SFU
SIMON FRASER UNIVERSITY

ATLAS EXPERIMENT

Dark Showers: ATLAS Experimental Overview

Dark Showers Workshop
21 January 2025

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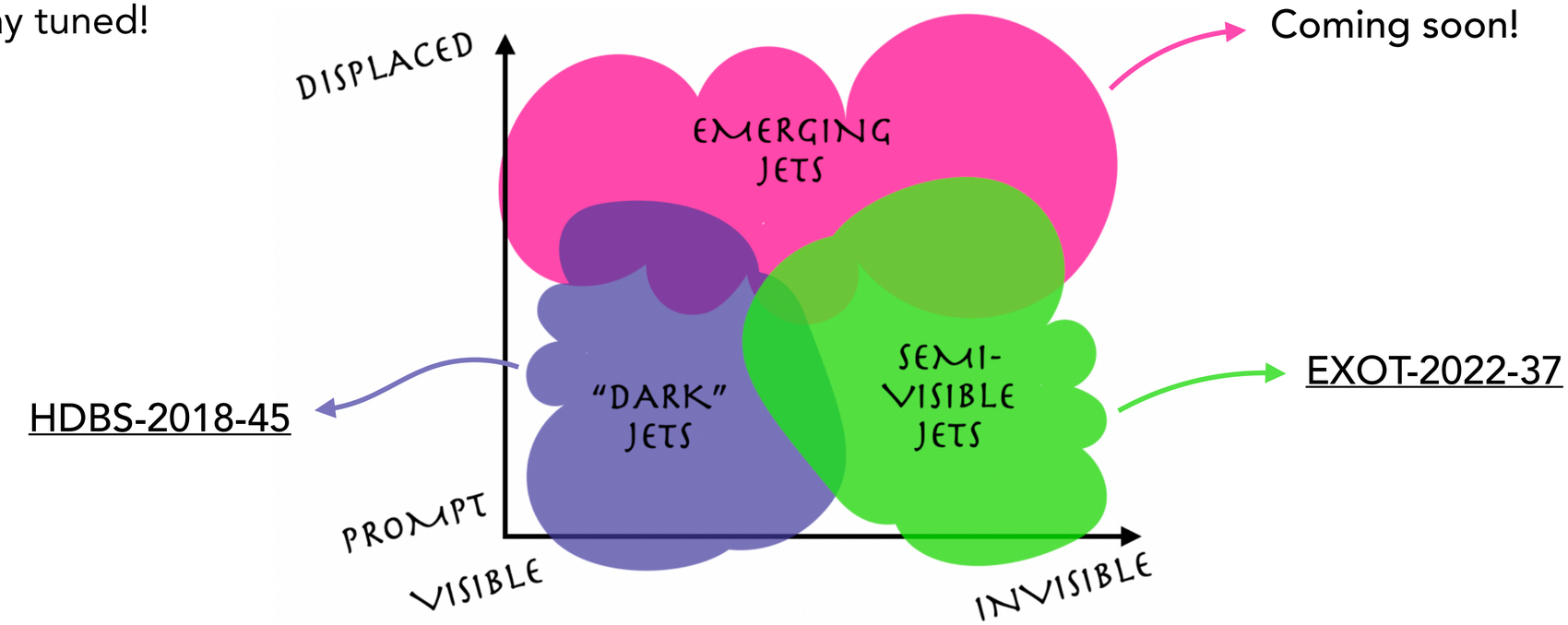
Overview

ATLAS has a robust and ongoing Dark QCD search program

- **Semivisible jets**: t-channel production using Run 2 data
- **Dark jets**: s-channel production using Run 2 data
- **Emerging jets:** 🧐 … stay tuned!



Not discussed today but also relevant: search for dark mesons decaying to top and bottom quarks (EXOT-2023-09)

Semivisible jets

Phys. Lett. B 848 (2024) 138324

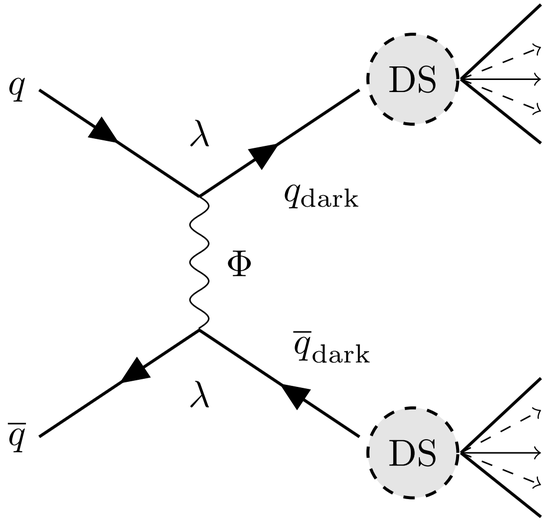
Search for t-channel production of dark quarks via bifundamental mediator Φ

Model parameters:

- m_{q_d}: mass of dark quark
- m_{π_d}/m_{ρ_d}: mass of dark pion/rho
- r_{inv}: #stable dark hadrons/#all dark hadrons
- m_{Φ}: mass of mediator

Parameters used:

- $m_{q_d} = 10$ GeV ($n_f = 1$)
- $m_{\pi_d} = 10$ GeV, $m_{\rho_d} = 20$ GeV
- $r_{\text{inv}} = 0.1 - 0.9$
- $m_{\Phi} = 1 - 5$ TeV



The general topology of the signal events shows negligible sensitivity to the chosen mass values

Detailed Pythia HV module settings:

Parameter	value
HiddenValley:Ngauge	2
HiddenValley:FSR	on
HiddenValley:spinFv	0
HiddenValley:fragment	on
HiddenValley:pTminFSR	1.1
HiddenValley:probVector	0.75
HiddenValley:alphaOrder	1
HiddenValley:Lambda	0.1
HiddenValley:alphaFSR	1.0

Semivisible jets

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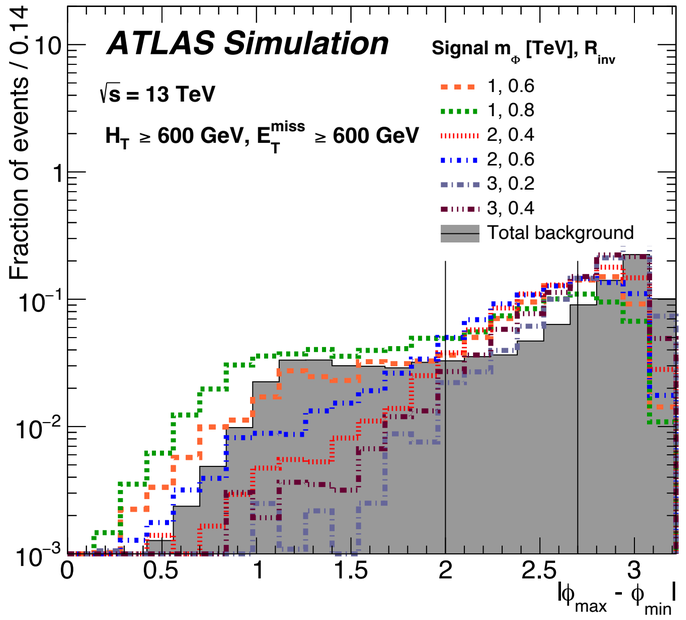
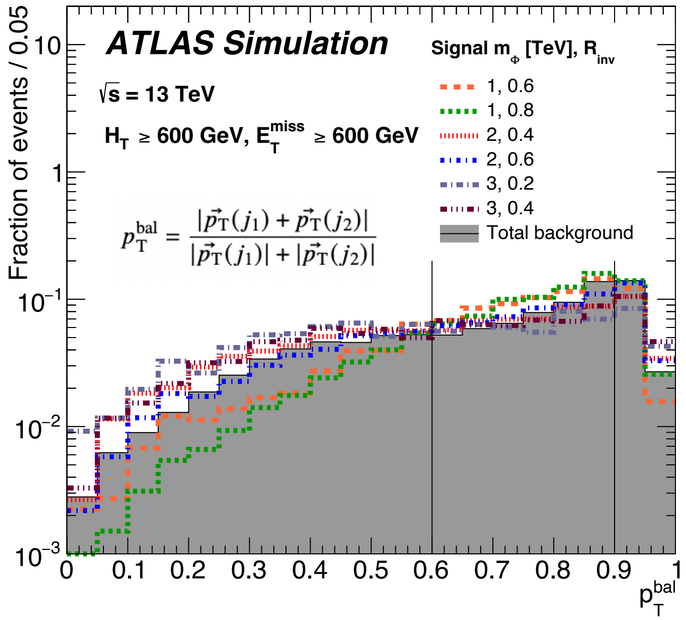
Baseline analysis selections:

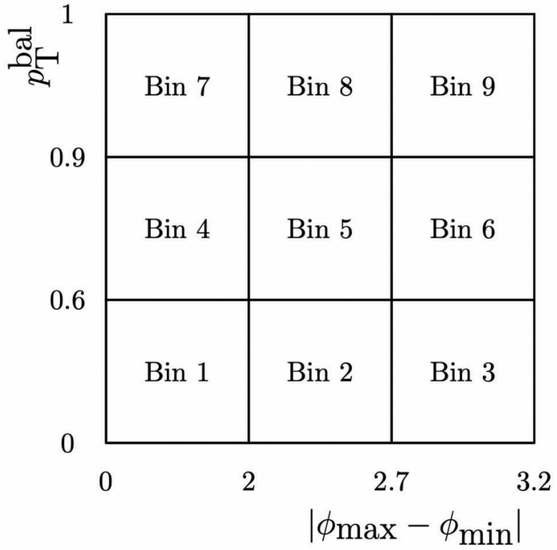
- $n_{\text{jet}} \geq 2$, $E_{\text{T}}^{\text{miss}} > 250$ GeV, $\Delta\phi(\text{closest jet}, \vec{\text{E}}_{\text{T}}^{\text{miss}}) < 2$
- Events selected with $E_{\text{T}}^{\text{miss}}$ trigger

Signal region defined by requiring $H_{\text{T}} > 600$ GeV, $E_{\text{T}}^{\text{miss}} > 600$ GeV, and zero leptons

Two key observables used to design a 9 bin grid: yield in each bin treated as an observable







Semivisible jets

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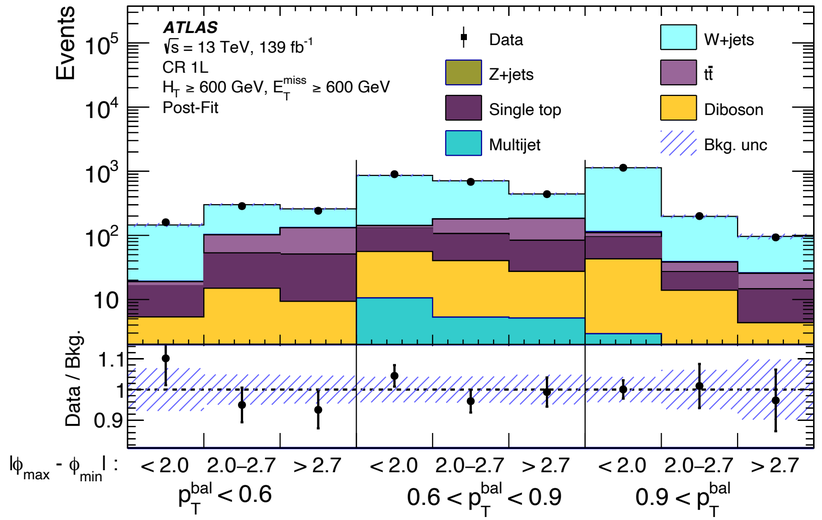
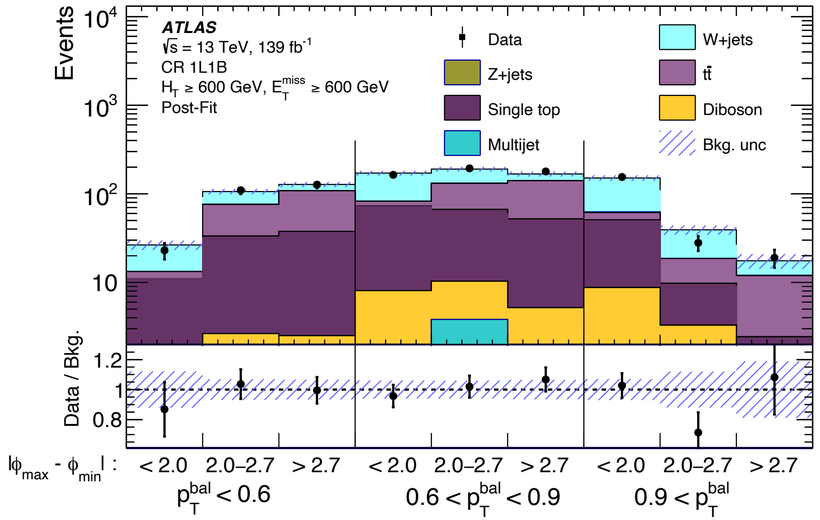
Background estimated from simulated background samples constrained from three dedicated CRs:

- Dominant backgrounds: V + jets, $t\bar{t}$, single top, VV, QCD

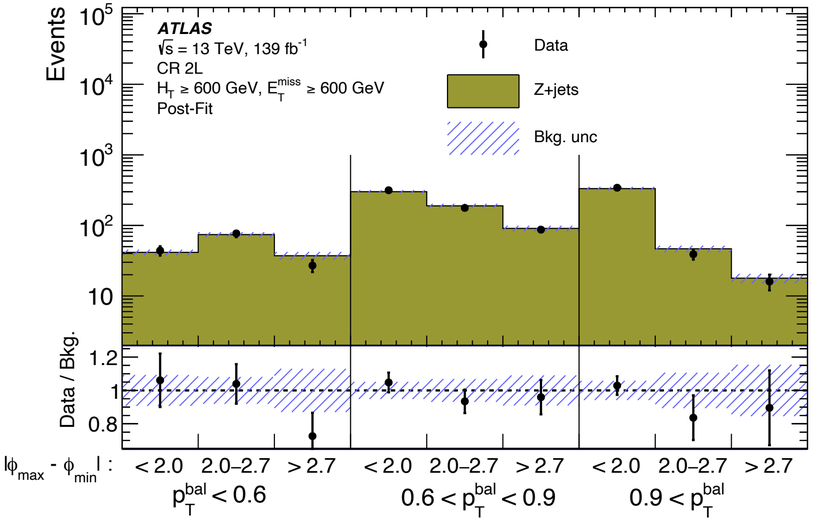
1ℓ



$1\ell 1b$



2ℓ



low-$E_{\mathrm{T}}^{\mathrm{miss}}$ multijet reweighting region ($250 < E_{\mathrm{T}}^{\mathrm{miss}} < 300$ GeV) used to correct simulated QCD background normalization

Semivisible jets

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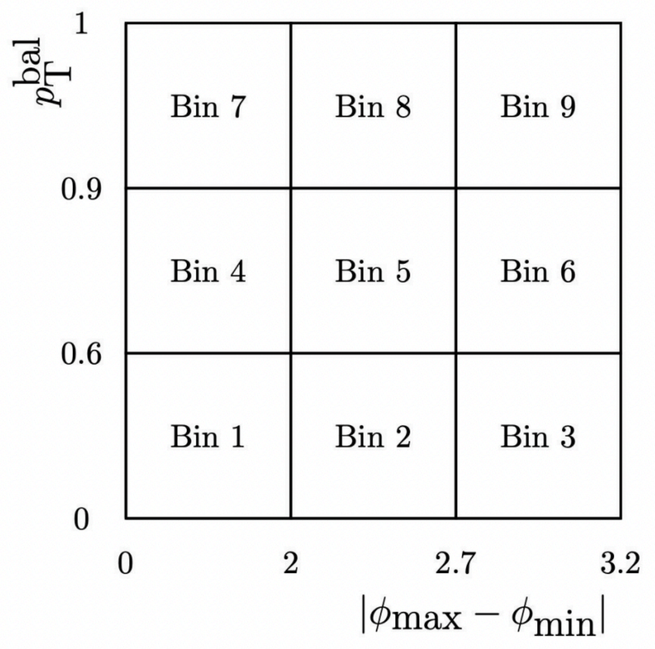
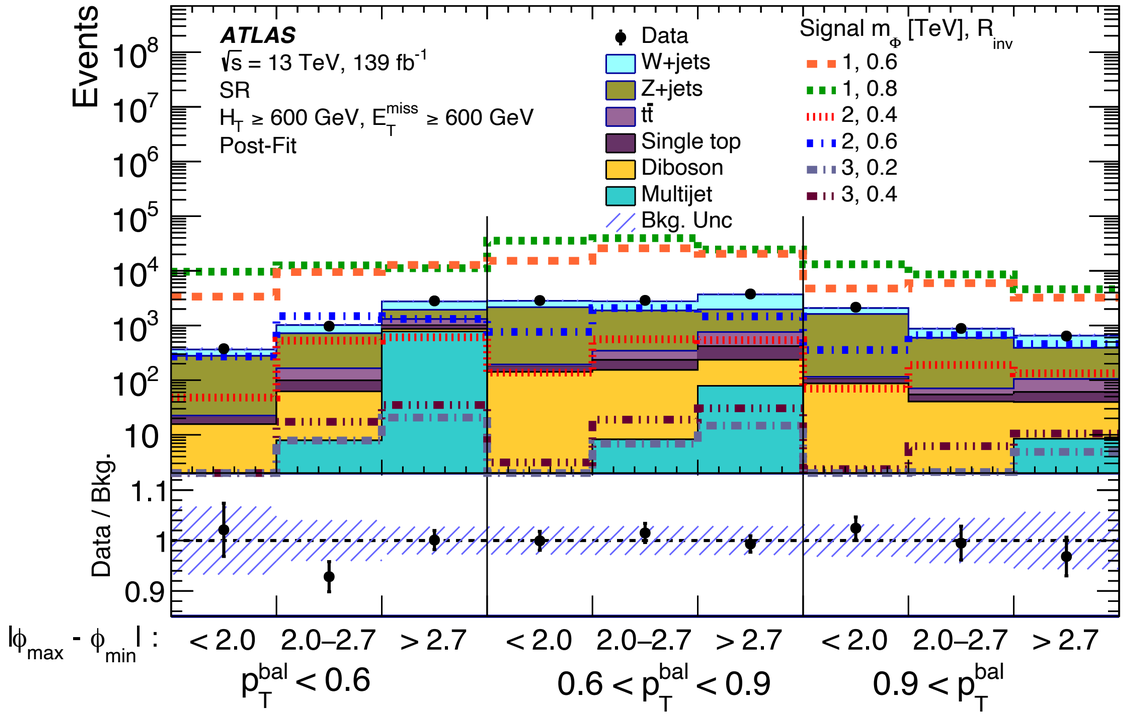
Simultaneous fit is performed to the SR and three CRs





Good agreement is observed between post-fit background estimate and observed data within uncertainties

Semivisible jets

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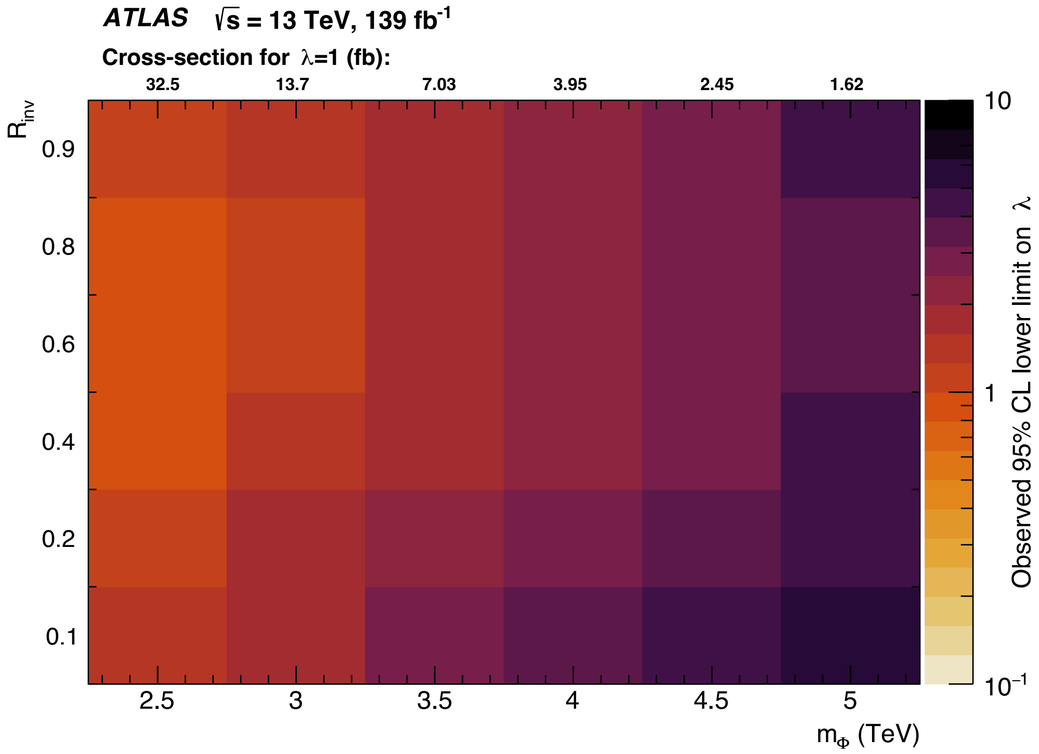
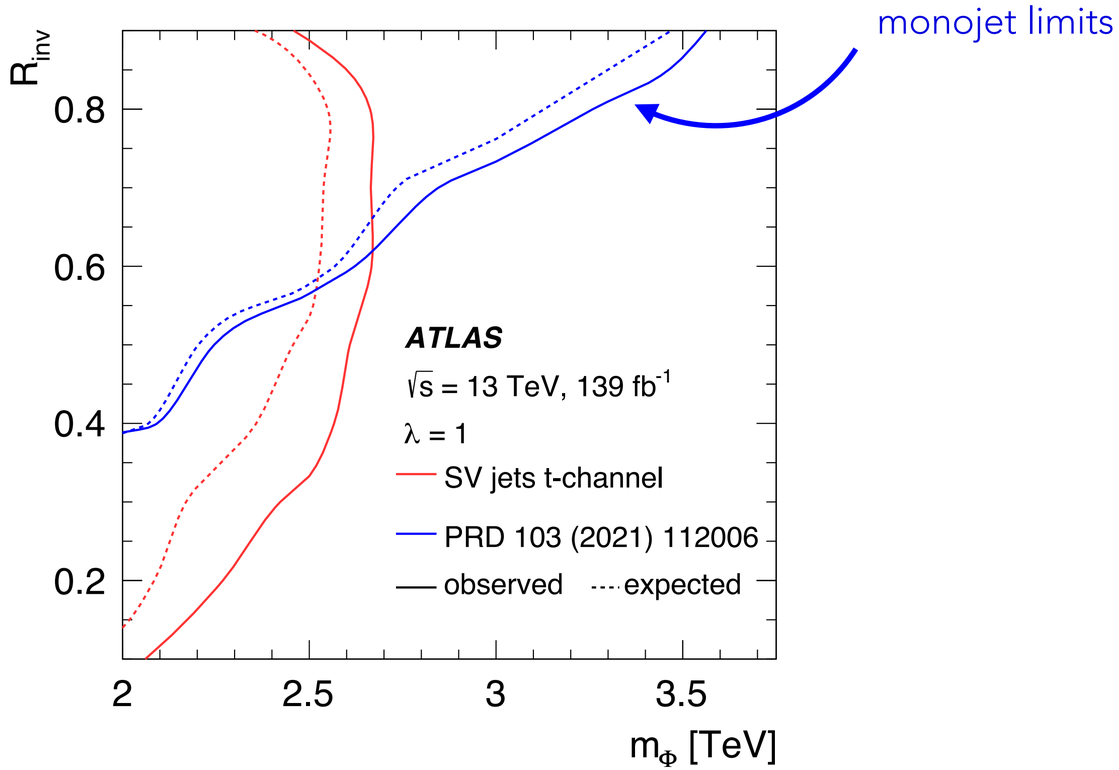
Upper limits extracted on σ as a function mediator mass for different r_{inv}

- Assuming $\lambda = 1$, mediator masses up to 2.7 TeV are excluded





Monojet search reinterpreted using SVJ signal and found to offer complementary sensitivity

Dark jets

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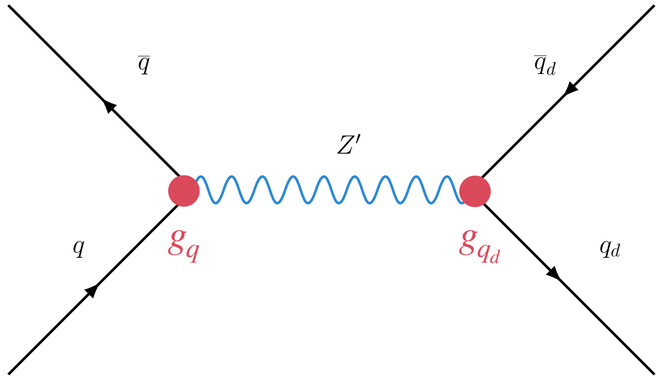
Search for s-channel production of dark quarks via vector mediator Z'

- Consider unstable, promptly decaying dark mesons



Z' production and decay governed by coupling to quarks (g_q) and dark quarks (g_{q_d})

- For $g_{q_d} \gg g_{q'}$ dark jet final state dominates
- Dark shower dynamics lead to weakened constraints from dijet resonance searches

Four combinations of parameters are chosen to cover different phase space:

Model	n_f	Λ_d (GeV)	$\tilde{m}_{q'}$ (GeV)	m_{π_d} (GeV)	m_{ρ_d} (GeV)	π_d decay mode
A	2	15	20	10	50	$\pi_d \to c\bar{c}$
B	6	2	2	2	4.67	$\pi_d \to s\bar{s}$
C	2	15	20	10	50	$\pi_d \to \gamma'\gamma'$ with $m_{\gamma'} = 4.0$ GeV
D	6	2	2	2	4.67	$\pi_d \to \gamma'\gamma'$ with $m_{\gamma'} = 0.7$ GeV

Consider $\rho_d \to \pi_d\pi_d \to 4q$,
or $\rho_d \to \pi_d\pi_d \to 4\gamma_d$

Goal: exploit dark shower signature to improve on constraints set by $Z' \to qq$ dijet resonance searches

Dark jets

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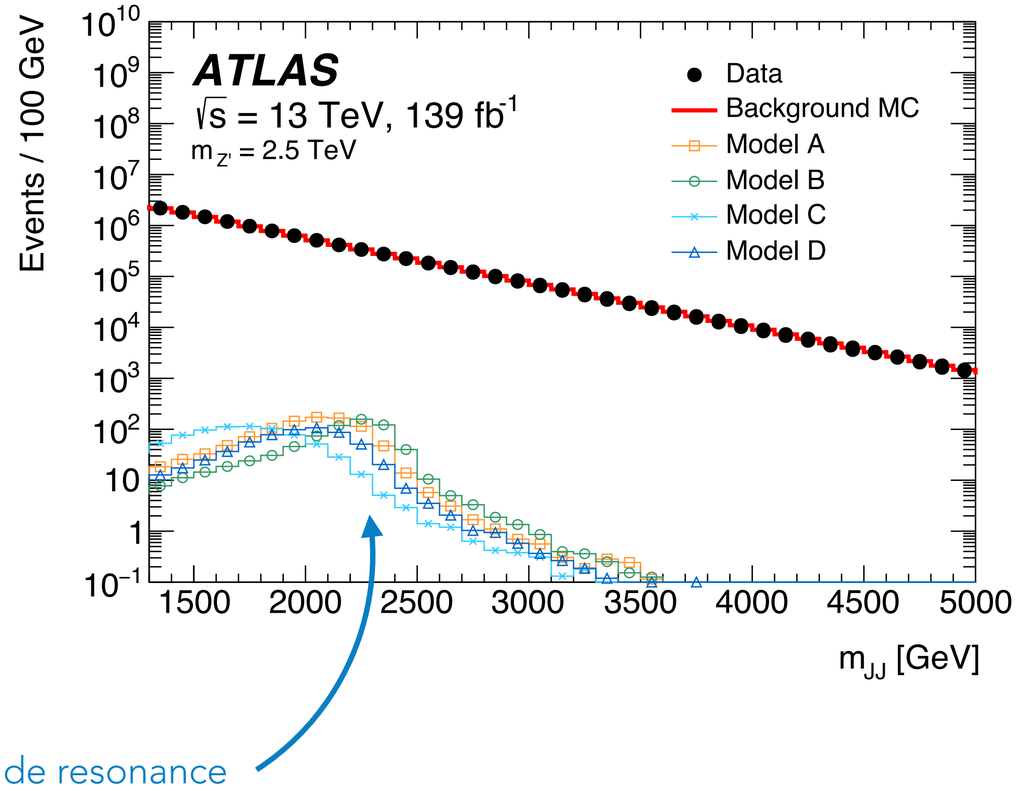
Analysis strategy: search for resonant excess in the dijet invariant mass distribution above QCD background

Baseline selections:

- Large-R jet trigger
- At least two Large-R jets with $R = 1.0,\ |\eta| < 2$
- Lead jet $p_{\mathrm{T}} > 500\ \mathrm{GeV}$, sublead jet $p_{\mathrm{T}} > 400\ \mathrm{GeV}$
- $50 < m_J < 600\ \mathrm{GeV}$
- $m_{jj} > 1.3\ \mathrm{TeV}$ to ensure full trigger efficiency



Dark jet topology characterized by a wide resonant peak

- Key feature which makes standard dijet resonance searches ineffective

Dark jets

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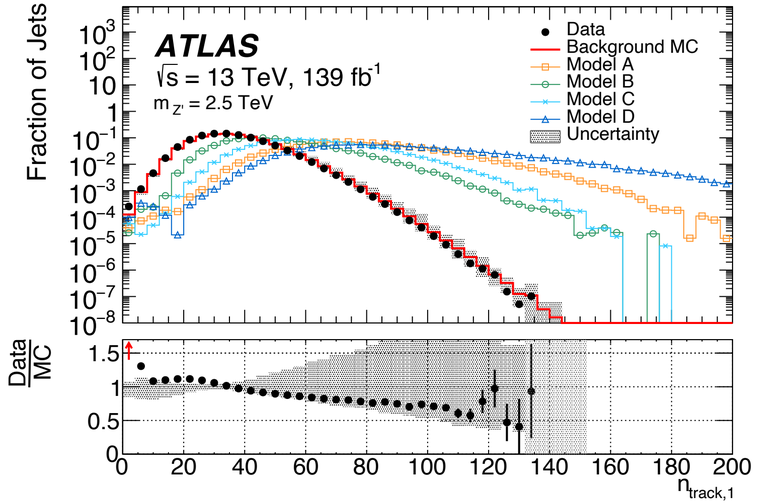
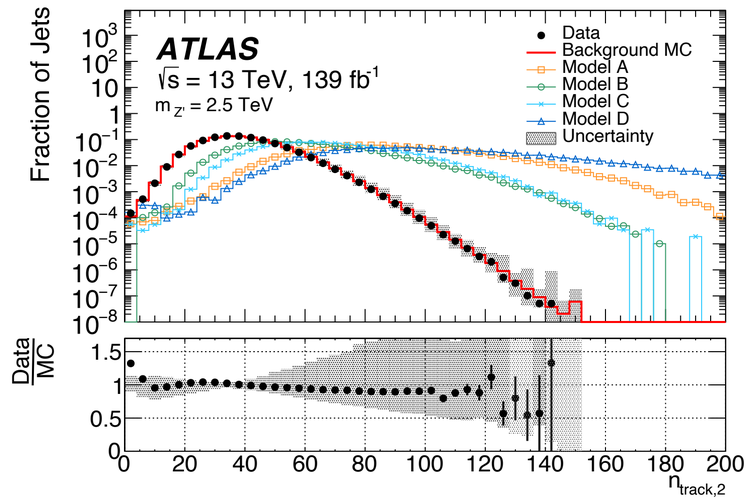
Main discriminating variables: number of tracks ghost-associated to leading ($n_{\text{track},1}$) and subleading jet ($n_{\text{track},2}$)





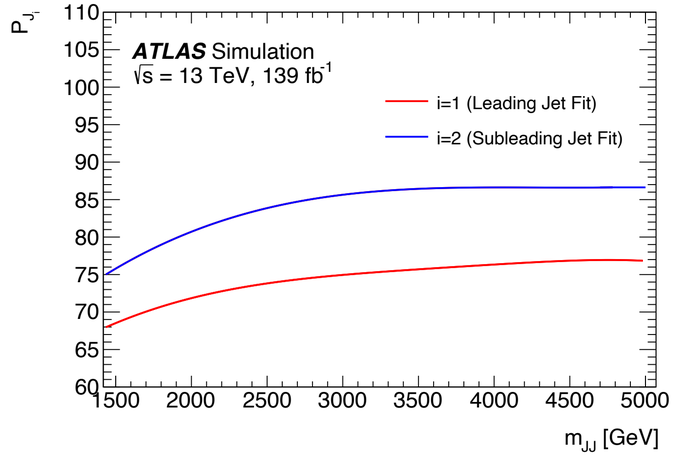
Problem: cutting on n_{track} would sculpt the m_{jj} distribution

Solution: define decorrelated observable: $n^{\epsilon}_{\text{track}}(m_{jj}) = n_{\text{track}} - P(m_{jj})$

- Defined to select background jets with efficiency of $\epsilon = 1\,\%$

Signal region is defined by requiring $n^{\epsilon}_{\text{track},1} > 0$ and $n^{\epsilon}_{\text{track},2} > 0$

- Reduces the multijet background by approximately 99.99%



Dark jets

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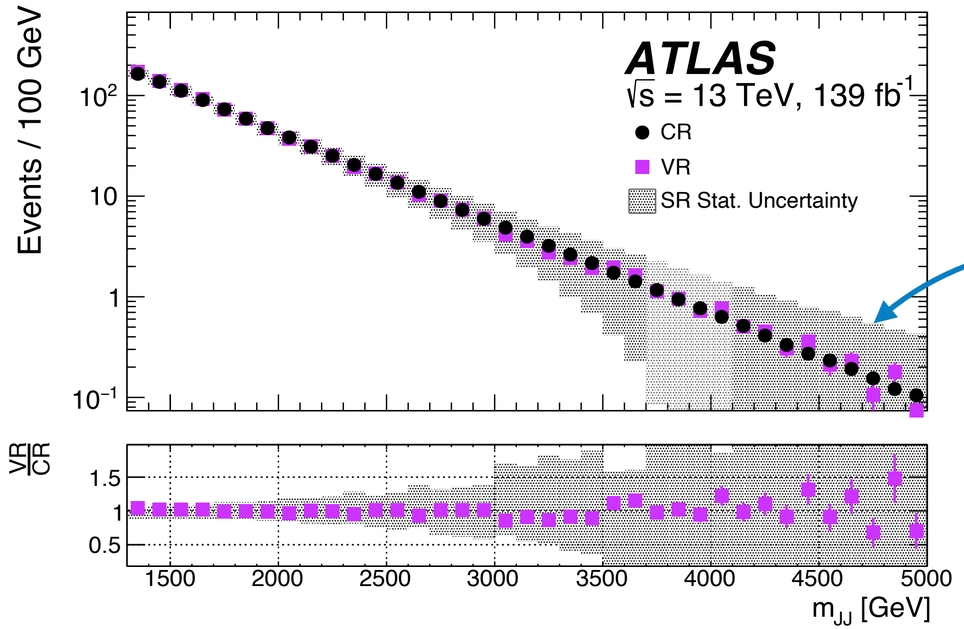
Background shape template derived from control region with $n^{\epsilon}_{\text{track}} < 0$ for two leading jets

- Decorrelated from m_{jj} by construction

Validation region built by requiring $n^{\epsilon}_{\text{track},1} > 0$ and $n^{\epsilon}_{\text{track},2} < 0$

- Used to test ability of scaled CR template to describe data in signal-adjacent region



excellent agreement observed!

Dark jets

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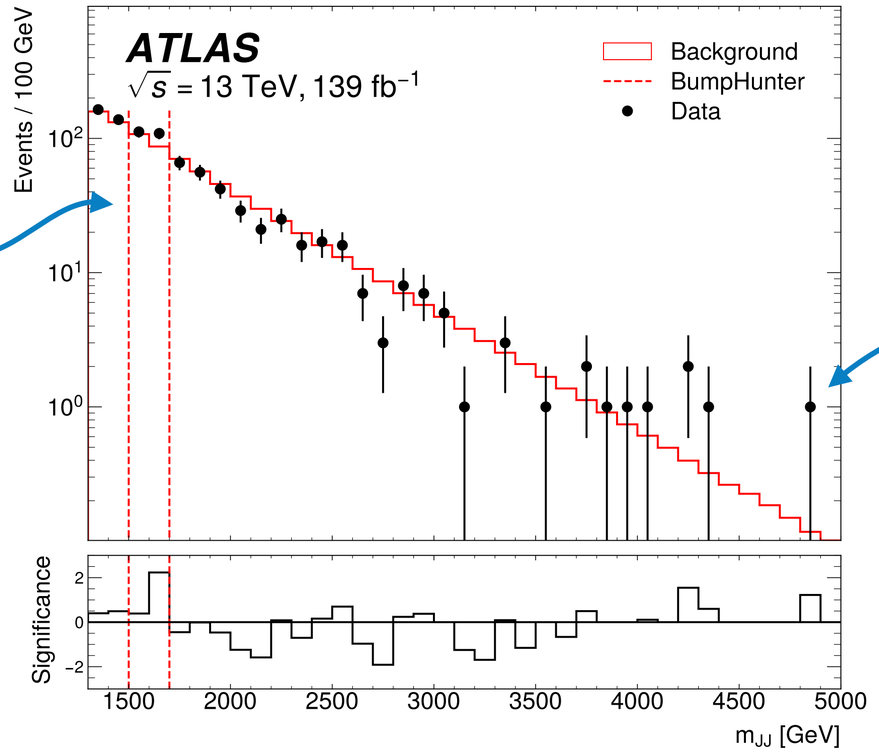
Background template then normalized to observed data in the SR from a maximum likelihood fit

- Bumphunter algorithm used to test compatibility with the background-only hypothesis
- No significant excess observed

Most discrepant interval identified at $1500 < m_{jj} < 1700$ GeV with p_0-value of 0.63



Highest m_{jj} event observed at 4.8 TeV

Dark jets

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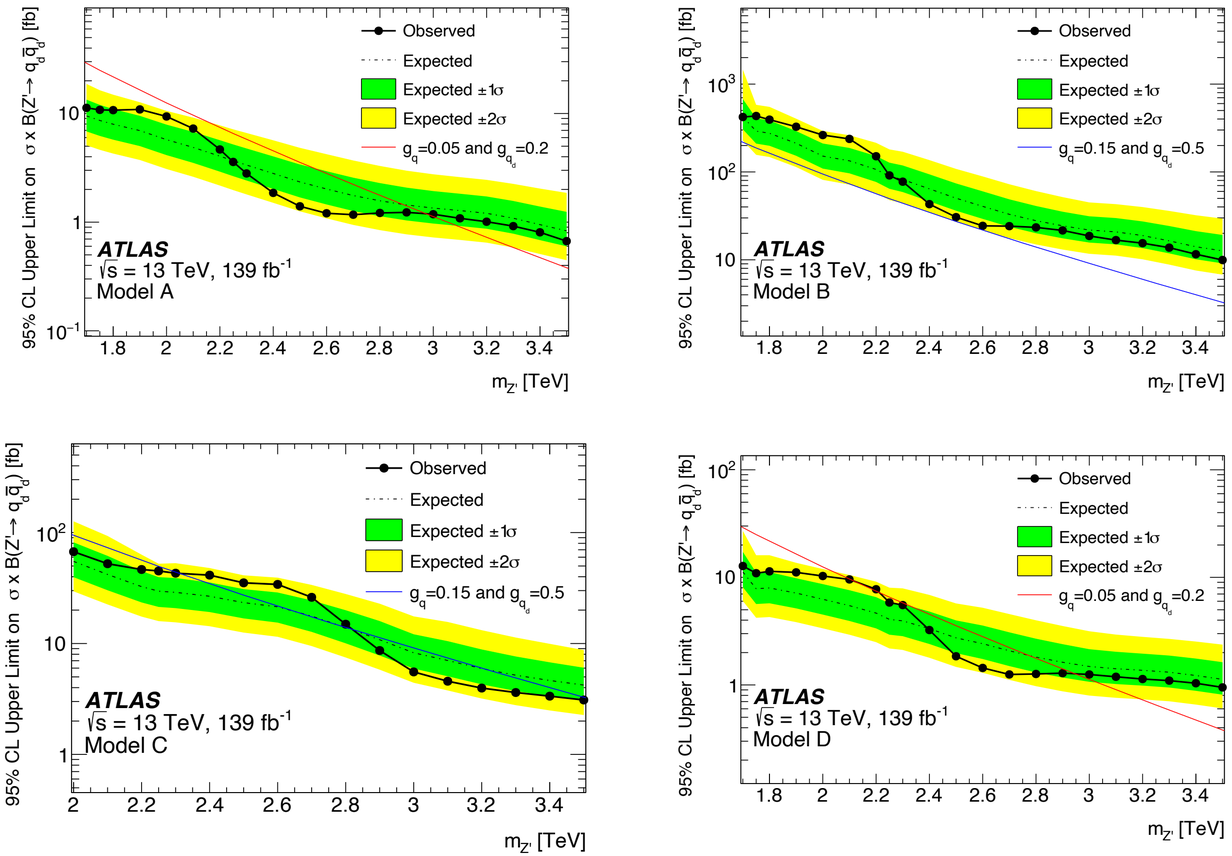
Limits set on $\sigma \times B(Z' \to q_d q_d)$ for four benchmark models

- Probe g_q values down to 0.05 for Z' masses up to ~3-3.5 TeV



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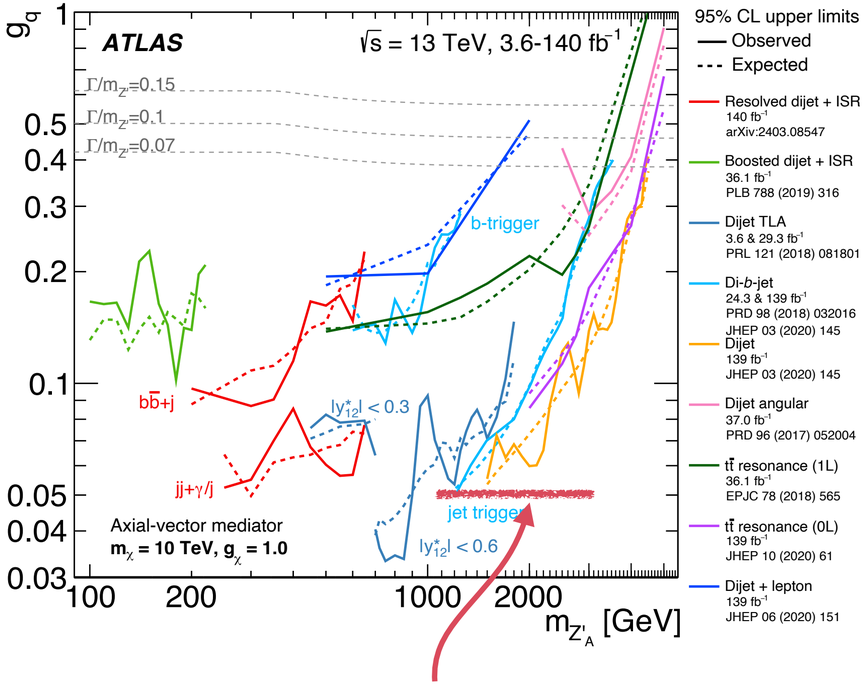
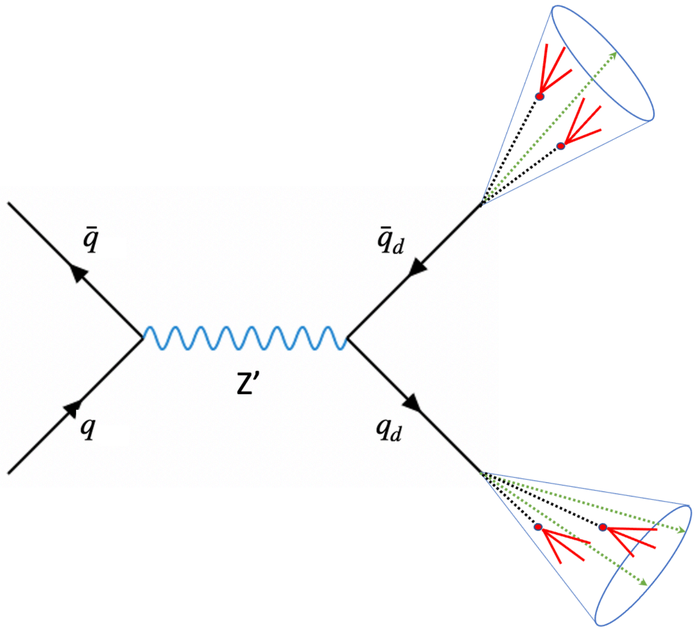


Significantly stronger than vanilla dijet constraints!

Emerging jets

No results yet on emerging jets from ATLAS, but…

New Run 3 triggers will enable searches for resonant s-channel emerging jet production via Z' mediator



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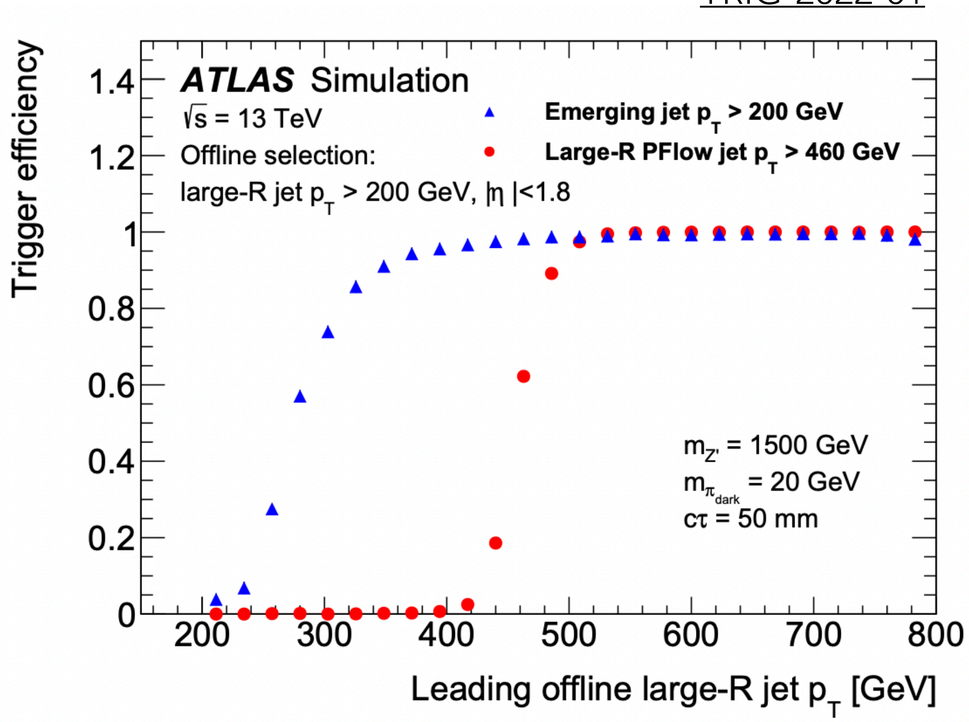

Stay tuned!

Summary

ATLAS dark QCD search program is just getting started!

- First results published for semi-visible and dark jets using full Run 2 dataset
- More Run 2 results on the way, stay tuned!

New triggers for Run 3 and lessons learned from Run 2 will expand and improve upon first wave of dark QCD results

- Very timely to begin these benchmarking discussions :)

Some personal food for thought:

- The landscape of potential dark QCD parameter space is extremely vast…

  → Beyond settling on common benchmark points, we must also dedicate significant effort to making our dark QCD searches reinterpretable to facilitate constraints on future benchmarks

  → LHC reinterpretation workshop next month a good forum to continue these discussions!