Hidden Photons in Electron Beam Dump Experiments

Sarah Andreas

DESY

June 25th, 2013

Workshop on Particle Physics Opportunities at IRIDE

in collaboration with Mark Goodsell, Carsten Niebuhr and Andreas Ringwald

based on: Phys.Rev. D87 (2013) 025007, Phys.Rev. D86 (2012) 095019

proceedings: arXiv:1008.4519, arXiv:1110.2636, arXiv:1211.5160, arXiv:1212.4520, arXiv:1306.1168

Outline

Hidden Sectors

Hidden Sector (HS)

- set of SM-neutral particles
- charged under additional gauge group

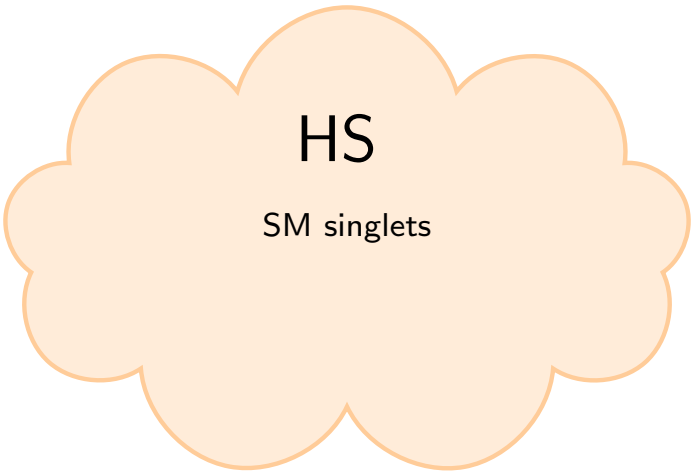
SM

$SU(3)_C \times SU(2)_L \times U(1)_Y$

Visible Sector

- Standard Model (SM) particles and interactions

Hidden Sectors



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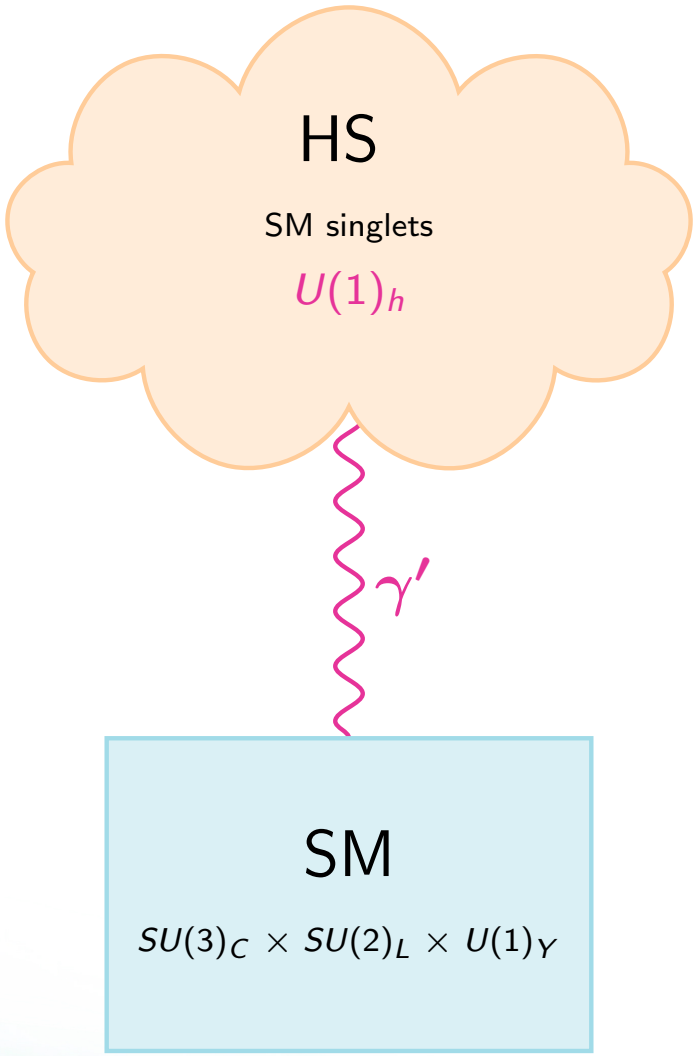

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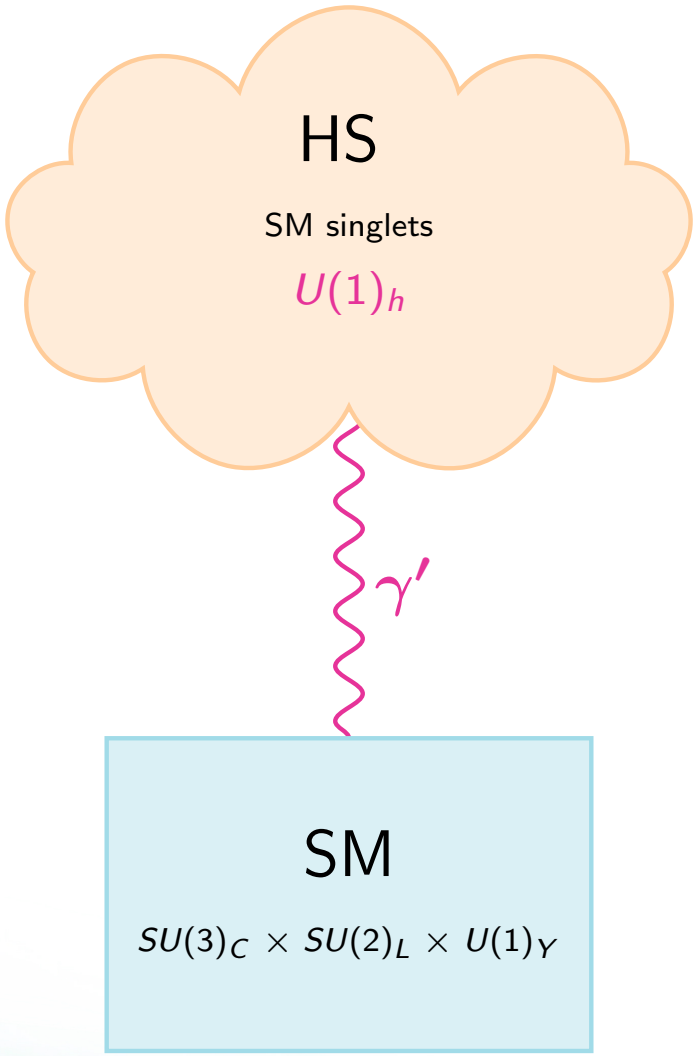

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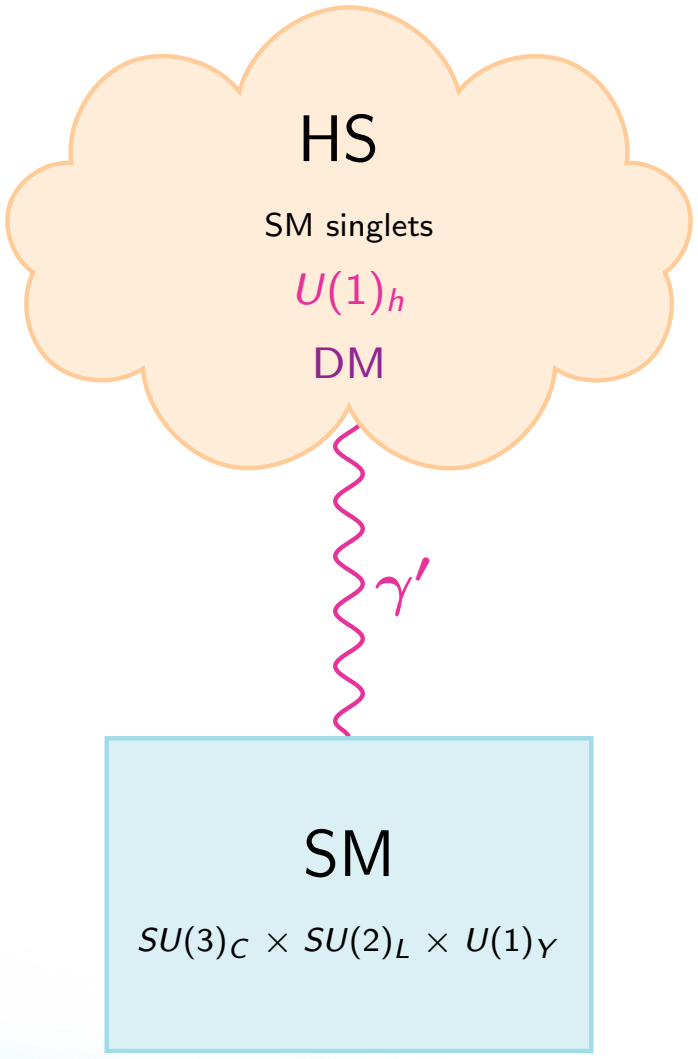

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  breaking of large gauge groups yields extra $U(1)$s
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- good hideout for Dark Matter (DM)

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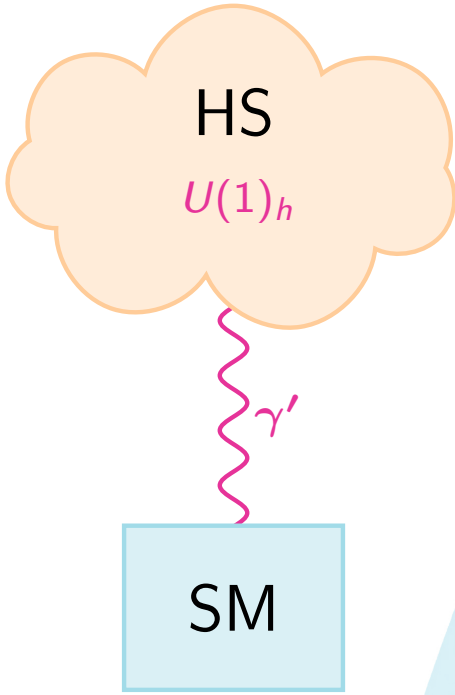
Hidden Photons and Dark Matter

interaction via a messenger e.g. γ'

$\Rightarrow$ phenomenologically interesting features:



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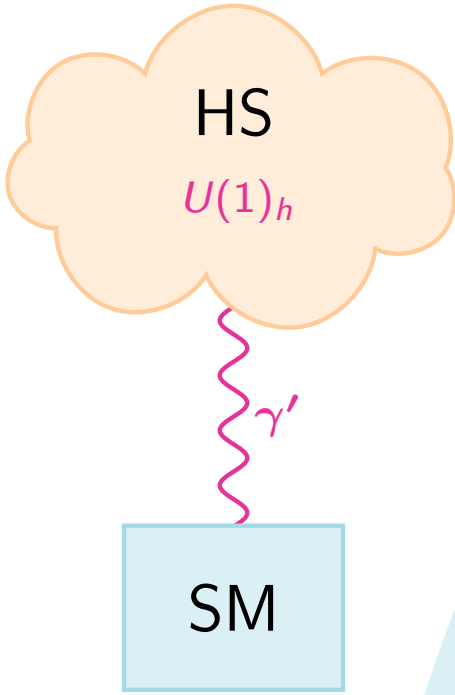

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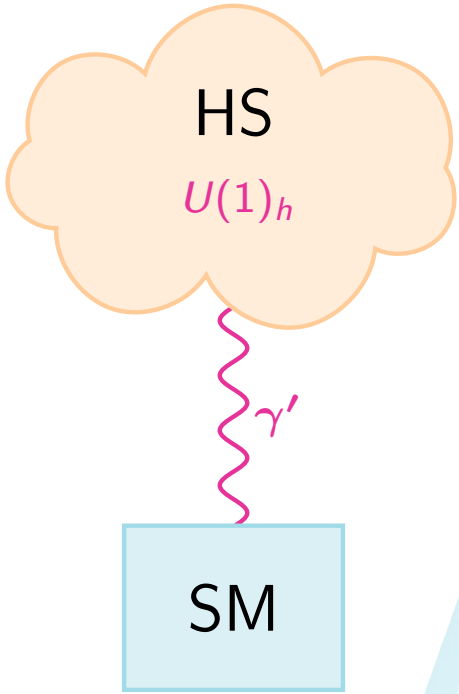

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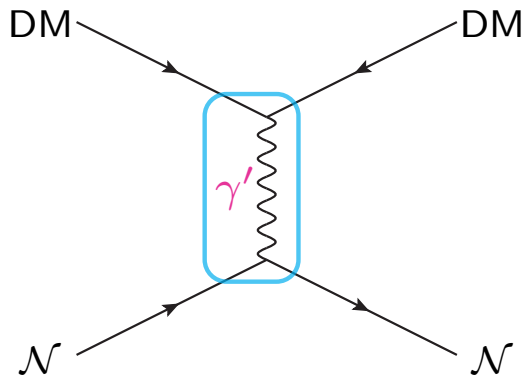

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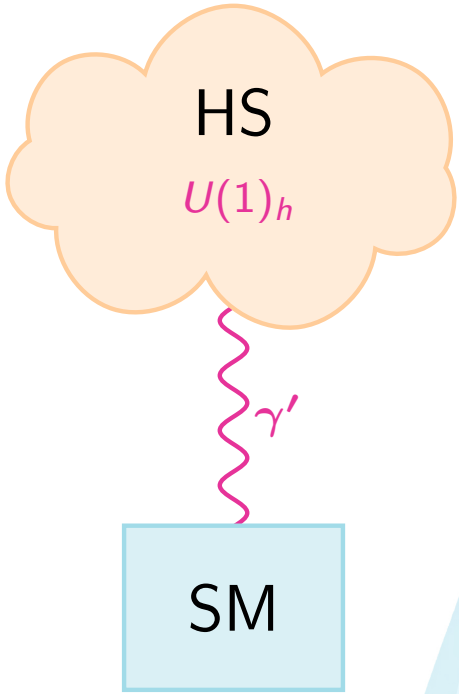

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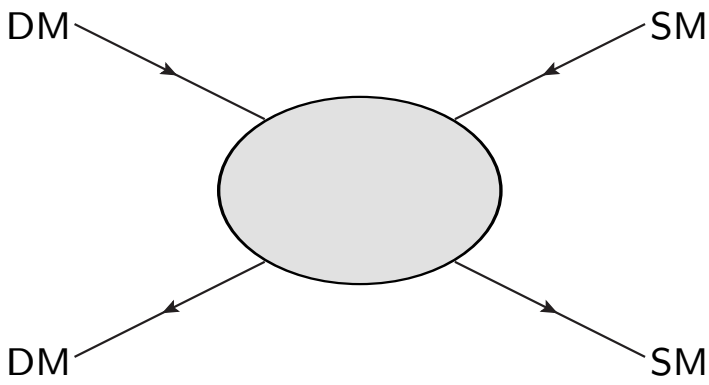

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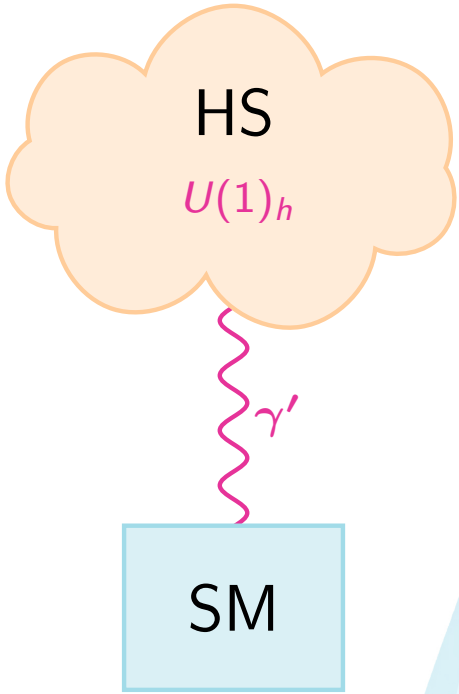

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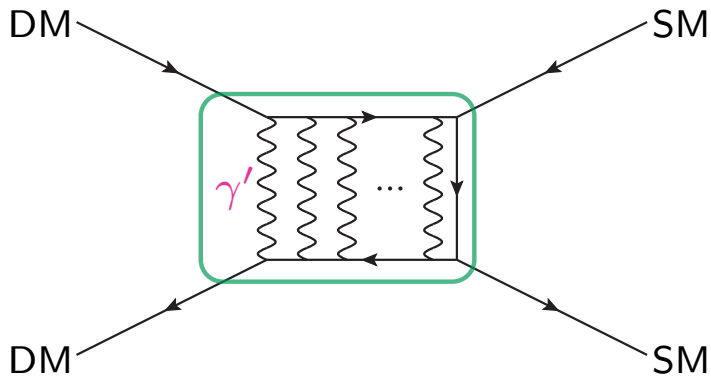

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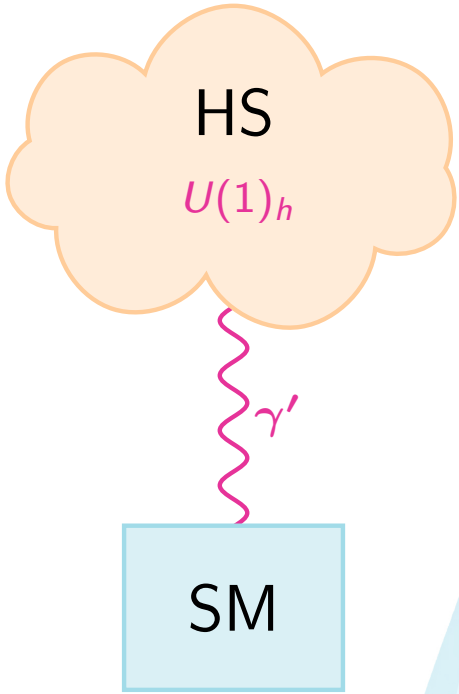

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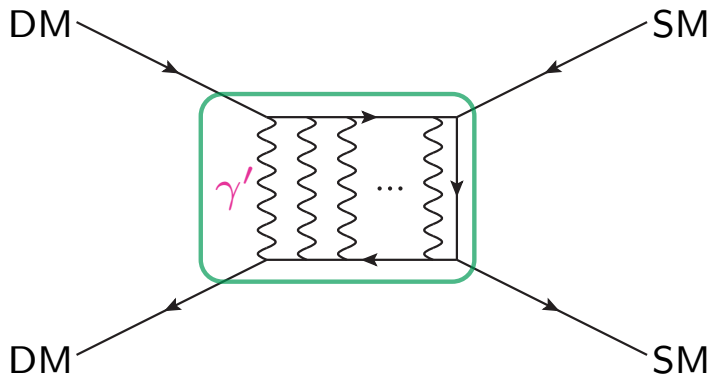

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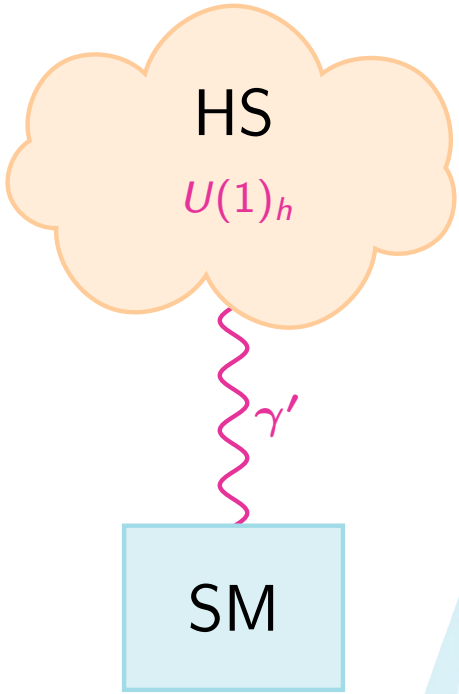

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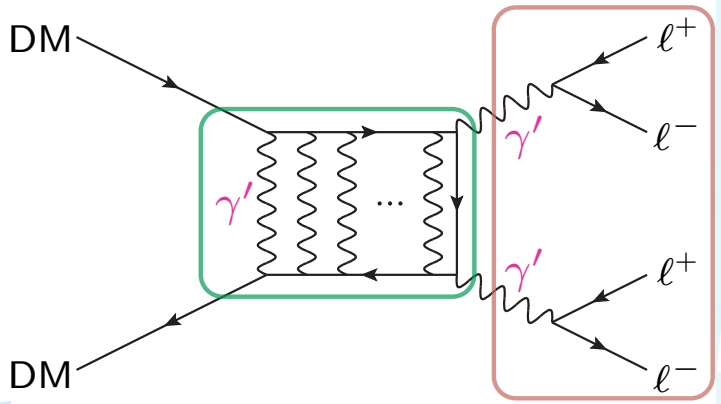
  - ◇ annihilation via light messenger naturally leptophilic



$\Rightarrow$ MeV to GeV scale hidden photon

Hidden Photon

- low energy effective Lagrangian

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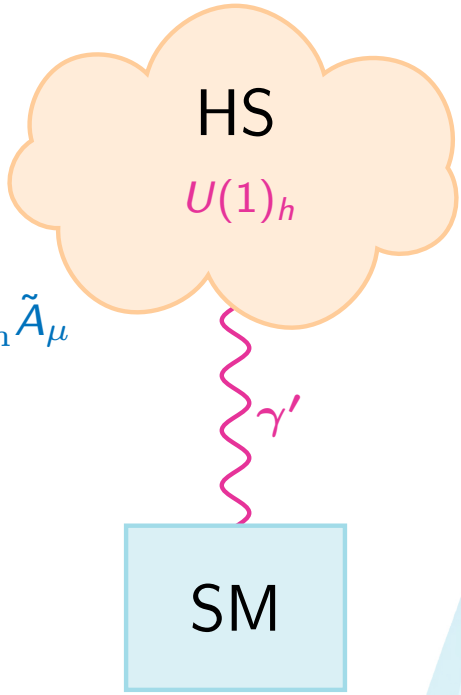

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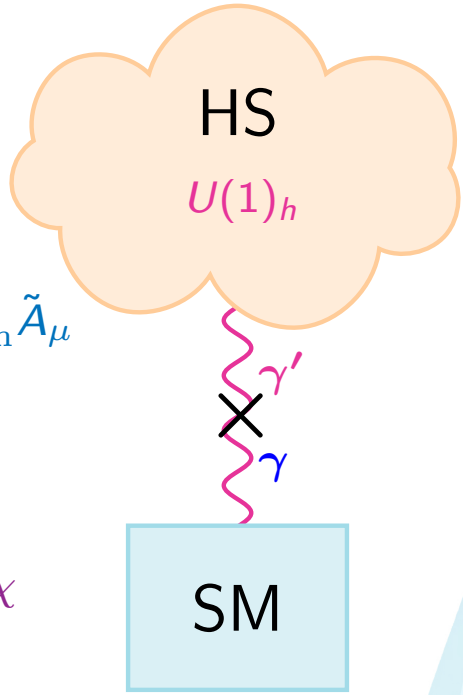
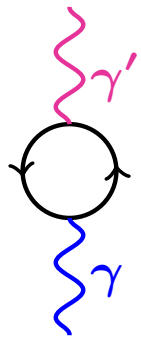
- dominant interaction: kinetic mixing of hidden & visible $U(1)$
  - renormalisable term with dimensionless kinetic mixing parameter χ
  - integrating out heavy particles charged under both $U(1)$s
  - χ generated at loop level: $\chi \sim 10^{-3} - 10^{-4}$





[Okun '82; Holdom '86; Galison, Manohar '84]

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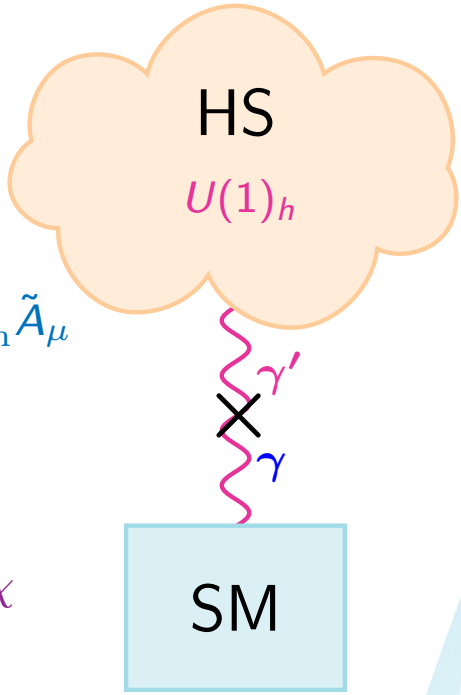
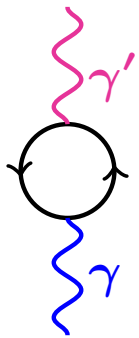
  light hidden photon with $m_{\gamma'} \sim \text{MeV} - \text{GeV}$





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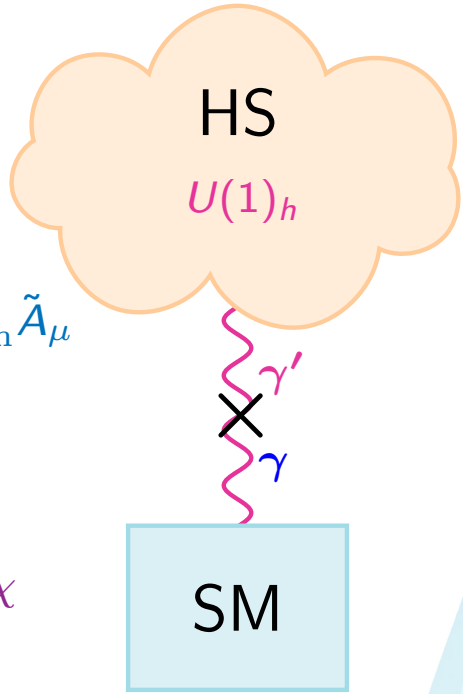

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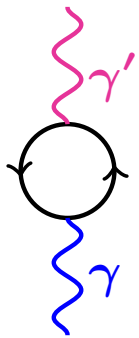

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- diagonalize kinetic terms: $\tilde{A}_\mu = A_\mu + \frac{\chi}{\sqrt{1-\chi^2}}X_\mu\,, \quad \tilde{X}_\mu = \frac{1}{\sqrt{1-\chi^2}}X_\mu$

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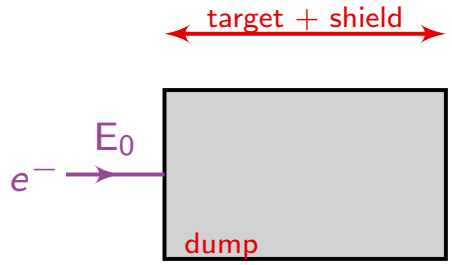
Outline

Production in e^- Beam Dumps



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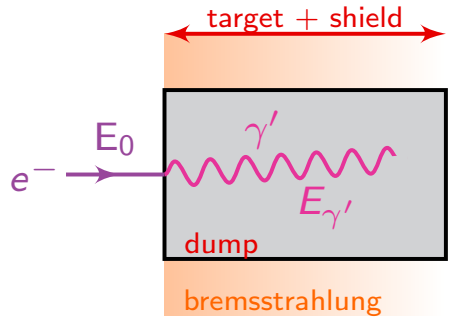
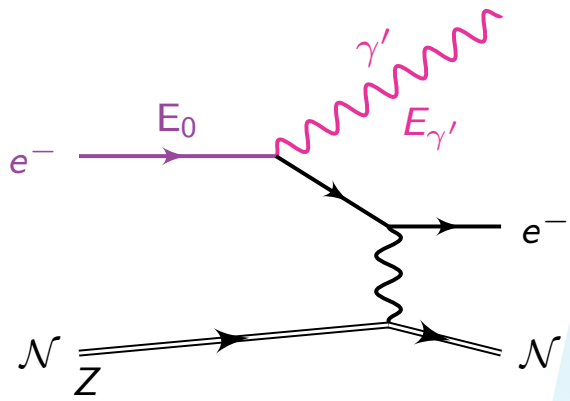


- e^--beam dumped onto target
- γ' emitted from e^--beam

  in process similar to ordinary bremsstrahlung

  highly boosted in forward direction
- production cross section

$$\sigma_{\gamma'} \propto \alpha^3 Z^2 \frac{\chi^2}{m_{\gamma'}^2} \sim \mathcal{O}(\text{pb})$$



[Kim, Tsai '73; Tsai '74; Tsai '86;
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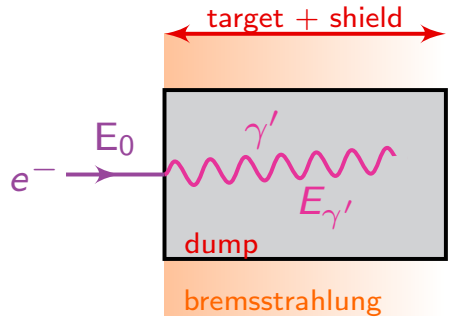

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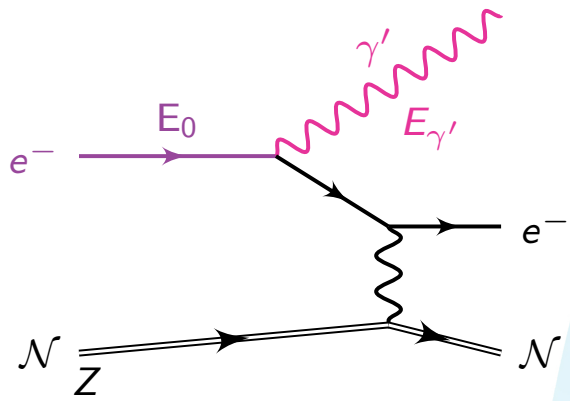
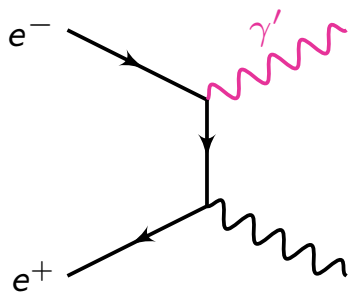


compared to e^+e^- collider case:

$$\sigma_{\gamma'} \propto \frac{\alpha^2\chi^2}{E^2} \sim \mathcal{O}(\text{fb})$$



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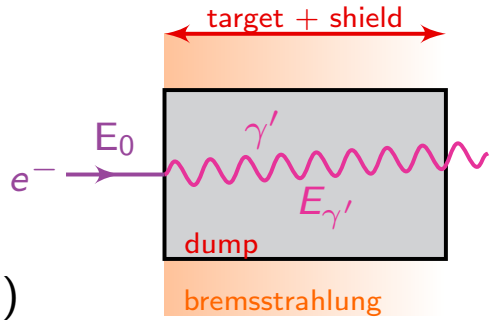
Decay & Detection



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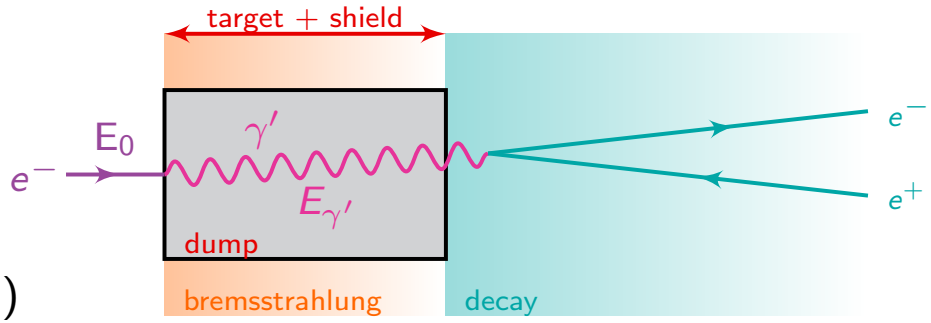

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$$l_{\gamma'} \sim 10\text{cm}\,\frac{E_{\gamma'}}{1\text{GeV}}\left(\frac{10^{-4}}{\chi}\right)^2\left(\frac{10\text{MeV}}{m_{\gamma'}}\right)^2 \sim \mathcal{O}(\text{mm} - \text{km})$$

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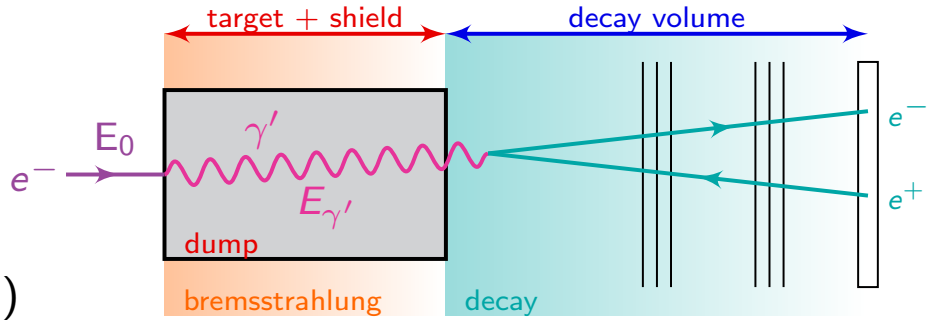

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- detect decay products (mostly e^+e^-)

- number of expected events:

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

  energy distribution $I_e(E_0, E_e, l)$ of electrons in dump has to be taken into account

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  - geometry of set-up and finite detector size
  - possibly energy cuts

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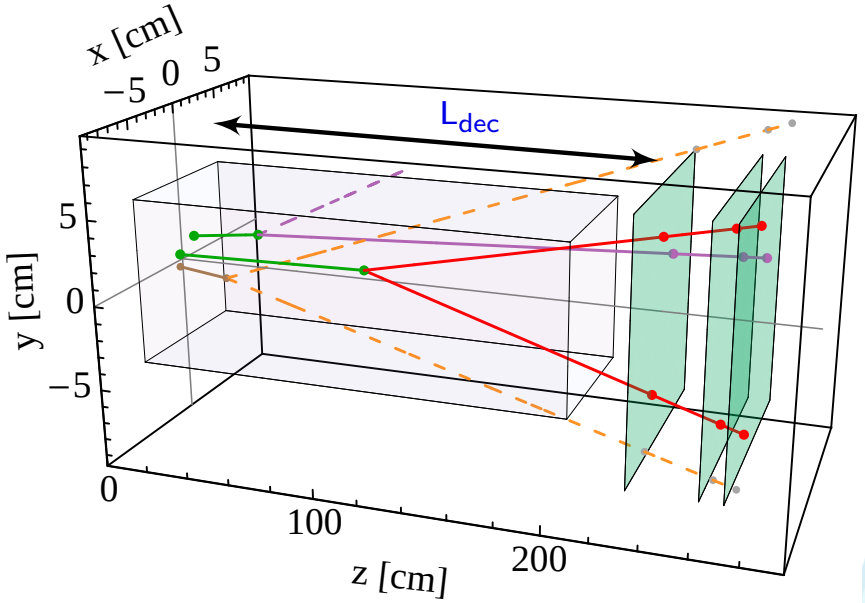

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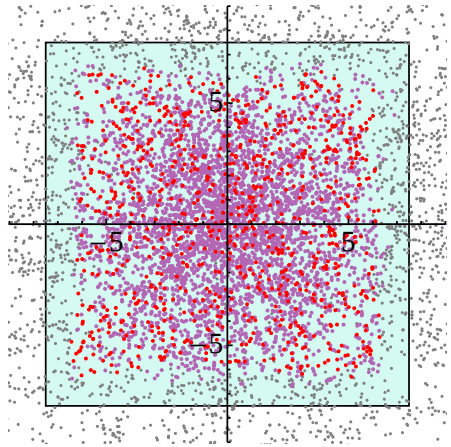
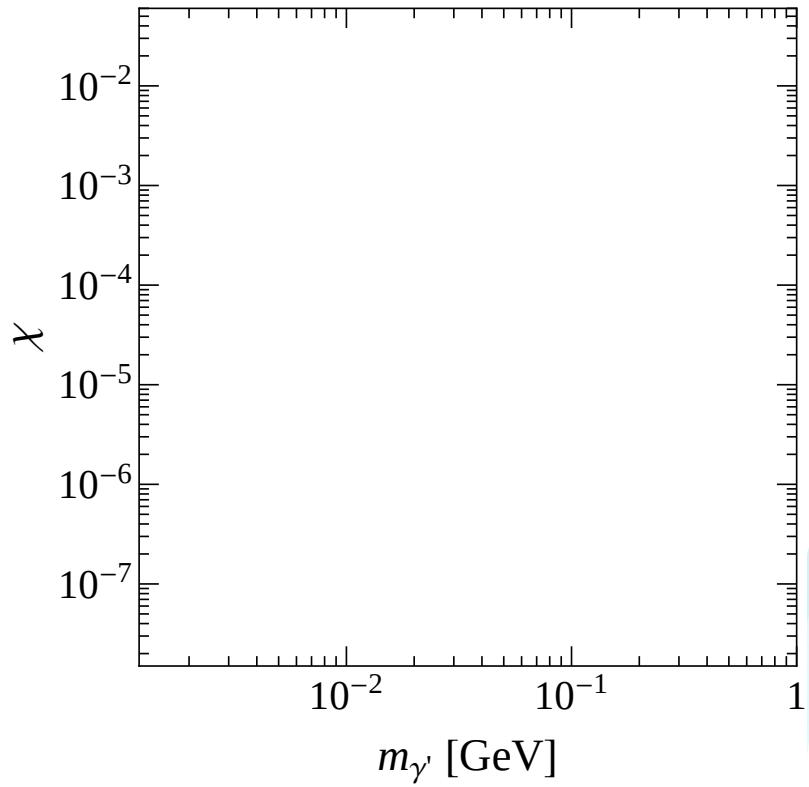
- Monte Carlo simulations with MadGraph
  - four-momentum of produced γ' and decay leptons
  - construct tracks and energies for particles in the events
  - compare to experimental set-up



$\Rightarrow$ experimental acceptance

[Monte Carlo by Rouven Essig, Philip Schuster, Natalia Toro]

Shape & Experimental Limitations



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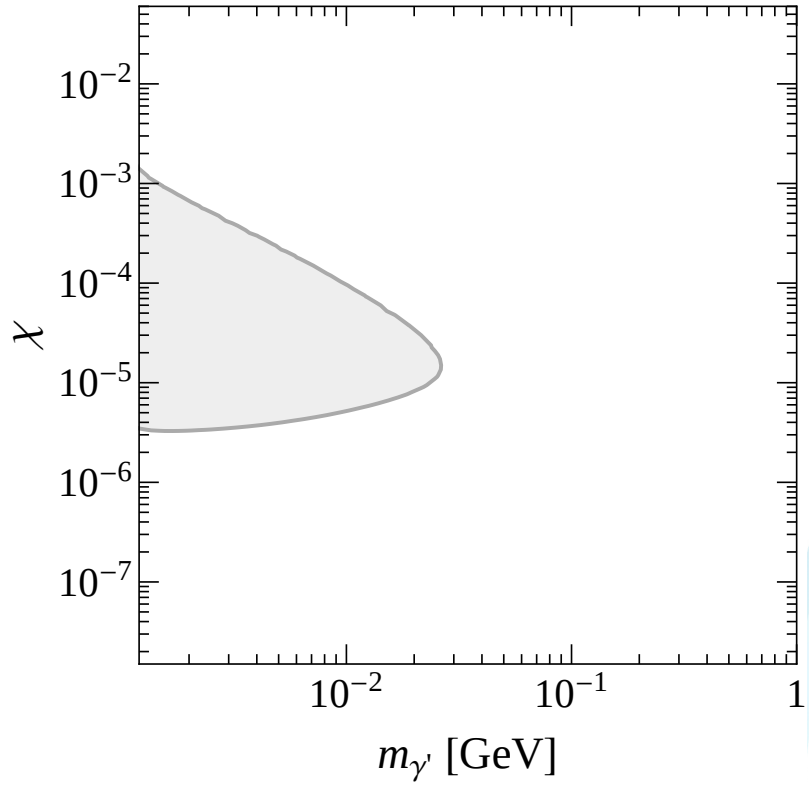

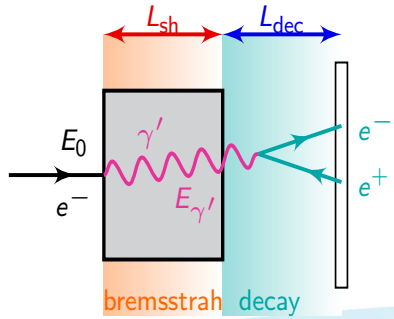

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γ' has to traverse shield

for small $l_{\gamma'} \ll L_{\text{sh}}$:

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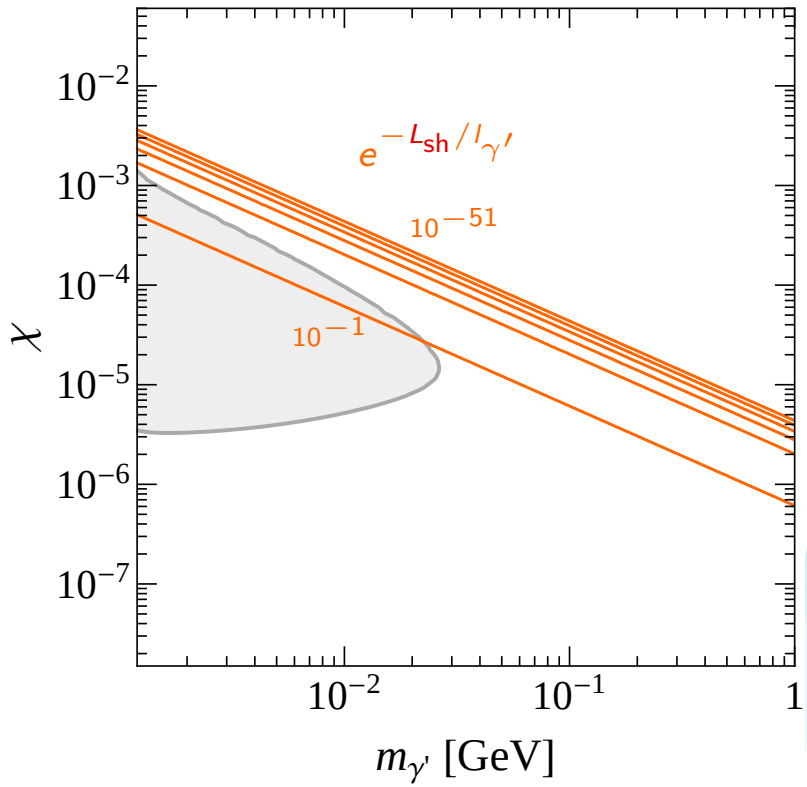

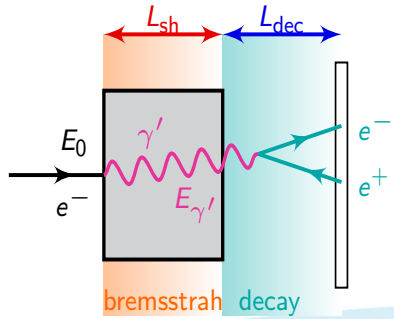

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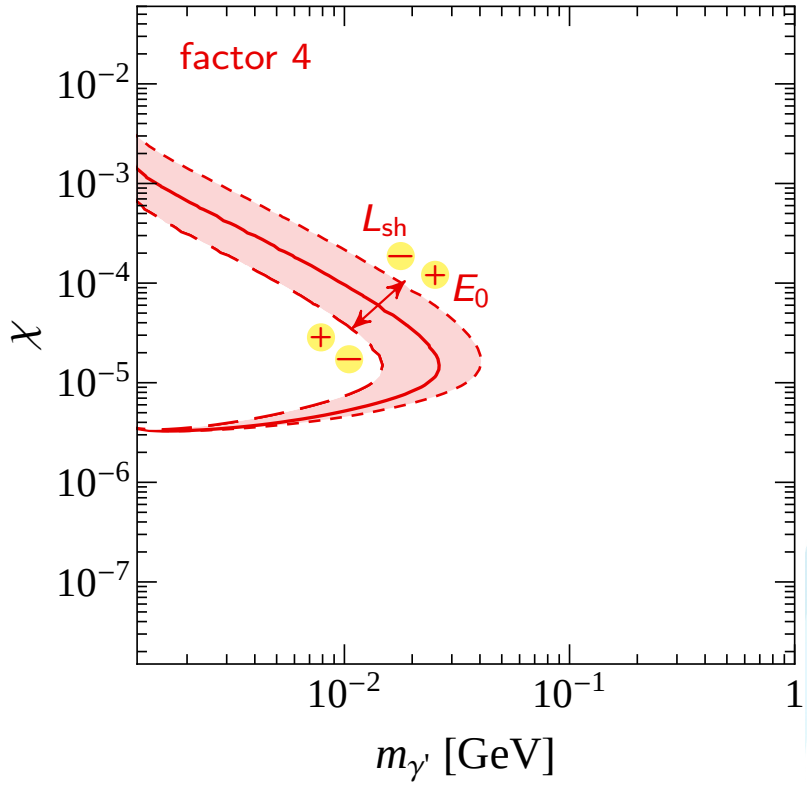

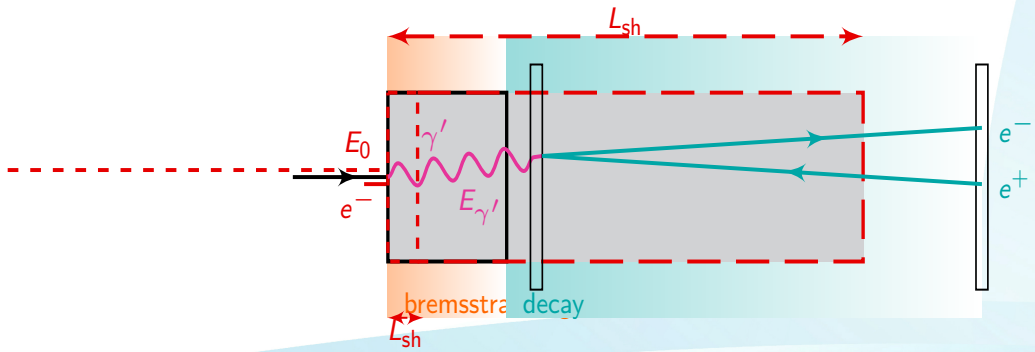

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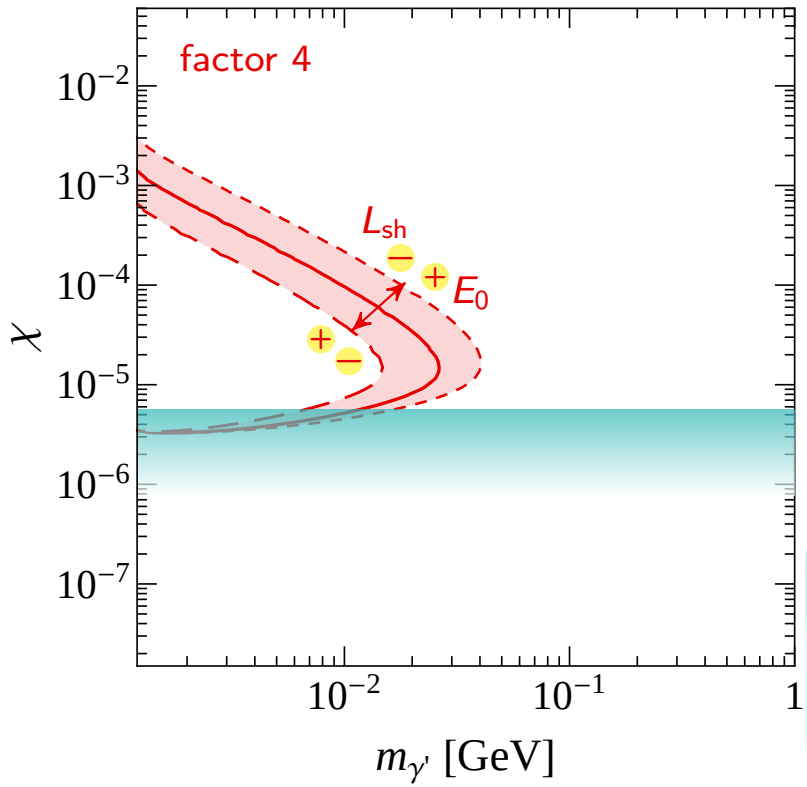

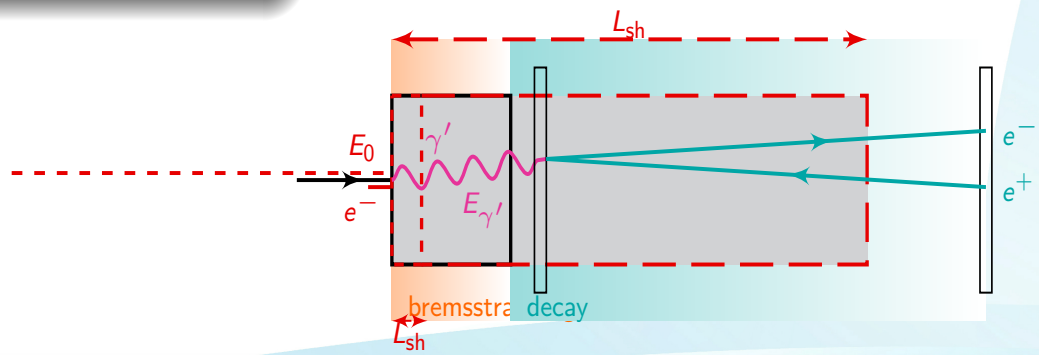

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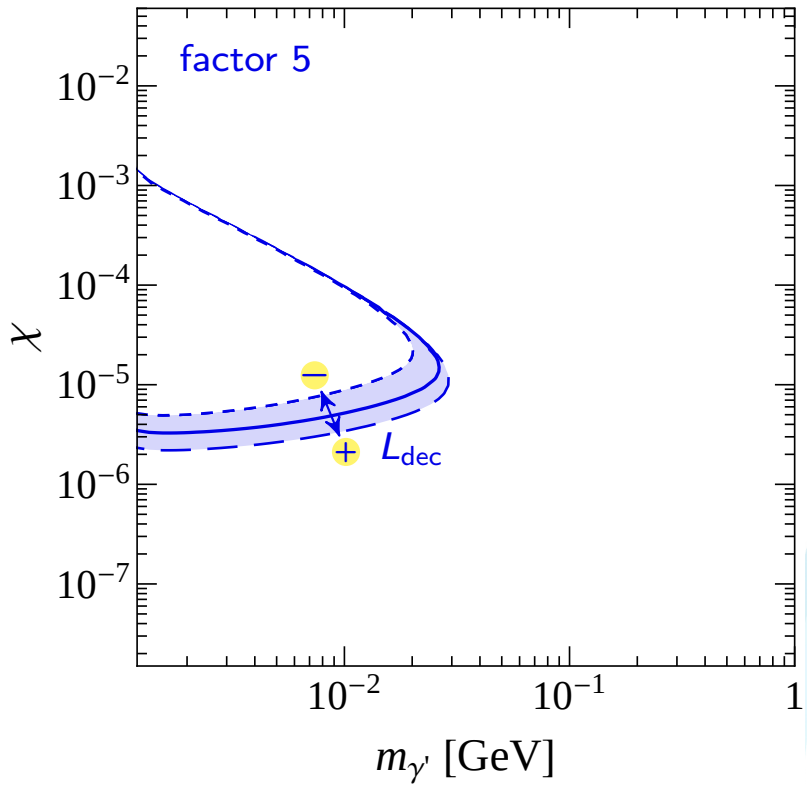

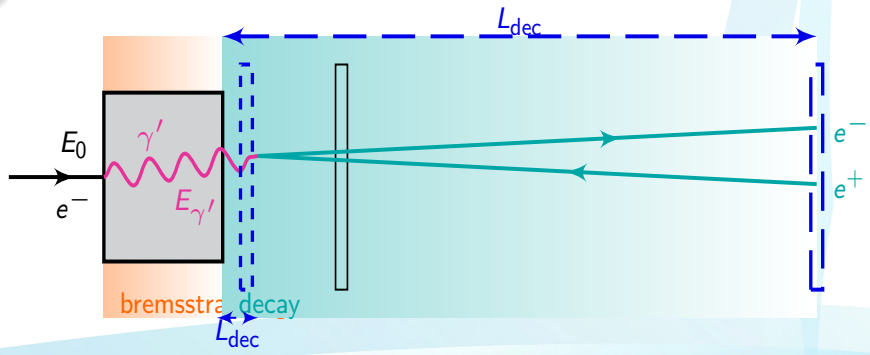

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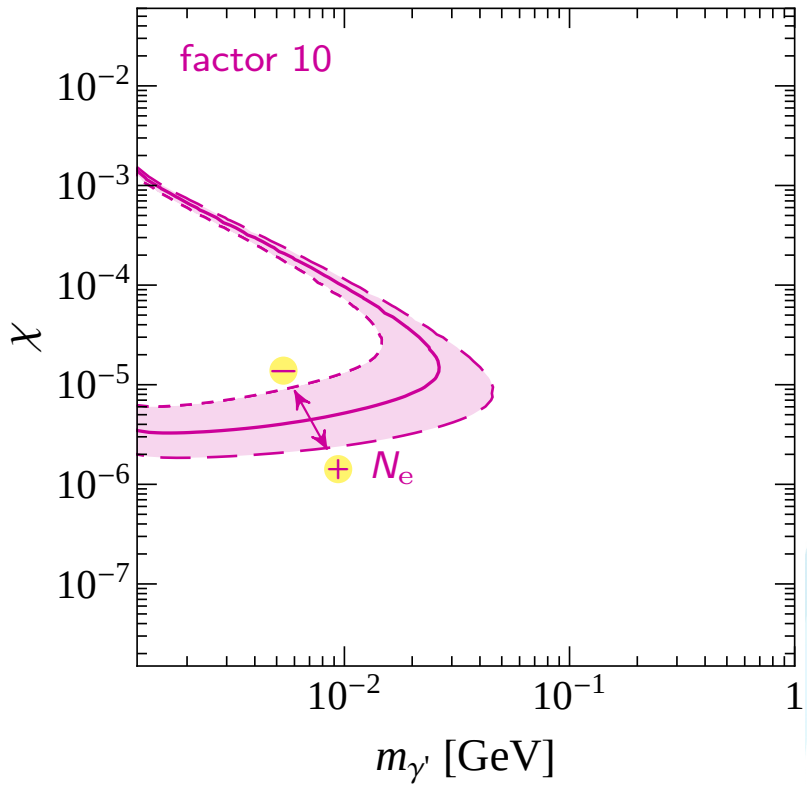

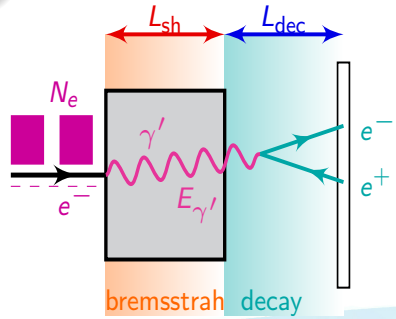

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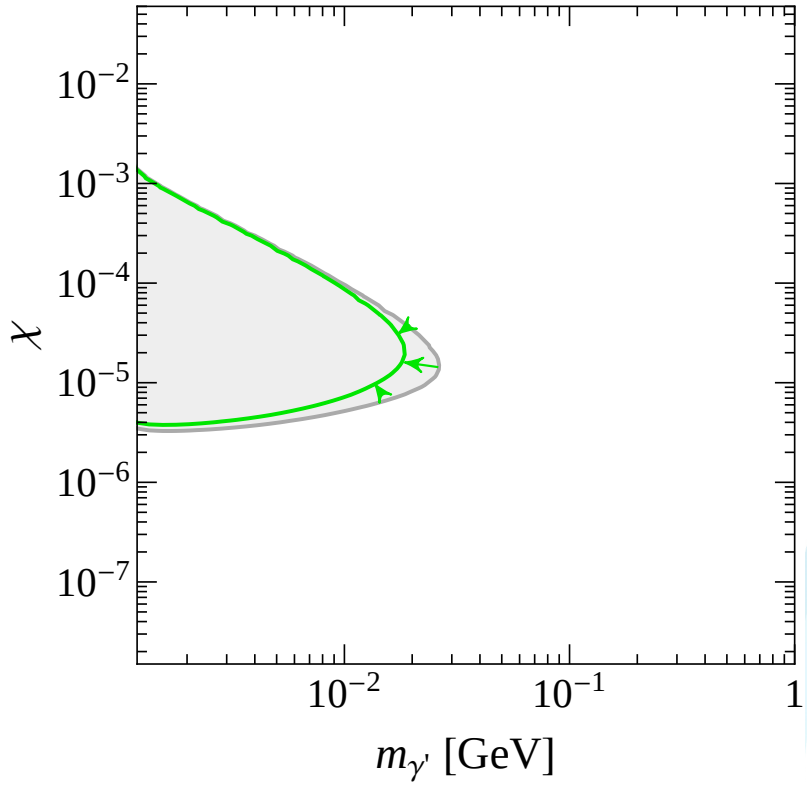
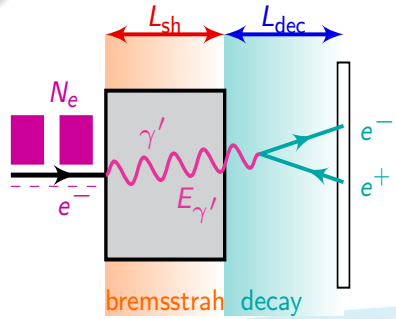


experimental acceptance

from Monte Carlo simulations with MadGraph



Limits from Experiments

- **KEK Japan (1986)** [Konaka *et al.* '86]
  - $E_0 = 2.5$ GeV, $N_e = 27$ mC
  - tungsten target, $L_{sh} = 2.4$ m, $L_{dec} = 2.2$ m
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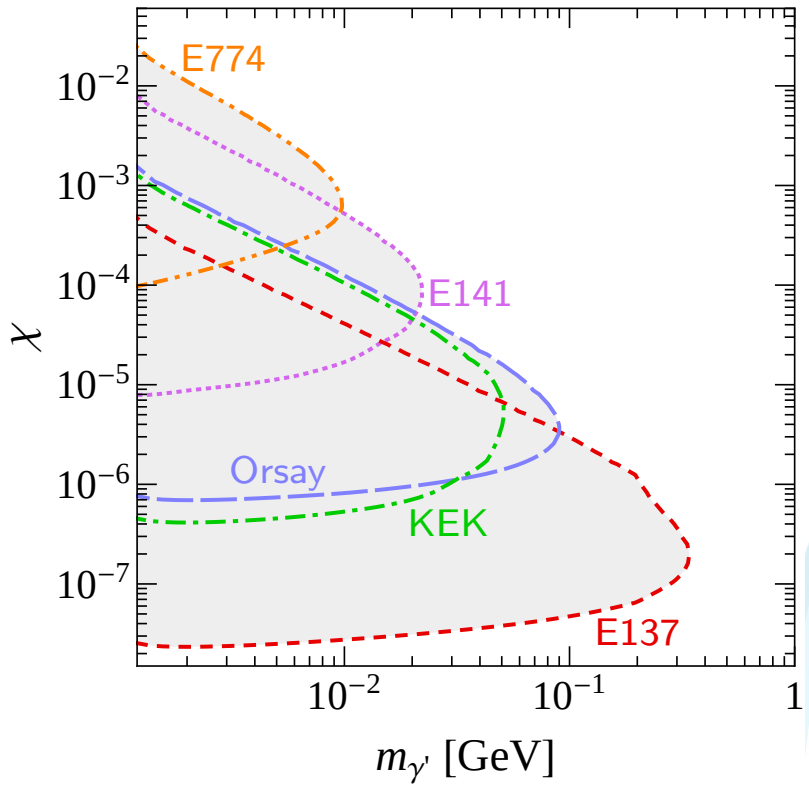

[SA, Niebuhr, Ringwald '12]

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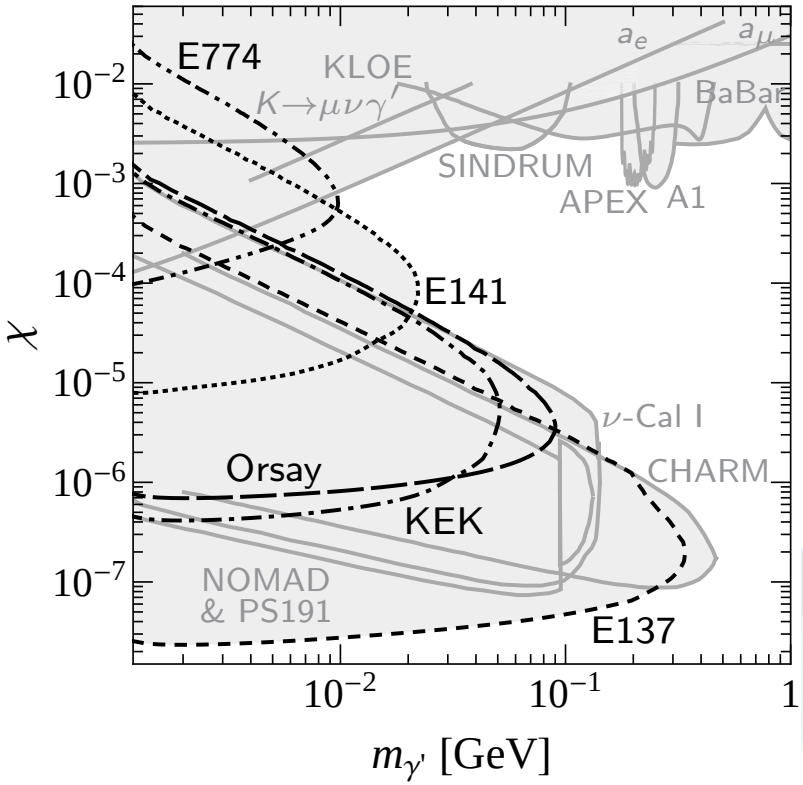

- **current constraints**
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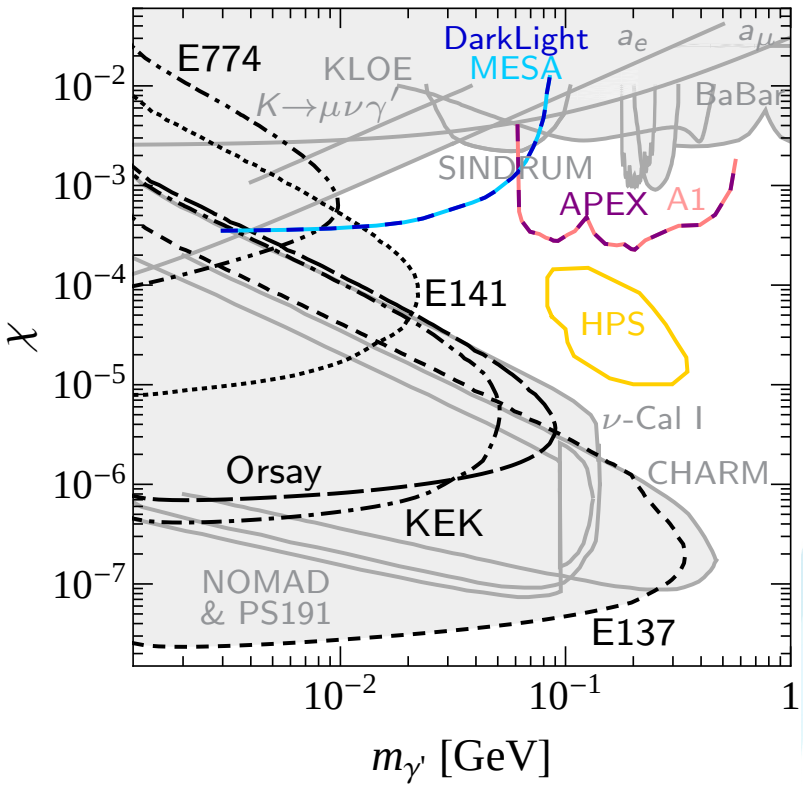


- **current constraints**
  - various experiments
- **future searches**
  - thin target experiments

Outline

Toy Model: Dirac fermion DM

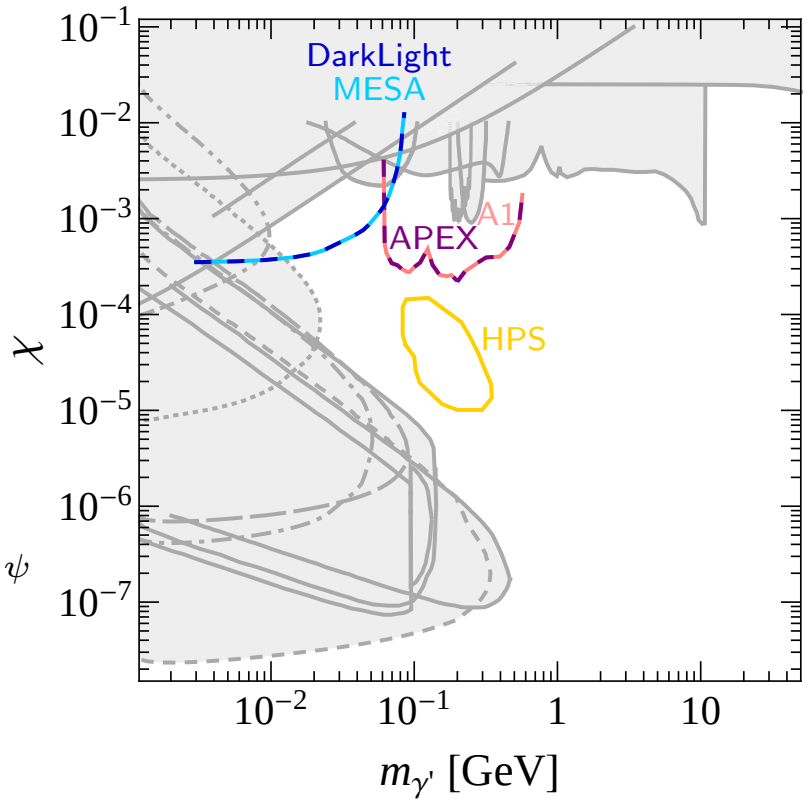
simplest hidden sector with DM

- hidden photon γ'
- Dirac fermion ψ

$\Rightarrow$ extra parameter m_ψ

$$\mathcal{L}_{\text{eff}} \supset -\frac{1}{4}\tilde{X}_{\mu\nu}\tilde{X}^{\mu\nu} + \frac{\chi_\gamma}{2}\tilde{X}_{\mu\nu}\tilde{B}^{\mu\nu} + \frac{\tilde{m}^2_{\gamma'}}{2}\tilde{X}_\mu\tilde{X}^\mu + g_h\bar{\psi}\gamma^\mu\psi\tilde{X}^\mu + m_\psi\bar{\psi}\psi$$

$$\chi = g_h \frac{g_Y c_W}{16\pi^2} \times \kappa \qquad (0.1 \leq \kappa \leq 10)$$



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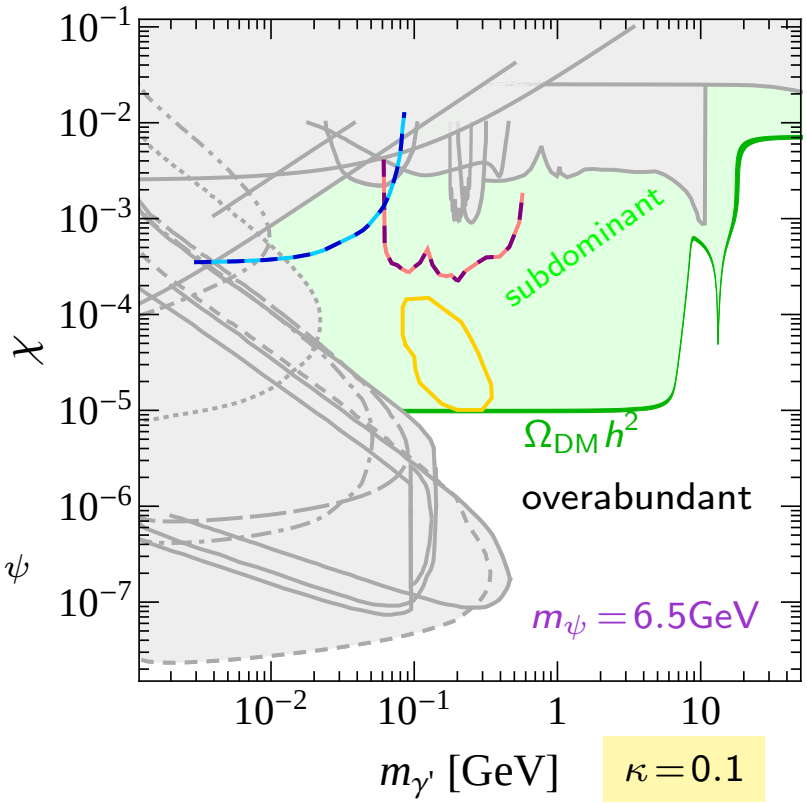
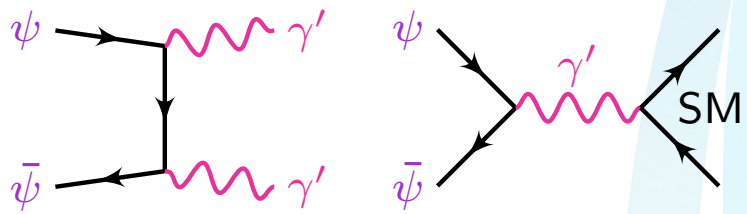


Relic abundance Ωh^2

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

$\Rightarrow$ ψ total DM or subdominant component

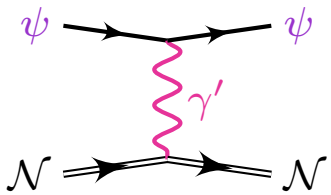


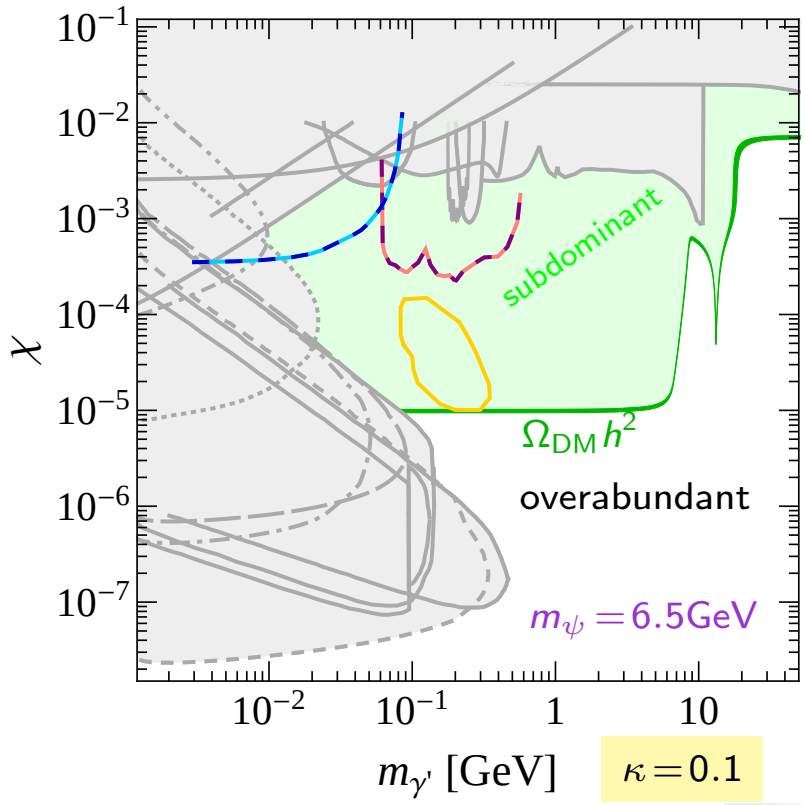
[SA, Goodsell, Ringwald '11,

Toy Model: Dirac fermion DM

Direct Detection

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





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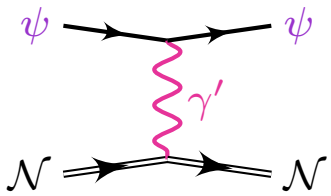
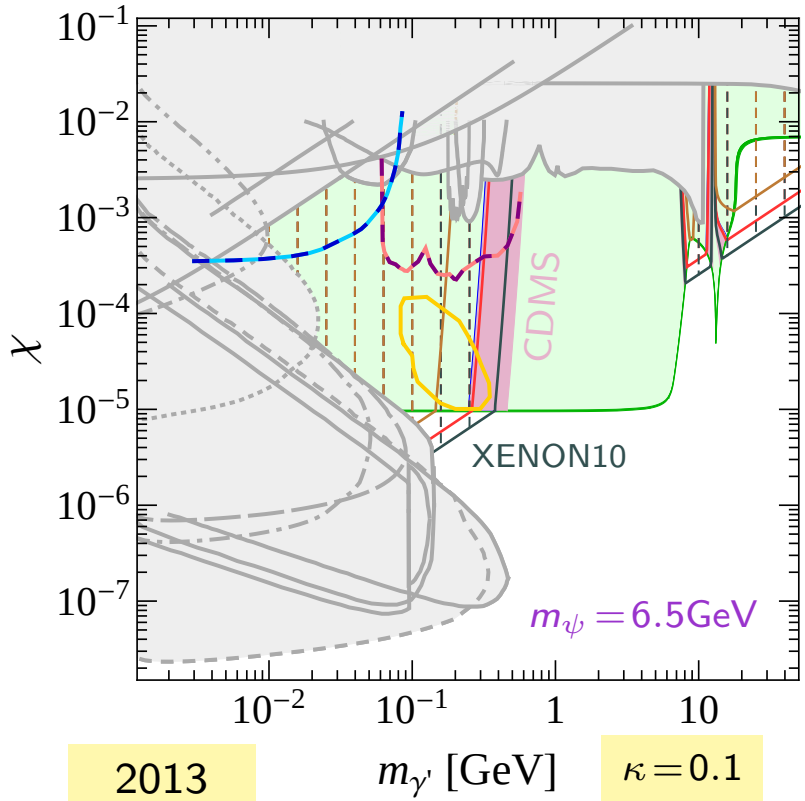
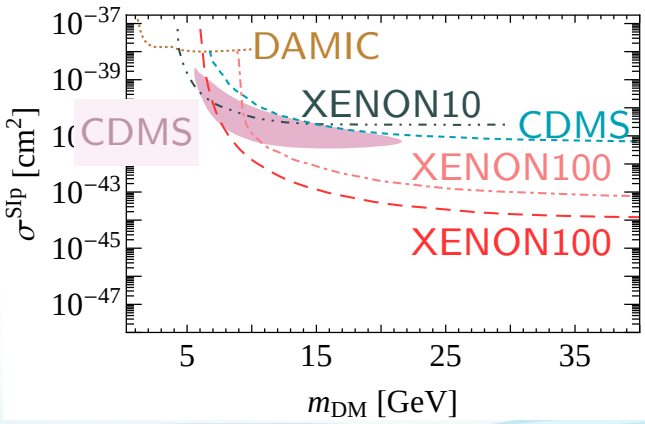


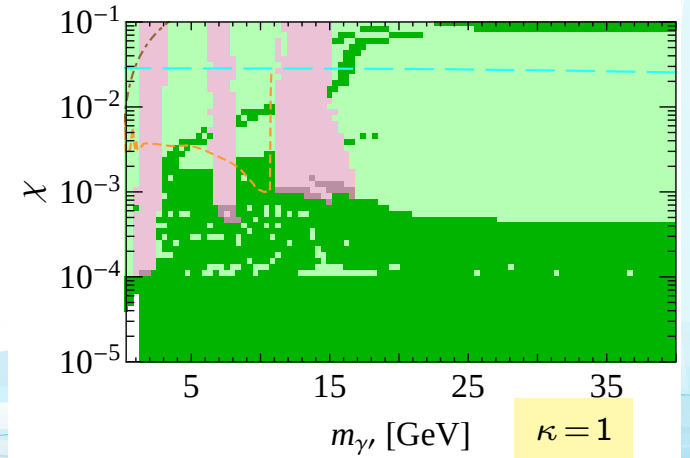


2013 SHM

$\kappa = 0.1$

DD limits and signals





$\kappa = 1$

[SA, Goodsell, Ringwald '11, '13]

Supersymmetric Dark Force Models

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

    (assume MSSM in visible sector)
- hidden gauge symmetry breaking:
  - radiative breaking domination
  - visible sector induced breaking
- DM can consist of stable hidden sector particle
- relation between g_h and χ: $\chi = g_h \frac{g_Y c_W}{16\pi^2} \kappa$

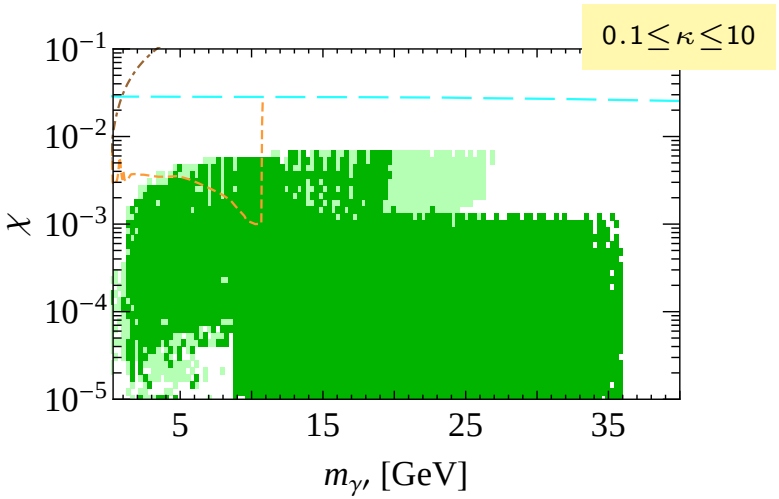
Radiative Breaking Domination

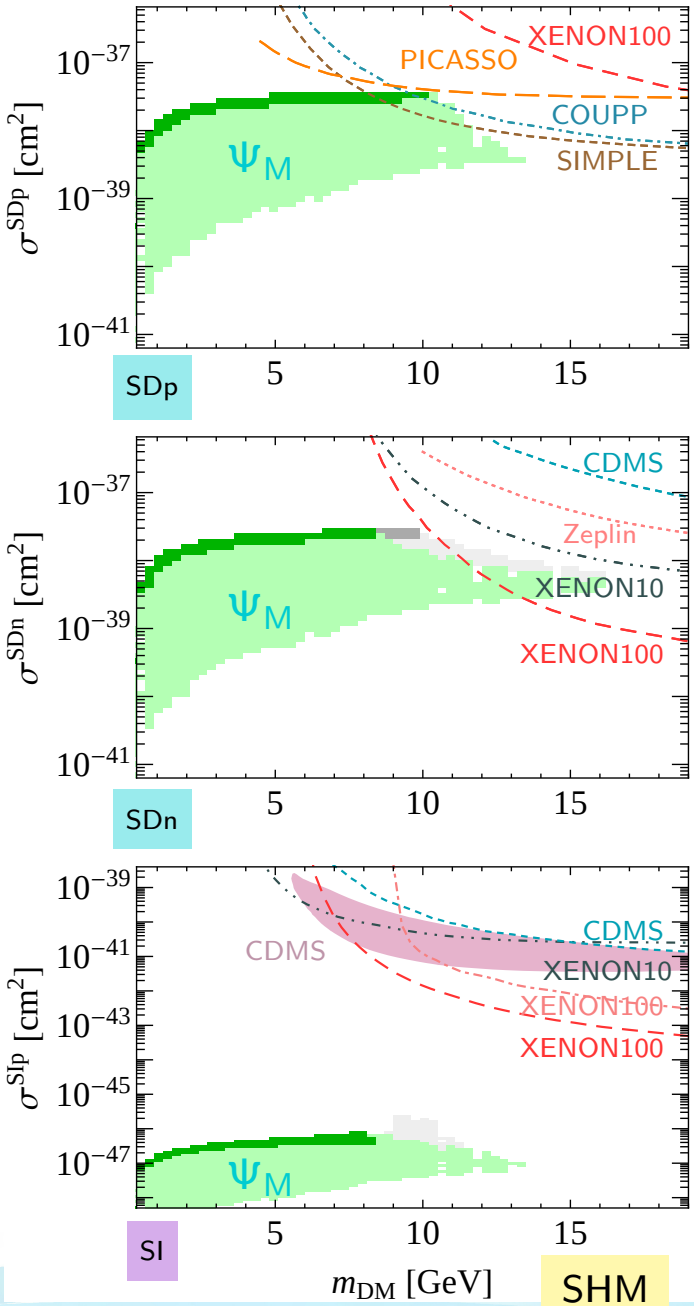
- running of Yukawa coupling λ_S induces breaking of hidden gauge symmetry
  - choose masses & couplings at high scale

[SA, Goodsell, Ringwald '11, '13]

Radiative Breaking Domination

- running of Yukawa coupling λ_S induces breaking of hidden gauge symmetry
  - ◇ choose masses & couplings at high scale
- Majorana fermion Ψ_M: total & subdominant DM
  - ◇ axial coupling generates SD scattering
  - ◇ minor SI scattering





⇒ SD in reach of experiments

SI bejond reach

[SA, Goodsell, Ringwald '11, '13]

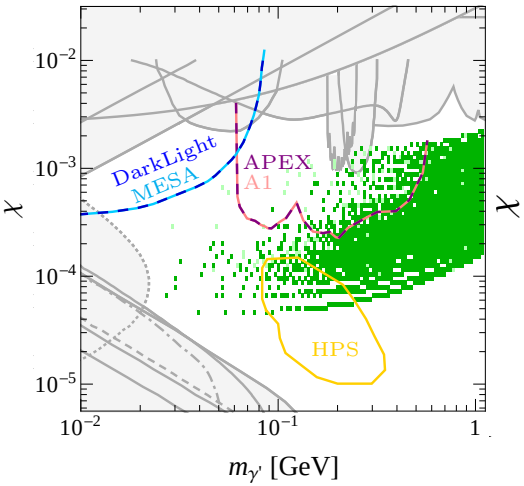
Visible Sector Induced Breaking

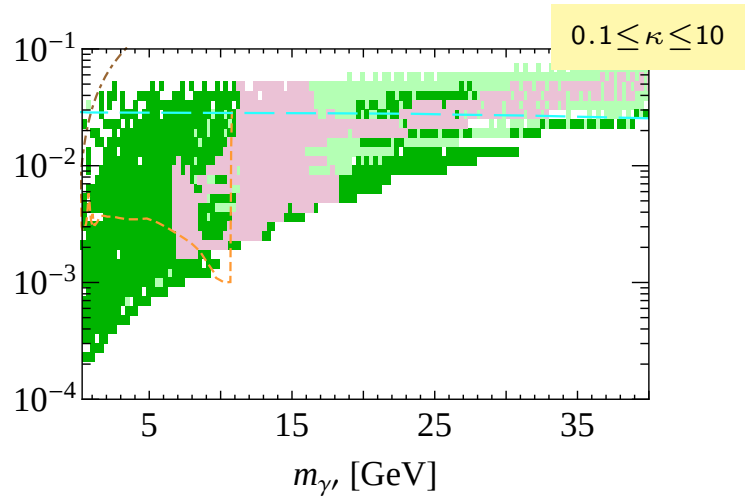
- hidden gauge symmetry broken via effective Fayet-Iliopoulos term

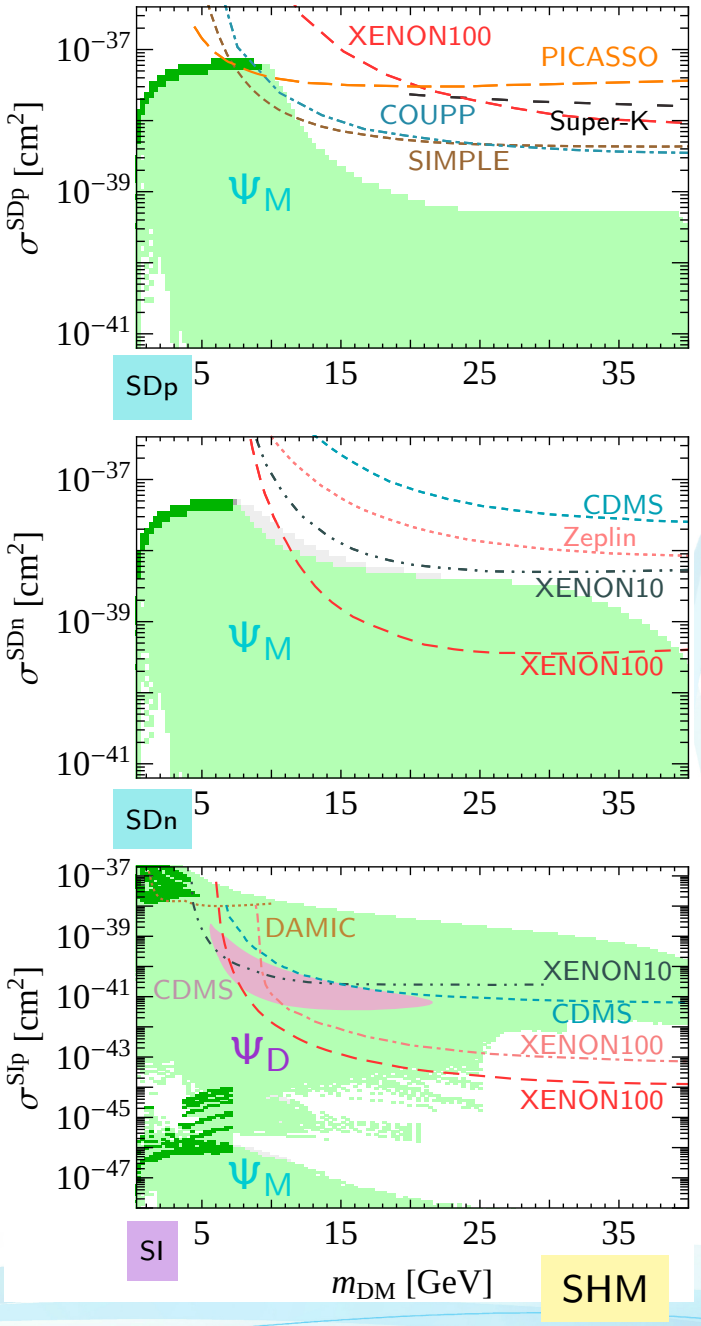
[SA, Goodsell, Ringwald '11, '13]

Visible Sector Induced Breaking

- hidden gauge symmetry broken via effective Fayet-Iliopoulos term
- Majorana Ψ_M & Dirac Ψ_D fermion as DM
  - Ψ_M: mostly SD (like rad. breaking)
  - Ψ_D: mostly SI (like Toy-Model, but $m_{DM} < m_{\gamma'}$)







$\Rightarrow$ SI probe Ψ_D SD probe Ψ_M

[SA, Goodsell, Ringwald '11, '13]

Outline

Conclusions

- hidden sector
  - well motivated in many BSM scenarios and for dark matter
- hidden photons as dark force
  - probed with high intensity experiments, e.g. beam dumps
  - need short L_{sh} to probe large χ
  - need large N_e and/or long L_{dec} to probe small χ
- dark matter in HS
  - viable DM candidates
  - provide total & subdominant DM with interesting DD potential

Thank you!