

Search for semi-visible jets produced via t-channel with the CMS experiment

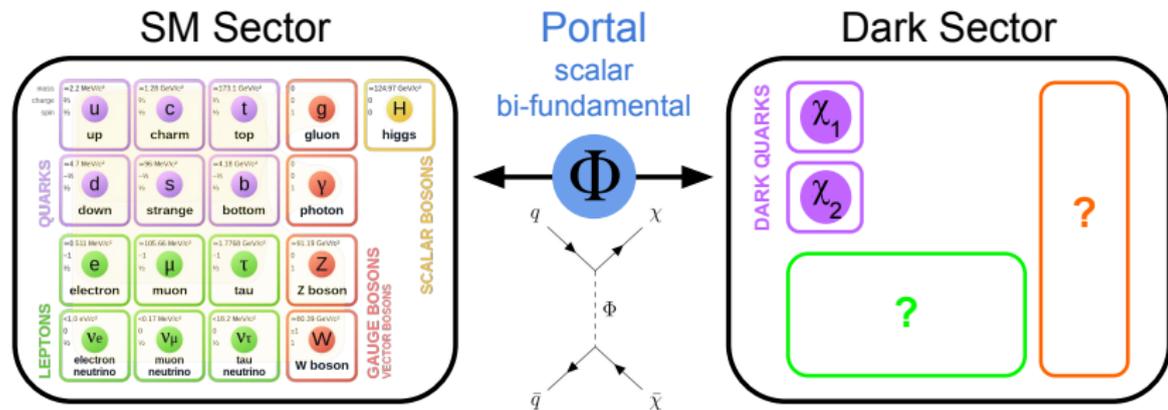
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Strongly coupled dark sector

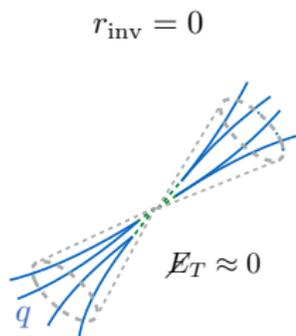
- Hidden Valley [1] with new particles and forces forms the dark sector
- There could exist a new $SU(N)$ force (*i.e.* dark QCD) and dark quarks
- Mediator particle makes a portal between the SM and dark sectors



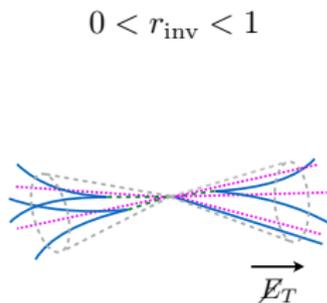
Motivations

- Can be probed with collider experiment
- Signatures mostly unexplored as WIMP searches reject this region of phase-space

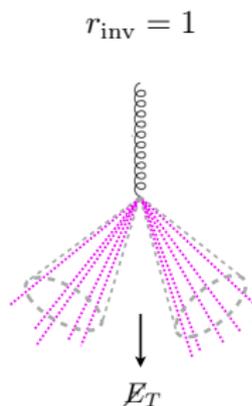
- Dark quarks hadronize in the dark sector
 - A fraction of dark hadrons promptly decays to SM hadrons
- Production of semi-visible jets (SVJ) [2]



dijet search



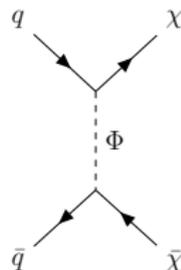
SVJ search



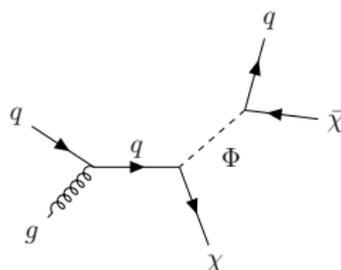
WIMP search

$$r_{\text{inv}} = \left\langle \frac{\text{Number of stable dark hadrons}}{\text{Number of dark hadrons}} \right\rangle$$

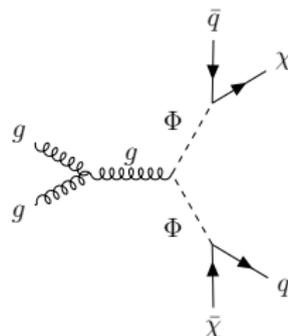
SM hadrons
Stable dark hadrons



(a) Direct production

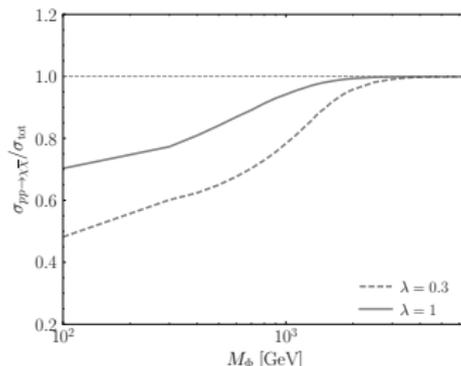


(b) Associated production



(c) Pair production

- Different production modes
- Direct production (a) (no resonance) is dominant
- Production mode with resonance, (b) and (c), may provide cleaner signatures, but at the expense of lower event yield



Direct production cross-section relative to total cross-section. [3]

QCD multijet

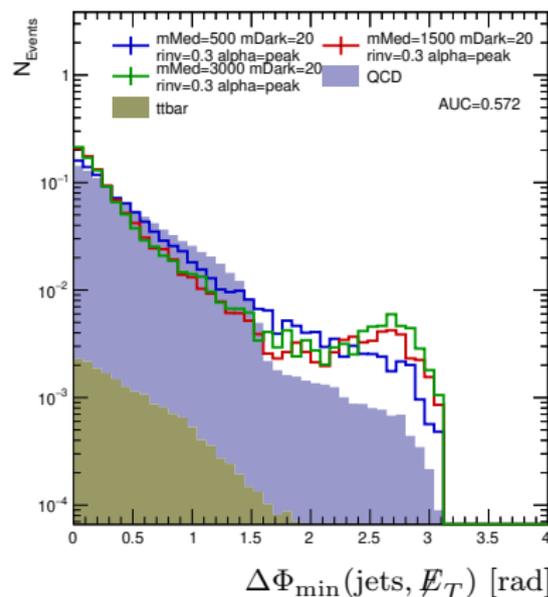
- Artificial missing transverse energy \cancel{E}_T aligned with jet from jet energy mismeasurement
- Large cross-section
- **Main background**

$t\bar{t}$

- Large jet from boosted t
- Semi-leptonic decay ($W \rightarrow l\nu$) with lost lepton, genuine \cancel{E}_T from neutrino
- Jet aligned with \cancel{E}_T

Other backgrounds:

- $Z(\rightarrow \nu\nu) + \text{jets}$
- $W(\rightarrow l\nu) + \text{jets}$



Background

- Overwhelming QCD multijet background in the region of interest (E_T aligned with jet)
- SM jets in t-channel SVJ final state!

Detector effects

- Energy mismeasurement in calorimeter could mimic the SVJ signature

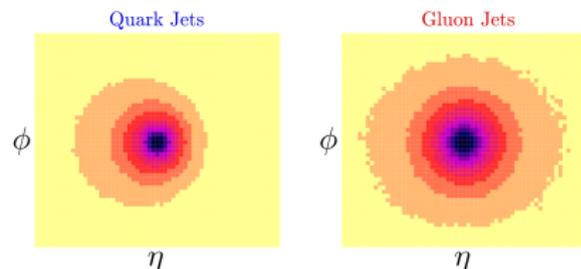
Signal modeling

- Non perturbative QCD theory parameters obtained from measurements
- Not possible for dark QCD!
- Analysis strategy should not rely on details of the signal simulation

Key idea: **Exploit jet substructure**

There can be two different approaches:

- Supervised classification
- Unsupervised classification



Which can be applied at two different levels:

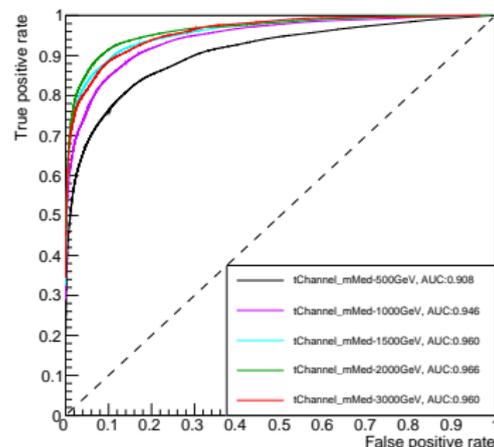
- jet-level: semi-visible jet tagger
- event-level: t-channel SVJ event tagger

Work of the SVJ community:

- Supervised jet tagger (BDT): CMS s-channel SVJ analysis [4]
- Unsupervised jet tagger: Autoencoders for Semivisible Jet Detection [5]

Development of a t-channel event classifier:

- For each jet, use a set of weakly correlated **jet substructure variables**
 - Energy Flow Polynomials (EFPs)
 - Energy Correlation Functions (ECFs)
 - Jet shapes (e.g. major axis)
 - Jet angularities
- Use discriminating **event-level variables**
 - Missing transverse energy \cancel{E}_T
 - Minimum azimuthal angle between jets and \cancel{E}_T
- One-layer ANN to learn classification from these high-level jet and event variables



ROC curves for an ANN trained on a mixture of signal masses against QCD and tested on each signal.

References

- [1] Matthew J. Strassler and Kathryn M. Zurek. Echoes of a hidden valley at hadron colliders. *Phys. Lett. B*, 651:374, 2007.
- [2] Timothy Cohen, Mariangela Lisanti, and Hou Keong Lou. Semivisible Jets: Dark Matter Undercover at the LHC. *Phys. Rev. Lett.*, 115:171804, 2015.
- [3] Timothy Cohen, Mariangela Lisanti, Hou Keong Lou, and Siddharth Mishra-Sharma. LHC Searches for Dark Sector Showers. *JHEP*, 11:196, 2017.
- [4] Search for resonant production of strongly-coupled dark matter in proton-proton collisions at 13 TeV. Technical report, CERN, Geneva, 2021.
- [5] Florencia Canelli, Annapaola de Cosa, Luc Le Pottier, Jeremi Niedziela, Kevin Pedro, and Maurizio Pierini. Autoencoders for Semivisible Jet Detection. 2021.

Backup

QCD multijet

- Artificial missing transverse energy \cancel{E}_T aligned with jet from jet energy mismeasurement
- Large cross-section
- **Main background**

$t\bar{t}$

- Jet from boosted t
- Leptonic decay $W(\rightarrow l\nu)$ with lost lepton, genuine \cancel{E}_T from neutrino
- Jet aligned with \cancel{E}_T

$Z(\rightarrow \nu\nu) + \text{jets}$

- Genuine \cancel{E}_T from Z decay to neutrinos
- Not aligned with jet

$W(\rightarrow l\nu) + \text{jets}$

- Lost/not reconstructed lepton or hadronic decay of τ lepton
- Genuine \cancel{E}_T from neutrino
- Not aligned with jet

