Indirect Detection Signatures of a Dark Glueball Spectrum

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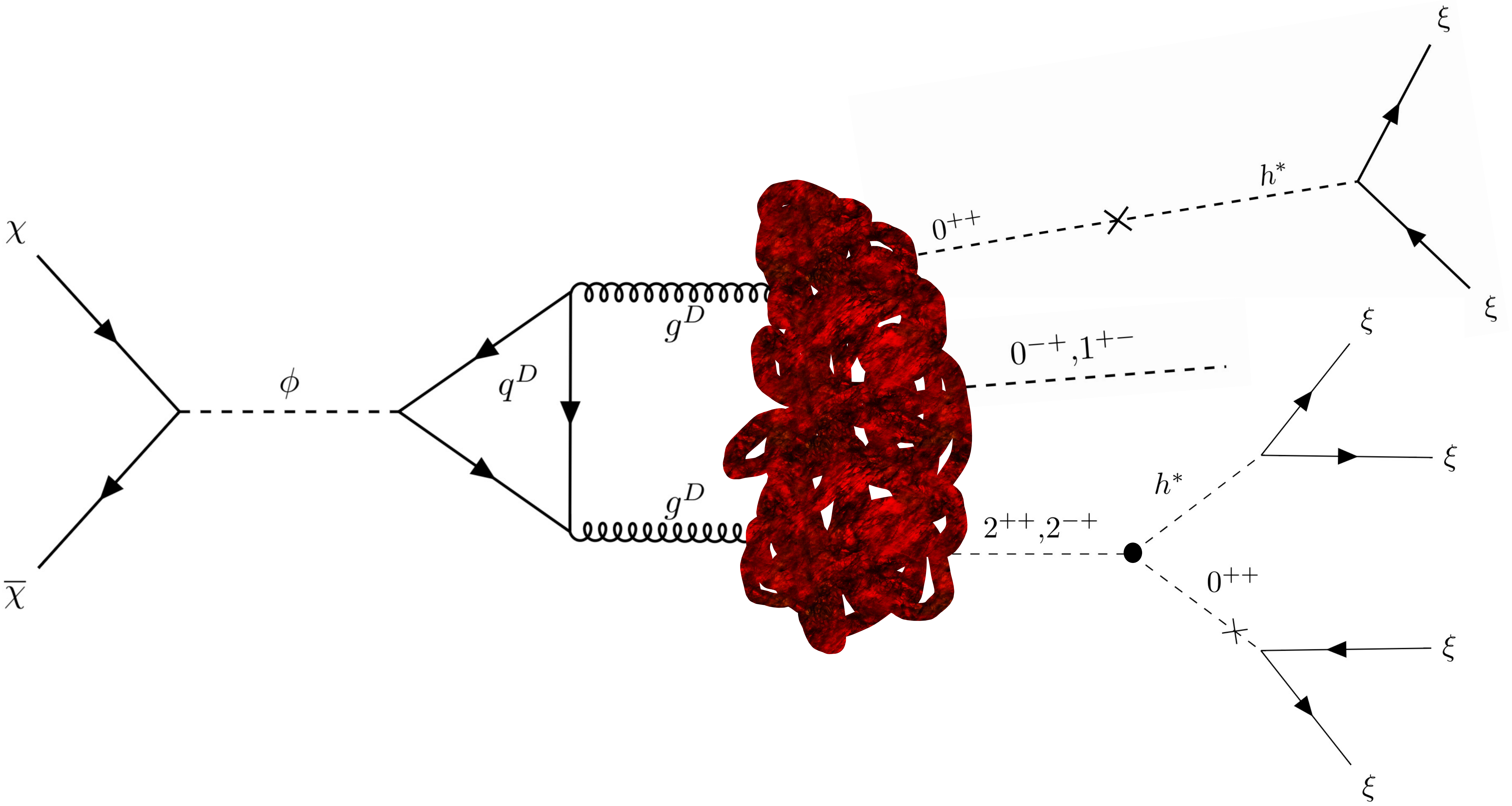
Introduction

Indirect Detection and Dark Showers

One benefit of indirect detection experiments is that they probe astrophysical length scales, possibly giving insight into more of the dark sector spectrum, not just the short living states

Benchmark Model

- Generic possibility of hidden valley models
- Dark showers are theoretically motivated by neutral naturalness, e.g. Fraternal Twin Higgs
- In this work we consider a theory-agnostic model:
  - Dark SU(3) group
    - Any dark quark masses are above the confinement scale, couple to Higgs
    - Dark gluons hadronise into dark glueballs
  - Dark fermion, χ, uncharged under dark SU(3)
  - Scalar mediator, ϕ
- Integrating out the heavy dark quarks gives an effective dimension 6 operator between dark gluons and the Higgs
- Possible fields charged under both the dark sector and standard model would lead to a dimension 8 operator between dark gluons and SM gauge bosons
- Fraternal Twin Higgs Analogy:
  - Twin QCD = dark confining sector
  - Twin tau = dark matter candidate
  - Twin Higgs = scalar mediator



χ
$\overline{\chi}$
ϕ
q^D
g^D
g^D
0^{++}
h^*
ξ
ξ
$0^{-+}, 1^{+-}$
ξ
ξ
h^*
$2^{++}, 2^{-+}$
0^{++}
ξ
ξ

Dark Glueballs

Dark Glueball Spectrum

- Hierarchy of masses set by the confinement scale/mass of lightest glueball
- Dimension 6 Higgs operator allows dark glueballs to decay back into the standard model

$$0^{++} \to (h^*) \to b\bar{b}, \tau^-\tau^+, c\bar{c}...$$

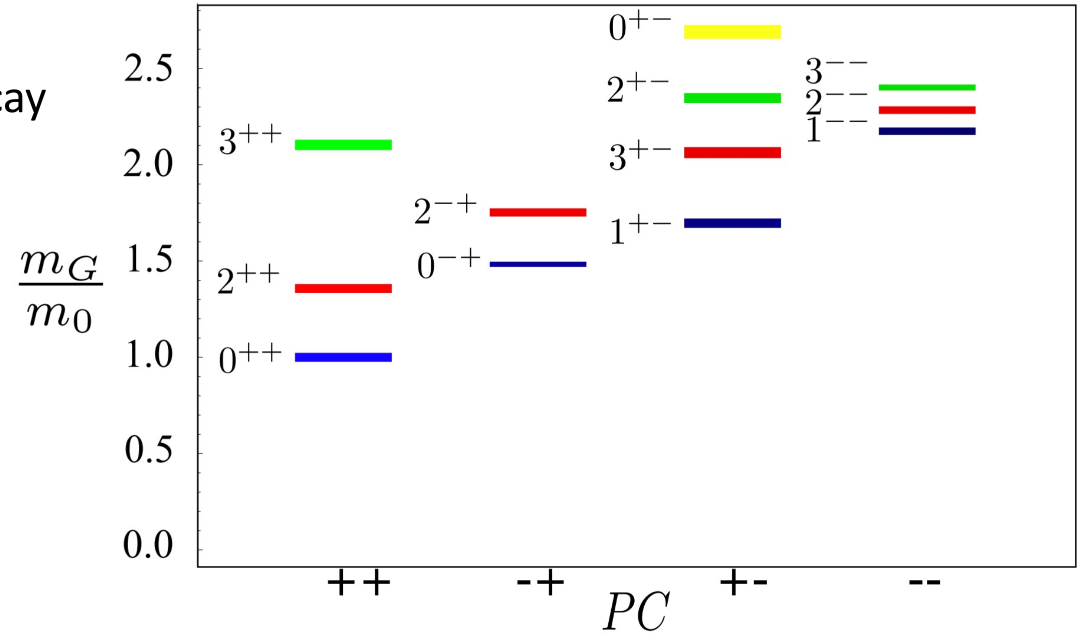
$$2^{++} \to (h^*)0^{++} \to 0^{++}(c\bar{c}, gg, \mu^-\mu^+...)$$

$$2^{-+} \to (h^*)0^{++} \to 0^{++}(b\bar{b}, c\bar{c}, gg...)$$

- Possible dimension 8 operator could also couple the dark glueballs directly to SM gauge bosons

$$0^{\pm+}, 2^{\pm+} \to V_{SM}V_{SM}$$

$$1^{+-} \to \gamma\, 0^{++}, \gamma\, 2^{++}, \gamma\, 0^{-+}$$



Morningstar, Peardon, arXiv:9901004
Jukncvich, arXiv:0911.5616

Dark Glueball Production (Analytical)

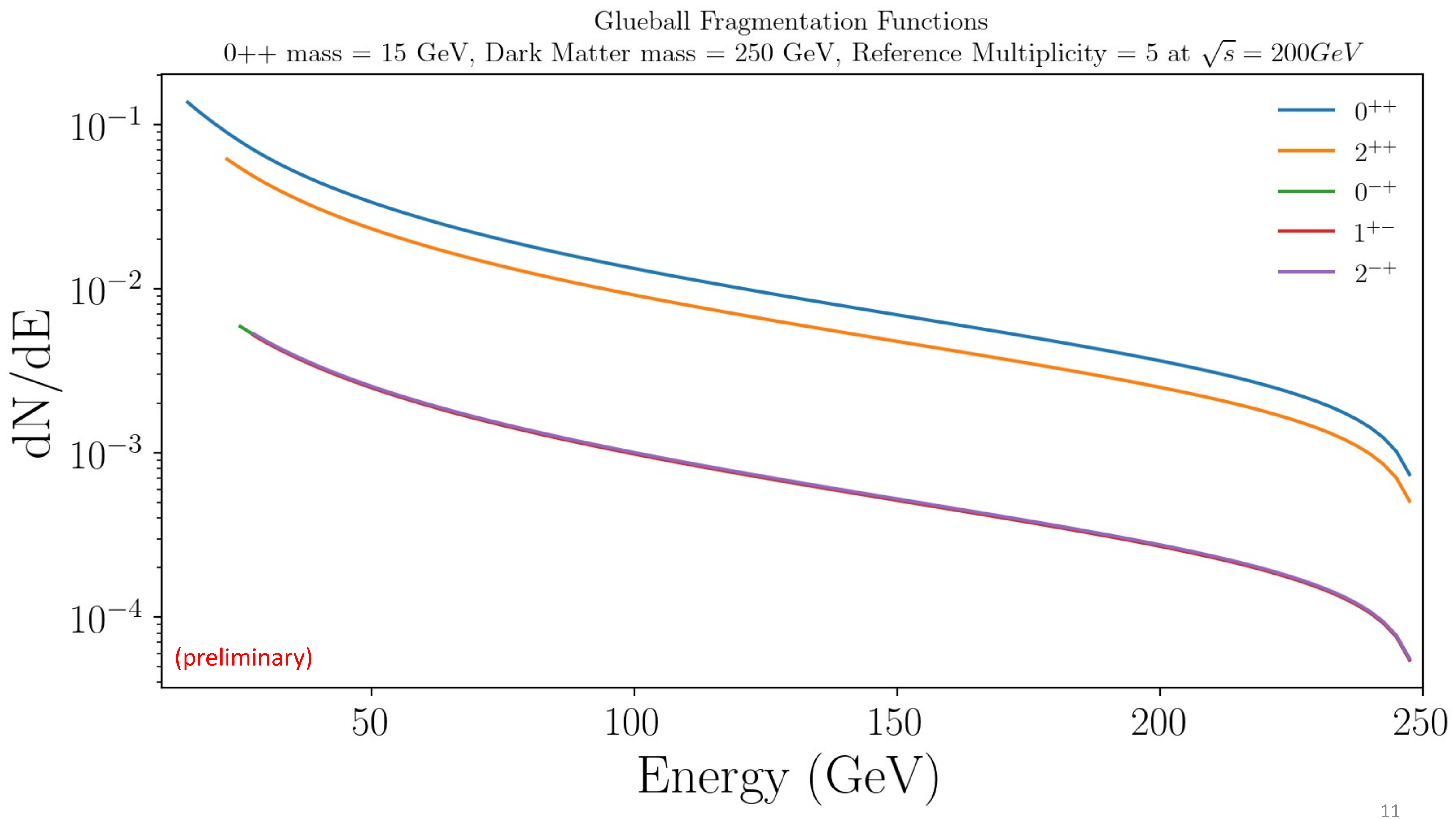
- Intra-event information not required for indirect detection, only need to parameterise fragmentation function, encodes energy distribution and multiplicity
- Low-x regime, dominated by the gluon-to-gluon splitting function, analytical form known
  - x is the scaled hadron energy
- Evolution of the average total multiplicity is also determined from splitting functions
  - Needs input multiplicity at a scale to set normalization, free parameter, could be determined by simulated pure glue shower

"QCD and collider physics" Ellis, Stirling, Webber

Dark Glueball Production (Simulation)

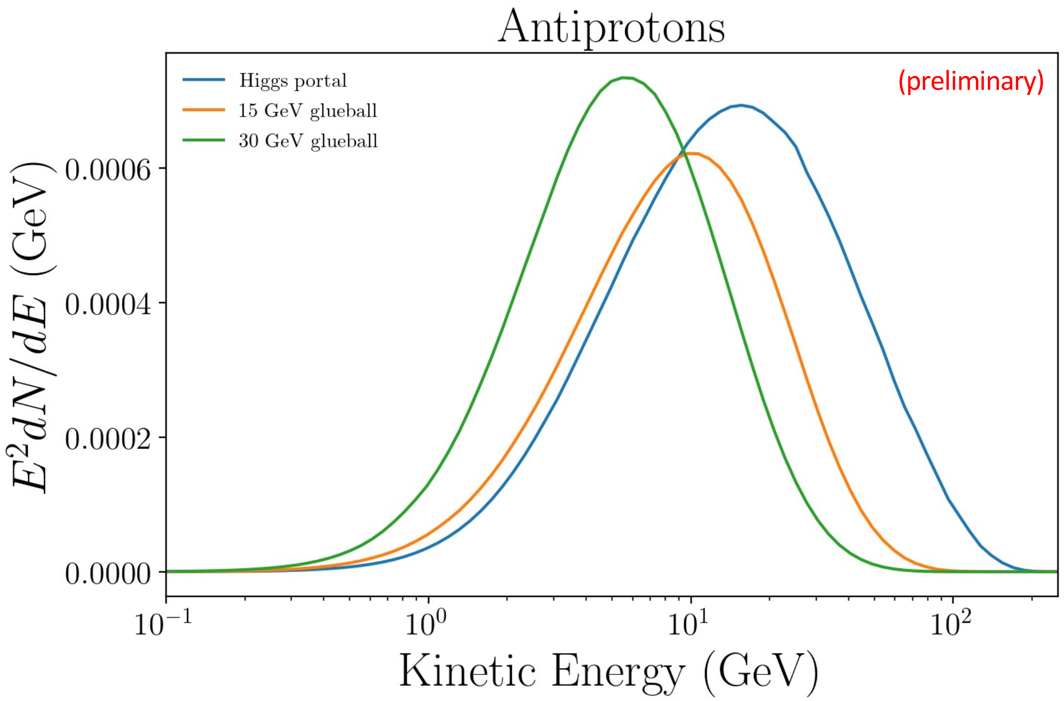
- High-x regime usually fit to data as is a priori unknown, here constrained by energy conservation, expected average multiplicity, and matched to low-x regime
- Multiplicity of individual states is approximated using a thermal model, Boltzmann distribution
  - Temperature $\sim$ confinement scale
  - Five lowest lying states account for 98% of glueballs
  - Limitations: Non local effects…
- Future work / in progress:
  - Simulation code for pure glue parton shower, takes account of finite mass effects

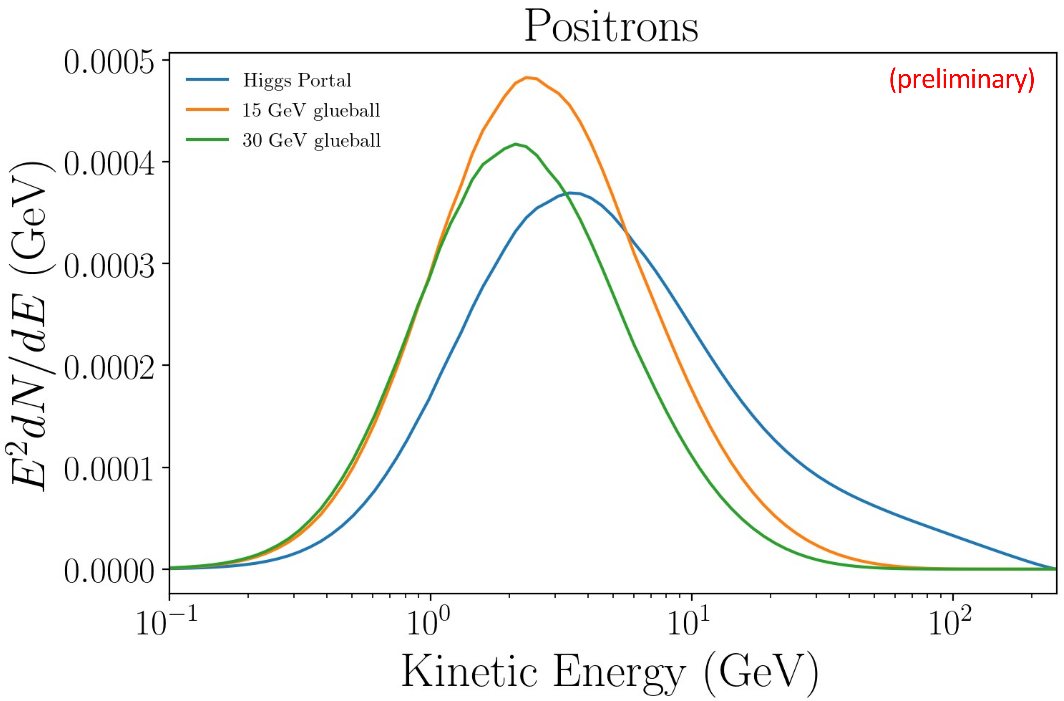
Burdman, Lichtenstein, arXiv:1807.0380 (2018)



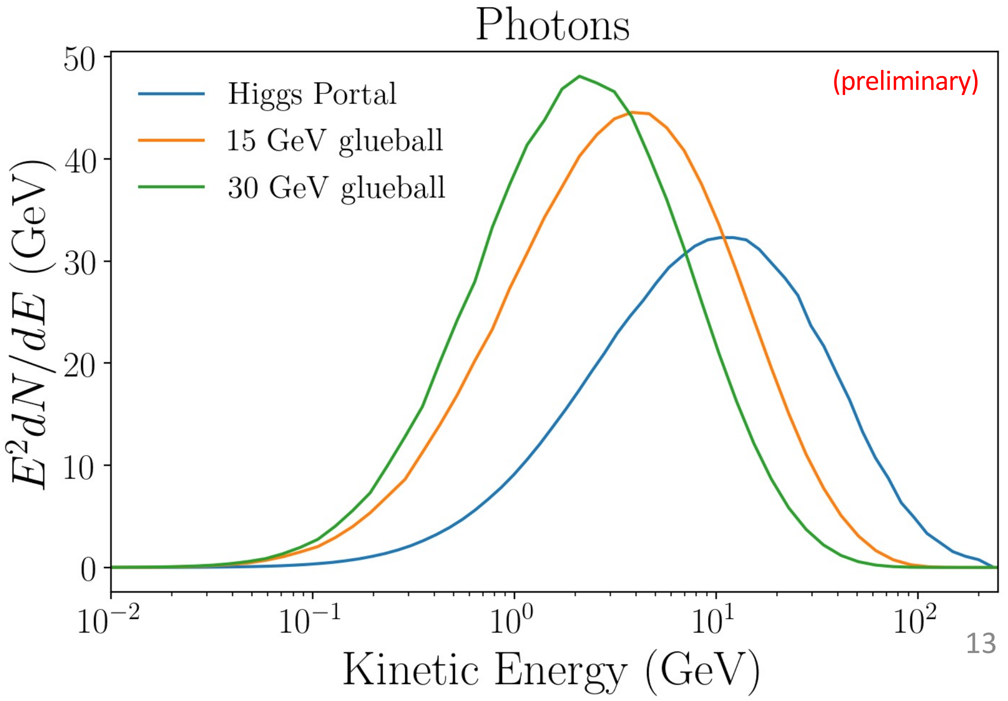
Glueball Fragmentation Functions
0++ mass = 15 GeV, Dark Matter mass = 250 GeV, Reference Multiplicity = 5 at $\sqrt{s} = 200GeV$
0^{++}
2^{++}
0^{-+}
1^{+-}
2^{-+}
dN/dE
Energy (GeV)
(preliminary)

Results Preview



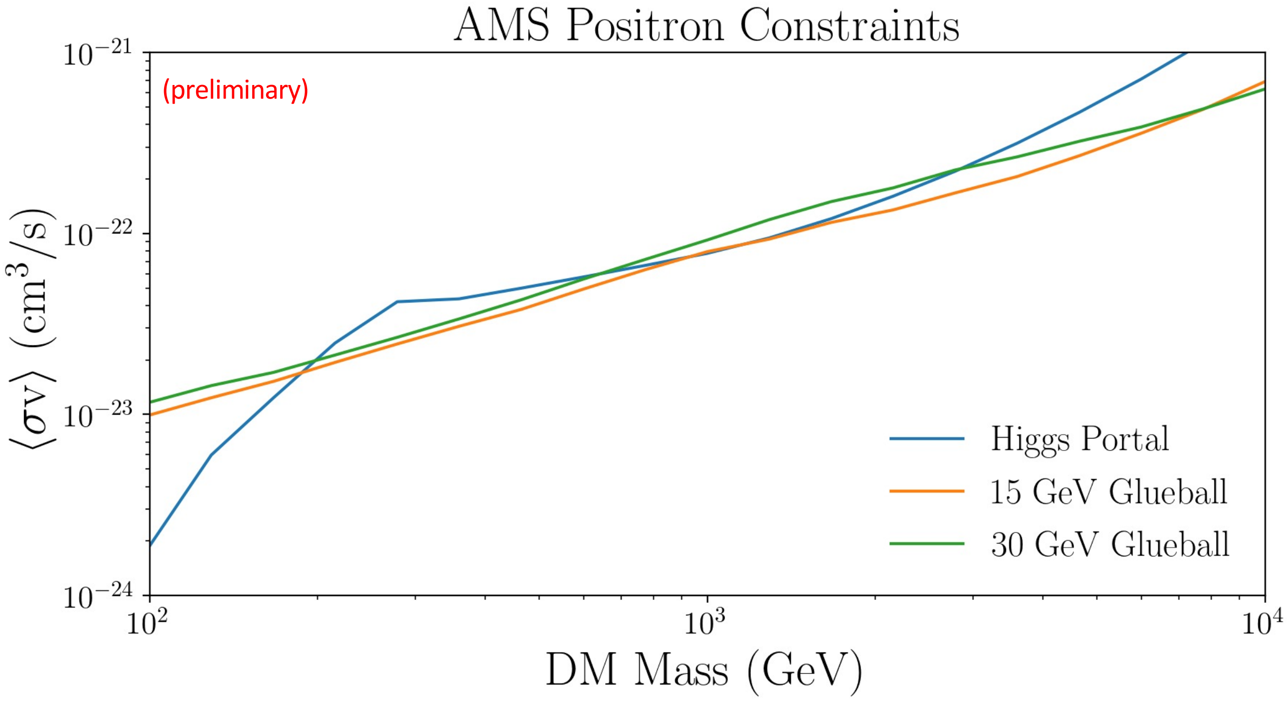


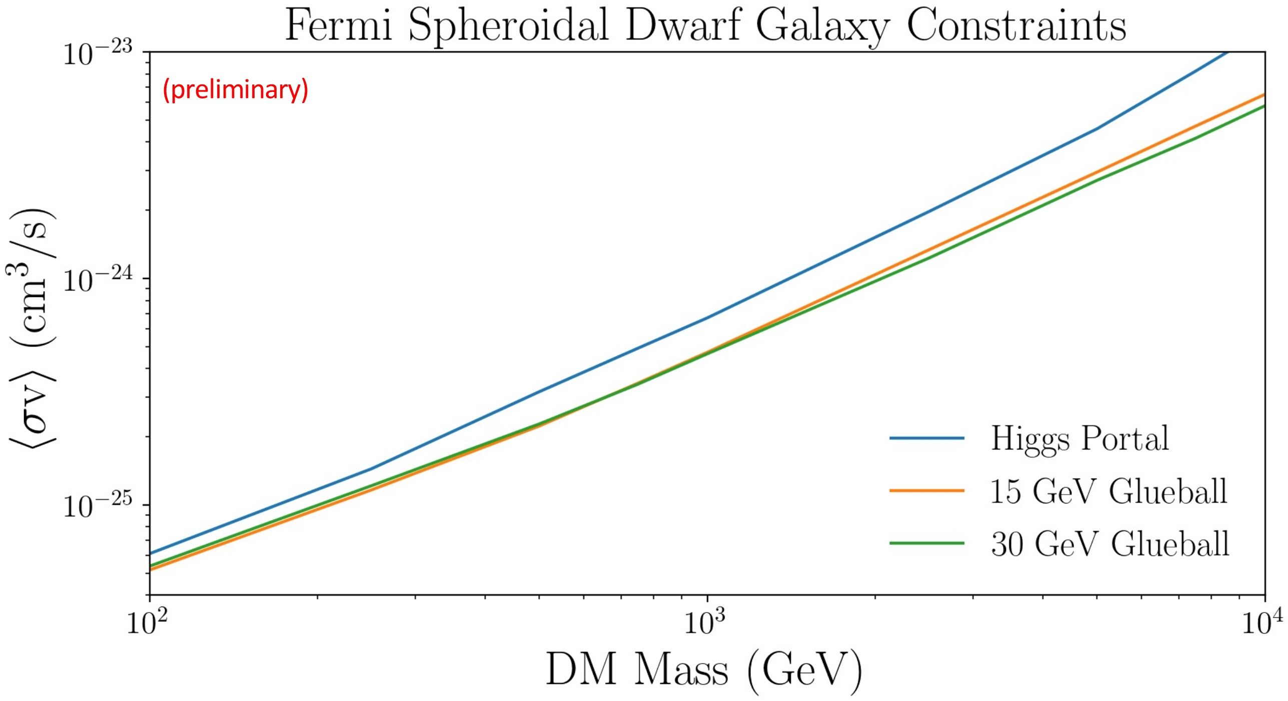
- Spectra are as they appear at Earth
  - Cosmic Rays propagated using DRAGON2, solar modulation accounted for using force field approximation with Φ = 0.6 GV
- Parameters
  - Dark matter mass = 250 GeV
  - Reference multiplicity = 5
  - Reference scale = 200 GeV



Exclusion Plots

- Constraints
  - AMS-02 measurements of cosmic ray positron spectra
  - Fermi-LAT measurements of gamma-ray spectra from 44 dwarf galaxies
- Observations
  - In general, dark glueball showers are more constrained than Higgs portal dark matter
  - Difference in shape for positron constraint is due to availability of electroweak decay channel for Higgs portal dark matter
  - Glueball mass doesn't make large difference in constraints





Conclusions

- Dark showers are a general signature of hidden valley models, motivated by neutral naturalness
- The benefit of indirect detection is that it probes astrophysical scales, allowing us to see possibly the entire dark glueball spectrum of decays
- Currently in progress, we intend to properly parameterise our glueball hadronization, careful consideration of the model / simulation
- Using this framework we will be able to provide the first indirect detection constraints on the Fraternal Twin Higgs Model

Thank you!

Questions?

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Fragmentation Function

$$D_{low}(x,s) \propto \frac{1}{x} e^{-\frac{(\xi-\xi_p)^2}{2\sigma^2}}$$

$$x = \frac{2E_g}{\sqrt{s}} \qquad \xi \equiv \ln\frac{1}{x} \qquad \xi_p \equiv \frac{\pi}{b\alpha_F(s)} \qquad \sigma \equiv \left(\frac{\pi}{6b}\sqrt{\frac{2\pi}{C_A\,\alpha_F^3(s)}}\right)^{1/2}$$

$$D_{high}(x) \propto (1-x)^\alpha x^\beta$$

$$\langle n(s)\rangle \propto e^{\frac{4\pi}{b}\sqrt{\frac{6}{\pi\alpha_s^D(s)}}+\frac{1}{4}\ln(\alpha_s^D(s))}$$

"QCD and collider physics" Ellis, Stirling, Webber
Burdman, Lichtenstein, arXiv:1807.0380 (2018)

Twin Higgs Framework

- Solves the Little Hierarchy problem
- Mechanism
  - Introduce twin copy of the standard model, SM_B
  - SM Higgs doublet is embedded in Higgs sector that has SU(4) symmetry
  - H gets a VEV, f, and spontaneously breaks SU(4) to SU(3) generating 7 pNGBs, 4 of which are the SM Higgs doublet
    - Higgs mass protected from quadratic divergence due to Z_2 symmetry of model
- Analogous to our generic model
  - Twin QCD = dark confining sector
  - Twin tau = possible dark matter candidate
  - Twin Higgs = scalar mediator
- Fraternal Twin Higgs reduces particle content of twin sector, less constrained

$$\mathbb{Z}_2 : SM_A \Leftrightarrow SM_B$$

$$H = (H_A, H_B)^T$$

$$V = \lambda\left(H^\dagger H - \frac{f^2}{2}\right)^2 + \text{breaking terms}$$

$$\Delta V = \frac{3\Lambda^2}{8\pi^2}\left(\lambda_A^2 H_A^\dagger H_A + \lambda_B^2 H_B^\dagger H_B\right) = \frac{3\lambda^2\Lambda^2}{8\pi^2} H^\dagger H$$

Chacko, Goh, Harnik, arXiv: 0506256 (2005)
Craig,Katz,Strassler,Sundrum, arXiv: 1501.05310 (2015)