Defining and Simulating Lepton Jets

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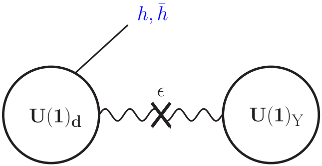
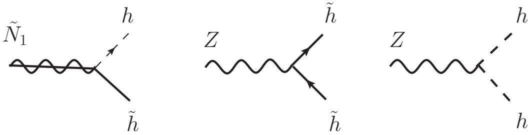
A Benchmark Model

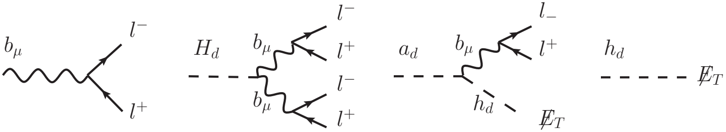
Supersymmetric $U(1)$ dark sector with two higgs.



Decays to the dark sector:

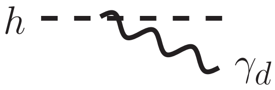


Dark scalar decays in terms of the mass eigenstates (b_d, H_d, a_d, h_d)



Dark Radiation and Decays to Hadrons

Boosted dark particles shower through dark interactions:

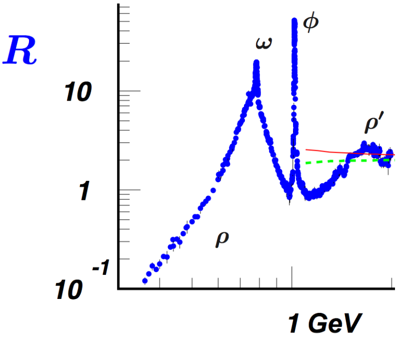


The number of radiated photons is determined by the Sudakov double log,

$$N_{\gamma_d} \sim \frac{\alpha_d}{2\pi} \log\left(\frac{M^2_{\rm decay}}{M^2_{\rm dark}}\right)^2$$

We Monte Carlo this with a virtuality-ordered parton shower.

Dark photons couple to $J^\mu_{\rm EM}$ which includes hadrons.



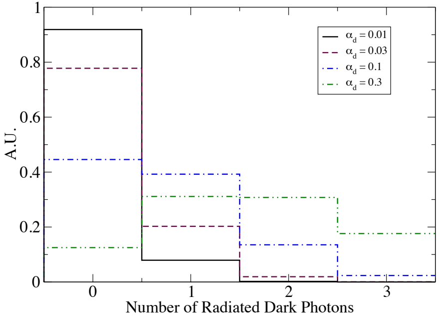
The branching fraction to hadrons for a given m_{b_μ} is determined by:

$$R = \frac{\sigma(e^+e^- \to {\rm hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

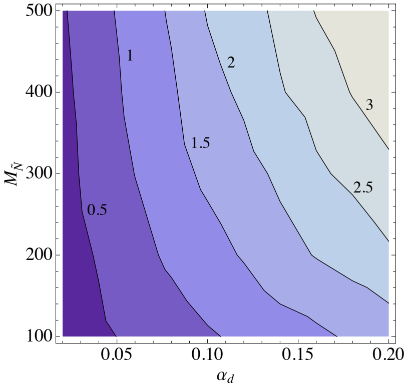
Radiation Rate

The number of radiated dark photons depends on α_d and $M_{\tilde{N}_1}$.

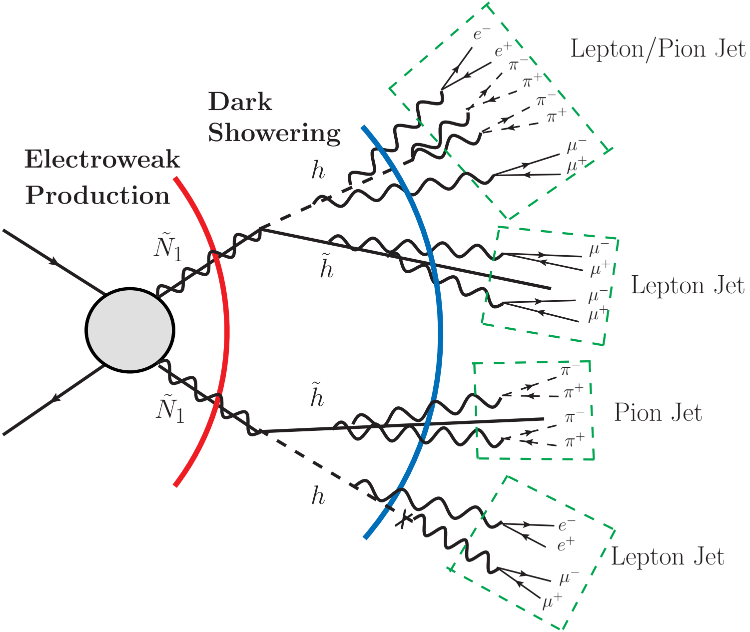
Rare Z decays:



Neutralino decays:

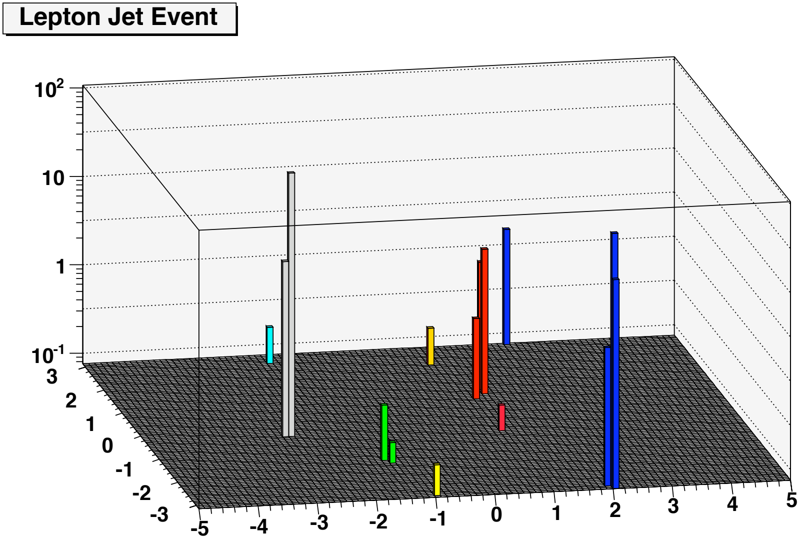


Lepton Jets and Pion Jets



Lepton Jet Monte Carlo

We simulate lepton jets with Madgraph and our own simple parton shower and decay routines.



An Experimental Definition

An experimental definition should be as *inclusive* as possible, while controlling the background of QCD jets.

As a template, we suggest an inclusive lepton cone surrounded by an isolation annulus*:

- $\Delta R < 0.1$
  ≥ 2 leptons each with $p_T > 10\ \mathrm{GeV}$.

  hadronic isolation cut $\Sigma p_T < 3\ \mathrm{GeV}$.

- $0.1 < \Delta R < 0.4$,
  hadronic/leptonic isolation cut of $\Sigma p_T < 3\ \mathrm{GeV}$

* We thank the participants of Boost 2009 for useful discussions concerning this definition.

Signal Efficiency

The efficiency to find 1 or 2 lepton jets per event, $M_{\tilde{N}_1} = 300$ GeV.

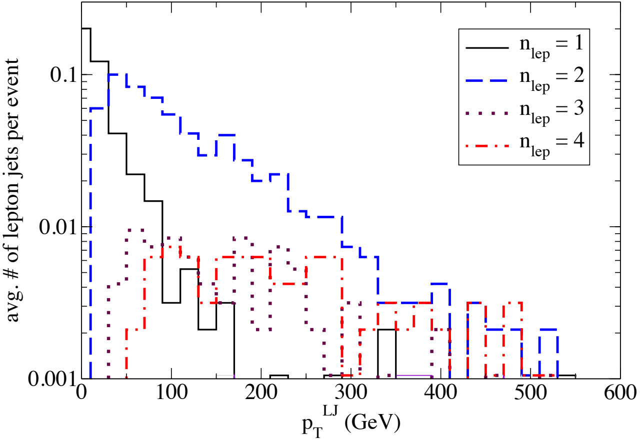
Lepton Jet Efficiencies						
	1 Lepton-Jet			2 Lepton-Jet		
α_d \ $\mathrm{Br}_{b\to\pi\pi}$	1/7	1/3	3/5	1/7	1/3	3/5
0	0.49 (0.49)	0.47 (0.47)	0.31 (0.31)	0.28 (0.28)	0.14 (0.15)	0.05 (0.05)
0.01	0.47 (0.47)	0.44 (0.45)	0.31 (0.32)	0.3 (0.31)	0.16 (0.16)	0.04 (0.04)
0.03	0.43 (0.41)	0.47 (0.48)	0.3 (0.3)	0.27 (0.3)	0.14 (0.16)	0.04 (0.05)
0.1	0.43 (0.39)	0.41 (0.44)	0.29 (0.32)	0.23 (0.3)	0.13 (0.18)	0.05 (0.07)
0.3	0.38 (0.32)	0.34 (0.36)	0.25 (0.34)	0.16 (0.3)	0.11 (0.22)	0.05 (0.09)

The lepton multiplicity of the hardest lepton jet, $M_{\tilde{N}_1} = 300$ GeV.

Lepton Multiplicity in Clean Lepton Jets									
	2 Leptons			4 Leptons			6 Leptons		
α_d \ $\mathrm{Br}_{b\to\pi\pi}$	1/7	1/3	3/5	1/7	1/3	3/5	1/7	1/3	3/5
0	0.49	0.44	0.29	0.28	0.17	0.07	0.	0.	0.
0.01	0.53	0.43	0.29	0.25	0.18	0.06	0.	0.	0.
0.03	0.47	0.46	0.29	0.26	0.16	0.06	0.01	0.01	0.
0.1	0.42	0.43	0.32	0.25	0.16	0.06	0.04	0.02	0.
0.3	0.35	0.38	0.34	0.21	0.11	0.05	0.07	0.04	0.01

Lepton Jet p_T vs Number of Leptons

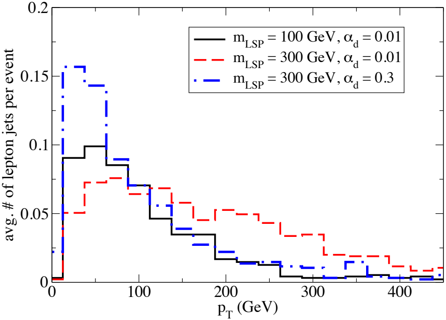
We find a population of isolated soft leptons accompanying harder lepton jets.



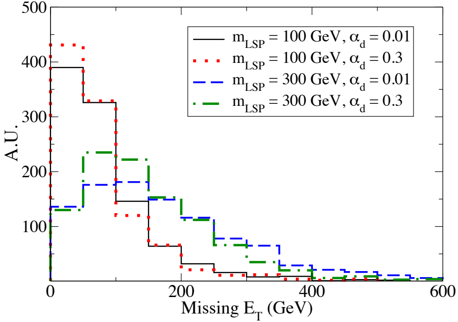
$$M_{\tilde{N}_1} = 300 \text{ GeV}, \quad \alpha_d = 0.1, \quad \mathrm{Br}(b_\mu \to \pi^+\pi^-) = 1/3$$

p_T and $\not{E}_T$

Lepton Jet p_T



Missing E_T



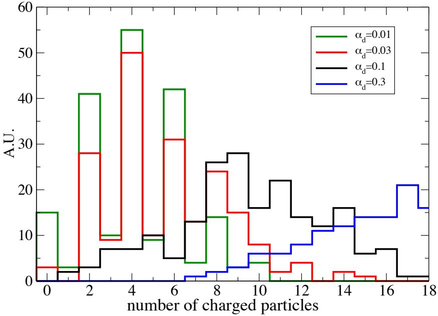
Showering reduces lepton jet p_T's.

Showering slightly reduces $\not{E}_T$.

Showering and Charge Multiplicity

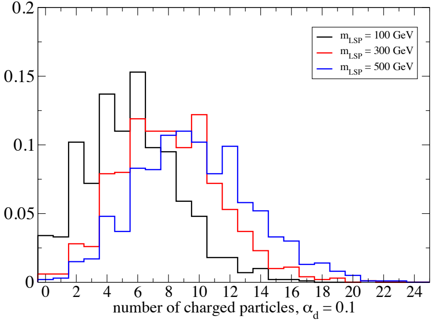
Showering increases the number of charged particles (with $p_T > 3\ \mathrm{GeV}$) per event and makes odd numbers more likely.

Varying α_d,



$M_{\tilde{N}_1} = 300\ \mathrm{GeV}$

Varying $M_{\tilde{N}_1}$,



The Rest of the Event

We have been focusing on the lepton jets, but there's typically more going on in these events.

- Showering produces soft photons which can decay to pairs of isolated and soft leptons.

- Depending on the SM LSP, decay into the dark sector can be accompanied by the production of hard SM states.

  For example,

$$\begin{aligned} \tilde{l}^{\pm} &\rightarrow l^{\pm} + LJ \\ \tilde{W}^{\pm} &\rightarrow W^{\pm} + LJ \\ \tilde{q} &\rightarrow j + LJ \end{aligned}$$

- SM SUSY cascades.

These additional states complicate the events but can be triggered on.

SM Background and Detector Effects

As a next step, it is important to study the SM backgrounds that slip through this lepton jet definition.

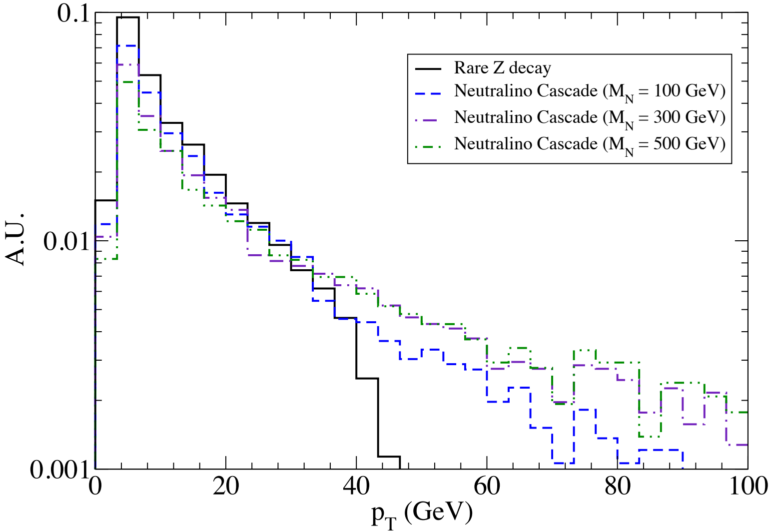
Such a study should include detector simulation.

- QCD jets that fake lepton jets
- Off-shell photons and photon conversion
- J/ψ decays

Additional cuts will probably be required.

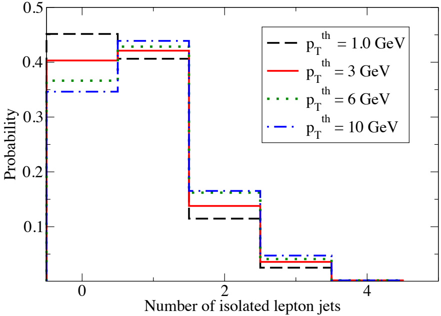
Backup Slides:

Radiation p_T

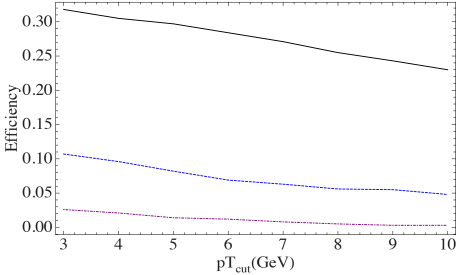


Varying the Lepton Jet Definition

Lowering the isolation requirement,

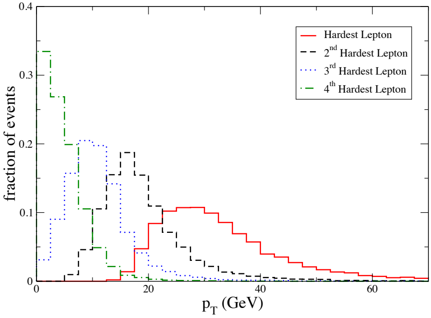


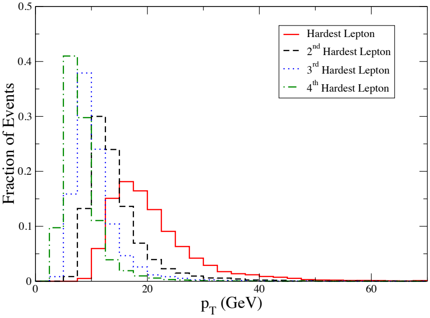
Lowering the p_T requirement of the second hardest lepton,



Individual Lepton p_T's

The spread in lepton p_T's should allow them to be differentiated.

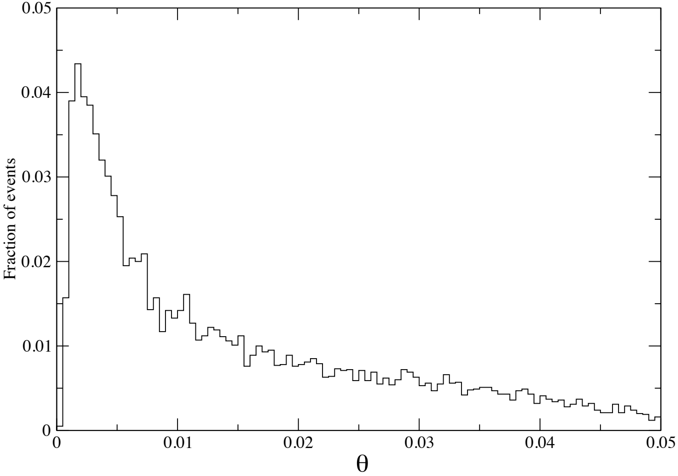




Events resulting from prompt b_μ production with $p_T > 50\ \mathrm{GeV}$.

Lepton Opening Angle

Maximum opening angle in lepton jets with 4 leptons, $\theta \sim m_b/p_T$.



Lepton Jet Edges

The $\tilde{N}_1$ mass can be determined by measuring lepton jet edges.