Hidden Photons

in beam dump experiments

and in connection with Dark Matter

Sarah Andreas
DESY

October 16, 2012

DARK2012 - Dark Forces at Accelerators

based on: 1209.6083 and 1109.2869

with A. Ringwald, C. Niebuhr, M. Goodsell

Outline

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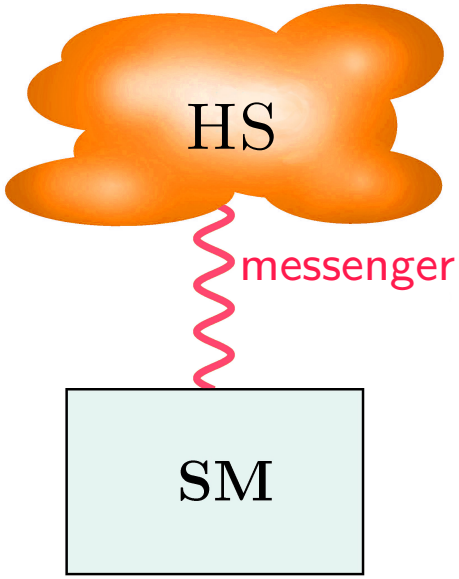
Hidden Sector

- Hidden Sectors often present in
  - string theories
  - supersymmetry
- HS not charged under SM gauge groups and v.v.
  - no direct interaction between HS and SM
  - connection only through messenger particles



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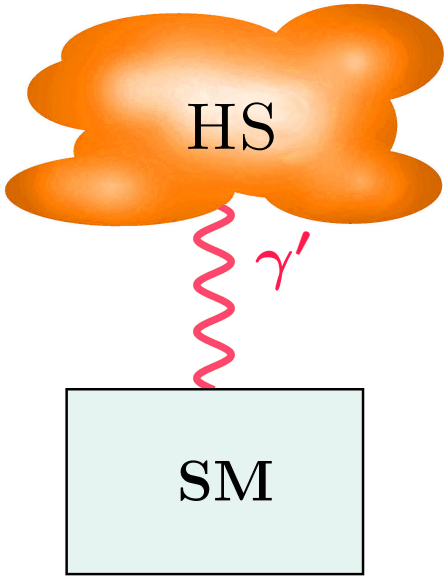


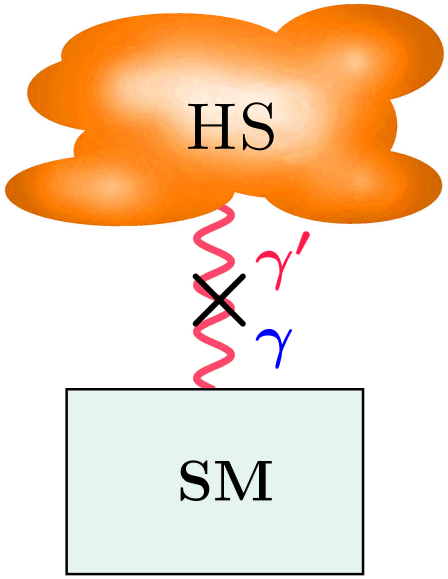
- Hidden Sectors often present in
  - string theories
  - supersymmetry
- HS not charged under SM gauge groups and v.v.
  - no direct interaction between HS and SM
  - connection only through messenger particles
- breaking of large gauge groups can yield hidden U(1)s

  (e.g. heterotic or type II strings, supersymmetric models)

$\Rightarrow$ (massive) Hidden Photon as messenger

Hidden Sector with Hidden Photon

talk M. Pospelov



- simplest scenario: HS with extra U(1)
  - mass-term for hidden Photon γ'
  - kinetic mixing χ with γ [Holdom'86; Galison, Manohar '84]

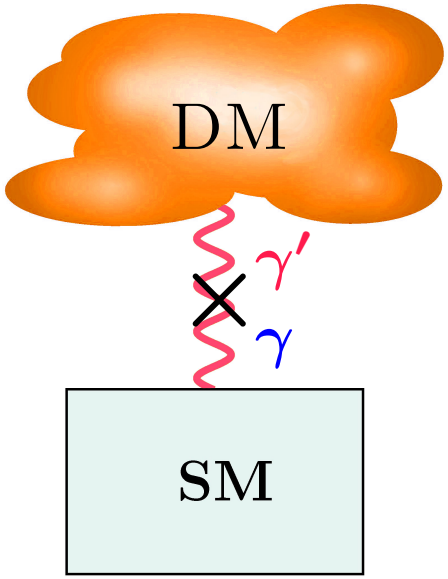
- most general Lagrangian

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} - \frac{1}{4} X_{\mu\nu} X^{\mu\nu} - \frac{\chi}{2} X_{\mu\nu} F^{\mu\nu} + \frac{m_{\gamma'}^2}{2} X_\mu X^\mu$$

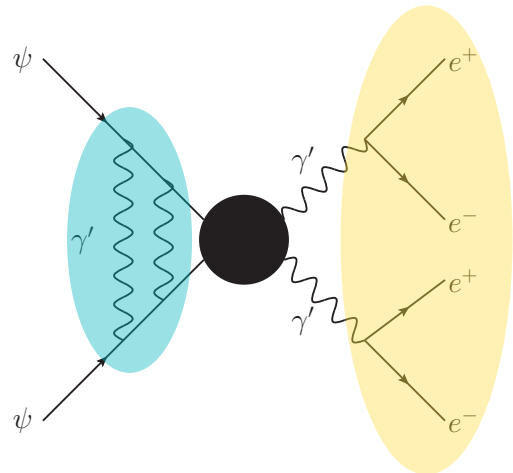
- γ' couples and decays to SM fermions through kinetic mixing

Dark Force and Dark Matter

talk C. Boehm

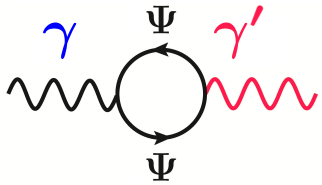


- HS can contain matter in addition to gauge fields
- observations by indirect & direct DM experiments
  - PAMELA & Fermi
  - DAMA, CoGeNT & CRESST
- interesting DM models where light messenger particle
  - generates Sommerfeld enhancement, [Arkani-Hamed, Finkbeiner, Slatyer, Weiner '09]
  - allows leptophilic DM annihilation,
  - mediates scattering on nuclei



$\Rightarrow$ experiments motivate GeV-scale Hidden Photon

Typical values for χ and $m_{\gamma'}$



Kinetic mixing

- from integrating out heavy particles charged under both U(1)s [Essig, Schuster, Toro '09; Cheung *et al.* '09, ...]
- χ generated at loop level: $\chi \sim \frac{g_Y g_h}{16\pi^2} \times \kappa \sim 10^{-3} - 10^{-4}$ for $\kappa \sim \mathcal{O}(1)$

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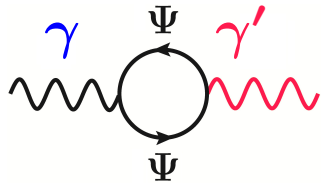

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Higgs mechanism

- masses roughly suppressed by χ: $m_{\gamma'} \simeq \sqrt{g_Y g_h c_{2\beta}}\sqrt{\chi}\,\mathrm{v}$ [Baumgart *et al.* '09, and following papers]

Stückelberg mechanism

- in certain (large volume) string compactifications [Goodsell *et al.* '09]

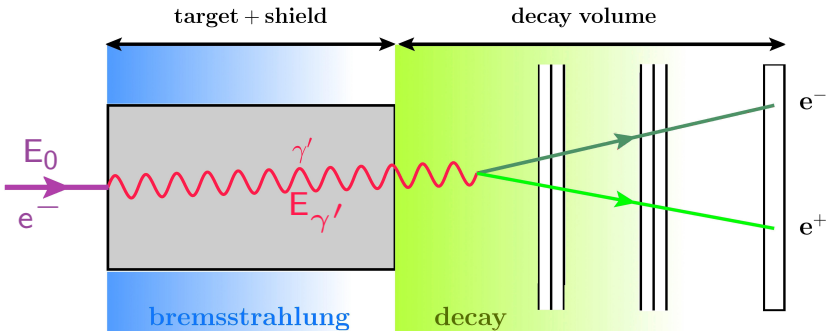
  mass depends on volume of extra dimension i.e. string-scale: $m_{\gamma'} \gtrsim \frac{M_S^2}{M_{Pl}}$
- intermediate string-scale: $M_S \sim 10^{9-10}$ GeV

  gives right regime for axion decay constant and ~~SUSY~~ scales

$\Rightarrow m_{\gamma'} \sim$ GeV-scale

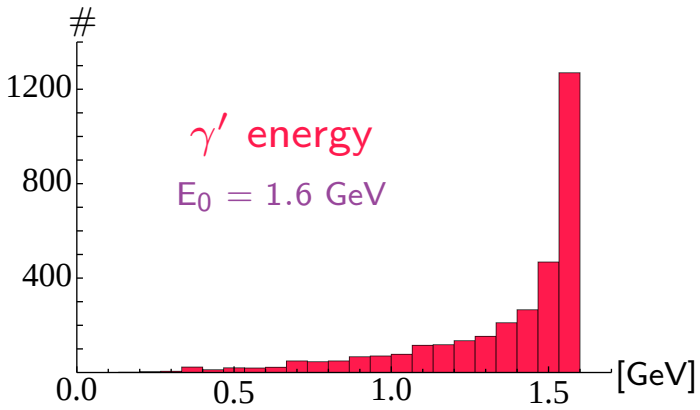
Outline

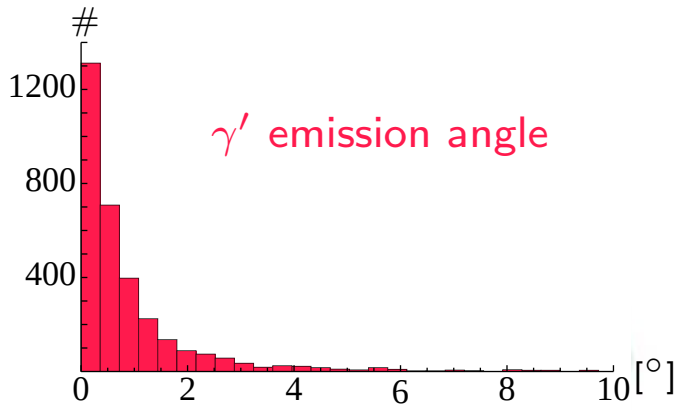
Beam dump experiments



- e^--beam incident on thick target
- production of γ'

  in process similar to ordinary Bremsstrahlung
- γ' carries most of beam energy
- emission of γ' at small angle in forward direction





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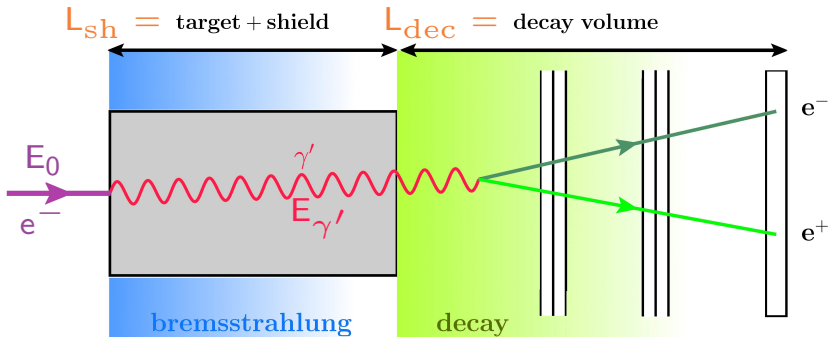


- γ' can penetrate the dump and decay before detector

$$l_{\gamma'} \sim \frac{E_{\gamma'}}{\alpha \chi^2 m_{\gamma'}^2} \sim 10\text{cm}\, \frac{E_{\gamma'}}{1\text{GeV}} \left(\frac{10^{-4}}{\chi}\right)^2 \left(\frac{10\text{MeV}}{m_{\gamma'}}\right)^2 \sim \mathcal{O}(\text{mm} - \text{km})$$

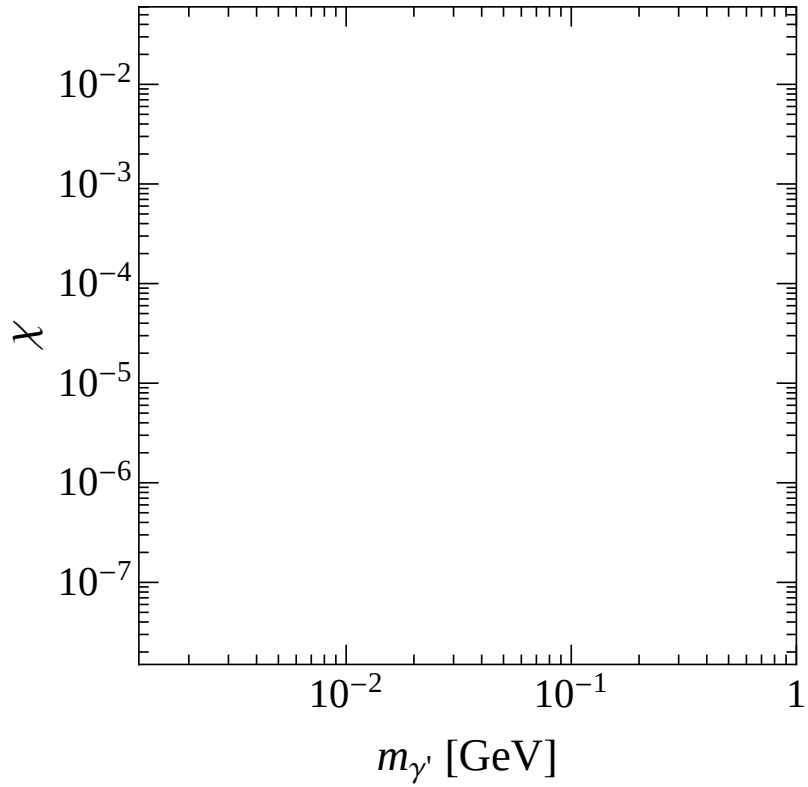
- number of expected γ' decays detected via decay products:

$$N_{\text{events}} \sim N_e\, n_{\text{sh}} \int dE_{\gamma'} \int dE_e \int dl\; I_e(E_0, E_e, l)\, \frac{d\sigma(E_{\gamma'}, E_e)}{dE_{\gamma'}}\, e^{-L_{\text{sh}}/l_{\gamma'}} \left(1 - e^{-L_{\text{det}}/l_{\gamma'}}\right) \text{BR}_{e^+e^-}$$

- generate events with Monte Carlo simulation [thanks to Rouven & Natalia]

  experimental acceptance from detector geometry & energy cuts [SA, Niebuhr, Ringwald '12]

Beam dump limits



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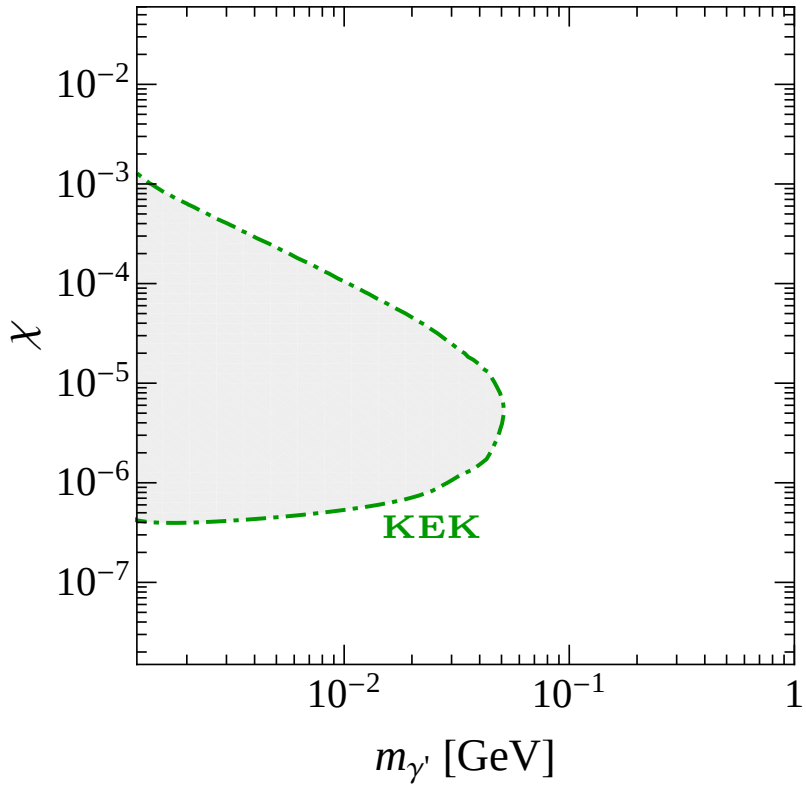

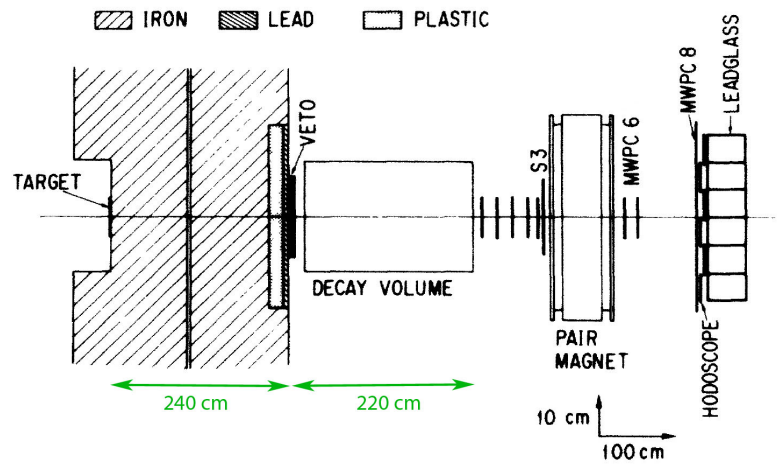

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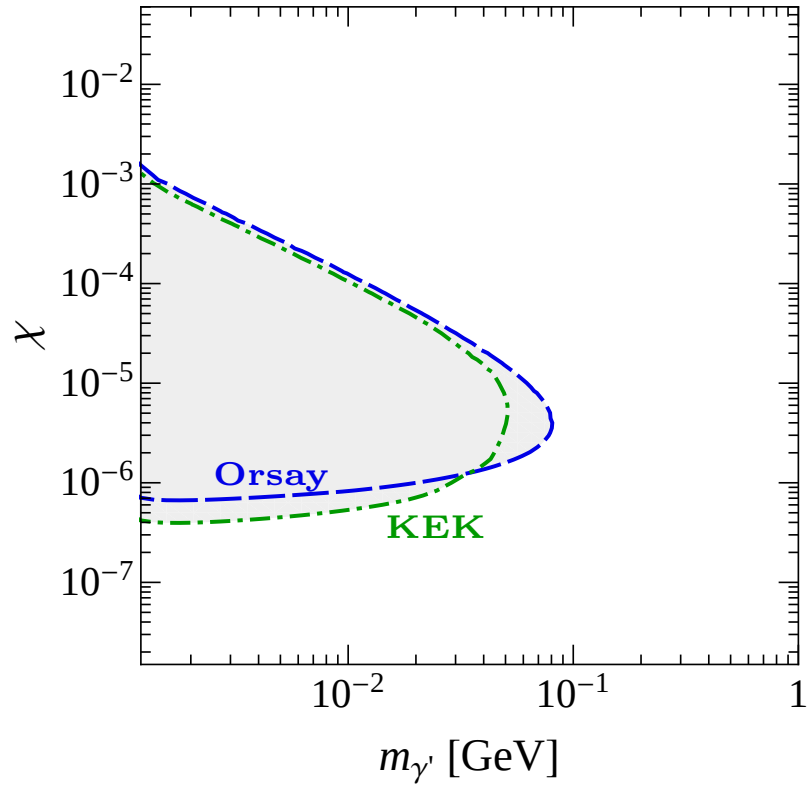

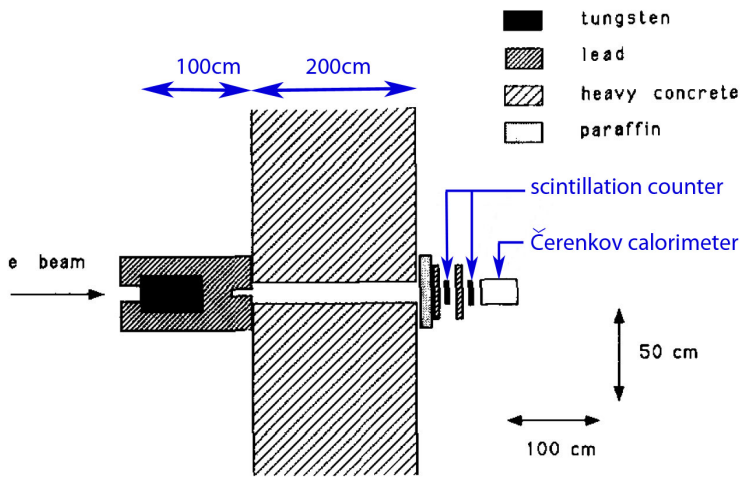

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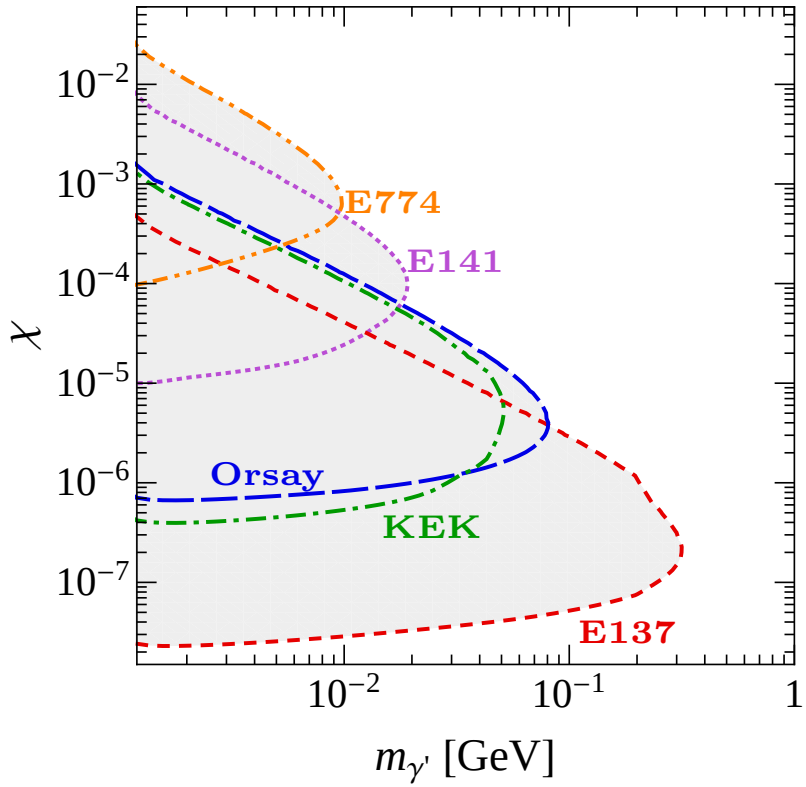

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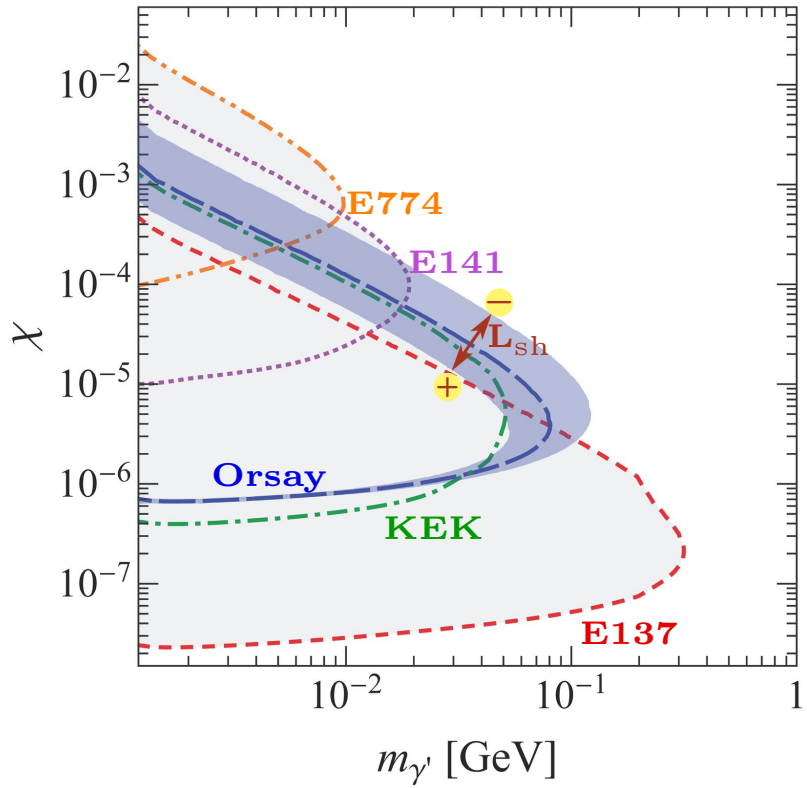

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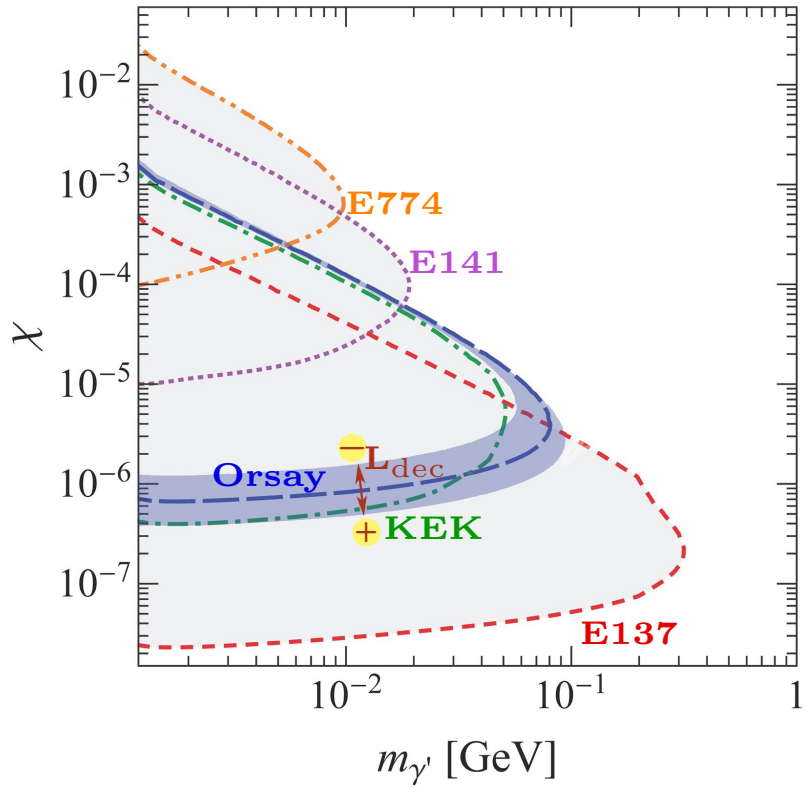

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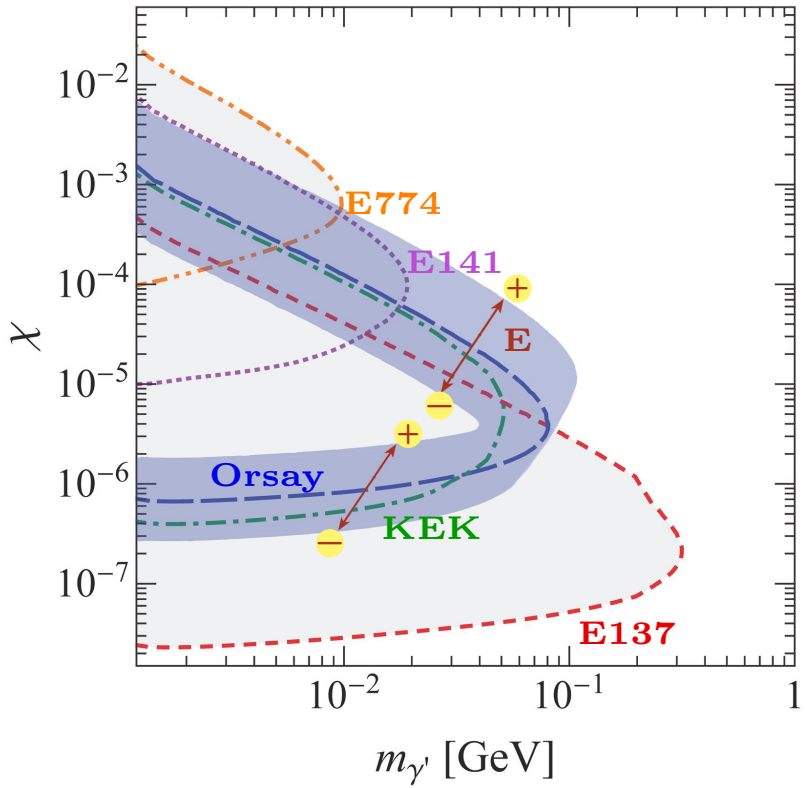

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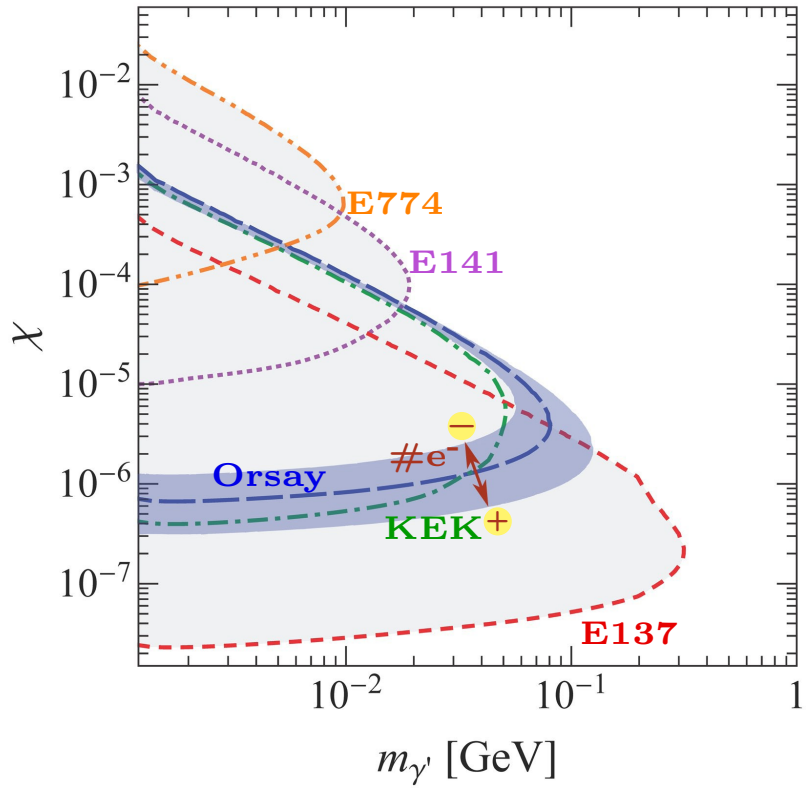

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Overview of all constraints

γ' from meson decays in proton beam dumps

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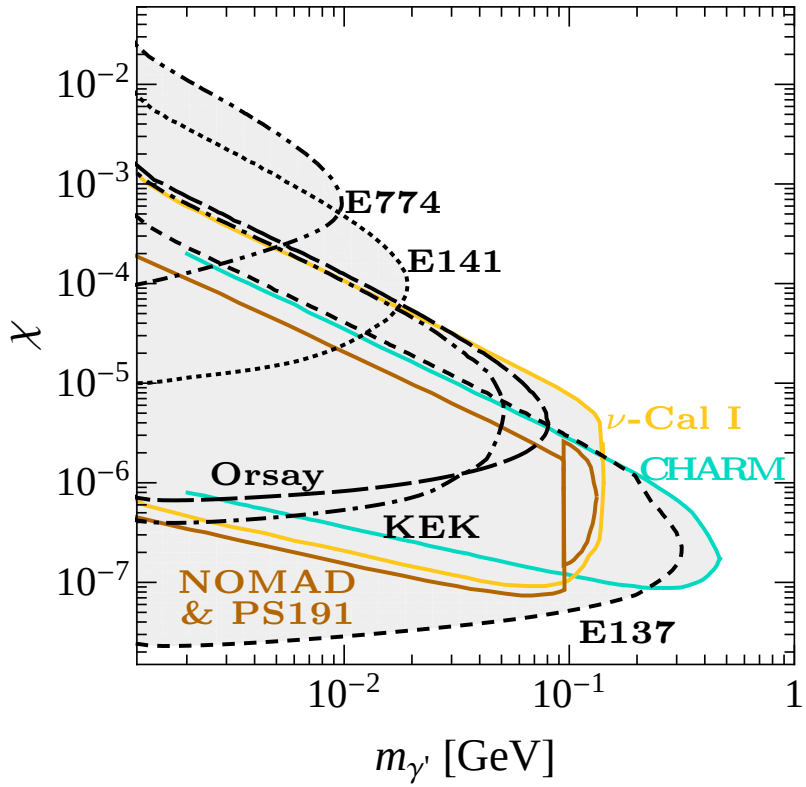

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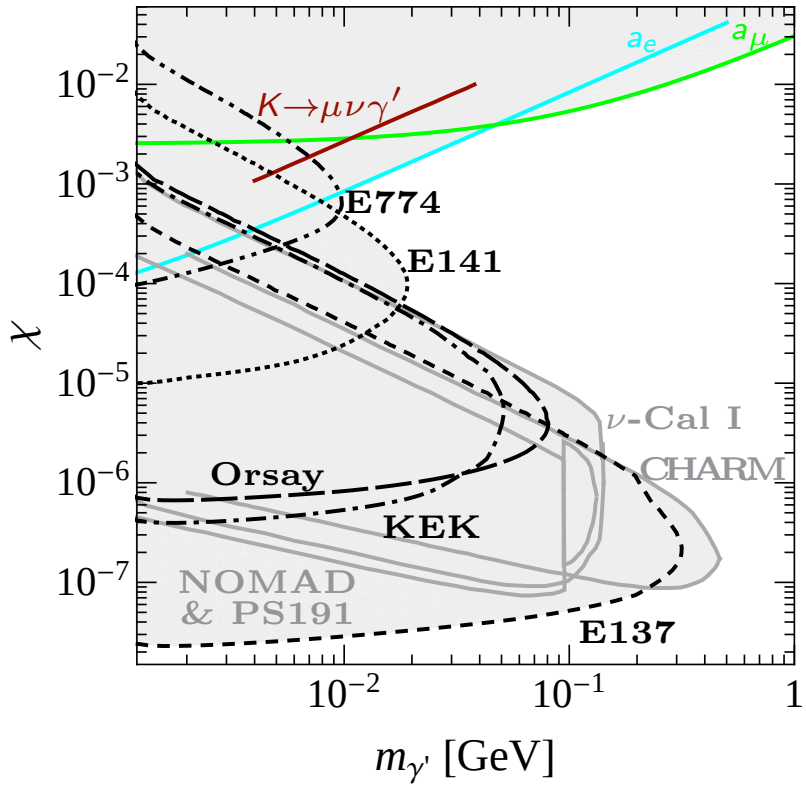

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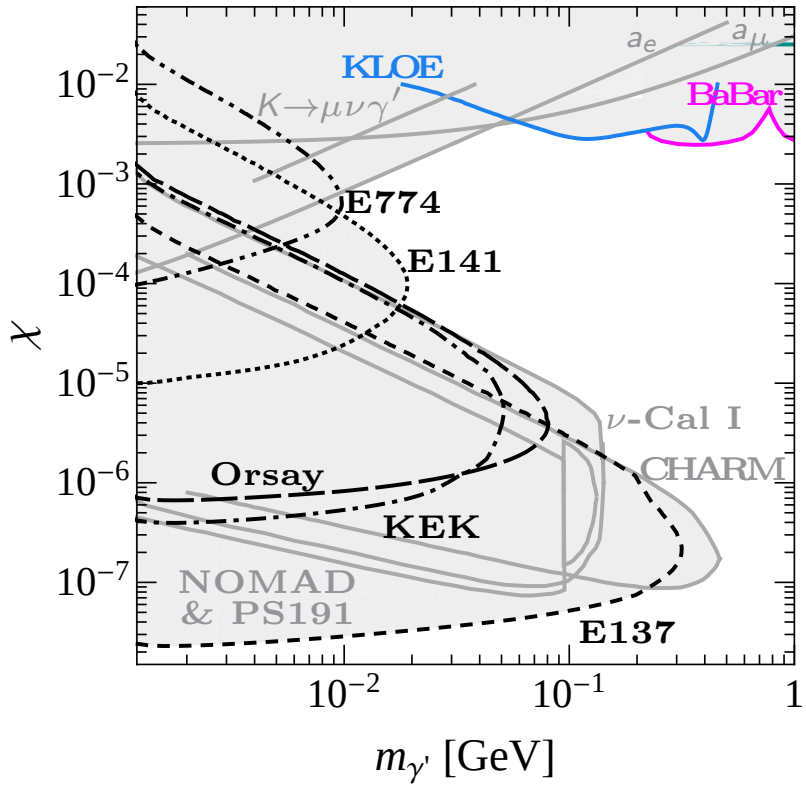

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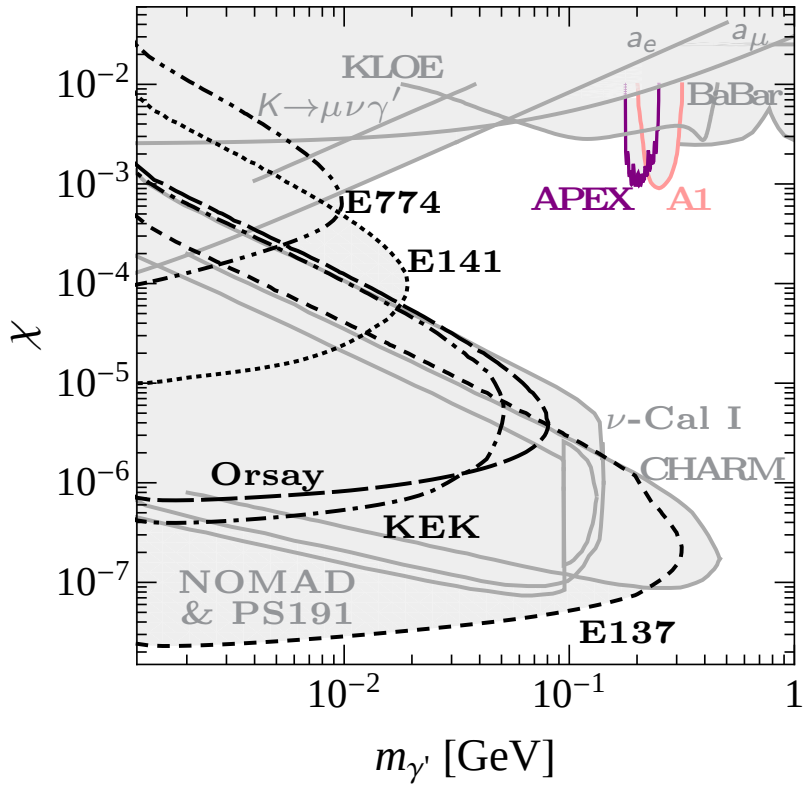
fixed target experiments with thin target

- A1 at MAMI in Mainz talk H. Merkel [Merkel *et al.* '11]
- APEX at JLab talk J. Beacham [Abrahamyan *et al.* '11]



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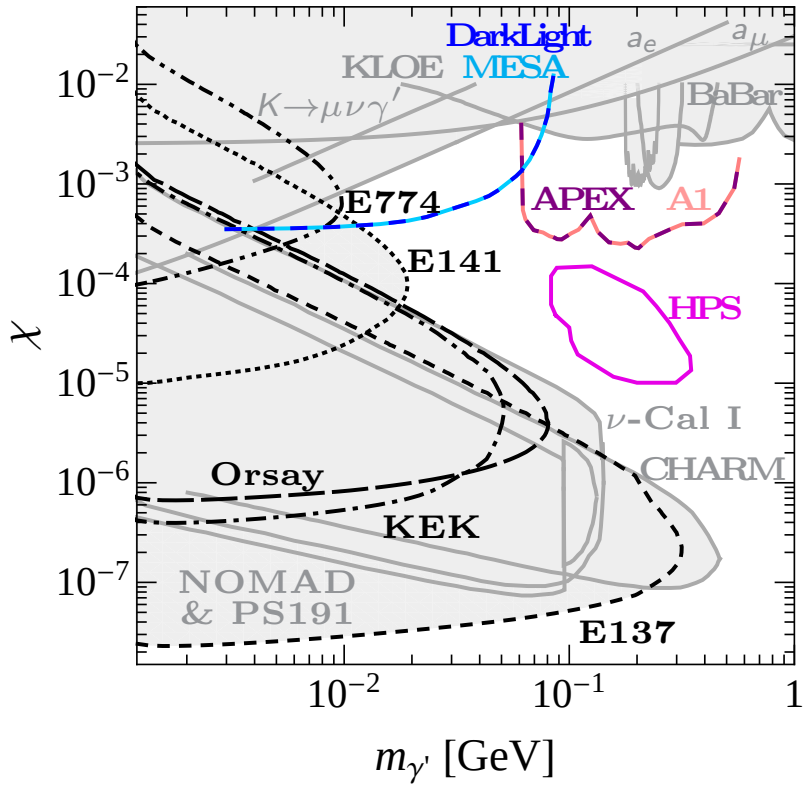


future searches

- JLab: APEX, DarkLight, HPS talk J. Boyce
- Mainz: A1, MESA talk J. Jaros talk T. Beranek

Outline

Toy-Model: Fermionic DM

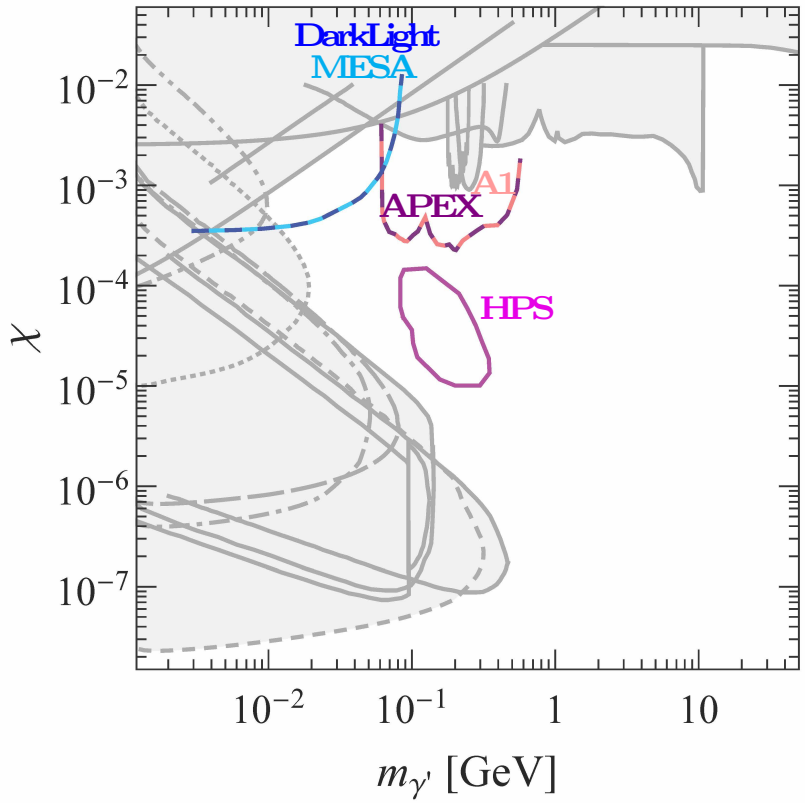
talk M. Pospelov

Simplest hidden sector with DF & DM

Hidden Photon with mass $m_{\gamma'}$ and mixing χ

Additional Dirac fermion ψ

- one extra mass parameter m_ψ



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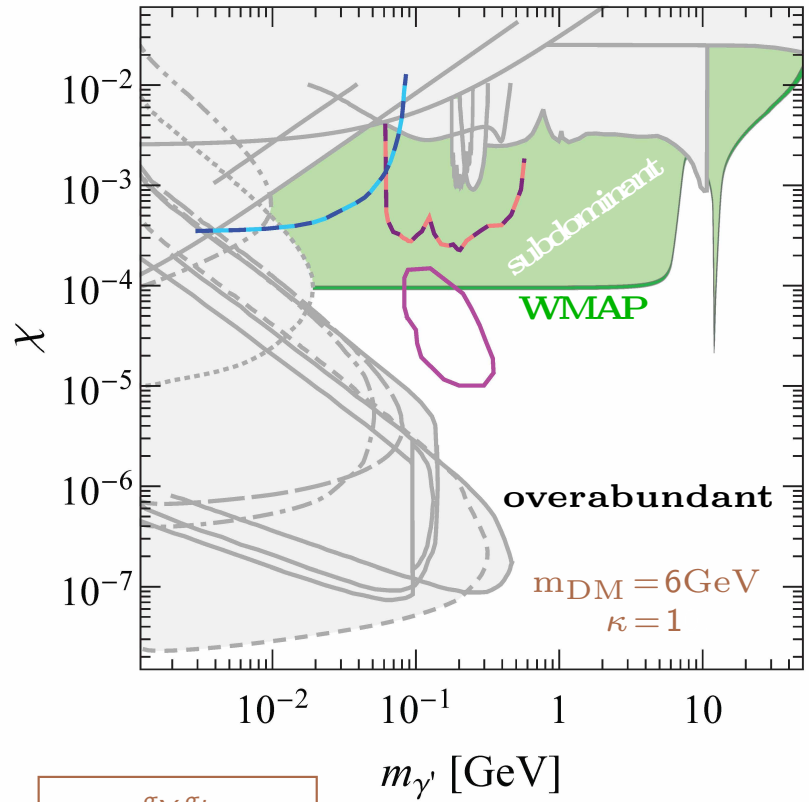
Relic abundance Ωh^2

- annihilation of ψ through and into γ'
- s-channel: resonance for $m_{\gamma'} = 2\ m_\psi$
- t-channel only when $m_{\gamma'} < m_\psi$

$\Rightarrow$ ψ total DM or subdominant component



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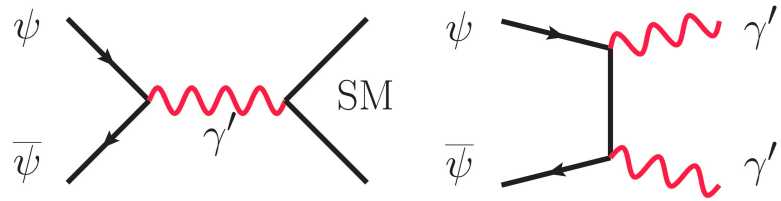

[Fayet '04; Pospelov, Ritz, Voloshin '08; Cheung, Ruderman, Wang, Yavin '09; Morrissey, Poland, Zurek '09; Dudas, Mambrini, Pokorski, Romagnoni '09; Chun, Park '10; Essig, Kaplan, Schuster, Toro '10; Mambrini '10; Cline, Frey '12; Hooper, Weiner, Xue '12]

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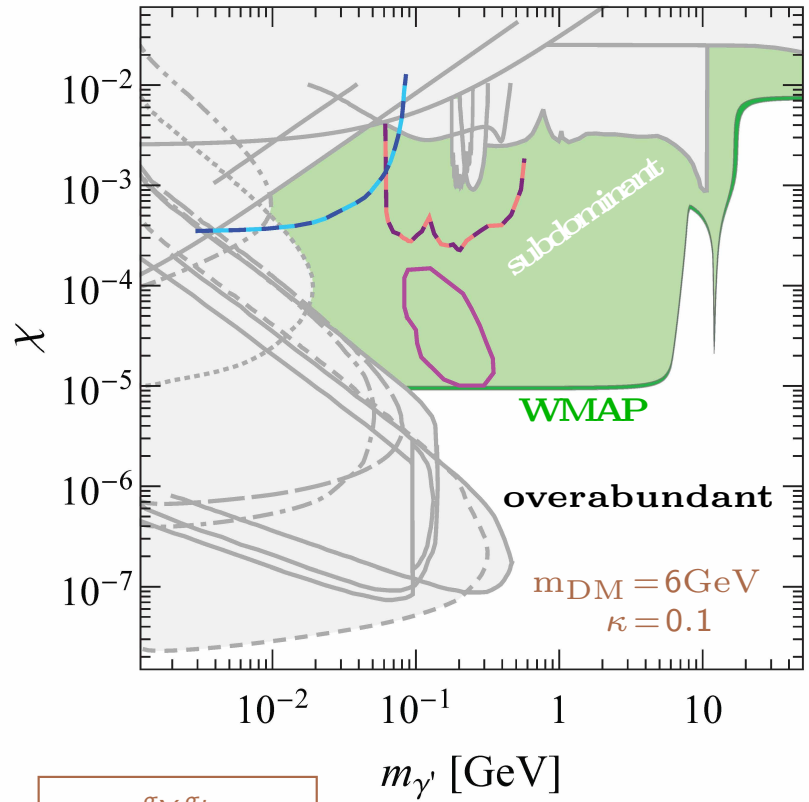
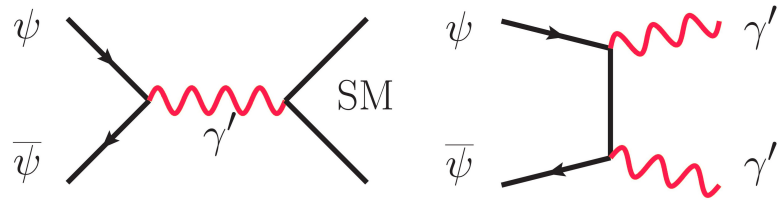
- t-channel only when $m_{\gamma'} < m_\psi$

$\Rightarrow$ ψ total DM or subdominant component



$$\chi = \frac{g_Y g_h}{16\pi^2} \times \kappa$$



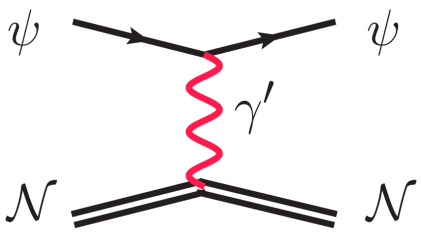
[Fayet '04; Pospelov, Ritz, Voloshin '08; Cheung, Ruderman, Wang, Yavin '09; Morrissey, Poland, Zurek '09; Dudas, Mambrini, Pokorski, Romagnoni '09; Chun, Park '10; Essig, Kaplan, Schuster, Toro '10; Mambrini '10; Cline, Frey '12; Hooper, Weiner, Xue '12]

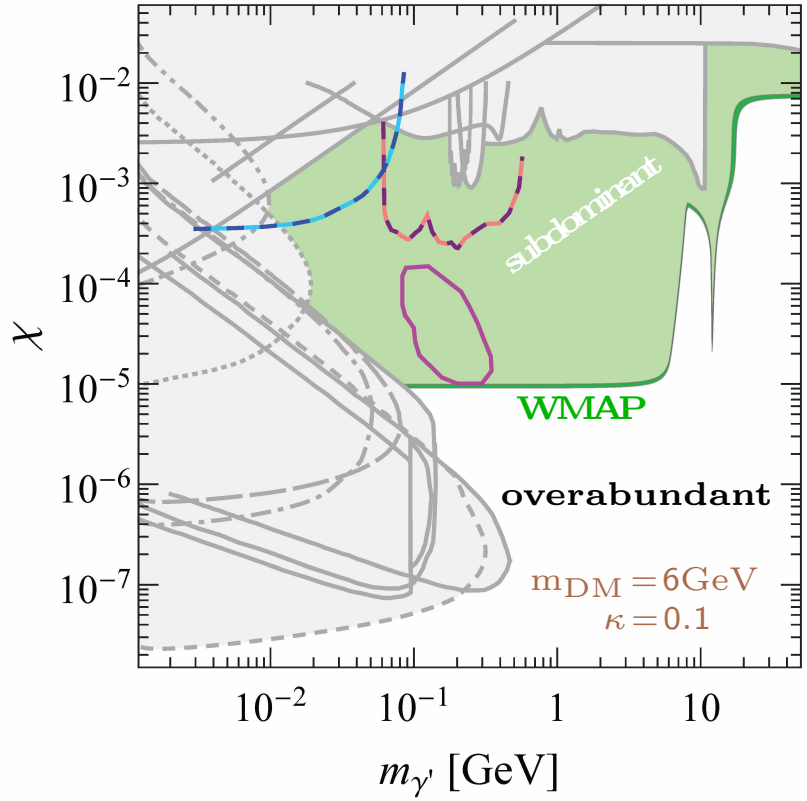
[SA, Goodsell, Ringwald '11]

Toy-Model: Fermionic DM

Direct Detection

- elastic scattering on nuclei
- mediated by γ'
- spin-independent vector-like interaction





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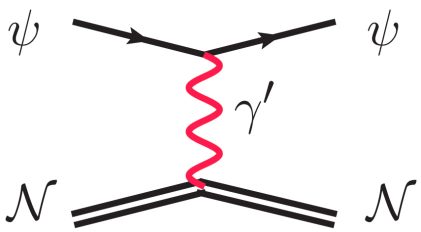

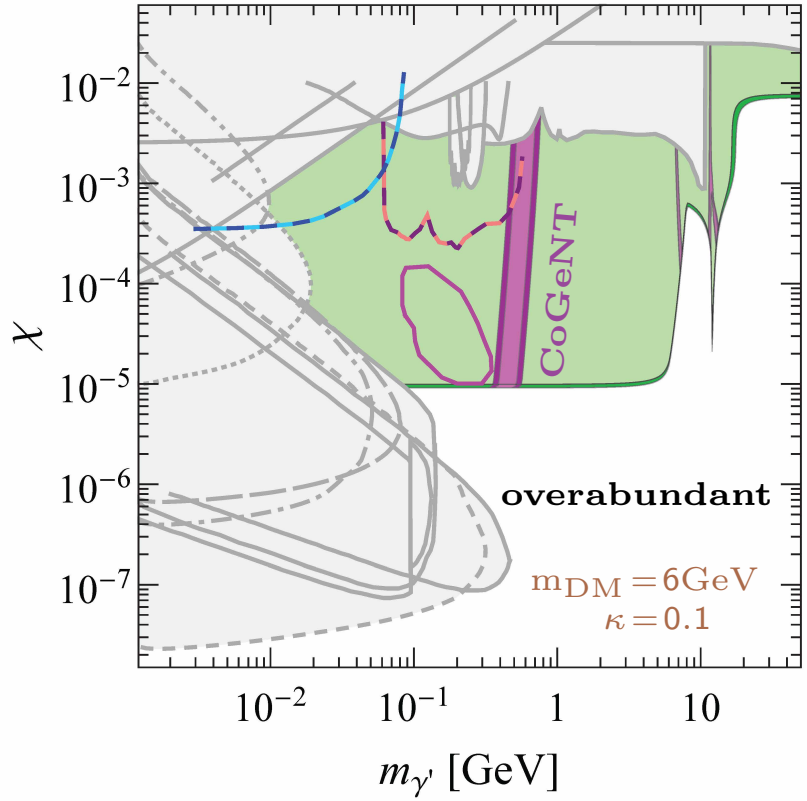

Comparison with experiments

- limits on σ_{SI} from CDMS & XENON
- potential signature in CoGeNT & DAMA

talk R. Cerulli

[SA, Goodsell, Ringwald '11]

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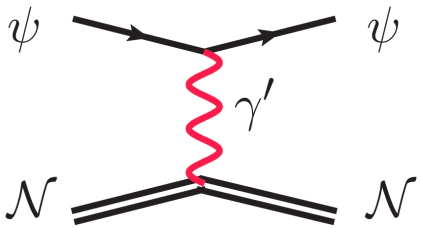

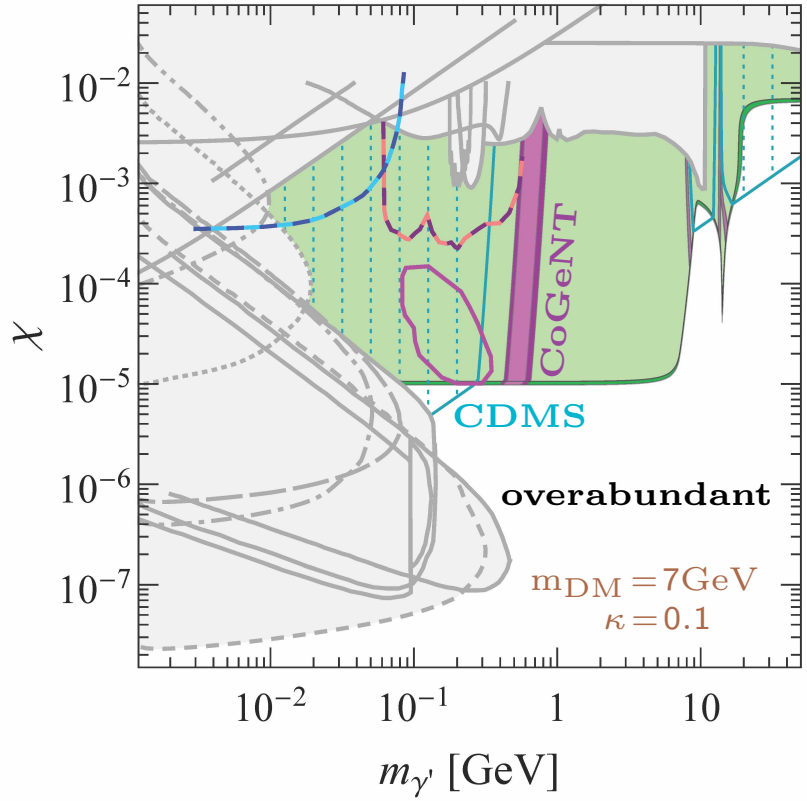

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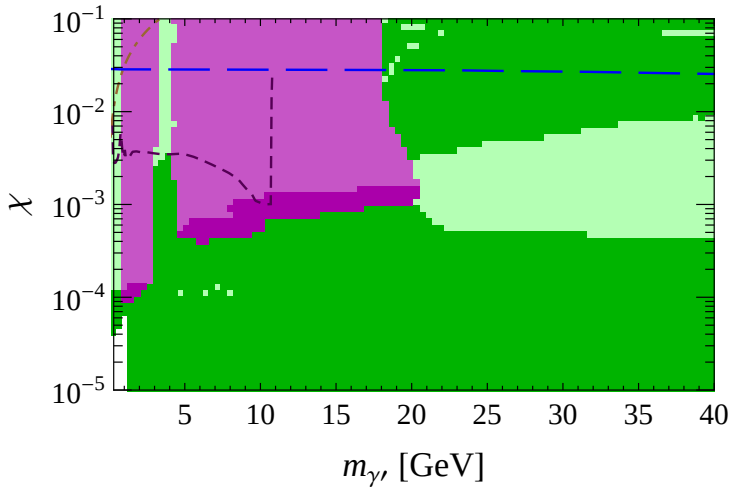

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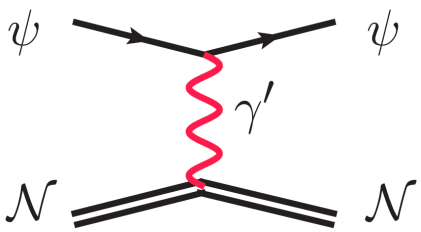

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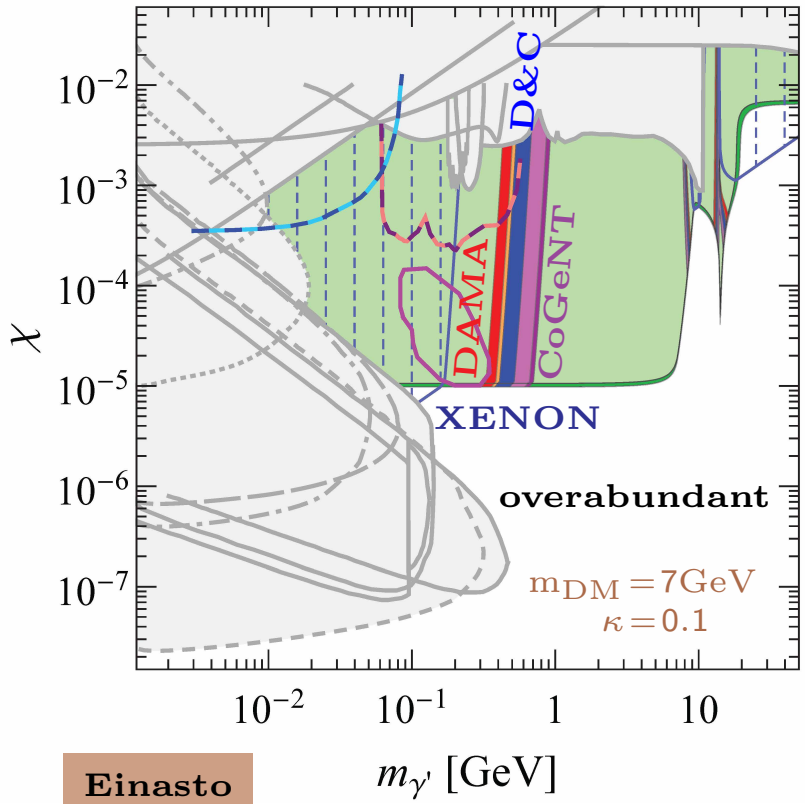
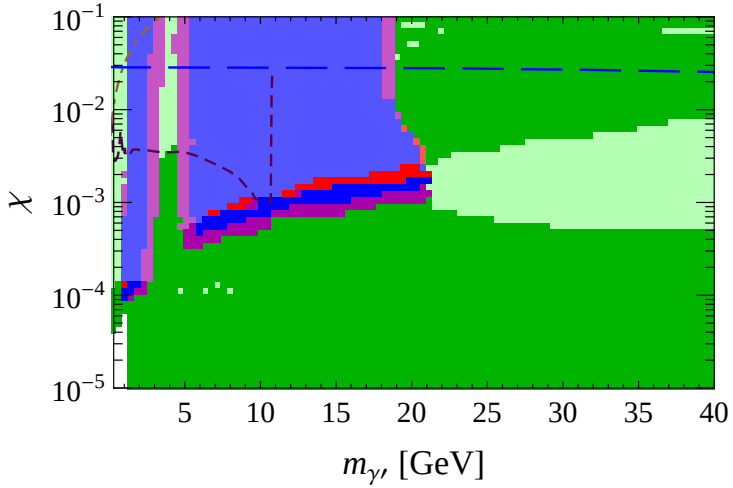


Einasto



Supersymmetric Dark Force models

- most simple anomaly-free HS:
  - three chiral superfields S, H_+, H_- charged under $\mathrm{U}(1)_h$
  - superpotential: $W \supset \lambda_S \, S H_+ H_-$

    (assume MSSM in visible sector)

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- consider gravity mediation gauge med. in [Morrissey, Poland, Zurek '09]

  $\Rightarrow$ gravitino is not the LSP

  $\Rightarrow$ DM can consist of stable hidden sector particle

  is either Majorana or Dirac fermion

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- hidden gauge symmetry breaking:
  - radiatively through running
  - induced by visible sector

[SA, Goodsell, Ringwald '11]

Radiative breaking

- running of Yukawa coupling λ_S induces breaking of hidden gauge symmetry
  - choose suitable masses and couplings at high energy scale and run down

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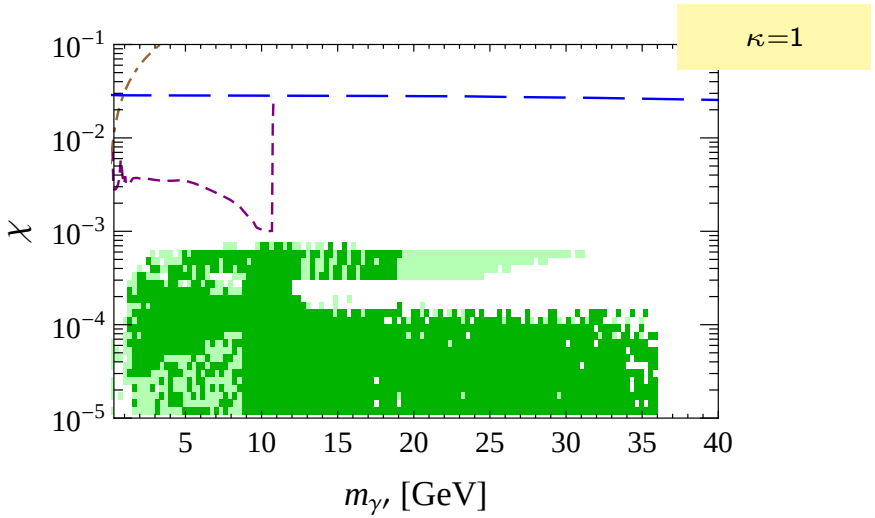
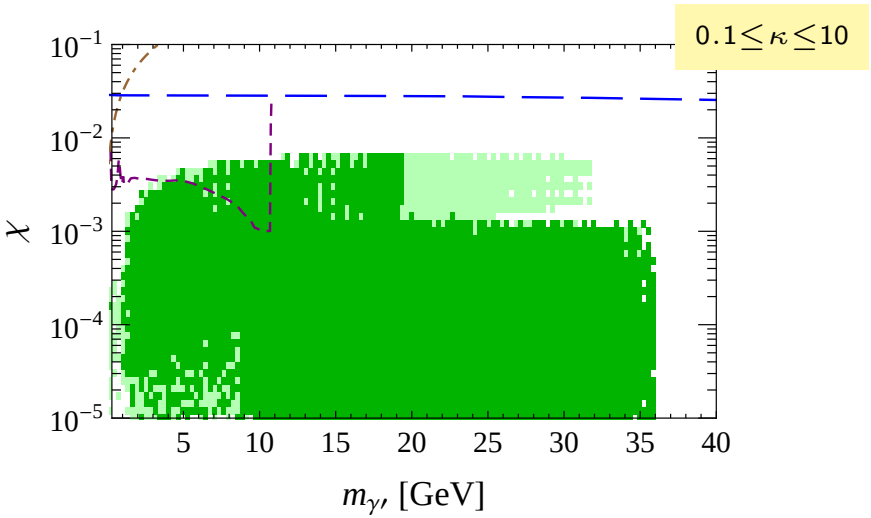
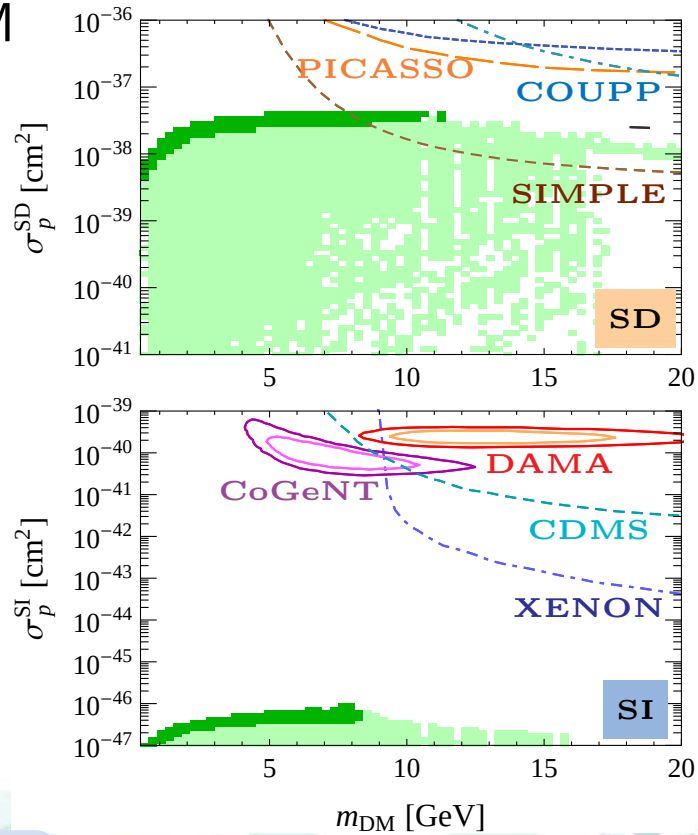


[SA, Goodsell, Ringwald '11]

Radiative breaking

- running of Yukawa coupling λ_S induces breaking of hidden gauge symmetry
  - choose suitable masses and couplings at high energy scale and run down
- Majorana fermion Ψ_M: total & subdominant DM
  - axial coupling generates SD scattering
  - minor SI scattering (Higgs Portal $\sim 10^{-46}\text{cm}^{-2}$)





⇒ SD in reach of experiments | SI bejond reach

[SA, Goodsell, Ringwald '11]

Visible sector induced breaking

- via effective Fayet-Iliopoulos term
  - assume gravitino heavier than HS

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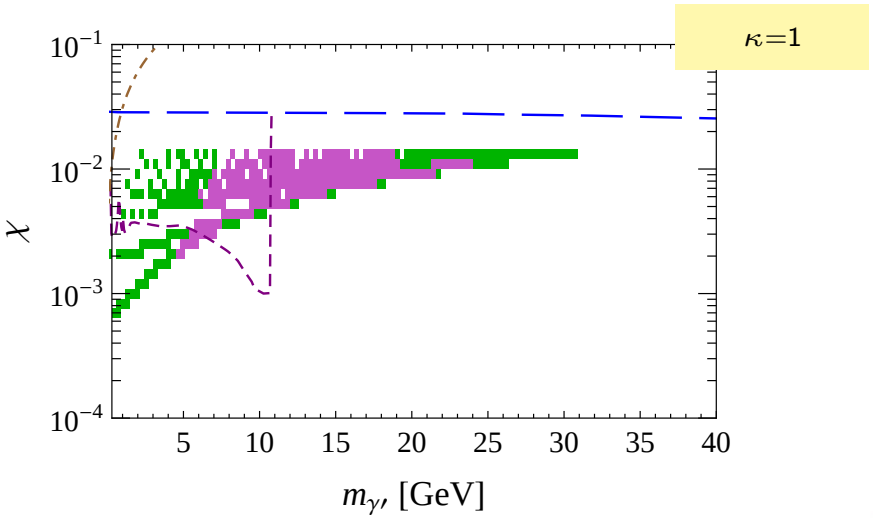
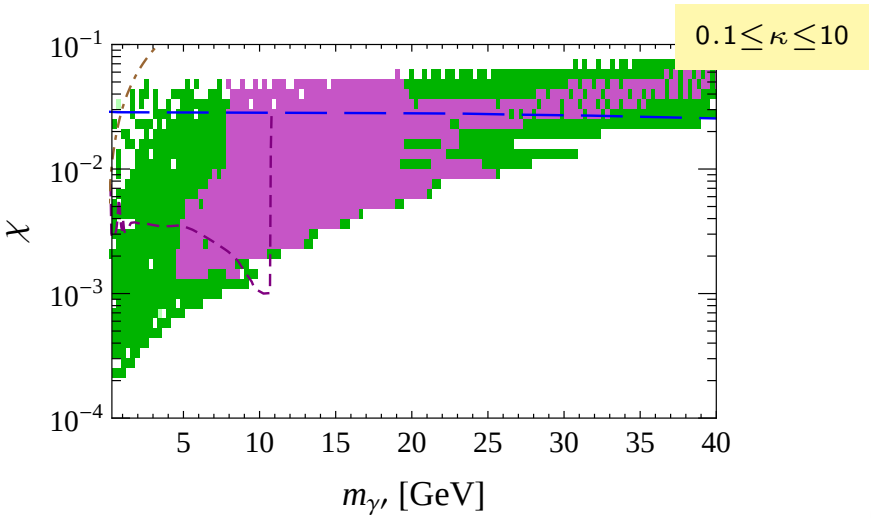
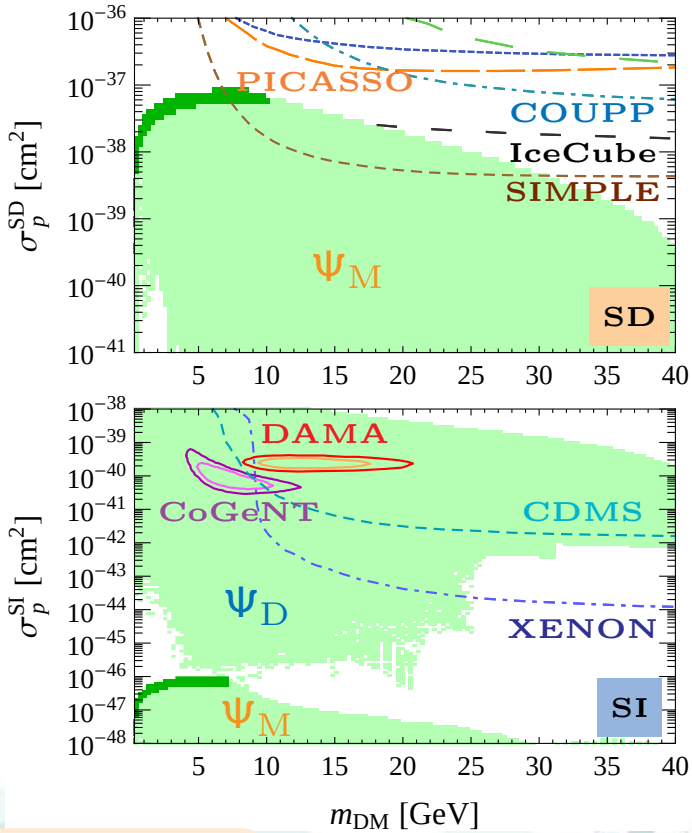


[SA, Goodsell, Ringwald '11]

Visible sector induced breaking

- via effective Fayet-Iliopoulos term
  - assume gravitino heavier than HS
- Majorana & Dirac fermion as DM
  - Ψ_M: mostly SD (like rad. breaking)
  - Ψ_D: mostly SI (like Toy-Model, but $m_\Psi < m_{\gamma'}$)





⇒SI fits DAMA & CoGeNT SD in reach of experiments

[SA, Goodsell, Ringwald '11]

Outline

Conclusions

- hidden sector
  - well motivated & interesting phenomenology
- hidden photons as dark force
  - need high intensity experiments, e.g. beam dumps
  - constrained and currently further explored
- dark matter in HS
  - viable as total & subdominant DM with potential for DD
  - SUSY models with gravity mediation

    yield Majorana or Dirac fermion as viable DM candidates