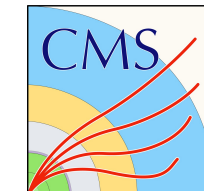


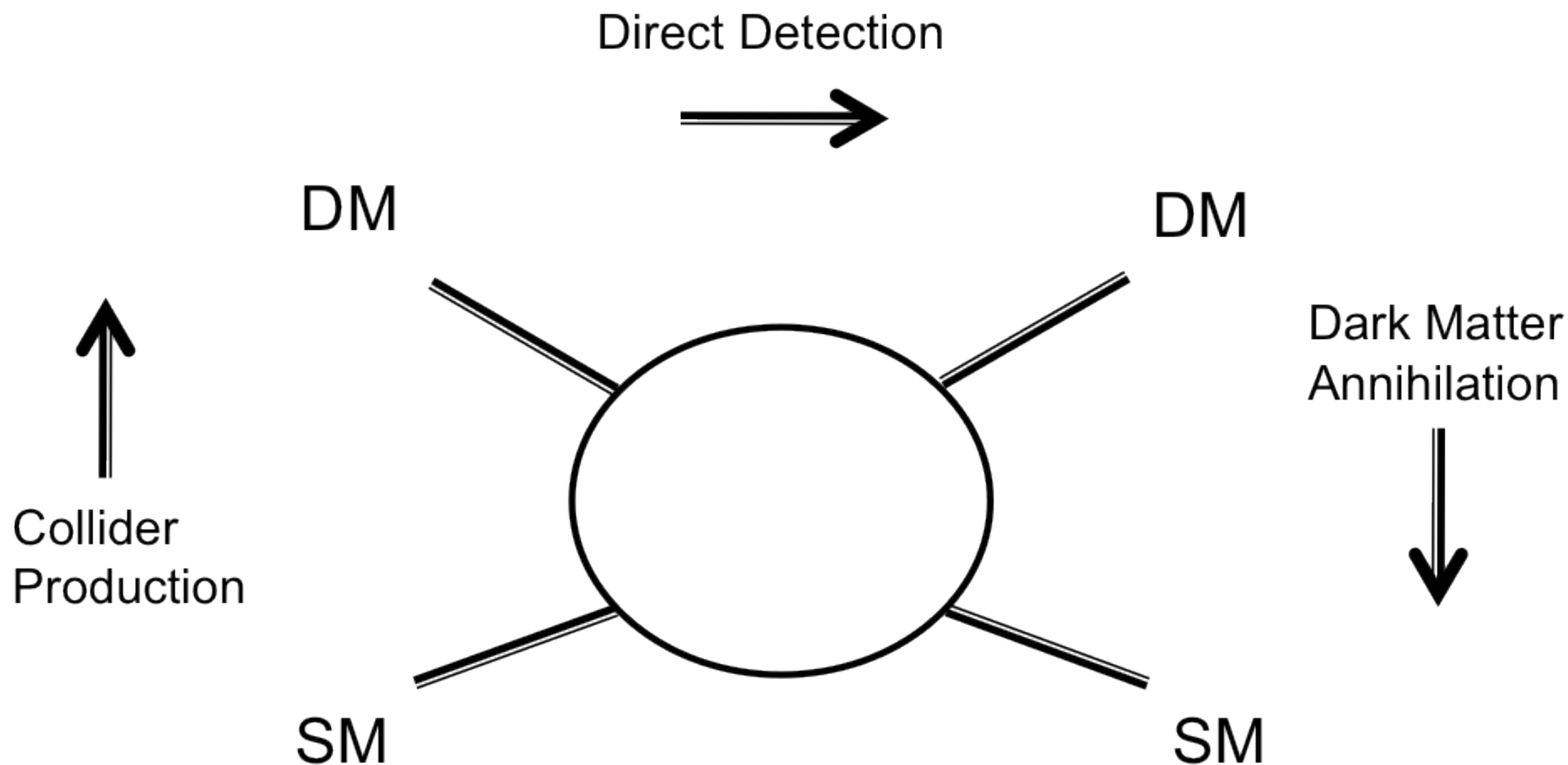
Semi-visible jets from a strongly-interacting dark sector

Alison Elliot (RAL PPD)

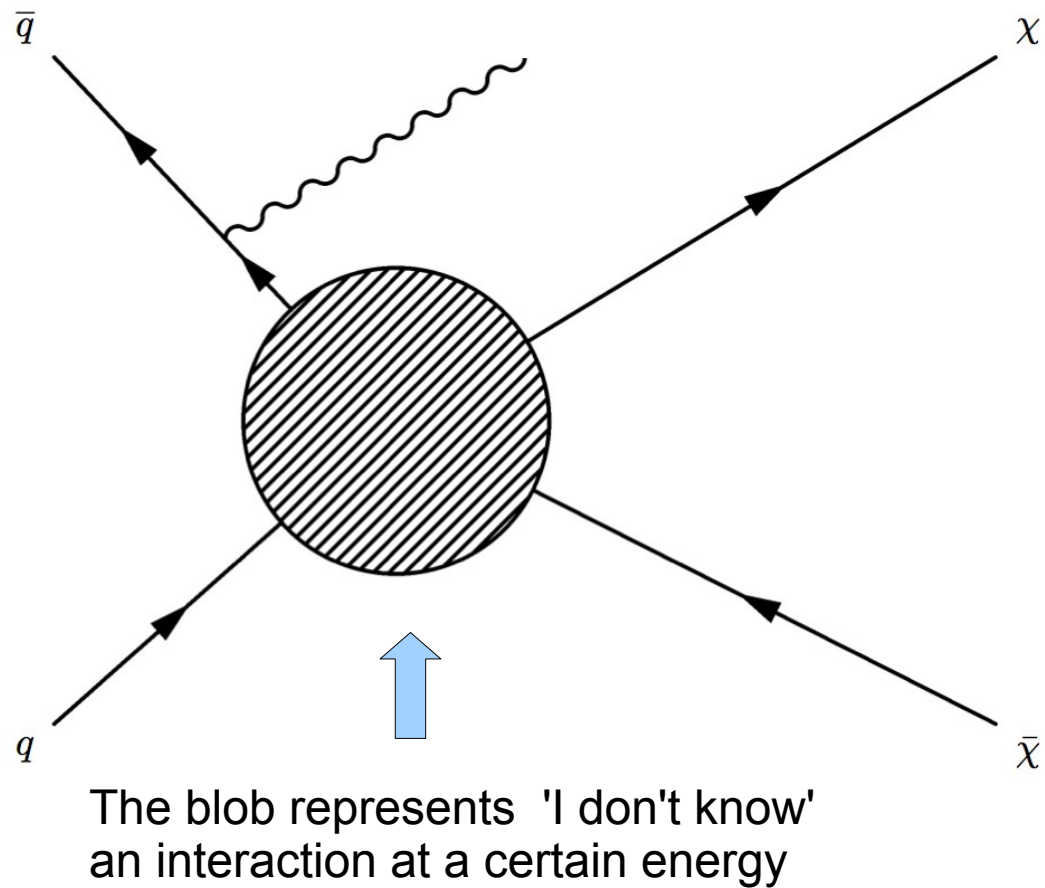


Motivation: dark matter. It's there. What is it?

A matter of perspective



An *effective field theory* model of dark matter



Benefits:

- A very simple but complete model
- The model is characterized by the energy, or mass scale

Limitations:

- Validity of model depends on momentum transfer in a collision being less than the mass scale of the model

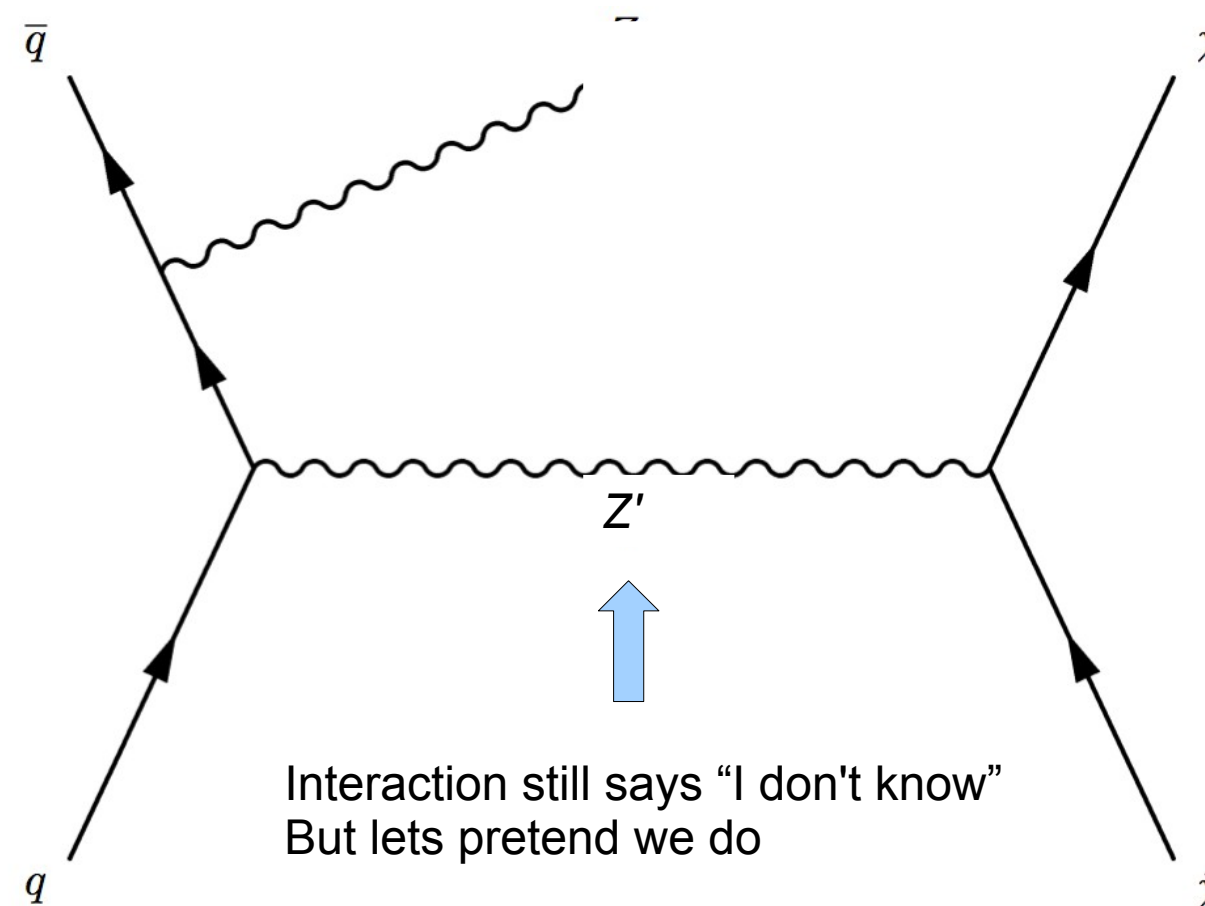
A simple mediator model of dark matter

Benefits:

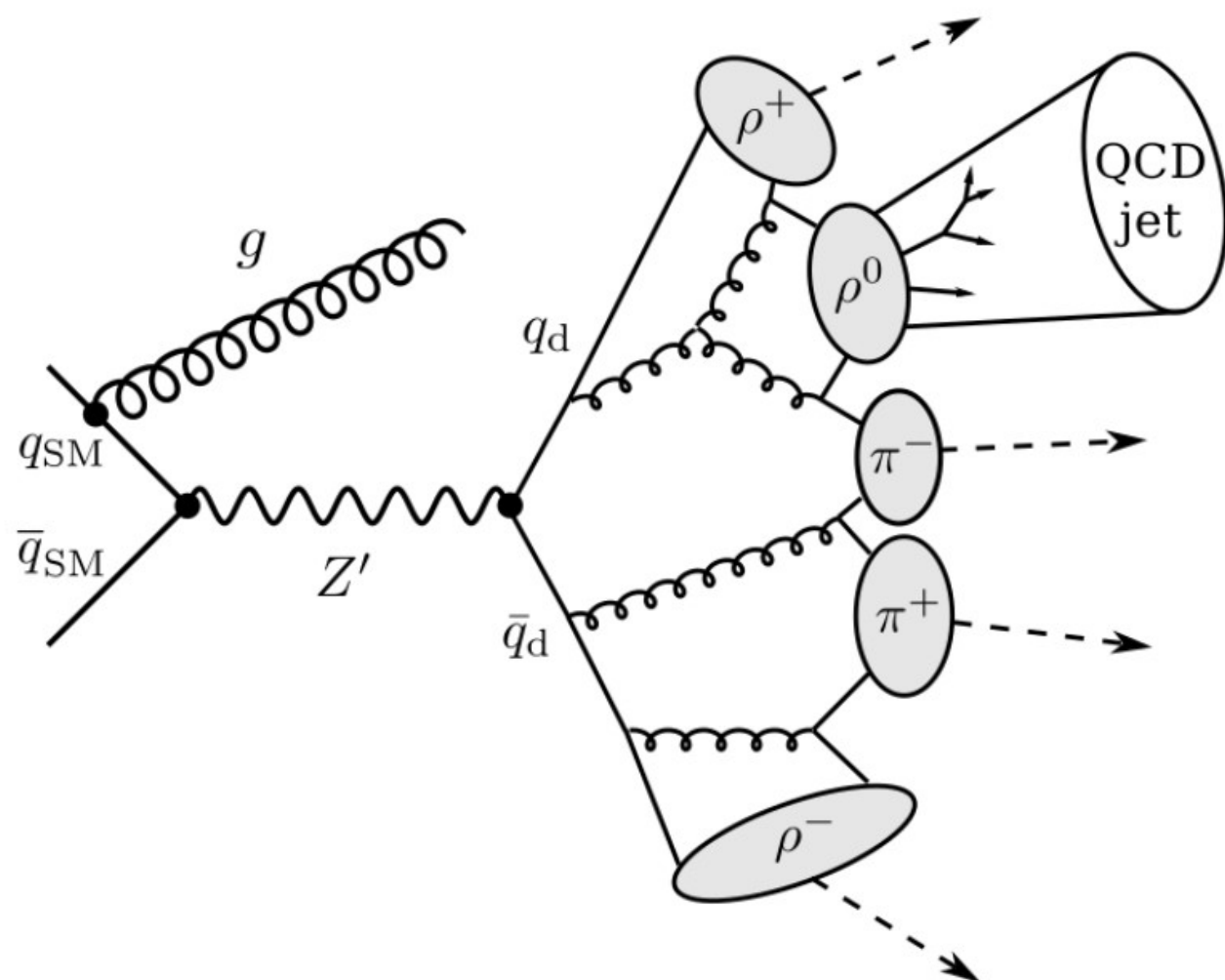
- Valid for LHC collision energies (≥ 13 TeV)
- Provides a coherent model to compare results between different channels and experiments

Limitations:

- Several parameters to tune
- Not a physically complete theory, just a guideline



What about something messier?

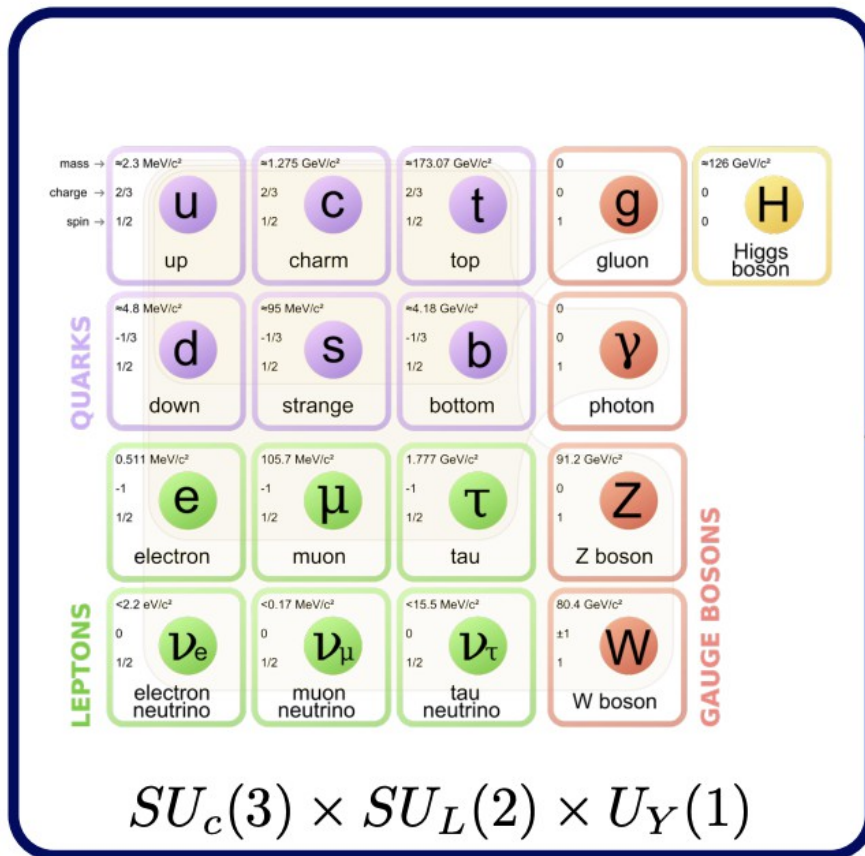


The big idea

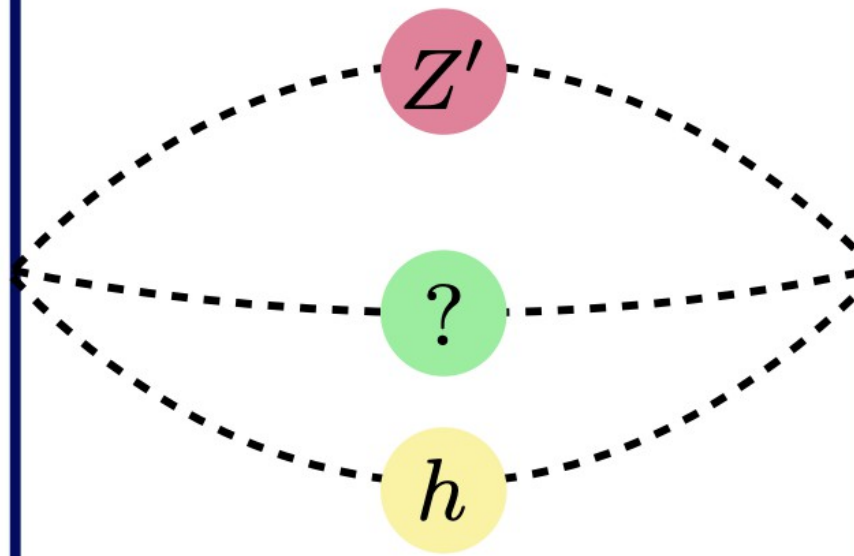
What if the jets that we might normally throw away... are the ones that contain the new physics?

A hidden dark sector

Visible Sector



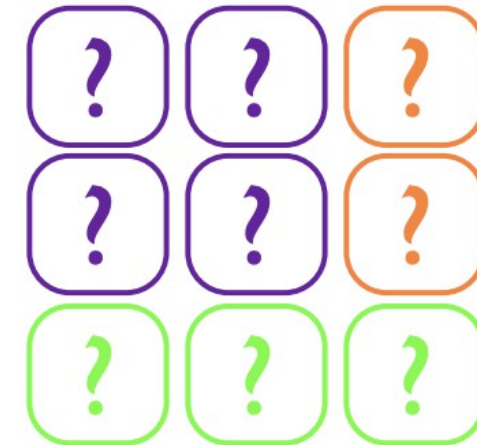
Portal



Lisanti, 2015

Dark Sector

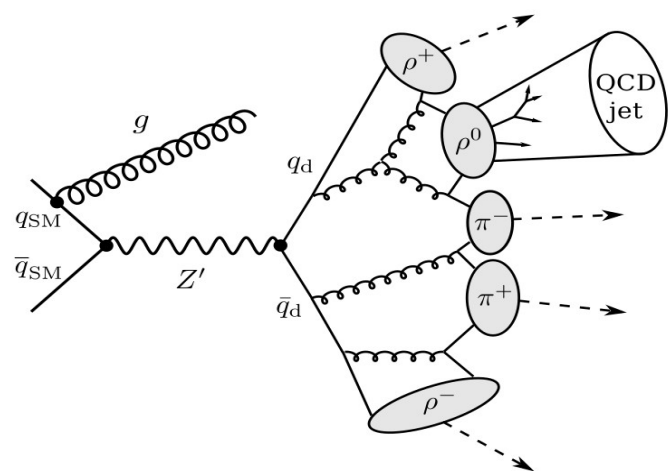
Multiparticle Spectrum



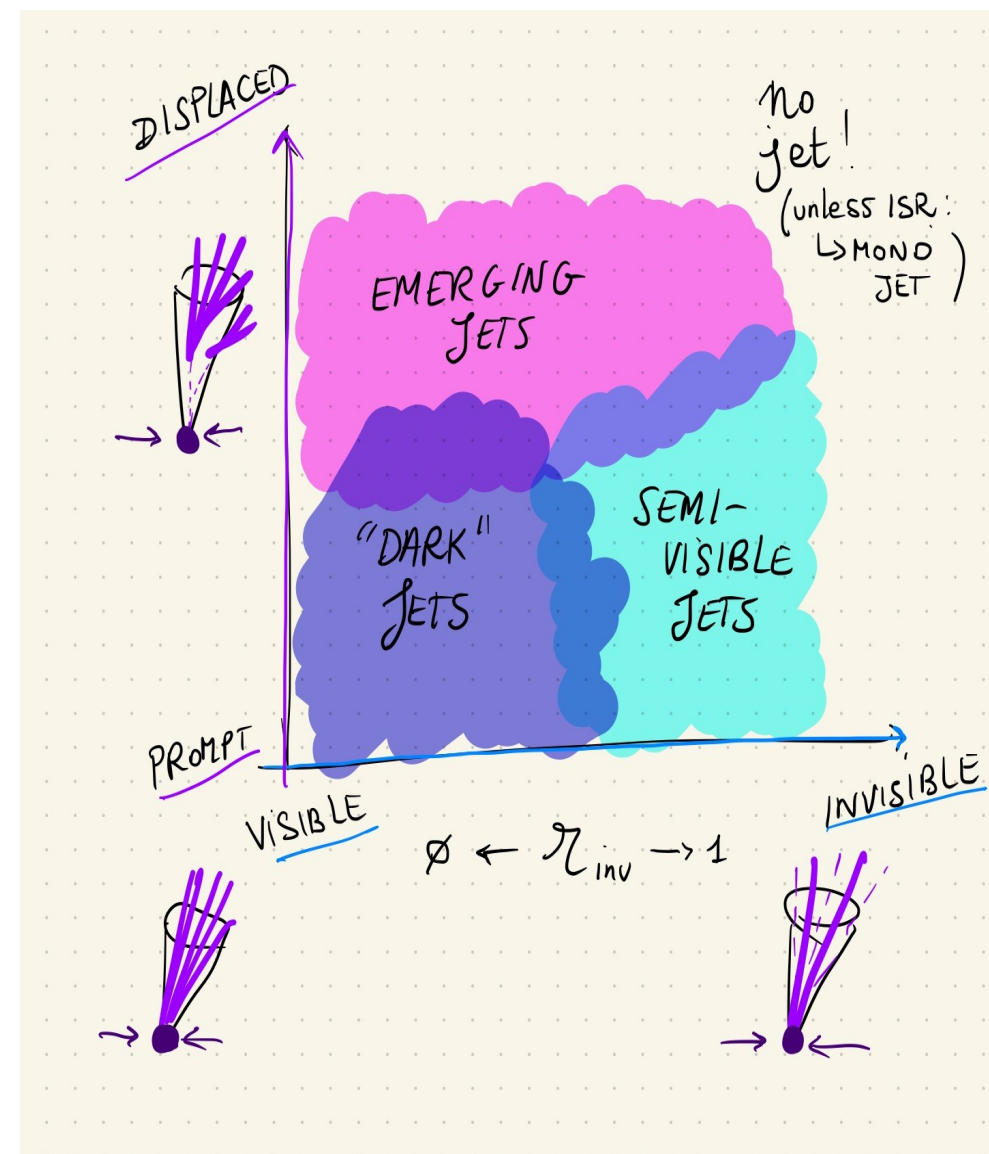
New Gauge Symmetries

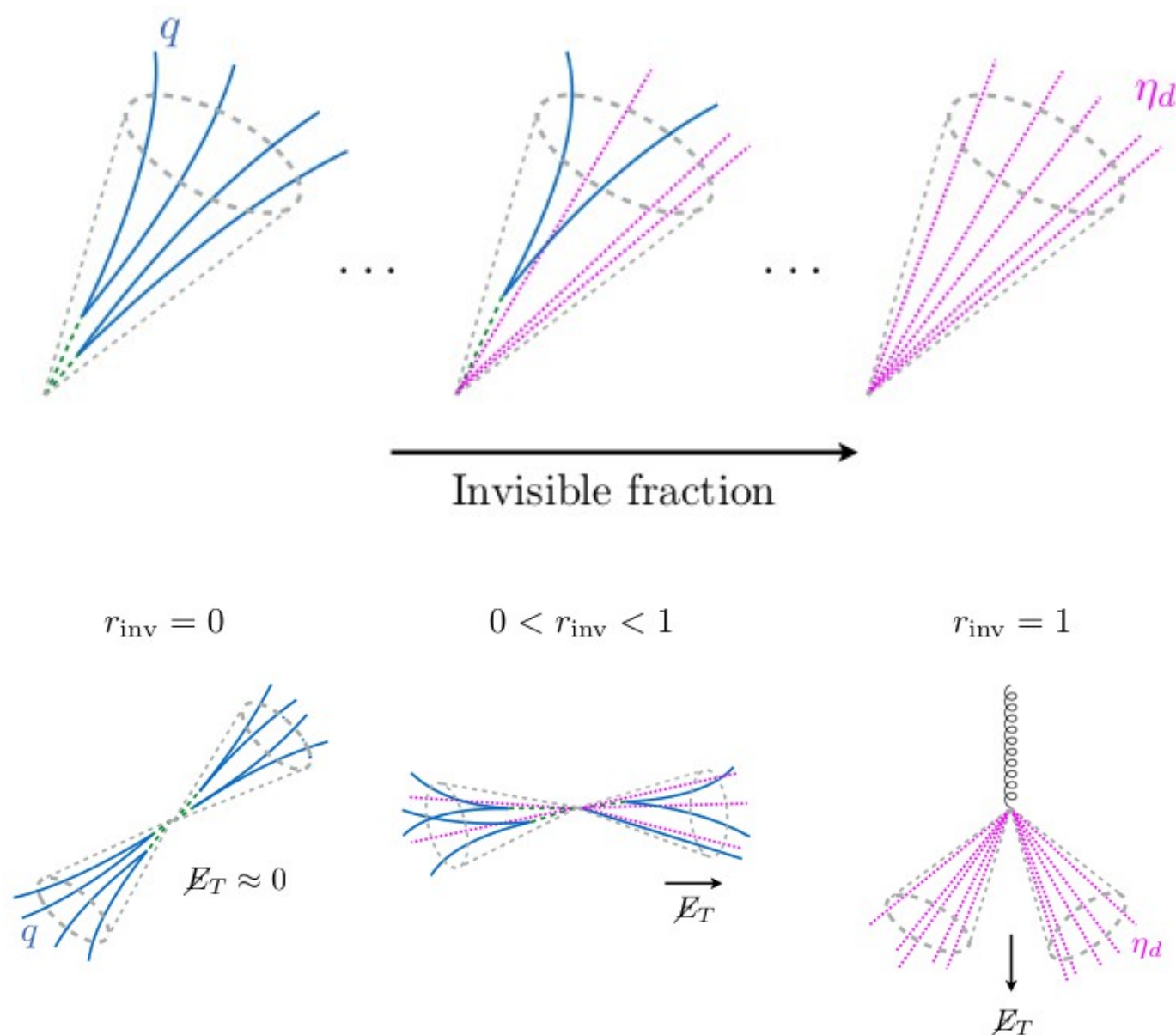
Dark sector phenomenology

- Semi-visible jets motivation
 - Complex, prompt signature that has the unusual signature of jets aligned with missing ET
 - Dark hadrons decaying in a QCD-like fashion, fully (**dark jets**) or partially back to visible sector (**semi-visible jets: SVJ**)



Hard scatter either via Madgraph or via Pythia's Z'
Showering using Pythia Hidden Valley module





- Dark quarks hadronise to form dark mesons and baryons → 'dark showers'
 - Some dark hadrons are stable: invisible
 - Some dark hadrons decay back to SM particles: visible
- r_{inv} is the fraction of stable (invisible/dark-matter-like) particles inside the jet
- This fraction determines event topology and the analysis strategy
 - $r_{\text{inv}} = 0$: dark jets analysis
 - $r_{\text{inv}} = 1$: mono-X search
 - $0 < r_{\text{inv}} < 1$: Semi Visible Jets

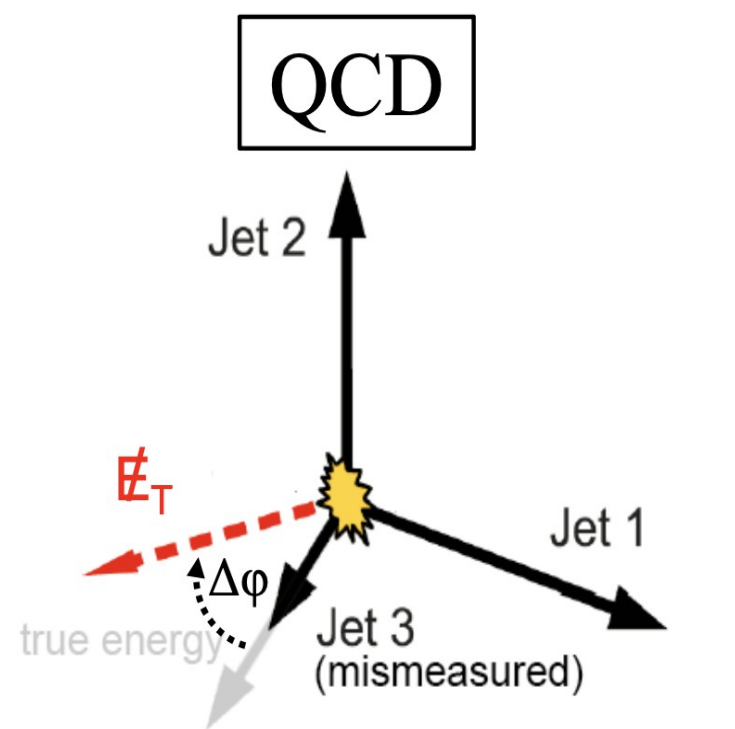
Models

- The hidden sector / dark sector couples to the Standard Model weakly via massive mediators (for example Z' in the resonant model)
- A new 'dark QCD' force SU_{dark} with scale Λ_{dark}
- Dark quarks χ_{dark} are charged under SU_{dark} .
- These dark quarks hadronise to form dark baryons and mesons
- Stable dark hadrons form dark matter candidates, they are invisible to the detector
- Unstable dark hadrons decay back into Standard Model particles

Model parameters

- Dark QCD parameters
 - Scale
 - Number of colours
- Mediators
 - Masses
 - Couplings
- Dark Quarks
 - Number of flavours
 - Masses
- Dark Hadrons
 - Masses
 - Spins
 - Lifetimes
- QCD details
 - Hadronisation
 - Fragmentation
 - Etc
- Etc

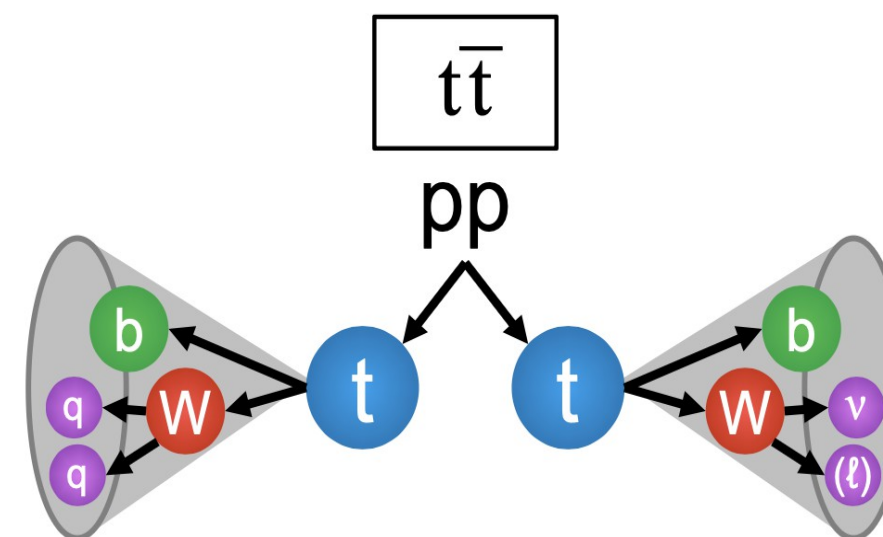
SVJ backgrounds



- Jet mismeasurement induces E_T aligned with jet
- Major background

$W(\ell\nu)+\text{jets}$

- Lost lepton or hadronic τ
- Less likely than $t\bar{t}$ to mimic semivisible jet, but higher σ

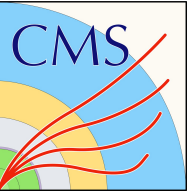


- Wide, high- p_T jets: boosted tops
- “Lost” lepton ℓ : out of acceptance, can’t veto (or hadronic τ)
- Neutrino aligned w/ wide jet: mimics semivisible jet

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

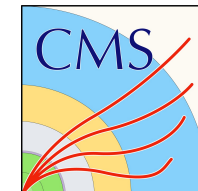
- Real E_T from $\nu\nu$, but least likely to align with jet

Analysis strategies



- Machine Learning methods employed in both ATLAS and CMS
 - Unsupervised (train on Standard Model Background)
 - Semi-supervised (give the ML some simulation information to label signal)
 - Supervised (full model details available to ML)

Strategy for collider triggers



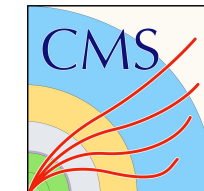
- Hadronic activity is key for most of the SVJ models
 - One or two jets, maybe lots of hadronic activity, jets often defined as large radius
- An unusual feature of semivisible jets is missing transverse momentum aligned with one of the jets.
- Some of the models could trigger on non-isolated leptons or photons that occur near or inside jet activity

Anomaly Triggers

- However, since a key of these models is that they are weird, they could be perfectly suited to a trigger that selects events that are anomalous (ie, weird)
- CMS has deployed two anomaly detection algorithms in the level-1 hardware trigger during Run-3:
 - **AXOL1TL** (Anomaly eXtraction Online Level-1 Trigger Lightweight)
 - A variational autoencoder trained on all global L1 bits
 - **CICADA** (Calorimeter Image Convolutional Anomaly Detection Algorithm)
 - Convolutional autoencoder trained on calorimeter energy deposits.

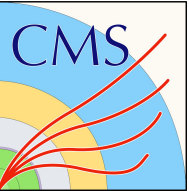
Benchmark work going on across collider and theory communities

- Benchmarking exercise kicked off at last LHC dark showers workshop at CERN (end of 2025): <https://indico.cern.ch/event/1574504/>
- LHC Dark Showers taskforce meeting under the new LHC BSM WG
 - <https://indico.cern.ch/category/20694/>
 - Regular meetings started to produce a whitepaper this year.
- Whitepaper deliverables include:
 - List of parameters, list of observables for each final state
 - How to assess uncertainties
 - Trigger suggestions
 - Tool to give the correct Pythia/Herwig/Sherpa settings & madgraph cards for chosen benchmarks



backup

Some key literature



- Dark sector searches with the CMS experiment,
<https://doi.org/10.1016/j.physrep.2024.09.013>
- Theory, phenomenology, and experimental avenues for dark showers: a Snowmass 2021 report,
<https://doi.org/10.1140/epjc/s10052-022-11048-8>
- Semivisible Jets: Dark Matter Undercover at the LHC,
<https://doi.org/10.1103/PhysRevLett.115.171804>
- Echoes of a hidden valley at hadron colliders,
<https://doi.org/10.1016/j.physletb.2007.06.055>