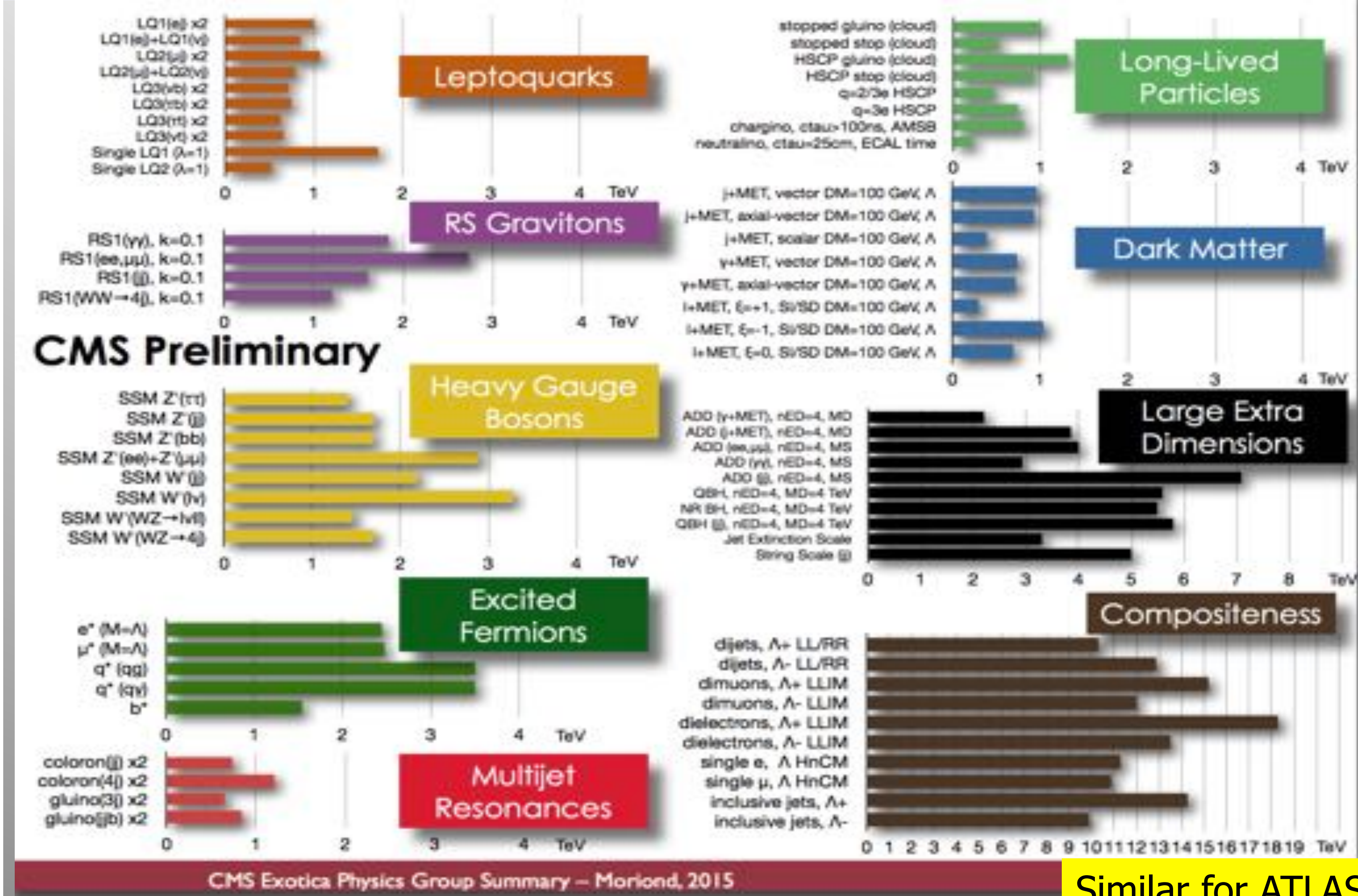
What can LHC contribute to the DM Q?

Summary of SUSY Searches

No sign of SUSY with the data collected so far (similar for CMS)



Summary of Exotica Searches



Similar for ATLAS

What Deviations did we Observe?

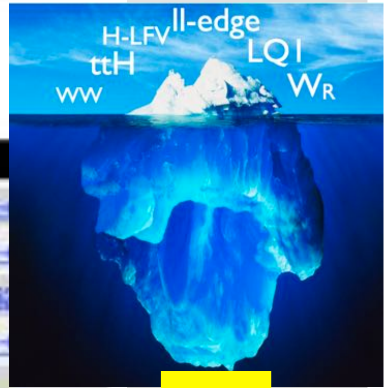
LHC Beyond-the-SM Anomalies (April 2015)

https://www.dropbox.com/s/2xrrcxns5wnc4ek/LHC_anomalies.pdf?dl=0

	Search	Dataset	Max Significance	Reference
Strong SUSY (jets+E_T^{miss}+X)	Z+jets+E_T^{miss}	ATLAS 8 TeV	3.0σ	arXiv:1503.03290 [hep-
	Dilepton mass edge	CMS 8 TeV	2.6σ	arXiv:1502.06031 [hep-
	Soft 2ℓ+E_T^{miss}	ATLAS 8 TeV	2.3σ	ATLAS-CONF-2013-06
	Same-sign ≥2ℓ+b+E_T^{miss}	ATLAS 8 TeV	2.5σ	arXiv:1504.04605 [hep-
EWK SUSY (leptons+E_T^{miss})	3ℓ+E_T^{miss} (WZ→3ℓ channel)	CMS 8 TeV	~2σ	EPJC 74 (2014) 3036
	4ℓ+E_T^{miss} (3ℓ+τ_{had} channel)	CMS 8 TeV	~3σ	PRD 90, 032006 (2014)
	3ℓ+E_T^{miss}	ATLAS 8 TeV	2.2σ	JHEP 04 (2014)169
Resonances	Dijet resonance search (M_{jj} ~ 1.8 TeV)	CMS 8 TeV	~2σ	PRD 91 (2015) 052009
	W(ℓν)H(bb) resonance (M_{WH} ~ 1.8 TeV)	CMS 8 TeV	2.2σ	CMS-PAS-EXO-14-010
	X→h(bb)h(γγ) (M_X ~ 300 GeV)	ATLAS 8 TeV	3.0σ	PRL 114 (2015) 081802
	1st gen. leptoquarks (eejj / eνjj channels)	CMS 8 TeV	2.6σ / 2.4σ	CMS-PAS-EXO-12-041
	Heavy right-handed neutrinos	CMS 8 TeV	2.8σ	EPJC 74 (2014) 3149
Higgs	ttH (same-sign muon channel)	CMS 8 TeV	$\mu_{ttH} = 8.5^{+3.3}_{-2.7}$	JHEP 09 (2014) 087
	Higgs→μτ (lepton flavor violation)	CMS 8 TeV	2.5σ	CMS-PAS-HIG-14-005
Flavor	B → Kℓℓ (Kμμ / Kee)	LHCb 8 TeV	2.6σ	PRL 113 (2014) 151601
	B → Kμμ (branching ratio)	LHCb 8 TeV	2.2σ	JHEP 06 (2014) 133
	B → Kμμ (P_5' angular distribution)	LHCB 8 TeV	3.7σ	LHCb-CONF-2015-002
SM measurements	WW cross section*	CMS 7 TeV	1.0σ	EPJC 73 2610 (2013)
	WW cross section*	CMS 8 TeV	1.7σ	PLB 721 (2013)
	WW cross section*	ATLAS 7 TeV	1.4σ	PRD 87, 112001 (2013
	WW cross section*	ATLAS 8 TeV	2.0σ	ATLAS-CONF-2014-033

* See Jaiswal and Okui 2014 and Monni and Zanderighi 2014 for likely explanation

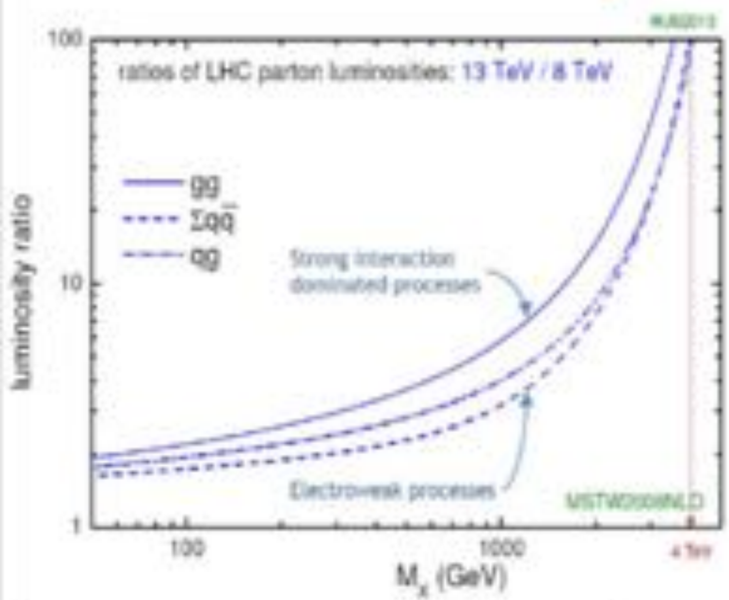
Send comments/updates to Ben Hooberman, benhoob@illinois.edu



?

To be watched in Run-II !!

Prospects for Searches at 13/14 TeV



~Reach we had with 8 TeV 20 fb-1

With 1 fb-1 we will produce ~twice as many gluino pairs at 1.5 TeV as in full Run 1
With 5 fb-1 we will produce ~twice as many stop pairs at 0.7 TeV as in full Run 1

Higgs Cross Sections @ 14 TeV

With 100 fb^{-1} approx 10 x more signal (8 x more background) than run-I

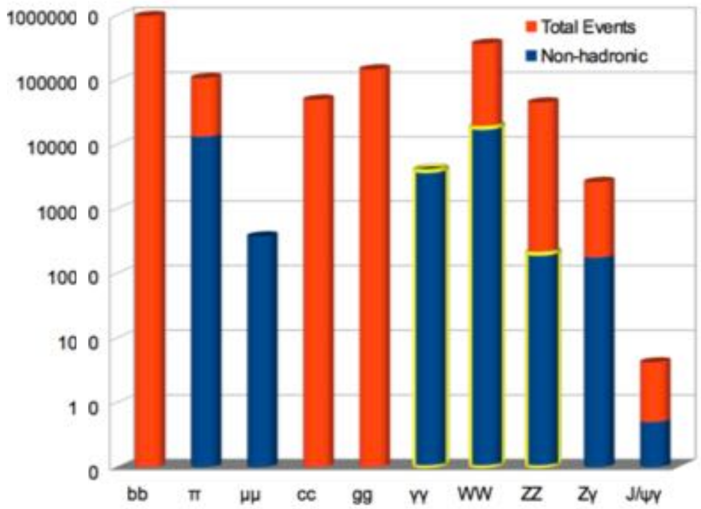
Signal	14 TeV/8 TeV
ggF	2.6
VBF	2.6
ttH	4.7
WH	2.1
ZH	2.1
qq to WW background	2.1
gamma gamma bkg	2.1

ttH approx 20 x more signal

Preparing for Run-II Higgs…

- 2015: we expect about 10 fb^{-1}. This gives as many Higgses as collected in 2012 (and 2 times as many ttH events): Repeat 2012 analyses with increased precision. Faster increasing reach in high mass searches.
- 2016/2017: Increase total statistical sensitivity by factor 3-4 with respect to 2012.
- 2022: End of run-II: factor 6 increased statistical sensitivity IFFFF we can keep the data quality at least the same (pile-up and run conditions…)

•Higgs mass precisions
~ 100-200 MeV enough?
•Higgs self-coupling precision
Better than 20% needed?
•Higgs couplings? Few %? Better?
(e.g. J. Wells et al., arXiv:1305.6397)



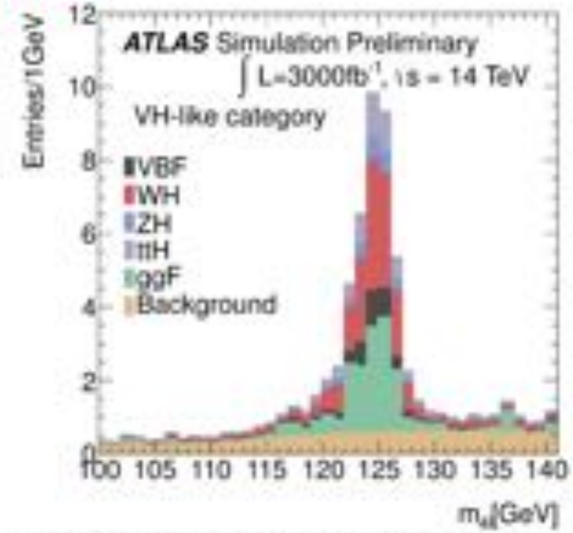
Higgs → ZZ

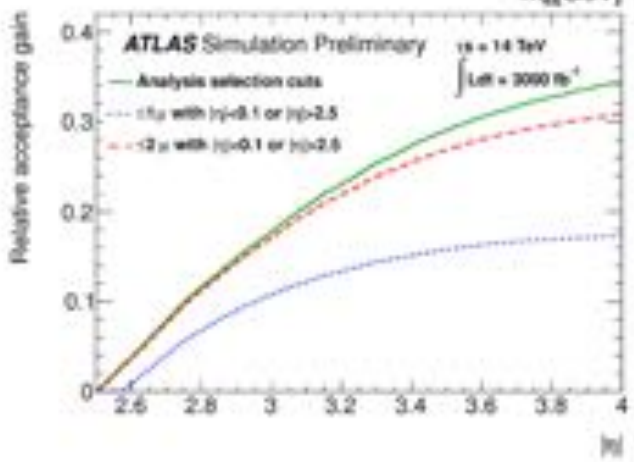
Prospects of observation of Higgs→ ZZ final state at HL

- Experimentally, very clean signal

$\Delta\mu/\mu$	Total	Stat.	Expt. syst.	Theory
Production mode		300 fb^{-1}		
ggF	0.152	0.066	0.053	0.124
VBF	0.625	0.545	0.233	0.226
WH	1.074	1.064	0.061	0.085
$t\bar{t}$H	0.535	0.516	0.038	0.120
Combined	0.125	0.042	0.044	0.108
		3000 fb^{-1}		
ggF	0.131	0.025	0.040	0.124
VBF	0.371	0.187	0.225	0.226
WH	0.390	0.375	0.061	0.085
ZH	0.532	0.526	0.038	0.073
$t\bar{t}$H	0.224	0.184	0.034	0.120
Combined	0.100	0.016	0.036	0.093

- Significant acceptance gain is expected due to extension of muon η coverage





Higgs → bb

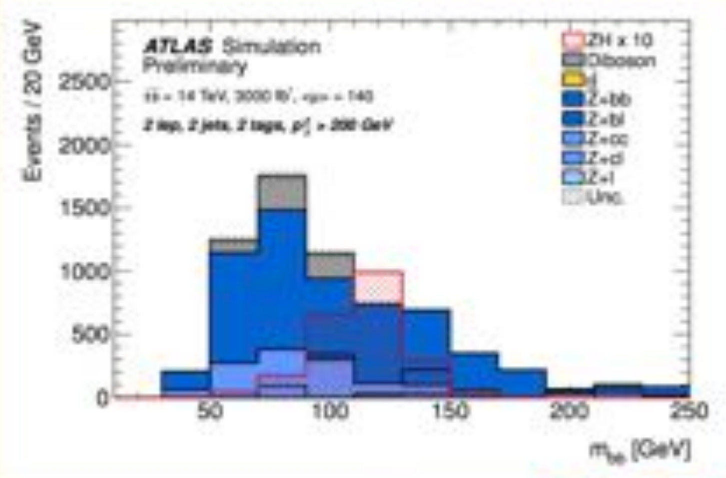
Higgs coupling to b-quarks

- CMS : Extrapolate using Run1 analysis
- ATLAS : Categorize in $N_{leptons}$, and $p_{T\ W/Z}$

Extrapolate improved detector performance from expected upgrades

Observation with large significance expected after 3000 fb^{-1}
Eg. ATLAS Projection : 9σ

Projection	300 fb^{-1}	3000 fb^{-1}
Uncertainty on σ x BR CMS (ATLAS)	14 (26%)	7% (14%)



Can do better including VBF channels

Higgs coupling to top quark

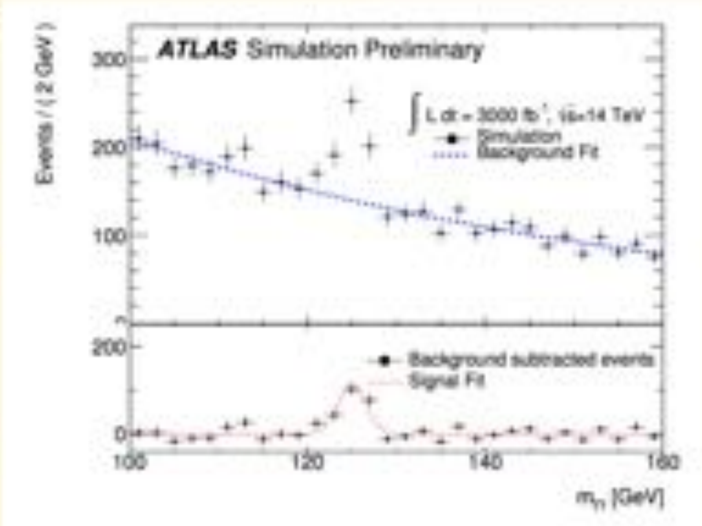
ttH Production

- CMS : Extrapolate using Run1 combination
- ATLAS : Combination of H→ZZ→4l, H→γγ and H→μμ

Observation with large significance expected after 3000 fb^{-1}

Eg. ATLAS Projection : 8σ for ttH , H→γγ

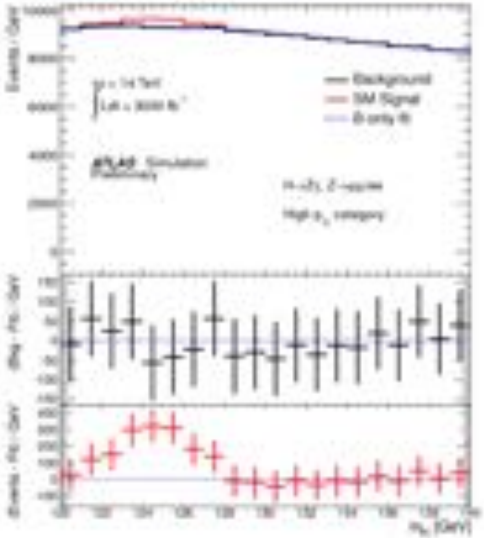
Projection	300 fb^{-1}	3000 fb^{-1}
Uncertainty κ_{top} CMS (ATLAS)	15% (22%)	10% (11%)



Rare Higgs Decays

Rare Higgs boson decays

- $H \rightarrow Z\gamma$ is sensitive to potential new particles in the loop. ATLAS expects to observe $H \rightarrow Z\gamma$ decay at ~4σ level on 3000 fb^{-1} dataset.
- Expected uncertainty on signal strength: 0.46 at 300 fb^{-1} → 0.30 at 3000 fb^{-1}



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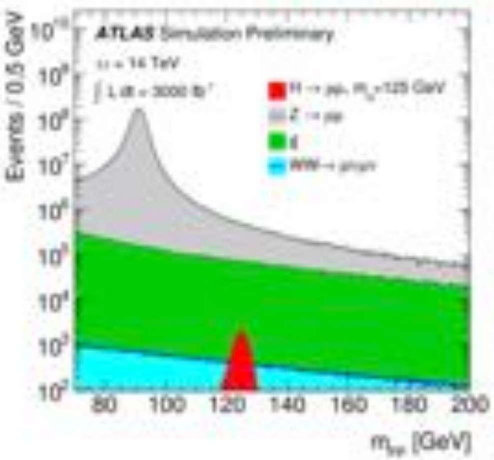
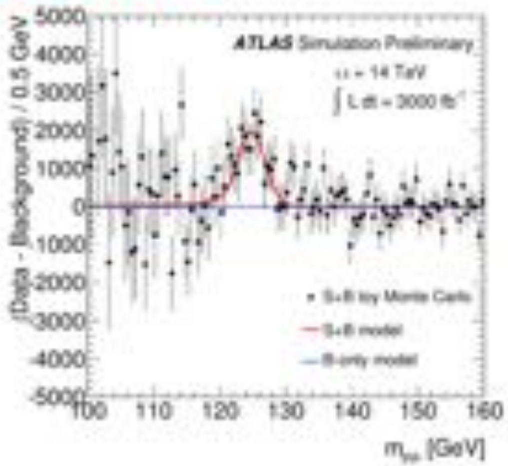


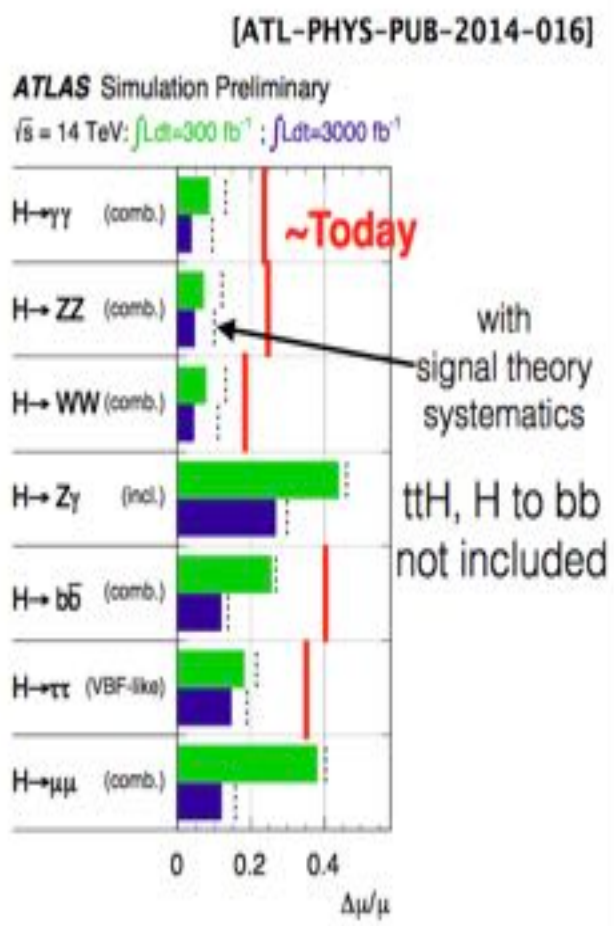


- $H \rightarrow \mu\mu$ is sensitive to the 2nd generation coupling
- Expect to see at 7σ level

Higgs Signal Strength

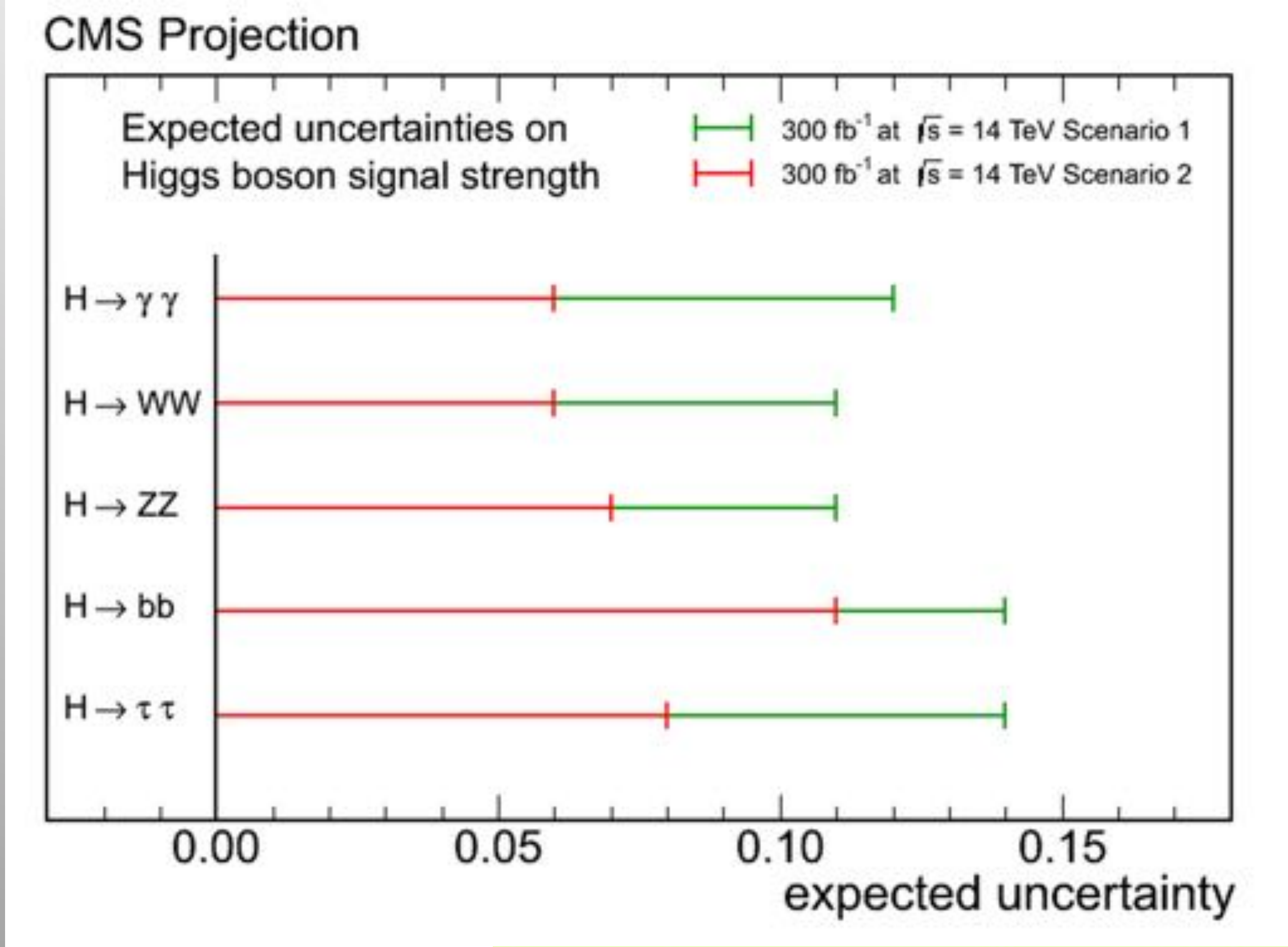
Higgs signal strengths

- Signal strength $\mu=\sigma xBR/(\sigma xBR)_{SM}$
- Separation by production modes
  - Important for coupling measurements
- Projection assumptions:
  - 300/fb: μ=60, 3000/fb: μ=140
  - Used dedicated 14 TeV samples
- Systematics:
  - Conservative estimation (including propagation of the large statistics in control regions)
  - Large impact from theory uncertainties (shown by dashed areas), like QCD scale, PDFs



Based on parametric simulation

Anticipated Precision with Run-II



Assumptions on systematic uncertainties
Scenario 1: no change
Scenario 2: Δ theory / 2, rest ∝ $1/\sqrt{L}$

Based on run-I extrapolation

Predicted Precision on Couplings

CMS

Translated to coupling measurements…
(with current systematics)

L (fb^{-1})	κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	κ_μ	BR_{invis}
300	7%	6%	6%	8%	13%	15%	8%	41%	23%	28%
3000	5%	5%	4%	5%	7%	10%	5%	12%	8%	17%

ATLAS

L (fb^{-1})	κ_γ	κ_W	κ_Z	κ_g	κ_b	κ_t	κ_τ	$\kappa_{Z\gamma}$	κ_μ	BR_{invis}
300	9%	9%	8%	14%	23%	22%	14%	24%	21%	22%
3000	5%	5%	4%	9%	12%	11%	10%	14%	8%	14%

Predicted Precision on Couplings

Coupling	LHC Run1	LHC (300 fb⁻¹)
κ_W	15%	4-6%
κ_Z	20%	4-6%
κ_t	50%	14-15%
κ_b	40%	10-13%
κ_τ	25%	6-8%

Results for Snowmass and the European strategy group study

- Example of expected deviations if new physics scale is at 1 TeV

	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$< 1.5\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim -3\%$

Typically, expect deviations:

$\Delta\kappa/\kappa < \sim 5\,\% / \Lambda^2$

(with Λ in TeV)

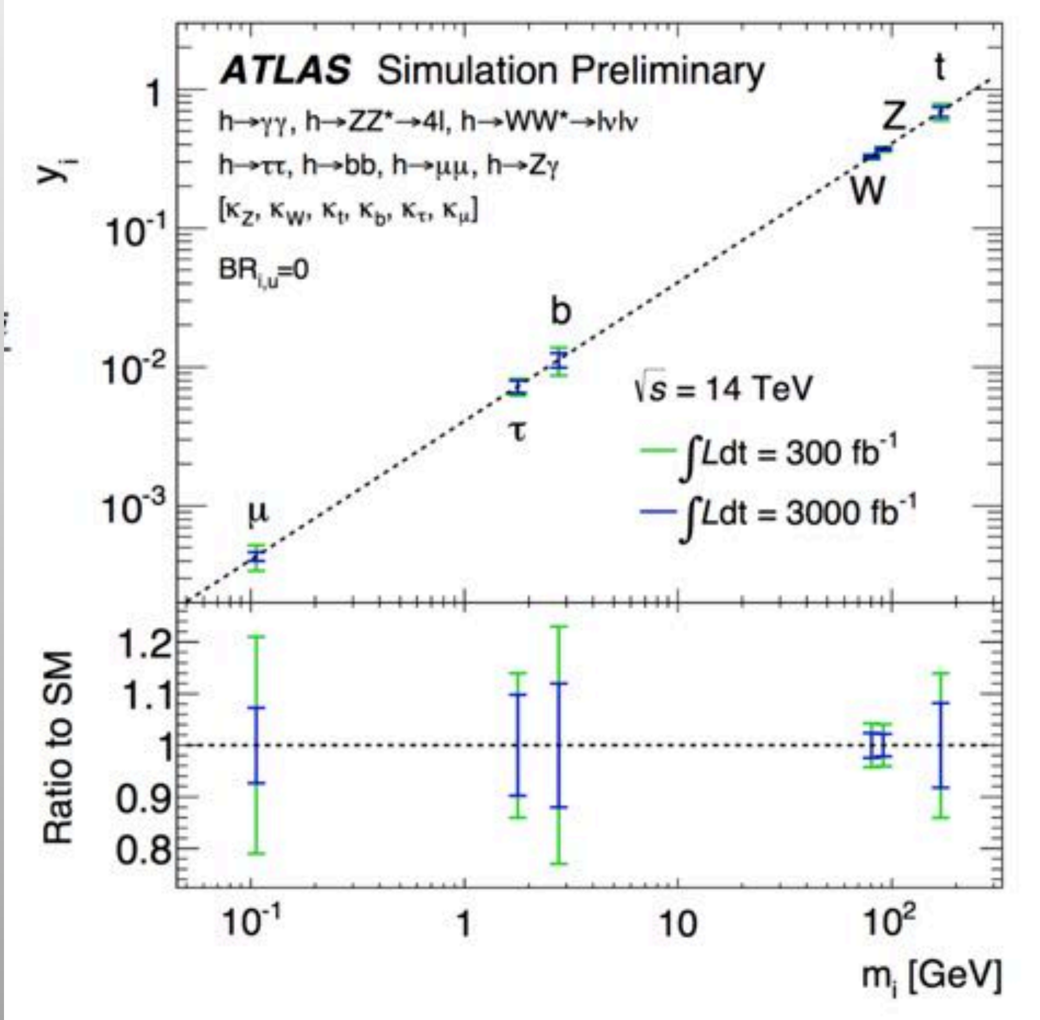
TLEP publication
arXiv:1308.6176

High Luminosity LHC Precision

Higgs couplings: ….

$$y_{V,i} = \sqrt{\kappa_{V,i}\frac{g_{V,i}}{2v}} = \sqrt{\kappa_{V,i}}\frac{m_{V,i}}{v}$$

$$y_{F,i} = \kappa_{F,i}\frac{g_{F,i}}{\sqrt{2}} = \kappa_{F,i}\frac{m_{F,i}}{v}$$

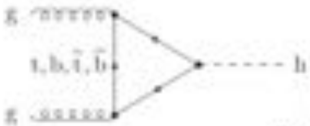


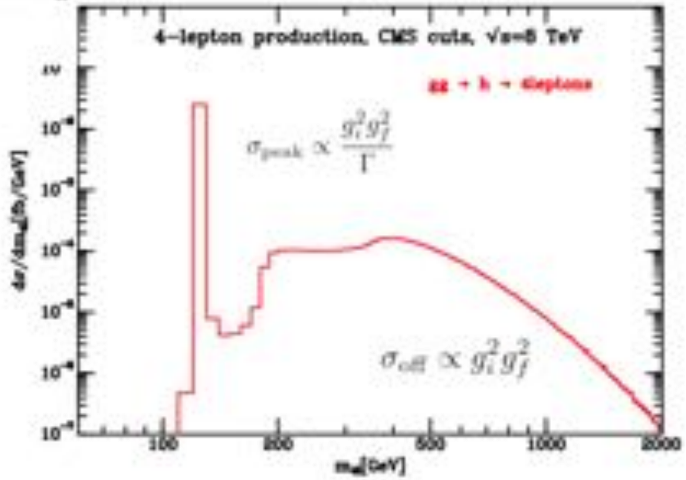
Determine the Higgs couplings to a few % precision…

New opportunities: Higgs width

Higgs properties: width

Keith Ellis





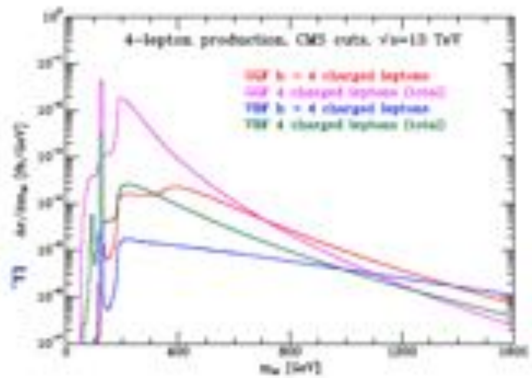
Caola Melnikov method

$$\frac{\left(\frac{\sigma_{\rm off}}{\sigma_{\rm peak}}\right)_{\rm experimental\ gg}}{\left(\frac{\sigma_{\rm off}}{\sigma_{\rm peak}}\right)_{\rm theoretical\ SM}} = \frac{\Gamma}{\Gamma^{\rm SM}}$$

Used by ATLAS and CMS: 5-6 x SM:
2 orders of magnitude improvement
Caveat: true if couplings are the same
(Englert and Spannowsky)

Using VBF events

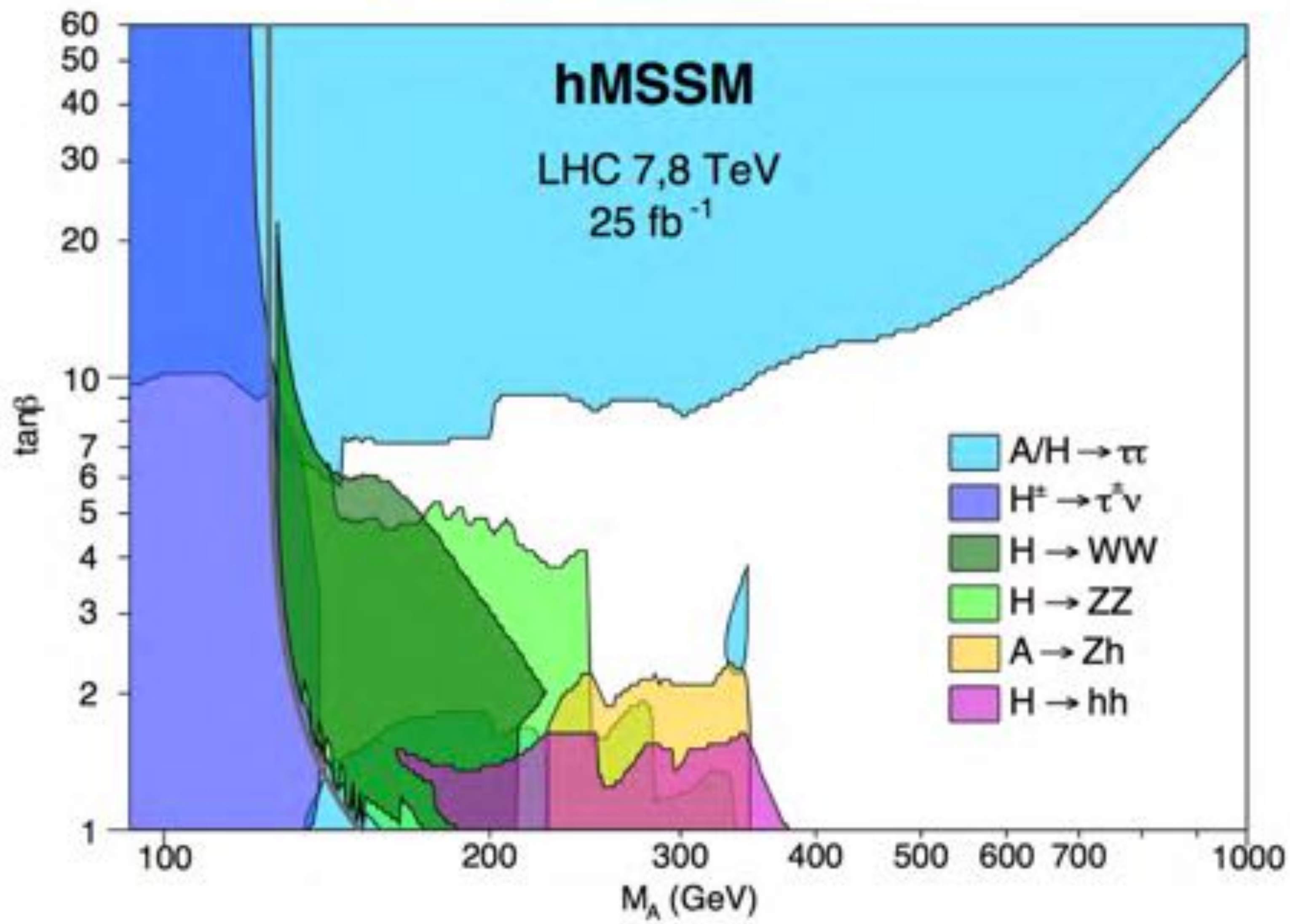
Idea: look at VBF which is tree-level, not loop-induced in the SM



- Possible width bounds with (100, 300fb^{-1}) are similar to those currently obtained from gg fusion (20fb^{-1}).

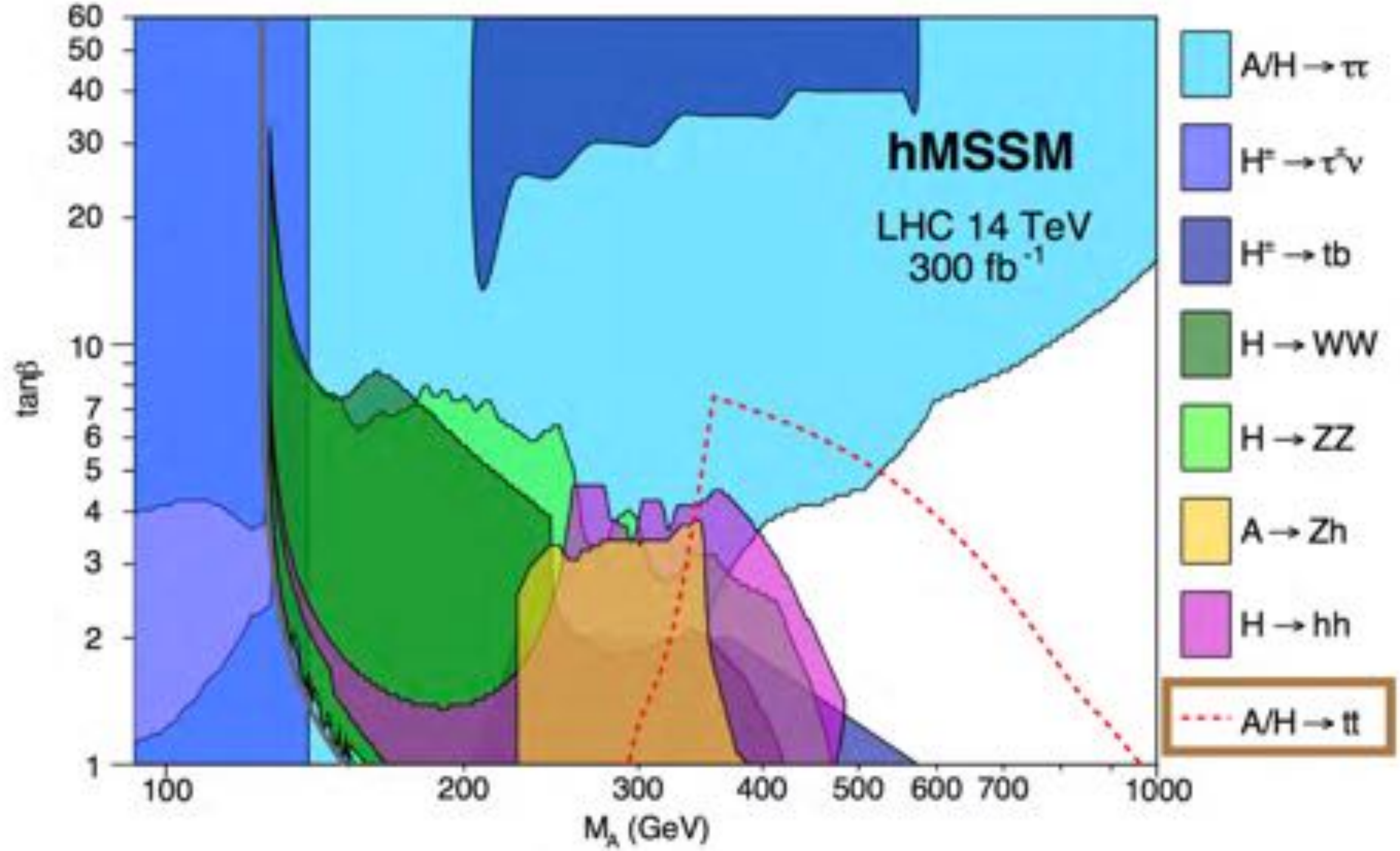
MSSM Higgs Search (Now)

A. Djouadi et al: arXiv:1502.05653



MSSM Higgs Search (Next)

A. Djouadi et al: arXiv:1502.05653

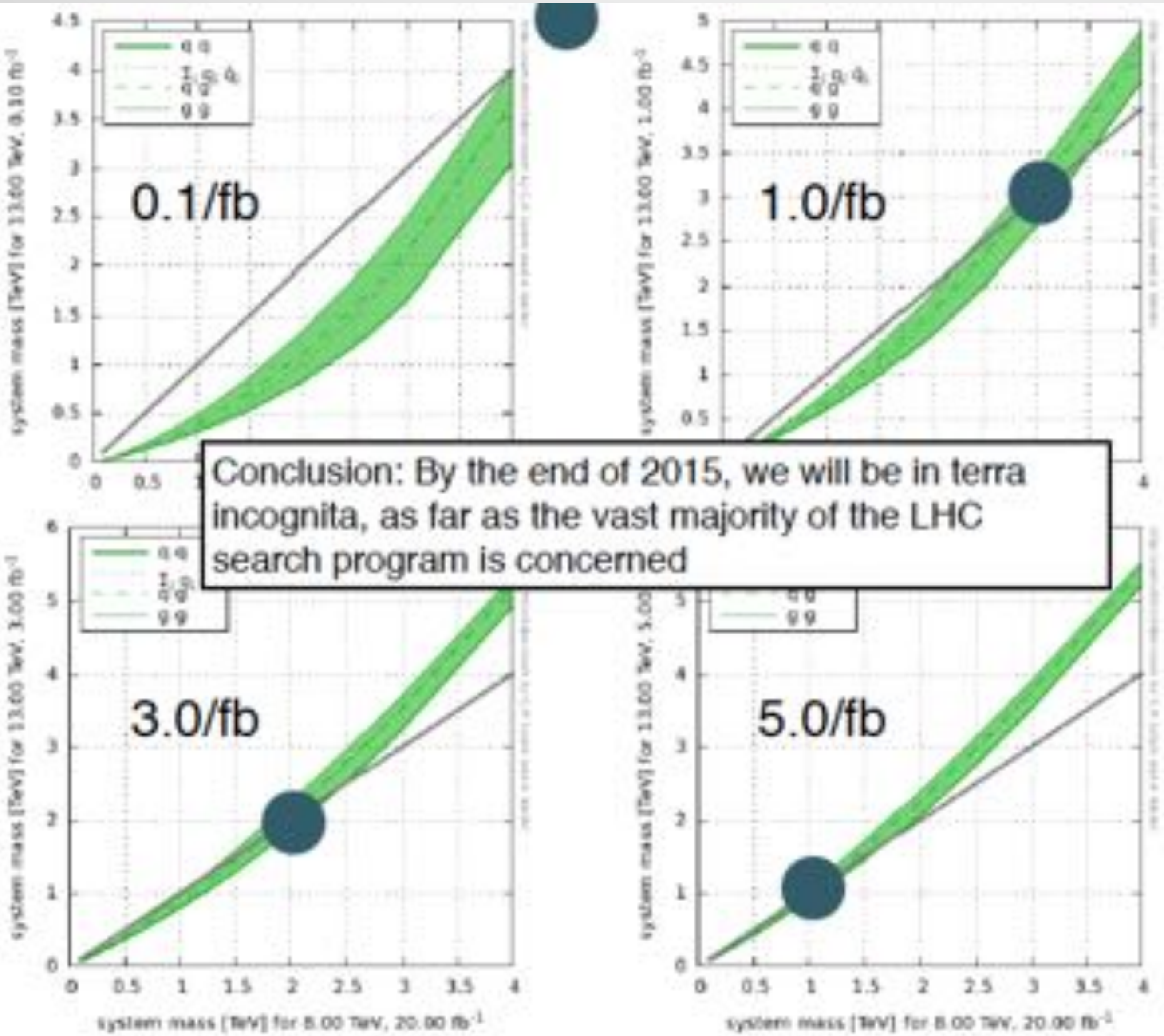


What we can measure in Run II…

- Many couplings to a precision of ~ 5% (b to 10%)
- Top Yukawa couplings to 15-20%
- Higgs to mumu to about 30%
- Higgs to Zgamma? Maybe combining ATLAS & CMS
- Access to more difficult channels such as VBF with H->bb
- Differential distributions and fiducial cross sections…
- Constrain invisible decay width to 20 %
- Total width of the Higgs if the theory follows data precision
- No access to triple Higgs coupling so far. With LH-LHC? Unless we have some new ideas!!
- Note: we will produce ~ 25 Million Higgses in run-II @ LHC Better experimental methods to use more than a few per mille? New Theoretical ideas to extract information from the data? New Theoretical precision? This is the job description

Search for Massive Objects

When do we overtake the run-I sensitivity?



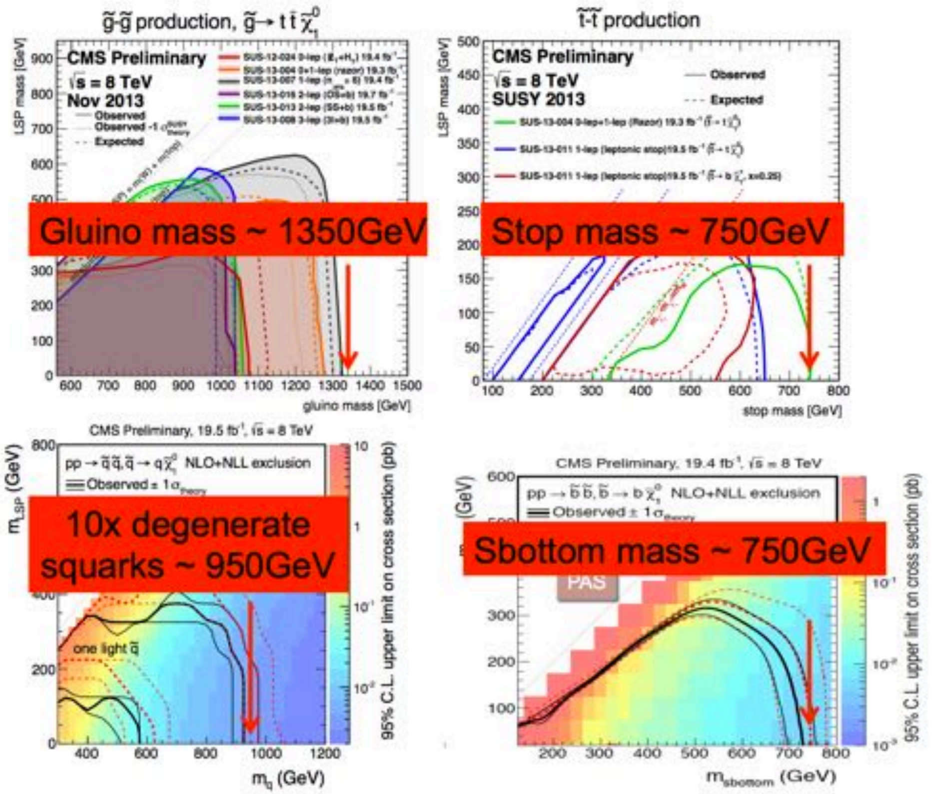
Conclusion: By the end of 2015, we will be in terra incognita, as far as the vast majority of the LHC search program is concerned

- With 1/fb we have added sensitivity to ~3 TeV objects
  - (~1.5 TeV for pair production)
- With 5/fb we have added sensitivity to ~1 TeV objects
  - (~0.5 TeV pair production)

SUSY Prospects @ 2015/2016

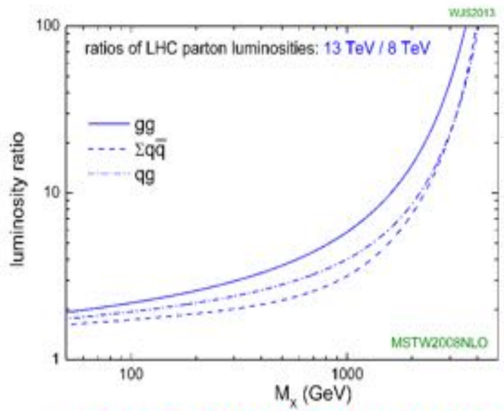
Expect ~ 10-20 fb^{-1} in 2015 & 40 fb^{-1} in 2016 (present guestimates)

2014



2015-2016

Cross Section Scaling 8 -> 13 TeV



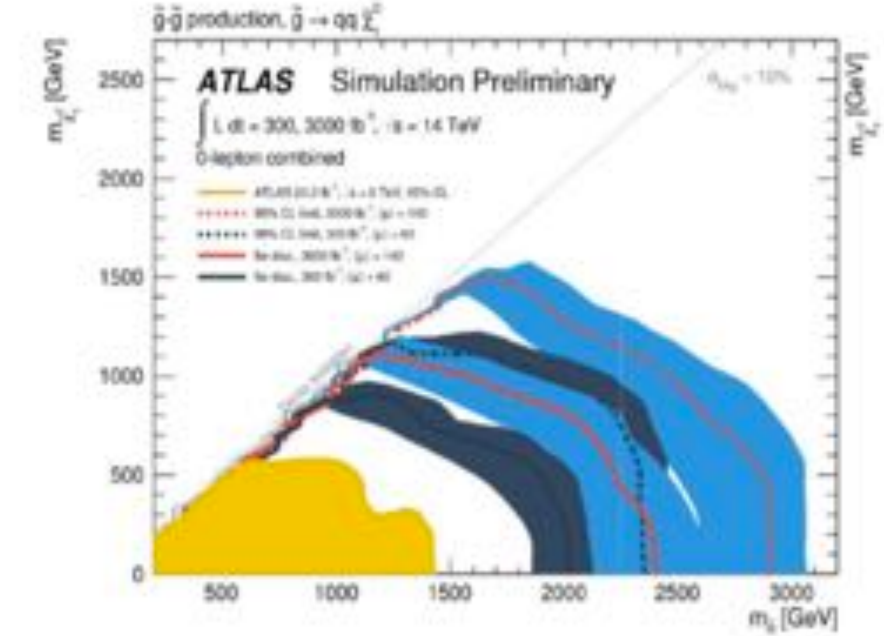
Xsection Ratios 13/8 TeV

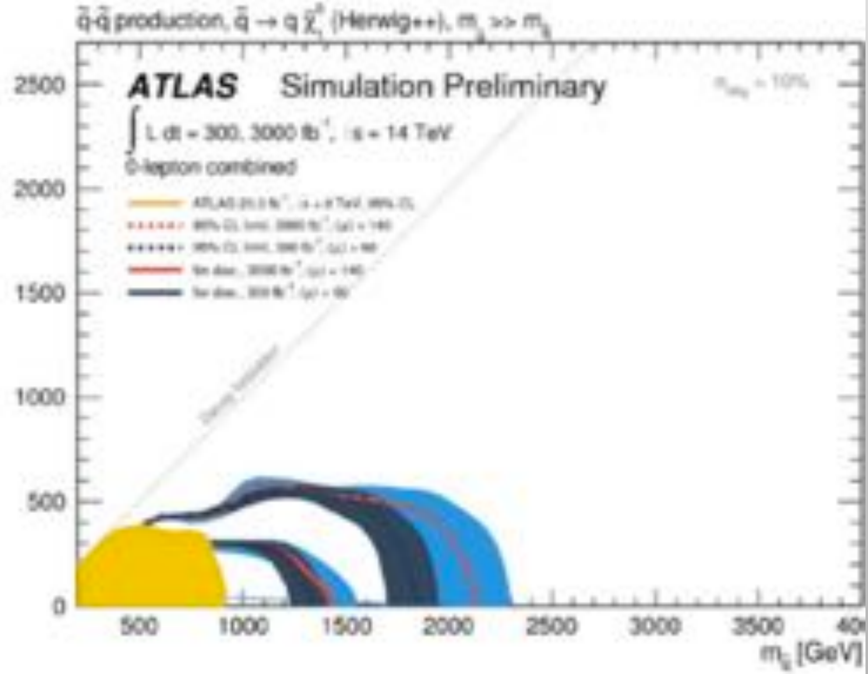
1350GeV gluino: x30
950GeV squark: x20
750GeV squark: x9
350GeV $X^{+-}X^0$: x3
top pairs: x4

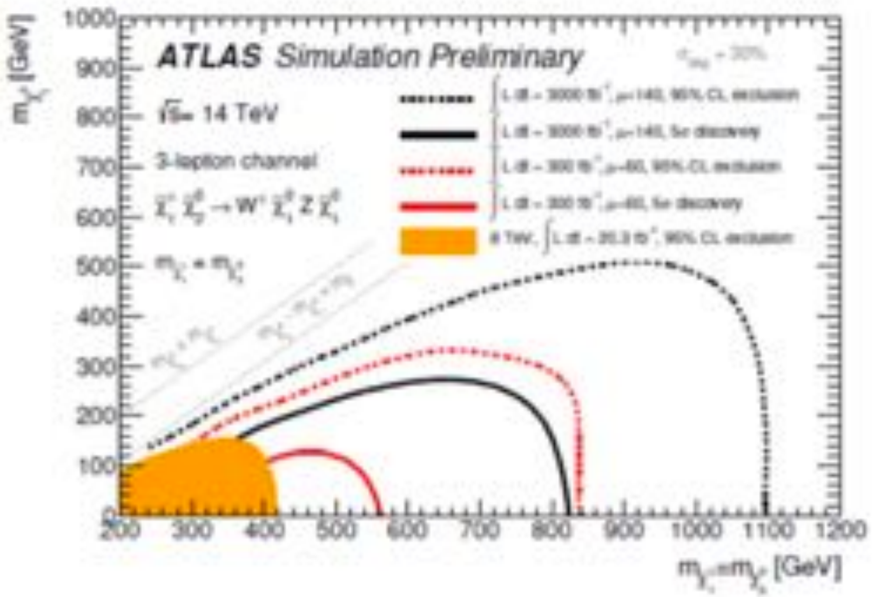
~1/fb of 13TeV data surpasses our best gluino limits.
~3/fb of 13TeV data surpasses our sbottom and stop limits.
There will be no relevant SM measurements at 13TeV
by the time we have already stepped well into new territory!!!

0.5-1 fb^{-1} would be enough for first analyses entering new territory
We expect that have such a sample by Summer 2015!!

Prospects for SUSY Searches







Reach for squarks, gluinos
and EWKinos
Simulation with expected pile-up

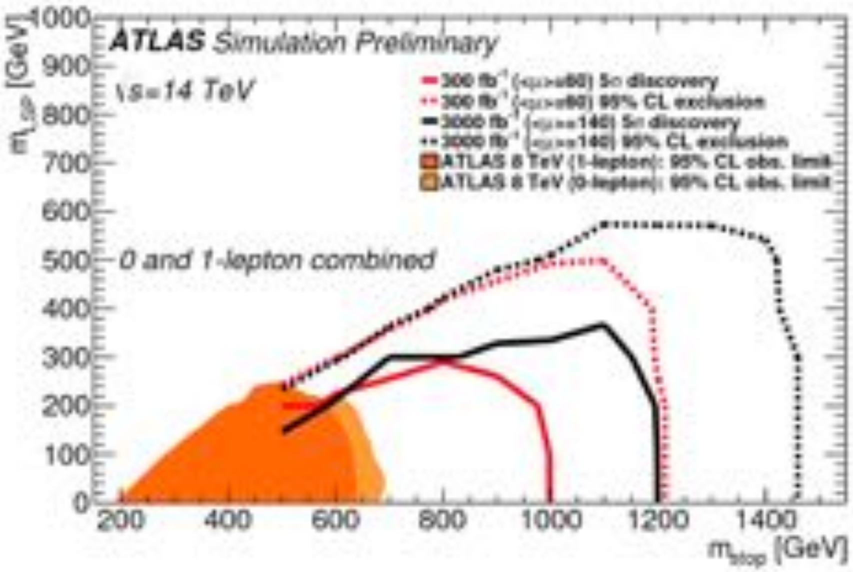
ATLAS Snowmass Report

Stop Squark Production

Strong production of stop quarks

- Naturalness requires stop/sbottom mass to be < ~1 TeV
- Studies performed only for standard cases t+LSP
- Final state: 0/1 lepton + ≥6/4 jets + ≥2/1 b-jets + Etmiss
- 5σ discovery potential up to 1 TeV with 300 fb^{-1} and 1.2 TeV with 3000 fb^{-1}.

ATL-PHYS-PUB-2013-011



Bottom Squark Production

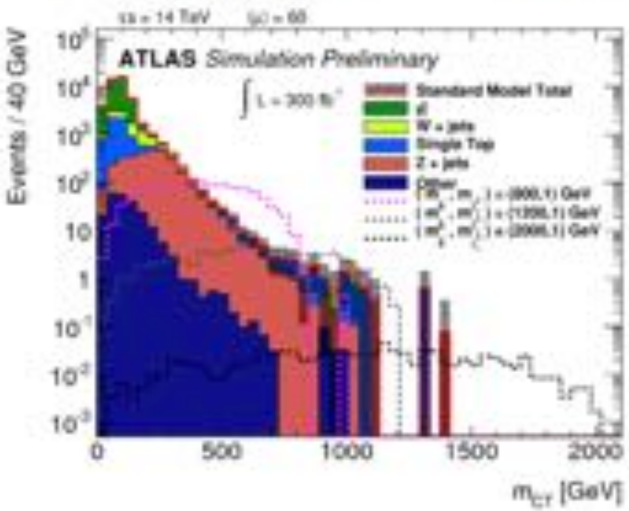
Strong production of sbottom quarks

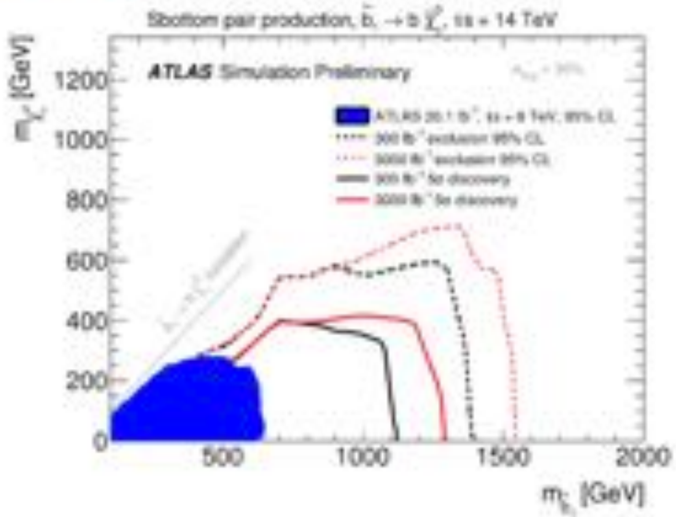
- Feasibility studies performed for direct production and decay (b+LSP)
- Discriminator between signal and main background (ttbar): boost-corrected contransverse mass

$$m_{CT} = \frac{m^2(\tilde{b}) - m^2(\tilde{\chi}_1^0)}{m(\tilde{b})}$$

- 5σ discovery potential up to 1.1 TeV with 300 fb^{-1} and 1.3 TeV with 3000 fb^{-1}.

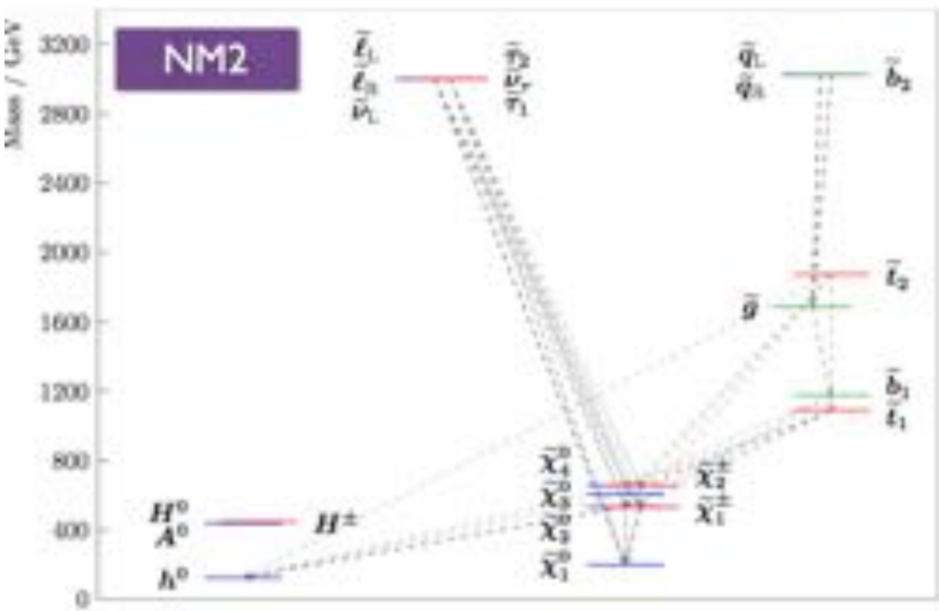
ATL-PHYS-PUB-2014-010





Snowmass Benchmark Models

- Five phenomenological models motivated by naturalness explored through a number of signature-based searches
  - models vary nature of the LSP (bino-, higgsino-like), EWK-inos and sleptons hierarchies
  - STC (stau) and STOC (stop) co-annihilation models satisfy dark matter constraints



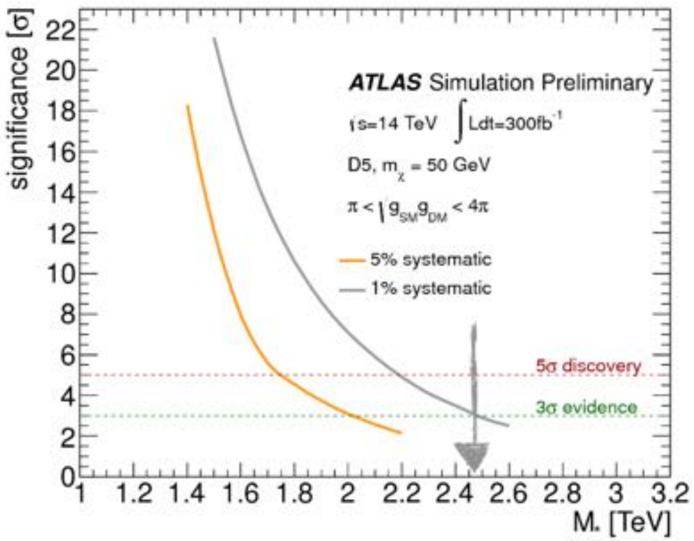
Analysis	Luminosity (fb^{-1})	Model				
		NM1	NM2	NM3	STC	STOC
all-hadronic (H_T-H_T^{miss}) search	300				< 3σ	3 – 5σ
	3000				3 – 5σ	> 5σ
all-hadronic (M_{T2}) search	300	3 – 5σ	> 5σ	> 5σ		
	3000	> 5σ	> 5σ	> 5σ		
all-hadronic $\tilde{b}_1$ search	300	< 3σ	< 3σ	< 3σ	3 – 5σ	< 3σ
	3000	< 3σ	< 3σ	< 3σ	> 5σ	< 3σ
1-lepton $\tilde{t}_1$ search	300	> 5σ	> 5σ	> 5σ	3 – 5σ	< 3σ
	3000	> 5σ	> 5σ	> 5σ	> 5σ	> 5σ
monojet $\tilde{t}_1$ search	300					3 – 5σ
	3000					3 – 5σ
$m_{\ell^+\ell^-}$ kinematic edge	300	< 3σ	< 3σ	< 3σ		
	3000	> 5σ	< 3σ	< 3σ		
multilepton + b-tag search	300	> 5σ	> 5σ	> 5σ	3 – 5σ	
	3000	> 5σ	> 5σ	> 5σ	> 5σ	
multilepton search	300	< 3σ	< 3σ	< 3σ	< 3σ	
	3000	3 – 5σ	3 – 5σ	< 3σ	3 – 5σ	
ewkino WH search	300		< 3σ			
	3000		3 – 5σ			

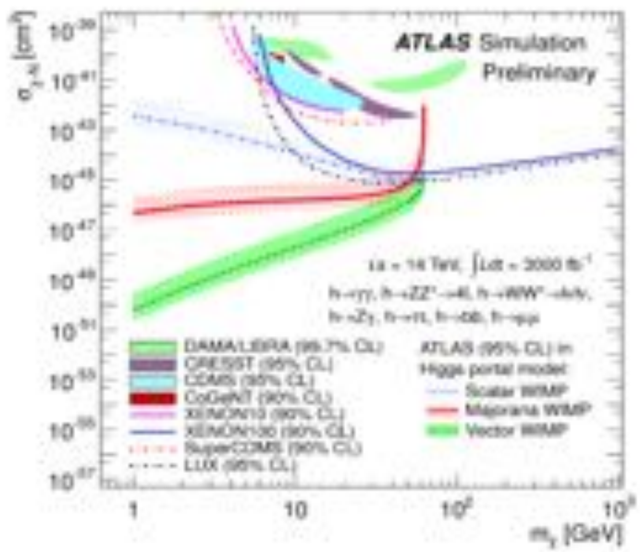
< 3σ | 3 – 5σ | > 5σ

Dark Matter Prospects

Searches for WIMP Dark Matter

- Models:
  - contact interactions between SM and DM particles – EFT
  - simplified models with mediators (e.g. Z')
  - Higgs portal models – weak interaction with SM particles except the Higgs boson
- Signatures: mono-jet + Etmiss   any higgs-like event



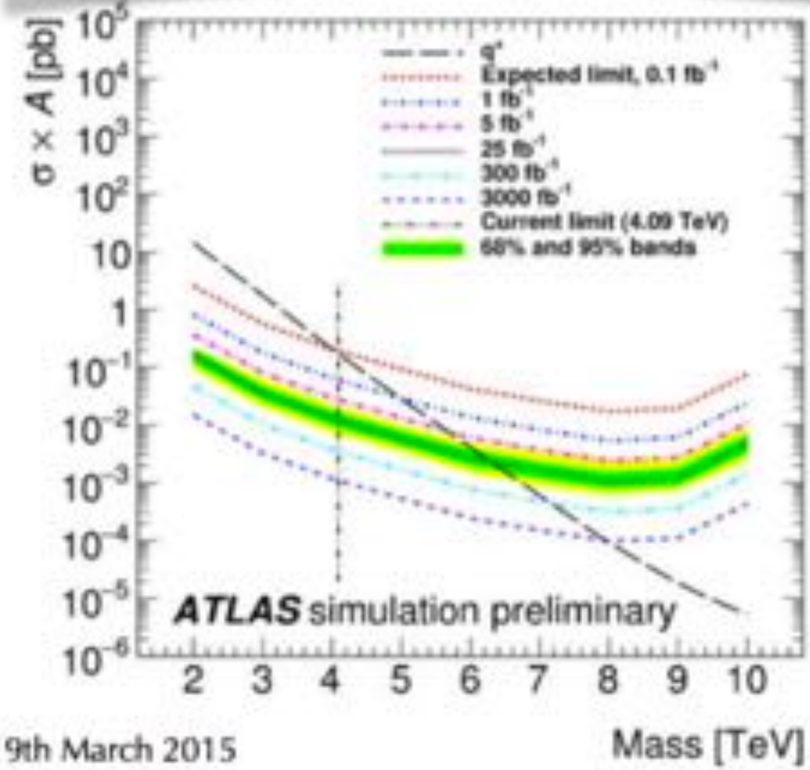


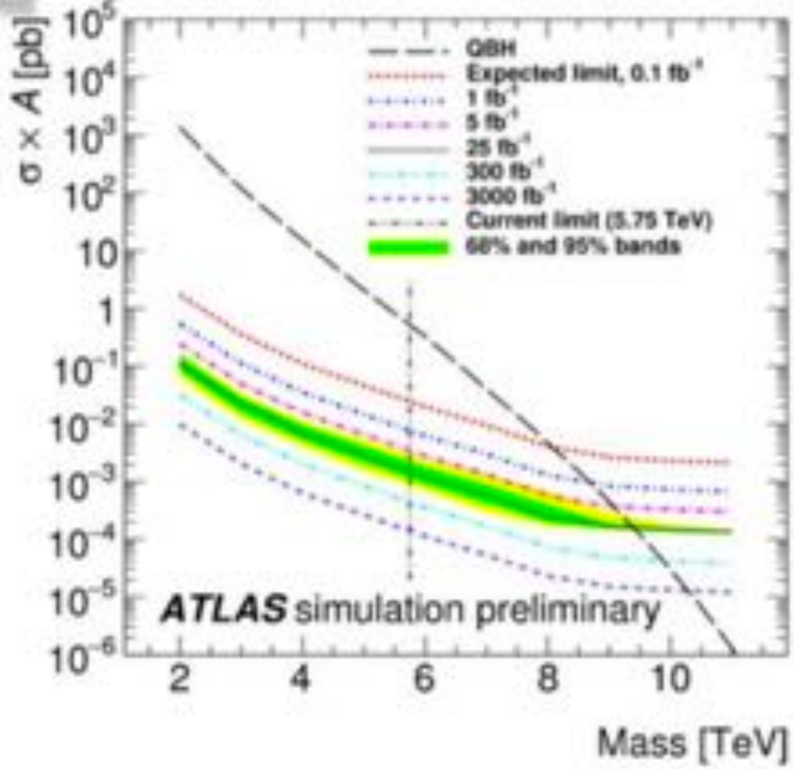
Prospects for Di-jet Resonances

ATLAS-PHYS-15-004

$\int \mathscr{L}$ [fb^{-1}]	M_{q^*} [TeV]	M_{QBH} [TeV]
0.1	4.0	8.2
1	5.0	8.0
5	5.9	9.2
25	6.6	9.7
300	7.4	10.0
3000	8.0	10.1

100 pb^{-1} of 14 TeV data can provide limits competitive to 20 fb^{-1} of 8 TeV collisions.

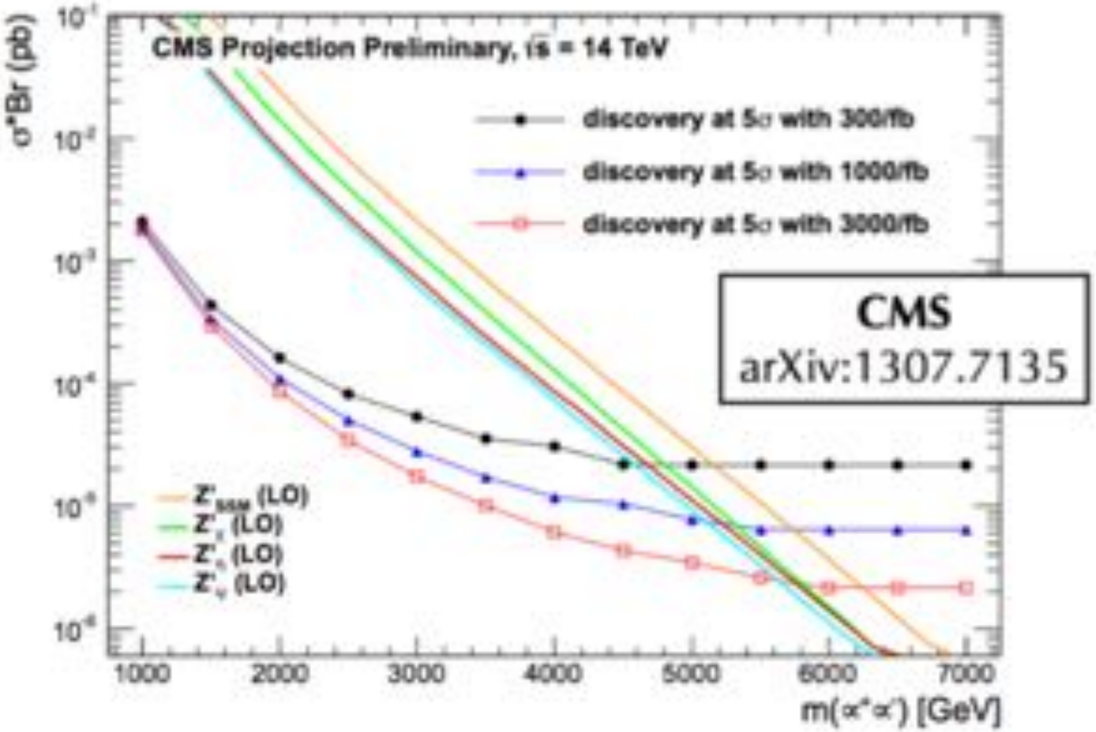




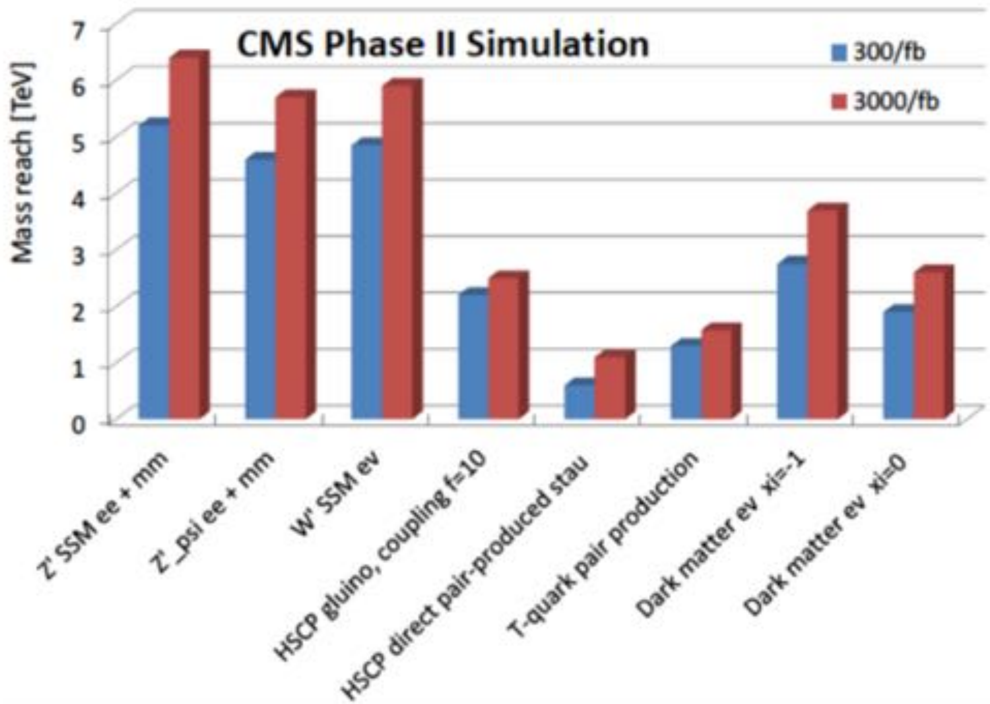
The Prospects for ll Resonances

Z′SSM 95% CL Limit	Run 1 8 TeV (20 fb^{-1})	Run 3 14 TeV (300 fb^{-1})	HL-LHC 14 TeV (3000 fb^{-1})
Z′→ee	> 2.79 TeV	> 6.5 TeV	> 7.8 TeV
Z′→ μμ	> 2.53 TeV	>6.4 TeV	> 7.6 TeV

ATLAS
ATL-PHYS-PUB-2013-007
(no systematics)

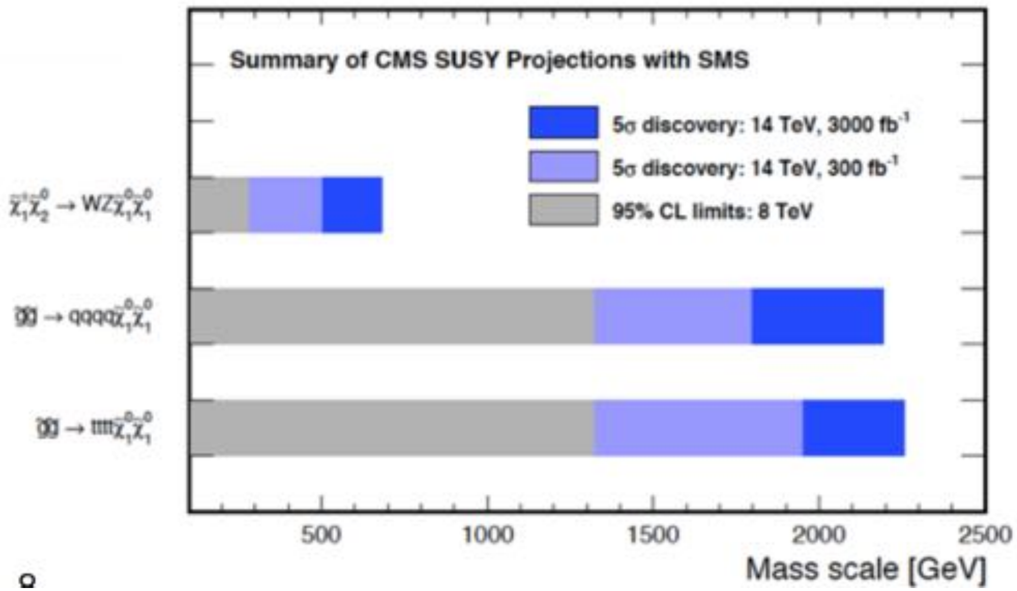


Overview on SUSY and Exotica



Mass reach for discovery for various Exotica

Mass reach for discovery for SUSY searches

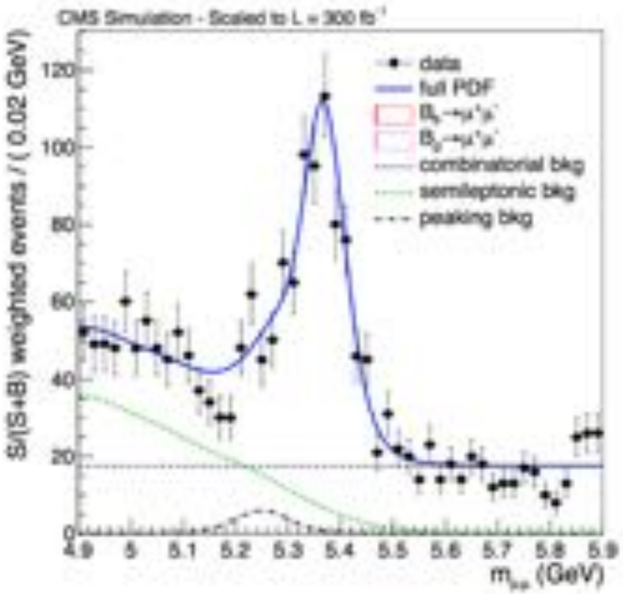


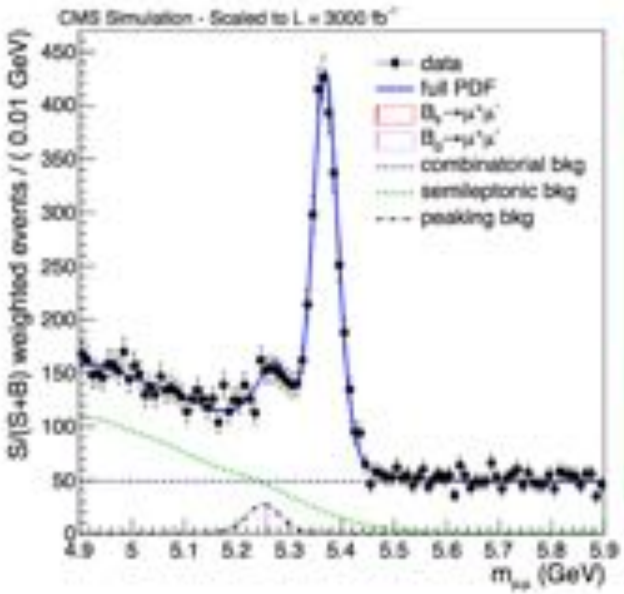
Heavy Flavor: $B_{s(d)} \rightarrow \mu\mu$

- Rare decays $B^0_s \rightarrow \mu\mu$ and $B^0 \rightarrow \mu\mu$ only through FCNC, highly suppressed in the SM
  - modification to the BF predicted in several BSM scenarios (SUSY, non-SM Higgs,…)
- **Both CMS and LHCb observed the $B^0_s \rightarrow \mu\mu$ and achieved evidence of $B^0 \rightarrow \mu\mu$!**

1411.4413	$B^0_s \rightarrow \mu\mu$	$B^0 \rightarrow \mu\mu$
Significance	6.2σ	3.2σ
BF	$(2.8^{+0.7}_{-0.6})\times10^{-9}$	$(3.9^{+1.6}_{-1.4})\times10^{-10}$

L (fb^{-1})	No. of B^0_s	No. of B^0	$\delta\mathcal{B}/\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-)$	$\delta\mathcal{B}/\mathcal{B}(B^0 \rightarrow \mu^+\mu^-)$	B^0 sign.	$\delta\frac{\mathcal{B}(B^0\rightarrow\mu^+\mu^-)}{\mathcal{B}(B^0_s\rightarrow\mu^+\mu^-)}$
20	16.5	2.0	35%	>100%	0.0–1.5 σ	>100%
100	144	18	15%	66%	0.5–2.4 σ	71%
300	433	54	12%	45%	1.3–3.3 σ	47%
3000	2096	256	12%	18%	5.4–7.6 σ	21%





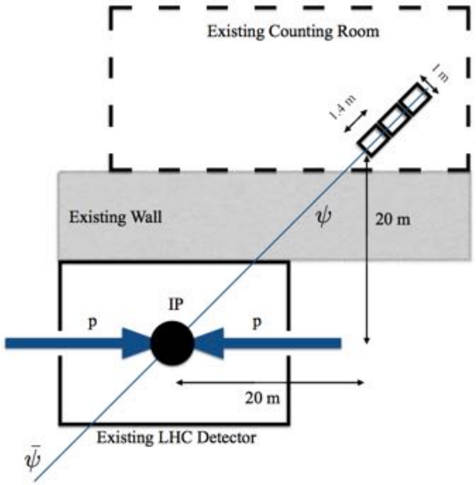
HL-LHC will allow for stringent tests of the $B^0_s \rightarrow \mu\mu$ and to observe the $B^0 \rightarrow \mu\mu$.
Excellent performance of the trigger and tracker is essential to the success of the program

FTR-13-022-pas

Particles with Milli-Charges?

CMS search for fractional charged particle arXiv:1210.2311
Q=1/3e > 140 GeV; Q=2/3e >310 GeV (95% CL. dE/dx)

A "new" idea -> Hunting for particles with charges ~ 0.1-0.001e arXiv:1410.6816

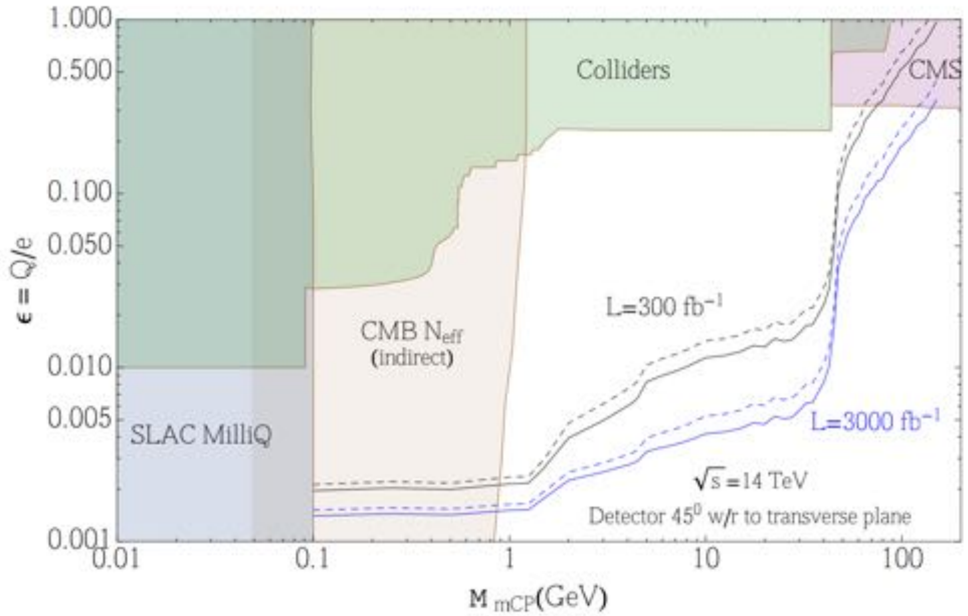


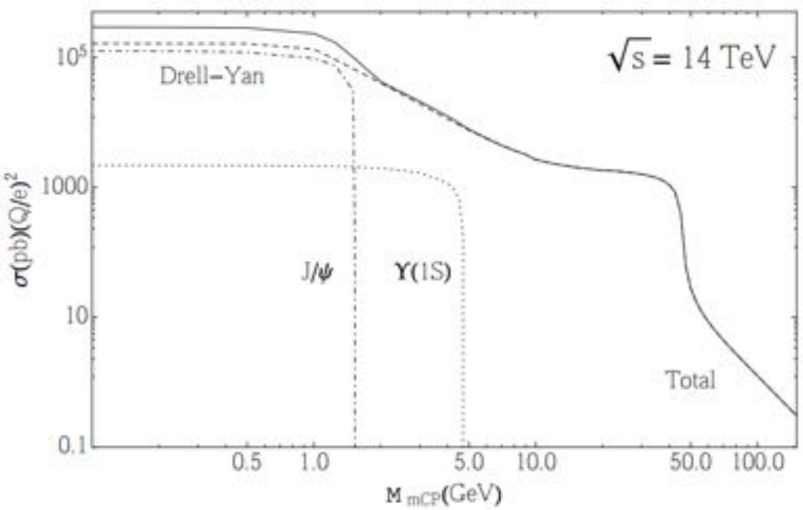
Looking for milli-charged particles with a new experiment at the LHC

Andrew Haas, Christopher S. Hill, Eder Izaguirre, Itay Yavin

(Submitted on 24 Oct 2014)

We propose a new experiment at the Large Hadron Collider (LHC) that offers a powerful and model-independent probe for milli-charged particles. This experiment could be sensitive to charges in the range $10^{-3}e - 10^{-1}e$ for masses in the range $0.1 - 100$ GeV, which is the least constrained part of the parameter space for milli-charged particles. This is a new window of opportunity for exploring physics beyond the Standard Model at the LHC.

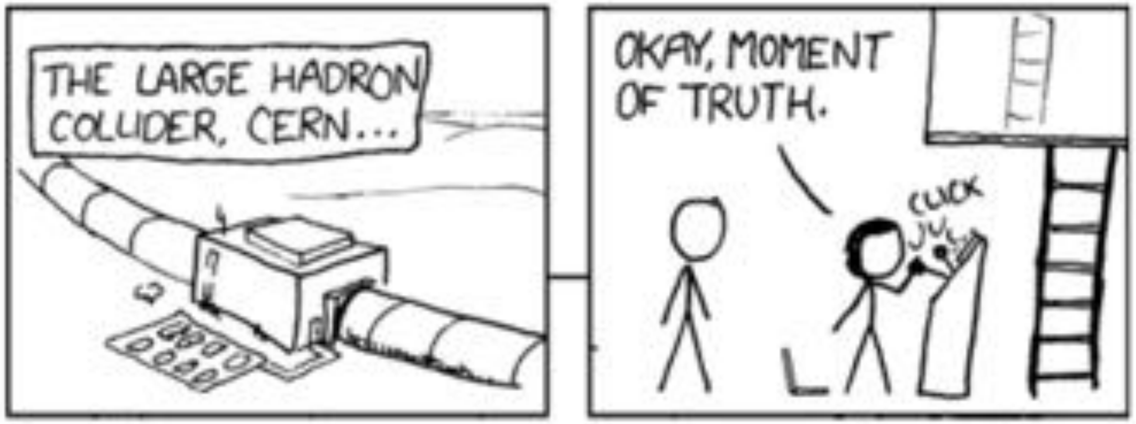




Summary: The LHC is Back! (almost)

- The LHC is gearing up for a swift restart. The experiments are ready for run-II. Let the collisions come!! (expected for June)
- The run-II data will allow for the first precision measurements in the Higgs sector. Maybe we'll see cracks in the SM?
- A prime goal for the LHC is to look for New Physics. The run-I data have cut strongly in the phase space of New Physics: eg supersymmetry and exotica. Mass range extended at 13 TeV
- Understanding Dark Matter is the next big challenge! Generic studies with MET are a high priority for the upcoming studies Maybe dark matter couples to the Higgs directly?
- With one to a few fb^{-1} of 2015 data, the LHC will overtake the run-I searches. 2015-2016 could well be very crucial – and very exciting years!!!

Epilogue…



Eagerly awaiting LHC restart!