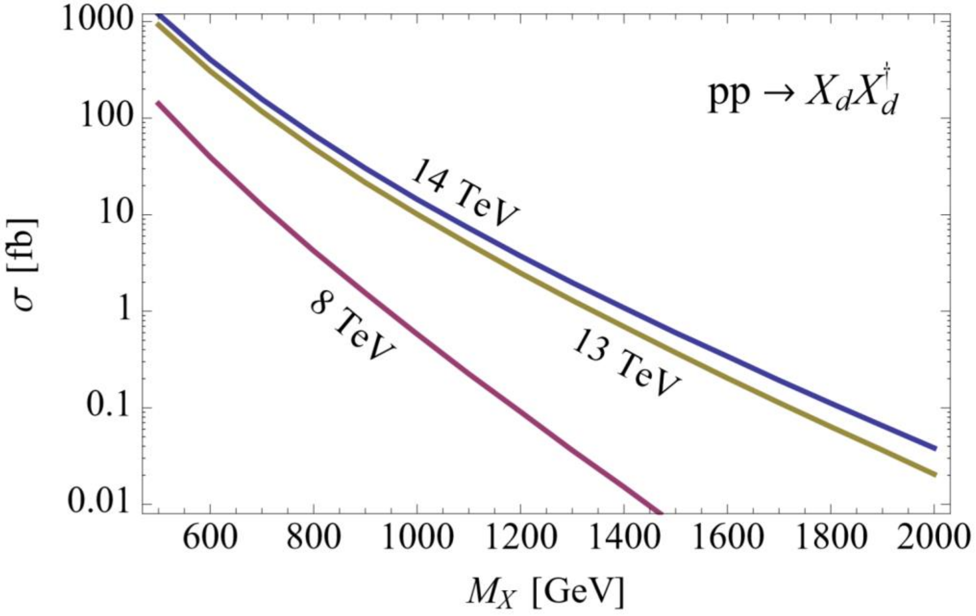
Emerging Jets Run 2 Analysis

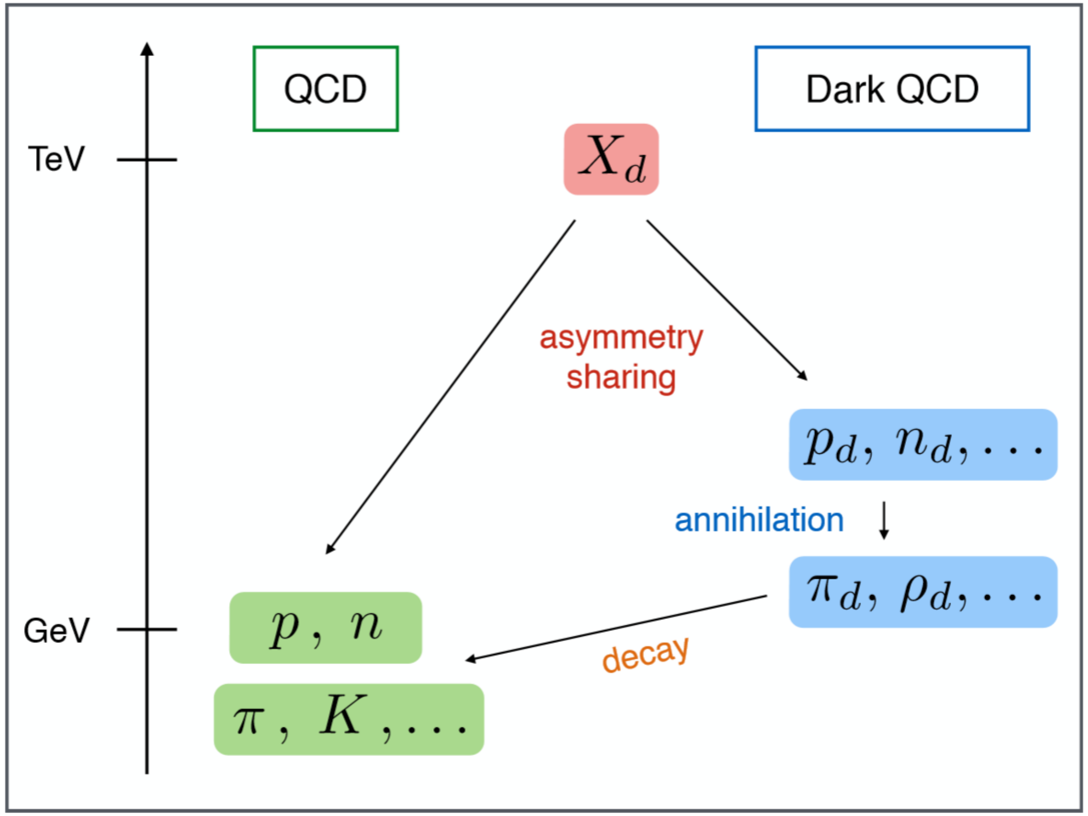
Jérémie LePage-Bourbonnais

Outline

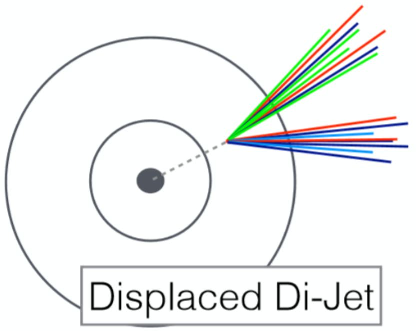
- Emerging Jets Overview
- Analysis Flow
- Sample Distributions
- ABCD Background Estimation Method
- MC Validation Tests
- Efficiency Studies
- TMVA Potential Applications
- Comparison with CMS Results

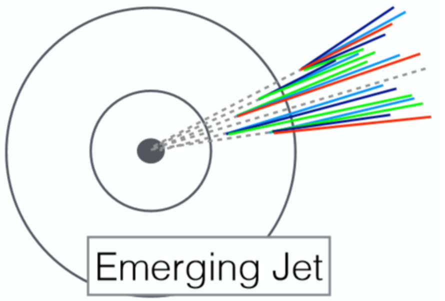
Dark QCD





Field	$SU(3) \times SU(2) \times U(1)$	$SU(3)_{\text{dark}}$	Mass	Spin
Q_d	$(1, 1, 0)$	(3)	m_d $\mathcal{O}(\text{GeV})$	Dirac Fermion
X_d	$(3, 1, \frac{1}{3})$	(3)	M_{X_d} $\mathcal{O}(\text{TeV})$	Complex Scalar
Z_d	$(1, 1, 0)$	(1)	M_{Z_d} $\mathcal{O}(\text{TeV})$	Vector Boson





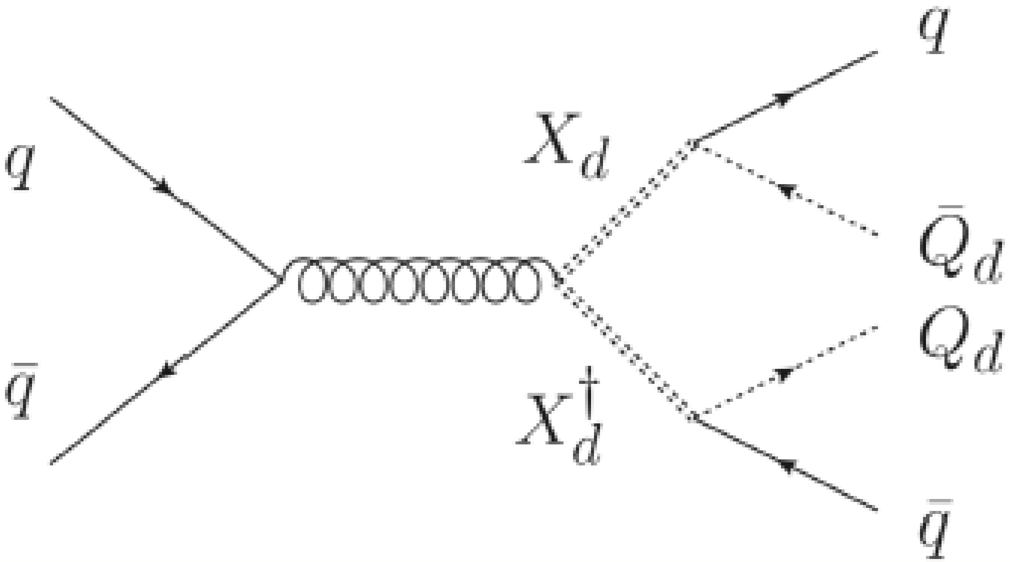
$$\mathcal{L} \supset \bar{Q}_{d_i}(\not{D} - m_{d_i})Q_{d_i} + (D_\mu X_d)(D^\mu X_d)^\dagger - M_{X_d}^2 X_d X_d^\dagger - \frac{1}{4}G_d^{\mu\nu}G_{\mu\nu,d} + \mathcal{L}_\kappa + \mathcal{L}_{\text{SM}}$$

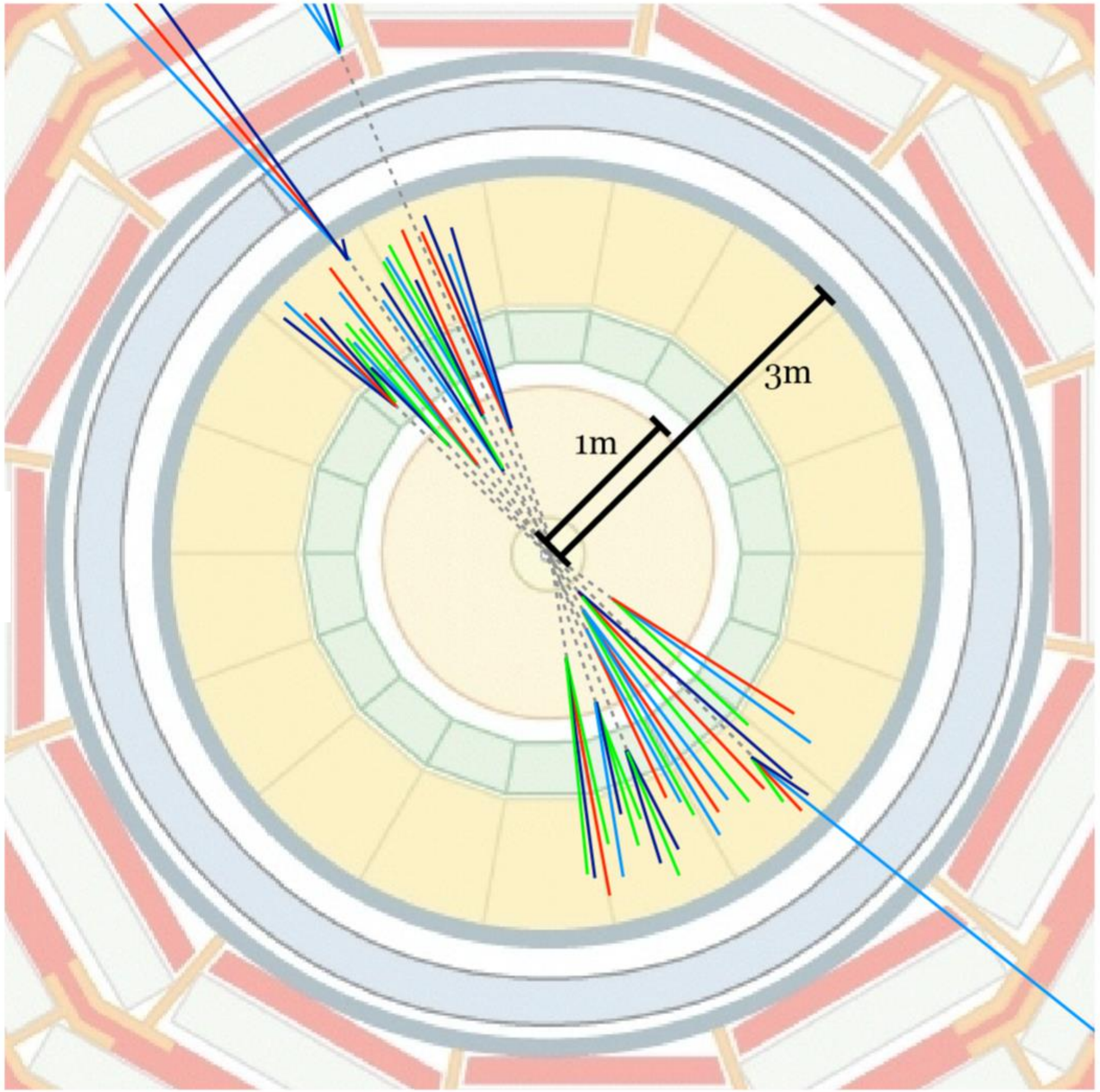
arxiv:1502.05409

Emerging Jets Models

- Multiple emerging tracks from dark mesons decaying to SM particles
- The decays occur at slightly different radii from interaction point

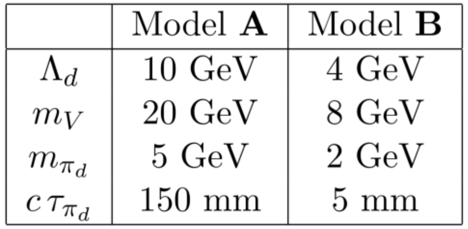
$$c\tau_0 = \frac{c\hbar}{\Gamma} \approx 80\,\mathrm{mm} \times \frac{1}{\kappa^4} \times \left(\frac{2\ \mathrm{GeV}}{f_{\pi_d}}\right)^2 \left(\frac{100\ \mathrm{MeV}}{m_{\mathrm{down}}}\right)^2 \left(\frac{2\ \mathrm{GeV}}{m_{\pi_d}}\right) \left(\frac{M_{X_d}}{1\ \mathrm{TeV}}\right)^4$$





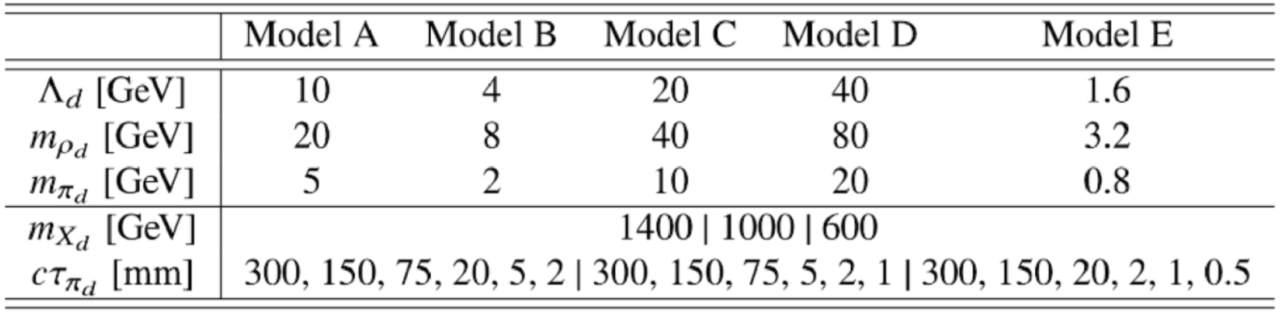
arxiv:1502.05409

Signals/Backgrounds in ATLAS

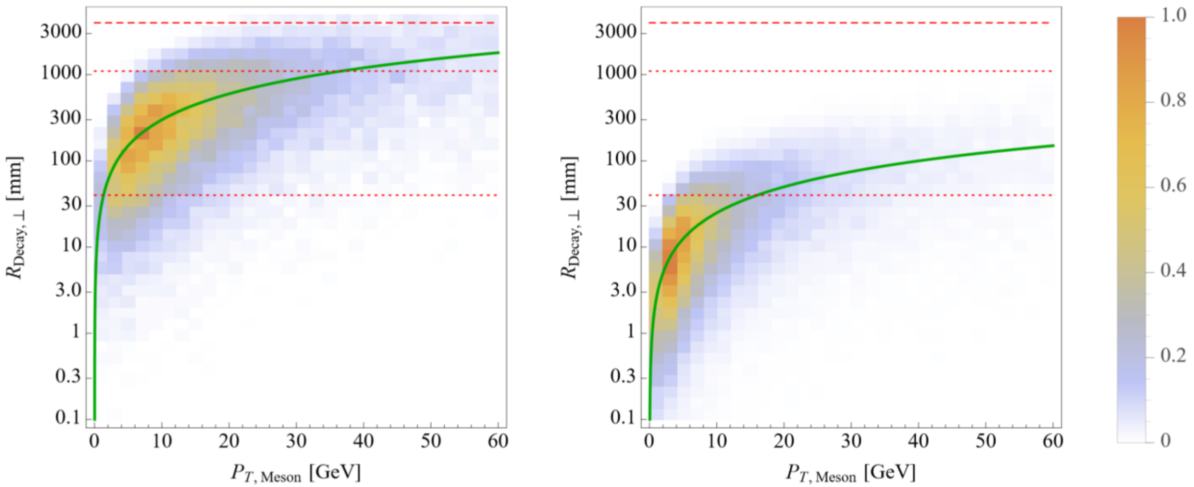


	Model **A**	Model **B**
Λ_d	10 GeV	4 GeV
m_V	20 GeV	8 GeV
m_{π_d}	5 GeV	2 GeV
$c\tau_{\pi_d}$	150 mm	5 mm

- 90 Simulated points in total



	Model A	Model B	Model C	Model D	Model E
Λ_d [GeV]	10	4	20	40	1.6
m_{ρ_d} [GeV]	20	8	40	80	3.2
m_{π_d} [GeV]	5	2	10	20	0.8
m_{X_d} [GeV]	1400 | 1000 | 600				
$c\tau_{\pi_d}$ [mm]	300, 150, 75, 20, 5, 2 | 300, 150, 75, 5, 2, 1 | 300, 150, 20, 2, 1, 0.5				



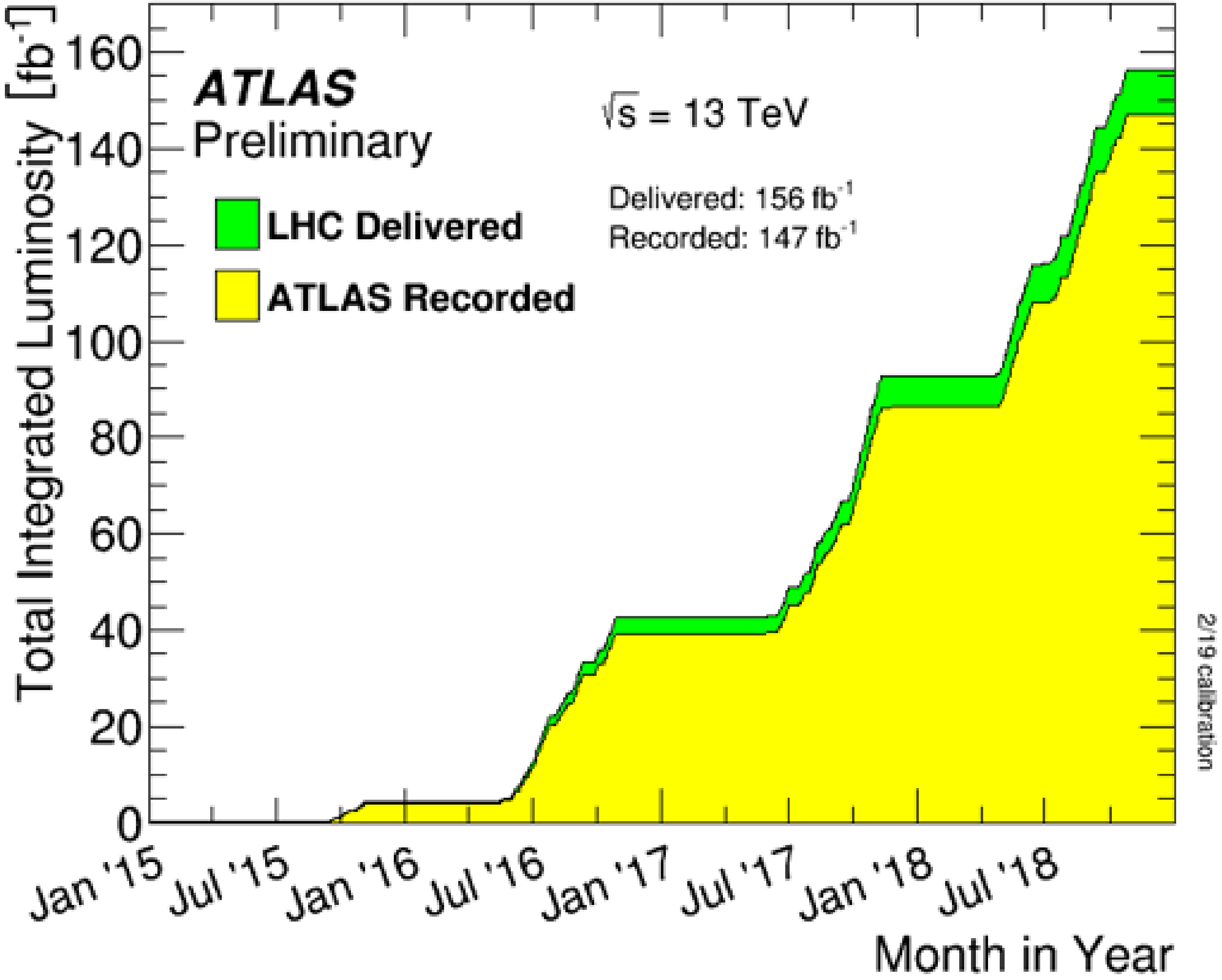
arxiv:1502.05409

- Assume background completely dominated by 4-jet
- Events pass through GEANT4 ATLAS detector reconstruction
- Event generation uses modified Pythia 8.230 HiddenValley models to increase signal efficiency
  - Includes dark coupling and truth-level 4-jet generator filter

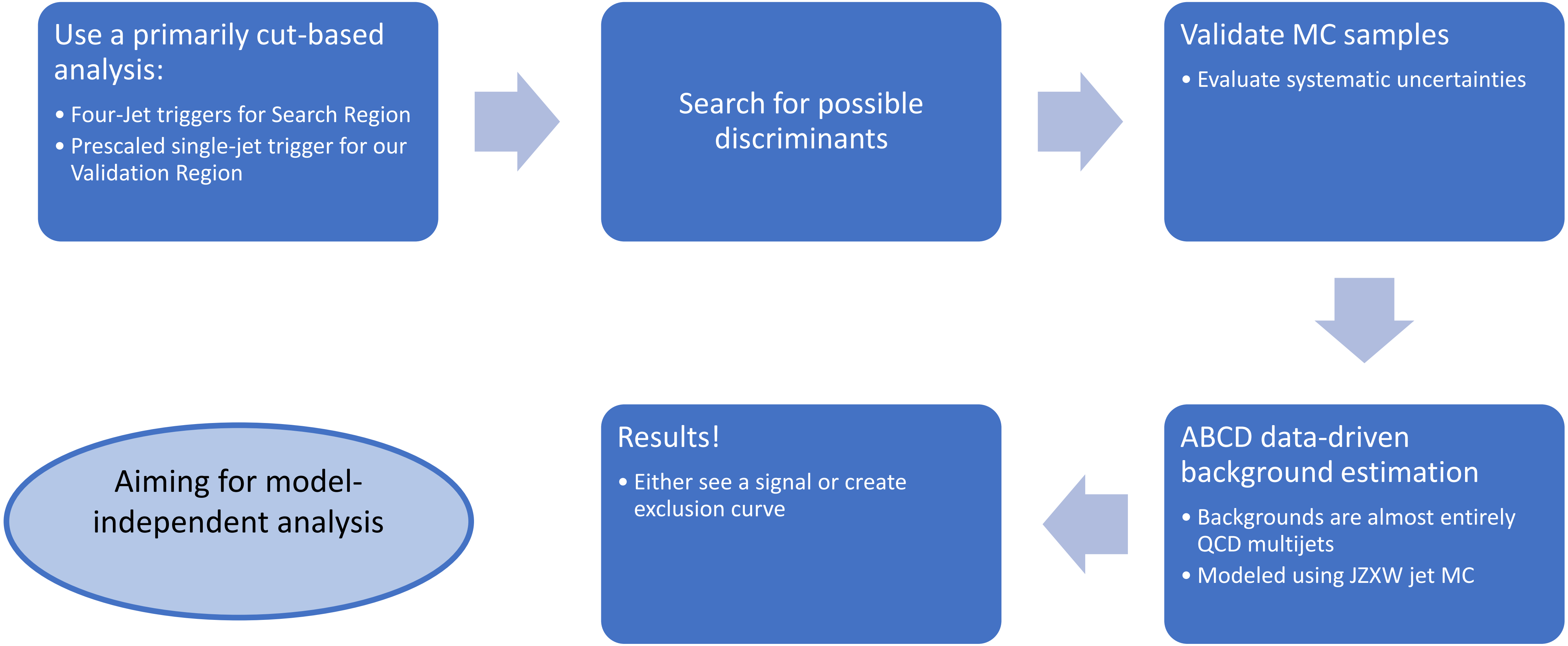
Run-2 Dataset

- Collision centre-of-mass energy: $\sqrt{s} = 13\ \mathrm{TeV}$

- Total integrated luminosity of 139 fb^{-1}



Analysis Flow



Use a primarily cut-based analysis:

- Four-Jet triggers for Search Region
- Prescaled single-jet trigger for our Validation Region

Search for possible discriminants

Validate MC samples

- Evaluate systematic uncertainties

ABCD data-driven background estimation

- Backgrounds are almost entirely QCD multijets
- Modeled using JZXW jet MC

Results!

- Either see a signal or create exclusion curve

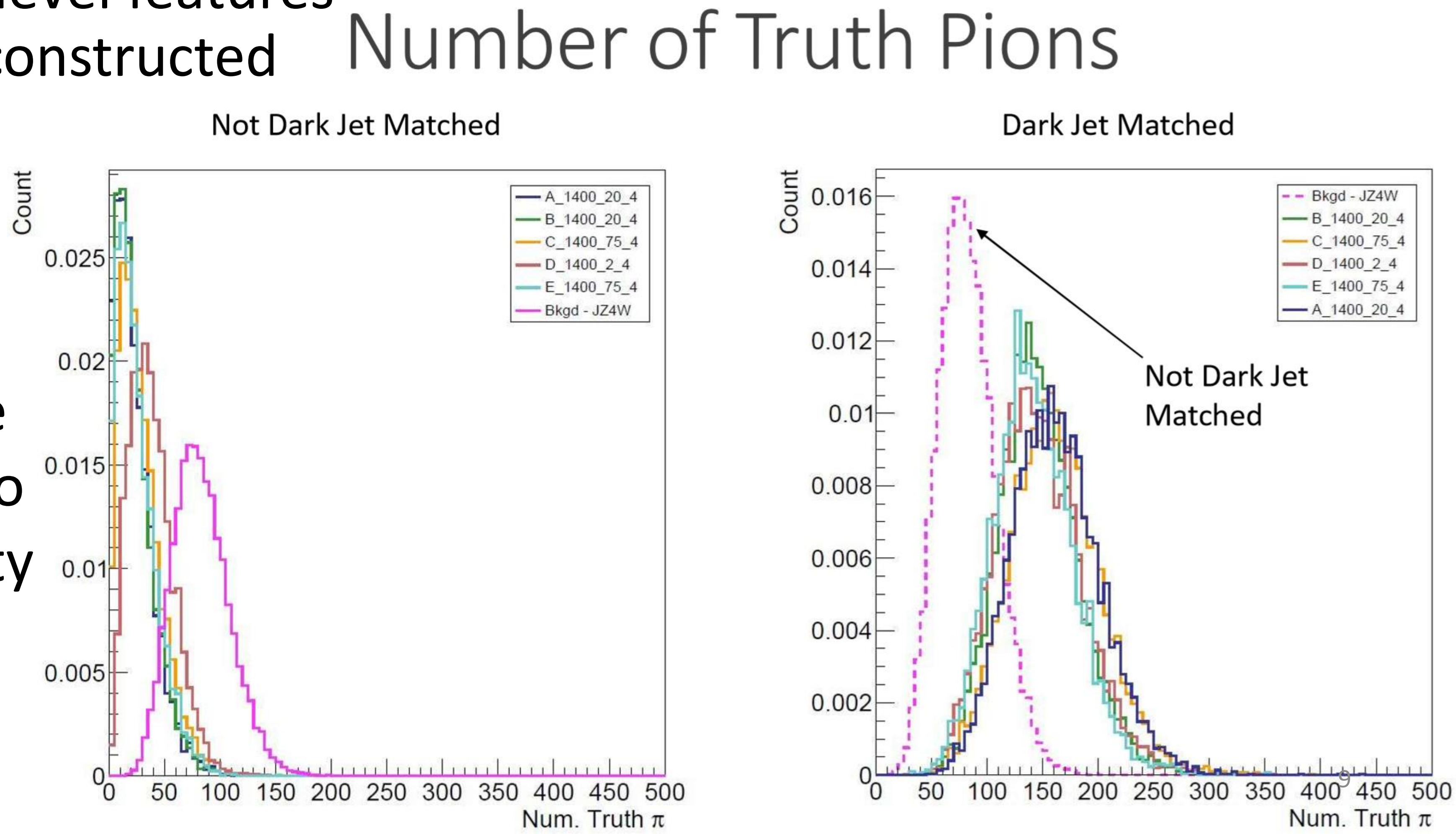
Aiming for model-independent analysis

List of key variables

- Number of Secondary Vertices – Determined using dR matching
- Secondary Vertex dR = $\sqrt{\left(\Delta\varphi_{Jet-Vertex}\right)^2 + \left(\Delta\theta_{Jet-Vertex}\right)^2}$
- HT- Scalar sum of jet pT
- pT – Transverse Momentum
- Signal Region:
  - Jet multiplicity >= 4
  - 4 Leading jets have pT >= 120 GeV
  - 4 Leading Jets have |η| <= 2.5
  - 4-Jet HT >= 1000 GeV

Sample Truth-level distributions

- Search for truth-level features that could be reconstructed



Number of Truth Pions

Not Dark Jet Matched

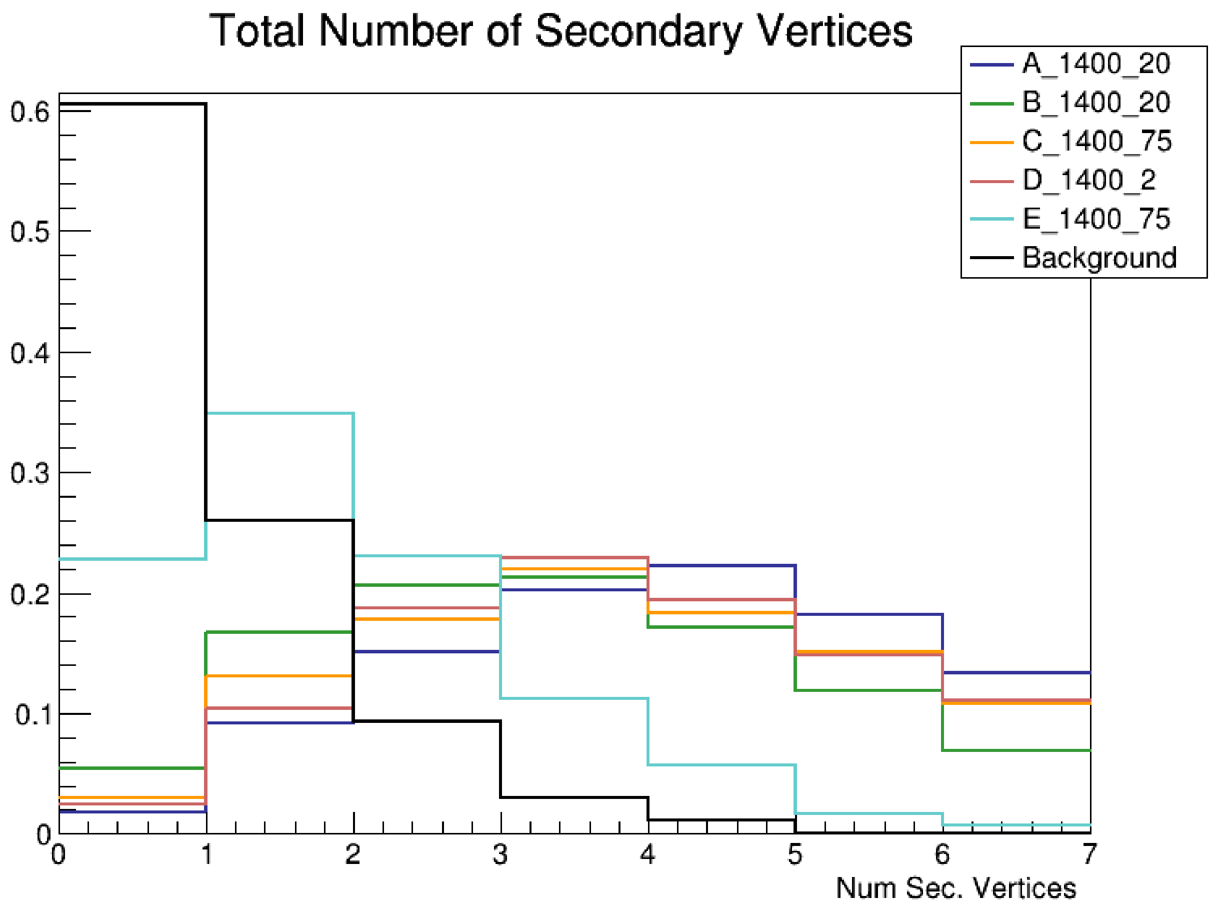
Dark Jet Matched

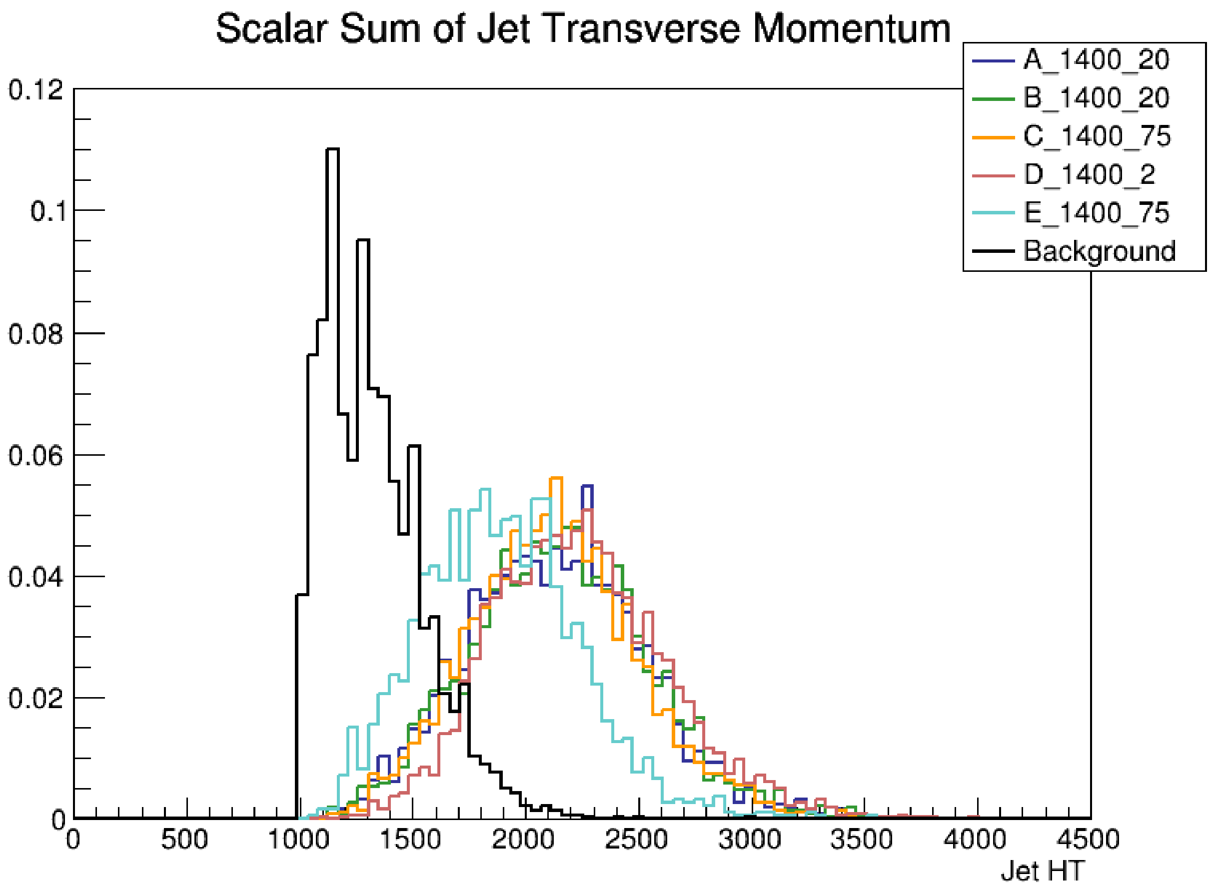
Not Dark Jet Matched

This could motivate an investigation into the track multiplicity

B. Death

Sample Event-Level Distributions

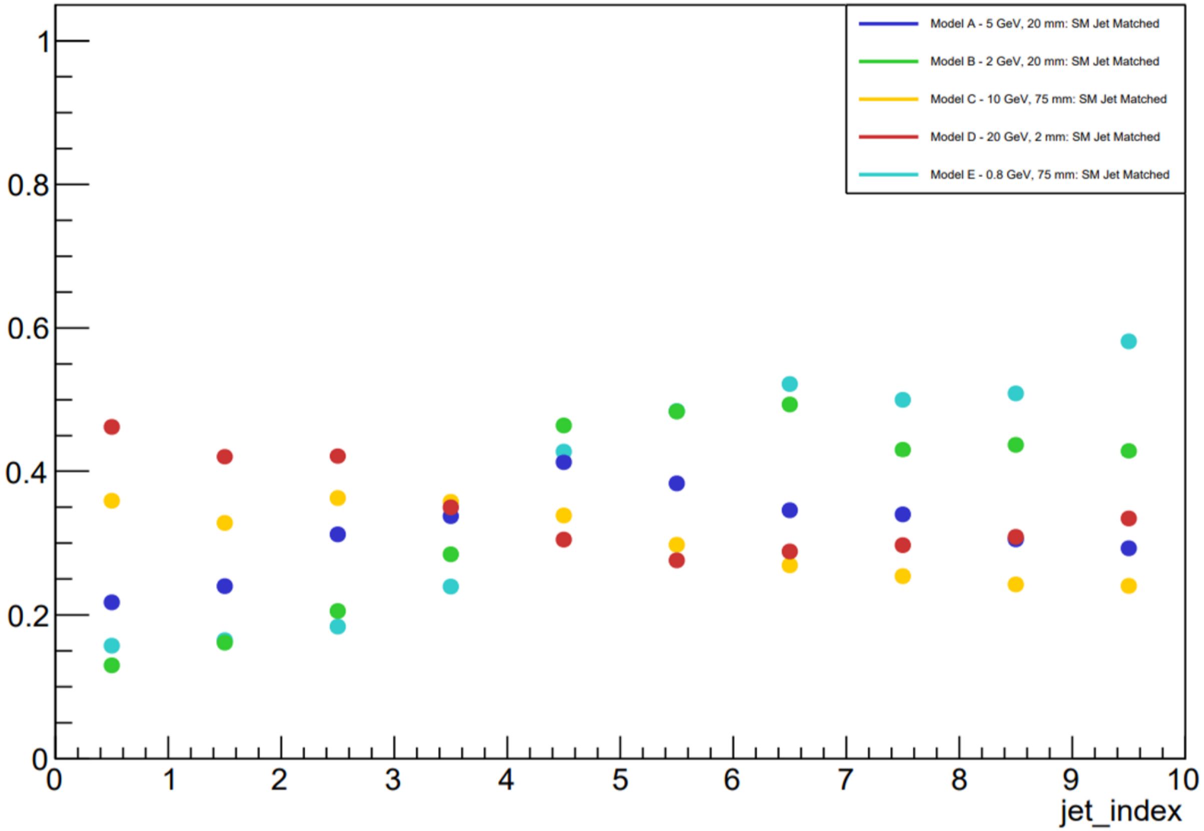

Total Number of Secondary Vertices


Scalar Sum of Jet Transverse Momentum

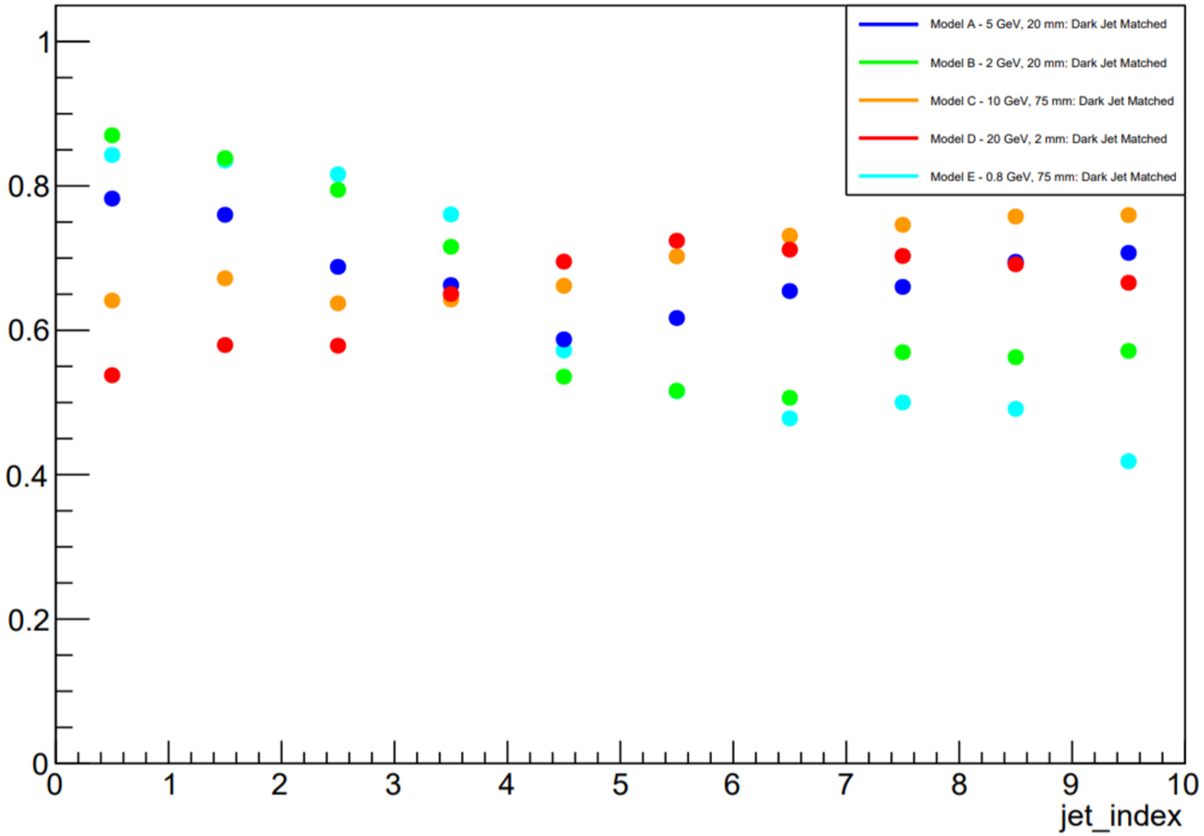
Jets indexed according to pT – leading jet, second leading jet.. etc.

Sample Jet-Level Distributions

Fraction of Jets which are SM Matched by Index



Fraction of Jets which are Dark Matched by Index

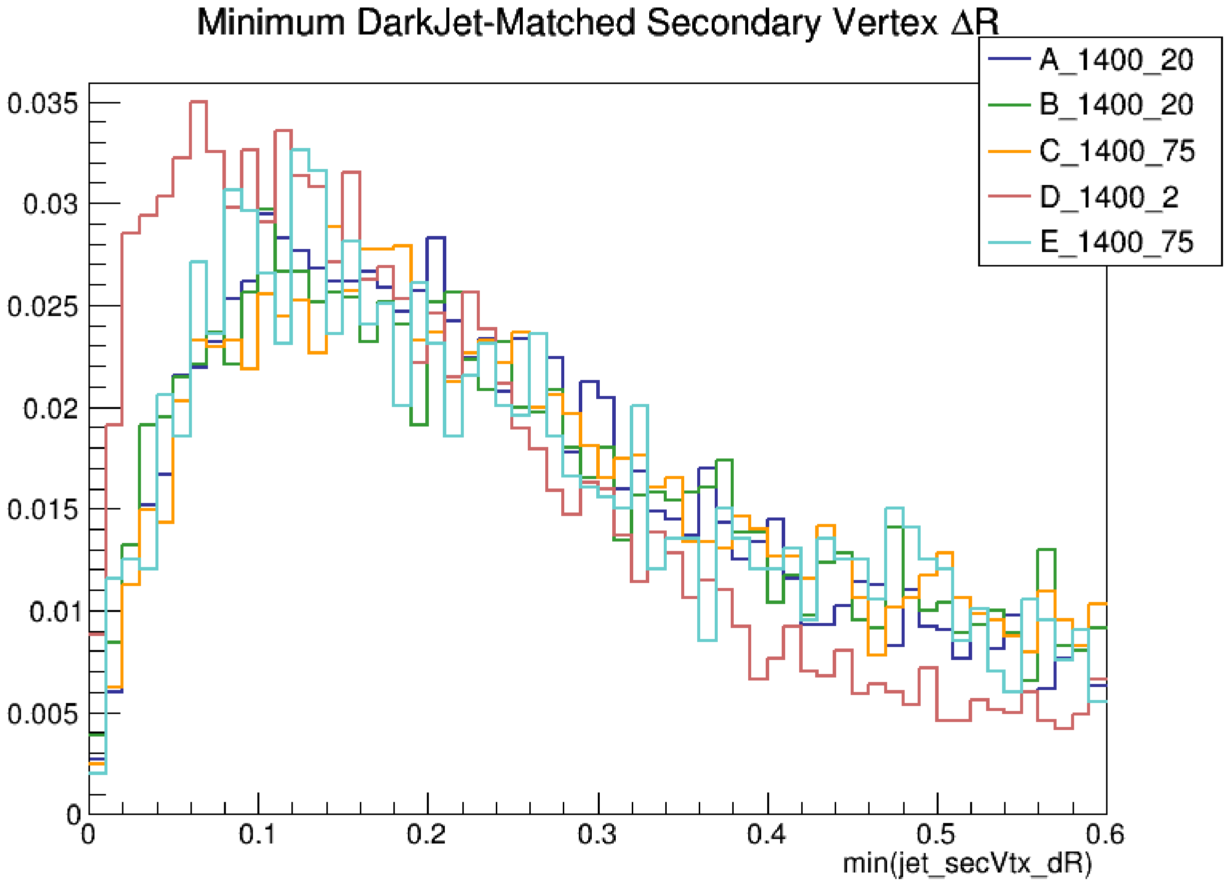


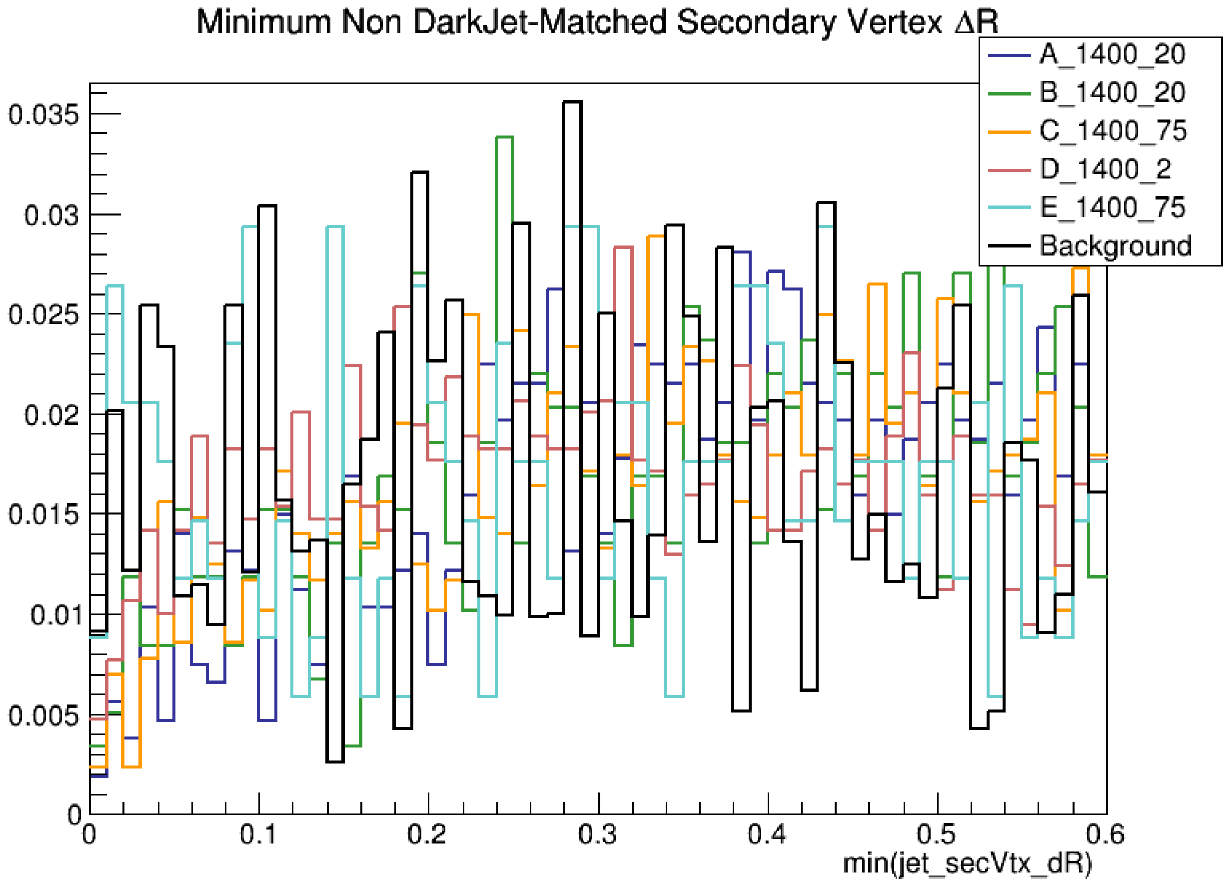
I. Ramirez-Berend

- Dark Match: Jet is matched to a truth level jet, both are matched to a dark jet
- SM Jet Match: Jet is matched to a truth jet, neither are matched to a dark jet

$$\text{jet\_secVtx\_dR} = \sqrt{(\Delta\varphi)^2 + (\Delta\theta)^2}$$

Sample SubJet-Level Distributions





- Dark Match: Jet is matched to a truth level jet, both are matched to a dark jet
- SM Jet Match: Jet is matched to a truth jet, neither are matched to a dark jet

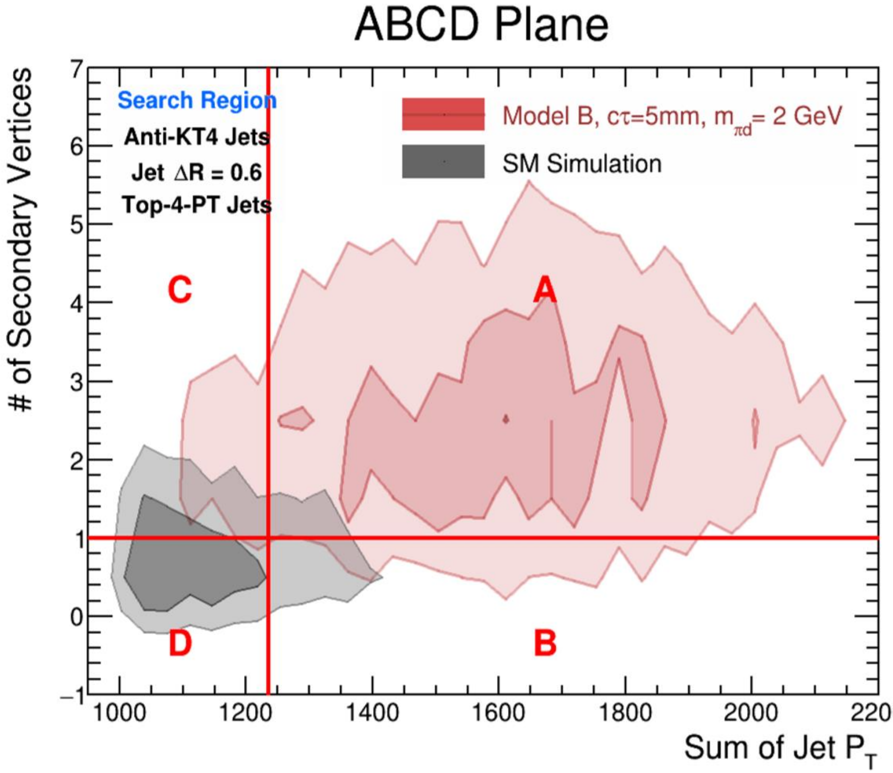
ABCD Background Estimation Method

- Data-driven background estimation method
- For Un-Correlated backgrounds:

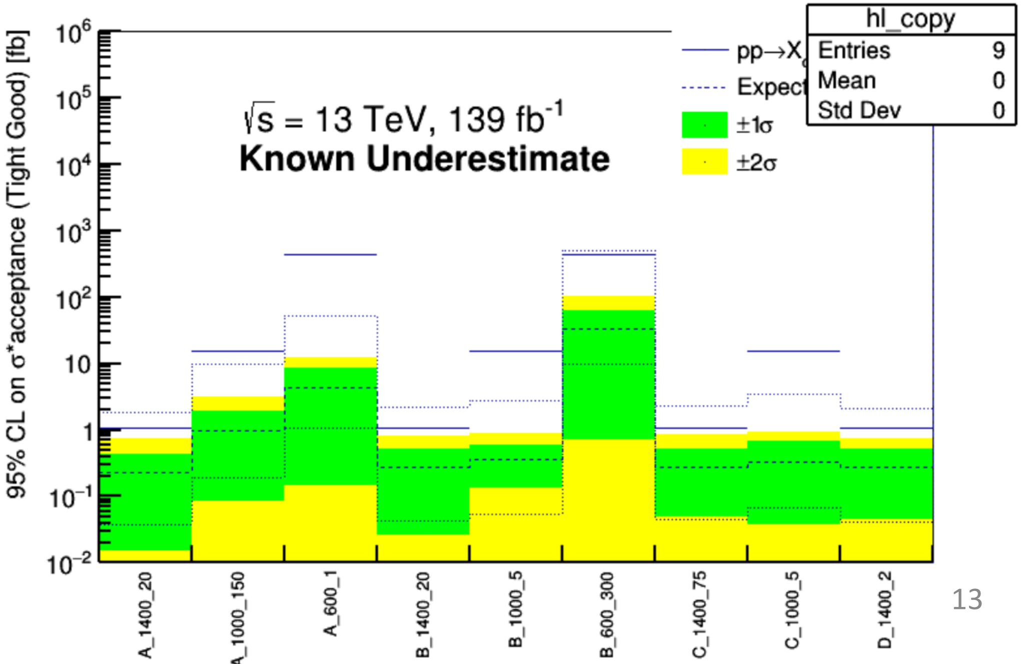
$$\frac{N_C^{bkg}}{N_D^{bkg}} = \frac{\boxed{N_A^{bkg}}}{N_B^{bkg}}$$

- Can solve for background estimate in region A

$$\boxed{N_A^{bkg}} = N_B^{bkg} \frac{N_C^{bkg}}{N_D^{bkg}}$$



D. Rocha

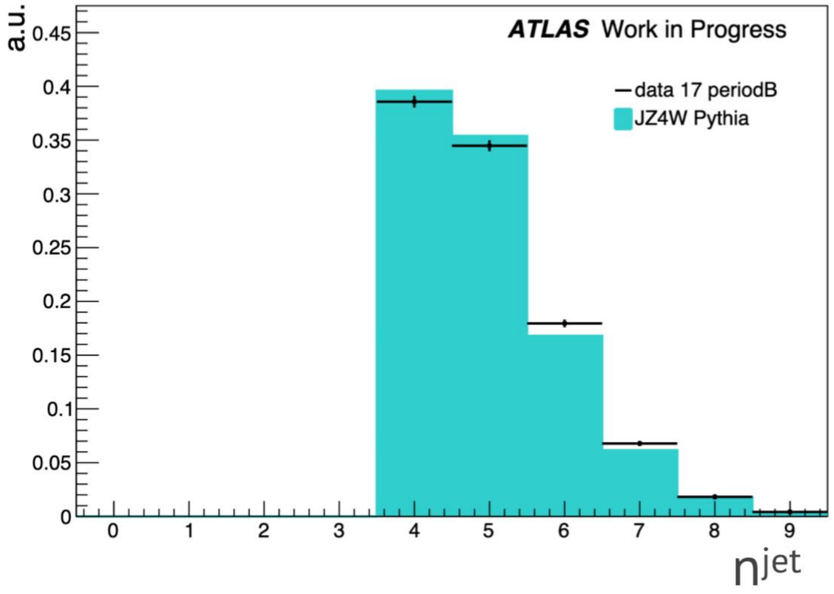


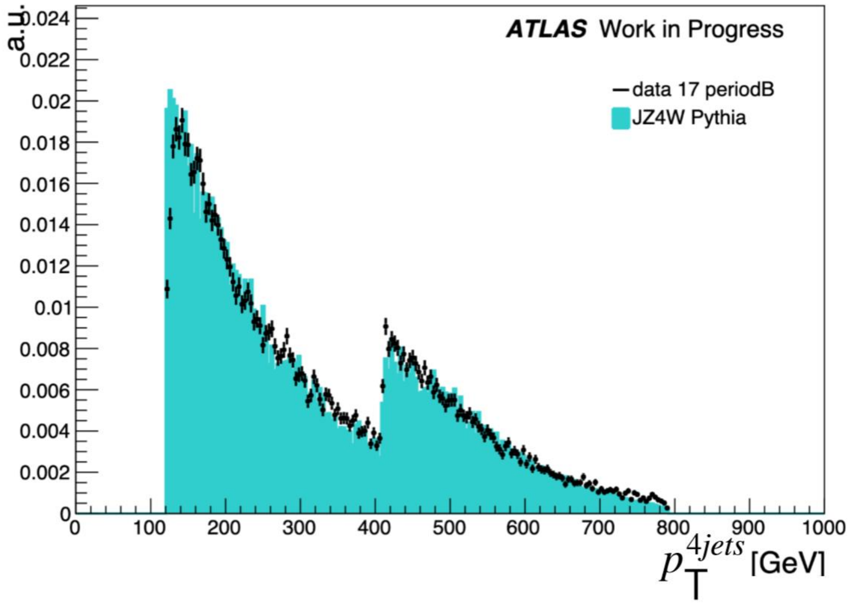
G. Gonella

Data MC Validation Region comparisons

Baseline Selection:

- Search Region
- $r_{SV} < 300$ mm
- $|z_{SV}| < 300$ mm
- $410 < p_T^{\text{leadJet}} < 790$ GeV





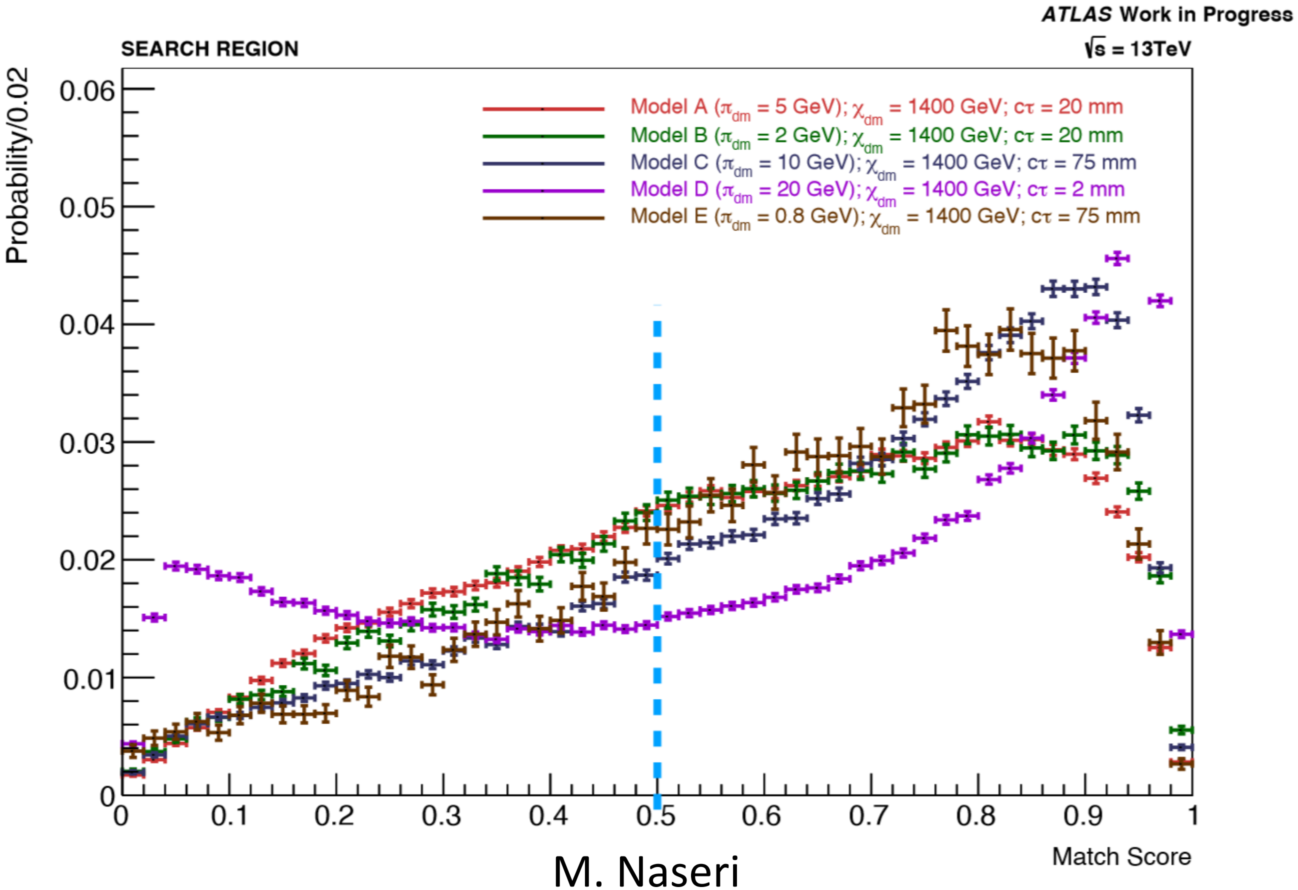
G. Gonella

Histograms normalized to unity

Only periodB data considered

Secondary Vertex Match Score

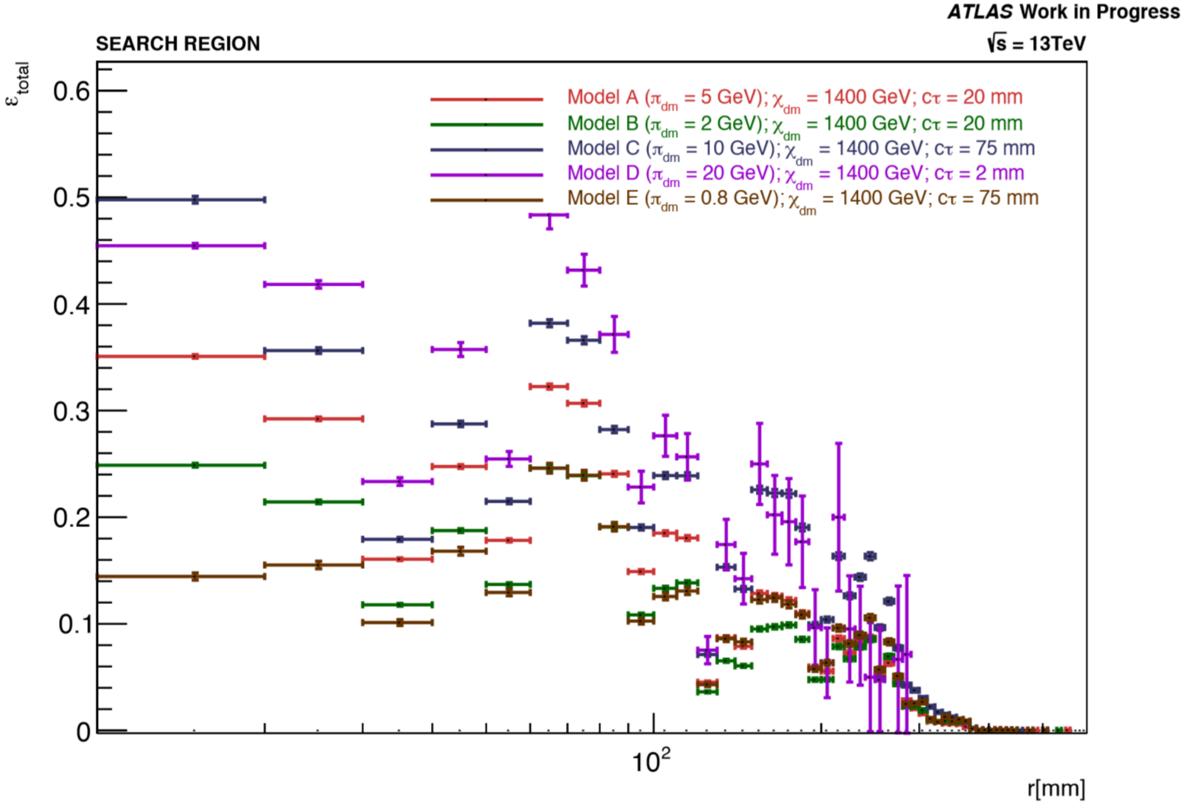
Match Score: ratio of sum pT of the representative truth vertex position to the sum pT of tracks in reco vertex

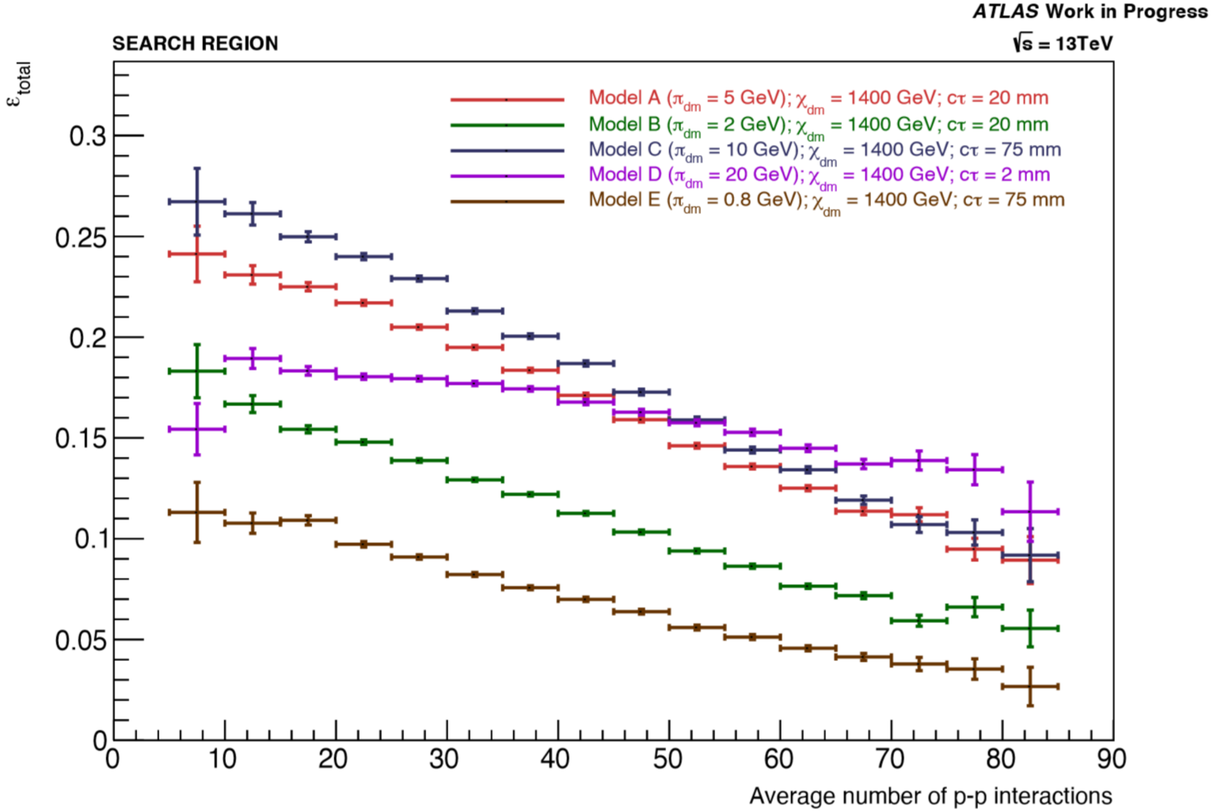


M. Naseri

Secondary Vertex Reconstruction Efficiency

Efficiency: The ratio of Long Lived Particle (LLP) decays with at minimum one matched reconstructed vertex (with a match score > 0.5) to the number of reconstructible LLP decays

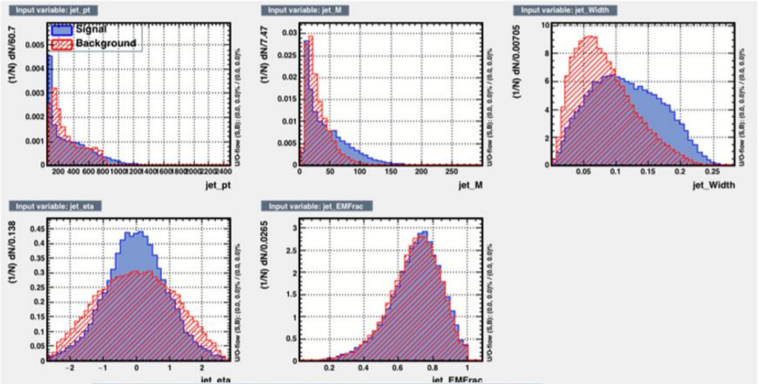


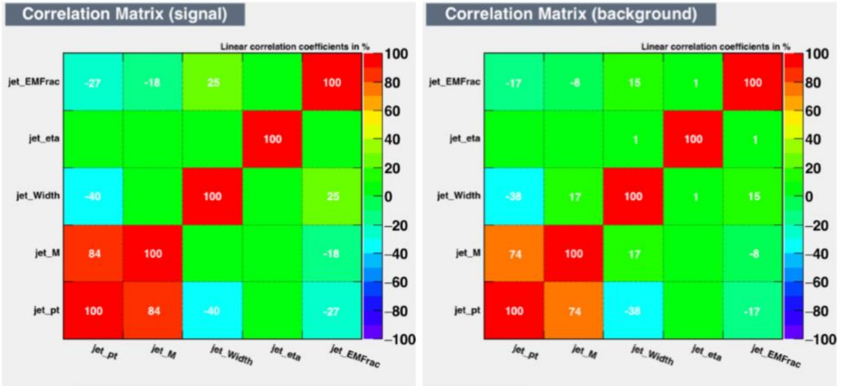


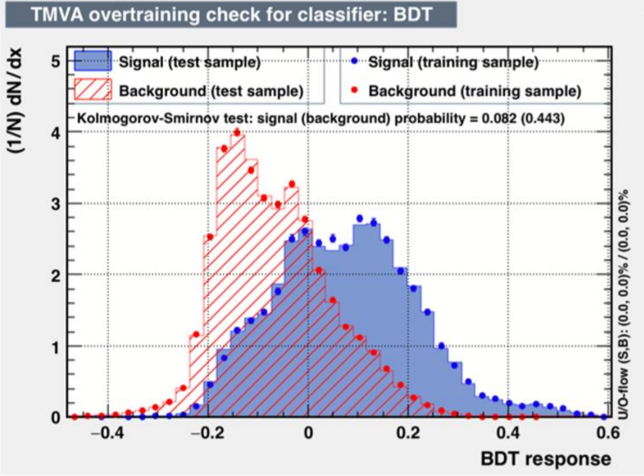
Boosted Decision Tree Applications?

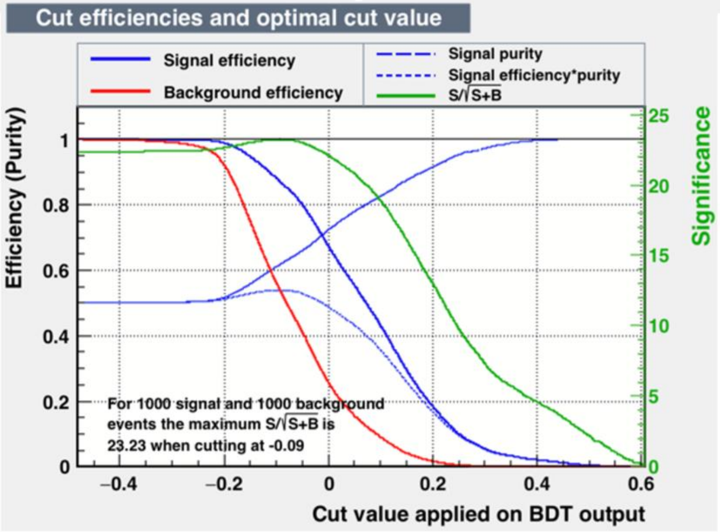
- Can be used for Run 3 sensitivity study
- BDT and/or other ML methods can help discriminate between signal and background
- Construct event-level variables from jet/subject information

ModelA_1400_20 Case



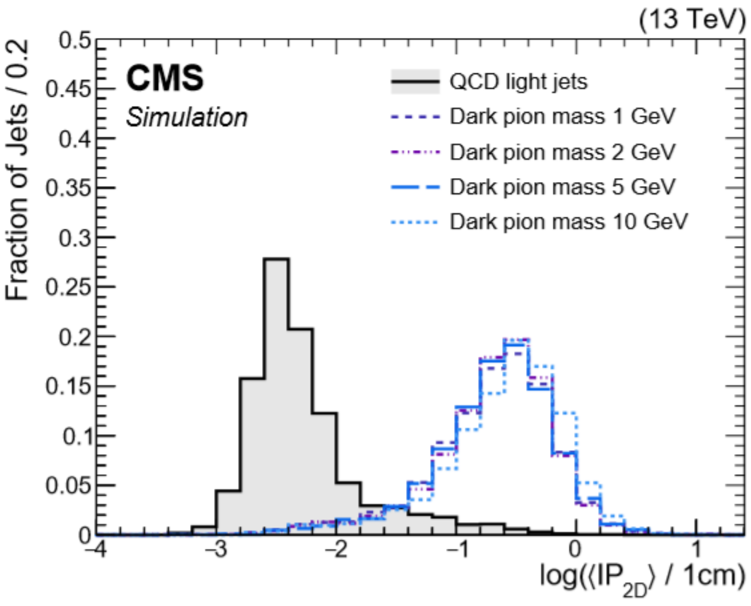


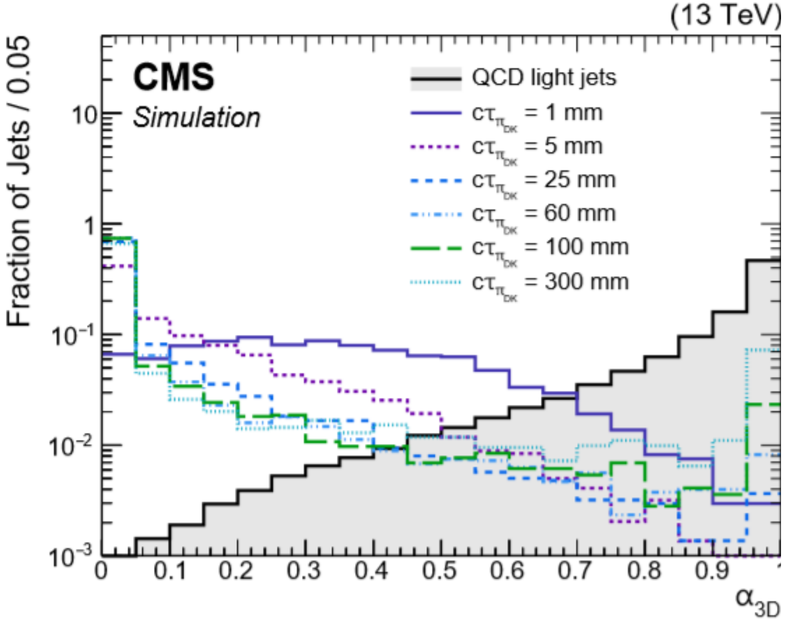




K. Graham

CMS Emerging Jets Search Results





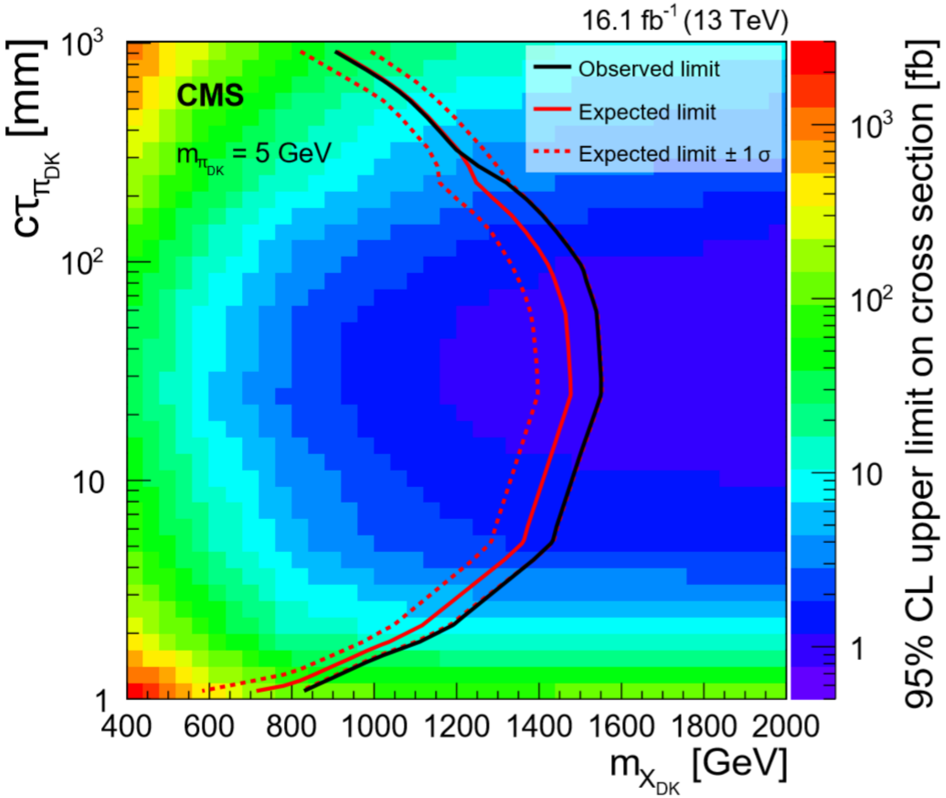
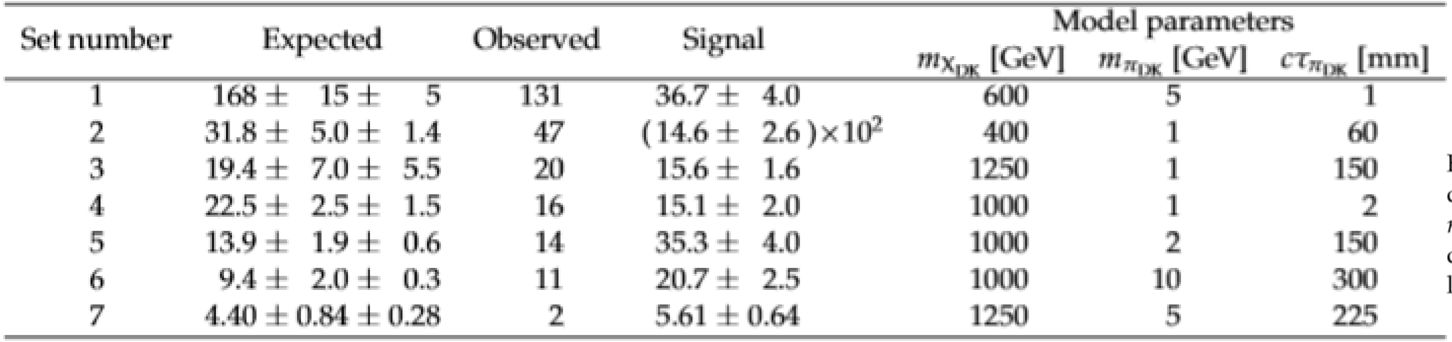


Figure 10: Upper limits at 95% CL on the signal cross section and signal exclusion contours derived from theoretical cross sections for models with dark pion mass $m_{\pi_{DK}}$ of 5 GeV in the $m_{X_{DK}} - c\tau_{\pi_{DK}}$ plane. The solid red contour is the expected upper limit, with its one standard-deviation region enclosed in red dashed lines. The solid black contour is the observed upper limit. The region to the left of the observed contour is excluded.



Set number	Expected	Observed	Signal	Model parameters		
				$m_{X_{DK}}$ [GeV]	$m_{\pi_{DK}}$ [GeV]	$c\tau_{\pi_{DK}}$ [mm]
1	168 ± 15 ± 5	131	36.7 ± 4.0	600	5	1
2	31.8 ± 5.0 ± 1.4	47	(14.6 ± 2.6) × 10^2	400	1	60
3	19.4 ± 7.0 ± 5.5	20	15.6 ± 1.6	1250	1	150
4	22.5 ± 2.5 ± 1.5	16	15.1 ± 2.0	1000	1	2
5	13.9 ± 1.9 ± 0.6	14	35.3 ± 4.0	1000	2	150
6	9.4 ± 2.0 ± 0.3	11	20.7 ± 2.5	1000	10	300
7	4.40 ± 0.84 ± 0.28	2	5.61 ± 0.64	1250	5	225

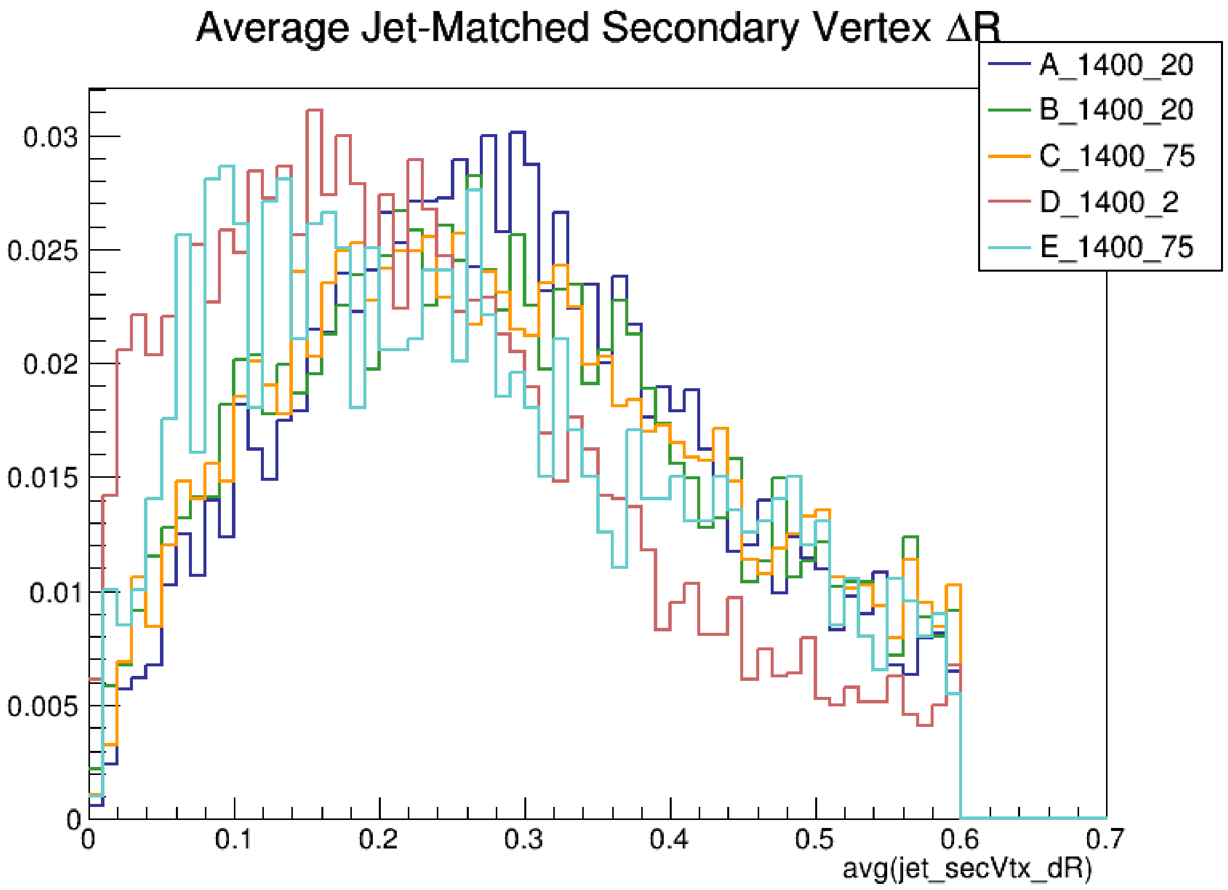
arxiv:1611.09661

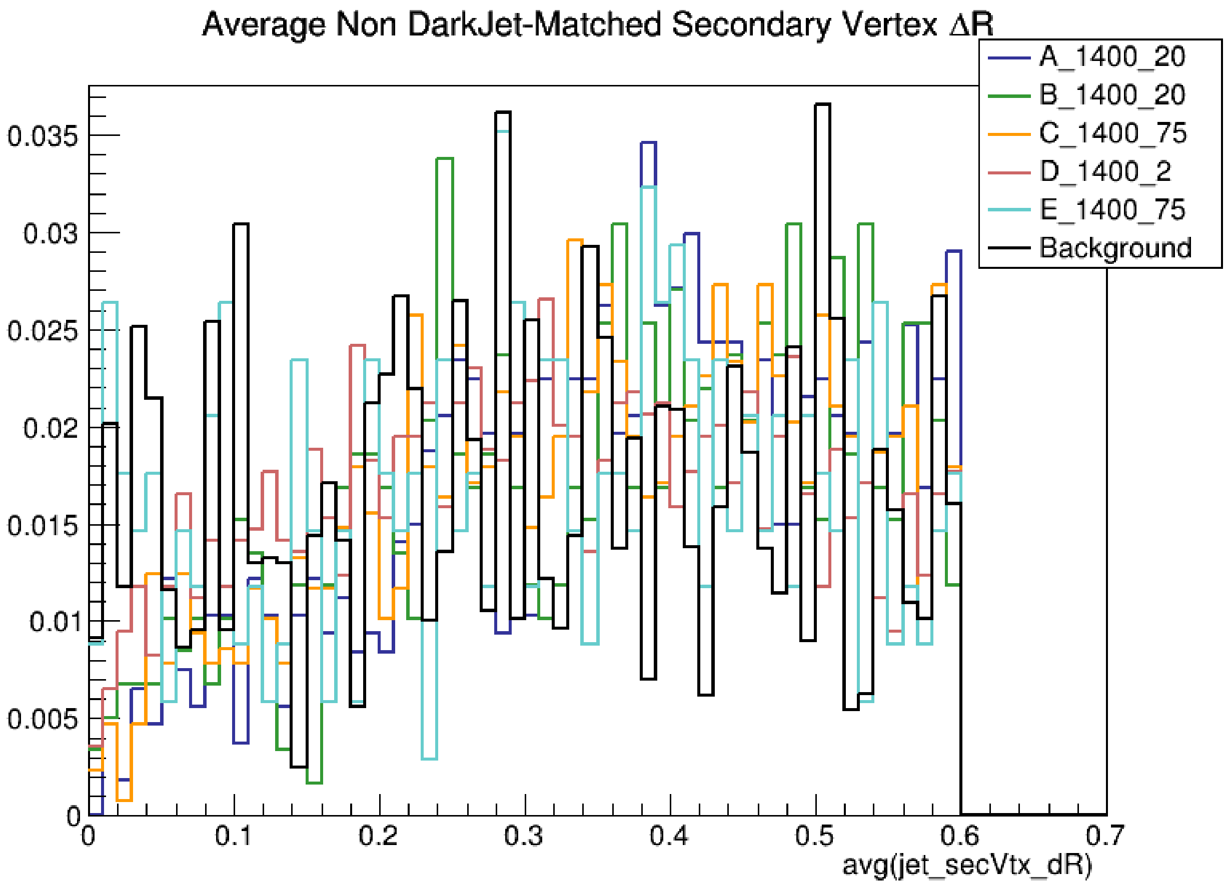
Future Goals

- Carry out detailed Monte-Carlo study towards Run 3 data and a broader range of models
- Continue developing Machine Learning tools
- Look into pileup effects
- Sensitivity vs luminosity

Extra Content

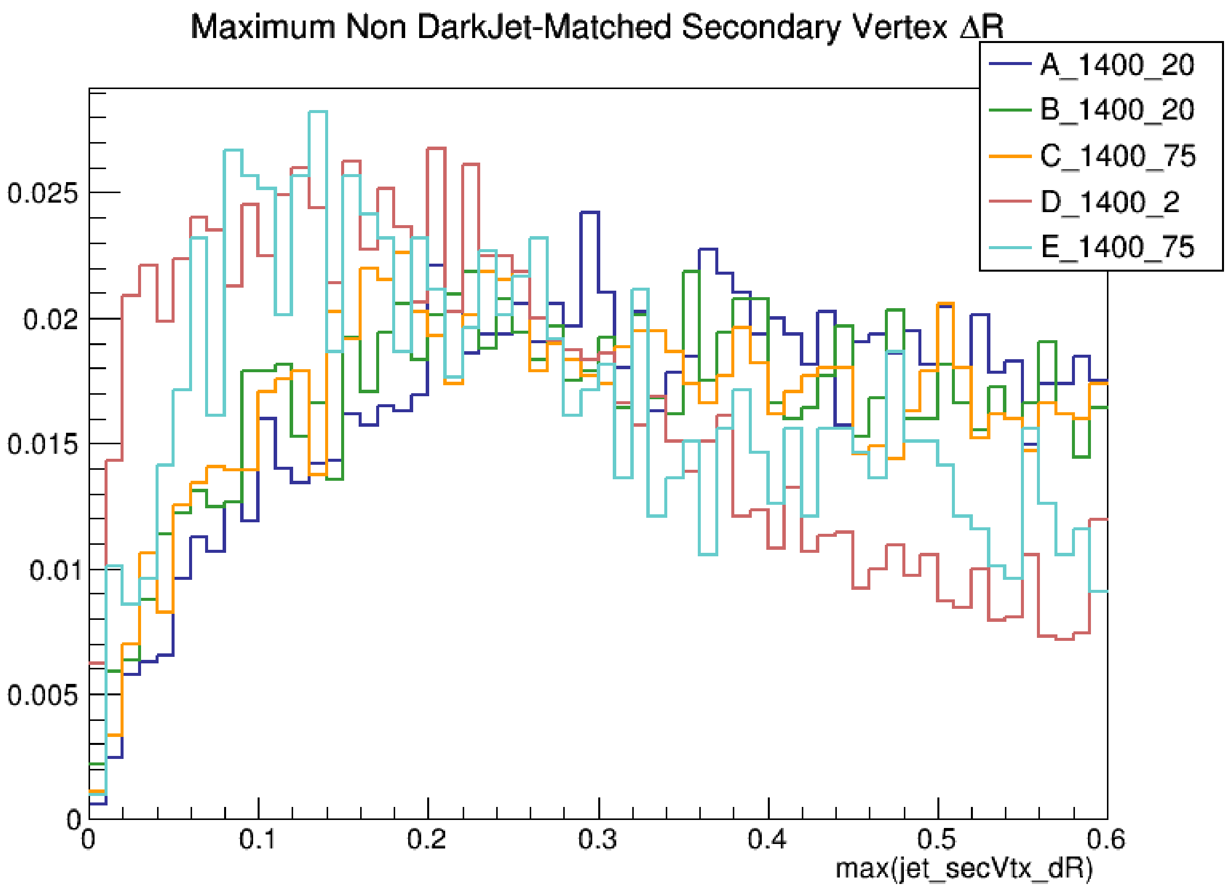
Sample SubJet-Level Distributions

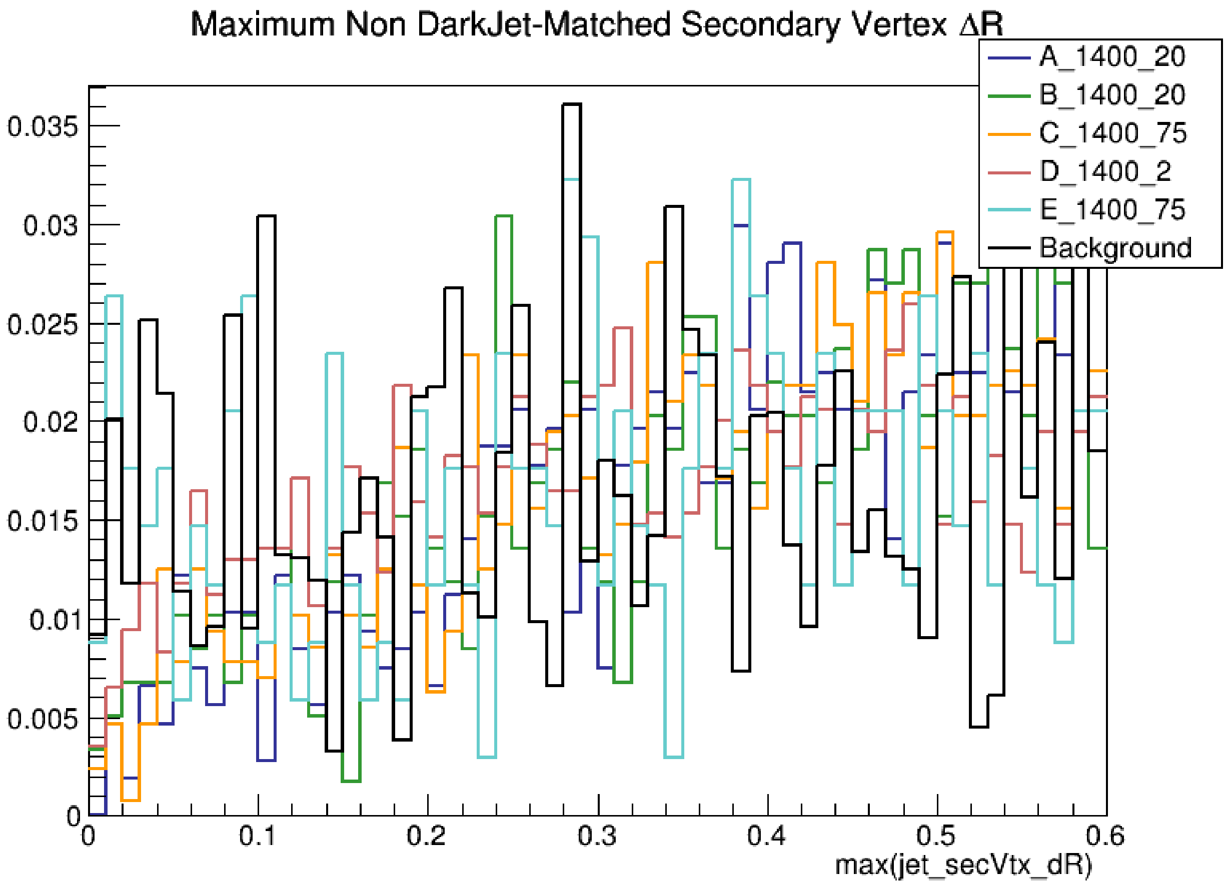

Average Jet-Matched Secondary Vertex ΔR


Average Non DarkJet-Matched Secondary Vertex ΔR

$$\text{jet\_secVtx\_dR} = \sqrt{(\Delta\varphi)^2 + (\Delta\theta)^2}$$

Sample SubJet-Level Distributions


Maximum Non DarkJet-Matched Secondary Vertex ΔR


Maximum Non DarkJet-Matched Secondary Vertex ΔR

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