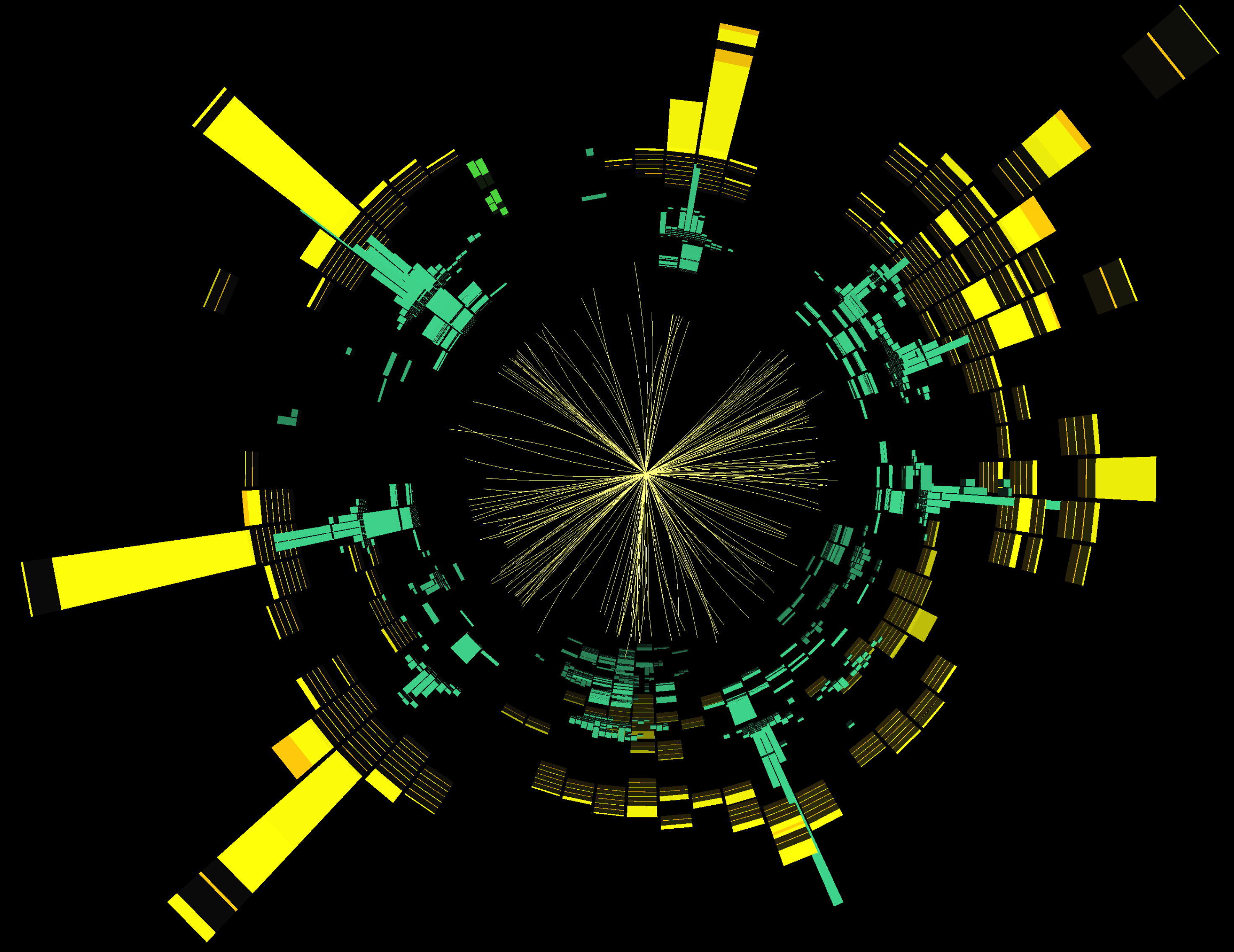
EPS-HEP CONFERENCE
07-11 JULY, 2025
PALAIS DU PHARO
MARSEILLE, FRANCE

Searches for new phenomena in hadronic final states using the ATLAS detector



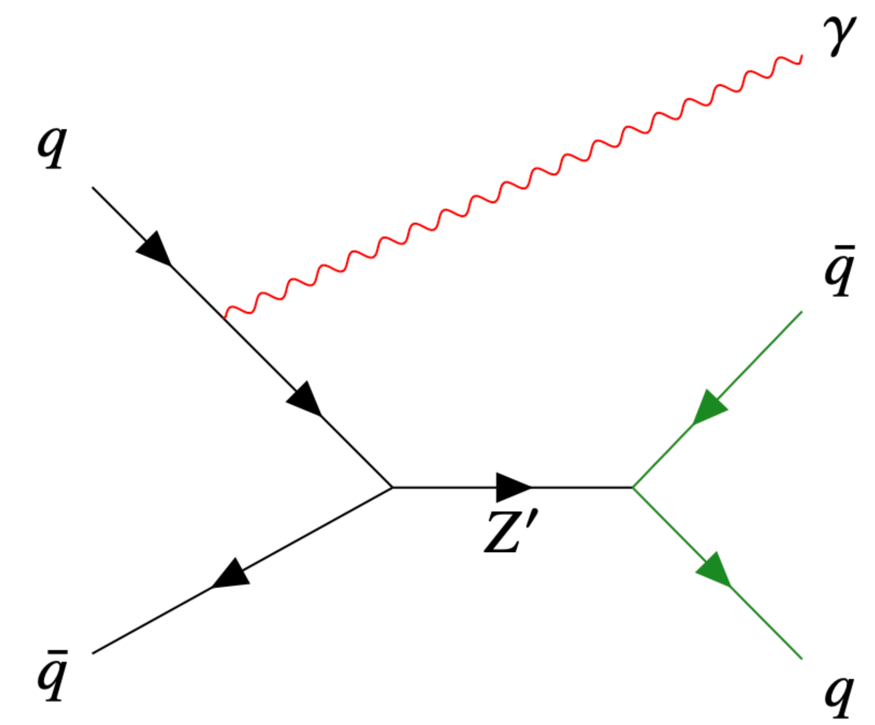
Marawan Barakat
On behalf of the ATLAS collaboration

09/07/2025

Why the hadronic final state ?

- **High statistics available** due to large QCD cross section in pp collisions
- BSM particles **decay predominantly to quarks and gluons**
- **Rich BSM phenomenology**, including dark QCD and WIMP-inspired dark sector models
- Many models predict couplings between new physics and **3rd generation quarks**
- Fully hadronic channels enable broad and inclusive **model-independent** searches

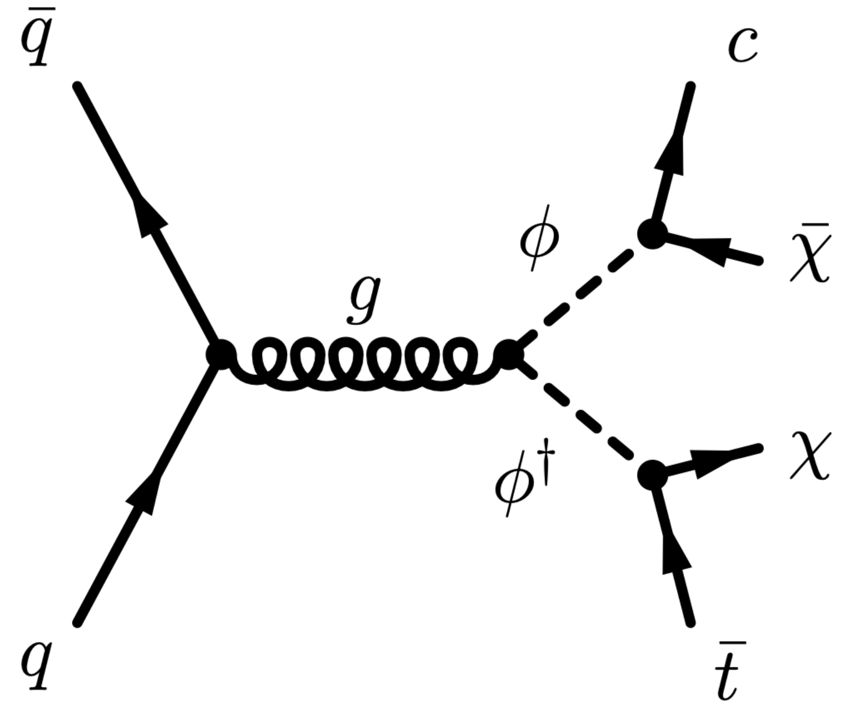
Outline



Boosted Dijet+ISR γ

Search for boosted low-mass resonances decaying into hadrons produced in association with a photon in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

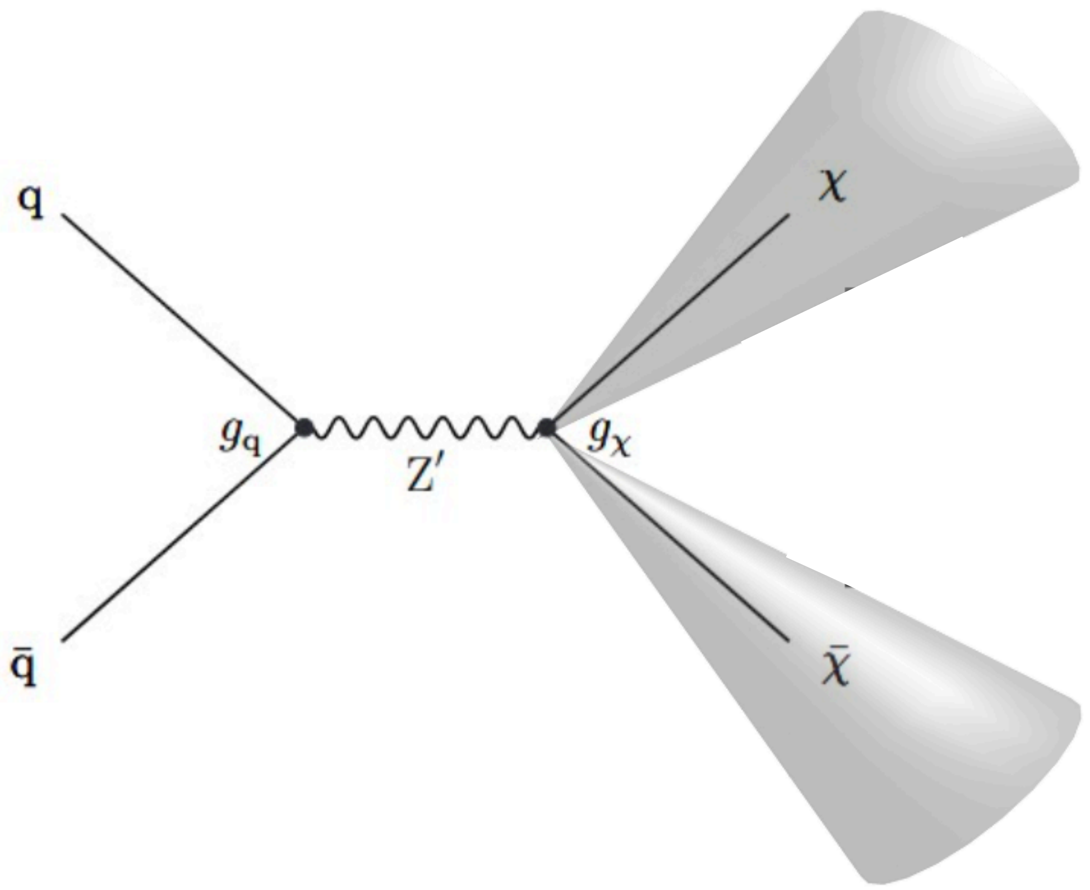
JHEP01(2025)099



top, charm + E_T^{miss}

Reinterpretation of searches for flavour-violating supersymmetry into flavour-violating dark matter models using 139 fb^{-1} of ATLAS Run 2 data

ATL-PHYS-PUB-2025-010

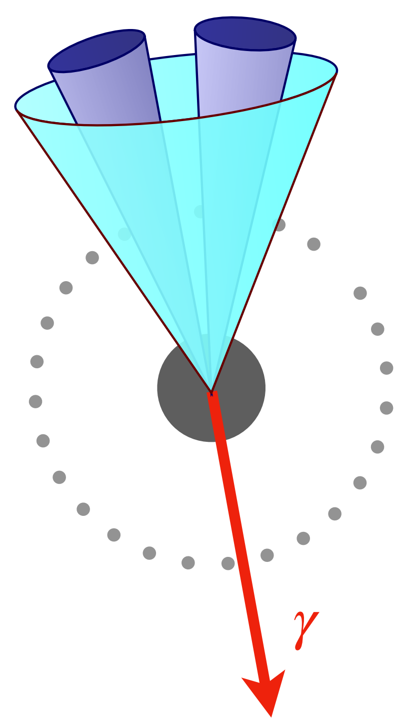


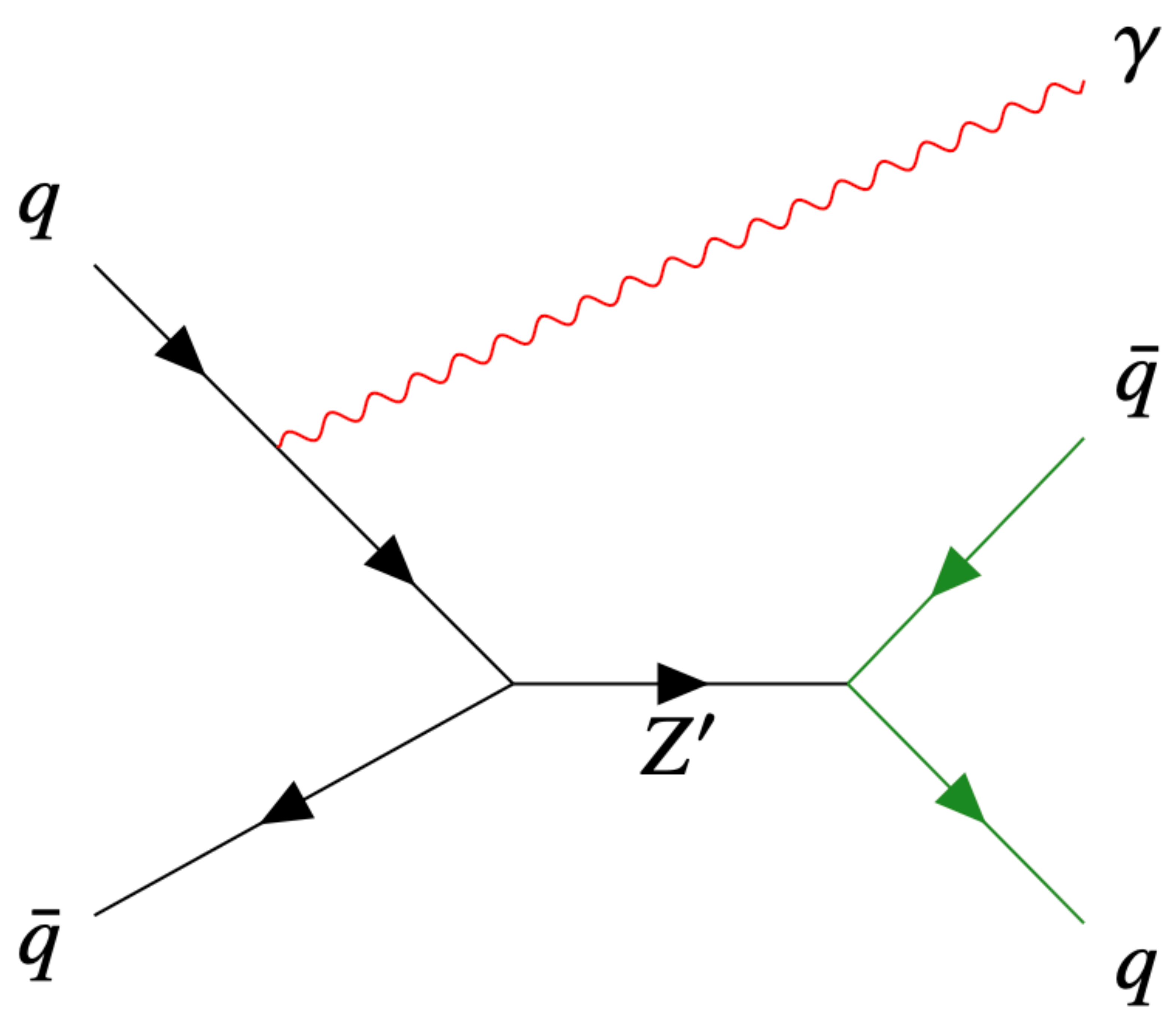
Semi-Visible Jets

Search for new physics in final states with semi visible jets or anomalous signatures using the ATLAS detector

arXiv:2505.01634

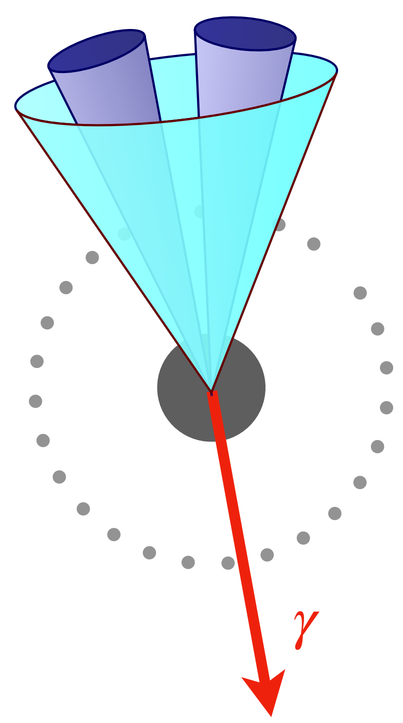
Boosted **dijet+ISR γ**

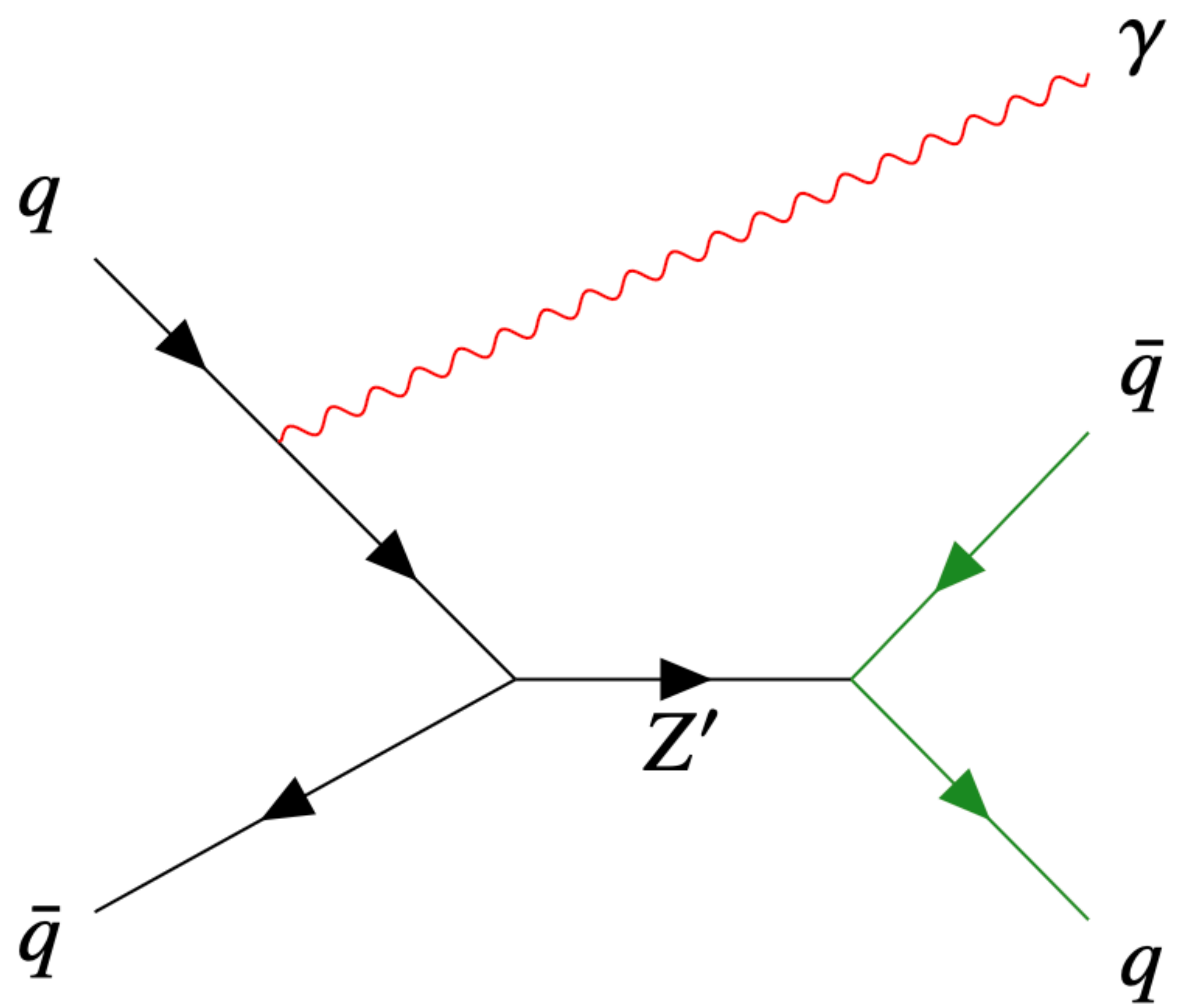




- Z' a spin-1 mediator coupling the SM to the dark sector
- A versatile candidate for both visible and invisible signatures
- Resonant production of a **Z'** mediator via $q\bar{q} \to \gamma + Z' \to \gamma + q\bar{q}$

Boosted **dijet+ISR γ**

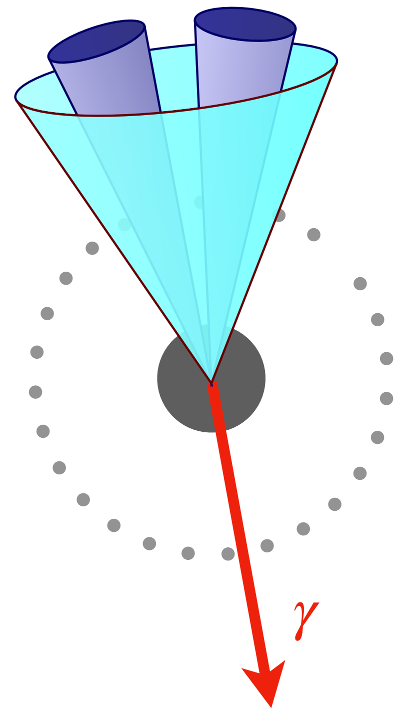


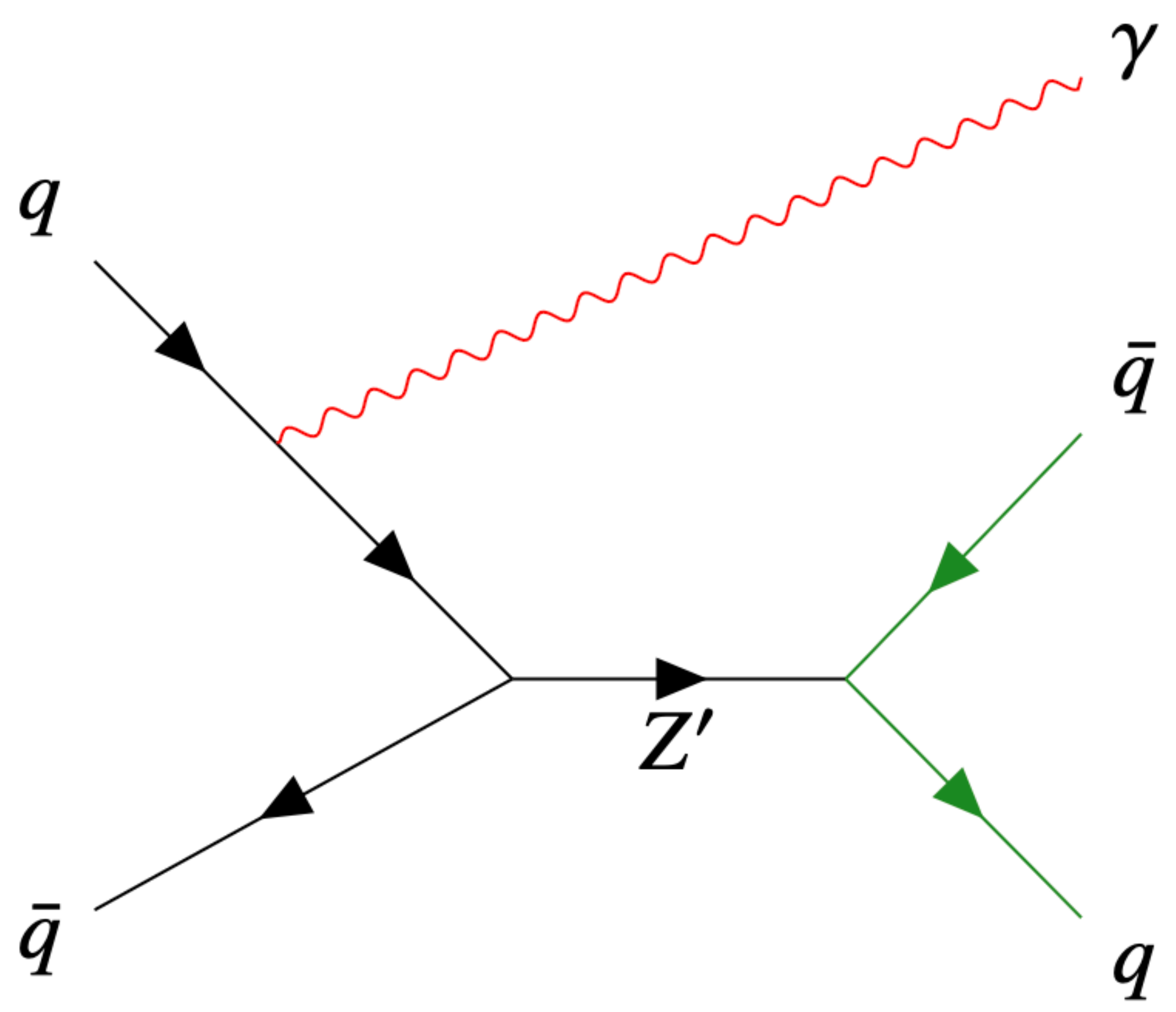


- Z' a spin-1 mediator coupling the SM to the dark sector
- A versatile candidate for both visible and invisible signatures
- Resonant production of a **Z'** mediator via $q\bar{q} \rightarrow \gamma + Z' \rightarrow \gamma + q\bar{q}$
- Challenging $m_{Z'}$ range from **20-100 GeV**

JHEP01(2025)099

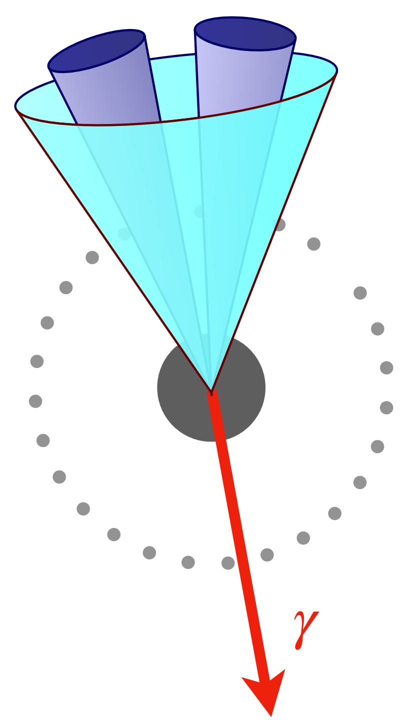
Boosted **dijet+ISR γ**



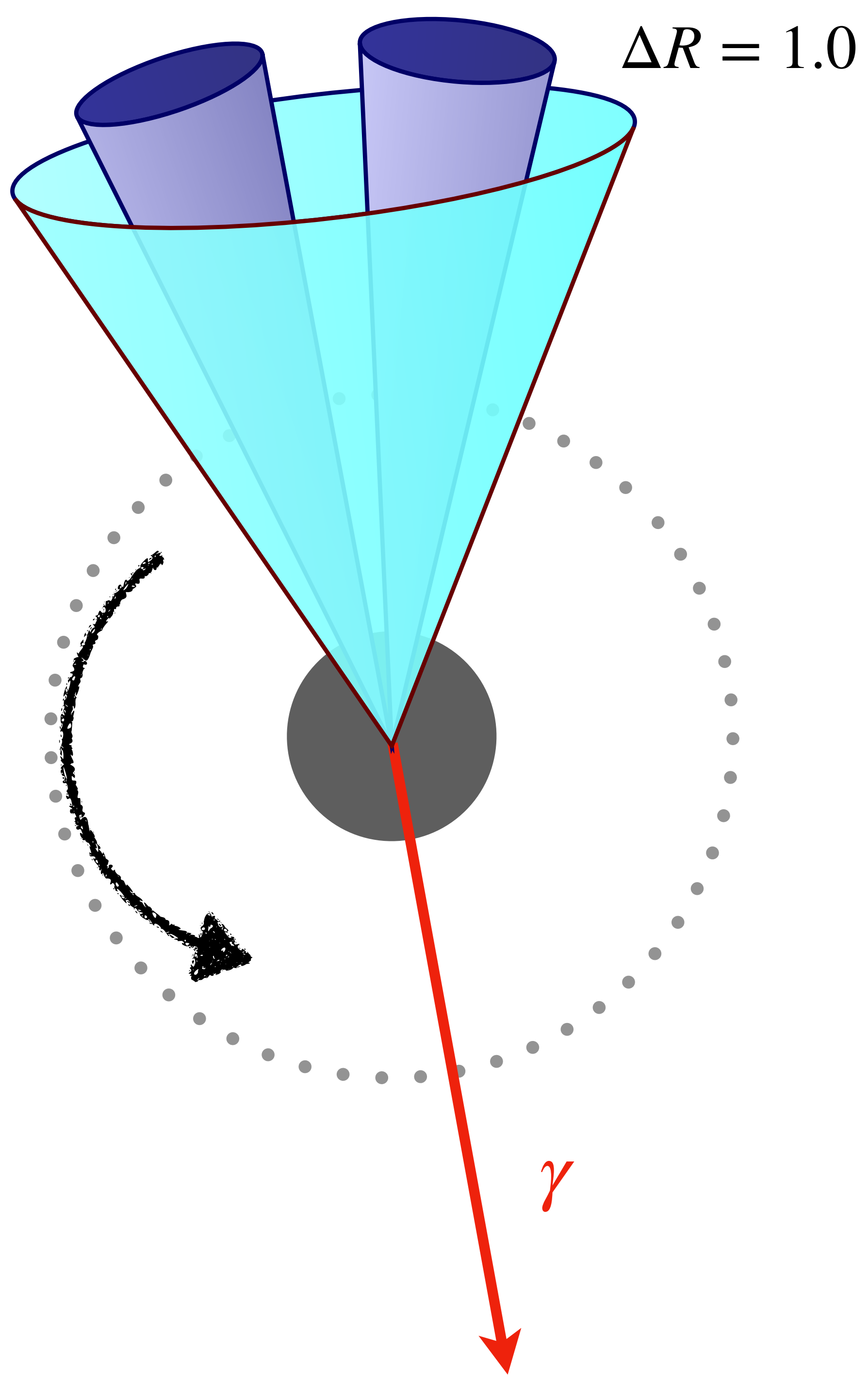


- The Lorentz boost of the Z' boson results in the $Z' \rightarrow q\bar{q}$ decay to be more **collimated**
- The system is recoiling **against an energetic ISR photon**
- Using the **photon as a trigger** to a trigger to bypass limitations on the **maximum data recording rate**

Boosted **dijet+ISR γ**

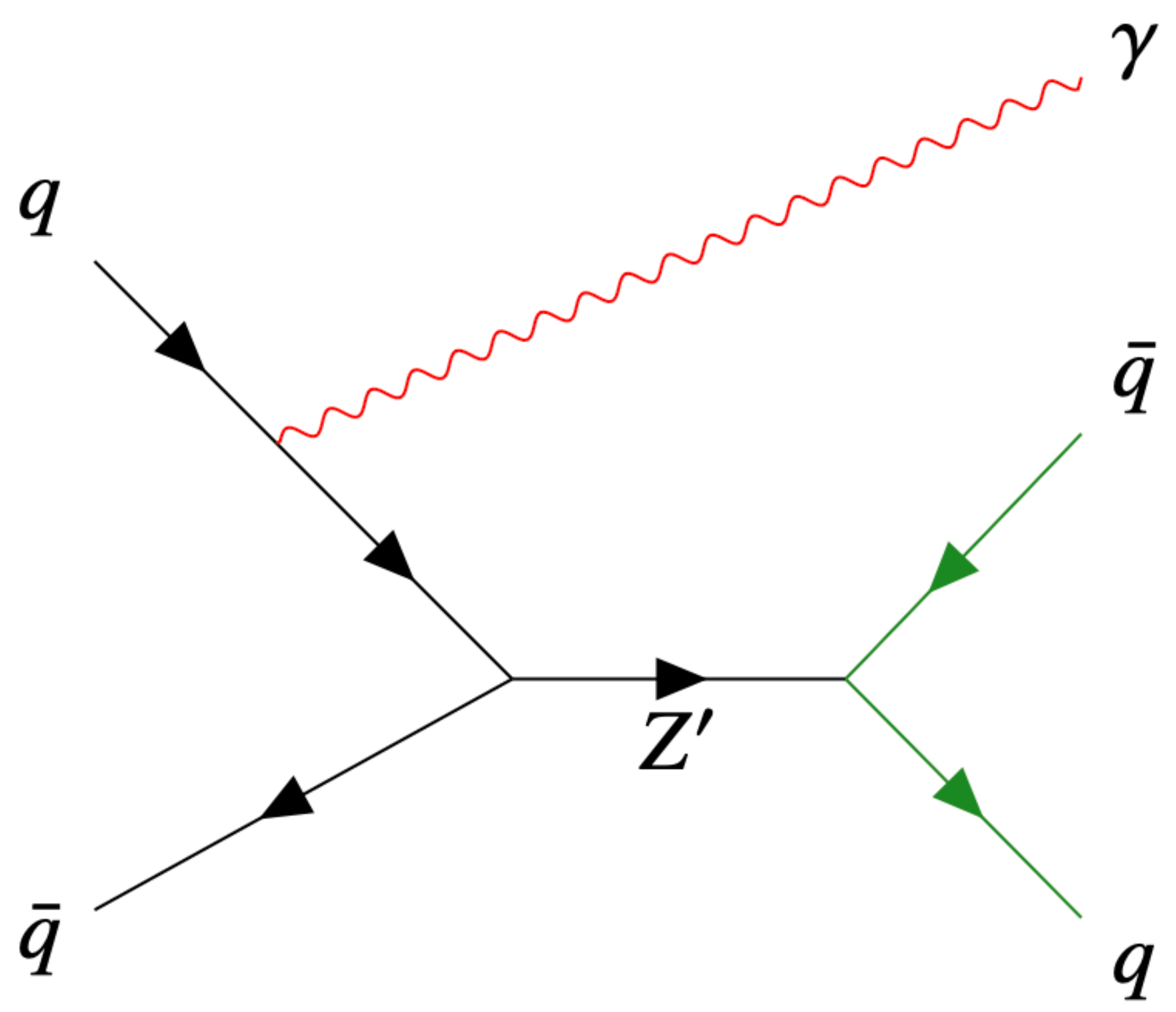


At least one Large Jet



ΔR>0.4

At least one photon



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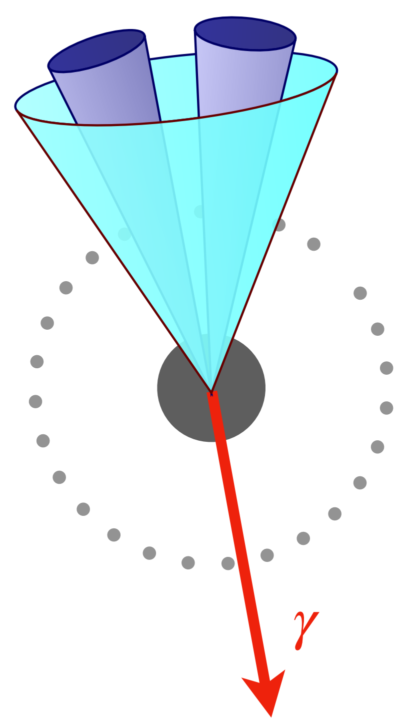
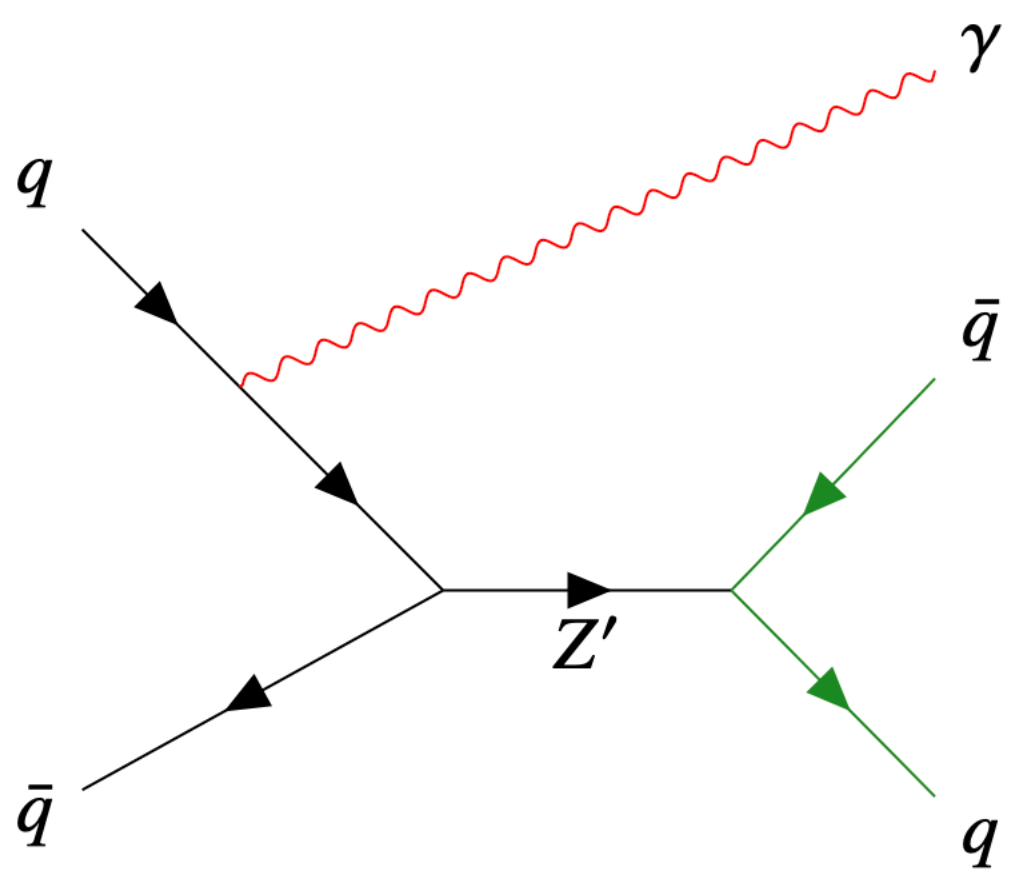
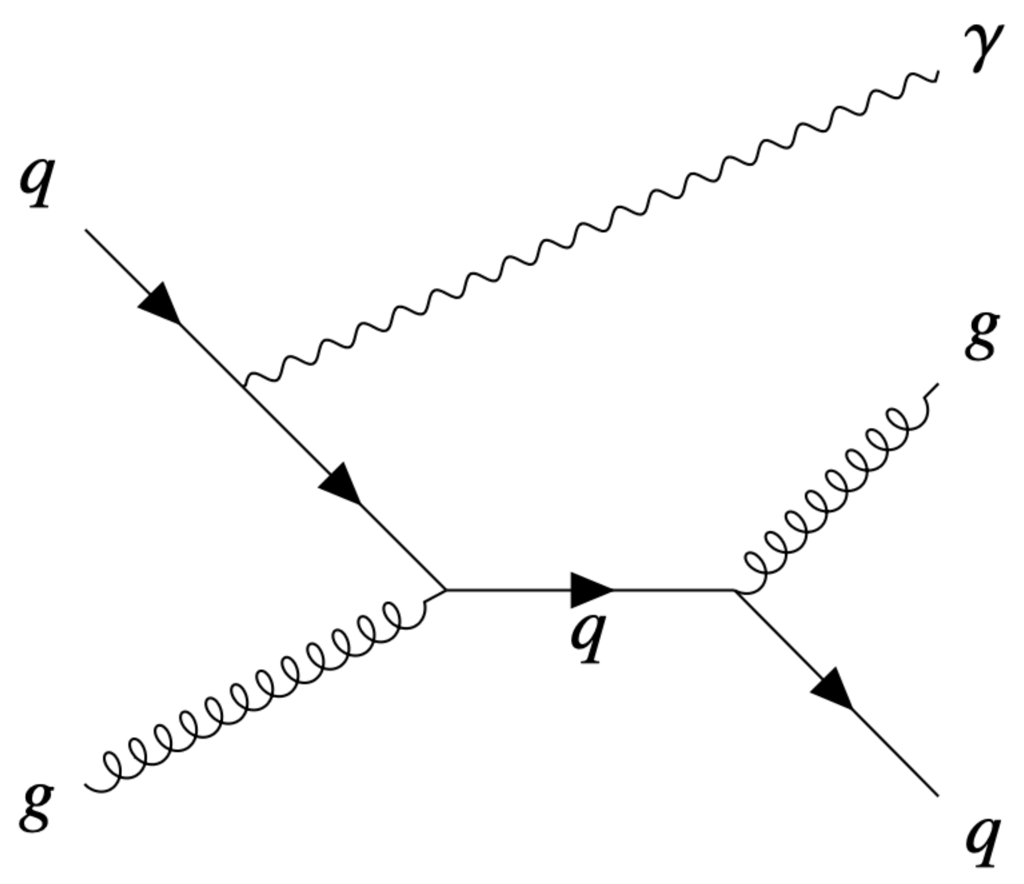
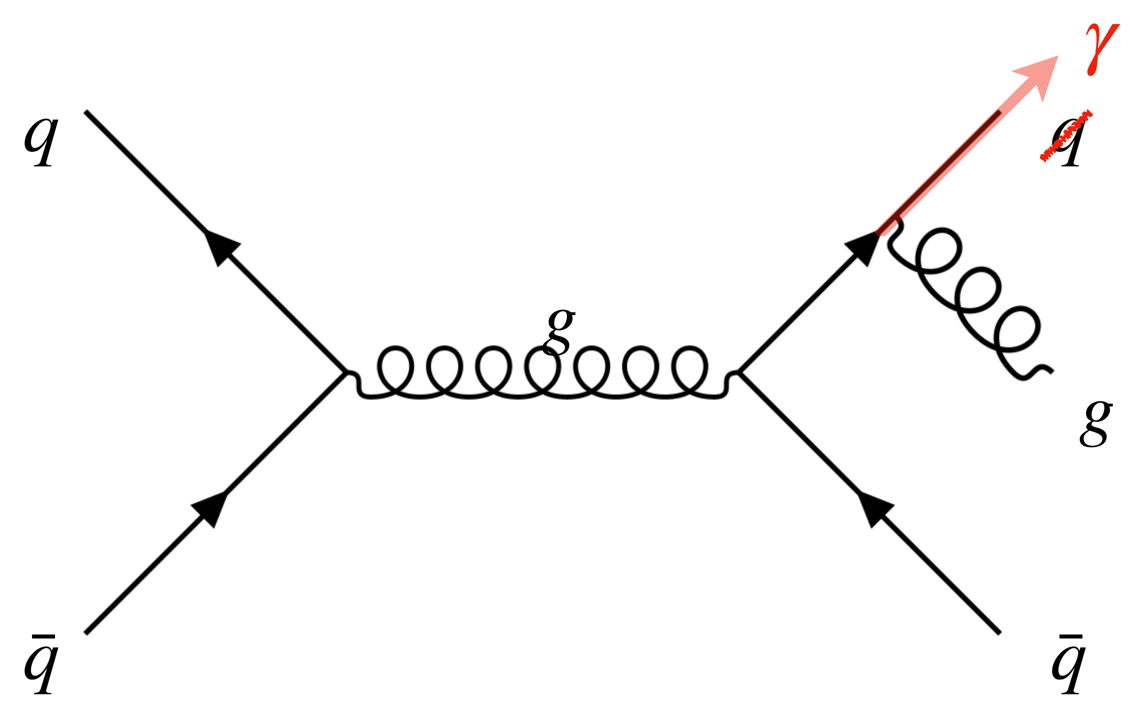
Boosted dijet+ISR γ



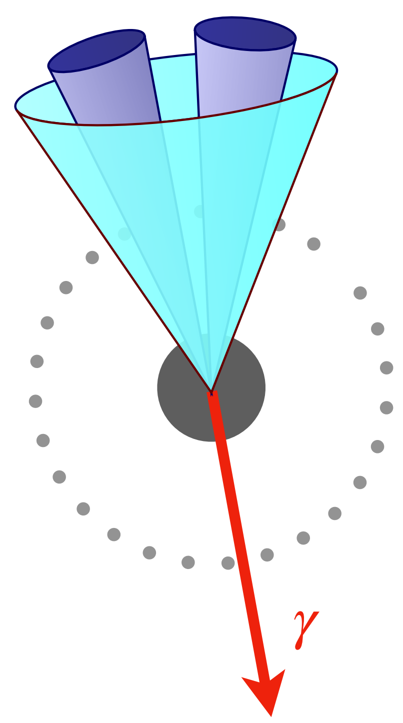


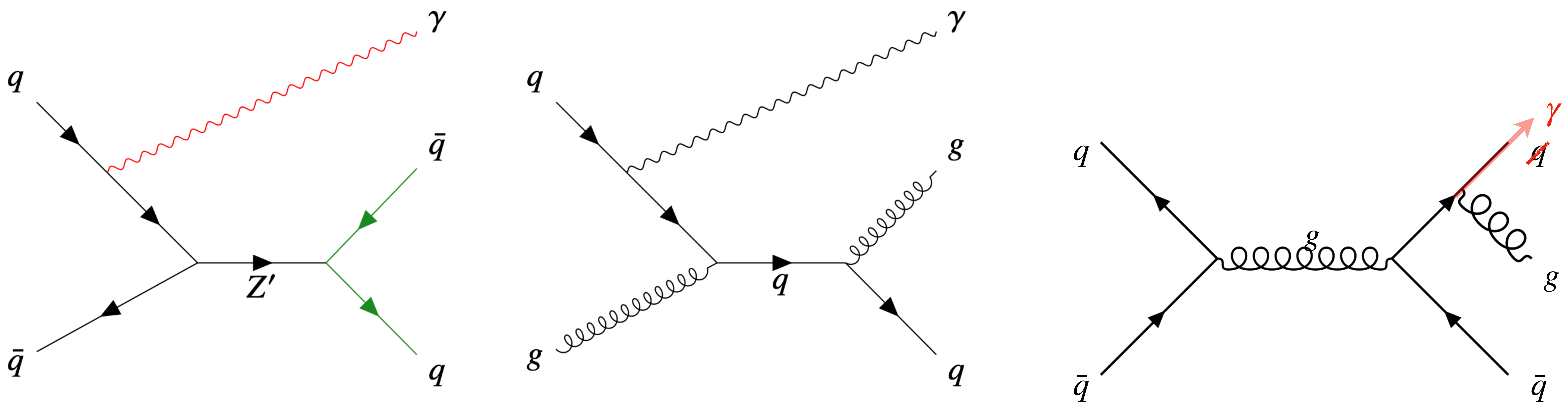




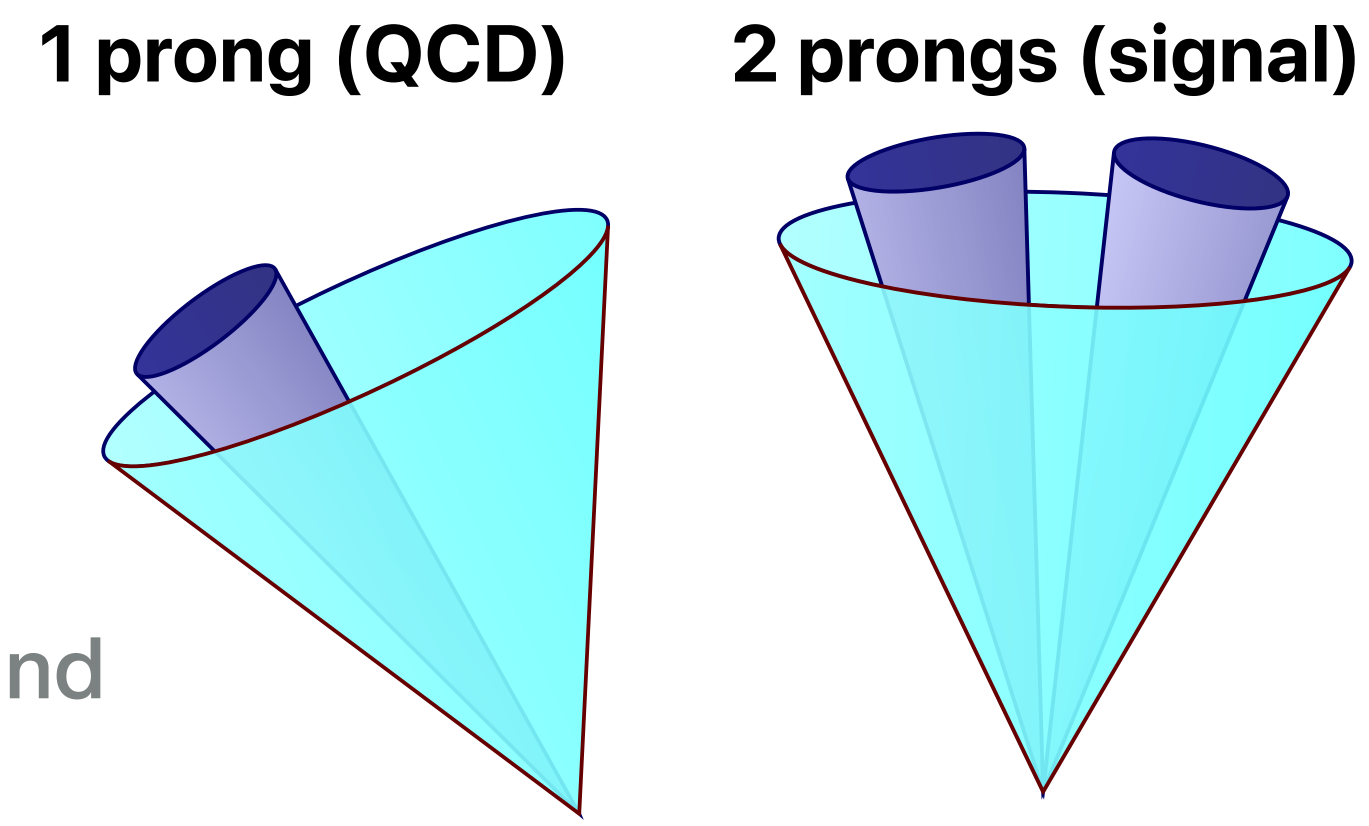
- Challenging background from **QCD + ISR γ**
- Jets from multi-jets events can **fake photons**

Boosted dijet+ISR γ

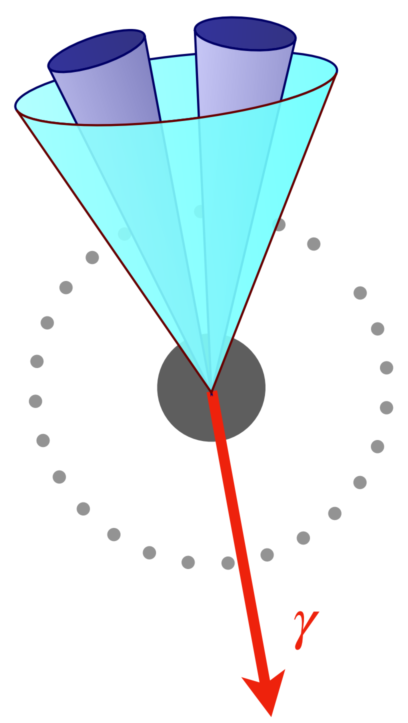


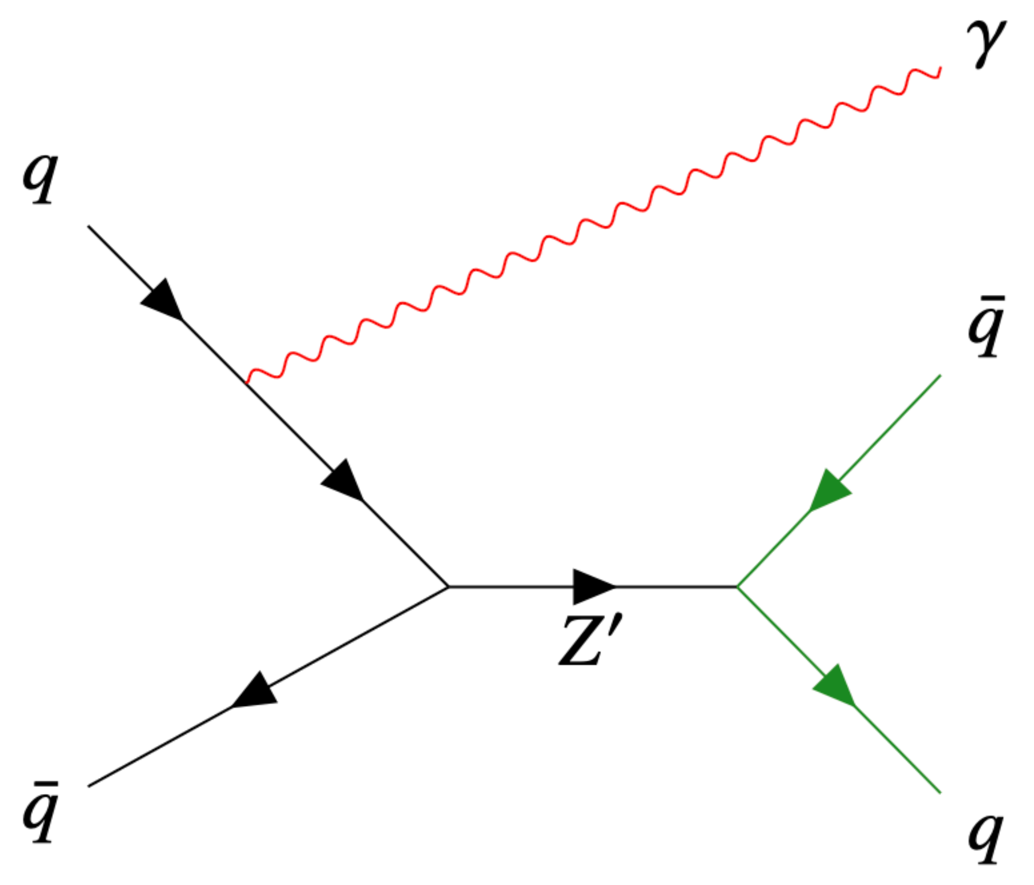


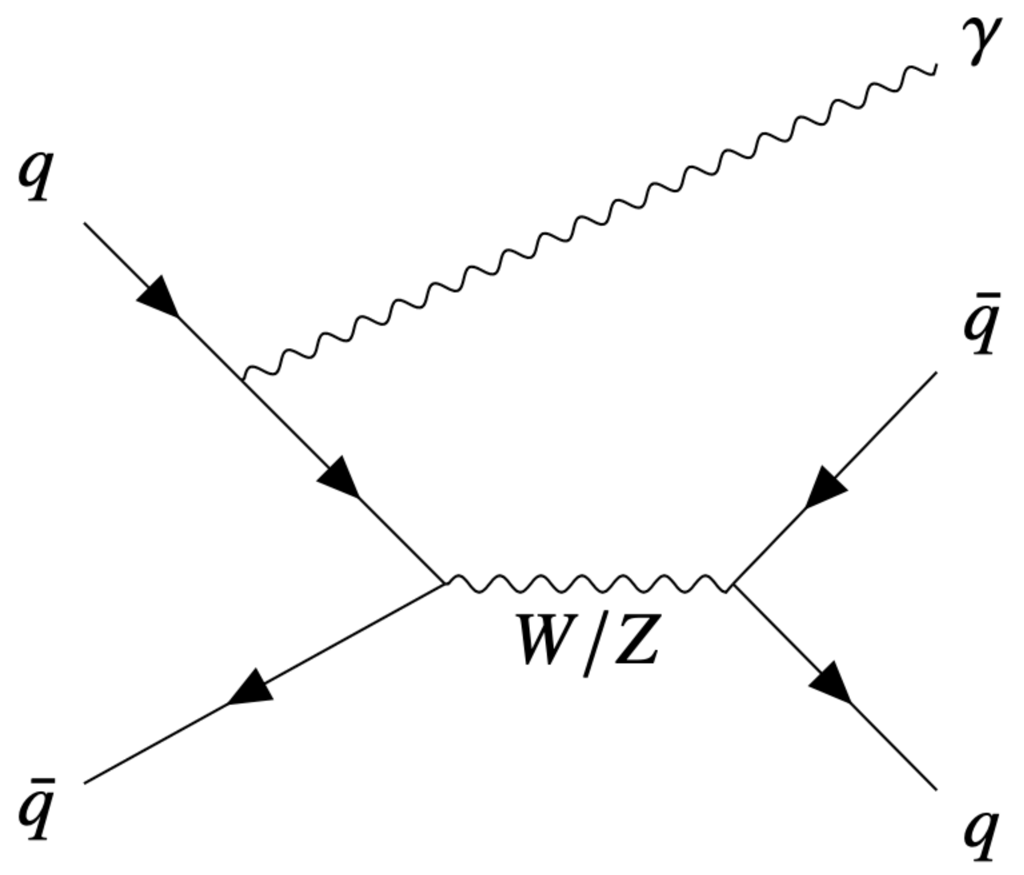
- Challenging background from **QCD + ISR γ**
- Jets from multi-jets events can **fake photons**
- Events are split using the **two-prong tagger D_2^{DDT}**
    - **Tagged region:** $D_2^{\mathrm{DDT}} < 0$ → signal and resonant background
    - **Anti-tagged region:** $D_2^{\mathrm{DDT}} \geq 0$ → non-resonant QCD background



Boosted **dijet+ISR** γ

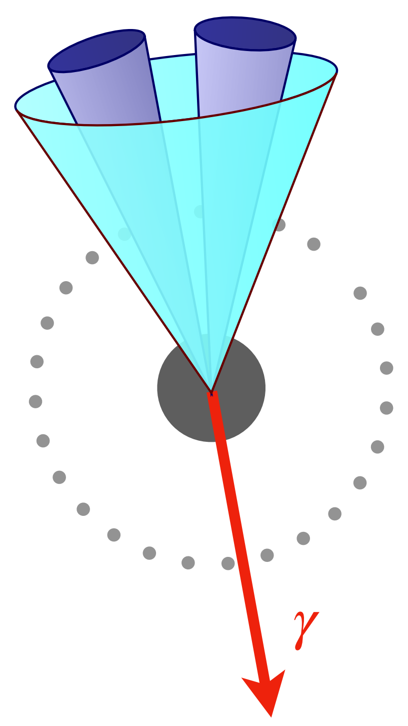




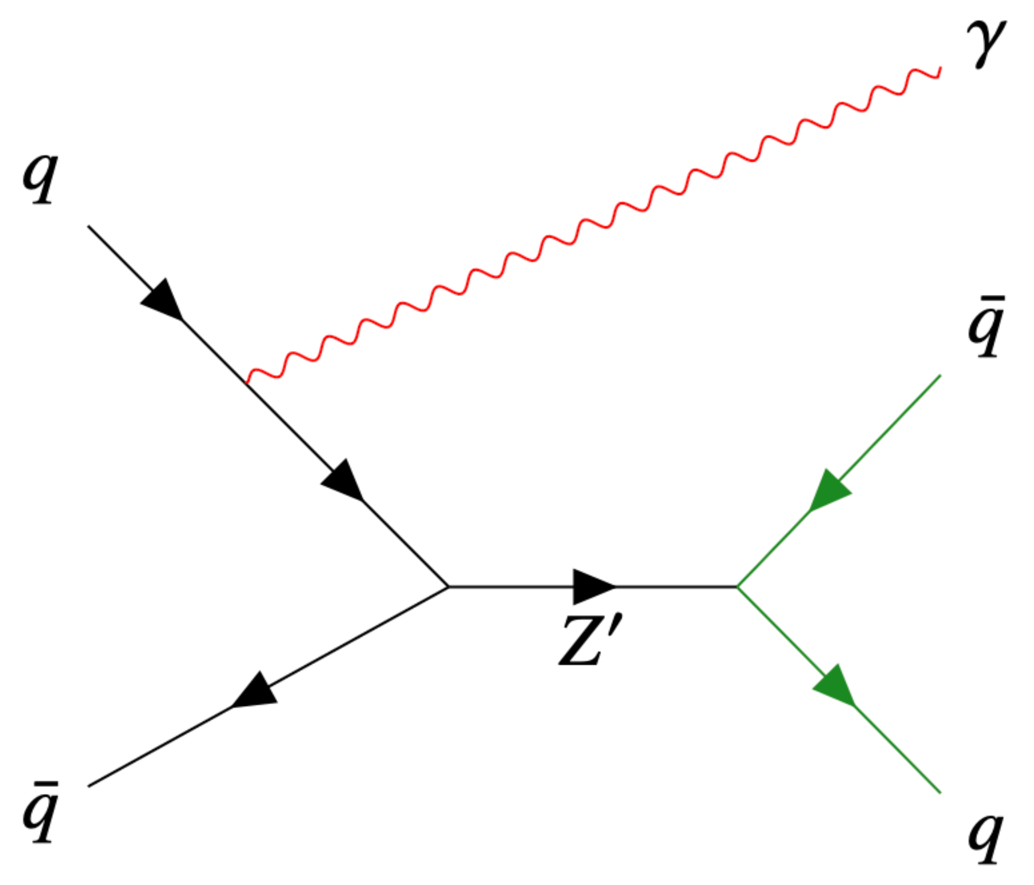


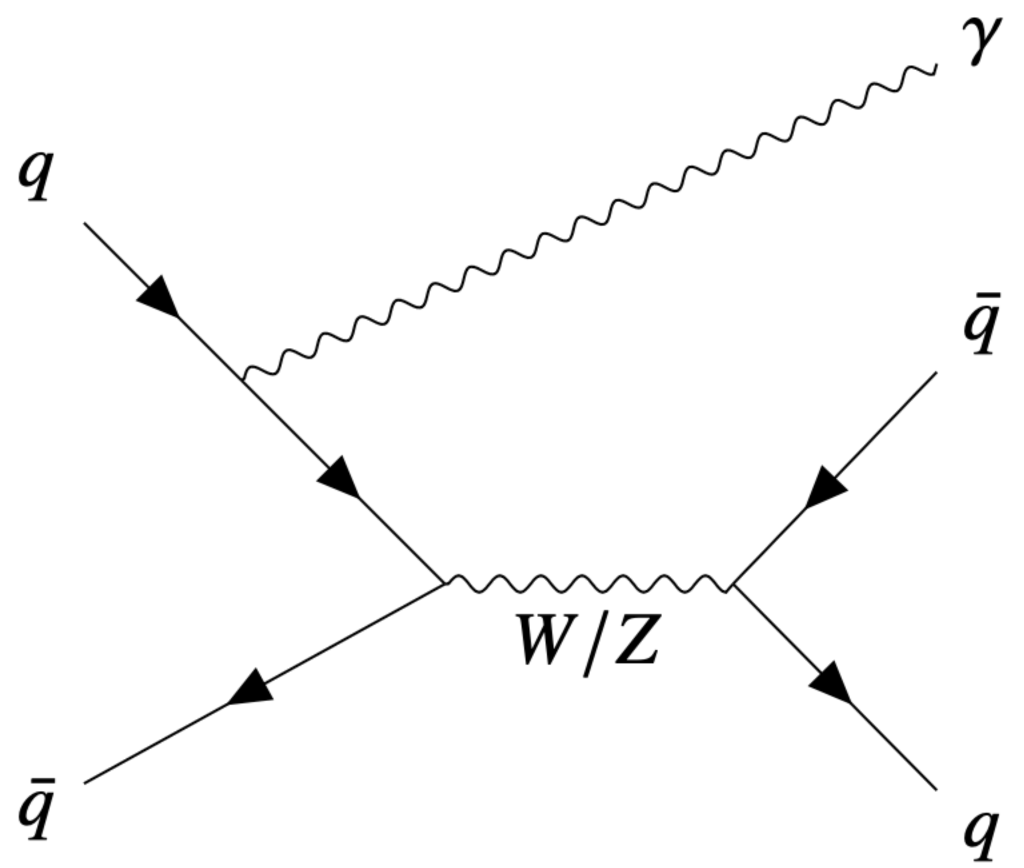
- Backgrounds from $\gamma + V$ are **modelled using MC** simulation
- Their normalization and tagging efficiency are calibrated using a dedicated **control regions**

Boosted **dijet+ISR γ**



Developing regions based on the **centrality of the γ** and the D_2^{DDT} **Category**

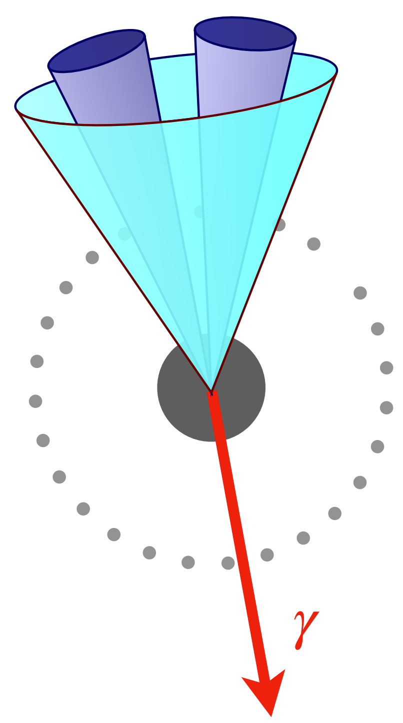




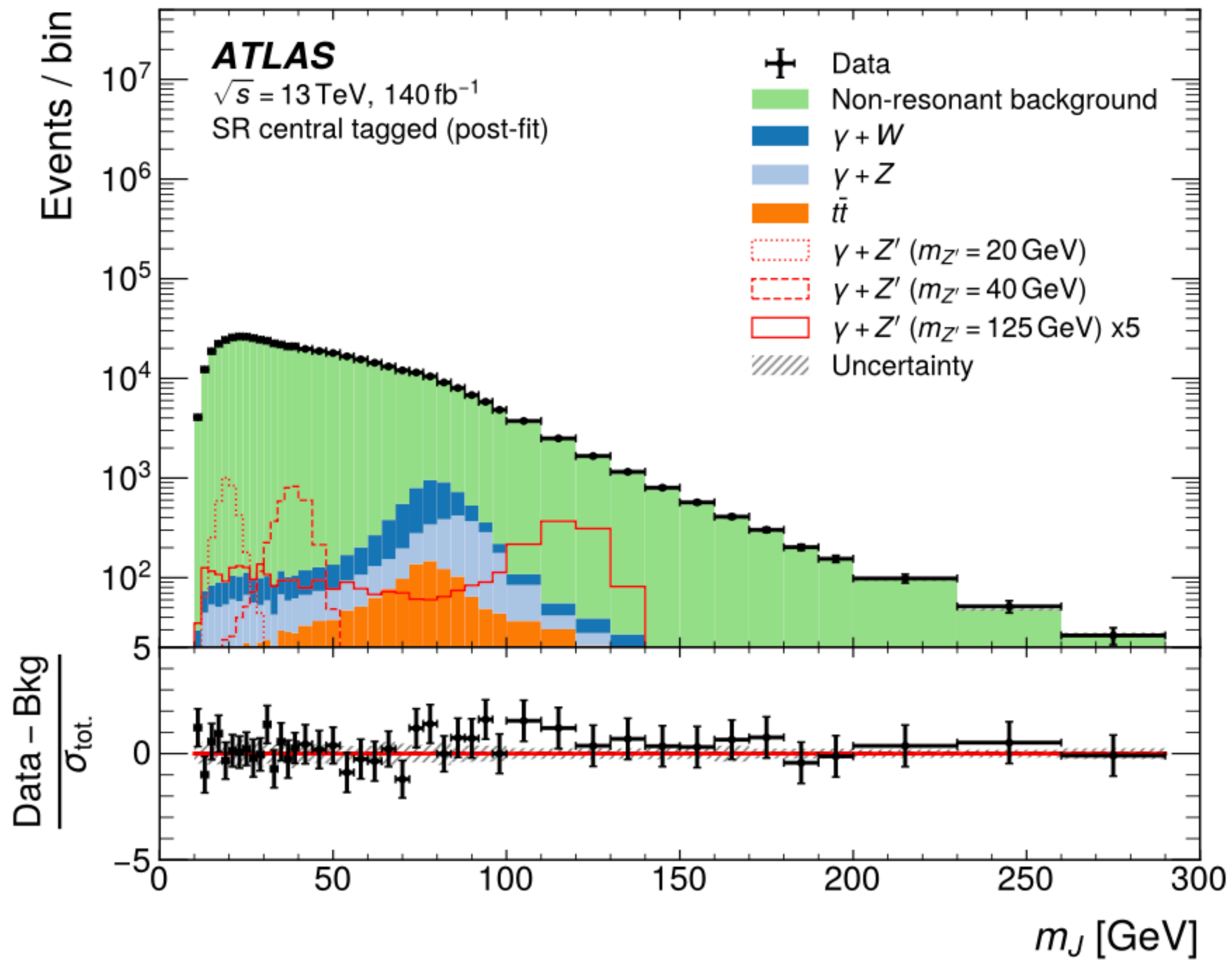
Region	**Photon Region**	D_2^{DDT} **Tag Category**
Signal Region (SR)	$\lvert\eta_\gamma\rvert \leq 1.3$ (Central)	Tagged ($D_2^{\mathrm{DDT}} < 0$)
Control Region 1 (CR1)	$\lvert\eta_\gamma\rvert > 1.3$ (Forward)	Tagged
Control Region 2 (CR2)	$\lvert\eta_\gamma\rvert \leq 1.3$ (Central)	Anti-tagged ($D_2^{\mathrm{DDT}} \geq 0$)
Control Region 3 (CR3)	$\lvert\eta_\gamma\rvert > 1.3$ (Forward)	Anti-tagged

- Backgrounds from $\gamma + V$ are **modelled using MC** simulation
- Their normalization and tagging efficiency are calibrated using a dedicated **control regions**

Boosted dijet+ISR γ

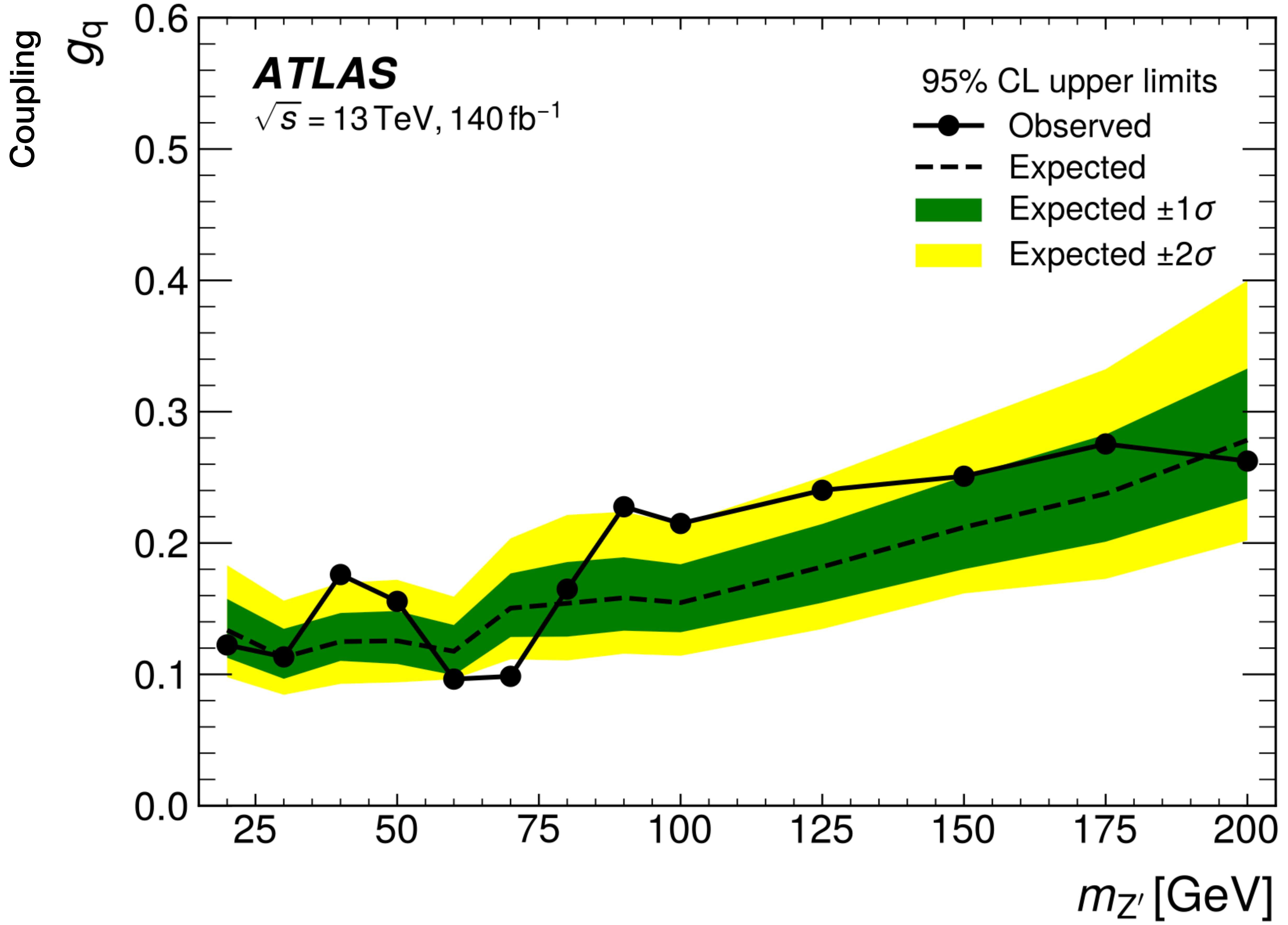


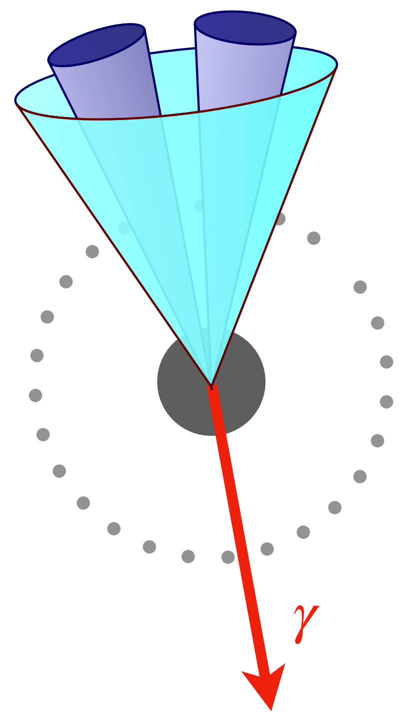
No significant excess is observed in the invariant **mass of the large jet**



Boosted **dijet+ISR** γ

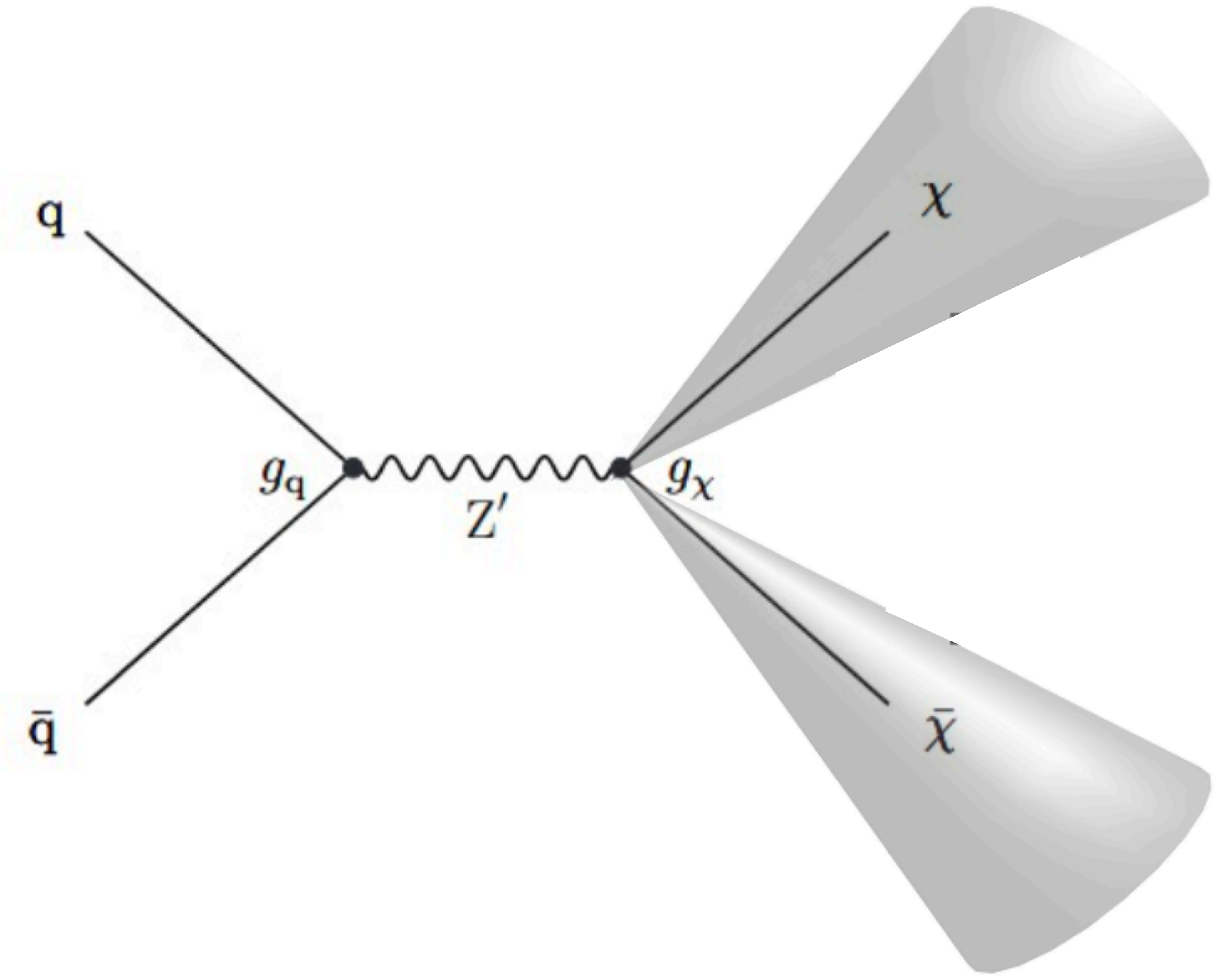
Exclusion limit on the **coupling g_q up to 0.1** for the $m_{Z'} < 100$ GeV

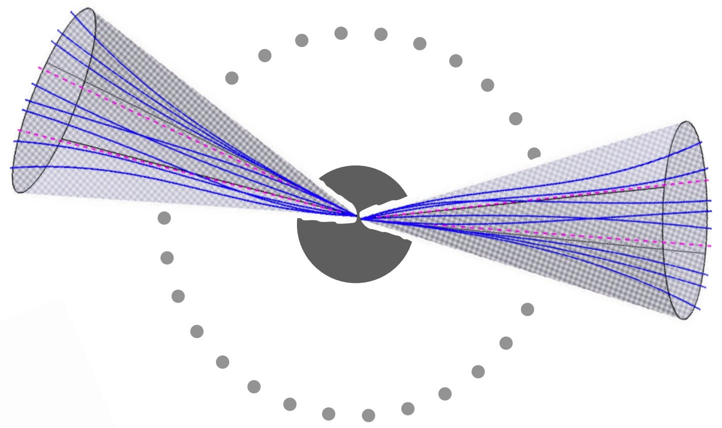


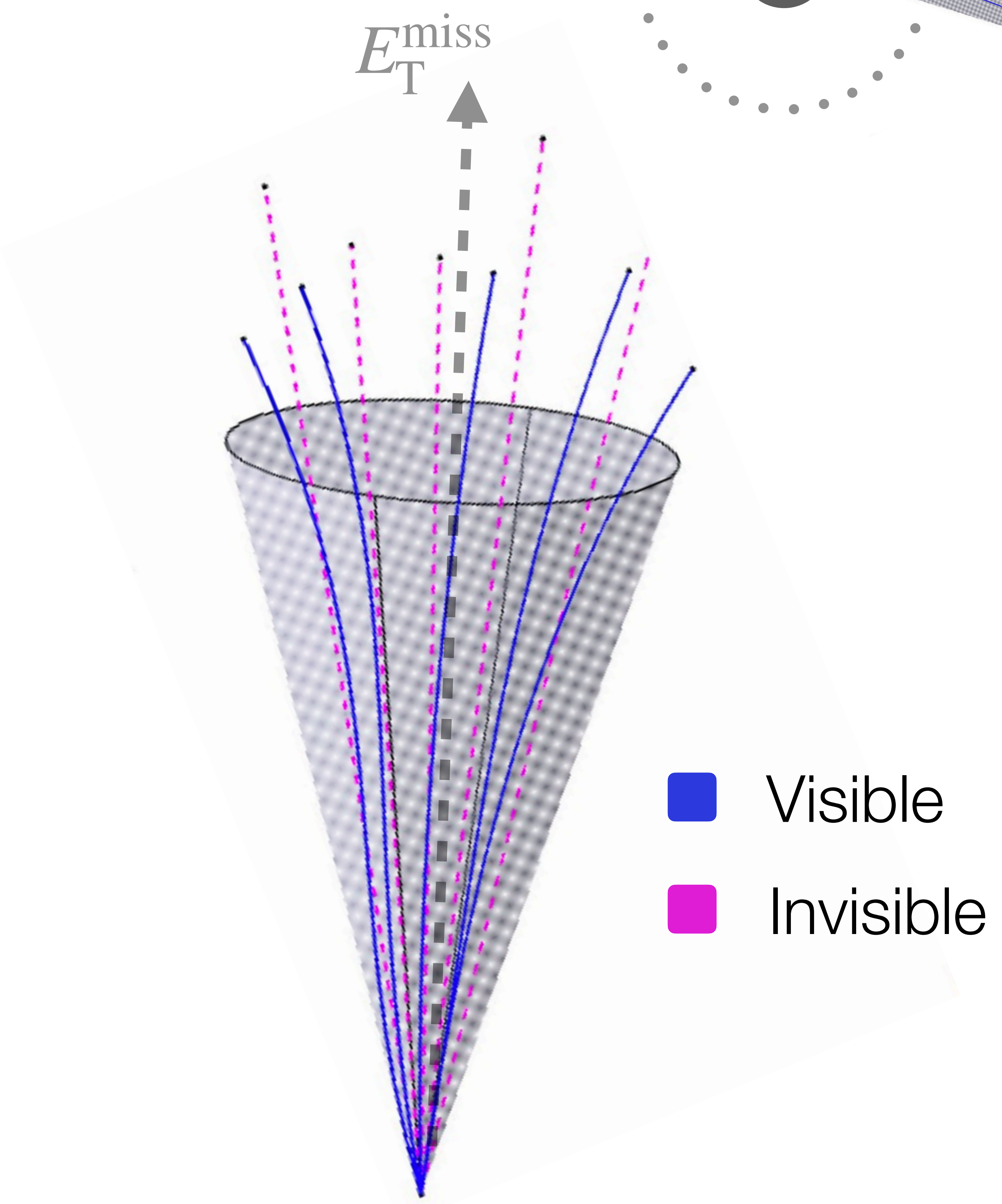


arXiv:2408.00049

Semi-Visible **Jets**

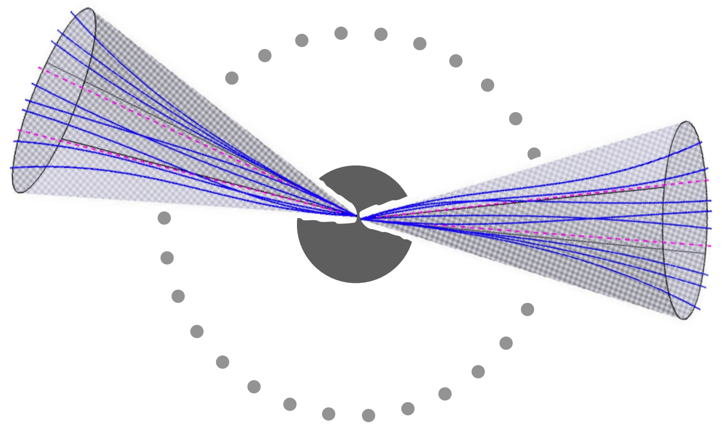


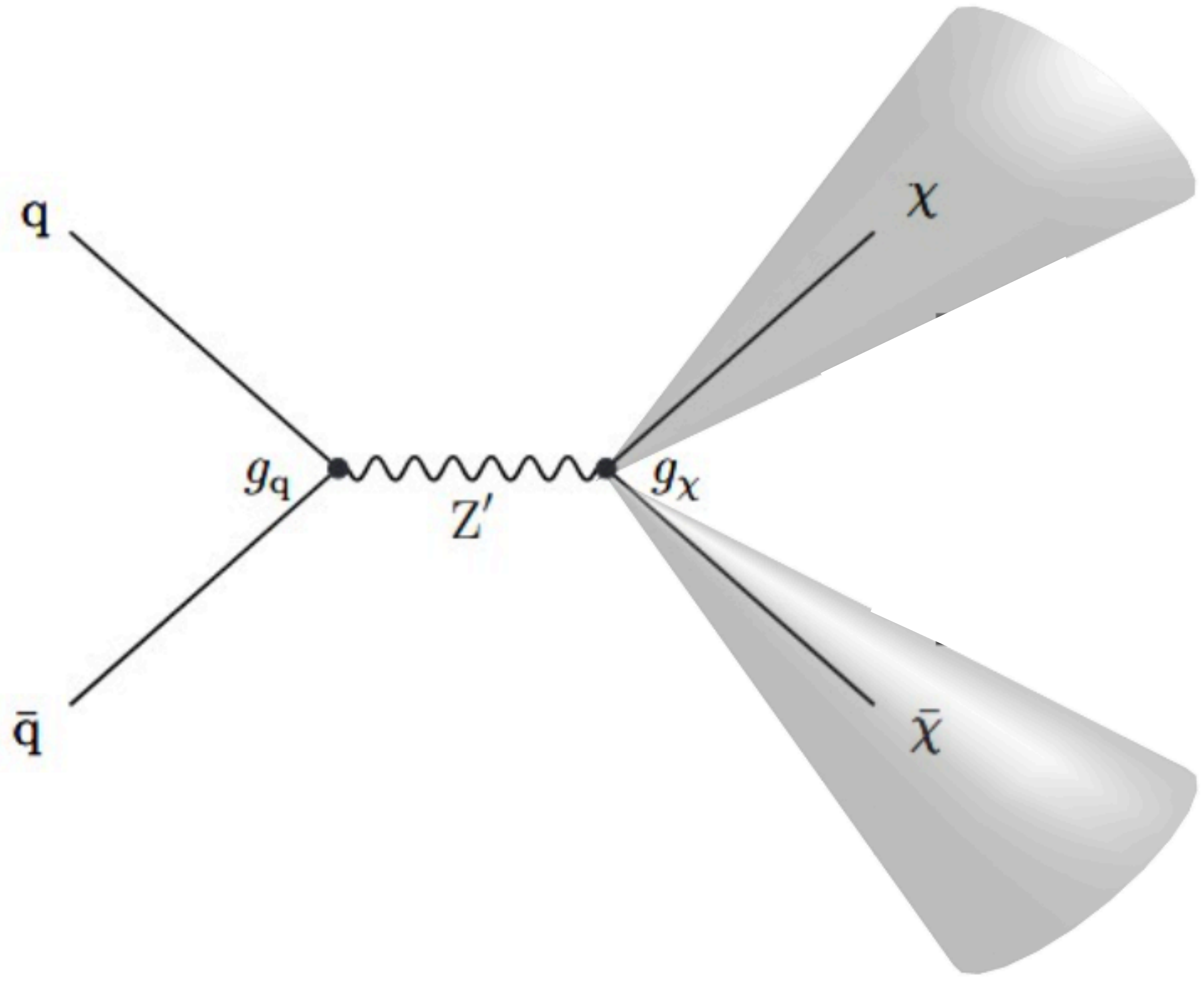


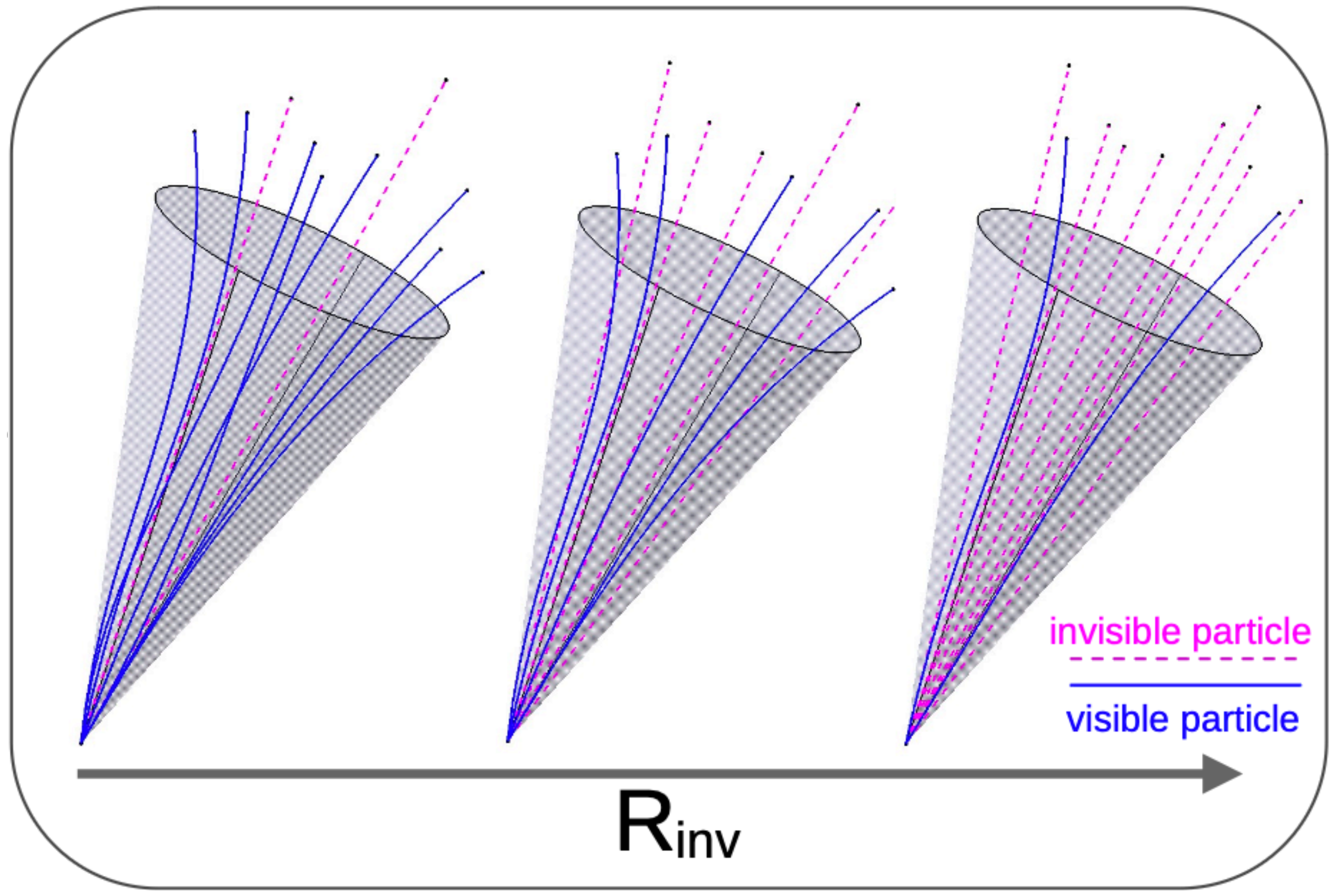


- **Resonant** production of a **heavy Z'** mediator via $pp \to Z' \to \chi_d \chi_d$
- High mass $m_{Z'}$ from **2 to 5 TeV**
- Each χ_d hadronizes into a **dark shower** with **visible** and **invisible** components

Semi-Visible **Jets**

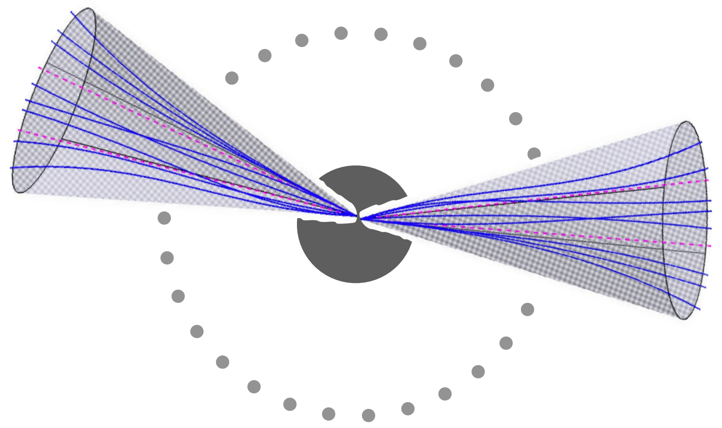


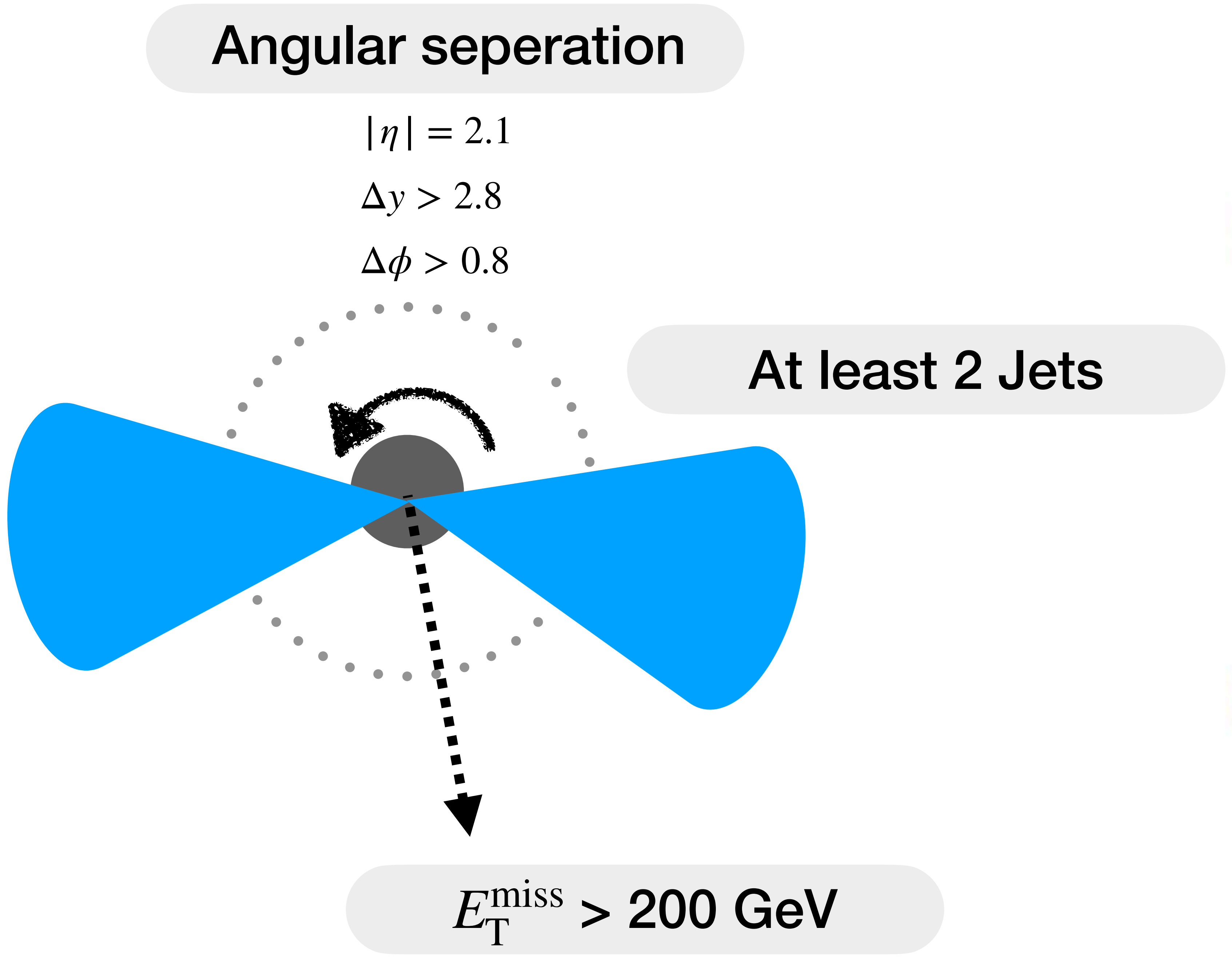


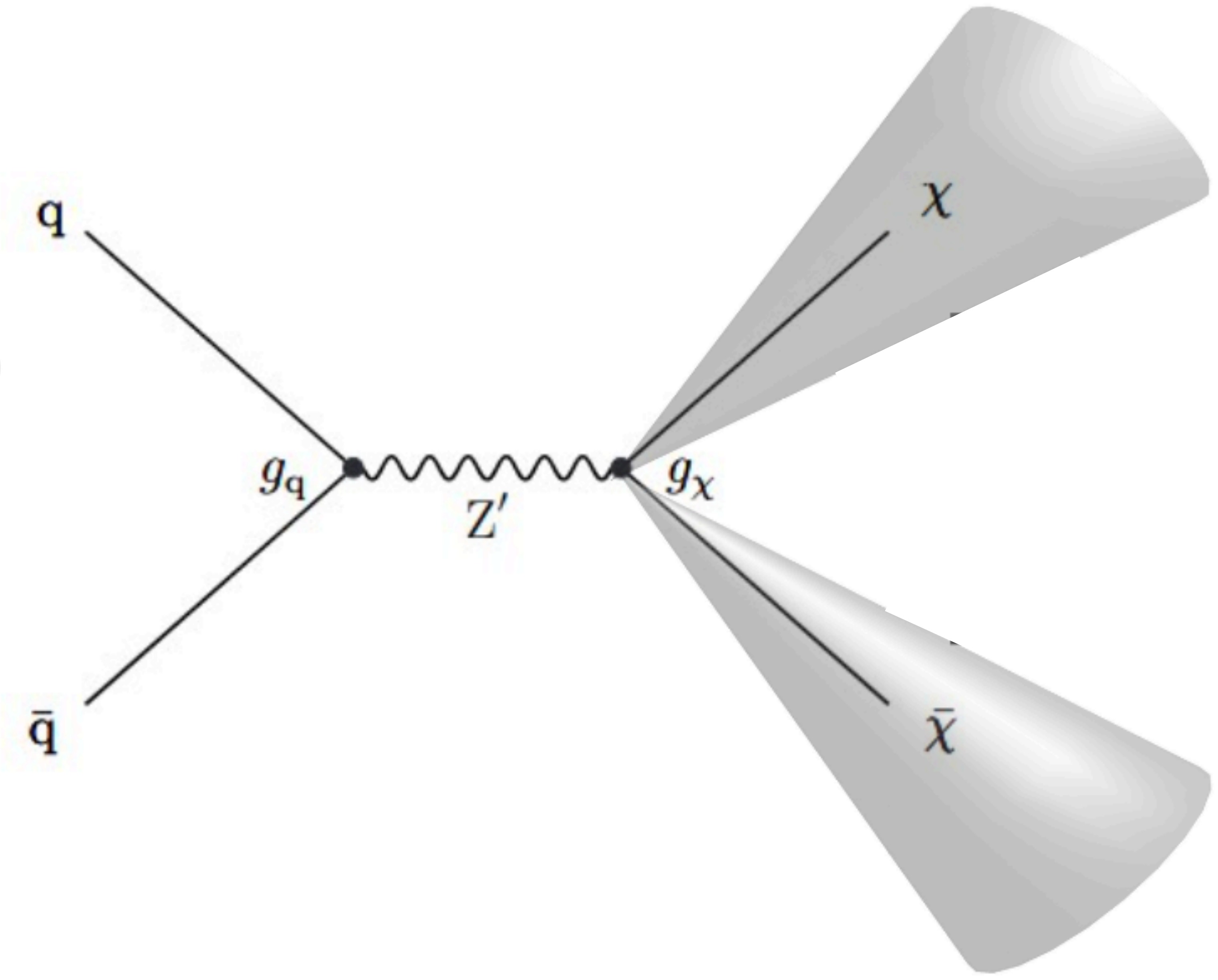


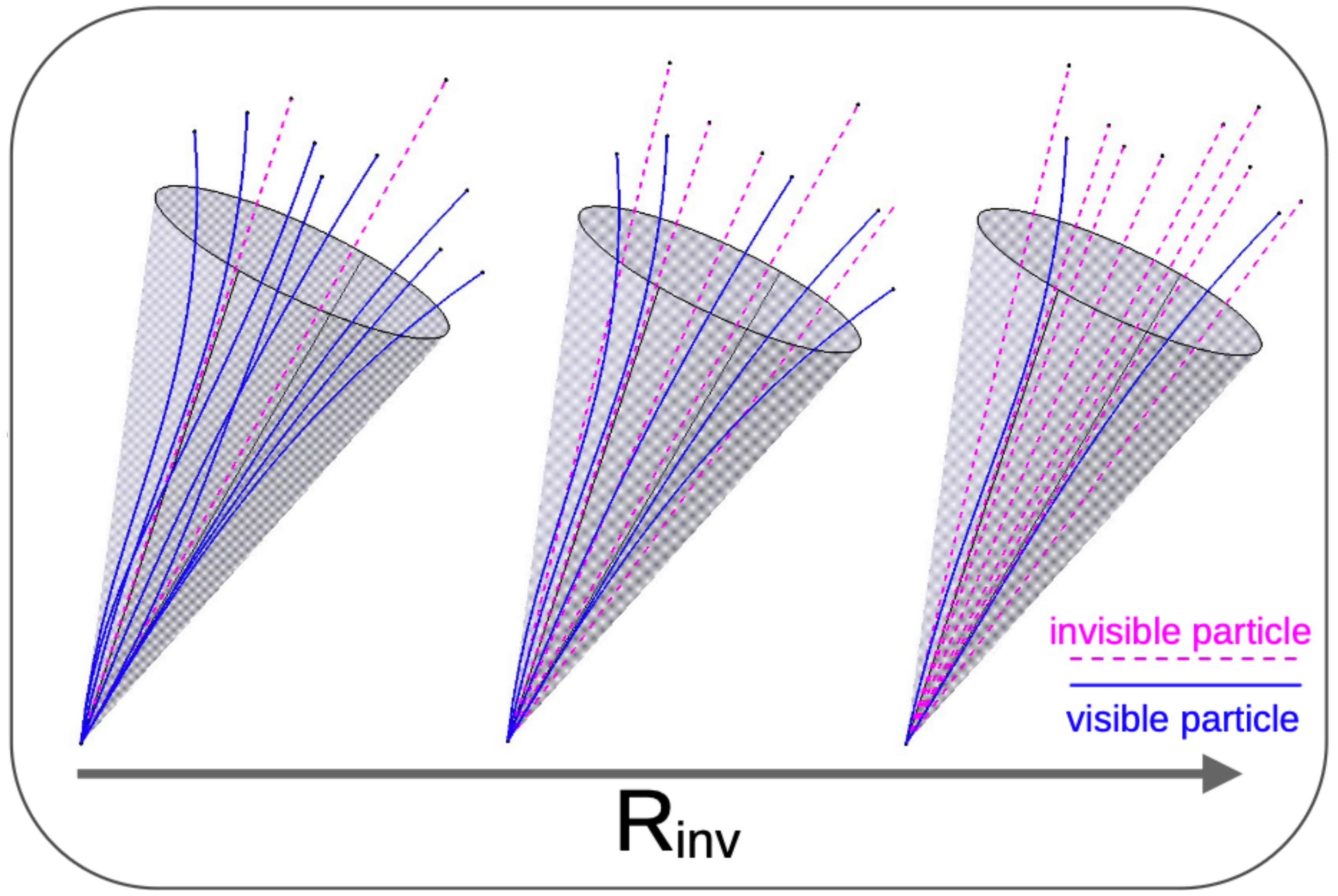
- **Resonant** production of a **heavy Z'** mediator via $pp \to Z' \to \chi_d \chi_d$
- High mass $m_{Z'} \in$ **2.0 to 3.0 TeV**
- Each χ_d hadronizes into a **dark shower** with **visible** and **invisible** components
- Invisible fraction controlled by **parameter** R_{inv}

Semi-Visible **Jets**









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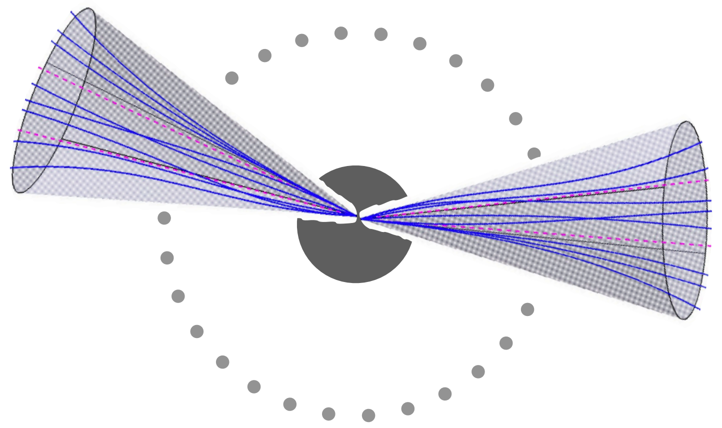
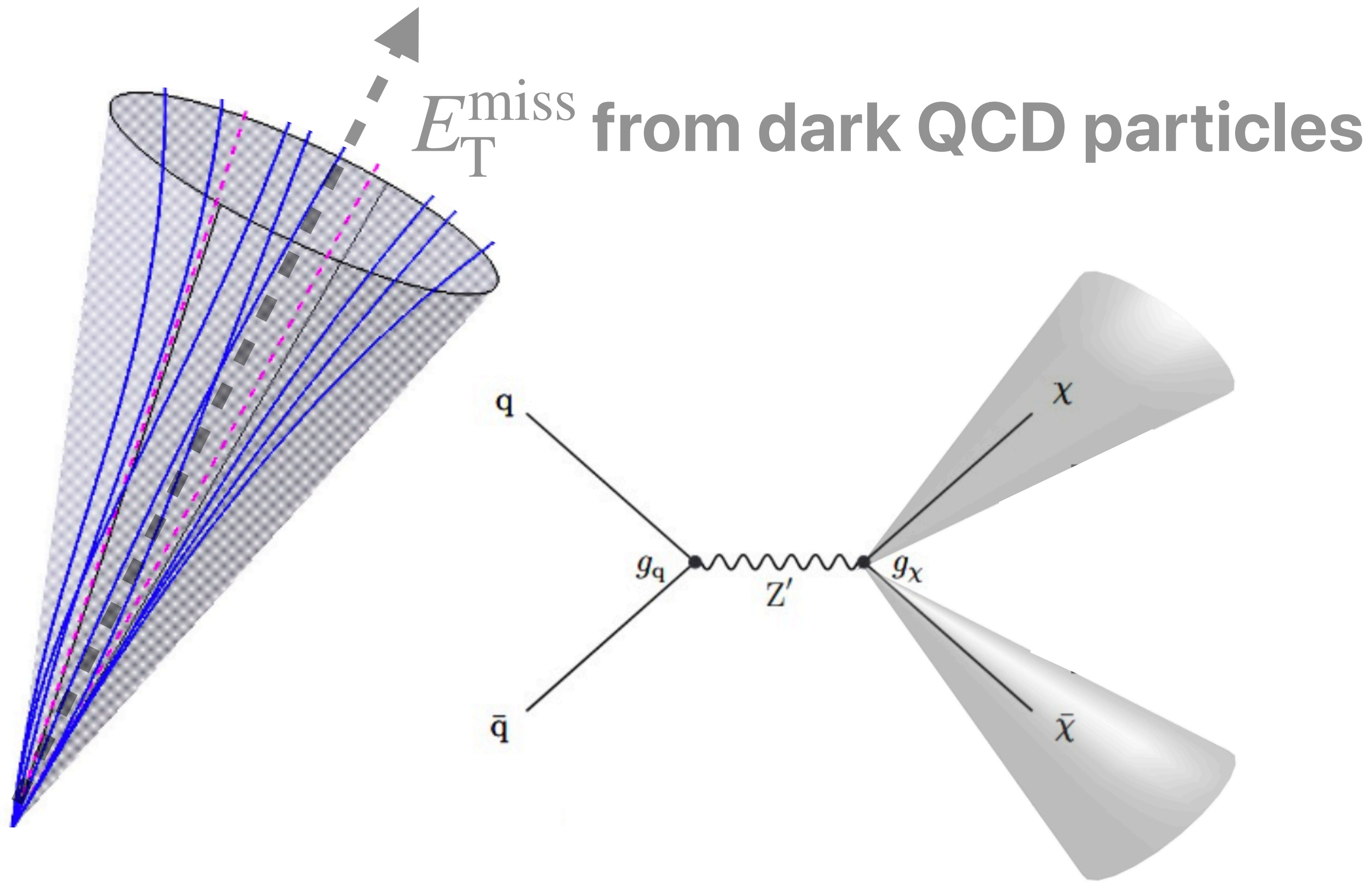
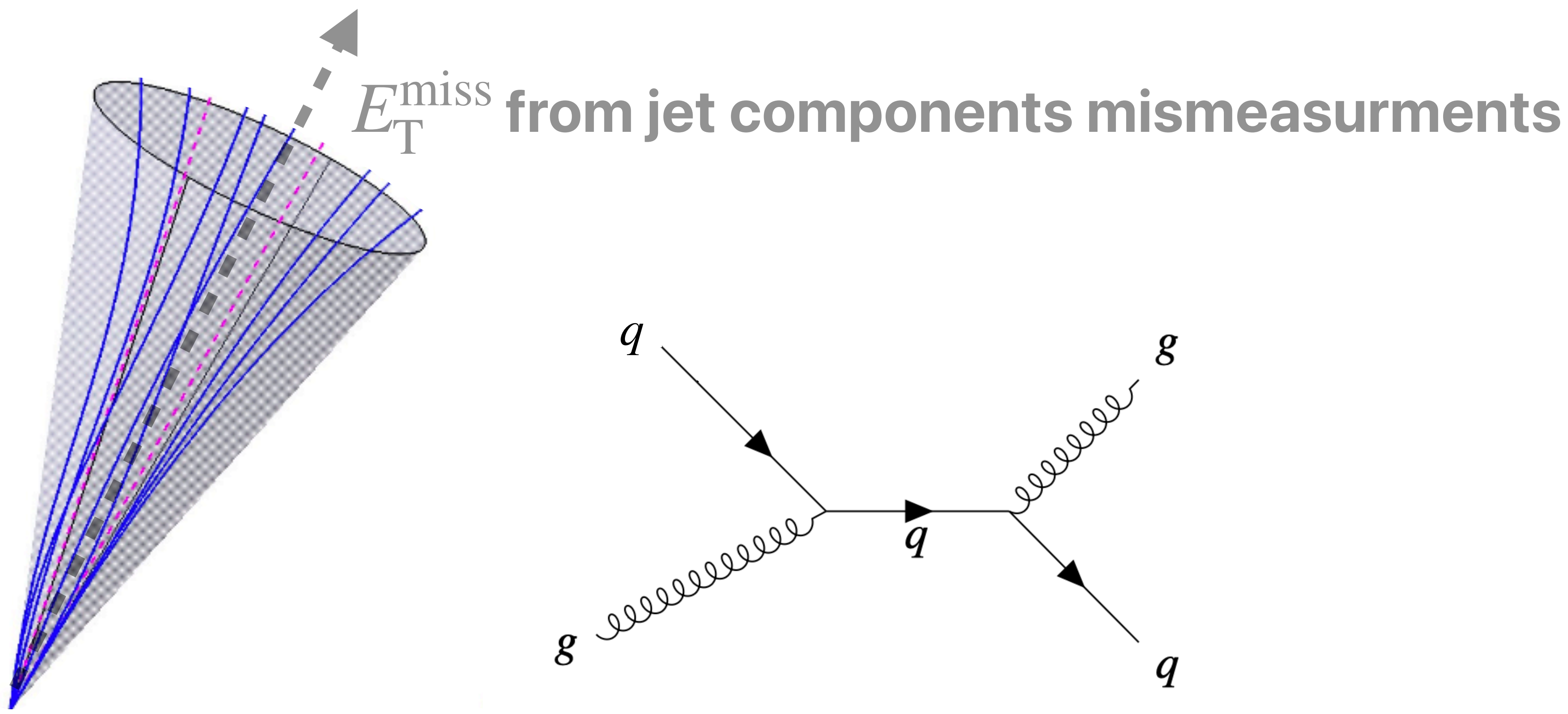


Signal

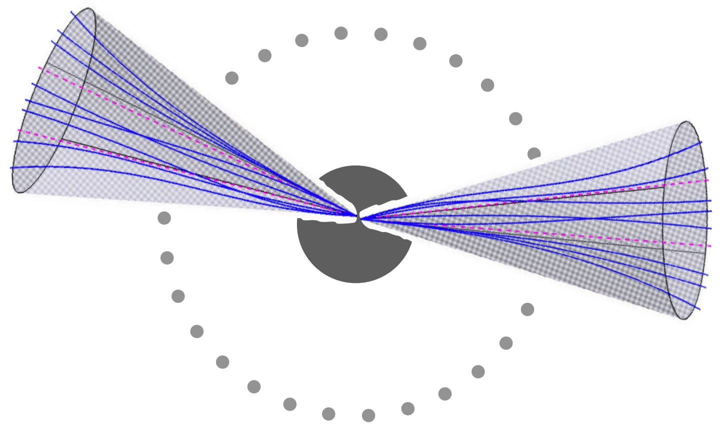


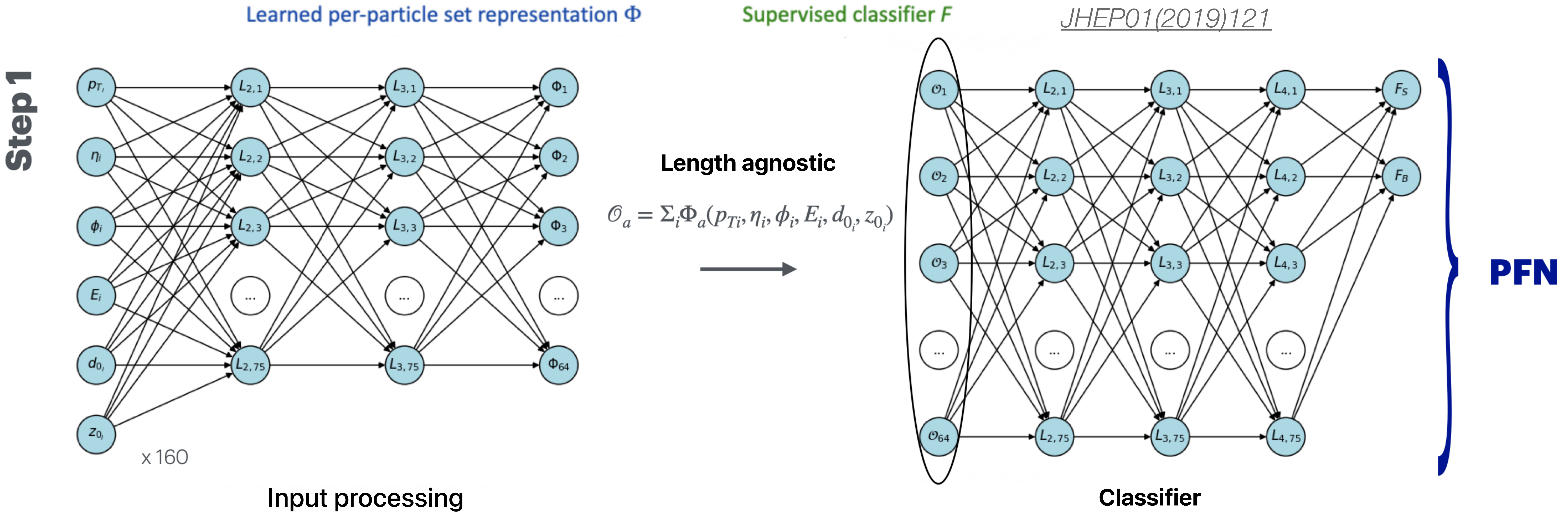
Background (QCD)



- Jet mismeasurements → **fake aligned E_T^{miss}** mimicking signal topology
- Poor MC modelling for QCD **motivates data driven** background estimation

Semi-Visible **Jets**

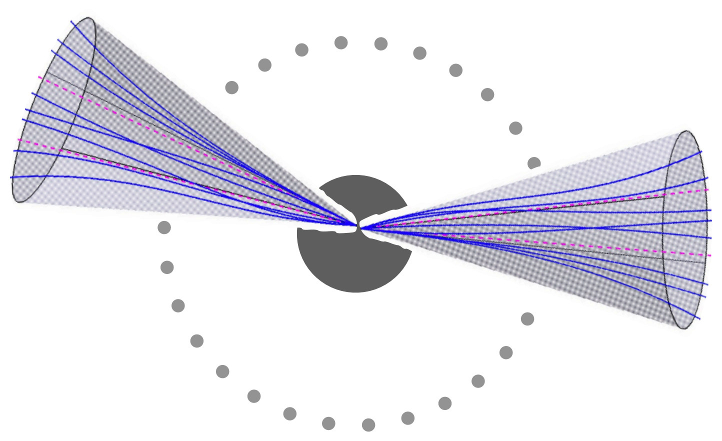


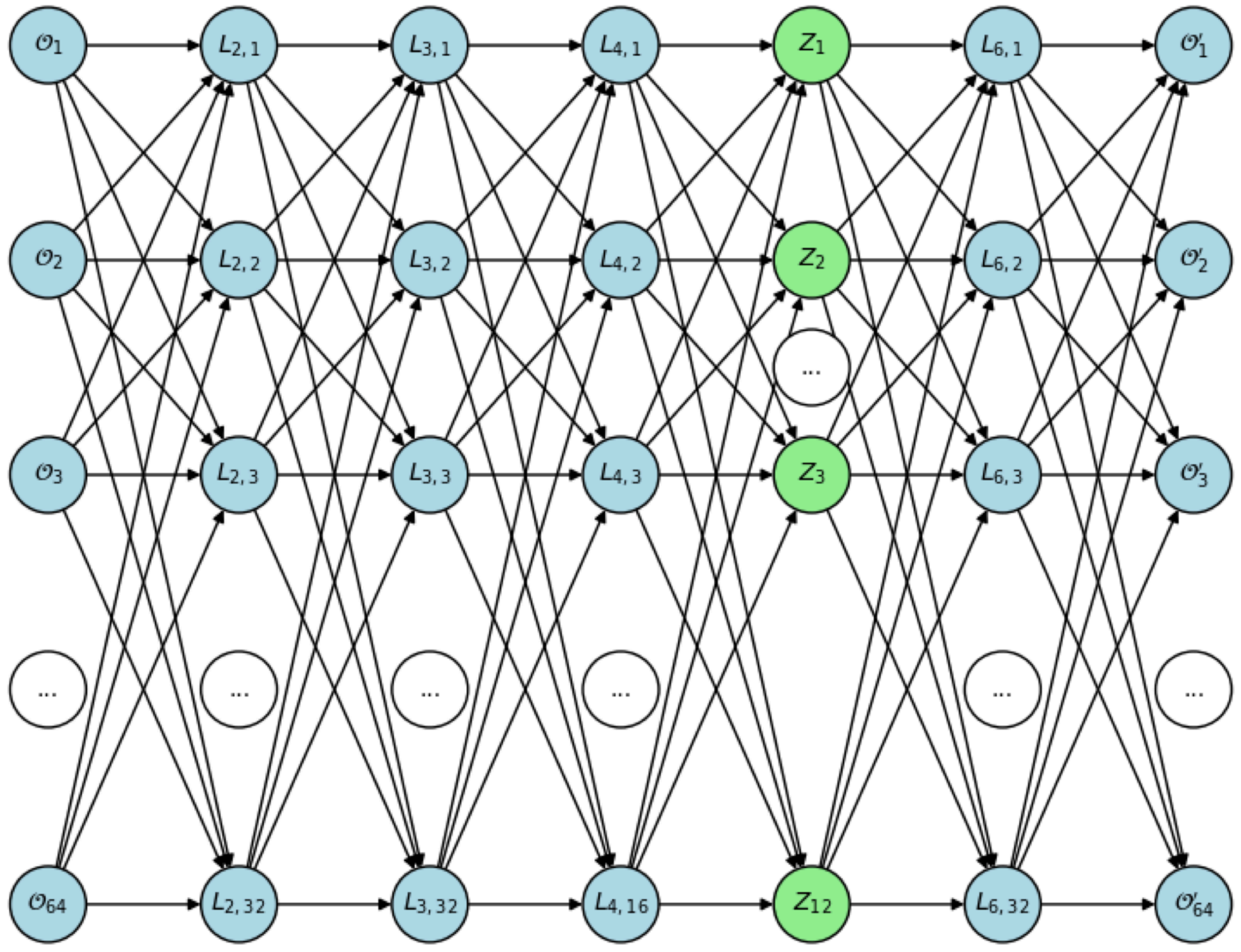


Particle Flow Network (PFN) – Supervised Classifier

- **Inputs**: Up to 160 leading tracks (80 per jet) using 6 features: $p_T, \eta, \phi, E, d_0, z_0$
- **Goal**: Optimized for semi-visible jets signal vs. QCD background classification
- **Architecture** : An **order and length agnostic classifier** is trained over latent input space to learn the key features of the events

Semi-Visible **Jets**



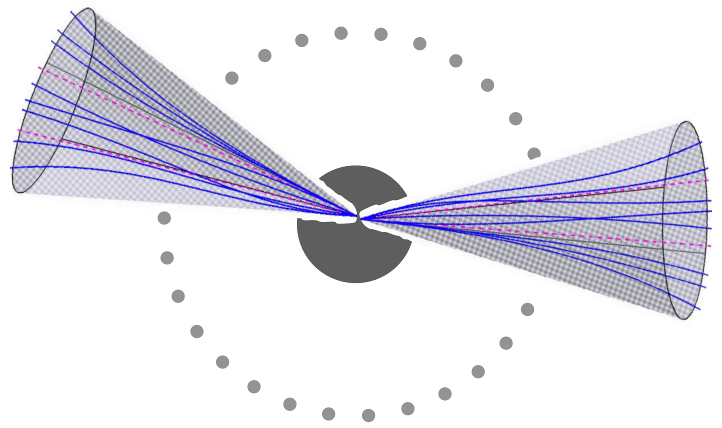


arXiv:2408.17409

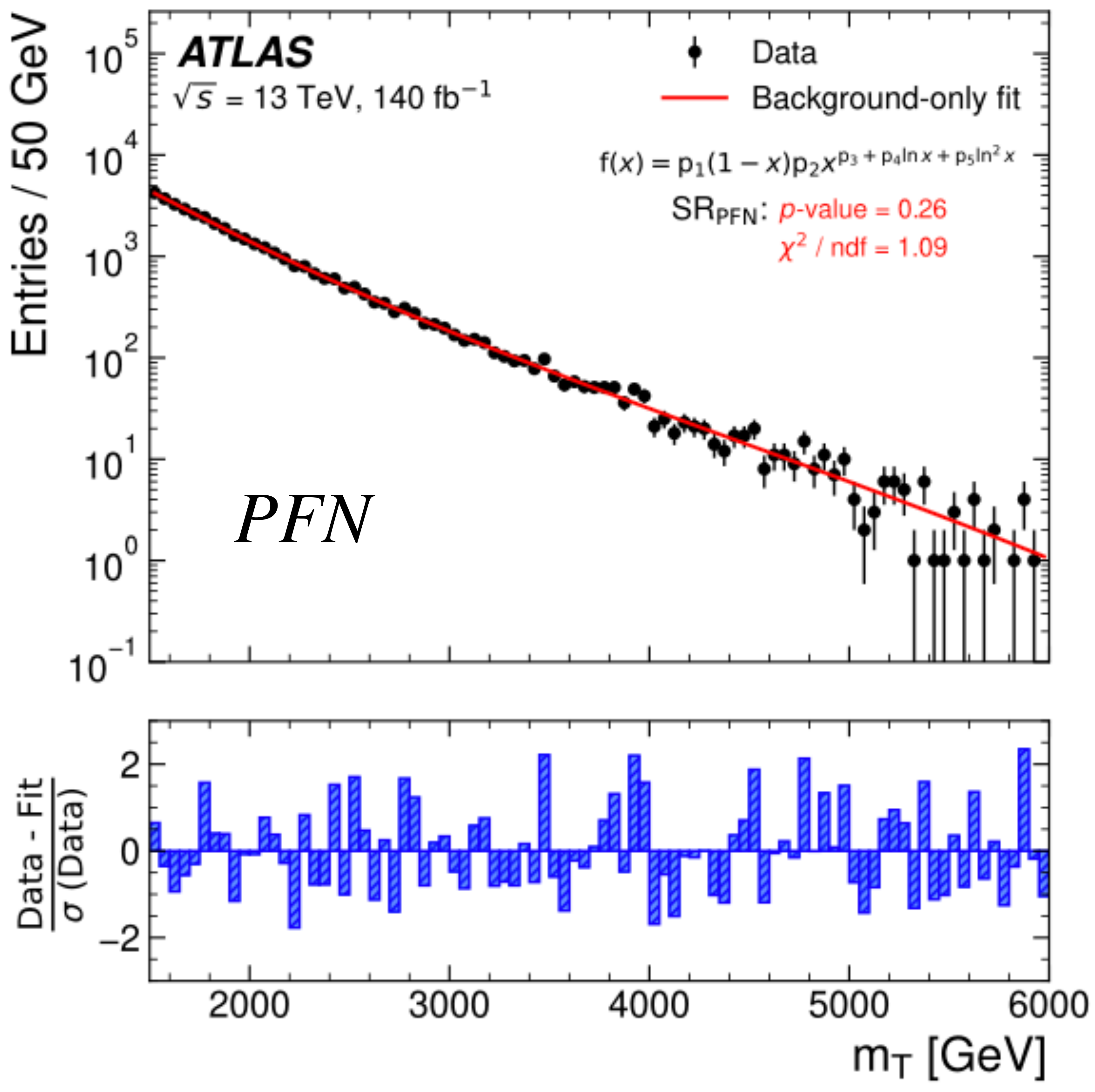
ANTELOPE – Semi-Supervised Anomaly Detection

- **Inputs**: Up to 160 leading tracks (80 per jet) using 6 features: $p_T, \eta, \phi, E, d_0, z_0$
- **Goal**: Generalize to unknown BSM topologies (model independent)
- **Architecture**: a variational auto encoder is trained over the same PFN inputs to check for **any deviations from the SM in data**

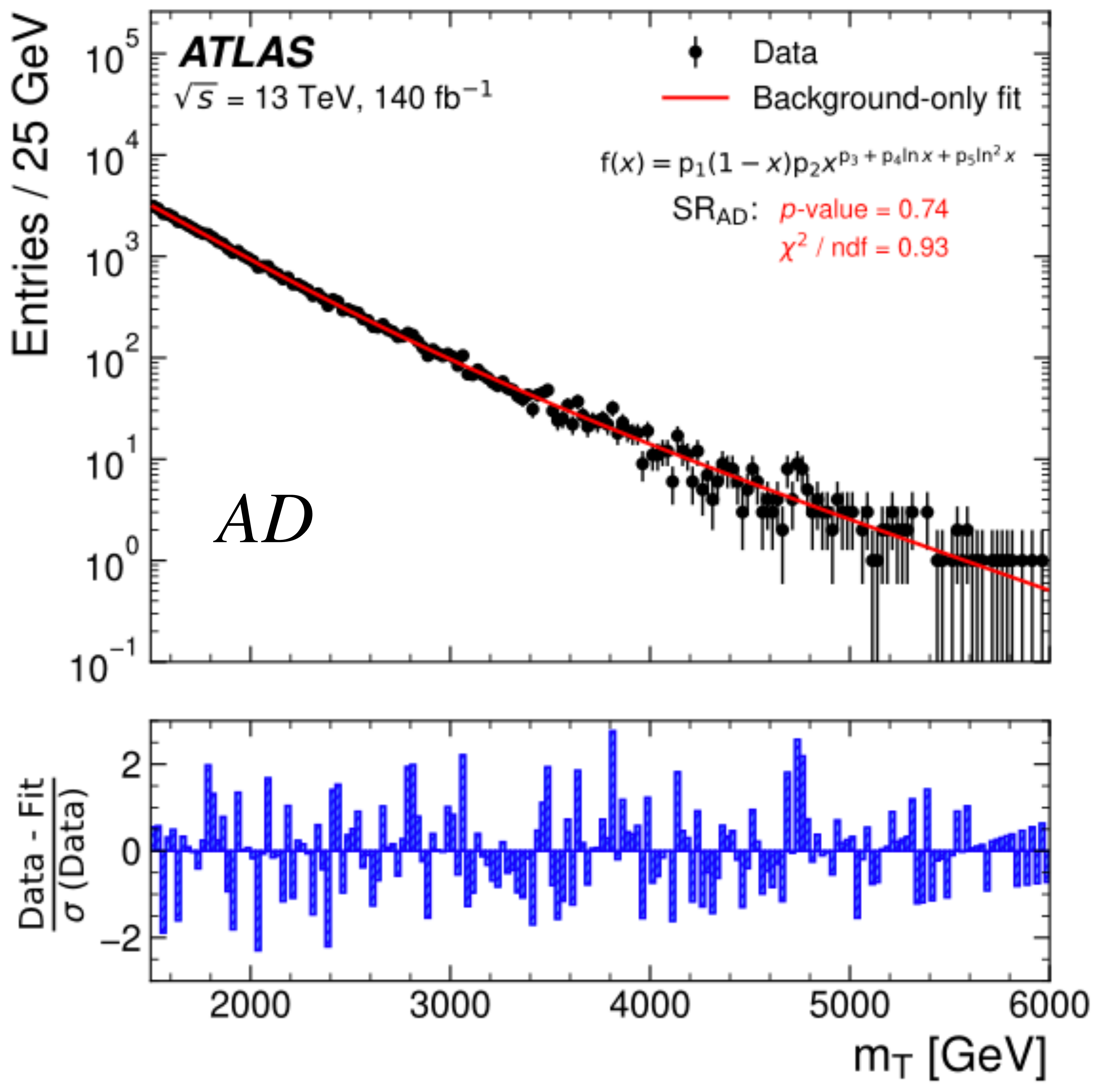
Semi-Visible **Jets**



No significant excess is observed, and **good background-only fit quality** obtained with PFN and ANTELOPE regions



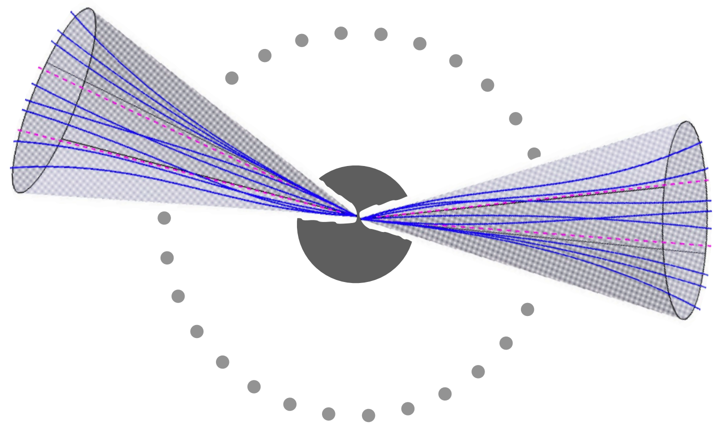
Transverse Mass



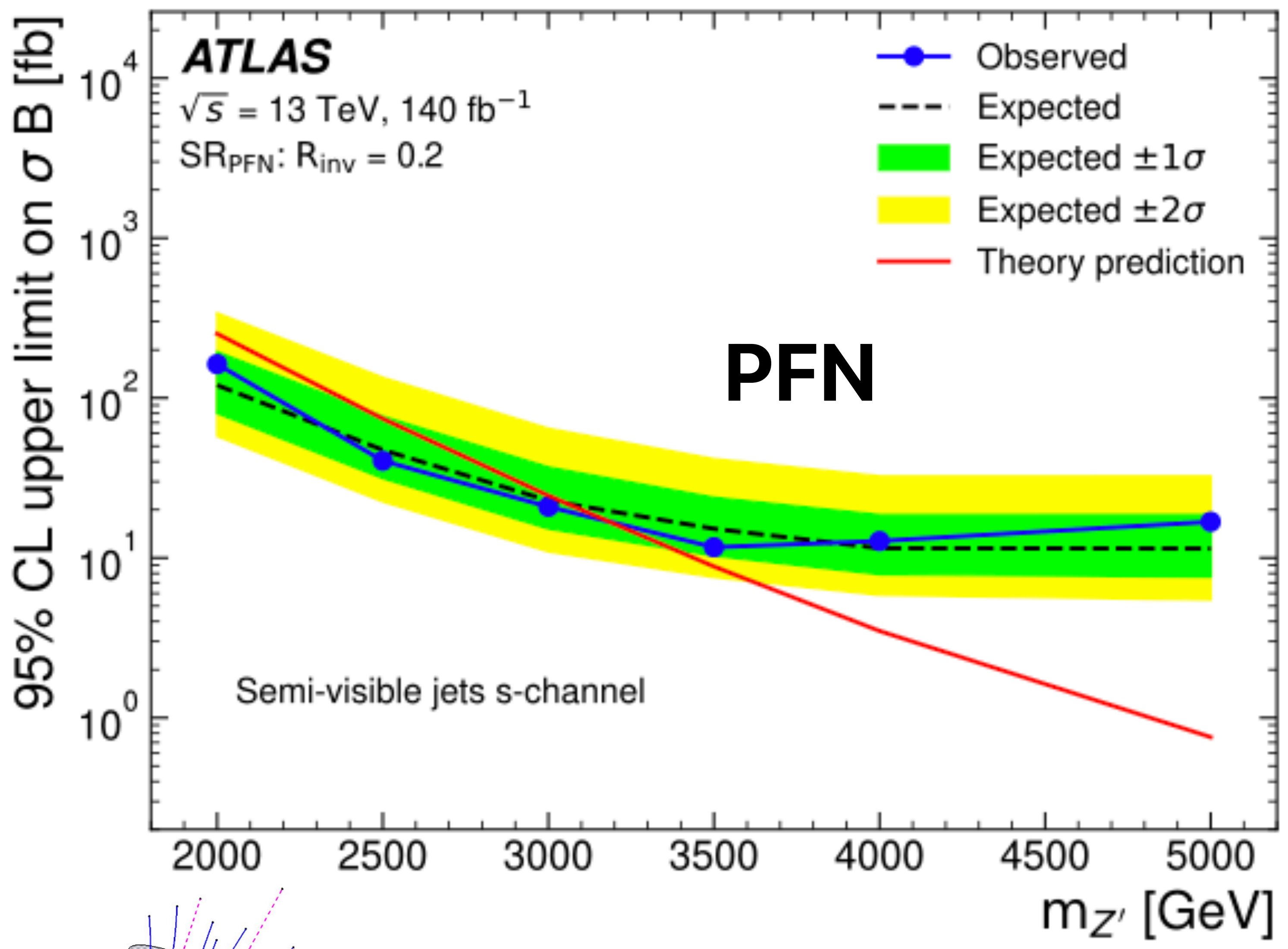
Transverse Mass

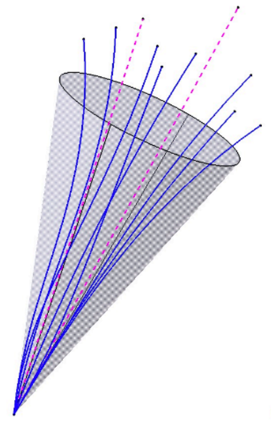
arXiv:2505.01634

Semi-Visible **Jets**



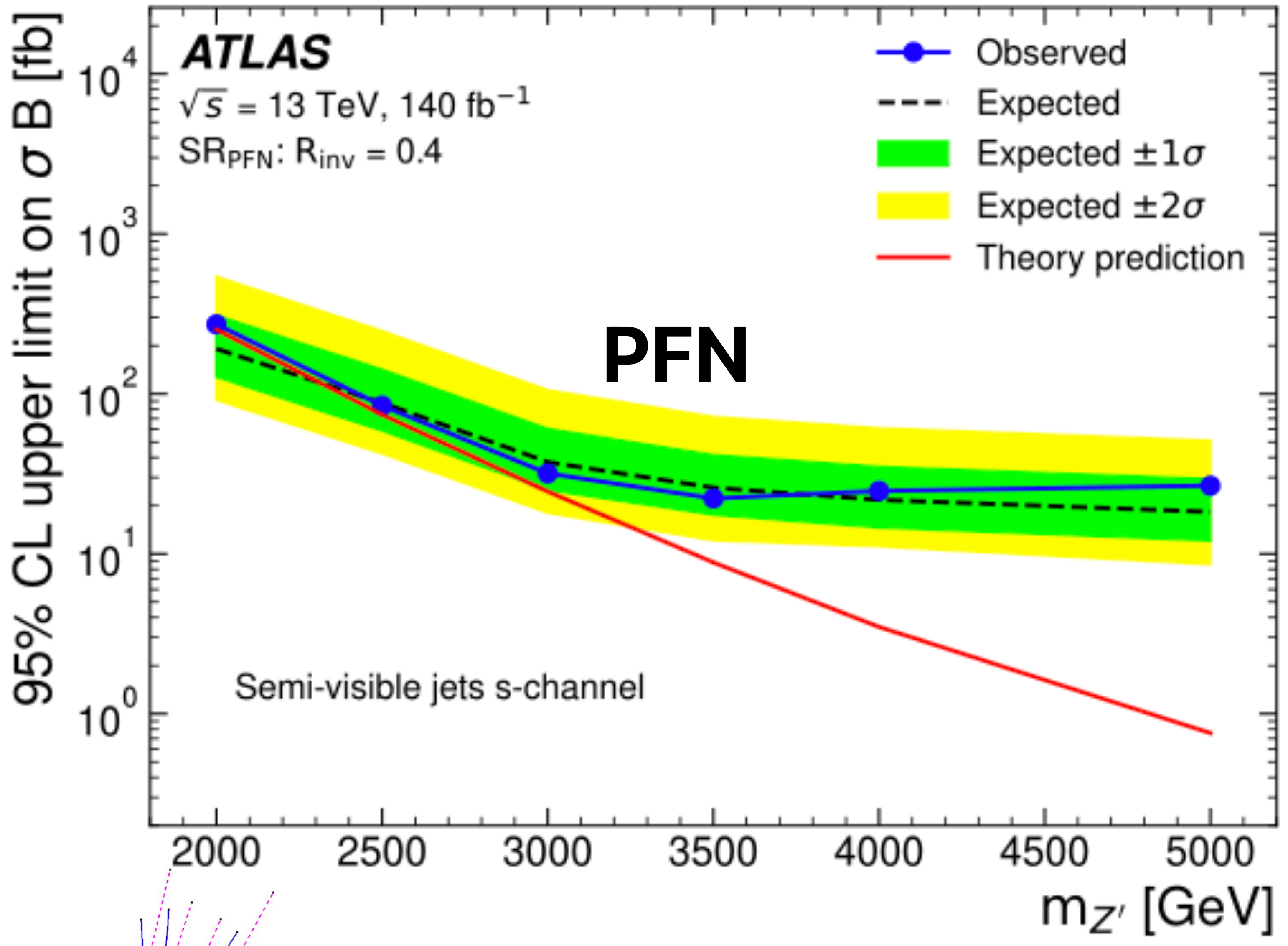
Setting upper-limit on the production **cross section x BR**

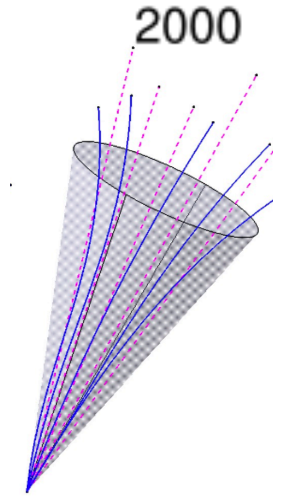




R_{inv} = **0.2**

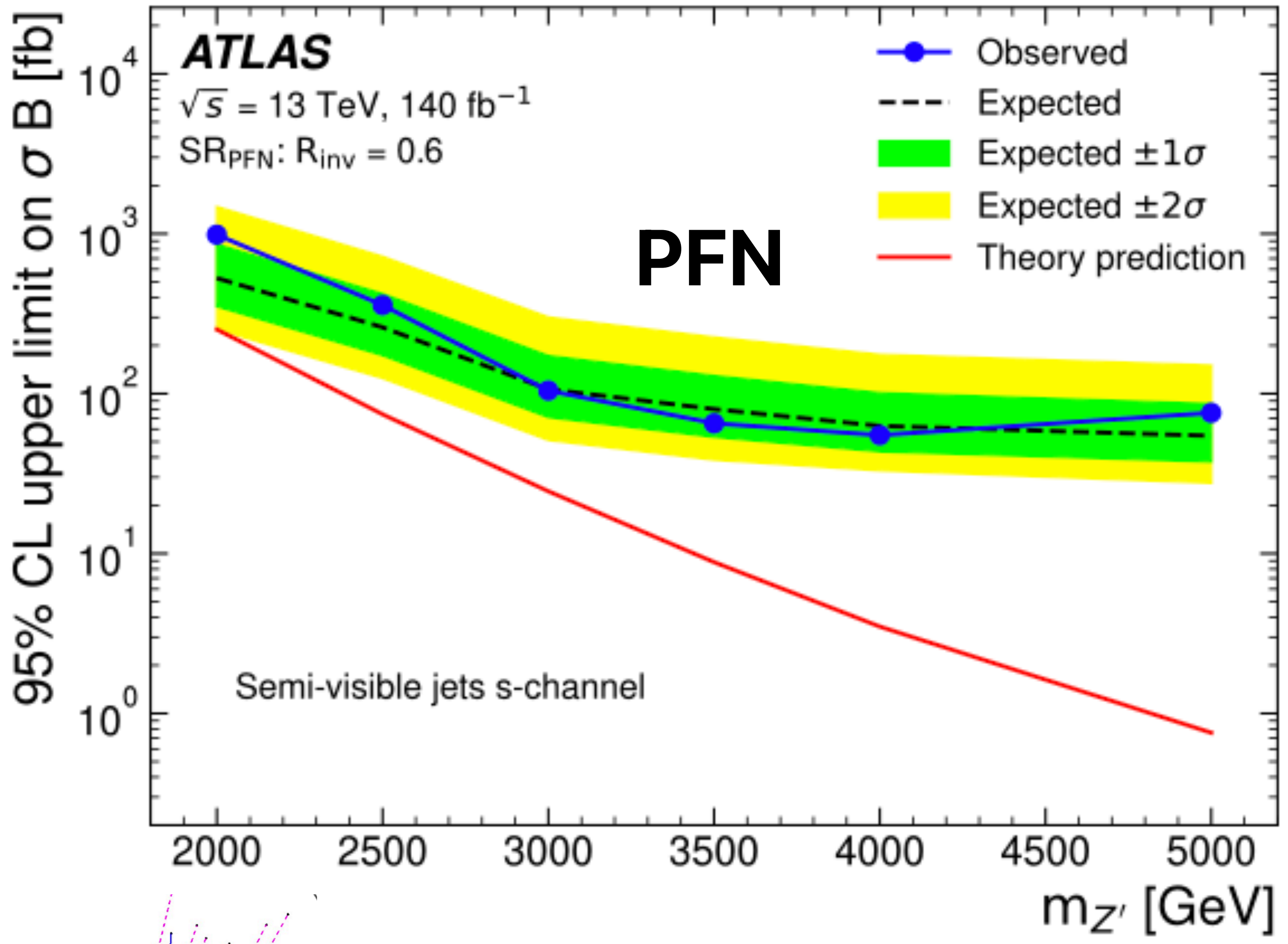
The most stringent limits are achieved here, excluding Z' masses up to ~3.2 TeV

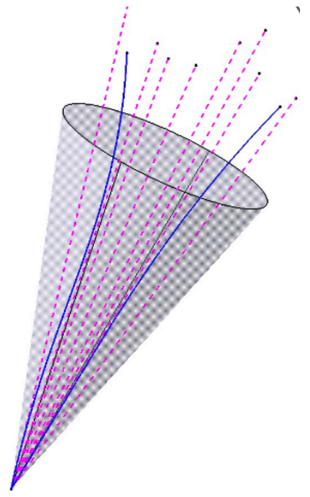




R_{inv} = **0.4**

Sensitivity is moderately reduced, with exclusion limits reaching up to ~2.6 TeV

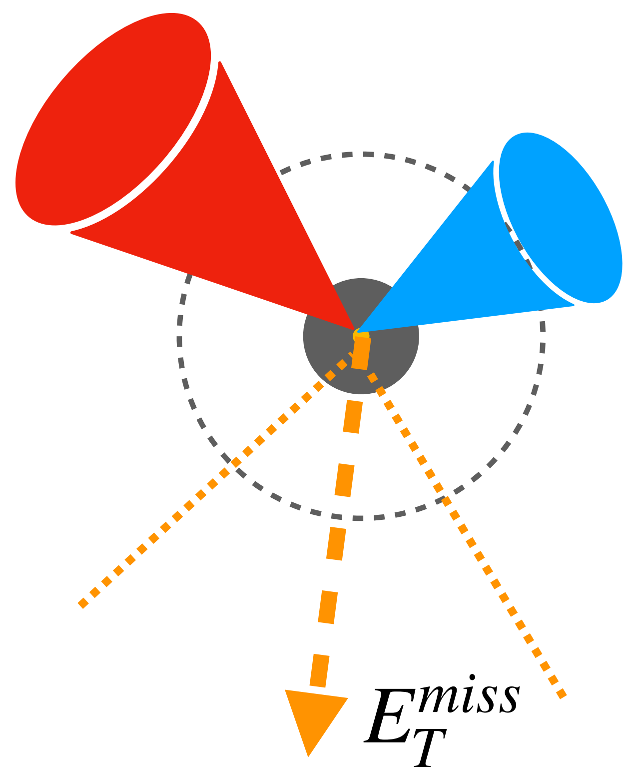


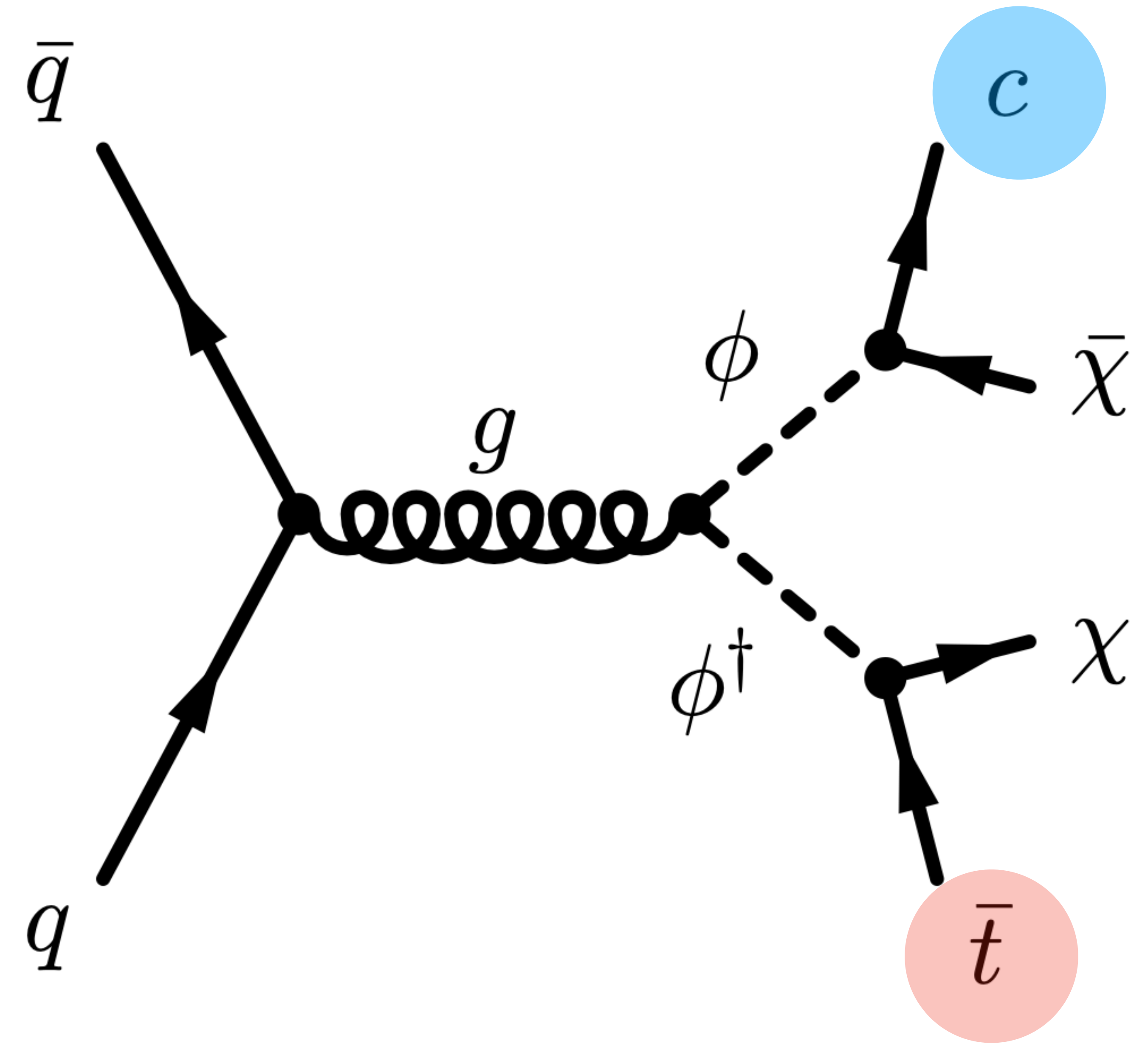


R_{inv} = **0.6**

The weakest limits are obtained reflecting the challenge of detecting highly invisible jet signatures

Dark Matter Flavour Violation

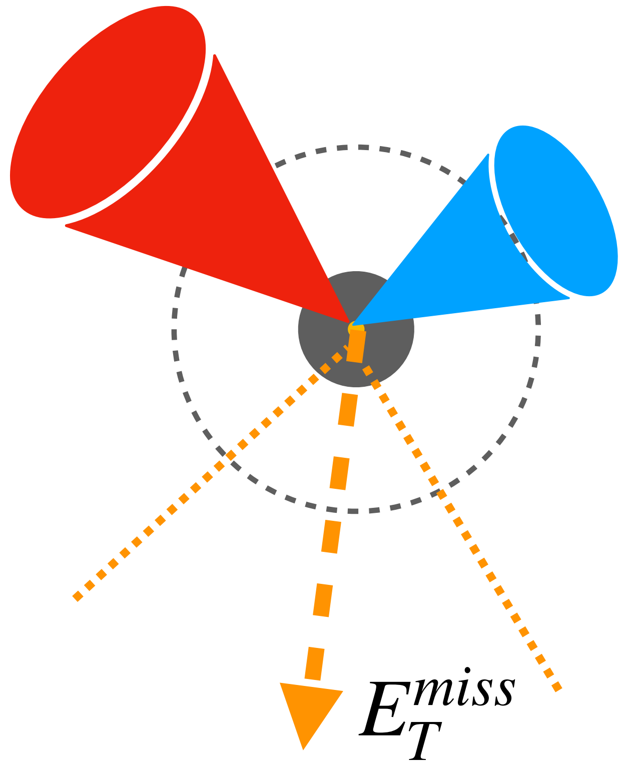


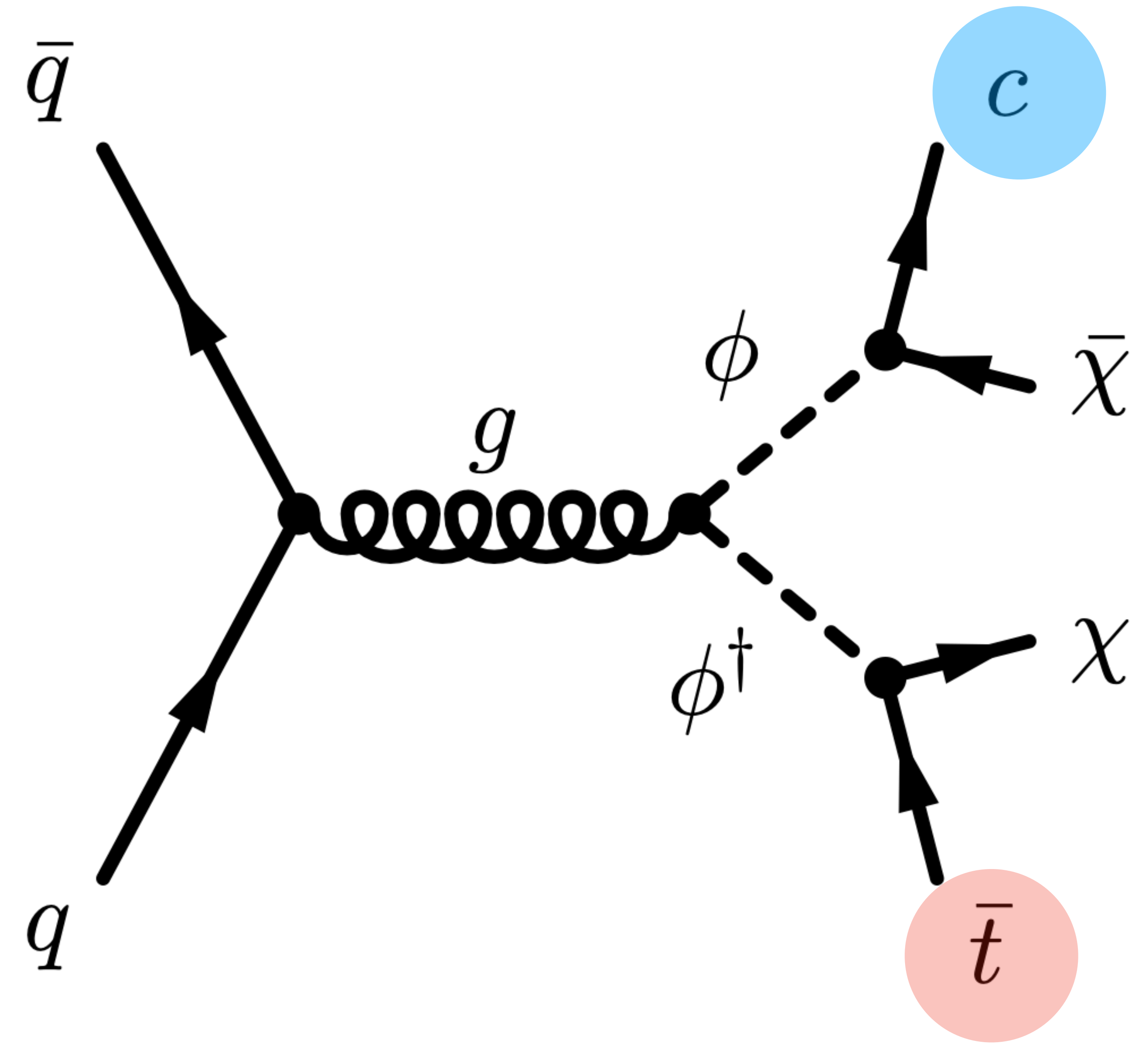


χ_i **Flavoured DM sector** with 3 fermions representing 3 DM flavours χ_1, χ_2, χ_3

ϕ A colour charged **scalar mediator** coupling DM-SM introducing flavour violation

Dark Matter Flavour Violation





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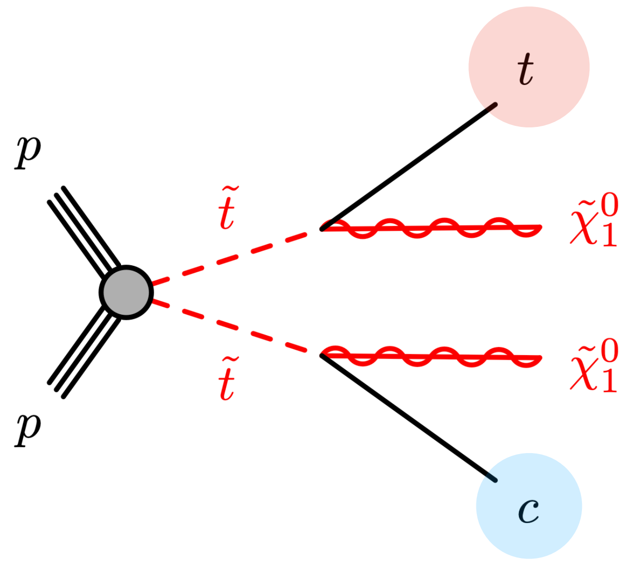
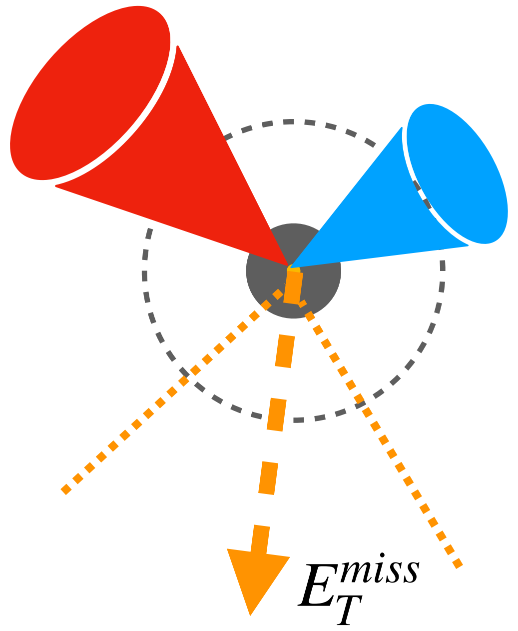


This analysis reuses a **previous SUSY search** with the same **t,c+**$E_{\mathrm{T}}^{\mathrm{miss}}$ finale state

First time at the LHC

JHEP07(2024)250, ATL-PHYS-PUB-2025-010

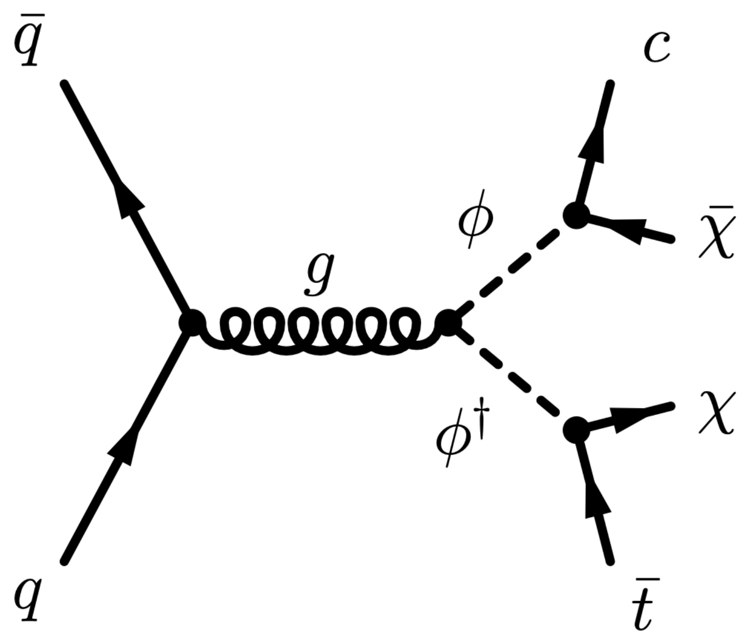
Dark Matter Flavour Violation



Re-interpretation by plugging the new DMFV signal into the SUSY analysis

Dark Matter Signal

~~SUSY Signal~~



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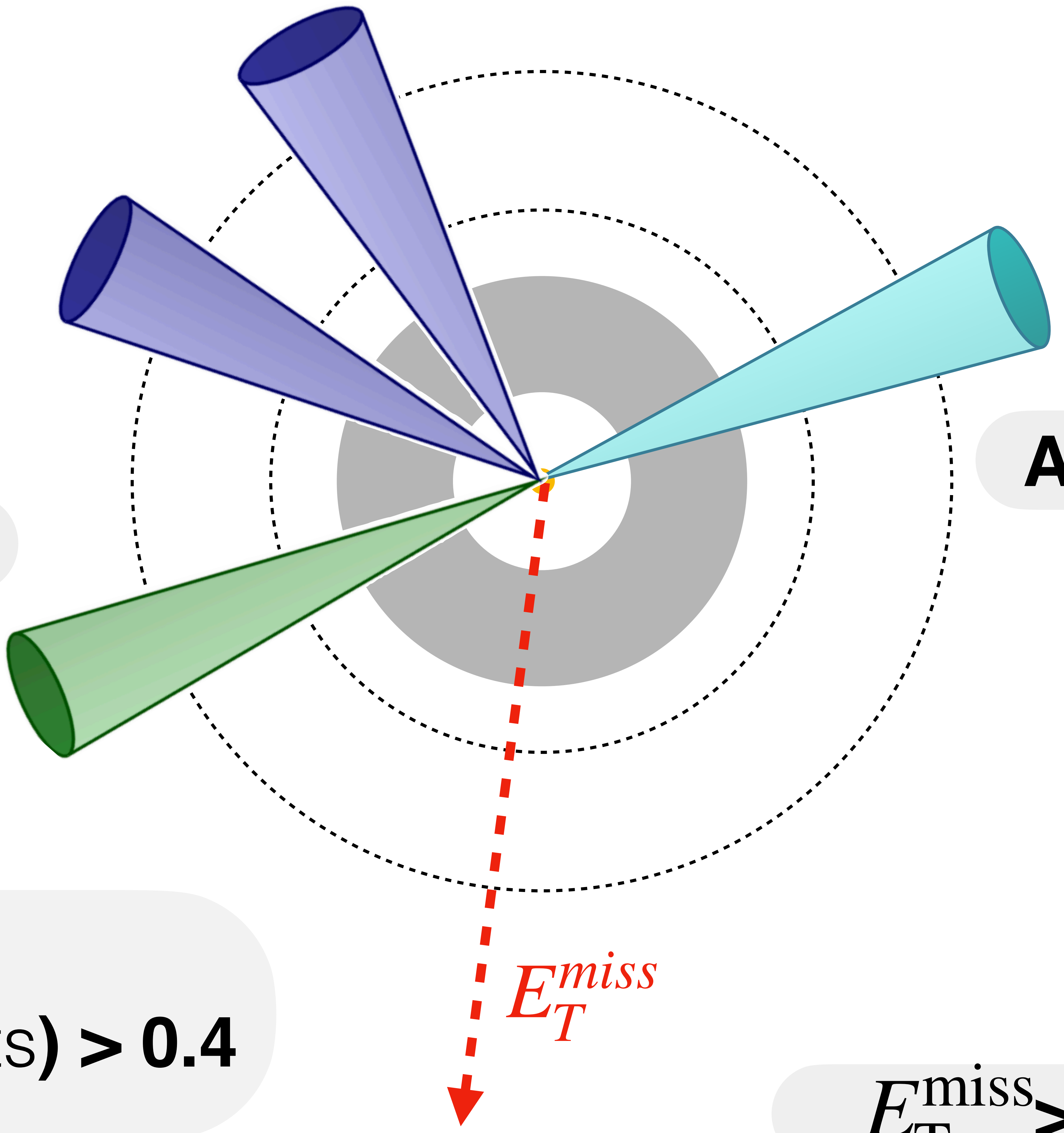
JHEP07(2024)250

SUSY Analysis

→

Exclusion Limits

Dark Matter Flavour Violation



At least 1 c-jet

At least 1 b-jet

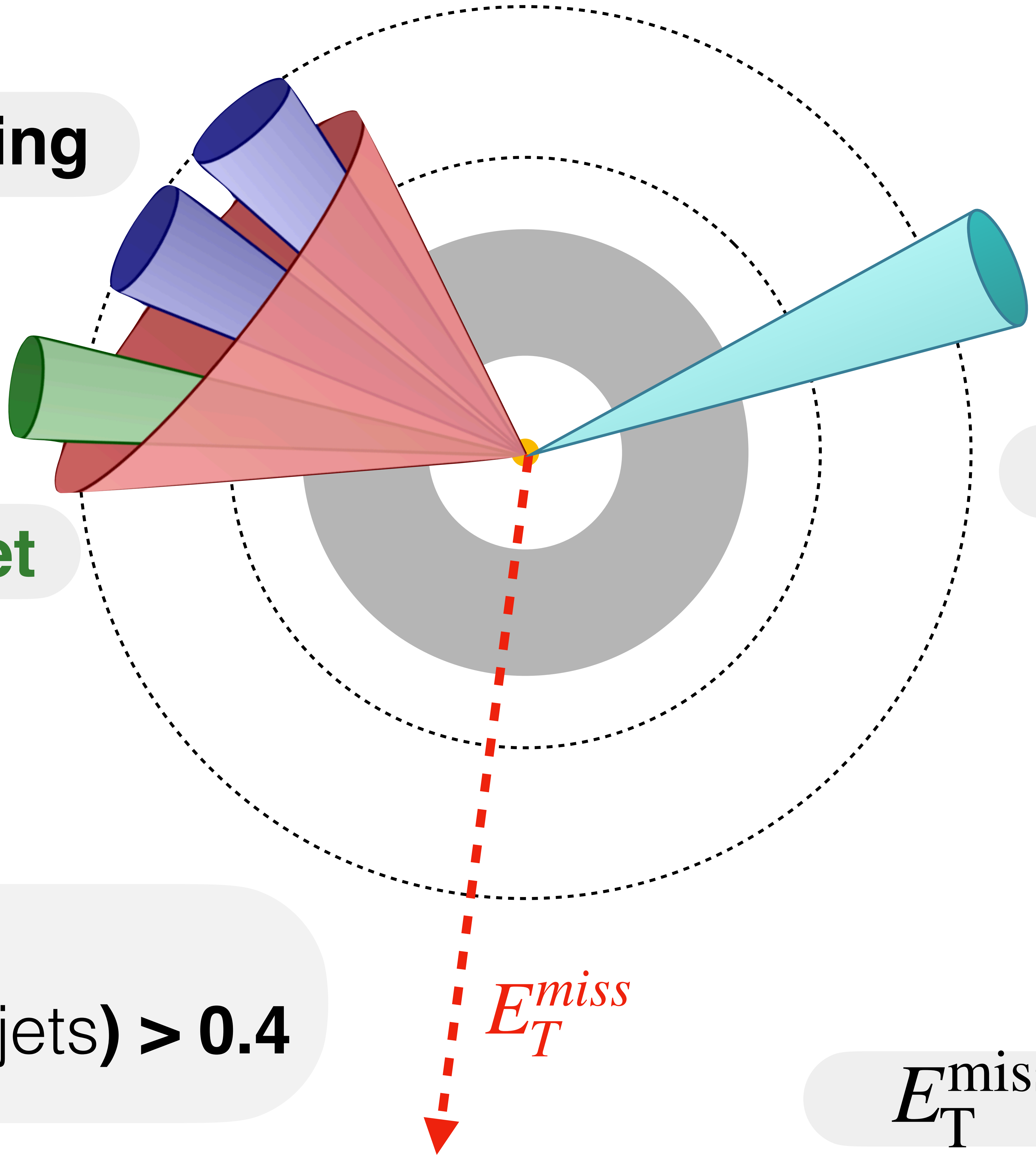
$min\Delta\phi$
(E_T^{miss} **and** 4 Leading jets) **> 0.4**

$E_{\mathrm{T}}^{\mathrm{miss}}$ **> 250 GeV**

Dark Matter Flavour Violation

Selection optimised to reduce backgrounds from **QCD and V+jets**

DNN Boosted Top Tagging



At least 1 c-jet

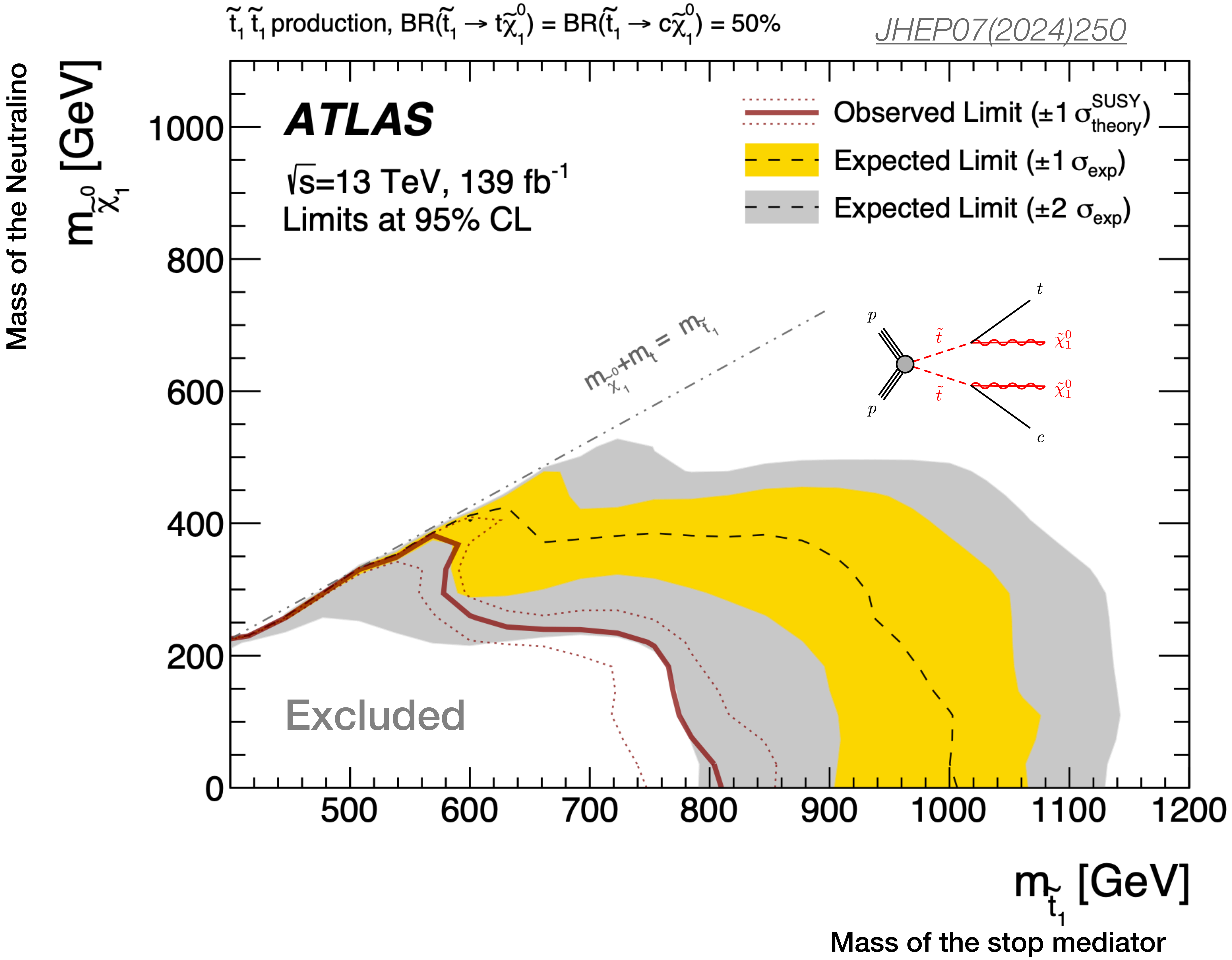
At least 1 b-jet

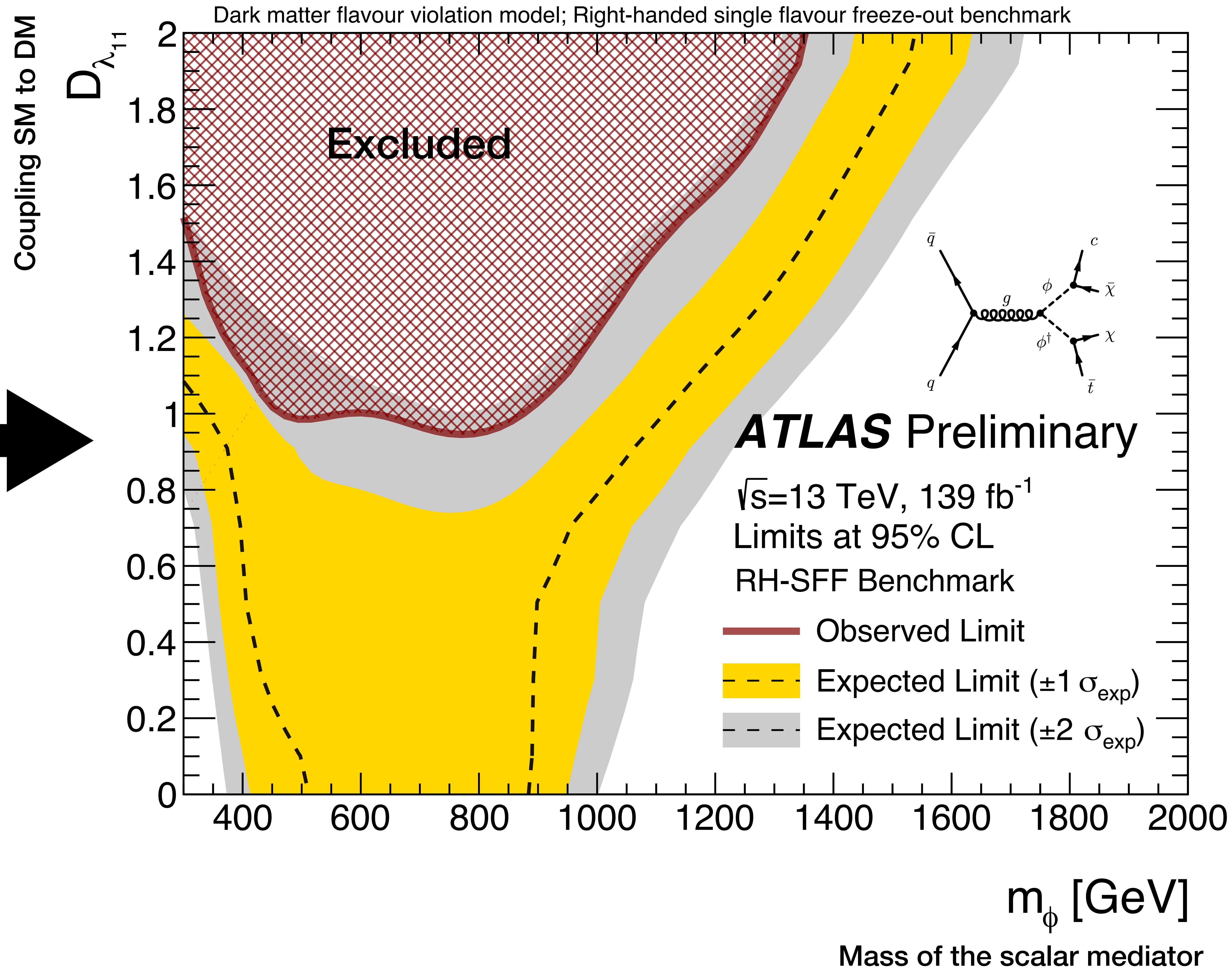
$min\Delta\phi$
(E_T^{miss} **and** 4 Leading jets**) > 0.4**

$E_{\mathrm{T}}^{\mathrm{miss}}$ **> 250 GeV**

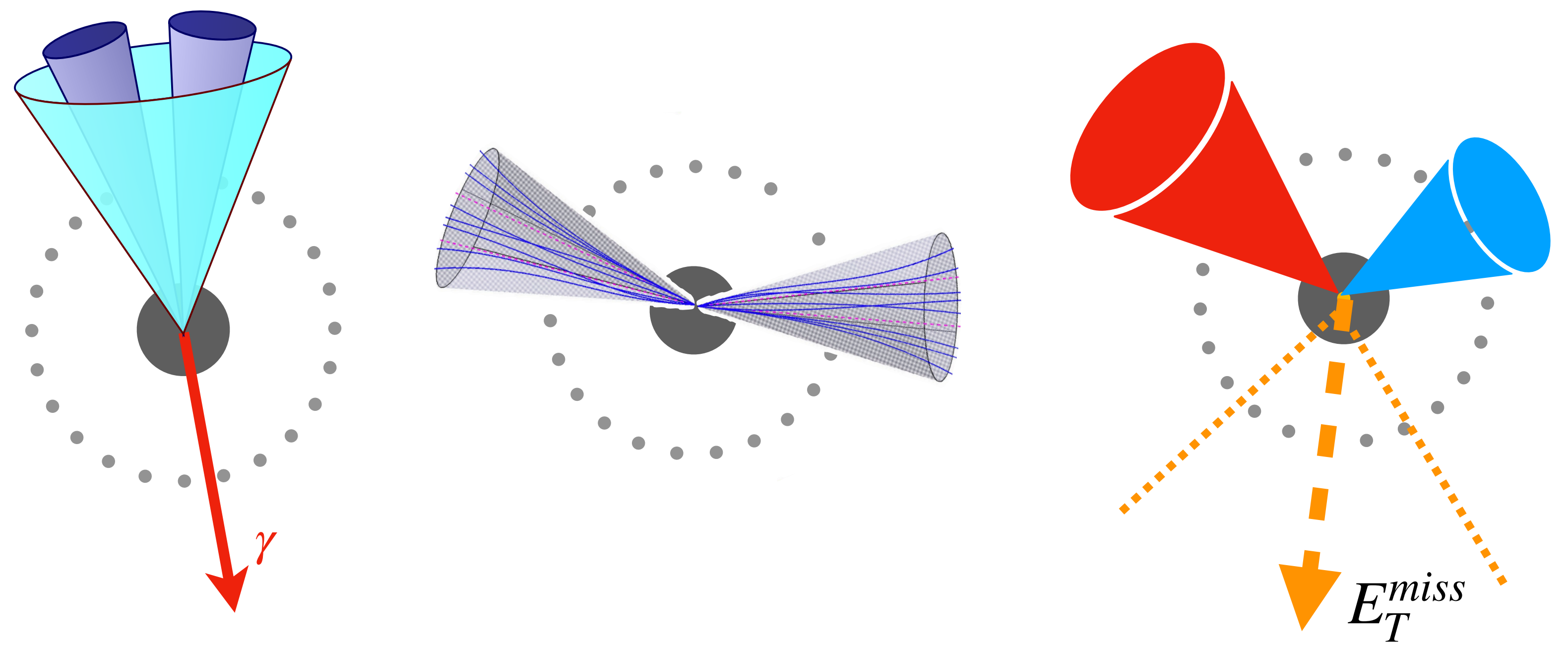
Dark Matter Flavour Violation

Excluded up to **1.2 TeV** for the high coupling D_λ region





Summary



- Explored different **fully hadronic final states**
- Wide range of BSM models aiming to explain open questions
- Heavy use of **advanced ML** for **object reconstruction** and **background estimation**
- To be continued with **Run 3**

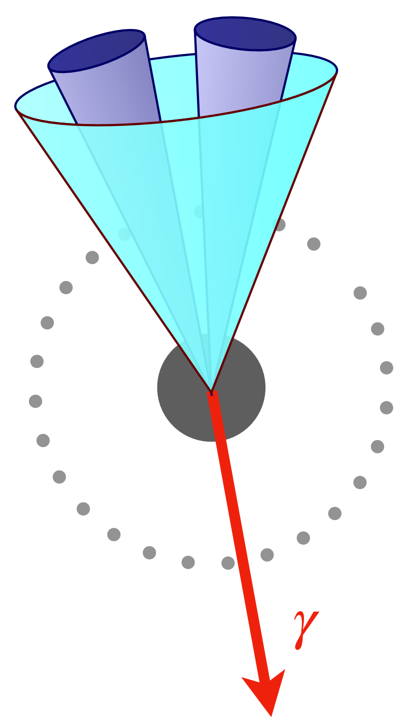
Thank you

ATLAS EXPERIMENT

DESY.

Backup

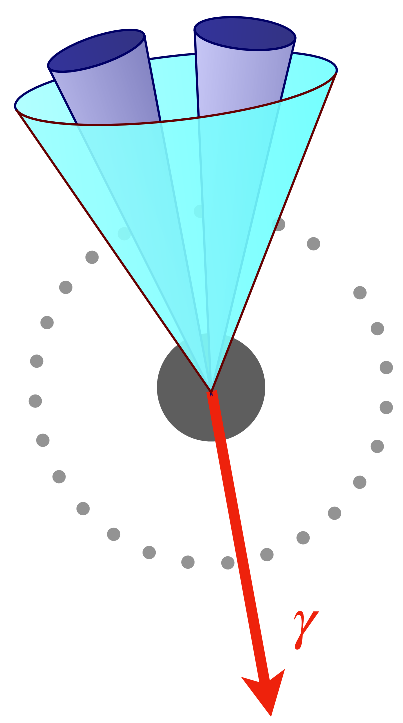
Boosted dijet+ISR γ

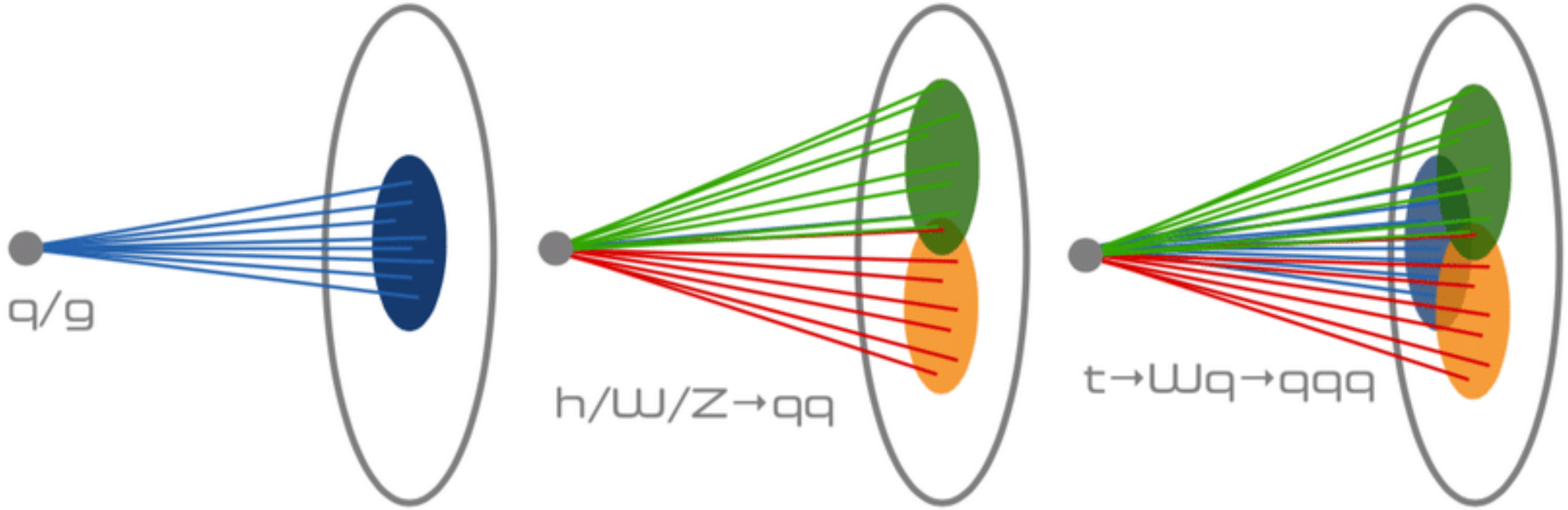


Object / Variable	Selection Criteria
Primary vertex	≥ 2 tracks with $p_T > 0.5$ GeV
Photon	$p_T > 150$ GeV, tight ID, $\lvert\eta\rvert < 1.37$ or $1.52 < \lvert\eta\rvert < 2.37$
Leading TAR jet	$p_T > 150$ GeV, $\lvert\eta\rvert < 2.0$, $2m_J/p_T < 1$, $\Delta\phi(\gamma, J) > \pi/2$
Jet isolation	No $R = 0.2$ jet within $\Delta R \leq 1.2$ of TAR jet with $p_T > p_T^\gamma$
Jet width	$\rho \equiv \log(m_J^2/p_T^2) > -5.4$
Track multiplicity	TAR jets must have ≥ 3 associated tracks

Region	Photon Region	D_2^{DDT} Tag Category
Signal Region (SR)	$\lvert\eta_\gamma\rvert \leq 1.3$ (Central)	Tagged ($D_2^{\mathrm{DDT}} < 0$)
Control Region 1 (CR1)	$\lvert\eta_\gamma\rvert > 1.3$ (Forward)	Tagged
Control Region 2 (CR2)	$\lvert\eta_\gamma\rvert \leq 1.3$ (Central)	Anti-tagged ($D_2^{\mathrm{DDT}} \geq 0$)
Control Region 3 (CR3)	$\lvert\eta_\gamma\rvert > 1.3$ (Forward)	Anti-tagged

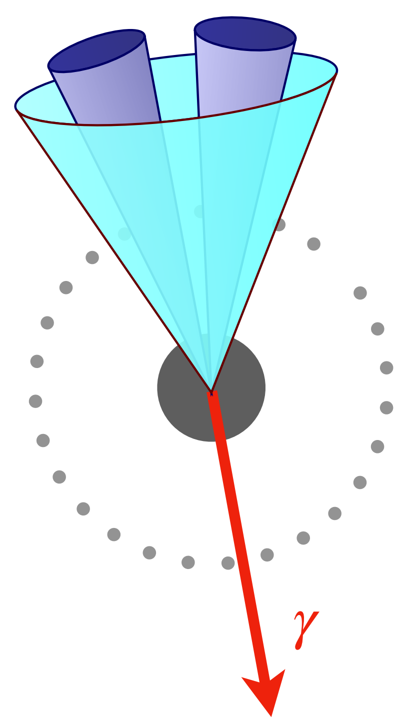
Boosted **dijet+ISR** γ

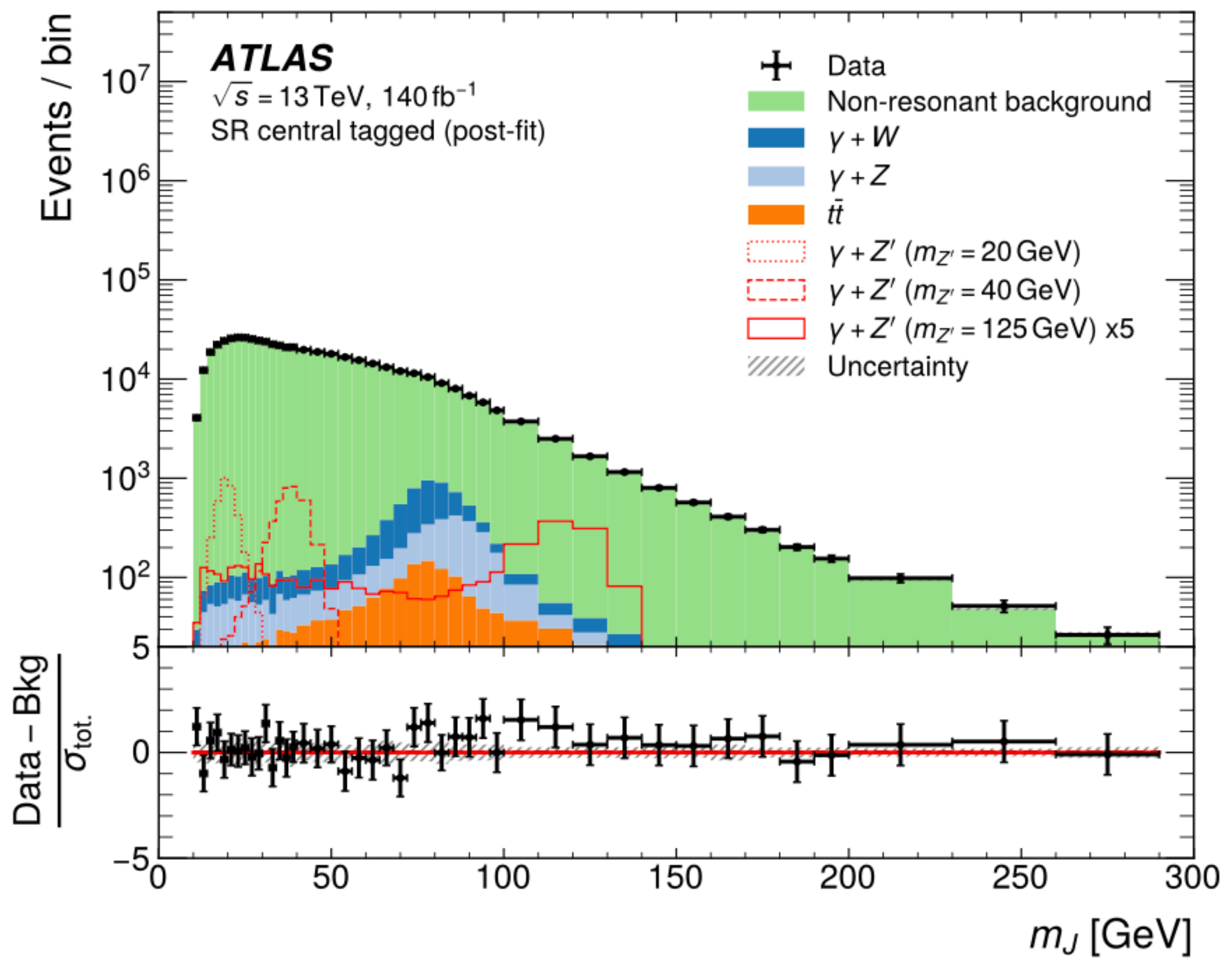




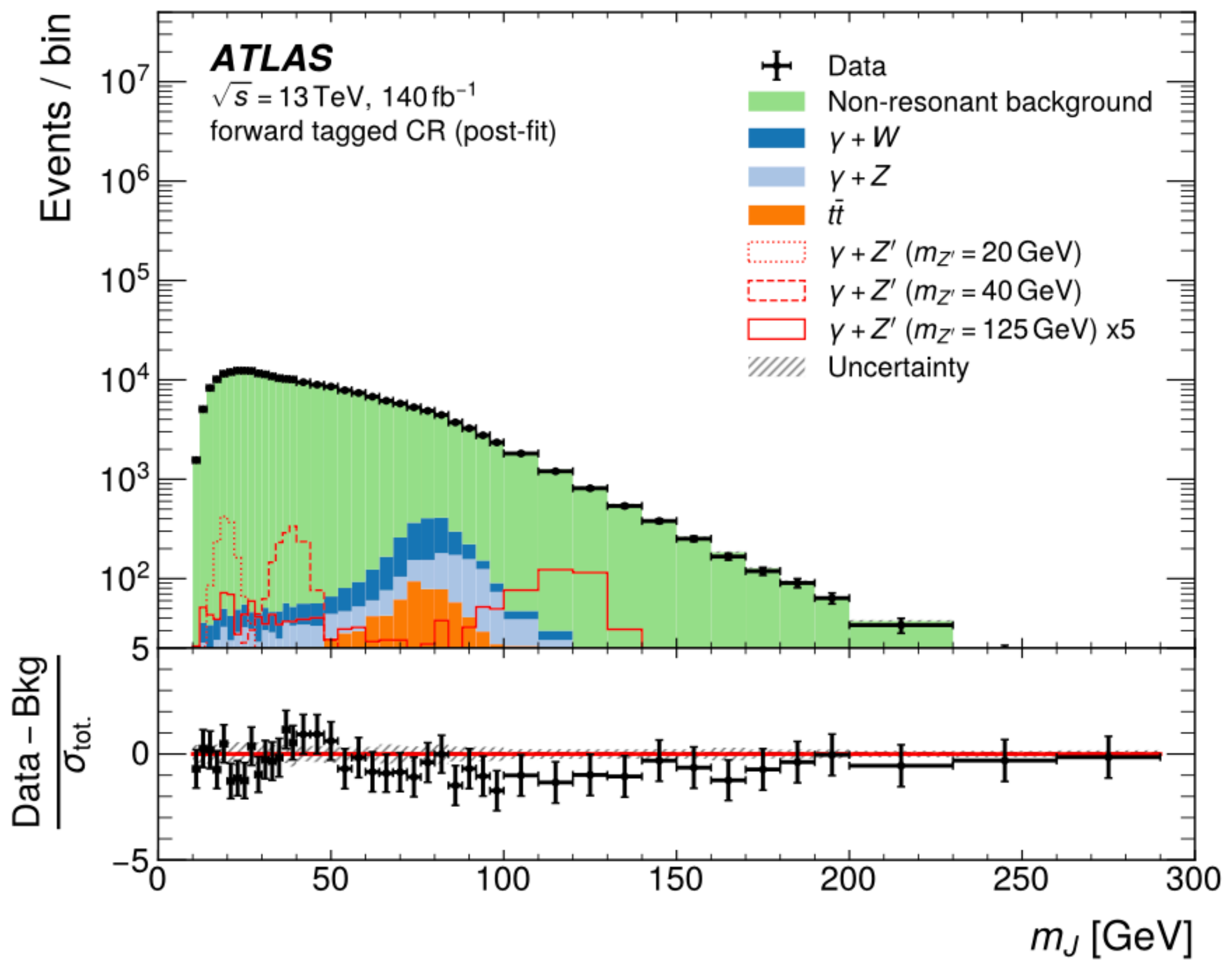
1 prong **2 prongs** **3 prongs**

Boosted dijet+ISR γ

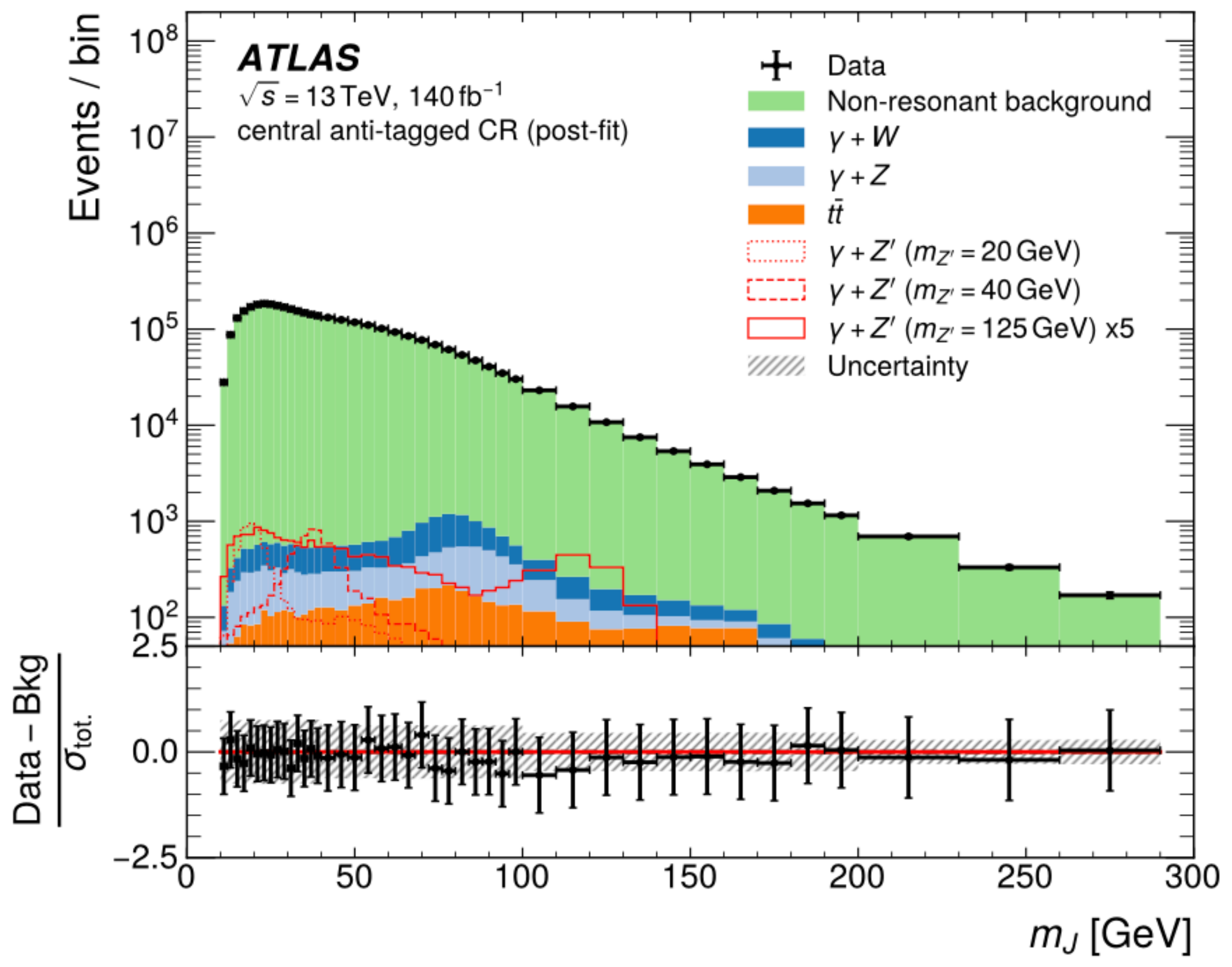


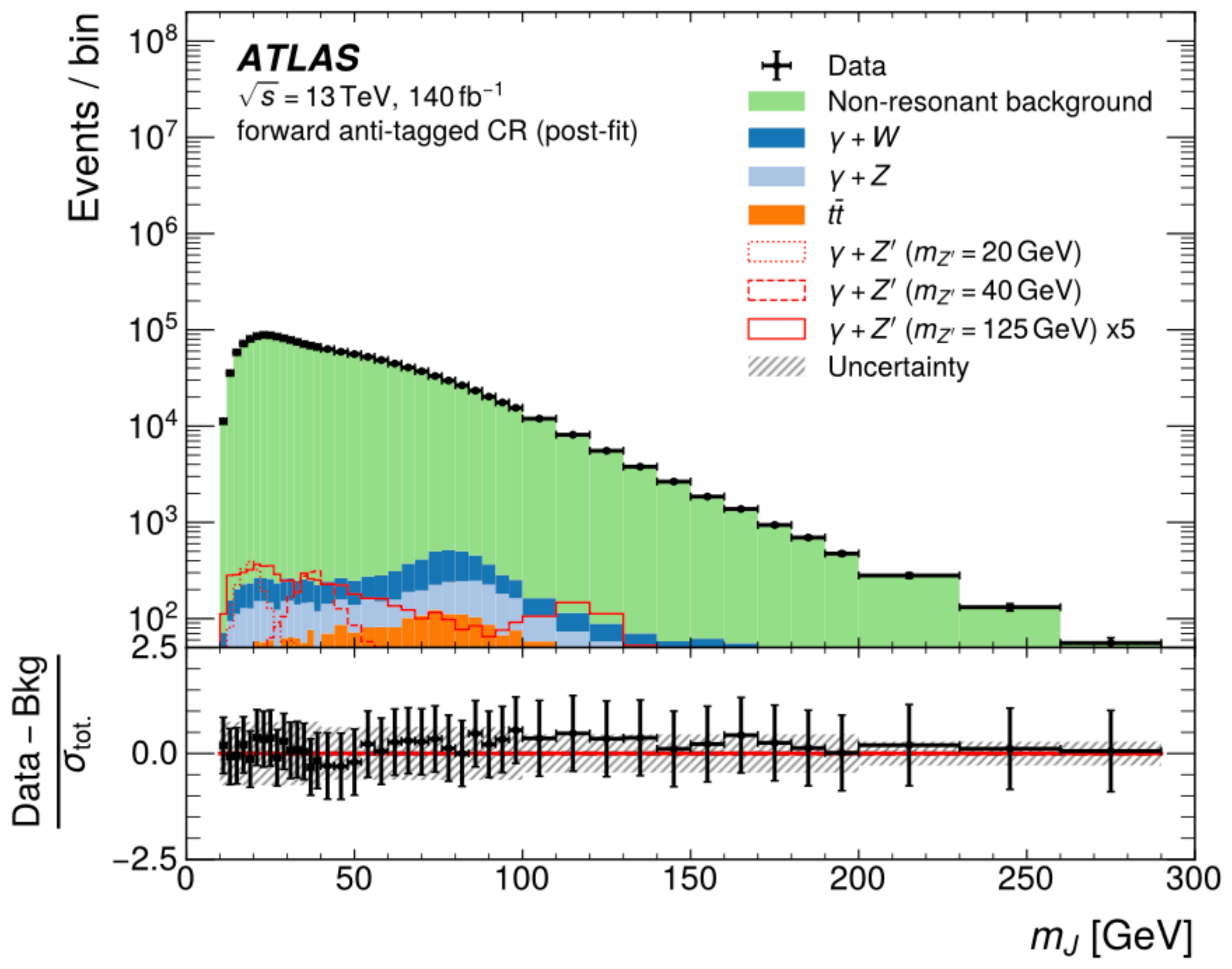


(a)

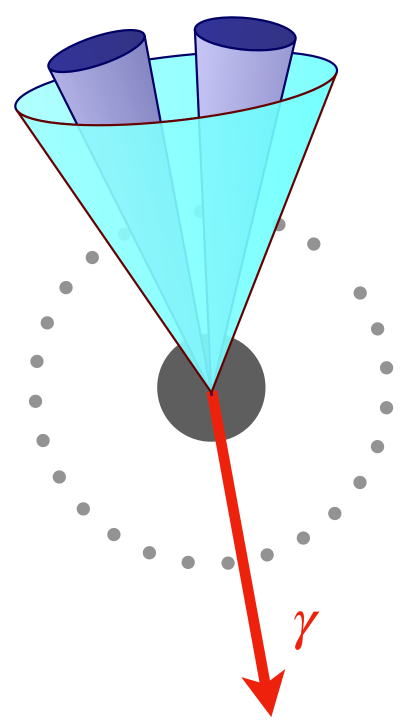


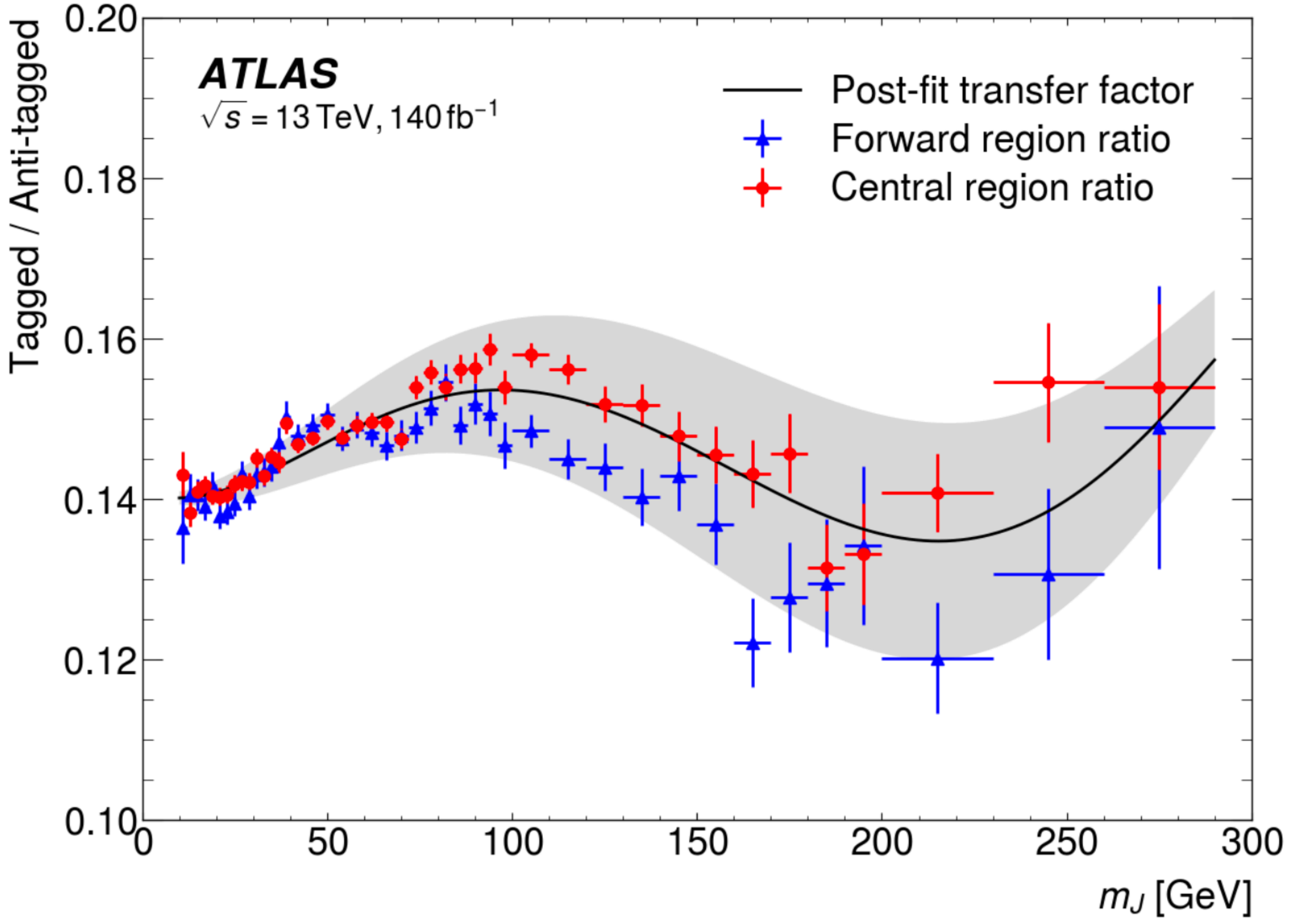
(b)



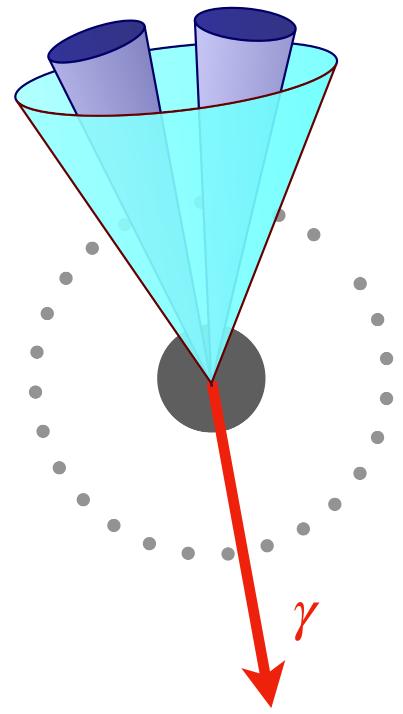


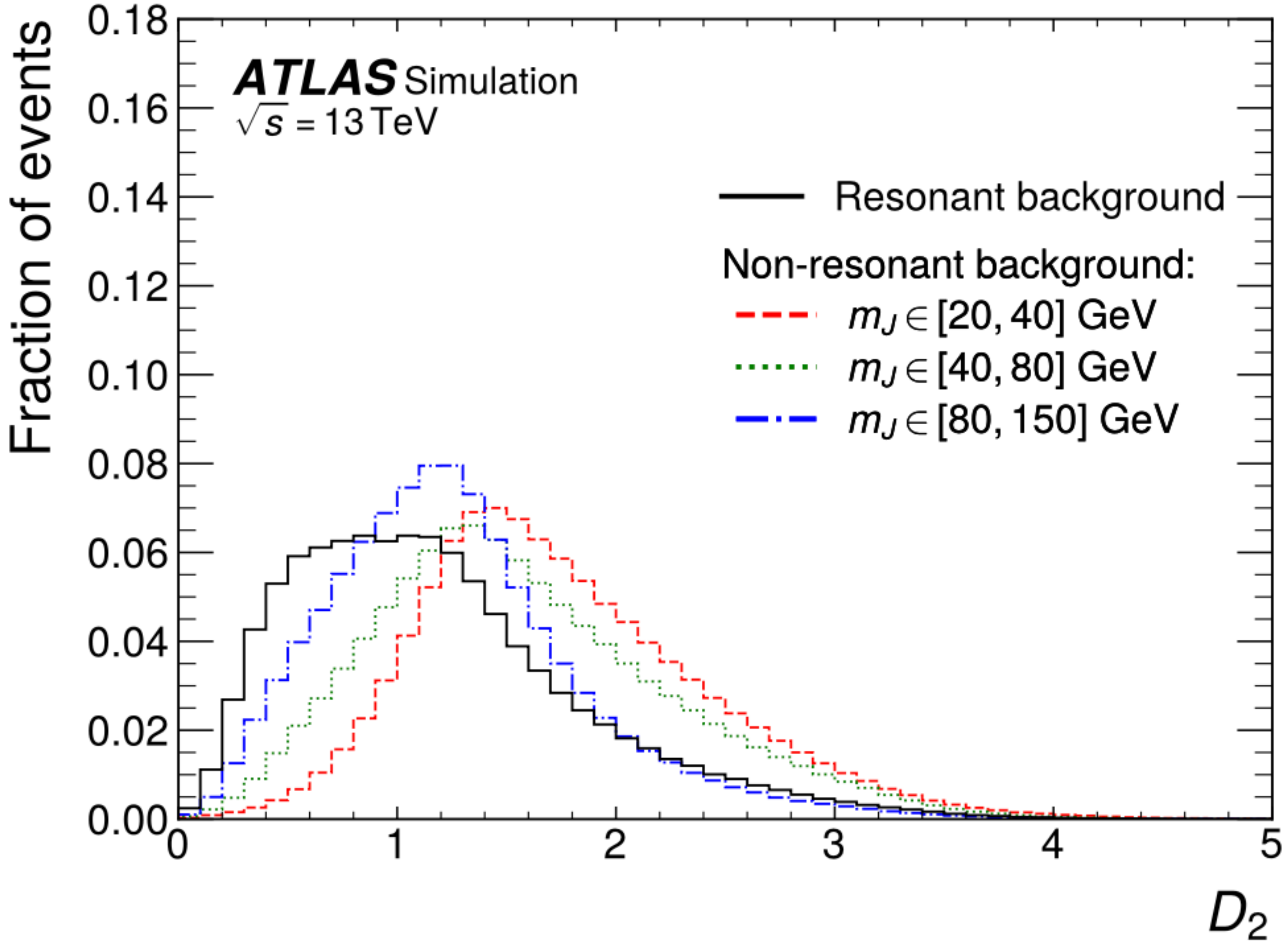
Boosted **dijet+ISR** γ

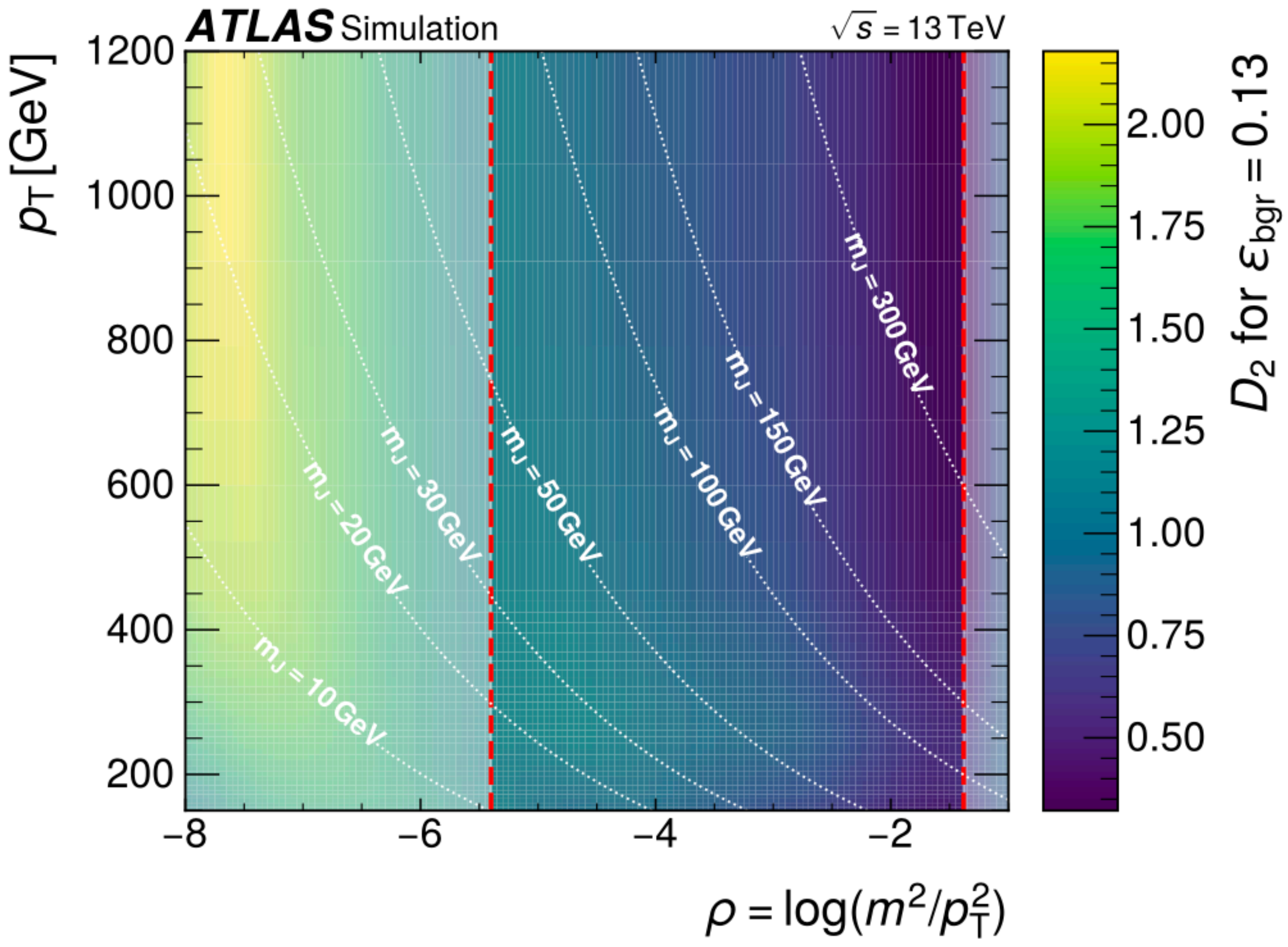




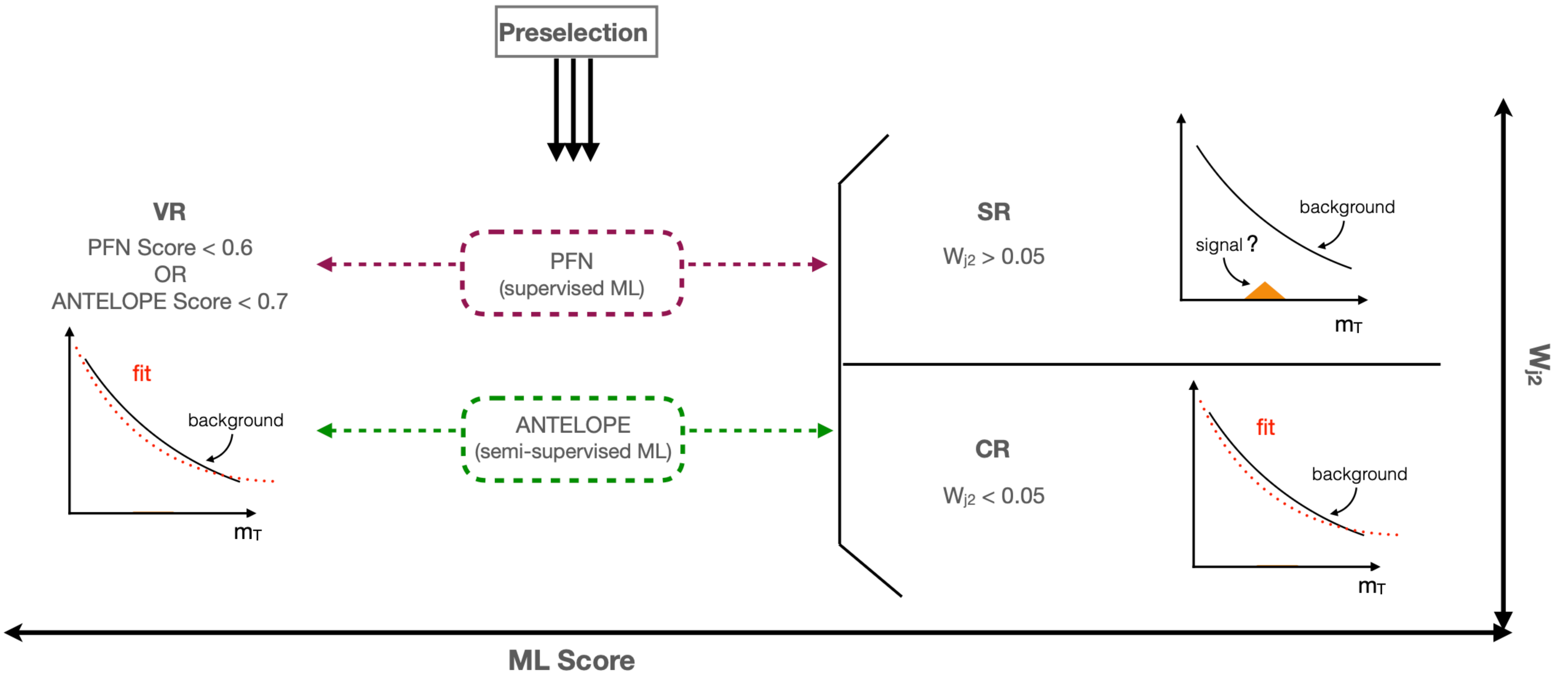
Boosted dijet+ISR γ





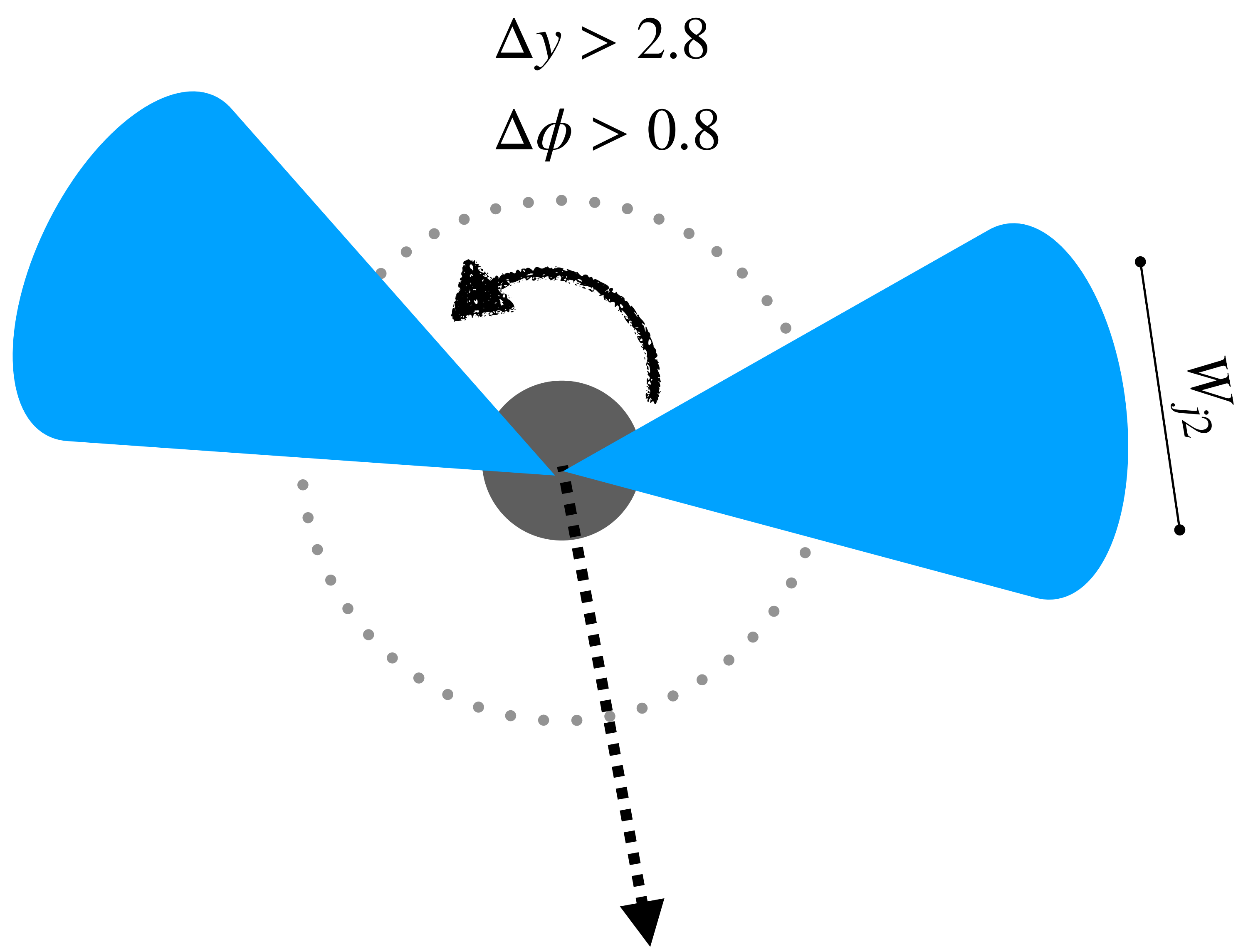


Semi-Visible **Jets**



Semi-Visible **Jets**

Using **angle separation** and **transverse variables** for the preselection

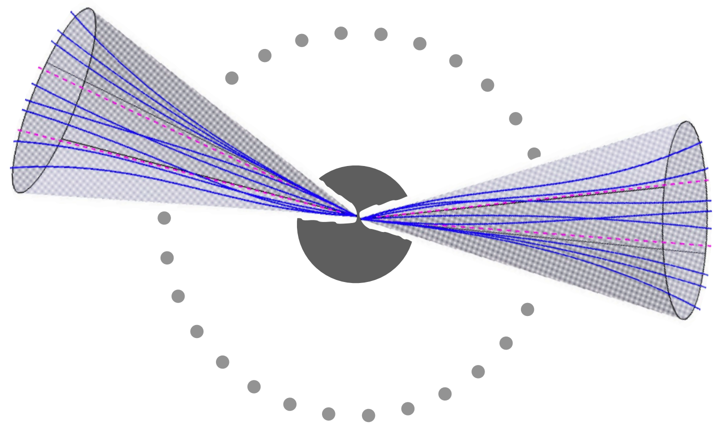


Variable	Preselection requirements
N_{jets}	≥ 2
N_{tracks} (jet)	≥ 3
N_{lep}	$= 0$
$p_T j_1(j_2)$ [GeV]	> 450 (> 150)
$\Delta\phi$ (j_1, j_2)	> 0.8
$\lvert\eta_{j_1,j_2}\rvert$	< 2.1
Δ y	< 2.8
E_T^{miss} [GeV]	> 200
m_T[GeV]	> 1500

	SR_{PFN}	SR_{AD}	VR_{PFN}	VR_{AD}	CR
W_{j_2}	> 0.05				< 0.05
PFN score	> 0.6	–	< 0.6	–	–
ANTELOPE score	–	> 0.7	–	< 0.7	–

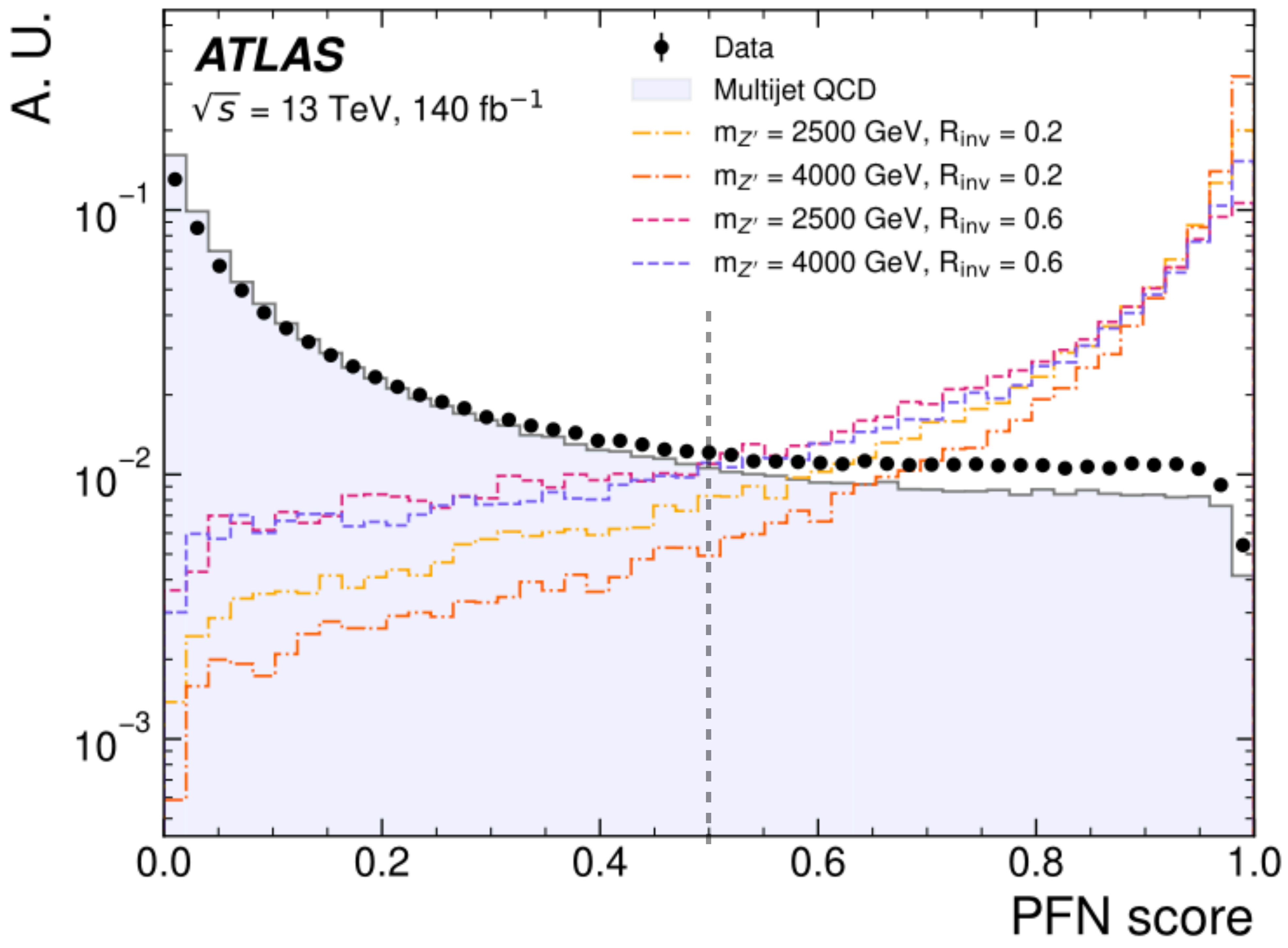
Analysis Strategy

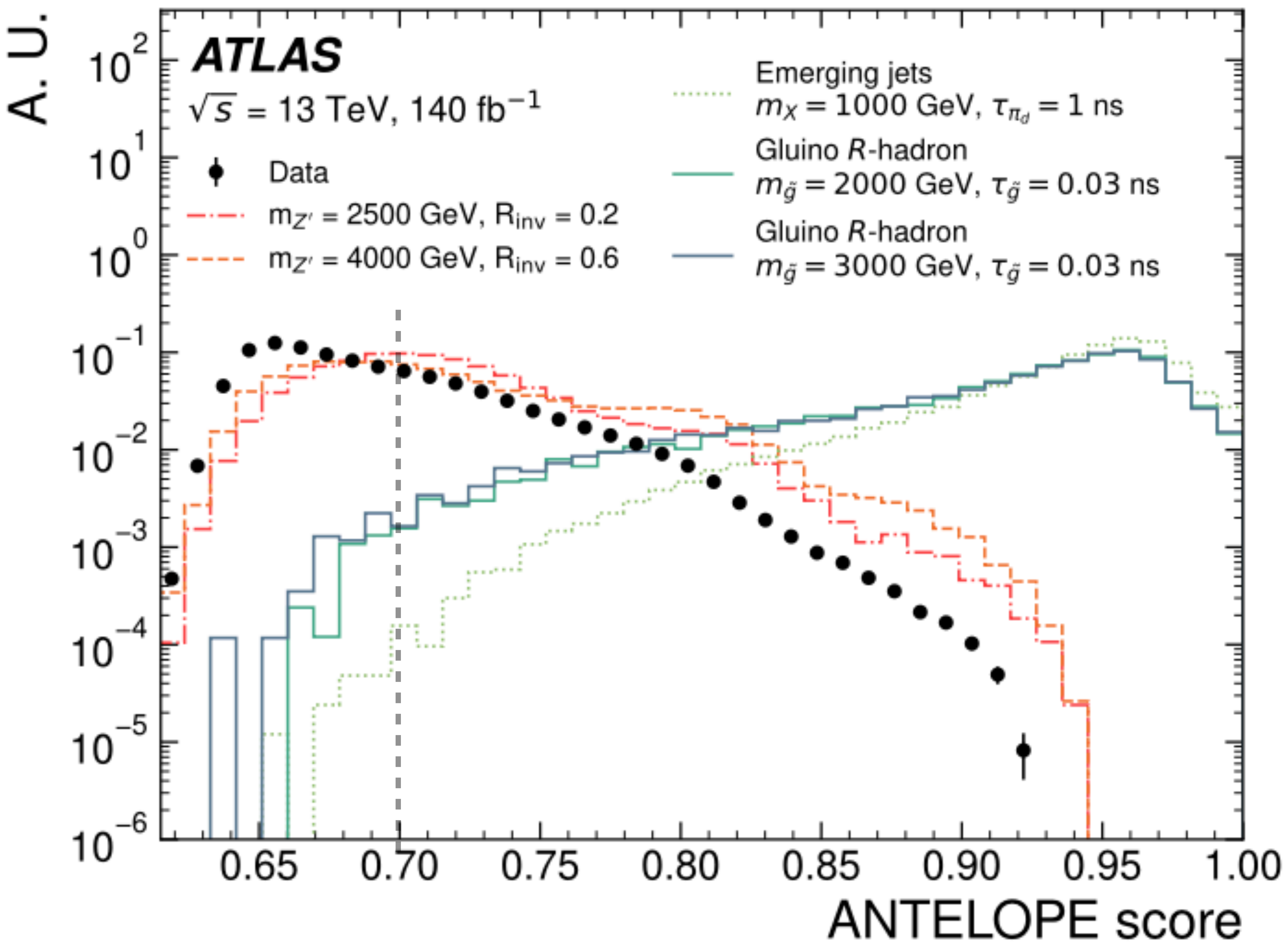
Semi-Visible **Jets**



Regions developed based on **ML score** and **Jet Width**

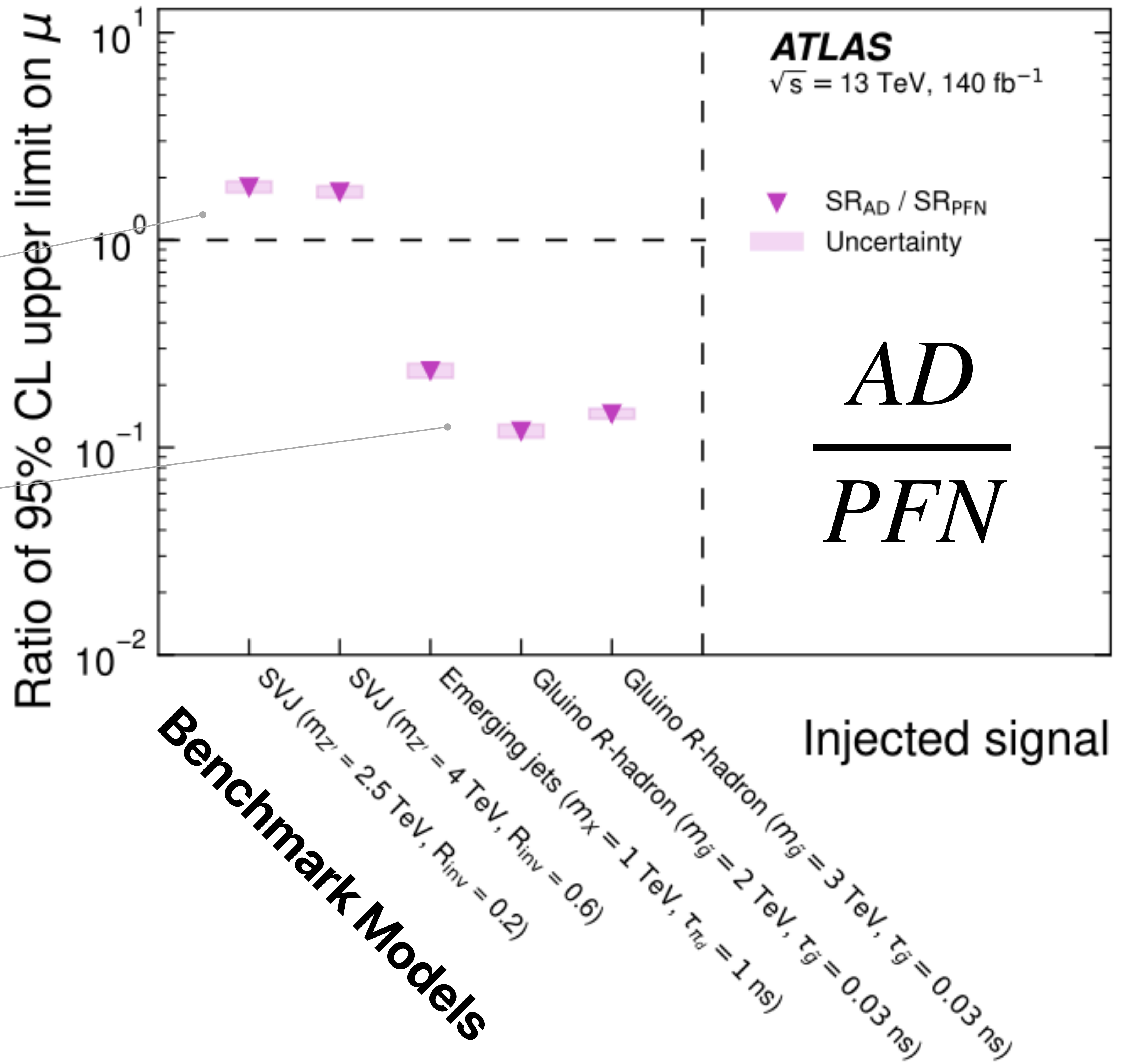
Region	**Jet Width W_{j2}**	**ML Score Requirement**
SR_{PFN}	$W_{j2} > 0.05$	PFN score > 0.6
SR_{AD}	$W_{j2} > 0.05$	ANTELOPE score > 0.7
VR_{PFN}	$W_{j2} < 0.05$	PFN score < 0.6
VR_{AD}	$W_{j2} < 0.05$	ANTELOPE score < 0.7
CR (Common)	$W_{j2} < 0.05$	—



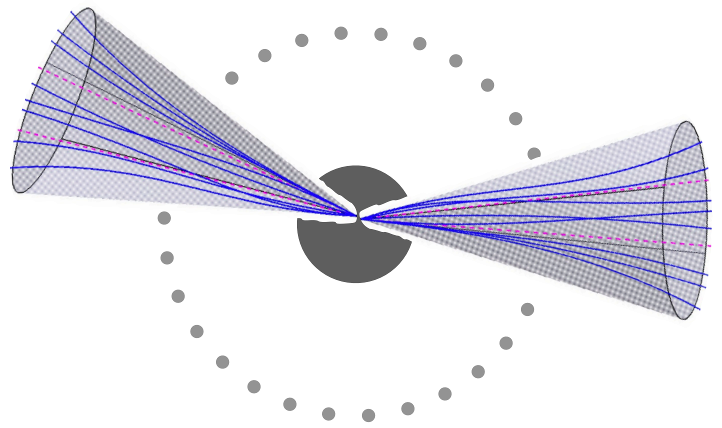


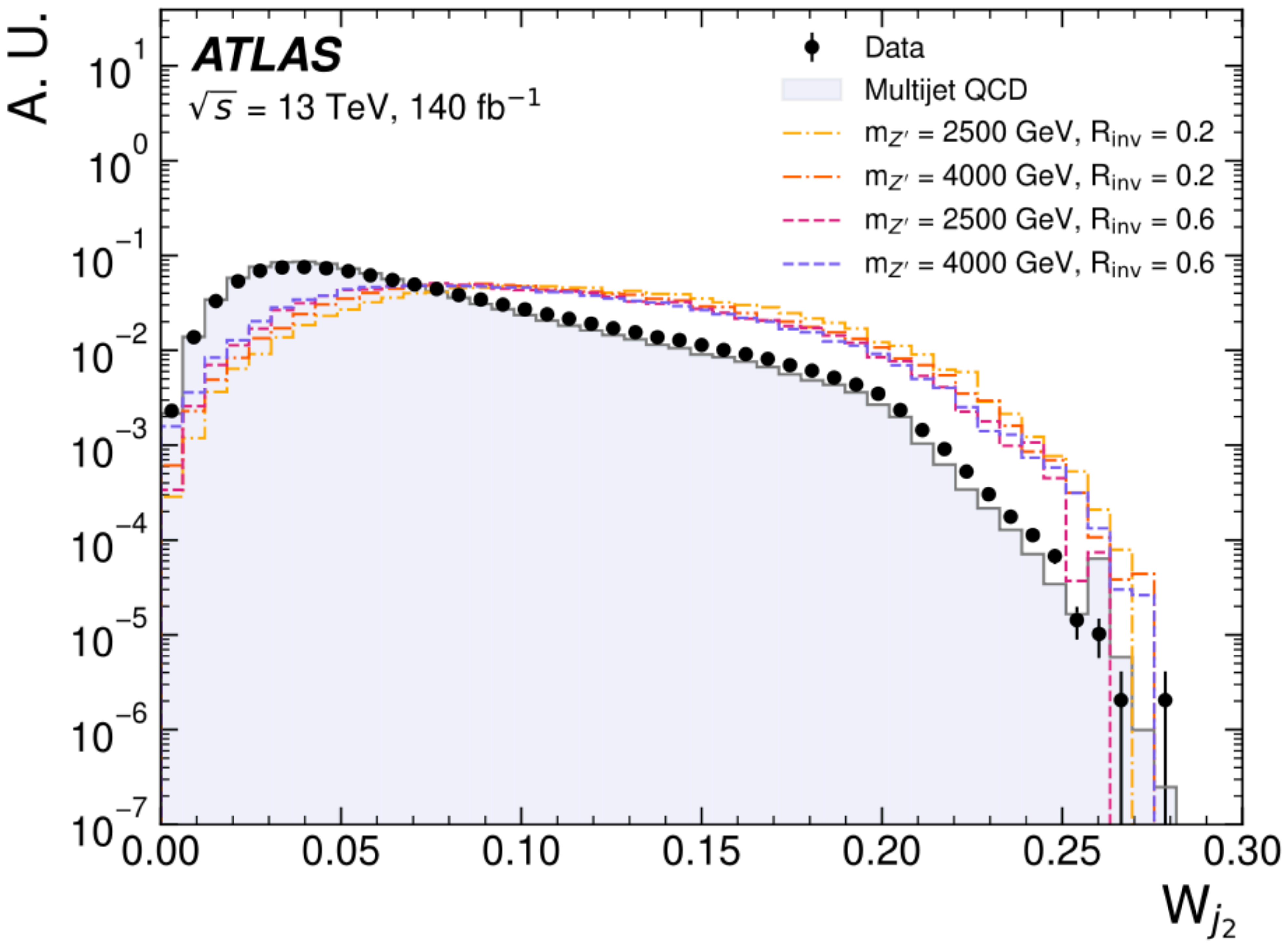
Semi-Visible **Jets**

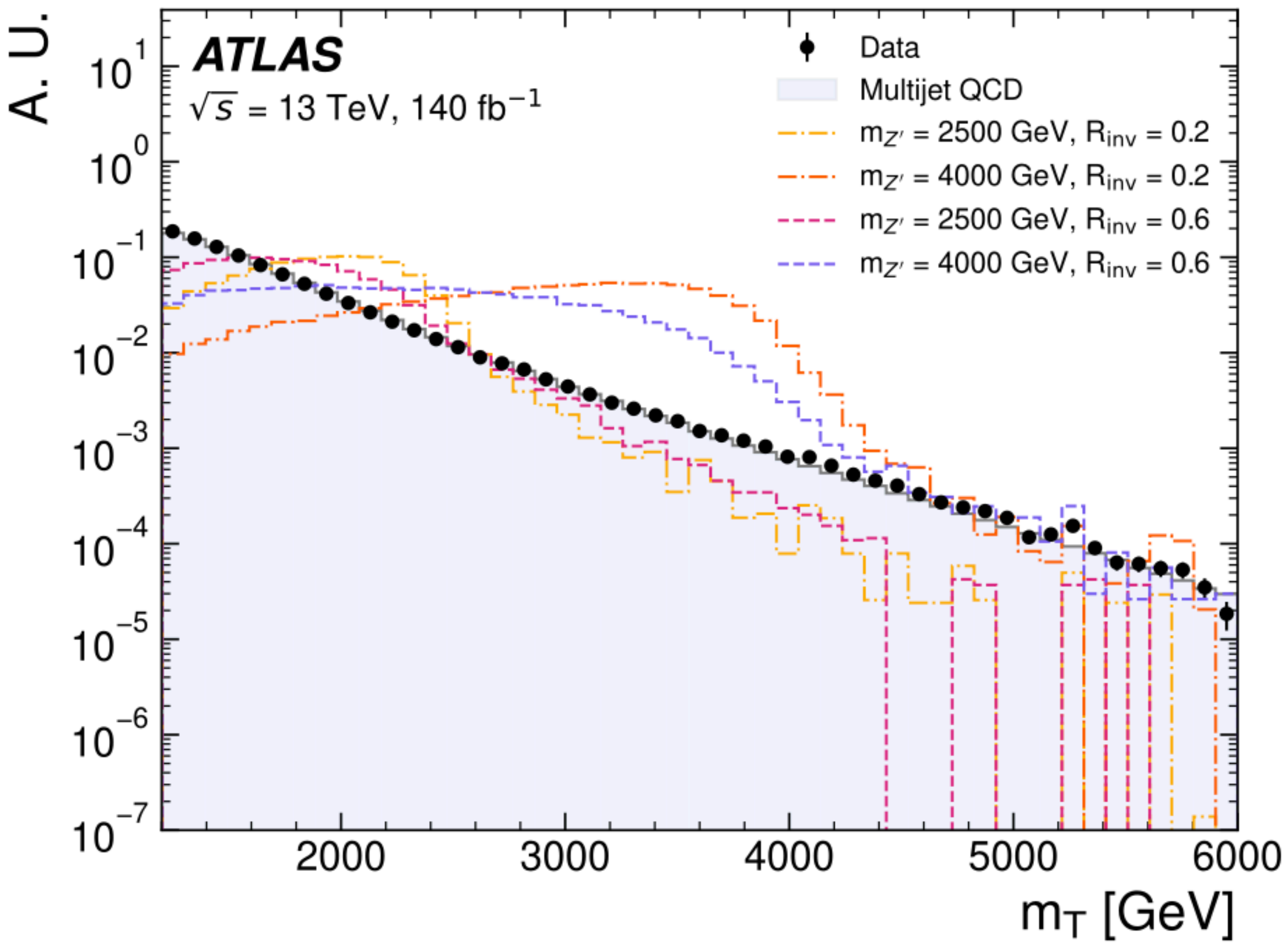
- Comparing **PFN** and **ANTELOPE** signal regions
- **PFN** region provides the **better limit on the SVJ** grid points by approximately a factor of two
- **ANTELOPE** region takes over with nearly an order of magnitude improvement on the **emerging jet** and **gluino R-hadron** alternate signals



Semi-Visible **Jets**

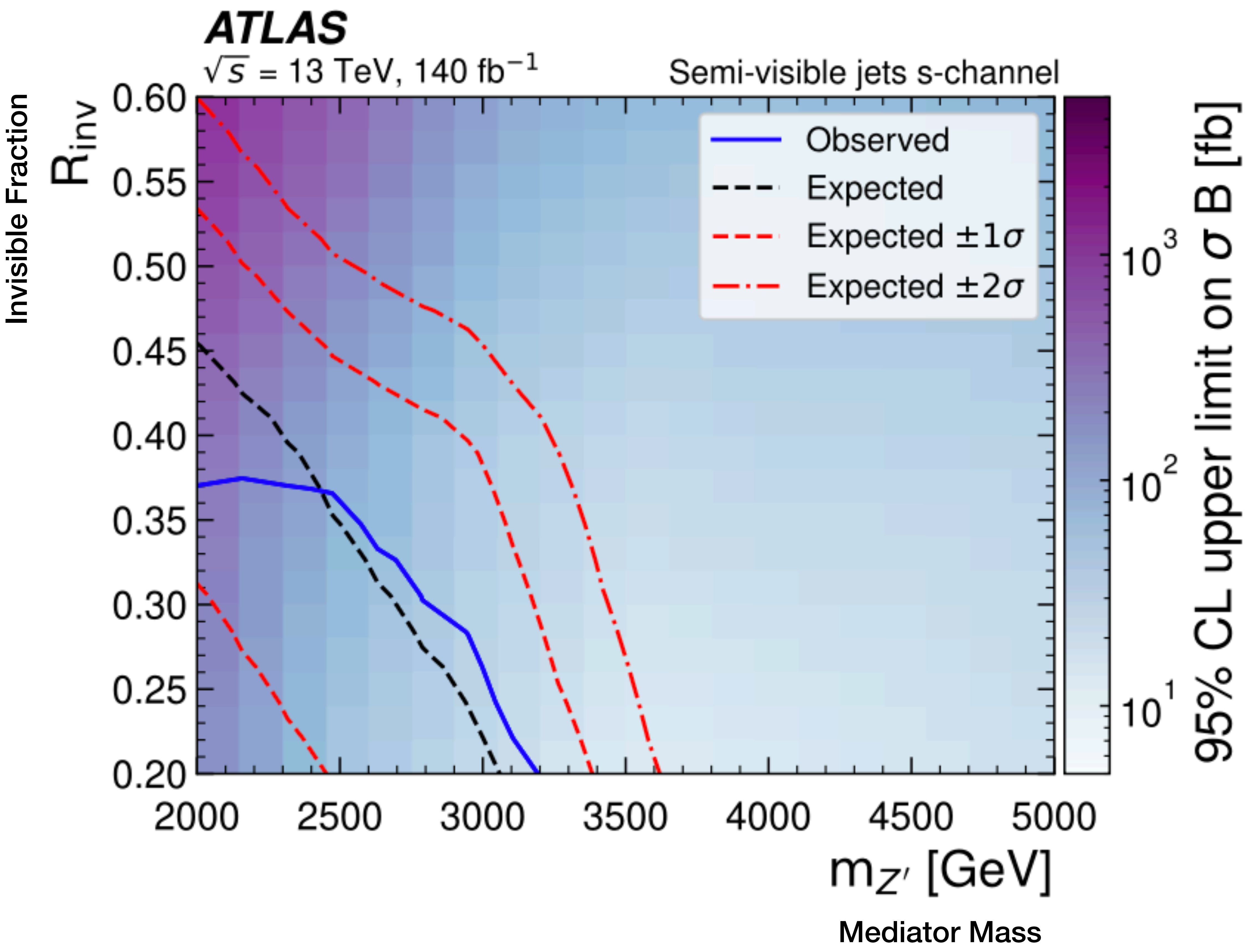






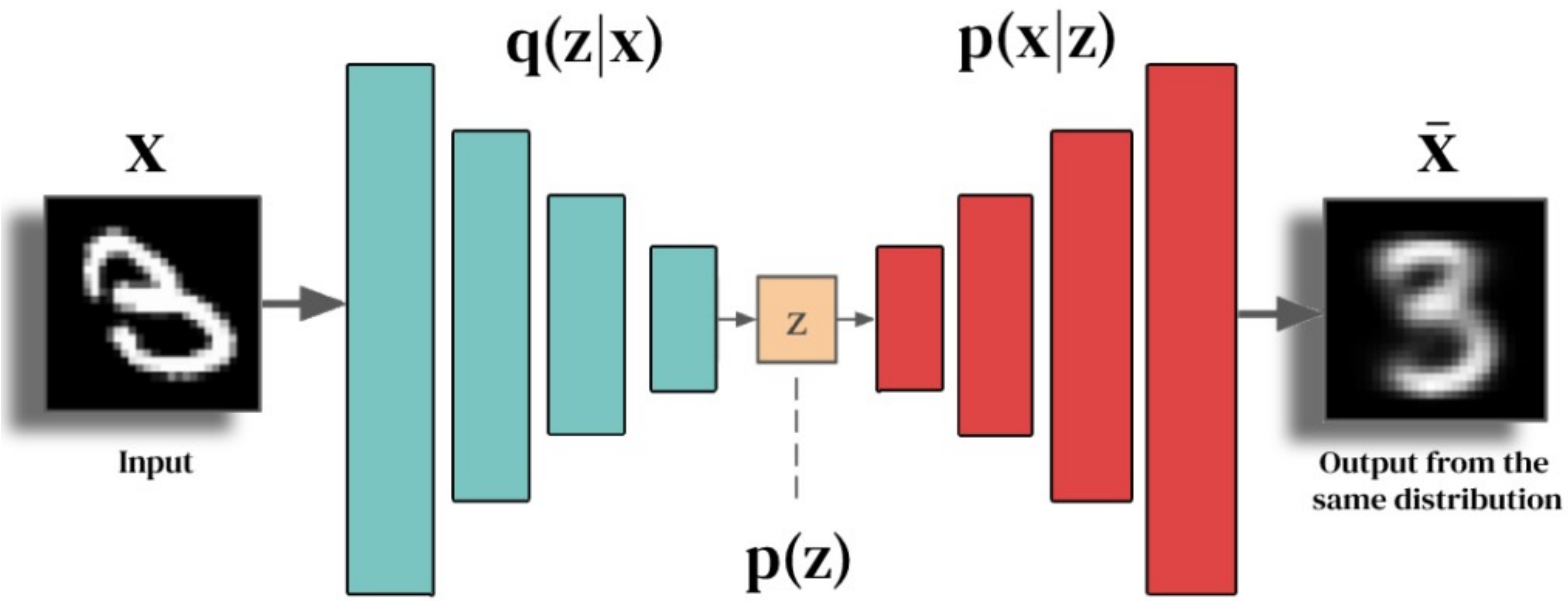
$$W_{\mathrm{j}} = \frac{\Sigma_i p_{\mathrm{T}}^i \times \Delta R_{i,\mathrm{jet}}}{\Sigma_i p_{\mathrm{T}}^i}$$

Semi-Visible **Jets**



- Exclusion contour based on the **PFN** signal region.
- Sensitivity is strongest for **lower** R_{inv} and **lower mediator mass**, where production cross section is higher

Semi-Visible **Jets**



c-tagging

Discriminant formula

Jet →

b-tagger 77% WP

$$\mathtt{DL1r} = log\left(\frac{p_b}{f_c * p_c + (1 - f_c) * p_u}\right)$$

Veto all b-tagged jets

→

c-tagger 20% WP

$$\mathtt{DL1r}_c = log\left(\frac{p_c}{f_b * p_b + (1 - f_b) * p_u}\right)$$

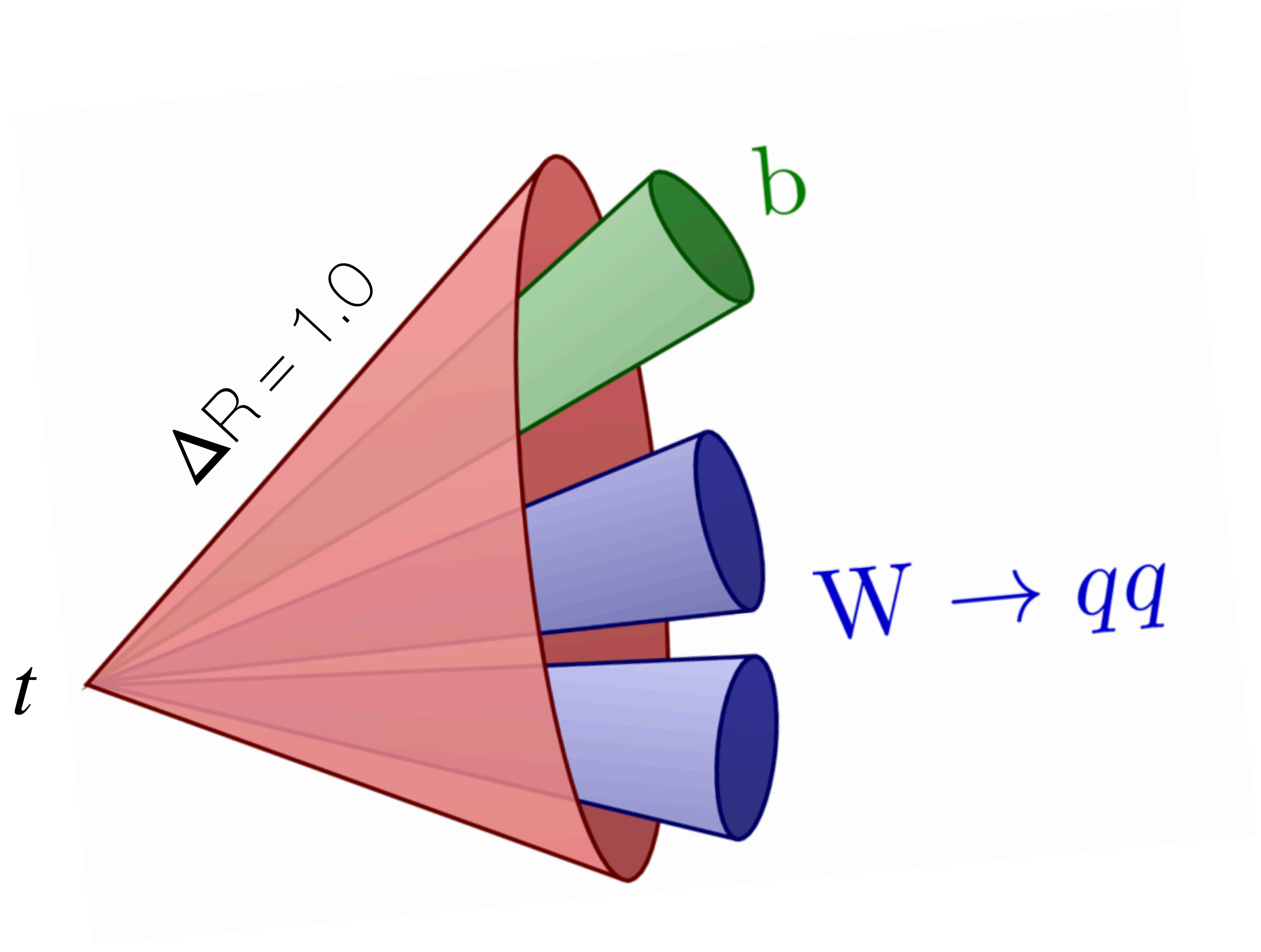
Modified Discriminant to enhance b-rejection

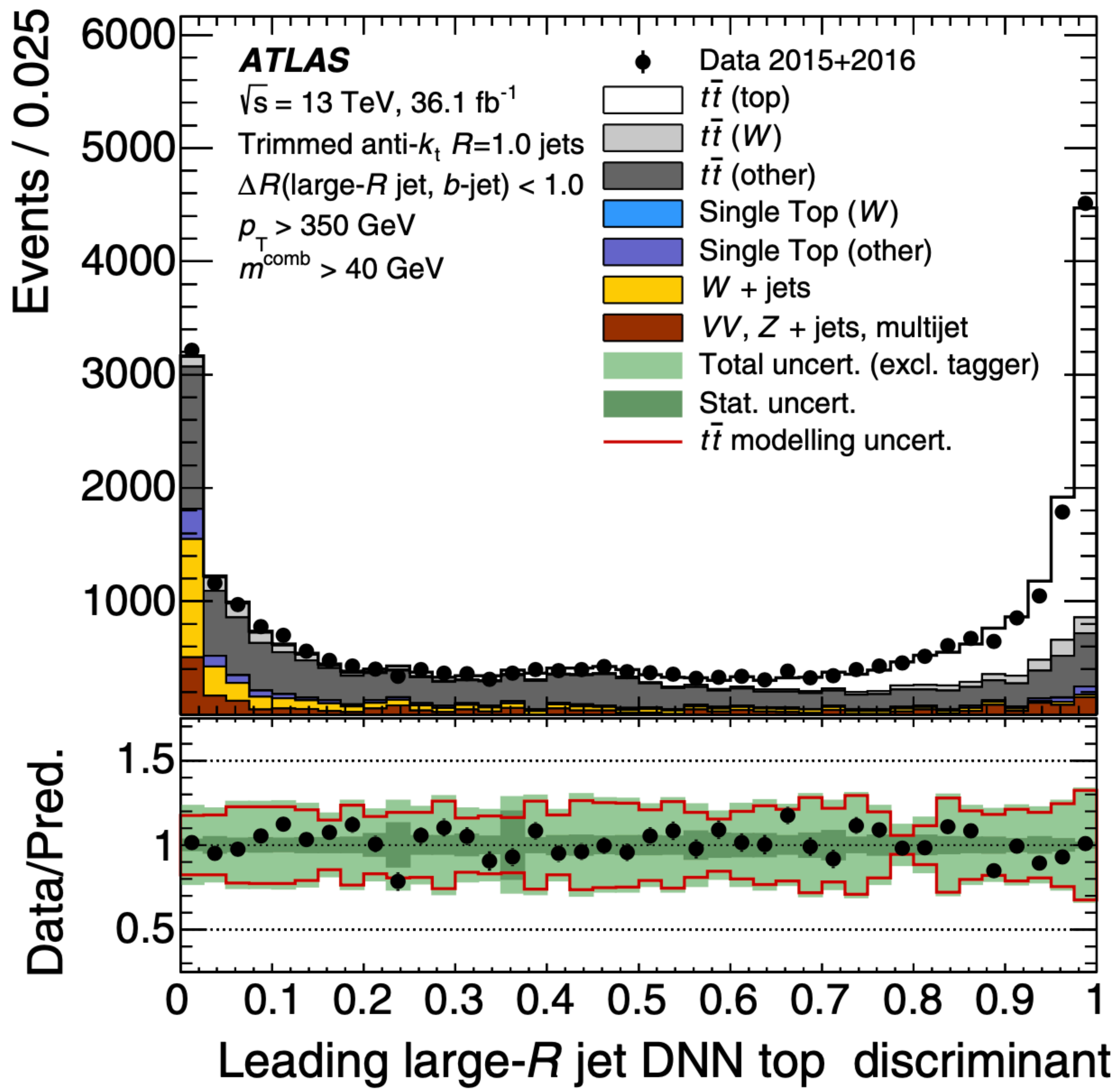
- Two tagging algorithms, **DL1r** and **DL1rc** are running in **sequence**
- If a jet is classified as a b-jet, it is no longer considered as an input to the c-tagging algorithm
- This technique is very helpful to avoid large b-jet mistag rate

Backup

Top-tagging

80% efficiency WP
$p_{\mathrm{T}} \in [350, 2500]$ GeV
$m \in [40, 600]$ GeV

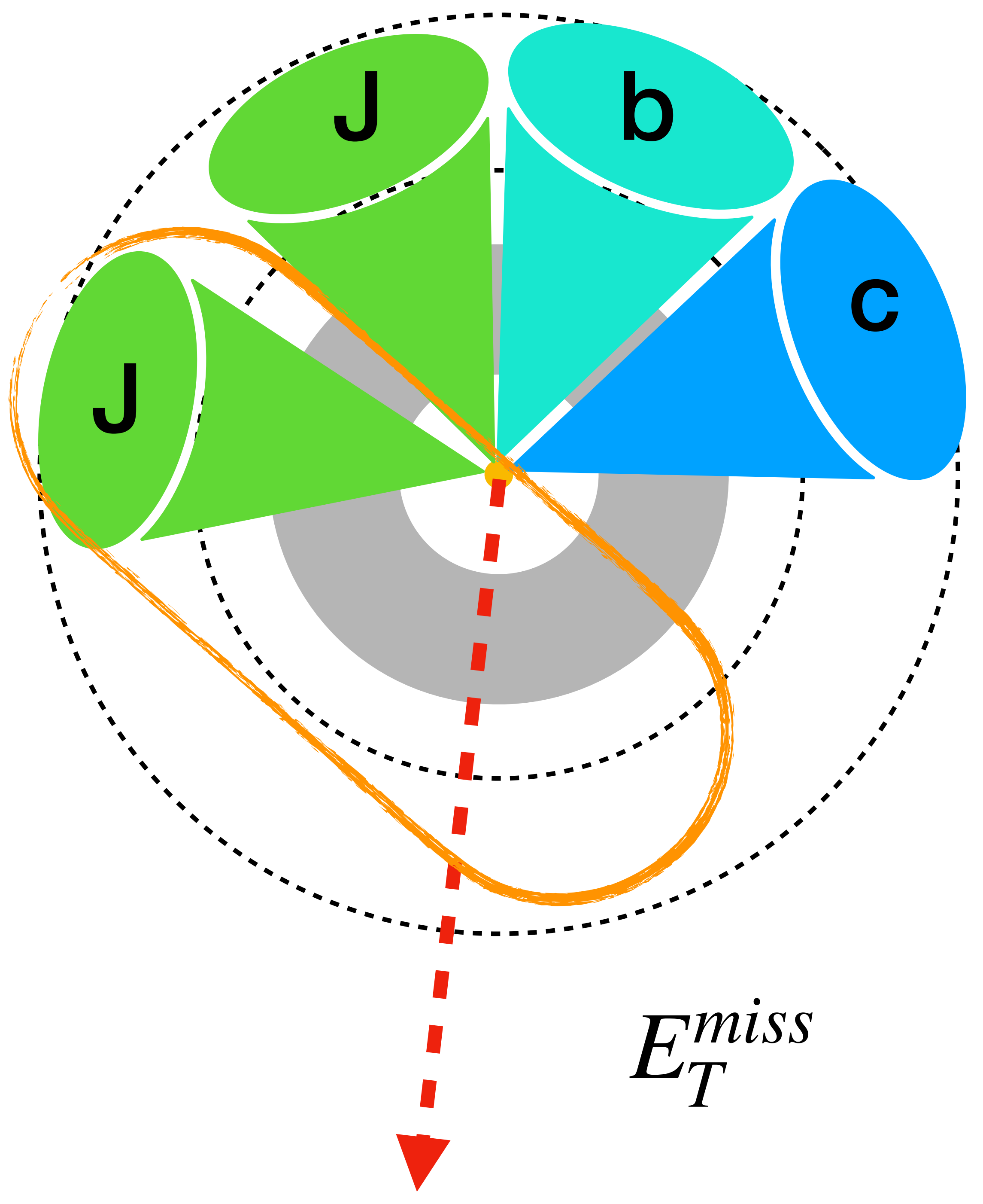




Boosted top tagging

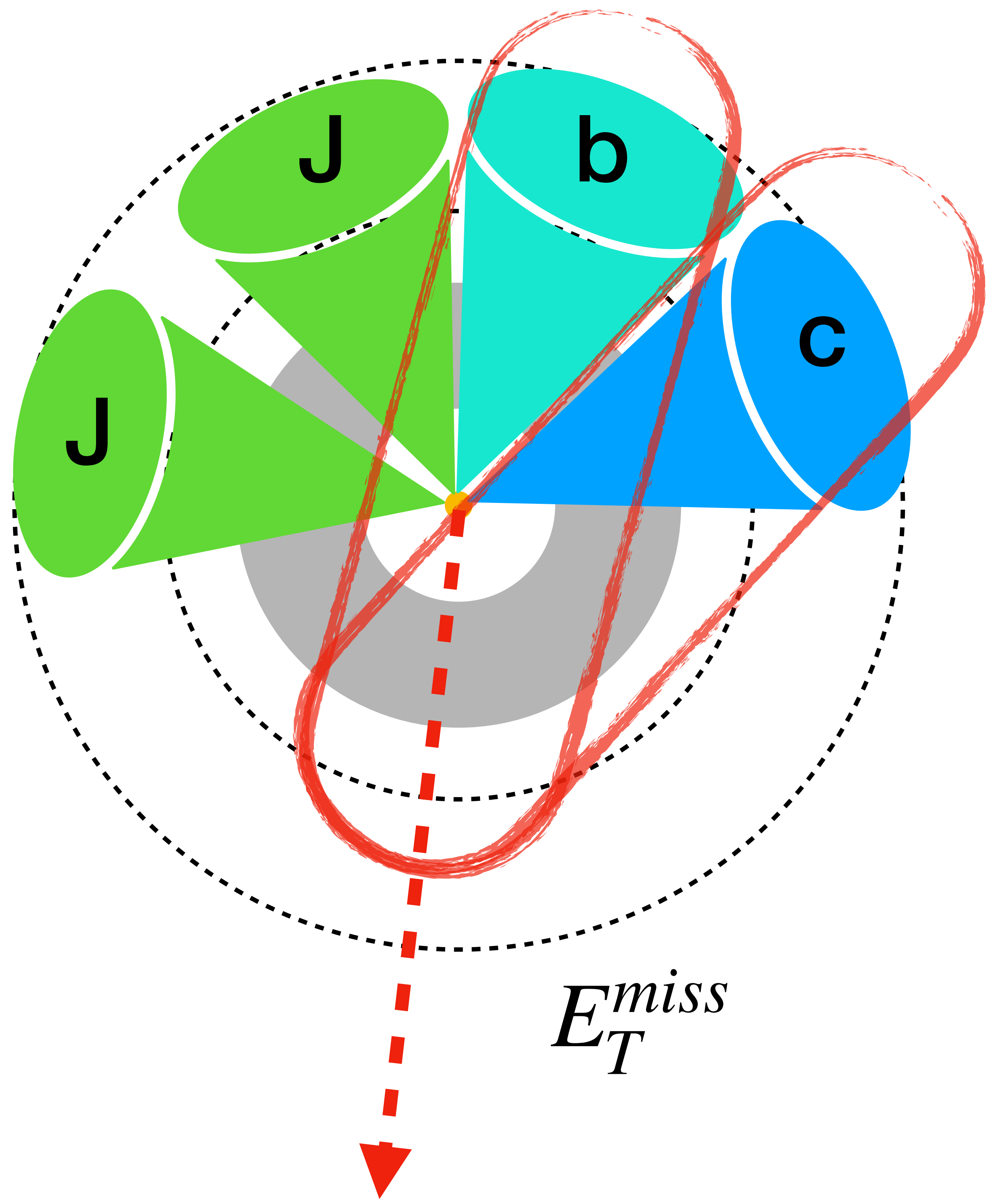
Boosted top quark decays are close enough to be reconstructed as a large-R jet

Sensitive **Variables**



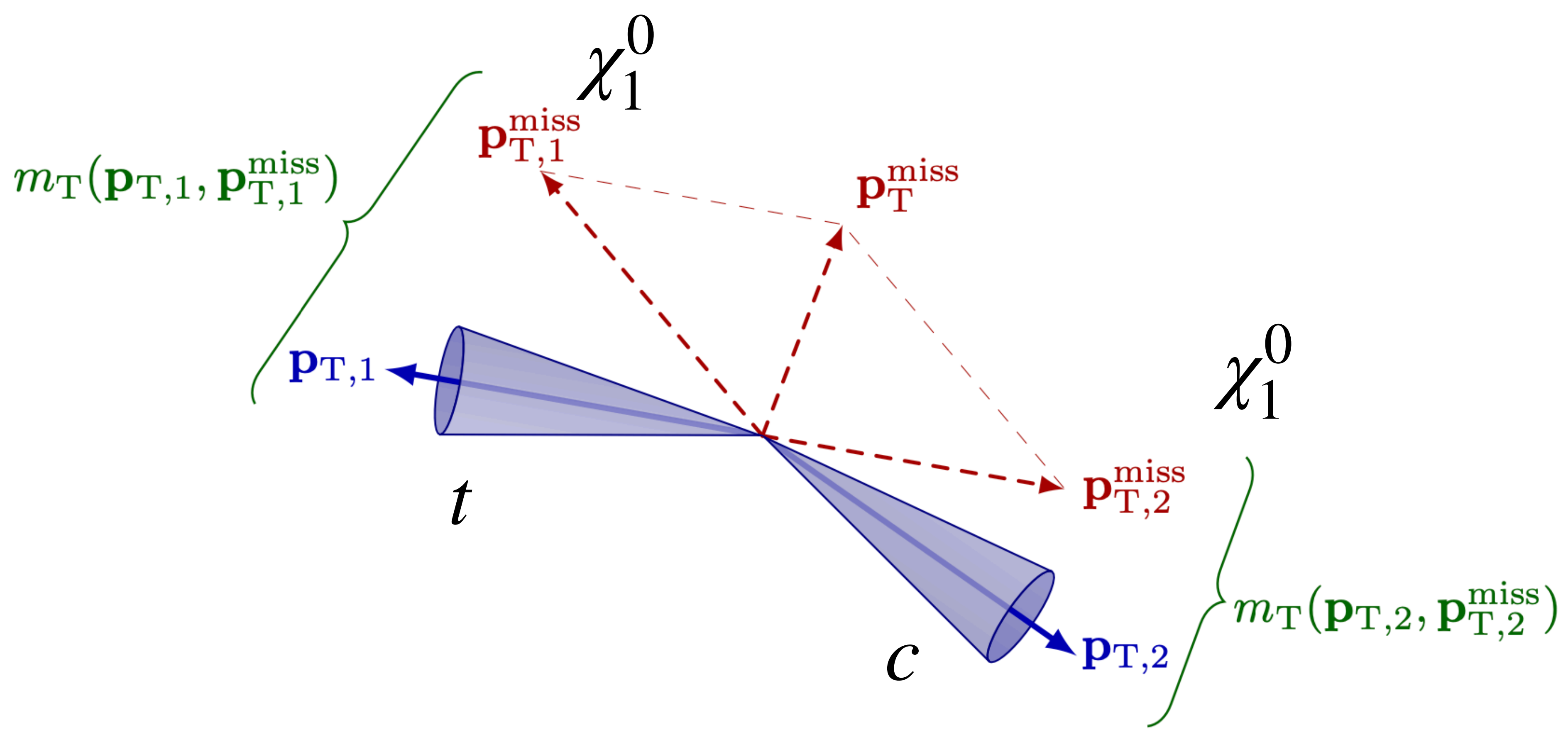
$m_T(j, E_T^{miss})_{close}$

Transverse mass between the closest jet to E_T^{miss} and the E_T^{miss}



$min[m_T(b/c, E_T^{miss})]$ and $max[m_T(b/c, E_T^{miss})]$

Minimum and **maximum transverse mass** between **b-tagged** and **c-tagged** jets and the E_T^{miss}



m_{T2} **STransverse mass**

Looping over **all possible combinations of** $p_{T,1}$ **and** $p_{T,2}$