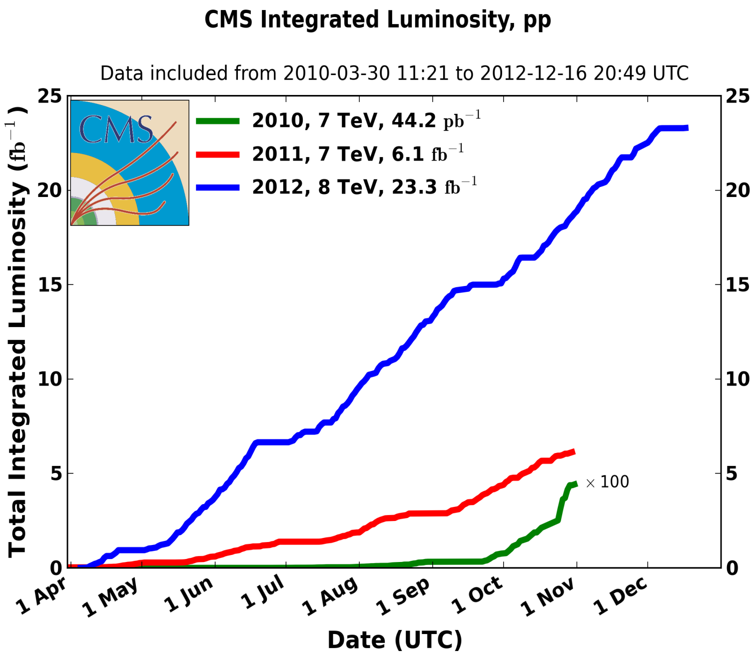
Highlights from the LHC Run1

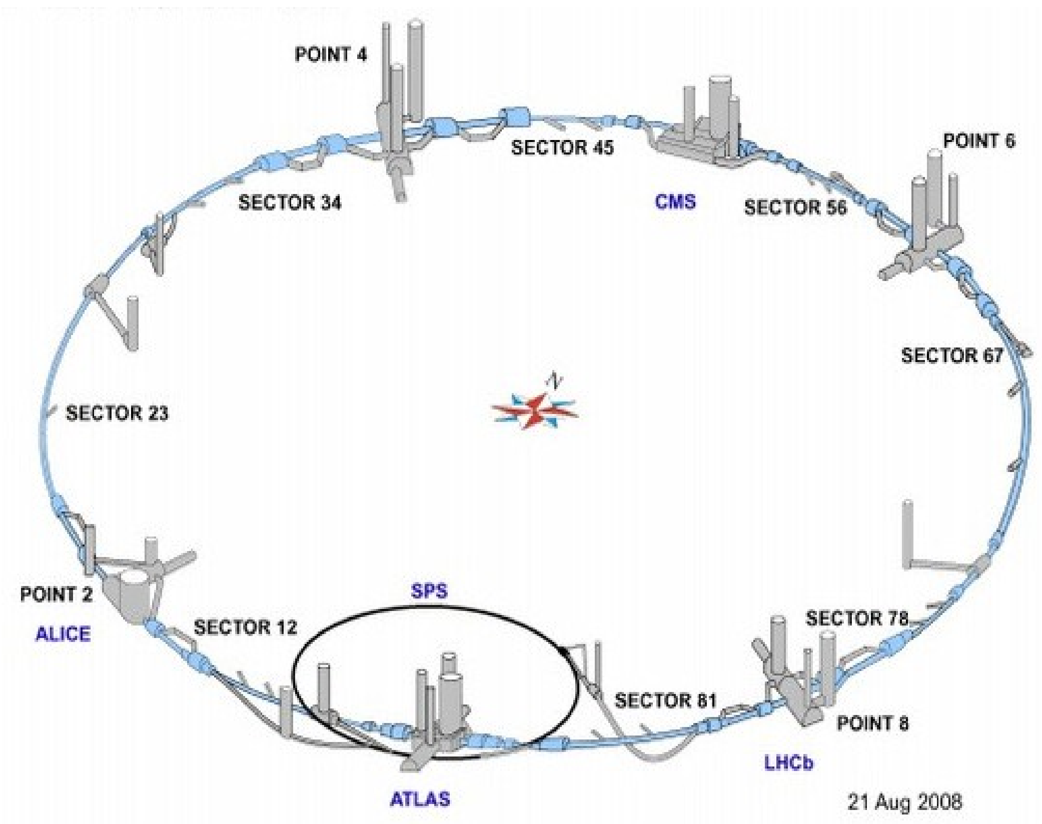
Conseil Scientifique de l'IRFU, 15/1/2015

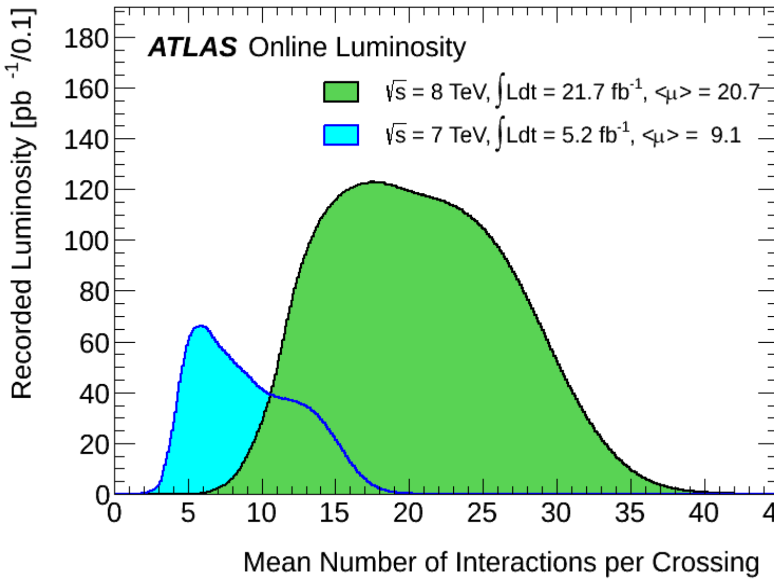
- Machine and detector performance
- Tests of the Standard Model
- Searches beyond the SM

The LHC Run 1

	Int. Lum.	√s	Collisions/crossing
2010	40 pb^{-1}	7 TeV	~1
2011	5 fb^{-1}	7 TeV	~9
2012	21 fb^{-1}	8 TeV	~21







Precision Luminosity Determination

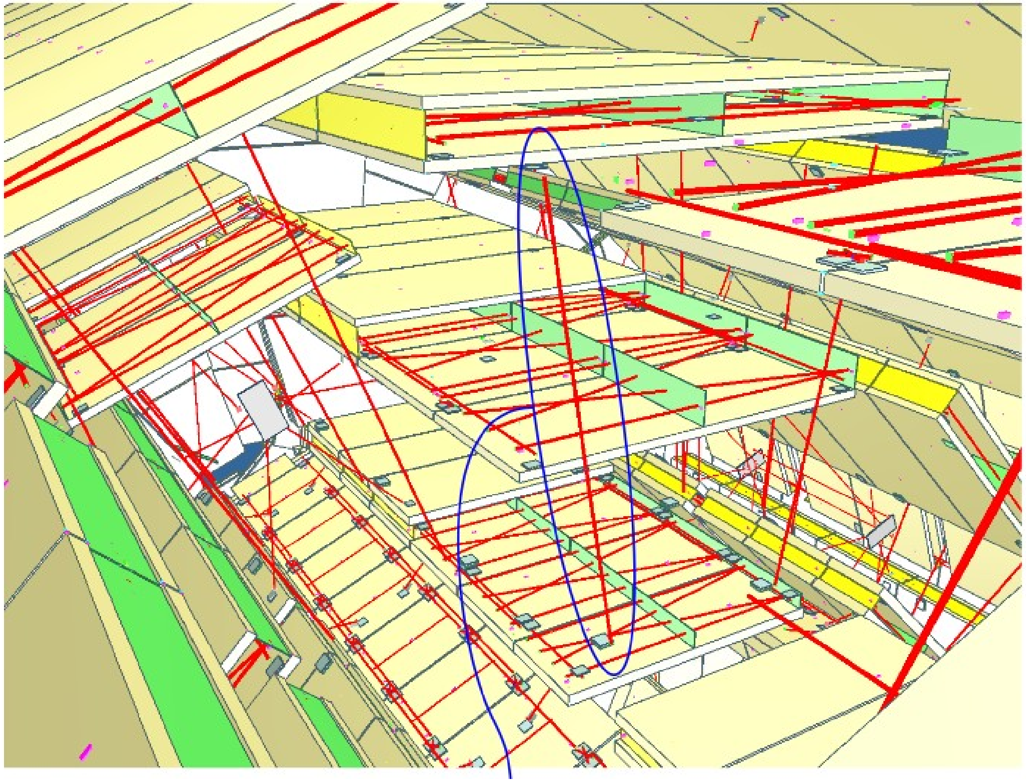
- Physics measurements require δL/L ~ 2%
  - high-precision measurements of cross-sections such as pp → W, Z, ttbar,... and of their √s-dependence provide Standard Model constraints

- Contributions of Saclay
  - within ATLAS: in charge of ATLAS Luminosity coordination since 2009
    - Pioneered the absolute-L calibration & monitoring strategy based on van der Meer scans, emphasizing the need for redundancy across multiple luminometers
    - At √s = 7 TeV, ATLAS published the most precise (**1.8%**) L determination ever since the CERN-ISR [until 2 months ago: now beaten by the LHCb VELO!]
    - Demonstrated the impact of beam-dynamics effects on L determination. Most notably, the non-factorizability of x & y proton distributions: violates fundamental vdM assumption, never considered at any previous hadron collider; now independently confirmed by LHCb
  - across the entire LHC program: a leading role
    - ATLAS methodology now largely adopted by all 4 experiments
    - An SPP physicist is Deputy LHC Program Coordinator for Luminosity and chairman of LHC-wide Luminosity Working Group

arXiv:1302.4393; doi:10.1016/j.ppnp.2014.11.002 (Saclay ed.)

Performance of ATLAS and CMS

- After successful construction and operation, the focus moved to understanding and quantifying the achieved performance, which is the primary input when turning detector-level distributions into measurements of fundamental parameters
- **ATLAS Muon spectrometer**
  - Contributions of SPP: design; construction; muon reconstruction; alignment; calibration



Design: $\delta p/p$ ~ 10% at 1 TeV
Implies σ(sagitta) ~ 40 μm

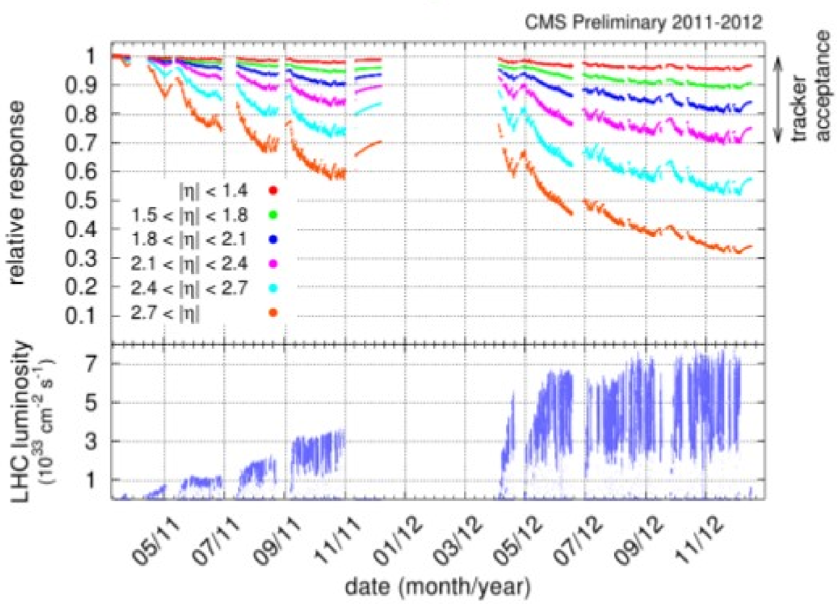
Achieved (optical alignment, tested with straight tracks):

$\sigma_{\text{ali}}(\text{tot.})$ [μm]	Repro. 2012	DC14
BA large	45 ± 2	42 ± 2
BA small	41 ± 5	43 ± 5
EC large	47 ± 5	38 ± 5
EC small	88 ± 9	90 ± 9
CS large	135 ± 12	59 ± 6
CS small	237 ± 22	67 ± 9
EE large	72 ± 8	38 ± 6
EE small	145^{+50}_{-34}	57^{+33}_{-23}

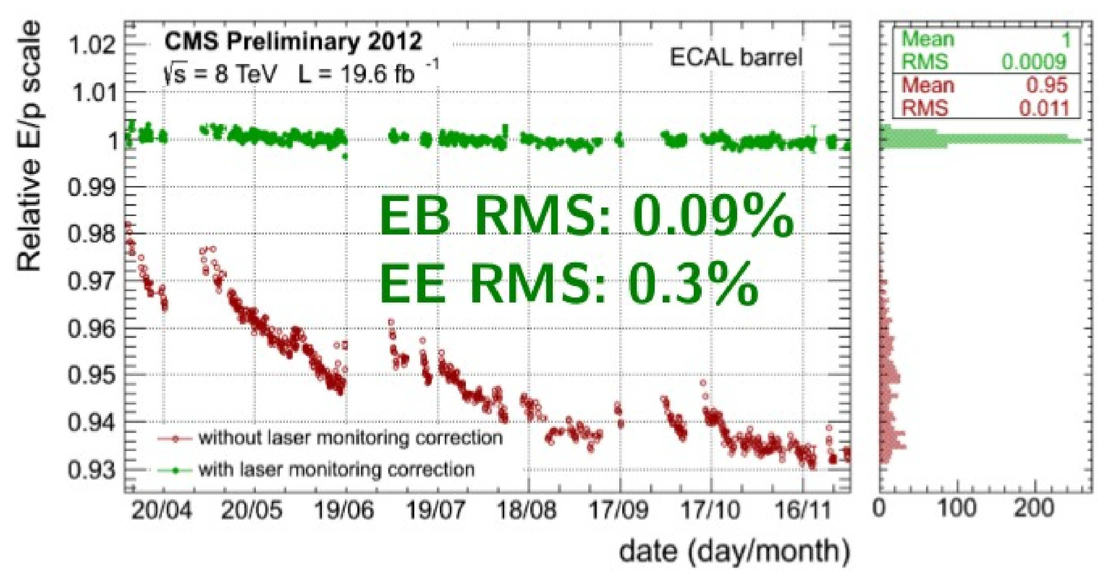
Performance of ATLAS and CMS

- Challenges of EM calibration: disentangle uncertainties in the modeling of particle-matter interactions, detector material description, and intrinsic detector response
- **CMS Electromagnetic Calorimeter**
  - Designed and strongly involved in laser monitoring (hardware and software) and calibration. Convenership of the ECAL Detector Performance Group.

Laser monitoring measurements

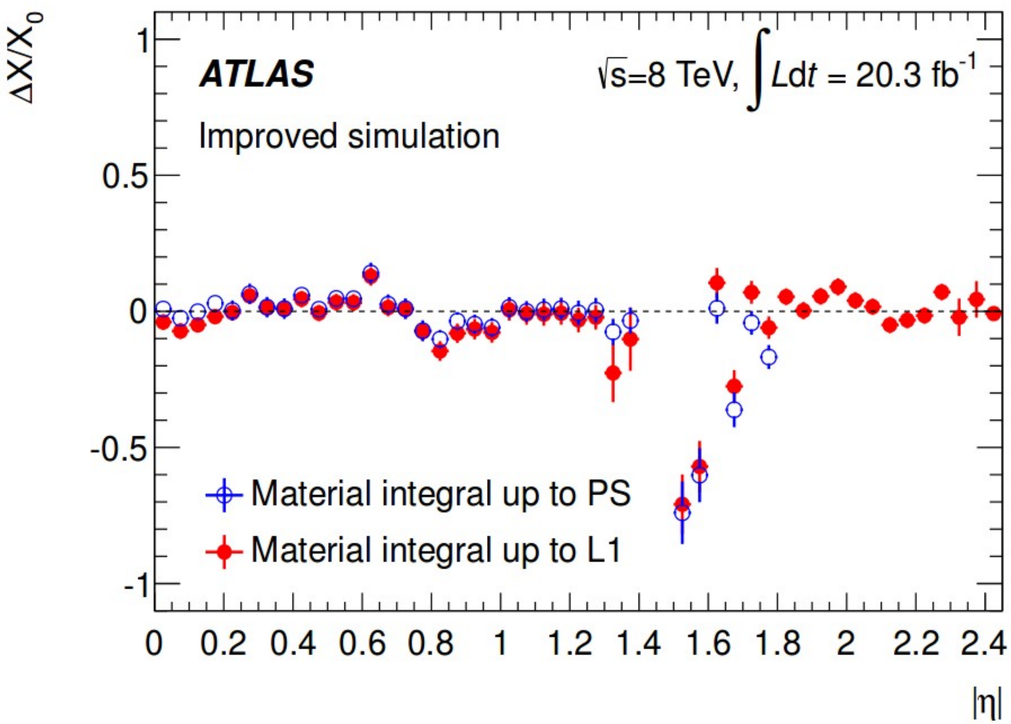


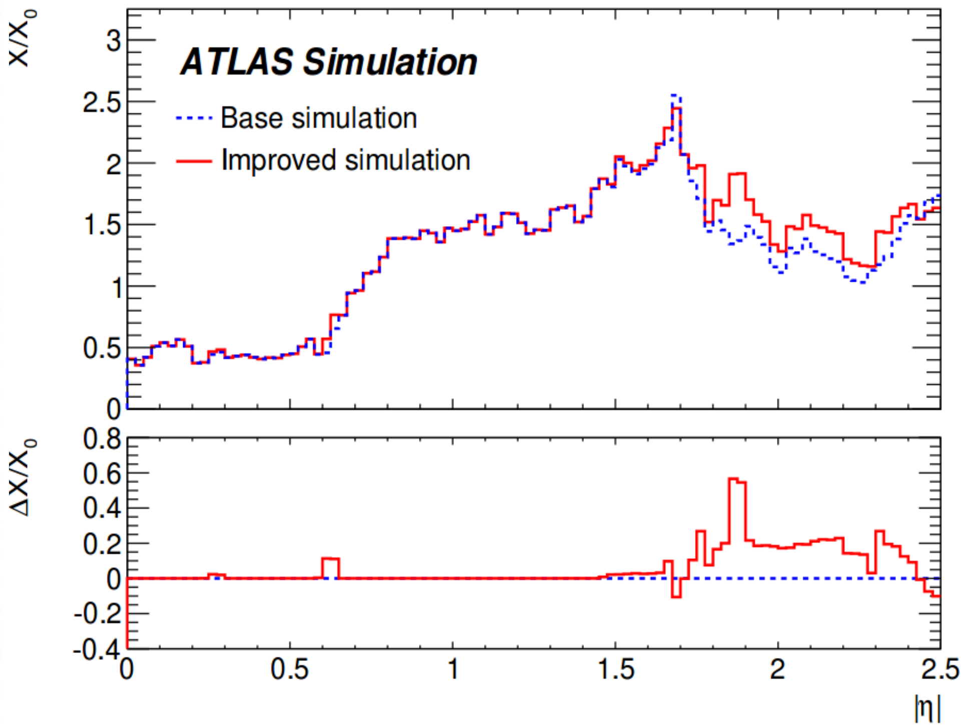
Validation of the corrections with E/p



Performance of ATLAS and CMS

- **ATLAS Electromagnetic Calorimeter**
  - SPP led construction and quality control; convened final e/γ calibration for Run 1 data
  - Shown here: detector passive material determination, using EM shower depth

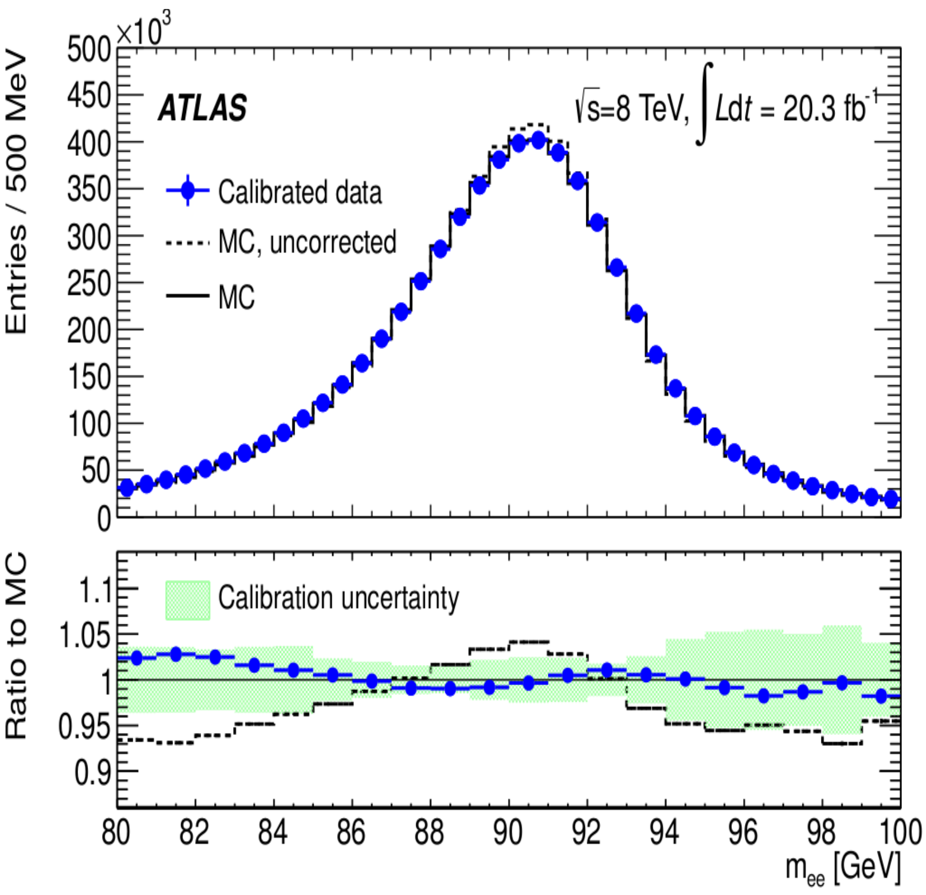


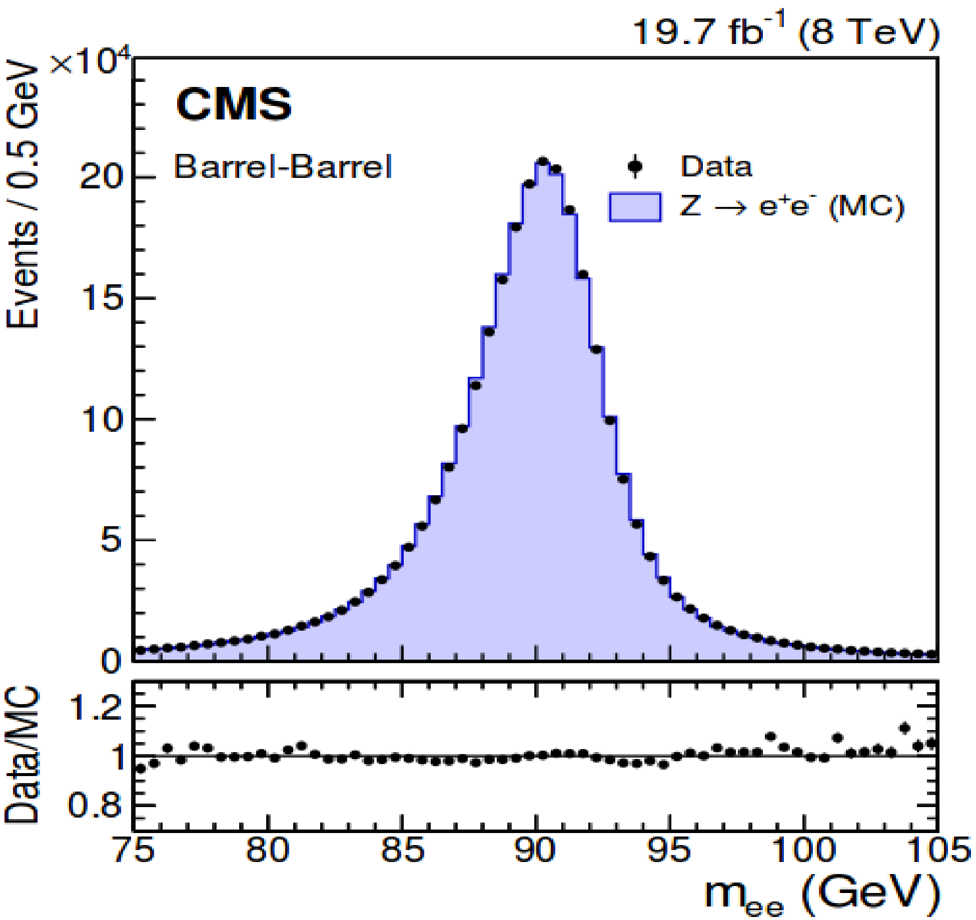


arXiv:1407.5063 (Saclay ed.)

Performance of ATLAS and CMS

- **Physics performance**
  - Ultimate test: quality of “standard candles” simulation: J/Psi, Upsilon, Z (momentum scale; resolution; energy and momentum tails)





Performance of ATLAS and CMS

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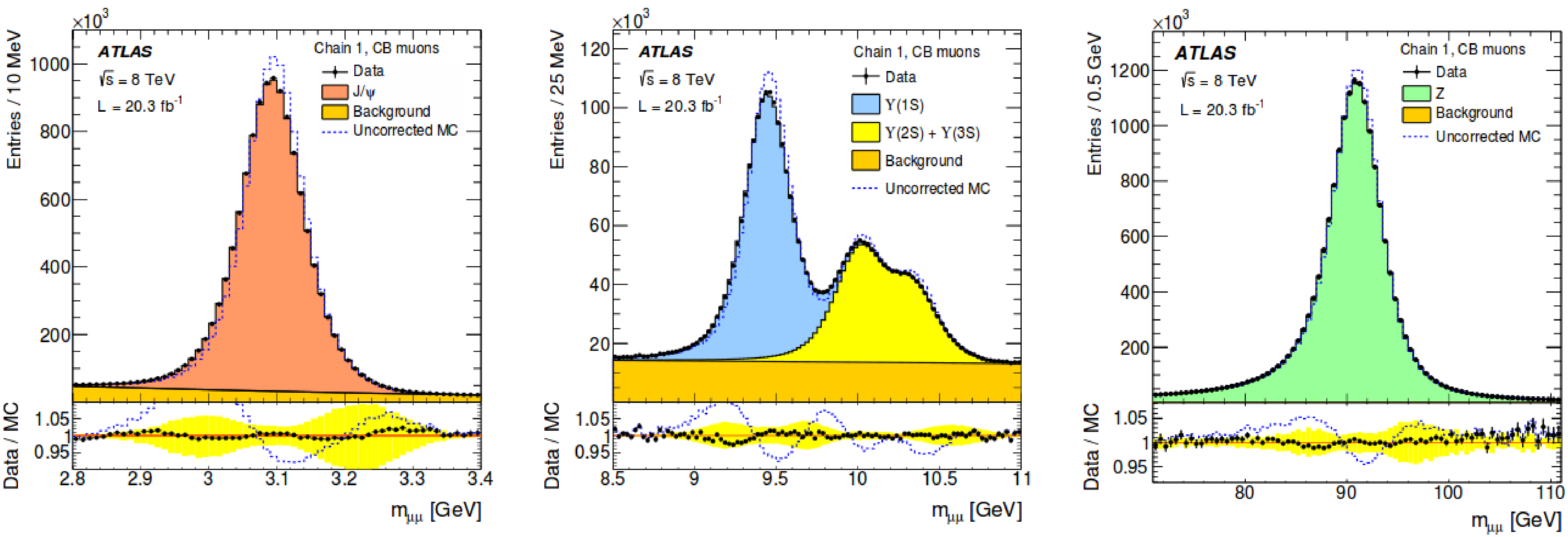
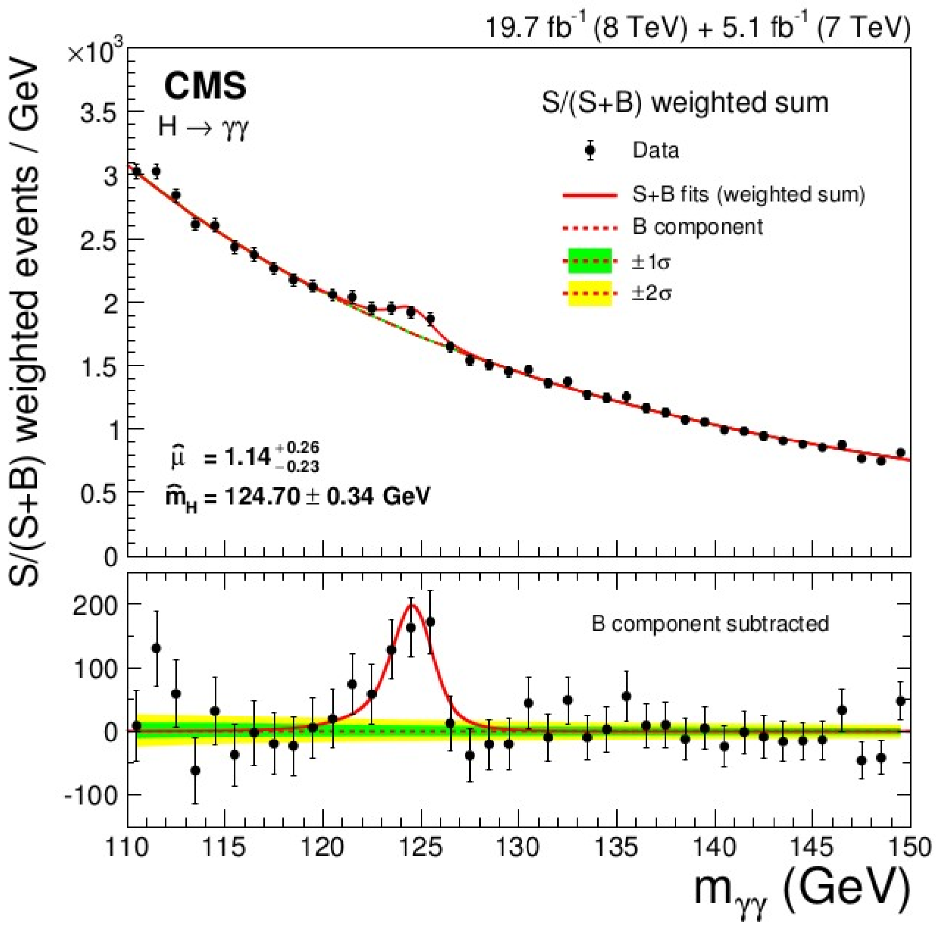
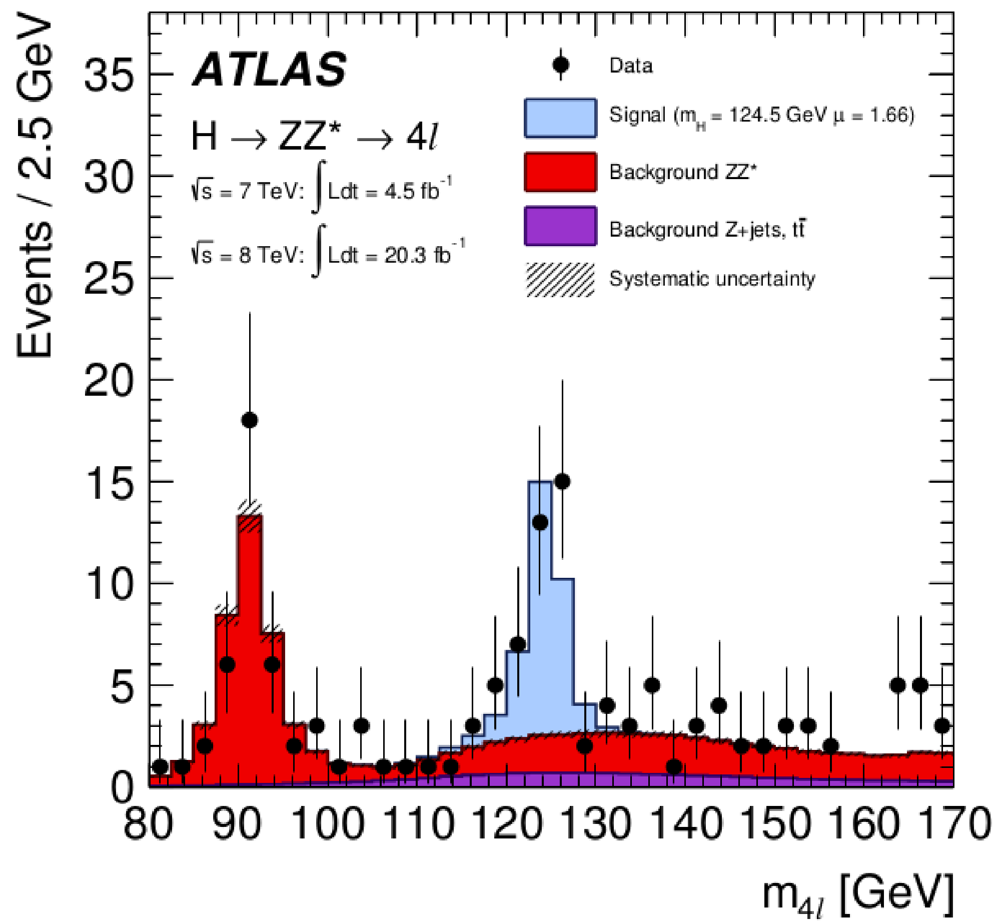


arXiv:1408.3179 (Saclay ed.)

Electroweak symmetry breaking

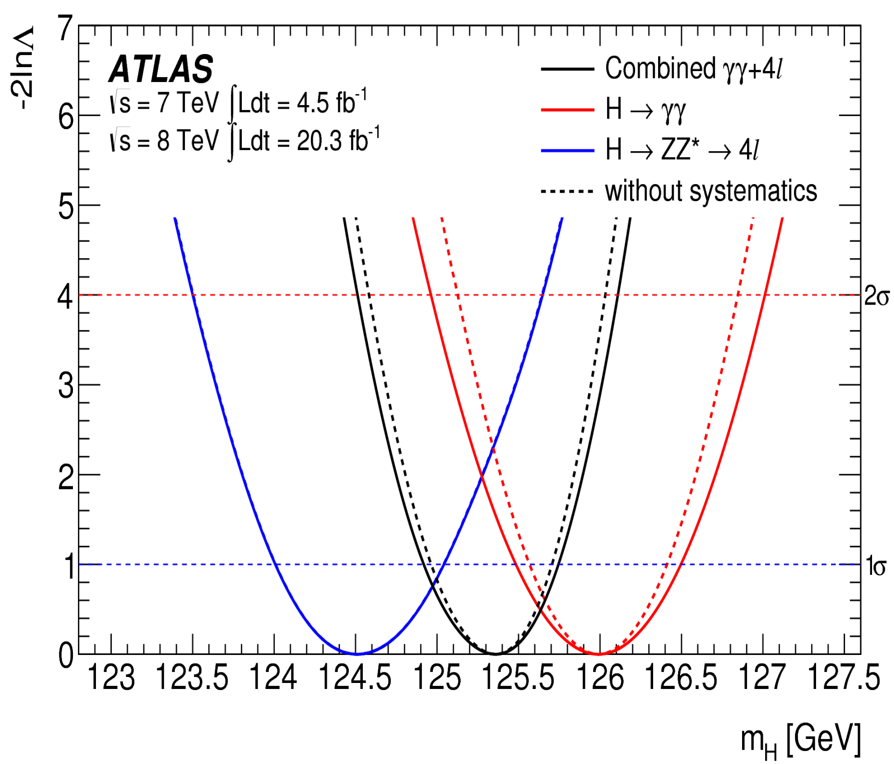
- Reminder - Higgs boson discovery
  - Single main objective of the LHC. Announced July 4, 2012
  - Updated with full statistics and final calibration and analysis:



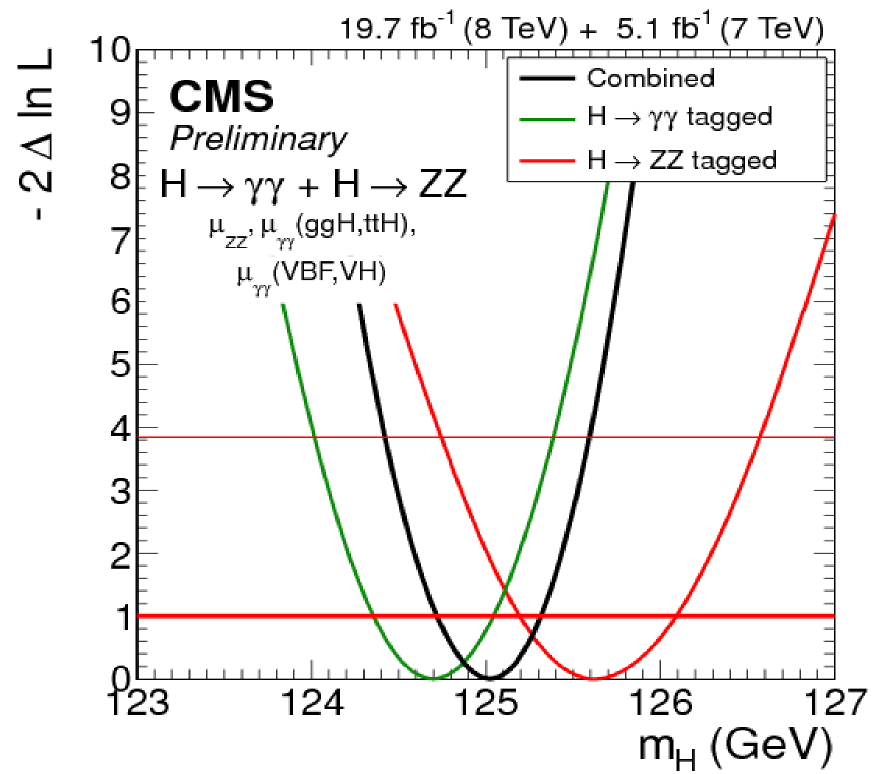


Electroweak symmetry breaking

- Property measurements / testing the SM: **Higgs boson mass**
  - Direct result of calibration efforts described above. Improvements in detector description, calibration, and measurement procedure. In both experiments, calibration systematics divided by a factor 2-3 compared to initial measurements.



125.36 ± 0.37 (stat.) ± 0.18 (syst.)



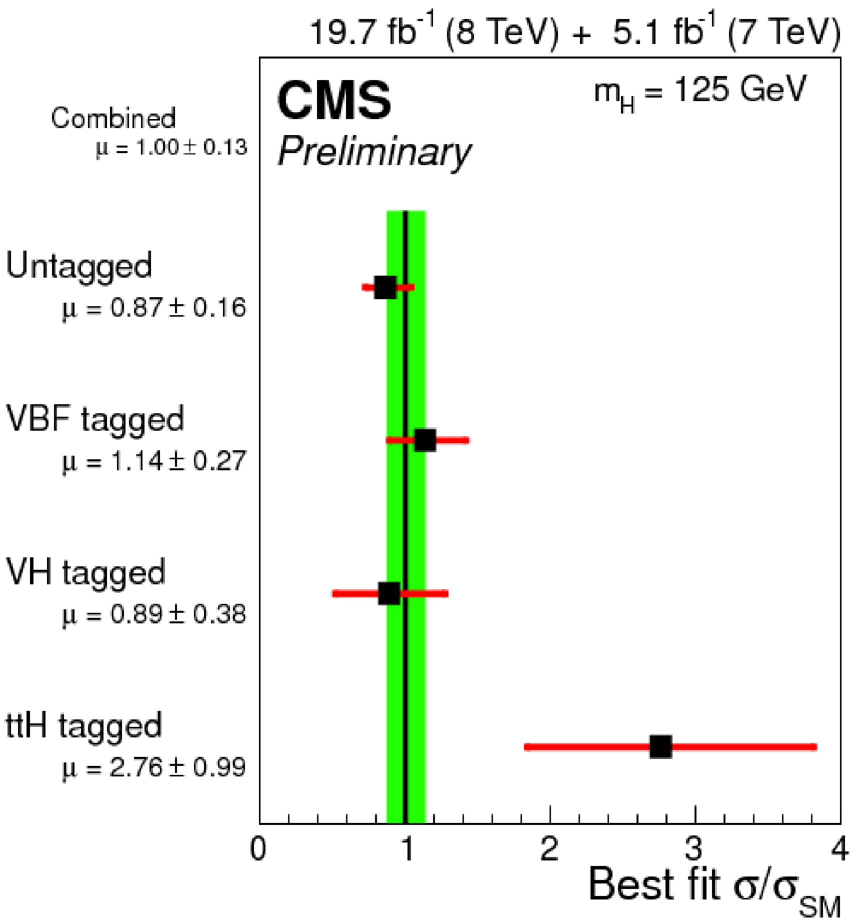
125.03 ± 0.26 (stat.) ± 0.14 (syst.)

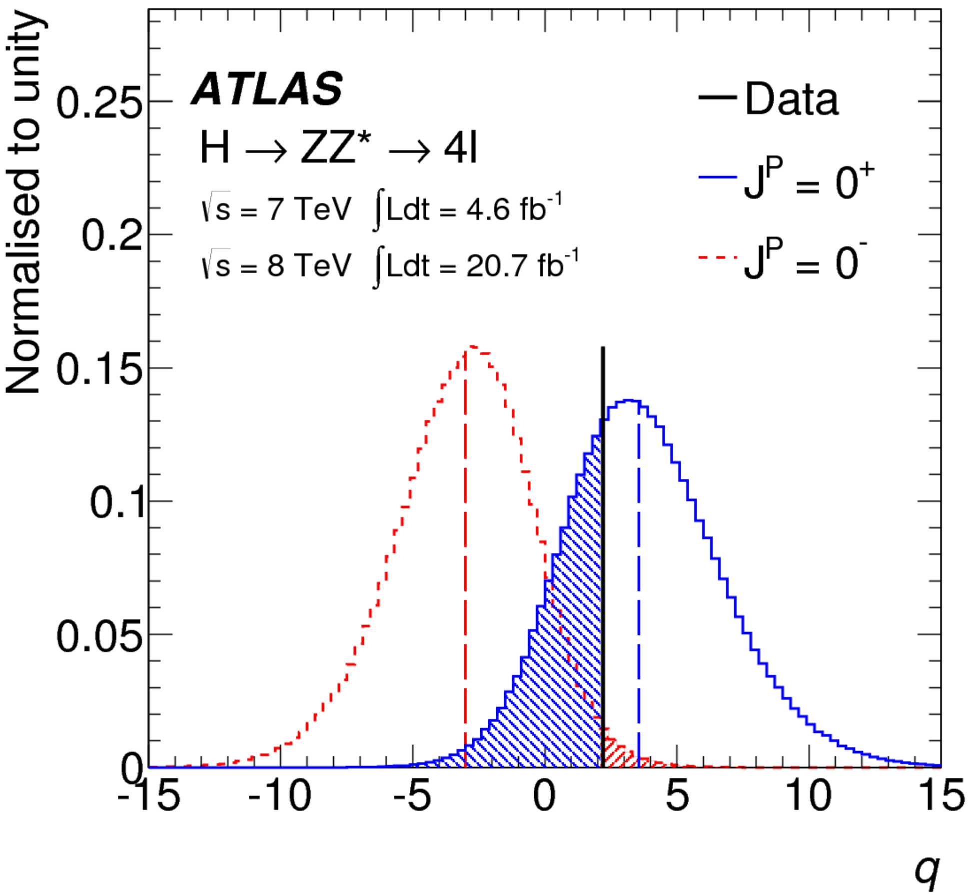
arXiv:1406.3827 (ATLAS, Saclay ed.)

arXiv:1412.8662 (CMS)

Electroweak symmetry breaking

- Property measurements / testing the SM: **coupling strength & spin/CP**
  - Strong analysis contributions from SPP.
  - arXiv:1307.1432 (ATLAS), arXiv:1412.8662 (CMS)





Electroweak symmetry breaking

- Property measurements / testing the SM: **coupling to fermions**
  - Nature Physics 10, 557–560 (2014) (Saclay ed.)
  - Combining weaker observations of $H \rightarrow bb$ and $H \rightarrow \tau\tau$, a stronger evidence of Higgs boson decays to fermions is achieved.

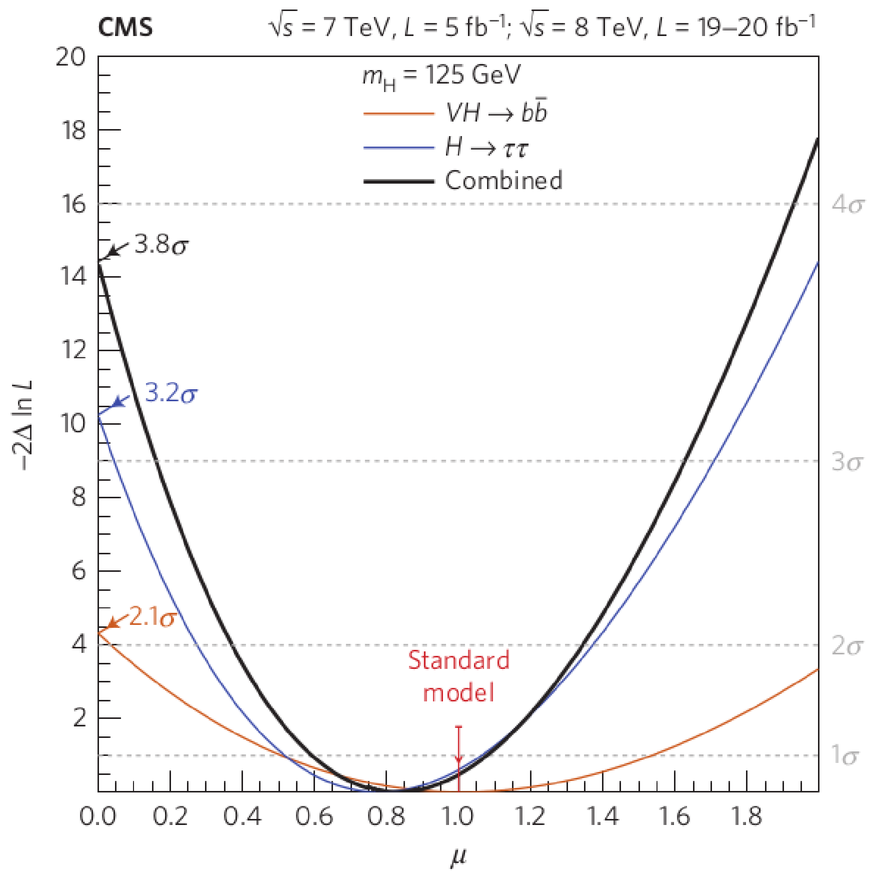


Table 1 | Summary of results for the Higgs boson mass hypothesis of 125 GeV.

Channel ($m_H = 125$ GeV)	Significance (σ) Expected	Significance (σ) Observed	Best-fit μ
$VH \rightarrow b\bar{b}$	2.3	2.1	1.0 ± 0.5
$H \rightarrow \tau\tau$	3.7	3.2	0.78 ± 0.27
Combined	4.4	3.8	0.83 ± 0.24

The p-values for the background-only hypothesis are expressed in terms of one-sided Gaussian tail significances and are provided in units of standard deviation (σ). The expected significance is that obtained after the fit of the signal-plus-background hypothesis to the data. Note that the expected significance of 2.1σ quoted in ref. 15 for the $VH \rightarrow b\bar{b}$ channel was obtained before the fit of the signal-plus-background hypothesis to the data. The best-fit value of the signal strength relative to the expectation from the standard model, μ, summarizes the profile likelihood scan of Fig. 2. For simplicity, uncertainties have been symmetrized. The statistical component represents more than 80% of the uncertainties.

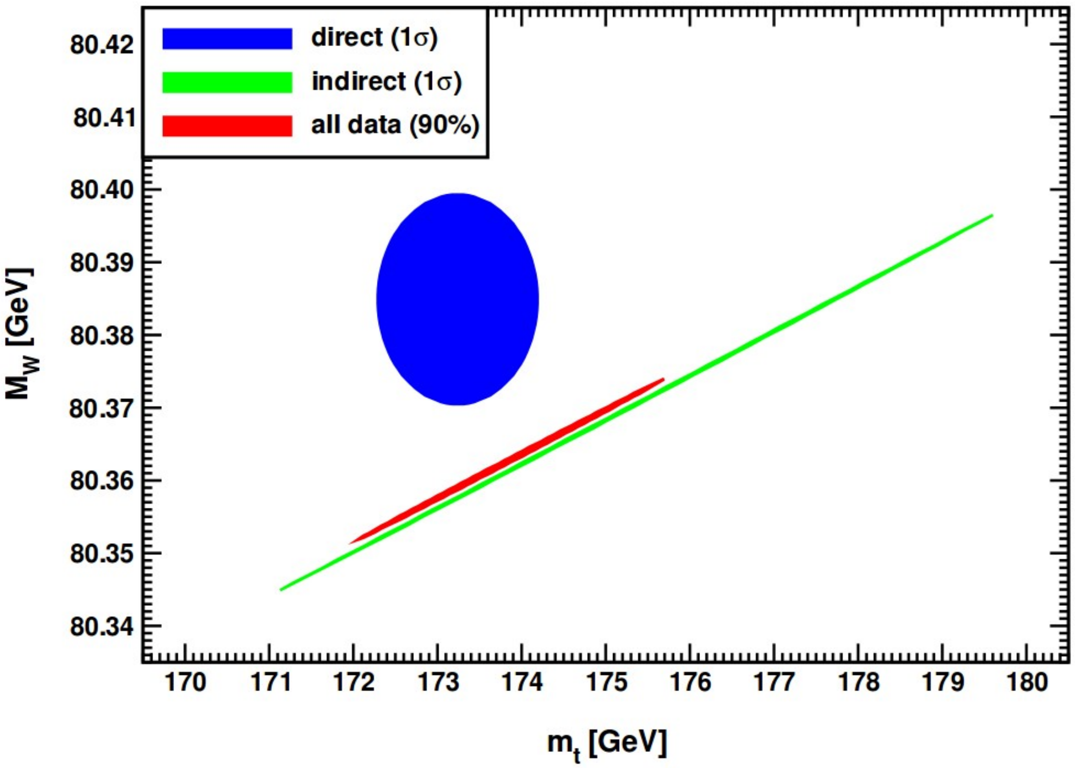
SPP Convenerships:

CMS: $H \rightarrow \gamma\gamma$

ATLAS: Higgs WG and $H \rightarrow 4l$

Electroweak symmetry breaking

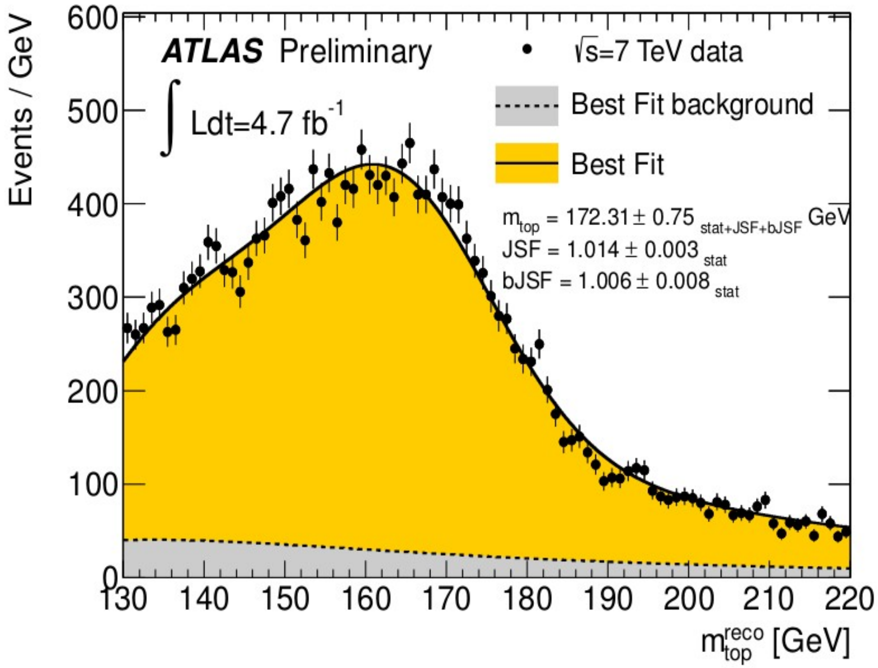
- Next steps: consistency tests of the SM at the quantum level
  - For given M_H, $M_W = f(m_{TOP})$ is fixed:



  - Precise measurements of the top quark and W boson masses are the next major step in confirming the validity of the Standard Model

Electroweak symmetry breaking

- ATLAS regularly involved in top mass measurements since start of data taking
  - Working group convenerships (top mass, combinations)
  - Contributed to latest ATLAS result, http://cds.cern.ch/record/1547327



- Leading role in W boson mass measurement
  - ERC grant dedicated to this project (funding 3 PhD, 2 post-docts, partnerships; 2011-2016)
  - First result still pending. SPP group led several preparatory publications, all edited at SPP:
    - Electron/photon calibration, arXiv:1407.5063 ; Muon calibration, arXiv:1408.3179
    - Z boson transverse momentum distribution (most precise measurement ever), arXiv:1406.3660

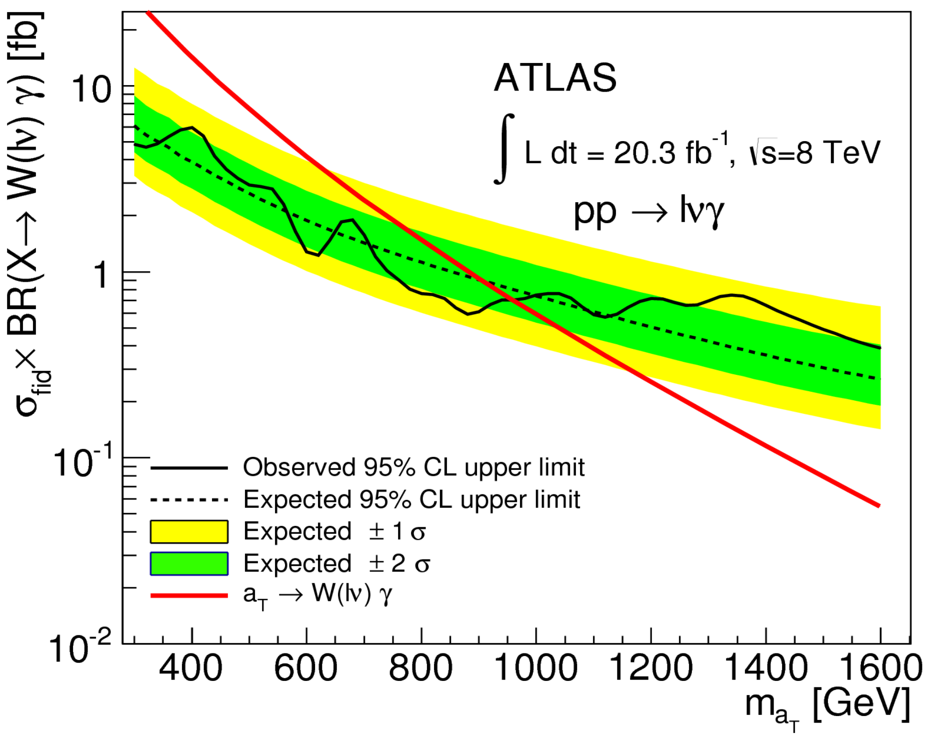
Gauge boson interactions

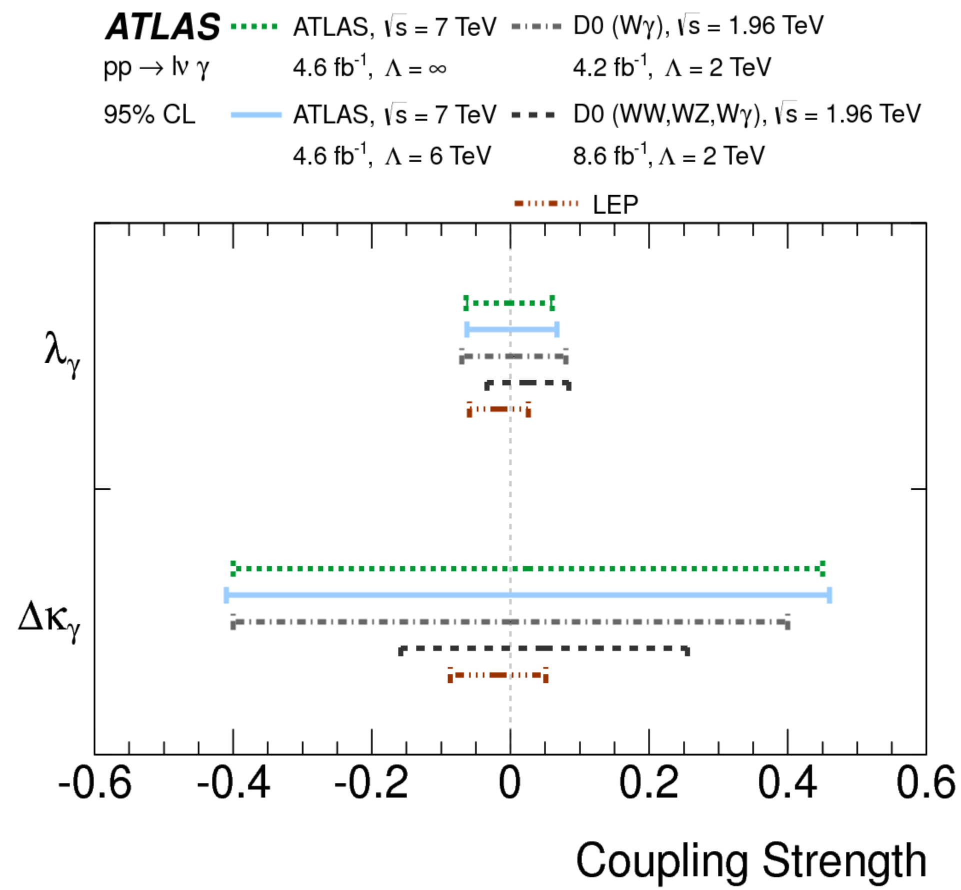
- ATLAS-Saclay very active in tests of the Standard Model in gauge boson pair production:
  - pp → WW, WZ, ZZ, (W,Z)γ, (W,Z)γγ
  - Cross section measurements; interpretation in terms of anomalous gauge couplings
  - Search for new resonances in di-boson final states

- Leading role in these analyses:
  - Dedicated ERC grant (2011-2016), financing 4 post-docs and 1 PhD program
  - analysis coordinator and paper editor for several measurements with 7 and 8 TeV data
    - Measurements of Wγ and Zγ production at 7 Te V (PhysR evD.87.112003)
    - Measurements of WZ production at 7 TeV (Eur. Phys. J. C (2012) 72:2173)
    - Measurement of the WW production cross at 8 TeV (ATLAS-CONF-2014-033)
    - WZ Production Cross Section at 8 TeV (ATLAS-CONF-2013-021)
    - ZZ Production Cross Section at 8 TeV (ATLAS-CONF-2013-020)
    - Search for new resonances in Wγ and Zγ at 8 TeV (PLB 738 (2014) 428-447)
    - Measurement of the Wγγ production at 8 TeV (to be submitted to PRL)
    - The Inclusive 4ℓ lineshape measurement at 8 TeV (under preparation)

Gauge boson interactions

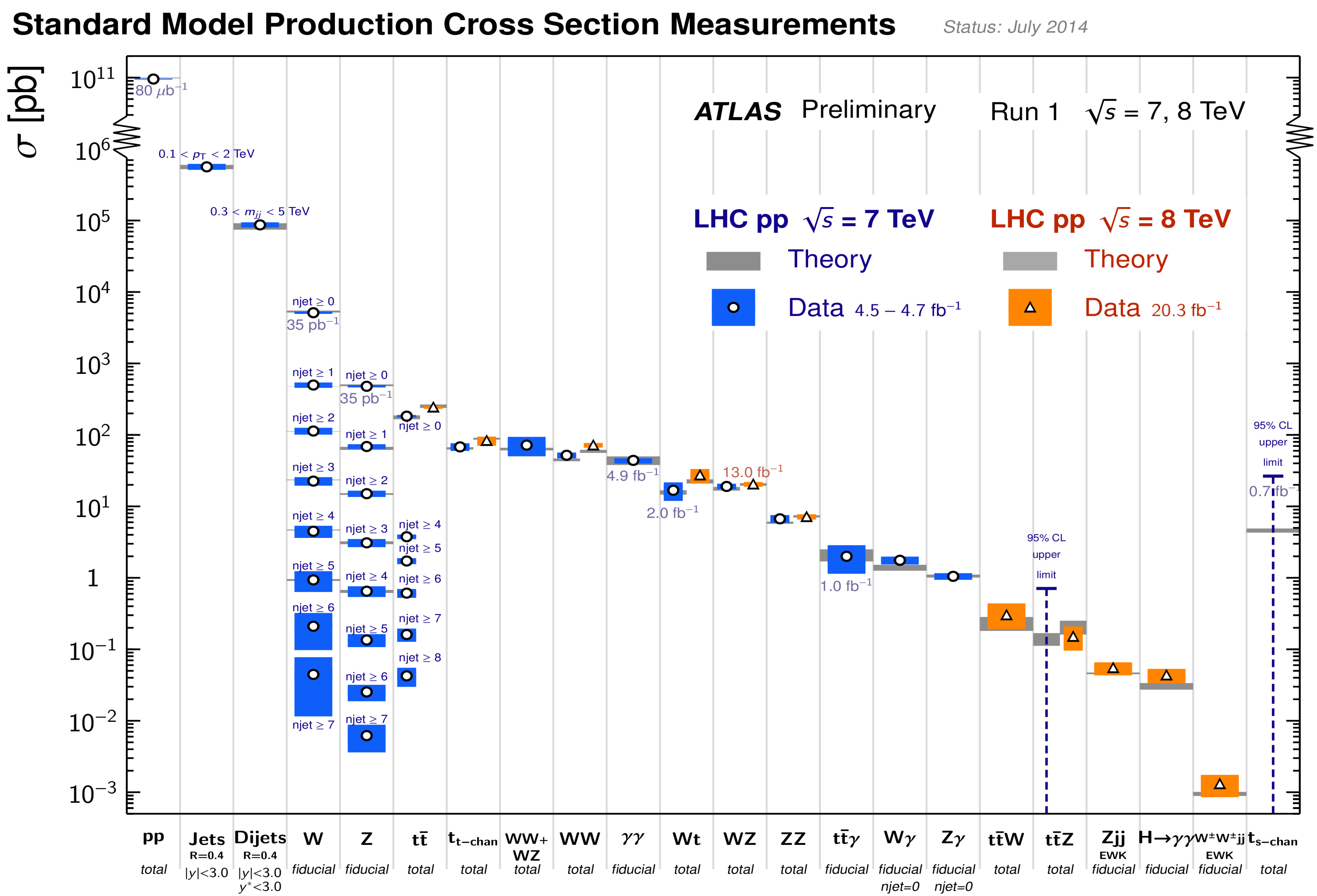
- Example results from the $(W \rightarrow l\nu)\gamma$ final state
  - Resonance searches and limits on anomalous couplings





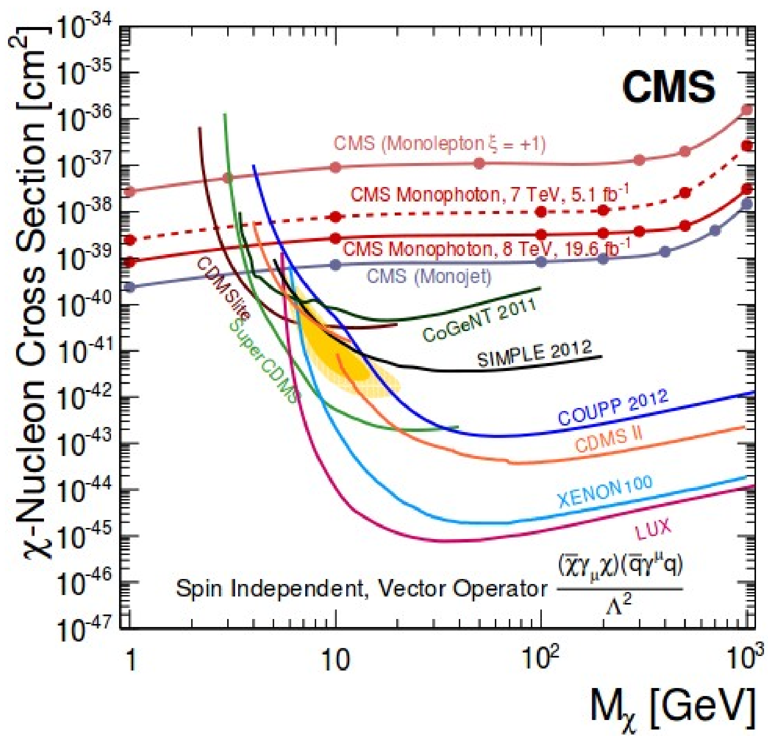
SM Summary

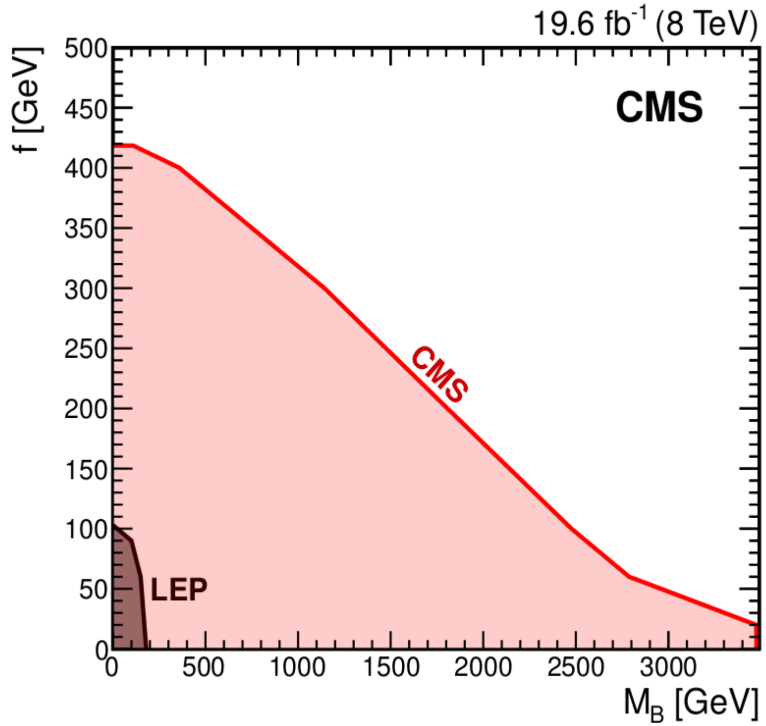
- Cross section measurements cover (and confirm predictions over) 10 orders of magnitude! (similar plots from both collaborations)



Beyond the Standard Model

- CMS: leadership in searches for new physics in (γ, l, jet) + MET final states
  - Process: qq → χχ arXiv:1410.8812 (Saclay ed.)
  - Capitalizing on expertise in photon calibration and identification





- ATLAS involved in searches for new physics with top-quarks (four-top production, Q=5/3-charged heavy quarks).

Perspectives – Run2 and beyond

- Run2 projects, for ATLAS and CMS:
  - Electron, photon and muon calibration
  - W and Z production (with jets), M_W;
  - Top: concentrate on new physics (no immediate plans for m_{TOP})
  - WW, WZ, (W,Z)g : concentrate on resonance searches
  - Di-photon and 4-lepton final states (SM, Higgs, ZZ);
  - Search for the ttH process; searches for dark matter (final states with MET)
- Involvement in upgrade projects
  - **ATLAS**
    - EM Calorimeter: LAr Trigger Digitizer Board
    - Muon spectrometer: New Small Wheel

    Both projects aim at improved resolution at L1, reducing backgrounds and rates
  - **CMS**
    - Replacement of ECAL front-end electronics
    - Forward calorimetry for HL-LHC