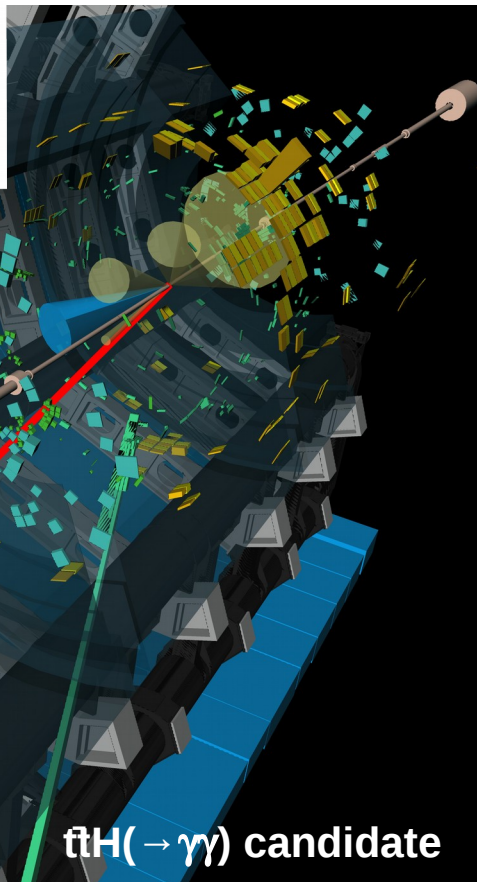
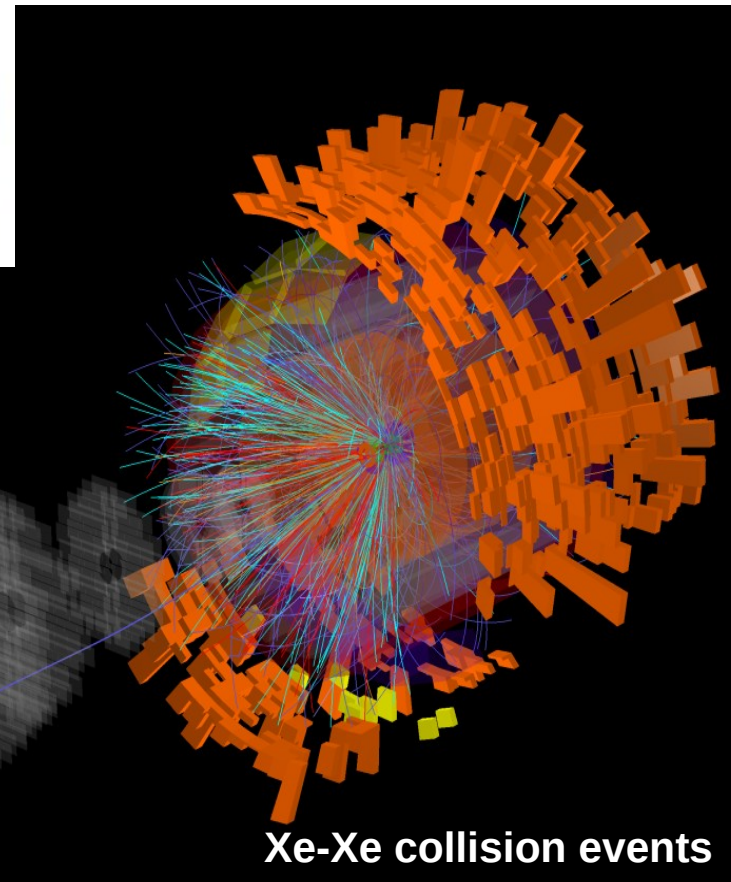


# Physics Highlights of ATLAS and ALICE



$ttH(\rightarrow \gamma\gamma)$  candidate



Xe-Xe collision events



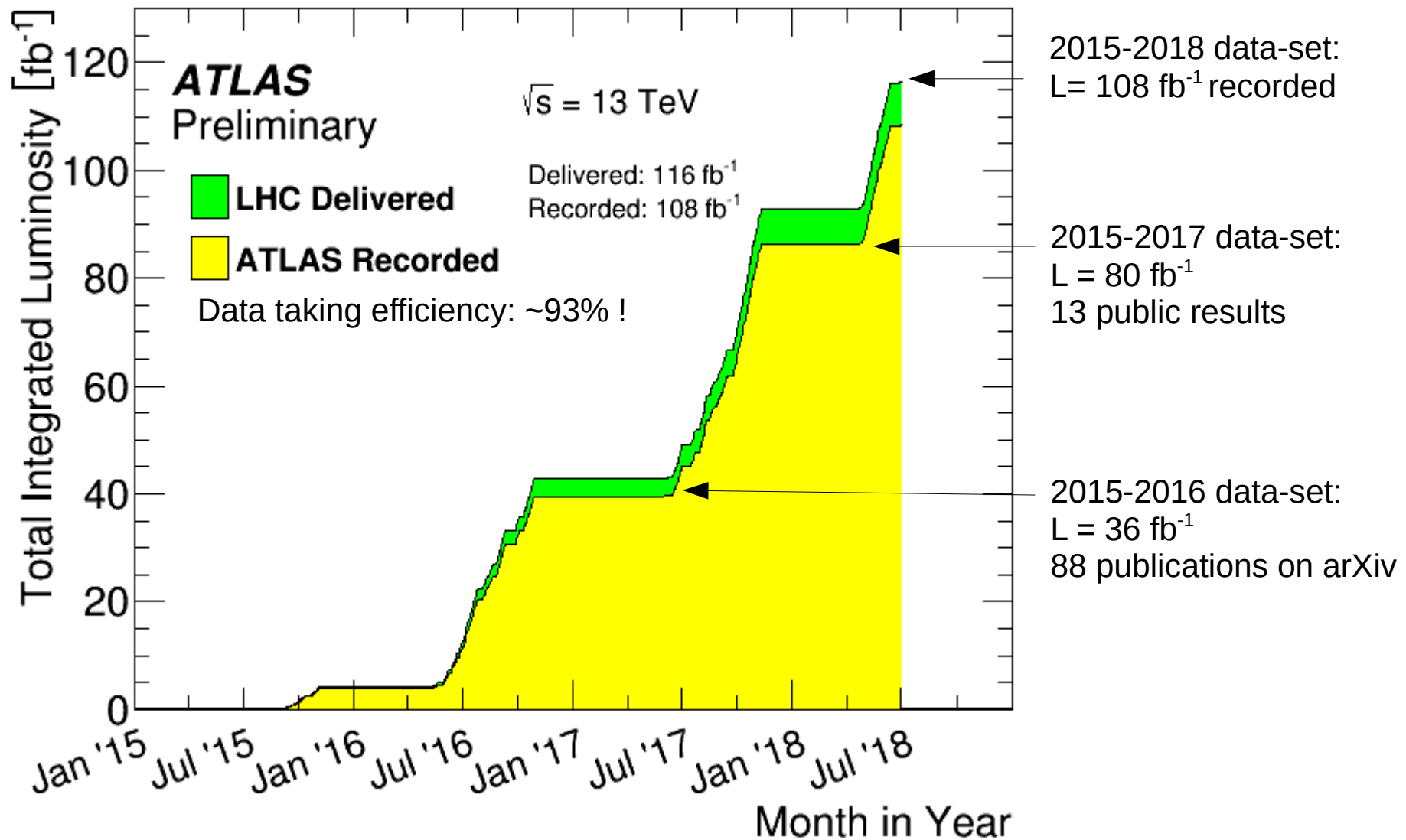
ICHEP2018 SEOUL

XXXIX INTERNATIONAL CONFERENCE ON

JULY 4 - 11, 2018 COEX, SEOUL

*high energy* PHYSICS

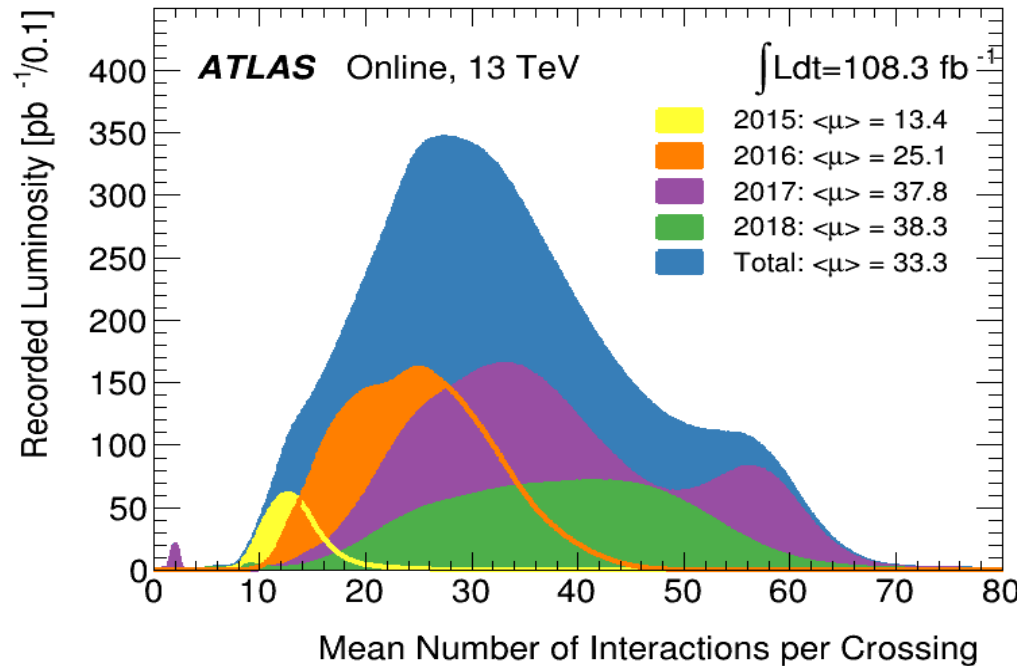
# LHC performance and data-set



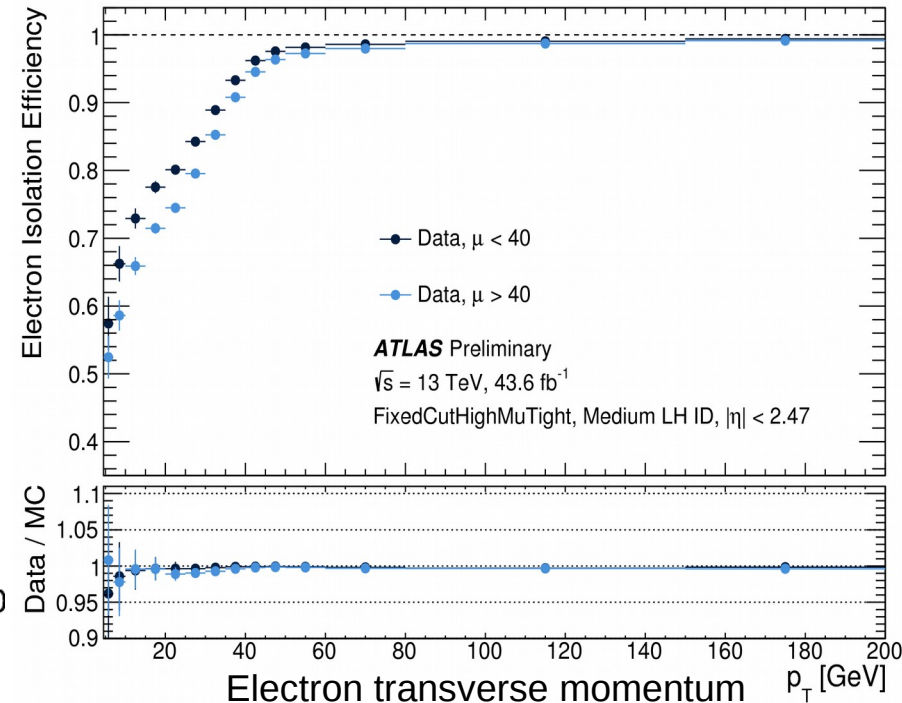
We are about a factor of 2 above LHC design luminosity.  
Expect  $L = 140 - 150 \text{ fb}^{-1}$  for full 2015-2018 data-set.

# Challenge to cope with pile-up interactions

Interactions per bunch per crossing:



Electron isolation efficiency:



Large number of additional interactions (pile-up) cause performance degradation.  
Powerful pile-up mitigation techniques developed.  
The performance loss is well described by Monte Carlo simulation.

## Example: $H (\rightarrow ZZ \rightarrow 4l)$ channel

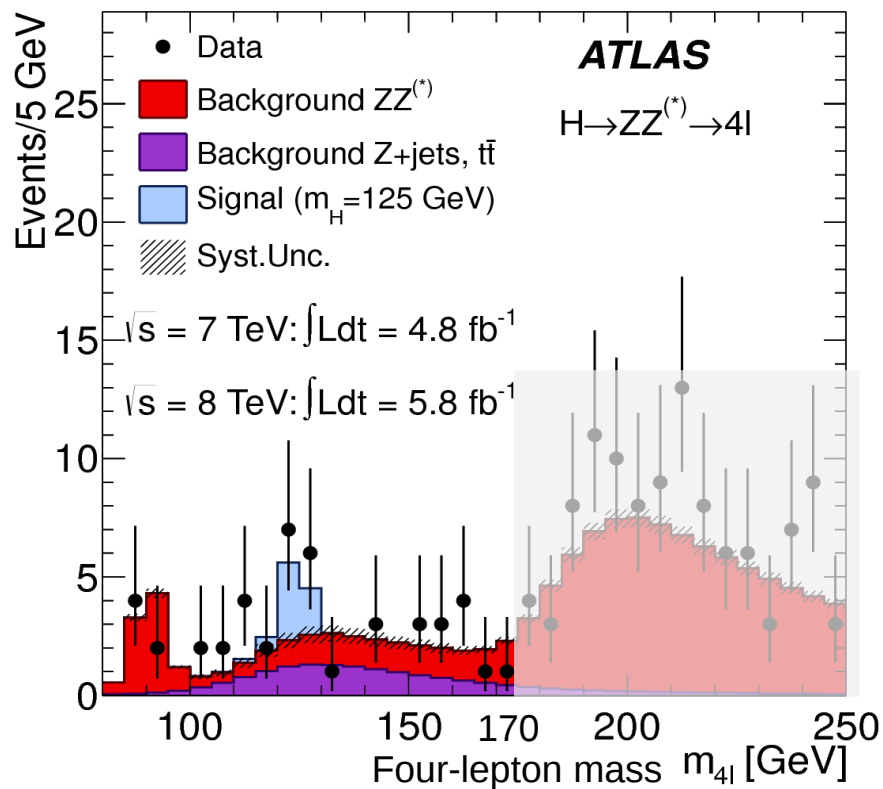
Higgs boson discovered in July 2012 at LHC.

Is the new particle the SM Higgs boson ?  $\rightarrow$  measure its properties !

Example for high purity but low branching fraction Higgs decay to four leptons  $H (\rightarrow ZZ \rightarrow 4l)$ :

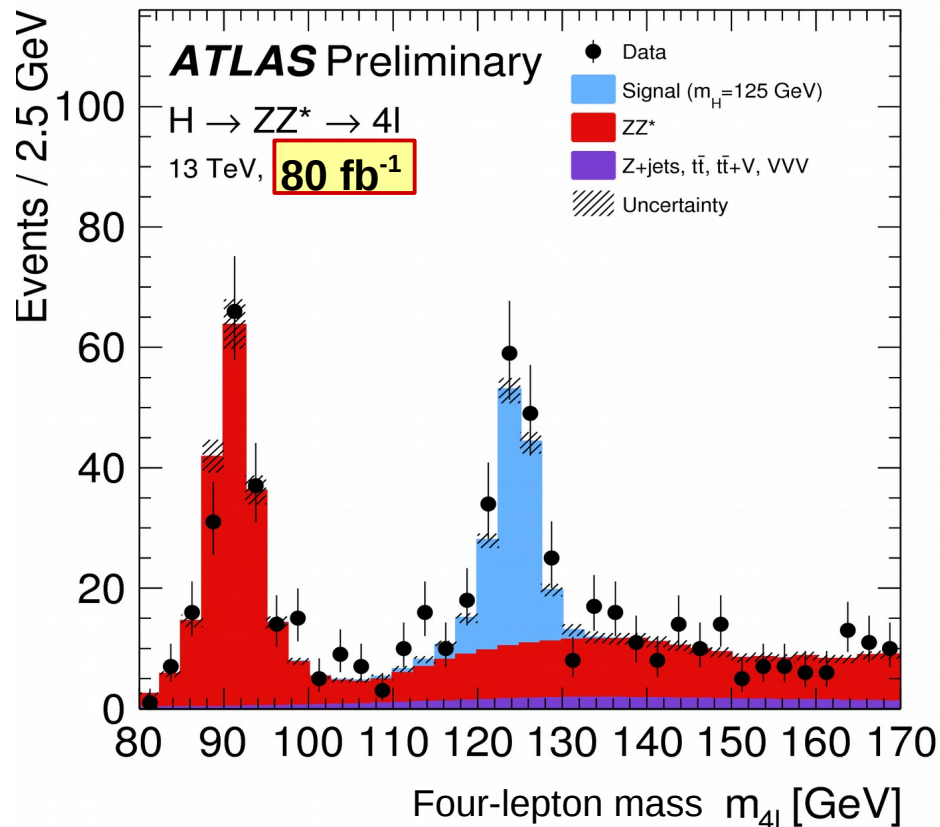
$L=4.8 \text{ fb}^{-1}$  and  $5.8 \text{ fb}^{-1}$  at 7 and 8 TeV

$L=80 \text{ fb}^{-1}$  at 13 TeV



13 events  $120 < m_{4l} < 130 \text{ GeV}$

Phys. Lett. B 716 (2012) 1-29



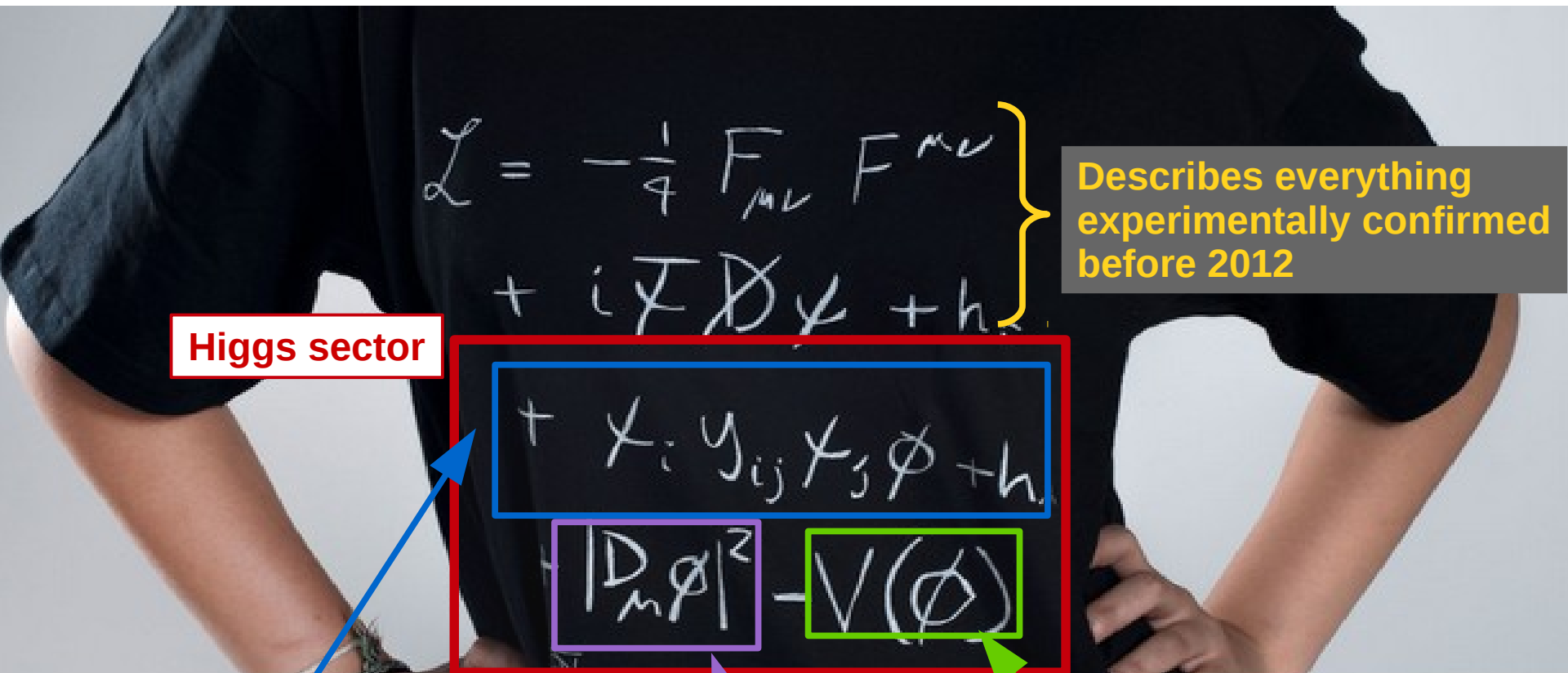
195 events for  $115 < m_{4l} < 130 \text{ GeV}$

ATLAS-CONF-2018-018

Nice peak of new fundamental scalar !



# Standard Model Lagrangian



Describes everything experimentally confirmed before 2012

Higgs sector

$$+ \sum_i y_{ij} \bar{\psi}_i \psi_j \phi + h.c.$$

$$+ |D_\mu \phi|^2 - V(\phi)$$

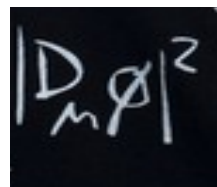
Yukawa coupling with new scalar  
(completely new interaction type)  
 $t\bar{t}H$ ,  $H \rightarrow b\bar{b}$  and  $H \rightarrow \tau\tau$  are important !

Gauge boson interaction with new scalar  
(new for scalar, but known for fermions)

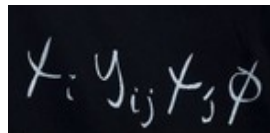
Higgs potential ( $\mu^2 \phi^2 + \lambda \phi^4$ )  
(to be explored by High Lumi-LHC)

Higgs measurements at LHC test new part of SM

# Gauge boson and Yukawa fermion coupling



Interaction with gauge bosons:



Yukawa coupling to fermions:

Earlier 7 and 8 TeV results:

At 7 and 8 TeV Higgs boson discovered.  
Main channels:  $H \rightarrow \gamma\gamma$ ,  $H \rightarrow ZZ$ ,  $H \rightarrow WW$

Only glimpse at 7 and 8 TeV (2012)

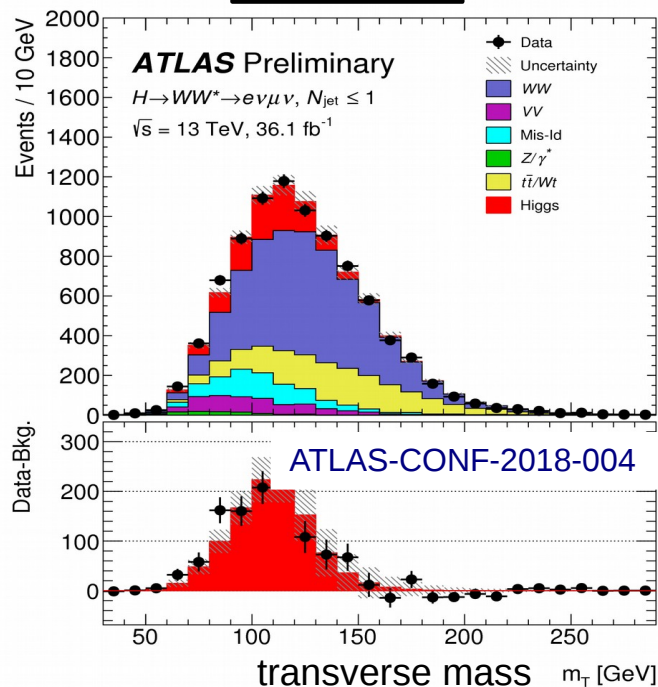
ATLAS/CMS combined  $H \rightarrow \tau\tau$ :

$5.5\sigma$  ( $5.0\sigma$ ) obs (exp) for 7/8 TeV

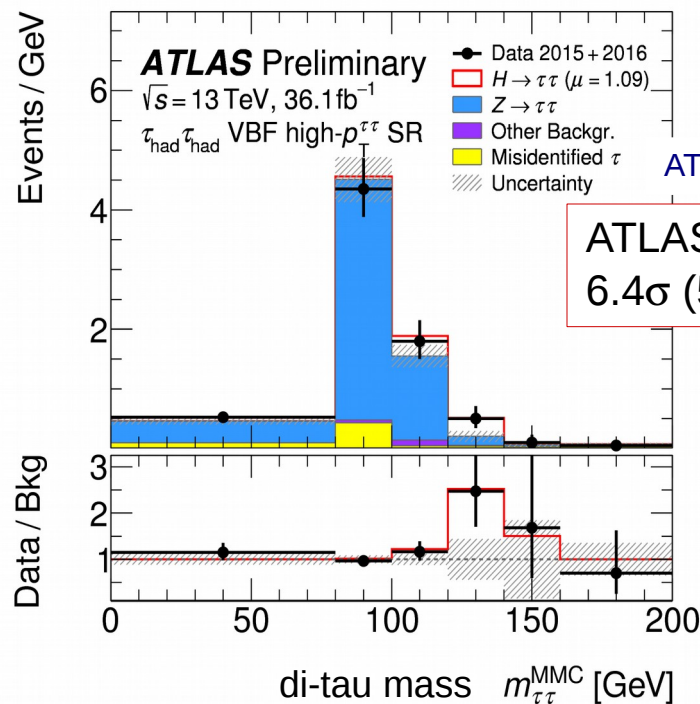
JHEP 08 (2016) 045

Recent 13 TeV results:

$H \rightarrow WW$



$H \rightarrow \tau\tau$



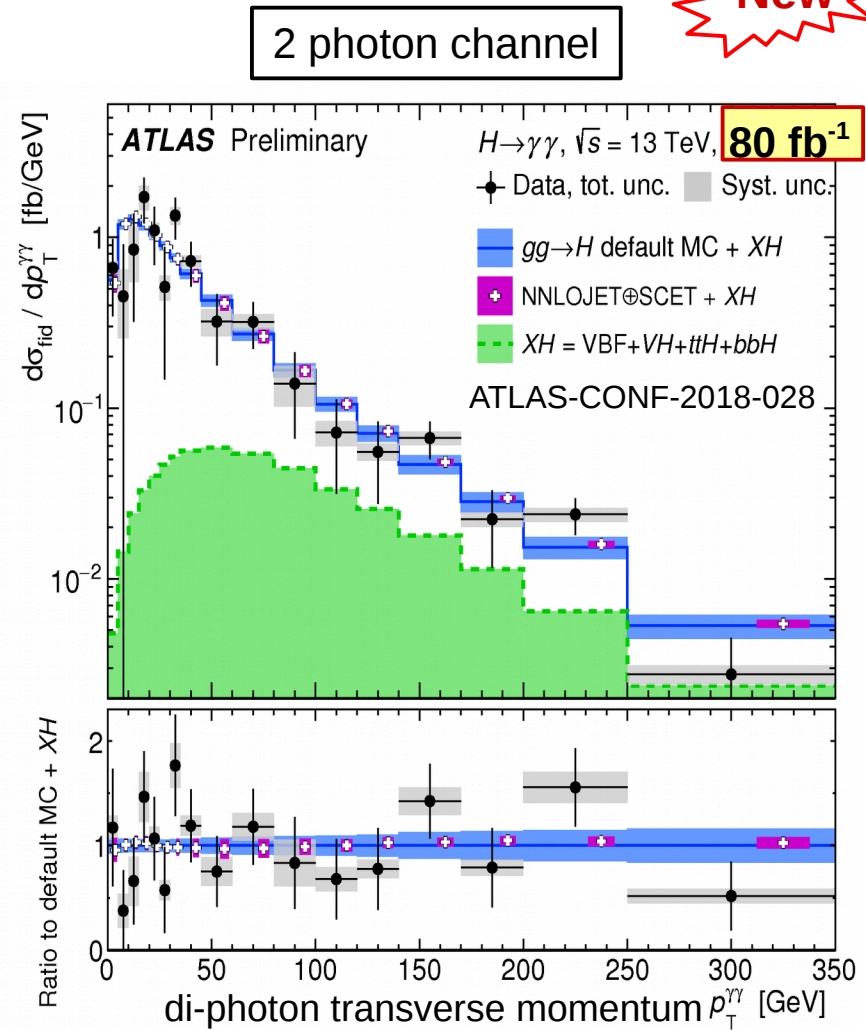
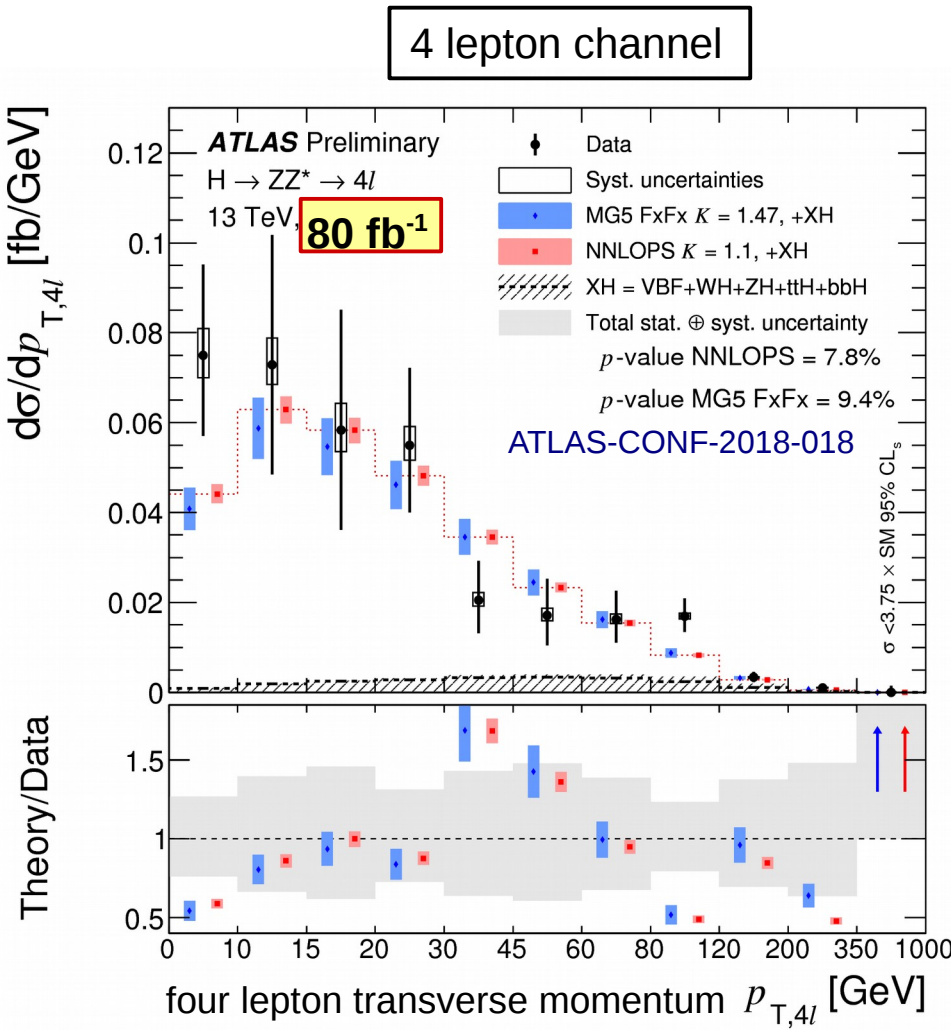
ATLAS 7/8/13 TeV:  
 $6.4\sigma$  ( $5.4\sigma$ ) obs (exp)

Example of mass in  
1/13 signal categories

# Differential cross-section using gauge boson decays

Higgs decays to gauge bosons used for differential cross-section measurements.

New



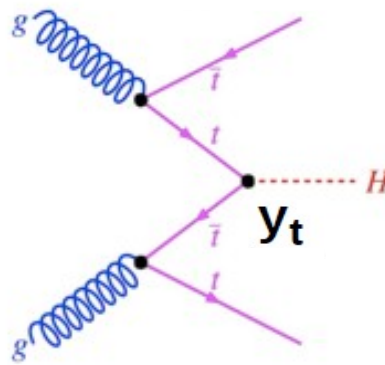
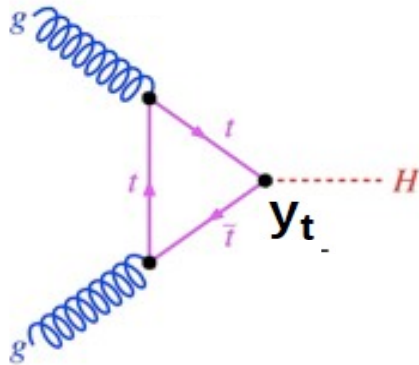
Differential cross-section becoming more and more precise with increasing statistics.  
Data well described by recent SM predictions.

# Associated Higgs top quark pair production

Higgs production:

Gluon-gluon fusion (ggF)

Associated ttH production (ttH)



Yukawa coupling:

$$y_t \approx v/(m_t \sqrt{2}) \approx 1$$

Large top mass  $\rightarrow$  Higgs coupling is strong.

Top Yukawa  $y_t$  coupling is in loop for ggF

(might contain BSM contribution).

but ttH production gives direct constraint on  $y_t$

$$\sigma(ttH) \sim 1\% \sigma(H)$$

Branching fraction:

$H \rightarrow b\bar{b}$	58%
$H \rightarrow WW^*$	21%
$H \rightarrow \tau\tau$	6%
$H \rightarrow ZZ^*$	2.6%
$H \rightarrow \gamma\gamma$	0.2%

For  $H \rightarrow WW$  and  $H \rightarrow ZZ$   
only leptonic decays

Evidence in December 2017 ( $36 \text{ fb}^{-1}$ ):

Channel	Significance	
	Observed	Expected
Multilepton	$4.1\sigma$	$2.8\sigma$
$H \rightarrow b\bar{b}$	$1.4\sigma$	$1.6\sigma$
$H \rightarrow \gamma\gamma$	$0.9\sigma$	$1.7\sigma$
$H \rightarrow 4\ell$	—	$0.6\sigma$
Combined	<b><math>4.2\sigma</math></b>	<b><math>3.8\sigma</math></b>

Phys.Rev. D 97 (2018) 072003  
Phys. Rev. D 97 (2018) 072016  
arXiv:1802.04146



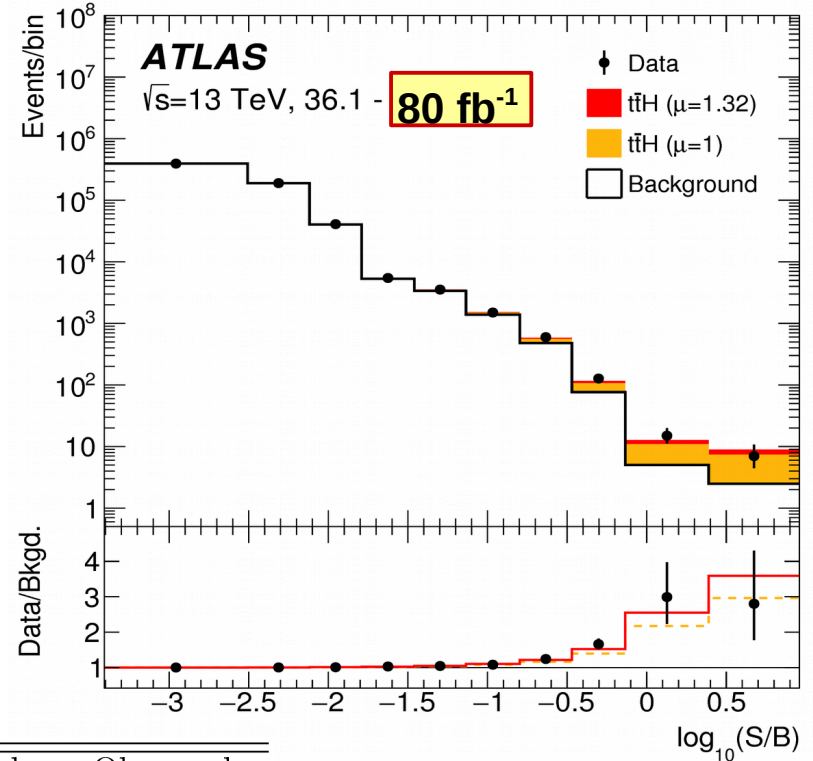
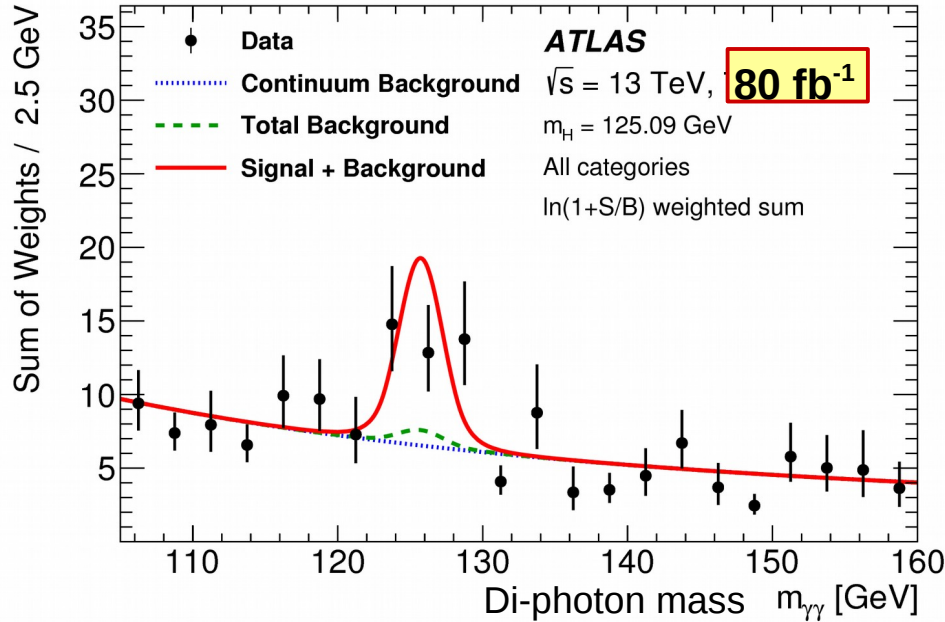
# Observation of $t\bar{t}H$ production

arXiv:1806.00425

June 2018 update:  $t\bar{t}H(\rightarrow \gamma\gamma)$  and  $t\bar{t}H(ZZ \rightarrow 4\ell)$  with  $80 \text{ fb}^{-1}$

All channels combined:

$t\bar{t}H(\rightarrow \gamma\gamma)$ :



Analysis	Integrated luminosity [ $\text{fb}^{-1}$ ]	Expected significance	Observed significance
$H \rightarrow \gamma\gamma$	79.8	$3.7 \sigma$	$4.1 \sigma$
$H \rightarrow \text{multilepton}$	36.1	$2.8 \sigma$	$4.1 \sigma$
$H \rightarrow b\bar{b}$	36.1	$1.6 \sigma$	$1.4 \sigma$
$H \rightarrow ZZ^* \rightarrow 4\ell$	79.8	$1.2 \sigma$	$0 \sigma$
Combined (13 TeV)	36.1–79.8	$4.9 \sigma$	$5.8 \sigma$
Combined (7, 8, 13 TeV)	4.5, 20.3, 36.1–79.8	$5.1 \sigma$	$6.3 \sigma$

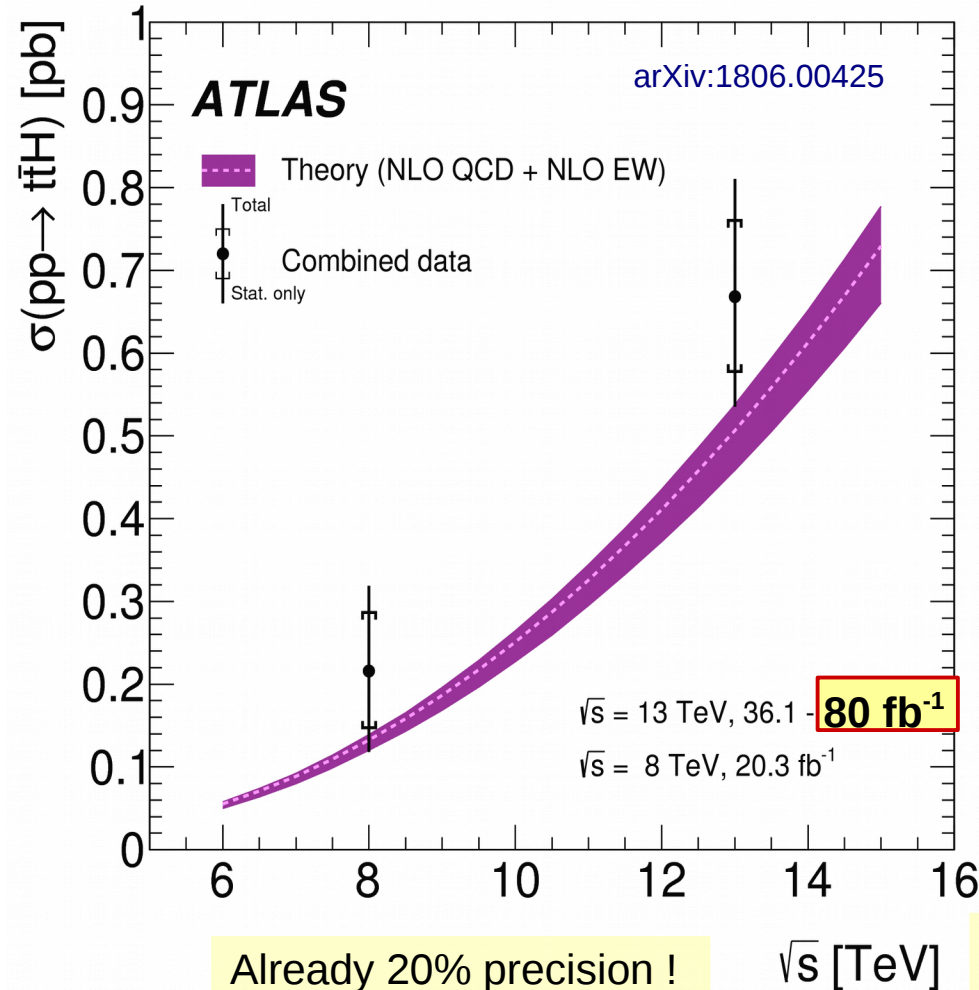
Direct observation of top Higgs coupling.  
Confirmation of Yukawa coupling to fermions.

# ttH production cross-section

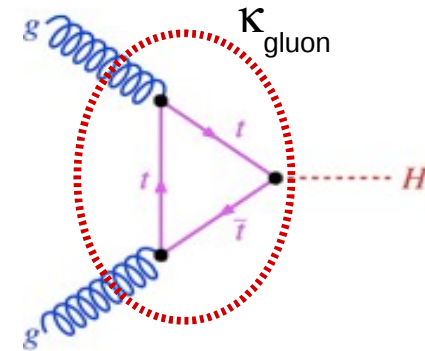
June 2018 update: ttH( $\rightarrow \gamma\gamma$ ) and ttH( $\rightarrow ZZ \rightarrow 4l$ ) with 80 fb<sup>-1</sup>

ATLAS-CONF-2018-031

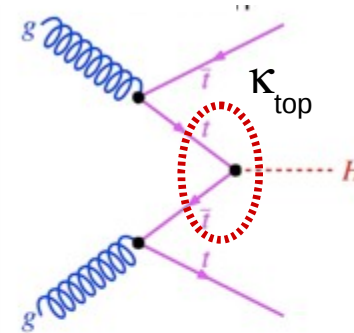
Inclusive ttH production cross-section



Gluon-gluon fusion



Associated ttH production



Effective coupling  $\kappa_{\text{gluon}} / \kappa_{\text{top}} = 1.09 \pm 0.14$

Consistent with Higgs boson coupling as in SM.  
 Constrains BSM contributions.



# Associated VH production and $H \rightarrow bb$

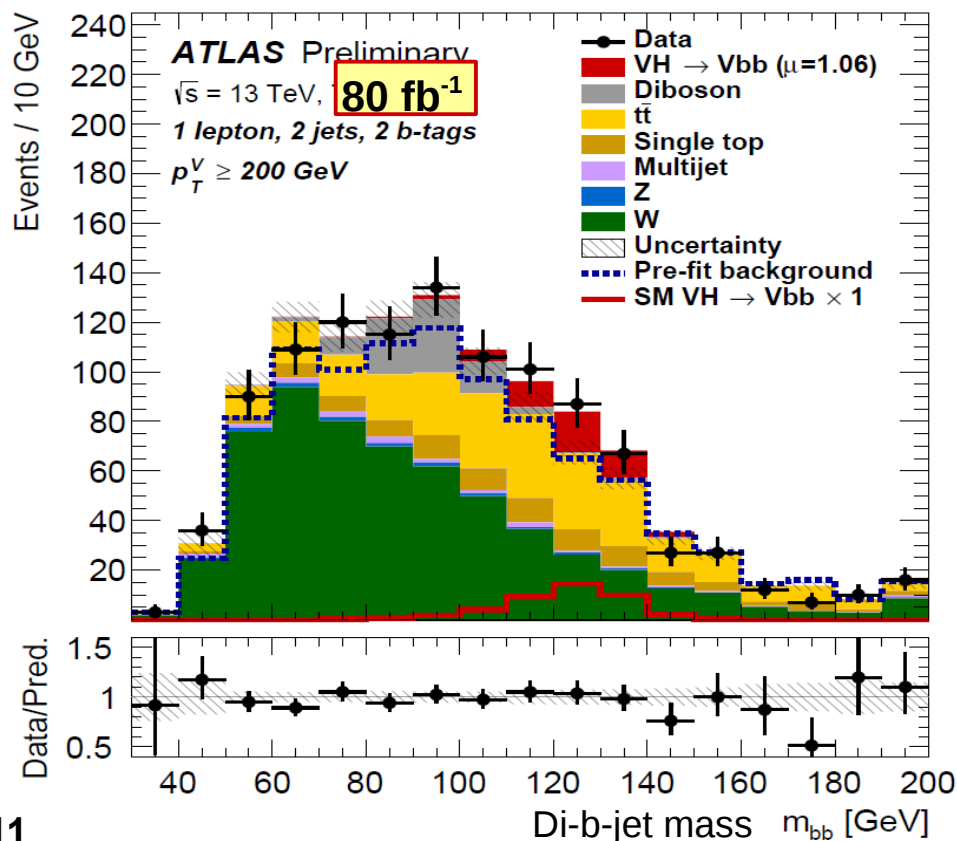
$H \rightarrow bb$  highest branching ratio:  $\text{Br}=58\%$

- $\text{Br}(H \rightarrow bb)$  constrains invisible Higgs decays
- Tests Higgs Yukawa coupling to fermions

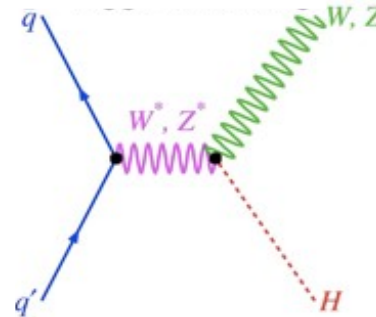
Analysis with large background:

- Use high- $p_T$  boson region
- Multi-variate analysis in 0, 1 and 2 lepton channels
- Dijet mass analysis as cross-check

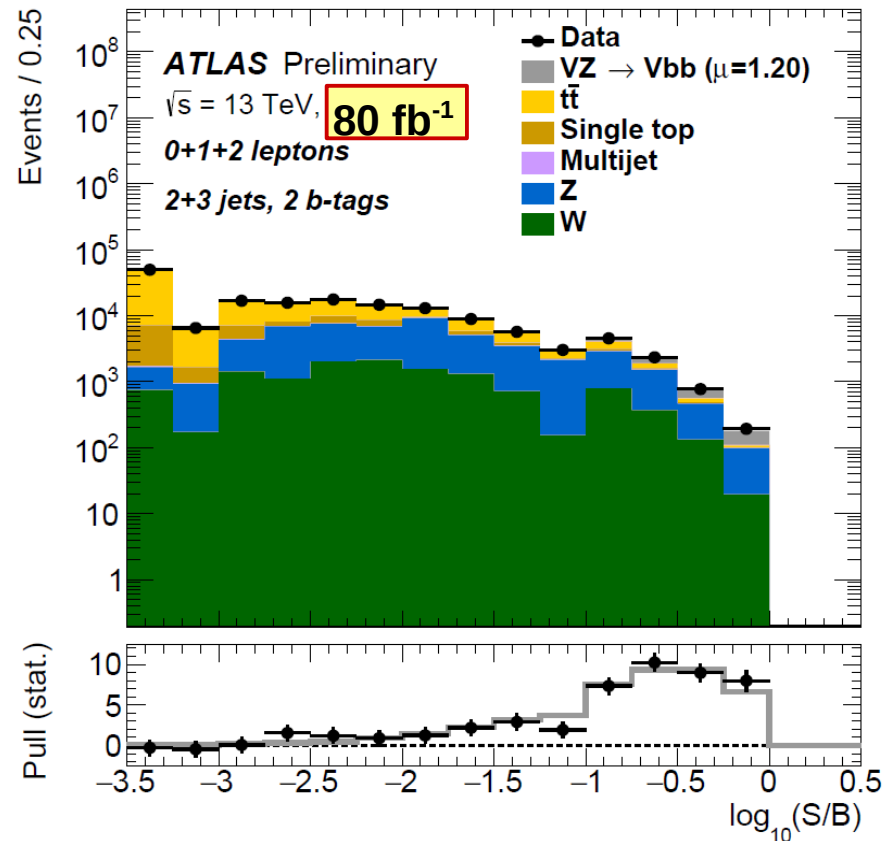
Example: One input to di-jet mass analysis global fit



Associated WH or ZH production (VH)



Di-boson validation analysis VZ ( $\rightarrow bb$ ):

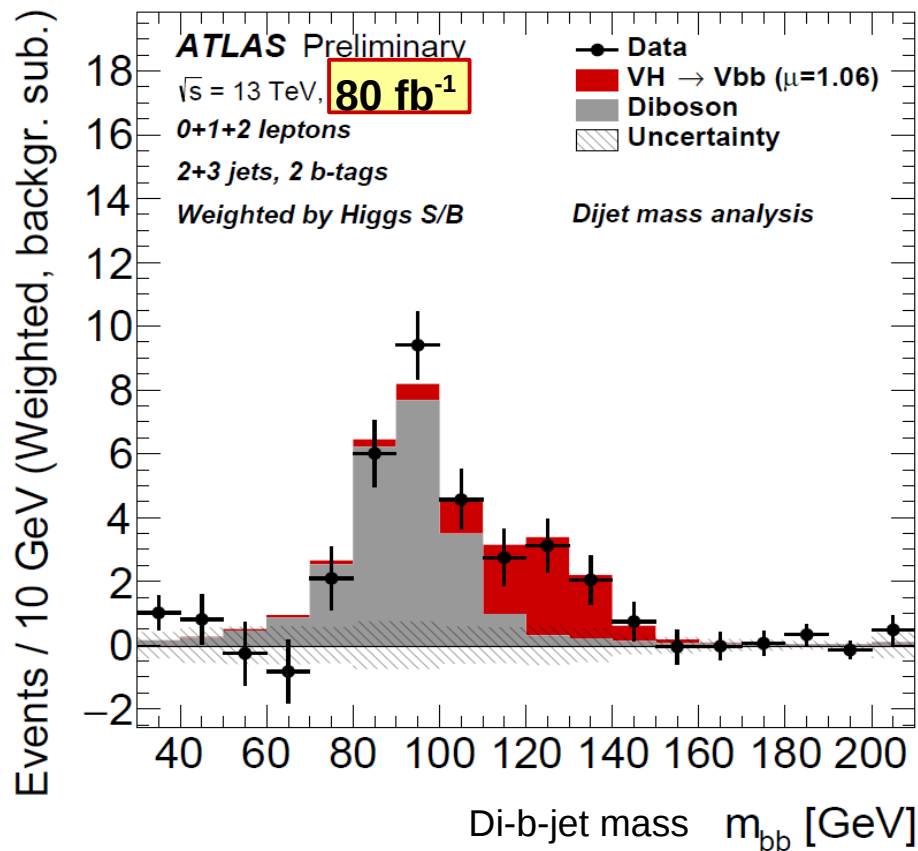


New

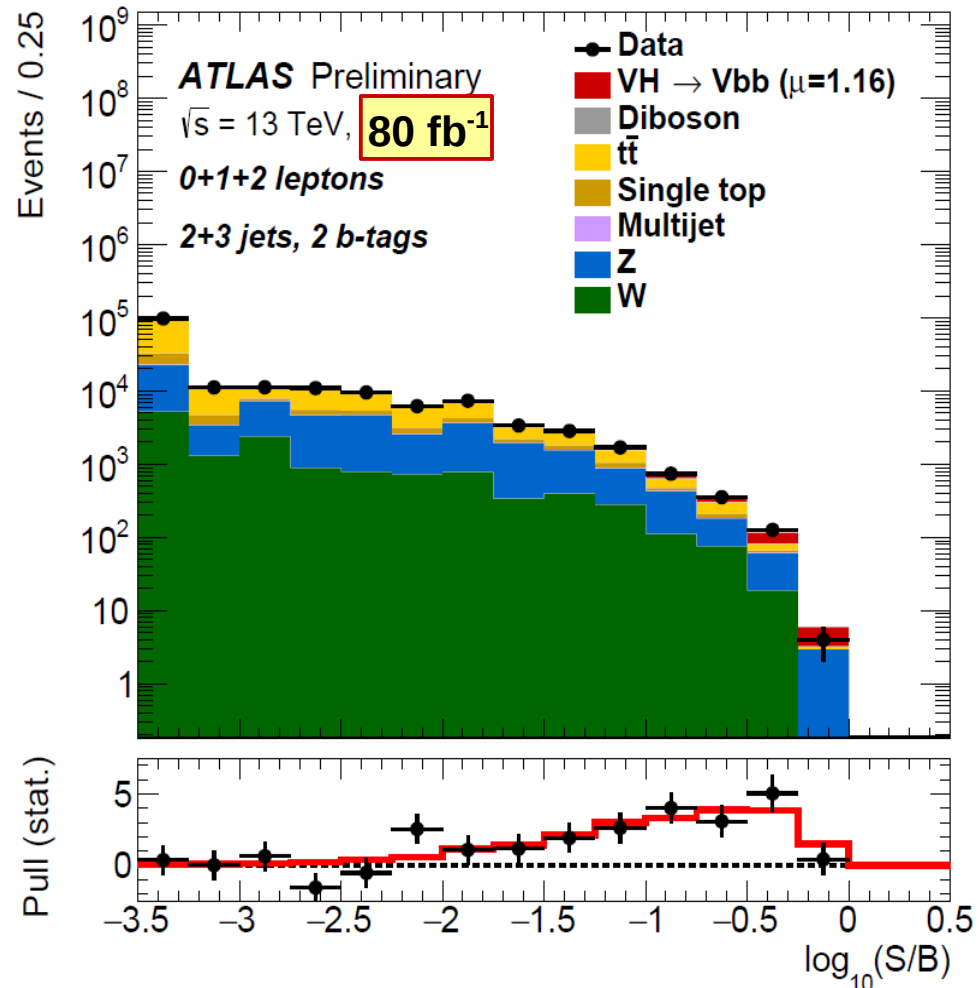
# Observation of $H \rightarrow b\bar{b}$

ATLAS-CONF-2018-036

Di-jet mass analysis:



Main multi-variate analysis:



Observation of Higgs decay to beauty quarks !

VH alone:  $4.9\sigma$  ( $4.3\sigma$ ) obs (exp) (13 TeV)

Combined (7,8,13 TeV) VBF, ttH, VH:

**$5.4\sigma$  ( $5.5\sigma$ ) obs (exp)**

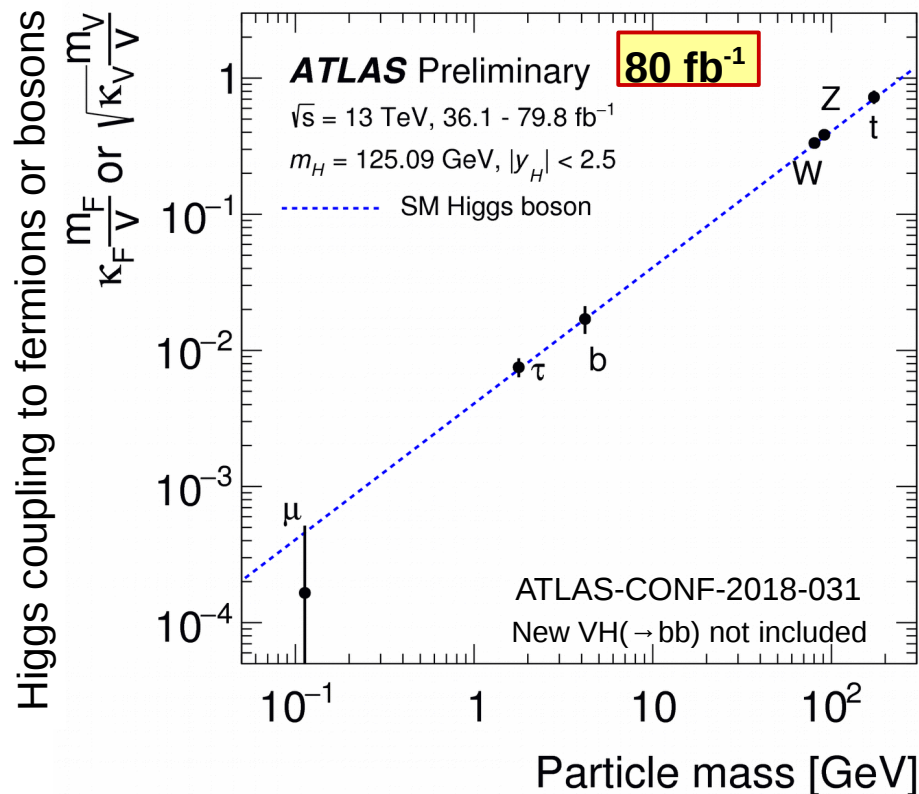


**New**

# Higgs coupling measurements

## Key feature:

Higgs coupling depends on the particle mass



All couplings to high mass particles measured.  
Next challenge: muon, charm-quark...

+ detailed cross-section measurements !

## Interaction with gauge bosons:

$H \rightarrow ZZ^*$

ATLAS-CONF-2018-018

Well established in run-1

$H \rightarrow WW^*$

ATLAS-CONF-2018-004

6.3 (5.2)  $\sigma$  obs (exp) (run-2 only)

## Yukawa coupling to fermions:

Top-quark:  $ttH$

**80 fb<sup>-1</sup>**

6.3 $\sigma$  (5.1 $\sigma$ ) obs (exp)

arXiv:1806.00425

Beauty-quark  $H \rightarrow bb$ :

**80 fb<sup>-1</sup>**

**New**

5.4 $\sigma$  (5.5 $\sigma$ ) obs (exp)

ATLAS-CONF-2018-036

Tau-lepton:  $H \rightarrow \tau\tau$

6.4 $\sigma$  (5.4 $\sigma$ ) obs (exp)

ATLAS-CONF-2018-021

Muon  $H \rightarrow \mu\mu$ :

**80 fb<sup>-1</sup>**

**New**

$\sigma_{\text{limit}} / \sigma_{\text{SM}} < 2.1$  (obs)

ATLAS-CONF-2018-026

Charm-quark:  $H \rightarrow cc$ :

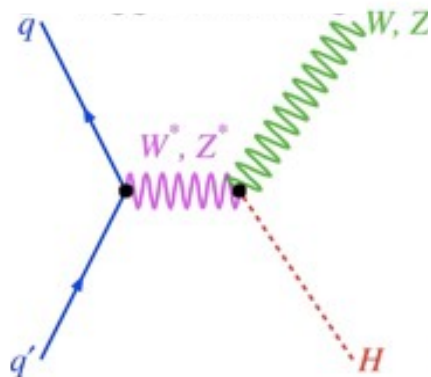
$\sigma_{\text{limit}} / \sigma_{\text{SM}} < 104$  (obs)

PRL 120 (2018) 211802

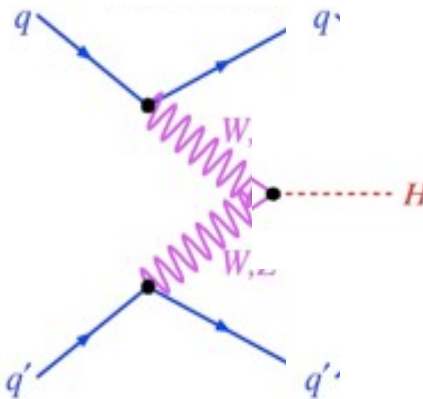


# Higgs production modes

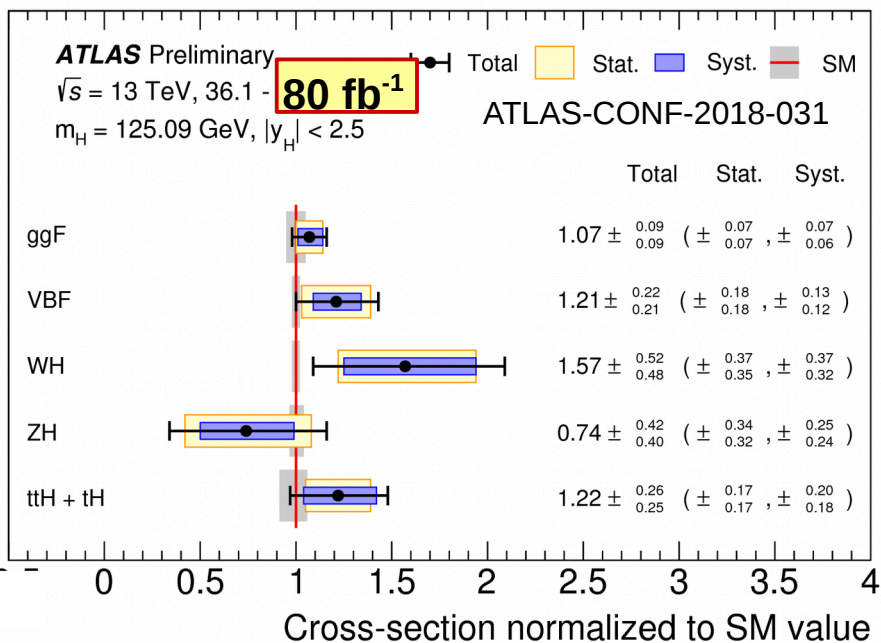
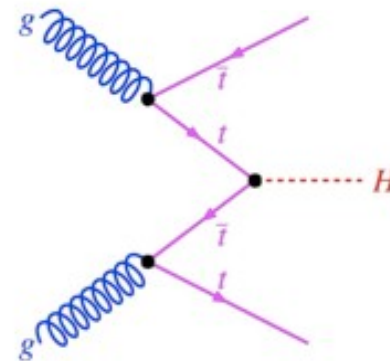
Associated WH or ZH production (VH)



Vector-boson fusion (VBF)



Associated ttH production (ttH)



Gluon-gluon fusion (ggF) observed since 2012 and used for precision measurements ( $\sim 10\%$ ).

VH  $5.3\sigma$  ( $4.8\sigma$ ) obs (exp)

ATLAS-CONF-2018-036

VBF  $6.5\sigma$  ( $5.3\sigma$ ) obs (exp)

ATLAS-CONF-2018-031

ttH  $6.3\sigma$  ( $5.1\sigma$ ) obs (exp)

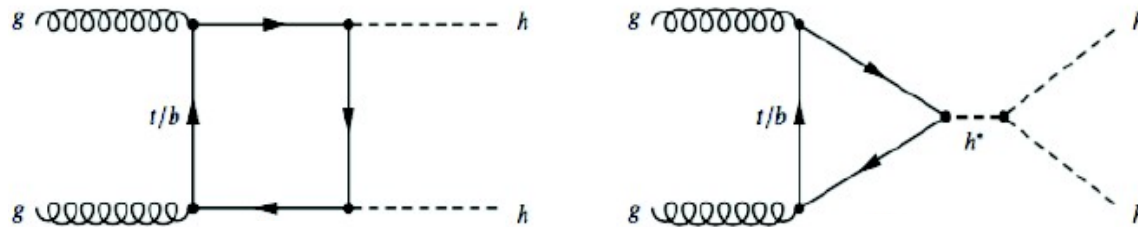
arXiv:1806.00425

Observed all major Higgs production modes !  
Consistent with SM.



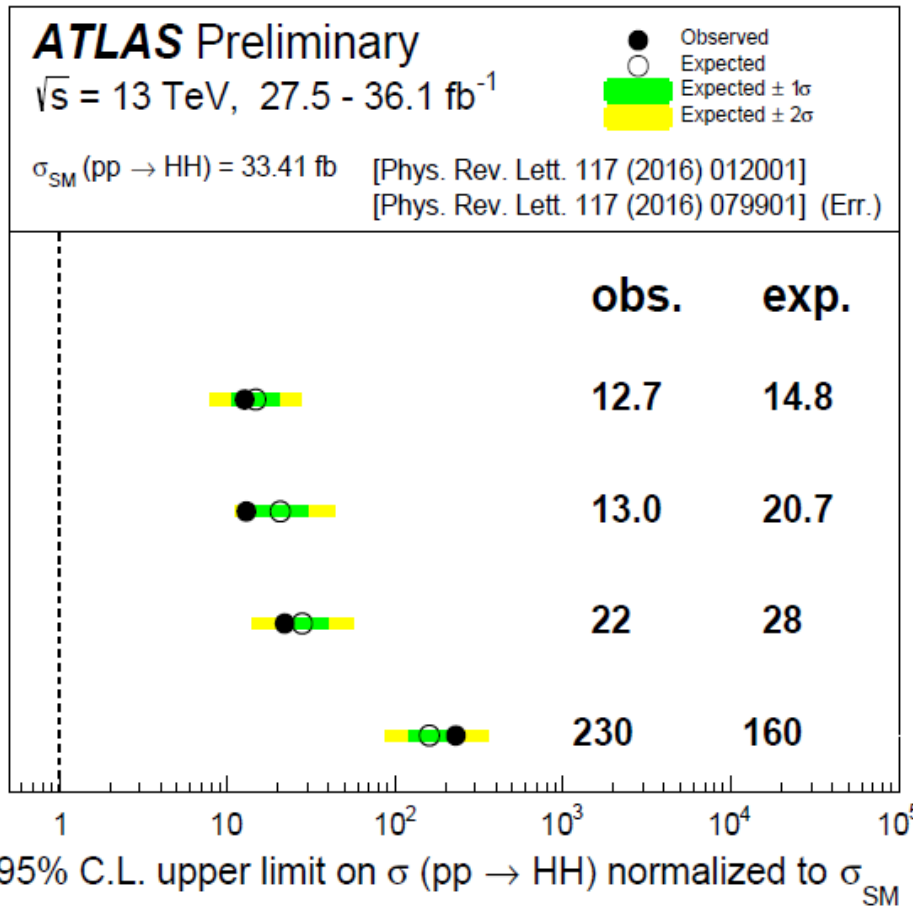
# SM Di-Higgs production

Production processes:



Di-Higgs production process is direct probe of SM trilinear coupling.

Strong destructive interference between processes.



Actively working on new techniques with increased sensitivity.

Considerably improved  $\text{HH} \rightarrow b\bar{b} \tau\tau$  result.

Limit approaching:

$$\sigma_{\text{limit}}/\sigma_{\text{SM}} \sim 10$$



# Observation of same-sign WWjj

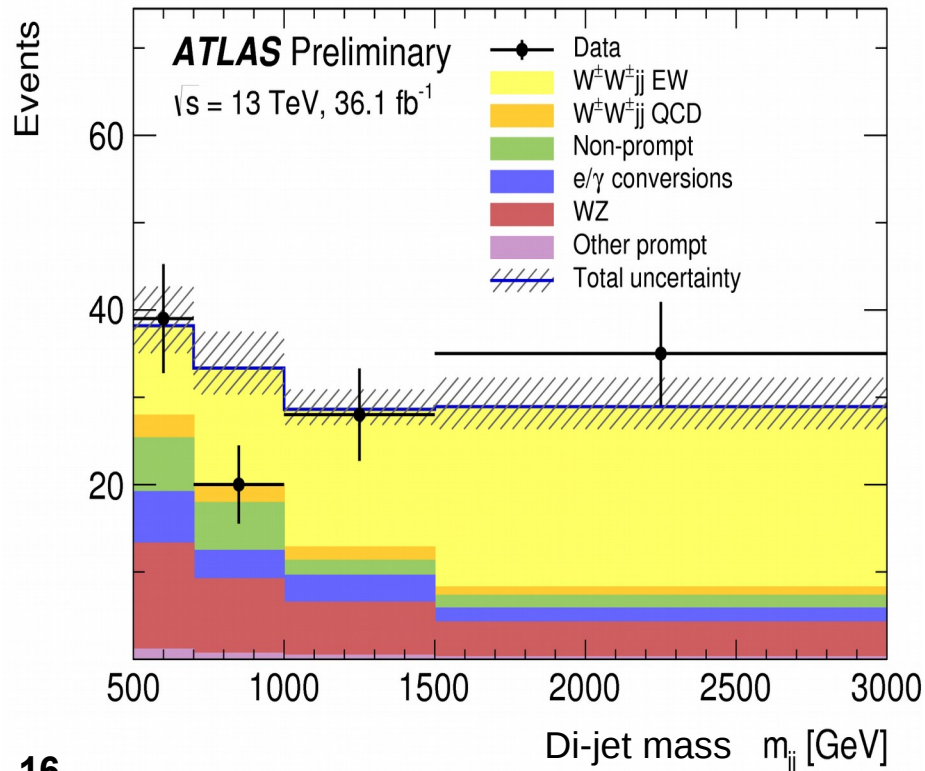
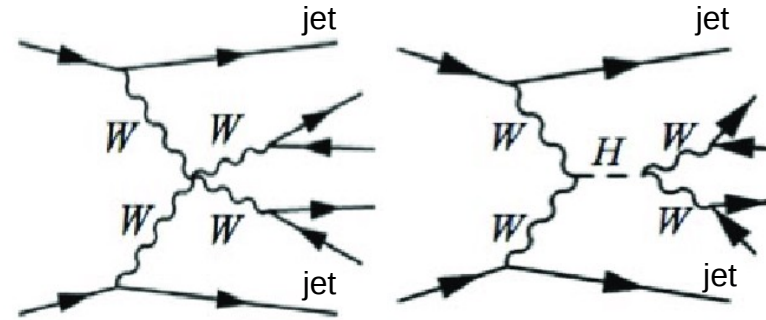
ATLAS-CONF-2018-030

Higgs boson needed to restore unitarity of the WW scattering cross-section.

- Higgs boson leads to strong suppression via gauge cancellation of individual EW diagrams.
- Part of electroweak symmetry breaking studies.

$pp \rightarrow W^{+/-} W^{+/-} \text{jet jet}$  process:

- Large electroweak cross-section fraction ( $\sigma_{\text{EW}}/\sigma_{\text{QCD}}$ ).
- and a strong background suppression.



Significance:  
 $6.9\sigma$  ( $4.6\sigma$ ) obs (exp)

Fiducial cross-

$$\sigma_{\text{fid}} = 2.91^{+0.51}_{-0.47} (\text{stat.}) \pm 0.27 (\text{syst.}) \text{ fb}$$

$$\sigma_{\text{fid}}^{\text{Sherpa}} = 2.01^{+0.33}_{-0.23} \text{ fb}$$

$$\sigma_{\text{fid}}^{\text{Powheg}} = 3.08^{+0.45}_{-0.46} \text{ fb}$$

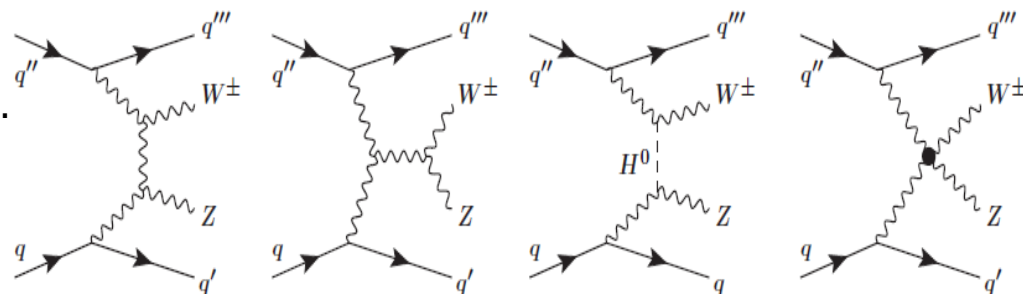




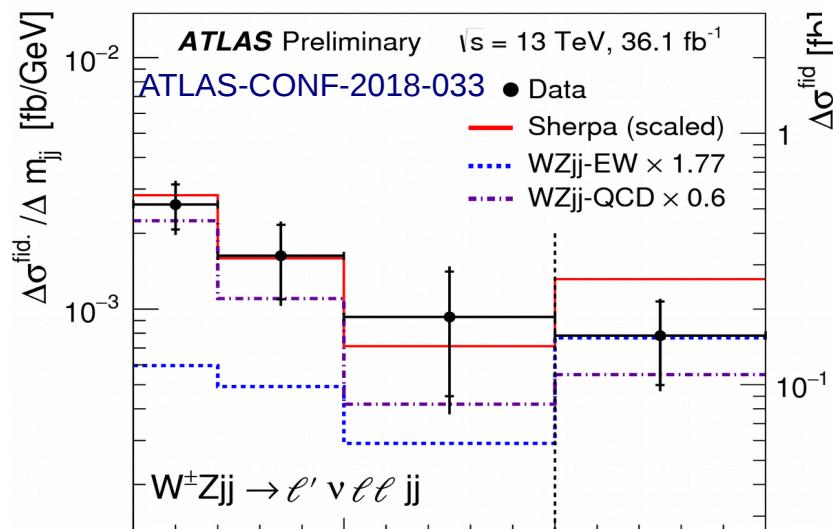
# WZ and WZjj production

Electroweak production of WZ boson in association with two jets  $pp \rightarrow W^\pm Z \text{ jet jet}$

Process sensitive to triple and quartic gauge couplings and anomalous couplings.



Differential EW cross-section:



5.6σ (3.3σ) obs (exp)

ATLAS-CONF-2018-033

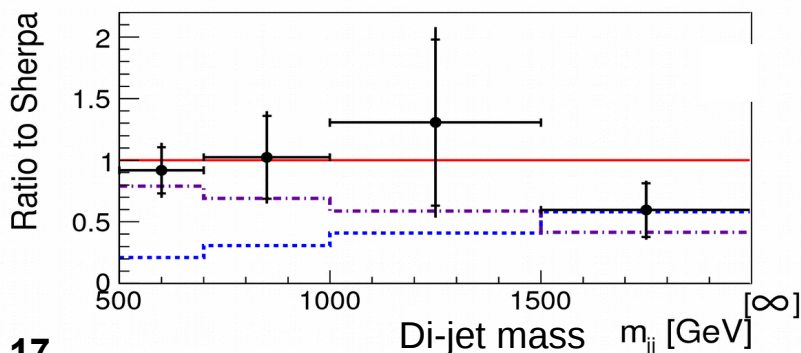
Observation of electroweak W/Z jet+jet process.

Total fiducial WZ jet jet cross section:  
 $\sigma_{EW}(pp \rightarrow W^\pm Z \text{ jet jet}) = 0.57 \pm 0.15 \text{ fb}$   
LO (Sherpa):  $0.32 \pm 0.03 \text{ fb}$

Also new result on inclusive WZ production:

- 1) Fiducial cross-section in agreement with NNLO QCD (inclusive and differential)
- 2) Evidence of longitudinally W polarization (4.2σ)
- 3) Measurement of Z polarization

ATLAS-CONF-2018-034





# Measurements of electroweak parameters

## Measurement of electroweak mixing angle:

Drell-Yan cross-section  $q\bar{q} \rightarrow Z \rightarrow \ell\bar{\ell}$  expanded as sum of 9 harmonic polynomials (NNLO QCD).  
In LO QCD (Z-boson rest frame):

$A_4$  (and  $A_3$ ) sensitive to weak mixing angle

$$\frac{d\sigma}{dy^{\ell\ell} dm^{\ell\ell} d\cos\theta} = \frac{3}{16\pi} \frac{d\sigma^{U+L}}{dy^{\ell\ell} dm^{\ell\ell}} \left\{ (1 + \cos^2\theta) + A_4 \cos\theta \right\}$$

$A_4$  measured using two leptons  $|\eta| < 2.4$  (cc)  
and at least one forward electron  $2.5 < |\eta| < 4.6$  (cf).  
Using 8 TeV data (2012).

Result from likelihood fit:

$$\sin^2\theta_{eff}^l = 0.23140 \pm 0.00036$$

Uncertainty break-down:

$$0.00021(stat) \pm 0.00024(PDF) \pm 0.00016(syst)$$

Main limitation knowledge initial quark direction.

## Other recent electroweak measurements:

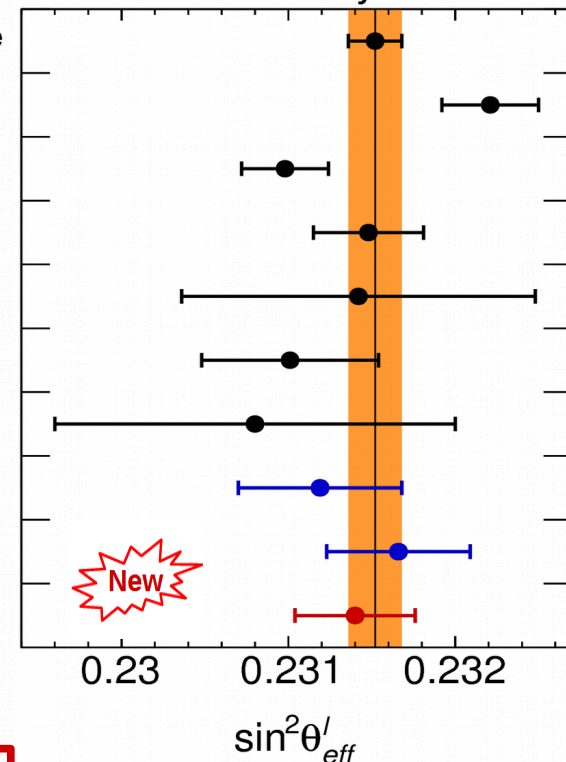
W-mass:	80370 +- 19 MeV	EPJ C78 (2018) 110
Higgs mass:	124970 +- 240 MeV	arXiv:1806.00242
Top-mass:	172510 +- 500 MeV	ATLAS-CONF-2017-071

Precision:

~0.02%
~0.2%
~0.3%

ATLAS-CONF-2018-037

**ATLAS Preliminary**



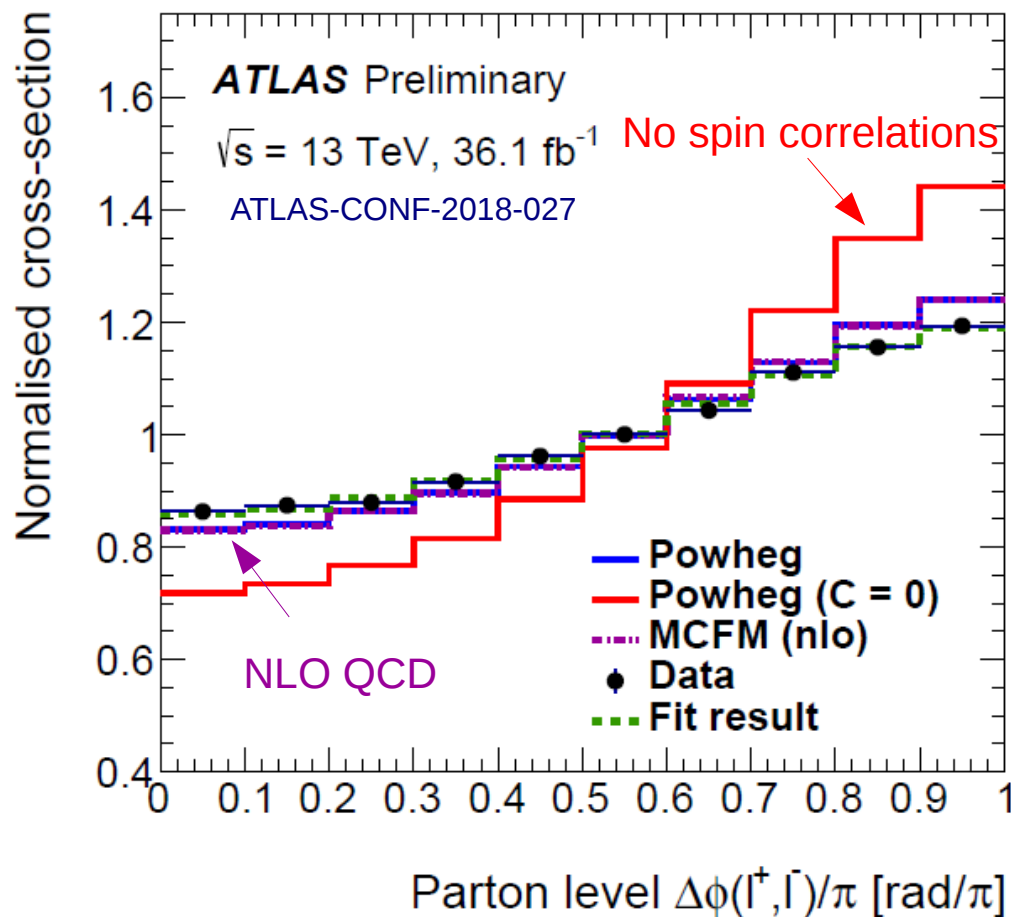
0.15% precision



# Spin correlation in top pair events

Spin correlation for  $pp \rightarrow tt \rightarrow e \mu b b$  measured between the top decay products and a spin axis.  $\Delta\Phi(e\mu)$  is a sensitive variable.

Example inclusive result:



Template fit on  $\Delta\Phi(e\mu)$ :

- $f_{\text{SM}}$  fraction of expected cross-section under the SM spin hypothesis
- No spin correlation template: top decay with spin correlation disabled

Stronger spin correlations observed than expected by NLO QCD.

Fit result:  $f=1.250\pm0.026\pm0.063$   
3.2 $\sigma$  discrepancy with NLO QCD

ATLAS-CONF-2018-027

Previous analyses also measured stronger spin correlations (with large uncertainties).

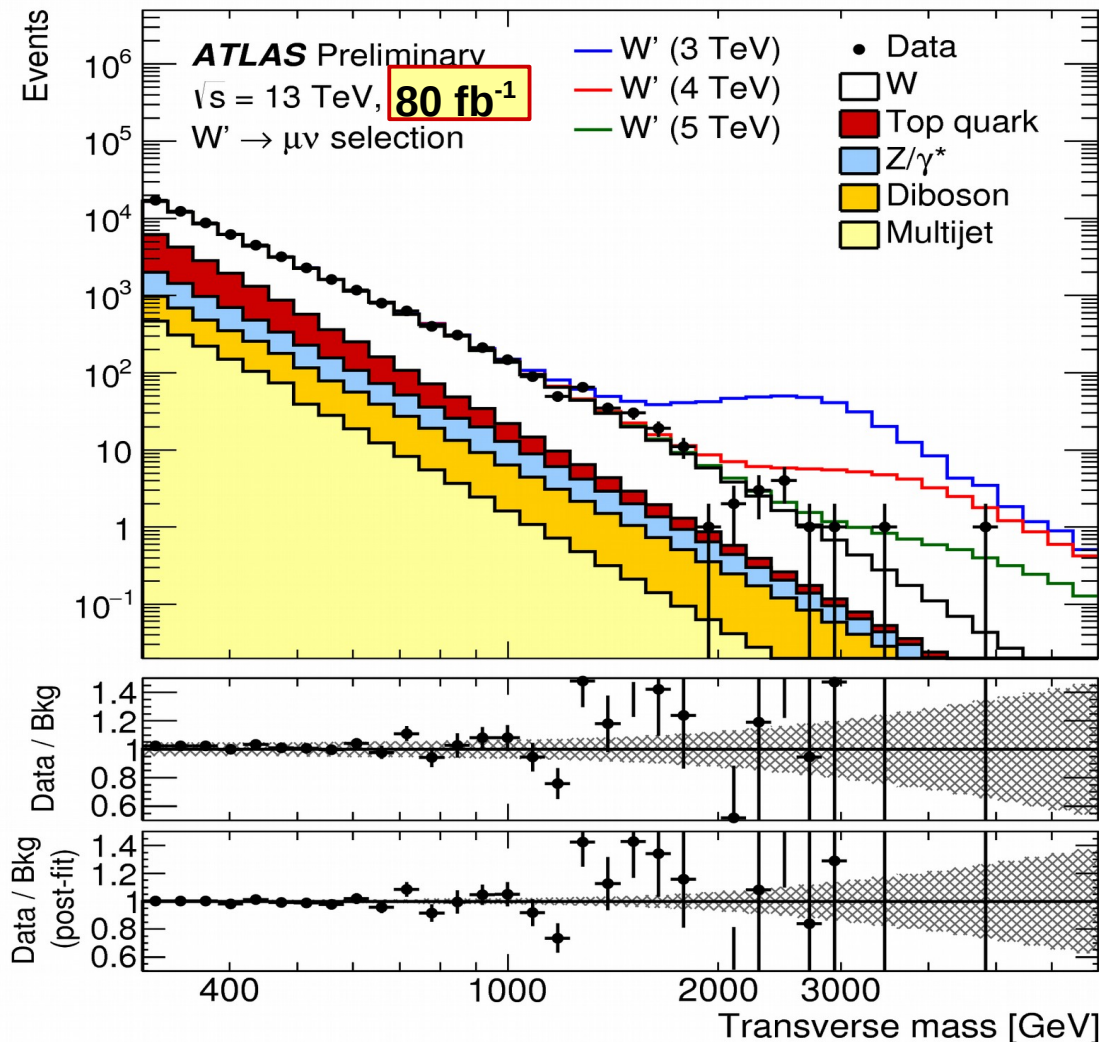
Similar results for fiducial particle-level and comparisons of ME generators.

# Search for new electro-weak boson

Very active search program (SUSY, dark matter, new Higgs models...)

In total, 62 search papers submitted ( $36 \text{ fb}^{-1}$ ). 8 new preliminary new physics searches with  $80 \text{ fb}^{-1}$ .

New electro-weak gauge boson ( $W'$ ) in context of sequential SM benchmark model.



ATLAS-CONF-2018-017

Assuming SM coupling:

Masses below excluded at 95%CL:

5.6 TeV ( $80 \text{ fb}^{-1}$ )

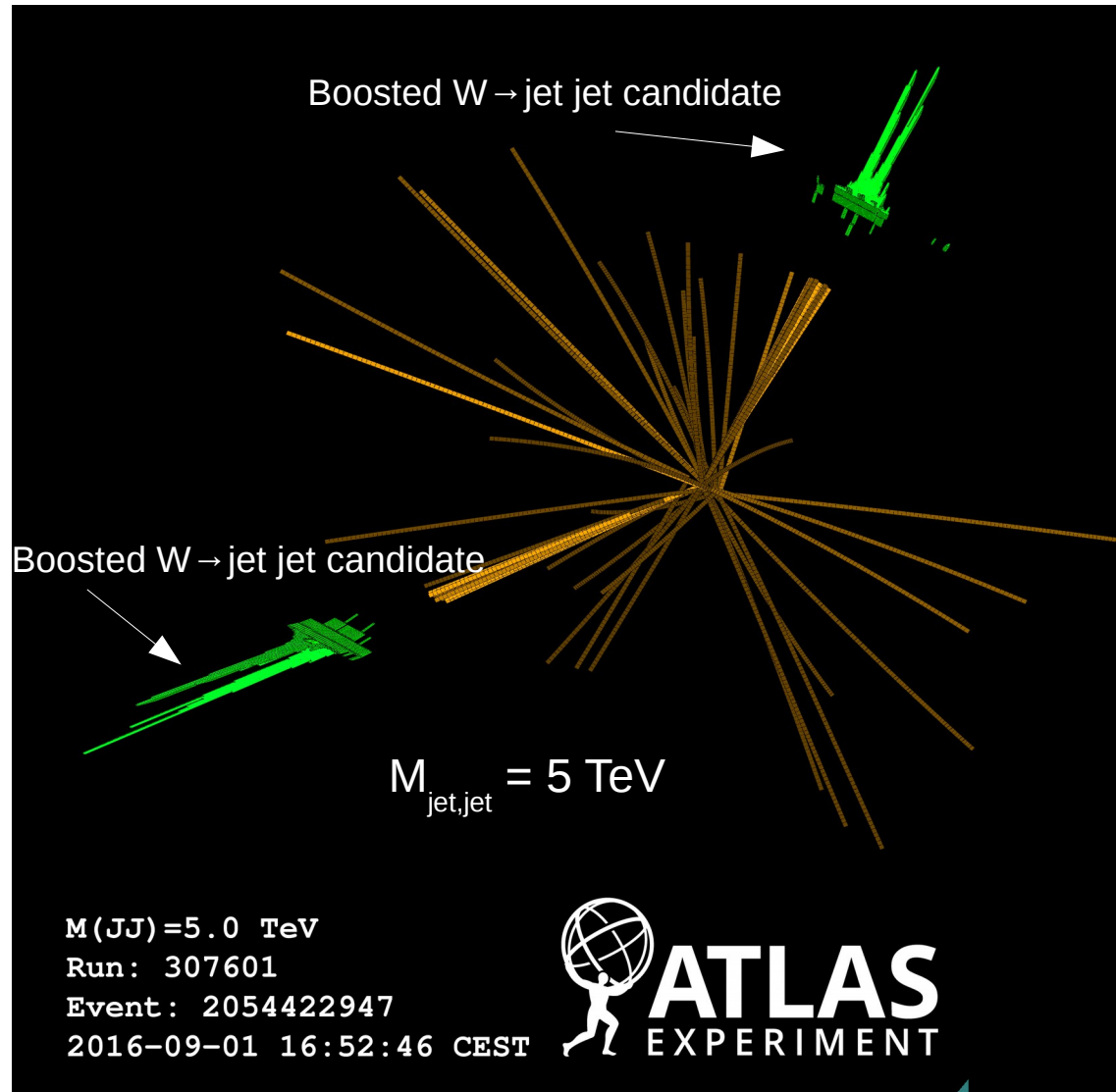
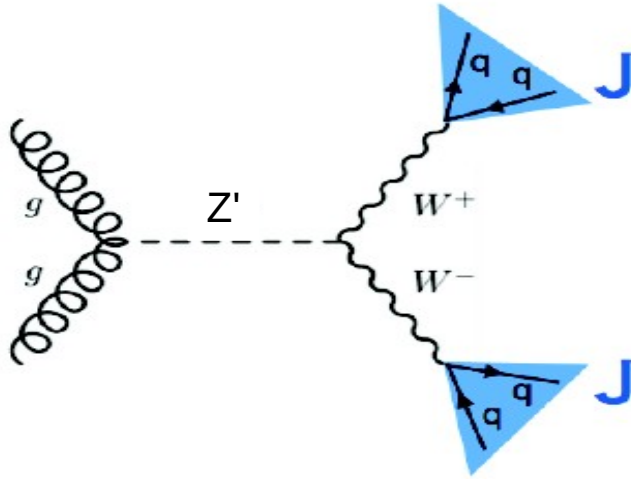
5.2 TeV ( $36 \text{ fb}^{-1}$ ) [arXiv:1706.04786](https://arxiv.org/abs/1706.04786)

→ Need new techniques  
to increase further sensitivity.



# High-mass Di-jet event from WW production

At high  $p_t$  jets from the  $W \rightarrow qq$  decay are close-by and merge in a large-R jet.



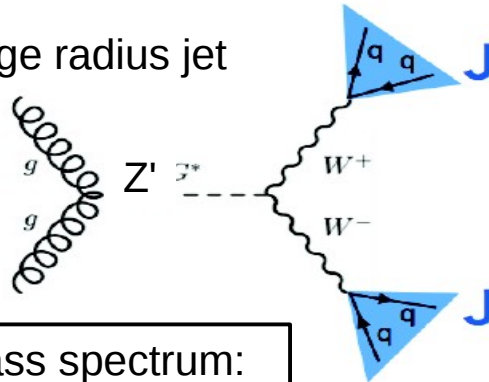
Many techniques developed to reconstruct boosted particles.

W-boson tagging based on large-R jet substructure.

New experimental technique:  
Energies from calorimeter clusters,  
but angles from tracks.

# Di-boson resonance search

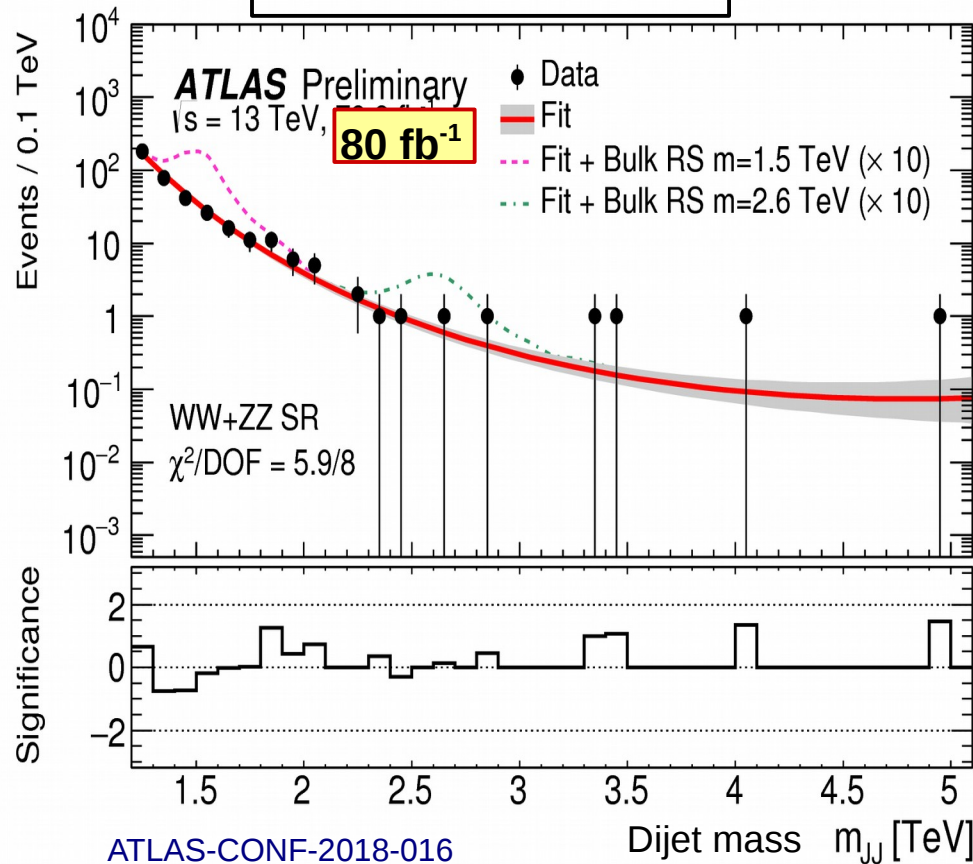
Select large  $p_t$  and large radius jet  
with boosted W-tag



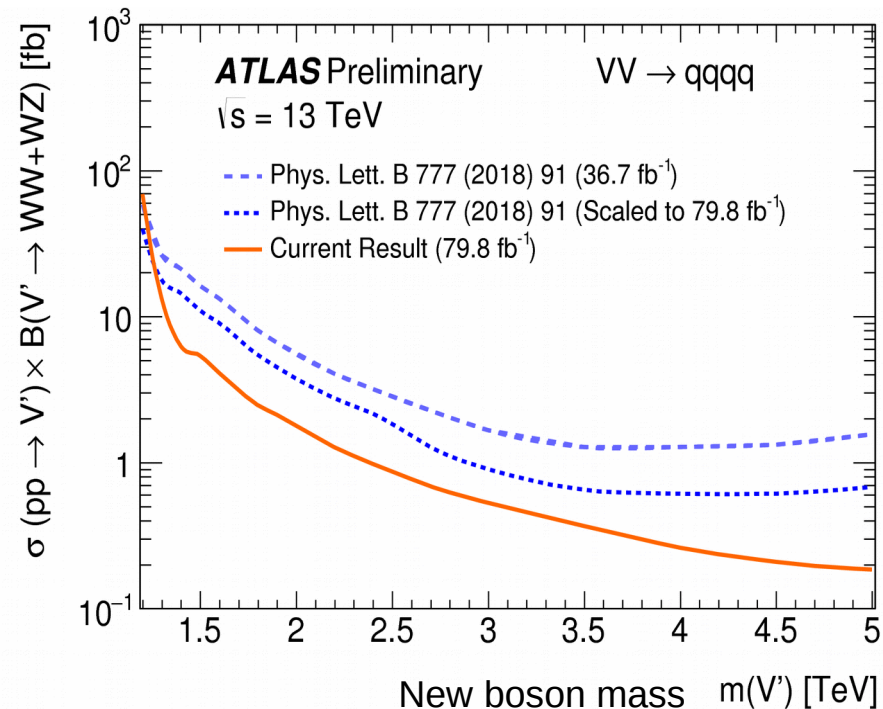
Recent improvements:

- W-boson tagging using angles from tracker and energies from calorimeter
- Tagger working point optimization at high  $p_t$

Di-jet mass spectrum:



Cross-section limit:



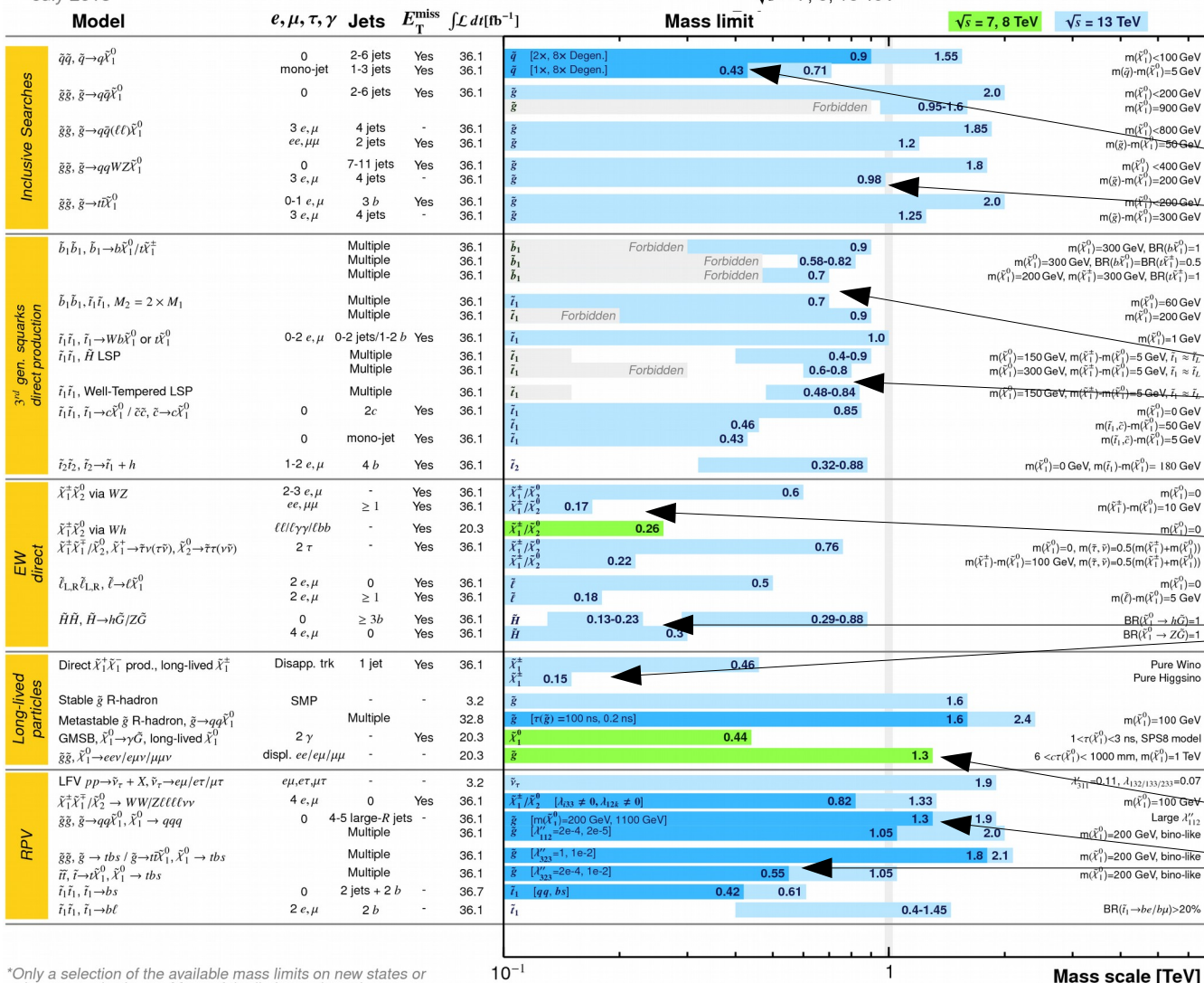
## Active SUSY search program

28 publications on SUSY searches with 2015-2016 data ( $36 \text{ fb}^{-1}$ ).

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

July 2018

**ATLAS** Preliminary

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

Compressed spectrum  
squark degeneracy:  
squarks  $O(500 \text{ GeV})$   
gluinos  $O(1 \text{ TeV})$

- sbottom  $O(700 \text{ GeV})$
- stop  $O(700 \text{ GeV})$

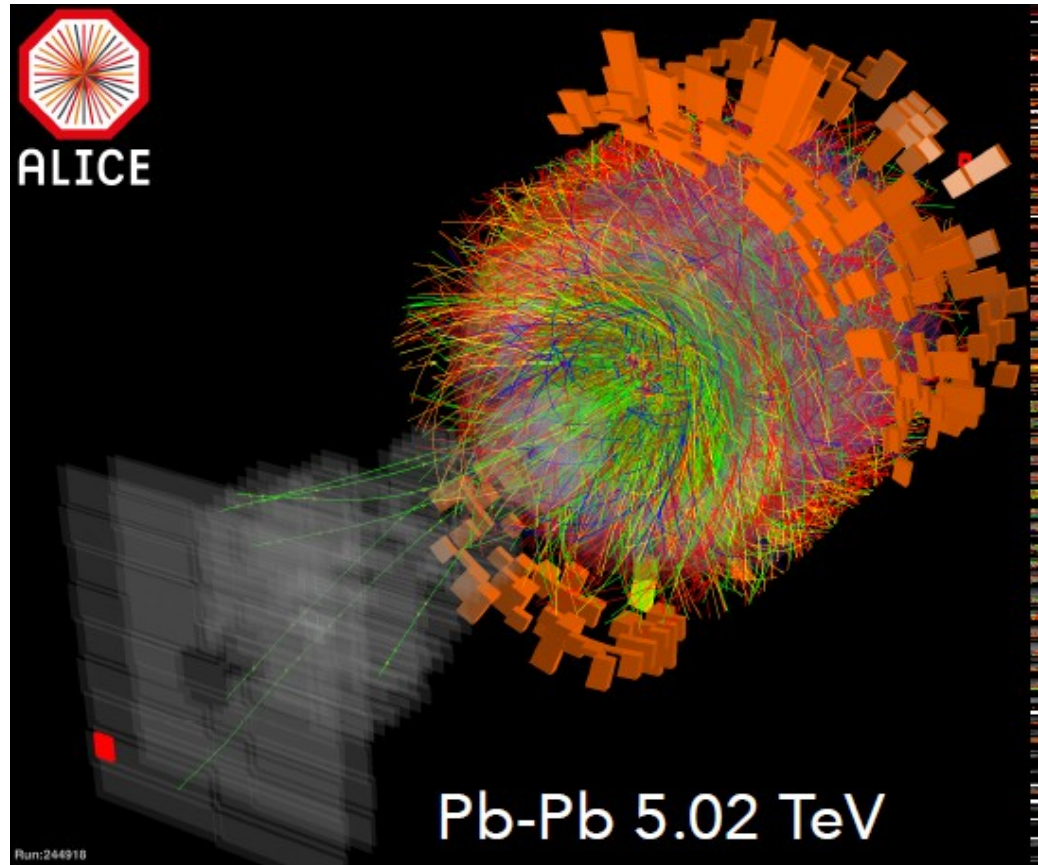
Low rate, compressed:  
winos  $O(\sim 100 \text{ GeV})$   
sleptons  $O(\sim 100 \text{ GeV})$   
higgsino  $O(\sim 100 \text{ GeV})$

Complexity, long-lived:  
gluinos  $O(1 \text{ TeV})$   
stop  $O(500 \text{ GeV})$

*\*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.*

23 Simplified signatures covered to high masses, but plenty of low mass unexplored model space.

# Heavy Ion Data-set



System	Year(s)	$\sqrt{s_{NN}}$ (TeV)	$L_{int}$
<b>Pb-Pb</b>	2010-2011	2.76	$\sim 75 \mu b^{-1}$
	2015	5.02	$\sim 250 \mu b^{-1}$
	<i>by end of 2018</i>	5.02	$\sim 1 nb^{-1}$
<b>Xe-Xe</b>	2017	5.44	$\sim 0.3 \mu b^{-1}$
<b>p-Pb</b>	2013	5.02	$\sim 15 nb^{-1}$
	2016	5.02, 8.16	$\sim 3 nb^{-1}, \sim 25 nb^{-1}$
<b>pp</b>	2009-2013	0.9, 2.76, 7, 8	$\sim 200 \mu b^{-1}, \sim 100 nb^{-1},$ $\sim 1.5 pb^{-1}, \sim 2.5 pb^{-1}$
	2015, 2017	5.02	$\sim 1.3 pb^{-1}$
	2015-2017	13	$\sim 25 pb^{-1}$

Special data-sets:  
p-p, Xe-Xe, p-Pb, Pb-Pb collisions.

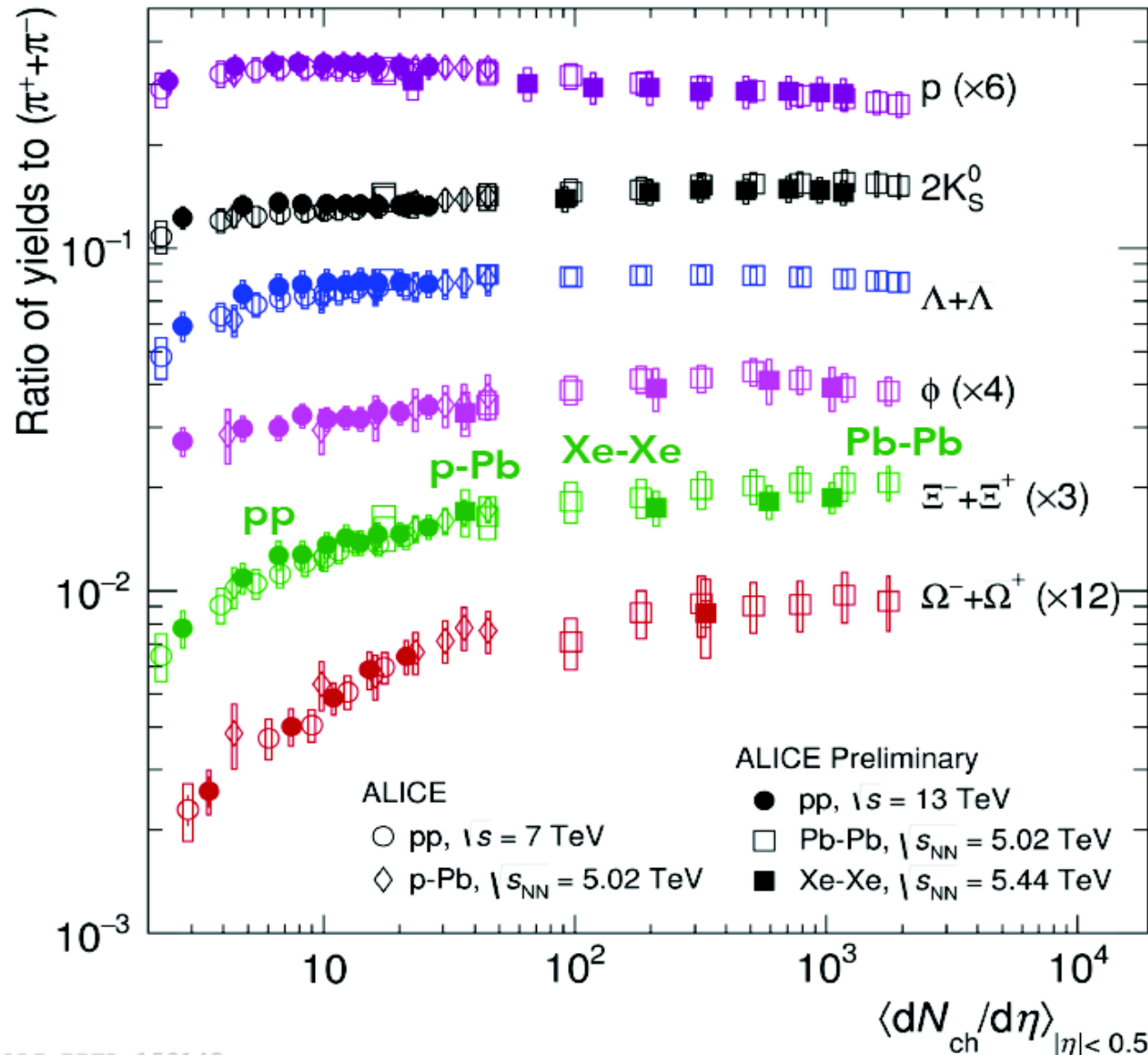
6h Xe-Xe run in 2017

Significant increase in luminosity to study rare processes more and more precisely.  
LHC scheduled: 3.5 week of Pb-Pb collision in November 2018.



# Strange particle yields in pp, Xe-Xe, Pb-Pb

Alice detector with impressive particle-ID capabilities



Smooth evolution of charged particle multiplicities from small (pp), medium (Xe-Xe) to large (Pb-Pb) systems.

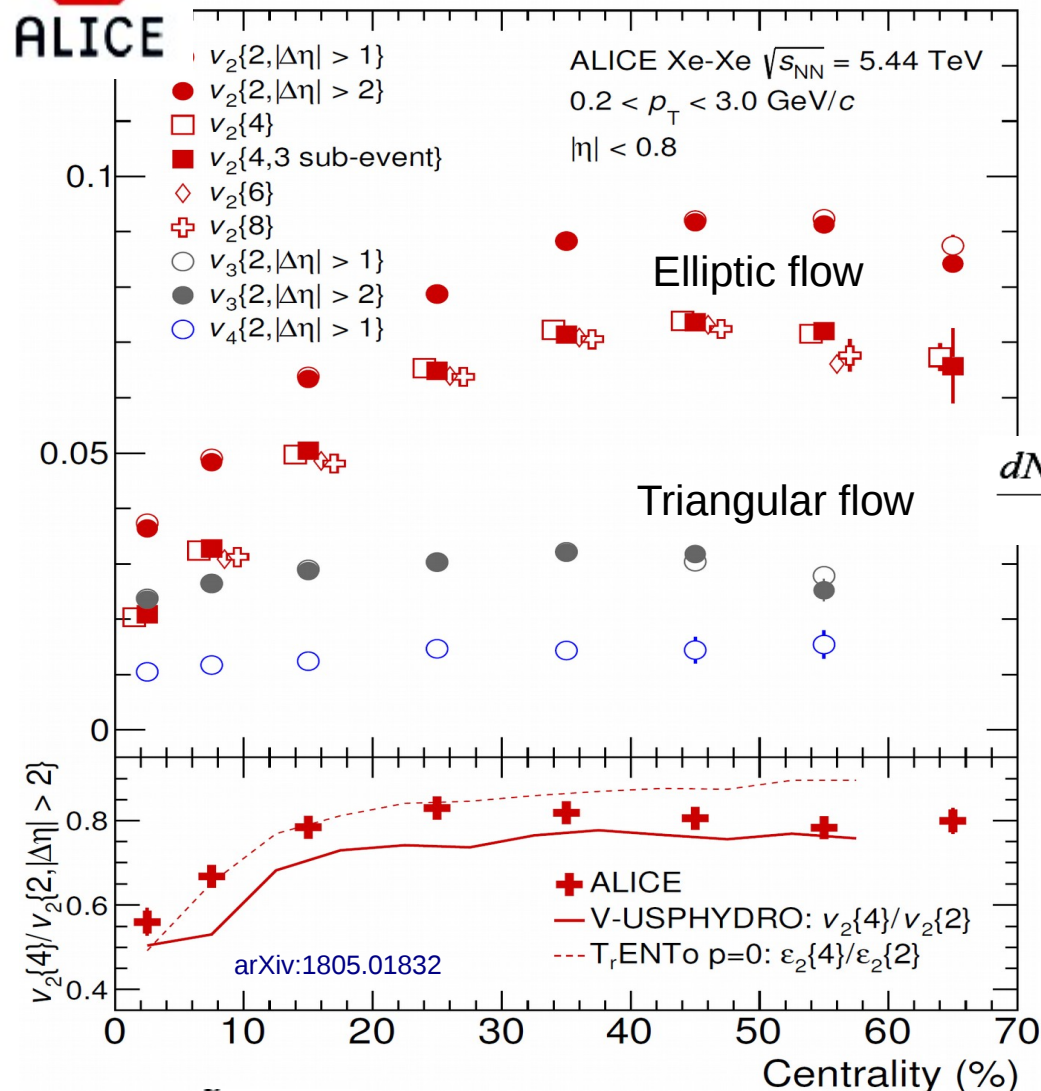
Increasing strange particle production with multiplicity until plateau is reached.

Confirmed by recent Xe-Xe data.

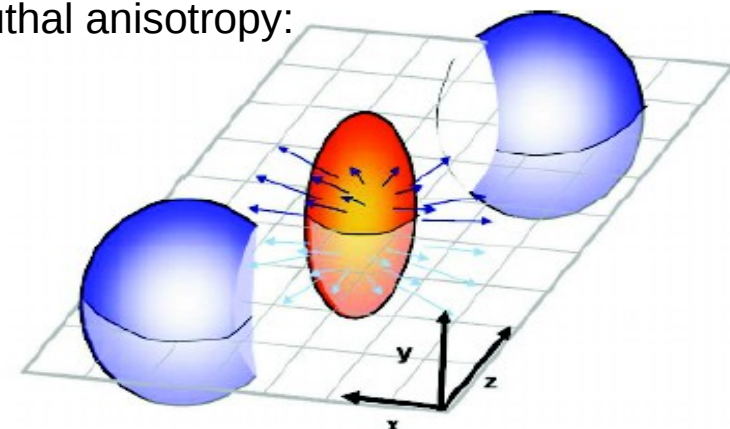




# Anisotropic flow in Xe-Xe collisions



Azimuthal anisotropy:



$$\frac{dN(p_T, \varphi)}{d\varphi} \propto 1 + 2v_1 \cos(\varphi - \psi_1) + 2v_2 \cos(2[\varphi - \psi_2]) + \dots$$

Elliptic flow:  $v_2$  (initial density profile)  
 Triangular flow:  $v_3$  (viscosity)  
 (due to nucleons fluctuations in nuclei)

Models tuned in Pb-Pb data agree with Xe-Xe

Good understanding of initial density and viscosity in nucleus-nucleus collision.

Central:  
 Head-on:



Peripheral:





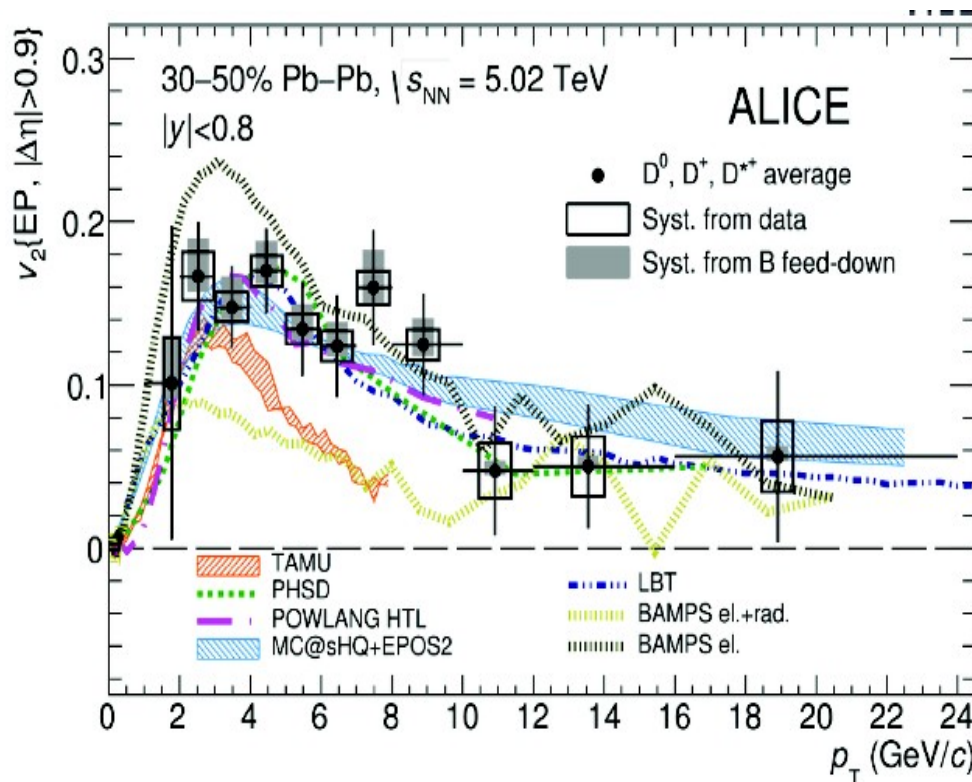
ALICE

# D-meson suppression in Pb-Pb collisions

Elliptic flow:

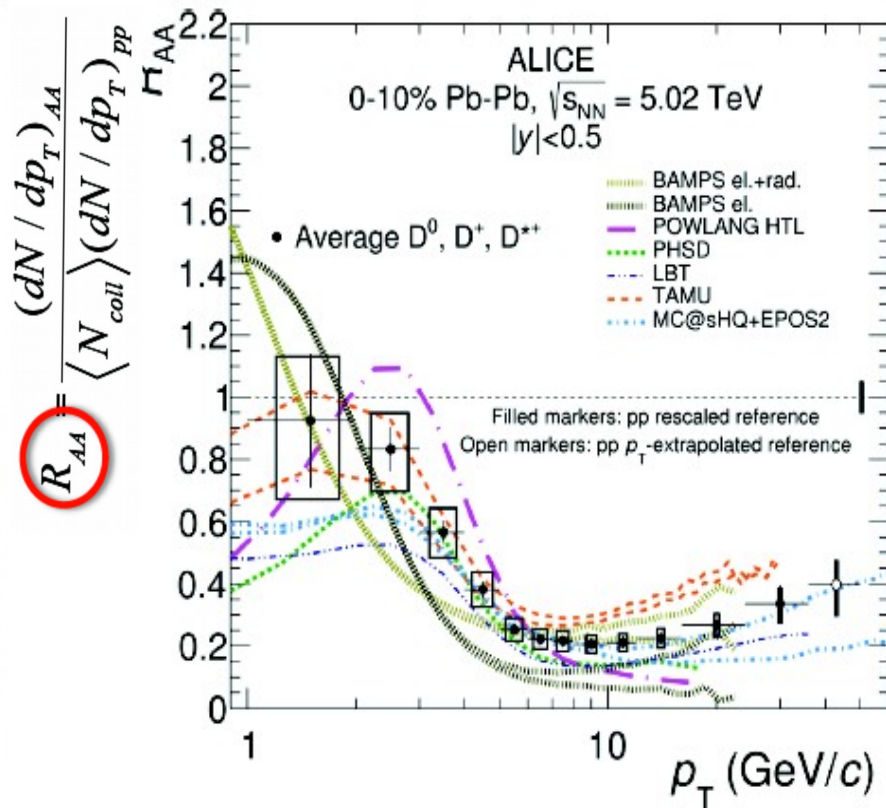
arXiv:1804.09083

Charged particle spectra:



$$\frac{dN(p_T, \varphi)}{d\varphi} \propto 1 + 2v_1 \cos(\varphi - \psi_1) + 2v_2 \cos(2[\varphi - \psi_2]) + \dots$$

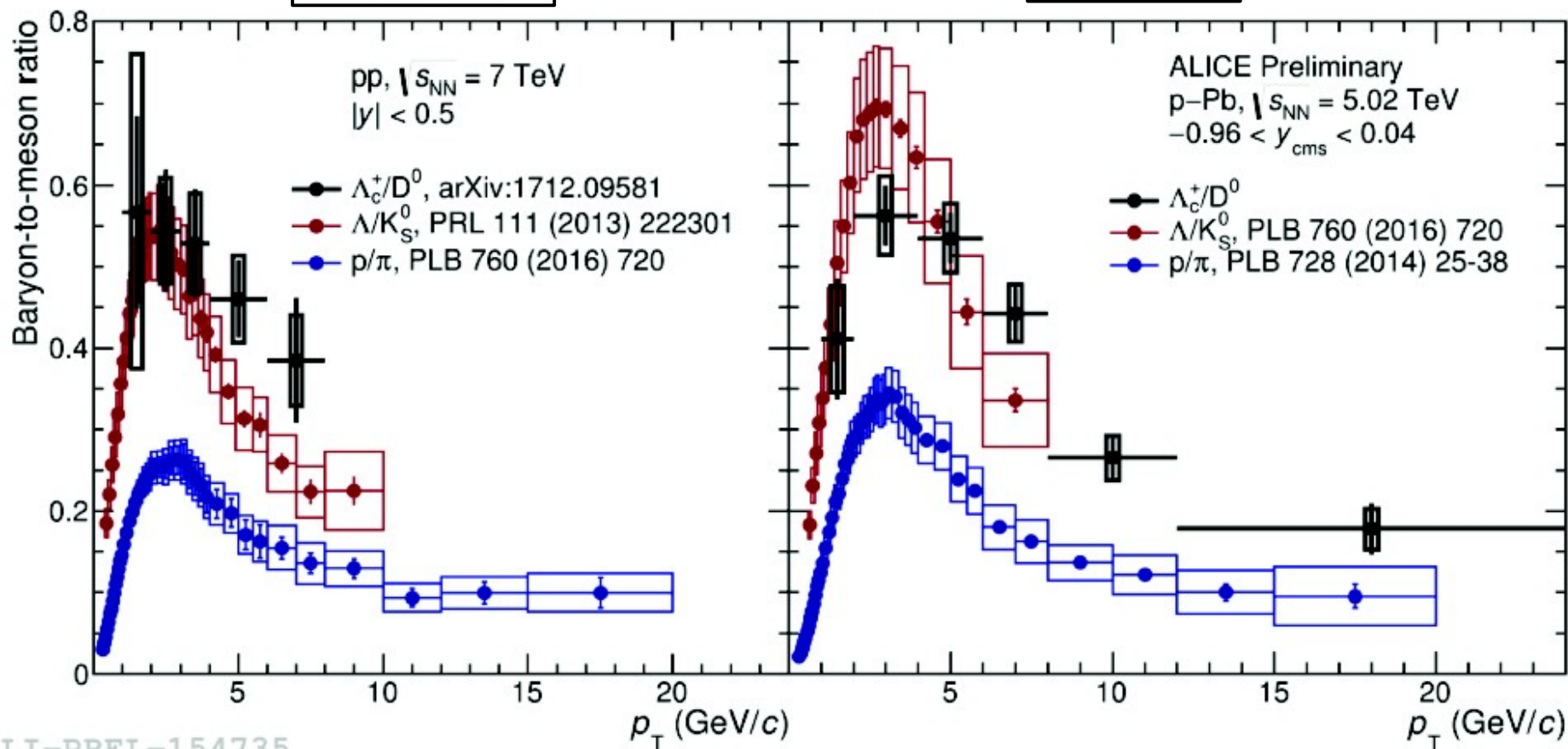
Less elliptic flow at high-pt. Strong charged particle suppression at high pt.  
 → constrains charm transport in dense nucleonic environment.



# Baryon to Meson ratio in pp and p-Pb collisions

Proton-proton

Proton-Pb



Clear increase in  $\Lambda_c/D$ -meson towards  $p_T \sim 3$  GeV (similar to  $\Lambda/K$ aon and  $p/\pi$ ).

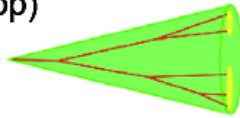
This specific effect in baryon formation is difficult to describe with pQCD+fragmentation.

# Parton energy loss in jets

Soft-drop jet substructure grooming:

e.g.: declustering: “peel apart” the shower

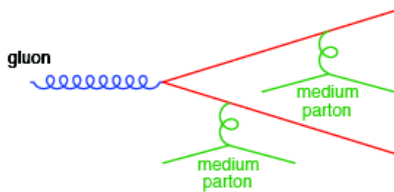
(Soft Drop)



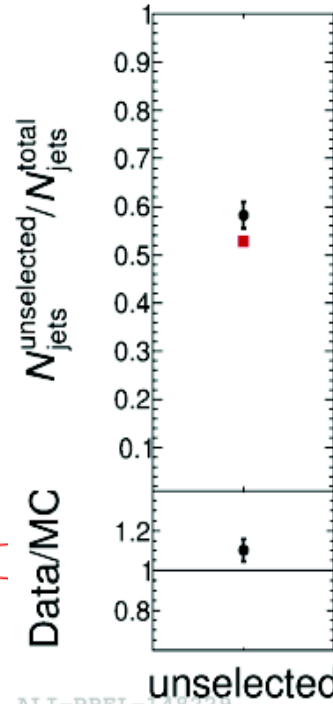
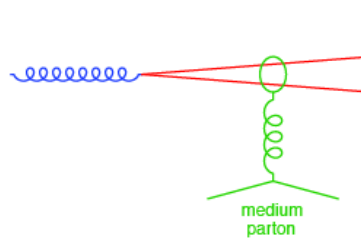
$$z_g = \frac{\min(p_{\perp,1}, p_{\perp,2})}{p_{\perp,1} + p_{\perp,2}} \quad z_g > 0.1$$

sensitive to coherence of energy loss

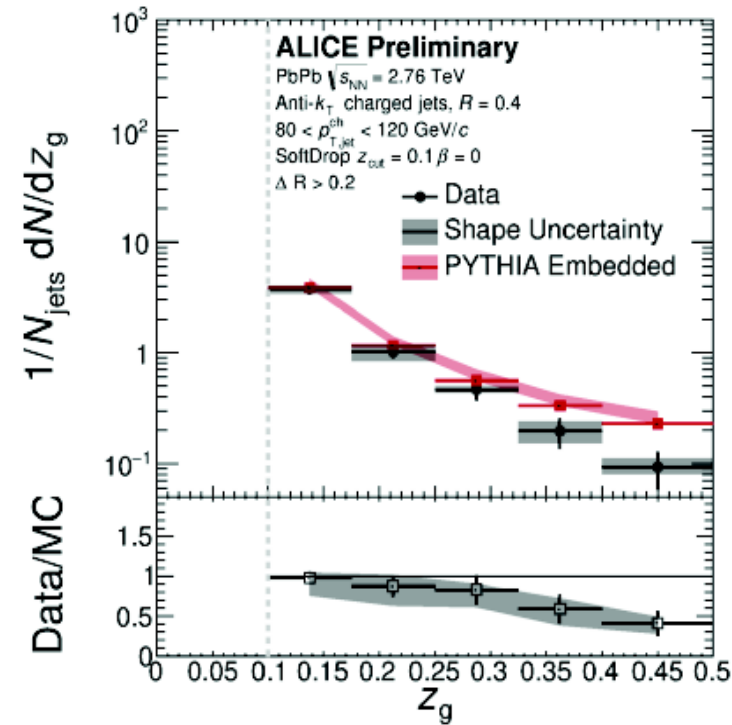
incoherent



coherent



ALI-PREL-148229



Result shown for  $dR > 0.2$ : suppression of symmetric splittings.

Soft drop mass also used by ATLAS and CMS to characterize internal jet substructure.



# Conclusions

**ATLAS** 13 TeV data analysis is in full swing. 13 results with  $80 \text{ fb}^{-1}$  (2015-2017 data).

Important new Higgs physics results:

- $H \rightarrow b\bar{b}$  observation. Main Higgs decays are now observed.
- Direct observation of Higgs coupling to top quark (via  $t\bar{t}H$ ).
- Yukawa coupling to fermions confirmed ( $t\bar{t}H$ ,  $H \rightarrow b\bar{b}$ ,  $H \rightarrow \tau\tau$ )
- $VH$  production observed. All major Higgs production modes observed.

Observation of electro-weak processes with dominant vector boson scattering:

Same-sign  $WWjj$  and  $WZjj$  production.

→ Important test of SM electro-weak sector.

New electro-weak mixing angle measurement with precision of 0.15%.

Top pairs: Indication for stronger top spin correlation than expected by NLO QCD.

Extensive and active search program for full run-2 ( $>150 \text{ fb}^{-1}$  achievable).

New directions looking at more refined signatures.

## **ALICE:**

Heavy-ion collisions: understanding the properties of QCD matter:

- Azimuthal anisotropies: Xe-Xe results confirm understanding of expanding QGP, viscosity
- Charm, jets probe the QGP with partons:  
Quantitative understanding of charm transport and QCD bremsstrahlung progressing.

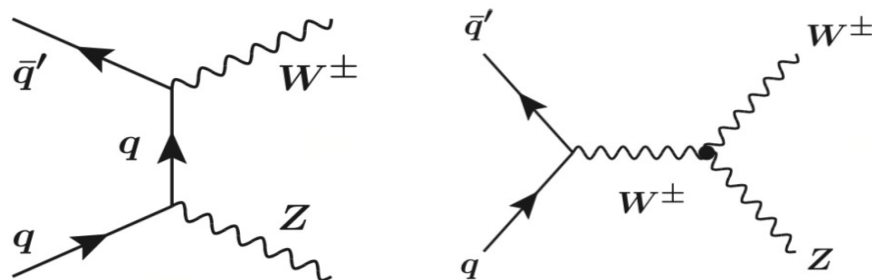


# Back-up



# WZ cross-section and polarization

Electroweak production of WZ boson  $pp \rightarrow W^{\pm}Z$ :



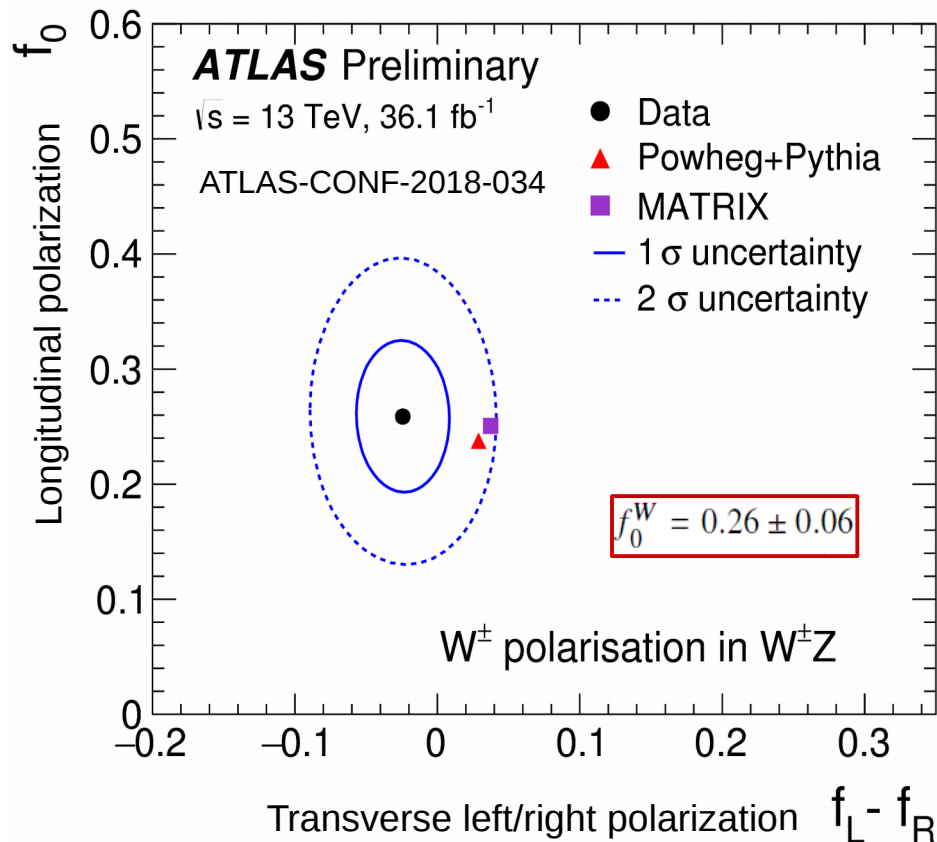
Total fiducial cross section:

$$\sigma_{\text{EW}}(WZ) = 63.7 \pm 2.9 \text{ fb}$$

NNLO (Matrix):  $61.5 \pm 1.4 \text{ fb}$

→ good agreement inclusive and differential cross-sections

Polarization measurement:



In WZ production:

- 1) Evidence of longitudinally W polarization ( $f_0$ )
- 2) Measurement of Z polarization

Longitudinal W-polarisation:

$4.2\sigma$  ( $3.8\sigma$ ) obs (exp)

ATLAS-CONF-2018-034

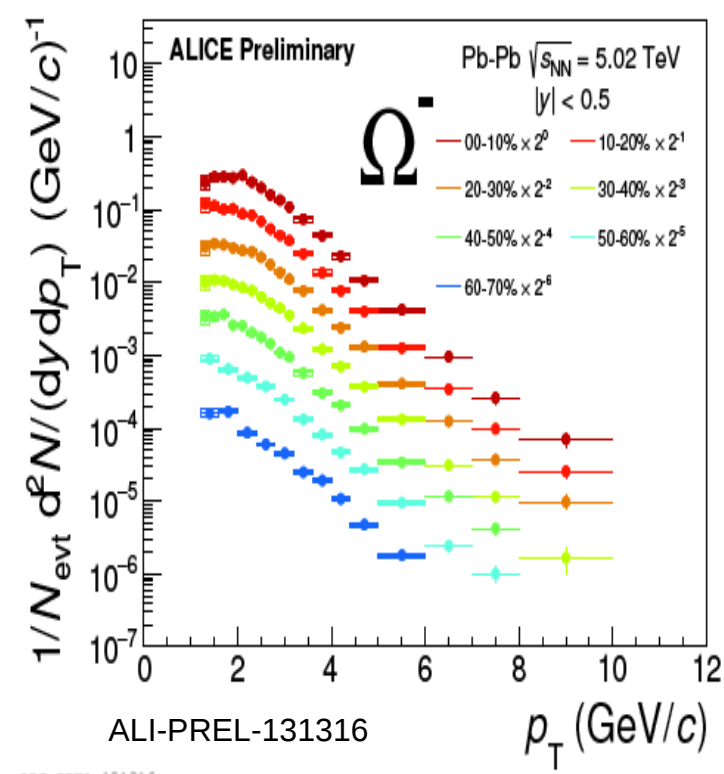
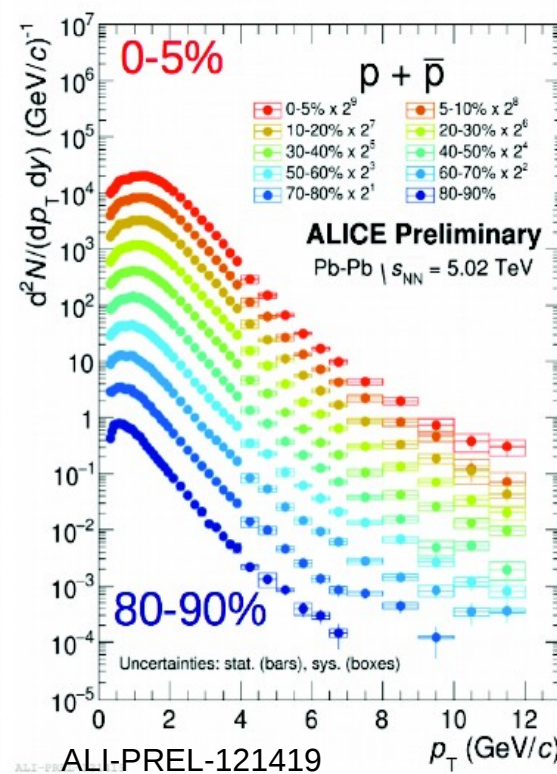
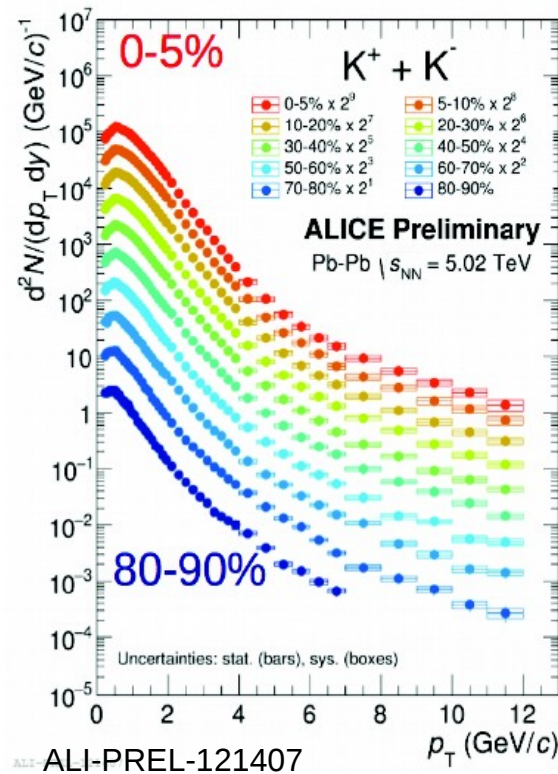
Compatible with NLO QCD and LO EW (Powheg)

# Identified particle spectra in Pb-Pb collisions

Alice detector with impressive particle-ID capabilities.

Particle spectra: pions, kaons, protons, Phis, Omegas, deuterons...

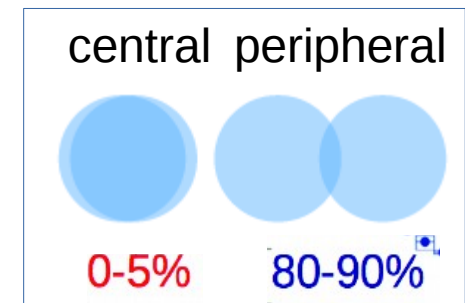
Examples:



Increase in mean pt with centrality.

Centrality: 0-5% head-on nucleus collision (many nucleons) (central)

80-90% nucleon-nucleon collision peripheral



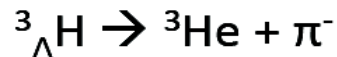
# Hyper-triton lifetime



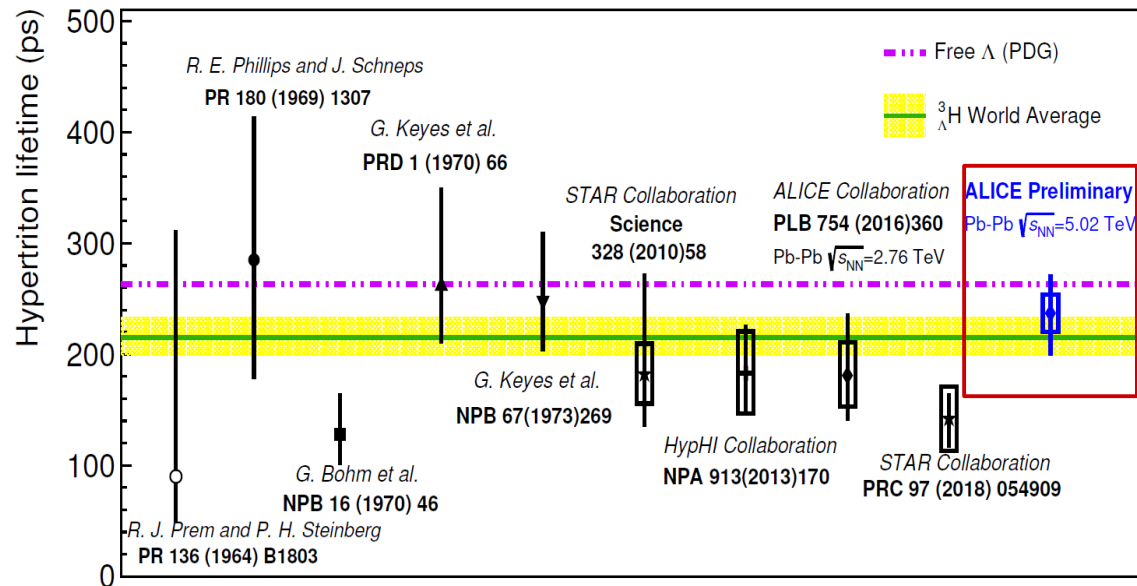
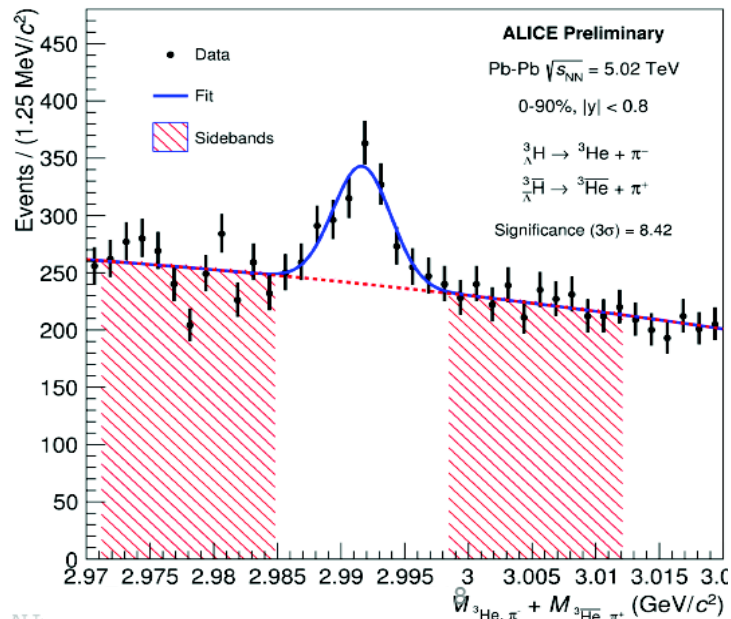
ALICE

Hyper-triton: Hyper-nucleus formed by proton, neutron and Lambda

${}^3_{\Lambda}\text{H}$ : pn $\Lambda$  bound state



One of the most precise Hyper-triton lifetime measurements



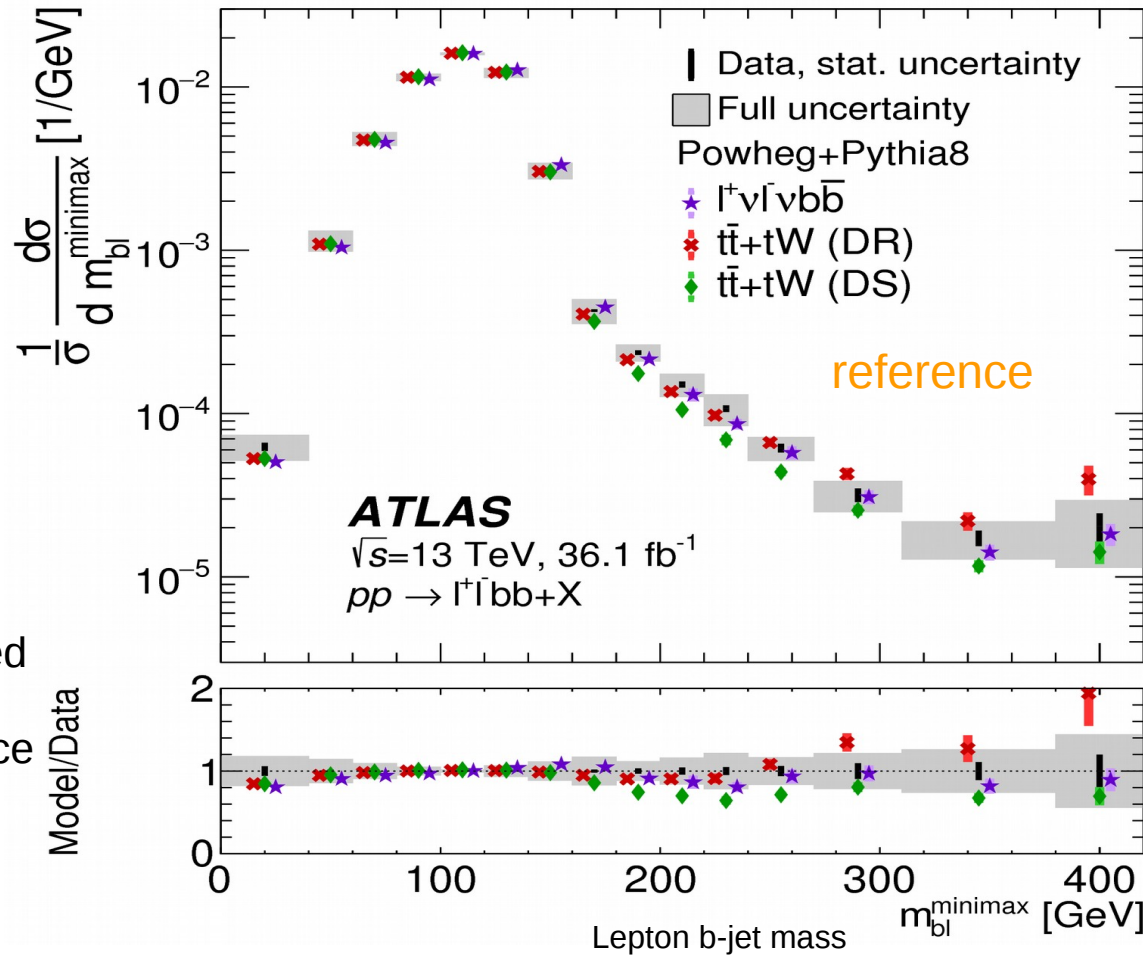
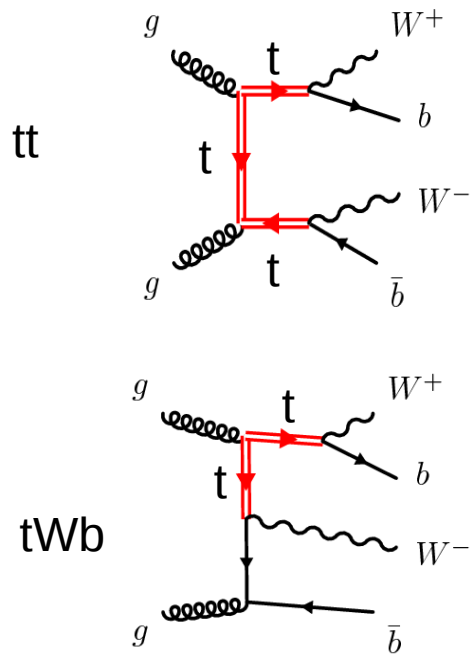
Live time agrees with the free lambda live time (expected since hyper-triton is loosely bound).

Resolution of hyper-triton live time puzzle.

Heavy ion collisions as a laboratory for strange/exotic nuclei.

# Tests of advanced $t\bar{t} \rightarrow WW b\bar{b}$ calculation

$Wt$  and  $t\bar{t}$  processes have same final state at NLO QCD  $|\mathcal{A}_{WWb\bar{b}}|^2 \sim |\mathcal{A}^{(Wtb)}|^2 + |\mathcal{A}^{(t\bar{t})}|^2 + 2\mathcal{R}\{\mathcal{A}^{(Wtb)}\mathcal{A}^{(t\bar{t})}\}$



So far, tops produce stable and decayed (narrow width approximation)  
 Systematic handled  $t\bar{t}$ /Wt interference  
 DR:  $t\bar{t}$  removed at amplitude level  
 DS:  $t\bar{t}$  removed at cross-section level

New calculation  $pp \rightarrow WW b\bar{b}$   
 (full matrix element)

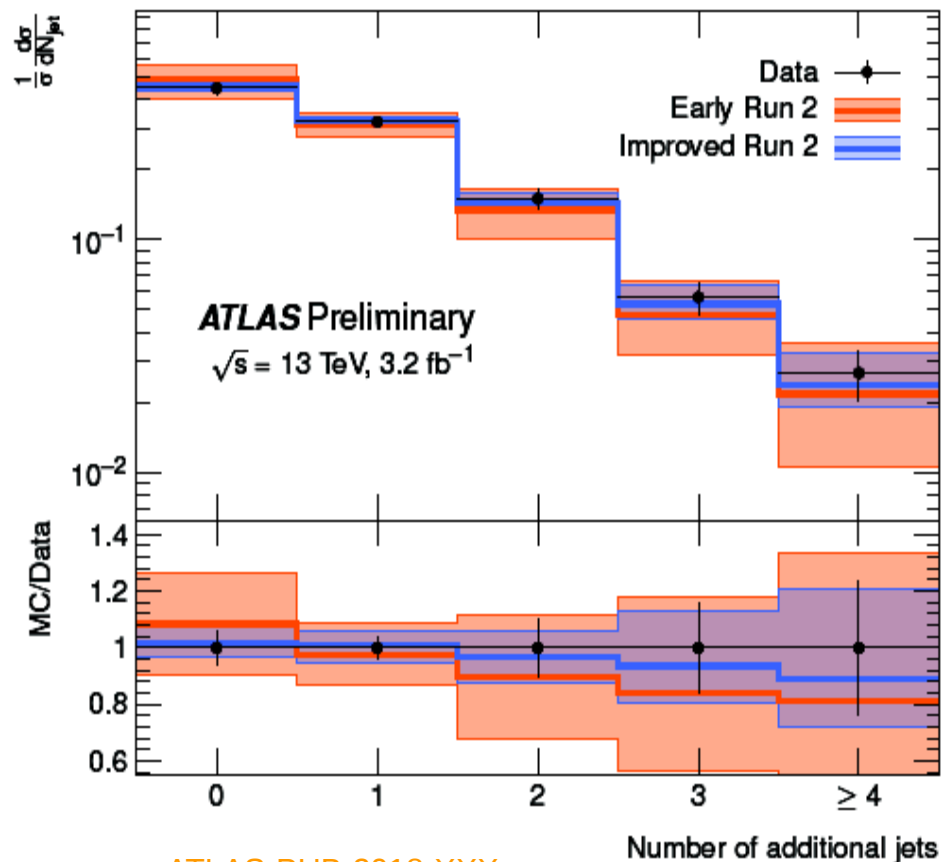
$$m_{b\ell}^{\text{minimax}} \equiv \min\{\max(m_{b_1\ell_1}, m_{b_2\ell_2}), \max(m_{b_1\ell_2}, m_{b_2\ell_1})\}$$





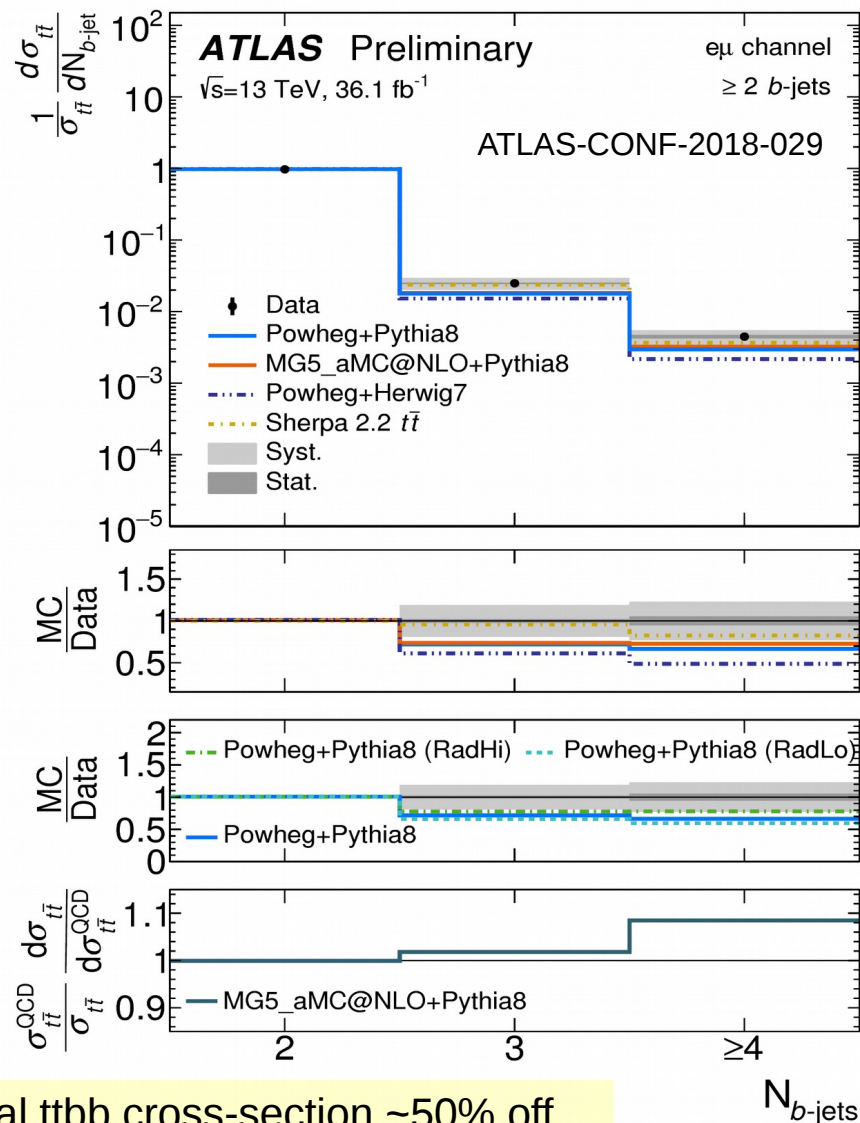
# Top final state modeling progress

Since several years ATLAS has measured fiducial cross-sections defined using the particles entering the detector. Indispensable for the tuning of modern ME(2->n)+PS MC simulations.



ATLAS-PUB-2018-XXX

tt+bb cross-section



Total ttbb cross-section ~50% off, but shapes ~ok after tuning efforts.

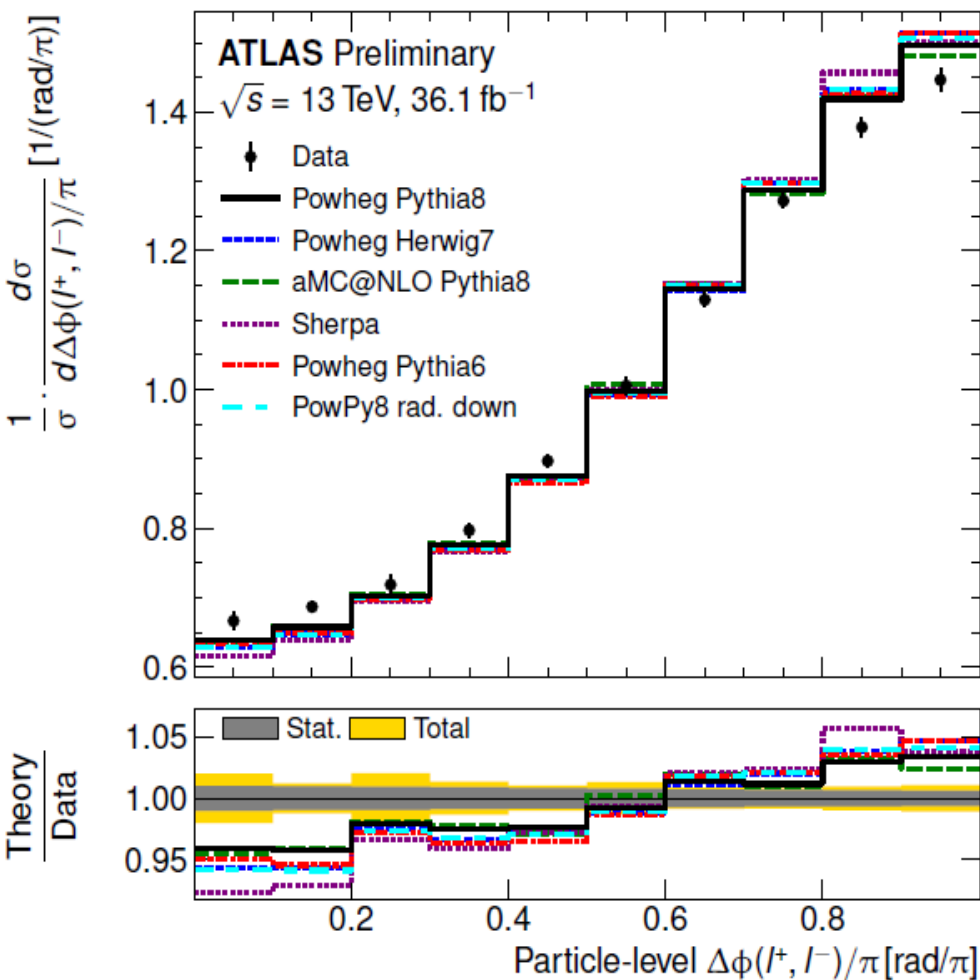
# ttbb cross-section measurement

Generator	Process	Matching	Tune	Use
POWHEG-BOX v2 + PYTHIA 8.210	$t\bar{t}$ NLO	Powheg $h_{\text{damp}}=1.5 m_t$	A14	nom.
MADGRAPH5_aMC@NLO + PYTHIA 8.210	$t\bar{t} + V/H$ NLO	MC@NLO	A14	nom.
POWHEG-BOX v2 + PYTHIA 8.210 RadLo	$t\bar{t}$ NLO	Powheg $h_{\text{damp}}=1.5 m_t$	A14Var3cDown	syst.
POWHEG-BOX v2 + PYTHIA 8.210 RadHi	$t\bar{t}$ NLO	Powheg $h_{\text{damp}}=3.0 m_t$	A14Var3cUp	syst.
POWHEG-BOX v2 + HERWIG 7.01	$t\bar{t}$ NLO	Powheg $h_{\text{damp}}=1.5 m_t$	H7UE	syst.
SHERPA 2.2.1	$t\bar{t} + 1\text{jet}$ NLO +3 jets LO	MC@NLO	SHERPA	syst.
SHERPA 2.2.1	$t\bar{t}b\bar{b}$ NLO	NLO $t\bar{t}b\bar{b}$	SHERPA	comp.
MADGRAPH5_aMC@NLO + PYTHIA 8.210	$t\bar{t}$ NLO	MC@NLO	A14	comp.
POWHEL + PYTHIA 8.210	$t\bar{t}b\bar{b}$ NLO	NLO $t\bar{t}b\bar{b}$	A14	comp.



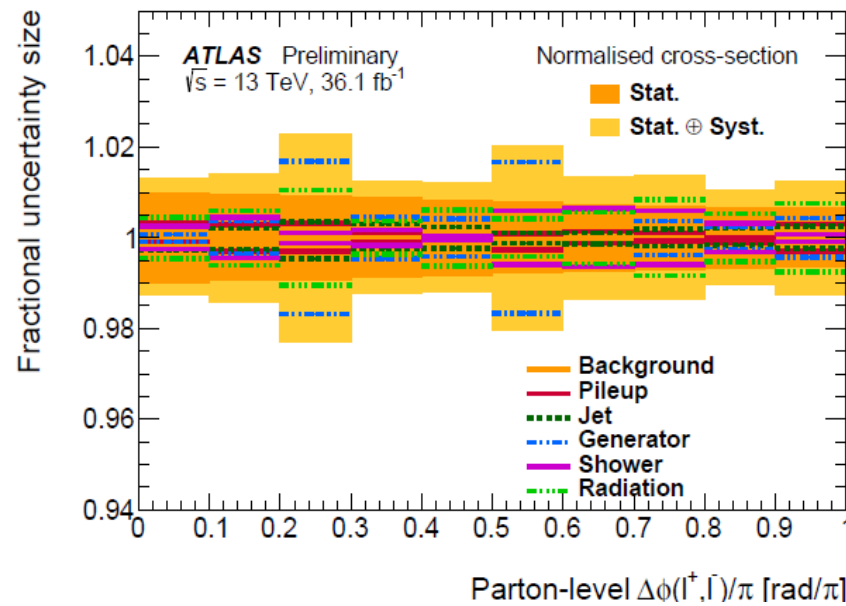
# Spin correlation in top pair events

ATLAS-CONF-2018-027



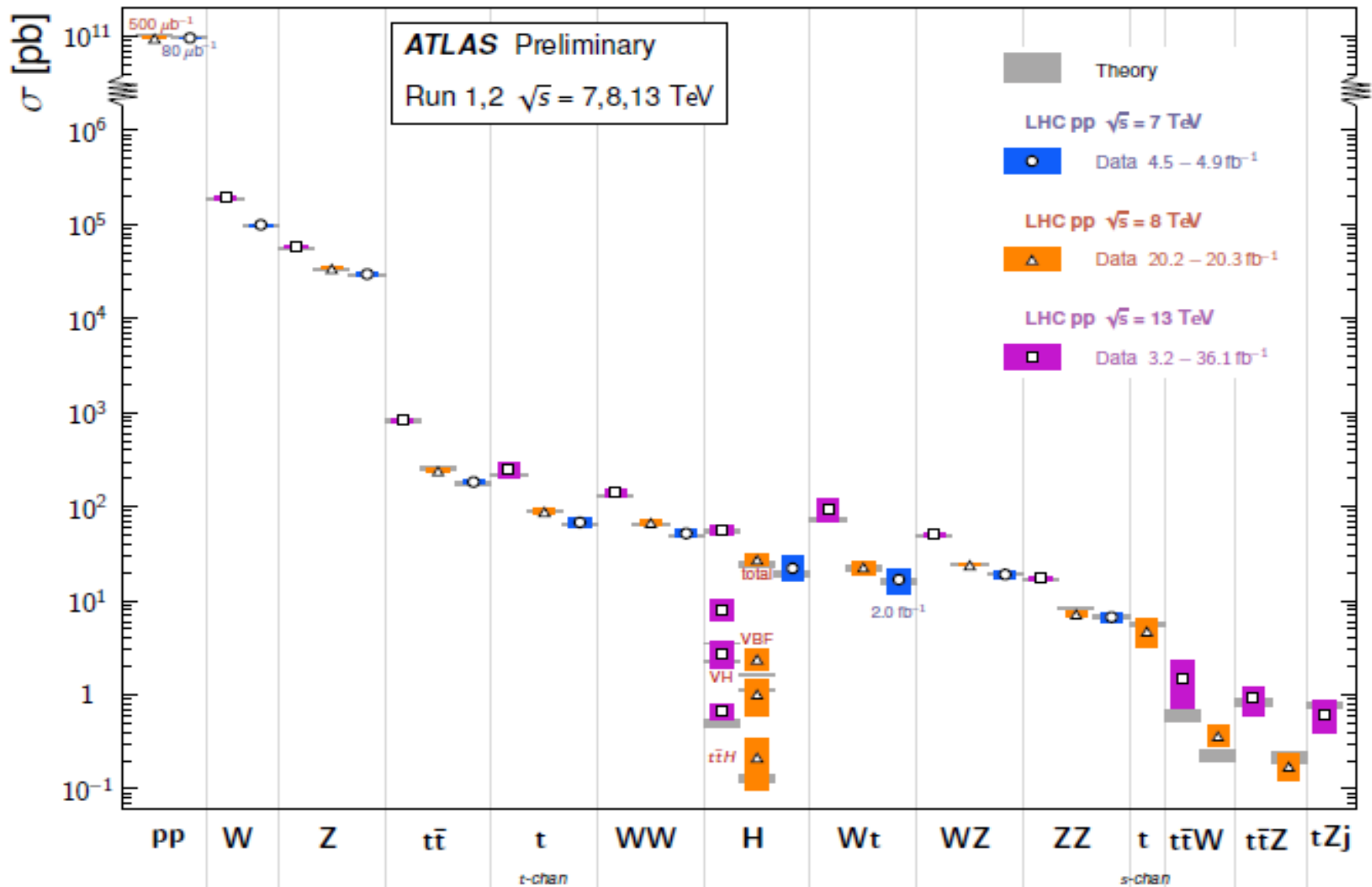
Generator	inclusive
<i>f<sub>SM</sub></i> values	
POWHEG + PYTHIA 8	1.25
POWHEG + PYTHIA 8 (2.0 $\mu_F$ , 2.0 $\mu_R$ )	1.29
POWHEG + PYTHIA 8 (0.5 $\mu_F$ , 0.5 $\mu_R$ )	1.18
POWHEG + PYTHIA 8 (PDF variations)	1.26
POWHEG + PYTHIA 8 RadLo tune	1.29
POWHEG + HERWIG7	1.32
MADGRAPH5_aMC@NLO + PYTHIA 8	1.20

Table 3: Summary of the extracted spin correl



# Measurements overview

Standard Model Total Production Cross Section Measurements *Status: June 2018*



# Measurements of weak mixing angle

Polarized Drell-Yann cross-section  $pp \rightarrow Z \rightarrow \ell\ell$  can be expanded as sum of 9 harmonic polynomials

Z-boson CM frame

$$\frac{d\sigma}{dp_T^{\ell\ell} dy^{\ell\ell} dm^{\ell\ell} d\cos\theta d\phi} = \frac{3}{16\pi} \frac{d\sigma^{U+L}}{dp_T^{\ell\ell} dy^{\ell\ell} dm^{\ell\ell}} \left\{ (1 + \cos^2\theta) + \frac{1}{2} A_0(1 - 3\cos^2\theta) + A_1 \sin 2\theta \cos\phi + \frac{1}{2} A_2 \sin^2\theta \cos 2\phi + A_3 \sin\theta \cos\phi + A_4 \cos\theta + A_5 \sin^2\theta \sin 2\phi + A_6 \sin 2\theta \sin\phi + A_7 \sin\theta \sin\phi \right\}$$

unpolarized

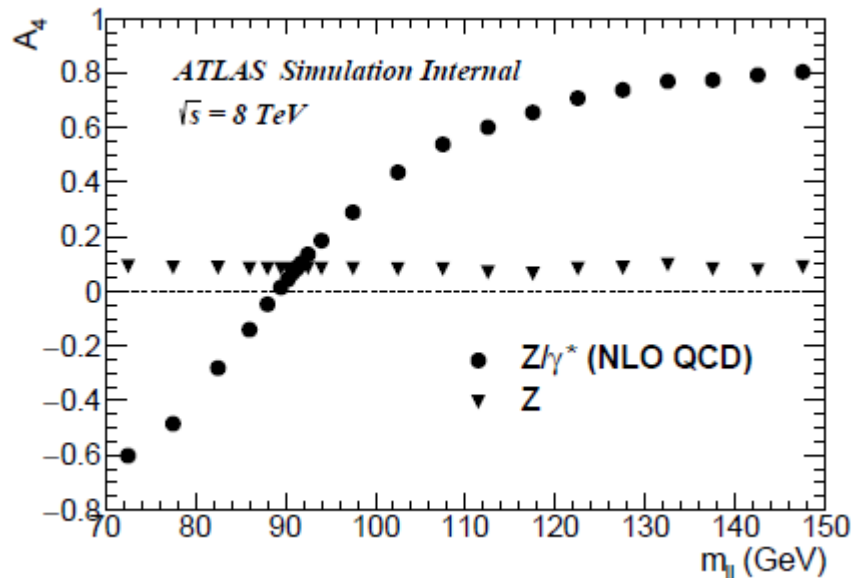
$A_4$  non-zero in LO  
 $A_0$ - $A_3$  non-zero only in NLO  
 $A_5$ - $A_7$  non-zero only in NNLO

$A_3$  and  $A_4$  depend on vector and axial couplings to Z-boson ~ sensitive to  $\sin\theta_w$

$A_4$  sensitive to weak mixing angle  $3/8 A_4 \sim \sin^2\theta_w$

Measurement for  $|\eta| < 2.4$  (cc) and with one electron in forward region  $2.5 < |\eta| < 4.6$  (cf)

$A_4$  is parity violating, best sensitivity at Z-pole



Limitation by radiation of initial state quarks  
 → large systematics from PDFs

PDF set	CT10	CT14	MMHT14	NNPDF31
Central value	0.23118	0.23141	0.23140	0.23146
Uncertainties in measurements				
Total	40	37	36	38
Stat.	21	21	21	21
Syst.	32	31	29	31

Final uncertainty from PDF spread

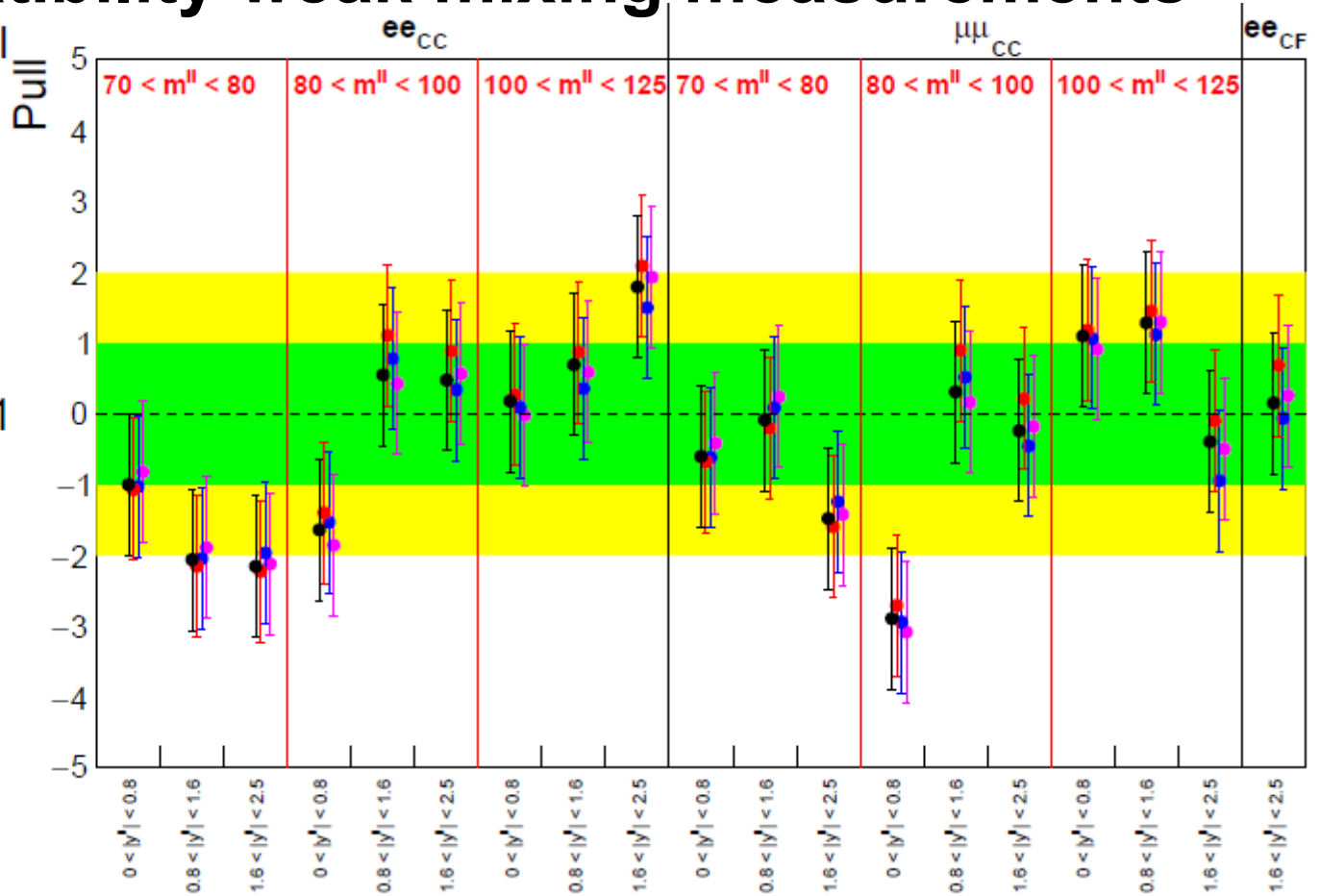


# Compatibility weak mixing measurements

**ATLAS Internal**  
8 TeV, 20.2 fb<sup>-1</sup>

PDFs

- CT10
- CT14
- MMHT14
- NNPDF31



Z-boson rapidity bins

Central value	0.23118	0.23141	0.23140	0.23146
	Uncertainties in measurements			
Total	40	37	36	38
Stat.	21	21	21	21
Syst.	32	31	29	31

Result also compatible with reinterpretation of recent triple-differential Drell-Yan cross-section measurement.

Final uncertainty from PDF spread.  
CT10 considered since it fits best the 7 TeV Drell-Yan data.

# Search for dark matter at LHC

Particle physics relevant for understanding of early universe.

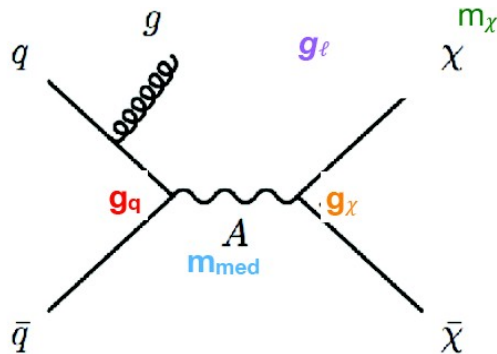
DM model require new stable particle beyond SM.

Coupling to SM particle via mediator (A).

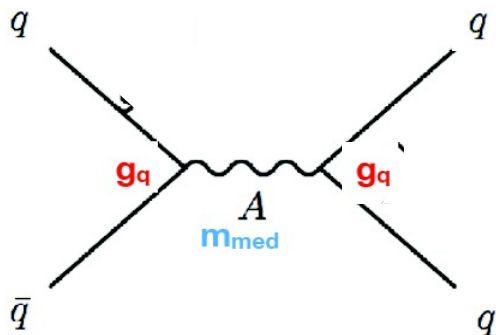
Two strategies:

1) Events only visible if strong boost by radiation

Signature: Mono-X, X=jet, photon, Z/W etc.



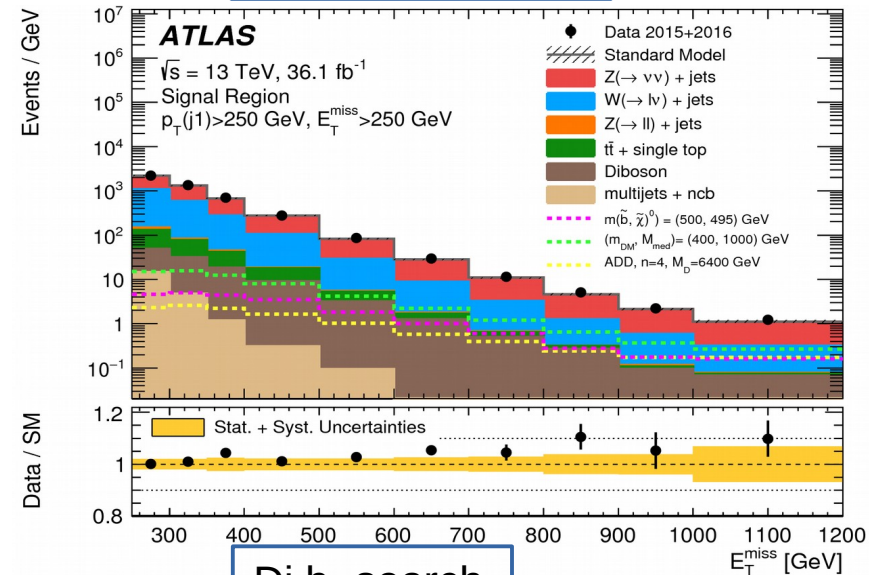
2) Look for mediator decay to SM particles.



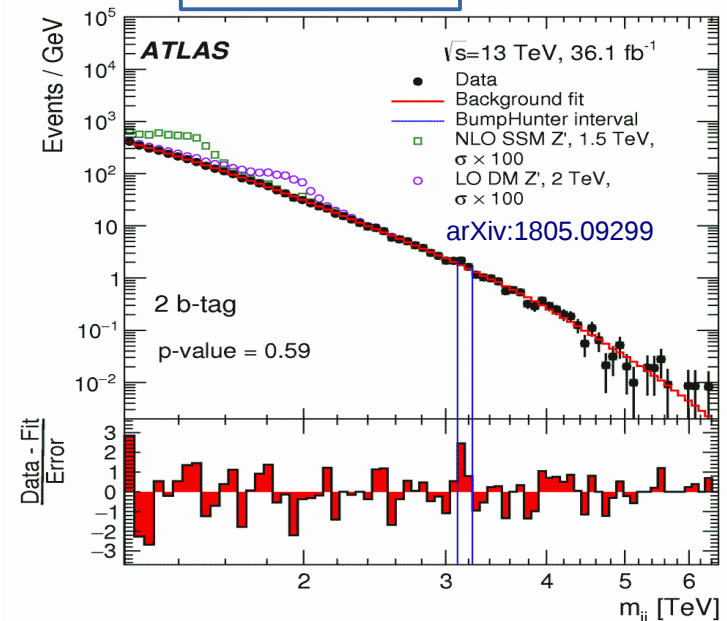
LHC is sensitive to some models  
(not too heavy, sizable couplings)

## MET + jet search

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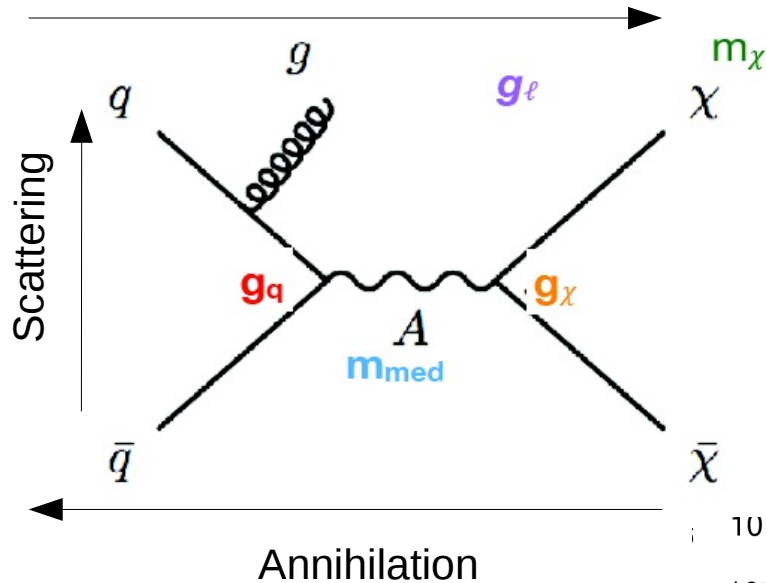
## Di b- search



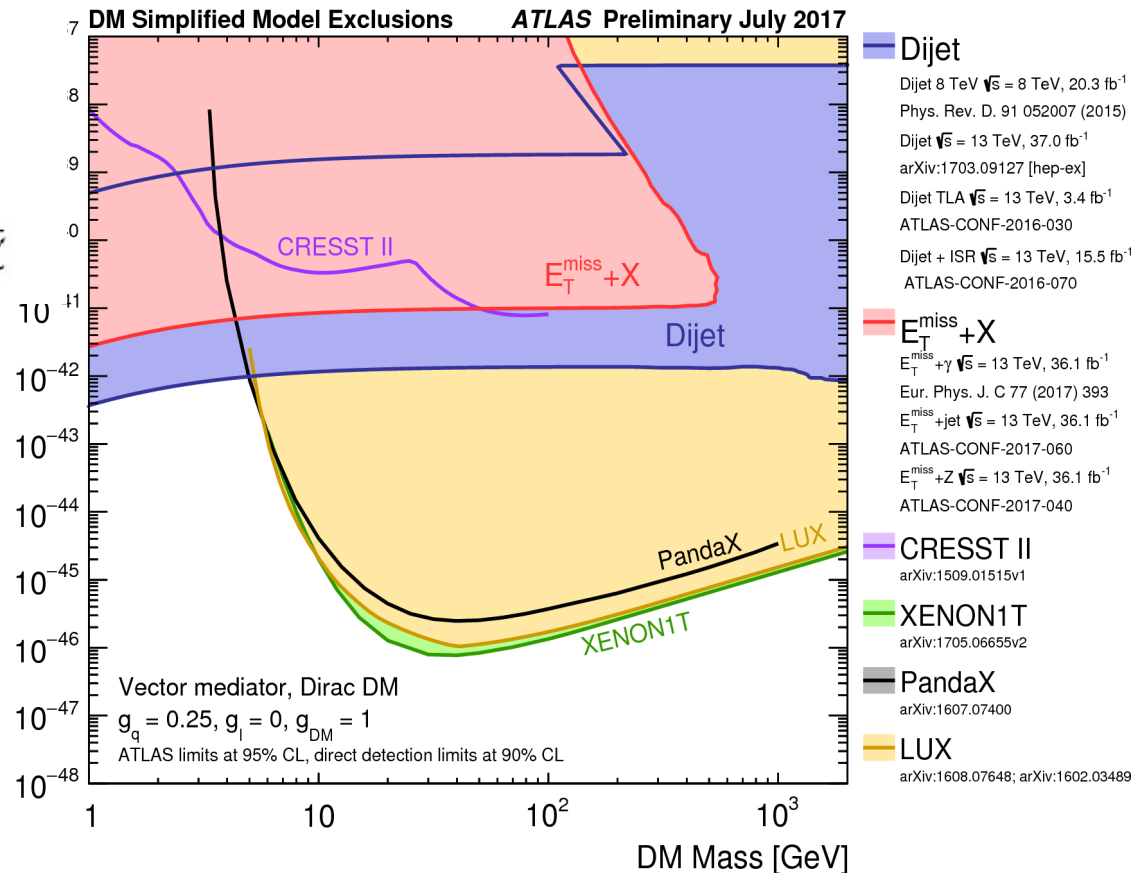
# Search for dark matter at LHC

Complementarity to direct detection experiments

Production at LHC

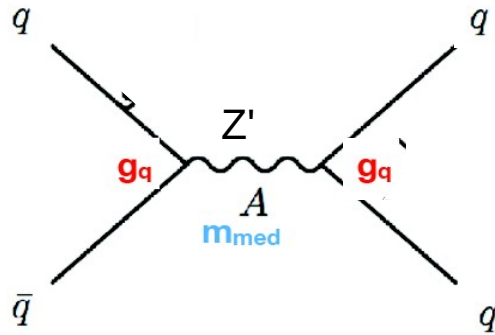


Example for  $g_q=0.25$   $g_\chi=1$  for vector mediator:

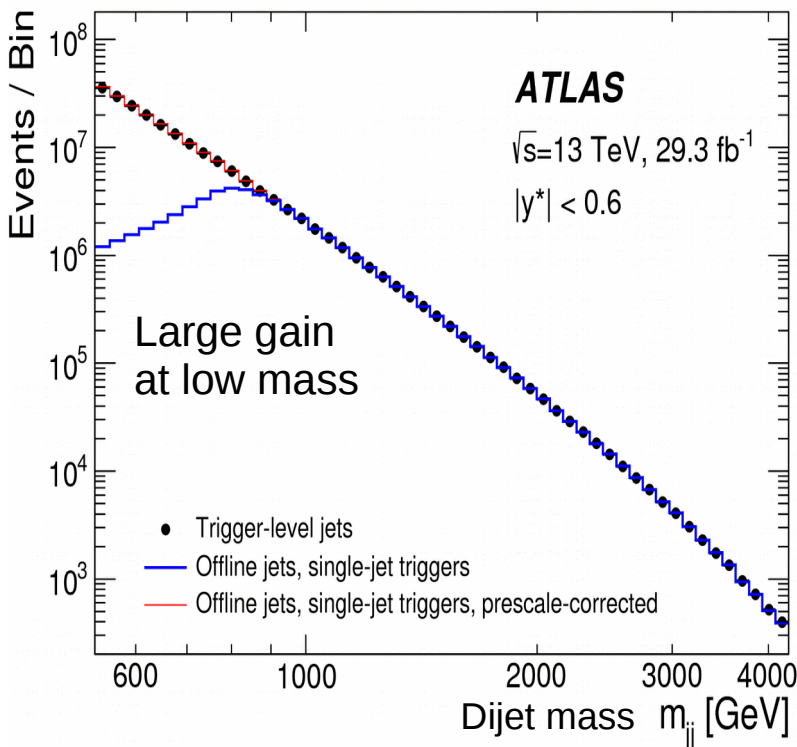


# Dijet resonance search

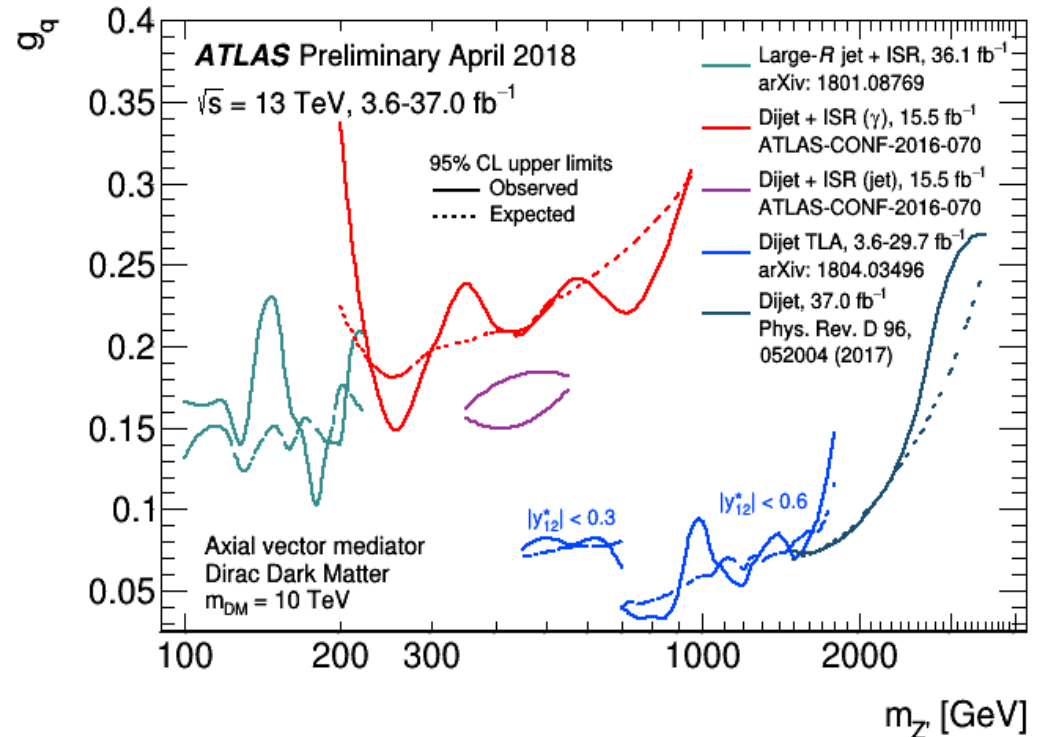
arXiv:1804.03496



Dijet resonance search limited by trigger  $p_{t,jet}$  threshold.  
In sub-TeV regime need to do analysis on trigger level  
overcoming bandwidth limitations by writing  
only small amount of trigger jet information.  
Need full jet calibration for trigger-level jets.



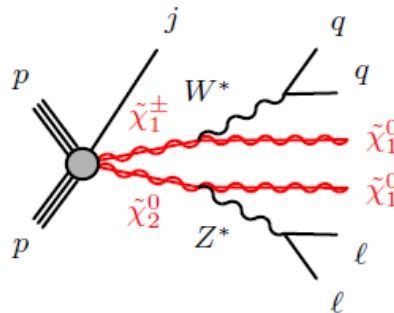
Example coupling limits for DM axial vector mediator:



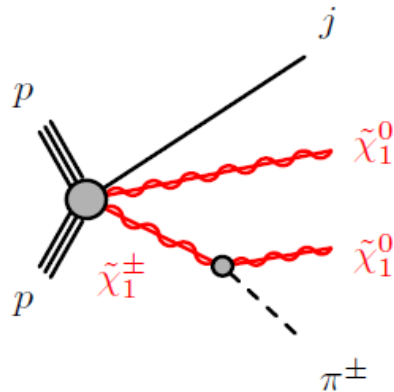
Trigger-level      offline

# Search for electroweak SUSY particles

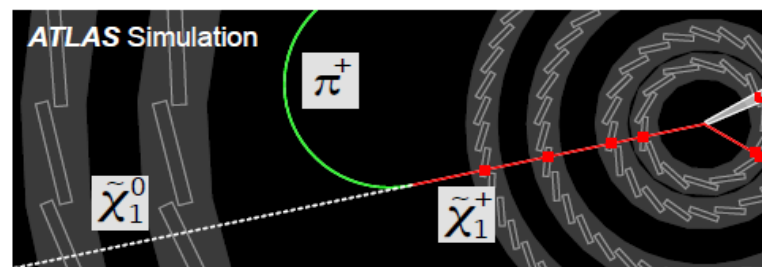
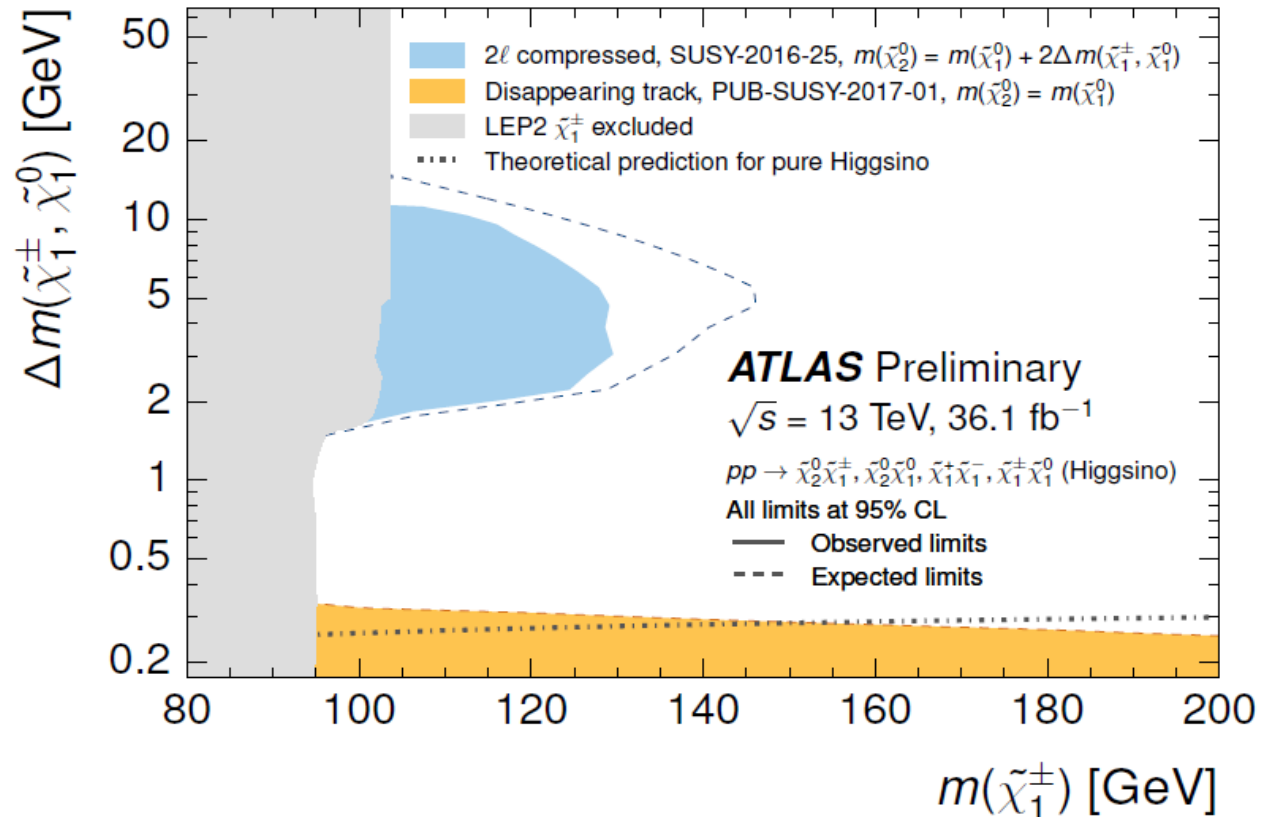
December 2017



**2ℓ compressed**  
Soft  $p_T^{e,\mu} > 4.5, 4 \text{ GeV}$   
[1712.08119]



**Disappearing track**  
IBL+Pixel tracklets  
[PHYS-PUB-2017-019]



[CONF-2017-081]



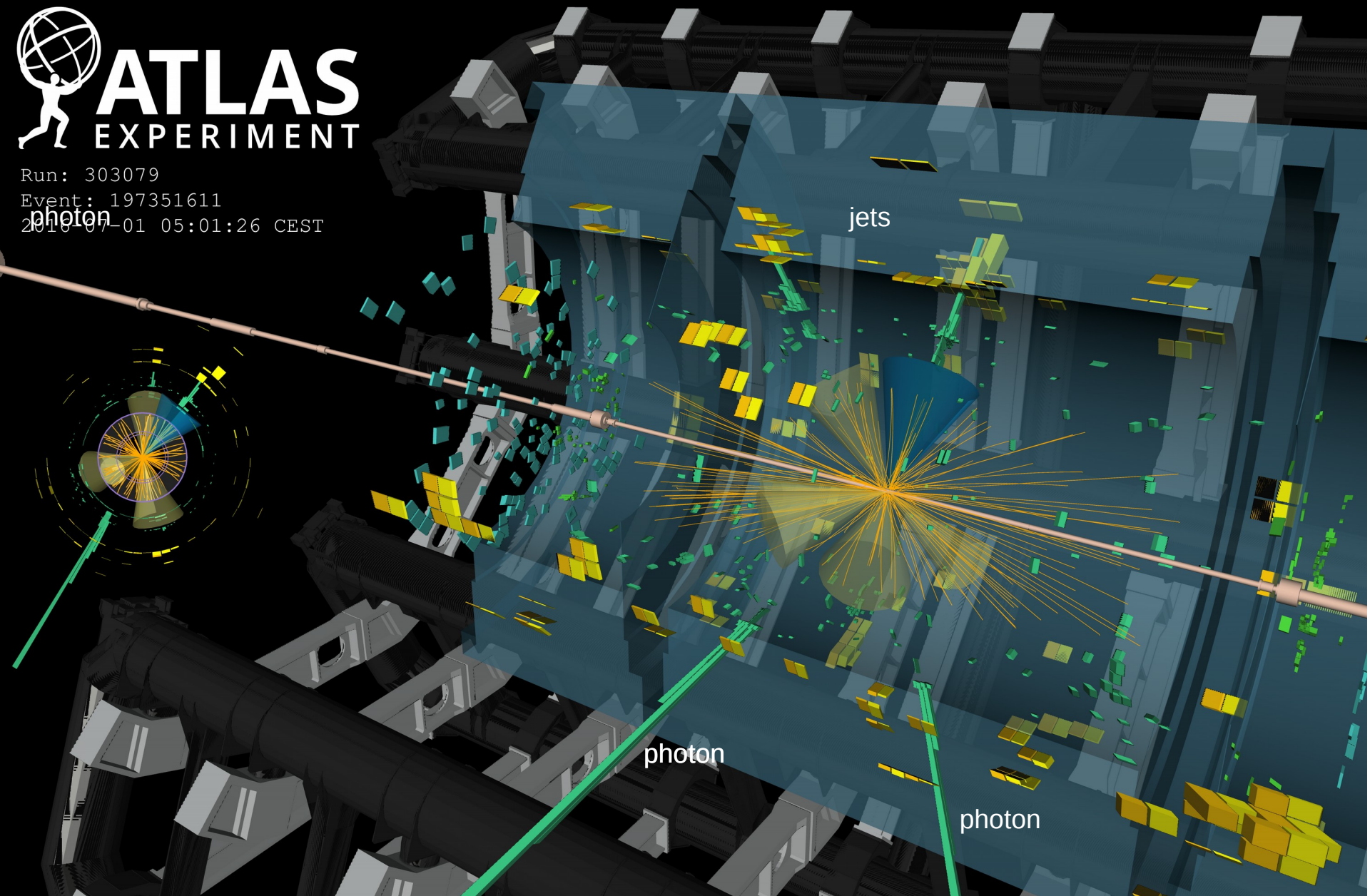
# ttH event candidate



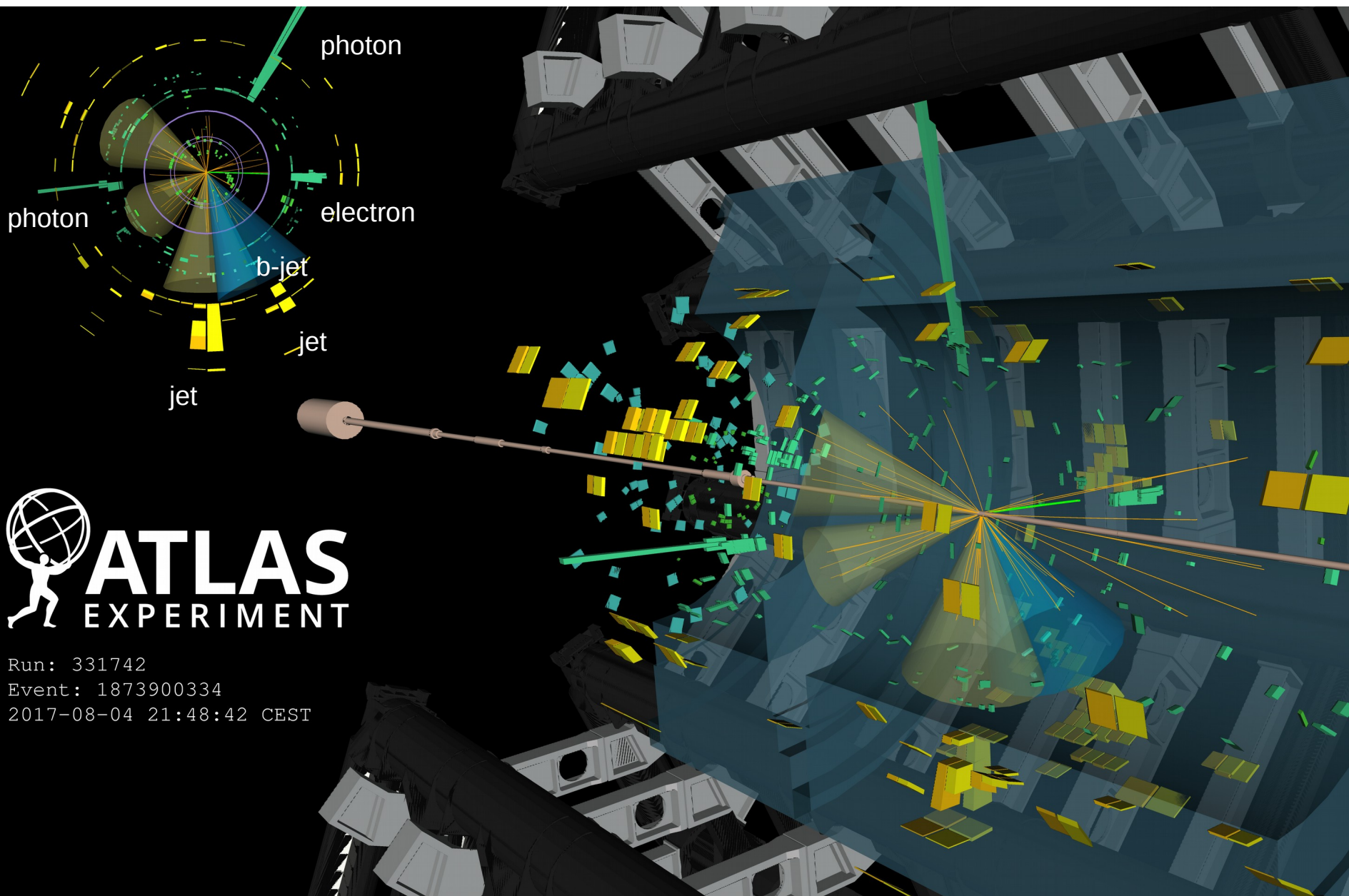
Run: 303079

Event: 197351611

2016-07-01 05:01:26 CEST

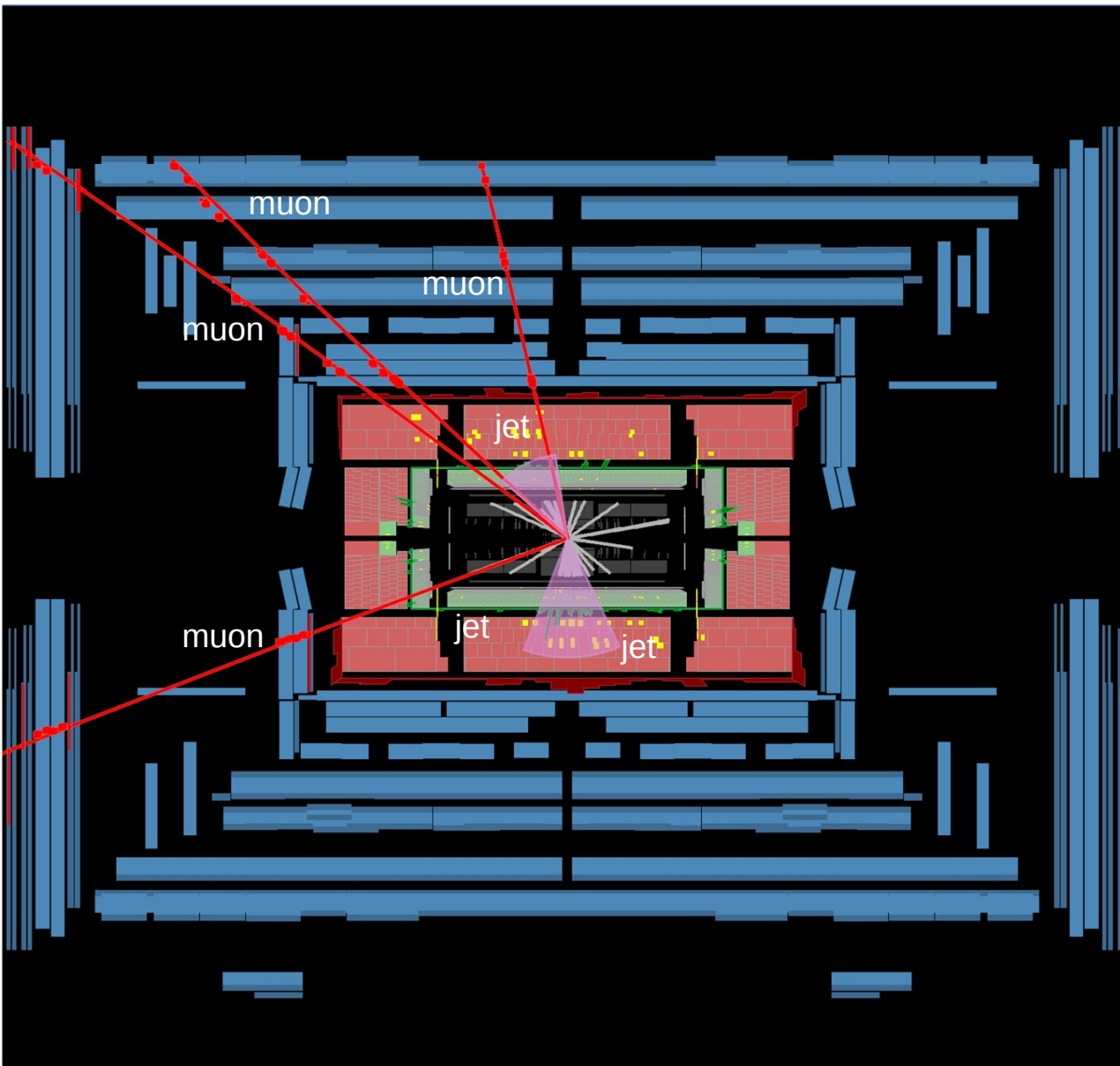


# ttH event candidate



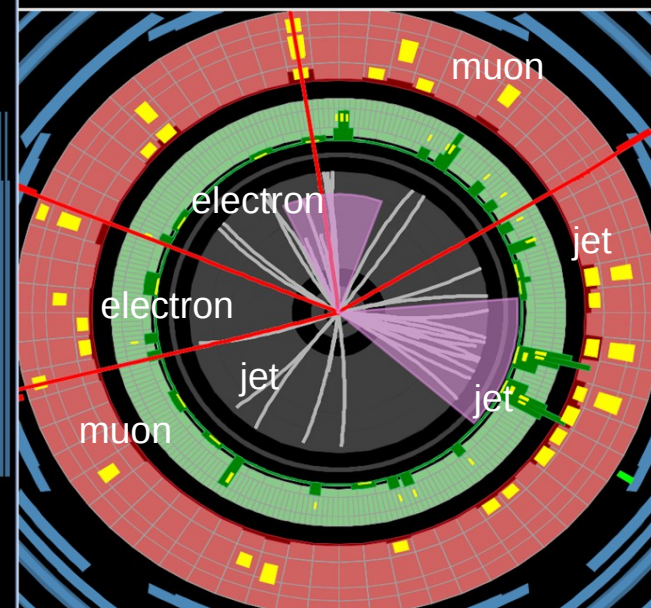


# ttH four lepton event candidate



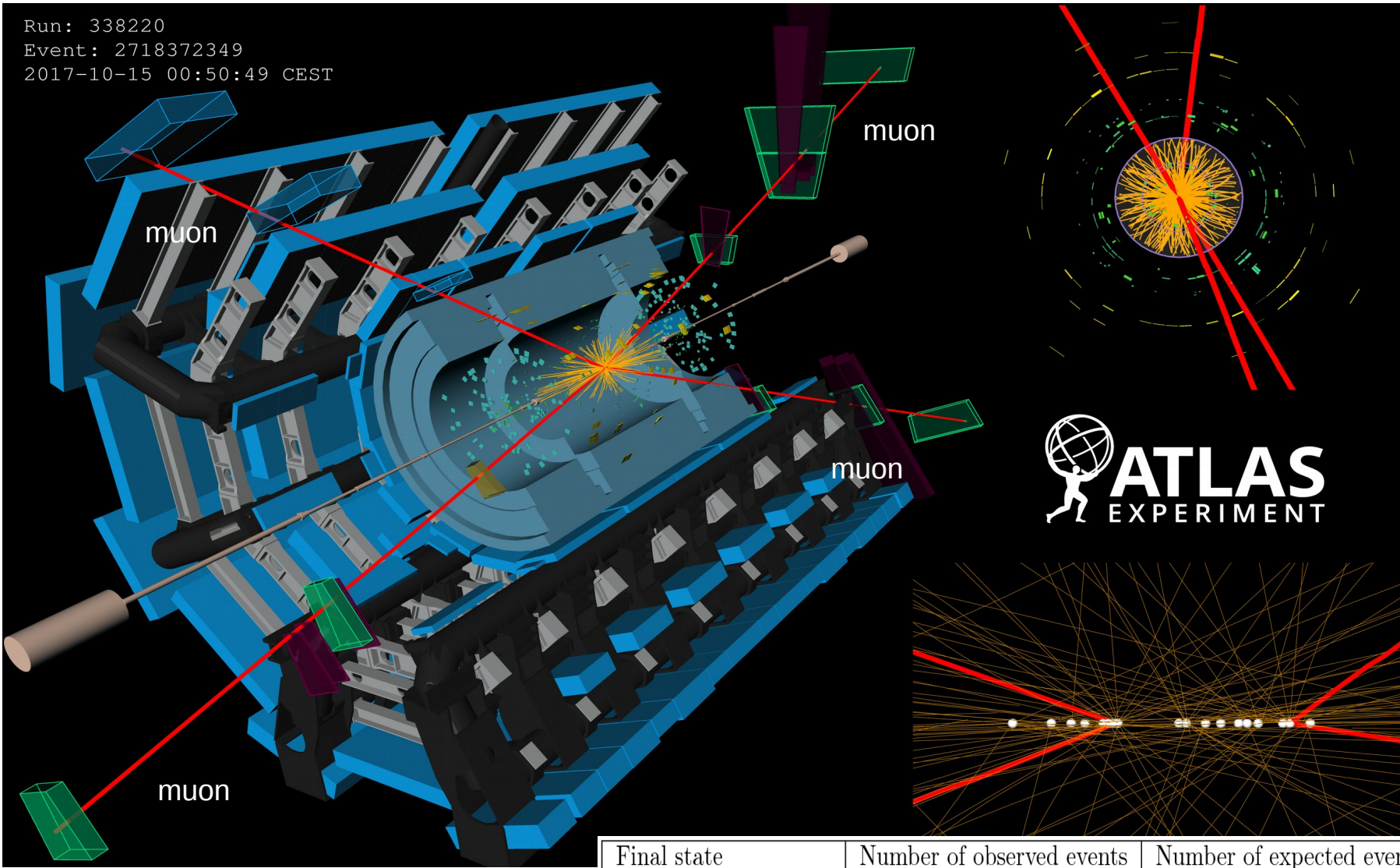
Run Number: 331875, Event Number: 2155358561

Date: 2017-08-08 02:55:43 CEST



Event display of the  $4\mu$  VH-Had candidate with the with BDTVH-Had = 0.47. The invariant mass of the 4-lepton system is 128.2 GeV, the muons are indicated by red tracks ( $p_T = 103.7, 16.9, 16.4$  and  $15.4$  GeV). The two jets, with an invariant mass of 96.2 GeV, are marked with purple cones ( $p_{T,j1} = 64.9$  GeV and  $p_{T,j2} = 64.9$  GeV).

# Four muon event

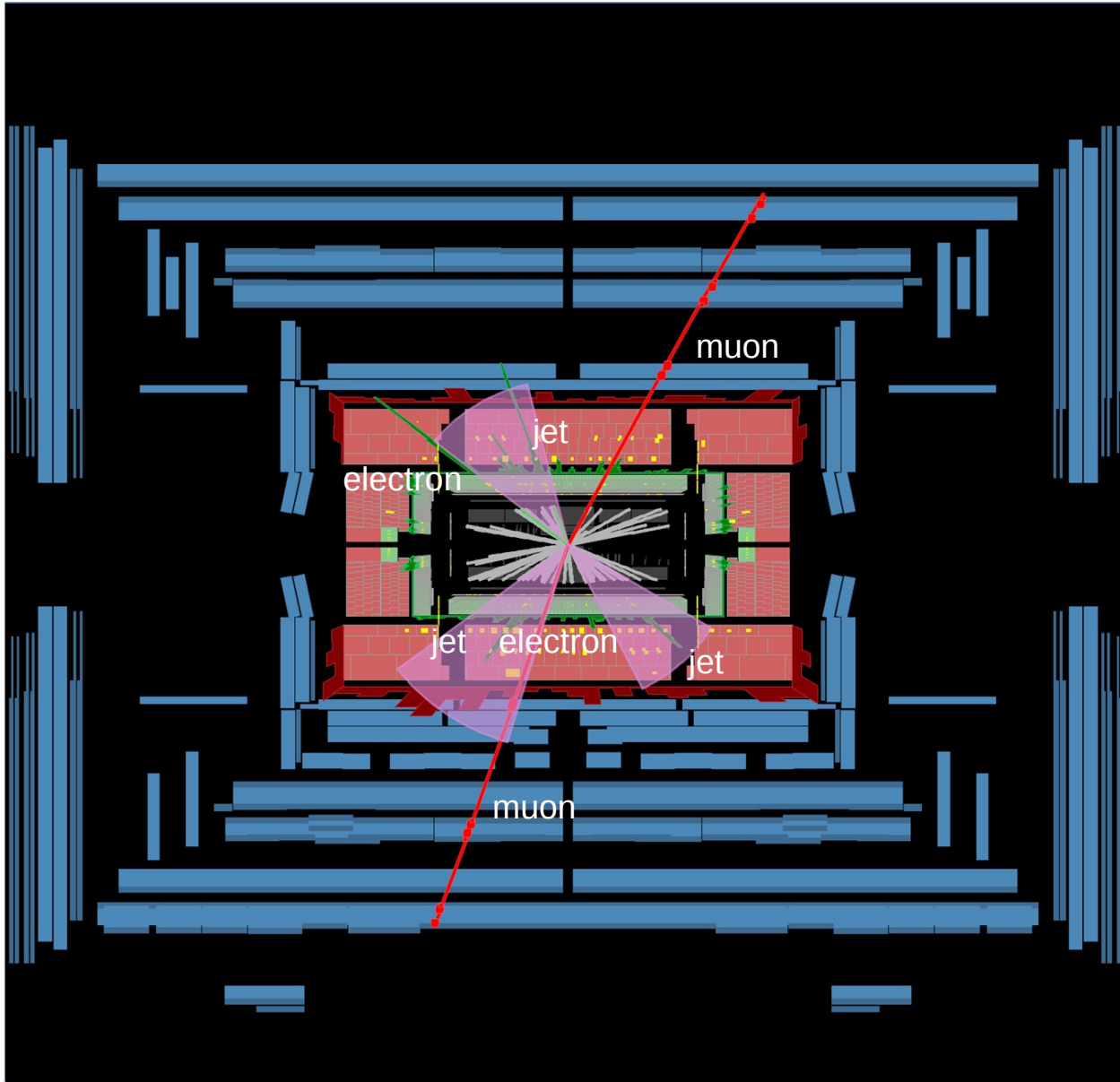


Two  $Z \rightarrow \mu\mu$  events superimposed.  
With high LHC luminosity starts to matter  
even for rare processes.

Final state	Number of observed events	Number of expected events
$e^+e^-e^+e^-$	2	2.1
$\mu^+\mu^-e^+e^-$	6	6.6
$\mu^+\mu^-\mu^+\mu^-$	5	5.4
Sum over all channels	13	14.1



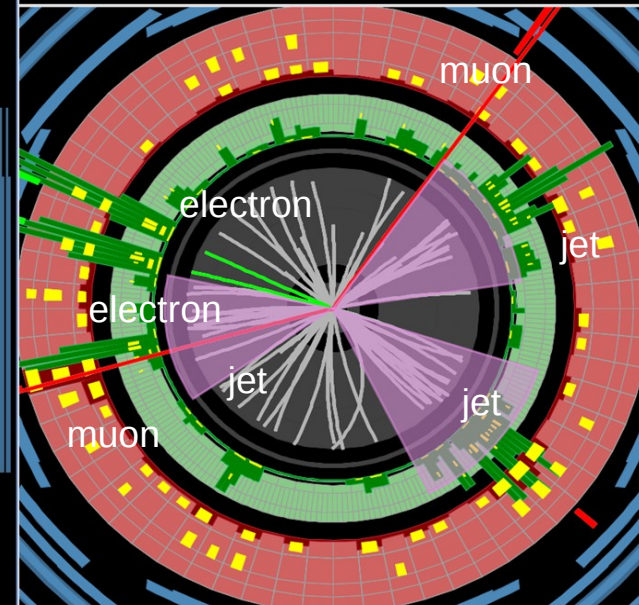
# Four lepton event



**ATLAS**  
EXPERIMENT

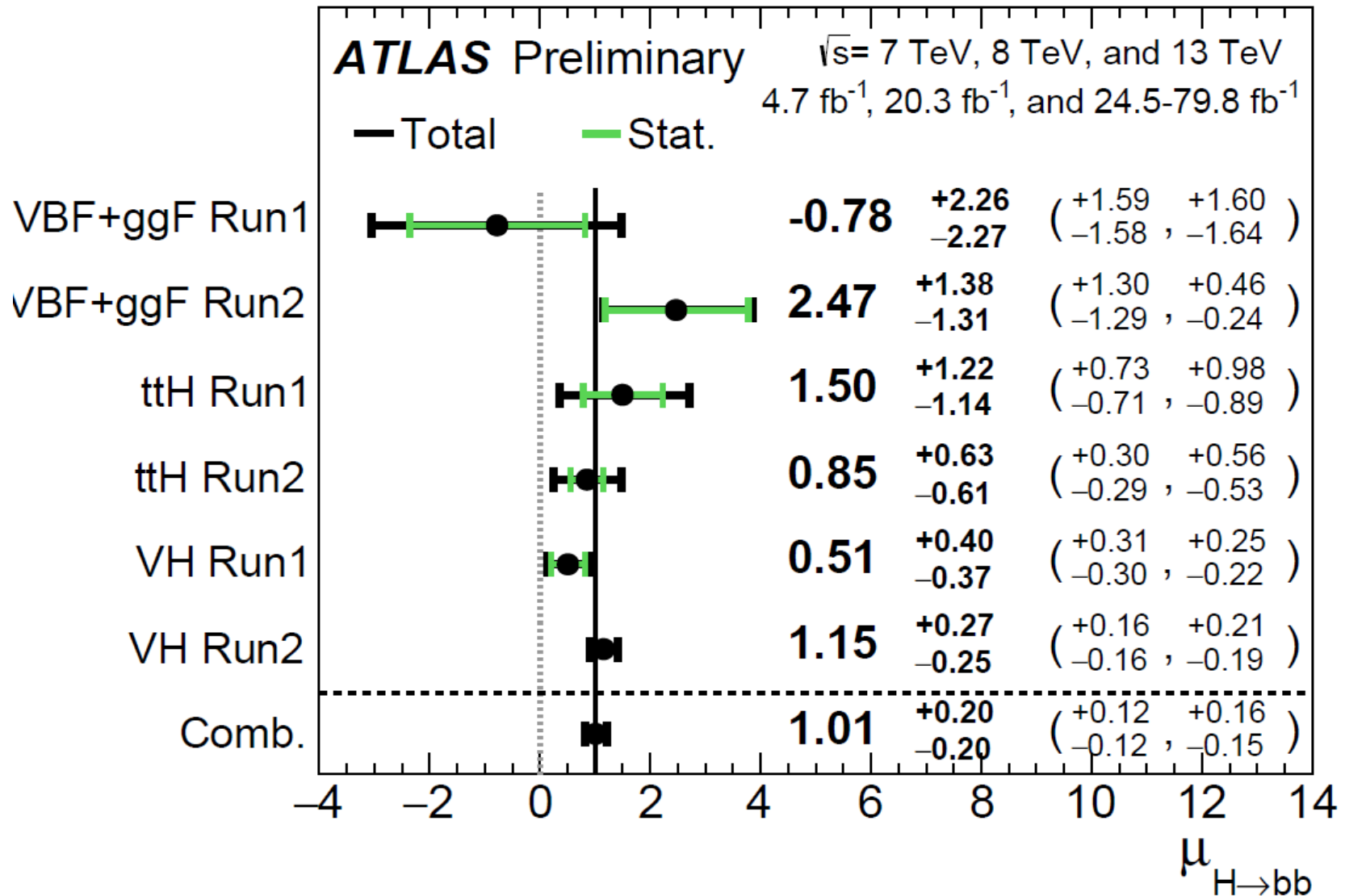
Run Number: 338498, Event Number: 480031171

Date: 2017-10-18 15:15:56 CEST





# Coupling fits in $H \rightarrow b\bar{b}$ analysis

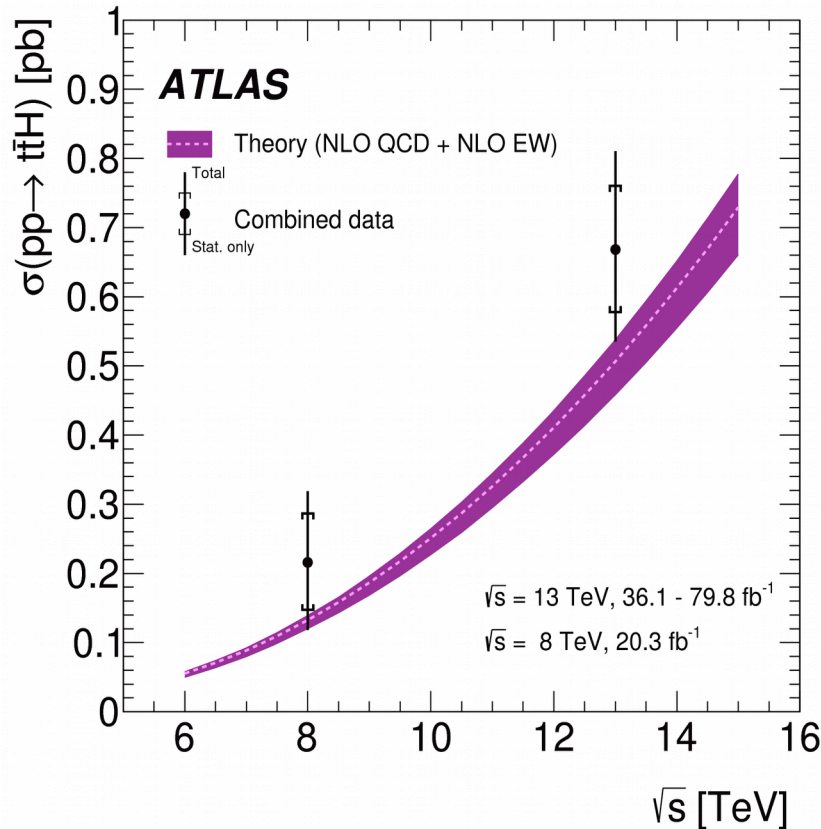


# ttH production cross-section

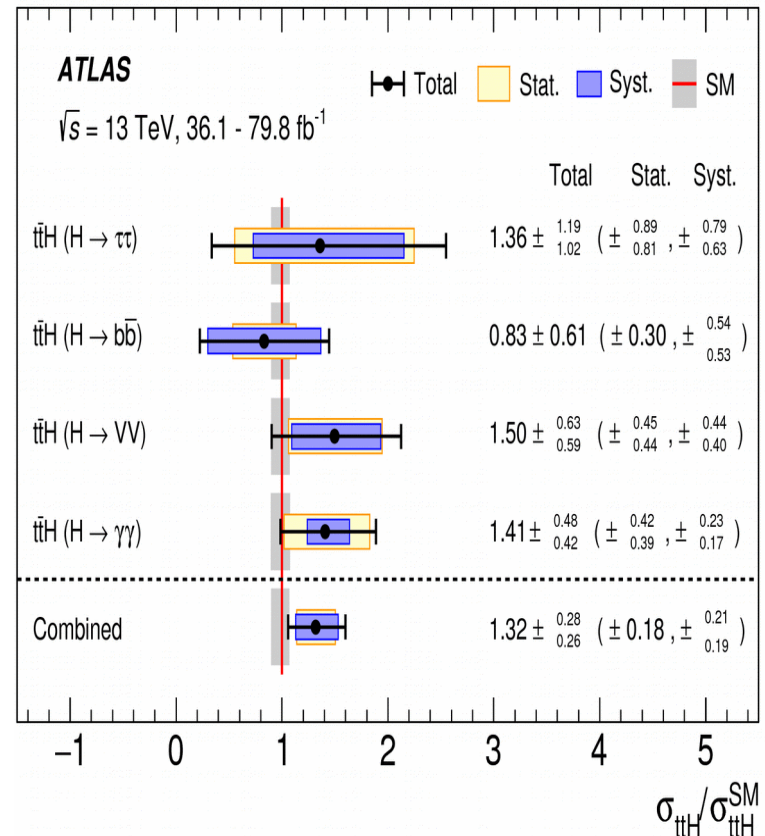
June 2018 update: ttH  $\rightarrow \gamma\gamma$  and tt(ZZ  $\rightarrow 4l$ ) with **80 fb<sup>-1</sup>**

arXiv:1806.00425

Inclusive ttH production cross-section



ttH cross-section per production modes



ttH cross-section

at 8 TeV:  $\sigma_{t\bar{t}H} = 220 \pm 100 (\text{stat}) \pm 70 (\text{syst})$

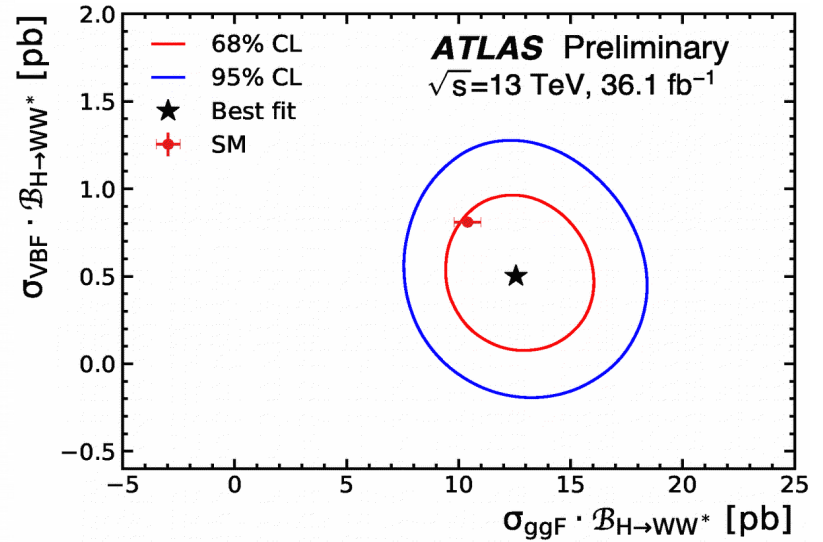
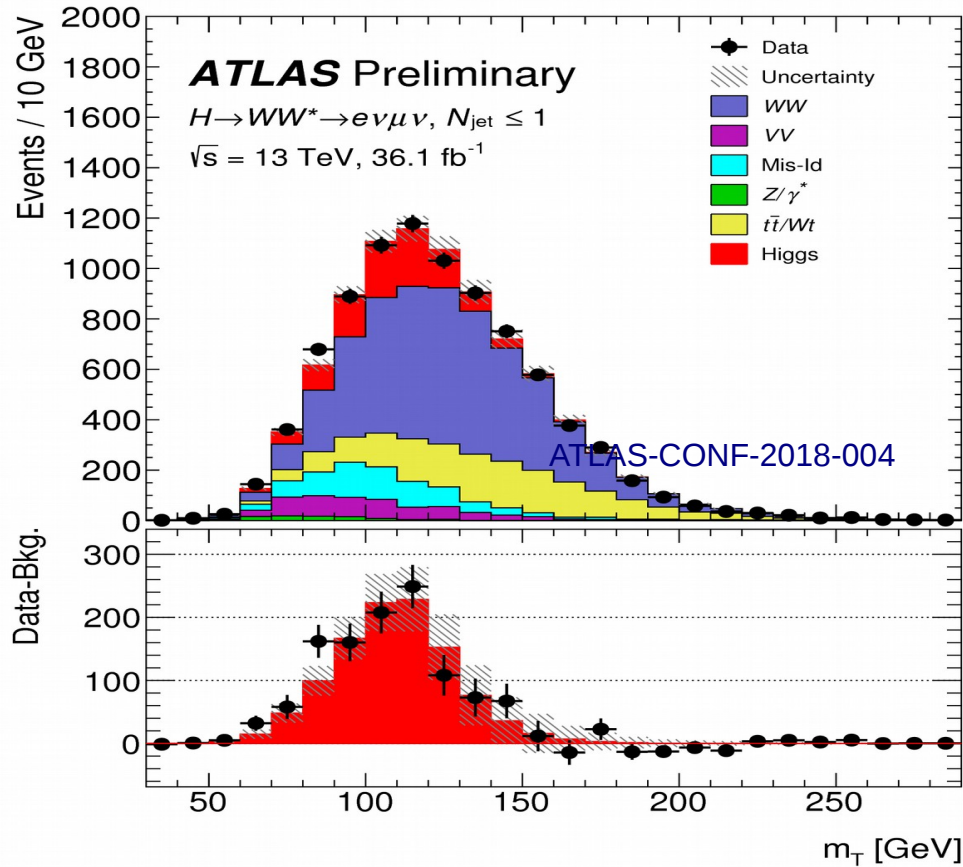
at 13 TeV:  $\sigma_{t\bar{t}H} = 670 \pm 90 (\text{stat}) \pm 105 (\text{syst})$

Already 20% precision !

# Coupling ratios in Kappa-framework

Parameter	Definition in terms of $\kappa$ modifiers	Result
$\kappa_{gZ}$	$\kappa_g \kappa_Z / \kappa_H$	$1.06 \pm 0.07$
$\lambda_{tg}$	$\kappa_t / \kappa_g$	$1.09^{+0.14}_{-0.14}$
$\lambda_{Zg}$	$\kappa_Z / \kappa_g$	$1.06^{+0.14}_{-0.13}$
$\lambda_{WZ}$	$\kappa_W / \kappa_Z$	$0.99^{+0.09}_{-0.08}$
$\lambda_{\gamma Z}$	$\kappa_\gamma / \kappa_Z$	$0.95^{+0.08}_{-0.07}$
$\lambda_{\tau Z}$	$\kappa_\tau / \kappa_Z$	$0.95 \pm 0.13$
$\lambda_{bZ}$	$\kappa_b / \kappa_Z$	$0.91^{+0.17}_{-0.16}$

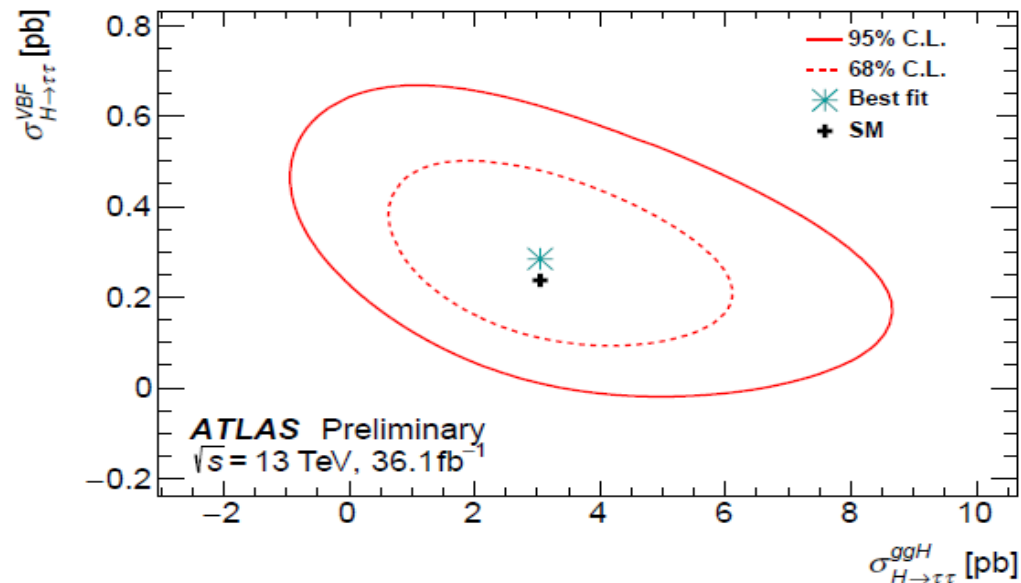
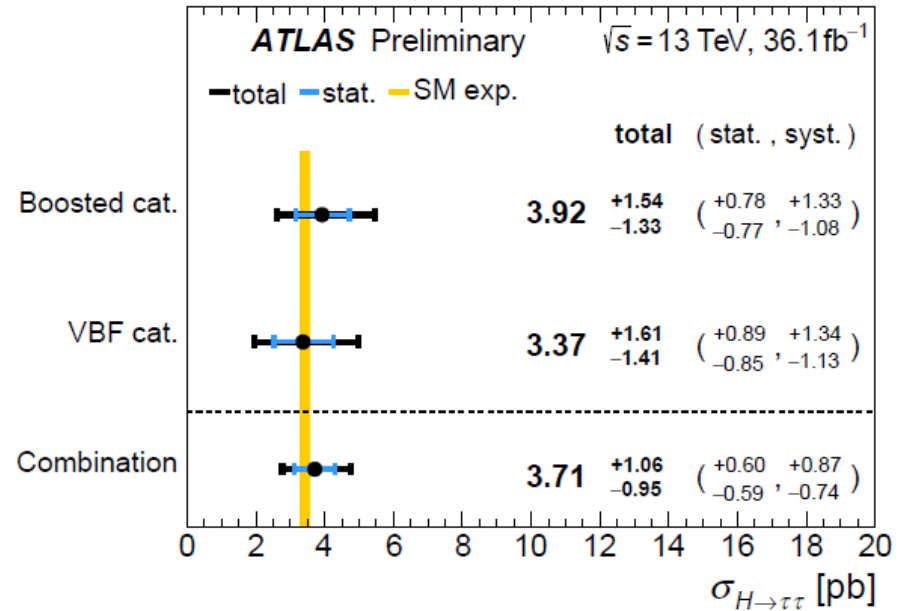
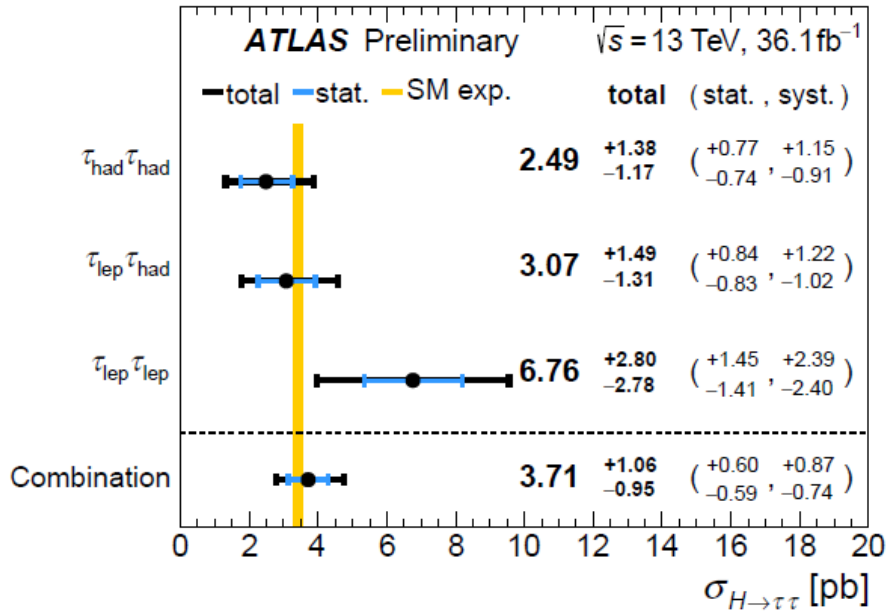
# $H \rightarrow WW$



$$\mu_{\text{ggF}} = 1.21^{+0.12}_{-0.11}(\text{stat.})^{+0.18}_{-0.17}(\text{sys.}) = 1.21^{+0.22}_{-0.21}$$

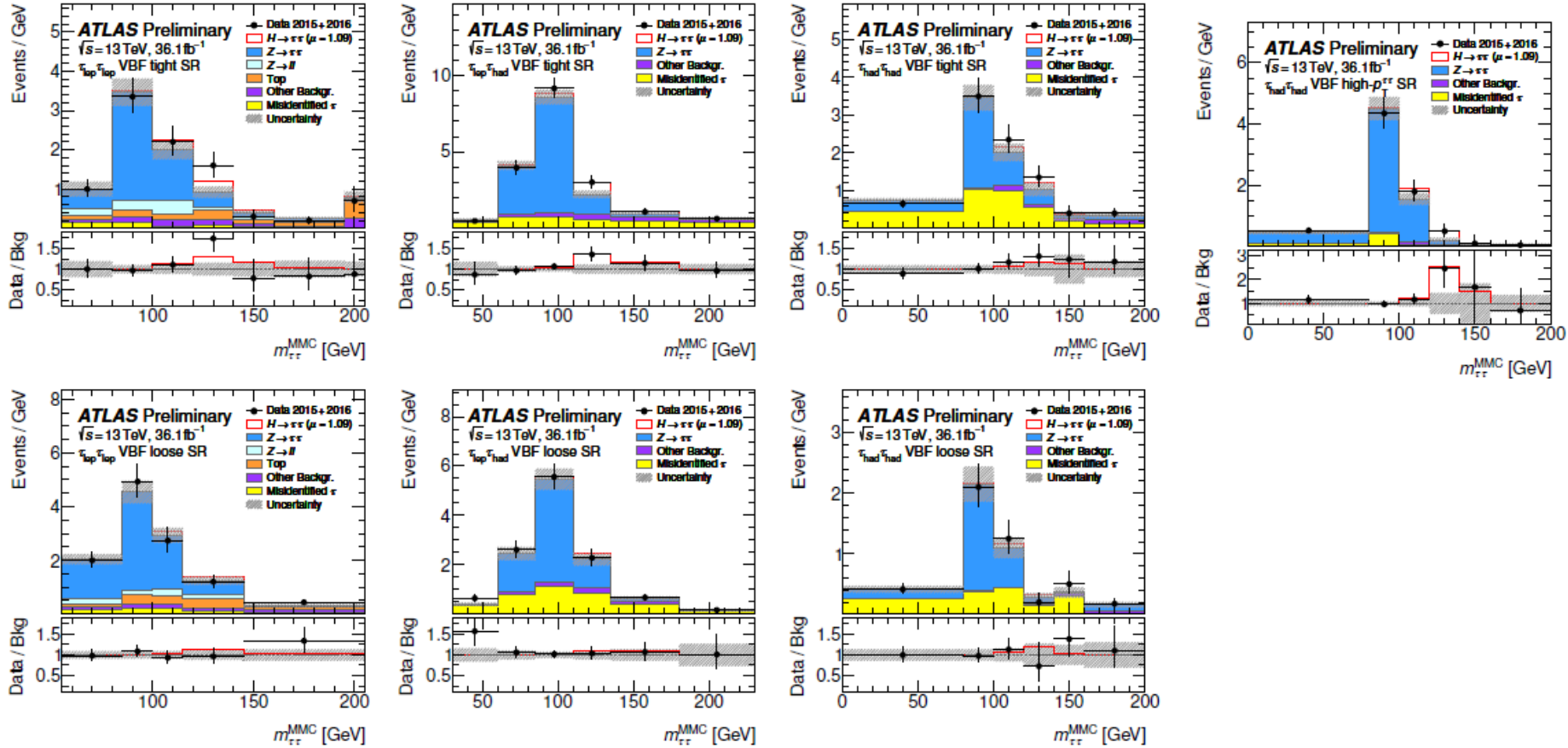
$$\mu_{\text{VBF}} = 0.62^{+0.30}_{-0.28}(\text{stat.}) \pm 0.22(\text{sys.}) = 0.62^{+0.37}_{-0.36}$$

# Cross-section measurement for $H \rightarrow \tau\tau$

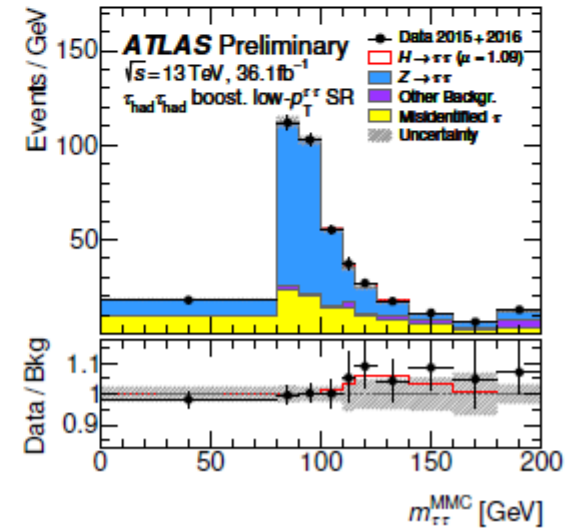
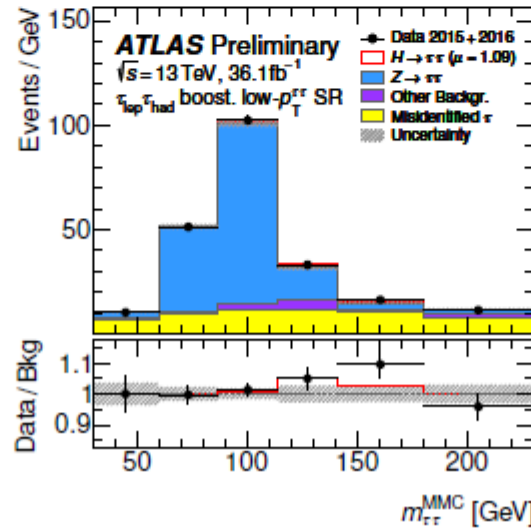
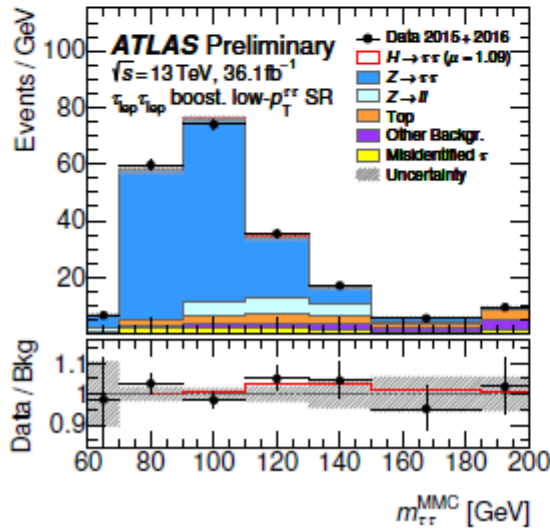
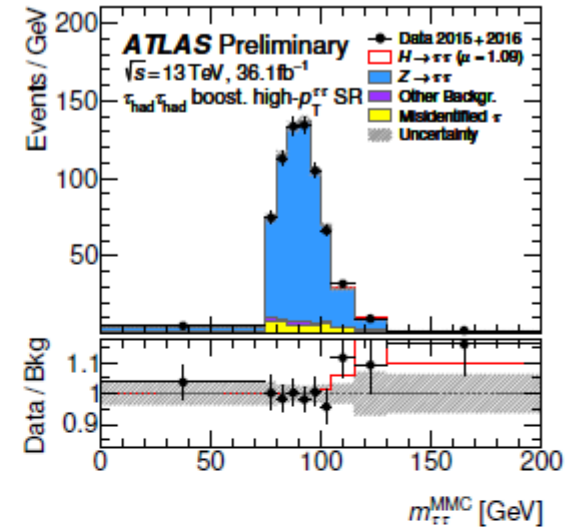
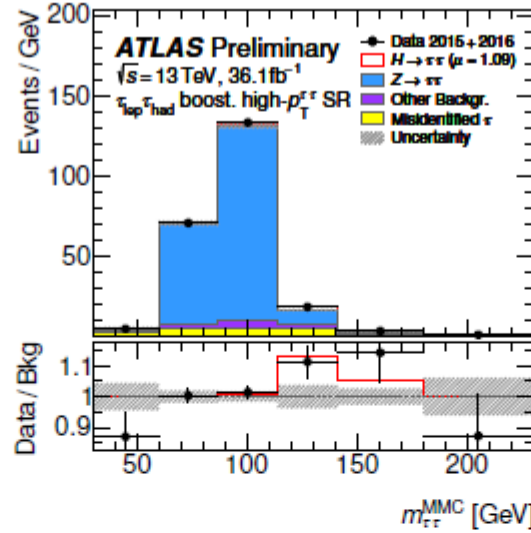
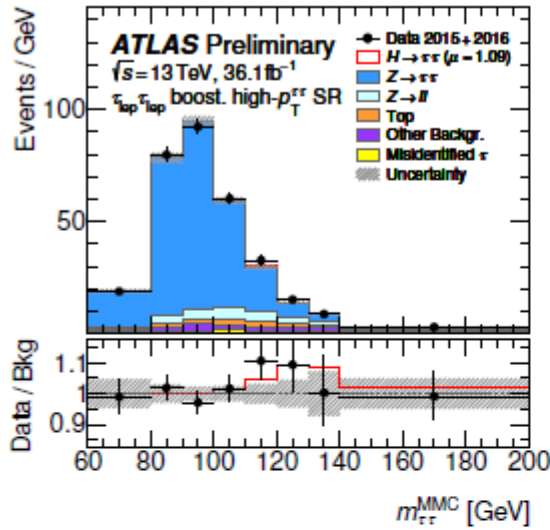




# Mass distributions in $H \rightarrow \tau\tau$ VBF categories



# Mass distributions in $H \rightarrow \tau\tau$ boosted categories



# Search summary

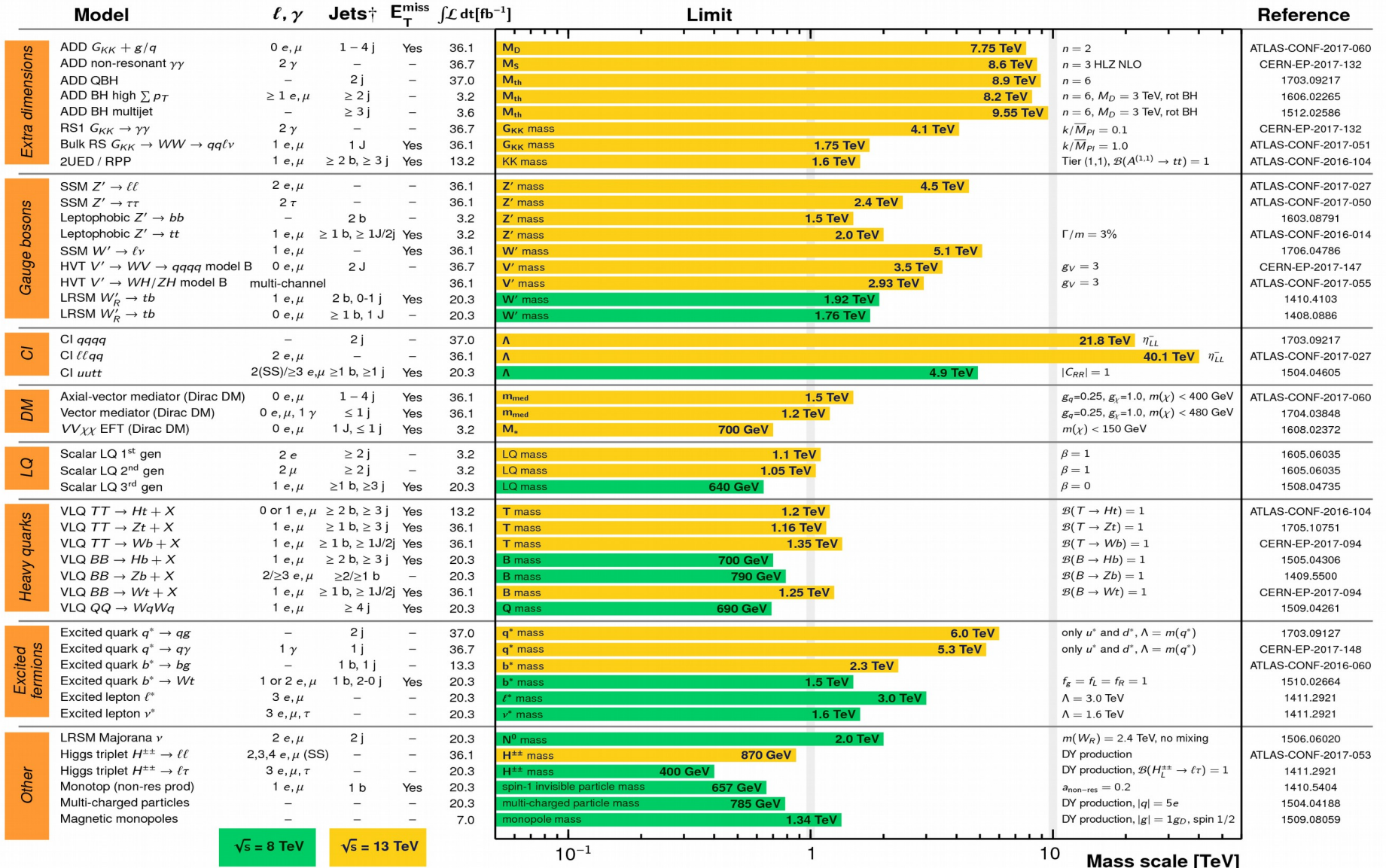
## ATLAS Exotics Searches\* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$$\int \mathcal{L} dt = (3.2 - 37.0) \text{ fb}^{-1}$$

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



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

<sup>†</sup>Small-radius (large-radius) jets are denoted by the letter j (J).

# Vector-like Quark summary

