Dark Showers with the Herwig Generator

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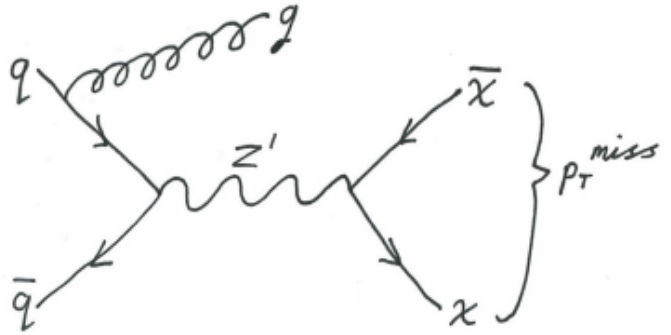
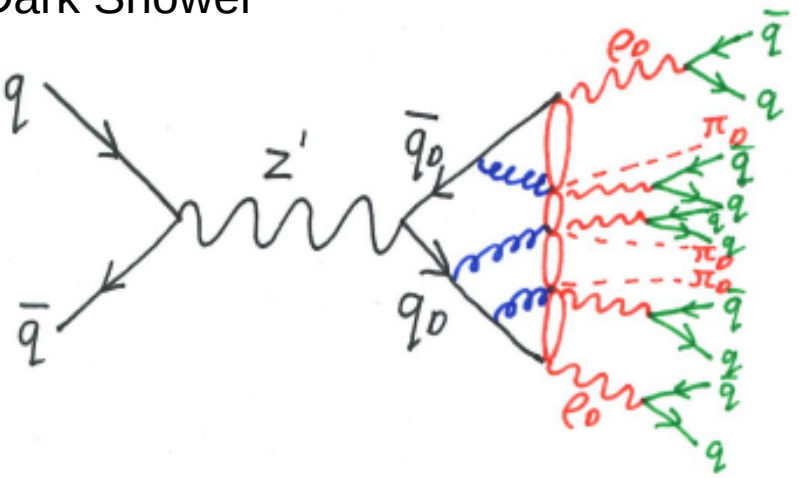
Dark Showers

- One of the main LHC goals is to search for “WIMP” dark matter
  - However no significant evidence from traditional mising transverse momentum (p_T^{miss}) searches
- Dark sector could be much richer
  - More particles
  - Forces between dark particles
- If new force is confining, it would lead to “dark shower” and hadronisation

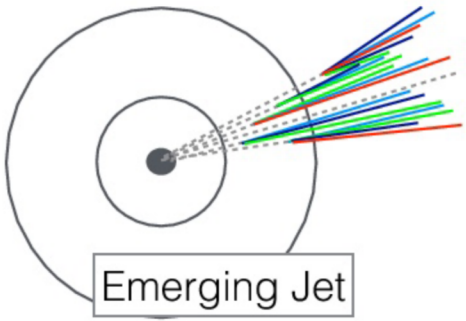
Traditional “mono jet” DM production

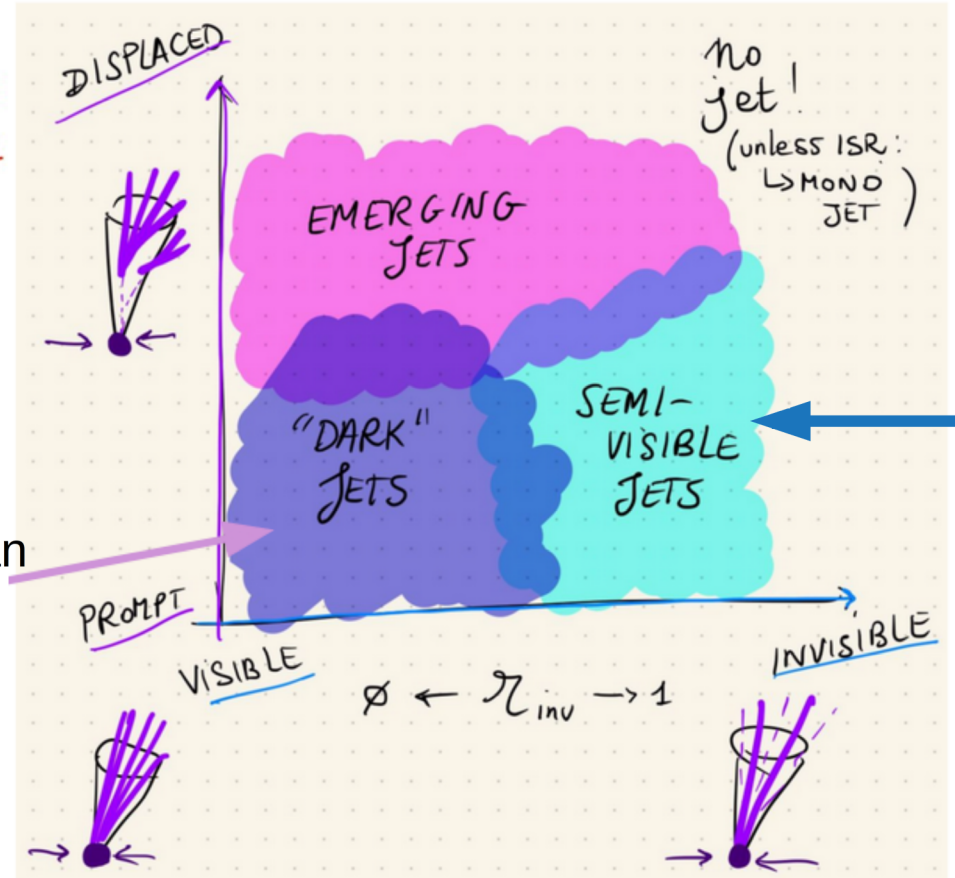


Dark Shower



Signatures



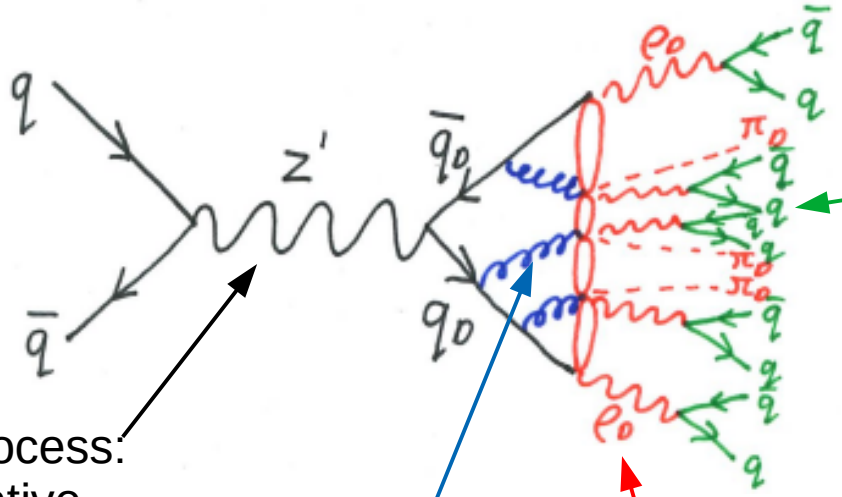


Little p_T^{miss}, but can be distinguished through jet substructure

p_T^{miss} aligned with jets, jet substructure also useful

Generating Dark Showers

Involves Physics at a range of scales:



Hard Process:
Perturbative,
well known

Parton Shower:
Perturbative,
calculable

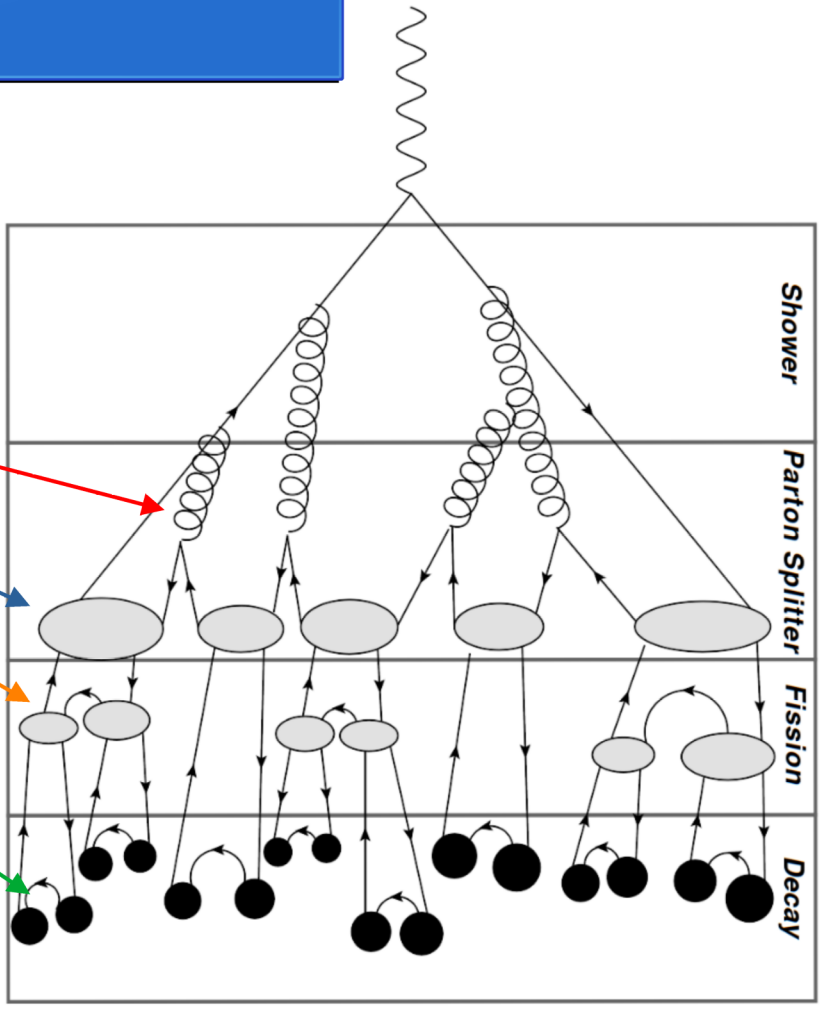
Hadronisation:
Non-perturbative
semi-empirical models
– challenging!

Decays:
2 body phase space (trivial)
3 body perturbative
(calculable)

- So far, only implemented in Pythia
- Herwig uses different hadronisation models
- Can act as a useful complement

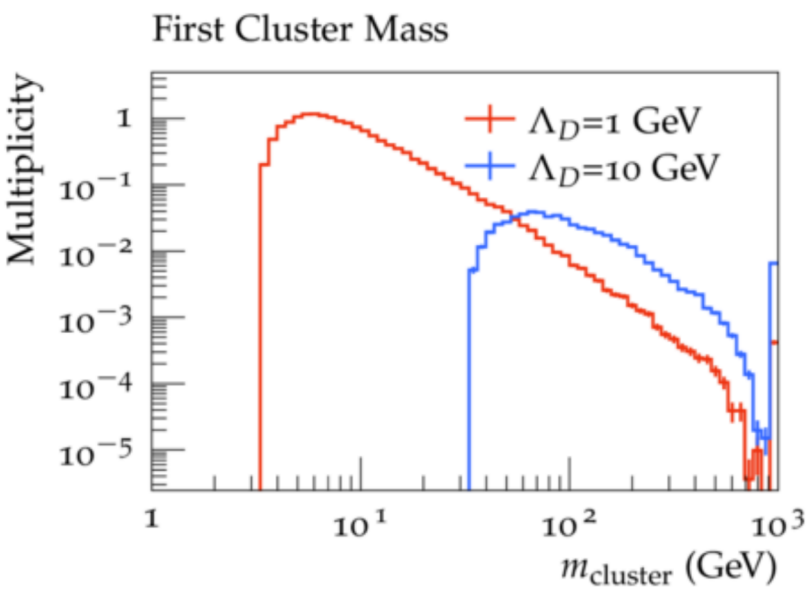
Cluster Hadronisation Model

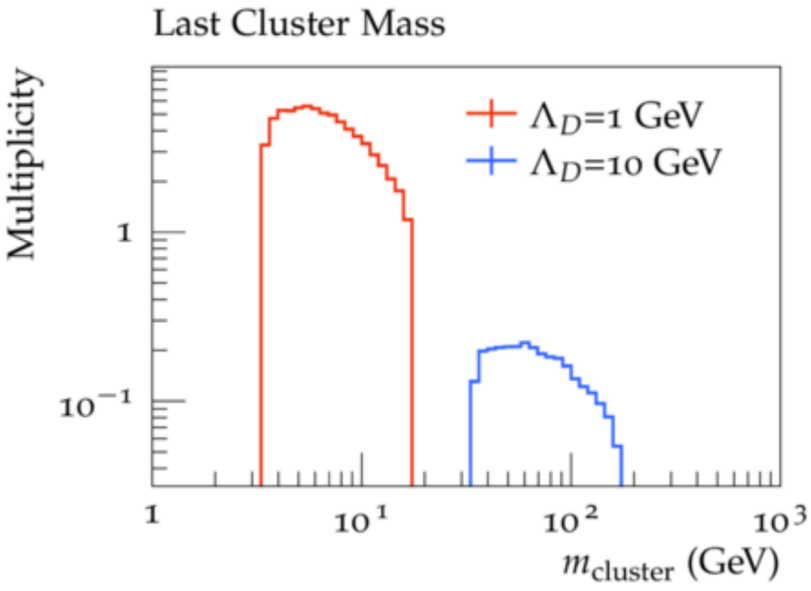
- Hadronisation is **non-peturbative** => Semi-empirical models, tuned to SM data
- Herwig uses the cluster hadronisation model:
  - Gluons are split into $q\bar{q}$ pairs
  - Colour connected $q\bar{q}$ pairs form clusters (representing heavy pseudo-hadrons)
  - Very heavy clusters decay by springing $q\bar{q}$ pair from vacuum
  - Clusters decay to two hadrons according to phase space and number of available spin-states



Cluster fissioning

- Numerous parameters describing different aspects of hadronisation
- Most important is parameter controling scale at which heavy clusters are split
  - Developed recommendation based on intuition from SM
- More advanced models of cluster evolution (in development) should reduce dependence on this parameter





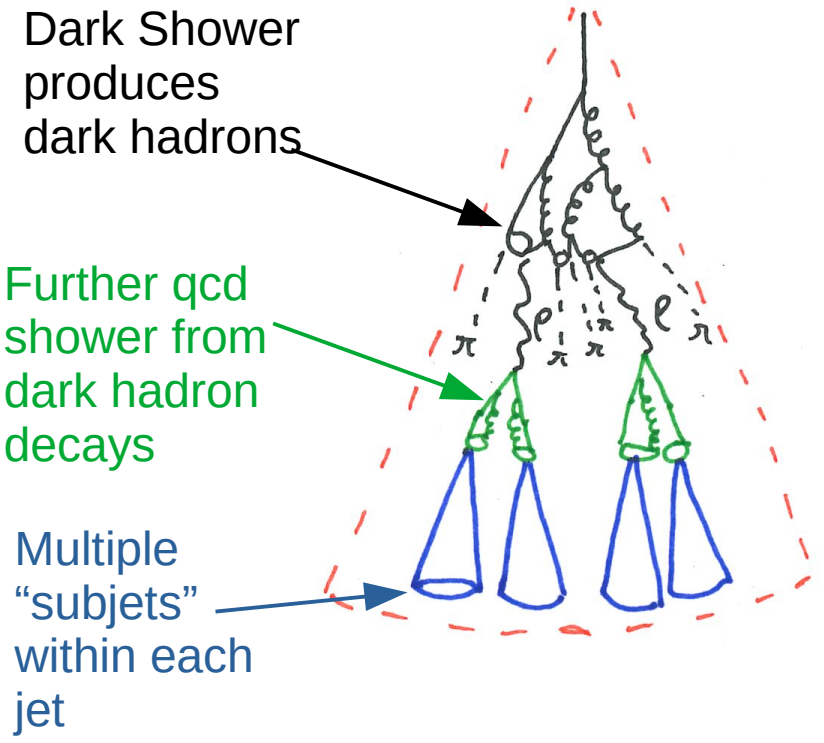
Dark Hadronisation

- Can predict the fractions of unstable ρ_D relative to stable π_D (and η_D, which decays to π_D)
  - In Pythia these are input parameters
- Varying the cluster fission scale could give estimate of uncertainties
  - Working on prescription for uncertainty estimation

		Pythia parameters	Herwig prediction
Invisible	π_D	42%	43%
	η_D	Neglected	0.9%
Visible	ρ_D	58%	56%

Jet substructure

- Jets from dark showers can appear very different to SM QCD jets
  - Multiple “subjets”
- Can use variables sensitive to angular structures within a jet to search for these models
- Sensitive to details of dark shower and hadronisation

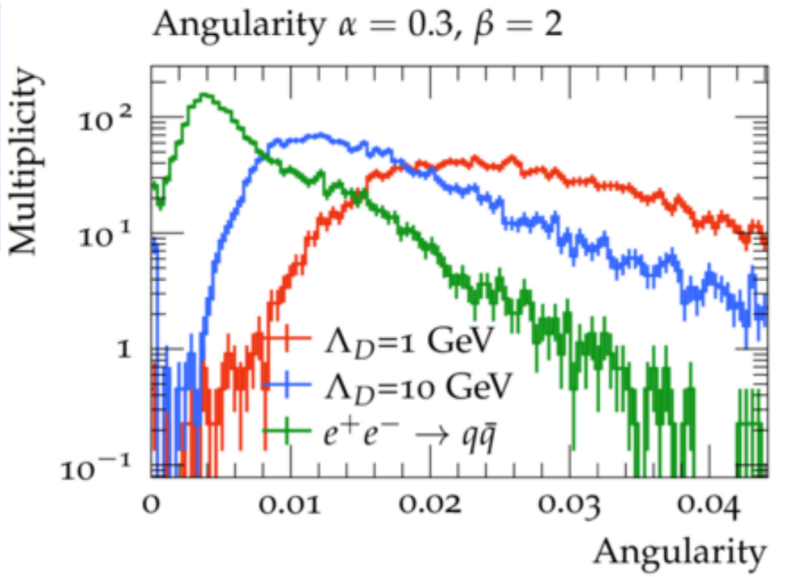


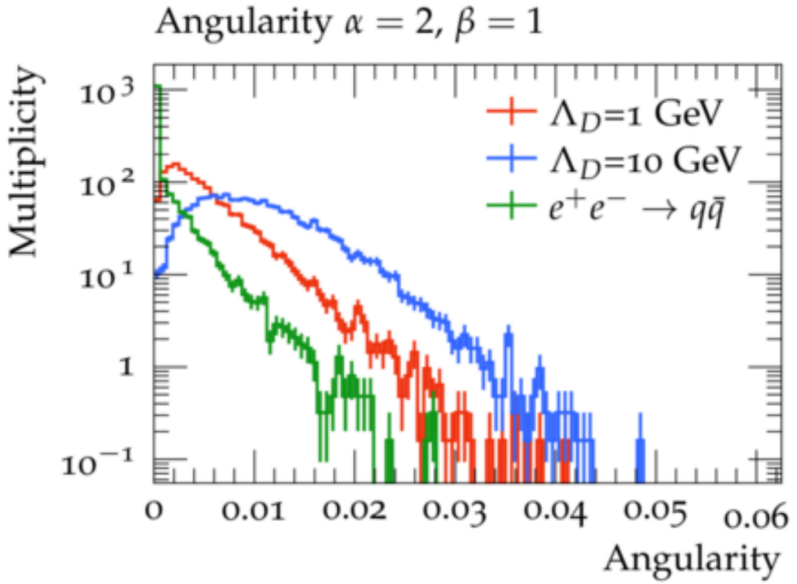
Phenenomological studies

- Investigated angularities:

$$\sum_{i \in jet} \left(\frac{E_i}{E_{Tot}} \right)^{\beta} \left(2\sqrt{1 - cos\theta_i} \right)^{\alpha}$$

- Two different values of dark shower confinement scale, Λ_D
- Varying α and β probes different values of Λ_D





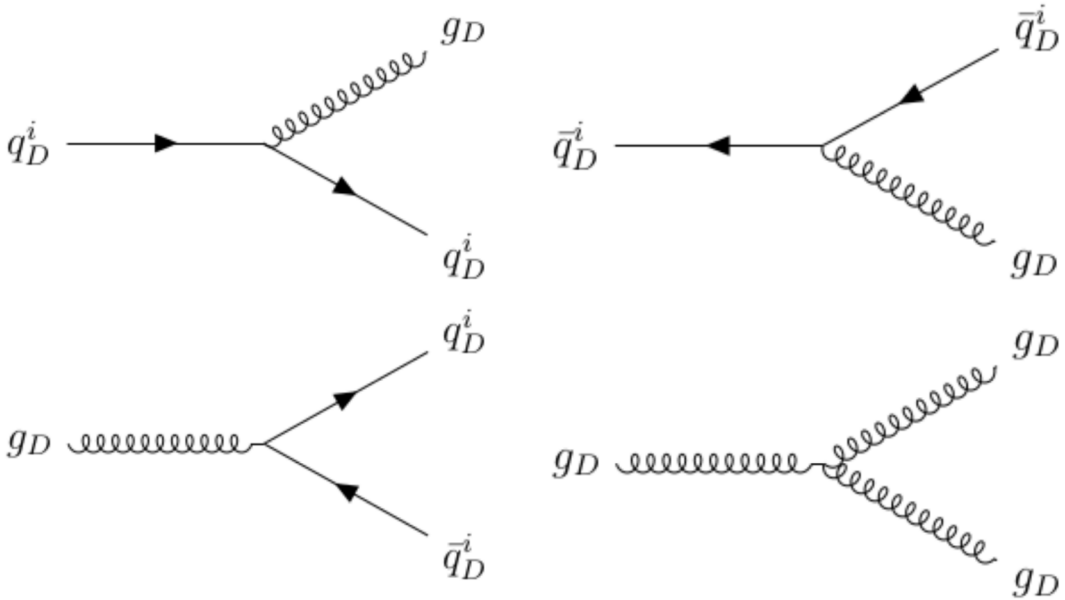
Conclusions and Outlook

- Dark shower model implemented into the Herwig generator
  - Will be included in Herwig 7.4 release
- Cluster hadronisation model provides useful counterpoint to Pythia's Lund string model
  - More predictive for some observables, e.g. spin state production rates
- Have performed some initial studies of sensitivities of jet substructure variables to different benchmarks
- Plan to carry out a full search for one such dark shower signature

Backup

Dark parton shower

- Model assumes a structure similar to QCD, with a number of “dark quarks”, q^i_D, and “dark gluons”, g_D, mediating the force between them
- Now implemented based on BSM extension of Herwig angular ordered parton shower [Massoumina, in progress]



Dark decays

- Unstable dark hadrons decay to SM quarks (which undergo a further parton shower and hadronise)
- Most decays can be implemented in input cards using existing Herwig classes
- New class added for three body decay to dark hadron + SM quarks
  - Full decay matrix element still to be added