ATLAS Status Overview

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on behalf of the ATLAS Collaboration

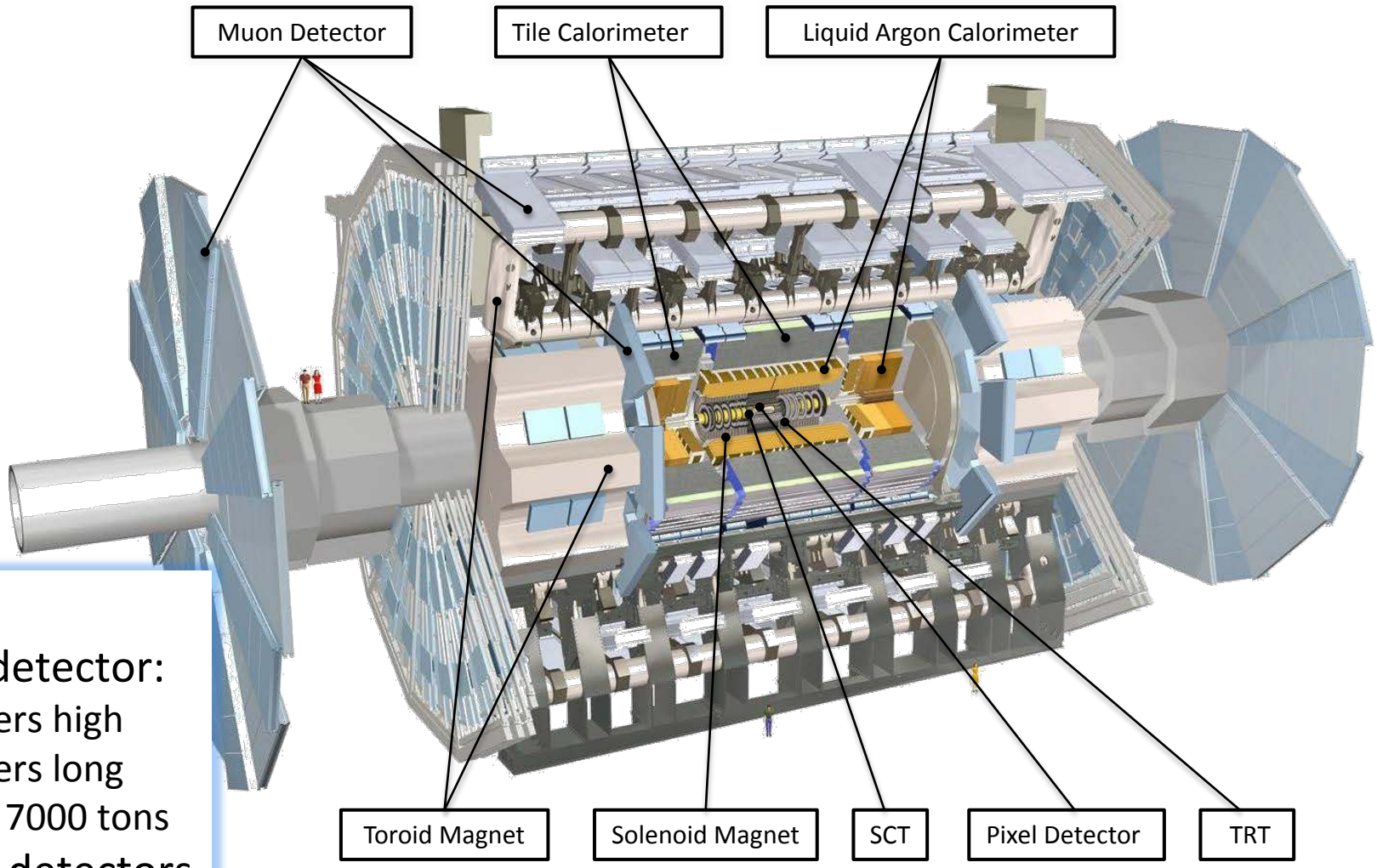
Outline:

- The ATLAS detector
- Run-2 Status and Performance
- Recent Physics Highlights*
- Upgrade Plans

- *Only few Highlights shown here:
- See dedicated presentations:

  - Higgs properties (ATLAS+CMS) - *Marcello Fanti*
  - BSM Higgs searches in ATLAS - *Takanori Kono*
  - Search for Higgs pair production → WWγγ at 13 TeV - *Qi Li*
  - Higgs boson production and decays in ATLAS - *Haifeng Li*
  - Higgs rare decays (ATLAS+CMS) - *Liang Li*
  - Data driven W+Jet background for WW→lνlν final state - *Weimin Song*
  - Study on VBF H → γγ - *Yu Zhang*
  - High mass H → WW →lνlν search - *Yongke Zhao*
  - Early Search for Supersymmetry at ATLAS - *Xuai Zhuang*
  - Searches for heavy ZZ and ZW resonances in llqq and ννqq final states - *S. Patrick Alkire*
  - Exotics searches at ATLAS - *Chunhui Chen*
  - Search for pair production of Higgs bosons in the $b\bar{b}$ $b\bar{b}$ final state - *Baojia Tong*
  - Collider Dark Matter searches (ATLAS+CMS) - *Francesca Ungaro*

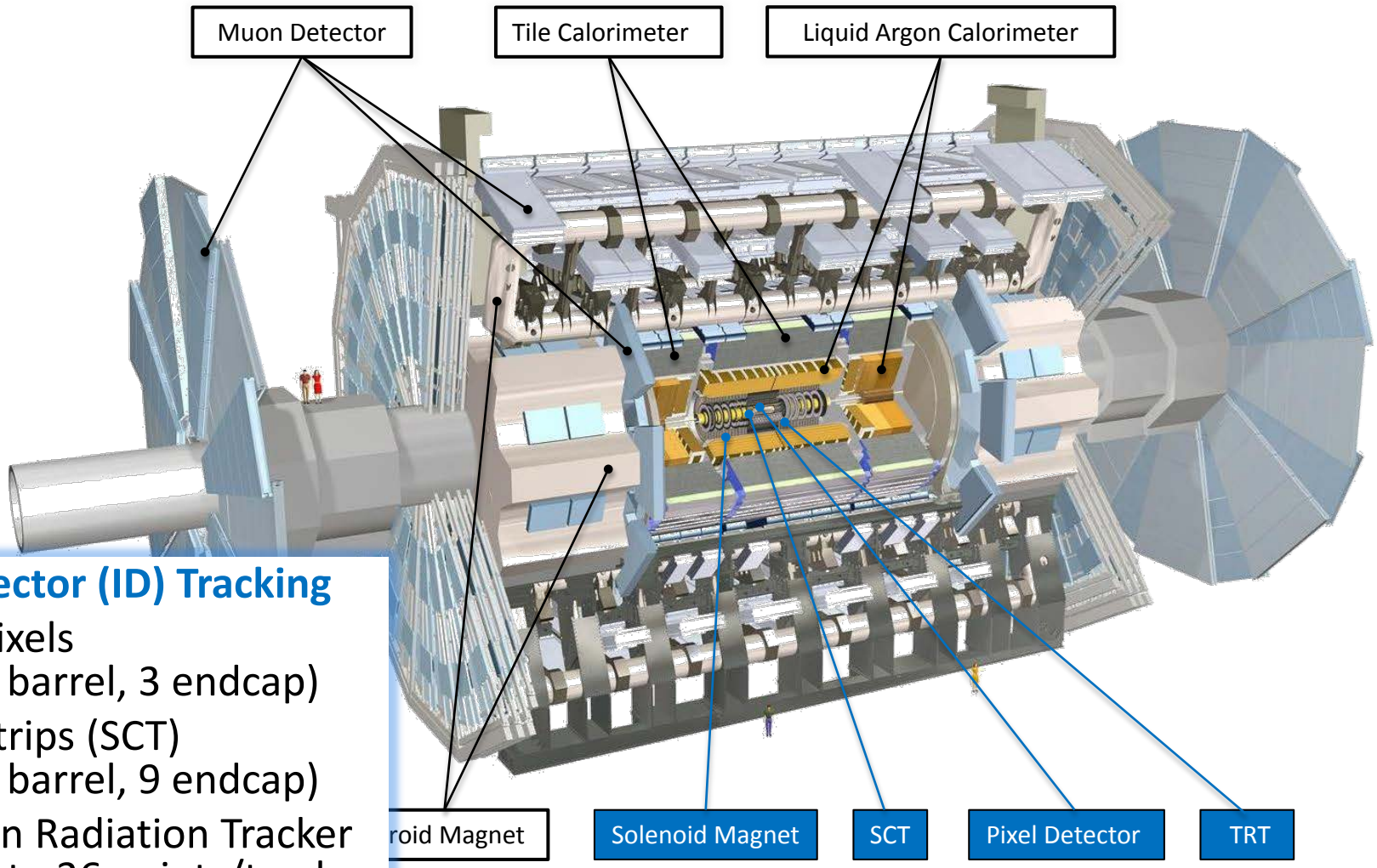
The ATLAS Detector



ATLAS

- Central detector:
  - 25 meters high
  - 44 meters long
  - Weight 7000 tons
- Forward detectors not shown

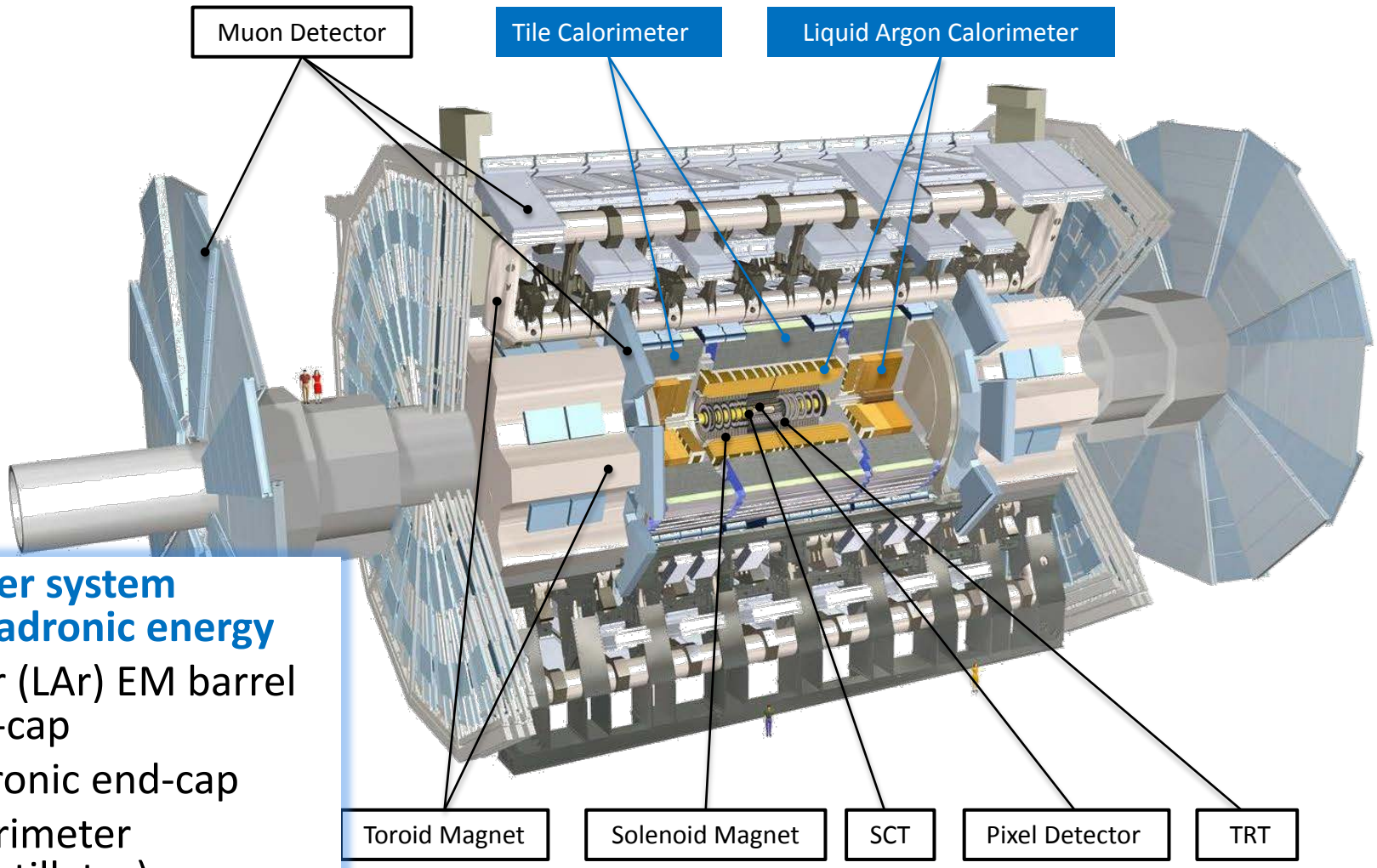
The ATLAS Detector



Inner Detector (ID) Tracking

- Silicon Pixels
  (4 layers barrel, 3 endcap)
- Silicon Strips (SCT)
  (4 layers barrel, 9 endcap)
- Transition Radiation Tracker (TRT) up to 36 points/track
- 2T Solenoid Magnet

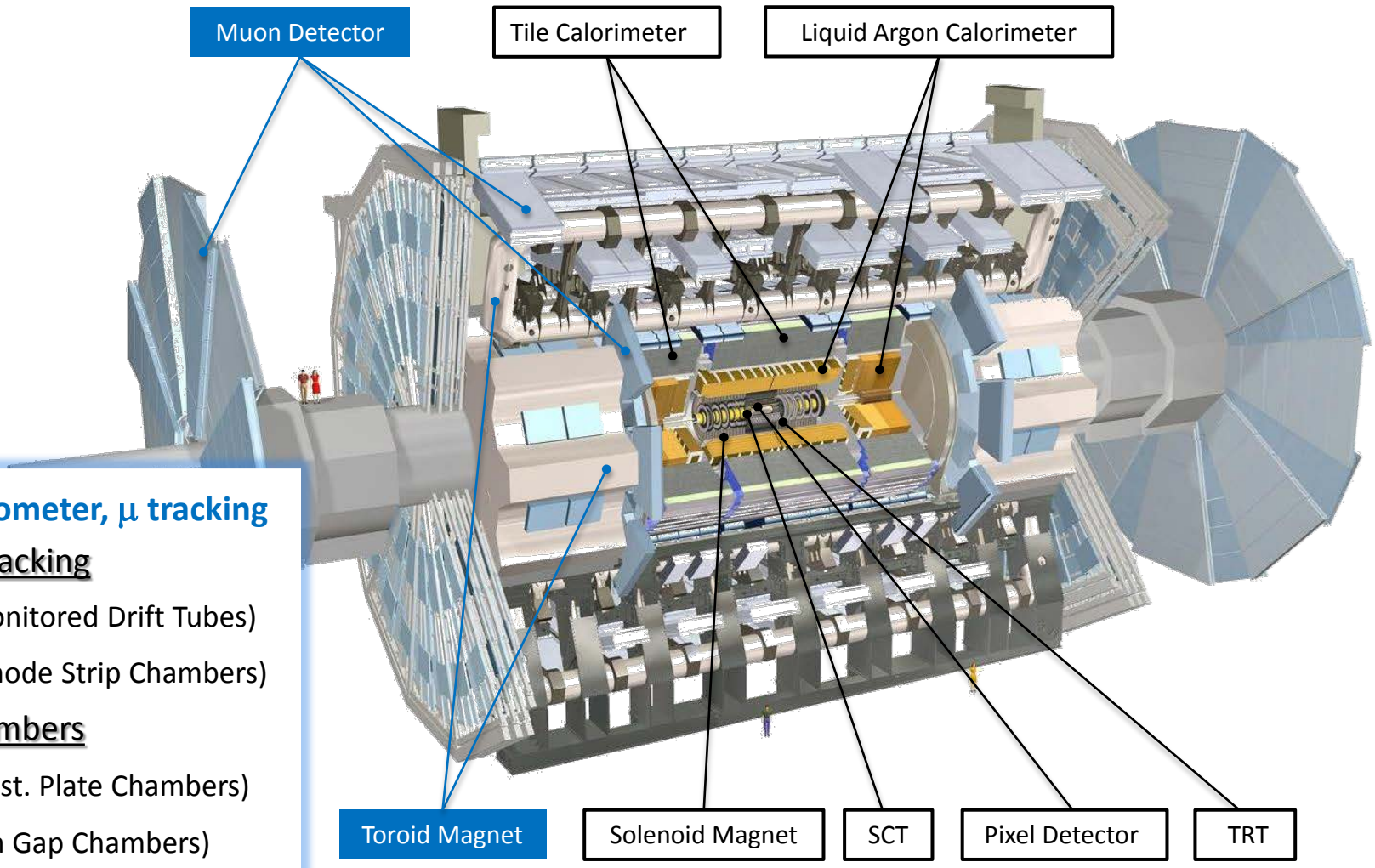
The ATLAS Detector



Calorimeter system
EM and Hadronic energy

- Liquid Ar (LAr) EM barrel and end-cap
- LAr Hadronic end-cap
- Tile calorimeter (Fe – scintillator) hadronic barrel

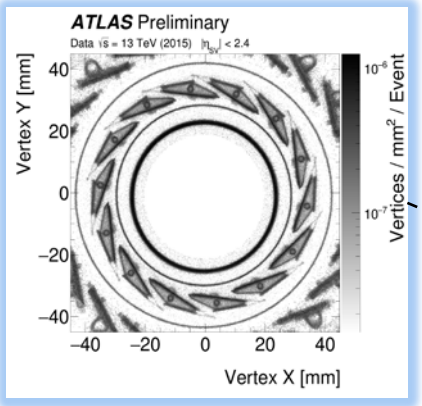
The ATLAS Detector

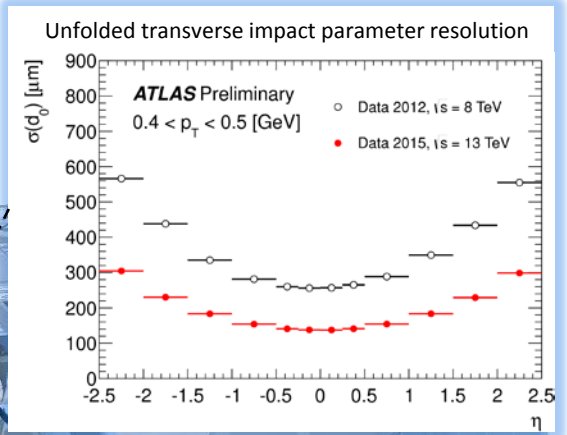


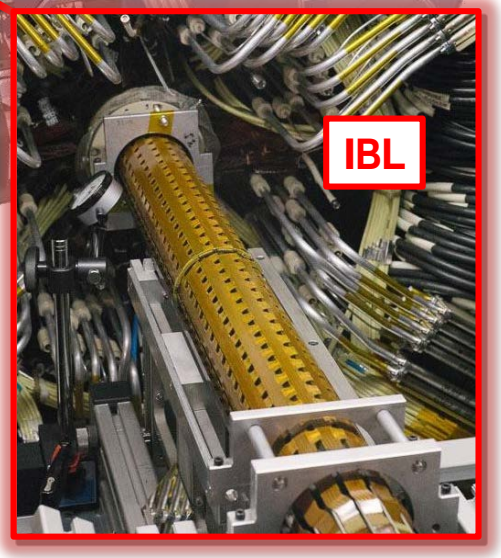
Muon spectrometer, μ tracking

- Precision tracking
  - **MDT** (Monitored Drift Tubes)
  - **CSC** (Cathode Strip Chambers)
- Trigger chambers
  - **RPC** (Resist. Plate Chambers)
  - **TGC** (Thin Gap Chambers)
- Toroid Magnets

The ATLAS Detector in Run-2



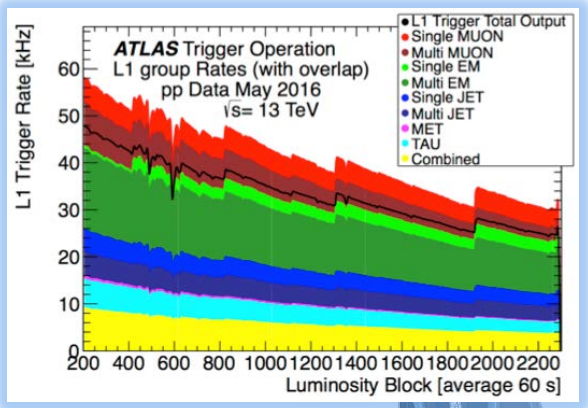


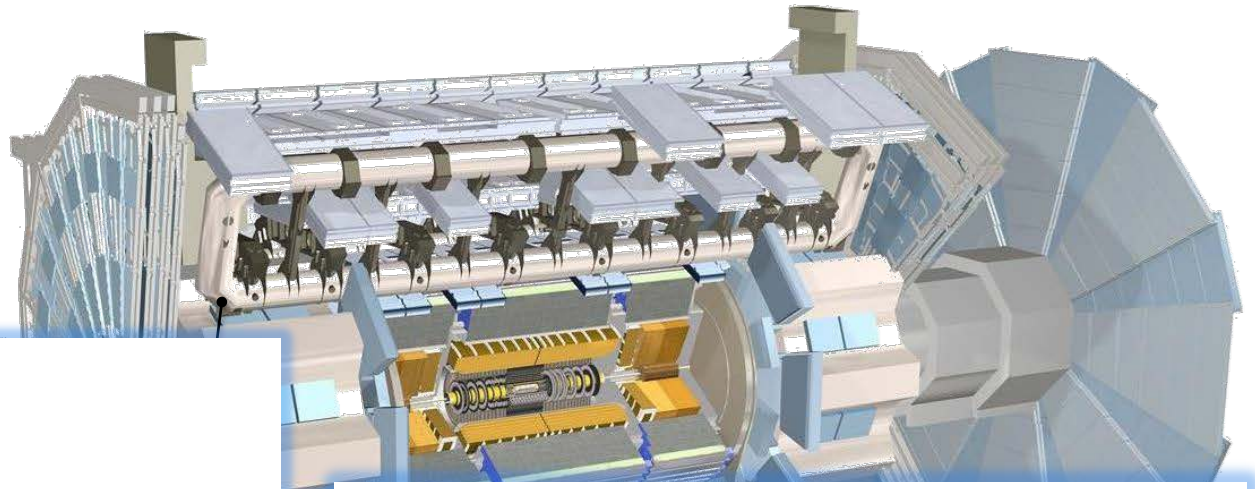


New detectors in Run-2:

- Innermost pixel layer IBL, 3.4 cm from interaction point
- Muons: MDT in $1.1 < |\eta| < 1.3$, RPC in Barrel Feet Sectors
- Forward proton detectors, AFP (one arm in 2016, 205+217m from IP)
- In addition, **various consolidations** provide improved running at high luminosities and rates (**tracking, calorimetry, muon, luminosity measurement, etc.**)

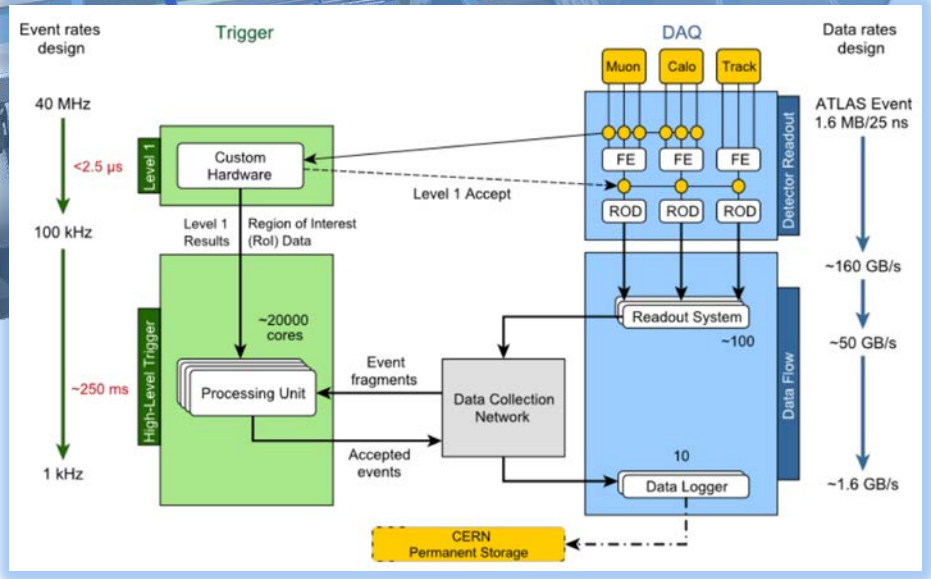
The ATLAS Detector in Run-2





Trigger system (Run-2)

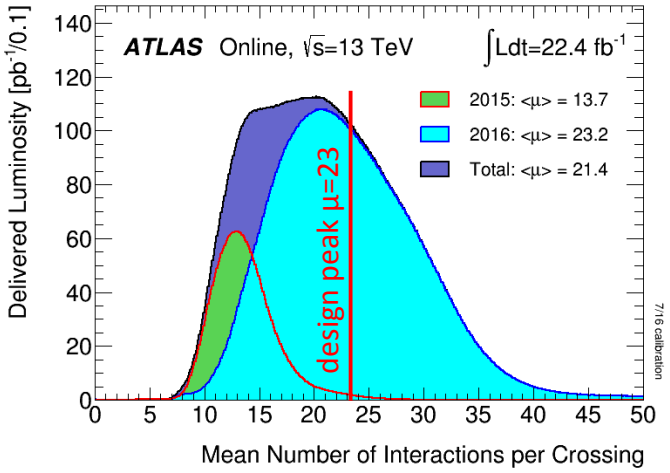
- L1 – hardware
  - output rate: 100 kHz latency: < 2.5 ms
  - New Central Trigger Processor
  - Improved resolution in calorimetry readout and trigger
  - Topological trigger at L1 (Calo+Muons)
- HLT – software
  - output rate: 1 kHz
  - proc. time: ~ 550 ms
- Wide upgrade to DAQ infrastructure

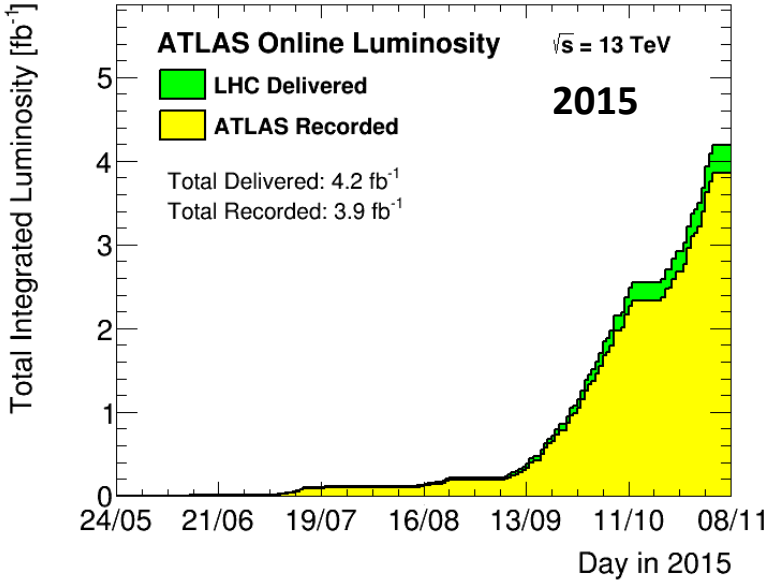


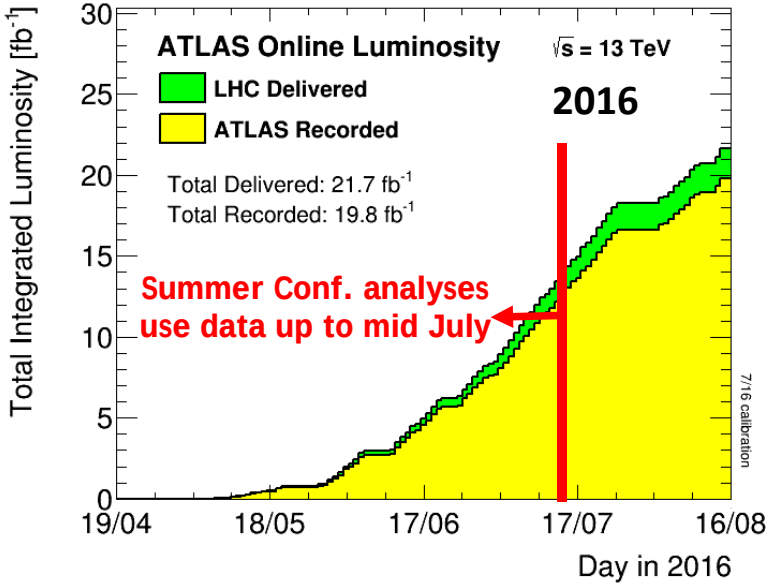
ATLAS data taking from 2015 to 2016

Year	C.M.S. Energy	β*	Peak Inst Lum.	Bunch Spacing
2010-2012	7+8 TeV	80 cm	7.73 x 10^{33} $cm^{-2}s^{-1}$	50 ns
2015	**13 TeV**	80 cm	5.02 x 10^{33} $cm^{-2}s^{-1}$	**25 ns**
2016	**13 TeV**	**40 cm**	**1.16 x 10^{34} $cm^{-2}s^{-1}$**	**25 ns**

2016: LHC reached inst. luminosity and Pile-up (Mean Number of interactions per crossing) beyond original design







- Exceptional LHC performance in 2016 following 13 TeV commissioning in 2015

➔ **Run-2 results reported with 3-15 fb^{-1}**

Luminosity uncertainty
±2.1% (2015)
±3.7% (2016, preliminary)
±2.9% (2015+2016, prel.)

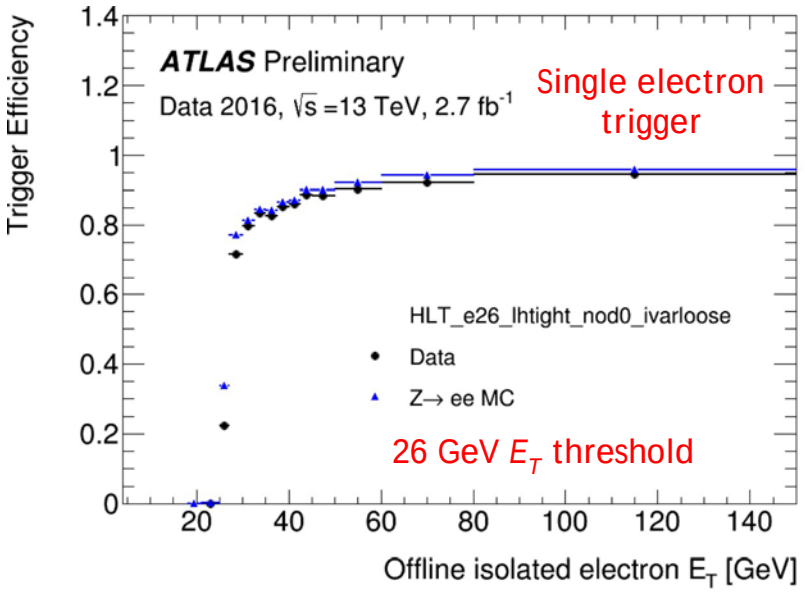
Run-2 Operation: the Trigger Challenge

Complex trigger menu designed to meet varied physics, monitoring and performance requirements

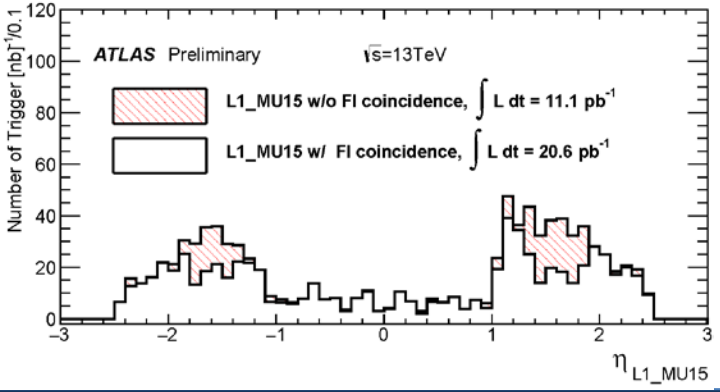
- Typically ~2000 active menu items
- Stable main primary triggers
- Level-1 running at ~85 kHz
- Average physics output rate ~1kHz

A few, example, trigger thresholds (GeV):

- E_T(e) > 24-26
- p_T(μ) > 24-26
- E_T^{miss} > 90-110
- E_T(jet) > 380
- E_T(γ) > 140
- p_T(μ1,μ2) > 6,6 + topo/mass selections
- E_T(γ1,γ2) > 35,25



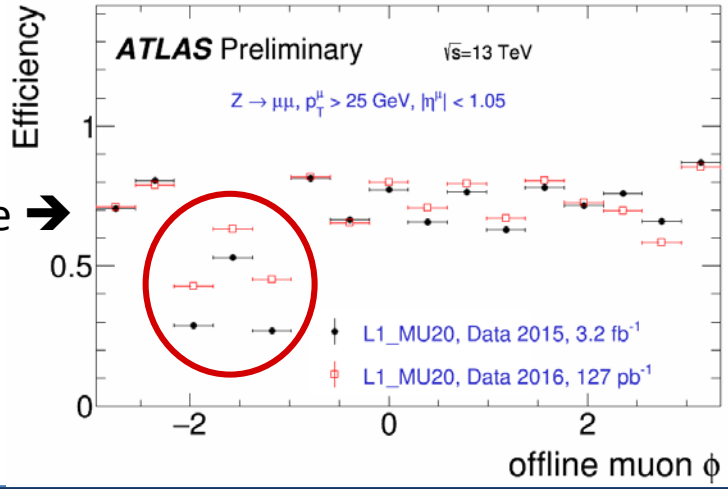
Endcap L1 Muon trigger rate reduction (Muon FI chambers coincidence)



Increase acceptance ➔

➔ Remove fakes

L1 Muon trigger efficiency barrel 2015/2016



Run-2 Data Quality

Many challenges:

- Detectors (occupancies, SEUs …)
- Trigger (thresholds, rates)
- Readout (bandwidth)
- Offline (Tier-0, Grid)

➔ ATLAS has risen to meet these challenges:

Data quality overall good

- 2015: 2 fills with IBL off due to FE current raising. Understood.
- 2016: few occasional short toroid-off periods (power glitches)

Detector operational channel fractions remains at Run-1 levels

End of 2015 data sample

ATLAS pp run: August-November 2015

Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
93.5	99.4	98.3	99.4	100	100	100	100	100	100	97.8

All Good for physics: 87.4% (3.3 fb^{-1})

Luminosity weighted relative detector uptime and good data quality (DQ) efficiencies (in %) during stable beams in pp collisions with 25ns bunch spacing at √s=13 TeV between August-November 2015, corresponding to an integrated luminosity of 3.8 fb^{-1}. The lower DQ efficiency in the Pixel detector is due to the IBL being turned off for two runs, corresponding to 0.2 fb^{-1}. Analyses that don't rely on the IBL can use those runs and thus use 3.5 fb^{-1} with a corresponding DQ efficiency of 93.4%.

2016 Summer Conferences data sample

ATLAS pp 25ns run: April-July 2016

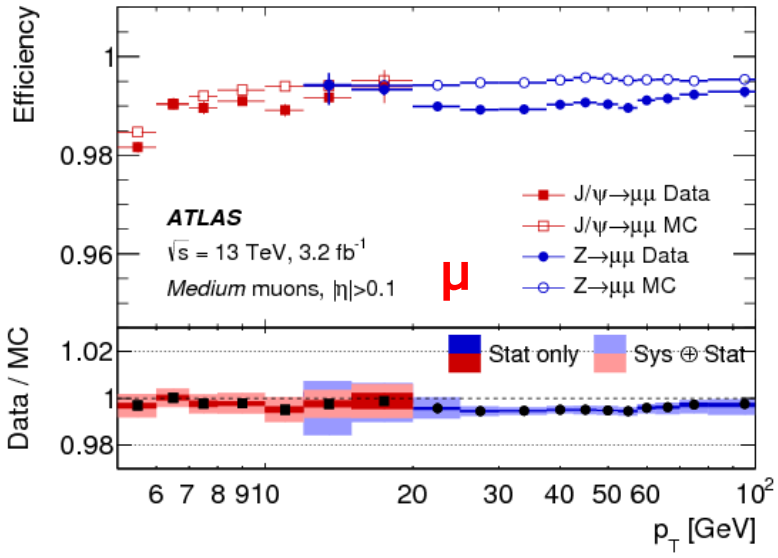
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
98.9	99.9	100	99.8	100	99.6	99.8	99.8	99.8	99.7	93.5

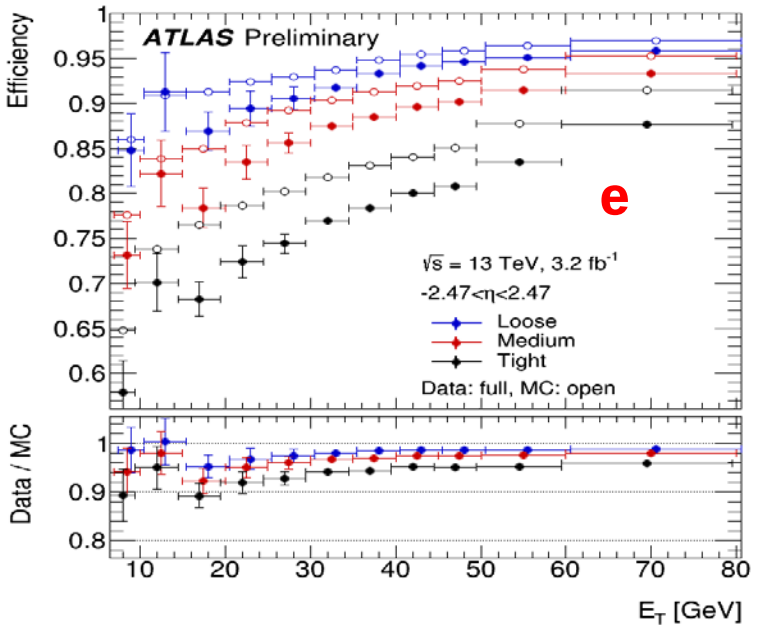
Good for physics: 91-98% (10.1-10.7 fb^{-1})

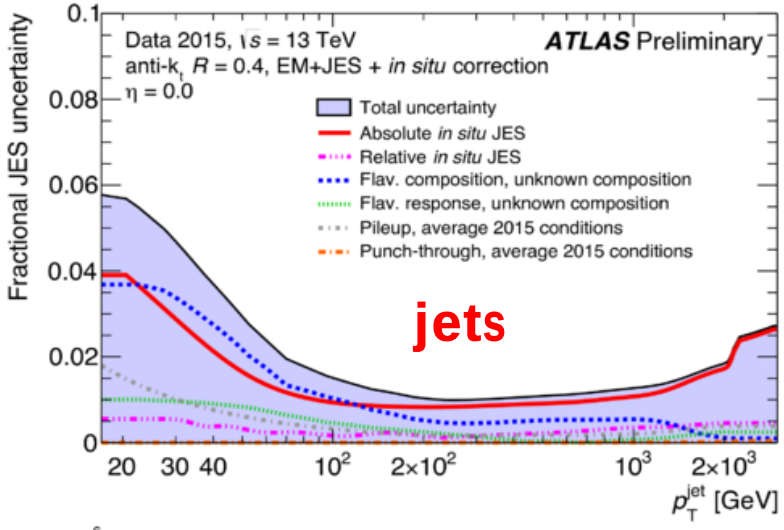
Luminosity weighted relative detector uptime and good data quality efficiencies (in %) during stable beam in pp collisions with 25ns bunch spacing at √s=13 TeV between 28th April and 10th July 2016, corresponding to an integrated luminosity of 11.0 fb^{-1}. The toroid magnet was off for some runs, leading to a loss of 0.7 fb^{-1}. Analyses that don't require the toroid magnet can use that data.

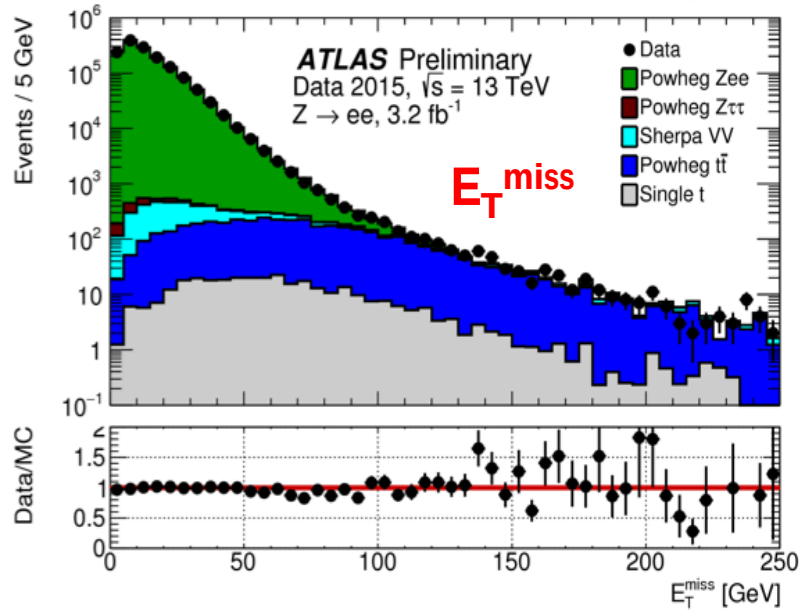
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	92 M +12M wrt Run-1	98.2%
SCT Silicon Strips	6.3 M	98.7%
TRT Transition Radiation Tracker	350 k	97.2%
LAr EM Calorimeter	170 k	100%
Tile calorimeter	5200 +0.8 % wrt 2015	100%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.7%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	383 k +13k wrt 2015	99.8%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	357 k	99.7%
CSC Cathode Strip Chambers	31 k	98.4%
RPC Barrel Muon Chambers	383 k +13k wrt 2015	96.6%
TGC Endcap Muon Chambers	320 k	99.6%
ALFA	10 k	99.9 %
AFP NEW for 2016	188 k	98.8 %

Physics Performance





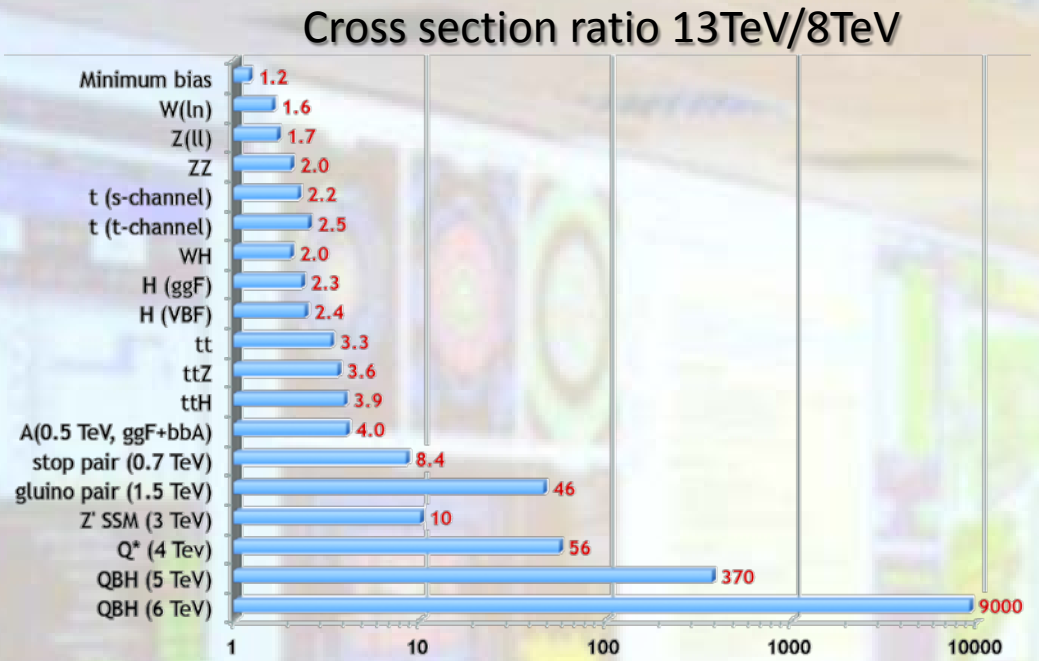




➔ Fast turn-around from end of data taking

Results

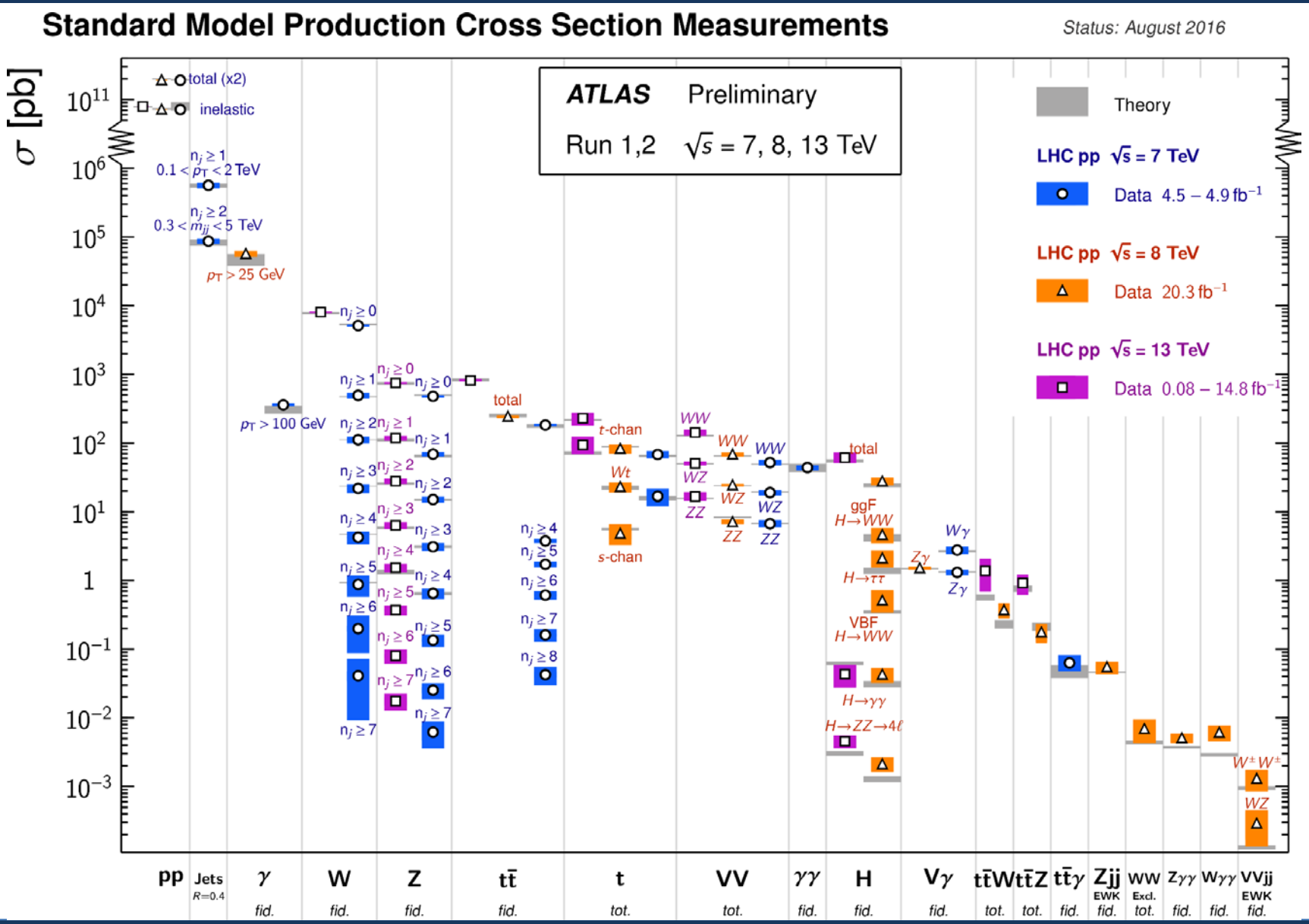
- After a little more than a year the Run-2 pp sample is approaching the integrated luminosity of Run-1, at 1.6 times higher √s
- Major new physics sensitivity has opened up



ATLAS:

- In total 64 new results from for the Summer Conferences: 56 using 13 TeV data and 45 with 2015+2016
- 40 papers with Run-2 data (576 total with collision data) have been submitted while Run-1 results are still coming

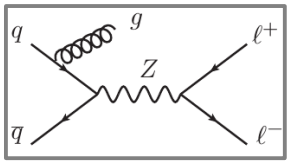
Inclusive Cross-Sections



Z+Jets

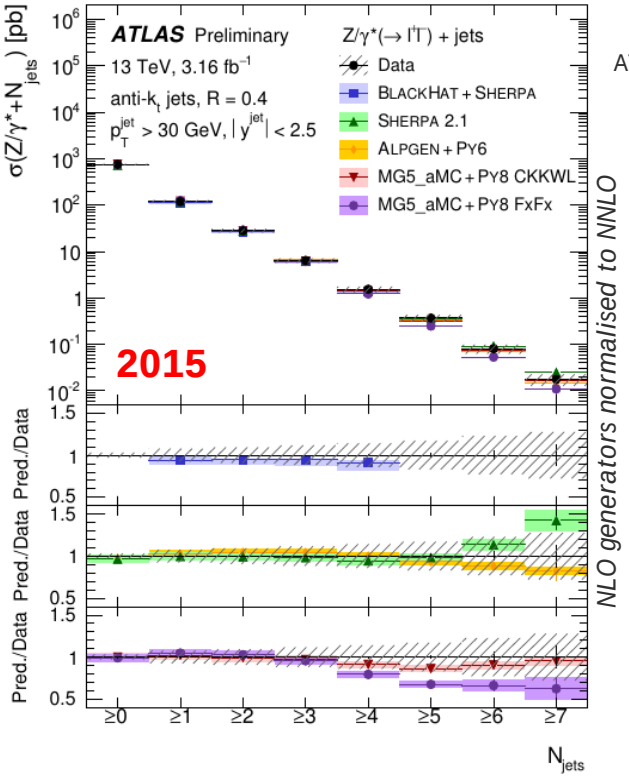
Access and measure high jet multiplicities in 13 TeV data

- Test NLO generators on easily triggered events with high jet multiplicities
- Vector-boson plus jet events are a major background in searches



Fully corrected fiducial and differential cross-sections

- Z with up to 7 additional jets measured

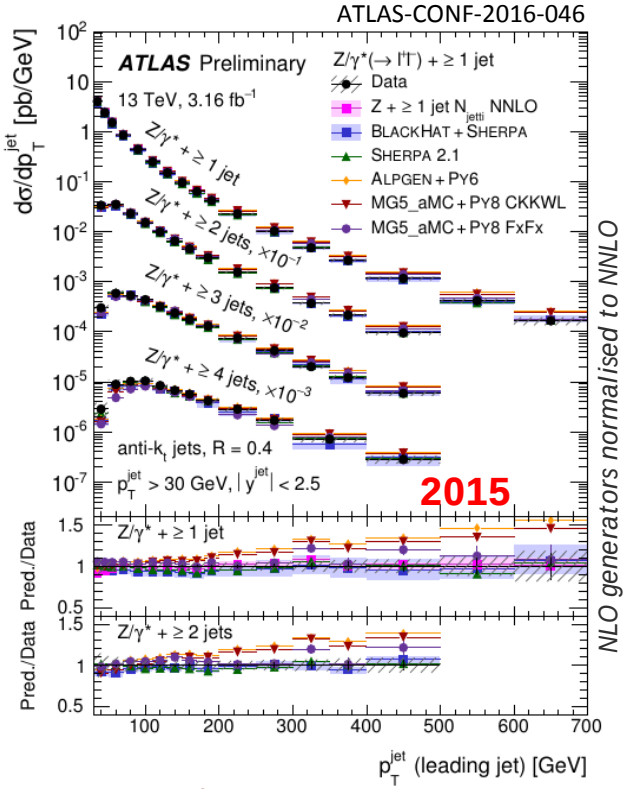


ATLAS-CONF-2016-046

~6M Z→ℓℓ event sample (3.2 fb^{-1})

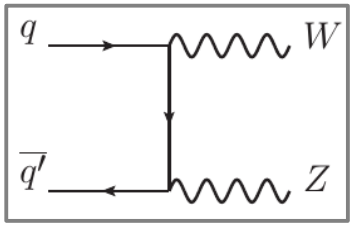
Jet multiplicity: main NLO generators do a good job, at least up to 6 jets

ATLAS-CONF-2016-046



Leading jet p_T spectra:
LO generators over-predict high-p_T tail
NLO generators provide better description

Massive Diboson Production



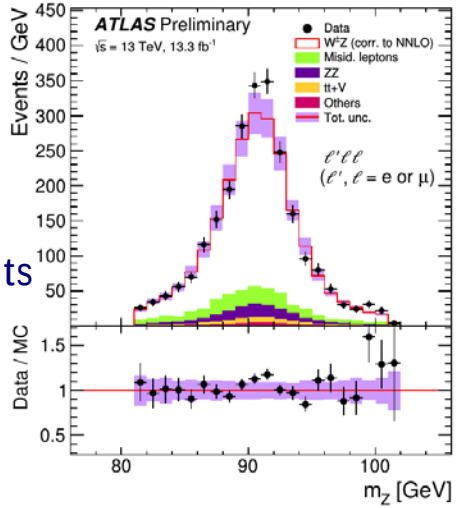
Run-1 puzzle to describe inclusive diboson cross-sections

- Measurements tended to lie above NLO calculations

NNLO calculations → ~20% corrections and better agreement

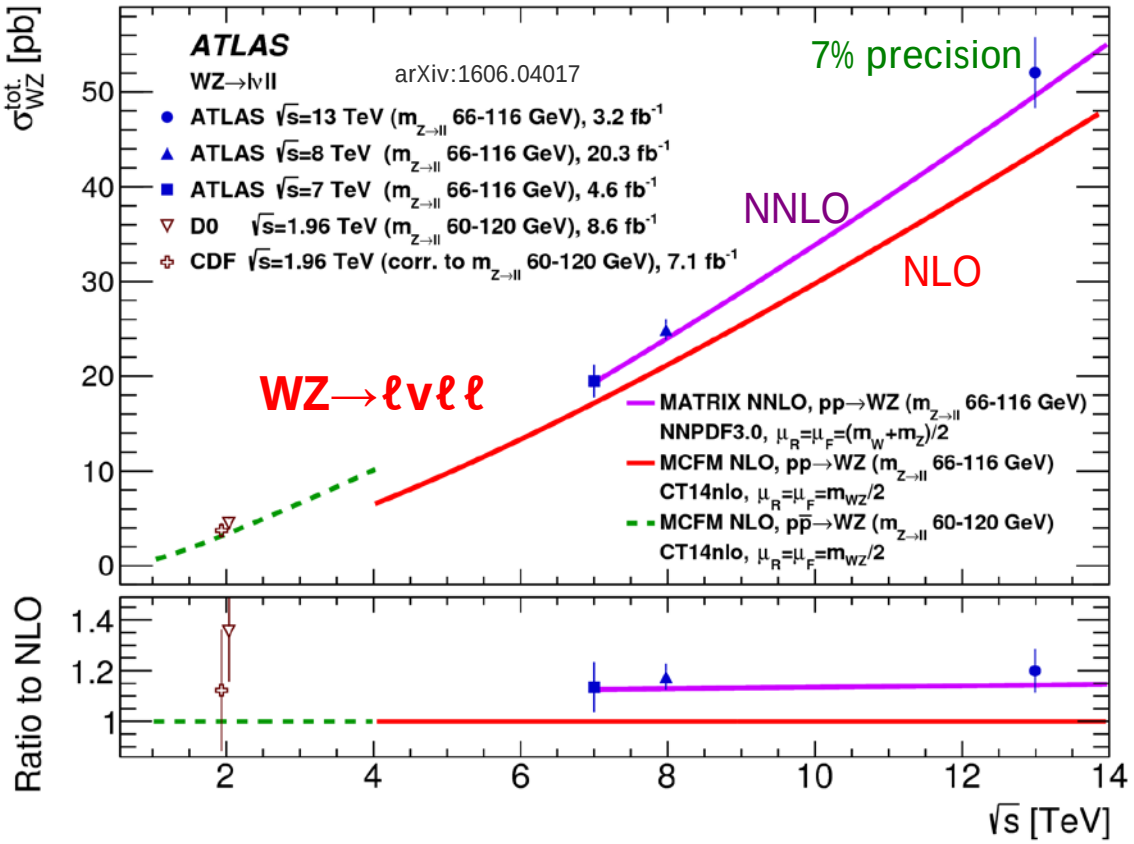
Presented measurements at 13 TeV of WW, WZ, ZZ leptonic channels

$Z \to \ell\ell$ in selected WZ events

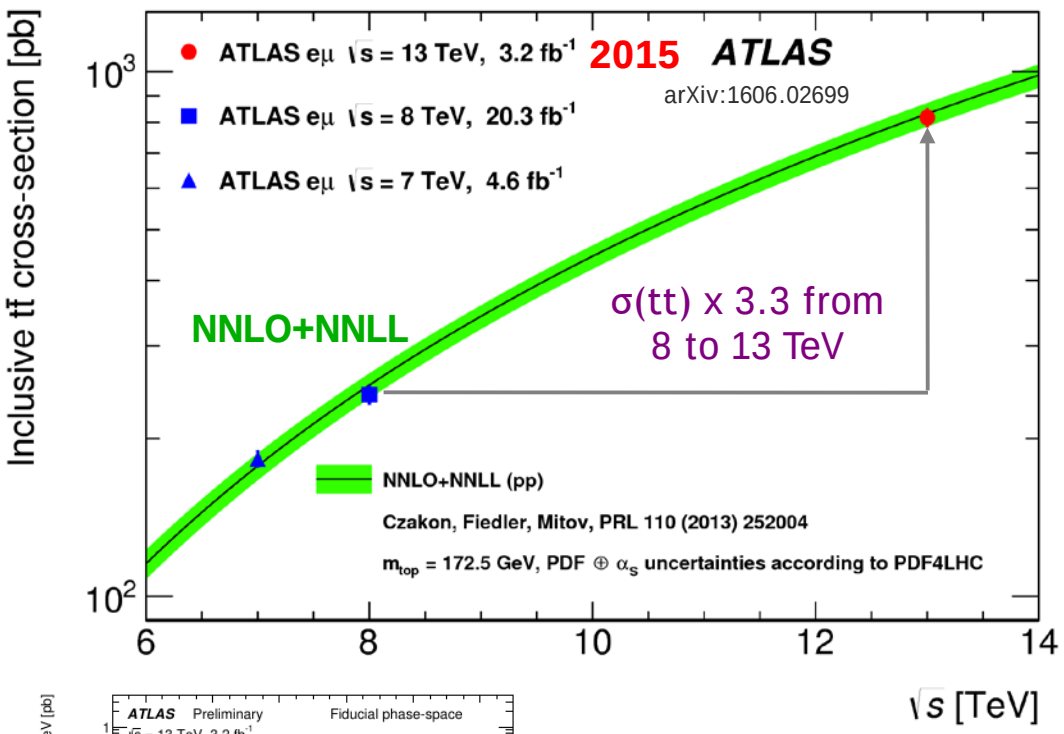


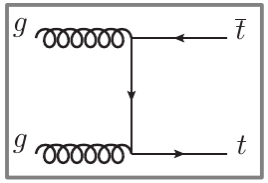
Example:
WZ leptonic decays
NNLO calculations describe data much better than NLO

arXiv:1606.04017



tt̄ Production

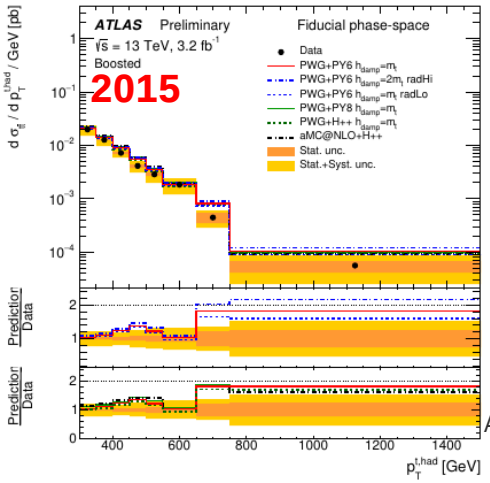




Single and double b-tagged $tt \to be\nu b\mu\nu$ events allow to measure tt cross-section and b-tagging efficiency simultaneously

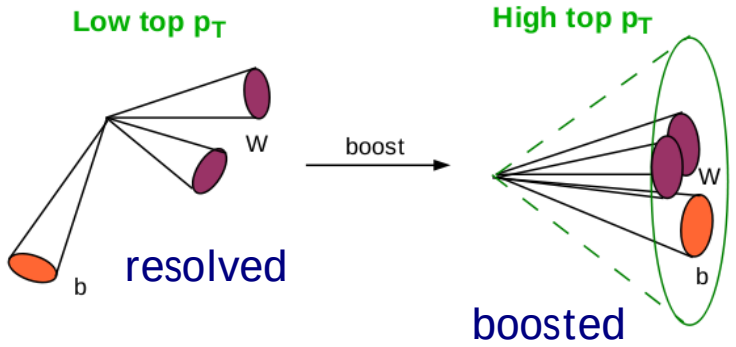
Precision ±(3.9-4.4)% (7-13 TeV) betters NNLO+NNLL predictions (~5%)

High tt statistics → detailed studies of production properties

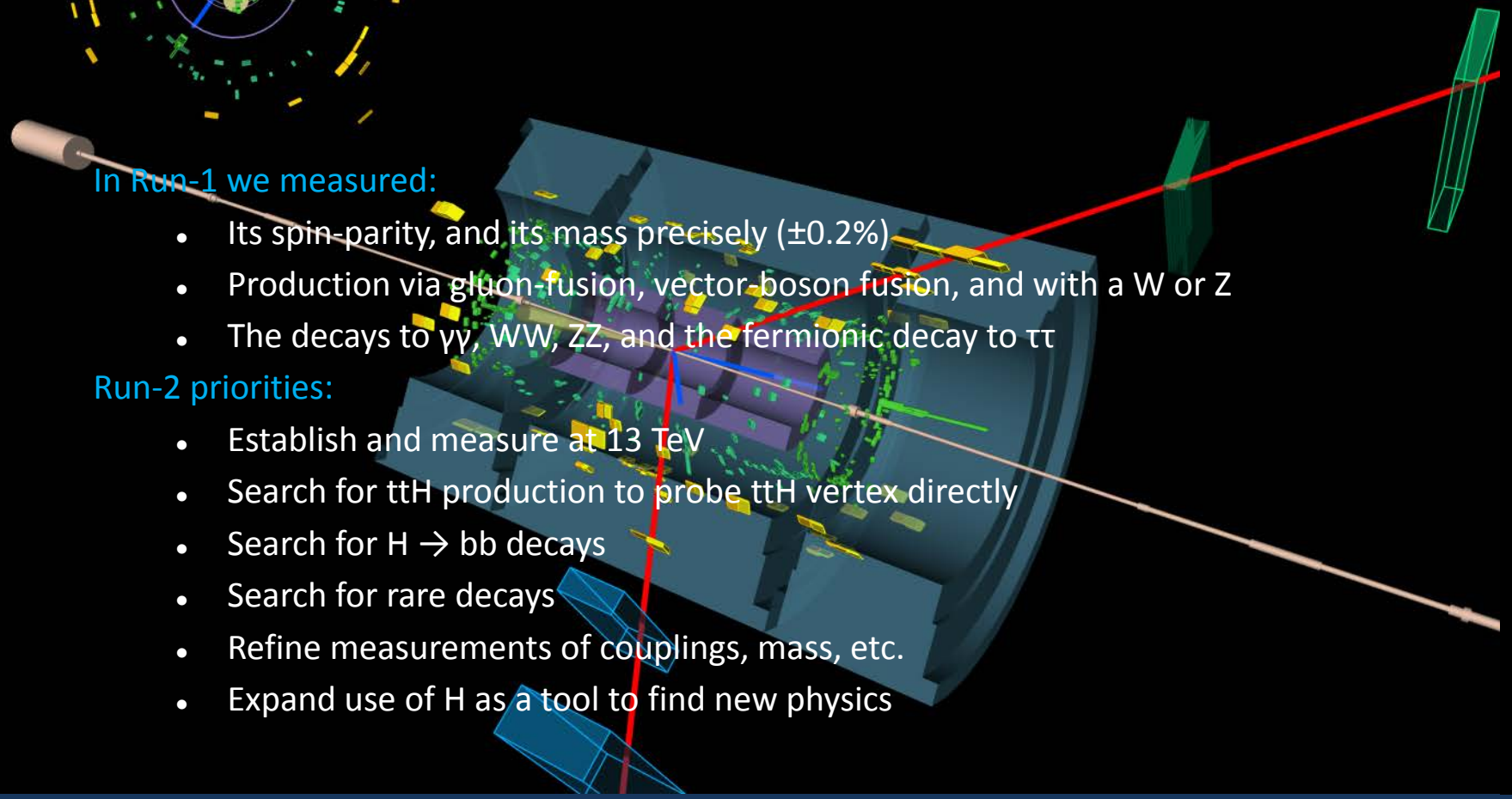


ATLAS-CONF-2016-040

ℓ+jet channel high-p_T differential cross-section from boosted analysis (also resolved)



Refining the Higgs Investigation



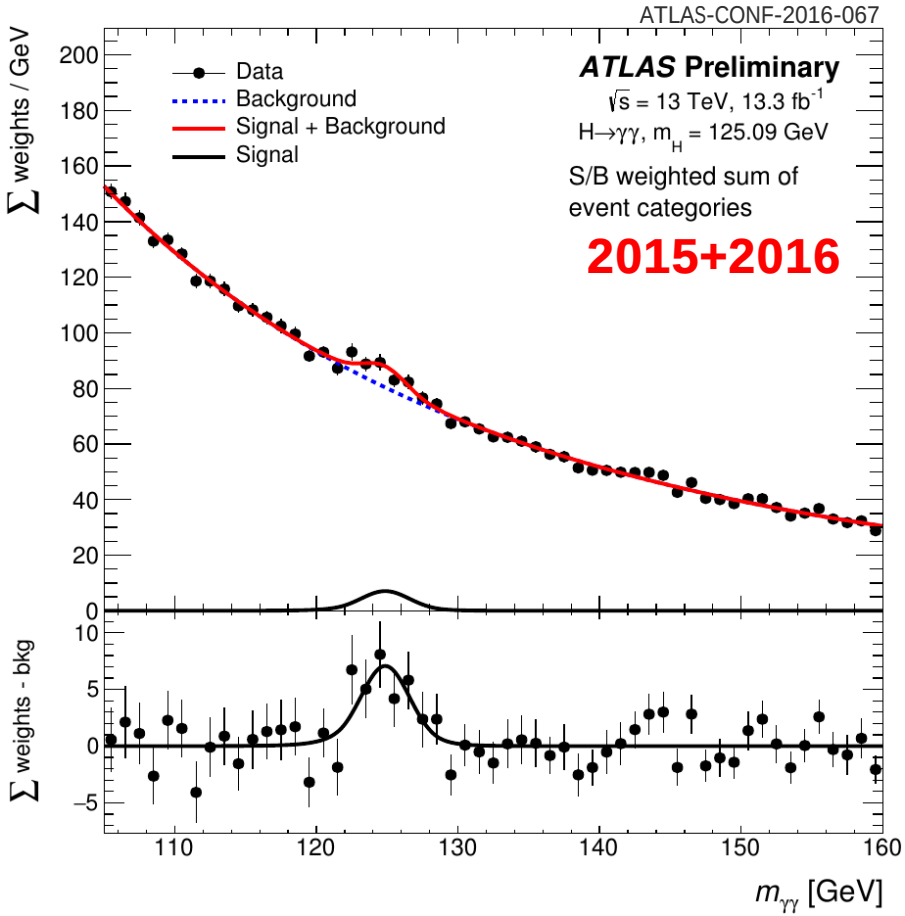
In Run-1 we measured:

- Its spin-parity, and its mass precisely (±0.2%)
- Production via gluon-fusion, vector-boson fusion, and with a W or Z
- The decays to γγ, WW, ZZ, and the fermionic decay to ττ

Run-2 priorities:

- Establish and measure at 13 TeV
- Search for ttH production to probe ttH vertex directly
- Search for H → bb decays
- Search for rare decays
- Refine measurements of couplings, mass, etc.
- Expand use of H as a tool to find new physics

Higgs: H→γγ

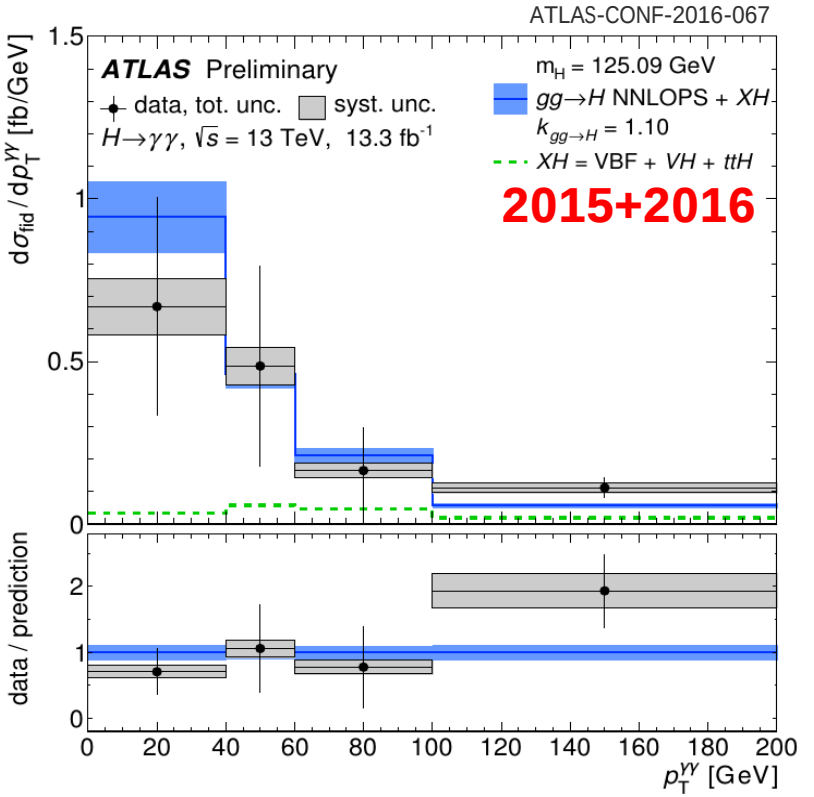


$$\sigma_{\text{fid}} = 47.0 \pm 13.9\,(\text{stat.}) \pm 5.4\,(\text{syst.})\ \text{fb}$$

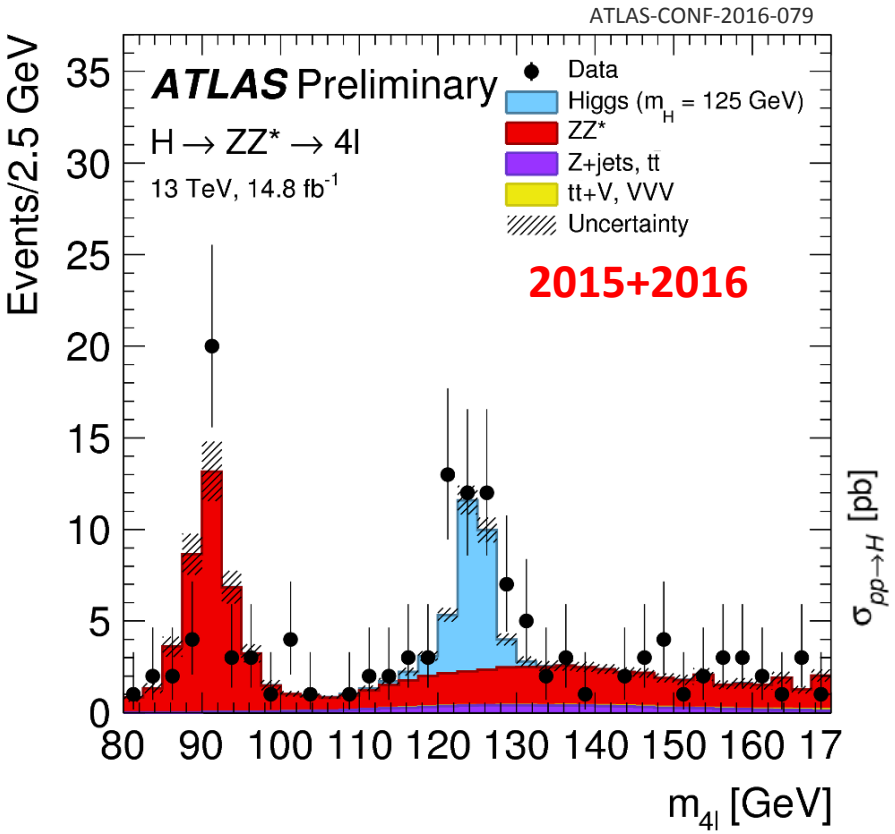
SM prediction $62.8\,^{+3.4}_{-4.4}$ fb

Event categories enhance sensitivity and help separate production modes

- Clear signal, rate consistent with SM H expectation
- Fiducial and differential cross-section measurements



H→4ℓ & Cross-Section Combination



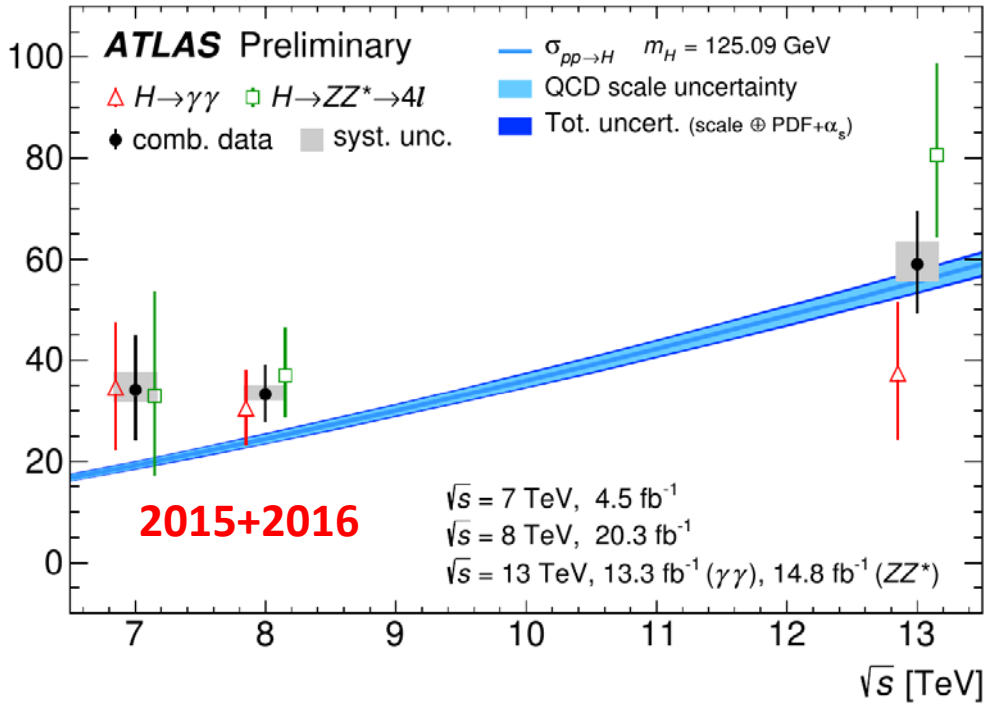
H→ZZ*→4ℓ: event categories again used

- Clear re-observation, rate consistent with SM H expectation (1.6σ high)

Combining γγ+4ℓ channels

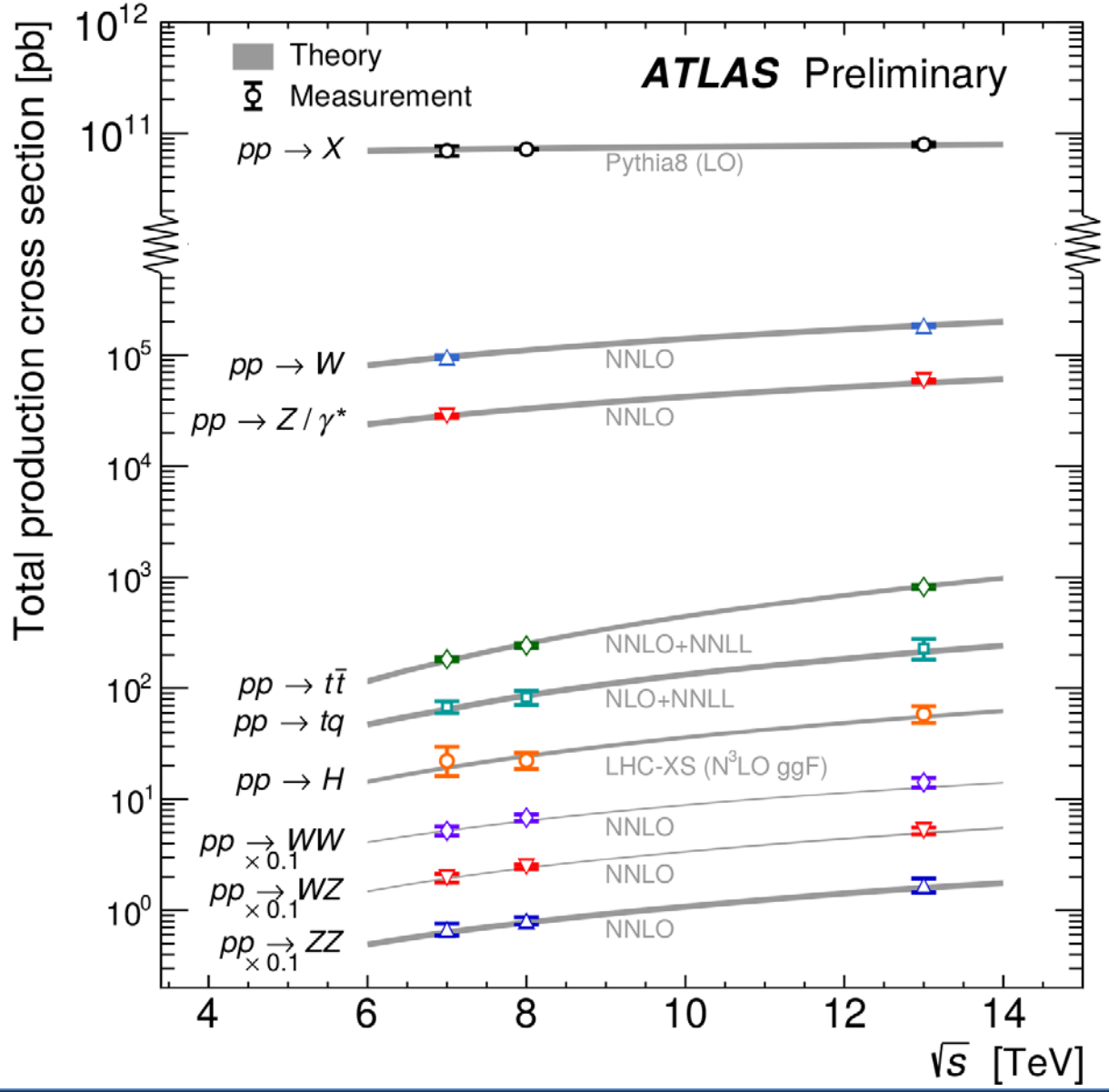
σ(pp→H+X,13 TeV) = $59.0^{+9.7}_{-9.2}$ (stat.) $^{+4.4}_{-3.5}$ (syst.) pb

SM prediction $55.5^{+2.4}_{-3.4}$ pb



Overall significance at 13 TeV ~10σ

Total Production Cross Section



$pp \to X$
7 TeV, 20 μb^{-1}, Nat. Commun. 2, 463 (2011)
8 TeV, 500 μb^{-1}, arXiv:1607.06605
13 TeV, 60 μb^{-1}, arXiv:1606.02625

$pp \to W$ $pp \to Z/\gamma^*$
7 TeV, 36 pb^{-1}, PRD 85, 072004 (2012)
13 TeV, 81 pb^{-1}, PLB 759 (2016) 601

$pp \to t\bar{t}$
7 TeV, 4.6 fb^{-1}, Eur. Phys. J. C 74:3109 (2014)
8 TeV, 20.3 fb^{-1}, Eur. Phys. J. C 74:3109 (2014)
13 TeV, 3.2 fb^{-1}, arXiv:1606.02699

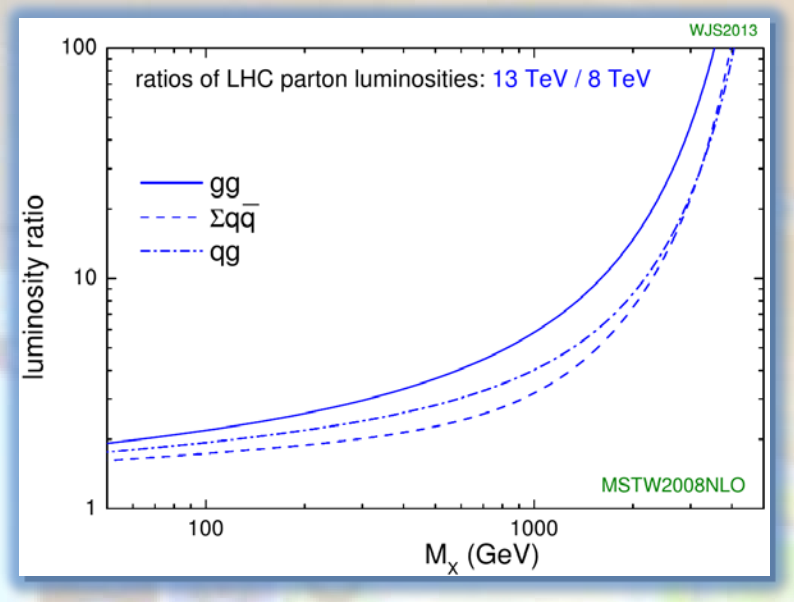
$pp \to tq$
7 TeV, 4.6 fb^{-1}, PRD 90, 112006 (2014)
8 TeV, 20.3 fb^{-1}, ATLAS-CONF-2014-007
13 TeV, 3.2 fb^{-1}, ATLAS-CONF-2015-079

$pp \to H$
7 TeV, 4.5 fb^{-1}, Eur. Phys. J. C76 (2016) 6
8 TeV, 20.3 fb^{-1}, Eur. Phys. J. C76 (2016) 6
13 TeV, 13.3 fb^{-1}, ATLAS-CONF-2016-081

$pp \to WW$
7 TeV, 4.6 fb^{-1}, PRD 87, 112001 (2013)
8 TeV, 20.3 fb^{-1}, arXiv:1608.03086
13 TeV, 3.2 fb^{-1}, ATLAS-CONF-2016-090

$pp \to WZ$
7 TeV, 4.6 fb^{-1}, Eur. Phys. J. C (2012) 72:2173
8 TeV, 20.3 fb^{-1}, PRD 93, 092004 (2016)
13 TeV, 3.2 fb^{-1}, arXiv:1606.04017

$pp \to ZZ$
7 TeV, 4.6 fb^{-1}, JHEP 03, 128 (2013)
8 TeV, 20.3 fb^{-1}, ATLAS-CONF-2013-020
13 TeV, 3.2 fb^{-1}, PRL 116, 101801 (2016)

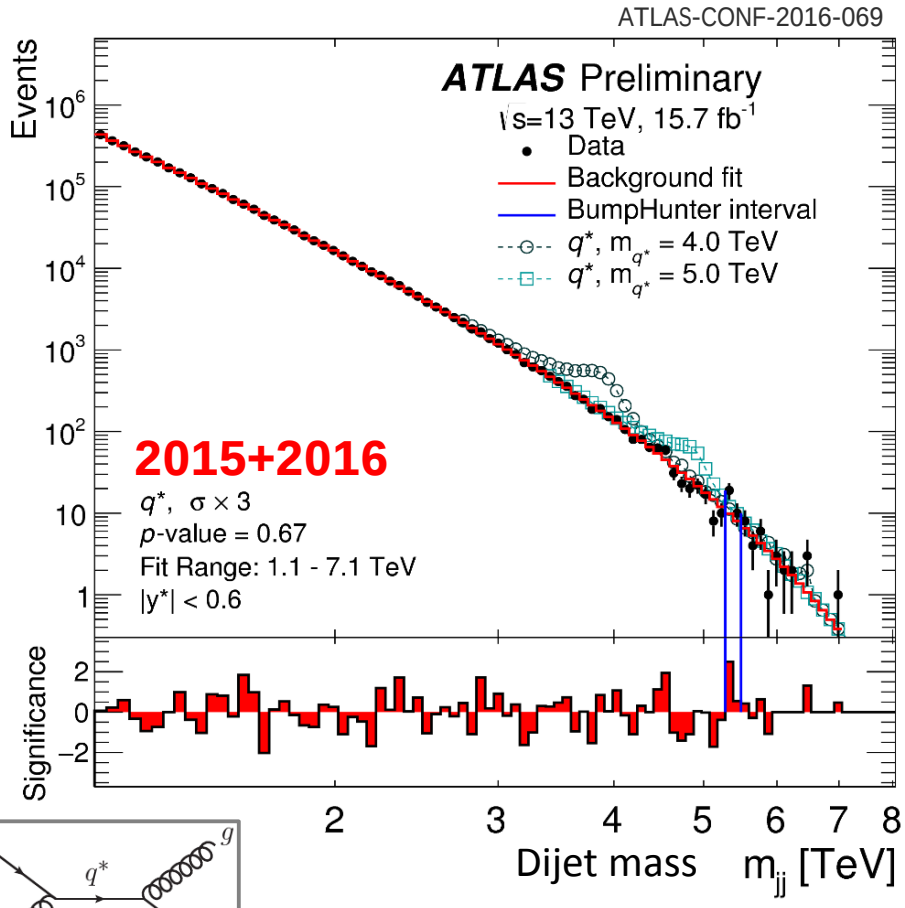


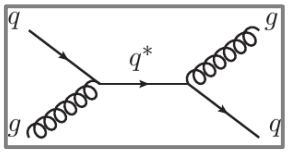
New Physics Searches

- Major extension of reach compared to Run-1
- All results shown here include 2016 data
- They probe well into the TeV, even multi-TeV, mass scale range
- Many more searches will yet come with the 2016 dataset

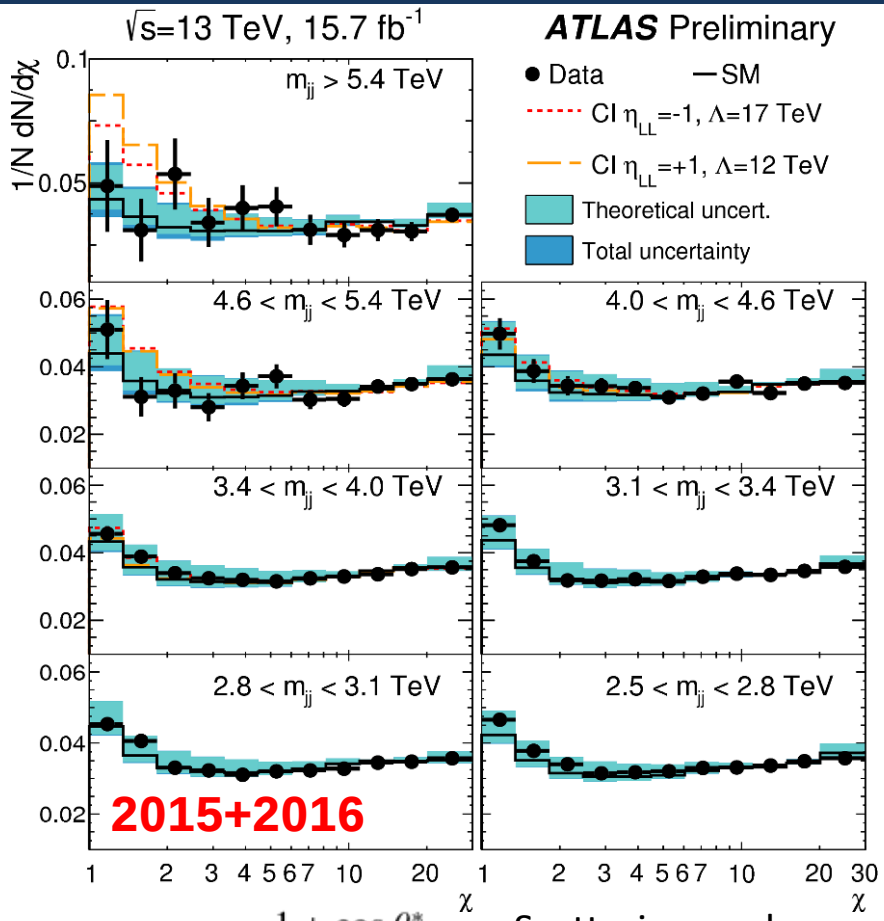
Dijet Search

Search for new physics in dijet mass spectrum and angular distributions





Examples (@95% CL):
m(q*) > 5.6 TeV
(ATLAS Run-1: 4.1 TeV)

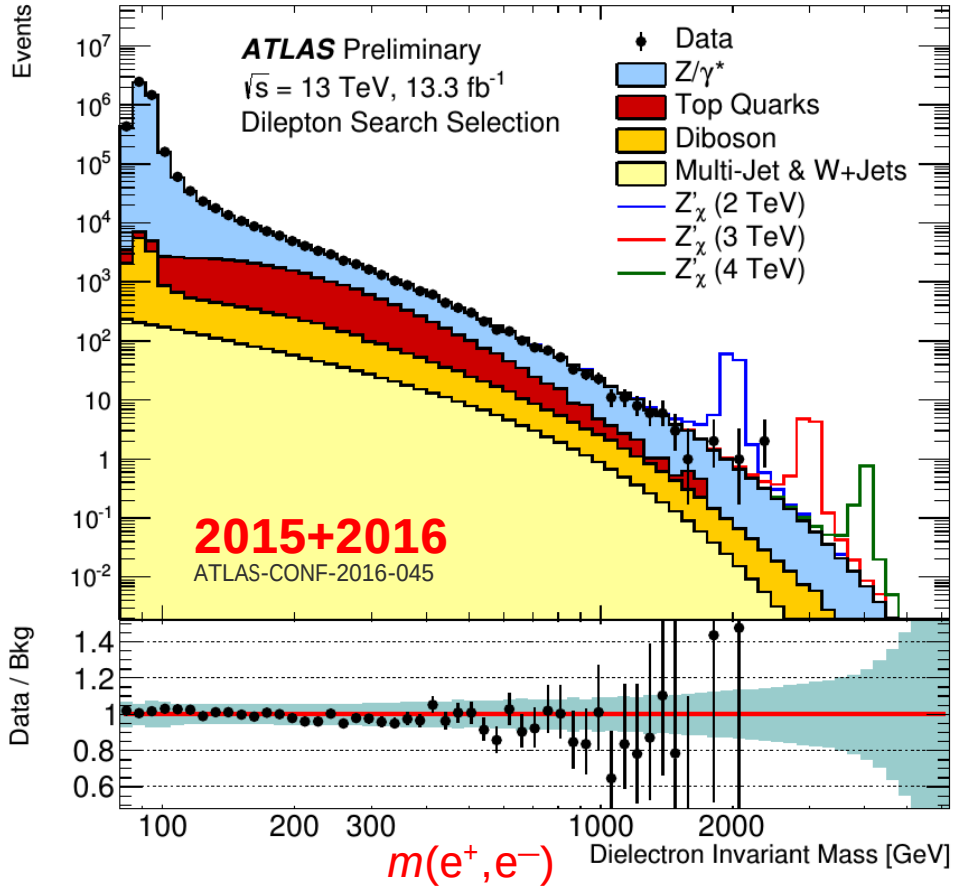


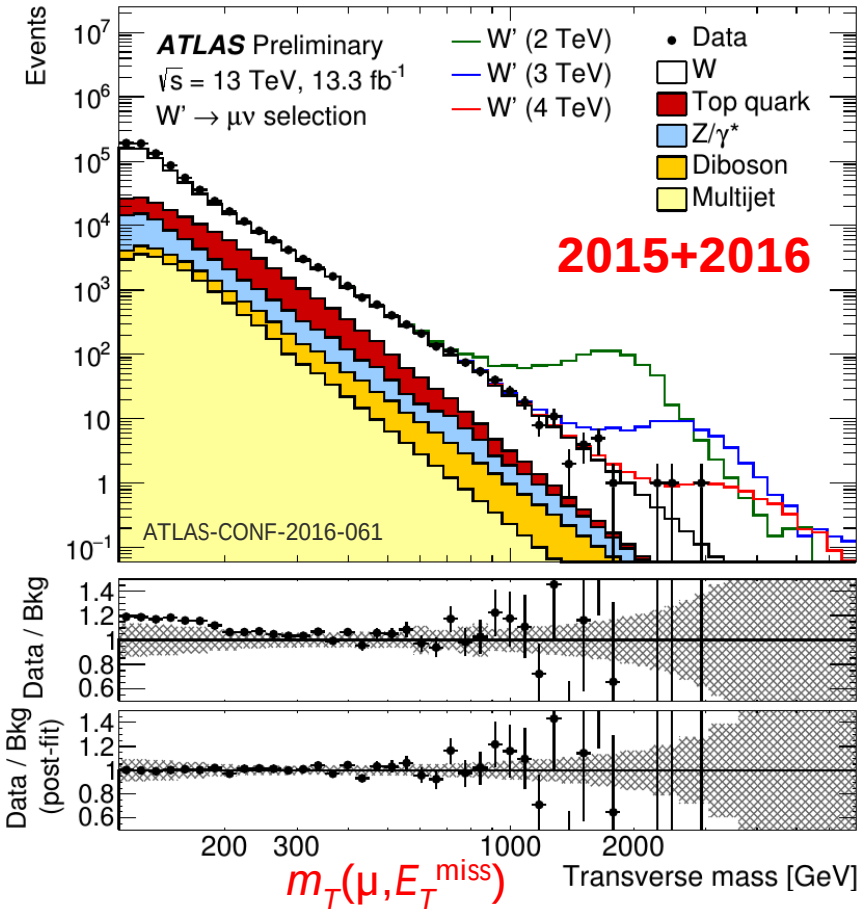
$$\chi = e^{2|y^*|} \sim \frac{1+\cos\theta^*}{1-\cos\theta^*}$$

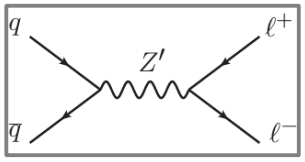
$$L_{qq} = \frac{2\pi}{\Lambda^2}\eta_{LL}(\bar{q}_L\gamma^\mu q_L)(\bar{q}_L\gamma_\mu q_L)$$

- Contact interaction scale (η_{LL}=+1/-1)
  Λ > 12.6 / 19.9 TeV (8.1/12.0 TeV in Run-1)

Dilepton Resonance Searches





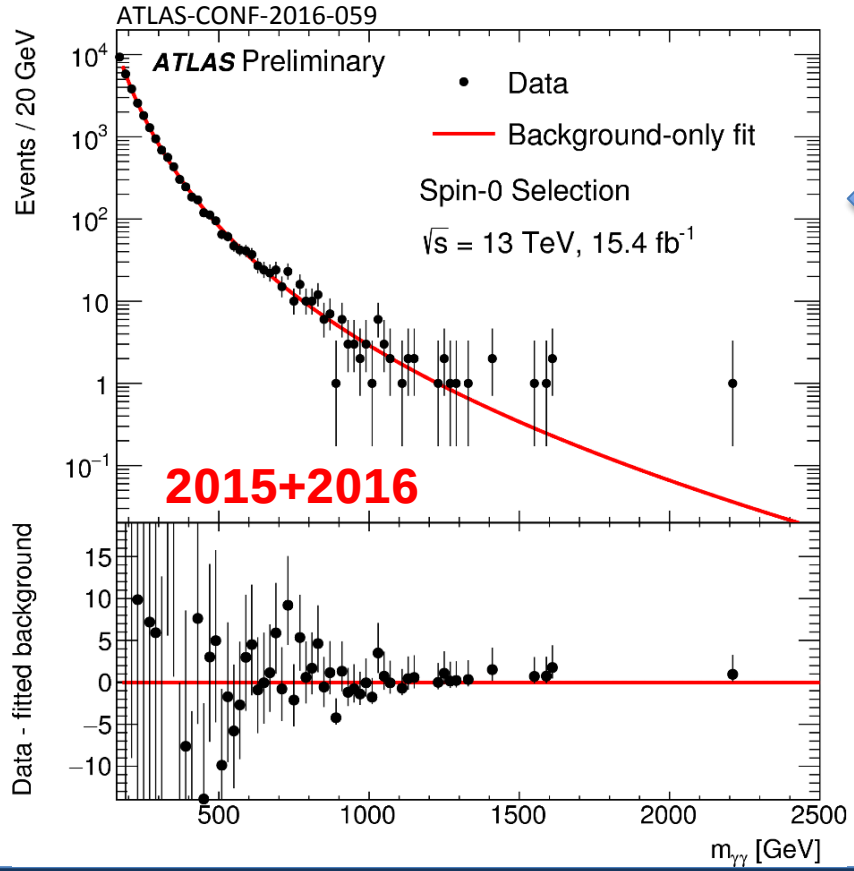


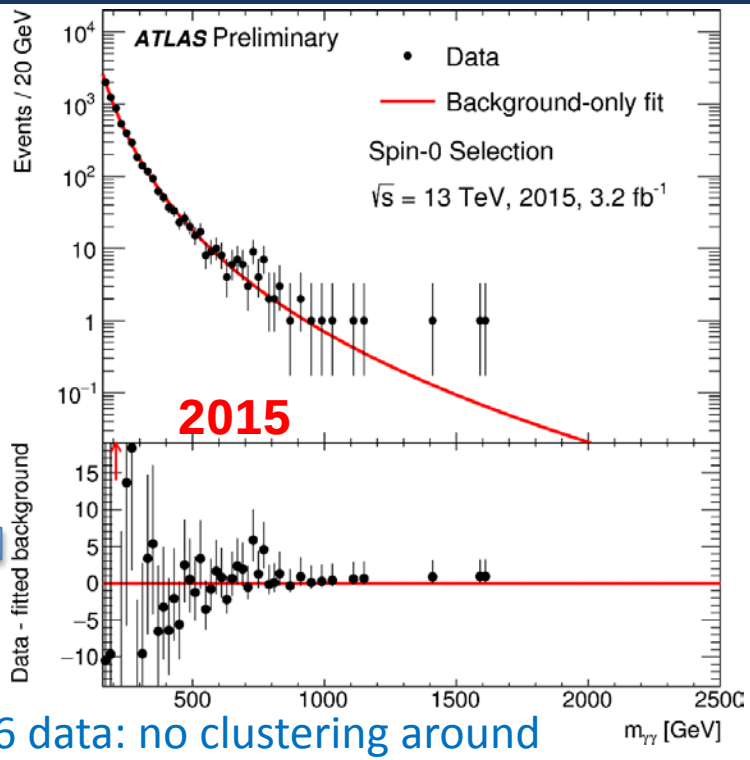
Z'_{SSM} (@95%CL): m > 4.05 TeV
(Run-1 m>2.90 TeV)

W' (@95%CL): m > 4.74 TeV
(Run-1 m>3.24 TeV)

Di-photon Search

- Localised excess seen in 2015 ATLAS data:
  - 2.1σ global (3.9σ local) significance at 750 GeV (spin-0 search), width ~50 GeV
  - After reprocessing, new 2016 reconstruction → 3.4σ local, at ~730 GeV





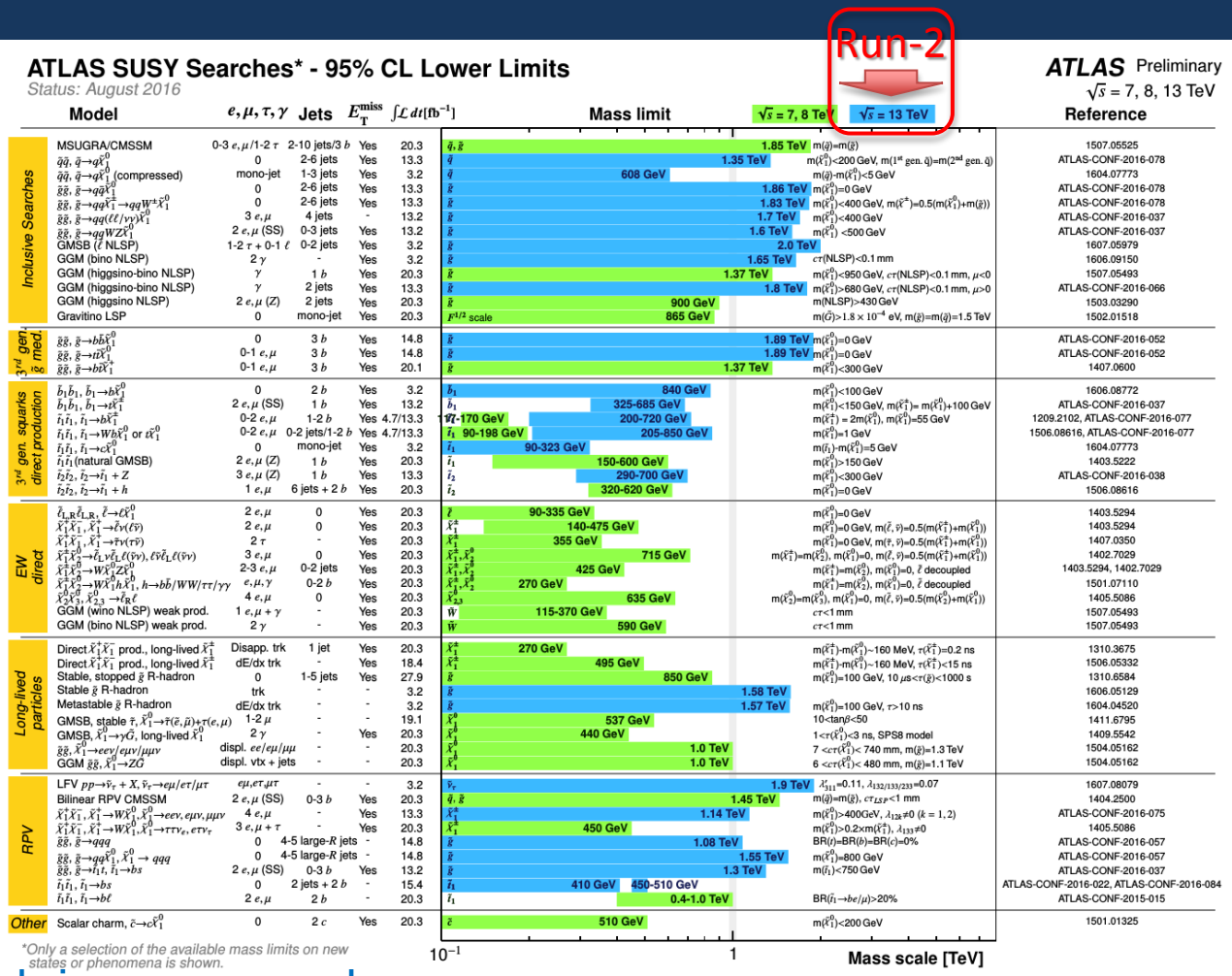
- 2016 data: no clustering around 730-750 GeV, and 3.8 times more data
  - 2015 and 2016 consistent at the 2.7σ level
  - It appears that the 2015 excess was very likely a statistical fluctuation
- With 2015+2016 data:
  - Small excess at 710 GeV (Γ/m~10%)
  - Local significance 1.4σ, global <1σ

SUSY Searches

Very broad set of SUSY search results reported with 2015+2016 data

Just one example shown:

- $\tilde{g}/\tilde{q}$ search with jets+$E_T$miss

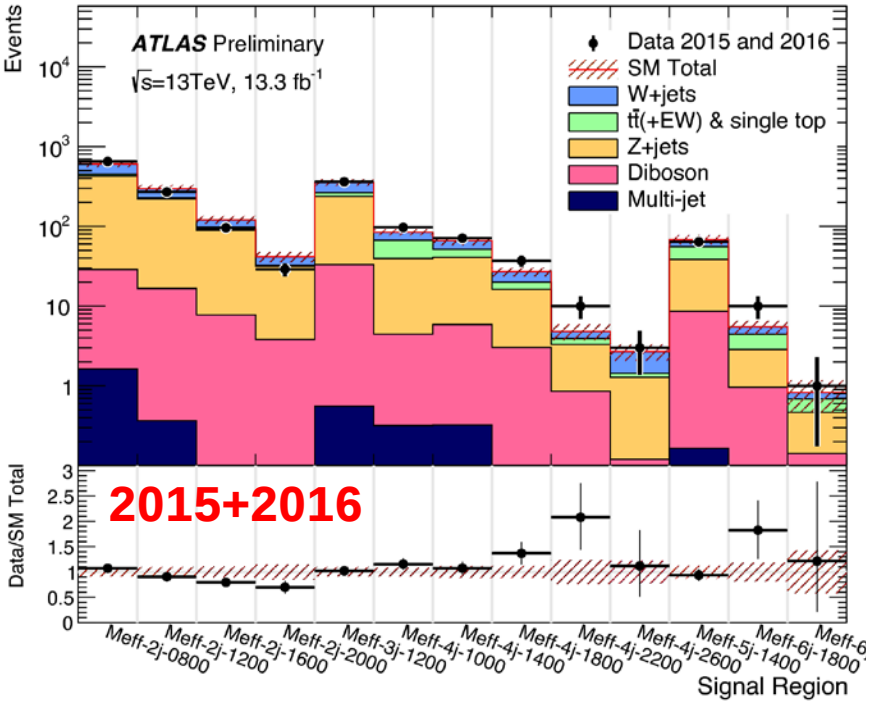


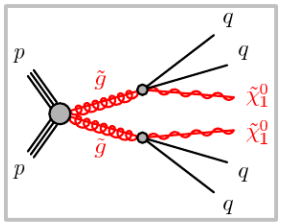
Standard ATLAS approach in many searches:

- Focus on specific signatures, simplified models guide optimisation
- Data-driven backgrounds: multiple control regions to constrain MC predictions and systematics
- Validation regions: verify background descriptions
- Signal regions: sensitivity!

SUSY: Jets + E_T^{miss} (0ℓ)

ATLAS-CONF-2016-078

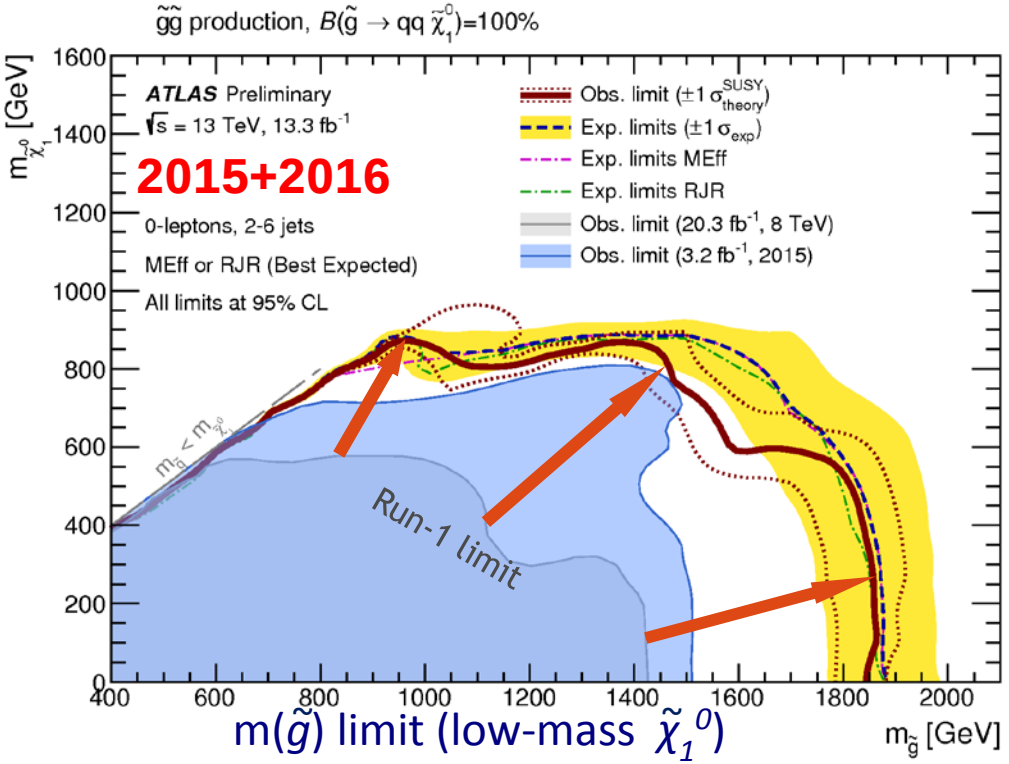




Require 2-6 jets and veto isolated leptons

- Sensitive to $\tilde{g}$ and $\tilde{q}$ production

Main backgrounds Z/W+jets and *tt*



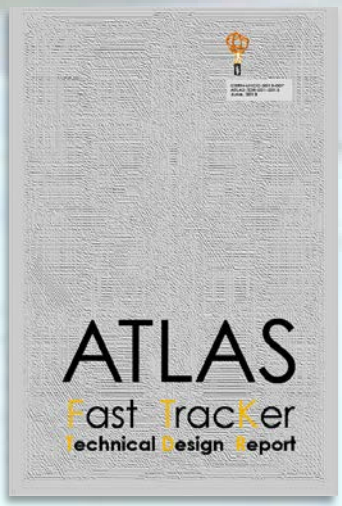
m($\tilde{g}$) limit (low-mass $\tilde{\chi}_1^0$)

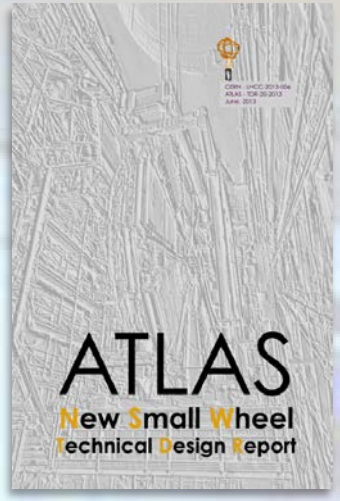
(Run-1) 1.4 TeV → 1.86 TeV

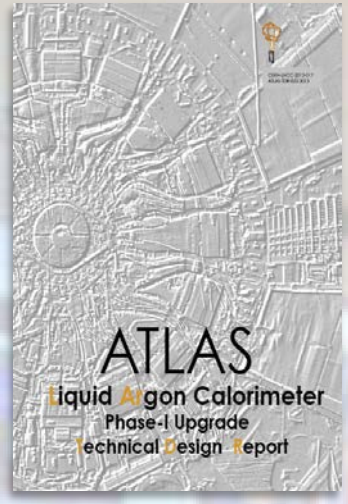
Total of 30 signal regions:

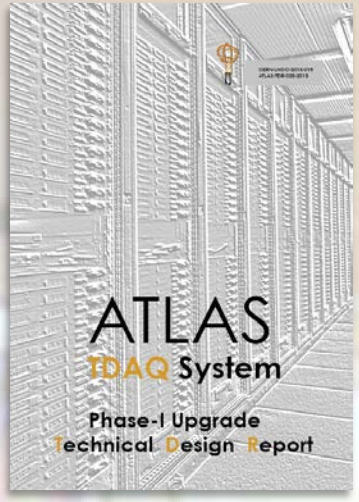
- 13 shown with different m_{eff} cuts
- Largest excess 1.6σ
- No significant excesses overall

$$m_{eff} = E_T^{miss} + \Sigma\, |p_T(\text{jet})|$$

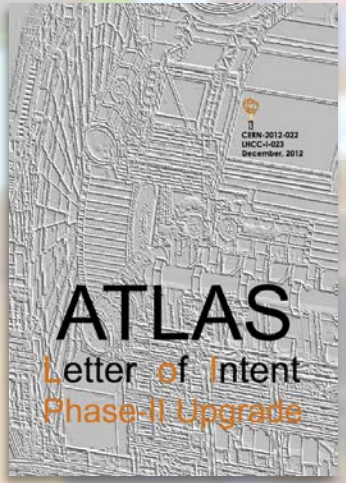


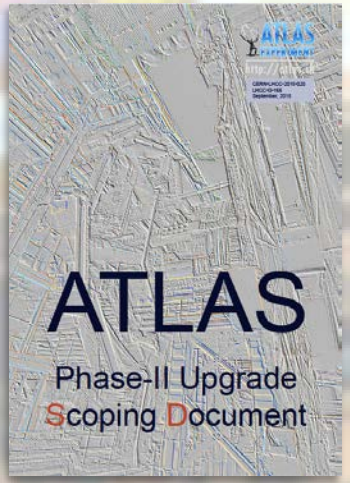




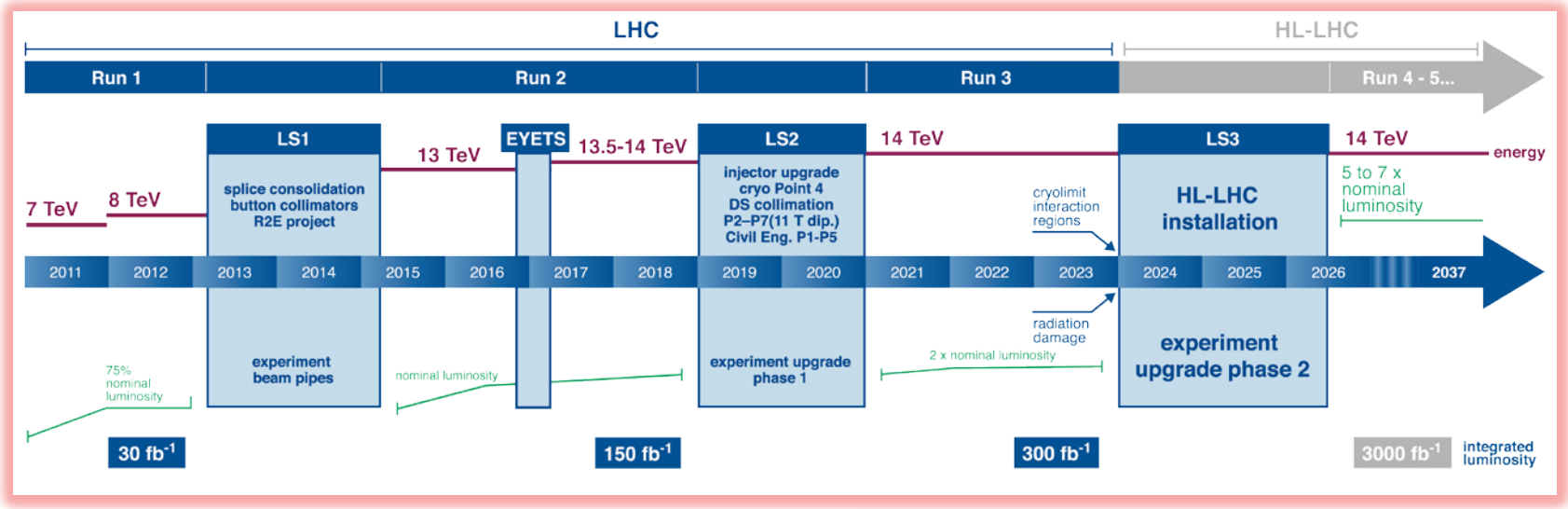


Upgrade Plans





LHC and ATLAS Upgrade Roadmap



- Detector challenges:
  - 10 times more radiation (~ 10^{16} neq/cm^2 ; 10 MGy)
  - 10 times more pile-up:
    - Run-1
    - HL-LHC

x 10 ($\langle\mu\rangle$=20 ; $\langle n_{PU\ jets\ pT>30GeV}\rangle$ ~ 0.04 ; $\langle\mu\rangle$=200 ; $\langle n_{PU\ jets\ pT>30GeV}\rangle$ ~ 7.4) x 185

Upgrade goal:

- Keep performance (tracking, b-tag, jet/E_T^{miss},...)
- Trigger rates acceptable with low PT thresholds
- Pile-up mitigation up to large η is needed

Motivations

- Electroweak Symmetry Breaking
  - Higgs precision measurements (coupling and spin-CP quantum numbers)
  - Higgs rare and invisible decays ($H \rightarrow \mu\mu$, $H \rightarrow Z\gamma$,…)
  - Top Yukawa coupling (ttH)
  - Higgs self coupling
- Beyond the Standard Model
  - Higgs sector (search for deviations from SM)
  - Dark matter
  - SUSY
  - Exotics

ATL-PHYS-PUB-2013-003, 2014-007

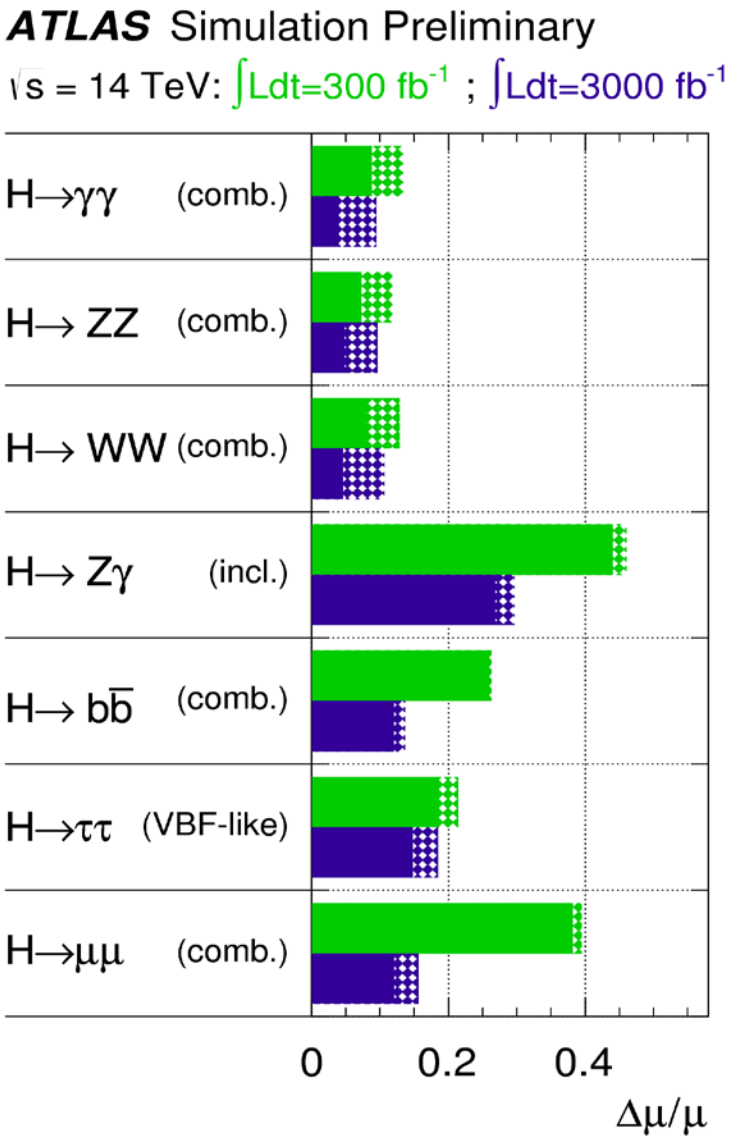
ATLAS Mass reach for Exotic signatures

ATLAS @14 TeV	Z' → ee SSM 95% CL limit	g_{KK} → t t RS 95% CL limit	Dark matter M* 5σ discovery
300 fb^{-1}	6.5 TeV	4.3 TeV	2.2 TeV
3000 fb^{-1}	7.8 TeV	6.7 TeV	2.6 TeV

ATL-PHYS-PUB-2014-010 , 2013-011, 2015-032

ATLAS Mass reach for SUSY particles

ATLAS projection	gluino mass	squark mass	stop mass	sbottom mass	χ_1^+ mass WZ mode	χ_1^+ mass WH mode
300 fb^{-1}	2.0 TeV	2.6 TeV	1.0 TeV	1.1 TeV	560 GeV	None
3000 fb^{-1}	2.4 TeV	3.1 TeV	1.2 TeV	1.3 TeV	820 GeV	650 GeV



ATLAS Phase 1 Upgrades (2019-2020)

Fast Track Trigger (FTK) (ATLAS-TDR-021-2013)
HW based tracking of Si-tracking layers at "Level 1.5"
Status/Plans:
- 2016: Commissioning
- 2017: Full coverage operation (already in Run-2)

Muons: New Small Wheel (NSW)
(ATLAS-TDR-020-2013)
sTGC + MicroMegas (trigger & precise tracking)
Status/Plans:
- Now: Modules 0 construction in various sites
- 2016: Final Design Review and PRR for all sites
- 2017/2018: Production
- 2019: Installation

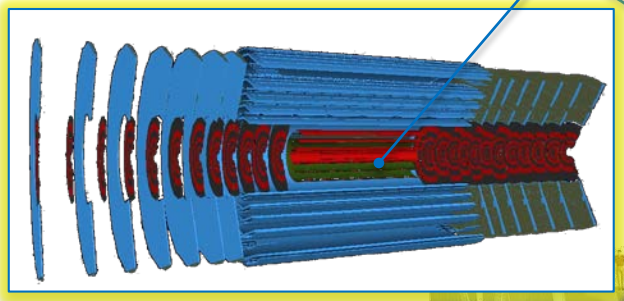
High Granular L1 Calorimeter Trigger
(ATLAS-TDR-022-2013)
Status/Plans:
- 2014: Installed FE demonstrator
- 2015: Successful data taking
- On-going: FE-BE prototype and production
- 2019: Installation

Trigger/DAQ Phase 1 Upgrade (ATLAS-TDR-023-2013)
- **L1Calo:** improved lepton triggering, feature extractors for e/γ, jets, MET...
- **L1Muon:** new/improved sector logic (and information to central trigger), NSW

Main Target:

- Better trigger capabilities (efficiency, fake rejection)
- Maintain same acceptance/p_T thresholds with higher pileup.

ATLAS Phase 2 Upgrades (HL-LHC 2024-2026)



ITK Inner Tracker
- Pixel + Strip
- |η| <2.7 → |η|<4.0*

Muons:
- Inner Barrel Layer (thin-gap RPC + μMDT)
- New electronics
- Muon Tag |η| <2.7 → |η|<4.0*

Trigger & DAQ
- L0 (Calo+Muon): 1 MHz
- L1 (Calo+Muon+ITK): 400 KHz
- HLT/EF: 10 KHz

Calorimeters
- FE, BE Electronics LAr/Tilecal
- sFCAL w/ better granularity*
- HGTD Timing Detector 2.5<|η|<5*

Large eta scenarios (part of the reference detector layout)*

ATLAS References:

- Phase II LoI CERN-LHCC-2012-022
- Scoping doc. CERN-LHCC-2015-020 (Impact of different cost scenarios on physics/perf.)
- All Initial Design Reports-IDRs until end 2016 → Technical Design Reports-TDRs until end 2017

Conclusions

- The LHC has gone beyond its design and is now in full production phase
- ATLAS Enhanced detectors and trigger systems working very well
  - ATLAS coping well with pileup levels approaching twice design
- Wealth of measurements already from 13 TeV data
  - Simple and complex final-states
  - Inclusive cross-sections to multi-boson, top, b-physics
  - Starting precise measurements of H(125) at 13 TeV
- Exploring the 2016 data in many topologies
  - Many complex searches with multiple signal regions probed
  - No significant excesses yet, though some ~2-3σ effects – more data will tell if they will remain
- Huge thanks to the LHC and injector teams for the excellent performance
- An intense program of upgrade will allow ATLAS to run at its best as LHC and HL-LHC will deliver up to 3000 fb^{-1} of luminosity

More results in the several ATLAS and ATLAS+CMS talks in the coming days

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Thank You!