Recent Searches for *New Resonances* and *Contact Interactions* with **ATLAS**

CERN LHC Seminar

April 25th, 2017

Arely Cortes-Gonzalez
(CERN)
On behalf of the **ATLAS Collaboration**

Recent Searches for *New Resonances* and *Contact Interactions* with **ATLAS**

2015 and 2016 dataset!

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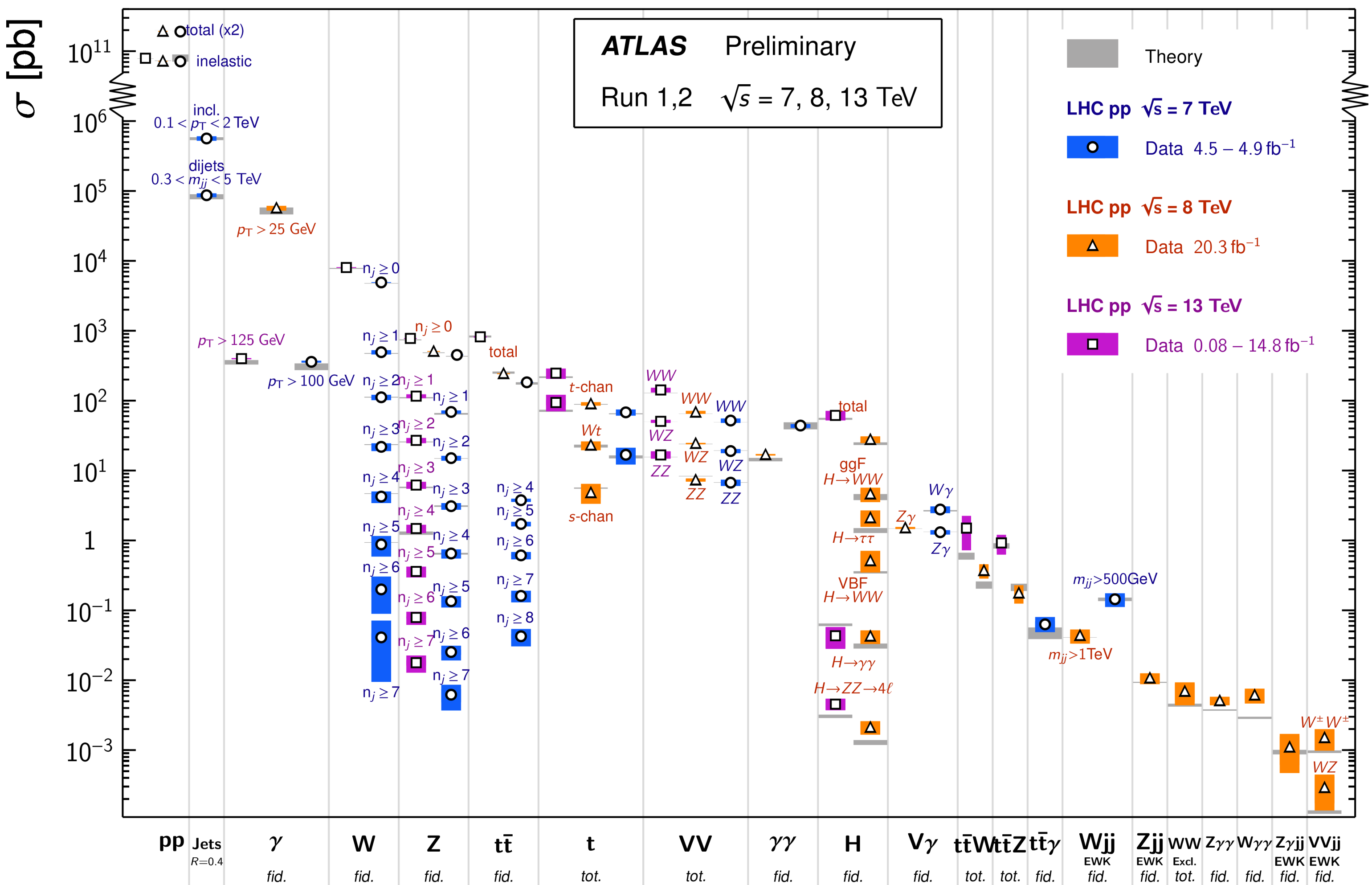
Standard Model

Very **successful** theory.

- **Precise measurements** in great agreement with predictions.

Standard Model Production Cross Section Measurements *Status: March 2017*

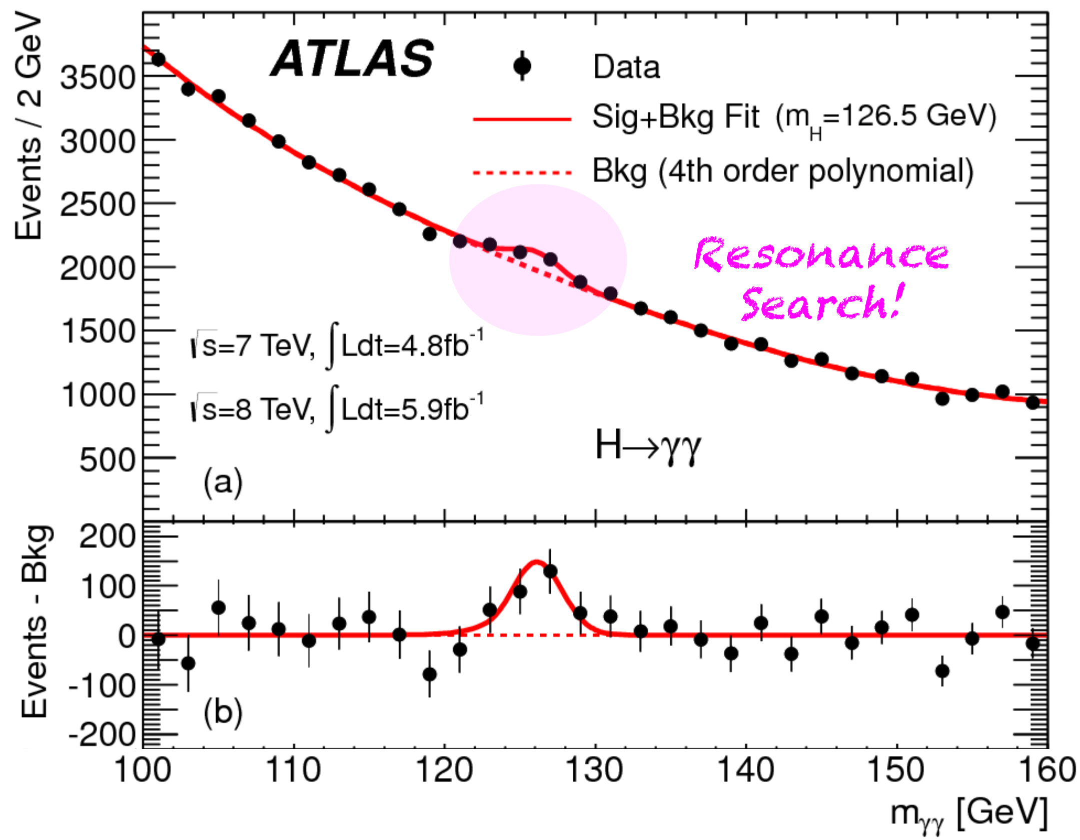


Standard Model

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

The **Higgs discovery** further validated the SM (*self-consistent* theory).

Run I *legacy*: Higgs discovery
The discovery of a new particle also opened a new channel for searches.



Still left with many open questions....

e.g. High-levels of **fine tuning** needed to avoid divergences in Higgs mass corrections.

Why **BSM**?

SM is a self-consistent theory, with predictions in agreement with measurements, but...

- **Hierarchy** problem (of mass scales).

  Large discrepancy between weak force and gravity: $m_{EW}/m_{Plank} \sim 10^{-16}$.

- **Fine tuning** needed to avoid divergences in Higgs mass corrections.
- No **Dark matter** candidate.
- Baryon **asymmetry**.
- **Neutrino** masses.

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How to solve these?

* **SUSY.**
* **Extra Dimensions.**
* **Compositeness.**
* **Sequential Standard Model.**
* **Hidden Sectors.**
* **Top partners,**
* **… New TeV scale interactions/ particles!**

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- **Excited** states of leptons and quarks (**q** *) can be predicted from **composite models**.

  Explains generational structure and mass hierarchy of quarks.

- **Composite Higgs**

  Heavy Vector triplet model (**HVT**), with new $W'^{\pm}$, Z' states.
  - Model A: *Extended gauge symmetry*.
  - Model B: *Minimal composite Higgs model*.

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Several extensions of the SM with extended gauge symmetries.

- **Sequential Standard Model**.

  SM + new spin-1 heavy gauge bosons with similar couplings as SM $W^{\pm}$ and Z.

New bosons at the TeV scale.

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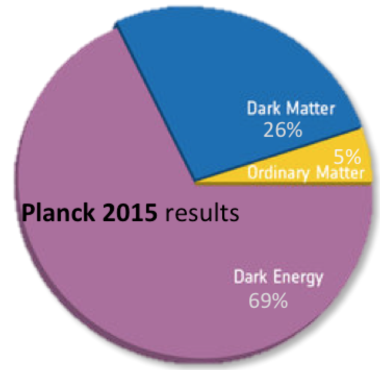
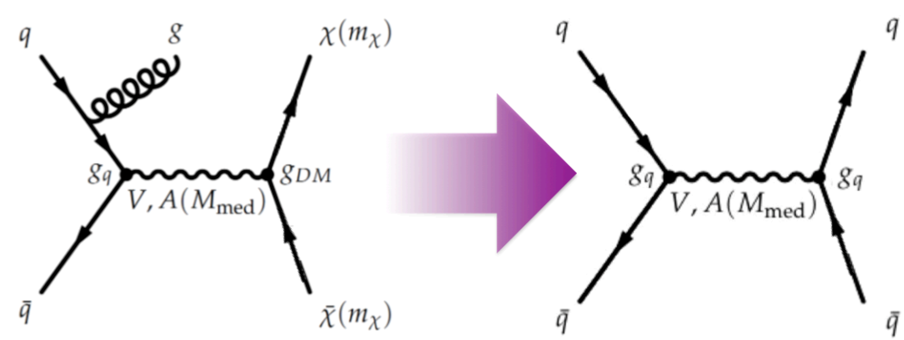
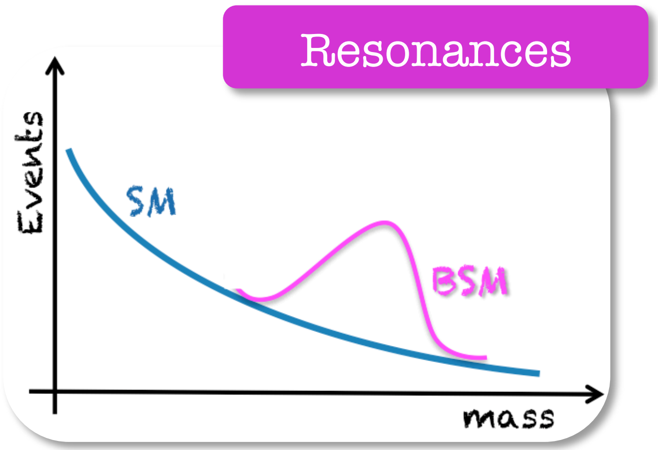
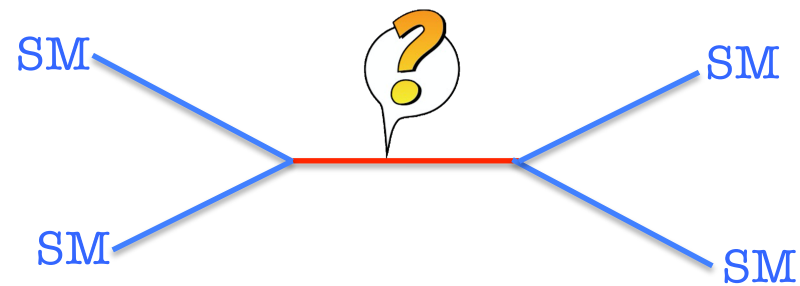


***Resonance searches** can also be interpreted in terms of **DM models**.*





We look for observations of new resonances in the ***tails of the SM distributions***. These resonances could decay into e.g. vector bosons or fermions.

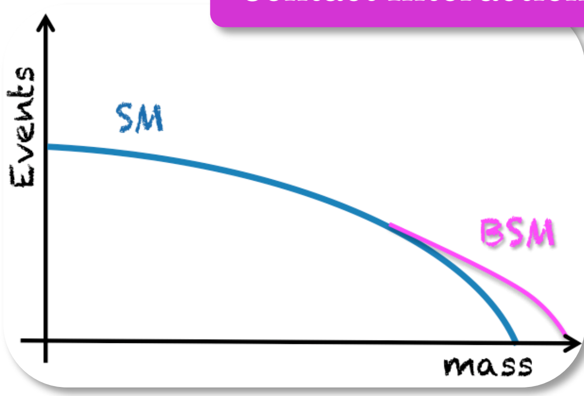


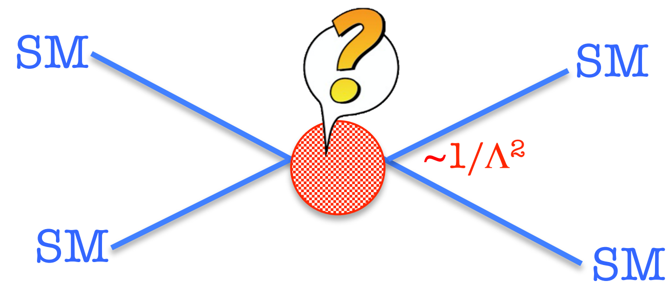
SM background can be modeled in a data driven fashion.
Different searches sensitive to **narrow** resonances (*wide variety of **signatures** to be explored!*).

- Fully hadronic
  - di-jet, V(qq)+H(qq)
- With leptons
  - dileptons, lepton + E_T^{miss}
- with Photons
  - photon + E_T^{miss}

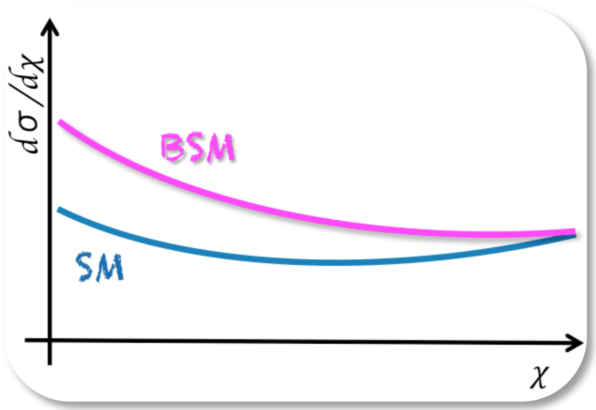
We look for modifications in angular and mass distributions arising from **new contact interaction (CI) scales**.

Contact Interactions



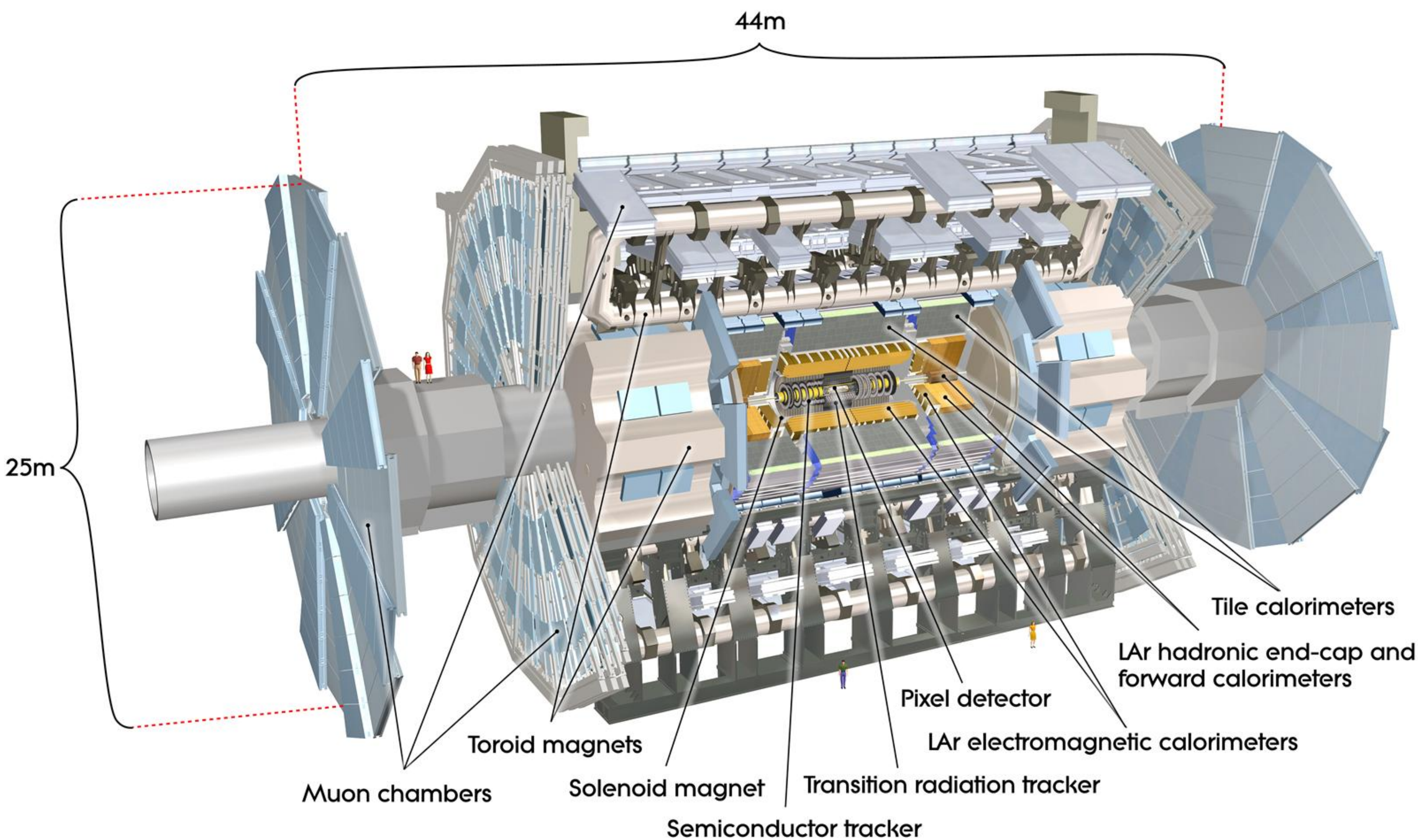


New **mediating particle** with a mass much higher than the energy exchange modeled as contact interaction with new physics at **energy scale Λ**.



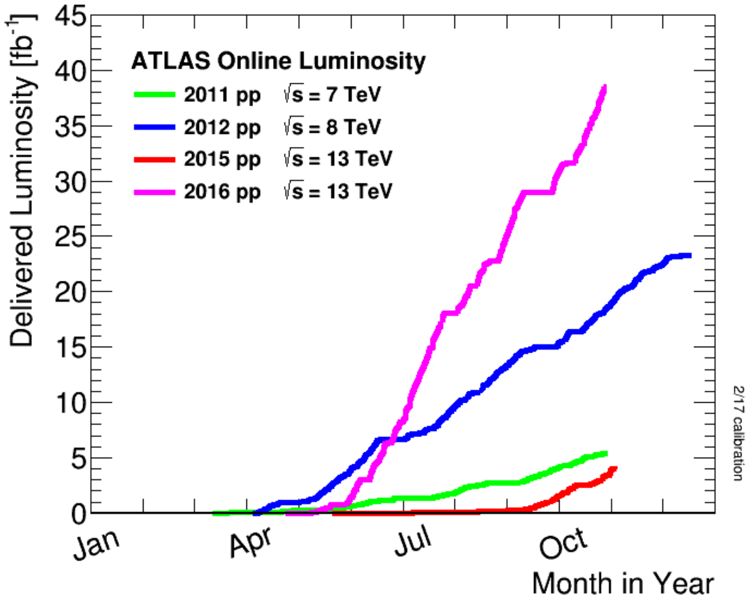
- Dileptons
  - Broad excess in invariant mass distributions.
- Dijets
  - CI is often more isotropic than QCD → use angular information.

ATLAS Detector

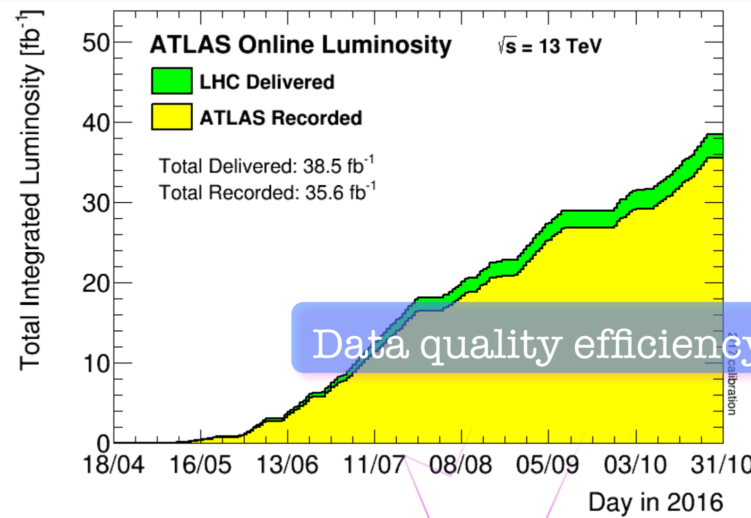


ATLAS Data

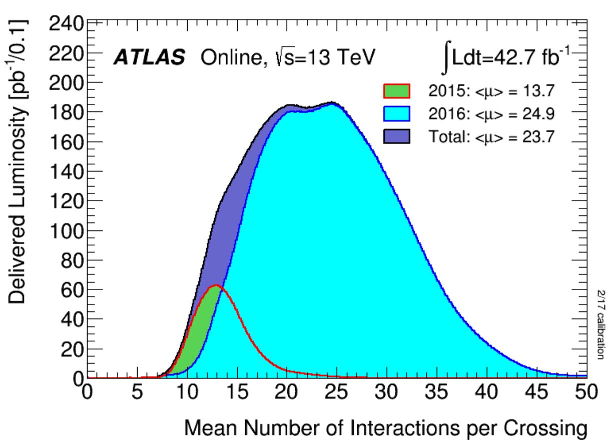
Excellent **performance by the LHC** and high **data taking efficiency** by detectors in the **13 TeV pp** collisions period (2015, 2016).

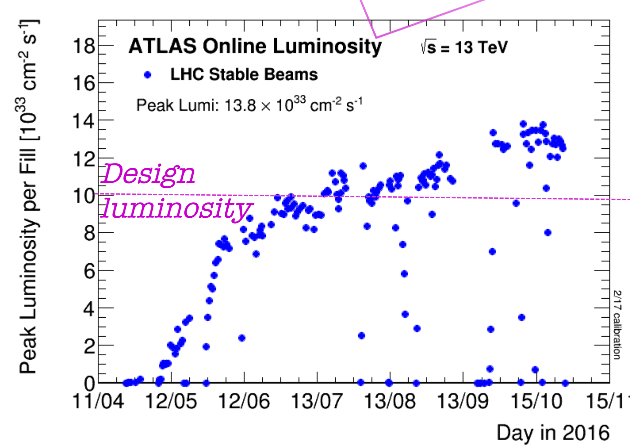


~40 fb^{-1} @ 13 TeV recorded in 2015 and 2016



Data quality efficiency 93-95%

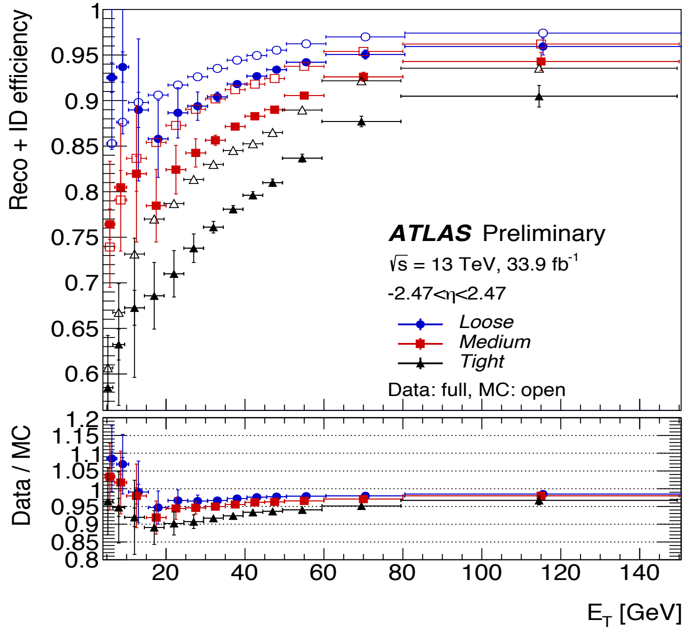


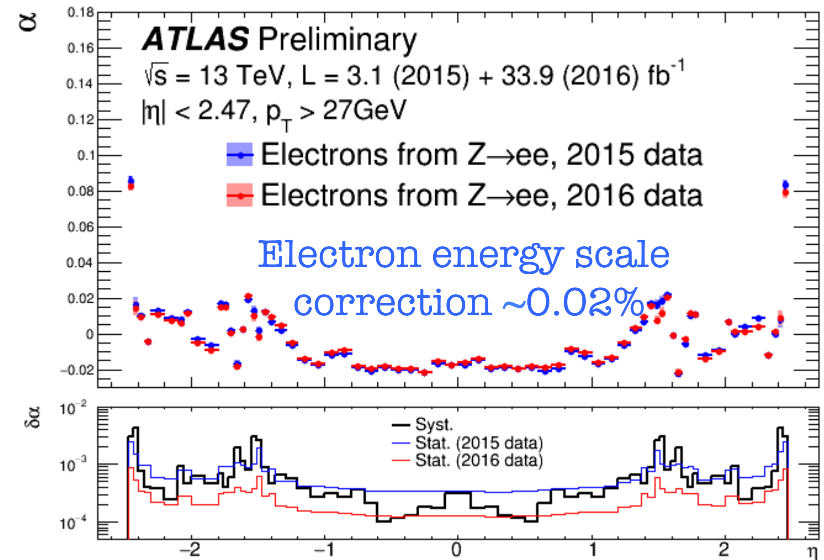


ATLAS-CONF-2016-024
Eur. Phys. J. C. (2016) 76:292

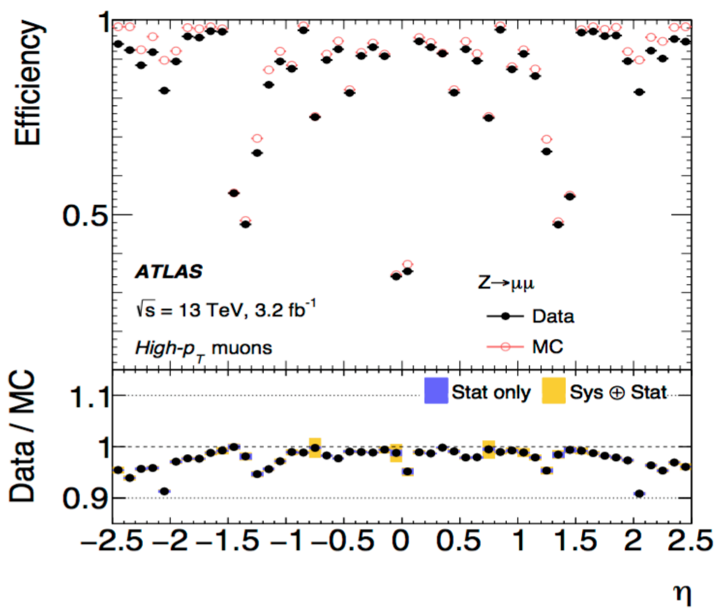
Performance: Leptons

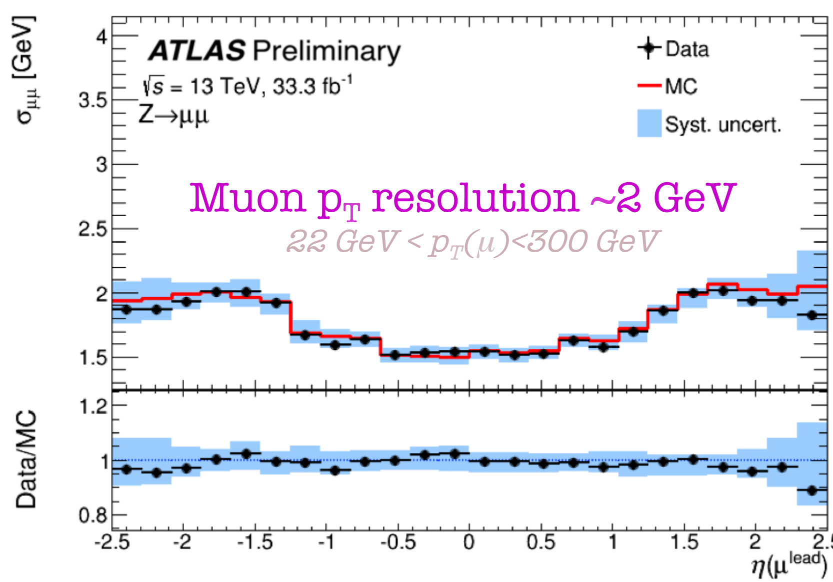
Electrons





Muons

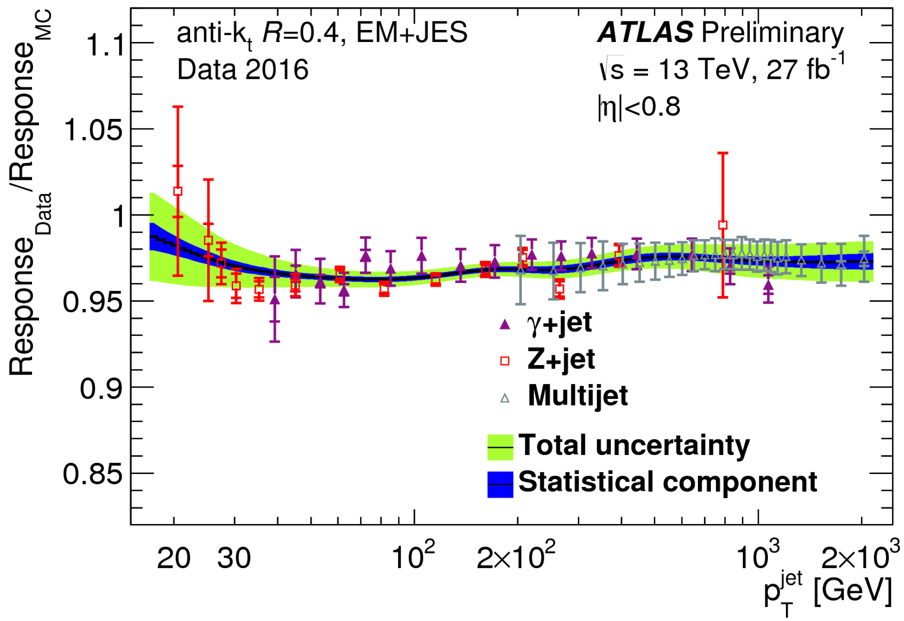


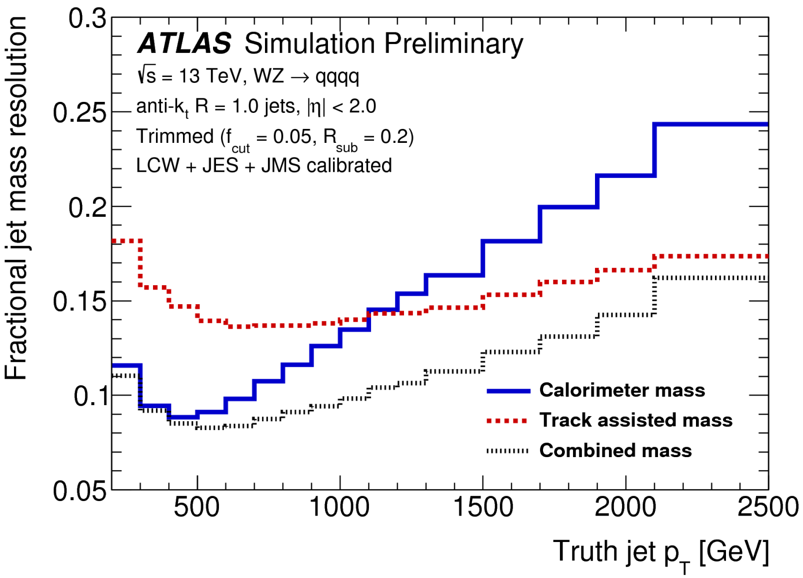


Performance: Jets

Jets

Analyses rely on a good understanding of **jet calibration** up to multi-TeV scale.



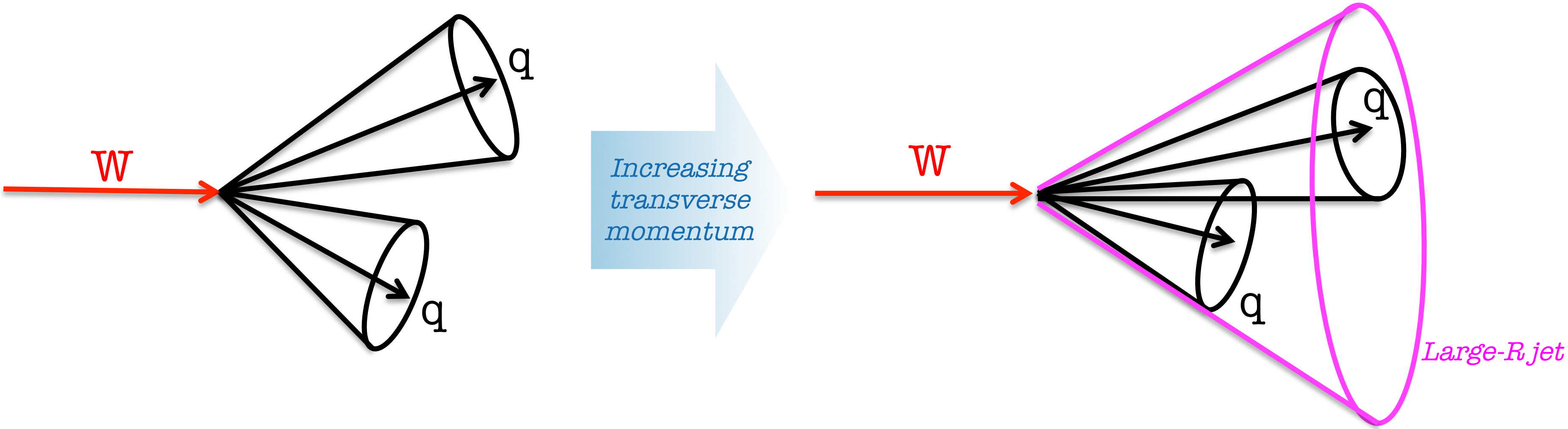


Jet mass improvements

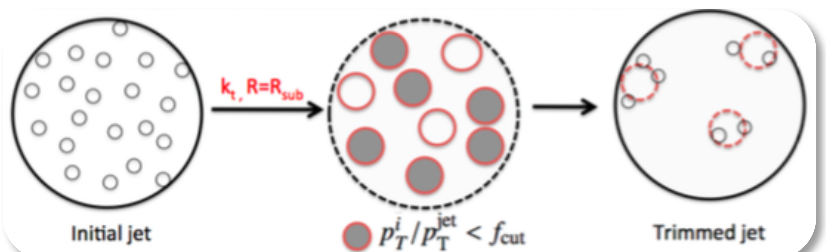
Optimizes **large-R jet mass** computed using combination of calorimeter and tracking information

$$m_J \equiv w_{\text{calo}} \times m_{\text{J}}^{\text{calo}} + w_{\text{track}} \times \left(m_{\text{J}}^{\text{track}} \frac{p_{\text{T}}^{\text{calo}}}{p_{\text{T}}^{\text{track}}} \right)$$

Performance: *Boson Tagging*



Energy depositions in calorimeter used to form topological clusters: reconstruct **large R-jets**: **Anti-k_t, R=1.0 jets**.



Re-cluster with R_{sub} = 0.2.
Remove sub-jets with f_{cut} < 0.05.

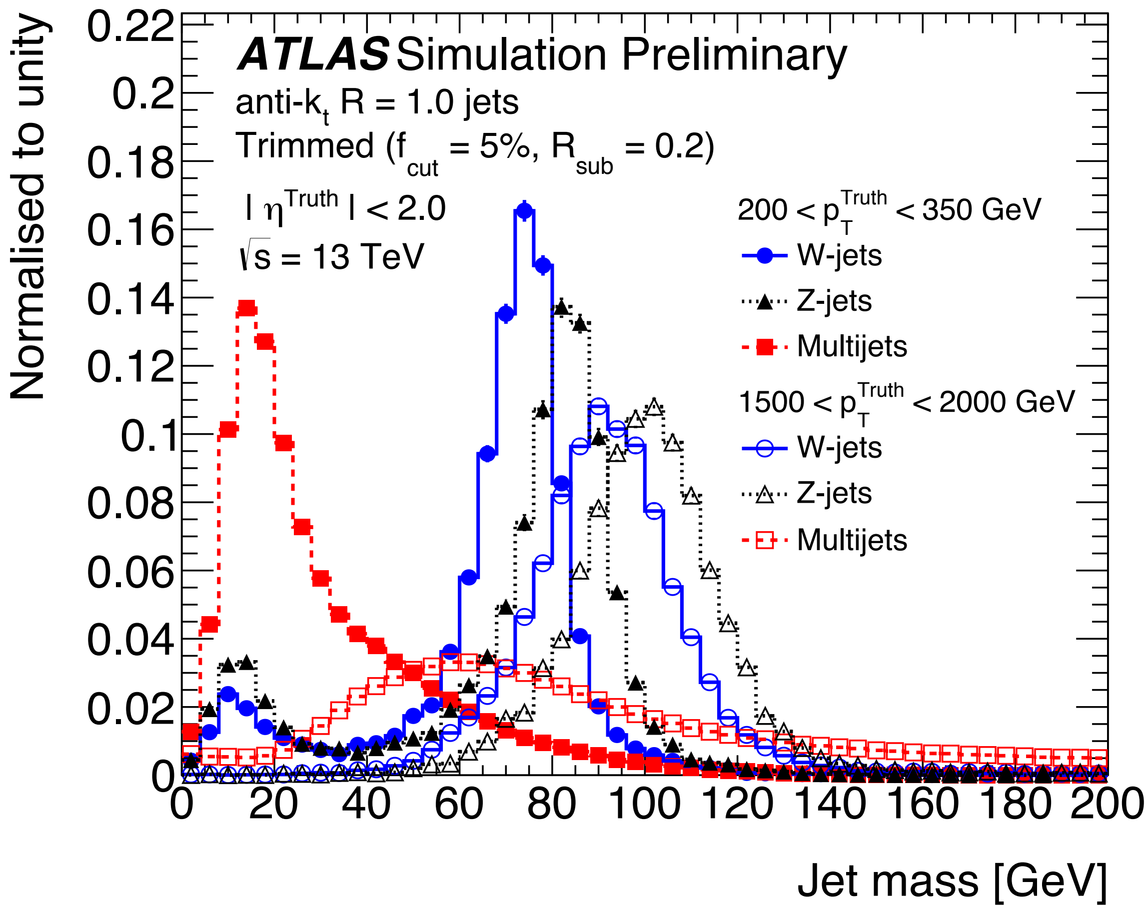
Trimming

Remove softer components (mainly from UE and pileup).

Improved *mass resolution*.

Performance: *Boson Tagging*

Discriminating against background: boson tagging.
Use differences in the jet characteristics between signal and background jets.



Jet mass is consistent with m_W or m_Z.

Mass windows for W/Z bosons are p_T-dependent.

Performance: *Boson Tagging*

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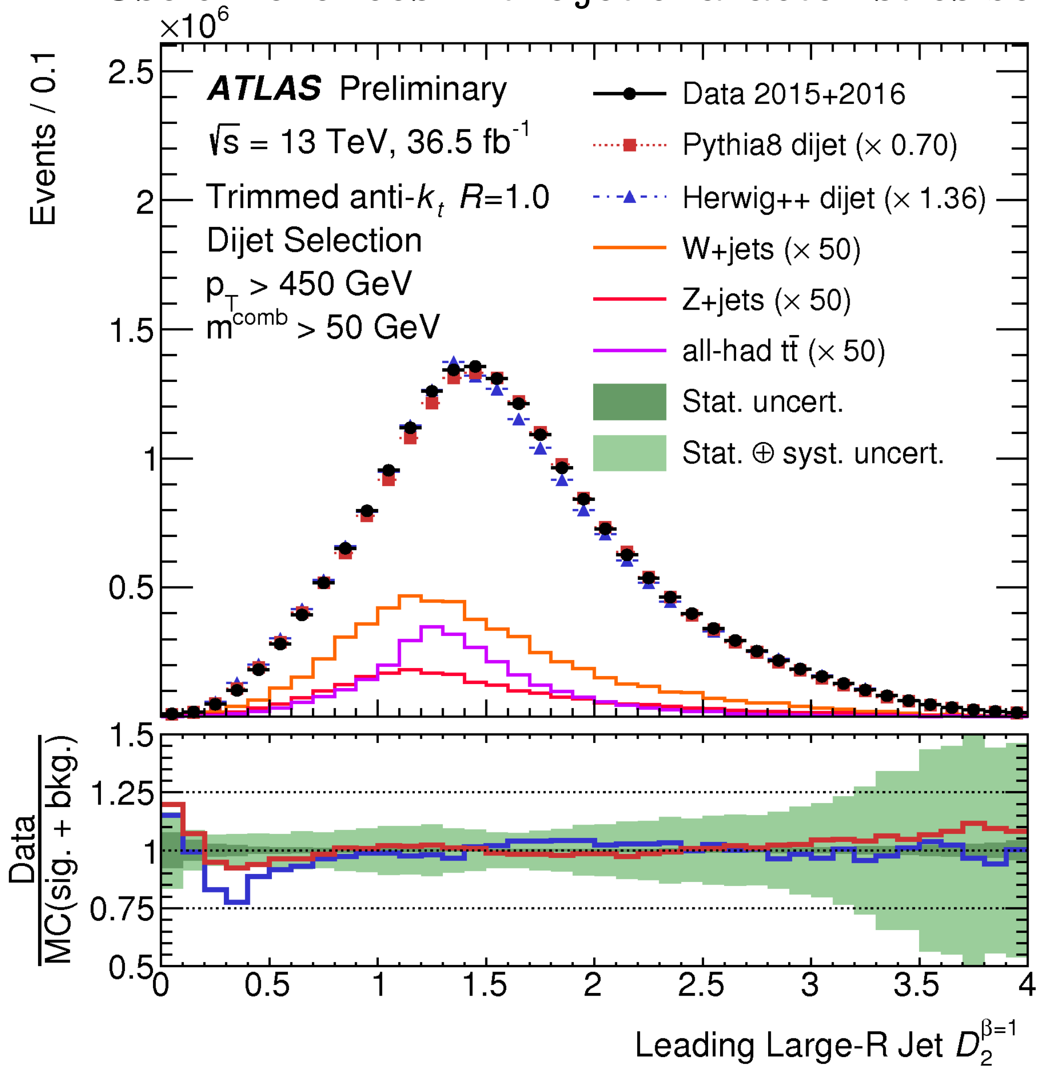
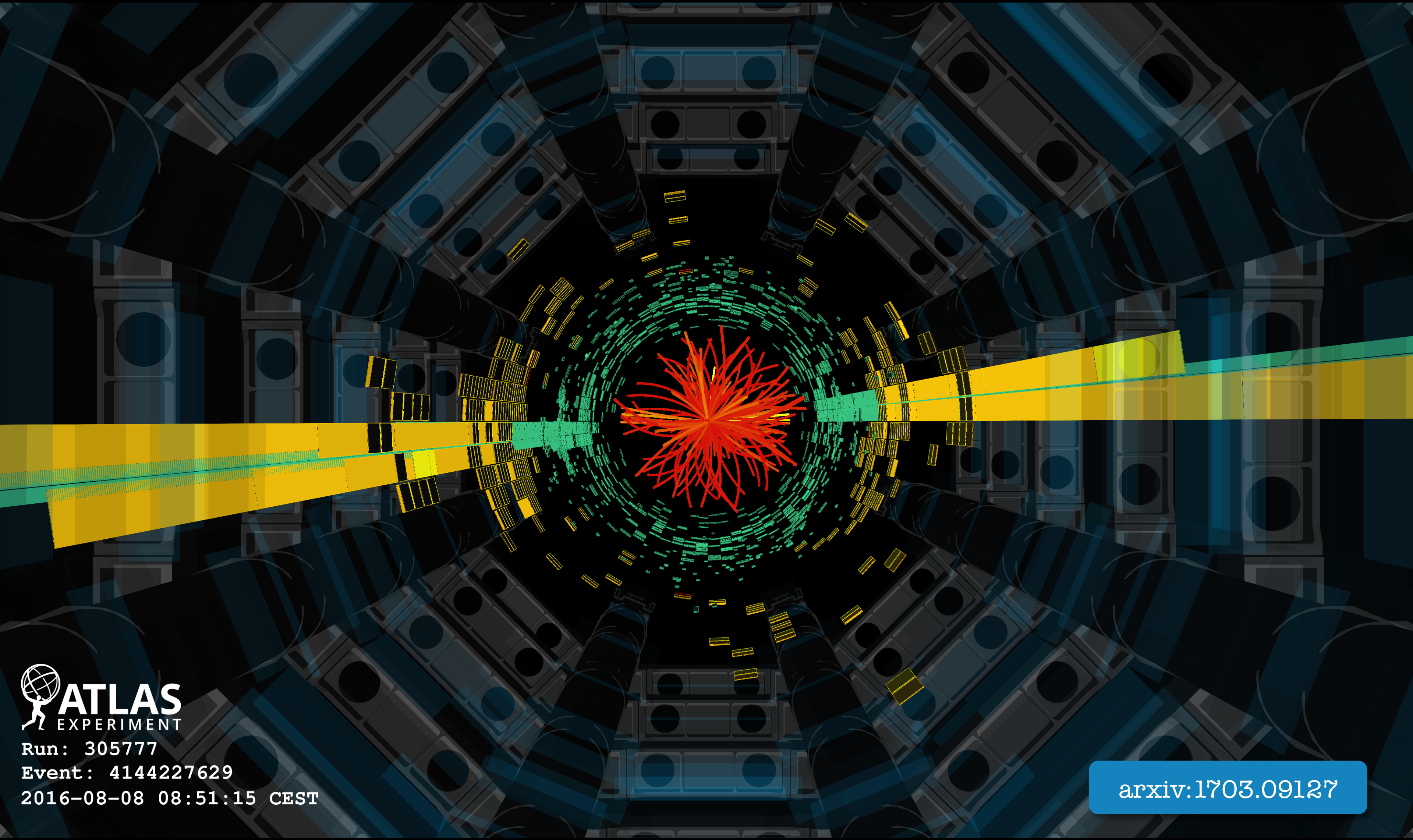


Substructure variable $D_2^{\beta=1}$ consistent with two prong decays.

$D_2^{\beta=1}$ exploits energy correlations functions to tag boosted objects with two-prong structures.

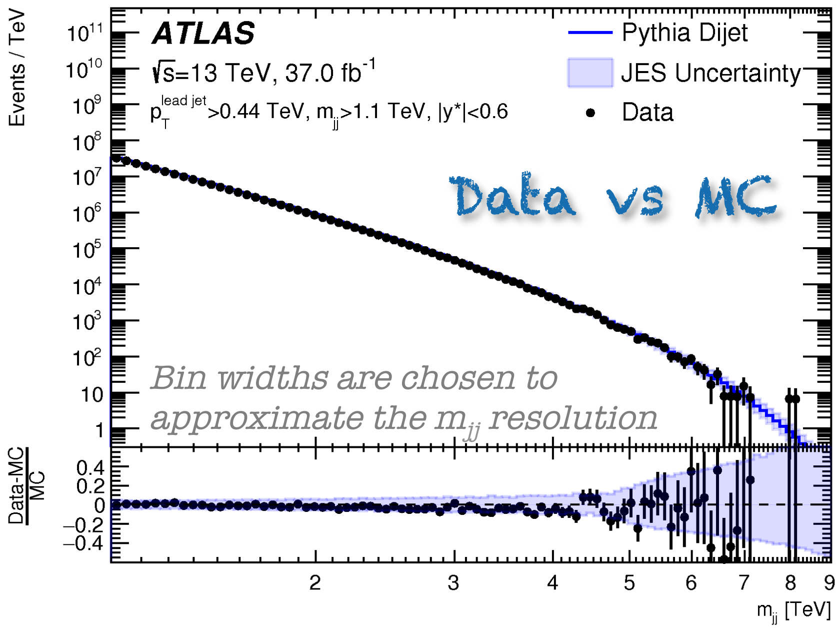
Constant ~50% efficiency in V-jet p_T. for ~2% fake rate.

High Mass **Di-Jet** Search



Highest-mass dijet event: m_{jj} *= 8.12 TeV,* $|y^*|$*=0.38*

High Mass **Di-Jet** Search



Selection

Events selected with lowest un-prescaled single jet trigger (p_T> 380 GeV).

	$p_T^{leading}$	$p_T^{subleading}$	$\lvert y^*\rvert$	$\lvert y_B\rvert$	m_{jj}
Resonance	> 0.44 TeV	> 0.06 TeV	< 0.6	-	> 1.1 TeV
W^*	> 0.44 TeV	> 0.06 TeV	< 1.2	-	> 1.7 TeV
Angular	> 0.44 TeV	> 0.06 TeV	< 1.7	< 1.1	> 2.5 TeV

$|y^*| = |y_1 - y_2|/2$ *Rejects forward peaking t-channel QCD processes.*

Strategy: **Resonance**

$$f(z) = p_1(1-z)^{p_2} z^{p_3} z^{p_4 \log z}$$

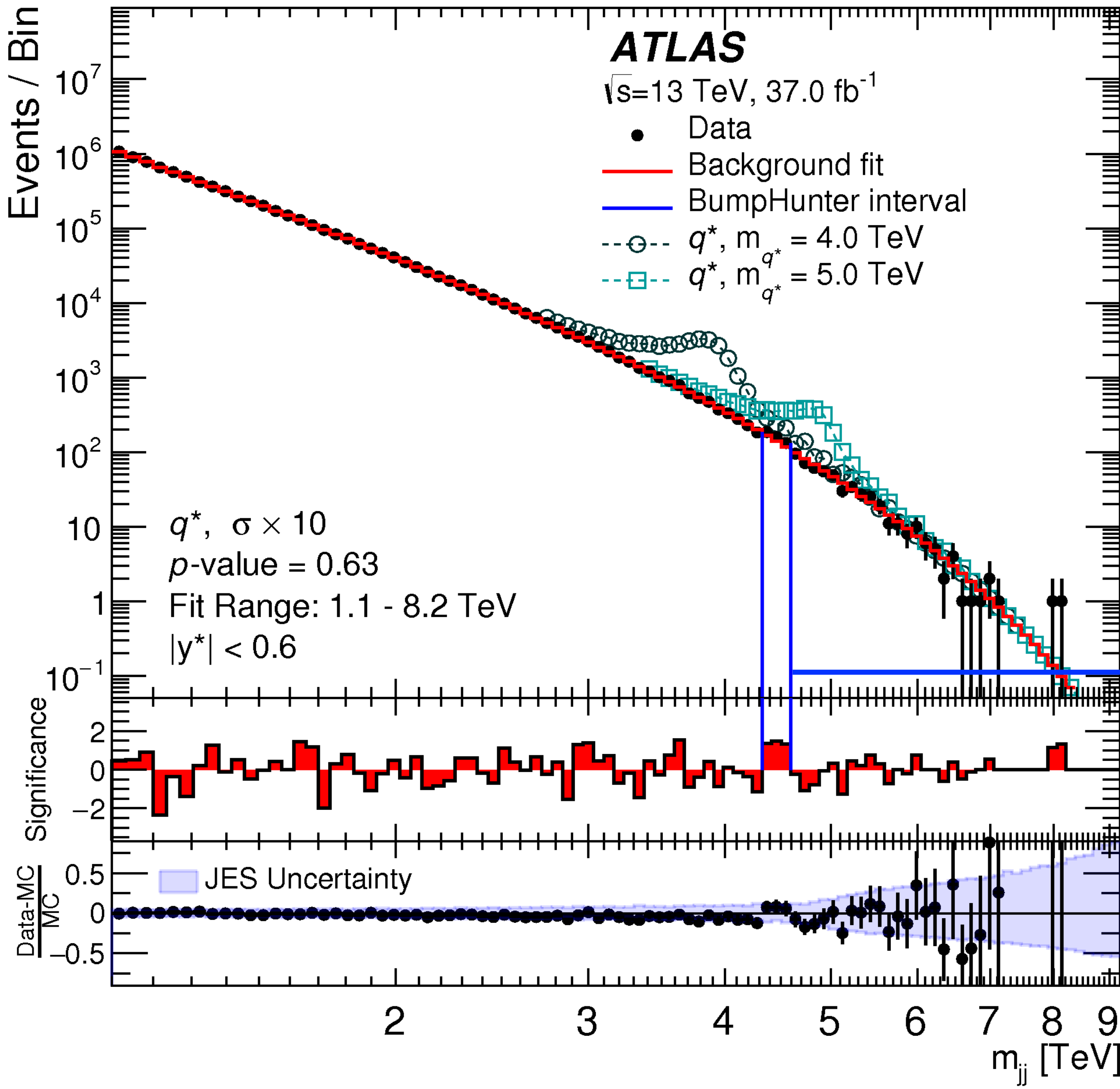
With increasing luminosity and corresponding m_{jj} range extension, a single global fit may not necessarily work.

Sliding Window Fit NEW

- Perform the f(z) fit in restricted (sliding) ranges (***more flexible***!).
- The limited range allows to use a 3-parameter function.
- Excellent linearity between injected and extracted signal.

arxiv:1703.09127

High Mass **Di-Jet** Search



Resonance Search

○ **BumpHunter** algorithm compares the binned m_{jj} of data to the fitted bkg estimate.

○ Global significance is computed with pseudo-experiments.

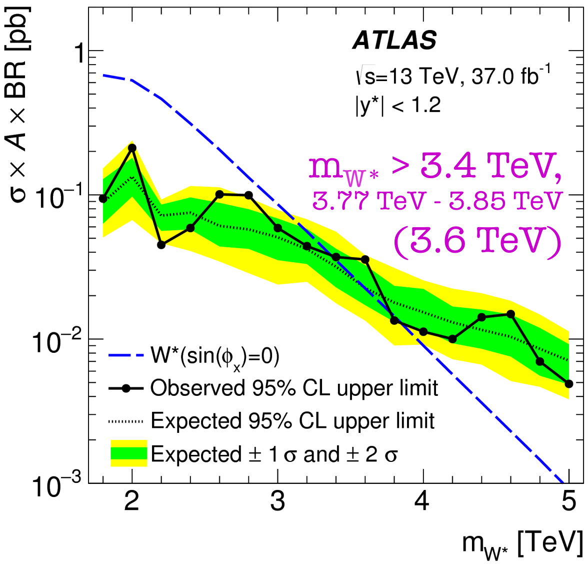
Most discrepant region:
(global p=0.63) 4326–4595 GeV

No evidence of a localized contribution from **BSM** observed.

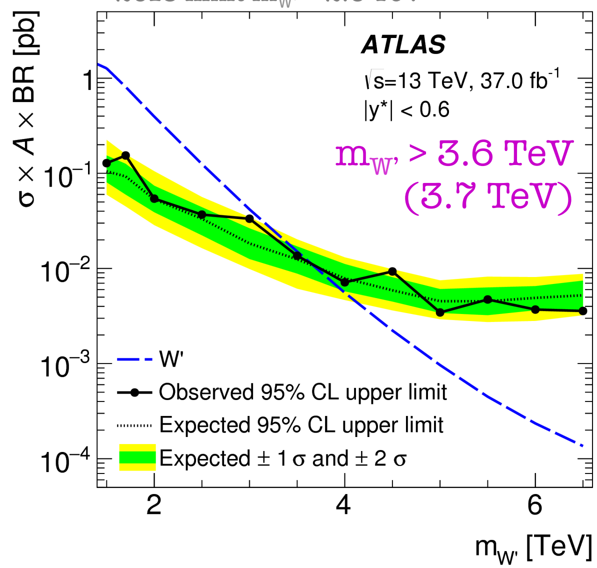
arxiv:1703.09127

High Mass **Di-Jet** Search

Resonance Limits



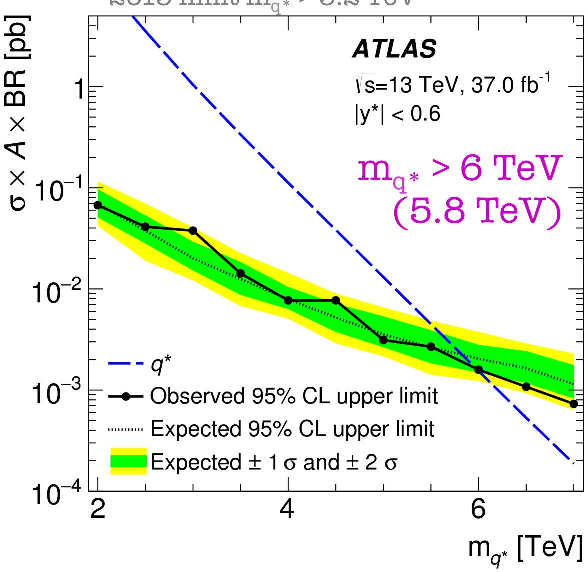
2015 limit $m_{W'}$ > 2.6 TeV

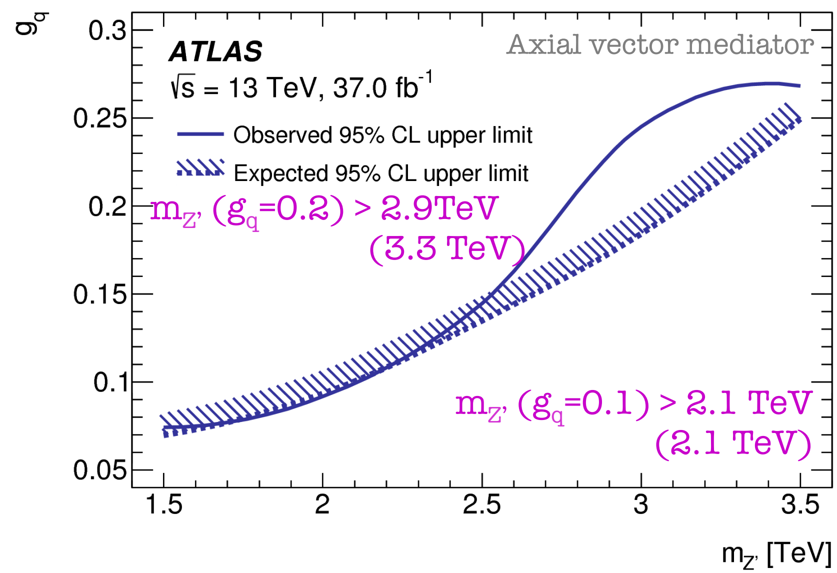


95% CL upper observed (expected) limits on the cross section times acceptance for different signal models.

QBH Limits:
m_{Th} > 8.9 TeV (8. TeV)

2015 limit m_{q*} > 5.2 TeV



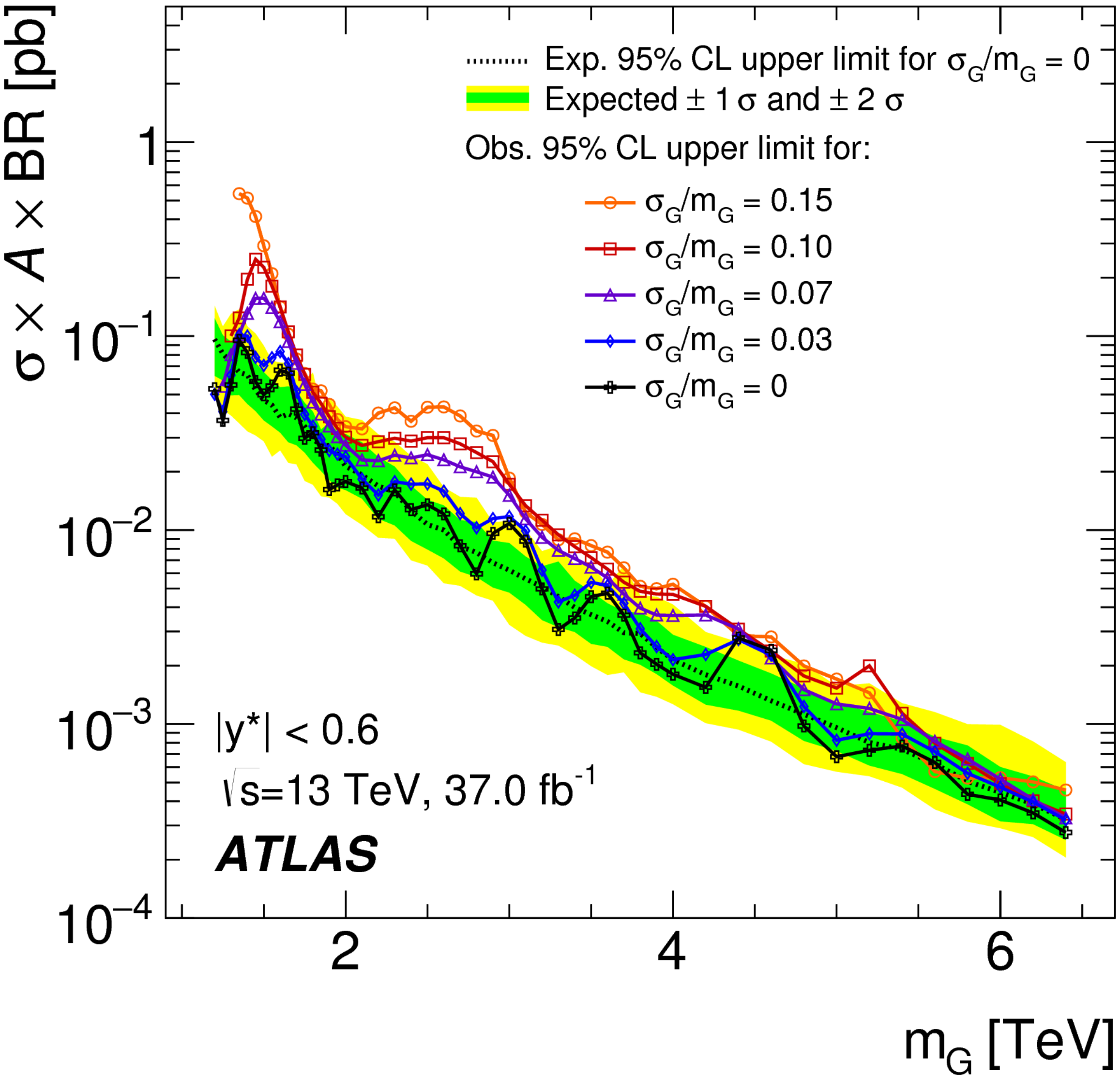


For g_q=0.6 the intrinsic width of the Z' in the mass range of interest increases to 15%.

Results limited to $g_q \leq 0.5$

arxiv:1703.09127

High Mass **Di-Jet** Search



Gaussian Limits

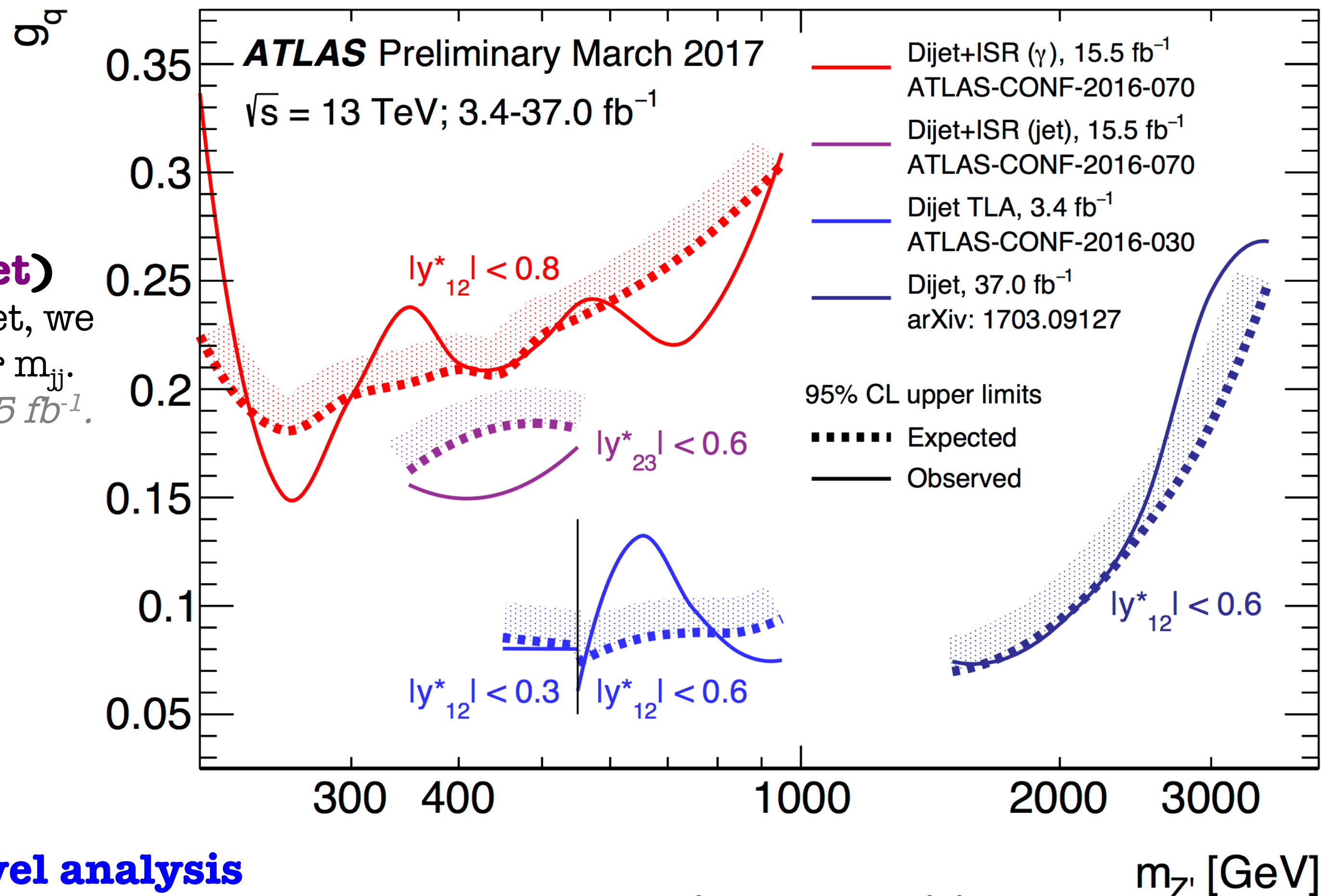
- Limits on *generic Gaussian signals* used to recast results for new signal models.
- Folding method using MC based transfer matrix used to factorized out physics and detector effects. **NEW**
  - The predicted signals can now be compared at *particle level* (assuming Gaussian signal shape).

arxiv:1703.09127

Other Di-Jet *Searches*

*Di-Jet searches covering the **low and high mass** regime!*

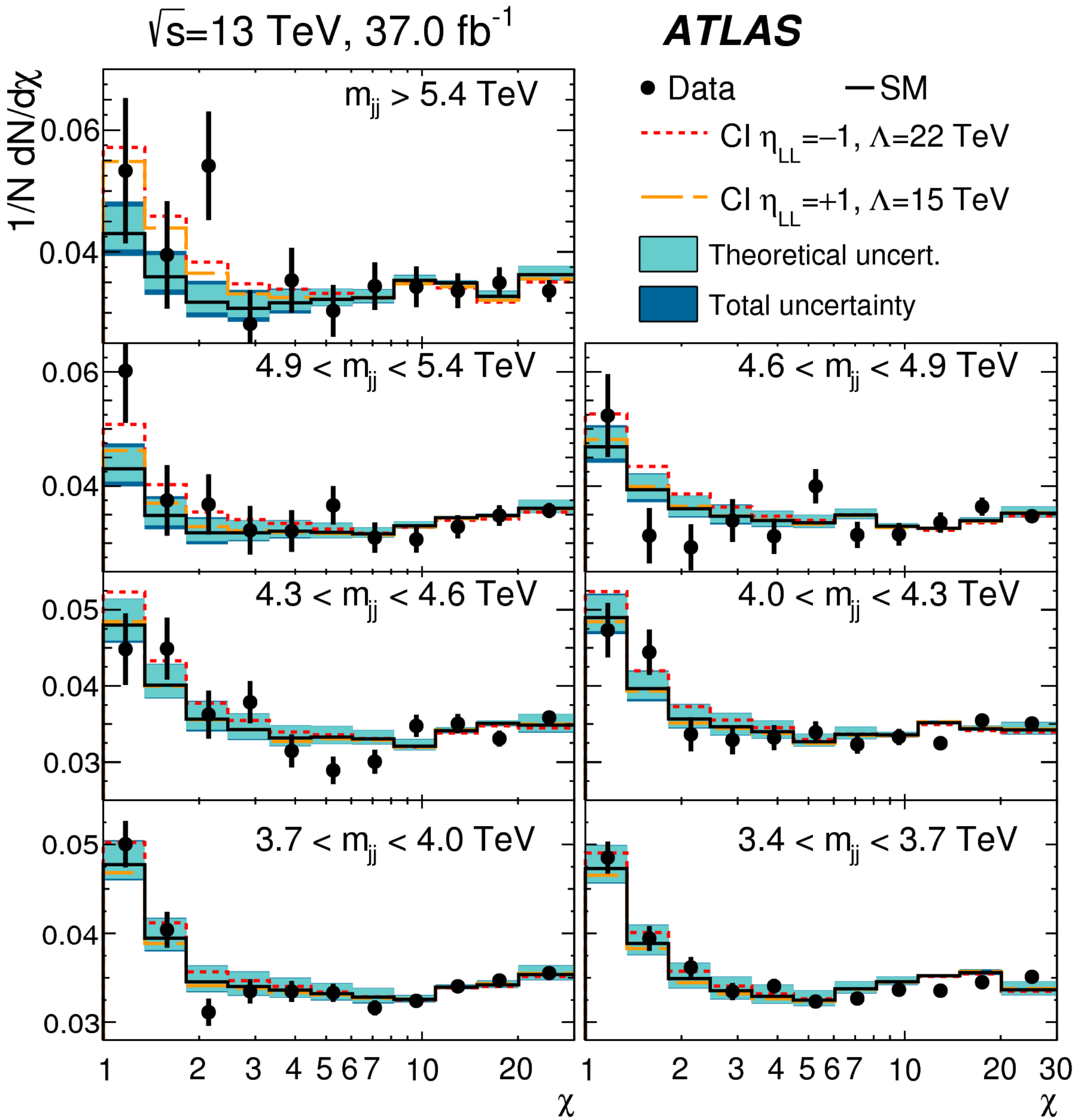
Di-jet + ISR (γ/jet)
Triggering on ISR γ/jet, we can also reach lower m_{jj}.
Last results with 15.5 fb^{-1}.



Trigger level analysis
Strategy: reduce data size/complexity to increase rate of recorded data .
Last results with 3.4 fb^{-1}.

High mass di-jets
Reach at low masses limited by trigger bandwidth and storage.

High Mass **Di-Jet** Search



Strategy: Angular

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

Background prediction based on Pythia (used as template) corrected for **NLO** and **EW** effects.

- Correction factors are mass and angle dependent.

Uncertainties:

- Jet Energy Scale is the dominant experimental uncertainty.
- Main theoretical uncertainties: renormalization and factorization scales, PDFs.

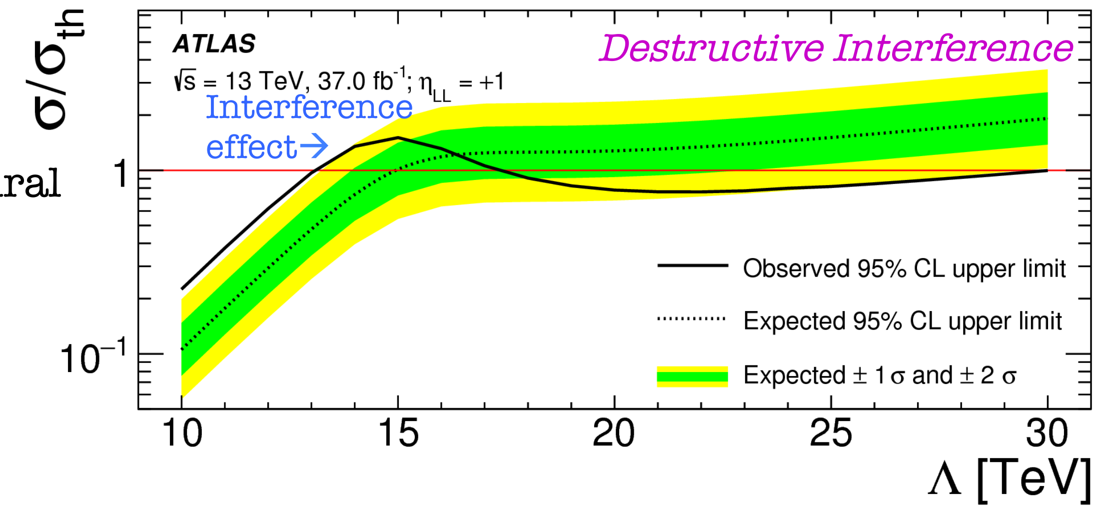
High Mass **Di-Jet** Search

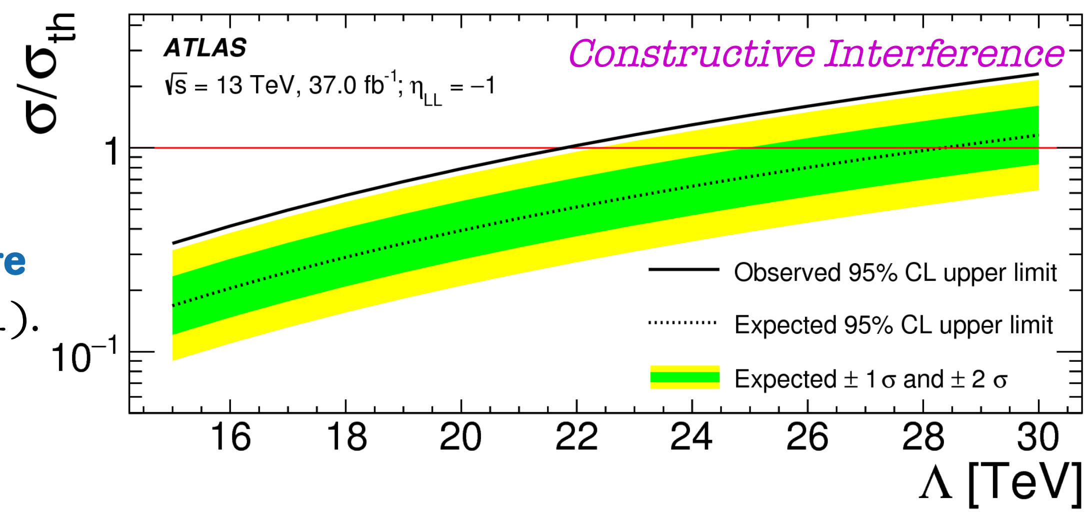
Angular Limits

- Limits on CI with non-zero left-chiral color coupling.
  - Resulting angular distribution is representative of other BSM models (e.g. Z’).

$$\mathcal{L}_{qq} = \frac{2\pi}{\Lambda^2}[\,\eta_{LL}(\bar{q}_L\gamma^\mu q_L)(\bar{q}_L\gamma_\mu q_L) + \cancel{\eta_{RR}}(\bar{q}_R\gamma^\mu q_R)(\bar{q}_R\gamma_\mu q_R) + 2\cancel{\eta_{RL}}(\bar{q}_R\gamma^\mu q_R)(\bar{q}_L\gamma_\mu q_L)]$$

- Both **destructive** and **constructive** interference are considered ($\eta_{LL} = \pm 1$).



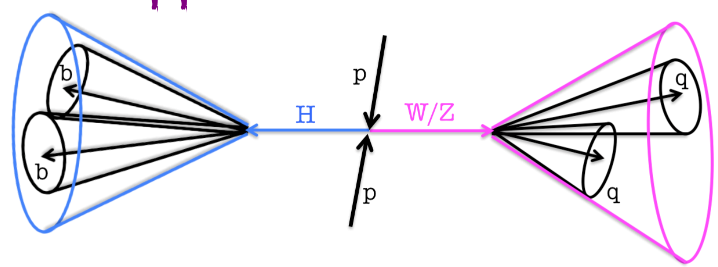


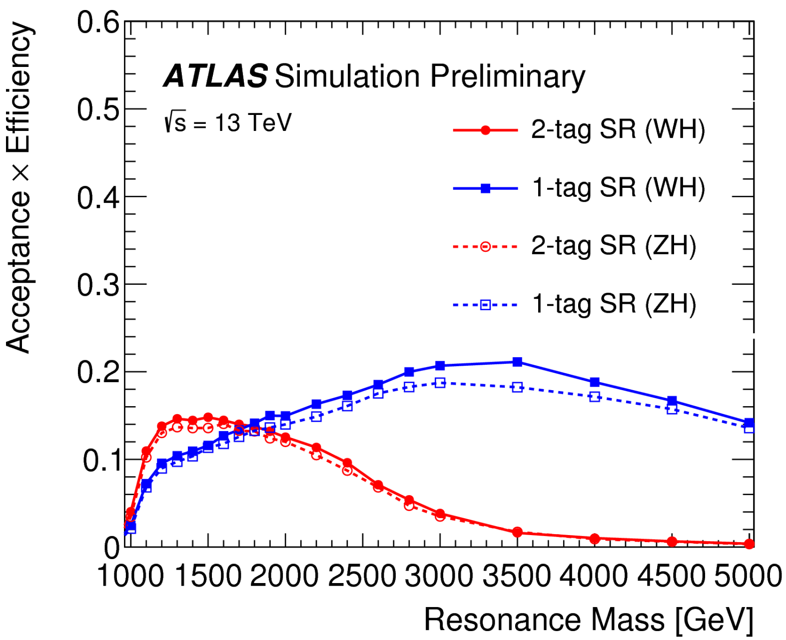
V(qq)H(bb) Search

Selection

- *Large BRs: W/Z→qq (67%), H→bb (~70%).*
- Select events with large-R jets consistent with highly boosted V→qq and H→bb.
  - Use **boson tagging**:
    - V-tagging: mass + $D_2^{\beta=1}$.
    - H-tagging: mass + b-tagging.

Looking for V(qq)H(bb) resonances!



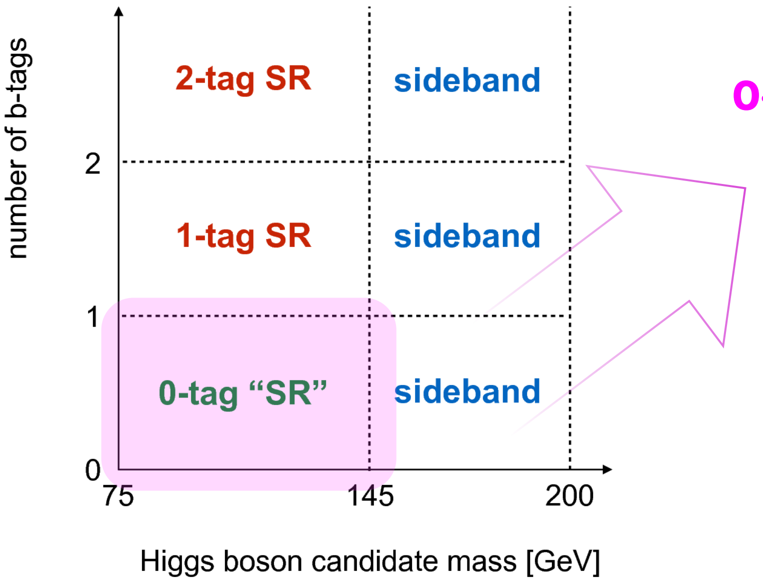


- Leading jet p_T>450 GeV, sub-leading jet p_T > 250 GeV.
- Larger mass jet assigned as Higgs candidate.
- Events categorized in 1-tag and ≥2-tag.
- ***WH and ZH SRs not orthogonal*** *(~60% overlap).*

V(qq)H(bb) Search

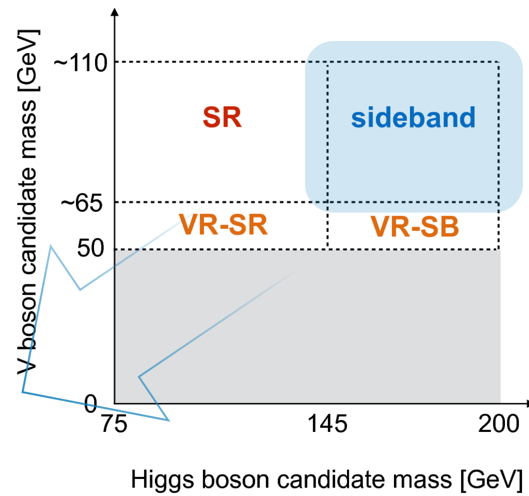
Strategy

Main background from **multijet** events.
~10% contributions from t-tbar, ~1% from V+jets (taken from MC),



0-tag region in **data** is used to extract a template of the multijet background.

High mass side-bands used to extract normalization and re-weighting corrections.



Multijet in SR

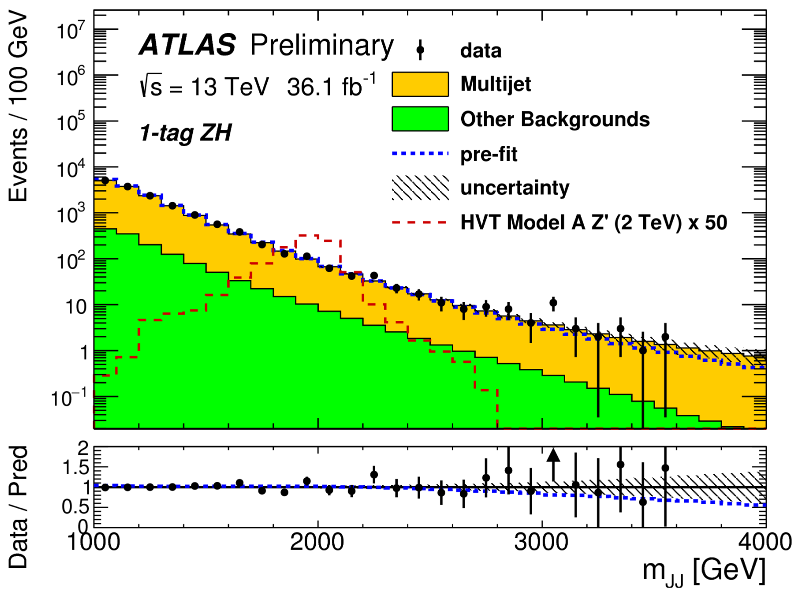
$$\mu^{1(2)-\mathrm{tag}}_{\mathrm{Multijet}} = \frac{N^{1(2)-\mathrm{tag}}_{\mathrm{Multijet}}}{N^{0-\mathrm{tag}}_{\mathrm{Multijet}}} = \frac{N^{1(2)-\mathrm{tag}}_{\mathrm{data}} - N^{1(2)-\mathrm{tag}}_{t\bar{t}} - N^{1(2)-\mathrm{tag}}_{V+\mathrm{jets}}}{N^{0-\mathrm{tag}}_{\mathrm{data}} - N^{0-\mathrm{tag}}_{t\bar{t}} - N^{0-\mathrm{tag}}_{V+\mathrm{jets}}}$$

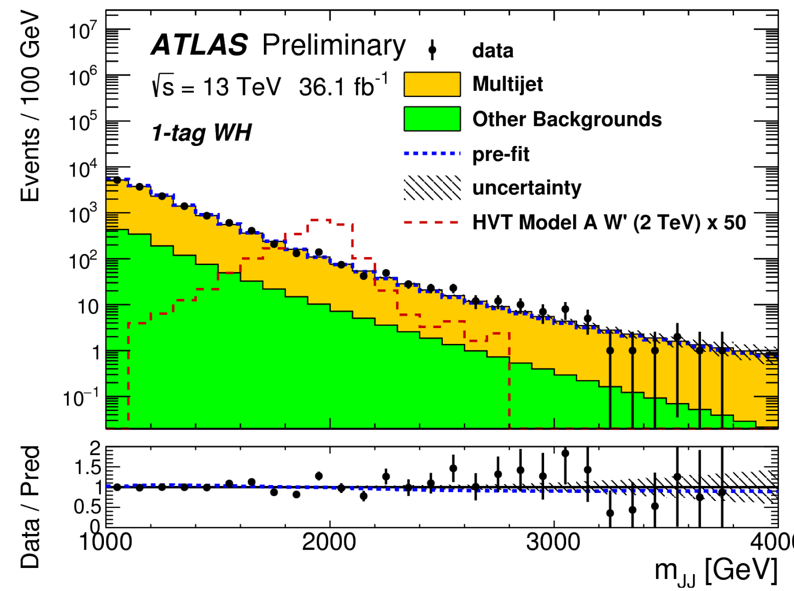
Extract $\mu_{multijets}$ from high mass sideband,
different for each SR:
1- and 2-tag, and WH, ZH.

ATLAS-CONF-2017-018

V(qq)H(bb) Search

ATLAS EXPERIMENT

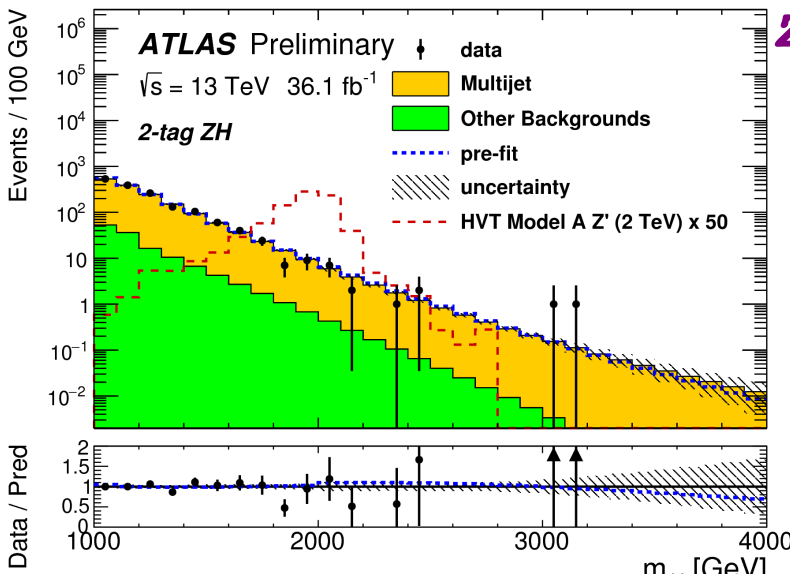


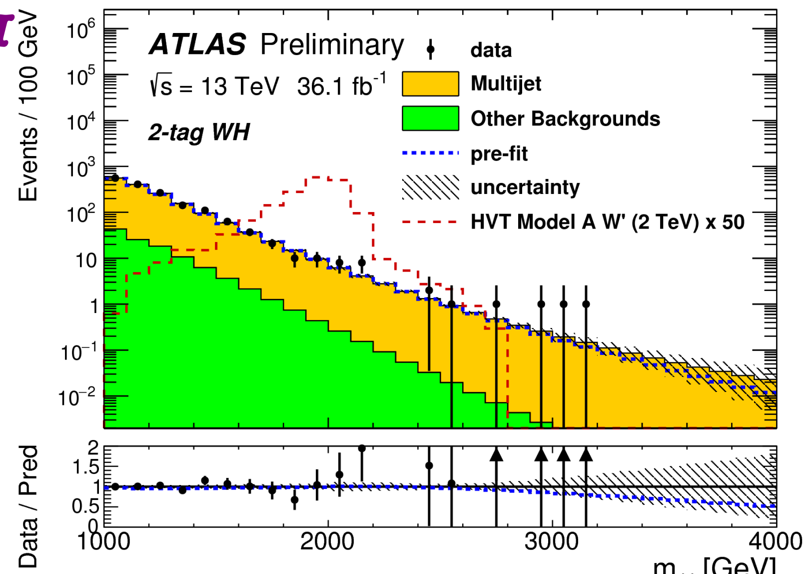


Probing

ZH* and *WH

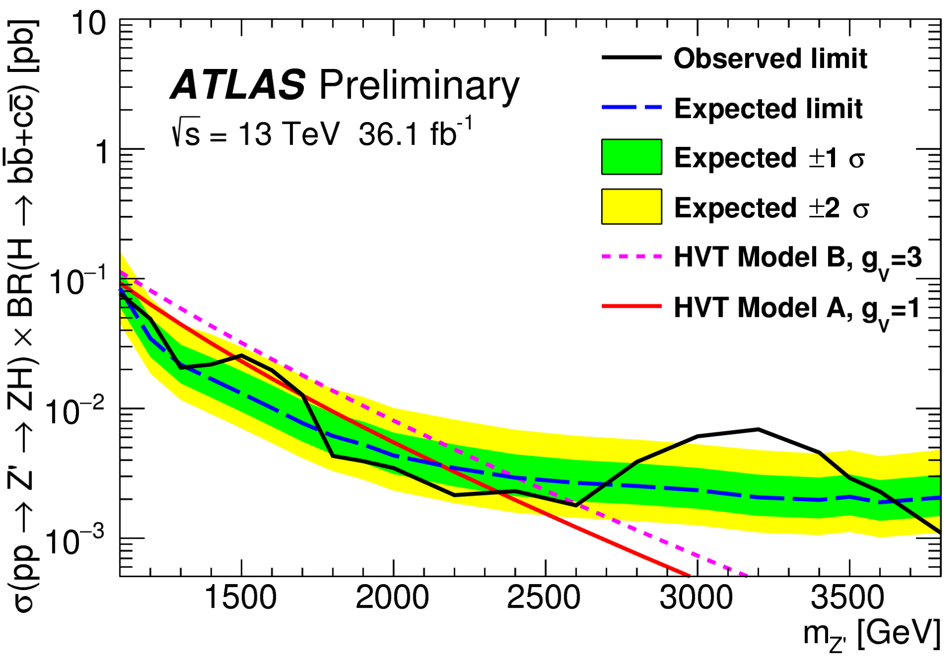
not orthogonal

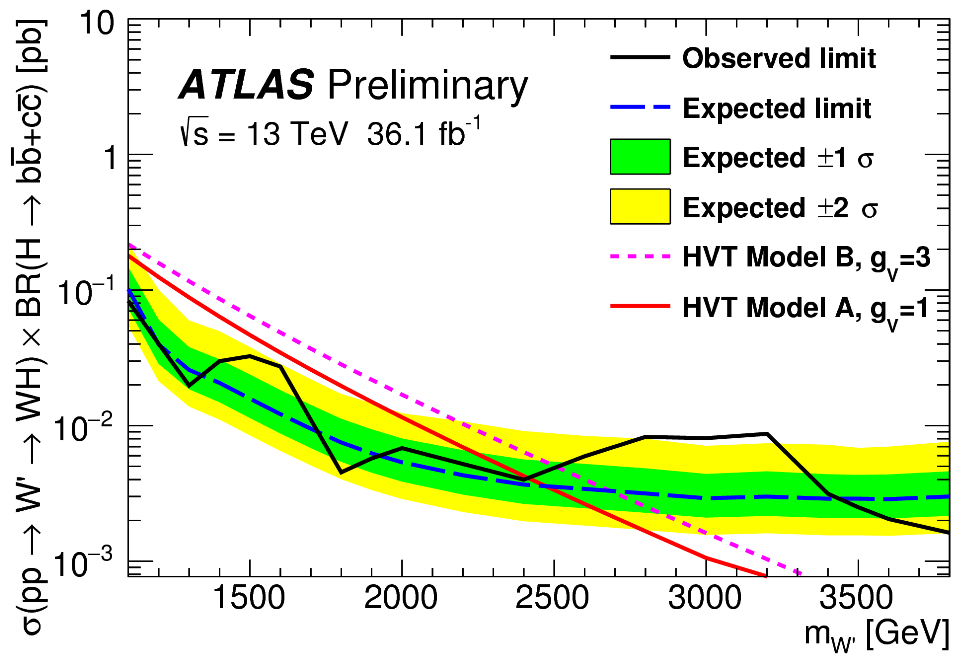




V(qq)H(bb) Search

- **Normalization and shape of multijet bkg**: estimated from largest deviation between data and prediction yields in validation region.
  - Normalization: 2-tag: 13%(sys), 3%(stat); 1-tag: 5% (sys), 1% (stat).
  - Shape (split for <2TeV and >2TeV).
- Fit **WH** and **ZH** signal regions separately.
  - Combining 1-tag and 2-tag regions in each case.



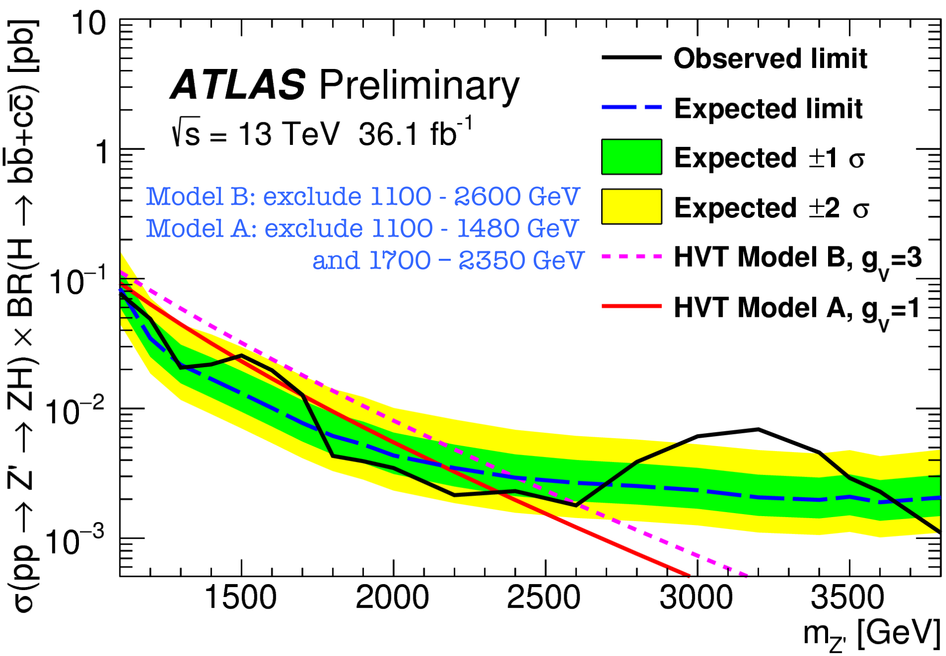


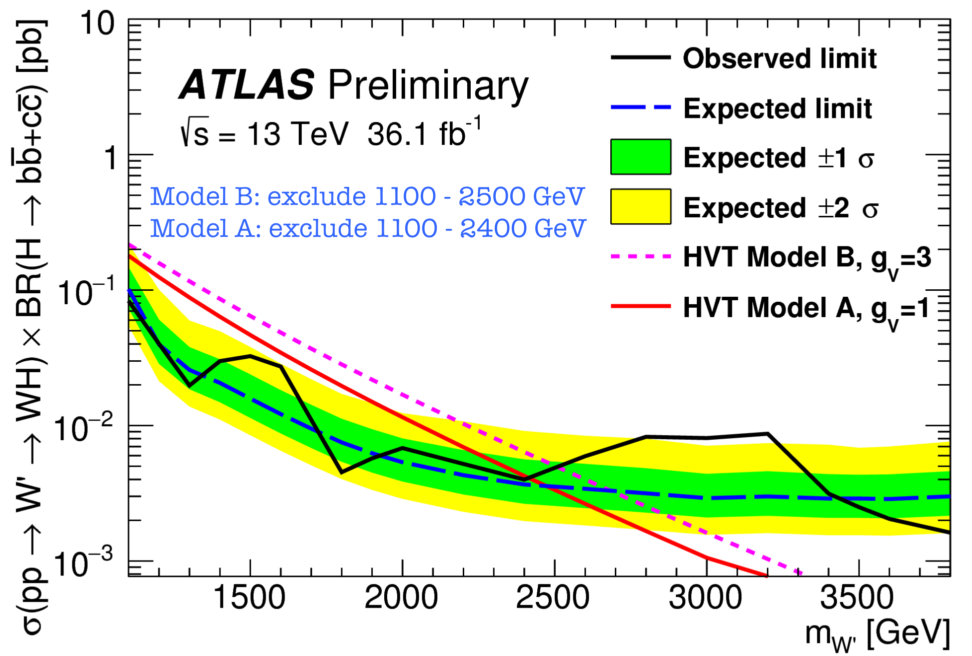
V(qq)H(bb) Search

Heavy Vector Triplet (HVT) W' and Z'.

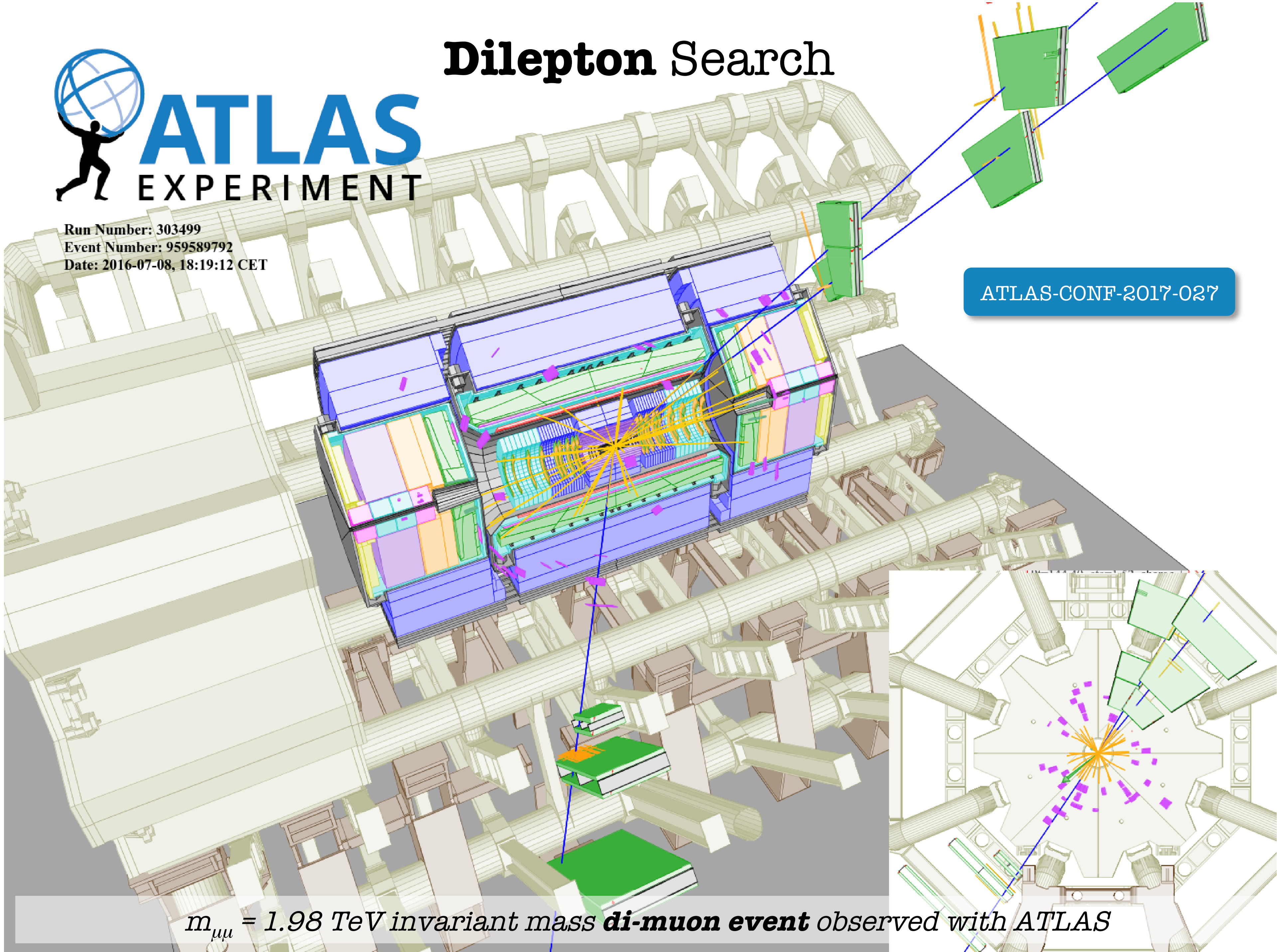
- Model A: comparable BR to fermions and gauge bosons.
- Model B: Suppressed couplings to fermions.

Largest excess found at 3.0 TeV in ZH channel, with **global** significance of **2.2σ**.





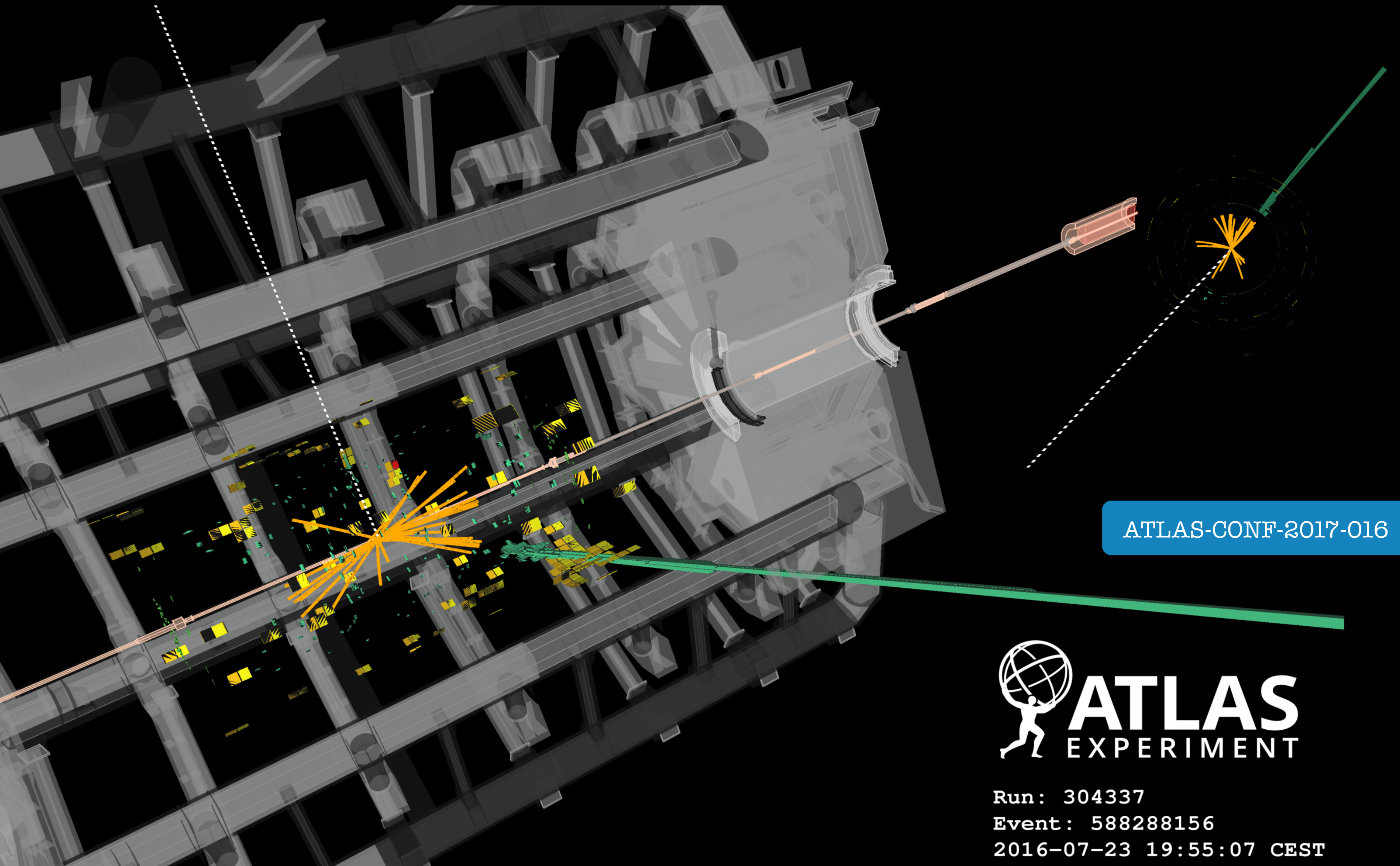
Dilepton Search



ATLAS-CONF-2017-027

*$m_{\mu\mu}$ = 1.98 TeV invariant mass **di-muon event** observed with ATLAS*

Lepton + E_T^{miss} Search



*Highest- m_T event in the **electron** channel observed with ATLAS: m_T = 2.26 TeV*
(p_T^e = 1.11 TeV, E_T^{miss} = 1.16 TeV)

Searches with **Leptons**

ATLAS EXPERIMENT

Medium **Electrons**
Loose isolation

High p_T WP **Muons**
(Trk-based) Loose isolation

Lepton + E_T^{miss}

- Single electron triggers.
- $E_T^{(electron)} > 65$ GeV.
- *Tight* ID.
- $m_T > 130$ GeV.
- $E_T^{miss} > 65$ GeV.

- Single muon triggers.
- $p_T^{(muon)} > 55$ GeV.
- $m_T > 110$ GeV.
- $E_T^{miss} > 55$ GeV.

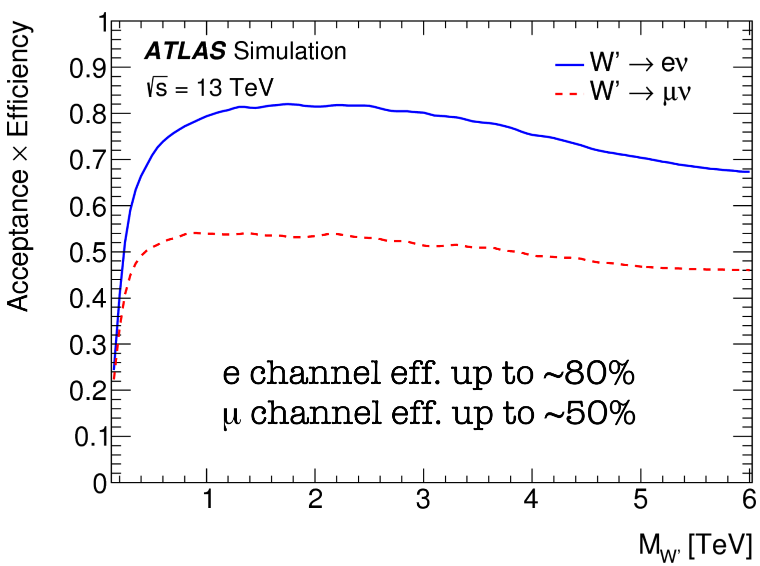
Veto on additional leptons

Dilepton

- Di-electron triggers.
- $E_T^{(electrons)} > 30$ GeV.

- Single muon triggers.
- $p_T^{(muons)} > 30$ GeV.

Highest $m_{\ell\ell}$ pair (> 80 GeV).



- Reduced acceptance in the muon channels:
  - Lower *muon identification efficiency*,
  - *tighter selection criteria* (to improve muon resolution).
- Opposite charge required for *di-muons*.
  - Charge mis-identification does not affect energy measurement for electrons.

Searches with **Leptons**

ATLAS EXPERIMENT

Strategy

Main background from **Drell-Yan production**.

Additional contributions from processes with **real leptons** in the final state (t-tbar, single top quark, diboson). *Estimated using MC samples.*

DY *events are simulated with NLO Powheg generator.*
Events yields are corrected with mass dependent rescaling from NLO to NNLO QCD.
Mass-dependent EW-corrections at NLO are also applied.

- ***Fakes*** background: e.g. from multijet events, where one or more jets satisfies the lepton selection.
  - Negligible in muon channels. Minor background in the electron channels.
  - Using data-driven approach: ***matrix method***. Measure fake and real rates: probabilities of a jet or an electron ***to be identified as an electron***.

Background estimates may suffer from low statistics in the high mass tails (e.g. multijets). Extrapolation performed by fitting the lower mass distribution and using the fitted function to predict the background at higher mass.

Dilepton Search

ATLAS EXPERIMENT

PRE-FIT

Source	Dielectron channel		Dimuon channel	
	Signal	Background	Signal	Background
Luminosity	3.2% (3.2%)	3.2% (3.2%)	3.2% (3.2%)	3.2% (3.2%)
MC statistical	<1.0% (<1.0%)	<1.0% (<1.0%)	<1.0% (<1.0%)	<1.0% (<1.0%)
Beam energy	2.0% (4.1%)	2.0% (4.1%)	1.9% (3.1%)	1.9% (3.1%)
Pile-Up effects	<1.0% (<1.0%)	<1.0% (<1.0%)	<1.0% (<1.0%)	<1.0% (<1.0%)
DY PDF choice	N/A	<1.0% (8.4%)	N/A	<1.0% (1.9%)
DY PDF variation	N/A	8.7% (19%)	N/A	7.7% (13%)
DY PDF scale	N/A	1.0% (2.0%)	N/A	<1.0% (1.5%)
DY α_S	N/A	1.6% (2.7%)	N/A	1.4% (2.2%)
DY EW corrections	N/A	2.4% (5.5%)	N/A	2.1% (3.9%)
DY γ-induced corrections	N/A	3.4% (7.6%)	N/A	3.0% (5.4%)
Top Quarks theoretical	N/A	<1.0% (<1.0%)	N/A	<1.0% (<1.0%)
Dibosons theoretical	N/A	<1.0% (<1.0%)	N/A	<1.0% (<1.0%)
Reconstruction efficiency	<1.0% (<1.0%)	<1.0% (<1.0%)	10% (17%)	10% (17%)
Isolation efficiency	9.1% (9.7%)	9.1% (9.7%)	1.8% (2.0%)	1.8% (2.0%)
Trigger efficiency	<1.0% (<1.0%)	<1.0% (<1.0%)	<1.0% (<1.0%)	<1.0% (<1.0%)
Identification efficiency	2.6% (2.4%)	2.6% (2.4%)	N/A	N/A
Lepton energy scale	<1.0% (<1.0%)	4.1% (6.1%)	<1.0% (<1.0%)	<1.0% (<1.0%)
Lepton energy resolution	<1.0% (<1.0%)	<1.0% (<1.0%)	2.7% (2.7%)	<1.0% (6.7%)
Multi-jet & W+jets	N/A	10% (129%)	N/A	N/A
Total	10% (11%)	18% (132%)	11% (18%)	14% (24%)

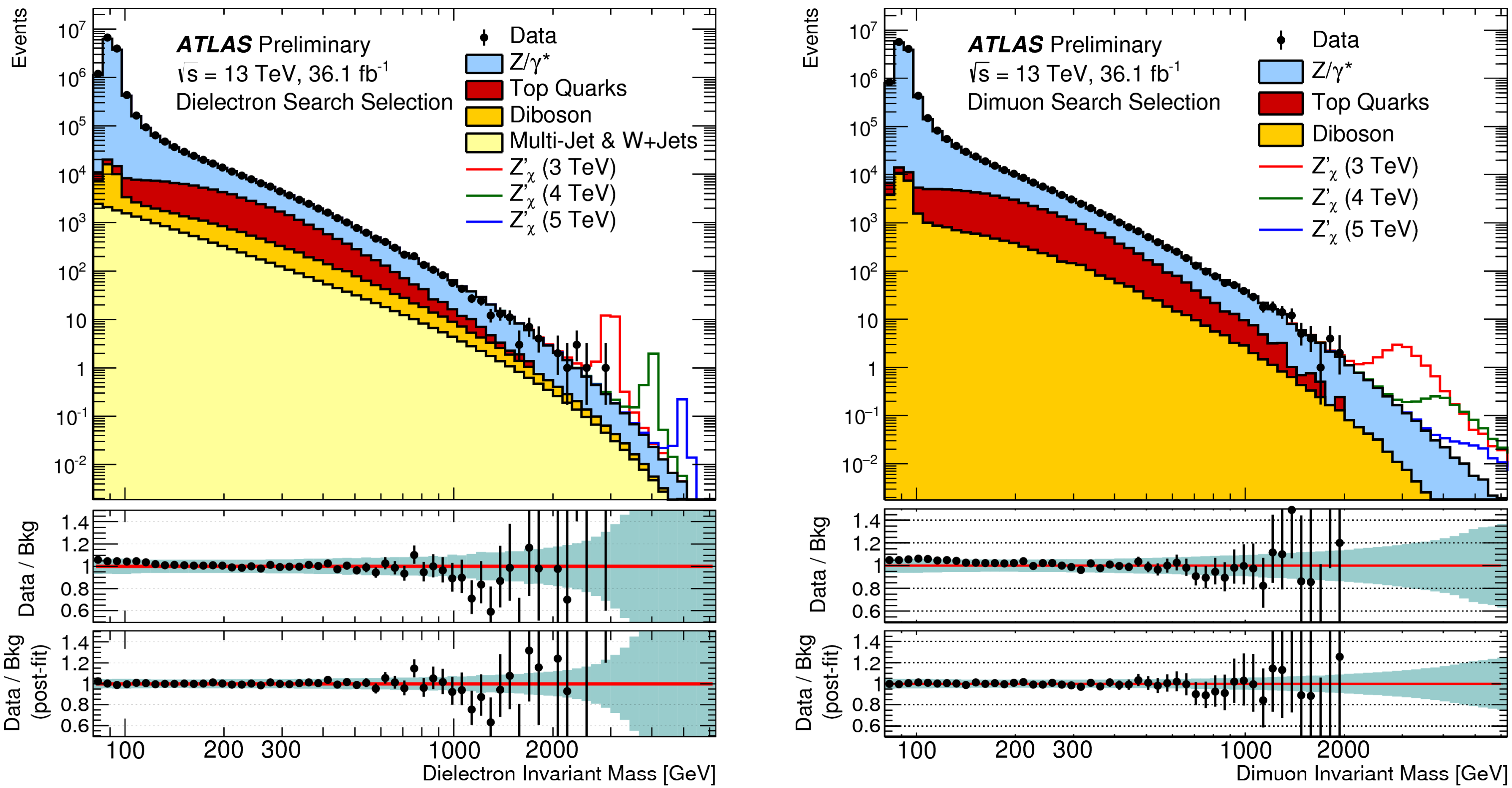
Largest theory uncertainty.

Largest exp uncertainty.

Large uncertainty at high masses due to extrapolation.

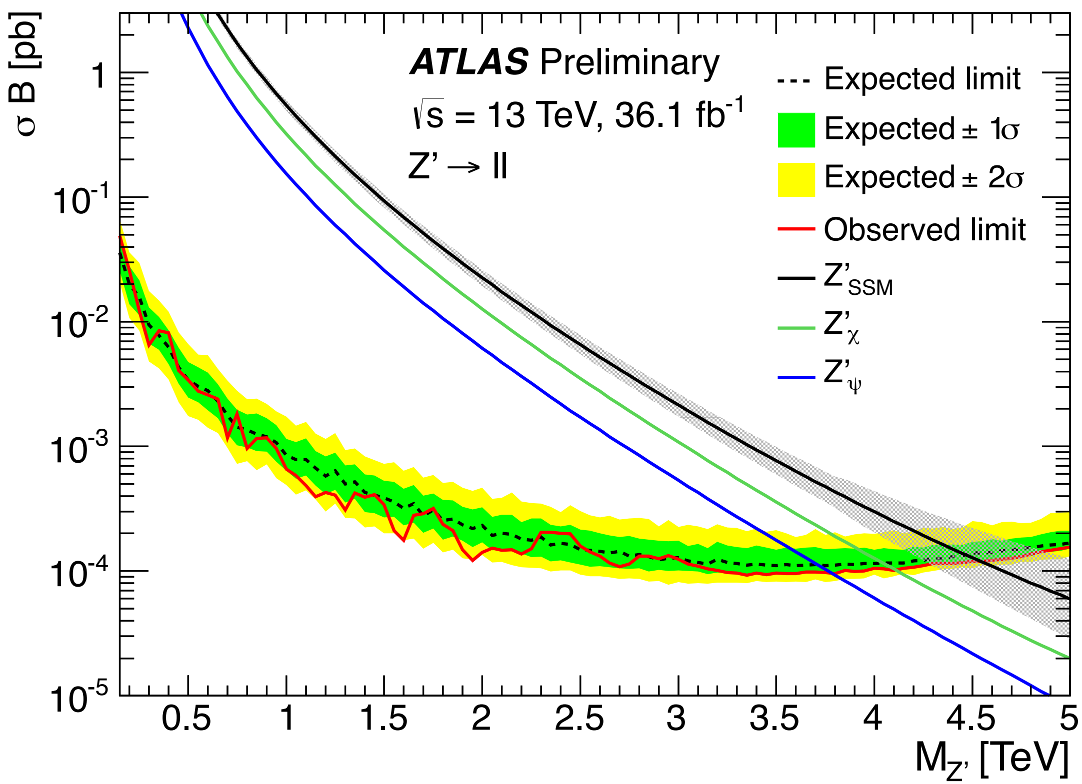
Background and signal systematic uncertainties at dilepton masses of 2 TeV (4 TeV).

Dilepton Search



○ Most significant excess in di-electron mass spectrum is observed at 2.37 TeV, global significance of -0.2σ.

Dilepton Search



Model	Width [%]	θ_{E_6} [Rad]	Lower limits on $m_{Z'}$ [TeV]					
			ee		$\mu\mu$		$\ell\ell$	
			Obs	Exp	Obs	Exp	Obs	Exp
Z'_{SSM}	3.0	-	4.3	4.3	4.0	3.9	4.5	4.5
Z'_{χ}	1.2	0.50 π	3.9	3.9	3.6	3.6	4.1	4.0
Z'_{S}	1.2	0.63 π	3.9	3.8	3.6	3.5	4.0	4.0
Z'_{I}	1.1	0.71 π	3.8	3.8	3.5	3.4	4.0	3.9
Z'_{η}	0.6	0.21 π	3.7	3.7	3.4	3.3	3.9	3.8
Z'_{N}	0.6	-0.08 π	3.6	3.6	3.4	3.3	3.8	3.8
Z'_{ψ}	0.5	0 π	3.6	3.6	3.3	3.2	3.8	3.7

Limits

Upper limits are set for Z' cross sections times BR wrt $m_{Z'}$, for various Z' scenarios.

Limits weaken above 3.5 TeV:
Rapidly falling signal x-sections and off-shell low mass signal tail.

Limits for minimal Z' models are also discussed in the paper.

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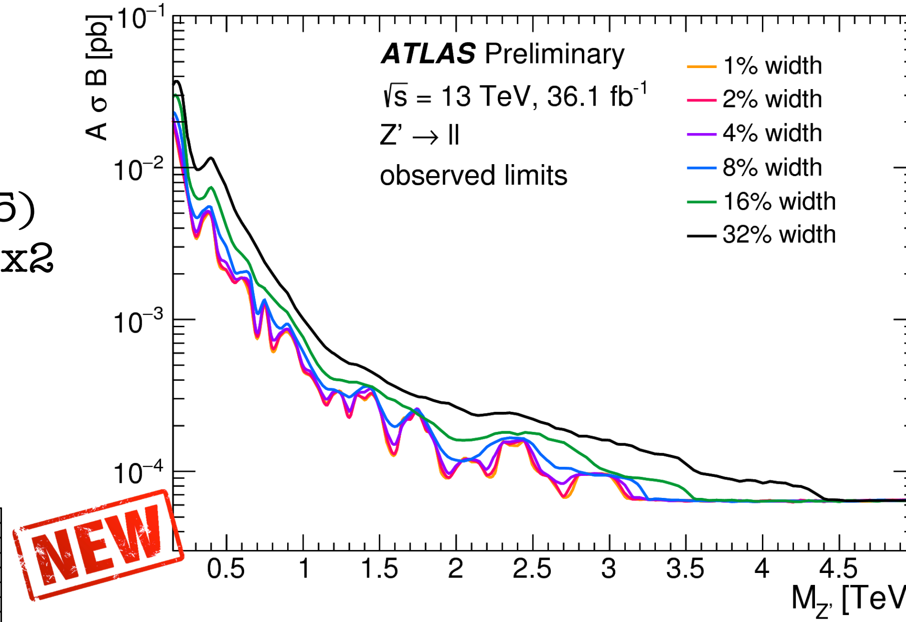
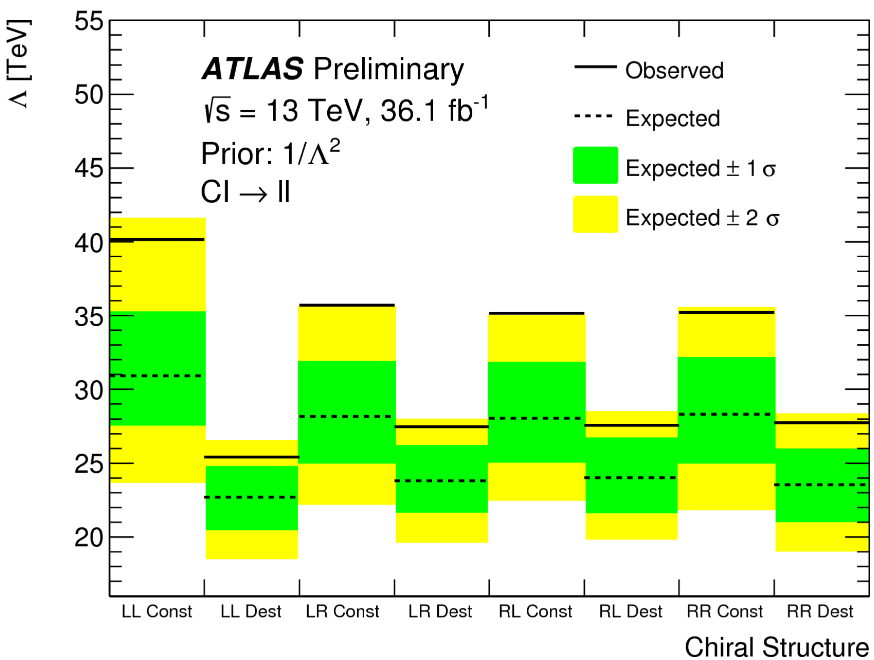
Dilepton Search

Generic Z' limits

Aim to provide more general limits. Applying fiducial cuts (p_T>30 GeV, $|\eta|$<2.5) on signal templates and a mass window of x2 the signal width (Breit-Wigner).

Other models can be interpreted with these cross-sections!



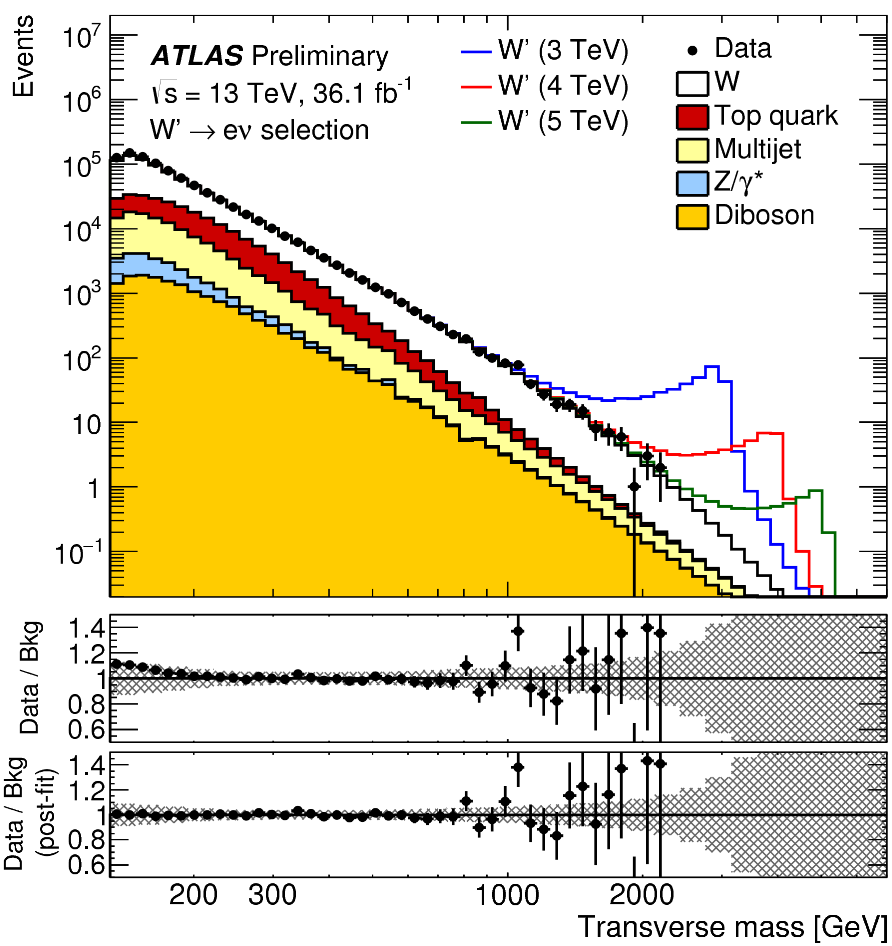


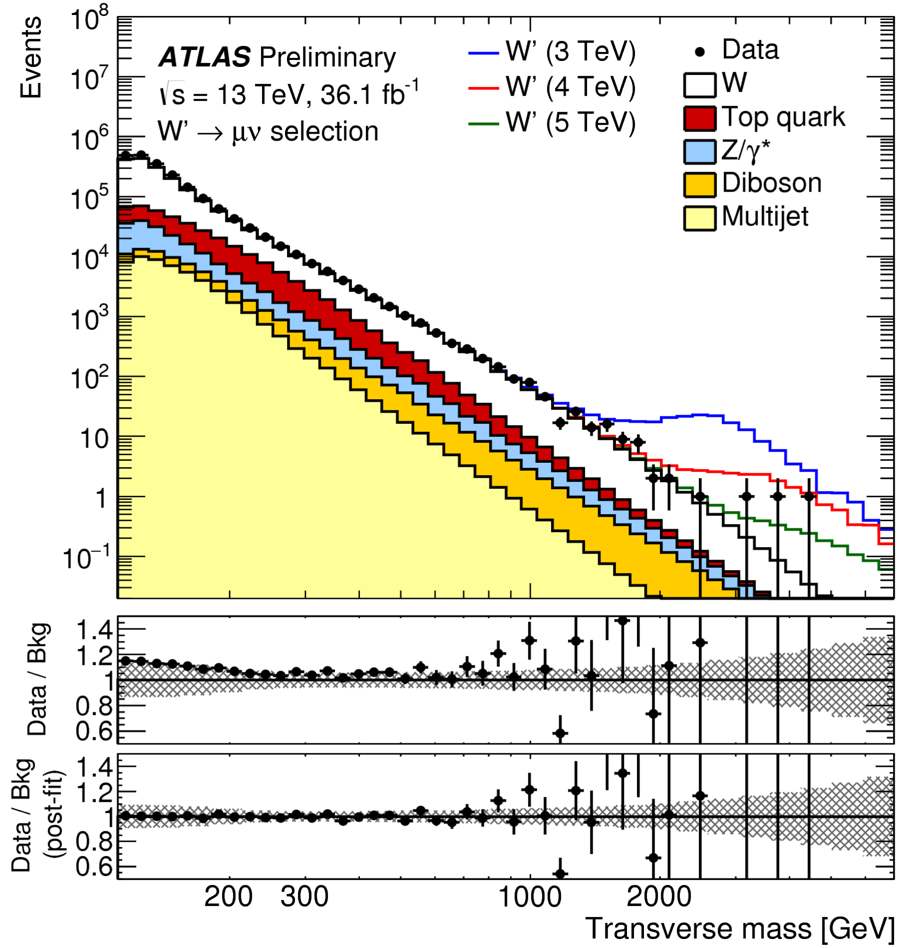
CI Limits

$$\mathcal{L} = \frac{g^2}{\Lambda^2}\left[\eta_{LL}(\bar{q}_L\gamma_\mu q_L)(\bar{\ell}_L\gamma^\mu\ell_L) + \eta_{RR}(\bar{q}_R\gamma_\mu q_R)(\bar{\ell}_R\gamma^\mu\ell_R) + \eta_{LR}(\bar{q}_L\gamma_\mu q_L)(\bar{\ell}_R\gamma^\mu\ell_R) + \eta_{RL}(\bar{q}_R\gamma_\mu q_R)(\bar{\ell}_L\gamma^\mu\ell_L)\right]$$

Different chiral structures are studied; with the left-right (right-left) model obtained by setting $\eta_{LR} = \pm1$ ($\eta_{RL} = \pm1$) and all other parameters to zero.

Lepton + E_T^{miss} Search

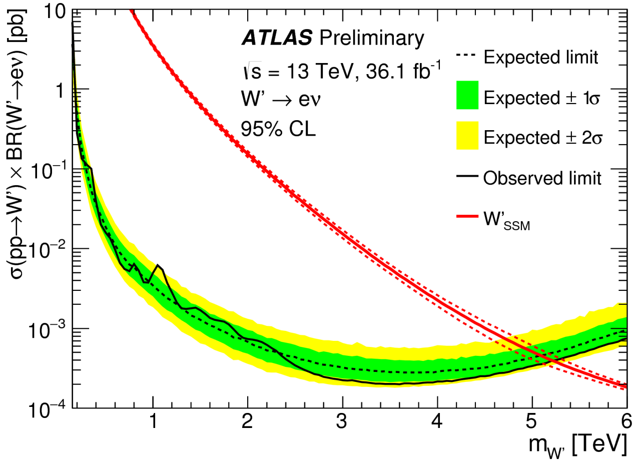


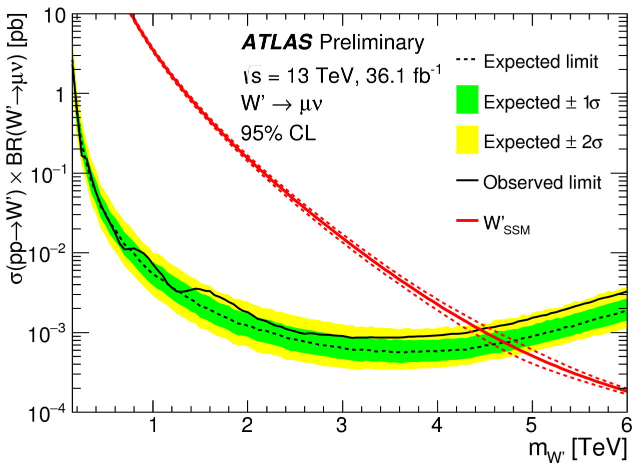


- Most significant excess in electron channel is at $m_{W'}$ = 1.1 TeV, global significance of 0.6σ.
- Most significant excess in muon channel is at $m_{W'}$ ~ 5 TeV, global significance of 0.1σ.

ATLAS-CONF-2017-016

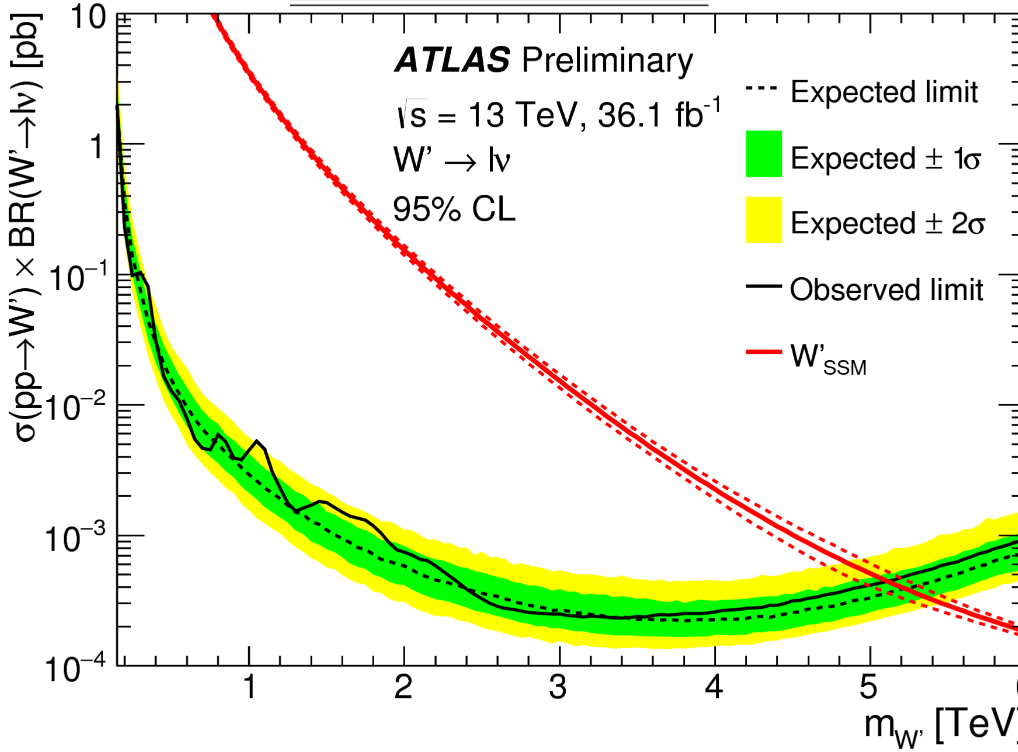
Lepton + E_T^{miss} Search





Upper limits on cross section times BR for the electron and muon channels.

Decay	$m_{W'}$ lower limit [TeV]	
	Expected	Observed
$W' \to e\nu$	5.09	5.22
$W' \to \mu\nu$	4.70	4.45
$W' \to \ell\nu$	5.22	5.11

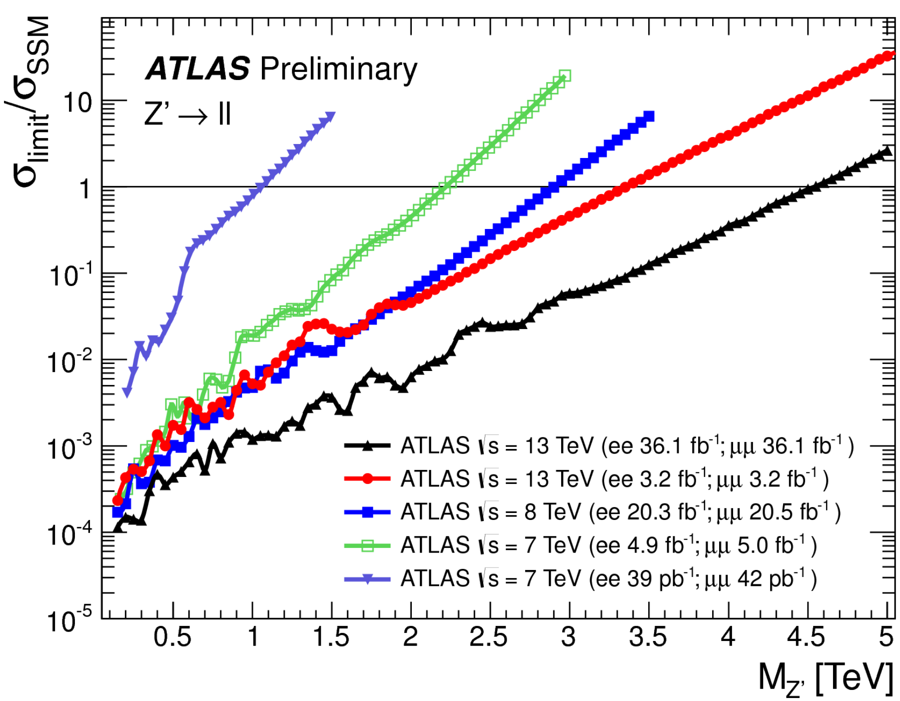


- Combination of the two channels
  - Uncertainties treated as correlated.
- Stronger expected limits from electron channel.
  - Larger acceptance times efficiency,
  - better momentum resolution.

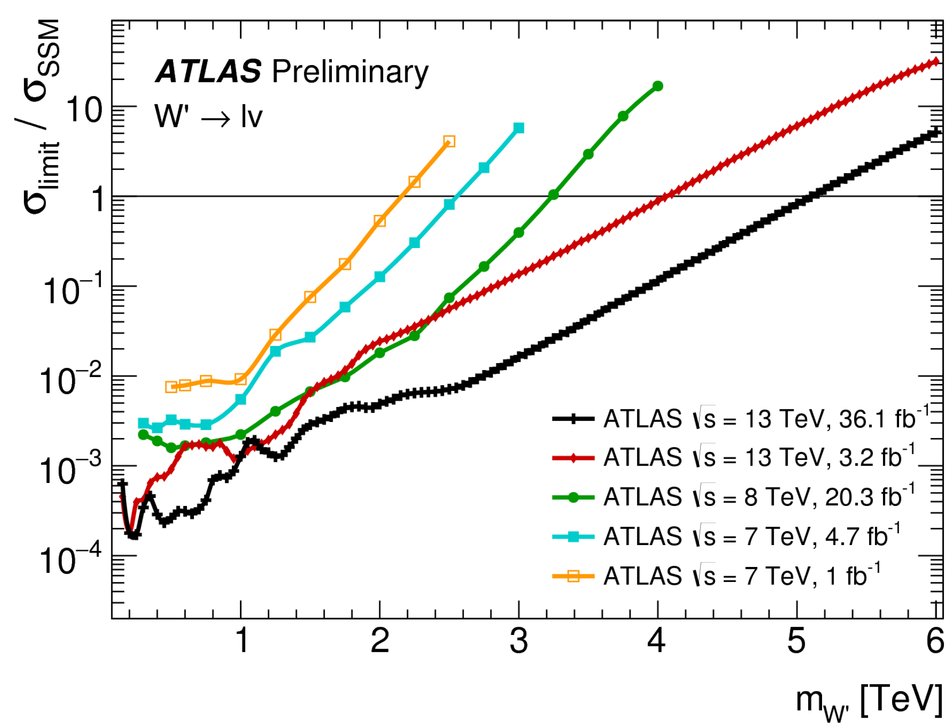
ATLAS-CONF-2017-027
ATLAS-CONF-2017-016

Searches with **Leptons**

Significant improvement wrt previous ATLAS searches!

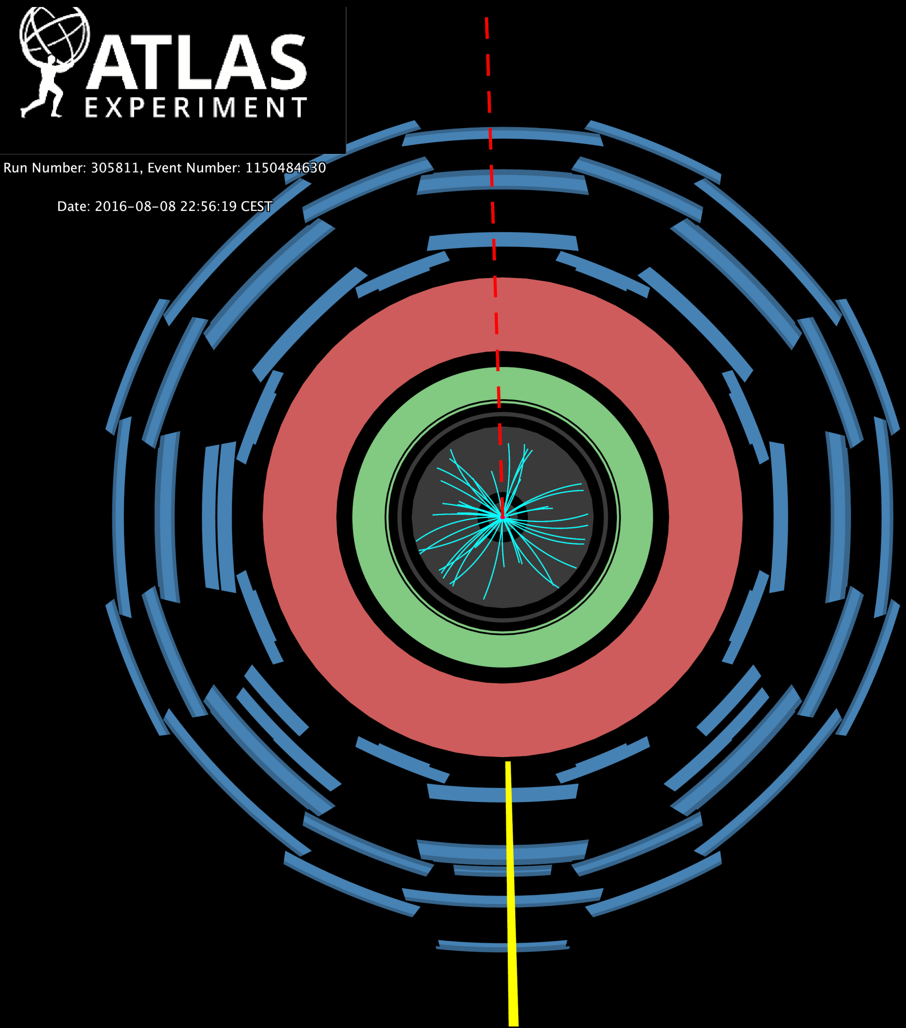


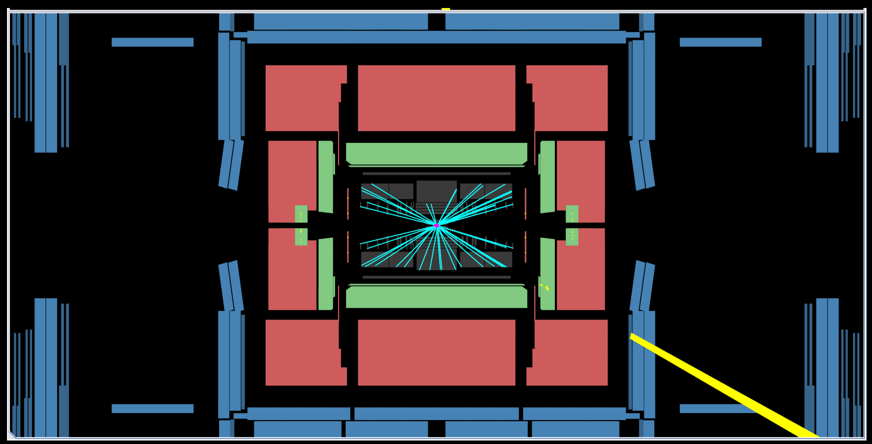
Observed limits to the $\mathbf{Z'}_{SSM}$ cross section from the combination of di-electron and di-muon channels.



Observed limits to the $\mathbf{W'}_{SSM}$ cross section from the combination of electron and muon channels.

Photon + E_T^{miss} Search





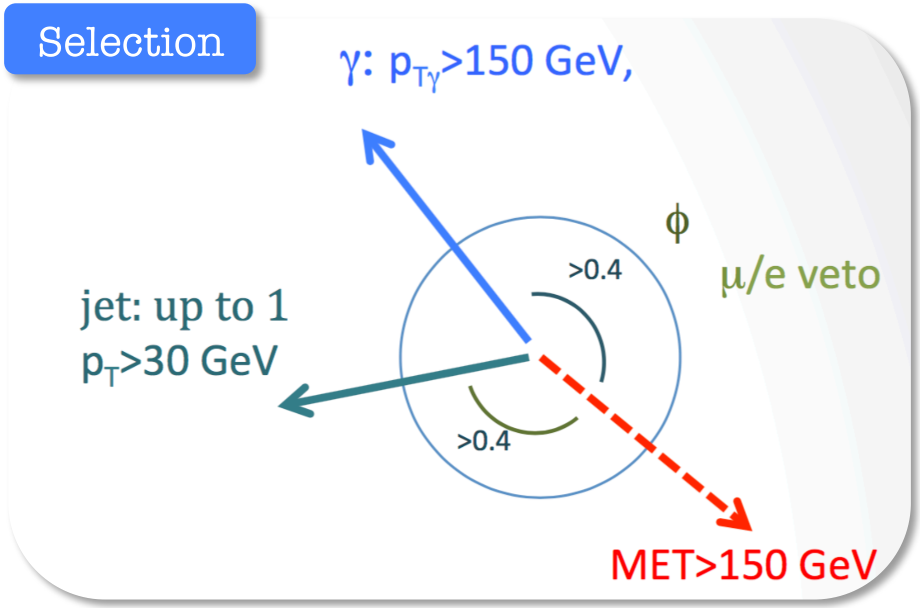
arxiv:1704.03848

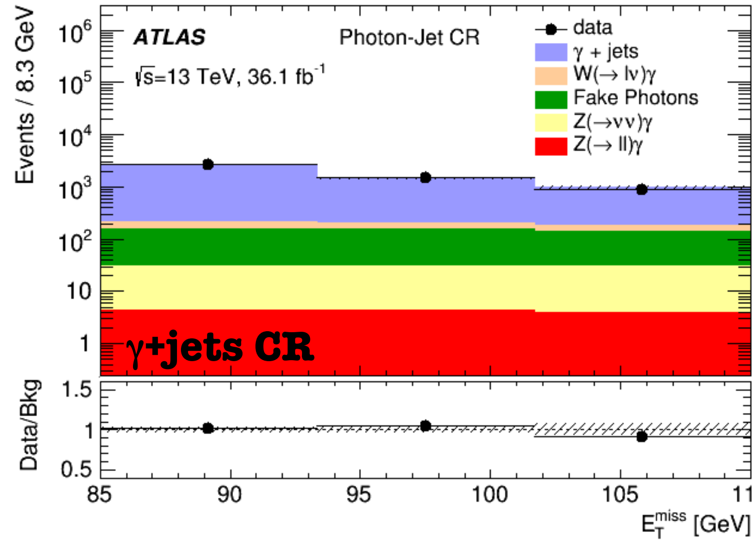
A photon with E_T = 265 GeV is balanced by E_T^{miss} of 268 GeV.

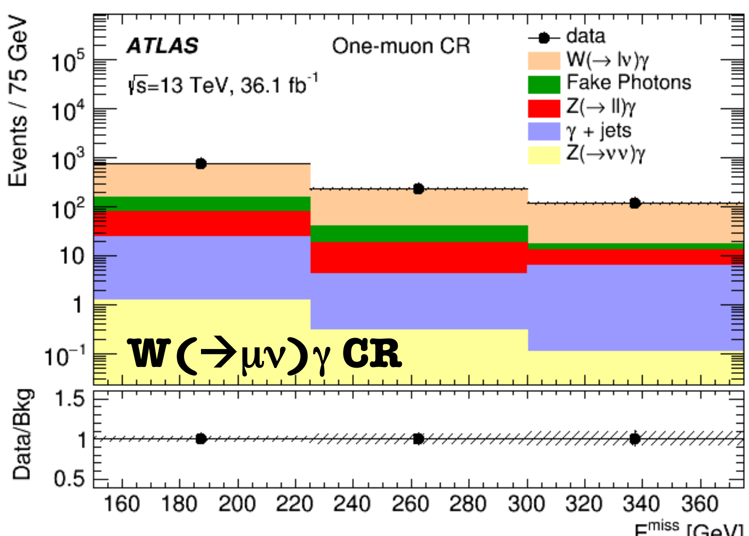
Photon + E_T^{miss} Search

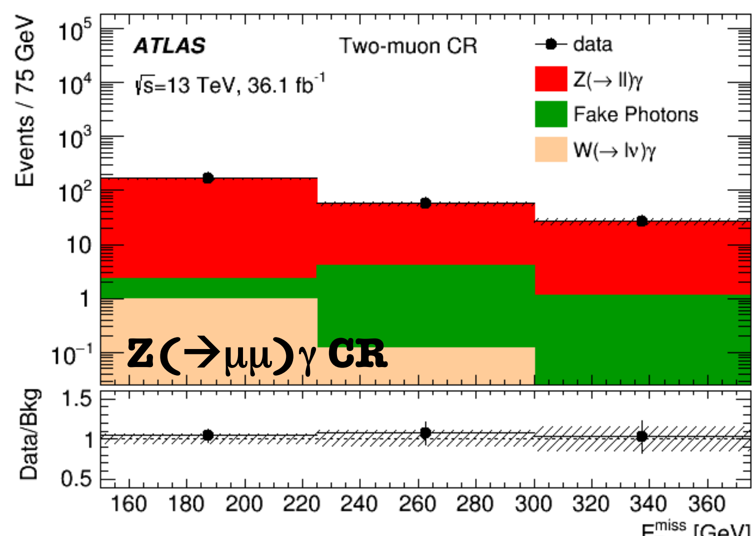
Multiple CRs defined to constrain SM bkgs

Selection









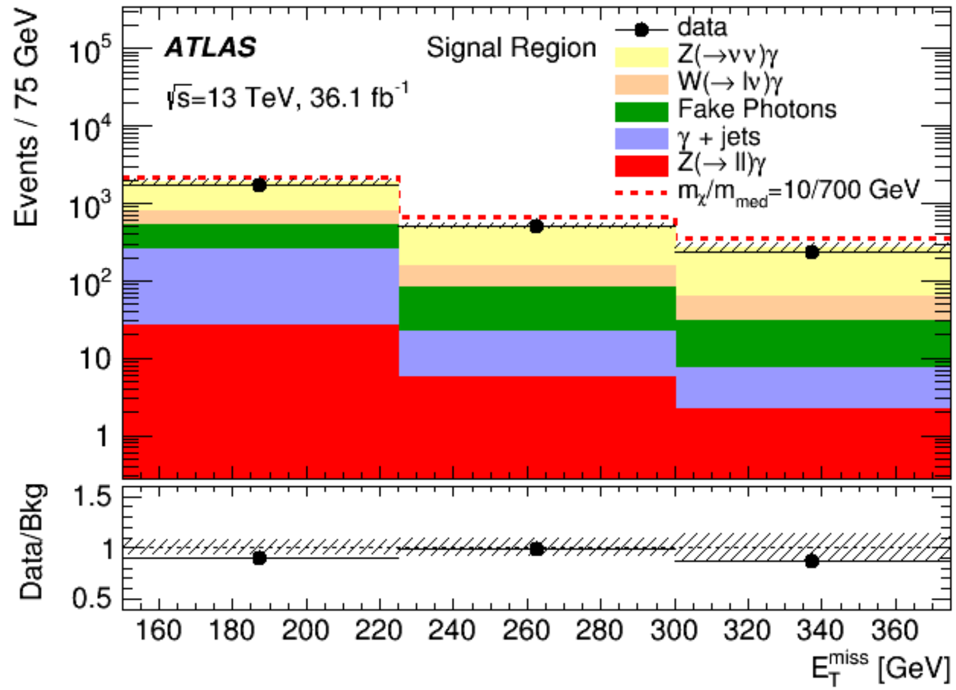
Photon + E_T^{miss} Search

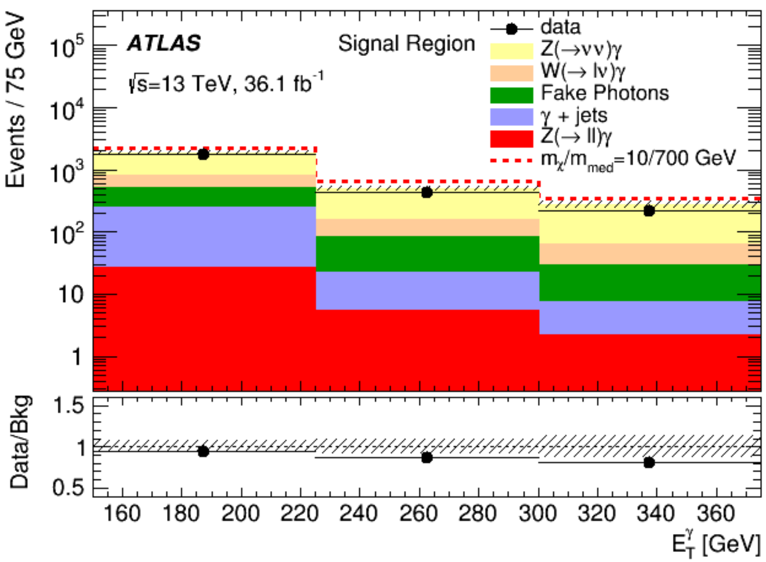
Strategy

- Dominant: **Z(νν)+ γ** (ISR), followed by Wγ and fake γ.
- **Vγ+jets** normalized in dedicated CRs.

NEW

  - 3 E_T^{miss} **dependent** scale factors: k_Z, k_W, $k_{\gamma jet}$.
    - *Z(νν) normalized in 2μ + 2e CRs.*
- γ+jets bkg from γ+jet CR.



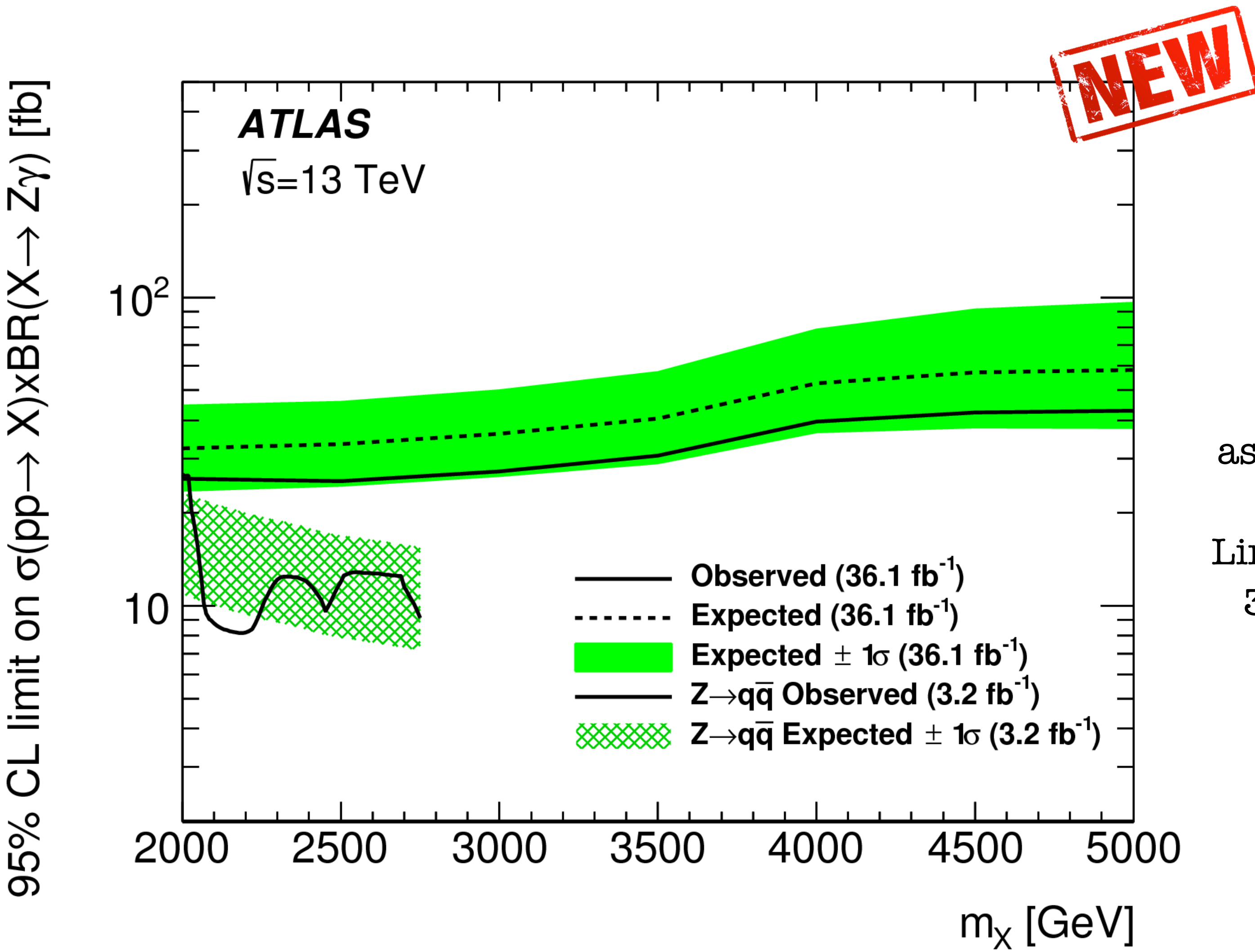


Main uncertainties: Statistical from CRs: 9%.

This analysis places limits on simplified DM models (photon from ISR) and EFT DM models (probing the γγχχ coupling).

arxiv:1704.03848

Photon + E_T^{miss} Search



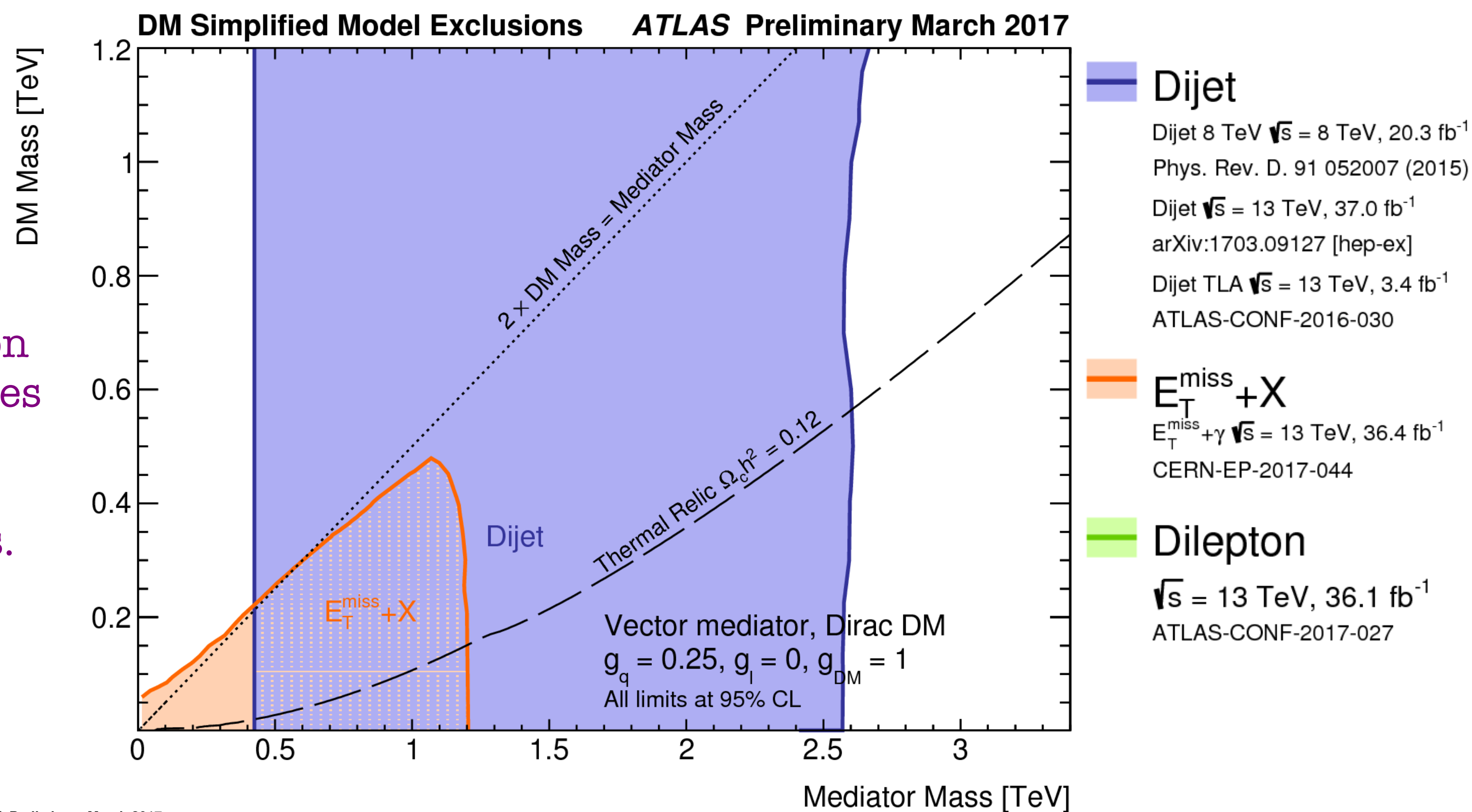
New results for **Z(νν)γ resonance** as a function of its mass.

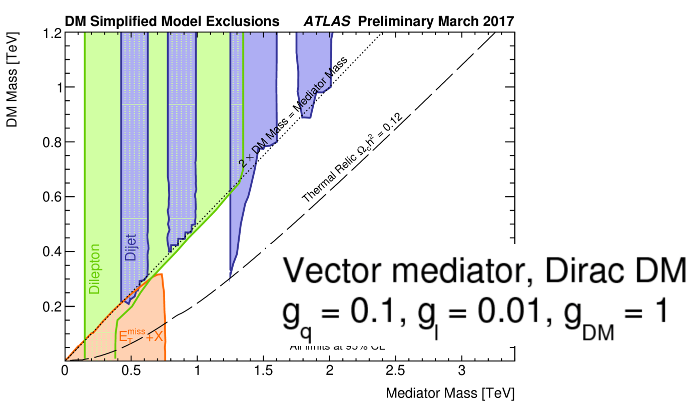
Limits from **Z(qq)**γ with 3.2 fb^{-1} are shown for comparison.

BONUS!

Connection to **Dark Matter**

Di-jet and dilepton resonance searches interpreted in terms of DM mediators limits.





*However, note that the **choice of couplings** is very relevant to study the complementarity of these and other mono-X searches.*

Conclusions

- Searches for new physics have been performed with the full 2015+2016 dataset.
  - ***Not possible to achieve without the amazing performance of the LHC machine and injector chain. Thanks to all involved!***
- New resonances and contact interactions are a strong components of the LHC physics program.
  - New techniques are being developed and new models are studied.
  - *So far, no significant deviations from Standard Model observed.*
  - Improved limits on multiple signal models!
    - Di-jet searches now exclude excited quarks up to 6 TeV.
    - Upper limits on σxBR to the $qq^{(')}bb$ final state are set for masses between 1.1-3.8 TeV.
    - W'_{SSM} excluded for $m_{W'}$>5.1 TeV from the lepton+E_T^{miss} search,
    - Z'_{SSM} excluded for $m_{Z'}$>4.5 TeV from di-lepton searches.
    - Upper limits on σxBR for a Z(νν)gamma resonance set for masses between 2-5 TeV.

Di-Jet	**arXiv:1703.09127**
V(qq)H(bb)	ATLAS-CONF-2017-018
Dilepton	ATLAS-CONF-2017-027
Lepton + E_T^{miss}	ATLAS-CONF-2017-016
Photon + E_T^{miss}	**arXiv:1704.03848**

Many thanks!

ATLAS
EXPERIMENT

Bonus Slides

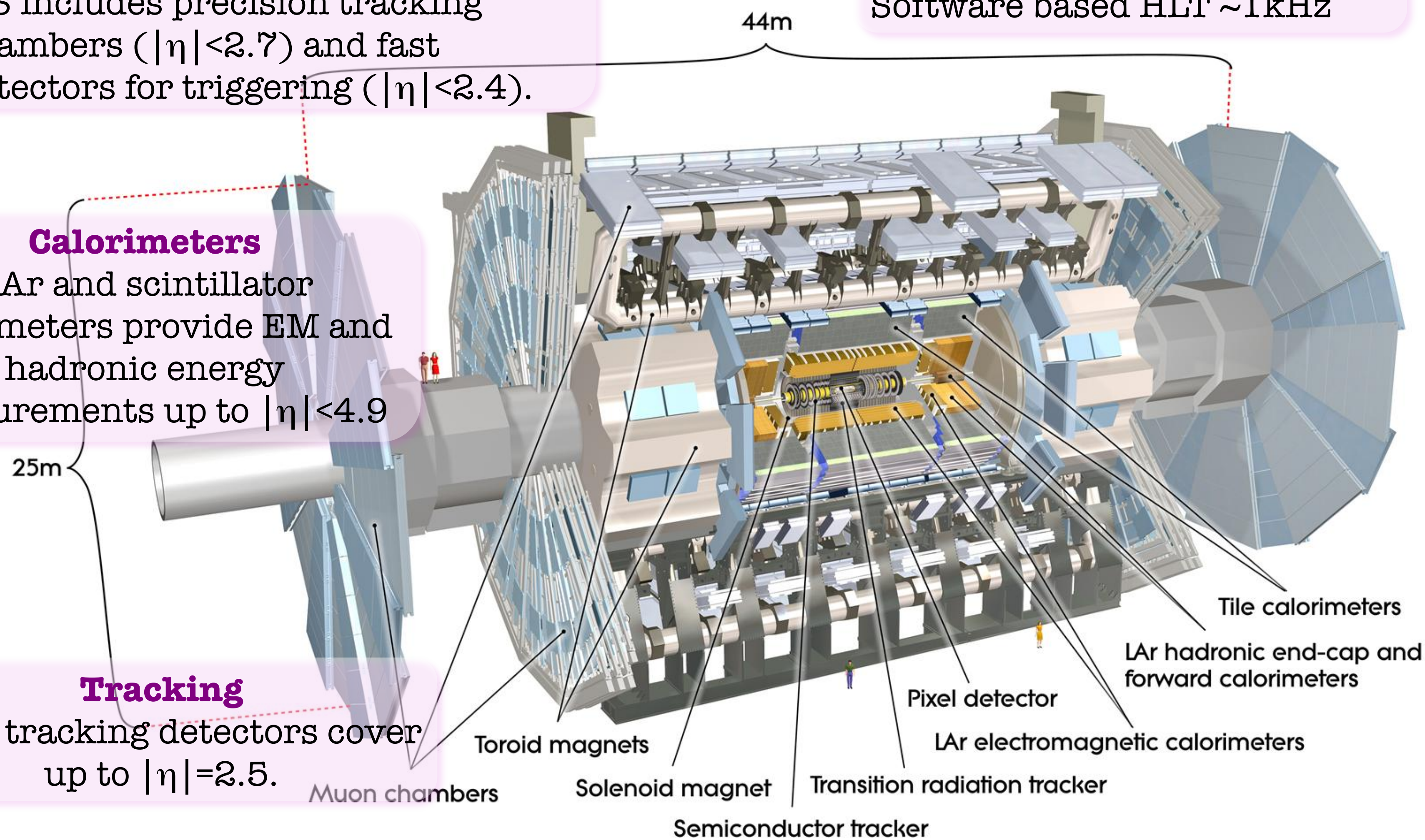
ATLAS Detector

Muons Spectrometer
MS includes precision tracking chambers ($|\eta|<2.7$) and fast detectors for triggering ($|\eta|<2.4$).

Trigger
Hardware based L1 ~100kHz
Software based HLT ~1kHz

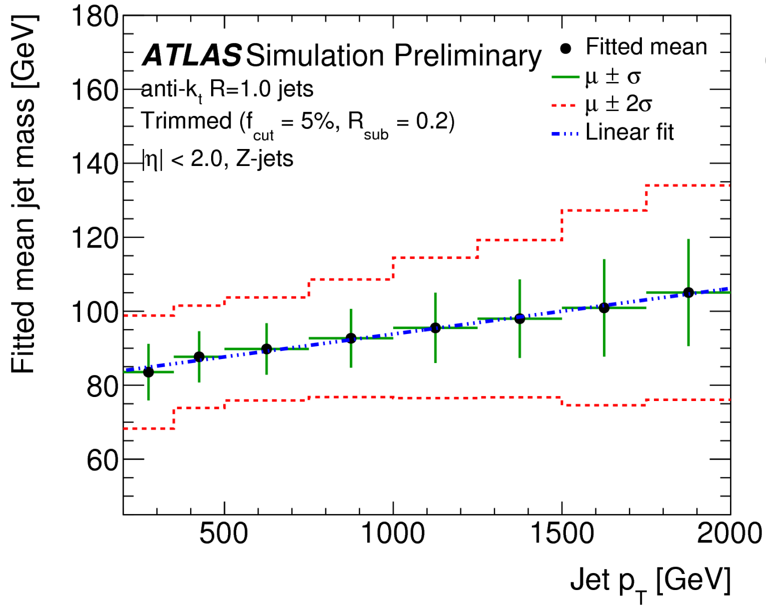
Calorimeters
LAr and scintillator calorimeters provide EM and hadronic energy measurements up to $|\eta|<4.9$

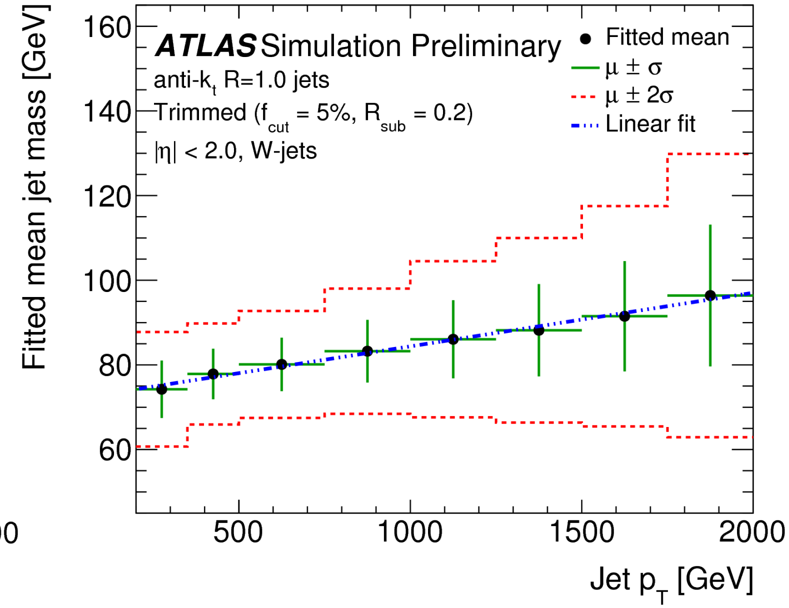
Tracking
Inner tracking detectors cover up to $|\eta|=2.5$.

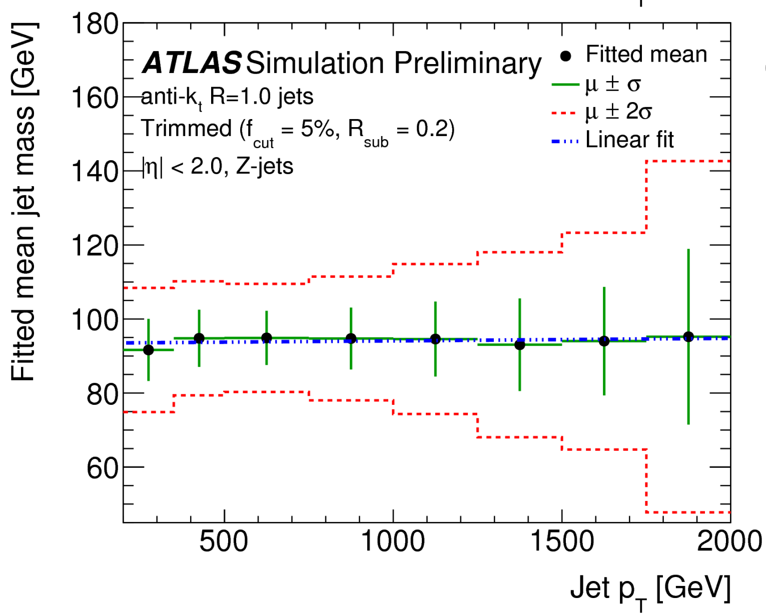


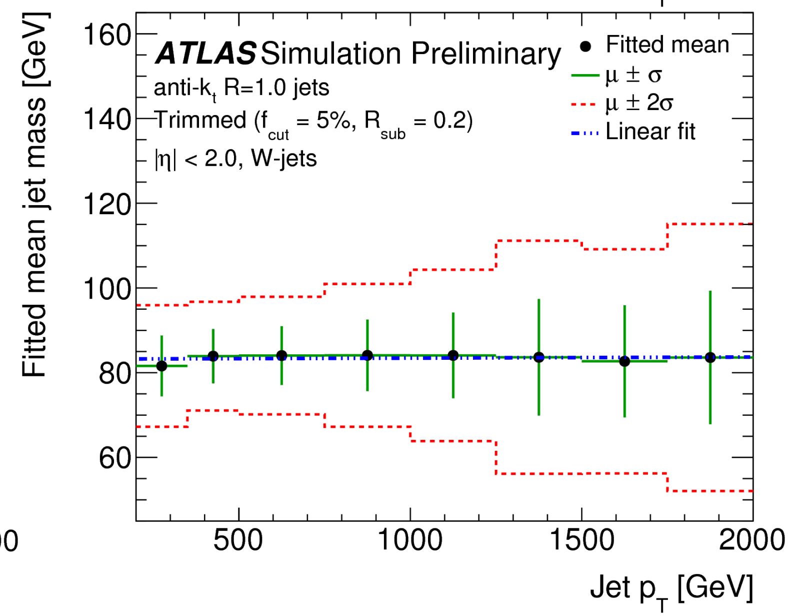
ATLAS-PHYS-PUB-2015-033

Performance: *Boson Tagging*



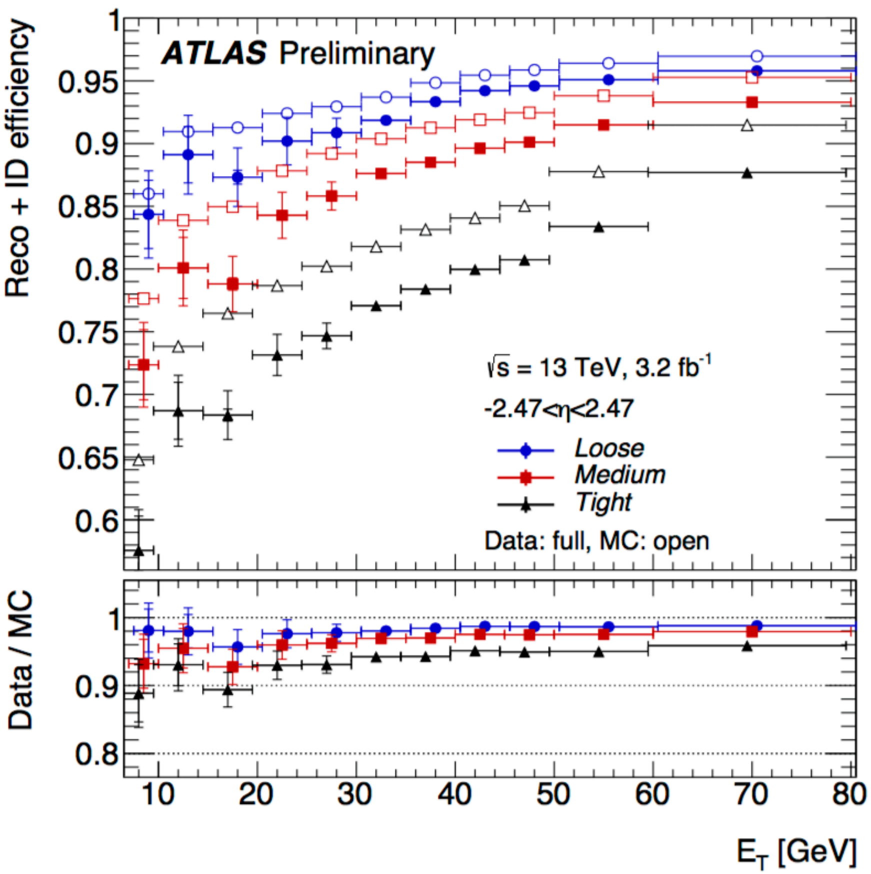


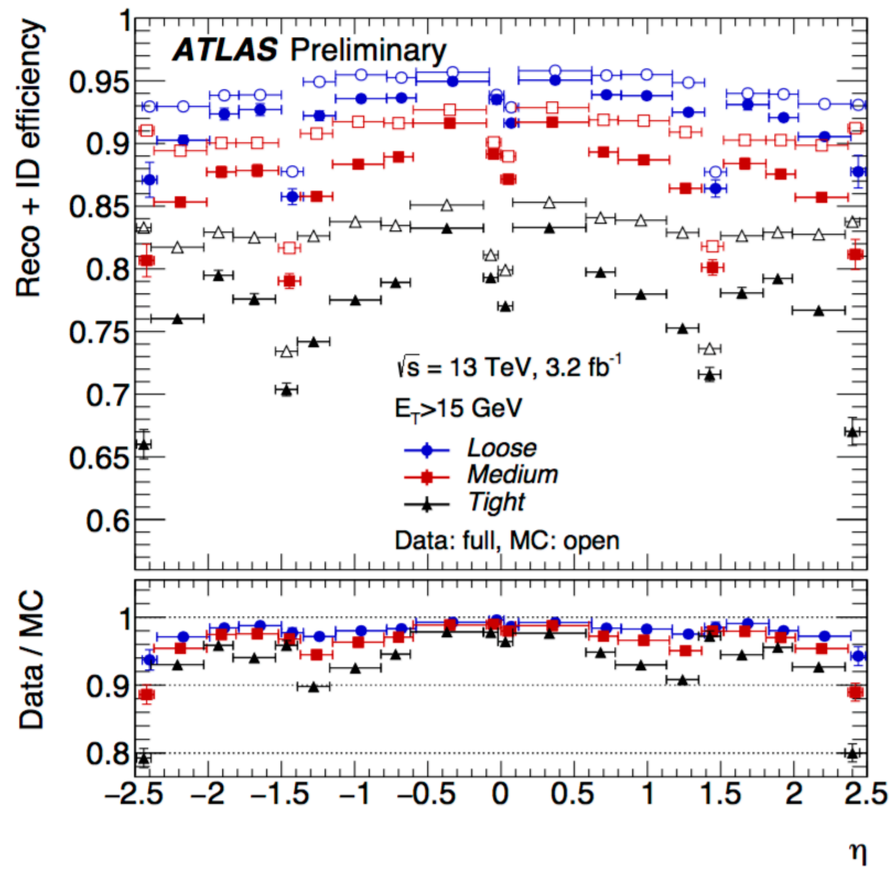




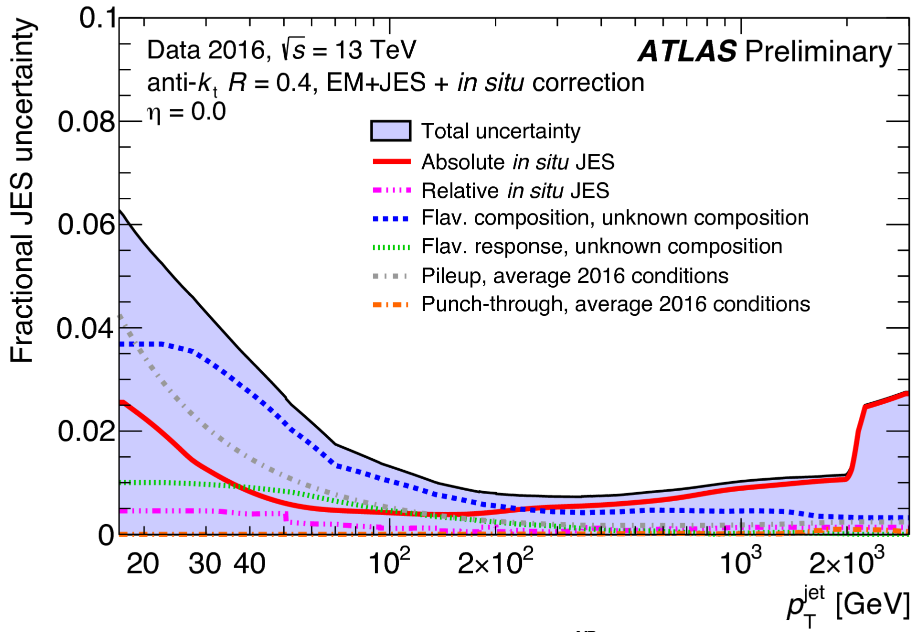
ATLAS-CONF-2016-024
Eur. Phys. J. C. (2016) 76:292

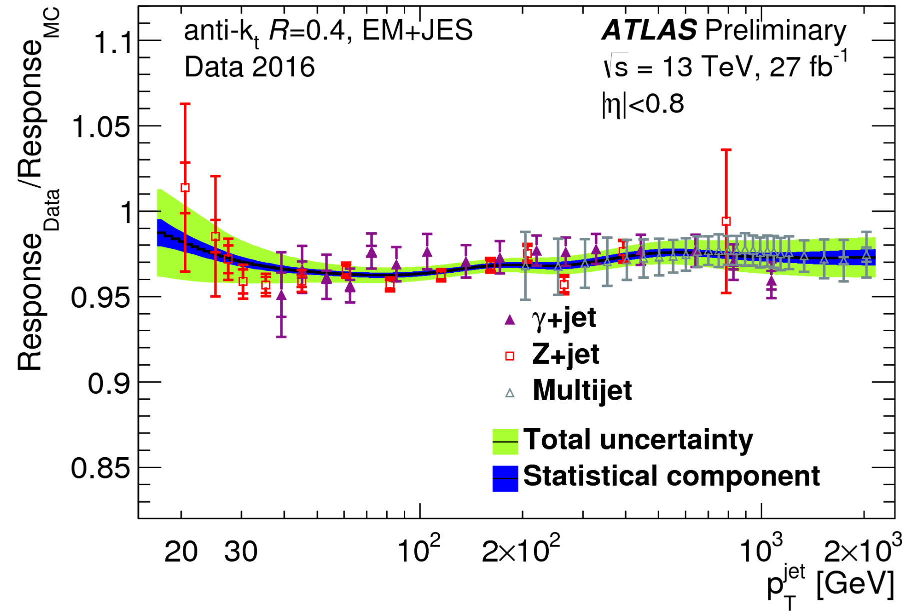
Performance: Electrons

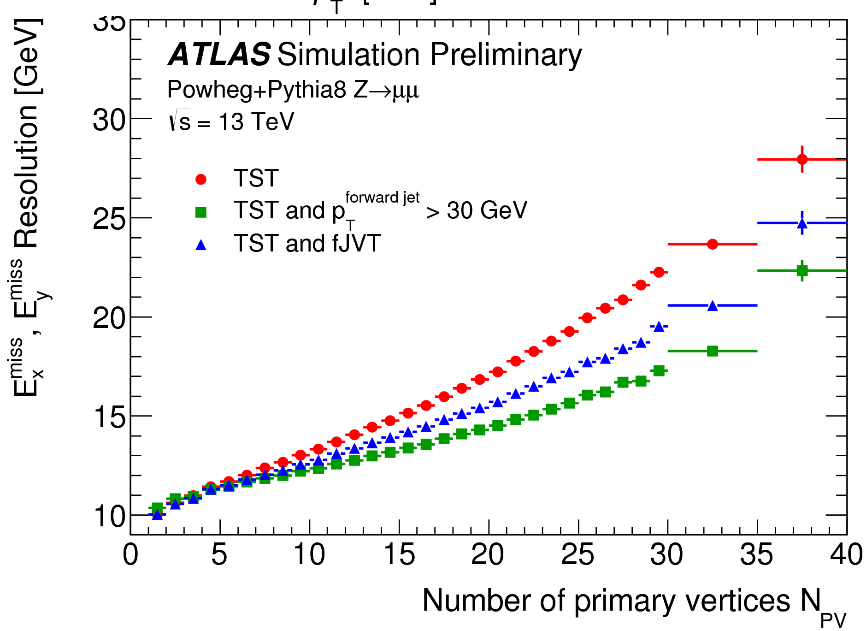




Performance: Jets/E_T^{miss}







arxiv:1704.03848

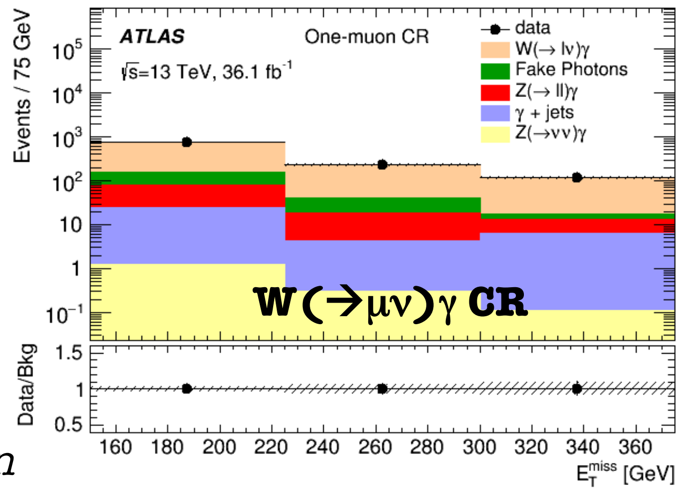
Photon + E_T^{miss} Search

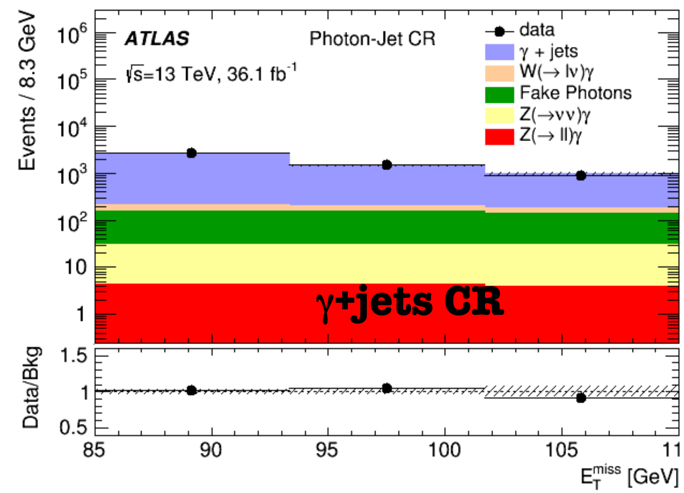
ATLAS EXPERIMENT

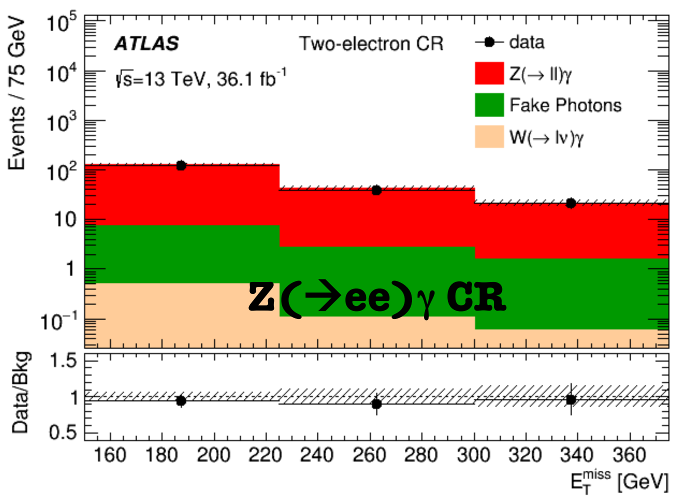
Selection

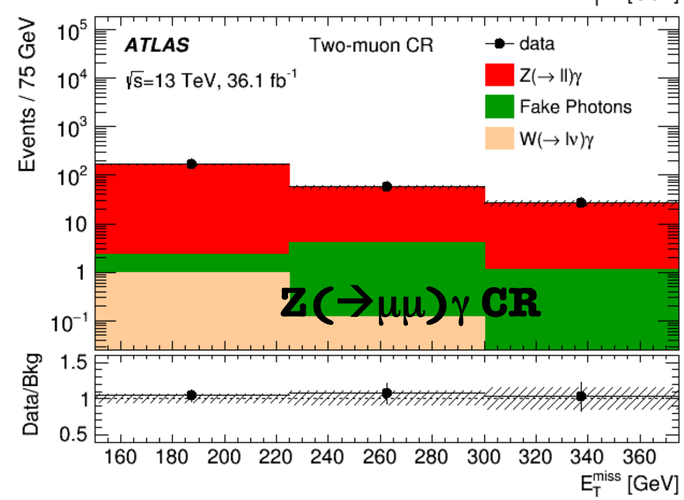
- **High p_T photon.**
  - p_T>150 GeV, $|\eta|$<2.37, tight, isolated.
- **E_T^{miss} > 150 GeV.**
  - $\Delta\phi(\gamma, E_T^{miss}) > 0.4$
- N_{jets} (p_T>30GeV, $|\eta| < 4.5$) ≤ 1
- $\Delta\phi(E_T^{miss}$, jet) > 0.4.
- **SR**: veto on muons (p_T>6 GeV) and electrons (p_T > 7 GeV).

Multiple CRs defined to constrain SM backgrounds (*inverting lepton vetoes, or in different E_T^{miss} regions*).

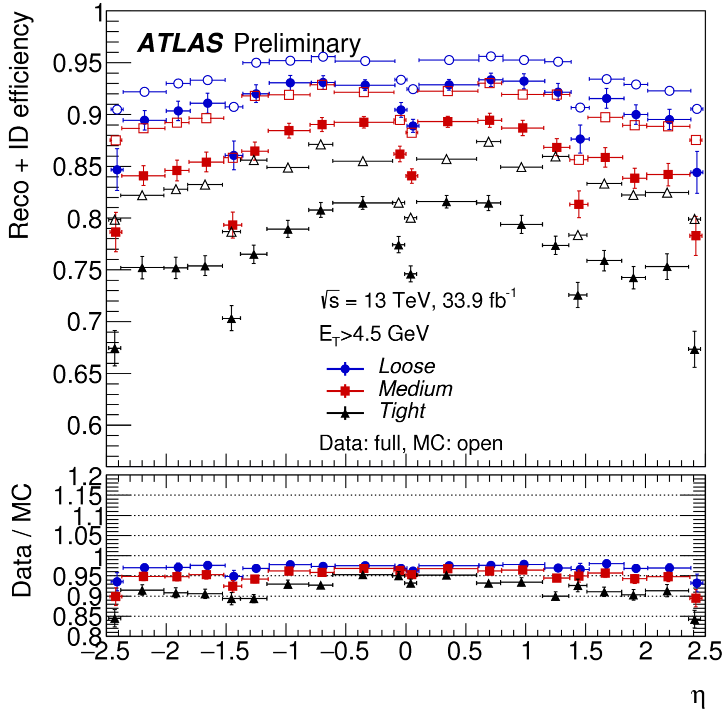


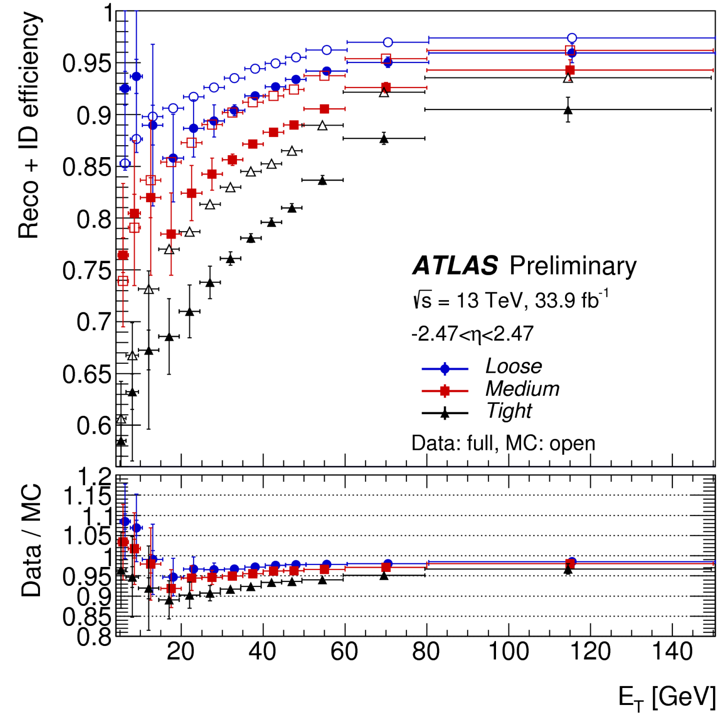


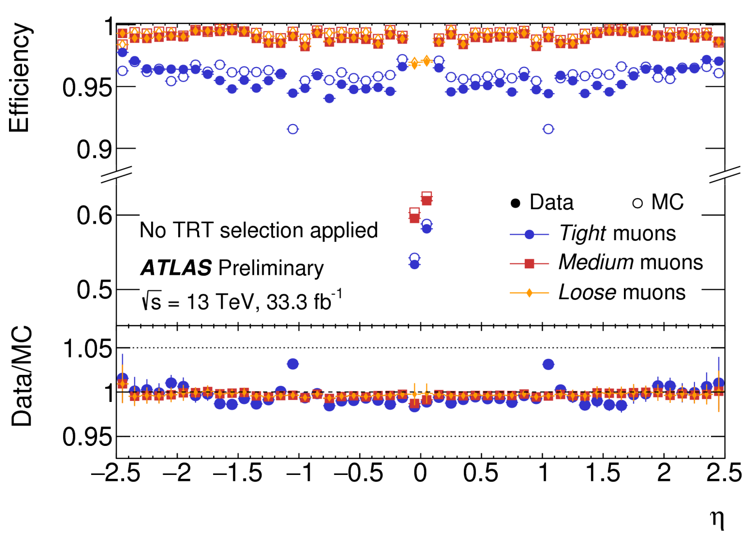


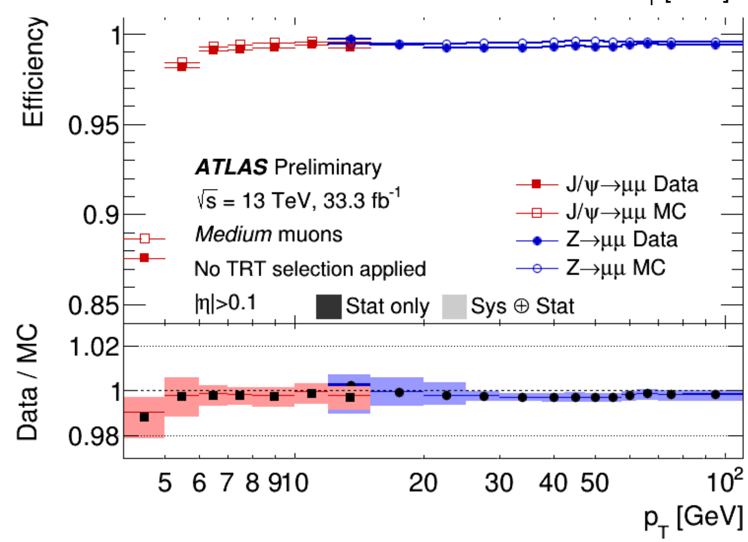


Performance: **Leptons**









Dilepton Search

Strategy

- Main background from Drell-Yan production. Additional contributions from processes including 2 real leptons in the final state (t-tbar, single top quark, diboson).
  - Estimated using MC samples.

***DY** events are simulated with NLO Powheg generator.*
Events yields are corrected with mass dependent rescaling from NLO to NNLO QCD. Mass-dependent EW-corrections at NLO are also applied.

- *Fakes* background: multijet and W+jets events, where one or more jets satisfies the lepton selection.
  - Negligible in di-muon channel.
  - Using data-driven approach: *matrix method*. Measure fake (**f**) and real (**r**) rates: probabilities of a jet or an electron ***to be identified as an electron***.

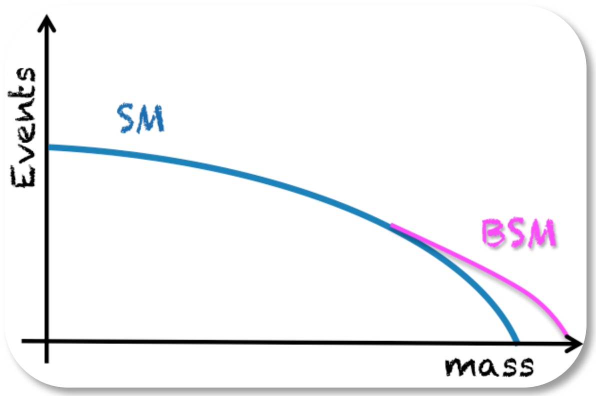
$$\begin{pmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{pmatrix} = \begin{pmatrix} r^2 & rf & fr & f^2 \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)^2 & (1-r)(1-f) & (1-f)(1-r) & (1-f)^2 \end{pmatrix} \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

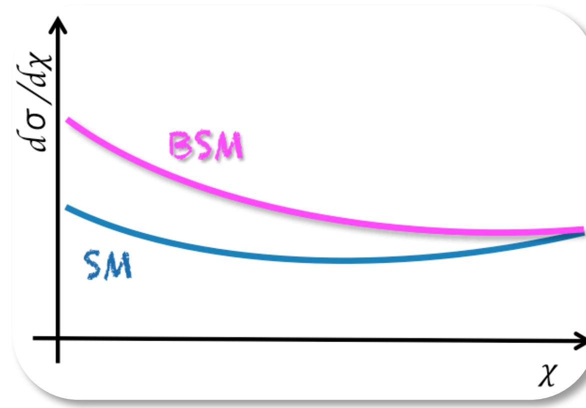
$$N_{TT}^{\text{Multi-jet \& W+jets}} = rf(N_{RF} + N_{FR}) + f^2 N_{FF}$$

  - N_{RF}, N_{FR}, and N_{FF} obtained through matrix inversion

expressed in terms of measurable quantities: N_{TT}, N_{TL}, N_{LT}, N_{LL})

Motivation



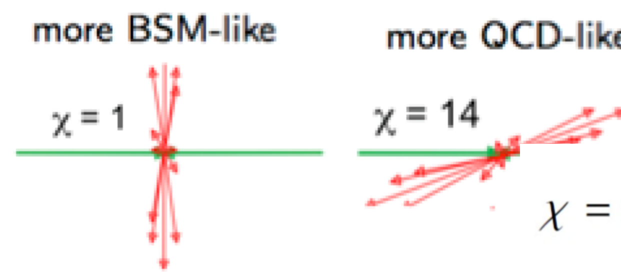


CI in **mass** distributions:

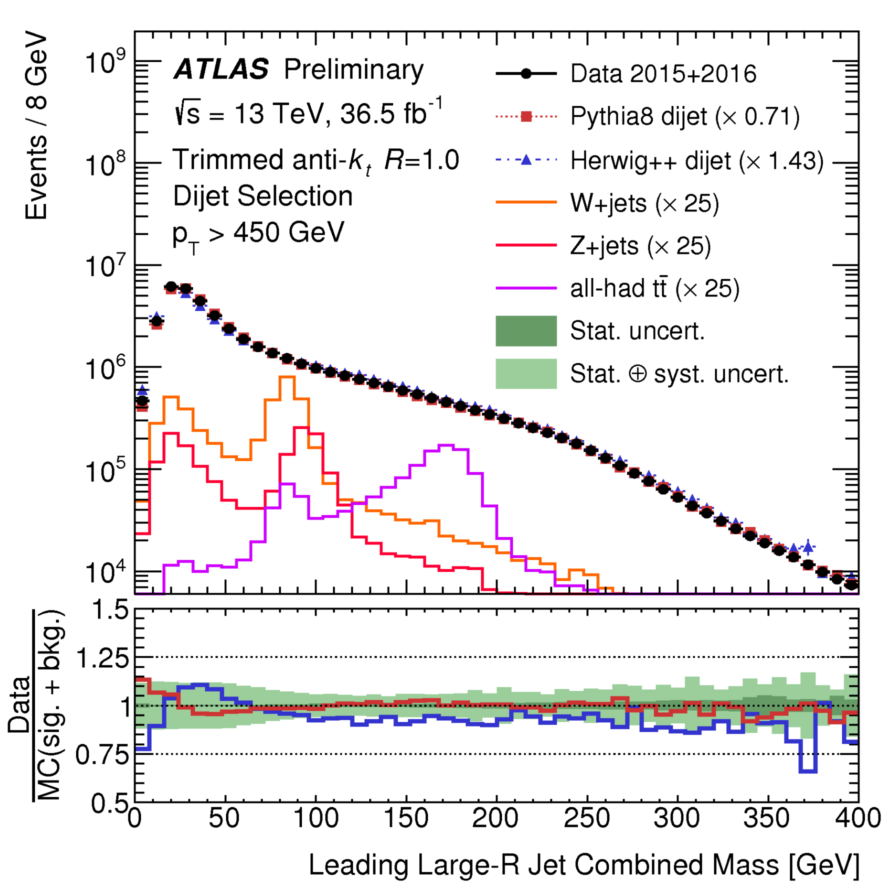
- Observable as broad excess in dilepton invariant mass spectrum.
  - Observation in m_{ll} distribution requires precise understanding of QCD cross section.

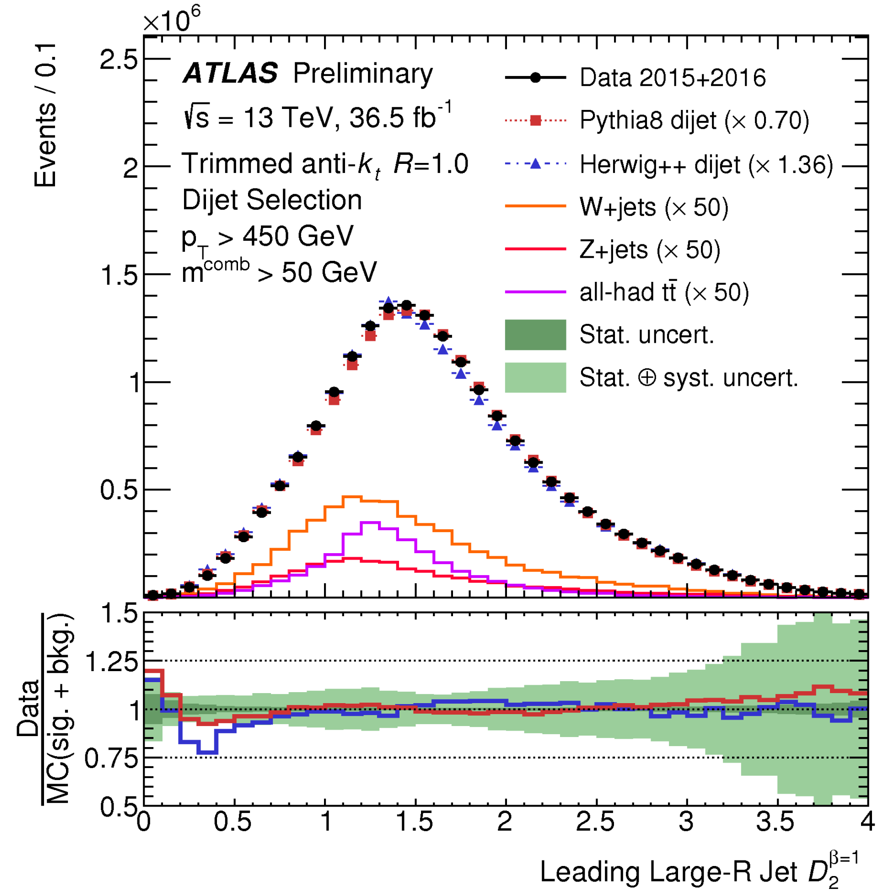
CI in **angular** distributions:

- CI is often more isotropic than QCD.
  - As function of cosθ*.
- Angular distributions have much smaller systematic uncertainties than cross section vs mjj.
- Some sensitivity to resonant signals too.



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


ATLAS Preliminary
√s = 13 TeV, 36.5 fb-1
Trimmed anti-kt R=1.0
Dijet Selection
pT > 450 GeV
Data 2015+2016
Pythia8 dijet (× 0.71)
Herwig++ dijet (× 1.43)
W+jets (× 25)
Z+jets (× 25)
all-had tt̄ (× 25)
Stat. uncert.
Stat. ⊕ syst. uncert.
Events / 8 GeV
Data / MC(sig. + bkg.)
Leading Large-R Jet Combined Mass [GeV]


×10^6
ATLAS Preliminary
√s = 13 TeV, 36.5 fb-1
Trimmed anti-kt R=1.0
Dijet Selection
pT > 450 GeV
mcomb > 50 GeV
Data 2015+2016
Pythia8 dijet (× 0.70)
Herwig++ dijet (× 1.36)
W+jets (× 50)
Z+jets (× 50)
all-had tt̄ (× 50)
Stat. uncert.
Stat. ⊕ syst. uncert.
Events / 0.1
Data / MC(sig. + bkg.)
Leading Large-R Jet D2β=1

Standard Model

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

The **Higgs discovery** further validated the SM (*self-consistent* theory).

Run I legacy: Higgs discovery
The discovery of a new particle also opened a new channel for searches.

Still left with many open questions….

e.g. High-levels of **fine tuning** needed to avoid divergences in Higgs mass corrections.