Hidden Sectors and Dark Forces

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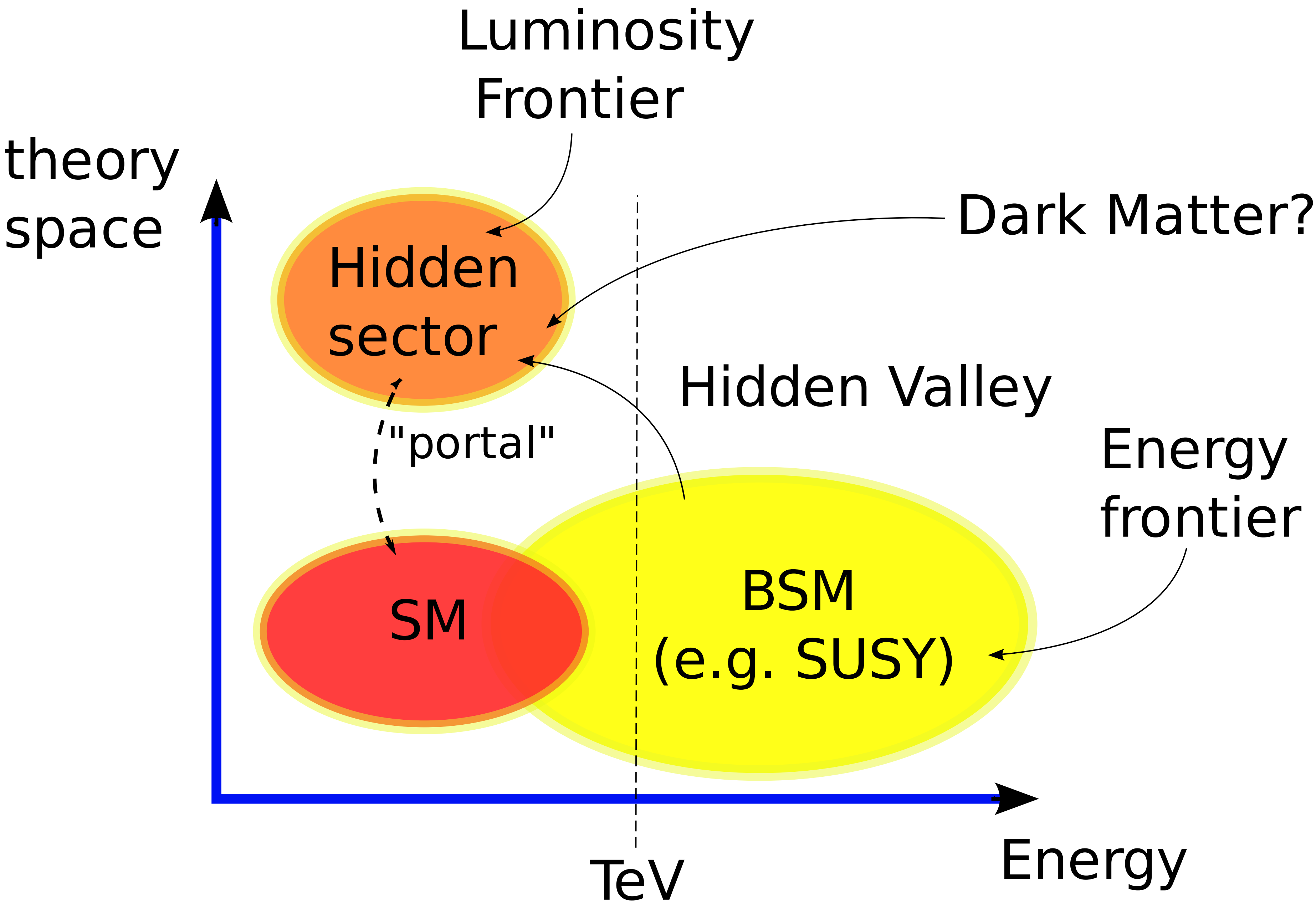
International Workshop on Linear Colliders 2010

Plan

- Hidden sectors and portals
- Dark Matter
- Dark Forces
- Hidden sectors at high-energy colliders
- Implications for linear collider


Luminosity
Frontier
theory
space
Hidden
sector
Dark Matter?
Hidden Valley
"portal"
Energy
frontier
SM
BSM
(e.g. SUSY)
TeV
Energy

e.g. the Standard Model

- L, e_R, H singlets under $SU(3)_c$
- e_R, q_R singlets under $SU(2)_L$
- N singlets under $SU(3)_c \times SU(2)_L \times U(1)_Y$

Hidden sector a generic possibility for new physics!

Hide and Seek

How to find the hidden sector:

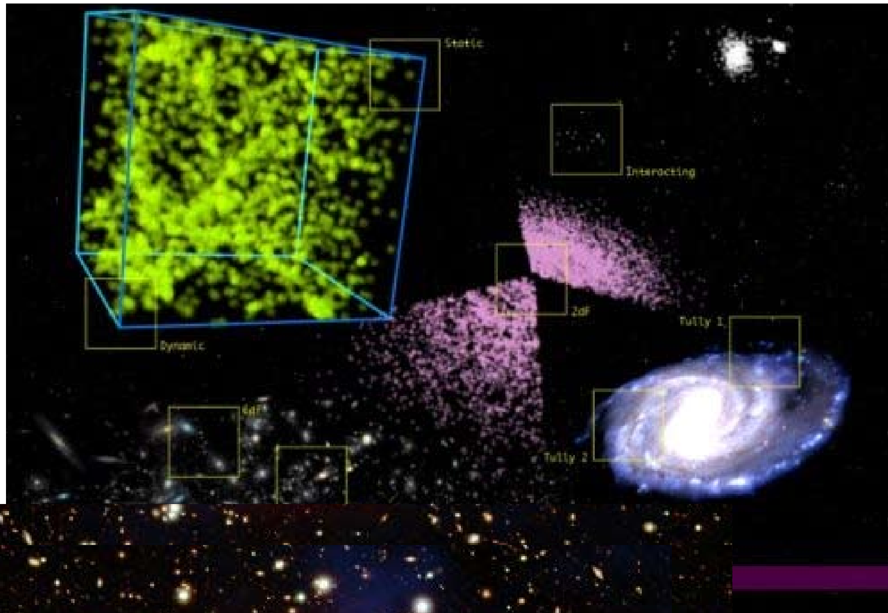
- 'Connector' - particle charged under both sectors
- Higher dimensional operator
- "Portal" - renormalizable, gauge invariant operator to connect SM and hidden sector

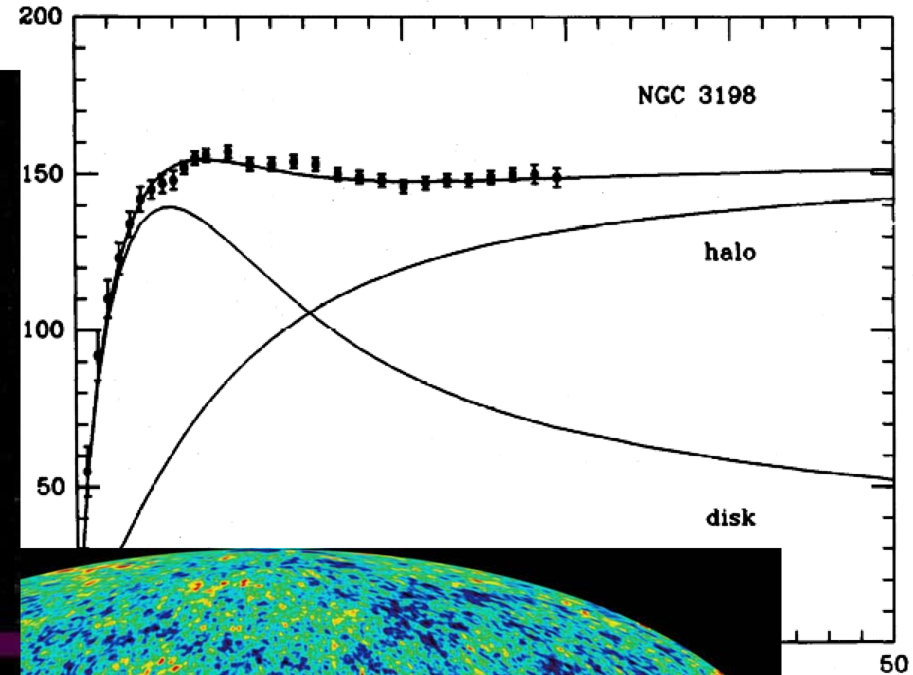
$$B_{\mu\nu} V^{\mu\nu} \qquad \text{U(1) portal (dim = 2)}, \qquad \text{Holdom '86}$$

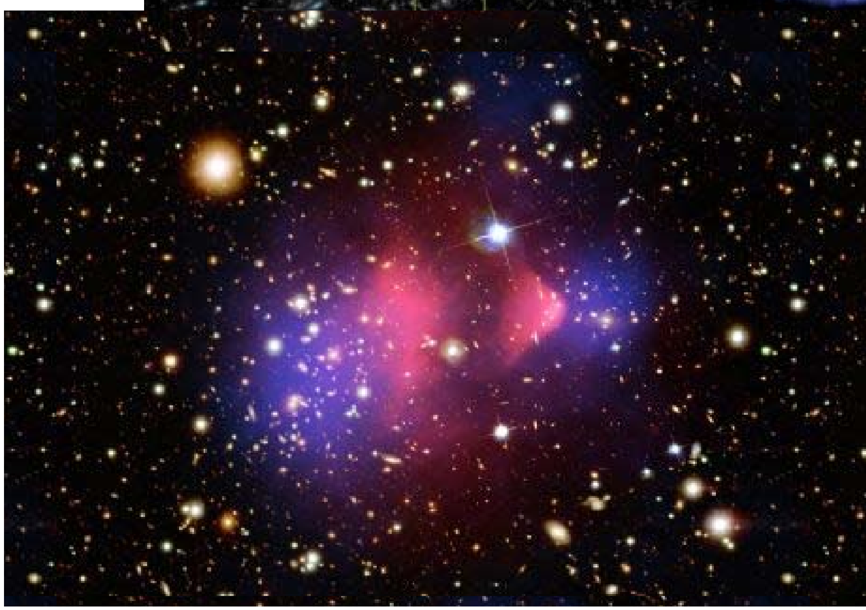
$$H^\dagger H (AS + BS^2) \qquad \text{Higgs portal (dim = 2)},$$

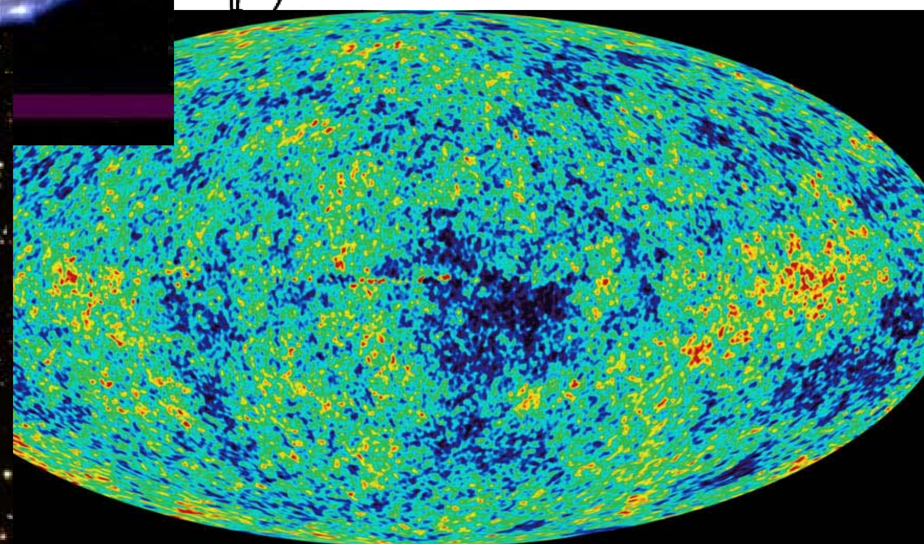
$$LHN \qquad \text{Neutrino portal (dim = 5/2)},$$

Dark Matter









Canonical Dark Matter (WIMP) assumptions:

- Single new elementary particle
- Mass $\sim$ weak scale
- Weakly interacting
- Thermal Relic
- Neutral under color and electromagnetism
- Stable

Canonical Dark Matter (WIMP) assumptions:

-
-
-
-
- Neutral under color, electromagnetism $\Longrightarrow$ either:
  - DM in $SU(2)_L \times U(1)_Y$ multiplet (such that $Q_{EM} = 0$)
  - DM in the hidden sector
-

Secluded Dark Matter

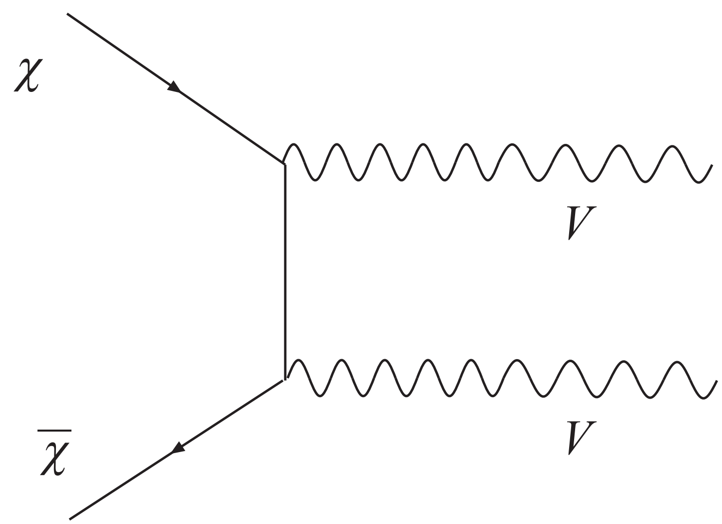
Pospelov, Ritz, Voloshin '07

- Dark Matter is a SM gauge singlet
- Talks to SM through mediator

Example model: dark matter via kinetic mixing

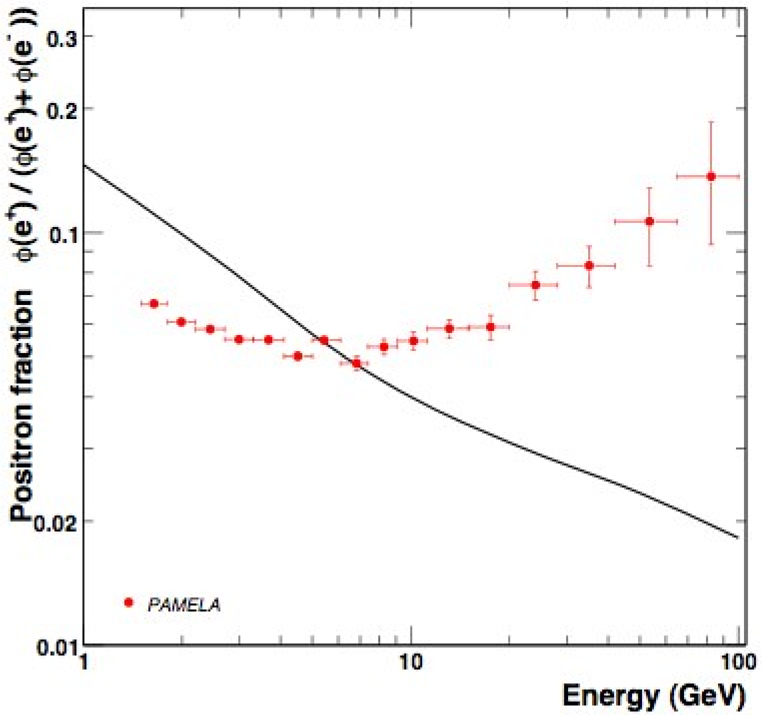
$$\mathcal{L} = i\overline{\chi}\gamma^{\mu}(\partial_{\mu} - ig_D V_{\mu})\chi - \frac{\kappa}{2}V_{\mu\nu}B^{\mu\nu} + \ldots$$

- Annihilation of dark matter into mediators: $\overline{\chi}\chi \to VV$
- Relic abundance independent of WIMP-SM coupling
- Connection between $\langle\sigma v\rangle_{ann}$ and σ_{nuc}, $\sigma_{pp\to\chi\chi}$ broken

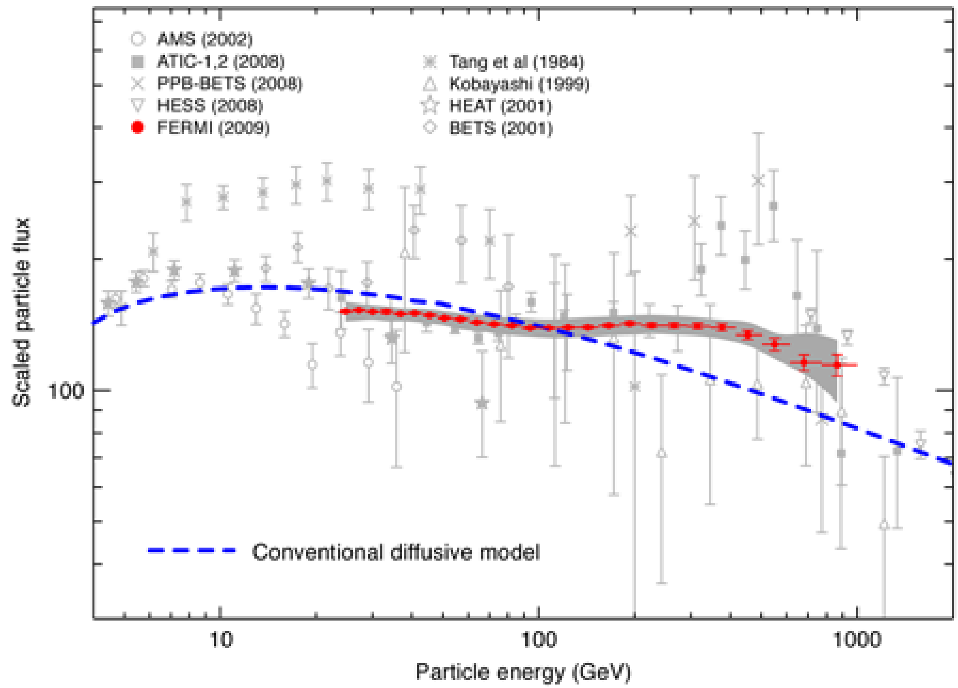


Are cosmic rays hinting at a dark sector?

PAMELA



FERMI



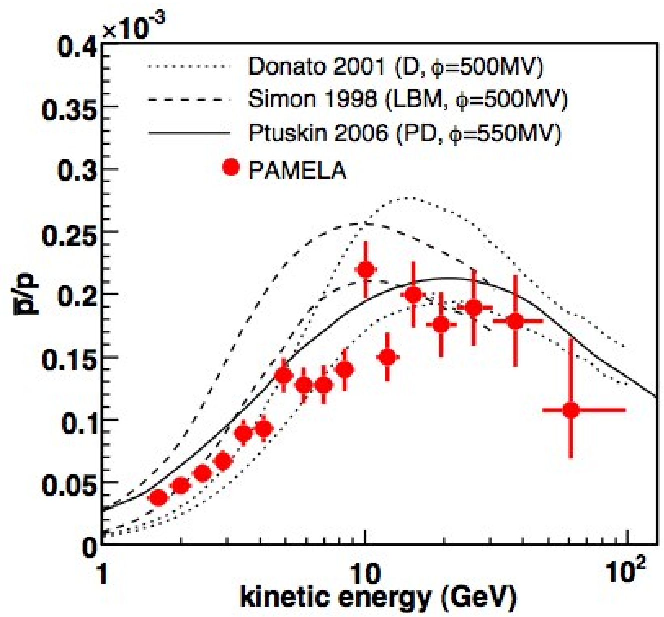
Dark matter annihilation? $\chi\overline{\chi} \rightarrow \text{leptons}$

Require:

- Large galactic annihilation cross section:

$$\frac{\langle \sigma v \rangle_{\text{halo}}}{\langle \sigma v \rangle_{\text{freeze-out}}} \sim 10 - 1000$$

- No excess hadrons

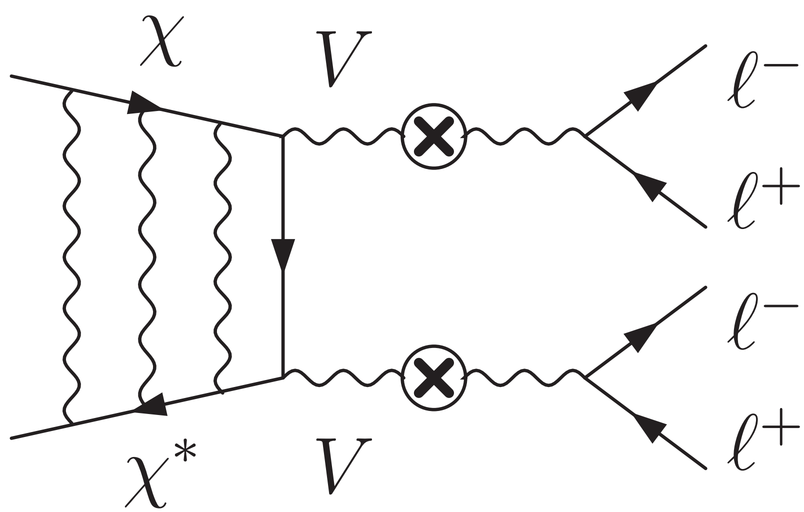


GeV-scale 'Dark' force

Arkani-Hamed, Finkbeiner, Slatyer, Weiner '08

Pospelov, Ritz '08

- Long range attractive force enhances $\langle \sigma v \rangle_{\rm halo}$
- Annihilation products cannot decay to anti-protons by kinematics



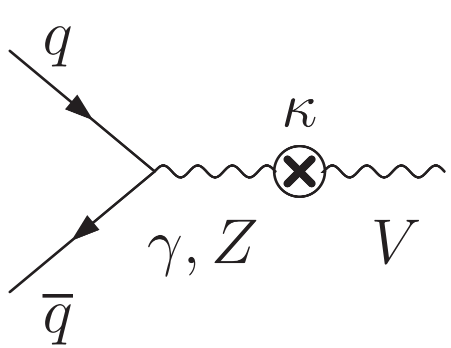
Hidden sectors at high-energy colliders

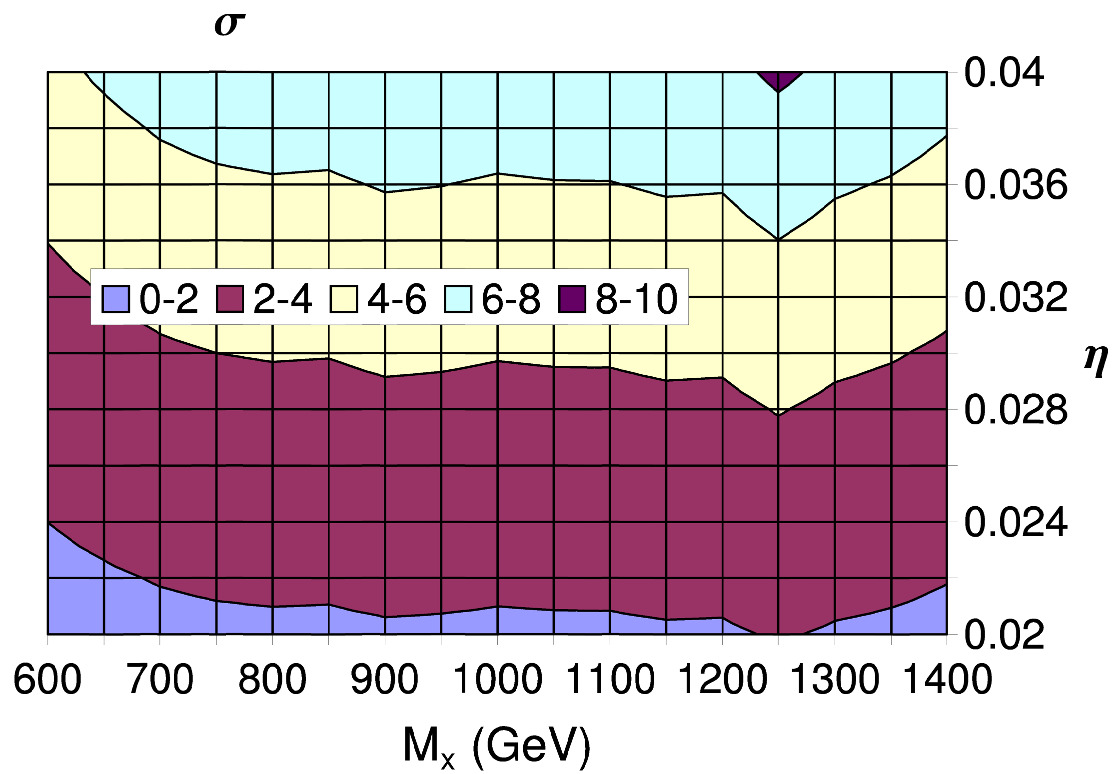
$$\mathcal{L} \supset \kappa \mathcal{O}_{SM} \mathcal{O}_{HS}$$

- Direct production $\Longrightarrow$ pay κ^2
- Decays
  - Rare decays of broad states $\Longrightarrow$ pay κ^2
  - Decays of would-be narrow or stable states $\Longrightarrow$ free

Direct production of hidden sector states

$$\mathcal{L} \supset -\frac{\kappa}{2} B_{\mu\nu} V^{\mu\nu}$$





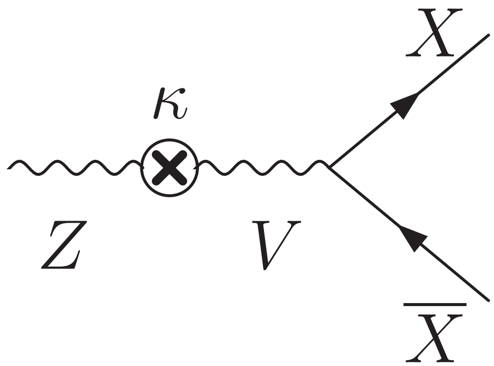
LHC reach - 100 fb^{-1}

Kumar, Wells '06

Pay κ^2 in production

Rare decays into hidden sector

$$\mathcal{L} \supset i\overline{X}\gamma^\mu(\partial_\mu - ie'V_\mu)X - \frac{\kappa}{2}B_{\mu\nu}V^{\mu\nu}$$



$$Br(Z \to X\overline{X}) \sim \frac{\kappa^2 \times 50\text{MeV}}{2.5\text{GeV} + \kappa^2 \times 50\text{MeV}}$$

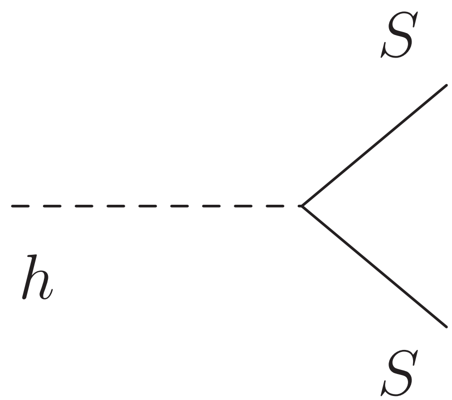
$$= 0.02\kappa^2$$

Pay κ^2 in rare decay

Decays of would-be narrow states

e.g. Higgs portal

$$\mathcal{L} \supset \lambda H^\dagger H S^2$$

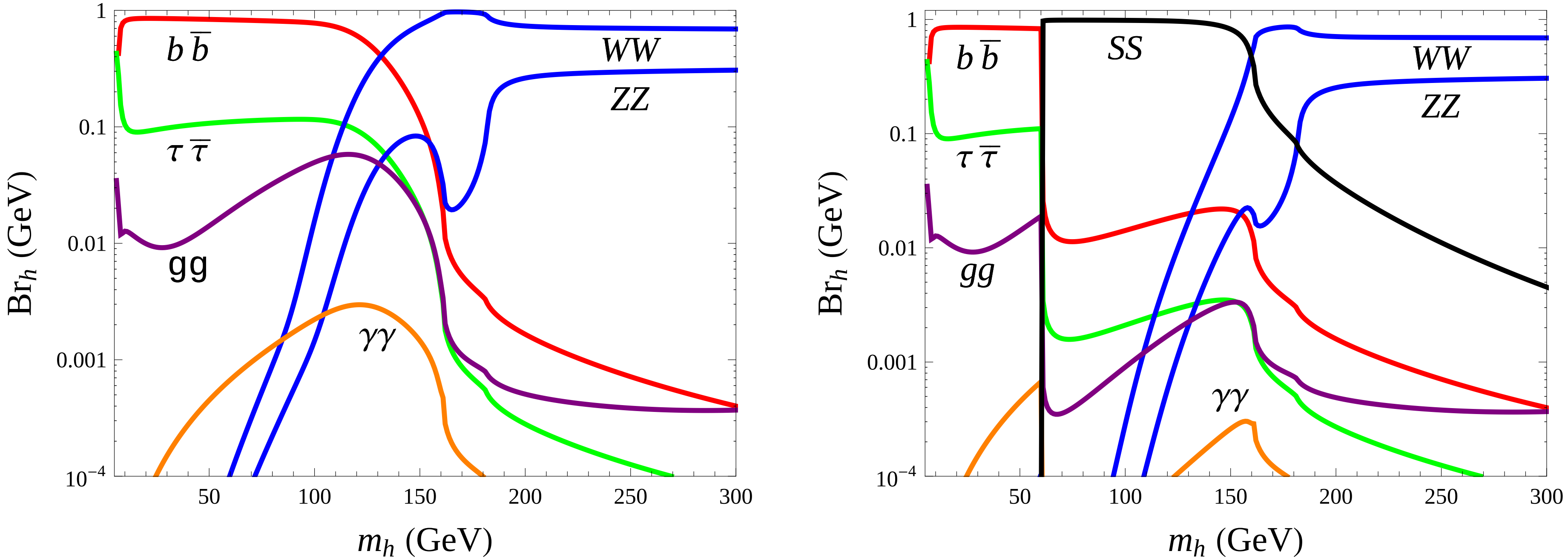


$$Br(h \to SS) \;\sim\; \frac{\lambda^2 \times \mathcal{O}(10\mathrm{GeV})}{y_b^2 \times \mathcal{O}(10\mathrm{GeV}) + \lambda^2 \times \mathcal{O}(10\mathrm{GeV})}$$

$$\sim\; \mathcal{O}(1) \quad \text{for} \quad \lambda > y_b$$

Free

Higgs Branchings: $m_S = 30$ GeV, $\lambda_2 \sim 3y_b$



Signature of Higgs depends on decays of S ...

Exotic Higgs Decays:

- $h \to SS \to$ missing energy

Silveira, Zee '85

- $h \to aa \to 4b, 4c, 4\tau \ldots 4\gamma$

Dobrescu, Landsberg, Matchev '01

Dermisek, Gunion '04

Chang, Fox, Weiner '05

- $h \to VV \to 4l$

Gopalakrishna, Jung, Wells '08

- $h \to \eta\eta \to 4g, 4c$

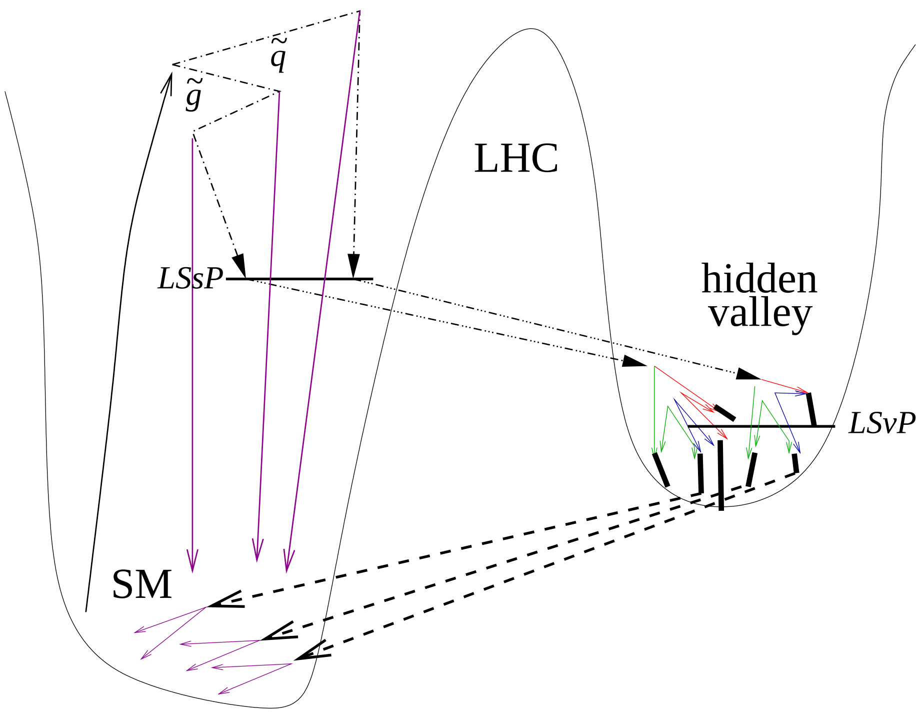
Bellazzini, Csaki, Falkowski, Weiler '01

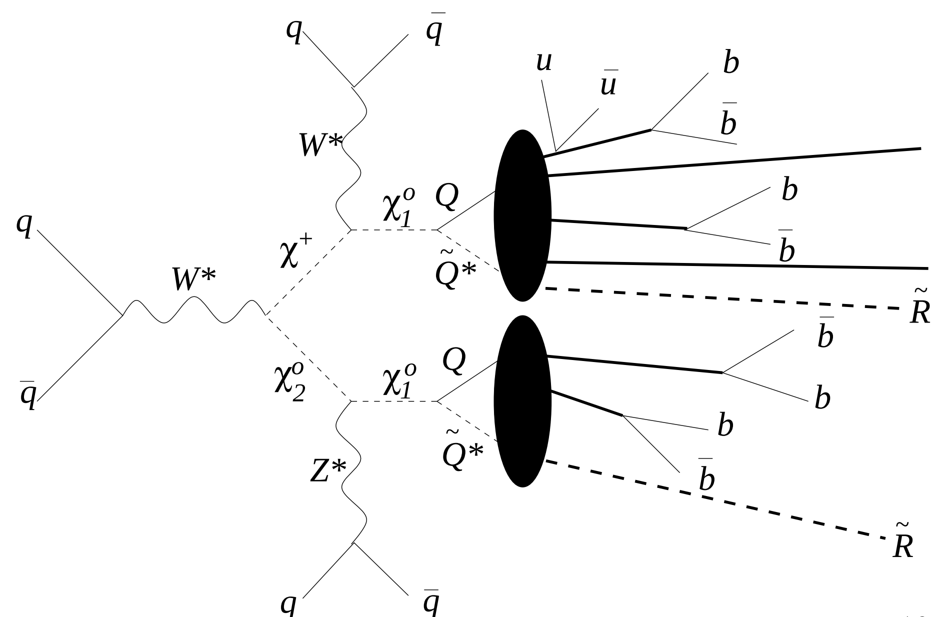
and so on . . .

Decays of would-be stable states

Hidden valley vis LSP: Strassler '06

- Already need at least one HS for SUSY breaking
- Lightest R-parity odd particle could be in the hidden sector

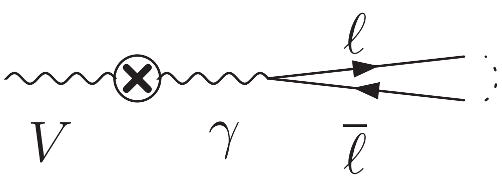




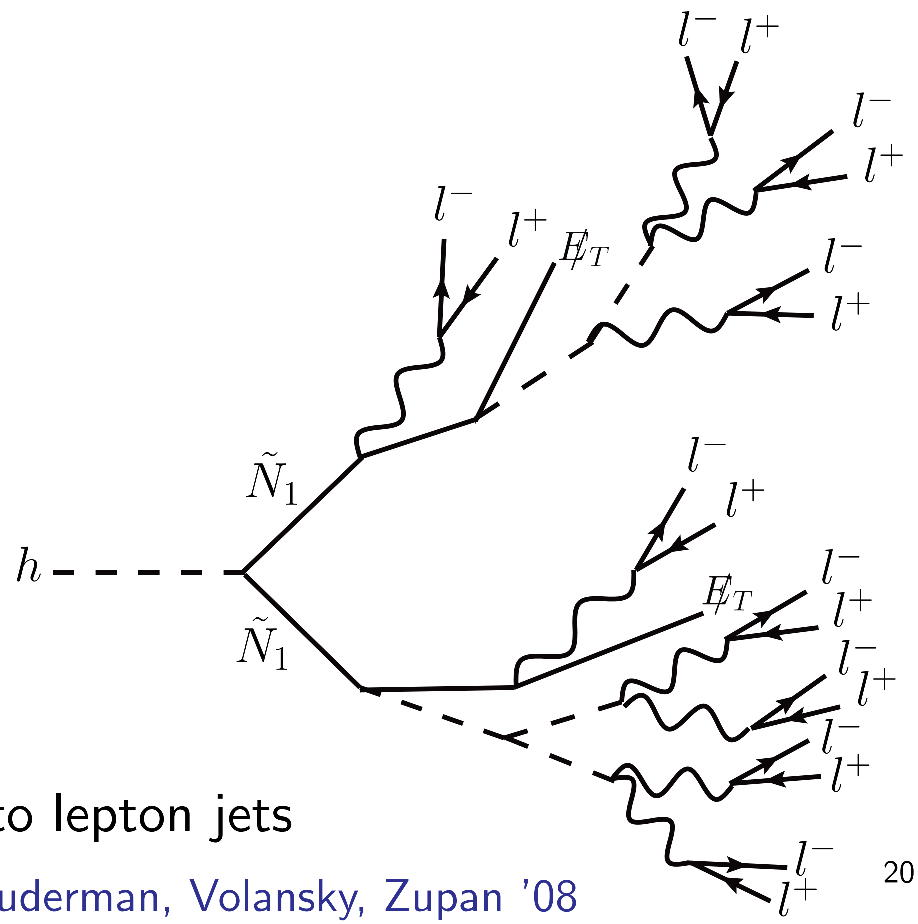
'Lepton Jets' at Colliders

Arkani-Hamed, Weiner '08
Cheung, Ruderman, Wang, Yavin '09

- Heavy state (Higgs, LSP) decays into (sub) GeV dark states
- Dark states highly boosted
- Cascade back to highly collimated leptons



$\theta \sim m_V/E_V < 0.1$



e.g. Higgs to lepton jets

Falkowski, Ruderman, Volansky, Zupan '08

Possible bridges to the hidden sector

- W, Z
- Higgs
- LSP, LKP, LTP, ...
- Z'
- Techni-ρ
- RS Gravitons

Bunk, Hubisz '10

and so on

If there is a hidden sector ...

- What states? How many?
- How do we know these states are SM gauge singlets?
- Masses/spins of states
- Symmetries of the hidden sector (maybe even new organizing principles!)
- How does it talk to SM; What portal? What mediator?

LHC - ILC/CLIC interplay

- Obvious: Discovery (energy reach, larger cross sections) vs. precision (mass, spin measurements)

- Data Acquisition/Trigger:
  - An issue at LHC; e.g. 40 MHZ $\rightarrow$ 100 HZ; might miss long lived states/soft states.
  - Less of a challenge at ILC: event rate smaller, though more information in each event.

- LHC might provide guidance:
  - Energy scale of 'Bridge' to Hidden sector (light LSP, or heavy Z'?)

- Discovery of HS may only be possible at ILC
  - e.g. If Higgs has $rare$ decays into a HS, will not be seen at LHC

Linear collider to do list

- Relatively few studies for linear collider - see e.g. Espinosa, Gunion hep-ph/9807275; Kumar, Wells hep-ph/0606183

- Benchmark scenarios/models? See http://www.physics.rutgers.edu/ strassler/hv/bench

  – Criteria - minimality? signatures? other motivations (e.g. Dark matter, SUSY)?

- Mass/spin determination could be qualitatively different; higher multiplicity, final states soft; less MET

- Complementarity of linear collider with other experimental programs:

  – LHC; Dark matter experiments; Intensity-frontier experiments;

Summary

- Hidden sector generic possibility for BSM physics
- Motivated by dark matter
- Despite being “hidden” still hopeful for colliders
- Lots of work to do for ILC/CLIC!