Supersymmetric Kinetic Mixing at High and Low Energies

arXiv: 1112.2705, 1206.xxxx

Yuk Fung Chan[1] Matt Low[2]
David Morrissey[3] Andrew Spray[3]

[1]Program in Applied and Computational Mathematics, Princeton University

[2]Enrico Fermi Institute, University of Chicago

[3]Theory Group, TRIUMF

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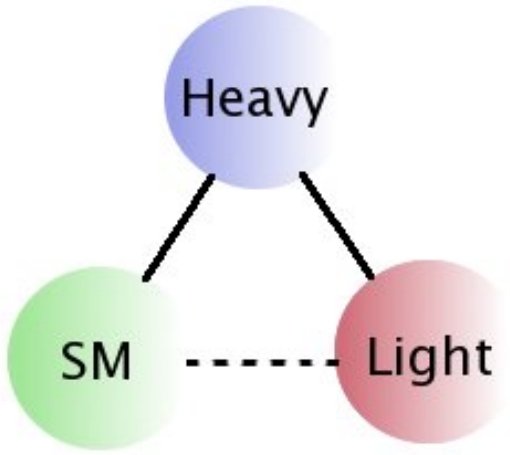
Motivation: Light Sectors and Supersymmetry

Model: A Minimal Hidden Extension of the MSSM

High Energies: the LHC

Low Energies: the CHARM Beam Dump

Hidden Valleys



Hidden Valley comprises:

- New Heavy sector
- New Light sector
- Feeble SM-Light coupling

Supersymmetric Hidden Sectors:

- Superpartners are Heavy
- Natural hierarchy of scales
- Extend SUSY phenomenology
- Expected from GUTs?

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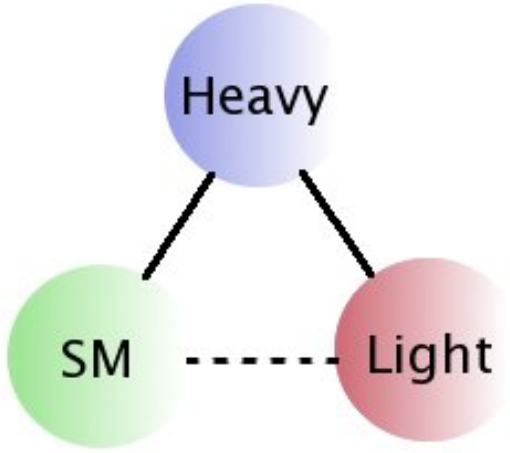

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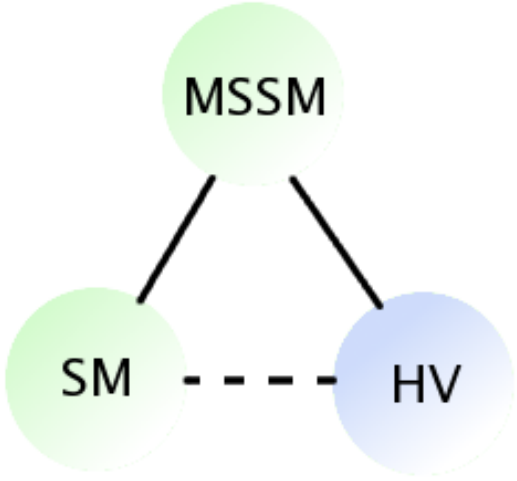
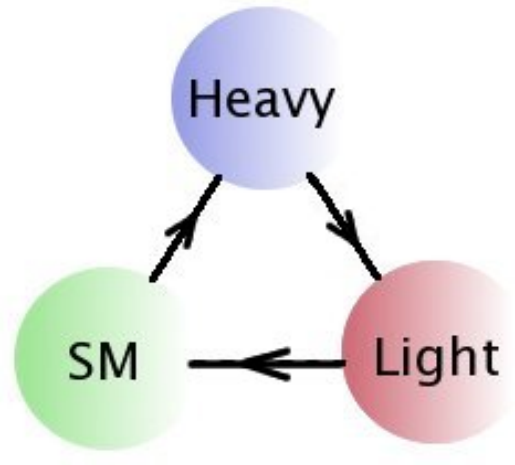


Hidden Sector Phenomenology

High Energy:

- Decay of Heavy $\Rightarrow$ Light Sector
  - *e.g.* Decay of would-be LSP
  - R-hadrons, CHAMPs . . .
- Decay of Light Sector $\Rightarrow$ SM
  - Boosted: Lepton Jets
  - Long-lived: Displaced Vertices



Low Energy:

- Feeble SM–Light Sector coupling
  $\Rightarrow$ Luminosity Frontier
- *e.g.* Beam dump experiments

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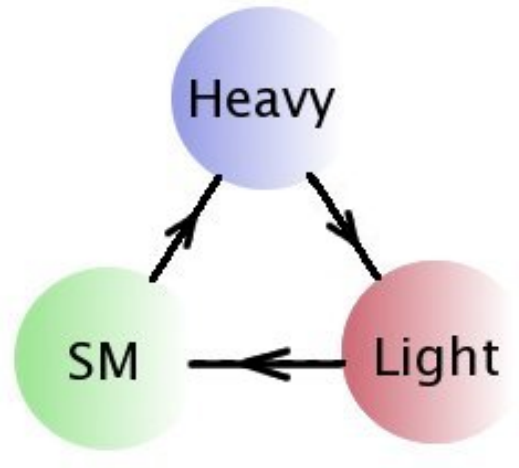

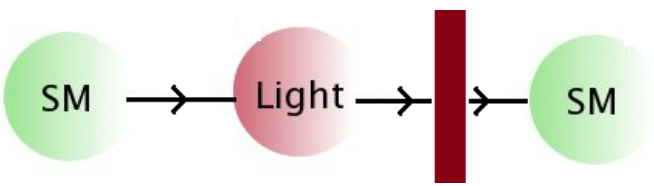

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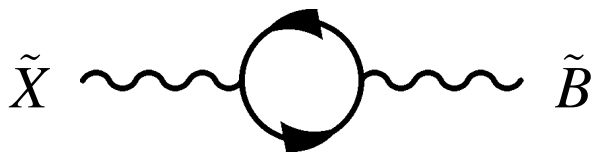
A Minimal Hidden Sector

Philosophy more Bottom-Up than Top-Down

Extend MSSM with Hidden Sector:

- Vector Superfield X
- Two Higgses (anomalies) H, H'
- Kinetic mixing with hypercharge:



$$\mathcal{L} \supset \frac{\epsilon}{2} \int \mathrm{d}^2\theta \, X^\alpha B_\alpha$$

$\langle H, H' \rangle \sim 1$ GeV $\Rightarrow$ scalars, fermions mix;

One vector X_μ; Three real scalars h_1^x, h_2^x, A^x; Three Majorana fermions $\chi_1^x, \chi_2^x, \chi_3^x$.

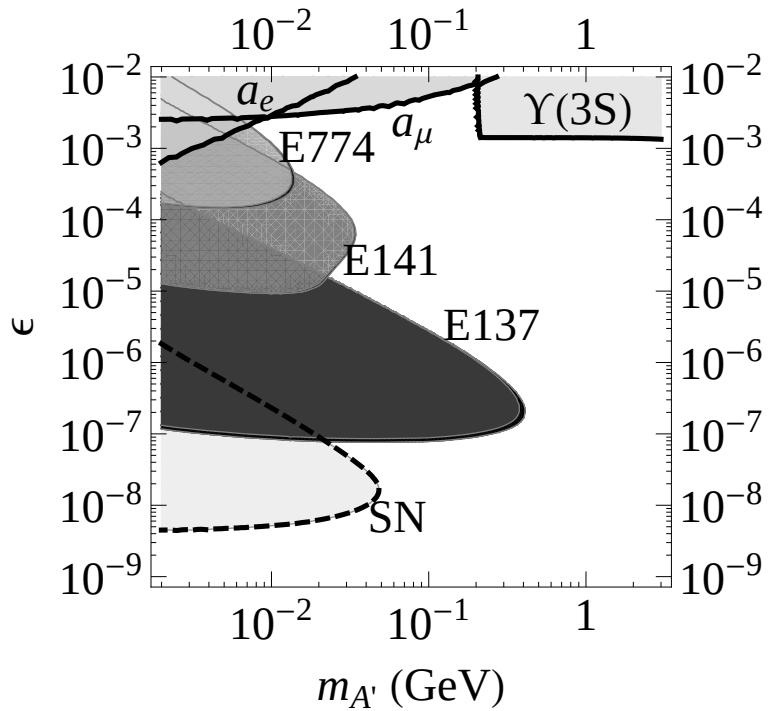
Kinetic Mixing I: Vectors

$$\mathcal{L} \supset -\frac{1}{4}B^{\mu\nu}B_{\mu\nu} - \frac{1}{4}X^{\mu\nu}X_{\mu\nu} - \frac{\epsilon}{2}X^{\mu\nu}B_{\mu\nu}$$

- Rotate to diagonal basis:

$$X_\mu \to X_\mu + \epsilon \sin\theta_W Z_\mu;$$
$$Z_\mu \to Z_\mu;$$
$$A_\mu \to A_\mu - \epsilon \cos\theta_W X_\mu$$

- X_μ couples to charge
- Primary decay channel to SM
- Low-energy production channel



[0906.0580, Bjorken, Essig, Schuster, Toro]

Kinetic Mixing II: Gauginos

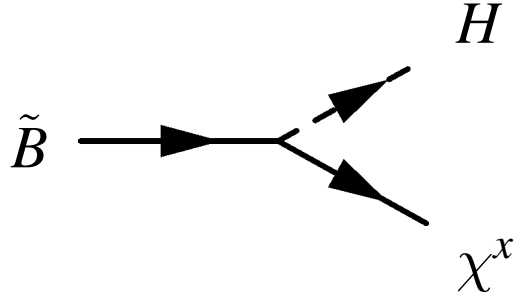
$$\mathcal{L} \supset i\tilde{B}^\dagger \bar{\sigma} \cdot \partial \tilde{B} + i\tilde{X}^\dagger \bar{\sigma} \cdot \partial \tilde{X} + \frac{i}{2}\epsilon \tilde{B}^\dagger \bar{\sigma} \cdot \partial \tilde{X} + \frac{i}{2}\epsilon \tilde{X}^\dagger \bar{\sigma} \cdot \partial \tilde{B}$$

- Rotate to diagonal basis:

$$\tilde{X} \to \tilde{X} - \epsilon \tilde{B}$$
$$\tilde{B} \to \tilde{B}$$

- MSSM can decay to light sector
- Would-be LSP is unstable
- True LSP in hidden sector

$$g_x H^* \tilde{X} \tilde{H} \Rightarrow g_x \epsilon H^* \tilde{B} \tilde{H}$$



Hidden sector boost

$$\gamma \sim \frac{m_{\tilde{B}}}{2m_x} \sim 10 - 100$$

Kinetic Mixing III: D Terms

- Vector superfield D-terms:

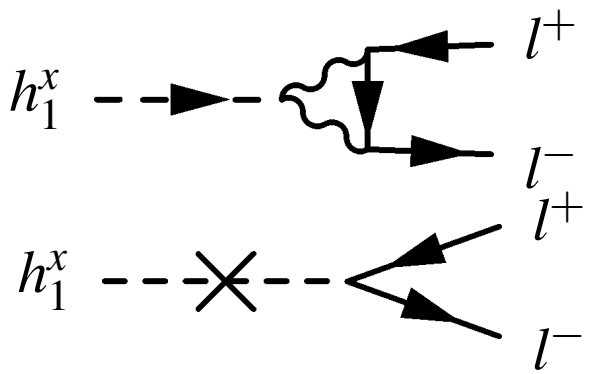
$$\mathcal{L} \supset \frac{1}{2} D_B^2 + \frac{1}{2} D_X^2 + \epsilon D_B D_X$$

- Leads to mixing in scalar potential:

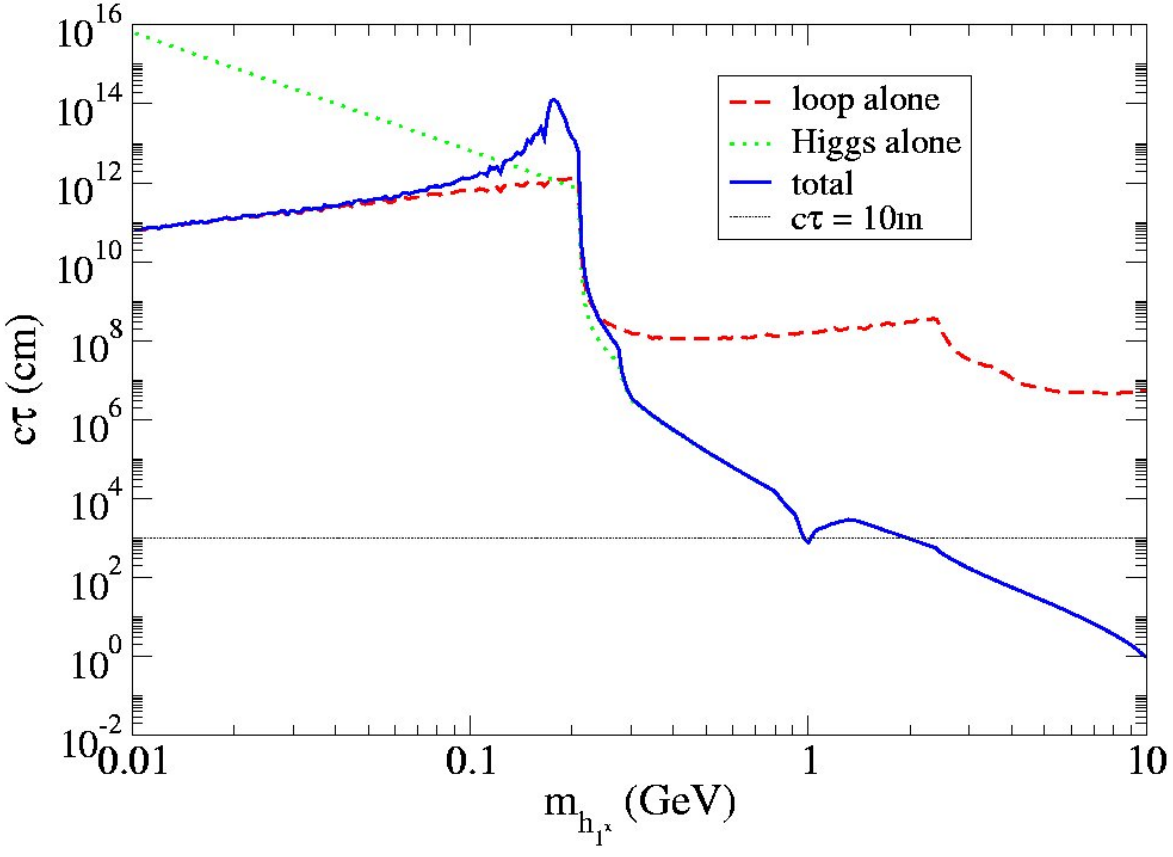
$$V \supset \epsilon g_x g_y (|H_u|^2 - |H_d|^2)(|H|^2 - |H'|^2)$$
$$\to \epsilon m_x m_Z \mathcal{R} h^0 h_1^x + \epsilon m_x m_Z \mathcal{S} h^0 h_2^x$$

- $\mathcal{R}$, $\mathcal{S}$ order-one mixing matrices

- New decay diagram for Higgses
- Relevant when h_1^x lighter than X_μ
  Always true for our model



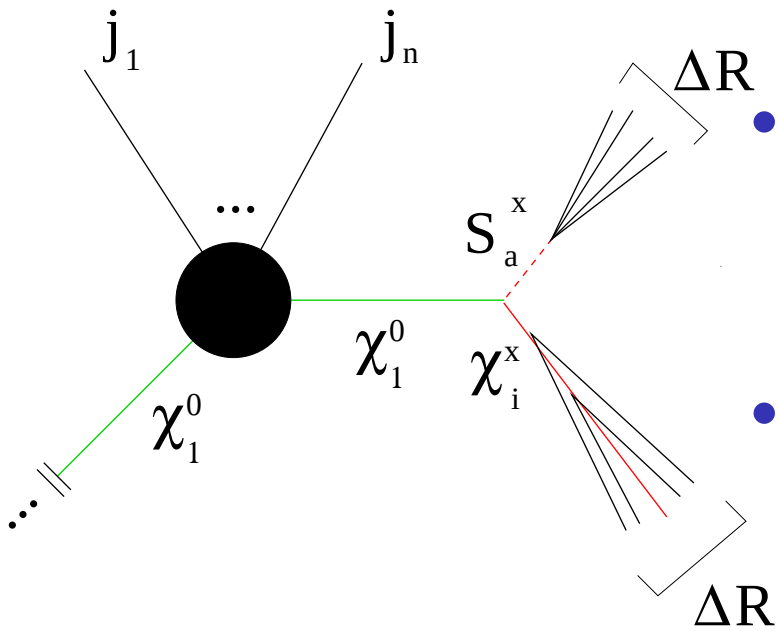
Hidden Higgs Decay Width



- Higgs mixing contribution dominant for $m \gtrsim 0.2$ GeV
- Scalar still long-lived at colliders

Phenomenology Overview

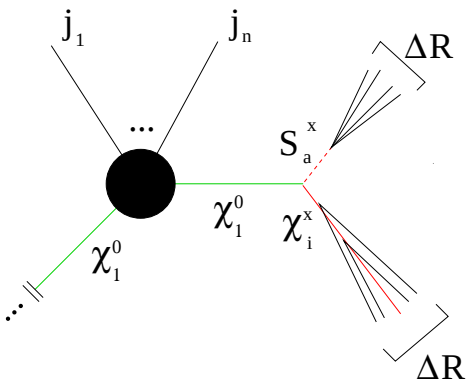
- Event = MSSM Cascade $\oplus$ Hidden Cascade
- MSSM as usual till would-be LSP (which need not be Bino)



- Hidden states decay to:
  - SM through vector;
  - Collider stable particle (χ_1^x, h_1^x)
- Lepton Jets:
  - Hidden states boosted
  - Decays collimated, $\Delta R \lesssim 0.1$
  - High fraction of leptons
- Displaced vertices:
  - Long lived states
  - *e.g* Degenerate Higgsinos
- 0 – 4 such objects per event

Parameter Scan I: Set Up

- Seven hidden parameters
- Scanned over 20 000 points:
- Classification:

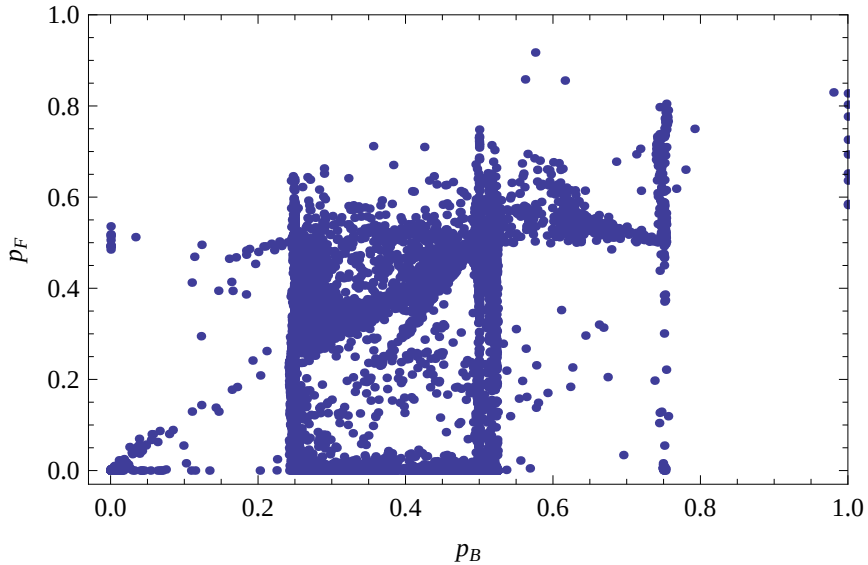


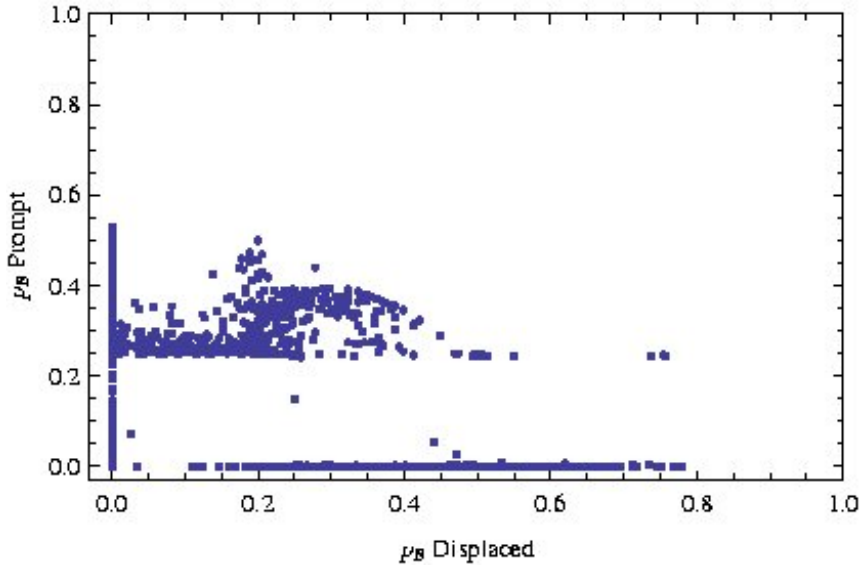
Parameter	Range
g_x	0.3
ϵ	10^{-3}
m_x	0.1–10 GeV
m_{A^x}	0.1–10 GeV
$\tan\zeta$	0.1–10
μ'	$\pm$0.1–10 GeV
M_X	0.1–10 GeV

$$P_B = \sum \chi_1^0 \to S^x \to \text{SM} \qquad P_F = \sum \chi_1^0 \to \chi^x \to \text{SM}$$

Similarly define $P_{B,F}^{disp}$, $P_{B,F}^{prom}$

Parameter Scan II: Results

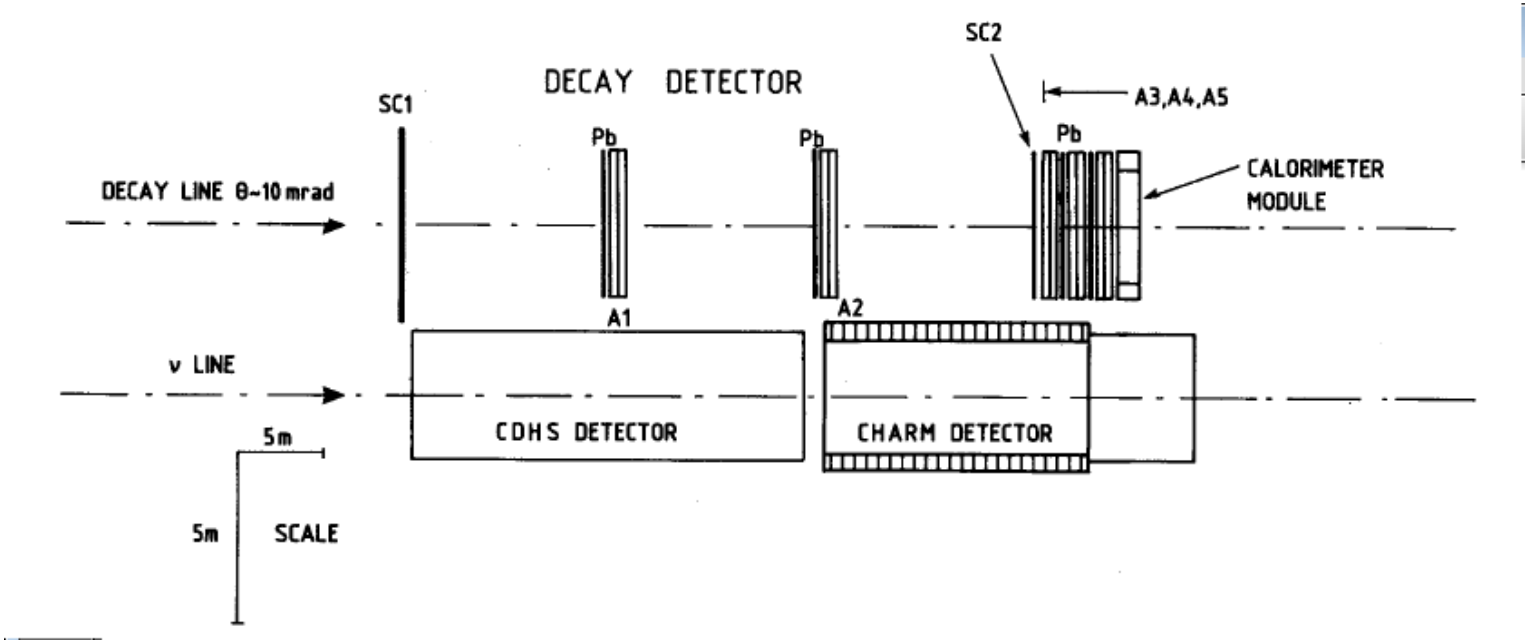




- Structure determined by spectrum (decay kinematics):
  - $P_B \Rightarrow$ how many hidden bosons decay to SM
  - $P_F \Rightarrow$ heavy or light Higgsinos
  - Displaced vertices $\Rightarrow$ On- or Off-shell decays
- Note $\sim 7\,000$ points at (0, 0)

The CHARM Experiment

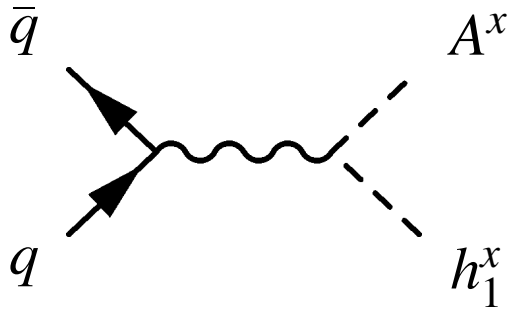
- 1985 Axion search at CERN (SpS) [Phys.Lett.B157 (1985) 458]
- Beam dump: $\sim 10^{18}$ 400 GeV protons, Copper target



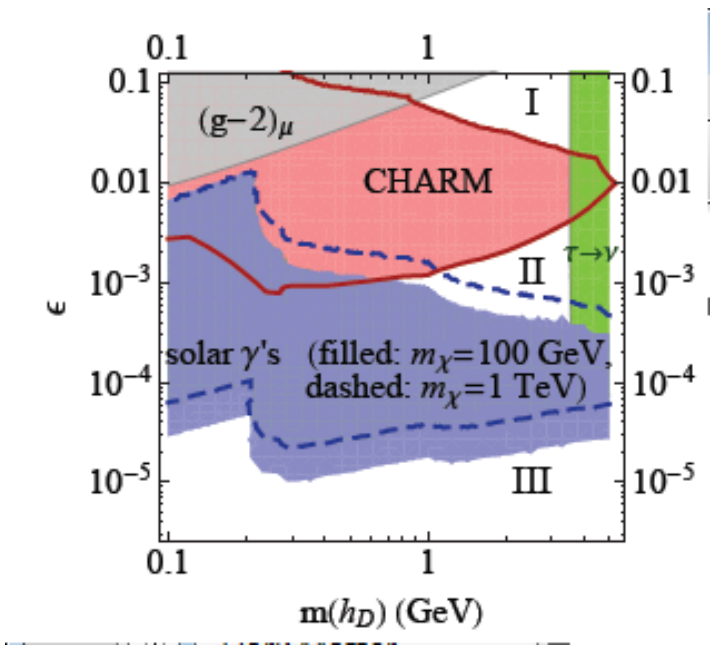
- SC2 Signal detector
- SC1 Veto
- $\sqrt{s} \sim 28$ GeV beats other beam-dump experiments

Low Energy Constraints

- Production via s-channel vector
- Look for decay of long-lived hidden states (h_1^x, χ_2^x, A^x)



- Previous work: See Right
- Assumed loop Higgs decay (not SUSY)
- Different width $\Rightarrow$ Different limits
- Generically true for beam dumps; CHARM just most constraining



[0910.1602, Schuster, Toro, Yavin]

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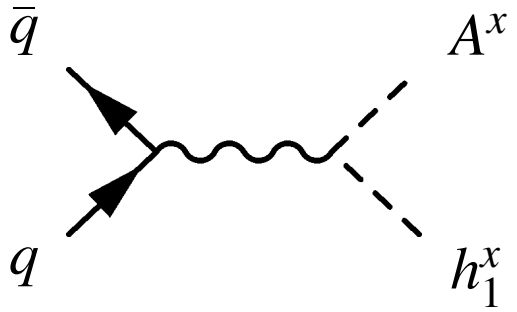

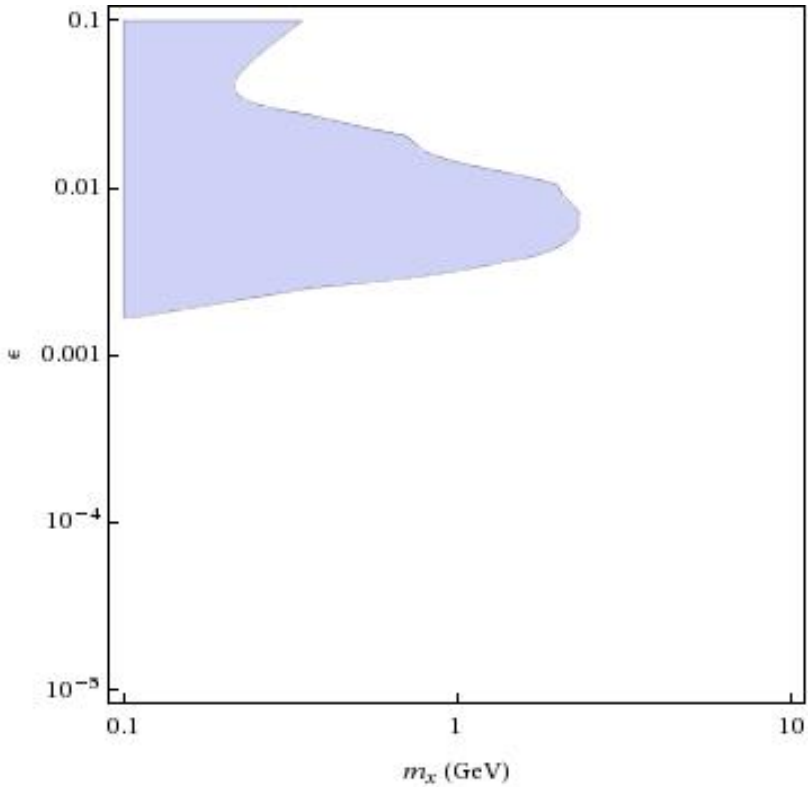

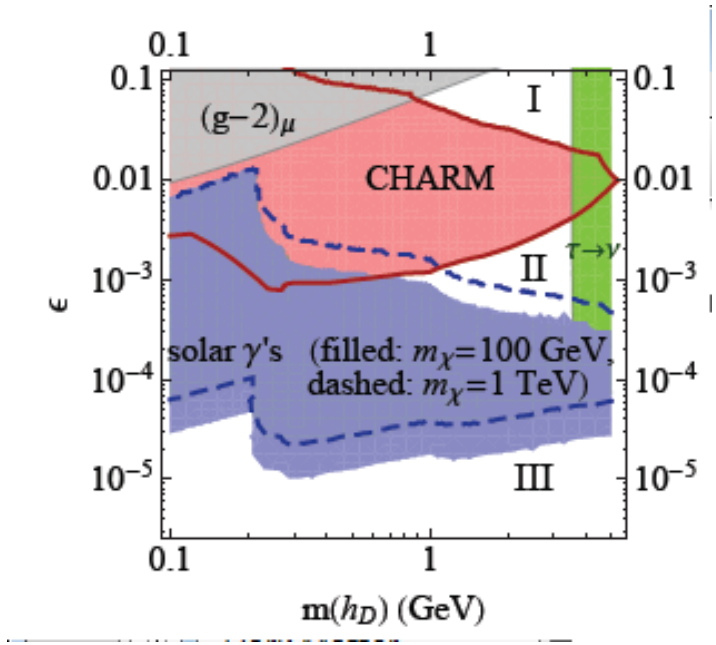

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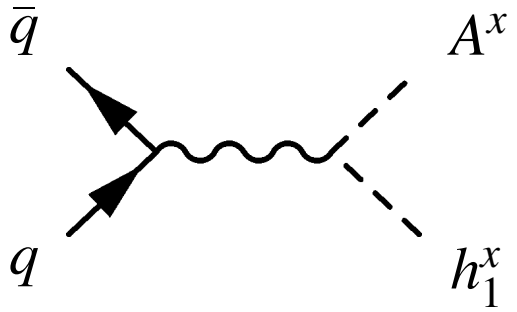

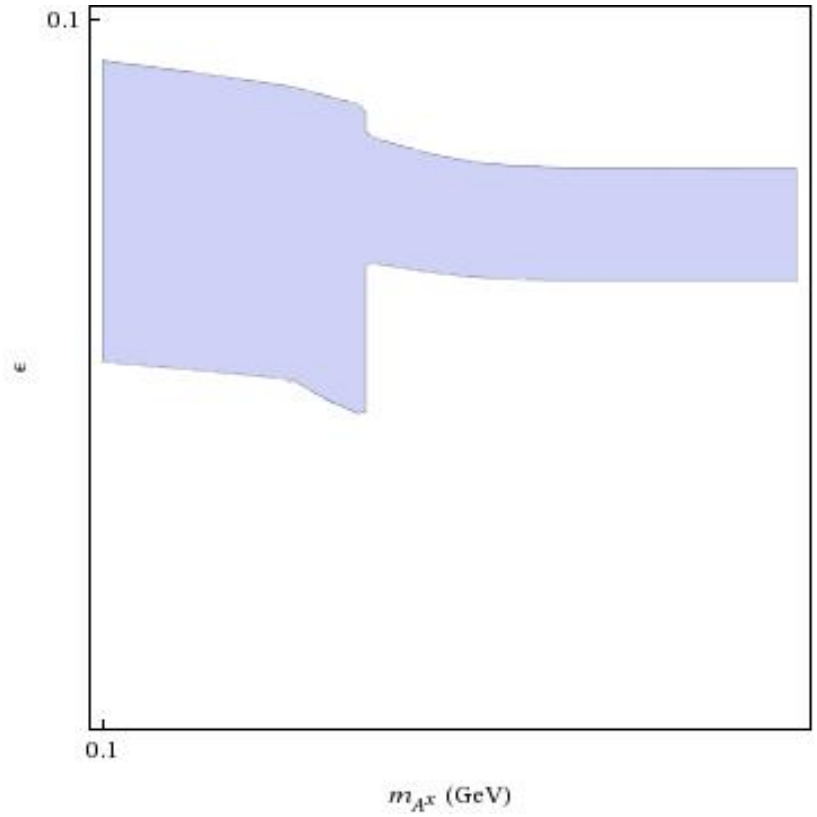

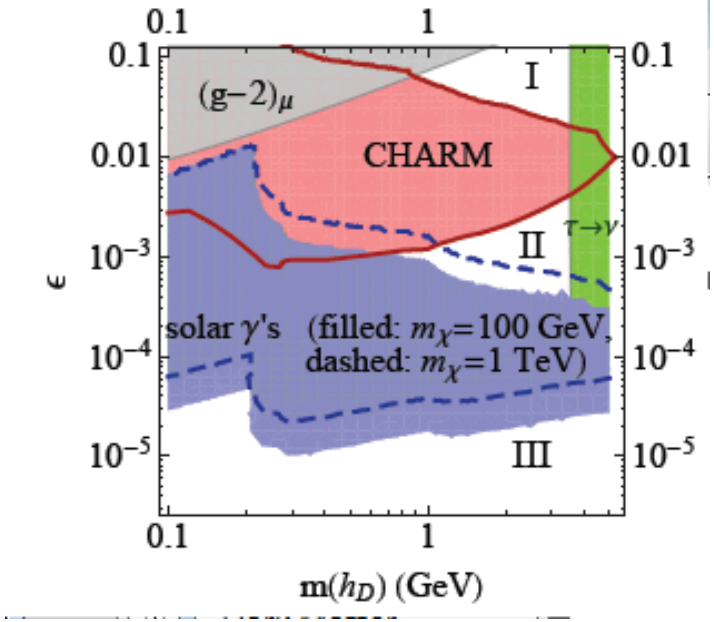

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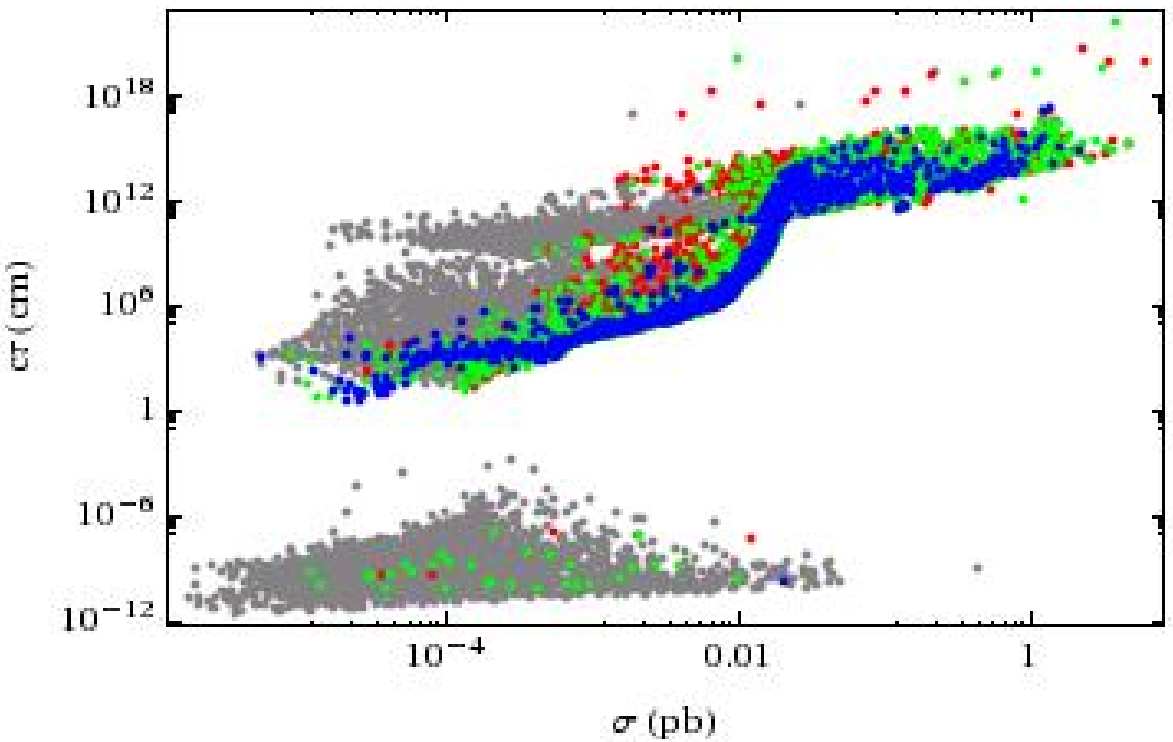
Relating Low and High Energies

- CHARM/LHC signals both depend on hidden cascades
- Correlations between experiments:
  - Collider-stable $h_1^x, \chi_2^x \Rightarrow$ visible at CHARM
  - High P_B, $P_F \Rightarrow$ unconstrained at low energies
- Currently using scan to explore these relations



Conclusions

1. Supersymmetric Vector Kinetic Portal implies Higgs Portal
2. Correlations between LHC and Low Energy Phenomena
3. LHC behaviour explored with Parameter Scan
4. Scan being used to Investigate low energies