Search for Dark Matter Produced in Association with a Higgs Boson Decaying to a pair of bottom quarks with the ATLAS Detector

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THESIS DEFENSE
24-10-2018

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OUTLINE

The Dark Matter Paradigm

- Evidence of Dark Matter and Dark Matter searches
- Dark Matter searches at LHC: Mono-X signatures and model interpretations
- The mono-Higgs dark matter signature

Missing Transverse Energy Signifiance

- Missing Transverse Energy reconstruction
- Missing Transverse Energy Significance motivation
- Object-based Missing Transverse Energy Significance [**ATLAS-CONF-2018-038**]

Mono-Higgs Dark Matter Search

- Mono-Higgs with H→bb Analysis
- Result with data collected during 2015-2016. [**Phys. Rev. Lett. 119 (2017) 181804**]
- Results with data collected during 2015-2016 and 2017 [**ATLAS-CONF-2018-039**]

Complementarity

- Mono-h(bb) vs. Mono-h($\gamma\gamma$)
- Mono-X vs. Di-X searches and collider vrs. direct detection

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Mono-Higgs Dark Matter Search

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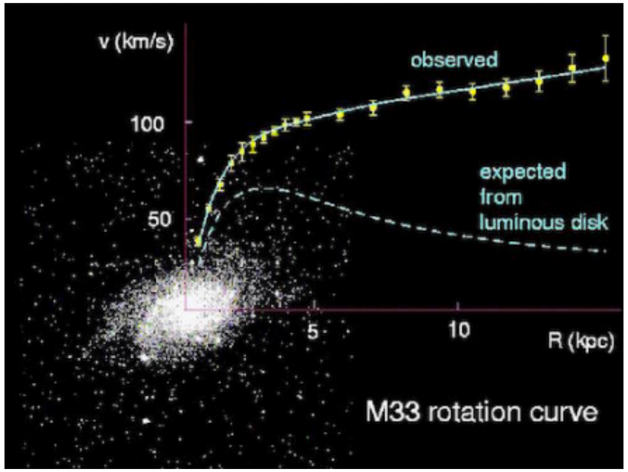
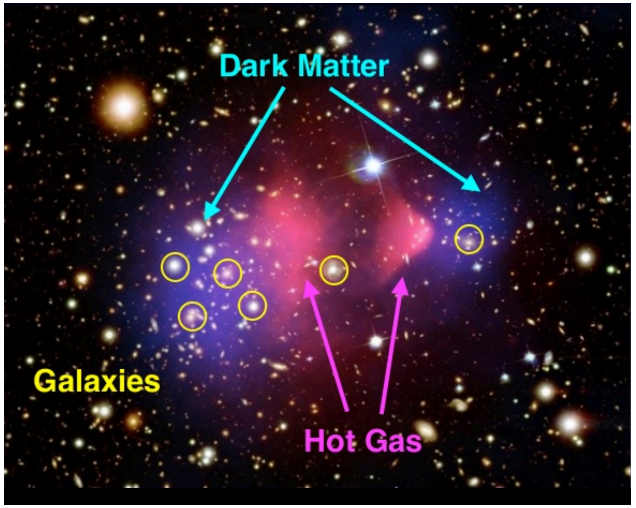
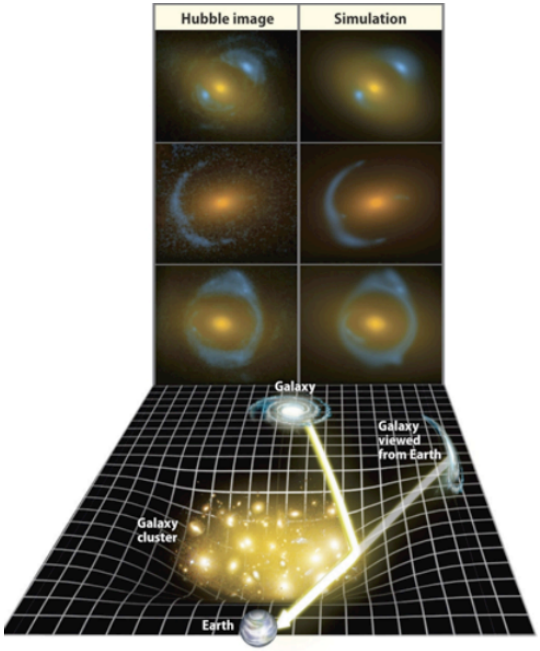
DARK MATTER EVIDENCE

Evidence of Dark Matter (DM) ⟶ Inferred from astrophysical-cosmological observations

- Galaxies rotation curves
- X-ray observation of galaxy collisions
- Gravitational lensing



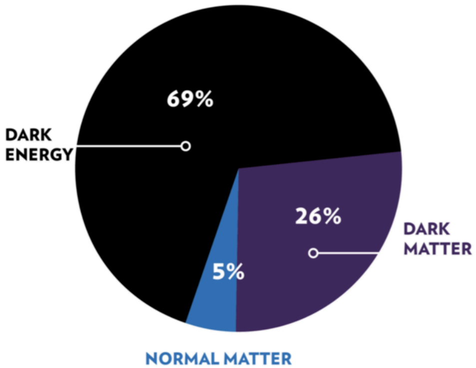




There is no evidence yet for non-gravitational interactions between DM and Stardard Model particles

Nature of DM is unknown and it represent ~25 % of the content of the Universe!

No viable DM candidate Standard Model (SM)



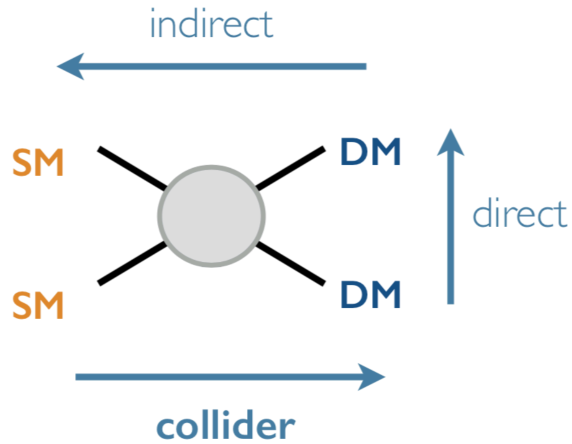
DARK MATTER SEARCHES

- Popular generic DM candidate: Weakly Interacting Massive Particle **WIMP**

What do we know about WIMP DM?

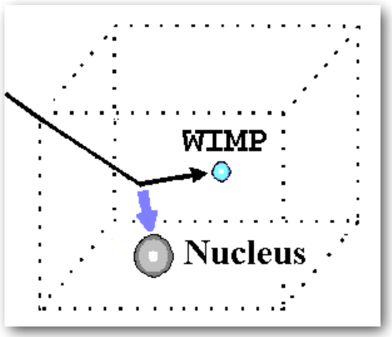
- How much: Ω~0.26
- Cold (Non-relativistic during structure formation)
- Non-baryonic
- Massive
- Electrically **neutral** (Dark)
- **Stable**
- **Weakly interacting**

How to detect DM?



Direct Detection

Momentum transfer to detector through elastic scattering



Indirect Detection

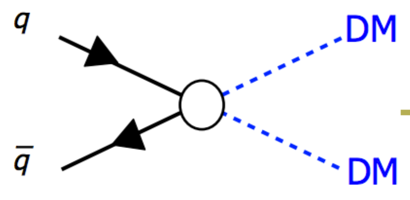
Observation of annihilation products (γ, ν, e+, p, etc)

Production at Colliders

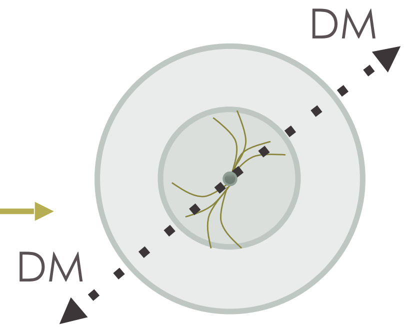
- WIMPs can be produced in *pp* collisions at the LHC
- Cannot directly detect DM particles.
- Instead infer production through large amounts of **Missing Energy** from undetected particles

DARK MATTER PRODUCTION AT LHC

The **basic diagram** of DM production and detection



DM **does not interact** with the detector



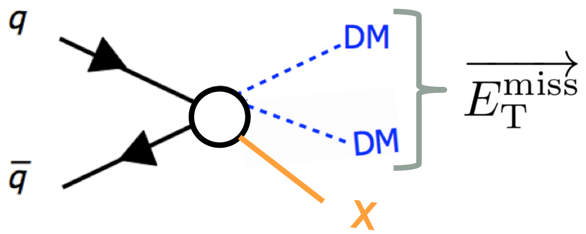
In the transverse plane:

Invisible particles

Then…how to trigger a DM event?

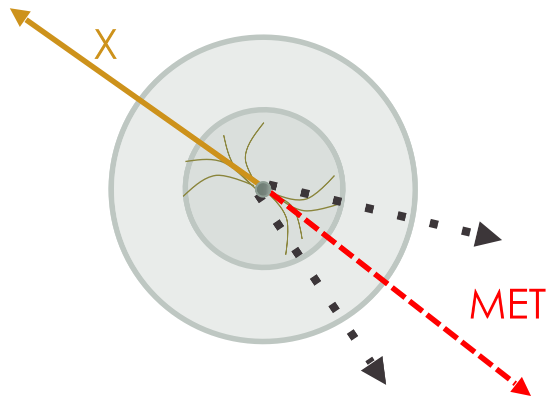
The "Mono-X" Topology

Standard Model (SM) particles ('**X**') **recoils against missing transverse momentum**



In the final state we look for…

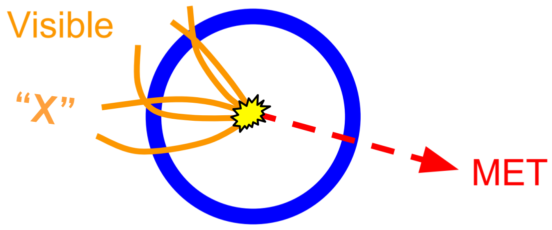
- Large Missing Transverse Momentum (**MET**)
- Well defined SM particle 'X'



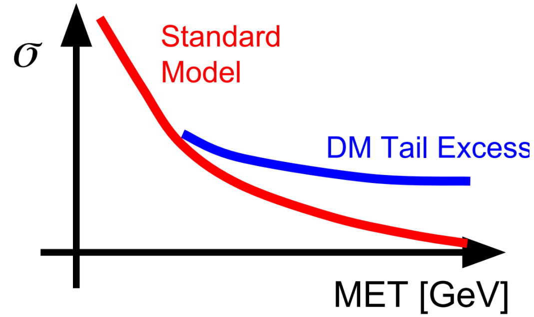
MONO-X DARK MATTER SIGNATURES AT LHC

Searching for excess in energy imbalance on the transverse plane, **MET**

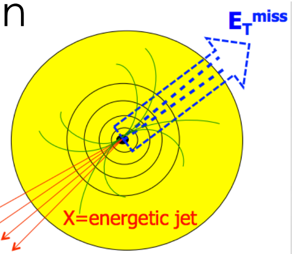
Select - Select events with "X"
- veto other activity



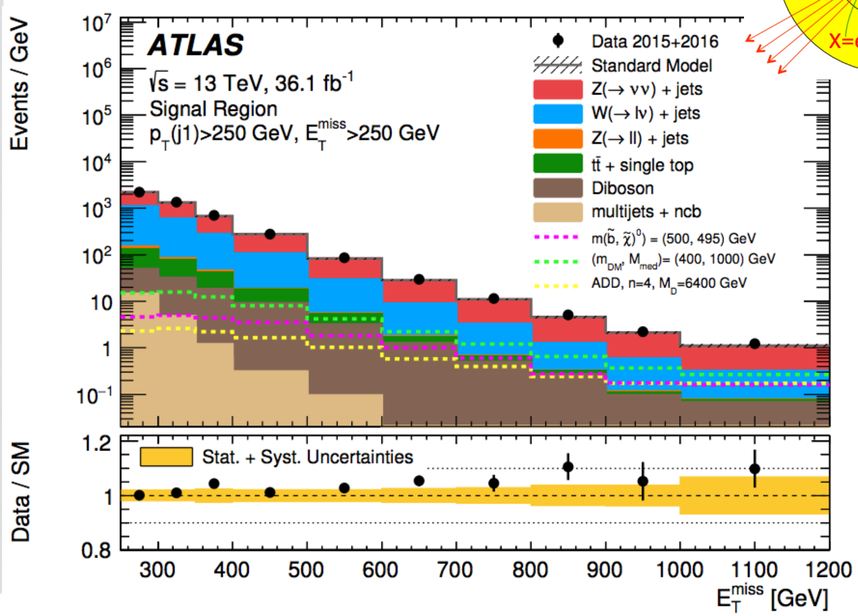
Goal - Search for excess in MET tail



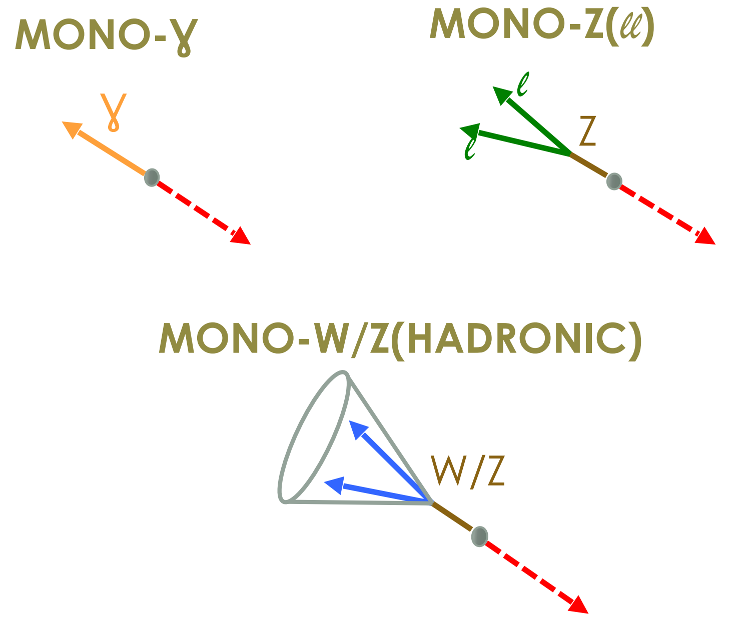
E.g: If **'X'** is a initial state radiated gluon
MONO-jet



JHEP 01(2018)126

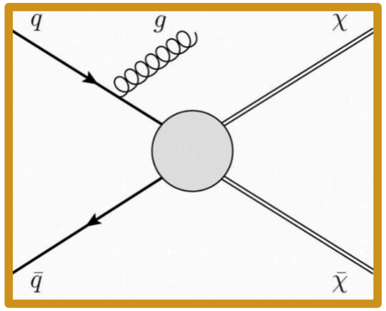


Some members of the mono-X family



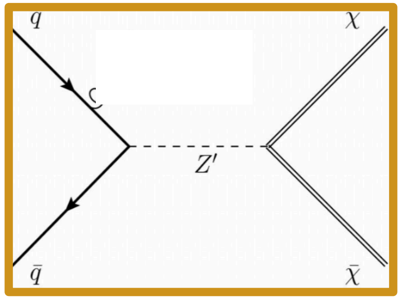
DARK MATTER MODELS

Completeness / Complexity



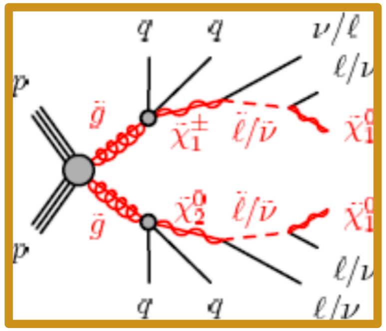
Effective Field Theories

- Contact interaction assumed between DM and SM



Simplified Models

- Renormalizable minimal extension of SM
- Involving ***DM candidate*** + ***Mediator***

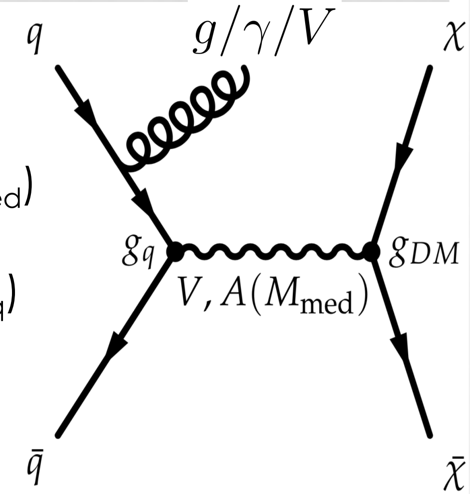


UV complete Model

- Can explain the hierarchy and other SM problem
- Naturally provide DM candidate

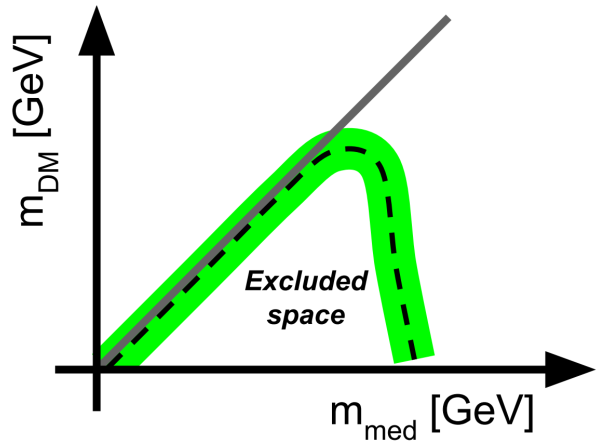
Free parameters:

- mediator mass (M_{Med})
- WIMP mass (m_χ)
- 2 couplings (g_{DM}, g_q)



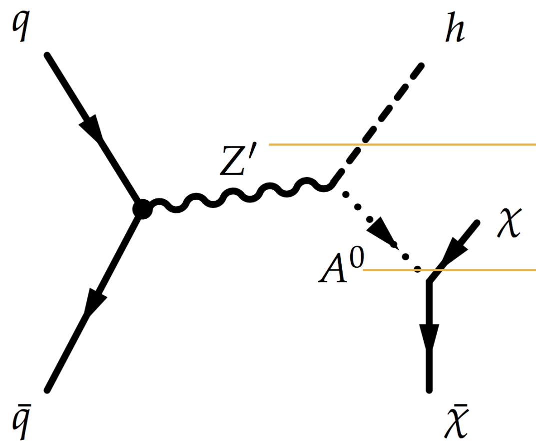
4-dimensional problem, projecting limits onto a 2-D plane

Ex.: Choose {g_q, g_{DM}}
→ Exclude {m_{med}, m_{DM} }



MONO-H SIMPLIFIED MODELS

Vector+Pseudoscalar (Z'-2HDM)



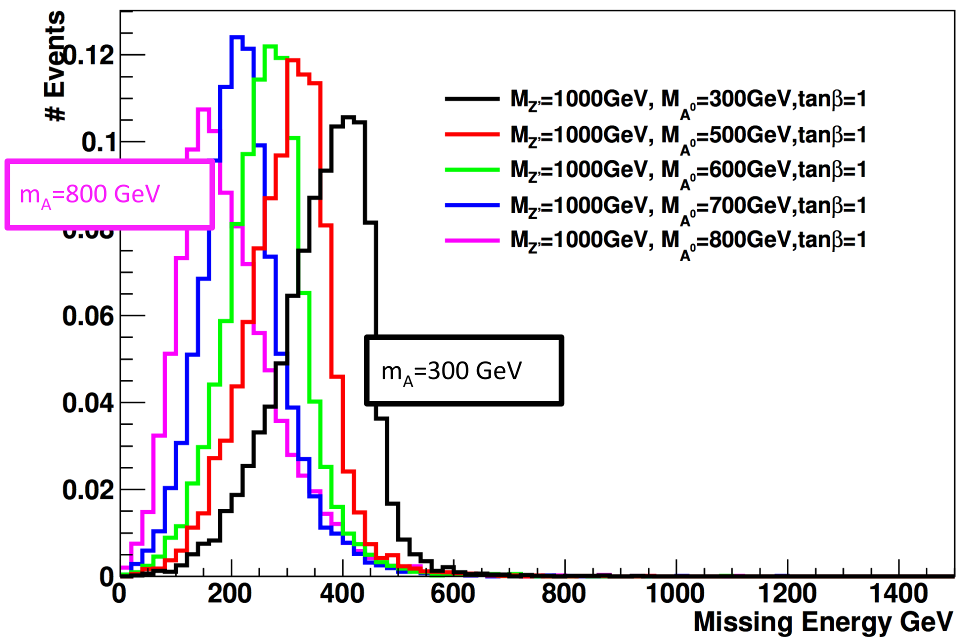
New massive vector boson

Pseudoscalar from a 2HDM Type 2

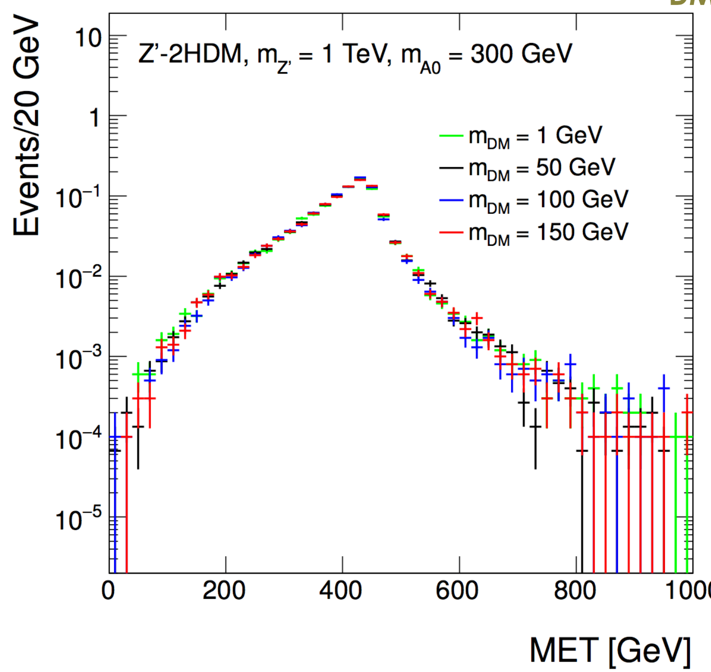
Fixed Parameters

- m_χ = 100 GeV
- $\tan\beta$ = 1.0
- g_{Z0} = 0.8
- $m_H = m_{H\pm}$ = 300 GeV
- $BR(A \rightarrow \chi\chi)$ = 100%

Different pseudoscalar masses m_A



Different dark matter masses m_{DM}

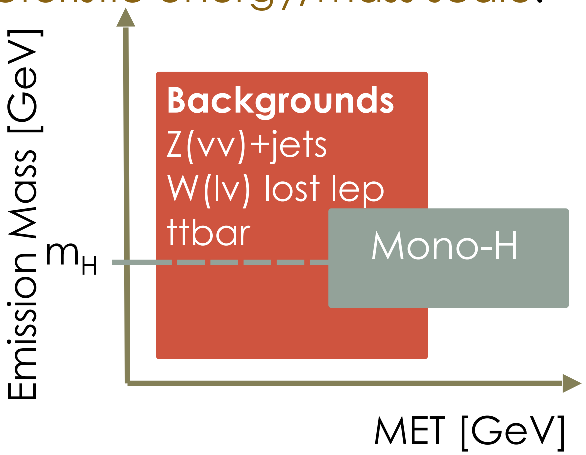


MONO-H SEARCH FOR DARK MATTER

Higgs boson discovery in Run1 provides unique method for probing dark matter at LHC

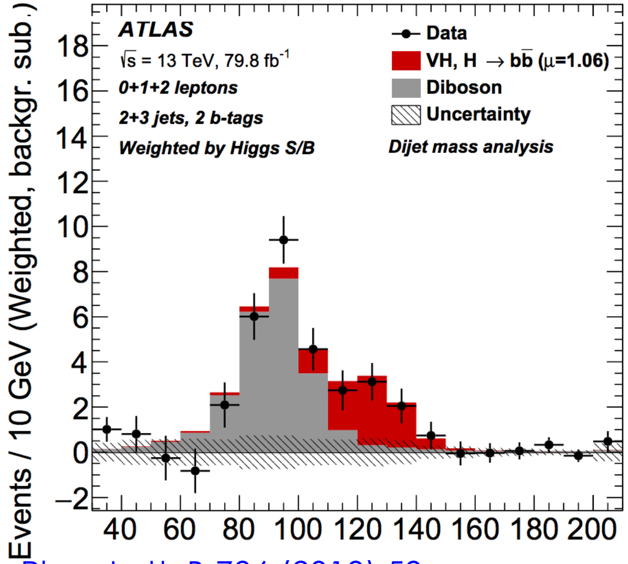
◇ **No Initial State Radiation Higgs**
- More closely connected to DM production
- Provides direct probe of DM-SM coupling

◇ **Signature extended beyond a high MET tail**
- The visible part of the event has a characteristic energy/mass scale.

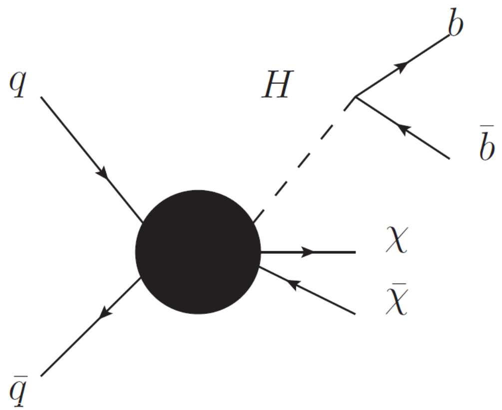


◇ **H→bb dominant decay mode**
- H(125)→bb branching ratio is ~57%

◇ Observation H→bb



[Phys. Lett. B 786 (2018) 59]

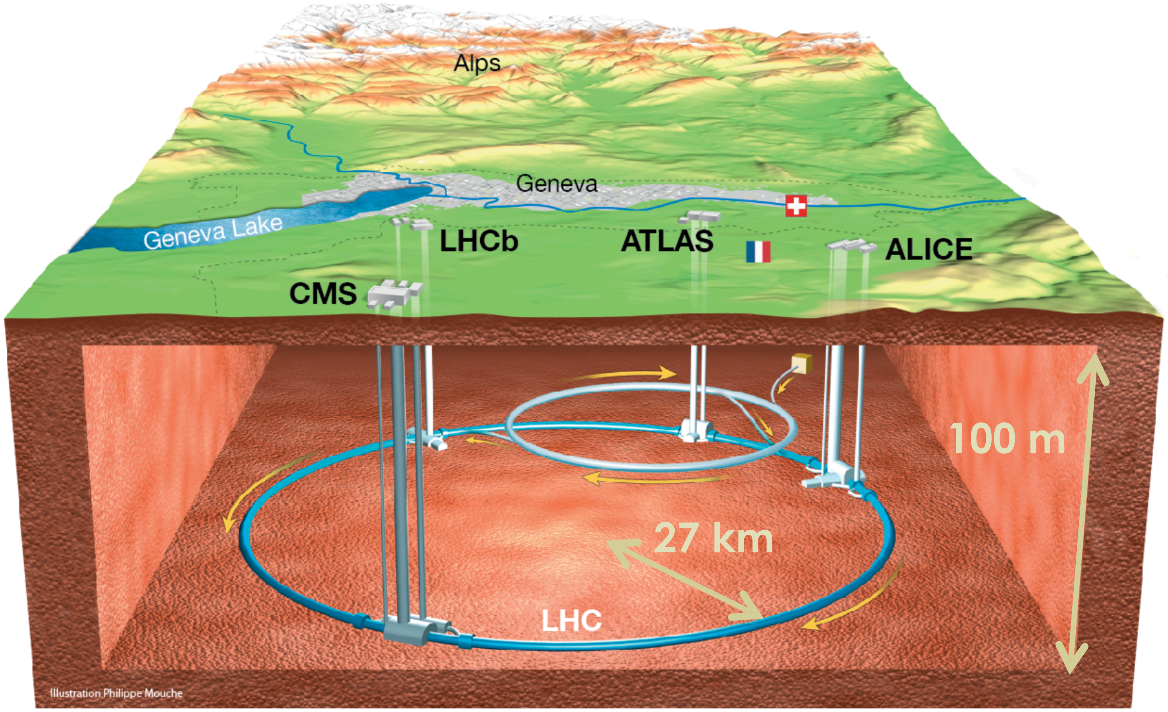


Main ingredients:
- Jets
- b-tagging
- MET

THE LARGE HADRON COLLIDER (LHC)

Proton-proton circular accelerator providing collisions each 25 ns

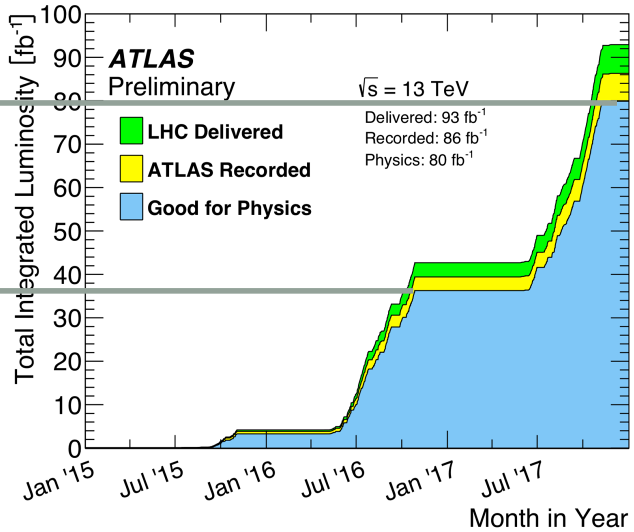
Designed to achieve high centre of mass energy and high luminosity

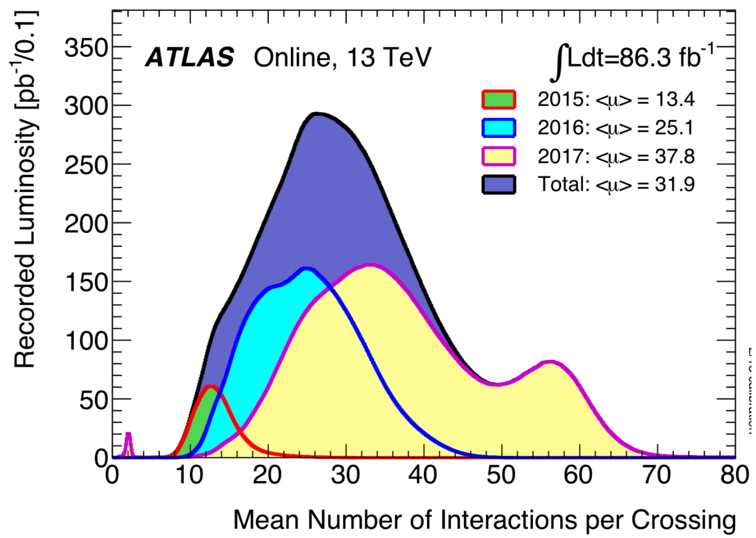


Run 2 (2015-2018) data-taking
$\sqrt{s}$ = 13 TeV

79.8 fb^{-1}

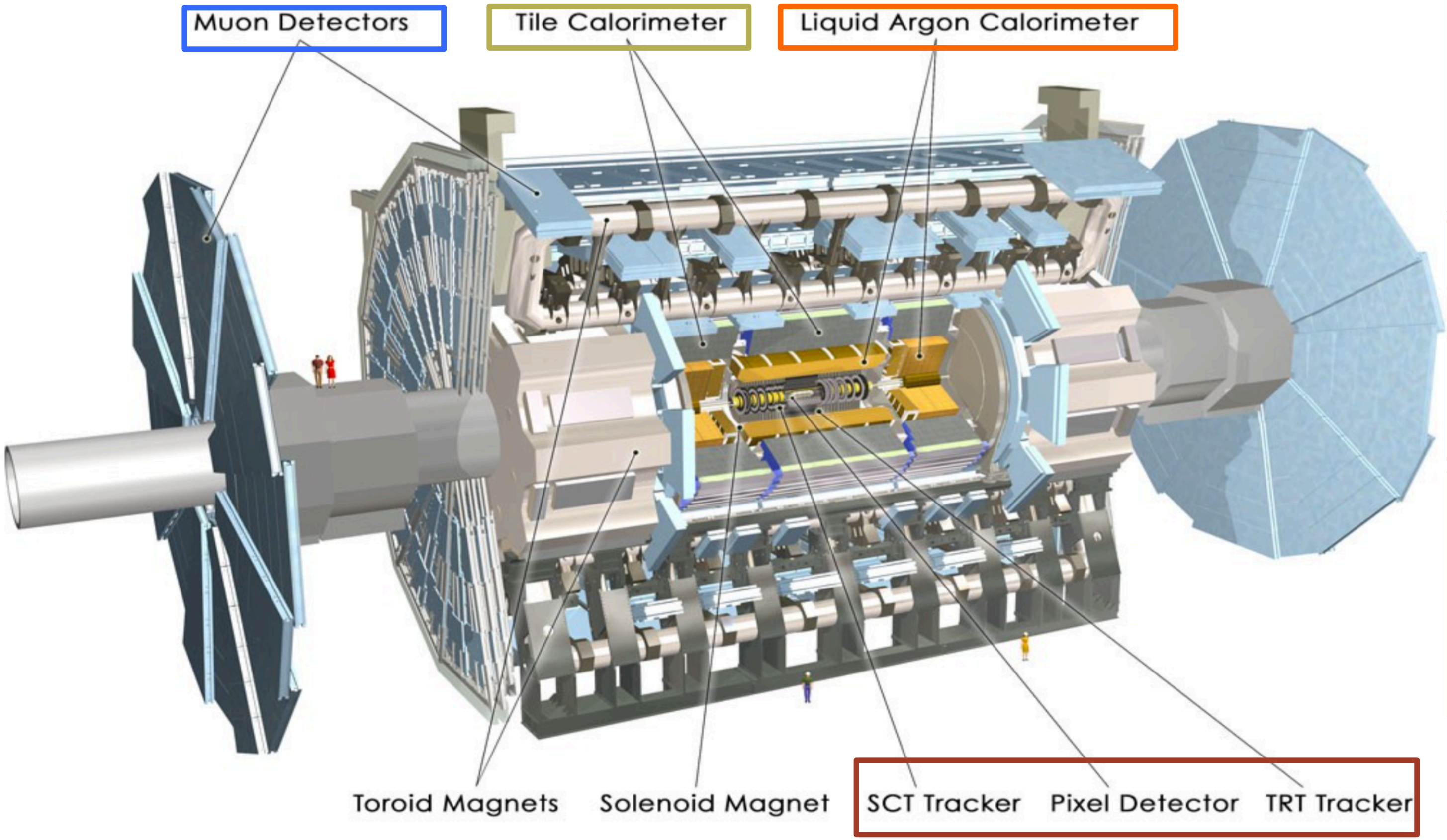
36.5 fb^{-1}





ATLAS DETECTOR

General-purpose, ~4π detector for multi-TeV *pp* collisions



Sub-detectors

Inner Detector
- Charged particles tracks
- Decay vertices

Electromagnetic Calorimeter
- Electron and photon energy/direction

Hadronic Calorimeter
- Charged and neutral hadrons energy/ direction

Muon spectrometer
- Muon tracks

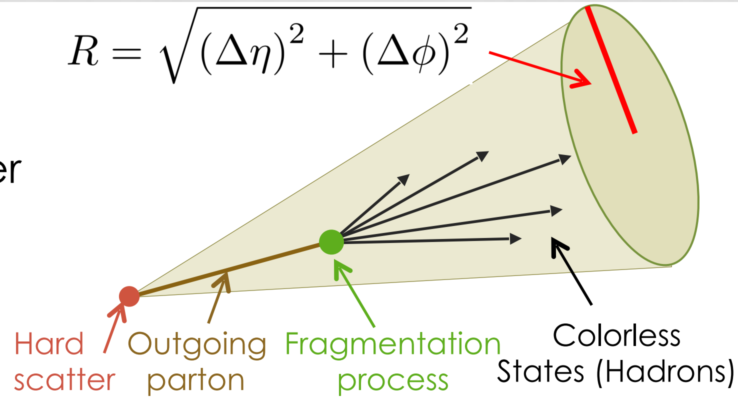
JET RECONSTRUCTION

Jets represent hadronic showers in a detector

ATLAS primarily uses the anti-kt algorithm, with topo-cluster inputs: **Calorimeter jets**

- Topo-clusters: topological groups of noise-suppressed calorimeter cells

$$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

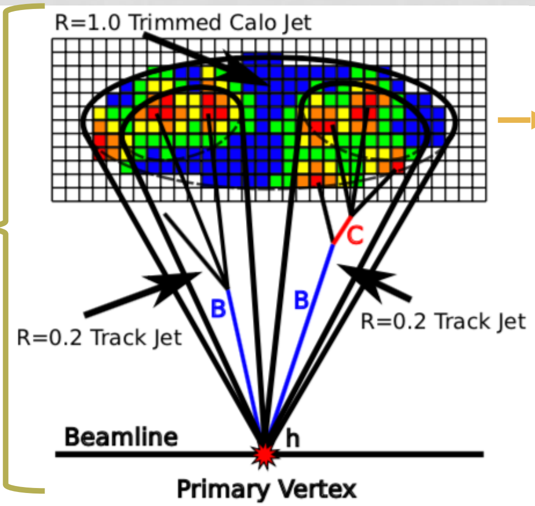


Depending on physics intent, different types of jets are useful

- **Small-R jets: R = 0.4**

For boosted topologies:

- **Large-R jets: R = 1.0**



Calorimeter jet

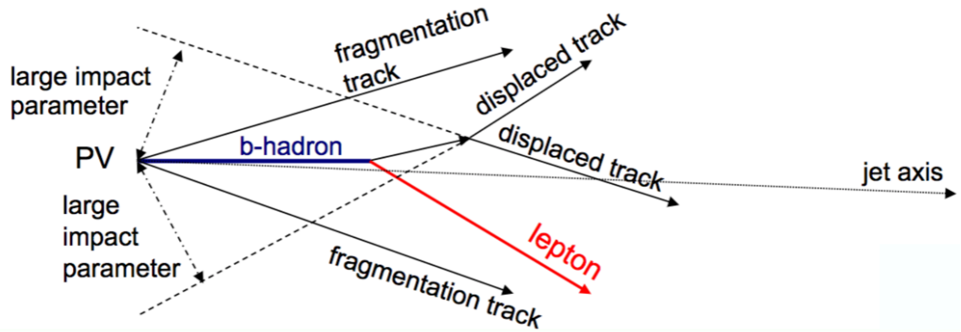
Track jet

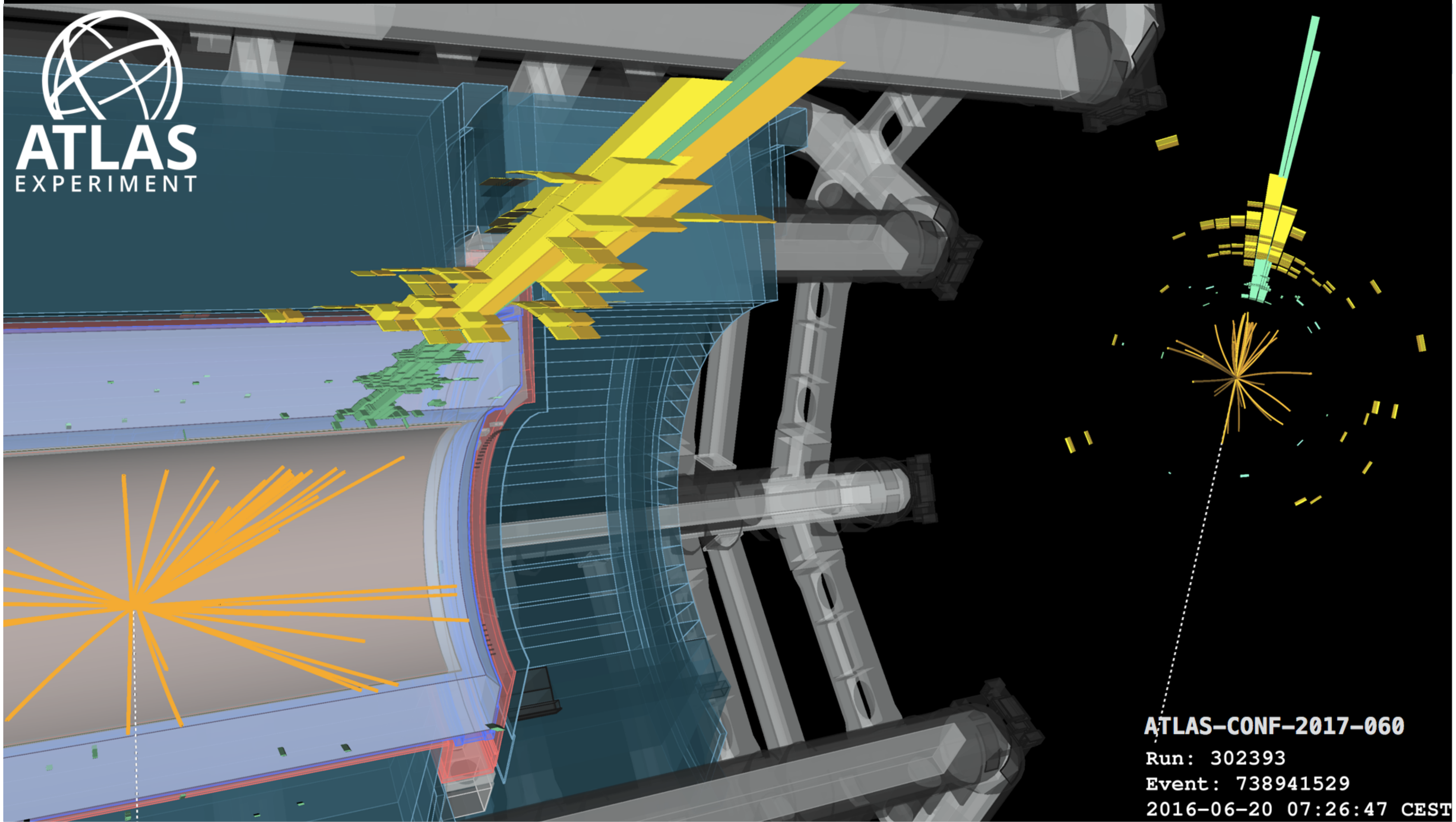
Reconstructed from tracks R=0.2

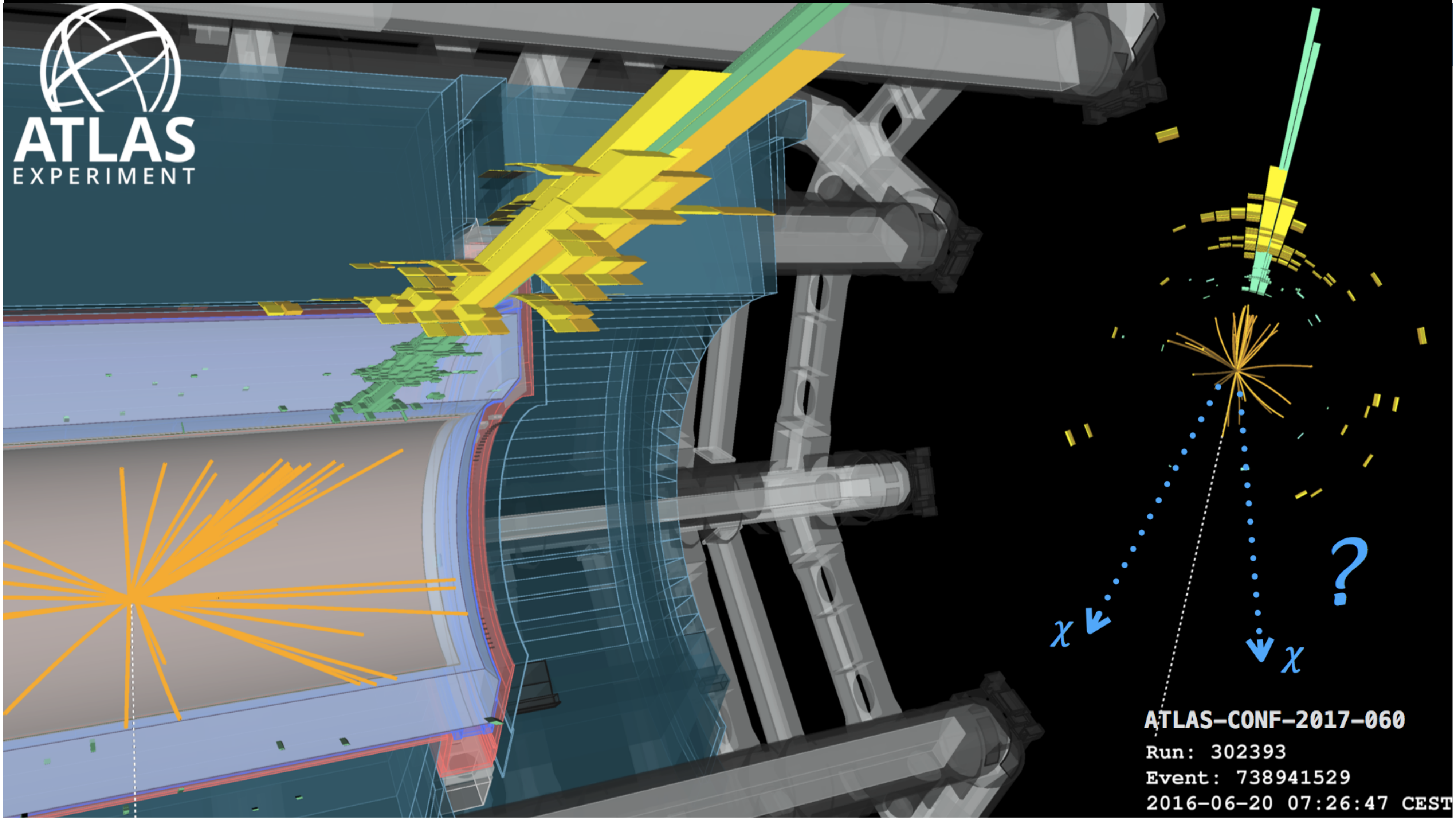
B-jet identification : "b-tagging"

MVA algorithm. Uses b-hadron properties:

- Large lifetime
- High decay multiplicity
- Often decays semi-leptonically ~42%




ATLAS
EXPERIMENT
ATLAS-CONF-2017-060
Run: 302393
Event: 738941529
2016-06-20 07:26:47 CEST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MISSING TRANSVERSE ENERGY RECONSTRUCTION

◇ **Missing Transverse Energy (MET)**

$$\sum_i \vec{p}_i = 0 \quad \Longrightarrow \quad \sum_{\text{observable}} \vec{p}_i + \vec{E}_T^{\text{miss}} = 0 \qquad \vec{E}_T^{\text{miss}} = -\sum_{\text{observable}} \vec{p}_i$$

When something is missing

Two effects could imply an imbalance in the total transverse momentum (MET ≠ 0)

- ◇ **Non-interacting particles** (Real MET): SM particles (neutrinos), new physics (Dark Matter, SUSY, etc.)
- ◇ **Fake detection** (Fake MET): Objects misreconstruction, detector effects (dead regions).

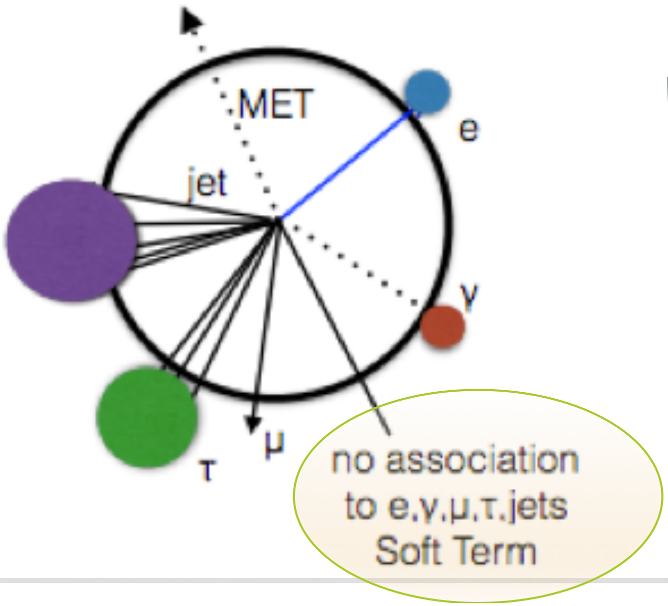
Reconstructed Met = Calorimeter Objects + Muons + Soft Terms

Calorimeter Objects: Electrons, Photons, Taus, Jets

Calorimeter Objects + Muons: Hard Objects

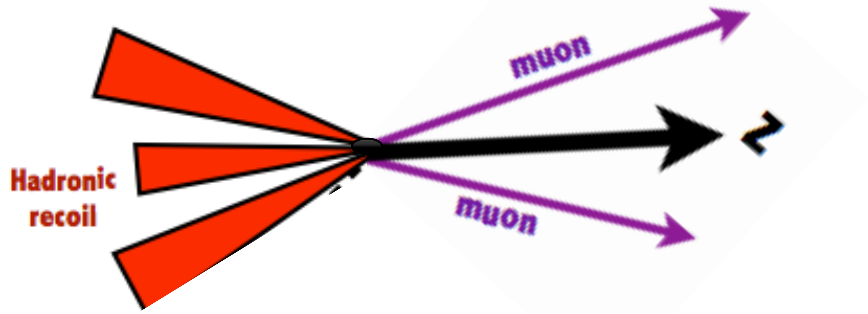
Soft Terms: Every signal which can't be clearly identified/calibrated.

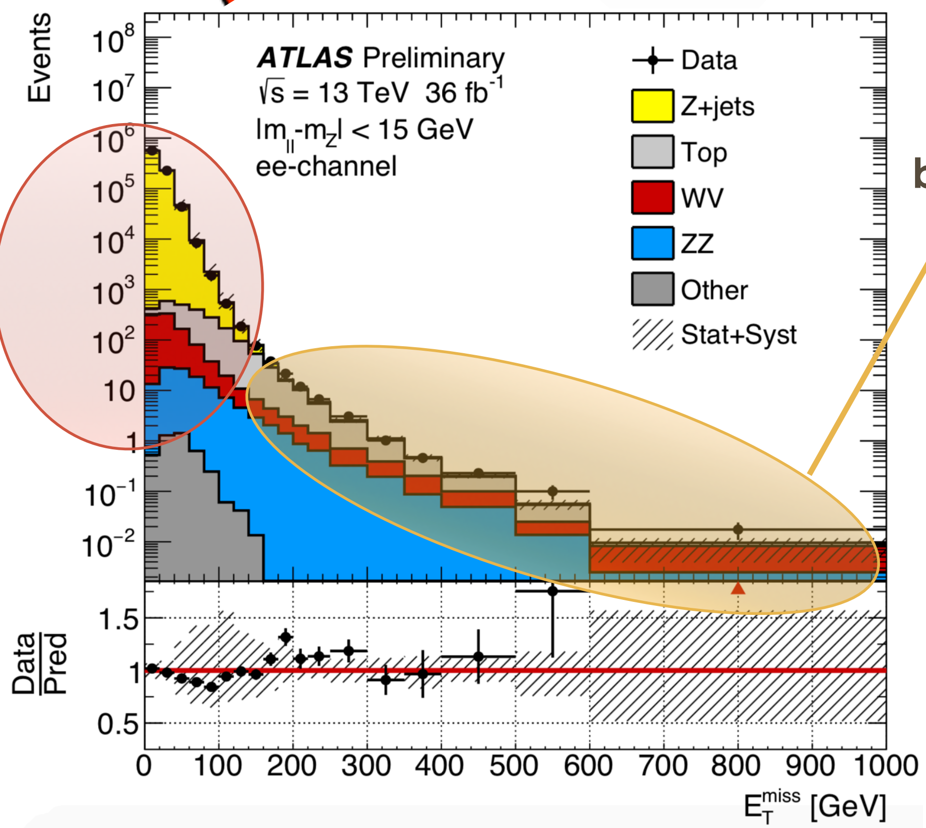
- Track based Soft Term (TST)
- Calorimeter based Soft Term (CST)



MISSING TRANSVERSE ENERGY PERFORMANCE

In order to study the performance of the MET, we want to consider **a clean process without genuine MET: Z → ℓℓ + jet**





The **bulk** of the distribution mostly provided by **fake MET** reconstruction

True MET issued from **background** processes

Eg. ZZ → ℓℓ + νν

MET SIGNIFICANCE INTRODUCTION

Significance of an observable

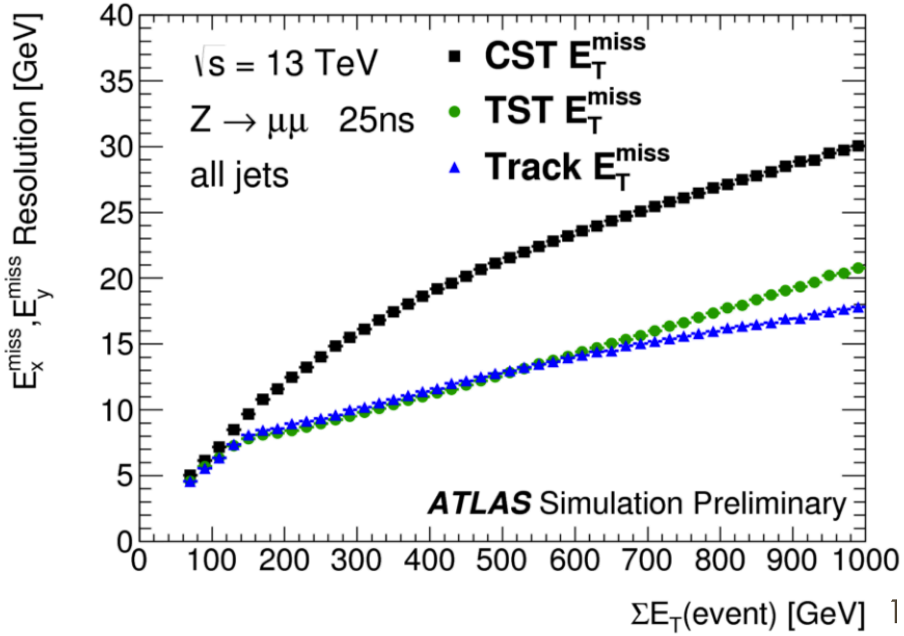
- Useful for signal-background discrimination
- Accounts also for the observable resolution → $\mathrm{Signif}(X) = \frac{X}{\sigma_X}$

A **high value** of **MET significance** is an indication that the observed MET is not well explained by resolution smearing alone, suggesting that the event may contain **unseen objects** such as neutrinos or more exotic weakly interacting particles.

"Old" MET Significance used in ATLAS

$$\mathcal{S} = \frac{E_{\mathrm{T}}^{\mathrm{miss}}}{\sqrt{\sum E_{\mathrm{T}}}} \qquad \mathcal{S} = \frac{E_{\mathrm{T}}^{\mathrm{miss}}}{\sqrt{H_{\mathrm{T}}}}$$

- Proxies for the MET resolution
- Event based quantities, neglecting the nature of the objects.
- Do not take into account directional correlations



BEYOND THESE APPROXIMATIONS: OBJECT-BASED MET SIGNIFICANCE

Object-based MET significance definition

- Based on the **expected resolutions** for all objects that enter the MET reconstruction
- **Event by event** calculated

How likely is the measured MET to be genuine MET or a resolution effect?

This can be evaluated with the log-likelihood ratio:

$$\mathcal{S}^2 = 2\ \ln\left(\frac{\max_{p_{\mathrm{T}}^{inv}\neq 0} \mathcal{L}(\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}|\boldsymbol{p}_{\mathrm{T}}^{inv})}{\max_{p_{\mathrm{T}}^{inv}=0} \mathcal{L}(\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}|\boldsymbol{p}_{\mathrm{T}}^{inv})}\right)$$

If we assume that …

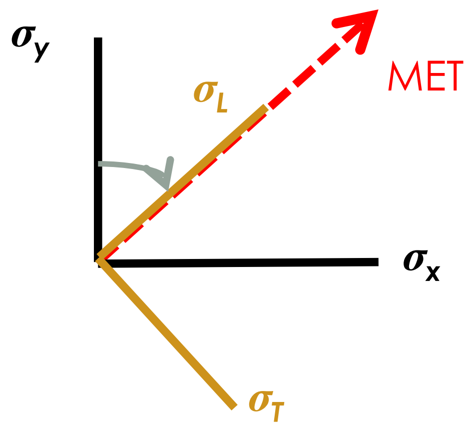
- The sum of all the truth transverse momentum is equal to zero
- Gaussian object resolutions

Met Significance corresponds to a χ^2 variable:

$$\mathcal{S}^2 = \left(\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}\right)^{\mathsf{T}} \left(\sum_i \mathbf{V}^i\right)^{-1} \left(\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}\right)$$

Covariance matrix for each object

In a coordinate system **longitudinal** and **transverse** to the total MET axis:



$$\sum_i \mathbf{V}^i = \begin{pmatrix} \sigma_L^2 & \rho_{LT}\sigma_L\sigma_T \\ \rho_{LT}\sigma_L\sigma_T & \sigma_T^2 \end{pmatrix}$$

OBJECT-BASED MET SIGNIFICANCE DEFINITION

$$\mathcal{S} = \frac{|E_{\mathrm{T}}^{\mathrm{miss}}|}{\sqrt{\sigma_L^2\,(1-\rho_{LT}^2)}}$$

Resolutions

- Hard object variances
- Soft Terms variance

Total Variance Longitudinal

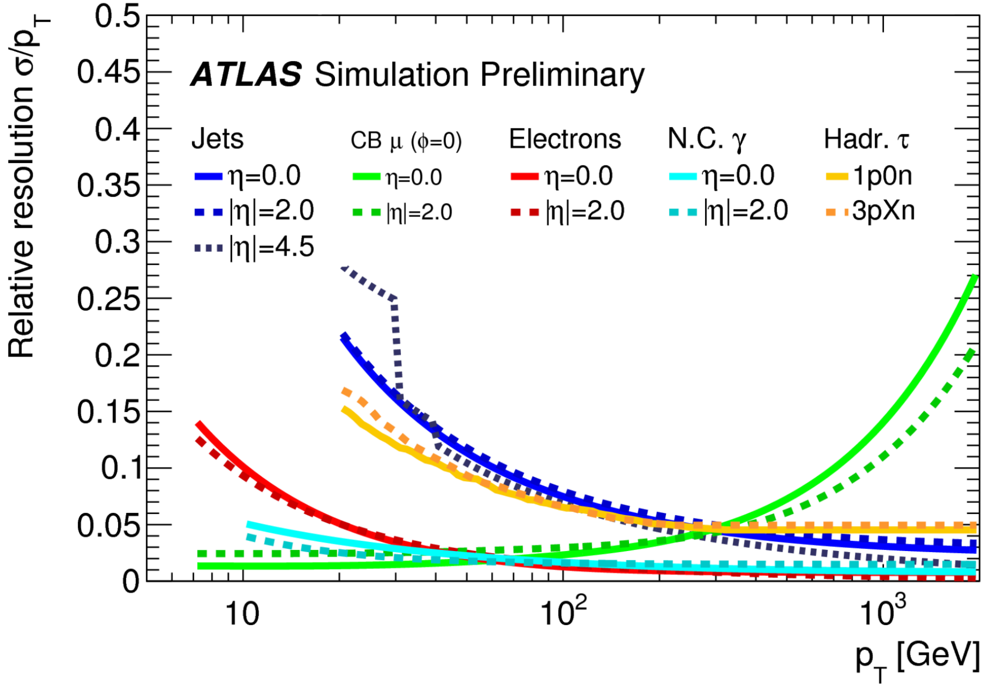
$$\sigma_L^2 = \sigma_L^{hard^2} + \sigma_L^{soft^2}$$

Transverse momentum resolution in the transverse plane for the hard objects

$$\mathbf{V}_i = \begin{pmatrix} \sigma_{p_{T\,i}}^2 & 0 \\ 0 & {p_{T\,i}}^2 \sigma_{\phi_i}^2 \end{pmatrix}$$

Resolution parallel to the direction of the object

Resolution perpendicular to the direction of the object



Object	Kinematic	Relative resolution Parallel	Relative resolution Perpendicular
Electrons	$p_{\mathrm{T}} = 100$ GeV, $\eta = 0$	1.7%	0.4%
Photons	$p_{\mathrm{T}} = 100$ GeV, $\eta = 0$	1.9%	0.4%
Hadronic τ	$p_{\mathrm{T}} = 100$ GeV, $\eta = 0$	5.5% – 6.7%	1%
Jets	$p_{\mathrm{T}} = 20$ GeV, $\eta = 0$	22%	4.6%–7.1%
	$p_{\mathrm{T}} = 100$ GeV, $\eta = 0$	7%	1.1%–1.6%
Muons	$p_{\mathrm{T}} = 100$ GeV, $\eta = 0$	2–4%	0.1%
Track Soft Term		8.9 GeV	8.9 GeV

OBJECT-BASED MET SIGNIFICANCE DEFINITION

$$\mathcal{S} = \frac{\left|E_{\mathrm{T}}^{\mathrm{miss}}\right|}{\sqrt{\sigma_L^2\left(1-\rho_{LT}^2\right)}}$$

Resolutions

- ◇ Hard object variances
- ◇ Soft Terms variance

Total Variance Longitudinal

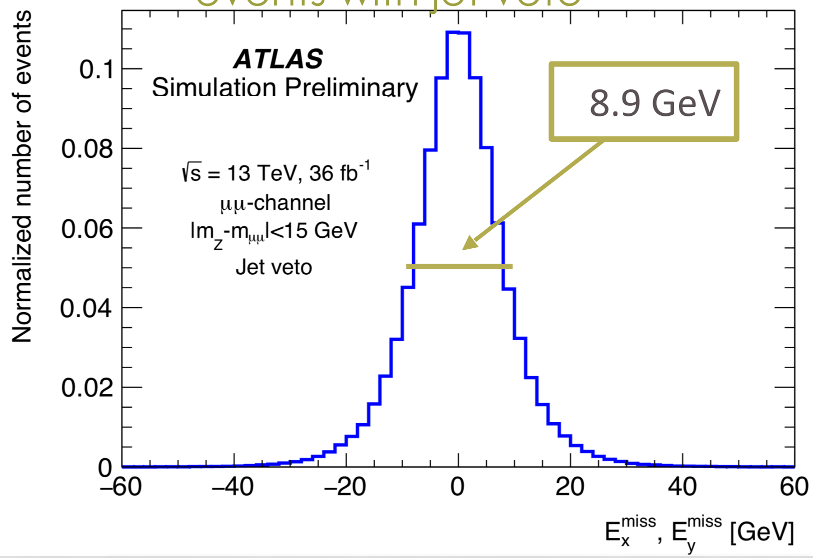
$$\sigma_L^2 = \sigma_L^{hard^2} + \sigma_L^{soft^2}$$

An additional **covariance matrix** associated to the soft term is also considered:

$$\mathbf{V}_{\mathrm{soft}} = \begin{pmatrix} \sigma_{\mathrm{soft}}^2 & 0 \\ 0 & \sigma_{\mathrm{soft}}^2 \end{pmatrix}$$

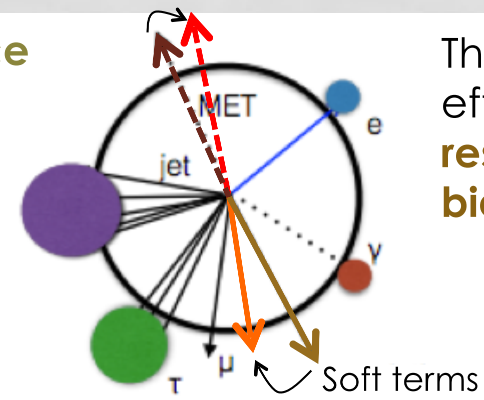
Constant soft Term resolution

RMS of the MET projection on x in $Z \rightarrow \mu\mu$ events with jet veto



Improving object-based MET significance

The neutrals not associated to any hard objects are not in the Soft Term. As a result we expect to have a **bias**.



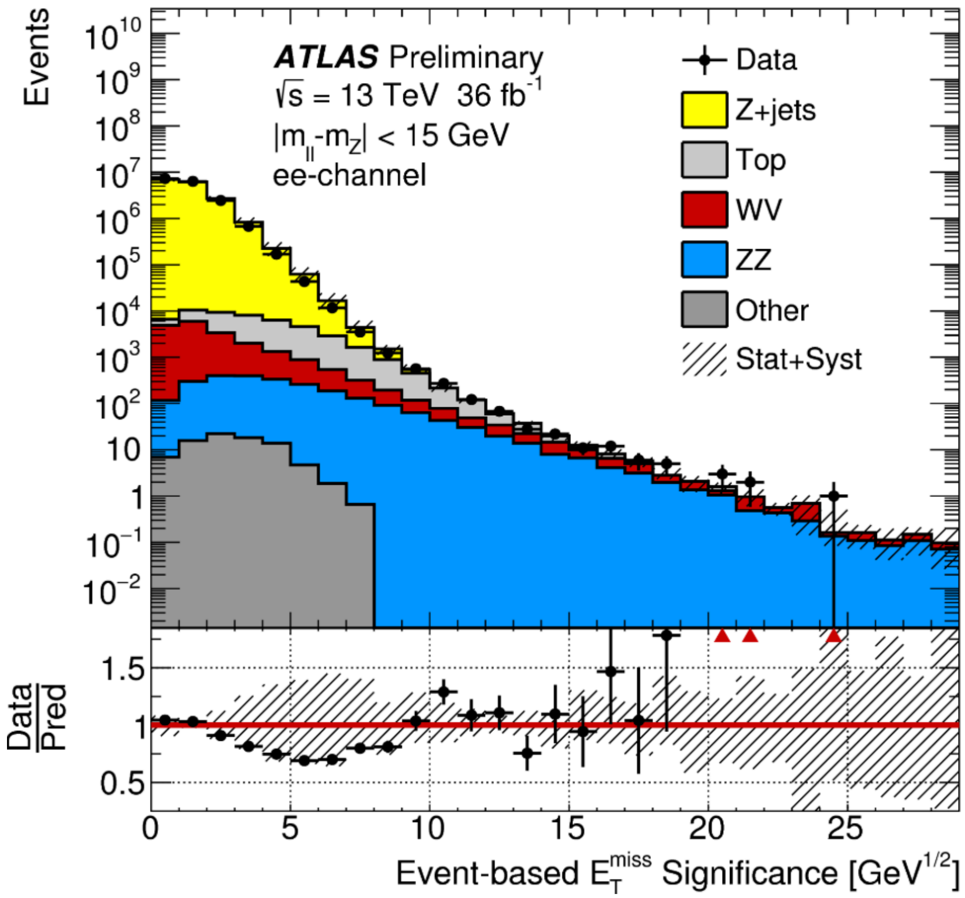
The **8.9 GeV resolution** mixes the effect of the intrinsic Soft Term **resolution** and the presence of the **bias**.

$$\mathcal{S}^2 = \frac{\left|\boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}} - \boldsymbol{bias}\right|^2}{\sigma_{L'}^2\left(1-\rho_{L'T'}^2\right)}$$

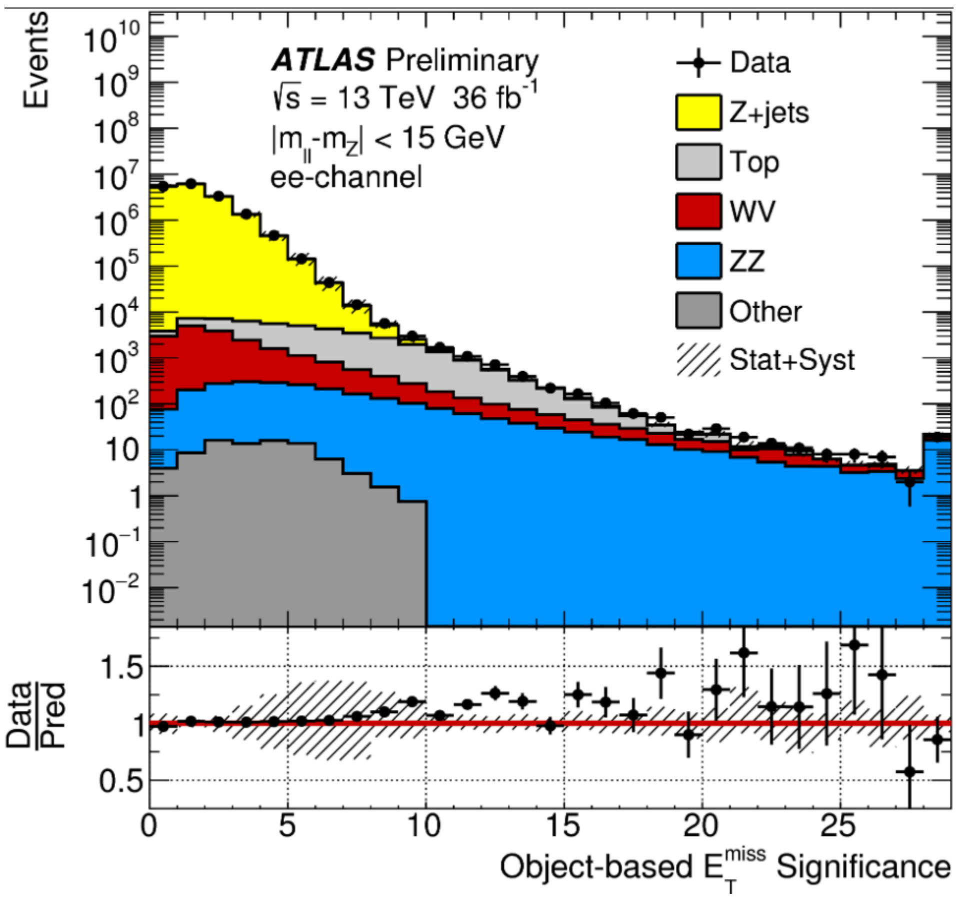
EVENT- VS. OBJECT-BASED MET SIGNIFICANCE

- Data collected at 13 TeV during 2015-2016 corresponding to an integrated luminosity of 36 fb−1
- Selecting Z+Jets events: Two leptons with $|m_Z - m_{ll}| < 15$ GeV, with $m_Z = 91.187$ GeV

Event based MET significance



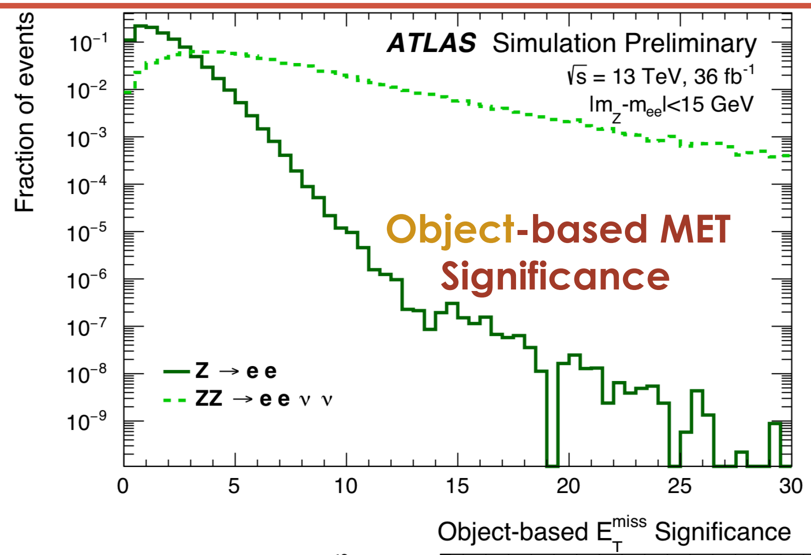
Object based MET significance

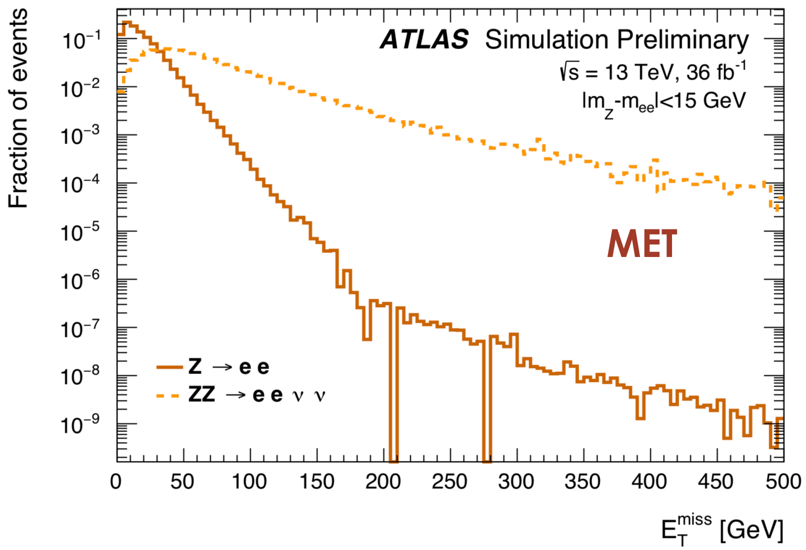


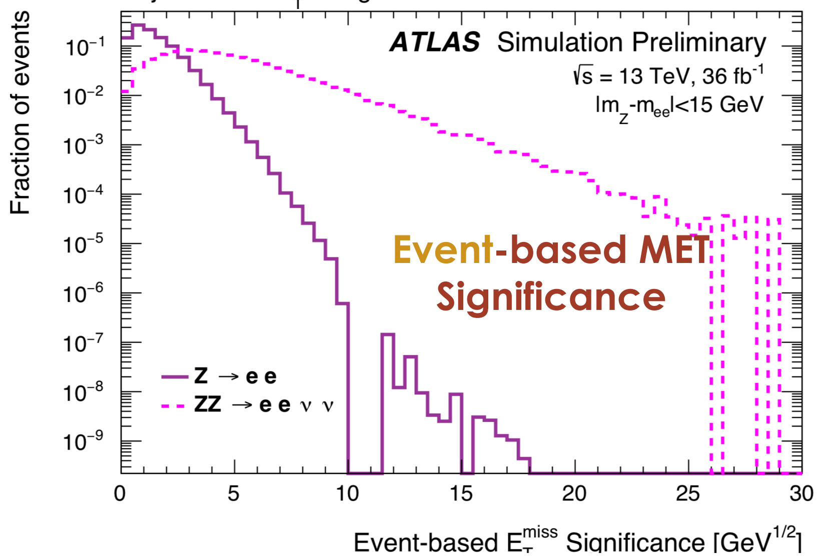
In both cases, events with genuine MET are dominant above 9-10 GeV

PERFORMANCE STUDY

- Comparison of the separation power between
  - Background: Z→ee + jets → No genuine MET
  - Signal: ZZ→eeνν + jets → Neutrinos!

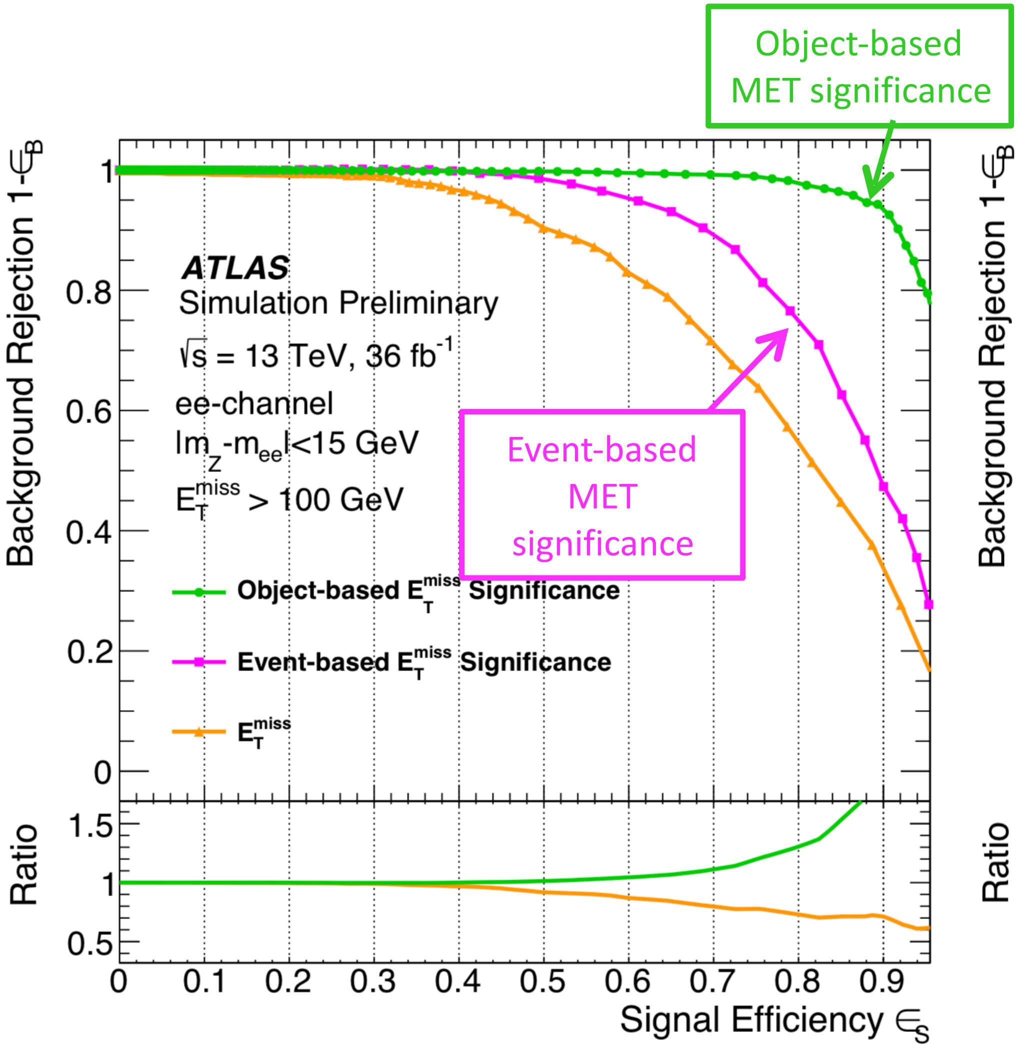




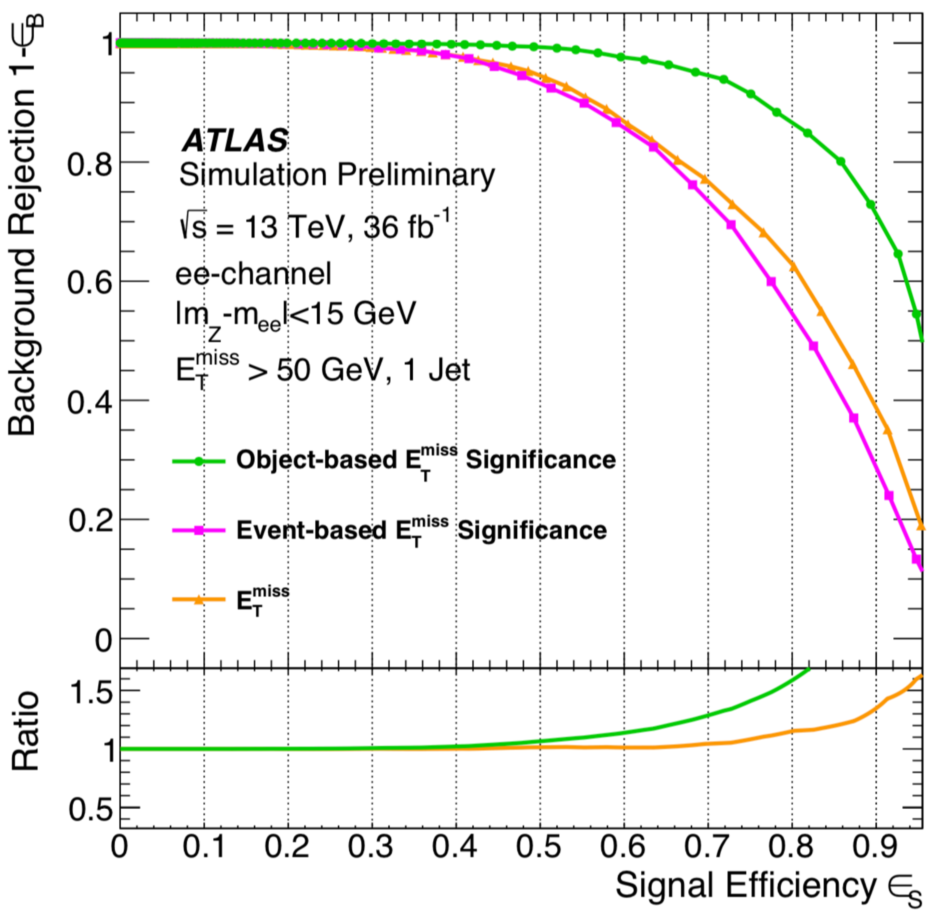


SEPARATION POWER COMPARISON

MET>100 GeV



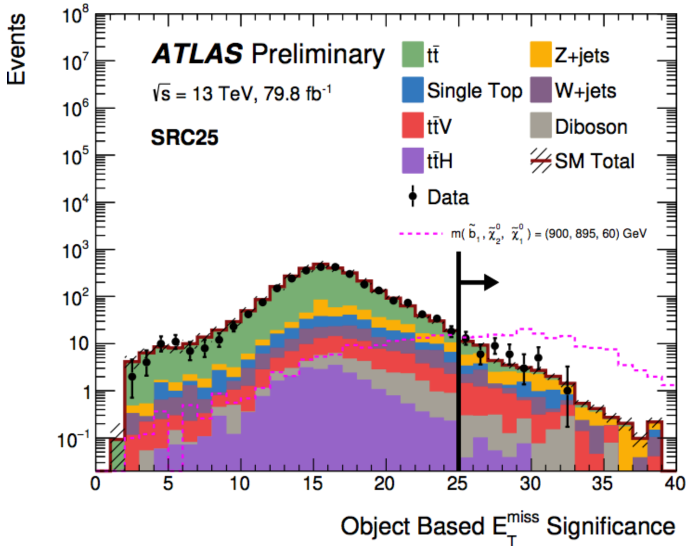
1 Jet, MET>50 GeV

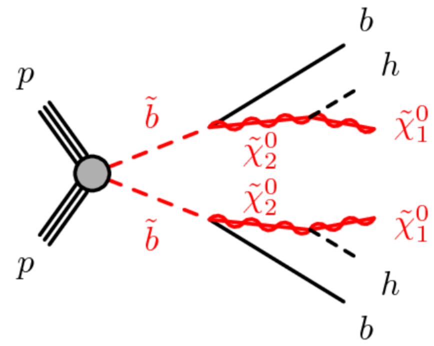


Significant improvements!

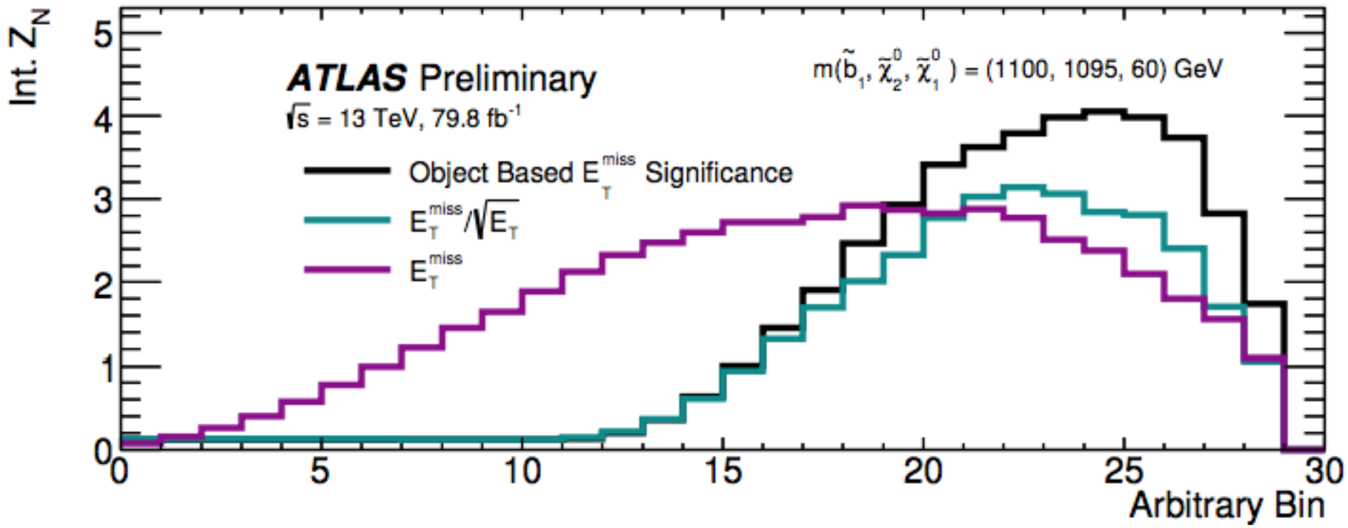
MET SIGNIFICANCE IN OTHER ANALYSIS

Used for final state with high hadronic activity: Search for bottom-squark pair production in final states containing Higgs bosons, b-jets and missing transverse momentum





MET>250, 0 leptons, >=4 jets, >=2 b



Also considered in other SUSY multijet analysis for multi-jet rejection

OUTLINE

The Dark Matter Paradigm

- Evidence of Dark Matter and Dark Matter searches
- Dark Matter production at LHC: Mono-X signatures
- Dark matter simplified model interpretations
- The mono-Higgs dark matter signature

Missing Transverse Energy Signifiance

- Missing Transverse Energy reconstruction
- Missing Transverse Energy Significance motivation
- Object-based Missing Transverse Energy Significance definition [ATLAS-CONF-2018-038]
- Performance Study

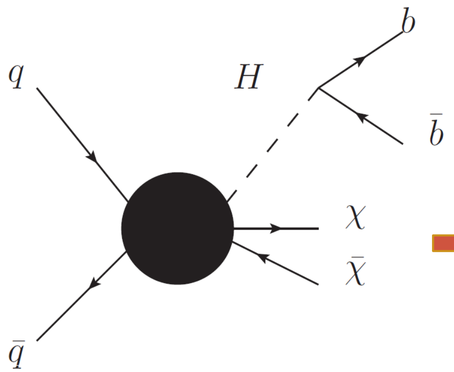
Mono-Higgs Dark Matter Search

- Mono-Higgs with H→bb Analysis: Strategy, backgrounds and control regions
- Result with data collected during 2015-2016. [Phys. Rev. Lett. 119 (2017) 181804]
- Missing transverse energy significance implementation to reject multijet background
- Results with data collected during 2015-2016 and 2017 [ATLAS-CONF-2018-039]

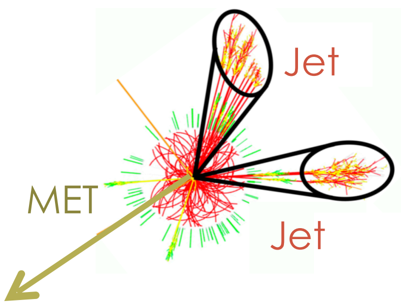
Complementarity

- Mono-h(bb) vs. Mono-h($\gamma\gamma$)
- Mono-X vs. Di-X searches and collider vrs. direct detection

Search for DM produced in association with Higgs→bb



MET + h(bb)

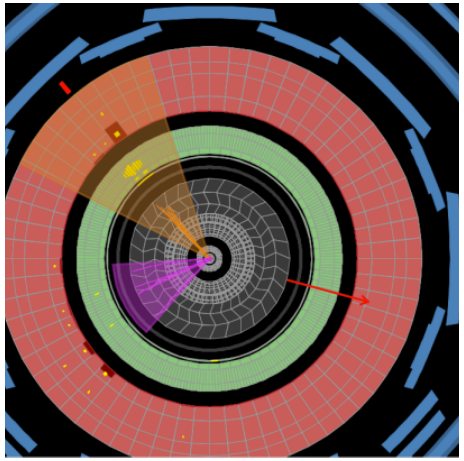


Event selection overview:

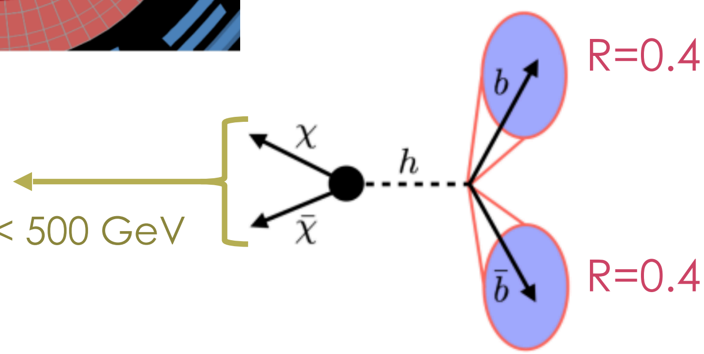
- Trigger on high MET
- No leptons (e/μ/τ veto)
- Identify h→bb decay

→ Look for excess in reconstructed Higgs mass m_{jj}/m_J

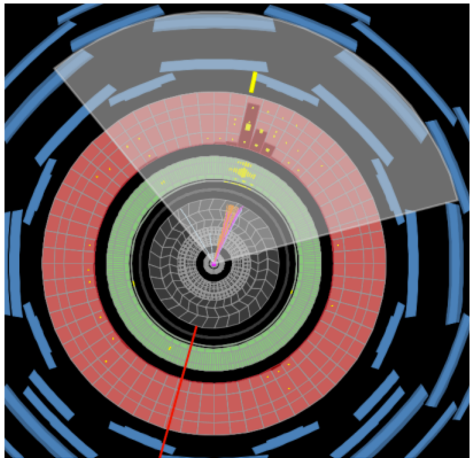
Resolved Regime



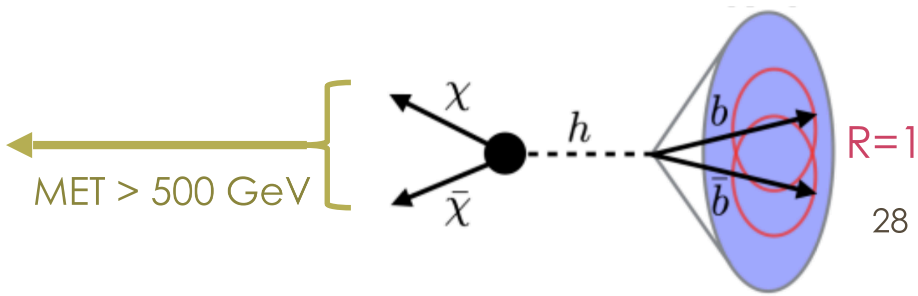
Higgs is reconstructed with a pair of small radius jets (j)



Merged Regime

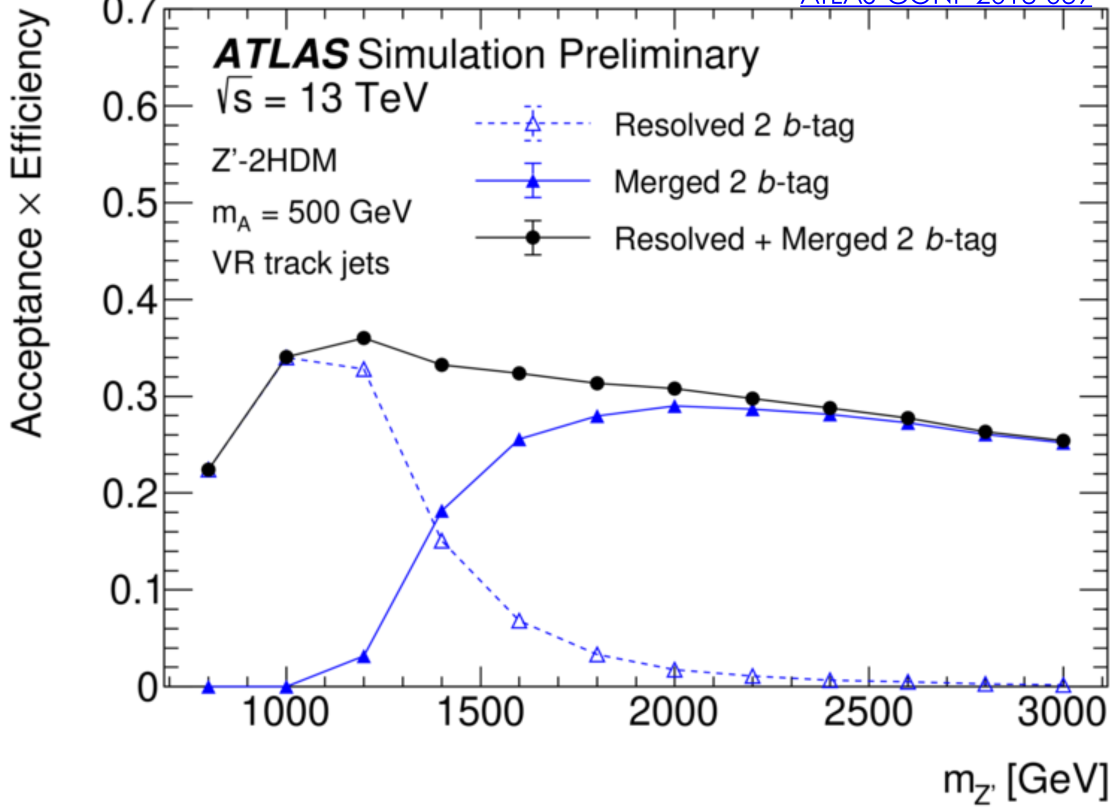


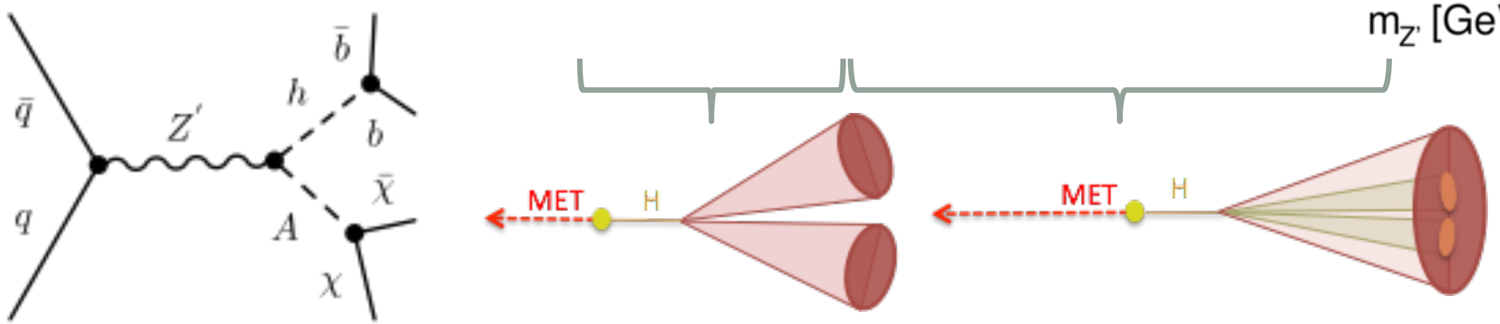
For boosted events, the Higgs is reconstructed with a large radius jet (J) with substructure



RESOLVED AND MERGED REGIME COMPLEMENTARITY

ATLAS-CONF-2018-039





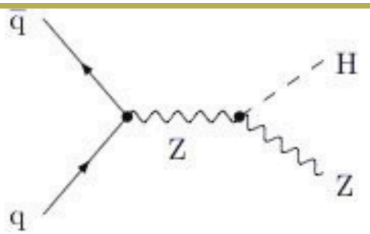
Good complementarity of two regimes

MONO-H BACKGROUNDS

Backgrounds

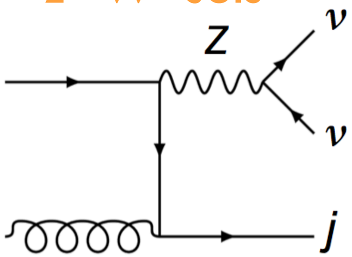
Irreducible

Zh→νν + bb



Dominant

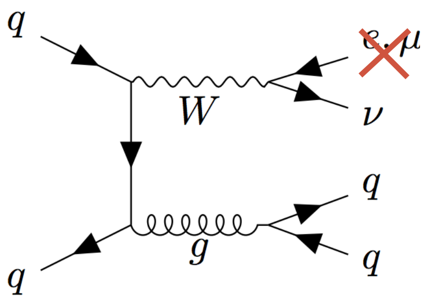
Z→νν+ Jets



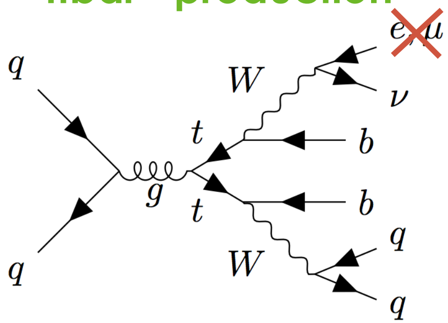
Real MET

→ Real jets

W→ l(e/μ)ν



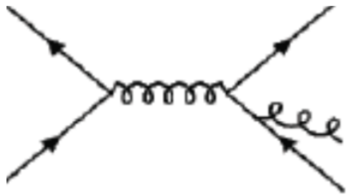
ttbar +production



Other....

Multijet background

Requires a data-driven estimate

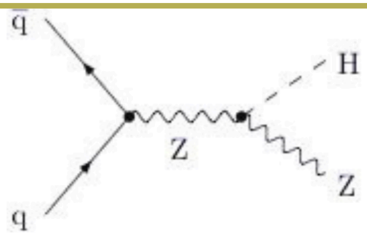


MONO-H CONTROL REGIONS

Backgrounds

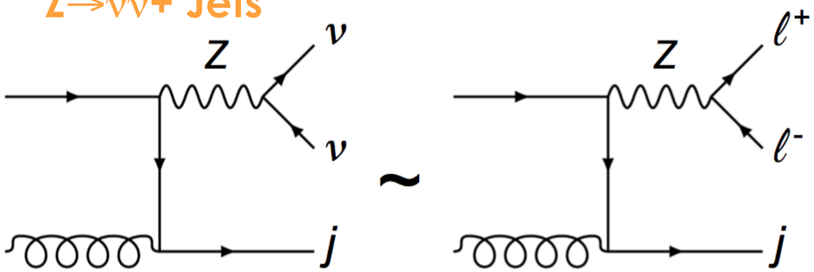
Irreducible

Zh→νν + bb

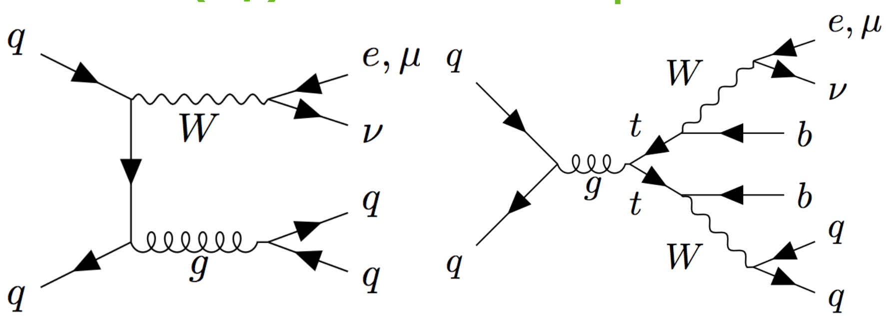


Dominant

Z→νν+ Jets



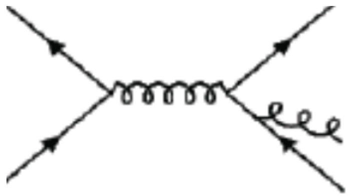
W→ l(e/μ)ν **ttbar +production**



Other....

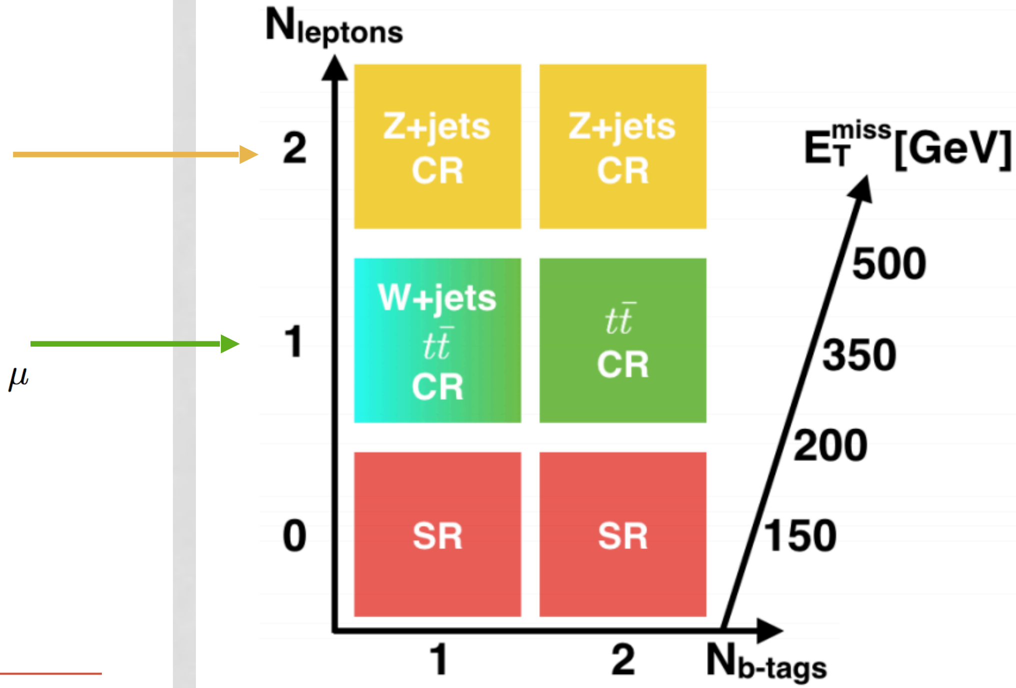
Multijet background

Requires a data-driven estimate



Signal and Control Regions

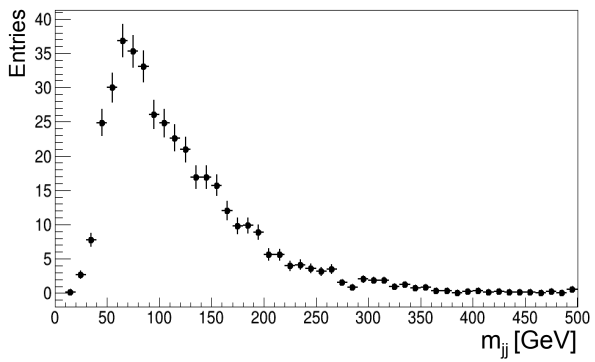
- ◇ Signal Region: 0-lepton (SR)
- ◇ Control Regions:
  - 1-lepton (1μ-CR)
  - 2-lepton (2ℓ-CR)
- ◇ Binned in N(b-tags), MET



Simultaneous combined fit

MULTIJET BACKGROUND ESTIMATION FOR 2015 AND 2016 DATA

1) Derive multi-jet template from multijet enriched region



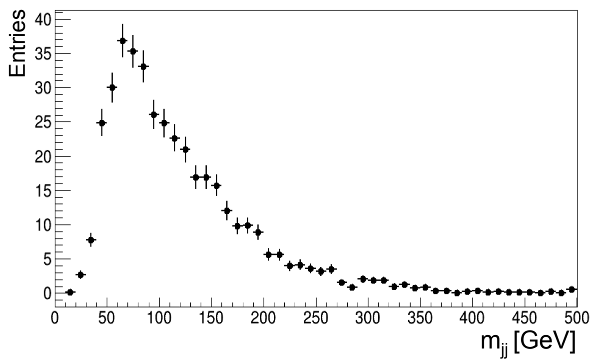
Invariant mass template

MULTIJET BACKGROUND ESTIMATION FOR 2015 AND 2016 DATA

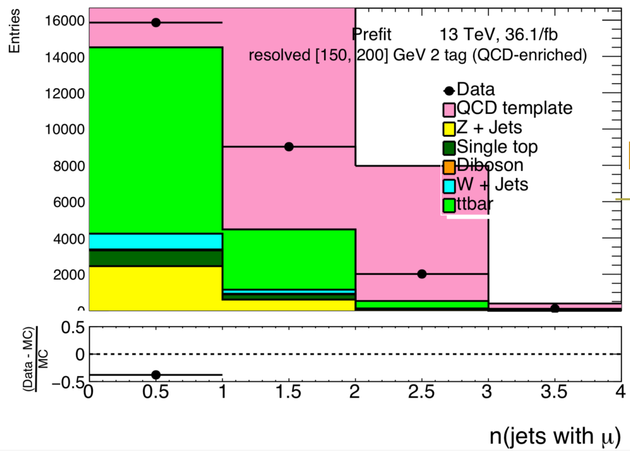
1) Derive multi-jet template from multijet enriched region

2) Normalisation factor from fit using a multijet-sensitive variable

POSTFIT 150<MET<200   2 b-tag

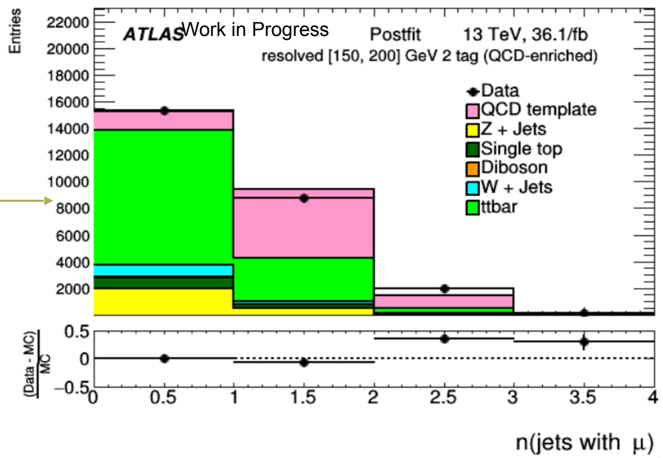


Invariant mass template



Template without normalisation taken from QCD CR

FIT



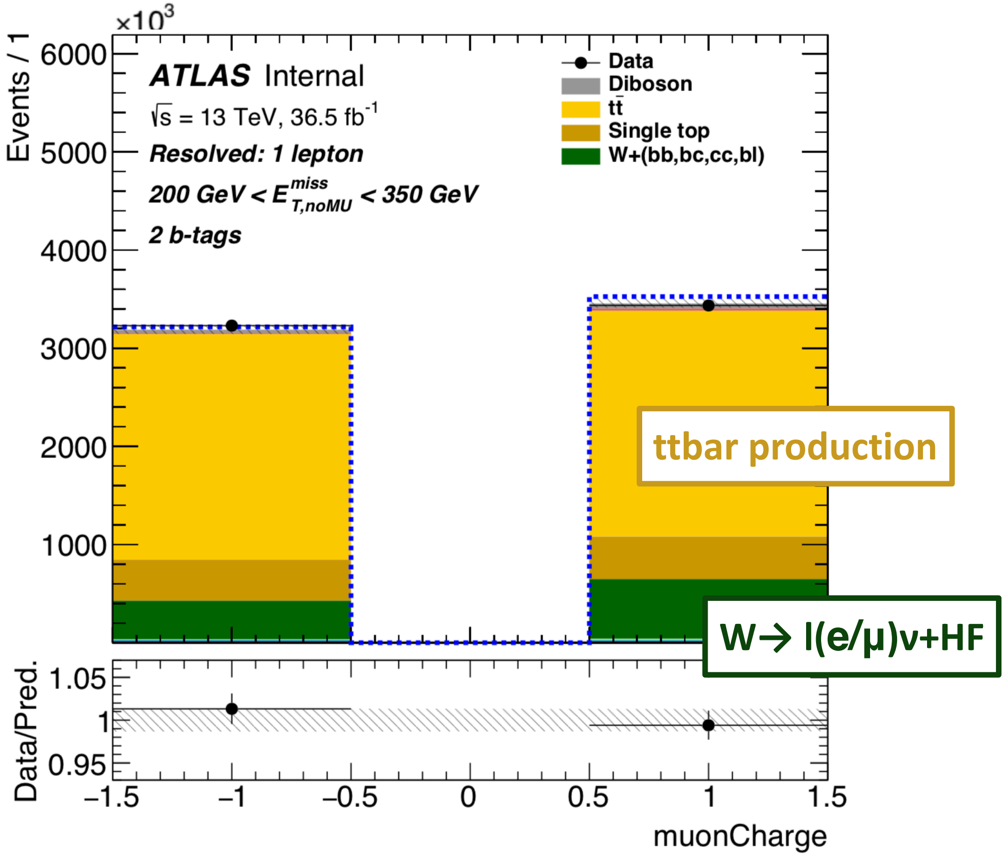
Template scaled determined by fit

Multijet Normalisation				
	150 GeV < E_T^{miss} < 200 GeV		200 GeV < E_T^{miss} < 200 GeV	
	1-btag	2-btag	1-btag	2-btag
normalisation	0.121	0.130	0.054	0.073
relative uncertainty	0.068	0.036	0.199	0.081

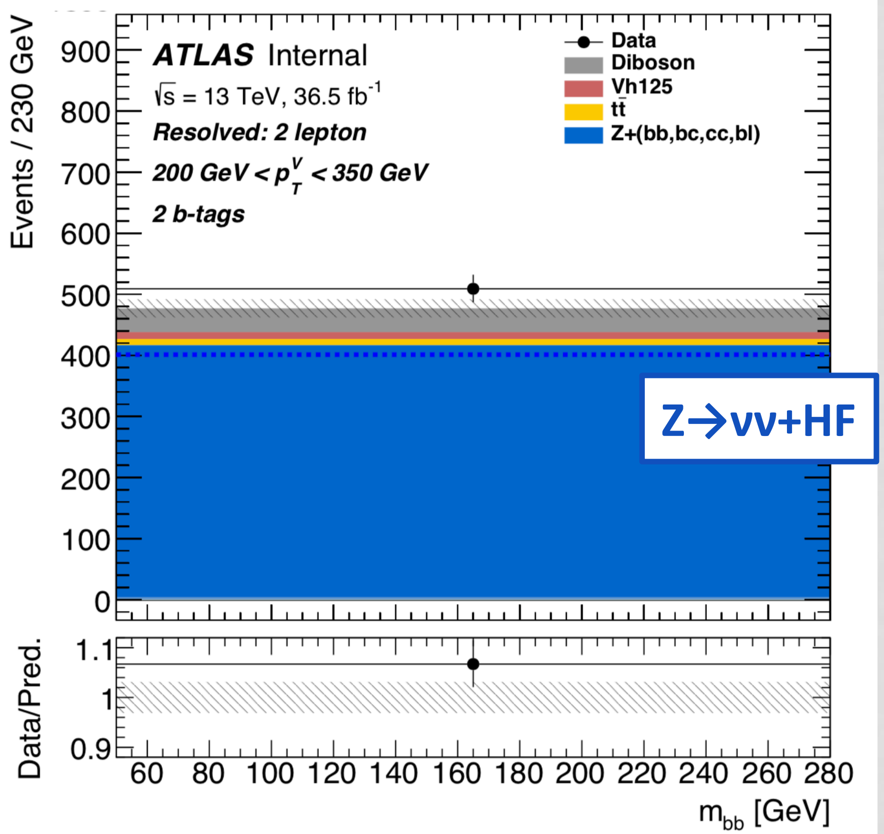
POST-FIT RESULTS

200 GeV<MET<350 GeV, 2 b-tag

1μ-CR

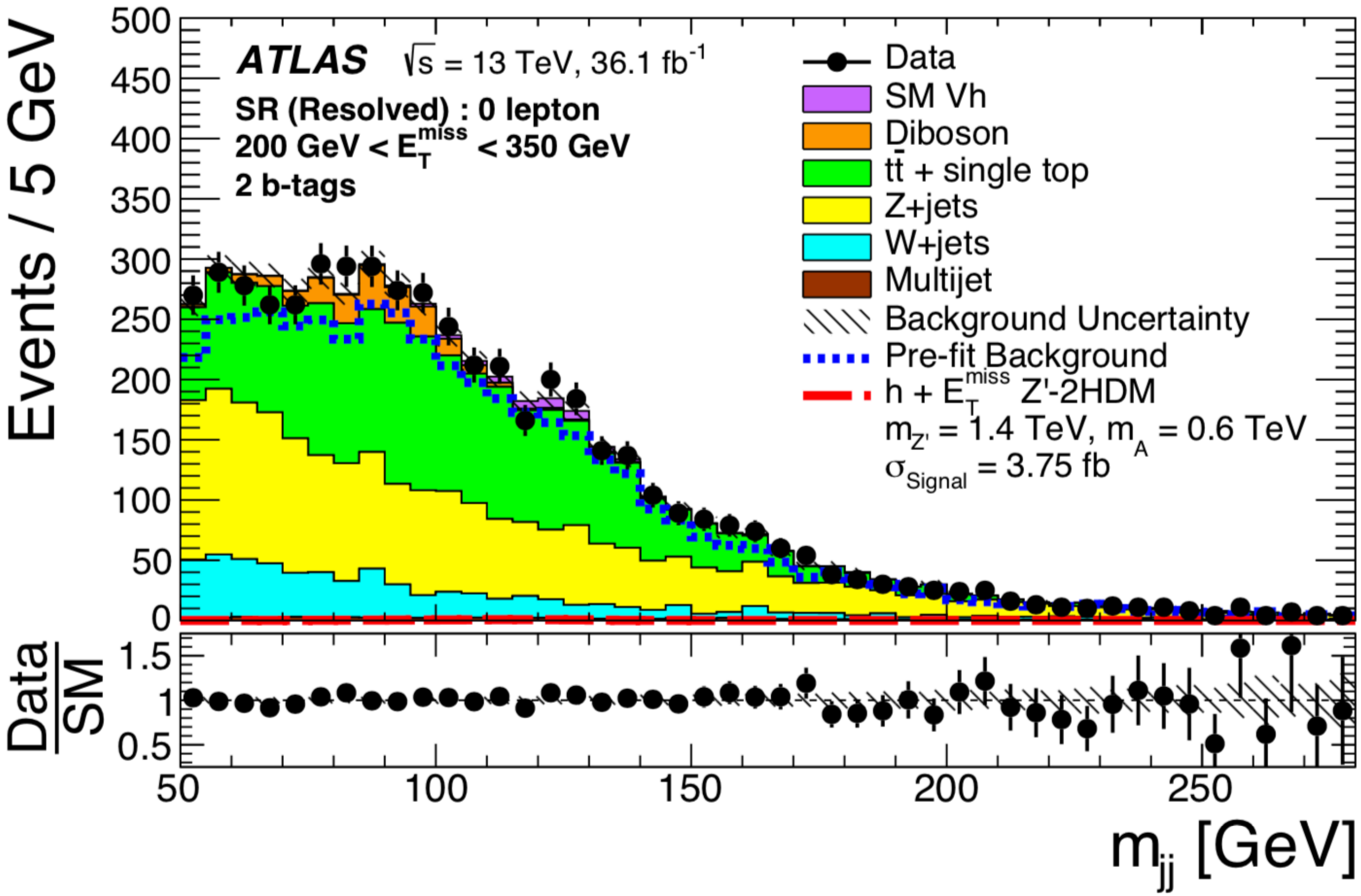


2ℓ-CR



FINAL DISCRIMINANT: HIGGS MASS CANDIDATE

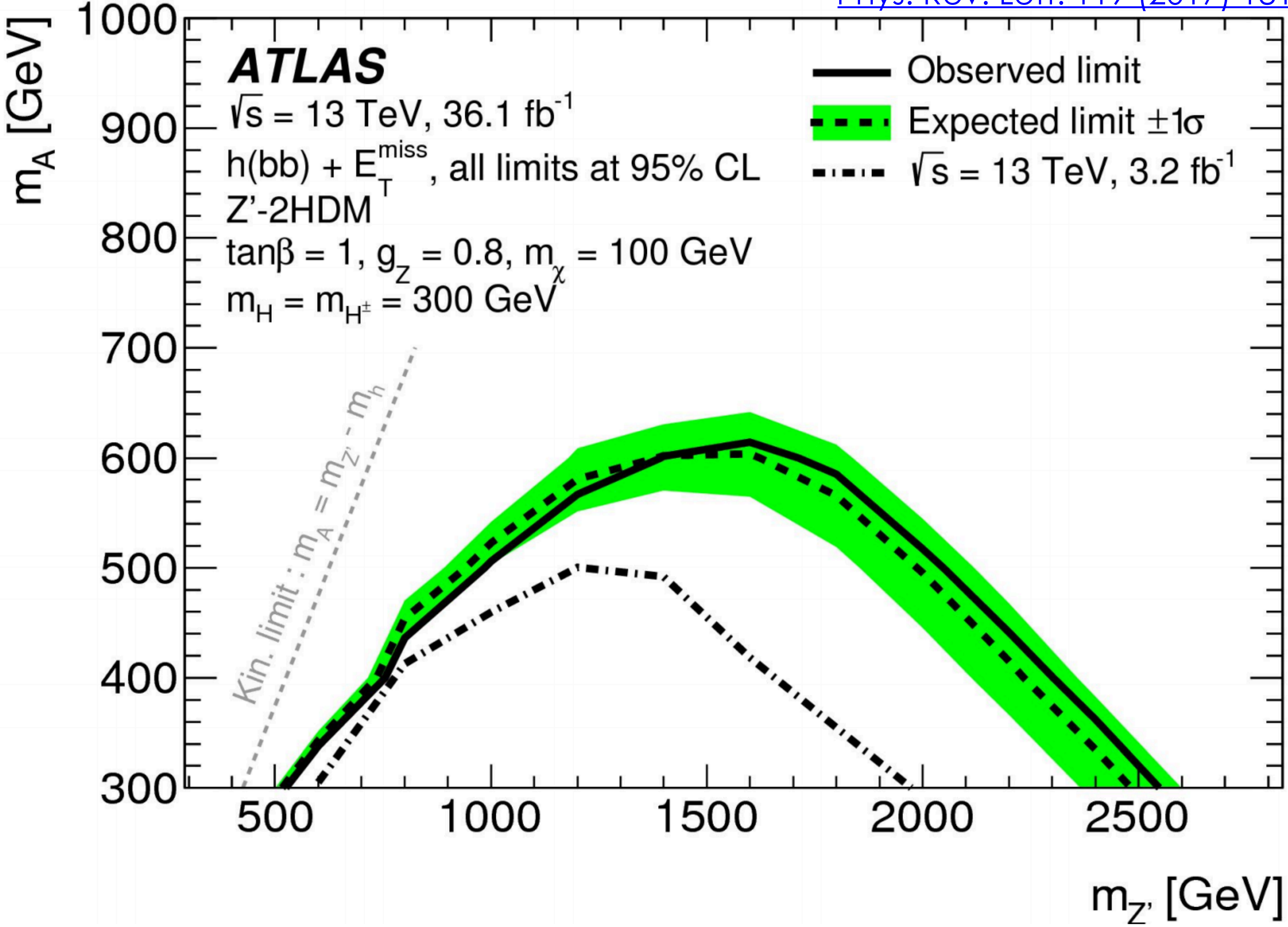
200 GeV<MET<350 GeV, 2 b-tag



MONO-H: RESULT WITH DATA RECORDED IN 2015 AND 2016

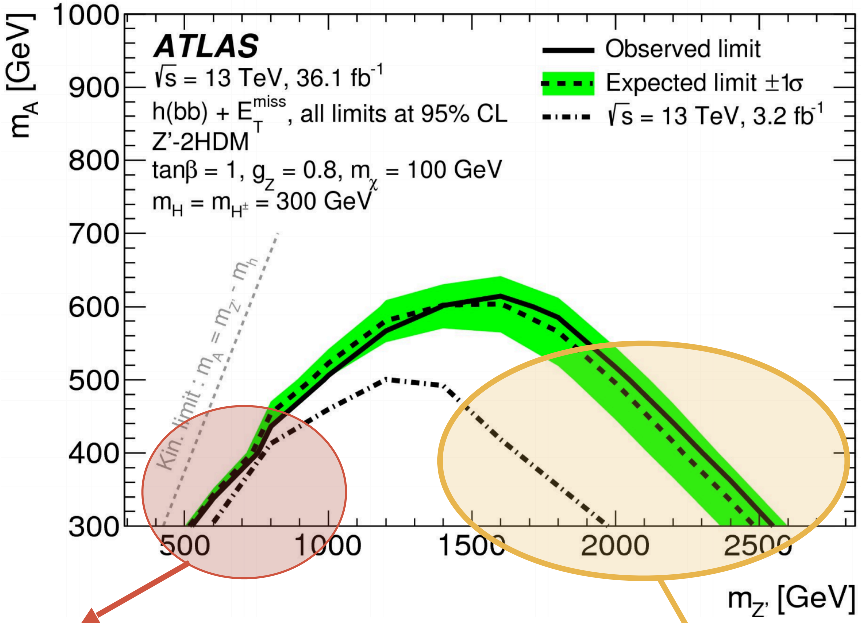
Since **no significant deviation from SM** prediction is observed, the results are interpreted as **exclusion limits**.

[Phys. Rev. Lett. 119 (2017) 181804]



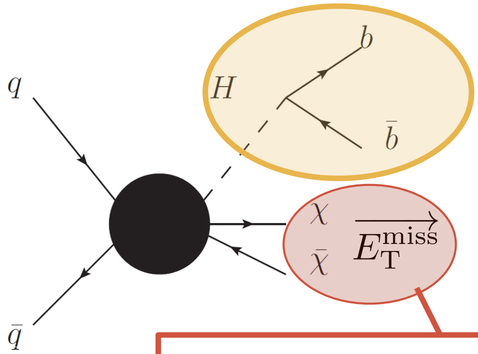
HOW TO IMPROVE MONO-H ANALYSIS?

Commissioning and exercising **NEW reconstructions thechniques**



Object based MET Significance

Test the impact of an object-based MET Significance in order to reduce the multi-jet background and/or improve its estimation



Variable Radius track jets

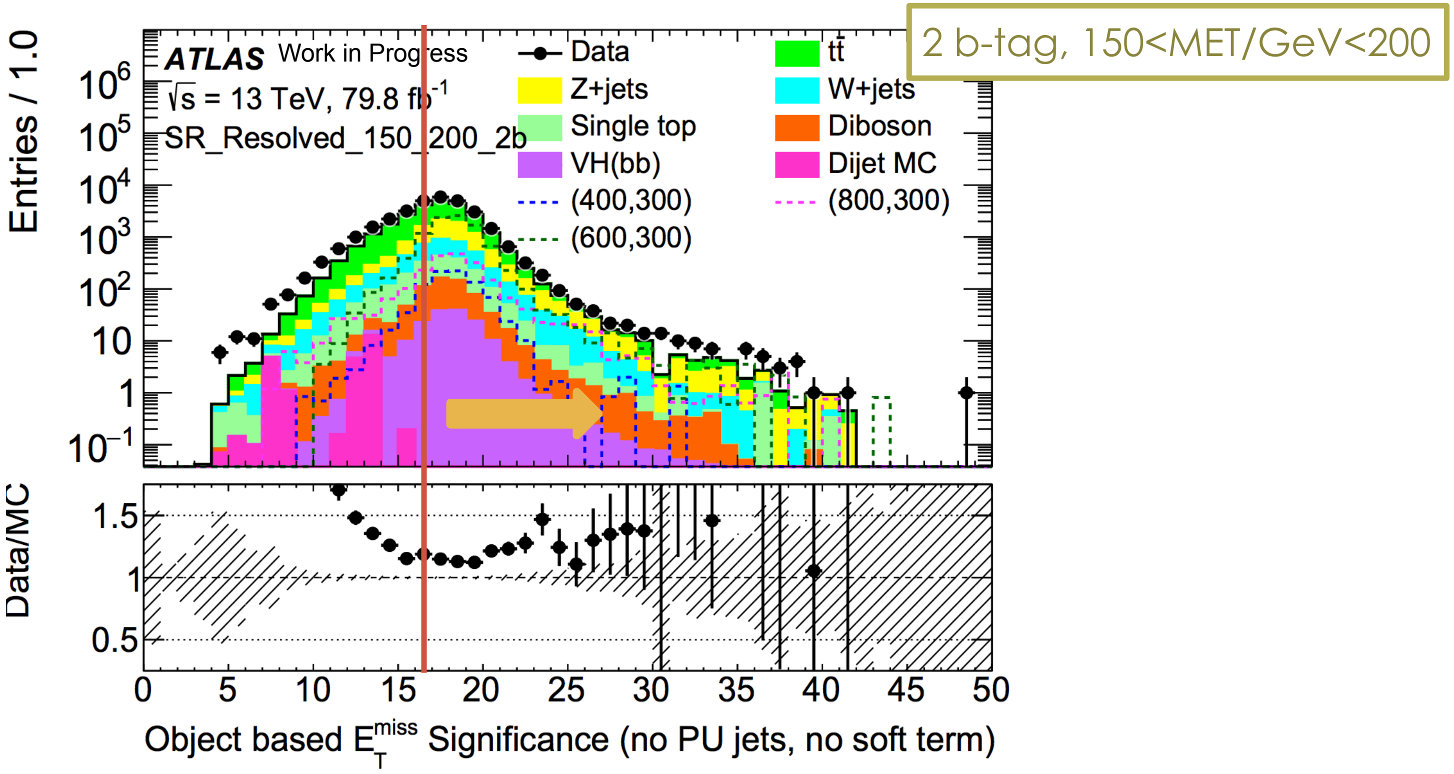
Establish VR track jets as a technique to increase the sensitivity in boosted topologies with b-tagging.

MET performance is critical for dark matter searches

MULTIJET SUPRESSION VIA OBJECT-BASED MET SIGNIFICANCE

- Multijet background introduces **fake MET** mainly due to **mis-measured jet momenta**
- Met significance can **identify and separate** multijet background with respect to EW backgrounds and DM signals

New requirement in resolved selection to **suppress multijet** background at low values of the distribution.



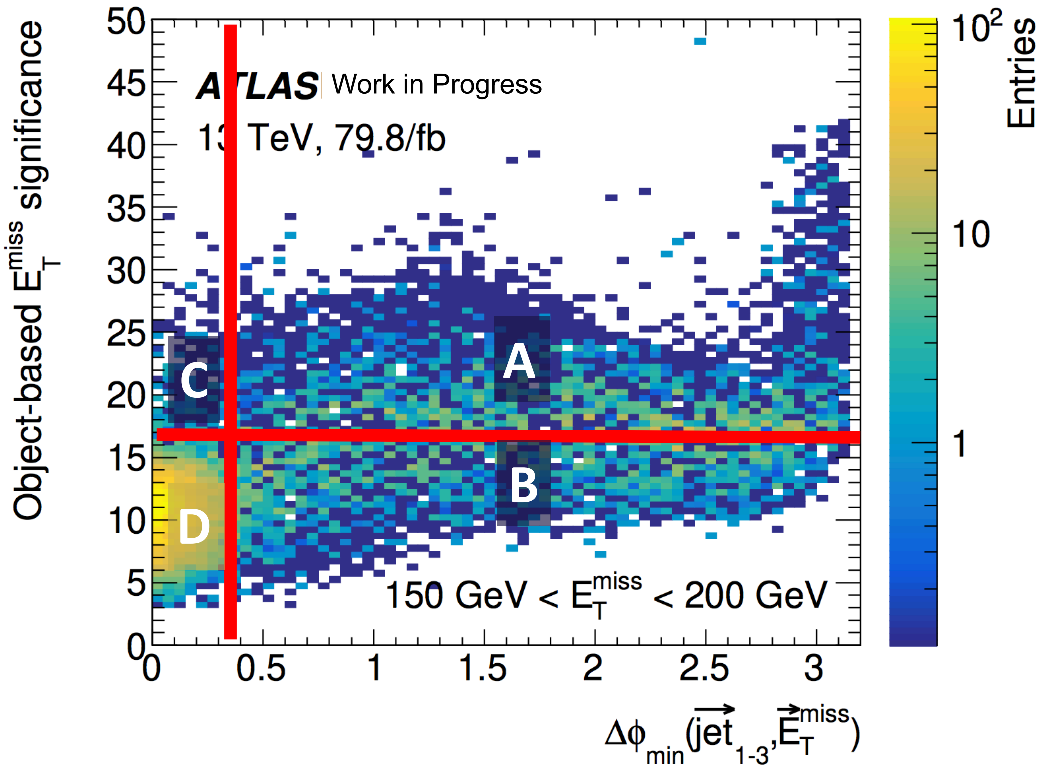
With a **object-based MET significance>16** requirement:

- More **than 95% of dijet can be rejected** while retaining a **signal efficiency ~90%**
- **Signal significance gain** between 6%-9%

MULTIJET ESTIMATE AFTER OBJECT-BASED MET SIGNIFICANCE REQUIREMENT

Estimate residual multijet event yield after object-based MET significance and other anti-QCD cuts with ABCD method:

- Define regions A,B,C by cut values on min $\Delta\phi(j_{1,2,3}$, MET) and MET Significance



Multijet yield prediction for signal region (SR)

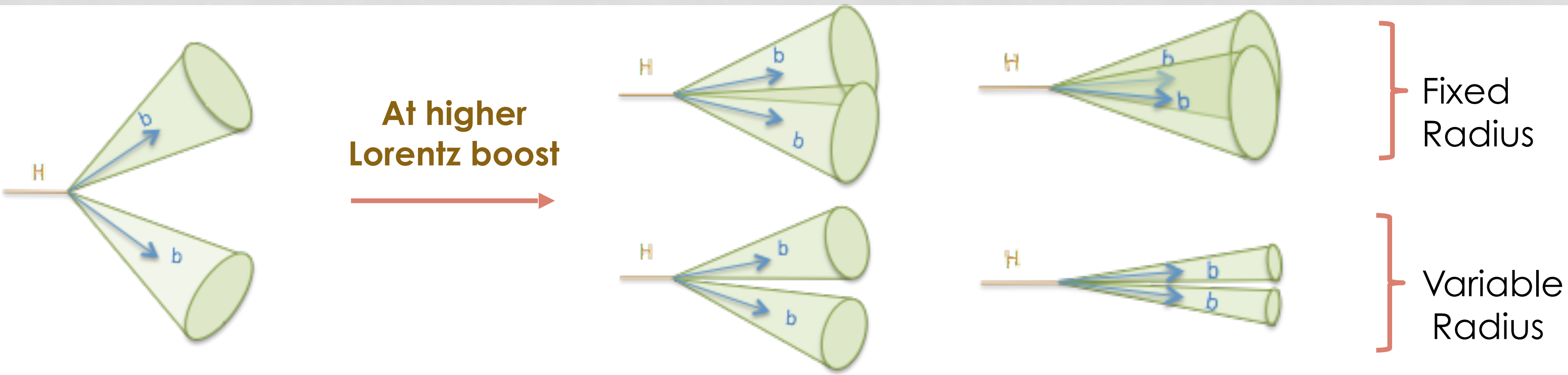
$$N_A = \frac{N_B N_C}{N_D}$$

Negligible since smaller than data statistical uncertainty

Region	Data	Background	ABCD prediction
$150\,\text{GeV} < E_T^{miss} < 200\,\text{GeV}$	7698 ± 88	6397 ± 45	20 ± 3.3
$200\,\text{GeV} < E_T^{miss} < 350\,\text{GeV}$	5429 ± 74	4731 ± 36	8 ± 2.9
$350\,\text{GeV} < E_T^{miss} < 500\,\text{GeV}$	484 ± 22	434 ± 9	0.1 ± 0.76

VARIABLE RADIUS JETS

Merging of Fixed Radius (FR) track jets causes loss of acceptance × efficiency for signals with highly boosted topologies.

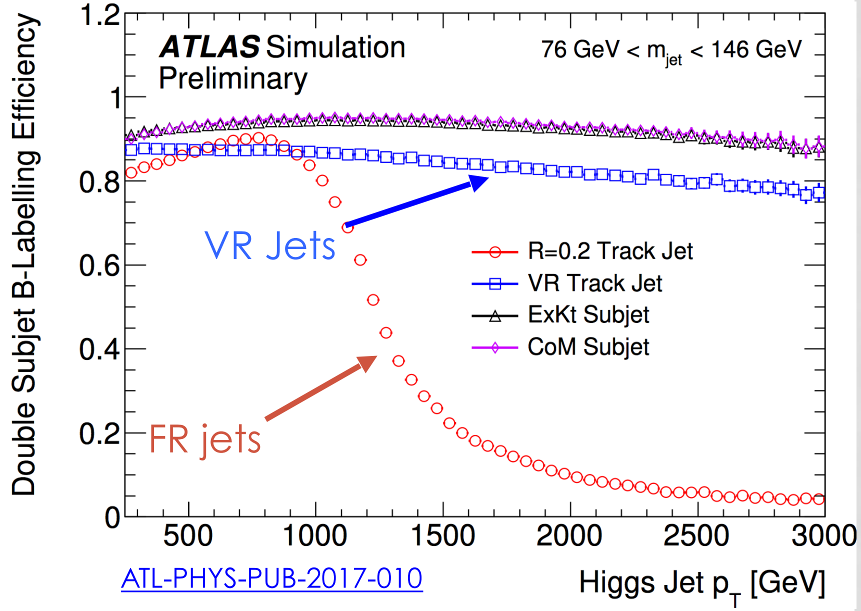


The reconstruction of sub-jets used for b-tagging in the merged regime improves using the VR track jets, resulting in a **higher b-tagging efficiency**.

VR track-jets

- Used for the first time in analysis!
- anti-kt, R = 0.02-0.4, ρ = 30 GeV

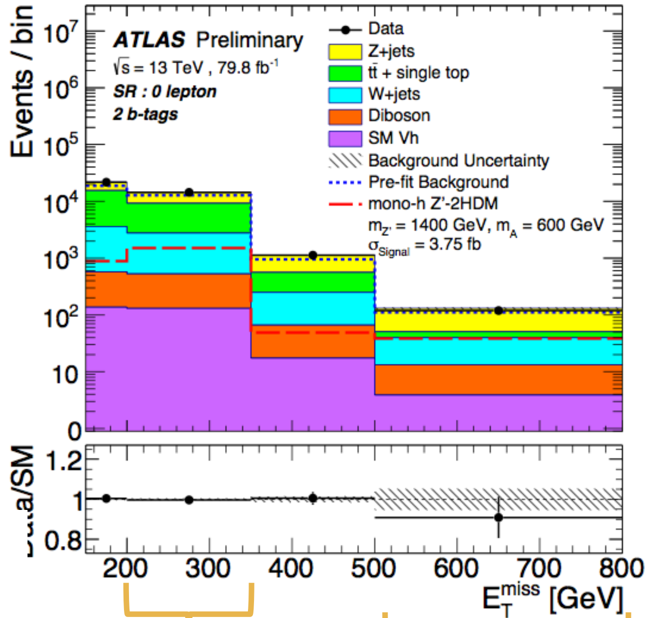
$$R \rightarrow R_{\mathrm{eff}}(p_T) \approx \frac{\rho}{p_T}$$

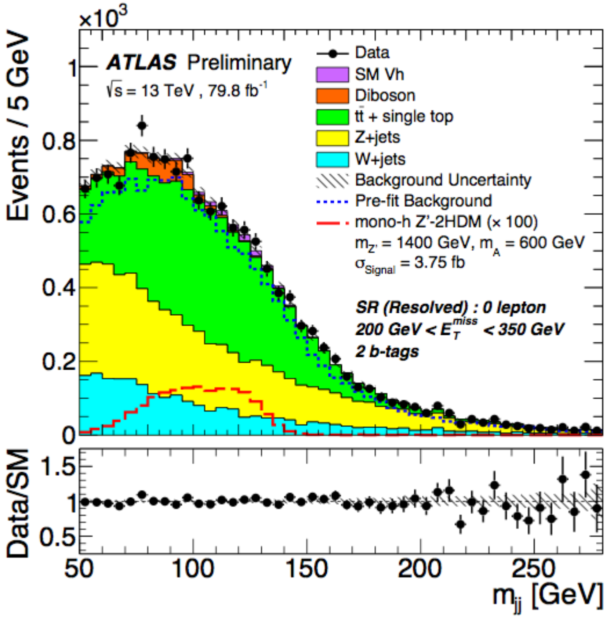


ATL-PHYS-PUB-2017-010

DISTRIBUTIONS AFTER FIT

ATLAS-CONF-2018-039



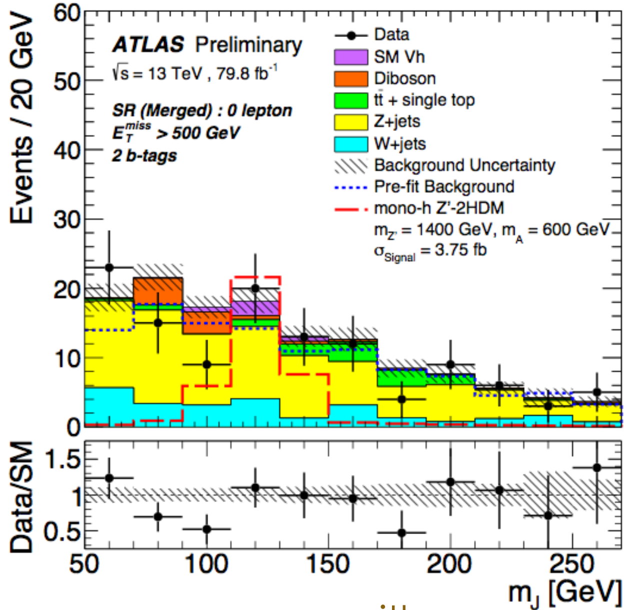


m_{jj} with
200 GeV<MET<350 GeV

No excess in data observed

↓

constrain model parameters with exclusion limit contour

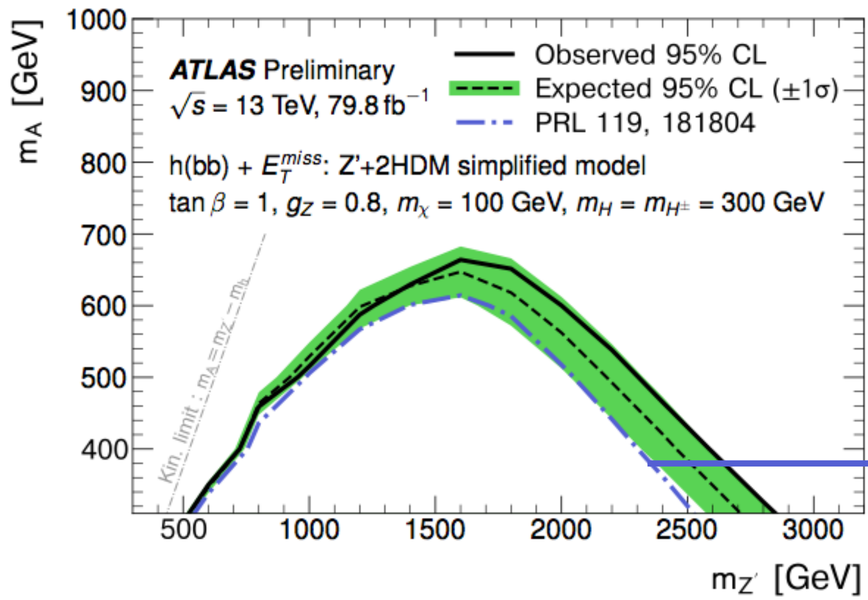


m_J with
200 GeV<MET<350 GeV

EXCLUSION LIMIT

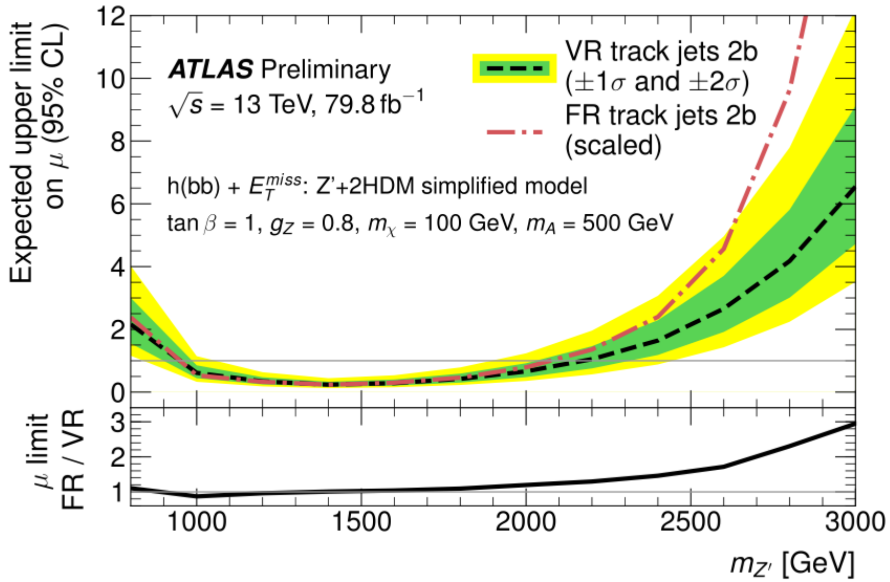
ATLAS-CONF-2018-039

Model parameters excluded at 95%CL_S:
mZ' ≤ 2.8 TeV and
mA ≤ 600 GeV



36fb⁻¹ using FR

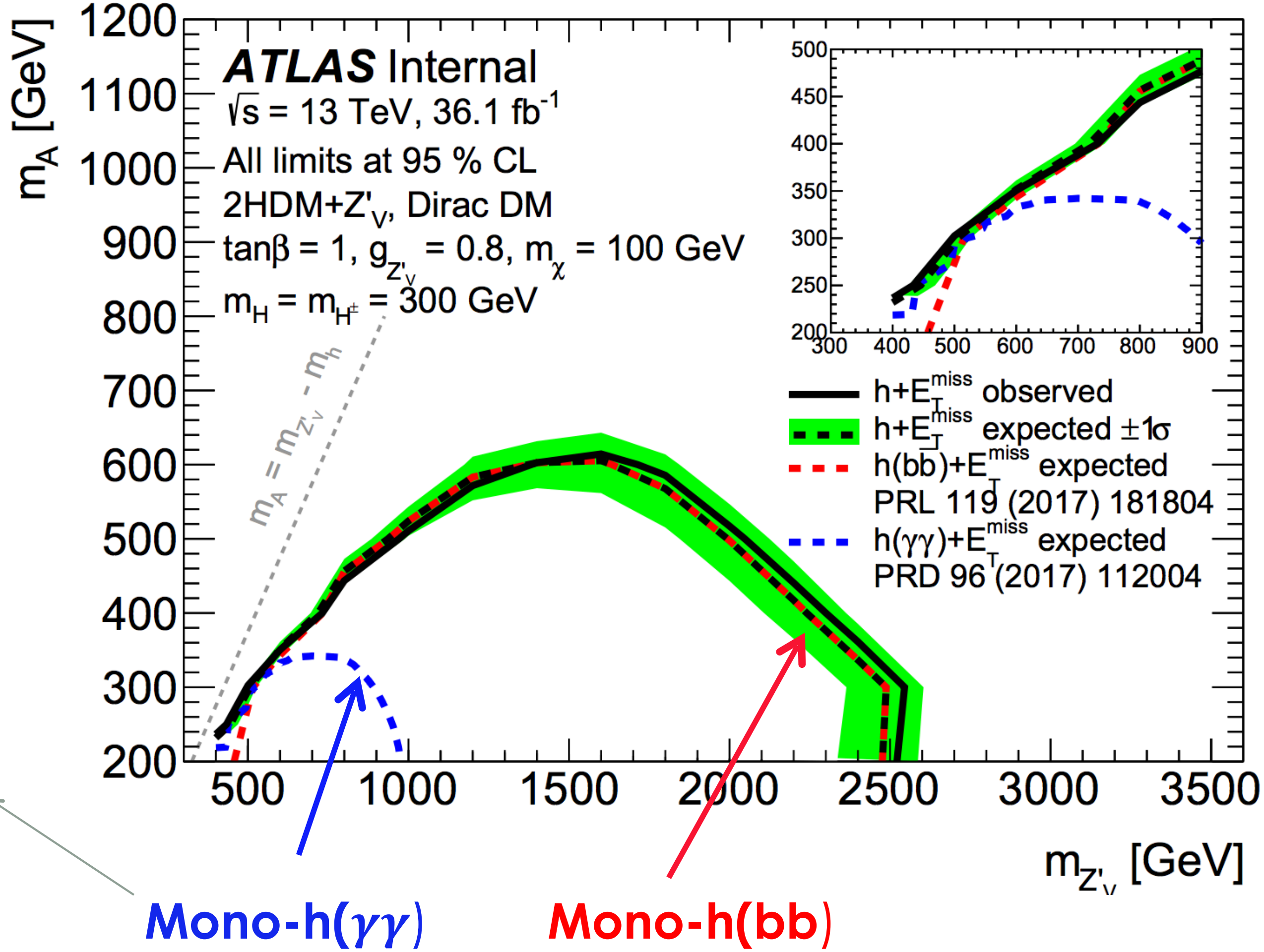
The improvement from using VR track jets



3× improvement driven by VR tracks-jets in boosted region!

Mono-h(bb) vs. Mono-h($\gamma\gamma$)

Exclusion contour limit comparison



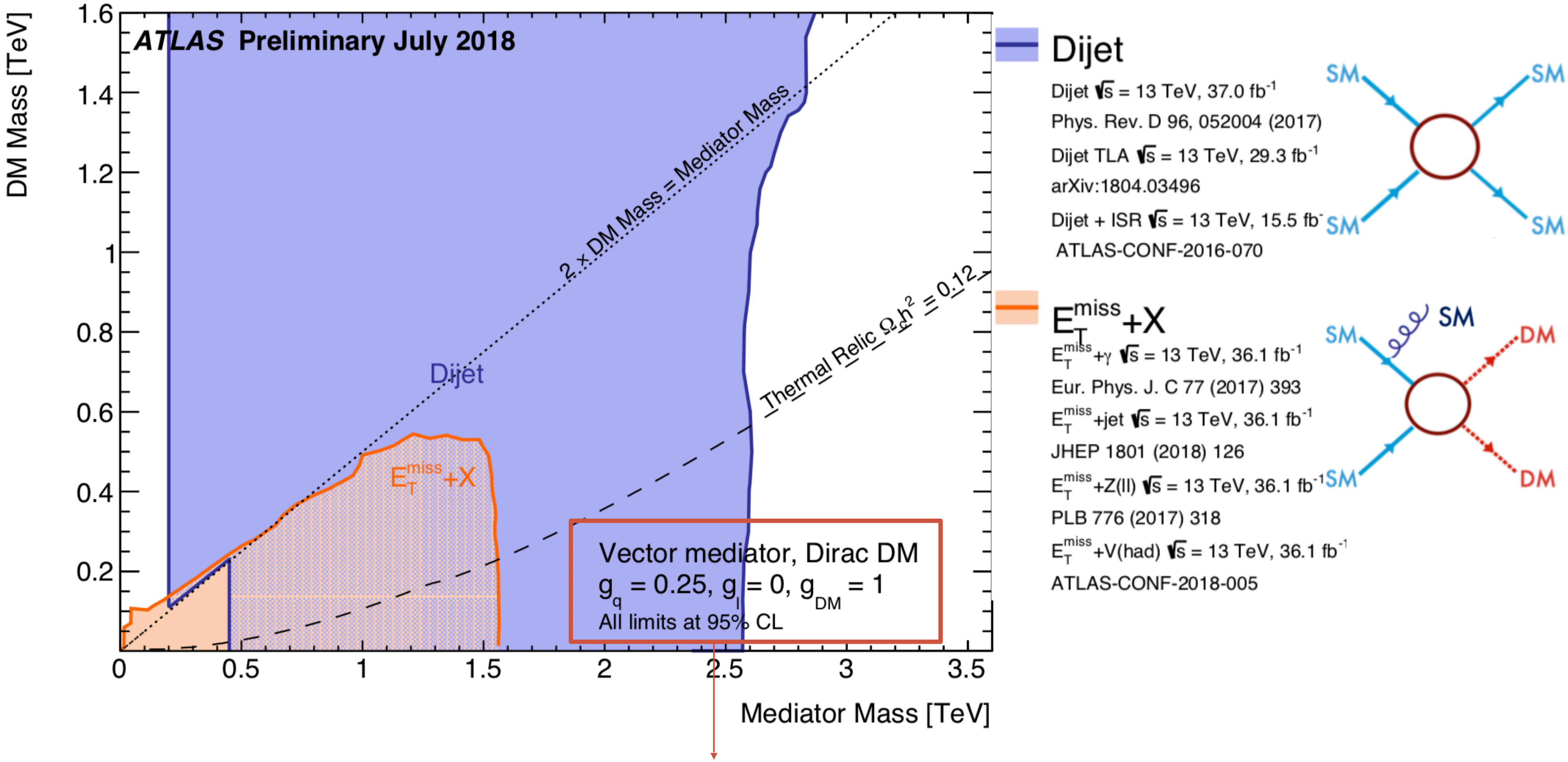
h→$\gamma\gamma$

Low BR = 0.2%

High purity in mh window

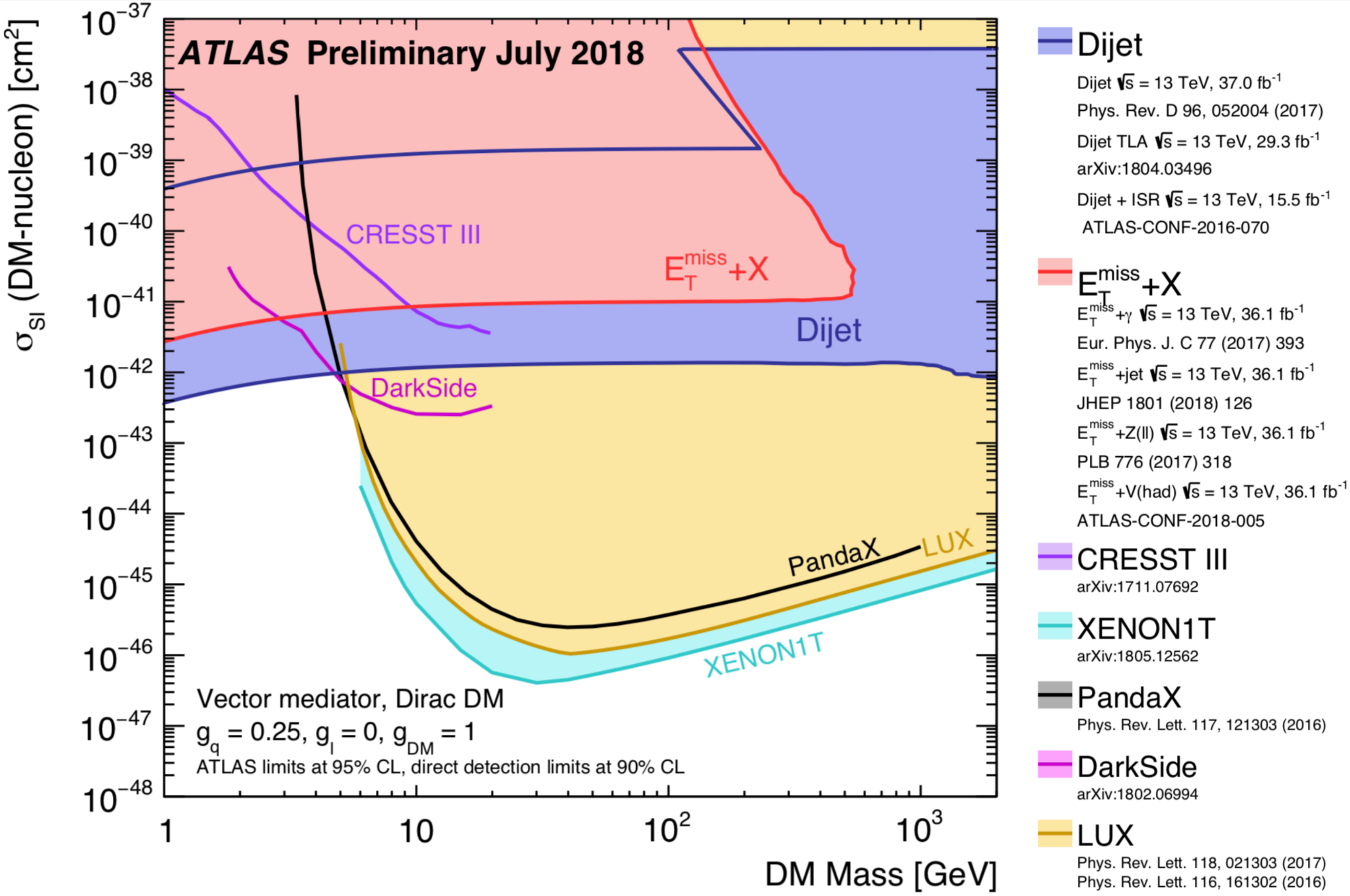
- Stronger sensitivity than mono-h($\gamma\gamma$) for p_T(h)>150 GeV
- Complementarity for p_T(h)<150 GeV

COMPLEMENTARITY BETWEEN MONO-X AND DI-X SEARCHES



Relative exclusion power depends on the model couplings

COMPLEMENTARITY BETWEEN COLLIDER AND DIRECT DETECTION SEARCHES



Nice complementarity between ATLAS and direct detection experiments

SUMMARY

- **Object-based Missing transverse momentum Significance**

◇ A novel definition of MET significance has been developed. It depends on the multiplicities, types, and kinematics of the objects measured in each event.

◇ The new definition, in a Z+jets topology, has a clear improvement in the separation power between samples with genuine MET and samples with no genuine MET
  ◇ Study published as conference note: [**ATLAS-CONF-2018-038**]

- **Search for dark matter in association to a Higgs boson decaying to b quarks**

◇ Results were shown for a search for dark matter with 36.1fb^{-1} of pp collisions at $\sqrt{s}$=13TeV.
  ◇ Result published as paper: [**Phys. Rev. Lett. 119 (2017) 181804**]

◇ Improved search for dark matter with 79.8 fb^{-1}, commissioning and validating novel reconstruction techniques: VR track jets and object-based MET significance
  ◇ Results published as conference note: [**ATLAS-CONF-2018-039**]

◇ Object based MET significance was implemented this analysis. It successfully reject multijet background maintaining signal significance.

◇ These results are complementary to those from to mono-h($\rightarrow\gamma\gamma$)