Dark Jet Resonance Search

Status and Outlook

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Motivation: Composite Dark Matter

- Direct and indirect **WIMP searches have come up empty** so far
- Cosmological simulations allow self-interacting dark matter (DM)
  - E.g. composite DM arising from a hidden sector with confinement ("dark QCD")

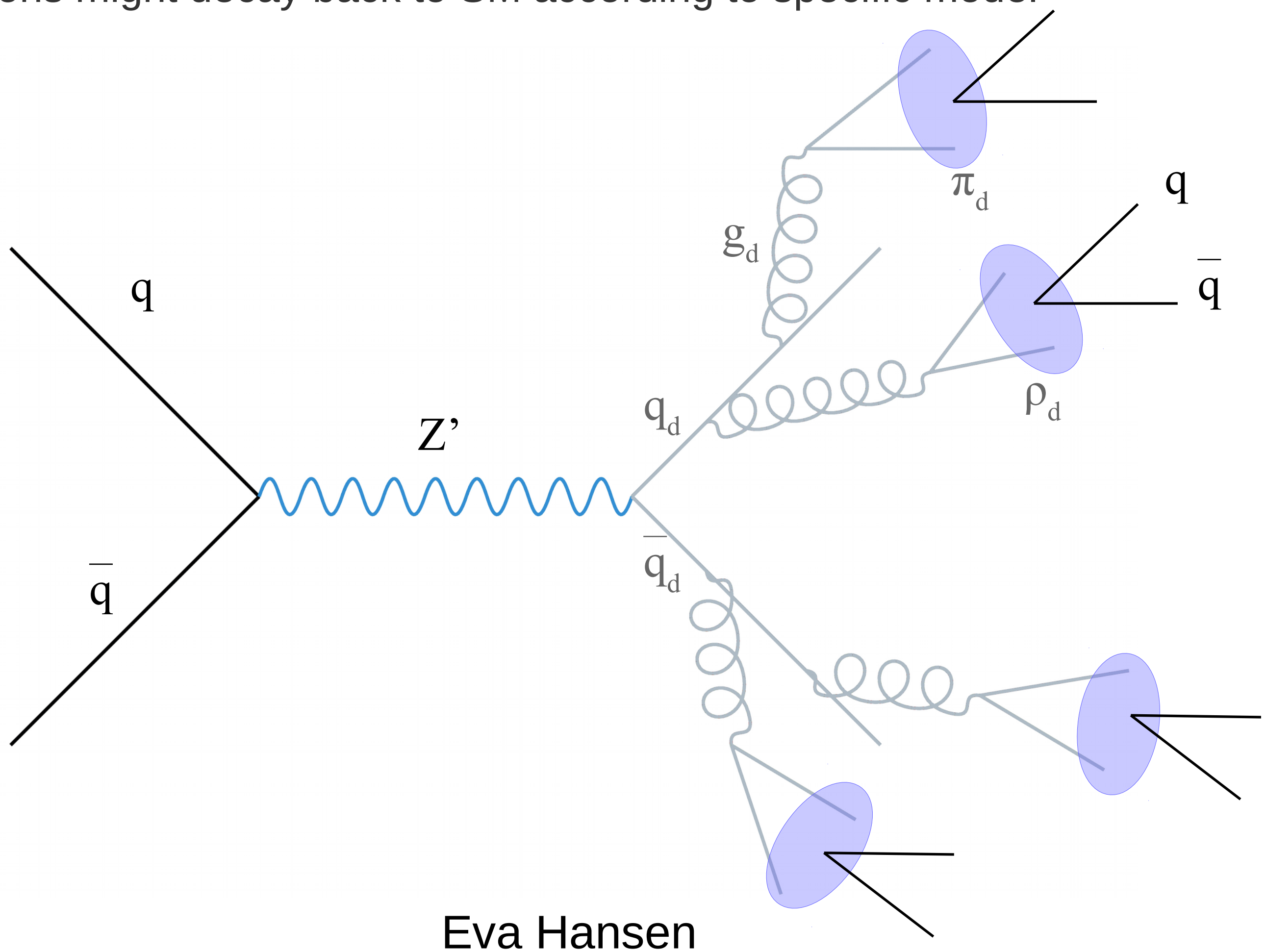
References in Backup

- Combined with asymmetric production, composite DM could explain mass and number density of DM and Baryons
- Requires heavy mediator linking hidden sector to visible sector

→ Perhaps we can **produce and detect hidden sector particles at the LHC!**

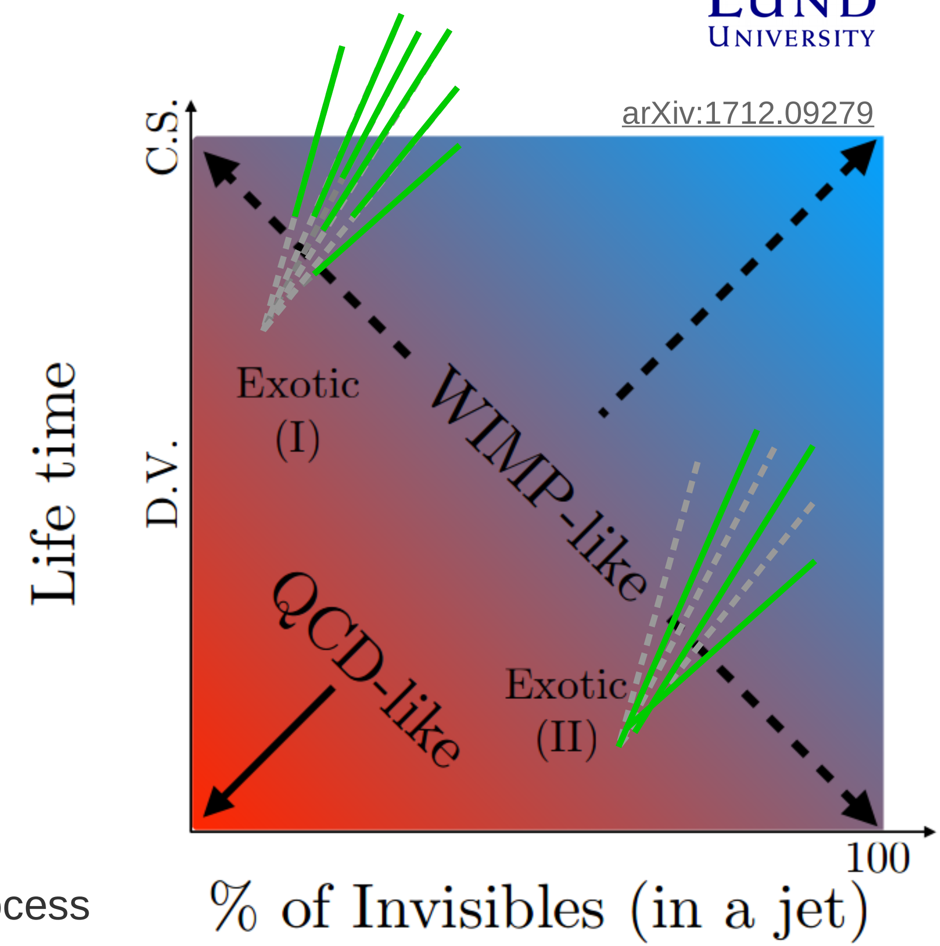
”Dark QCD”

- Hidden sector with confinement coupled to SM through a heavy mediator
- Showering and hadronisation happens in the dark sector
- The lightest baryon is stable and a DM candidate
- Some mesons might decay back to SM according to specific model



Benchmark Signal Models

- Different realisations can lead to very different detector signatures
- Composition of **visible** and **invisible** partons in the jet dependent on parameter choice:
  - Exotic I: Displaced vertices, emerging jets
  - Exotic II: Semi-visible jets
  - **We target SM QCD-like models**
    - With *s*-channel mediator decaying to two dark quarks

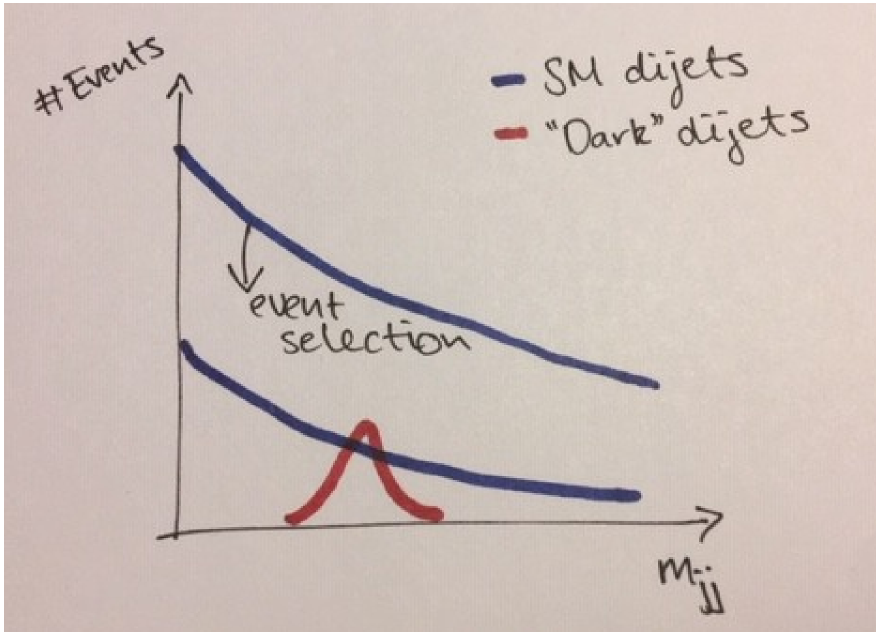


- Four models implemented in Pythia Hidden Valley process
  - **All have larger confinement scales than SM QCD**
    - Based on arXiv:1712.09279

Search strategy

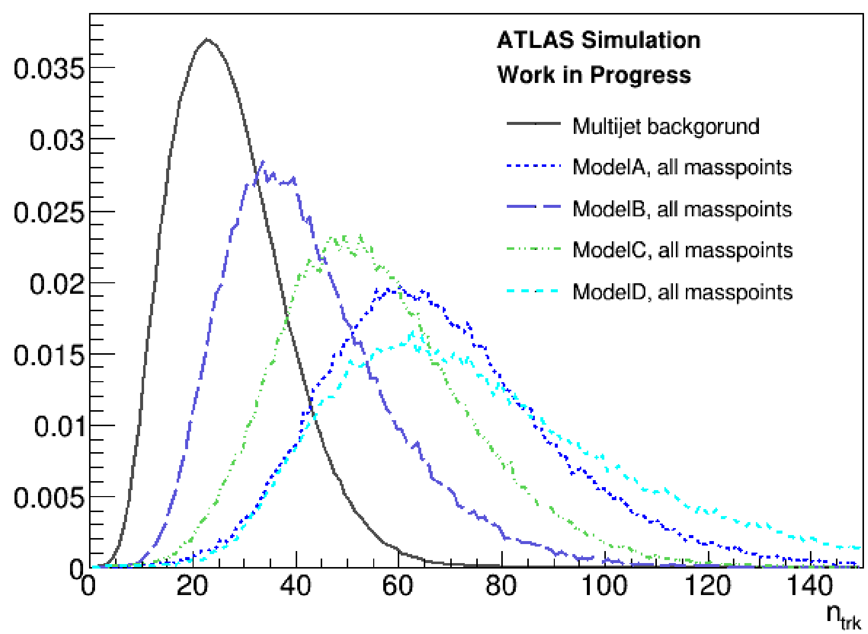
arXiv:1712.09279

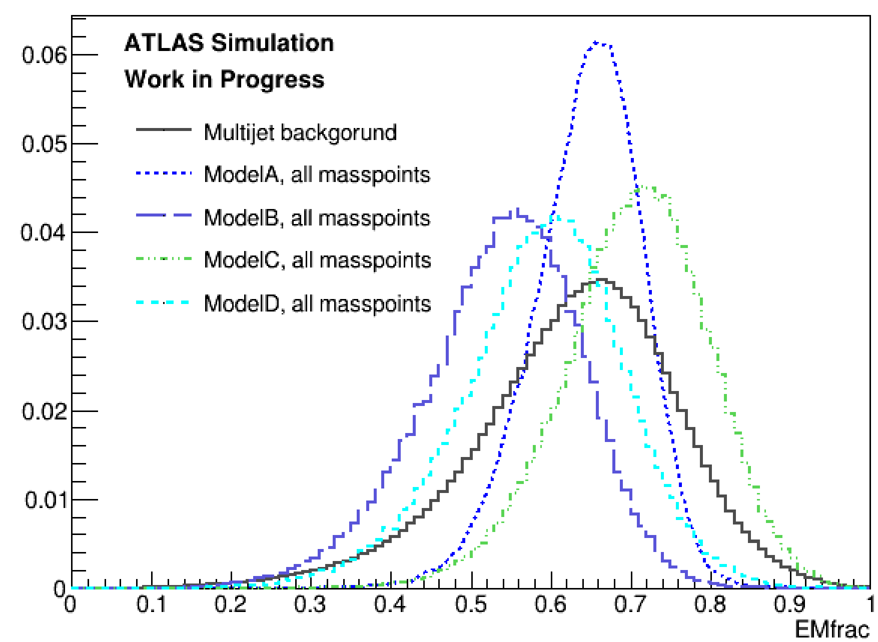
- Dominant background is Standard Model dijet events
  - Invariant mass spectrum is a smoothly falling
- Larger dark α_s means wider jets with larger particle multiplicity
- Strategy:
  - Reconstruct large-radius jets using Anti-kt algorithm with R=1.0
  - Select signal-like dijet events based on **substructure variables**
  - Look for a bump in the dijet invariant mass spectrum



Signal Selection

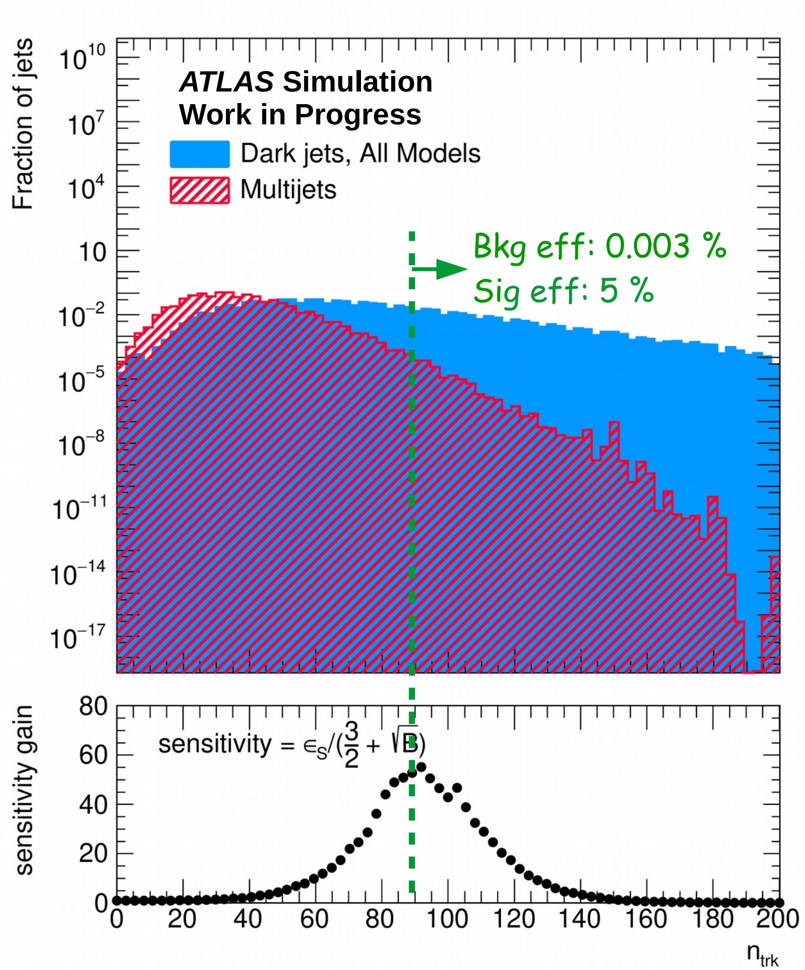
- Charged track multiplicity n_{trk} is strongest discriminating variable for a most models
  - But not for Model B!
- Two signal regions:
  - **SR1:** High sensitivity, very pure, based on strict n_{trk} cut
  - **SR2:** More inclusive, less sensitive based on softer cuts on n_{trk} and EM_{frac}

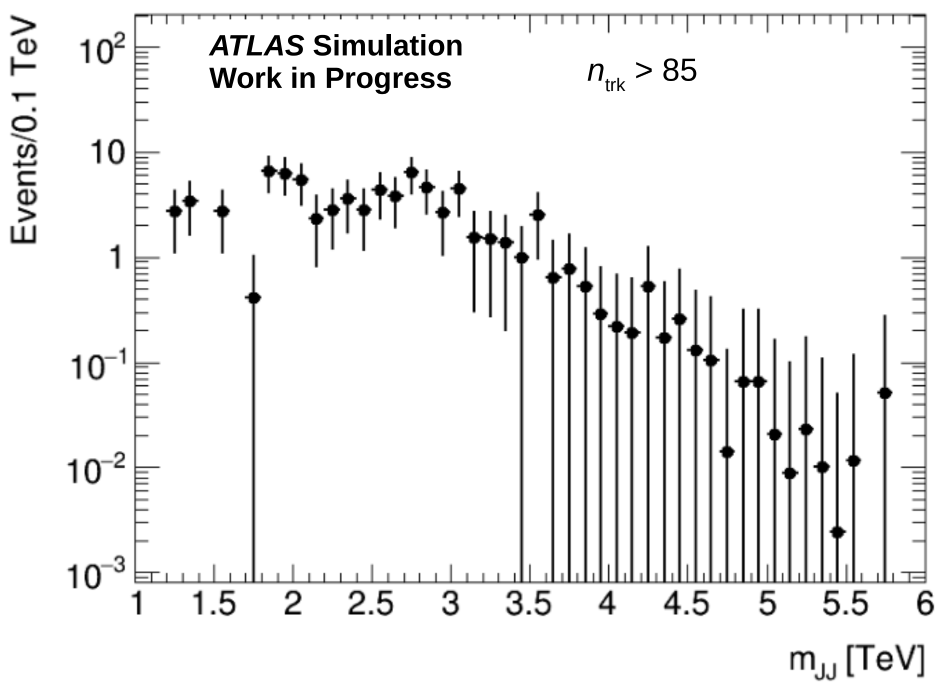




Signal Region 1: Challenge

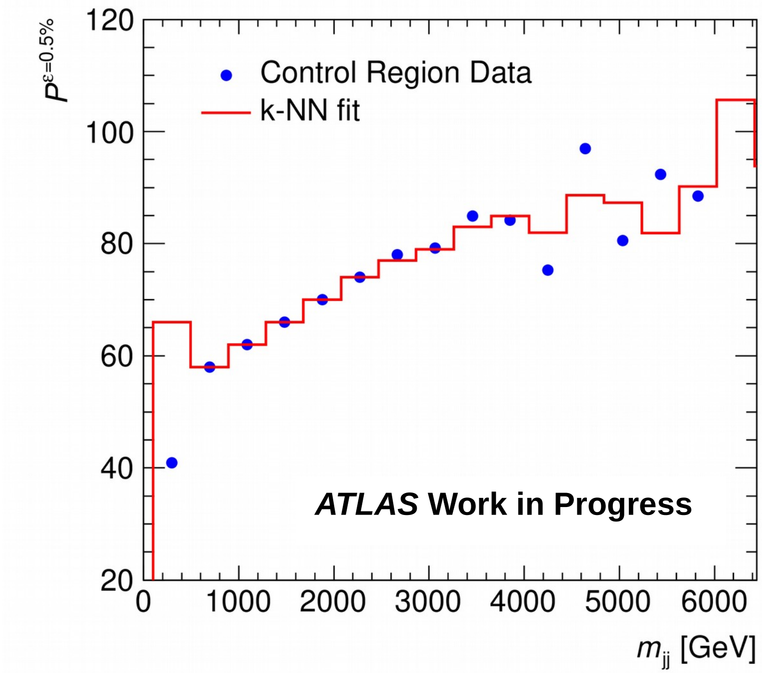
- Best sensitivity for a range of models obtained with very strict cut
- Strict n_{trk} cut significantly sculpts the background dijet mass spectrum
- Solution: Decorrelate n_{trk}-cut efficiency from dijet mass!

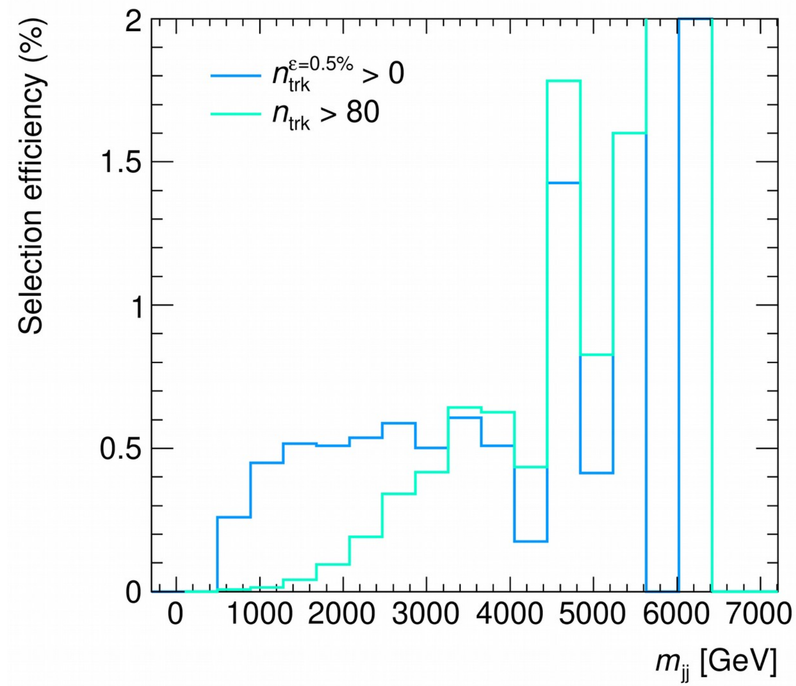




Signal Region 1: Decorrelation method

- ”Fixed-efficiency-regression” decorrelates a discriminating variable from other variables
  - Described and tested in for *W*-tagging in ATL-PHYS-PUB-2017-004

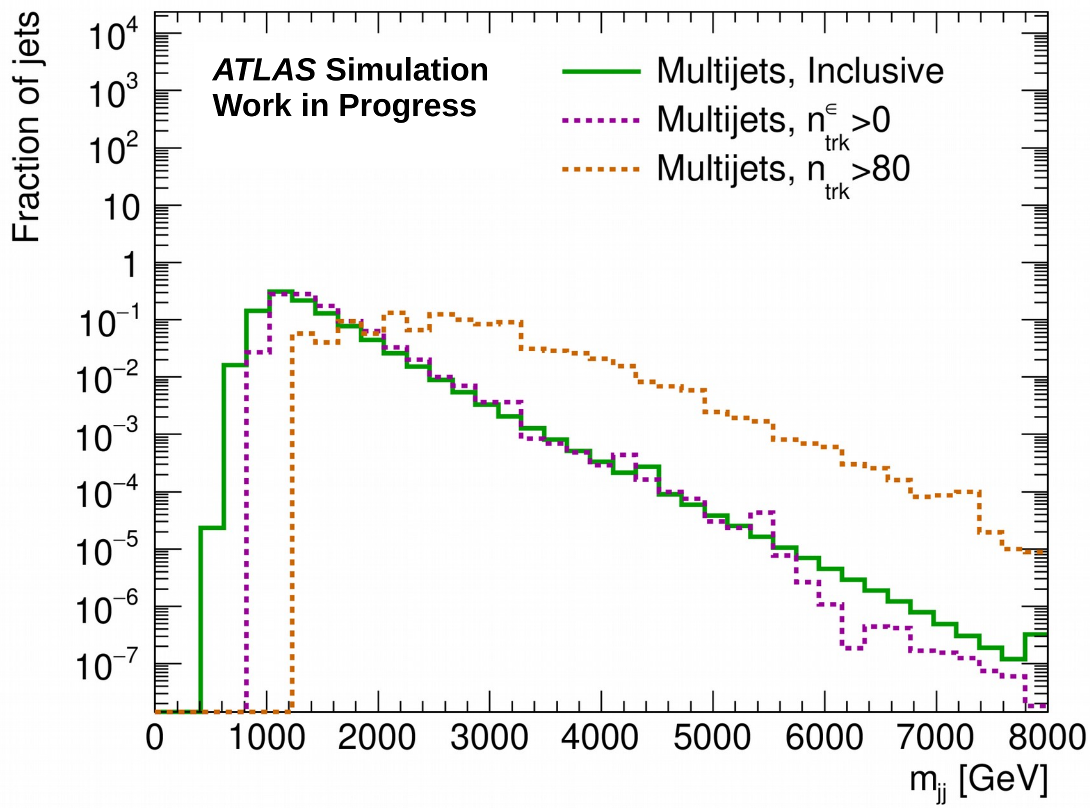




- For each jet, the new decorrelated observable is computed as $n_{trk}^{\varepsilon} = n_{trk} - p^{\varepsilon=0.5\%}$
- Here n_{trk}^{ε} is defined from data in a control region with signal efficiency ~ 0.4 %

Signal Region 1: Results (preliminary)

- Gives a smoothly falling spectrum up to ~5 TeV in MC
- Breaks down at higher mjj because of too low statistics in data sample
- Cut: Leading and sub-leading jet $n_{trk}^{\varepsilon} > 0$
  - Background efficiency: 0.03 %
  - Signal efficiency (all tested models): 31 %



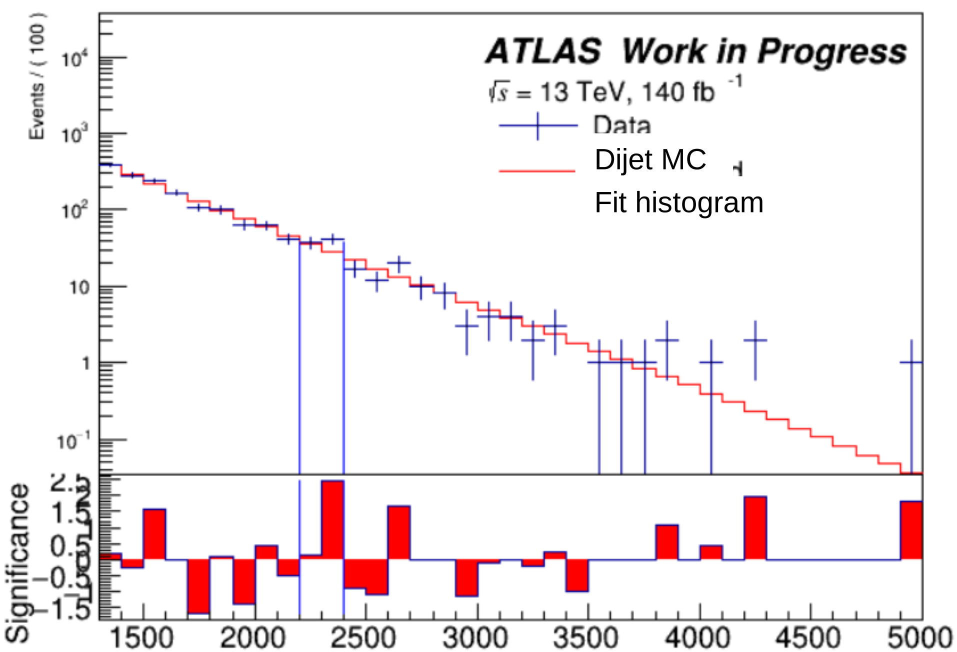
Background description

- The background contribution is determined by fitting data with the parametric function:

$$\frac{dn}{dx} = p_1 (1-x)^{p_2 - \xi p_3} x^{-p_3}$$

- Currently validating the fitting strategy on dijet MC samples doing
  - ”Signal injection test”
  - ”Spurious signal test”

The background only fit: No signal injected



Conclusion and outlook

- Lots of uncovered phase space in hidden sector models
  - We can probe (a small) part of it by searching for dark jets
  - Fun challenges for jet substructure fans!

- Ongoing task:
  - Complete validation of background estimation
  - Optimise binning
  - Evaluate systematic uncertainties on signal and background

- Long term:
  - Optimise choice of jet definition and pile-up removal
  - Study more features, such as muons in jets and missing Et aligned with a jet
  - Combine efforts with emerging jets and semi-invisible jets searches

Backup

- Table of benchmark models

arXiv:1712.09279

	N_d	n_f	Λ_d (GeV)	$\tilde{m}_{q'}$ (GeV)	m_{π_d} (GeV)	m_{ρ_d} (GeV)	π_d Decay Mode	ρ_d Decay Mode
A	3	2	15	20	10	50	$\pi_d \to c\bar{c}$	$\rho_d \to \pi_d \pi_d$
B	3	6	2	2	2	4.67	$\pi_d \to s\bar{s}$	$\rho_d \to \pi_d \pi_d$
C	3	2	15	20	10	50	$\pi_d \to \gamma'\gamma'$ with $m_{\gamma'} = 4.0$ GeV	$\rho_d \to \pi_d \pi_d$
D	3	6	2	2	2	4.67	$\pi_d \to \gamma'\gamma'$ with $m_{\gamma'} = 0.7$ GeV	$\rho_d \to \pi_d \pi_d$

Backup

In all models, Zv → qv qvbar (BR~1.) and qv and qvbar hadronize to piv and rhov with rhov → piv piv (BR=1.)

Model A: piv → c cbar (BR=1.)

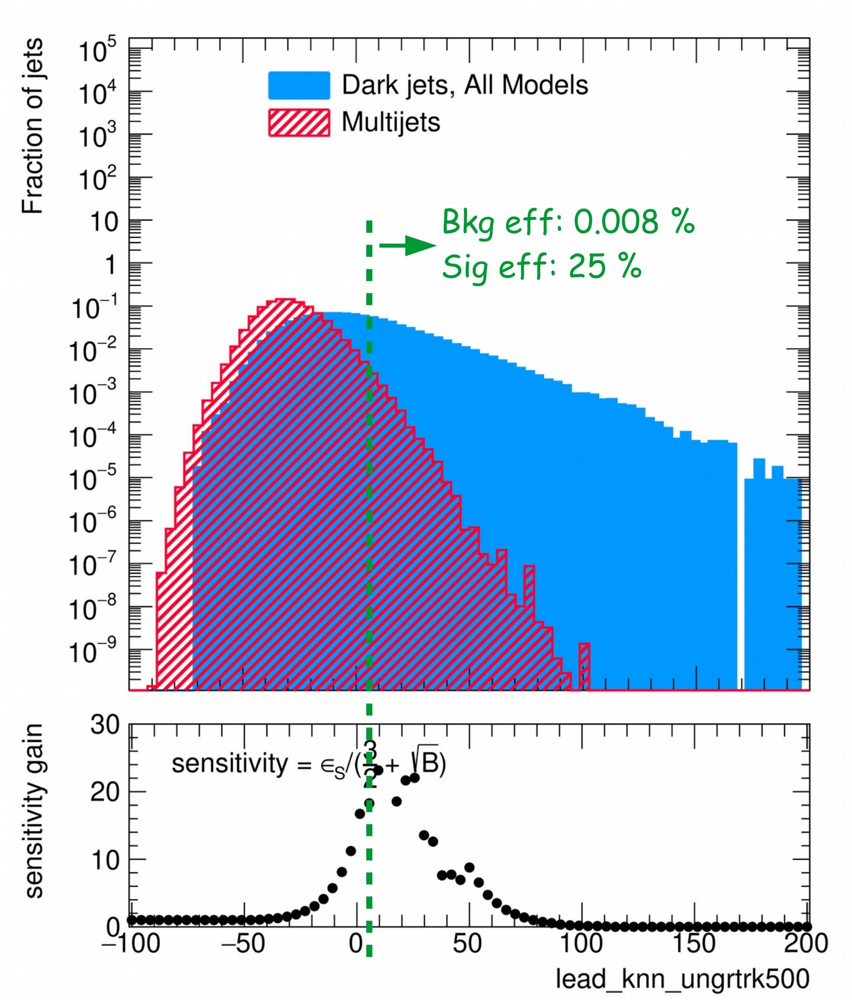
Model B: piv → s sbar (BR=1.)

Model C: piv → gammav gammav (BR=1.)
gammav → d dbar (BR=0.22)
u ubar (BR=0.06)
s sbar (BR=0.06)
c cbar (BR=0.22)
e+e- (BR=0.17)
mu+mu- (**BR=0.17**)
tau+tau- (BR=0.10)

Model D: : piv → gammav gammav (BR=1.)
gammav → e+e- (BR=0.15)
mu+mu- (**BR=0.15**)
pi+pi- (BR=0.70)

Backup

- Sensitivity distribution of *ntrk*$^{\mathrm{kNN}}$
- Cut at peak sensitivity does not leave enough background events to fit



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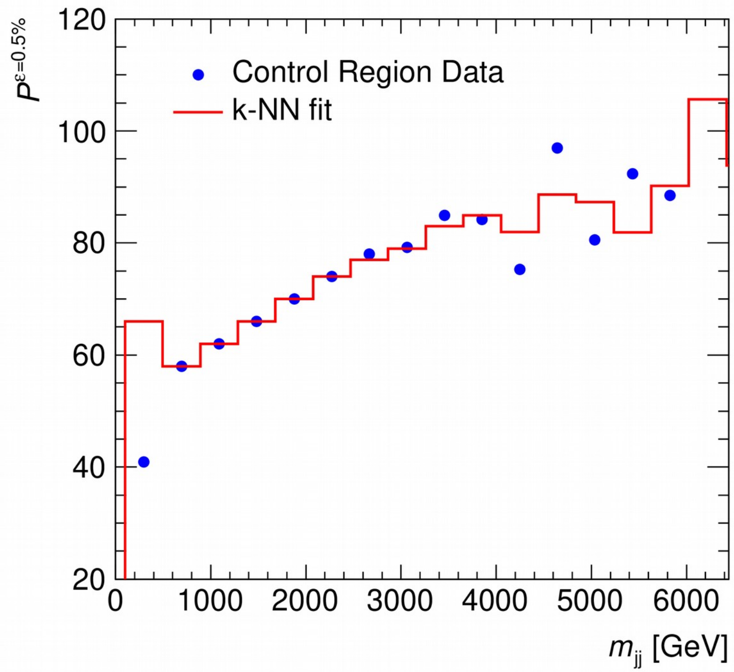

- Principal:
  - Choose a substructure variable with good clissification power (here *ntrk*)
  - Decide on a fixed background single jet efficiency ε (0.5%, giving a signal eff. of 30%)
  - Evaluate the cut value on n_{trk} that gives desired bkg. eff. in bins of p_T and m_{jj}
  - Fit the distribution using the *k-nearest neighbours* (kNN) algorithm
  - For each jet, the new decorrelated observable is computed as $n_{trk}{}^{\varepsilon} = n_{trk} - p^{\varepsilon=0.5\%}$
- Here $n_{trk}{}^{\varepsilon}$ is defined from data in a control region with signal efficiency ~ 0.4 %

Backup

- Some Hidden Valley papers
  - https://arxiv.org/abs/0712.2041
  - https://arxiv.org/pdf/1502.05409.pdf
  - https://arxiv.org/pdf/0712.2041.pdf
- Astro papers that investigate self-interacting DM:
  - https://arxiv.org/pdf/1208.3025.pdf
  - https://arxiv.org/pdf/1208.3026.pdf
  - https://arxiv.org/pdf/1201.5892.pdf
  - https://arxiv.org/pdf/1211.6426.pdf