Searching for Dark Matter with Semi-Visible Jets at CMS

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Semi-Visible Jets Analysis Team

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Searching

- This analysis is a Work-In-Progress.
- These plots are not official.
- Please do not distribute these slides outside this conference.

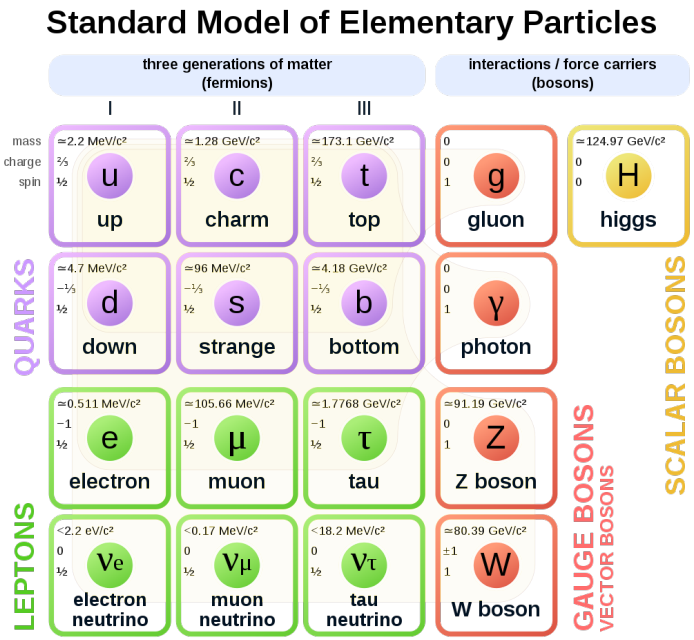
This presentation will deal mostly with the theory that allows for Semi Visible Jet production at hadron colliders anyway, but towards the end there are some MC plots that are technically WIP.

What is Dark Matter?

- Practically - Anything that isn't Standard Model matter
- Experimentally - Astronomical observations
- Theoretically - Pick your poison!
  - SuperSymmetry!
  - It Doesn't Exist! (Entropic Gravity, and others...)
  - Hidden Valley

2 Minute Primer on Hidden Valley Dark Matter

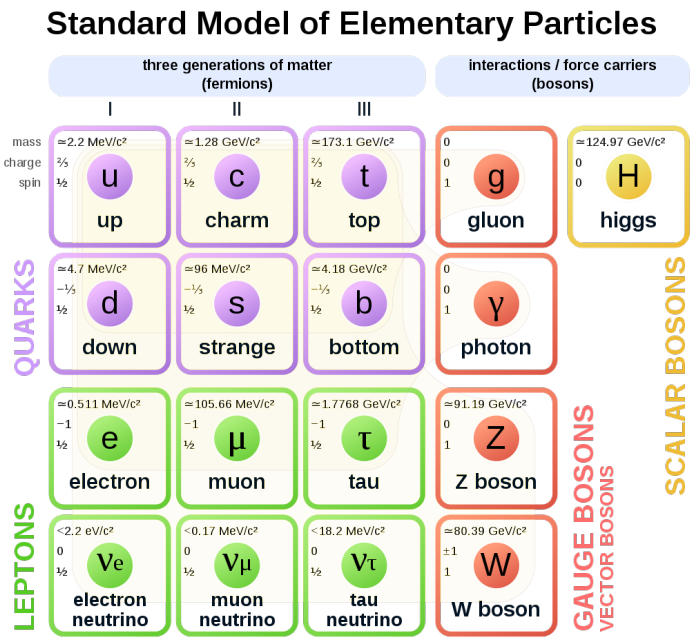
- The realm of Dark Matter is a second gauge group (G_v) that exists independently of the SM gauge group (G_{SM}).
- All SM particles are neutral in the G_v gauge, while all HV particles are neutral in the G_{SM} gauge.



Connecting SM to HV

If the two gauge groups are independent, how can SM colliders produce DM?

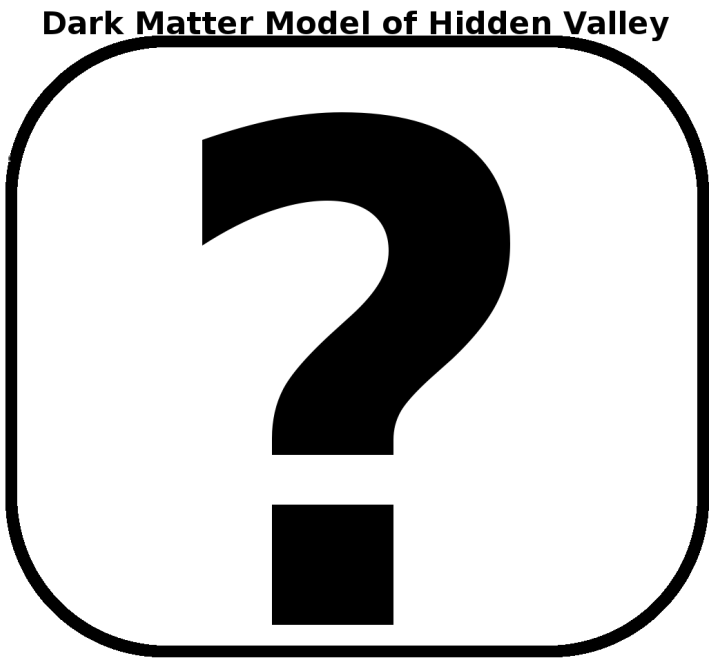
- To 'bridge the gap' between SM and HV, a messenger particle is postulated that is charged under both gauges.
- This messenger, hereafter referred to as Z', can be produced by and can decay into both SM and HV particles.

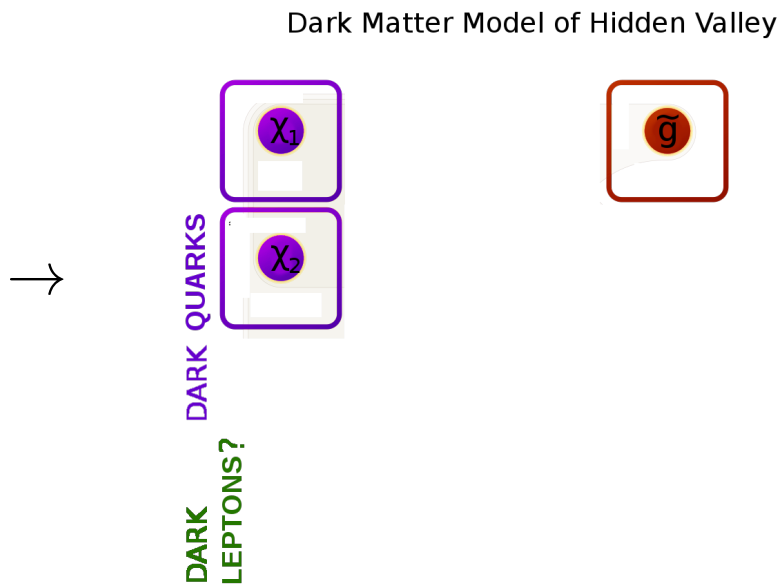


$\leftrightarrow Z' \leftrightarrow$

What could the HV sector look like?

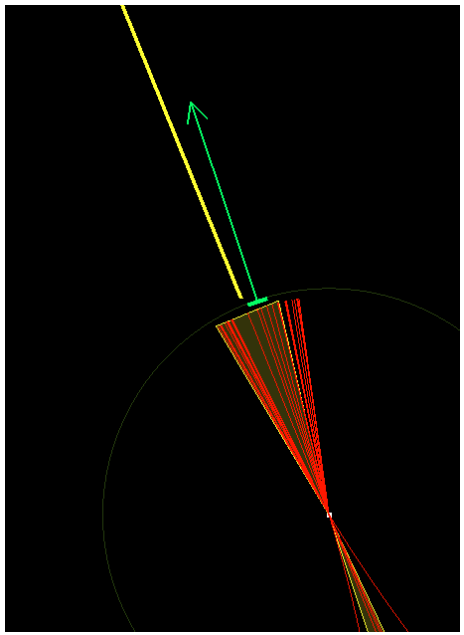
- If G_v is made up of a QCD-like gauge, then dark matter would be comprised of dark quarks which form dark hadrons.
- Here we have a realativly simple sector of two dark quarks and dark gluons to bind them.





Side Note: Whats a Jet!?

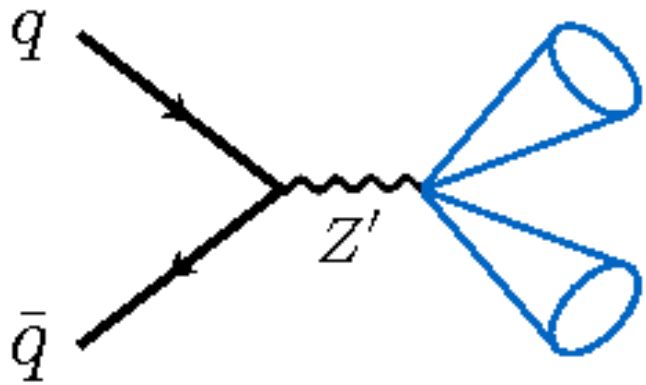
- Jet:
  - a cone of hadrons produced from the hadonization of quarks and gluons
- Jets exist because of color confinement of QCD.
- Jets are not *detected* but *reconstructed* through *jet clustering algorithms*.



- This is a Jet (yellow) that has many particles (red) and is 'inline' with the Missing Transverse Energy (green)

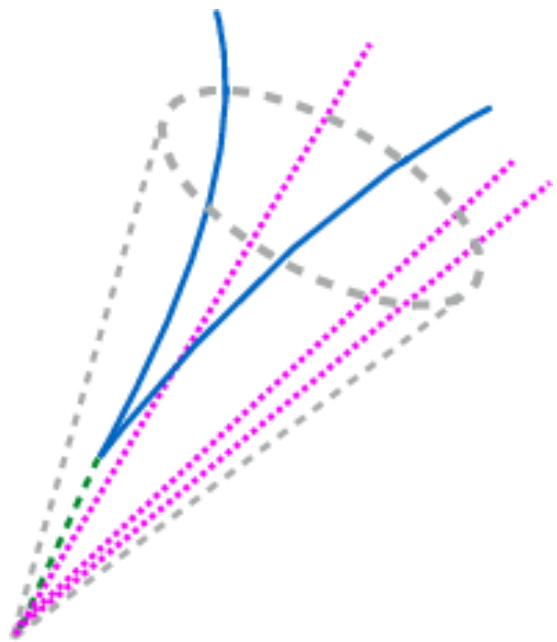
How does that HV sector produce Semi-Visible Jets?

- SM quarks interact and produce a Z'.
- The messenger does as its name implies and decays into a pair of dark quarks.
- These initial dark quarks hadronize, and form two dark mesons.
- Heavy dark matter mesons would decay through 'dark' hadronization; light dark mesons are stable.



How does that HV sector produce Semi-Visible Jets?

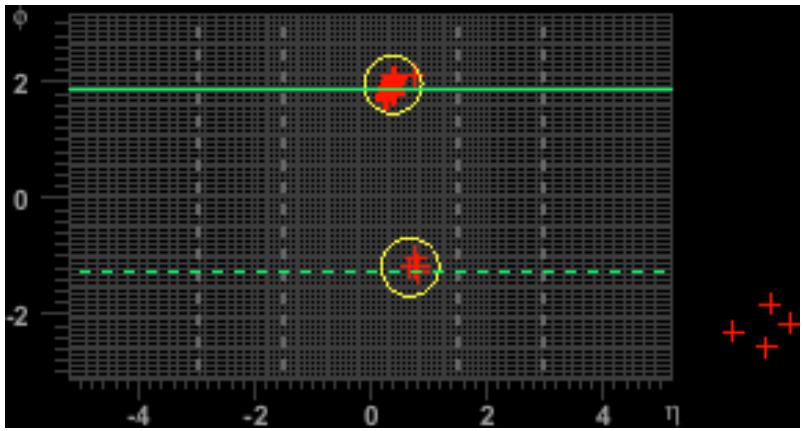
- Dark hadronization will produce more Z' messengers and light dark mesons.
- These Z' messengers can then decay into more HV mesons or back into SM hadrons.
- SM hadrons will hadronize.
- This continues until all that remains are light dark mesons and SM hadrons.



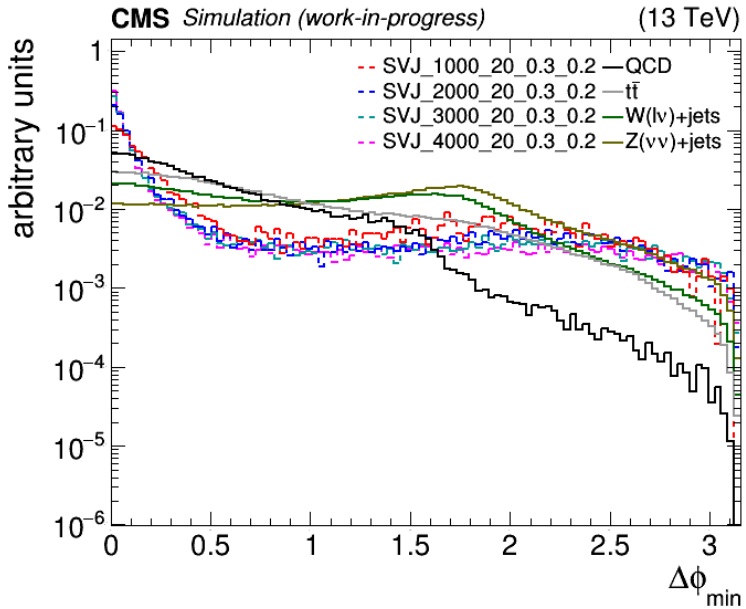
Thats how SemiVisible Jets are produced, but how can we find them?

Understand what they look like

Event Display Plot of Signal MC at GEN level

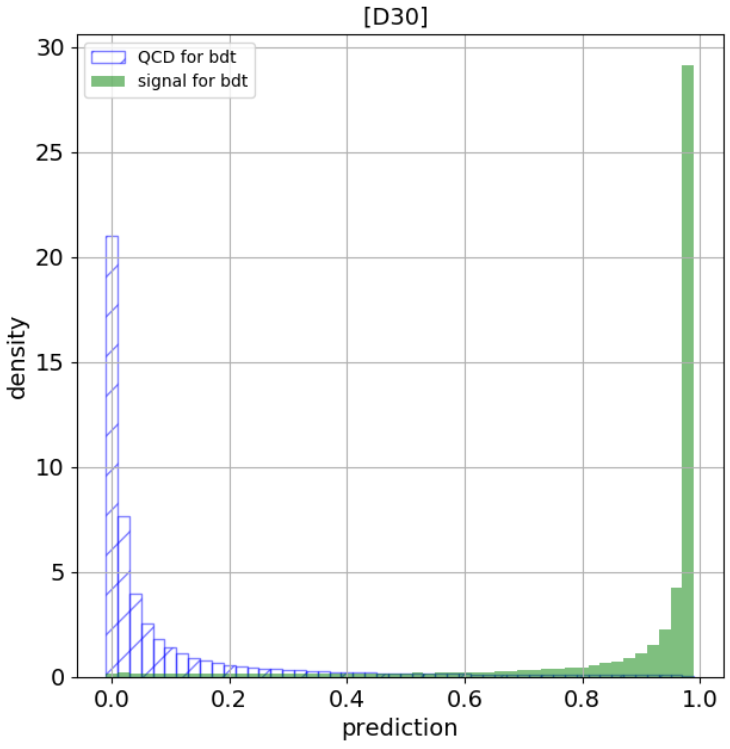


- Standard cut-based analysis to select events and filter backgrounds, but that's not good enough...



Reality is much more grim, with low $\Delta\phi$ events being popular in all our backgrounds

Tag them with a Boosted Decision Tree

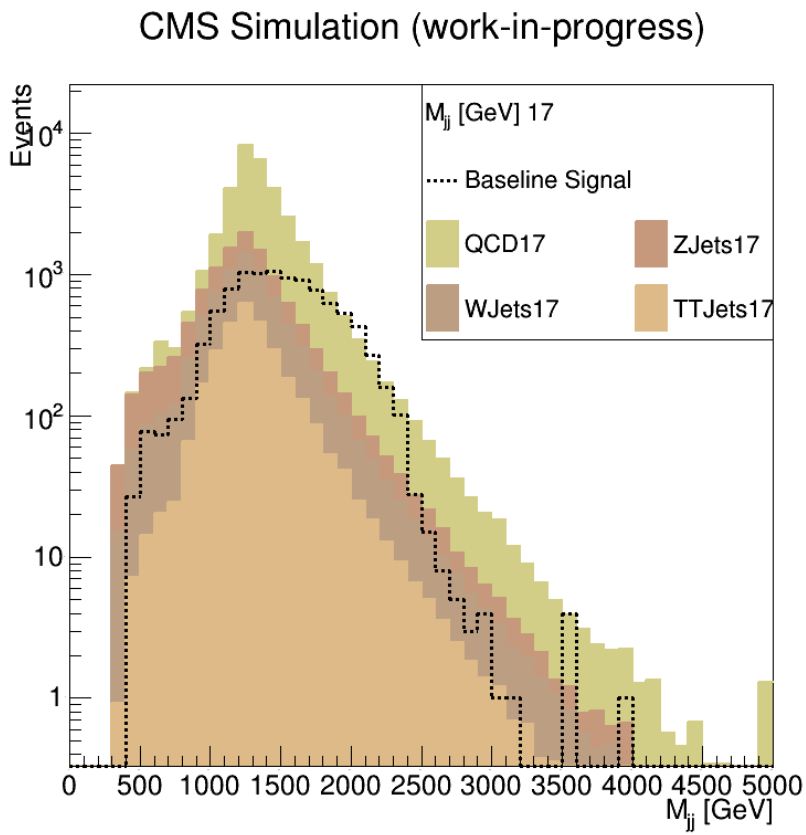


Girth, τ_{21}, τ_{32}, SoftDrop Mass, $min\Delta\phi$, Major and Minor Axis, ptD, energy correlation functions, ptdrlog, particle type energy fractions, b-tagging variable

- Form of Machine Learning
- Finds a set of 1D cuts to identify signal and background
- In this case, we're using the BDT to tag individual *jets* as a SVJ or not.

Hunt for a Bump

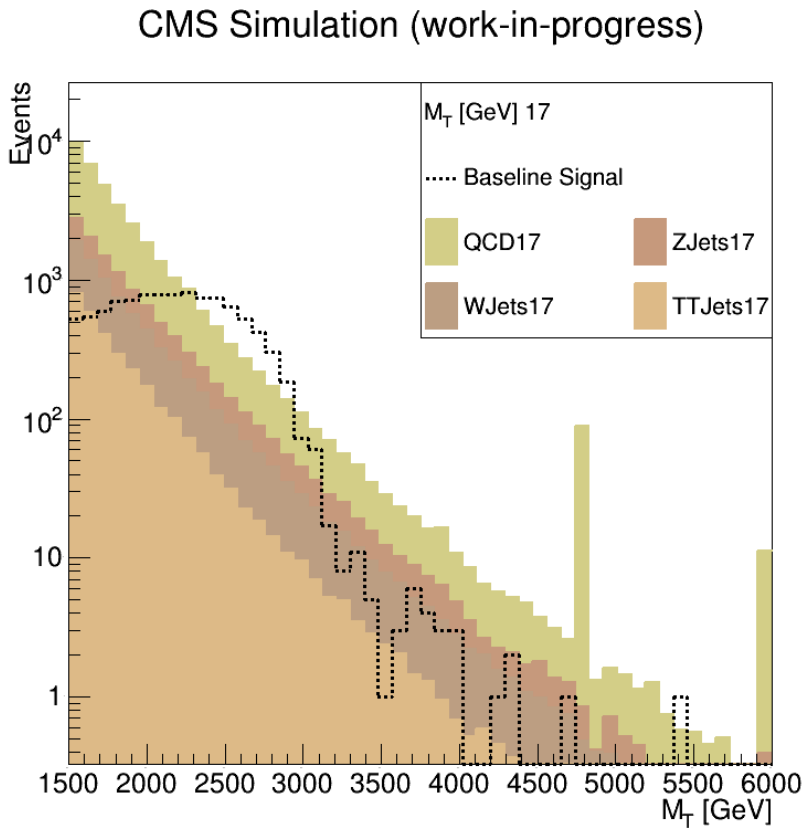
Used often for resonant searches.
Typically use an invariant mass, where it be dijet mass, jet-lepton mass, diphoton mass...
However, the dijet mass of SVJs doesn't really look too nice for a bump hunt...



Hunt for a better Bump!

Instead, we use the transverse mass variable:

$$m_T = \sqrt{m_{jj}^2 + 2(\sqrt{m_{jj}^2 + p_{Tjj}^2}\not{E}_T - \vec{p}_{Tjj} \cdot \vec{\not{E}}_T)}$$



- Hidden Valley Dark Matter[1]
- SemiVisible Jets [2]
- BDT to identify Semi-Visible Jets[3]
- Bump Hunt in m_T to find Z'

Thank you!

Any Questions?

[1] Matt Stassler and Echos of a Hidden Valley at Hadron Colliders

[2] Tim Cohen and Mariangela Lisanti for SVJ phenomenology papers

[3] CMS Analysis Note AN-19-064