A faint, grayscale background image of the ATLAS detector, showing its complex structure of support beams and the central barrel region.

# ATLAS: Physics Results, Performance and Prospects

Tetiana Berger  
(LAPP, CNRS, France)

Kick-off meeting Indo-French Collaboration

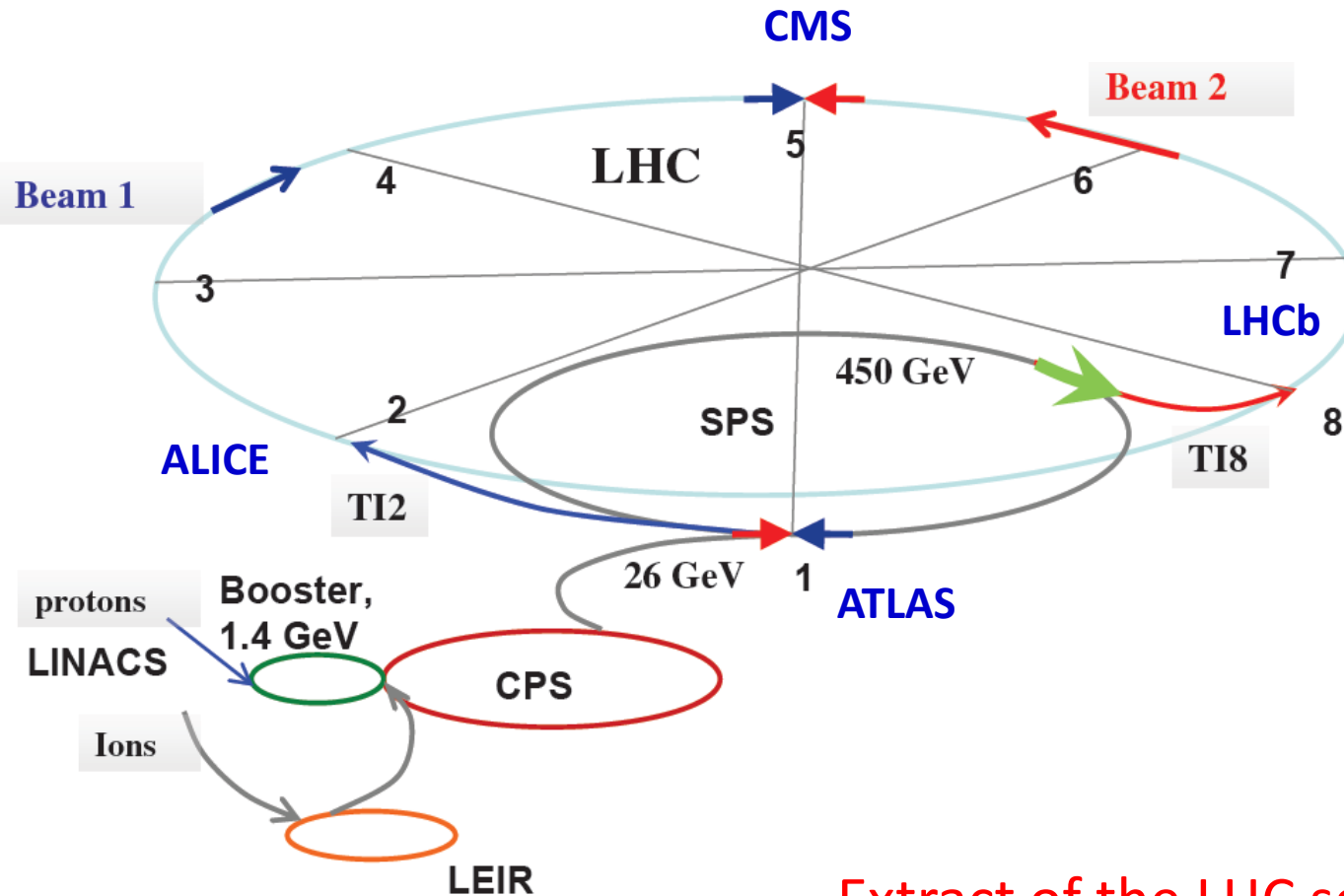
2 May 2016

# Outline

- The Large Hadron Collider
- The ATLAS Detector & Performance
- ATLAS Physics results
  - Higgs physics
  - Non-Higgs Standard Model (SM) physics
  - Searches for phenomena beyond SM

# The Large Hadron Collider (LHC)

# CERN accelerator complex



## LHC Design:

- Centre-of-mass energy ( $\sqrt{s}$ ) of proton-proton collisions **14TeV**
- Peak luminosity  **$10^{34} \text{ cm}^{-2}\text{s}^{-1}$**
- Collisions each **25ns** (2808 bunches)
- Pile-up **25 events**

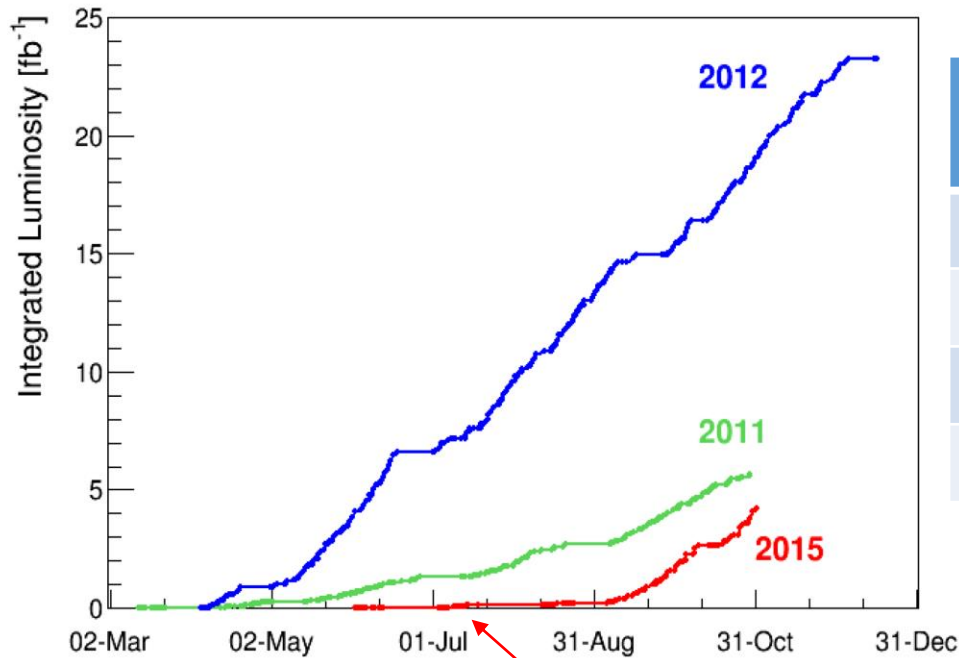
Use Nb-Ti dipoles  
@ 1.4 K (B field 8.3T)  
in 27km tunnel

## Extract of the LHC schedule



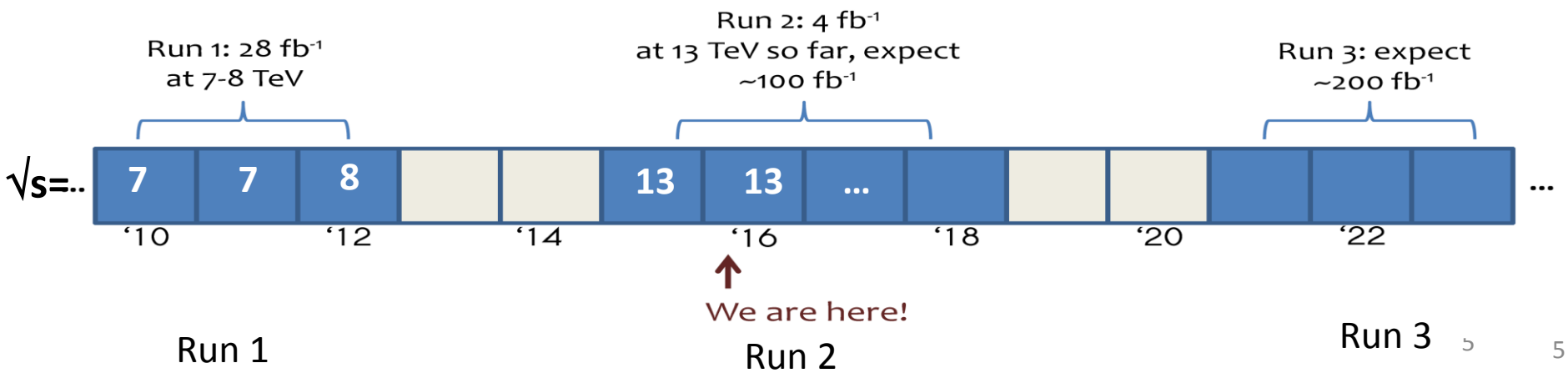


# LHC Run 2: 2015

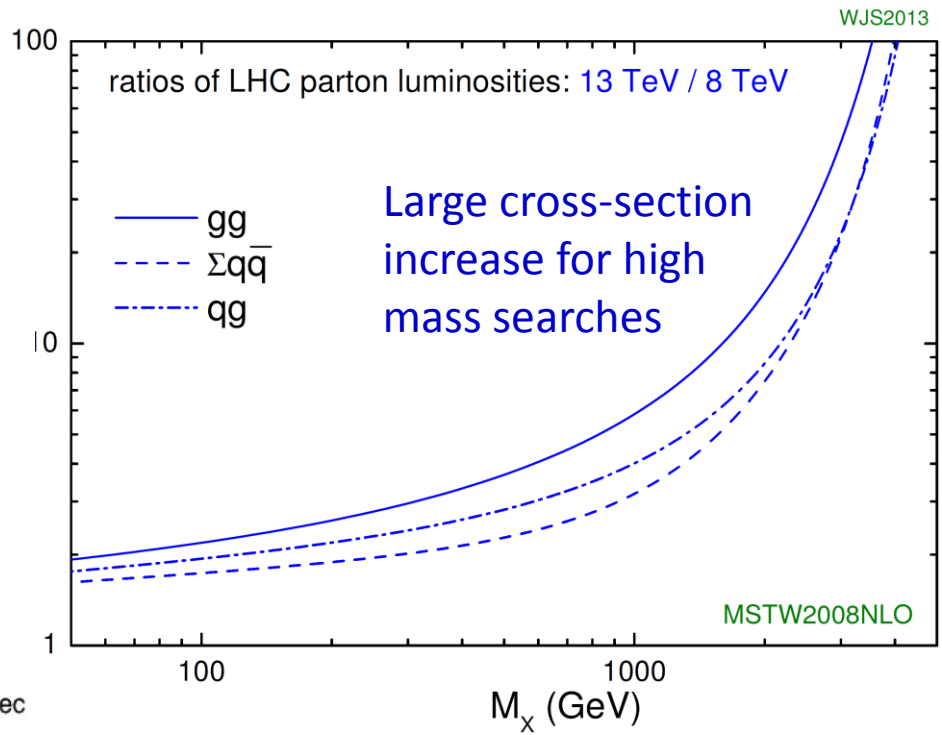
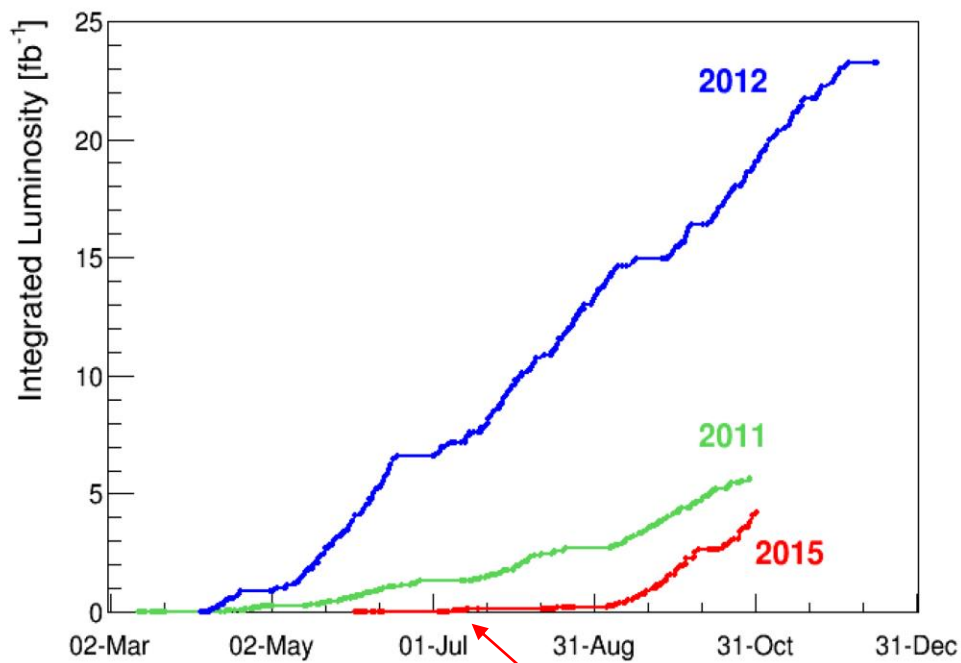


Problems with radiation resistance of tunnel quench protection system lead to slow start.

## Extract of the LHC schedule

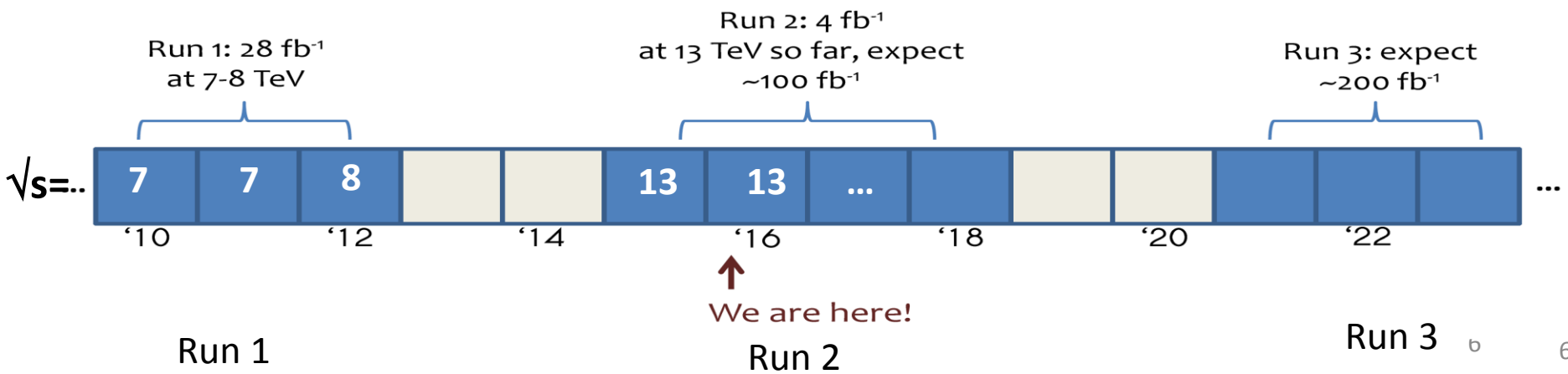


# LHC Run 2: 2015



Problems with radiation resistance of tunnel quench protection system lead to slow start.

## Extract of the LHC schedule





13TeV  
Stable Beam  
running restarted  
on April 22<sup>nd</sup> 2016

Run: 297041  
Event: 59057181  
2016-04-24 05:41:50 CEST

	Apr				May				June				
Wk	14	15	16	17	18	19	20	21	22	23	24	25	26
Mo	4	11	18	25	2	9	Whit 16	23	30	6	13	20	27
Tu							VdM		beta* 2.5 km dev.				
We		Injector TS (8 hours)								TS1			
Th					Ascension								
Fr					May Day comp				MD 1				
Sa	Recommissioning with beam				Intensity ramp-up Scrubbing as required								
Su				1st May									

	July				Aug				Sep				
Wk	27	28	29	30	31	32	33	34	35	36	37	38	39
Mo	4	11	18	25	1	8	15	22	29	5	12	19	26
Tu													
We				MD 2						MD 3	TS2		
Th							MD			Jeune G			
Fr													
Sa				beta* 2.5 km dev.									
Su													

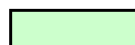
	Oct				Nov				Dec				
Wk	40	41	42	43	44	45	46	47	48	49	50	51	52
Mo	3	10	17	24	31	7	14	21	28	5	12	19	26
Tu							lons setup				Extended year end technical stop		
We						TS3							
Th												Lab closed	
Fr					MD 4								
Sa													
Su												Xmas	New Year



Technical Stop



Machine development



Recommissioning with beam




Special physics runs - provisional dates



Scrubbing (indicative - dates to be established)

# Weasel

	Apr				Wed	May				June					
Wk	14	15	16	17		18	19	20	21	22	23	24	25	26	
Mo	4	11	18		25	2	9	Whit	16	23	30	6	13	20	27
Tu															
We		Injector TS (8 hours)						VdM		beta* 2.5 km dev.					
Th											TS1				
Fr	Recommissioning with beam					Ascension									
Sa						May Day comp					MD 1				
Su															
							Intensity ramp-up Scrubbing as required								



	July				Aug				Sep					
Wk	27	28	29	30	31	32	33	34	35	36	37	38	39	
Mo	4	11	18	25	1	8	15	22	29	5	12	beta* = 2.5 km data taking	19	26
Tu														
We				MD 2						MD 3	TS2			
Th							MD			Jeune G				
Fr														
Sa				beta* 2.5 km dev.										
Su														

	Oct				Nov				Dec				End of run [06:00]	
Wk	40	41	42	43	44	45	46	47	48	49	50	51	52	
Mo	3	10	17	24	31	7	14	21	28	5	12	19	26	
Tu							lons setup				Extended year end technical stop			
We						TS3								
Th									Ion run (p-Pb)			Lab closed		
Fr					MD 4									
Sa														
Su												Xmas	New Year	

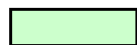
End of run  
[06:00]



Technical Stop



Machine development



Recommissioning with beam



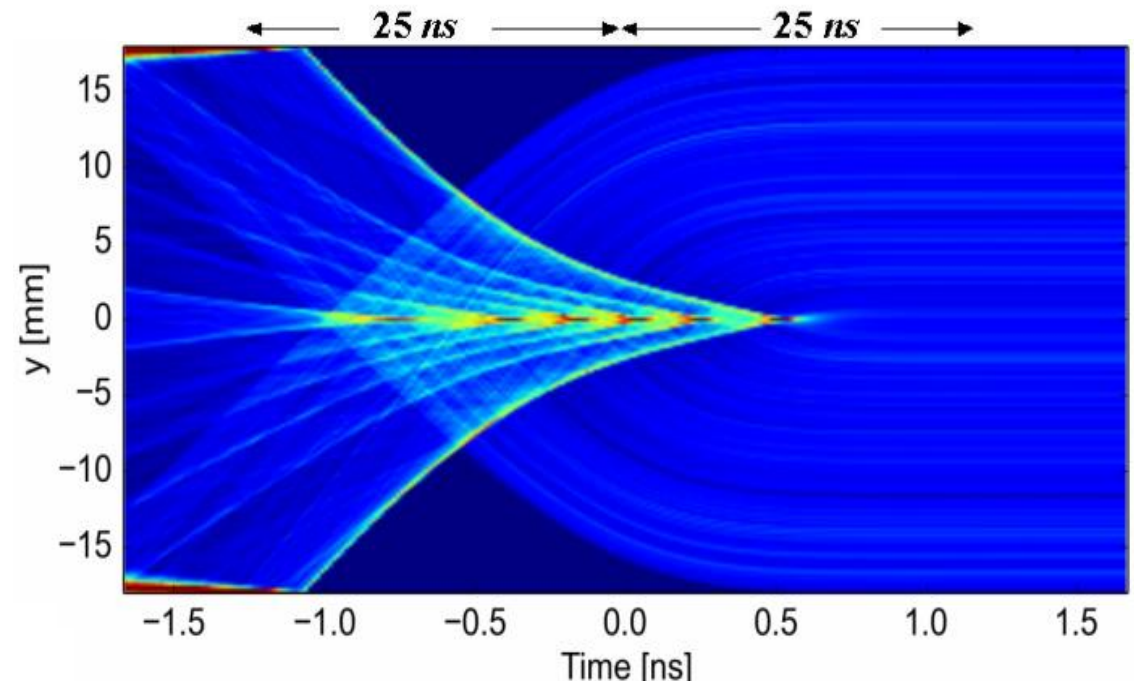
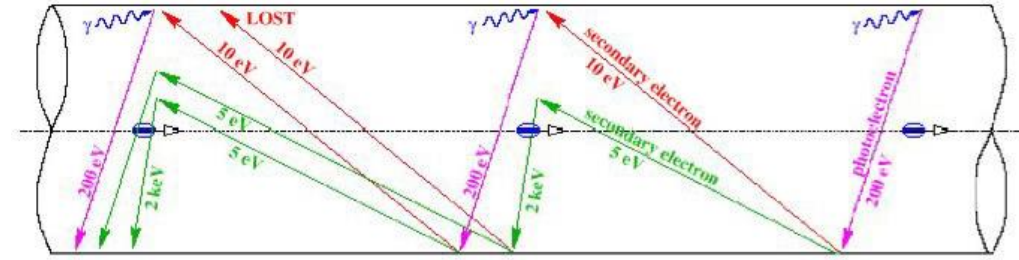
Special physics runs - provisional dates



Scrubbing (indicative - dates to be established)

# Run 2 LHC (cont)

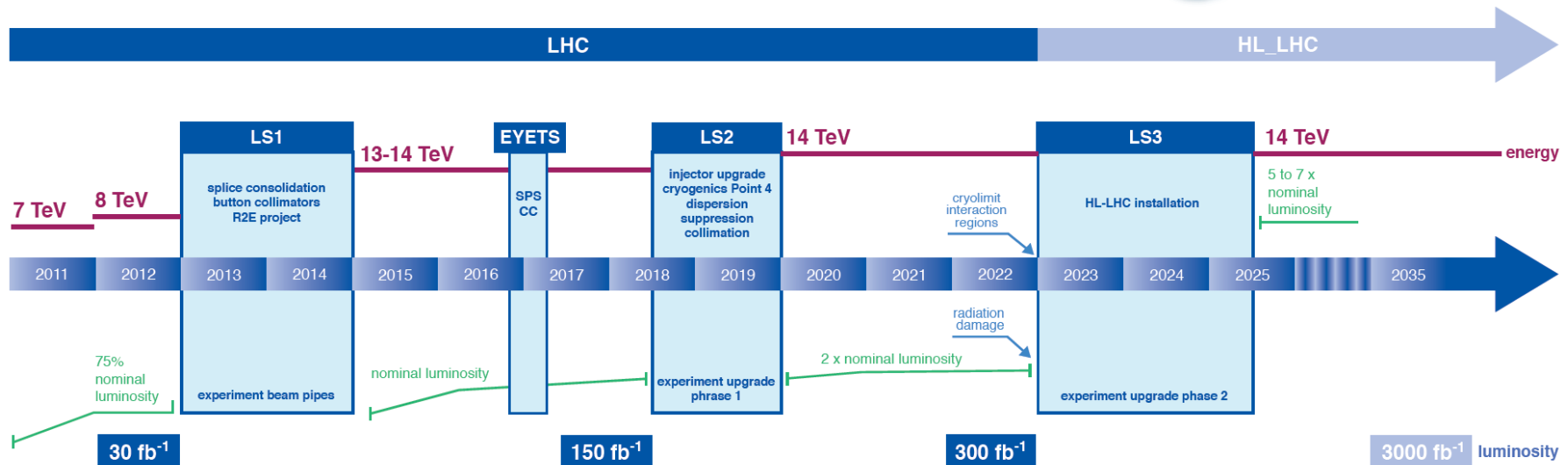
- Electron cloud effects reduce with data-taking and scrubbing (running high number of bunches at low energy)
- To be able to increase energy to 14TeV magnets need to undergo a certain number of quenches which happen during data-taking



Extract of the LHC schedule



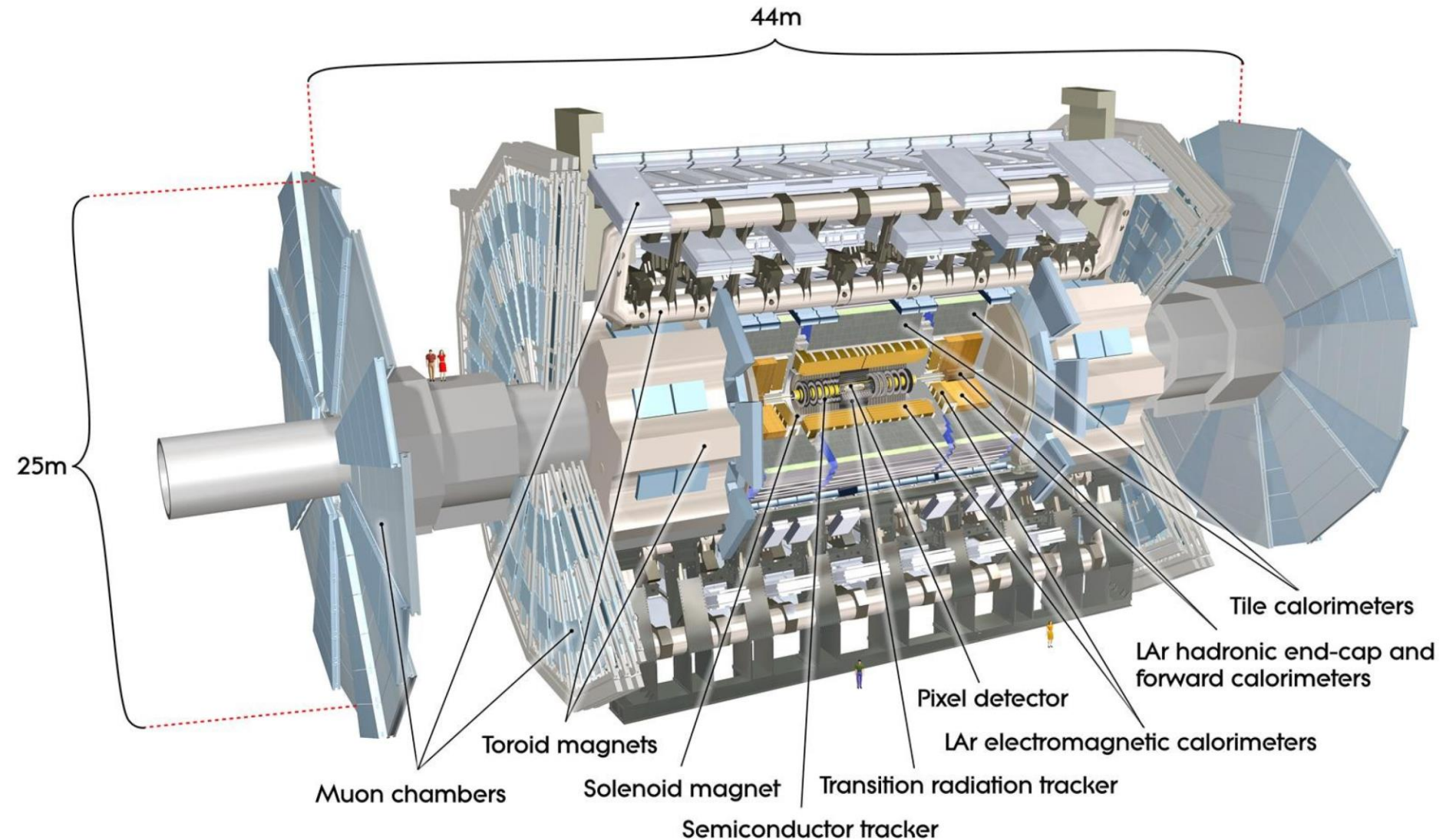
# LHC beyond Run 2



- $100 \text{ fb}^{-1}$  in the end of Run 2 (2018)
- $300 \text{ fb}^{-1}$  in the end of Run 3 (2023)
- $3000 \text{ fb}^{-1}$  in the end of the LHC program ( $\sim 2037$ )



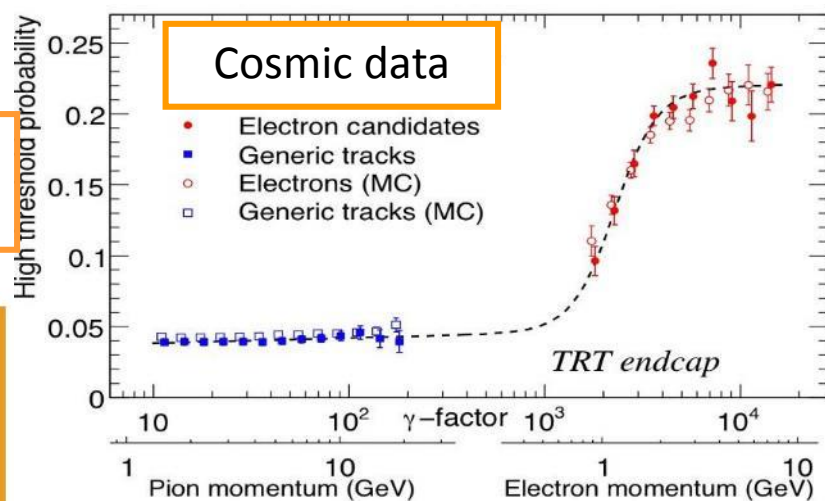
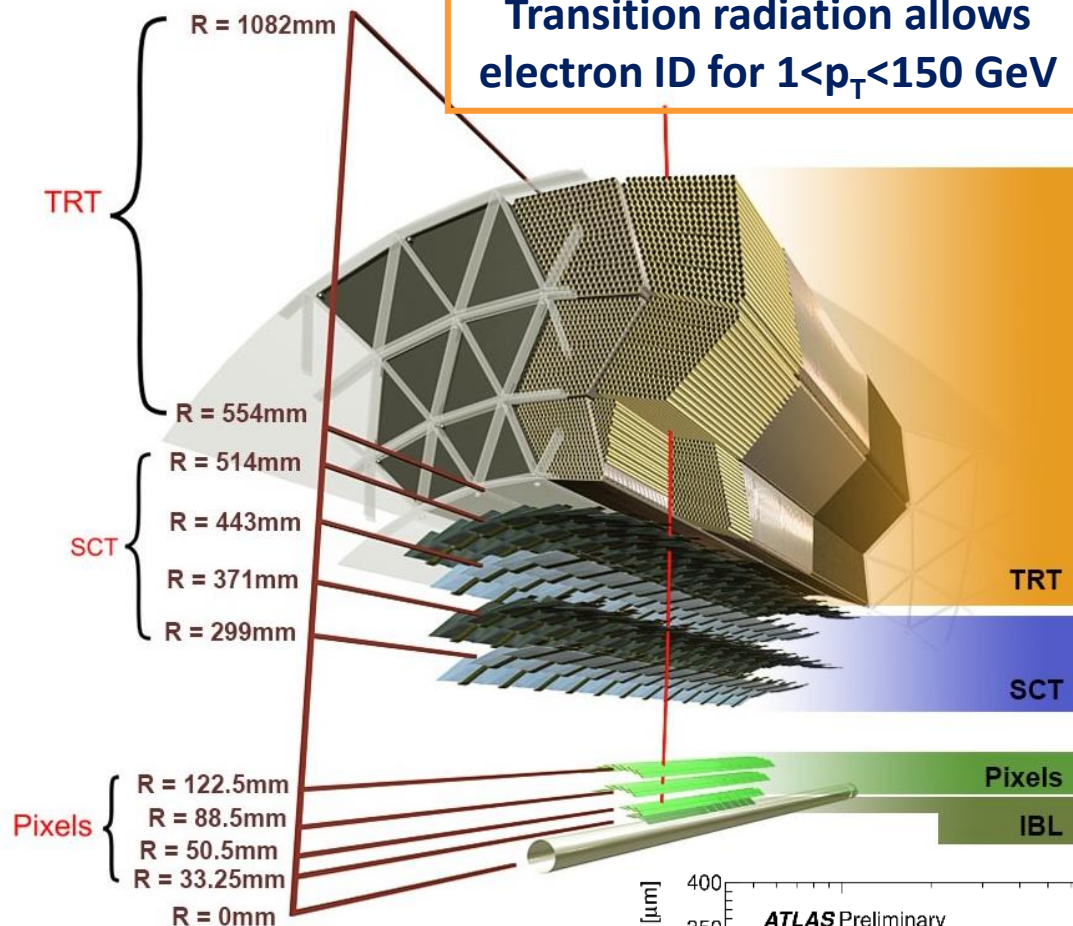
# The ATLAS Detector & Performance





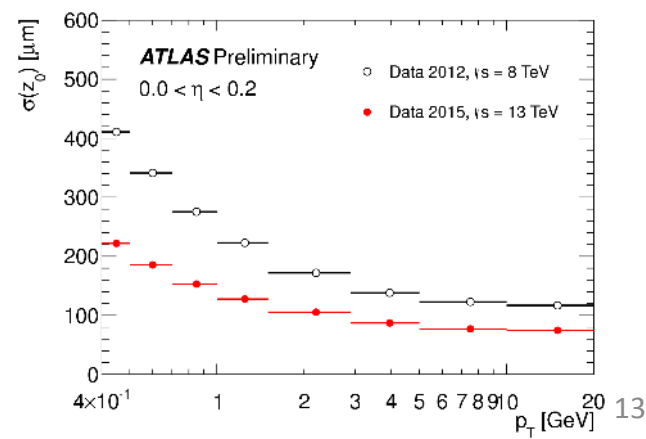
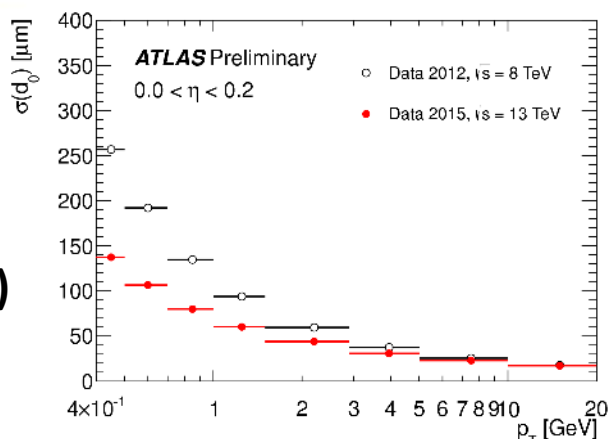
# Inner Detector

Transition radiation allows  
electron ID for  $1 < p_T < 150$  GeV



**Transition Radiation Tracker (TRT):**  
drift tubes with gas (Xe or Kr), 350 k channels, 36 measurement points  
**Semiconductor Tracker (SCT)** Silicon, 6.2 M channels, 4 layers  
**Pixel Detector:** Silicon, 92 M channels, 4 layers

Impact parameter  
resolution improvement  
due to Insertable B-Layer (IBL)  
added for Run 2



# ATLAS Calorimeters

## Hadronic Barrel :

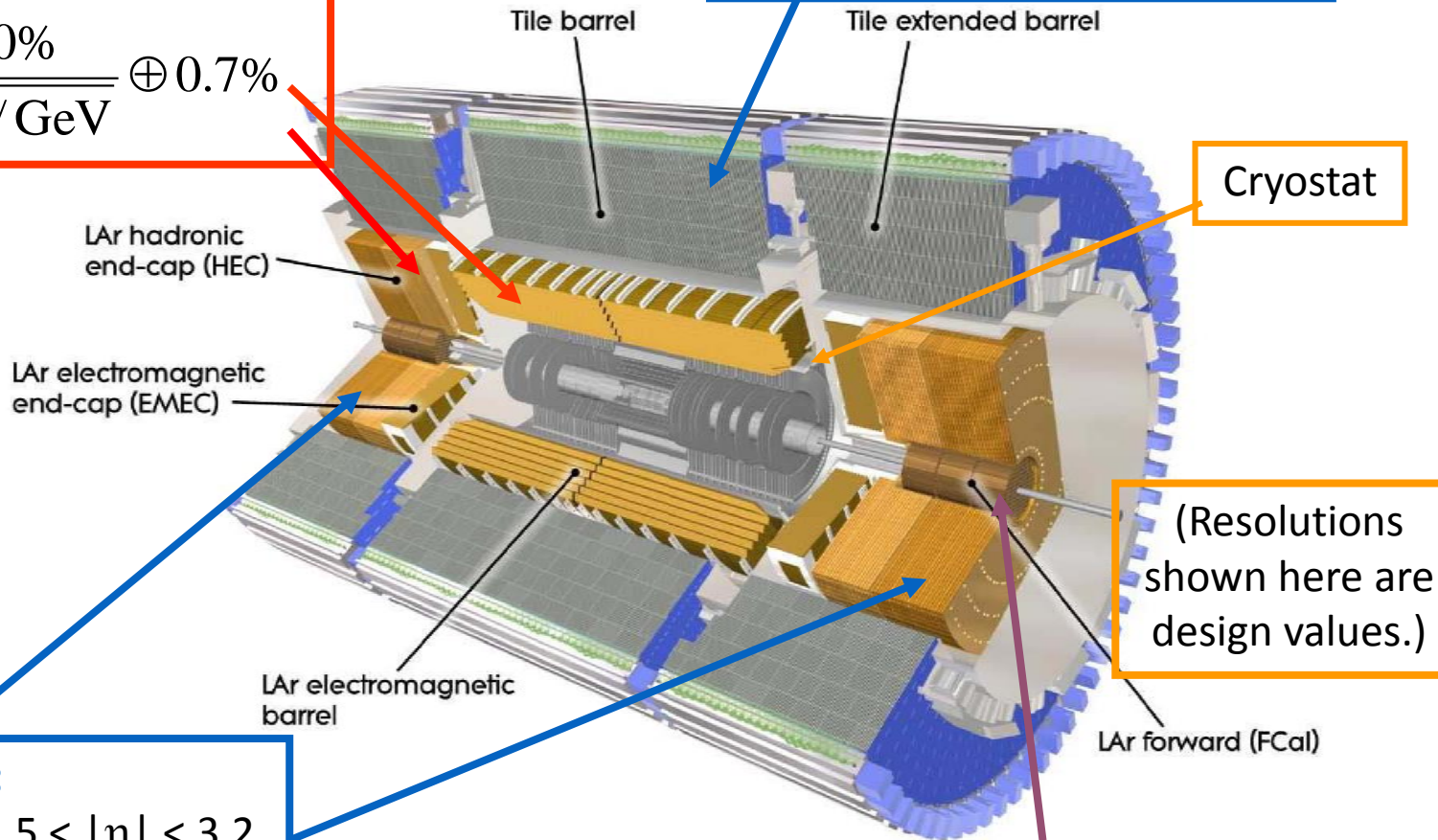
Scintillator/Fe,  $|\eta| < 1.7$

$$\left. \frac{\sigma(E)}{E} \right|_{Jet} \cong \frac{50\%}{\sqrt{E / \text{GeV}}} \oplus 3\%$$

## EM Calorimetry :

Liquid-Argon/Pb accordeon,  $|\eta| < 3.2$

$$\left. \frac{\sigma(E)}{E} \right|_{e/\gamma} \cong \frac{10\%}{\sqrt{E / \text{GeV}}} \oplus 0.7\%$$



## Hadronic End-cap:

Liquid Argon/Cu,  $1.5 < |\eta| < 3.2$

$$\left. \frac{\sigma(E)}{E} \right|_{Jet} \cong \frac{50\%}{\sqrt{E / \text{GeV}}} \oplus 3\%$$

## Forward Calorimeters:

Liquid Argon/Cu/W,  
 $3.1 < |\eta| < 4.9$

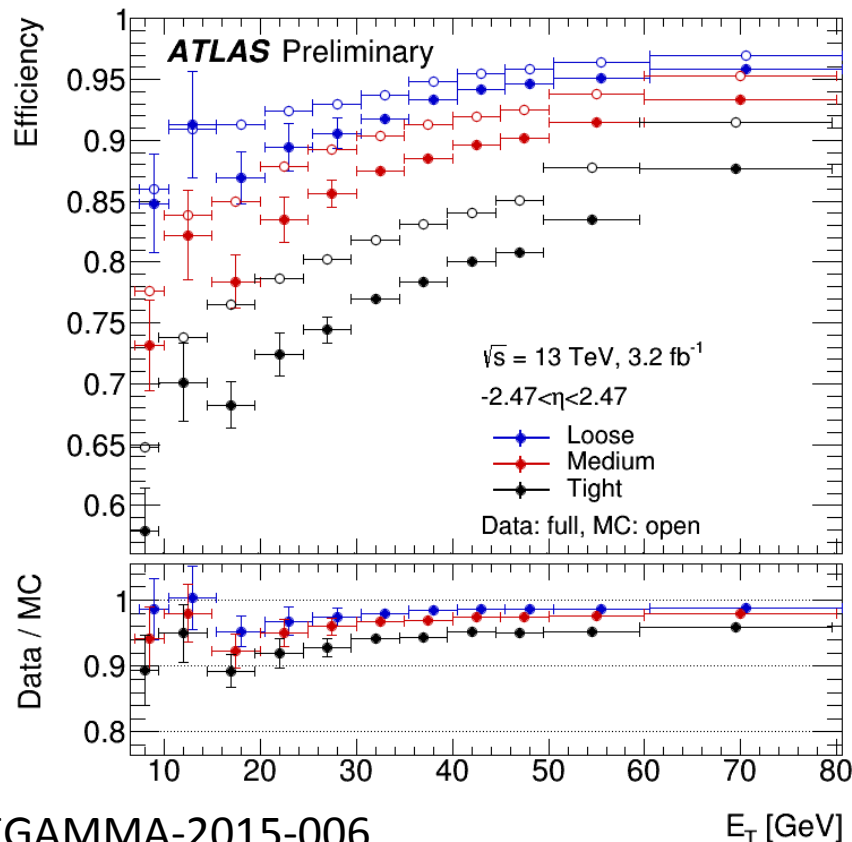
$$\left. \frac{\sigma(E)}{E} \right|_{Jet} \cong \frac{100\%}{\sqrt{E / \text{GeV}}} \oplus 10\%$$

# Electron and photon identification (ID)

## Electron ID

*Likelihood identification* improves background rejection wrt cut-based by 50% for the same efficiency

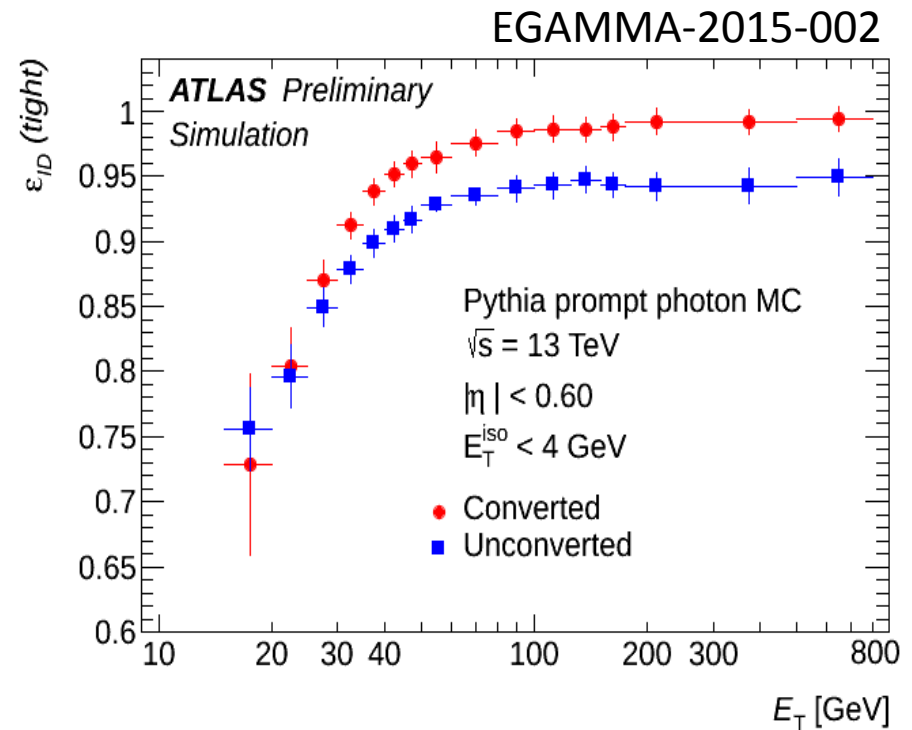
*Inputs:* calorimeter shower shapers, tracking and track-cluster matching, TRT PID



## Photon ID

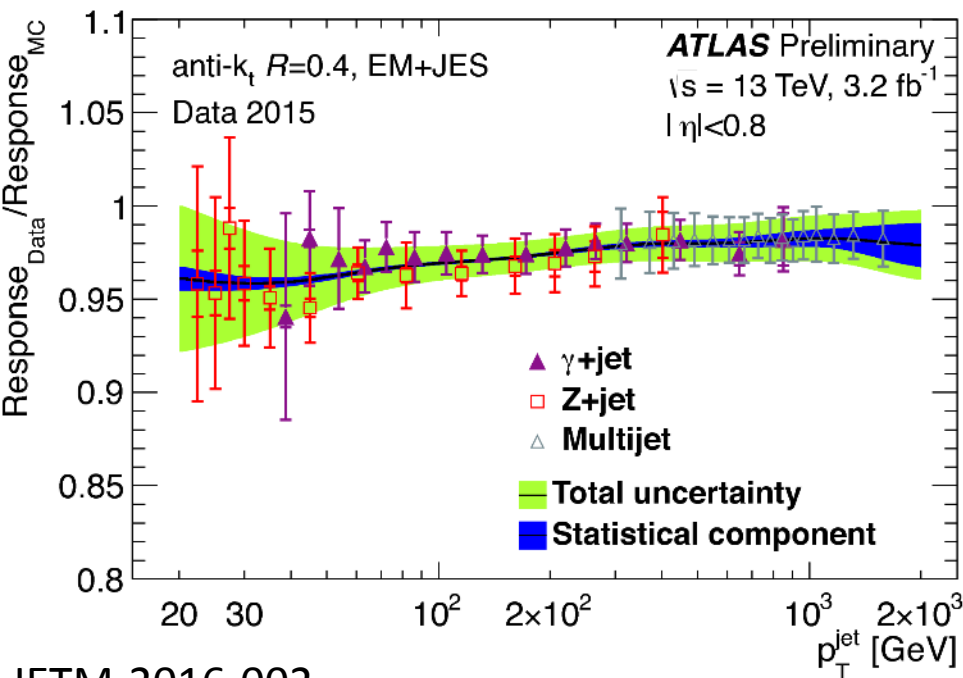
Using *cut-based selection*

*Inputs:* calorimeter shower shapers for unconverted photons; add tracking and track-cluster matching for converted photons

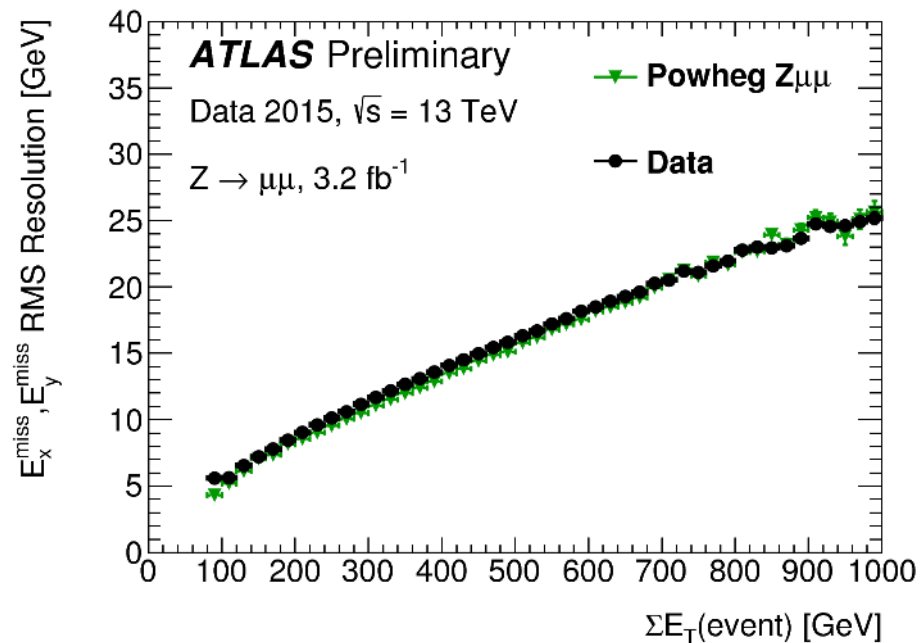


# Jets and $E_T^{\text{Miss}}$ reconstruction

## In-situ energy scale correction



## $E_T^{\text{Miss}}$ resolution



JETM-2016-006

Jet energy scale and resolution  
extracted from data

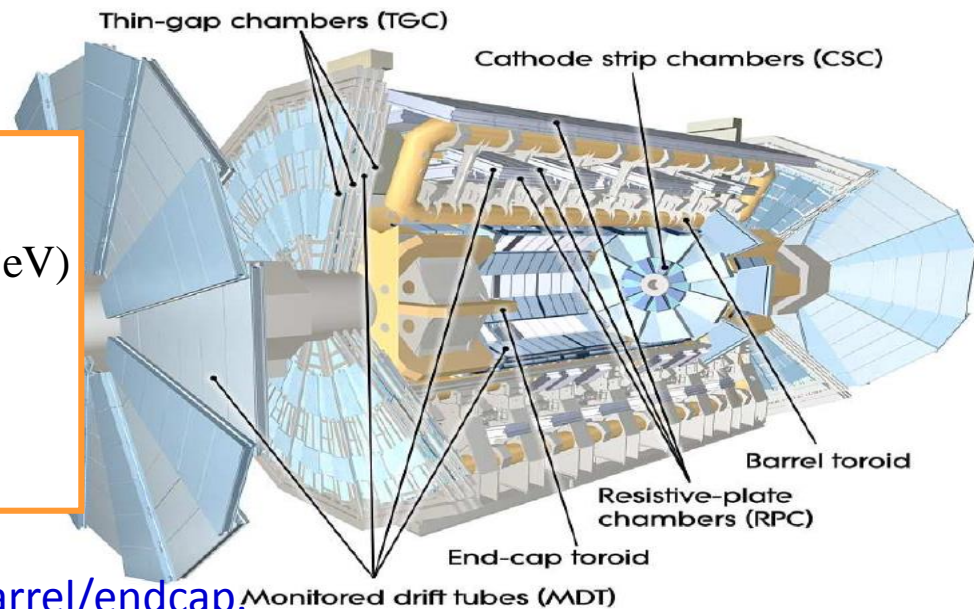
$E_T^{\text{Miss}}$  uncertainties  
extracted from data



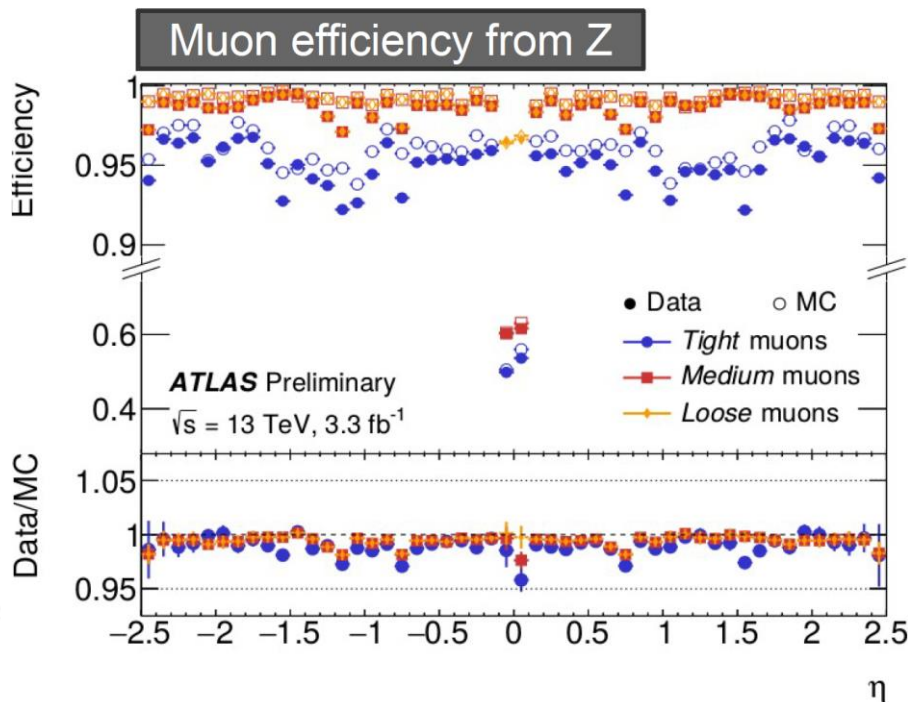
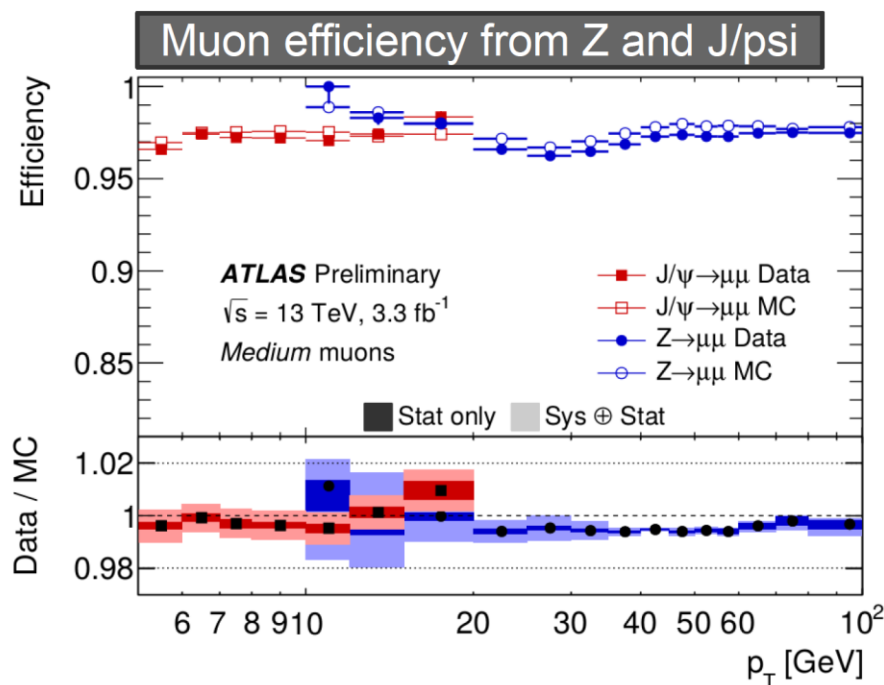
# Muon Spectrometer

## Muon Spectrometer : $|\eta| < 2.7$

- Standalone:  $\left. \frac{\sigma(p)}{p} \right|_{\mu} \cong 3\% (100 \text{ GeV}) - 10\% (1 \text{ TeV})$
- Combined with inner tracker:  $\left. \frac{\sigma(p)}{p} \right|_{\mu} \cong 2\% \quad (p_T < 50 \text{ GeV})$

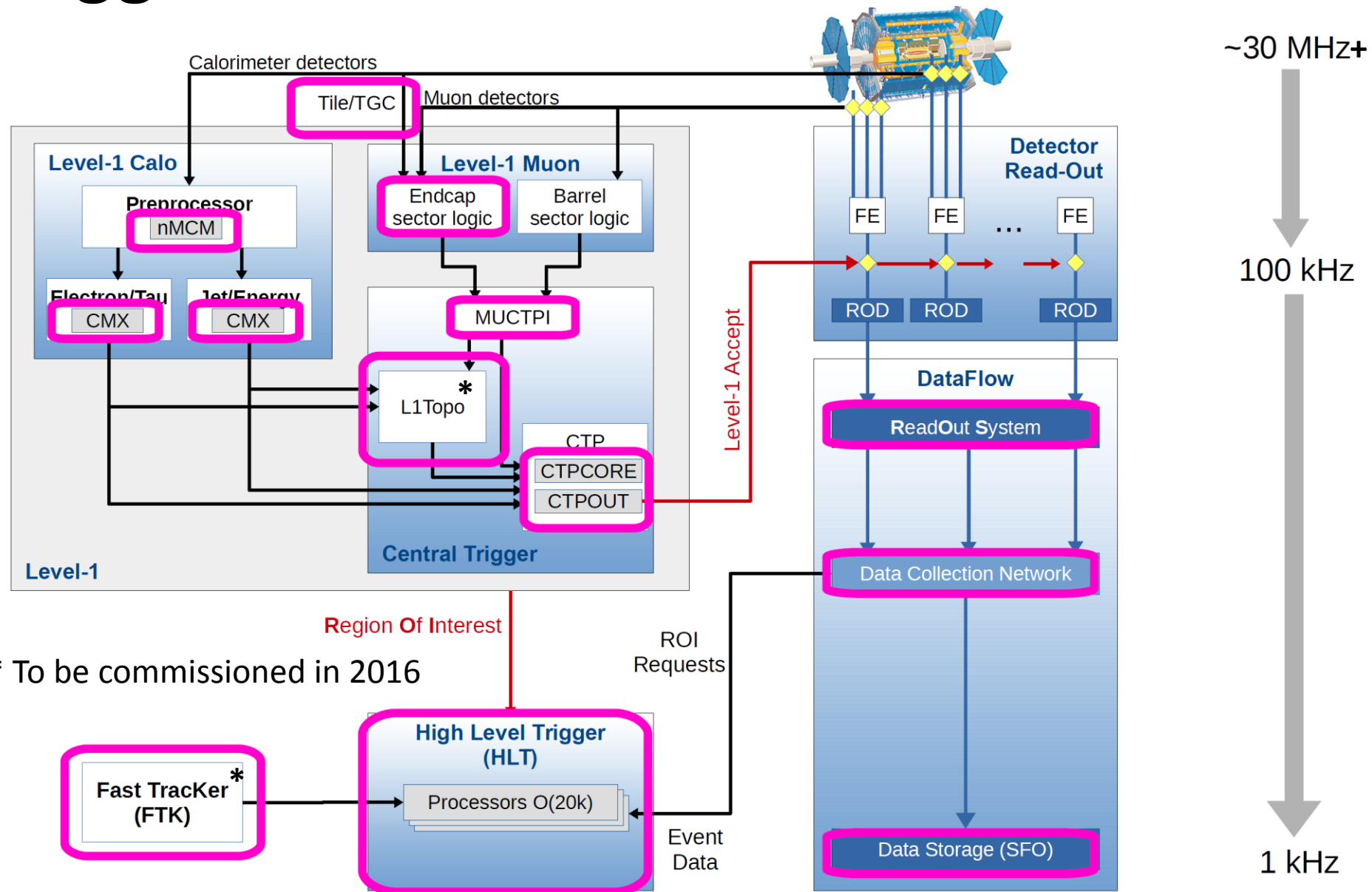


2015 alignment better than  $O(50/100\mu\text{m})$  in barrel/endcap.



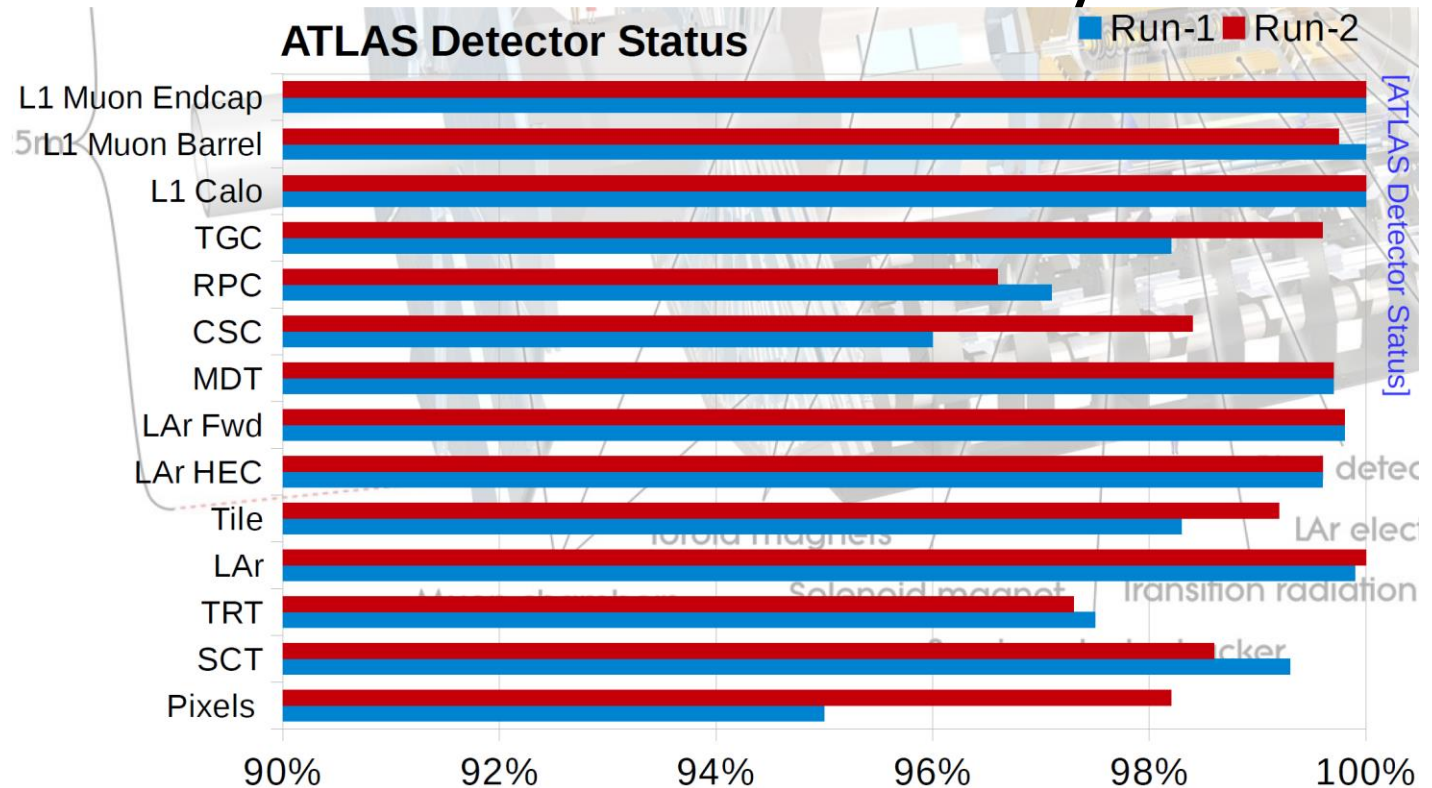
Very good data/MC agreement.

# Trigger & DAQ in Run 2



2015 triggers very similar or even lower than the Run 1 ones.

# Detector status and Data Quality



## ATLAS pp 25ns 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: 87.1% ( $3.2 \text{ fb}^{-1}$ )**

Luminosity weighted relative detector uptime and good data quality (DQ) efficiencies (in %) during stable beam in pp collisions with 25ns bunch spacing at  $\sqrt{s}=13 \text{ TeV}$  between August-November 2015, corresponding to an integrated luminosity of  $3.7 \text{ fb}^{-1}$ . The lower DQ efficiency in the Pixel detector is due to the IBL being turned off for two runs, corresponding to  $0.2 \text{ fb}^{-1}$ . Analyses that don't rely on the IBL can use those runs and thus use  $3.4 \text{ fb}^{-1}$  with a corresponding DQ efficiency of 93.1%.

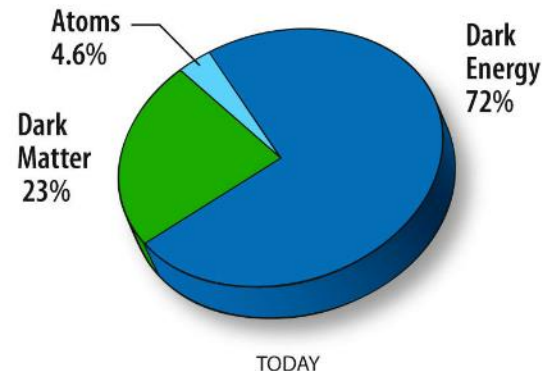
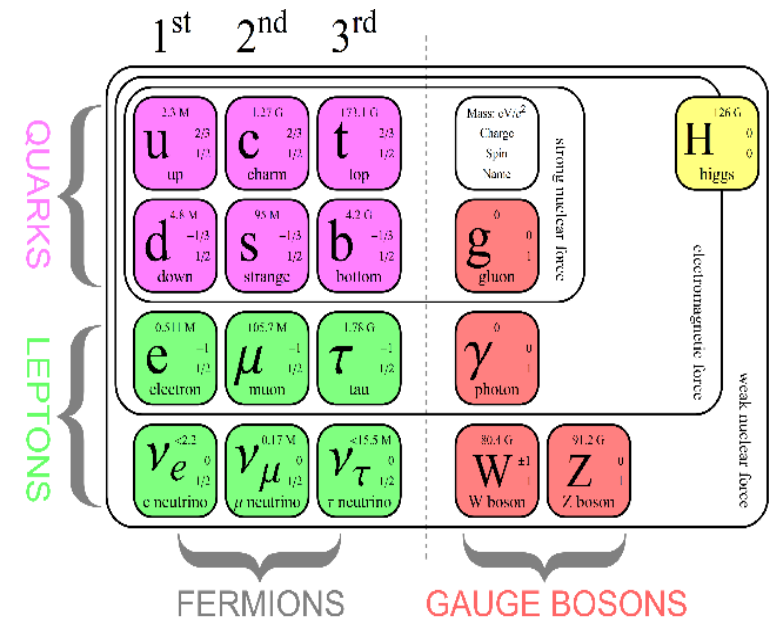
[Ref]

# ATLAS Physics results



# Physics Introduction

- Following a discovery of a scalar boson in Run 1 of LHC Standard Model (SM) is complete and self-consistent
- Certain aspects of SM do not have an explanation
  - Why is Higgs light?
  - What is dark matter?
  - How to accommodate gravity?
  - What is the solution of the hierarchy problem?
  - Why are there three generations?
  - ...



# Physics Introduction (cont)

Search for any deviations from Standard Model predictions

Direct observation:  
new (e.g. **Exotic**) resonant or  
non-resonant structures



“Physics Beyond SM”

Indirect observation:  
discrepancies in rates of rare processes,  
couplings measurements, etc.

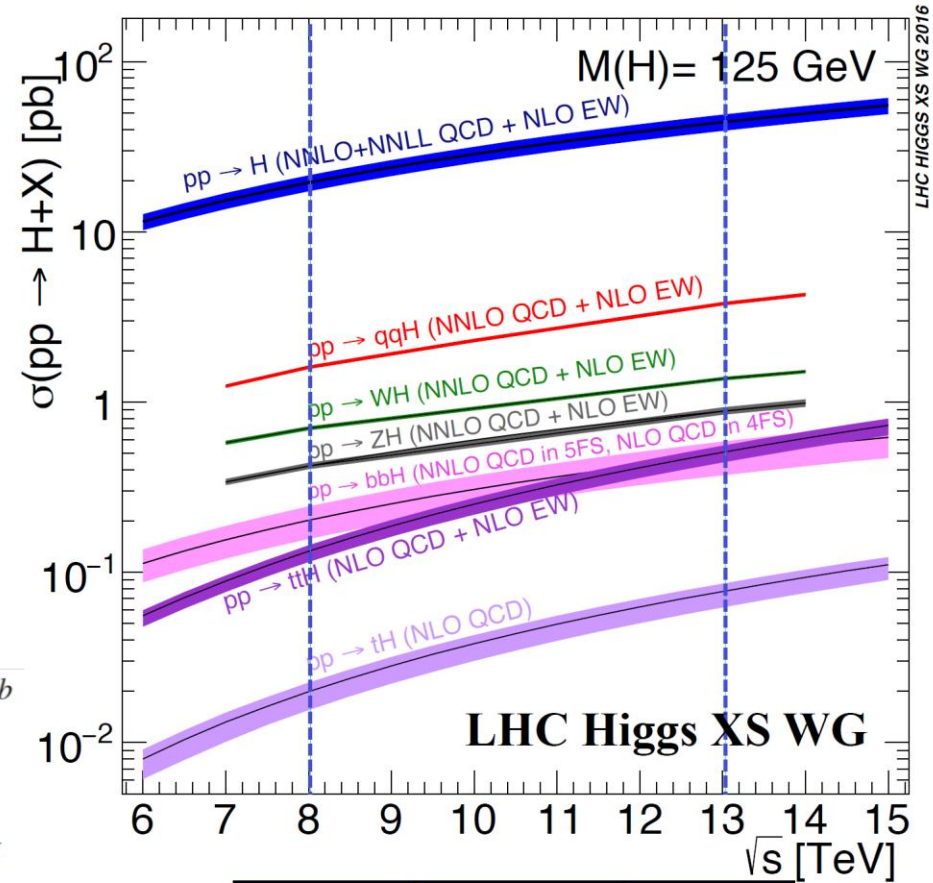
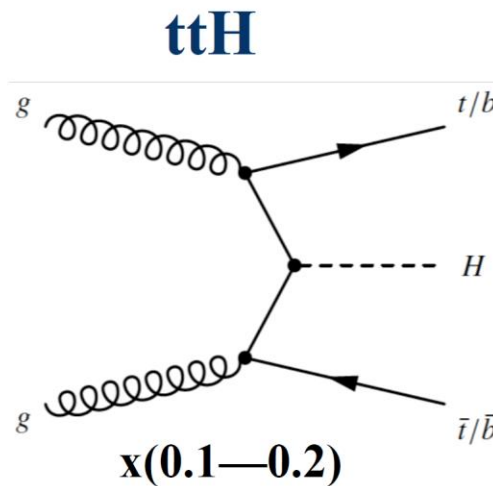
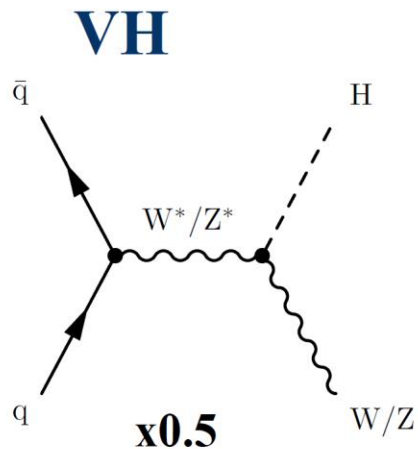
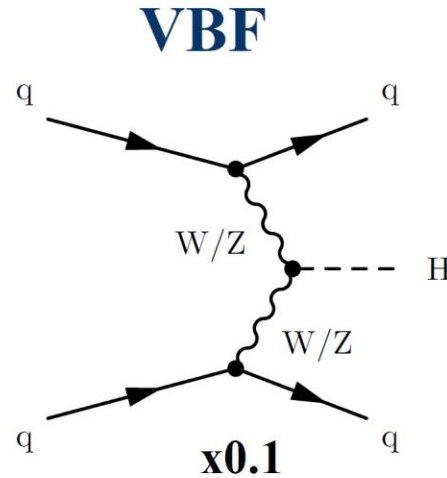
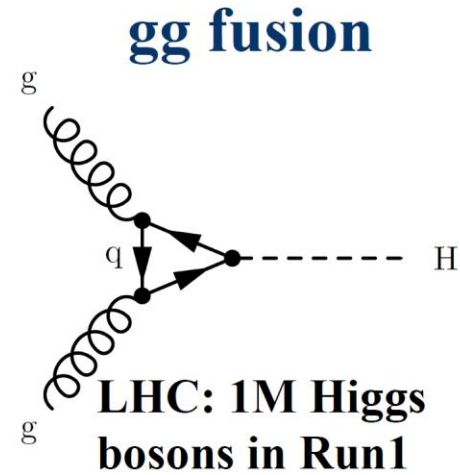


“SM Physics (Higgs & Non-Higgs)”

# Higgs Physics



# Higgs Boson Production



Mode	8 TeV	13 TeV
ggF	19	44
VBF	1.6	3.8
WH	0.70	1.4
ZH	0.42	0.88
ttH	0.13	0.51
bbH	0.20	0.49

**$\sigma$  [pb],  
 $m_H = 125 \text{ GeV}$**

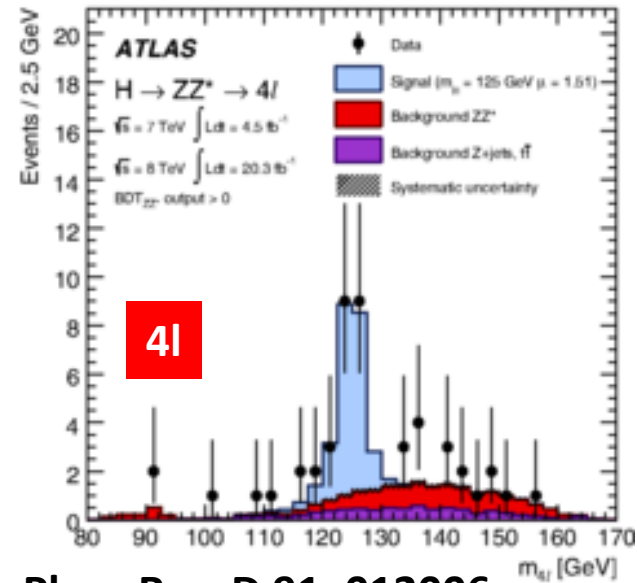
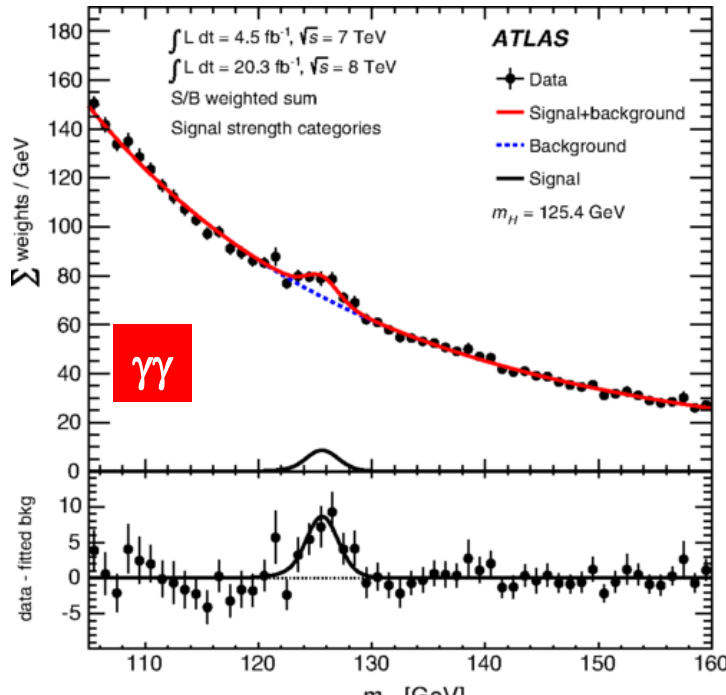


# Higgs Boson Decays ( $m_H=125\text{GeV}$ )

Mode	Sensitivity	Mass res.	S/B (incl)	rate	comments
$ZZ^* \rightarrow 4l$					very pure; $m_H$ ; SpinCP
$\gamma\gamma$					$m_H$ ; via loop
$WW \rightarrow l\nu l\nu$					high rate
$\tau\tau$					mainly VBF (sensitivity)
$bb$					mainly VH (trigger,QCD)
$ZZ^* \rightarrow llqq/ll\nu\nu$					high-mass (mainly)
$WW \rightarrow l\nu qq$					high-mass (mainly)
$\mu\mu$					rare
$Z\gamma$					

Mode	BR
$bb$	57.7%
$WW$	21.5%
$gg$	8.6%
$\tau\tau$	6.3%
$cc$	2.9%
$ZZ$	2.6%
$\gamma\gamma$	0.23%
$Z\gamma$	0.15%
$\mu\mu$	0.022%

Phys. Rev. D 90, 112015



Phys. Rev. D 91, 012006

# Higgs Mass & Width Measurement

- Higgs mass only unknown parameter in the SM
- Use the two channels with best mass resolution:

$$m_{4l} = 124.51 \pm 0.52 \text{ (stat)} \pm 0.06 \text{ (syst)} \text{ GeV}$$

$$m_{\gamma\gamma} = 125.98 \pm 0.42 \text{ (stat)} \pm 0.28 \text{ (syst)} \text{ GeV}$$

- Measurement in the two channels is model independent (production mode, spin,...)

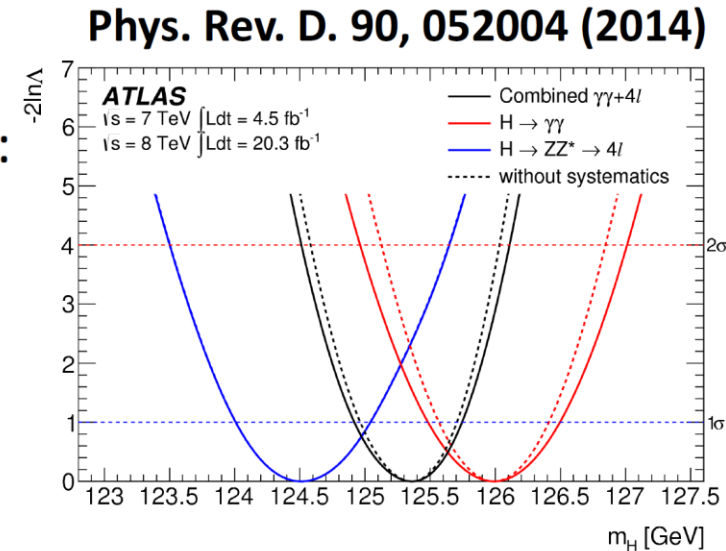
- Ratio of the cross sections of different production modes fixed to SM values
- **Combination**: use profile likelihood ratio  $\Lambda(m_H)$

$$m_h = 125.36 \pm 0.37 \text{ (stat)} \pm 0.18 \text{ (syst)} \text{ GeV}$$

**Values** used in spin and coupling studies.

## Direct width measurement

- Assume no interference with the SM background processes ( $\Gamma_H^{\text{SM}} \sim 4.1 \text{ MeV}$ )
- $\Gamma_H$  derived from fits to the mass peak
  - $\Gamma_H^{\gamma\gamma} < 5.0 \text{ GeV}$  &  $\Gamma_H^{ZZ^*} < 2.6 \text{ GeV}$  (exp 6.2 GeV) @ 95% CL



# Decay signal strength

- Decay signal strength:  $\mu_f = (\sigma \cdot \text{BR})_{\text{obs}} / (\sigma \cdot \text{BR})_{\text{SM}}$
- Assumption:
  - Higgs SM-like ( $p_T$  and  $y$ -distributions assumed to be as in SM)
  - SM relative ratios of production modes
- Largest systematic from background estimations in single decays
- Likelihood fits to the data for decay-dependent  $\mu_f$  (independent of  $\sigma_i$ )
- Combining all**  $\mu_f$ -measurements:

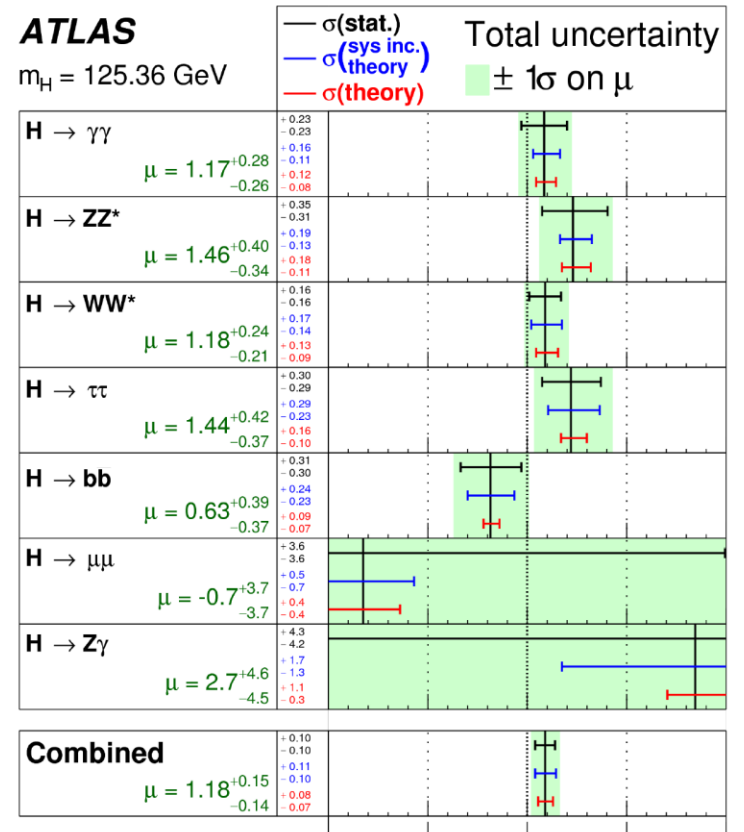
$$\mu = 1.18^{+0.15}_{-0.14} = 1.18 \pm 0.10 (\text{stat.}) \pm 0.07 (\text{syst.})^{+0.08}_{-0.07} (\text{theo.})$$

(Consistent with the SM expectation with a  $p$ -value of 18% )

**arXiv:1507.04548**

**ATLAS**

$m_H = 125.36 \text{ GeV}$



$\sqrt{s} = 7 \text{ TeV}, 4.5\text{-}4.7 \text{ fb}^{-1}$

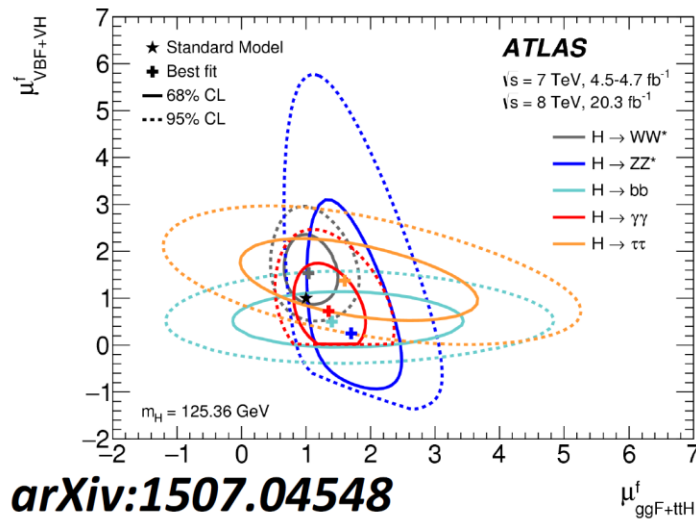
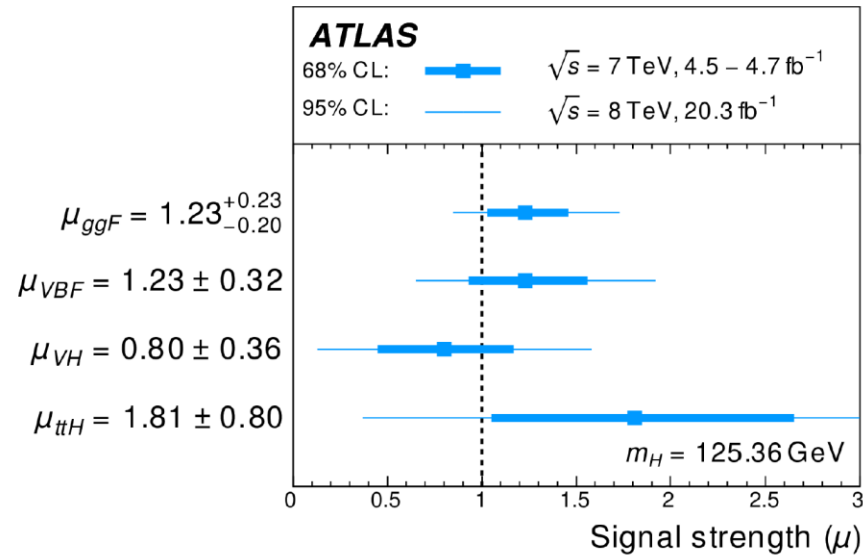
$\sqrt{s} = 8 \text{ TeV}, 20.3 \text{ fb}^{-1}$

**No sensitivity** to  $Z\gamma$  and  $\mu\mu$  decays yet

Signal strength ( $\mu$ )

# Production Signal Strength

- Production signal strength:  $\mu_i = \sigma_{\text{obs}}/\sigma_{\text{SM}}$  corresponding to:  $\mu_{\text{ggF}}$ ,  $\mu_{\text{VBF}}$ ,  $\mu_{\text{VH}}$  and  $\mu_{\text{ttH}}$
- Assumption: SM values for the ratios of the BR of different Higgs decays
- ttH needs more data to be firmly established



- Can divide into bosonic and fermionic production signal strengths:  $\mu_{\text{VBF+VH}}$   $\mu_{\text{ggF+ttH}}$
- Probe relative production cross section for all decay channels combined:

$$R = \mu_{\text{VBF+VH}} / \mu_{\text{ggF+ttH}} = 0.96^{+0.43}_{-0.31}$$

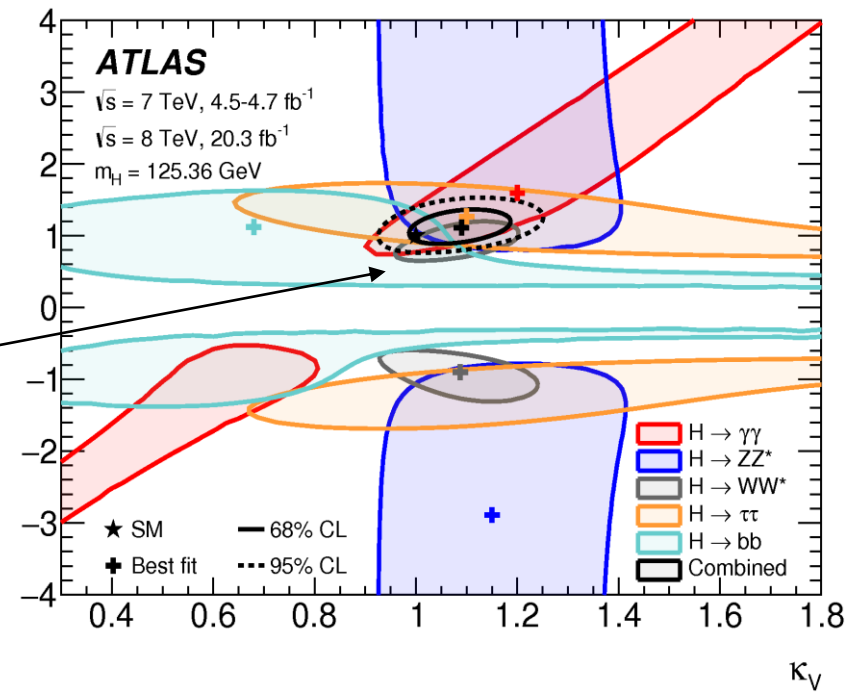


# Coupling Strength (1) <sub>$\kappa_F$</sub>

Coupling strength modifier  $\kappa$   
(ratio to SM expectation):

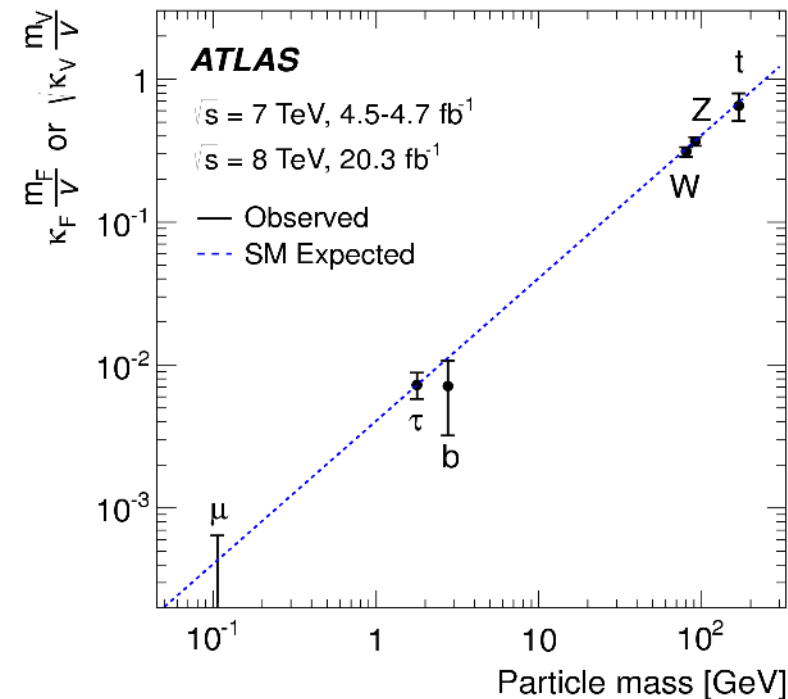
- $\kappa_i^2 = \sigma_i / \sigma_i^{\text{SM}}$
- $\kappa_f^2 = \Gamma_f / \Gamma_f^{\text{SM}}$

**41% SM  
compatibility**



Total width

- Assume no BSM contribution
- No BSM decays



# Coupling Strength (2)

Coupling strength modifier  $\kappa$   
(ratio to SM expectation):

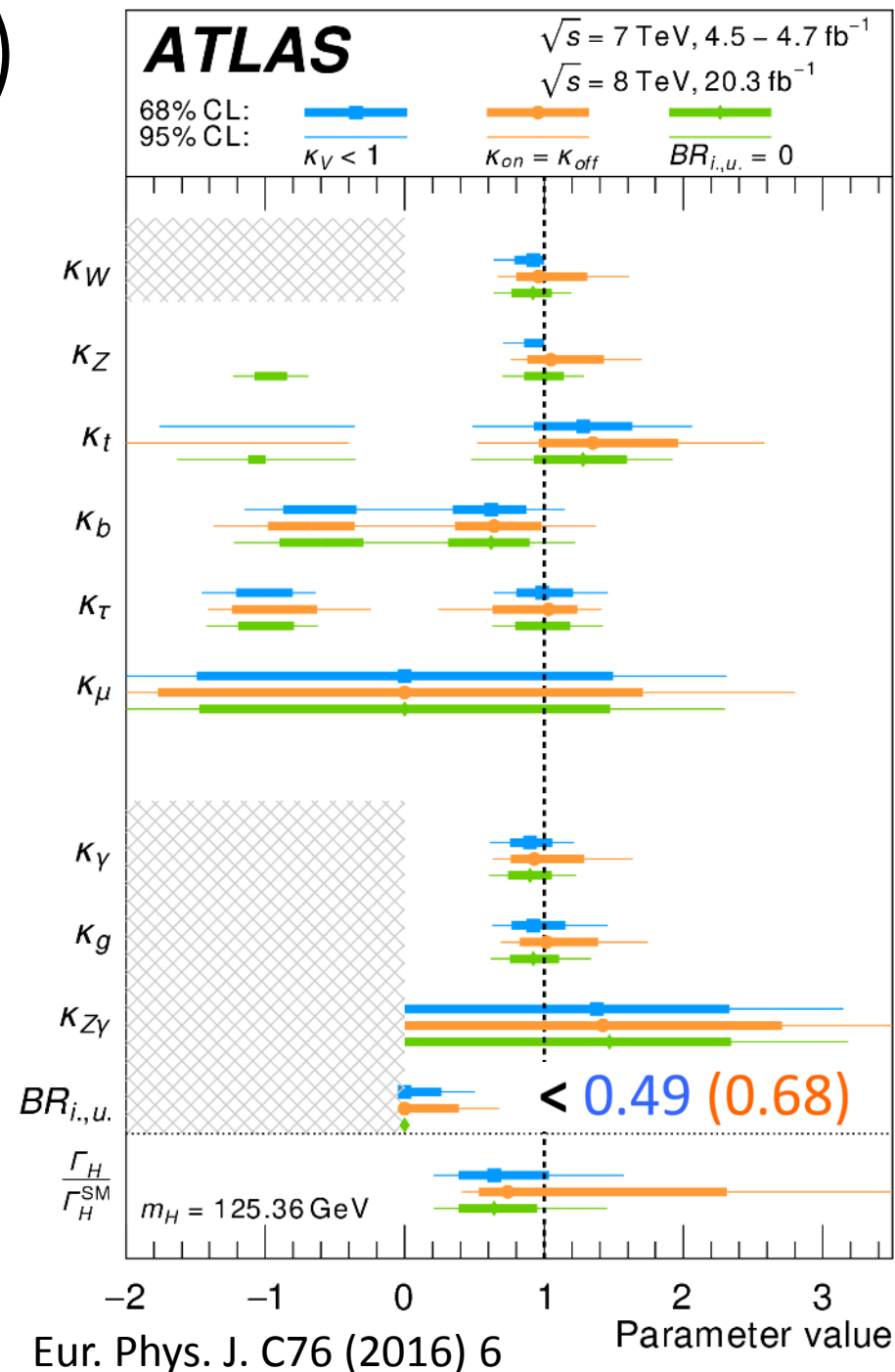
- $\kappa_i^2 = \sigma_i / \sigma_i^{\text{SM}}$
- $\kappa_f^2 = \Gamma_f / \Gamma_f^{\text{SM}}$

Total width

- Assume no BSM contribution
- Allow BSM decays

Compatibility with SM

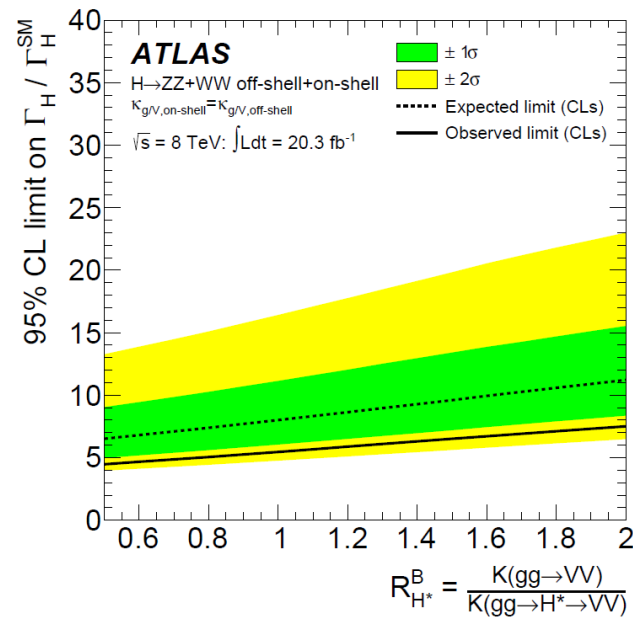
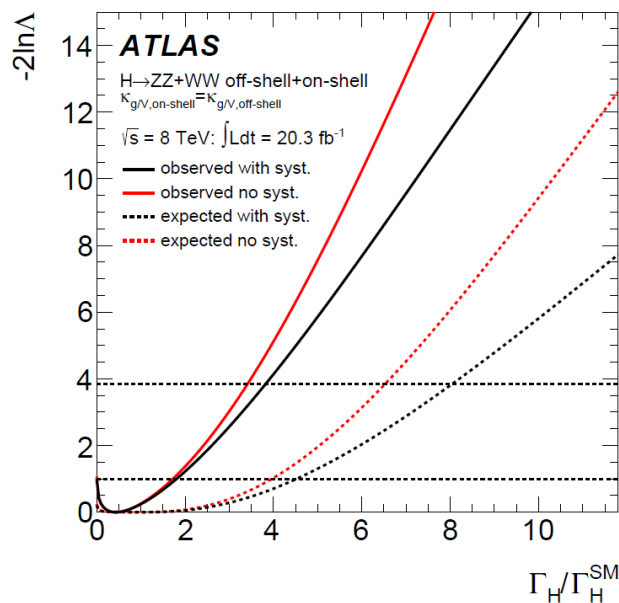
80%, 57% and 73%



# Width via off-shell production

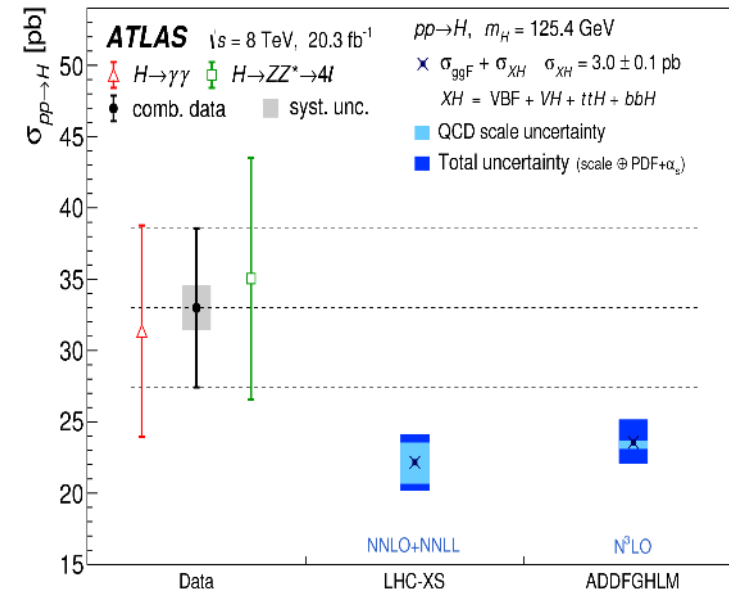
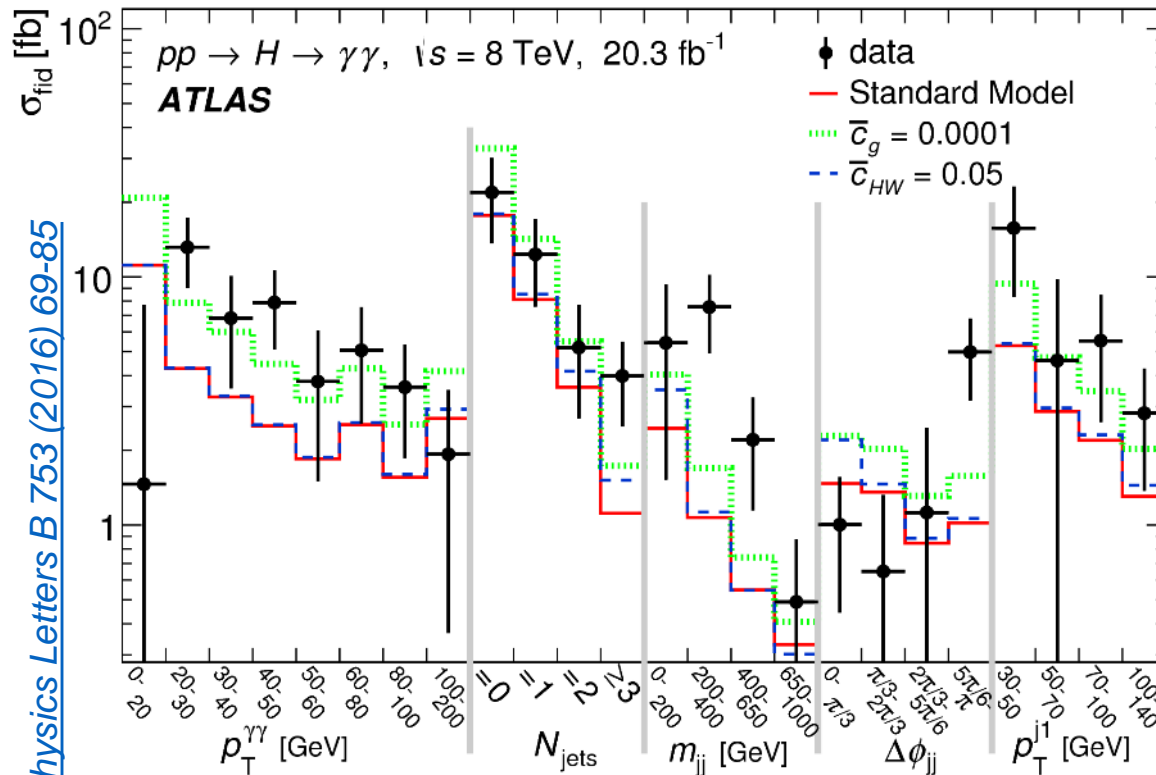
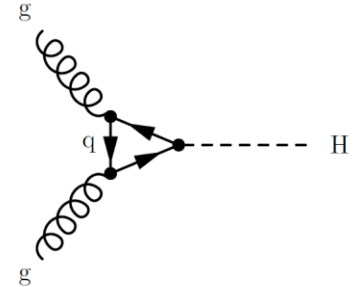
- High mass off-peak region ( $> 2 \cdot m_V$ ) in  $H \rightarrow VV$  is sensitive to Higgs off-shell production and background interference effects, use  $gg \rightarrow H^{(*)} \rightarrow WW \rightarrow e\nu\mu\nu$ ,  $gg \rightarrow H^{(*)} \rightarrow ZZ \rightarrow 4l/2l2\nu$
- Assume:** relevant Higgs boson couplings independent of the energy scale of the Higgs production
- Only** signal strength  $\mu_{\text{on-shell}}$  depends on  $\Gamma_H / \Gamma_H^{\text{SM}}$  -> assuming identical off-shell and on-shell boson coupling scale factor:  $\mu_{\text{off-shell}}(s) / \mu_{\text{on-shell}} = \Gamma_H / \Gamma_H^{\text{SM}}$
- Upper limit range:  $\Gamma_H / \Gamma_H^{\text{SM}} < 4.5-7.5$  (exp: 6.5-11.2) at 95% CL

Range from varying the unknown  $gg \rightarrow VV$  background k-factor from higher order QCD corrections (0.5x and 2x known signal k-factor)



# Total and Differential Cross-section

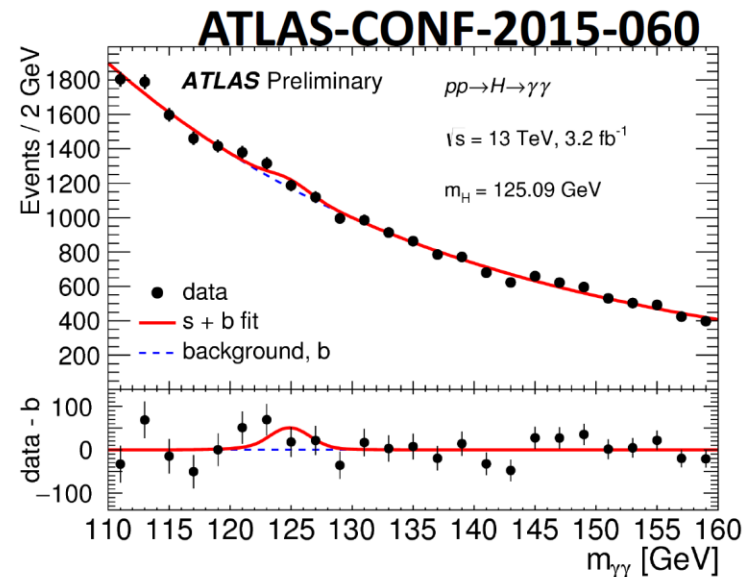
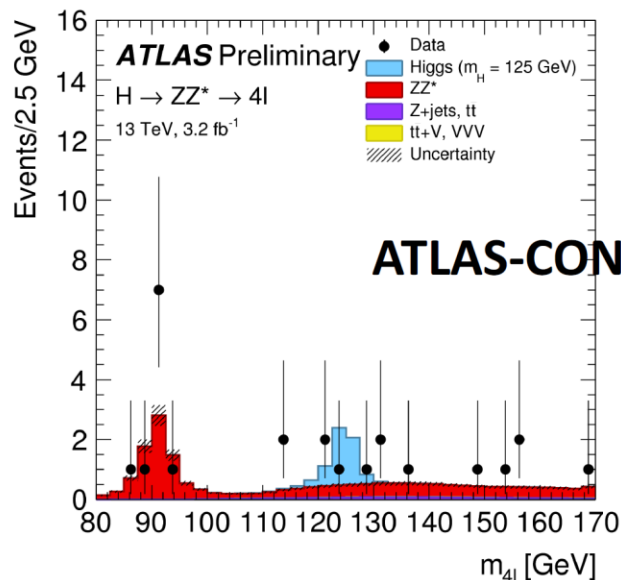
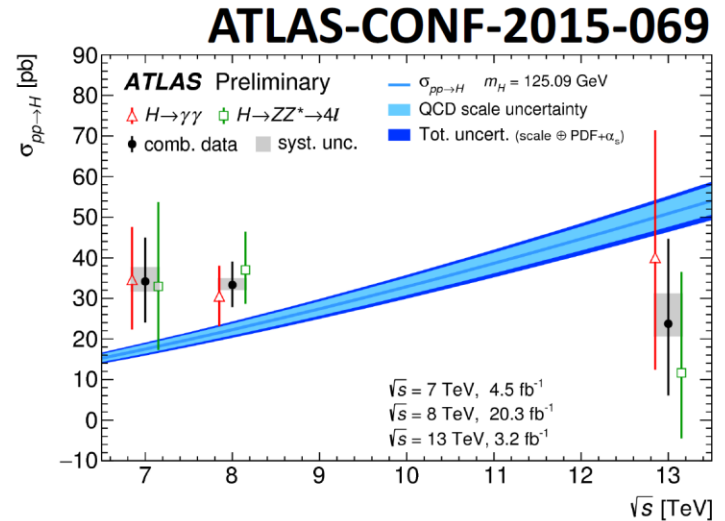
- Differential distributions in H events: test for BSM interactions.
  - $d\sigma / d\mathbf{p}_T^H$ : BSM in (ggF production) loops
  - $d\sigma / d\mathbf{N}_{\text{jets}}$ : QCD calculations
  - $d\sigma / d\Delta\phi^{\text{jj}}$ : CP properties
- No significant deviation from SM expectation



[Phys. Rev. Lett. 115 \(2015\) 091801](#)

# First Run 2 results

- Luminosity of  $3.2 \text{ fb}^{-1}$  at  $13 \text{ TeV}$  not enough to reach Run-1 sensitivity for  $h(125)$
- ATLAS performed fiducial cross-section measurements in  $4l$  and  $\gamma\gamma$  channels ( $1.4\sigma$  (obs)  $3.4\sigma$  (exp.) combined sensitivity)

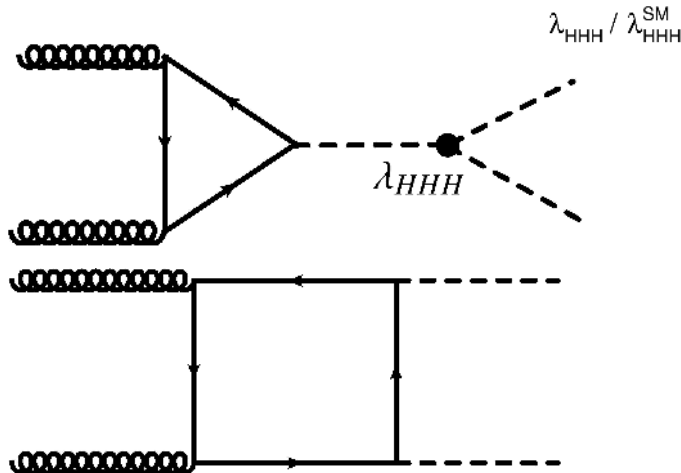
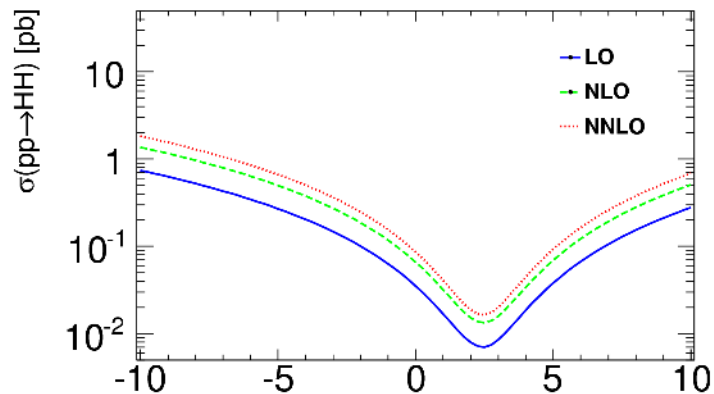


# Future outlook for Higgs sector

Future measurements:  $t\bar{t}H$ ,  $HH$  production,  $H \rightarrow Z\gamma$ ,  $\mu\mu$  decays

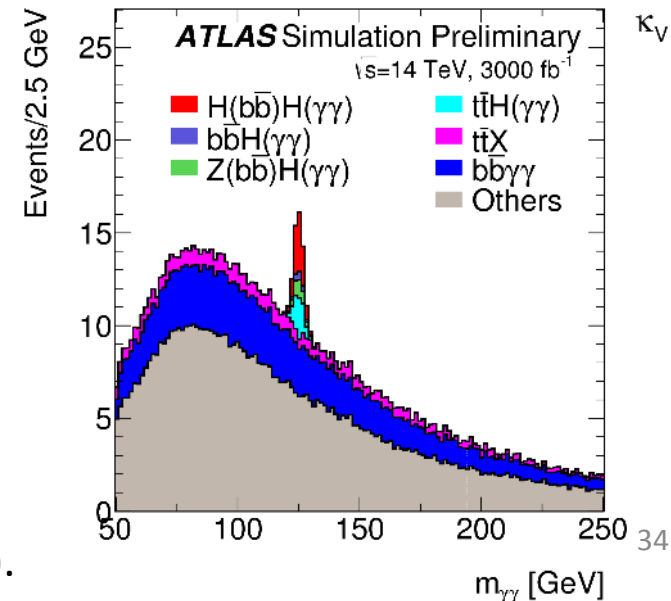
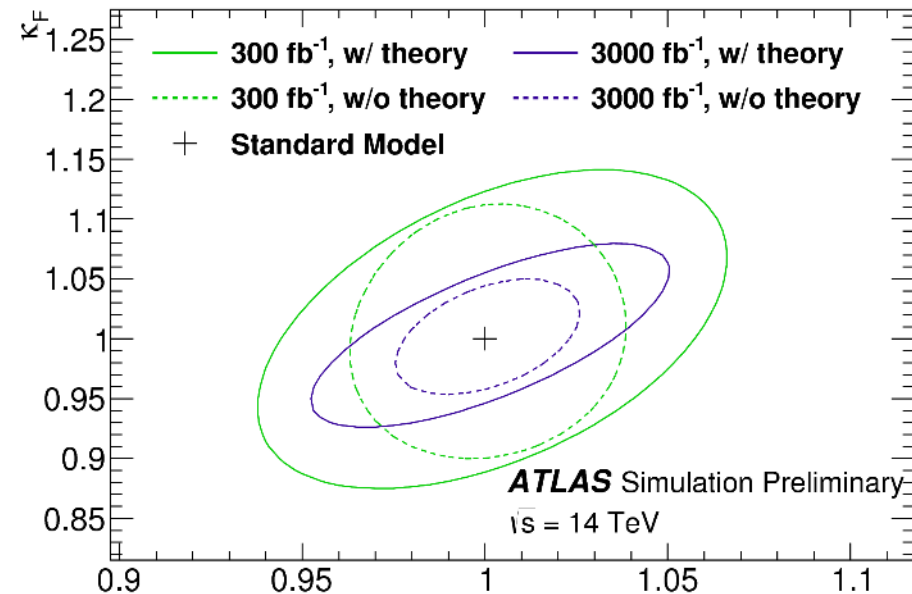
Couplings (now/ $0.3\text{ab}^{-1}$ / $3\text{ab}^{-1}$ ):

- Fermions 30/10/5%
- Bosons 20-30/5/3%



Negative interference  
between  $HH$   
production with and  
w/o  $HHH$  vertex.

Expect 8-10 events in  
 $3\text{ab}^{-1}$ : measurement  
potential is low  
(exp. significance  $1.3\sigma$ ).



# Double Higgs production

- In Run 1 observed 5 events  $\sim 300\text{GeV}$  ( $<1$  exp.)

- $3\sigma$  local/ $2\sigma$  global tension with SM

- Search for both resonant (**BSM**) and non-resonant (**SM**) pairs of higgs (hh)

- **Final state**  $\gamma\gamma b\bar{b}$  with enhanced BR ( $b\bar{b}$ ) and clean signature ( $\gamma\gamma$ )

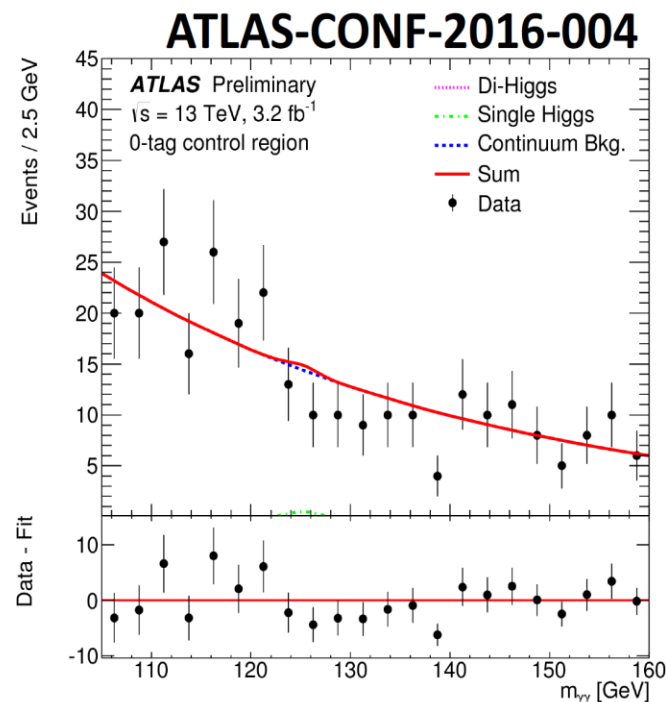
- Event **selection** using cut on:  $m_{\gamma\gamma}$  (analysis dep.)  
 $95 < m_{b\bar{b}} < 135\text{ GeV}$  and  $275 < m_X < 400\text{ GeV}$

- **Background** from side-band regions using fit resp. counting approach with efficiencies

- Upper limits on the production cross section are derived from pseudo-experiment assuming SM BR:

**Non-resonant:**  $\sigma_{hh} < 3.9\text{ pb}$  at 95% CL

**Resonant:**  $\sigma_{hh} < 7.5\text{ pb}$  ( $m_X = 275\text{ GeV}$ );  $\sigma_{hh} < 4.4\text{ pb}$  ( $m_X = 400\text{ GeV}$ ) at 95% CL

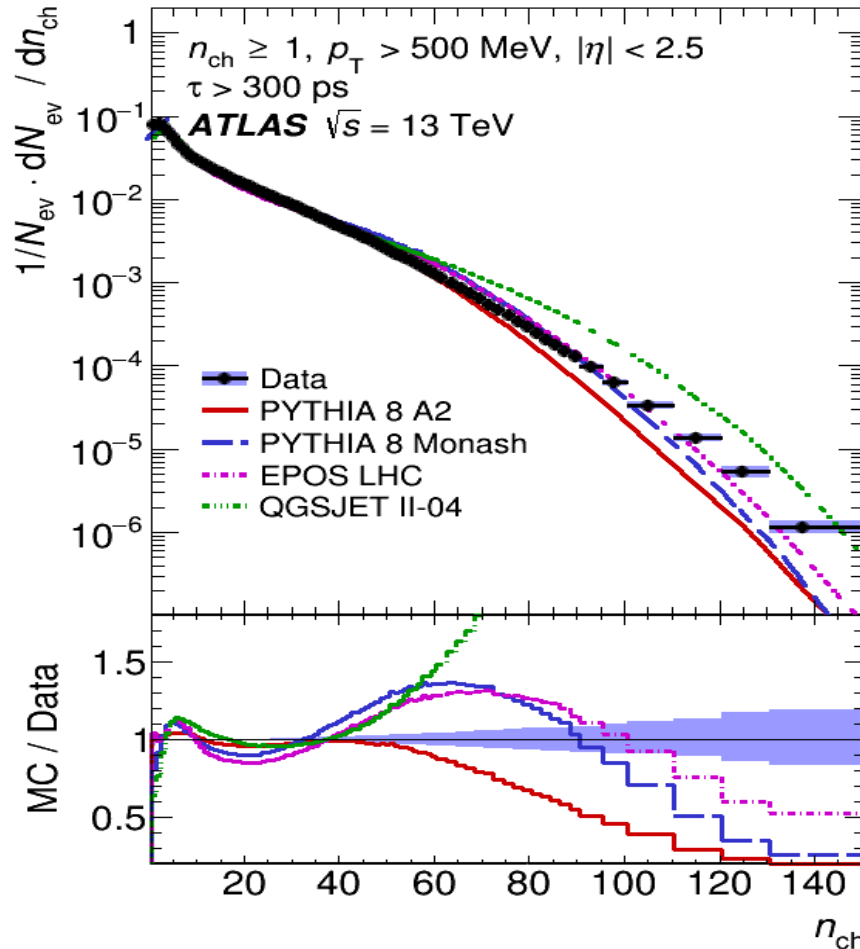


# Non-Higgs SM Physics



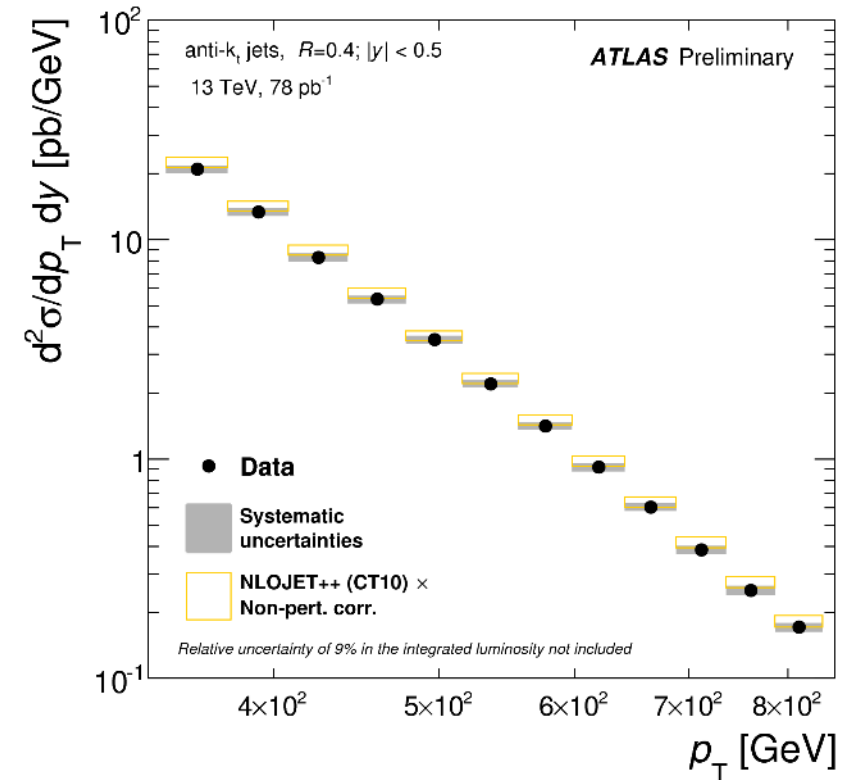
# QCD physics

Inclusive charged particle measurements provide insight into the strong interaction in the low-energy, non-perturbative QCD region



MC tunes describe data well at 13 TeV.

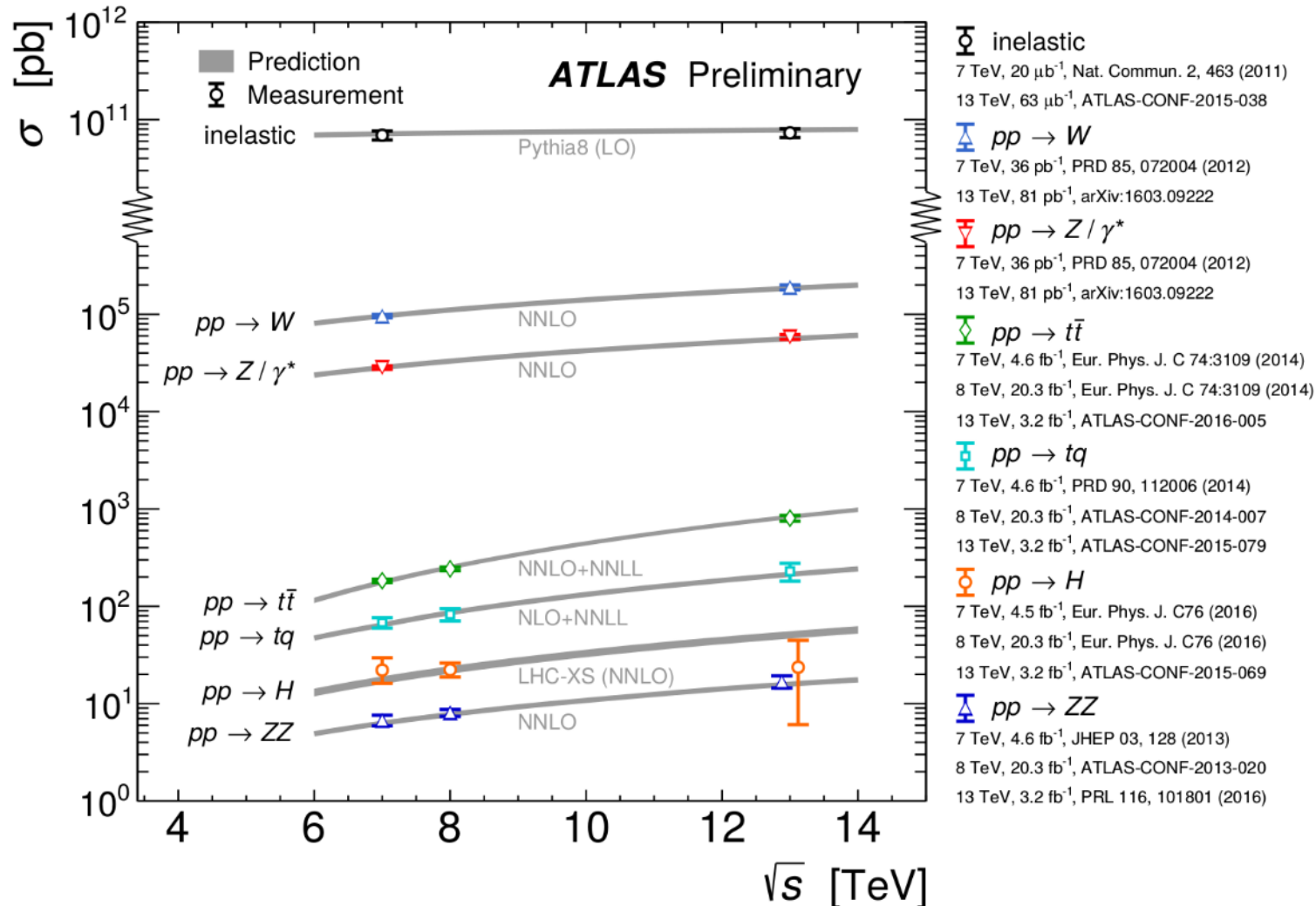
Inclusive jet cross-section measurement provides test of the validity of perturbative QCD



The predictions are consistent with measured cross-sections (within uncertainties)

# Cross-section measurements

- Increase in  $\sqrt{s}$  allows study of SM processes in new kinematic regime
- SM processes are background processes to searches for new physics
- Theoretical predictions at (N)NLO+(N)NLL compatible with measured total/differential cross-section of different SM processes.

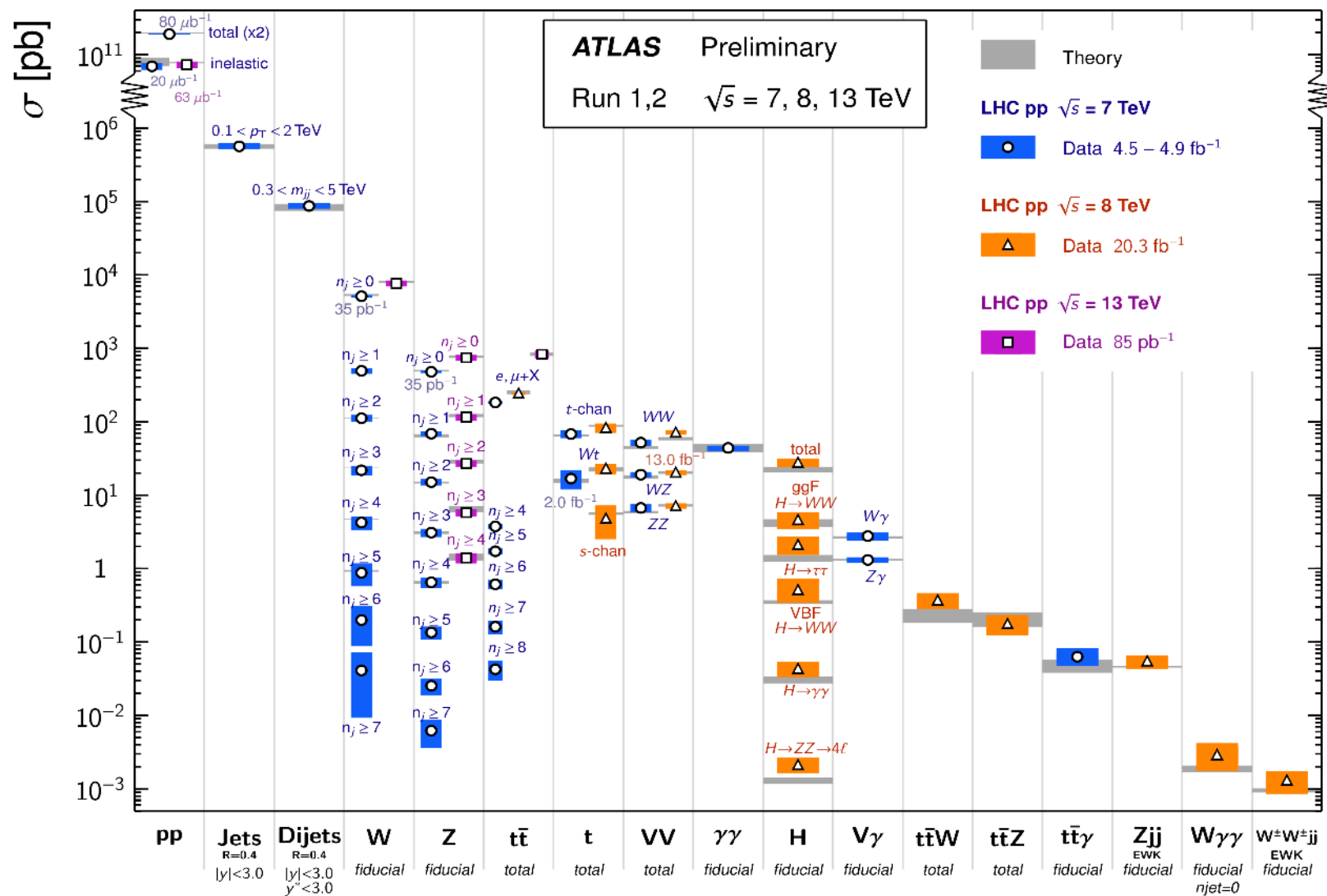


# Cross-section measurements

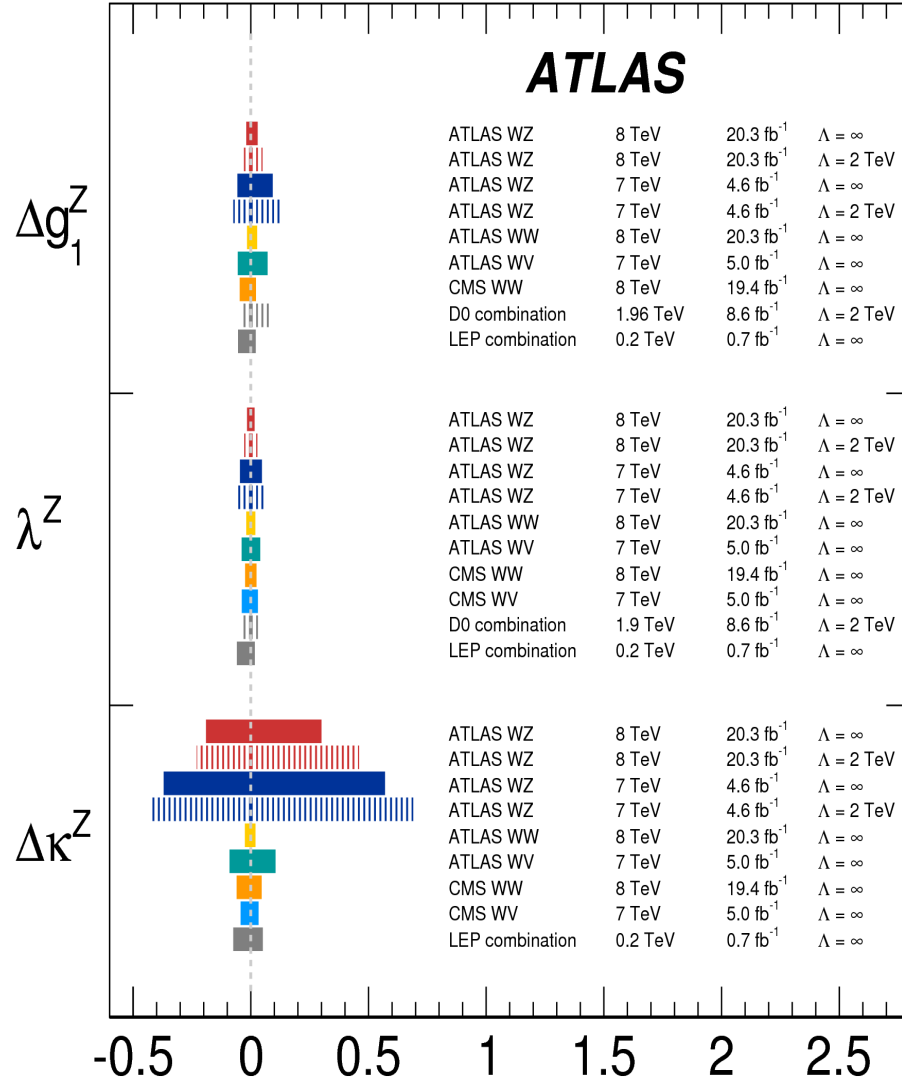
Calculations at NNLO accuracy are in excellent agreement with measurements of SM cross-sections.

## Standard Model Production Cross Section Measurements

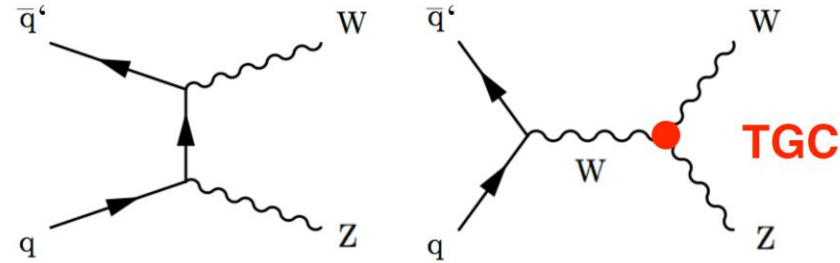
Status: Nov 2015



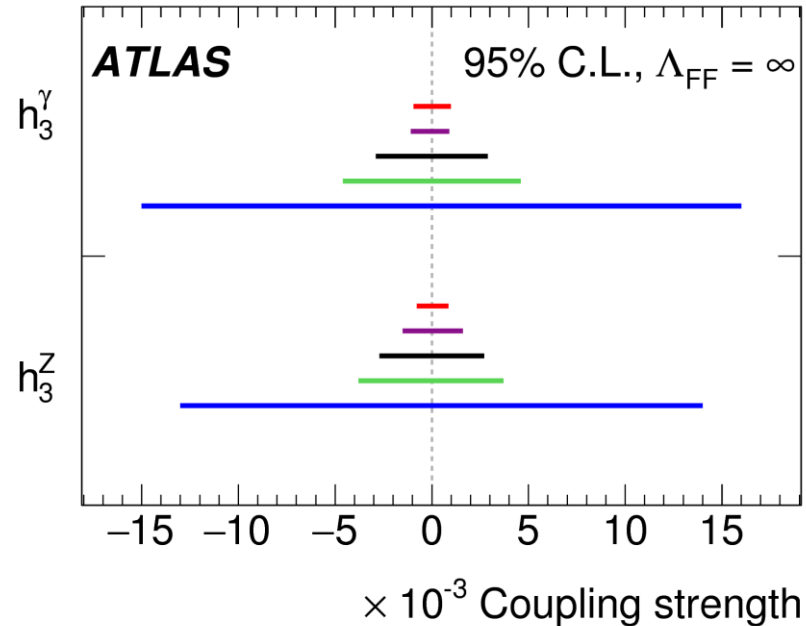
# Anomalous Triple Gauge Couplings



aTGC Limits at 95% CL

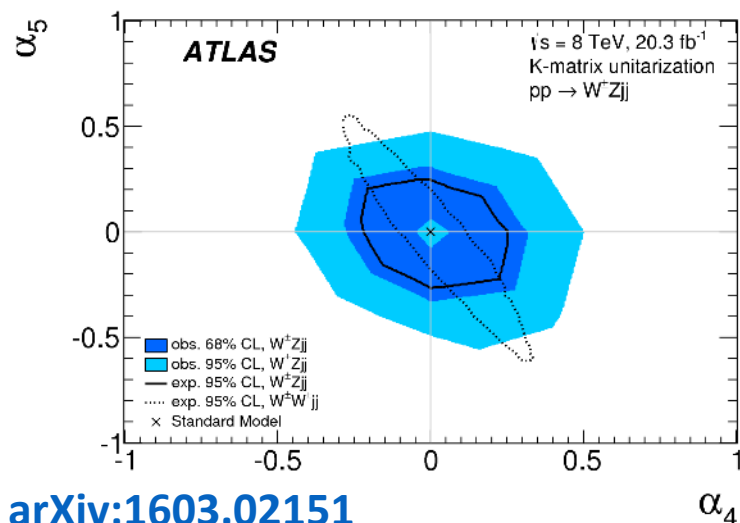
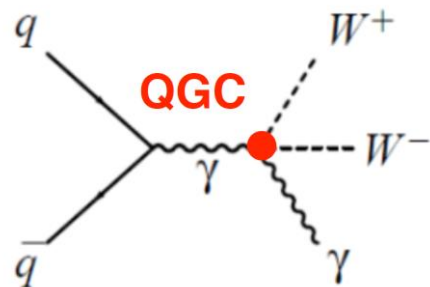
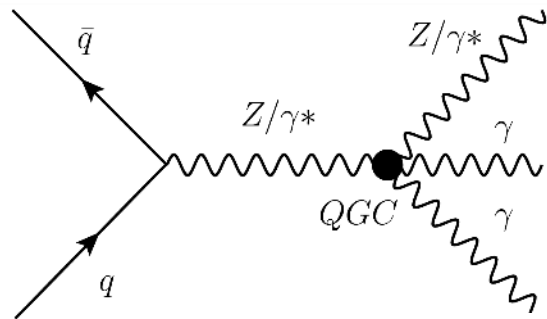
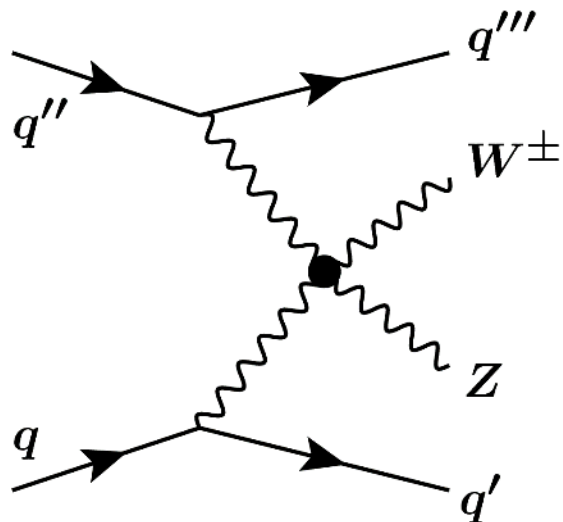


- ATLAS,  $l\bar{l}\gamma$  and  $\nu\bar{\nu}\gamma$ ,  $\sqrt{s}=8$  TeV, 20.3 fb<sup>-1</sup>
- CMS,  $\nu\bar{\nu}\gamma$ ,  $\sqrt{s}=8$  TeV, 19.6 fb<sup>-1</sup>
- CMS,  $l\bar{l}\gamma$  and  $\nu\bar{\nu}\gamma$ ,  $\sqrt{s}=7$  TeV, 5.0 fb<sup>-1</sup>
- CMS,  $l\bar{l}\gamma$ ,  $\sqrt{s}=8$  TeV, 19.5 fb<sup>-1</sup>
- ATLAS,  $l\bar{l}\gamma$  and  $\nu\bar{\nu}\gamma$ ,  $\sqrt{s}=7$  TeV, 4.6 fb<sup>-1</sup>



[arXiv:1604.05232](https://arxiv.org/abs/1604.05232)

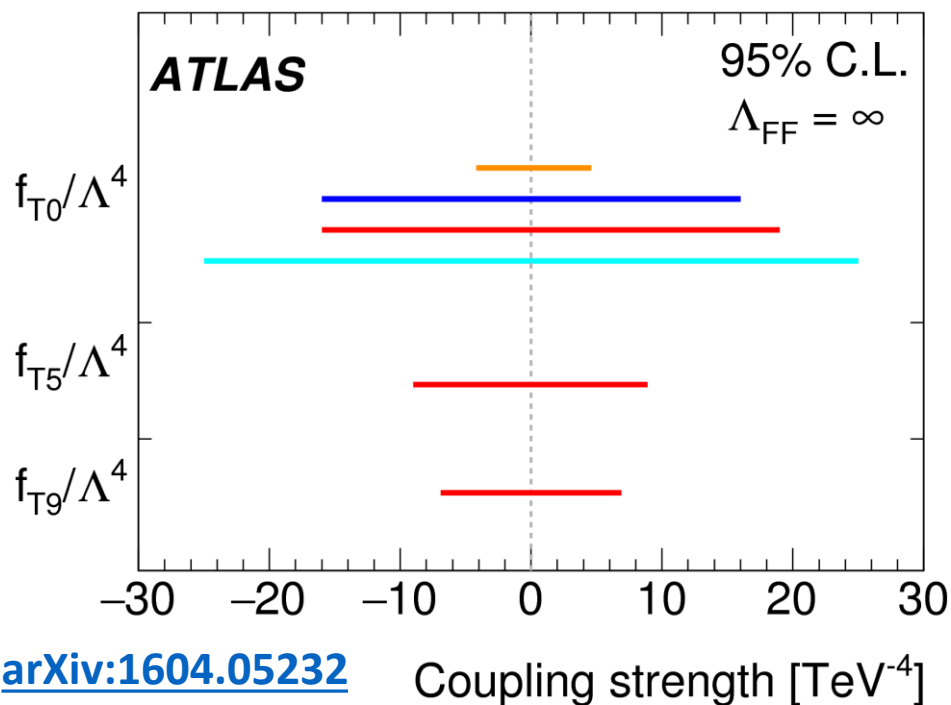
# Anomalous Quartic Gauge Couplings



[arXiv:1603.02151](https://arxiv.org/abs/1603.02151)

No hint of aT/QGC seen.

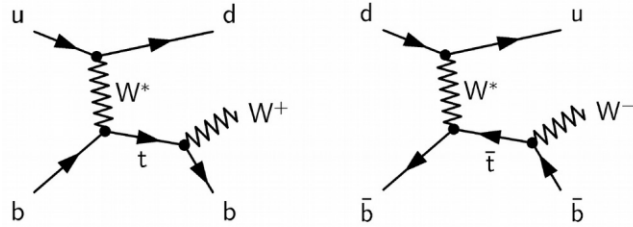
- $W^+W^+$  CMS,  $\sqrt{s}=8 \text{ TeV}, 19.4 \text{ fb}^{-1}$
- $W\gamma\gamma$  ATLAS,  $\sqrt{s}=8 \text{ TeV}, 20.3 \text{ fb}^{-1}$
- $Z\gamma\gamma$  ATLAS,  $\sqrt{s}=8 \text{ TeV}, 20.3 \text{ fb}^{-1}$
- $WV\gamma$  CMS,  $\sqrt{s}=8 \text{ TeV}, 19.3 \text{ fb}^{-1}$



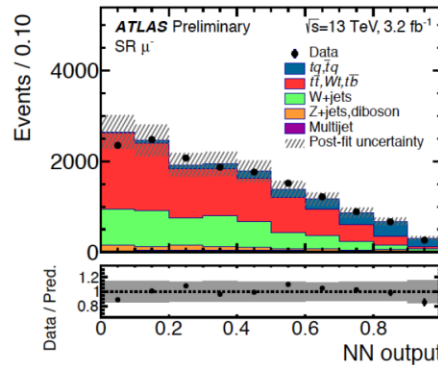
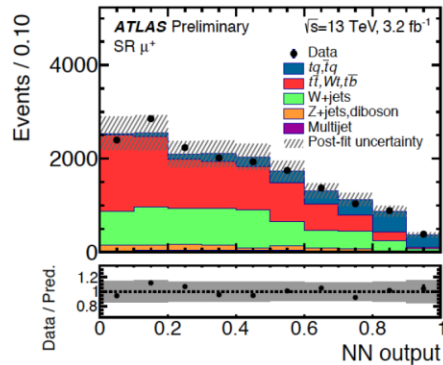
[arXiv:1604.05232](https://arxiv.org/abs/1604.05232)

# Top quark production

## Electroweak production of single top quark



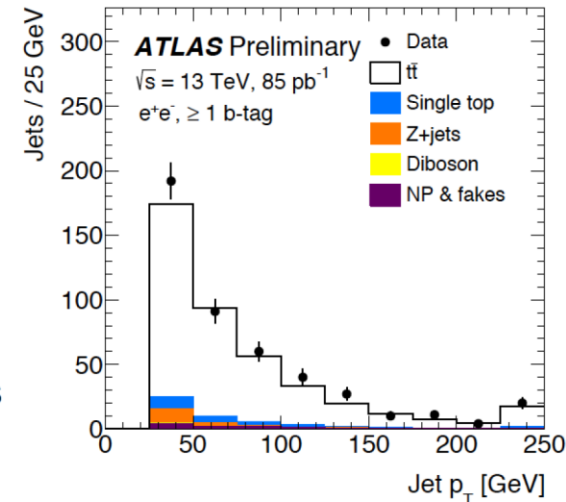
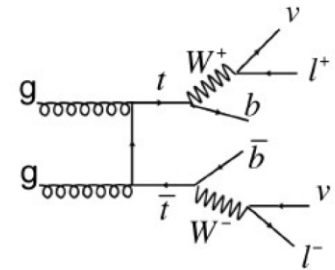
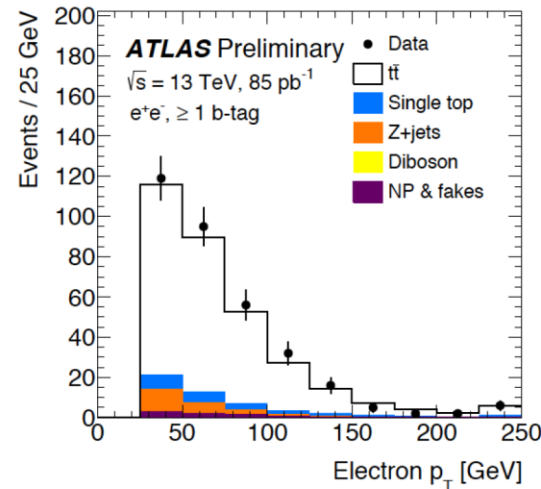
10 variables are used in the training of a Neural Network.  
One output node which gives a continuous output in the interval  $[0; 1]$ .



$$\begin{aligned}\sigma(tq) &= 133 \pm 6 \text{ (stat.)} \pm 24 \text{ (syst.)} \pm 7 \text{ (lumi.) pb} \\ &= 133 \pm 25 \text{ pb,} \\ \sigma(\bar{t}q) &= 96 \pm 5 \text{ (stat.)} \pm 23 \text{ (syst.)} \pm 5 \text{ (lumi.) pb} \\ &= 96 \pm 24 \text{ pb,} \\ &\text{(limited by systematics)}\end{aligned}$$

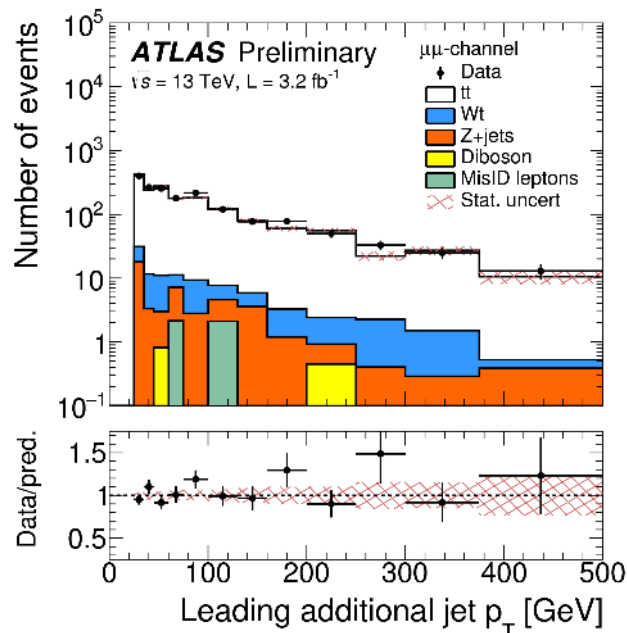
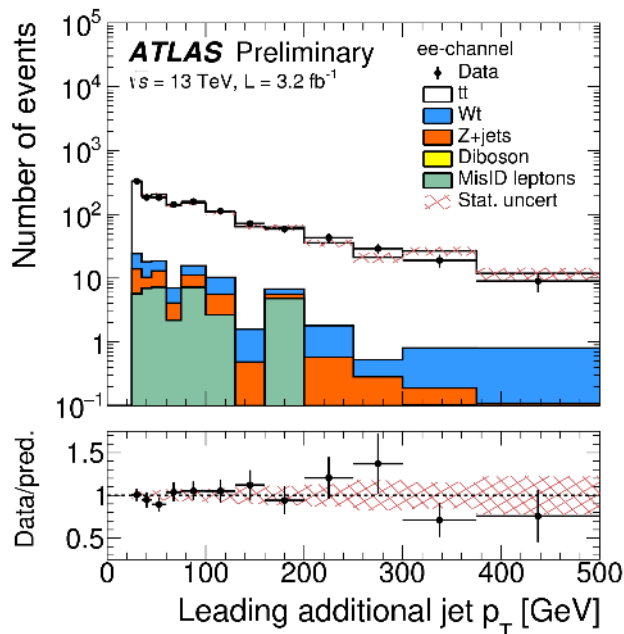
Good agreement in cross-sections and kinematics with NLO/NNLO MC predictions

## Top pair production in lepton channels ( $ee, \mu\mu, e\mu$ ) and b-tags jets





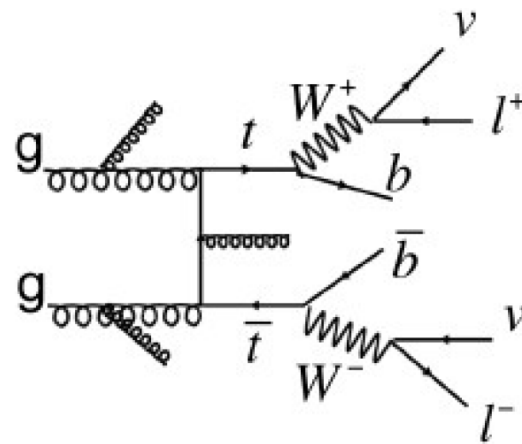
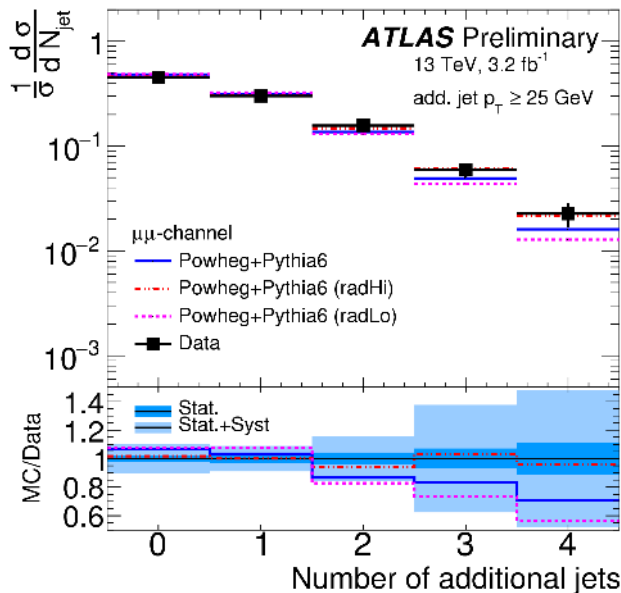
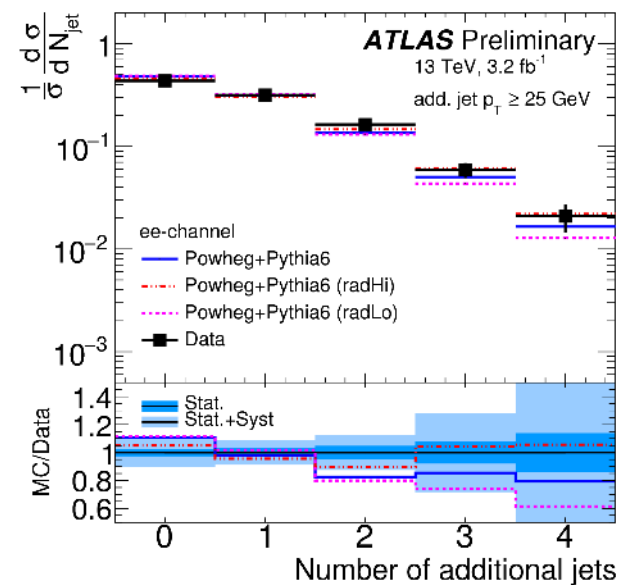
# Production of $t\bar{t}$ +jets



Important for  $t\bar{t}H$  MC tuning to estimate ISR/FSR uncertainties.

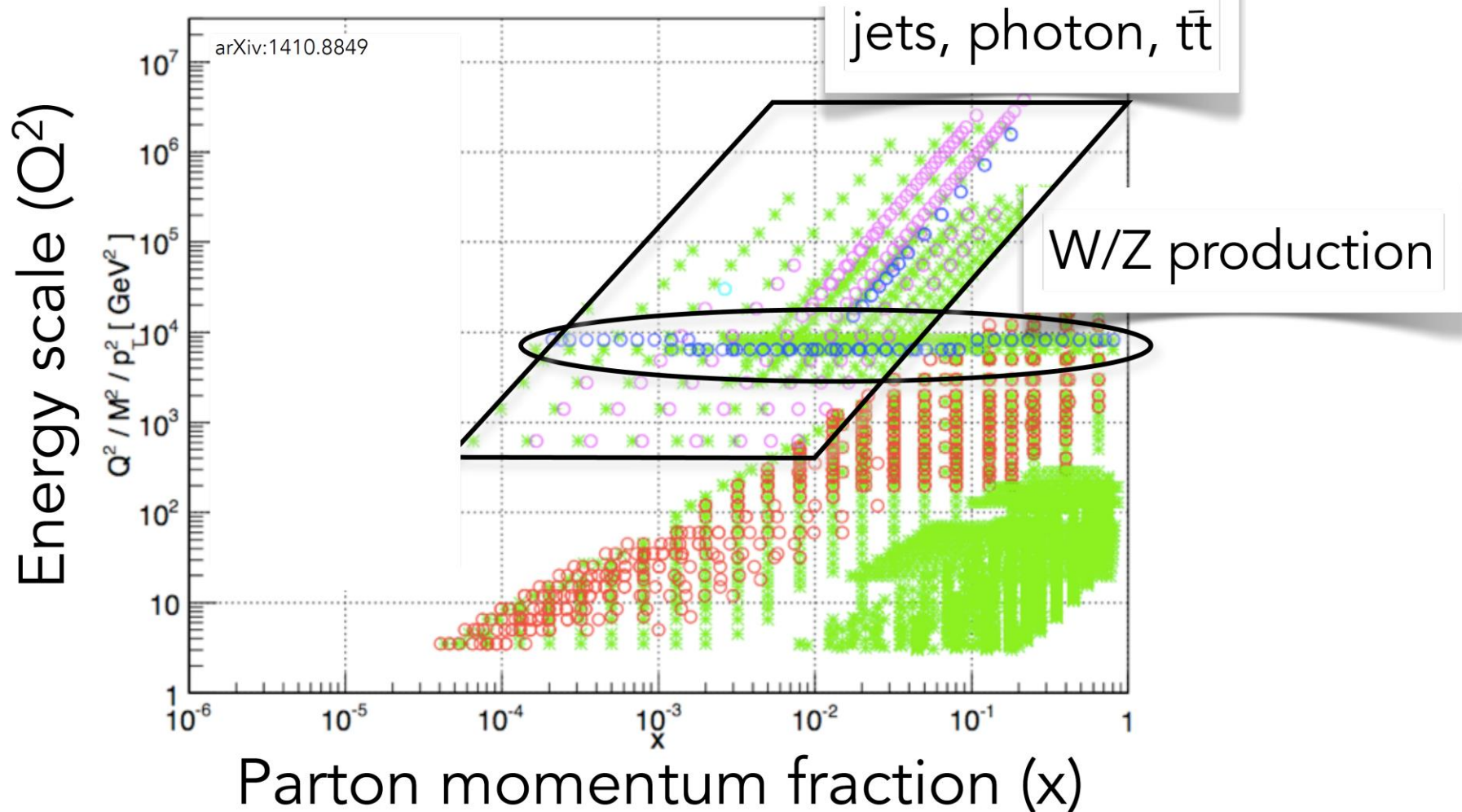
Dilepton channels ( $ee, \mu\mu, \mu e$ ) have good agreement of jet kinematics.

Unfolded jet multiplicity in good agreement with MC predictions

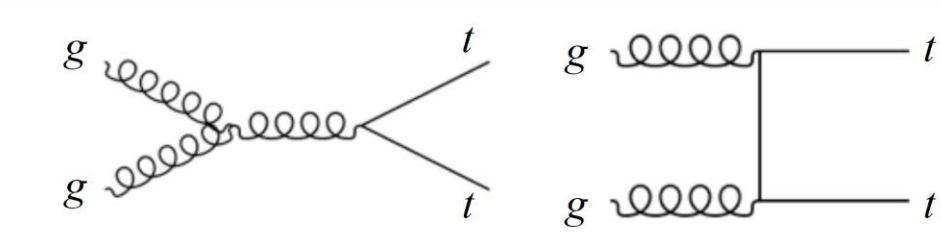


# Constraints on PDFs

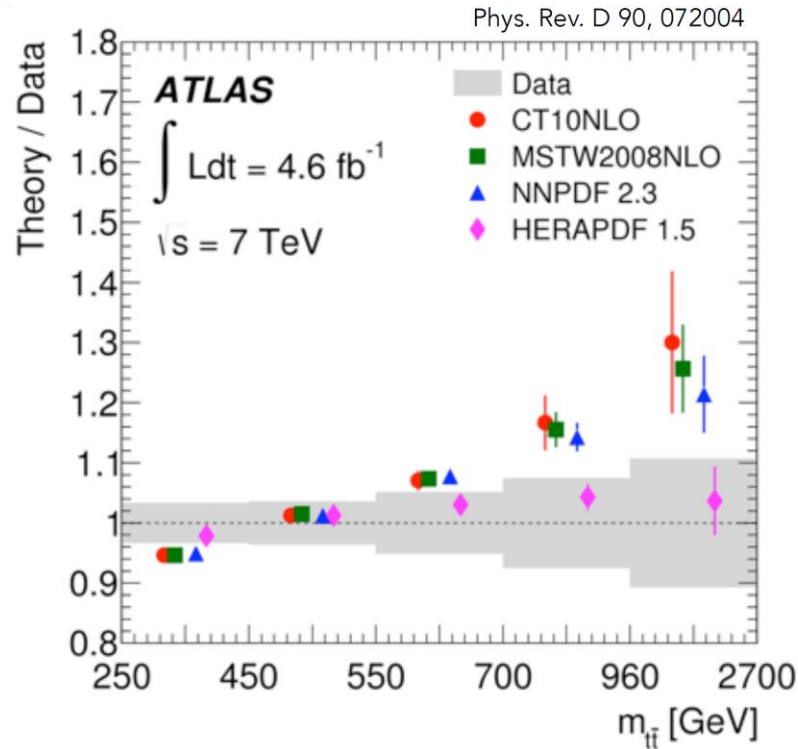
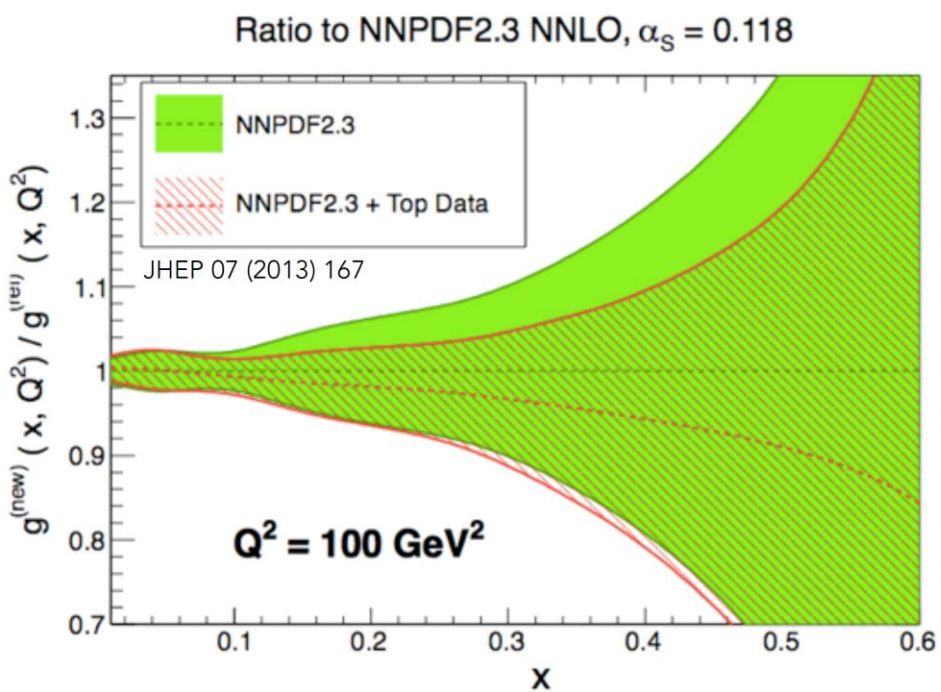
Extraction of PDF via global fits to fixed-target, collider DIS, collider pp data



# PDF constraints from top quark

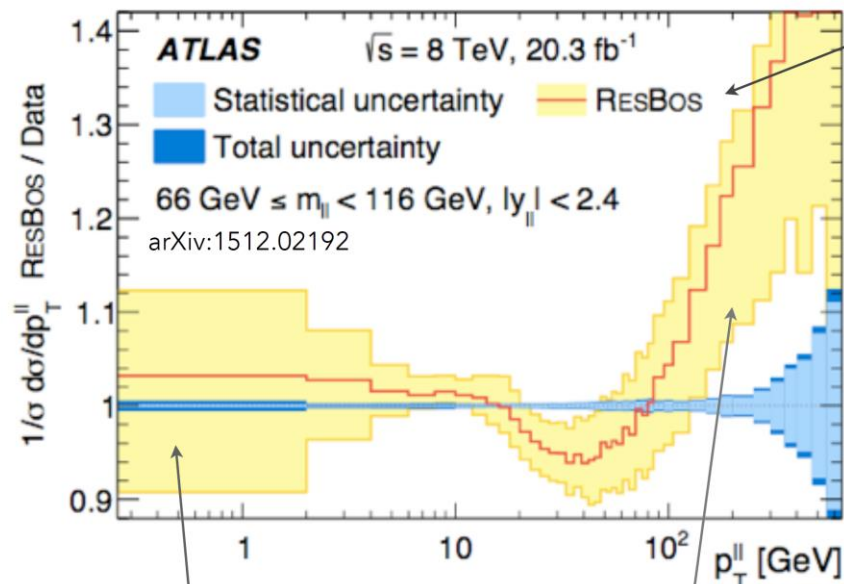


Top pair differential cross-section now available at NNLO



Improved knowledge of gluon PDF over wide region of x by up to 20%

# Precision Tests of SM predictions



non-perturbative  
effects and soft-  
gluon resummation  
are most important

sensitive to the  
emission of  
hard partons

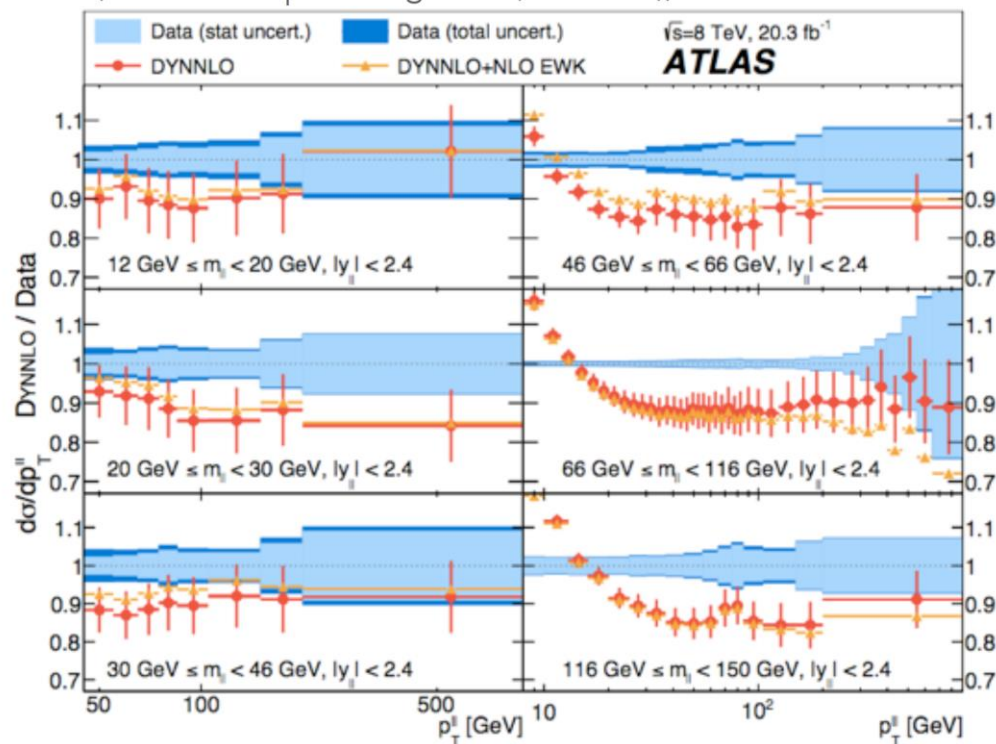
Not quite sensitive to  
EW corrections.

approximate NNLO  
(QCD ISR) + full NNLL

$$pp \rightarrow Z/\gamma \rightarrow \ell^+ \ell^-$$

Data much more precise  
than predictions!

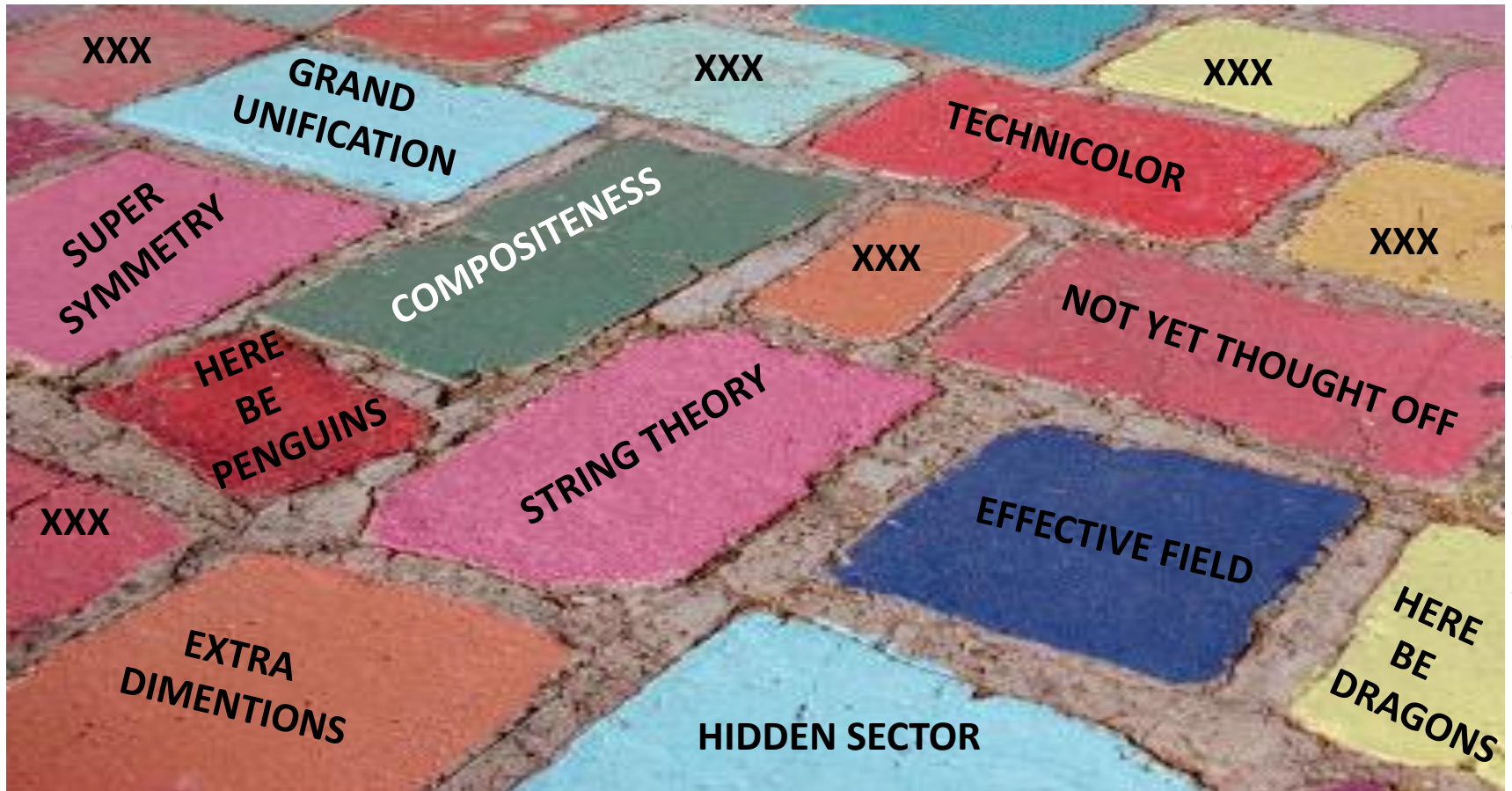
DYNNLO: Full NLO (QCD ISR)+NLO EWK added  
(but no multiple soft gluons (i.e. no LL))



# Searches Beyond Standard Model



# Theoretical Approach: Exotic Theory



Balboa Park, San Diego, USA, from <https://beautifulbalboapark.wordpress.com>

Theories not enough! Need models to derive phenomenology  
(particle spectrum, production & decays modes)



# Theoretical Approach: what to look for

## EXTRA DIMENSIONS

Kaluza-Klein excitations of particles ( $G^*$ ,  $Z_{KK}$ ,  $W_{KK}$ ,  $g_{KK}$ ,  $q_{KK}$ , ...), Black Holes, string resonances...

## GRAND UNIFICATION

new vector bosons ( $Z'$ ,  $W'$ ,...), heavy fermions ( $t'$ ,  $b'$ ,  $T$ ,  $B$ ...),  $\nu_R$ , leptoquarks, diquarks, Higgses, etc.

## SUPERSYMMETRY

sleptons, squarks, stops, gluinos, etc...

## COMPOSITENESS

excited states of known particles ( $l^*$ ,  $q^*$ ,  $Z^*$ ,  $W^*$ ,...), leptoquarks, etc...

## DARK MATTER

## HIDDEN/DARK SECTOR

dark photons, hidden particles, stealth-susy-particles etc...

## TECHNICOLOR

new composite particles: techni-hadrons ( $\rho_{TC}$ ,  $\eta_{TC}$ , etc...), leptoquarks,  $T_{5/3}$ ,...

# Experimental Approach:

Search for any deviations from Standard Model predictions

Direct observation:  
new (e.g. **Exotic**) resonant or  
non-resonant structures

**LOOK FOR SIGNATURES  
MADE OF BASIC OBJECTS**

Jets,  
b-jets,  
 $E_{\text{T}}^{\text{Miss}}$

Bosons  
( $\gamma$ , W, Z)

Leptons  
(e,  $\mu$ ,  $\tau$ )

Unconventional  
Particles



**AS MANY  
SIGNATURES  
AS POSSIBLE**

**AS MODEL  
INDEPENDENT AS  
POSSIBLE**

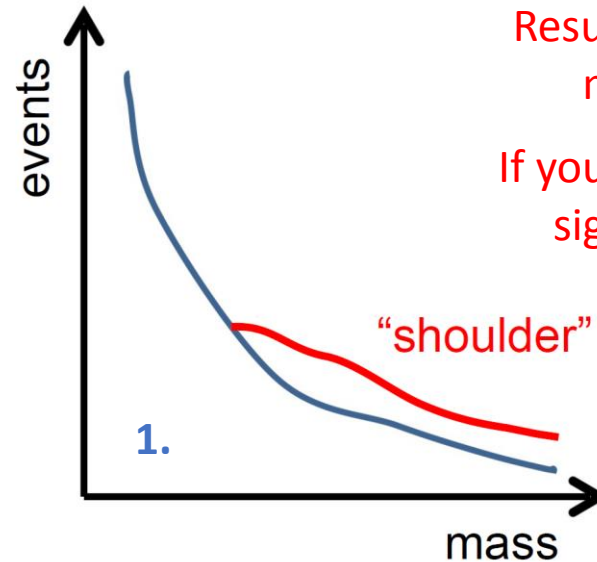
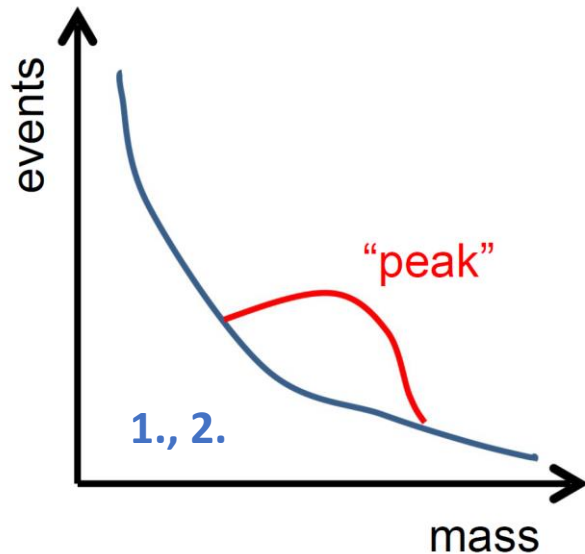
**PROVIDE  
BENCHMARK  
MODEL RESULTS**

# Signature-Based Searches

Caveat:

Need signal-shape hypothesis  
Results are not completely  
model-independent

If your model does not have  
signal shape as studied  
tricky to interpret

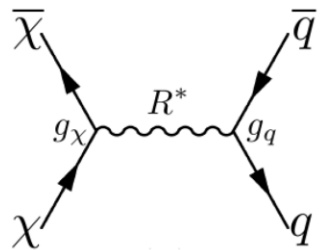


To estimate background:

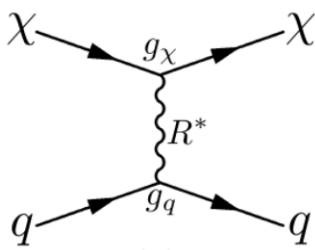
1. Detailed simulations of mass-spectrum shape
2. Smooth functional form fitted from data

# Dark Matter searches

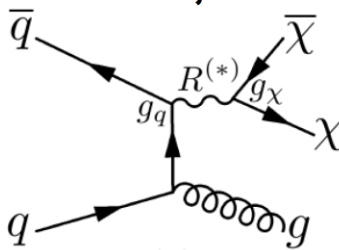
indirect detection



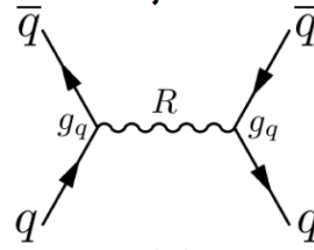
direct detection



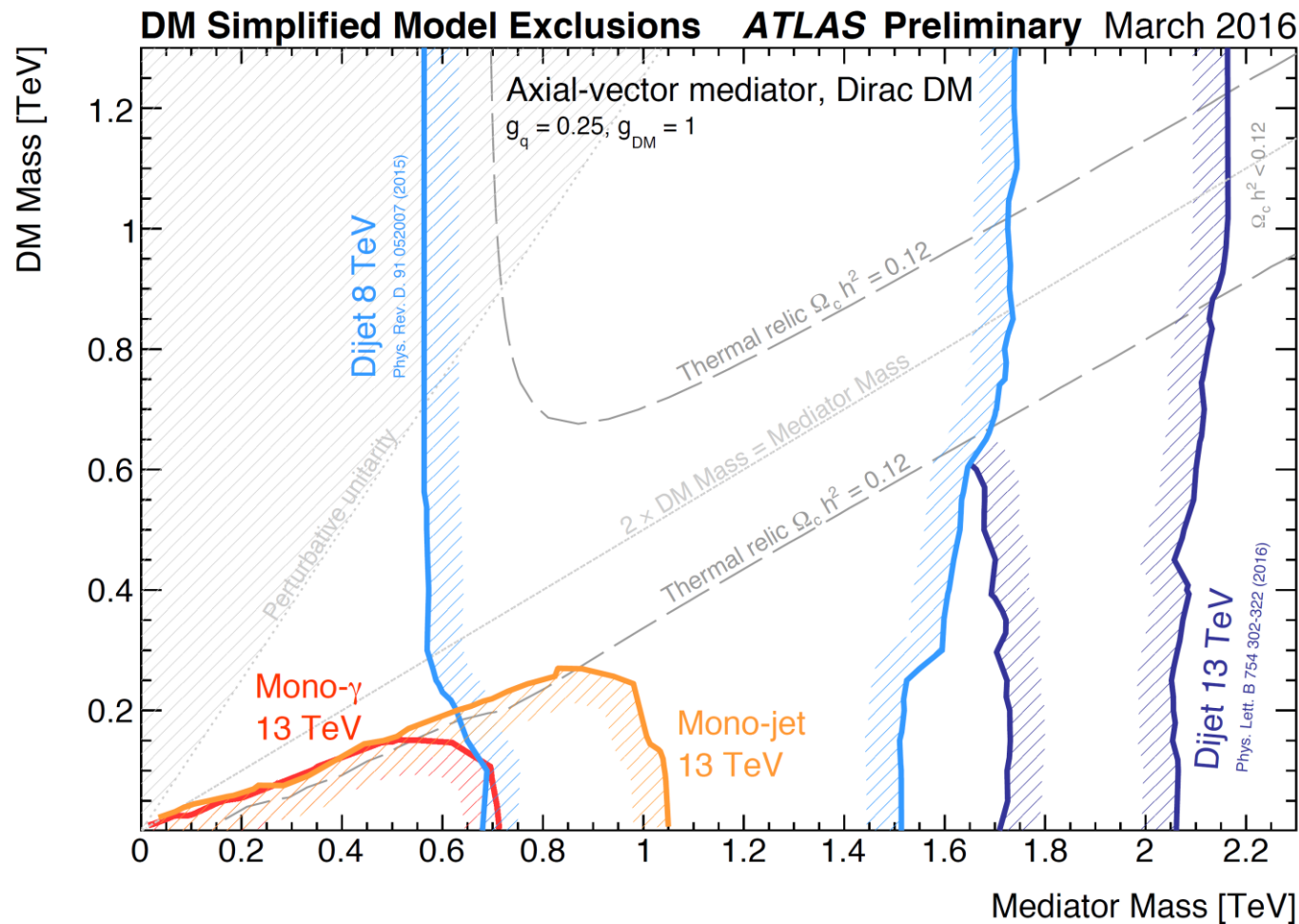
mono-jets



di-jets



**s-channel  
simplified models  
4 free parameters:  
 $m_\chi, m_R, g_q, g_\chi$**

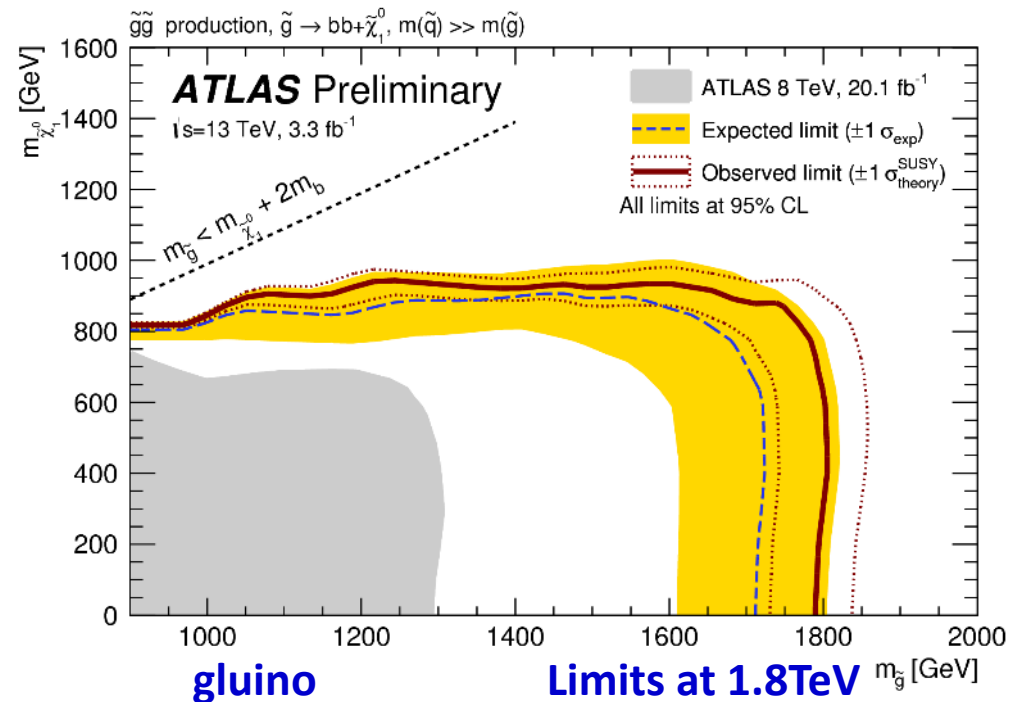
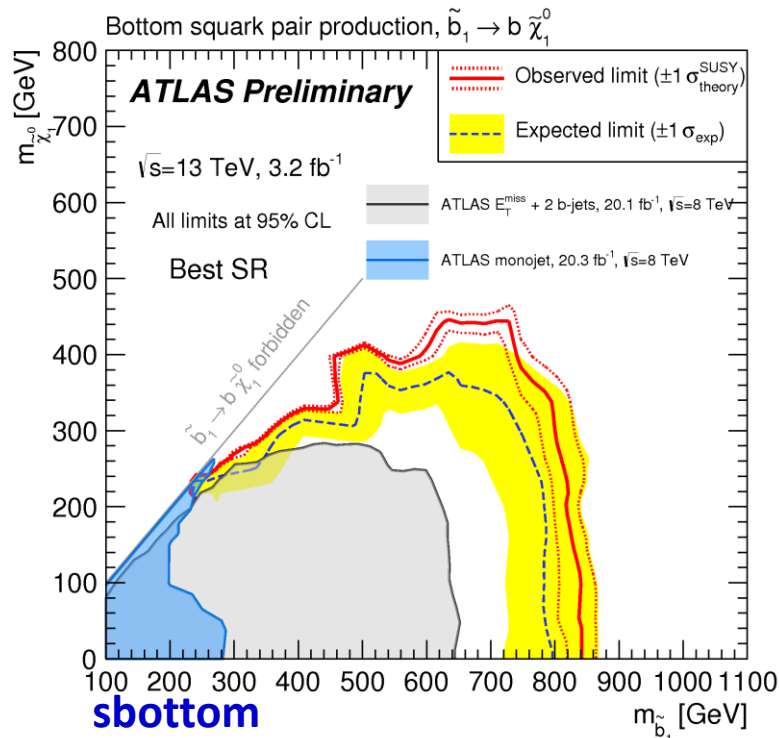
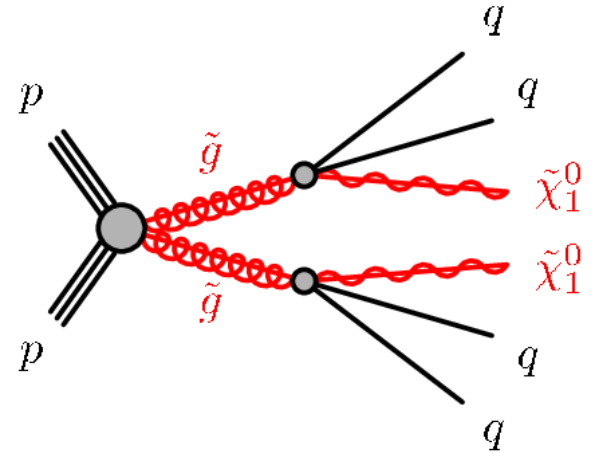


# SUSY searches: jets+MET

ATLAS-CONF-2015-062  
ATLAS-CONF-2015-066  
ATLAS-CONF-2015-067  
ATLAS-CONF-2015-077

Searches for squarks and gluinos

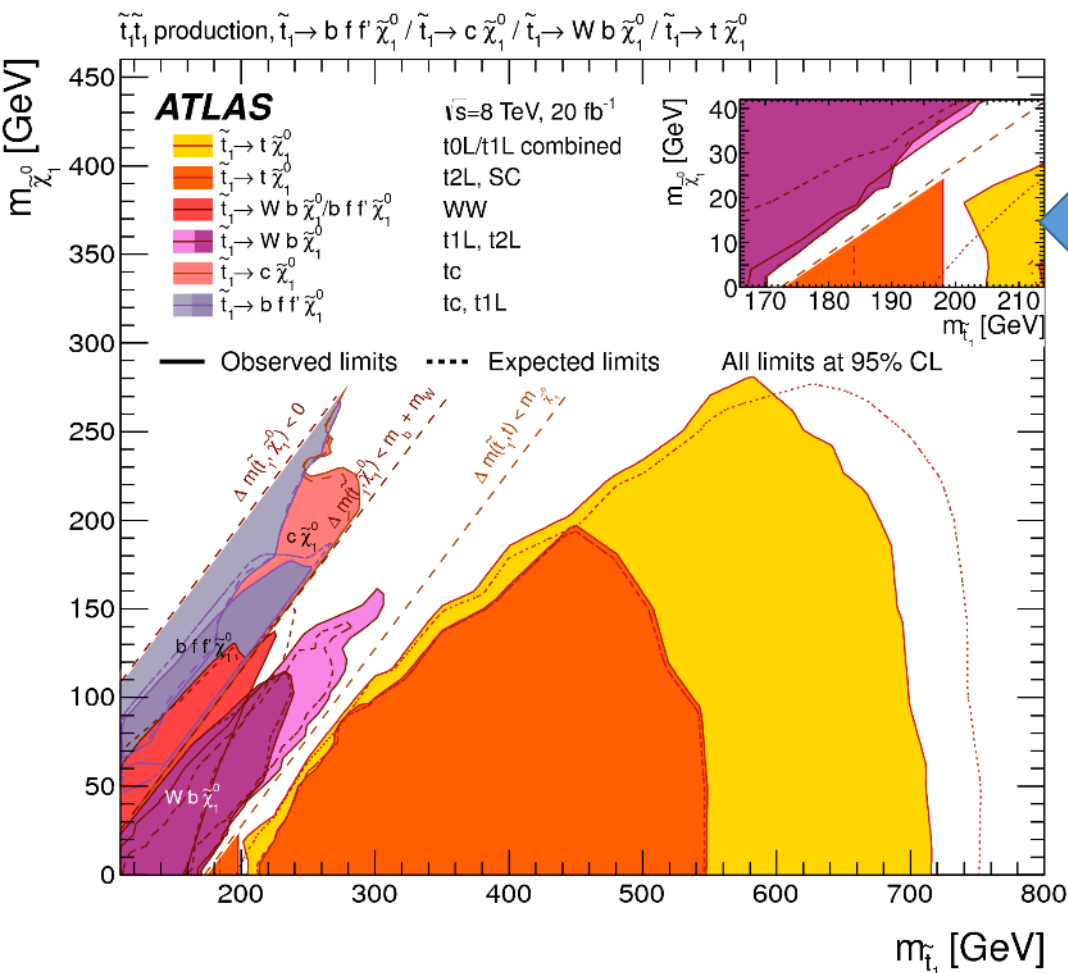
- Many regions depending on jet multiplicity, number of b-jets
- Increasing complexity of decay chain
- Sensitivity to sbottom quarks
- No excess found



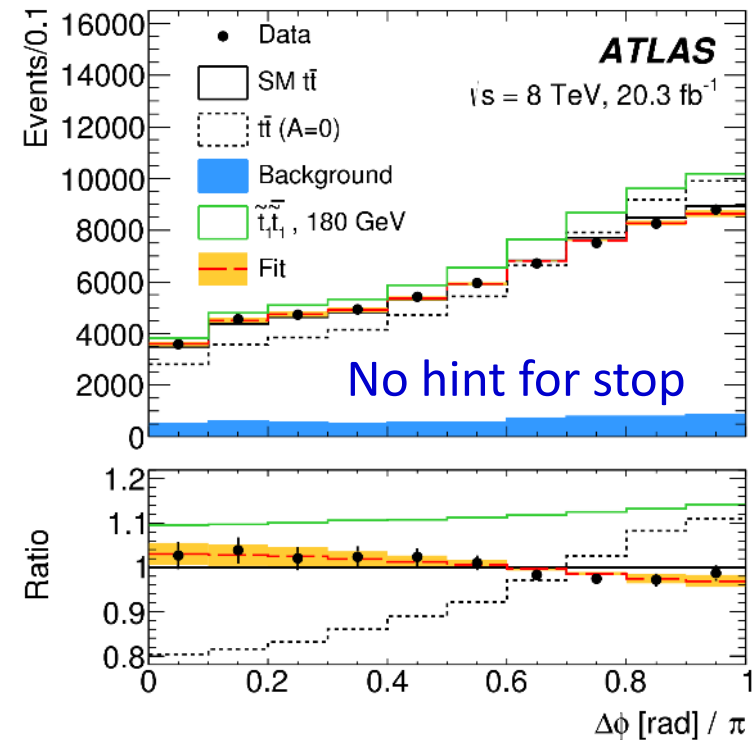
# SUSY searches: stop

Searches are done in every corner.

Top property measurements are used for complimentary exclusion



## Top spin correlation measurement

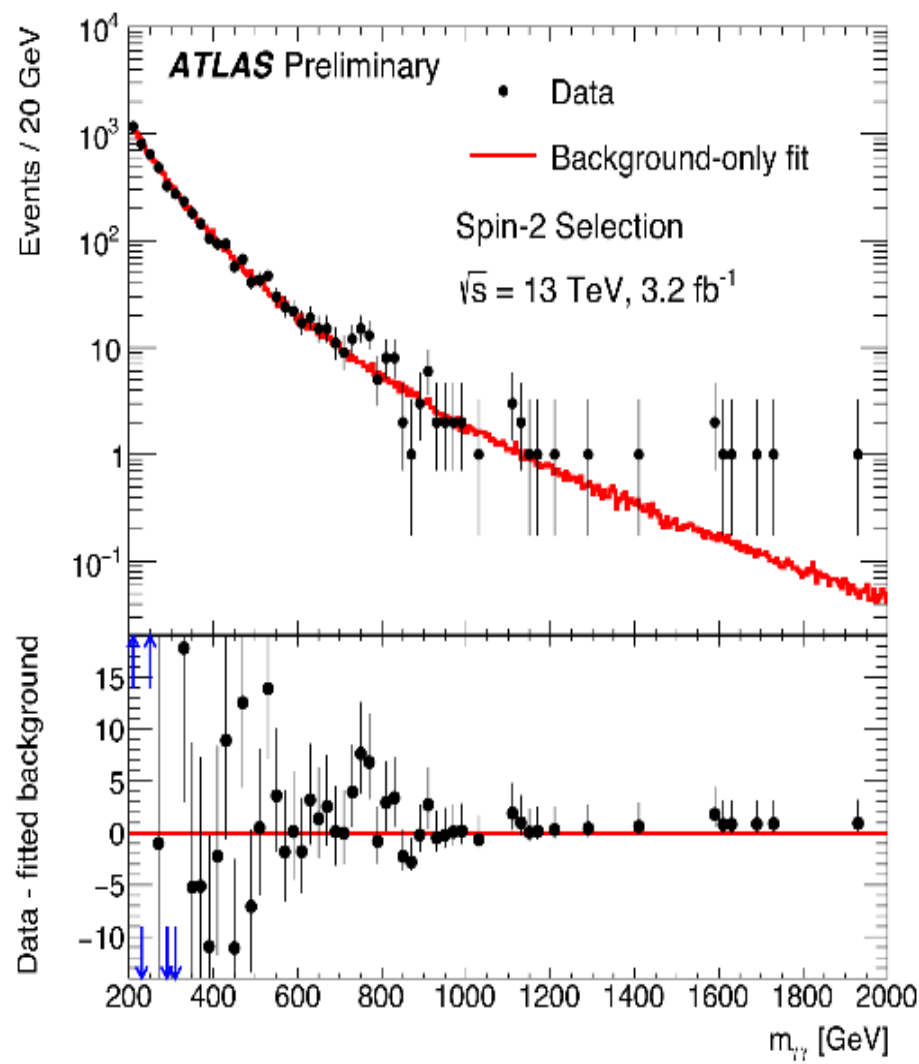
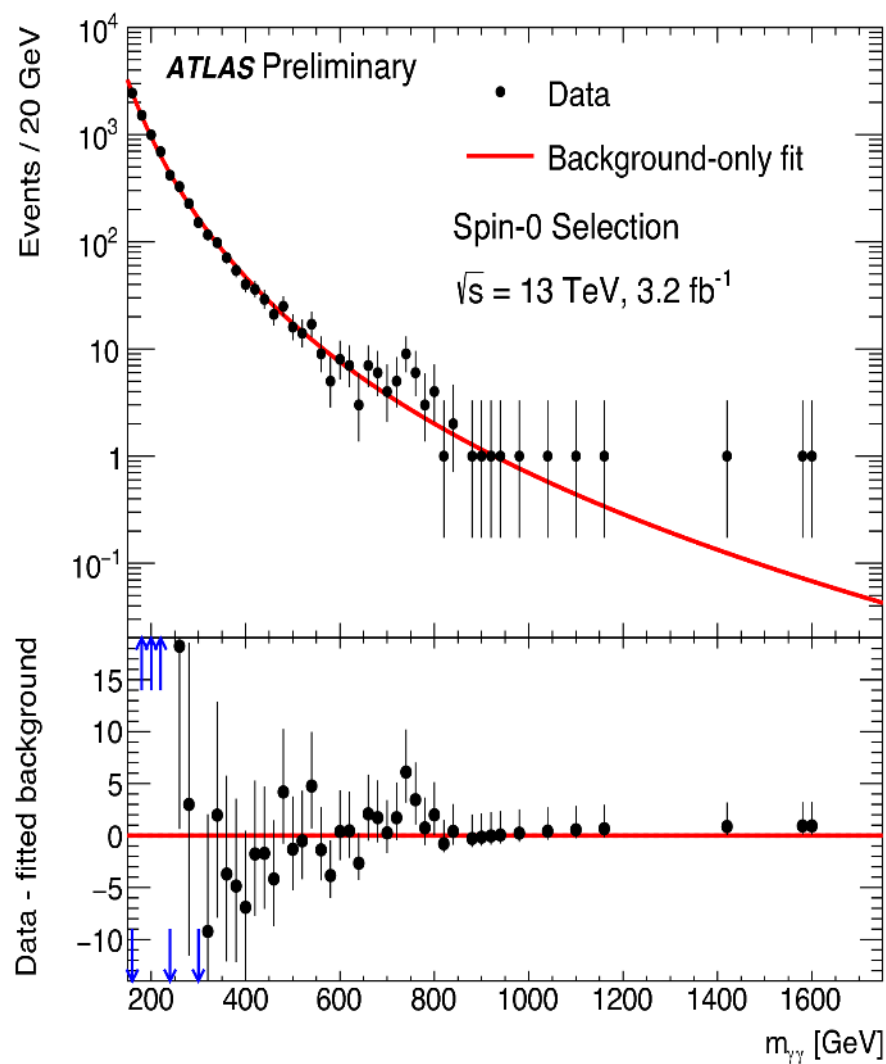


[\*Phys. Rev. Lett.\* 114, 142001 \(2015\)](#)

Note that most SUSY limits assume signal BF of 100% so in reality exclusions could be weaker than plotted.

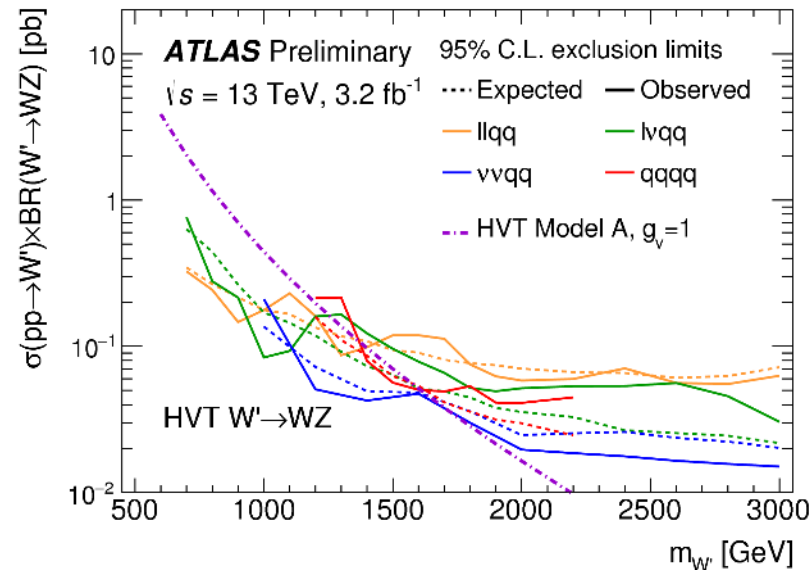
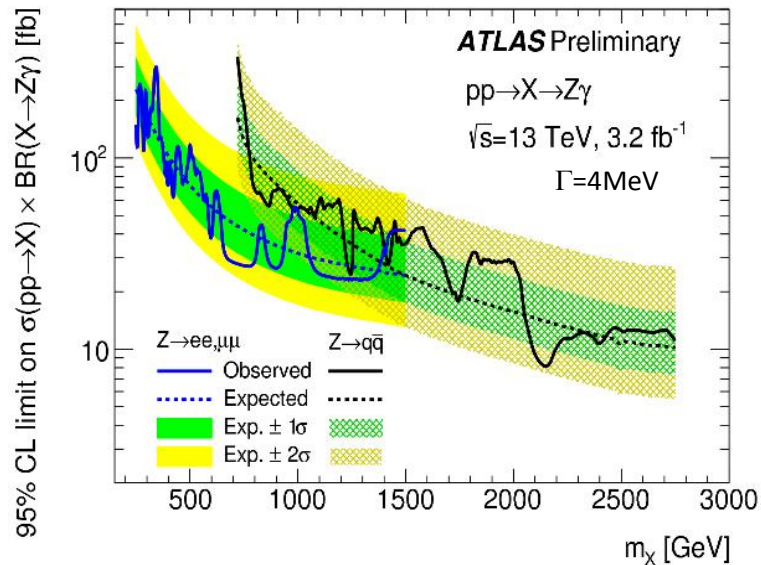
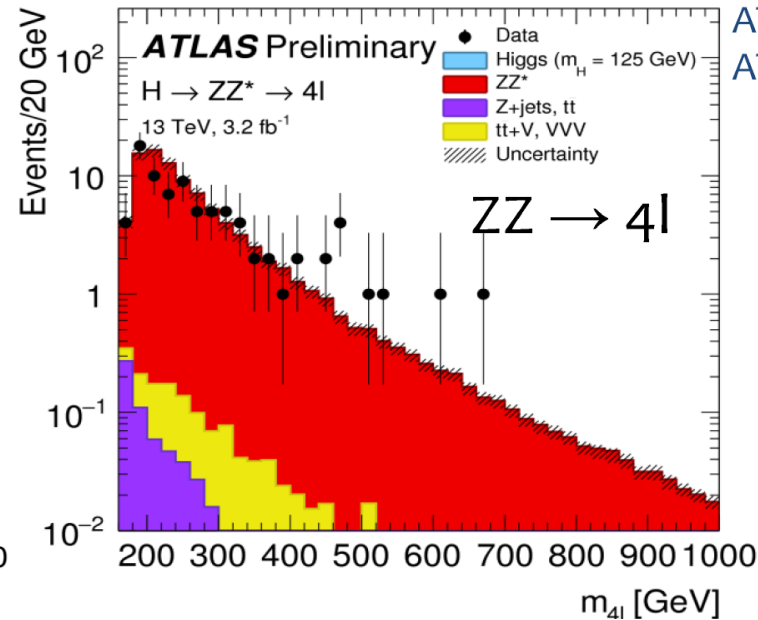
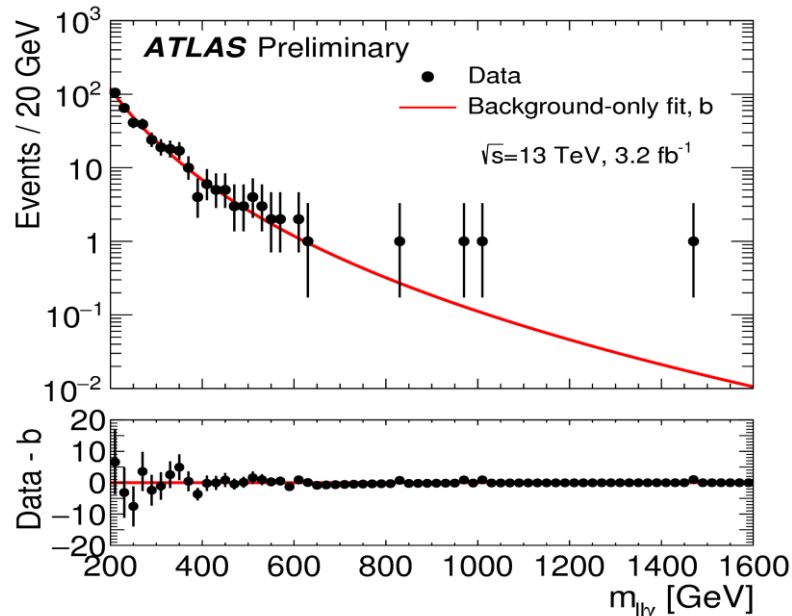


# Diphoton Searches

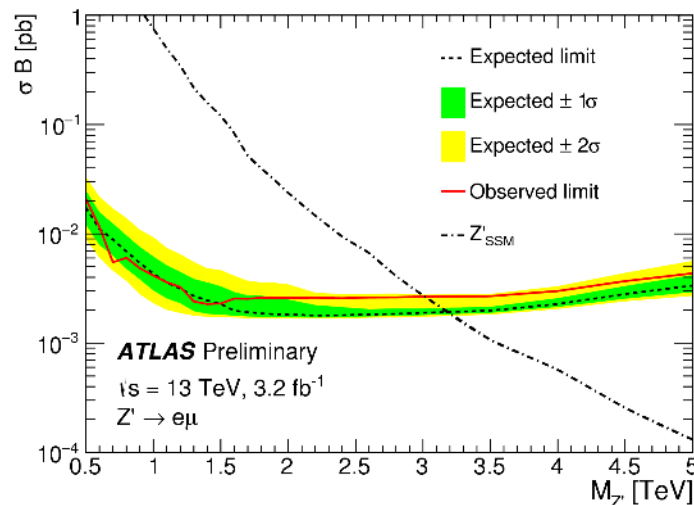
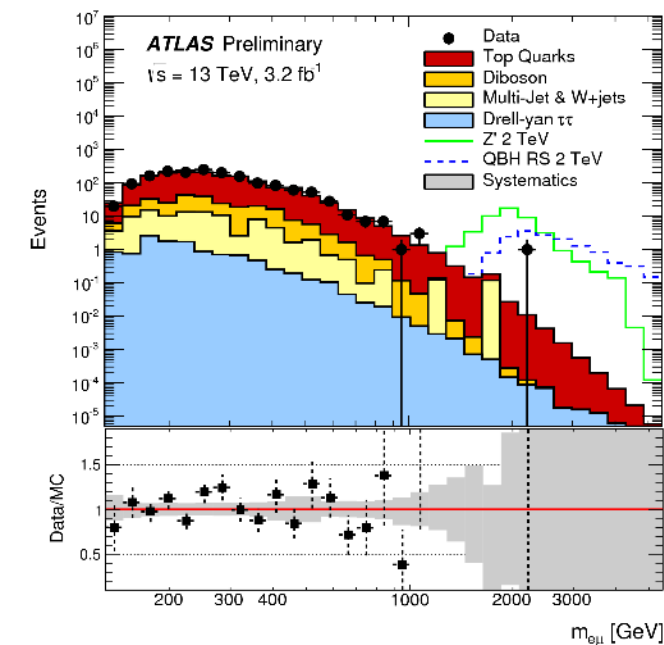
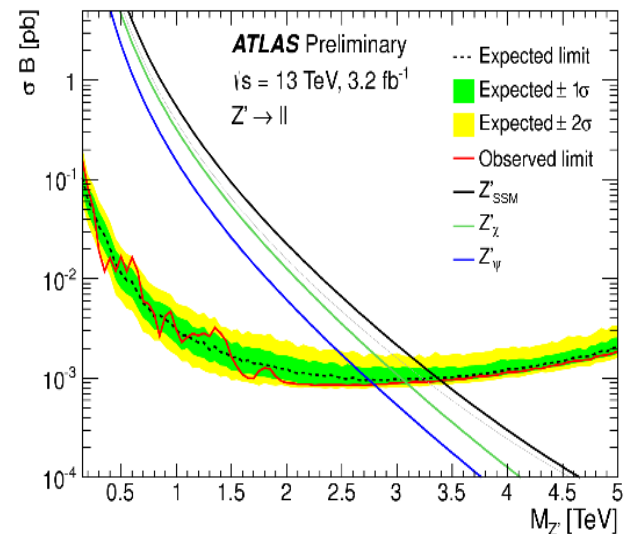
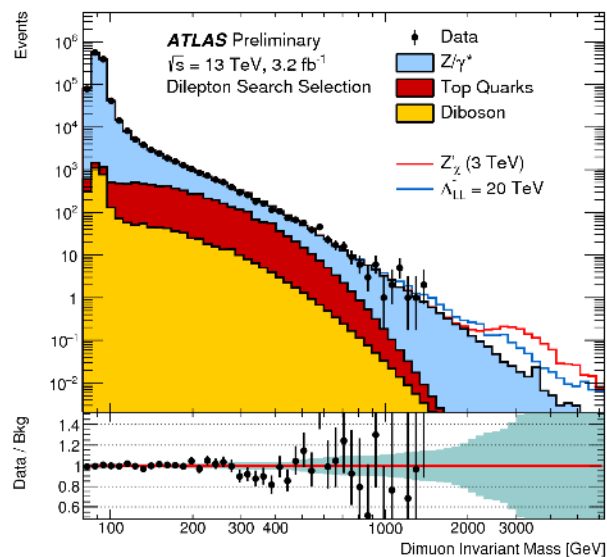
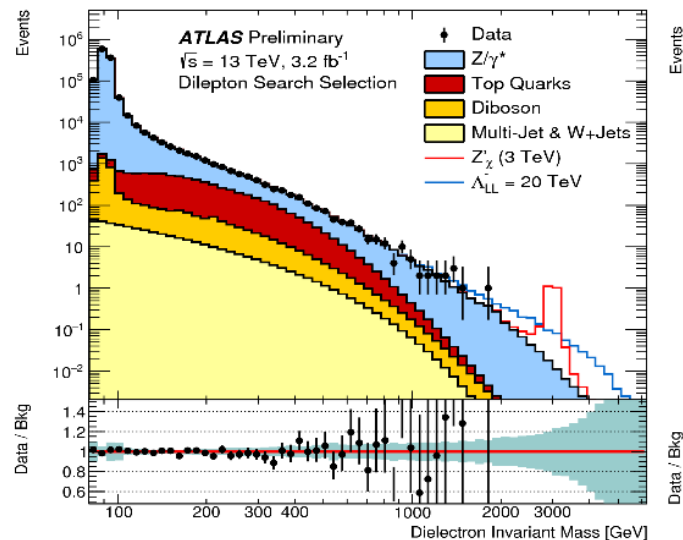


**More details in N. Berger's talk on Thursday**

# Other di-boson channels



# Dileptons

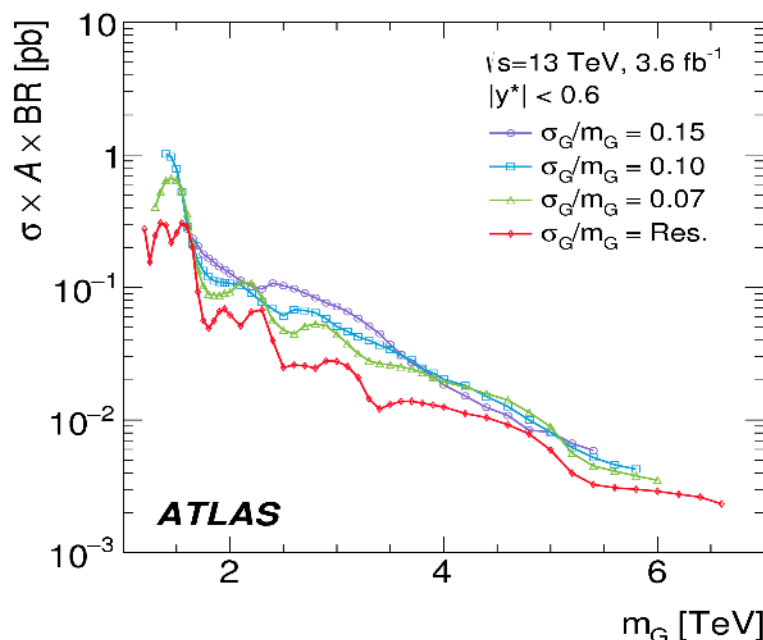


No excesses  
seen.

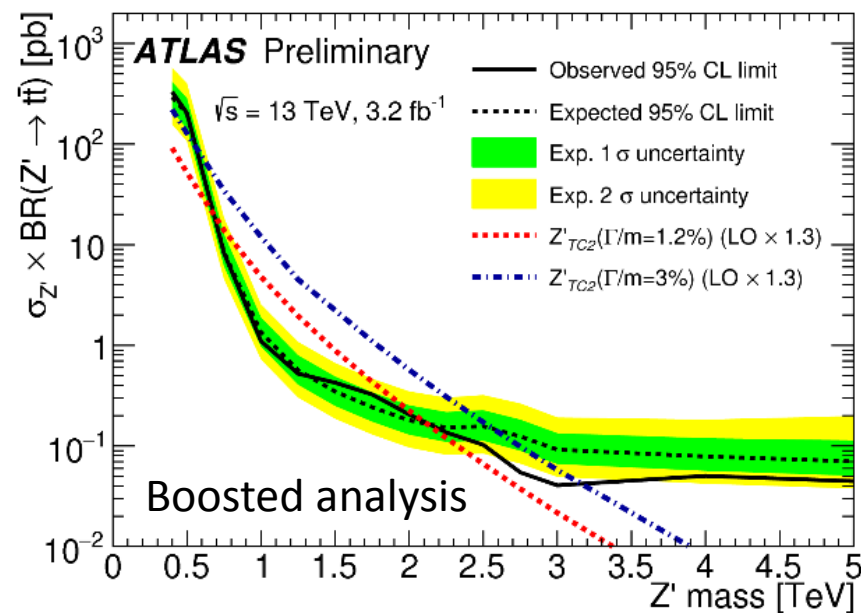
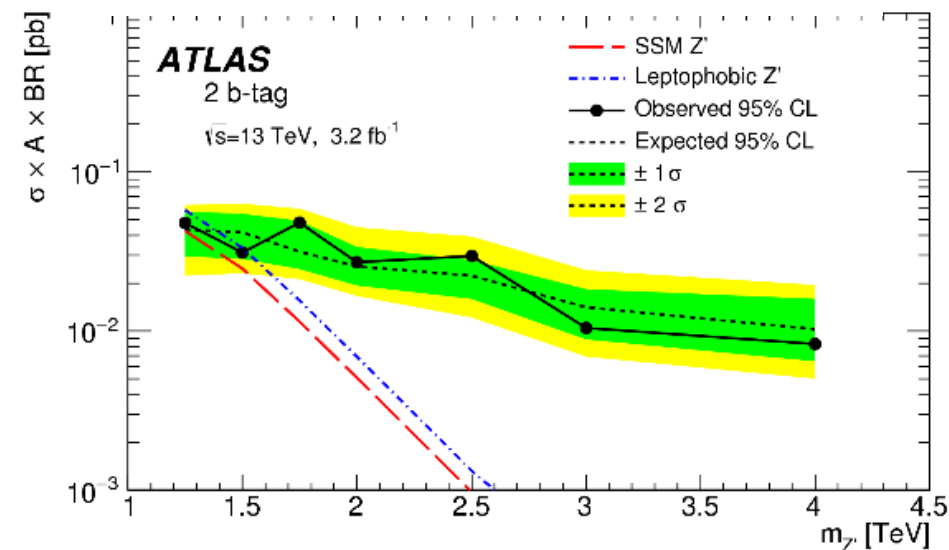
Cross-section  
limits for same  
flavor close to  
 $\gamma\gamma$  ones.

# “Di-jet” searches

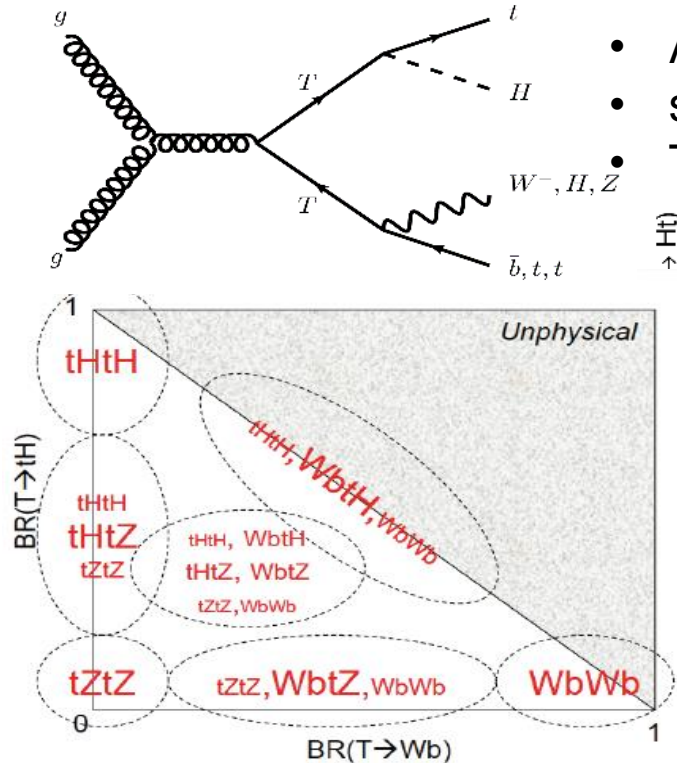
ATLAS Physics Letters B 754 (2016) 302-322  
ATLAS-CONF-2016-014, [arxiv:1603.08791](https://arxiv.org/abs/1603.08791)



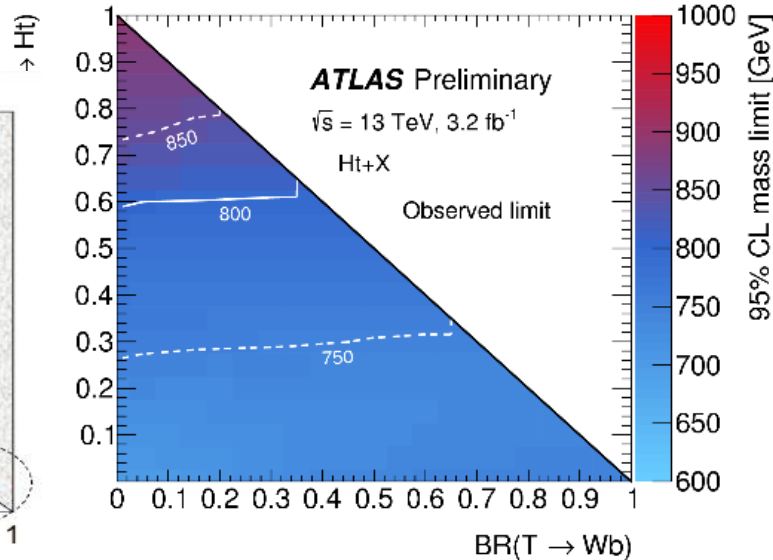
- No excesses seen in dijet channels
- Backgrounds are very high, leading to weak limits
- Very limited sensitivity at masses below 1 TeV, need to wait for
  - trigger level analysis for dijets
  - resolved analysis for  $t\bar{t}$
  - and much more data



# Heavy Vector-Like-Quarks



- Appear in BSM theories with strong EWSB
- same EW charges for LH and RH components
- $T$  stabilizes Higgs mass divergence (like stop in SUSY)



No excess of events seen in leptons+jets channel.

ATLAS:  $m(T) > 900 \text{ GeV}$   
@  $BR(T \rightarrow Ht) = 100\%$

- As the limits for VLQ are already high, rather unusual VLQs (e.g. with large electric charges) need to be considered
- the limits for VLL are weaker  $\rightarrow$  interesting area to explore

# Where did we look in Run 1 & Run 2?\*

↓,→	jet	bjet	top	$\gamma$	W,Z	lepton	Higgs	$E_{\text{Miss}}^T$
jet	Many	1,1	1,1	1,1		Many, 1-3		Many
bjet		2-4	1,1		1,1	2,2	1,1	1-2
top			2-4		1,1	2,2	1,1	1
$\gamma$				2-4	1,1	1,1		1
W,Z					2	1,1	1,1	1
lepton						2-4		1
Higgs							2	1
$E_{\text{Miss}}^T$								Done

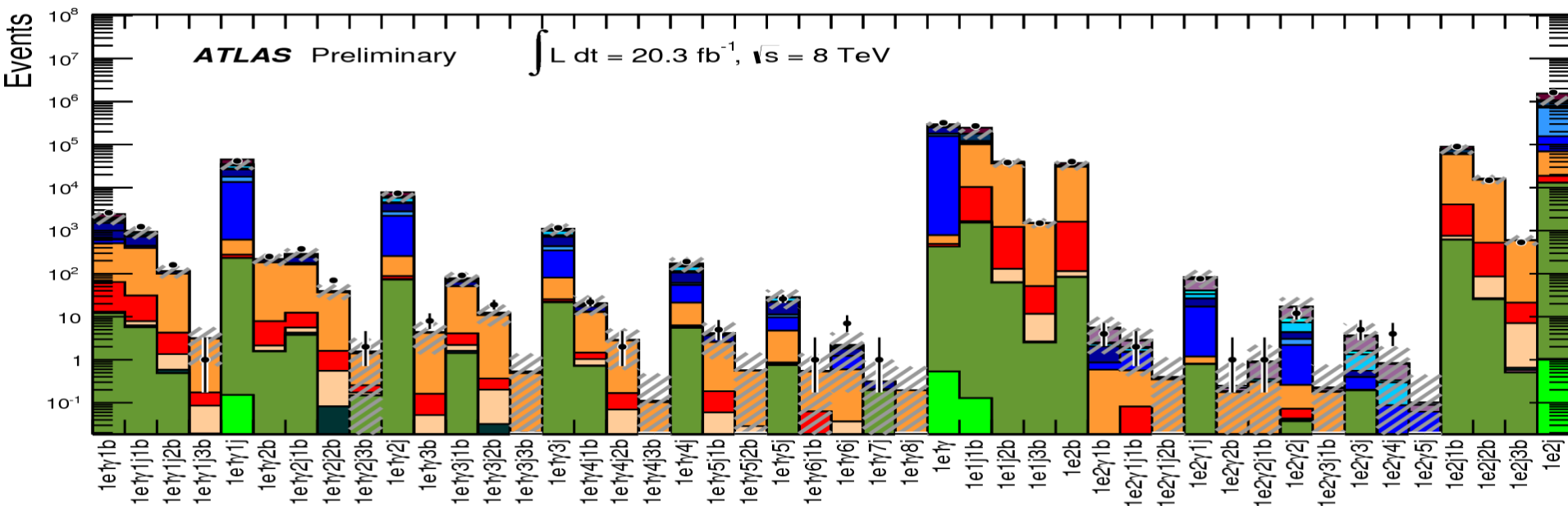
A large fraction of conventional signatures are covered (but not all!),  
unconventional signatures are important.

\*This table is not exhaustive



## No evidence for New Phenomena Seen!

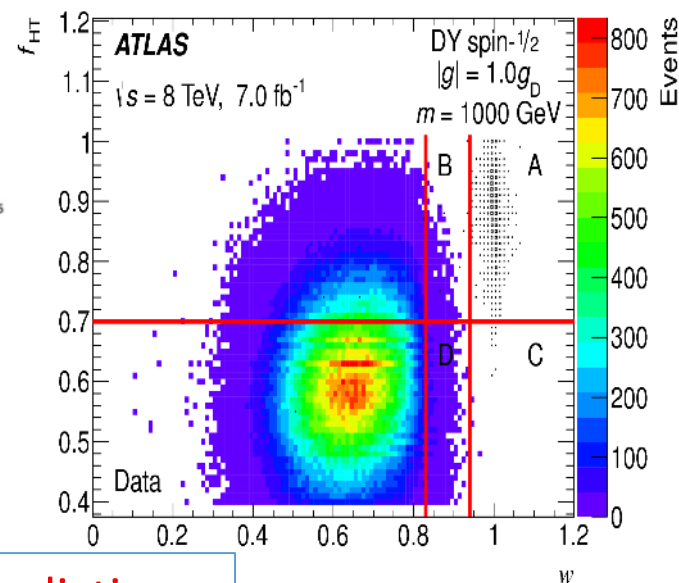
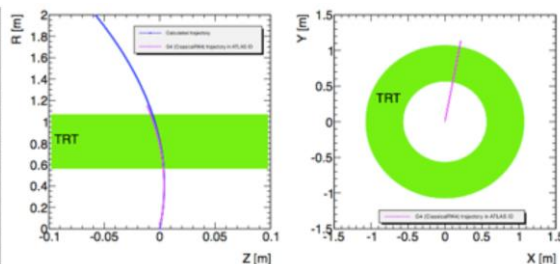
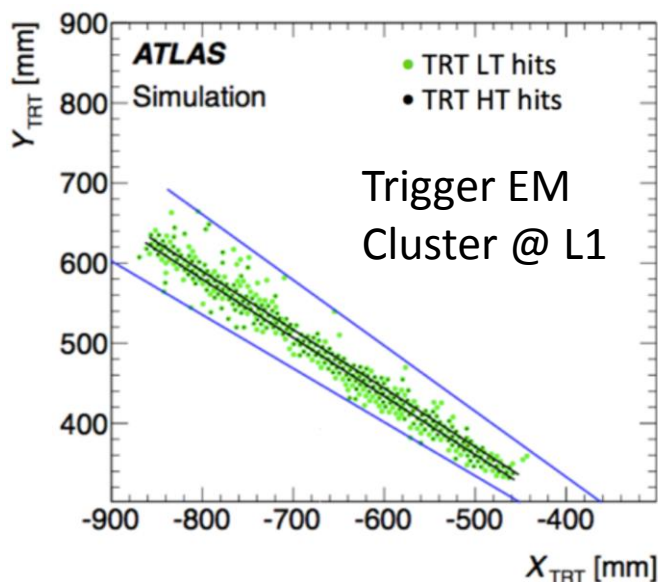
- A search based on combinations of high- $p_T$  objects (e,  $\mu$ ,  $\gamma$ ,  $\nu$ , jet, bjet)
- Standard Model backgrounds from MC only
  - 573 categories have data events; 697 have  $>0.1$  events in MC simulation
- Searches for largest data/MC variations (MC mis-modelling is a problem)
- Need dedicated analysis if discrepancy is observed



# Unconventional Signatures @ LHC

- Low mass (pseudo)scalars
- Highly ionizing particles (HIP) / monopoles
- Charged particles decaying into heavy neutral particles (disappearing tracks, kinks etc.)
- Long-lived particles decaying only in the outer detector components
- Boosted final states: objects close together or overlapping
- Neutral particles (delayed photons) decaying late into neutral states
- ...

Analysis need  
dedicated reconstruction  
techniques & triggers.



# ATLAS Exotics Searches\* - 95% CL Exclusion

Status: March 2016

ATLAS Preliminary

$$\int \mathcal{L} dt = (3.2 - 20.3) \text{ fb}^{-1}$$

$$\sqrt{s} = 8, 13 \text{ TeV}$$

Model	$(\ell, \gamma)$	Jets <sup>†</sup>	$E_{\text{miss}}^{\text{max}}$	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference
<b>Extra dimensions</b>						
ADD $G_{\mu\nu} + g/q$	-	$\geq 1j$	Yes	3.2	$M_{\text{Pl}} = 6.86 \text{ TeV}$	$n=2$ Preliminary
ADD non-resonant $ll$	$2e, \mu$	-	-	20.3	$M_{\text{Pl}} = 4.7 \text{ TeV}$	$n=3 \text{ HLZ}$ 1407.2410
ADD OBH $\rightarrow q\bar{q}$	$1e, \mu$	$1j$	-	20.3	$M_{\text{Pl}} = 5.2 \text{ TeV}$	$n=6$ 1311.2006
ADD OBH	-	$2j$	-	3.6	$M_{\text{Pl}} = 8.3 \text{ TeV}$	$n=6$ 1512.01530
ADD BH high $\Sigma p_T$	$\geq 1e, \mu$	$\geq 2j$	-	3.2	$M_{\text{Pl}} = 8.2 \text{ TeV}$	$n=6, M_{\text{Pl}} = 3 \text{ TeV, rot BH}$ ATLAS-CONF-2016-006
ADD BH multijet	-	$\geq 3j$	-	3.6	$M_{\text{Pl}} = 9.55 \text{ TeV}$	1512.02586
RS1 $G_{\mu\nu} \rightarrow ll$	$2e, \mu$	-	-	20.3	$k/\bar{M}_{\text{Pl}} = 0.1$	1405.4123
RS1 $G_{\mu\nu} \rightarrow \gamma\gamma$	$2\gamma$	-	-	20.3	$k/\bar{M}_{\text{Pl}} = 0.1$	1504.05511
Bulk RS $G_{\mu\nu} \rightarrow WW \rightarrow q\bar{q}l\bar{l}$	$1e, \mu$	$1j$	Yes	3.2	$k/\bar{M}_{\text{Pl}} = 1.0$	ATLAS-CONF-2015-075
Bulk RS $G_{\mu\nu} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$	-	$4b$	Yes	3.2	$k/\bar{M}_{\text{Pl}} = 1.0$	ATLAS-CONF-2016-017
Bulk RS $G_{\mu\nu} \rightarrow tt$	$1e, \mu$	$\geq 1b, \geq 1j, \geq 1\bar{j}$	Yes	20.3	$k/\bar{M}_{\text{Pl}} = 1.0$	BR $\rightarrow 0.925$ 1505.07018
2UED / RPP	$1e, \mu$	$\geq 2b, \geq 4j$	Yes	3.2	$k/\bar{M}_{\text{Pl}} = 1.46 \text{ TeV}$	Tier (1,1), BR( $A^{(1,1)} \rightarrow tt$ ) = 1 ATLAS-CONF-2016-013
<b>Gauge bosons</b>						
SSM $Z' \rightarrow ll$	$2e, \mu$	-	-	3.2	$Z'$ mass $3.4 \text{ TeV}$	ATLAS-CONF-2015-070
SSM $Z' \rightarrow \tau\tau$	$2\tau$	-	-	19.5	$Z'$ mass $2.02 \text{ TeV}$	1502.07177
Leptophobic $Z' \rightarrow b\bar{b}$	$1e, \mu$	$2b$	-	-	$Z'$ mass $1.5 \text{ TeV}$	Preliminary
SSM $W' \rightarrow l\nu$	$1e, \mu$	-	Yes	3.2	$W'$ mass $4.07 \text{ TeV}$	ATLAS-CONF-2015-063
HVT $W' \rightarrow WZ \rightarrow q\bar{q}l\nu$ model A	$0e, \mu$	$1j$	-	-	$W'$ mass $1.6 \text{ TeV}$	ATLAS-CONF-2015-068
HVT $W' \rightarrow WH \rightarrow l\nu b\bar{b}$ model A	$1e, \mu$	$2j$	-	3.2	$W'$ mass $1.38-1.6 \text{ TeV}$	ATLAS-CONF-2015-073
HVT $Z' \rightarrow WH \rightarrow l\nu b\bar{b}$ model B	$1e, \mu$	$1-2b, 1-1j$	Yes	3.2	$W'$ mass $1.62 \text{ TeV}$	ATLAS-CONF-2015-074
HVT $Z' \rightarrow ZH \rightarrow \nu\nu b\bar{b}$ model B	$0e, \mu$	$1-2b, 1-1j$	Yes	3.2	$Z'$ mass $1.76 \text{ TeV}$	ATLAS-CONF-2015-074
LRSM $W'_2 \rightarrow tb$	$1e, \mu$	$2b, 0-1j$	Yes	20.3	$W'$ mass $1.92 \text{ TeV}$	1410.4103
LRSM $W'_2 \rightarrow tb$	$0e, \mu$	$\geq 1b, 1j$	Yes	20.3	$W'$ mass $1.76 \text{ TeV}$	1408.0886
<b>CI</b>						
CI $q\bar{q}q\bar{q}$	-	$2j$	-	3.6	$A$ mass $17.5 \text{ TeV}$	$\eta_{1,2} = -1$ 1512.01530
CI $q\bar{q}l\bar{l}$	$2e, \mu$	$\geq 1j$	-	3.2	$A$ mass $23.1 \text{ TeV}$	$\eta_{1,2} = -1$ ATLAS-CONF-2015-070
CI $u\bar{u}t\bar{t}$	$2e, \mu$	$(SS) \geq 1b, 1-4j$	Yes	20.3	$A$ mass $4.3 \text{ TeV}$	$C_{4LL} = 1$ 1504.04605
<b>DM</b>						
Axis-vector mediator (Dirac DM)	$0e, \mu$	$\geq 1j$	Yes	3.2	$m_A = 650 \text{ GeV}$	$g_A = 0.25, g_V = 1.0, m(\chi) < 140 \text{ GeV}$ Preliminary
Axis-vector mediator (Dirac DM)	$0e, \mu, 1\gamma$	$1j$	Yes	3.2	$m_A = 550 \text{ GeV}$	$g_A = 0.25, g_V = 1.0, m(\chi) < 10 \text{ GeV}$ Preliminary
ZZ EFT (Dirac DM)	$0e, \mu$	$1-4, \leq 1j$	Yes	3.2	$m_A = 550 \text{ GeV}$	$m(\chi) < 150 \text{ GeV}$ ATLAS-CONF-2015-080
<b>LQ</b>						
Scalar LQ 1 <sup>st</sup> gen	$2e$	$\geq 2j$	-	3.2	$LQ$ mass $1.07 \text{ TeV}$	$\beta = 1$ Preliminary
Scalar LQ 2 <sup>nd</sup> gen	$2\mu$	$\geq 2j$	-	3.2	$LQ$ mass $1.03 \text{ TeV}$	$\beta = 1$ Preliminary
Scalar LQ 3 <sup>rd</sup> gen	$1e, \mu$	$\geq 1b, \geq 3j$	Yes	20.3	$LQ$ mass $640 \text{ GeV}$	$\beta = 0$ 1508.04735
<b>Heavy quarks</b>						
VLO $TT \rightarrow Ht + X$	$1e, \mu$	$\geq 2b, \geq 3j$	Yes	20.3	$T$ mass $655 \text{ GeV}$	T in (TB) doublet 1505.04306
VLO $YY \rightarrow Wb + X$	$1e, \mu$	$\geq 1b, \geq 3j$	Yes	20.3	$Y$ mass $770 \text{ GeV}$	Y in (BY) doublet 1505.04306
VLO $BB \rightarrow Hb + X$	$1e, \mu$	$\geq 2b, \geq 3j$	Yes	20.3	$B$ mass $735 \text{ GeV}$	isospin singlet 1505.04306
VLO $BB \rightarrow Zb + X$	$2\gamma, 3e, \mu$	$\geq 2b, 1-1j$	-	20.3	$B$ mass $755 \text{ GeV}$	B in (BY) doublet 1409.5500
VLO $QQ \rightarrow Wt + X$	$1e, \mu$	$\geq 2j$	Yes	20.3	$Q$ mass $690 \text{ GeV}$	1509.04261
$T_{3/2} \rightarrow Wq$	$1e, \mu$	$\geq 1b, \geq 5j$	Yes	20.3	$T_{3/2}$ mass $840 \text{ GeV}$	1503.05425
<b>Excited fermions</b>						
Excited quark $q^* \rightarrow q\gamma$	$1\gamma$	$1j$	-	3.2	$q^*$ mass $4.4 \text{ TeV}$	only $u^*$ and $d^*$ , $A = m(q^*)$ 1512.05910
Excited quark $q^* \rightarrow qg$	-	$2j$	-	3.6	$q^*$ mass $5.2 \text{ TeV}$	only $u^*$ and $d^*$ , $A = m(q^*)$ 1512.01530
Excited quark $b^* \rightarrow b\gamma$	-	$1b, 1j$	-	3.2	$b^*$ mass $2.1 \text{ TeV}$	Preliminary
Excited quark $b^* \rightarrow Wt$	$1 \text{ or } 2e, \mu$	$1b, 2-3j$	Yes	20.3	$b^*$ mass $1.5 \text{ TeV}$	$f_q = f_b = f_{\bar{q}} = 1$ 1510.02964
Excited lepton $l^* \rightarrow l\gamma$	$3e, \mu$	-	-	20.3	$l^*$ mass $3.0 \text{ TeV}$	$A = 3.0 \text{ TeV}$ 1411.2921
Excited lepton $\nu^*$	$3e, \mu, \tau$	-	-	20.3	$\nu^*$ mass $1.6 \text{ TeV}$	$A = 1.6 \text{ TeV}$ 1411.2921
<b>Other</b>						
LSTC $p_T \rightarrow W\gamma$	$1e, \mu, 1\gamma$	-	Yes	20.3	$p_T$ mass $960 \text{ GeV}$	$m(W_{\text{eff}}) = 2.4 \text{ TeV}$ no mixing 1407.8150
LRSM Majorana $\nu$	$2e, \mu$	$2j$	-	20.3	$\nu$ mass $2.8 \text{ TeV}$	DY production, BR( $H_{\text{eff}}^{\text{SM}} \rightarrow ll$ ) = 1 1506.06020
Higgs triplet $H^{\text{SM}} \rightarrow ll$	$2e, \mu$	(SS)	-	20.3	$H^{\text{SM}}$ mass $551 \text{ GeV}$	DY production, BR( $H_{\text{eff}}^{\text{SM}} \rightarrow l\nu$ ) = 1 1412.02327
Higgs triplet $H^{\text{SM}} \rightarrow l\bar{l}$	$3e, \mu, \tau$	-	-	20.3	$H^{\text{SM}}$ mass $400 \text{ GeV}$	DY production, BR( $H_{\text{eff}}^{\text{SM}} \rightarrow l\nu$ ) = 1 1411.2921
Monopole (non-res prod)	$1e, \mu$	$1b$	Yes	20.3	$\mu$ mass $557 \text{ GeV}$	$\mu_{\text{non-res}} = 0.2$ 1510.5404
Multi-charged particles	-	-	-	20.3	$\mu$ mass $785 \text{ GeV}$	DY production, $ q  = 5e$ 1504.04188
Magnetic monopoles	-	-	-	7.0	$\mu$ mass $1.34 \text{ TeV}$	DY production, $ q  = 1e_{\text{D}}, \text{spin } 1/2$ 1509.08059

\*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.

†Small-radius (large-radius) jets are denoted by the letter  $j$  ( $J$ ).

# A lot of results available...

## ATLAS SUSY Searches\* - 95% CL Lower Limits

Status: March 2016

ATLAS Preliminary

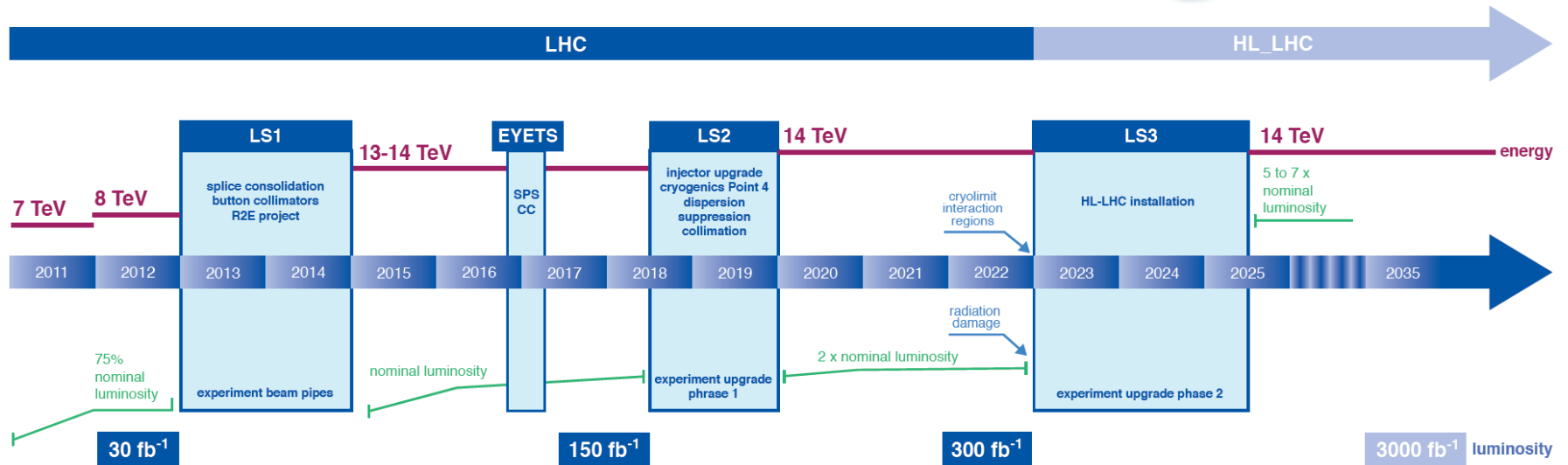
$$\sqrt{s} = 7, 8, 13 \text{ TeV}$$

Model	$(\ell, \mu, \tau, \gamma)$	Jets	$E_{\text{miss}}^{\text{max}}$	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	$\sqrt{s} = 7, 8 \text{ TeV}$	$\sqrt{s} = 13 \text{ TeV}$	Reference	
Inclusive Searches	MSUGRA/CMSM	$0-3e, \mu, 1-2\tau$	$2-10$ jets/3 $b$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}$	880 GeV	1.85 TeV	$m(\tilde{g}) = m(\tilde{q})$ 1507.05525	
	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}$	$0-2$ jets	Yes 3.2	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}$ (compressed)	610 GeV	820 GeV	$m(\tilde{g}) = 0 \text{ GeV}, m(\tilde{l}) = m(1^{\text{st}} \text{ gen. jet}) = m(2^{\text{nd}} \text{ gen. jet})$ ATLAS-CONF-2015-082		
	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	$1-3$ jets	Yes 3.2	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	610 GeV	820 GeV	$m(\tilde{g}) = m(\tilde{l}) < 5 \text{ GeV}$ $\tilde{l} \rightarrow \nu q$ 1503.02690		
	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	$2e, \mu$ (dH-Z)	$2$ jets	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	610 GeV	820 GeV	$m(\tilde{g}) = 0 \text{ GeV}$ ATLAS-CONF-2015-082	
	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	$1e, \mu$	$2-6$ jets	Yes 3.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	610 GeV	820 GeV	$m(\tilde{g}) = 0 \text{ GeV}$ ATLAS-CONF-2015-076	
	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	$2e, \mu$	$0-3$ jets	- 20	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	610 GeV	820 GeV	$m(\tilde{g}) = 0 \text{ GeV}$ 1501.05555	
	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	$0$	$7-10$ jets	Yes 3.2	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	610 GeV	820 GeV	$m(\tilde{g}) = 0 \text{ GeV}$ 1507.05480	
	GMSB (bino NLSP)	$1-2\tau + 0-1l$	$0-2$ jets	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	610 GeV	820 GeV	$m(\tilde{g}) = 0 \text{ GeV}$ 1507.05480	
	GGM (higgsino-bino NLSP)	$2\gamma$	-	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	610 GeV	820 GeV	$m(\tilde{g}) = 0 \text{ GeV}$ 1503.02690	
	GGM (higgsino-bino NLSP)	$7$	$1b$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	610 GeV	820 GeV	$m(\tilde{g}) = 0 \text{ GeV}$ 1503.02690	
	GGM (higgsino NLSP)	$2e, \mu$ (Z)	$2$ jets	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	610 GeV	820 GeV	$m(\tilde{g}) = 0 \text{ GeV}$ 1503.02690	
	Gravitino LSP	$0$	mono-jet	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ ( $l = \nu, \tau, \mu, e$ )	610 GeV	820 GeV	$m(\tilde{g}) = 0 \text{ GeV}$ 1503.02690	
	3 <sup>rd</sup> gen. squarks & gluinos	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$0$	$3b$	Yes 3.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	1.78 TeV	1.78 TeV	$m(\tilde{g}) = 800 \text{ GeV}$ ATLAS-CONF-2015-067
$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$		$0-1e, \mu$	$3b$	Yes 3.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	1.78 TeV	1.78 TeV	$m(\tilde{g}) = 0 \text{ GeV}$ 1407.2690	
$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$		$0-1e, \mu$	$3b$	Yes 20.1	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	1.78 TeV	1.78 TeV	$m(\tilde{g}) = 0 \text{ GeV}$ 1407.2690	
$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$		$0$	$2b$	Yes 3.2	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	840 GeV	840 GeV	$m(\tilde{g}) = 100 \text{ GeV}$ ATLAS-CONF-2015-066	
$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$		$2e, \mu$ (SS)	$0-3b$	Yes 3.2	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	325-540 GeV	325-540 GeV	$m(\tilde{g}) = 50 \text{ GeV}, m(\tilde{l}) = m(\tilde{q}) = 100 \text{ GeV}$ 1602.09558	
$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$		$1-2e, \mu$	$1-2b$	Yes 4.7/20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	170-170 GeV	200-500 GeV	$m(\tilde{g}) = 2m(\tilde{l}), m(\tilde{l}) = 55 \text{ GeV}$ 1209.2102, 1407.0593	
$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$		$0-2e, \mu$	$0-2$ jets/1-2 $b$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	90-198 GeV	255-715 GeV	$m(\tilde{g}) = 1 \text{ GeV}$ 1508.08616, ATLAS-CONF-2016-007	
$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$		$0$	mono-jet+tag $b$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	90-245 GeV	255-715 GeV	$m(\tilde{g}) = m(\tilde{l}) = 85 \text{ GeV}$ 1407.0608	
$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$		$2e, \mu$ (Z)	$1b$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	150-500 GeV	150-500 GeV	$m(\tilde{g}) = 150 \text{ GeV}$ 1403.5222	
$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$		$3e, \mu$ (Z)	$1b$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	290-610 GeV	290-610 GeV	$m(\tilde{g}) = 200 \text{ GeV}$ 1403.5222	
$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$		$1e, \mu$	$6$ jets + $2b$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	320-420 GeV	320-420 GeV	$m(\tilde{g}) = 0 \text{ GeV}$ 1508.08616	
EW direct		$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$2e, \mu$	$0$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	90-335 GeV	90-335 GeV	$m(\tilde{g}) = 0 \text{ GeV}$ 1403.5222
		$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$2e, \mu$	$0$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	140-475 GeV	140-475 GeV	$m(\tilde{g}) = 0 \text{ GeV}, m(\tilde{l}), m(\tilde{q}) = 0.5(m(\tilde{g}) + m(\tilde{l})))$ 1403.5222
	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$2\tau$	-	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	355 GeV	355 GeV	$m(\tilde{g}) = 0 \text{ GeV}, m(\tilde{l}), m(\tilde{q}) = 0.5(m(\tilde{g}) + m(\tilde{l})))$ 1407.0594	
	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$3e, \mu$	$0$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	425 GeV	425 GeV	$m(\tilde{g}) = m(\tilde{l}), m(\tilde{l}), m(\tilde{q}) = 0.5(m(\tilde{g}) + m(\tilde{l})))$ 1402.7029	
	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$2-3e, \mu$	$0-2$ jets	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	425 GeV	425 GeV	$m(\tilde{g}) = m(\tilde{l}), m(\tilde{l}), m(\tilde{q}) = 0.5(m(\tilde{g}) + m(\tilde{l})))$ 1403.5222, 1402.7029	
	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$2e, \mu$	$0-2b$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	270 GeV	270 GeV	$m(\tilde{g}) = 0 \text{ GeV}, m(\tilde{l}), m(\tilde{q}) = 0.5(m(\tilde{g}) + m(\tilde{l})))$ 1501.07110	
	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$4e, \mu$	$0$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	635 GeV	635 GeV	$m(\tilde{g}) = m(\tilde{l}), m(\tilde{l}), m(\tilde{q}) = 0.5(m(\tilde{g}) + m(\tilde{l})))$ 1405.5086	
	GGM (bino NLSP) weak prod.	$1e, \mu, \tau$	-	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	115-370 GeV	115-370 GeV	$m(\tilde{g}) = m(\tilde{l}), m(\tilde{l}), m(\tilde{q}) = 0.5(m(\tilde{g}) + m(\tilde{l})))$ 1507.05480	
	Long-lived particles	Direct $\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$ prod., long-lived $\tilde{g}, \tilde{q}$	Disapp. trk	$1$ jet	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	270 GeV	270 GeV	$m(\tilde{g}) = m(\tilde{l}) = 160 \text{ MeV}, m(\tilde{l}) = 0.2 \text{ ms}$ 1310.3975
		Stable, stopped $\tilde{g}, \tilde{q}$ prod., long-lived $\tilde{g}, \tilde{q}$	dE/dx trk	$0-15$ jets	Yes 27.9	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	495 GeV	495 GeV	$m(\tilde{g}) = 100 \text{ GeV}, m(\tilde{l}) = 15 \mu\text{s}, m(\tilde{q}) = 1000 \text{ s}$ 1506.05332
		Metastable $\tilde{g}, \tilde{q}$ prod., long-lived $\tilde{g}, \tilde{q}$	dE/dx trk	-	- 3.2	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	850 GeV	850 GeV	$m(\tilde{g}) = 100 \text{ GeV}, m(\tilde{l}) = 10 \mu\text{s}, m(\tilde{q}) = 1000 \text{ s}$ 1503.02690
		GMSB, stable $\tilde{g}, \tilde{q} \rightarrow \tilde{g}, \tilde{q} + \tilde{g}, \tilde{q} + \tilde{g}$	$1-2\mu$	-	- 19.1	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	537 GeV	537 GeV	$m(\tilde{g}) = 100 \text{ GeV}, m(\tilde{l}) = 10 \mu\text{s}, m(\tilde{q}) = 1000 \text{ s}$ 1411.6795
		GMSB, $\tilde{g}, \tilde{q} \rightarrow \tilde{g}, \tilde{q} + \tilde{g}, \tilde{q} + \tilde{g}$	$2\gamma$	-	- 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	440 GeV	440 GeV	$m(\tilde{g}) = 100 \text{ GeV}, m(\tilde{l}) = 10 \mu\text{s}, m(\tilde{q}) = 1000 \text{ s}$ 1409.5452
$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$		displ. $e\bar{e}/\mu\bar{\mu}$	-	- 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	1.0 TeV	1.0 TeV	$1-7\tau(\tilde{g}) < 740 \text{ nm}, m(\tilde{g}) = 1.3 \text{ TeV}$ 1504.05162	
$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$		displ. $\nu\bar{\nu}$ + jets	-	- 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	1.0 TeV	1.0 TeV	$6-8\tau(\tilde{g}) < 480 \text{ nm}, m(\tilde{g}) = 1.1 \text{ TeV}$ 1504.05162	
RPV		LFV $pp \rightarrow \tilde{g}, \tilde{q} + X, \tilde{g}, \tilde{q} \rightarrow \nu\bar{\nu} + \tilde{g}, \tilde{q}$	$e\bar{e}/\mu\bar{\mu}$ trk	-	- 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	1.7 TeV	1.7 TeV	$m(\tilde{g}) = 0.11, m(\tilde{l}) = 0.07$ 1503.04430
		Bilinear RPV CMSM	$2e, \mu$ (SS)	$0-3b$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	760 GeV	760 GeV	$m(\tilde{g}) = m(\tilde{l}), m(\tilde{l}) = 0.1$ 1404.2500
		$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$4e, \mu$	-	- 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	760 GeV	760 GeV	$m(\tilde{g}) = 0.2m(\tilde{l}), m(\tilde{l}) = 0.1$ 1405.5086
		$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$3e, \mu$ (Z)	$0-2b$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	450 GeV	450 GeV	$m(\tilde{g}) = 0.1m(\tilde{l}), m(\tilde{l}) = 0.1$ 1405.5086
		$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$0$	$6-7$ jets	- 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	917 GeV	917 GeV	$m(\tilde{g}) = 0.1m(\tilde{l}), m(\tilde{l}) = 0.1$ 1502.05686
		$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$0$	$6-7$ jets	- 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	960 GeV	960 GeV	$m(\tilde{g}) = 0.1m(\tilde{l}), m(\tilde{l}) = 0.1$ 1502.05686
	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$2e, \mu$ (SS)	$0-3b$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	880 GeV	880 GeV	$m(\tilde{g}) = 0.1m(\tilde{l}), m(\tilde{l}) = 0.1$ 1404.2500	
	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$0$	$2$ jets + $2b$	- 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	320 GeV	320 GeV	$m(\tilde{g}) = 0.1m(\tilde{l}), m(\tilde{l}) = 0.1$ 1601.07453	
	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	$2e, \mu$	$2b$	- 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	510 GeV	510 GeV	$m(\tilde{g}) = 0.1m(\tilde{l}), m(\tilde{l}) = 0.1$ ATLAS-CONF-2015-015	
	Other	Scalar charm, $\tilde{g} \rightarrow c\bar{c}$	$0$	$2c$	Yes 20.3	$\tilde{g}, \tilde{q} \rightarrow q\bar{q}l$	510 GeV	510 GeV	$m(\tilde{g}) = 0.1m(\tilde{l}), m(\tilde{l}) = 0.1$ 1501.0325

Only a selection of the available mass limits on new states are shown

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# Outlook



- We are in regime of non-linear luminosity increase
  - 2016 dataset = 6 x 2015 dataset!
- Stay tuned to 2016 results

# Acknowledgements

All information used for this talk can be found at:

<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/>

This talk derived inspiration and images from the following talks:

Frank Wilkenmeier & Hernan Wahlberg @ HEP in LHC era January 2016

Brigitte Vachon @ CNPLHC 2016

Nicolas Venturi & Martin Flechl @ LHCski, April 2016