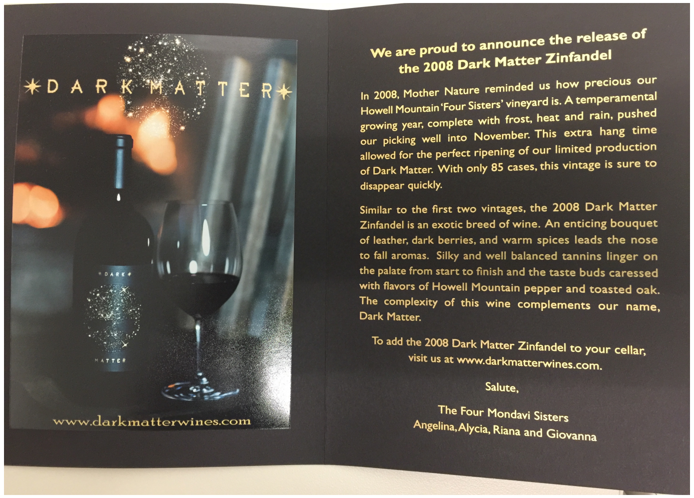
Extra Dimensions Are Dark



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Talk Outline :

1) Quick review of the 4-D 'dark photon' model & kinetic mixing

2) Kinetic mixing in 5-D & implications

3) The Complex Scalar (vev = 0) DM Model

4) Short look at other scenarios

5) Summary & Conclusions

~~The Dark Side of The Force~~ → The Force of the Dark Side

To Begin: A Lightening 'Dark Photon' Model Review

A new $U(1)_D$, not coupled to the SM, kinetically mixes with hypercharge field

$$\mathcal{L} \subset -\frac{1}{4}\,\hat{B}_{\mu\nu}\,\hat{B}^{\mu\nu} - \frac{1}{4}\,\hat{Z}_{D\mu\nu}\,\hat{Z}_D^{\mu\nu} + \frac{1}{2}\,\frac{\epsilon}{\cos\theta}\,\hat{Z}_{D\mu\nu}\,\hat{B}^{\mu\nu} + \frac{1}{2}\,m_{D,0}^2\,\hat{Z}_D^{\mu}\,\hat{Z}_{D\mu}$$

1412.0018

w/ the symmetry broken by the vev of a Dark (SM singlet) Higgs boson S:

$$V_0(H,S) = -\mu^2|H|^2 + \lambda|H|^4 - \mu_S^2|S|^2 + \lambda_S|S|^4 + \kappa|S|^2|H|^2$$

..to which we add a DM field via a L_{DM} (as yet unspecified).

1: Make linear transformation to bring L to canonical form

→ 2: Diagonalize H-induced mass-mixing between Z & V (aka Z_D)

3: 'Light' (~100 MeV) V couples to ~eεQ, hence, a Dark Photon

DM Properties: anything goes BUT s-wave annihilation

LIU, SLATYER, and ZAVALA **CMB limits** PHYSICAL REVIEW D **94,** 063507 (2016)

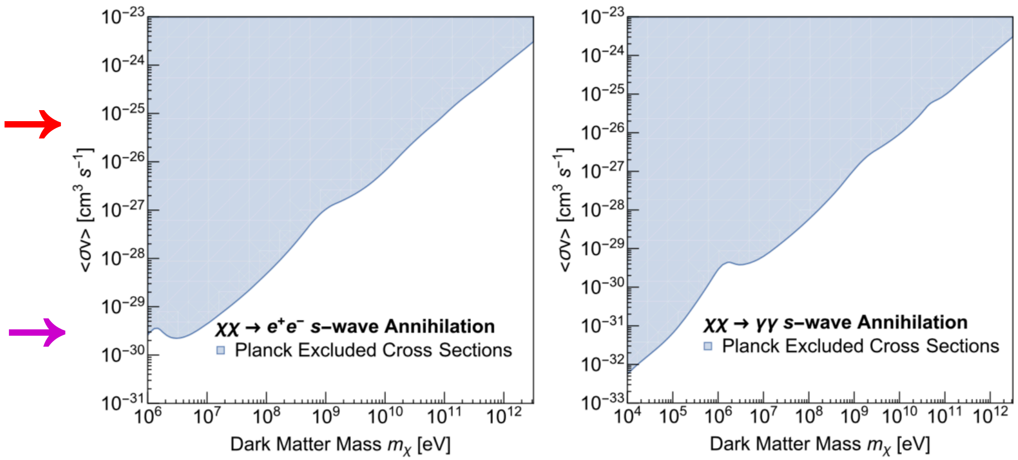


FIG. 1. The 95% excluded cross section based on Planck's upper limit given by Eq. (8) for (left) $\chi\chi \to e^+e^-$ and (right) $\chi\chi \to \gamma\gamma$ s-wave annihilation.

..otherwise $\sigma v_{FO} \approx \sigma v_{CMB}$!

→ DM is NOT Dirac

→ $m_{DM} < m_V$

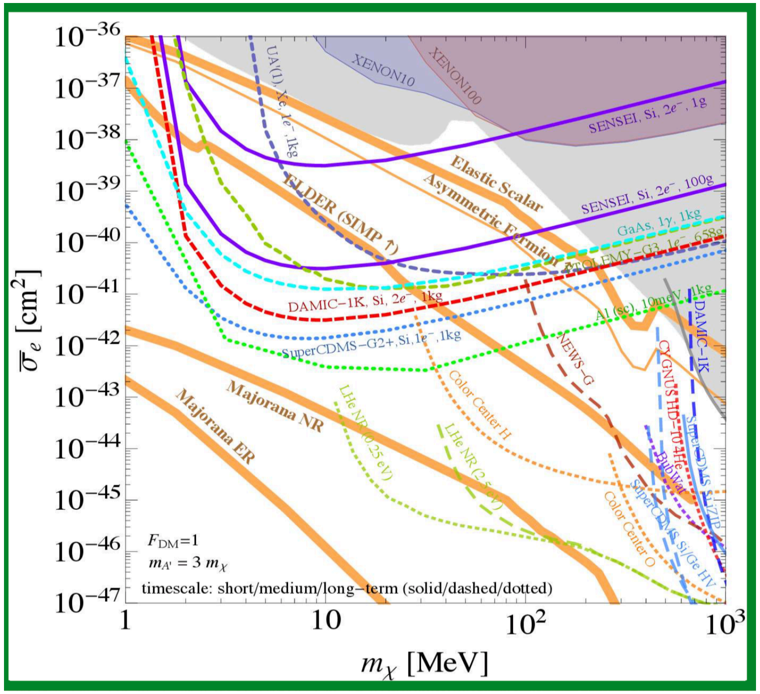
→ No ID signal today!

Schuster & Toro ↓

Model	Mass terms	J_D^μ	scattering $\mathcal{M} \propto$	scattering $\sigma \propto$	Annilhilation $\sigma v \propto$	CMB-viable?	Model
Fermion DM – Direct Annihilation							
Majorana	$\not{U}(1)_D$	$\bar{\Psi}\gamma^\mu\gamma_5\Psi$	$\vec{\sigma}\cdot\vec{v}$	v^2	p-wave $\propto v^2$	Y	3
Dirac	$U(1)_D$-inv.	$\bar{\Psi}\gamma^\mu\Psi$	1	1	s-wave $\propto v^0$	N	X
Pseudo-Dirac	$U(1)_D$-inv. & $\not{U}(1)_D$	$\bar{\Psi}_L\gamma^\mu\Psi_H$	1 (inelastic)	kin. forbidden [a]	kin. forbidden	Y	3
Scalar DM – Direct Annihilation							
Complex	$U(1)_D$-inv.	$\phi^*\partial^\mu\phi - \phi\partial^\mu\phi^*$	1	1	p-wave $\propto v^2$	Y	1
Pseudo-complex	$U(1)_D$-inv. & $\not{U}(1)_D$	$\phi_L\partial^\mu\phi_H - \phi_H\partial^\mu\phi_L$	v^2 (inelastic)	kin. forbidden	kin. forbidden [b]	Y	2

· If $m_V > 2m_{DM}$ then V → DM .. otherwise V → e^+e^- etc.

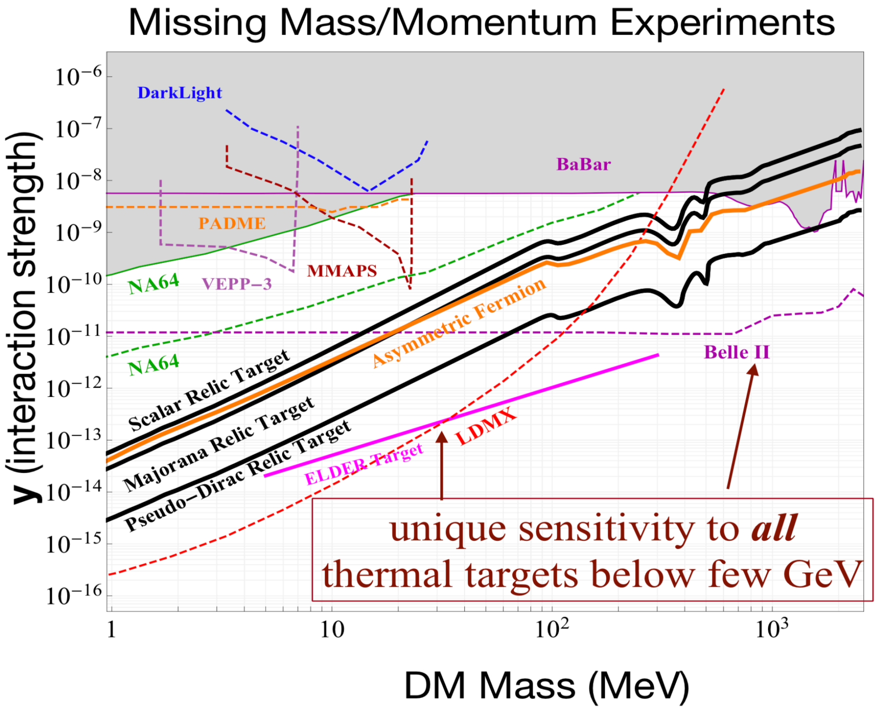
Queue the plots…

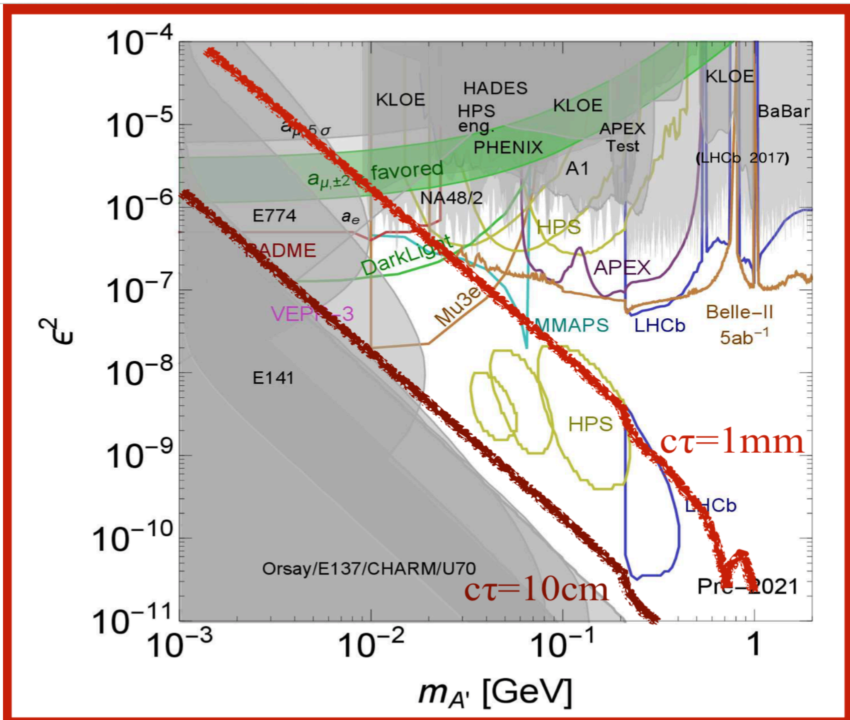


Lots of work by <u>many</u> people..

→ ε ≲10^{-3} & m_{DM} ~ m_V needed

m_{DM} & m_V are not necessarily related by the model..





Some possible(??) issues…

1: Why is $m_{DM} \sim m_V$? These are generally uncorrelated…

2: How do we prevent the Higgs portal (via κ) from acting or even dominating? No symmetry can forbid a coupling of S to the SM Higgs

3: Can we provide a more complete framework for the DM model?

4: etc. etc. …

· How do we generalize the model to address (some of) these ??

Let's have some fun by extending this model to EDs !

Setup :

- One, flat ED as an interval, bounded at either end by a brane. This is not an orbifold! R^{-1}~10-10^3 MeV similar to the ADD model w/ n=6,7

- SM fields are localized on one of the 4-D branes while the DM & the mediator 'Dark Fields' can freely roam the 5-D bulk

- Ignore gravity as in UED

Relevant part of 5-D gauge action

$$S = \int d^4x \int_{y_1}^{y_2} dy \left[-\frac{1}{4}\hat{V}_{AB}\hat{V}^{AB} \left(-\frac{1}{4}\hat{B}_{\mu\nu}\hat{B}^{\mu\nu} + \frac{\epsilon_5}{2c_w}\hat{V}_{\mu\nu}\hat{B}^{\mu\nu} + L_{SM} \right) \delta(y - y_{SM}) \right]$$

Note: KM takes place on the SM brane between brane-localized hypercharge field B and dark bulk field V

- KM now involves an infinite tower of KK modes of the Dark gauge field, V, determined by their wavefunctions evaluated on the SM brane → 1st problem = 'control' KK expansion :

$$\int_{y_1}^{y_2} dy \; \frac{\epsilon_5}{2c_w}\hat{V}_{\mu\nu}\hat{B}^{\mu\nu}\delta(y-y_{SM})$$ insert KK expansion $$\hat{V}^A(x,y) = \sum f_n(y)\hat{V}_n^A(x)$$

→ $$\epsilon_n = \epsilon_5 f_n(y_{SM})$$ thus → $$\sum_n \frac{\epsilon_n}{2c_w}\hat{V}_n^{\mu\nu}\hat{B}_{\mu\nu}$$ Infinite sum!

Linear transformation to bring 4-D Lagrangian into canonical form → $\hat{B} = B + \sum_n \alpha_n V_n$, etc.

Introduce for convenience $s_n = \sin\theta_n = -\epsilon_n/c_w$

→ Goal: find the α_n etc. in terms of the set of s_i/ϵ_i

Define the sums: $\Sigma_i = (1 - \sum_{a=1}^{i} s_a^2)^{1/2}$; then

→ $\alpha_1 = -s_1/(\Sigma_1\Sigma_0)$, $\alpha_2 = -s_2/(\Sigma_2\Sigma_1)$ ... $\alpha_n = -s_n/(\Sigma_n\Sigma_{n-1})$

These sums must converge or a canonical basis won't exist !

$$\Sigma_n^2 = 1 - \frac{\epsilon_1^2}{c_w^2}\sum_{a=1}^{n}\frac{\epsilon_a^2}{\epsilon_1^2}$$

(n → ∞)

→ The ε's must shrink with increasing n ..they can't be n-independent!

This imposes a non-trivial constraint on the eigenfunctions $f_n(y)$ independent of the nature of the DM -- as does the by-parts integration requirement on applied BCs w/o orbifiolding

$$f_m \partial_y f_n |_{y_1}^{y_2} = 0$$

· Next: all the V_i couple to hypercharge & so will mix with the Z & each other via the Higgs vev producing an ∞ x ∞ matrix

$$\mathcal{M}^2 = \begin{pmatrix} M_Z^2 & -t_w\epsilon_1 M_Z^2 & -t_w\epsilon_2 M_Z^2 & \dots \\ -t_w\epsilon_1 M_Z^2 & M_1^2 + t_w^2\epsilon_1^2 M_Z^2 & t_w^2\epsilon_1\epsilon_2 M_Z^2 & \dots. \\ -t_w\epsilon_2 M_Z^2 & t_w^2\epsilon_1\epsilon_2 M_Z^2 & M_2^2 + t_w^2\epsilon_2^2 M_Z^2 & \dots. \\ \dots & \dots & \dots & \dots \end{pmatrix} .$$

M_i determined by KK (model dependent !) eigenvalue equation

Small ε's → we can diagonalize employing a PT expansion…

$$V_i \rightarrow V_i + t_w \frac{\epsilon_i M_Z^2}{M_i^2 - M_Z^2} Z$$

$$Z \rightarrow Z - t_w \sum_i \frac{\epsilon_i M_i^2}{M_i^2 - M_Z^2} V_i ,$$

$$M_i^2 \rightarrow M_i^2 \left[1 + \frac{t_w^2 \epsilon_i^2 M_Z^2}{M_i^2 - M_Z^2}\right]$$

$$M_Z^2 \rightarrow M_Z^2 \left[1 - t_w^2 M_Z^2 \sum_n \frac{\epsilon_n^2}{M_n^2 - M_Z^2} + (t_w^2 M_Z^2)^2 \sum_{n,m} \frac{\epsilon_n^2 \epsilon_m^2 M_n^2}{(M_n^2 - M_Z^2)^2 (M_m^2 - M_Z^2)}\right]$$

The mass eigenvalues then shift too

The physical V_i then couple to

$$\frac{g}{c_w} t_w \epsilon_i \left[T_{3L} \frac{M_i^2}{M_Z^2 - M_i^2} + Q \frac{c_w^2 M_Z^2 - M_i^2}{M_Z^2 - M_i^2}\right] ;$$

For $M_i \rightarrow 0$ this is $e\varepsilon_i Q$ ... For $M_i \rightarrow \infty$ this is $g'\varepsilon_i Y$

There is also a shift in the SM Z couplings:

$$\frac{e}{s_w c_w}\left[(1+F)T_{3L} - (s_w^2 + F)Q\right], \quad \text{where} \quad F = \sum_i \frac{(t_w \epsilon_i)^2 M_Z^2}{M_Z^2 - M_i^2}$$

Which results in non-zero oblique parameters:

$$\left\{ \begin{array}{rcl} T & = & \frac{2F}{\alpha_w} \\ S & = & \frac{4c_w^2 F}{\alpha_w} \\ U & = & 0\,, \end{array} \right. \quad \leq \text{ ~0.05}$$

...& other couplings are induced & to LO are given by

$$K_{HZV_i} = \frac{2M_Z^2}{v_H}\left[\frac{t_w \epsilon_i M_i^2}{M_Z^2 - M_i^2}\right] \qquad K_{HV_iV_j} \simeq \frac{2M_Z^2}{v_H}\left[\frac{t_w \epsilon_i M_i^2}{M_Z^2 - M_i^2}\right]\left[i \to j\right]$$

All this happens before any introduction of the specific DM model !

DM Models:

You saw these already in the Table above but here they take on some somewhat different aspects..

- Complex scalar w/ no vev: DM is lightest state in complex scalar KK tower. No bulk Higgs field needed! ‘Simplest’ possibility.

- Complex scalar w/ vev..breaks up into real CP even scalar KK tower (the lightest being DM) + a CP odd field which mixes w/ V_5 to generate the Goldstone’s + a CP-odd KK tower. Very different but more complex

- Majorana/Psuedo Dirac: Most complex w/lots of moving parts.. different still & w/ very interesting phenomenology!

Unfortunately time permits only an examination of the simplest case

Model 1

$$S_{5D} = \int d^4x \int_{y_1}^{y_2} dy \left[-\frac{1}{4} V_{AB} V^{AB} + (D_A S)^\dagger (D^A S) - V(S^\dagger S) \right]$$

$$D_A = \partial_A + i g_{5D} Q_D V_A;$$

S **MUST** be complex to carry a charge (Q_D=1); for simplicity we ignore a possible bulk mass for S. Assume no kinetic or potential terms on either brane for V,S (for now)

· $f_n(y)$ satisfy: $\partial^2_y f_n = -m_n^2 f_n$ so $f_n = A_n \cos m_n y + B_n \sin m_n y$

BUT we must also have: $f_m \partial_y f_n |_{y_1}^{y_2} = 0$ with $y_1=0$ & $y_2=\pi R$

Now imagine taking → which satisfy requirement $\partial_y v_n(\pi R) = v_n(0) = 0$ while $\partial_y s_n(0) = s_n(\pi R) = 0.$

· Then: $m^{V,S}_n = (n+1/2)/R$ V,S form degenerate KK towers

So $v_n \sim \sin x_n y/R$ & $s_n \sim \cos x_n y/R$ with $x_n = n + 1/2.$

→ More interestingly, there are no massless modes! V_5's are the eaten Goldstones. No Dark Higgs w/ vev is needed !

→ Next, this term is ZERO as the s_n vanish on the SM brane. NO symmetry can do this but we can w/ ED BCs !

$$S_{HS} = \int d^4x \int_{y_1}^{y_2} dy \ \lambda_{HS} H^\dagger H S^\dagger S \ \delta(y - y_{SM})$$

→ Trivially, the DM & the Dark Photon (the n=0 modes) have comparable (i.e., the same) masses w/o tuning

There remain, however some phenomenological problems :

→ As is, all the $|\varepsilon_n|$ have the same value X

→ We actually need $m(S_1) < m(V_1)$ but now they're equal X

BLT

· Both problems can be simultaneously solved by adding a common element for both the V & S fields: a Brane Localized Kinetic Term(BLKT) on the brane where the field doesn't already vanish, e.g., for V:

$$\int dy\ \delta(y-y_{SM}) \cdot \delta_A R \cdot \frac{-1}{4} V_{\alpha\beta} V^{\alpha\beta}$$

δ_A is an dimensionless positive semi-definite O(1) parameter

Not too different from the kinetic mixing term.. Similarly a δ_S for S.

The BLKT induces a discontinuity in $\partial_y f$ at the relevant brane:

$$\partial_y f(y_{br}+) - \partial_y f(y_{br}^-) = -\delta_A R\, m_n^2 f(y_{br})$$

modifying the BCs.

This alters: masses, wavefunctions & normalization factors, ie, ε_n's

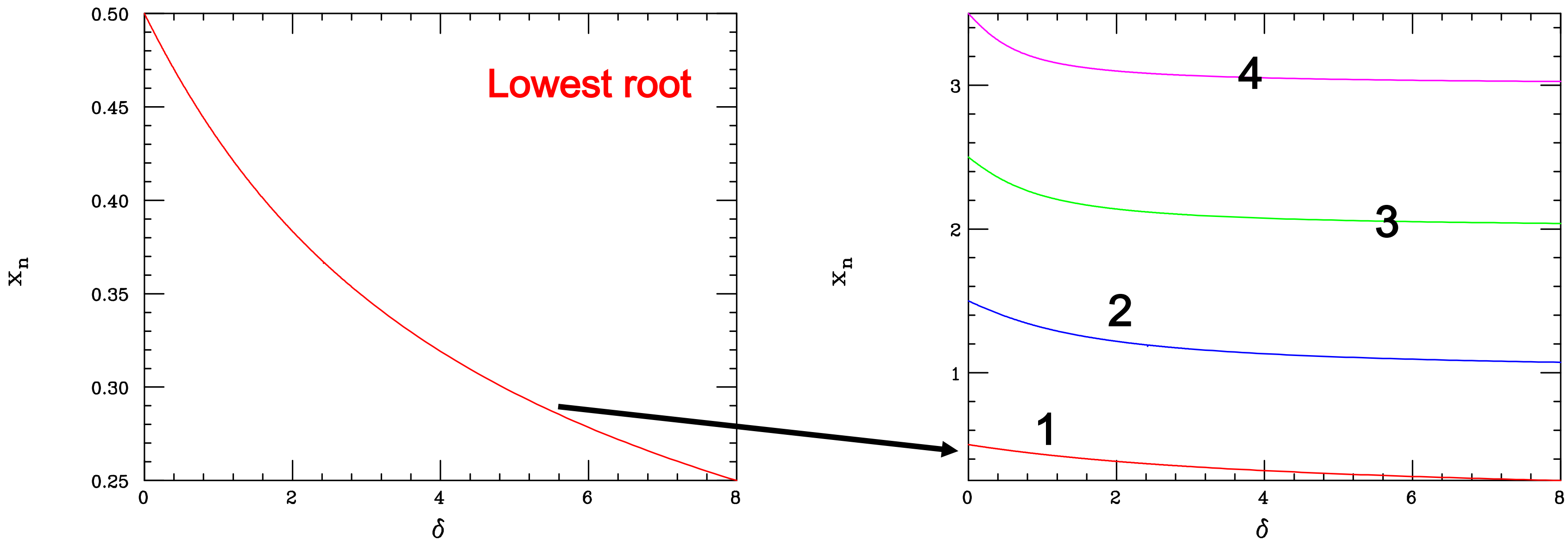
$$\rightarrow \quad \cot \pi x_n^V = \frac{\delta_A}{2} x_n^V$$

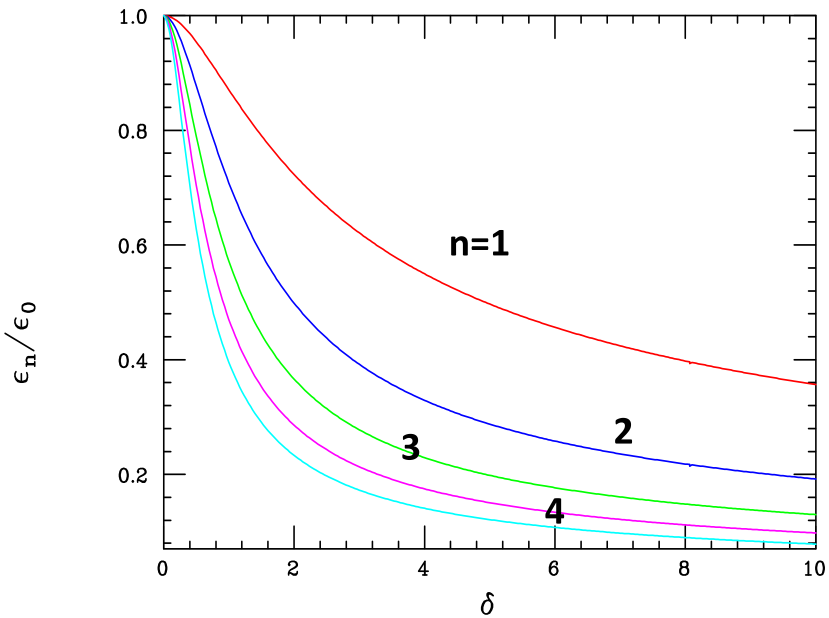
$$\varepsilon_n^{\ 2} \sim \left[1 + \left(\frac{\delta_A x_n^V}{2}\right)^2 + \frac{\delta_A}{2\pi}\right]^{-1}$$

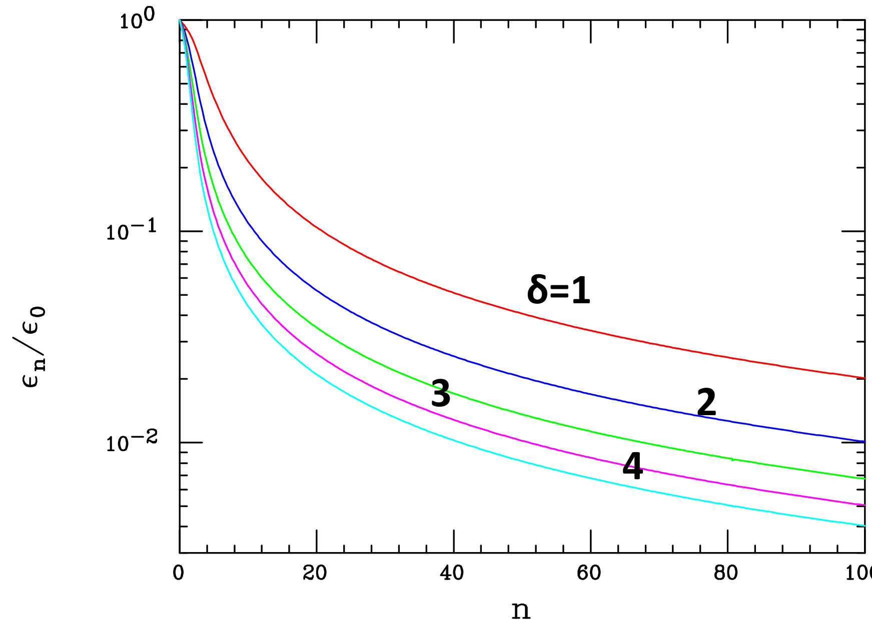
Increasing δ_A reduces x_n's → m_n's

& also makes ε_n's decrease !

$\delta_{A,S} \neq 0$ will make BOTH KK's lighter but we need a fixed ordering





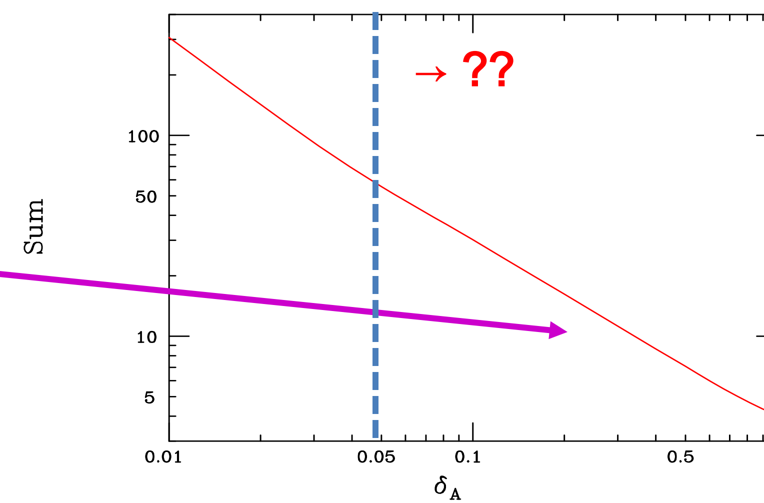


The ε_n's fall off rapidly with increasing n as well as increasing δ_A's

Remember $\Sigma_n^2 = 1 - \frac{\epsilon_1^2}{c_w^2} \sum_{a=1}^{n} \frac{\epsilon_a^2}{\epsilon_1^2}$?

We can now evaluate the sum..

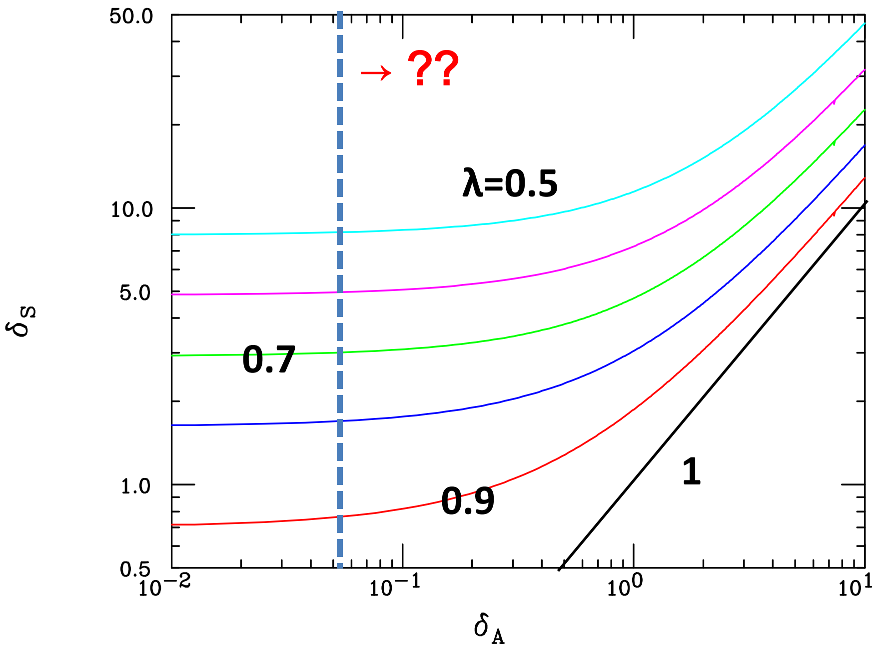
Well controlled.. this problem is solved by the BLKT !

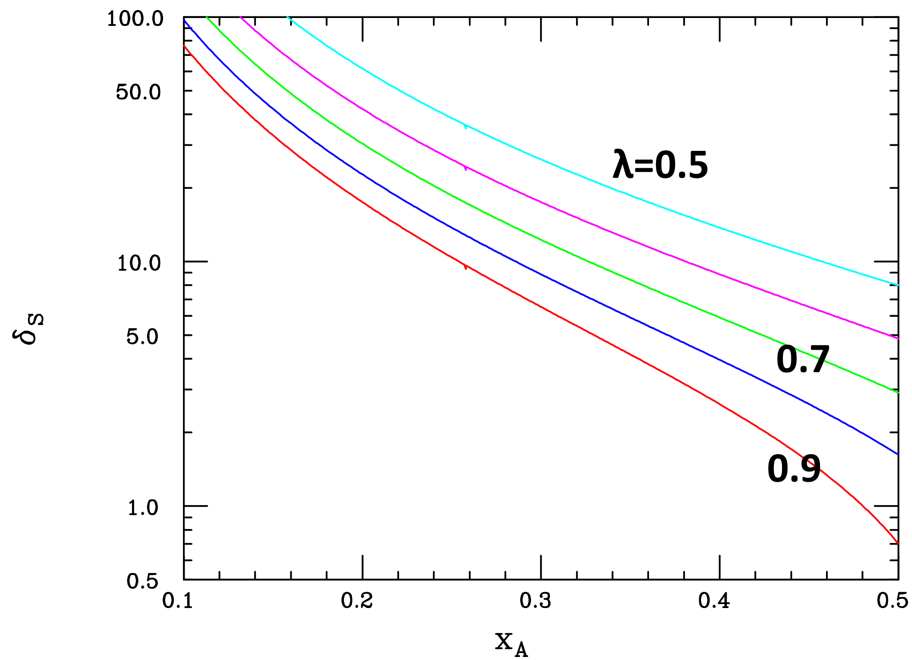


Now we need $m(S_1) < m(V_1)$ so this means the values of δ_S & δ_A are correlated..

$\lambda = m(S_1)/m(V_1)$ ..for a given δ_A and desired λ, we can determine δ_S

Values of λ below ~0.5 are 'disfavored' by largish δ_S requirements.. But this is a special region as here all KK's will decay down to DM !





$x(V_1)$

- Gauge KK's are produced via their SM couplings & undergo 2-body decays to pairs of scalars which then decay further producing a cascade (more later)

- Eventually we are left with $S_1, S_1^\dagger$ (= DM) & V_1 only… if V_1 decays just to DM, then the whole cascade is totally DARK !

- Since $g_D \gg e\varepsilon_1$ this will happen when $\lambda<0.5$ (the 'disfavored' region) & the signatures will no longer be (directly**) λ-dependent, e.g., just missing energy in a DP production experiment

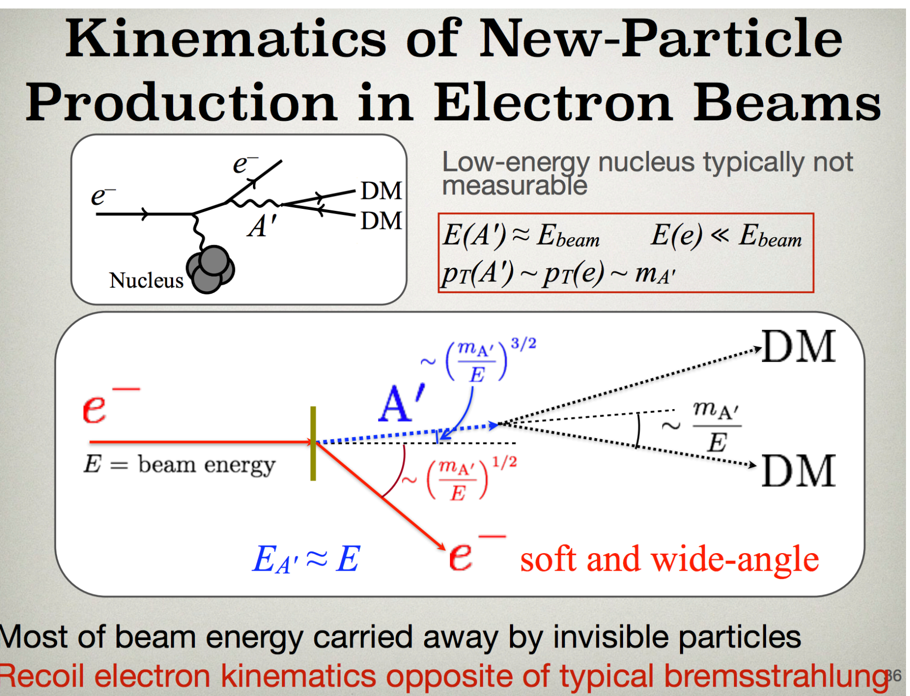
- DD experiments are qualitatively insensitive to λ (as we'll see) but the relic density calculation MAY sometimes have sensitivity due to the potential proximity of the V_1 resonance when λ is below but ~0.5.

** Couplings & detailed kinematics, etc., will remain λ-dependent

- If the KKs just result in ME can this scenario be distinguished from the usual 4-D DP model where something similar can happen ?

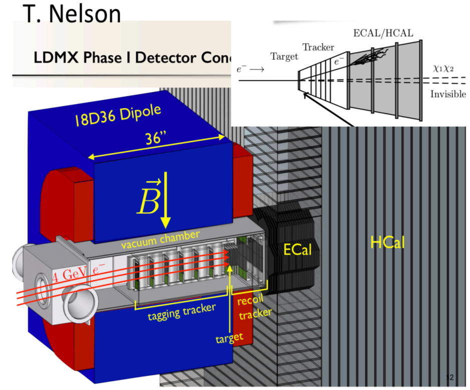
- LDMX1: an example e-recoil experiment. 4 GeV beam on a tungsten target.. E_e^{recoil} & p_T^e are the only observables !

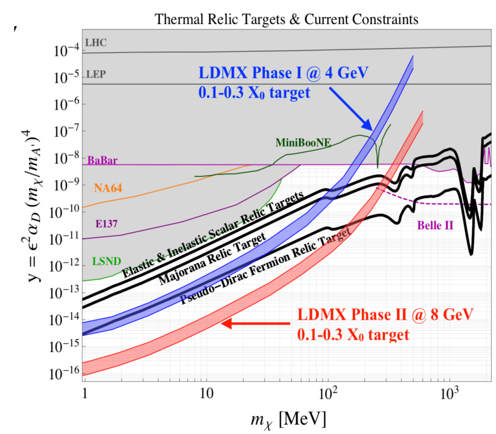
- Straightforward to include multiple KKs contributing here..



LDMX

T. Nelson

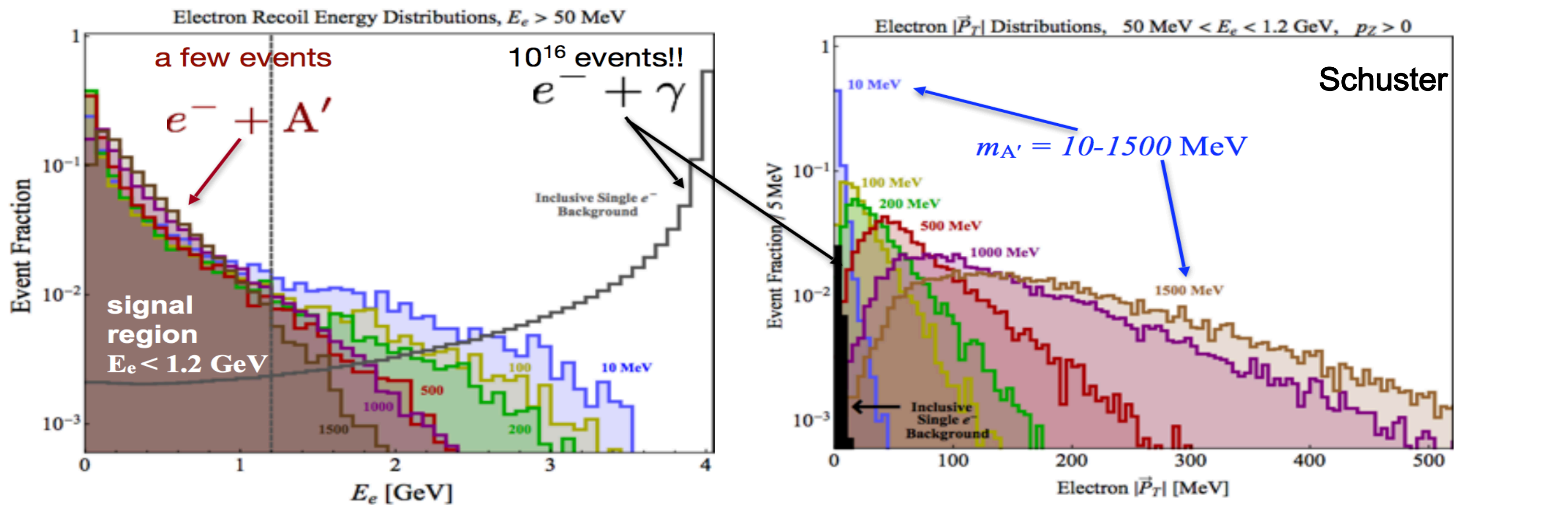


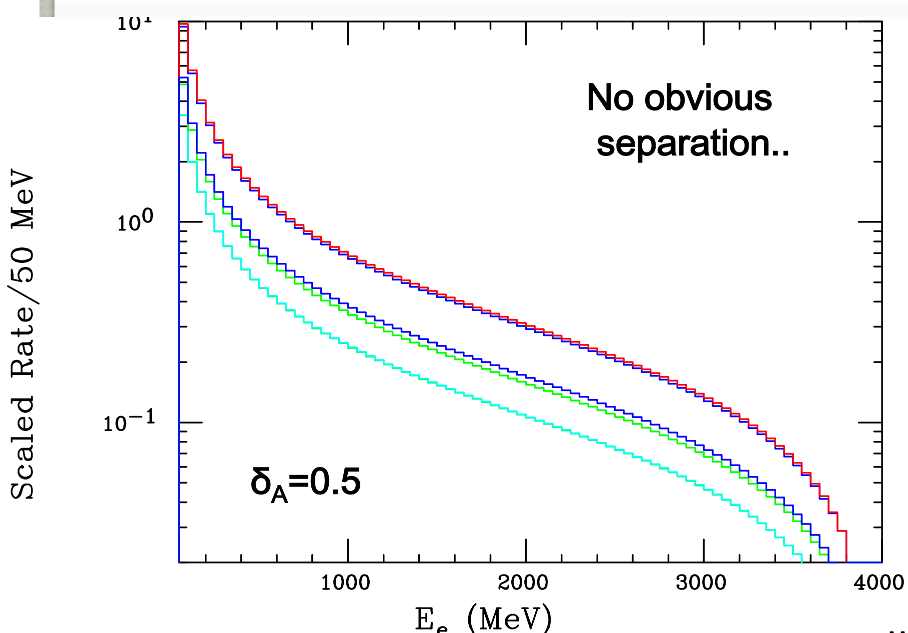


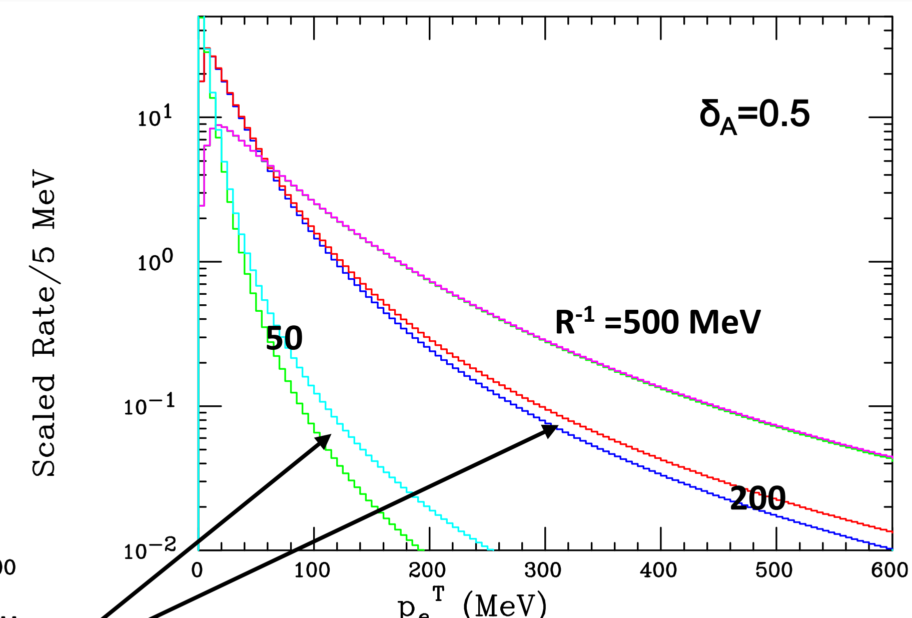
Two-stage experiment:

- Start at 4 GeV towards the end of 2021 -- sensitivity to 10^{-14}
- BES plans accelerator upgrade (LCLS-II HE / 8 GeV) -- sensitivity to 10^{-16}

recoil distributions, 4 GeV e^- on 10% X_0 target – NOT TO SCALE







small differences

· Small δ_A → ε_n's at low n's remain largish. Small R^{-1} → many KKs contribute, hence, the greatest sensitivity.

· Meson decays/colliders may do better looking for multiple γ peaks with ME recoiling with shrinking rates due to falling ε_n

→ Interesting possibility: via Z-V_i mixing, we have Z→$S_iS_j^\dagger$ +h.c. w/ the S_i decaying down to DM. In one of our BMs below this is ~763k decay modes!!! Violation of the Γ(Z→ inv) <~1 MeV bound?

Amazingly, no! Including 2k gauge KKs to determine the mixings & taking R^{-1} =100 MeV w/ $g_D\varepsilon_1$ =10^{-4} we get Γ(Z→ inv) ~0.02 MeV

This is the result of the couplings falling off quickly as we go up the KK towers & gives us a little room for other parameter choices

- To go any further we need to determine the $S_n S_m^\dagger V_i$ couplings (these would *vanish* for orbifolds!)

$$c^i_{mn} = \int_0^{\pi R} s_n(y) s_m(y) v_i(y)\ dy \rightarrow \tilde{c}^i_{nm} = c^i_{nm}/c^1_{11}$$

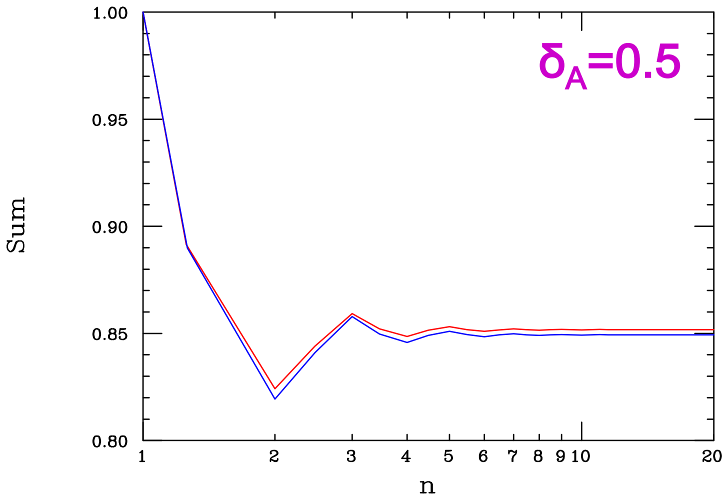
as c^1_{11} is used to define the 4-D coupling g_D

Then we can, e.g., determine the e-DM elastic scattering cross section:

$$\sigma_e = \frac{4\alpha\mu^2 g_D^2 \epsilon_1^2}{(m_1^V)^4} \left[\sum_n (-1)^{n+1} \frac{\epsilon_n}{\epsilon_1} \tilde{c}^n_{11} \frac{(m_1^V)^2}{(m_n^V)^2} \right]^2 \rightarrow \sigma_e \simeq 2.97 \cdot 10^{-40}\mathrm{cm}^2 \left(\frac{100\mathrm{MeV}}{\mathrm{m}_1^\mathrm{V}}\right)^4 \left(\frac{\mathrm{g_D}\epsilon_1}{10^{-4}}\right)^2 \times \mathrm{Sum}$$

To get real numbers out we need some benchmarks: take $\delta_A = 0.5$

BM1: $\lambda = 0.8$, $\delta_S = 2.38$ BM2: $\lambda = 0.6$, $\delta_S = 6.03$



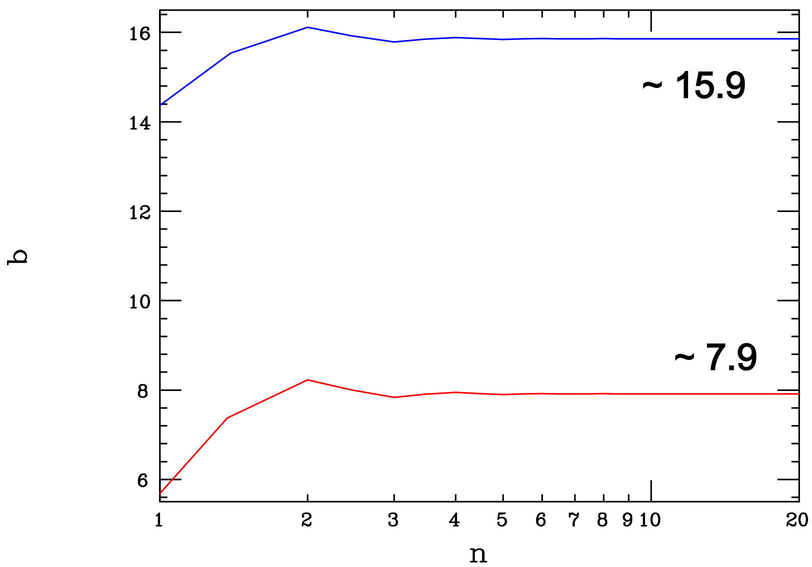
The Sum converges rapidly after a few KKs & yields ~ 0.85 for both BMs

We can now calculate the annihilation cross section for $S_1S_1^\dagger \rightarrow e^+e^-$..

$$\sigma v_{rel} = \tilde{b} v_{rel}^2 \qquad \tilde{b} = \frac{g_D^2 \epsilon_1^2}{192\pi m_{DM}^2} \frac{\gamma^4}{\gamma^2 - 1} \sum_{n,m} (-1)^{n+m} \left[\frac{(\epsilon_n \epsilon_m / \epsilon_1^2)\ \tilde{c}_{11}^n \tilde{c}_{11}^m}{(\gamma^2 - r_n)(\gamma^2 - r_m)} \right]$$

Where $\gamma^2 = s/4m_{DM}^2$ and $r_n = (m_n^V)^2/4m_{DM}^2$

Rescale $\tilde{b} = b \left[\frac{g_D^2 \epsilon_1^2}{m_{DM}^2 (\text{GeV}^2)} \right] 10^{-20} \text{cm}^3 \text{s}^{-1}$. & determine b for BM1,2



These again converge rapidly but they differ by a factor of ~2

What are the decays of these KK states? Depends on couplings & PS available. S_1 is DM so is stable, $V_1 \rightarrow$ SM only & $S_2 \rightarrow S_1 V_1$ only. For the others:

KK masses in R^{-1} units

KK level	V	S(BM1)	S(BM2)
1	0.463	0.371	0.278
2	1.393	1.198	1.094
3	2.332	2.123	2.051
4	3.281	3.087	3.035

$$S_n(m) \rightarrow S_m(m')V_l(m_V)$$

$$\Gamma_S = \frac{g_D^2(\tilde{c}^l_{nm})^2 m^5}{16\pi m_V^4}\left[1 - 2\frac{m_V^2 + m'2}{m^2} + \frac{(m_V^2 - m'^2)^2}{m^4}\right]^{3/2}$$

$$V_i(m_V) \rightarrow S_j^\dagger(m_j)S_k(m_k) + \text{h.c.},$$

$$\Gamma_V = \frac{g_D^2(\tilde{c}^i_{jk})^2 m_V}{24(1+\delta_{jk})\pi}\left[1 - 2\frac{m_j^2 + m_k^2}{m_V^2} + \frac{(m_j^2 - m_k^2)^2}{m_V^4}\right]^{3/2}$$

BFs in % for Heavier KKs

Process	BF(BM1)	BF(BM2)
$S_3 \to V_2 S_1$	1.20	0.62
$S_3 \to V_1 S_1$	5.10	1.78
$S_3 \to V_1 S_2$	93.7	97.6
$V_3 \to S_1^\dagger S_1$	74.9	97.3
$V_3 \to S_1^\dagger S_2$+h.c.	25.1	2.71
$V_4 \to S_1^\dagger S_1$	45.9	39.5
$V_4 \to S_1^\dagger S_2$+h.c.	51.5	18.9
$V_4 \to S_2^\dagger S_2$	1.67	38.8
$V_4 \to S_3^\dagger S_1$+h.c.	0.95	2.81

Some similarities but many significant differences for the two BMs due to coupling & PS variations.

The production of the heavier KKs can initiate long cascades with model-dependent contents

Interesting signatures!!

Maybe a few comments about other scenarios if time permits..

Model 2: Complex Scalar w/ vev, $S \sim v_s + h + i\chi$

- Non-orbifold BCs are again employed and χ + V_5 mix to form the CP-odd field a + unphysical Goldstones level by level. V still has BLKT but none for S. $g_D v_s R$ naturally is ~ O(1).

- h_1 or a_1 is DM.. BUT m_{DM} must be < m_{v1} However one finds

$$(m_n^h)^2 = (\tfrac{n+1/2}{R})^2 + 2\lambda_S v_s^2 \qquad (m_n^V)^2 = \left(\frac{x_n^V}{R}\right)^2 + g_D^2 v_s^2 \qquad (m_n^a)^2 = \left(\frac{n+1/2}{R}\right)^2 + g_D^2 v_s^2$$

so that $m_{v1} < m_{a1}$ & thus h_1 is the DM with $2\lambda_s < g_D^2$

- $h_1 - a_1$ fractional mass splitting, δ, must be small as they can only co-annihilate via V_n to get relic density → the entire spectrum at a given level is compressed! Resonance enhancement can occur.

- Tree-level DD is absent due to δ, loop-level ~<10^{-51} cm^2 tiny!

- $a_1 \to h_1 e^+ e^-$ unboosted lifetimes ~10-1000 cm due to small δ

Model 3: Majorana/Pseudo-Dirac Fermion

Many moving parts here… but again NOT an orbifold

- Gauge pieces as above w/ BLKT
- Bulk SM singlet fermion w/ bulk mass m_D
- Complex bulk SM Higgs S getting vev for fermion Majorana mass but contributes to gauge masses as in model 2 → h,a
- Fermions form two relatively close mass Majorana towers → another pair of close-mass objects, one long-lived like a_1. $F_{1,2}F_{1,2}V$ & F_1F_2V+h.c. interactions both exist due to..
- Fermion BCs induce $g_L \neq g_R$ → DP has PV interactions with Dark Sector... an additional complexity
- Interesting new interactions between h,a & $F_{1,2}$.
- …

Still making more plots for this case ! Fun stuff !

Summary & Conclusions

· Generalizing the 4-D DP model to 5-D can lead to many different & interesting scenarios some of which address 4-D issues

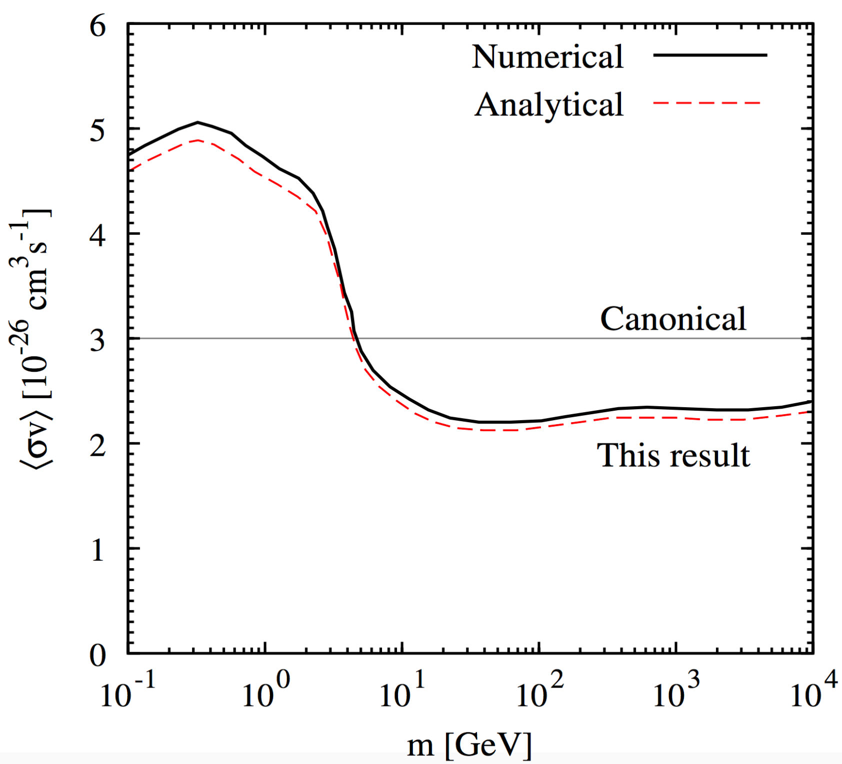
· 5-D model building of DP extensions is not trivial or straightforward.. given the generality of 5-D the restrictions are quite strong

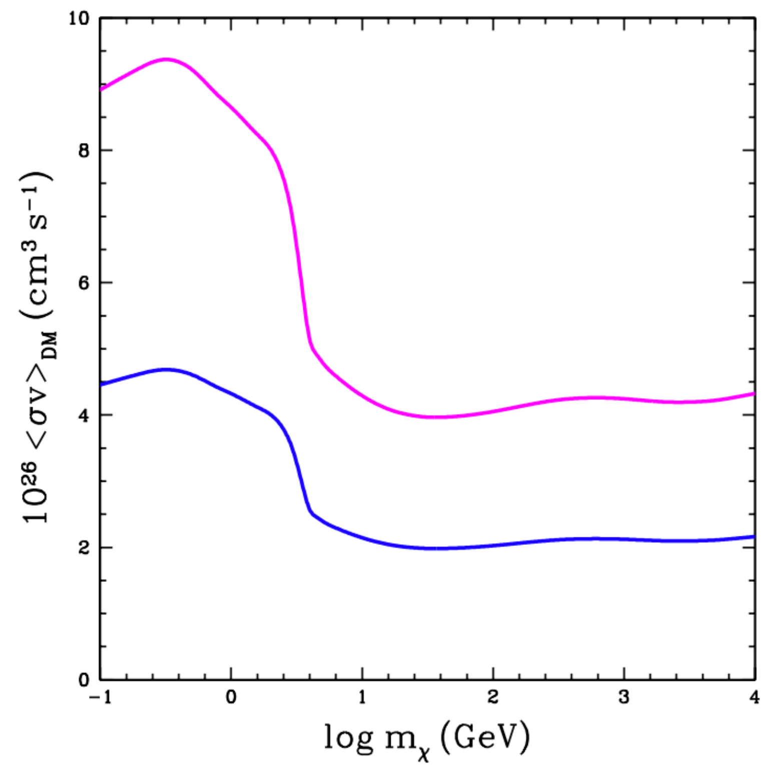
· The 5-D models can lead to complex & interesting phenomenology & unique signals in searches

· This is a new area of work & much needs doing for us to understand it

· Hopefully DM of some kind (maybe not the liquid variety !) will soon be convincingly discovered

Backup

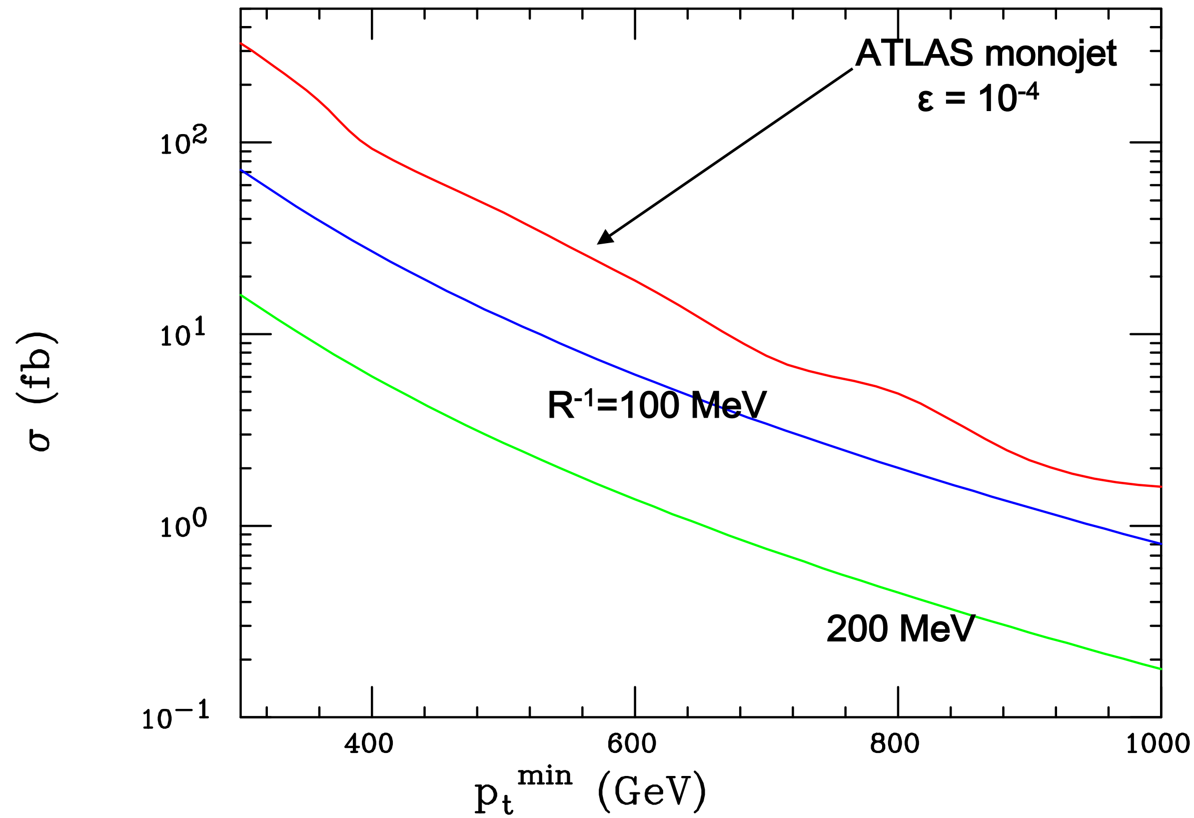




Steigman 1502.01884 ↑

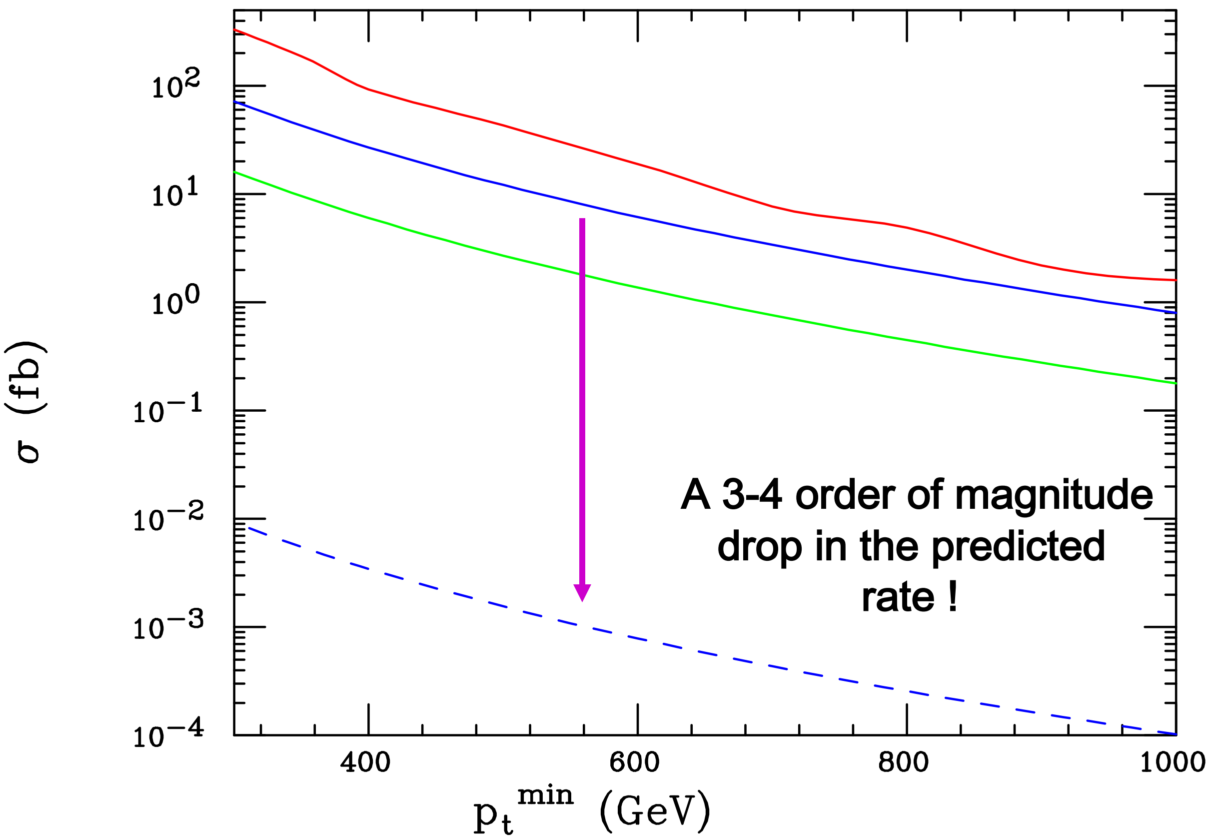
← update 2017

Can the 'monojet' searches probe these models? No..even the constant $\varepsilon_n = 10^{-4}$ case survives !



~10^4 gauge KKs contributing

What if we employed realistic BM1 couplings?



10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
σ (fb)
400
600
800
1000
p_t^{min} (GeV)
A 3-4 order of magnitude drop in the predicted rate !