Probing Dark Forces and Light Hidden Sectors at Low-Energy e^+e^- Colliders

Rouven Essig (SLAC)

Pheno 09, May 12th, 2009

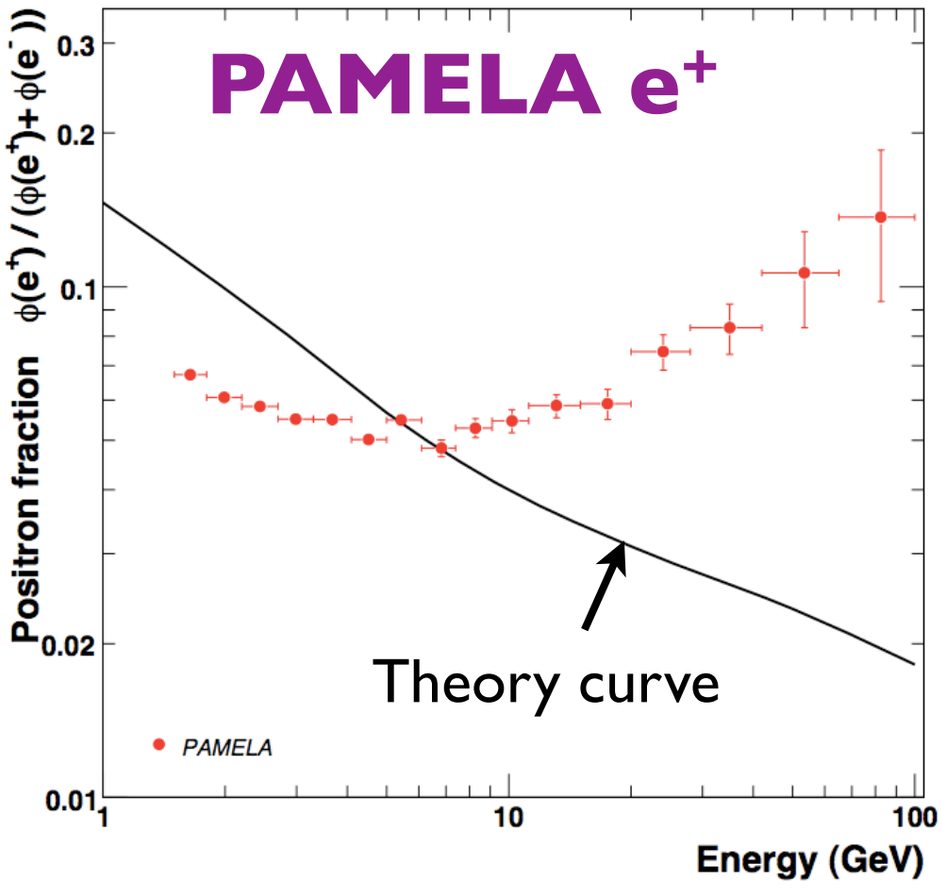
based on:

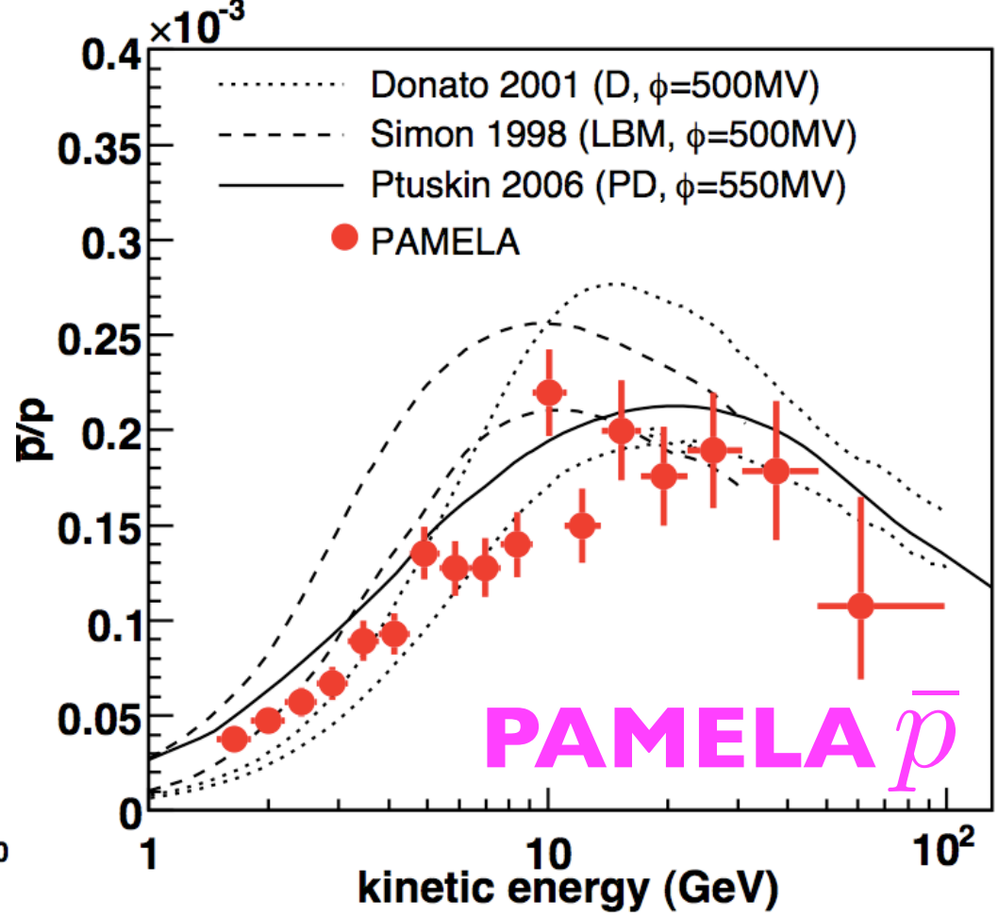
RE, Philip Schuster, Natalia Toro (arXiv: 0903.3941)

Astrophysical and Terrestrial anomalies motivate a ~1 GeV dark sector interacting with Dark Matter

Dark sector can have rich structure with many light states

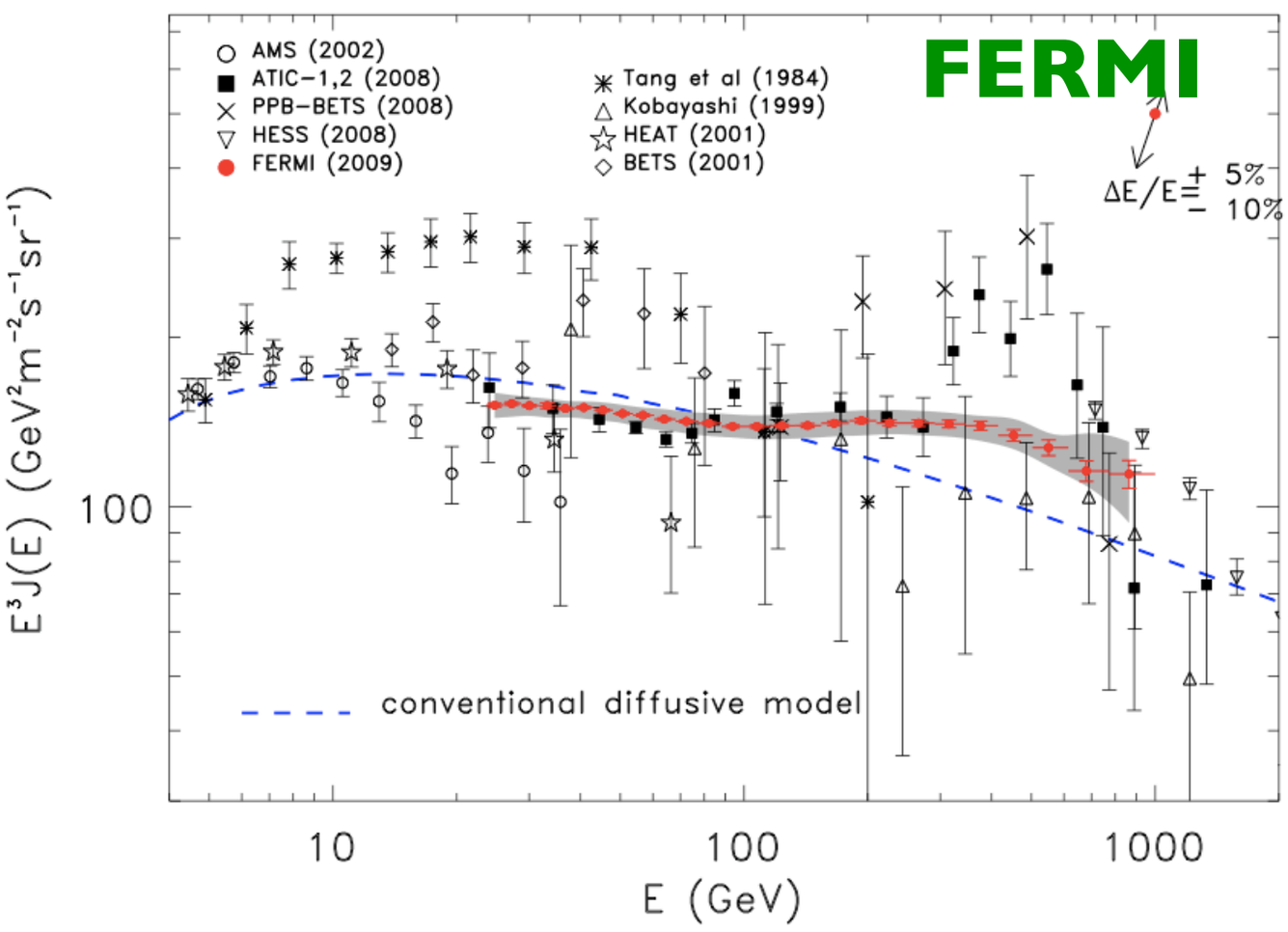
Can be probed at low-energy e^+e^- colliders !





e^+, e^- excess

No $\bar{p}$ excess



If DM annihilation, need:

- annihilations to charged leptons, NOT $\bar{p}$
- σ ~1000 times larger than thermal freeze-out

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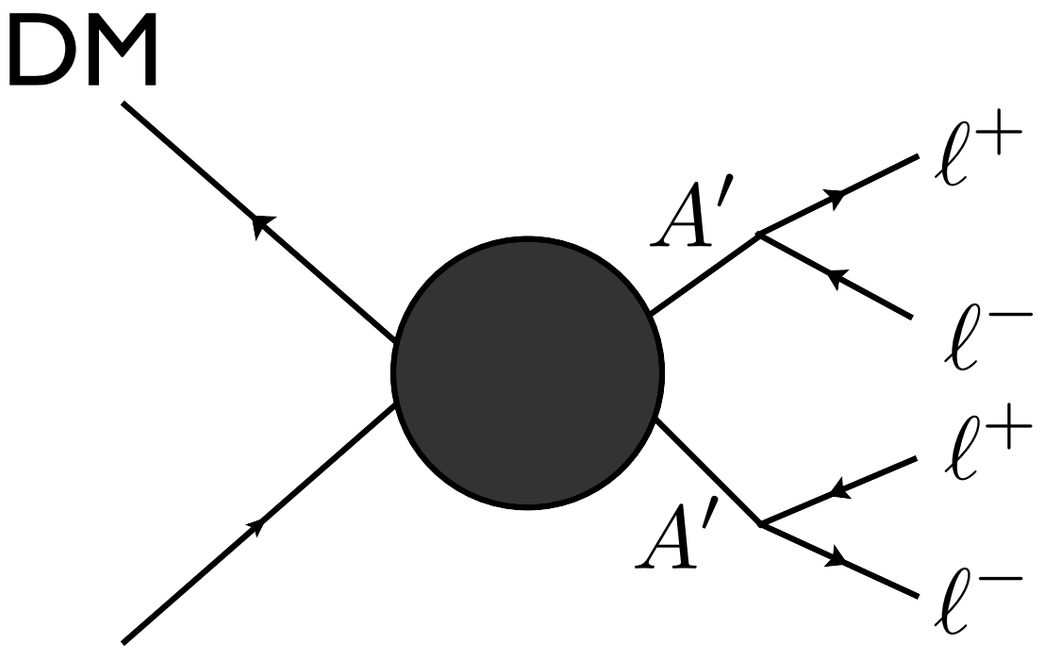
A compelling scenario: new particle A'



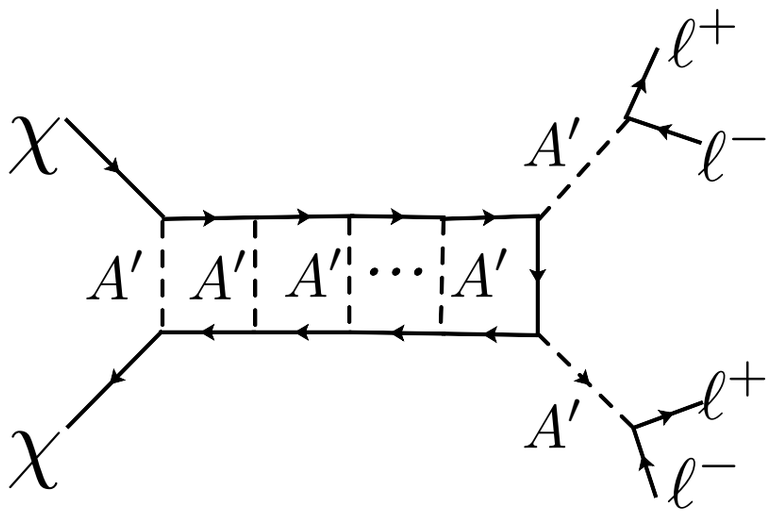
$m_{A'} \sim$ 1 GeV

- $\bar{p}$ kinematically forbidden
- cross-section large due to Sommerfeld enhancement

DM

(e.g. Arkani-Hamed, Finkbeiner, Slatyer, Weiner)

Sommerfeld enhancement:



$$\sigma v \propto \frac{1}{v} \Longrightarrow$$

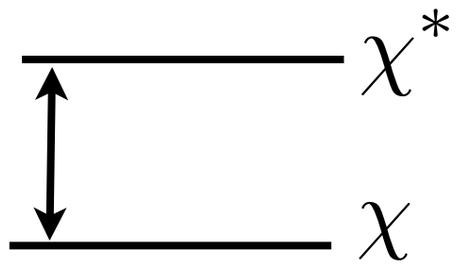
Cross-section:
large today
small at freeze-out

More hints for non-minimal DM structure

- DAMA/LIBRA and null result of other direct detection experiments can be explained by Inelastic Dark Matter

Tucker-Smith & Weiner

$$\delta \sim 100\,\mathrm{keV}$$



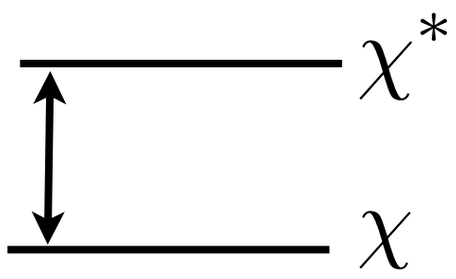
$$m_\chi v^2 \sim (100\,\mathrm{GeV})\,(10^{-3})^2 \sim 100\,\mathrm{keV}$$

in DAMA:

$$\chi N \to \chi^* N$$

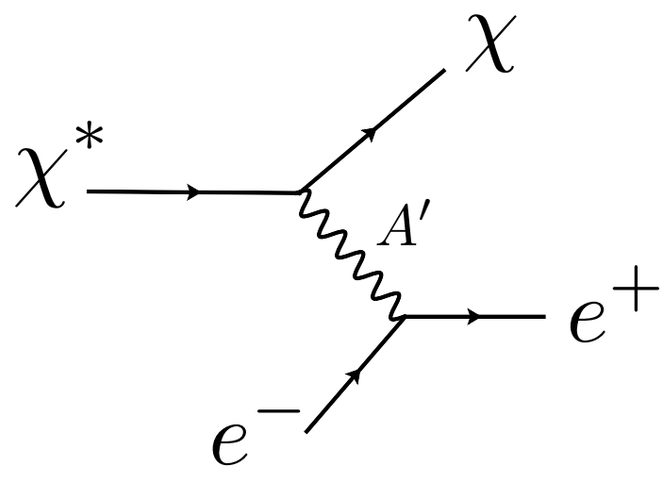
- INTEGRAL 511 keV line can be explained by eXciting DM

$$\delta_2 \sim 1\,\mathrm{MeV}$$



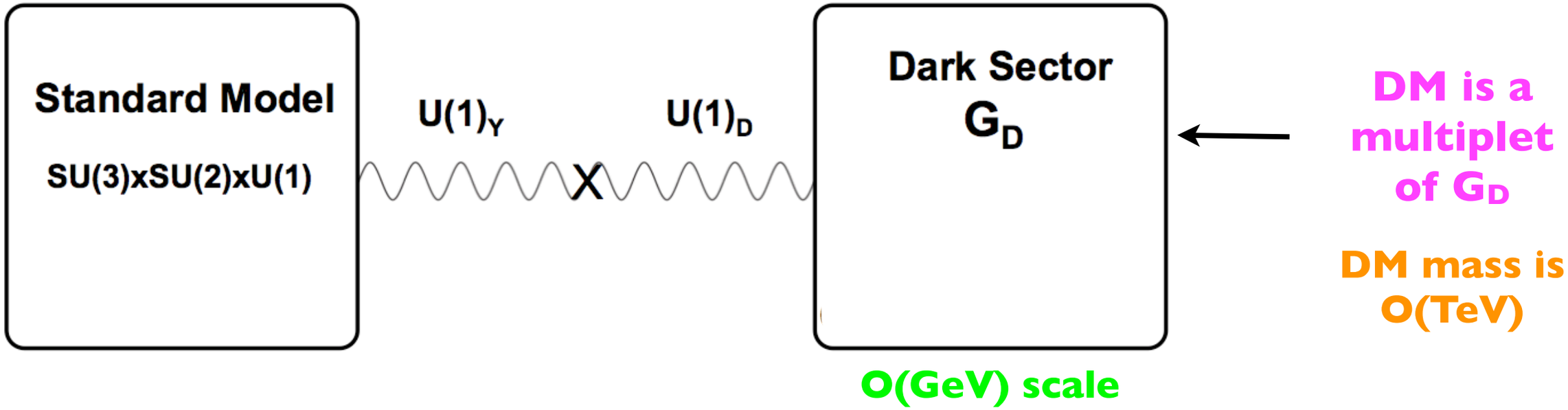
Finkbeiner & Weiner

in galactic center:

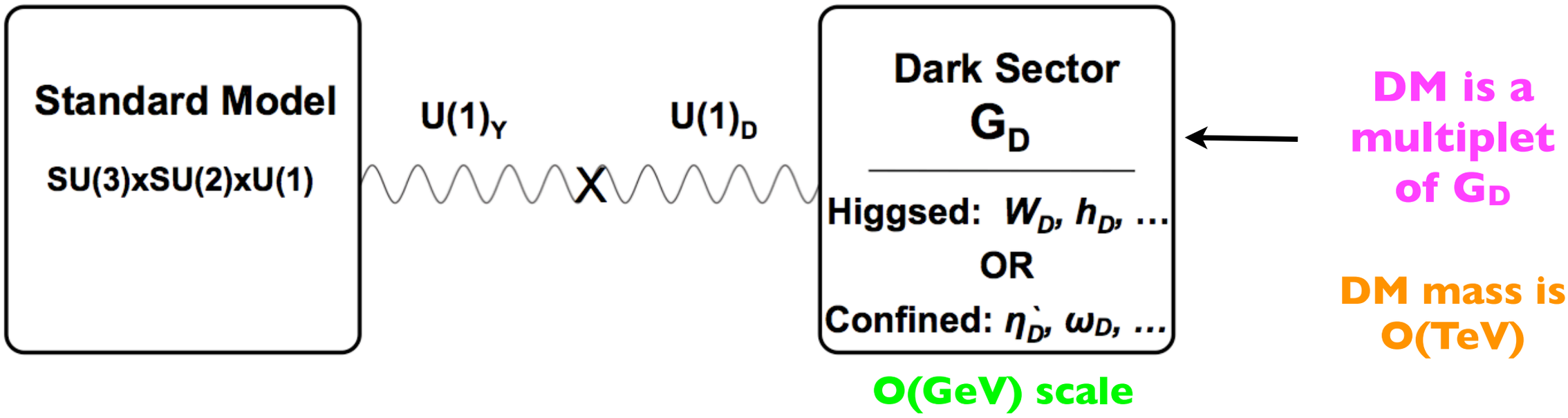


How can the 100 keV (1 MeV) splittings among DM states be obtained?

A new low-mass dark sector at the GeV scale!



Two choices for the dark sector



Two choices for non-abelian G_D:

- Higgsed (broken) near ~1 GeV — Arkani-Hamed, Finkbeiner, Slatyer, Weiner

  DM charged under $U(1)_D$

- Confined near ~1 GeV — Alves, Behbahani, Schuster, Wacker

  DM is heavy flavor meson neutral under $U(1)_D$

Both mechanisms predict many new light states !

Mass splittings from a Higgsed dark sector

Dark gauge-bosons, W_D, split the mass of various components in DM multiplet

Thomas, Wells

Arkani-Hamed, Finkbeiner, Slatyer, Weiner

Baumgart, Cheung, Ruderman, Wang, Yavin

$$\delta \sim \alpha_D \, m_{W_D}$$

$$\delta \sim (10^{-4})(1\,\mathrm{GeV}) \sim 100\,\mathrm{keV}$$

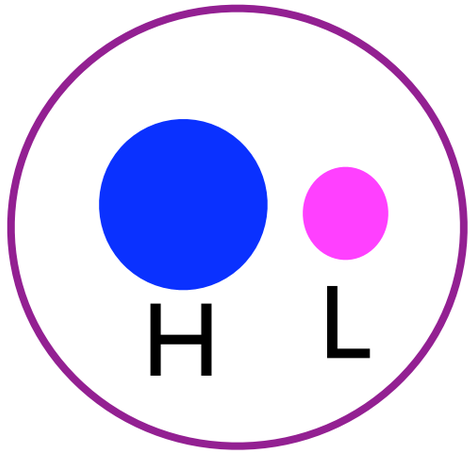
~1 GeV dark gauge bosons give required splitting

$\Longrightarrow$ generically have dark gauge and Higgs bosons at the GeV scale

Mass splittings from a Confined dark sector

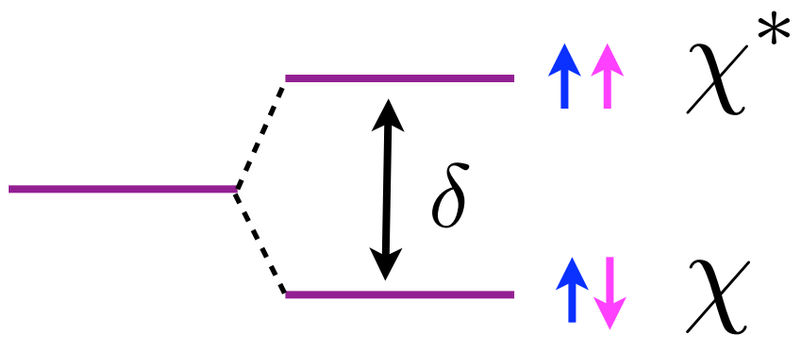
Alves, Behbahani, Schuster, Wacker

DM is a ~1 TeV Dark Meson



Heavy & Light quark

$$m_L \lesssim \Lambda_D$$



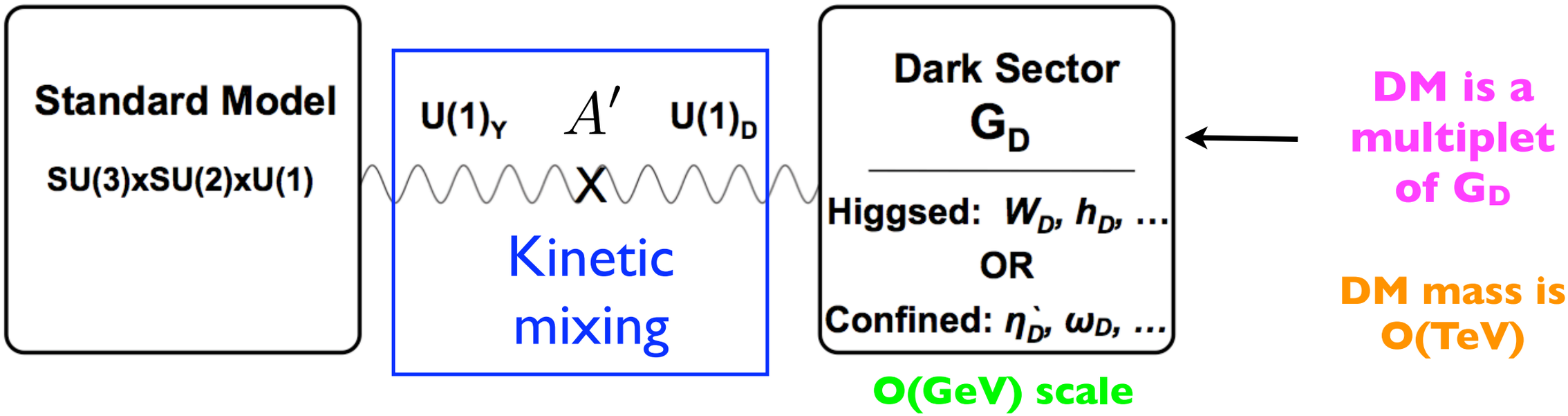
Hyperfine splitting

$$\delta \sim \frac{\Lambda_D^2}{m_{\rm DM}}$$

$$m_{\rm DM} \sim 1\,{\rm TeV}, m_L \lesssim \Lambda_D \sim 1\,{\rm GeV} \Longrightarrow \delta \sim 100\,{\rm keV}$$

$\Longrightarrow$ generically have light-flavor dark mesons, baryons and glueballs at the GeV scale

Kinetic mixing couples dark sector to SM



A' couples SM to dark sector through kinetic mixing

$$\mathcal{L} \supset e\,\epsilon\,A'_\mu\,J^\mu_{EM}$$ Holdom

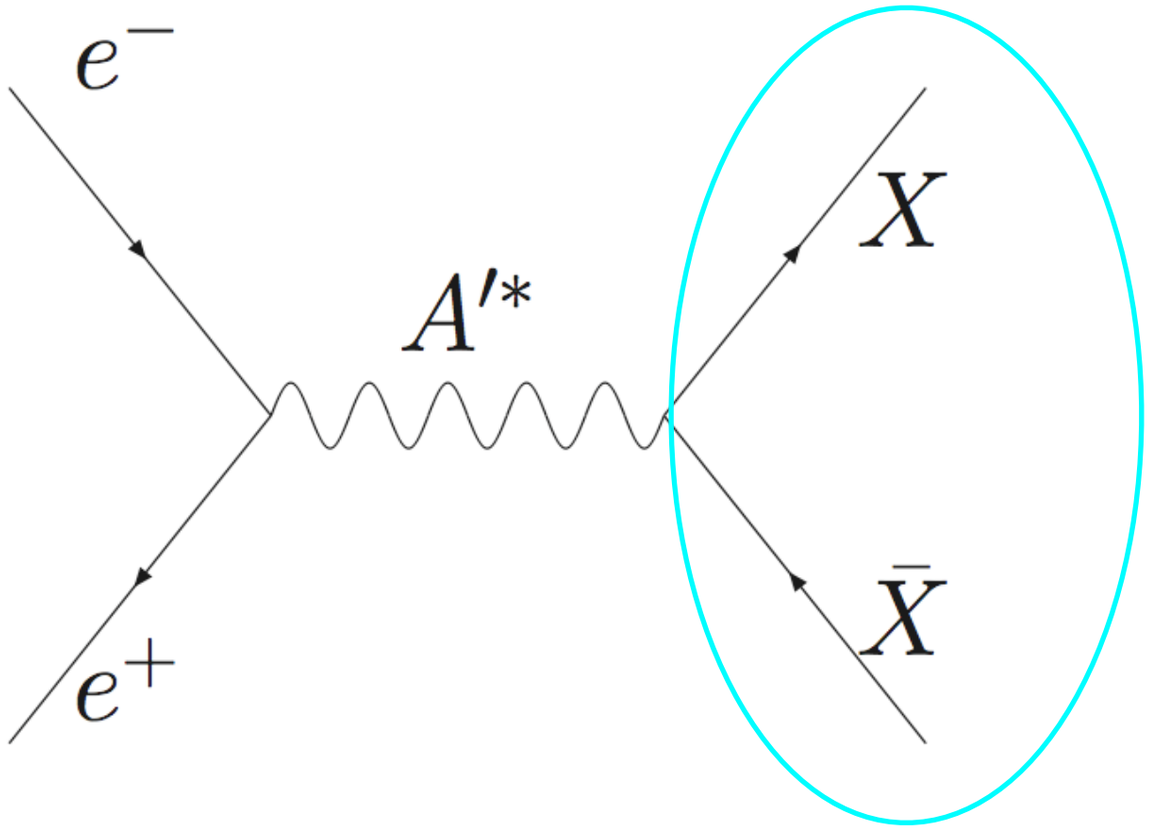
$\Longrightarrow$ all EM charged matter couples to A'

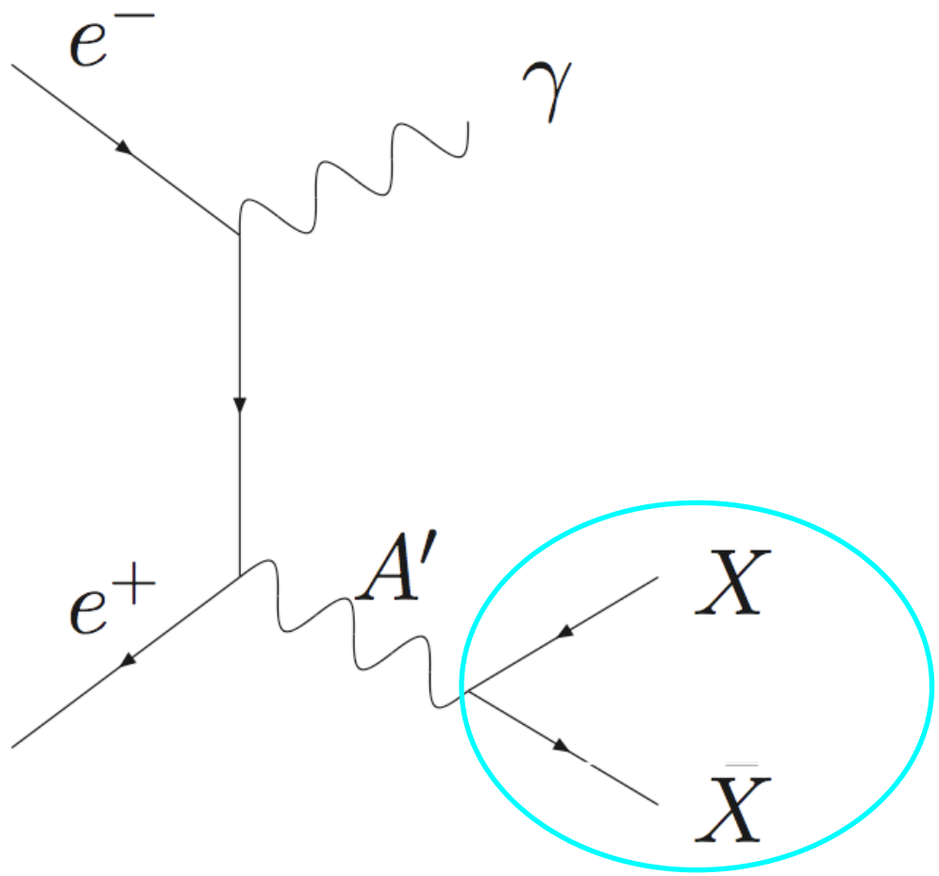
A' could give Sommerfeld enhancement
& allow DM to produce leptons and no $\bar{p}$

How can we test whether such a low-mass dark sector exists?

At low-energy e+e- colliders!

Low-mass particles can be produced at colliders





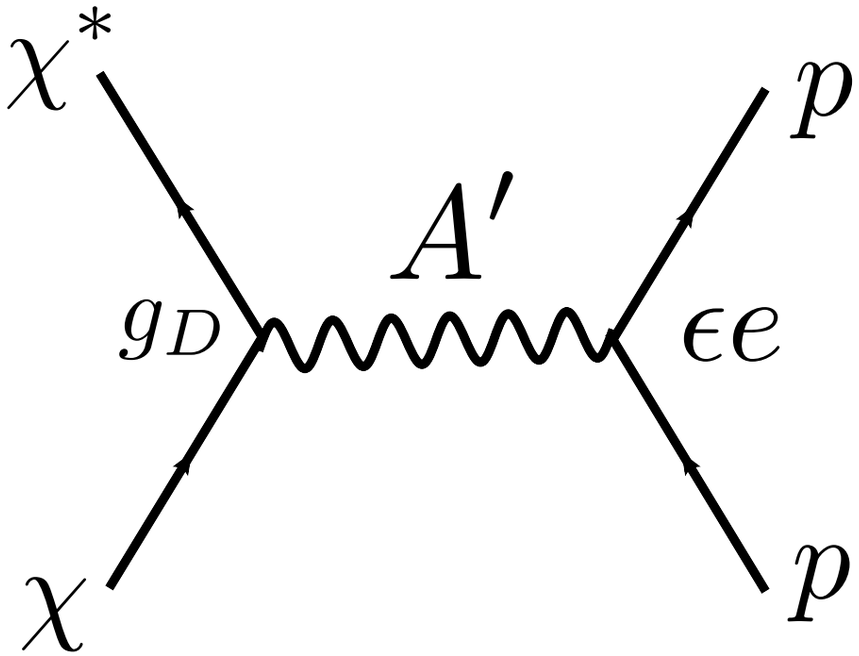
Model dependent

X = dark sector particles

$\sigma \propto 1/E_{cm}^2$: want *low*-energy collider with *large integrated luminosity*

$\Longrightarrow$ BaBar, BELLE, KLOE, CLEO-c, BESIII, ...

A' can mediate scattering at DAMA



$$\sigma_{\text{DAMA}} \propto \frac{\alpha_D \epsilon^2}{m_{A'}^4}$$

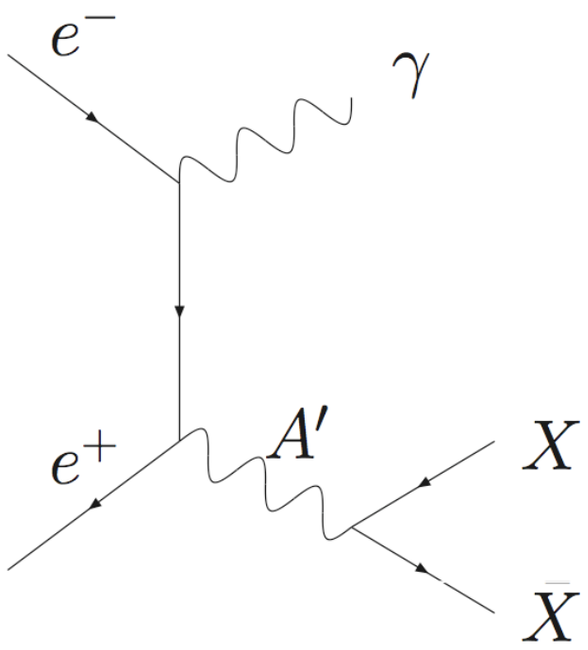
$$\sigma_{\text{B-factory}} \propto \alpha_D \epsilon^2$$

$$\propto \sigma_{\text{DAMA}} m_{A'}^4$$

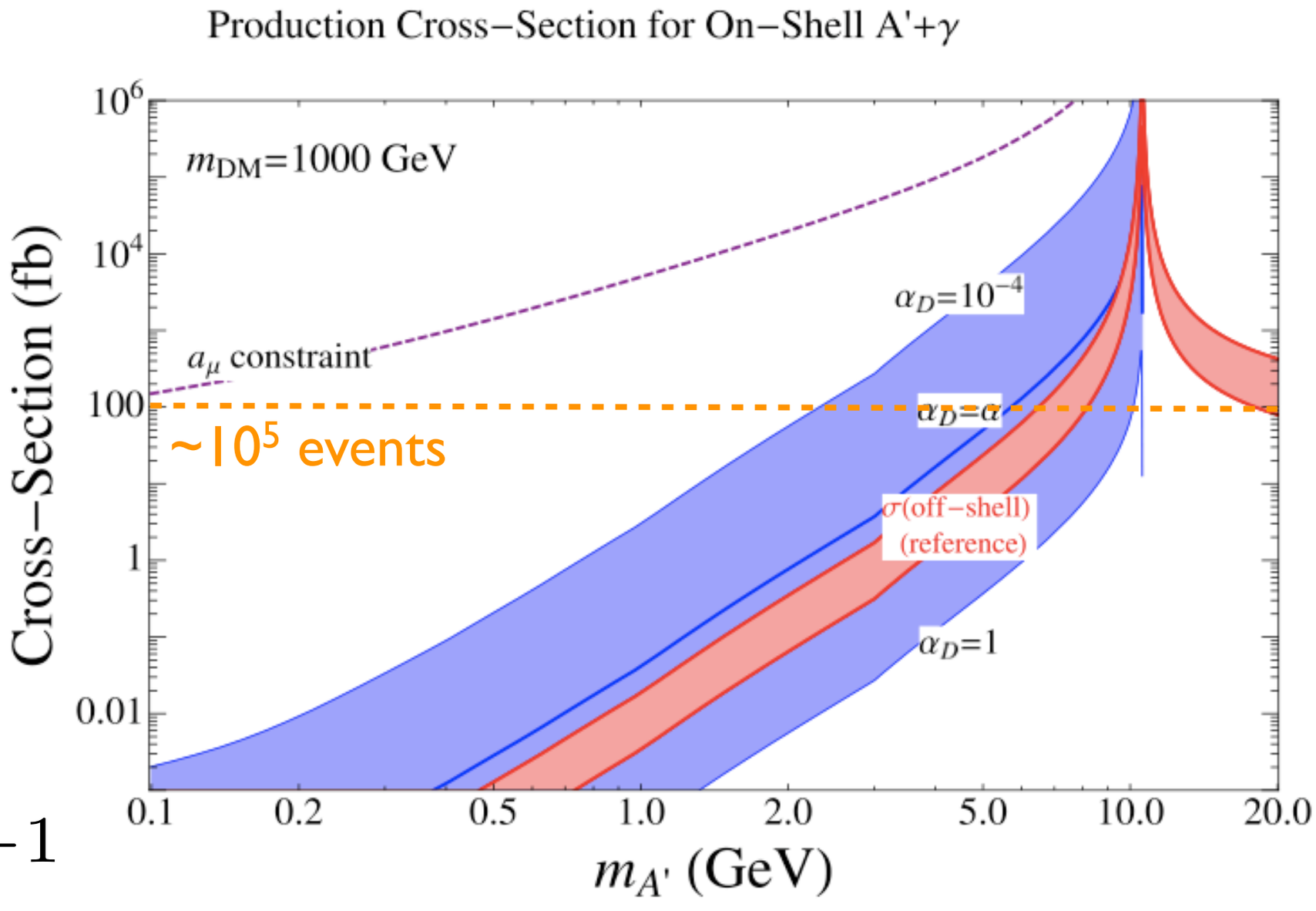
fixed

$\Longrightarrow$ can normalize couplings to DAMA as a function of $m_{A'}$

DAMA-normalized production cross-section



e.g. Higgsed scenario



B-factories:

$\sqrt{s} \simeq 10.6\,\mathrm{GeV}$

$\mathcal{L}_{\rm int} \sim 1.4\,\mathrm{ab}^{-1}$

$\sigma \sim 10^2 - 10^3\,\mathrm{fb}$ **is possible,** >10^5 events !!!

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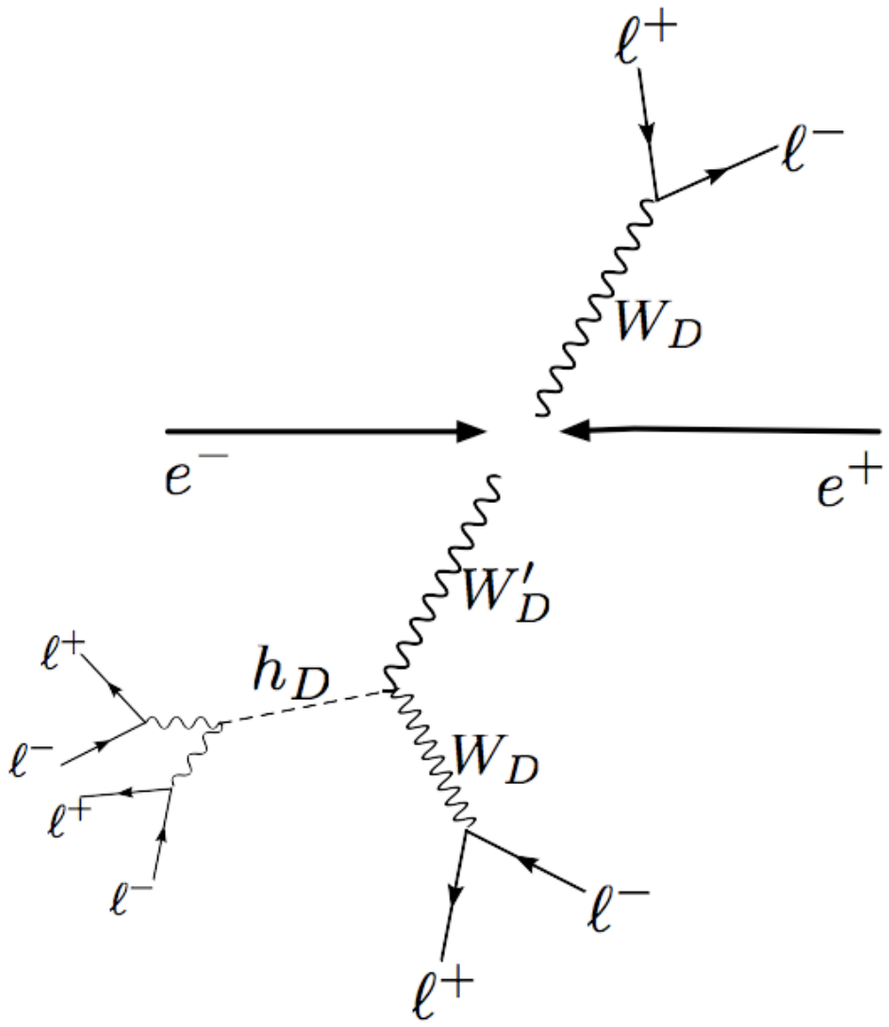
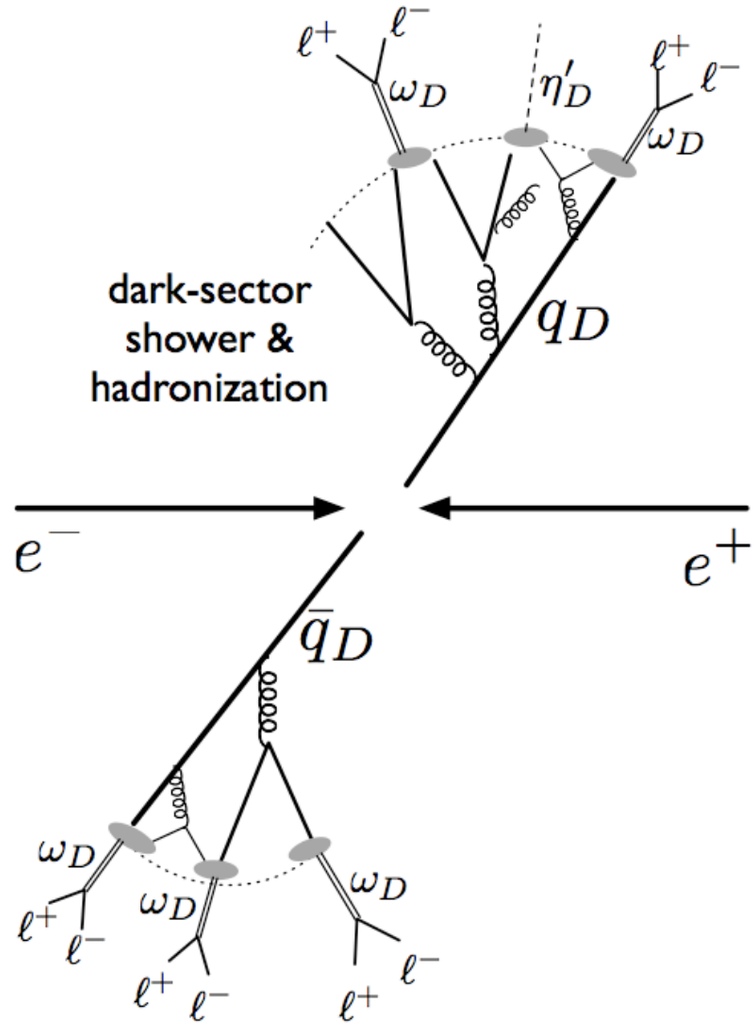
Examples of spectacular events

Higgsed



Confined



Very rich phenomenology possible!

Many leptons (4, 6, 8, ...), resonances, displaced vertices, MET...

Strassler, Zurek; Han, Si, Strassler, Zurek

Arkani-Hamed, Finkbeiner, Slatyer, Weiner; Baumgart, Cheung, Ruderman, Wang, Yavin; Batell, Pospelov, Ritz; Borodatchenkova, Choudhury, Drees

Summary

- Astrophysical and Terrestrial anomalies motivate a rich ~1 GeV dark sector interacting with DM
- Low-energy e^+e^- colliders can spectacularly probe this low-mass sector
- 100,000s of multi-lepton events could be contained in B-factory data sets

Should probe existence of such dark sectors irrespective of DM hints

Backup

BaBar & BELLE

$\sqrt{s} \simeq 10.6\,\mathrm{GeV}$

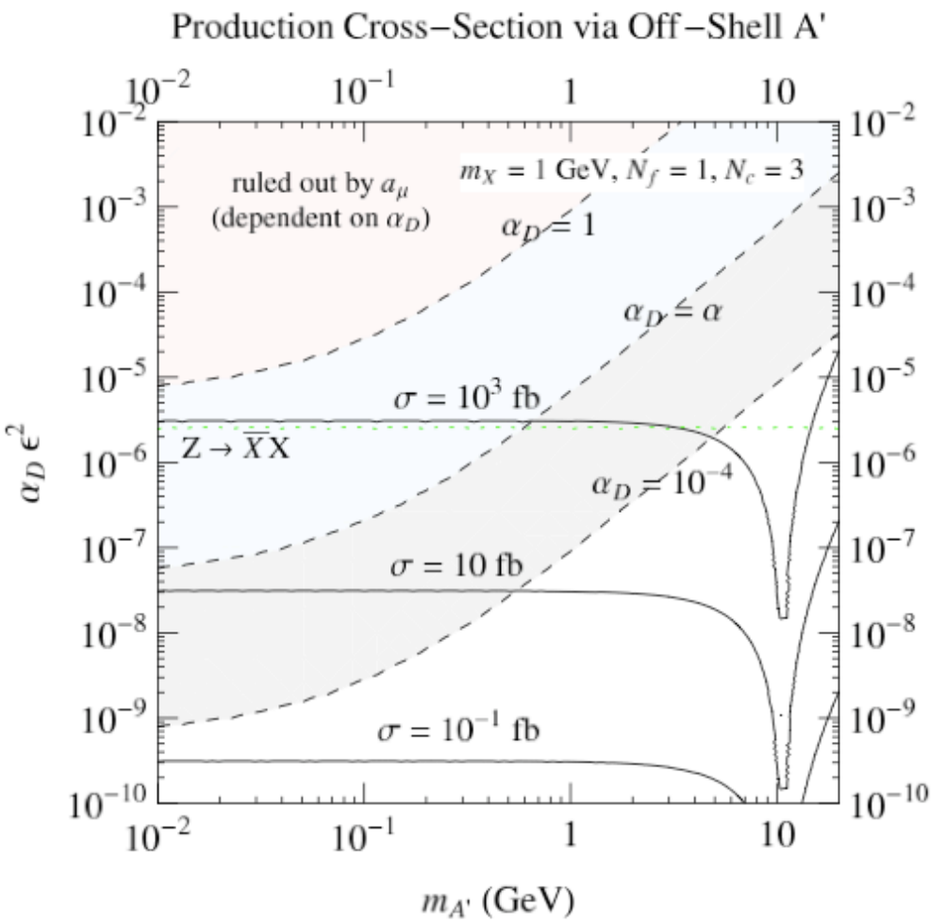
$\mathcal{L}_{\mathrm{int}} \sim 1.4\,\mathrm{ab}^{-1}$

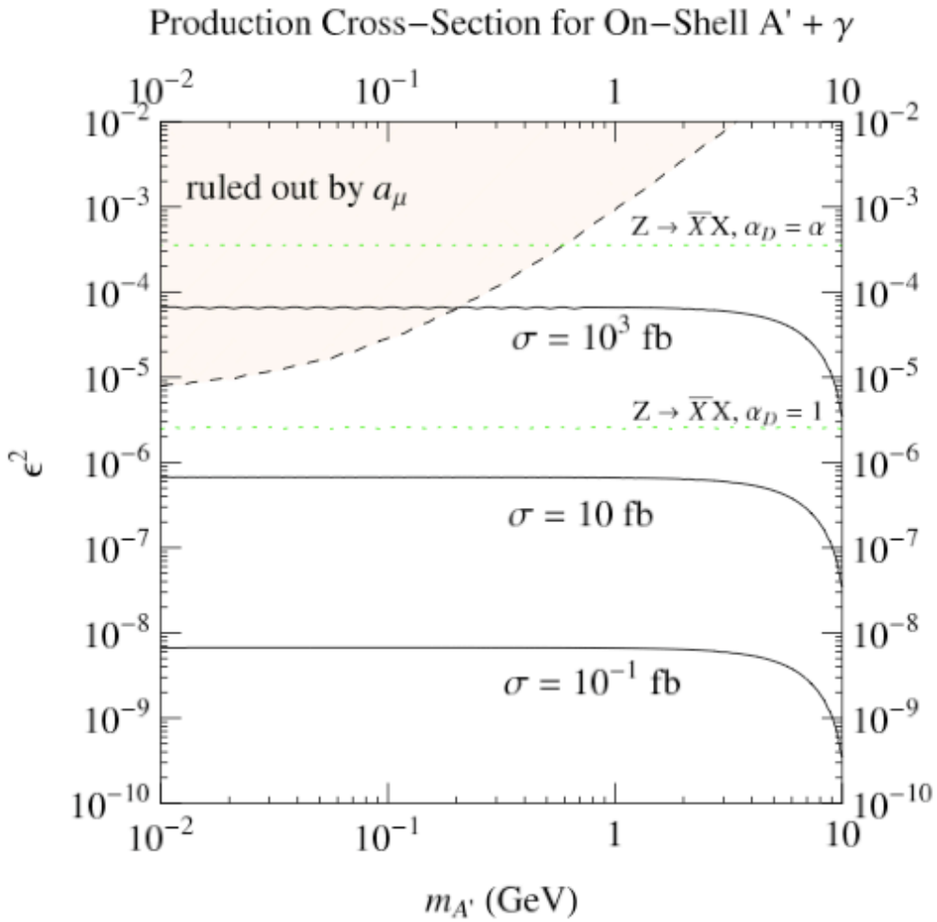
combined

$\sigma \sim 10^2 - 10^3\,\mathrm{fb}$

is possible with

> 10^5 events





Daphne (KLOE)

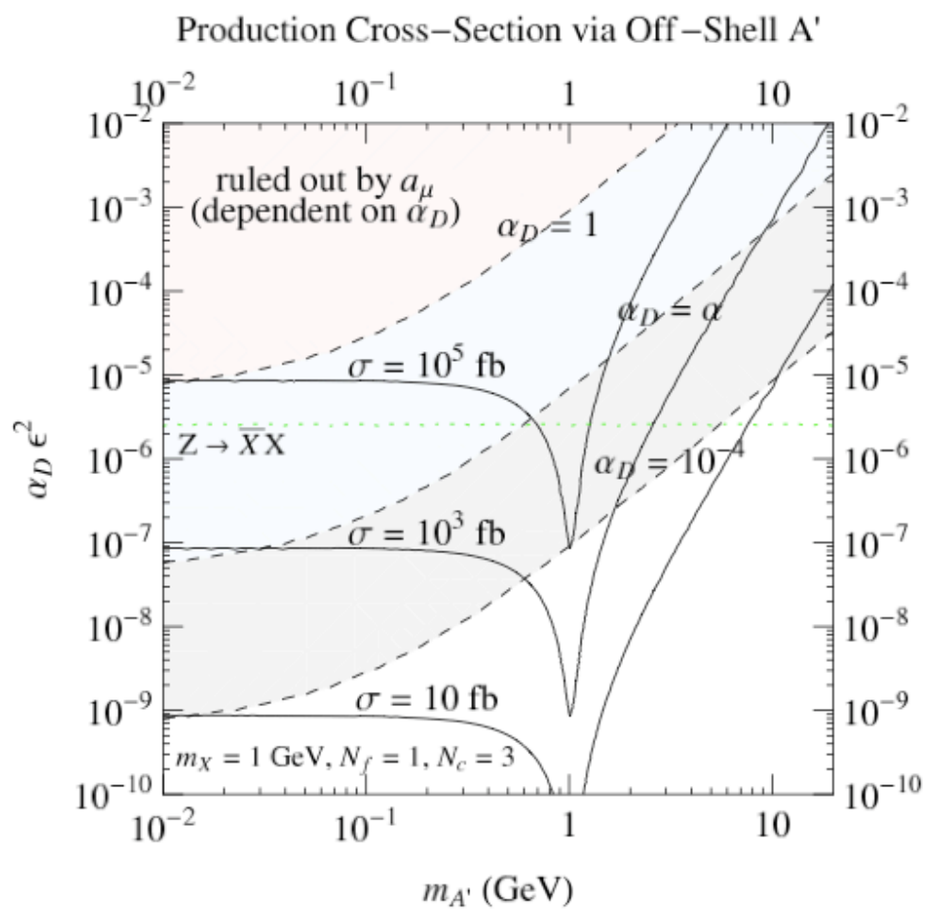
$\sqrt{s} \simeq 1.0\,\mathrm{GeV}$

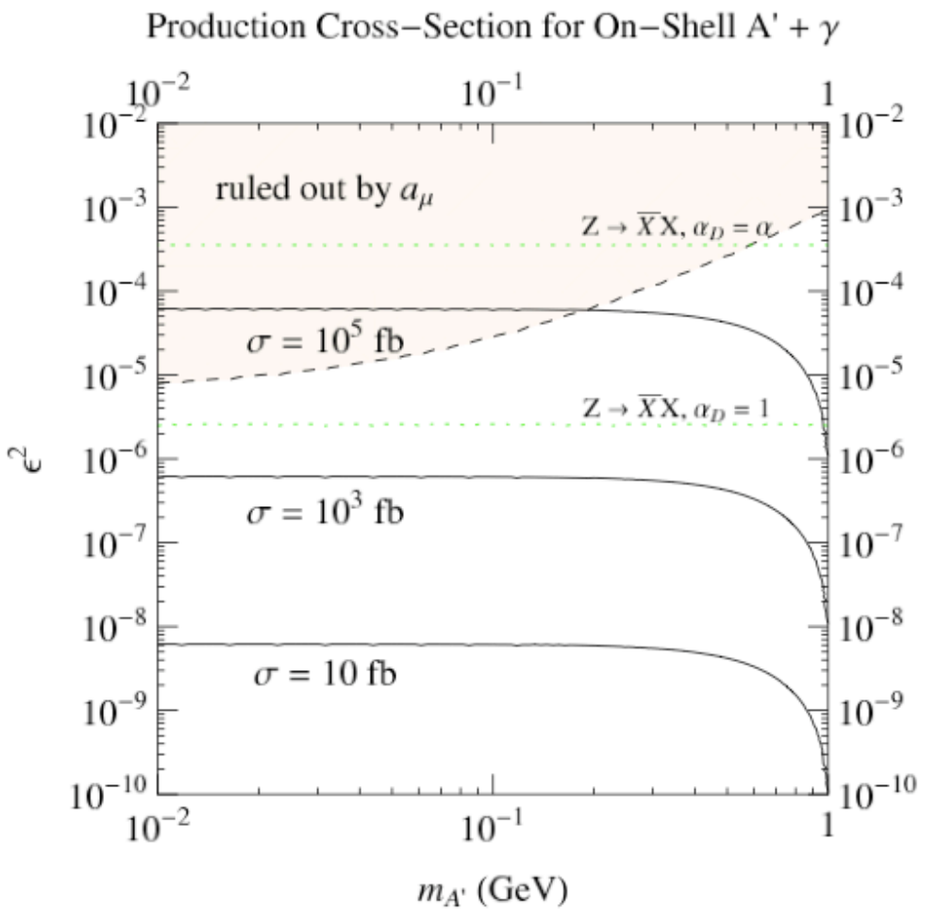
$\mathcal{L}_{\mathrm{int}} \sim 2.5\,\mathrm{fb}^{-1}$

$\sigma \sim 10^3 - 10^5\,\mathrm{fb}$

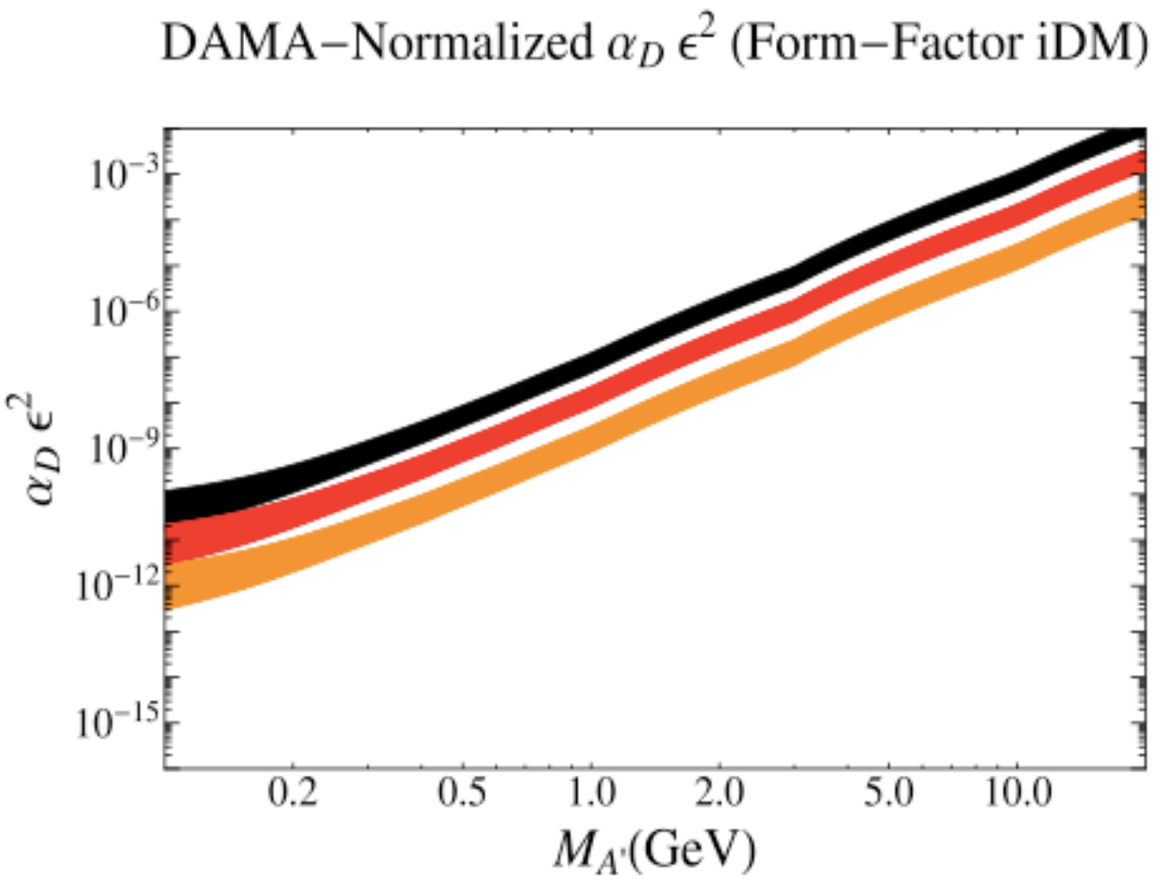
is possible with

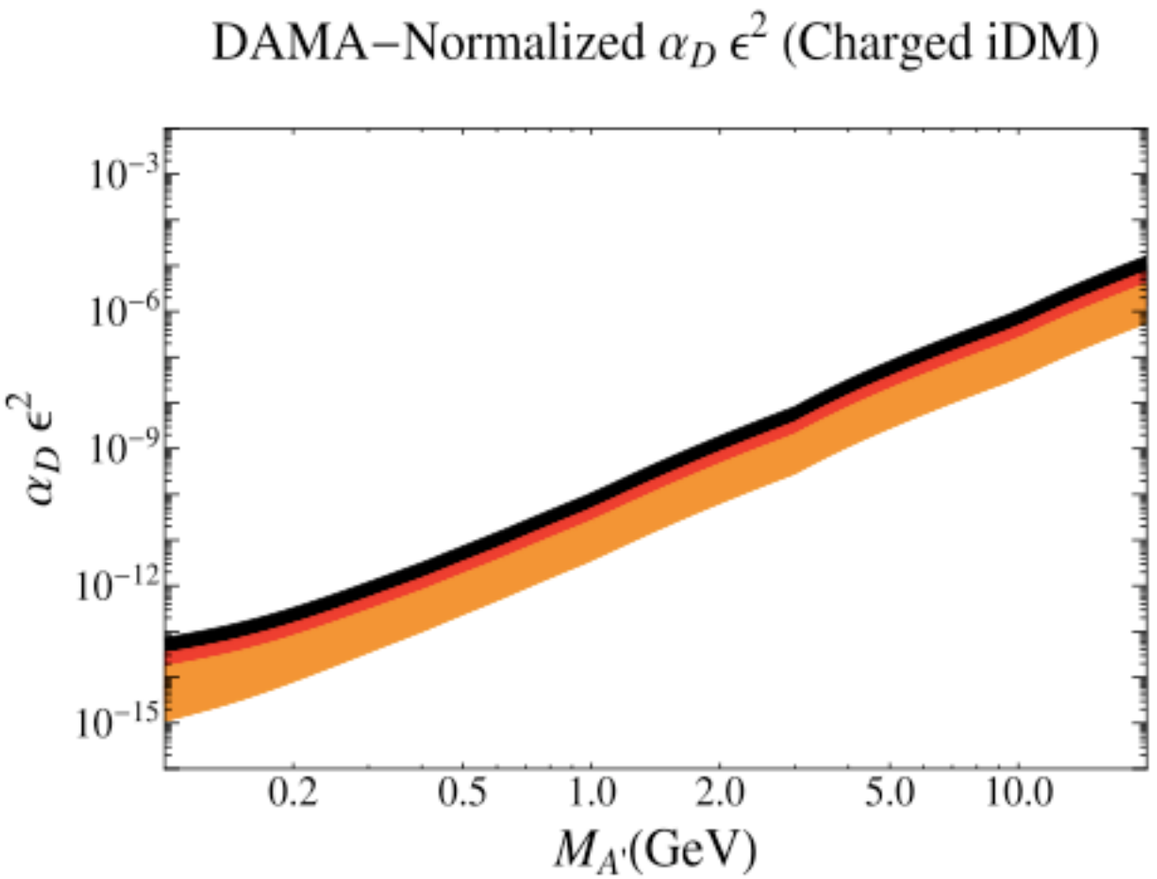
> 10^3-10^5 events





DAMA normalized couplings



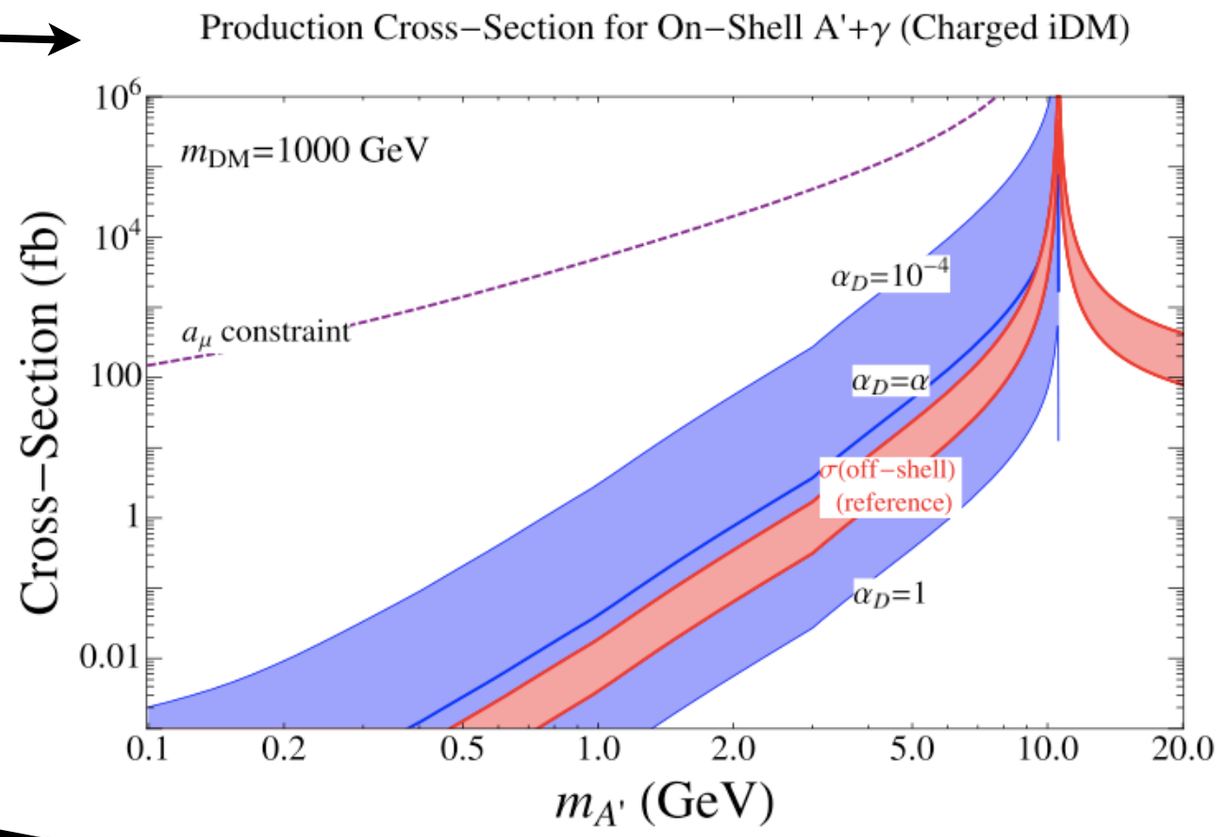


$$\alpha_D \epsilon^2 \propto m_{A'}^4$$

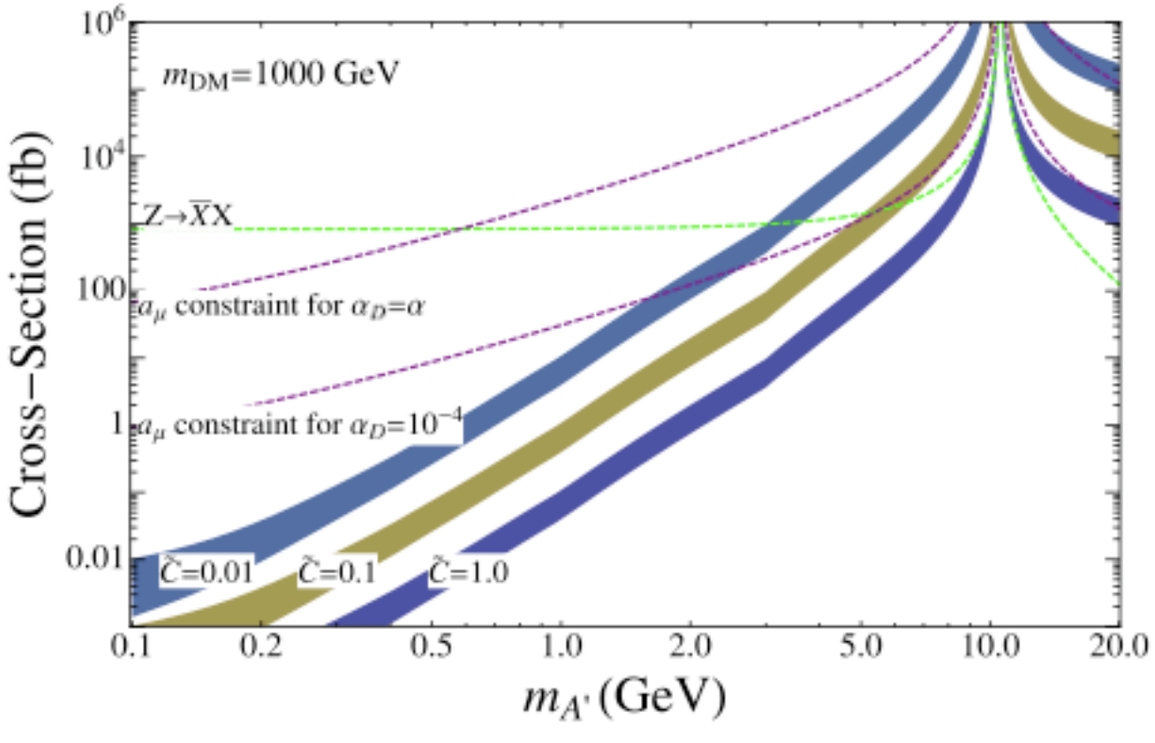
DAMA normalized production cross-sections

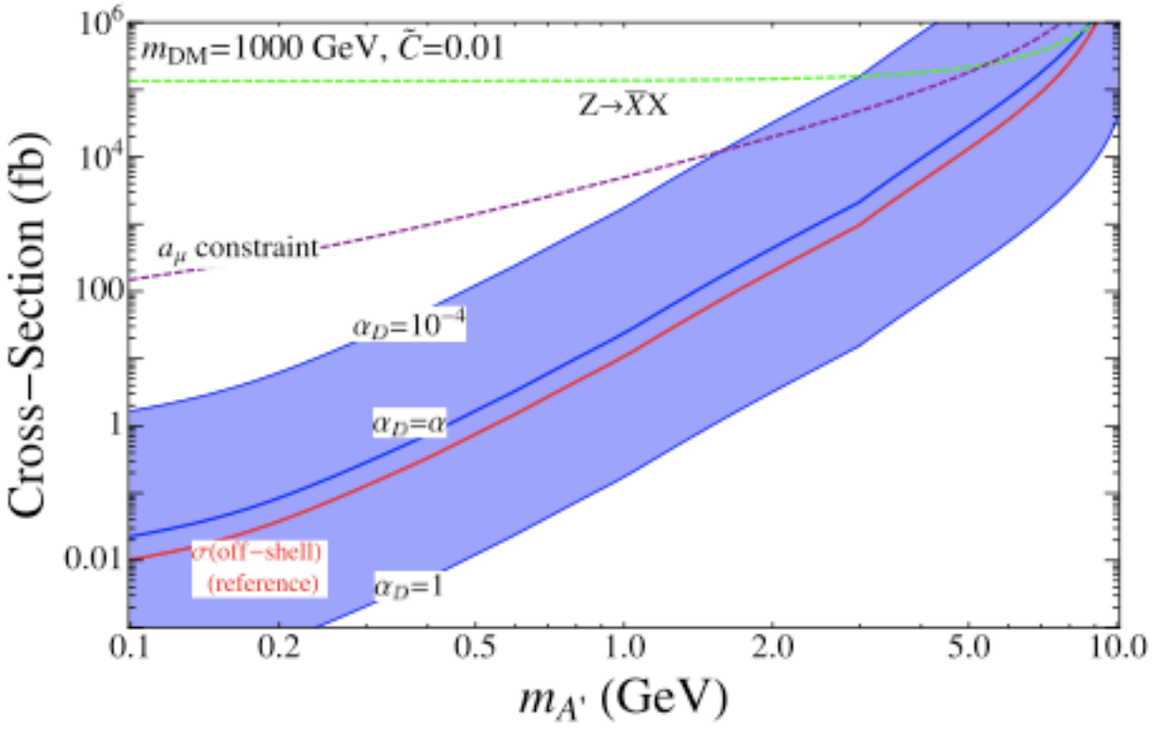
Higgsed case →

$$\sigma_{\text{B-factory}} \propto m_{A'}^4$$



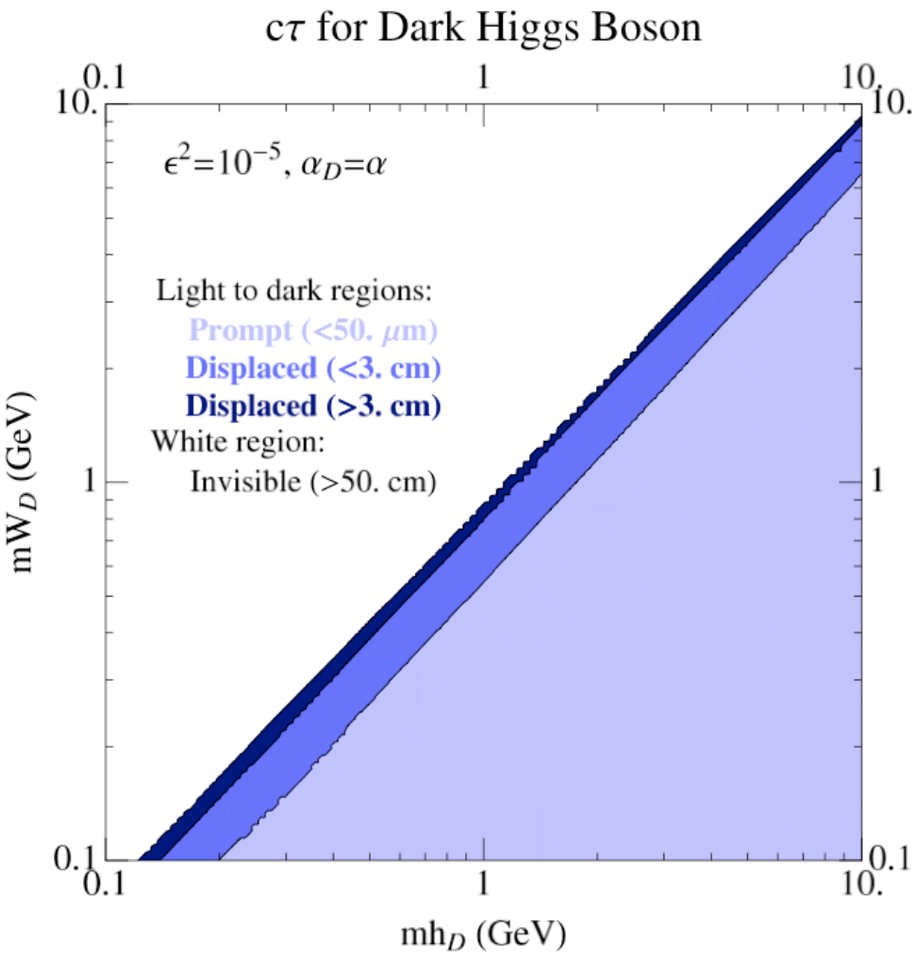
Confined case

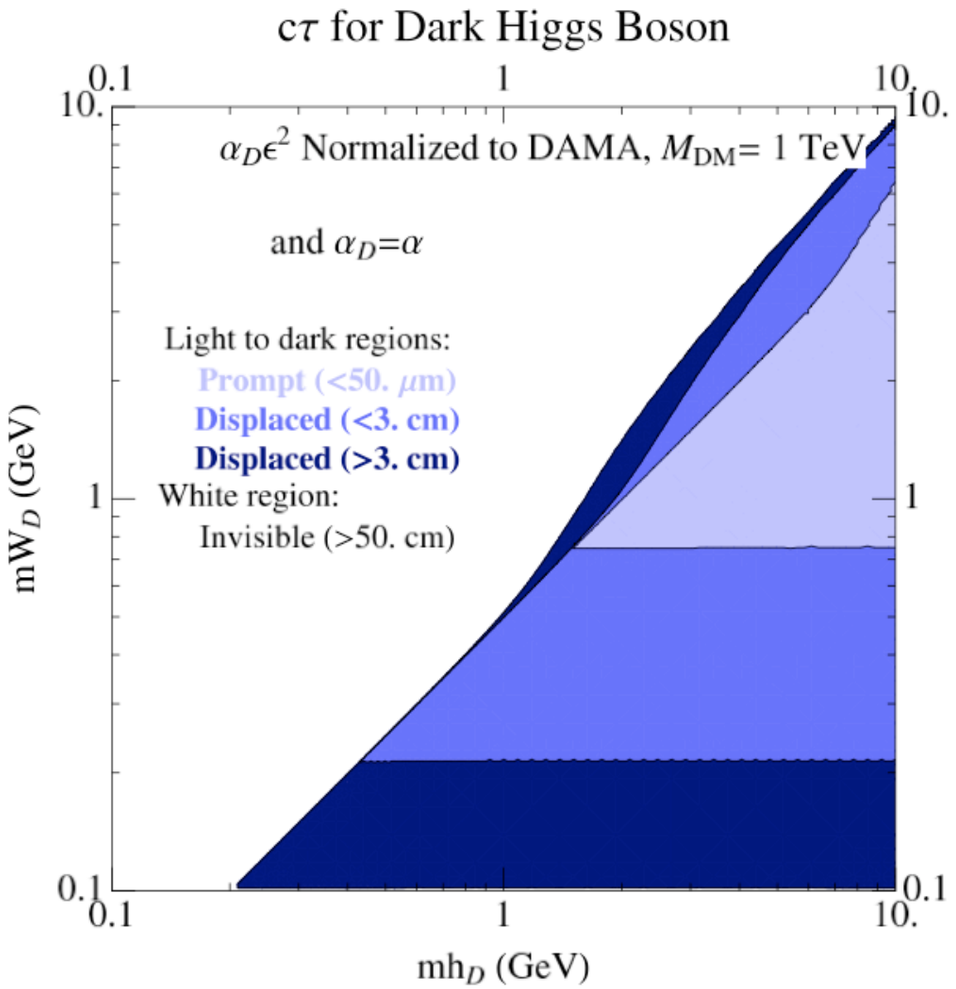




Decays in a Higgsed sector

$$c\tau(W_D \to \ell^+\ell^-) \sim 8 \times 10^{-6}\ \text{cm} \left(\frac{10^{-3}}{\epsilon}\right)^2 \theta^{-2} \left(\frac{1\,\text{GeV}}{m_{W_D}}\right)$$



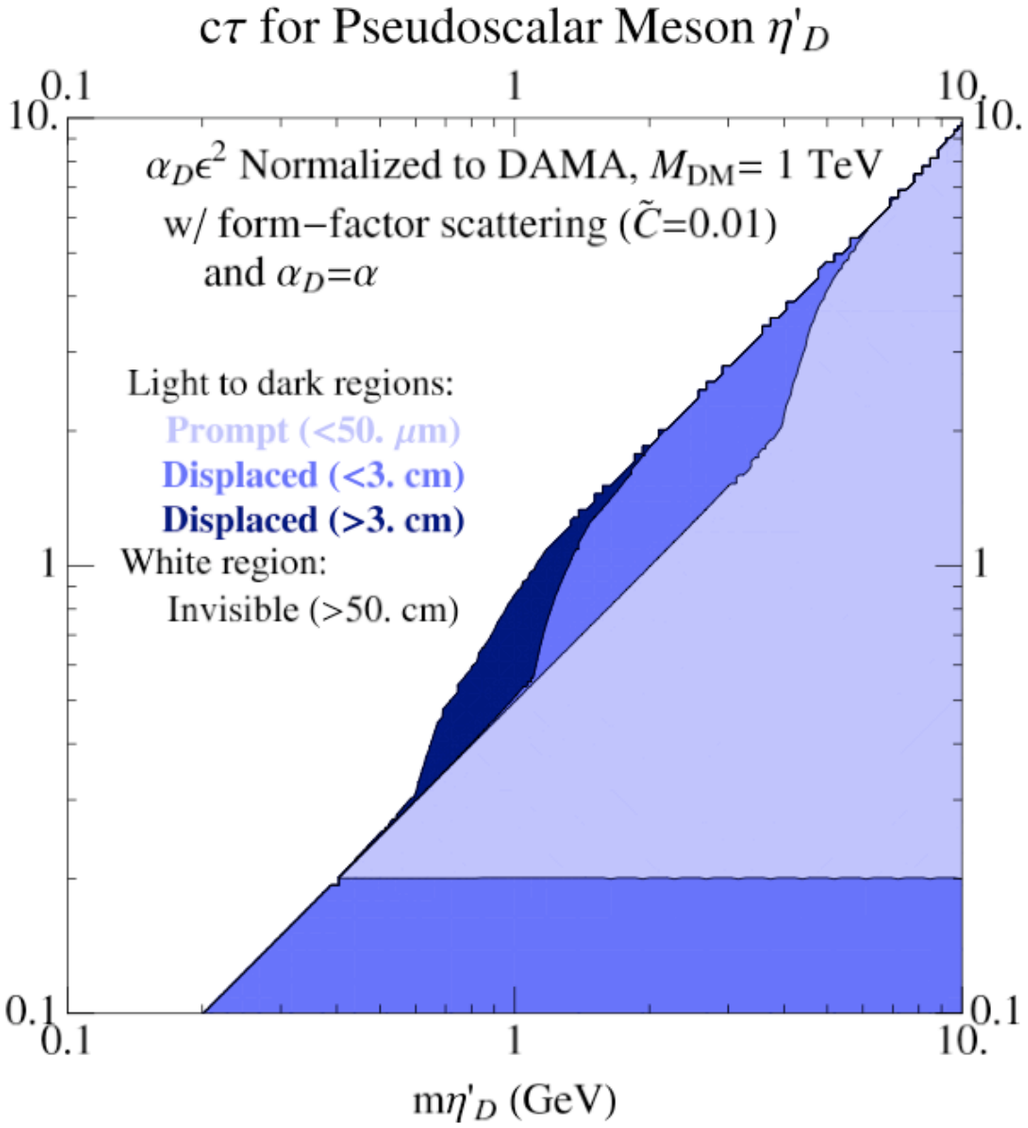


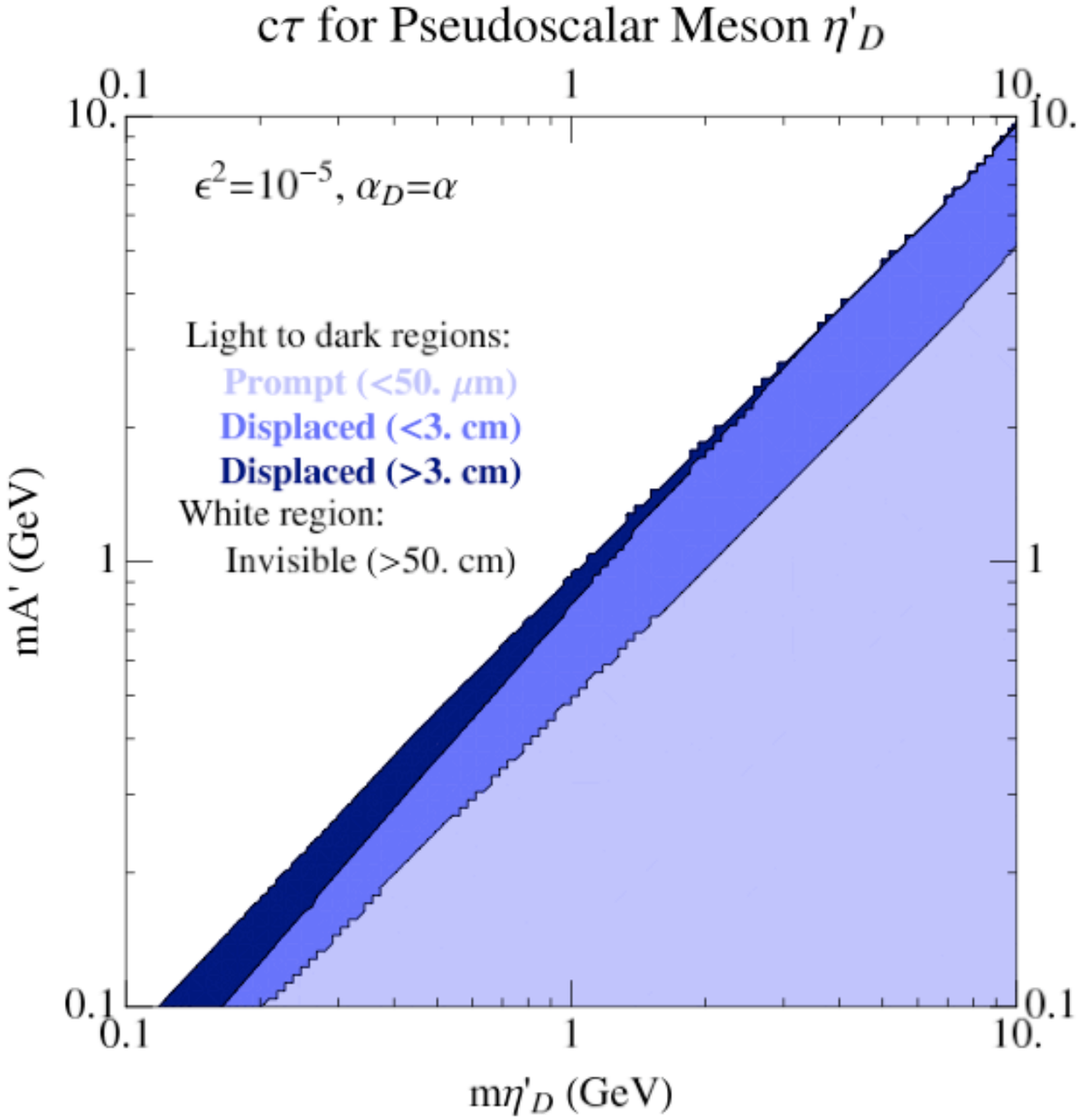
$$h_D \to W_D W_D$$ prompt

$$\Gamma(h_D \to W_D W_D^* \to W_D \ell^+\ell^-) \sim \frac{\alpha\alpha_D\epsilon^2}{128\pi} m_{h_D}$$ prompt, displaced, or invisible

Higgs decays through two off-shell W_D's are invisible

Decays in a confined sector





Searches at B-factories

- 4ℓ (exclusive), reconstructing $E_{\rm cm}$ (also $4\ell + \gamma$)
- 4ℓ (exclusive), with displaced dilepton vertices (also $4\ell + \gamma$)
- $\geq 5\ell + tracks$ (inclusive), reconstructing $E_{\rm cm}$ (also $+ \gamma$)
- $\geq 5\ell + tracks$ (inclusive), with displaced dilepton vertices (also $+ \gamma$)
- Very high track multiplicity, with many tracks consistent with leptons
- γ + nothing