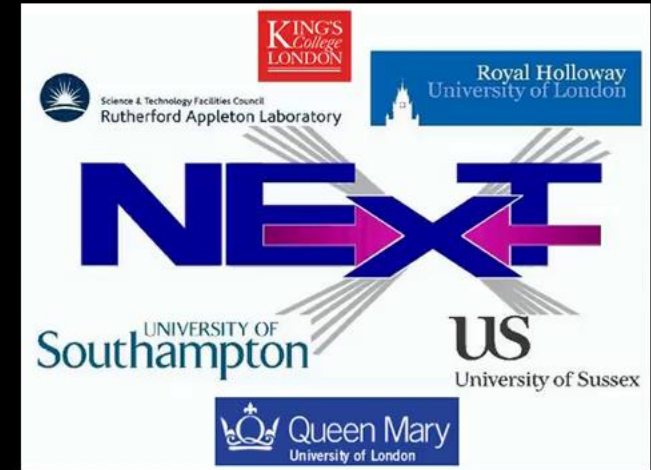




Hunting the unseen: Deep Learning Analysis for Semi Visible Jet Tagging

Speaker: Miguel Ángel Avendaño Bernal

In collaboration with

Srinandan Dasmahapatra, Ahmed Hammad, Stefano Moretti, Mihoko Nojiri, Michael H. Seymour and Claire Shepherd-Themistocleous

Based on the work published on arXiv:



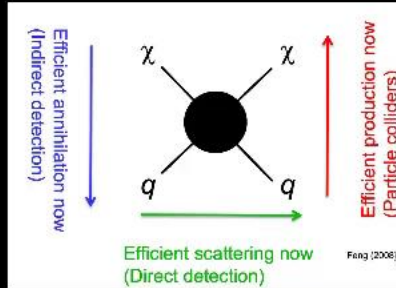
Contents

1. Context about Dark Showers searches and Semi Visible Jets (SVJ) theory
2. Description of MC Event generators
3. SVJ Datasets characterisation
4. SVJ Jet-Level observables: Basic Kinematics
5. SVJ Global observables: Global MET
6. SVJ Sub-structure observables: The Lund Jet Plane
7. Deep Learning Analyses
8. Further work
9. Conclusions and summary

DARK SHOWERS AS A CANDIDATE FOR DARK MATTER (DM)

SEMI VISIBLE JETS (SVJ) IN A NUTSHELL:

DARK SHOWERS AS A CANDIDATE FOR DARK MATTER (DM)

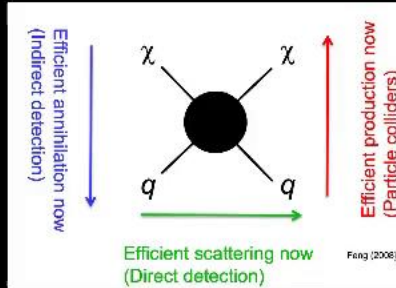


Motivation:

1. Dark-sector particles are (quasi-)stable viable DM candidates.
2. Detections lead to non-standard decays with atypical signatures (jets)
3. Current searches led by the DarkShowers LHC Taskforce

SEMI VISIBLE JETS (SVJ) IN A NUTSHELL:

DARK SHOWERS AS A CANDIDATE FOR DARK MATTER (DM)



Motivation:

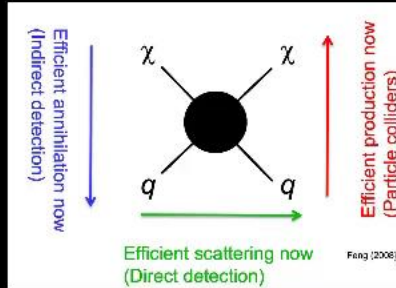
1. Dark-sector particles are (quasi-)stable viable DM candidates.
2. Detections lead to non-standard decays with atypical signatures (jets)
3. Current searches led by the DarkShowers LHC Taskforce

Key idea and observables:



SEMI VISIBLE JETS (SVJ) IN A NUTSHELL:

DARK SHOWERS AS A CANDIDATE FOR DARK MATTER (DM)



Motivation:

1. Dark-sector particles are (quasi-)stable viable DM candidates.
2. Detections lead to non-standard decays with atypical signatures (jets)
3. Current searches led by the DarkShowers LHC Taskforce

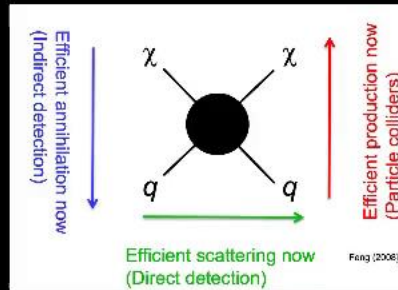
Key idea and observables:



- Final-state jet kinematics
- Global variables (e.g., MET)
- Internal jet structure

SEMI VISIBLE JETS (SVJ) IN A NUTSHELL:

DARK SHOWERS AS A CANDIDATE FOR DARK MATTER (DM)



Motivation:

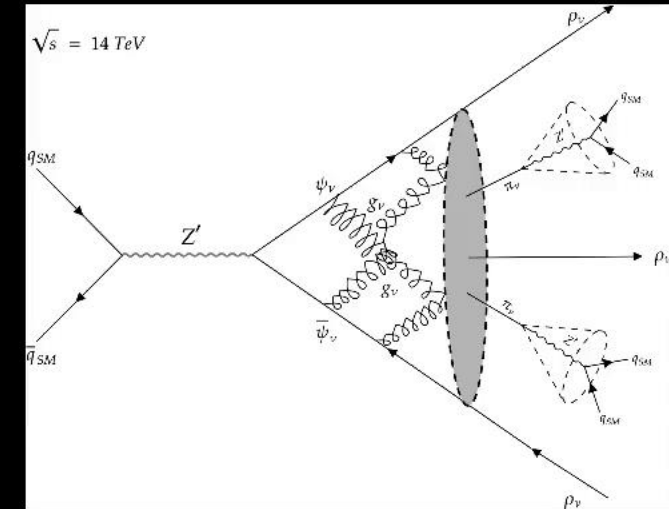
1. Dark-sector particles are (quasi-)stable viable DM candidates.
2. Detections lead to non-standard decays with atypical signatures (jets)
3. Current searches led by the DarkShowers LHC Taskforce

Key idea and observables:

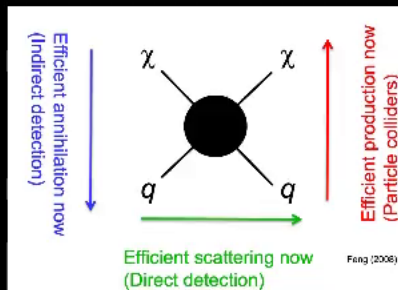


- Final-state jet kinematics
- Global variables (e.g., MET)
- Internal jet structure

SEMI VISIBLE JETS (SVJ) IN A NUTSHELL:



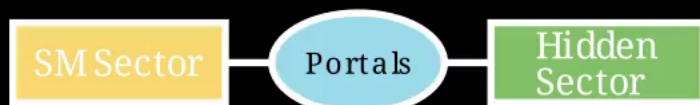
DARK SHOWERS AS A CANDIDATE FOR DARK MATTER (DM)



Motivation:

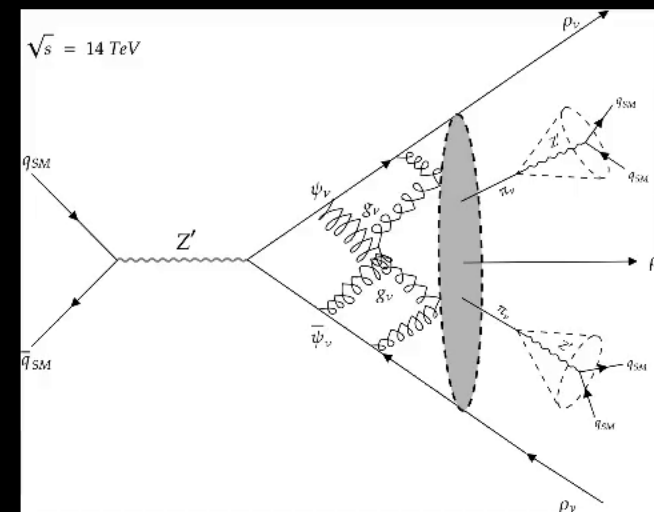
1. Dark-sector particles are (quasi-)stable viable DM candidates.
2. Detections lead to non-standard decays with atypical signatures (jets)
3. Current searches led by the DarkShower LHC Taskforce

Key idea and observables:



- Final-state jet kinematics
- Global variables (e.g., MET)
- Internal jet structure

SEMI VISIBLE JETS (SVJ) IN A NUTSHELL:



- Production mode through a resonance (Higgs, Z' , etc)
- Dark Shower and Dark hadronisation (Complex part)
- Decay into visible observables, via the invisible fraction:

$$r_{\text{inv}} \equiv \left\langle \frac{n_{\text{dark;hadrons;stable}}}{n_{\text{dark;hadrons;total}}} \right\rangle$$

MONTE CARLO EVENT GENERATORS

MONTE CARLO EVENT GENERATORS



Hidden valley processes in Pythia8

Recovered from: Bierlich, C (2022)

1. Dark QCD sector pre-computed on the hidden valley module
2. Dark parton shower and dark hadronisation (String hadronisation model)
3. Abelian and Non-abelian HV gauge groups for production processes



Herwig Dark showers package: H7

Recovered from: Kulkarni, S., et al. (2024)

1. Modern pre-computed (beta version) library for studies on the dark sector
2. Dark parton showers and dark hadronisation (Cluster hadronisation model)
3. Studies around e^+e^- collision focused on meson momenta.



Detector analysis

Recovered from: DeFavereau, J., et al. (2014)

1. Computation on final-state particles for SM and BSM stable hadrons
2. Pre-computed CMS and ATLAS detector card for .root file generation.
3. CMS card used in this analysis.

MONTE CARLO EVENT GENERATORS



Hidden valley processes in Pythia8

Recovered from: Bierlich, C (2022)

1. Dark QCD sector pre-computed on the hidden valley module
2. Dark parton shower and dark hadronisation (String hadronisation model)
3. Abelian and Non-abelian HV gauge groups for production processes



Herwig Dark showers package: H7

Recovered from: Kulkarni, S., et al. (2024)

1. Modern pre-computed (beta version) library for studies on the dark sector
2. Dark parton showers and dark hadronisation (Cluster hadronisation model)
3. Studies around e+e- collision focused on meson momenta.



Detector analysis

Recovered from: DeFavereau, J., et al. (2014)

1. Computation on final-state particles for SM and BSM stable hadrons
2. Pre-computed CMS and ATLAS detector card for .root file generation.
3. CMS card used in this analysis.

SEMI-VISIBLE JETS CHARACTERISATION

- Anti- k_T jet clustering algorithm
- Jet radius = 0.8 (Looking at Fat jets)
- Current applied cuts in table 1.
- 18 BPs generated, compared to QCD bck.
- Plus 3 more for testing.

MONTE CARLO EVENT GENERATORS



Hidden valley processes in Pythia8

Recovered from: Bierlich, C (2022)

1. Dark QCD sector pre-computed on the hidden valley module
2. Dark parton shower and dark hadronisation (String hadronisation model)
3. Abelian and Non-abelian HV gauge groups for production processes



Herwig Dark showers package: H7

Recovered from: Kulkarni, S., et al. (2024)

1. Modern pre-computed (beta version) library for studies on the dark sector
2. Dark parton showers and dark hadronisation (Cluster hadronisation model)
3. Studies around e^+e^- collision focused on meson momenta.



Detector analysis

Recovered from: DeFavereau, J., et al. (2014)

1. Computation on final-state particles for SM and BSM stable hadrons
2. Pre-computed CMS and ATLAS detector card for .root file generation.
3. CMS card used in this analysis.

SEMI-VISIBLE JETS CHARACTERISATION

- Anti- k_T jet clustering algorithm
- Jet radius = 0.8 (Looking at Fat jets)
- Current applied cuts in table 1.
- 18 BPs generated, compared to QCD bck.
- Plus 3 more for testing.



Recovered from: Caixian, M., et al. (2012)

Cut	Requirement
Large-R jets multiplicity	≥ 2 jets
Large-R jet pT (Leading Jet, $m_0=2.5$ TeV)	$p_T > 1.0$ TeV
Large-R jet pT (Leading Jet, $m_0=4.5$ TeV)	$p_T > 1.25$ TeV
Missing transverse energy	$MET > 200$ GeV

PREPARED DATASETS FOR QCD BCK AND SVJ SIGNALS

PREPARED DATASETS FOR QCD BCK AND SVJ SIGNALS

Dataset	m_{ψ_v} [GeV]	Λ_{dark} [GeV]	r_{inv} [%]
QCD	-	-	0.0
SVJs_BP_01_mzp_2.5TeV	10	2.50	40
SVJs_BP_02_mzp_2.5TeV	50	12.50	40
SVJs_BP_03_mzp_2.5TeV	100	25.0	40
SVJs_BP_04_mzp_4.5TeV	10	2.50	40
SVJs_BP_05_mzp_4.5TeV	50	12.50	40
SVJs_BP_06_mzp_4.5TeV	100	25.0	40
SVJs_BP_07_mzp_2.5TeV	50	20.0	30
SVJs_BP_08_mzp_2.5TeV	50	20.0	20
SVJs_BP_09_mzp_2.5TeV	50	20.0	50
SVJs_BP_10_mzp_4.5TeV	50	20.0	30
SVJs_BP_11_mzp_4.5TeV	50	20.0	20
SVJs_BP_12_mzp_4.5TeV	50	20.0	50
SVJs_BP_13_mzp_2.5TeV	50	4.0	40
SVJs_BP_14_mzp_2.5TeV	50	10.0	40
SVJs_BP_15_mzp_2.5TeV	50	30.0	40
SVJs_BP_16_mzp_4.5TeV	50	4.0	40
SVJs_BP_17_mzp_4.5TeV	50	10.0	40
SVJs_BP_18_mzp_4.5TeV	50	30.0	40

PREPARED DATASETS FOR QCD BCK AND SVJ SIGNALS

Dataset	m_{ψ_v} [GeV]	Λ_{dark} [GeV]	r_{inv} [%]
QCD	-	-	0.0
SVJs_BP_01_mzp_2.5TeV	10	2.50	40
SVJs_BP_02_mzp_2.5TeV	50	12.50	40
SVJs_BP_03_mzp_2.5TeV	100	25.0	40
SVJs_BP_04_mzp_4.5TeV	10	2.50	40
SVJs_BP_05_mzp_4.5TeV	50	12.50	40
SVJs_BP_06_mzp_4.5TeV	100	25.0	40
SVJs_BP_07_mzp_2.5TeV	50	20.0	30
SVJs_BP_08_mzp_2.5TeV	50	20.0	20
SVJs_BP_09_mzp_2.5TeV	50	20.0	50
SVJs_BP_10_mzp_4.5TeV	50	20.0	30
SVJs_BP_11_mzp_4.5TeV	50	20.0	20
SVJs_BP_12_mzp_4.5TeV	50	20.0	50
SVJs_BP_13_mzp_2.5TeV	50	4.0	40
SVJs_BP_14_mzp_2.5TeV	50	10.0	40
SVJs_BP_15_mzp_2.5TeV	50	30.0	40
SVJs_BP_16_mzp_4.5TeV	50	4.0	40
SVJs_BP_17_mzp_4.5TeV	50	10.0	40
SVJs_BP_18_mzp_4.5TeV	50	30.0	40

Performing a parameter scan over three key physical quantities:

Inv. Fraction : $r_{BSM} = r_{inv}$

Dark Quarks masses : m_{ψ_D}

Dark hadronisation cte : Λ_D

PREPARED DATASETS FOR QCD BCK AND SVJ SIGNALS

Dataset	m_{ψ_v} [GeV]	Λ_{dark} [GeV]	r_{inv} [%]
QCD	-	-	0.0
SVJs_BP_01_mzp_2.5TeV	10	2.50	40
SVJs_BP_02_mzp_2.5TeV	50	12.50	40
SVJs_BP_03_mzp_2.5TeV	100	25.0	40
SVJs_BP_04_mzp_4.5TeV	10	2.50	40
SVJs_BP_05_mzp_4.5TeV	50	12.50	40
SVJs_BP_06_mzp_4.5TeV	100	25.0	40
SVJs_BP_07_mzp_2.5TeV	50	20.0	30
SVJs_BP_08_mzp_2.5TeV	50	20.0	20
SVJs_BP_09_mzp_2.5TeV	50	20.0	50
SVJs_BP_10_mzp_4.5TeV	50	20.0	30
SVJs_BP_11_mzp_4.5TeV	50	20.0	20
SVJs_BP_12_mzp_4.5TeV	50	20.0	50
SVJs_BP_13_mzp_2.5TeV	50	4.0	40
SVJs_BP_14_mzp_2.5TeV	50	10.0	40
SVJs_BP_15_mzp_2.5TeV	50	30.0	40
SVJs_BP_16_mzp_4.5TeV	50	4.0	40
SVJs_BP_17_mzp_4.5TeV	50	10.0	40
SVJs_BP_18_mzp_4.5TeV	50	30.0	40

Performing a parameter scan over three key physical quantities:

Inv. Fraction : $r_{BSM} = r_{inv}$

Dark Quarks masses : m_{ψ_D}

Dark hadronisation cte : Λ_D

We also vary the Z' mass to study how the overall kinematical behaviour will change. Fixed parameters are:
Lund parameters {a,b} with perturbative Λ .

PREPARED DATASETS FOR QCD BCK AND SVJ SIGNALS

Dataset	m_{ψ_v} [GeV]	Λ_{dark} [GeV]	r_{inv} [%]
QCD	-	-	0.0
SVJs_BP_01_mzp_2.5TeV	10	2.50	40
SVJs_BP_02_mzp_2.5TeV	50	12.50	40
SVJs_BP_03_mzp_2.5TeV	100	25.0	40
SVJs_BP_04_mzp_4.5TeV	10	2.50	40
SVJs_BP_05_mzp_4.5TeV	50	12.50	40
SVJs_BP_06_mzp_4.5TeV	100	25.0	40
SVJs_BP_07_mzp_2.5TeV	50	20.0	30
SVJs_BP_08_mzp_2.5TeV	50	20.0	20
SVJs_BP_09_mzp_2.5TeV	50	20.0	50
SVJs_BP_10_mzp_4.5TeV	50	20.0	30
SVJs_BP_11_mzp_4.5TeV	50	20.0	20
SVJs_BP_12_mzp_4.5TeV	50	20.0	50
SVJs_BP_13_mzp_2.5TeV	50	4.0	40
SVJs_BP_14_mzp_2.5TeV	50	10.0	40
SVJs_BP_15_mzp_2.5TeV	50	30.0	40
SVJs_BP_16_mzp_4.5TeV	50	4.0	40
SVJs_BP_17_mzp_4.5TeV	50	10.0	40
SVJs_BP_18_mzp_4.5TeV	50	30.0	40

Performing a parameter scan over three key physical quantities:

Inv. Fraction : $r_{BSM} = r_{inv}$

Dark Quarks masses : m_{ψ_D}

Dark hadronisation cte : Λ_D

We also vary the Z' mass to study how the overall kinematical behaviour will change. Fixed parameters are:
Lund parameters {a,b} with perturbative Λ .

Changes are pointed in red

With the following BPs used as testing for the DL analysis

Dataset	m_{ψ_v} [GeV]	Λ_{dark} [GeV]	r_{SM} [%]
SVJs_BP_19_mzp_3.5TeV	75	2.50	60
SVJs_BP_20_mzp_3.5TeV	50	12.50	65
SVJs_BP_21_mzp_3.5TeV	50	20.0	40

SVJ Jet-Level observables: Basic Kinematics

SVJ Jet-Level observables: Basic Kinematics

2

DID OUR CUTS MATCHES WHAT DO WE EXPECT FROM THEM?

SVJ Jet-Level observables: Basic Kinematics

2

DID OUR CUTS MATCHES WHAT DO WE EXPECT FROM THEM?

We implemented some **cuts** but are they being properly applied in our current analysis? and will they be able to reconstruct the invariant and **transverse mass**? We should extract:

- Di-jet Energy: $E_{1,2}$
- Di-jet three-momentum: $\vec{p}_{1,2}$
- Di-jet Transverse-momentum: $\vec{p}_{T,jj}$
- MET: E_T^{miss}

and see if we can get an approximation to the Z' mass

SVJ Jet-Level observables: Basic Kinematics

2

DID OUR CUTS MATCHES WHAT DO WE EXPECT FROM THEM?

We implemented some **cuts** but are they being properly applied in our current analysis? and will they be able to reconstruct the invariant and **transverse mass**? We should extract:

- Di-jet Energy: $E_{1,2}$
- Di-jet three-momentum: $\vec{p}_{1,2}$
- Di-jet Transverse-momentum: $\vec{p}_{T,jj}$
- MET: E_T^{miss}

and see if we can get an approximation to the Z' mass

Invariant Di-jet mass M_{jj}

$$M_{jj} = \sqrt{(E_1 + E_2)^2 - |\vec{p}_1 + \vec{p}_2|^2},$$

SVJ Jet-Level observables: Basic Kinematics

2

DID OUR CUTS MATCHES WHAT DO WE EXPECT FROM THEM?

We implemented some **cuts** but are they being properly applied in our current analysis? and will they be able to reconstruct the invariant and **transverse mass**? We should extract:

- Di-jet Energy: $E_{1,2}$
- Di-jet three-momentum: $\vec{p}_{1,2}$
- Di-jet Transverse-momentum: $\vec{p}_{T,jj}$
- MET: E_T^{miss}

and see if we can get an approximation to the Z' mass

Invariant Di-jet mass M_{jj}

$$M_{jj} = \sqrt{(E_1 + E_2)^2 - |\vec{p}_1 + \vec{p}_2|^2},$$

Transverse mass

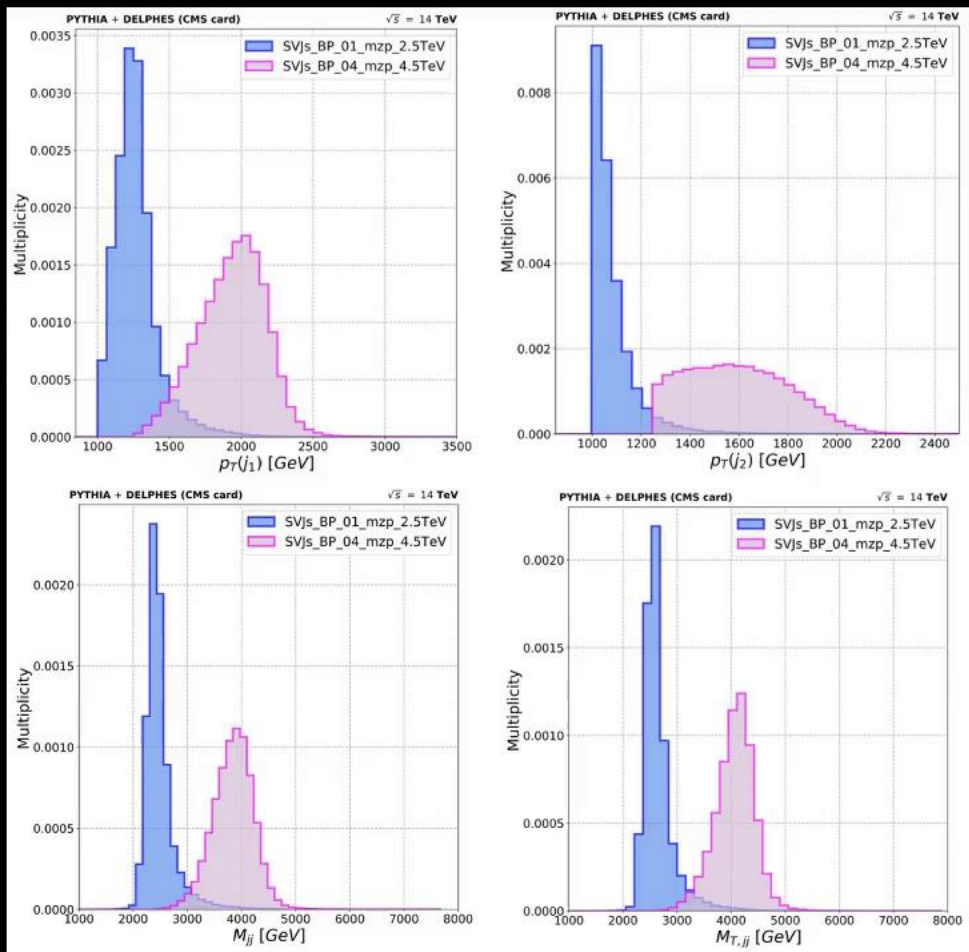
$$m_T^2 = M_{jj}^2 + 2 \left(|E_T^{miss}| \sqrt{M_{jj}^2 + |\vec{p}_{T,jj}|^2} - E_T^{miss} \cdot \vec{p}_{T,jj} \right),$$

Recovered from: (Asadi, P., et al. (2026))

RESULTS

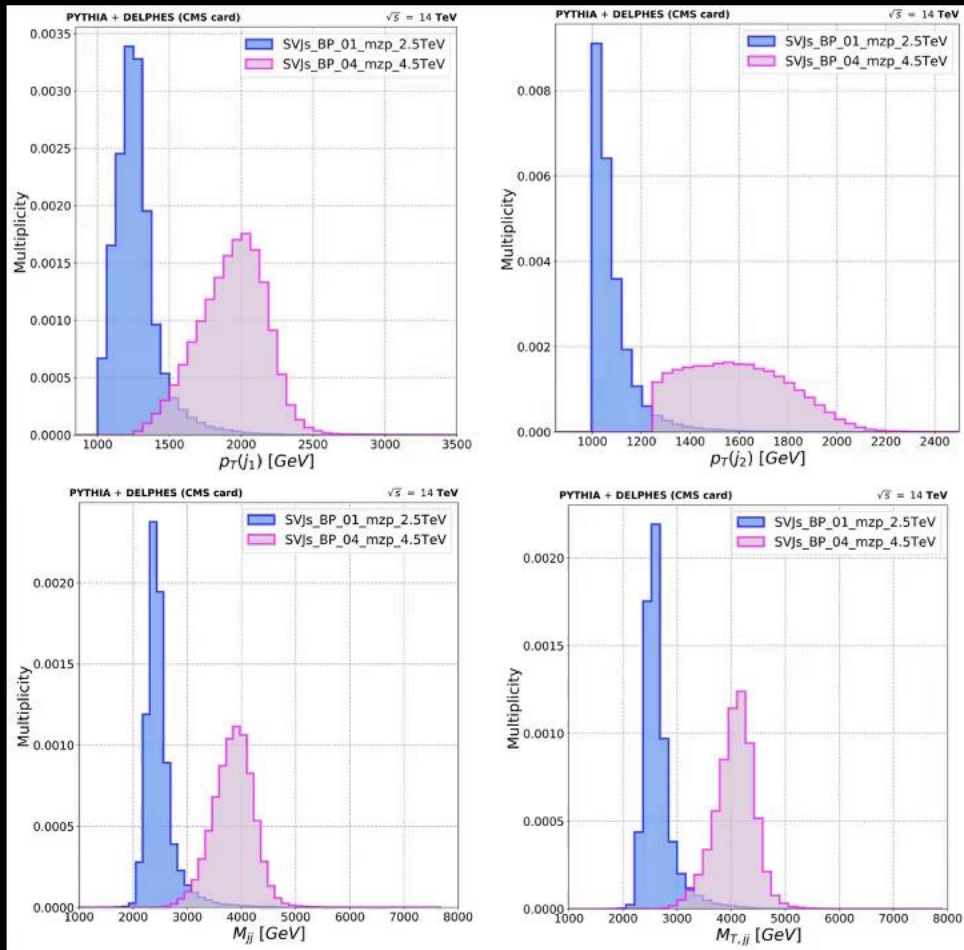
DO WE SATISFY OUR EXPECTATIONS?

RESULTS



DO WE SATISFY OUR EXPECTATIONS?

RESULTS



DO WE SATISFY OUR EXPECTATIONS?

All the cuts were satisfied!

The cut for the transverse momentum in both jets is correctly applied, and if we do measure the transverse and invariant mass we observed that

1. The invariant mass is lower than the transverse mass.
2. The invisible constituents from the stable dark hadrons contribute to the total Z' mass reconstruction.

Global MET and Difference on the Azimuthal

Global MET and Difference on the Azimuthal

2

THEORY BEHIND IT AND APPLICATION OF DELPHES COLLIDER ANALYSIS

Global MET and Difference on the Azimuthal

2

THEORY BEHIND IT AND APPLICATION OF DELPHES COLLIDER ANALYSIS

DELPHES allows us to compute the MET from the "tree" file which already takes into account:

- Detector dimensions
- Particle isolation
- Particle smearing

this includes the invisible particles (both neutrinos and BSM), within the detector.

We use CMS detector card for this analysis, where:

Global MET and Difference on the Azimuthal

2

THEORY BEHIND IT AND APPLICATION OF DELPHES COLLIDER ANALYSIS

DELPHES allows us to compute the MET from the "tree" file which already takes into account:

- Detector dimensions
- Particle isolation
- Particle smearing

this includes the invisible particles (both neutrinos and BSM), within the detector.

We use CMS detector card for this analysis, where:

Global missing E_T^{miss}

$$\sum p_T \in \text{Inv. Particles}$$

Global MET and Difference on the Azimuthal

2

THEORY BEHIND IT AND APPLICATION OF DELPHES COLLIDER ANALYSIS

DELPHES allows us to compute the MET from the "tree" file which already takes into account:

- Detector dimensions
- Particle isolation
- Particle smearing

this includes the invisible particles (both neutrinos and BSM), within the detector.

We use CMS detector card for this analysis, where:

Global missing E_T^{miss}

$$\sum p_T \in \text{Inv. Particles}$$

Difference on the azimuthal

$$\Delta\phi = \phi_{MET_{Global}} - \phi_{jet_{lead}}$$

Recovered from: (Franceschini, R., et al 2023)

Global MET and Difference on the Azimuthal

2

THEORY BEHIND IT AND APPLICATION OF DELPHES COLLIDER ANALYSIS

DELPHES allows us to compute the MET from the "tree" file which already takes into account:

- Detector dimensions
- Particle isolation
- Particle smearing

this includes the invisible particles (both neutrinos and BSM), within the detector.

We use CMS detector card for this analysis, where:

Global missing E_T^{miss}

$$\sum p_T \in \text{Inv. Particles}$$

Difference on the azimuthal

$$\Delta\phi = \phi_{MET_{Global}} - \phi_{jet_{lead}}$$

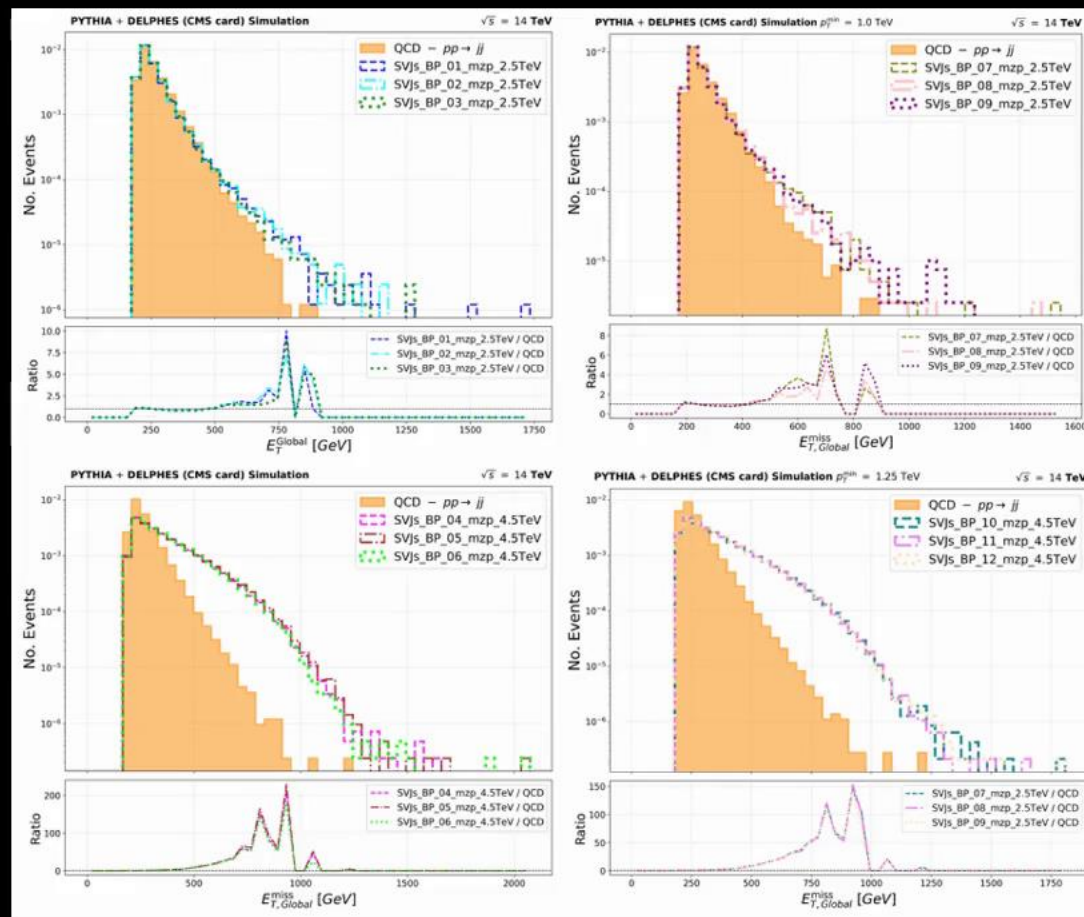
Recovered from: (Franceschini, R., et al 2023)

Plots from the difference on the azimuthal are on the backup. 8

RESULTS

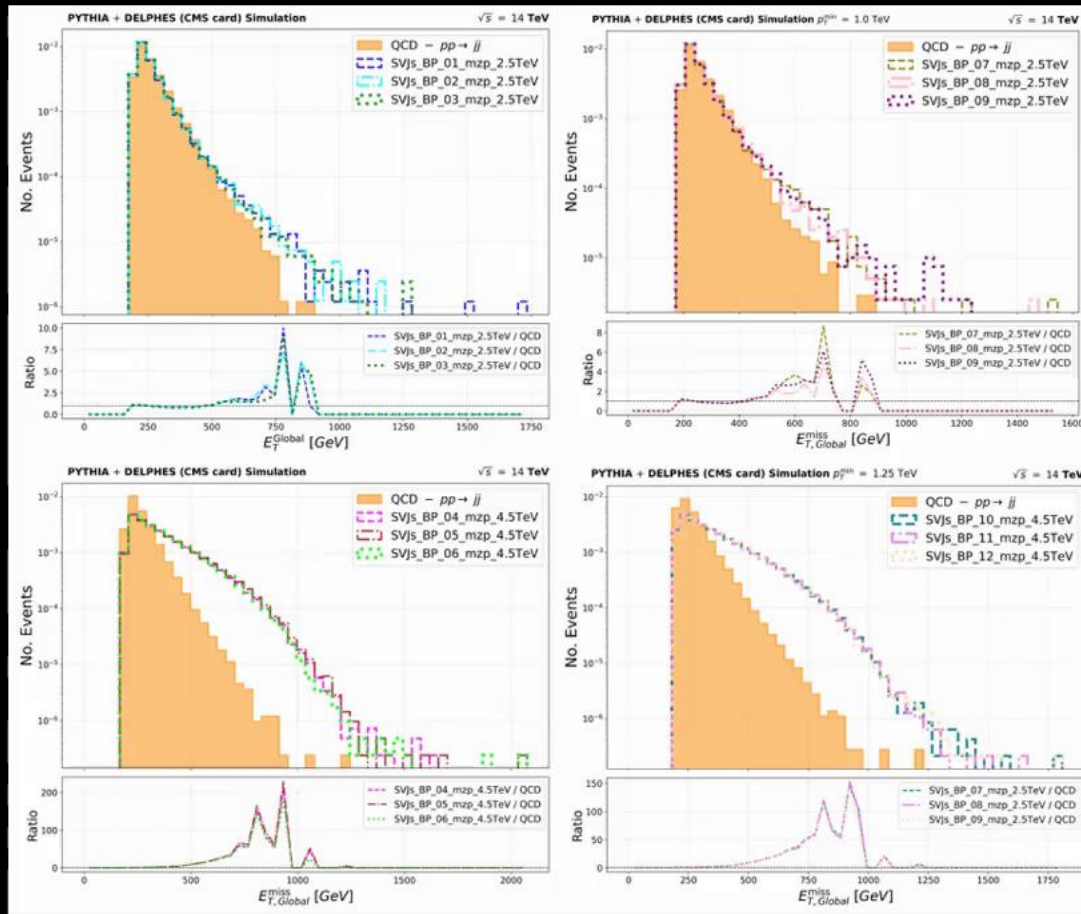
WHAT CAN WE LEARN FROM IT?

RESULTS



WHAT CAN WE LEARN FROM IT?

RESULTS



WHAT CAN WE LEARN FROM IT?

Main differences:

1. The HV parameters dependence is visible, where the dark hadrons mass and the invisible fraction produces the largest changes in the MET distribution
2. Increasing the mediator mass yields to a harder energy spectrum and higher MET values
3. SVJ BPs can overlap but all of the distributions exhibit differences.

The Lund-plane (Delphes-Level)

The Lund-plane (Delphes-Level)

1

THEORY BEHIND IT

The Lund-plane (Delphes-Level)

1

THEORY BEHIND IT

The Lund-plane (Delphes-Level)

1

THEORY BEHIND IT

**2D Representation of jet
visible constituents:**

1. Charged hadrons (in particular mesons:
Neutral Kaons and negative/positive pions)
2. Photons.

WHERE:

The Lund-plane (Delphes-Level)

1

THEORY BEHIND IT

**2D Representation of jet
visible constituents:**

1. Charged hadrons (in particular mesons:
Neutral Kaons and negative/positive pions)
2. Photons.

WHERE:

$$\Delta_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$

$$\Delta \equiv \Delta_{ab}, \quad k_t \equiv p_{tb} \Delta_{ab}$$

The Lund-plane (Delphes-Level)

1

THEORY BEHIND IT

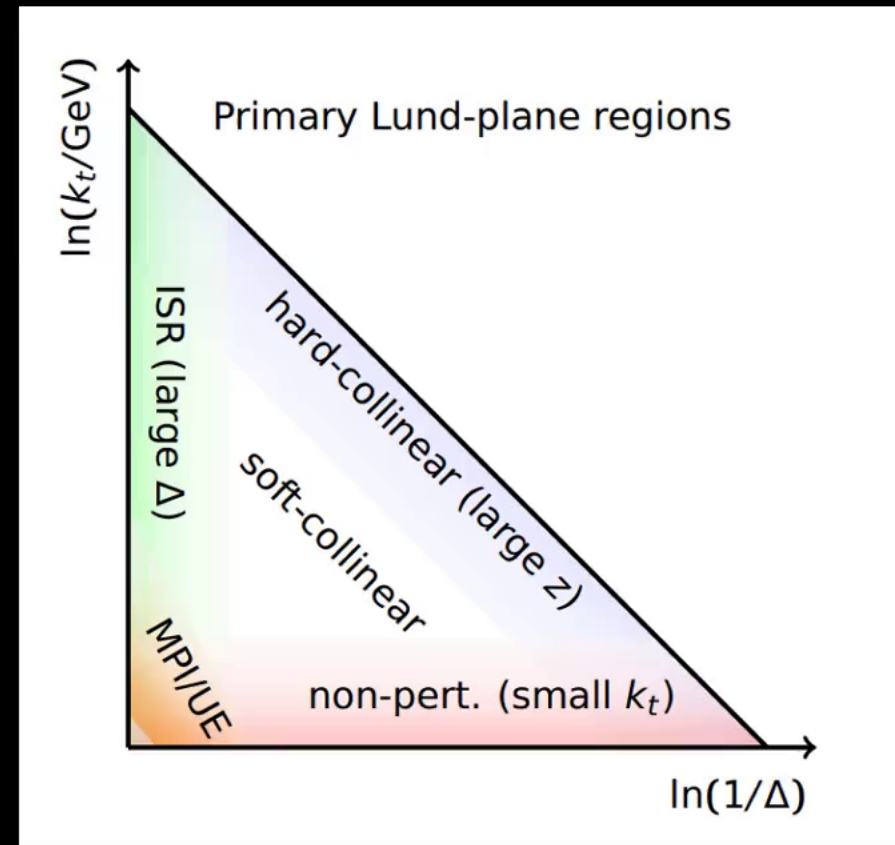
2D Representation of jet visible constituents:

1. Charged hadrons (in particular mesons: Neutral Kaons and negative/positive pions)
2. Photons.

WHERE:

$$\Delta_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$

$$\Delta \equiv \Delta_{ab}, \quad k_t \equiv p_{tb} \Delta_{ab}$$

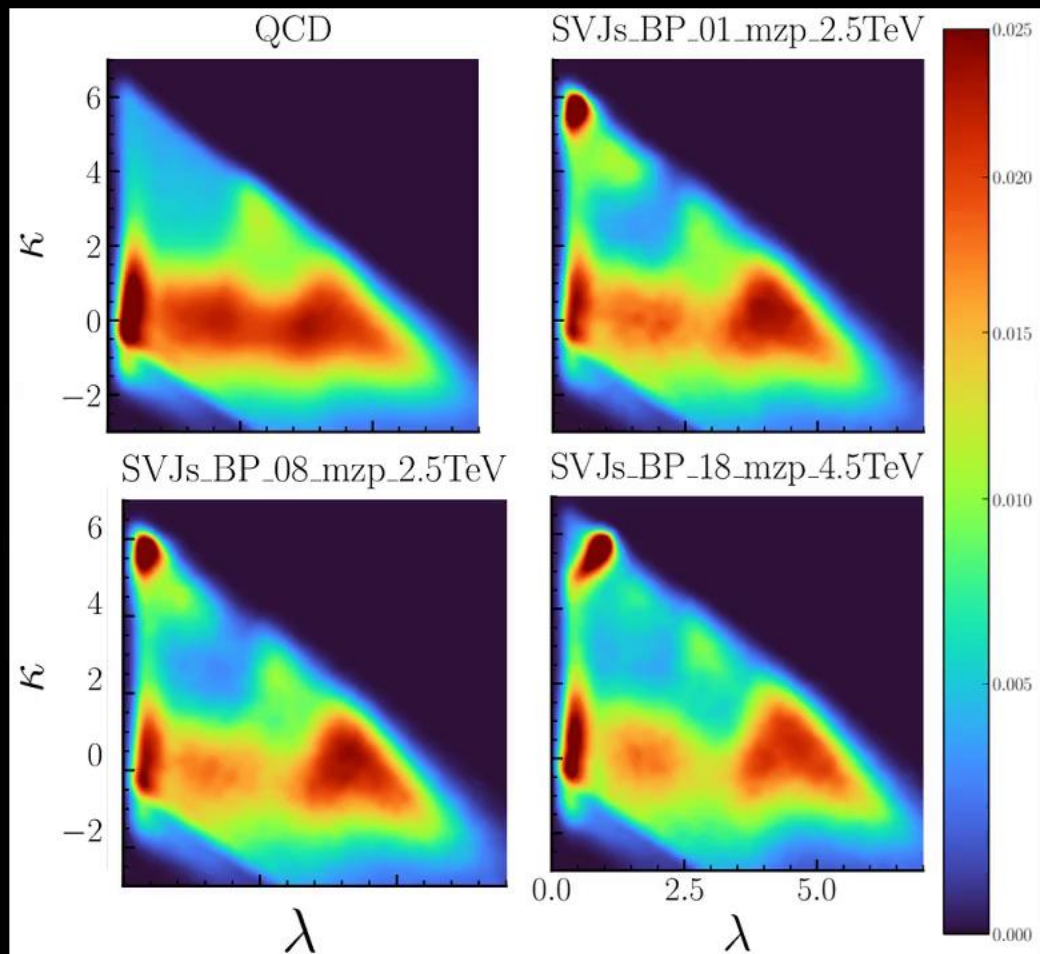


Recovered from: (Dreyer, EA., et al, 2018)

RESULTS

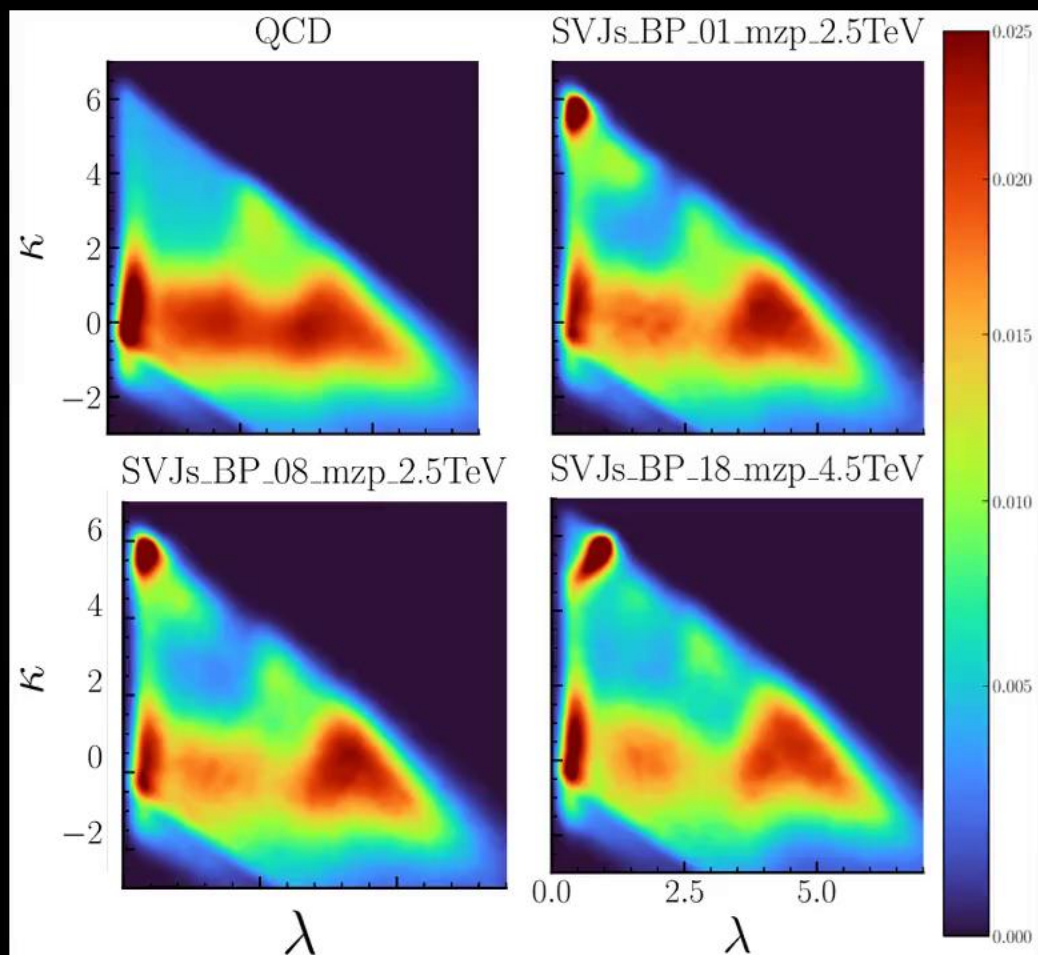
WHAT CAN WE LEARN FROM IT?

RESULTS



WHAT CAN WE LEARN FROM IT?

RESULTS



WHAT CAN WE LEARN FROM IT?

Visual differences from QCD/SVJ signals.

1. Dark quarks masses affect the boost of decay hadrons causing larger MPI emissions. (For $\ln(k_T)$)
2. The invisible fraction modifies the ISR and hard-collinear radiation
3. Dark hadronisation impacts the non-perturbative and soft collinear regions (For small k_T)

ML ANALYSIS IDEA

FUSION NETWORK

ML ANALYSIS IDEA

We want to know how much discrimination power we have using 5 NNs:

1. Vision Transformer (ViT) for the LJP images
2. JetLOV using the Lund variables from Lund tree
3. MLP for all the kinematical information
4. Fusion network between the ViT and the MLP
5. Fusion network between the JetLOV and the MLP

All trained on a common balanced dataset.

FUSION NETWORK

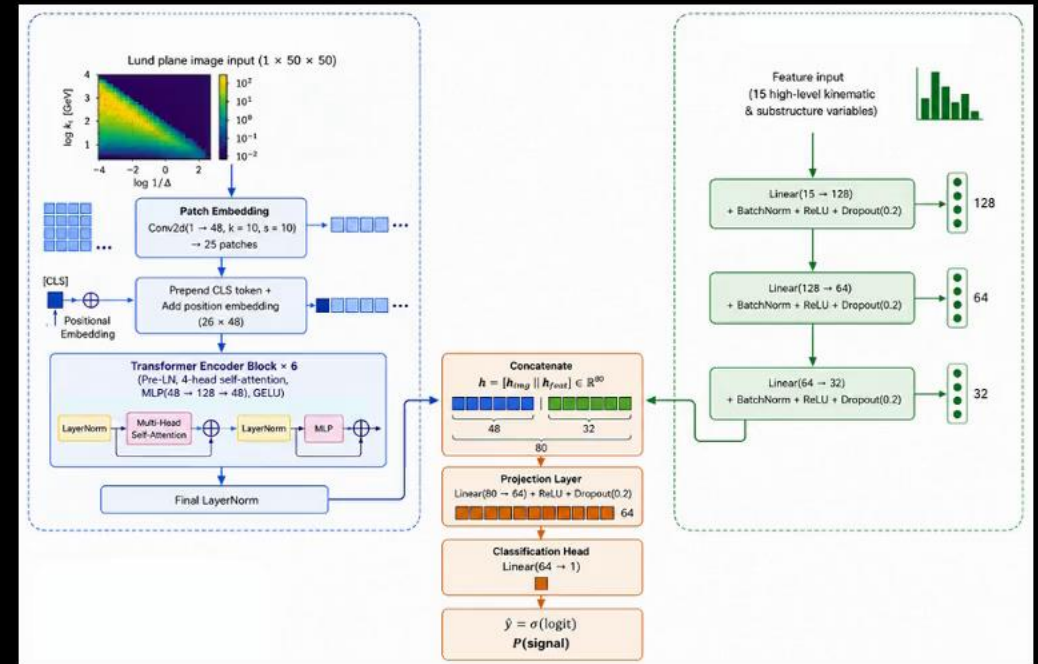
ML ANALYSIS IDEA

We want to know how much discrimination power we have using 5 NNs:

1. Vision Transformer (ViT) for the LJP images
2. JetLOV using the Lund variables from Lund tree
3. MLP for all the kinematical information
4. Fusion network between the ViT and the MLP
5. Fusion network between the JetLOV and the MLP

All trained on a common balanced dataset.

FUSION NETWORK



ML ANALYSIS IDEA

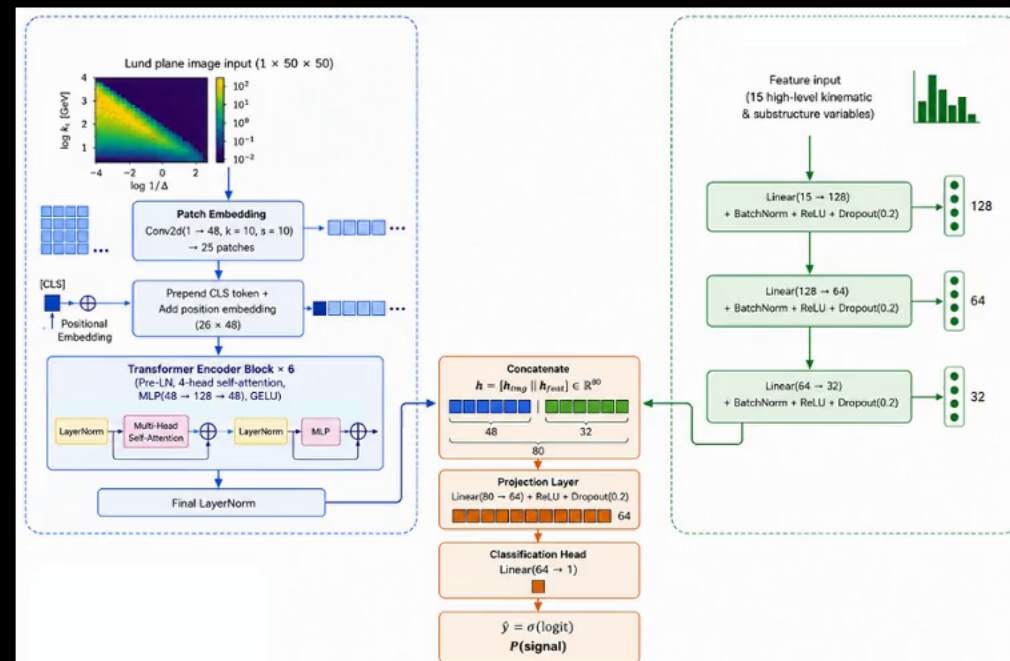
We want to know how much discrimination power we have using 5 NNs:

1. Vision Transformer (ViT) for the LJP images
2. JetLOV using the Lund variables from Lund tree
3. MLP for all the kinematical information
4. Fusion network between the ViT and the MLP
5. Fusion network between the JetLOV and the MLP

All trained on a common balanced dataset.

OBSERVABLES DISTRIBUTION

FUSION NETWORK



ML ANALYSIS IDEA

We want to know how much discrimination power we have using 5 NNs:

1. Vision Transformer (ViT) for the LJP images
2. JetLOV using the Lund variables from Lund tree
3. MLP for all the kinematical information
4. Fusion network between the ViT and the MLP
5. Fusion network between the JetLOV and the MLP

All trained on a common balanced dataset.

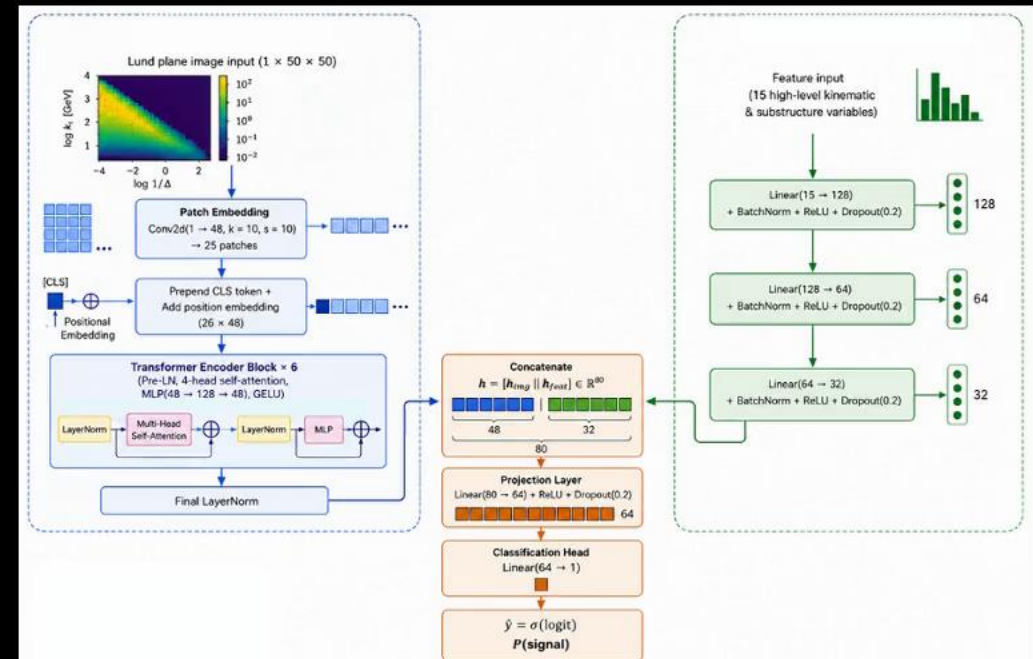
OBSERVABLES DISTRIBUTION

The Lund Jet Plane (LJP) for:

1. ViT
2. JetLOV

The MLP for:

FUSION NETWORK



ML ANALYSIS IDEA

We want to know how much discrimination power we have using 5 NNs:

1. Vision Transformer (ViT) for the LJP images
2. JetLOV using the Lund variables from Lund tree
3. MLP for all the kinematical information
4. Fusion network between the ViT and the MLP
5. Fusion network between the JetLOV and the MLP

All trained on a common balanced dataset.

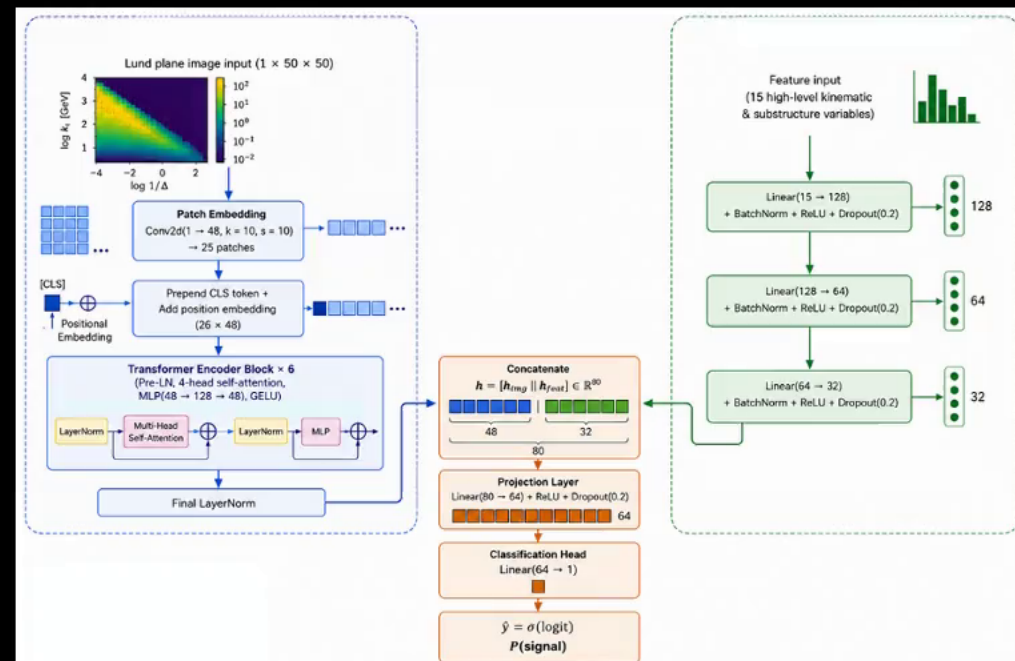
OBSERVABLES DISTRIBUTION

The Lund Jet Plane (LJP) for:

1. ViT
2. JetLOV

The MLP for:

FUSION NETWORK



Global

MET
 $\Delta\phi(MET, j_{\text{lead}})$

Local (Jet-Level)

Final-state

$p_T(j_1), p_T(j_2)$
 $\phi(j_1), \phi(j_2)$
 $\eta(j_1), \eta(j_2)$
 m_{jj}
 $\Delta\phi(j_1, j_2)$

Sub-structure

$\tau(0.1)$
 $\tau(0.8)$
 $\tau(1.5)$
 $c_2\text{-}EEC$

Hadron multiplicity

CLASSIFICATION RESULTS

ARE WE ABLE TO DISTINGUISH QCD AND SVJ?

CONFUSION MATRICES

CLASSIFICATION RESULTS

Model	Accuracy	ROC AUC
ViT	0.8629	0.9293
JetLOV	0.9003	0.9572
MLP (All)	0.9054	0.9653
ViT+MLP	0.9389	0.9846
JetLOV+MLP	0.9428	0.9872

CONFUSION MATRICES

ARE WE ABLE TO DISTINGUISH QCD AND SVJ?

CLASSIFICATION RESULTS

Model	Accuracy	ROC AUC
ViT	0.8629	0.9293
JetLOV	0.9003	0.9572
MLP (All)	0.9054	0.9653
ViT+MLP	0.9389	0.9846
JetLOV+MLP	0.9428	0.9872

CONFUSION MATRICES

Model	Trueneg. (TN)	Falsepos. (FP)
ViT	87.68%	12.32%
JetLOV	91.19%	8.81%
MLP	91.78%	8.22%
ViT+MLP	94.08%	5.92%
JetLOV+MLP	94.99%	5.01%

ARE WE ABLE TO DISTINGUISH QCD AND SVJ?

CLASSIFICATION RESULTS

Model	Accuracy	ROC AUC
ViT	0.8629	0.9293
JetLOV	0.9003	0.9572
MLP (All)	0.9054	0.9653
ViT+MLP	0.9389	0.9846
JetLOV+MLP	0.9428	0.9872

CONFUSION MATRICES

Model	True neg. (TN)	False pos. (FP)
ViT	87.68%	12.32%
JetLOV	91.19%	8.81%
MLP	91.78%	8.22%
ViT+MLP	94.08%	5.92%
JetLOV+MLP	94.99%	5.01%

ARE WE ABLE TO DISTINGUISH QCD AND SVJ?

From the previous tables we can say that:

- One observable such as the LJP won't provide enough discrimination rather than merging it with other observables.

Merging 2 different networks allow us

- to reconstruct and retain the dominant jet information.

The fusion model achieves the highest

- discrimination power between SVJ or QCD, and the best performance for identify true SVJ or QCD signals.

SUMMARY

FURTHER WORK

SUMMARY

FURTHER WORK

A large, empty, light gray rectangular box with rounded corners, intended for writing a summary.A light gray rectangular box with rounded corners, intended for writing further work. It is the top of a two-part section.A light gray rectangular box with rounded corners, intended for writing further work. It is the bottom of a two-part section.

SUMMARY

Can jet sub-structure observables help us to detect DS signatures for future CMS searches?

Short answer: **Yes!**, dark showers and SVJ searches allow us to distinguish them from a well-known QCD bck, and understand their kinematical parameters:

- Jet-substructure observables reveals which parameters have the strongest impact on the kinematics
- ML approaches showed that the discrimination power is sufficient for future SVJ searches at the LHC.

FURTHER WORK

SUMMARY

Can jet sub-structure observables help us to detect DS signatures for future CMS searches?

Short answer: **Yes!**, dark showers and SVJ searches allow us to distinguish them from a well-known QCD bck, and understand their kinematical parameters:

- Jet-substructure observables reveals which parameters have the strongest impact on the kinematics

- ML approaches showed that the discrimination power is sufficient for future SVJ searches at the LHC.

FURTHER WORK

- The actual paper with more detailed content is on arxiv :). You can find it in the QR code!
- Start the comparison with Herwig7 and pythia8 output
- Complement the analysis with other decay channel dataset?
- Start a more extended ML analysis.

More detail in the backup!

SUMMARY

Can jet sub-structure observables help us to detect DS signatures for future CMS searches?

Short answer: **Yes!**, dark showers and SVJ searches allow us to distinguish them from a well-known QCD bck, and understand their kinematical parameters:

- Jet-substructure observables reveals which parameters have the strongest impact on the kinematics

- ML approaches showed that the discrimination power is sufficient for future SVJ searches at the LHC.

FURTHER WORK

- The actual paper with more detailed content is on arxiv :). You can find it in the QR code!
- Start the comparison with Herwig7 and pythia8 output
- Complement the analysis with other decay channel dataset?
- Start a more extended ML analysis.

More detail in the backup!

Thanks!

ANY QUESTIONS?

:)



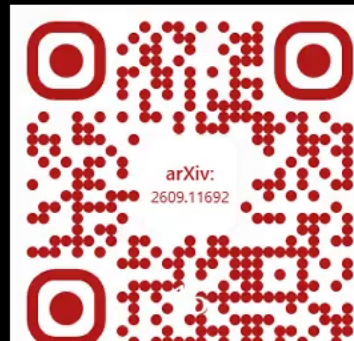
BACKUP

Speaker: Miguel Ángel Avendaño Bernal

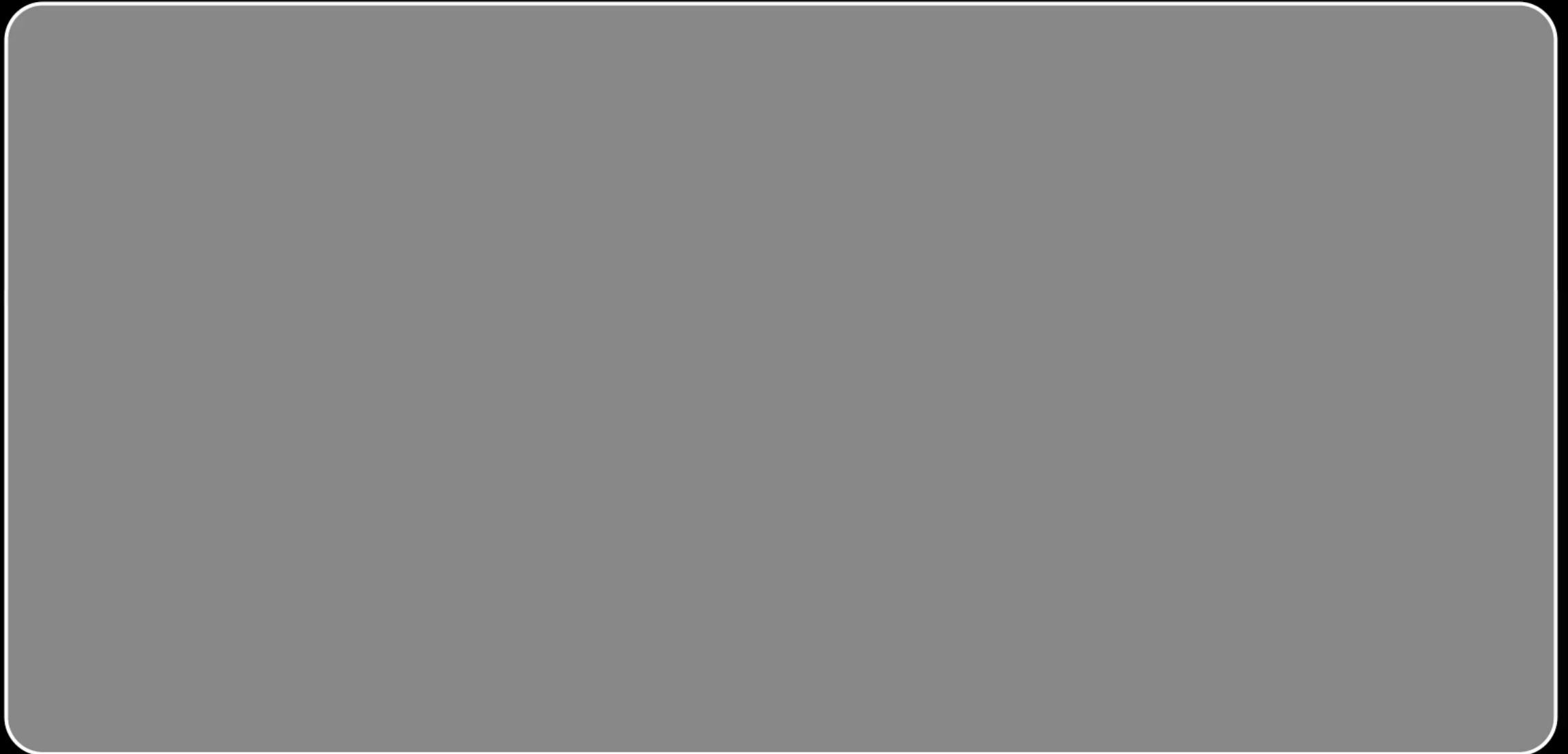
In collaboration with:

Srinandan Dasgupta, Ahmed Hammad, Stefano Moretti, Mihoko Nojiri, Michael H. Seymour and Claire Shepherd-Themistoclous

Based on the work published on arXiv:



What is a jet? The theoretical perspective



What is a jet? The theoretical perspective

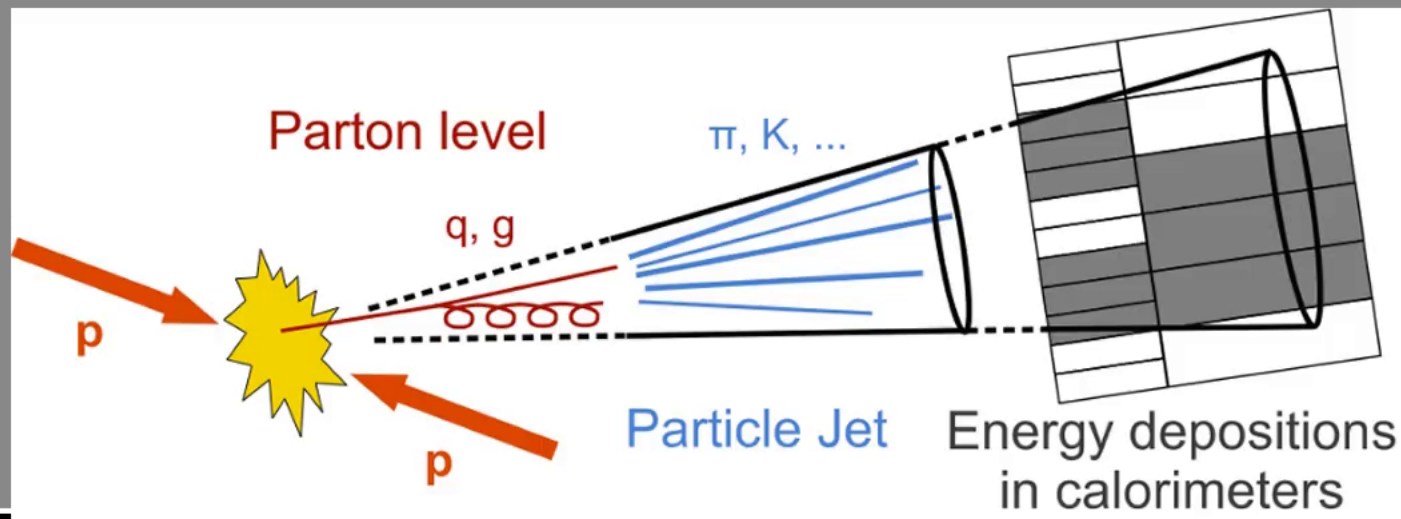
Jets are a reconstructed observable, normally described as a collimated spray of hadrons, partons and invisible particles that are being detected directly at the detector calorimeters as deposited clusters of energy after passing the hadronisation stage. For jet clustering the 3 most used jet algorithms are:

- Anti-kT jet algorithm
- Cambridge/Aachen jet algorithm
- KT jet algorithm

What is a jet? The theoretical perspective

Jets are a reconstructed observable, normally described as a collimated spray of hadrons, partons and invisible particles that are being detected directly at the detector calorimeters as deposited clusters of energy after passing the hadronisation stage. For jet clustering the 3 most used jet algorithms are:

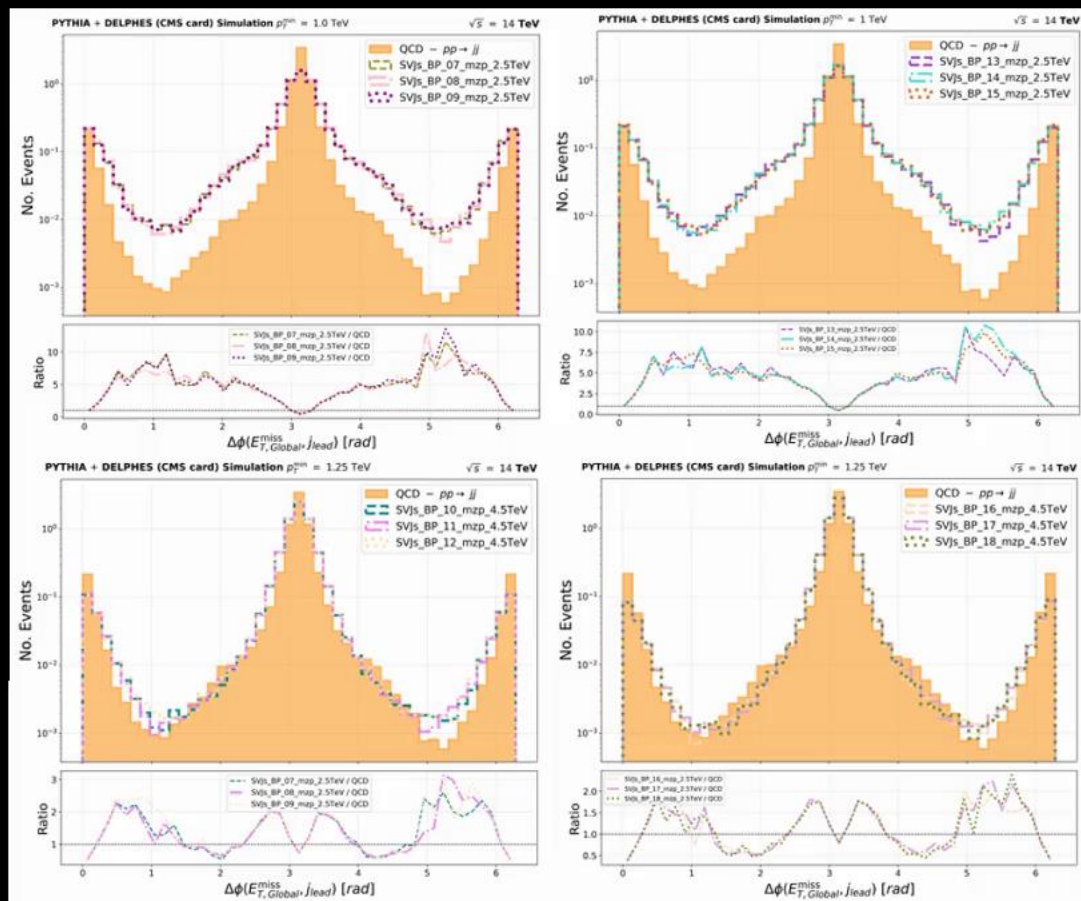
- Anti-kT jet algorithm
- Cambridge/Aachen jet algorithm
- KT jet algorithm



RESULTS

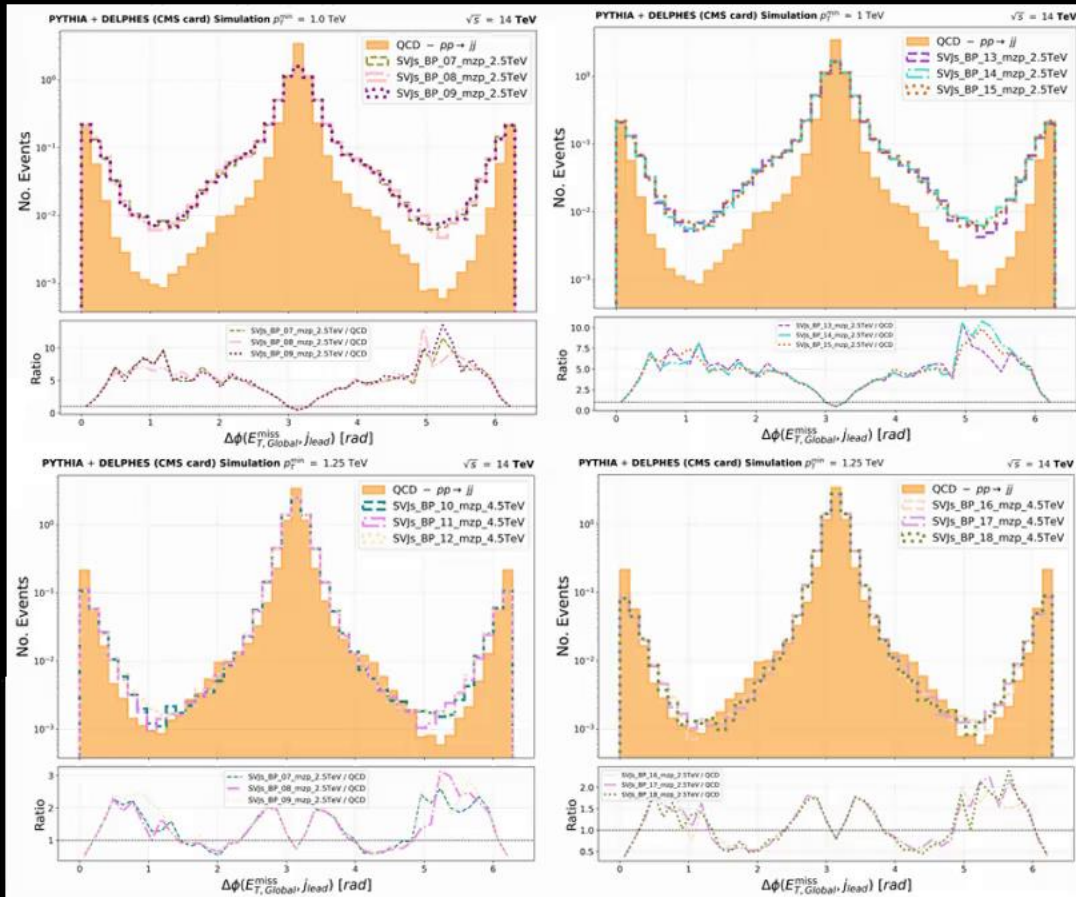
WHAT CAN WE LEARN FROM IT?

RESULTS



WHAT CAN WE LEARN FROM IT?

RESULTS



WHAT CAN WE LEARN FROM IT?

Now the dependence on the HV parameters is mainly driven for:

- The mediator mass
- The dark hadron mass
- The invisible fraction

Physics reveal:

- Mediator mass will control the available energy scale of the event, leading jet kinematics and the amount of energy from the dark sector and the phase space for DS evolution.

Angularity Function (Delphes Level)

Angularity Function (Delphes Level)

2

THEORY BEHIND IT

Angularity Function (Delphes Level)

2

THEORY BEHIND IT

Numerical computation between constituents to quantify the p_T weighted angular separation between the constituents and the selected jet, with:

1. θ_i^α is the angle from the particle within the jet.
2. E_i is the energy from the constituent
3. E_T represents the total energy

For the hadronic case we used the p_T as E_T .

Angularity Function (Delphes Level)

2

THEORY BEHIND IT

Numerical computation between constituents to quantify the p_T weighted angular separation between the constituents and the selected jet, with:

1. θ_i^α is the angle from the particle within the jet.
2. E_i is the energy from the constituent
3. E_T represents the total energy

For the hadronic case we used the p_T as E_T .

$$\tau_{\alpha,\beta} \simeq \sum_{j \in \text{jets}} \sum_{i \in j} \theta_i^\alpha \left(\frac{E_i}{E_j} \right)^\beta,$$

Angularity Function (Delphes Level)

2

THEORY BEHIND IT

Numerical computation between constituents to quantify the p_T weighted angular separation between the constituents and the selected jet, with:

1. θ_i^α is the angle from the particle within the jet.
2. E_i is the energy from the constituent
3. E_T represents the total energy

For the hadronic case we used the p_T as E_T .

$$\tau_{\alpha,\beta} \simeq \sum_{j \in \text{jets}} \sum_{i \in j} \theta_i^\alpha \left(\frac{E_i}{E_j} \right)^\beta,$$

$$\beta = 1$$

$$\alpha \geq 0;$$

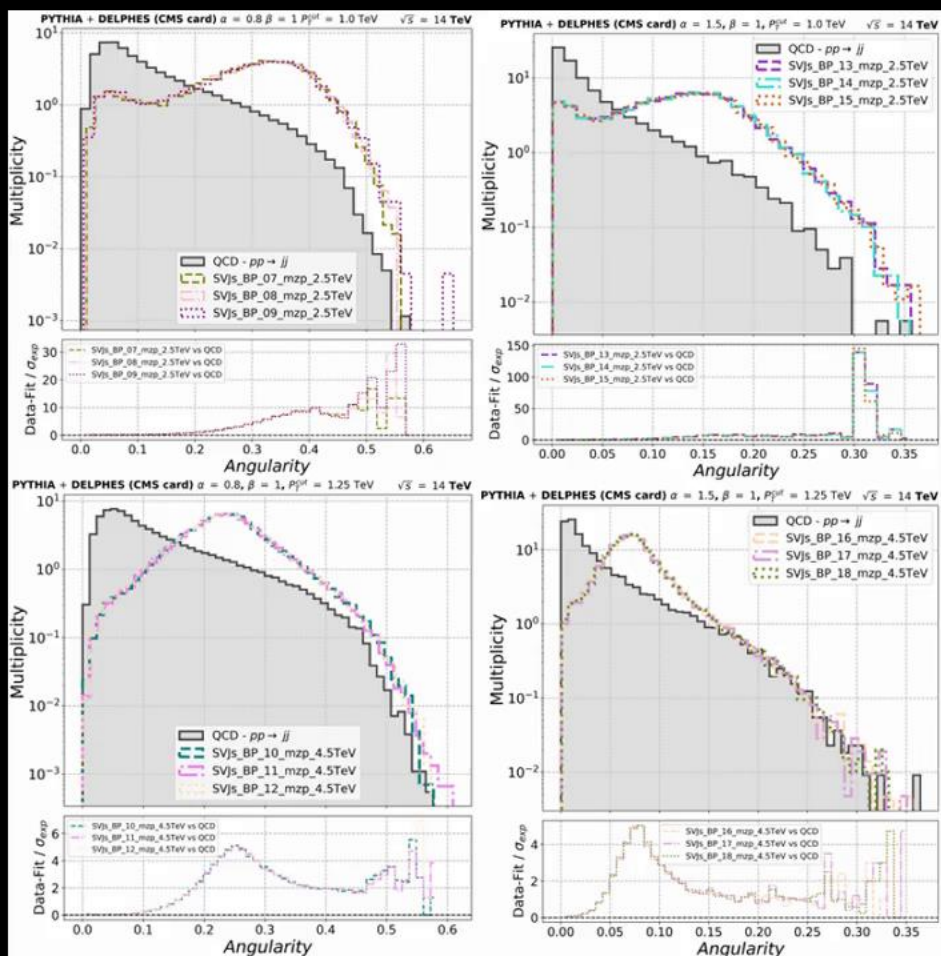
$$\alpha \in [0.1, 2]$$

Recovered from: (Kulkarni, S., et al., 2024)

RESULTS

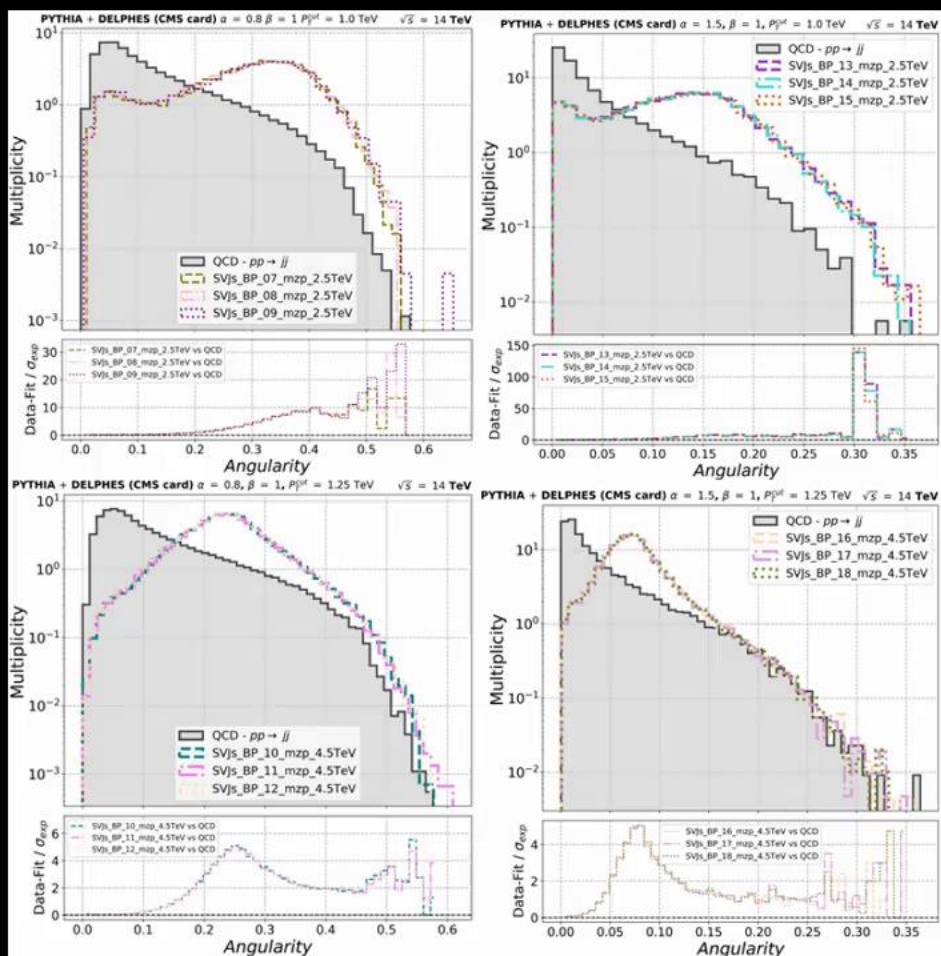
WHAT CAN WE LEARN FROM IT?

RESULTS



WHAT CAN WE LEARN FROM IT?

RESULTS



WHAT CAN WE LEARN FROM IT?

Physical changes:

- Varying α will change the relative sensitivity of the observable at the perturbative and non-perturbative emission level.
- Increasing α will enhance the radiation close to the jet axis with more collinear configurations
- For small α , emissions will be more alike to large angular separations, more sensitive to the broad radiation pattern of the jet.
- At $\alpha = 0.8$ the observable will be more balanced between collinear and wide-angle emissions.

Training hyperparameters

Training hyperparameters

Hyperparameter	ViT	MLP	JetLOV	ViT+MLP	JetLOV+MLP
Optimizer	Adam	Adam	Adam	Adam	Adam
Learning rate	7×10^{-4}	1×10^{-3}	1×10^{-3}	5×10^{-4}	5×10^{-4}
Adam (b1,b2)	0.9, 0.999	0.9, 0.999	0.9, 0.999	0.9, 0.999	0.9, 0.999
Batch size	128	256	256	128	128
Dropout	0.1	0.2	0.1	0.1 / 0.2	0.1 / 0.2
Weight decay	0	0	0	0	0
Max epochs	60	100	60	15	60
Early-stop patience	5 epochs	5 epochs	5 epochs	5 epochs	5 epochs
Early-stop min. delta	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}
Random seed	42	42	42	42	42
Epochs trained (max)	35 (60)	11 (100)	15 (20)	48 (60)	18 (69)
Best epoch	30	8	7	43	13
Best val. loss	0.3361	0.2356	0.2518	0.1567	0.1504
Avg. epoch time	75.2 s	5.3 s	516.7 s	63.8 s	335 s
Total train time	43.8 min	1.0 min	1.01 hrs	51.0 min	1.68 hrs