SVJ Workshop: Working Group 1 *All-Hadronic Final States*

Elias Bernreuther (FNAL), Adrian Carmona (Granada), Fatemeh Elahi (Mainz), Alison Eliot (RAL), Aran Garcia-Bellido (Rochester), Nukulsinh Parmar (Rochester), **Kevin Pedro** (FNAL), Christiane Scherb (Mainz), Pedro Schwaller (Mainz)

July 6, 2022

Charge

1) All-hadronic semi-visible jets

Concrete models with benchmarks that give these signatures.

Understand the connection between r_inv and model parameter space.

Improvements to search strategies depending on production mechanism, and as r_inv varies.

Explore the need for separate portal couplings for production versus decay.

This topic is the primary focus of the workshop.

Models

- We surveyed the following models*†:
  - “Cohen” model (arXiv:1503.00009, arXiv:1707.05326)
  - “Schwaller” model (arXiv:1502.05409, arXiv:1803.08080)
  - “Aachen” model (arXiv:1907.04346, arXiv:2006.08639)
  - “Snowmass” model (arXiv:2203.09503)
- Conventions:
  - SU(N_c^{dark}) force with scale Λ_{dark}
  - N_f^{dark} dark quarks χ_i
  - $r_{\text{inv}} = \langle N_{\text{stable}}/(N_{\text{stable}} + N_{\text{unstable}})\rangle$

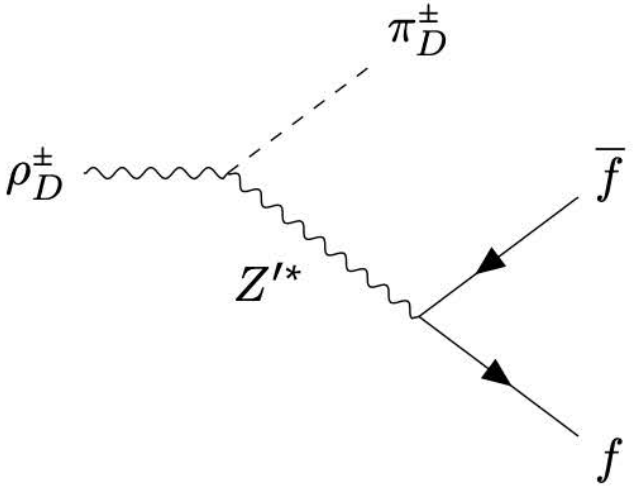
* Naming choices by KP

†All inspired by arXiv:hep-ph/0604261

Model Parameters & r_{inv}

- Summary of parameters that influence r_{inv} in above models:
  - N_c^{dark}: baryon suppression
  - N_f^{dark}: diagonal vs. off-diagonal meson frequency, other symmetries
  - dark quark mass splitting (relationship of m_{χ_i}, m_{χ_j}, Λ_{dark}): off-diagonal meson suppression
  - dark hadron mass spectrum ($m_{\pi_{\text{dark}}}$, $m_{\rho_{\text{dark}}}$, etc.): baryon suppression, heavier state decays (two-body vs. three-body), relative abundance of pseudoscalar vs. vector mesons
  - dark *G*-parity (if any): stability of dark pions
  - **Q** (mediator charges for dark quarks): decay availability (for $U(1)'$ mediators)
  - Mass mechanisms (dark Higgs sector or something else): determines Z' mixing
- See attached document for more details, including individual model surveys

3-body r_{inv}



- What is r_{inv} with decays like this? ($2m_{\pi_{\text{dark}}} > m_{\rho_{\text{dark}}}$, probVector = 0.58)
- Proposal: extend definition to
  $r_{\text{inv}} = \langle (N_{\text{stable}} + f_{\text{inv}} N_{\text{partial}}) / (N_{\text{stable}} + N_{\text{partial}} + N_{\text{unstable}}) \rangle$
  - N_{partial} are dark hadrons that decay to other dark hadrons and SM particles (as above), while N_{unstable} are dark hadrons that decay just to SM
  - f_{inv} is the momentum fraction carried by dark hadrons in "partial" decays; can be computed via integration for 3-body case, but not boost-invariant
    - Compare Pythia output to calculations to see if correction needed
  - Lower bound: $r_{\text{inv}} \geq 1 -$ probVector = 0.42

Open Questions

1. Is the list of r_{inv}-influencing parameters complete?
   a. Is the proposed scheme to extend the definition of rinv to 3-body decays adequate?
2. How many details can be simplified to create simplified models?
3. Proposed study: are there any major kinematic differences between simplified models and realistic models?
   a. If so, how can we account for them?
   b. Which parameters of complete models can be accurately simulated in Pythia?
4. How much do the “other considerations” (next slide) influence rinv and related kinematics toward simplified models?
5. What is a minimal mediator setup that allows r_inv to be close to any value between 0 and 1?

Other Considerations

- Dark hadron lifetimes: prompt, long-lived, detector-stable

  6. Detector-stable particles may still decay outside of detector: presents missing energy, but should they be included in N_{stable} for r_{inv}?

  7. Can we also make a complete list of parameters that influence lifetime? (mediator type, couplings, mass spectra…)

- Dark hadron decay patterns: e.g. flavor content

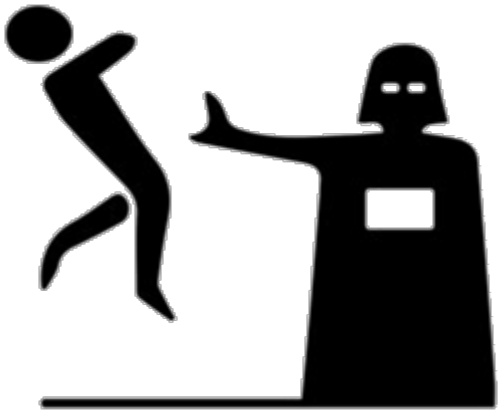
  8. How does this depend on decay portal type?

- Mediator/portal (production/decay):

  9. How do N_{stable}, N_{unstable} differ for *s*-channel vs. *t*-channel production, scalar vs. vector mediators?

  10. What other mediator scenarios are interesting? e.g. vector *t*-channel mediator, W' ($\rightarrow W Z'$?), Higgs…

Conclusions



- Many questions; few answers
  - Ripe for further study and publications
- Possible next steps for program:
  - Pythia studies to extent possible
  - Further model-building
  - Develop set of simplified models categorized by most crucial parameters (e.g. N_c^{dark}?)
- Experimentalists want to cover as much parameter space as possible
  - We are hungry for broad models with # parameters under control
- IANAT (I am not a theorist)
  - Thanks to all in the group for their contributions
  - Any errors here are mine

➢ May the dark force be with us all!

Backup