Nikhef

Veronica Fabiani

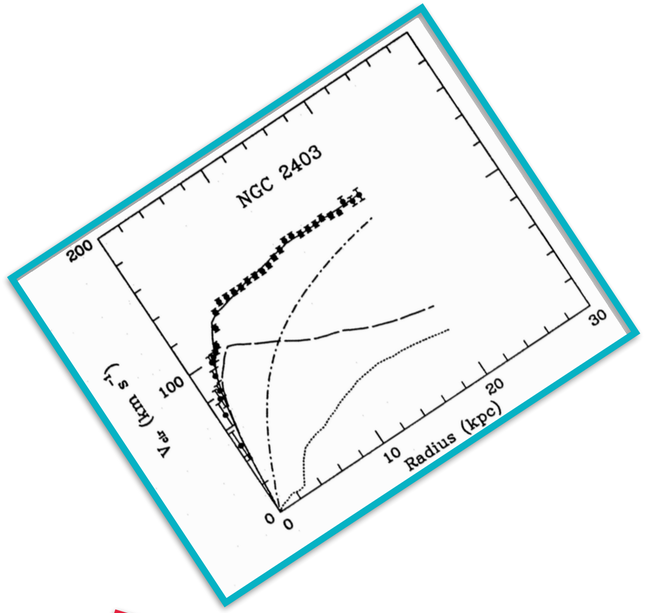
SEARCH FOR DARK MATTER IN MONO-H(BB) FINAL STATES IN ATLAS

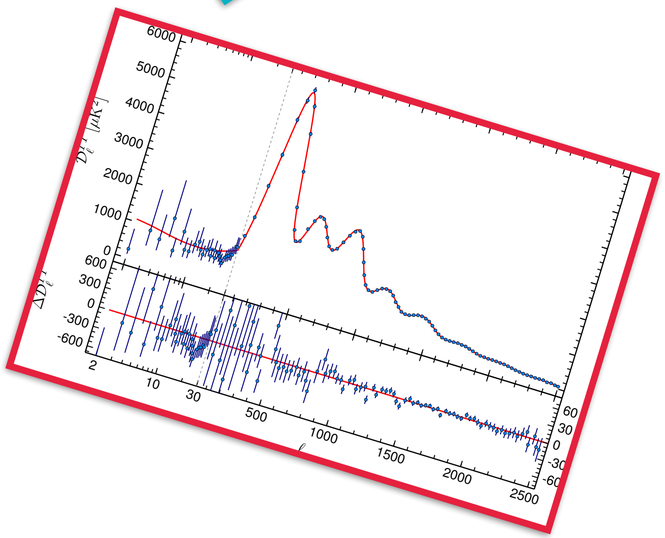
2nd November 2018
NNV annual meeting
Lunteren

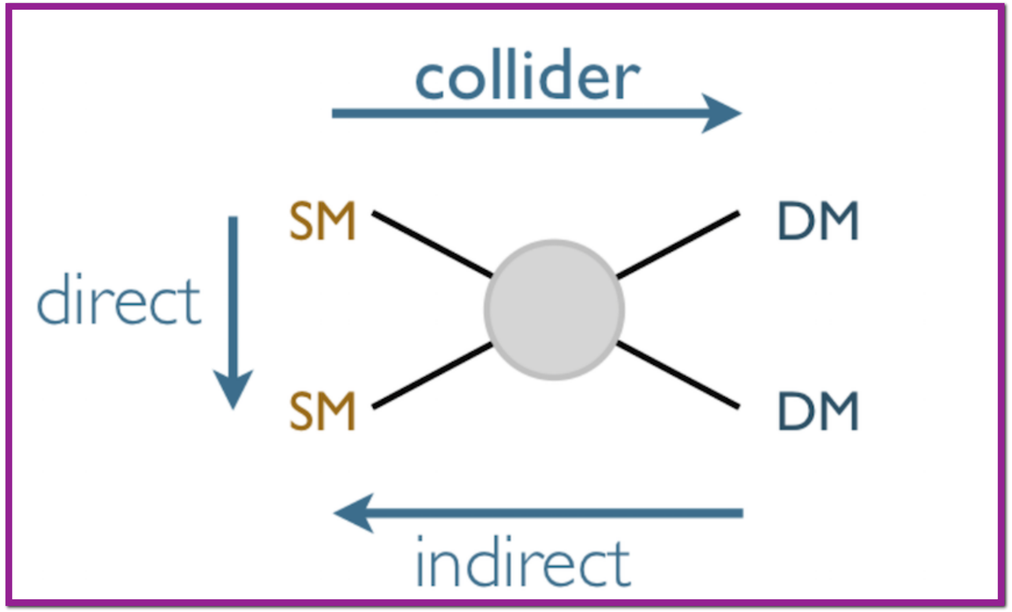
ATLAS EXPERIMENT

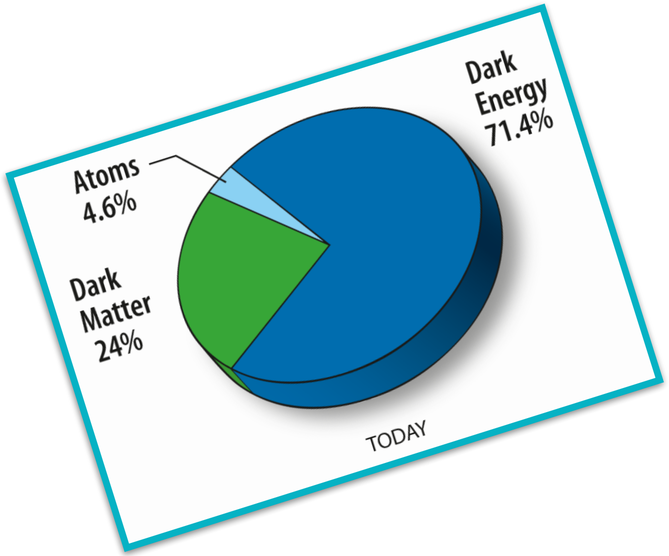
Radboud Universiteit

DARK MATTER SEARCHES









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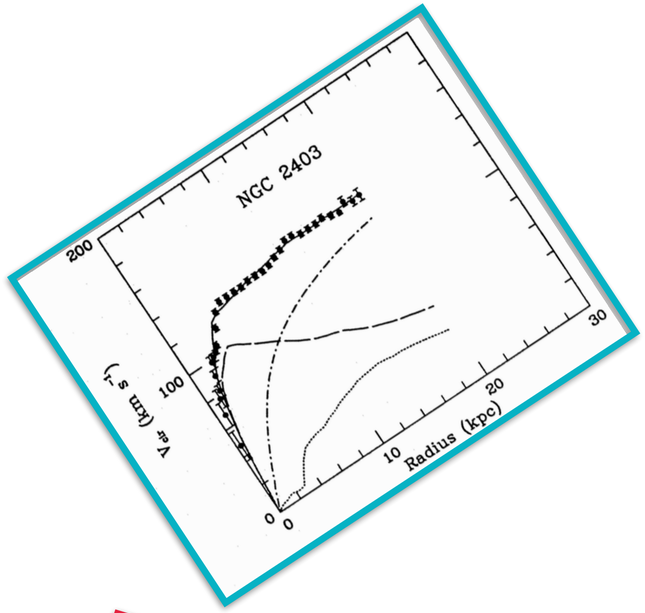
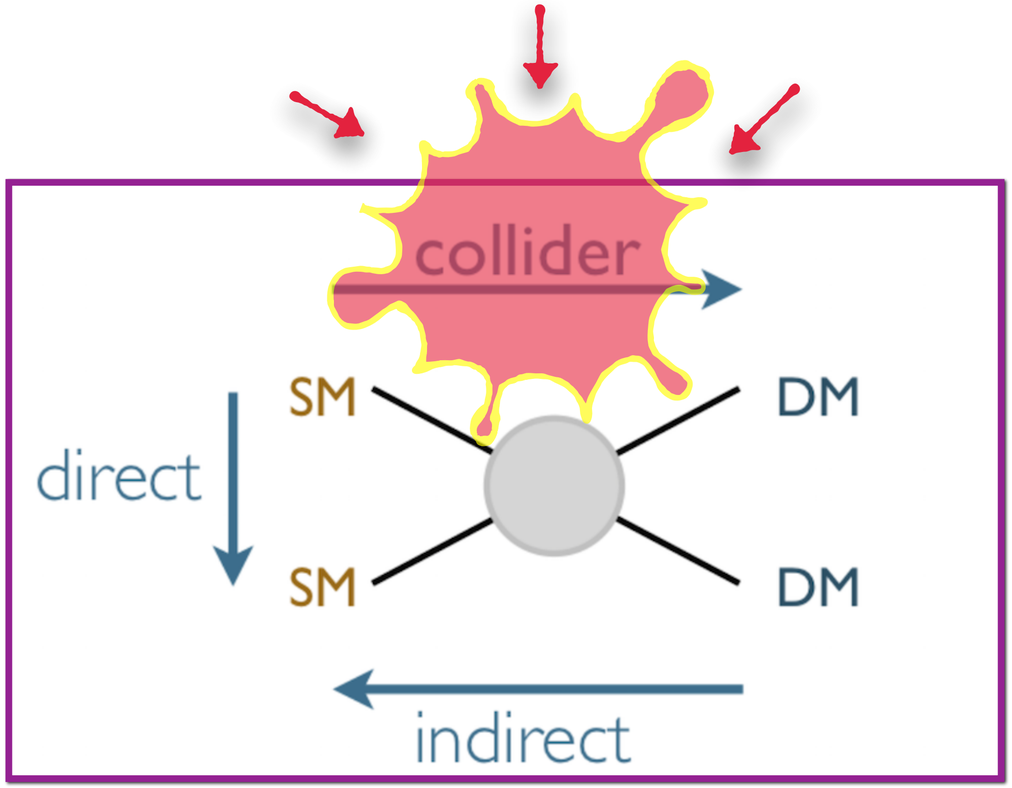
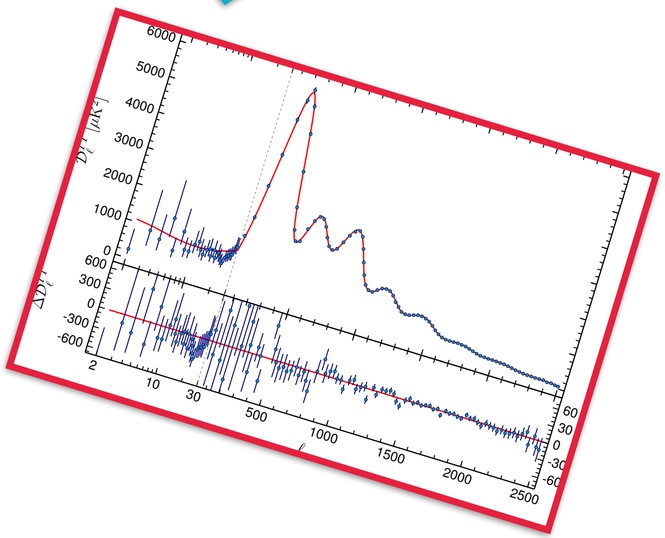
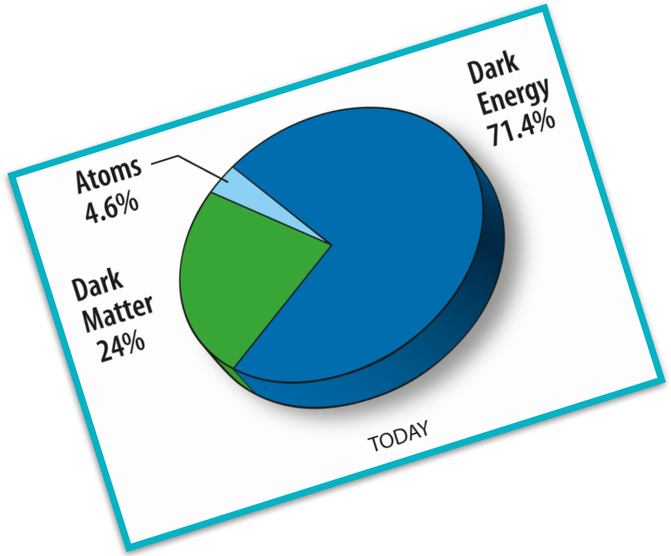




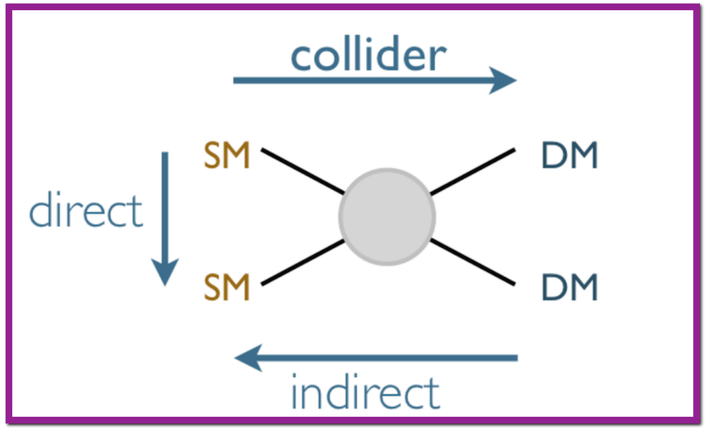




SEARCH FOR DARK MATTER AT THE LHC: THE MONO-X STRATEGY

Mono-X search as a probe for DM signals:

- DM particles do not interact with the detector
  - large amount of missing transverse momentum (**MET**)
- need an object **X** to trigger the event



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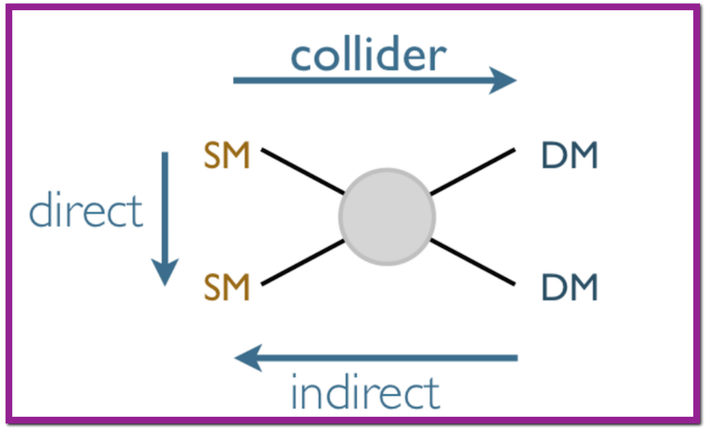

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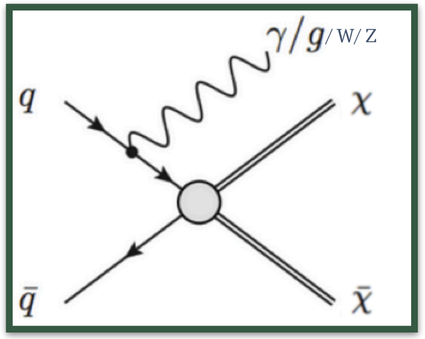

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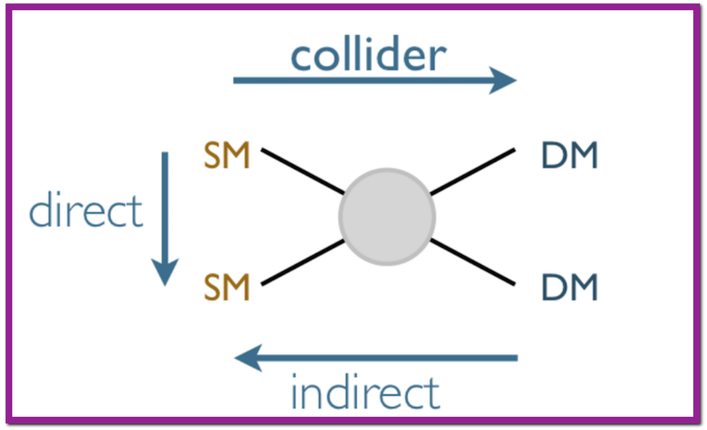

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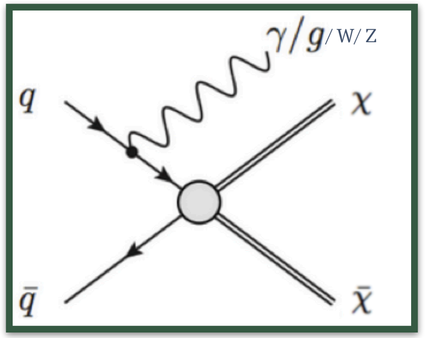
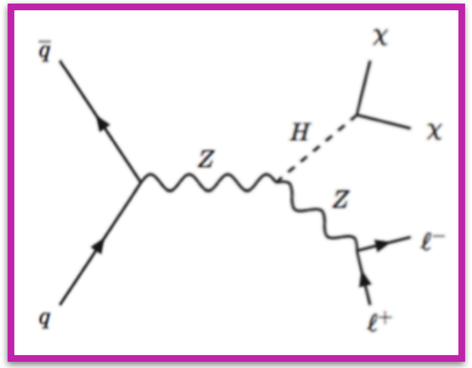


Higgs->invisible



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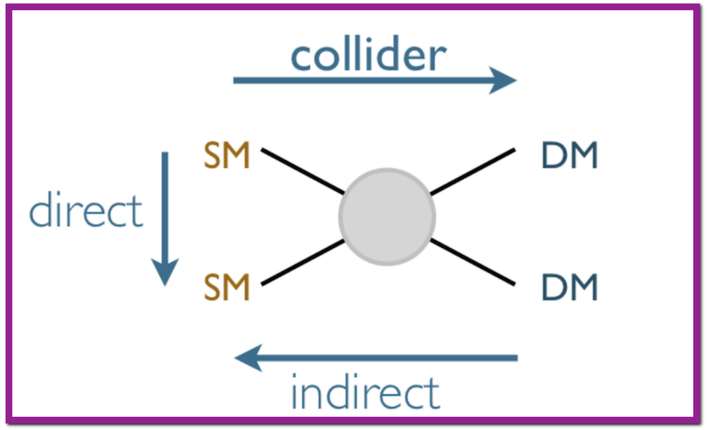

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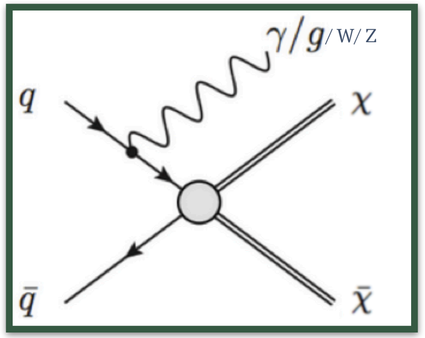
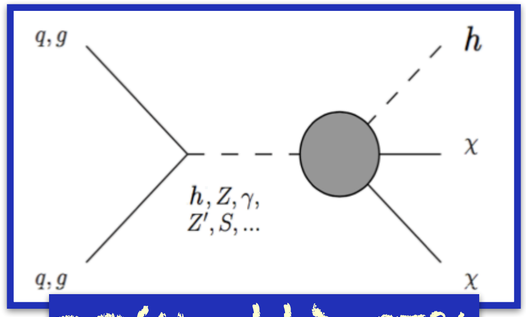


mono-Higgs

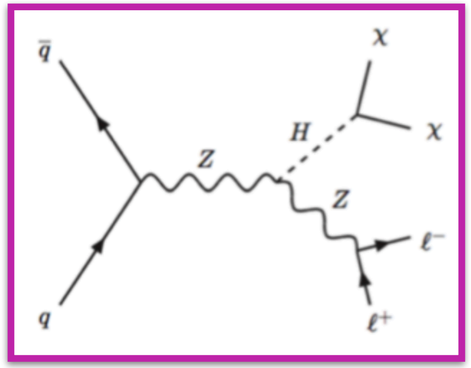


BR(H->bb)~57%

↓

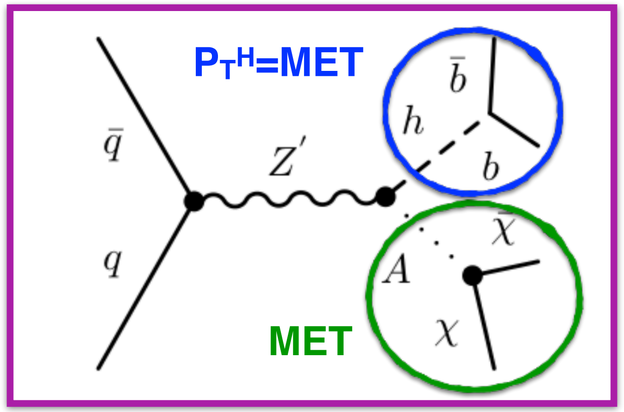
mono-H(bb)

Higgs->invisible



THE MONO-HBB CHANNEL

Z'-2HDM used as benchmark signal model.



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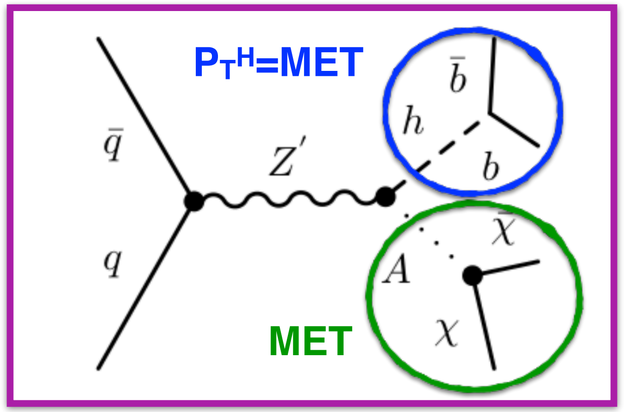

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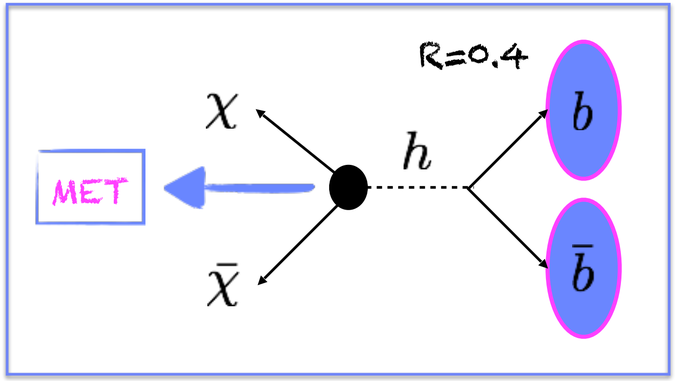
Distinction between resolved and merged region in order to maximize the sensitivity:

RESOLVED: MET≤500GEV



b-tagging on central small-R calo jets

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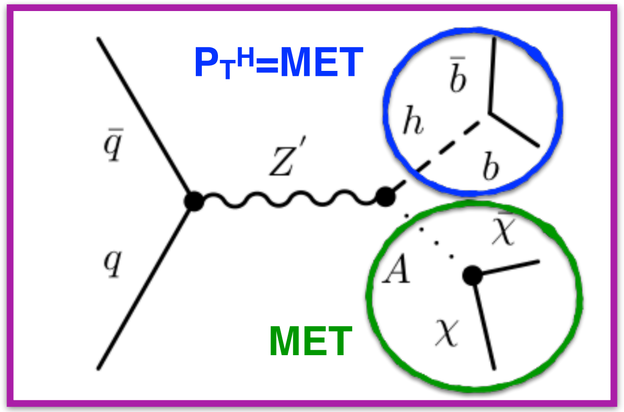

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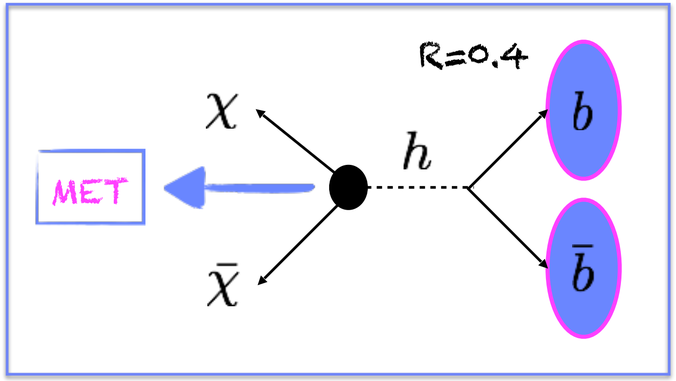


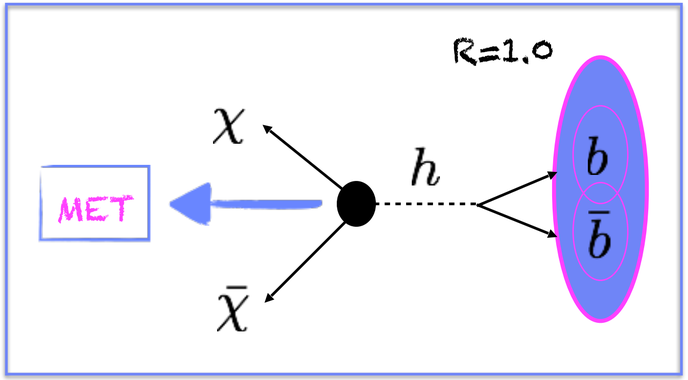
b-tagging on central small-R calo jets

higher p_T^H (MET)…higher $m_{Z'}$

$$\Delta R \sim \frac{2m}{p_T}$$

$$p_T >> m$$

MERGED: MET>500GEV

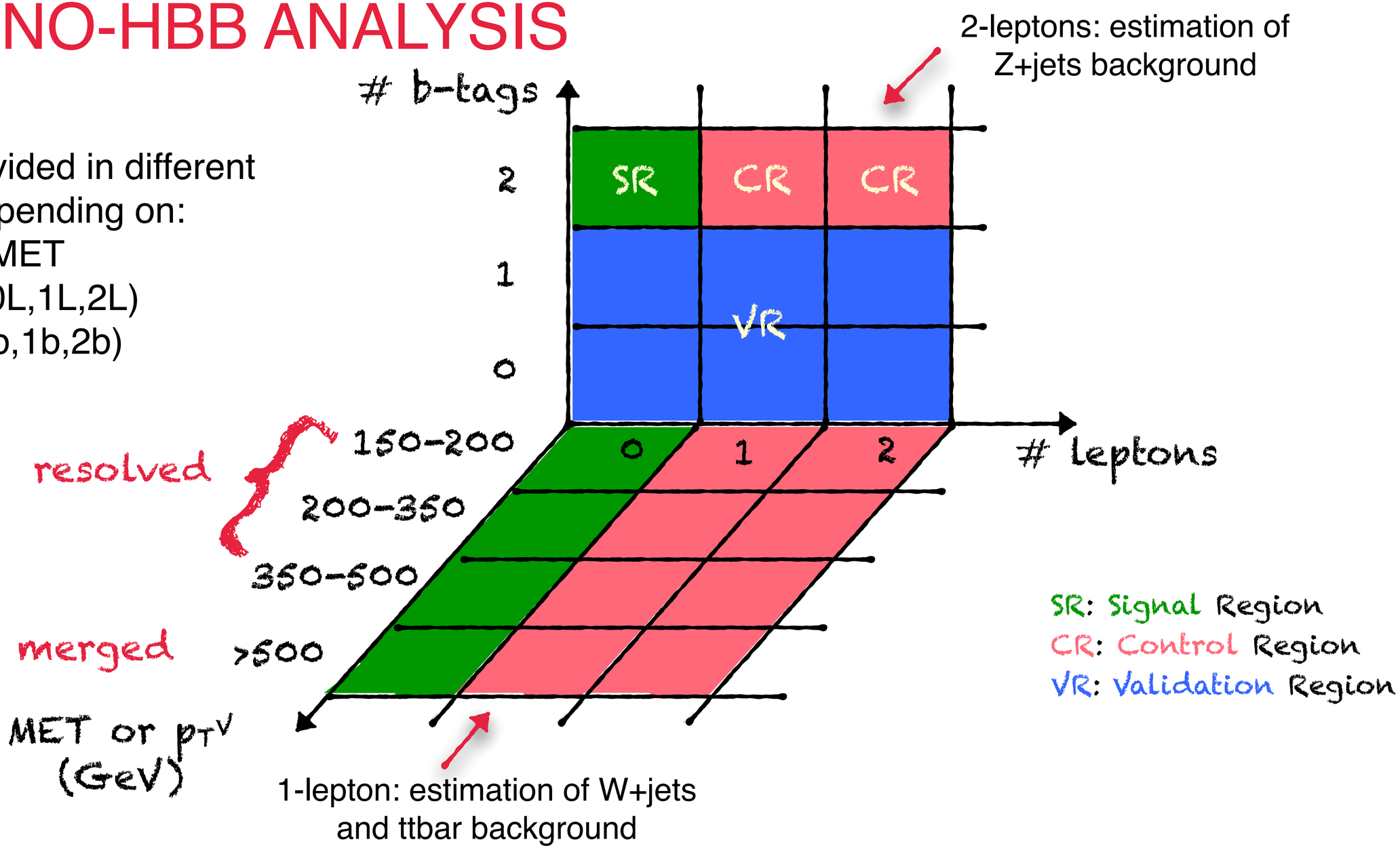


b-tagging on leading two track jets

THE MONO-HBB ANALYSIS

Events are divided in different categories depending on:

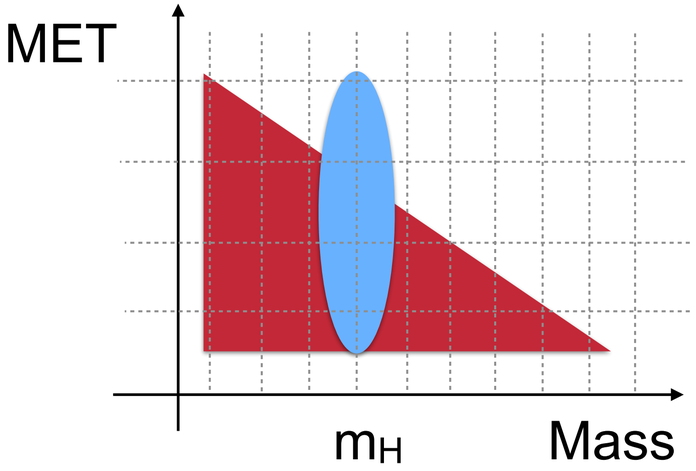
- amount of MET
- # leptons (0L,1L,2L)
- # b-tags (0b,1b,2b)

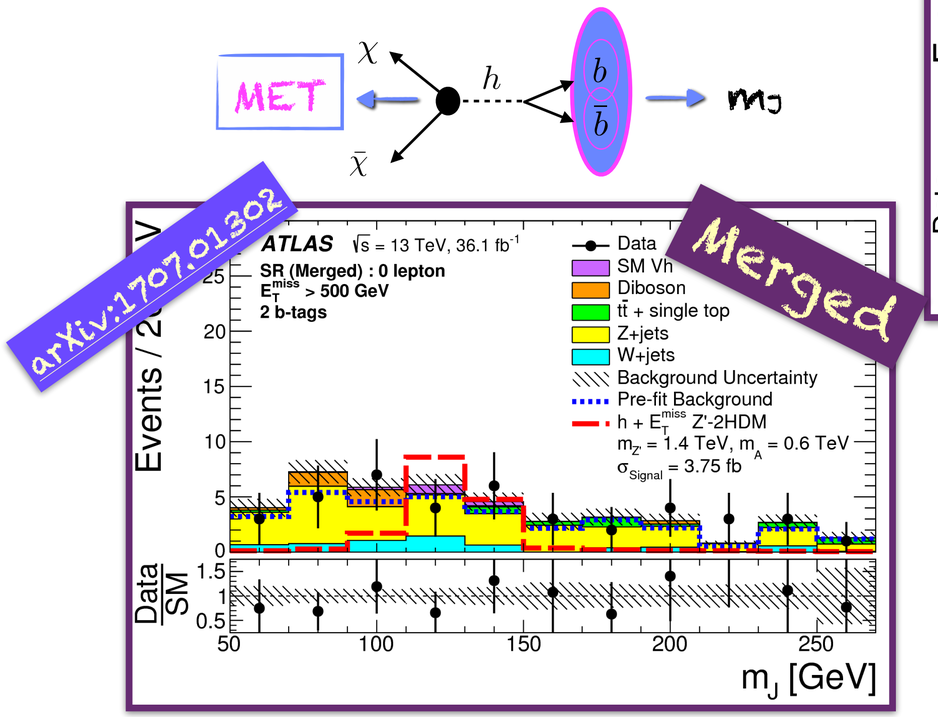


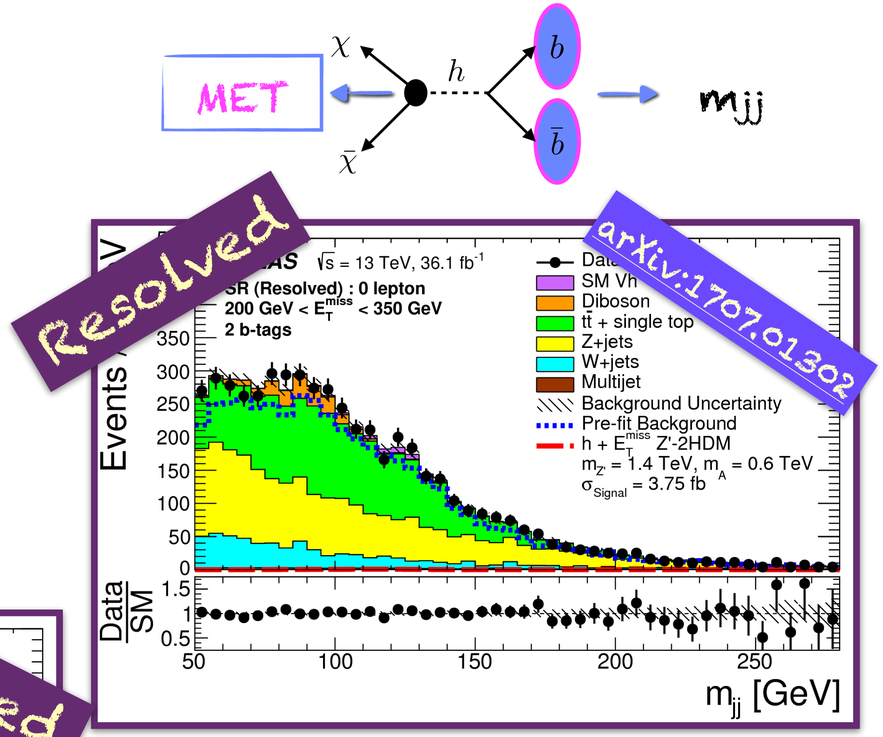
THE MONO-HBB ANALYSIS

Interpretation of final results done performing a profile likelihood fit in all SRs and CRs:

- 0-lepton SR: **m_{jj}/m_J as final discriminant**
- 1-lepton CR: muon charge as final discriminant
- 2-lepton CR: one single bin of m_{jj}/m_J as final discriminant







CURRENT STATUS

@79.8fb-1

Latest result (BOOST July 2018 CONF note):

- ☑ Run2 **2015+2016+2017** data: ATLAS-CONF-2018-039

Previous results:

- ☑ Run1: arXiv:1510.06218
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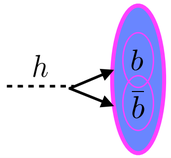
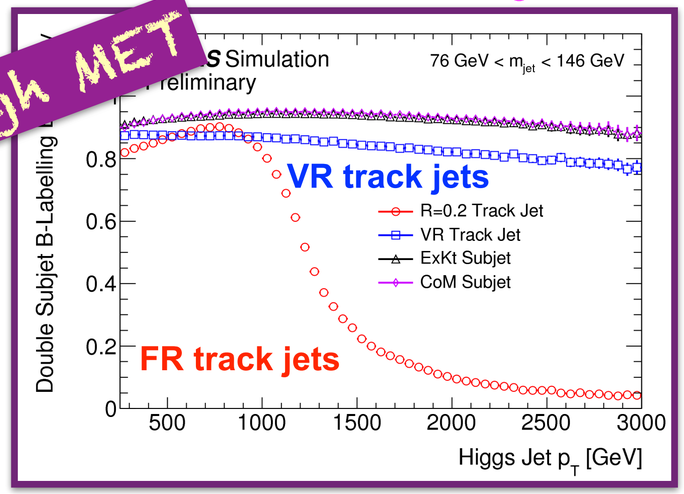


high MET



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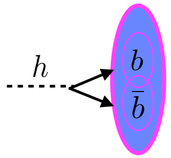

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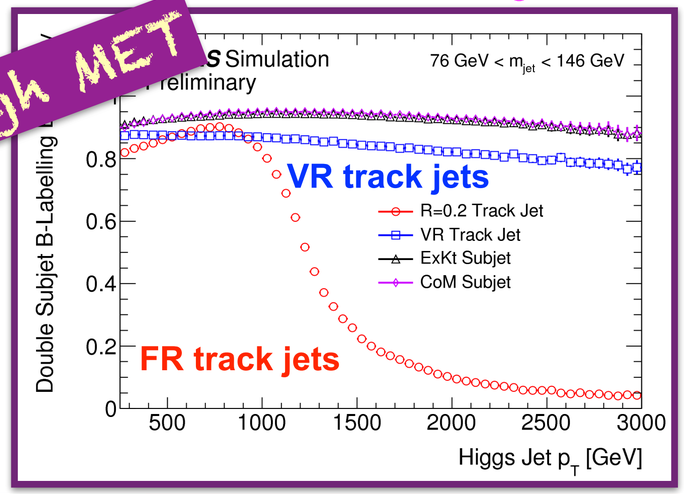
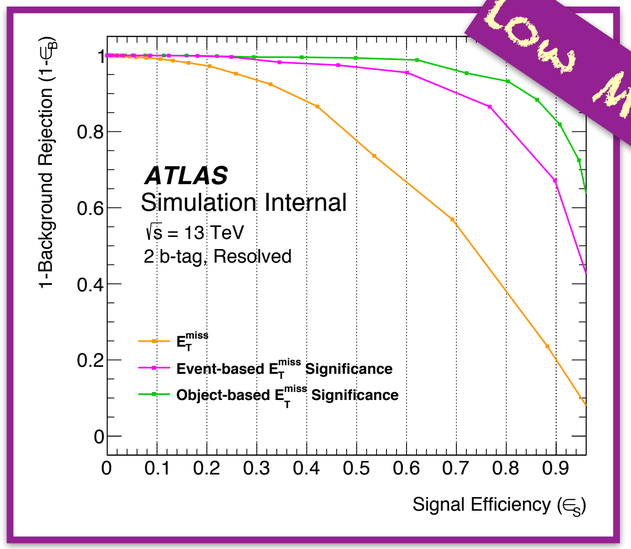


2) usage of the object-based MET significance to improve the multi jet background rejection

LOW MET



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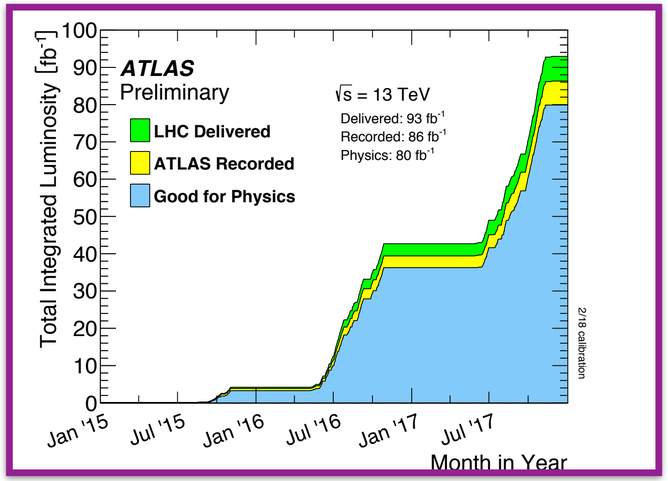
3) x2 luminosity



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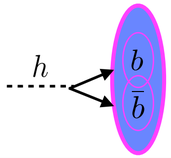

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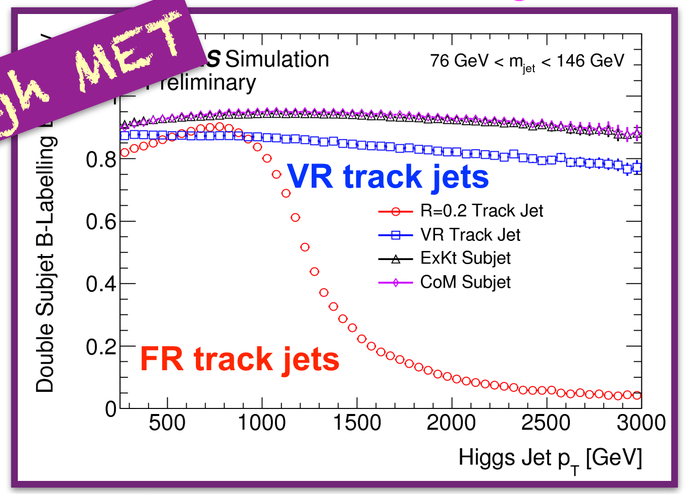

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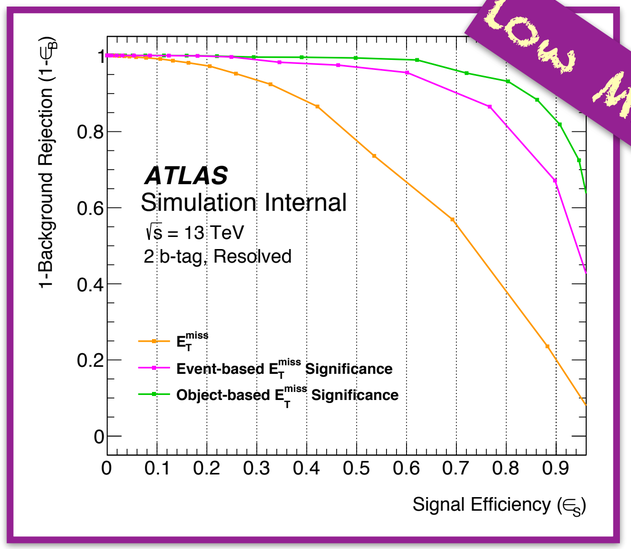
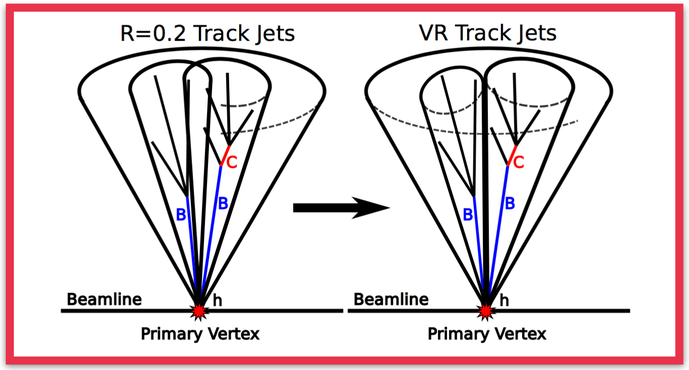


FROM FIXED TO VARIABLE-R TRACK JETS

At very high p_T, the two track jets tend to merge. This leads to a worse background rejection for fixed radius track jets.

Solution: adjust the radius on varying of the track jet p_T.

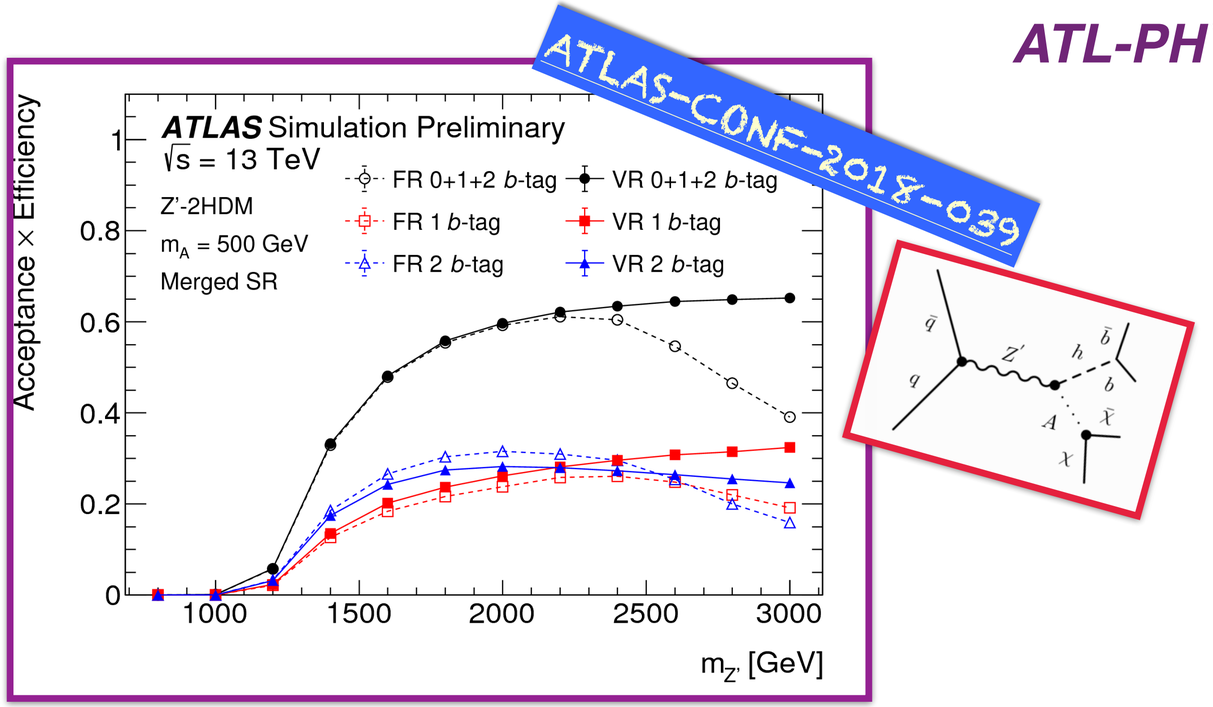


$R \rightarrow R_{eff}(p_T) = \rho/p_T$

$R_{max}=0.4$
$R_{min}=0.02$
$\rho=30$GeV

ATL-PHYS-PUB-2017-010

Improved subjet recover ability (hence enhanced signal acceptance) with VR track jets above 2 TeV.



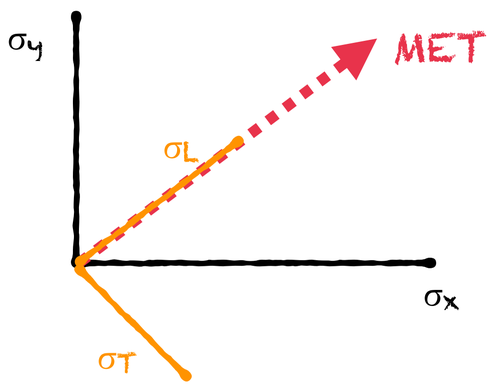
MET SIGNIFICANCE

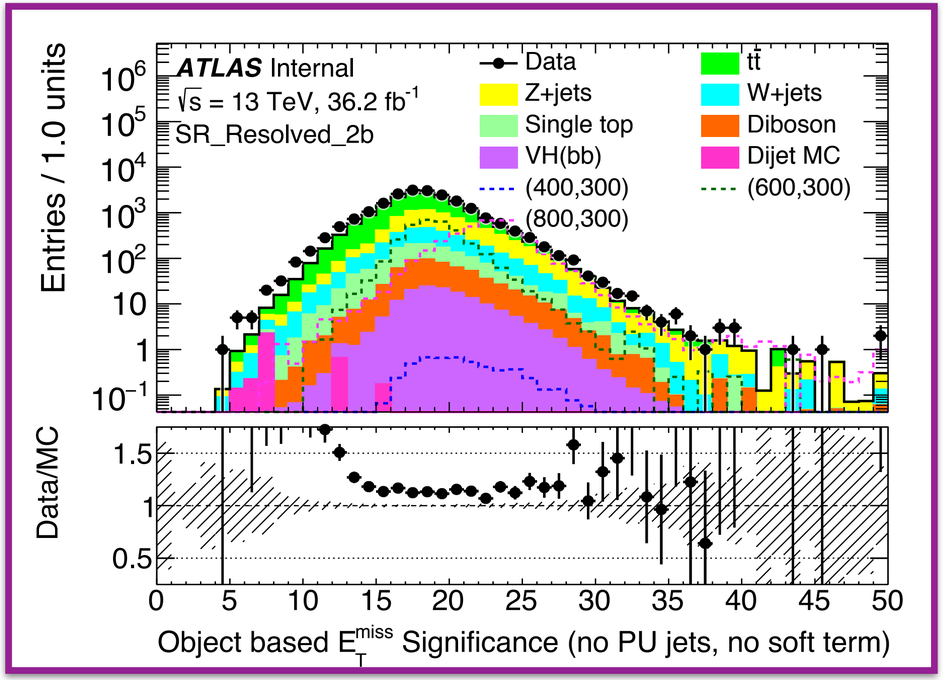
The MET significance *S* can help in distinguishing events with fake and real MET. A new improved **object-based** definition takes into account the expected resolutions and directional correlations of each object entering in the MET reconstruction:

$$S = \frac{\left|\overrightarrow{E_T^{miss}}\right|^2}{\sigma_L^2 (1 - \rho_{LT}^2)}$$

total longitudinal variance

correlation factor of longitudinal and transverse measurement





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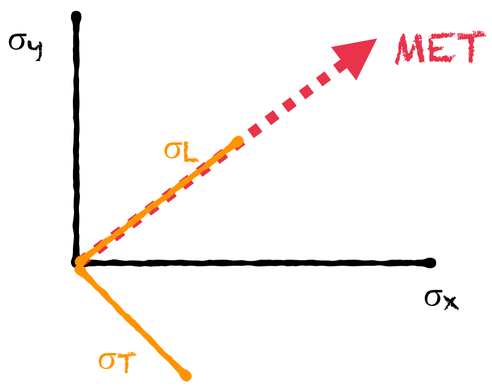

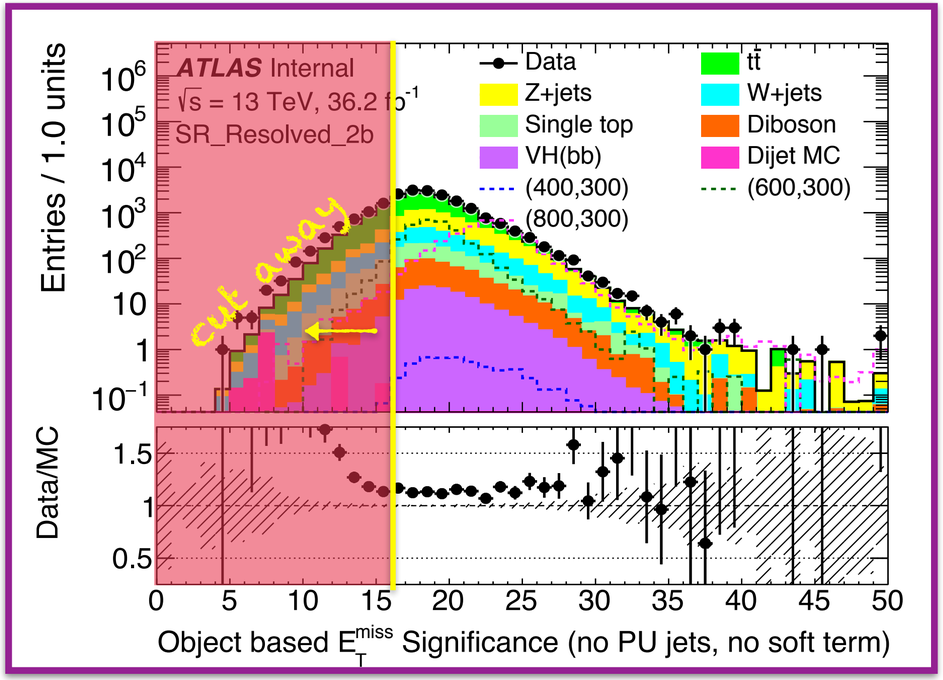

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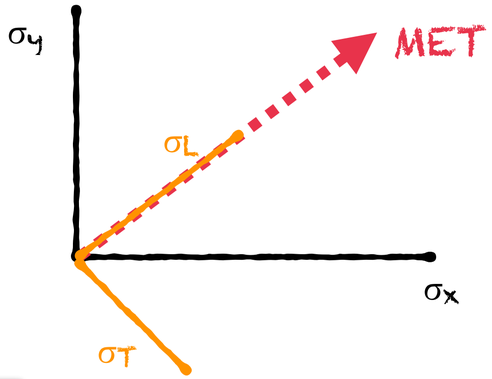

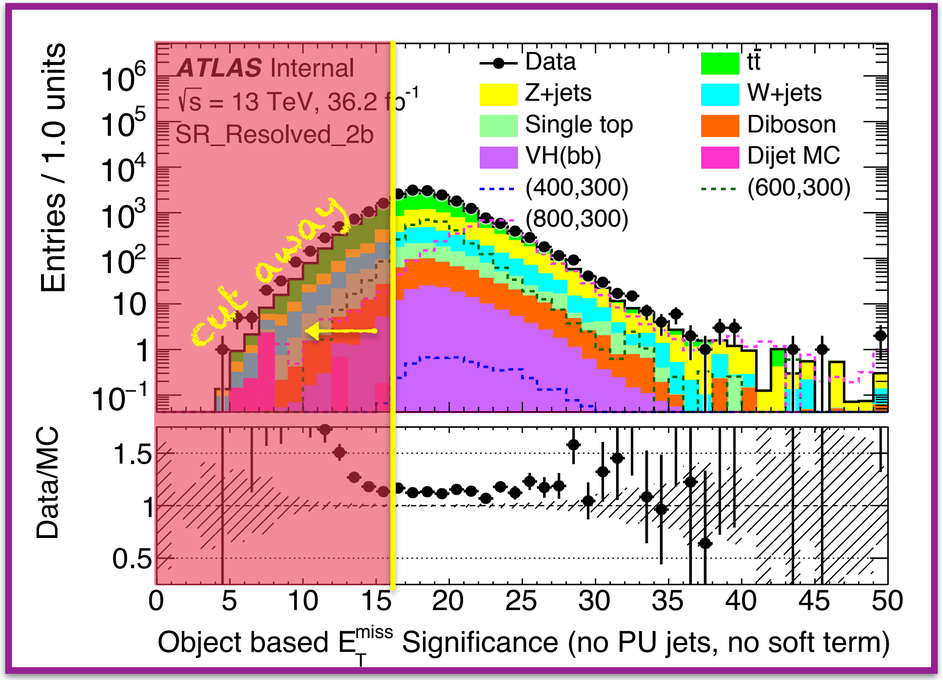

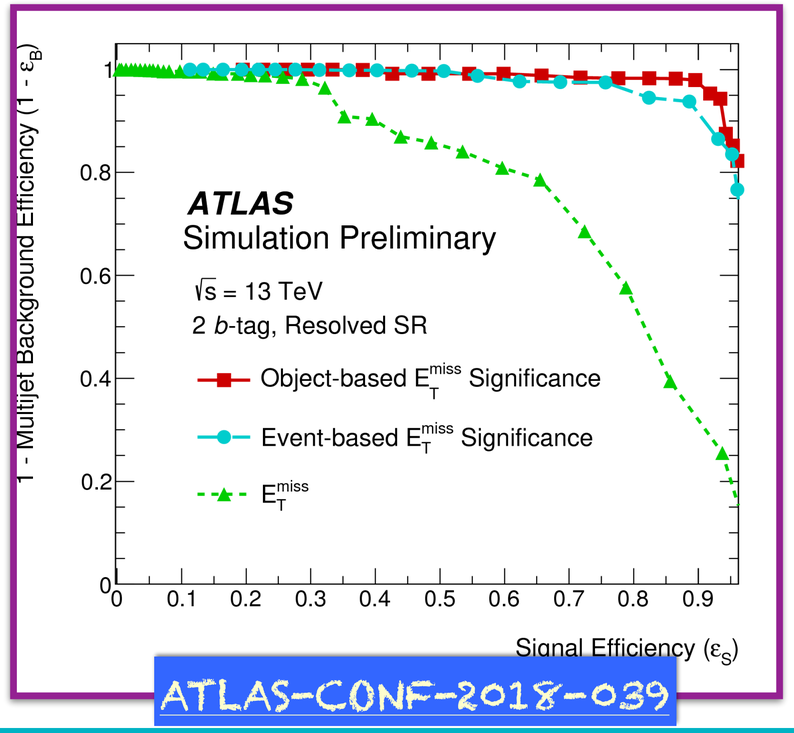

ATLAS-CONF-2018-039

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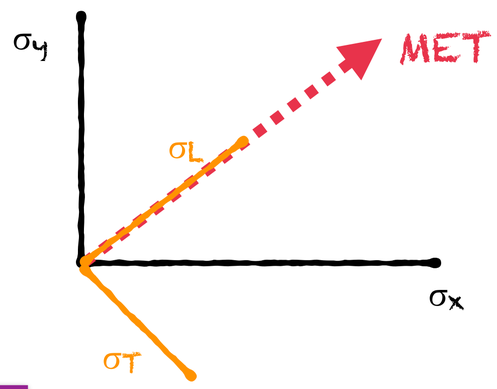
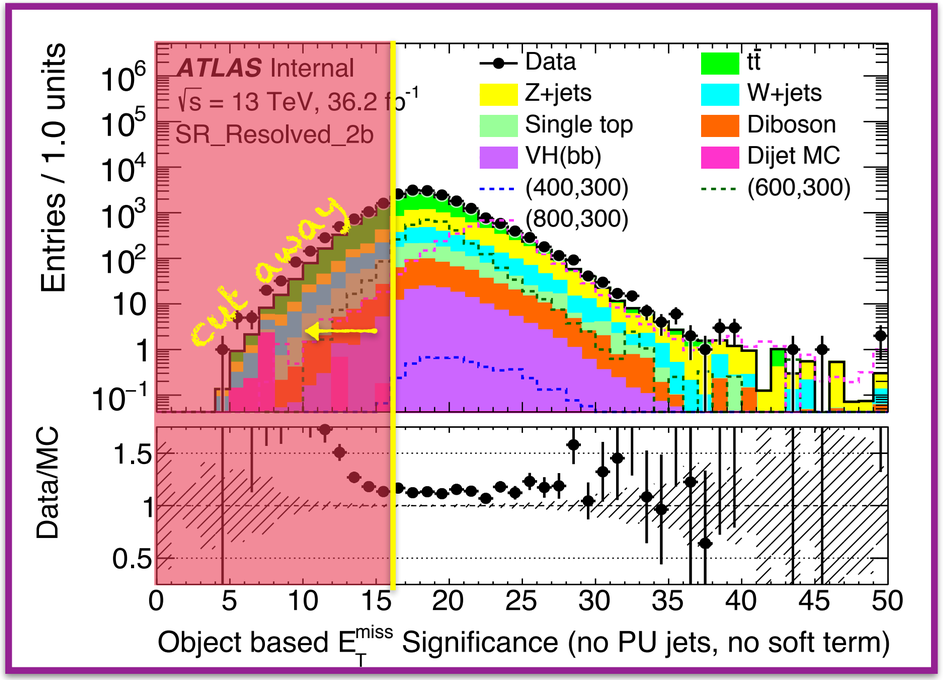
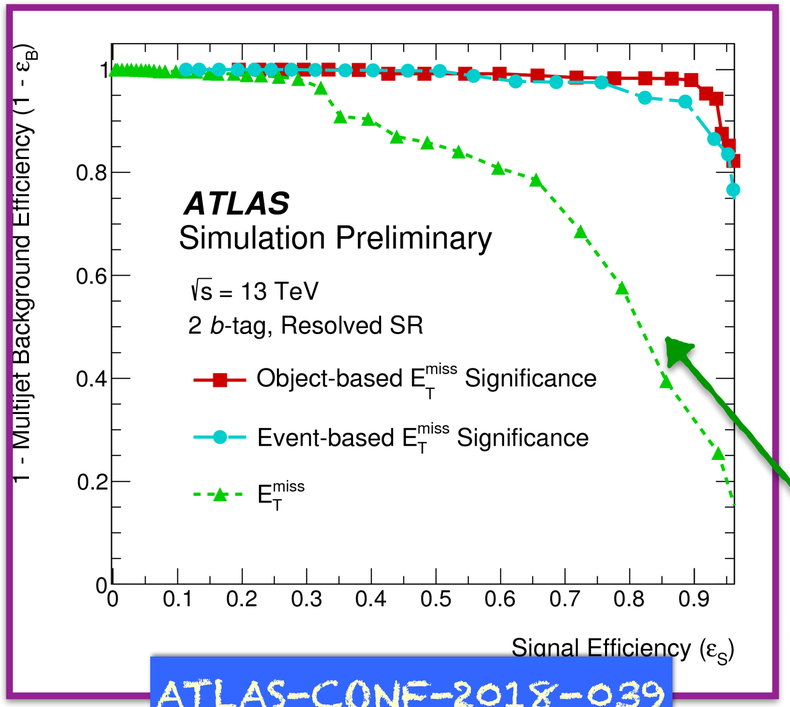






ATLAS-CONF-2018-039

"standard" anti-qcd cut

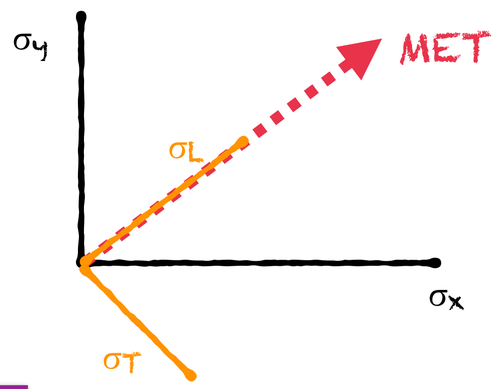
MET SIGNIFICANCE

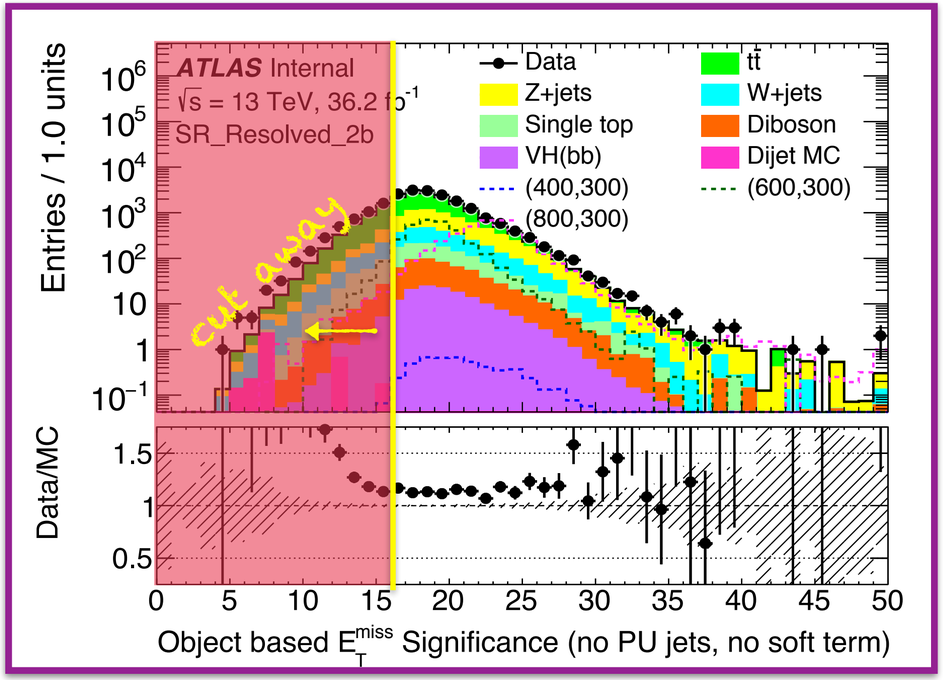
The MET significance *S* can help in distinguishing events with fake and real MET. A new improved **object-based** definition takes into account the expected resolutions and directional correlations of each object entering in the MET reconstruction:

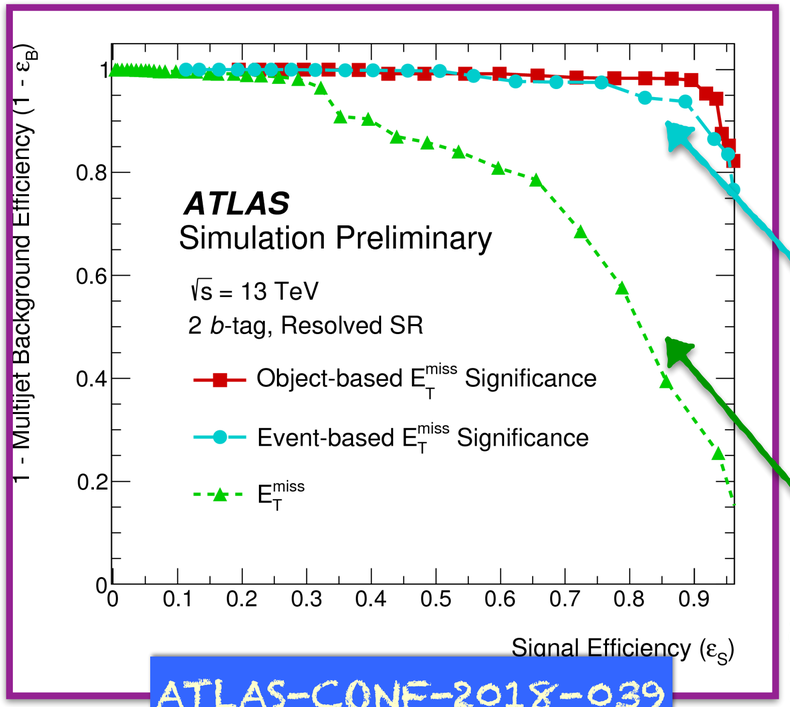
$$S = \frac{\left|\overrightarrow{E_T^{miss}}\right|^2}{\sigma_L^2 (1 - \rho_{LT}^2)}$$

total longitudinal variance

correlation factor of longitudinal and transverse measurement







ATLAS-CONF-2018-039

event-based

$$\frac{E_T^{miss}}{\sqrt{\sum E_T}}$$

"standard" anti-qcd cut

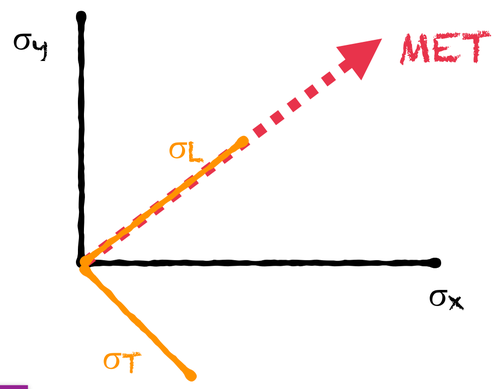
MET SIGNIFICANCE

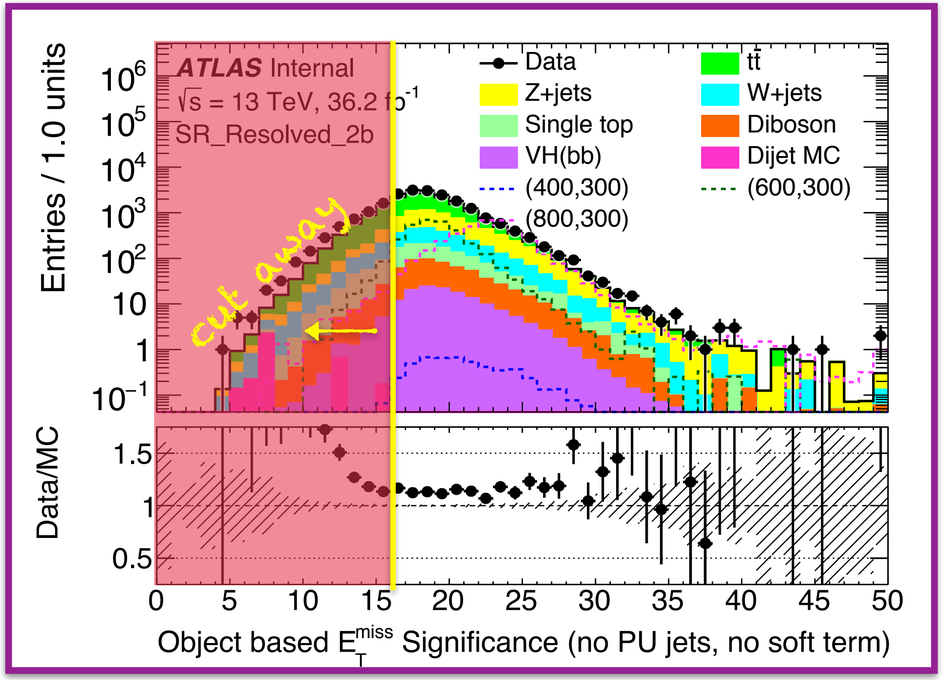
The MET significance *S* can help in distinguishing events with fake and real MET. A new improved **object-based** definition takes into account the expected resolutions and directional correlations of each object entering in the MET reconstruction:

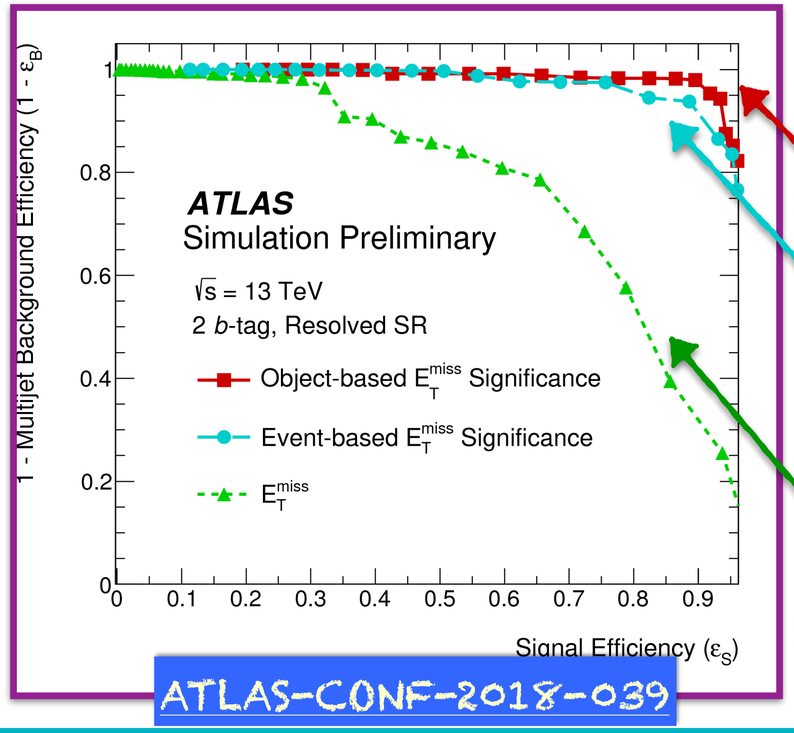
$$S = \frac{\left|\overrightarrow{E_T^{miss}}\right|^2}{\sigma_L^2 (1 - \rho_{LT}^2)}$$

total longitudinal variance

correlation factor of longitudinal and transverse measurement







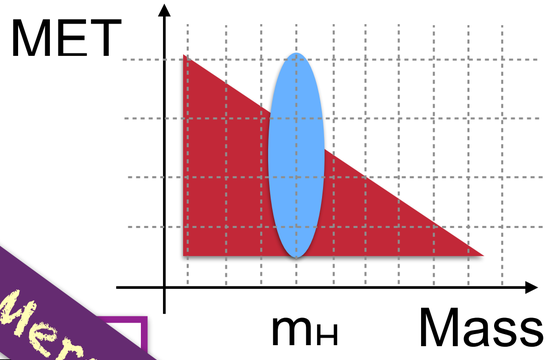
object-based

event-based

$$\frac{E_T^{miss}}{\sqrt{\sum E_T}}$$

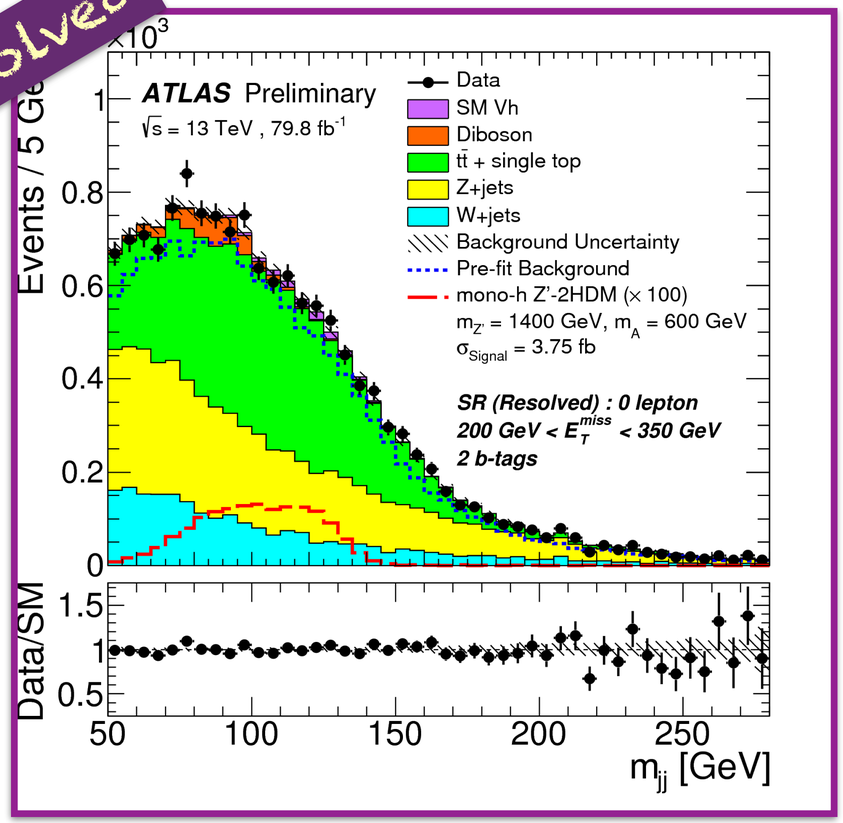
"standard" anti-qcd cut

RESULTS @79.8fb-1



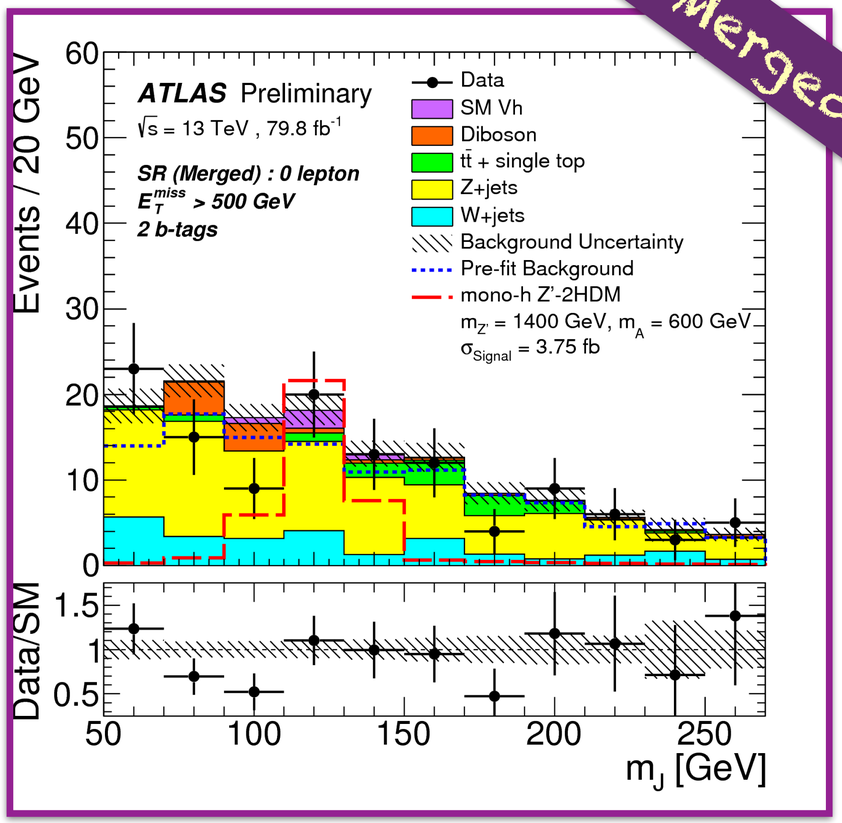
No excess observed over Standard Model prediction…

Resolved



ATLAS-CONF-2018-039

Merged

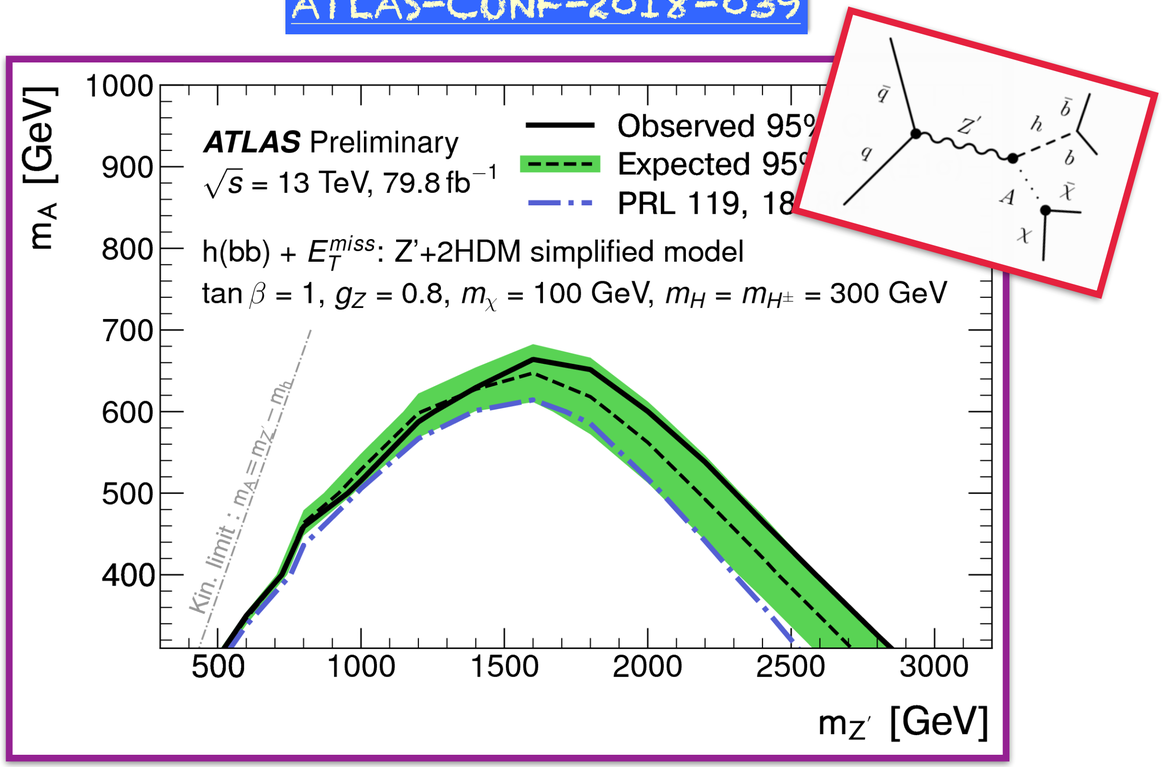


ATLAS-CONF-2018-039

RESULTS @79.8fb-1

Z'-2HDM signal model used as a benchmark

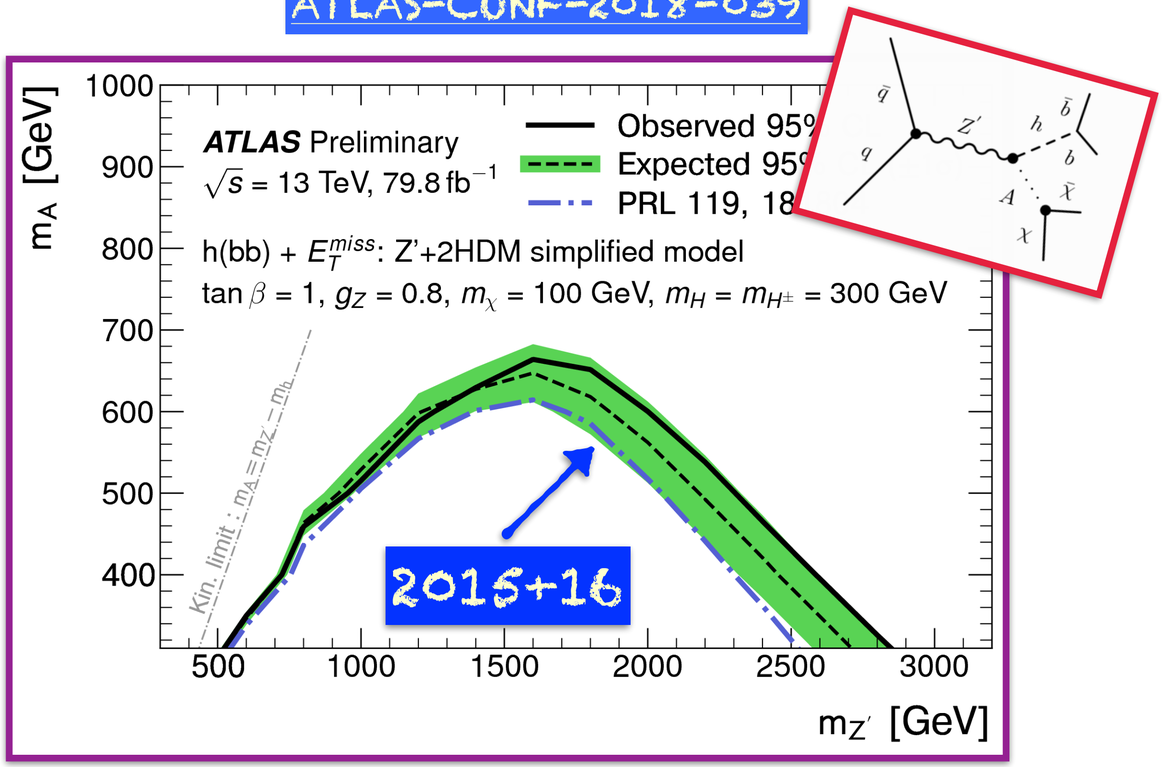
ATLAS-CONF-2018-039



RESULTS @79.8fb-1

Z'-2HDM signal model used as a benchmark

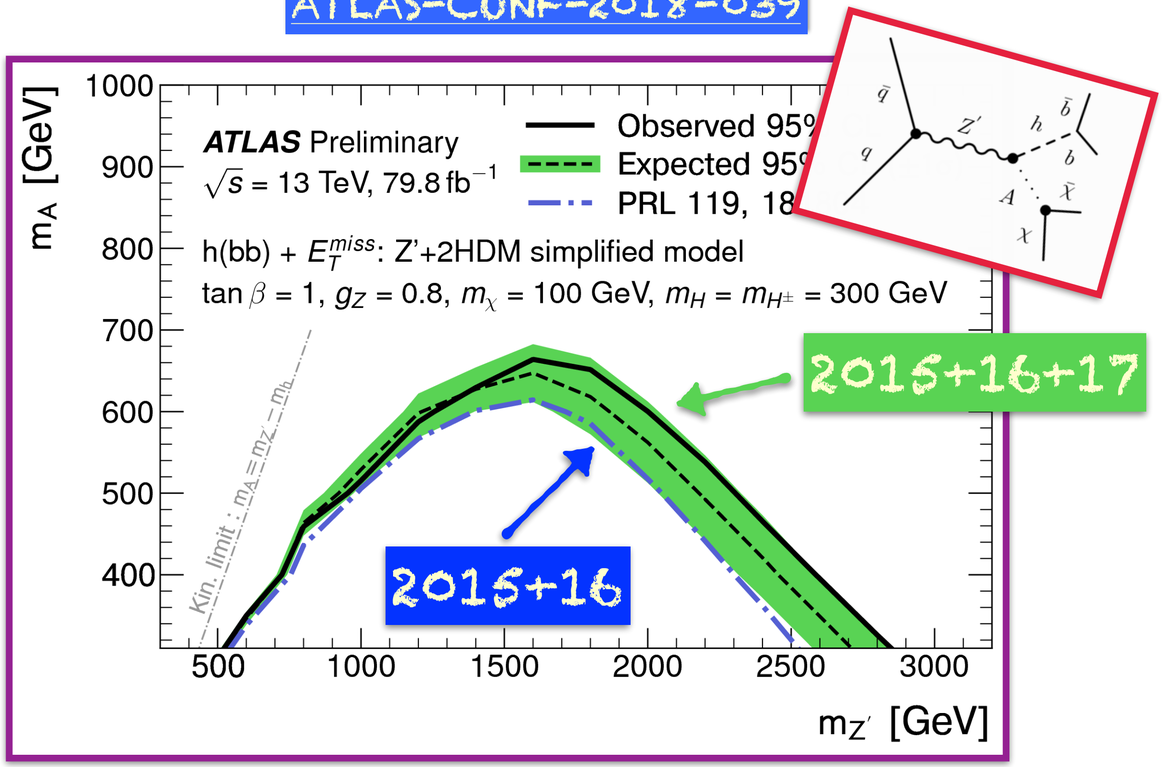
ATLAS-CONF-2018-039



RESULTS @79.8fb-1

Z'-2HDM signal model used as a benchmark

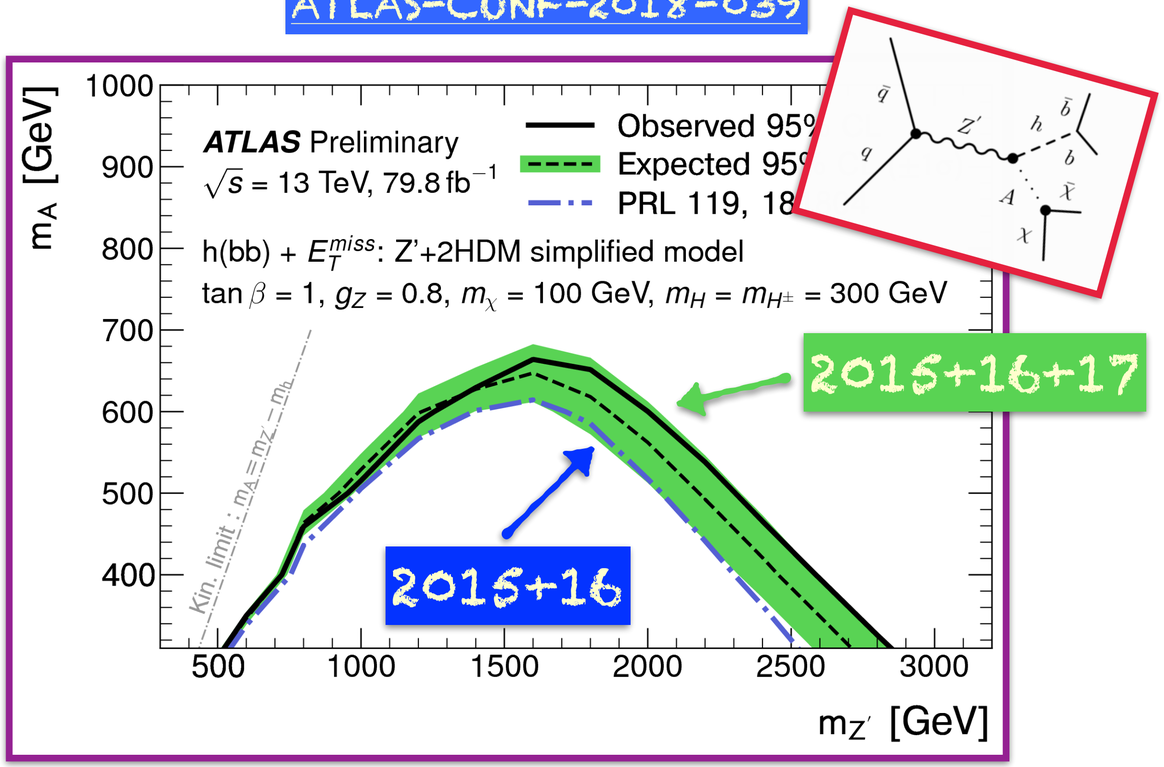
ATLAS-CONF-2018-039



RESULTS @79.8fb-1

Z'-2HDM signal model used as a benchmark

ATLAS-CONF-2018-039

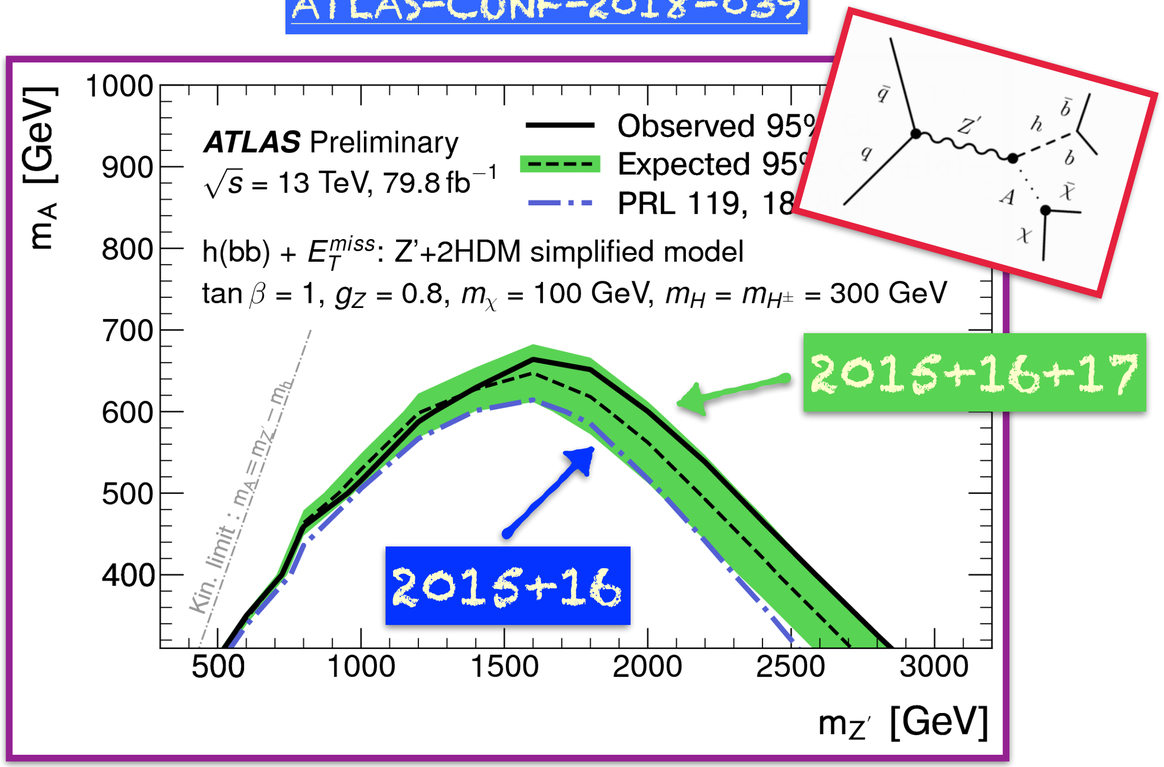


Is it the luminosity or the VR track jets?

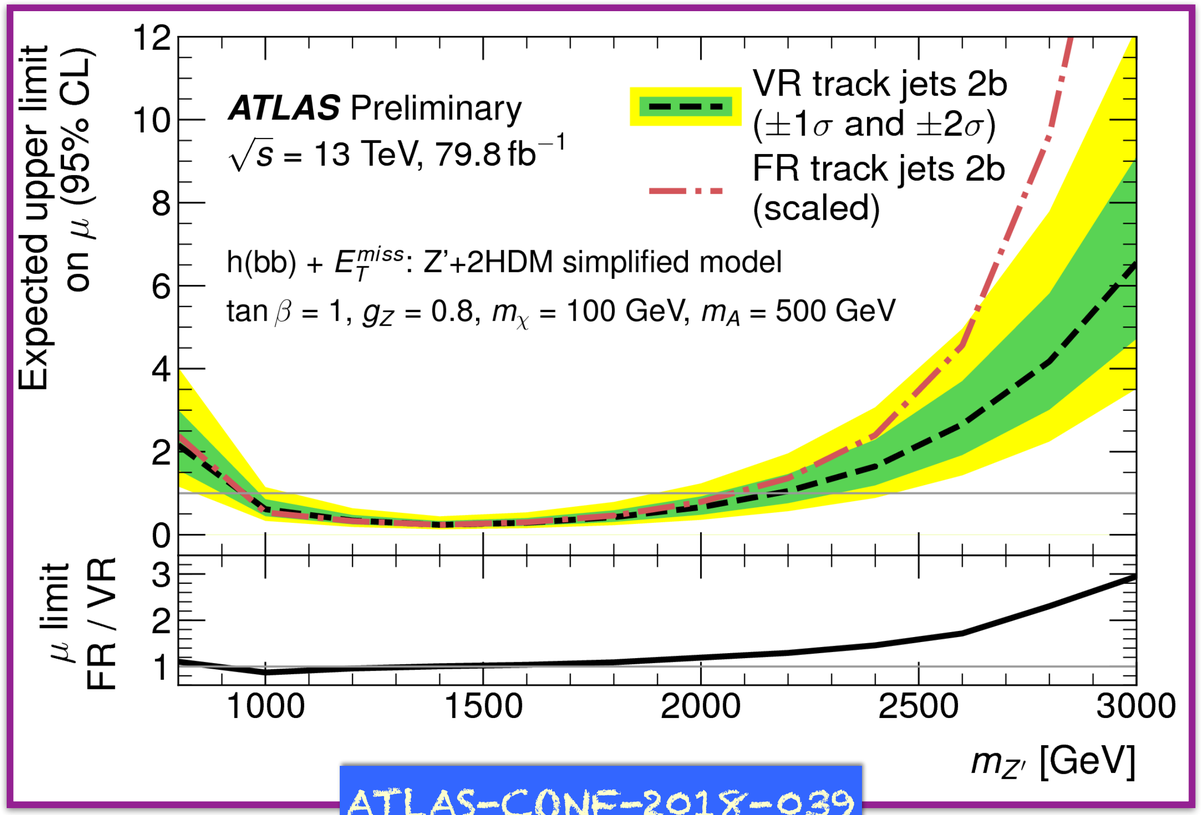
RESULTS @79.8fb-1

Z'-2HDM signal model used as a benchmark

ATLAS-CONF-2018-039



Improvement up to 200% only due to the usage of VR track jets!

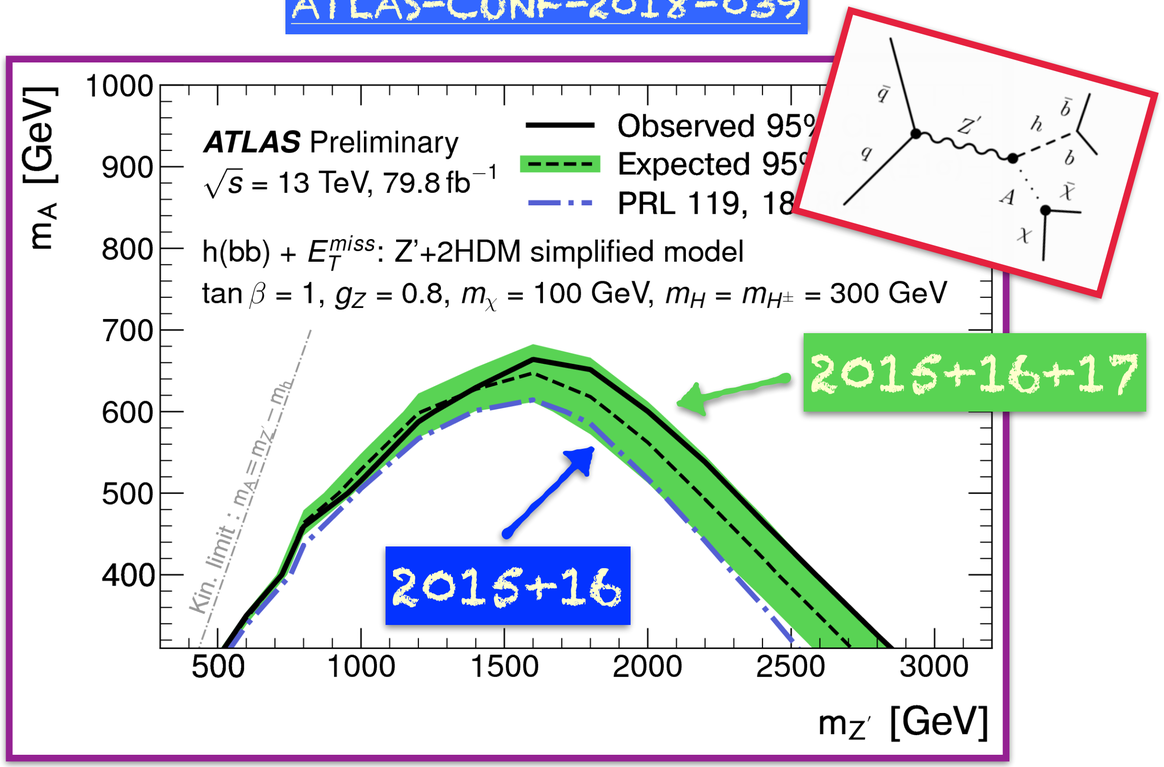


ATLAS-CONF-2018-039

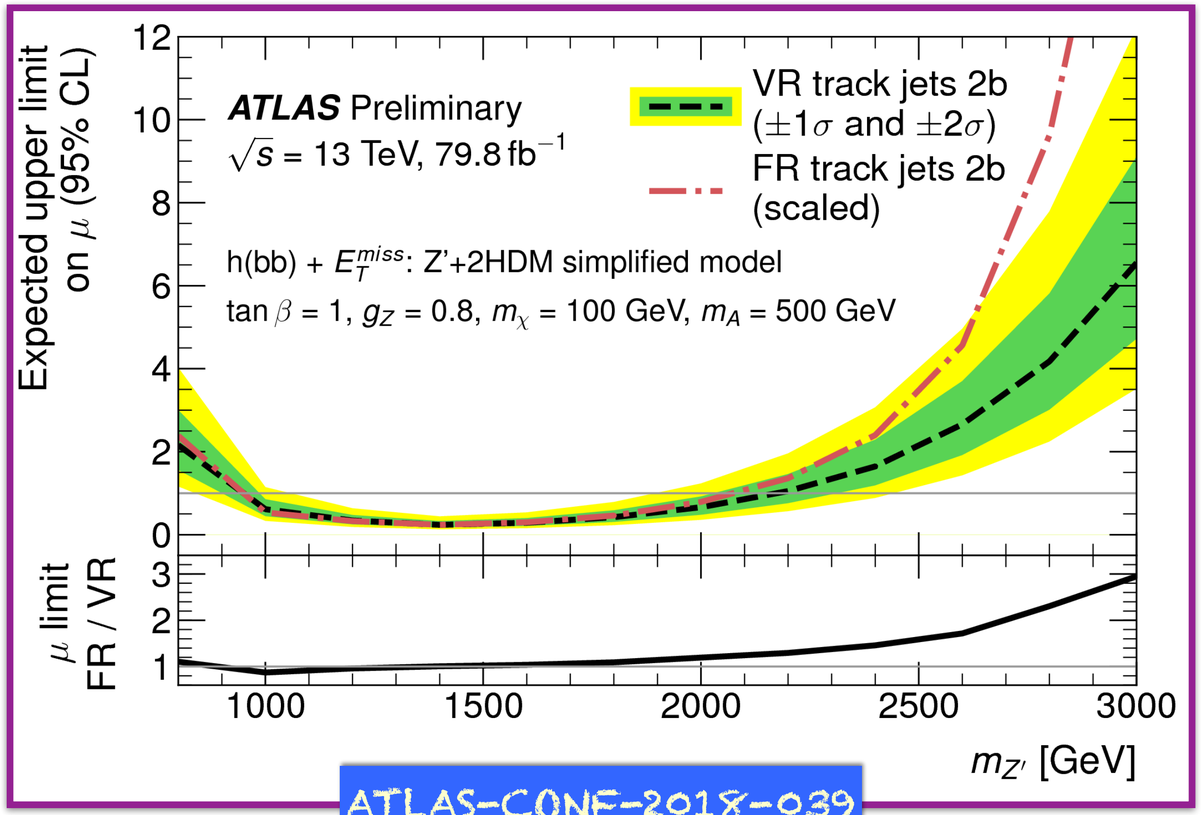
RESULTS @79.8fb-1

Z'-2HDM signal model used as a benchmark

ATLAS-CONF-2018-039



Improvement up to 200% only due to the usage of VR track jets!



ATLAS-CONF-2018-039

First ever usage of VR track jets in ATLAS!

SYSTEMATICS BREAKDOWN

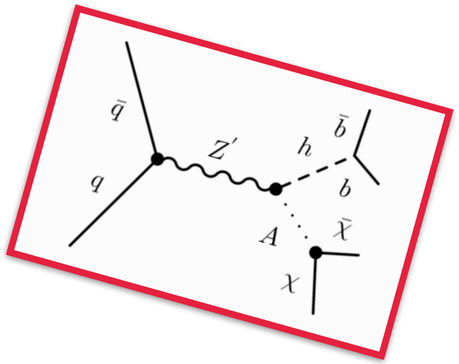
@79.8fb-1

Impact of systematic uncertainties for different Z'-2HDM models (different masses hence different MET regimes).

Source of uncert.	Impact [%] (a)	(b)	(c)
b-tagging	4.0	8.0	10
V+jets modeling	3.5	6.0	5.0
Top modeling	3.7	4.8	4.5
MC statistics	1.8	5.4	4.9
SM $Vh(b\bar{b})$	0.8	3.2	2.1
Diboson modeling	0.8	1.5	1.1
Signal modeling	3.0	2.5	1.5
Luminosity	2.0	2.5	2.5
Small-R jets	1.4	3.0	2.0
Large-R jets	0.2	1.0	2.0
E_T^{miss}	1.2	1.7	1.1
Leptons	0.2	0.8	0.7
Total syst. uncert.	6.5	13	13
Statistical uncert.	2.3	20	22
Total uncertainty	7	24	25

MET

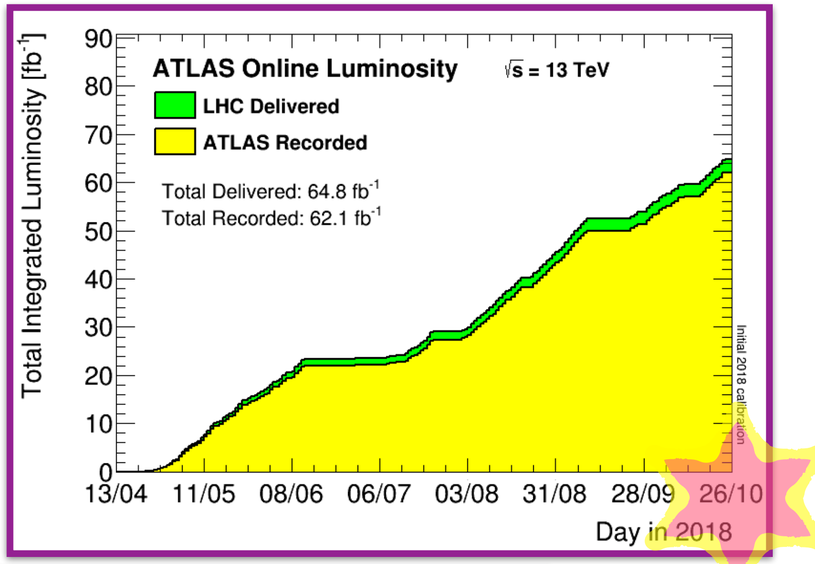
a) $(m_{Z'},m_A)=(0.6\text{TeV},0.3\text{TeV})$
b) $(m_{Z'},m_A)=(1.4\text{TeV},0.6\text{TeV})$
c) $(m_{Z'},m_A)=(2.6\text{TeV},0.3\text{TeV})$



- b-tagging and V+jets/Top modelling are the dominant sources of systematic uncertainty
- the analysis is statistically limited at medium-high MET

FUTURE PLANS

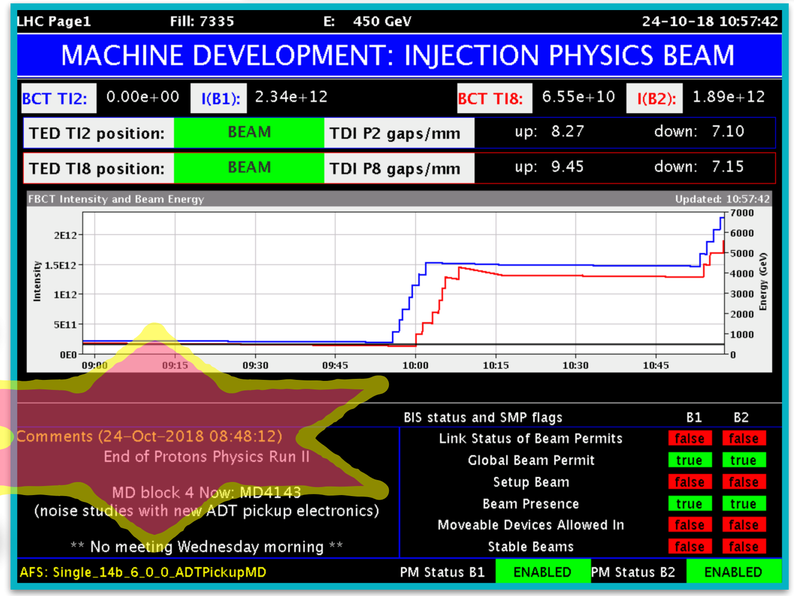
@149fb-1



Many ideas already being discussed in view of full Run-2 analysis:

- dedicate studies to decrease the dominant systematic uncertainties
  - V+jets/Top modeling, b-tagging…
- MET significance *in place of* standard anti-qcd cuts
- re-interpretations
  - include other signal models (also at low MET)
  - <u>RECAST</u>

Full Run-2 analysis has already started…



Thank you for the attention!

BACKUP SLIDES

SR EVENT SELECTION

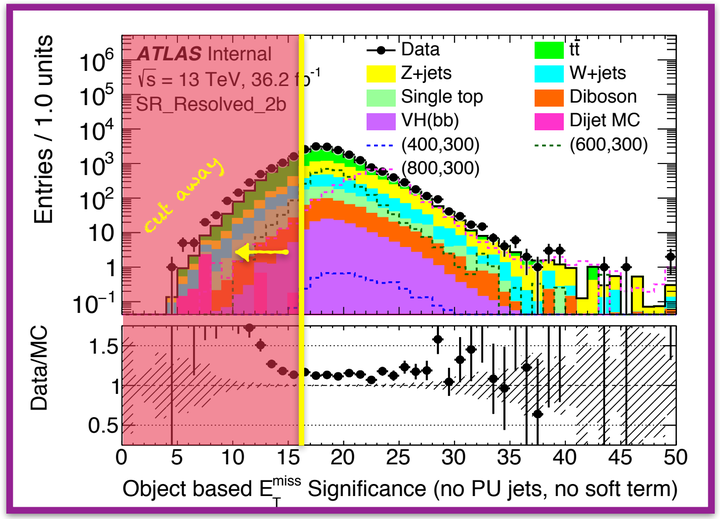
Resolved	Merged
trigger	
lepton veto (SR) or selection (CRs)	
(modified) $E_{\mathrm{T}}^{\mathrm{miss}} > 150\,\mathrm{GeV}$	
min $\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{jets}) > 20^{\circ}$	
$\Delta\phi\,(E_{\mathrm{T}}^{\mathrm{miss}}, p_{\mathrm{T}}^{\mathrm{miss}}) < 90^{\circ}$	
S >16 (SR only)	—
0ℓ SR: $E_{\mathrm{T}}^{\mathrm{miss}} < 500\,\mathrm{GeV}$ 1μ-CR: $E_{\mathrm{T}}^{\mathrm{miss,\,no}\,\mu} < 500\,\mathrm{GeV}$ 2ℓ-CR: $p_{\mathrm{T}}^{\ell\ell} < 500\,\mathrm{GeV}$	0ℓ SR: $E_{\mathrm{T}}^{\mathrm{miss}} > 500\,\mathrm{GeV}$ 1μ-CR: $E_{\mathrm{T}}^{\mathrm{miss,\,no}\,\mu} > 500\,\mathrm{GeV}$ 2ℓ-CR: $p_{\mathrm{T}}^{\ell\ell} > 500\,\mathrm{GeV}$
N(central small-R jets) ≥ 2	N(central large-R jets) ≥ 1
$p_{\mathrm{T}}^{\mathrm{jet}_1} > 45 \parallel p_{\mathrm{T}}^{\mathrm{jet}_2} > 45$	—
$\sum_{i=1}^{2(3)} p_{\mathrm{T}}^{\mathrm{jet}_i} > 120\ (150)\,\mathrm{GeV}$	—
$\Delta\phi(\mathrm{jet}_1, \mathrm{jet}_2) < 140^{\circ}$	—
$\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, h) > 120^{\circ}$	—
τ-veto	
additional b-jet veto	
H_T ratio	
$\Delta R(\mathrm{jet}_1, \mathrm{jet}_2) < 1.8$	$\frac{\Delta R(\mathrm{VR}_1, \mathrm{VR}_2)}{R_{\mathrm{min}}} > 1$
b-tag requirement on	
small-R jets	track-jets

SR EVENT SELECTION

Resolved	Merged
trigger	
lepton veto (SR) or selection (CRs)	
(modified) $E_T^{miss} > 150$ GeV	
min $\Delta\phi(E_T^{miss}, \text{jets}) > 20°$	
$\Delta\phi\,(E_T^{miss}, p_T^{miss}) < 90°$	
S >16 (SR only)	—
0ℓ SR: $E_T^{miss} < 500$ GeV 1μ-CR: $E_T^{miss,\,no\,\mu} < 500$ GeV 2ℓ-CR: $p_T^{\ell\ell} < 500$ GeV	0ℓ SR: $E_T^{miss} > 500$ GeV 1μ-CR: $E_T^{miss,\,no\,\mu} > 500$ GeV 2ℓ-CR: $p_T^{\ell\ell} > 500$ GeV
N(central small-R jets) ≥ 2	N(central large-R jets) ≥ 1
$p_T^{jet_1} > 45 \parallel p_T^{jet_2} > 45$	—
$\sum_{i=1}^{2(3)} p_T^{jet_i} > 120\ (150)$ GeV	—
$\Delta\phi(\text{jet}_1, \text{jet}_2) < 140°$	—
$\Delta\phi(E_T^{miss}, h) > 120°$	—
τ-veto	
additional b-jet veto	
H_T ratio	
$\Delta R(\text{jet}_1, \text{jet}_2) < 1.8$	$\frac{\Delta R(\text{VR}_1, \text{VR}_2)}{R_{min}} > 1$
b-tag requirement on small-R jets	 track-jets

(standard) anti-qcd cuts

SR EVENT SELECTION



Resolved	Merged
trigger	
lepton veto (SR) or selection (CRs)	
(modified) $E_T^{miss} > 150$ GeV	
min $\Delta\phi(E_T^{miss}, \text{jets}) > 20°$	
$\Delta\phi\,(E_T^{miss}, p_T^{miss}) < 90°$	
S >16 (SR only)	—
0ℓ SR: $E_T^{miss} < 500$ GeV 1μ-CR: $E_T^{miss,\,no\,\mu} < 500$ GeV 2ℓ-CR: $p_T^{\ell\ell} < 500$ GeV	0ℓ SR: $E_T^{miss} > 500$ GeV 1μ-CR: $E_T^{miss,\,no\,\mu} > 500$ GeV 2ℓ-CR: $p_T^{\ell\ell} > 500$ GeV
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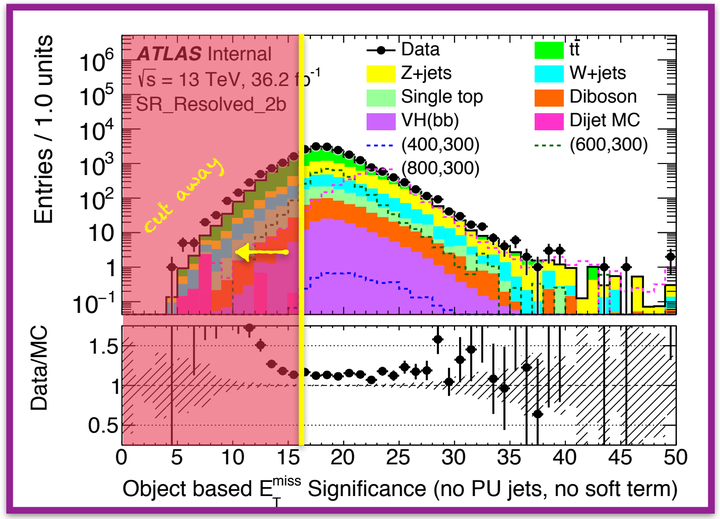
$\sum_{i=1}^{2(3)} p_T^{jet_i} > 120\ (150)$ GeV	—
$\Delta\phi(\text{jet}_1, \text{jet}_2) < 140°$	—
$\Delta\phi(E_T^{miss}, h) > 120°$	—
τ-veto	
additional b-jet veto	
H_T ratio	
$\Delta R(\text{jet}_1, \text{jet}_2) < 1.8$	$\frac{\Delta R(\text{VR}_1, \text{VR}_2)}{R_{min}} > 1$
b-tag requirement on small-R jets	 track-jets

NEW

(standard)
anti-qcd cuts

SR EVENT SELECTION



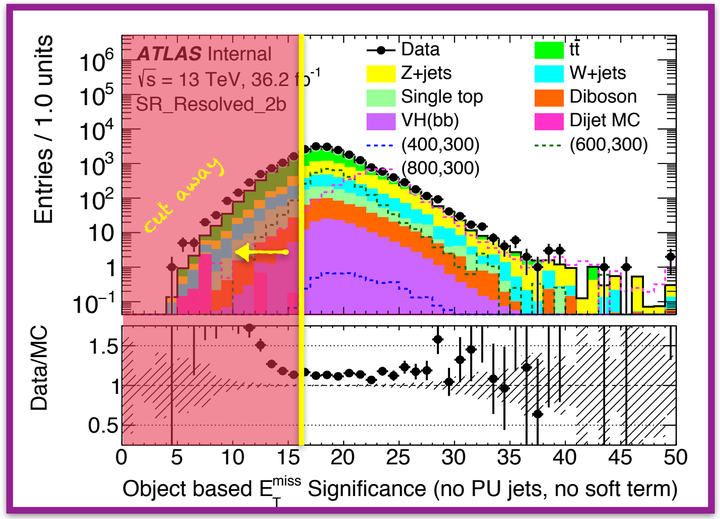
Resolved	Merged
trigger	
lepton veto (SR) or selection (CRs)	
(modified) $E_T^{miss} > 150$ GeV	
min $\Delta\phi(E_T^{miss}, \text{jets}) > 20°$	
$\Delta\phi\,(E_T^{miss}, p_T^{miss}) < 90°$	
S >16 (SR only)	—
0ℓ SR: $E_T^{miss} < 500$ GeV 1μ-CR: $E_T^{miss,\,no\,\mu} < 500$ GeV 2ℓ-CR: $p_T^{\ell\ell} < 500$ GeV	0ℓ SR: $E_T^{miss} > 500$ GeV 1μ-CR: $E_T^{miss,\,no\,\mu} > 500$ GeV 2ℓ-CR: $p_T^{\ell\ell} > 500$ GeV
N(central small-R jets) ≥ 2	N(central large-R jets) ≥ 1
$p_T^{jet_1} > 45 \,\|\|\, p_T^{jet_2} > 45$	—
$\sum_{i=1}^{2(3)} p_T^{jet_i} > 120\ (150)$ GeV	—
$\Delta\phi(\text{jet}_1, \text{jet}_2) < 140°$	—
$\Delta\phi(E_T^{miss}, h) > 120°$	—
τ-veto	
additional b-jet veto	
H_T ratio	
$\Delta R(\text{jet}_1, \text{jet}_2) < 1.8$	$\frac{\Delta R(\text{VR}_1, \text{VR}_2)}{R_{min}} > 1$
b-tag requirement on small-R jets	VR track-jets

new

new

(standard)
anti-qcd cuts

SR EVENT SELECTION



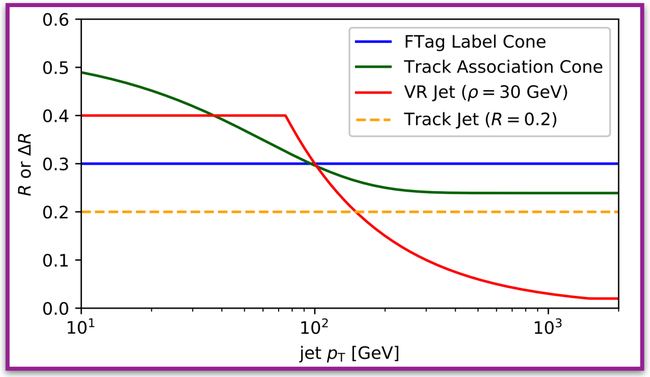
Resolved	Merged
trigger	
lepton veto (SR) or selection (CRs)	
(modified) $E_T^{miss} > 150$ GeV	
min $\Delta\phi(E_T^{miss}, \text{jets}) > 20°$	
$\Delta\phi\,(E_T^{miss}, p_T^{miss}) < 90°$	
S >16 (SR only)	—
0ℓ SR: $E_T^{miss} < 500$ GeV 1μ-CR: $E_T^{miss,\,no\,\mu} < 500$ GeV 2ℓ-CR: $p_T^{\ell\ell} < 500$ GeV	0ℓ SR: $E_T^{miss} > 500$ GeV 1μ-CR: $E_T^{miss,\,no\,\mu} > 500$ GeV 2ℓ-CR: $p_T^{\ell\ell} > 500$ GeV
N(central small-R jets) ≥ 2	N(central large-R jets) ≥ 1
$p_T^{jet_1} > 45 \,\|\|\, p_T^{jet_2} > 45$	—
$\sum_{i=1}^{2(3)} p_T^{jet_i} > 120\ (150)$ GeV	—
$\Delta\phi(\text{jet}_1, \text{jet}_2) < 140°$	—
$\Delta\phi(E_T^{miss}, h) > 120°$	—
τ-veto	
additional b-jet veto	
H_T ratio	
$\Delta R(\text{jet}_1, \text{jet}_2) < 1.8$	$\frac{\Delta R(\text{VR}_1, \text{VR}_2)}{R_{min}} > 1$
b-tag requirement on small-R jets	VR track-jets

new

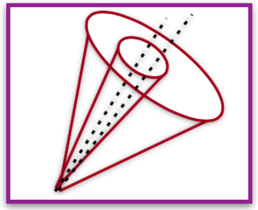
new

new

(standard) anti-qcd cuts



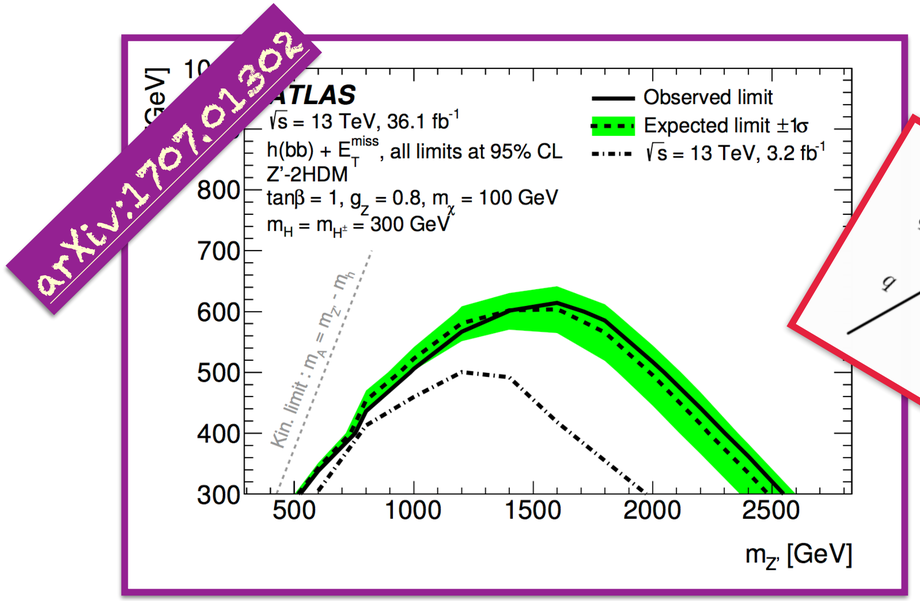
To reject events with collinear VR track jets, that can lead to ambiguous b-tagging

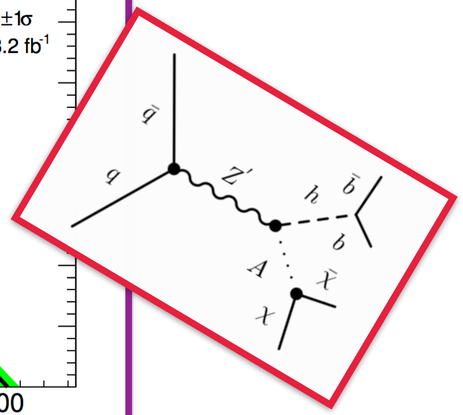


$\Delta R/R_{min}<1$

RESULTS @36fb-1

The results are interpreted as exclusion limits on **Z'-2HDM** models…

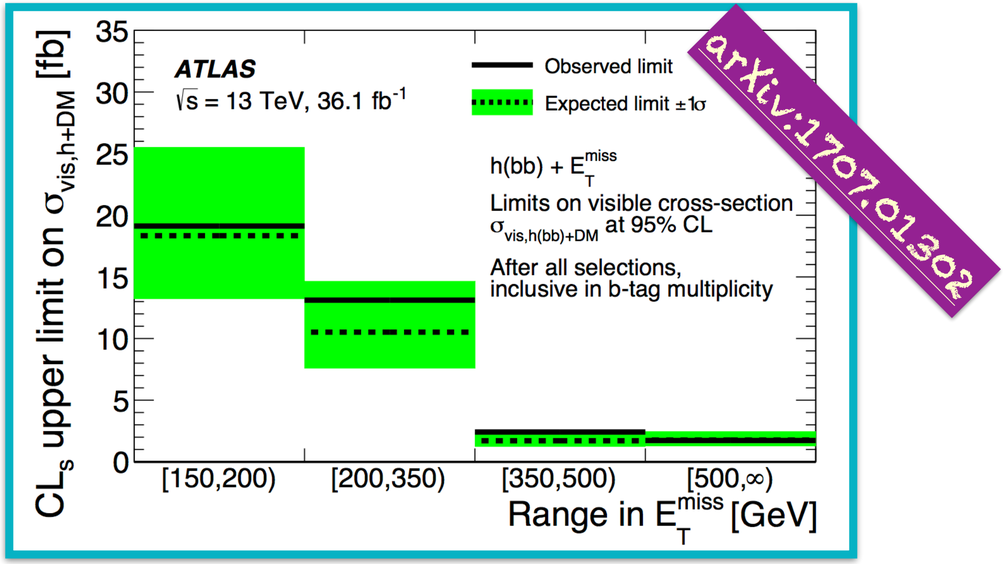




…and also as **less model-dependent** limits on:

$$\sigma_{\mathrm{vis},h(b\bar{b})+\mathrm{DM}} \equiv \sigma_{h+\mathrm{DM}} \times BR(h \to b\bar{b}) \times A \times \varepsilon$$

Fit one MET region at the time for SR, to minimise the dependance on a specific h+DM signal.



OLD SYSTS BREAKDOWN TABLE @36fb^{-1}

- MC statistics dominant systematic uncertainty at high MET
- significant impact also from b-tagging and V+jets modeling

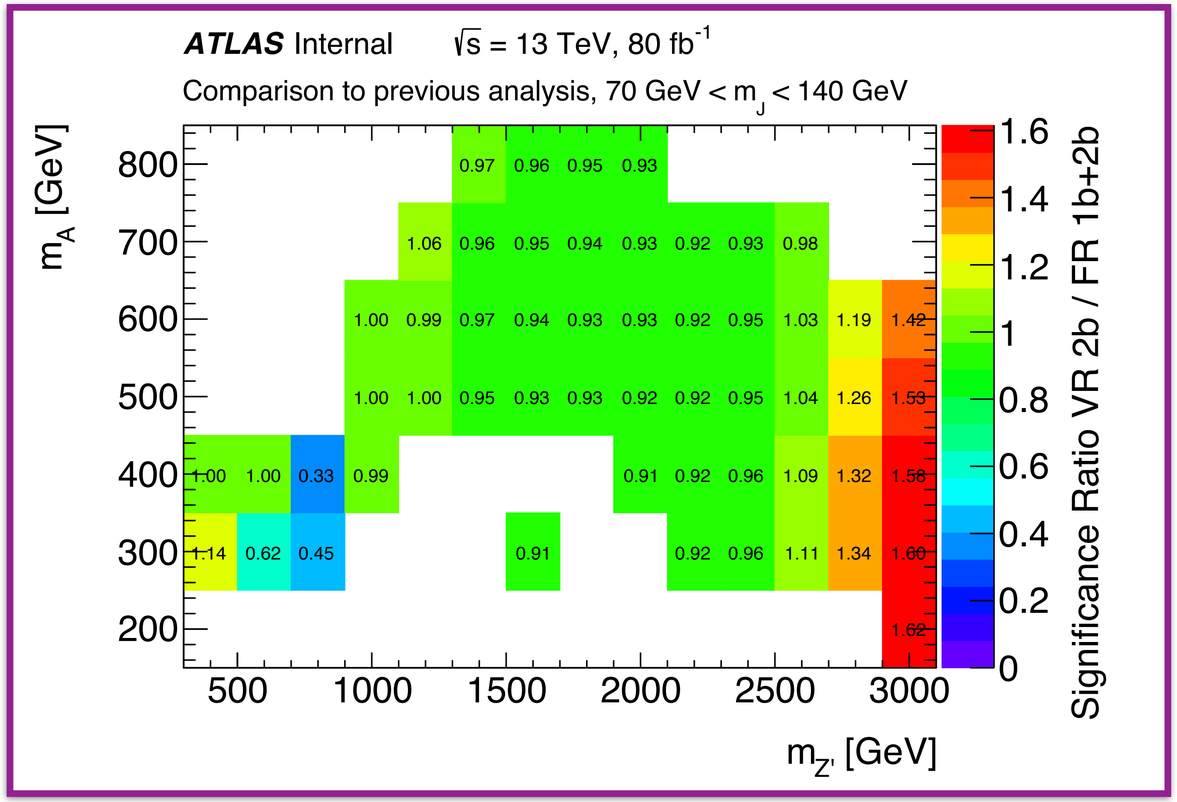
MET

Source of uncert.	Impact [%] (a)	(b)	(c)
V+jets modeling	5.0	5.7	8.2
$t\bar{t}$, single-t modeling	3.2	3.0	3.9
SM $Vh(b\bar{b})$ norm.	2.2	6.9	6.9
Signal modeling	3.9	2.9	2.1
MC statistics	4.9	11	22
Luminosity	3.2	4.5	5.4
b-tagging, track-jets	1.4	11	17
b-tagging, calo jets	5.0	3.4	4.7
Jets with $R = 0.4$	1.7	3.8	2.1
Jets with $R = 1.0$	<0.1	1.2	4.7
Total syst. uncert.	10	21	36
Statistical uncert.	6	38	62
Total uncert.	12	43	71

statistically limited at medium-high MET

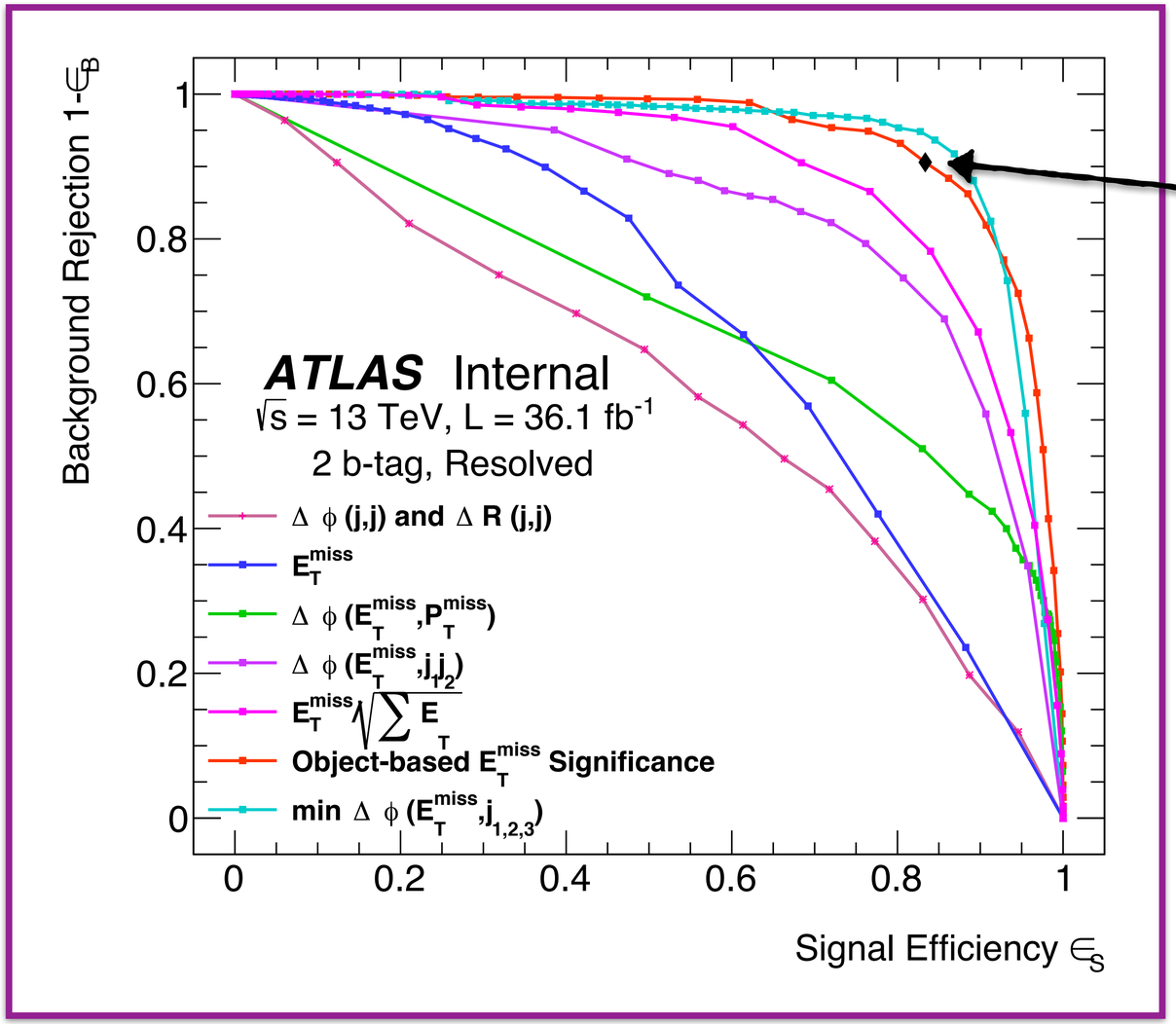
VR VS FR TRACK JETS

VR(2b) vs FR (1b+2b)



Still significant improvement at high $m_{Z'}$, using only 2btag region.
Drop 1-btag region!

MET SIGNIFICANCE VS ALL



S > 16