ATLAS Physics Prospects at the High-Luminosity LHC

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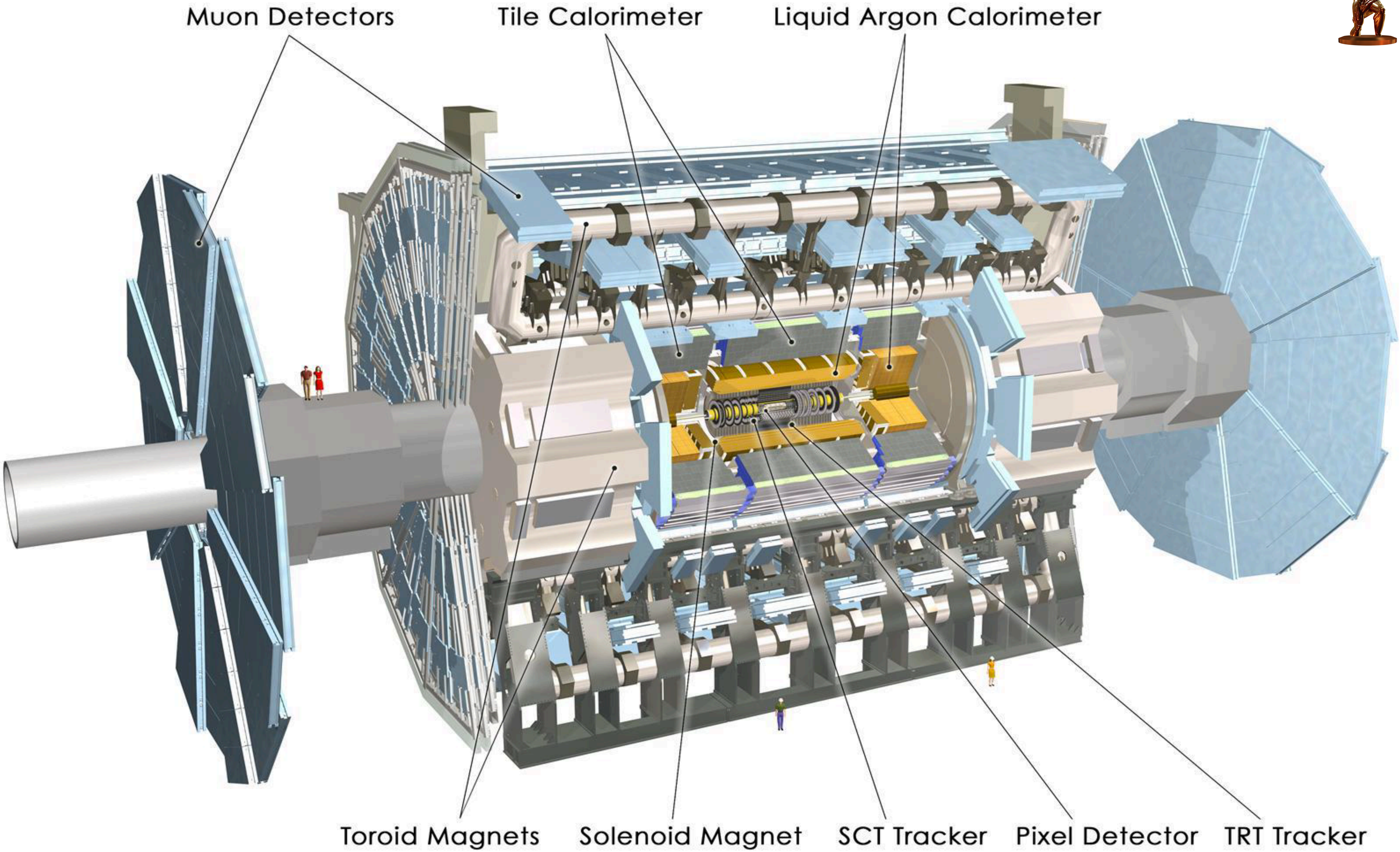
On behalf of the ATLAS Collaboration

ICNFP 2017 – Kolymbari, Greece; 24th August 2017

Outline

- The current ATLAS Detector performance
- The HL-LHC and Phase2 ATLAS detector upgrade and performance
- The ATLAS Physics Upgrade program
- Physics prospects at HL-LHC
- Conclusions and outlook

The ATLAS Detector



LHC and ATLAS Performance

Great performance for LHC in 2016:

- **~ 1.4x10^{34}cm^{-2}s^{-1}** record of inst. Lumi.
- **~ 40 fb^{-1}** Lumi. delivered

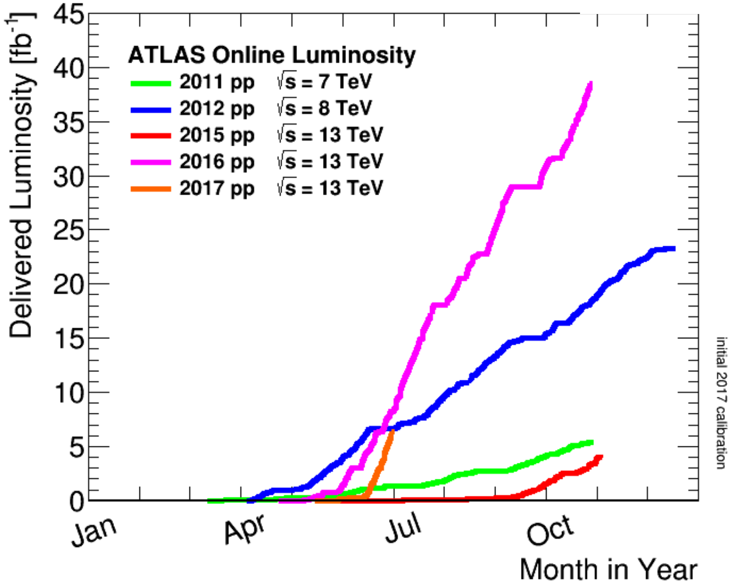
ATLAS 2016 p-p run conditions :

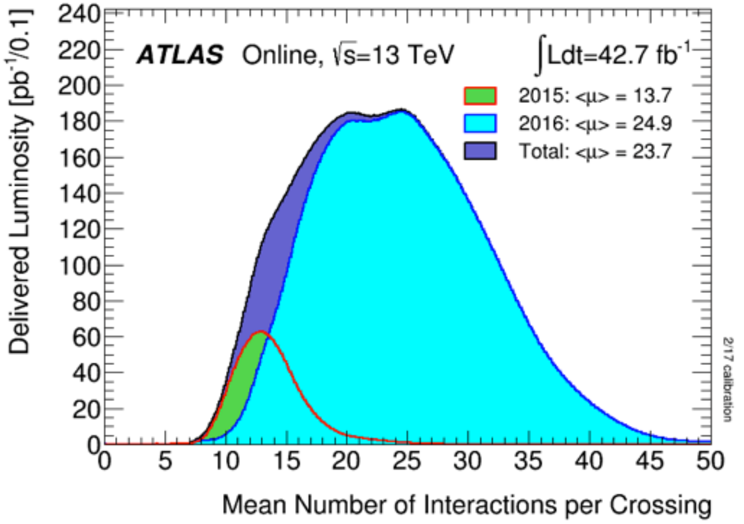
- good data taking efficiency ➔ **~ 93%**
- good data quality ➔ **> 96% work. channels**
- most of Run-2 results with combined 2015+2016 dataset: **36.1 fb-1**
- average (maximum) # interactions per bunch crossing a.k.a. **pile-up of ~ 25 (45)**

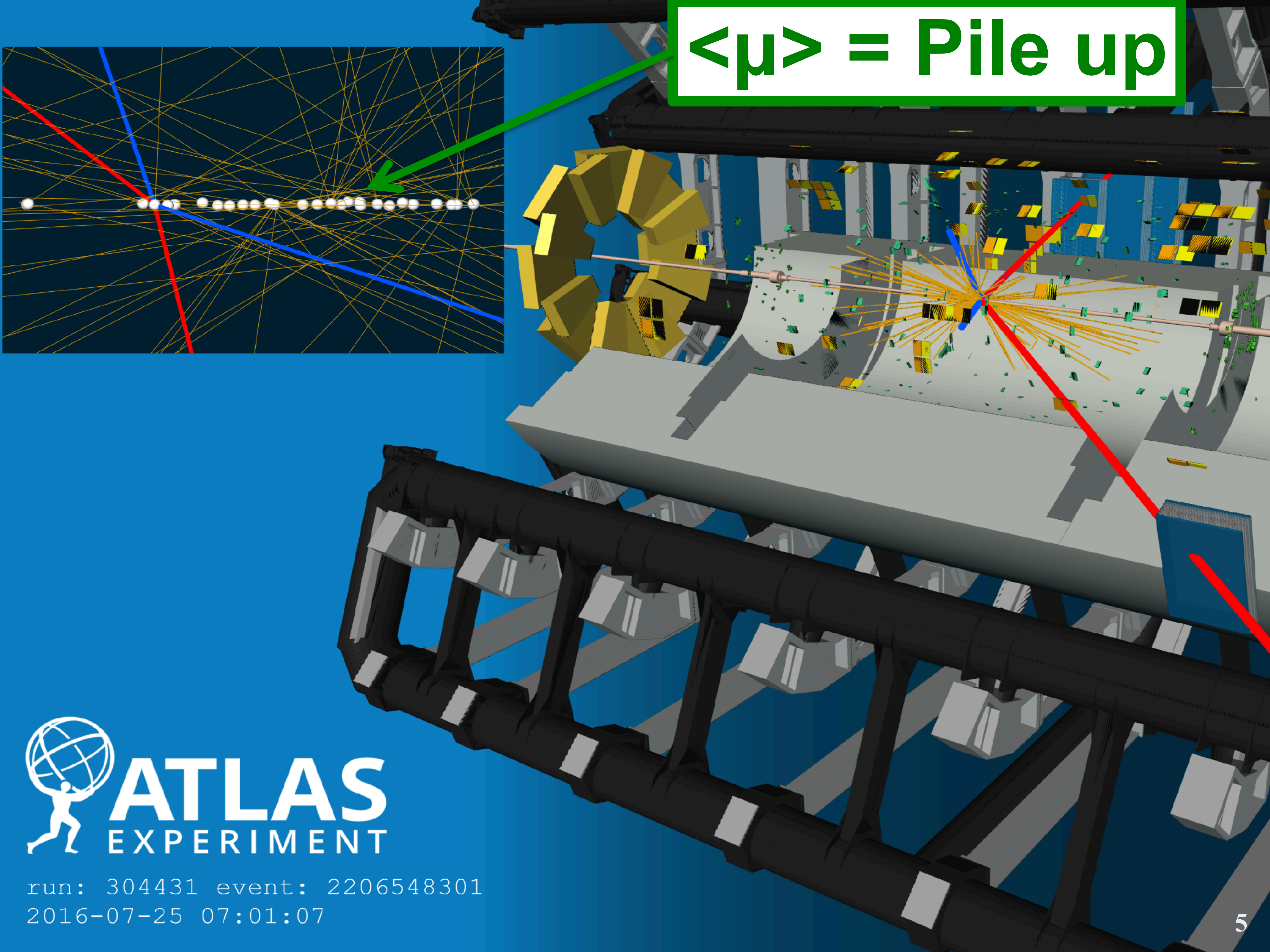
2017 p-p run conditions:

- ~ **1.7x10^{34} cm^{-2} s^{-1}** new record of inst. Lumi
- **maximum pile up of ~ 47**

➔ So far the detector is coping well with it!

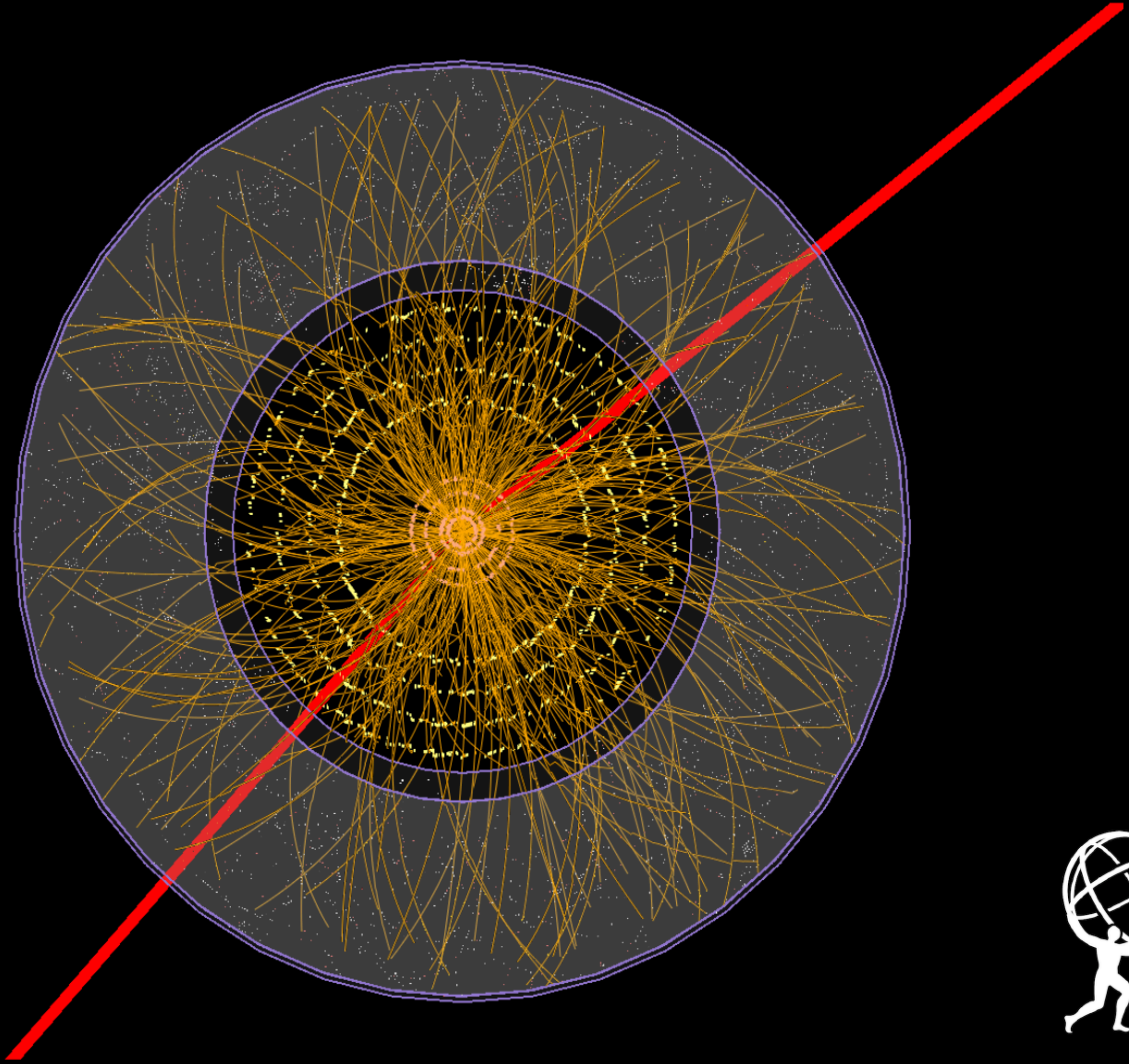






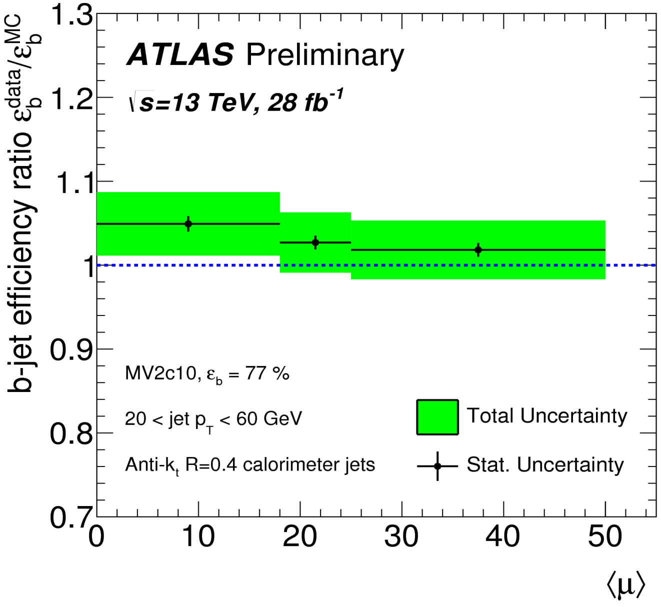
<μ> = Pile up

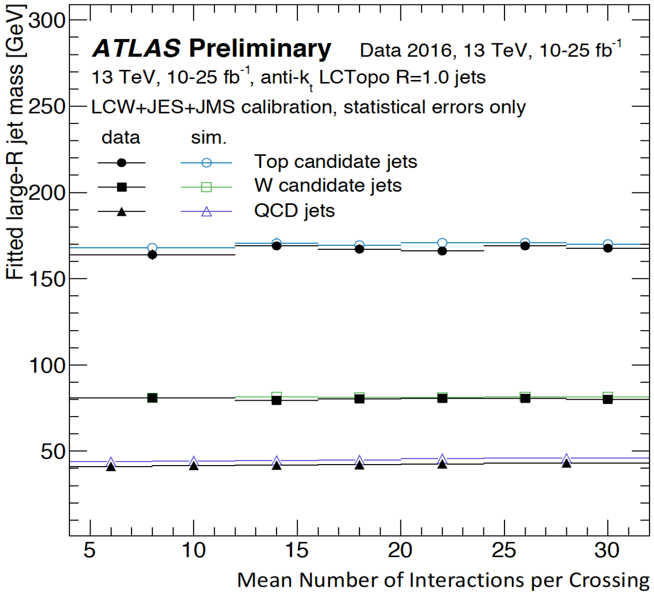
run: 304431 event: 2206548301
2016-07-25 07:01:07



Run: 267638
Event: 242090708
2015-06-14 01:01:14 CEST

ATLAS Detector performance





Pile-up stability

- b-tagging efficiency robust against <μ>
- Stable mass of jets coming from products of highly energetic W bosons and top quarks.

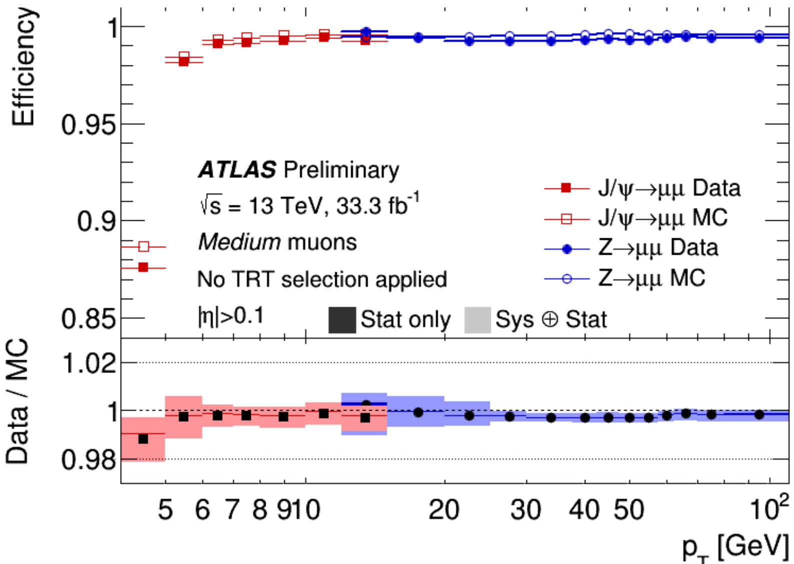
ATLAS Detector performance/2

- Stable muon reconstruction efficiency for a wide range of the muon p_T
- Jet Energy Scale calibration over 2 order of magnitude of the jet p_T

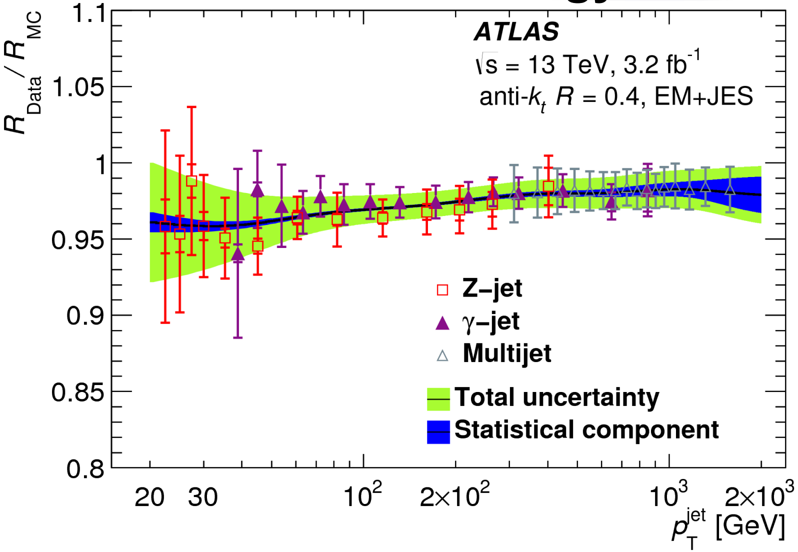
See L. Bellagamba talk for Physics highlights from 2016-2017

Many other ATLAS talks describing the actual detector performance….

Muon Reconstruction Efficiency

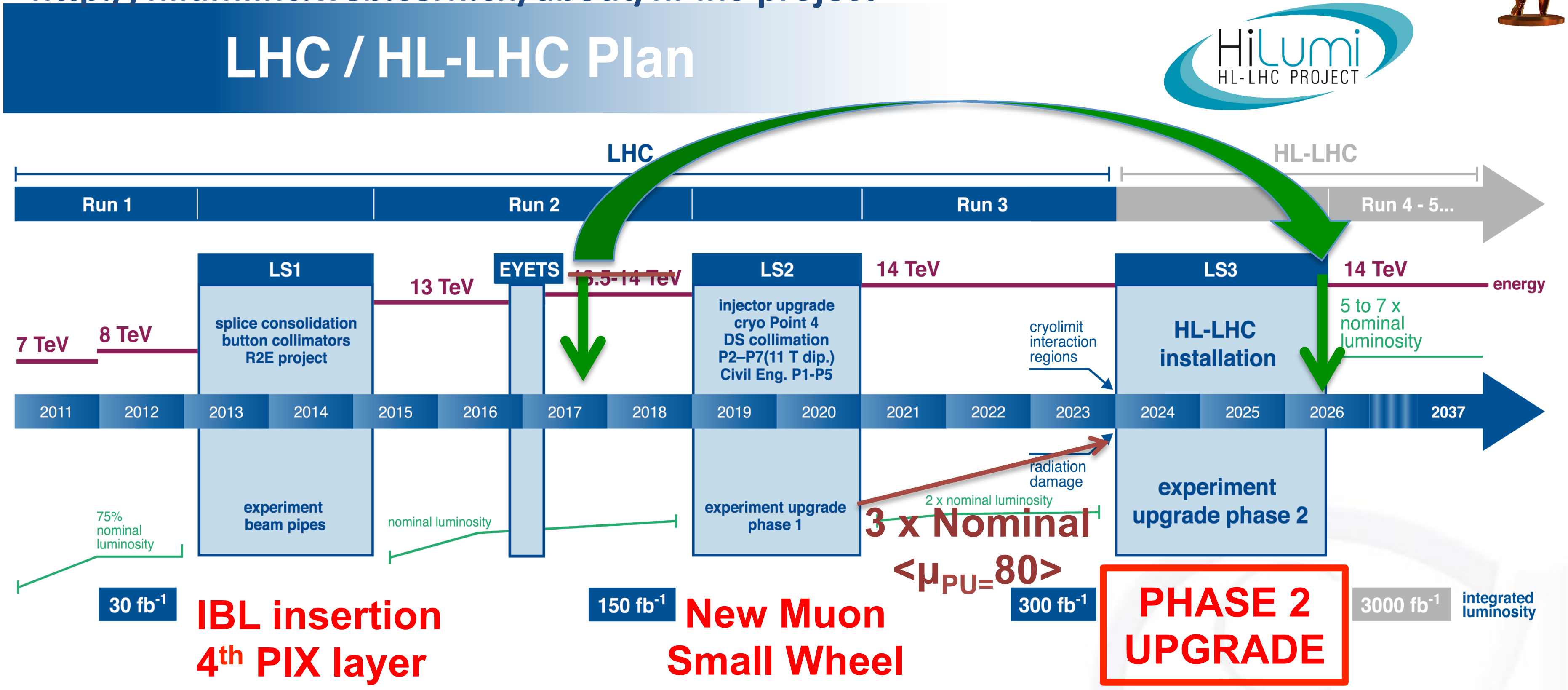


Jet Energy Scale



HL-LHC program

http://hilumilhc.web.cern.ch/about/hl-lhc-project



LHC / HL-LHC Plan

IBL insertion
4th PIX layer

New Muon Small Wheel

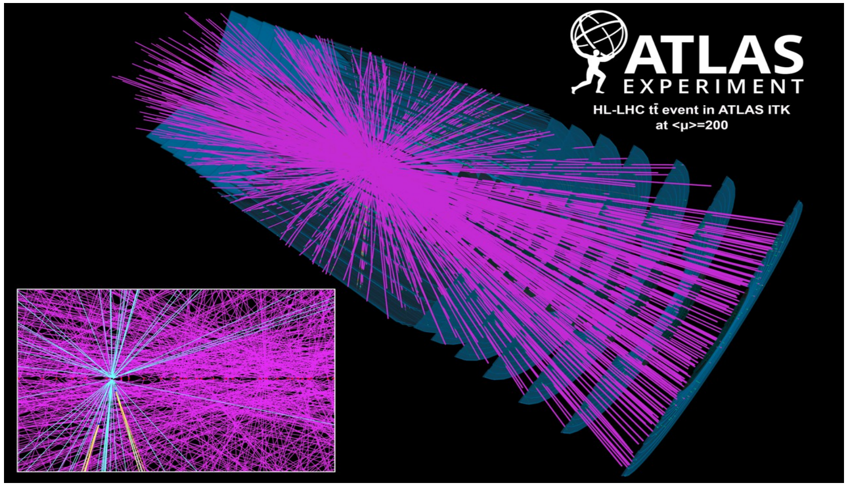
3 x Nominal
$\langle\mu_{PU}=80\rangle$

PHASE 2 UPGRADE

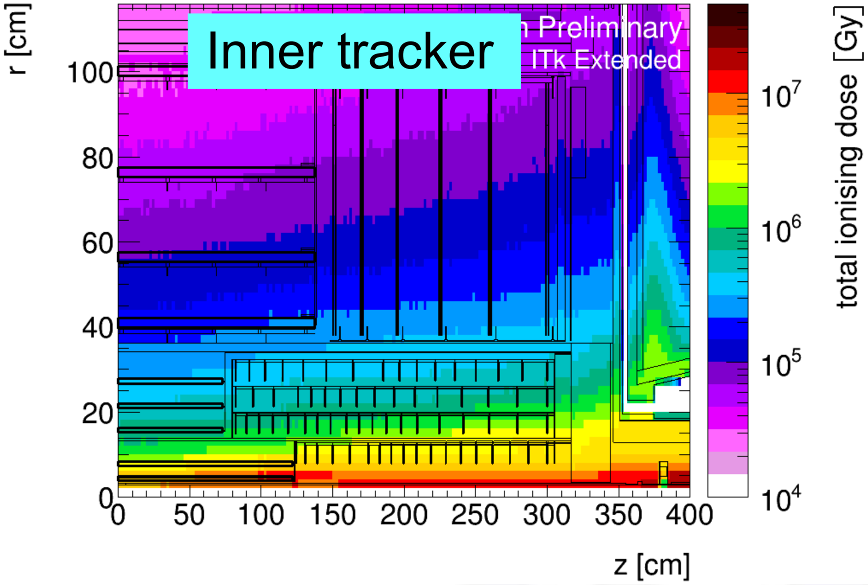
HL-LHC mode	Peak Luminosity ($cm^{-2}\,s^{-1}$)	Mean number of interactions per bunch-crossing $\langle\mu_{PU}\rangle$	Integrated luminosity (fb^{-1})
Baseline	5×10^{34}	**140**	**3000**
Ultimate	7.5×10^{34}	**200**	4000

ATLAS Expected Conditions @ HL-LHC

High particle density



High integrated radiation dose



Detector requirements to maximize benefits from high integrated luminosity:

- Withstand the radiation damage.
- Cope with higher bandwidth/trigger rate.
- Minimize pile-up effect (high granularity, fast timing).

➔ **Improve or maintain** current detector performance with harsher conditions!

ATLAS Detector Upgrade (2024-2026)

ATLAS Phase II upgrade scoping document foresees various upgrade scenarios: *CERN-LHCC-2015-020*

➔ maximize the physics performance and discovery potential of ATLAS

➔ **Physics targets: precision measurements/rare decays/beyond SM.**

ITK: New Inner detector, fully Silicon (strip and pixel) up to |η| = 4

- **STRIP** detector released the TDR earlier in 2017
- **PIXEL** system will do it by the end of 2017.

LAr Calorimeter: New Barrel electronics.

Tile Calorimeter: New electronics.

Muons: New Inner Muon barrel trigger chambers

- **MUON** TDR submitted in June 2017.

Trigger/DAQ: Longer latency system, use of tracking information.

- **TDAQ** TDR expected by the end of 2017.

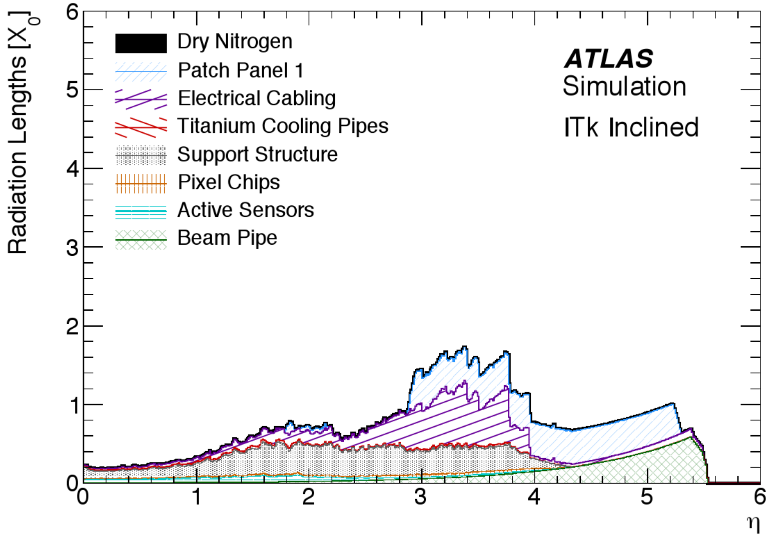
Other options under discussion:

- **Timing detectors (HGTD)** ➔ pile-up mitigation for trigger and offline
- **Forward muon tagger** ➔ gain in acceptance not negligible in some analysis

ATLAS Detector Upgrade (ITK)

- Larger radii than present silicon tracker
- Larger coverage in the forward region

  ➔ **coverage up to |η| = 4**
- Minimize amount of inactive material (2-3 x less than current tracker)
- Optimized for high and robust tracking efficiency, track parameter resolutions, two-track separation, while minimizing fake tracks.

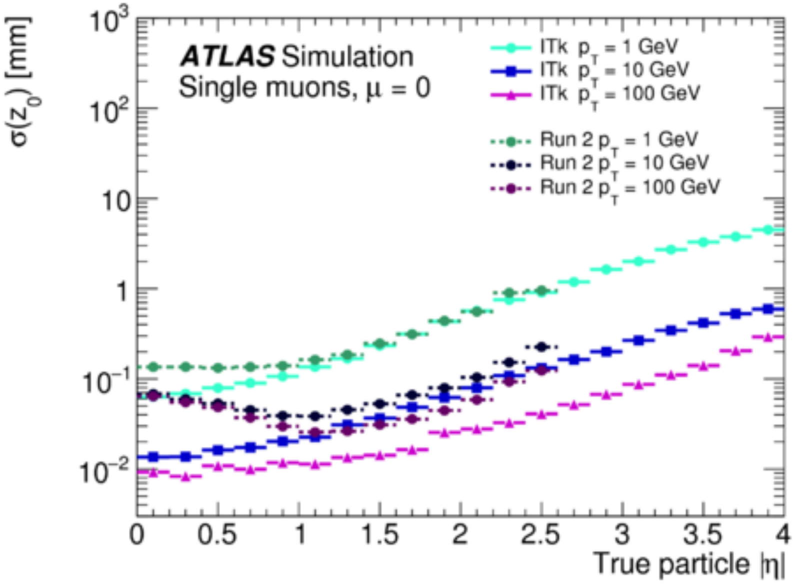


ATLAS-TDR-025

Resolution of z_0 impact parameter of tracks:

- crucial to assign tracks to the primary vtx
- better resolution wrt to Run2 inner tracker due to reduced material budget
- deterioration at large |η| due to increased material crossed.

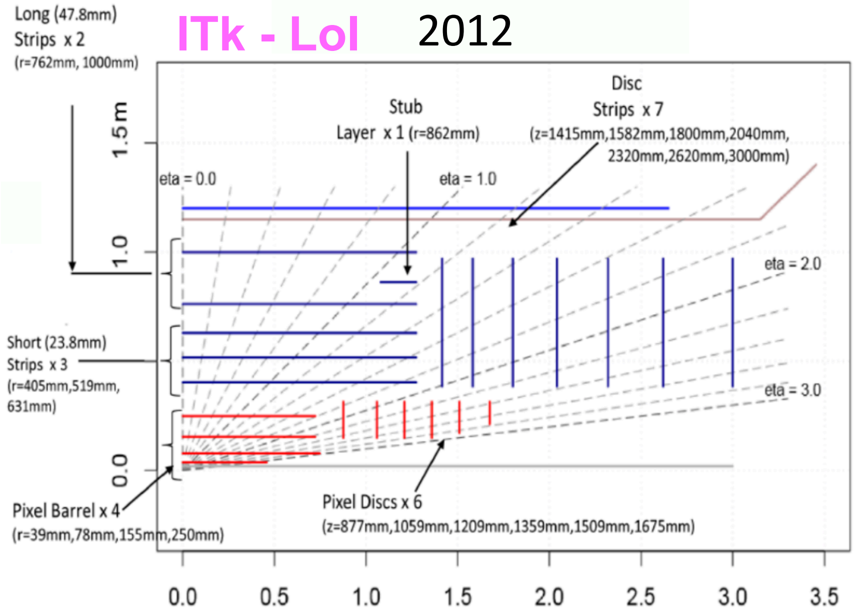
→ Different layout/implementation possibilities still being evaluated since they will impact the physics potential!



ITK Layout options

Letter-of-Intent Layout
(rapidity coverage up to |η|=2.7)
One quadrant of the layout in r-z shown

ITk - LoI 2012

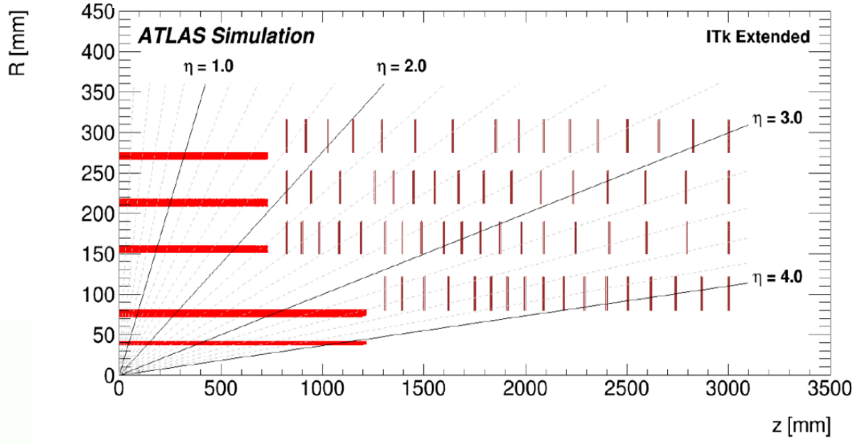


Recently, two layouts considered for Pixel:

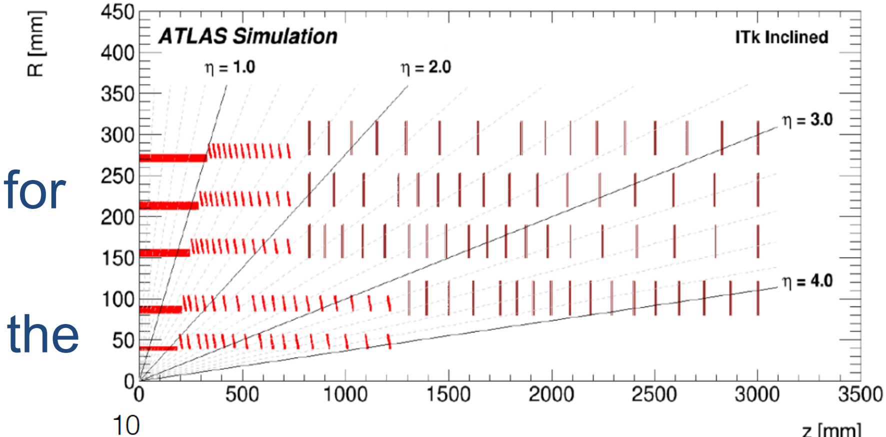
- ITk-Extended layout: uses a long barrel for the two inner-most layers
- ITk-Inclined layout: uses rings to incline the forward-most modules in the barrels (used in **Strip TDR - 2017**)

rapidity coverage up to |η|=4.0

ITk - Extended 2013-2014



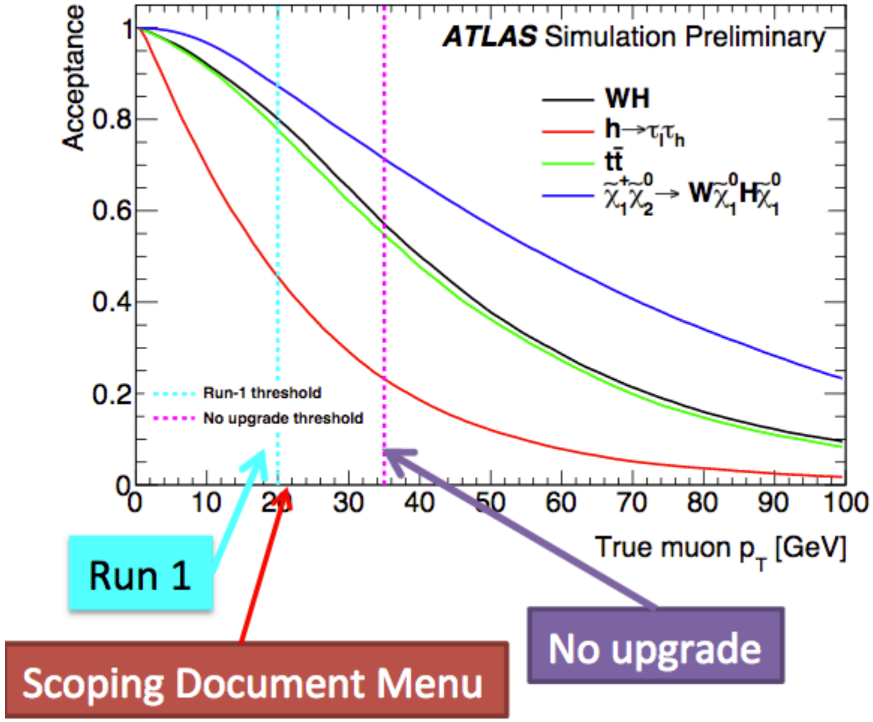
ITk - Inclined 2015-2016



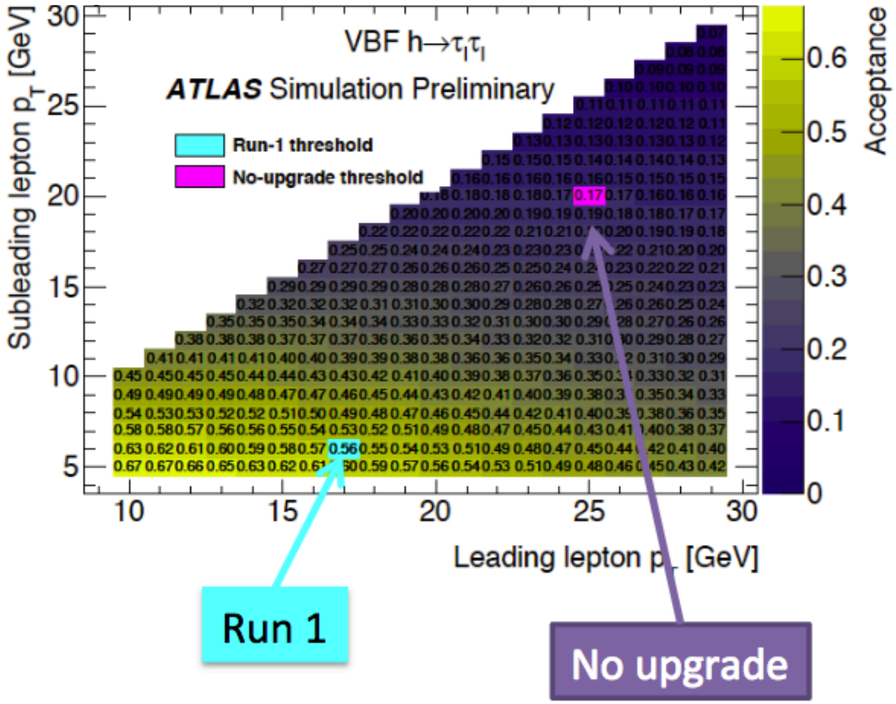
See S. Swift talk for tracking beyond Run 2

Physics motivations for Phase II-Trigger upgrade

Impact of muon threshold



Impact of τ threshold on VBF H→ ττ



- Interesting physics signals have low pT leptons
- Need to increase bandwidth at first trigger stage to access relevant signatures under HL-LHC conditions.

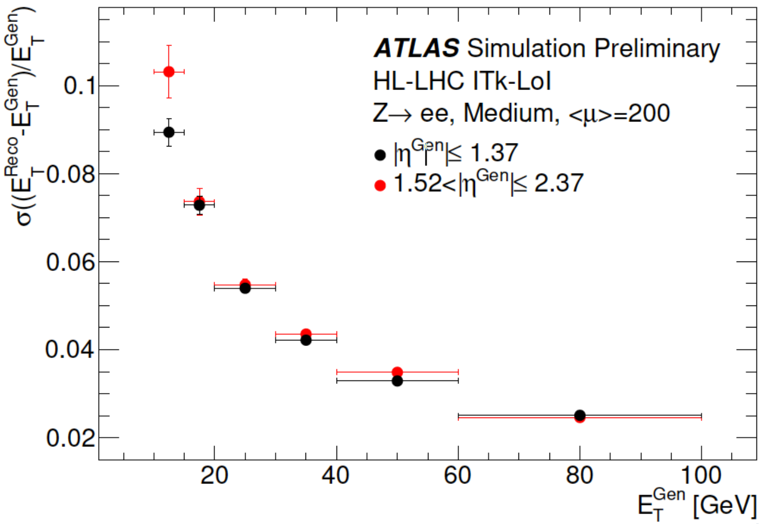
  ➔ **Hw track trigger essential**; feeds from Muon Drift chambers, Strip and outer Pixel Layers is foreseen.

Upgrade expected performances

ATL-PHYS-PUB-2016-026

Electron energy resolution

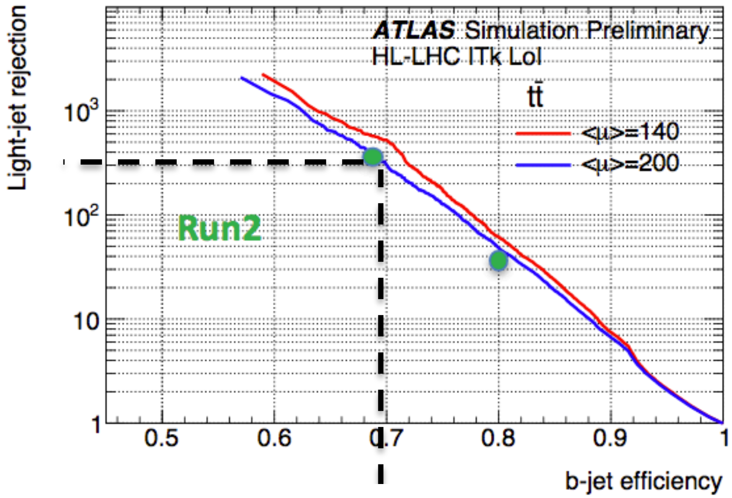
ITk - LoI



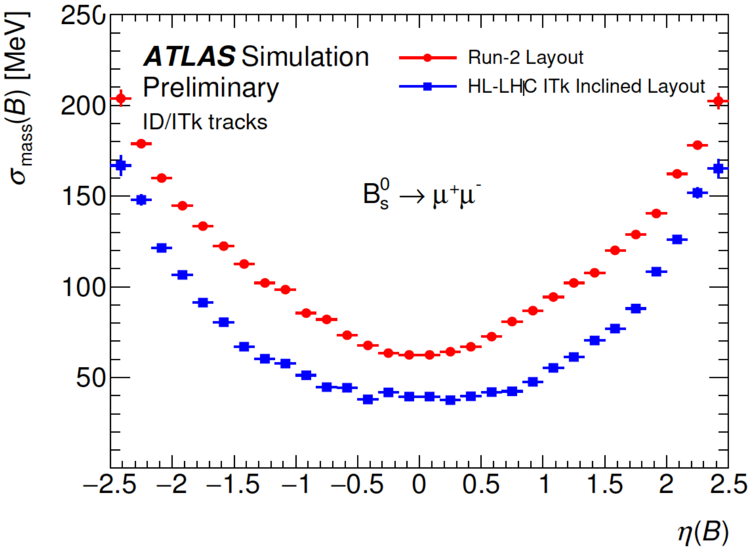
- Electrons energy resolution not affected by pileup:
  - electron calibration not re-tuned for high pileup samples (same as Run 2).
- For 70% b-jet efficiency (with MV1 tagger):
  - light jet rejection of ~380 with <mu> = 200 (same as best optimized Run-2 b-tagger).
- Muon with P_T < 200 GeV benefit from ITK momentum resolution:
  - B_s^0 mass resolution ($B_s^0 \rightarrow \mu+ \mu-$) will improve by ~1.65 (1.5) in the barrel (end-cap) region

B-tagging performance

ITk - LoI



ITk - Inclined

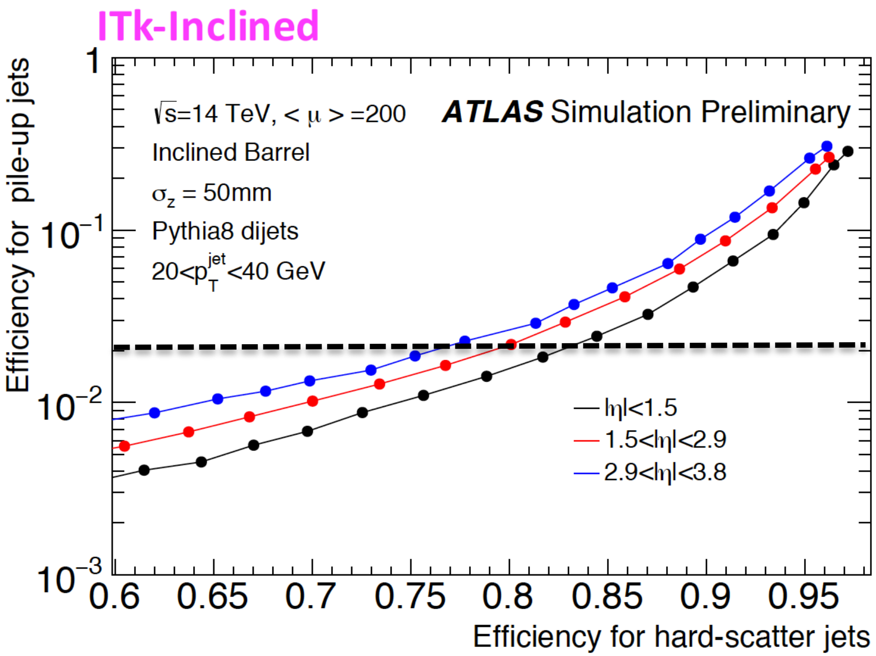


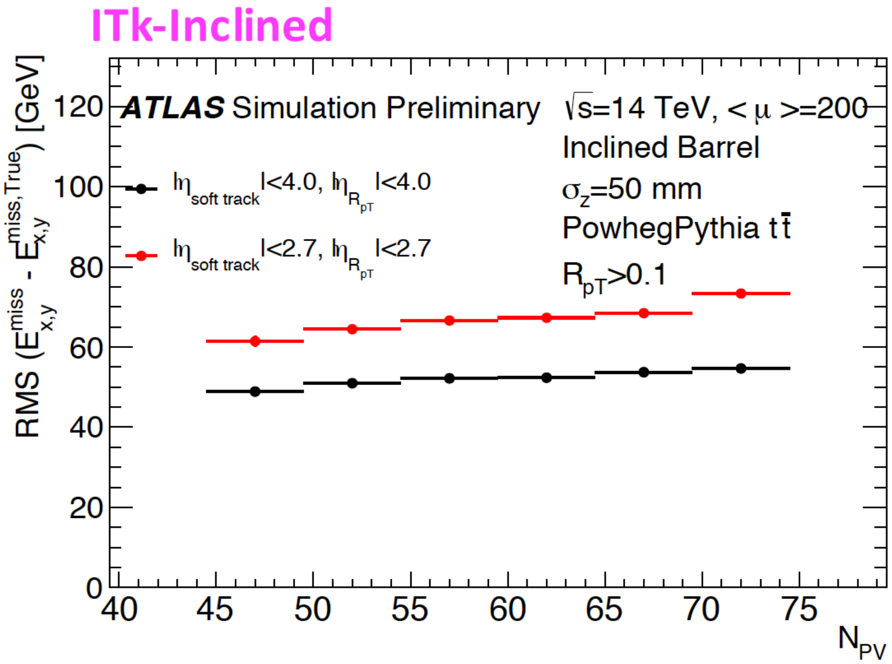
Tracking for Pileup suppression in Jet and MET

- Powerful pile-up jets rejection using jet vertex tagging discriminant   RpT = ΣpTtrk (PV0)/ pT jet
  also in the forward region with new tracker layouts
- With $<\mu_{PU}> = 200$, expected ~5 pileup jets per event
  Analyses typically use factor 50 rejection

➔2% pile-up survival probability for 75/80/85% hard-scat. jet efficiency (η dep.)

➔improved Missing ET resolution via the suppression of forward pileup jets





Physic prospects at HL-LHC

Analysis strategies

Higgs analysis prospects:

- Self-boson and Higgs boson coupling
- Higgs rare decays

SUSY analysis prospects:

- stau direct production
- chargino and neutralino direct production

Search for new heavy bosons/dark matter candidates

Anomalous top decays

ATLAS HL-LHC Analysis Strategy

ATLAS HL-LHC studies have been performed using:

- **Upgraded ATLAS detector and trigger systems**
- **$\sqrt{s}$ = 14 TeV**
- **$\langle \mu_{PU} \rangle$ = 140 or 200**

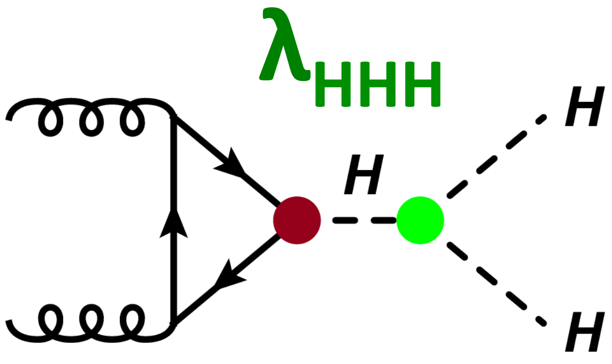
Only truth-level MC information was generated for all samples since a full simulated MC campaign (including digitization and reconstruction) was too costly.

'**Upgrade Performance Functions**', developed using limited samples of full simulated MC that used ATLAS HL-LHC geometry, includes:

- resolutions (for smearing functions)
- reconstruction and trigger efficiency (including fake rates)
- pile-up jets for not hard-scatter truth events.

Analysis are then performed on the smeared truth MC samples.

Higgs self-coupling



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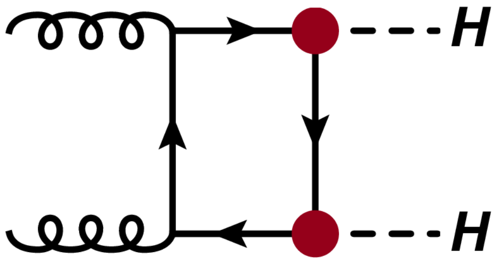
Destructive interference



- First opportunity to measure Higgs boson trilinear self-coupling λ_{HHH}
  ➔ strictly connected to the form of the Higgs potential.
- SM di-Higgs gives us access to λ^{SM}_{HHH}
  ➔ deviation of $\lambda_{HHH} / \lambda^{SM}_{HHH}$ from 1 would suggest new physics!
- SM di-Higgs production (~40 fb), mainly g-g fusion
  - three orders of magnitude smaller than single Higgs production (48 pb)

Decay channel	Branching ratio (%)	σ.Br (fb)
$b\bar{b}+b\bar{b}$	33	12.9
$b\bar{b}+W^+W^-$	25	9.9
$b\bar{b}+\tau^+\tau^-$	7.4	2.9
$W^+W^-+\tau^+\tau^-$	5.4	2.1
$ZZ+b\bar{b}$	3.1	1.2
$ZZ+W^+W^-$	1.2	0.48
$b\bar{b}+\gamma\gamma$	0.3	0.12
$\gamma\gamma+\gamma\gamma$	0.001	0.04

Signal Strength

$\mu = \sigma^{HH}/\sigma^{HH}_{SM}$

Higgs self-coupling

$HH \rightarrow b\bar{b}\, b\bar{b}$

$3000\ \mathrm{fb}^{-1}$, $\langle\mu_{PU}\rangle = 200$, 14 TeV

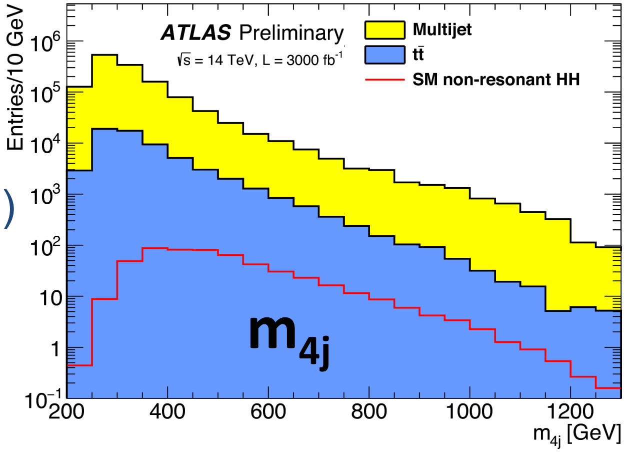
- Extrapolation from 2016 analysis ($10\ \mathrm{fb}^{-1}$), assuming same performance then Run 2.
- Signal Region (SR): 4 tagged b-jet.
- Effect of different trigger jet threshold studied (30 →75)
- Main background: QCD multi-jets (2016 analysis)

Upper limit on μ= 1.5/5.2 (w/o or with 2016 syst.);

it was **57 in Run 1** and **29 in Run 2**

$-0.2\ (-3.5) < \lambda_{HHH} / \lambda^{SM}_{HHH} < 7\ (11)$ 95% C.L., no syst. (2016 syst.)

ATL-PHYS-PUB-2016-024



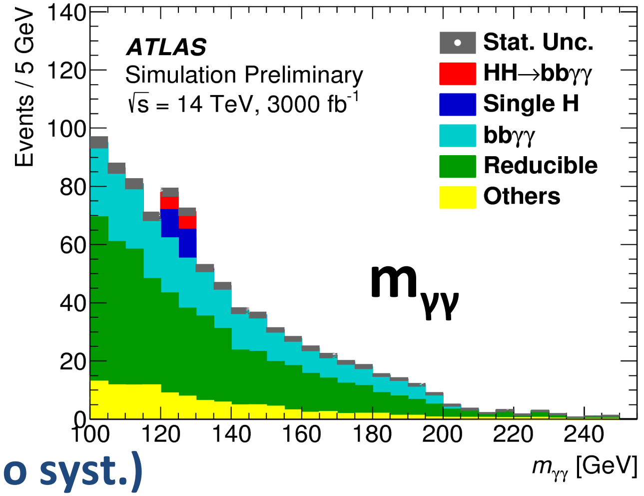
$HH \rightarrow b\bar{b}\,\gamma\gamma$

- Photon performance based on upgraded Scoping Document.
- Most recent ITK layout for b-tagging.
- Main background: multi-jets + photons

Significance: 1.052 σ (no syst.)

Self-coupling constraint: $-0.8 < \lambda_{HHH}/\lambda_{SM} < 7.7$ (95% C.L. , no syst.)

ATL-PHYS-PUB-2017-001



Higgs self-coupling

$3000\ \text{fb}^{-1}$, 14 TeV

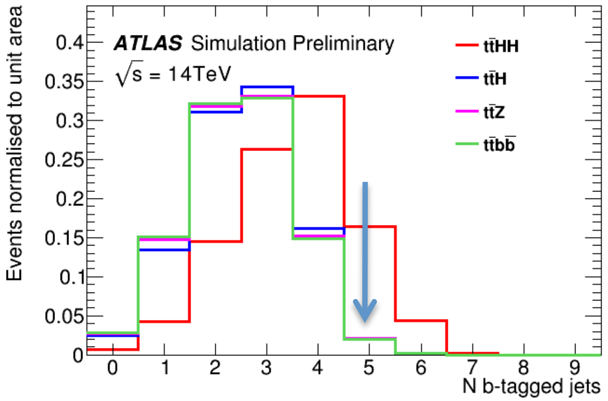
$t\bar{t}HH \to WbWb\ b\bar{b}b\bar{b}$ *with* $\langle\mu_{PU}\rangle = 200$

- $\sigma(t\bar{t}HH) \sim 1$ fb
- Final State: $HH \to b\bar{b}b\bar{b}\ t\bar{t} \to b\bar{b}l\nu qq$
- SR(≥5 b jets): background from c-jets mis-tagged as b-jets from $W \to cs$

Significance: ~ 0.35 σ (no syst.)

➔ small contribution to HH production

ATL-PHYS-PUB-2016-023



$HH \to b\bar{b}\ \tau\tau$ *with* $\langle\mu_{PU}\rangle = 140$

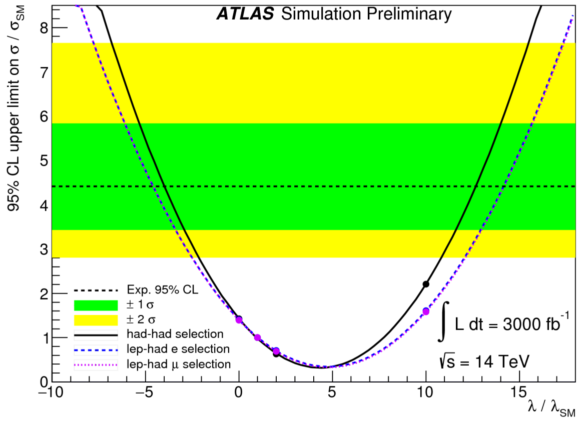
- All τ decays combination used but not $\tau_{lep}\tau_{lep}$
- Different triggers for the channels $\tau_{had}\tau_{hah}$ and $\tau_{had}\tau_{lep}$
- Constraints on $m(b\bar{b})$ $m(\tau\tau)$, 2% on lumi, 3% on Bck.
- Combining channels yields:

Significance: ~ 0.60 σ (syst.) **$\mu = 4.3$**

$-4 < \lambda_{HHH}/\lambda_{SM} < 12$ (95% C.L. with syst.)

ATL-PHYS-PUB-2015-046

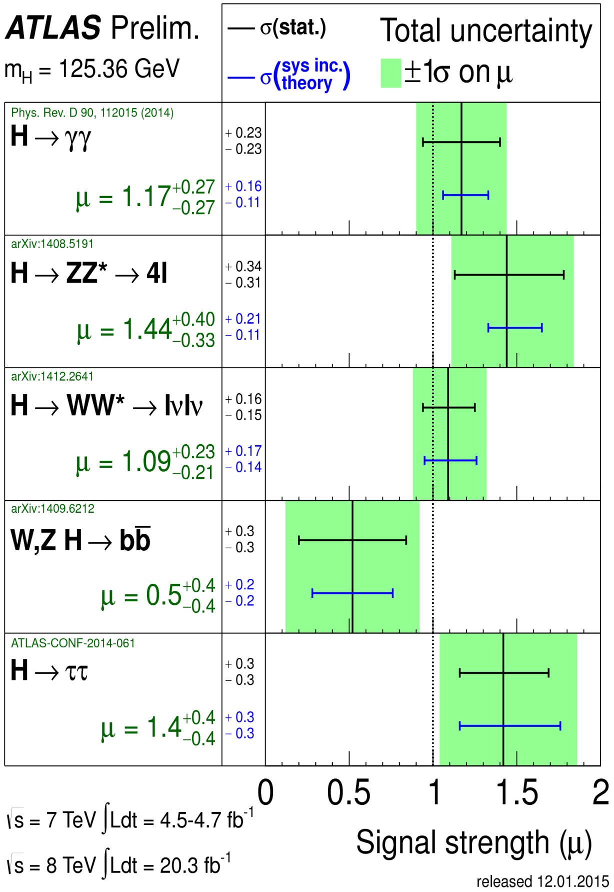
σ / σ_{SM} as a function of λ / λ_{SM}



Higgs couplings

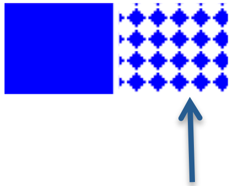
Extrapolation from Run-1 analysis at **$<\mu_{PU}> = 140$**

ATL-PHYS-PUB-2014-016

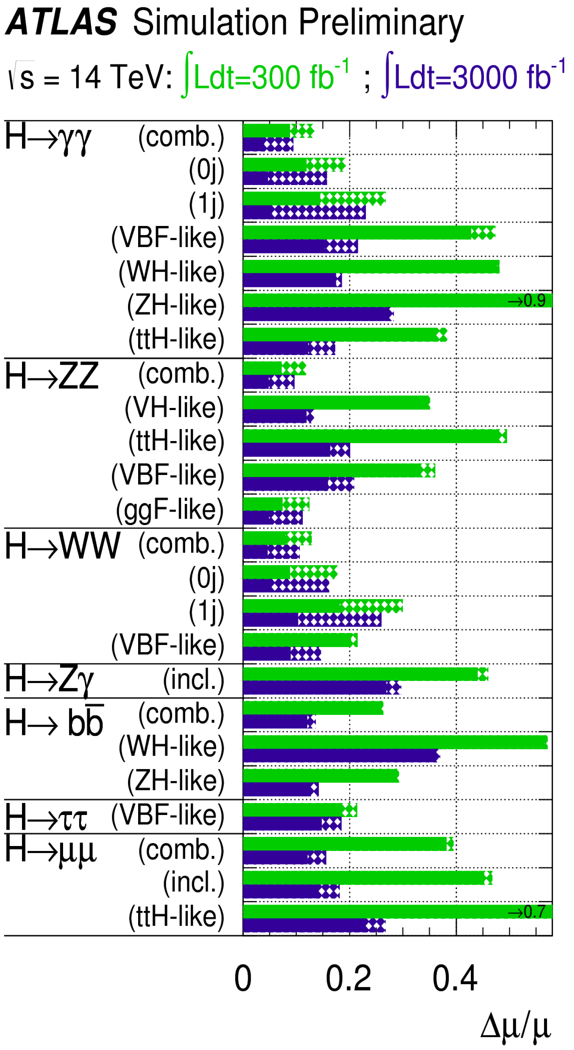


Signal Strength
$\mu = \sigma/\sigma_{SM}$

Projected accuracy of Higgs production rate measurements

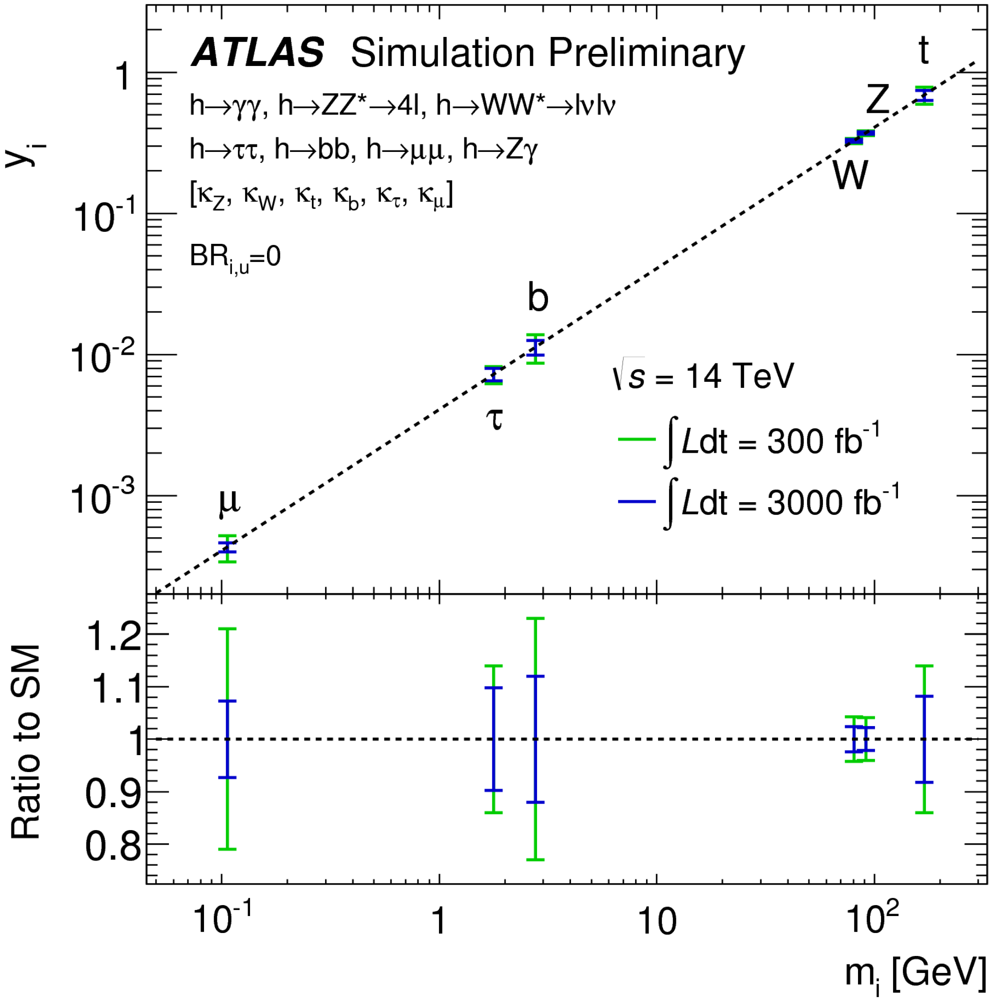


Theo. uncertainty



Higgs couplings

Couplings relative to the SM values with_(3000 fb^{-1})



W, Z couplings ~3%

μ coupling ~7%

t,b,τ couplings 8-12%

Higgs rare decays

3000 fb^{-1}, $\langle\mu_{PU}\rangle = 140$, 14 TeV

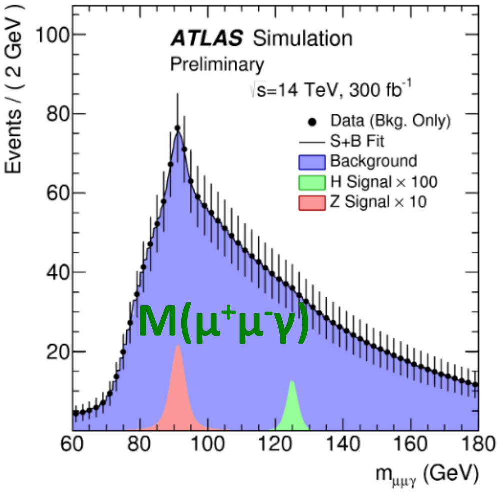
ATL-PHYS-PUB-2015-043

$H \rightarrow J/\Psi(\rightarrow\mu^+\mu^-)\,\gamma$ (probe Higgs coupling to c-quark)

- Run-1 detector performances
- Multivariate analysis : $p_T(\gamma)$, $p_T(\mu^+\mu^-)$, $\mu^+\mu^-$ -and γ-isolation
- Select mass window m($\mu^+\mu^-\gamma$) in 115-135 GeV

BR (H → J/Ψ (->μμ) γ): 44$^{+19}_{-22}$ x 10^{-6} (95% C.L.) (no syst.)

SM Calculation: 2.9 ±0.2 x 10^{-6} (Run-1 Limit: 1.5 x10^{-3})



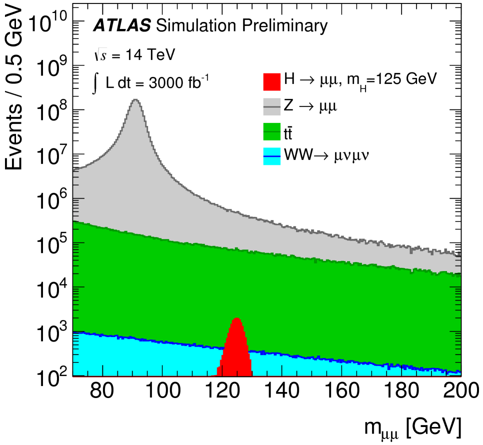
ATL-PHYS-PUB-2013-014

$H \rightarrow \mu^+\,\mu^-$

- Low BR, high Z/γ* background, high mass resolution
- Analysis based on Run-1 with cut optimization
- Total background shape and normalization data-driven
- Select mass window: $m_{\mu+\mu-}$ 122-128 GeV

Significance: 2.3 σ (300 fb^{-1}) 7.0 σ (3000 fb^{-1})

Δμ/μ: 46 % (300 fb^{-1}) 21 % (3000 fb^{-1})



SUSY Searches at HL-LHC

- SUSY is one possible extension of the SM:
  - predicts new bosonic/fermionic partner for existing fermion/ bosons
  - lightest SUSY particle is stable (if R-parity conservation)

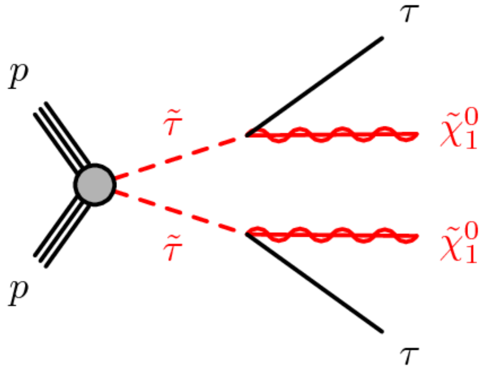
    → **DM candidate**
  - cancel out quadratic divergences in the Higgs mass corrections in case of "light stop"

    → can accommodate the **gauge coupling unification.**
- Minimal SUSY models predicts Higgs mass below 130 GeV
- Focus on HL-LHC benchmark studies:
  - 14 TeV, $<\mu_{PU}> = 200$, total integrated luminosity of 3000 fb^{-1}
  - upgrade ATLAS simulation
  - truth level particle corrected for detector effects

Direct stau pairs production

- Extend the ATLAS exclusion scenario of combined $\tilde{\tau}_L\tilde{\tau}_L$ and $\tilde{\tau}_R\tilde{\tau}_R$ production with $\chi^0{}_1$ massless
- Cut based analysis tau decaying hadronically, large $E_T{}^{Miss}$, low jet activity
- Main background from W+jets and $t\bar{t}$

For stau mass of 200 GeV:
$\sigma(\tilde{\tau}_L\tilde{\tau}_L)$ ~ 0.02 pb ; $\sigma(\tilde{\tau}_R\tilde{\tau}_R)$ ~ 0.01 pb



Exclusion limit ($\tilde{\chi}^0{}_1$ massless):

----- **700** GeV in $\tilde{\tau}$-mass for ($\tilde{\tau}_L\tilde{\tau}_L$ and $\tilde{\tau}_R\tilde{\tau}_R$) combined production

----- **650** GeV for pure $\tilde{\tau}_L\tilde{\tau}_L$

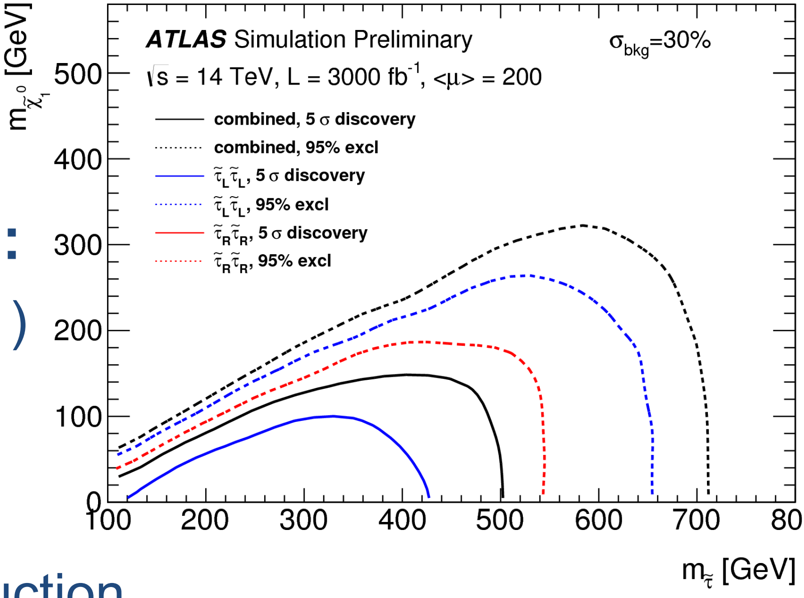
----- **540** GeV for pure $\tilde{\tau}_R\tilde{\tau}_R$

5σ discovery sensitivity ($\tilde{\chi}^0{}_1$ massless):

—— **100-500** GeV in $\tilde{\tau}$-mass for ($\tilde{\tau}_L\tilde{\tau}_L$ and $\tilde{\tau}_R\tilde{\tau}_R$) combined production

—— **120-430** GeV for pure $\tilde{\tau}_L\tilde{\tau}_L$

ATL-PHYS-PUB-2016-021

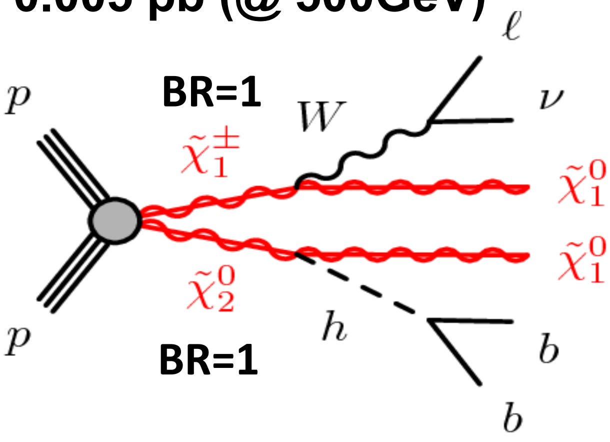


→ No discovery sensitivity for pure $\tilde{\tau}_R\tilde{\tau}_R$ production

Direct chargino/neutralino pair production

- Extend the present ATLAS sensitivity to electro-weakinos mass range O(100 GeV) with $<\mu_{PU}> = 140$
- Simplified model:
  - LSP $\tilde{\chi}_1^0$ **massless**
  - sleptons and sneutrino with high mass, SM Higgs
- Cut based and MVA analysis
- Main background: tt

$\sigma^{NLO}(\tilde{\chi}^\pm_1 \tilde{\chi}^0_2) \sim 0.005$ pb (@ 500GeV)



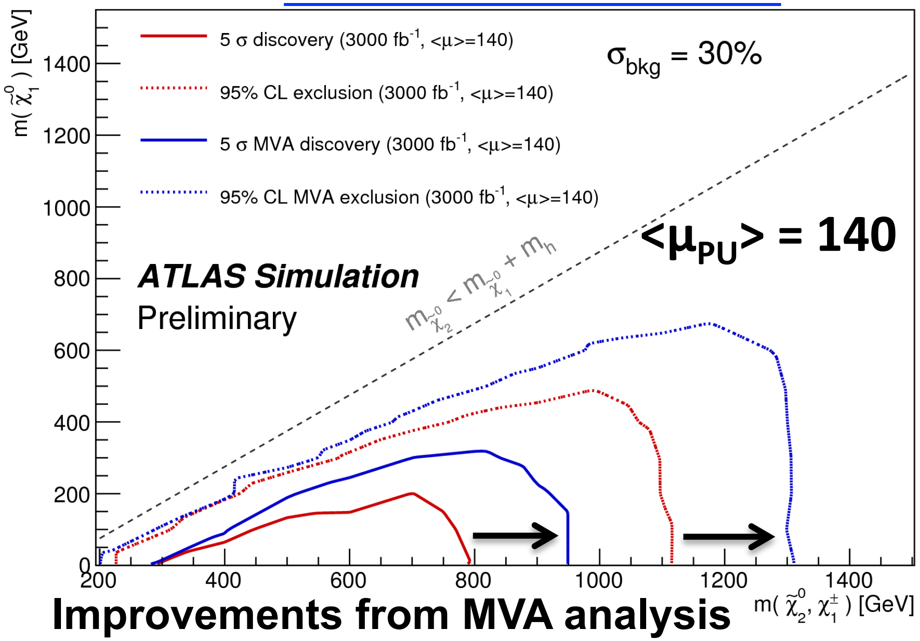
Exclusion limit :

╍╍╍╍ **1310 GeV** in mass $\tilde{\chi}^\pm_1 \tilde{\chi}^0_2$ mass for massless $\tilde{\chi}_1^0$

5σ discovery sensitivity:

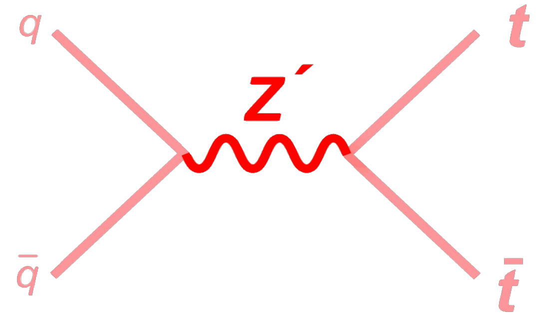
—— **950 GeV** in mass $\tilde{\chi}^\pm_1 \tilde{\chi}^0_2$ mass for massless $\tilde{\chi}_1^0$

ATL-PHYS-PUB-2015-032



Improvements from MVA analysis

New heavy bosons and DM candidates at HL-LHC

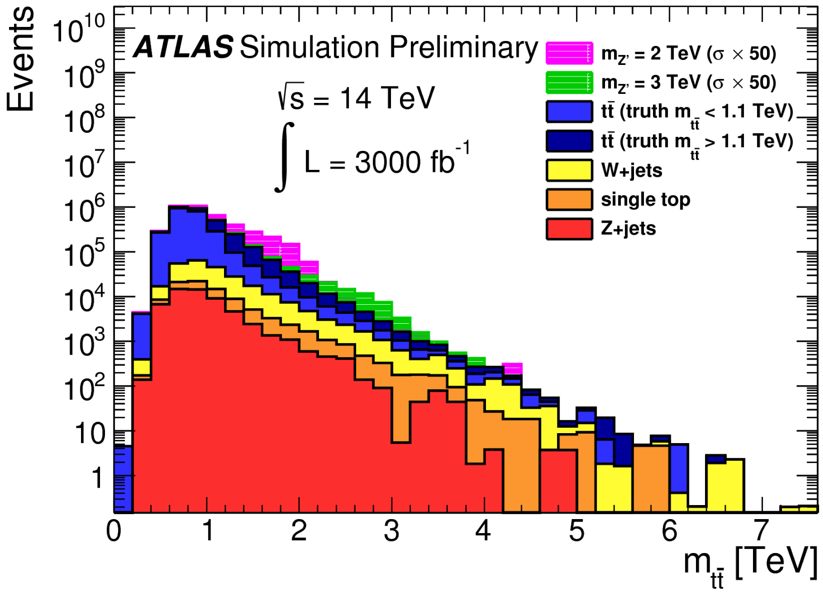


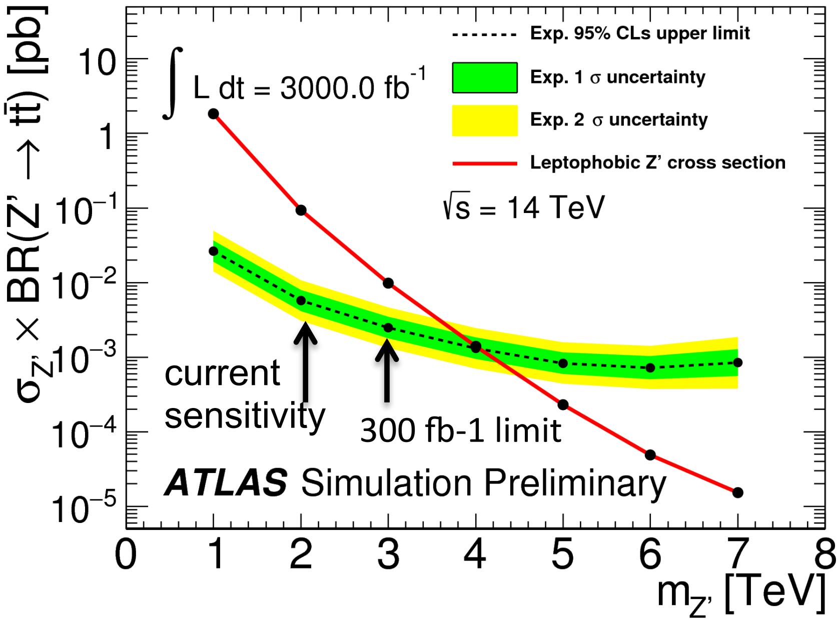
- Improved statistics for high p_T events at HL-LHC.
- High mass signal ⇒ boosted top quark decays ⇒ highly collimated jets.
- Search relies on a good reconstruction of boosted objects.
- Dependent on upgrade tracking performance in a dense environment for b-tagging and lepton isolation.

Extend HL-LHC mass reach to m(Z') ~ 4 TeV.

ATLAS Run 1 mass constraint (20.3 fb-1): **m(Z') > 2.1 TeV**

ATL-PHYS-PUB-2017-002

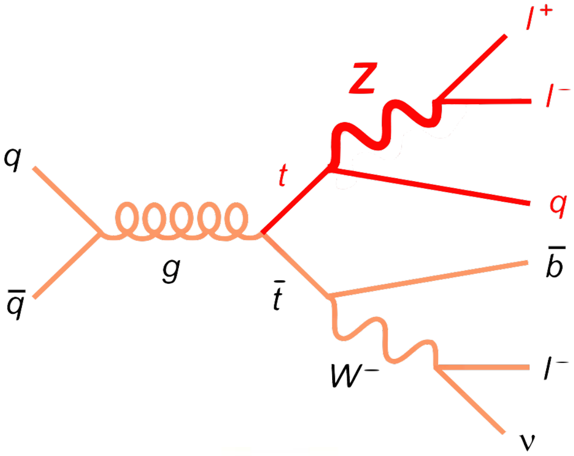




Anomalous top decays at HL-LHC

- Highly suppressed in Standard Model (rates < 10^{-10}).
- Detection would be sign of new physics.
- Expected sensitivity to FCNC top decays:
  - t→Zq (u or c) and t→Hq (u or c) in tt events

ATL-PHYS-PUB-2016-019



Expected upper 95% CL limits on FCNC top quark branching ratios ($5\text{-}45 \times 10^{-4}$ Run 1 results)

Uncertainties	t→Zq channels	t→Hq channels
statistics only	$(2.4-5.8)\cdot10^{-5}$	$(0.6-1.2)\cdot10^{-4}$
statistics + systematics (A)	$(12-41)\cdot10^{-5}$	$(1.1-2.4)\cdot10^{-4}$
statistics + systematics (B)	$(8.3-24)\cdot10^{-5}$	$(1.1-2.4)\cdot10^{-4}$

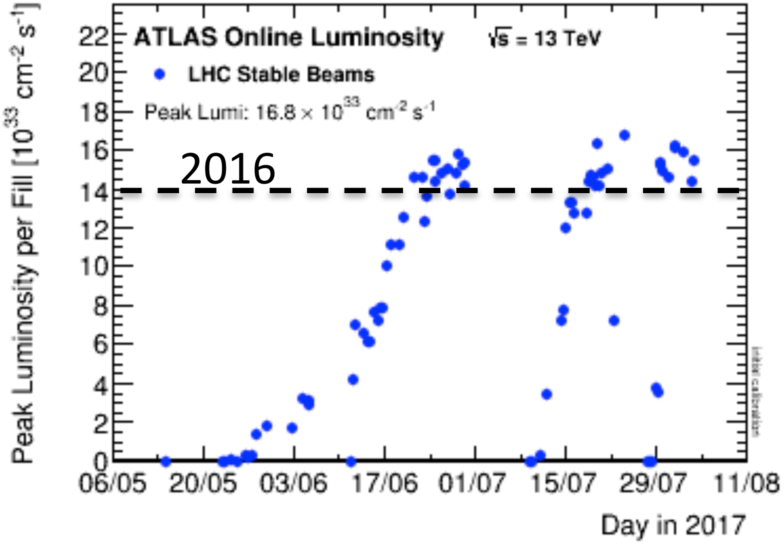
- Systematics A from 8 TeV Run 1 MC to data comparisons.
- Systematics B account for improvements to dominant theoretical and background normalization uncertainties from HL-LHC statistics.
- Detector related systematics (different scenarios considered) can be neglected.

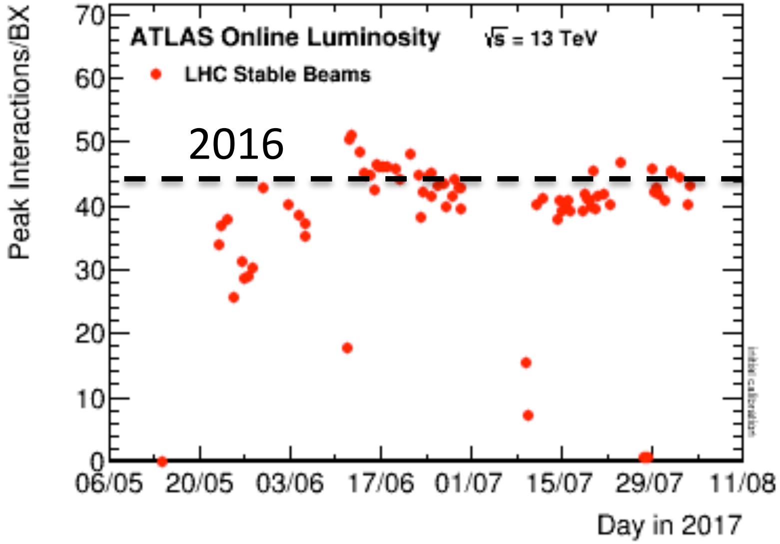
Conclusions

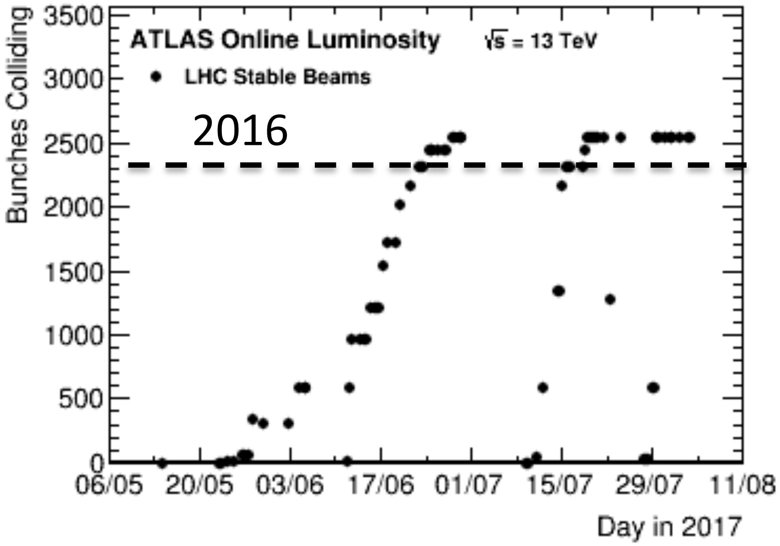
- HL-LHC will be a **challenging environment** for ATLAS ($<\mu_{PU}> \sim 200$, large background/radiation, high trigger/data rates).
- Significant increase of statistics for the physics analysis is expected:
  ➔ improve sensitivity to higher mass particles and rare processes.
- **Higgs, Exotics and SUSY physics** program will profit of it:
  → explore the ***HH*** production mechanism combining as many final states and production mechanisms as possible
  → precise measurements of Higgs couplings
  → extend the present/gain new sensitivities to heavy SUSY particles.
- Still a lot of space for improvements:
  - during 2017 the various sub-detector TDRs will be finalized; this could bring further detector/trigger capabilities
  - theoretical uncertainties expected to decrease with time.
  - better data-analysis techniques for background rejection will be available in Run 4.

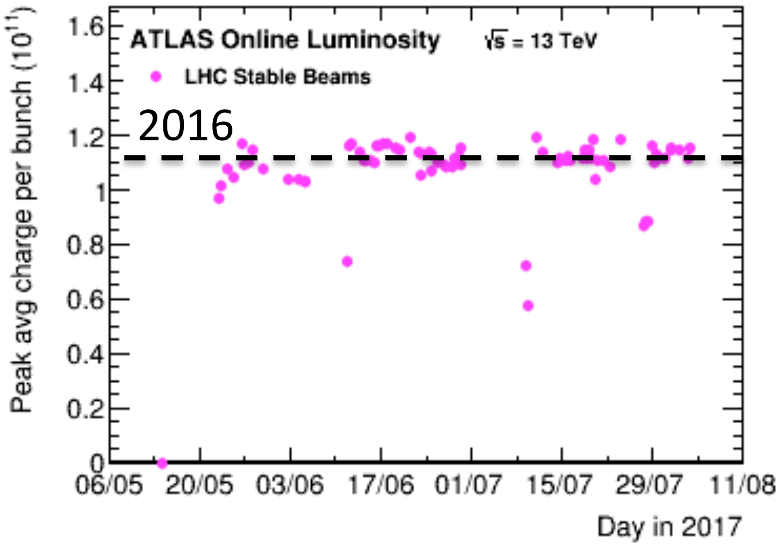
BACK UP

LCH/ATLAS 2017 vs 2016

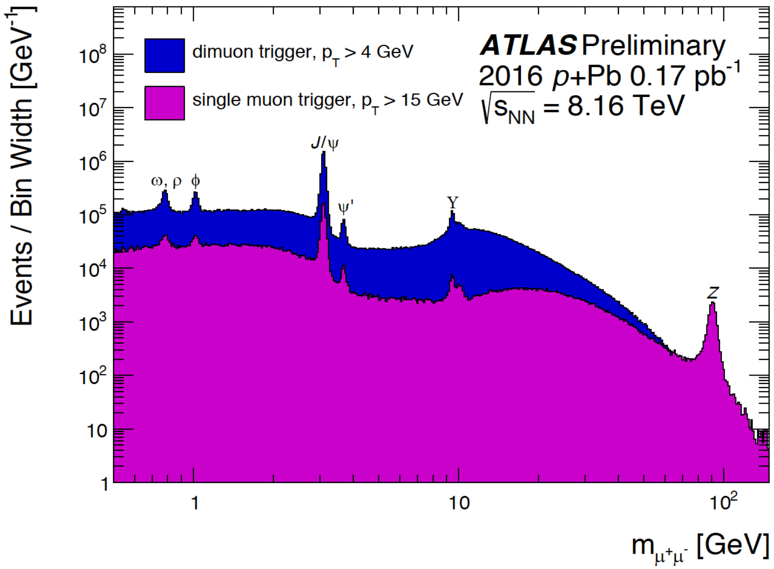


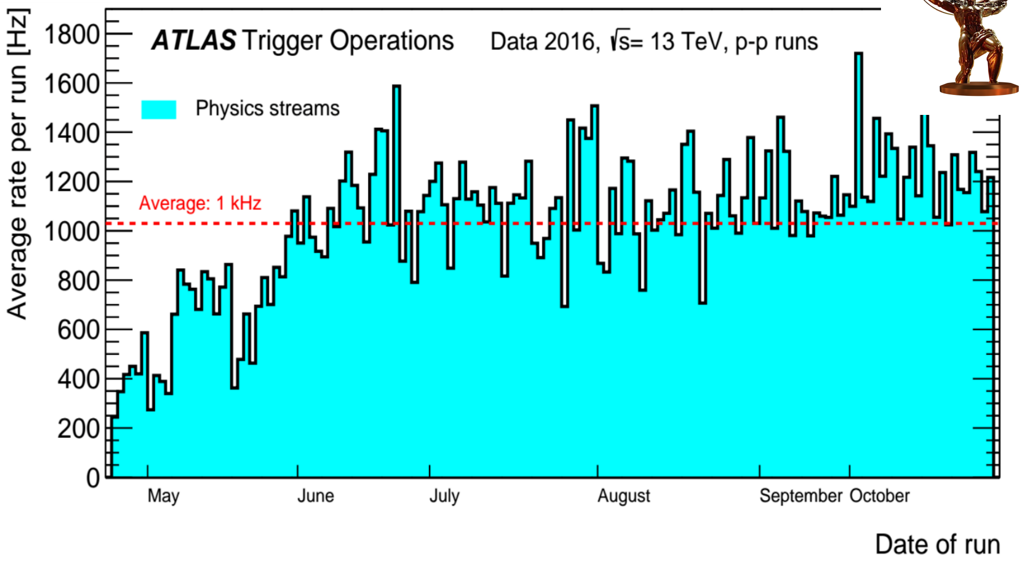


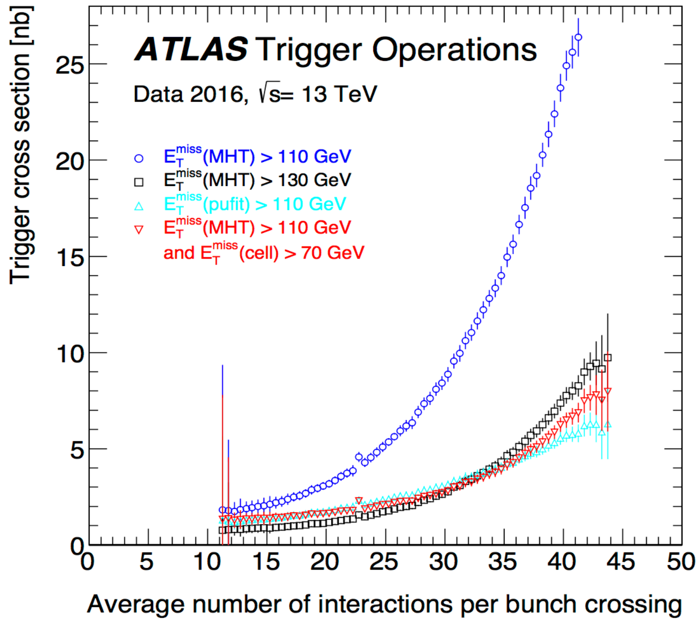


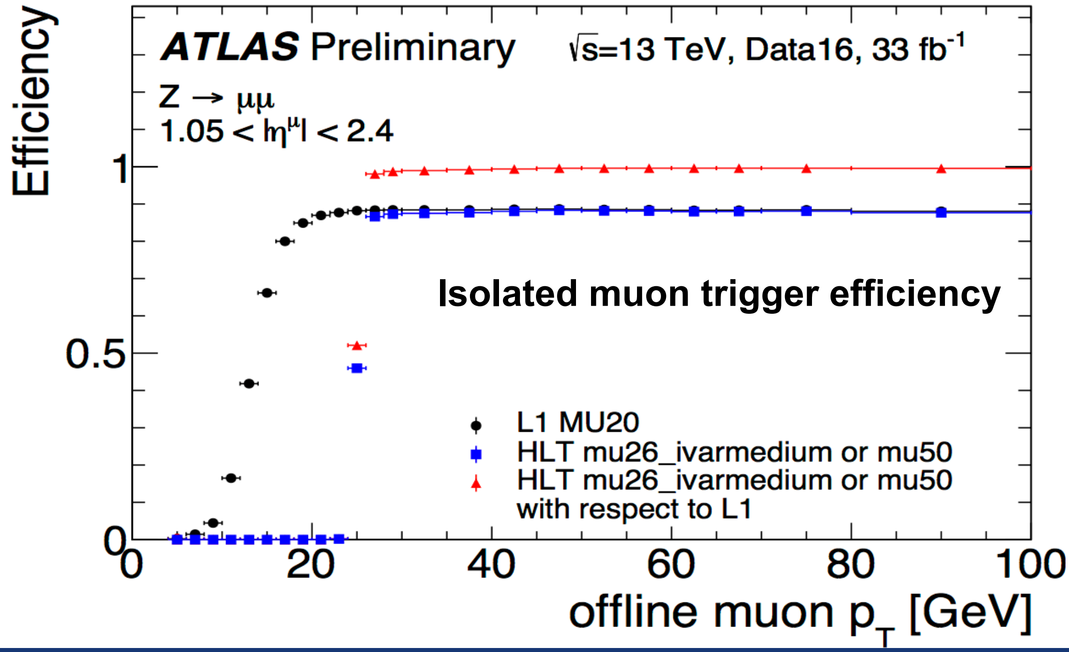


ATLAS Detector Performance/2





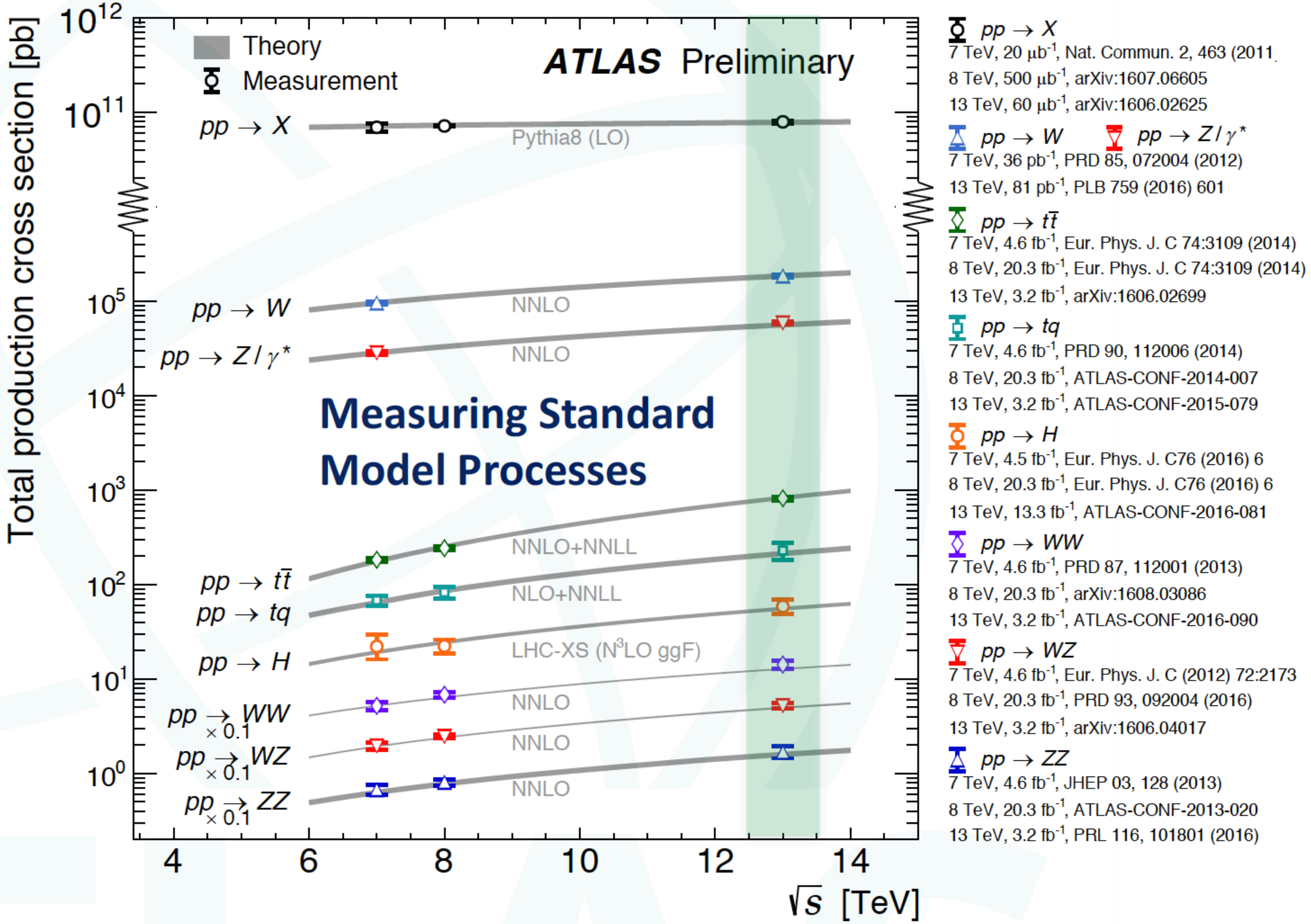




Isolated muon trigger efficiency

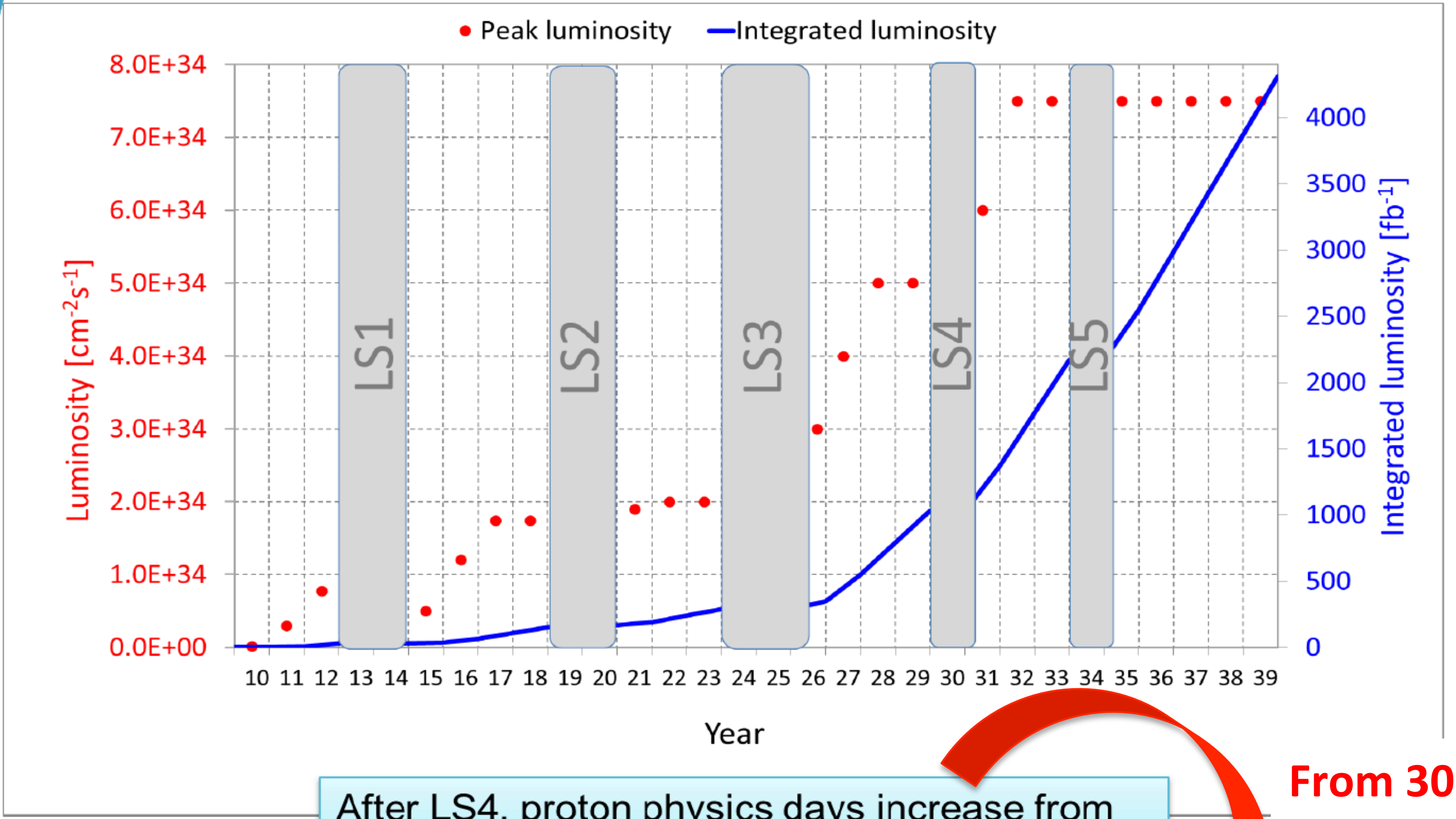
ATLAS 2016 cross-section measurements

Measuring Standard Model Processes



HL-LHC projection

Luminosity profile: ULTIMATE



After LS4, proton physics days increase from standard 160 days to 200 and after LS5 to 220

From 3000 fb^{-1} to 4000 fb^{-1}

Ultimate scenario assume 5% higher efficiency than nominal
Last run with 220 days and 5% higher efficiency: 440 fb-1/y

ATLAS Scoping Document layouts

Detector System	Reference (275 MCHF)	Scoping Scenarios Middle (235 MCHF)	Low (200 MCHF)
Inner Tracker			
Pixel Detector	$\|\eta\| \leq 4.0$	$\|\eta\| \leq 3.2$	$\|\eta\| \leq 2.7$
Barrel Strip Detector	✓	✓ [No stub layer]	✓ [No stereo in layers #2,#4] [Remove layer #3] [No stub layer]
Endcap Strip Detector	✓	✓ [Remove 1 disk/side]	✓ [Remove 1 disk/side]
Calorimeters			
LAr Calorimeter Electronics	✓	✓	✓
Tile Calorimeter Electronics	✓	✓	✓
Forward Calorimeter	✓	✗	✗
High Granularity Precision Timing Detector	✓	✗	✗

Analysis Techniques

ATLAS HL-LHC studies have to consider:
- upgraded ATLAS detector + trigger systems
- collision energy, $\sqrt{s} = 14$ TeV
- high pile-up, $\langle\mu_{PU}\rangle$, of 140 or 200

- We use **generator-level** $\sqrt{s} = 14$ TeV Monte Carlo samples
- Overlay with jets from dedicated ***pile-up library***
  - ➡ **pile-up library** contains fully simulated pile-up jets with $\langle\mu_{PU}\rangle = 140$ or 200
- Reconstruct electron, muons, jets, photons and missing-E_T from generator+overlay information

- To simulate the response of the detector:
  - ➡ smear p_T and energy of reconstructed physics objects using ***smearing functions***
  - ➡ apply **reconstruction efficiencies** for electrons, muons and jets

- To emulate triggers: apply **trigger efficiency** functions

- Smearing and efficiency functions determined from fully-simulated samples using ATLAS HL-LHC detector and high pile-up
  - ➡ Functions are dependent on p_T and η

- Most analysis presented use single lepton or di-lepton triggers (e, μ)
  - ➡ di-τ triggers and 4-jet triggers used for particular analyses

- Parametrised b-tagging (based on ATLAS Run 1 `MV1` tagger) is performed on reconstructed jets

- This approach to ATLAS HL-LHC prospects studies has been validated on a limited number of physics studies comparing full simulation and the *generator-level+smearing* technique

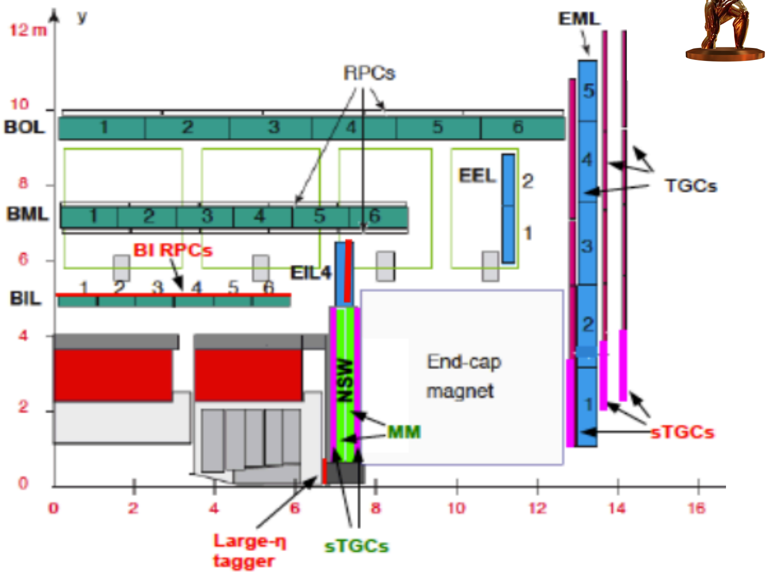
Level-0 Barrel trigger with the new inner layer + large η tagger

BI upgrade:

- 4th layer of new type RPC
- sMDT chambers

➔improve trigger acceptance

➔robustness against reduced efficiency on old RPC

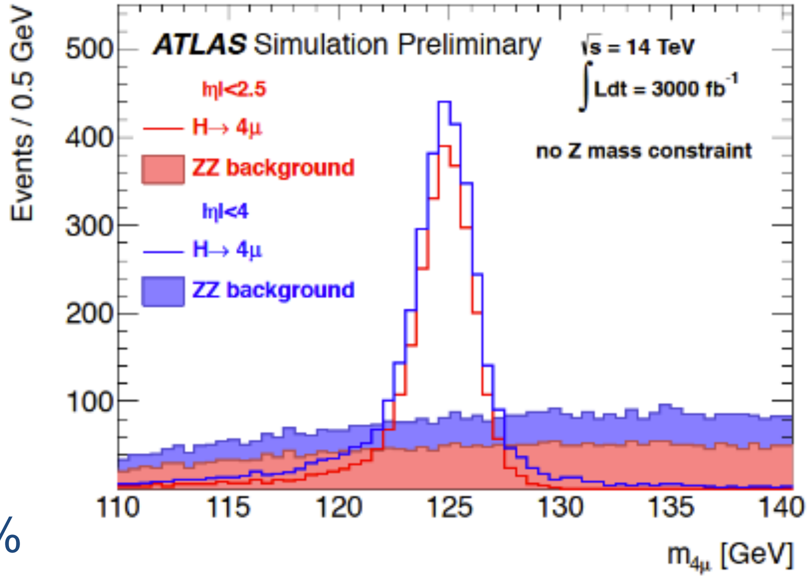


Extend the muon acceptance from 2.7 to 4.0

- B-field integral becomes zero around η=3: no momentum measurement from muon system
- Muon “segment” tagger to be used with ITK
- Benchmark physics channels from SD:

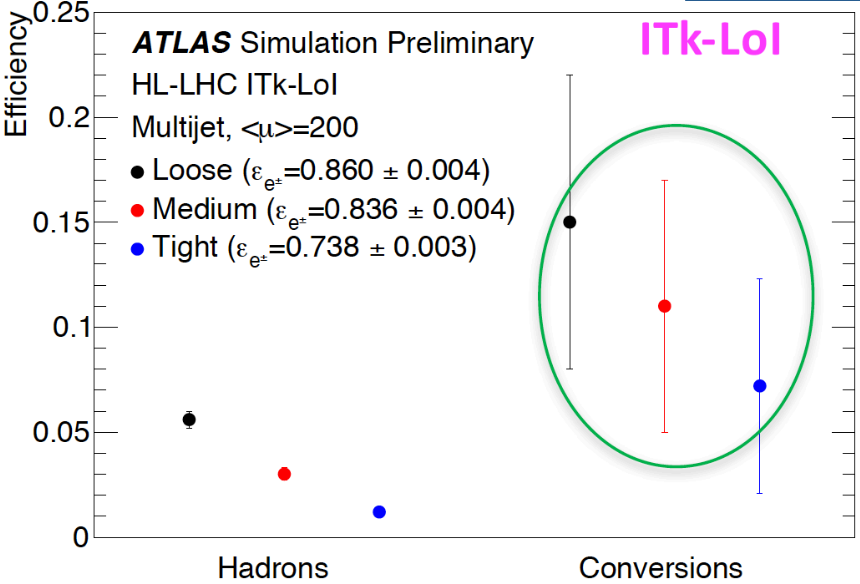
1. H➔ 4l
   - 20% increase of acceptance
   - Δμ/μ: 2.4% => 2.2% (10% improvement)
   - Larger impact for differential distributions

2. boson-boson scattering: W+W+ j j
   - same sign di-leptons
   - veto on 3rd lepton reduces WZ bkg by 50%



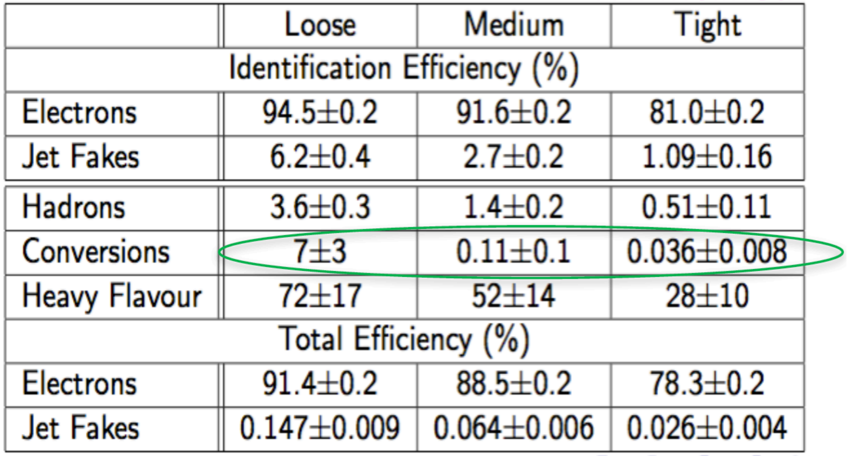
ATLAS performance @HL-LHC

Electron Performance



For Medium Selection: conversion ra
dropping from ~10% to 0,11 %

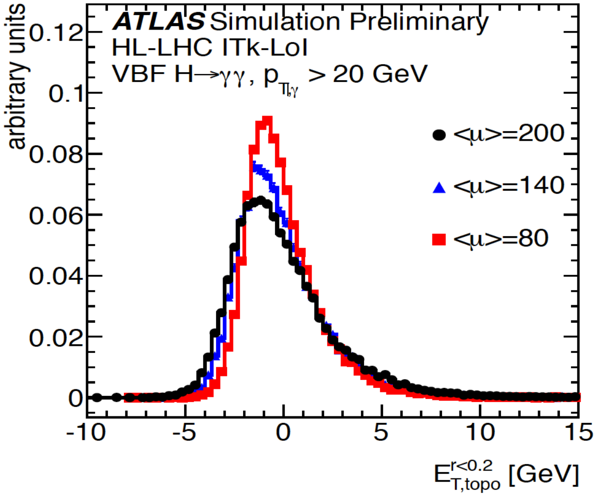
ITk-Inclined



	Loose	Medium	Tight
Identification Efficiency (%)			
Electrons	94.5±0.2	91.6±0.2	81.0±0.2
Jet Fakes	6.2±0.4	2.7±0.2	1.09±0.16
Hadrons	3.6±0.3	1.4±0.2	0.51±0.11
Conversions	7±3	0.11±0.1	0.036±0.008
Heavy Flavour	72±17	52±14	28±10
Total Efficiency (%)			
Electrons	91.4±0.2	88.5±0.2	78.3±0.2
Jet Fakes	0.147±0.009	0.064±0.006	0.026±0.004

Photon Performance

ITk-LoI



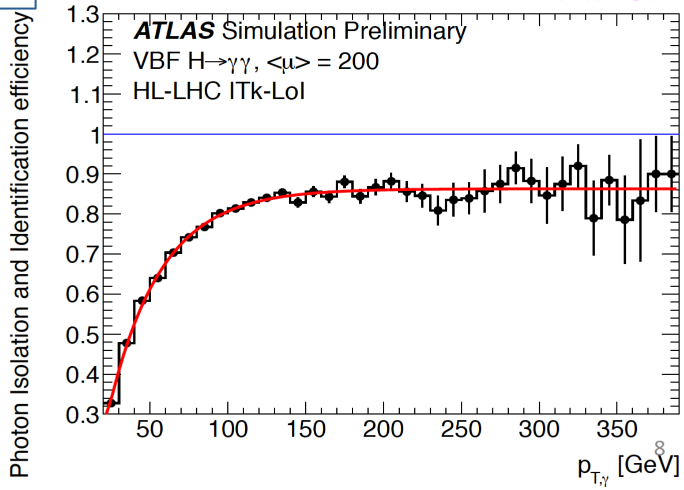
Calorimeter-based photon identification

- $\varepsilon = 70\%$
- fake rate ~10^{-3}

Using isolation $E_{r<0.2} < 6$ GeV

- $\varepsilon = 87\%$
- fake rate ~ 10^{-4}

ITk-LoI

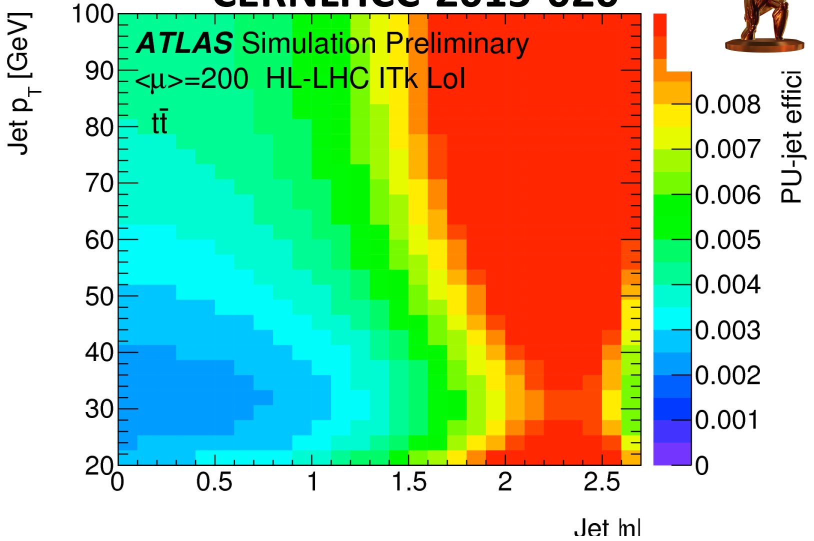


Fat jet performance @HL-LHC

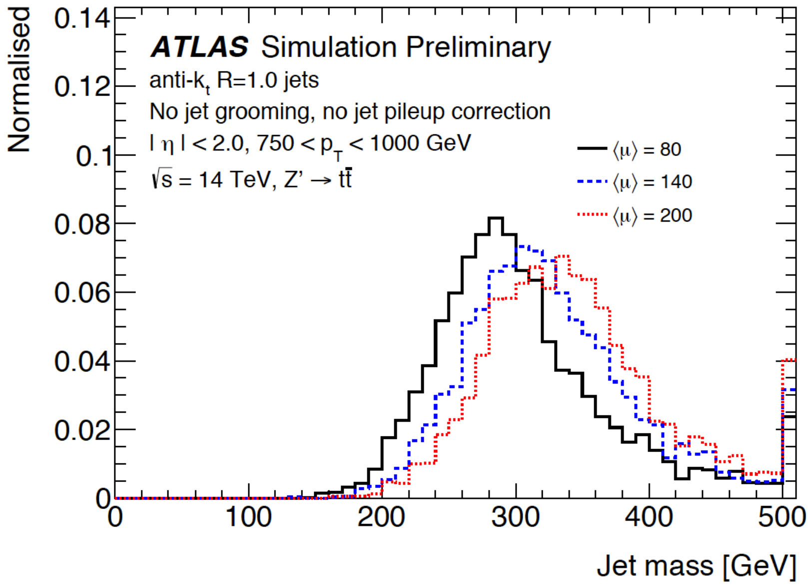
JET Performance

- Use of Fat Large (R=1.0,1.2) jets to identify boosted vector boson (V):
  - powerful discriminator between jets from V and multijets
  - strong dependence on pile-up
- combined trimming (fcut = 5% and Rsub = 0.2) and Jet Area subtraction restore the mass information

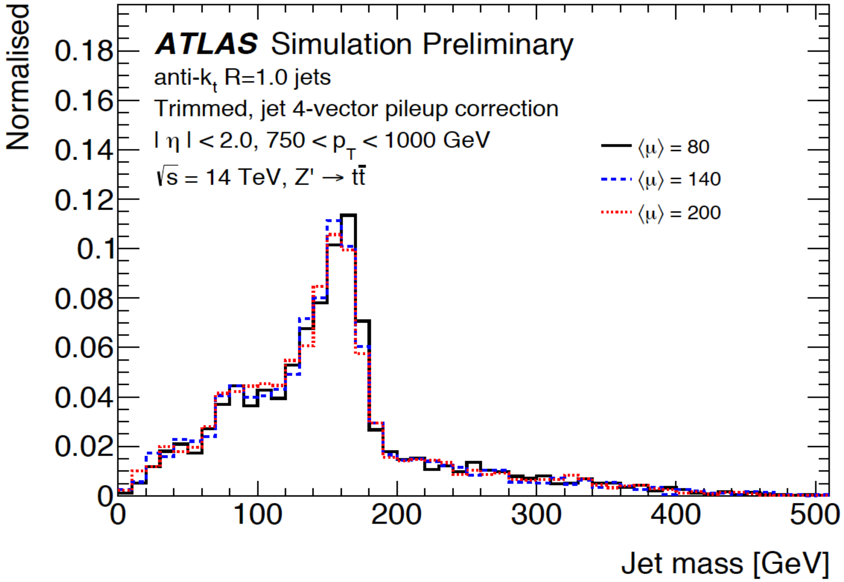
CERNLHCC-2015-020



ITk-LoI

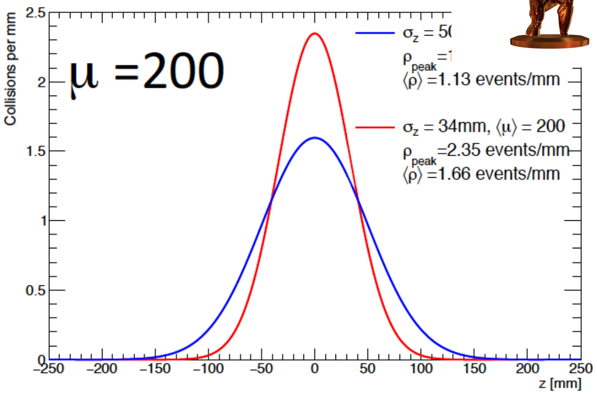


ITk-LoI

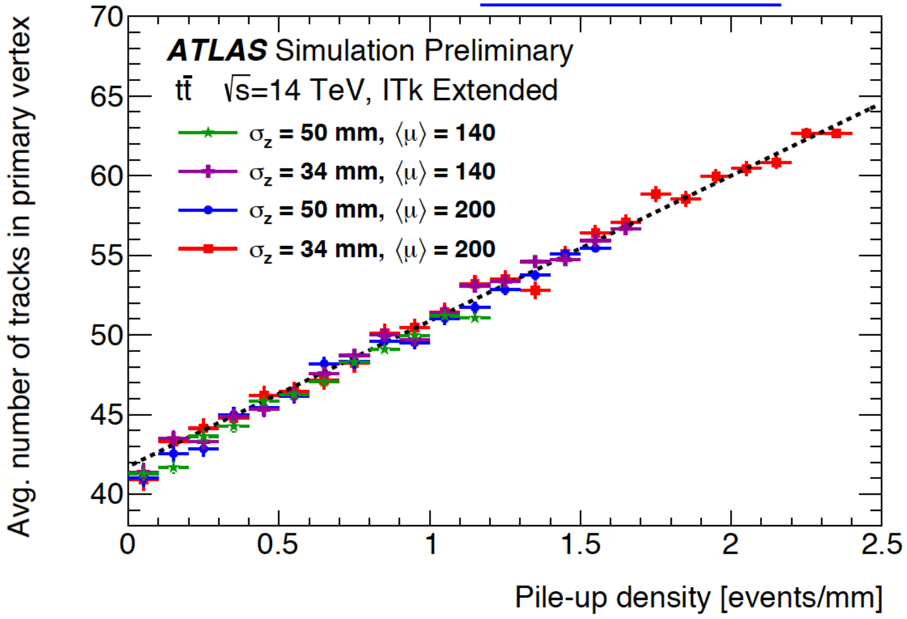


Luminosity region studies

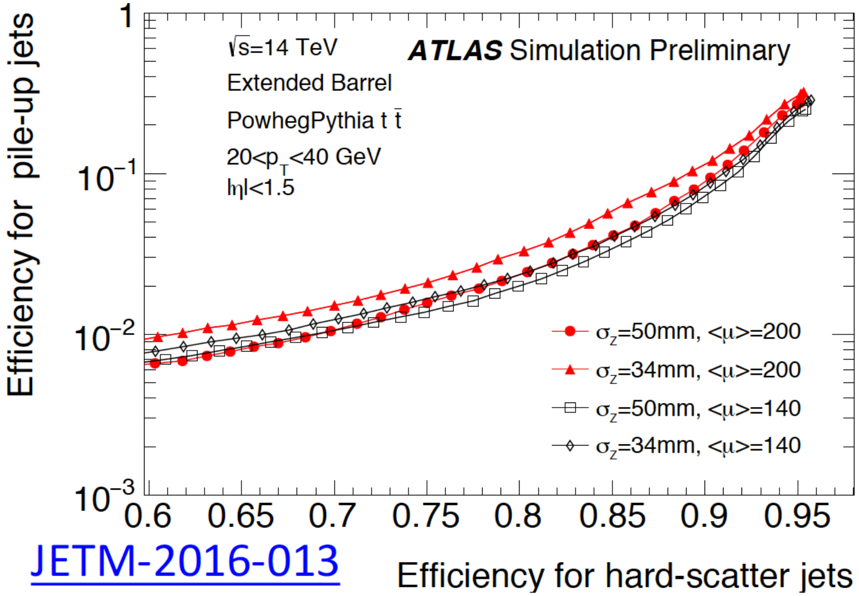
- Luminous regions width (z-coordinate) σ_z=34,50 mm for <μ> = 140, 200
- Largest dependence on the pile-up density (=avg. #collisions per mm)
  - track-to-vertex association: +50% in tracks from pile-up at highest pile-up density
  - jet vertex tagging: similar performances between <μ> = 140, σz =34mm and <μ>=200, σ_z=50mm but Jet resolution worse at higher <μ>



ITk-Extended IDTR-2016-012

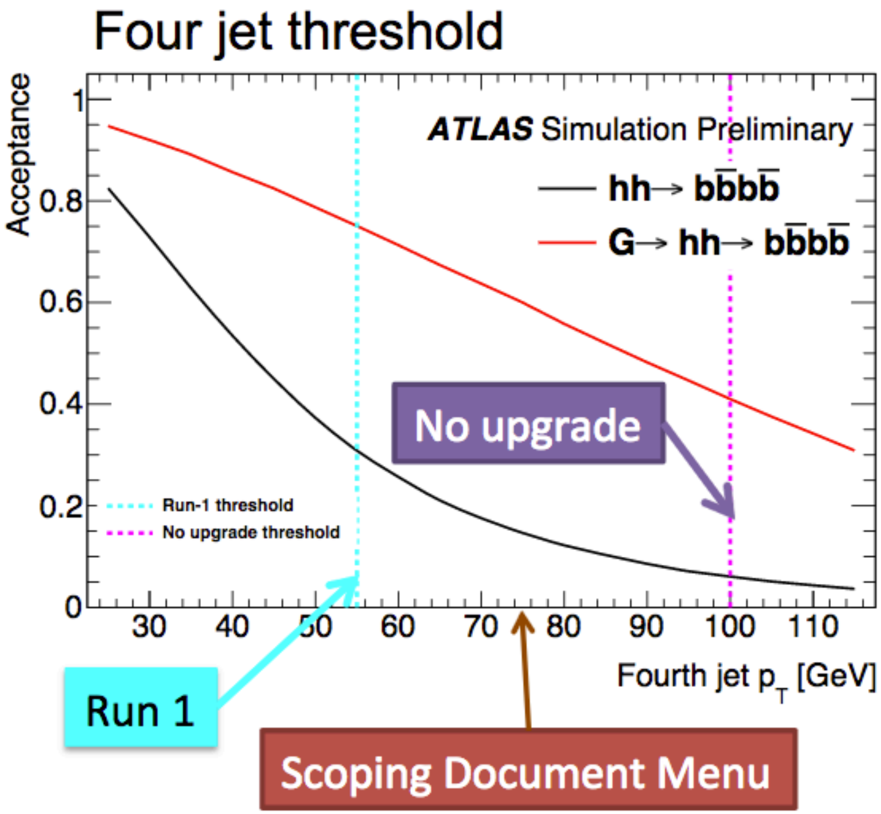


ITk-Extended



JETM-2016-013

Physics motivation for Phase II-Trigger upgrade



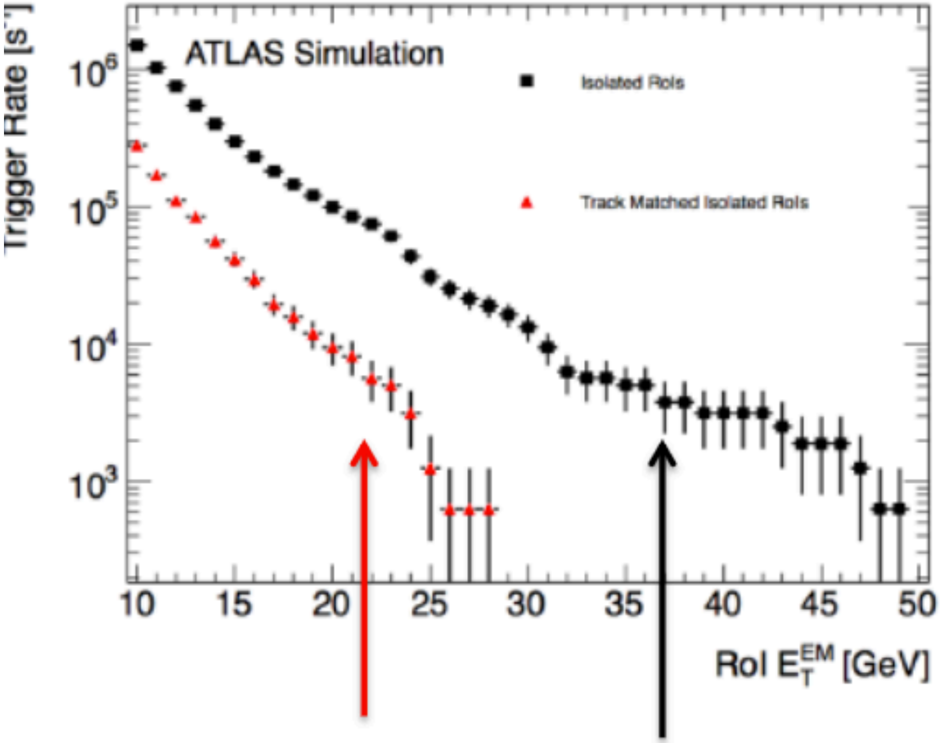
No upgrade

Run 1

Scoping Document Menu

- Open question on the best way to explore hadronic final states
  - for example HH → bbbb

- **General strategy**
  - **loosen Run-2 100 kHz L1 rate**
  - **access tracking information early**

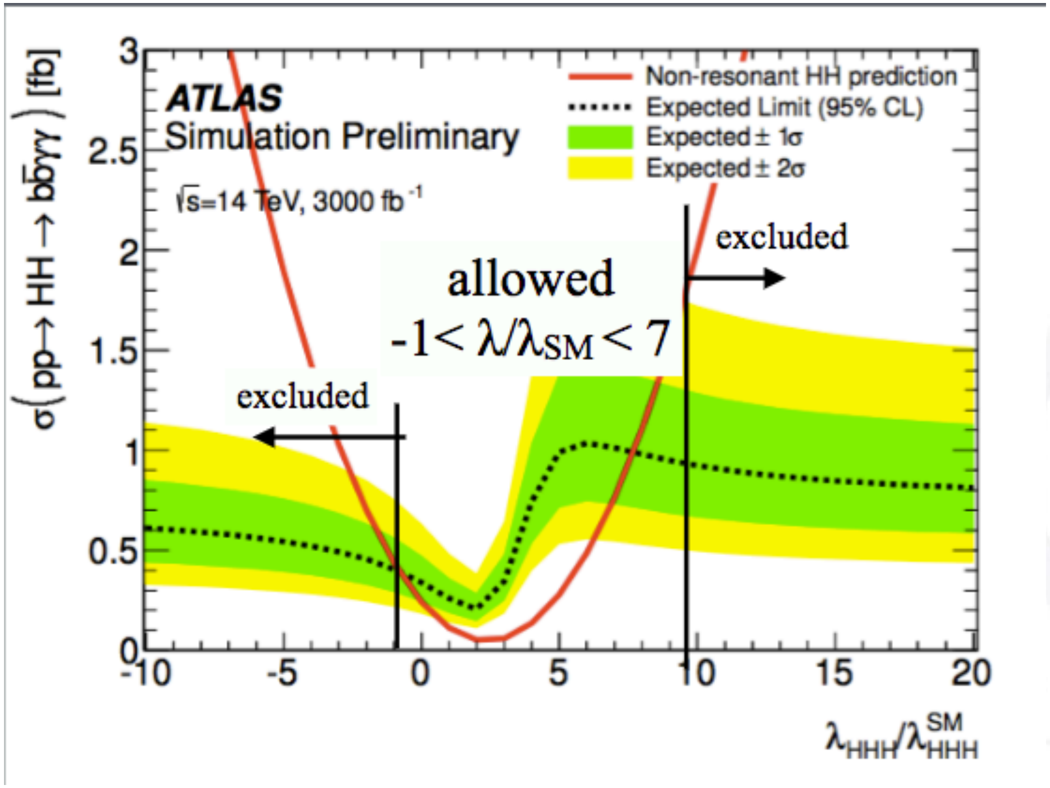


Isolated EM triggers associated with tracks

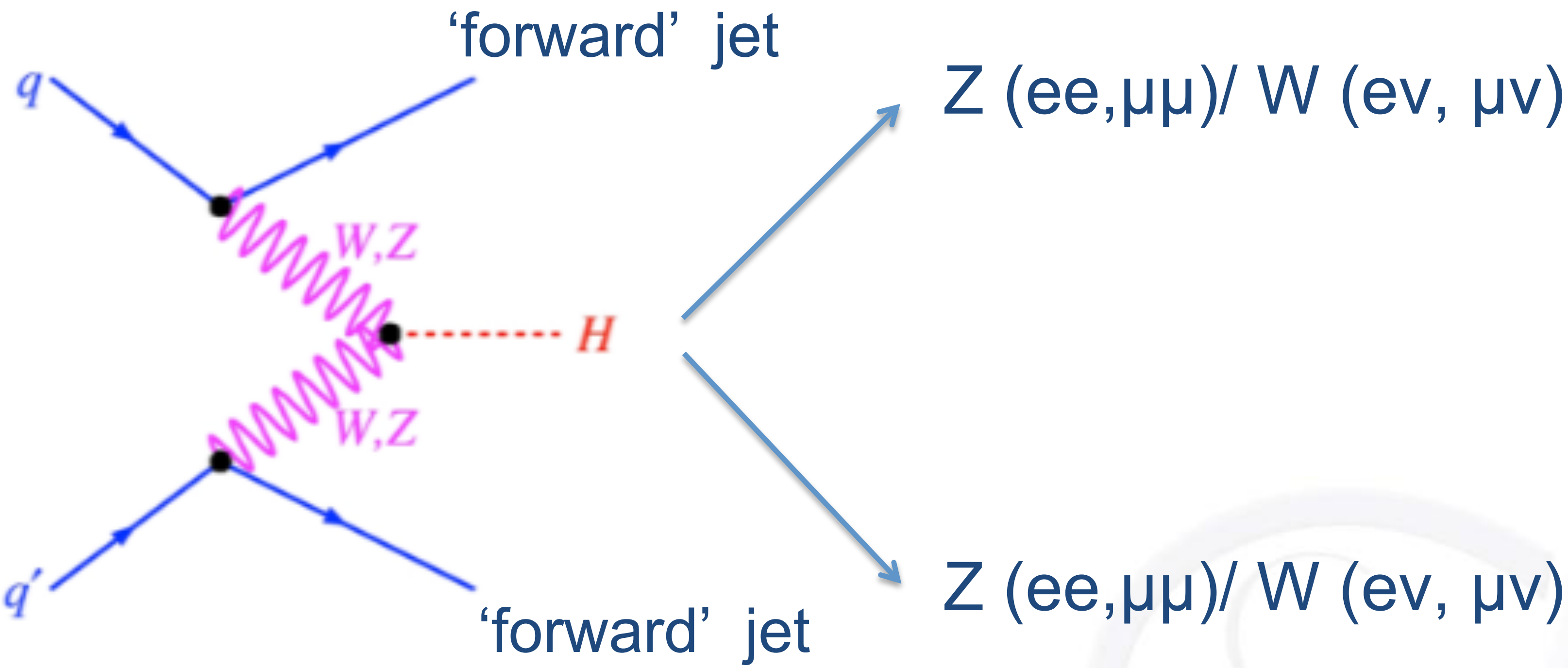
Isolated EM triggers

HH → $b\bar{b}$ γγ

- Cut based with Scope Document performance for photons
- Most recent ITK layout for b-tagging
- SR: 9.5 signal, 91 total background



VBF Higgs production



'forward' jet

Z (ee,μμ)/ W (eν, μν)

Z (ee,μμ)/ W (eν, μν)

'forward' jet

Important analysis to motivate the high η extension of the ATLAS ITK layout

VBF Higgs production

3000 fb^{-1}, $<\mu_{PU}>$ = 200, 14 TeV

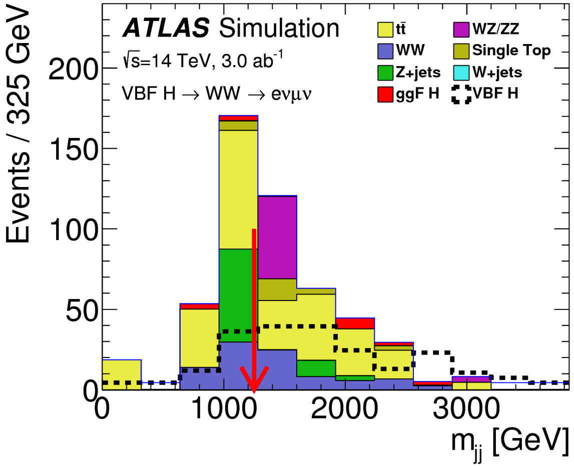
H → WW → eν μν*

- Detector performances: Run-1 (e/μ) and SD (jets, E_T^{Miss})
- Cut based: 2 forward jets (|η| > 2), E_T^{Miss} >20 GeV
- Tracking coverage extension in eta
  → stat.+ syst. uncertainty reduction by 40%

Z_0 : 8.0 (stat+syst) / 5.7 (stat. extrap. from Run1)

Δμ: 0.20 (stat+syst) / 0.14 (stat. extrap from Run-1)

ATL-PHYS-PUB-2016-018



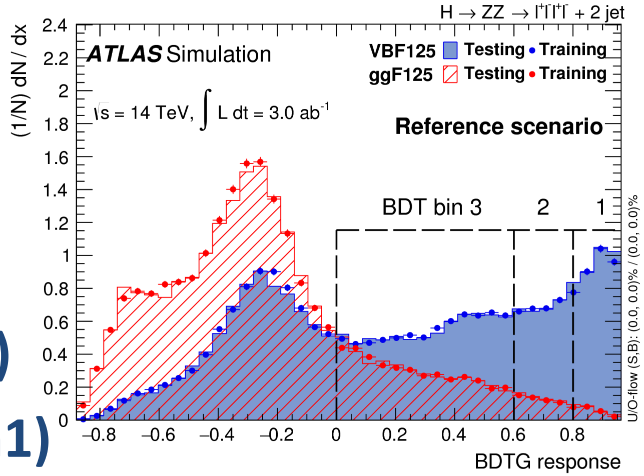
H→ ZZ → 4l*

- 2 jets with m(jj) > 130 GeV
- 4 lepton consistent with h->ZZ*->4l
- Use BDT to separate ggF and VBF production
- Systematic uncertainty is from signal QCD scale only

Z_0 : 10.2 (stat+syst) / 7.2 (stat. extrap. from Run1)

Δμ: 0.18 (stat+syst) / 0.15 (stat. extrap. from Run1)

ATL-PHYS-PUB-2016-008



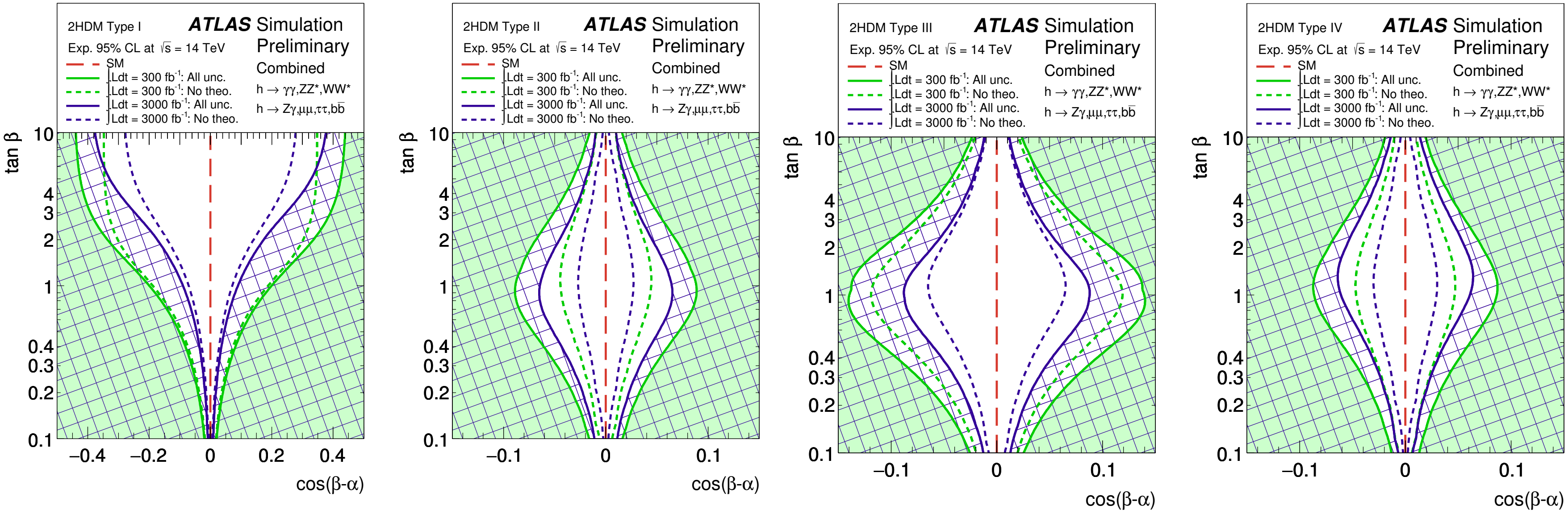
Summary of Higgs results at HL-LHC

Channels	Result	HH final State	Significance Coupling limit
VBF H->WW*	**$\Delta\mu/\mu \simeq$ 14 to 20%**	HH → $\bar{b}b\,\gamma\gamma$ (stat)	**1.05 σ** **$-0.8 < \lambda_{HHH}/\lambda_{SM} < 7.7$**
VBF H->ZZ*	**$\Delta\mu/\mu \simeq$ 15 to 18%**	HH →$\bar{b}b\,\tau^+\tau^-$ (stat+syst)	**0.6 σ** **$-4.0 < \lambda_{HHH}/\lambda_{SM} < 12.0$**
ttH, H->γγ	**$\Delta\mu/\mu \simeq$ 17 to 20%**	HH -> bbbb (stat+syst)	**--** **$-3.5 < \lambda_{HHH}/\lambda_{SM} < 11.0$**
VH, H→γγ	**$\Delta\mu/\mu \sim$ 25 to 35%**	ttHH, HH →$\bar{b}b\bar{b}b$	**0.35 σ** **--**
H-> Zy	**$\Delta\mu/\mu \sim$ 30%**	*H→ZZ*→4l* (m(4l)>220 GeV)	**$\Gamma_H = 4.2^{+1.5}_{-2.1}$ MeV** **(stat.+syst.)** Run-1: $\Gamma_H < 22.7$ MeV
H->$\mu^+\mu^-$	**$\Delta\mu/\mu \sim$ 15%**		
H-> J/ψ y	**BR < 44 x 10^{-6} @ 95 % C.L.**		**ATL-PHYS-PUB-2015-024**

Higgs BSM constraints

ATL-PHYS-PUB-2014-016
ATL-PHYS-PUB-2014-017

300, 3000 fb^{-1}
$<\mu_{PU}> = 140$



(a) Type I

(b) Type II

(c) Type III

(d) Type IV

Figure 4: Regions of the $(\cos(\beta-\alpha),\ \tan\beta)$ plane of four types of 2HDMs expected to be excluded by fits to the measured rates of Higgs boson production and decays. The confidence intervals account for a possible relative sign between different couplings. The expected likelihood contours where $-2\ln\Lambda = 6.0$, corresponding approximately to 95% CL (2σ), are indicated assuming the SM Higgs sector. The light shaded and hashed regions indicate the expected exclusions.

Higgs Width at HL-LHC

Measure off-shell production of $H \rightarrow ZZ^* \rightarrow 4\ell$ with $\mathbf{m(4\ell) > 220}$ **GeV**

Use $\mathbf{m(4\ell)}$ shape and matrix element to discriminate between signal and background

➡stat. uncertainties only: $\mu_{\text{off-shell}} = 1.00^{+0.23}_{-0.27}$

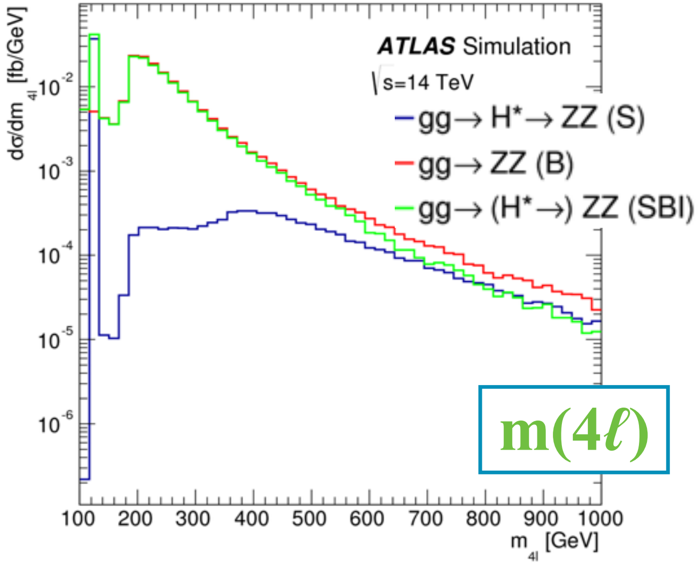
➡stat.+syst. uncertainties: $\mu_{\text{off-shell}} = 1.00^{+0.43}_{-0.50}$

- Off-shell production used to constrain the Higgs boson width Γ_H

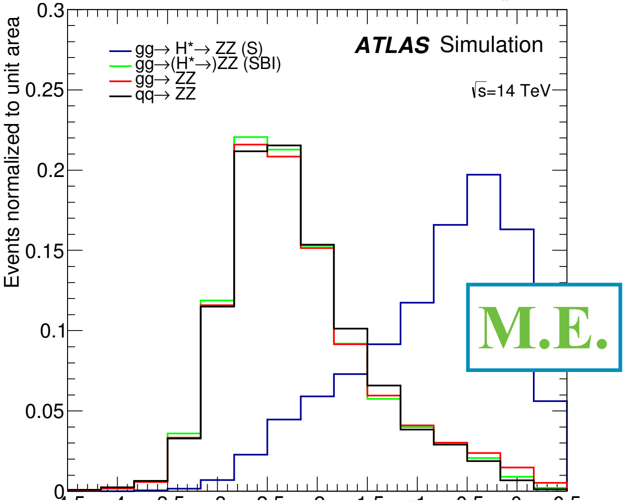
- For $\Gamma = \Gamma_{SM}$ combining with on-shell measurement, (assuming off-shell measurement dominates):

$$\boxed{\Gamma_H = 4.2^{+1.5}_{-2.1}\ \text{MeV (stat+sys)}}$$

- Run 1 limit: $\Gamma_H < 22.7$ **MeV** at 95% CL (*WW, ZZ*)



m(4ℓ)



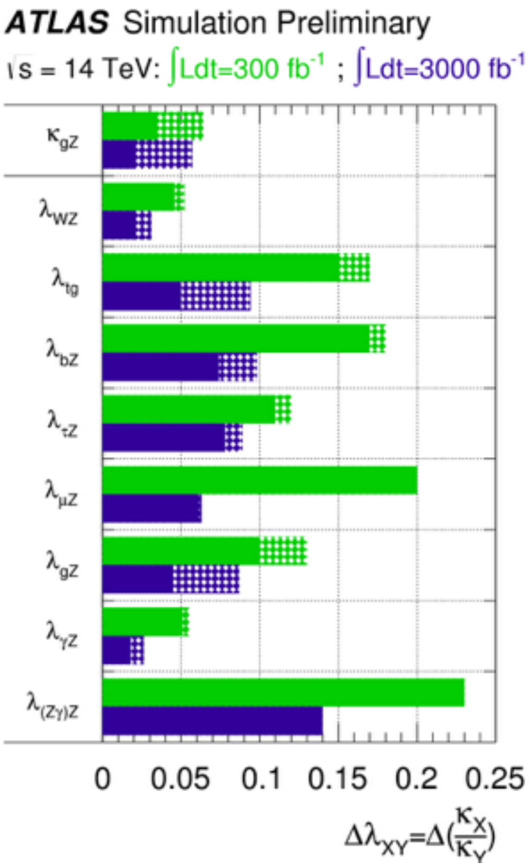
M.E.

Higgs coupling K-Framework

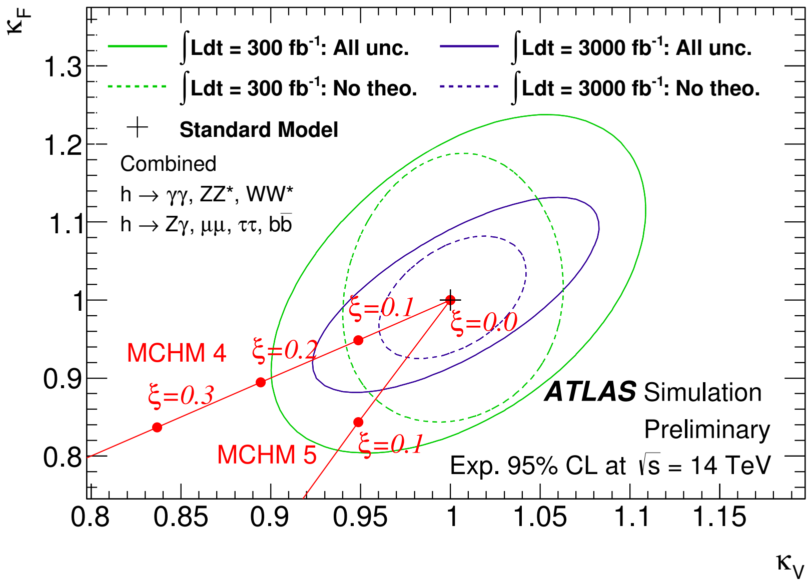
ATL-PHYS-PUB-2014-016

- Assuming Γ_H is sum of SM widths, calculate uncertainties on Higgs boson couplings.
- Deviations from the SM are quantified using κ multiplier, in SM $\kappa_i = 1$, *e.g.*:

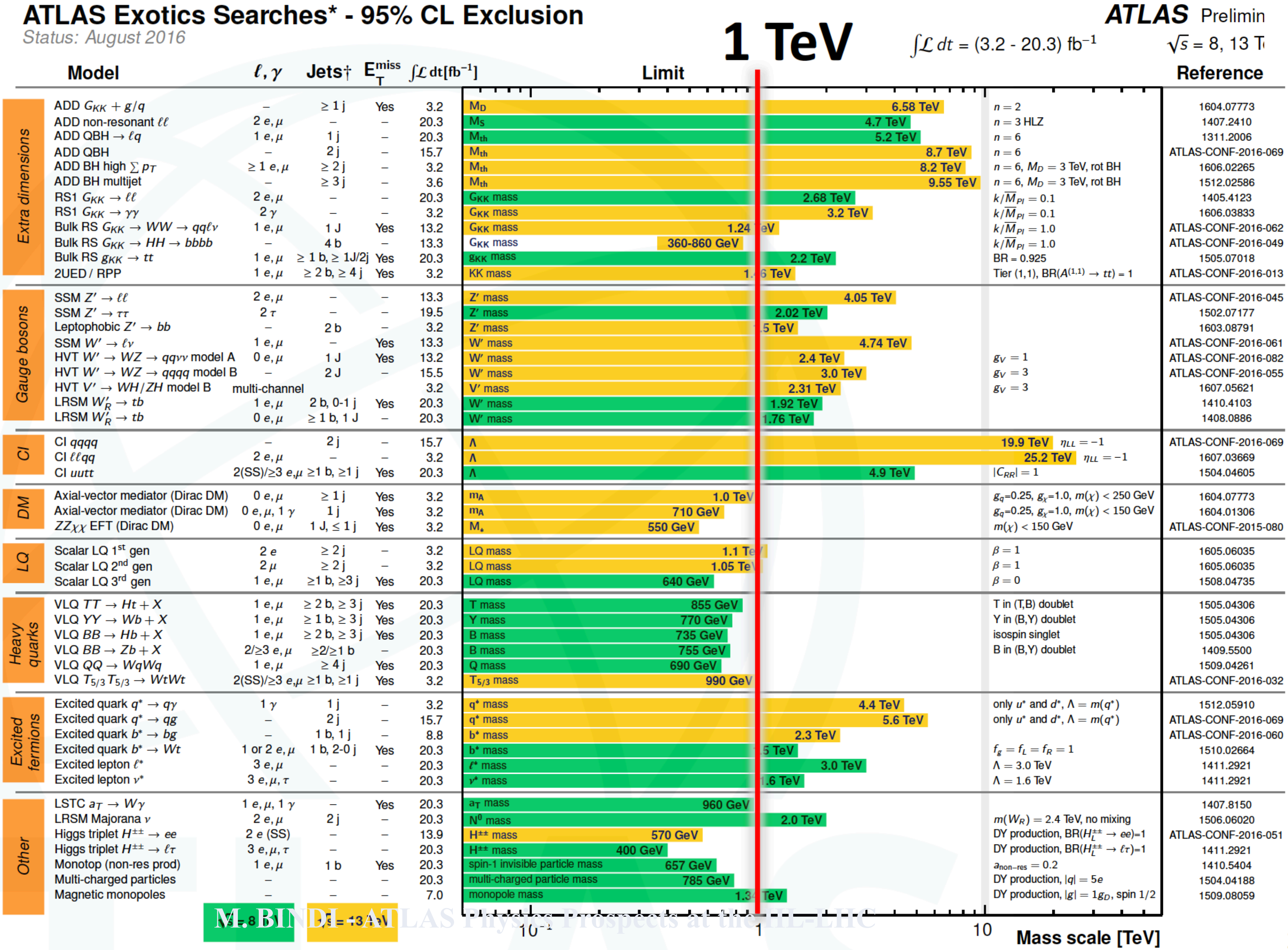
$$(\sigma \cdot \mathrm{BR})(gg \to H \to \gamma\gamma) = \sigma_{\mathrm{SM}}(gg \to H) \cdot \mathrm{BR}_{\mathrm{SM}}(H \to \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$



- Assume universal modifications to Higgs couplings to fermions (κ_F) and vector bosons (κ_V)



Exotic Searches Aug 2016



ATLAS Exotics Searches* - 95% CL Exclusion

Status: August 2016

ATLAS Prelimin

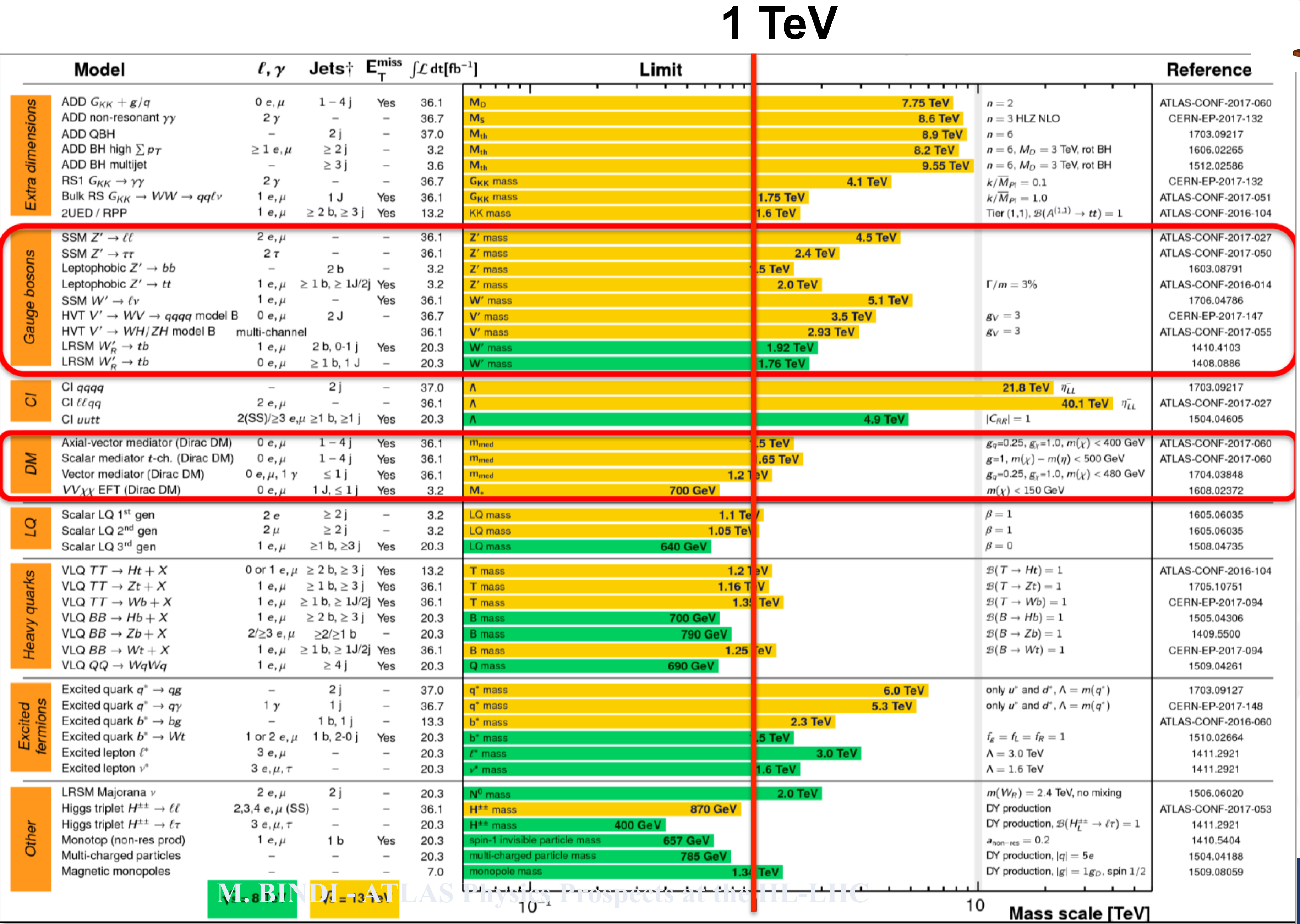
$\int \mathcal{L}\,dt = (3.2 - 20.3)\ \mathrm{fb}^{-1}$ $\sqrt{s}$ = 8, 13 T

1 TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	≥ 1 j	Yes	3.2	🟨 M_D 6.58 TeV	$n = 2$	1604.07773
	ADD non-resonant $\ell\ell$	2 e, μ	–	–	20.3	🟩 M_S 4.7 TeV	$n = 3$ HLZ	1407.2410
	ADD QBH $\to \ell q$	1 e, μ	1 j	–	20.3	🟩 M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	15.7	🟨 M_{th} 8.7 TeV	$n = 6$	ATLAS-CONF-2016-069
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	🟨 M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	🟨 M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \ell\ell$	2 e, μ	–	–	20.3	🟩 G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	3.2	🟨 G_{KK} mass 3.2 TeV	$k/\overline{M}_{Pl} = 0.1$	1606.03833
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	1 e, μ	1 J	Yes	13.2	🟨 G_{KK} mass 1.24 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2016-062
	Bulk RS $G_{KK} \to HH \to bbbb$	–	4 b	–	13.3	🟨 G_{KK} mass 360-860 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2016-049
	Bulk RS $g_{KK} \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	20.3	🟩 g_{KK} mass 2.2 TeV	BR = 0.925	1505.07018
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 4 j	Yes	3.2	🟨 KK mass 1.46 TeV	Tier (1,1), BR($A^{(1,1)} \to tt$) = 1	ATLAS-CONF-2016-013
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	13.3	🟨 Z' mass 4.05 TeV		ATLAS-CONF-2016-045
	SSM $Z' \to \tau\tau$	2 τ	–	–	19.5	🟩 Z' mass 2.02 TeV		1502.07177
	Leptophobic $Z' \to bb$	–	2 b	–	3.2	🟨 Z' mass 1.5 TeV		1603.08791
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	13.3	🟨 W' mass 4.74 TeV		ATLAS-CONF-2016-061
	HVT $W' \to WZ \to qq\nu\nu$ model A	0 e, μ	1 J	Yes	13.2	🟨 W' mass 2.4 TeV	$g_V = 1$	ATLAS-CONF-2016-082
	HVT $W' \to WZ \to qqqq$ model B	–	2 J	–	15.5	🟨 W' mass 3.0 TeV	$g_V = 3$	ATLAS-CONF-2016-055
	HVT $V' \to WH/ZH$ model B	multi-channel			3.2	🟨 V' mass 2.31 TeV	$g_V = 3$	1607.05621
	LRSM $W'_R \to tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	🟩 W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	0 e, μ	≥ 1 b, 1 J	–	20.3	🟩 W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	15.7	🟨 Λ 19.9 TeV	$\eta_{LL} = -1$	ATLAS-CONF-2016-069
	CI $\ell\ell qq$	2 e, μ	–	–	3.2	🟨 Λ 25.2 TeV	$\eta_{LL} = -1$	1607.03669
	CI $uutt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	20.3	🟩 Λ 4.9 TeV	$\lvert C_{RR} \rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	≥ 1 j	Yes	3.2	🟨 m_A 1.0 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 250$ GeV	1604.07773
	Axial-vector mediator (Dirac DM)	0 e, μ, 1 γ	1 j	Yes	3.2	🟨 m_A 710 GeV	g_q=0.25, g_χ=1.0, $m(\chi) < 150$ GeV	1604.01306
	$ZZ\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	🟨 M_* 550 GeV	$m(\chi) < 150$ GeV	ATLAS-CONF-2015-080
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	🟨 LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	🟨 LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	≥1 b, ≥3 j	Yes	20.3	🟩 LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	🟩 T mass 855 GeV	T in (T,B) doublet	1505.04306
	VLQ $YY \to Wb + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	20.3	🟩 Y mass 770 GeV	Y in (B,Y) doublet	1505.04306
	VLQ $BB \to Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	🟩 B mass 735 GeV	isospin singlet	1505.04306
	VLQ $BB \to Zb + X$	2/≥3 e, μ	≥2/≥1 b		20.3	🟩 B mass 755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	🟩 Q mass 690 GeV		1509.04261
	VLQ $T_{5/3} T_{5/3} \to WtWt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	3.2	🟨 $T_{5/3}$ mass 990 GeV		ATLAS-CONF-2016-032
Excited fermions	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	3.2	🟨 q^* mass 4.4 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1512.05910
	Excited quark $q^* \to qg$	–	2 j	–	15.7	🟨 q^* mass 5.6 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2016-069
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	8.8	🟨 b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	🟩 b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	🟩 ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	🟩 ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LSTC $a_T \to W\gamma$	1 e, μ, 1 γ	–	Yes	20.3	🟩 a_T mass 960 GeV		1407.8150
	LRSM Majorana ν	2 e, μ	2 j	–	20.3	🟩 N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to ee$	2 e (SS)	–	–	13.9	🟨 $H^{\pm\pm}$ mass 570 GeV	DY production, BR($H_L^{\pm\pm} \to ee$)=1	ATLAS-CONF-2016-051
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	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, μ	1 b	Yes	20.3	🟩 spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	🟩 multi-charged particle mass 785 GeV	DY production, $\lvert q \rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	🟩 monopole mass 1.34 TeV	DY production, $\lvert g \rvert = 1 g_D$, spin 1/2	1509.08059

🟩 $\sqrt{s}$ = 8 TeV 🟨 $\sqrt{s}$ = 13 TeV

Exotic Searches July 2017



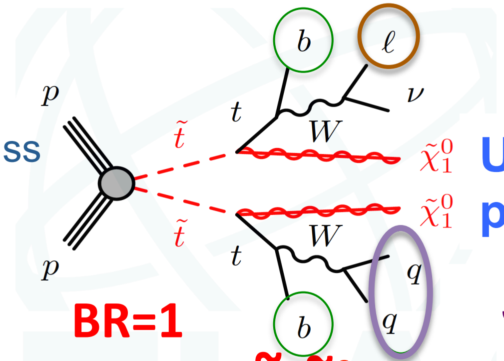
	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\,dt[fb^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1 − 4 j	Yes	36.1	🟨 M_D 7.75 TeV	$n = 2$	ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	2 γ	−	−	36.7	🟨 M_S 8.6 TeV	$n = 3$ HLZ NLO	CERN-EP-2017-132
	ADD QBH	−	2 j	−	37.0	🟨 M_{th} 8.9 TeV	$n = 6$	1703.09217
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	−	3.2	🟨 M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	−	≥ 3 j	−	3.6	🟨 M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	−	−	36.7	🟨 G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	CERN-EP-2017-132
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	1 e, μ	1 J	Yes	36.1	🟨 G_{KK} mass 1.75 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2017-051
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	🟨 KK mass 1.6 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	ATLAS-CONF-2016-104
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	−	−	36.1	🟨 Z' mass 4.5 TeV		ATLAS-CONF-2017-027
	SSM $Z' \to \tau\tau$	2 τ	−	−	36.1	🟨 Z' mass 2.4 TeV		ATLAS-CONF-2017-050
	Leptophobic $Z' \to bb$	−	2 b	−	3.2	🟨 Z' mass 5 TeV		1603.08791
	Leptophobic $Z' \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	3.2	🟨 Z' mass 2.0 TeV	$\Gamma/m = 3\%$	ATLAS-CONF-2016-014
	SSM $W' \to \ell\nu$	1 e, μ	−	Yes	36.1	🟨 W' mass 5.1 TeV		1706.04786
	HVT $V' \to WV \to qqqq$ model B	0 e, μ	2 J	−	36.7	🟨 V' mass 3.5 TeV	$g_V = 3$	CERN-EP-2017-147
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	🟨 V' mass 2.93 TeV	$g_V = 3$	ATLAS-CONF-2017-055
	LRSM $W'_R \to tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	🟩 W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	0 e, μ	≥ 1 b, 1 J	−	20.3	🟩 W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	−	2 j	−	37.0	🟨 Λ 21.8 TeV η_{LL}^-		1703.09217
	CI $\ell\ell qq$	2 e, μ	−	−	36.1	🟨 Λ 40.1 TeV η_{LL}^-		ATLAS-CONF-2017-027
	CI $uutt$	2(SS)/≥3 e, μ	≥1 b, ≥1 j	Yes	20.3	🟩 Λ 4.9 TeV	$\lvert C_{RR}\rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	1 − 4 j	Yes	36.1	🟨 m_{med} 5 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 400$ GeV	ATLAS-CONF-2017-060
	Scalar mediator t-ch. (Dirac DM)	0 e, μ	1 − 4 j	Yes	36.1	🟨 m_{med} .65 TeV	g=1, $m(\chi) - m(\eta) < 500$ GeV	ATLAS-CONF-2017-060
	Vector mediator (Dirac DM)	0 e, μ, 1 γ	≤ 1 j	Yes	36.1	🟨 m_{med} 1.2 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 480$ GeV	1704.03848
	$VV\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	🟨 M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	−	3.2	🟨 LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	−	3.2	🟨 LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	≥1 b, ≥3 j	Yes	20.3	🟩 LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	0 or 1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	🟨 T mass 1.2 TeV	$\mathcal{B}(T \to Ht) = 1$	ATLAS-CONF-2016-104
	VLQ $TT \to Zt + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	36.1	🟨 T mass 1.16 TeV	$\mathcal{B}(T \to Zt) = 1$	1705.10751
	VLQ $TT \to Wb + X$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	🟨 T mass 1.3[illegible] TeV	$\mathcal{B}(T \to Wb) = 1$	CERN-EP-2017-094
	VLQ $BB \to Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	🟩 B mass 700 GeV	$\mathcal{B}(B \to Hb) = 1$	1505.04306
	VLQ $BB \to Zb + X$	2/≥3 e, μ	≥2/≥1 b	−	20.3	🟩 B mass 790 GeV	$\mathcal{B}(B \to Zb) = 1$	1409.5500
	VLQ $BB \to Wt + X$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	🟨 B mass 1.25 TeV	$\mathcal{B}(B \to Wt) = 1$	CERN-EP-2017-094
	VLQ $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	🟩 Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	−	2 j	−	37.0	🟨 q^* mass 6.0 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1703.09127
	Excited quark $q^* \to q\gamma$	1 γ	1 j	−	36.7	🟨 q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	CERN-EP-2017-148
	Excited quark $b^* \to bg$	−	1 b, 1 j	−	13.3	🟨 b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	🟩 b^* mass 5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	3 e, μ	−	−	20.3	🟩 ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	−	−	20.3	🟩 ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LRSM Majorana ν	2 e, μ	2 j	−	20.3	🟩 N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	−	−	36.1	🟨 $H^{\pm\pm}$ mass 870 GeV	DY production	ATLAS-CONF-2017-053
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	−	−	20.3	🟩 $H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Monotop (non-res prod)	1 e, μ	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, $\lvert q\rvert = 5e$	1504.04188
	Magnetic monopoles	−	−	−	7.0	🟩 monopole mass 1.34 TeV	DY production, $\lvert g\rvert = 1g_D$, spin 1/2	1509.08059

Stop pair production

- R-Parity conservation SUSY model.
- Cut based analysis, top decaying leptonically
- Final state with 2 b-jets, leptons and E_T^{Miss}
- Small mass splitting among stop and neutralino → ISR jets to boost the stop-system

Long-lived particles

Charged leptons



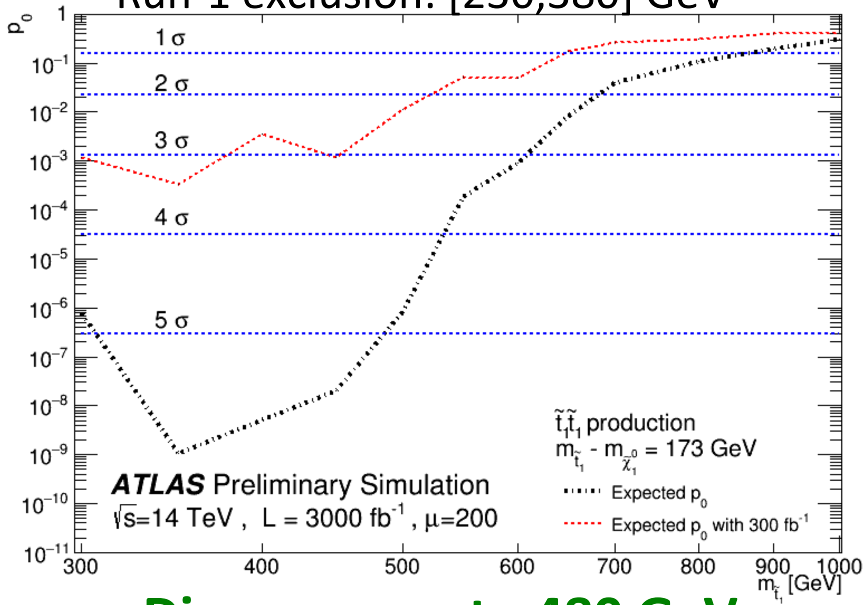
Undetected particles!

Jets

BR=1

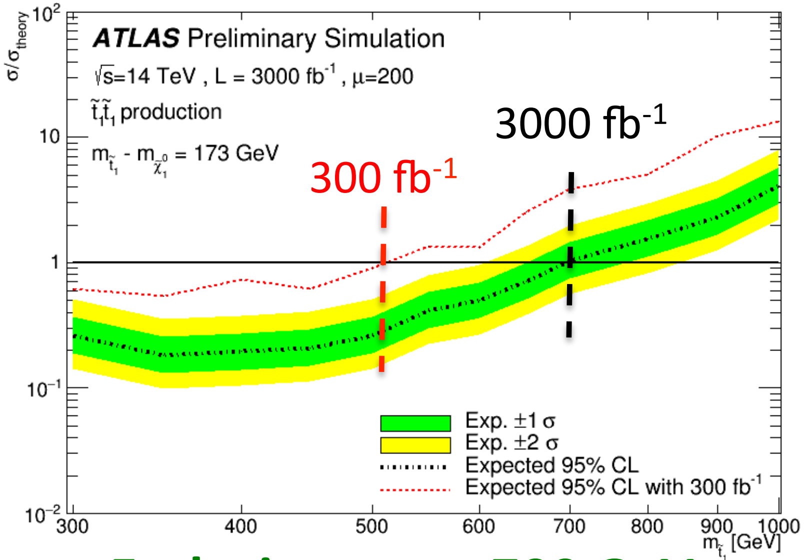
$\Delta M(\tilde{t}, \tilde{\chi}^0_1) = 173$ GeV

Run-1 exclusion: [230,380] GeV



Discovery up to 480 GeV

ATL-PHYS-PUB-2016-022



Exclusion up to 700 GeV

Stop pair production in Run2