The 1st LHC proton run (2009-2012)

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(CERN, PH)

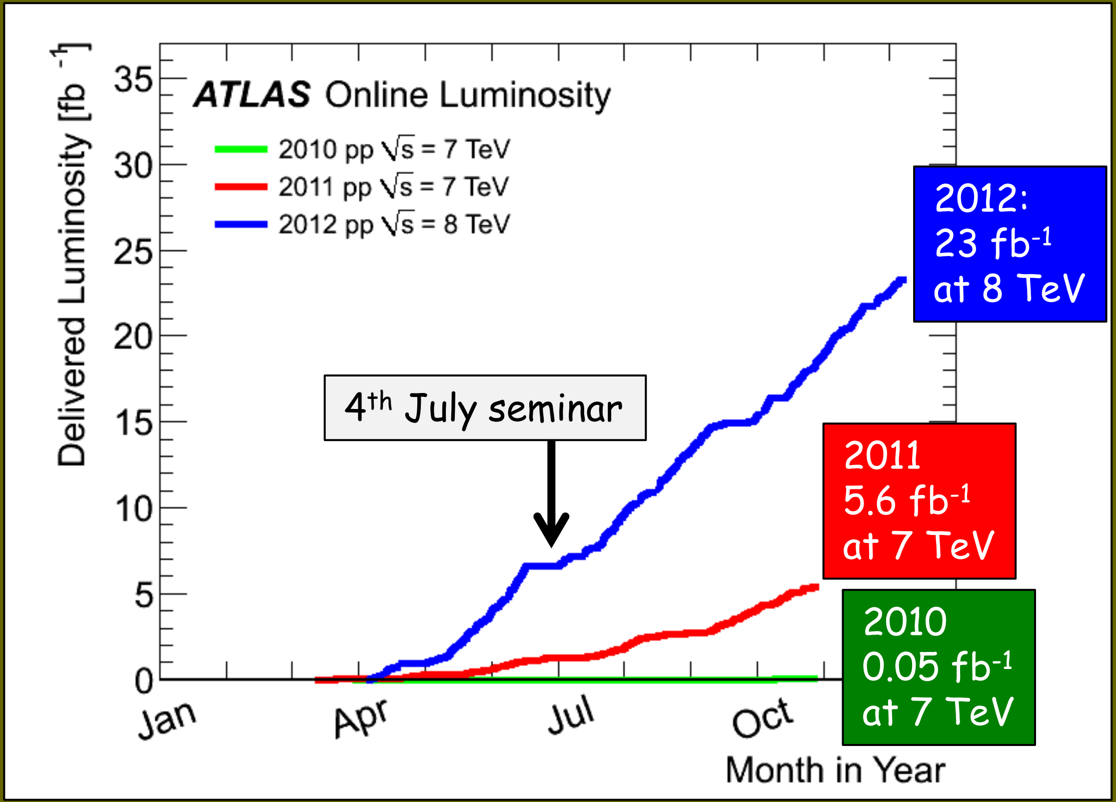
A success story for the LHC:

- great competence, skills, scientific talent
- hard work, sustained dedication
- excellent and pleasant team work between machine and experiments

→ Leading in particular to a very special discovery

→ We can all be proud of this and other achievements

CCC = CERN Control Centre
aka Competence, Commitment, Cooperation



Total 2010-2012:

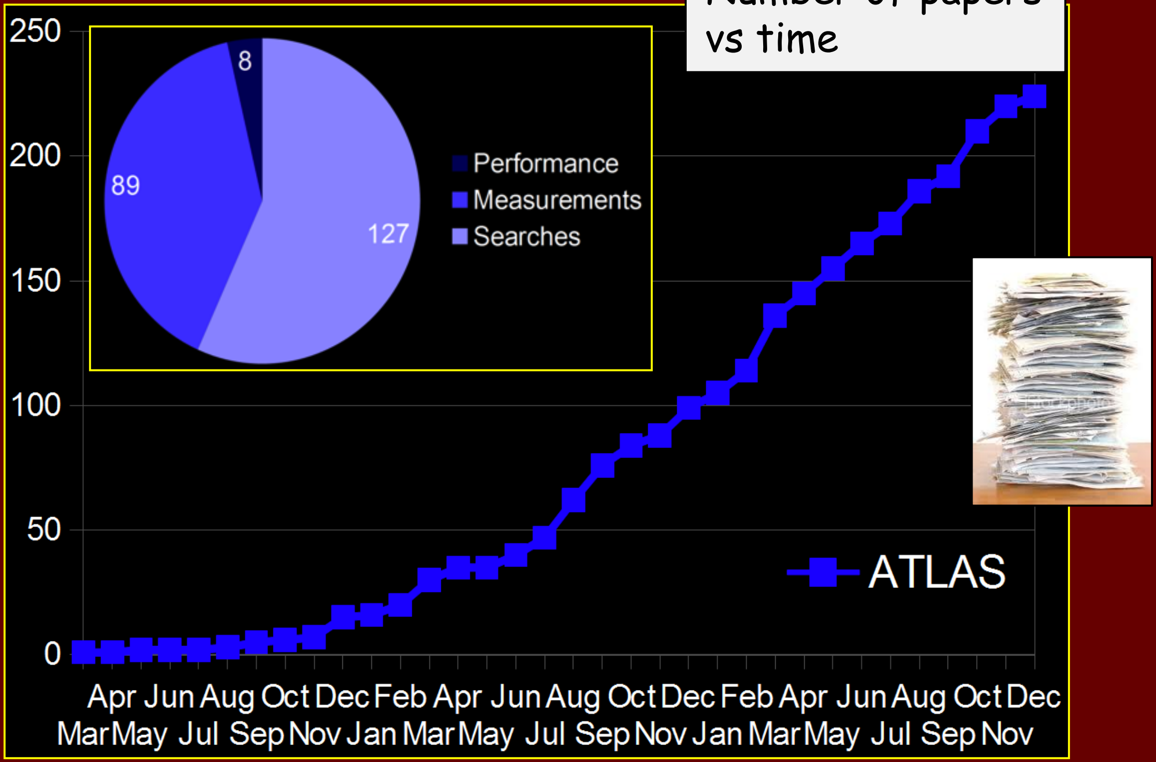
- 28.8 fb^{-1} delivered to ATLAS
- 27 fb^{-1} recorded
- ~26 fb^{-1} good-for-physics (~90% of delivered), in spite of challenging conditions

A few additional numbers:

- ~ 5 billion events recorded in total
- ~ 120 PB of data (including real and simulated data) as of today

A huge scientific output

Number of papers vs time



- 224 papers on collision data (~ 2.5/week recently)
- 437 conference notes with preliminary results

Number of events in full 2010-2012 dataset (~26 fb^{-1}) after all selection cuts

l=e,μ

$W \to l\nu$ ~ 100 M
$Z \to ll$ ~ 10 M (as many as at LEP)
$tt \to l+X$ ~ 0.4 M

SM Higgs ~ 400
Note: ~1 $H \to \gamma\gamma$ (~1 $H \to 4l$) produced every 50′ (14h) at 7x 10^{33}

We didn't start so well …

- First collisions at 3.5 TeV will be a major media event
  - And first collisions is first collisions, no Atlas sneaking in there while we're commissioning the ramp

M. Lamont, LHC commissioning WS, Evian, January 2010

- Access to replace heater discharge power supply S34
- **Experiments (~ 3%):**
  - ATLAS lost patrol (2 hours)
  - ATLAS up to 20 minutes to analyze PM and give back injection permit SYSTEMATICALL
  - ALICE problems to give the

Procedure to recover pretty simple, but only one person new it … Difficult to find in the middle of the night ➔ Better trained shifts crews in the experiments.

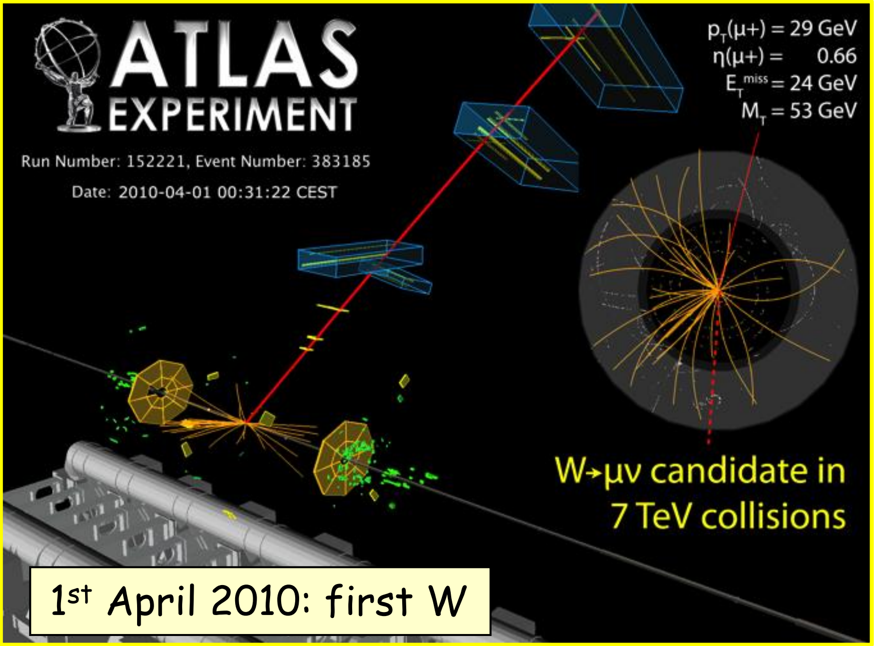
Unacceptable when beam dump not produced by ATLAS and safe beam. With unsafe beam we should discuss. Other experiments by far more fast.

R. Alemany, LHC commissioning WS, Evian, January 2010

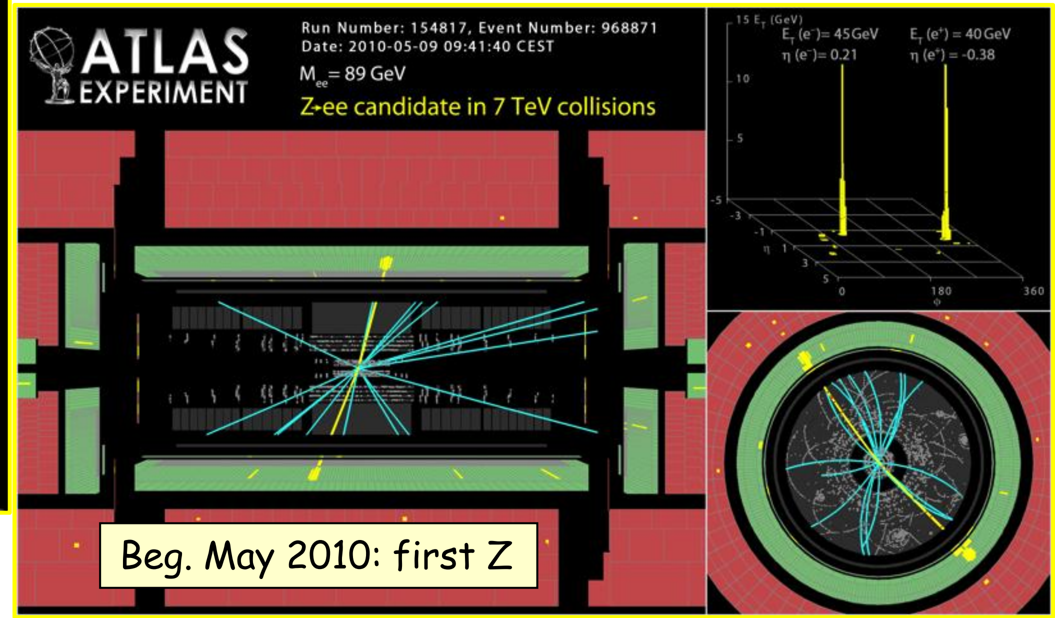
Moreover, a few days before first 3.5 TeV collisions (30 March 2010), and the related media-circus, ATLAS dumped the beam twice. Since then:

- our BCM have been masked in the abort logic
- we only dumped the beam two times in 3 years (UFO's detected by our BLM)

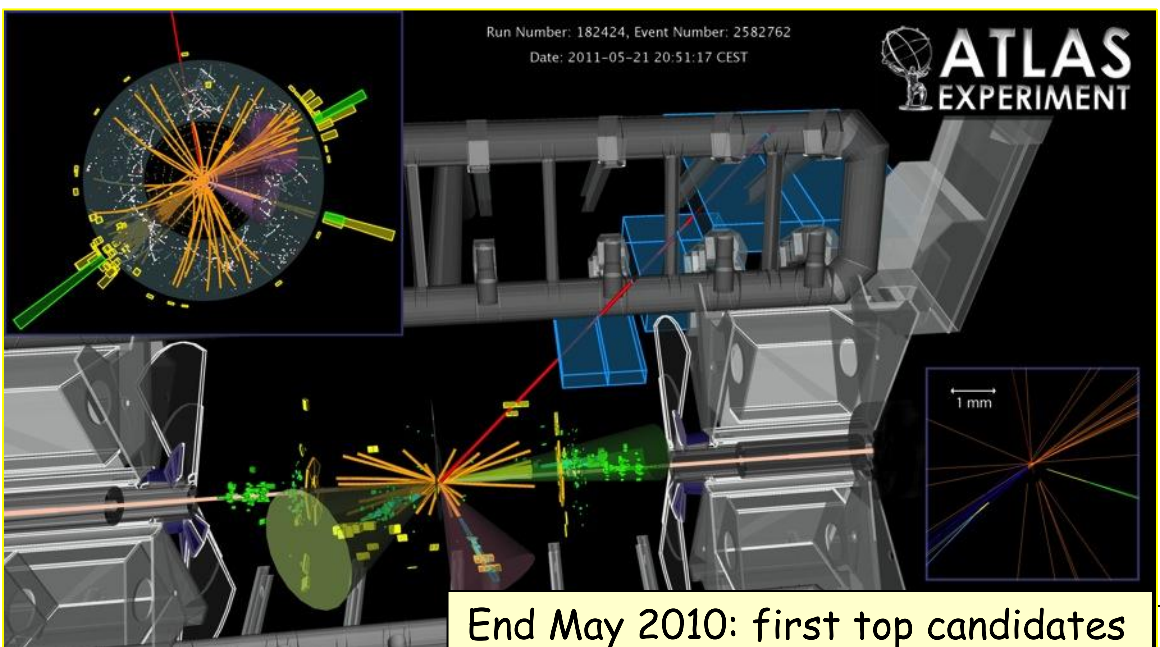
But then we improved …



1st April 2010: first W

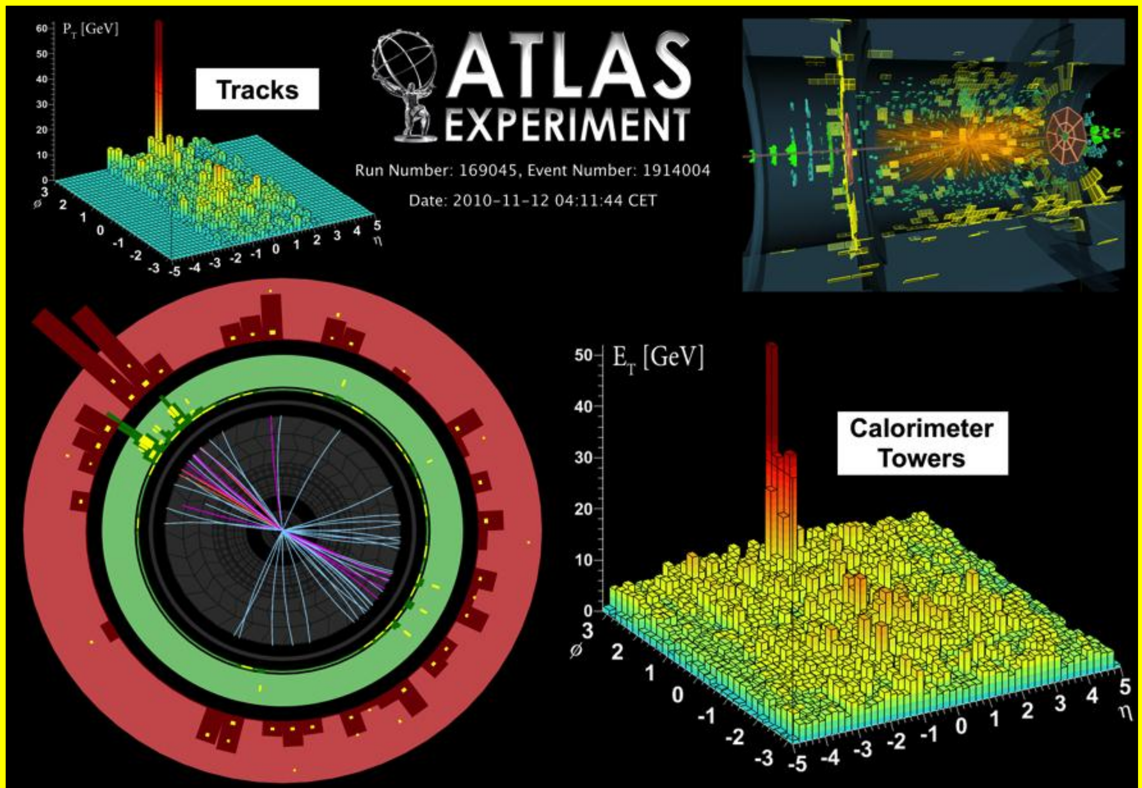


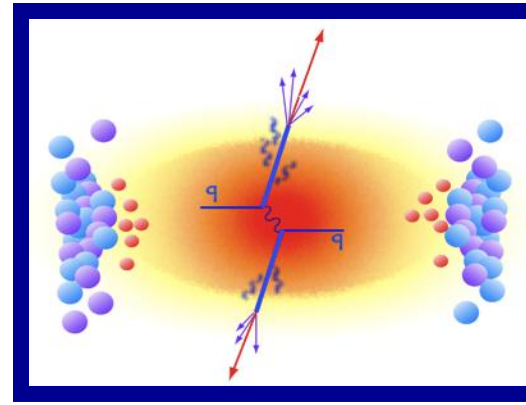
Beg. May 2010: first Z



End May 2010: first top candidates

November 2010: first <u>direct</u> observation of "jet quenching" in heavy-ion collisions





8 November: first Pb-Pb collisions
→ 25 Nov: paper submitted

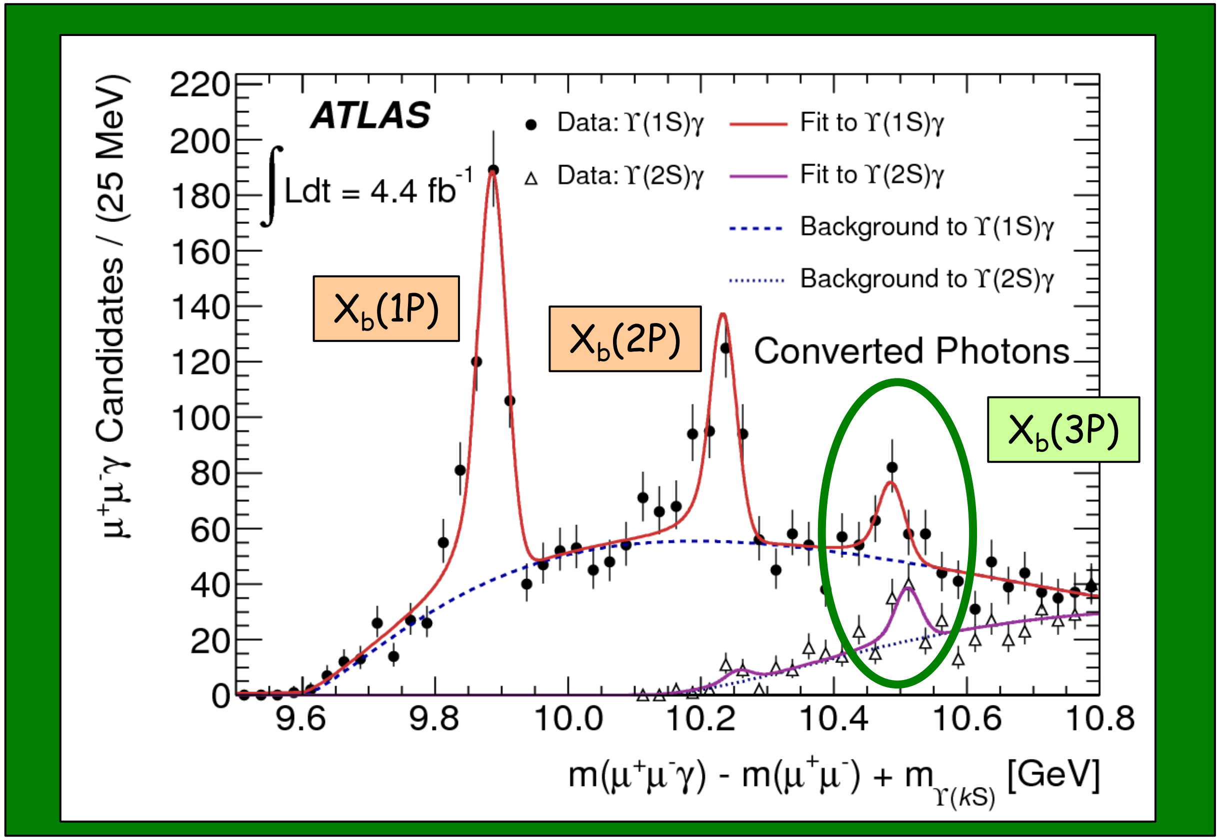
Observation of a Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ATLAS Detector at the LHC

G. Aad *et al.* (The ATLAS Collaboration)*

Using the ATLAS detector, observations have been made of a centrality-dependent dijet asymmetry in the collisions of lead ions at the Large Hadron Collider. In a sample of lead-lead events with a per-nucleon center of mass energy of 2.76 TeV, selected with a minimum bias trigger, jets are reconstructed in fine-grained, longitudinally-segmented electromagnetic and hadronic calorimeters. The underlying event is measured and subtracted event-by-event, giving estimates of jet transverse energy above the ambient background. The transverse energies of dijets in opposite hemispheres is observed to become systematically more unbalanced with increasing event centrality leading to a large number of events which contain highly asymmetric dijets. This is the first observation of an enhancement of events with such large dijet asymmetries, not observed in proton-proton collisions, which may point to an interpretation in terms of strong jet energy loss in a hot, dense medium.

December 2011: first discovery of a new particle at the LHC

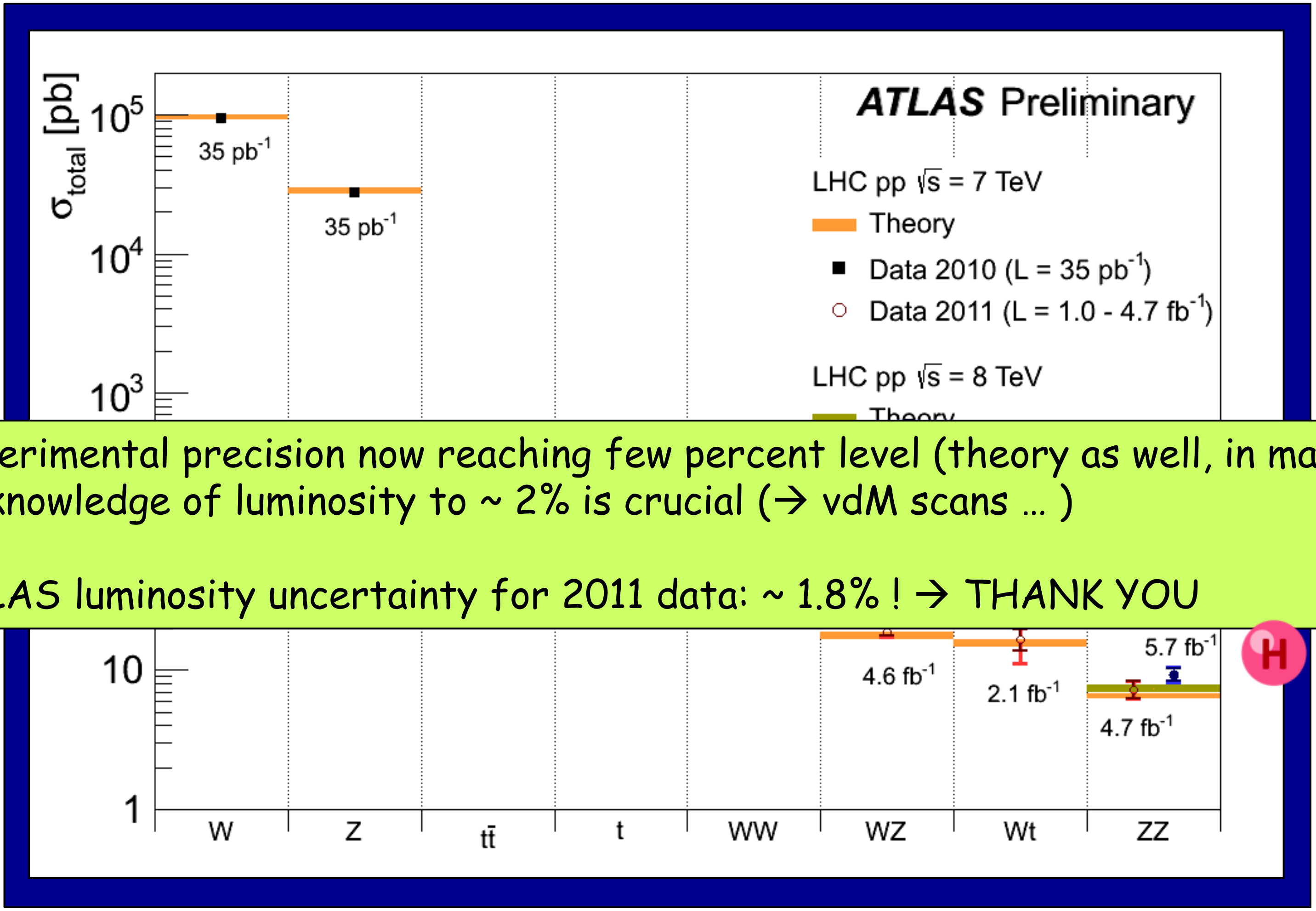
$X_b(3P) \rightarrow \Upsilon(1s,2s)\ \gamma \rightarrow \mu\mu\ \gamma$



$X_b(1P)$ m= 9.9 GeV and $X_b(2P)$ m= 10.2 GeV states clearly visible

New structure at 10.5 GeV observed by ATLAS → $X_b(3P)$

Cross-section measurements (examples ..)



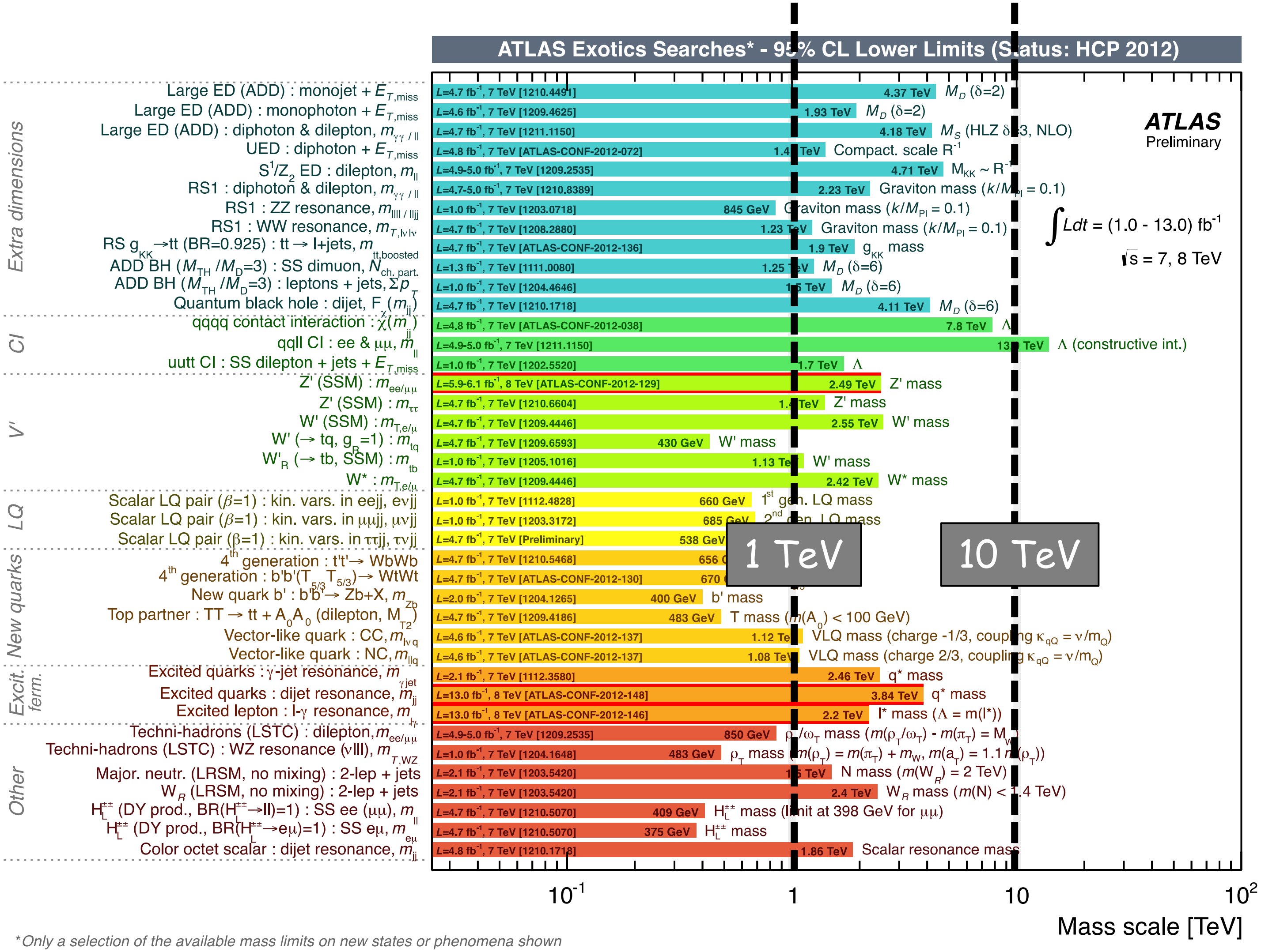
Experimental precision now reaching few percent level (theory as well, in many cases)
→ knowledge of luminosity to ~ 2% is crucial (→ vdM scans …)

ATLAS luminosity uncertainty for 2011 data: ~ 1.8% ! → THANK YOU

- ❑ Important processes to test SM at 8 TeV → very good agreement of SM with data
- ❑ Also backgrounds to searches → foundations for the Higgs discovery

Exploration of the energy frontier

Huge number of models and topologies investigated, but far from being complete
→ surprises may hide in the present data and/or in 2015++ data



Exotics Models:

Extra dimensions:
- RS KK Graviton (dibosons, dileptons, diphotons)
- RS KK gluons (top antitop)
- ADD (monojets, monophotons, dileptons, diphotons)
- KK Z/gamma boosns (dileptons)

Grand Unification symmetries
- (dielectons, dimuons, ditaus)
- Leptophobic topcolor Z' boson (dilepton ttbar, l+j, all had)

S8- color octet scalars (dijets)
String resonance (dijets,)
Benchmark Sequential SM Z', W'
W' (lepton+MET, dijets, tb)
W* (lepton+MET, dijets)
Quantum Black Holes (dijet)
Black Holes (l+jets, same sign leptons)
Technihadrons (dileptons, dibosons)
Dark Matter
- WIMPs (Monojet, monophotons)

Excited fermions
- q*, Excited quarks (dijets, photon+jet)
- l*, excited leptons (dileptons+photon)

Leptoquarks (1st, 2nd, 3rd generations)
Higgs -> hidden sector
- (displaced vertices, lepton jets)

Contact Interaction
- llqq CI
- 4q CI (dijets)

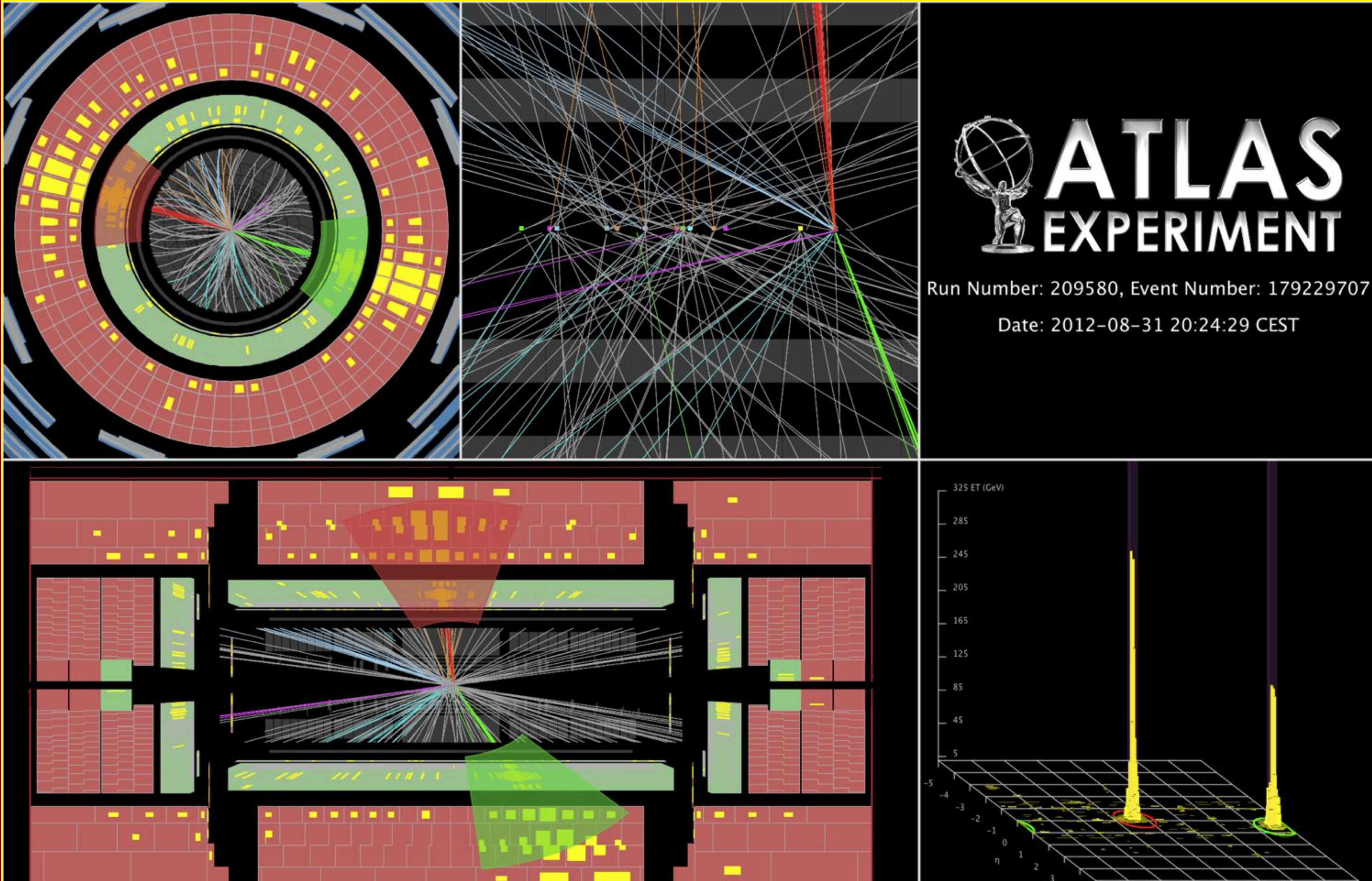
Doubly charged Higgs (
- multi leptons, same sign leptons)

4th generation
- t'->Wb, t'->ht, b'-Zb, b'->Wt
- (dileptons, same sign leptons, l+J)

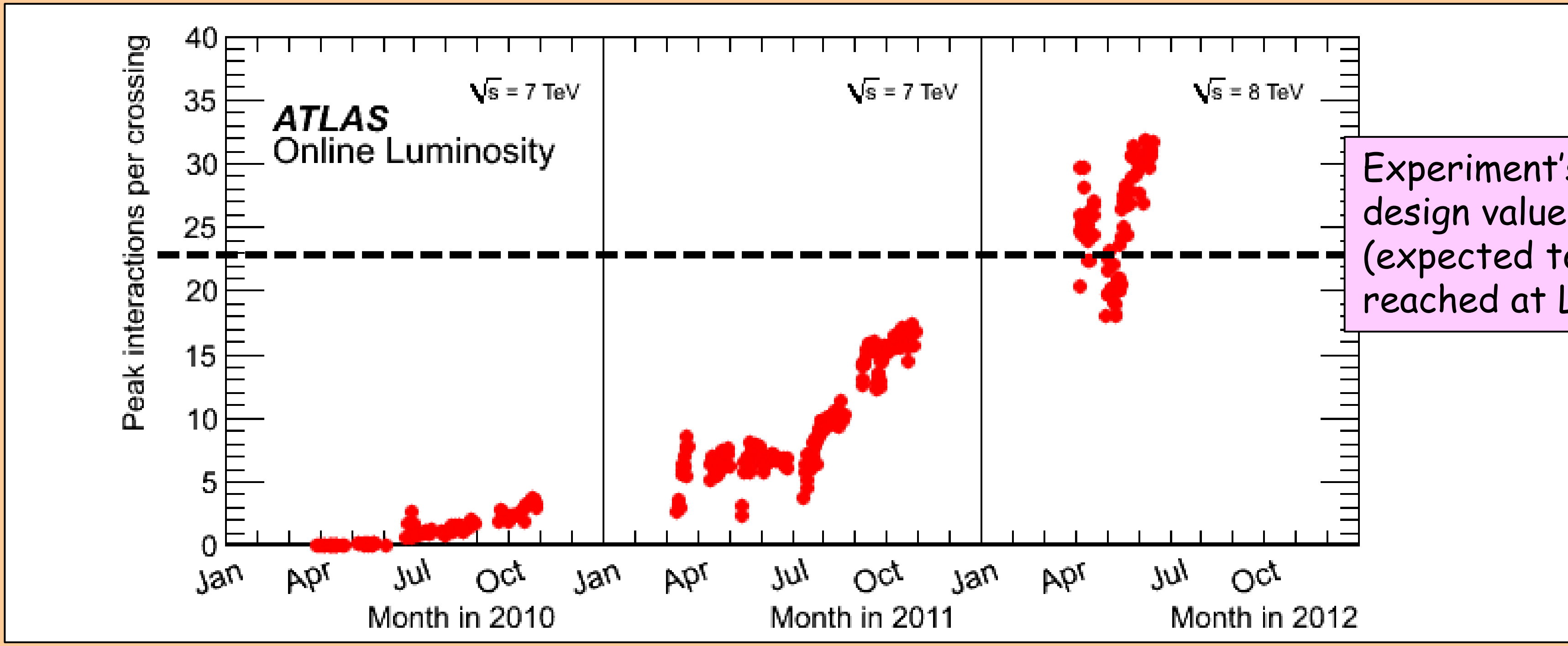
VLQ-Vector Like quarks
Magnetic Monopoles (and HIP)
Heavy Majorana neutrino and RH W

The energy frontier: a "monster" event

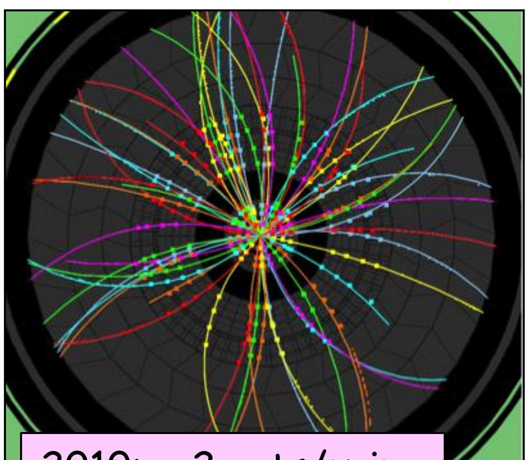
m_{jj} = 4.7 TeV, $p_T(j_1, j_2)$= 2.3-2.2 TeV
Very well measured: E_T^{miss} = 47 GeV



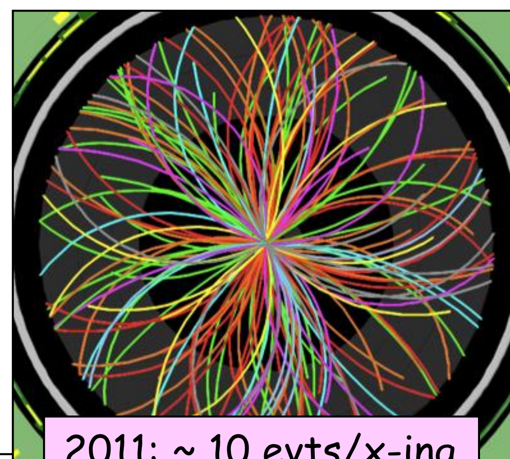
The BIG challenge in 2012: pile-up
(huge impact on detector, trigger, computing, physics performance)



Experiment's design value (expected to be reached at L=10^{34} !)



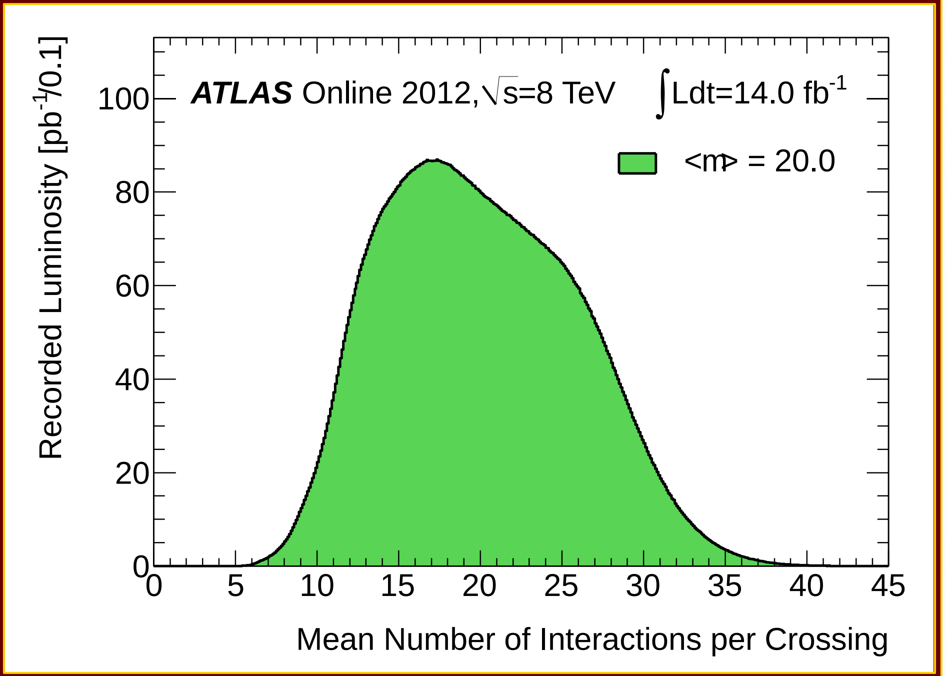
2010: ~ 2 evts/x-ing

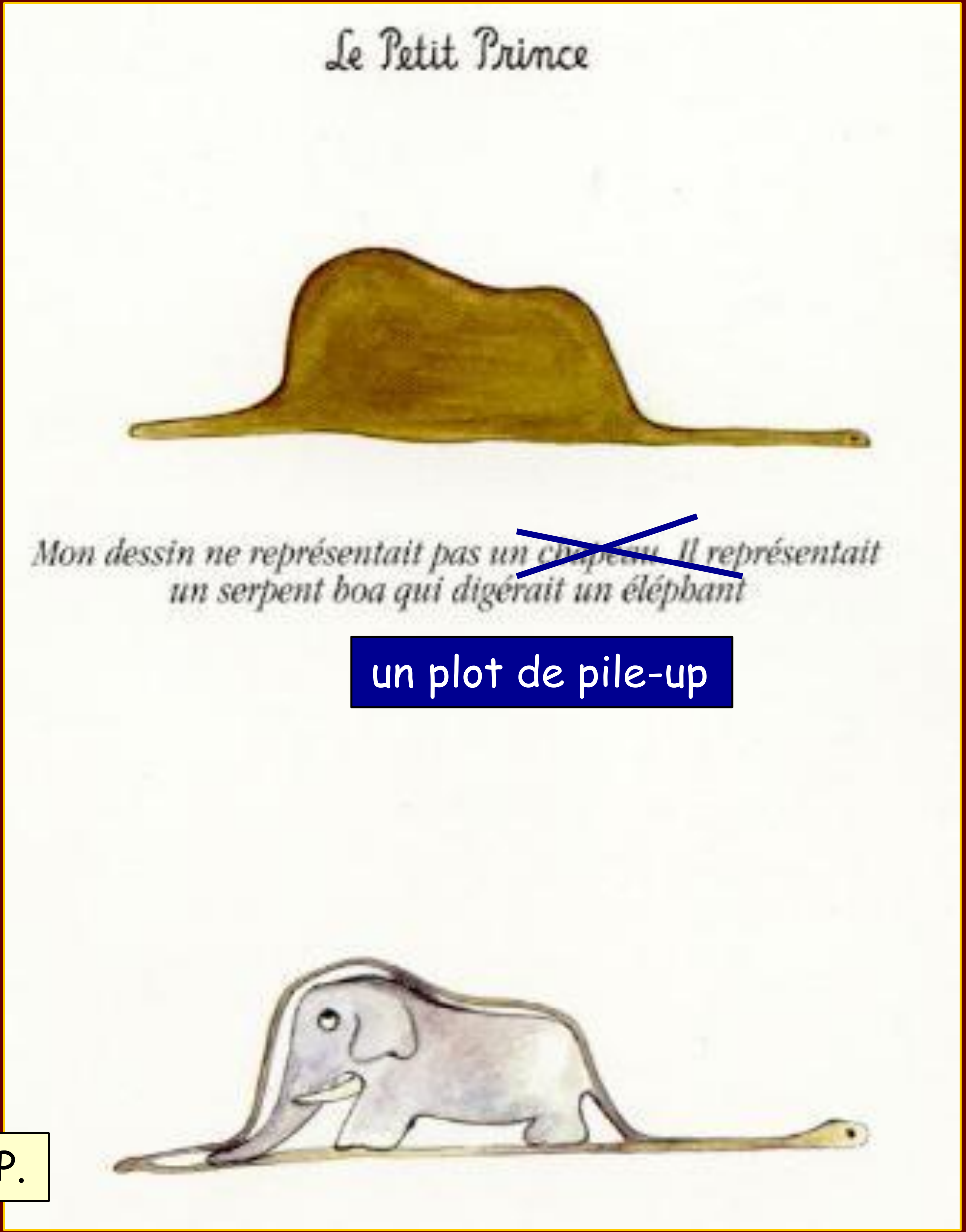


2011: ~ 10 evts/x-ing

2012: ~ 20 evts/x-ing

A more "poetic" view of pile-up

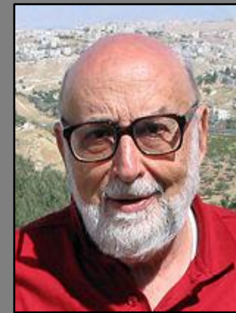




un plot de pile-up

Inspired by Thilo P.

Higgs



or, to be more correct and fair

the **Standard Model Scalar**

aka SMS

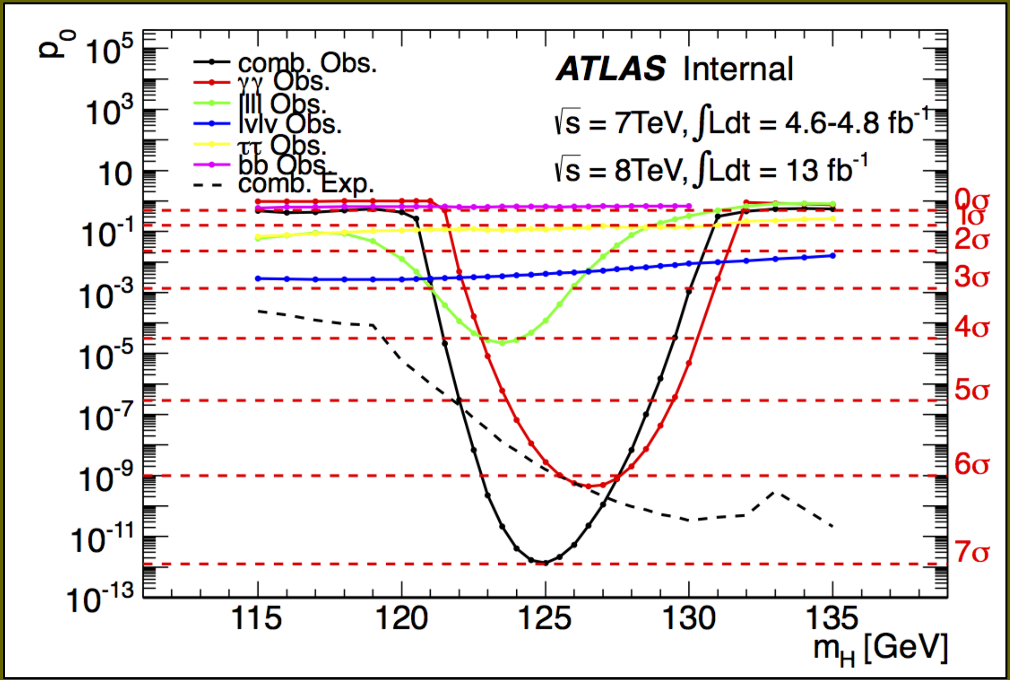
1 or 2

SMS ?

Here: latest ATLAS results based on 4.9 fb^{-1} of 7 TeV data (full 2011 sample) plus 13 fb^{-1} at 8 TeV (i.e. until TS3)

All channels together

p-value: it measures consistency of data with background-only expectation



H→ bb
H→ ττ
H→ WW → lνlν
H→ ZZ → 4l
H→ γγ
Combination

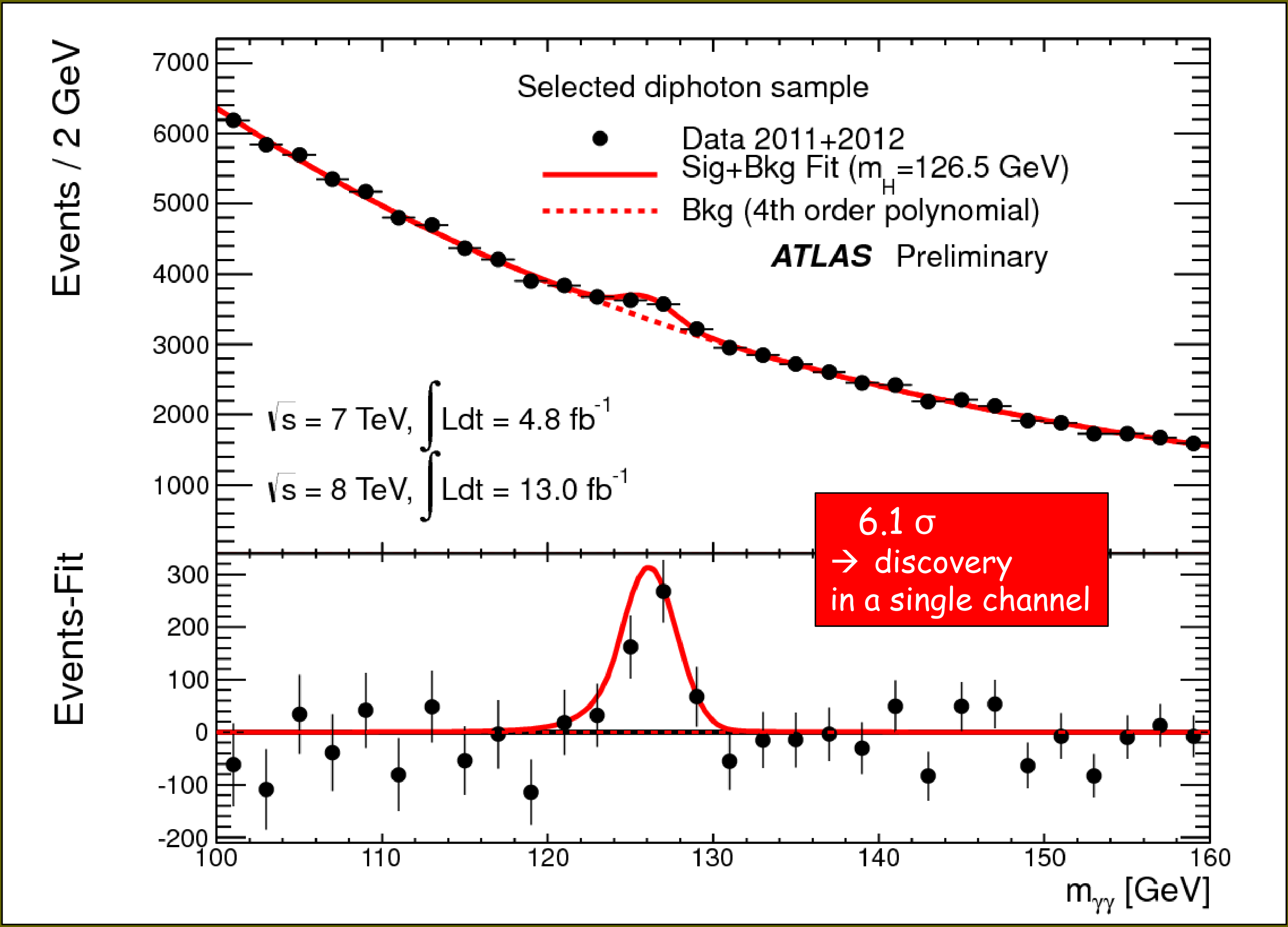
Only 1 peak

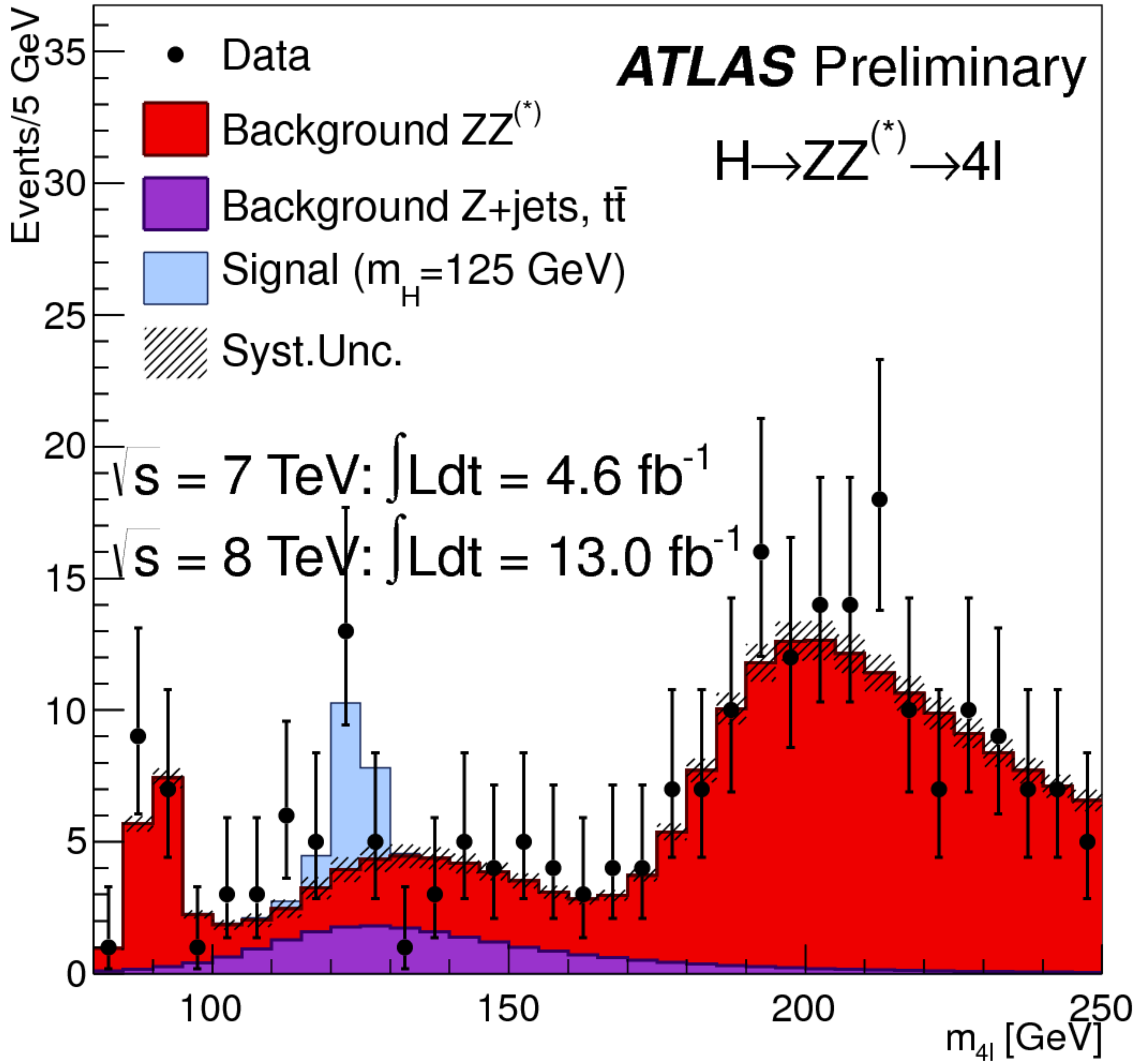
Signal continues to grow:
H→ 4l: 3.6 σ (July) → 4.1 σ (now)
H→ γγ: 4.5 σ (July) → 6.1 σ (now) → discovery in a single channel
Total: 5.9 σ (July) → ~7 σ (now)

Maximum significance at m_H ~ 125 GeV

~ 7 σ

H → γγ : "raw" (i.e. unweighted) mass spectrum

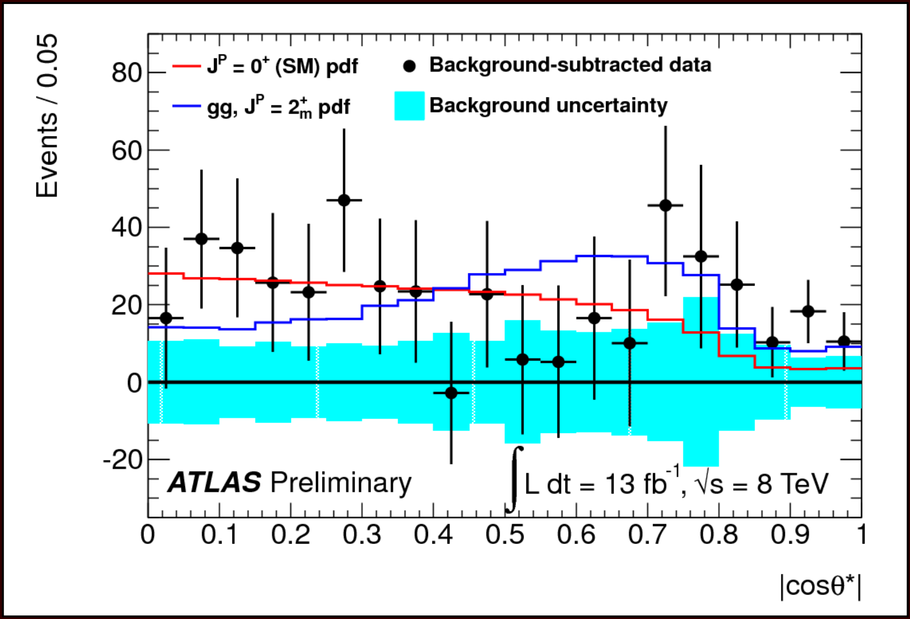


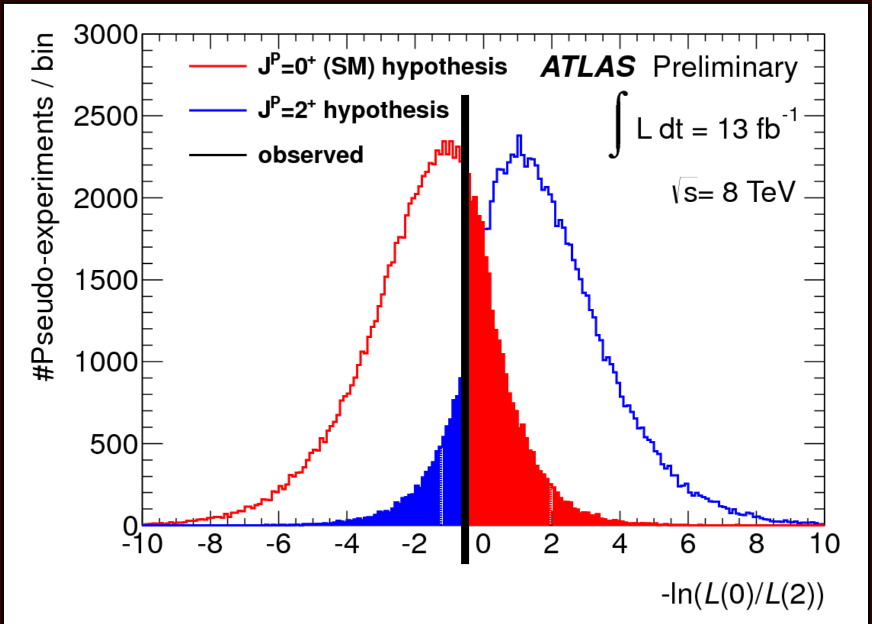

ATLAS Preliminary
H→ZZ(*)→4l
Data
Background ZZ(*)
Background Z+jets, tt̄
Signal (mH=125 GeV)
Syst.Unc.
√s = 7 TeV: ∫Ldt = 4.6 fb-1
√s = 8 TeV: ∫Ldt = 13.0 fb-1
Events/5 GeV
m4l [GeV]
0
5
10
15
20
25
30
35
100
150
200
250

Spin studies : H→ γγ

From distribution of polar angle θ* of the di-photon system in the Higgs rest frame

Compare θ* distribution in the region of the peak for:
- spin-0 hypothesis: flat before cuts
- spin-2 hypothesis: ~ $1+6\cos^2\theta^* + \cos^4\theta^*$ for Graviton-like ($gg \rightarrow G$ production)

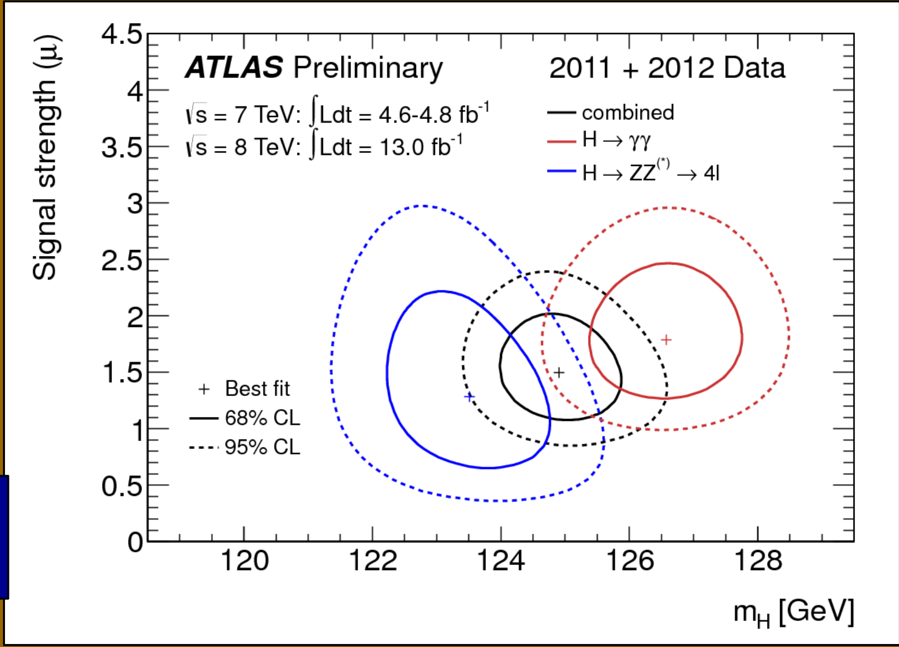




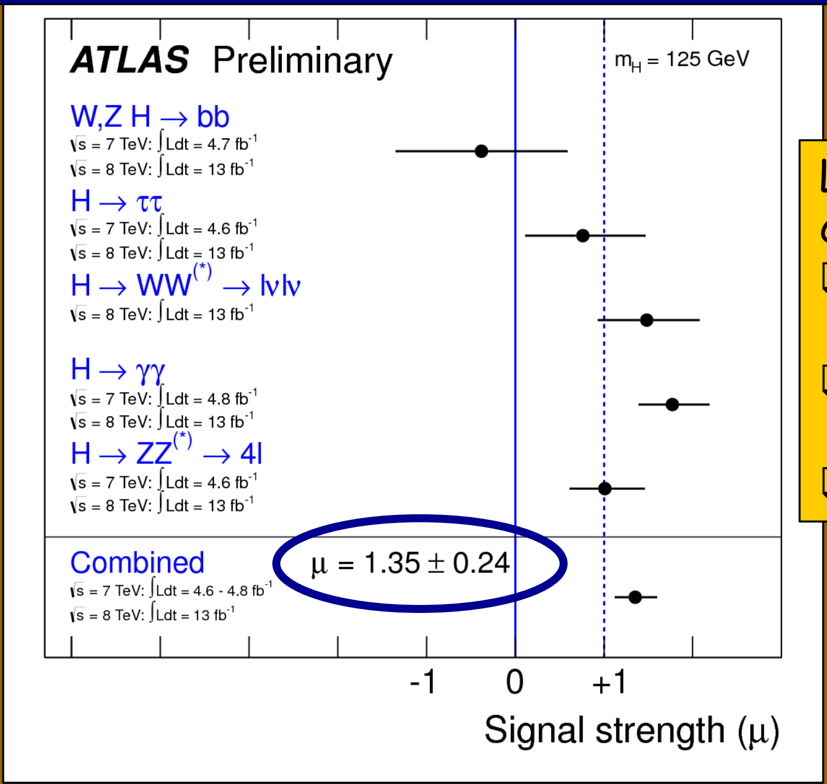
Fit to data gives: compatibility within 0.5σ with spin-0 and 1.4σ with spin-2 (i.e. spin-2 disfavoured at 91% CL)

Measured mass from H → γγ and H→ 4l
m_H = 125.2 ± 0.3 (stat) ± 0.6 (syst)

Consistency of the two individual measurements: ~ 2.5 σ



Measured (channel by channel and overall) signal strength divided by SM Higgs expectation



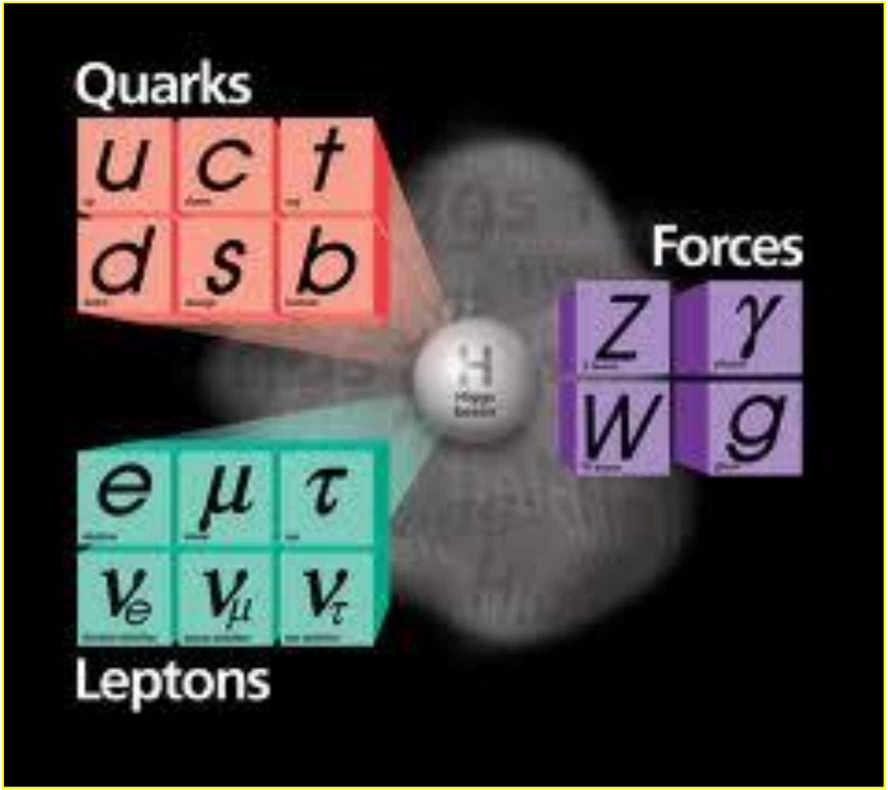
Looking forward to full 2012 dataset and combination ATLAS+CMS:

- ❑ Establish the observation in more channels (ττ, bb, more exclusive topologies ..)
- ❑ Measure properties with increasing precision
  → test more and more compatibility with SM Higgs
- ❑ Separation $0^+/2^+$ and O^+/O^- at 4σ level ?

→ hope to be able soon to remove "like" from "Higgs-like"

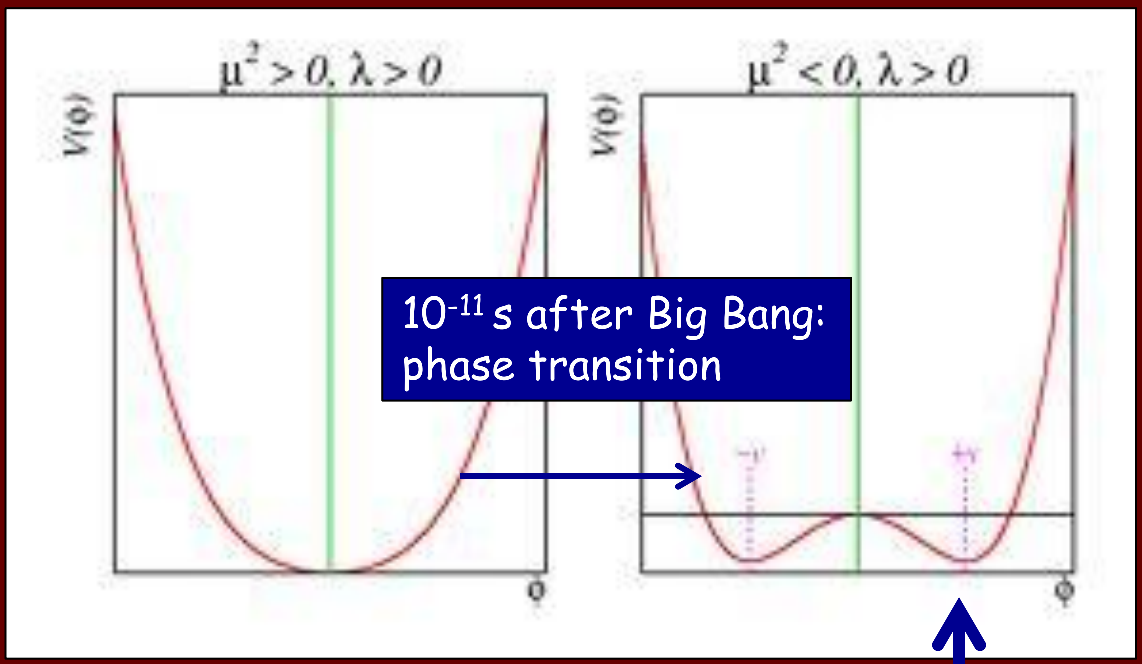
Note: the Higgs is a very special particle …

- Quarks and leptons: matter particles (spin ½)
- γ, W, Z, g : force carriers (spin 1)
- Higgs: not a matter constituent, not a force carrier → first elementary scalar (spin 0)
  Note: also implications for the evolution of the Universe: cosmologists think that the rapid initial expansion (inflation) provoked by scalar field → LHC would give first evidence of existence of scalar fields



How does the Higgs mechanism work ? An over-simplified picture …

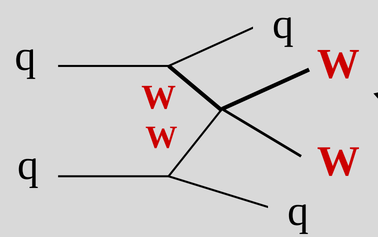
At the time of the Big Bang particles were all massless (→ were moving at speed of light) and Higgs field was there as an "non-interacting ether" (minimum of Higgs potential = 0).



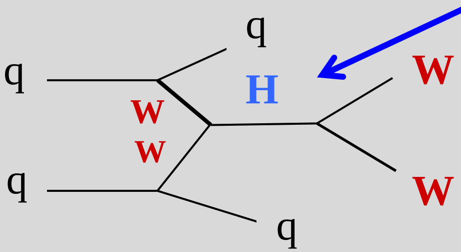
About 10^{-11} s after the Big Bang → temperature became low enough for phase transition (→ minimum of Higgs potential became negative) → ether becomes "molasses" → particles interacting with "molasses" acquire a mass and are slowed down

Two additional questions

Does this new particle fix the SM problems at high energy ?



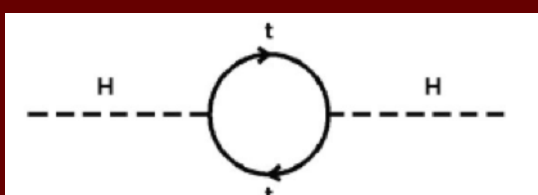
This process becomes unphysical (cross section diverges) at m(WW) ~ TeV
if this process does not exist

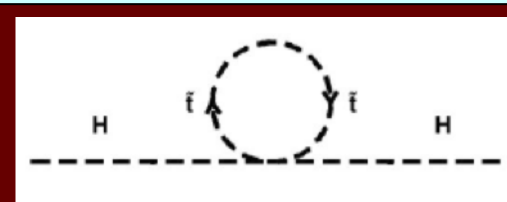


→ Need to verify that the discovered particle accomplishes this task → need √s ~ 14 TeV and Phase-2 upgrade

Why is the Higgs so light ?

→ Need new physics (close-by, ~TeV scale) to "stabilize" the divergent Higgs mass





In the SM, this correction to m_H diverges as ~ Λ^2 (energy scale up to which the SM is valid)

E.g. the supersymmetric partner of the top (stop) gives rise to the same diagram with opposite sign → cancellation
Only works if mass difference stop-top small (few hundreds GeV) → motivation for SUSY at TeV scale

In the coming years, we will (hopefully !) discover many more things. Perhaps more importantly, we will learn what are the right questions to ask and how to go on

It has been a LOOONG run, requiring the sustained effort and dedication of many people to ensure optimal operation of the accelerator and experiments

We are all exhausted ...

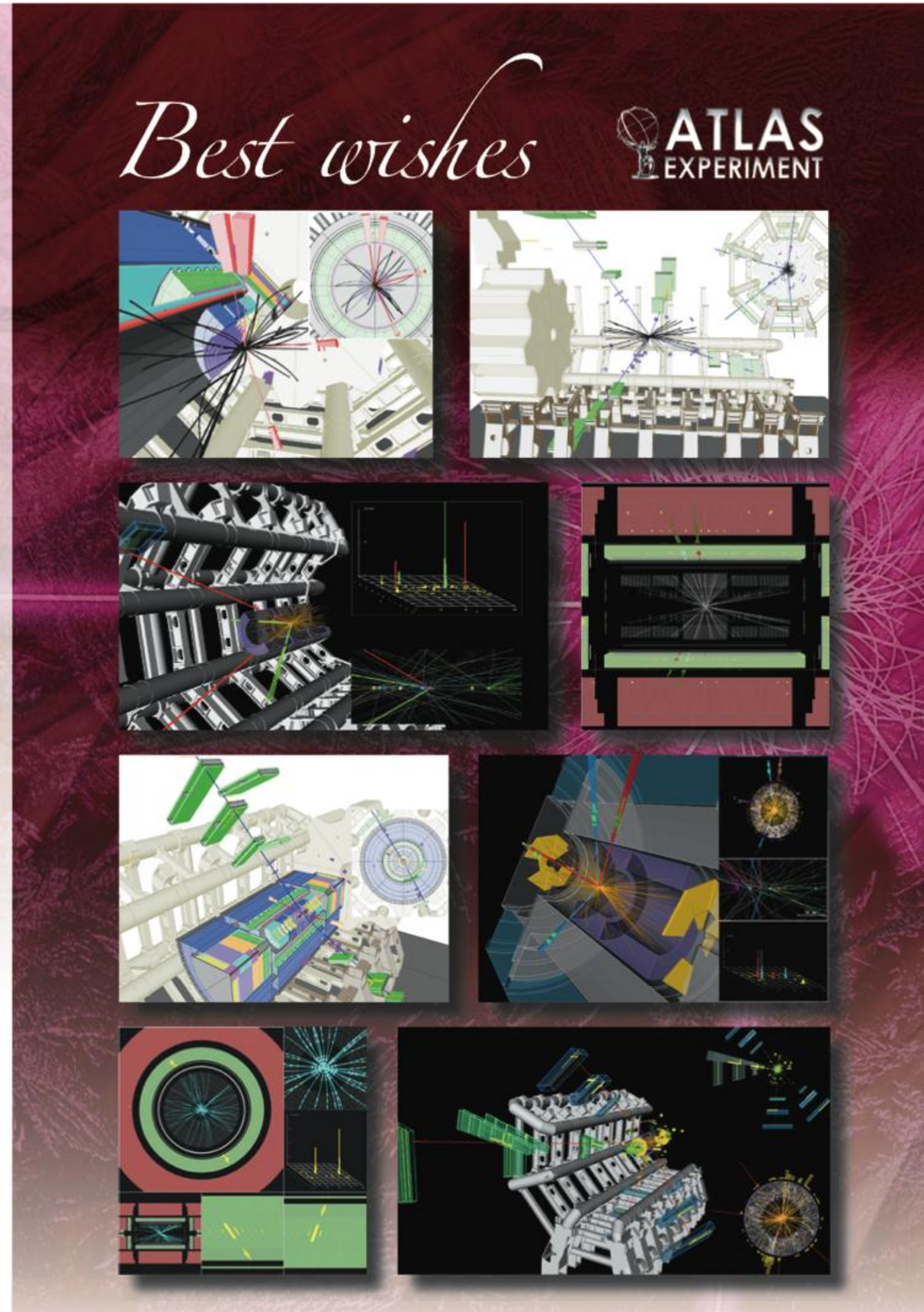
But HAPPY !

BIG THANKS

from ATLAS

TO ALL OF YOU

for making all of this possible

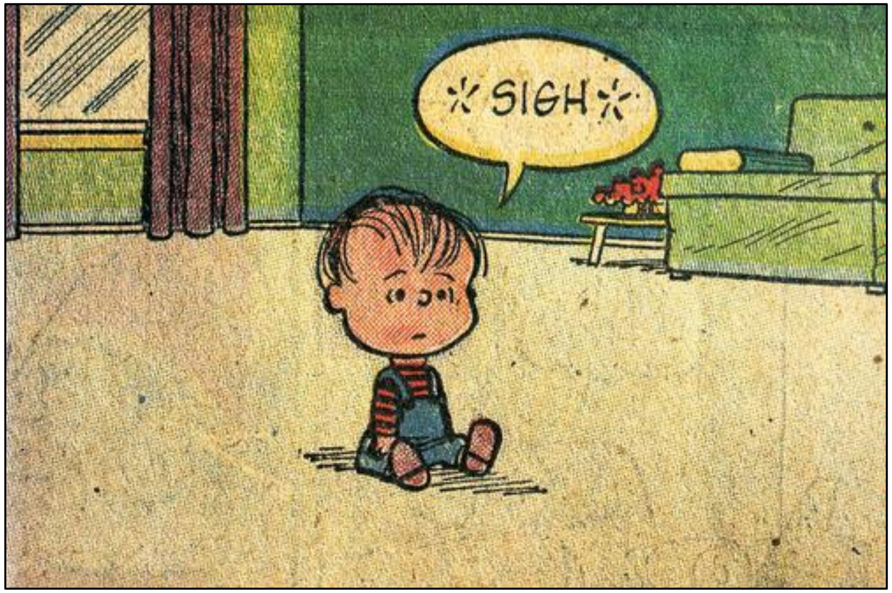


Event displays of Higgs boson candidate events

On a more personal level: it has been a honour and a pleasure for me to share with you over the last 3 years the challenges, the nice and grim moments and the excitement from first collisions at 900 GeV to the Higgs discovery and more …

My term as Spokesperson ends on 28 February 2013
Dave Charlton will take over as 1st March 2013

THANK YOU



Mass determination and mass difference between H→ γγ and H→ 4l

From the individual channels

$m_H(\gamma\gamma) = 126.6 \pm 0.3\ (stat) \pm 0.7\ (syst) = 126.6\ GeV \pm 0.8\ GeV$

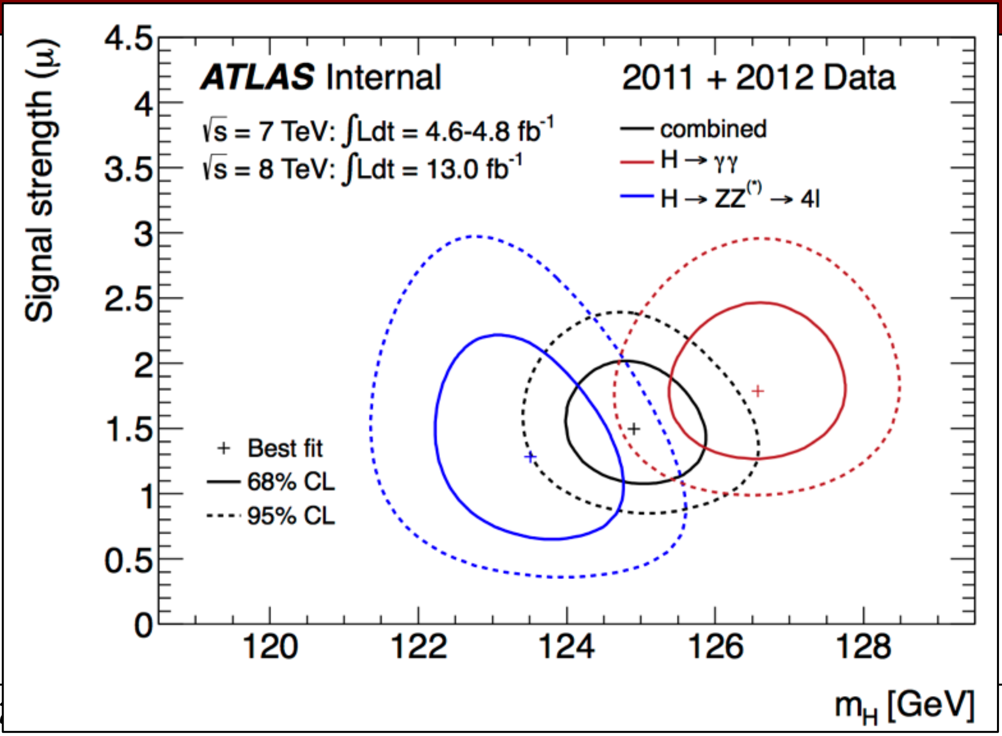
$m_H\ (4\ell) = 123.5 \pm 0.9\ (stat)\ ^{+0.4}_{-0.2}\ (syst)\ GeV = 123.5 \pm 0.9\ GeV$

From overall likelihood fit to both mass distributions taking into account correlations (between γγ and 4e E-scale), with μ(γγ) and μ(4l) free to vary within their measured values:

Best fitted overall mass: $m_H = 125.2 \pm 0.3\ (stat) \pm 0.6\ (syst) = 125.2\ GeV \pm 0.7\ GeV$

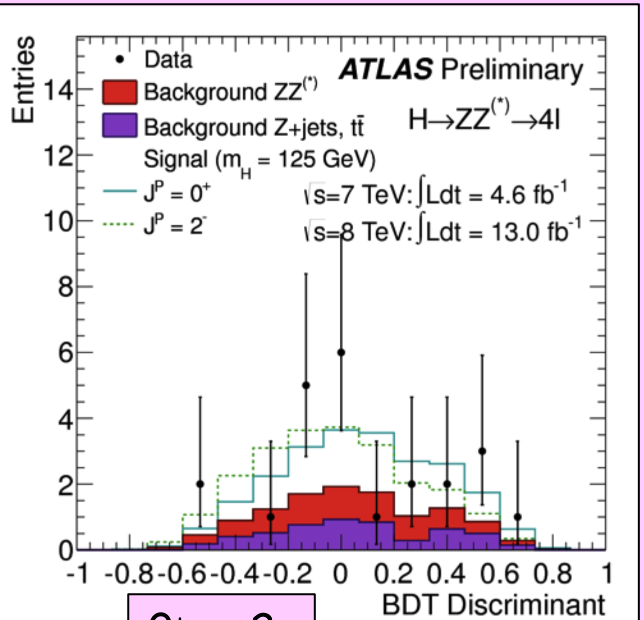
$Dm_H = m_H\ (gg) - m_H\ (4\ell) = 3.0 \pm 0.8\ (stat)\ ^{+0.7}_{-0.6}\ (syst)\ GeV = 3.0\ ^{+1.1}_{-1.0}\ GeV$

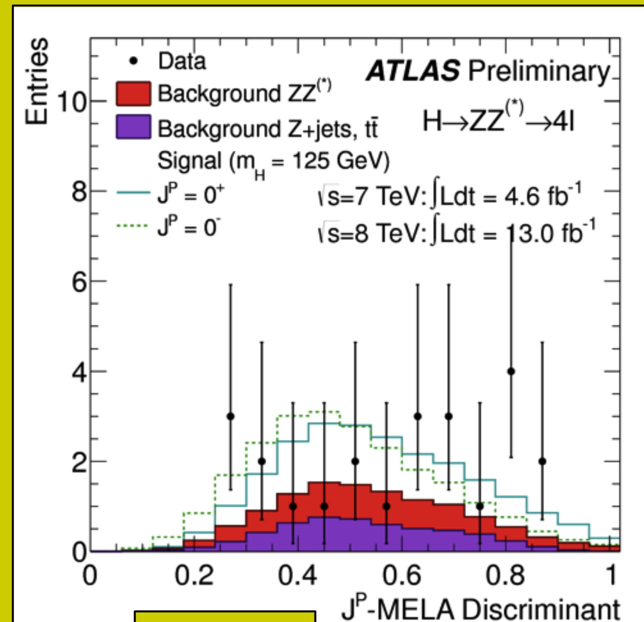
2.7 σ difference (~0.8% probability)

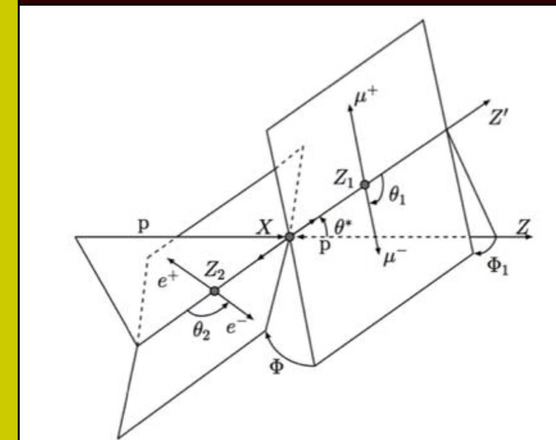


Spin-parity studies : H→ 4l

From distributions of 5 production and decay angles combined in BDT or Matrix Element (MELA) discriminants

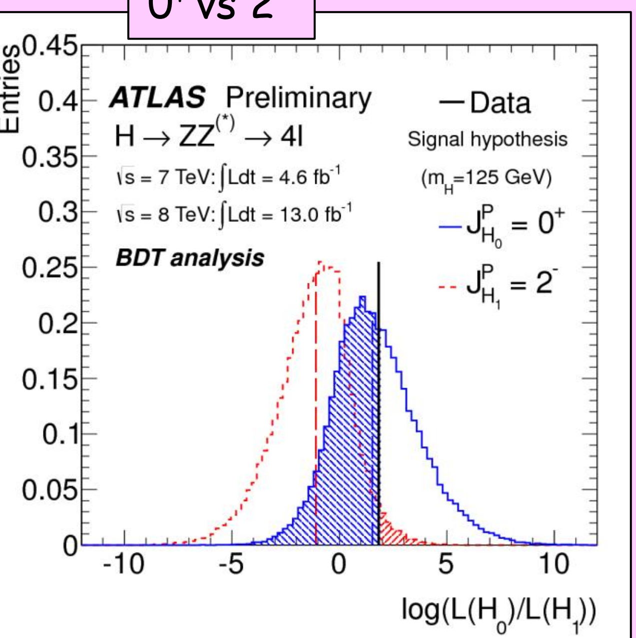




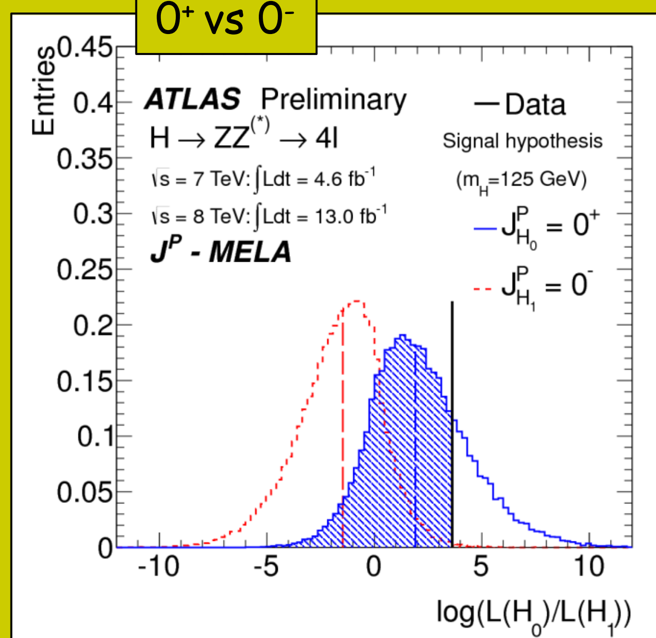


Graviton-like spin-2
gg → G production

0^+ vs 2^-



0^+ vs 0^-



0^+ vs 2^-
Compatibility with data:
0^+ : 0.15 σ
2^- : 1.9 σ

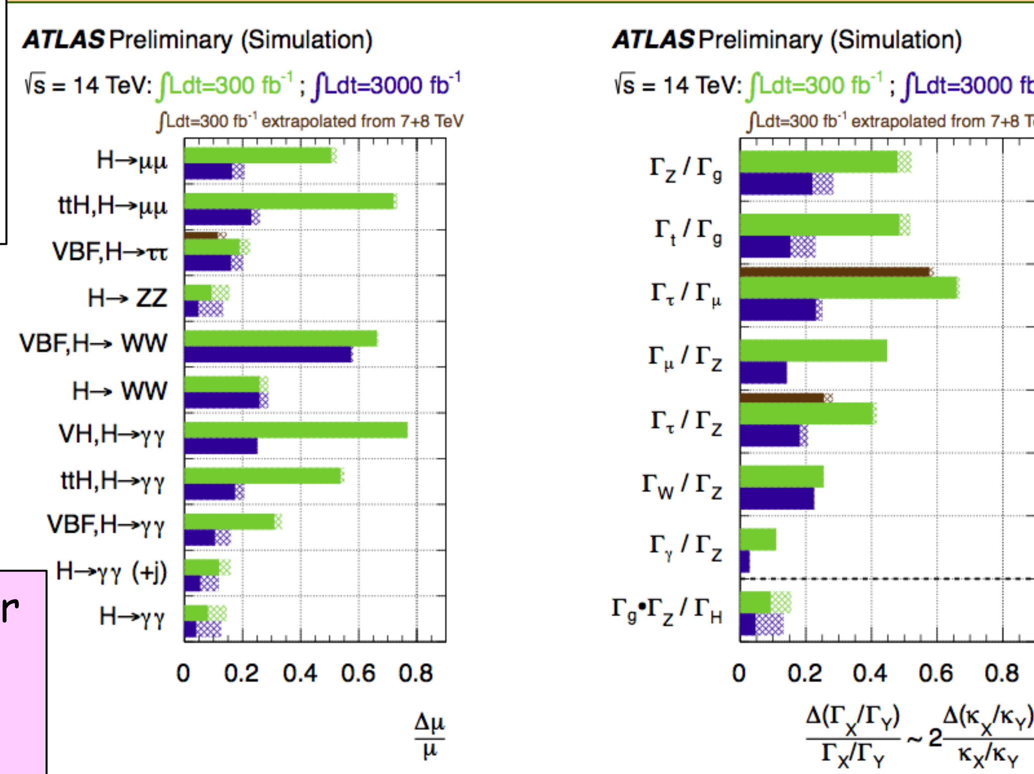
0^+ vs 0^-
Compatibility with data:
0^+ : 0.5 σ
0^- : 2.8 σ

Physics potential of the LHC upgrade: few examples from Higgs sector
(part of the ATLAS input to the European Strategy Workshop, Cracow, Sept. 2012)

Without constraints, ratios of couplings can be measured with typical precisions:

- ❑ 20-50% with ~ 300 fb^{-1}
- ❑ 5-25% with 3000 fb^{-1}

per experiment



Measurements of rare decays with 3000 fb^{-1} :

$ttH \rightarrow tt\gamma\gamma$: 200 events

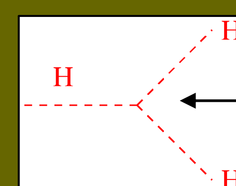
$H \rightarrow \mu\mu$: 6σ

per experiment

Assuming Γ_H (SM) and one scale factor for the fermion/vector sector → measure k_F, k_V to 6% (3%) with 300 (3000) fb^{-1} per experiment

Higgs self-couplings: ~ 3σ per experiment expected from $HH \rightarrow bb\gamma\gamma$ channel with 3000 fb^{-1}; $HH \rightarrow bb\tau\tau$ also promising

~ 30% measurement of λ/λ_{SM} may be achieved



~ λv

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

Note: -- these results are very preliminary (work of a few months) and conservative

-- physics potential of LHC upgrade is much more than just Higgs