Recent ATLAS results and preparations for Run2

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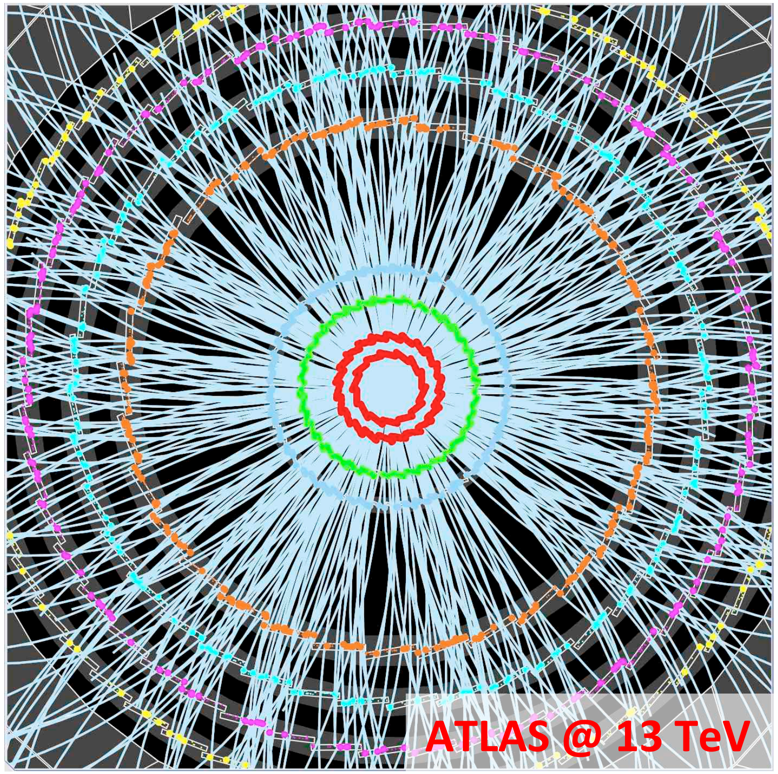
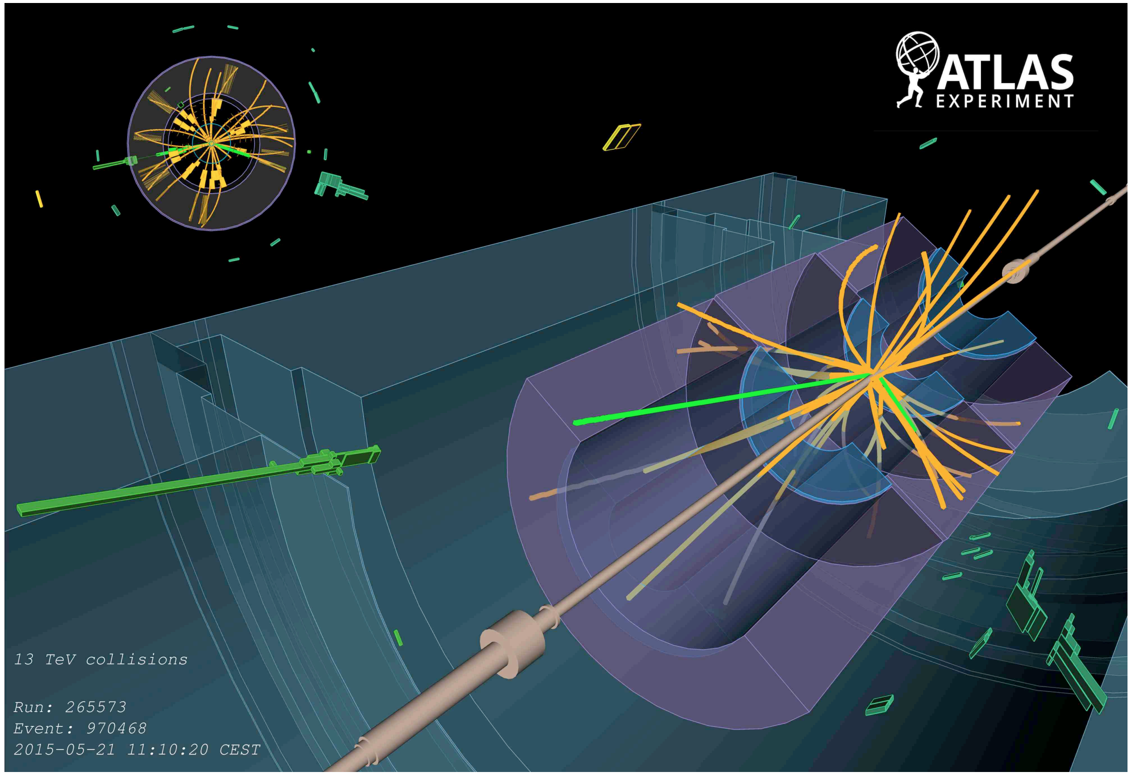
(Carleton University)

for the ATLAS collaboration

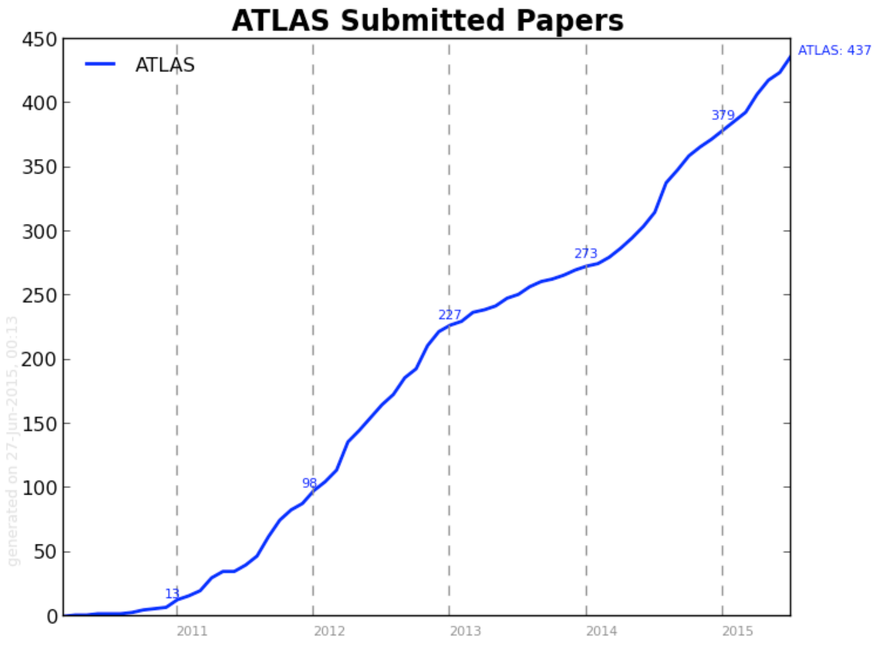
QFTHEP 2015, Samara, Russia





Introduction

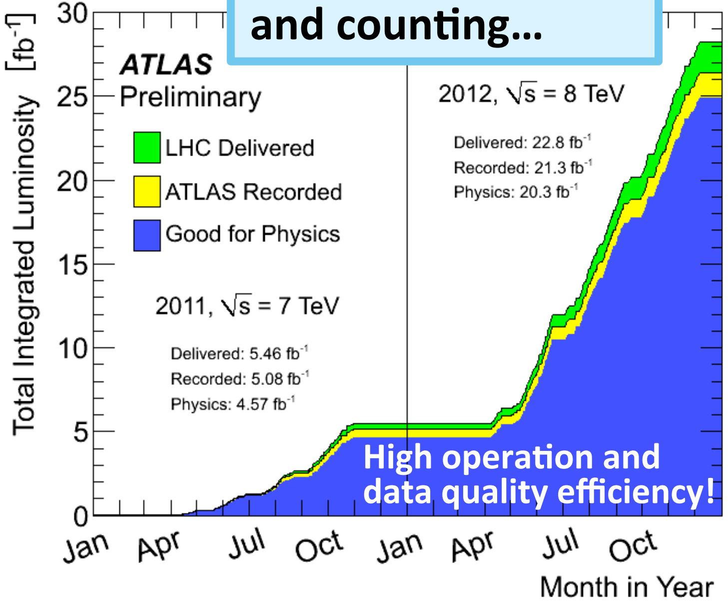
- LHC delivering data at record 13 TeV energies to ATLAS
    - Detector recommissioning and performance evaluation ongoing
    - First glimps at physics at E_{cm} = 13 TeV
- ATLAS submitted so far 437 papers for publication on Run1 E_{cm} = 7 – 8 TeV data
    - 58 in 2015
- Only a **subjective selection** of recent results presented today
    - Not covered: soft QCD, B physics and heavy ion physics



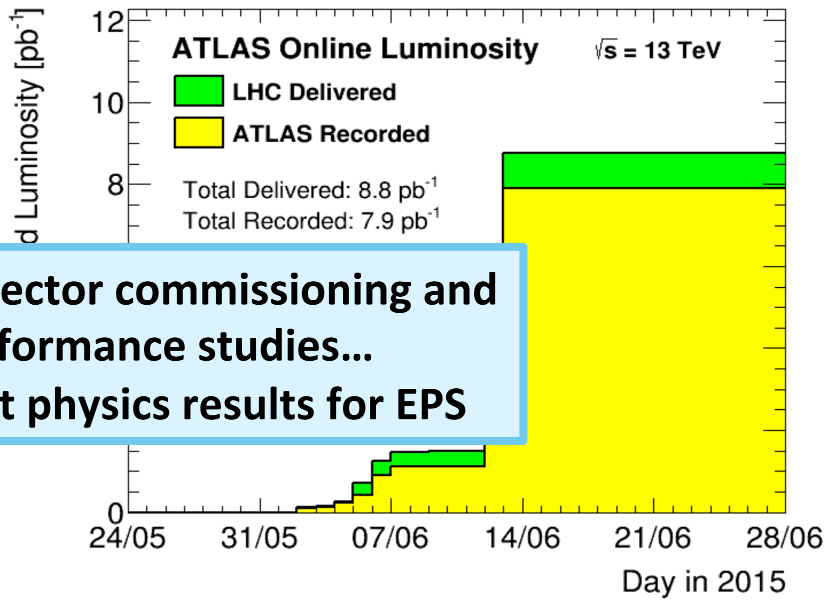
- Topical ATLAS physics talks in this conference
    - Huang Yanping: Higgs boson results (June 25)
    - Mateusz Dyndal: SM measurements (June 26)
    - Lorenzo Massa: Top physics results (June 26)
    - Rebecca Falla: Exotic searches (June 29)
    - Ewan Hill: SUSY searches (June 29)
    - Lukas Plazak: The ATLAS hadronic calorimeter at the LHC and the phase II upgrade program (June 29)
- For full list of results, see https://twiki.cern.ch/twiki/bin/view/AtlasPublic/WebHome

ATLAS data so far…

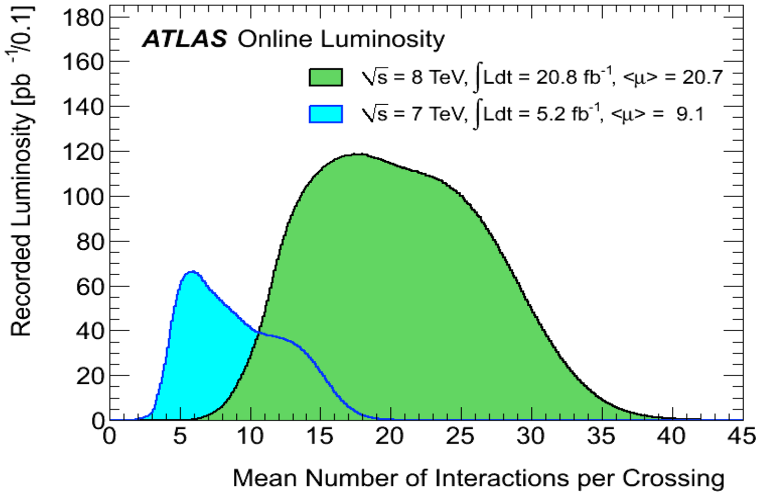
437 physics papers and counting…



High operation and data quality efficiency!



Detector commissioning and performance studies…
First physics results for EPS



Peak Stable Lumi	1.45×10^{32} cm^{-2} s^{-1}	
Peak Events/BX	44.6	
Peak <Events>/BX	29.1	
Avg <Events>/BX	19.9	
	Lumi (pb^{-1})	**Percent**
Physics Beams Del.	8.761	100.0%
ATLAS Ready Del.	8.375	95.6%
ATLAS Ready Rec.	7.909	90.3%
Del. after Warmstop	0.077	0.9%

The ATLAS detector in Run1

Muon Spectrometer

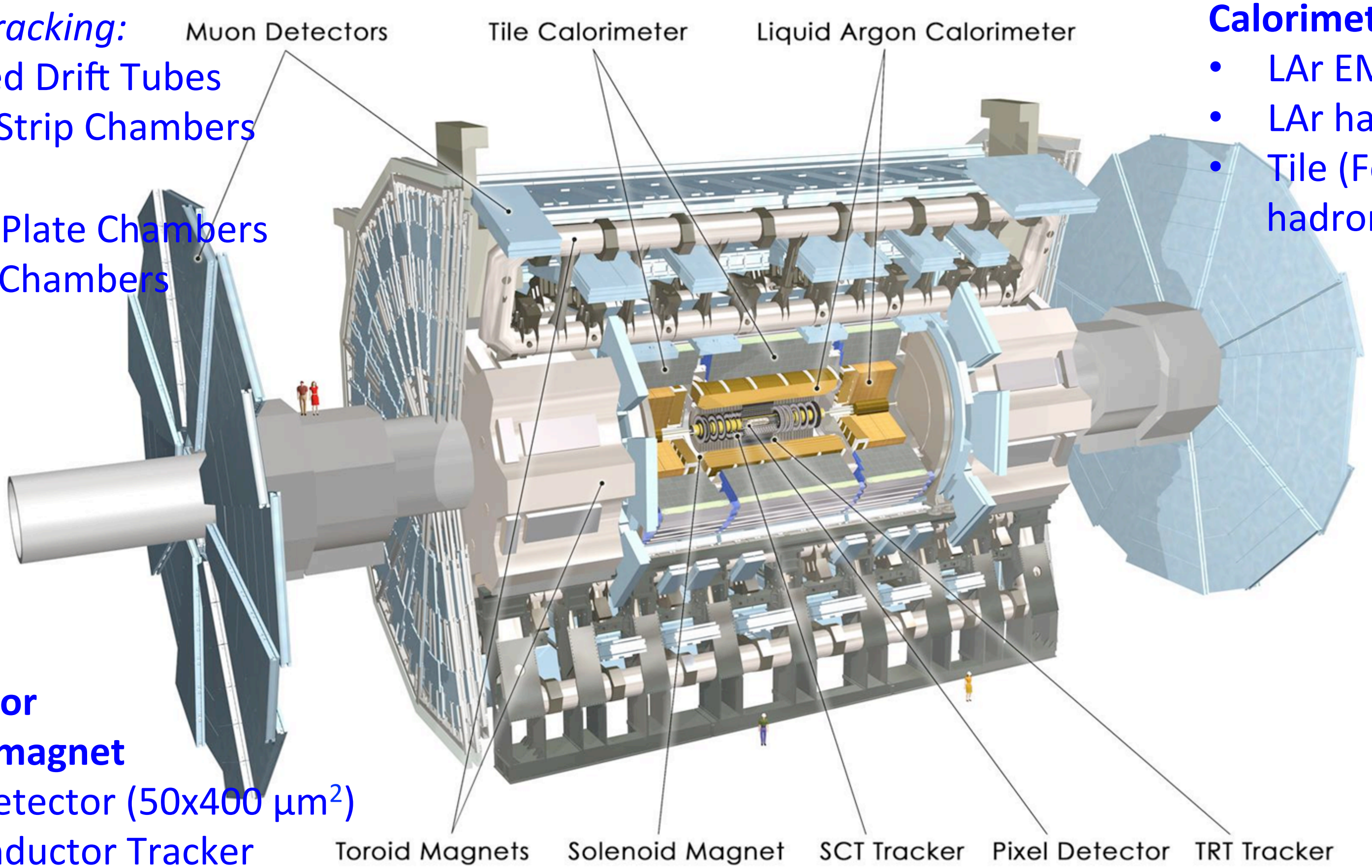
Toroid magnets

Precision μ tracking:

- Monitored Drift Tubes
- Cathode Strip Chambers

Trigger:

- Resistive Plate Chambers
- Thin Gas Chambers



Calorimeter system

- LAr EM calorimeter
- LAr hadronic endcap
- Tile (Fe-scintillator) hadronic barrel

Inner Detector

2T solenoid magnet

- Si Pixel detector (50x400 μm^2)
- Semi-Conductor Tracker
  (Si strip detector, 80 μm pitch)
- Transition Radiation Tracker
  <36 points / track
  e / hadron separation

Three level trigger system

- Level-1 hardware (70 kHz, 2.5 μs)
- Level-2 software (6.5 kHz, 10 ms)
- Event Filter software (600 Hz, 1-2 s)

Detector upgrades for Run2 (Phase-0)

Detector consolidations

- **New (4th) pixel layer close to the beam pipe: insertable B-layer**
- New beampipe to reduce background noise by 10-20% in the MS (in forward region stainless steel → aluminium)
- **Complete muon coverage**
- New Diamond Beam Monitor to measure luminosity and background at $\eta = 3.2 – 3.5$
- Upgrade Beam Conditions Monitors
- New LUCID (Luminosity measuring Cherenkov Integrating Detectors)
- Repairs (TRT, LAr, Tile,…)

Trigger and DAQ system

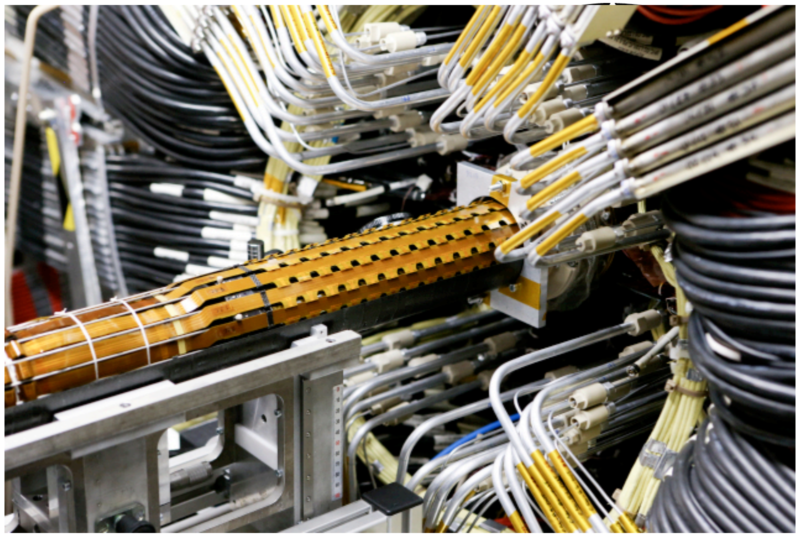
- **New Level-1 Topological Trigger Processor**
- New Central Trigger Processor
- **New hardware Fast TracKer** operating at 100 kHz providing tracks in 100 ms to HLT
- Merged L2 and EF computer farms
- Additional Sub-Farm Output to allow **higher HLT output rate** (HLT rate limited to 1.1 – 1.5 kHz by storage capacity)

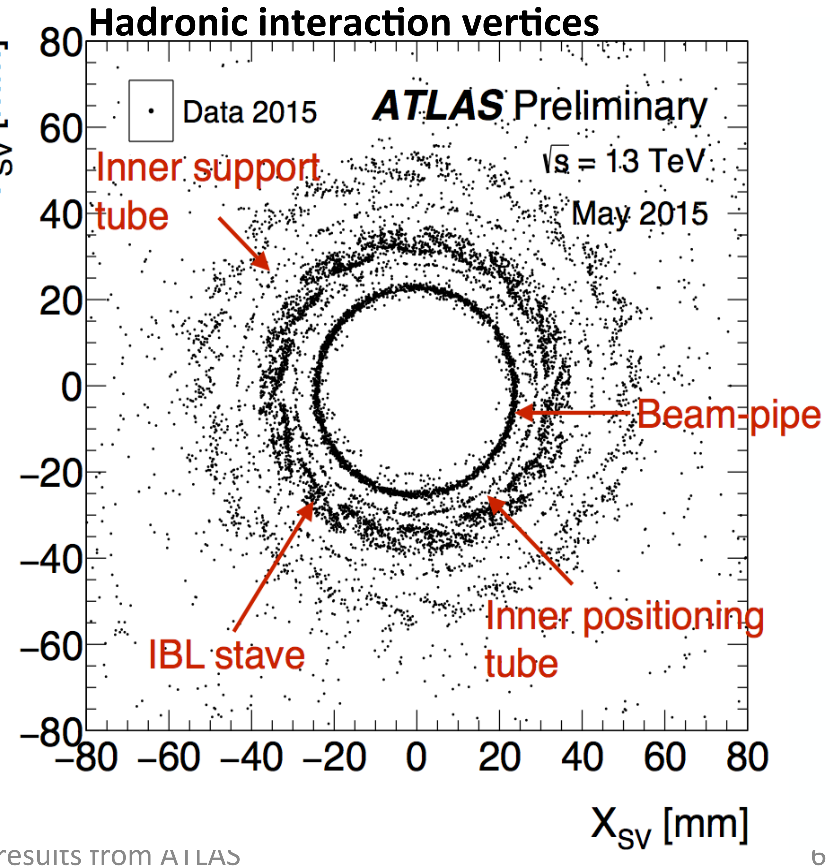
Software

- Improved reconstruction SW
- New data format and analysis framework

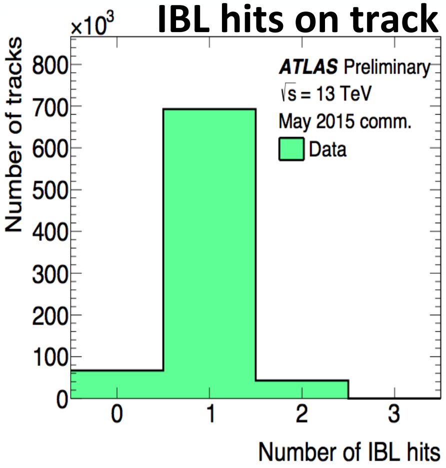
Insertable B-layer (IBL)

- Robustness against irreparable failures & high occupancy at high luminosities, improved tracking precision
- 4th pixel detector layer at r = 3.3 cm
- Faster read-out chips
- Two different silicon sensor technologies (planar, 3D)
- Pixel size: 50x250 um
- The insertion gap between the Inner Supporting Tube and IBL: 0.2 mm
- New lightweight carbon foam structures invented to support the modules
- New CO2-based cooling system

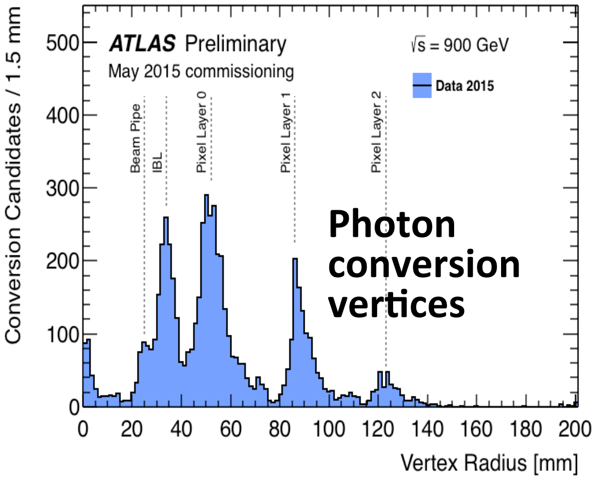




Hadronic interaction vertices



IBL hits on track

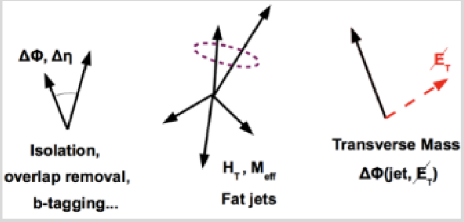


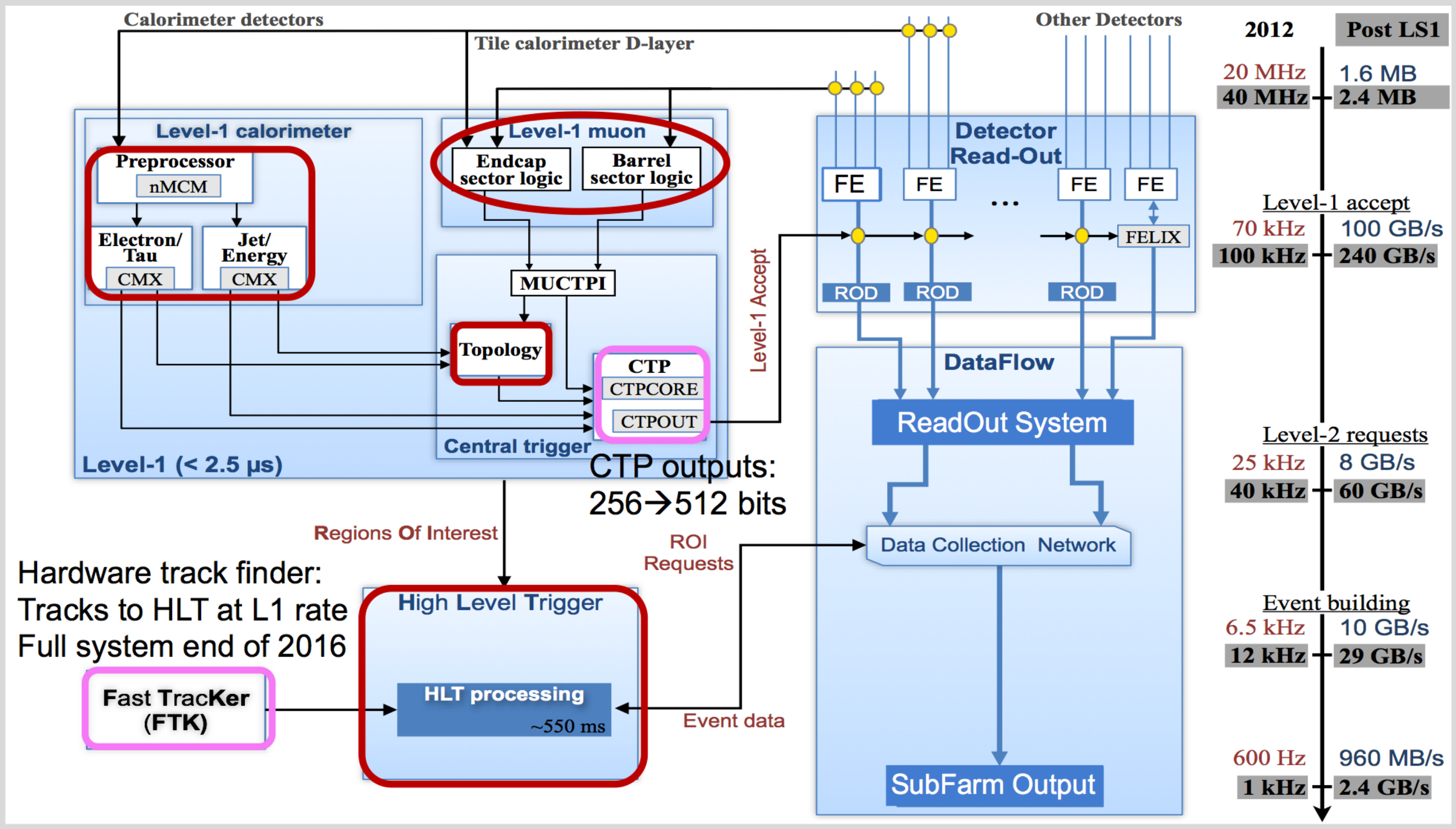
Photon conversion vertices

Trigger in Run2

Stage	Functionalities	Components	Latency	Rate reduction
Level-1 (L1)	Fast custom-made electronics finds regions of interests using Calorimeter/ Muon data with coarse information	L1Calo, L1Muon, L1Topo, Central Trigger Processor	< 2.5 µs	40 MHz → 100 kHz
High-Level Trigger (HLT)	Fast algorithms in RoI, or offline-like ones with full-event info on PC farm	(FTK,) HLT farm	~ 0.2 s (average)	→ 1 kHz (average)

L1Topo

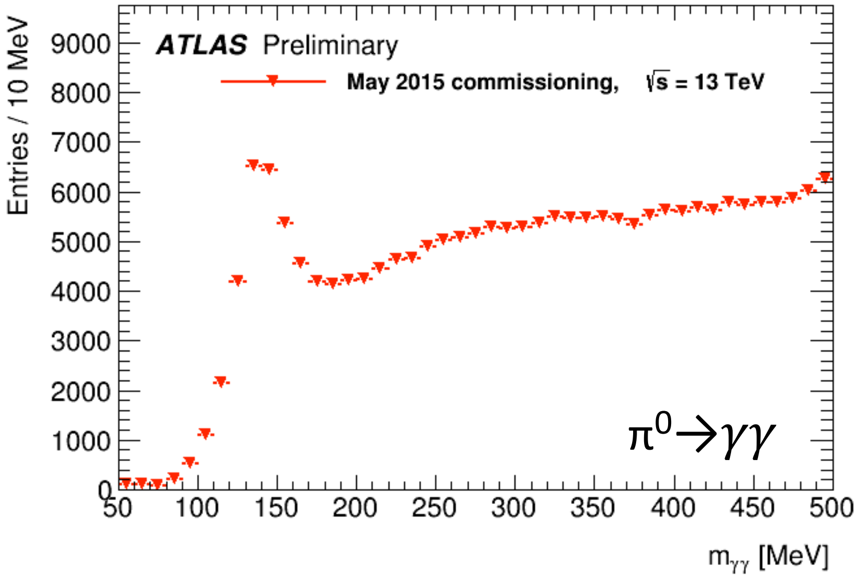




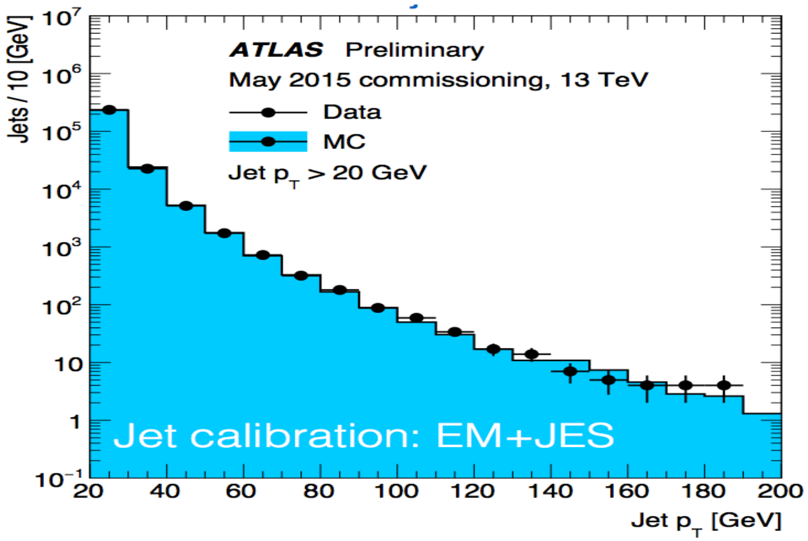
CTP outputs:
256→512 bits

Hardware track finder:
Tracks to HLT at L1 rate
Full system end of 2016

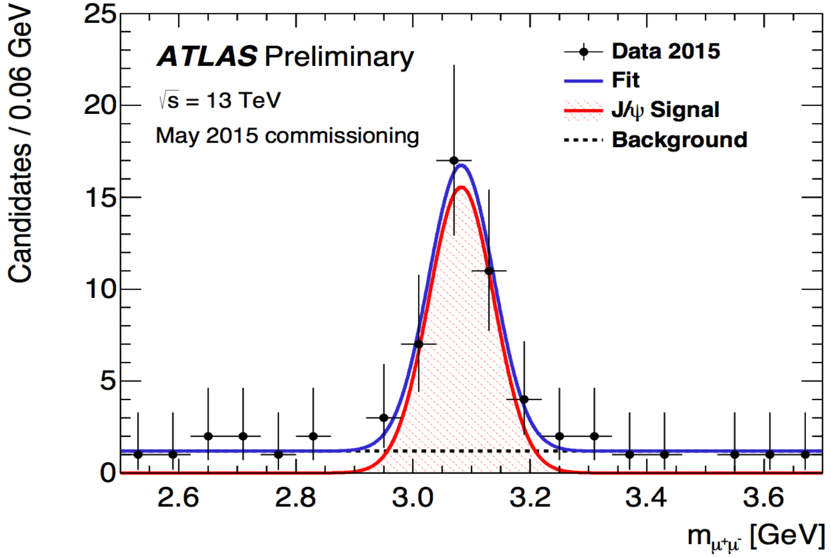
Run2 detector performance: 1st days

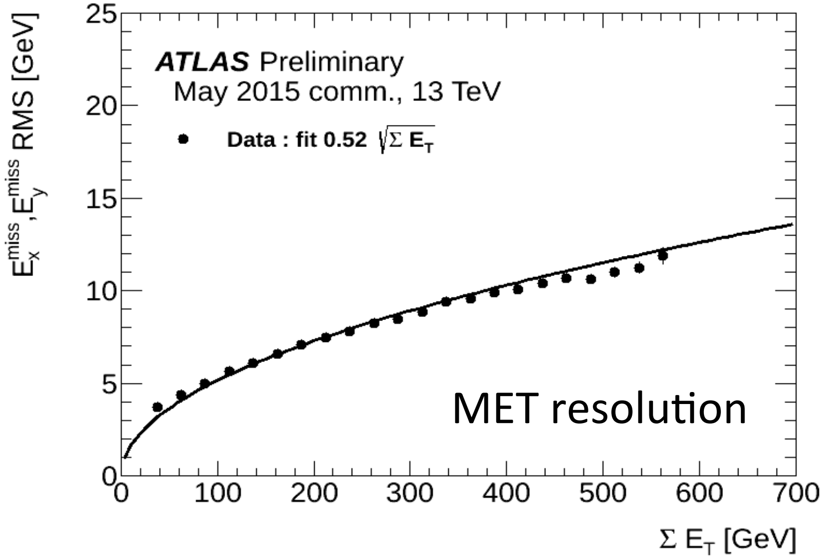


$\pi^0 \to \gamma\gamma$



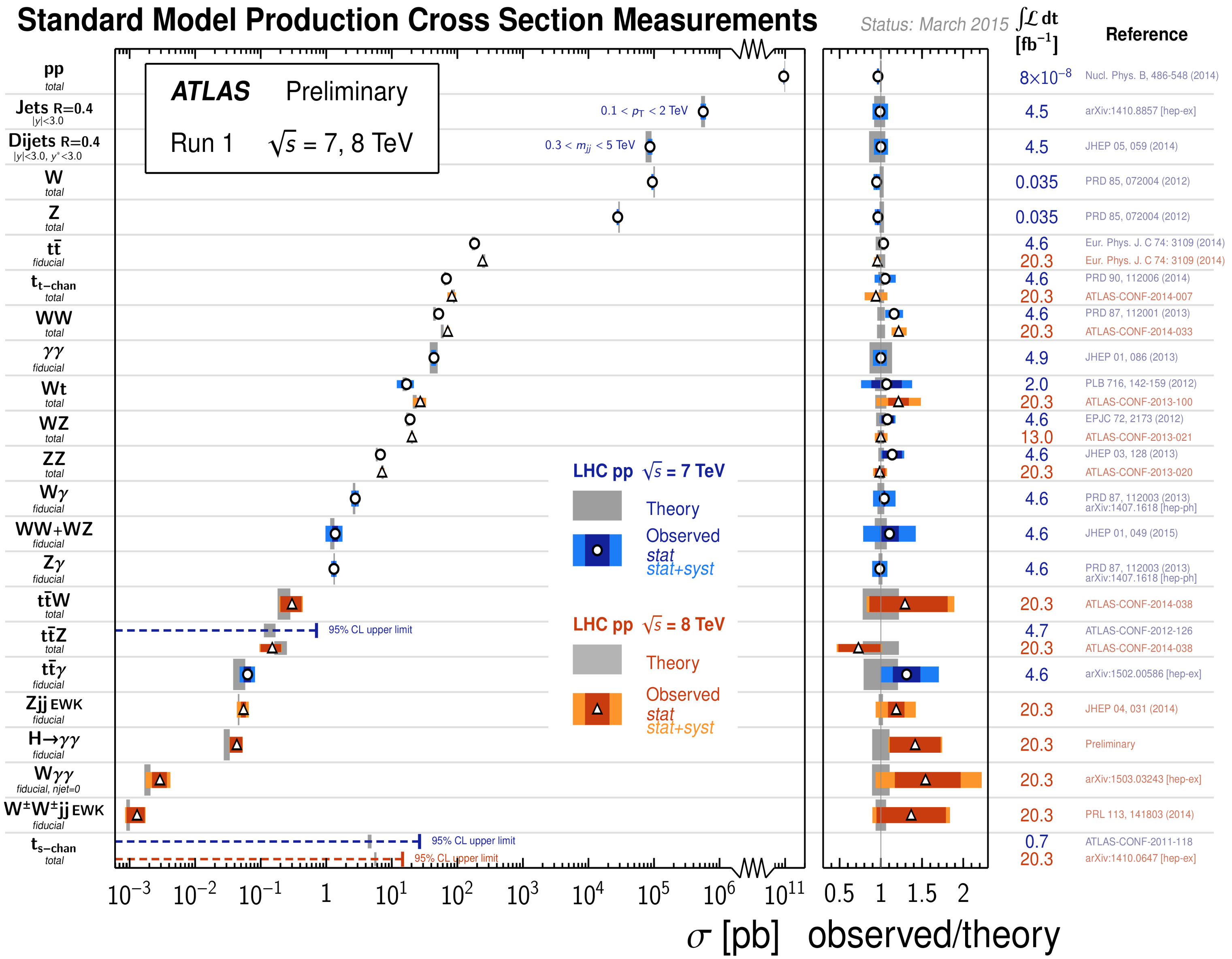
Jet calibration: EM+JES





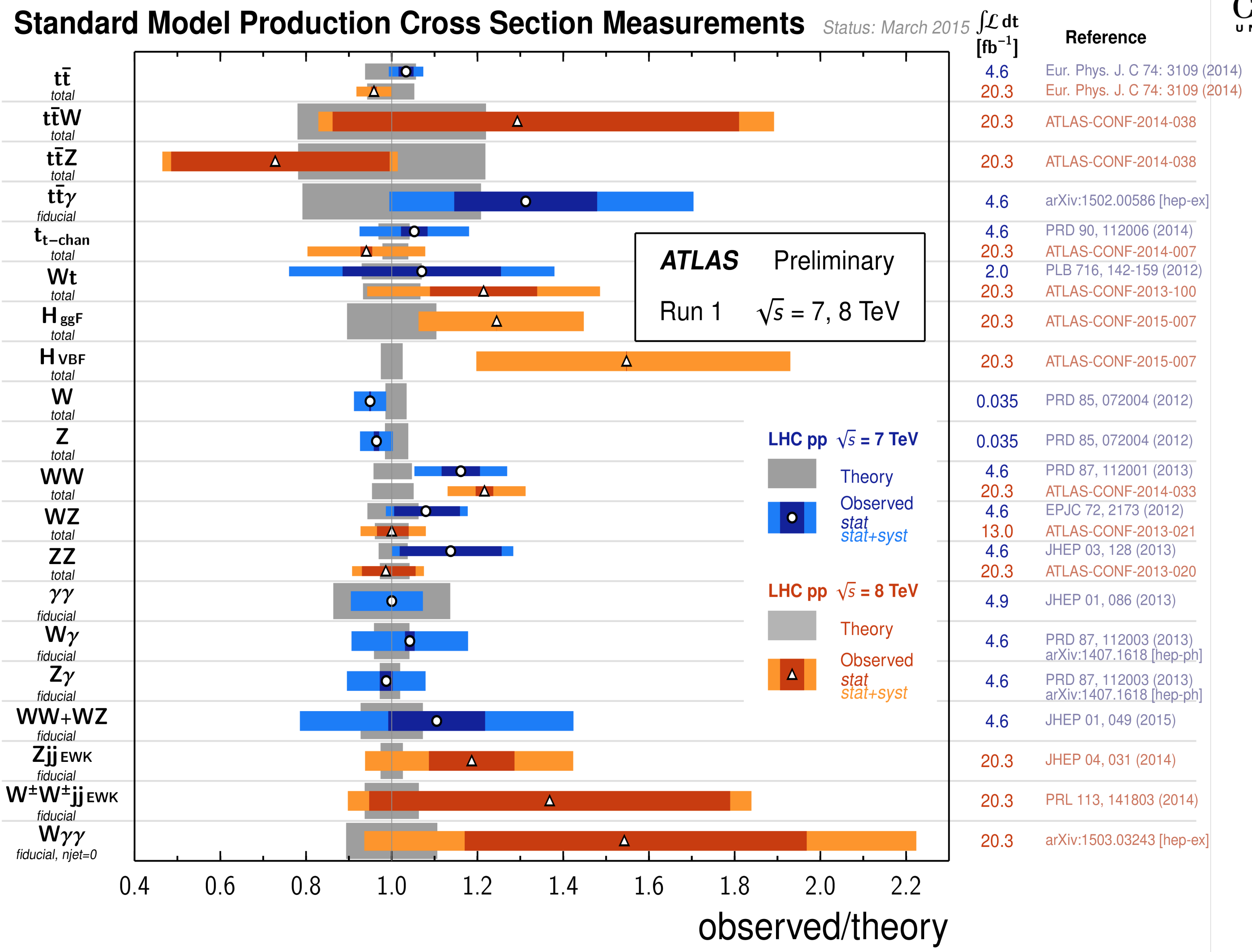
MET resolution

The SM is doing very well…



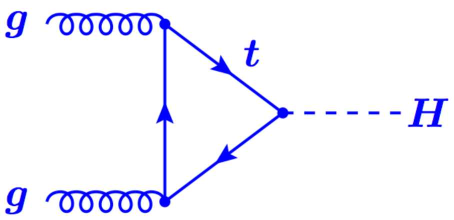
Over 14 orders of magnitude in cross-section: data and theory agree very well…

The SM is doing very well…

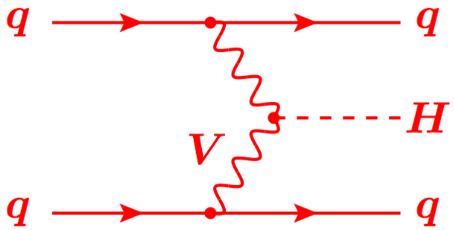


No significant discrepancy observed wrt theory predictions

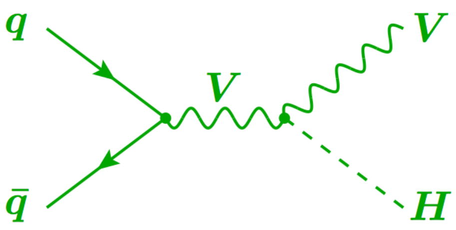
SM Higgs at the LHC



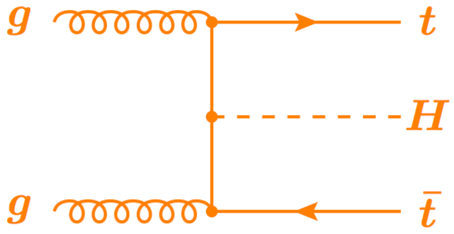
87%
Main production mode



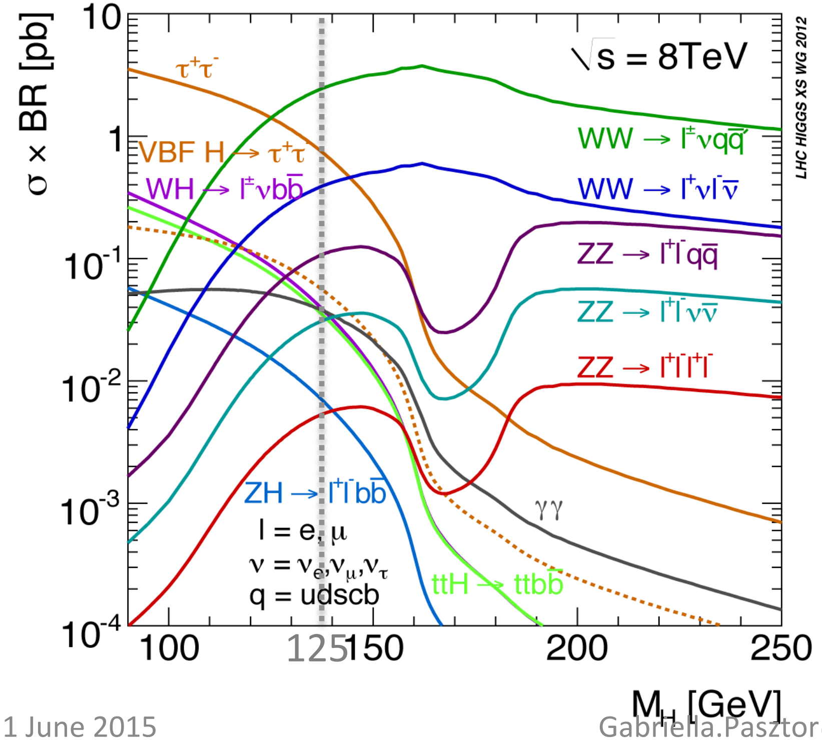
7%
Tag two forward jets with little hadronic activity between



5%
Tag Z and W leptonic and hadronic decays



<1%
Tag two top quarks



- **H→ZZ→llll**: “Golden channel”, low stat
- **H→γγ**: Good resolution
- **H→WW→lvlv**: High stat, low resolution
- **H→ττ**: Best fermionic channel
- **H→bb**: Not possible in gg fusion
- **H→WW→lvqq**,
- **H→ZZ→llvv**, **llqq**: High-mass searches

Mass, diff. xsections

Discovery, spin

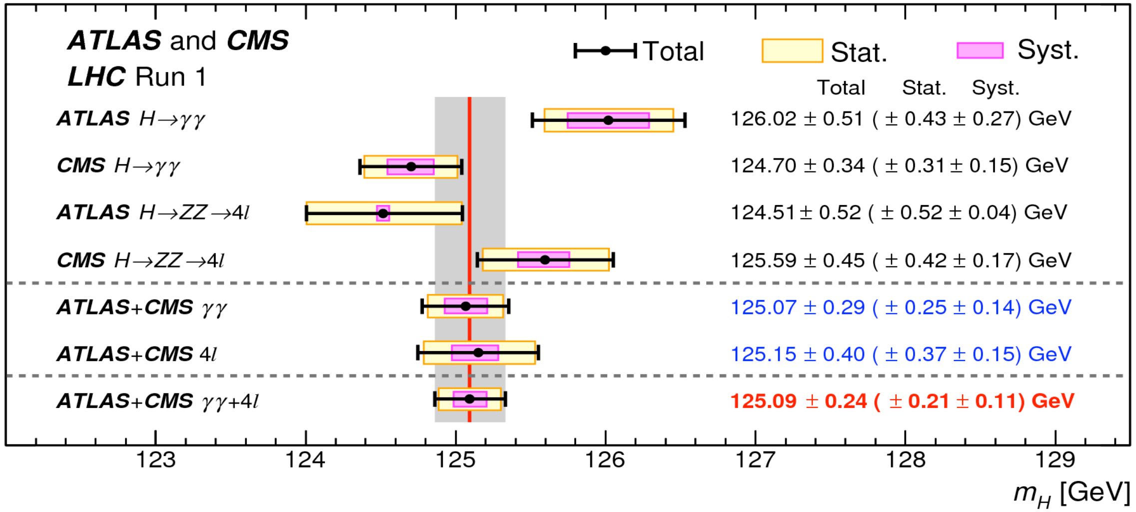
Cross-sections, couplings

Additional Higgs searches

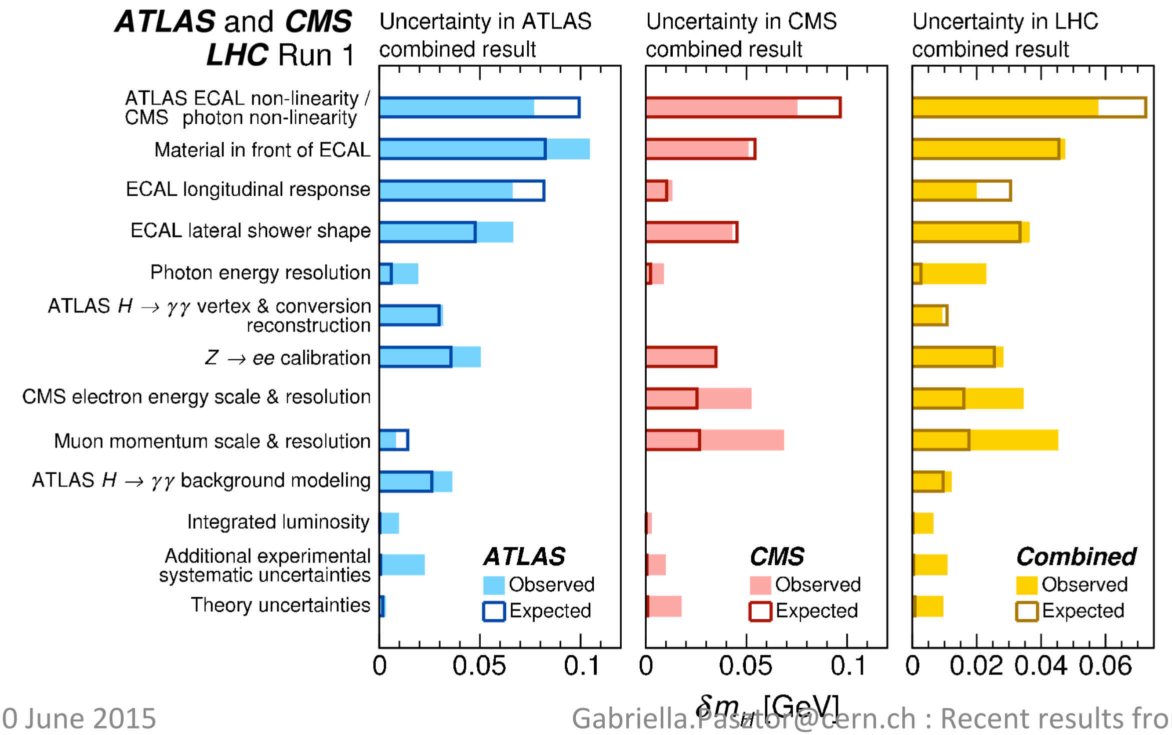
Discovery in bosonic channels

Clear observation of fermionic decays (4.5 σ in $\tau\tau$)

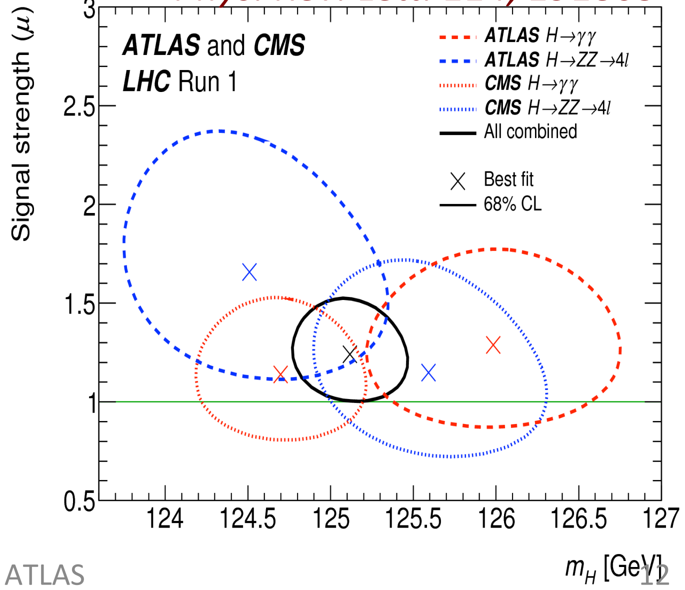
Combined Higgs mass measurement



- Using $\gamma\gamma$ & ZZ→4l channels
- Others less sensitive but consistent
- Signal strength floats in fit
- First combined ATLAS + CMS Higgs result with many more expected to come….
- Overall consistency good
- Stat uncertainty dominates: improvement in Run2



Phys. Rev. Lett. 114, 191803

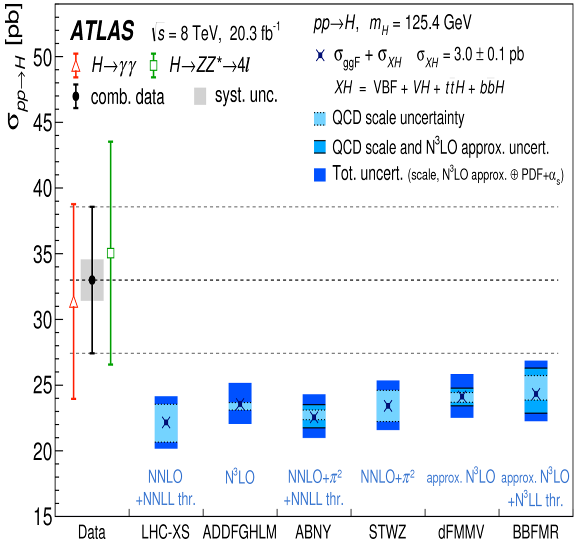


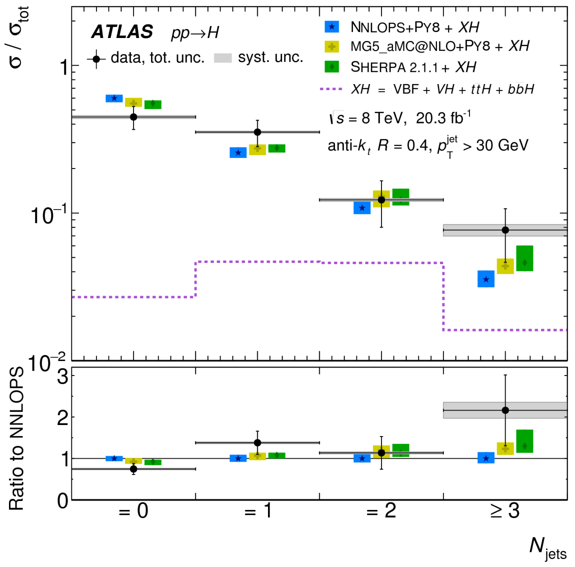
Fiducial and differential cross-sections

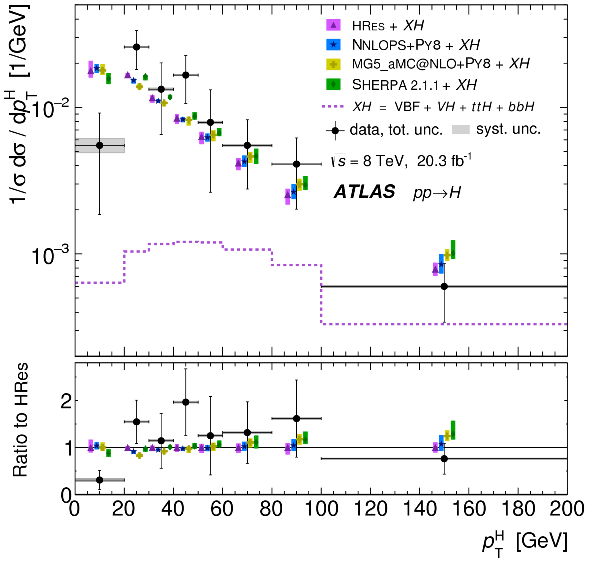
arXiv:1504.05833

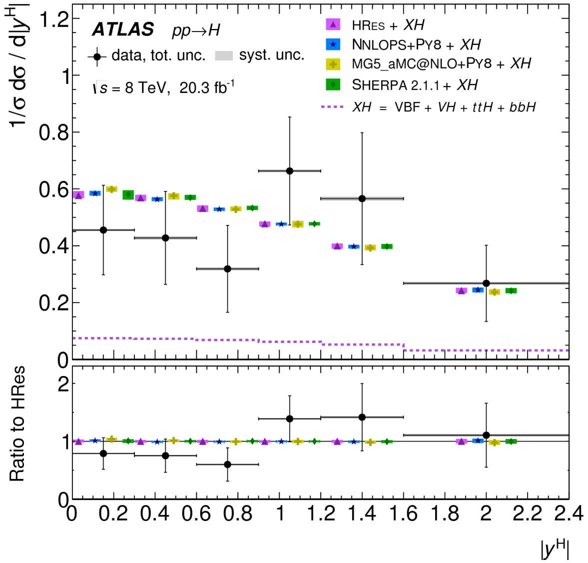
- Model-independent measurement of production and decay kinematics
- Allows comparison with precision calculations, alternative models
- Test theoretical modelling of different Higgs boson production mechanisms
- Sensitive to BSM physics
- Reasonable agreement within large (statistically-dominated) uncertainties with SM

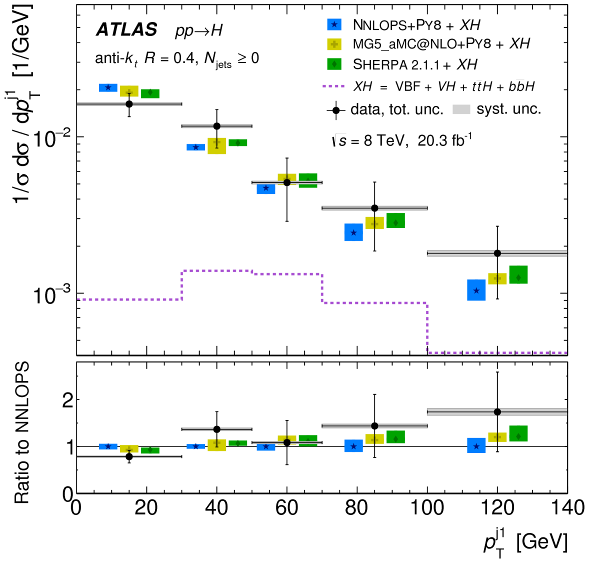
Total cross-section







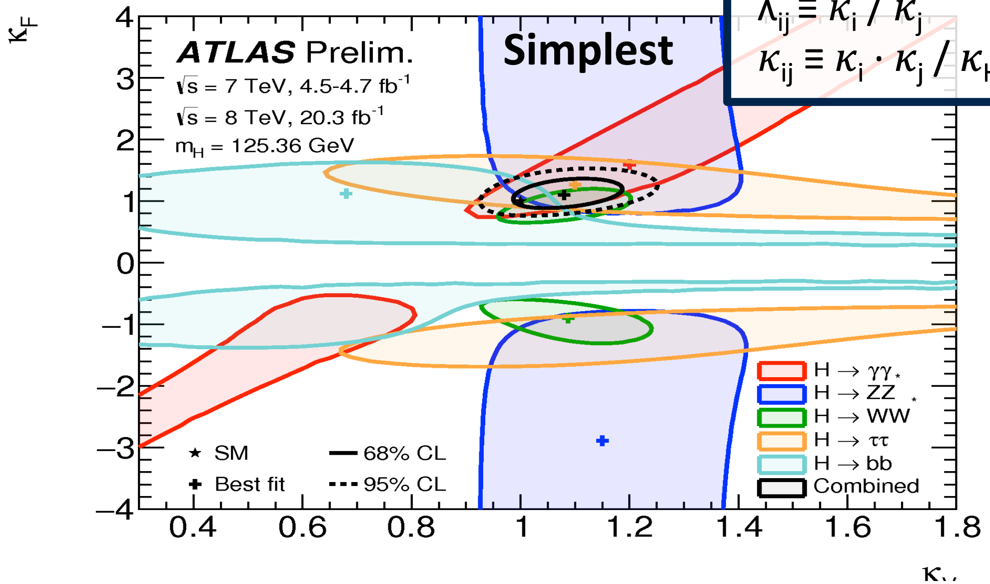




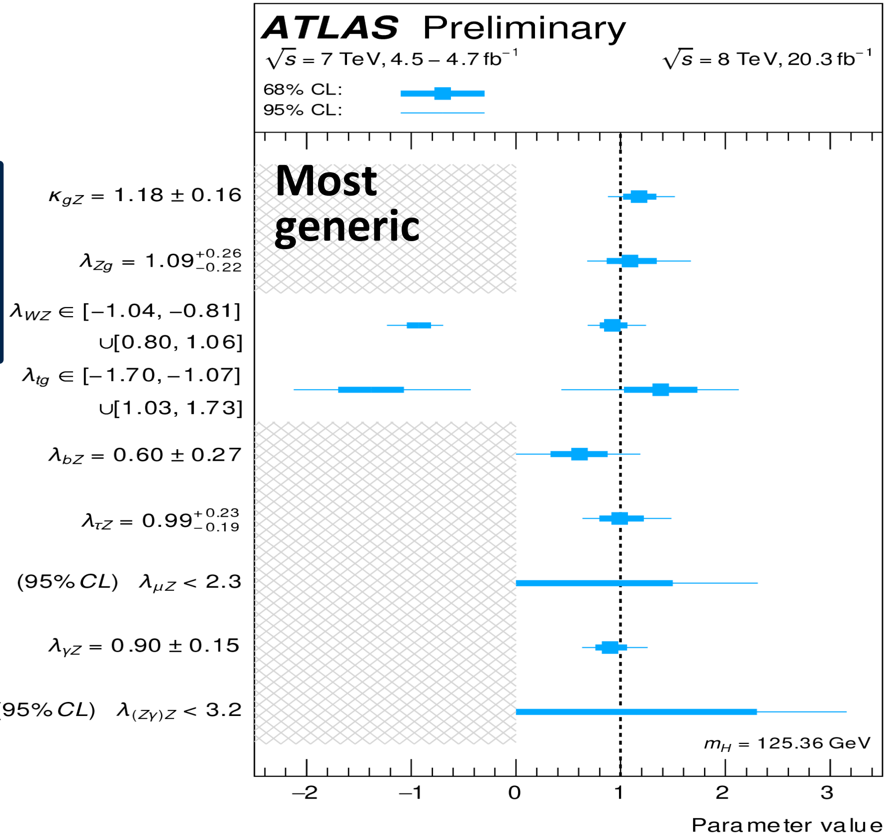
Higgs couplings

Global fit using all production and decay modes

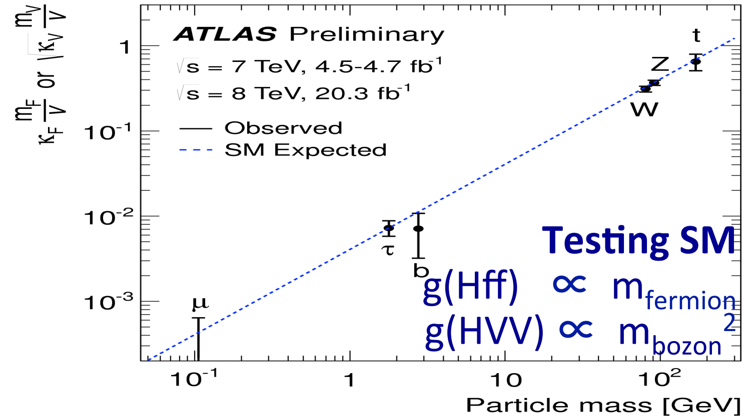
$\kappa_i \equiv g_i / g_i^{SM}$
$\lambda_{ij} \equiv \kappa_i / \kappa_j$
$\kappa_{ij} \equiv \kappa_i \cdot \kappa_j / \kappa_H$



Simplest



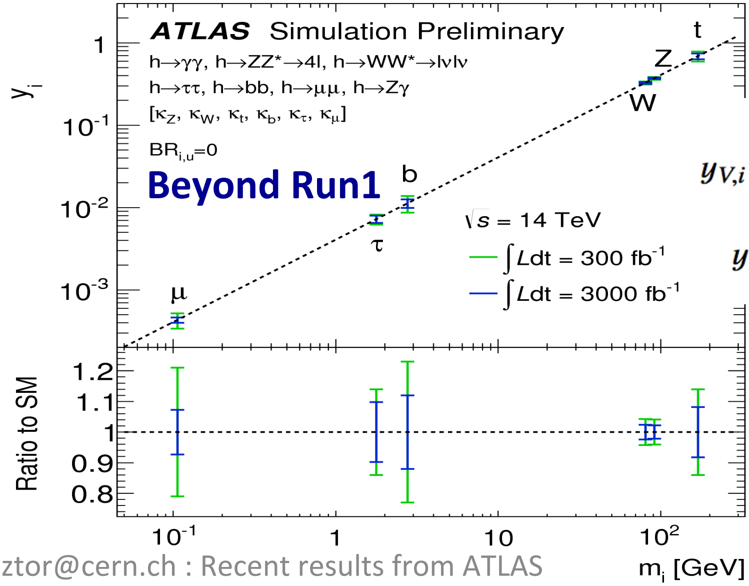
Most generic



Testing SM

g(Hff) ∝ m$_{fermion}$

g(HVV) ∝ m$_{bozon}^{2}$



Beyond Run1

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

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

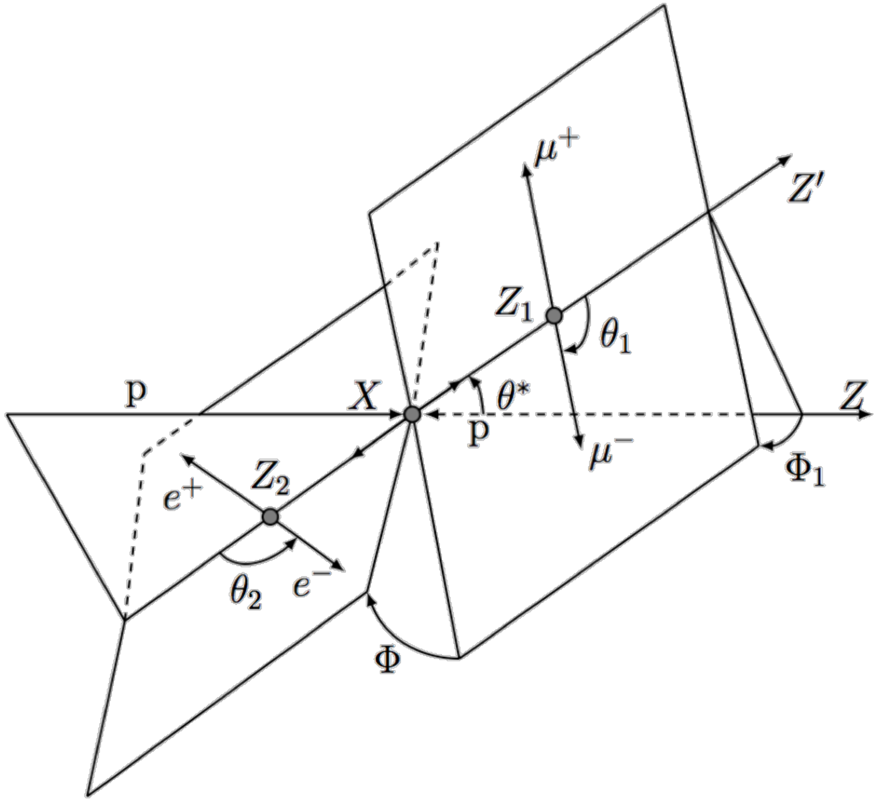
All measurements consistent with SM

With improved precision in Run2 and beyond deviations can show up

ATLAS-CONF-2015-007

Spin-parity measurements

- From decay kinematics
- H→ZZ→4l fully reconstructed
- Limited statistics: test models wrt SM
- H→$\gamma\gamma$, WW can also be used
- Best fit SM 0^+
- Large number of hypotheses assuming gg and qq production tested and excluded at >95% CL (including 0^-)



arXiv:1506.05669

Tested Hypothesis	$p^{\text{alt}}_{\text{exp},\mu=1}$	$p^{\text{alt}}_{\text{exp},\mu=\hat{\mu}}$	$p^{\text{SM}}_{\text{obs}}$	$p^{\text{alt}}_{\text{obs}}$	Obs. CL_s (%)
0_h^+	$2.5 \cdot 10^{-2}$	$4.7 \cdot 10^{-3}$	0.85	$7.1 \cdot 10^{-5}$	$4.7 \cdot 10^{-2}$
0^-	$1.8 \cdot 10^{-3}$	$1.3 \cdot 10^{-4}$	0.88	$< 3.1 \cdot 10^{-5}$	$< 2.6 \cdot 10^{-2}$
$2^+(\kappa_q = \kappa_g)$	$4.3 \cdot 10^{-3}$	$2.9 \cdot 10^{-4}$	0.61	$4.3 \cdot 10^{-5}$	$1.1 \cdot 10^{-2}$
$2^+(\kappa_q = 0;\ p_{\text{T}} < 300GeV)$	$< 3.1 \cdot 10^{-5}$	$< 3.1 \cdot 10^{-5}$	0.52	$< 3.1 \cdot 10^{-5}$	$< 6.5 \cdot 10^{-3}$
$2^+(\kappa_q = 0;\ p_{\text{T}} < 125GeV)$	$3.4 \cdot 10^{-3}$	$3.9 \cdot 10^{-4}$	0.71	$4.3 \cdot 10^{-5}$	$1.5 \cdot 10^{-2}$
$2^+(\kappa_q = 2\kappa_g;\ p_{\text{T}} < 300GeV)$	$< 3.1 \cdot 10^{-5}$	$< 3.1 \cdot 10^{-5}$	0.28	$< 3.1 \cdot 10^{-5}$	$< 4.3 \cdot 10^{-3}$
$2^+(\kappa_q = 2\kappa_g;\ p_{\text{T}} < 125GeV)$	$7.8 \cdot 10^{-3}$	$1.2 \cdot 10^{-3}$	0.80	$7.3 \cdot 10^{-5}$	$3.7 \cdot 10^{-2}$

Spin-parity measurements

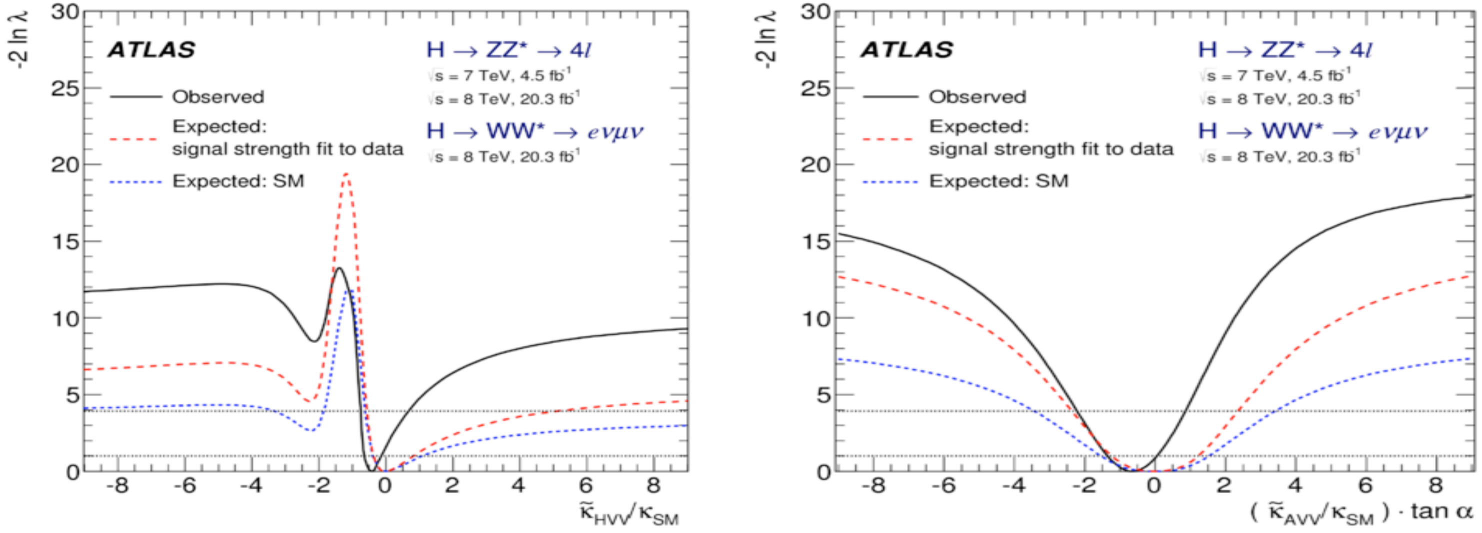
Constrain the parameters of the effective Lagrangian assumed to be valid up to a scale Λ (!= 1 TeV below), with SM coupling $g_{HVV} \propto m^2_{Z/W}$.

$$\begin{aligned}\mathcal{L}_0^V = \; & \left\{c_\alpha \kappa_{\rm SM}\left[\tfrac{1}{2} g_{HZZ} Z_\mu Z^\mu + g_{HWW} W^+_\mu W^{-\mu}\right]\right. \\ & -\tfrac{1}{4}\tfrac{1}{\Lambda}\left[c_\alpha \kappa_{HZZ} Z_{\mu\nu} Z^{\mu\nu} + s_\alpha \kappa_{AZZ} Z_{\mu\nu} \tilde{Z}^{\mu\nu}\right] \\ & \left. -\tfrac{1}{2}\tfrac{1}{\Lambda}\left[c_\alpha \kappa_{HWW} W^+_{\mu\nu} W^{-\mu\nu} + s_\alpha \kappa_{AWW} W^+_{\mu\nu} \tilde{W}^{-\mu\nu}\right]\right\} X_0\end{aligned}$$

Assume only one BSM contribution at a time

J^P	Model	Choice of tensor couplings			
		$\kappa_{\rm SM}$	κ_{HVV}	κ_{AVV}	α
0^+	Standard Model Higgs boson	1	0	0	0
0^+_h	BSM spin-0 CP-even	0	1	0	0
0^-	BSM spin-0 CP-odd	0	0	1	$\pi/2$

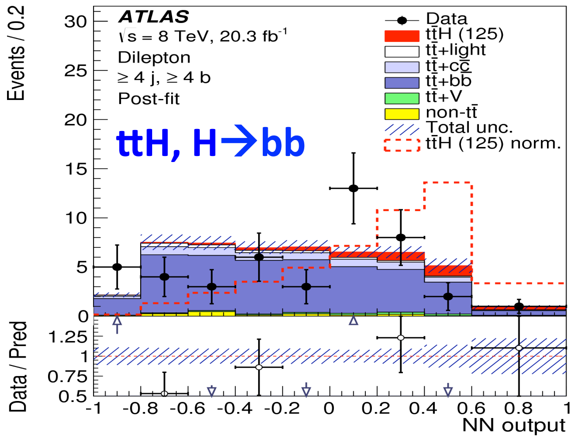
α: CP-mixing
for α ≠ 0, π:
CP-violation
s_α = sinα
c_α = cosα



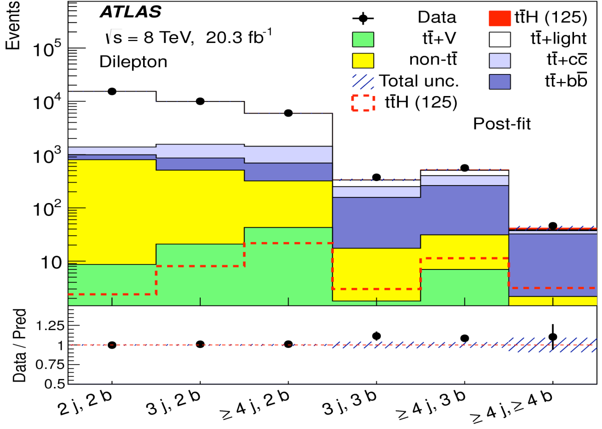
arXiv:1506.05669

Coupling ratio	Best fit value		95% CL Exclusion Regions	
Combined	Expected	Observed	Expected	Observed
$\tilde{\kappa}_{HVV}/\kappa_{\rm SM}$	0.0	−0.48	$(-\infty, -0.55] \bigcup [4.80, \infty)$	$(-\infty, -0.73] \bigcup [0.63, \infty)$
$(\tilde{\kappa}_{AVV}/\kappa_{\rm SM}) \cdot \tan\alpha$	0.0	−0.68	$(-\infty, -2.33] \bigcup [2.30, \infty)$	$(-\infty, -2.18] \bigcup [0.83, \infty)$

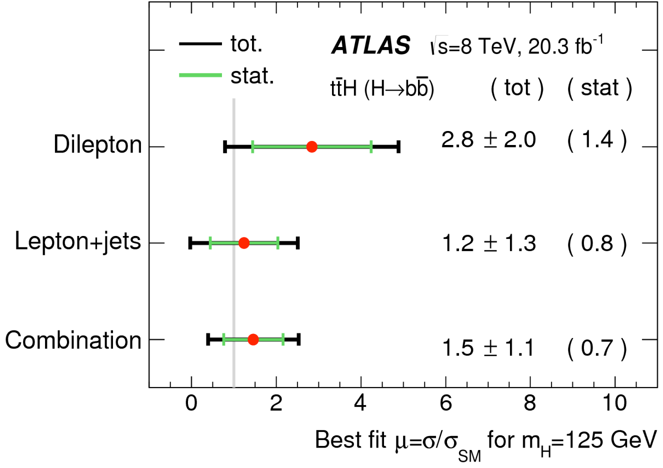
Accessing rare processes: ttH



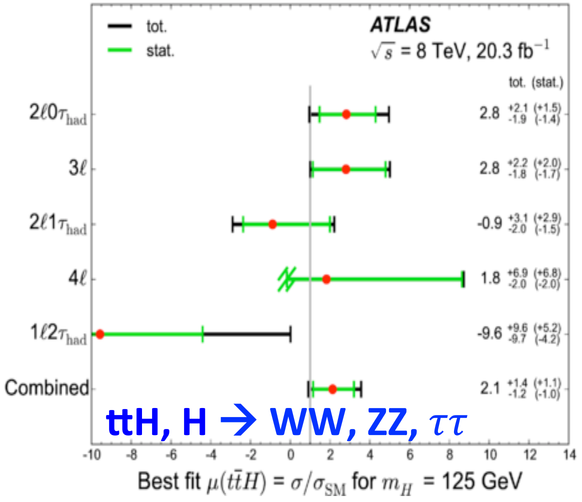
arXiv:1503.05066



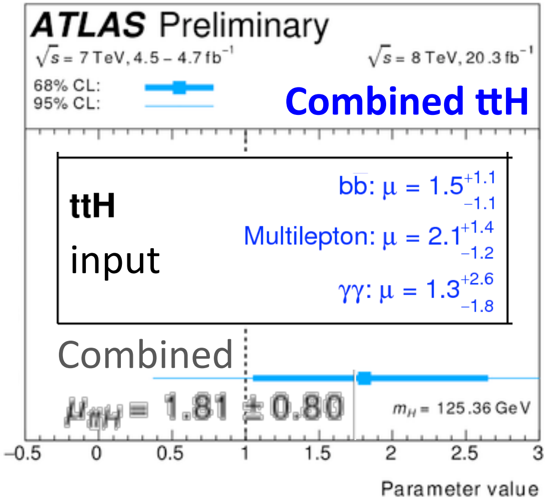
ttH, H→bb



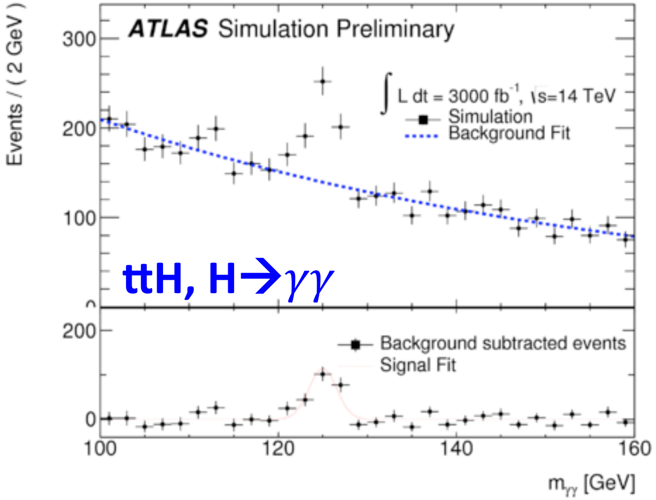
arXiv:1506.05988



ATLAS-CONF-2015-007



ATL-PHYS-PUB-2014-012

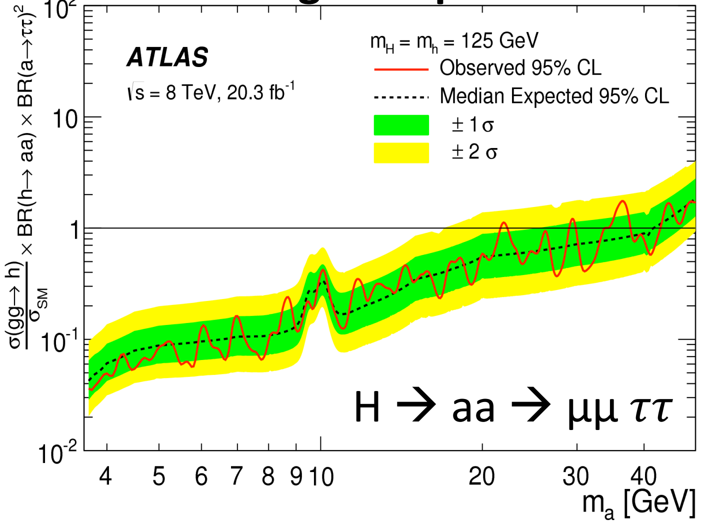


Run2: improved s/b due to E_{cm} increase + higher statistics!

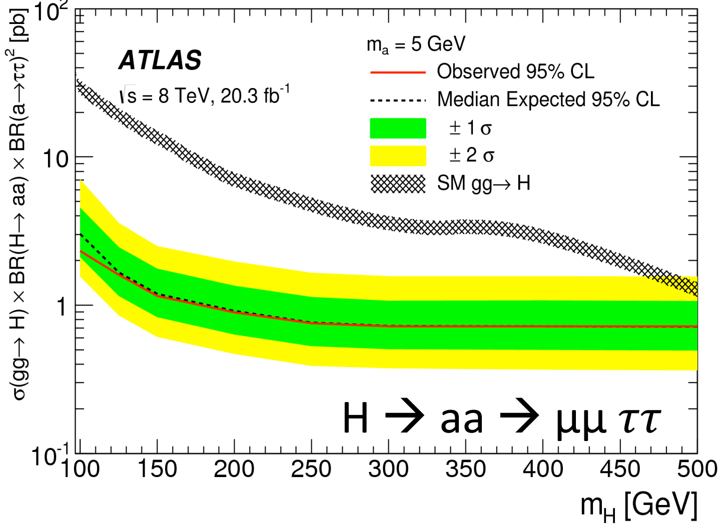
8.2σ at HL-LHC
Δμ/μ ~ 0.2

Searches for non-standard Higgs

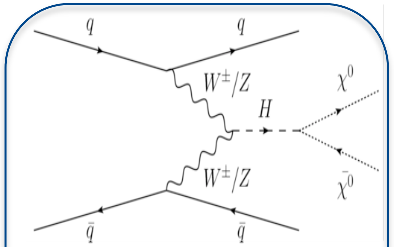
NMSSM lightest pseudoscalar



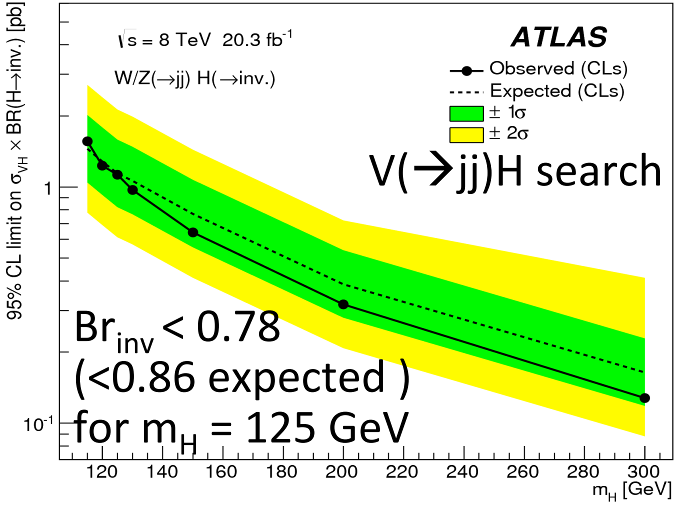
arXiv:1505.01609



Invisibly decaying Higgs



From VBF search:
$\mathrm{Br}_{inv} < 0.29$
(<0.36 expected)
for m_H = 125 GeV



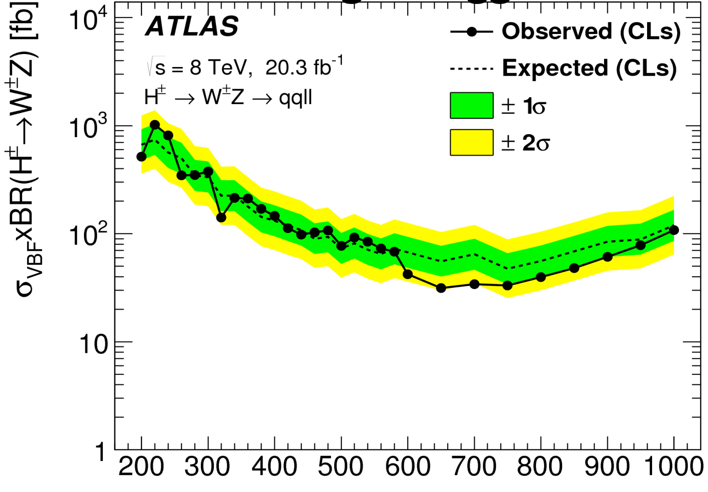
V(→jj)H search

$\mathrm{Br}_{inv} < 0.78$
(<0.86 expected)
for m_H = 125 GeV

ATLAS-CONF-2015-004

arXiv:1504.04324

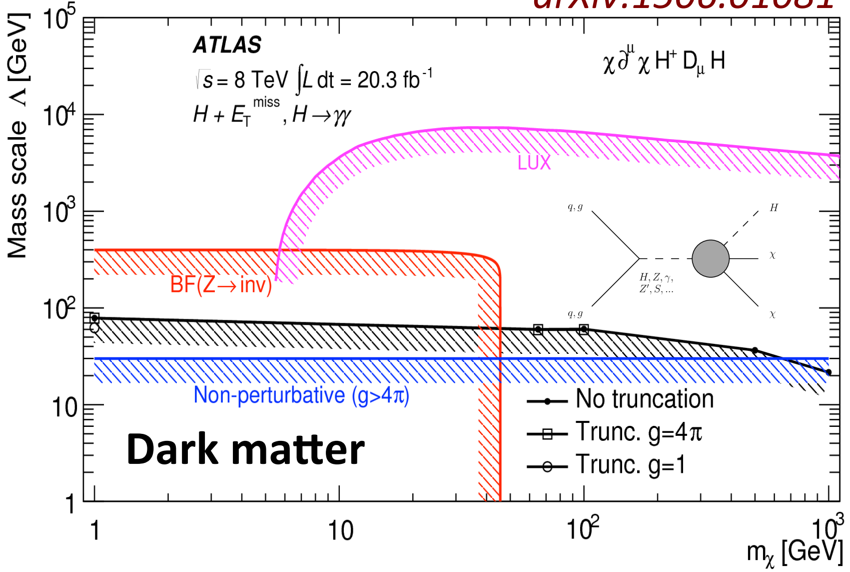
Charged Higgs



Phys.Rev.Lett. 114 (2015) 231801

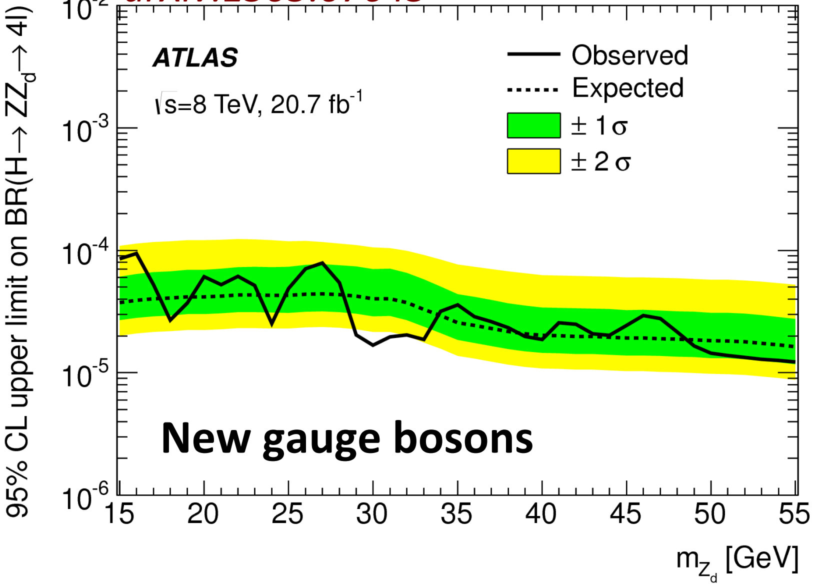
Searches for new physics with Higgs

arXiv:1506.01081



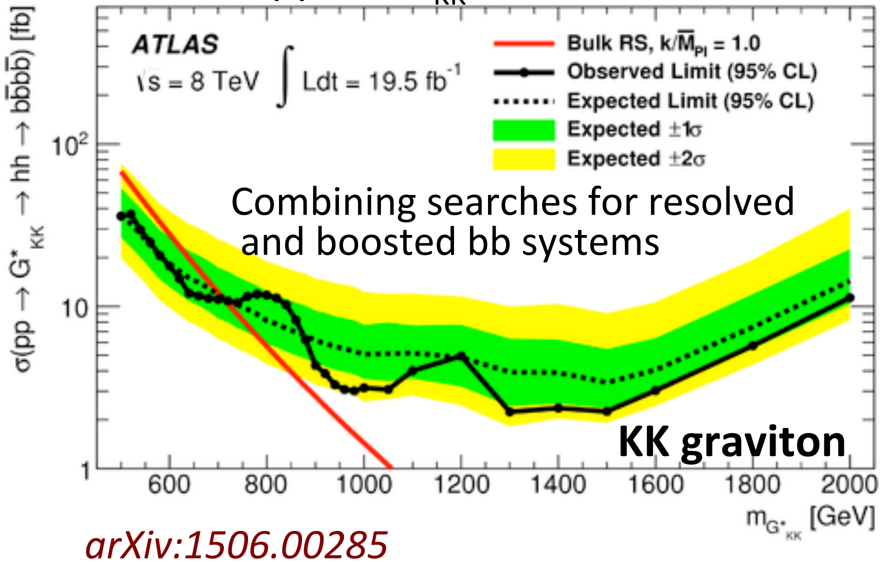
Dark matter

arXiv:1505.07645



New gauge bosons

pp → G$^*_{KK}$→ hh →bbbb



Combining searches for resolved and boosted bb systems

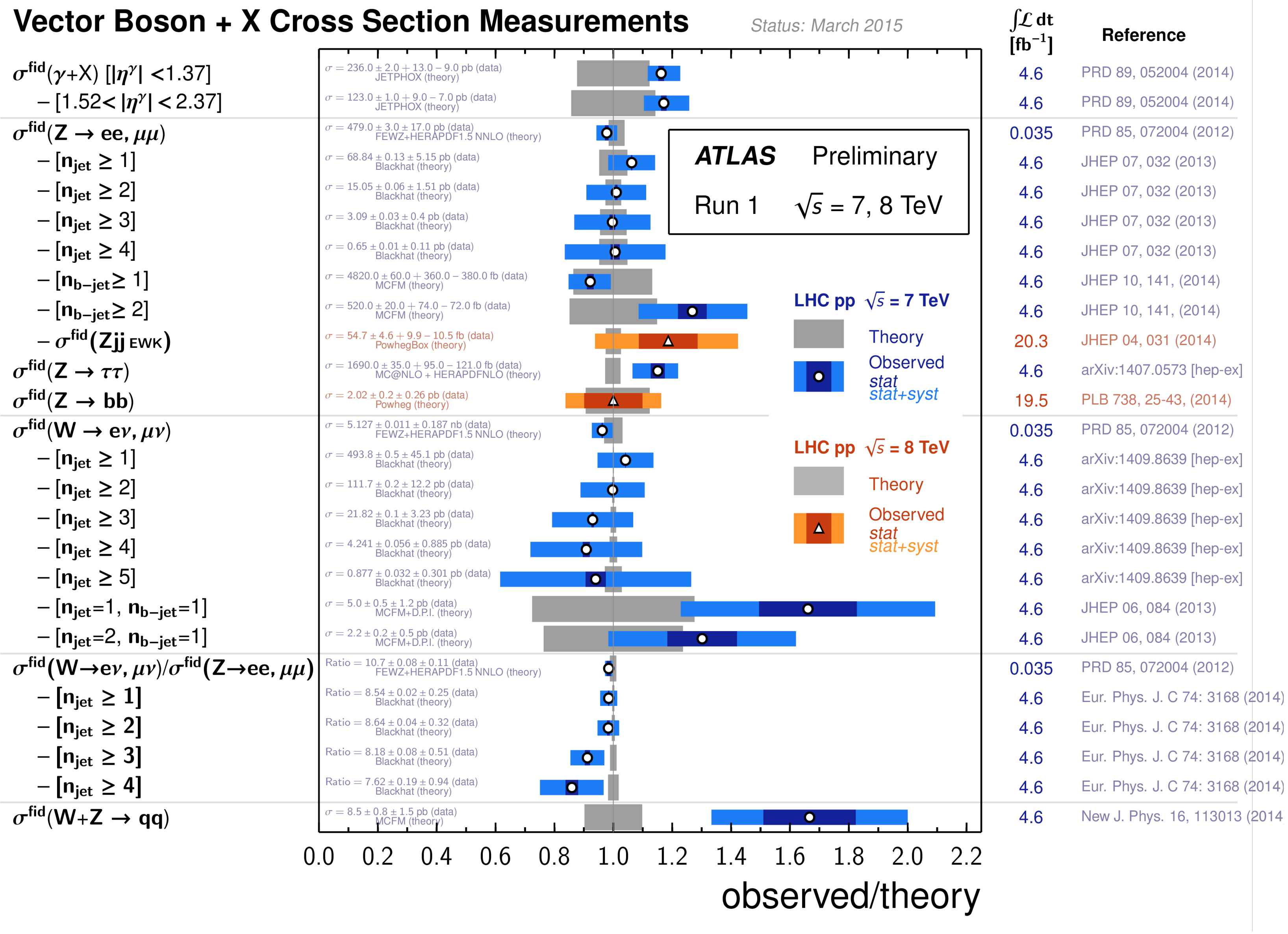
KK graviton

arXiv:1506.00285

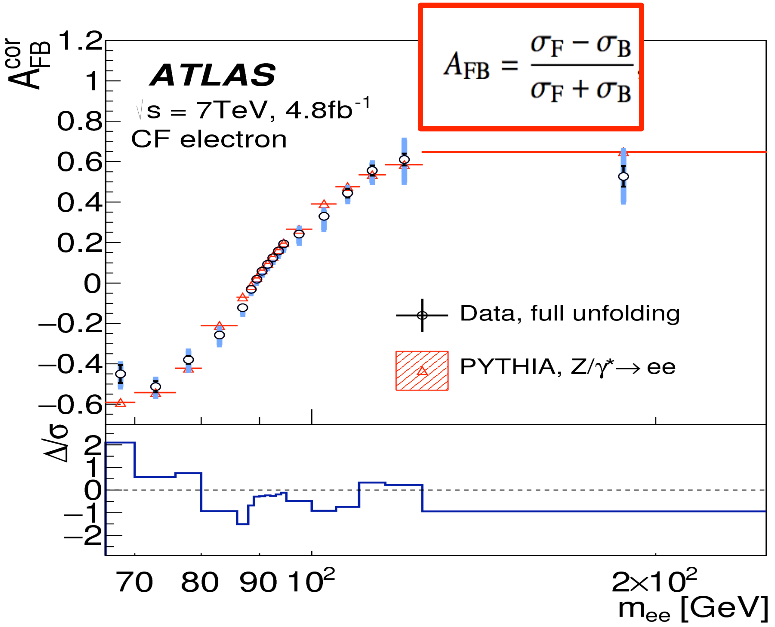
Exotics Higgs production and decay: no significant access (yet?)

Window to new physics?

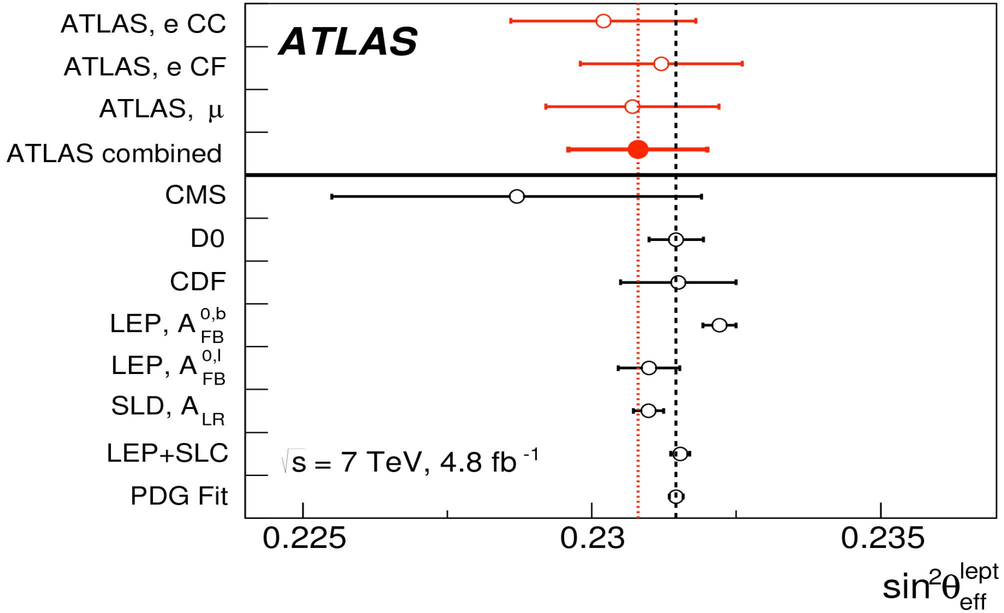
W/Z physics

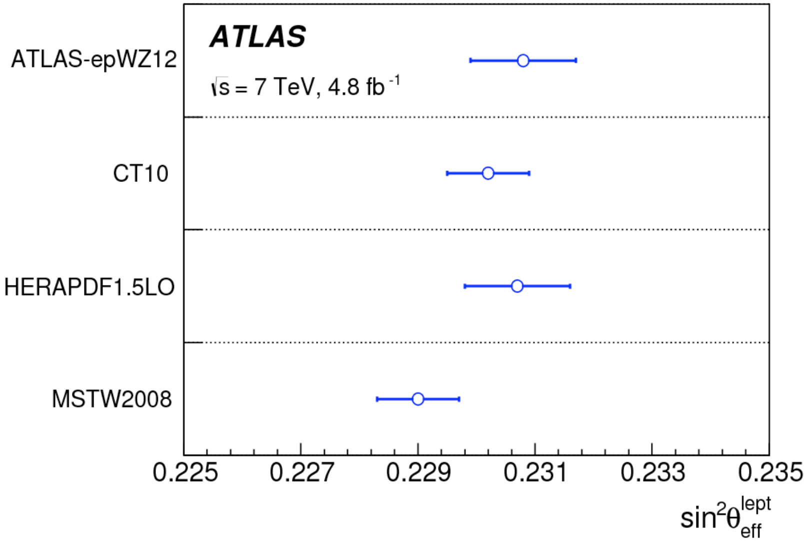

Vector Boson + X Cross Section Measurements
Status: March 2015
$\int\mathcal{L}\,dt$ [fb^{-1}]
Reference
$\sigma^{fid}(\gamma+X)$ [$|\eta^\gamma|$ <1.37]
– [1.52< $|\eta^\gamma|$ < 2.37]
$\sigma^{fid}(Z \to ee, \mu\mu)$
– [$n_{jet} \geq 1$]
– [$n_{jet} \geq 2$]
– [$n_{jet} \geq 3$]
– [$n_{jet} \geq 4$]
– [$n_{b-jet} \geq 1$]
– [$n_{b-jet} \geq 2$]
– σ^{fid}(Zjj EWK)
$\sigma^{fid}(Z \to \tau\tau)$
$\sigma^{fid}(Z \to bb)$
$\sigma^{fid}(W \to e\nu, \mu\nu)$
– [$n_{jet} \geq 1$]
– [$n_{jet} \geq 2$]
– [$n_{jet} \geq 3$]
– [$n_{jet} \geq 4$]
– [$n_{jet} \geq 5$]
– [n_{jet}=1, n_{b-jet}=1]
– [n_{jet}=2, n_{b-jet}=1]
$\sigma^{fid}(W \to e\nu, \mu\nu)/\sigma^{fid}(Z \to ee, \mu\mu)$
– [$n_{jet} \geq 1$]
– [$n_{jet} \geq 2$]
– [$n_{jet} \geq 3$]
– [$n_{jet} \geq 4$]
$\sigma^{fid}(W+Z \to qq)$
σ = 236.0 ± 2.0 + 13.0 – 9.0 pb (data) JETPHOX (theory)
σ = 123.0 ± 1.0 + 9.0 – 7.0 pb (data) JETPHOX (theory)
σ = 479.0 ± 3.0 ± 17.0 pb (data) FEWZ+HERAPDF1.5 NNLO (theory)
σ = 68.84 ± 0.13 ± 5.15 pb (data) Blackhat (theory)
σ = 15.05 ± 0.06 ± 1.51 pb (data) Blackhat (theory)
σ = 3.09 ± 0.03 ± 0.4 pb (data) Blackhat (theory)
σ = 0.65 ± 0.01 ± 0.11 pb (data) Blackhat (theory)
σ = 4820.0 ± 60.0 + 360.0 – 380.0 fb (data) MCFM (theory)
σ = 520.0 ± 20.0 + 74.0 – 72.0 fb (data) MCFM (theory)
σ = 54.7 ± 4.6 + 9.9 – 10.5 fb (data) PowhegBox (theory)
σ = 1690.0 ± 35.0 + 95.0 – 121.0 fb (data) MC@NLO + HERAPDFNLO (theory)
σ = 2.02 ± 0.2 ± 0.26 pb (data) Powheg (theory)
σ = 5.127 ± 0.011 ± 0.187 nb (data) FEWZ+HERAPDF1.5 NNLO (theory)
σ = 493.8 ± 0.5 ± 45.1 pb (data) Blackhat (theory)
σ = 111.7 ± 0.2 ± 12.2 pb (data) Blackhat (theory)
σ = 21.82 ± 0.1 ± 3.23 pb (data) Blackhat (theory)
σ = 4.241 ± 0.056 ± 0.885 pb (data) Blackhat (theory)
σ = 0.877 ± 0.032 ± 0.301 pb (data) Blackhat (theory)
σ = 5.0 ± 0.5 ± 1.2 pb (data) MCFM+D.P.I. (theory)
σ = 2.2 ± 0.2 ± 0.5 pb (data) MCFM+D.P.I. (theory)
Ratio = 10.7 ± 0.08 ± 0.11 (data) FEWZ+HERAPDF1.5 NNLO (theory)
Ratio = 8.54 ± 0.02 ± 0.25 (data) Blackhat (theory)
Ratio = 8.64 ± 0.04 ± 0.32 (data) Blackhat (theory)
Ratio = 8.18 ± 0.08 ± 0.51 (data) Blackhat (theory)
Ratio = 7.62 ± 0.19 ± 0.94 (data) Blackhat (theory)
σ = 8.5 ± 0.8 ± 1.5 pb (data) MCFM (theory)
ATLAS Preliminary
Run 1 $\sqrt{s}$ = 7, 8 TeV
LHC pp $\sqrt{s}$ = 7 TeV
Theory
Observed
stat
stat+syst
LHC pp $\sqrt{s}$ = 8 TeV
Theory
Observed
stat
stat+syst
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
observed/theory
4.6 PRD 89, 052004 (2014)
4.6 PRD 89, 052004 (2014)
0.035 PRD 85, 072004 (2012)
4.6 JHEP 07, 032 (2013)
4.6 JHEP 07, 032 (2013)
4.6 JHEP 07, 032 (2013)
4.6 JHEP 07, 032 (2013)
4.6 JHEP 10, 141, (2014)
4.6 JHEP 10, 141, (2014)
20.3 JHEP 04, 031 (2014)
4.6 arXiv:1407.0573 [hep-ex]
19.5 PLB 738, 25-43, (2014)
0.035 PRD 85, 072004 (2012)
4.6 arXiv:1409.8639 [hep-ex]
4.6 arXiv:1409.8639 [hep-ex]
4.6 arXiv:1409.8639 [hep-ex]
4.6 arXiv:1409.8639 [hep-ex]
4.6 arXiv:1409.8639 [hep-ex]
4.6 JHEP 06, 084 (2013)
4.6 JHEP 06, 084 (2013)
0.035 PRD 85, 072004 (2012)
4.6 Eur. Phys. J. C 74: 3168 (2014)
4.6 Eur. Phys. J. C 74: 3168 (2014)
4.6 Eur. Phys. J. C 74: 3168 (2014)
4.6 Eur. Phys. J. C 74: 3168 (2014)
4.6 New J. Phys. 16, 113013 (2014

Forward-backward asymmetry in $Z/\gamma^* \rightarrow ll$



$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$





- ATLAS has the ability to use forward electrons: μμ, CC ee, CF ee
- Uncertainty ~10x world average but only ~4x leading (discrepant) measurements
- 75% of the total uncertainty on A_{FB} due to PDFs

Detour: ultimate precision measurement at LHC: W mass with $\delta(m_W) < 10$ MeV from $p_T(l)$, m_T

- $\delta(m_W)$ leading uncertainty in SM precision tests
- Dominant systematics from QCD (PDFs, $p_T(W)$)

→ **Drell-Yan measurements important to constrain systematics!**

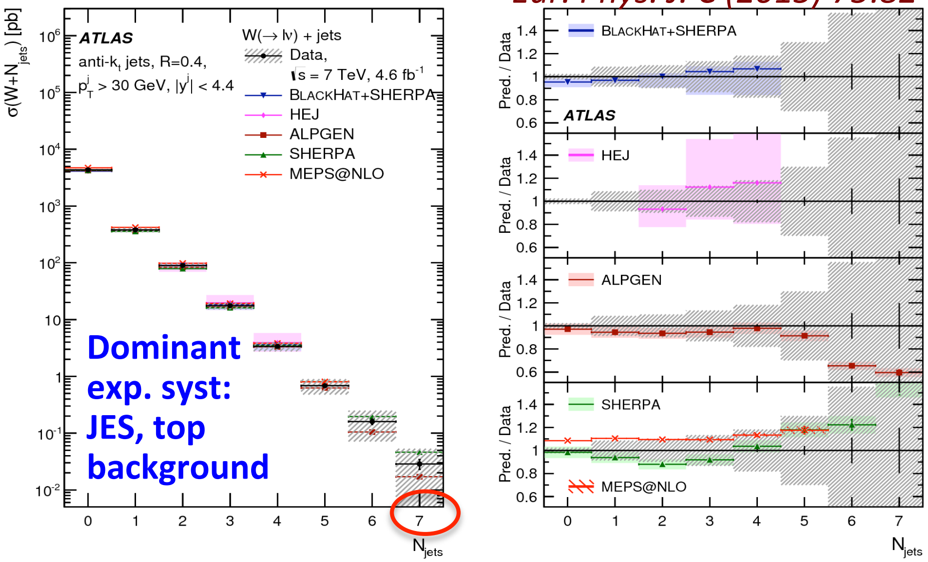
$$\sin^2\theta_{eff}^{lept} = 0.2308 \pm 0.0005(\text{stat.}) \pm 0.0006(\text{syst.}) \pm 0.0009(\text{PDF}),$$

W+jets production

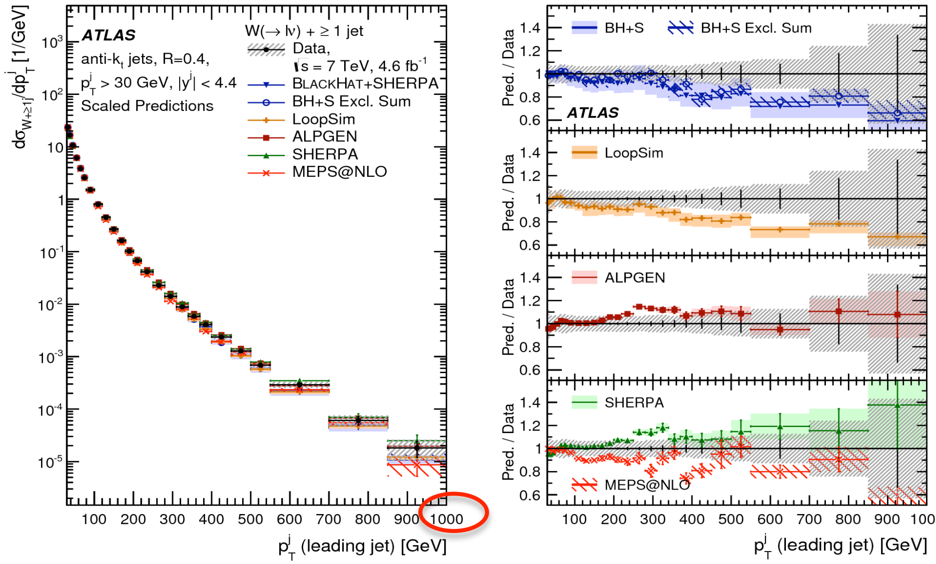
- Testing theoretical models up to N_{jet}=7 and p_T^{jet}= 1 TeV
- No model provides accurate description for all studied distributions

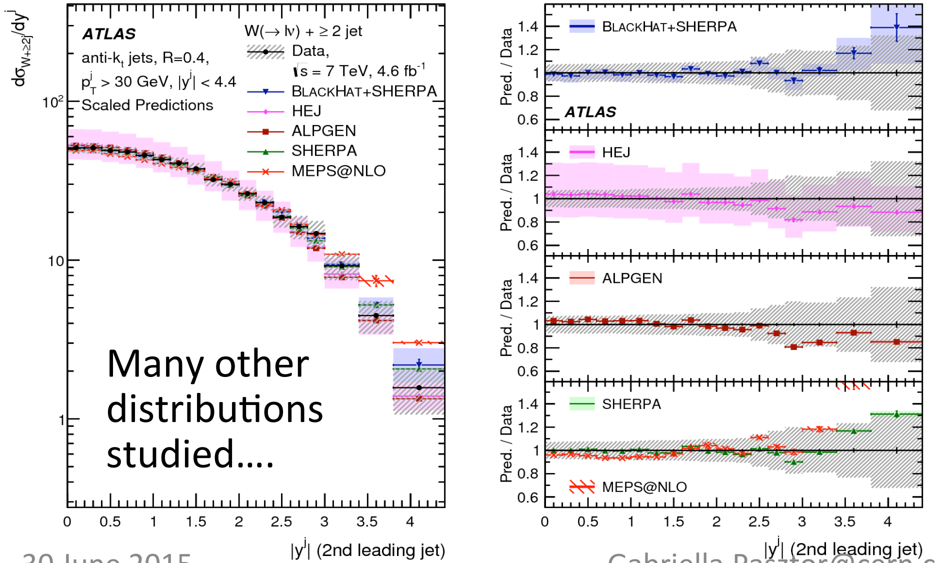
ALPGEN+HERWIG: LO multileg (up to 5 extra partons)
SHERPA: LO multileg (up to 4 extra partons)
BLACKHAT + SHERPA: NLO
Exclusive sum approach: combine NLO W + n jets & W + ≧n+1 jets
MEPS@NLO: Combine NLO (W + 1/2 jets) + LO multileg (up to 4 jets)
LoopSim: approx. NNLO
HEJ: approx. all order for W + ≧2 jets

Eur. Phys. J. C (2015) 75:82

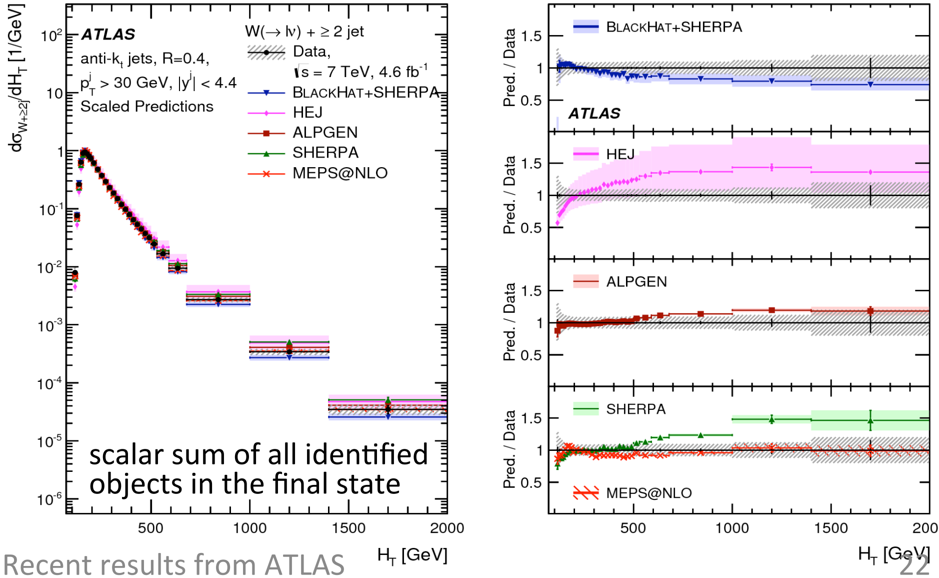


Dominant exp. syst: JES, top background





Many other distributions studied….

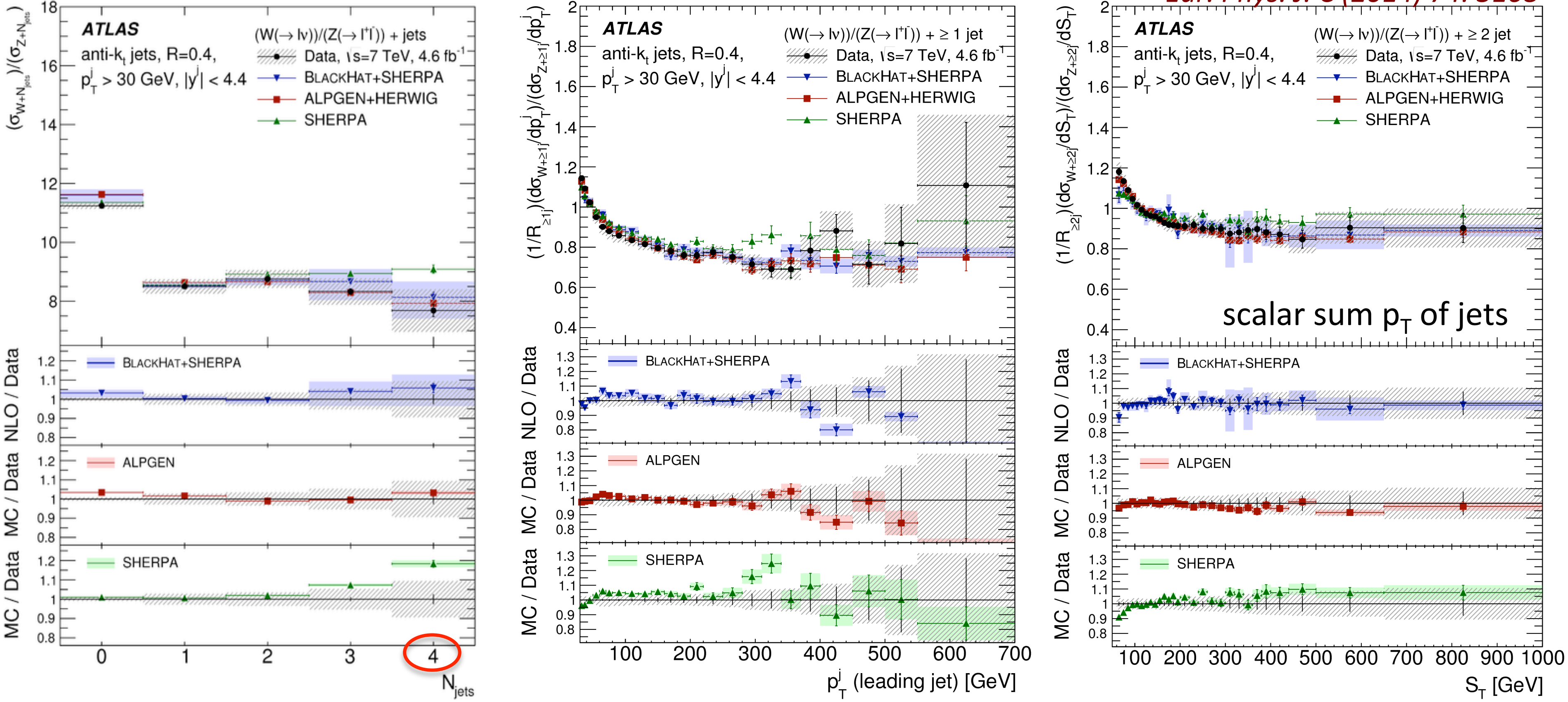


scalar sum of all identified objects in the final state

W+jets/Z+jets cross-section ratios

- Sensitivity for differences between Z+jets and W+jets
- Large cancellation of experimental uncertainties and non-perturbative QCD effects

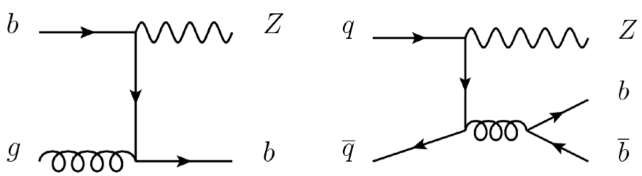
Eur. Phys. J. C (2014) 74: 3168

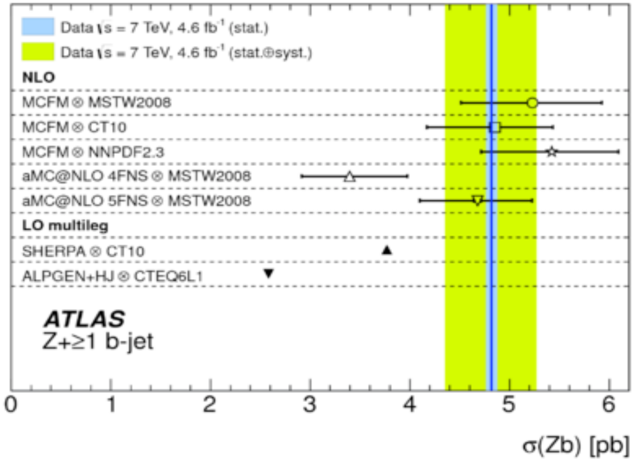


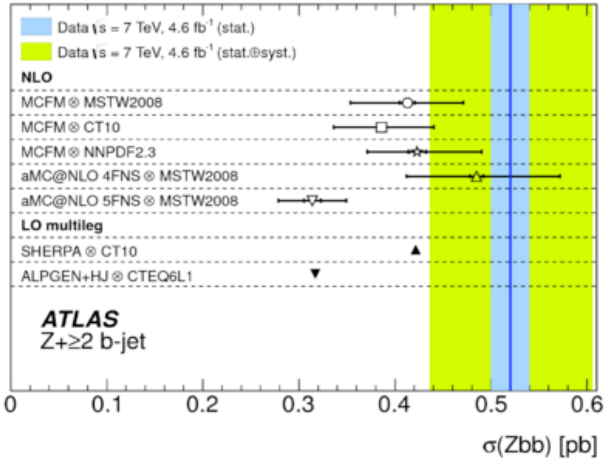
scalar sum p_T of jets

- NLO pQCD calculations of BlackHat+Sherpa agree well in general with the data, except in specific regions → large success of recent theory advances
- Still opportunities for further tuning

Z + b-jets production

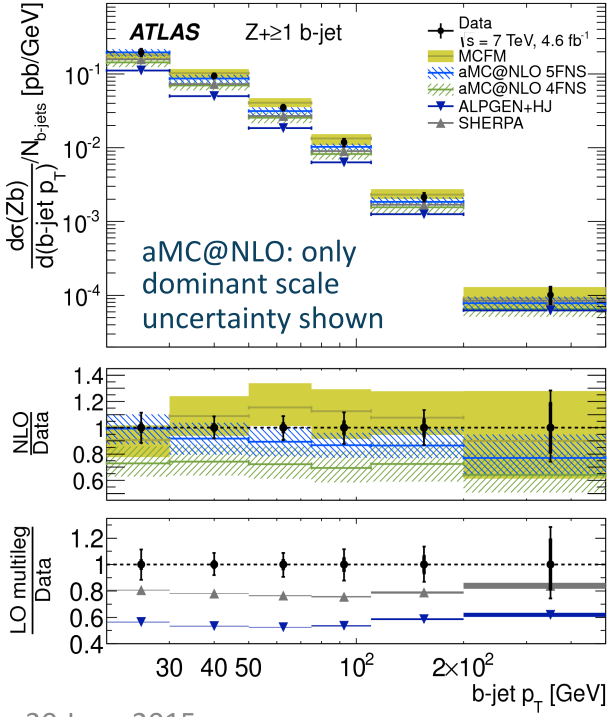




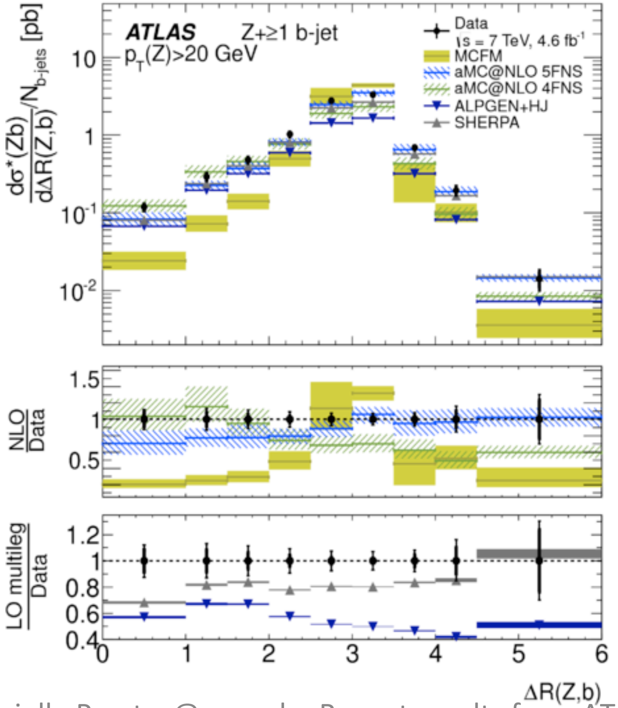


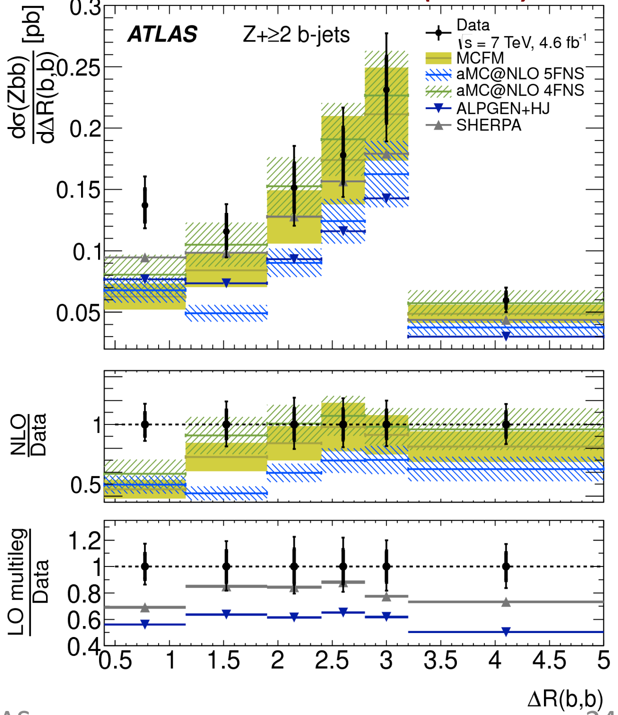
- Angular distributions for Z + b jets not well described by NLO calculations
- Certain distributions favour 5FS, others 4FS
- LO multileg generators do better (wrt shapes)

JHEP10(2014)141

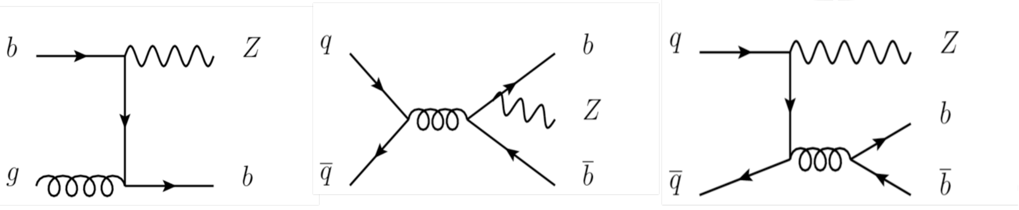


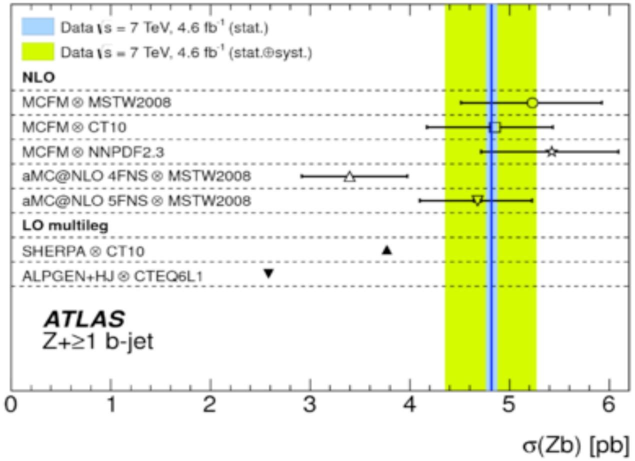
aMC@NLO: only dominant scale uncertainty shown

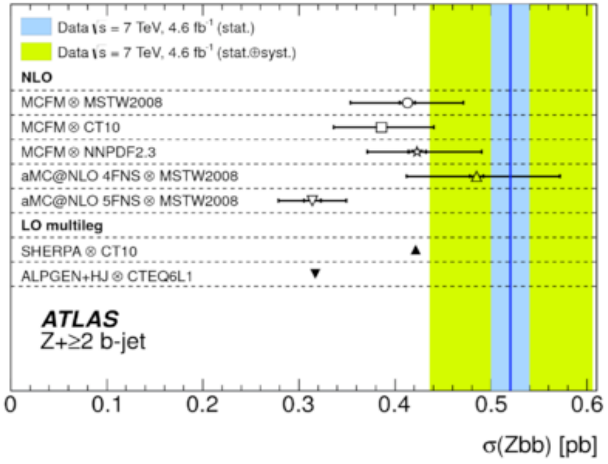




Z + b-jets production

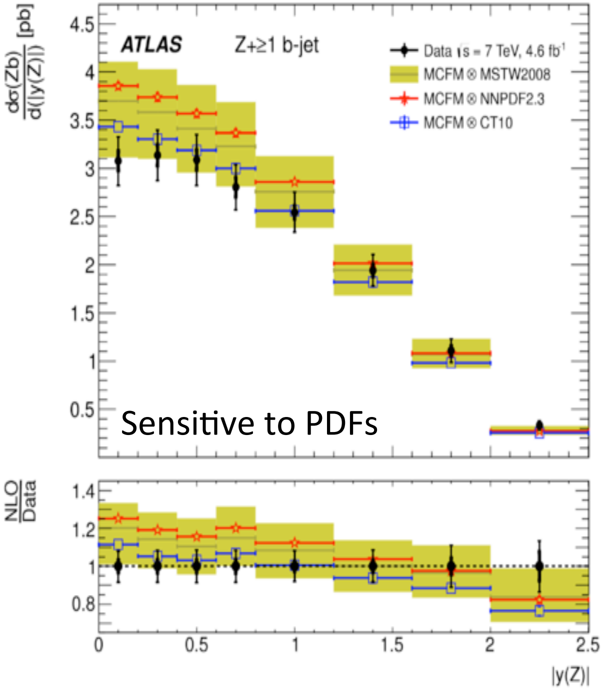




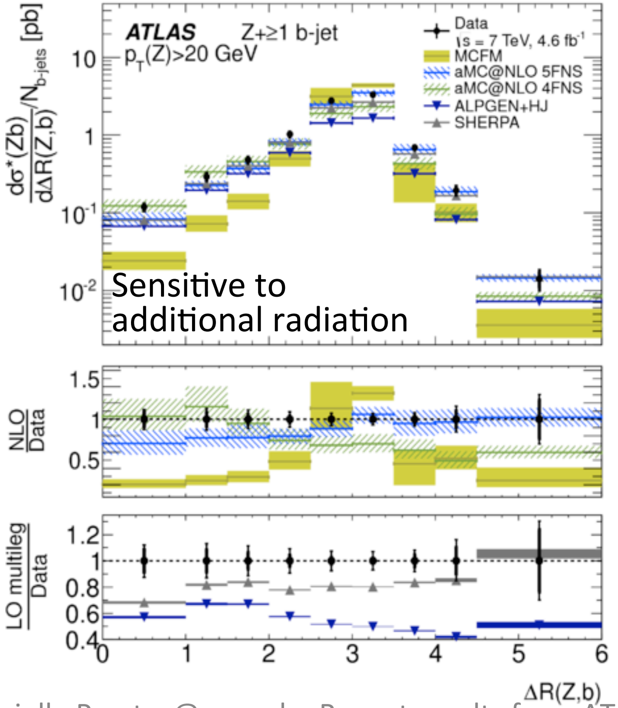


- Angular distributions for Z + b jets not well described by NLO calculations
- Certain distributions favour 5FS, others 4FS
- LO multileg generators do better (wrt shapes)

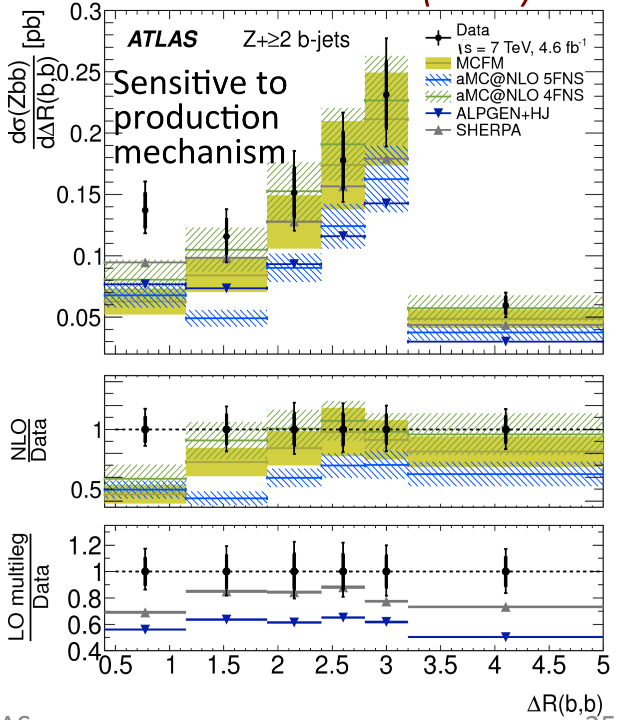
JHEP10(2014)141



Sensitive to PDFs

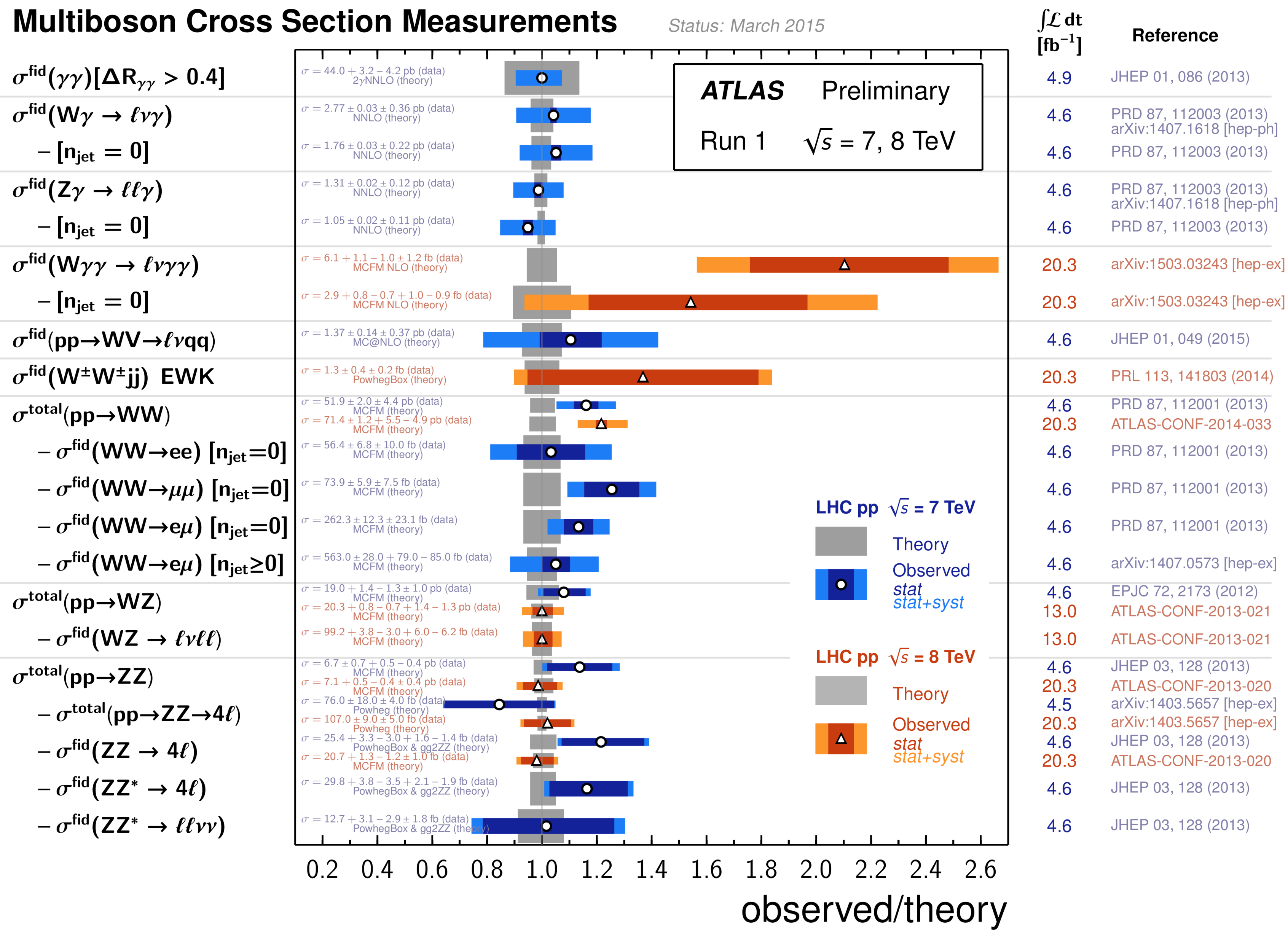


Sensitive to additional radiation



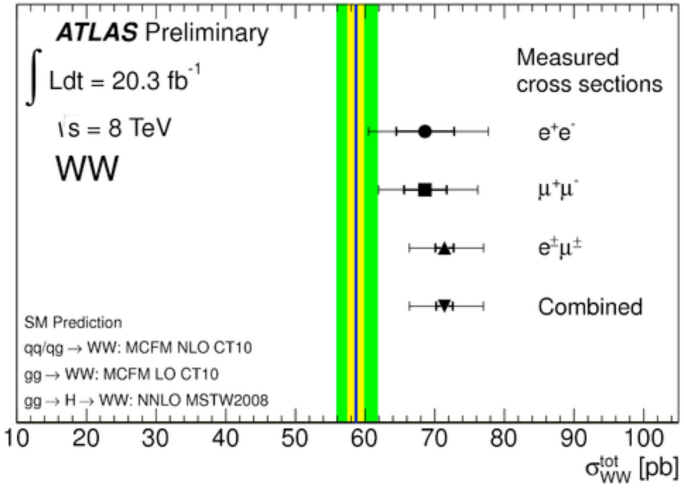
Sensitive to production mechanism

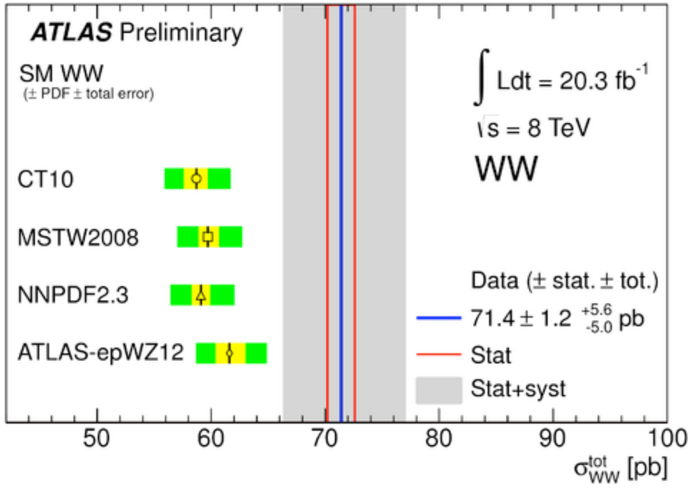
Multi-boson production

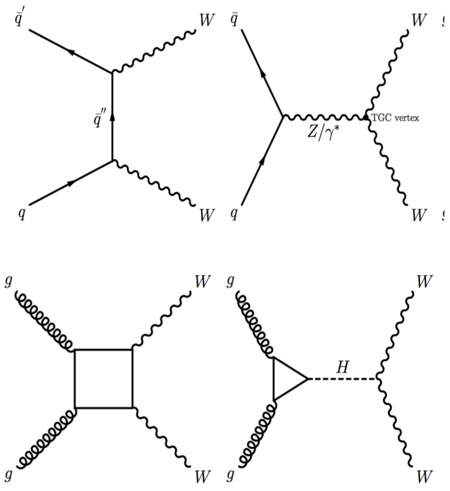


WW cross-section

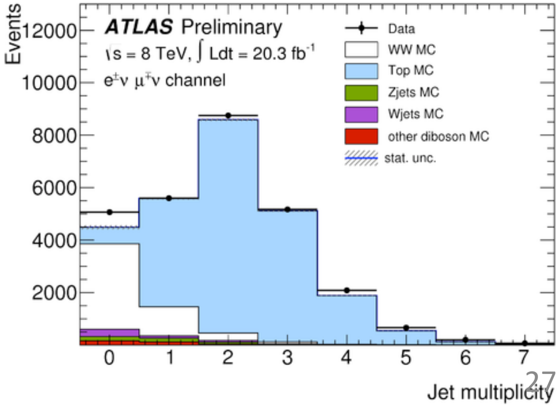
ATLAS-CONF-2014-033







- 2.1σ excess wrt SM prediction: $\sigma_{WW}^{tot} = 71.4\ ^{+1.2}_{-1.2}(\text{stat})\ ^{+5.0}_{-4.4}(\text{syst})\ ^{+2.2}_{-2.1}(\text{lumi})$ pb,
- Theory prediction by MCFM: $58.7^{+3.0}_{-2.7}$ pb
  - qq/qg → WW NLO QCD (including off-shell bosons and decays)
    - Large scale uncertainty 5-7% (but underestimated?)
    - First NNLO (on-shell only) predicts 10% increase in cross-section, with similar scale uncertainties: 54.8+3.7-2.9 → 59.7+2.2-1.8 @ 8 TeV, PRL 113 (2014) 212001
    - NNLO includes gg → WW
  - LO gg → WW: 1.4 +0.3-0.2 pb
    - higher order: factor 2-3 increase possible
  - NNLO+NNLL QCD, NLO EW gg → H → WW : 4.1 ± 0.5 pb
- NLO EW corrections can be as large as 15% at high p_T
- Jet veto (to supress large tt background) subject to large QCD uncertainty

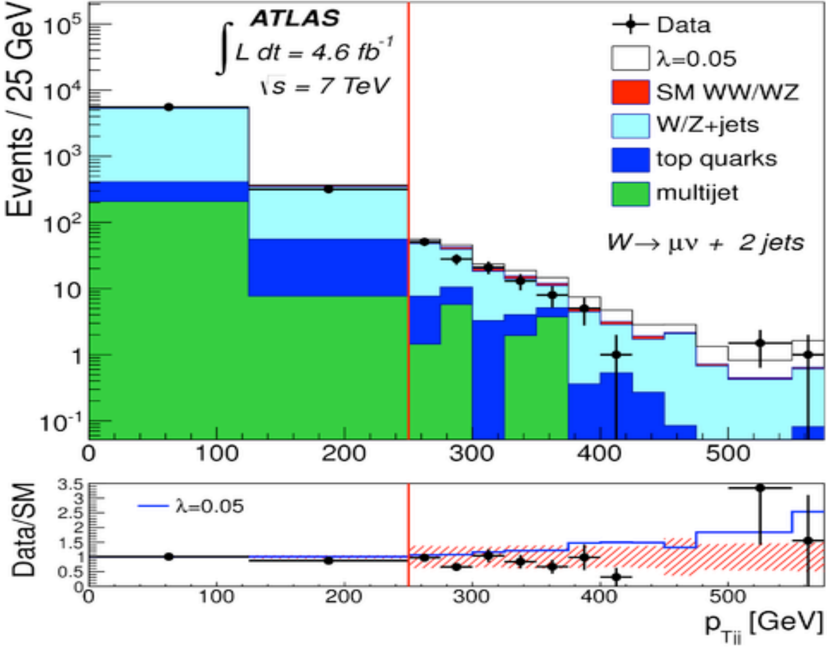


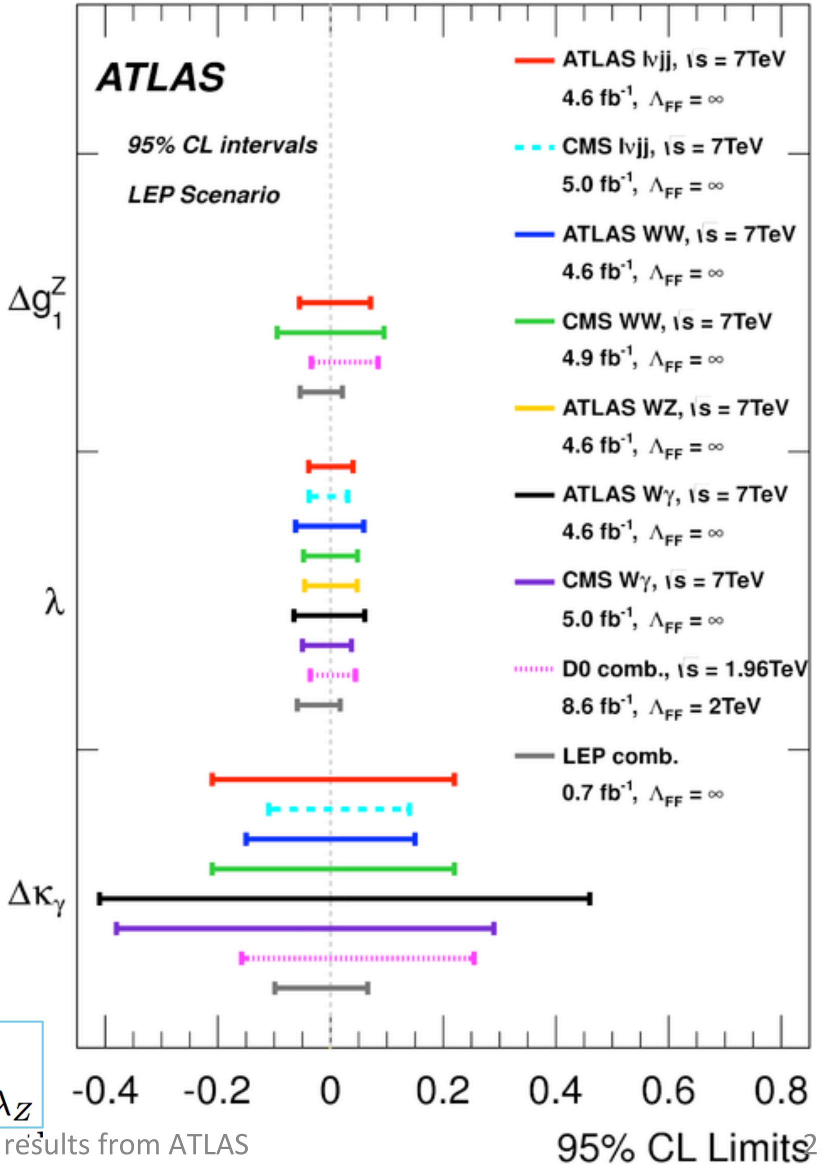
WW+WZ production

$$\mathcal{L} = i g_{WWV} \Big(g_1^V (W^+_{\mu\nu} W^{-\mu} - W^{+\mu} W^-_{\mu\nu}) V^\nu + \kappa_V W^+_\mu W^-_\nu V^{\mu\nu} + \frac{\lambda_V}{M_W^2} W^{\nu +}_\mu W^{- \rho}_\nu V^\mu_\rho$$
$$+ i g_4^V W^+_\mu W^-_\nu (\partial^\mu V^\nu + \partial^\nu V^\mu) - i g_5^V \epsilon^{\mu\nu\rho\sigma} (W^+_\mu \partial_\rho W^-_\nu - \partial_\rho W^+_\mu W^-_\nu) V_\sigma$$
$$+ \tilde{\kappa}_V W^+_\mu W^-_\nu \tilde{V}^{\mu\nu} + \frac{\tilde{\lambda}_V}{m_W^2} W^{\nu +}_\mu W^{- \rho}_\nu \tilde{V}^\mu_\rho \Big) \,,$$

- 2 jets+ e/μ final state: 3.4σ significance
- Observed cross-section:
  $68 \pm 7\ (\text{stat.}) \pm 19\ (\text{syst.})\ \text{pb}$
  with $61.1 \pm 2.2\ \text{pb}$ expected (MC@NLO)
- Dijet transverse momentum sensitive to new physics

JHEP01(2015)049



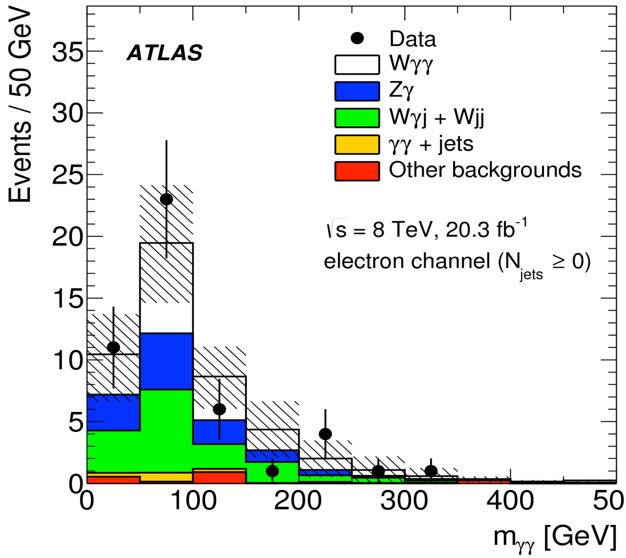


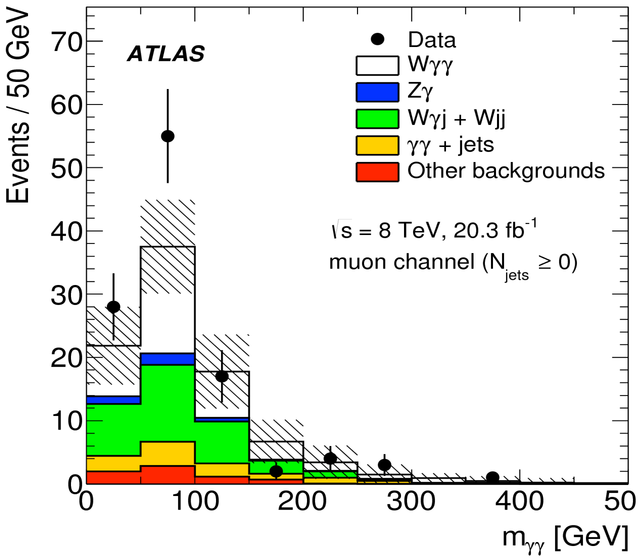
- Setting limits on aTGCs and on coefficients of dim-6 operators in an EFT

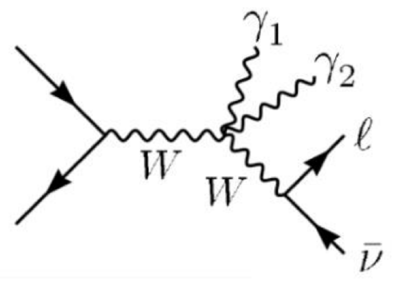
$$\Delta g_1^Z = g_1^Z - 1,\ \Delta\kappa_{\gamma,Z} = \kappa_{\gamma,Z} - 1,$$
$$\Delta g_1^Z = \Delta\kappa_Z + \tan^2\theta_W \Delta\kappa_\gamma,\ \lambda_\gamma = \lambda_Z$$

$W\gamma\gamma$ production

- First evidence for triple gauge boson production: >3σ significance
- High di-photon mass region sensitive to new physics
- $W\gamma\gamma$ production is particularly sensitive to f_{T0}/Λ^4 ($\mathcal{L}_{T,0} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \mathrm{Tr}\left[\hat{W}_{\alpha\beta}\hat{W}^{\alpha\beta}\right]$)



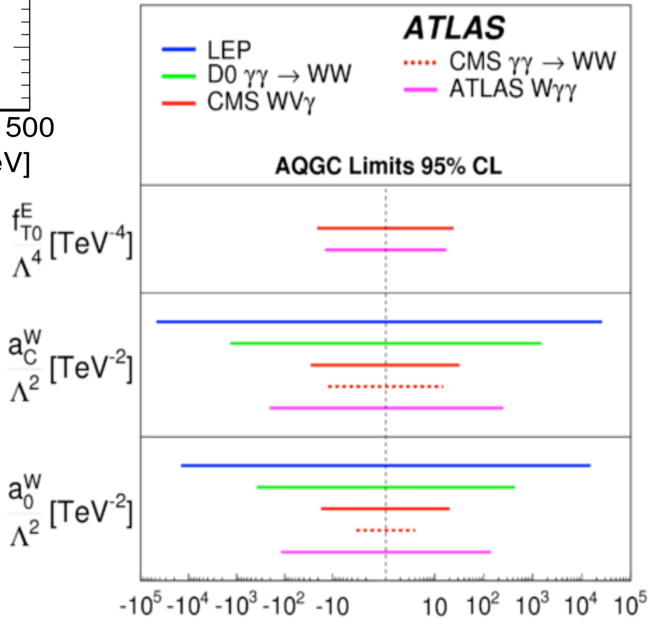




Phys. Rev. Lett. 113, 141803

	σ^{fid} [fb]	σ^{MCFM} [fb]
Inclusive ($N_{\mathrm{jet}} \geq 0$)		NLO SM
$\mu\nu\gamma\gamma$	$7.1\ ^{+1.3}_{-1.2}$ (stat.) ± 1.5 (syst.) ± 0.2 (lumi.)	2.90 ± 0.16
$e\nu\gamma\gamma$	$4.3\ ^{+1.8}_{-1.6}$ (stat.) $^{+1.9}_{-1.8}$ (syst.) ± 0.2 (lumi.)	
$\ell\nu\gamma\gamma$	$6.1\ ^{+1.1}_{-1.0}$ (stat.) ± 1.2 (syst.) ± 0.2 (lumi.)	
Exclusive ($N_{\mathrm{jet}} = 0$)		
$\mu\nu\gamma\gamma$	3.5 ± 0.9 (stat.) $^{+1.1}_{-1.0}$ (syst.) ± 0.1 (lumi.)	1.88 ± 0.20
$e\nu\gamma\gamma$	$1.9\ ^{+1.4}_{-1.1}$ (stat.) $^{+1.1}_{-1.2}$ (syst.) ± 0.1 (lumi.)	
$\ell\nu\gamma\gamma$	$2.9\ ^{+0.8}_{-0.7}$ (stat.) $^{+1.0}_{-0.9}$ (syst.) ± 0.1 (lumi.)	

1.9σ excess in inclusive measurement

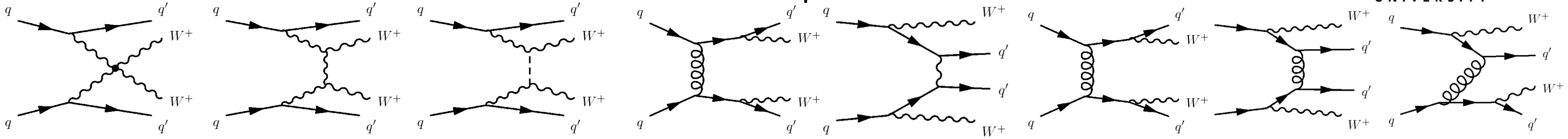


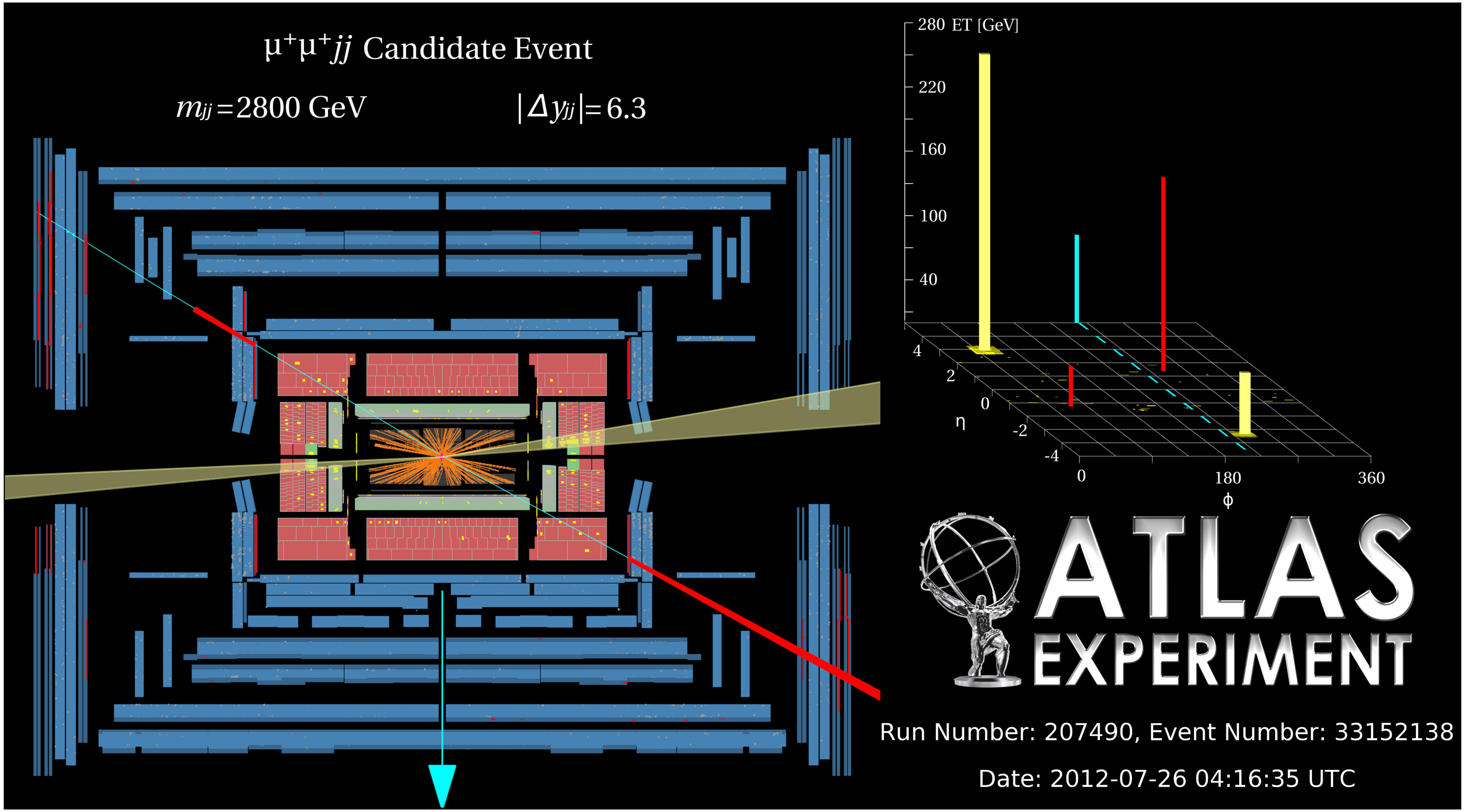
$W^{\pm}W^{\pm}jj$ production

Vector-boson scattering

Other EW production

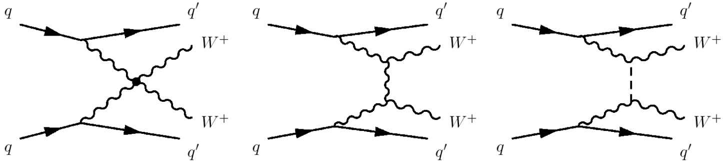
QCD production



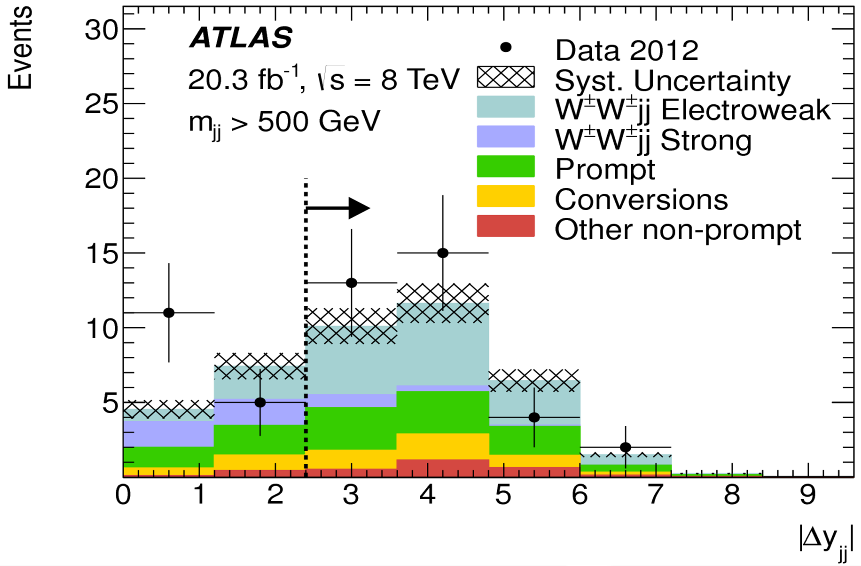


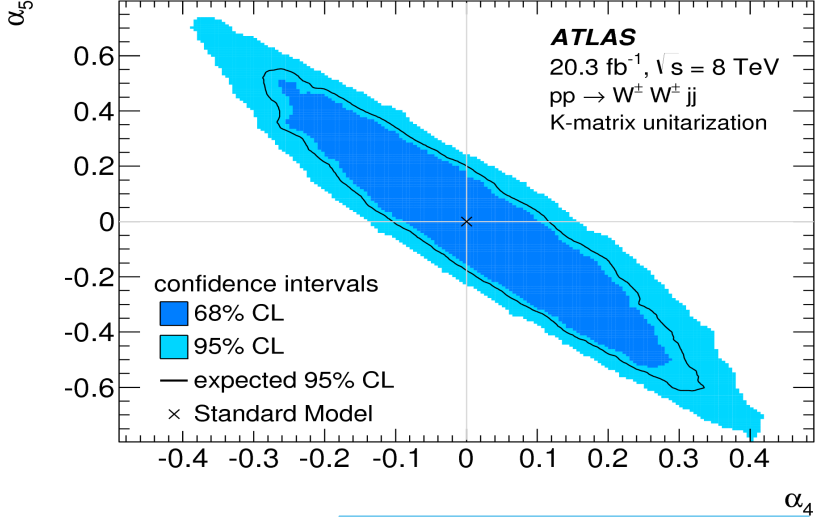
$W^{\pm}W^{\pm}jj$ production

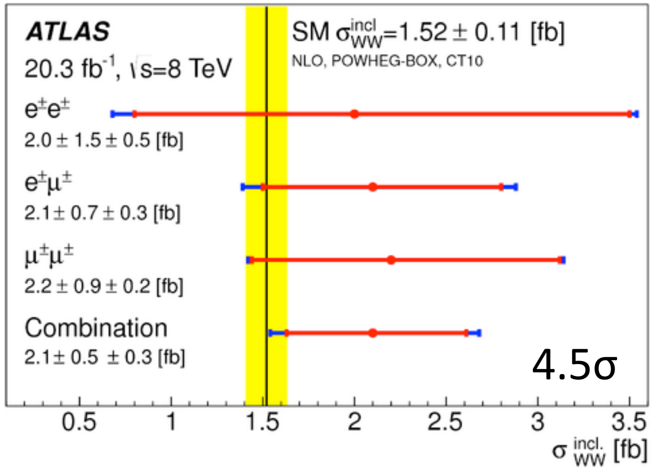
- Higgs regularises longitudinal VBS cross-section in SM
- VBS region is sensitive to new physics
- Rare process, require forward jets

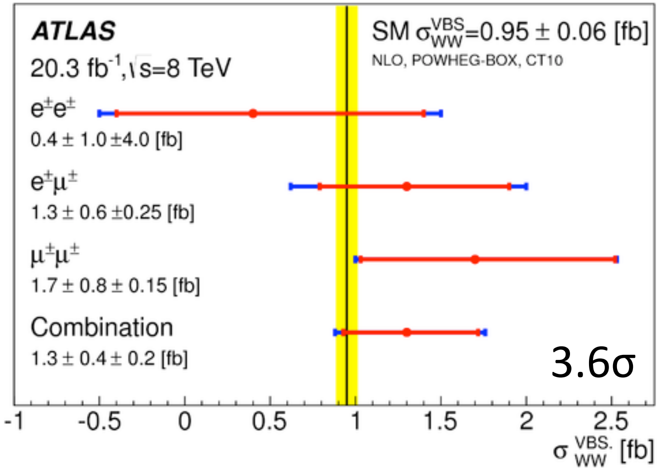


Phys. Rev. Lett. 113, 141803









$$\mathcal{L}_4^{(4)} = \alpha_4 \left[\mathrm{Tr}\left(V_\mu V_\nu\right)\right]^2$$

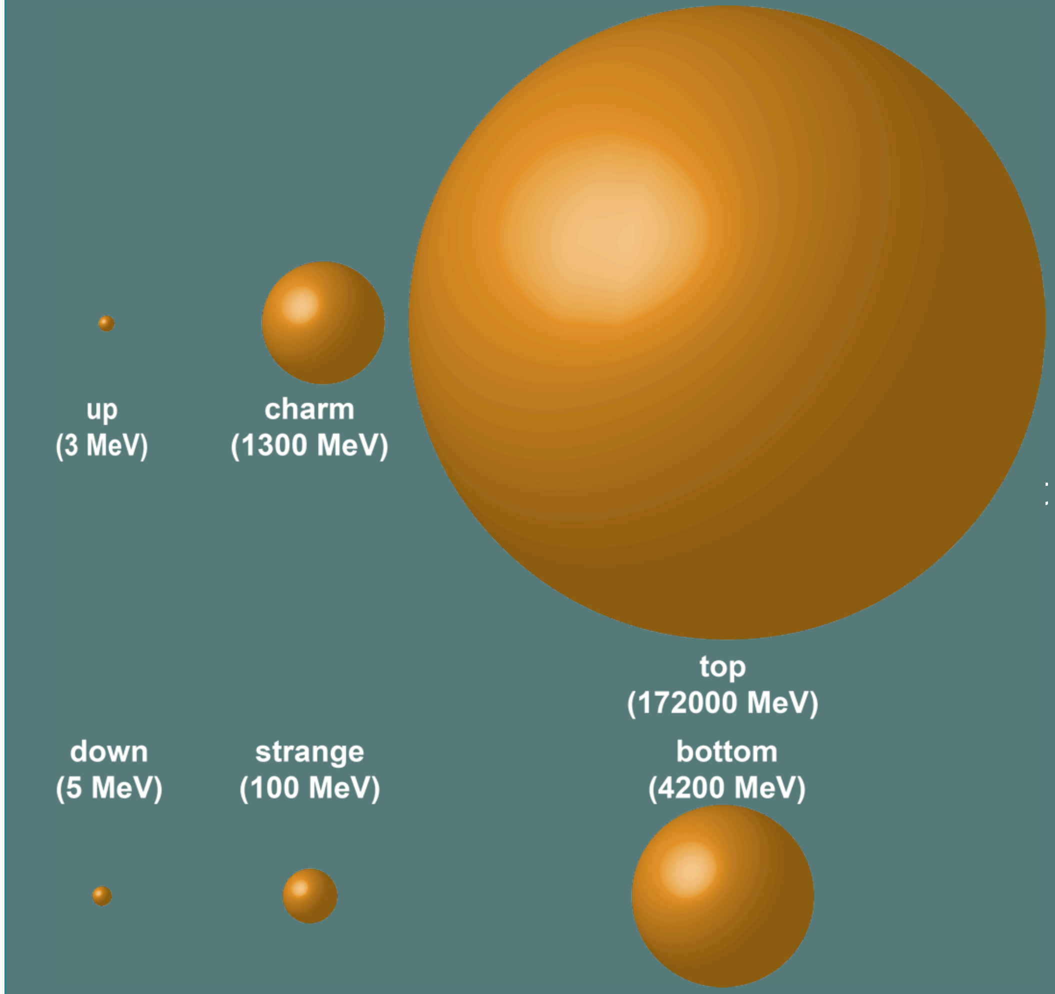
$$\mathcal{L}_5^{(4)} = \alpha_5 \left[\mathrm{Tr}\left(V_\mu V^\mu\right)\right]^2$$

for the WWWW-Vertex:

$$\alpha_4 = \frac{f_{S,0}}{\Lambda^4}\,\frac{v^4}{8}$$

$$\alpha_4 + 2\cdot\alpha_5 = \frac{f_{S,1}}{\Lambda^4}\,\frac{v^4}{8}$$

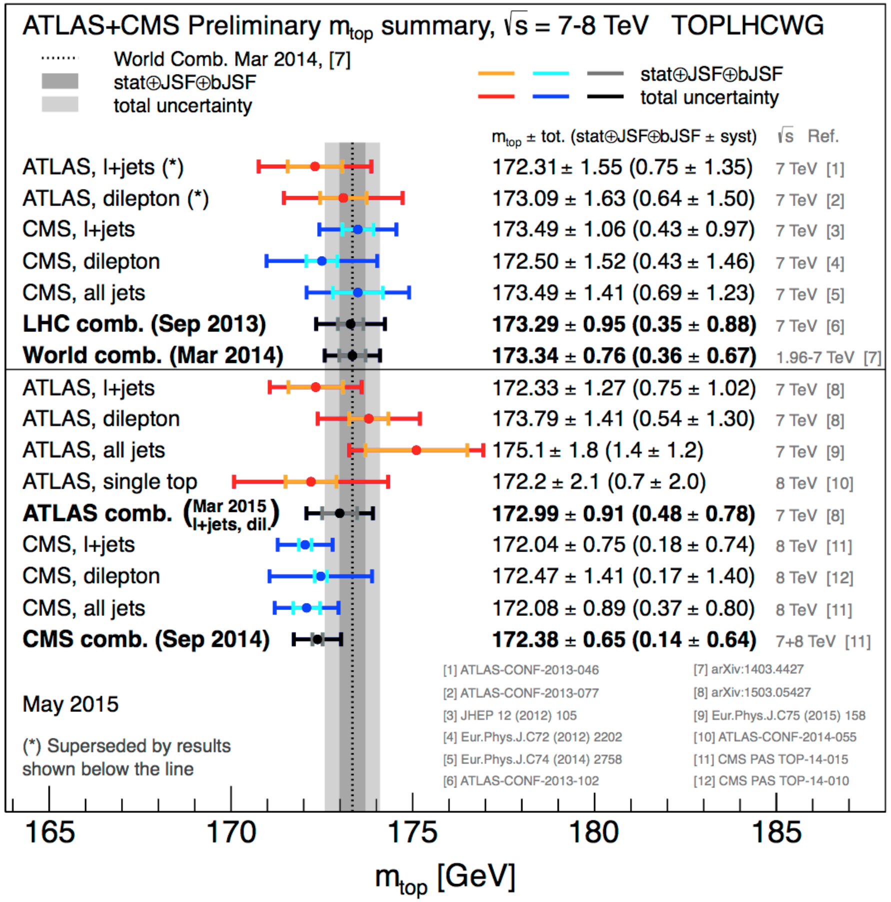
Top physics



Heaviest known elementary particle
Coupling to Higgs ~O(1)
→ Closely connected to EWSB

In BSM models, such as technicolor or other scenarios with strongly coupled Higgs sector, top couplings can be modified
→ Measure top couplings directly

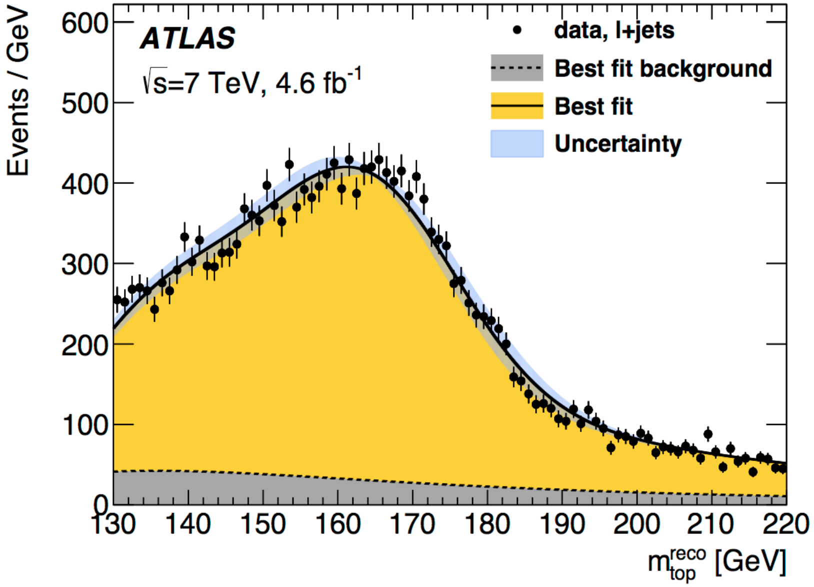
Top mass

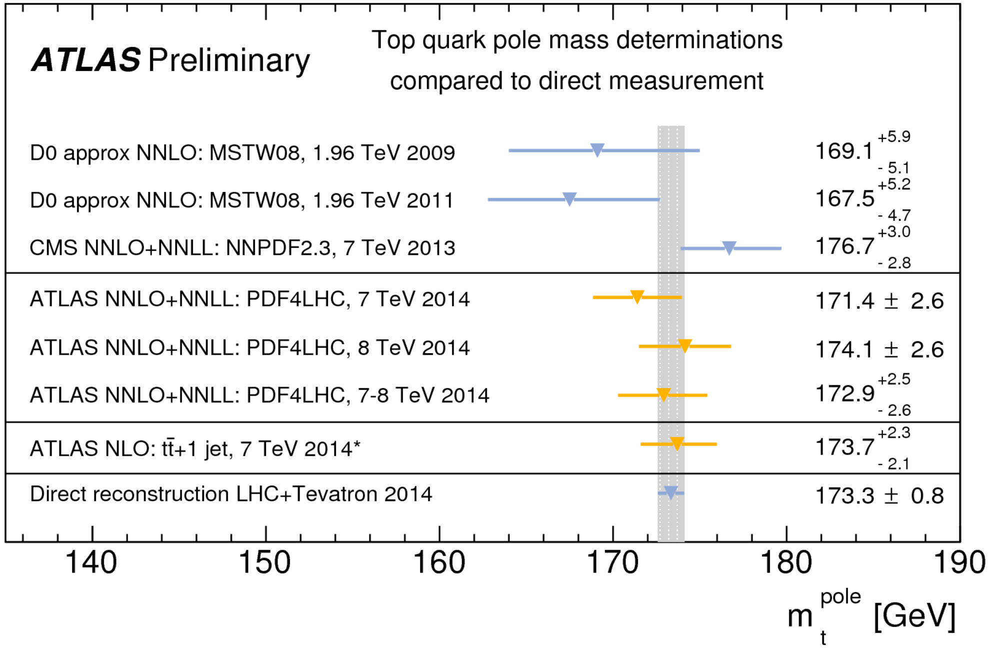


	m_{top} ± tot. (stat⊕JSF⊕bJSF ± syst)	$\sqrt{s}$	Ref.
ATLAS, l+jets (*)	172.31 ± 1.55 (0.75 ± 1.35)	7 TeV	[1]
ATLAS, dilepton (*)	173.09 ± 1.63 (0.64 ± 1.50)	7 TeV	[2]
CMS, l+jets	173.49 ± 1.06 (0.43 ± 0.97)	7 TeV	[3]
CMS, dilepton	172.50 ± 1.52 (0.43 ± 1.46)	7 TeV	[4]
CMS, all jets	173.49 ± 1.41 (0.69 ± 1.23)	7 TeV	[5]
LHC comb. (Sep 2013)	**173.29 ± 0.95 (0.35 ± 0.88)**	7 TeV	[6]
World comb. (Mar 2014)	**173.34 ± 0.76 (0.36 ± 0.67)**	1.96-7 TeV	[7]
ATLAS, l+jets	172.33 ± 1.27 (0.75 ± 1.02)	7 TeV	[8]
ATLAS, dilepton	173.79 ± 1.41 (0.54 ± 1.30)	7 TeV	[8]
ATLAS, all jets	175.1 ± 1.8 (1.4 ± 1.2)	7 TeV	[9]
ATLAS, single top	172.2 ± 2.1 (0.7 ± 2.0)	8 TeV	[10]
ATLAS comb. (Mar 2015 l+jets, dil.)	**172.99 ± 0.91 (0.48 ± 0.78)**	7 TeV	[8]
CMS, l+jets	172.04 ± 0.75 (0.18 ± 0.74)	8 TeV	[11]
CMS, dilepton	172.47 ± 1.41 (0.17 ± 1.40)	8 TeV	[12]
CMS, all jets	172.08 ± 0.89 (0.37 ± 0.80)	8 TeV	[11]
CMS comb. (Sep 2014)	**172.38 ± 0.65 (0.14 ± 0.64)**	7+8 TeV	[11]

[1] ATLAS-CONF-2013-046
[2] ATLAS-CONF-2013-077
[3] JHEP 12 (2012) 105
[4] Eur.Phys.J.C72 (2012) 2202
[5] Eur.Phys.J.C74 (2014) 2758
[6] ATLAS-CONF-2013-102
[7] arXiv:1403.4427
[8] arXiv:1503.05427
[9] Eur.Phys.J.C75 (2015) 158
[10] ATLAS-CONF-2014-055
[11] CMS PAS TOP-14-015
[12] CMS PAS TOP-14-010

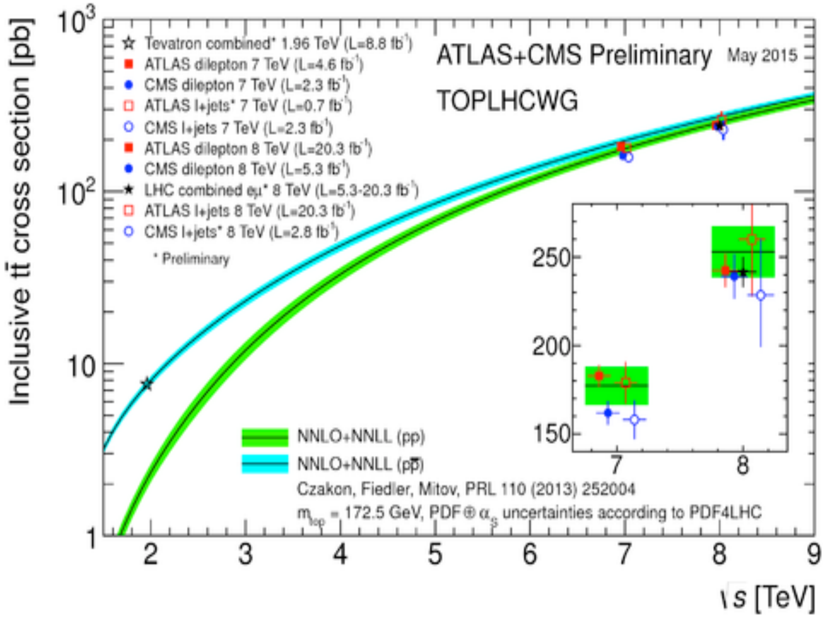
arXiv:1503.05427





D0 approx NNLO: MSTW08, 1.96 TeV 2009	$169.1^{+5.9}_{-5.1}$
D0 approx NNLO: MSTW08, 1.96 TeV 2011	$167.5^{+5.2}_{-4.7}$
CMS NNLO+NNLL: NNPDF2.3, 7 TeV 2013	$176.7^{+3.0}_{-2.8}$
ATLAS NNLO+NNLL: PDF4LHC, 7 TeV 2014	171.4 ± 2.6
ATLAS NNLO+NNLL: PDF4LHC, 8 TeV 2014	174.1 ± 2.6
ATLAS NNLO+NNLL: PDF4LHC, 7-8 TeV 2014	$172.9^{+2.5}_{-2.6}$
ATLAS NLO: $t\bar{t}$+1 jet, 7 TeV 2014*	$173.7^{+2.3}_{-2.1}$
Direct reconstruction LHC+Tevatron 2014	173.3 ± 0.8

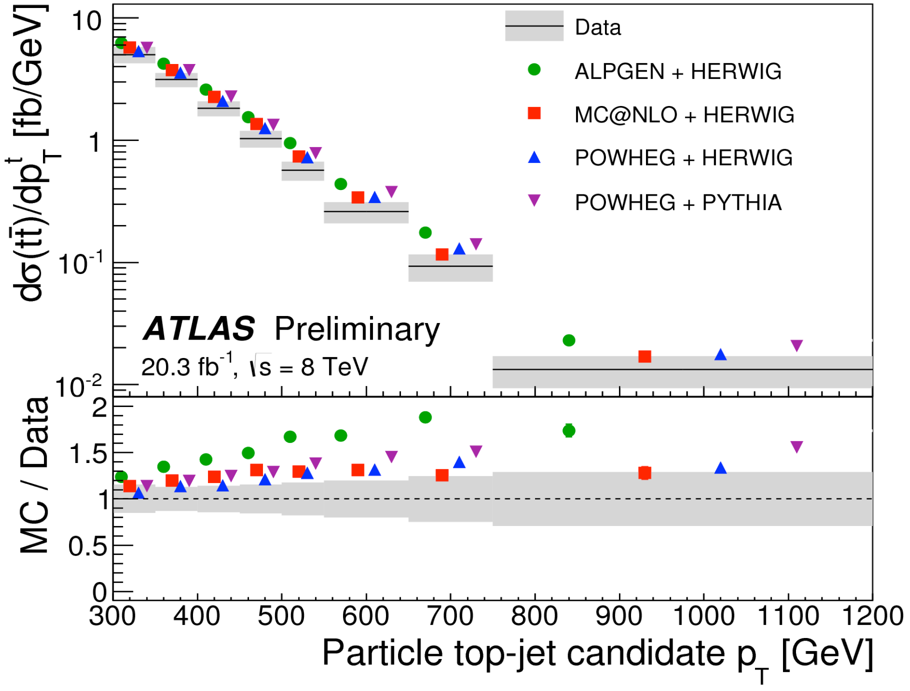
Measurement from many channels
Dominant systematics: jet energy scale
Theory question: what is top mass?



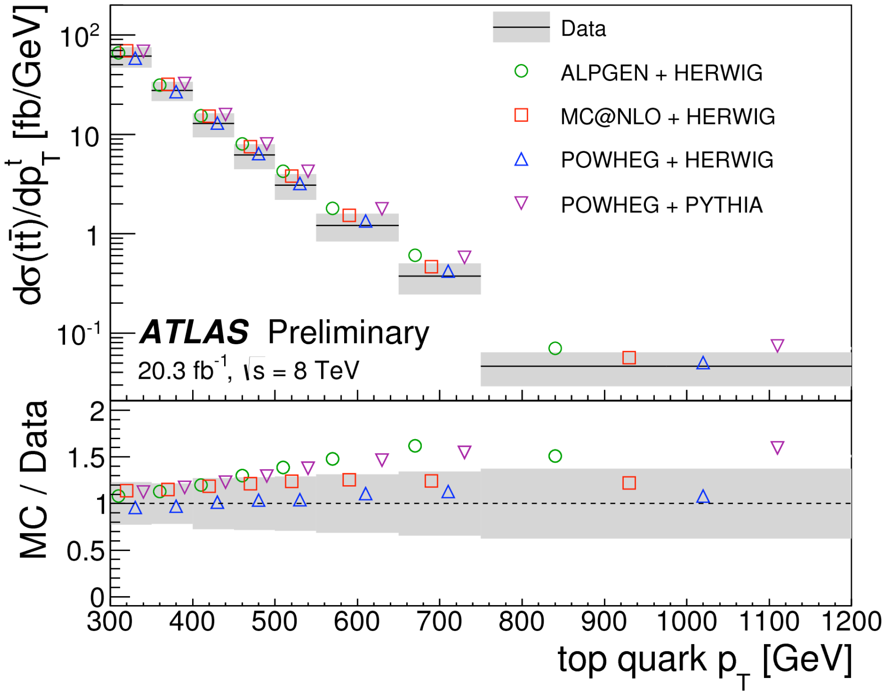
Top production

- Measured in many different final states
- Total cross-section well-described by NNLO+NNLL
- Differential (resolved and boosted) cross-sections are important to understand the tt process
- tt is main background for many searches
- Improved modelling uncertainties help sensitivity of searches (e.g. l+jets tt resonance search in this talk)

Particle level p_T of the boosted jet

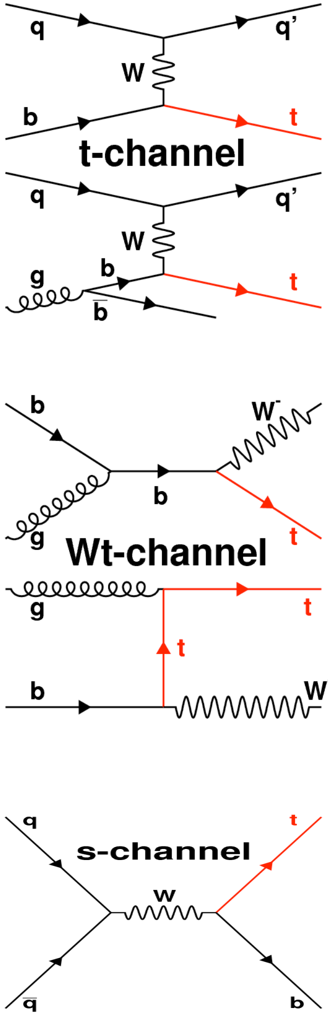


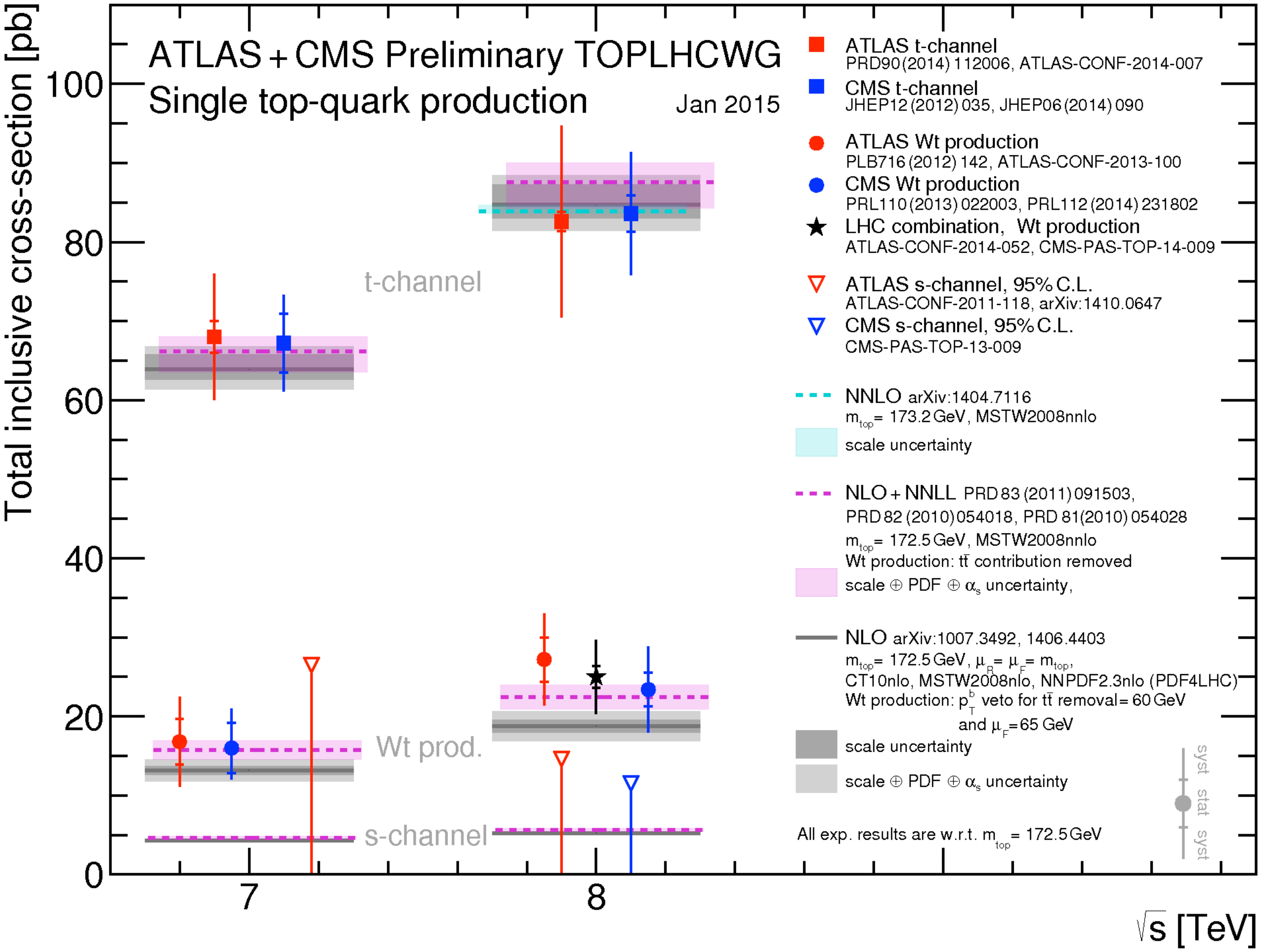
ATLAS-CONF-2014-057



Single top production

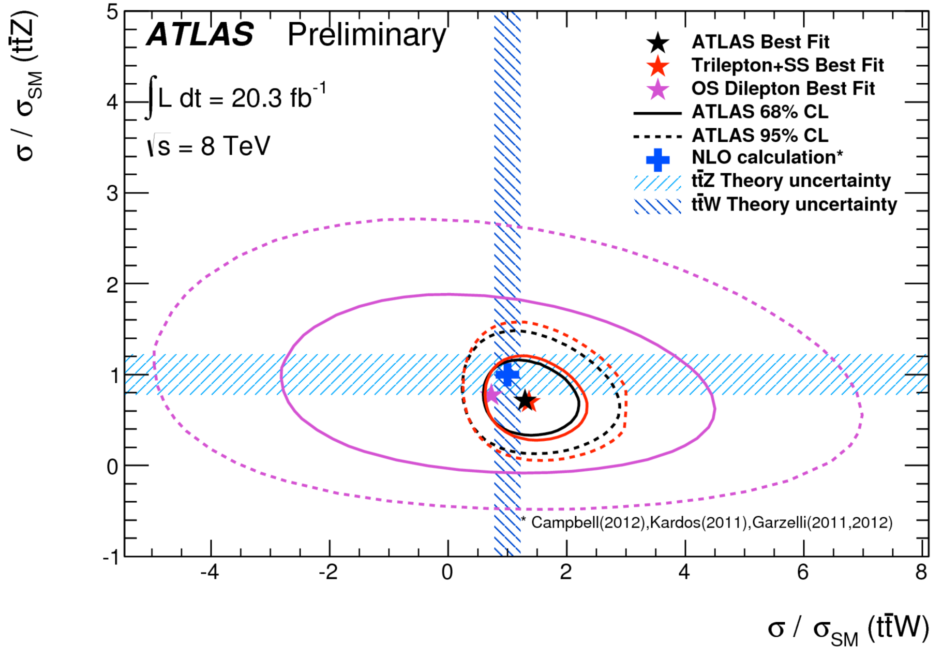
EW process via Wtb vertex





ttV production

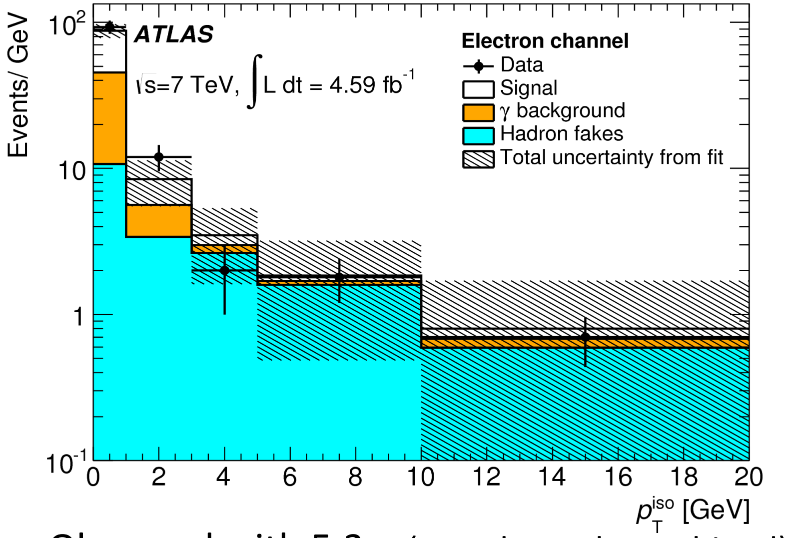
Direct search for ttZ, ttW production in three final states: 2lOS, 2lSS, 3l



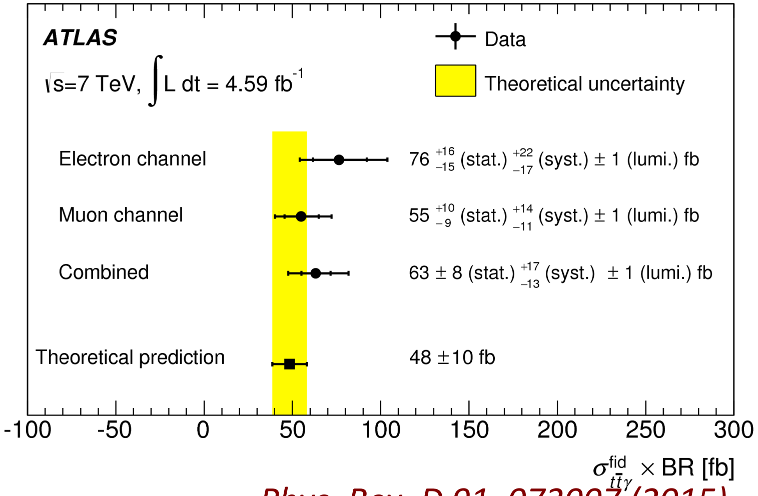
Assumption		Trilepton and same-sign dilepton channels		
	Process	Signal Strength	Observed σ	Expected σ
SM σ(ttZ)/σ(ttW)	$t\bar{t}V$	$0.91^{+0.27}_{0.24}$	4.6	4.6
SM σ(ttZ)	$t\bar{t}W$	$1.31^{+0.62}_{-0.50}$	3.0	2.3
SM σ(ttW)	$t\bar{t}Z$	$0.72^{+0.33}_{-0.28}$	2.8	3.4

ATLAS-CONF-2014-038

Direct search for ttγ production in l+jets+γ final state



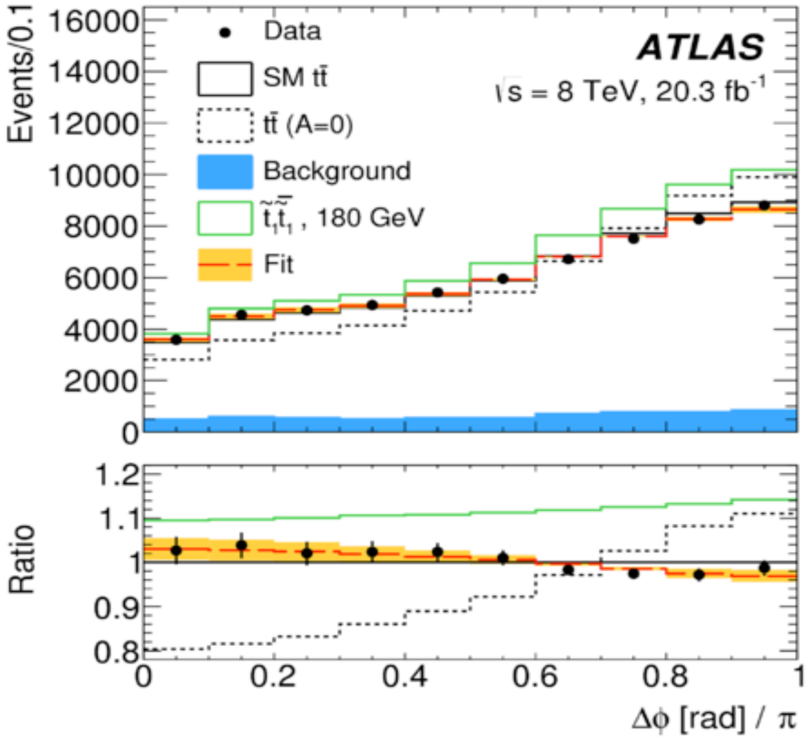
Observed with 5.3σ (e+μ channels combined)



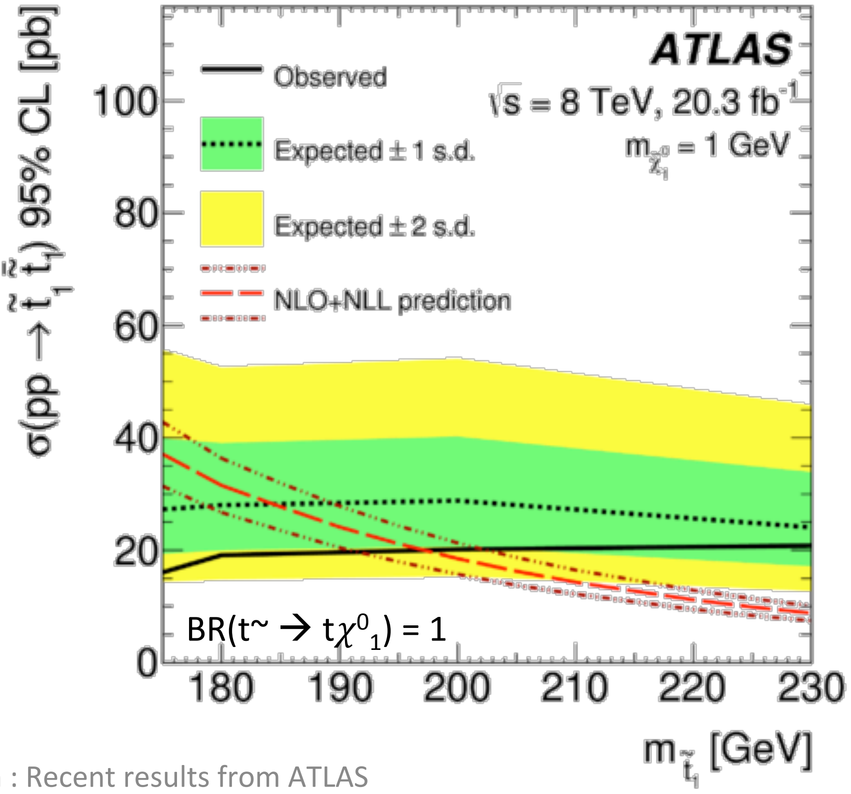
Phys. Rev. D 91, 072007 (2015)

Spin correlation and limits on SUSY

- Measurement of the correlation of the spins of the top and anti-top quarks in tt production provides a precision test of the SM and sensitive to new BSM physics
- Fit azimuthal angle difference between the charged leptons: f_{SM}*PDF(SM)+(1-f_{SM})*PDF(no correlation) → $f_{SM} = 1.2 \pm 0.05$ (stat) ± 0.13 (syst)
- Spin correlation strength: $A_{helicity} = (N_{\uparrow\uparrow}-N_{\uparrow\downarrow})/(N_{\uparrow\uparrow}-N_{\uparrow\downarrow}) = A_{helicity,SM} * f_{SM} = 0.38 \pm 0.04$
- Constrain BSM models, e.g. SUSY

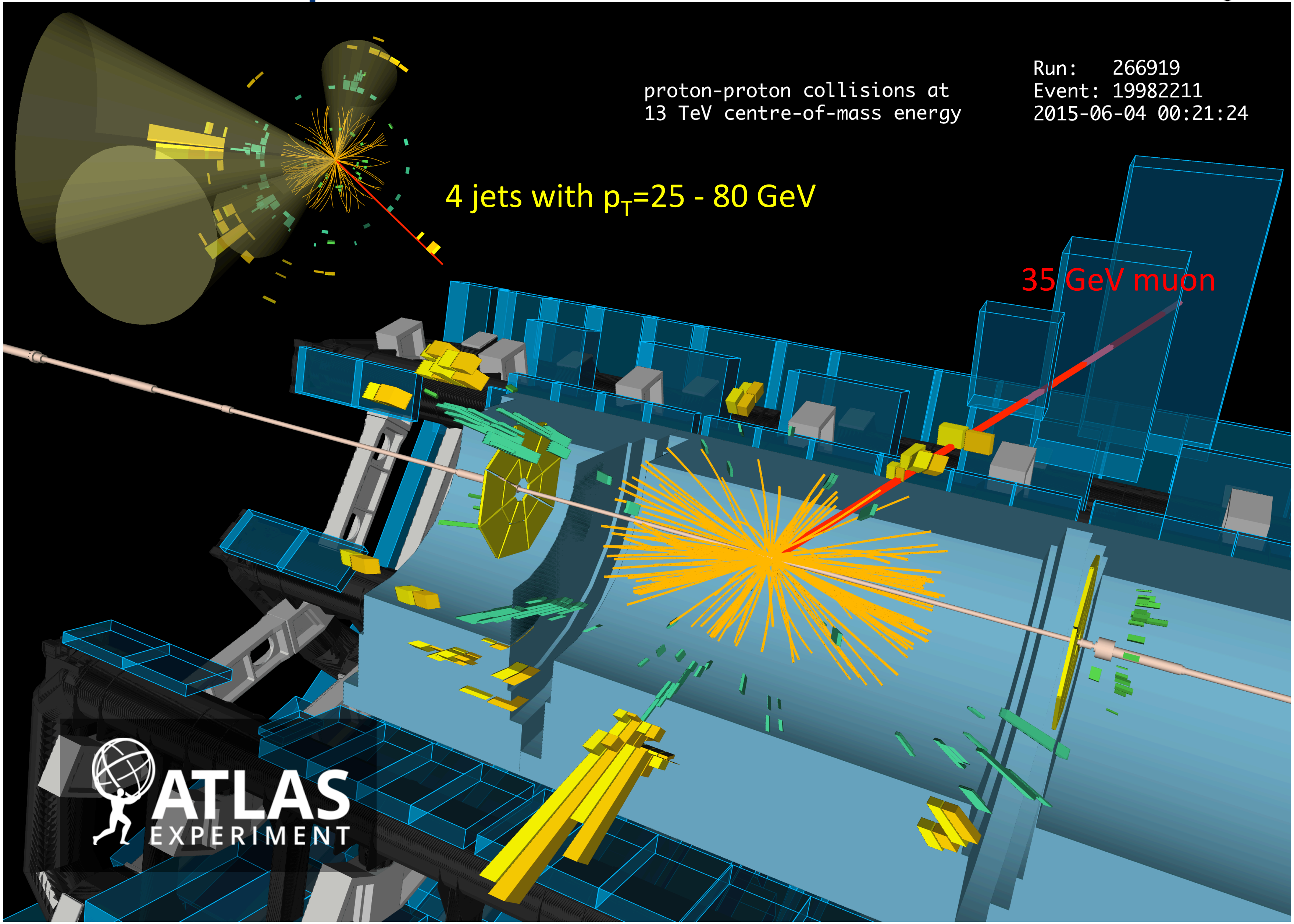


Phys. Rev. Lett. 114, 142001 (2015)



BR(t~ → $t\chi^0_1$) = 1

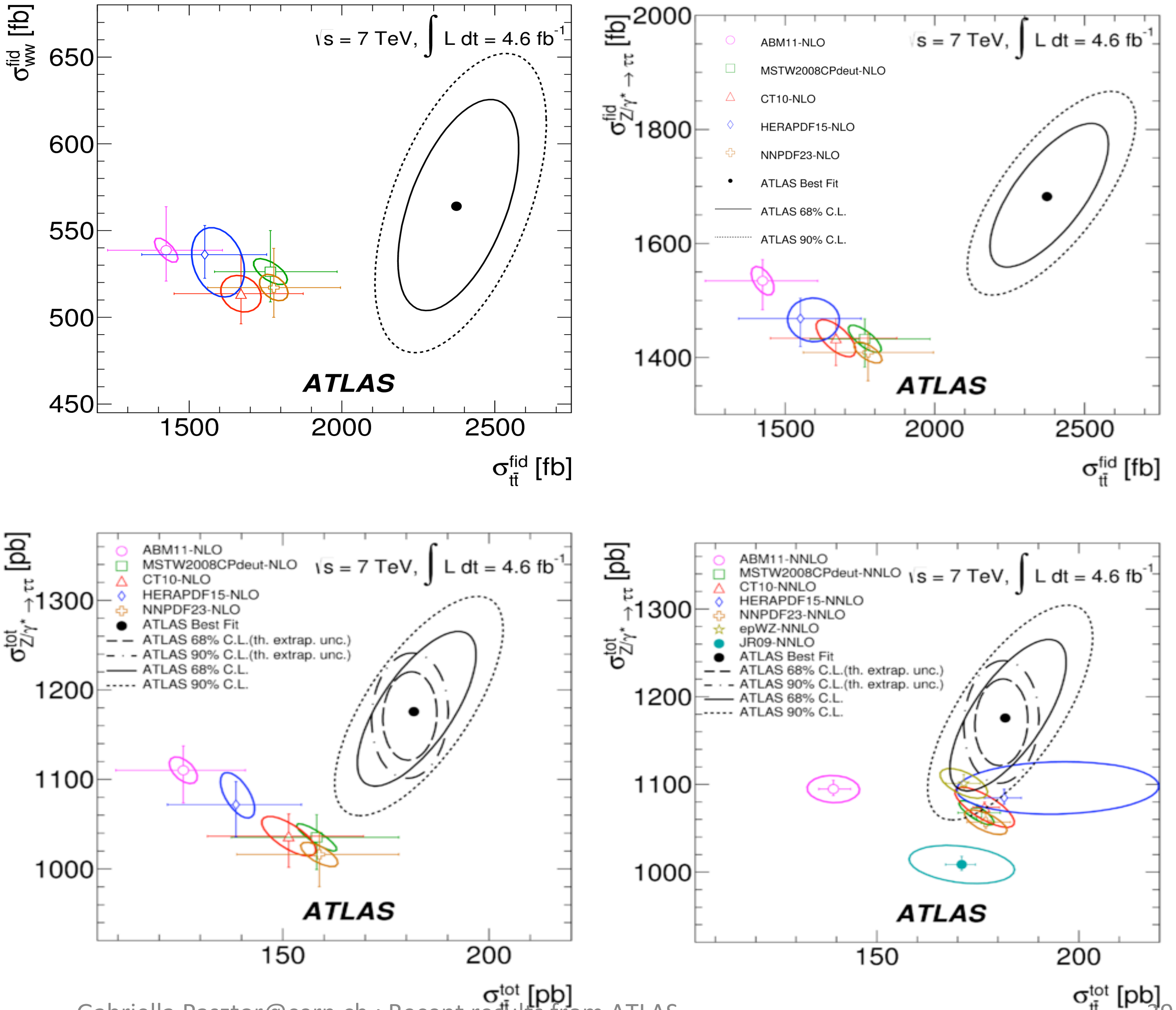
tt production at 13 TeV



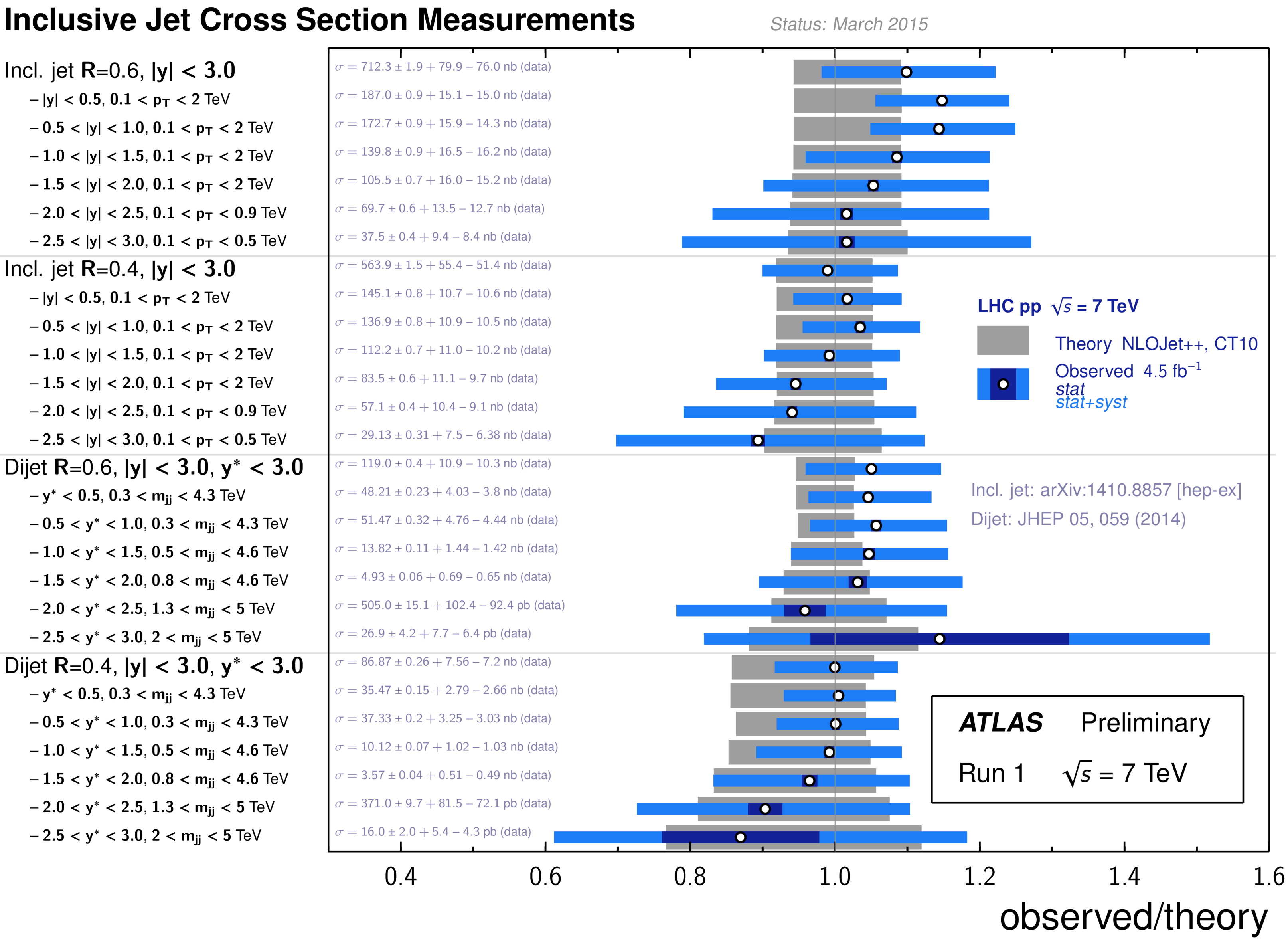
Simultaneous tt, WW, Z→$\tau\tau$ measurement

- Opposite-sign eμ
- Discriminants:
  - MET
  - 0 / ≧1 jet
- Unified measurement (object definitions, background estimation, fiducial volume)
- Correlations due to pdf's taken into account
- Correlated NLO predictions for tt and Z→$\tau\tau$ underestimate data, while NNLO describes them well

Phys. Rev. D 91, 052005 (2015)



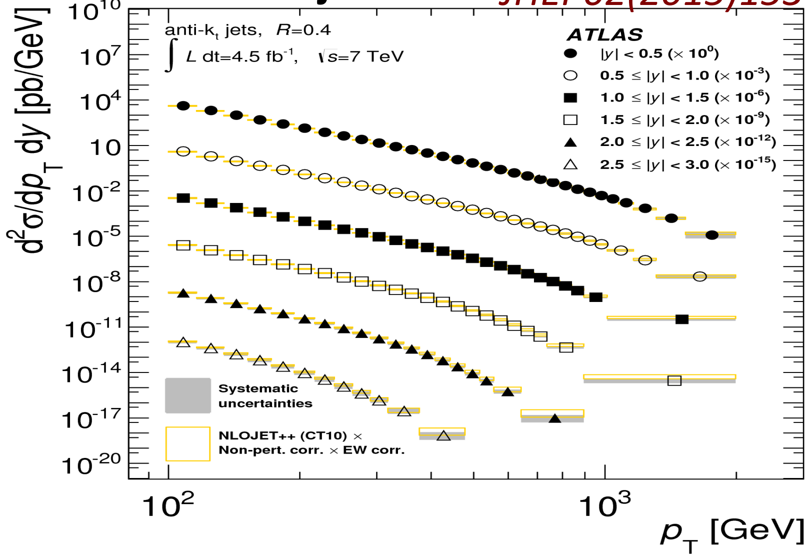
Jet physics

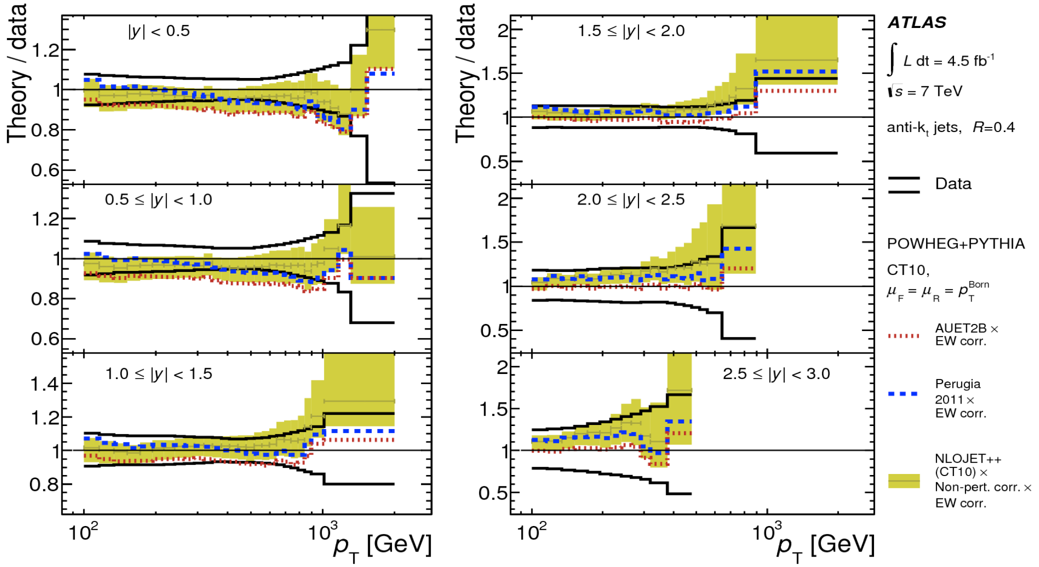

Inclusive Jet Cross Section Measurements
Status: March 2015
Incl. jet R=0.6, |y| < 3.0
– |y| < 0.5, 0.1 < p_T < 2 TeV
– 0.5 < |y| < 1.0, 0.1 < p_T < 2 TeV
– 1.0 < |y| < 1.5, 0.1 < p_T < 2 TeV
– 1.5 < |y| < 2.0, 0.1 < p_T < 2 TeV
– 2.0 < |y| < 2.5, 0.1 < p_T < 0.9 TeV
– 2.5 < |y| < 3.0, 0.1 < p_T < 0.5 TeV
Incl. jet R=0.4, |y| < 3.0
– |y| < 0.5, 0.1 < p_T < 2 TeV
– 0.5 < |y| < 1.0, 0.1 < p_T < 2 TeV
– 1.0 < |y| < 1.5, 0.1 < p_T < 2 TeV
– 1.5 < |y| < 2.0, 0.1 < p_T < 2 TeV
– 2.0 < |y| < 2.5, 0.1 < p_T < 0.9 TeV
– 2.5 < |y| < 3.0, 0.1 < p_T < 0.5 TeV
Dijet R=0.6, |y| < 3.0, y* < 3.0
– y* < 0.5, 0.3 < m_{jj} < 4.3 TeV
– 0.5 < y* < 1.0, 0.3 < m_{jj} < 4.3 TeV
– 1.0 < y* < 1.5, 0.5 < m_{jj} < 4.6 TeV
– 1.5 < y* < 2.0, 0.8 < m_{jj} < 4.6 TeV
– 2.0 < y* < 2.5, 1.3 < m_{jj} < 5 TeV
– 2.5 < y* < 3.0, 2 < m_{jj} < 5 TeV
Dijet R=0.4, |y| < 3.0, y* < 3.0
– y* < 0.5, 0.3 < m_{jj} < 4.3 TeV
– 0.5 < y* < 1.0, 0.3 < m_{jj} < 4.3 TeV
– 1.0 < y* < 1.5, 0.5 < m_{jj} < 4.6 TeV
– 1.5 < y* < 2.0, 0.8 < m_{jj} < 4.6 TeV
– 2.0 < y* < 2.5, 1.3 < m_{jj} < 5 TeV
– 2.5 < y* < 3.0, 2 < m_{jj} < 5 TeV
σ = 712.3 ± 1.9 + 79.9 – 76.0 nb (data)
σ = 187.0 ± 0.9 + 15.1 – 15.0 nb (data)
σ = 172.7 ± 0.9 + 15.9 – 14.3 nb (data)
σ = 139.8 ± 0.9 + 16.5 – 16.2 nb (data)
σ = 105.5 ± 0.7 + 16.0 – 15.2 nb (data)
σ = 69.7 ± 0.6 + 13.5 – 12.7 nb (data)
σ = 37.5 ± 0.4 + 9.4 – 8.4 nb (data)
σ = 563.9 ± 1.5 + 55.4 – 51.4 nb (data)
σ = 145.1 ± 0.8 + 10.7 – 10.6 nb (data)
σ = 136.9 ± 0.8 + 10.9 – 10.5 nb (data)
σ = 112.2 ± 0.7 + 11.0 – 10.2 nb (data)
σ = 83.5 ± 0.6 + 11.1 – 9.7 nb (data)
σ = 57.1 ± 0.4 + 10.4 – 9.1 nb (data)
σ = 29.13 ± 0.31 + 7.5 – 6.38 nb (data)
σ = 119.0 ± 0.4 + 10.9 – 10.3 nb (data)
σ = 48.21 ± 0.23 + 4.03 – 3.8 nb (data)
σ = 51.47 ± 0.32 + 4.76 – 4.44 nb (data)
σ = 13.82 ± 0.11 + 1.44 – 1.42 nb (data)
σ = 4.93 ± 0.06 + 0.69 – 0.65 nb (data)
σ = 505.0 ± 15.1 + 102.4 – 92.4 pb (data)
σ = 26.9 ± 4.2 + 7.7 – 6.4 pb (data)
σ = 86.87 ± 0.26 + 7.56 – 7.2 nb (data)
σ = 35.47 ± 0.15 + 2.79 – 2.66 nb (data)
σ = 37.33 ± 0.2 + 3.25 – 3.03 nb (data)
σ = 10.12 ± 0.07 + 1.02 – 1.03 nb (data)
σ = 3.57 ± 0.04 + 0.51 – 0.49 nb (data)
σ = 371.0 ± 9.7 + 81.5 – 72.1 pb (data)
σ = 16.0 ± 2.0 + 5.4 – 4.3 pb (data)
LHC pp $\sqrt{s}$ = 7 TeV
Theory NLOJet++, CT10
Observed 4.5 fb^{-1}
stat
stat+syst
Incl. jet: arXiv:1410.8857 [hep-ex]
Dijet: JHEP 05, 059 (2014)
ATLAS Preliminary
Run 1 $\sqrt{s}$ = 7 TeV
0.4
0.6
0.8
1.0
1.2
1.4
1.6
observed/theory

Jet physics

Inclusive jets

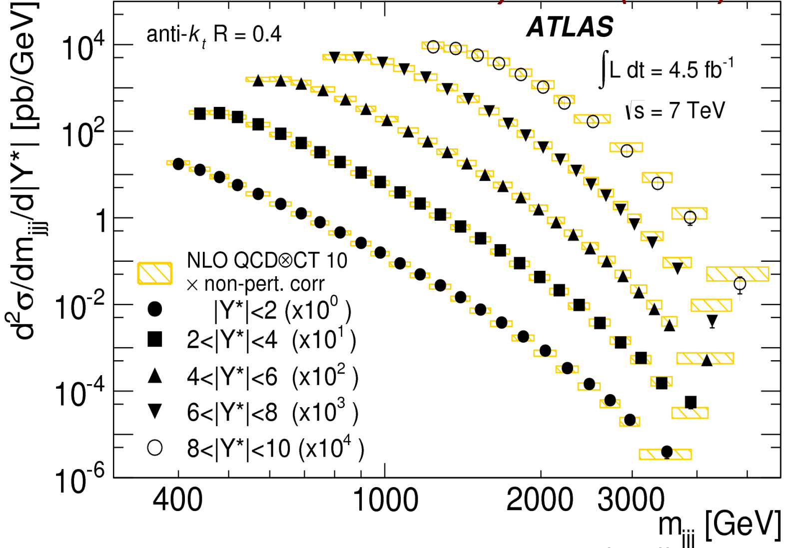
JHEP02(2015)153



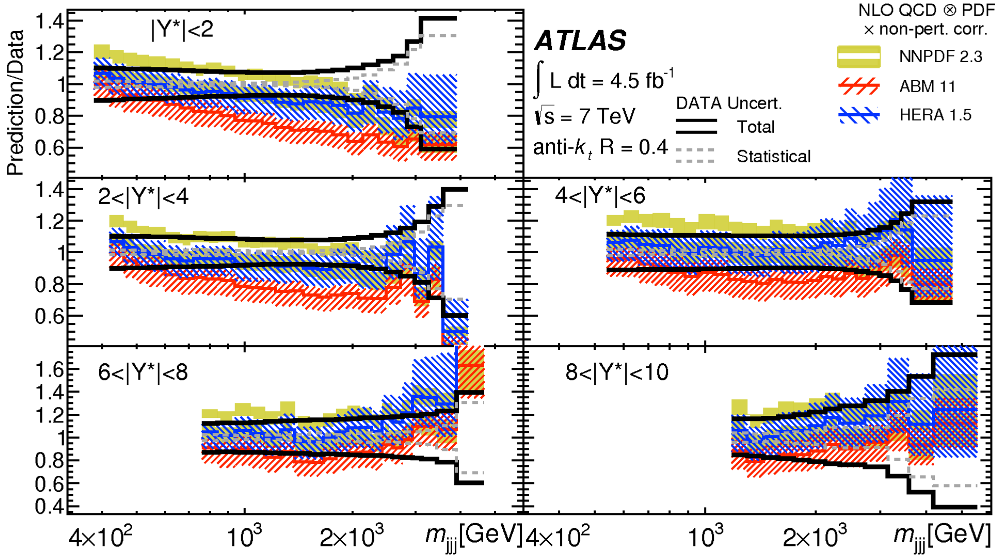


Three-jets

Eur. Phys. J. C (2015) 75



$$|Y^*| = |y_1 - y_2| + |y_2 - y_3| + |y_1 - y_3|$$



Beyond the Standard Model

Why are neutrinos massive?

Is nature supersymmetric?

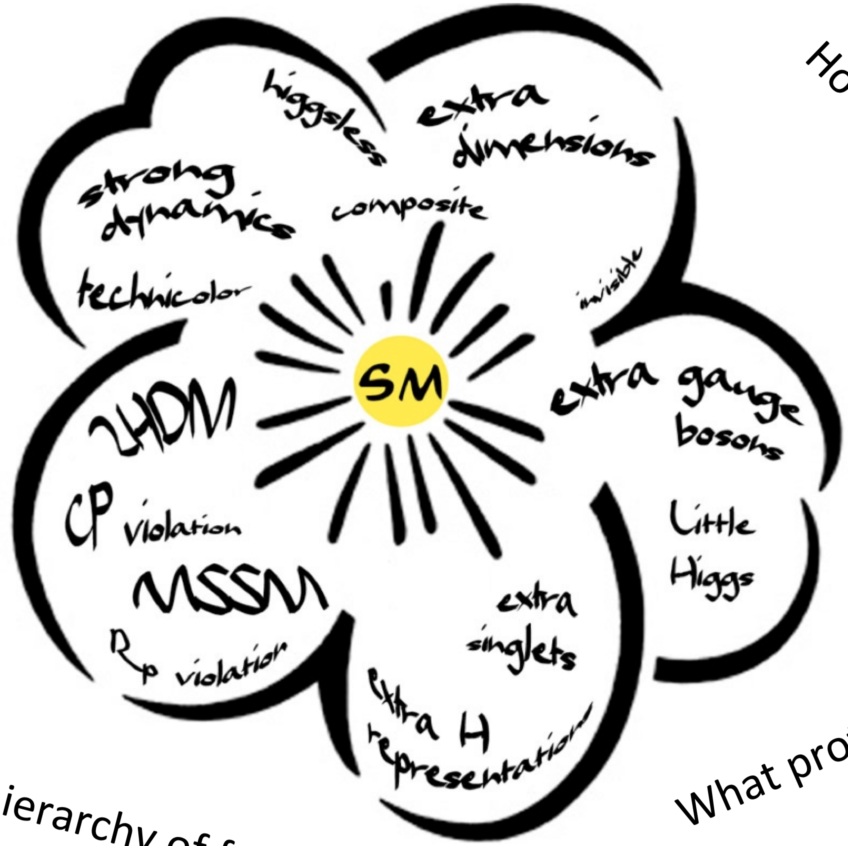
How does gravity fit into the picture?

What is dark matter?

Why three families?

How did anti-matter disappear?

Do the couplings unify?



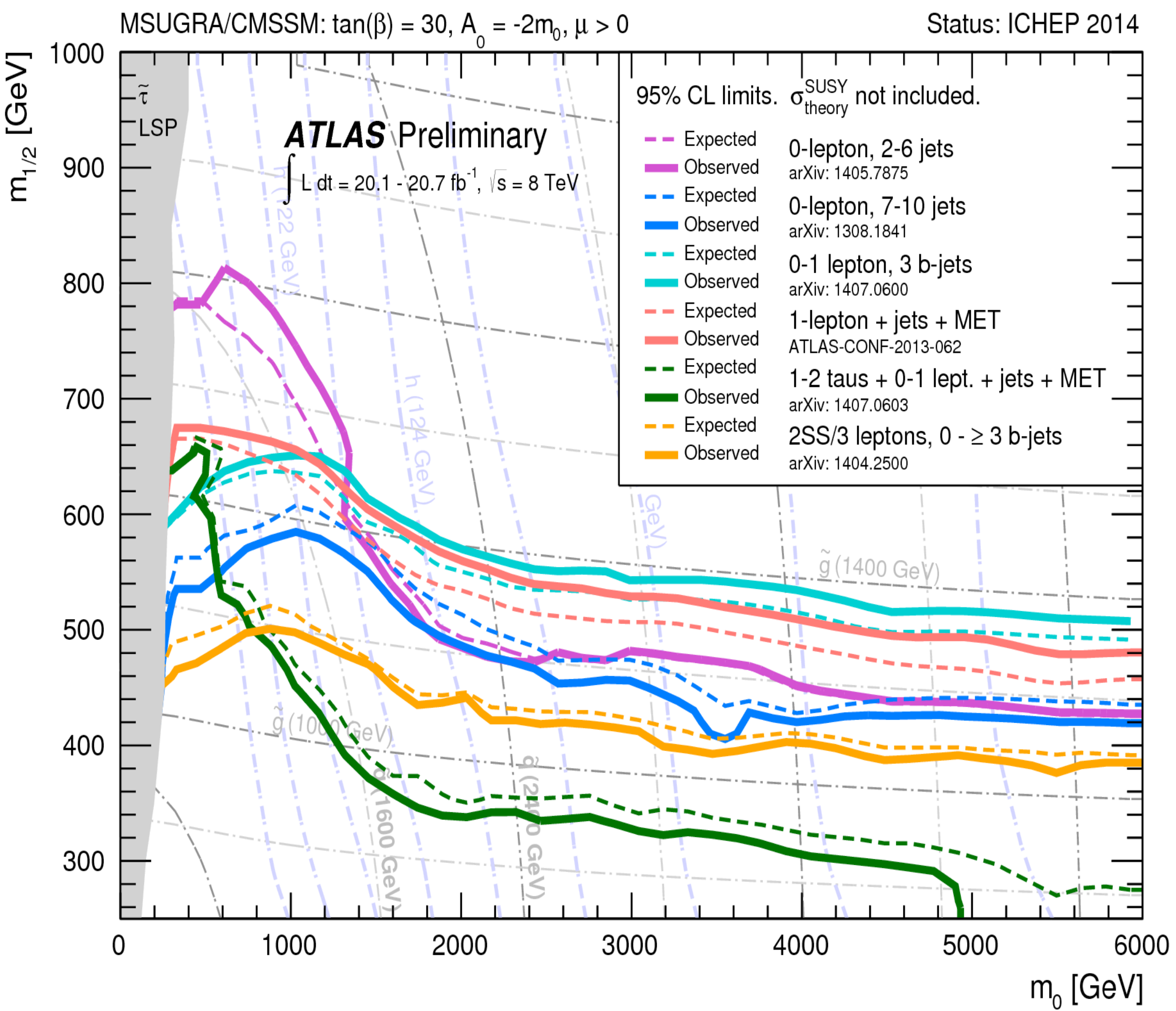
What protects the Higgs mass?

What about the mass hierarchy of fermions?

Are there hidden dimensions?

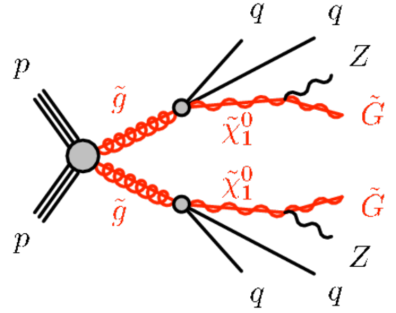
Are there new forces?

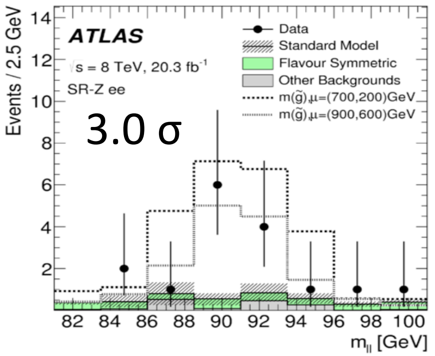
Inclusive searches within MSUGRA



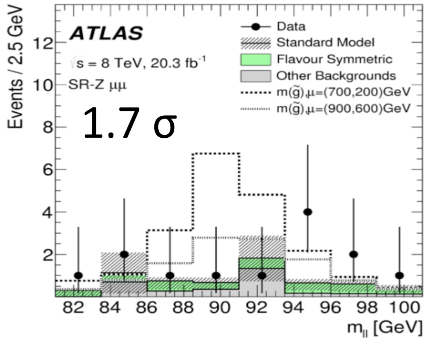
Many complementary inclusive searches…

ll + jets + MET



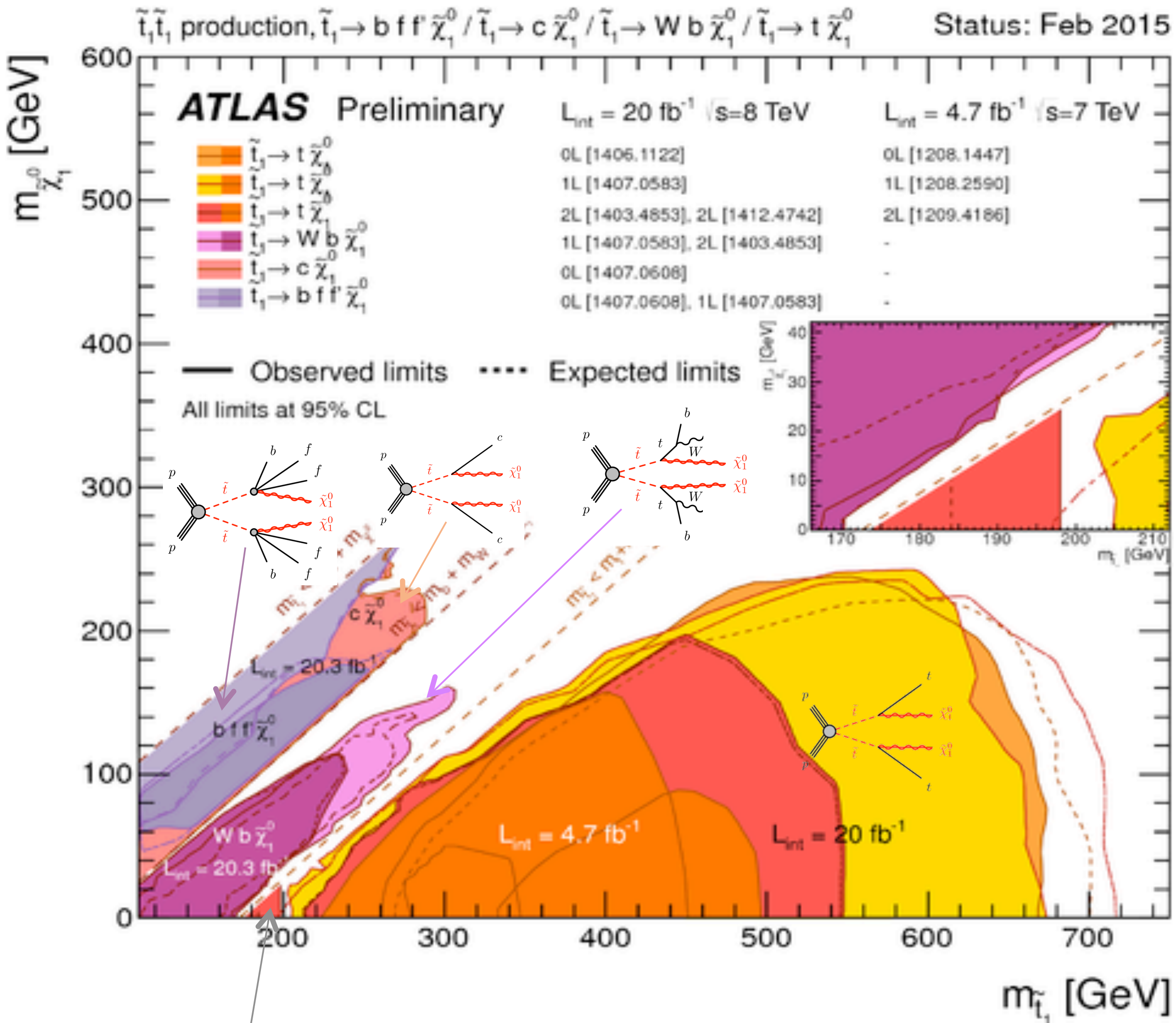


3.0 σ



1.7 σ

Searches for stop



From the measurement of the spin correlations in di-lepton tt events ('clever trick' to fill the gap)

Gaps in the exclusion come from cases where the stop signal looks like background, either tt or WW → "stealth stop"

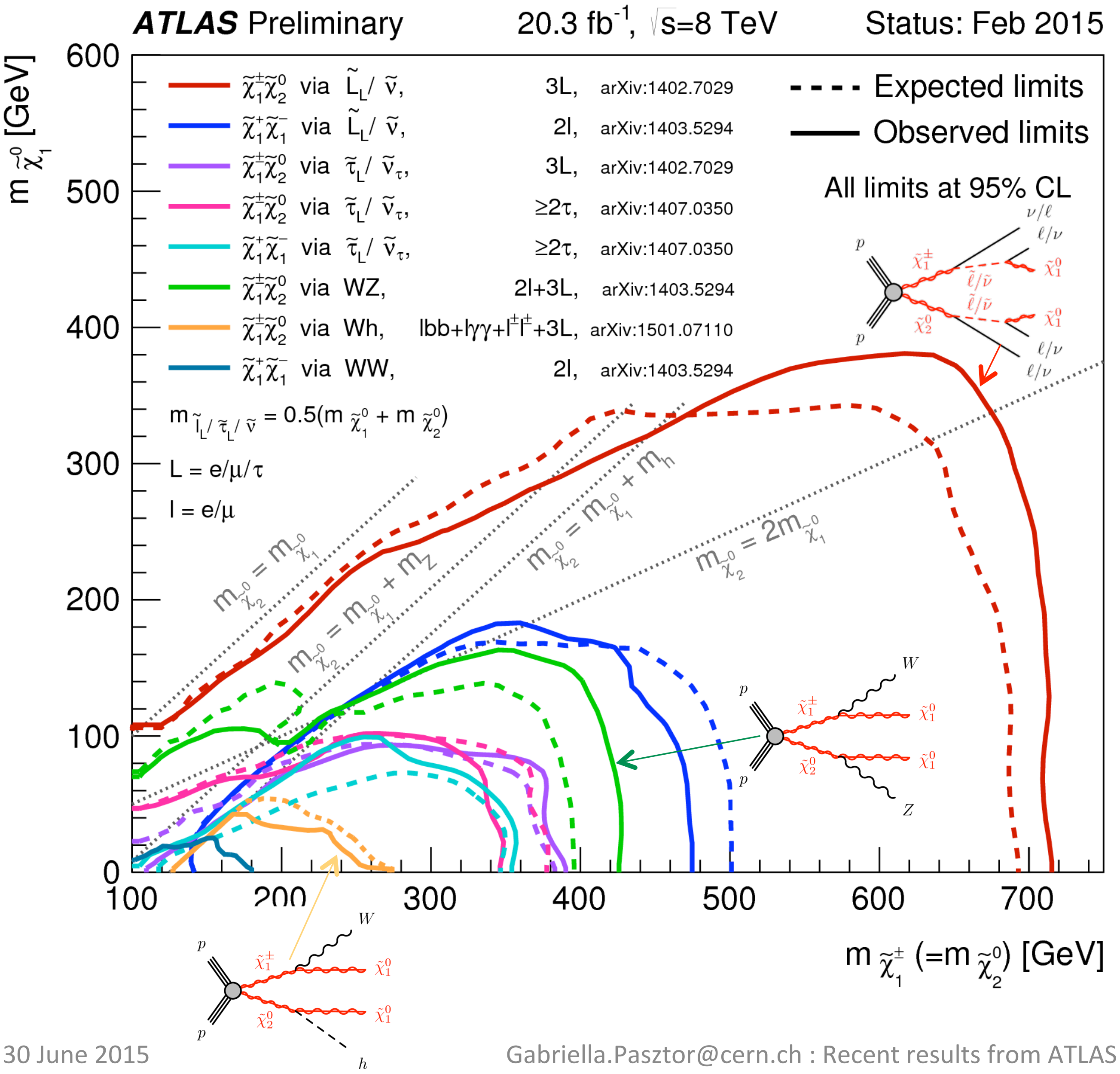
Light stop needed for SUSY to solve the Higgs mass fine-tuning in the SM

Assuming m(t~)<m(χ^+_1),
four decay modes separately considered with BR=100%

1) t~ → $t\chi^0_1$
2) t~ → $Wb\chi^0_1$
   for m(t~)<m(t)+m(χ^0_1)
   (off-shell top, 3-body decay)
3) t~ → $c\chi^0_1$
   (flavour changing 2-body decay)
4) t~ → $ff'b\chi^0_1$
   (off-shell W / 4-body decay)

Overlay contours belonging to different stop decay channels, different sparticle mass hierarchies, and simplified decay scenarios!

Searches for electroweak SUSY production



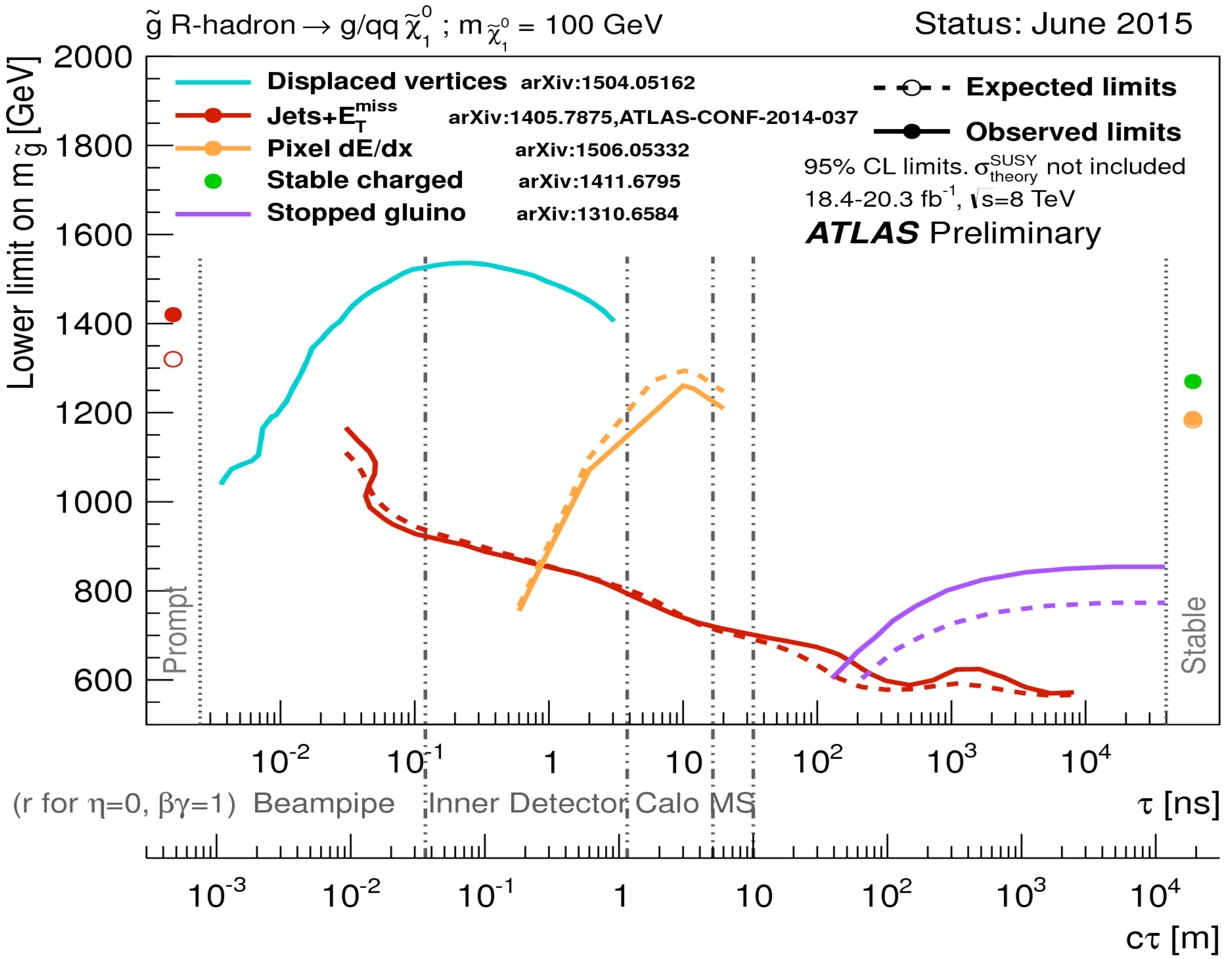
Theoretical signal cross section uncertainties not included

Four decay modes separately considered with BR=100%

1) $\chi^{\pm}_1 \rightarrow l\nu\chi^0_1$
   $\chi^0_2 \rightarrow 2l\chi^0_1 / 2\nu\chi^0_1$
2) $\chi^{\pm}_1 \rightarrow \tau\nu\chi^0_1$
   $\chi^0_2 \rightarrow 2\tau\chi^0_1 / 2\nu\chi^0_1$
3) $\chi^{\pm}_1 \rightarrow W^{\pm}\chi^0_1$
   $\chi^0_2 \rightarrow Z\chi^0_1$
4) $\chi^{\pm}_1 \rightarrow W^{\pm}\chi^0_1$
   $\chi^0_2 \rightarrow h\chi^0_1$

For $\chi^{\pm}_1\chi^0_2$:
m($\chi^{\pm}_1$)=m(χ^0_2)
m(l~ / v~ / τ~)
= ½ (m($\chi^{\pm}_1$)+m(χ^0_1))

Searches for long-lived SUSY particles



Split-SUSY scenario with a long-lived gluino R-hadron

Also showing for comparison the limits for prompt decay and stable particle

Split SUSY offers
- Dark matter candidate
- Gauge unification

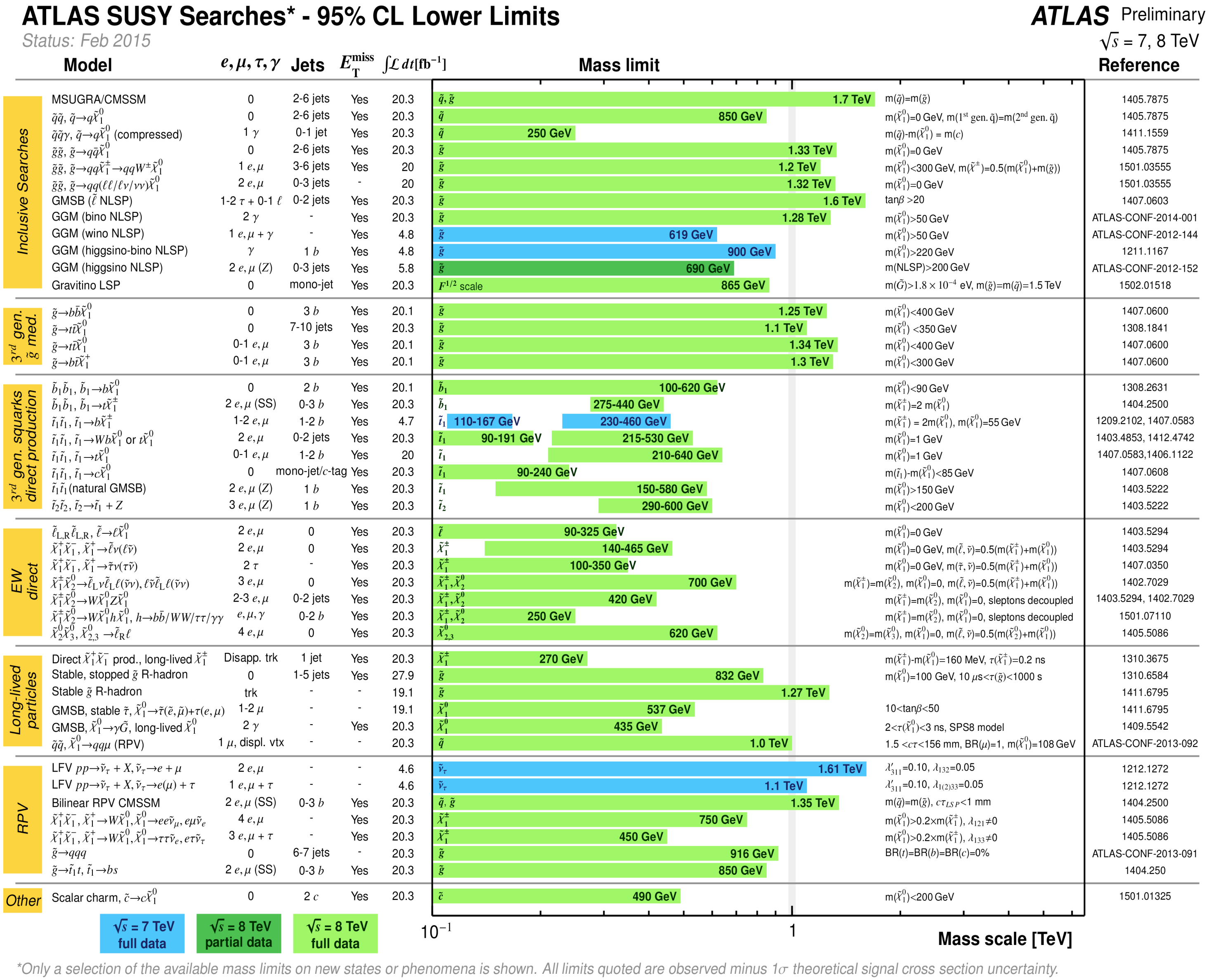
but does not solve naturalness

Light gauginos, higgsinos
Heavy gravitino, sfermions

- Gluinos are light but squarks are very heavy → gluino long-lived (decays via extremely virtual squark)
- Long lived gluino is coloured → forms R-hadron bound states with quarks/gluons
- Gluino decays to 2 quarks and the LSP with a lifetime depending on the squark mass

Mass limits in SUSY searches

A huge number of SUSY searches in run-1, but with no evidence of a signal



ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Feb 2015

ATLAS Preliminary

$\sqrt{s}$ = 7, 8 TeV

	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[fb^{-1}]$	Mass limit			Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q},\tilde{g}$	1.7 TeV	$m(\tilde{q})=m(\tilde{g})$	1405.7875
	$\tilde{q}\tilde{q}, \tilde{q}\rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$	850 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	1405.7875
	$\tilde{q}\tilde{q}\gamma, \tilde{q}\rightarrow q\tilde{\chi}_1^0$ (compressed)	1 γ	0-1 jet	Yes	20.3	$\tilde{q}$	250 GeV	$m(\tilde{q})-m(\tilde{\chi}_1^0) = m(c)$	1411.1559
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.33 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow qq\tilde{\chi}_1^{\pm}\rightarrow qqW^{\pm}\tilde{\chi}_1^0$	1 e,μ	3-6 jets	Yes	20	$\tilde{g}$	1.2 TeV	$m(\tilde{\chi}_1^0)$<300 GeV, $m(\tilde{\chi}^{\pm})=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	1501.03555
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ	0-3 jets	-	20	$\tilde{g}$	1.32 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	1501.03555
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$	1.6 TeV	tanβ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$	1.28 TeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 $e,\mu+\gamma$	-	Yes	4.8	$\tilde{g}$	619 GeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$	900 GeV	$m(\tilde{\chi}_1^0)$>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e,μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$	690 GeV	m(NLSP)>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale	865 GeV	$m(\tilde{G})>1.8\times10^{-4}$ eV, $m(\tilde{g})=m(\tilde{q})$=1.5 TeV	1502.01518
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\rightarrow b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$	1.25 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	$m(\tilde{\chi}_1^0)$ <350 GeV	1308.1841
	$\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.34 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\rightarrow b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\rightarrow b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$	100-620 GeV	$m(\tilde{\chi}_1^0)$<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\rightarrow t\tilde{\chi}_1^{\pm}$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$	275-440 GeV	$m(\tilde{\chi}_1^{\pm})=2\,m(\tilde{\chi}_1^0)$	1404.2500
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\rightarrow b\tilde{\chi}_1^{\pm}$	1-2 e,μ	1-2 b	Yes	4.7	$\tilde{t}_1$	110-167 GeV 230-460 GeV	$m(\tilde{\chi}_1^{\pm}) = 2m(\tilde{\chi}_1^0)$, $m(\tilde{\chi}_1^0)$=55 GeV	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\rightarrow Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	2 e,μ	0-2 jets	Yes	20.3	$\tilde{t}_1$	90-191 GeV 215-530 GeV	$m(\tilde{\chi}_1^0)$=1 GeV	1403.4853, 1412.4742
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\rightarrow t\tilde{\chi}_1^0$	0-1 e,μ	1-2 b	Yes	20	$\tilde{t}_1$	210-640 GeV	$m(\tilde{\chi}_1^0)$=1 GeV	1407.0583,1406.1122
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\rightarrow c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$	90-240 GeV	$m(\tilde{t}_1)-m(\tilde{\chi}_1^0)$<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$	150-580 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\rightarrow\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$	290-600 GeV	$m(\tilde{\chi}_1^0)$<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\rightarrow\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$	90-325 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}$	140-465 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$	100-350 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	1407.0350
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$	700 GeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0Z\tilde{\chi}_1^0$	2-3 e,μ	0-2 jets	Yes	20.3	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$	420 GeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0h\tilde{\chi}_1^0, h\rightarrow b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$	250 GeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0\rightarrow\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$	620 GeV	$m(\tilde{\chi}_2^0)=m(\tilde{\chi}_3^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_2^0)+m(\tilde{\chi}_1^0))$	1405.5086
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^{\pm}$	270 GeV	$m(\tilde{\chi}_1^{\pm})-m(\tilde{\chi}_1^0)$=160 MeV, $\tau(\tilde{\chi}_1^{\pm})$=0.2 ns	1310.3675
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$	832 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	19.1	$\tilde{g}$	1.27 TeV		1411.6795
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0\rightarrow\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$	537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$	435 GeV	2<$\tau(\tilde{\chi}_1^0)$<3 ns, SPS8 model	1409.5542
	$\tilde{q}\tilde{q}, \tilde{\chi}_1^0\rightarrow qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$	1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, $m(\tilde{\chi}_1^0)$=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\rightarrow\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\rightarrow e+\mu$	2 e,μ	-	-	4.6	$\tilde{\nu}_\tau$	1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\rightarrow\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\rightarrow e(\mu)+\tau$	1 $e,\mu+\tau$	-	-	4.6	$\tilde{\nu}_\tau$	1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q},\tilde{g}$	1.35 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0\rightarrow ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$	750 GeV	$m(\tilde{\chi}_1^0)>0.2\times m(\tilde{\chi}_1^{\pm})$, $\lambda_{121}\neq0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0\rightarrow\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e,\mu+\tau$	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$	450 GeV	$m(\tilde{\chi}_1^0)>0.2\times m(\tilde{\chi}_1^{\pm})$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\rightarrow qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\rightarrow\tilde{t}_1t, \tilde{t}_1\rightarrow bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$	850 GeV		1404.250
Other	Scalar charm, $\tilde{c}\rightarrow c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$	490 GeV	$m(\tilde{\chi}_1^0)$<200 GeV	1501.01325

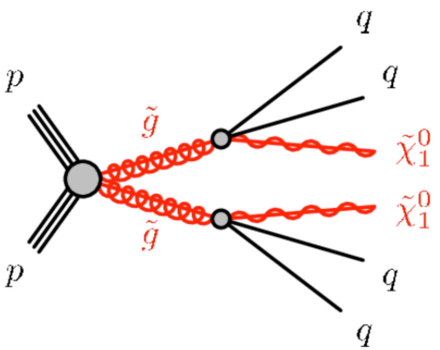
$\sqrt{s}$ = 7 TeV full data

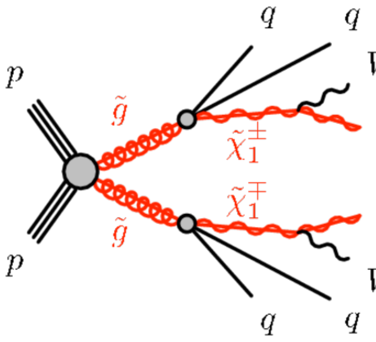
$\sqrt{s}$ = 8 TeV partial data

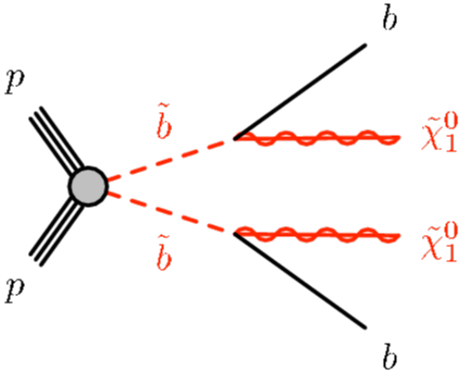
$\sqrt{s}$ = 8 TeV full data

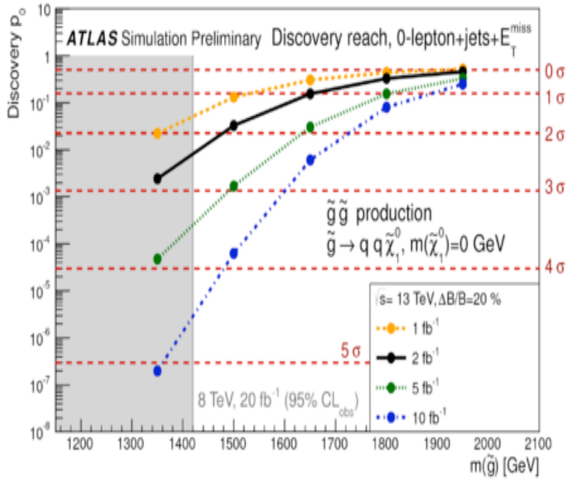
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

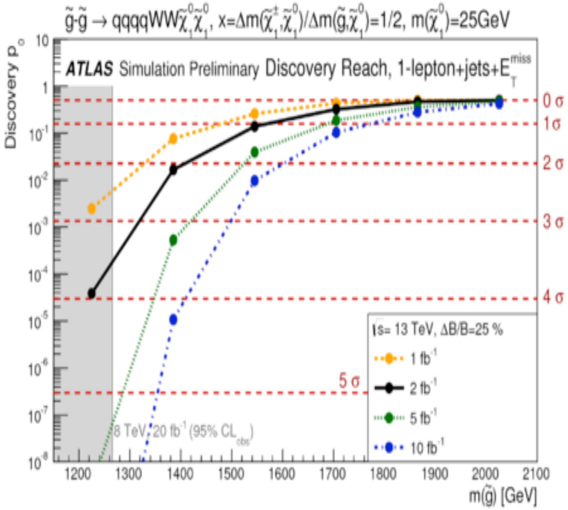
SUSY discovery potential in Run2

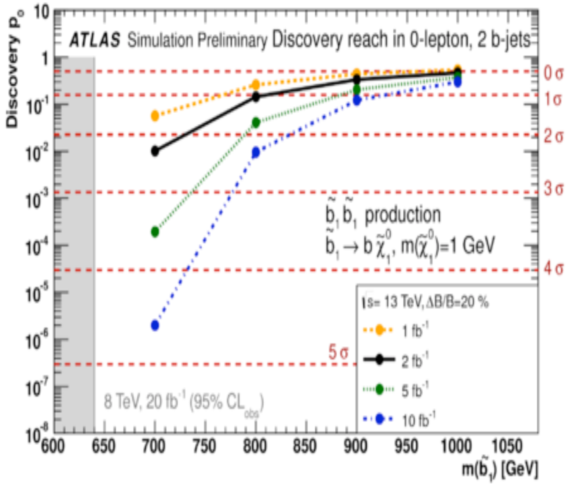








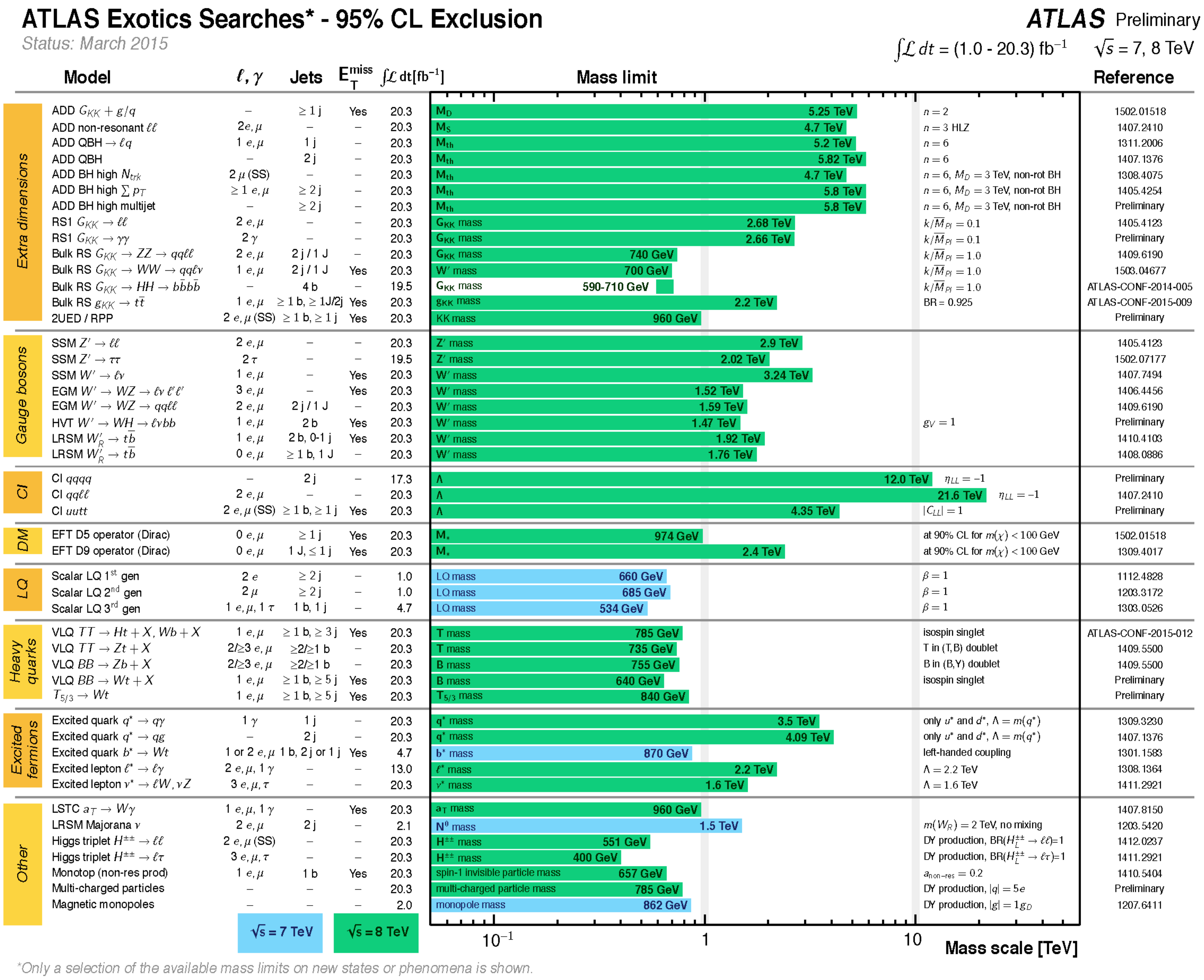




Assuming 20-25% uncertainty on total background rate based on Run-1 analysis experience

3σ evidence above the Run-1 limits cam be obtained with less than 5/fb of 13 TeV data

Beyond SUSY



ATLAS Exotics Searches* - 95% CL Exclusion

Status: March 2015

ATLAS Preliminary

$\int \mathcal{L}\,dt = (1.0 - 20.3)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 7, 8$ TeV

	Model	ℓ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Mass limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	≥ 1 j	Yes	20.3	🟩 M_D 5.25 TeV	$n = 2$	1502.01518
	ADD non-resonant $\ell\ell$	$2e, \mu$	–	–	20.3	🟩 M_S 4.7 TeV	$n = 3$ HLZ	1407.2410
	ADD QBH $\to \ell q$	$1\ e, \mu$	1 j	–	20.3	🟩 M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	20.3	🟩 M_{th} 5.82 TeV	$n = 6$	1407.1376
	ADD BH high N_{trk}	$2\ \mu$ (SS)	–	–	20.3	🟩 M_{th} 4.7 TeV	$n = 6$, $M_D = 3$ TeV, non-rot BH	1308.4075
	ADD BH high $\sum p_T$	$\geq 1\ e, \mu$	≥ 2 j	–	20.3	🟩 M_{th} 5.8 TeV	$n = 6$, $M_D = 3$ TeV, non-rot BH	1405.4254
	ADD BH high multijet	–	≥ 2 j	–	20.3	🟩 M_{th} 5.8 TeV	$n = 6$, $M_D = 3$ TeV, non-rot BH	Preliminary
	RS1 $G_{KK} \to \ell\ell$	$2\ e, \mu$	–	–	20.3	🟩 G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \to \gamma\gamma$	$2\ \gamma$	–	–	20.3	🟩 G_{KK} mass 2.66 TeV	$k/\overline{M}_{Pl} = 0.1$	Preliminary
	Bulk RS $G_{KK} \to ZZ \to qq\ell\ell$	$2\ e, \mu$	2 j / 1 J	–	20.3	🟩 G_{KK} mass 740 GeV	$k/\overline{M}_{Pl} = 1.0$	1409.6190
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	$1\ e, \mu$	2 j / 1 J	Yes	20.3	🟩 W' mass 700 GeV	$k/\overline{M}_{Pl} = 1.0$	1503.04677
	Bulk RS $G_{KK} \to HH \to b\bar{b}b\bar{b}$	–	4 b	–	19.5	🟩 G_{KK} mass 590-710 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2014-005
	Bulk RS $g_{KK} \to t\bar{t}$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	20.3	🟩 g_{KK} mass 2.2 TeV	BR = 0.925	ATLAS-CONF-2015-009
	2UED / RPP	$2\ e, \mu$ (SS)	≥ 1 b, ≥ 1 j	Yes	20.3	🟩 KK mass 960 GeV		Preliminary
Gauge bosons	SSM $Z' \to \ell\ell$	$2\ e, \mu$	–	–	20.3	🟩 Z' mass 2.9 TeV		1405.4123
	SSM $Z' \to \tau\tau$	$2\ \tau$	–	–	19.5	🟩 Z' mass 2.02 TeV		1502.07177
	SSM $W' \to \ell\nu$	$1\ e, \mu$	–	Yes	20.3	🟩 W' mass 3.24 TeV		1407.7494
	EGM $W' \to WZ \to \ell\nu\ \ell'\ell'$	$3\ e, \mu$	–	Yes	20.3	🟩 W' mass 1.52 TeV		1406.4456
	EGM $W' \to WZ \to qq\ell\ell$	$2\ e, \mu$	2 j / 1 J	–	20.3	🟩 W' mass 1.59 TeV		1409.6190
	HVT $W' \to WH \to \ell\nu bb$	$1\ e, \mu$	2 b	Yes	20.3	🟩 W' mass 1.47 TeV	$g_V = 1$	Preliminary
	LRSM $W'_R \to t\bar{b}$	$1\ e, \mu$	2 b, 0-1 j	Yes	20.3	🟩 W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to t\bar{b}$	$0\ e, \mu$	≥ 1 b, 1 J	–	20.3	🟩 W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	17.3	🟩 Λ 12.0 TeV	$\eta_{LL} = -1$	Preliminary
	CI $qq\ell\ell$	$2\ e, \mu$	–	–	20.3	🟩 Λ 21.6 TeV	$\eta_{LL} = -1$	1407.2410
	CI $uutt$	$2\ e, \mu$ (SS)	≥ 1 b, ≥ 1 j	Yes	20.3	🟩 Λ 4.35 TeV	$\lvert C_{LL}\rvert = 1$	Preliminary
DM	EFT D5 operator (Dirac)	$0\ e, \mu$	≥ 1 j	Yes	20.3	🟩 M_* 974 GeV	at 90% CL for $m(\chi) < 100$ GeV	1502.01518
	EFT D9 operator (Dirac)	$0\ e, \mu$	1 J, ≤ 1 j	Yes	20.3	🟩 M_* 2.4 TeV	at 90% CL for $m(\chi) < 100$ GeV	1309.4017
LQ	Scalar LQ 1^{st} gen	$2\ e$	≥ 2 j	–	1.0	🟦 LQ mass 660 GeV	$\beta = 1$	1112.4828
	Scalar LQ 2^{nd} gen	$2\ \mu$	≥ 2 j	–	1.0	🟦 LQ mass 685 GeV	$\beta = 1$	1203.3172
	Scalar LQ 3^{rd} gen	$1\ e, \mu, 1\ \tau$	1 b, 1 j	–	4.7	🟦 LQ mass 534 GeV	$\beta = 1$	1303.0526
Heavy quarks	VLQ $TT \to Ht + X, Wb + X$	$1\ e, \mu$	≥ 1 b, ≥ 3 j	Yes	20.3	🟩 T mass 785 GeV	isospin singlet	ATLAS-CONF-2015-012
	VLQ $TT \to Zt + X$	2/$\geq$3 e, μ	$\geq$2/$\geq$1 b	–	20.3	🟩 T mass 735 GeV	T in (T,B) doublet	1409.5500
	VLQ $BB \to Zb + X$	2/$\geq$3 e, μ	$\geq$2/$\geq$1 b	–	20.3	🟩 B mass 755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $BB \to Wt + X$	$1\ e, \mu$	≥ 1 b, ≥ 5 j	Yes	20.3	🟩 B mass 640 GeV	isospin singlet	Preliminary
	$T_{5/3} \to Wt$	$1\ e, \mu$	≥ 1 b, ≥ 5 j	Yes	20.3	🟩 $T_{5/3}$ mass 840 GeV		Preliminary
Excited fermions	Excited quark $q^* \to q\gamma$	$1\ \gamma$	1 j	–	20.3	🟩 q^* mass 3.5 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1309.3230
	Excited quark $q^* \to qg$	–	2 j	–	20.3	🟩 q^* mass 4.09 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1407.1376
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2 j or 1 j	Yes	4.7	🟦 b^* mass 870 GeV	left-handed coupling	1301.1583
	Excited lepton $\ell^* \to \ell\gamma$	$2\ e, \mu, 1\ \gamma$	–	–	13.0	🟩 ℓ^* mass 2.2 TeV	$\Lambda = 2.2$ TeV	1308.1364
	Excited lepton $\nu^* \to \ell W, \nu Z$	$3\ e, \mu, \tau$	–	–	20.3	🟩 ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LSTC $a_T \to W\gamma$	$1\ e, \mu, 1\ \gamma$	–	Yes	20.3	🟩 a_T mass 960 GeV		1407.8150
	LRSM Majorana ν	$2\ e, \mu$	2 j	–	2.1	🟦 N^0 mass 1.5 TeV	$m(W_R) = 2$ TeV, no mixing	1203.5420
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	$2\ e, \mu$ (SS)	–	–	20.3	🟩 $H^{\pm\pm}$ mass 551 GeV	DY production, BR($H_L^{\pm\pm} \to \ell\ell$)=1	1412.0237
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	$3\ e, \mu, \tau$	–	–	20.3	🟩 $H^{\pm\pm}$ mass 400 GeV	DY production, BR($H_L^{\pm\pm} \to \ell\tau$)=1	1411.2921
	Monotop (non-res prod)	$1\ e, \mu$	1 b	Yes	20.3	🟩 spin-1 invisible particle mass 657 GeV	$a_{non-res} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	🟩 multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert = 5e$	Preliminary
	Magnetic monopoles	–	–	–	2.0	🟦 monopole mass 862 GeV	DY production, $\lvert g\rvert = 1g_D$	1207.6411

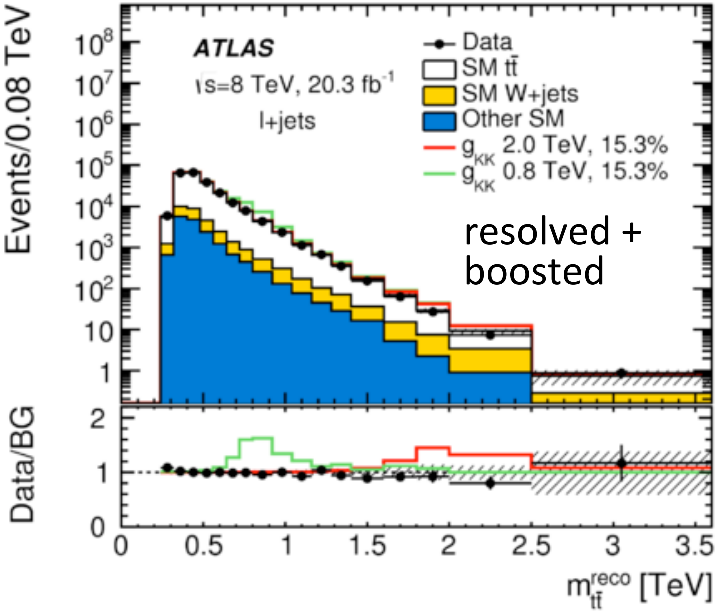
🟦 $\sqrt{s}$ = 7 TeV 🟩 $\sqrt{s}$ = 8 TeV

*Only a selection of the available mass limits on new states or phenomena is shown.

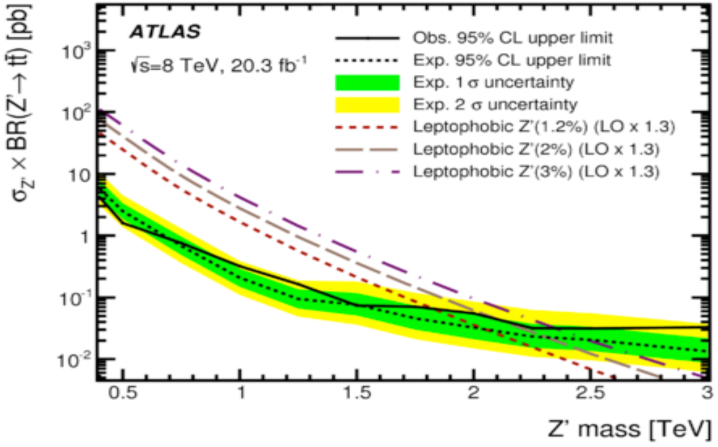
No evidence for new phenomena…

tt resonances with l + jets

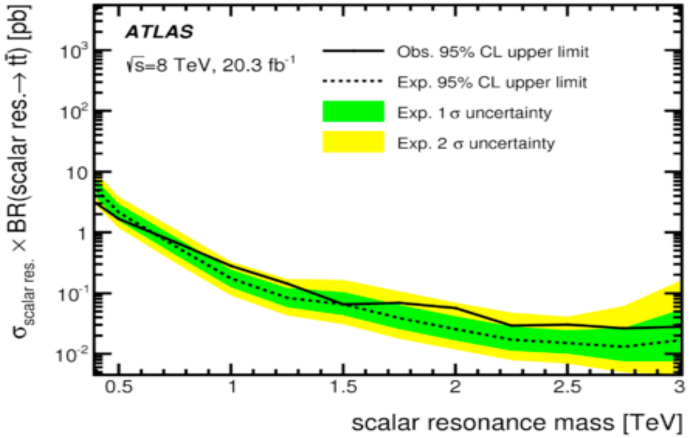
arXiv:1505.07018

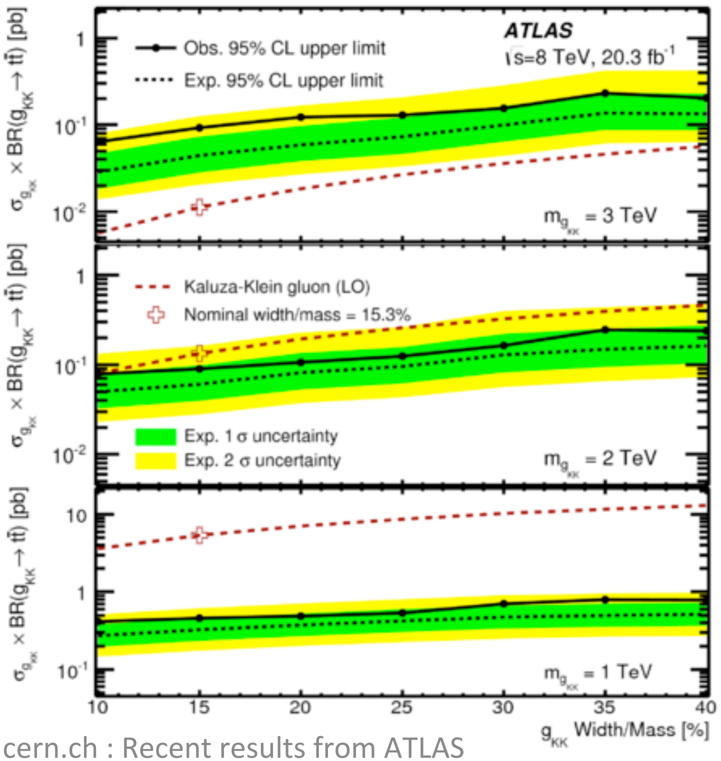


resolved + boosted



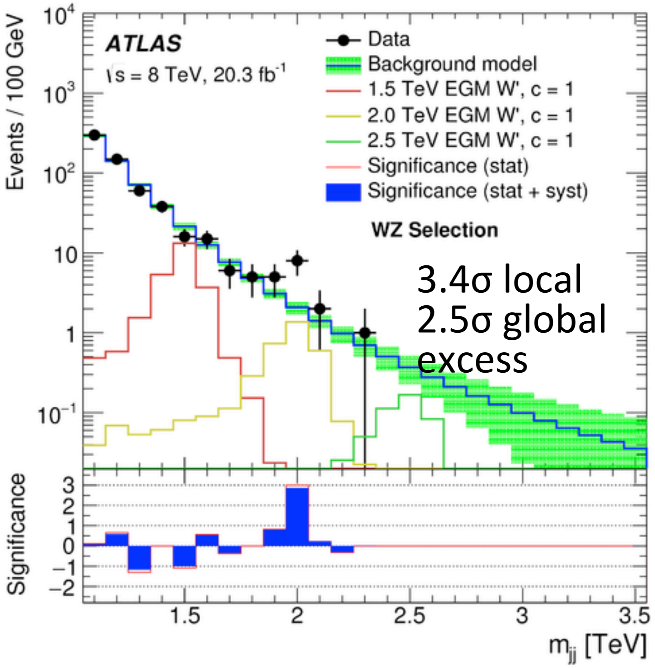
Interpret in many models:
Z', G_{KK}, g_{KK}, scalar resonance





Diboson resonances with boson tagged jets

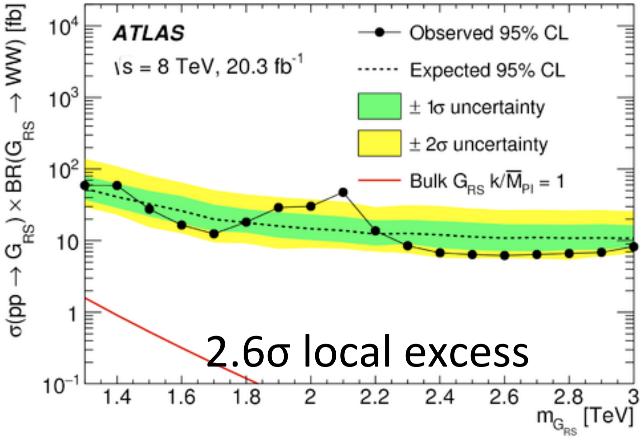
SSM W'→ WZ with modified couplings to W,Z (EGM)



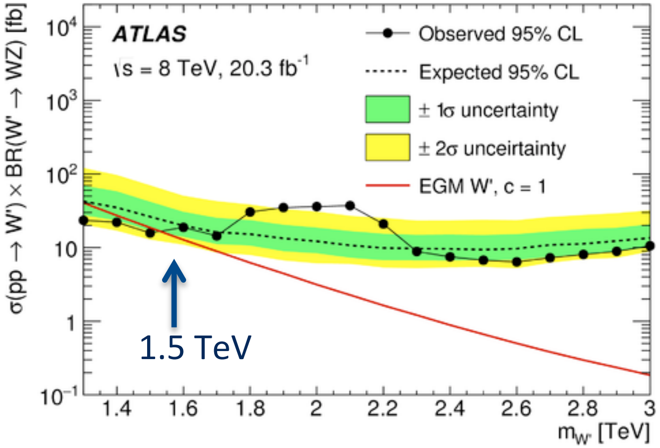
3.4σ local
2.5σ global
excess

arxiv:1506.00962

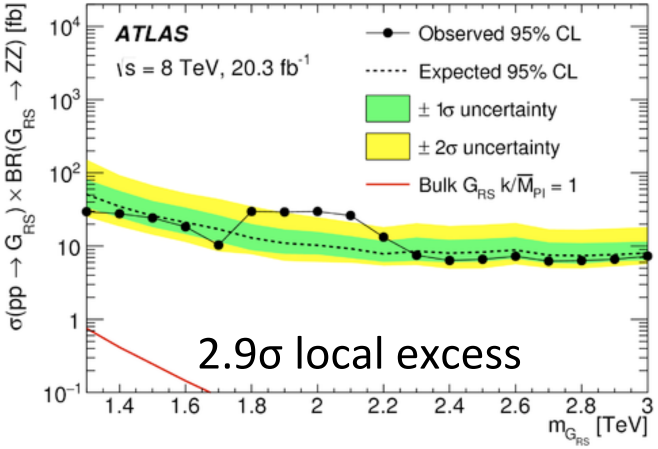
Excited bulk RS G_{KK}→ WW, ZZ



2.6σ local excess

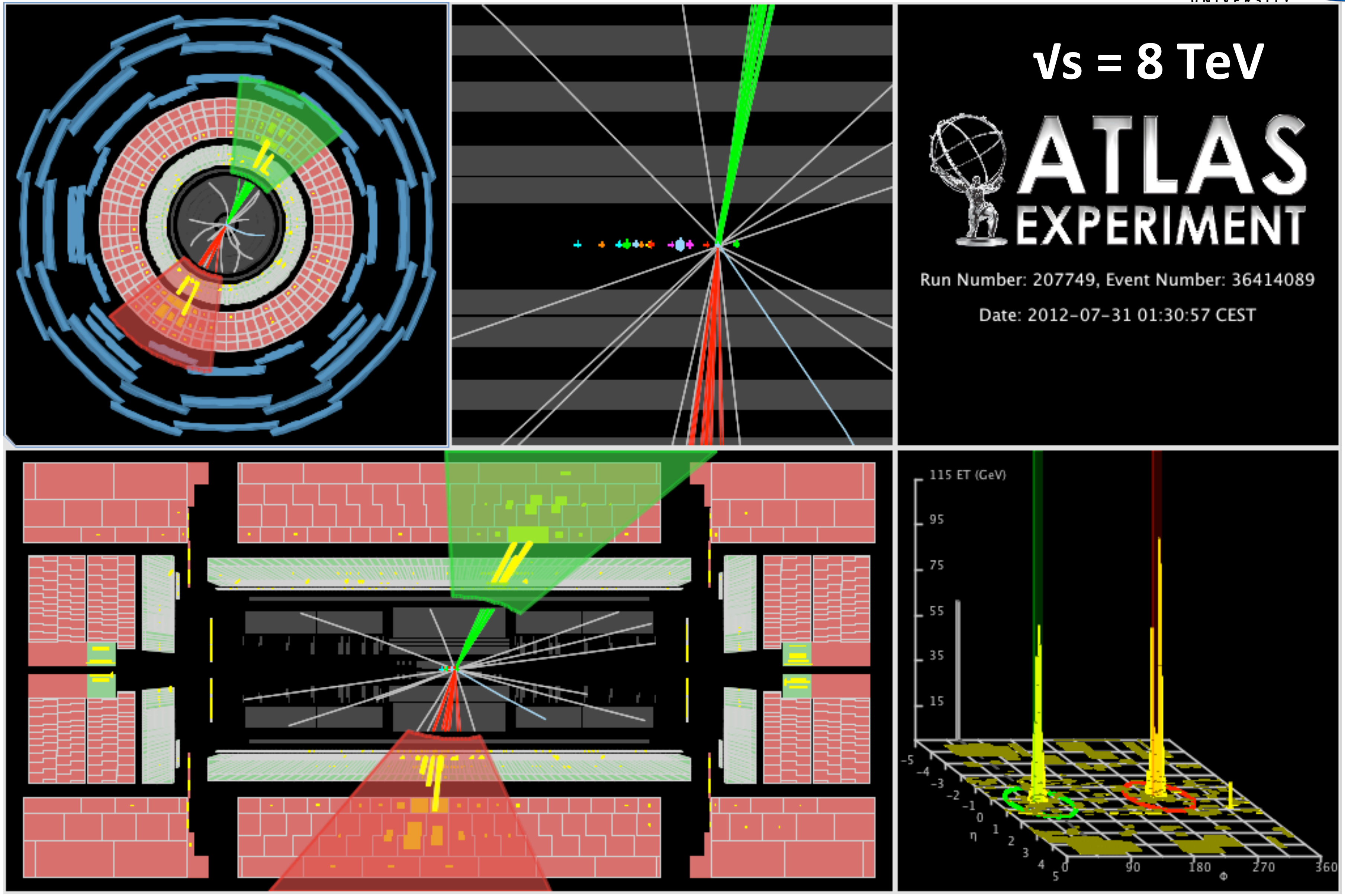


1.5 TeV



2.9σ local excess

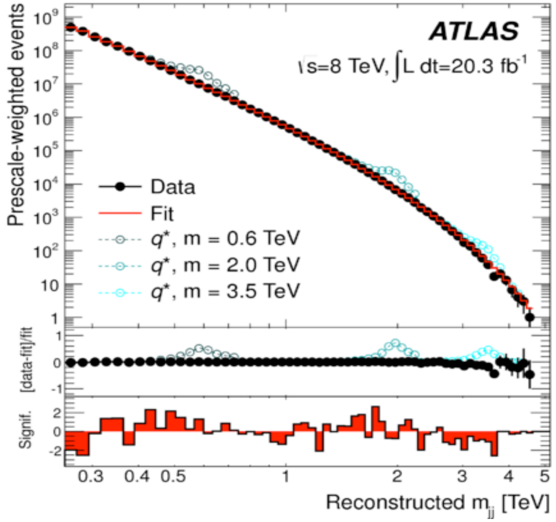
Keep looking for diboson events at 13 TeV!

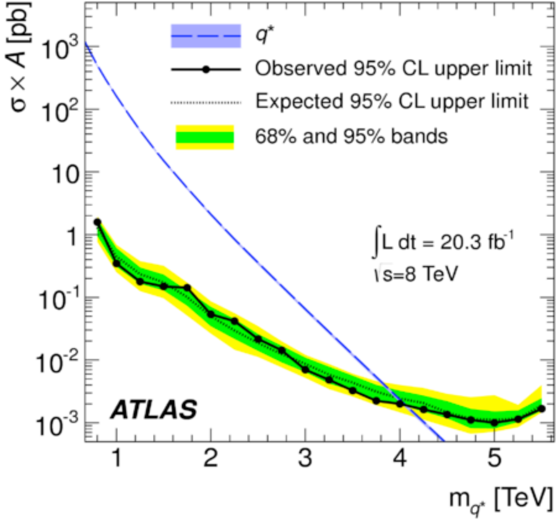


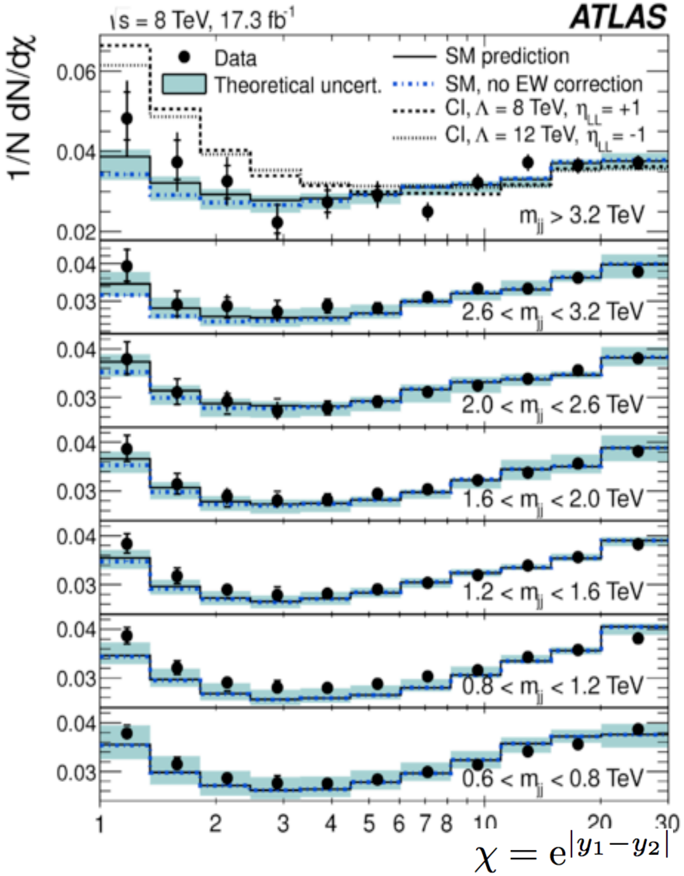
Dijet search

- No excess in dijet mass distribution
- Contact interactions searched for in angular distributions of high-mass events

PRD 91, 052007 (2015)







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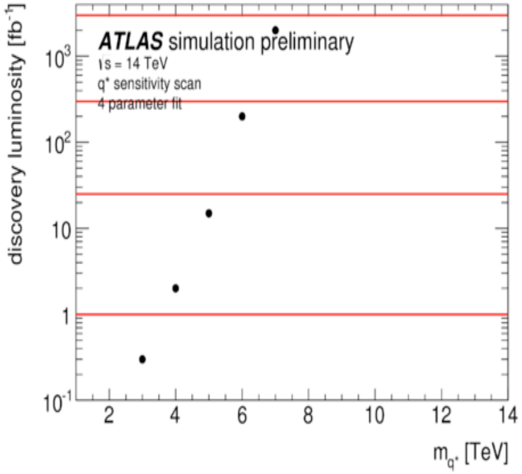
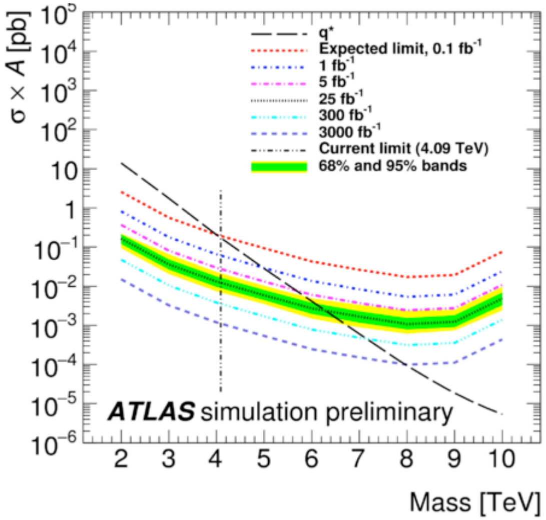
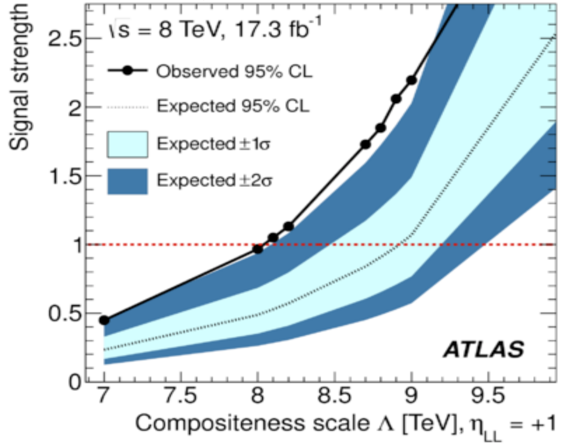




PRL 114, 221802



Summary

- Many interesting results from Run 1
- SM-like Higgs discovered and its properties are probed with increasing precision
- Large advances in experimental techniques and theoretical calculations promise high precision measurements and good sensitivity for new physics in Run2
- ATLAS started Run2 excellently with an improved detector
- Looking forward to new discoveries at LHC!