ATLAS Highlights and Outlook

US LHC Users Association

Argonne National Laboratory
November 13, 2014

Chip Brock, for the ATLAS Collaboration
Michigan State University

24 October

Hello,

This is a talk for the U.S. LHC Users Organization at Argonne Lab scheduled for November 13.

https://indico.hep.anl.gov/indico/conferenceDisplay.py?confId=410

The assigned title is "ATLAS Highlights and Outlook" and I've chosen to interpret this as not just the most recent results, but as much as possible a look back at Run I as compared with what we might have expected. Also a quick run-through of preparations for Run 2 are included. I've not included heavy ion physics, pleading time, a lack of expertise, and an audience dominated by, if not exclusively, particle physicists.

What's shown is a superset of what I can possibly include in a half-hour, but because I've got 2 talks in a couple of weeks, I hoped to get approval sooner rather than later so I can tweak during the first week of November.

In some cases, I've just included plots I might show without yet adding commentary. In some cases, I've still got some clips and notes to myself. My understanding for this review is that appropriate attribution and most recent results are the basic concern.

Thanks,
Chip Brock
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1%

x^2

ATLAS @work

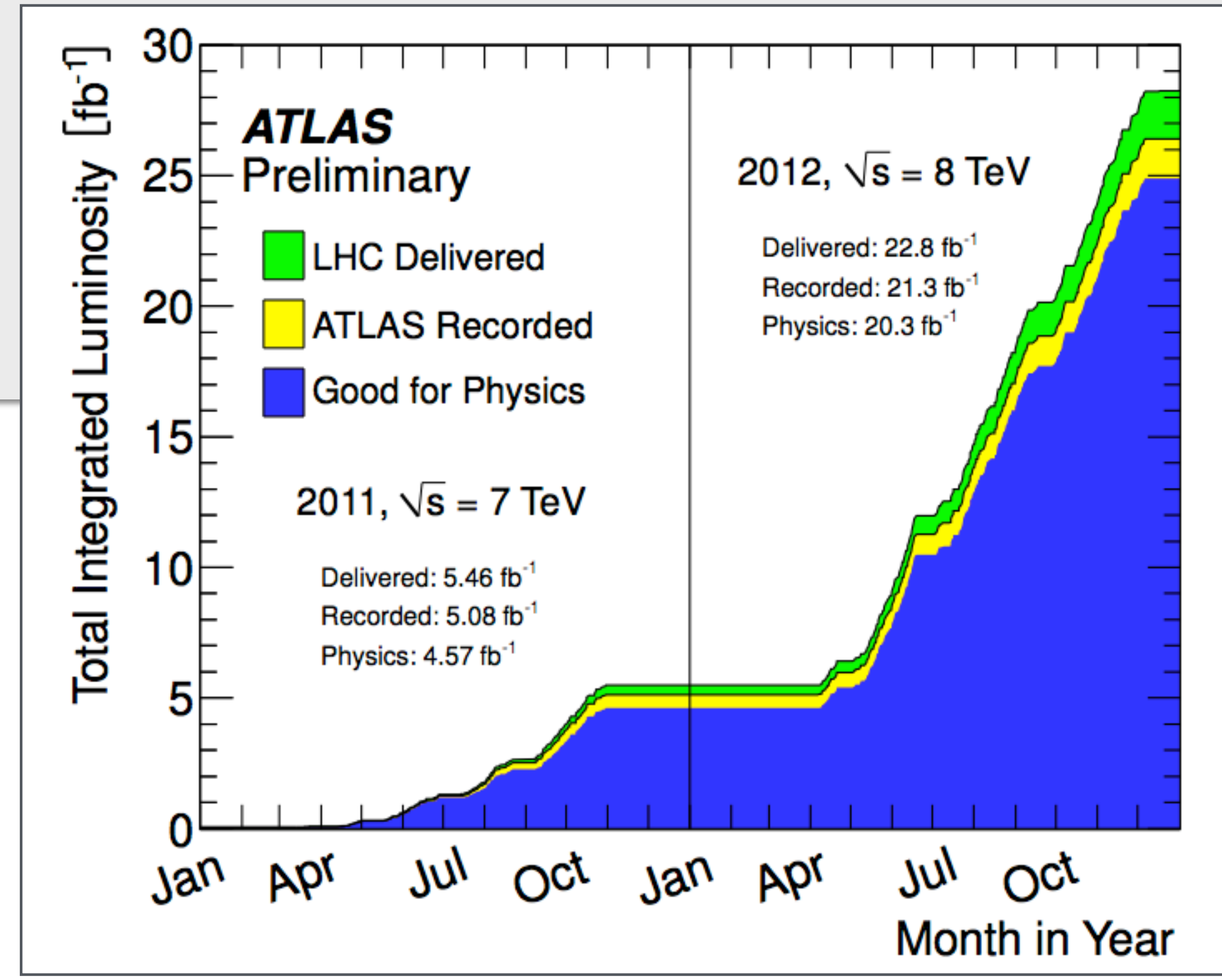
efficient and productive

~90% usable data efficiency

2010: $\sqrt{s}$ = 7 TeV, 0.05/fb

2011: $\sqrt{s}$ = 7 TeV, 4.6/fb

2012: $\sqrt{s}$ = 8 TeV, 20.3/fb



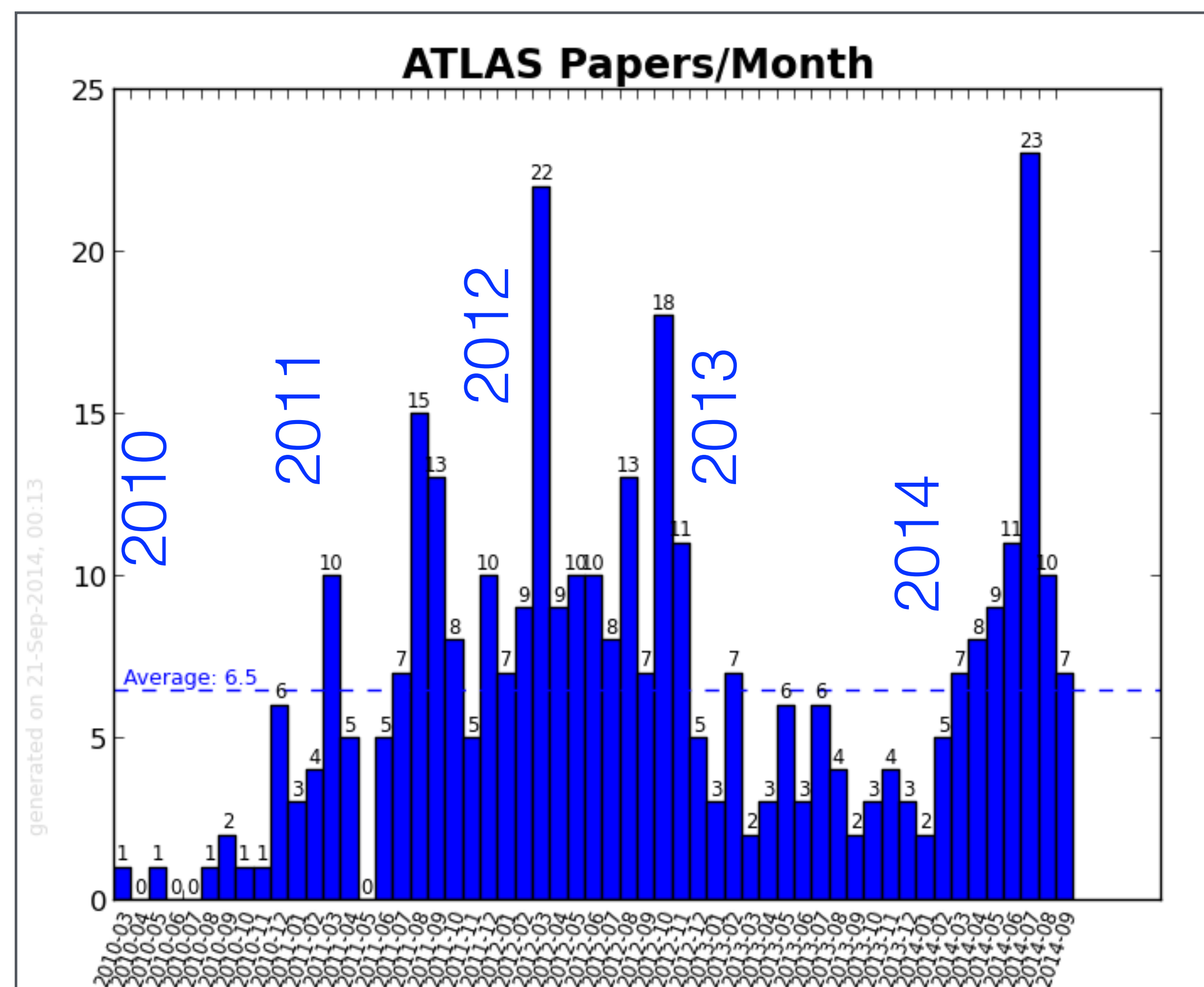
Run I results: a 2014 publication stream

350 publications, ~150 performance

~100 to come

600 CONF notes

660 conference talks



Snowmass Energy Frontier

Research Program:

1. **Measure properties of the Higgs boson.**

   Including: mass, CP properties, and especially couplings

2. **Measure properties of the: t, W, and Z**

   Because they talk “loudly” to the Higgs

3. **Search for TeV-scale particles**

   A scale inspired by naturalness

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I'll add:

4. **Wrestle the Standard Model to the ground.**
5. **Search for kinematical anomalies wrt SM (see #4)**

Is excitement about Run 2…

lost in the huge Phase 1 preparation?

a rule of  **: a x10 increase in $\mathscr{L}$ is like x2 in E_{cm}**

and visa versa

Run 2 gives us:

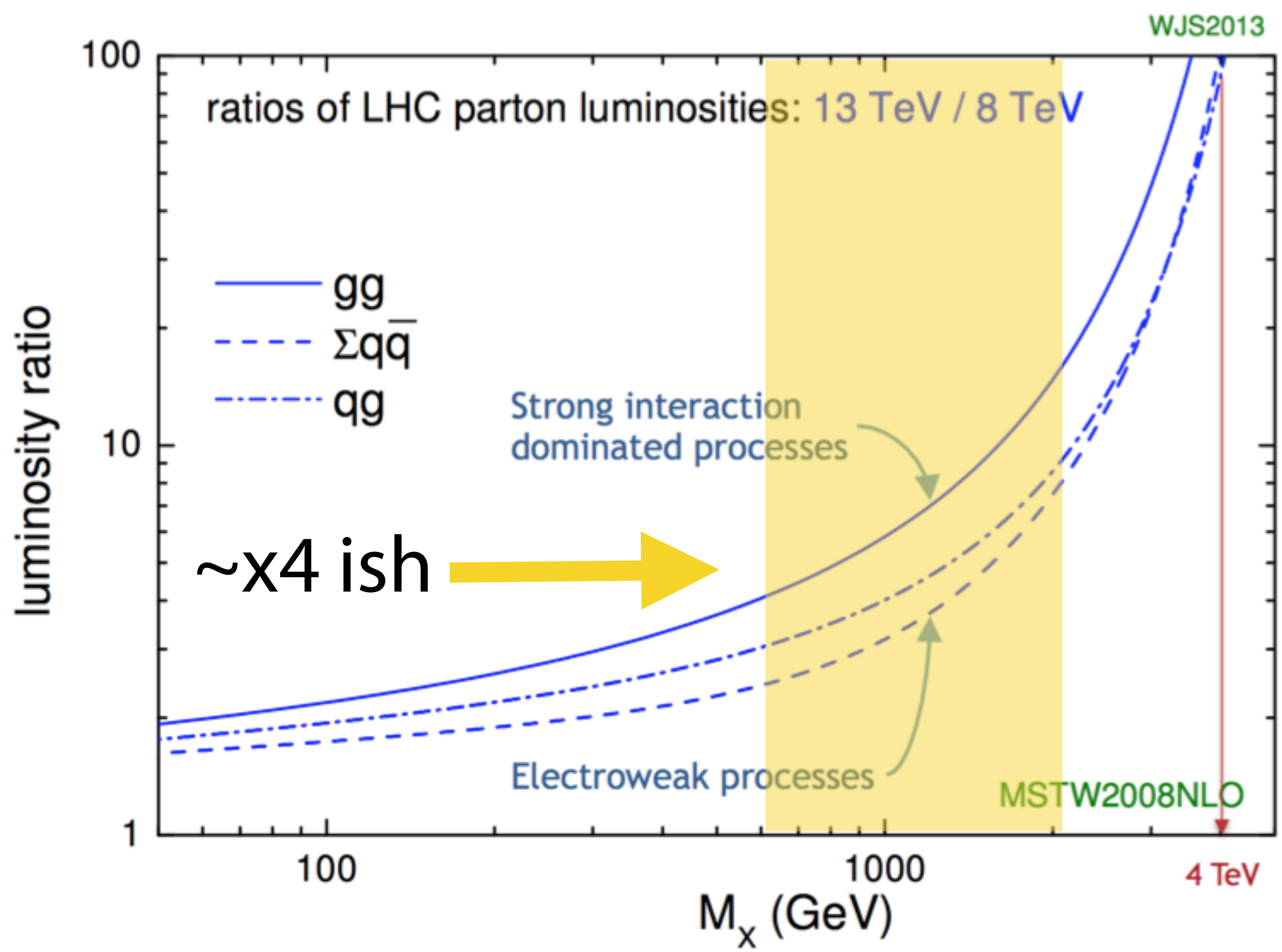
Unprecedented precision

W ’s, tops, Higgs!, flavor, inclusive σ ’s,

Enormous discovery reach

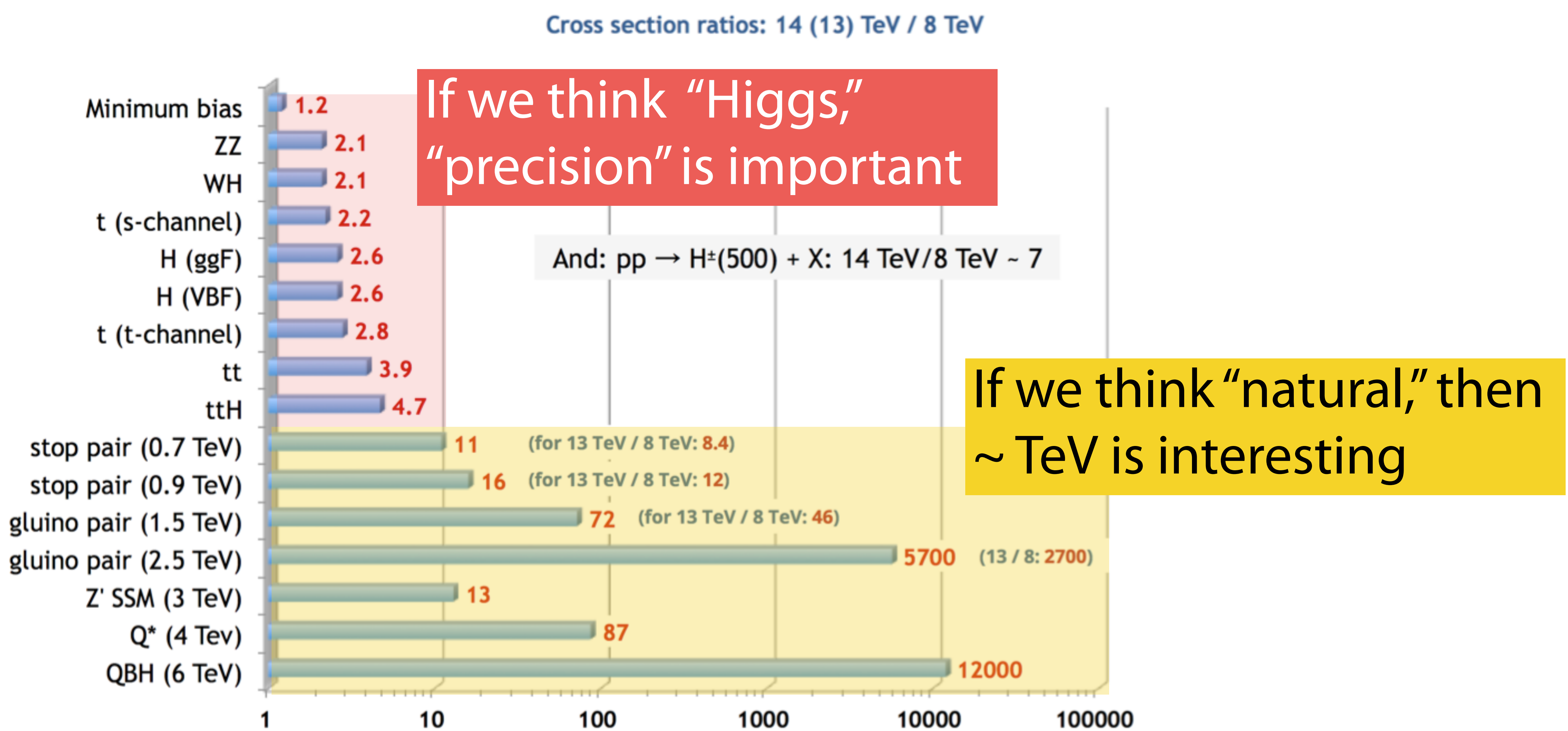
surpass the 1 TeV SUSY scale, *Z’/W’*, BSM Higgs

More parton luminosity



If we think "natural," then ~ TeV is interesting

+ Higher cross sections



Run 1 is essentially a wrap

Higgs Boson Physics

Notable results

from Run 1 we anticipated:

Discovery, first looks

from Run 1 we achieved:

Discovery, the beginnings of a precision Higgs program:

mass, couplings, important final states, differential distributions

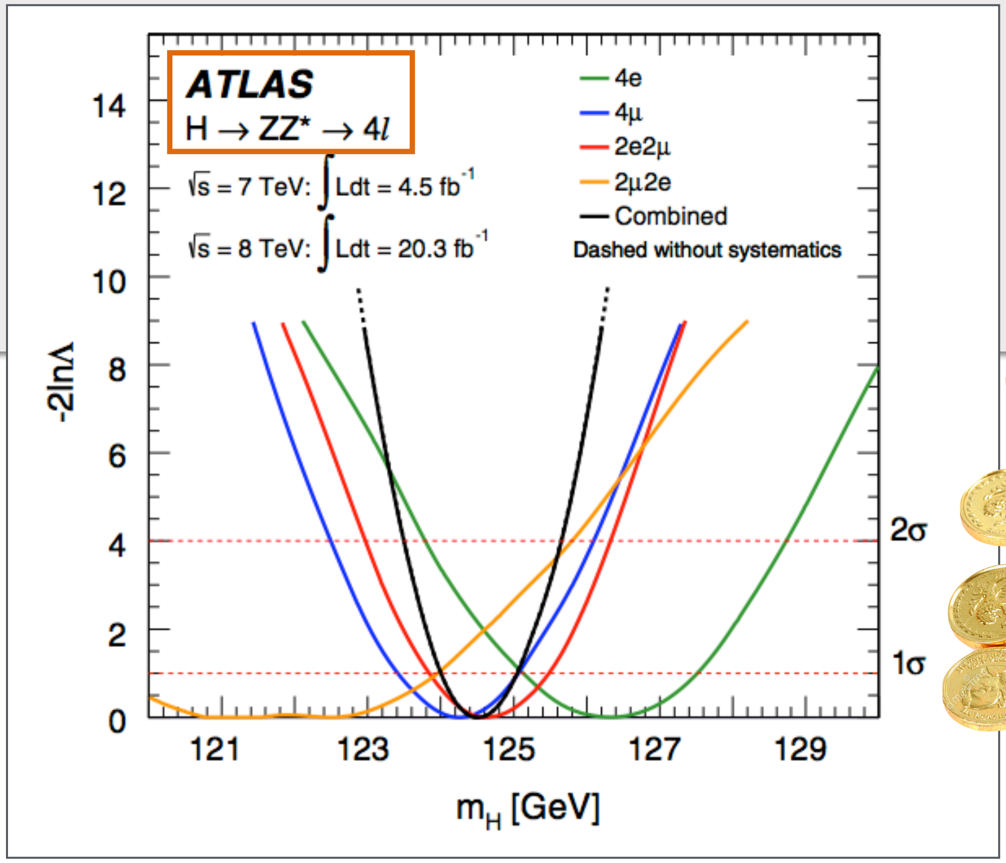
in Run 2, we expect:

Cross sections 13/14 TeV, ttH, high mass BSM searches, combination precision couplings, differential distributions

~x10 statistics

Higgs Boson mass

Agony and Ecstasy

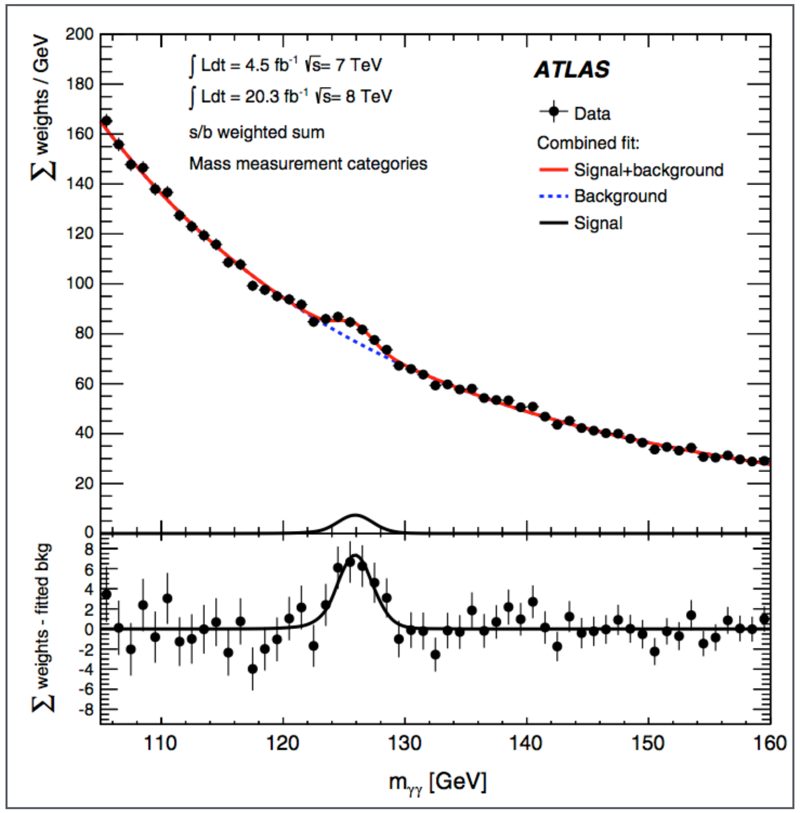


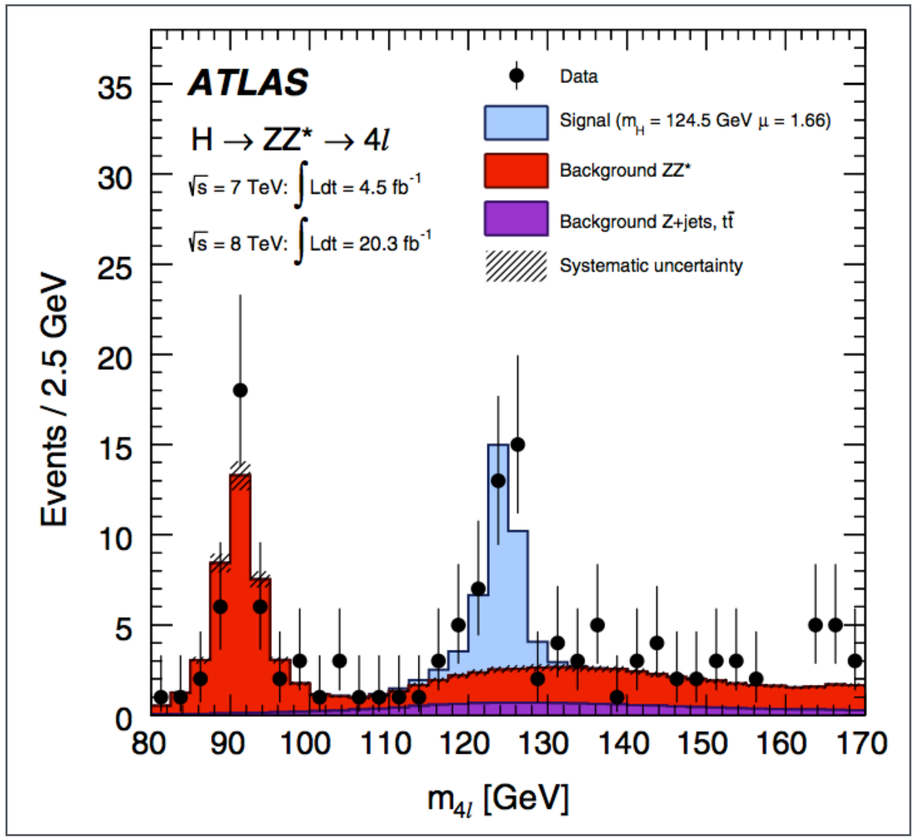
Agony:

m_H only ~ 125 GeV

Ecstasy:

m_H precisely = 125.36 ± 0.37 ± 0.18 GeV





~ 40 signal/channel

Run II: expect 400-500

PHYSICAL REVIEW D 90, 052004 (2014)

Higgs width?

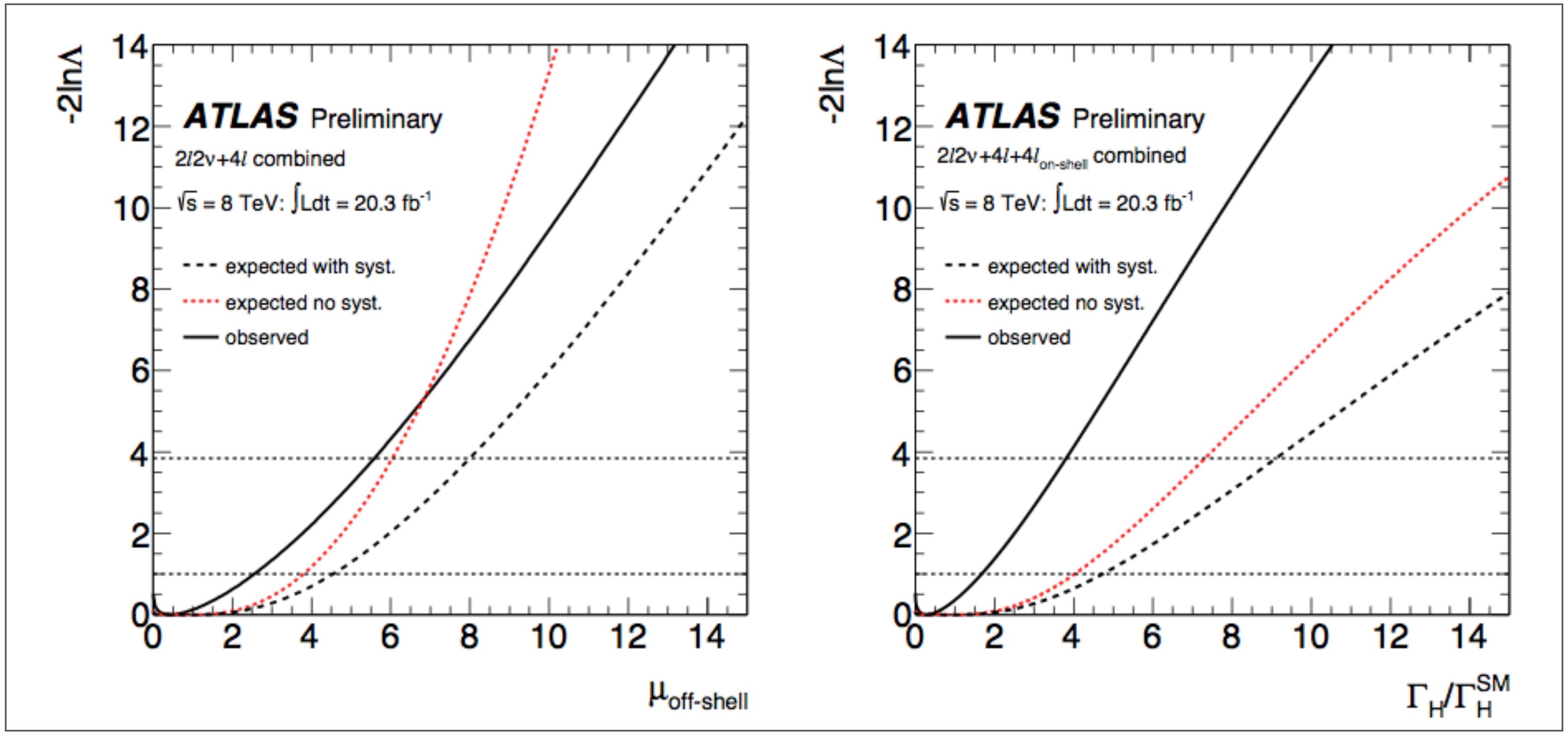
smart ideas

Infer

on-shell, vs off-shell

$$\mu_{\text{off-shell}} = \mu_{\text{on-shell}} \cdot \Gamma_H / \Gamma_H^{\text{SM}}$$

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = 0.3\,^{+1.4}_{-0.3}$$



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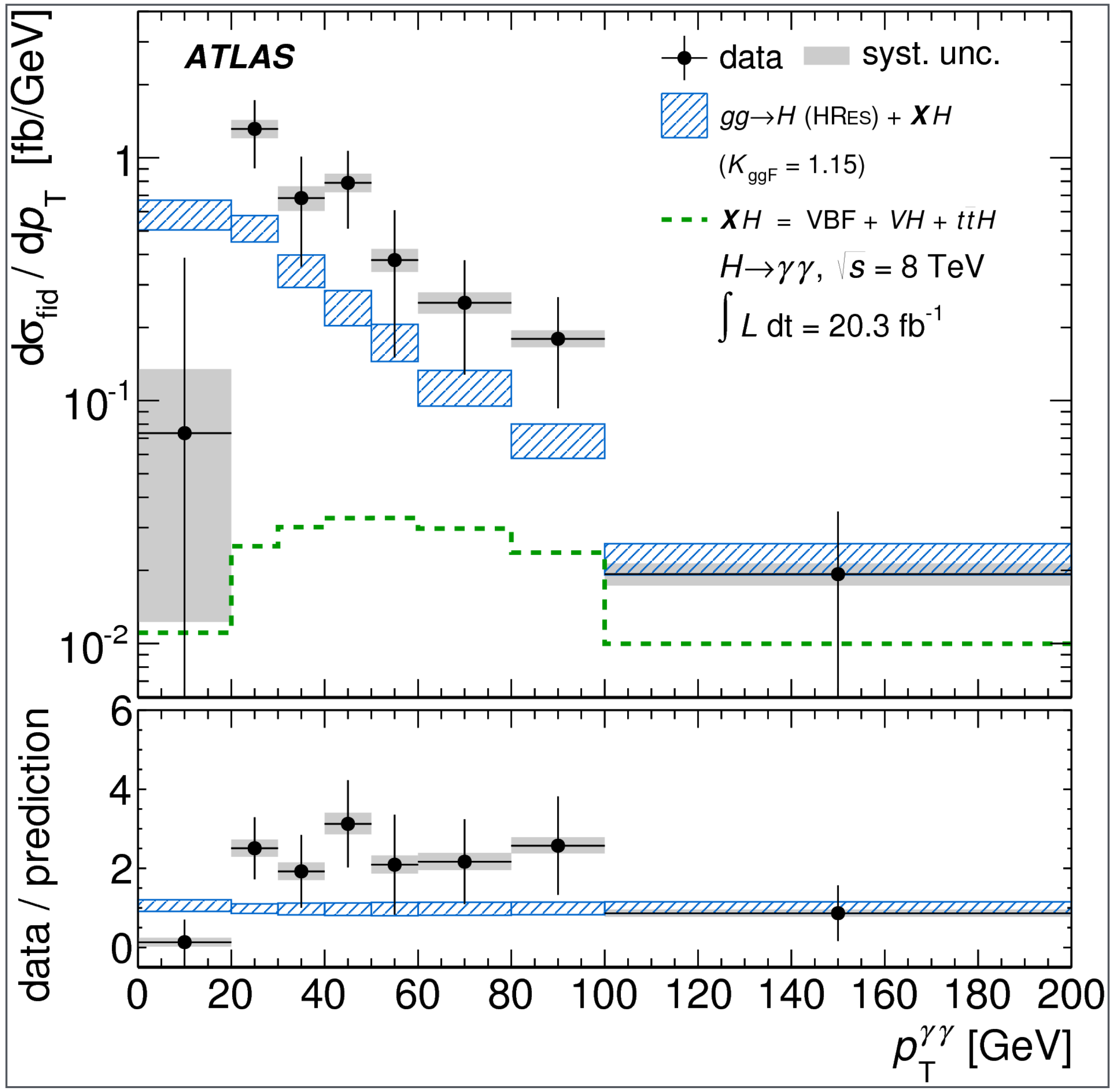
so far, 1 sd compatible

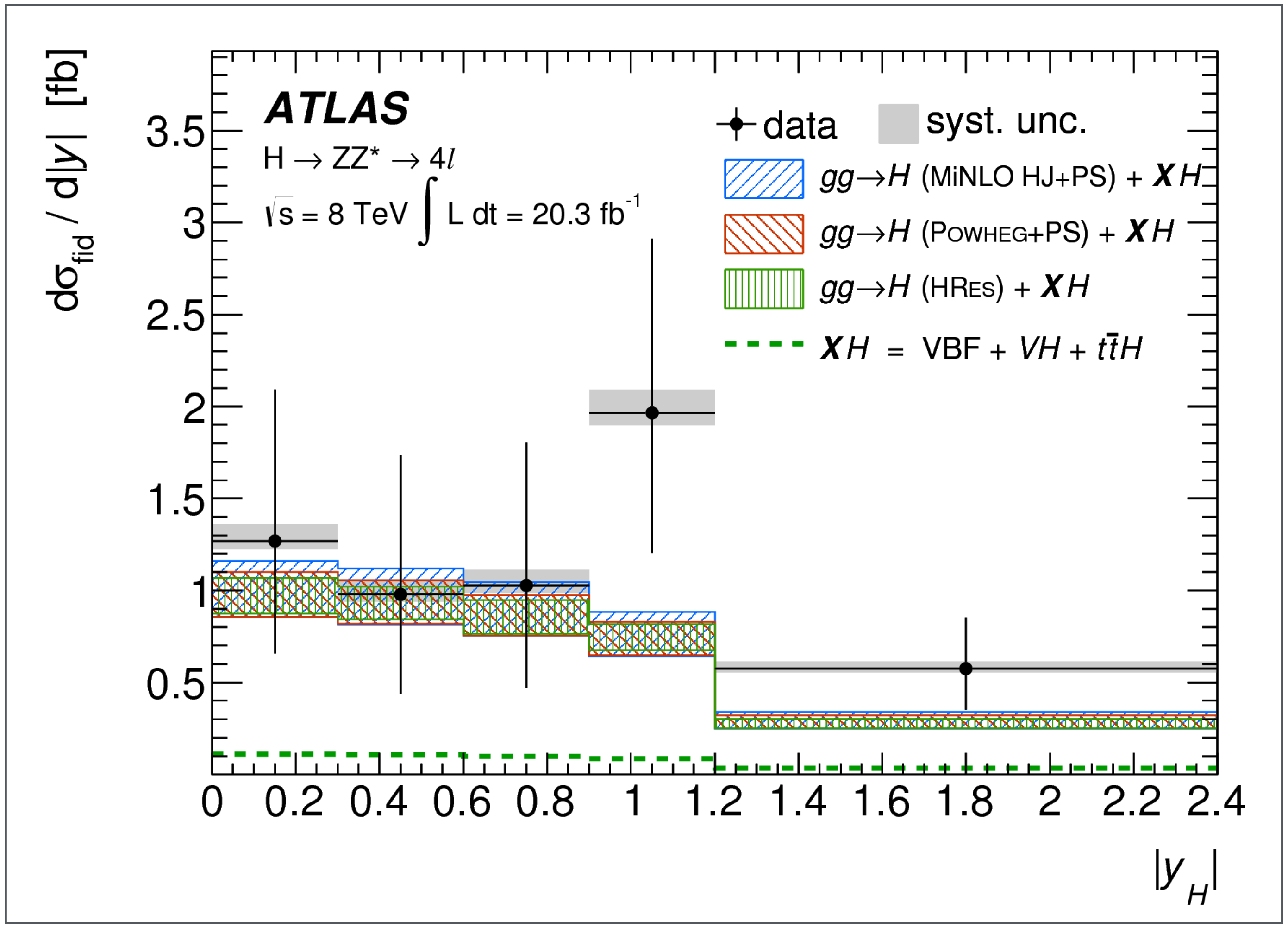
Higgs in slices

differential distributions

the details corrected to the particle level



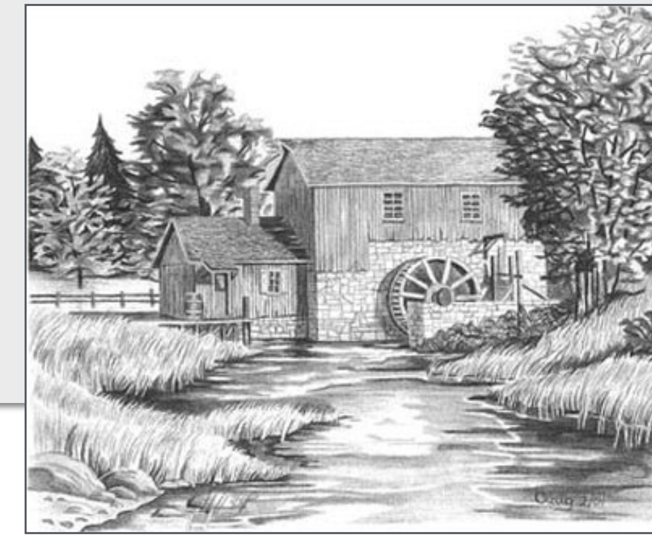
arXiv:1407.4222



arXiv:1408.3226

Higgs couplings, 1

signal strengths, small, vibrant industry

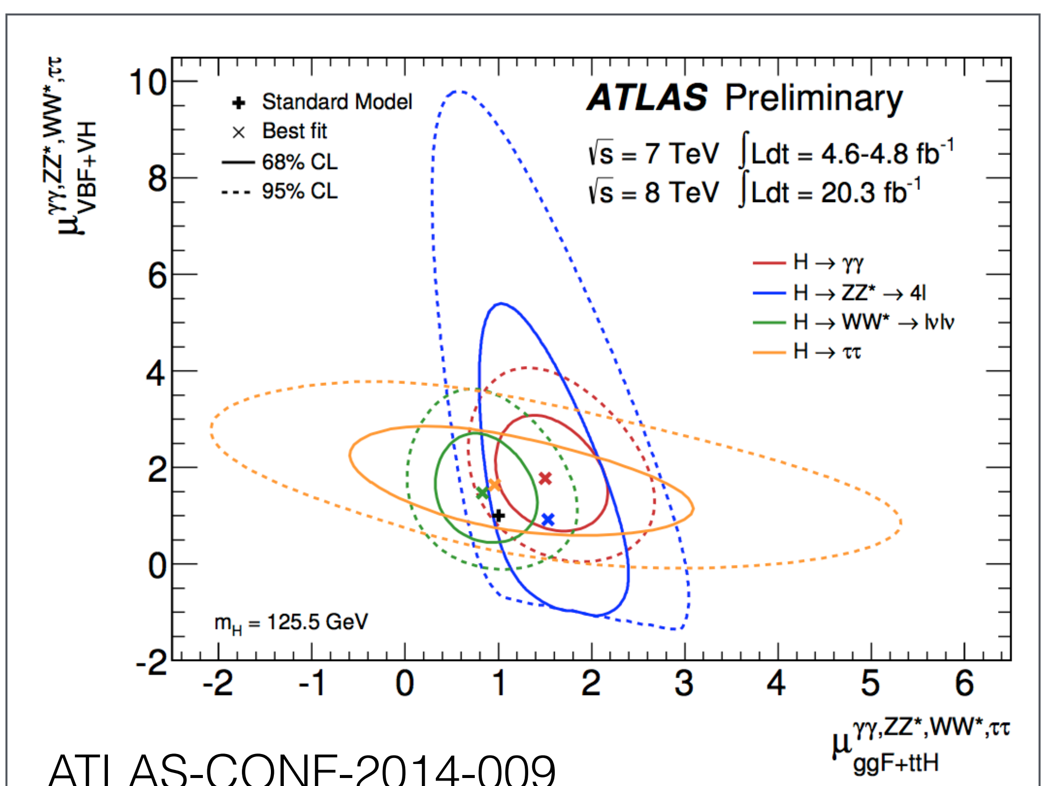


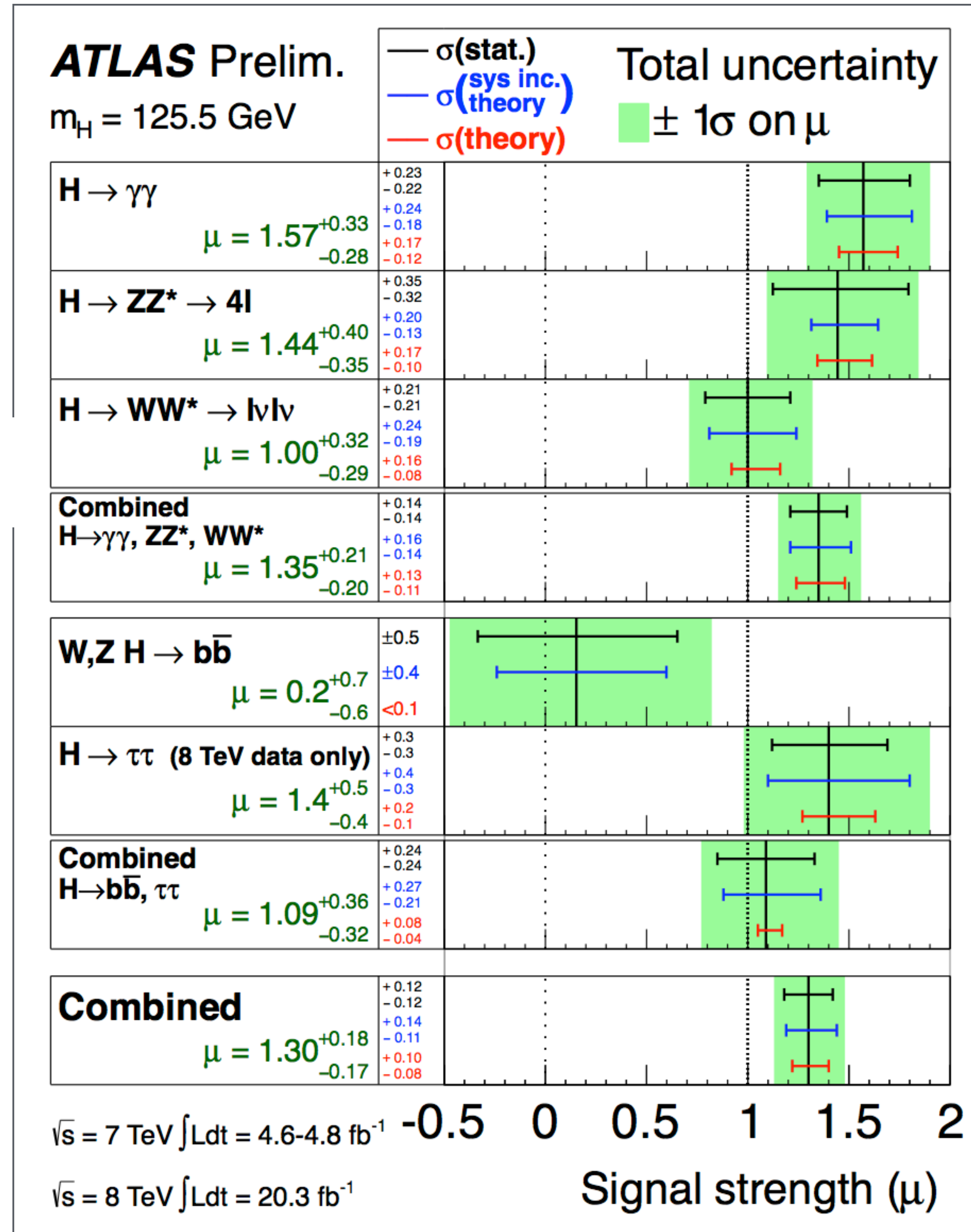
succession of assumptions

least constrained, signal strength:

other fits with constraints

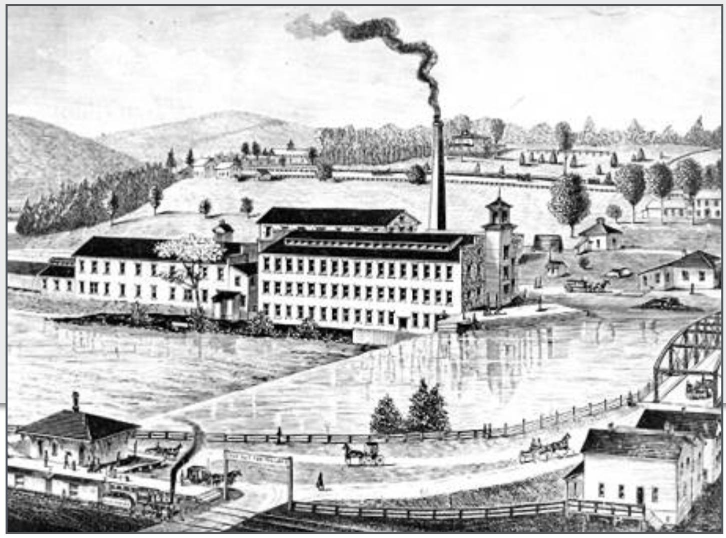
$$\mu_{VBF+VH} = \mu_{VBF} = \mu_{VH} \qquad \mu_{ggf+t\bar{t}H} = \mu_{ggf} = \mu_{t\bar{t}}$$



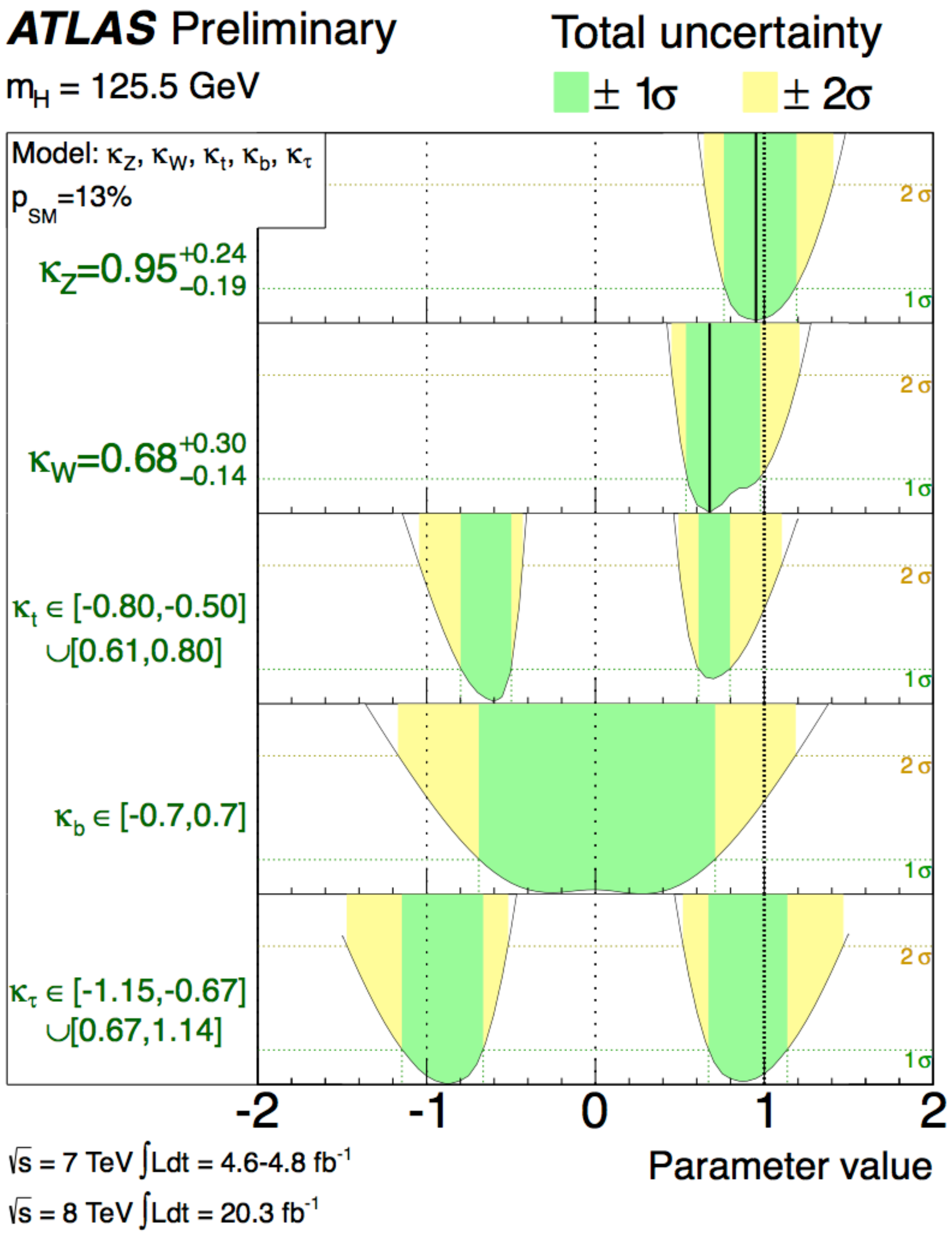


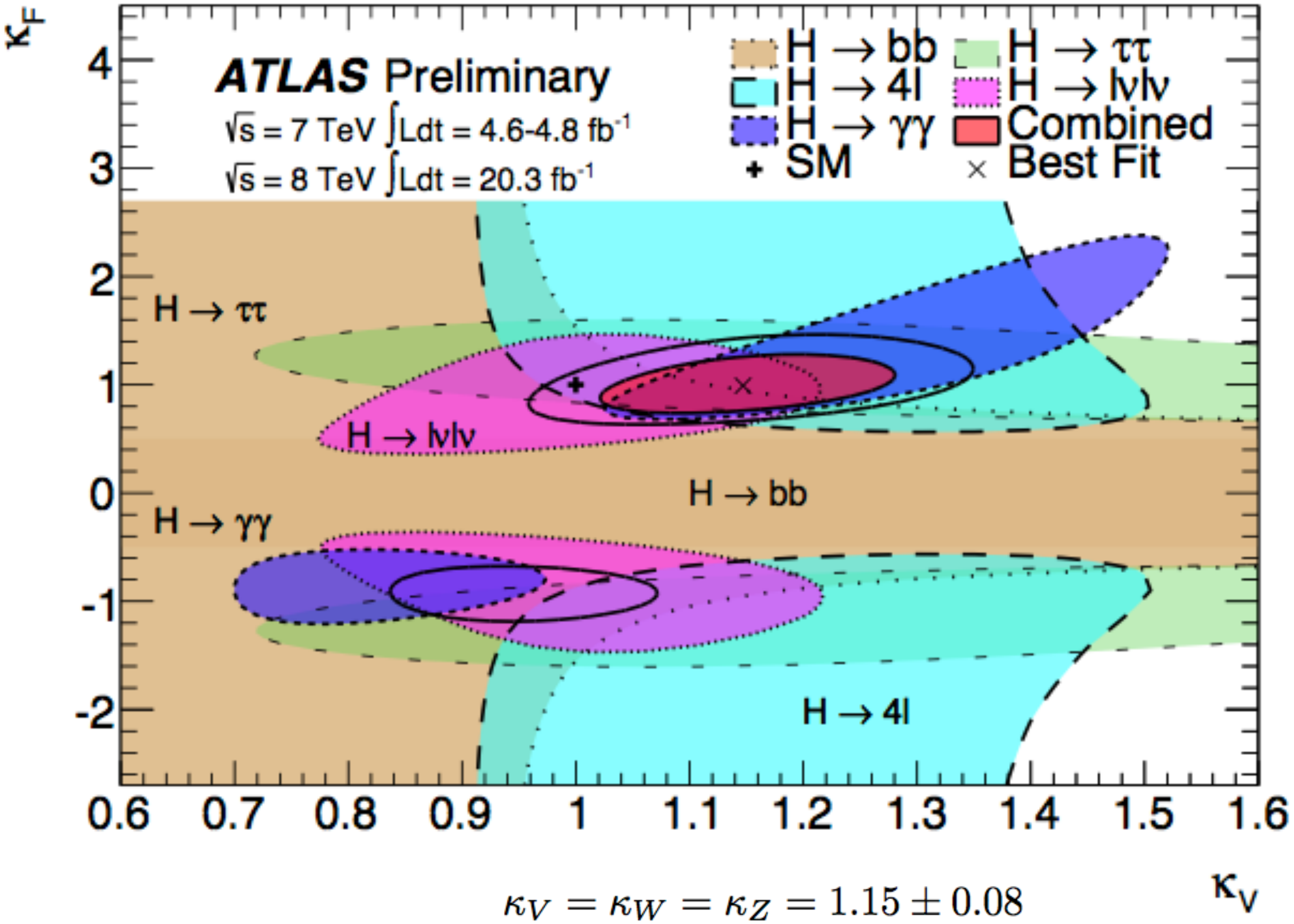
Higgs couplings, 2

global fitting, big, growing industry



global fitting





$$\kappa_V = \kappa_W = \kappa_Z = 1.15 \pm 0.08$$
$$\kappa_F = \kappa_t = \kappa_b = \kappa_\tau = \kappa_g = 0.99 \pm 0.17$$

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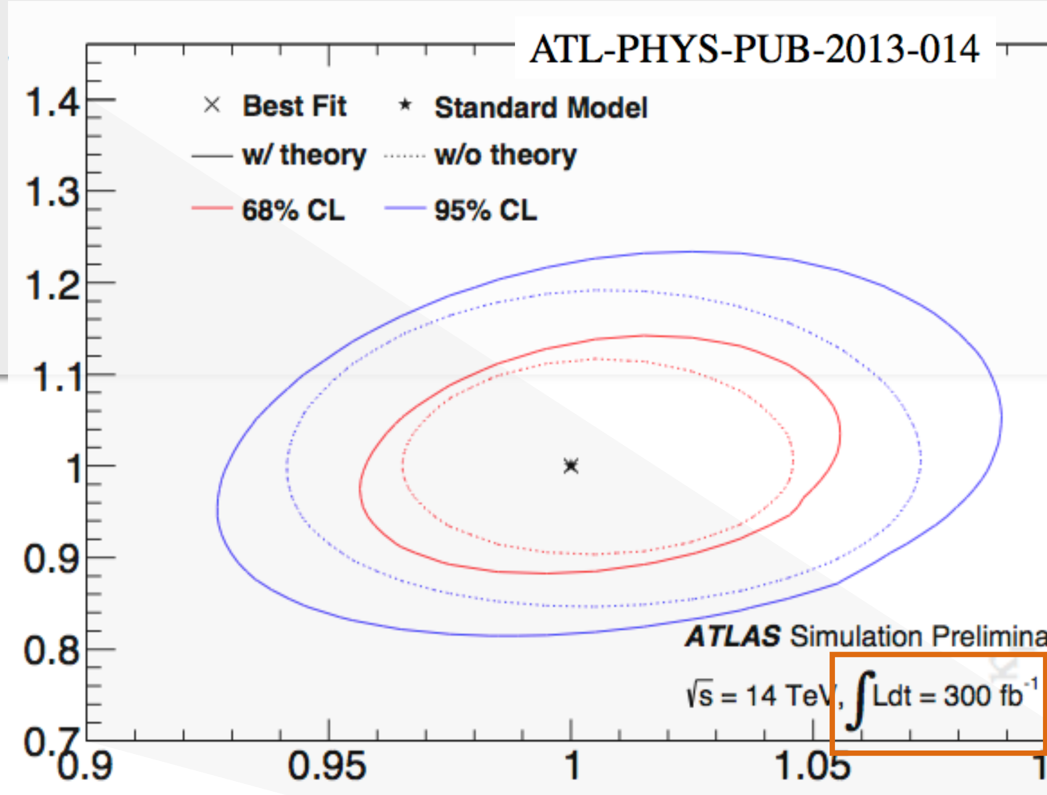

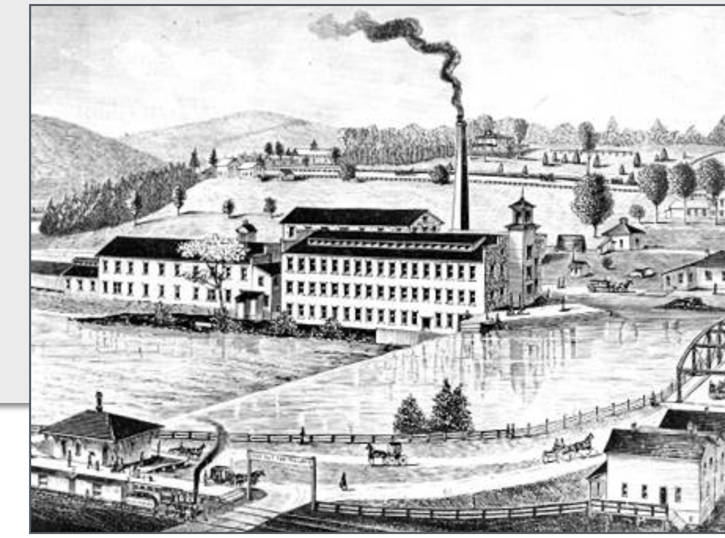

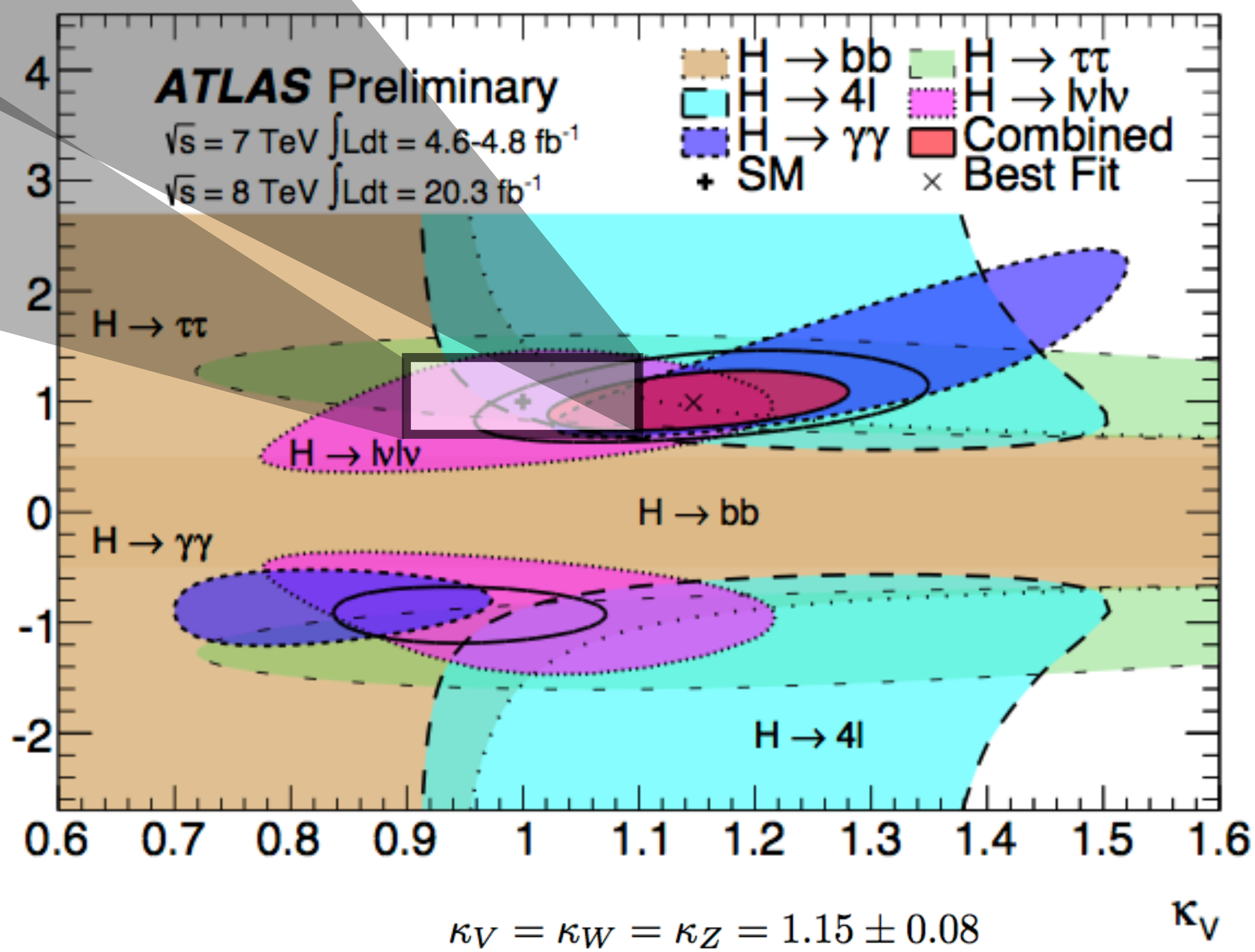

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ATLAS-CONF-2014-009

But Wait... THERE'S MORE!

higgs ww

higgs tau tau

VH bb

spin/CP gg, zz, ww,

Standard Model Physics

Notable results

from Run 1 we anticipated:

“Rediscovery”…Precision total & inclusive cross sections, VV studies, differential cross sections. Did we expect MW?

from Run 1 we achieved:

Rediscovery, indeed.

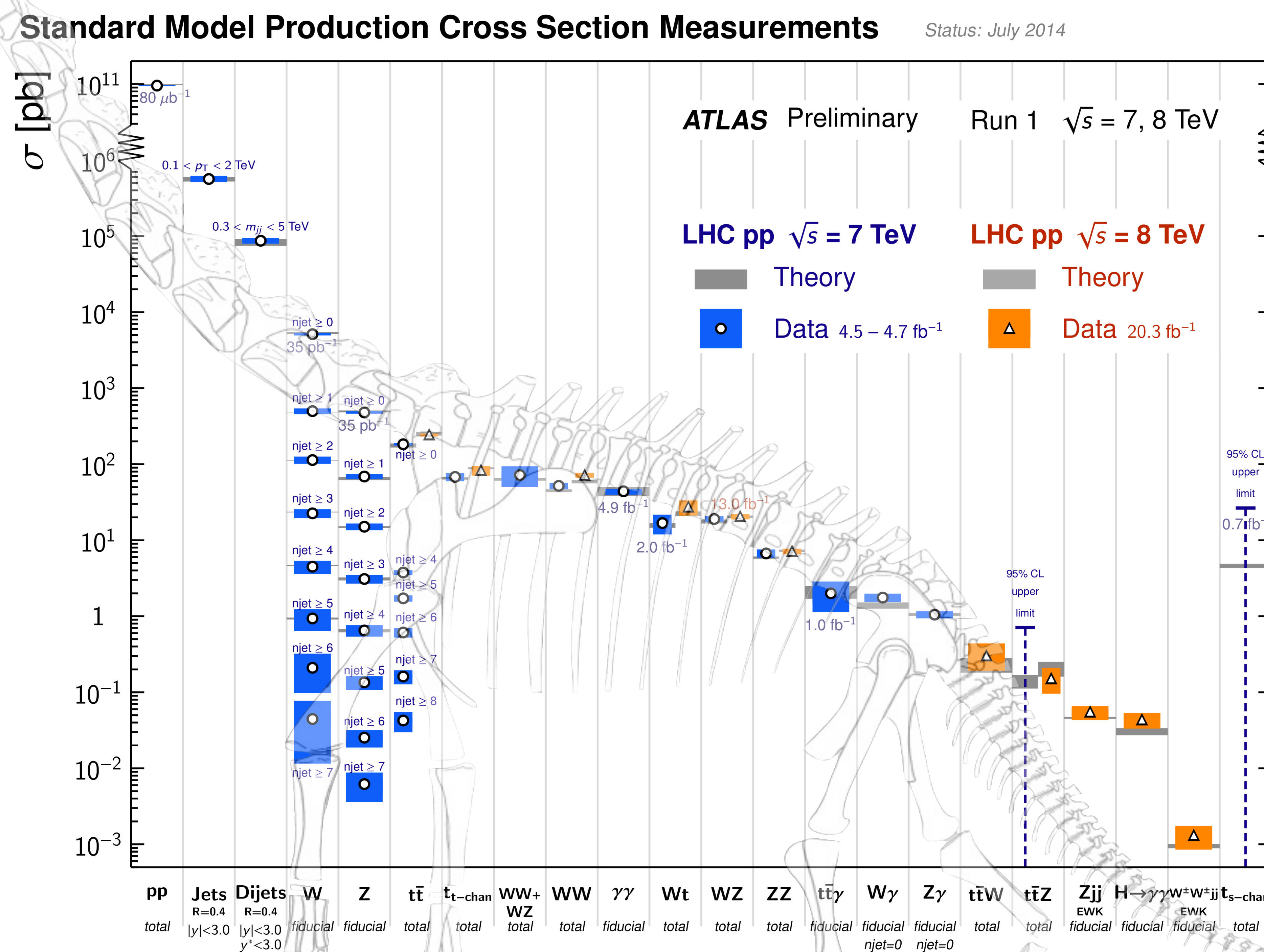
in Run 2, we expect:

Rerediscovery…Precision couplings, differential distributions, much pileup study.

First MW?

Standard Model Paleontology

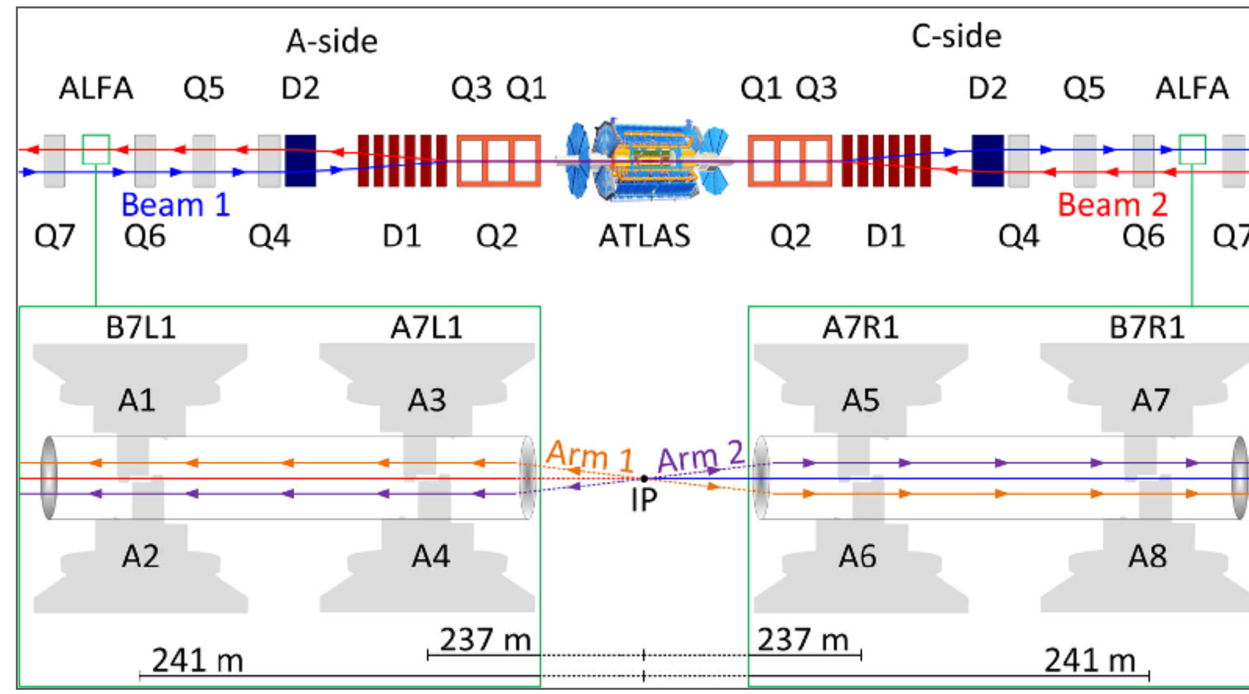
pick your favorite dinosaur

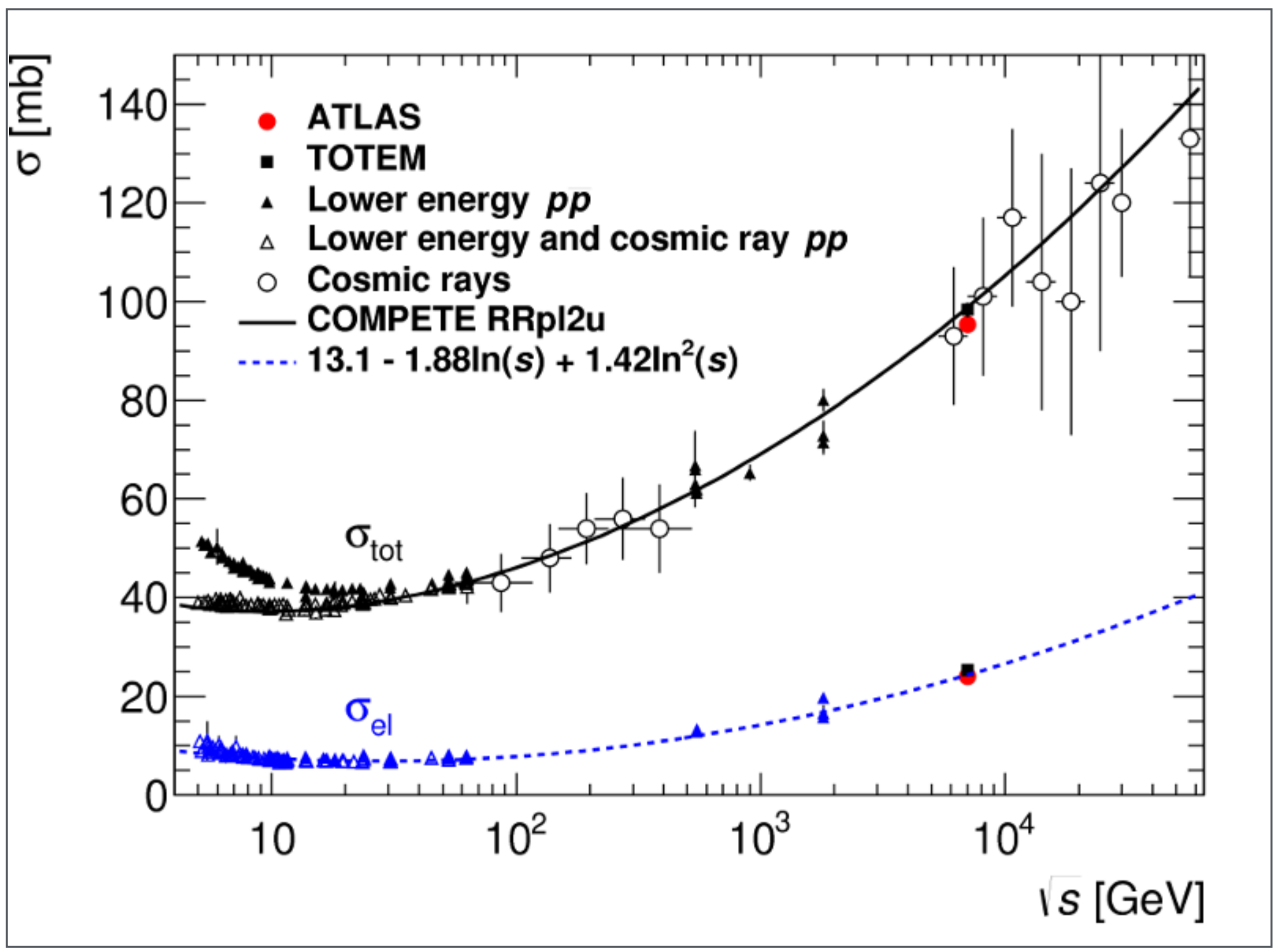


The basics

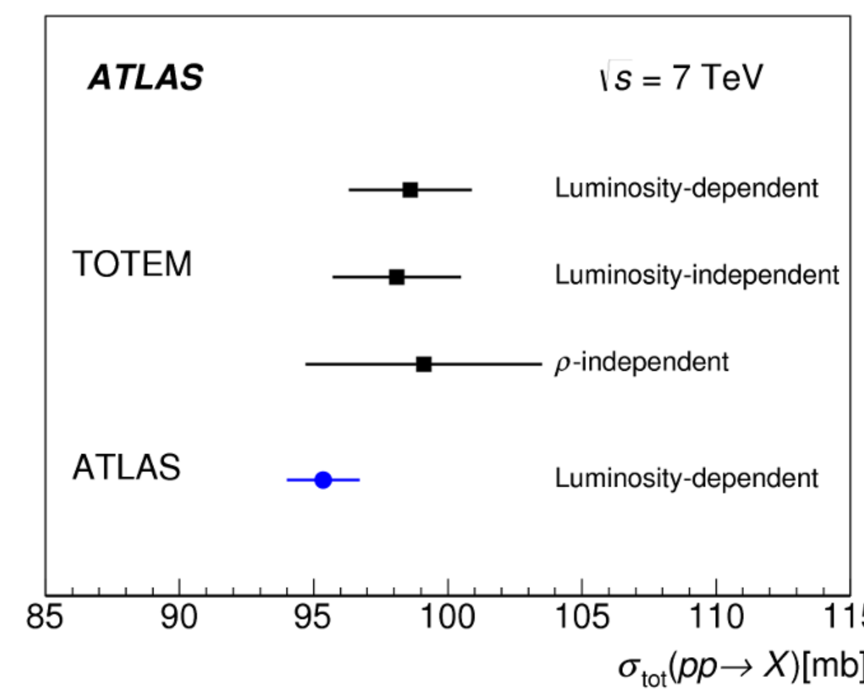
Elastic and total pp cross section

ALFA detectors at ±240m





arXiv:1408.5778



Result: $\sigma_{\mathrm{tot}}(pp \to X) = 95.35 \pm 0.38\,(\mathrm{stat}) \pm 1.25\,(\mathrm{exp}) \pm 0.37\,(\mathrm{extr})$ **mb**

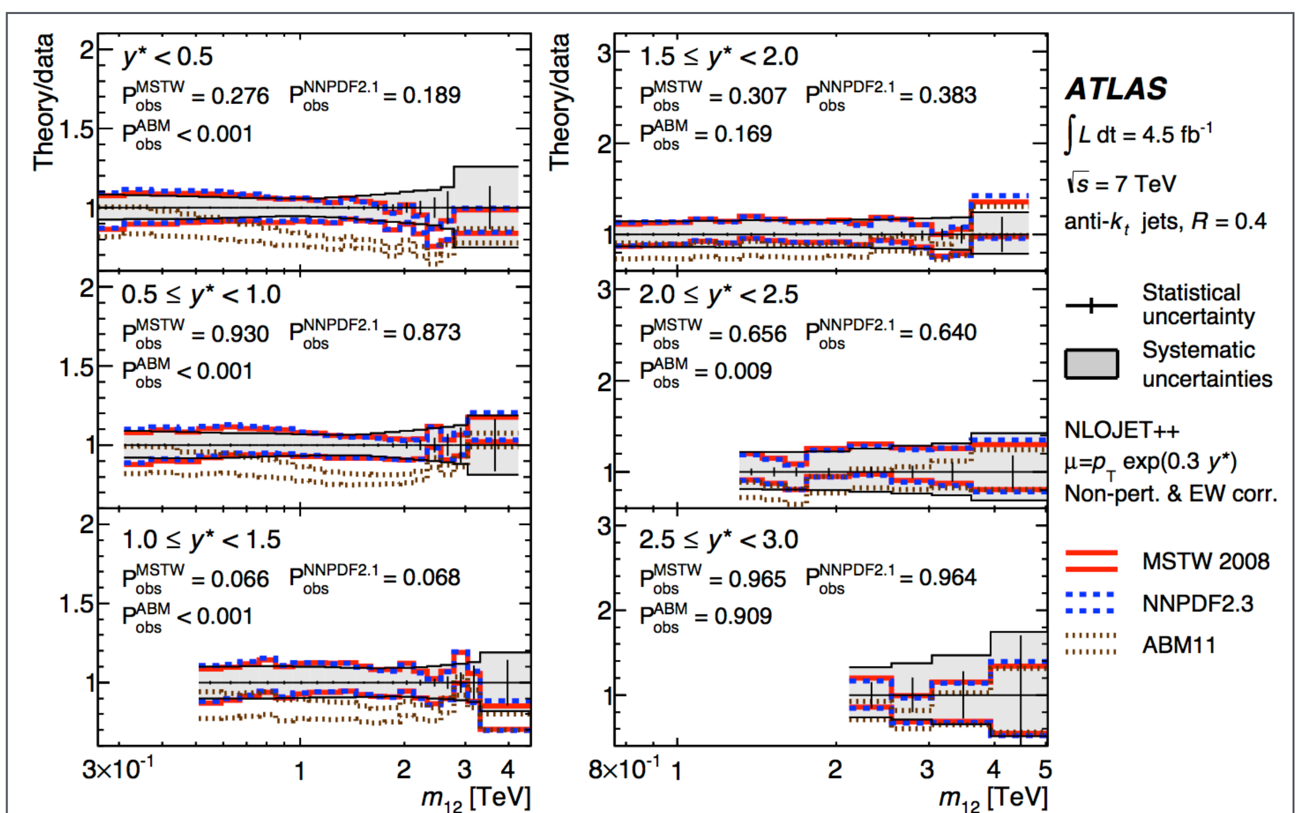
and elastic slope $B = 19.73 \pm 0.14\,(\mathrm{stat}) \pm 0.26\,(\mathrm{syst})\ \mathrm{GeV}^{-2}$

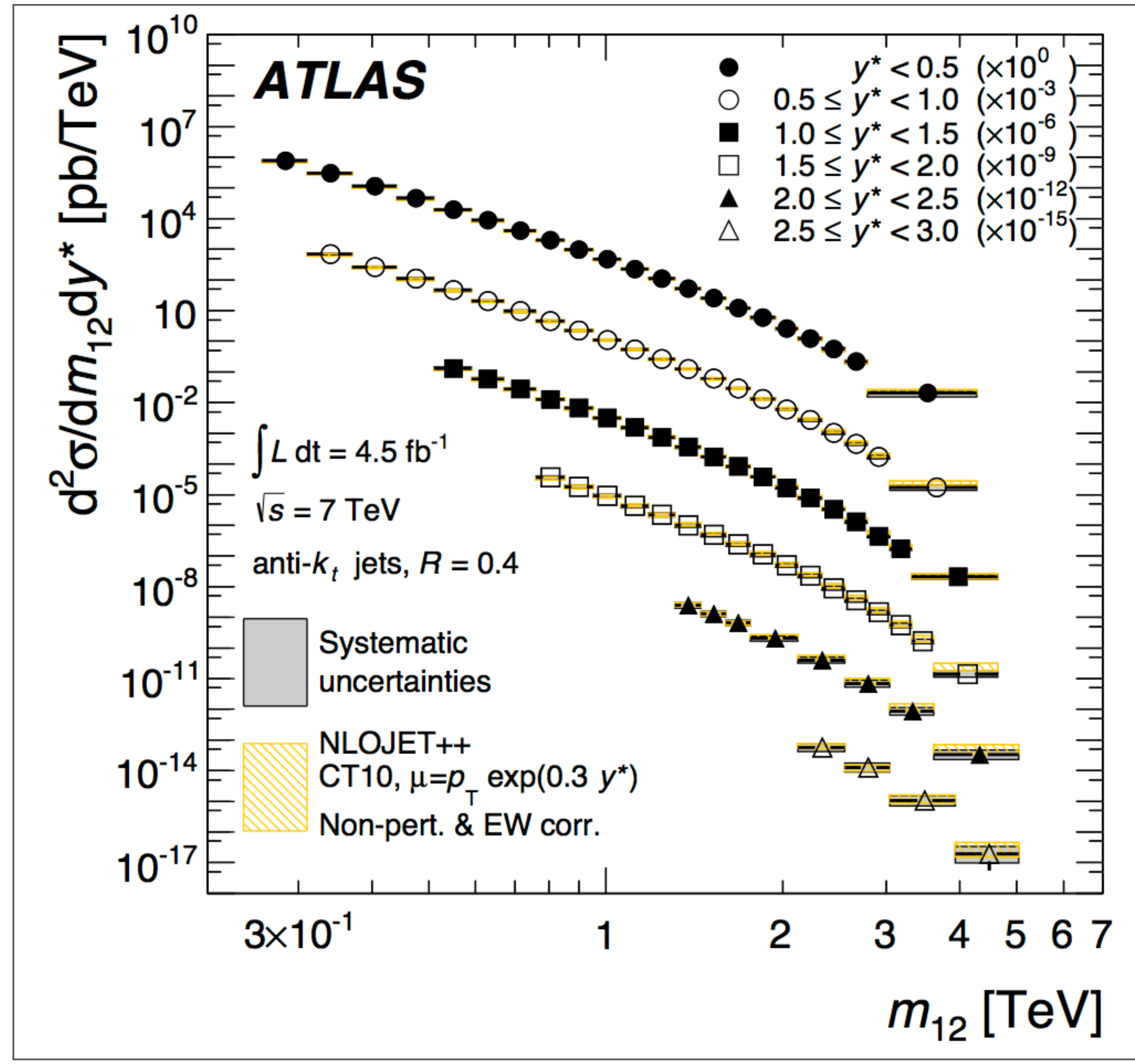
QCD jet physics

di- jet observables

Bins of m12 and rapidity

Sensitive test of NLO and pdf predictions

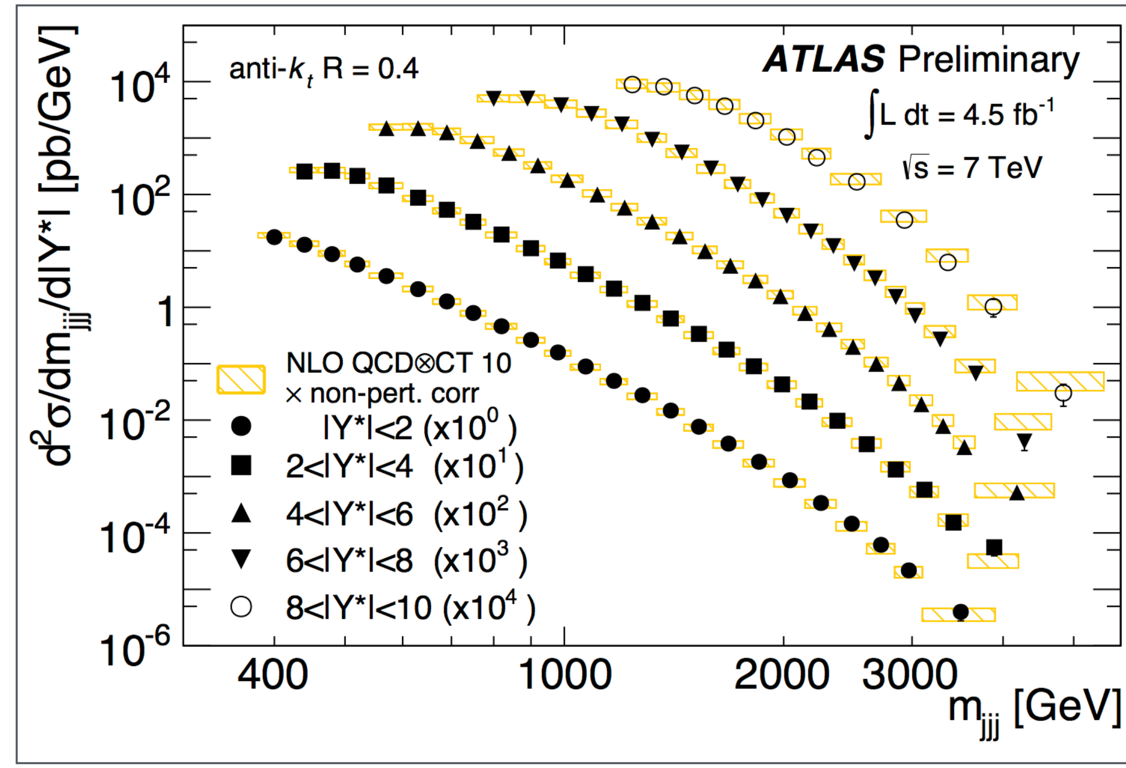


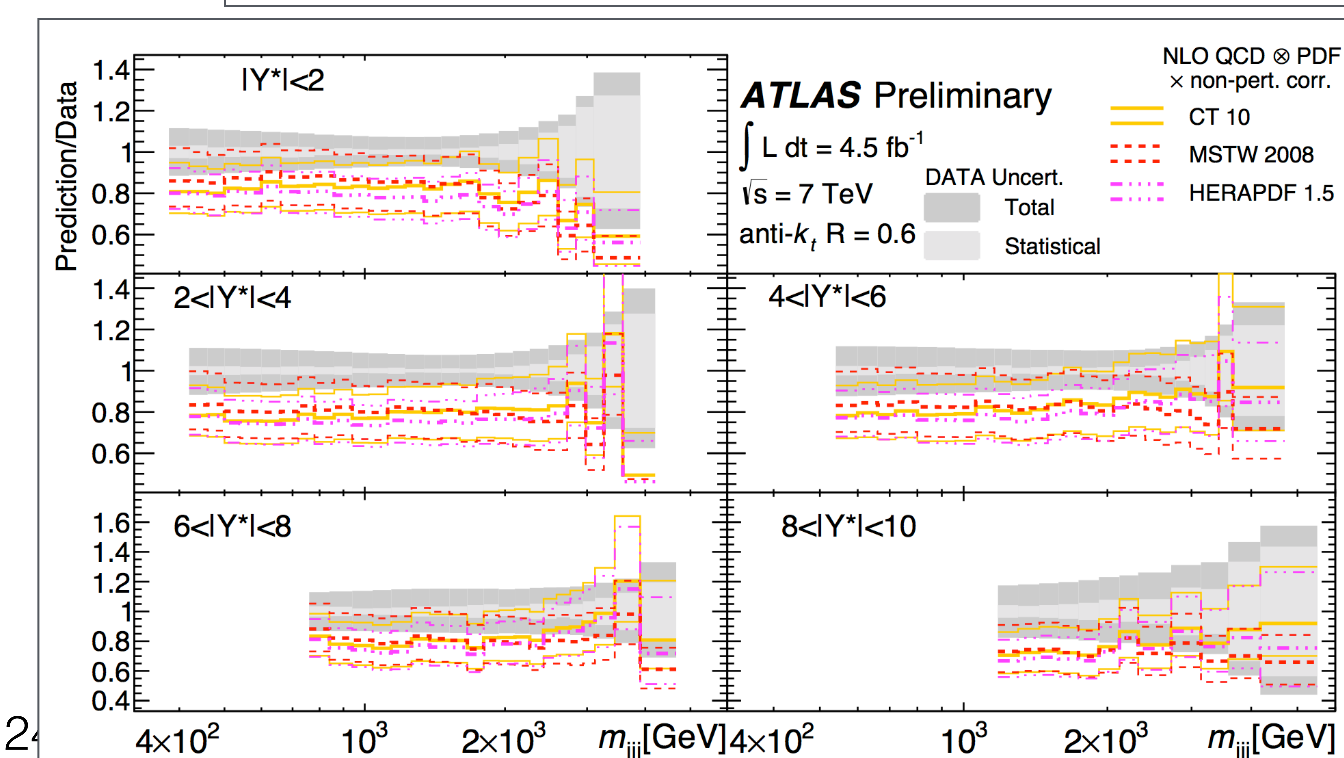


arXiv:1312.3524

QCD jet physics

3 jet cross sections





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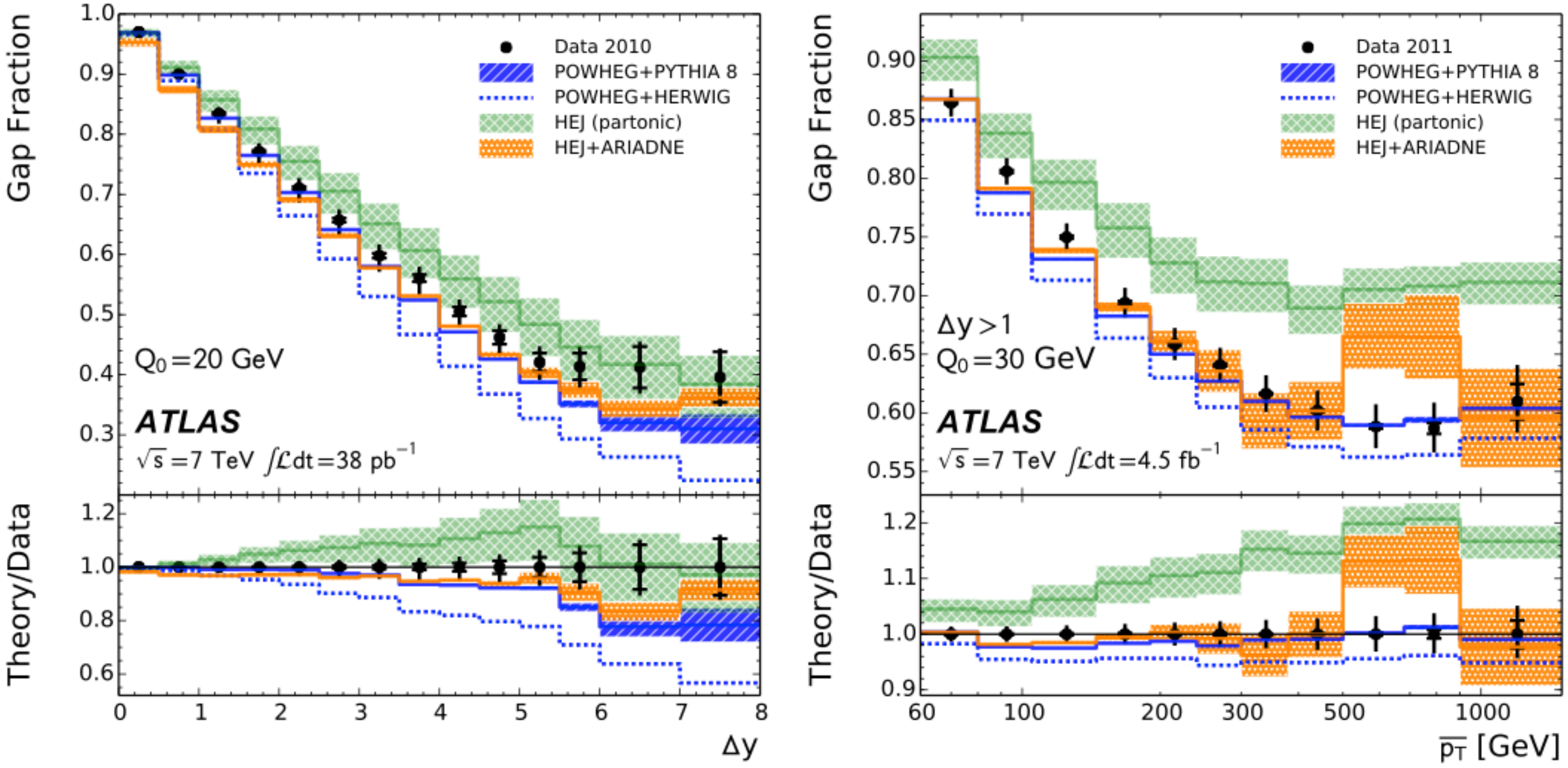
jet gaps



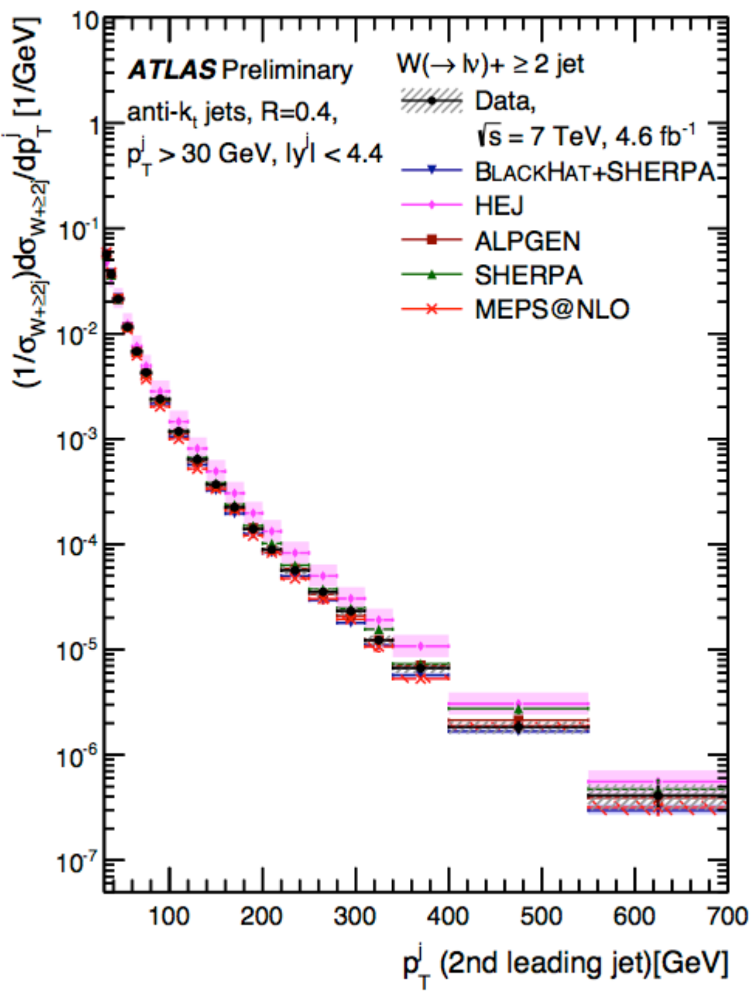
arXiv:1407.5756

W+jets

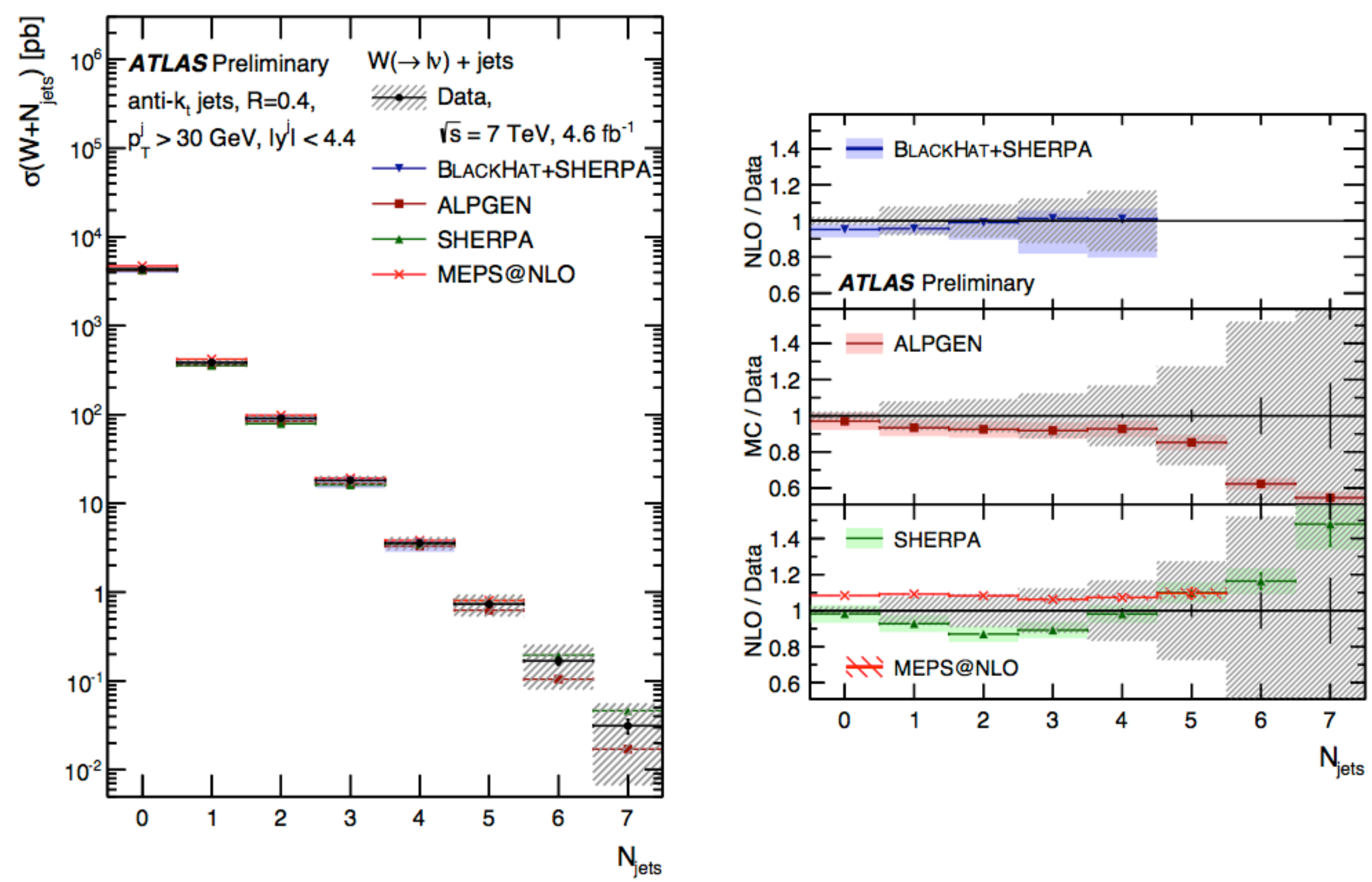
up to 8!

leptonic decay modes

differential in many quantities, e.g.



arXiv:1408.6510



Electroweak physics

multibosons

Standard Model processes

TCG for Z/γ - WW

QGC for $WWWW$

Non-standard (anomalous) couplings

Z/γ - Z/γ - Z/γ

Results on:

$W\gamma$, $Z\gamma$

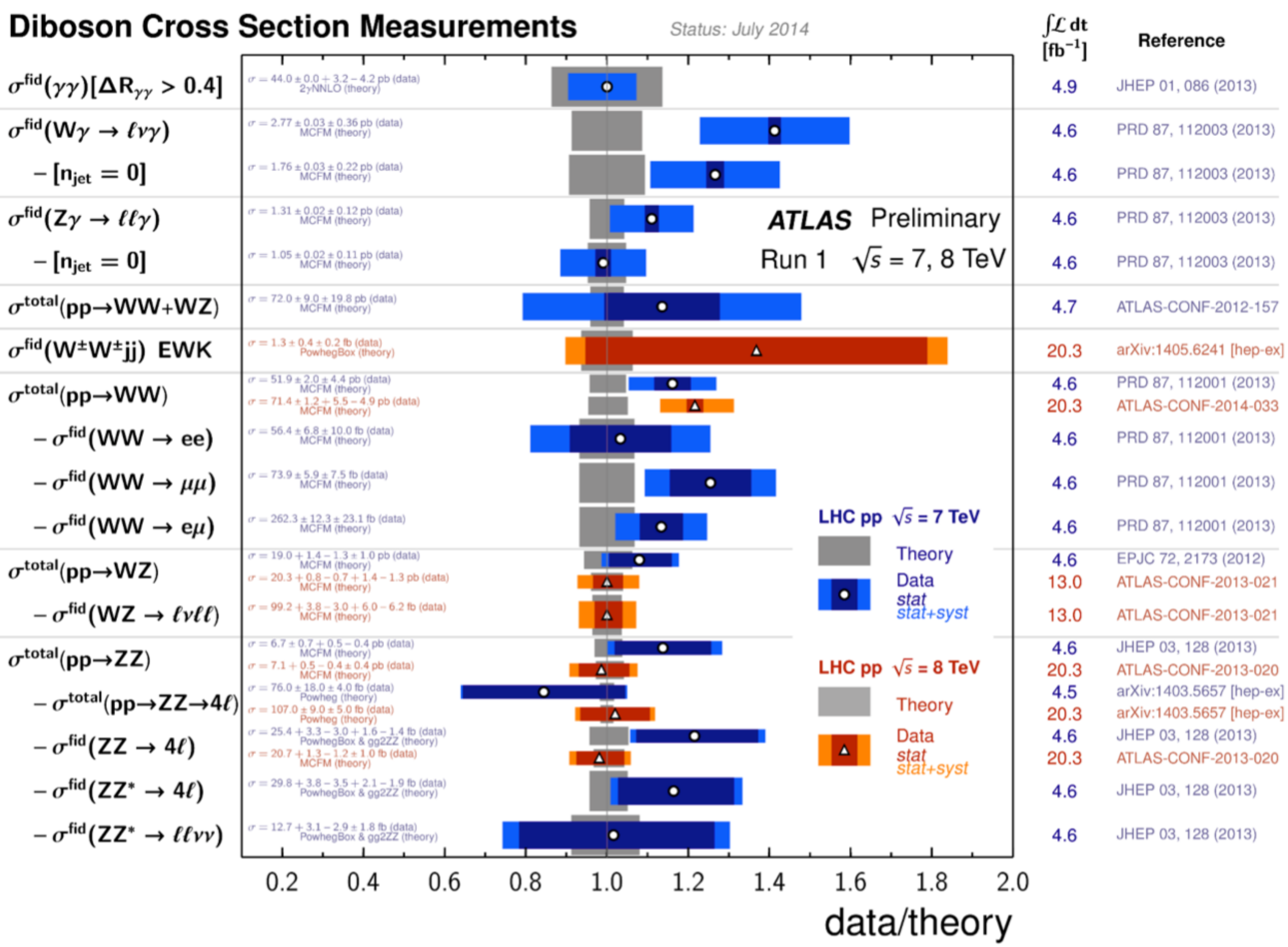
ZZ

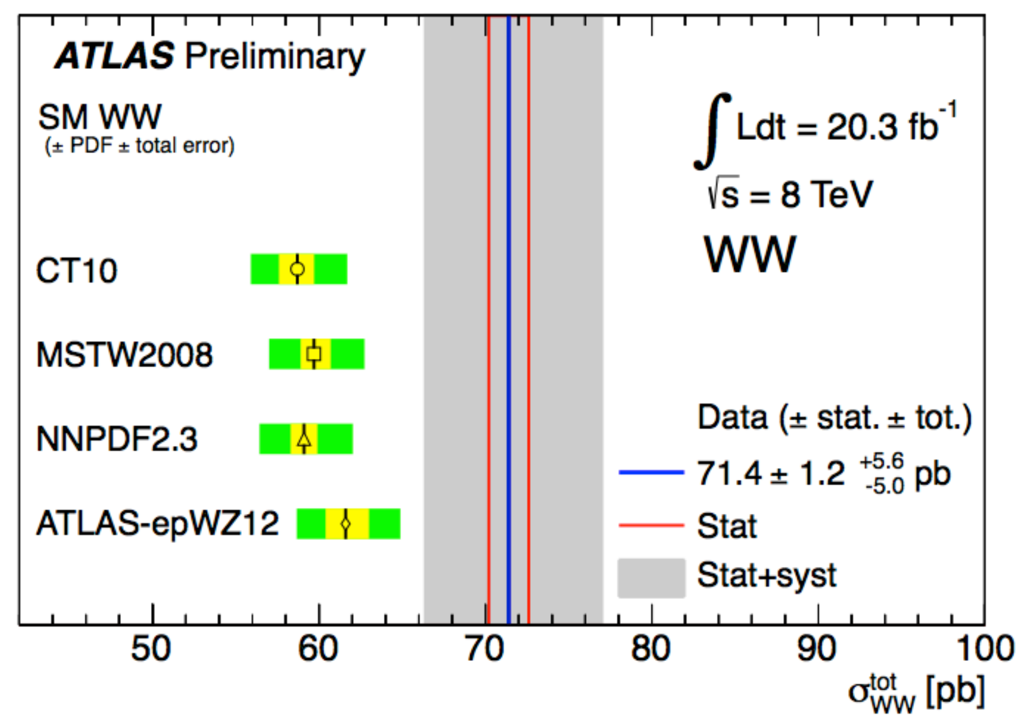
$W+W-$

$W\pm Z$, fully leptonic and semileptonic

W+W-

continues to be interesting





ATLAS-CONF-2014-033

But Wait...

THERE'S MORE!

Z production

heavy flavor: $W + c$ (arXiv:1402.6263) and $Z \rightarrow b\bar{b}$ (arXiv:1404.7042)

underlying event

ZpT

jet structure

boosted W/Zs

Multi-bosons

aQGCs

electroweak Zjj production

WWjj scattering

Top quark Physics

Notable results

from Run 1 we anticipated:

precision cross sections, precision mass of 1-3.5 GeV, rediscovery of single top, single top W_t channel

from Run 1, we achieved:

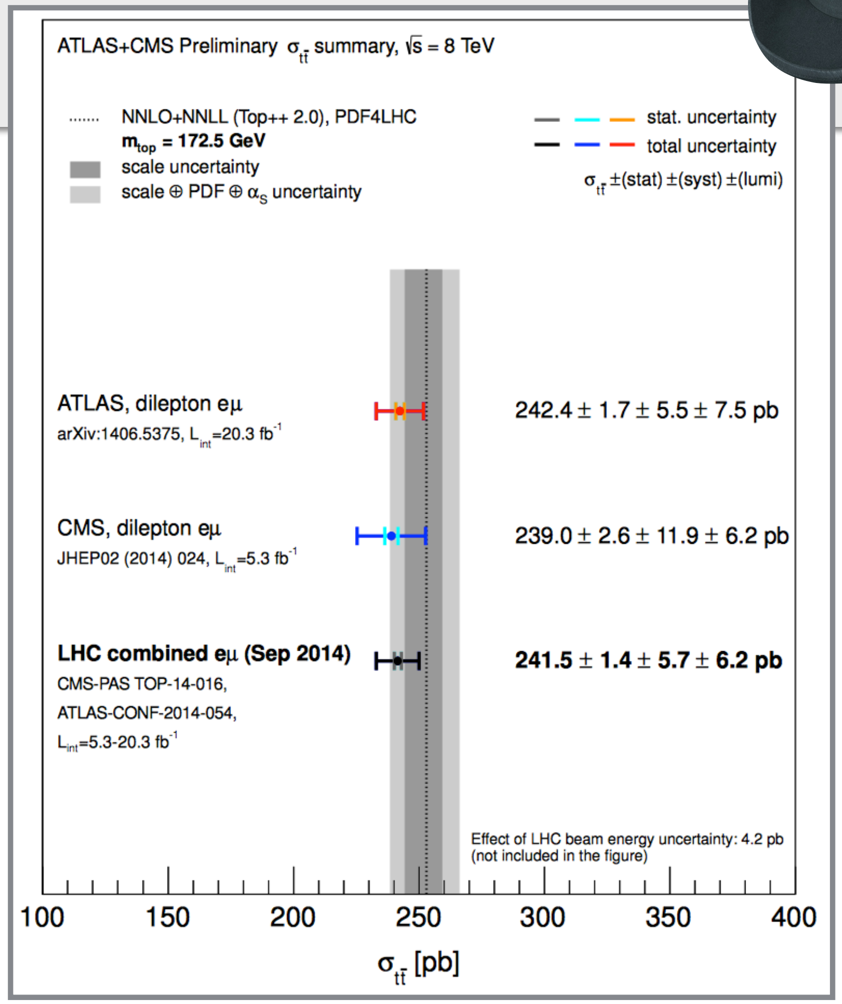
precise cross sections, mass, distributions ttbar and single top

in Run 2, we expect:

20x statistics!

Top quark cross section

win-win

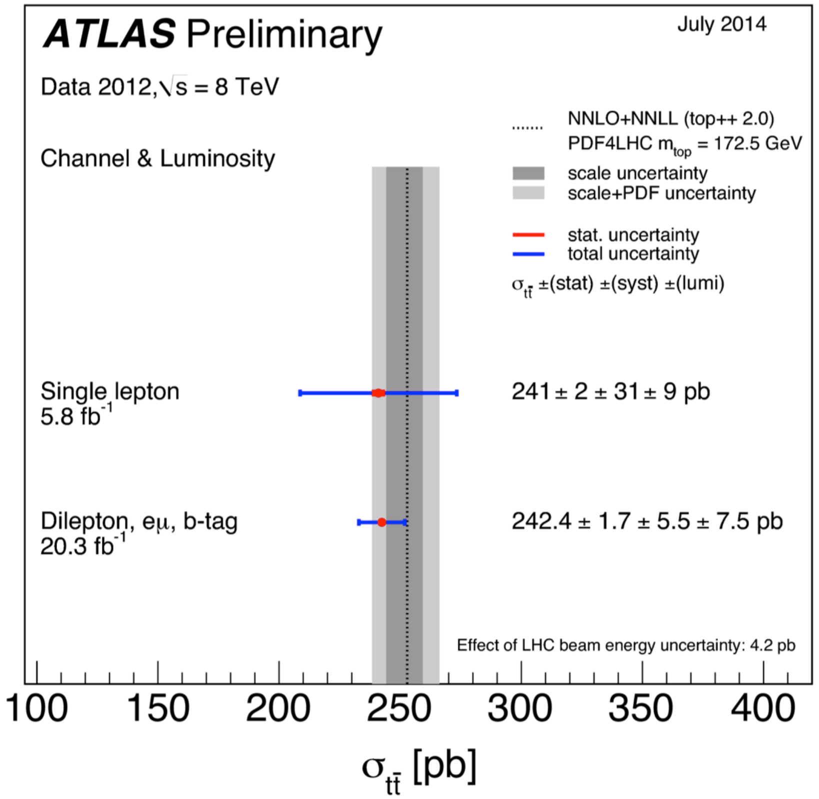


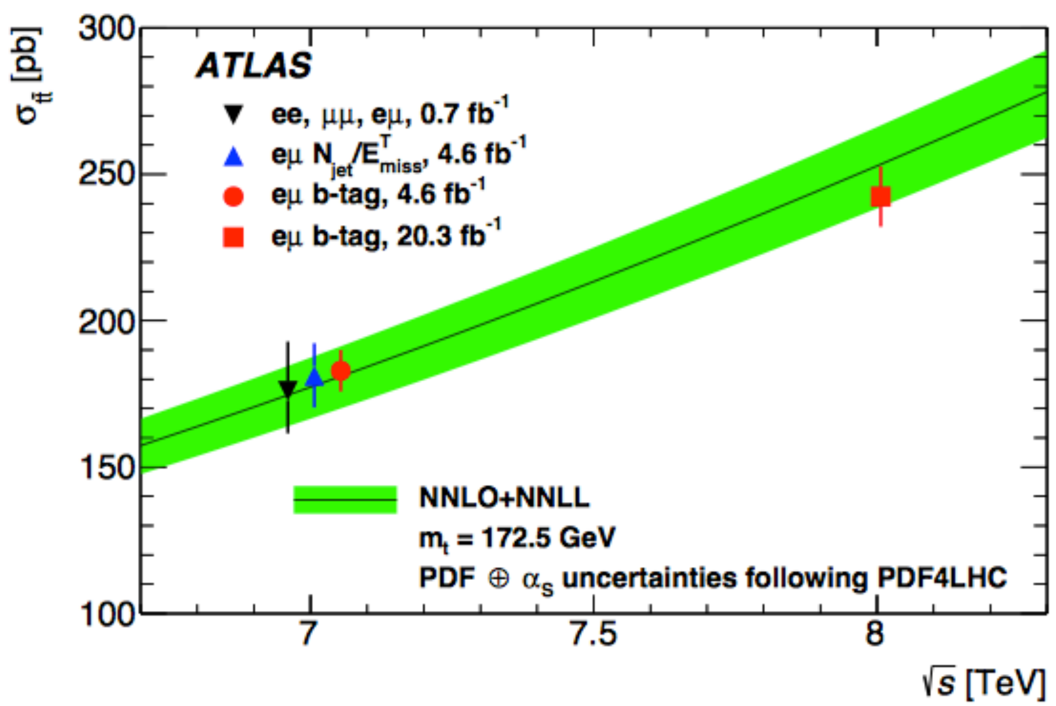
Combined ATLAS+CMS

$$\sigma_{t\bar{t}} = 242.4 \pm 1.7 \pm 5.5 \pm 7.5 \pm 4.2\,\text{pb}\ \ \text{(stat/syst/lumi/beam energy)}$$

$$\sigma_{t\bar{t}} = 241.4 \pm 1.4 \pm 5.7 \pm 6.2\,\text{pb}\ @m_t = 172.5\,\text{GeV}$$

(stat/syst/lumi)





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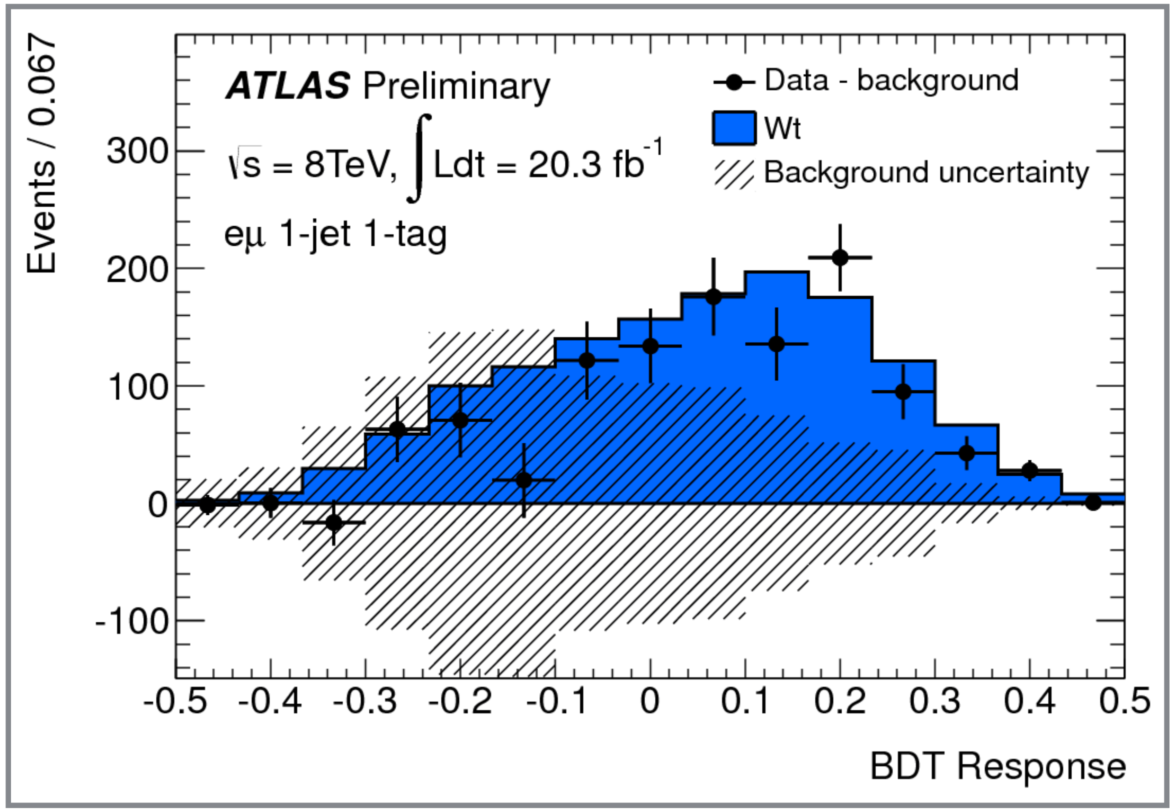
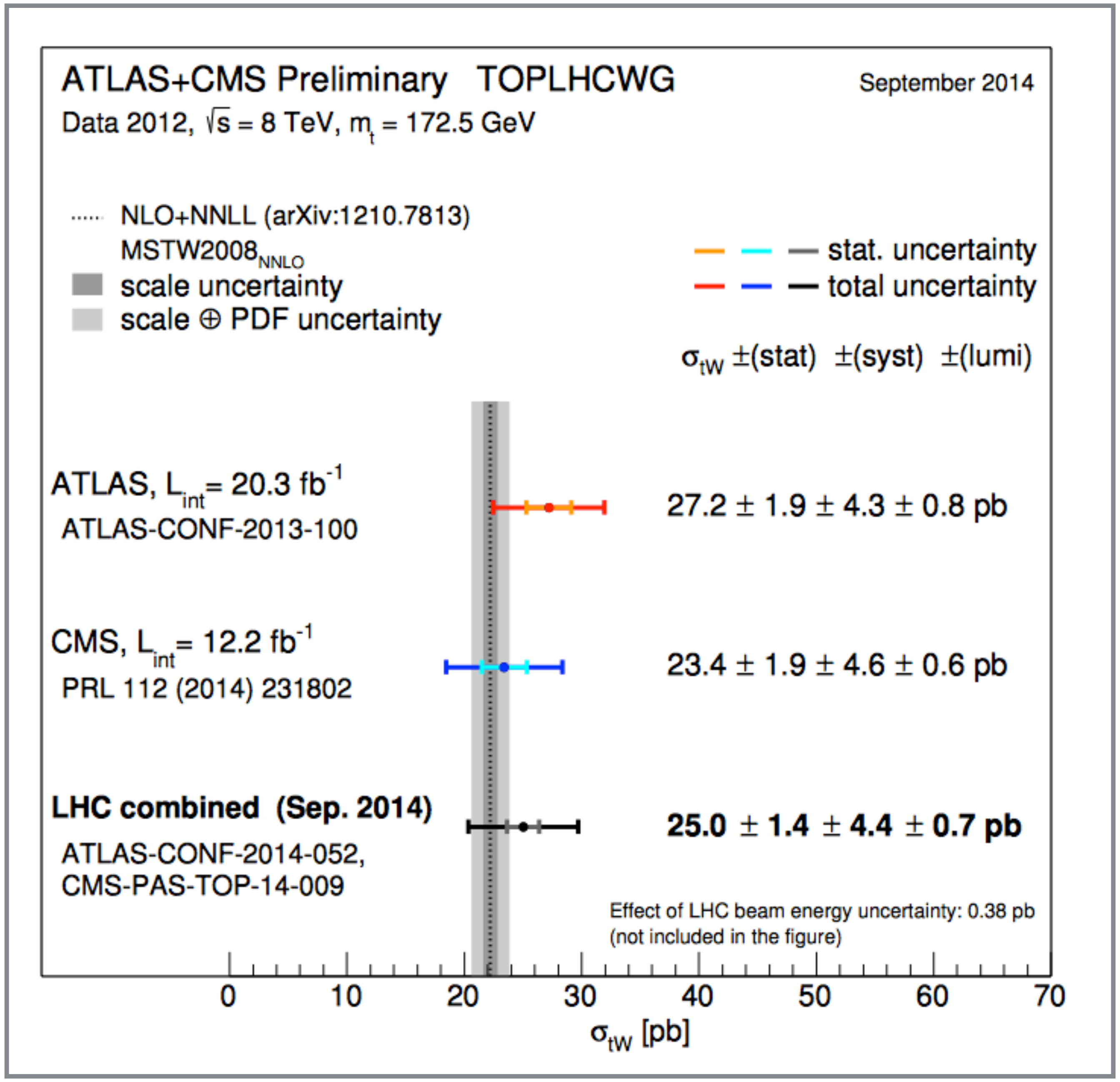
Single top, Wt

win-win

Evidence at 4.2 sigma

then ATLAS + CMS





ATLAS-CONF-2013-052

ATLAS-CONF-2013-100

Top quark mass

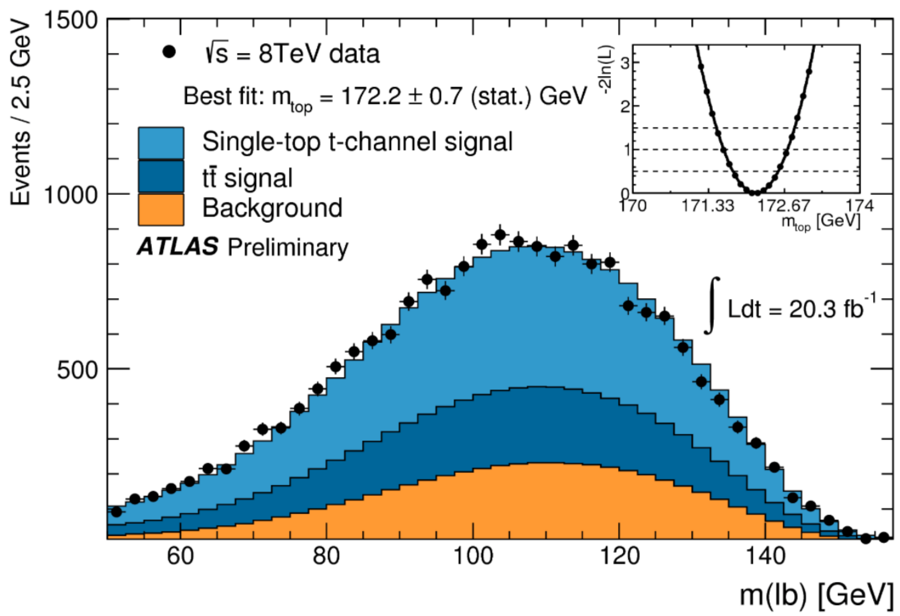
win-win-win

2008 estimates for 1/fb: ±1-3.5 GeV three channels

better than advertised

Single top

t channel template



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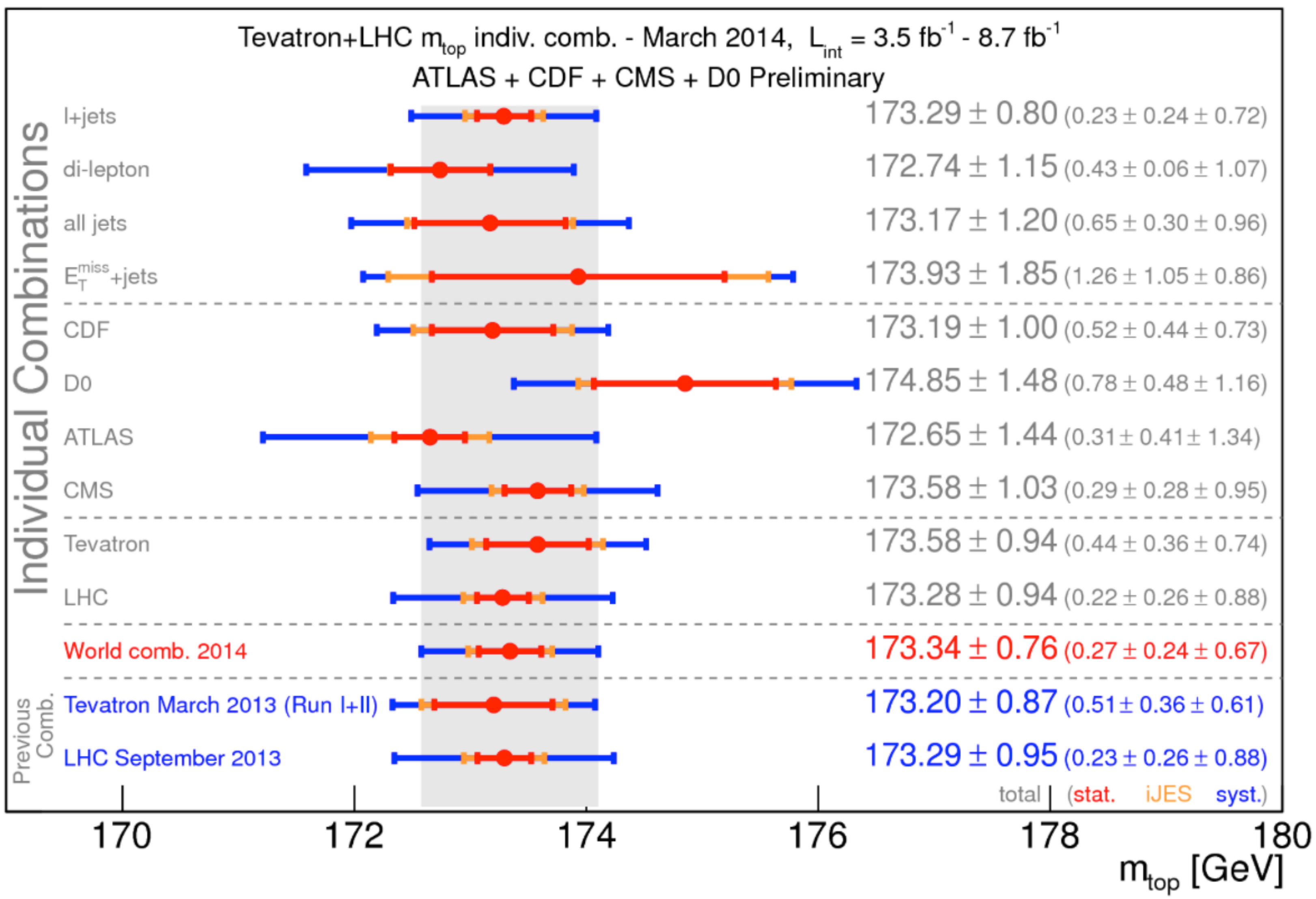


ATLAS-CONF-2014-008

top cross sections

all hadronic final states, tau final states, ttbar/Z/WW

differential distributions: parton level, boosted ttbar, associated production with jets and heavy flavor, W/Z, high pt boosted

single top

CP violation

top mass

pole mass from cross section tail, t -T mass difference

top properties

charge, W polarization, FCNC searches, charge asymmetry, t polarization

Exotic Physics

Notable results

from Run 1 we anticipated:

supersymmetry discovery? no Higgs? Higgs? BSM Higgses (SP?), extension of Tevatron IVB' searches by x2 or more,

from Run 1 we achieved:

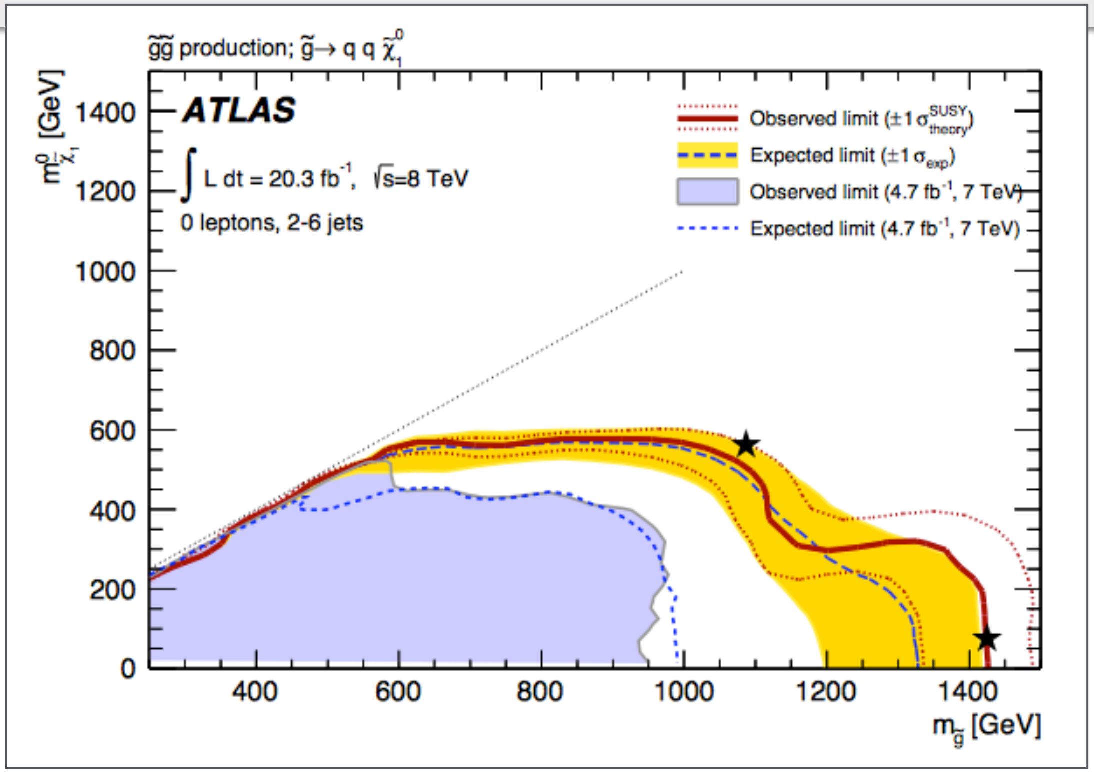
supersymmetry limits! one Higgs, BSM Higgs searches, IVB' searches

in Run 2, we expect:

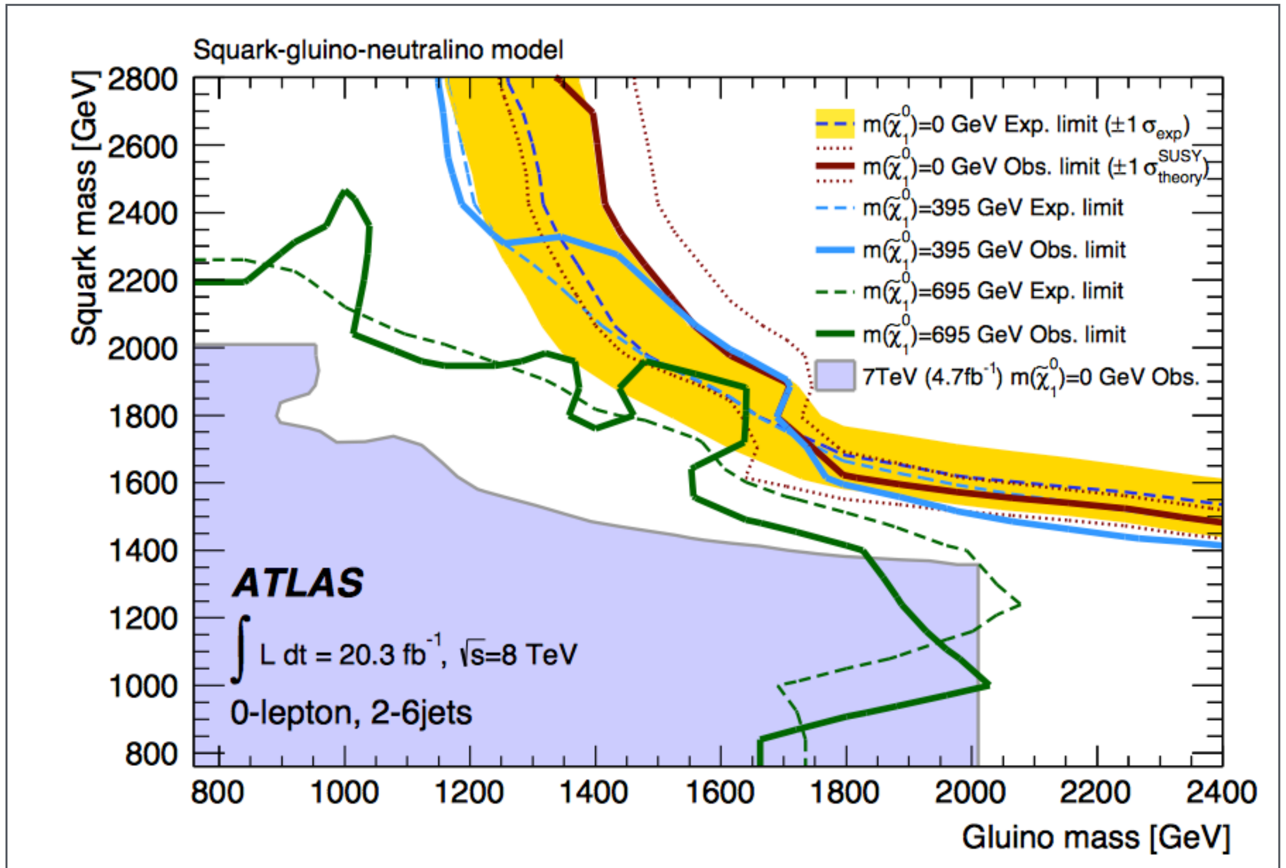
supersymmetry discovery? BSM Higgs hints, additional IVB' searches

Supersymmetric Physics

squarks and gluinos

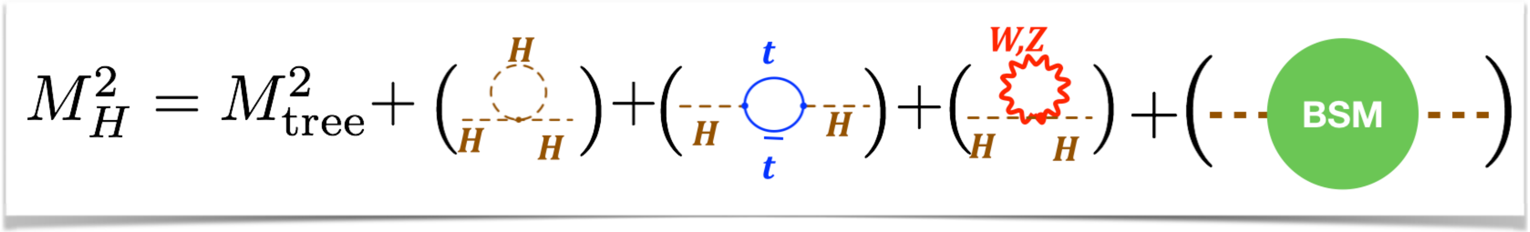


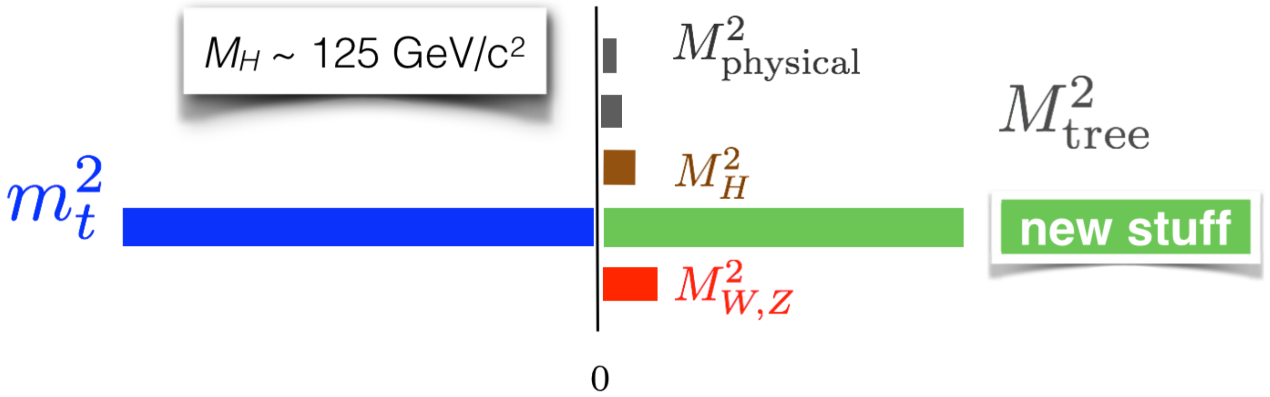
arXiv:1405.7875



stop

stealthy stop?

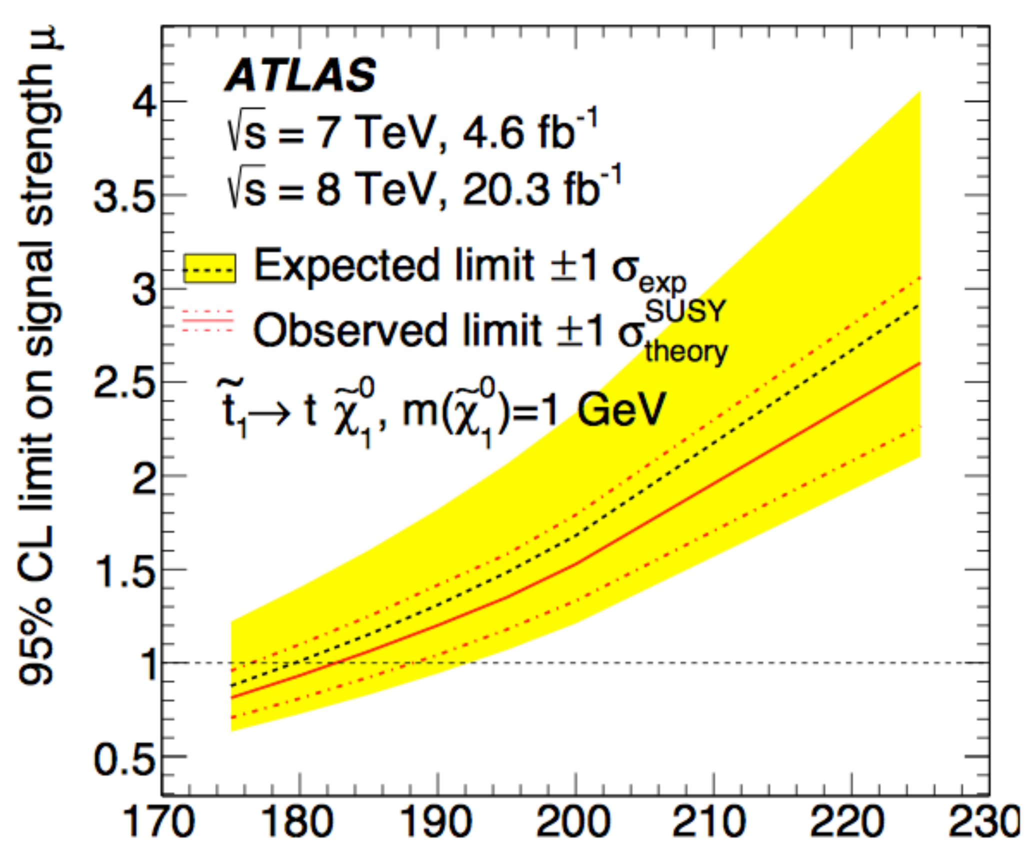




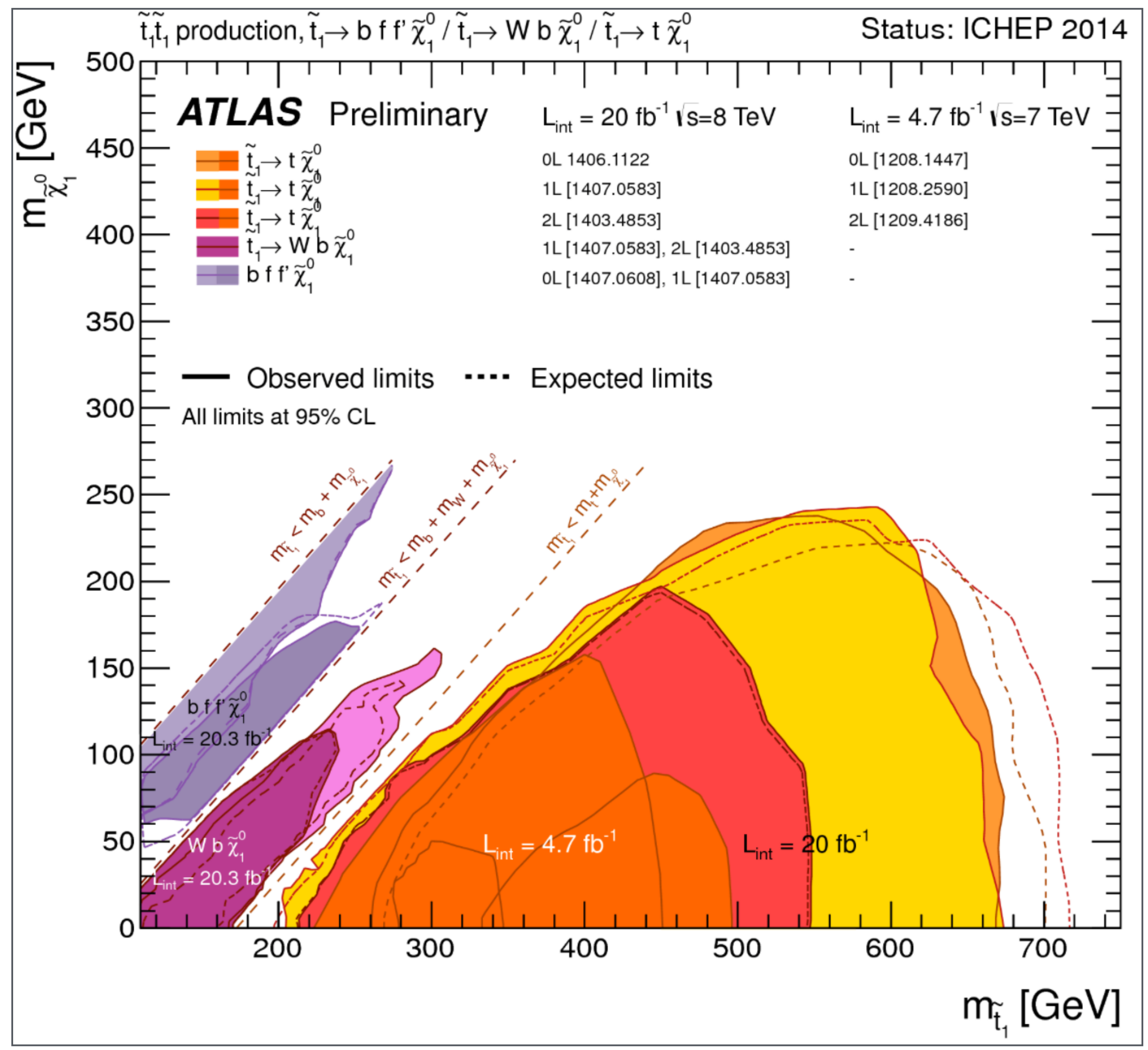
stop

stealthy stop?

arxiv:1208.1447 (0 lepton 7 TeV)
arxiv:1208.2590 (1 lepton 7 TeV)
arxiv:1209.4186 (2 leptons 7 TeV)
arxiv:1407.0583 (1 lepton 8 TeV, 20/fb)
arxiv:1406.1122 (0 lepton + 5/6 jets 8 TeV, 20/fb)
arxiv:1403.4853 (2 lepton + jets+ MET 8 TeV, 20/fb)
[7] arxiv:1407.0608 (0 lepton + jets (c-jets) + MET 8 TeV, 20/fb)

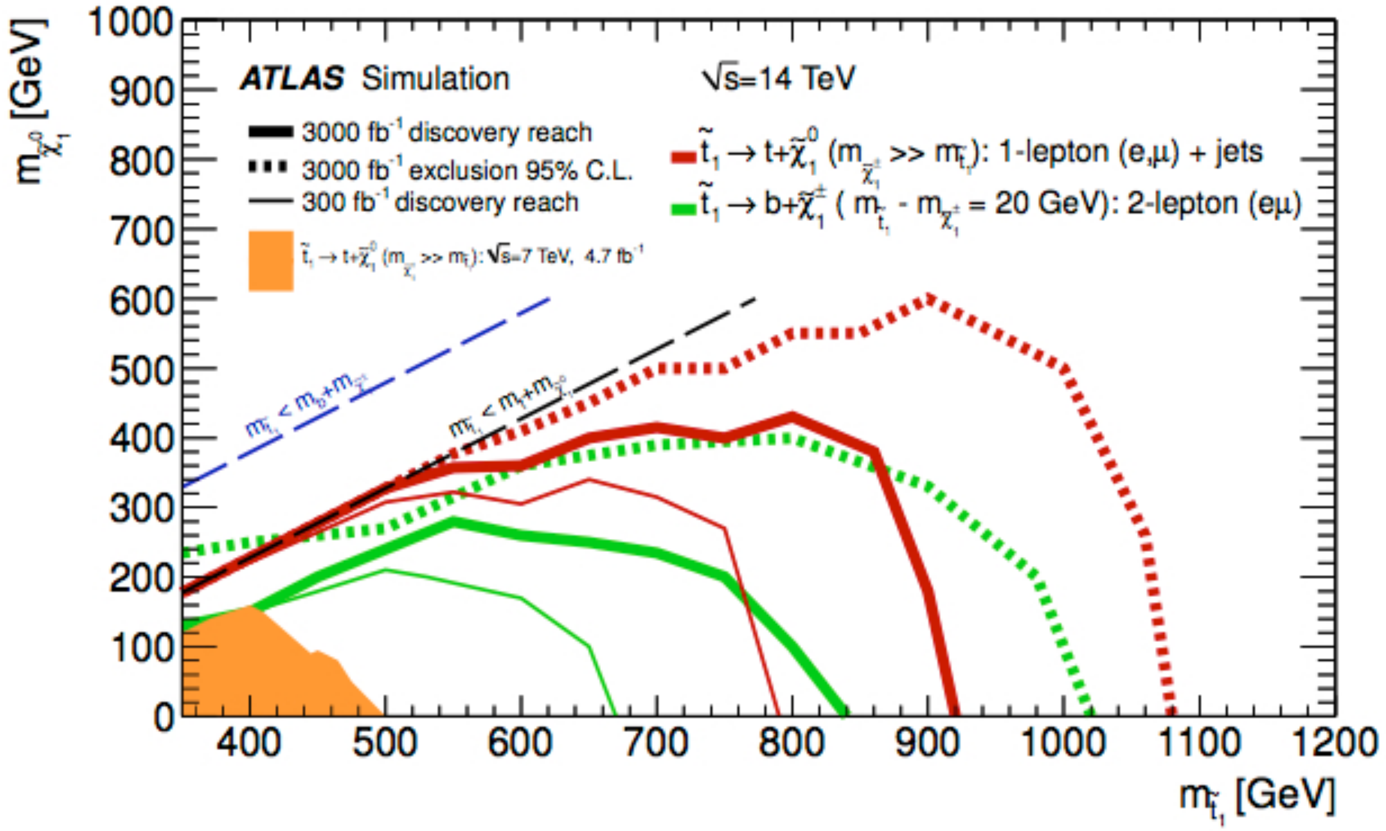


arXiv: 1406.5375



Run 2

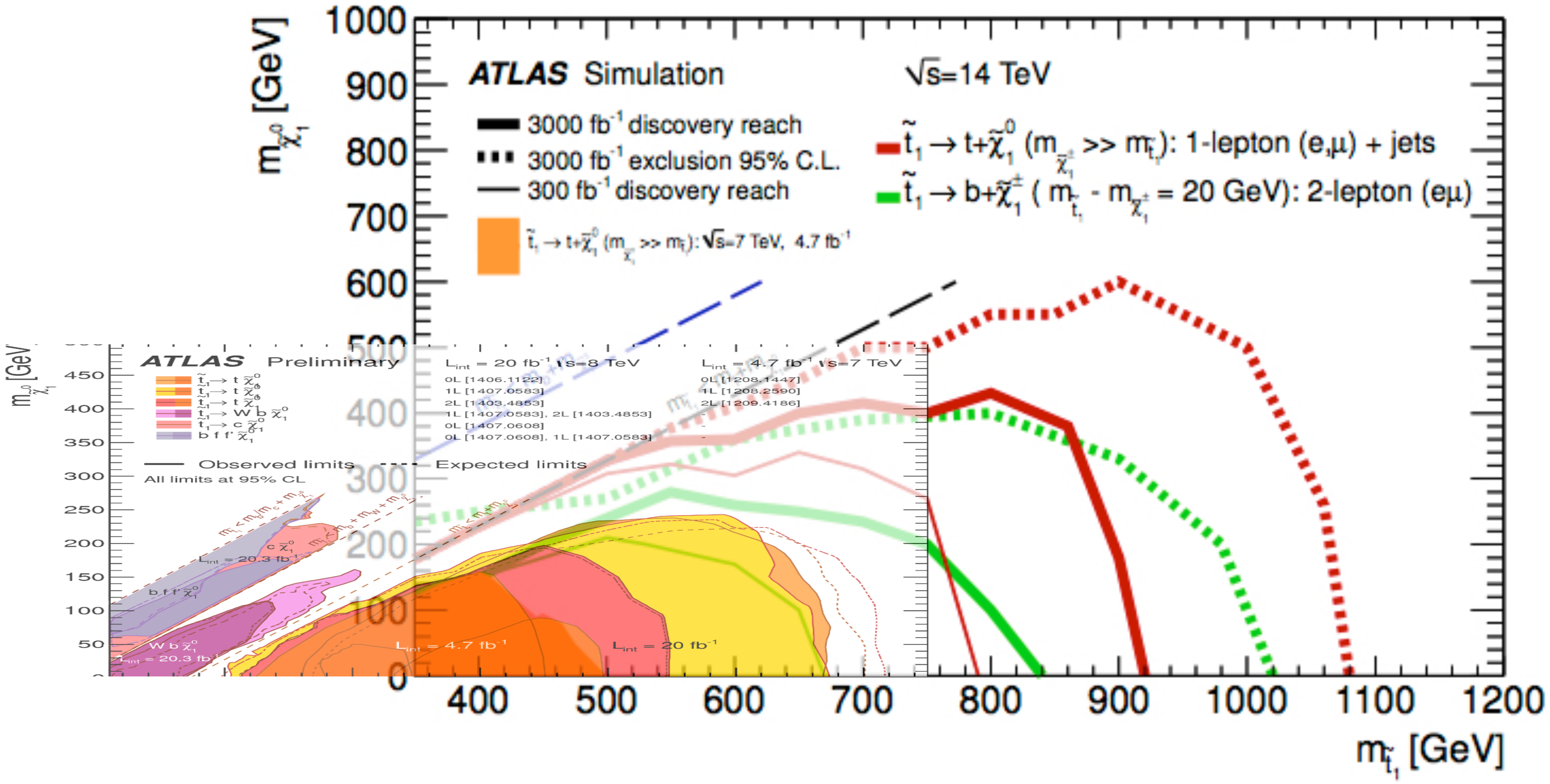
cms Energy directly extends searches



ATL-PHYS-PUB-2012-001

Run 2

cms Energy directly extends searches



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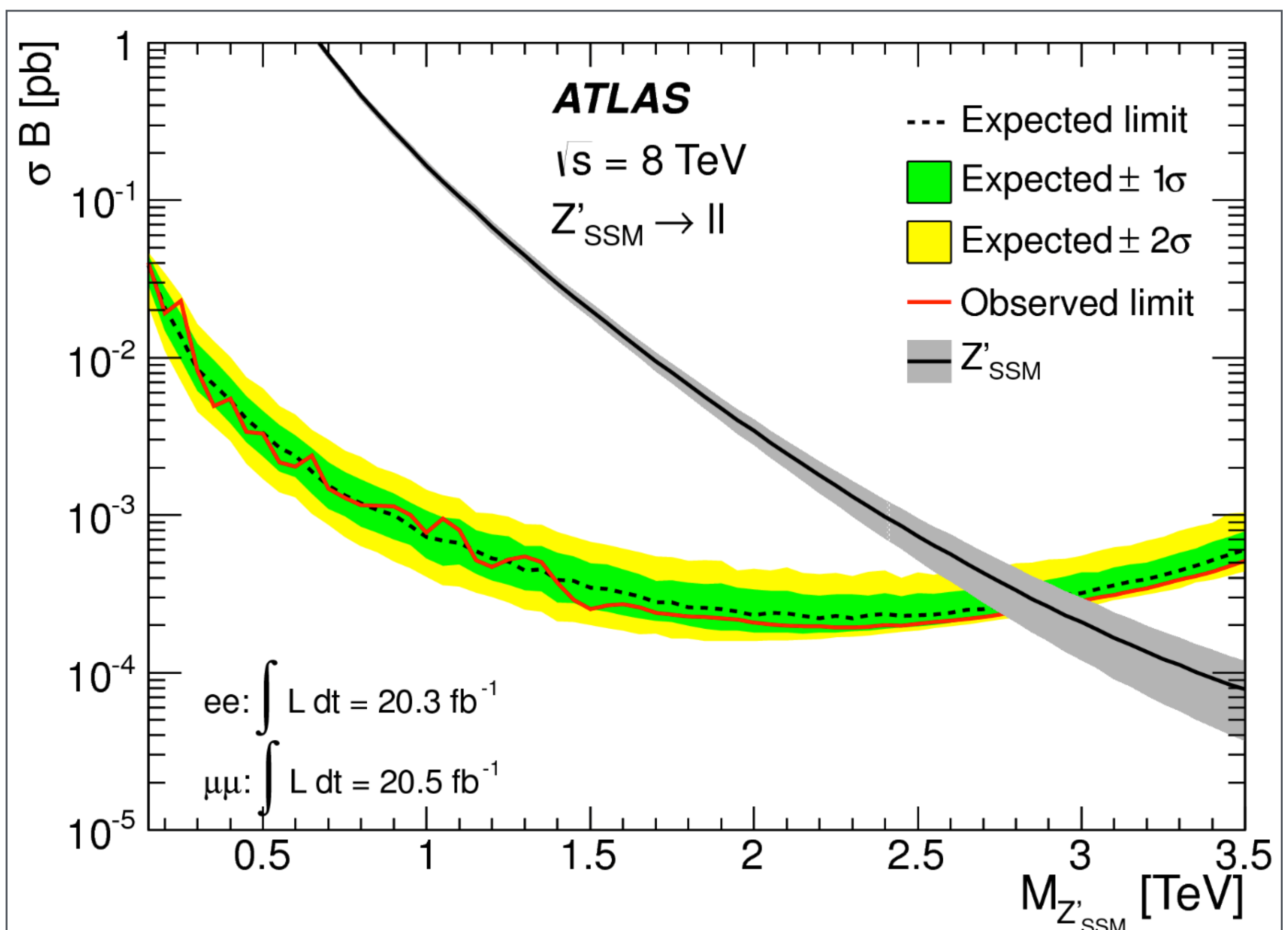
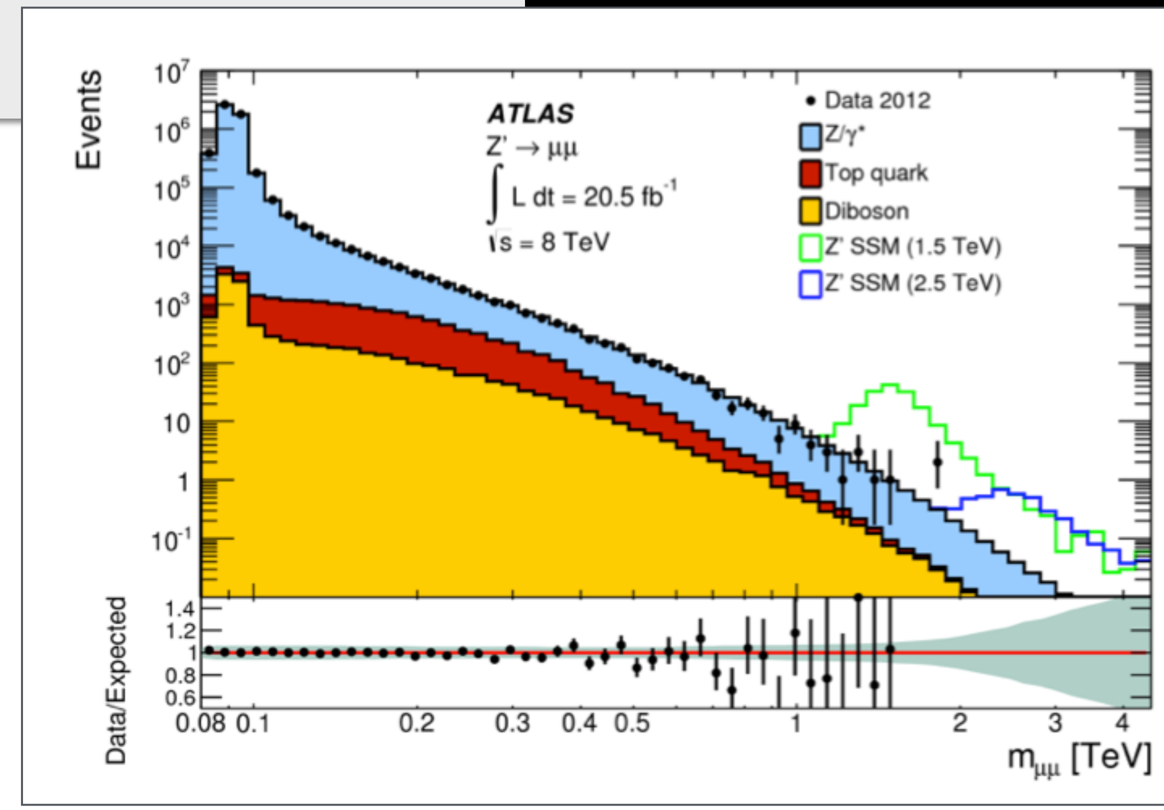
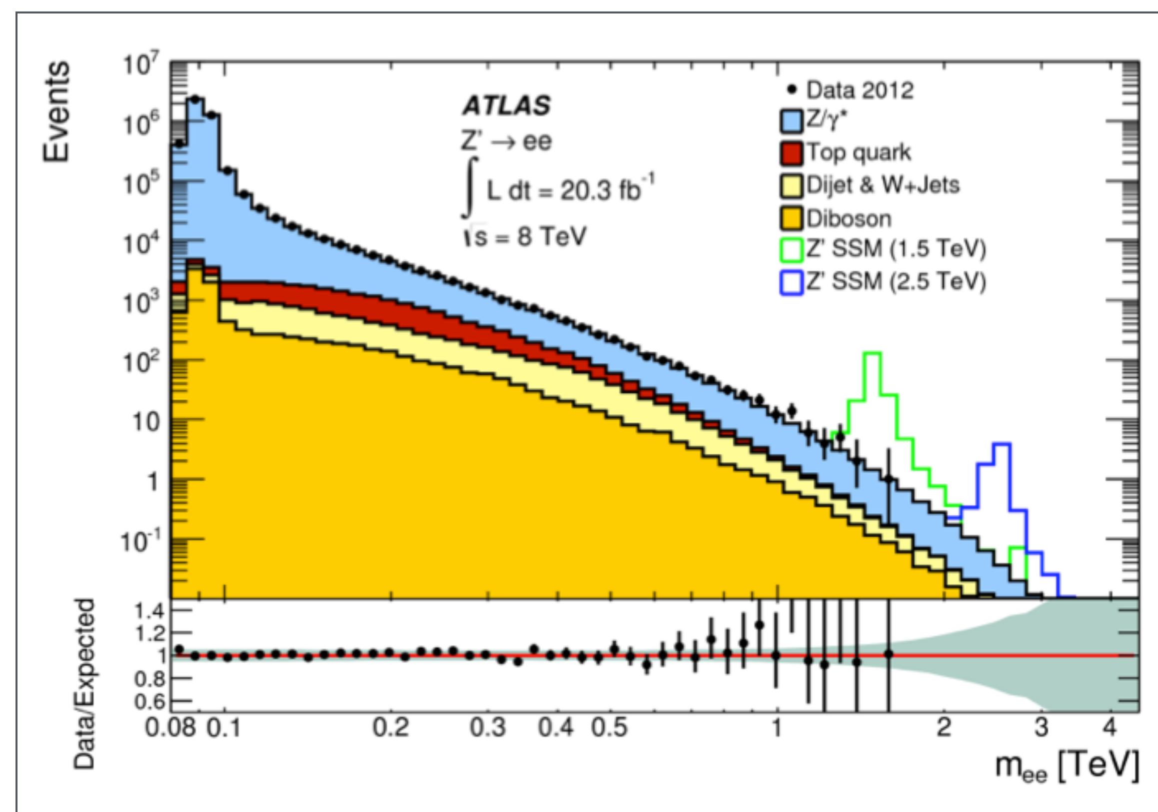
Z prime

electrons and muons

a standard way to extend the SM







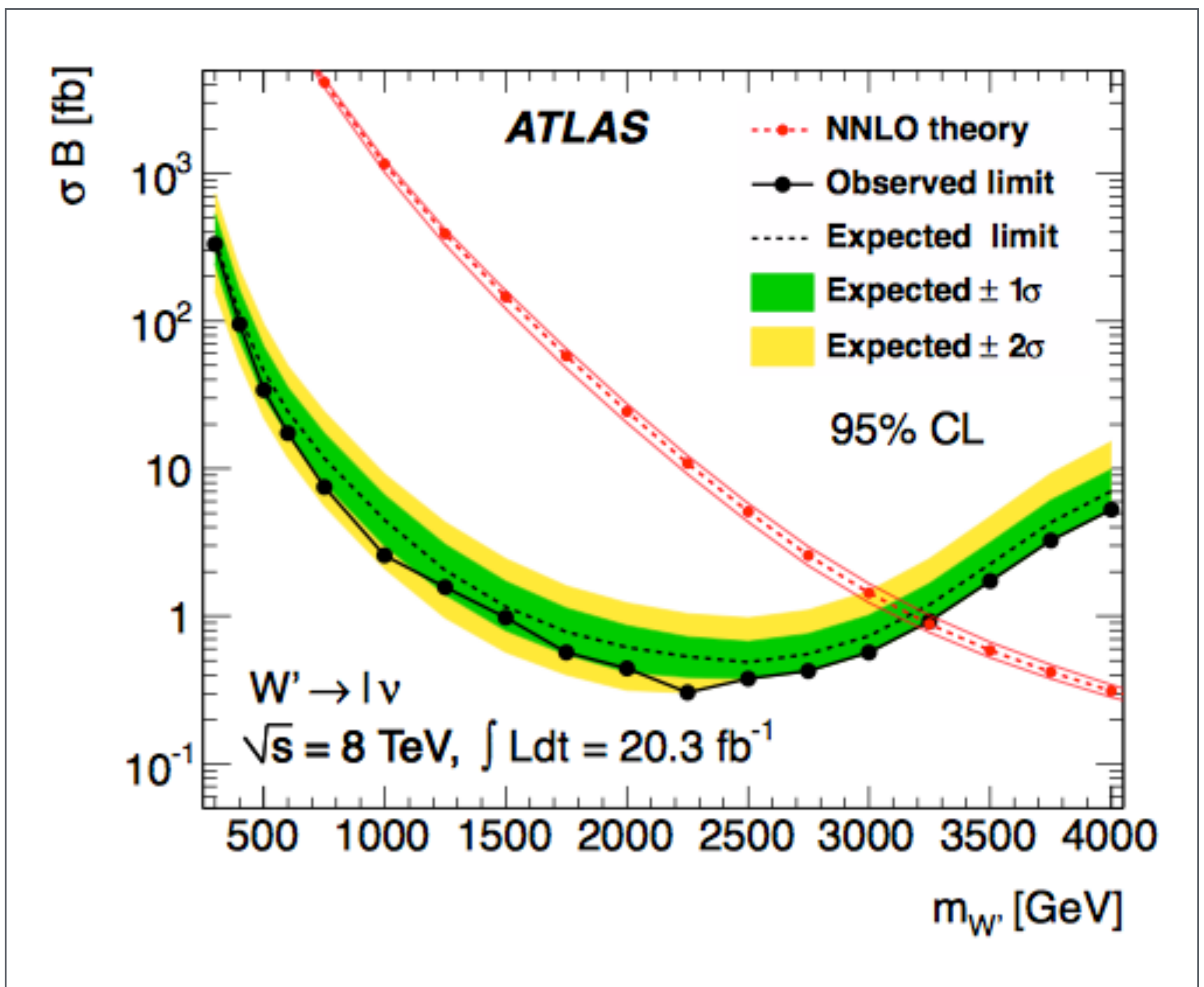
Phys. Rev. D 90, 052005 – Published 19 September 2014
G. Aad et al. (ATLAS Collaboration)

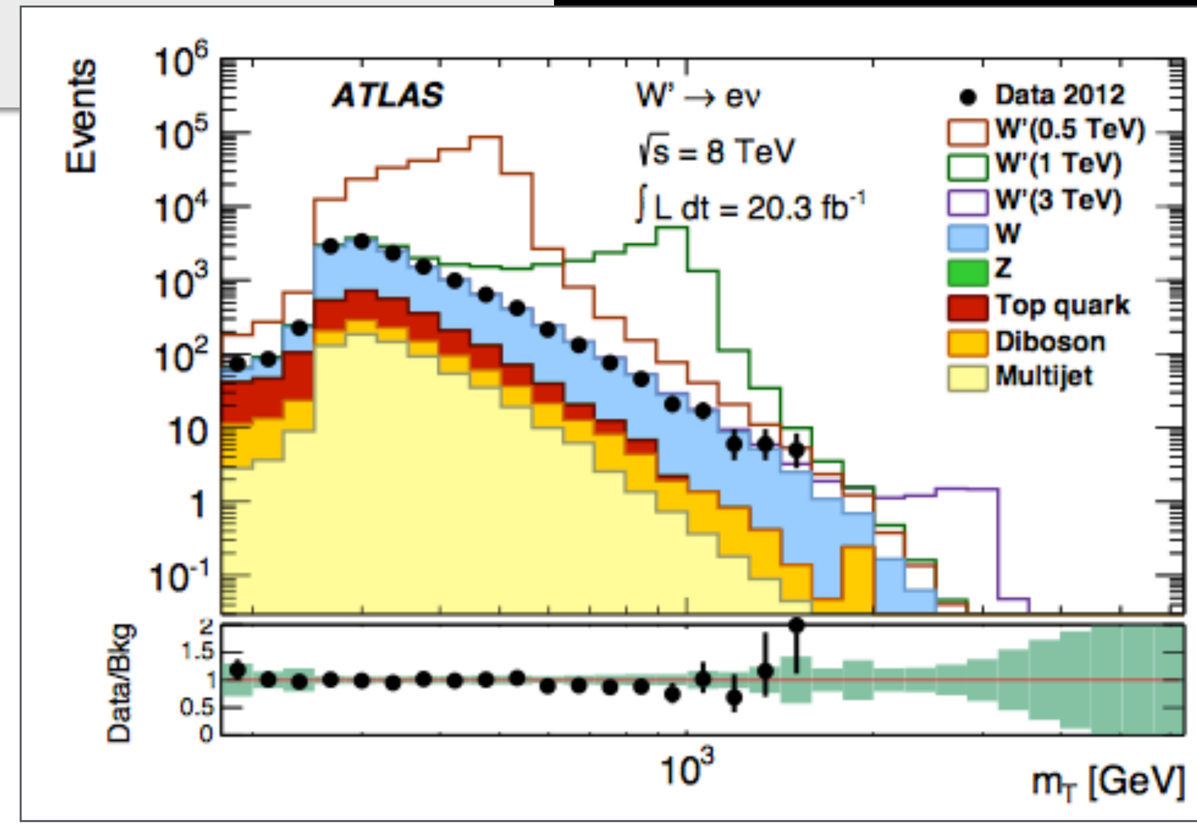
W prime

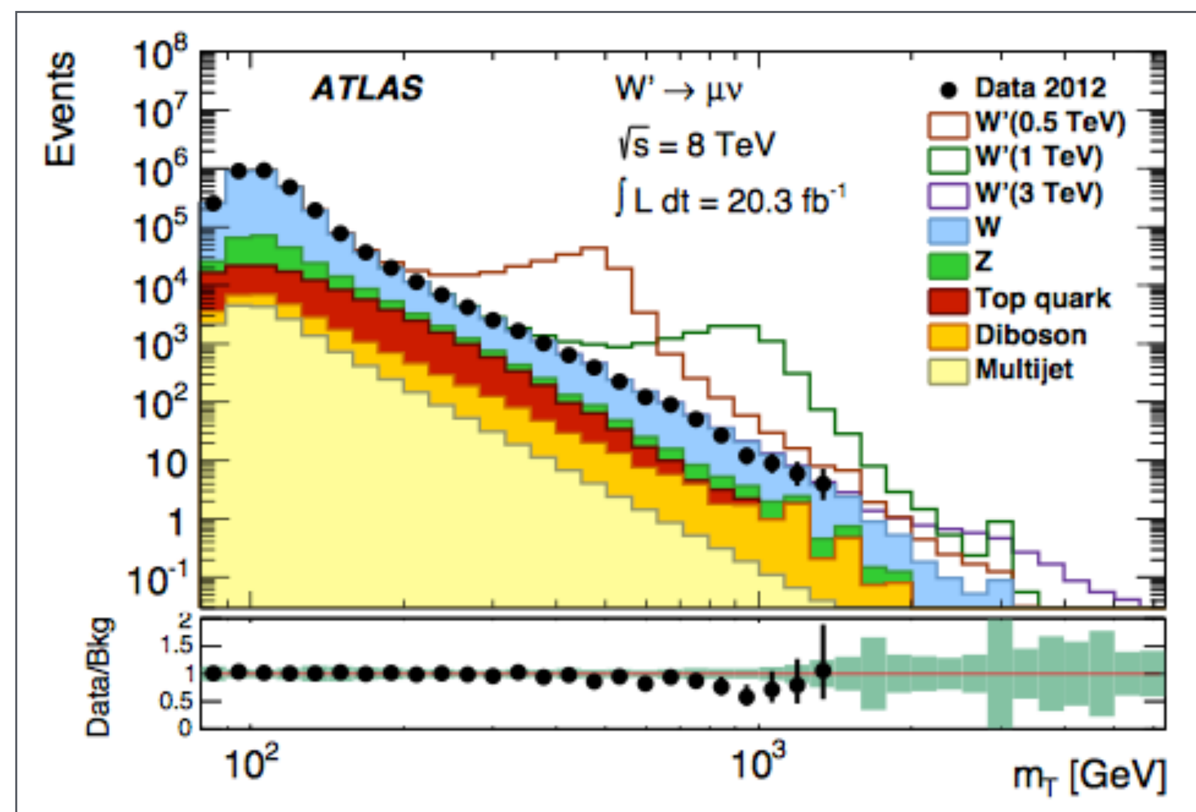
electrons and muons

a partner

arXiv:1407.7494v1

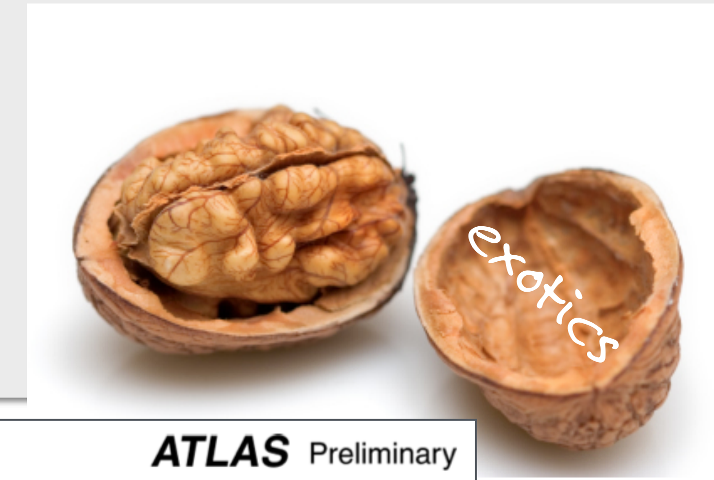


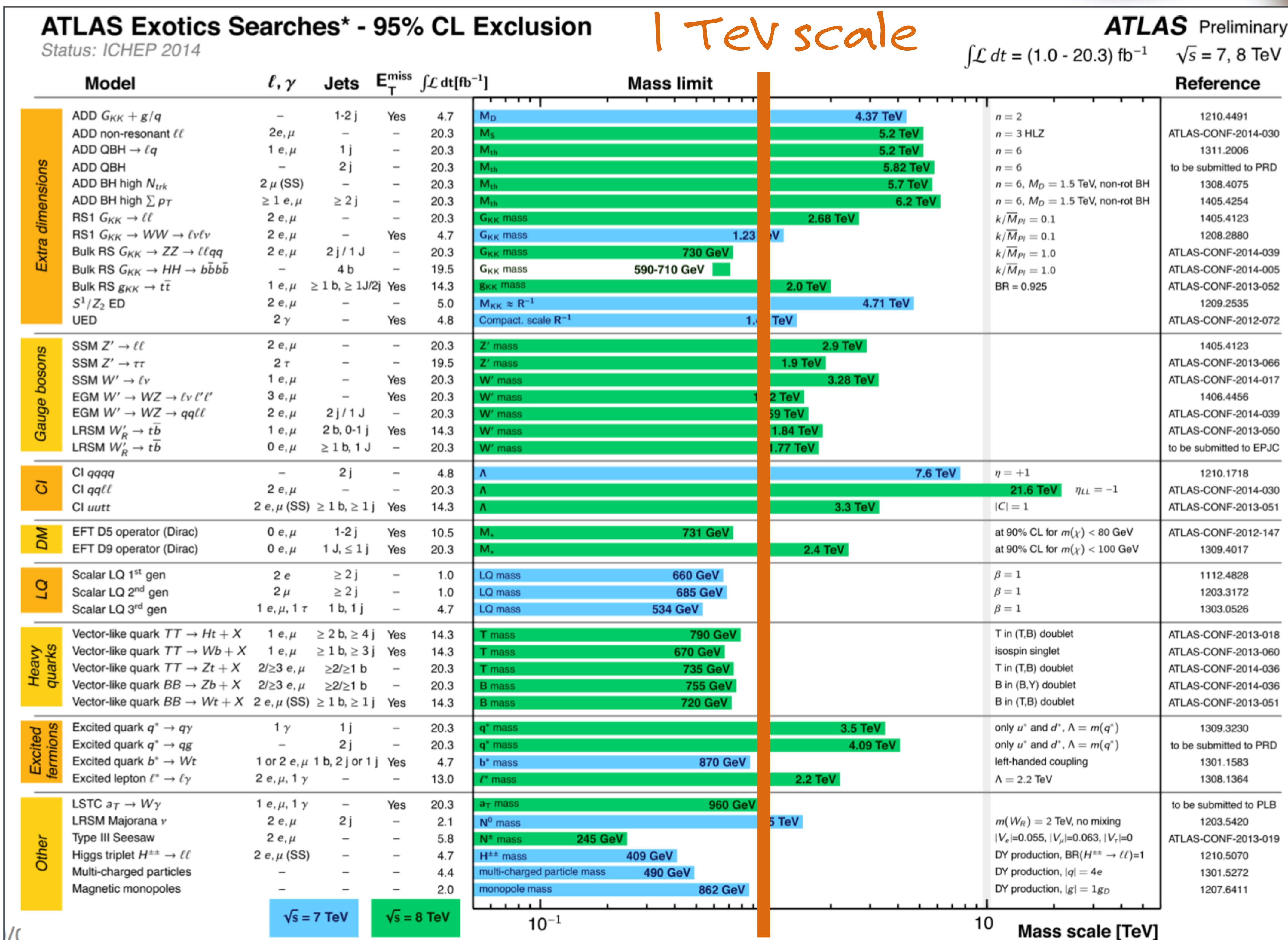




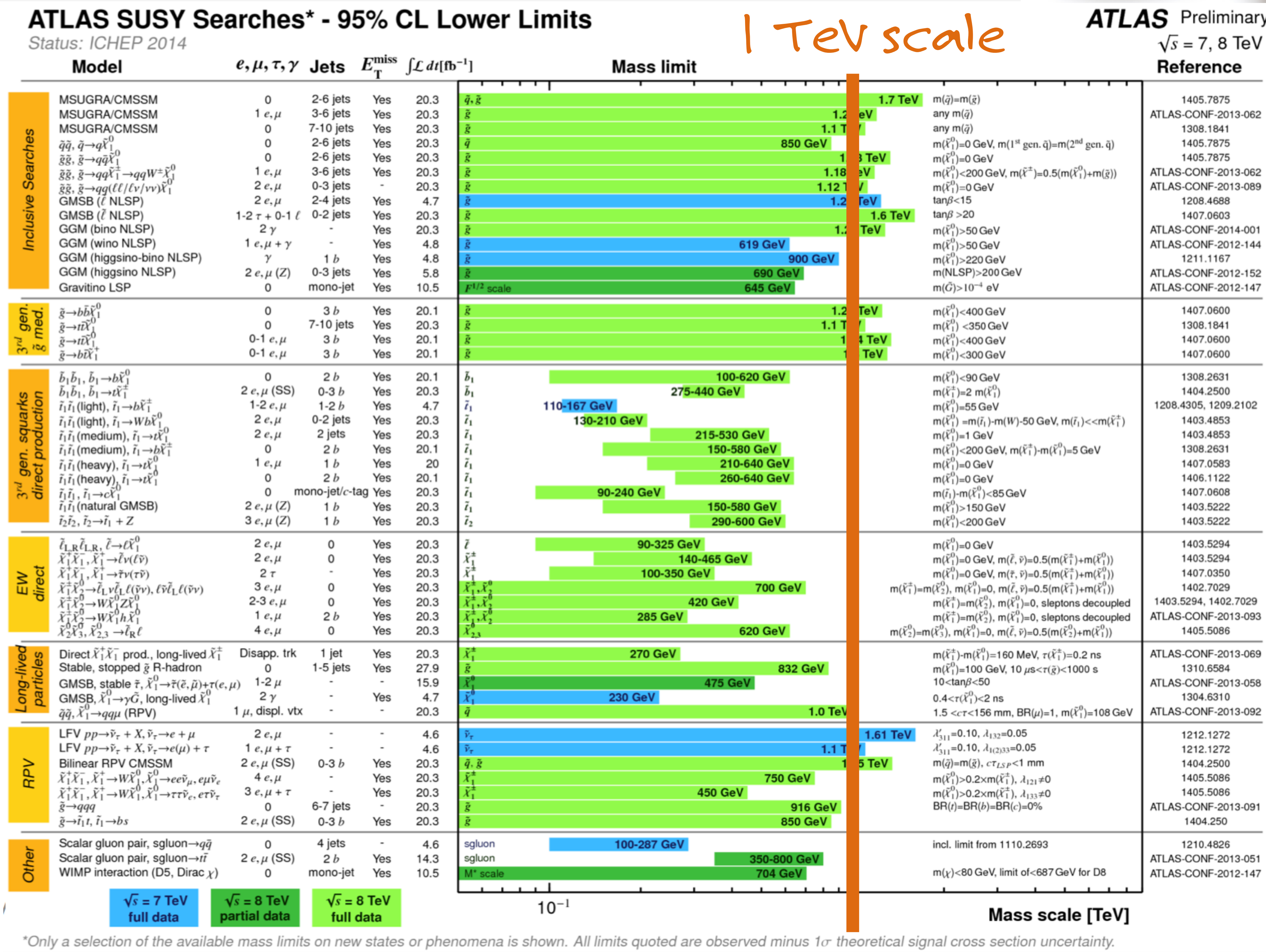
Exotics in a nutshell

a big nutshell





SUSY in a nutshell



But Wait...

THERE'S MORE!

SUSY

spin correlations

Electroweak-ino production, many channels and assumptions

GSMB models, delayed and non-pointing photons

out of time events and disappearing tracks

R-parity violating final states

Additional searches

W' searches to hadronic final states

dijet, ZZ, ZW, W\gamma, Z\gamma resonances

Vector like quarks

Mono jets, tT, b, t

LFV and long-lived neutral particles

Flavor Physics

Notable results

from Run 1 we anticipated:

measure: $bb \rightarrow J/\psi$, $pp \rightarrow J/\psi$, and $B^{+} \rightarrow J/\psi + K^{+}$ cross section ratios

begin to contribute to world averages on B-hadron properties; start to set limits on rare decays

from Run 1 we achieved:

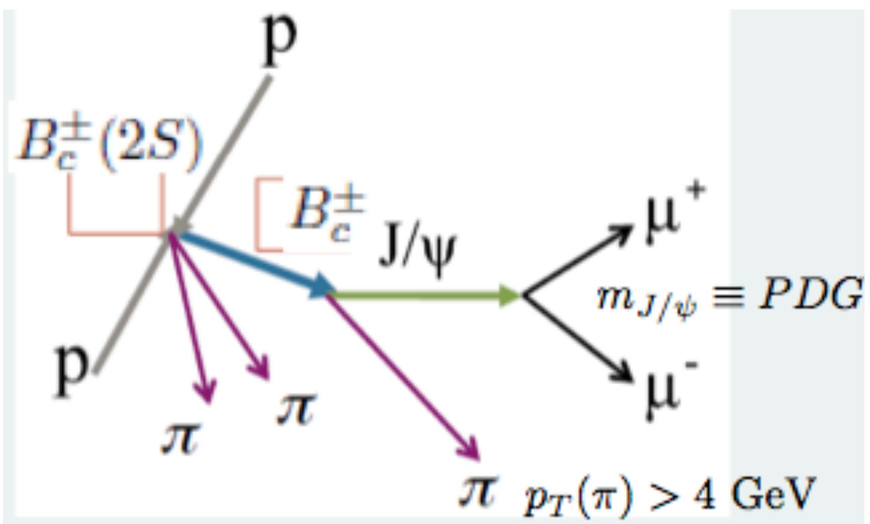
many production studies, χ, ψ studies, new physics searches, new b states

in Run 2, we expect:

increased statistics, improved performance/triggers, robust against $\mathscr{L}$

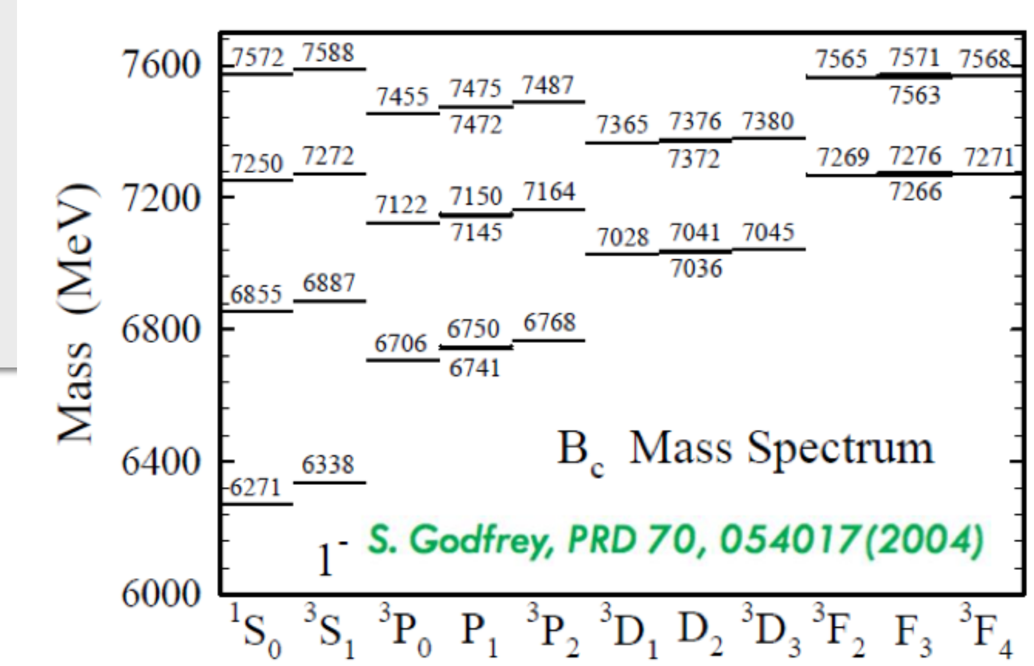
First excited B_c

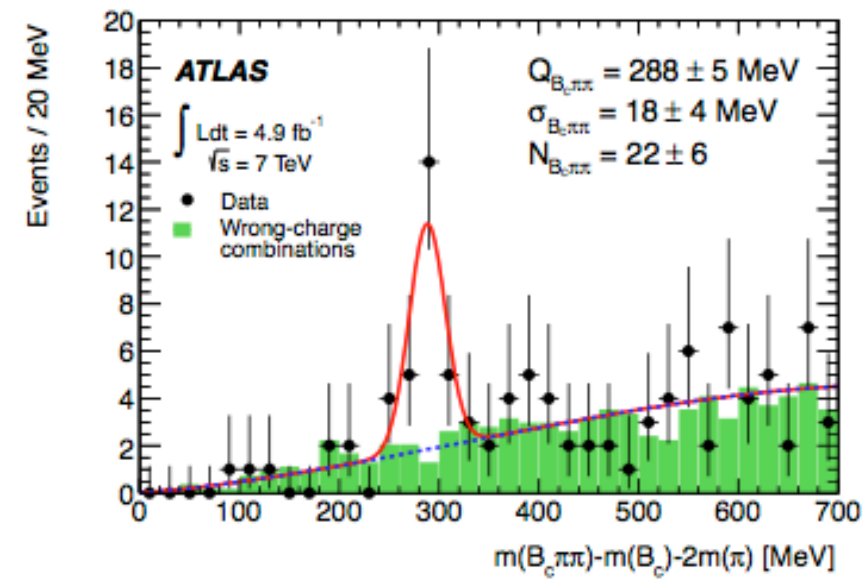
open beauty discovery



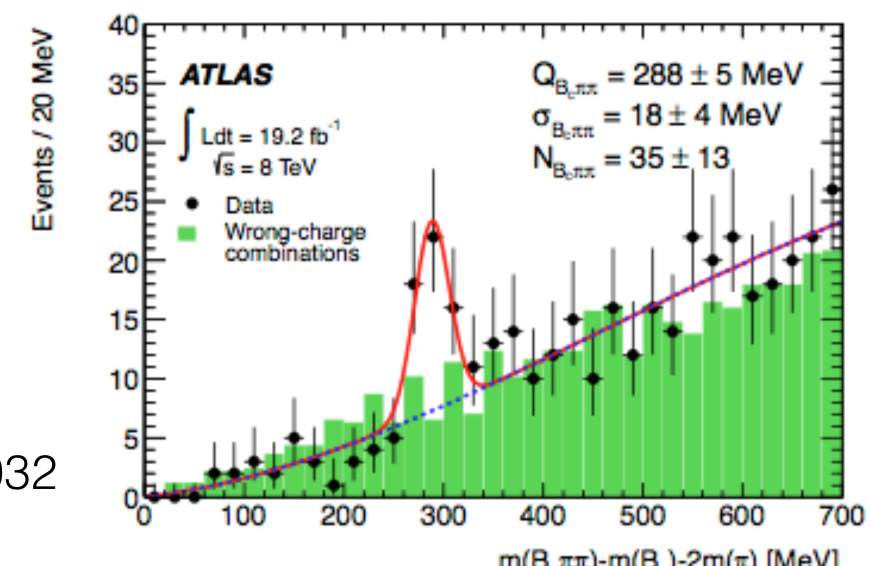
$$2^1S_0 \rightarrow 1^1S_0 \; + \; \pi\pi$$

In conclusion, the distribution of the mass difference $Q = m(B_c^{\pm}\pi^+\pi^-) - m(B_c^{\pm}) - 2m(\pi^{\pm})$ for events with the $B_c^{\pm}$ meson reconstructed in its decay to $J/\psi\pi^{\pm}$ has been investigated in *pp* collisions at the LHC using the ATLAS detector. The analysis is based on an integrated luminosity of 4.9 (19.2) fb^{-1} of *pp* collisions at a center-of-mass energy of 7 (8) TeV. A new state is observed at $Q = 288.3 \pm 3.5 \pm 4.1$ MeV (calculated as the error weighted mean of the 7 TeV and 8 TeV mass values) corresponding to a mass of $6842 \pm 4 \pm 5$ MeV, where the first error is statistical and the second is systematic. The significance of the observation is 5.2σ with the “look





arXiv:1407.1032



But Wait...

THERE'S MORE!

Production and Decays, incl

$\psi(2s)$ in many distributions, prompt and non-prompt

W+ incl double parton scattering contribution

χ_c production, prompt?

$\Upsilon(1s,2s,3s)$ production

open charm/beauty, in jets, inclusive

Spectroscopy, incl

$\chi_b(3P)$ discovery, Λ_b mass, lifetime, PV in $\Lambda_b \to J/\psi\ \Lambda^0$, Rare Decays

Searches, incl

FCNC search for $B_{d/s} \to \mu^+ \mu^-$

Long Shutdown 1 Projects

Tracking system

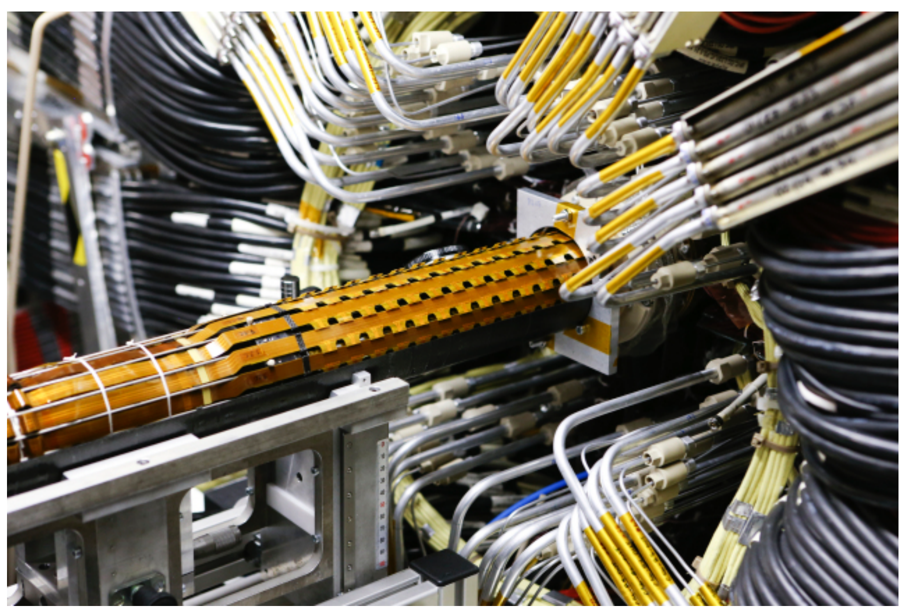
Insertable B Layer, aka IBL

5.1 to 3.3 cm to IP

pixels reduced: 50 x 250 μm

new sensors and readout chip

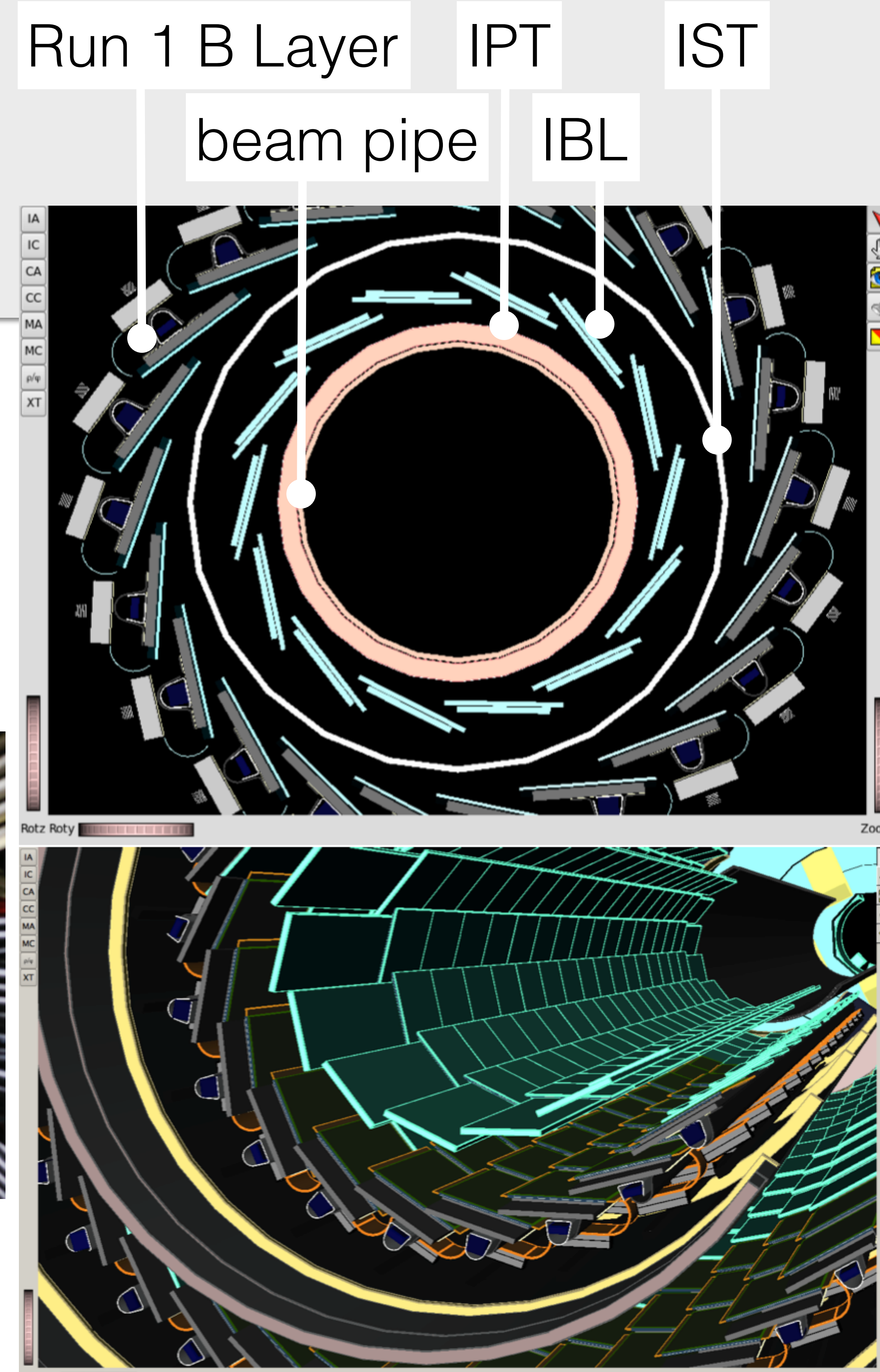
May 7:



Gains:

- impact param
- light jet reject
- redundancy

Status: live >99.9%



Tracking system

many other projects, "Consolidation"

SCT readout enhanced

- high pileup and trigger rate mandates enhanced readout
- 90 ->128 S links and compression
  - 100 kHz @ μ = 87

TRT

- enhanced readout, data compression, different gating
  - 104 KHz with 2% occupancy
- gas studies

Pixel brought to surface, reinstalled

- B layer, 6.3% to 1.4%; Layer 2, 7% to 1.9%; 98% functional of 1744
- new diamond/Si beam monitors installed

Calorimeter system

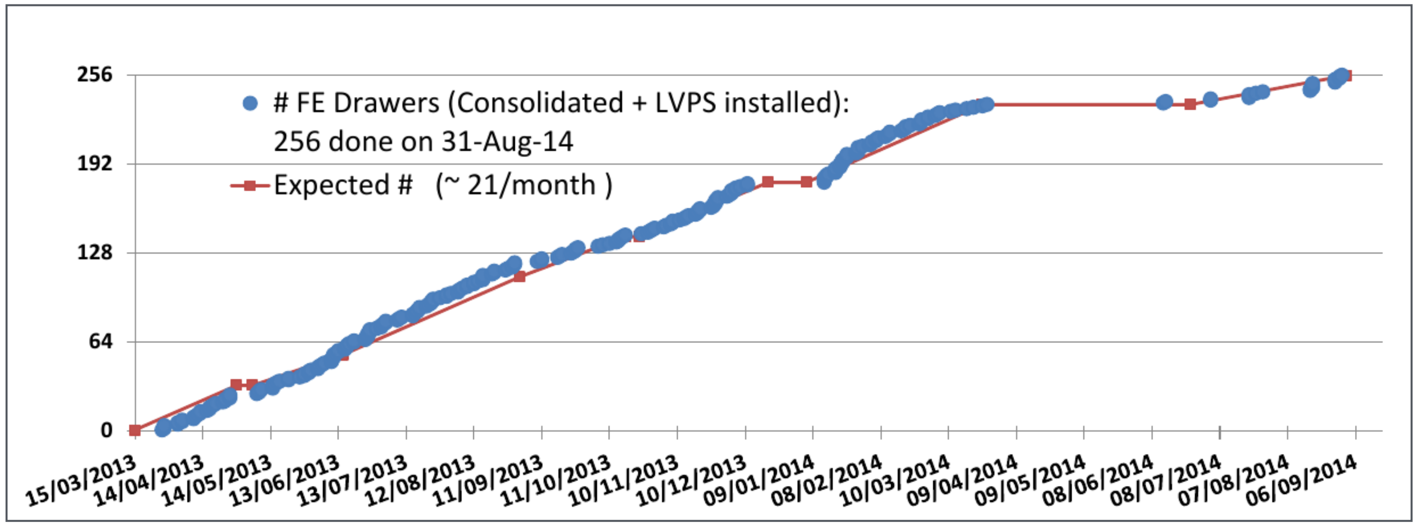
LAr and Tile

LAr

- LV power supplies replaced by manufacturer
- readout tested to more than 100 kHz
- Phase 1 "demonstrator" installed

Tile

- Power supply replacements
- Min-bias trigger scintillators



Muon system

staged from Run 1

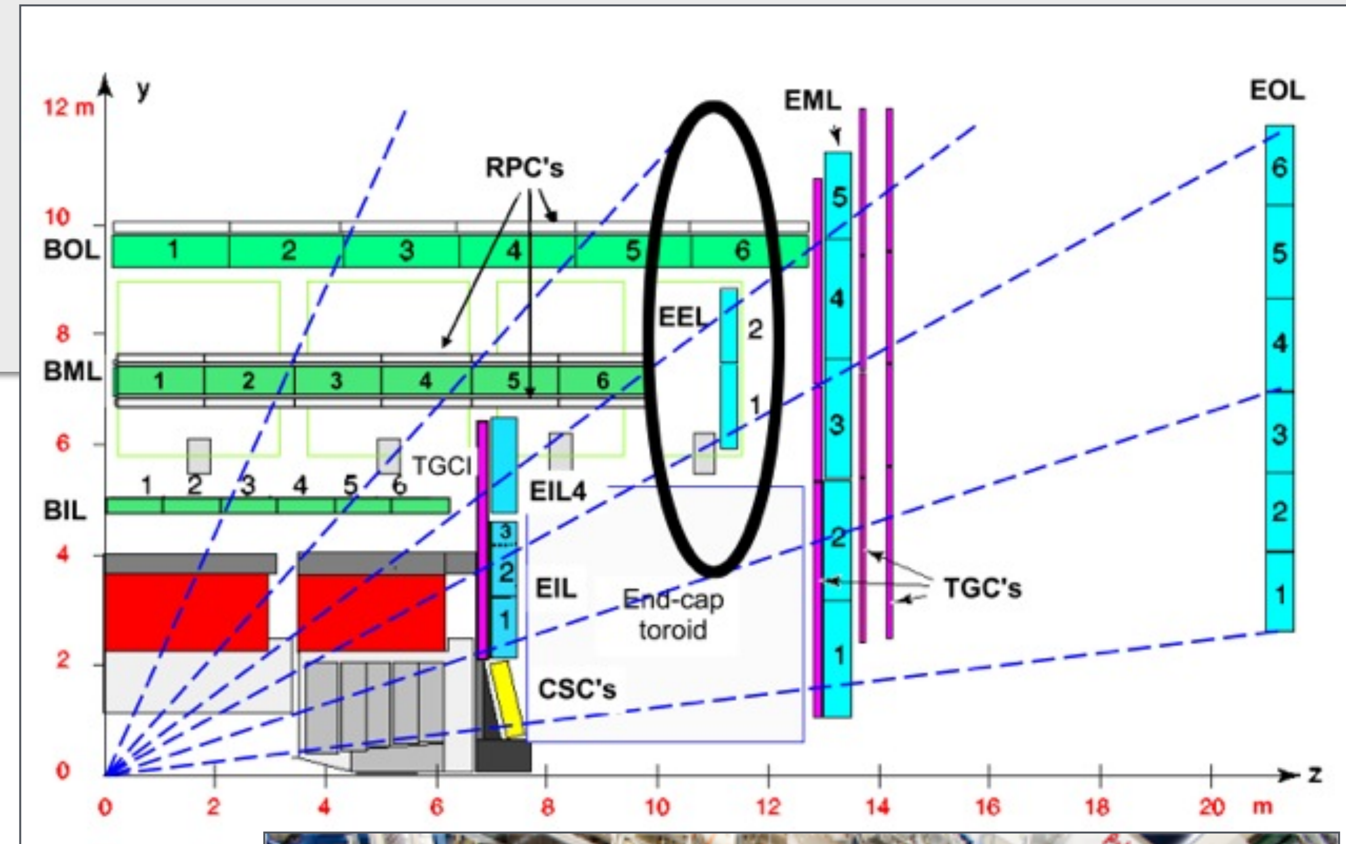
New ROD for CSC system

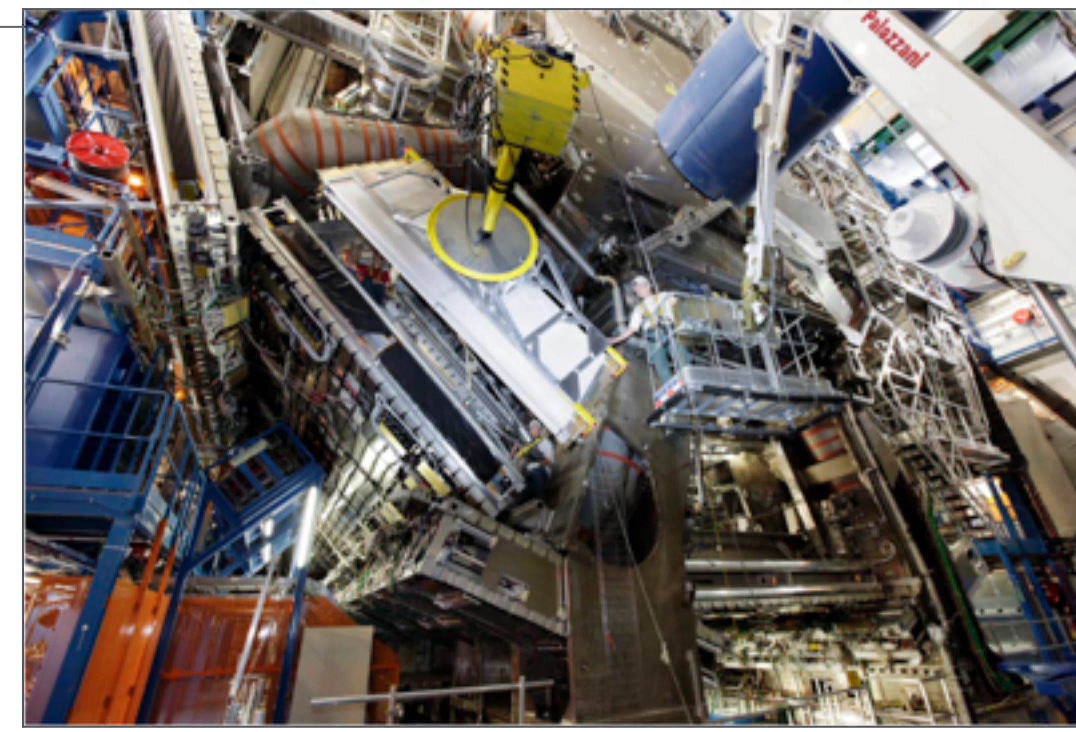
- limited ATLAS L1 trigger rate to 70 kHz…now 100 kHz

New EE endcap chambers

Repairs

- Broken CSC chambers, repaired, reinstalled
- RPC leak repairs
- TGC chamber replacement requires detector to be closed





Trigger system

considerable enhancements

E_{CM} from 8 to 13 TeV (x2.5) +

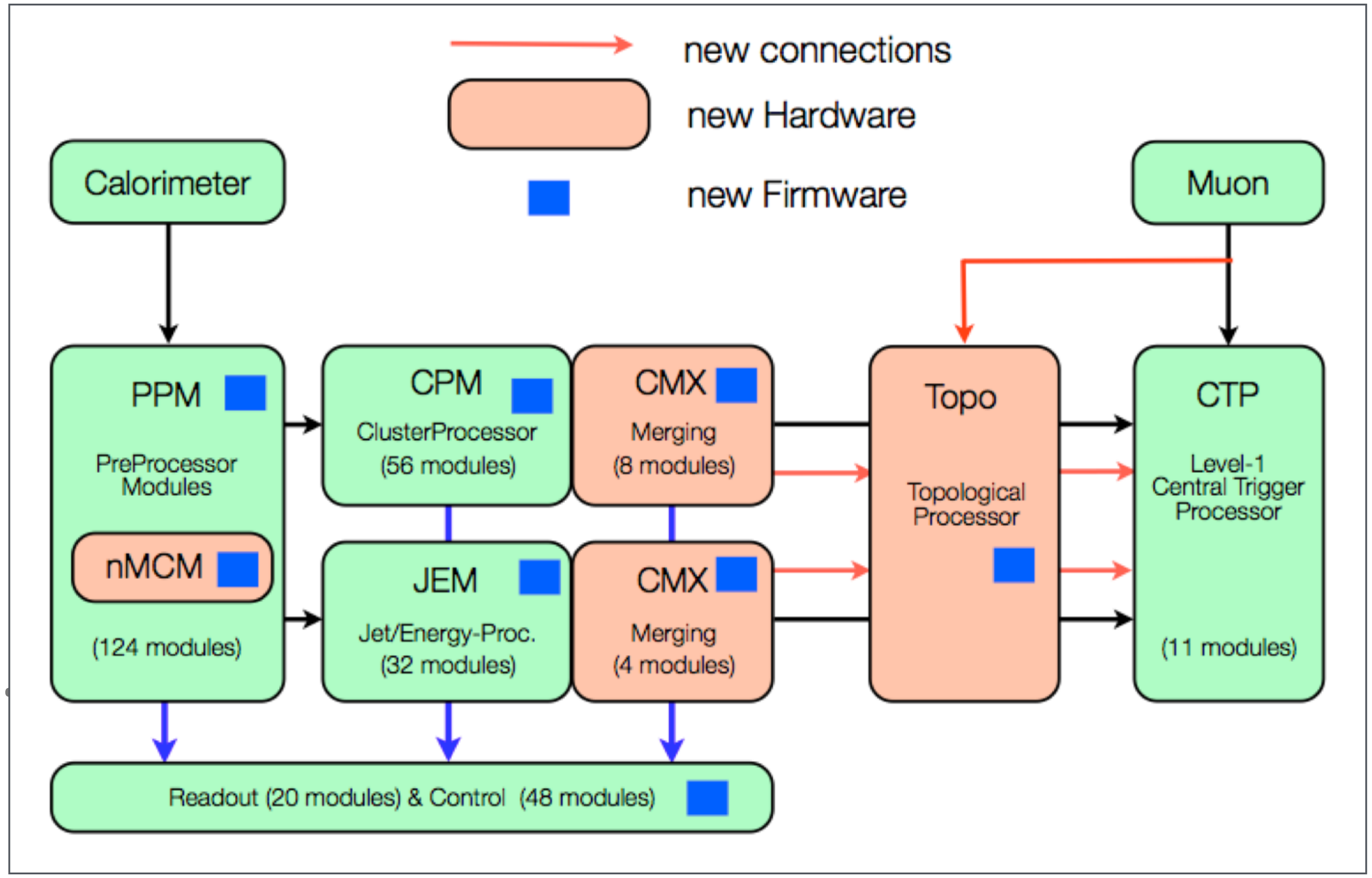
$\mathscr{L}_{peak}$ 0.8 to 1.6 x 10^{34}/cm^2/s

5x trigger rates from Run 1

Upgrades to:

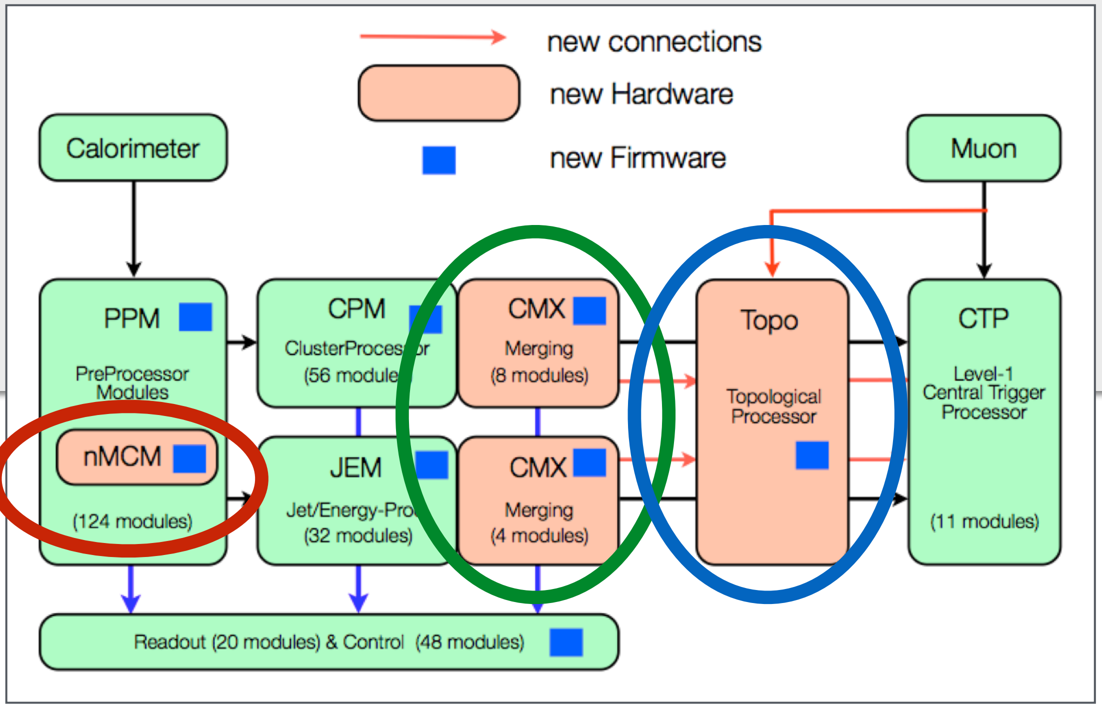
L1 rate, 70 kHz - 100 kHz operation, factor 4/3 increase. **hardware**

HLT rate, 400 Hz - ~1 kHz operation, factor of ~2 increase. **algorithms**



Trigger system

hardware



New preprocessors (nMCM)

80 MHz digitization, lower noise

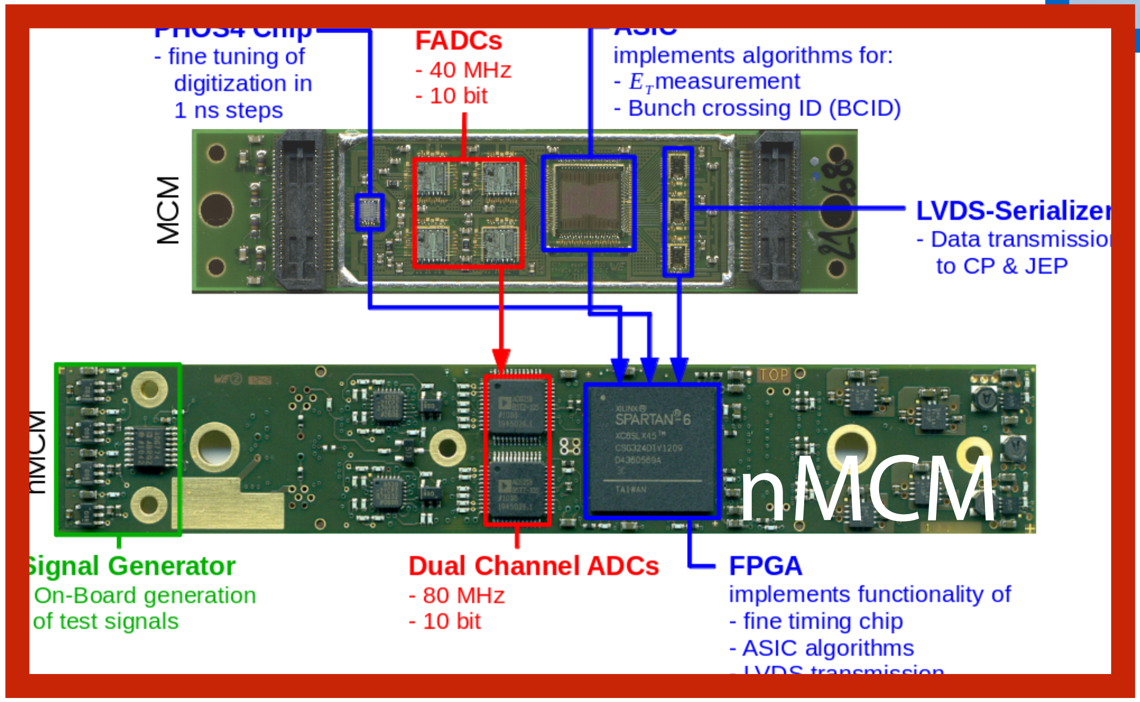
New merger modules (CMX)

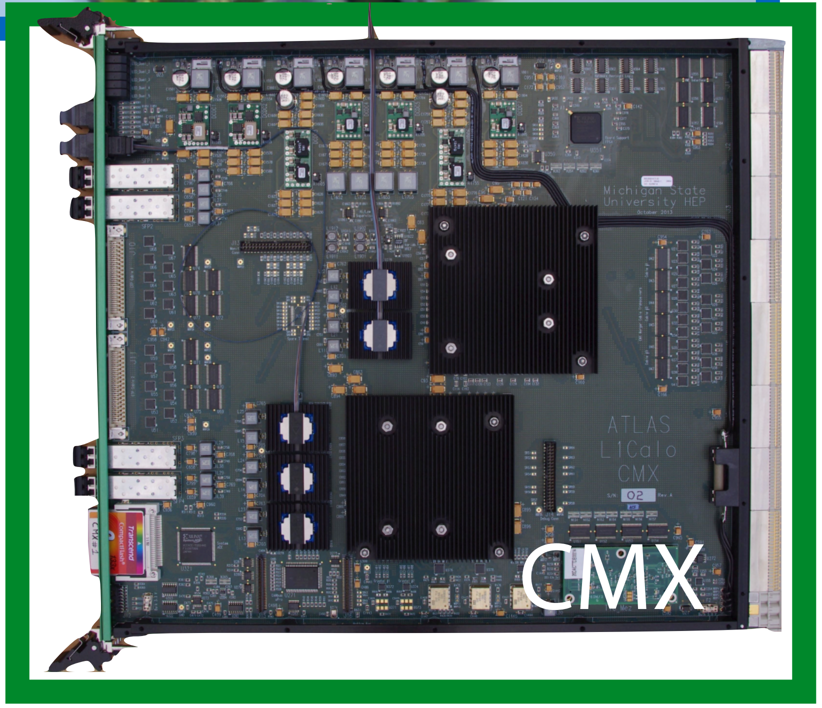
x4 speed enhancement over CMM

L1 Topo processor

trigger on object relations at L1 e.g. $\Delta\phi(E^{miss}{}_T, j)$

Commissioning underway in-situ

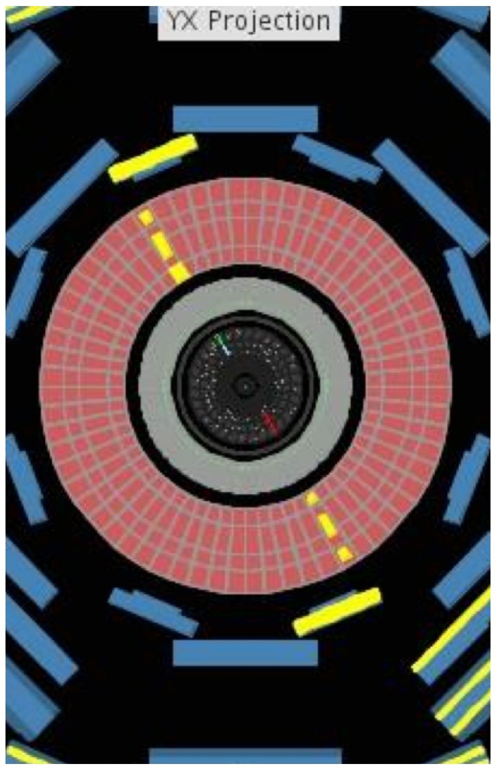




Commissioning

multiple “Milestone weeks”

24/5! M’s cosmic rays HLT & reco’d Tier 0

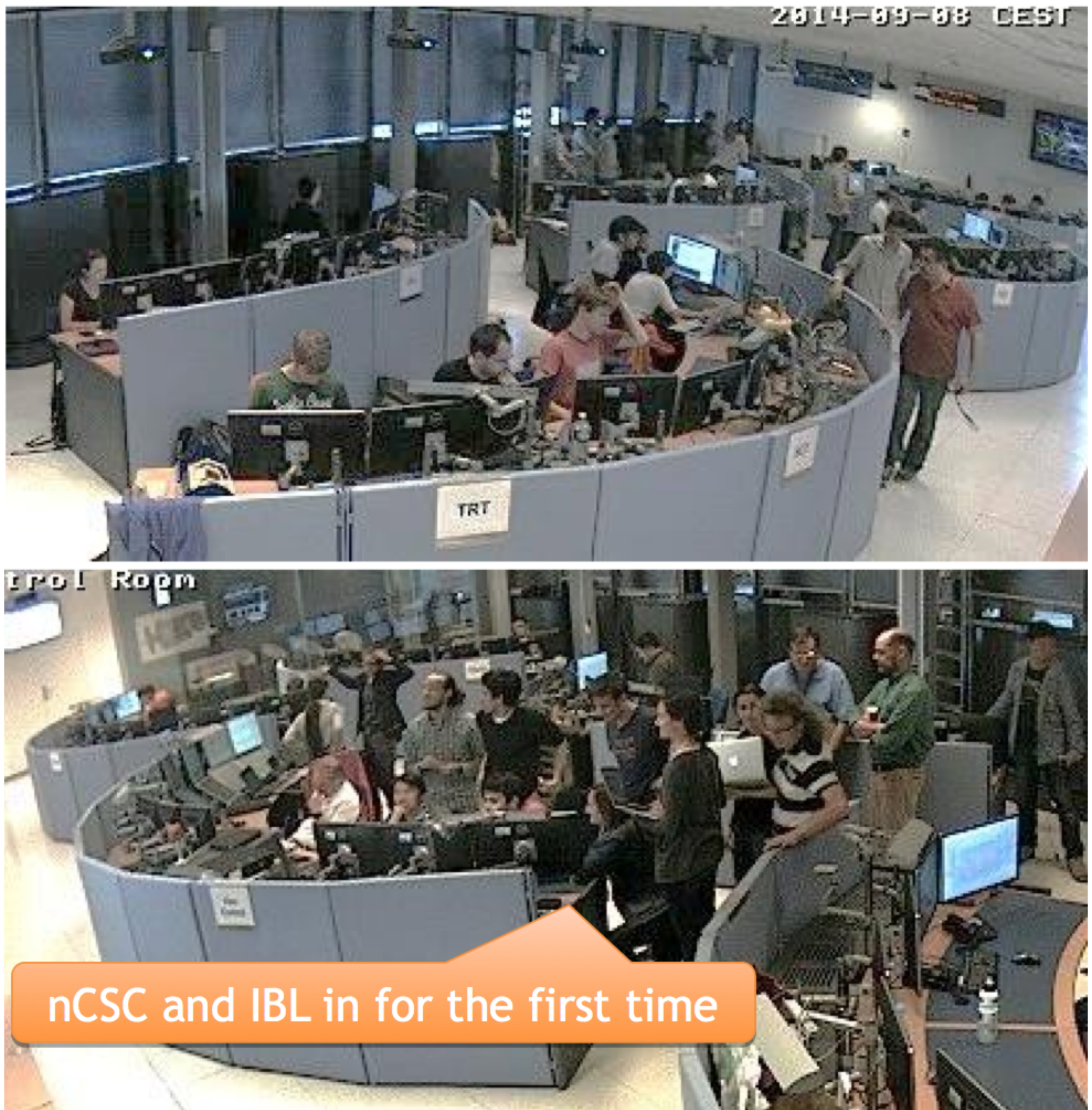


	M3	M4	M5	M6	M7
	May19-May 23	Jul 7-Jul 11	Sep 8-Sep 12	Oct 13-Oct 17	Nov 24-Dec 08
PIX		X[1], X[2]	X[2]		
IBL		X[1]	X[2]		
SCT		X	X[2]		
TRT					
LAR		X			
TIL		X			
MBTS		X			
L1Calo		X[2]	X[3]	X[4]	
CSC			X[2]	X[2]	
MDT					
RPC	X[1]				
TGC				X[2]	
BCM					
ALFA			X		
LUCID				X	
Lumi			X		

Commissioning

multiple “Milestone weeks”

24/5! M’s cosmic rays HLT & reco’d Tier 0



	M3	M4	M5	M6	M7
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PIX		X^1, X^2	X^2		
IBL		X^1	X^2		
SCT		X	X^2		
TRT					
LAR		X			
TIL		X			
MBTS		X			
L1Calo		X^2	X[illegible]	X^4	
CSC			X^2	X^2	
MDT					
RPC	X^1				
TGC				X^2	
BCM					
ALFA			X		
LUCID				X	
Lumi			X		

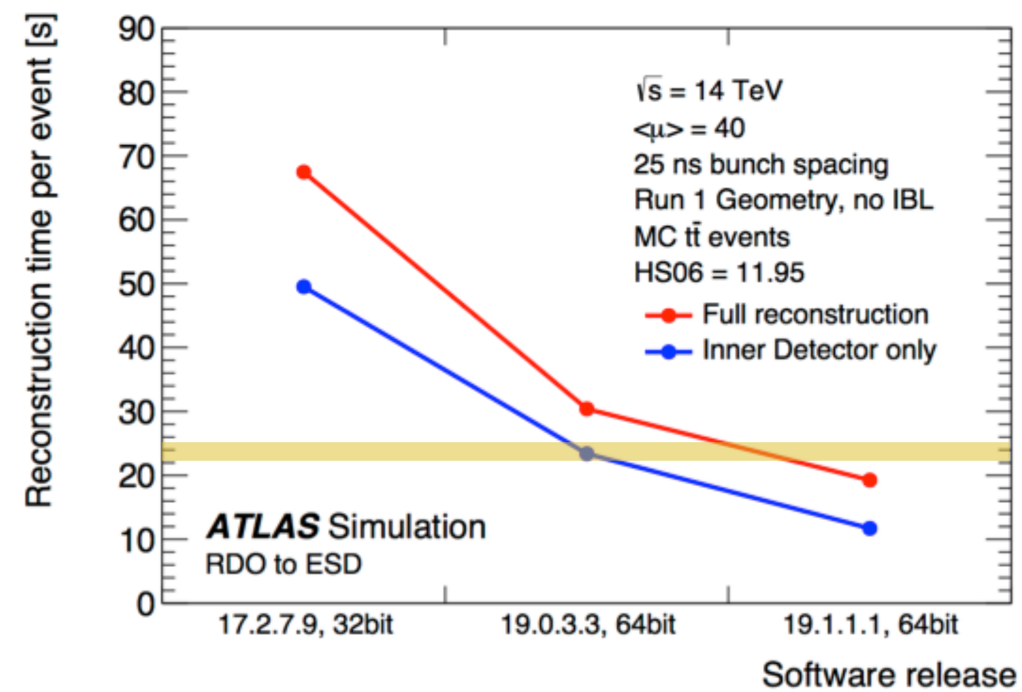
ATLAS

reading out since “M5”

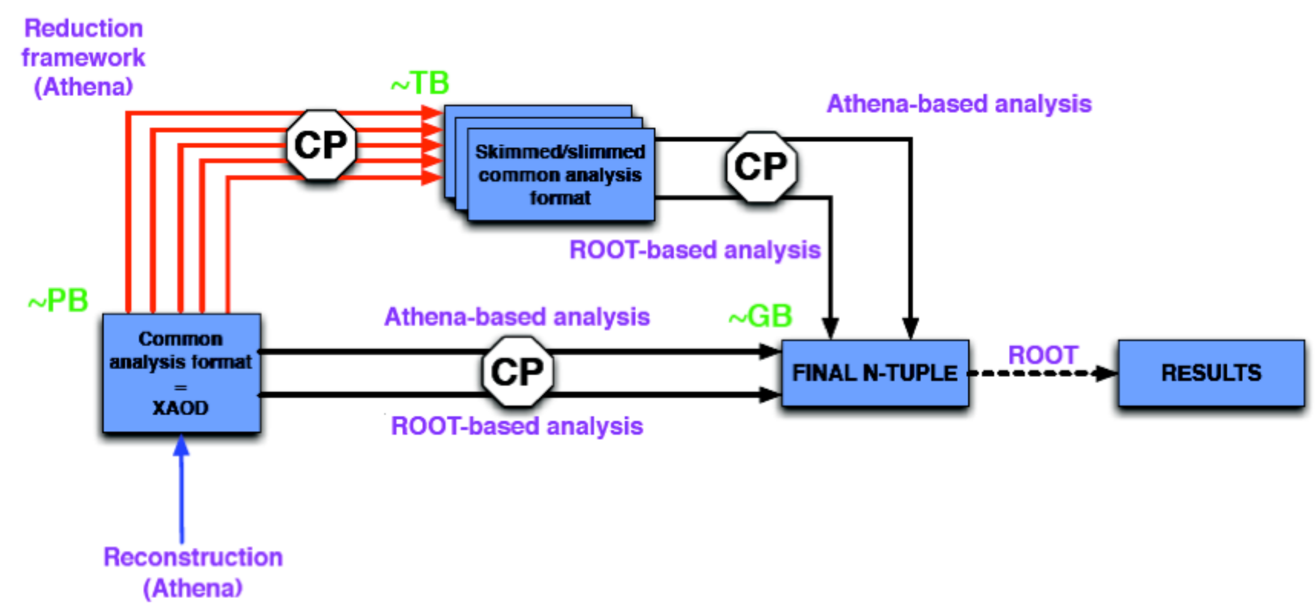
Computing & Software systems

speed/efficiency and pileup

- Many algorithmic, mathematical, fitting changes
  - factor >3 gains
  - pileup robustness
- Completely redesigned analysis model
  - “xAOD” Athena reconstruction is ROOT-readable, tuning.
  - disk usage tight…working on xAOD sizes
  - memory usage gymnastics
  - CP tools mostly migrated



budget @0.4 LHC eff



conclusion

nothing yet