

# Dark Forces Attack at DESY

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**FLC Seminar**  
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## 1. Motivation

- Models related to dark matter suggest existence of long-range forces mediated by new gauge bosons with masses in the **MeV to GeV** range and **very weak coupling** to ordinary matter:

### “Hidden” or “Dark” Photons

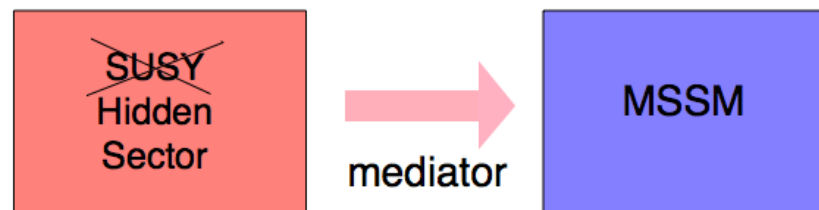
- Appear naturally in supersymmetric models descending from string theory
  - Current experimental constraints on such particles quite weak
  - Experimental HEP community now starting to develop strategies and to form collaborations to attack these dark forces
    - Fixed-target experiments exploiting **electron beams** especially sensitive
- ⇒ Opportunity for new experiments at **DESY**

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- 2. Physics case for dark forces**
- 3. Attacking dark forces with new fixed-target experiments**
- 4. Conclusions**

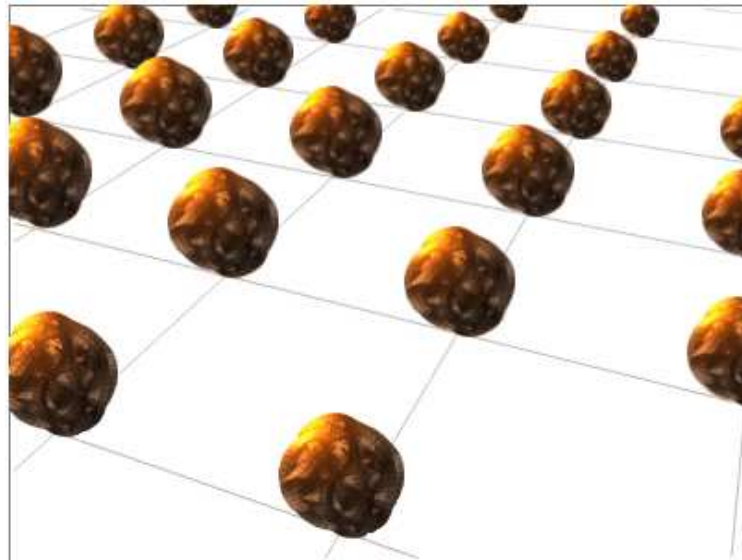
## 2. Physics case for dark forces

- Extensions of standard model based on supergravity or superstrings rely on “hidden sector” of particles which are very weakly coupled to the “visible sector” standard model particles; cf. “gravity mediation” of SUSY breaking ( $\Leftarrow$  condensation of non-Abelian hidden gaugino)



- Sector “hidden”  $\Leftrightarrow$  mediators heavy and/or very weakly coupled
- Possible light hidden particles: hidden sector U(1) gauge bosons (“hidden photons”  $\gamma'$ ) and hidden sector particles charged under the hidden U(1) ( $\Rightarrow$  “mini-charged particles” (MCPs))

- Hidden  $U(1)$  gauge factors generic feature of string compactifications



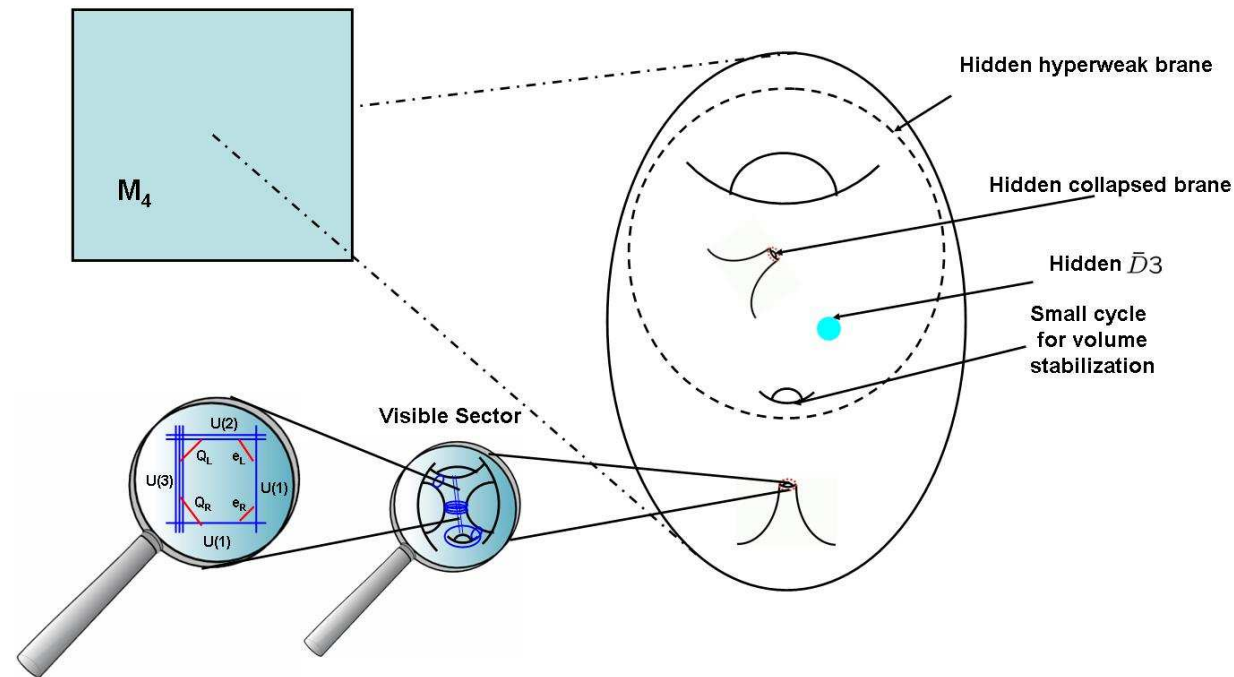
- both in heterotic compactifications, e.g.

[Lebedev, Ramos-Sanchez '09]

$$E_8 \times E_8 \rightarrow G_{\text{SM}} \times [SU(6) \times U(1)]$$

- as well as in type II orientifold compactifications with D-branes

- \* KK zero modes of form fields
- \* Massless excitations of space-time filling D-branes



- Hidden  $U(1)$  gauge bosons (“photons”) may be light,  $m_{\gamma'} \ll \text{TeV}$

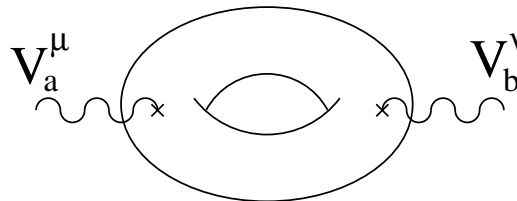
- Dominant interaction with  $U(1)_Y$  or  $U(1)_{\text{em}}$  via **kinetic mixing** [Holdom '85]

$$\mathcal{L} \supset -\frac{1}{4}F_{\mu\nu}^{(\text{vis})}F_{(\text{vis})}^{\mu\nu} - \frac{1}{4}F_{\mu\nu}^{(\text{hid})}F_{(\text{hid})}^{\mu\nu} + \frac{\chi}{2}F_{\mu\nu}^{(\text{vis})}F^{(\text{hid})\mu\nu} + m_{\gamma'}^2 A_{\mu}^{(\text{hid})}A^{(\text{hid})\mu}$$

$\chi \ll 1$  generated at loop level via messenger exchange  $\Rightarrow U(1)$  hidden

– Kinetic mixing in compactification of heterotic string:

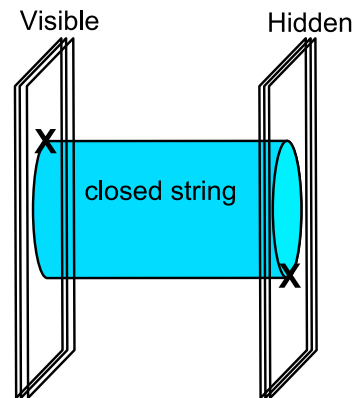
[Dienes, Kolda, March-Russell '97]



$$10^{-17} \lesssim \chi \simeq \frac{e^2}{16\pi^2} C \frac{\Delta m}{M_P} \lesssim 10^{-5},$$

$$\text{for } C \gtrsim 10; 10^5 \text{ GeV} \lesssim \Delta m \lesssim 10^{17} \text{ GeV}$$

- Kinetic mixing between D-brane localized U(1)s in type II compactifications: [Lüst,Stieberger '03;Abel,Schofield '04;Berg,Haack,Körs '05;...;Goodsell *et al.* '09]



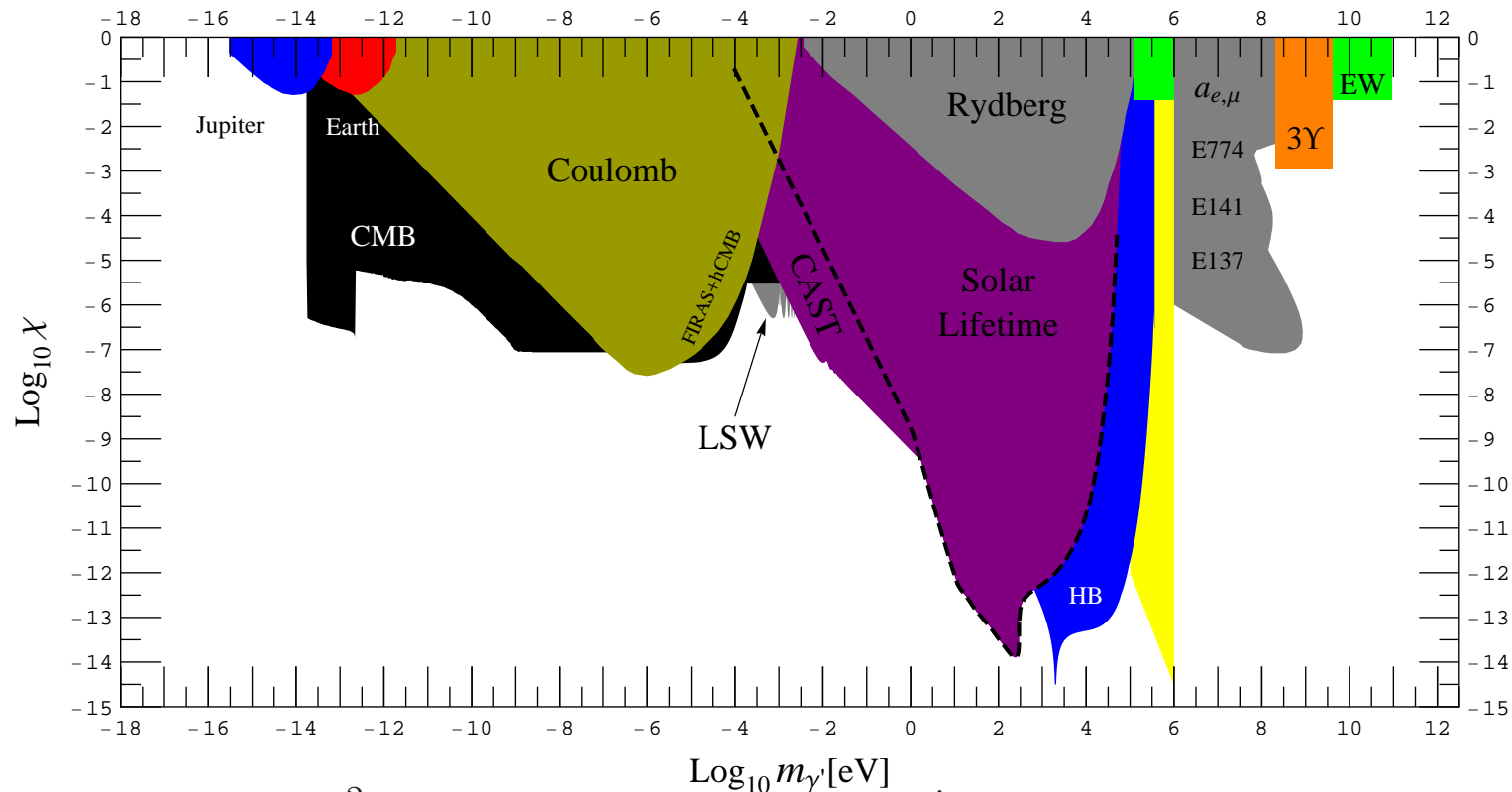
$$10^{-12} \lesssim \chi \sim \frac{ee_h}{16\pi^2} \sim 2\pi g_s \left( \frac{4\pi M_s^2}{g_s^2 M_P^2} \right)^{q/12} \lesssim 10^{-3},$$

$$\text{for } q = 0, 4; \quad 10^3 \text{ GeV} \lesssim M_s \lesssim 10^{17} \text{ GeV}$$



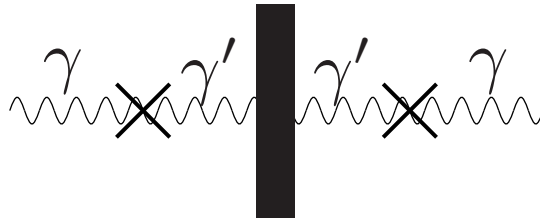
- Current constraints on hidden  $U(1)$ s:

[Bartlett,.. '88; Kumar,.. '06; Ahlers,.. '07; Jaeckel,.. '07; Redondo,.. '08; Postma, Redondo '08; Bjorken, Essig, Schuster, Toro '09; ...]



Deviations from  $1/r^2$  (Jupiter, Coulomb);  $\gamma \leftrightarrow \gamma'$  oscillations (CMB, Light Shining through a Wall (LSW)); stellar evolution (Sun, HB); fixed target;  $e^+e^-$  ( $\Upsilon$ , EW)

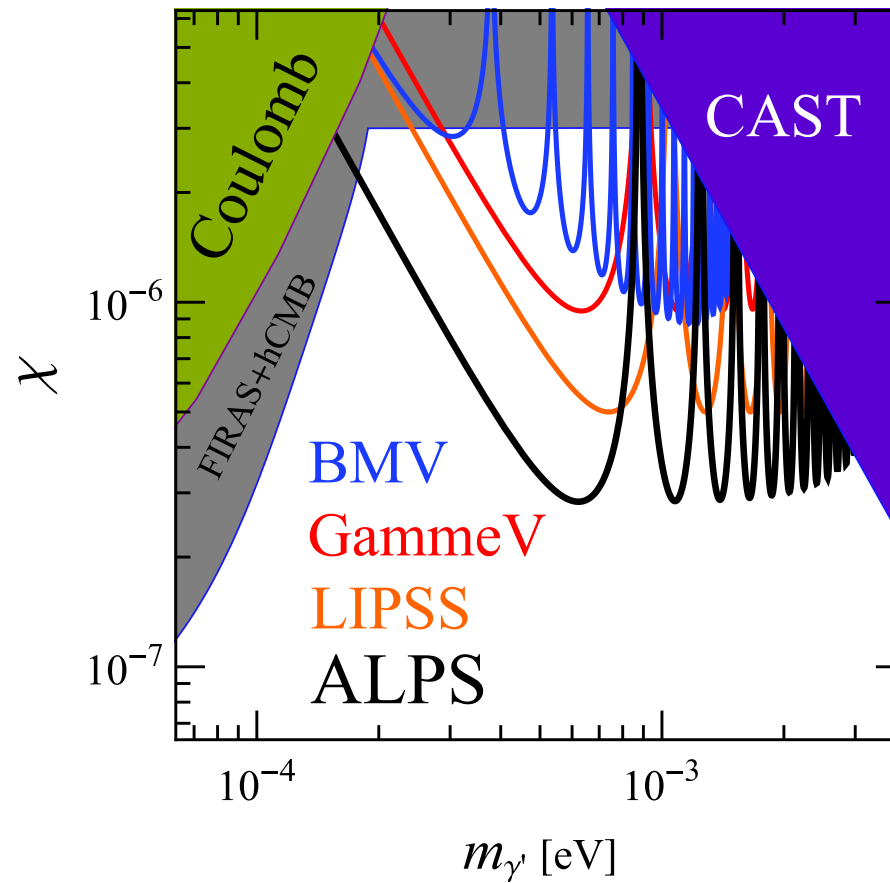
## Light Shining through a Wall (LSW):



**ALPS** (DESY), **BMV** (LULI), **GammeV** (Fermilab), **LIPSS** (JLab)



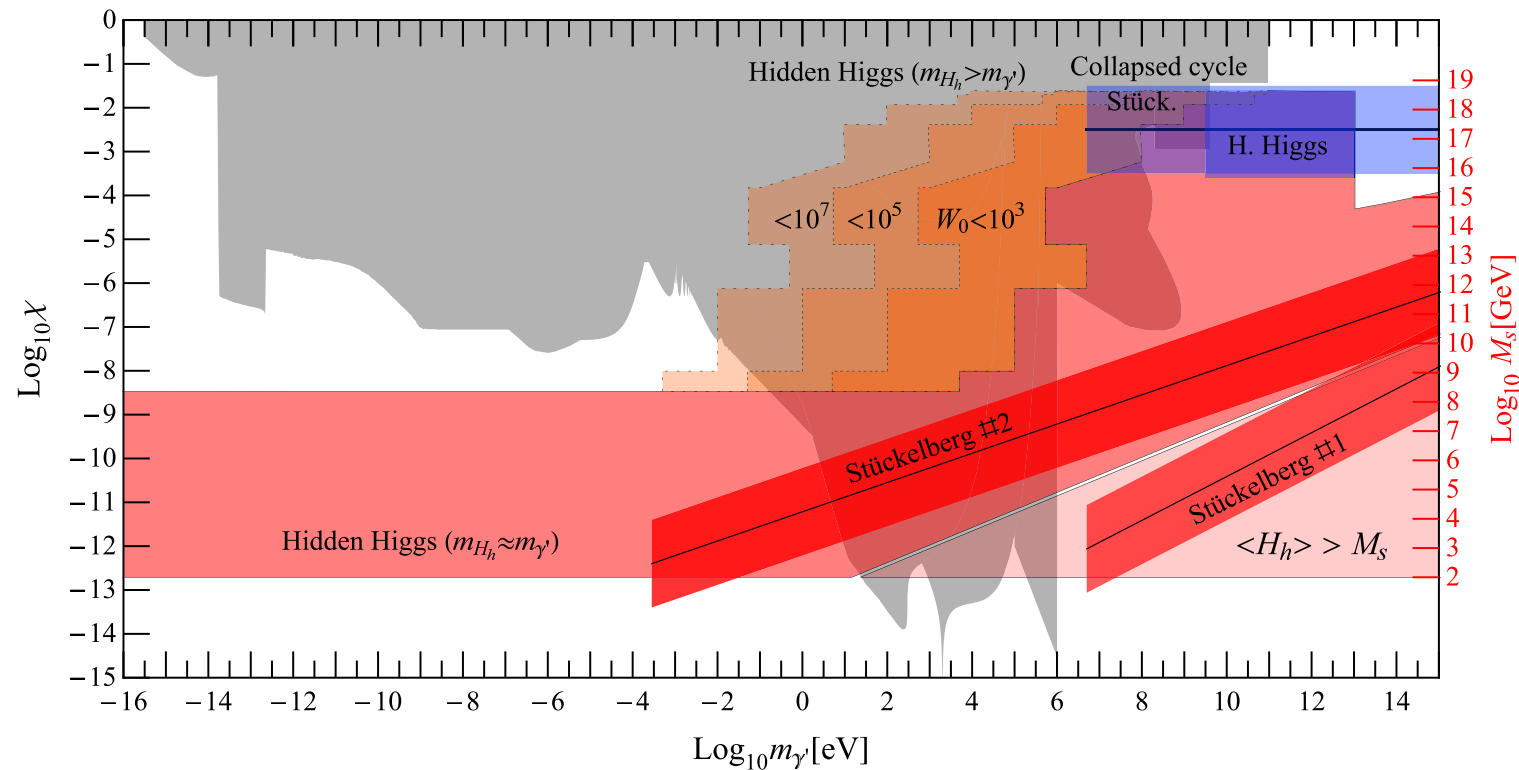
Preliminary limit from **ALPS** run in 10/2009:



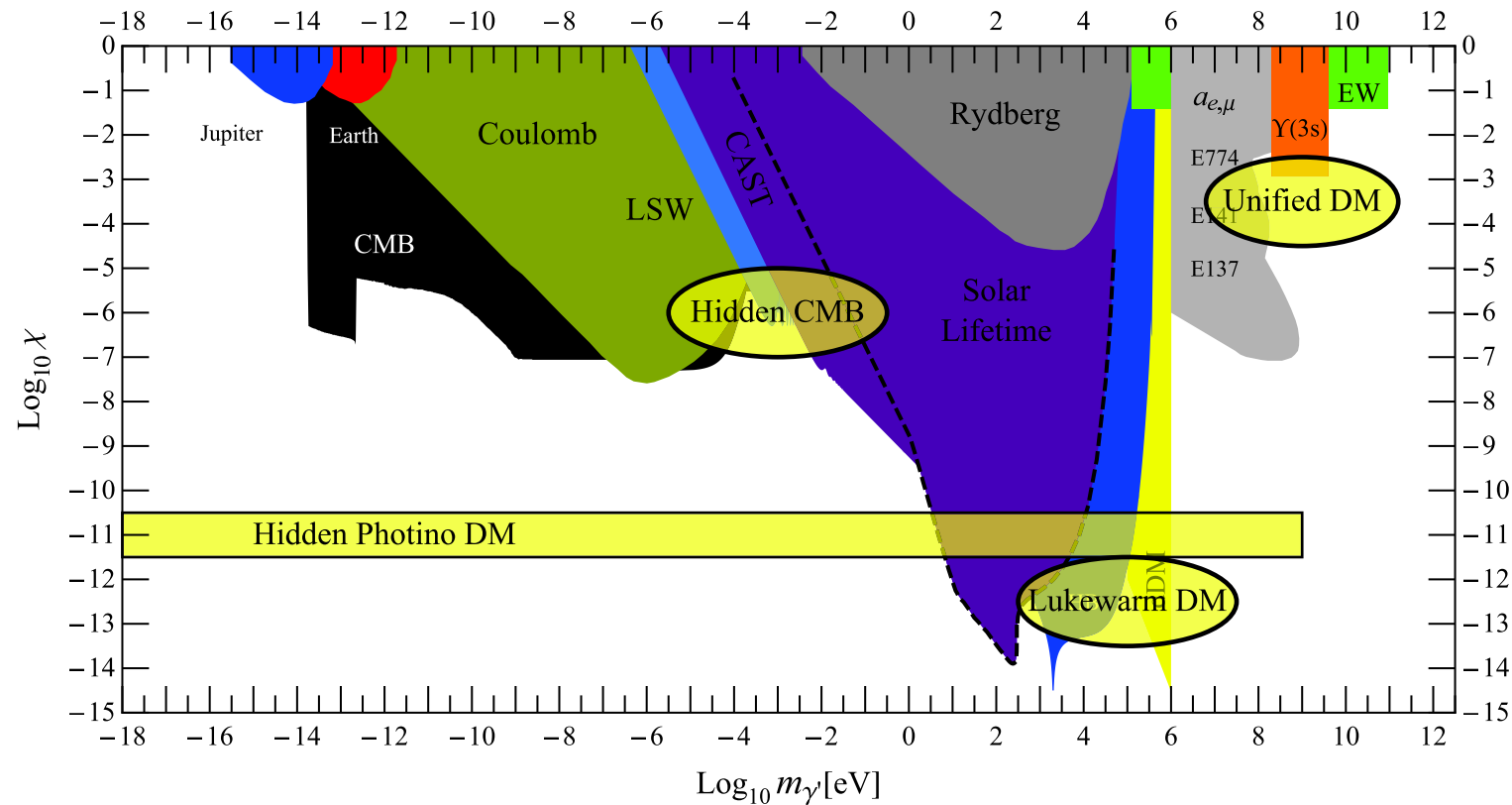
[ALPS Collaboration '09]

- Current constraints on hidden  $U(1)$ s confronted with string predictions:

[Goodsell, Jaeckel, Redondo, AR '09]



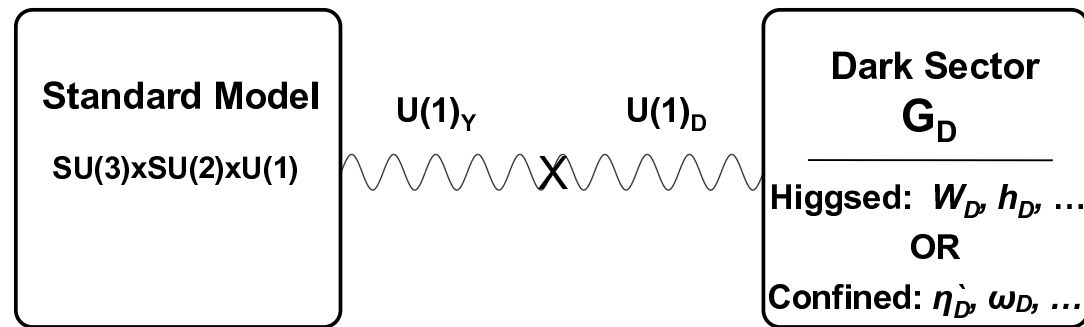
- Current constraints on hidden  $U(1)$ s vs. phenomenological very interesting islands: [Goodsell, Jaeckel, Redondo, AR '09]



- **Unified dark matter**

[Arkani-Hamed, Finkbeiner, Slatyer, Weiner '08;...]

Hidden sector dark matter interacting via GeV scale hidden sector dark gauge bosons

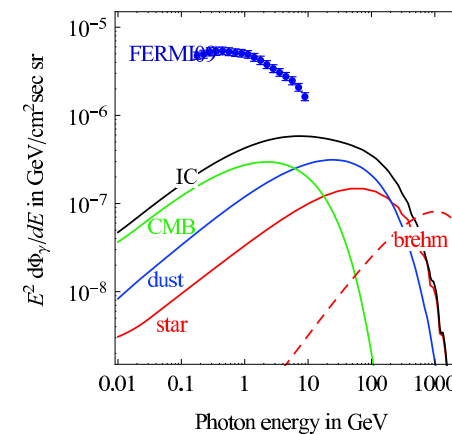
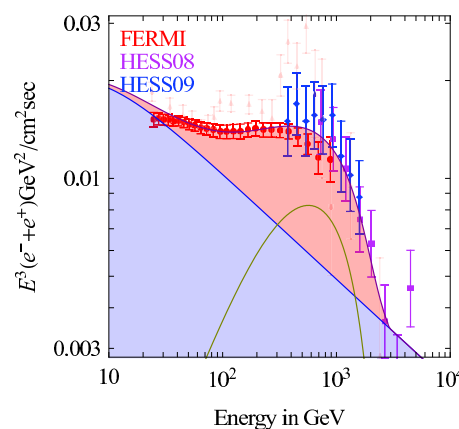
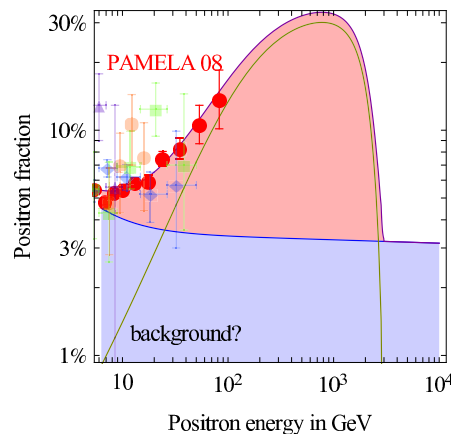


may explain astrophysical and terrestrial anomalies

- electron and/or positron excesses observed by PAMELA, ATIC, FERMI, HESS, ...
- annual modulation signal from DAMA/LIBRA and reconciliation with null results from other elastic scattering experiments

- Explanation of electron and/or positron excesses by PAMELA, FERMI, ... in terms of thermal relic dark matter annihilation requires
  - enhanced annihilation cross-section (boost factor)
  - leptophilic final state

DM with  $M = 3. \text{ TeV}$  that annihilates into  $4\mu$  with  $\sigma v = 8.8 \times 10^{-23} \text{ cm}^3/\text{s}$



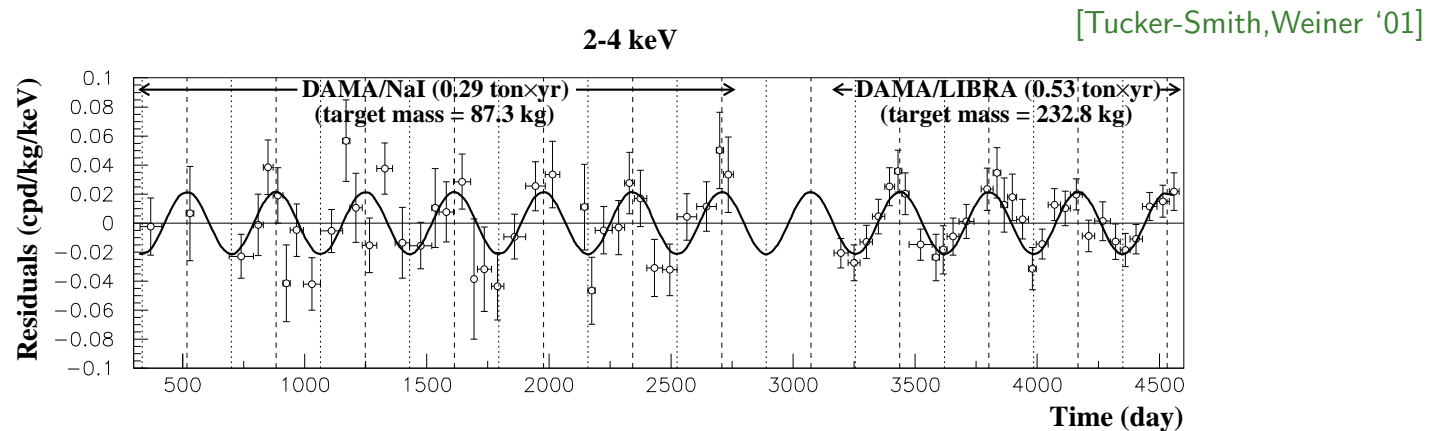
[Meade, Papucci, Strumia, Volansky '09]

$\Leftarrow$  Can be achieved via  $\chi + \chi \rightarrow \gamma' + \gamma'$ , if  $2m_e < m_{\gamma'} \lesssim m_p$

[Arkani-Hamed, Finkbeiner, Slatyer, Weiner '08; ...]

- Dark matter interpretation of annual modulation signal observed by DAMA not in conflict with null results of other direct detection experiments if  $\chi$ -nucleus scattering dominated by an inelastic process,

$$\chi + N \rightarrow \chi^* + N, \quad \text{with mass splitting } \Delta\delta \approx 100 \text{ keV}$$



[Bernabei *et al.* [DAMA Collaboration] '09]

⇐ Can be mediated by kinetically mixed  $\gamma'$  scattering off nuclei. Necessary mass splitting from more structure (e.g. additional gauge factors or SUSY) in dark sector

[Arkani-Hamed *et al.* '08;...;Cheung *et al.* '09]



### 3. Attacking dark forces with new fixed-target experiments

- High intensity frontier to search for MeV  $\div$  GeV-scale  $\gamma'$ :

- low-energy  $e^+e^-$  collider

talk of Bertrand Echenard

- \*  $\mathcal{O}(\text{few}) \text{ ab}^{-1}$  per decade

- \*  $\sigma \sim \frac{\alpha^2 \chi^2}{s}$

- fixed-target experiments

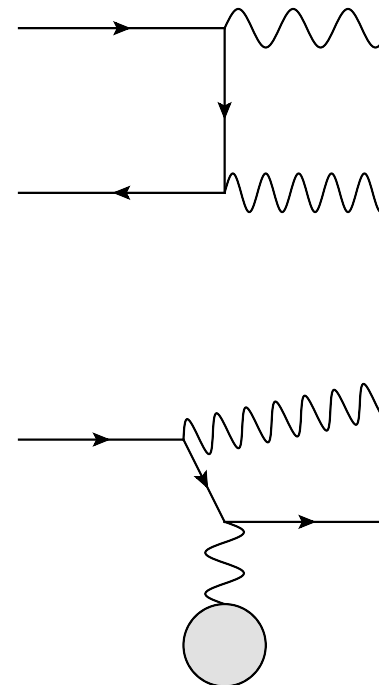
- \*  $\mathcal{O}(\text{few}) \text{ ab}^{-1}$  per day

- \*  $\sigma \sim \frac{\alpha^3 Z^2 \chi^2}{m_{\gamma'}^2}$

$\Rightarrow$  Beam dump and fixed-target experiments especially sensitive!

[Reece,Wang '09; Bjorken,Essig,Schuster,Toro '09;

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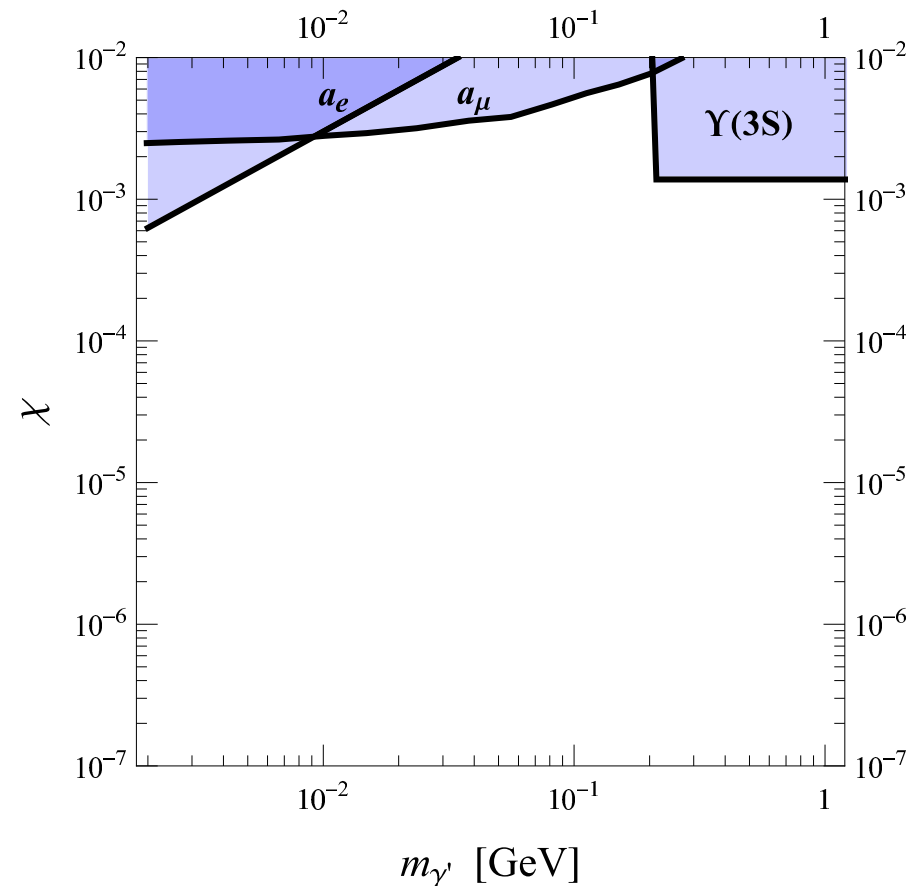
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A. Ringwald (DESY)



Hamburg, January 2010

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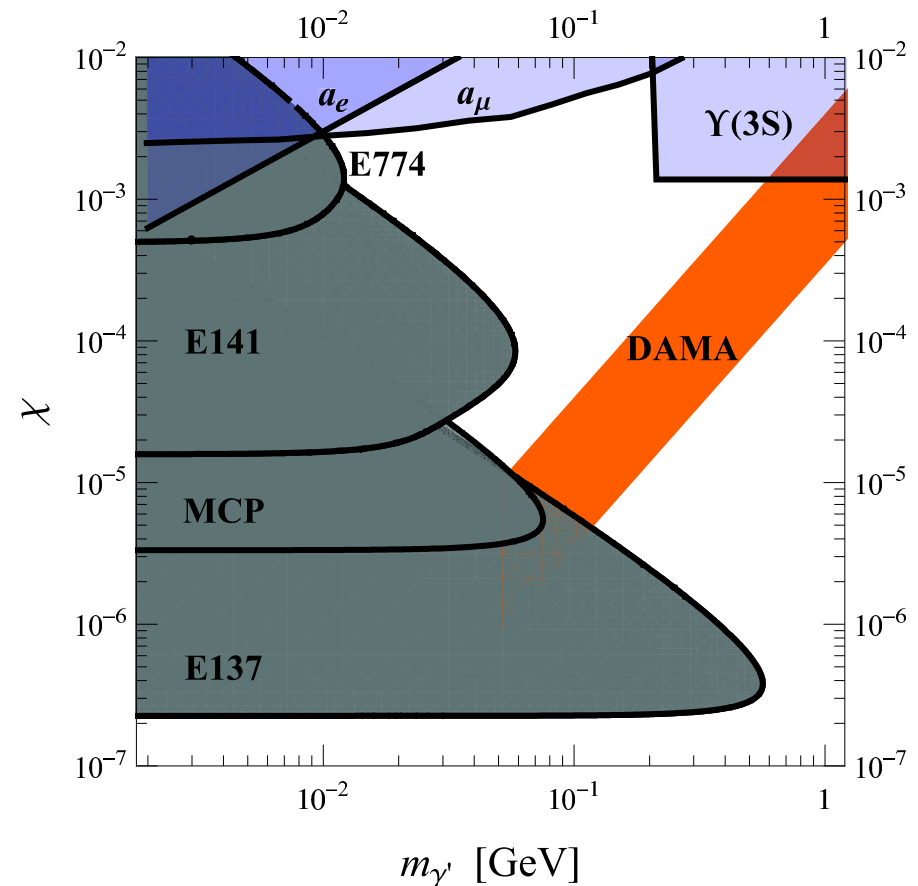
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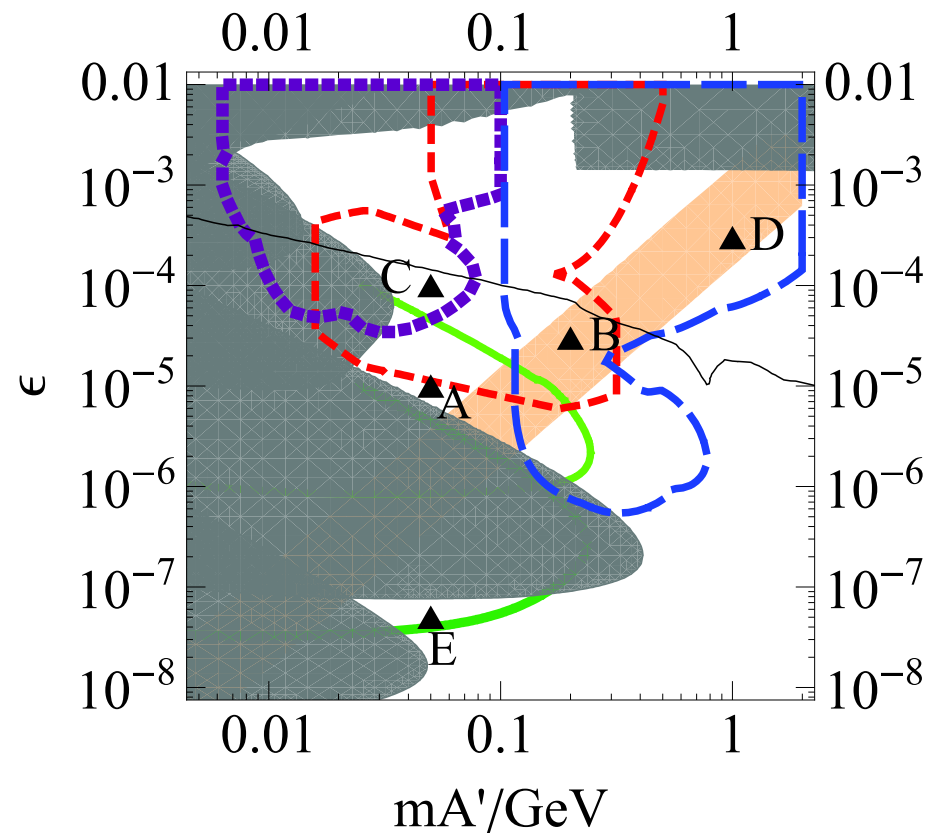
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A. Ringwald (DESY)



[Bjorken,Essig,Schuster,Toro '09]

Hamburg, January 2010

⇒ **Opportunities at DESY, ELSA, JLab, MAMI?**

- Production cross-section and decay length of  $\gamma'$ ,

$$\sigma_{\gamma'} \sim 100 \text{ pb} \left( \frac{\chi}{10^{-4}} \right)^2 \left( \frac{100 \text{ MeV}}{m_{\gamma'}} \right)^2$$

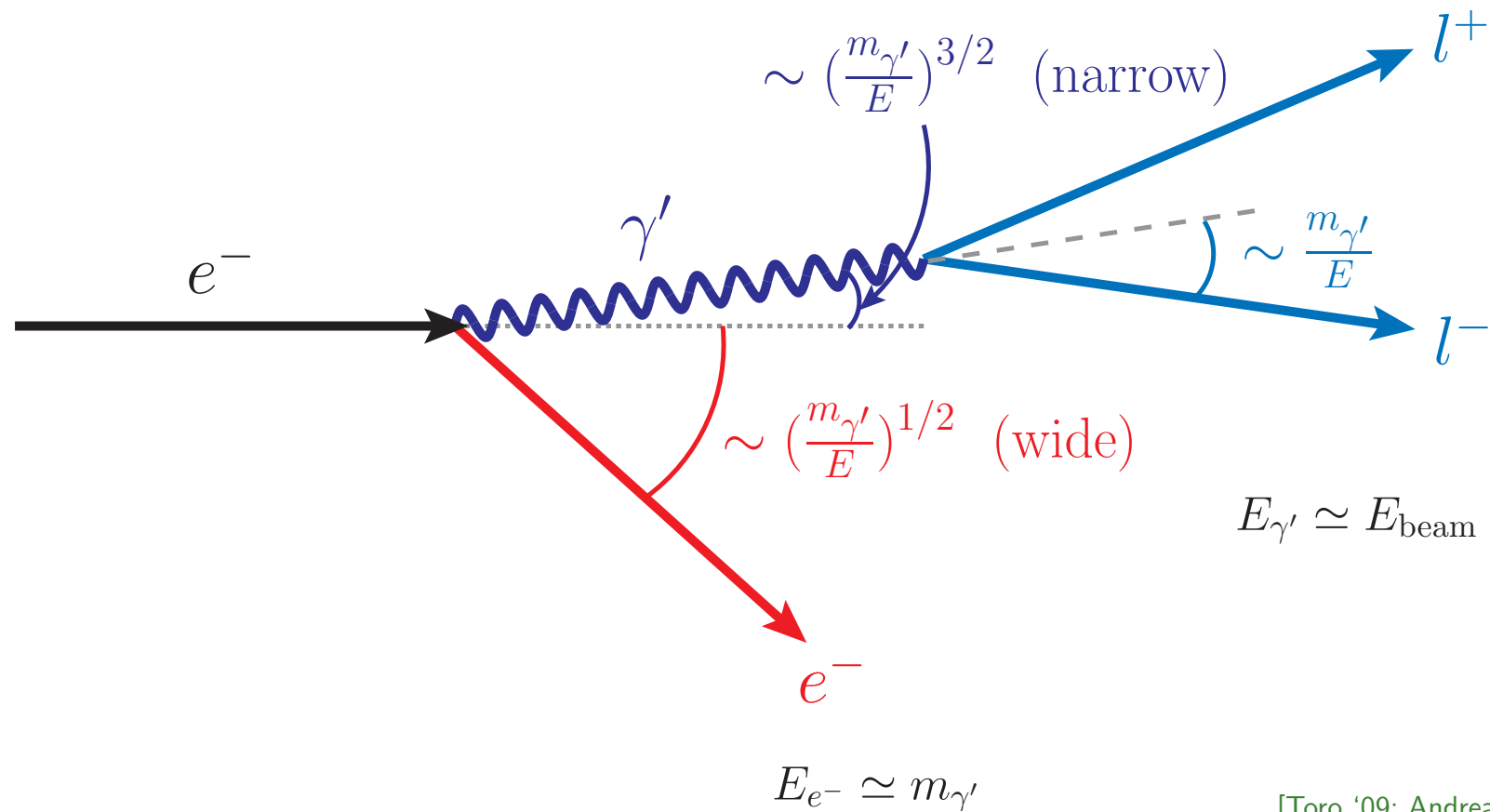
$$\ell_d = \gamma c \tau \sim 1 \text{ mm} \left( \frac{\gamma}{10} \right) \left( \frac{\chi}{10^{-4}} \right)^{-2} \left( \frac{100 \text{ MeV}}{m_{\gamma'}} \right)$$

- Vary over many orders of magnitude in interesting parameter range

⇒ Multiple experimental approaches, with different strategies for fighting backgrounds

- $\ell_d \gg \text{cm}$ : beam dump; low background
- $\ell_d \sim \text{cm}$ : vertex; limited by instrumental bkg
- $\ell_d \ll \text{cm}$ : bump hunt; fight bkg with high intensity, resolution

## Kinematics and geometry:

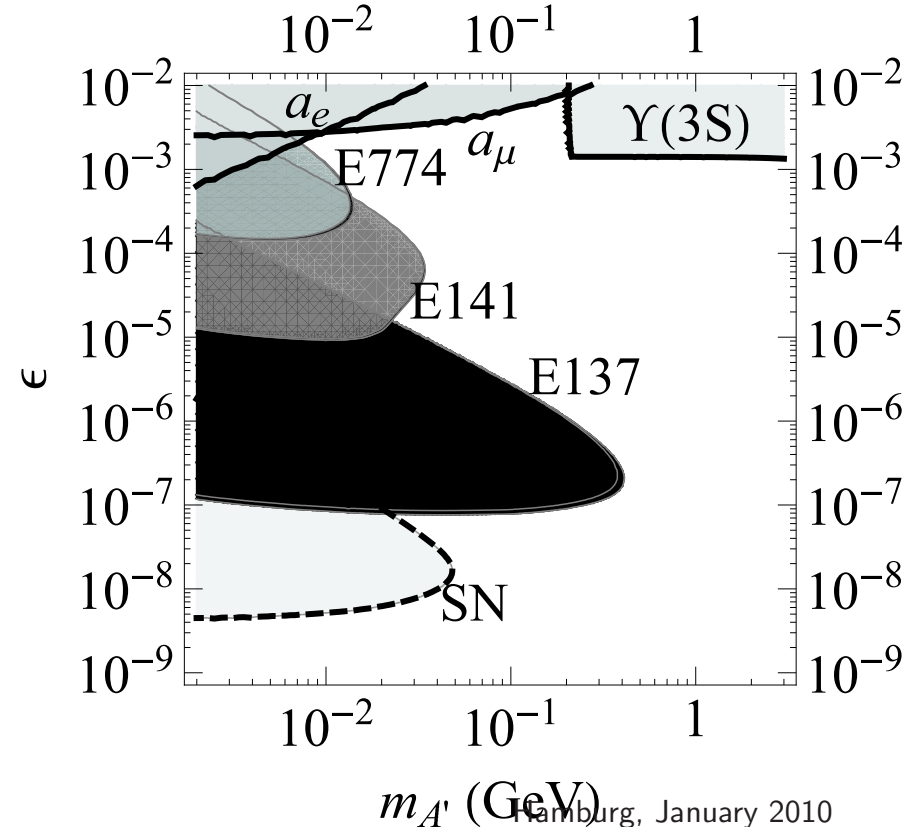
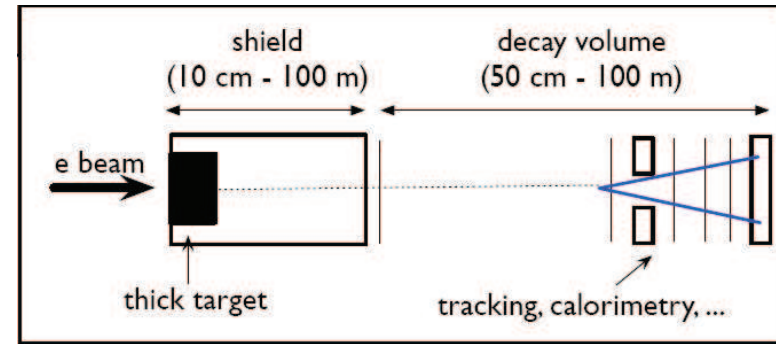


[Toro '09; Andreas '10]

## • Past beam dumps:

[Bjorken, Essig, Schuster, Toro '09]

- SLAC E137:  
30 C, 20 GeV, 200 m, 200 m
- SLAC E141:  
.3 mC, 9 GeV, 10 cm, 35 m
- Fermilab E774:  
.8 nC, 275 GeV, 30 cm, 7 m



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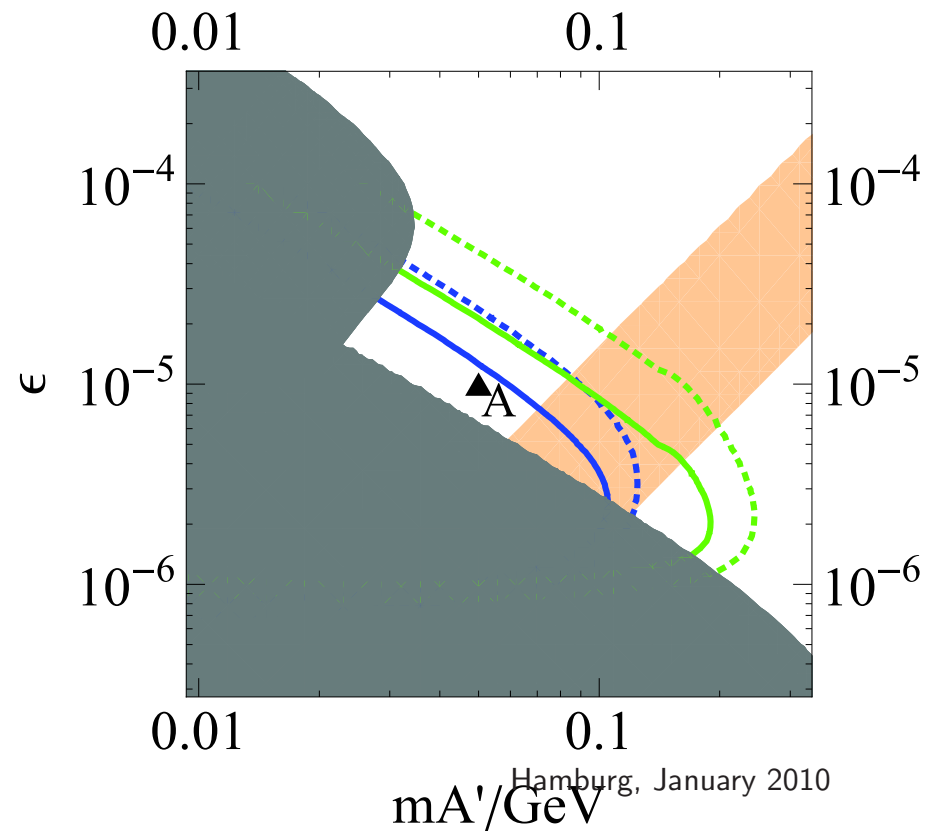
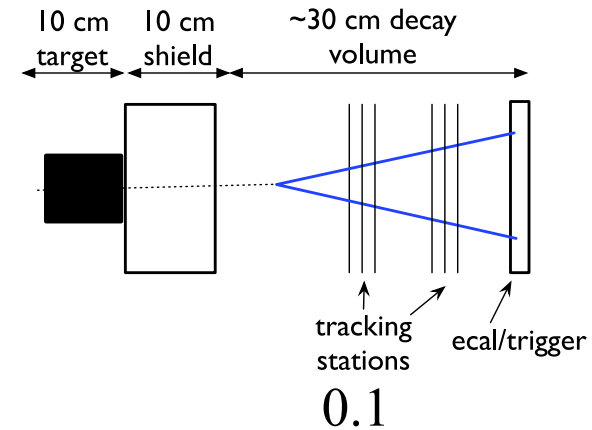
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## • New beam dump suggested:

[Bjorken,Essig,Schuster,Toro '09]

- Low power W beam dump  
.3 C, 200 MeV, 20 cm, 50 cm  
.1 C, 6 GeV, 3.9 m, 7 m





– Dark Forces Attack at DESY –

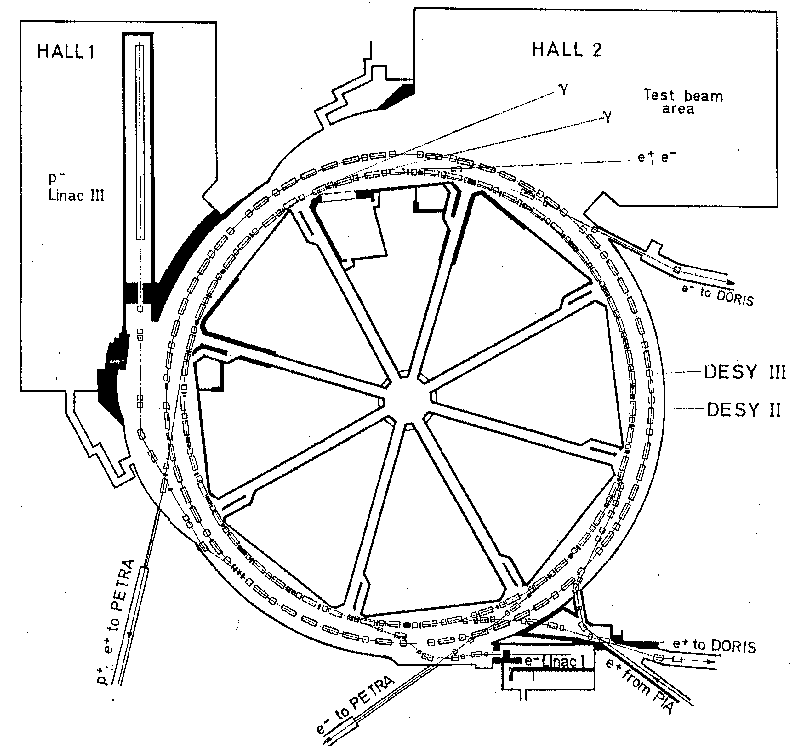
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- New experiment at **DESY**?

- **DarkDESY** at DESY II

[Andreas,Bechtle,Ehrlichmann,Garutti,Gregor,Lindner,Meyners,Redondo,AR]

\*  $\sim 10$  nA with 0.45 - 7 GeV

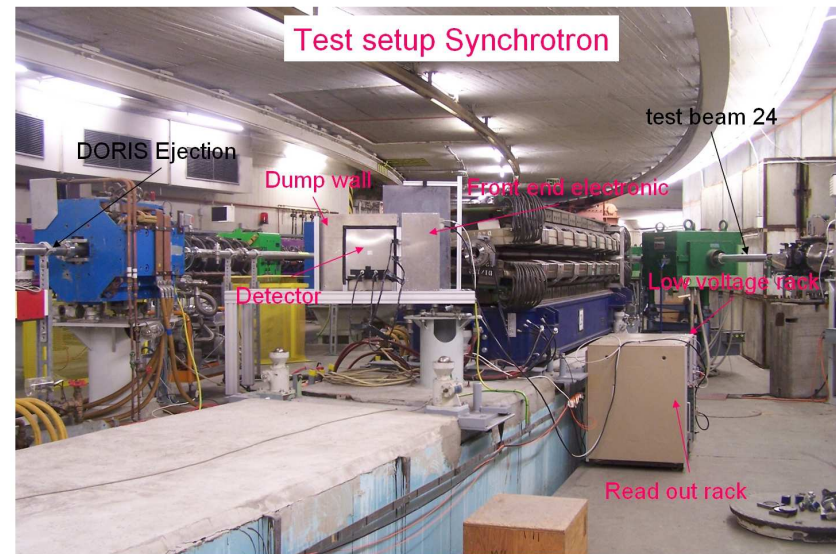


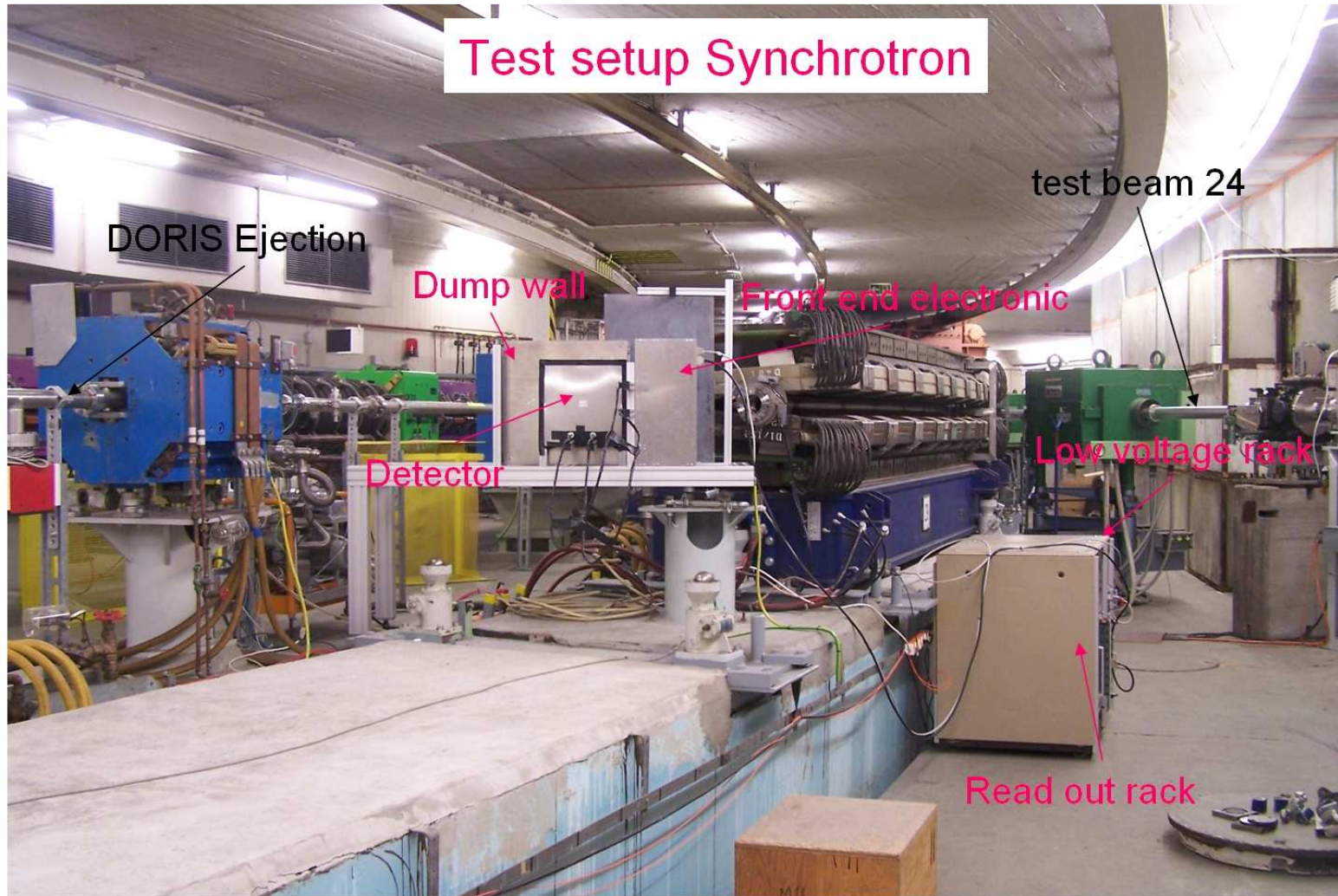
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- \*  $\sim 10$  nA with 0.45 - 7 GeV
- \* first estimates of beam dump sensitivity
- \* detector (spare parts of HERA experiments) installed this month



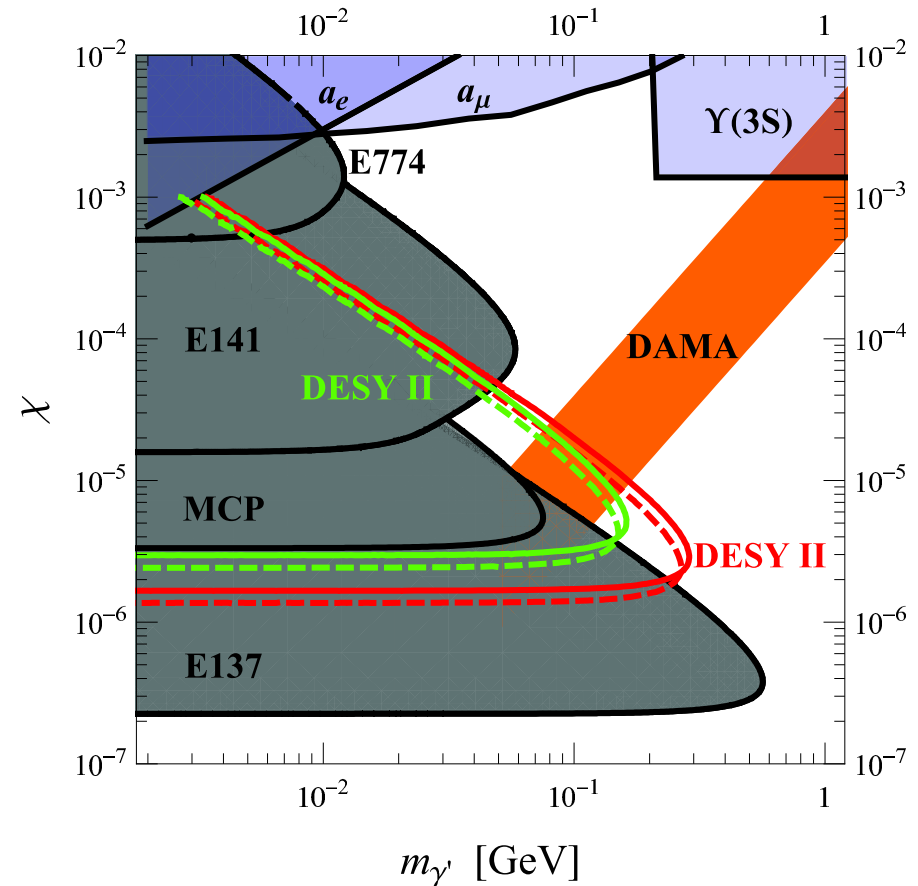


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- \* detector (spare parts of HERA experiments) installed this month
- \* if background handable, full proposal in spring; experiment can be done in 2010



- **Complementary region** can be probed by thin target bump hunt experiment:  
need very high integrated luminosity and high resolution (trident) spectrometer

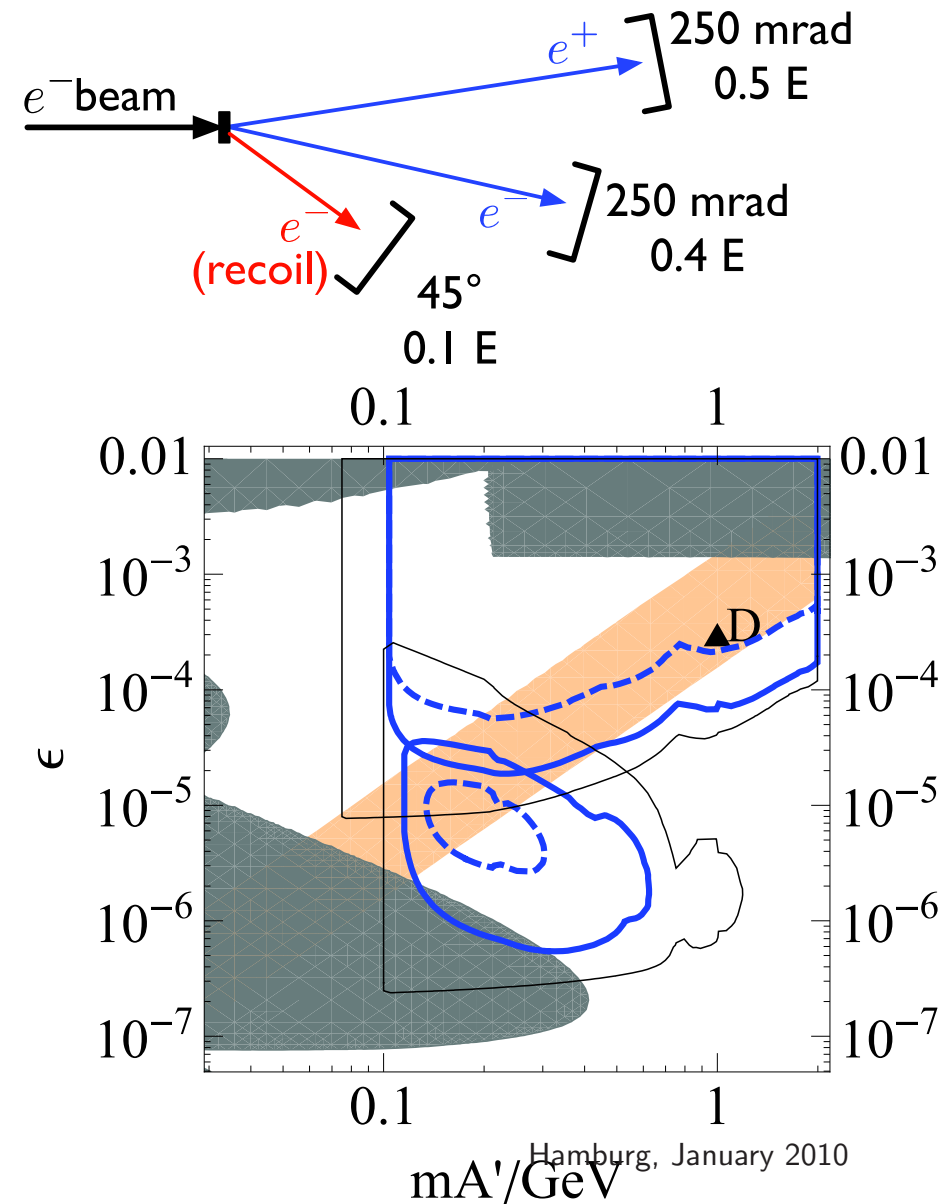
[Bjorken, Essig, Schuster, Toro '09]

⇒ **New experiment at JLab?**

- **Fixed-target experiment in CEBAF Hall A**

[Hall A Collaboration]

- \*  $80 \mu\text{A}$  at  $2 \div 4 \text{ GeV}$
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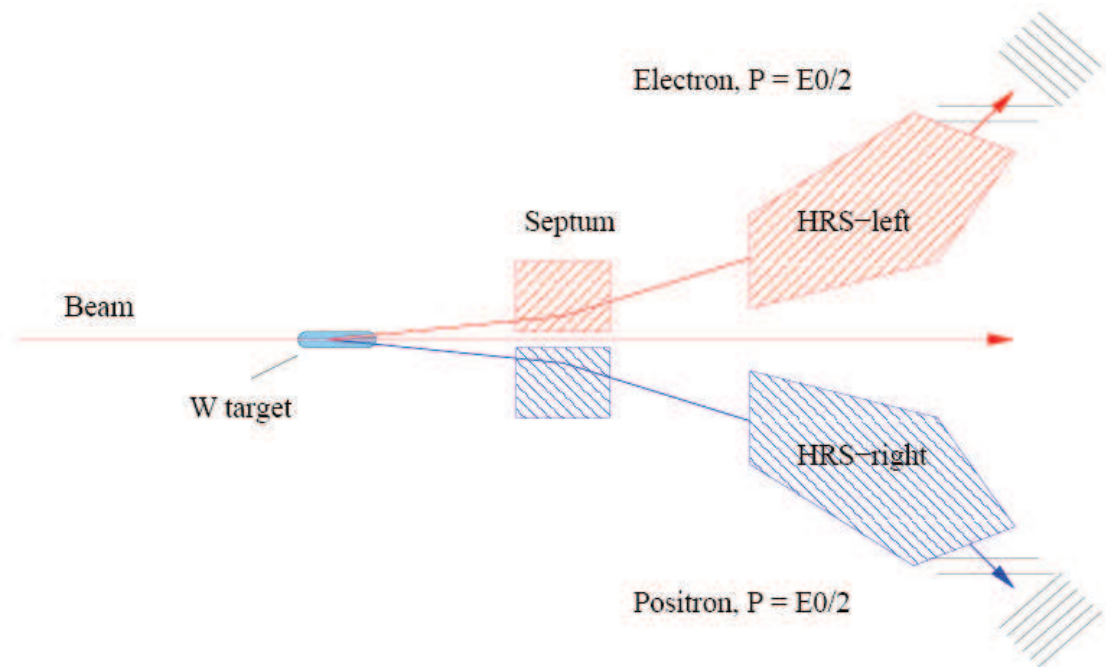
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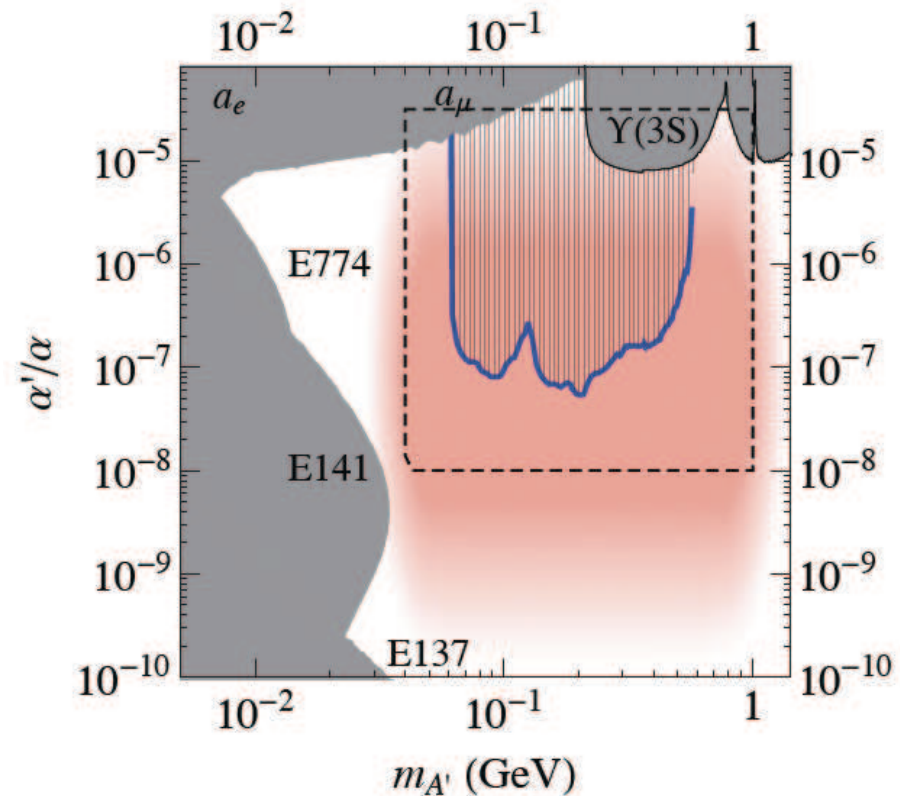
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## 4. Conclusions

- Strong physics motivation for the possible existence of hidden/dark photons mixing with the visible photon
    - top down: many extra  $U(1)$ s in string compactifications
    - bottom up: anomalies associated with dark matter
  - Fixed-target experiments well suited to attack dark forces
  - Large parameter space requires multiple search strategies and experiments
    - low coupling/mass: new beam dump experiments
    - intermediate region: new forward-geometry experiments
    - high coupling/mass: standard wide-angle spectrometers (e.g. [JLab](#))
- ⇒ Great opportunities for new particle physics experiments at [DESY](#)!