Improving Dark Matter searches using Track Assisted Reclustered (TAR) jets with the ATLAS detector at $\sqrt{s}$ = 13 TeV

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Universität Heidelberg

On behalf of the ATLAS collaboration

YSF - Interpreting the LHC Run 2 Data and Beyond

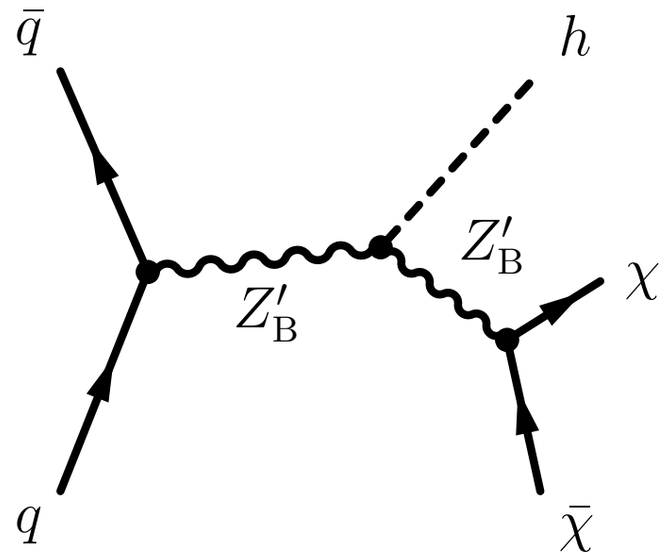
ICTP - Trieste

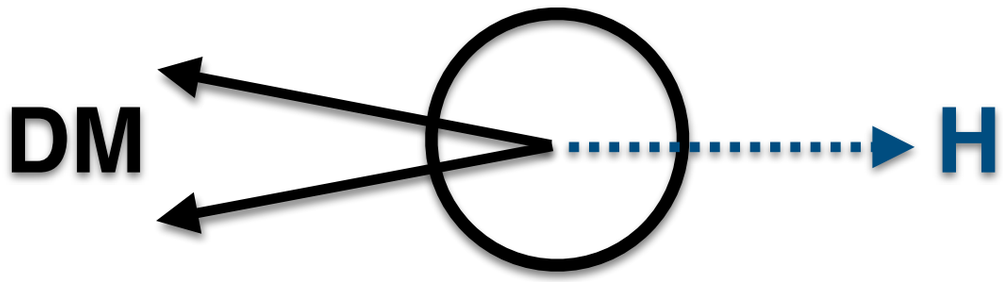
Dark Matter (DM) accounts for ~85% of the total matter in the universe

Higgs, W and Z bosons provide and interesting probe for DM @ LHC

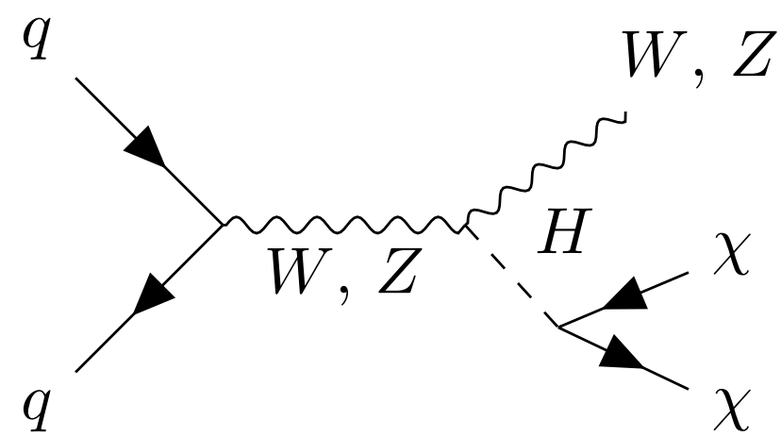
ATLAS-CONF-2018-039

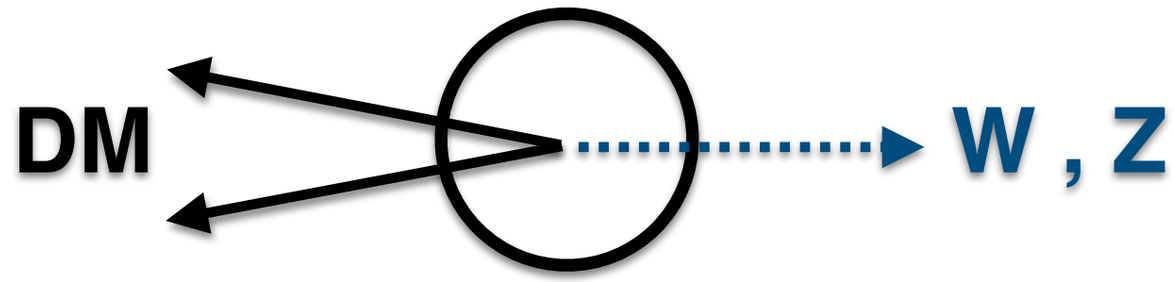
Mono - H





Mono - V





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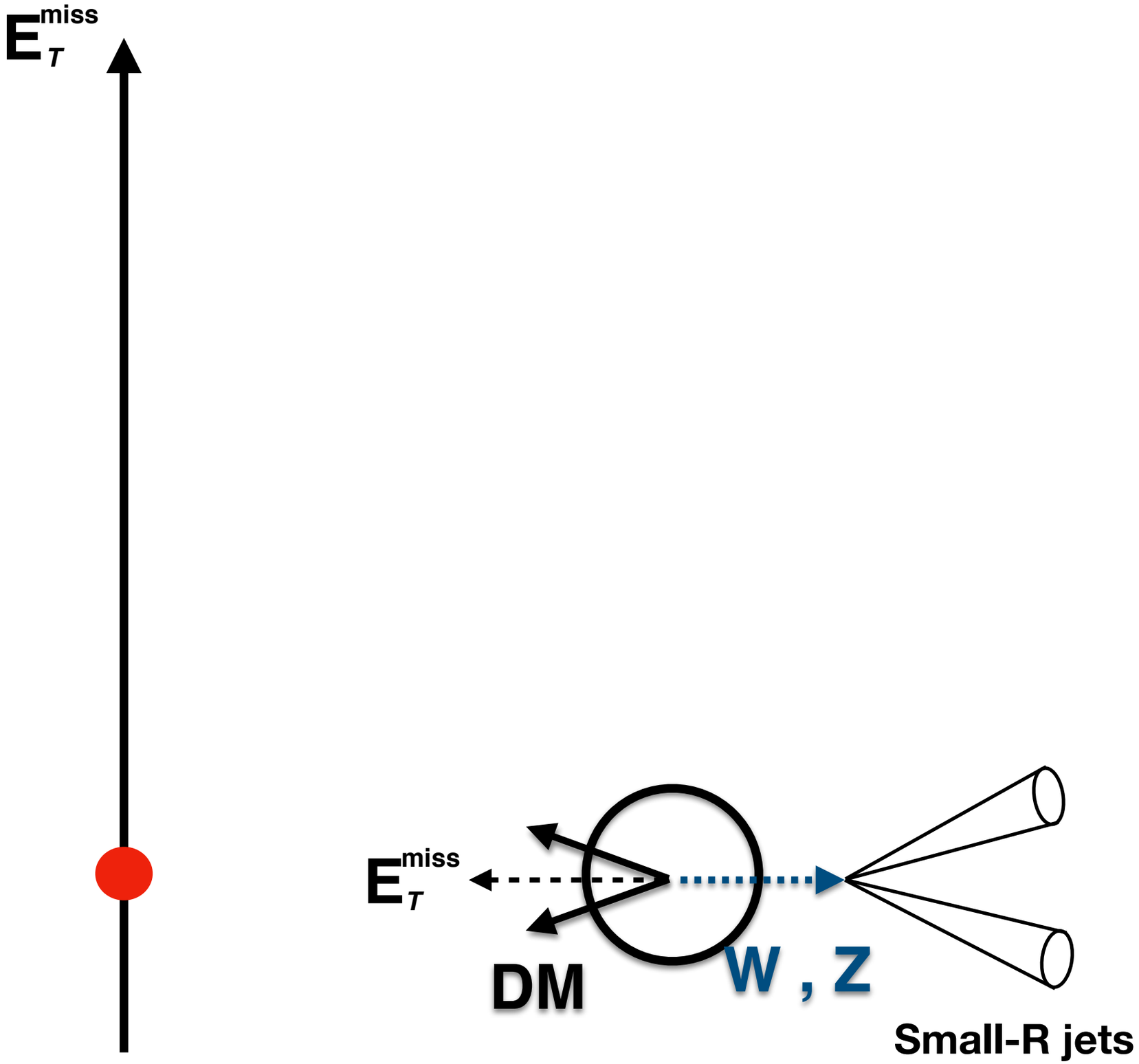
Most of the sensitivity comes from events where E_T^{miss} is very high.

The boosted recoil poses reconstruction challenge & opportunity.

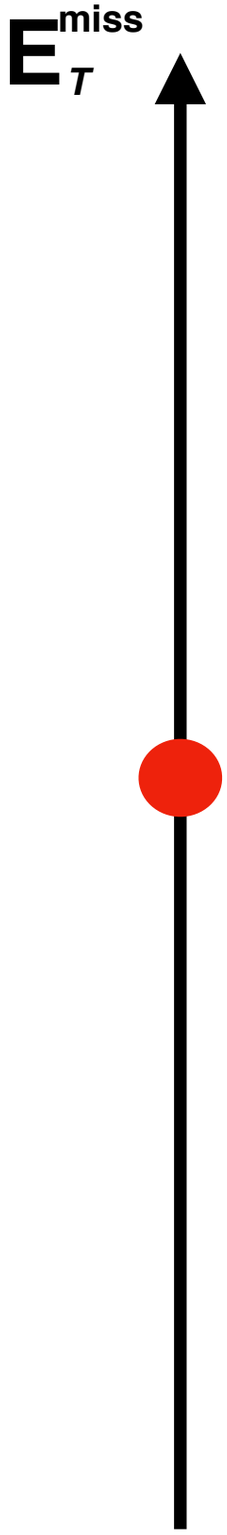
Aim for hadronic final states (highest branching ratio)

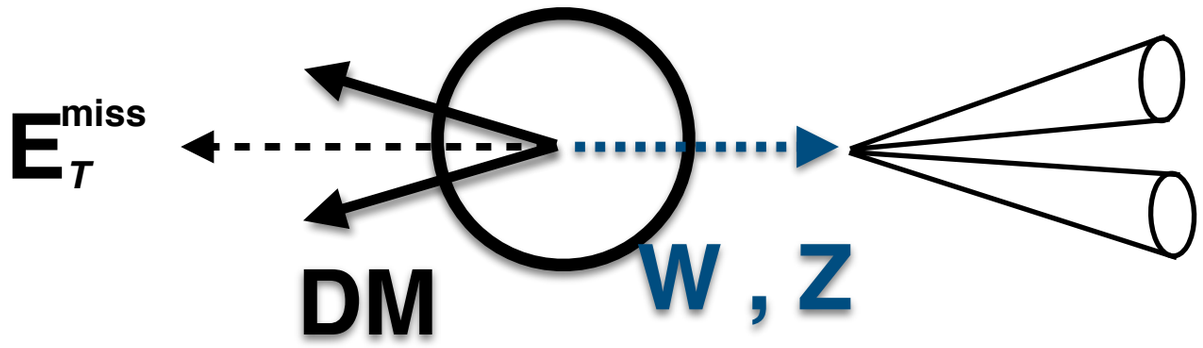


Can resolve decay products individually

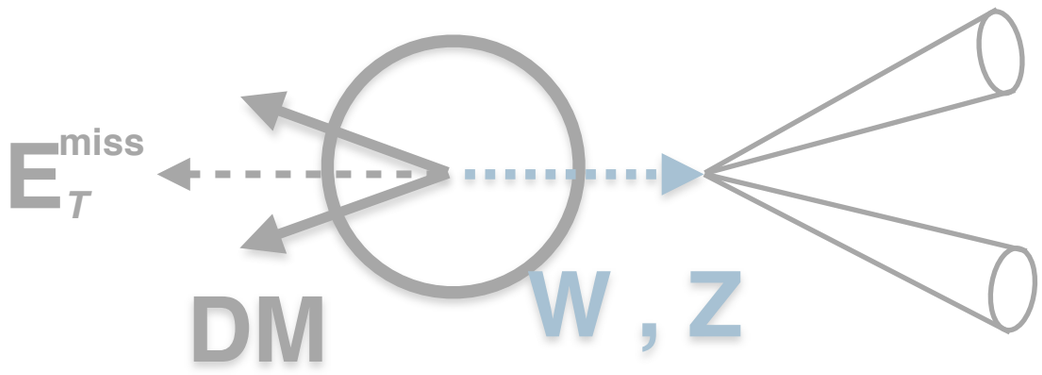
High background

Aim for hadronic final states (highest branching ratio)





Decay products start merging
Moderate background

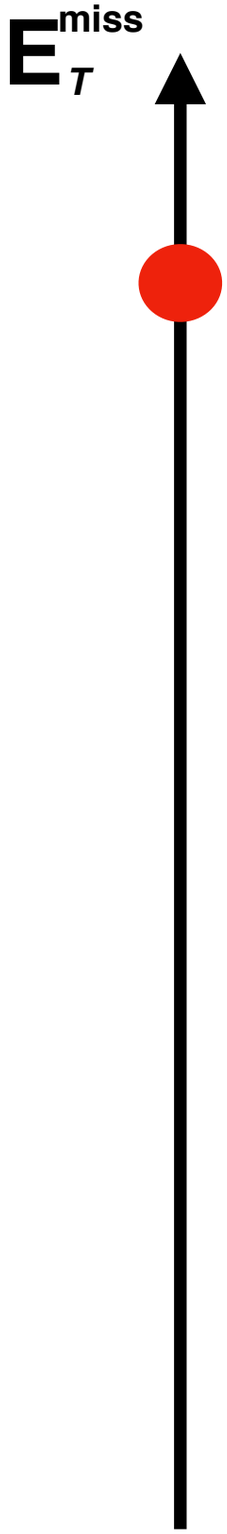


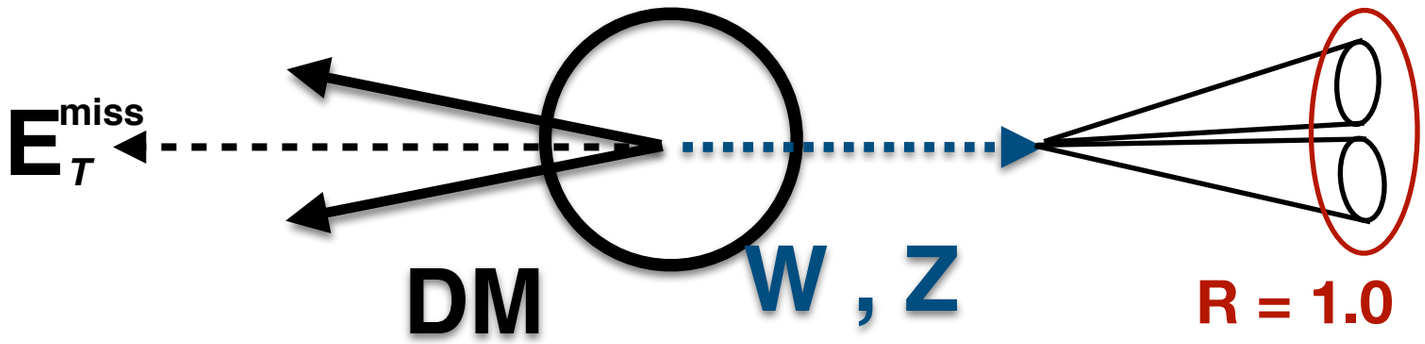
Can resolve decay products individually

High background

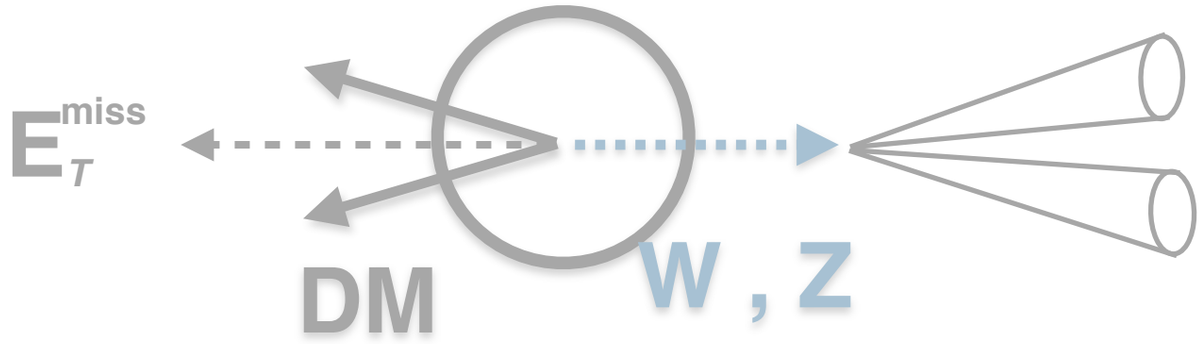
Small-R jets

Aim for hadronic final states (highest branching ratio)

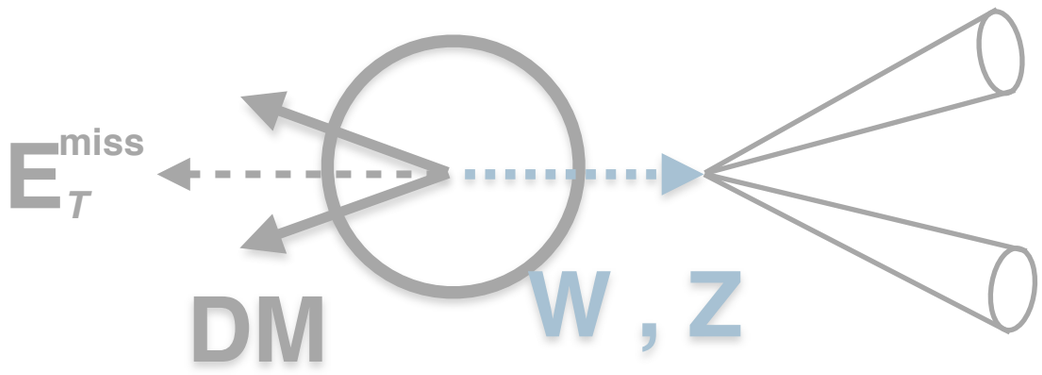




Large-R jet contains W,Z decay products Low background



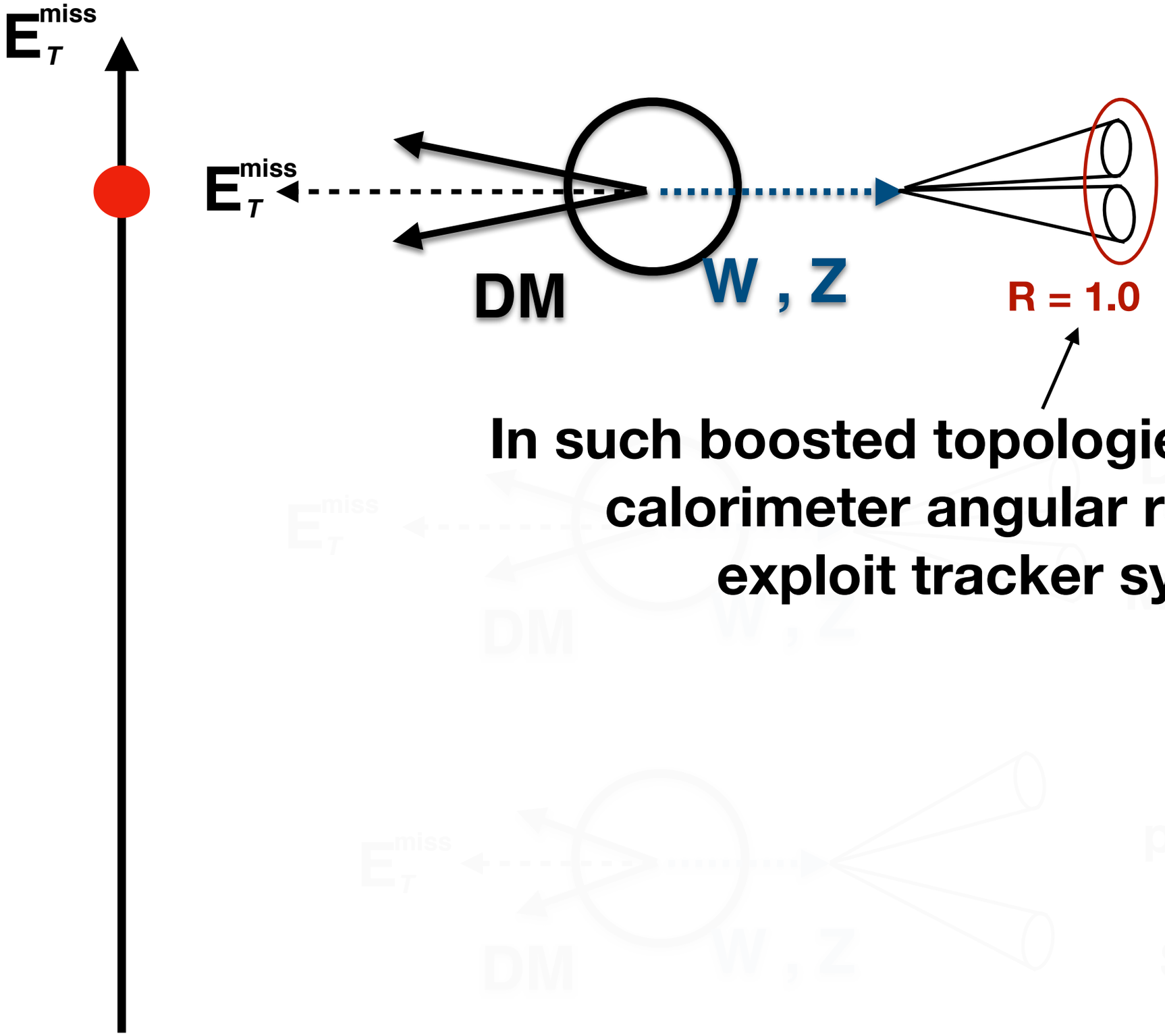
Decay products start merging Moderate background



Can resolve decay products individually

High background

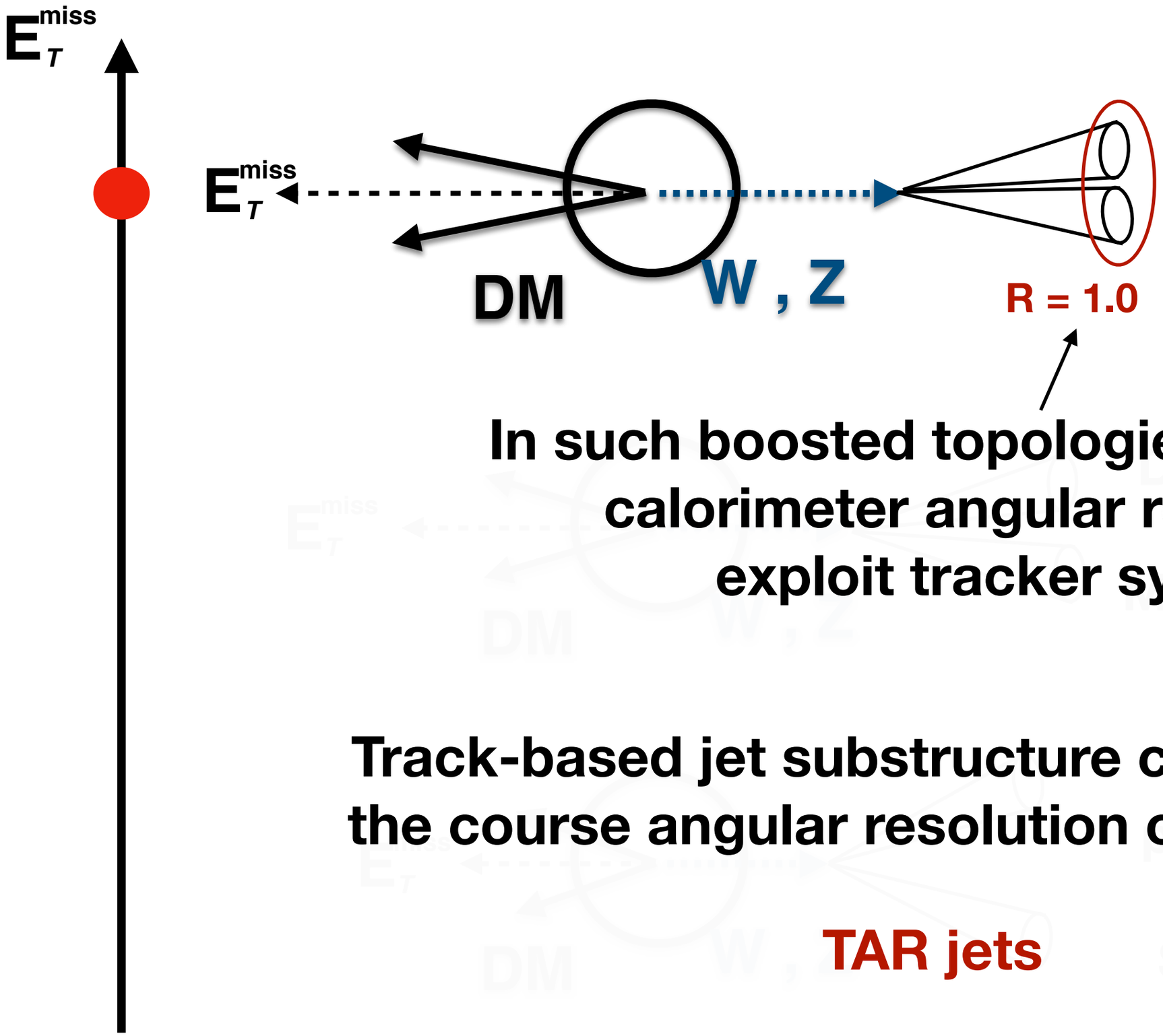
Aim for hadronic final states (highest branching ratio)



Large-R jet contains W,Z decay products
Low background

In such boosted topologies start hitting calorimeter angular resolution: exploit tracker system

Aim for hadronic final states (highest branching ratio)



Large-R jet contains W,Z decay products
Low background

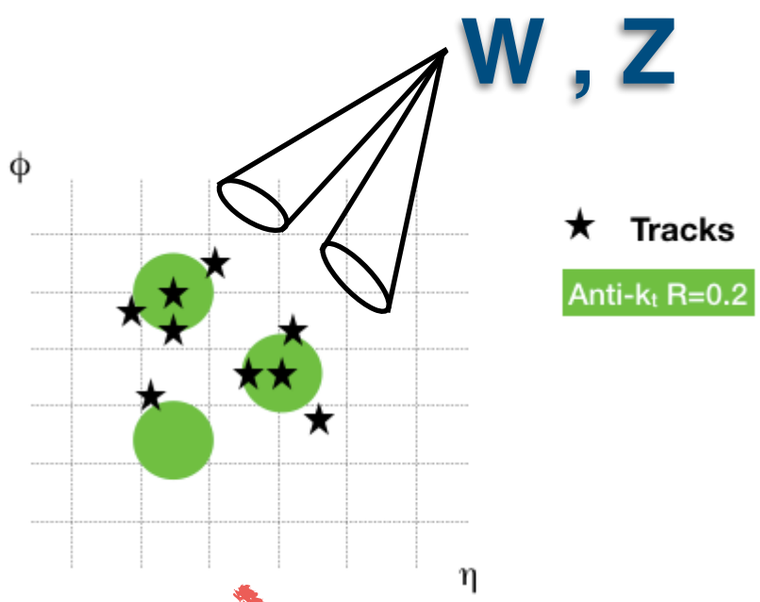
In such boosted topologies start hitting calorimeter angular resolution: exploit tracker system

Track-based jet substructure can overcome the course angular resolution of calorimeter

TAR jets

Track-Assisted-Reclustered (TAR) jets

ATL-PHYS-PUB-2018-012



TAR

Calibrated anti-k_t R = 0.2 jets → Recluster input jets into trimmed large-R jets → Match tracks to constituent R = 0.2 jets → Rescale tracks to p_T of the matched R = 0.2 jet → Calculate substructure from tracks

Tracks

Use excellent angular resolution of the ATLAS tracker system

$$p_{\mathrm{T}}^{\mathrm{track,new}} = p_{\mathrm{T}}^{\mathrm{track,old}} \times \frac{p_{\mathrm{T}}^{j}}{\sum_{i \in j} p_{\mathrm{T}}^{i}}$$

Track-Assisted-Reclustered (TAR) jets

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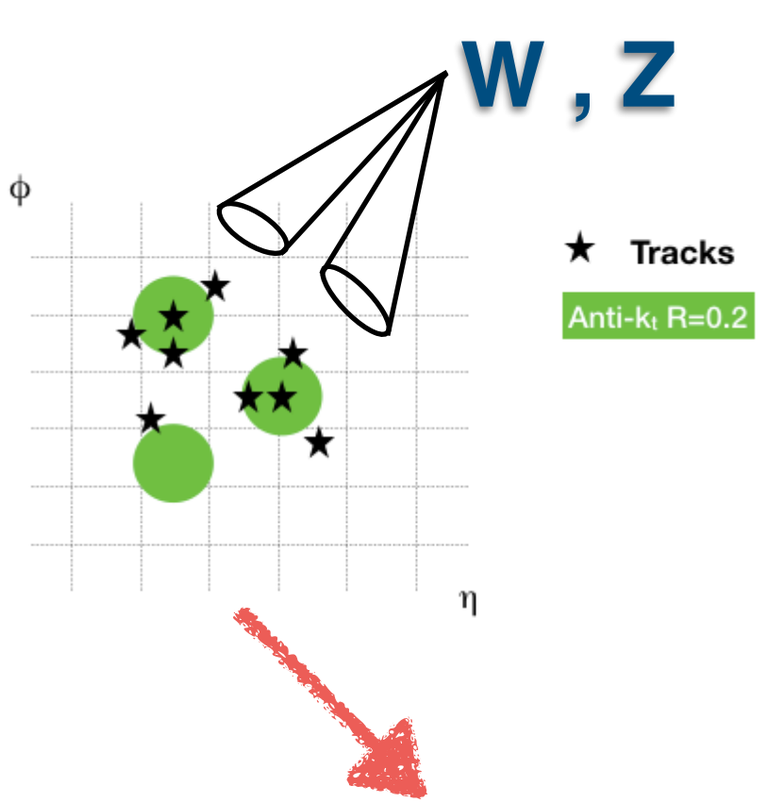

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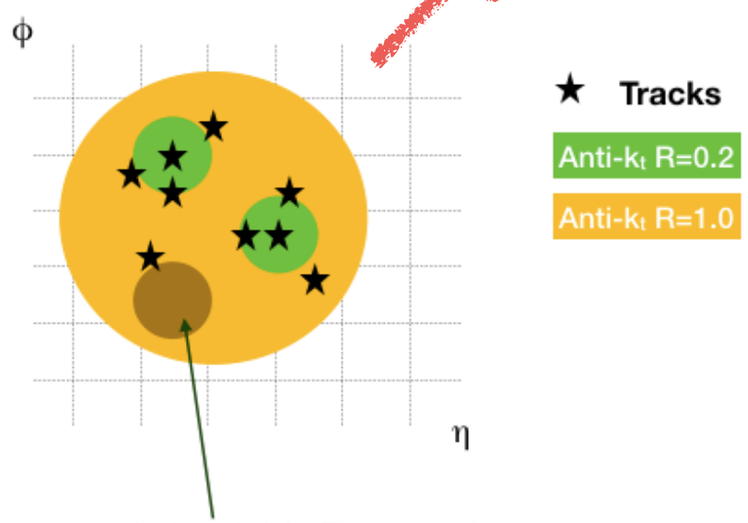
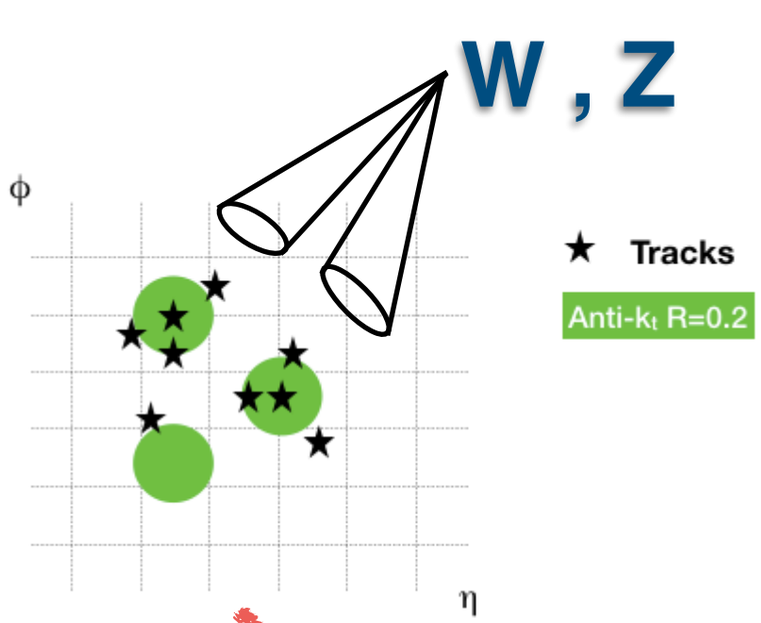
Tracks → Match tracks to constituent R = 0.2 jets



Removed Anti-K_t R=0.2 jet

Track-Assisted-Reclustered (TAR) jets



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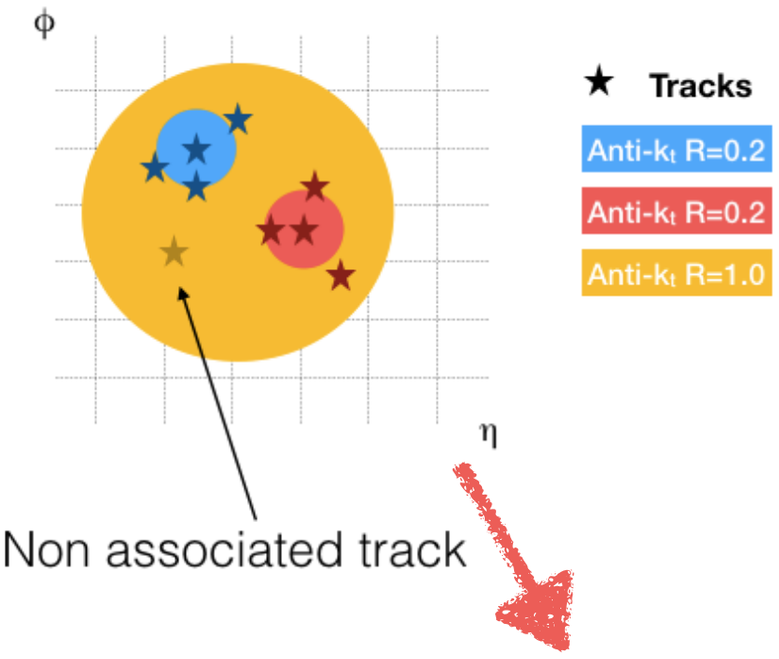

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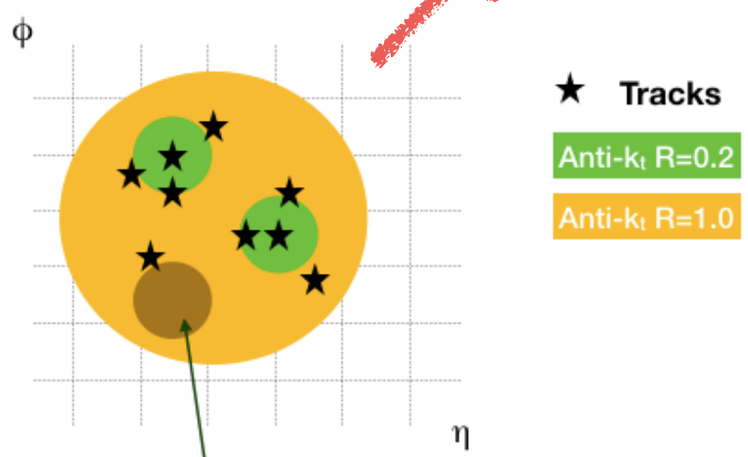

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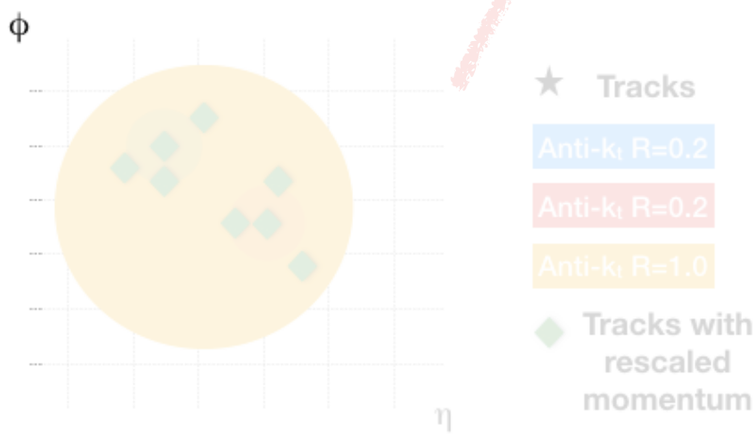
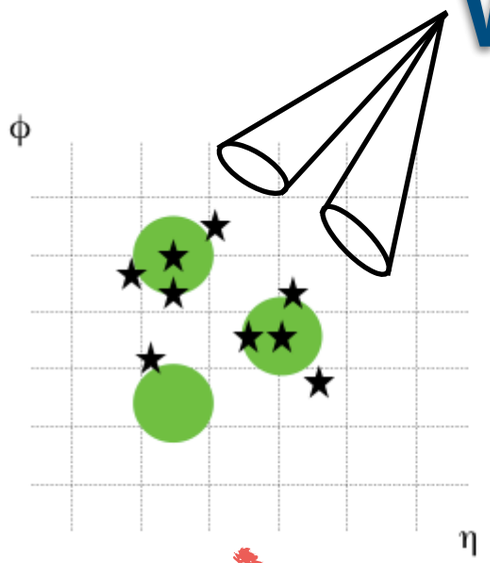


Track-Assisted-Reclustered (TAR) jets

W , Z



★ Tracks

Anti-k_t R=0.2

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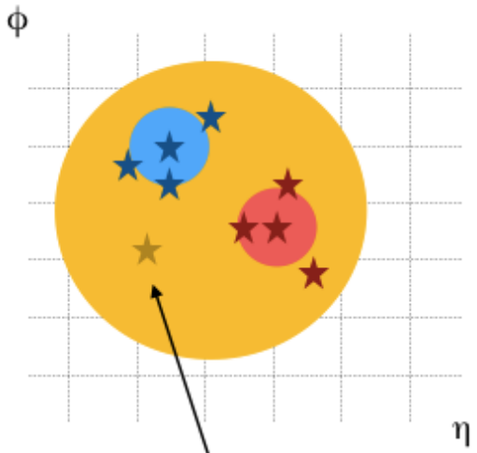

★ Tracks

Anti-k_t R=0.2

Anti-k_t R=0.2

Anti-k_t R=1.0

Non associated track

Use excellent angular resolution of the ATLAS tracker system

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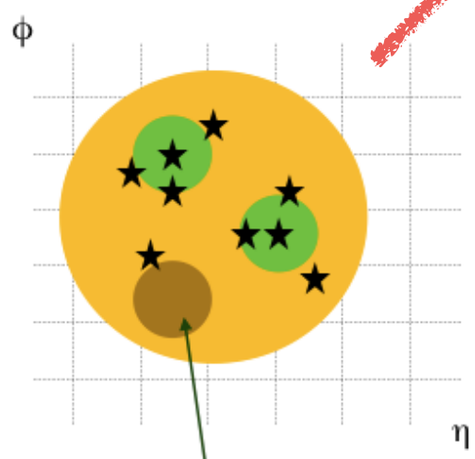
TAR

Calibrated anti-k_t R = 0.2 jets → Recluster input jets into trimmed large-R jets → Match tracks to constituent R = 0.2 jets → Rescale tracks to p_{T} of the matched R = 0.2 jet → Calculate substructure from tracks

Tracks → Match tracks to constituent R = 0.2 jets

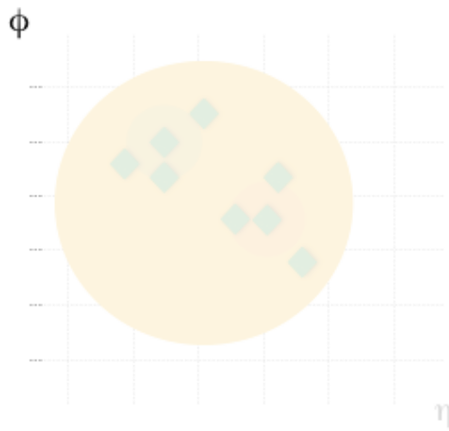


★ Tracks

Anti-k_t R=0.2

Anti-k_t R=1.0

Removed Anti-K_t R=0.2 jet



★ Tracks

Anti-k_t R=0.2

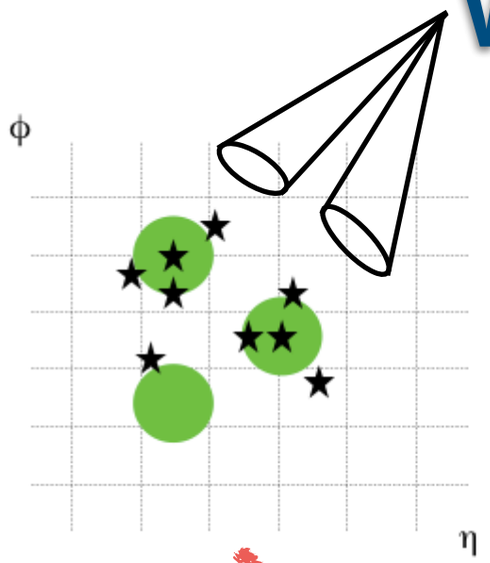
Anti-k_t R=0.2

Anti-k_t R=1.0

◆ Tracks with rescaled momentum

Track-Assisted-Reclustered (TAR) jets

W , Z



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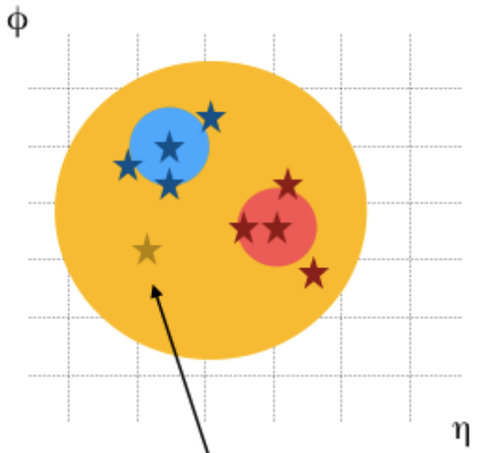

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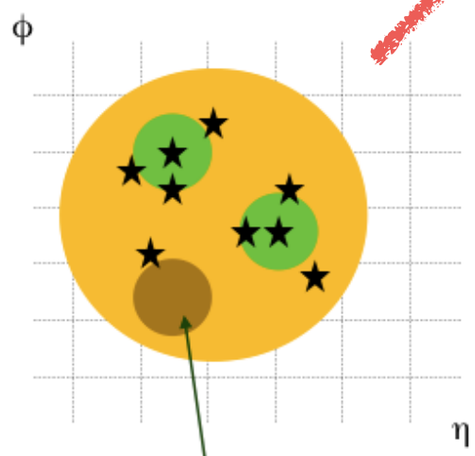
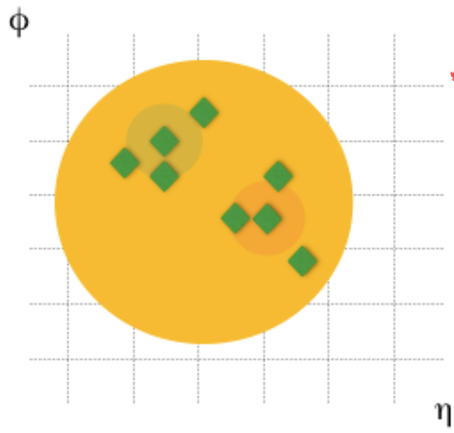


★ Tracks

Anti-k_t R=0.2

Anti-k_t R=1.0

Removed Anti-K_t R=0.2 jet



★ Tracks

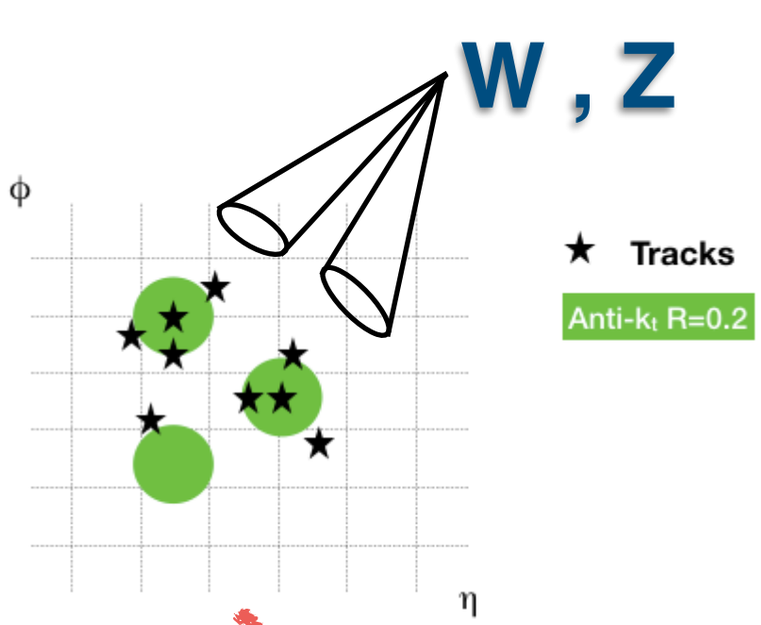
Anti-k_t R=0.2

Anti-k_t R=0.2

Anti-k_t R=1.0

◆ Tracks with rescaled momentum

Track-Assisted-Reclustered (TAR) jets



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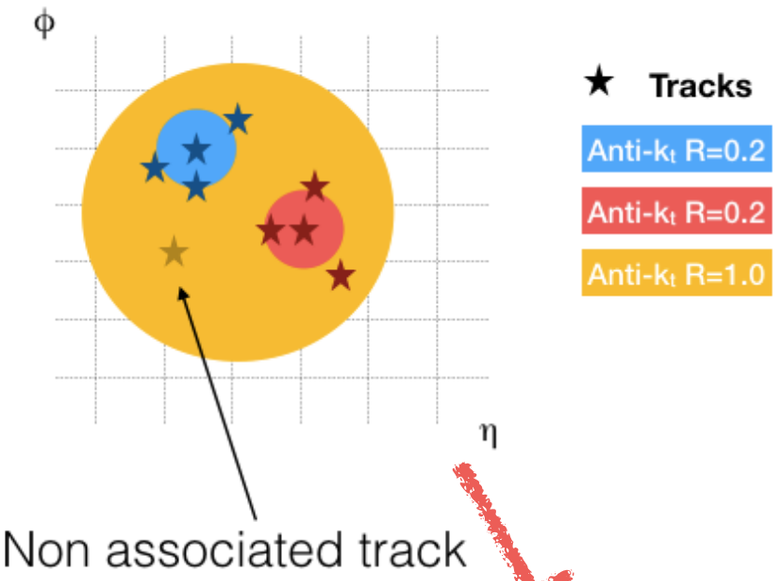

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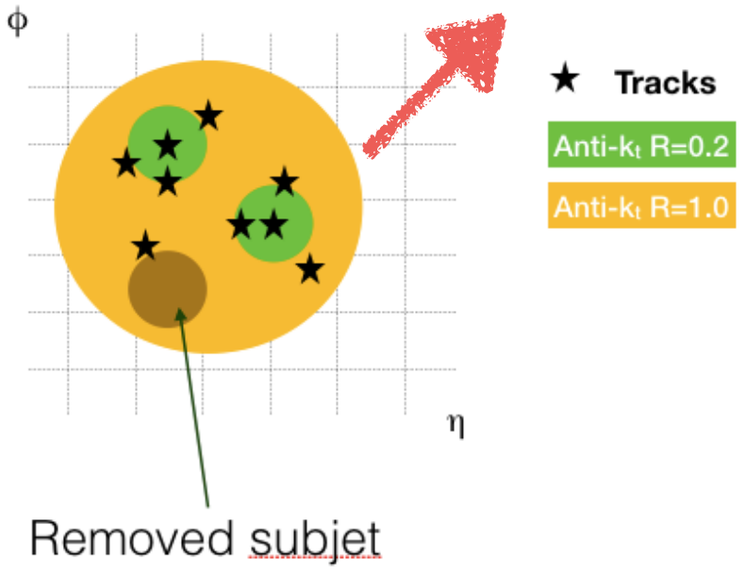
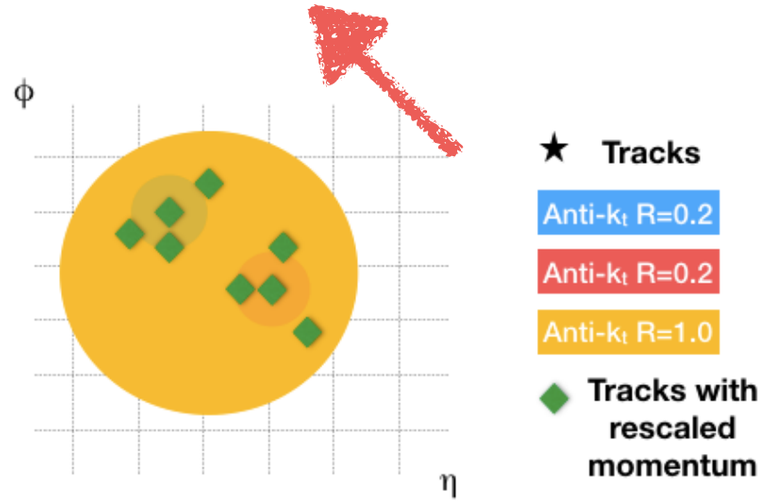
= flexibility of reclustered jets
(can optimize R depending on final state)
+ power of track-based substructure





Track-Assisted-Reclustered (TAR) jets

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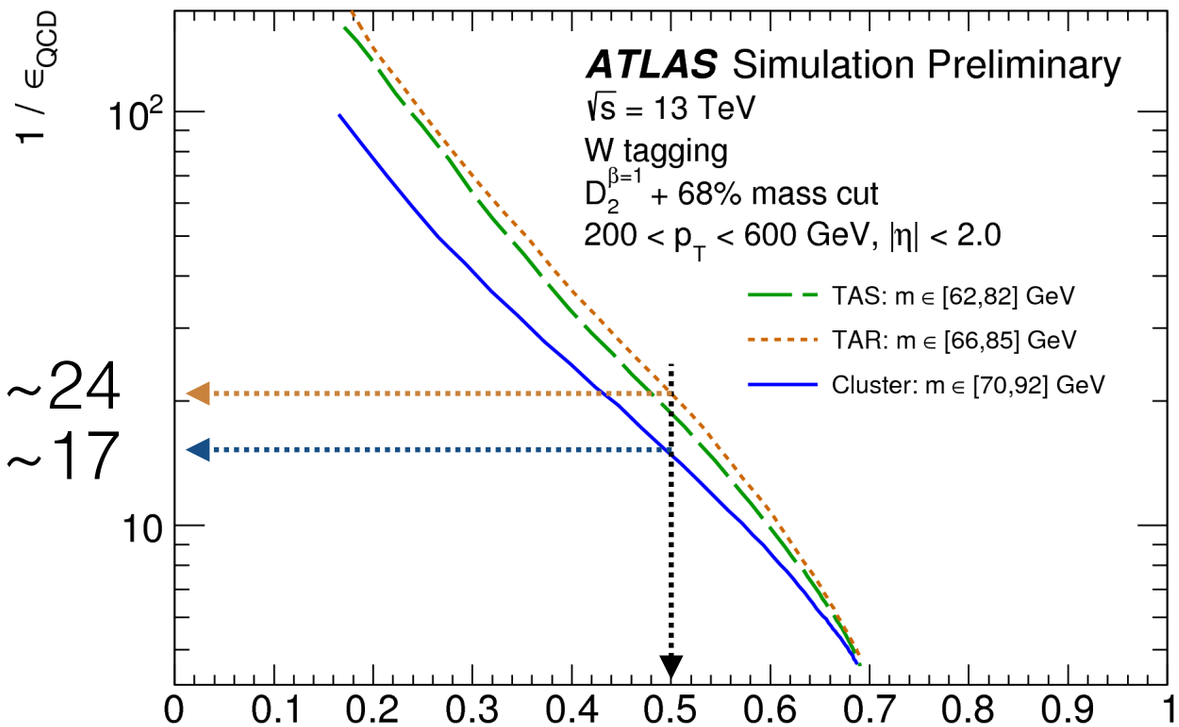
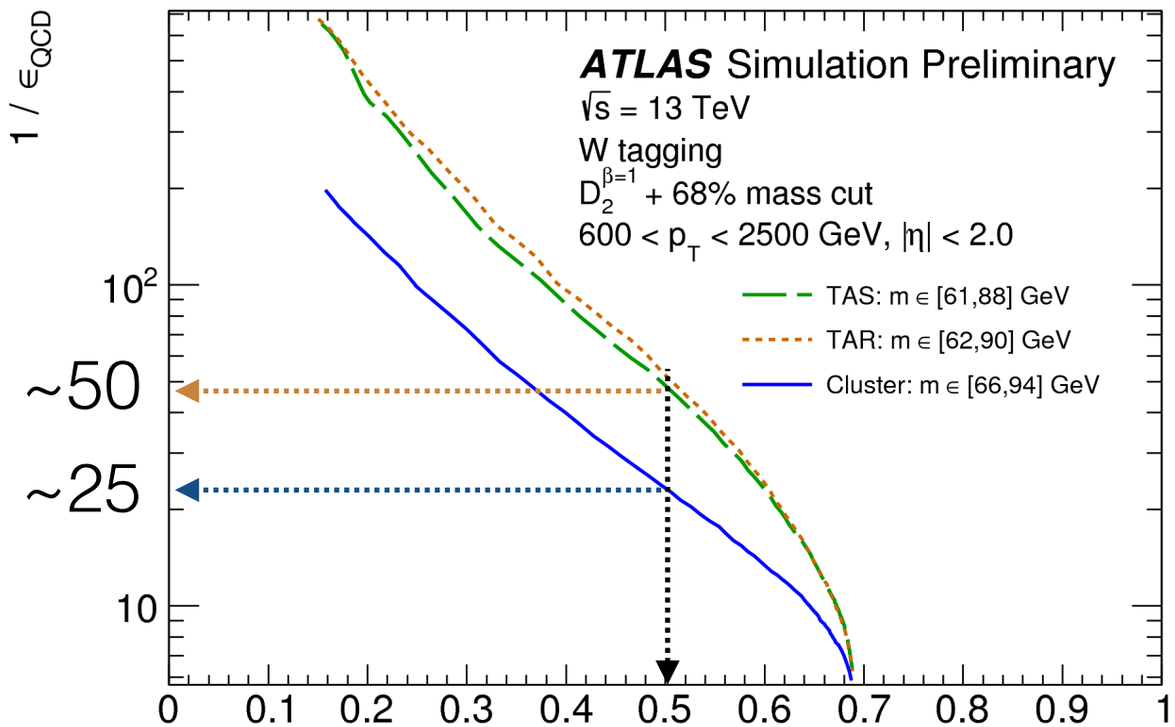




D_2 + mass cut tagging W jets vs QCD

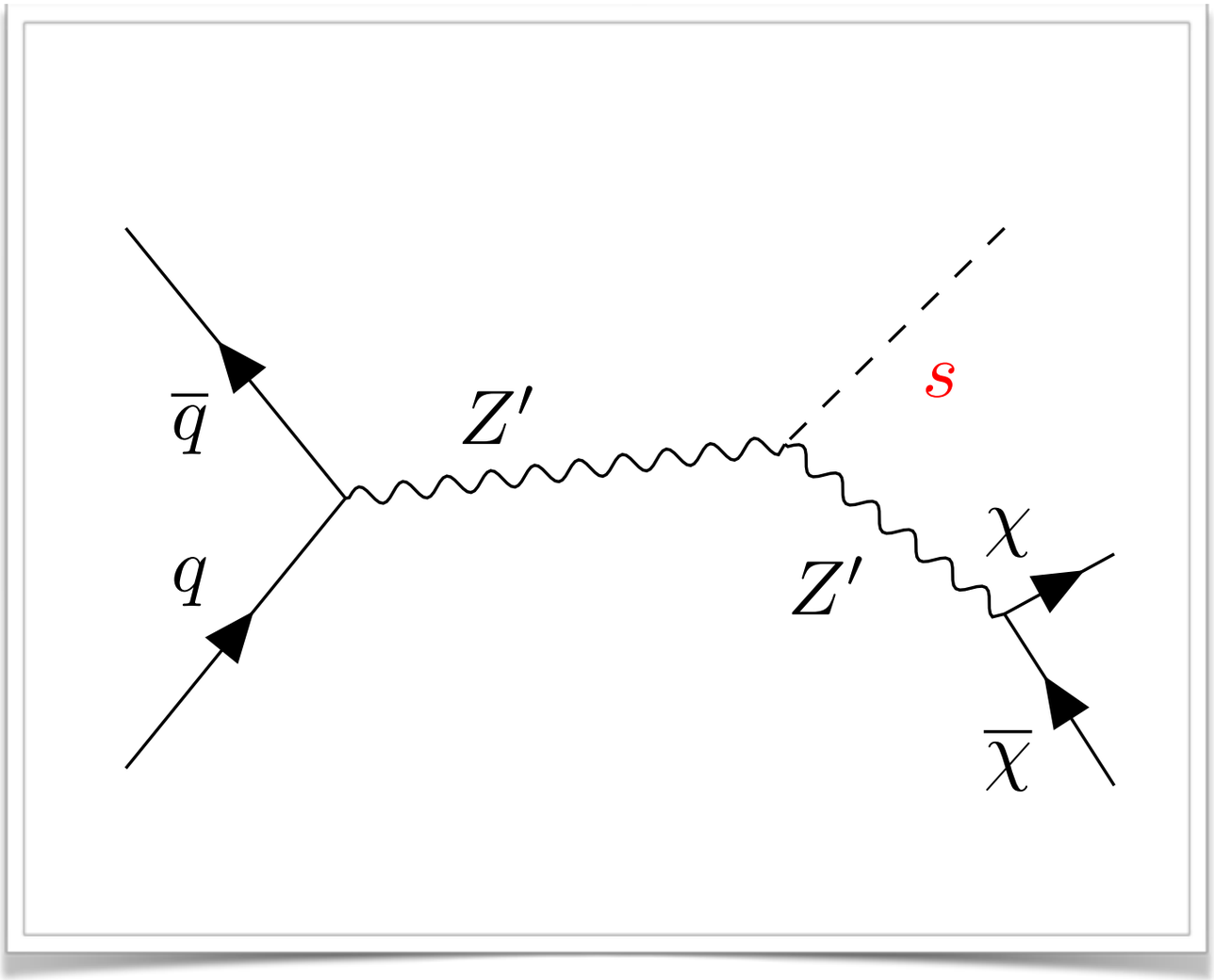
TAR mass vs Combined Mass

Superior background rejection using TAR jets

D_2 substructure variable helps discriminating 2-prong jets

Example application

Dark Higgs [1701.08780]



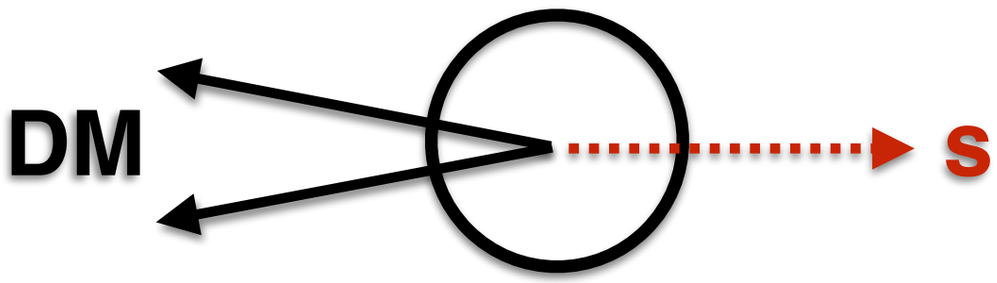
Simplified model with:

Dark Matter
Z' mediator
scalar Dark Higgs (s)

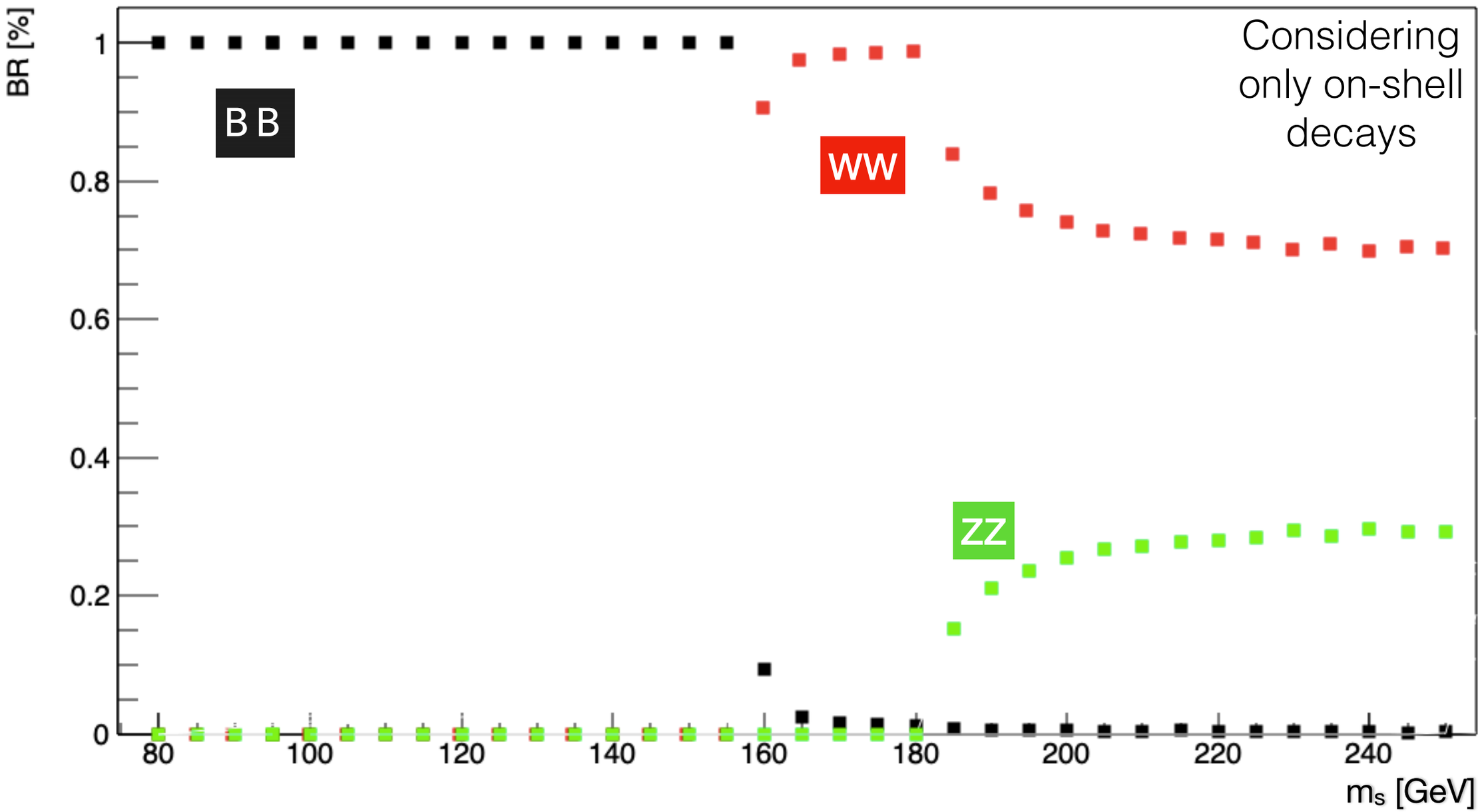
$m_s < m_\chi$

m(s)≠m(H)

new decay channels are possible

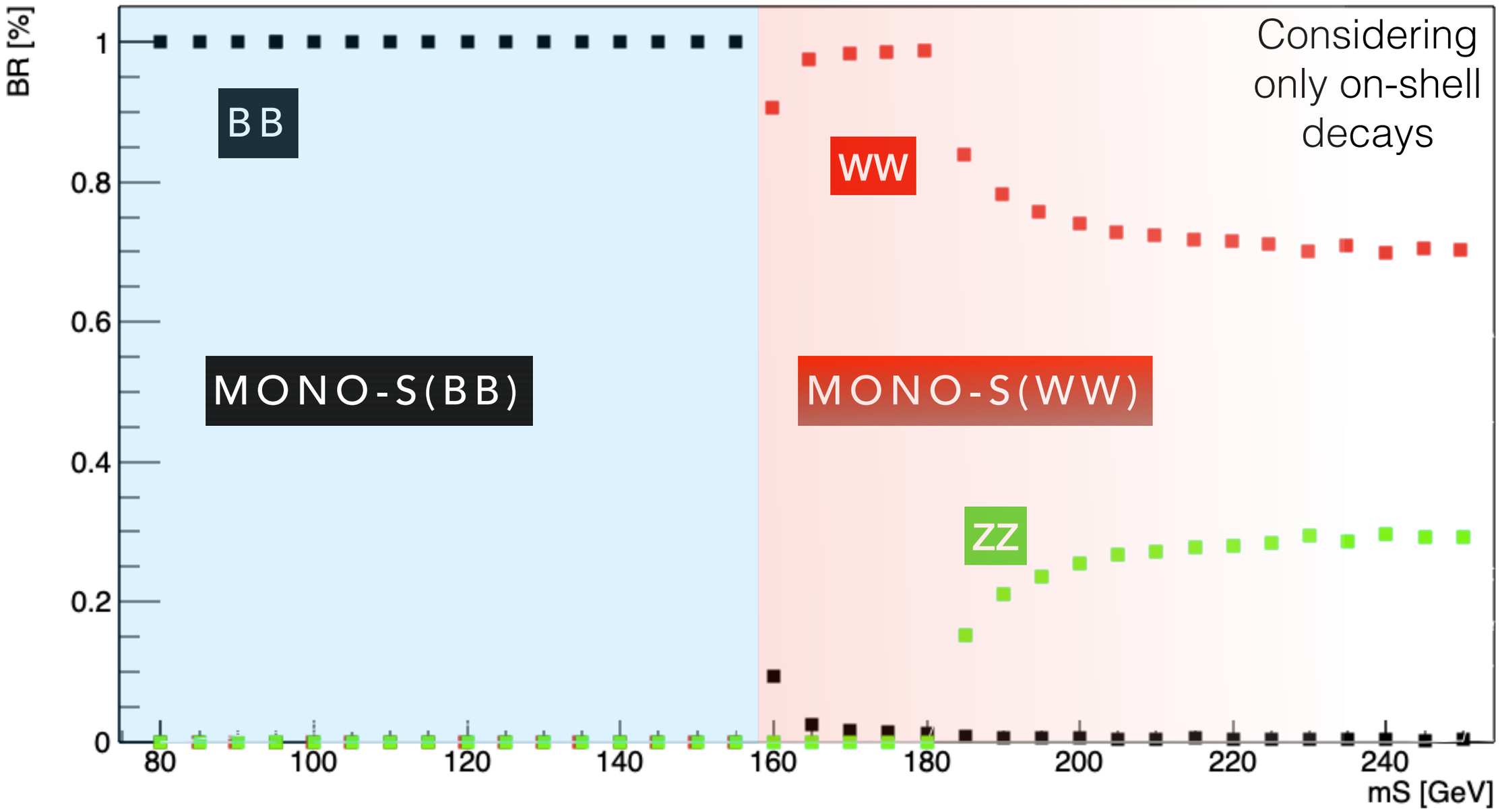


Dark Higgs decay to Standard Model depends on its mass (like the SM Higgs)

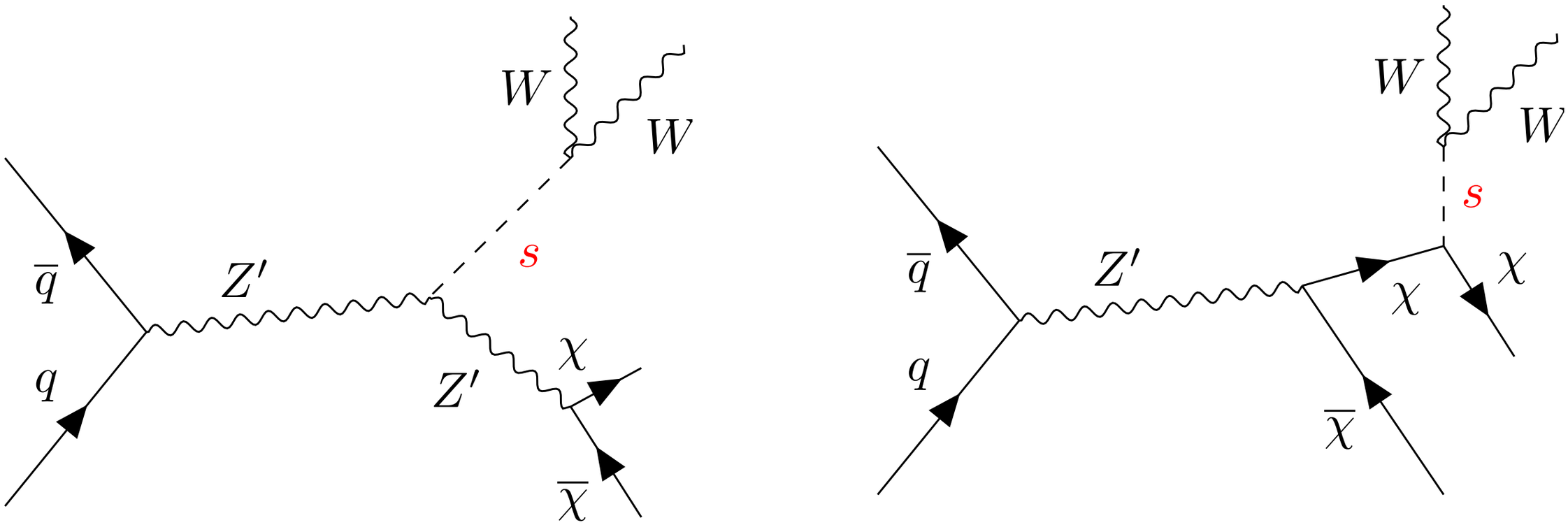


Dark Higgs decay to Standard Model depends on its mass (like the SM Higgs)

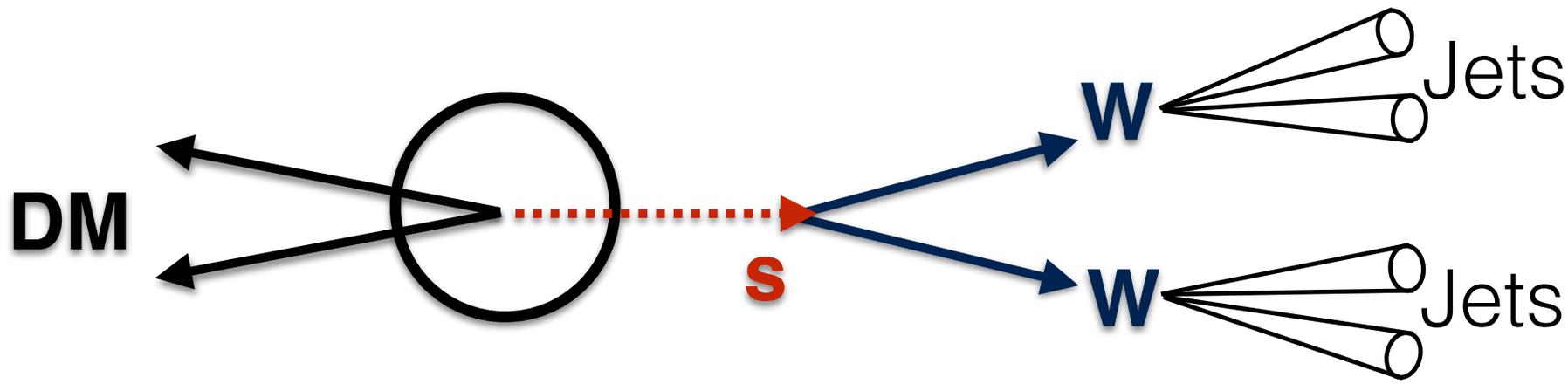
MadGraph Branching Ratios



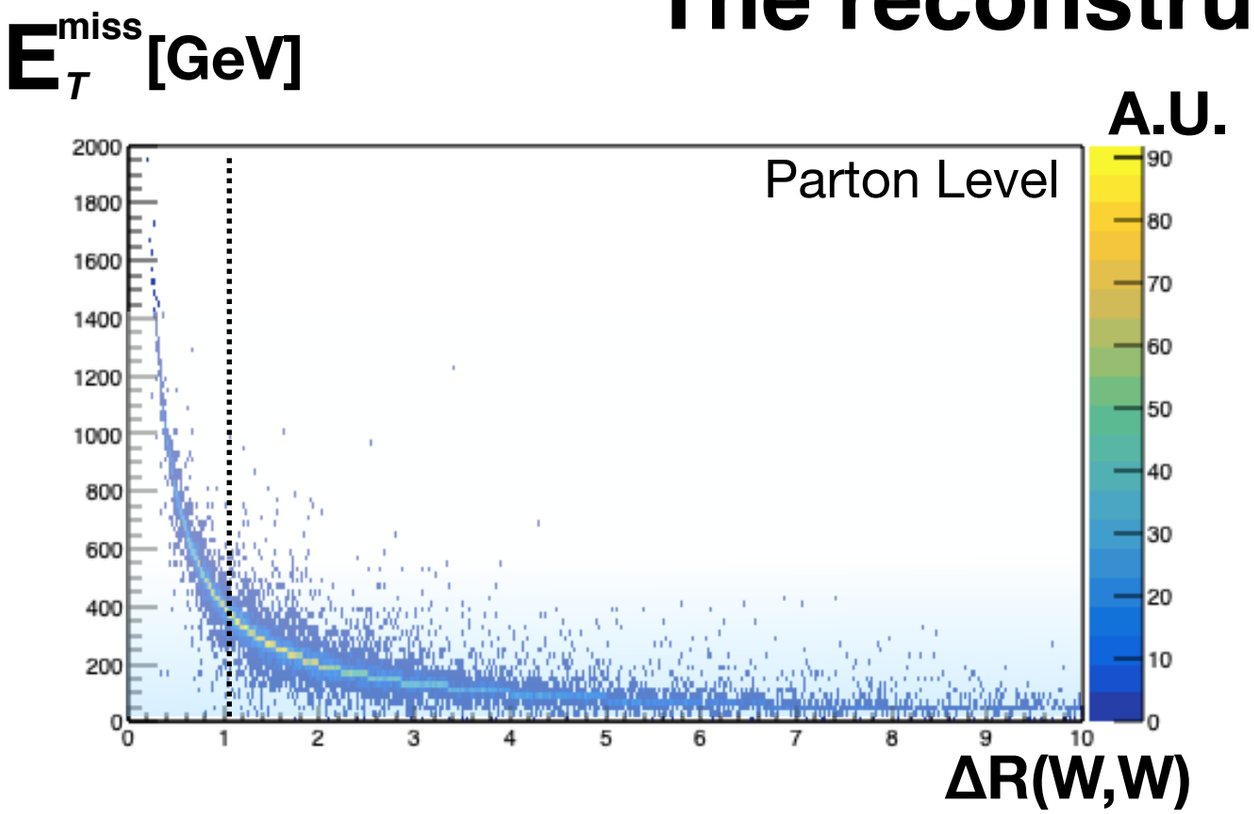
If $m_s > 160$ GeV, $s \to b\bar{b}$ is insensitive:

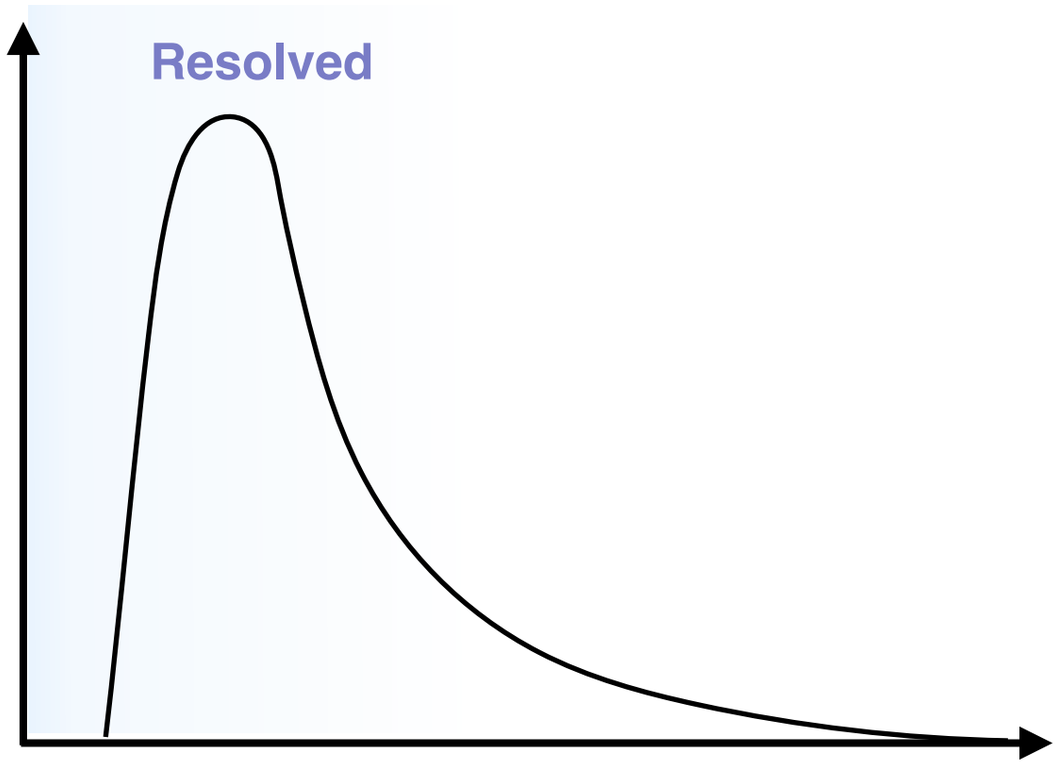


Unexplored final state: resonant WW +E_T^{miss}

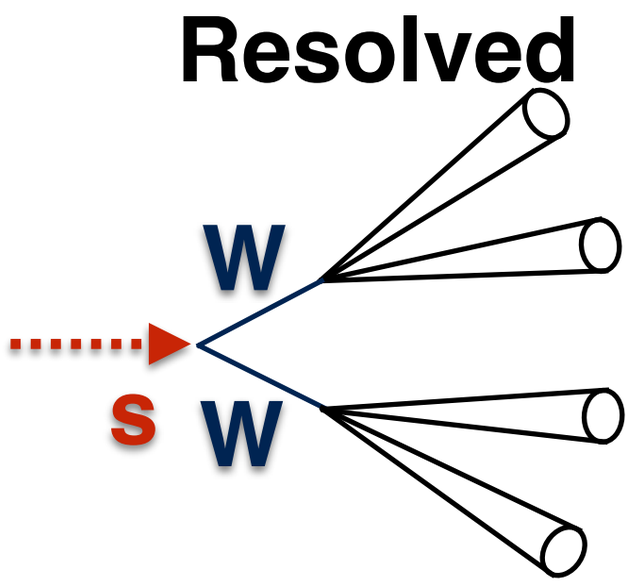


The reconstruction challenge



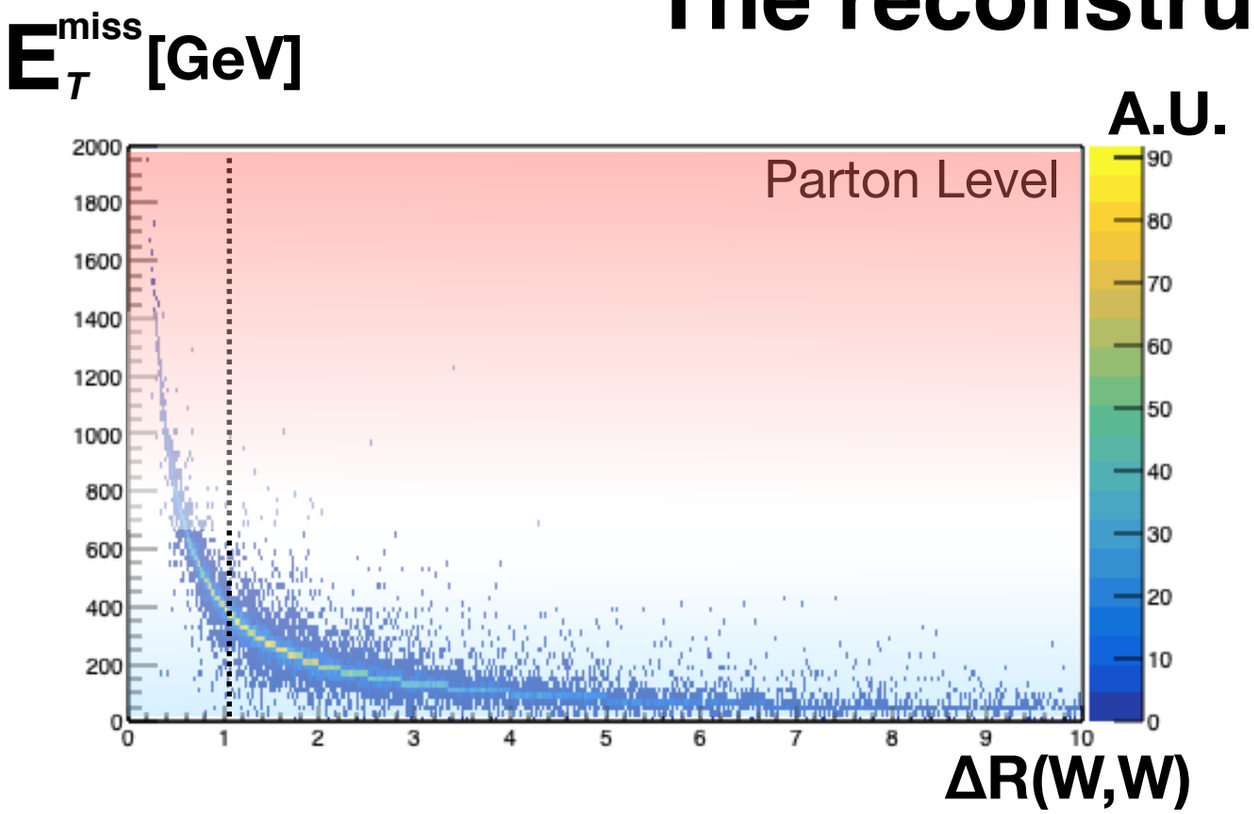


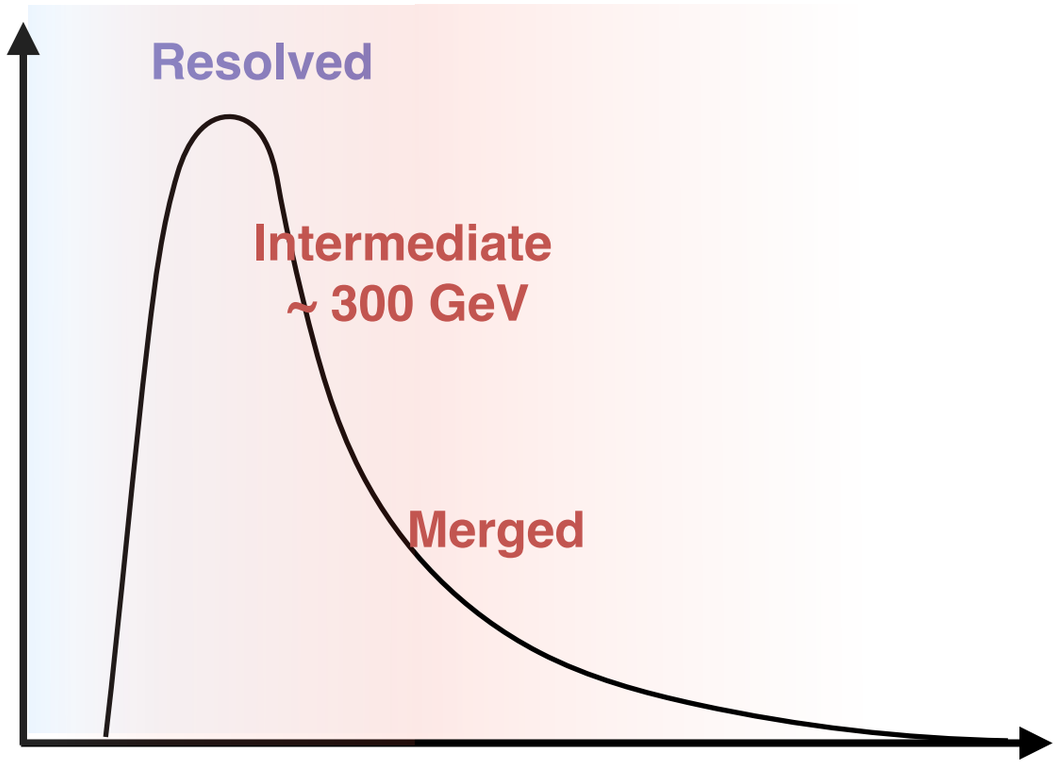
Regions:



E_T^{miss}

The reconstruction challenge

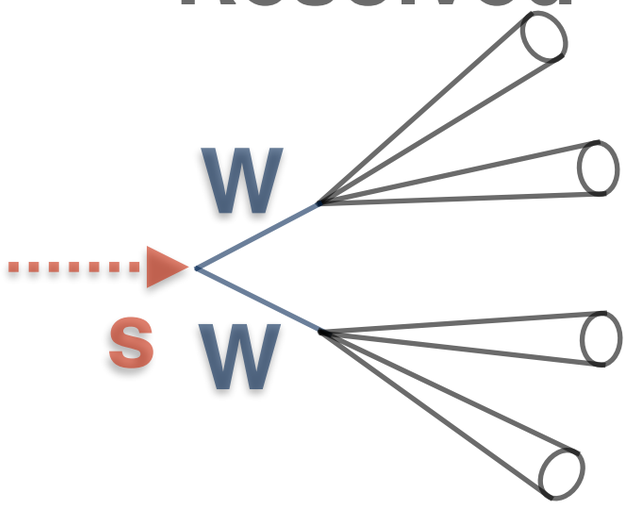




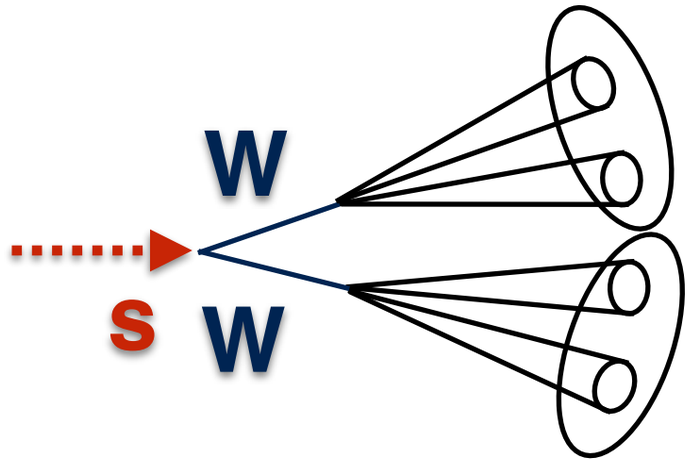
Regions:

E_T^{miss}

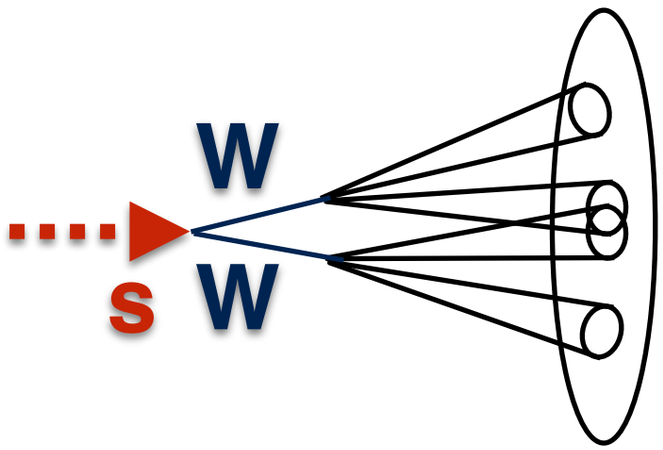
Resolved



Intermediate



Merged

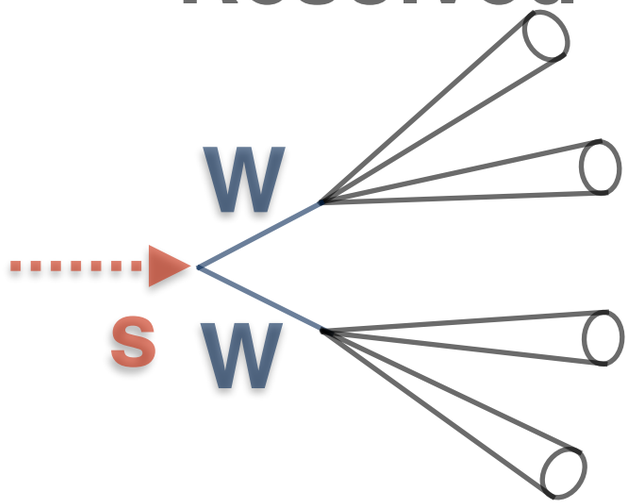


The reconstruction challenge

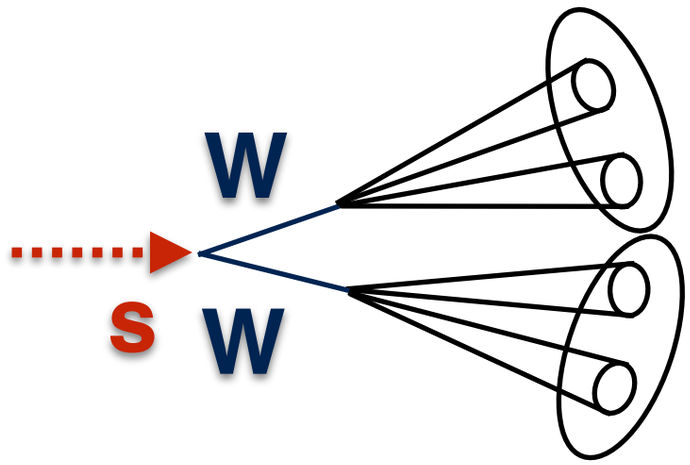
Intermediate region:
Could tune TAR jet radius
to contain individual W
Use D_2 to suppress background

Merged region:
Could tune TAR jet radius
to contain
full s decay
Use τ_{42} (N-subjettiness ratio)
to suppress background

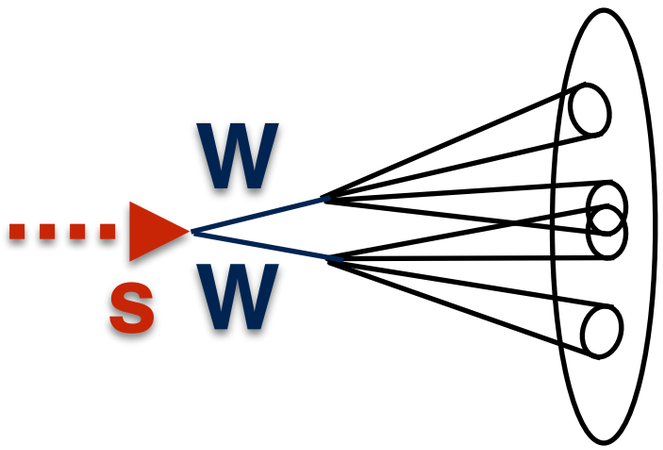
Resolved



Intermediate



Merged

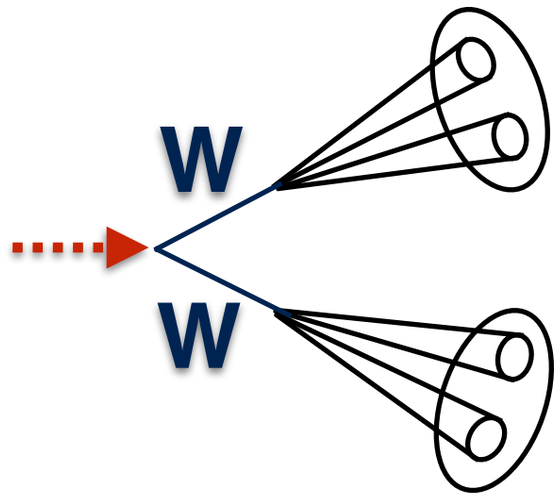


Conclusions

- **New reconstruction algorithm can improve searches with E_T^{miss} and boosted hadronically decaying objects: TAR jets**

  - **Offer superior mass resolution, substructure and flexibility: can be adapted to the E_T^{miss} regime**

- **Example application of TAR jet: mono-s(WW) search targeting a so far unexplored final state resonant WW + E_T^{miss}**



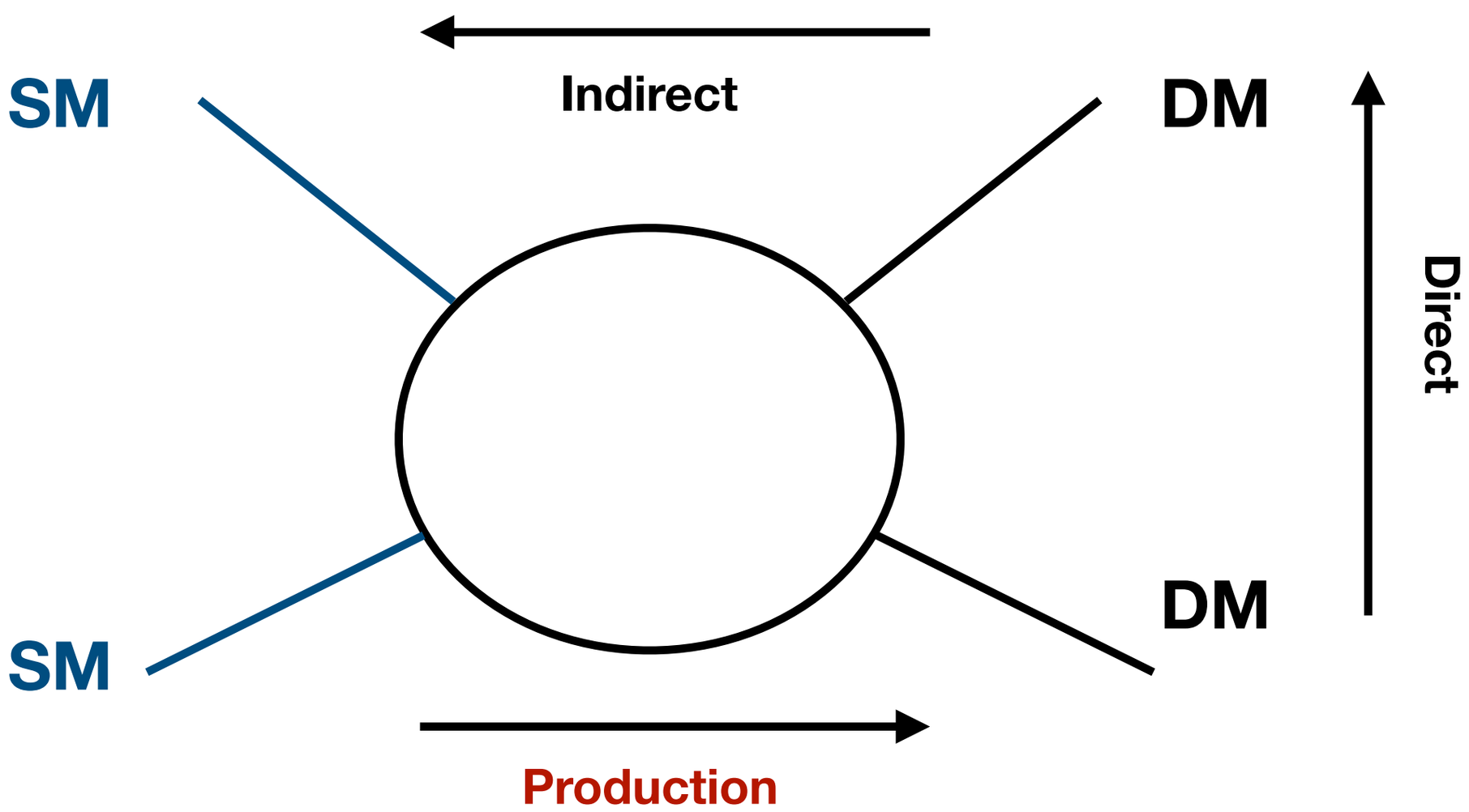
Many thanks!

Questions?

Back-up

Dark Matter (DM) accounts for ~85% of the entire matter in the universe

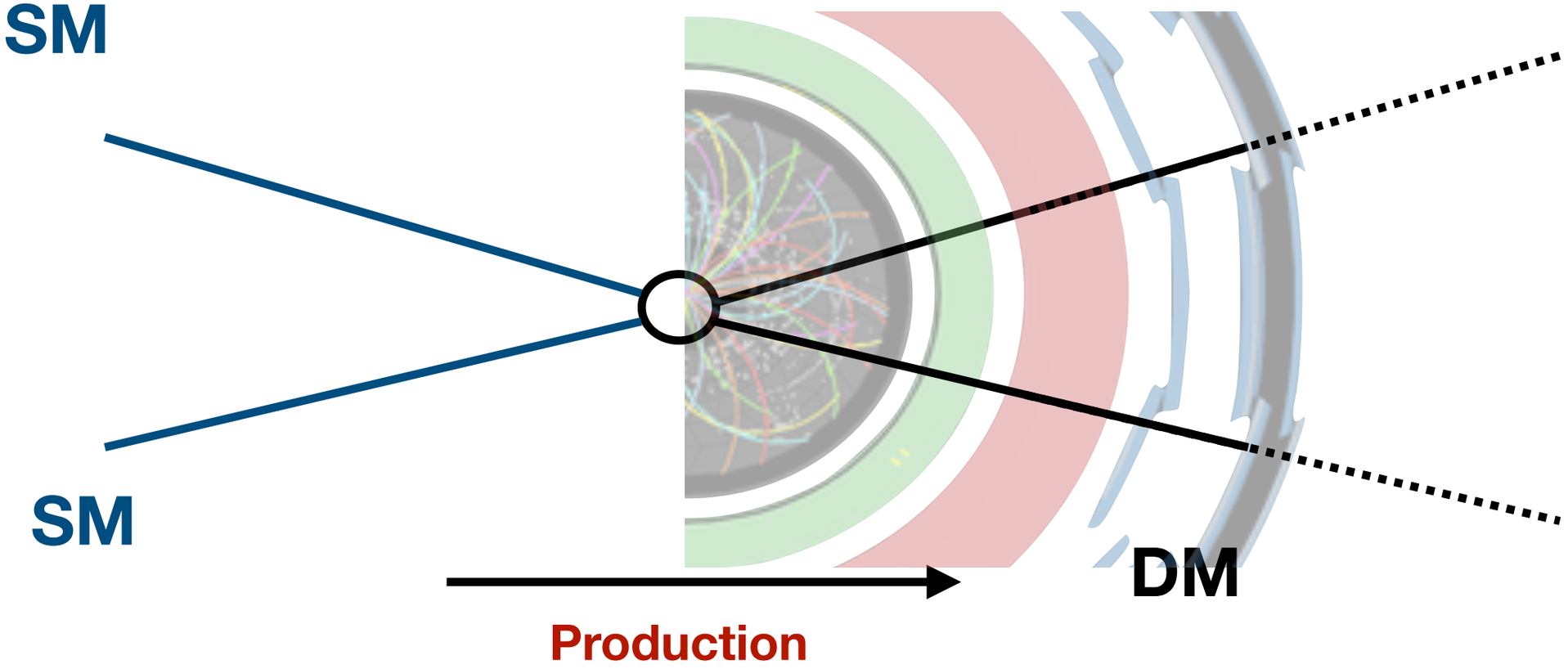
Assuming DM interacts with Standard Model (SM) particles → can produce it at colliders



Dark Matter (DM) accounts for ~85% of the entire matter in the universe

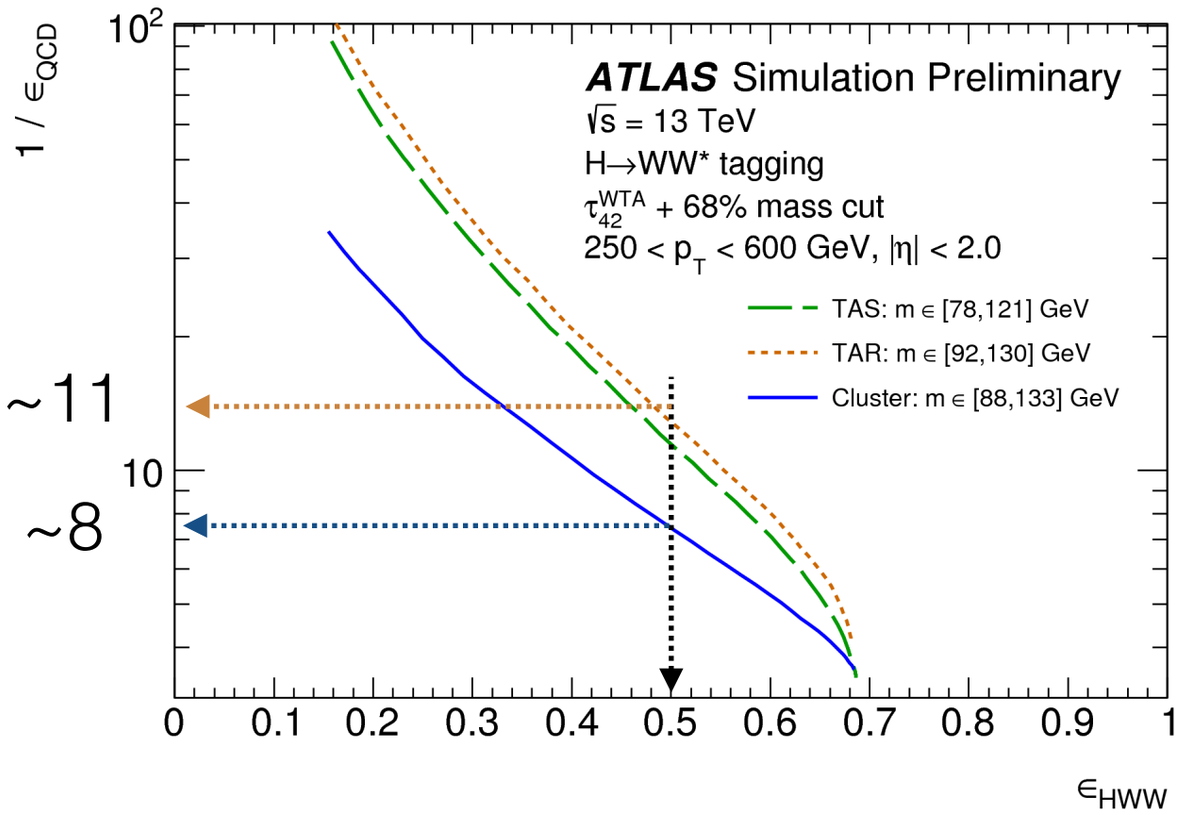
Assuming DM interacts with Standard Model (SM) particles → can produce it at colliders

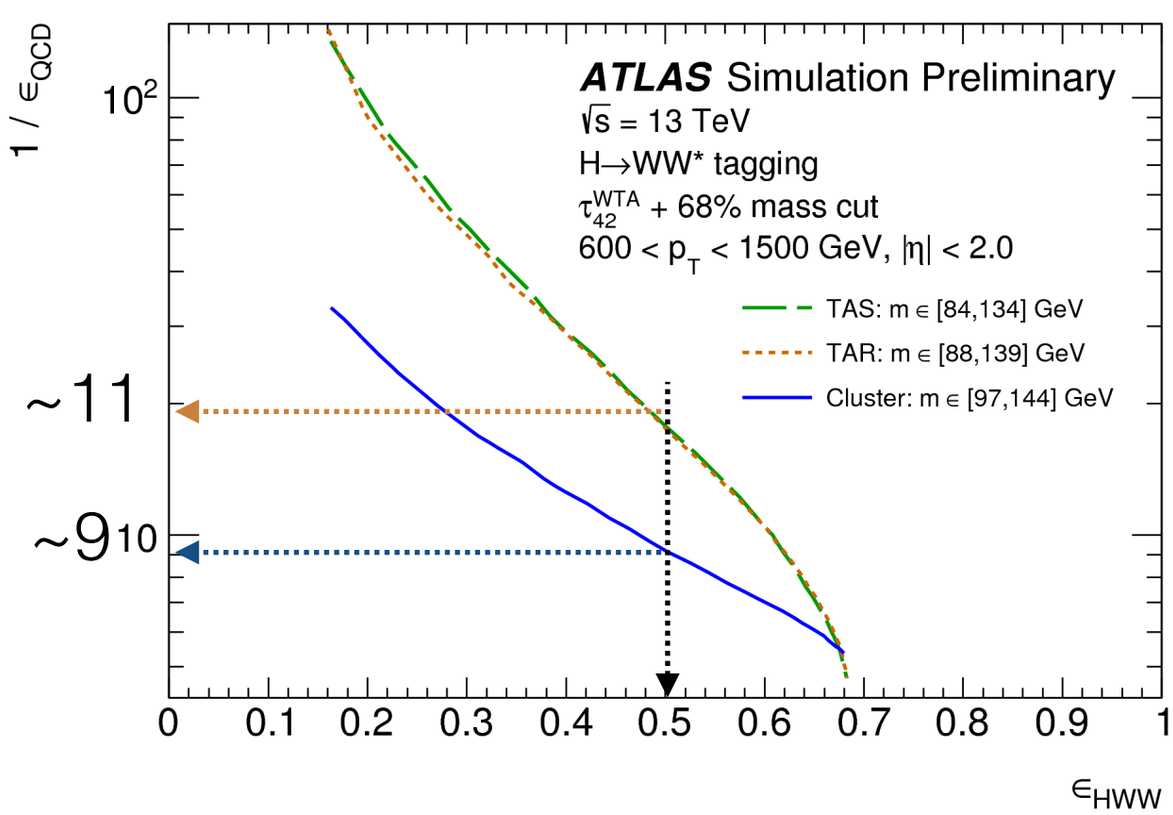
DM escapes undetected giving rise to E_T^{miss}



Track-Assisted-Reclustered (TAR) jets

ATL-PHYS-PUB-2018-012



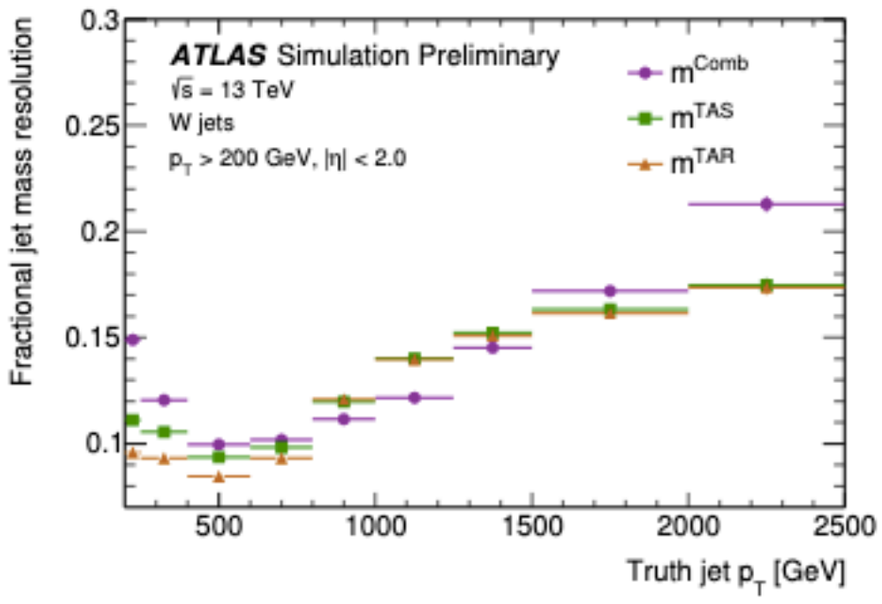


τ_{42} + mass cut tagging WW* jets vs QCD
(τ_{21} for W jets, τ_{32} top jets, for HWW in backup)

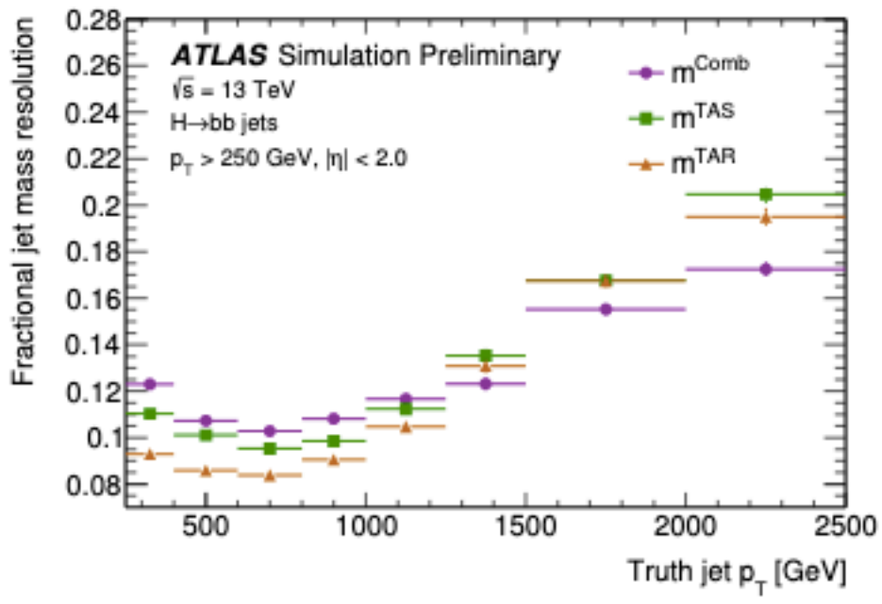
improvements using track-assisted objects

τ_{42} substructure variable helps
discriminating 4-prong jets

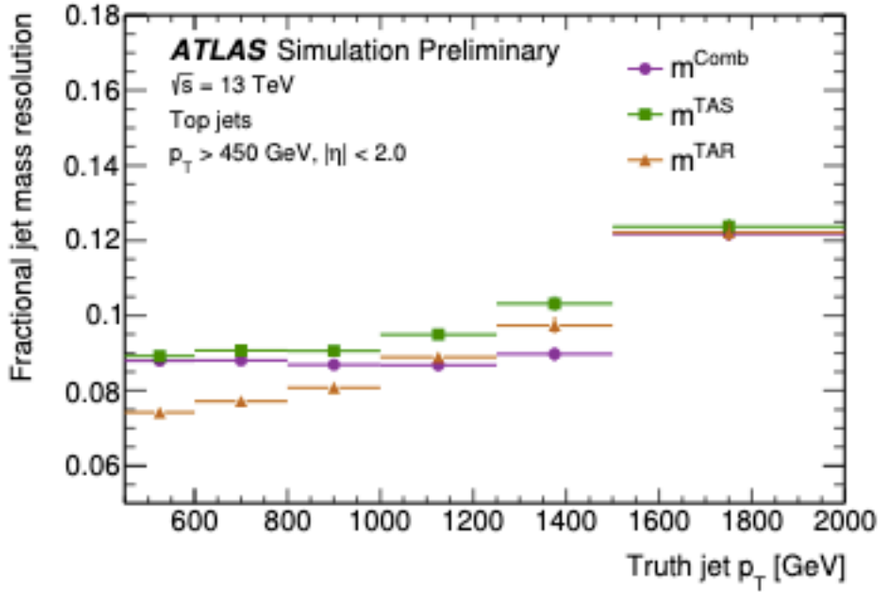
ATL-PHYS-PUB-2018-012

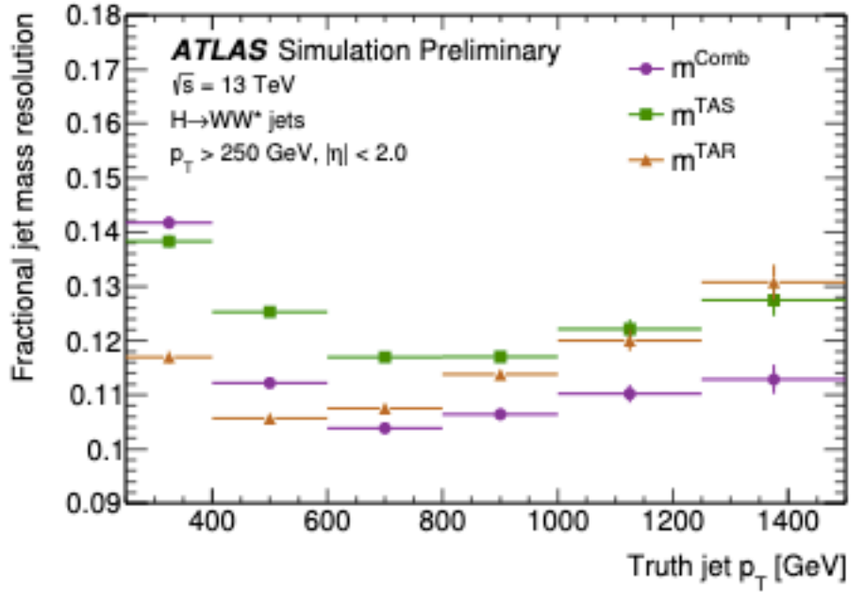


(a)



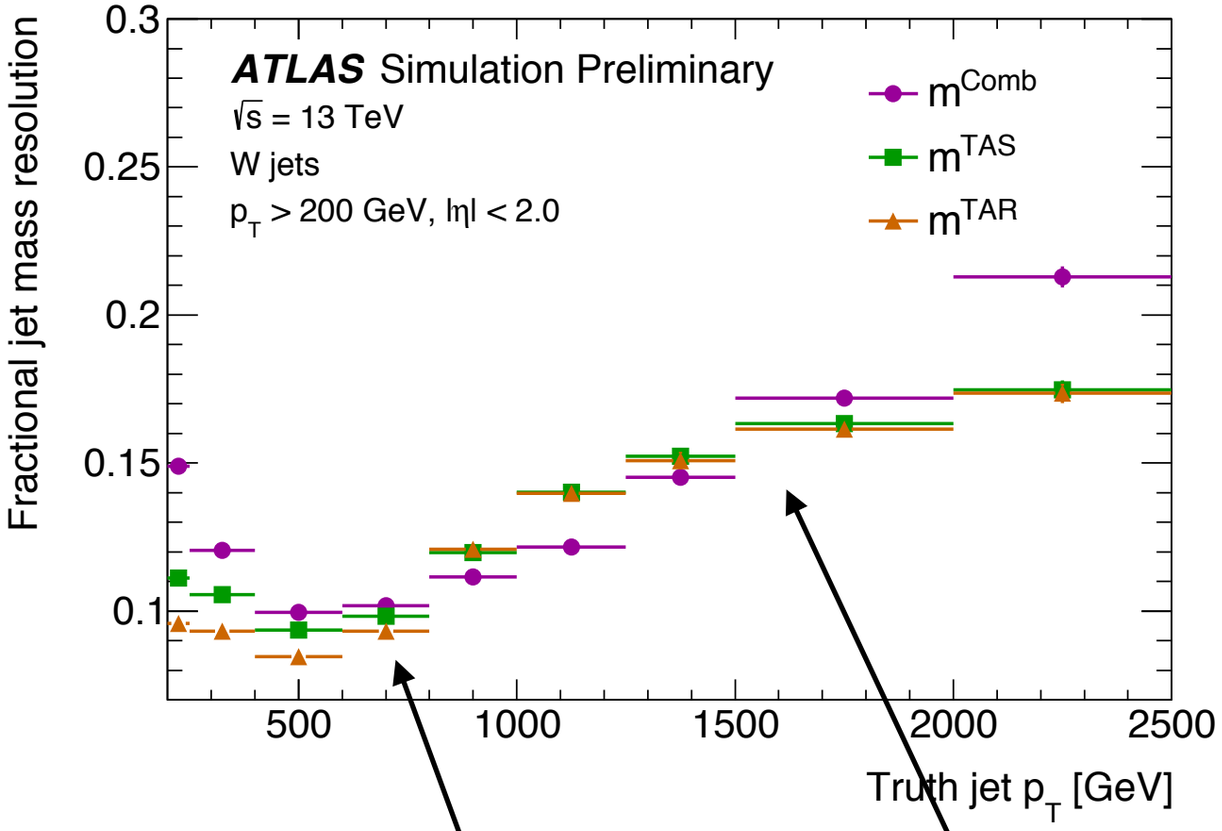
(b)



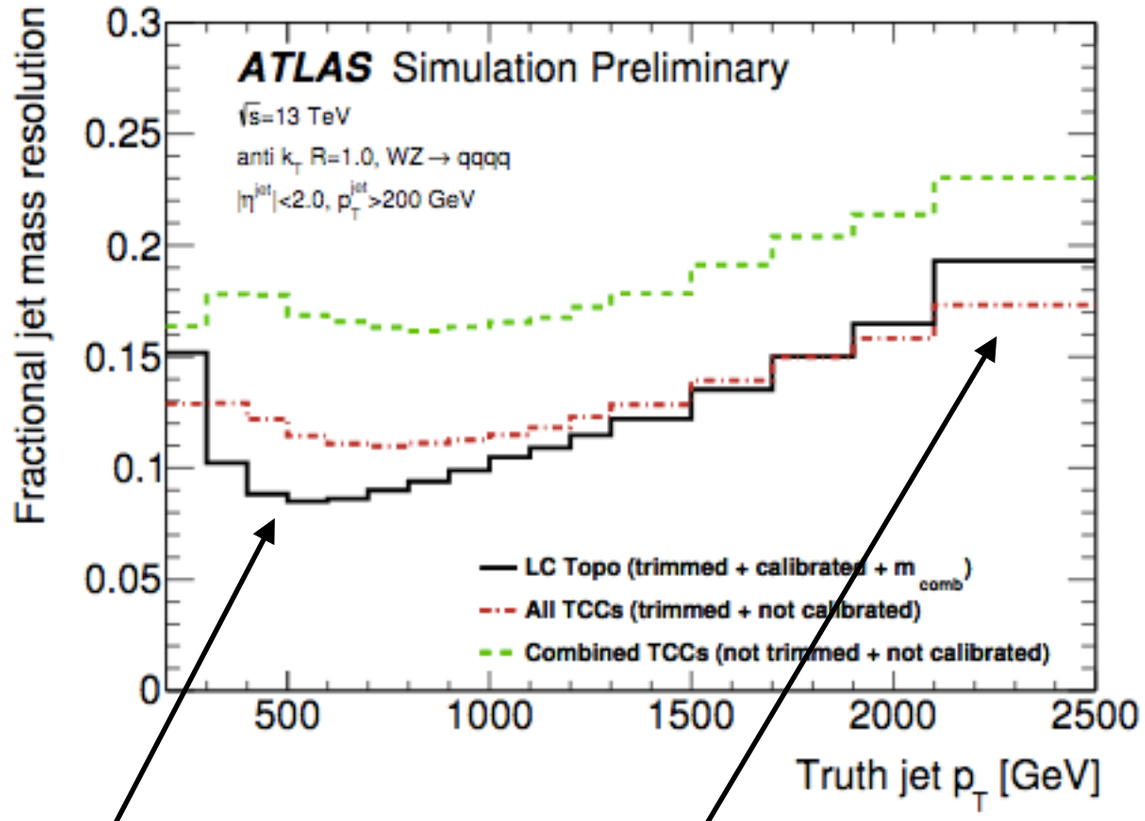


Mass resolution example: W jets

ATL-COM-PHYS-2018-455



ATL-PHYS-PUB-2017-015



mTAR

Best resolution
up to 800 GeV
for W jets

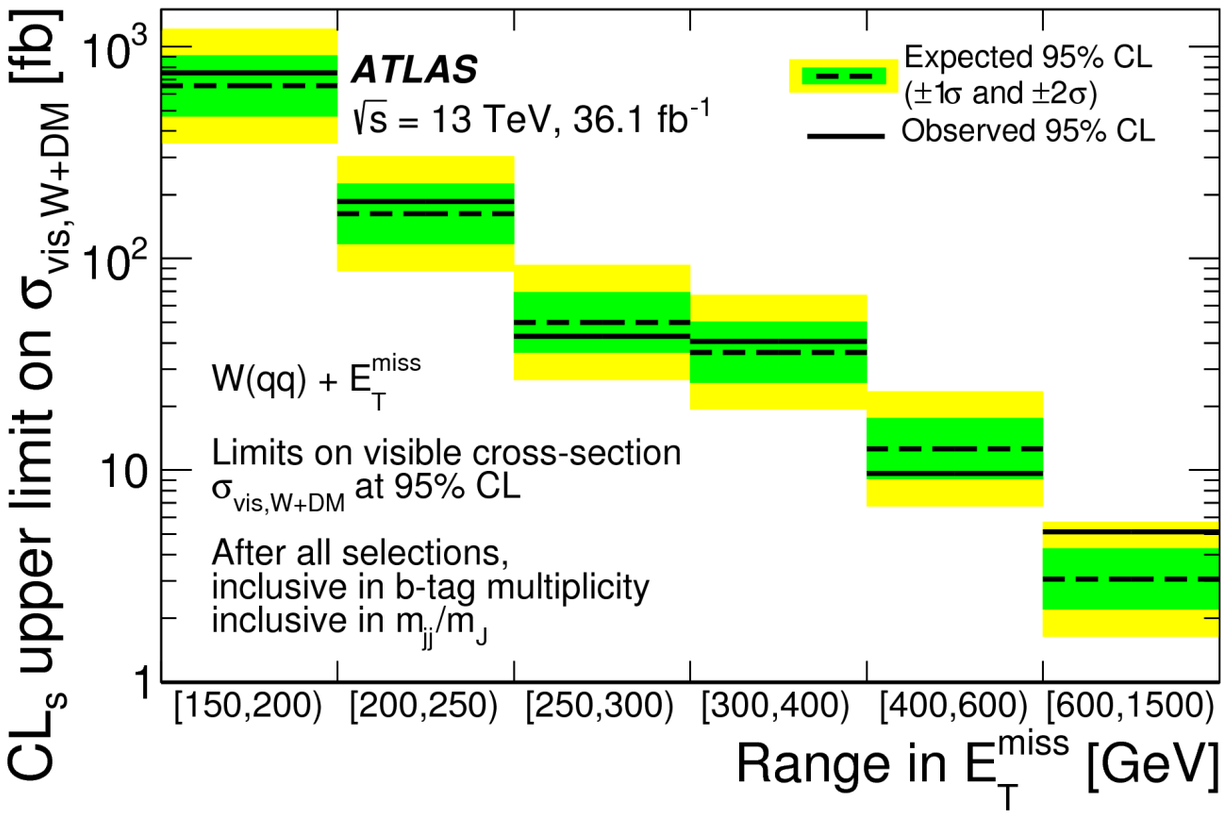
Combined mass

TCC

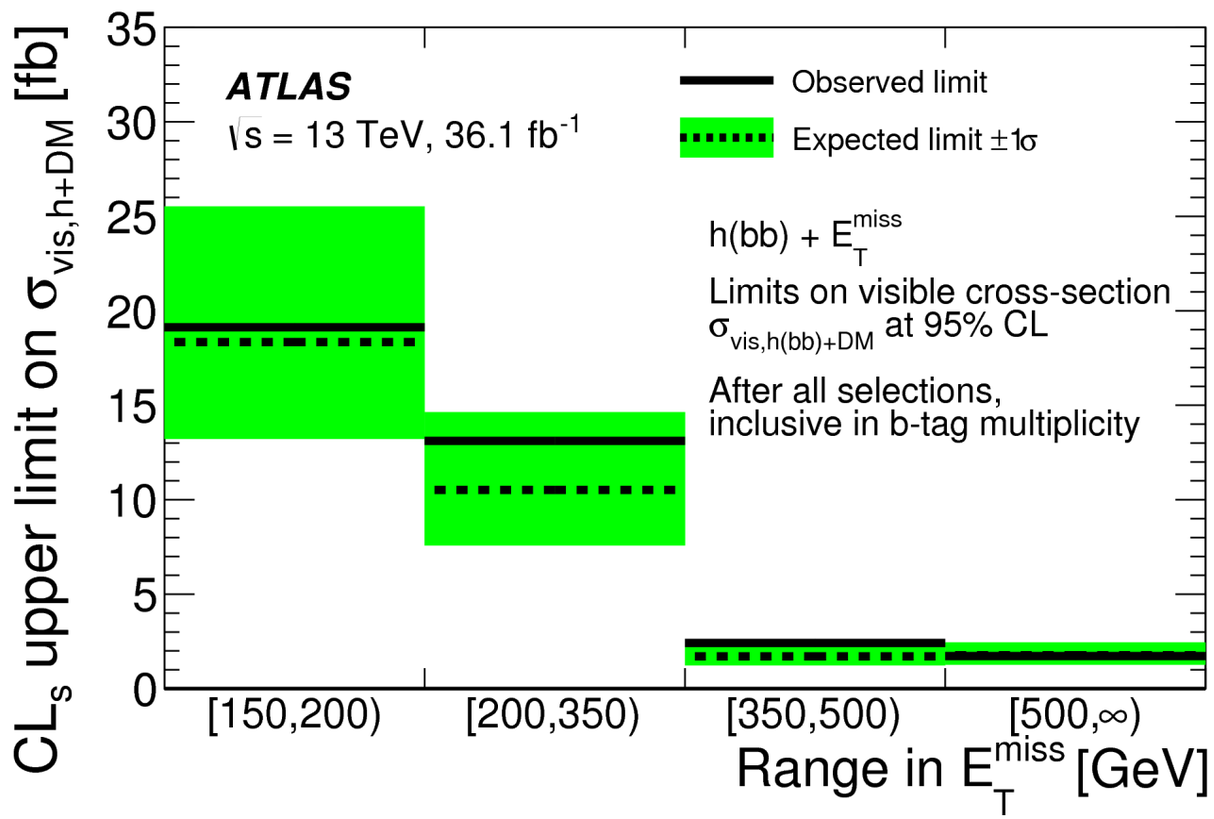
Best resolution
at high p_T ~2 TeV
for W jets

Exclusion limits for in bins of missing transverse momentum

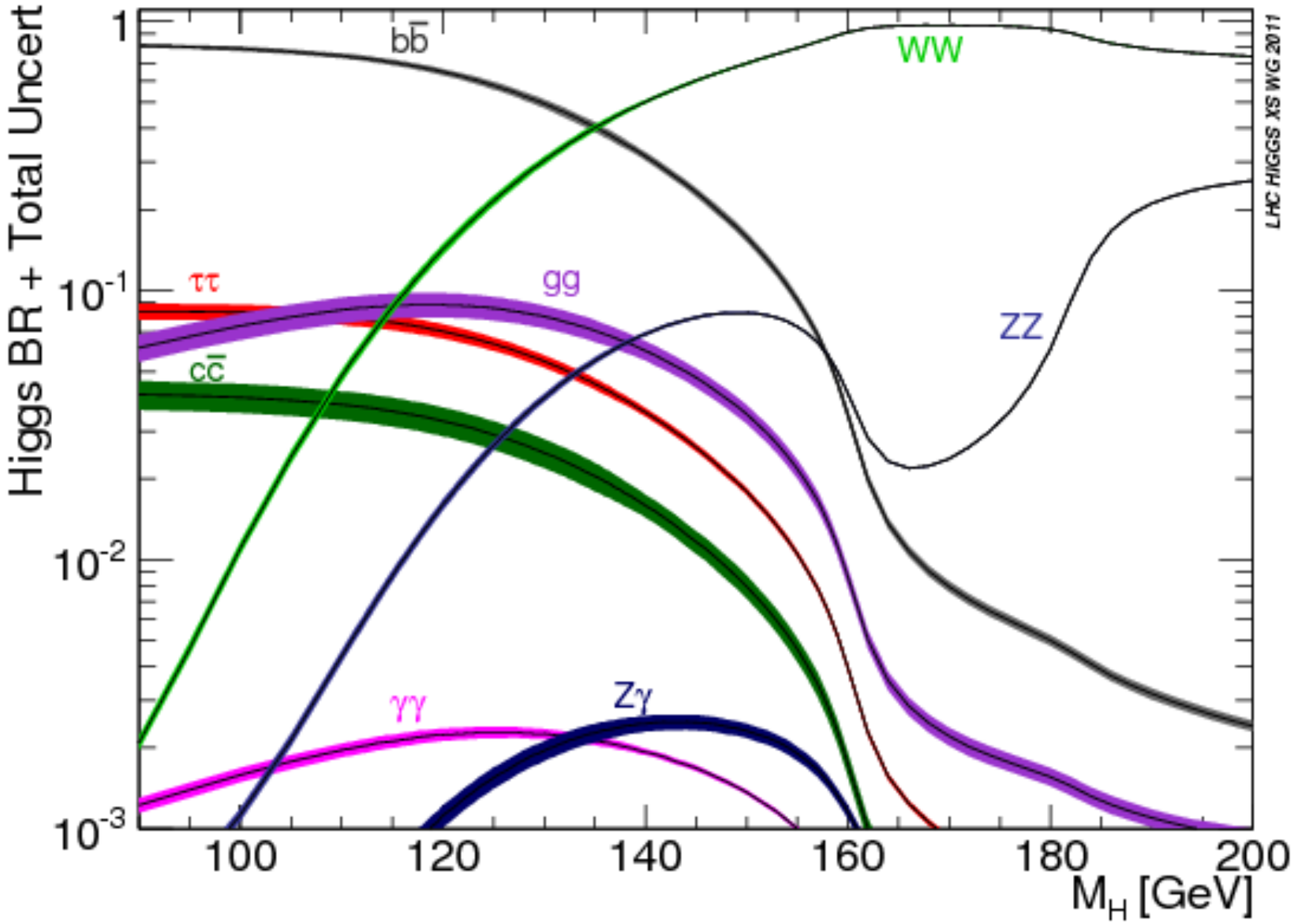
JHEP 10 (2018) 180



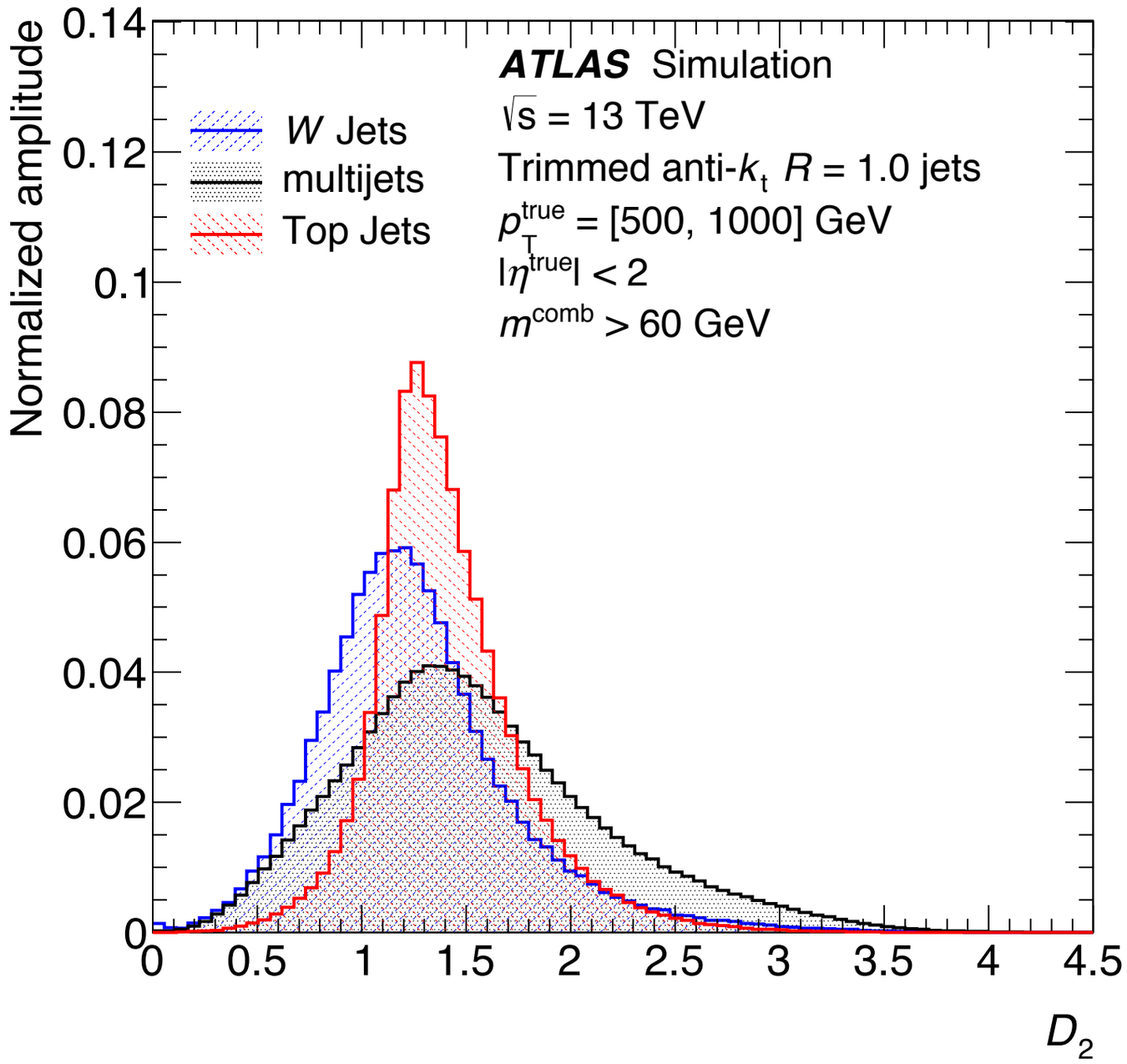
Phys. Rev. Lett. 119 (2017) 181804



Eur.Phys.J. C71 (2011) 1753



Eur. Phvs. J. C 79 (2019) 375.



$$C2 = \frac{ECF3 \cdot ECF1}{ECF2^2}$$

$$D2 = \frac{ECF3 \cdot ECF1^3}{ECF2^3}$$

$$ECF1 = \sum_{constituents} p_T$$

$$ECF2(\beta) = \sum_{i=1}^{n} \sum_{j=i+1}^{n} p_{T,i} p_{T,j} \Delta R_{ij}^{\beta}$$

$$ECF3(\beta) = \sum_{i=1}^{n} \sum_{j=i+1}^{n} \sum_{k=j+1}^{n} p_{T,i} p_{T,j} p_{T,k} (\Delta R_{ij} \Delta R_{ik} \Delta R_{jk})^{\beta}$$