FIRST LHC OBSERVATIONS AT 13 TEV

André David (CERN)
on behalf of the ATLAS and CMS collaborations

FIRST LHC MEASUREMENTS AT 13 TEV

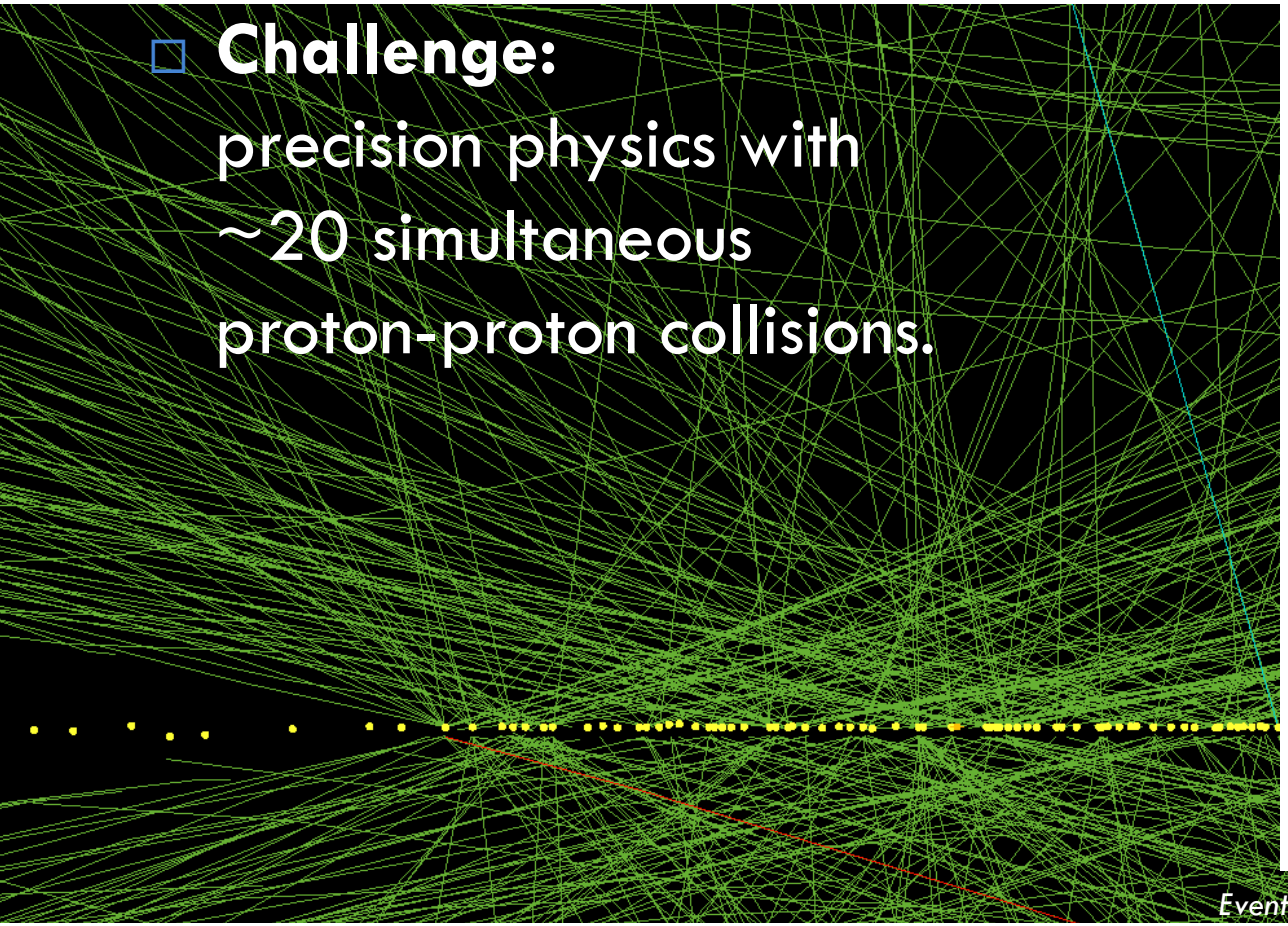
André David (CERN)
on behalf of the ATLAS and CMS collaborations

CLIC Workshop 2016

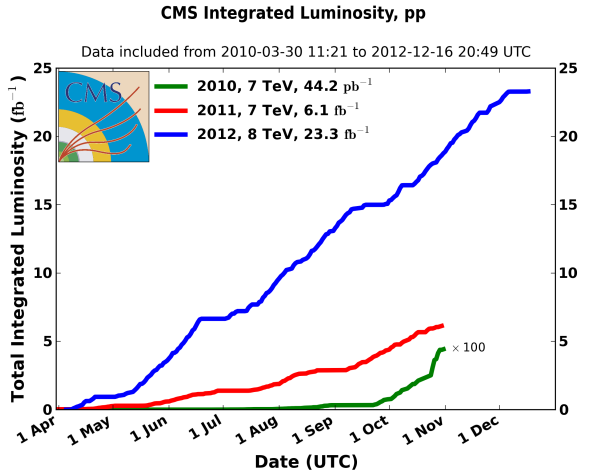
The LHC Run 1: a bountiful harvest

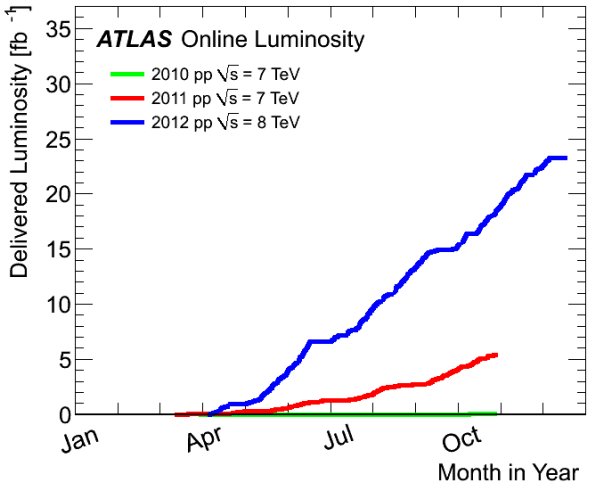
[http://cern.ch/go/K8Tj] [http://cern.ch/go/ZW9S]

- LHC delivered ~30 fb^{-1}.
- **Challenge:**
  precision physics with
  ~20 simultaneous
  proton-proton collisions.



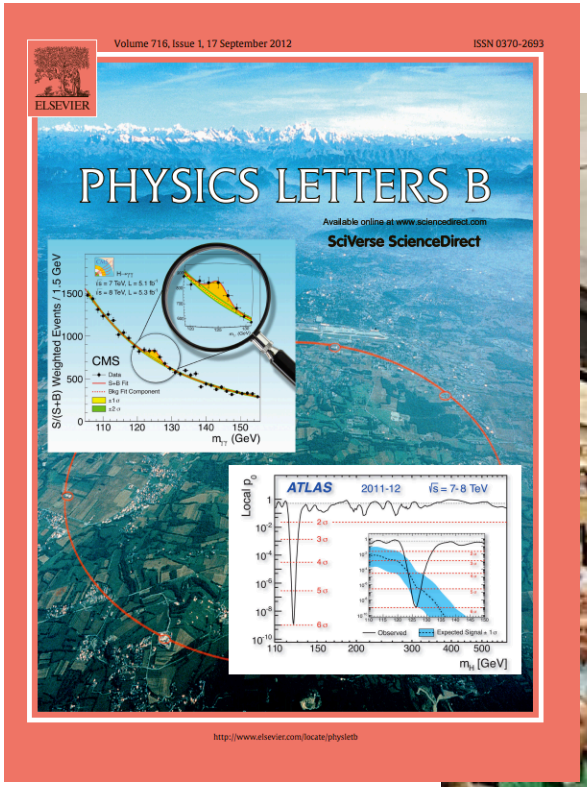
Event with 78 reconstructed vertices along ~10 cm.





July 4, 2012
Looking up to a new boson

[http://cern.ch/go/q8jx]



Who Should Be TIME's Person of the Year 2012?

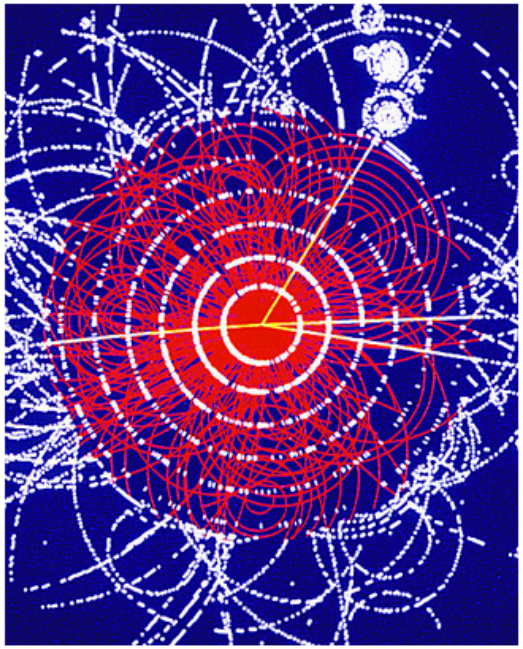
As always, TIME's editors will choose the Person of the Year, but that doesn't mean readers shouldn't have their say. Cast your vote for the person you think most influenced the news this year for better or worse. Voting closes at 11:59 p.m. on Dec. 12, and the winner will be announced on Dec. 14.

THE CANDIDATES

The Higgs Boson

18 of 40

By Jeffrey Kluger | Monday, Nov. 26, 2012



SSPL/GETTY IMAGES

Simulation of a Higgs-Boson decaying into four muons, CERN, 1990.

What do you think?

Should **The Higgs Boson** be TIME's Person of the Year 2012?

Definitely No Way

VOTE

Take a moment to thank this little particle for all the work it does, because without it, you'd be just inchoate energy without so much as a bit of mass. What's more, the same would be true for the entire universe. It was in the 1960s that Scottish physicist Peter Higgs first posited the existence of a particle that causes energy to make the jump to matter. But it was not until last summer that a team of researchers at Europe's Large Hadron Collider — Rolf Heuer, Joseph Incandela and Fabiola Gianotti — at last sealed the deal and in so doing finally fully confirmed Einstein's general theory of relativity. The Higgs — as particles do — immediately decayed to more-fundamental particles, but the scientists would surely be happy to collect any honors or awards in its stead.

Photos: Step inside the Large Hadron Collider.

WHO SHOULD BE TIME'S PERSON OF THE YEAR 2012?
The Candidates
Video
Poll Results

PAST PERSONS OF THE YEAR

2011: The Protester

2010: Facebook's Mark Zuckerberg

2009: Ben Bernanke

2008: Barack Obama

Most Read | Most Emailed

1 Who Should Be TIME's Person of the Year 2012?
2 LIFE Behind the Picture: The Photo That Changed the Face of AIDS
3 Nativity-Scene Battles: Score One for the Atheists
4 The $7 Cup of Starbucks: A Logical Extension of the Coffee Chain's Long-Term Strategy

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Simulation of a Higgs-Boson decaying into four muons, CERN, ~~1990~~ 1995

[http://cds.cern.ch/record/39448]

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Person of the Year

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2012 2011 2010 2009 2008

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Like 1.5k Tweet 536 +1 20 Share 7

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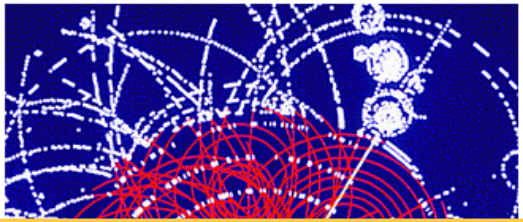

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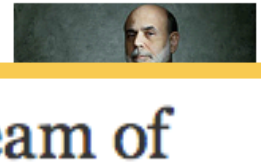

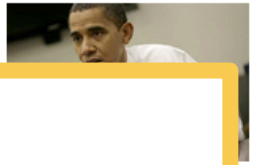

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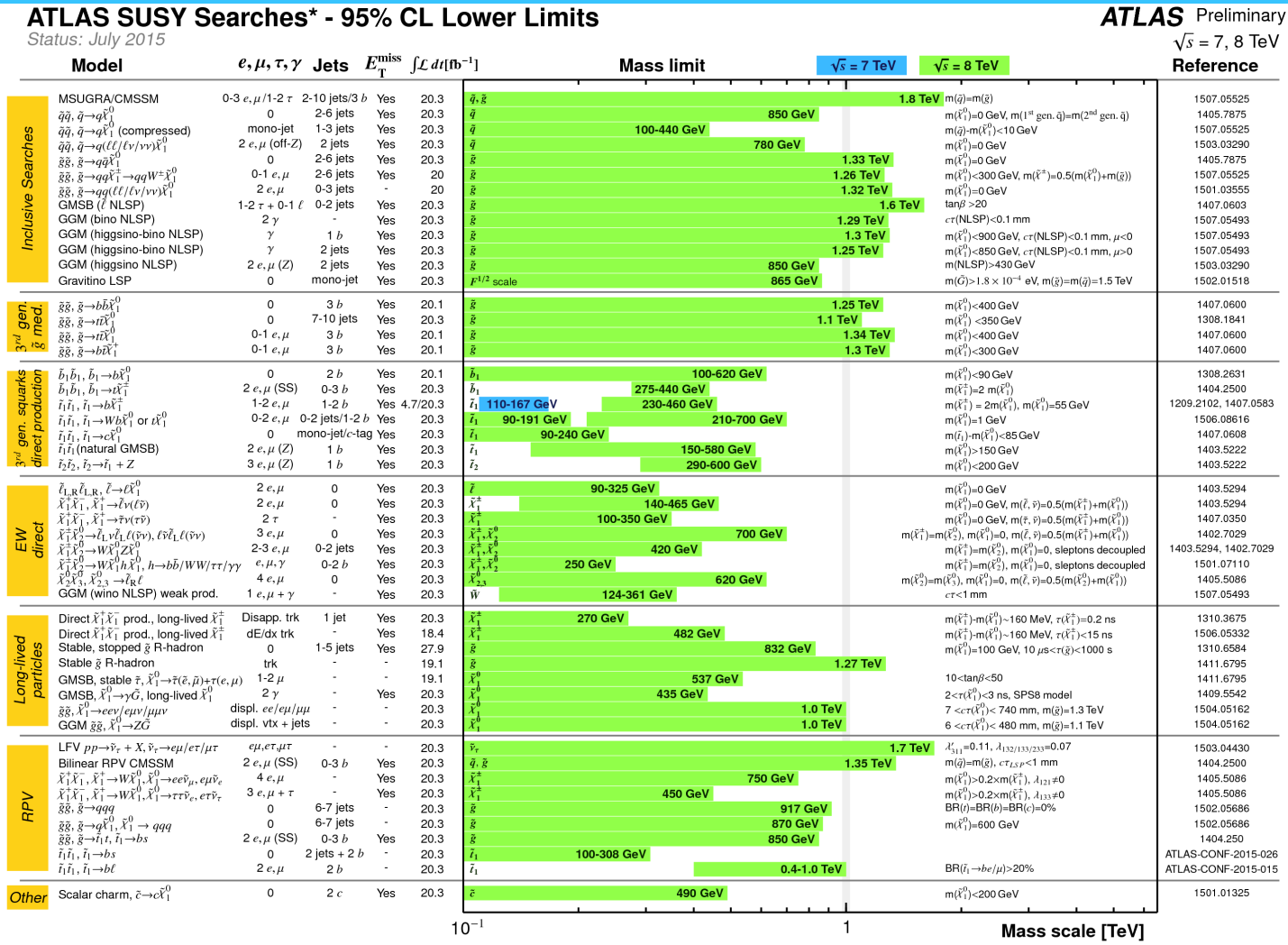
Photos: Step inside the Large Hadron Collider.

Excluding SUSY scenarios...

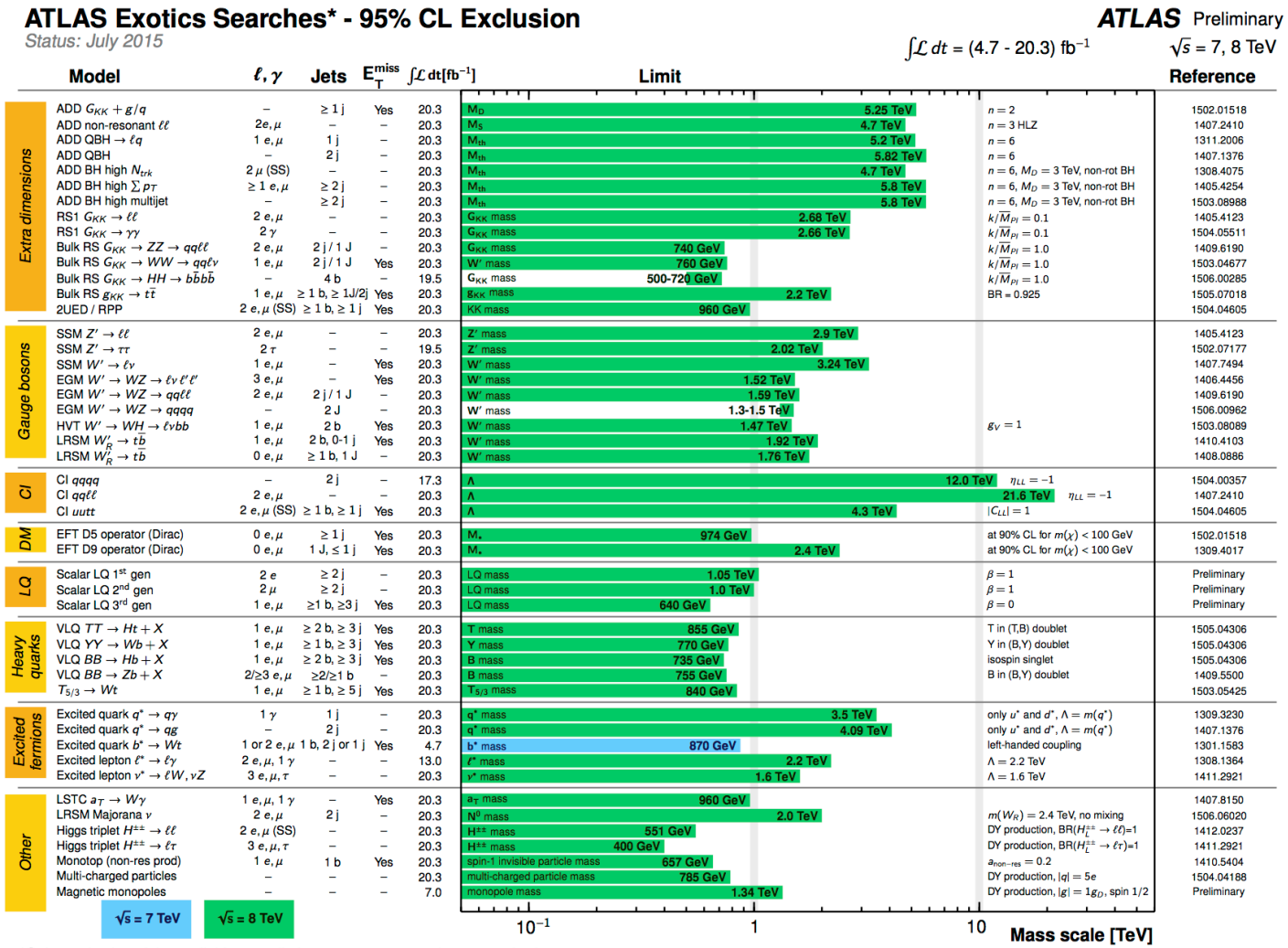
[http://cern.ch/go/W6Wp]



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

…and Exotics scenarios

[http://cern.ch/go/W6Wp]



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A possible Run1 summary

BBC News Sport Weather Shop Earth Travel

SPORT FOOTBALL

Home Football Formula 1 Cricket Rugby U Tennis Golf Athletics Cycling

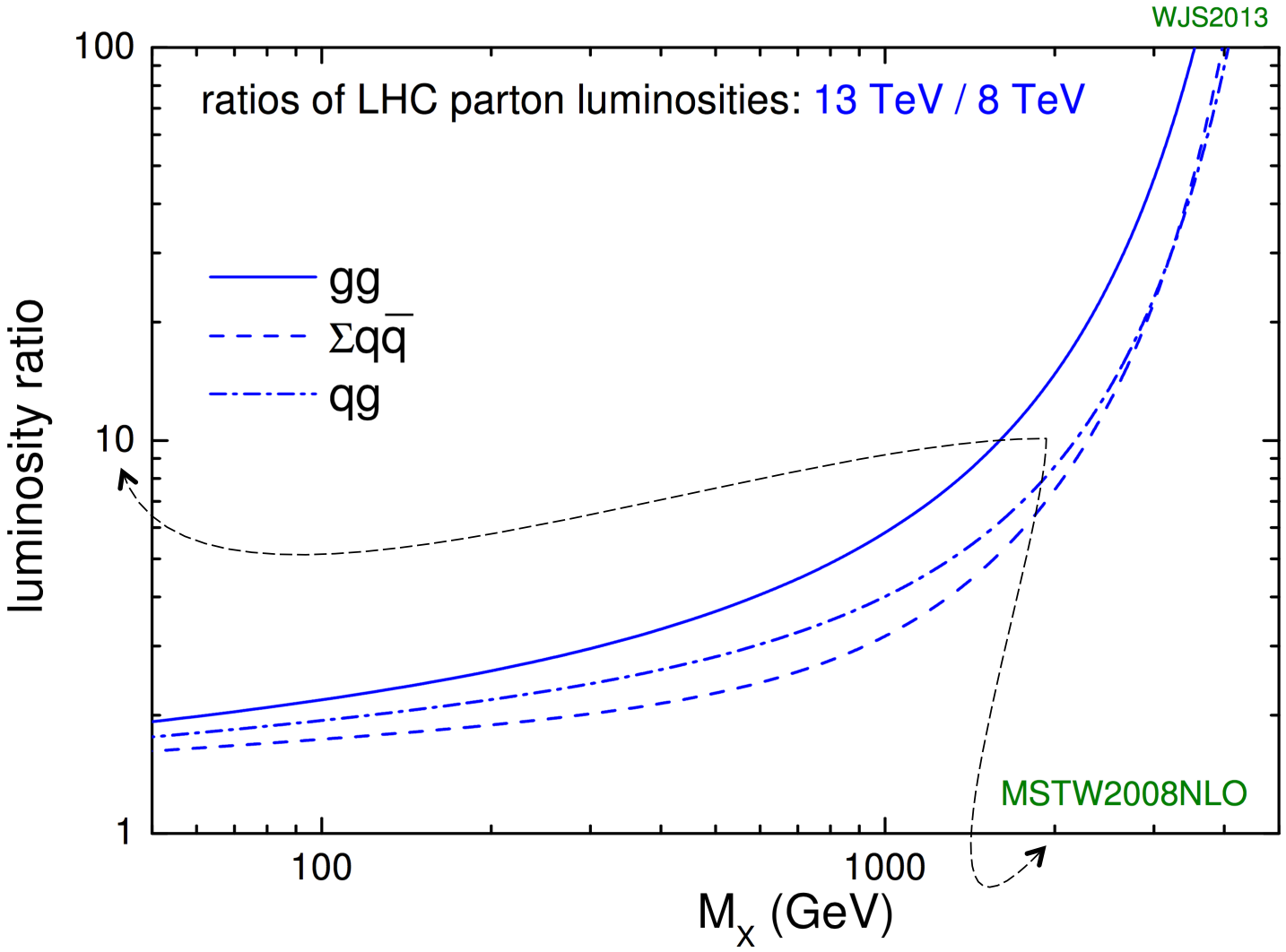
Premier League > Results Fixtures Table Predictor

All BSM FC 0 1 SM Utd

Run1 **5 yr** h(125) '12

The reach of higher energies

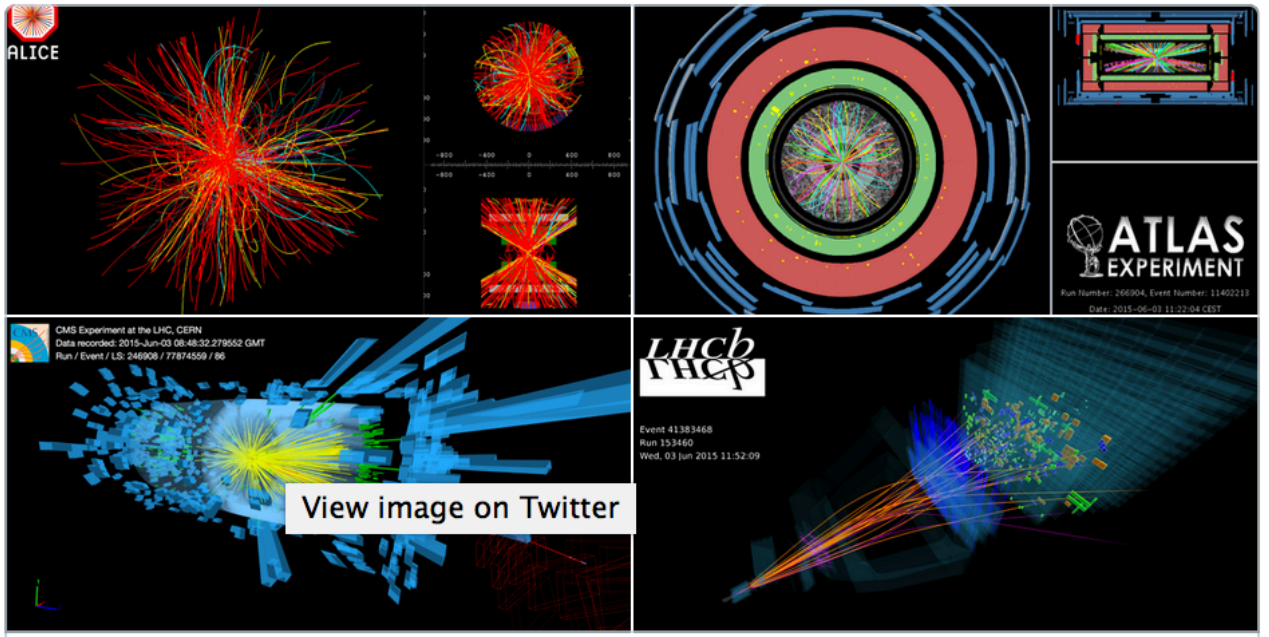
[http://cern.ch/go/FnH6]



Run2 preparation and operation

- 6.5 TeV.
- 25 ns bunch spacing.
- $\beta^* = 40$ cm.

Back to the #13TeV future



CERN
@CERN

Follow

The LHC experiments are back in business with record energy collisions of #13TeV: cern.ch/go/D7z6

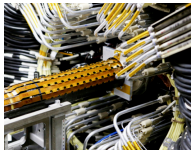
12:41 PM - 3 Jun 2015

853 558

Run2 preparation and operation

ATLAS

- **Inner b-layer (IBL).**
  - 4th Si pixel layer.



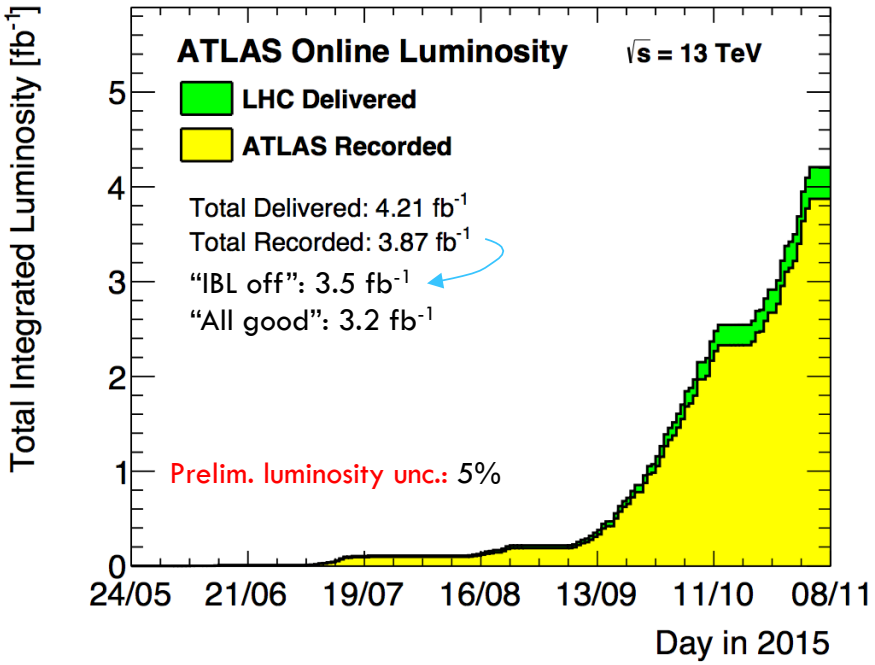
- Finalize muon coverage.
- Trigger/DAQ
  - L1 rate: 75 to 100 kHz.
  - L1Calo: better MET.
  - L1Muon: rate reduction from coincidences.

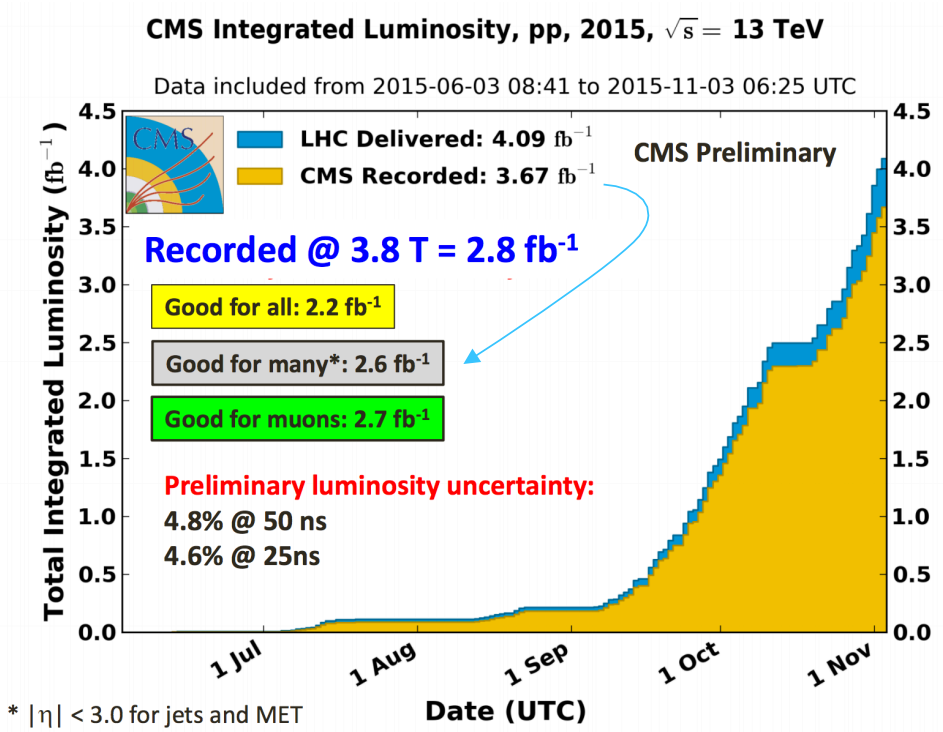
CMS

- **Liquid He supply to magnet.**
  - Field-off periods.
- New lumi. detectors.
- Trigger/DAQ
  - L1Calo: better tau trigger.
  - DAQ2: new hardware.

The 2015 harvest

- Already average **13 interactions per bunch crossing at 25 ns.**
- Gaining experience for the long haul:
  - **ATLAS IBL** operation.
  - **CMS liquid Helium supply** for solenoid.

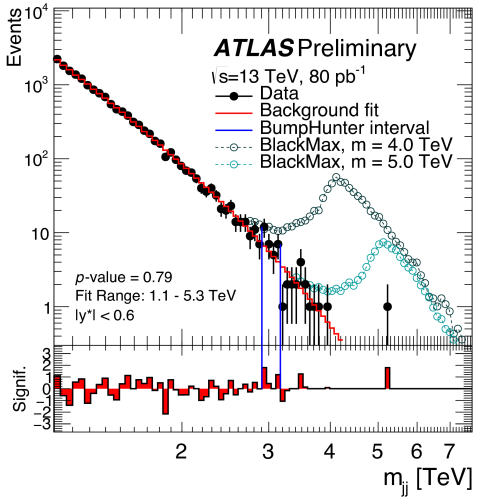


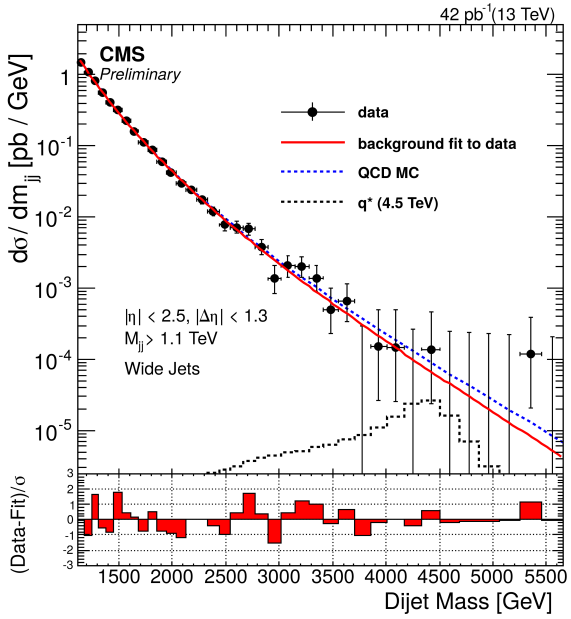


Many early results during Summer

[ATLAS-CONF-2015-042][CMS-PAS-EXO-15-001]

- Charged particle densities and correlations.
- (Single) top production.
- Single boson production.
- First (negative) search results.
  - *But the first events in the tails.*





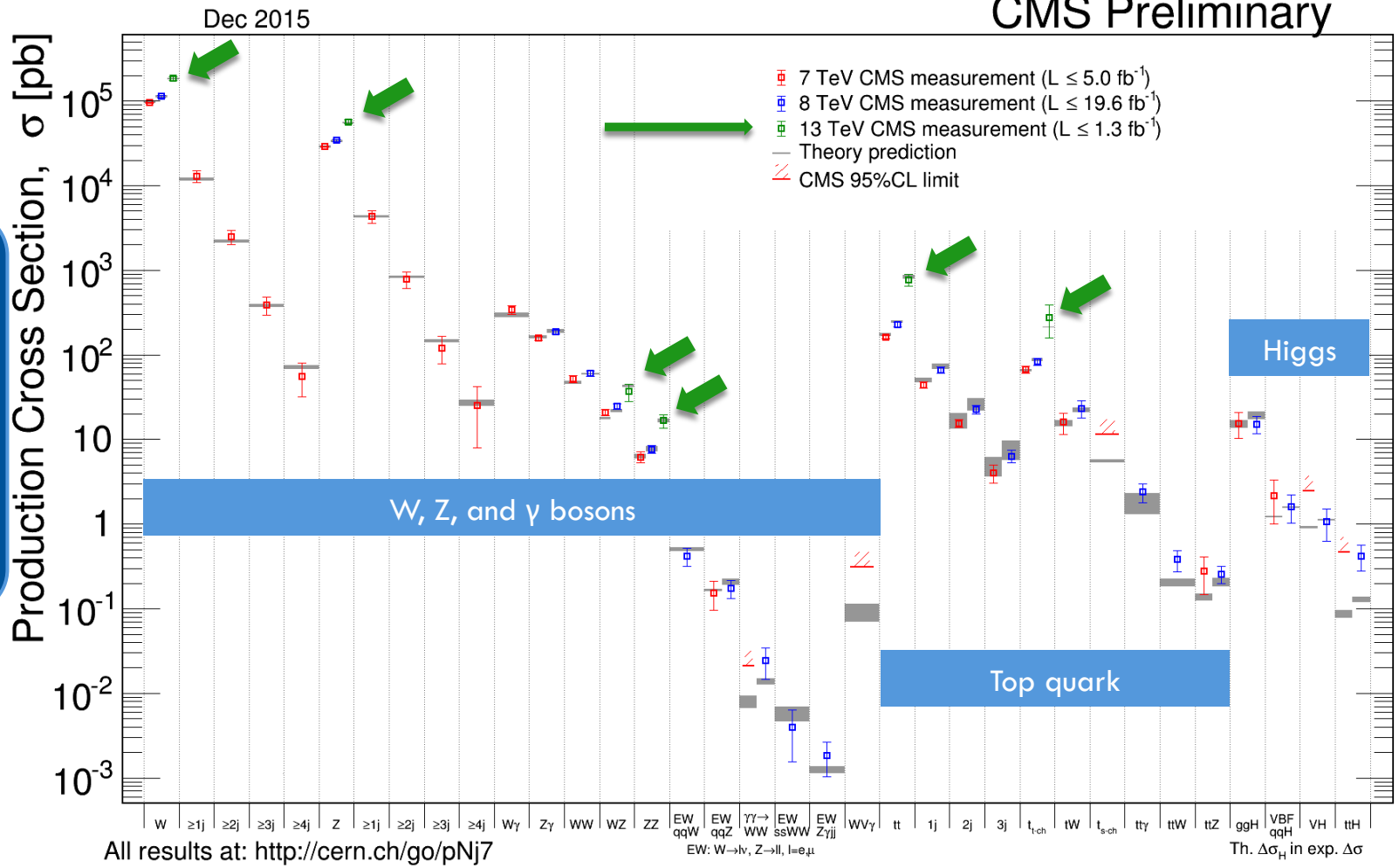
On the shoulders of giants

detector makers & theory calculators

"Yesterday's discovery is today's calibration, and tomorrow's background." – V. L. Telegdi [http://cern.ch/go/lf9C][http://cern.ch/go/KD8D]

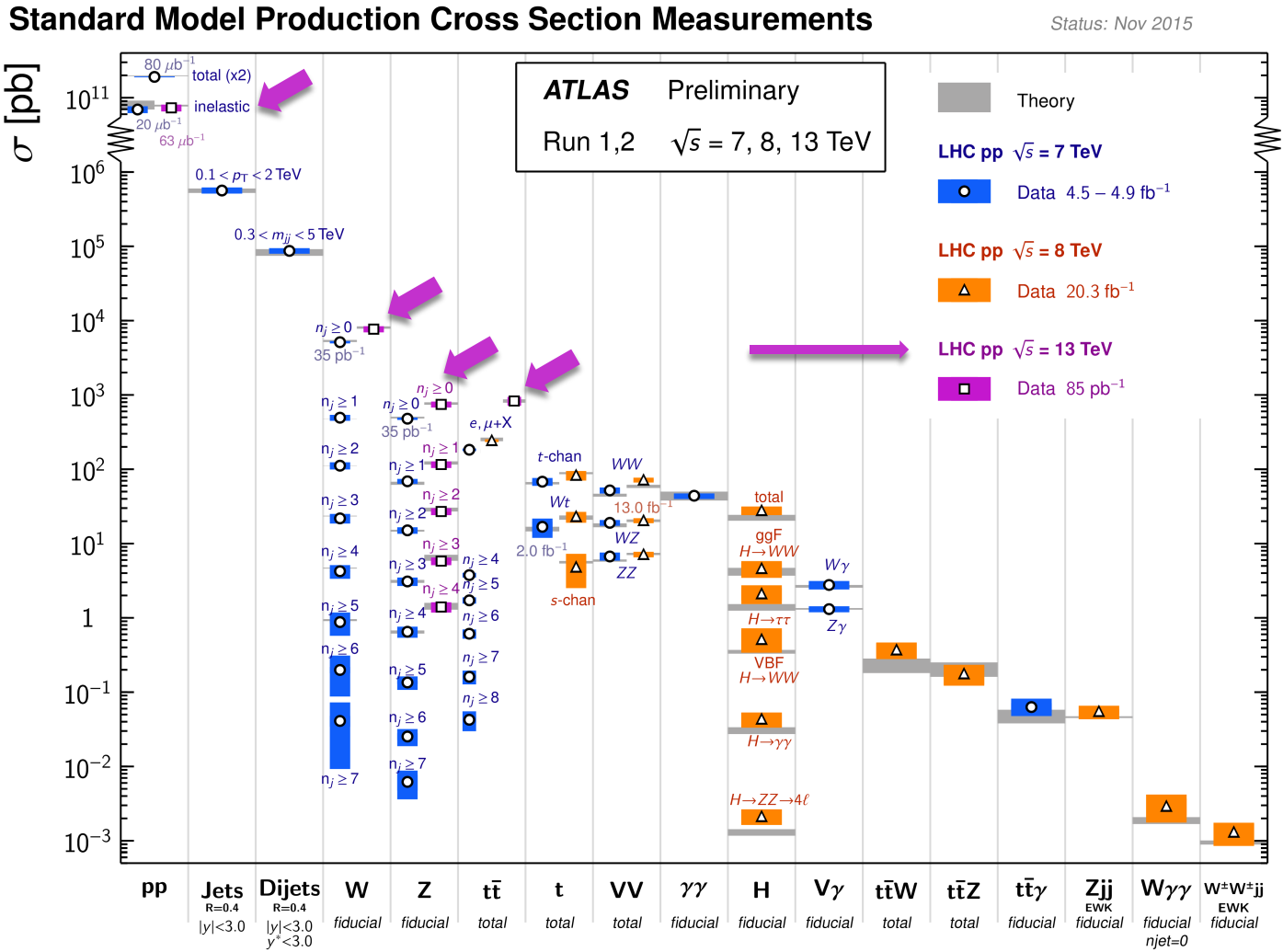
Inelastic collisions: ~7×10¹⁰

Eight orders of magnitude of EWK, top, and Higgs Physics



…on both sides of the ring

[http://cern.ch/go/W6Wp]



47+ analyses on full 2015 dataset

[http://cern.ch/go/hK8r][http://cern.ch/go/QT7H][See also https://indico.cern.ch/event/442432]

ATLAS EXPERIMENT - Public Results

CONF notes of the ATLAS Collaboration

This page lists ATLAS CONF notes. This series of notes covers preliminary results using data.

See also: List of ATLAS CONF notes by Group

Full Title	Ref Code	Publication Date	Groups
A search for Supersymmetry in events containing a leptonically decaying Z boson, jets and missing transverse momentum in $\sqrt{s}=13$ TeV pp collisions with the ATLAS detector	ATLAS-CONF-2015-082	2015/12/15	SUSY
Search for resonances decaying to photon pairs in 3.2 fb^{-1} of pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	ATLAS-CONF-2015-081	2015/12/15	EXOT / HIGG
Search for dark matter produced in association with a hadronically decaying vector boson in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector at the LHC	ATLAS-CONF-2015-080	2015/12/15	EXOT
Measurement of the inclusive cross-section of single top-quark t-channel production in pp collisions at $\sqrt{s}$ = 13 TeV	ATLAS-CONF-2015-079	2015/12/15	TOPQ
Search for supersymmetry at $\sqrt{s}$=13 TeV in final states with jets and two same-sign leptons or three leptons with the ATLAS detector	ATLAS-CONF-2015-078	2015/12/14	SUSY
Search for new phenomena in final states with large jet multiplicities and missing transverse momentum with ATLAS using $\sqrt{s}$=13 TeV proton-proton collisions	ATLAS-CONF-2015-077	2015/12/14	SUSY
Search for gluinos in events with an isolated lepton, jets and missing transverse momentum at $\sqrt{s}$ = 13 TeV with the ATLAS detector	ATLAS-CONF-2015-076	2015/12/15	SUSY
Search for WW/WZ resonance production in the $l\nu qq$ final state at $\sqrt{s}=13 TeV with the ATLAS detector at the LHC	ATLAS-CONF-2015-075	2015/12/14	EXOT / HIGG
Search for new physics in VH resonances at 13 TeV	ATLAS-CONF-2015-074	2015/12/14	EXOT / HIGG
Search for resonances with boson-tagged jets in 3.2 fb^{-1}$ of pp collisions at $\sqrt{s}=13 TeV collected with the ATLAS detector	ATLAS-CONF-2015-073	2015/12/15	EXOT / HIGG
Search for beyond the Standard Model phenomena in $e\mu$ final states in pp collisions at $\sqrt{s}=13 TeV with the ATLAS detector	ATLAS-CONF-2015-072	2015/12/14	EXOT
Search for diboson resonances in the $\ell\ell\ell\ell qq$ final state in pp collisions at $\sqrt{s}=13 TeV with the ATLAS detector	ATLAS-CONF-2015-071	2015/12/15	EXOT / HIGG
"Search for new phenomena in the dilepton final state using proton-proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector"	ATLAS-CONF-2015-070	2015/12/14	EXOT
Measurements of the total cross sections for Higgs boson production combining the H → γγ and H → ZZ* → 4ℓ decay channels at 7, 8 and 13 TeV center-of-mass energies with the ATLAS detector	ATLAS-CONF-2015-069	2015/12/14	HIGG / HIGG
Search for diboson resonances in the $\nu\nu qq$ final state in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	ATLAS-CONF-2015-068	2015/12/15	EXOT / HIGG
Search for gluino-mediated stop and sbottom pair production in events with b-jets and large missing transverse momentum in $\sqrt{s}$=13 TeV pp collisions with the ATLAS detector	ATLAS-CONF-2015-067	2015/12/14	SUSY
Search for Bottom Squark Pair Production with the ATLAS Detector in proton-proton Collisions at $\sqrt{s}$=13 TeV	ATLAS-CONF-2015-066	2015/12/14	SUSY
Measurement of jets produced in top quark events using the di-lepton final state with 2 b-tagged jets in p p collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	ATLAS-CONF-2015-065	2015/12/15	TOPQ
$B^\pm$ mass reconstruction in $B^\pm → J/ψ K^\pm$ decay at ATLAS at 13 TeV pp collisions at the LHC	ATLAS-CONF-2015-064	2015/12/14	BPHY
Search for new resonances in events with one lepton and missing transverse momentum in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector	ATLAS-CONF-2015-063	2015/12/15	EXOT
Search for squark and gluinos in final states with jets and missing transverse momentum at $\sqrt{s}$ = 13 TeV with the ATLAS detector	ATLAS-CONF-2015-062	2015/12/14	SUSY
Search for Neutral Minimal Supersymmetric Standard Model Higgs Bosons H/A → ττ produced in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS Detector	ATLAS-CONF-2015-061	2015/12/14	HIGG / EXOT
Measurement of the Higgs boson production cross section at 7, 8 and 13 TeV center-of-mass energies in the H→γγ channel with the ATLAS detector	ATLAS-CONF-2015-060	2015/12/15	HIGG
Measurement of the fiducial cross sections of the Higgs boson and search for new physics in the ZZ*→4ℓ final state with ATLAS using 2015 LHC pp collisions	ATLAS-CONF-2015-059	2015/12/14	HIGG

CMS Physics Results in Proton-Proton Collisions at 13 TeV

Forward Physics and Small-x QCD
- Pseudorapidity Distributions of Charged Hadrons
- Two-Particle Correlations (the ``Ridge'')
- Underlying Event

Standard Model
- Inclusive Jet Production
- Inclusive W and Z Production
- Z+jets Differential Cross Section
- WZ Production Cross Section
- ZZ Production Cross Section

Heavy Flavours
- B Production Cross Section

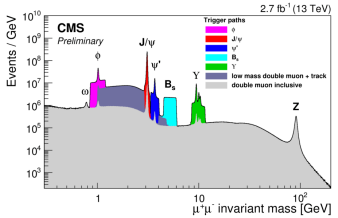
Top Quark
- Inclusive $t\bar{t}$ Cross Section in Dileptons
- Inclusive and Differential $t\bar{t}$ Cross Sections in ℓ+jets
- Differential $t\bar{t}$ Cross Sections in Dileptons
- Differential $t\bar{t}$ Distributions as a Function of Event Variables
- Underlying Event Measurements in $t\bar{t}$+X Events
- Single Top-Quark Cross Section

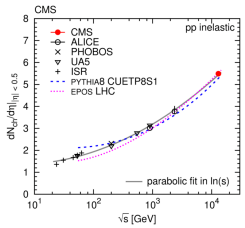
125-GeV Higgs Boson
- Performance Studies

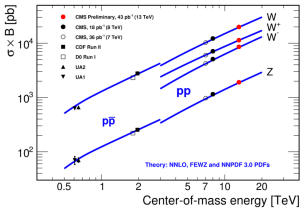
Search for Supersymmetry
- Supersymmetry in Multijet + Missing E_T
- Supersymmetry in All-Hadronic Using M_{T2}
- Supersymmetry in All-Hadronic Using α_T
- Supersymmetry in All-Hadronic Using Razor Variables
- Supersymmetry in One-Lepton Events Using Large Radius Jets
- Supersymmetry in Same-Sign Dilepton Events
- Supersymmetry in Opposite-Sign Dilepton Events

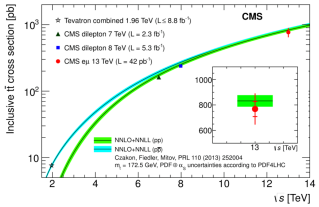
Search for Exotic Phenomena
- Search for Resonances in Dijet Events
- Search for Quark Compositness in Dijet Events
- Search for Z' in Dilepton Events
- Search for W' in Lepton+E_T^{miss} Events
- Search for Resonances in Diphoton Events
- Search for Resonances in Diboson Events
- Search for Dark Matter in Monojet Events
- Search for Quantum Black Holes
- Search for Heavy Stable Charged Particles

Search for Exotic Phenomena (Topologies with Heavy Quarks)
- Search for W' in tb Events
- Search for $X_{5/3}$ in SS Dilepton and Lepton+Jets Events



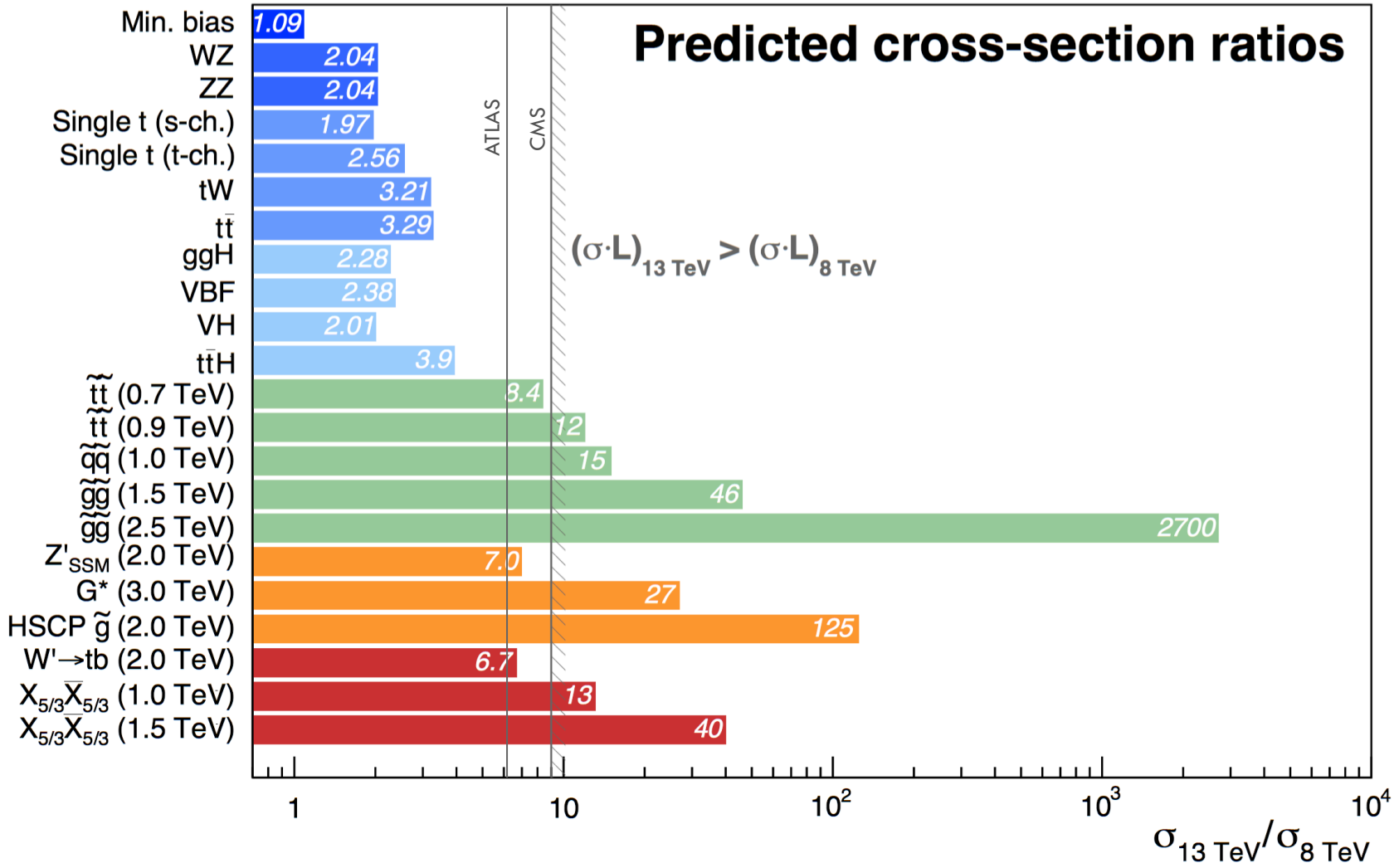




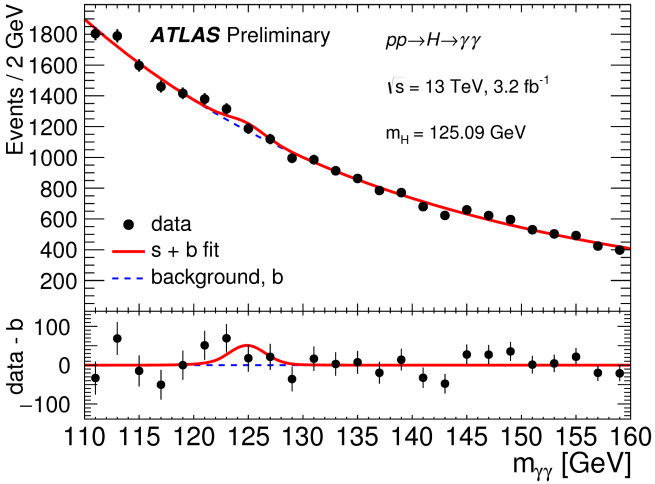


Cannot cover all. Focus on new reach and previous or new "hints".

Where 2015 goes beyond Run1

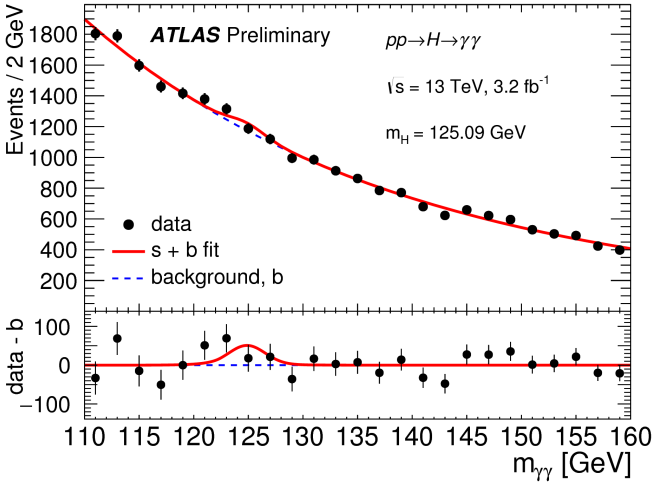


h(125) in ATLAS

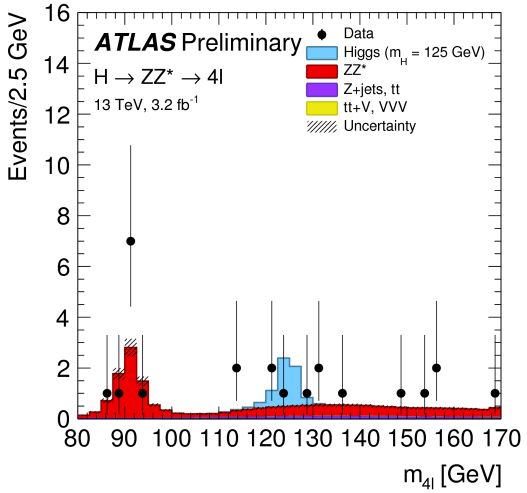


1.5σ obs.
(1.9σ exp.)

h(125) in ATLAS

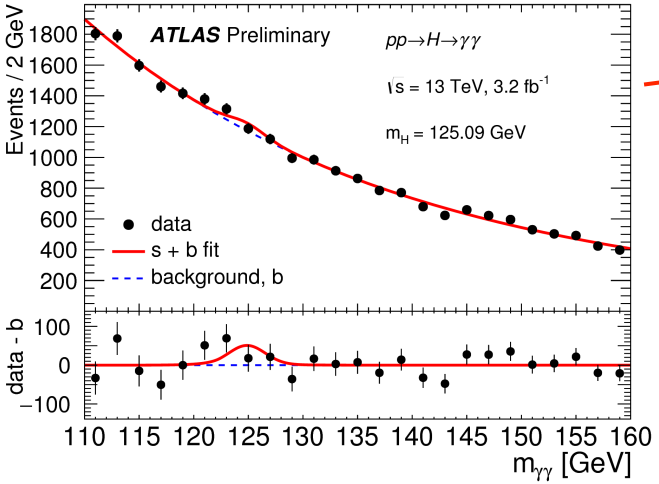


1.5σ obs.
(1.9σ exp.)

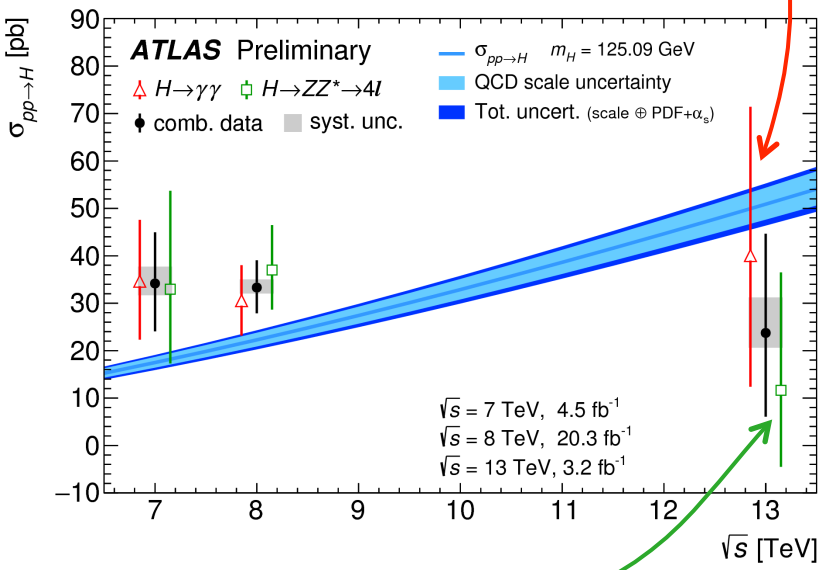


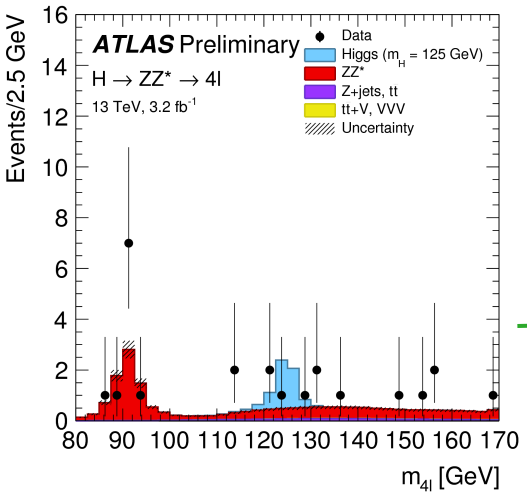
0.7σ obs.
(2.8σ exp.)

h(125) in ATLAS



1.5σ obs.
(1.9σ exp.)

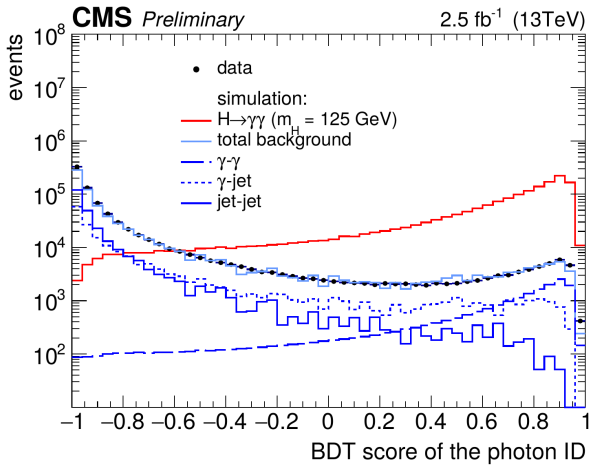




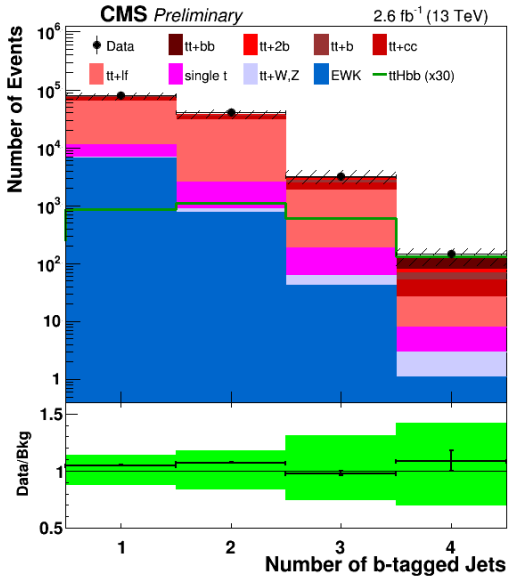
0.7σ obs.
(2.8σ exp.)

1.4σ obs.
(3.4σ exp.)
(-1.3σ to SM)

Towards h(125) in CMS

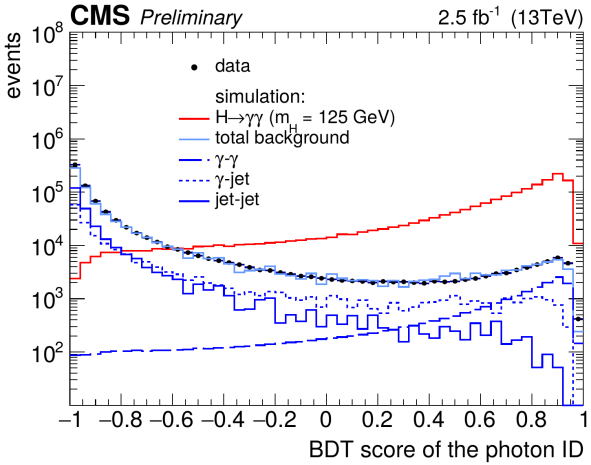


H→γγ: Photon identification score in diphoton events.

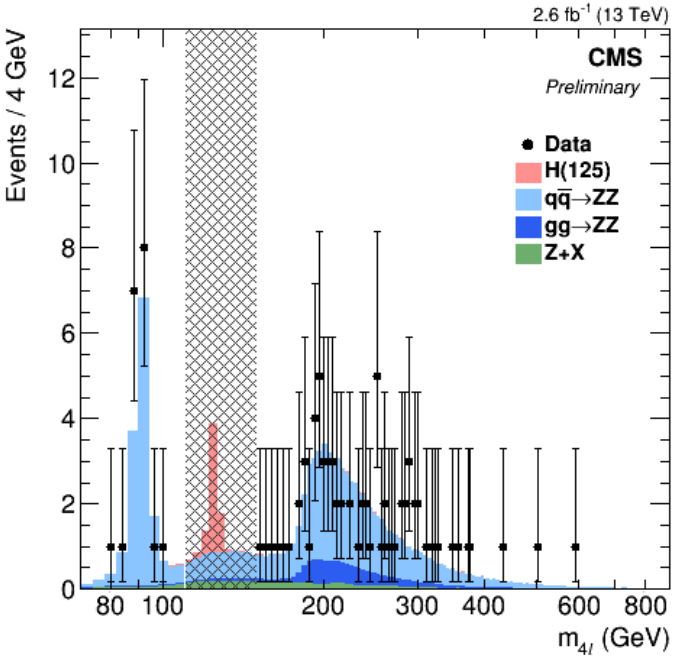


ttH, H→bb: multiplicity of b-tagged jets.

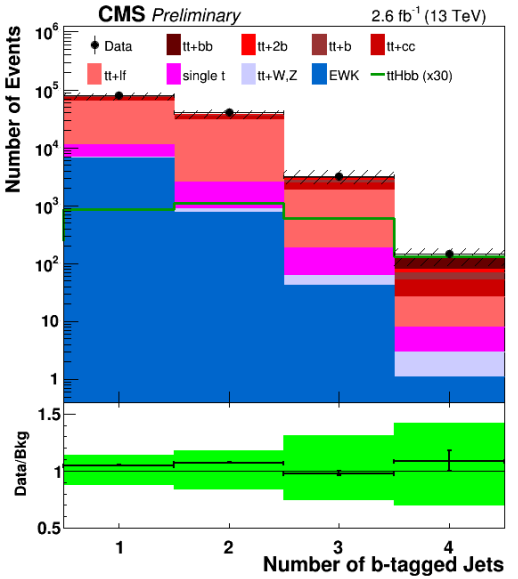
Towards h(125) in CMS



H→γγ: Photon identification score in diphoton events.

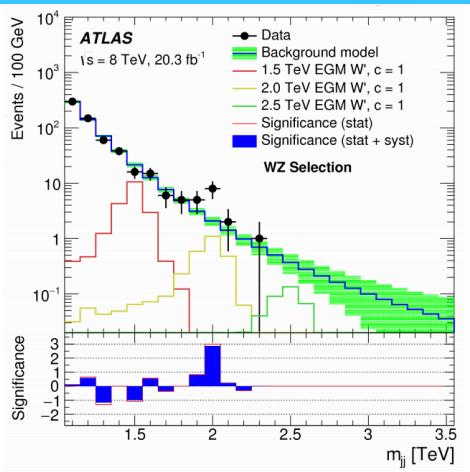


H→ZZ: four-lepton mass distribution; Z→4ℓ peak and on-shell ZZ turn-on visible.



ttH, H→bb: multiplicity of b-tagged jets.

Diboson resonance searches

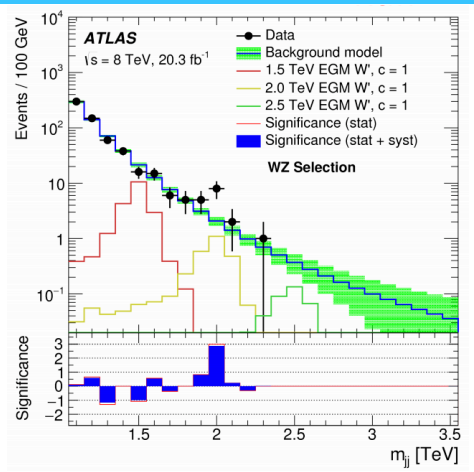


8 TeV

For m ~ 2 TeV

3.4σ → **2.5σ after LEE**

Diboson resonance searches



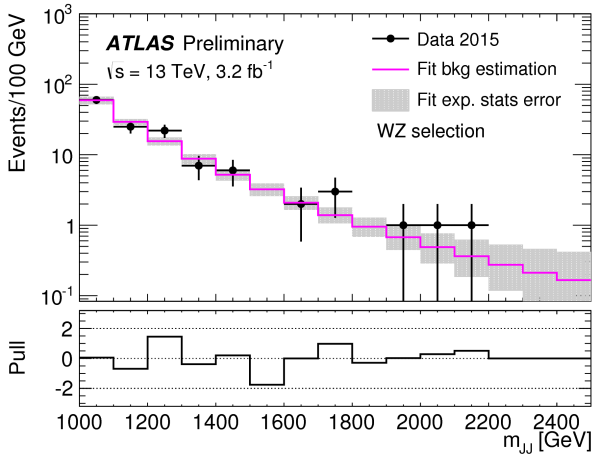
8 TeV

For m ~ 2 TeV

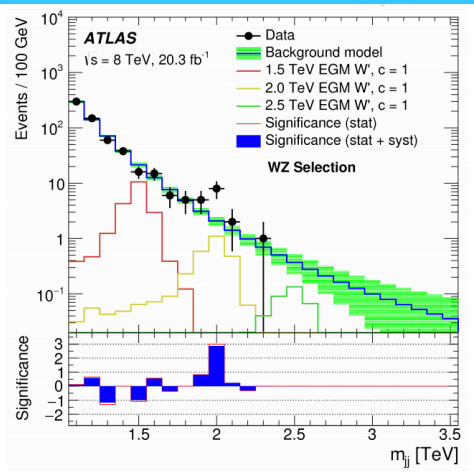
3.4σ → **2.5σ after LEE**

13 TeV

No significant excess, but not conclusive.



Diboson resonance searches



8 TeV
For m ~ 2 TeV
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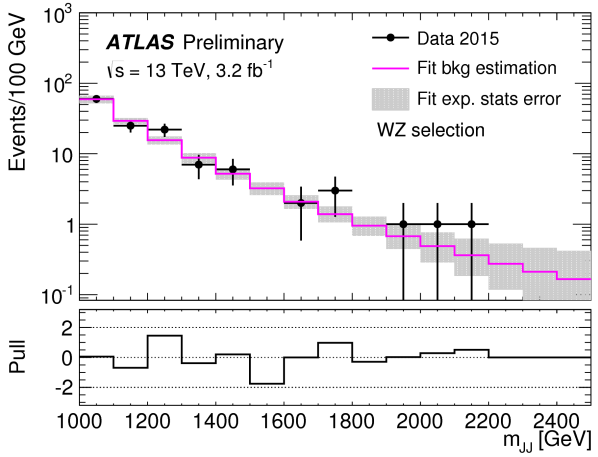
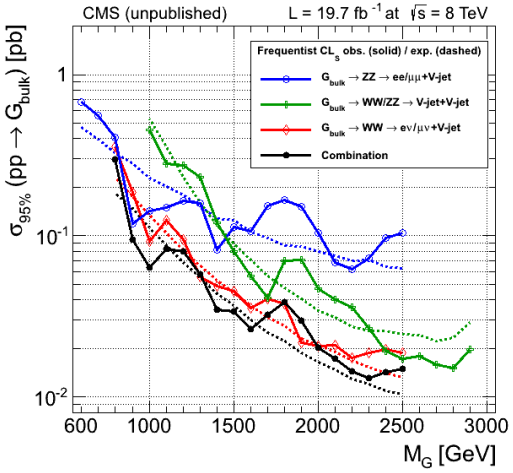
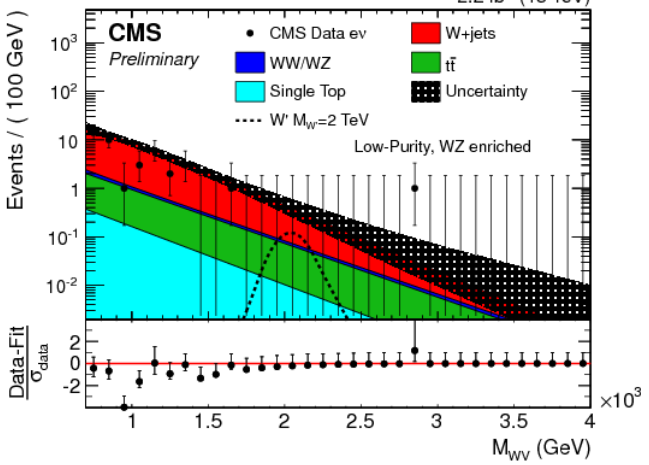
No significant excess, but not conclusive.



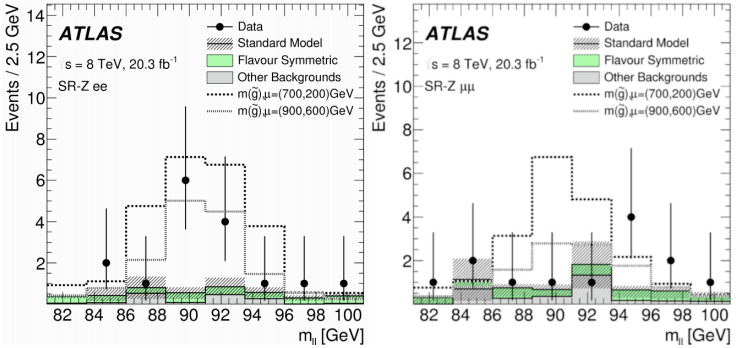


8 TeV
For m ~ 1.8 TeV
~ 2σ

13 TeV
No significant excess, but not conclusive.



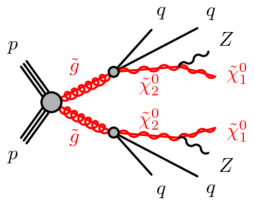
SUSY opposite-sign dileptons



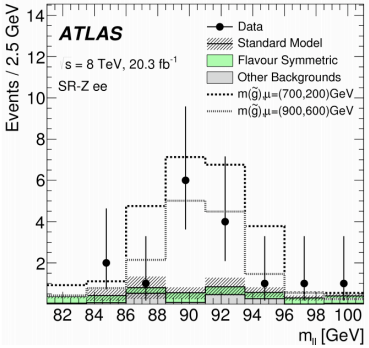
8 TeV [arXiv:1503.03290]

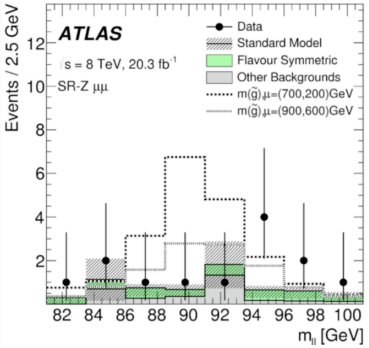
on-Z

3.0σ only in ATLAS



SUSY opposite-sign dileptons

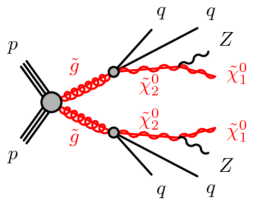




8 TeV [arXiv:1503.03290]

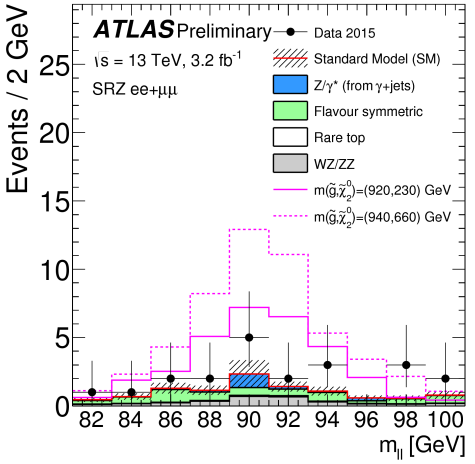
on-Z

3.0σ only in ATLAS

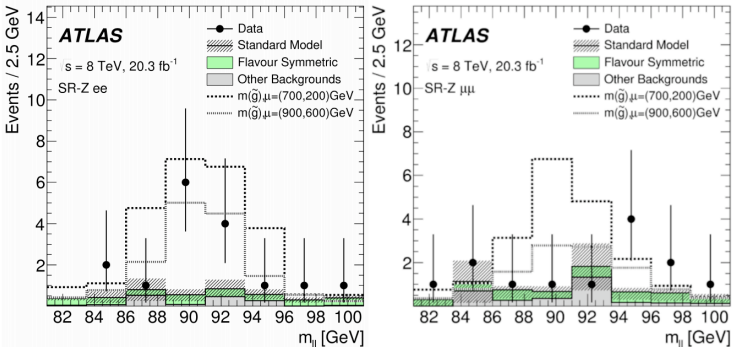


13 TeV

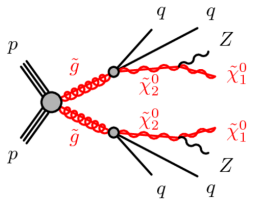
21 obs. (10.3±2.3 exp.): **2.2σ**



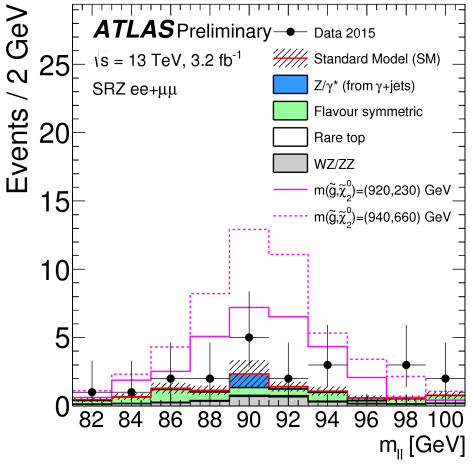
SUSY opposite-sign dileptons

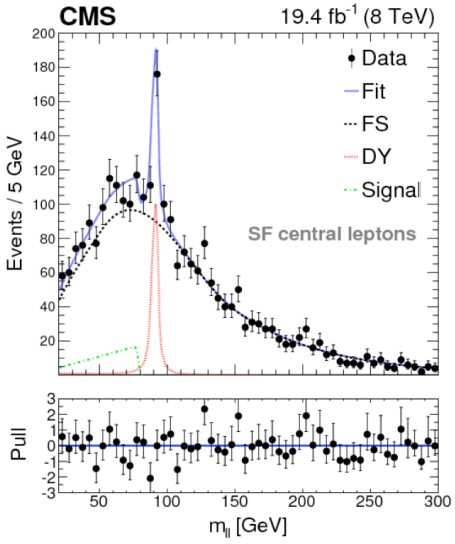


8 TeV [arXiv:1503.03290]
on-Z
3.0σ only in ATLAS



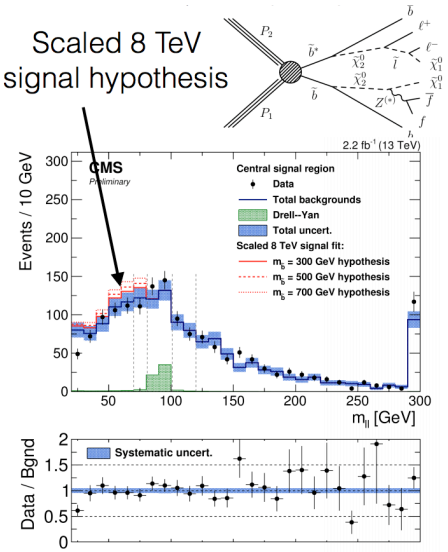
13 TeV
21 obs. (10.3±2.3 exp.): **2.2σ**





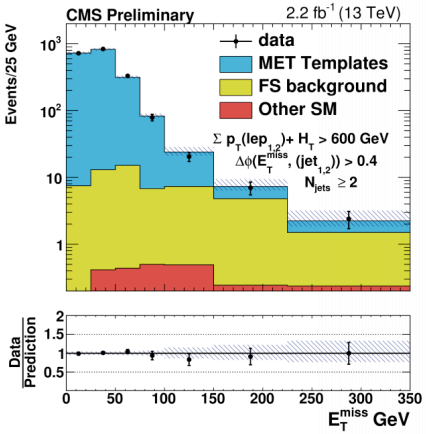
8 TeV [arXiv:1502.06031]
Below Z
2.6σ only in CMS

Scaled 8 TeV signal hypothesis

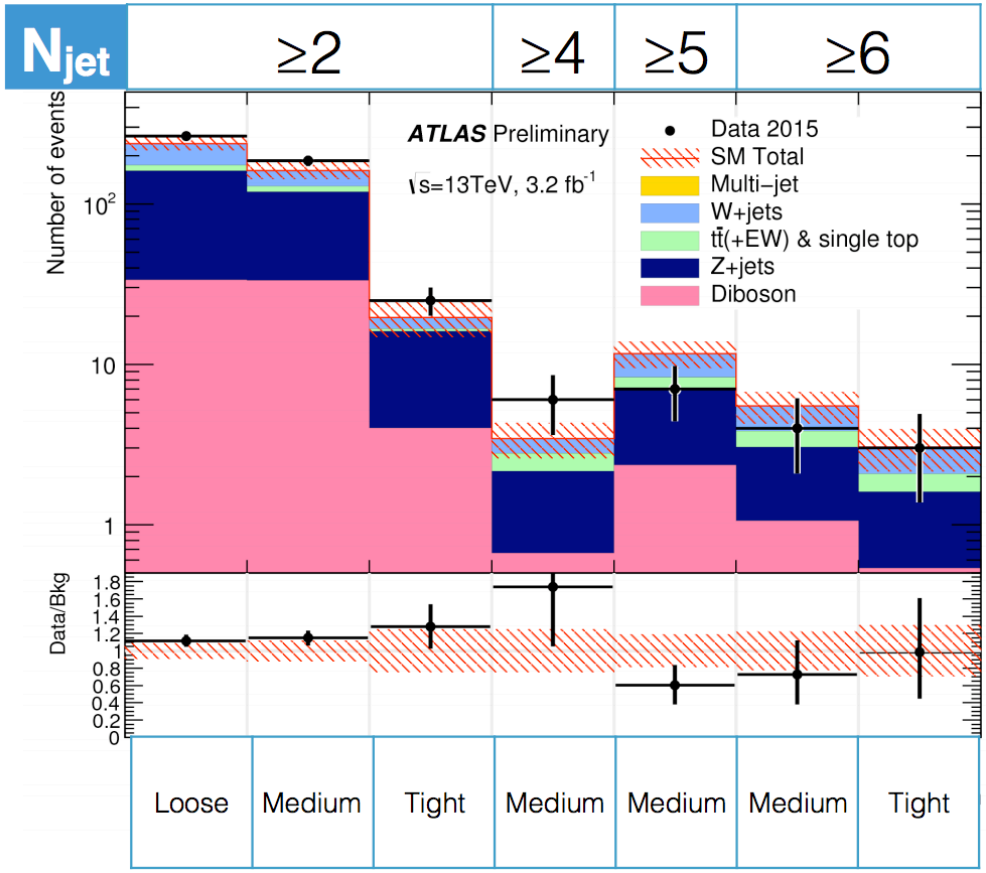


13 TeV
Both 8 TeV excesses disfavored

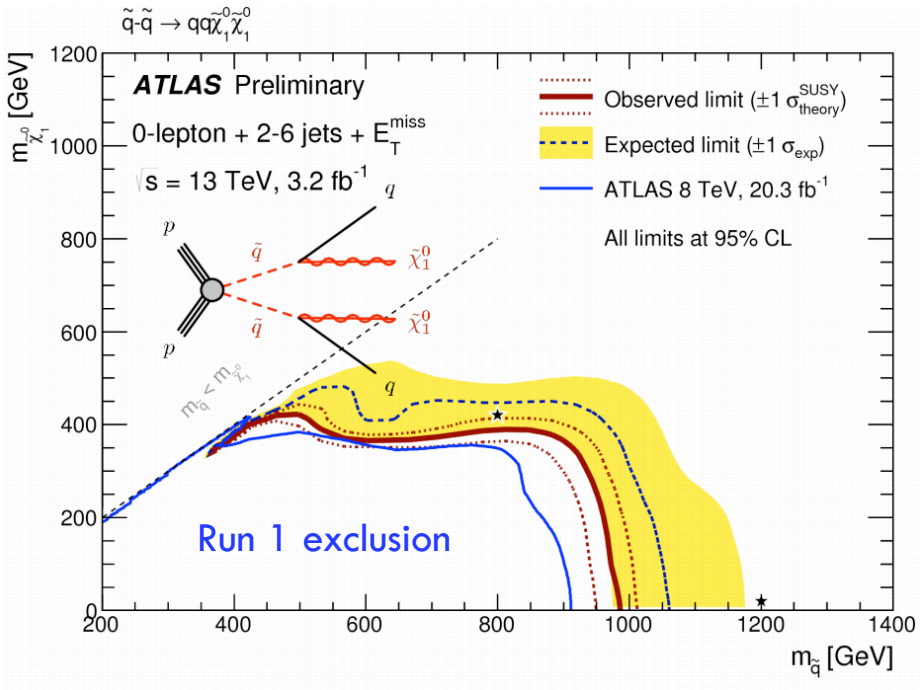
No excess seen with ATLAS selection

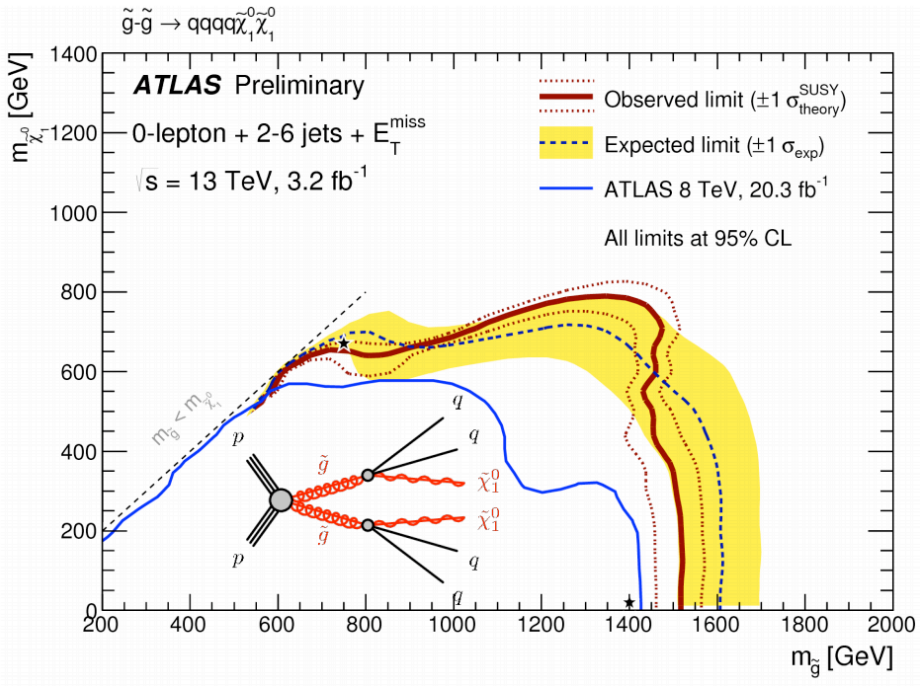


ATLAS fully hadronic



Background rejection

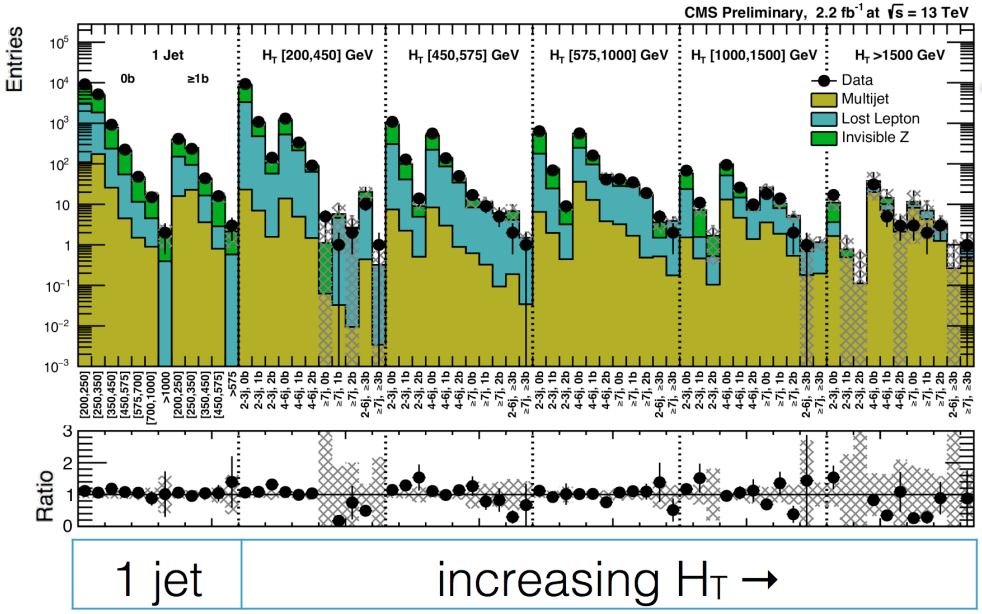




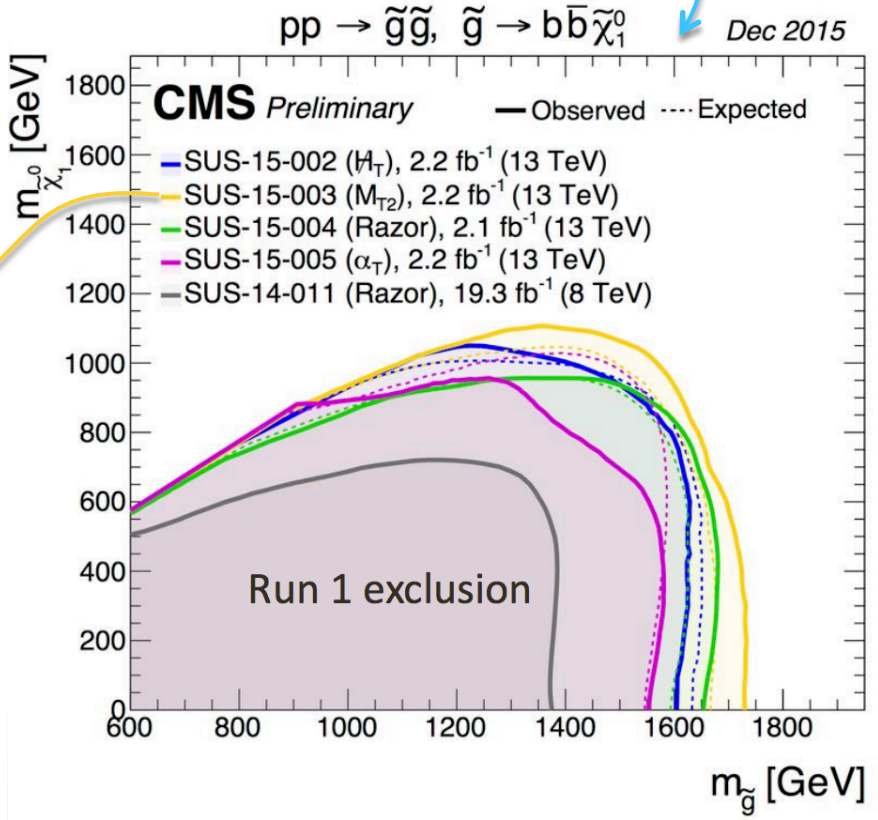
CMS fully hadronic

- Multiple analyses: MH_T, H_T, **M_{T2}**, Razor, α_T.
  - **M_{T2} analysis** in bins of H_T, N_j, N_b.

For each topological region below, bins in M_{T2}

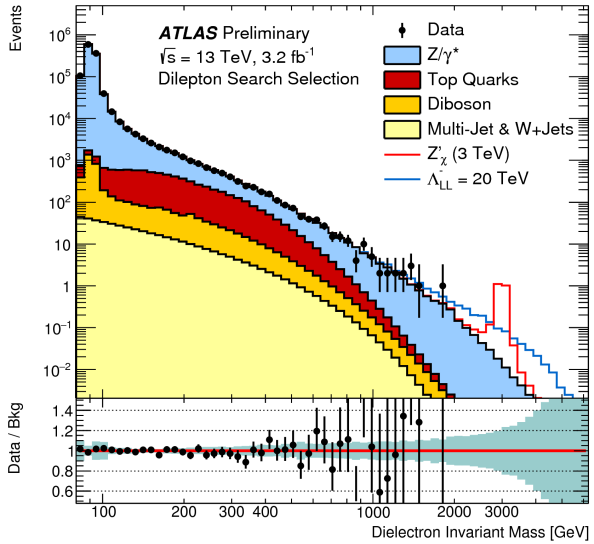


1 jet	increasing H_T →



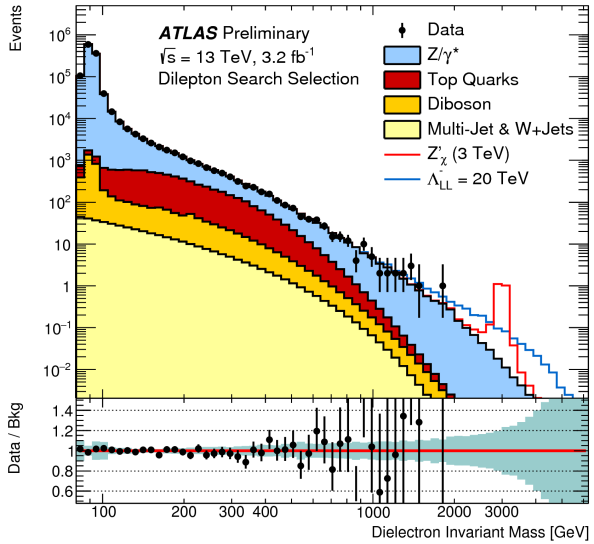
Dielectron resonance searches

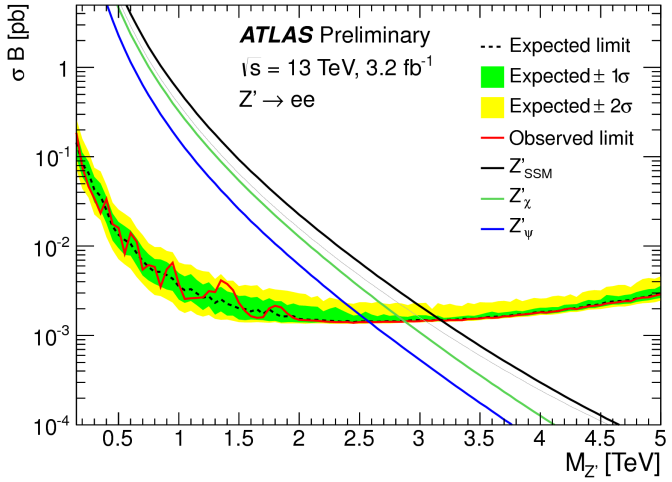
Similarly for dimuons.



Dielectron resonance searches

Similarly for dimuons.





Dielectron resonance searches

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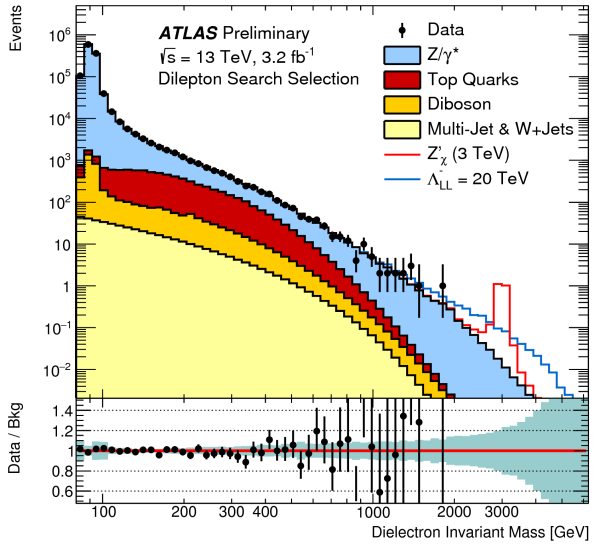
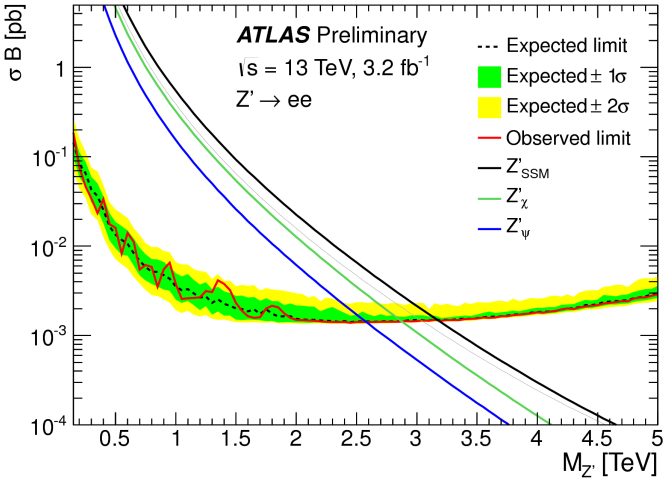
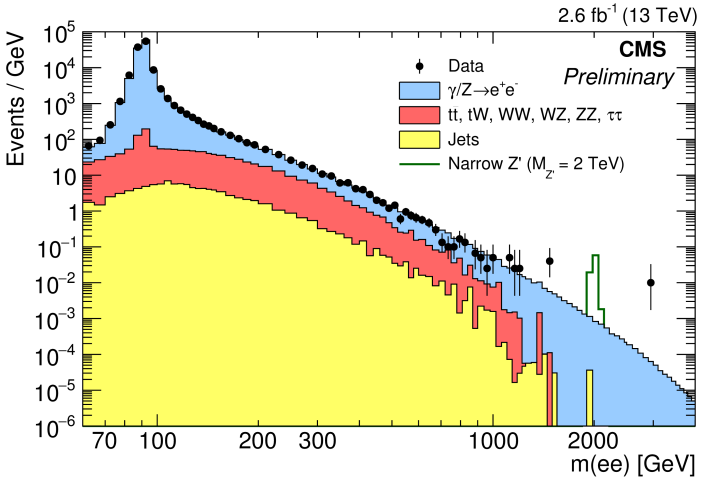
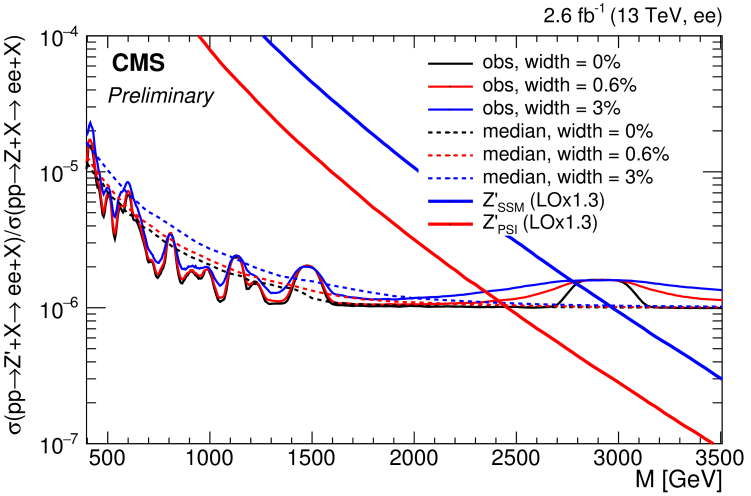


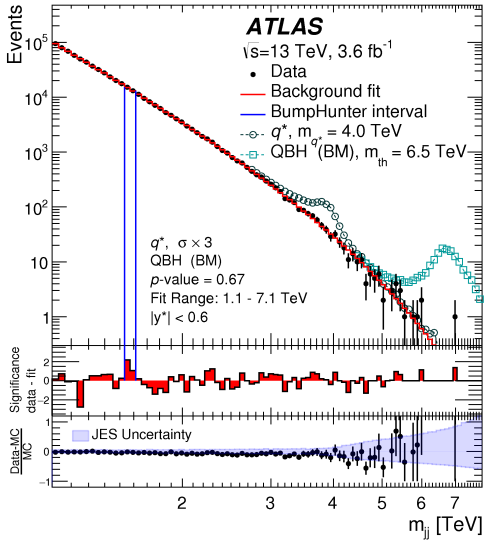






Dijet resonance searches

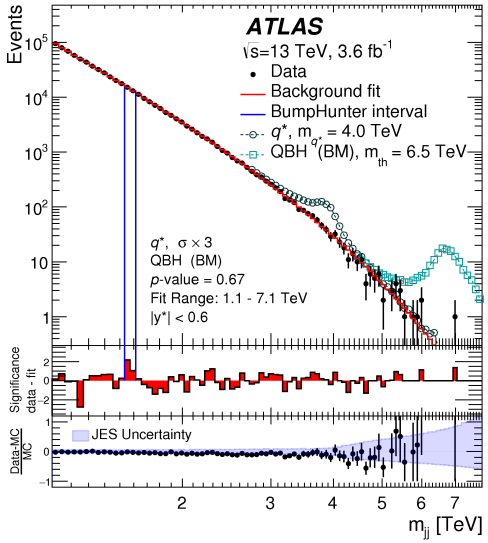
[arXiv:1512.01530][arXiv:1512.01224]

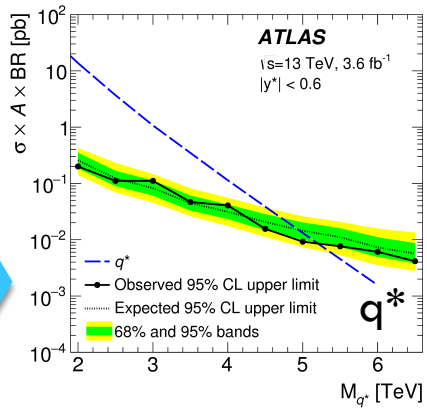


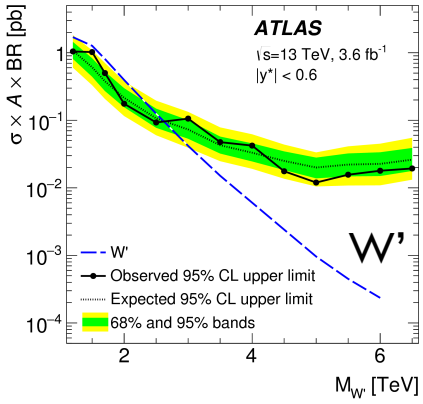
Z’

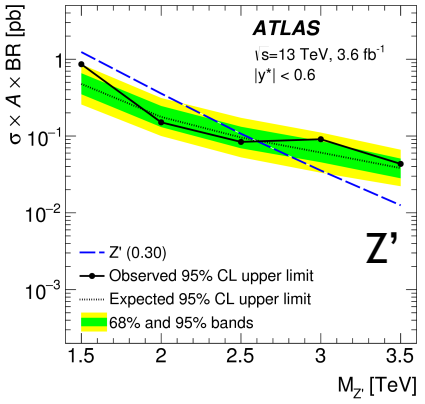
Dijet resonance searches

[arXiv:1512.01530][arXiv:1512.01224]



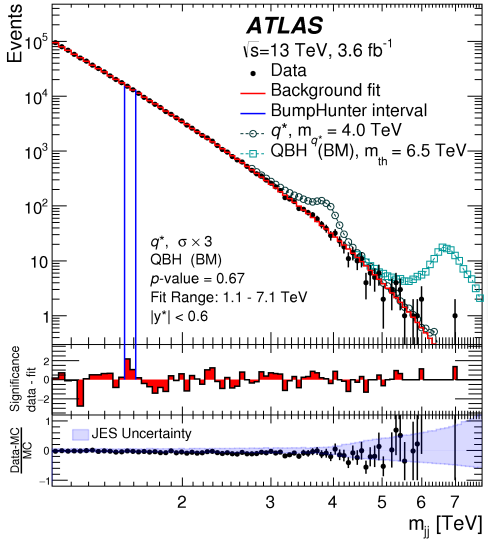


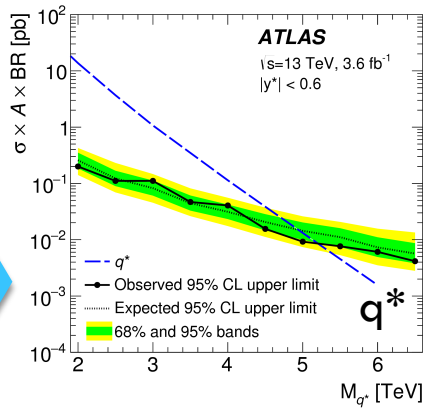


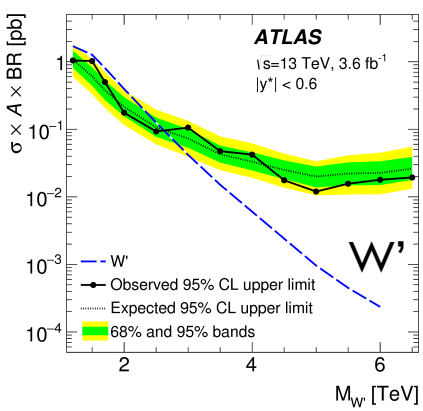


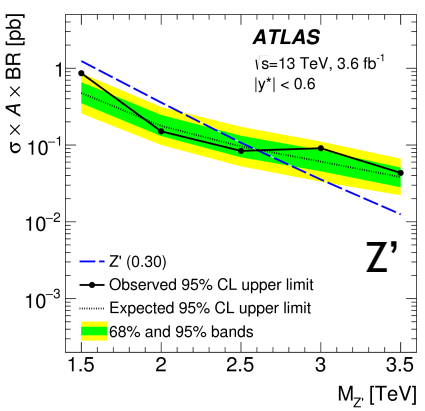
Dijet resonance searches

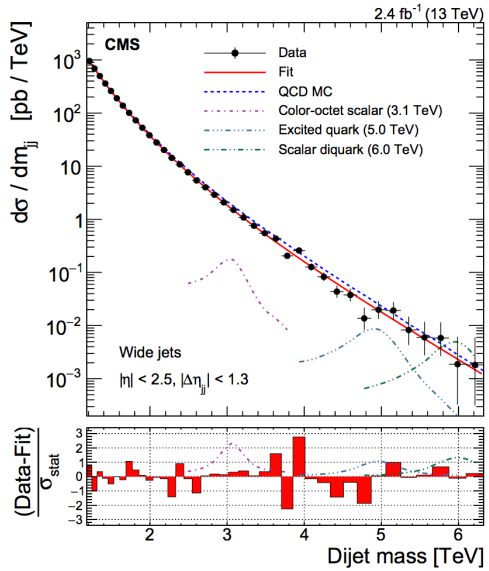
[arXiv:1512.01530][arXiv:1512.01224]

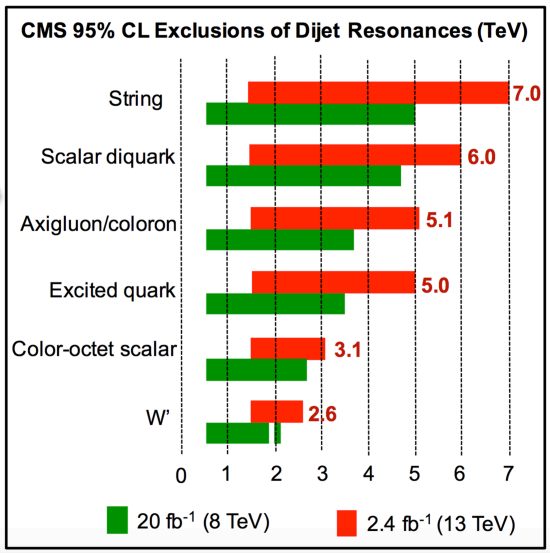




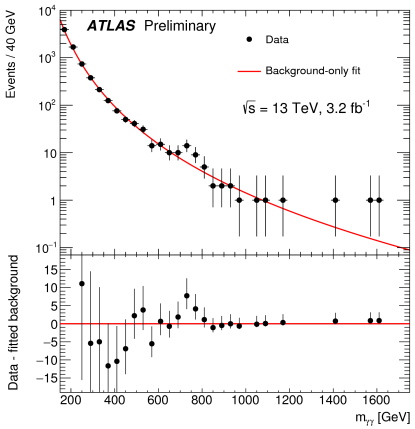






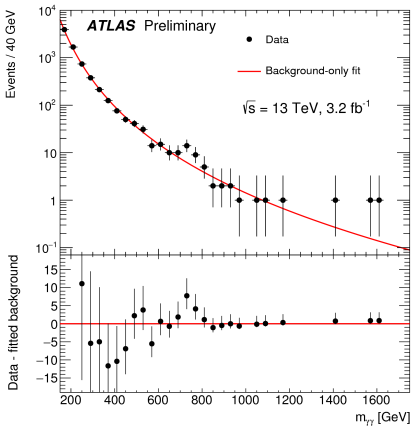


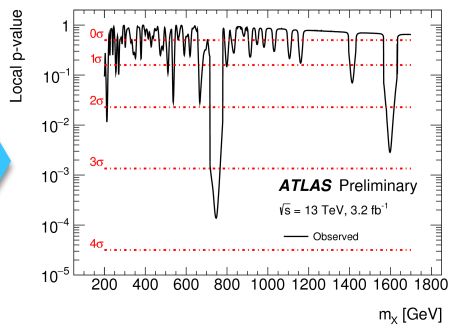
Diphoton resonances

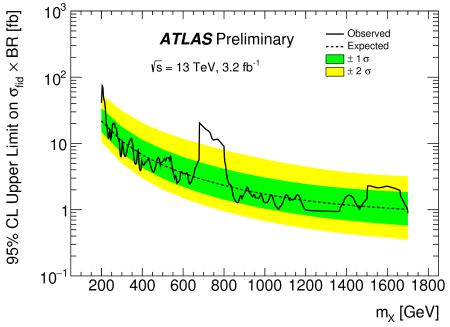


>90% prompt-prompt, σ_m/m ~1%

Diphoton resonances



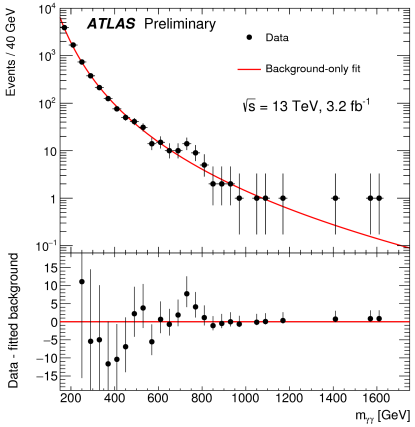


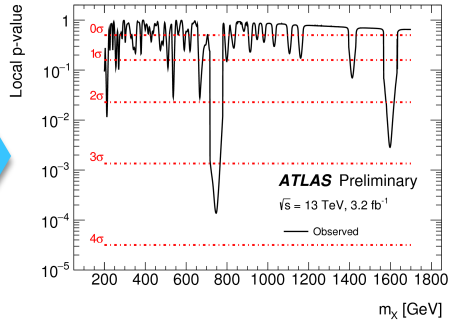


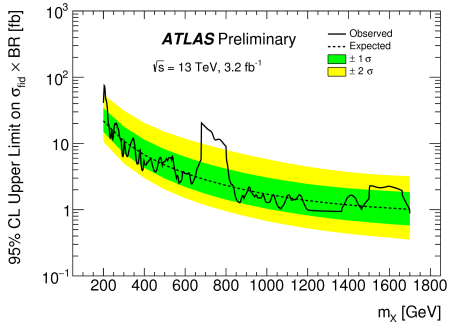
>90% prompt-prompt, σ_m/m ~1%

For m_X = 750 GeV
3.6σ → **2.0σ after LEE**
(3.9σ → 2.3σ for Γ = 6%)

Diphoton resonances

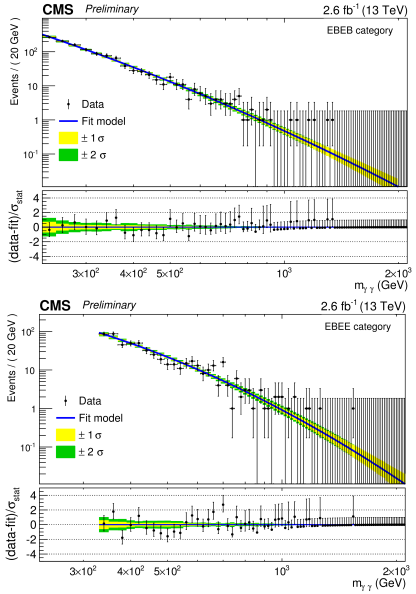


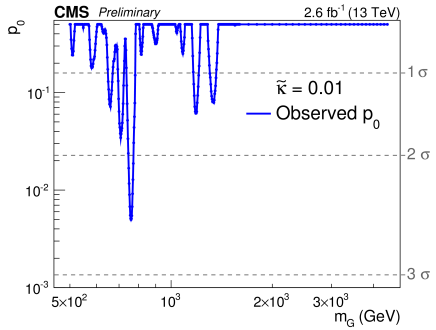


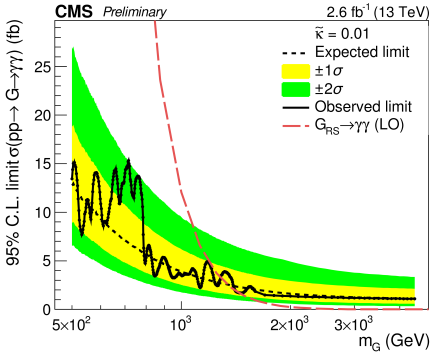


For m_X = 750 GeV
3.6σ → **2.0σ after LEE**
(3.9σ → 2.3σ for Γ = 6%)

>90% prompt-prompt, σ_m/m ~1%



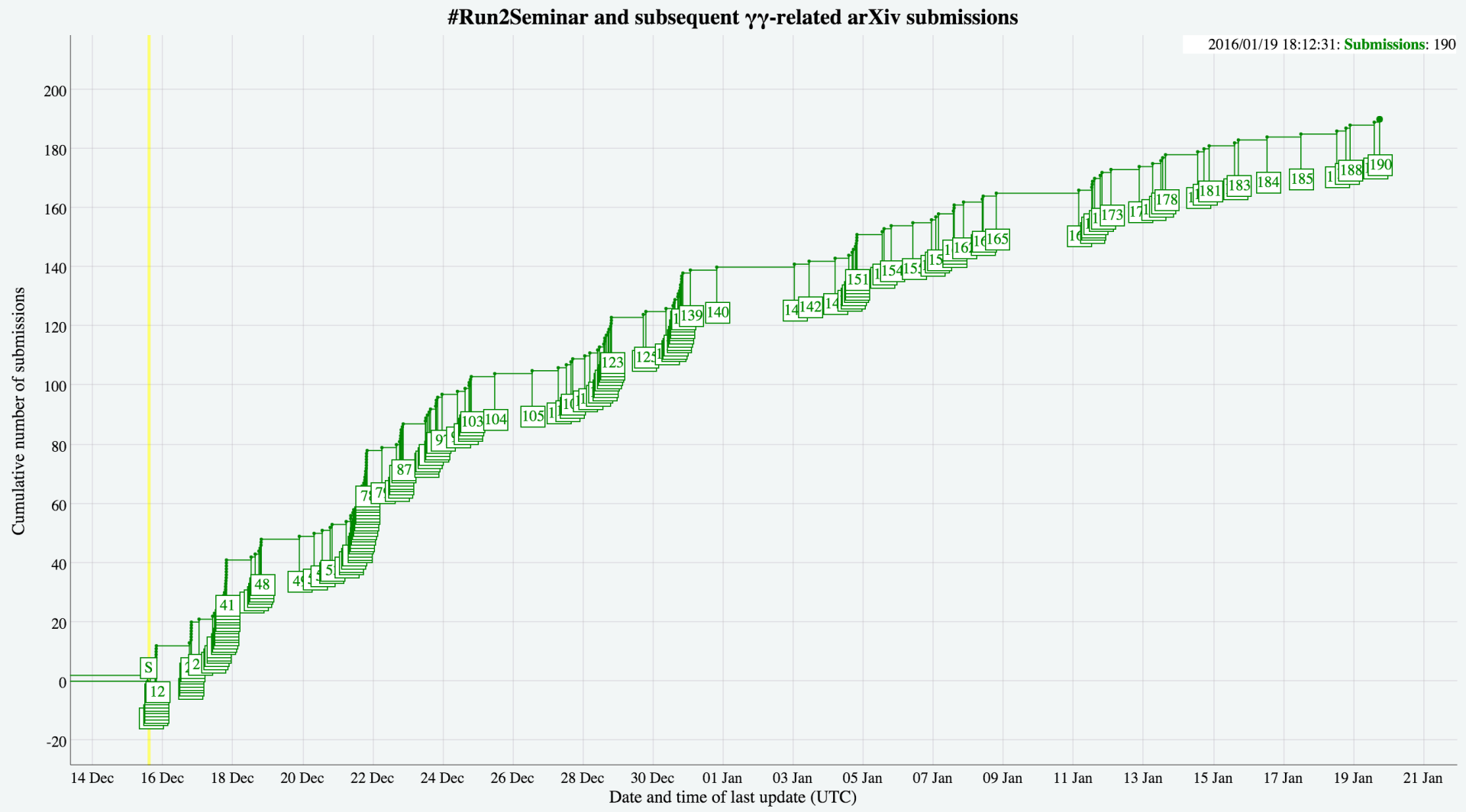




For m_G = 760 GeV
2.6σ → **1.2σ after LEE**

Post-seminar stampede

[http://cern.ch/go/DZt8]



Post-seminar stampede

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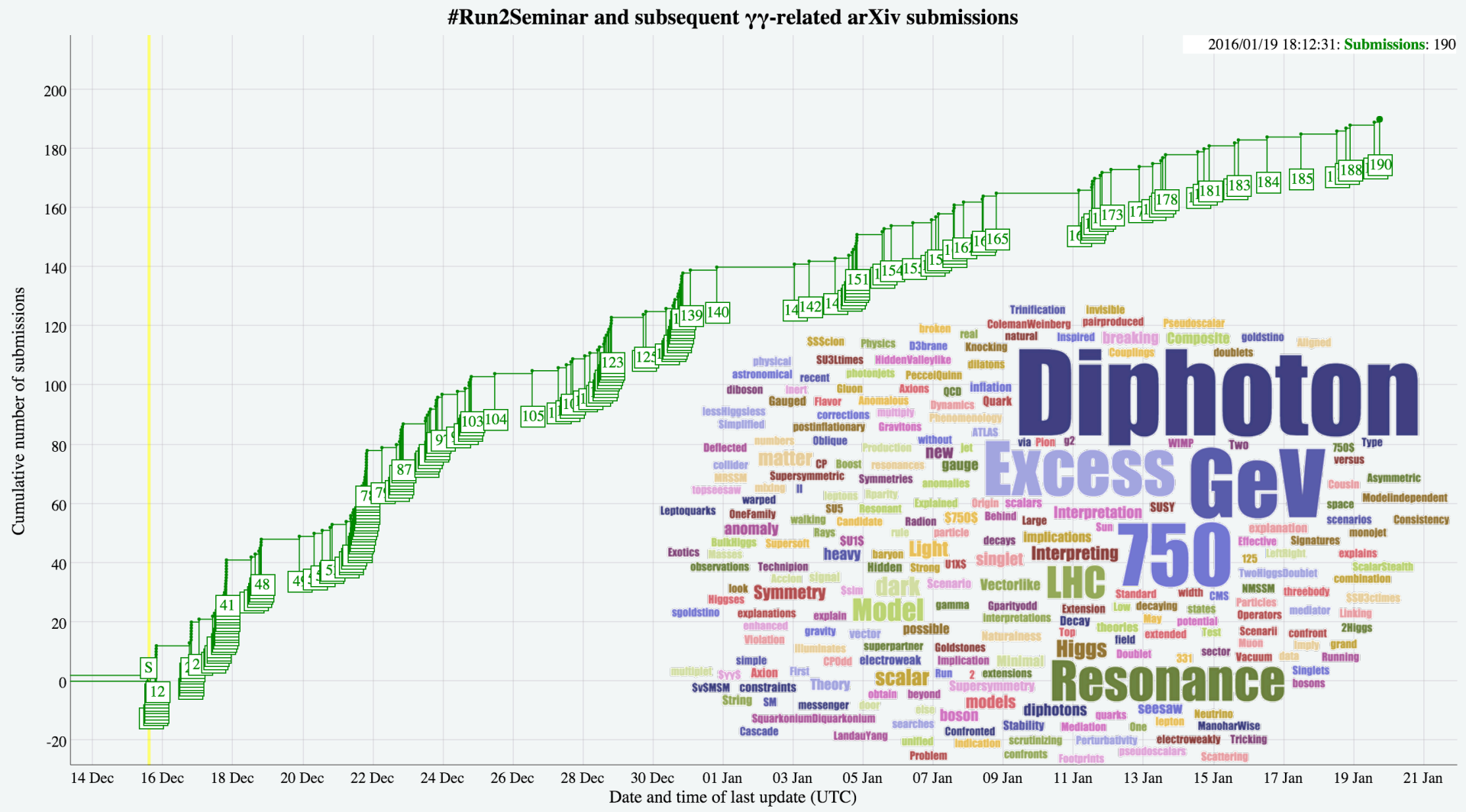

Post-seminar stampede

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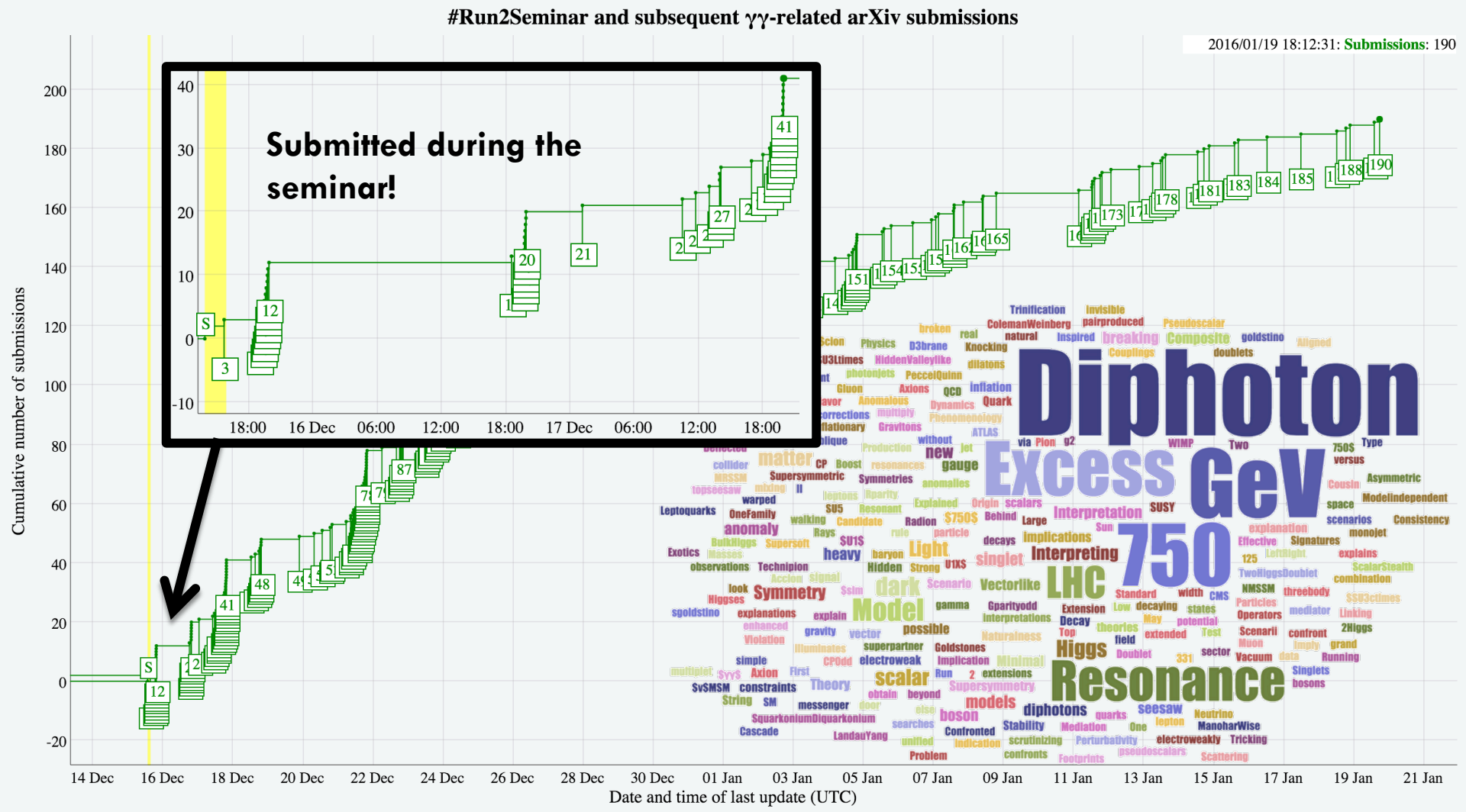
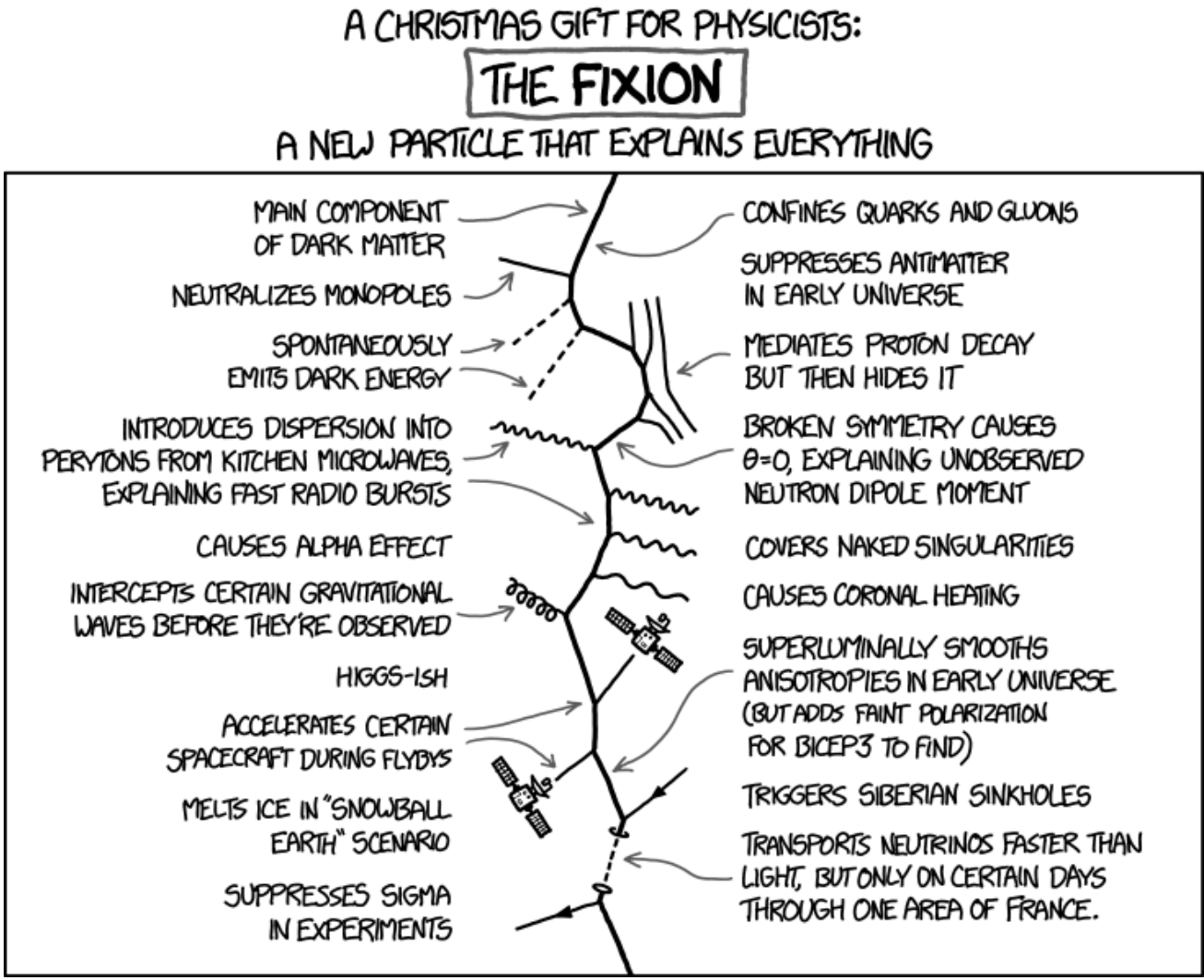


Perhaps a whole fixion sector?

[http://xkcd.com/1621]



Is it trivial to combine significances?

Mythology of Two Data Sets

Very **common myth re bump-hunting:**

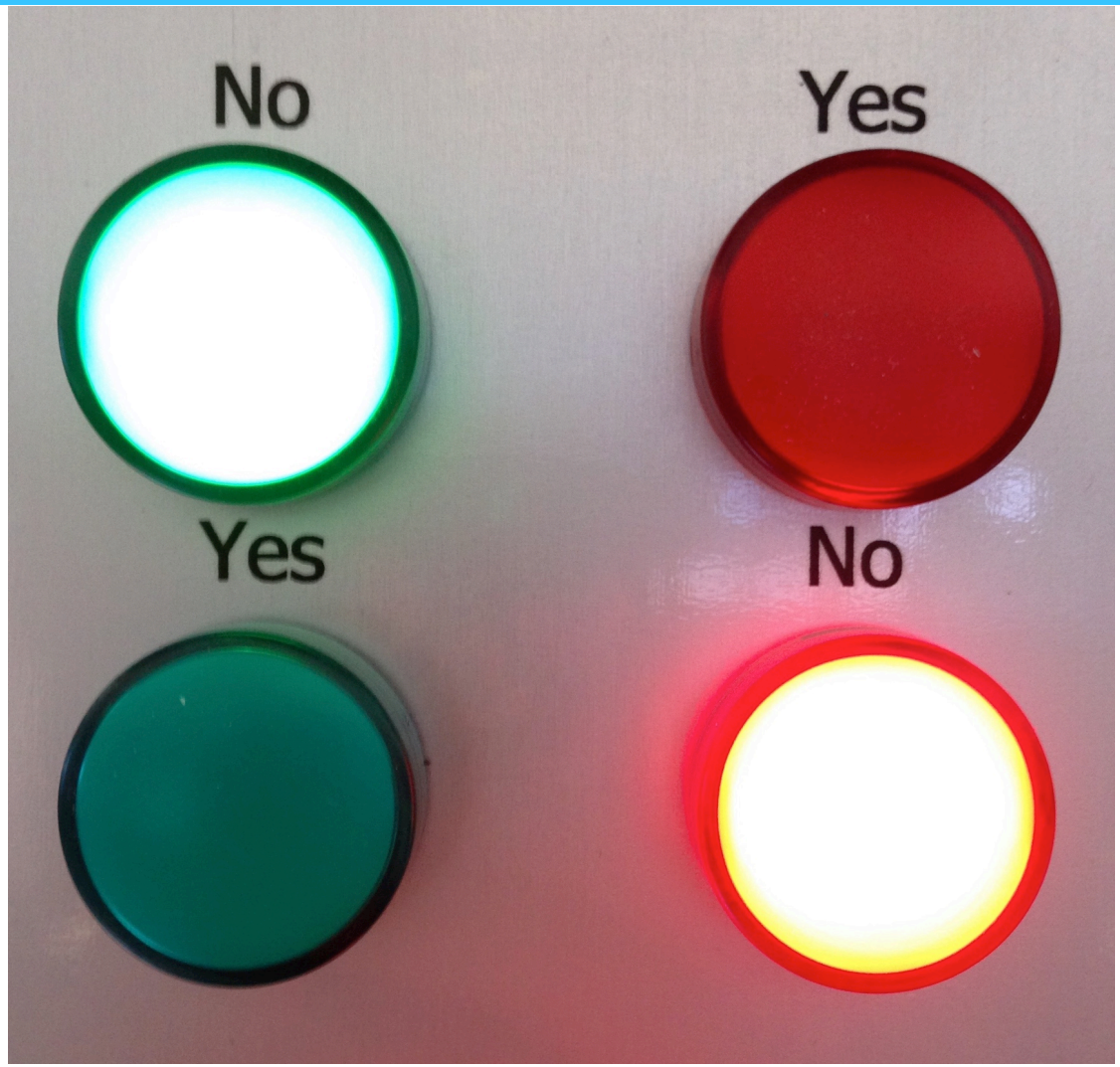
Look for bump in one data set (or one experiment), and identify candidate bump and its location in spectrum. Then in the next data set (or other experiment), look in same location. ***Then no LEE correction needed.***

This is "bad" on several levels, and the Gross-Vittels paper gives another reason why.

This is presumably known to experts, but I think it is useful to advertize, given the persistence of the myth.

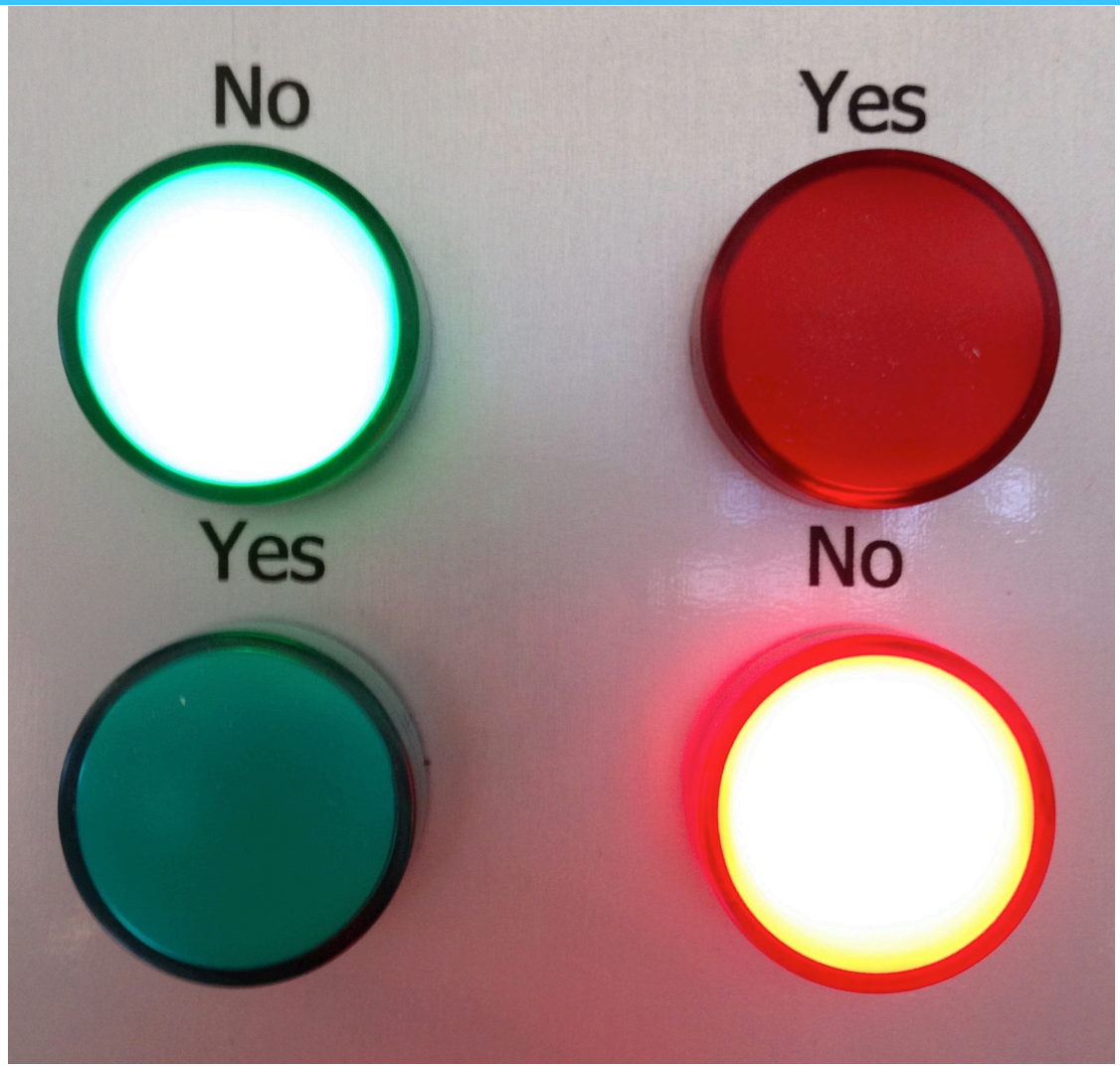
Bob Cousins, LEE, LL Wkshp, 13 Feb 2013

Summary



Summary

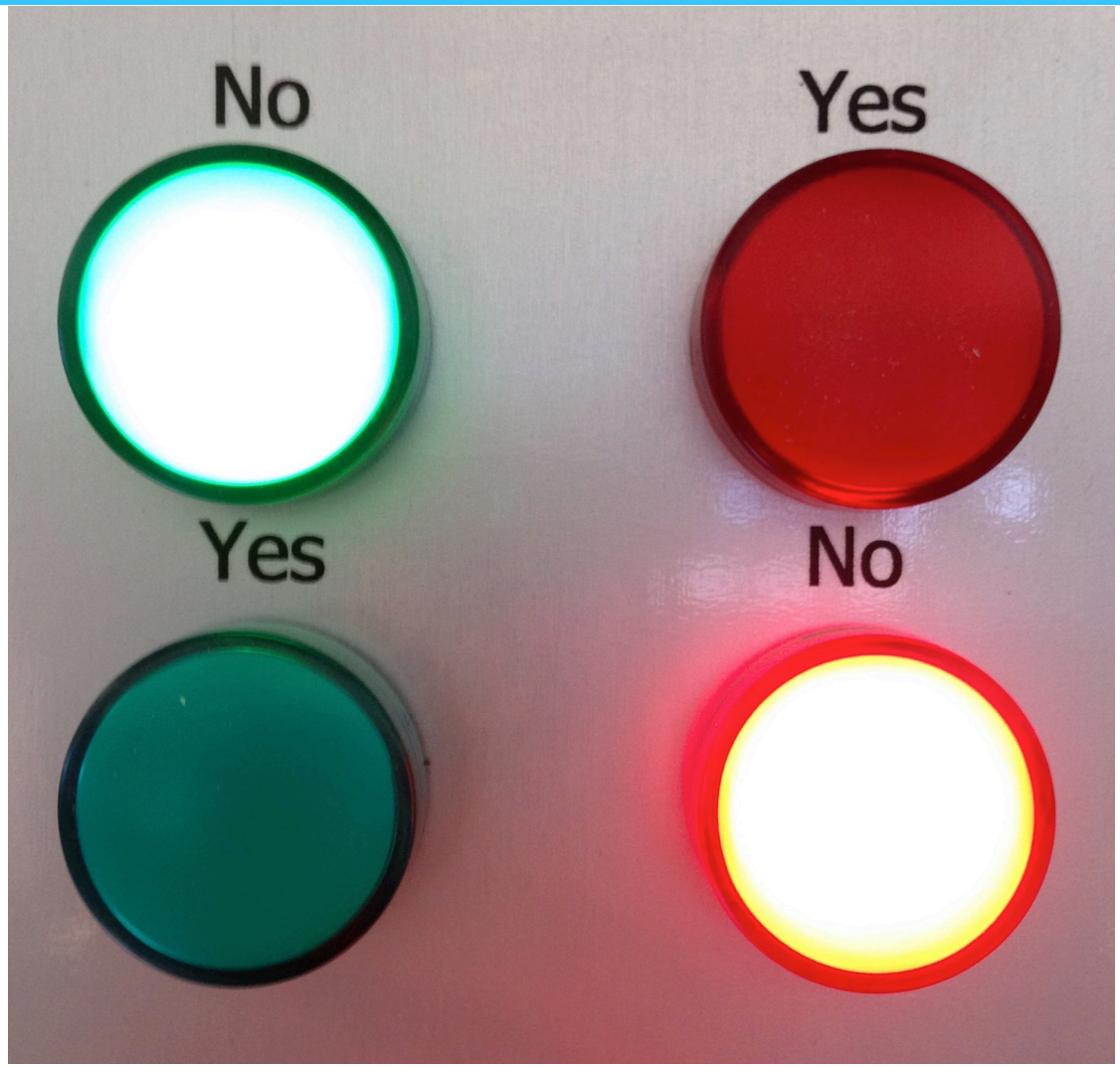
Is the SM all there is?



Summary

Is the SM all there is?

Do we know what's next?



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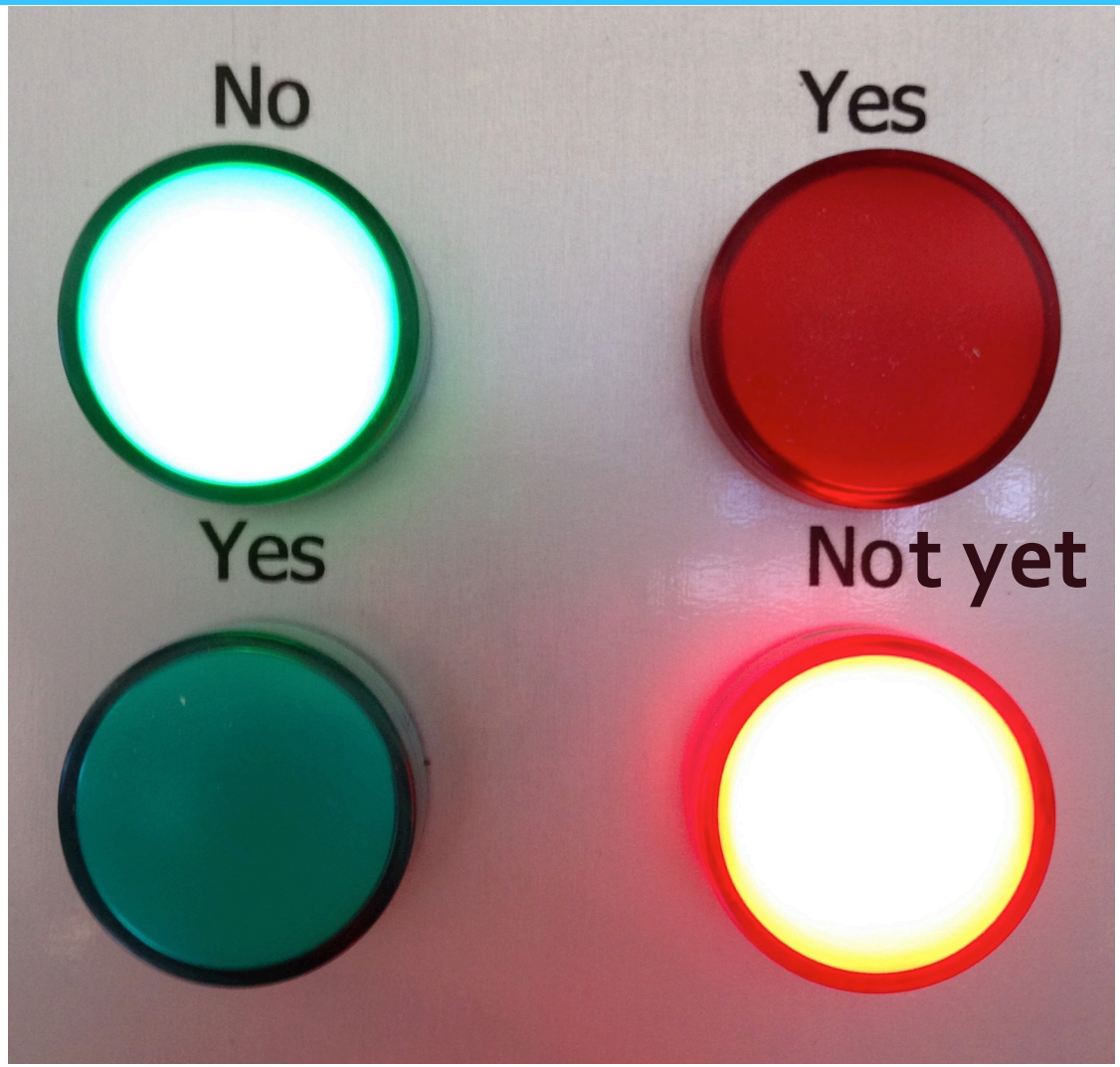
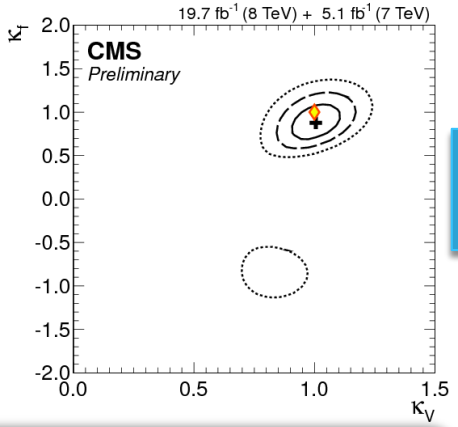
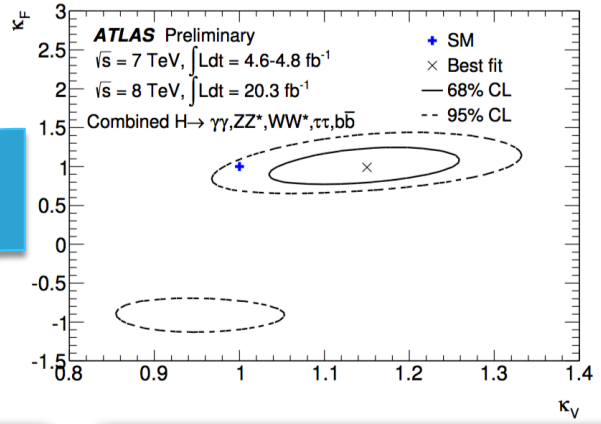


Outlook





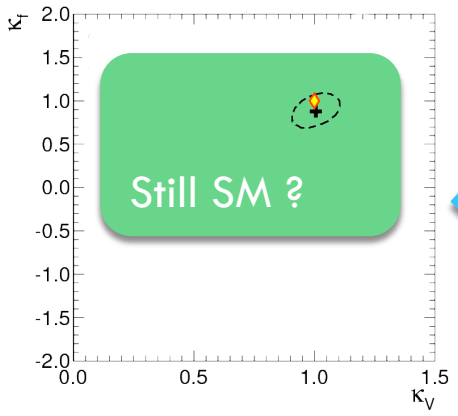
Present

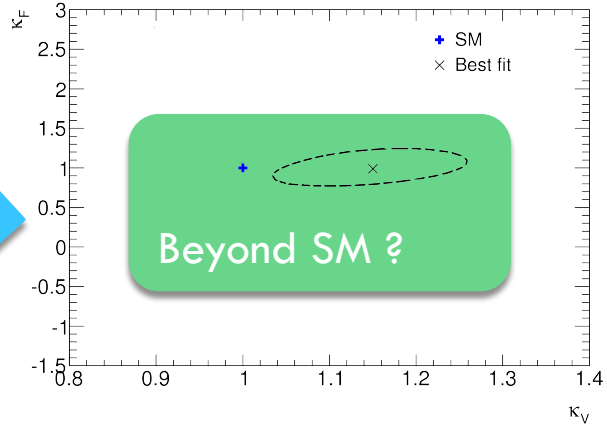
Accelerator physicists
More & other collisions

Experimentalists
Better detectors & analyses

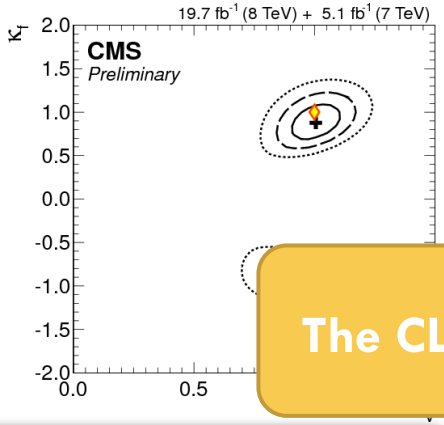
Theorists
Better predictions & tools

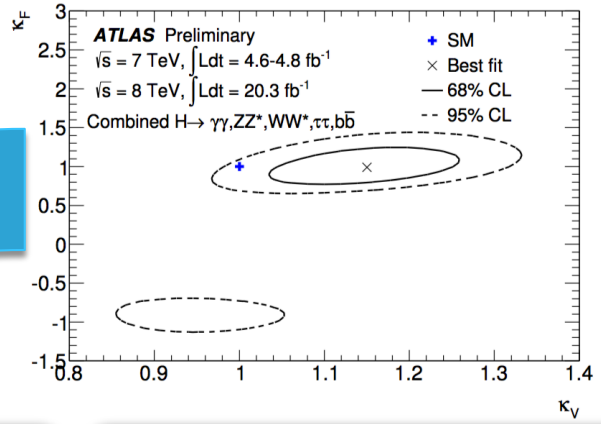
Future





Outlook





The CLIC effort

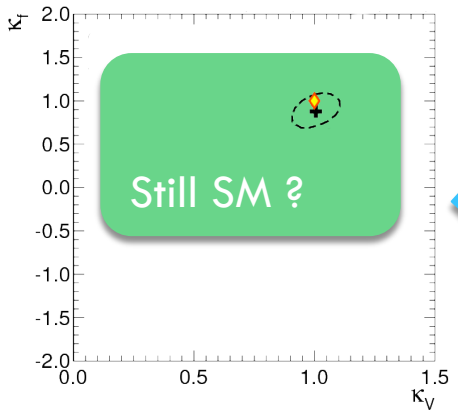
Present

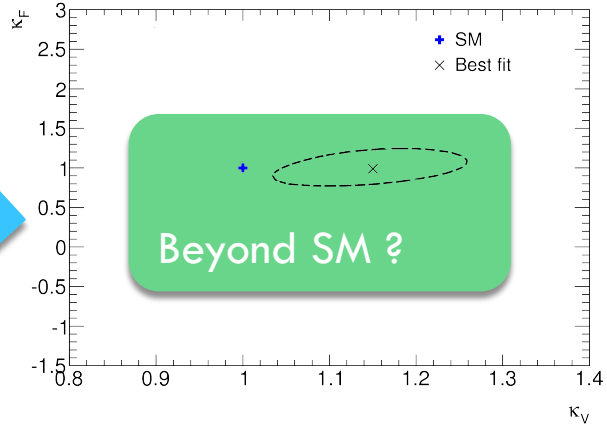
Accelerator physicists
More & other collisions

Experimentalists
Better detectors & analyses

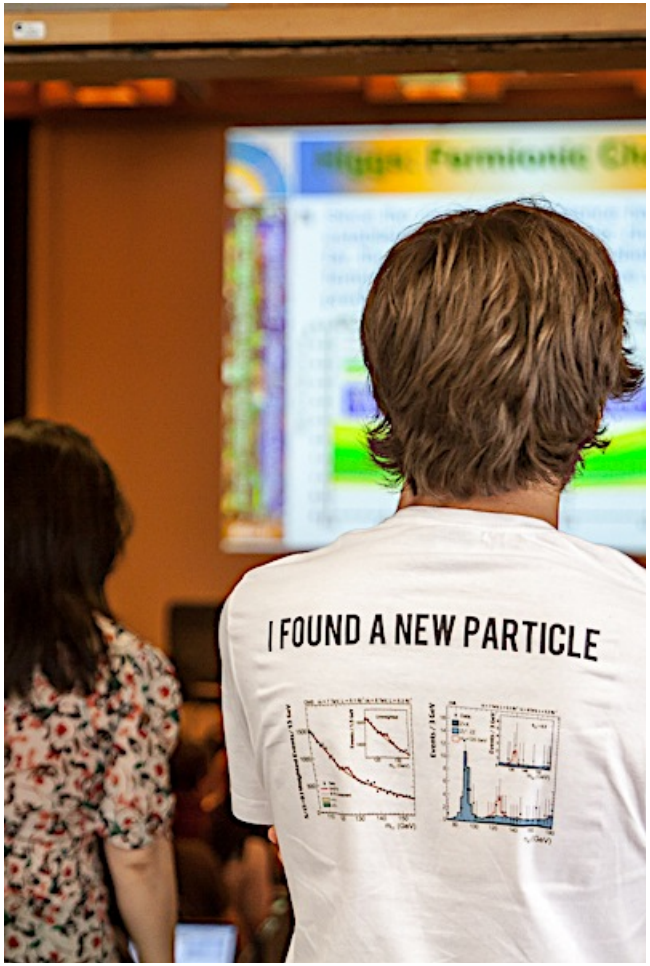
Theorists
Better predictions & tools

Future



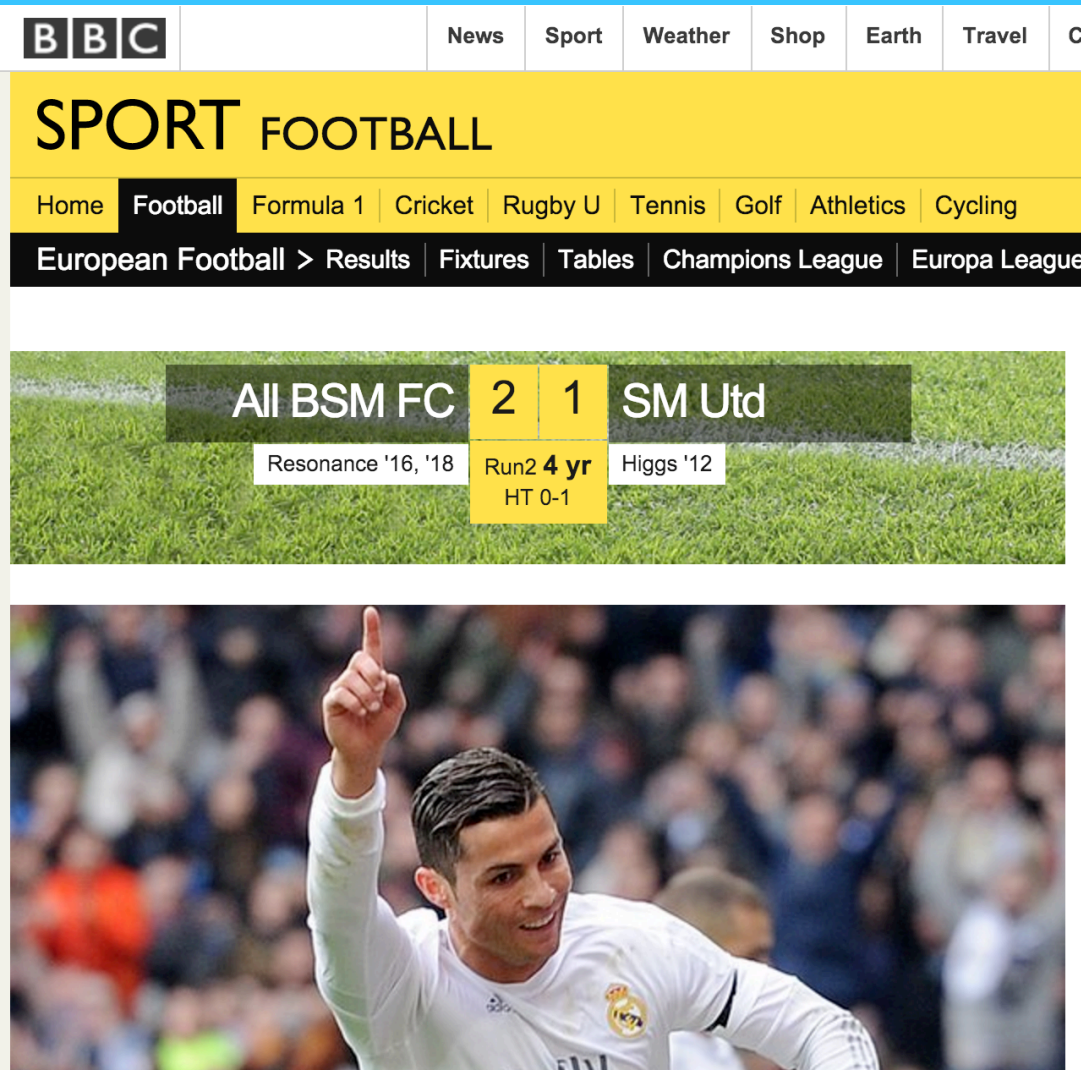


Outlook



- **LHC13: last chance before "direct BSM desert".**
  - Tevatron: Run I → top discovery, Run II → SM precision.
  - LHC 2010: early SUSY and EXO exclusions.
- **Run2 potential still to be fully explored.**
  - Higgs physics barely started.
  - Top physics to open new chapters.
  - SM measurements to be improved.
  - Much BSM phase-space still to be probed.
- **We have a long way to go.**
  All it takes is one deviation.

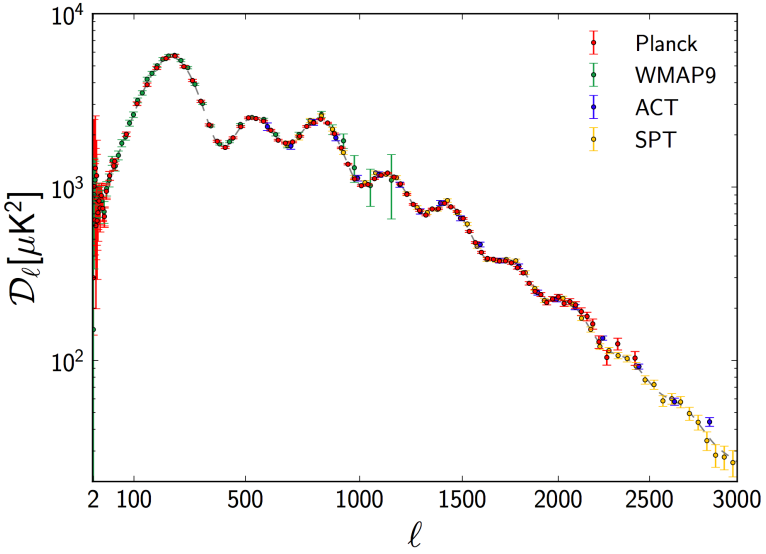
CLIC workshop 2019 ?



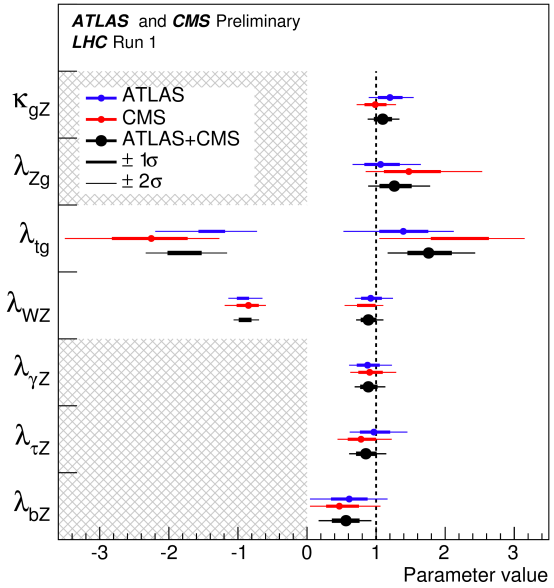
The ~~beautiful~~ ~~boring~~ Universe today

[arXiv:1303.5062][ATLAS-CONF-2015-044/CMS-PAS-HIG-15-002]

- **Up above:** "Simple six-parameter ΛCDM".



- **Down below:** (Not-as-simple) ~20-parameter Standard Model of Particle Physics.



Looking forward to surprises at higher energies: PeV neutrinos, LHC 13 TeV, …

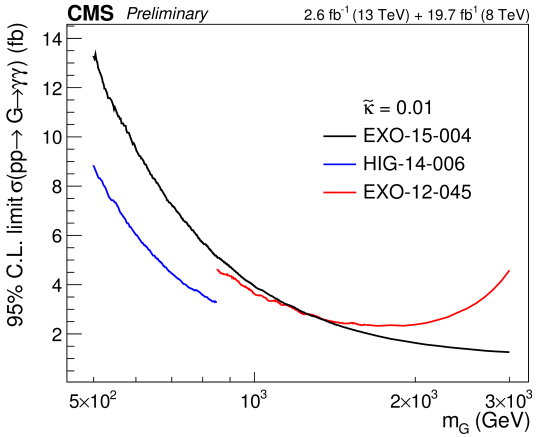
For discussion

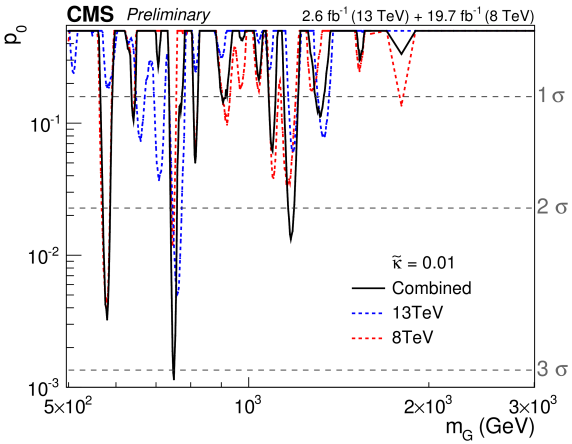
Diphoton resonance searches

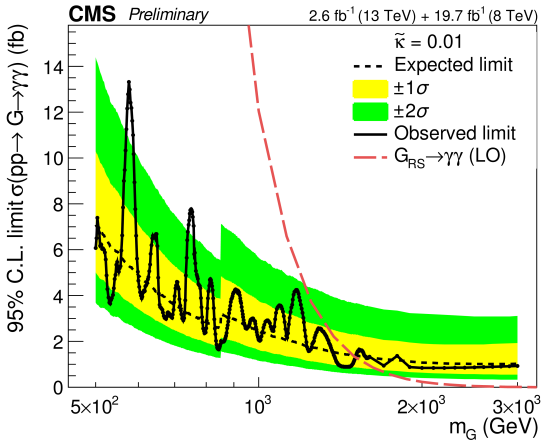
[http://cern.ch/go/8KNW]

Reference	Exp.	Collision energy [TeV]	m_X search range [GeV]	Interpretation benchmark
PRL 113 171801	ATLAS	8	65 – 600	Scalar
PRD 93 (2015) 3032004			500 – 2800	Spin-2
PLB 750 (2015) 494	CMS		150 – 800	Scalar and Spin-2
CMS-PAS-EXO-12-045			500 – 3000	Spin-2
ATLAS-CONF-2015-081	**ATLAS**	**13**	**200 – 2000**	**Scalar**
CMS-PAS-EXO-15-004	**CMS**		**500 – 4500**	**Spin-2**

CMS: combination with 8 TeV







Expected limits.
8 TeV cross-section scaled to 13 TeV assuming G_{RS}.

For m_G=750 GeV
3.0σ → **1.7σ after LEE**