



CERN Summer Student 2021

Semi-visible Jets

Study of semi-visible jets with machine learning method

Augustin Tribolet

Supervisors: Deepak Kar, Sukanya Sinha, Tasnuva Chowdhury



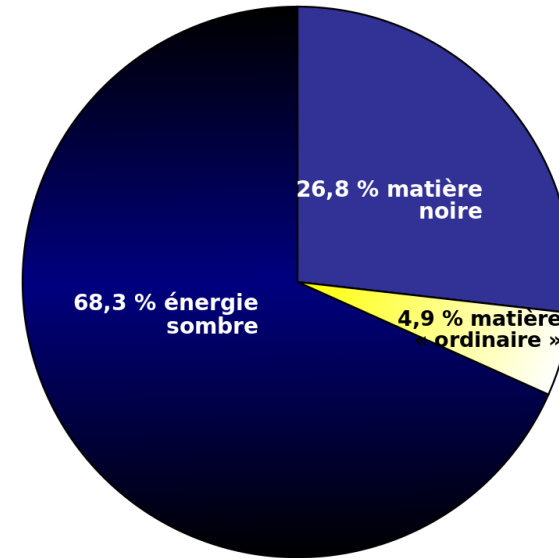
Extension of SM: Dark Matter

	masse →	charge →	spin →					
QUARKS	$\approx 2.3 \text{ MeV}/c^2$	$\frac{2}{3}$	$\frac{1}{2}$	u up	$\approx 1.275 \text{ GeV}/c^2$	$\frac{2}{3}$	$\frac{1}{2}$	c charm
					$\approx 173.07 \text{ GeV}/c^2$	$\frac{2}{3}$	$\frac{1}{2}$	t top
					0	0	1	g gluon
								$\approx 126 \text{ GeV}/c^2$ H boson de Higgs
					$\approx 4.8 \text{ MeV}/c^2$	$-\frac{1}{3}$	$\frac{1}{2}$	d down
					$\approx 95 \text{ MeV}/c^2$	$-\frac{1}{3}$	$\frac{1}{2}$	s strange
				$\approx 4.18 \text{ GeV}/c^2$	$-\frac{1}{3}$	$\frac{1}{2}$	b bottom	
				0	0	1	γ photon	
LEPTONS	$0.511 \text{ MeV}/c^2$	-1	$\frac{1}{2}$	e électron	$105.7 \text{ MeV}/c^2$	-1	$\frac{1}{2}$	μ muon
					$1.777 \text{ GeV}/c^2$	-1	$\frac{1}{2}$	τ tau
					$91.2 \text{ GeV}/c^2$	0	1	Z^0 boson Z^0
					$80.4 \text{ GeV}/c^2$	± 1	1	W^\pm boson W^\pm
	$< 2.2 \text{ eV}/c^2$	0	$\frac{1}{2}$	ν_e neutrino électronique	$< 0.17 \text{ MeV}/c^2$	0	$\frac{1}{2}$	ν_μ neutrino muonique
				$< 15.5 \text{ MeV}/c^2$	0	$\frac{1}{2}$	ν_τ neutrino tauïque	

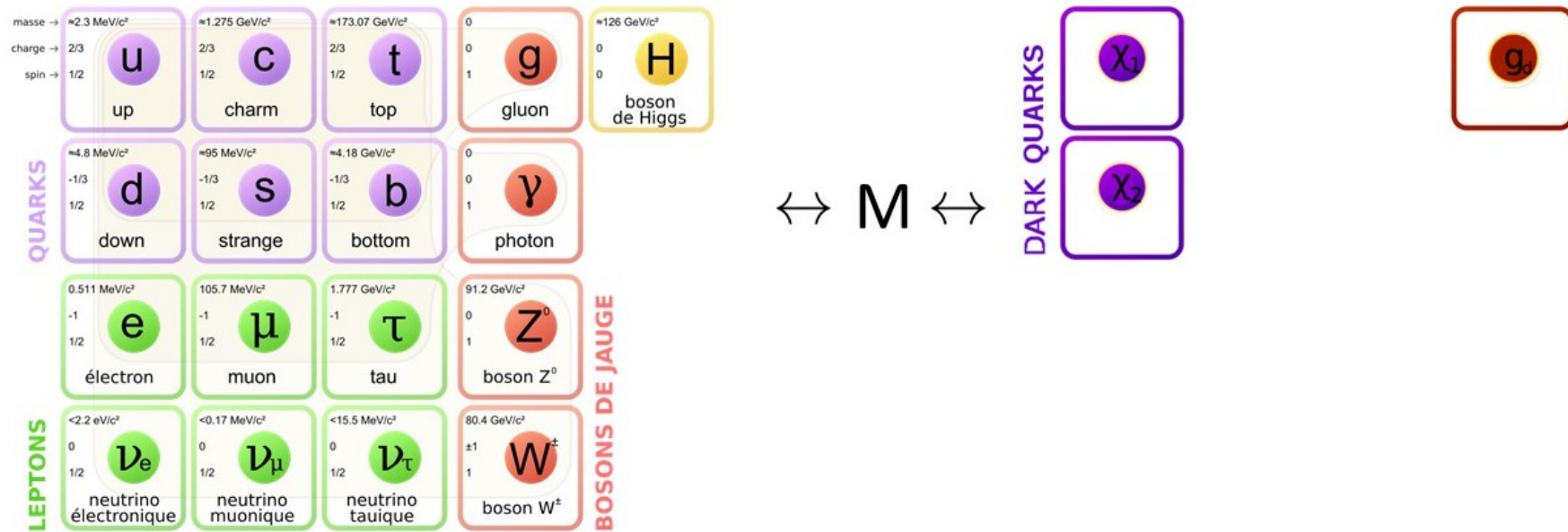
BOSONS DE JAUGE

Extension of SM: Dark Matter

masse →	$\approx 2.3 \text{ MeV}/c^2$	$\approx 1.275 \text{ GeV}/c^2$	$\approx 173.07 \text{ GeV}/c^2$	0	$\approx 126 \text{ GeV}/c^2$
charge →	$2/3$	$2/3$	$2/3$	0	0
spin →	$1/2$	$1/2$	$1/2$	1	0
	u up	c charm	t top	g gluon	H boson de Higgs
QUARKS	$\approx 4.8 \text{ MeV}/c^2$	$\approx 95 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
	$-1/3$	$-1/3$	$-1/3$	0	
	$1/2$	$1/2$	$1/2$	1	
	d down	s strange	b bottom	γ photon	
	$0.511 \text{ MeV}/c^2$	$105.7 \text{ MeV}/c^2$	$1.777 \text{ GeV}/c^2$	$91.2 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$1/2$	$1/2$	$1/2$	1	
	e électron	μ muon	τ tau	Z^0 boson Z^0	
LEPTONS	$< 2.2 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 15.5 \text{ MeV}/c^2$	$80.4 \text{ GeV}/c^2$	
	0	0	0	± 1	
	$1/2$	$1/2$	$1/2$	1	
	ν_e neutrino électronique	ν_μ neutrino muonique	ν_τ neutrino tauique	W^\pm boson W^\pm	
					BOSONS DE JAUGE

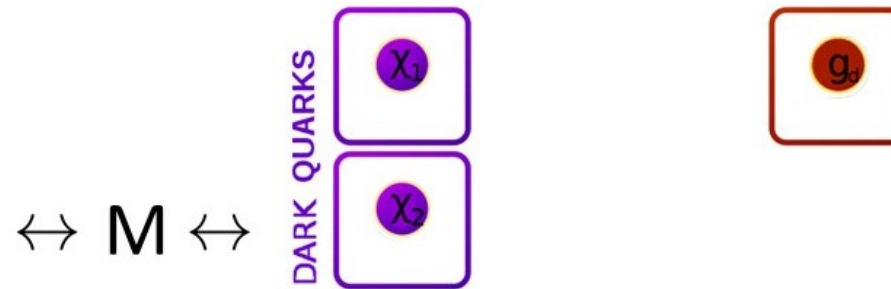


Extension of SM: Dark Matter



Extension of SM: Dark Matter

masse →	≈2.3 MeV/c ²	≈1.275 GeV/c ²	≈173.07 GeV/c ²	0	≈126 GeV/c ²
charge →	2/3	2/3	2/3	0	0
spin →	1/2	1/2	1/2	1	0
	u up	c charm	t top	g gluon	H boson de Higgs
QUARKS					
	≈4.8 MeV/c ²	≈95 MeV/c ²	≈4.18 GeV/c ²	0	
	-1/3	-1/3	-1/3	0	
	1/2	1/2	1/2	1	
	d down	s strange	b bottom	γ photon	
	0.511 MeV/c ²	105.7 MeV/c ²	1.777 GeV/c ²	91.2 GeV/c ²	
	-1	-1	-1	0	
	1/2	1/2	1/2	1	
	e électron	μ muon	τ tau	Z⁰ boson Z ⁰	
LEPTONS	<2.2 eV/c ²	<0.17 MeV/c ²	<15.5 MeV/c ²	80.4 GeV/c ²	
	0	0	0	±1	
	1/2	1/2	1/2	1	
	ν_e neutrino électronique	ν_μ neutrino muonique	ν_τ neutrino tauique	W[±] boson W [±]	
					BOSONS DE JAUGE



Hidden Valley:

- 2 dark quarks
- 1 dark gauge boson (for the strong interaction)
- 1 mediator between the two sectors

Semi-visible Jets

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- 1 dark gauge boson (for the strong interaction)

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Formation of dark hadrons: ρ_+, ρ_-, ρ_0
 Π^+, Π^-, Π^0

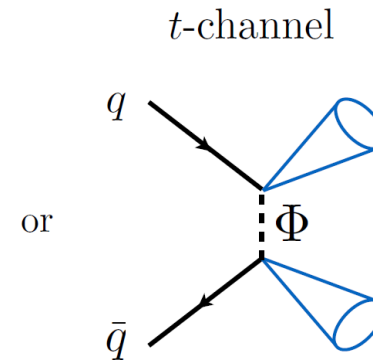
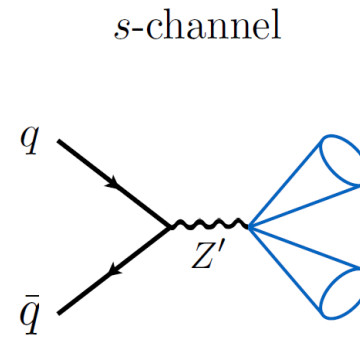
Semi-visible Jets

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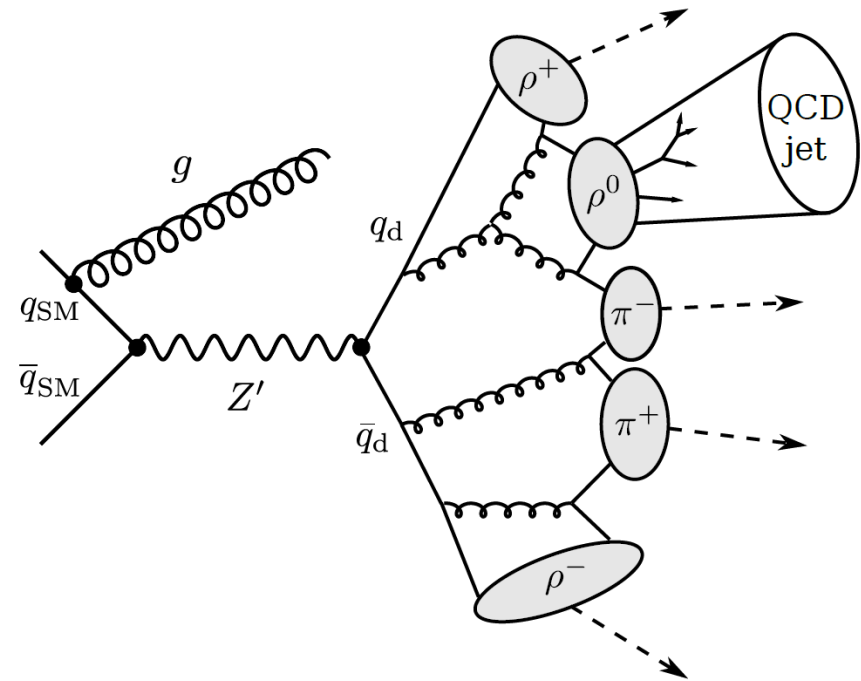
Formation of dark hadrons : ρ_+, ρ_-, ρ_0
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- 1 mediator between the two sectors:



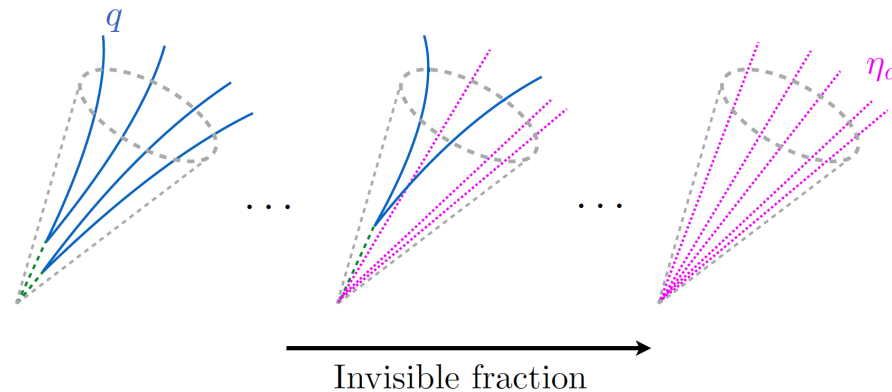
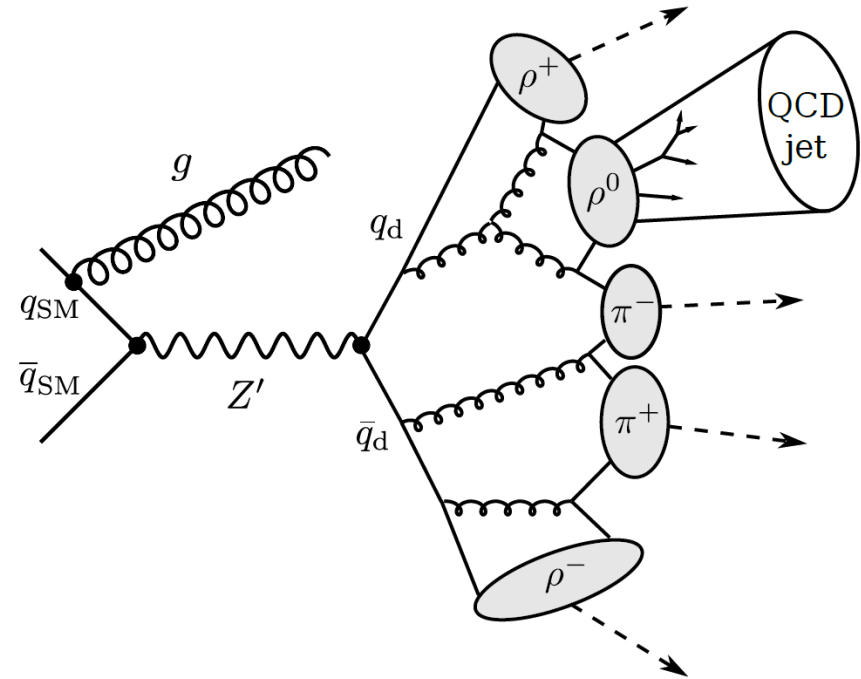
Semi-visible Jets

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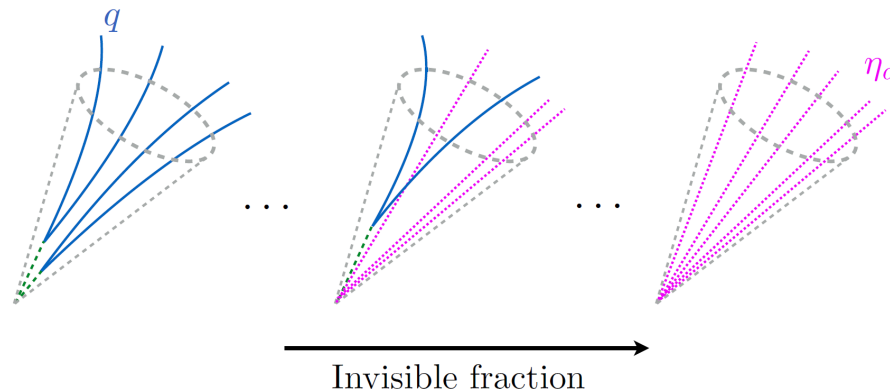
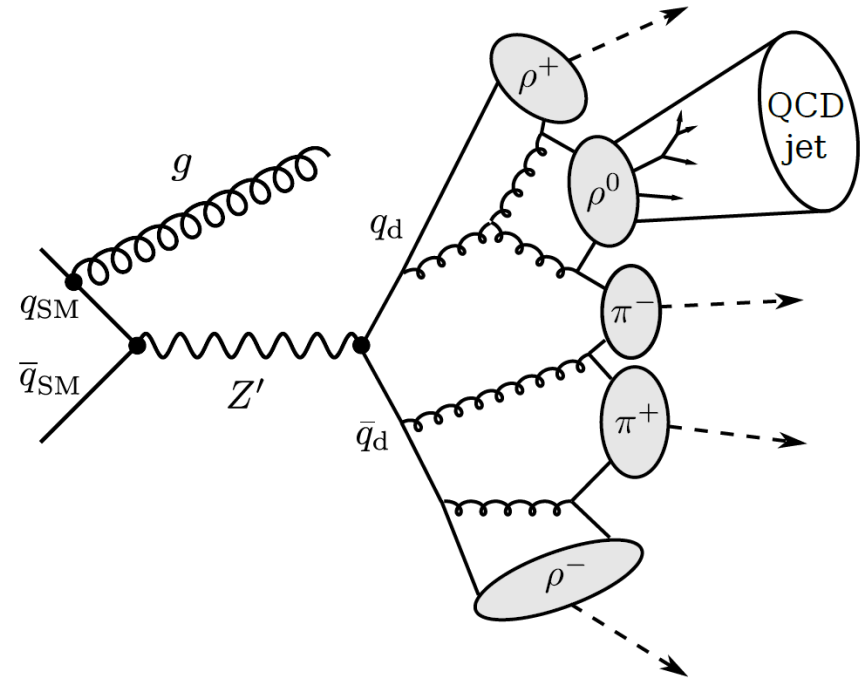
Semi-visible Jets

- 2 dark quarks: $\chi_a = \chi_{1,2}$
- 1 dark gauge boson (for the strong interaction)
- 1 mediator between the two sectors:
- Stable hadrons: Dark Matter
- Unstable hadron: ρ_0



Semi-visible Jets

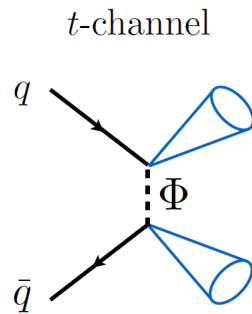
- 2 dark quarks: $\chi_a = \chi_{1,2}$
- 1 dark gauge boson (for the strong interaction)
- 1 mediator between the two sectors:
- Stable hadrons: Dark Matter
- Unstable hadron: ρ_0



$$r_{inv} = \frac{\# \text{ of stable dark hadrons}}{\# \text{ of dark hadrons}}$$

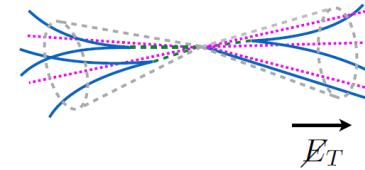
Semi-visible Jets: Properties

- Project:



Characteristic: Two jets

$$0 < r_{\text{inv}} < 1$$

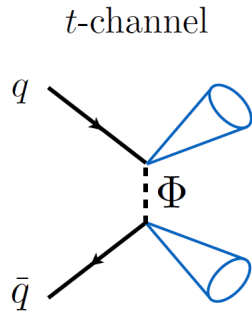


Characteristic: Two visible jets

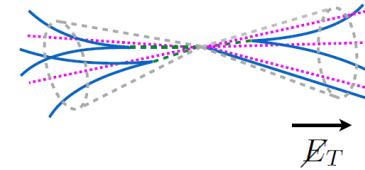
Signature: Subleading jet aligned with MET
(less pT bc more stable hadrons)

Semi-visible Jets: Properties

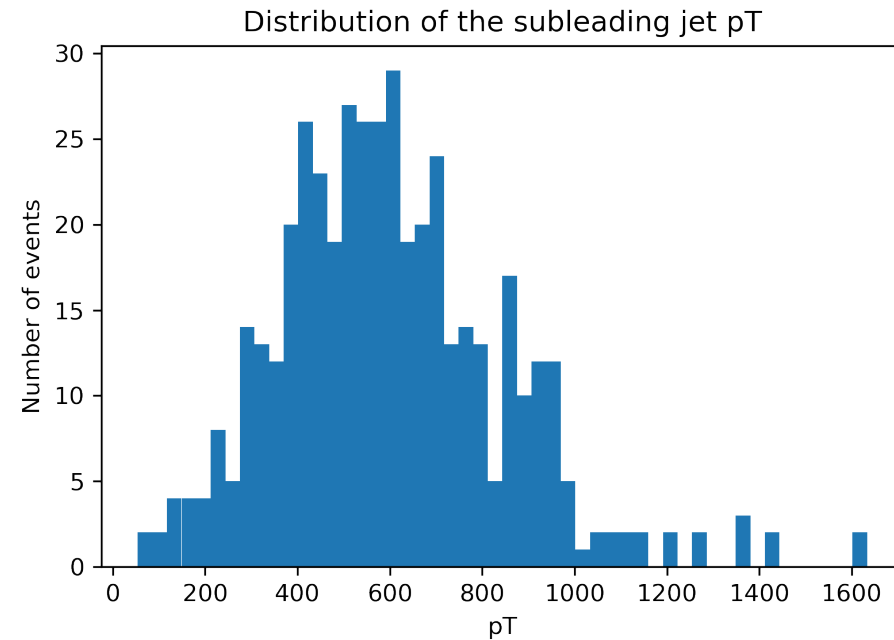
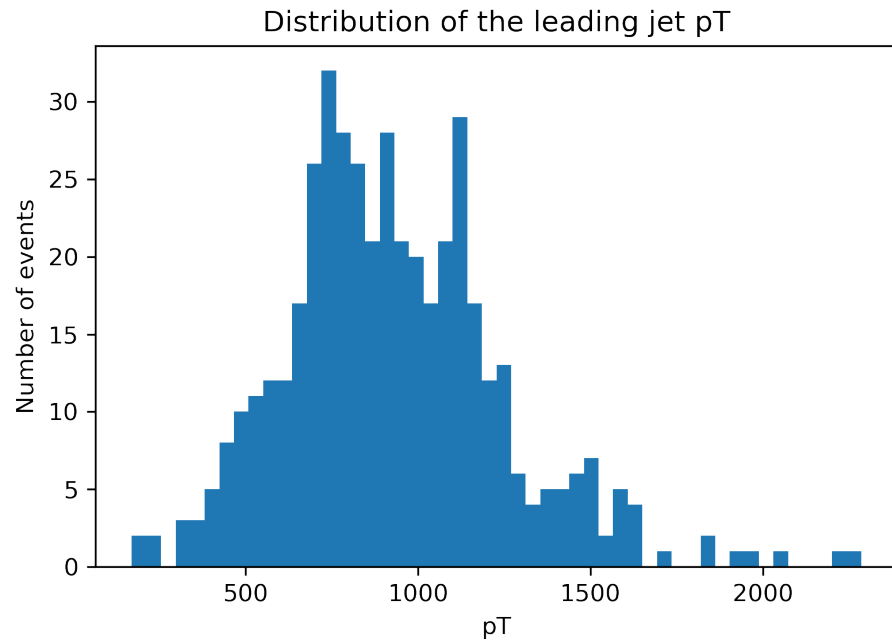
- Project:



$$0 < r_{\text{inv}} < 1$$

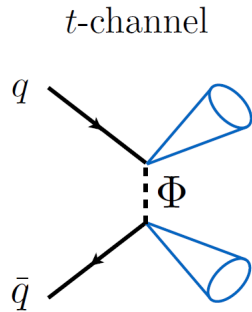


- Generation of the data using Hidden Valley module of Pythia:

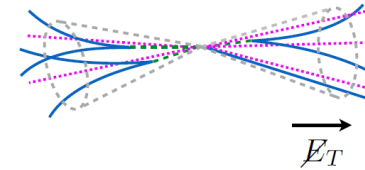


Semi-visible Jets: Properties

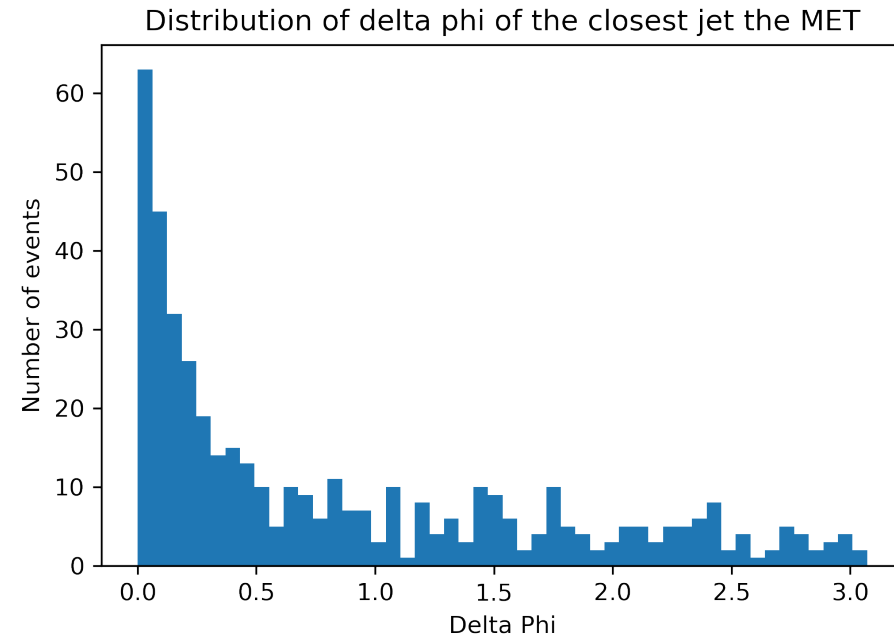
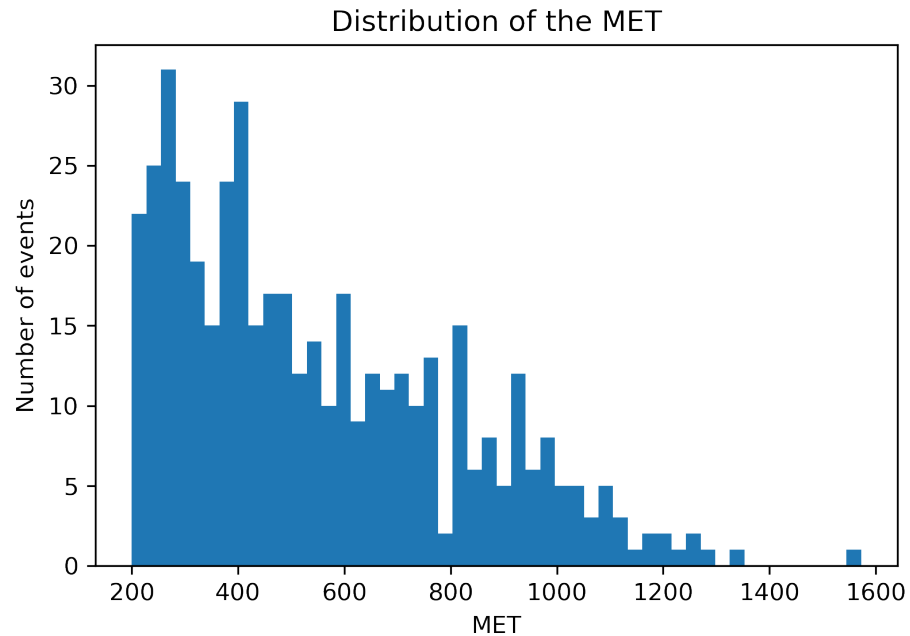
- Project:



$$0 < r_{\text{inv}} < 1$$

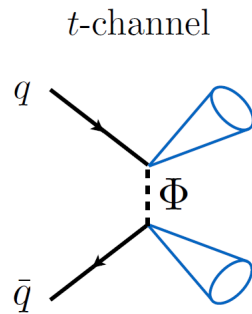


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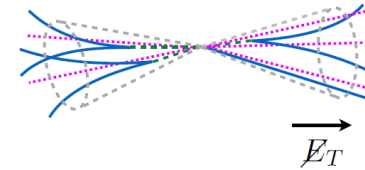


Semi-visible Jets: Properties

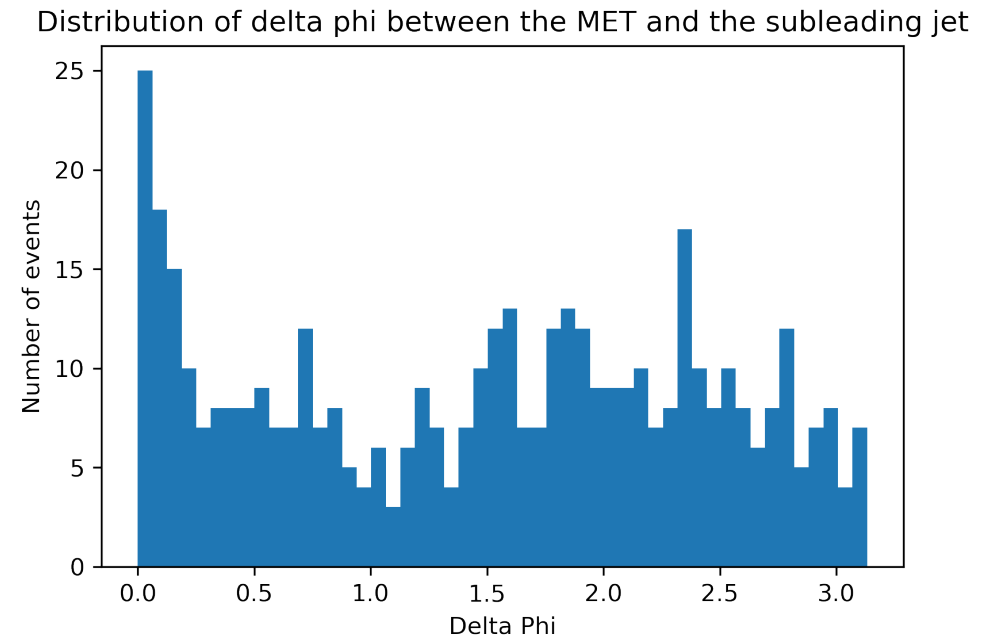
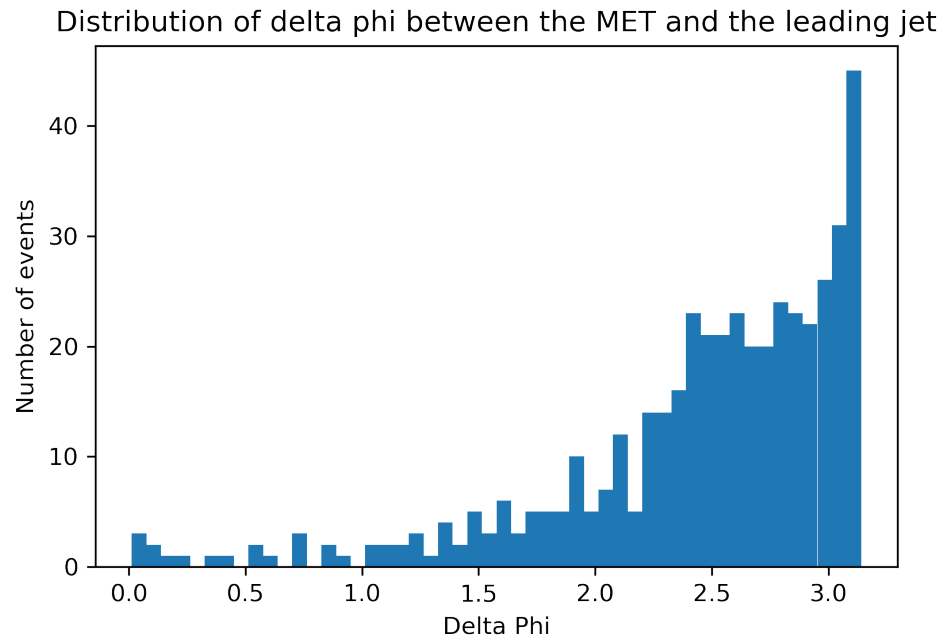
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$$0 < r_{\text{inv}} < 1$$

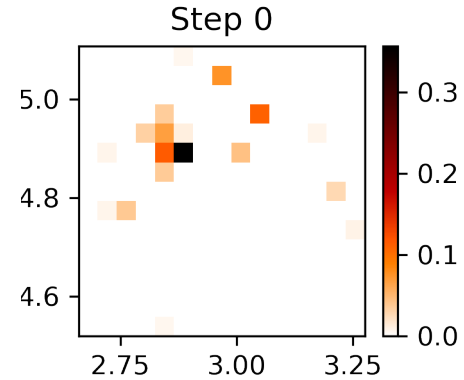


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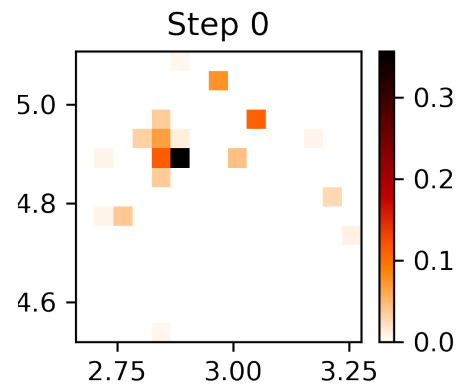


Jets Images

- Machine Learning part: Use Jet Images
- Jets images: Distribution of transverse energy of each constituents into the azimuthal and the pseudorapidity plane

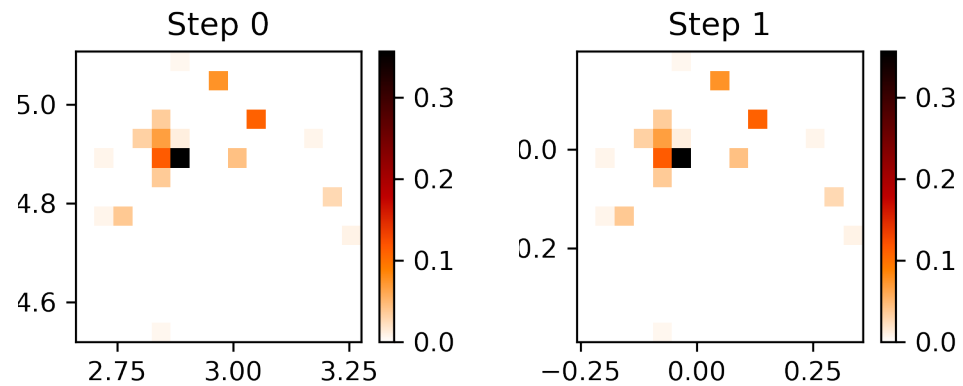


Jet Images: Preprocessing



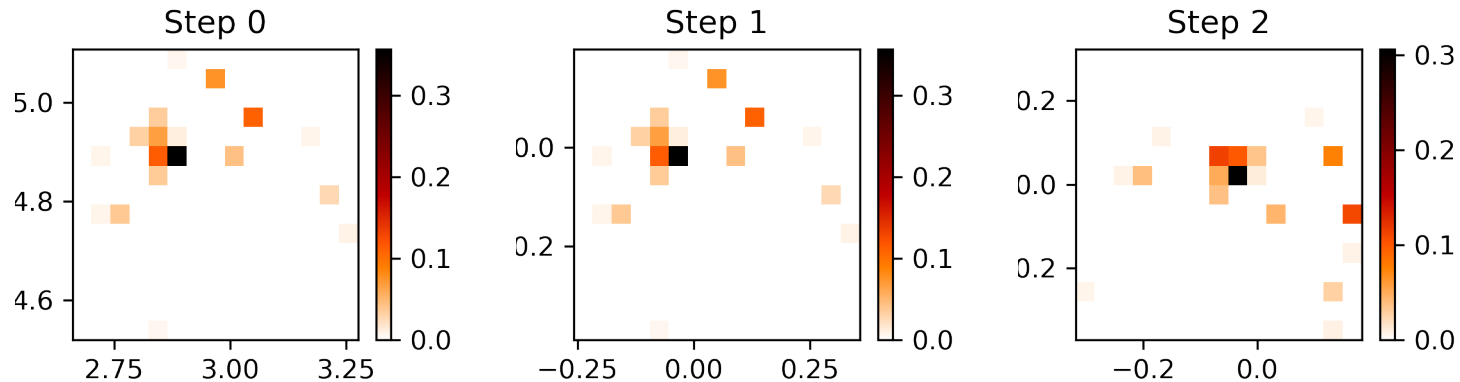
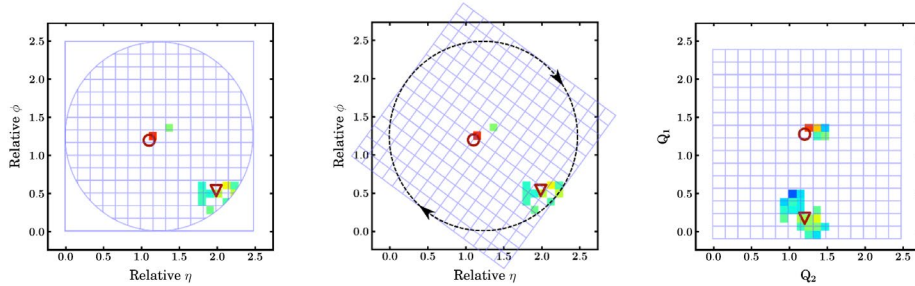
Jet Images: Preprocessing

- Step 1: Centering the axes on the center of the jet



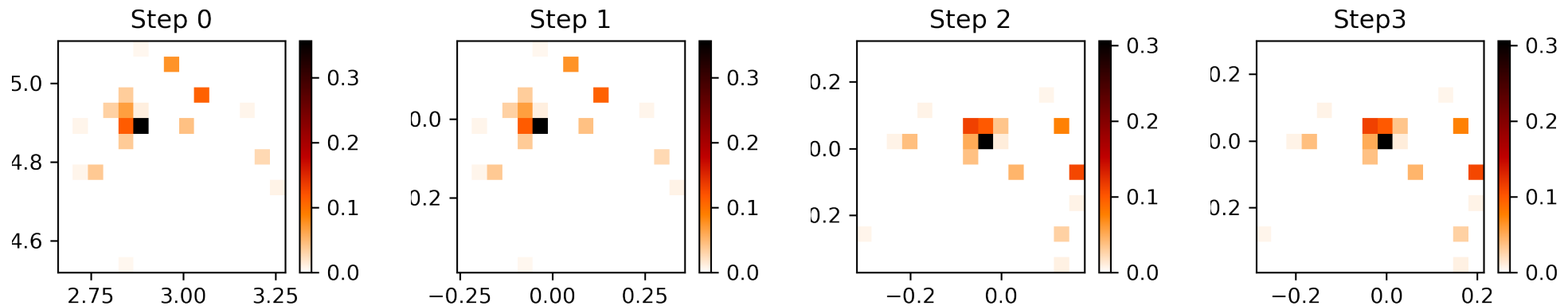
Jet Images: Preprocessing

- Step 1: Centering the axes on the center of the jet
- Step 2: Rotation of the jet (first and second highest pT particle parallel to the phi axis)



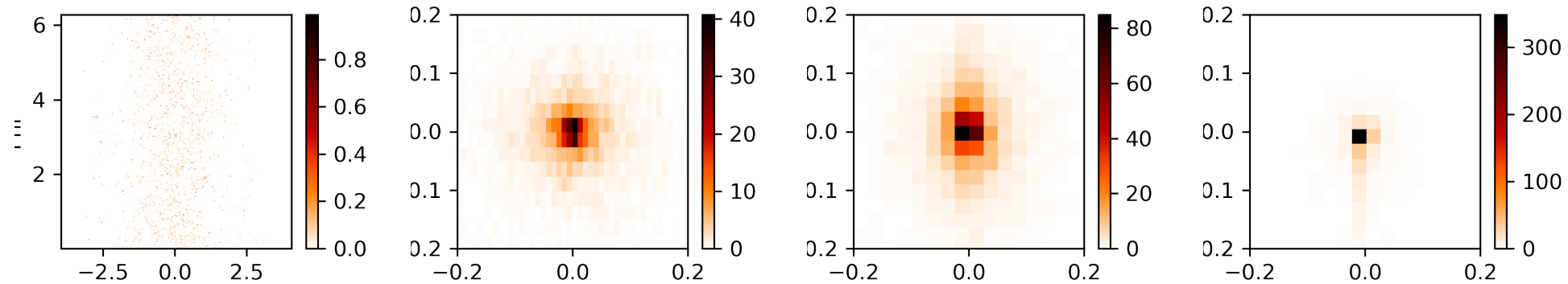
Jet Images: Preprocessing

- Step 1: Centering the axes on the center of the jet
- Step 2: Rotation of the jet (first and second highest pT particle parallel to the phi axis)
- Step 3: Translation of the highest pT constituents to the center of the images

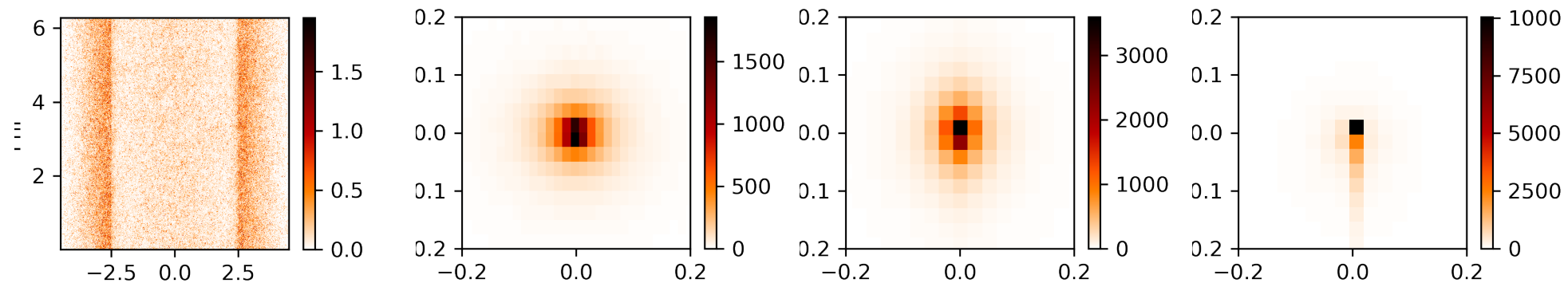


Jet Images: Preprocessing

- Average images for signal events



- Average images for background events



Machine Learning

- Third step of the project: On Going
- At the end: **Would jets formed partially from dark matter particles have a unique footprint, amenable to Machine Learning methods?**
- Future: Application on LHC data if positive answer

Thank you for your attention!