Dark Forces Attack

Andreas Ringwald

Seminar
December 3, 2009, Bonn, Germany

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:

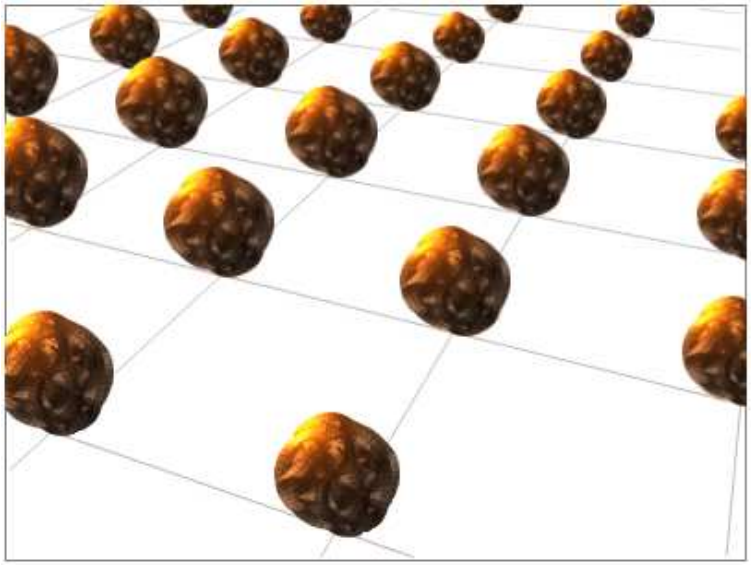
"Hidden" or "Dark" Photons

- 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
  - Opportunities in Germany at **DESY, ELSA, MAMI**?

Table of Content:

2. Physics case for dark forces

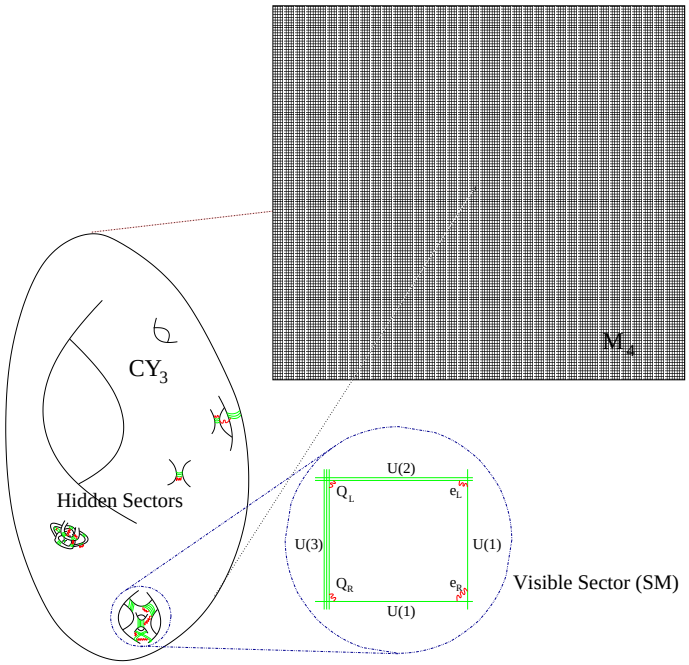
- **Top-down motivation for hidden sector dark photons:**
  - Hidden U(1) gauge factors generic feature of string compactifications



* both in heterotic compactifications, e.g. ask H.P. Nilles

$$\mathrm{E}_8 \times \mathrm{E}_8 \xrightarrow{4\mathrm{d}} \mathrm{G}_{\mathrm{SM}} \times \mathrm{U}(1)^4 \times \Big[\mathrm{SU}(4) \times \mathrm{SU}(2) \times \mathrm{U}(1)^4\Big] \longrightarrow \mathrm{G}_{\mathrm{SM}} \times \mathrm{U}(1)^?$$

* as well as in type II orientifold compactifications with D-branes, e.g. ask T. Grimm

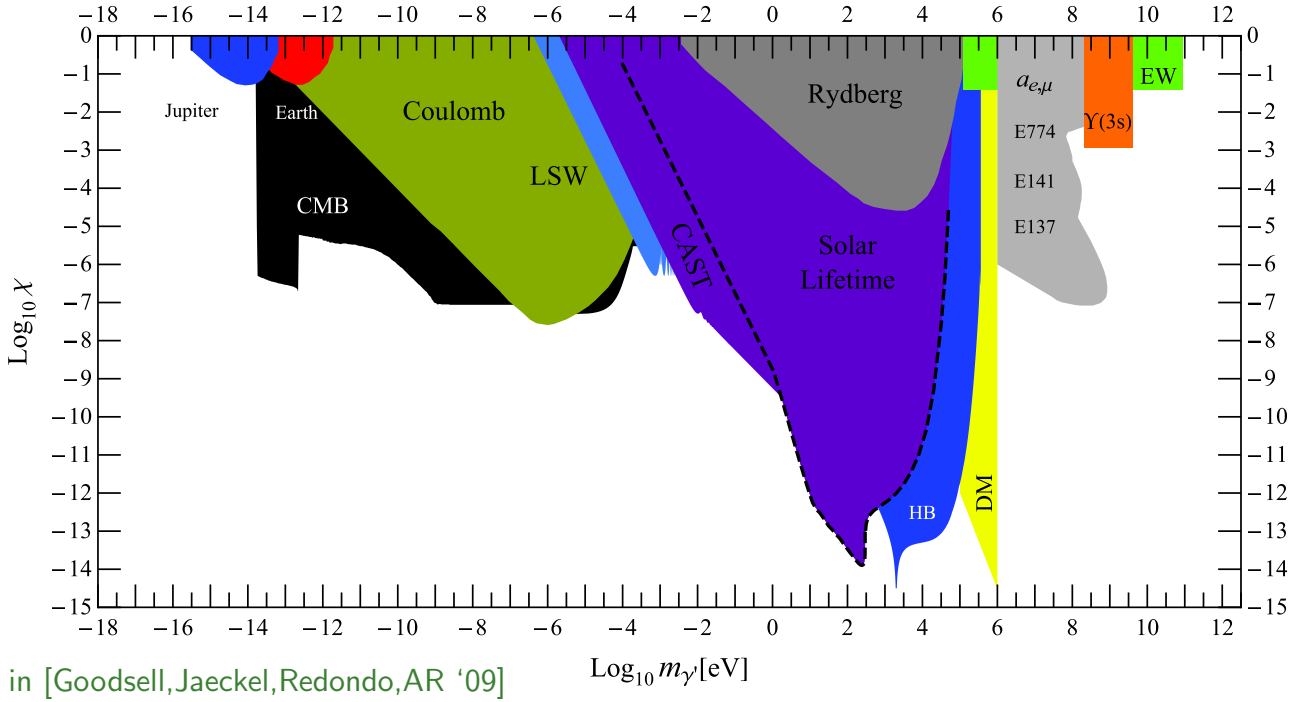


– Hidden U(1) gauge bosons ("photons") may have masses $m_{\gamma'} \ll$ TeV

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

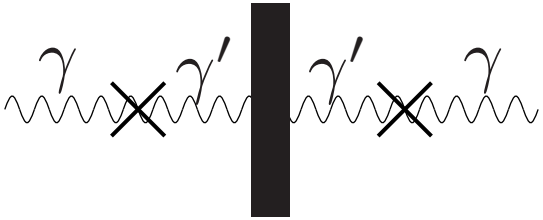
$$\mathcal{L} \supset -\frac{1}{4}F^{(\mathrm{vis})}_{\mu\nu}F^{\mu\nu}_{(\mathrm{vis})} - \frac{1}{4}F^{(\mathrm{hid})}_{\mu\nu}F^{\mu\nu}_{(\mathrm{hid})} + \frac{\chi}{2}F^{(\mathrm{vis})}_{\mu\nu}F^{(\mathrm{hid})\mu\nu} + m^2_{\gamma'}A^{(\mathrm{hid})}_{\mu}A^{(\mathrm{hid})\mu}$$

– Current constraints: Coulomb deviations, $\gamma \leftrightarrow \gamma'$ oscillations, beam dumps,.



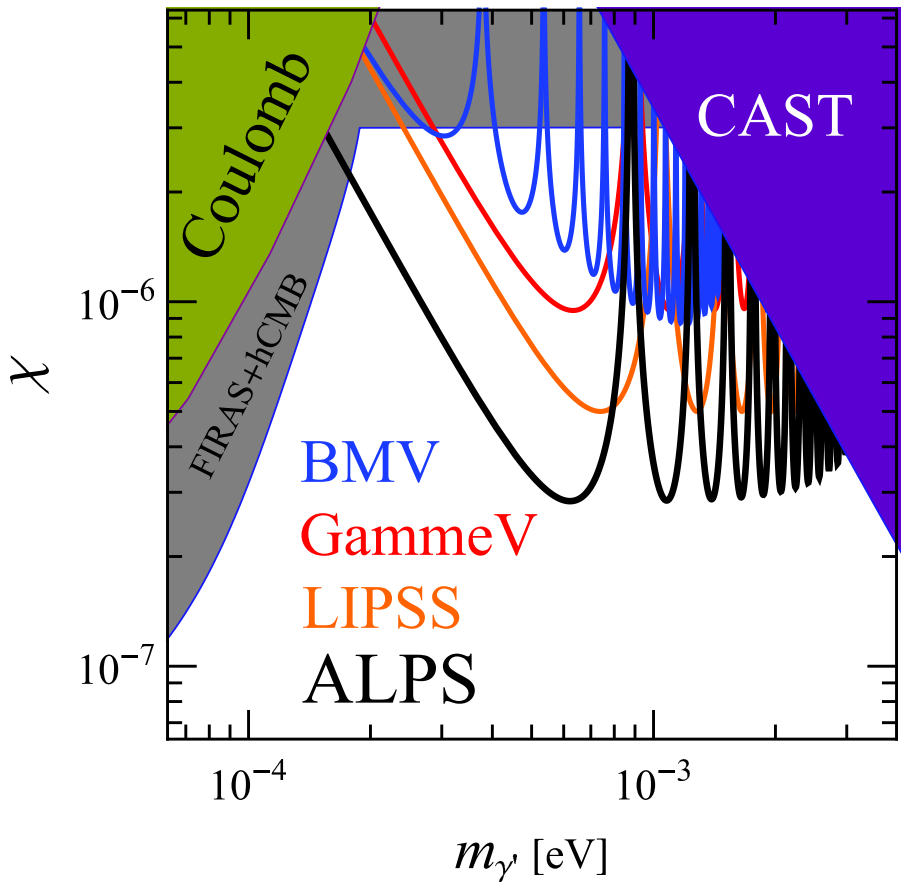
compilation in [Goodsell,Jaeckel,Redondo,AR '09]

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]

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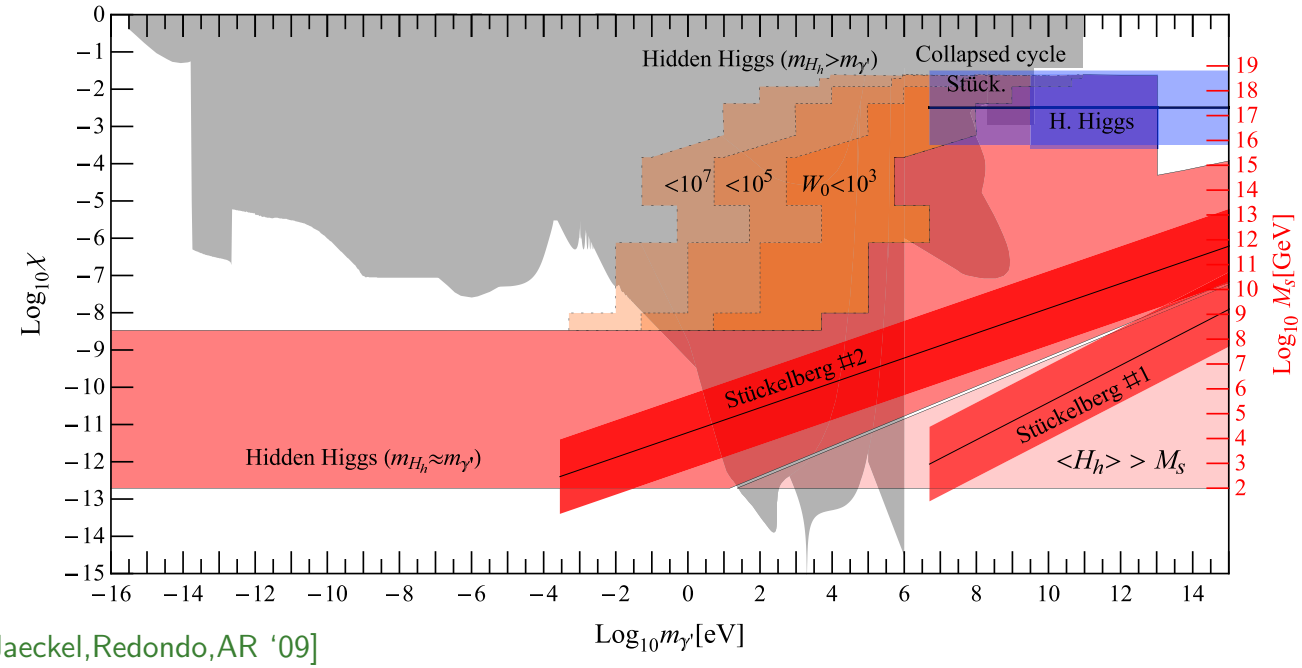
– Current constraints confronted with string predictions: type IIB



[Goodsell,Jaeckel,Redondo,AR '09]

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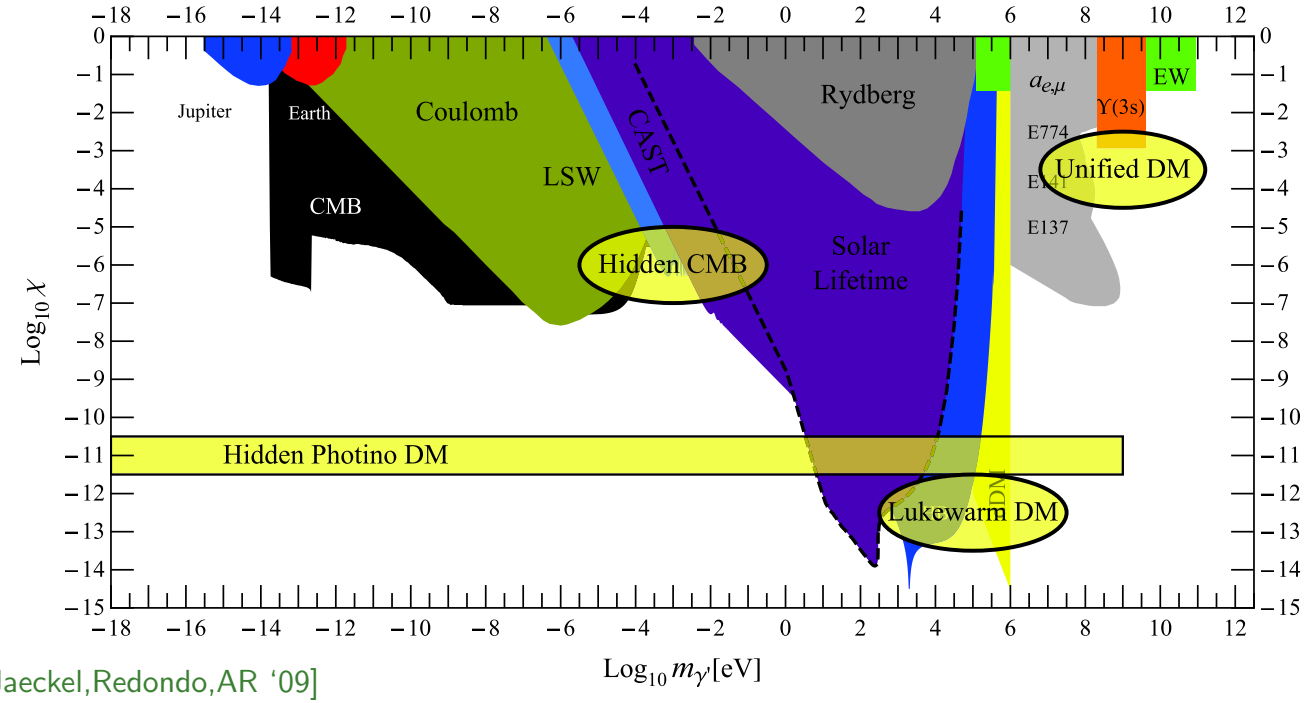
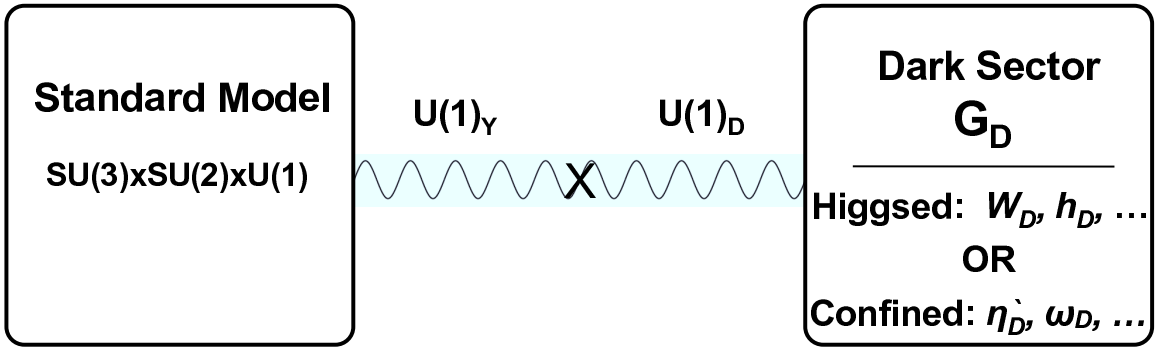
– Current constraints vs. phenomenologically very interesting islands:



[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

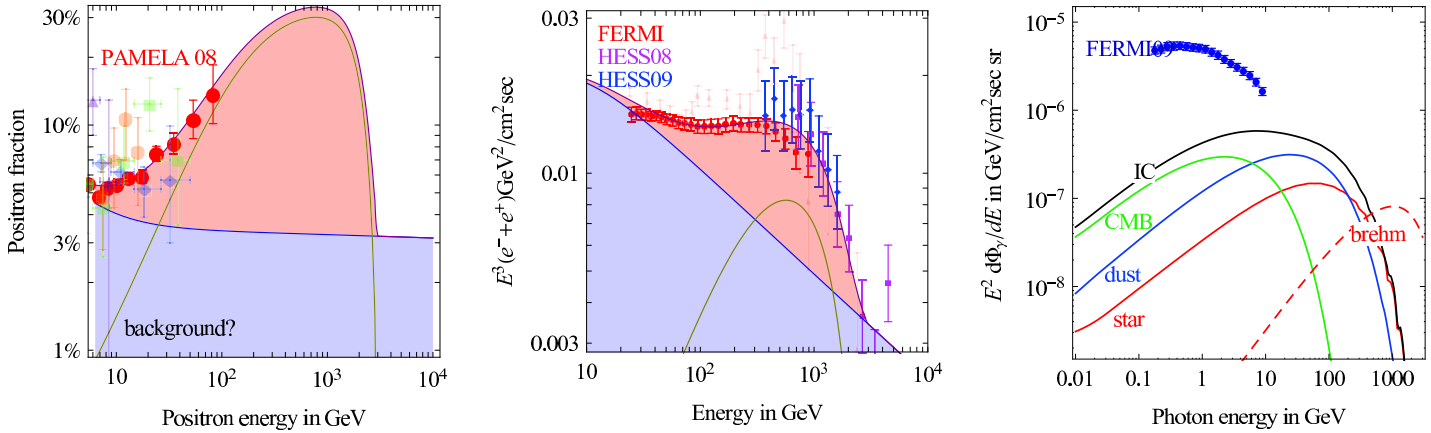


may explain astrophysical and terrestrial anomalies

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



[Meade,Papucci,Strumia,Volansky '09]

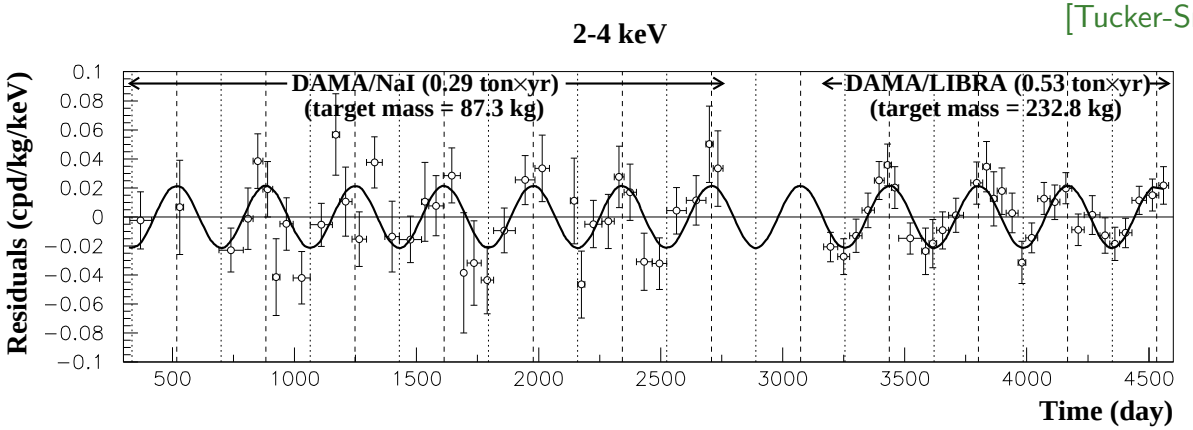
$\Leftarrow$ Can be achieved via $\chi + \chi \to \gamma' + \gamma'$, if $2\,m_e < m_{\gamma'} \lesssim m_p$

[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 χ-nucleus scattering dominated by an inelastic process,

$$\chi + N \to \chi^* + N, \qquad \text{with mass splitting } \triangle\delta \approx 100 \text{ keV}$$

[Tucker-Smith,Weiner '01]



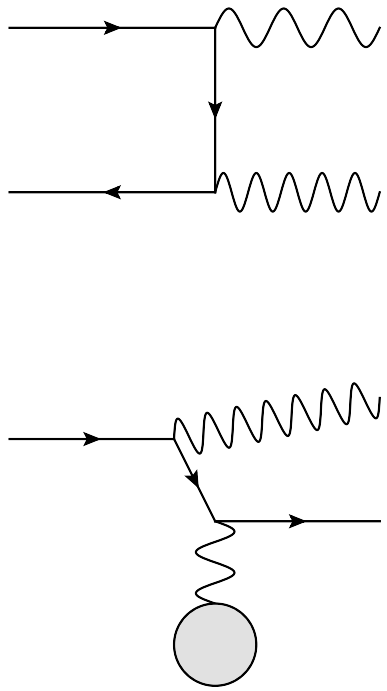
[Bernabei *et al.* [DAMA Collaboration] '09]

⇐ Can be mediated by kinetically mixed γ' 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 luminosity frontier:
  - low-energy e^+e^- collider
    - $\mathcal{O}$(few) ab^{-1} per decade
    - $\sigma \sim \frac{\alpha^2 \chi^2}{s}$
  - fixed-target experiments
    - $\mathcal{O}$(few) 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; Batell,Pospelov,Ritz '09]

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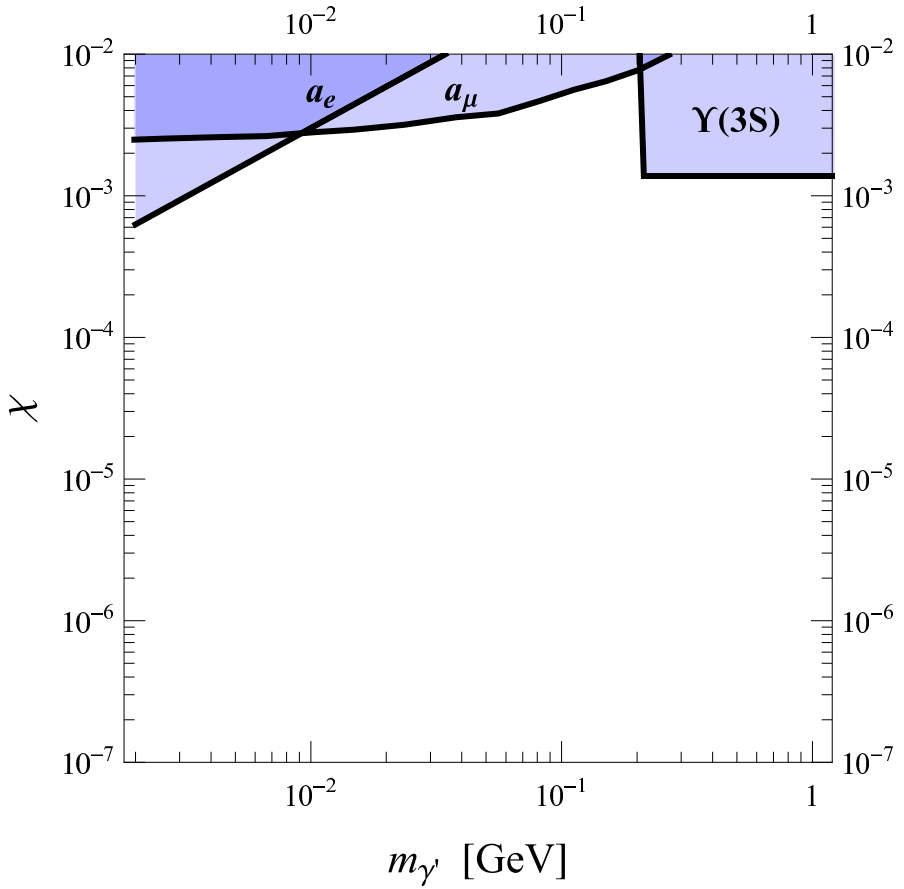

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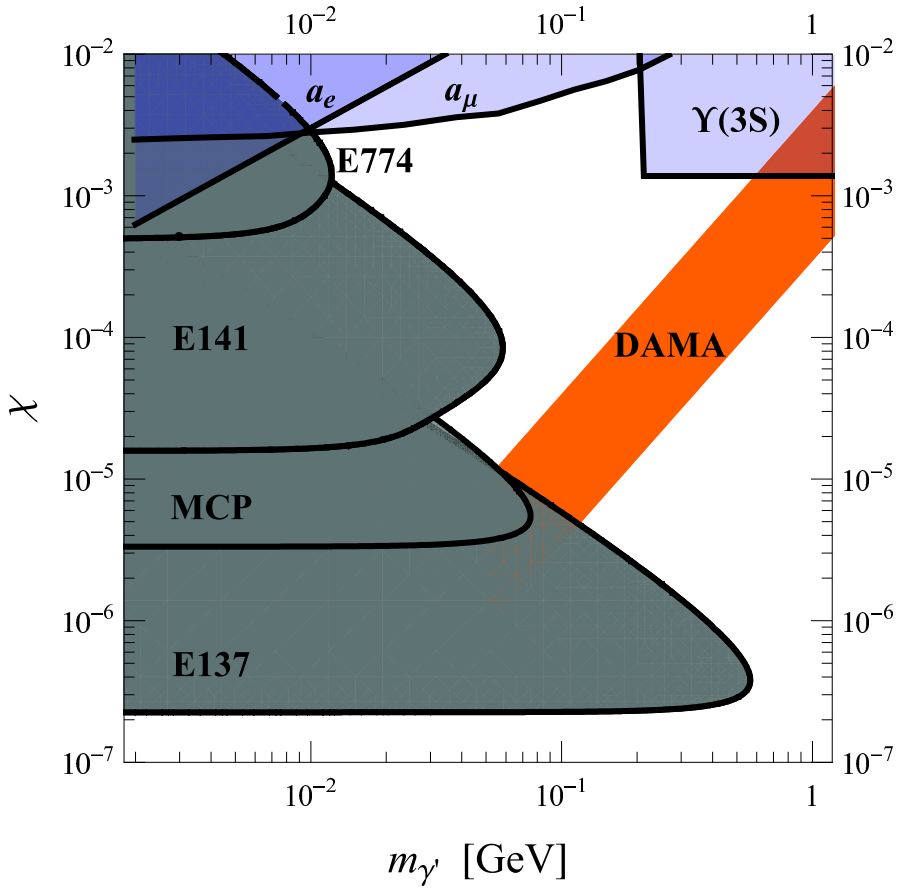

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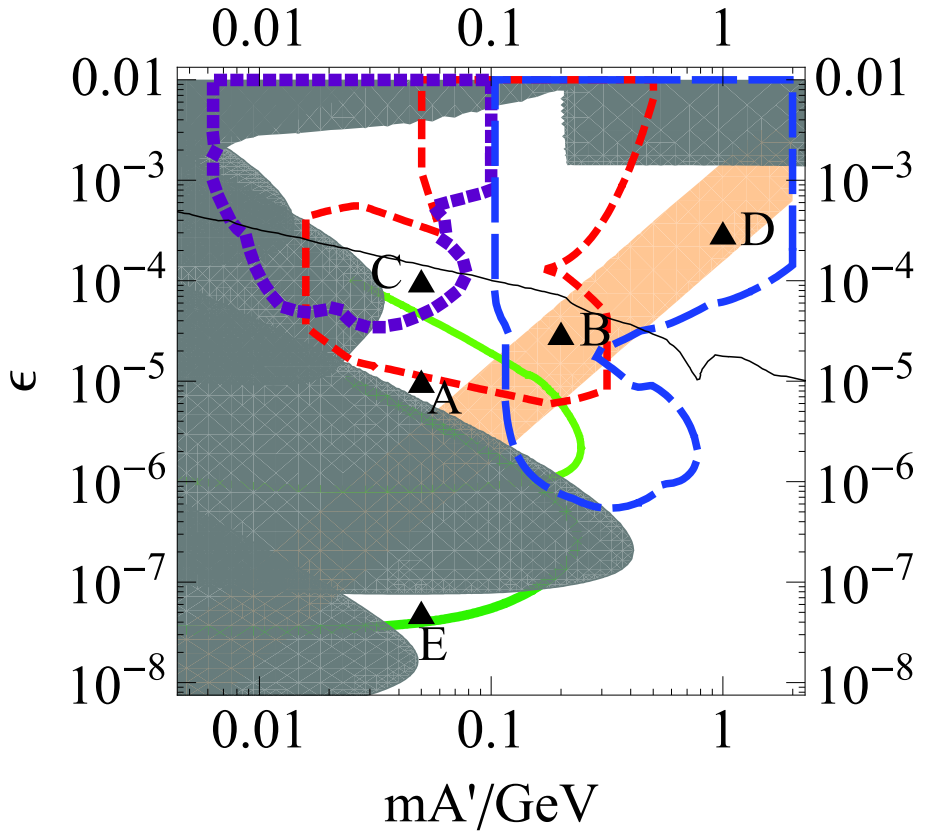


[Bjorken,Essig,Schuster,Toro '09]

- Production cross-section and decay length of γ',

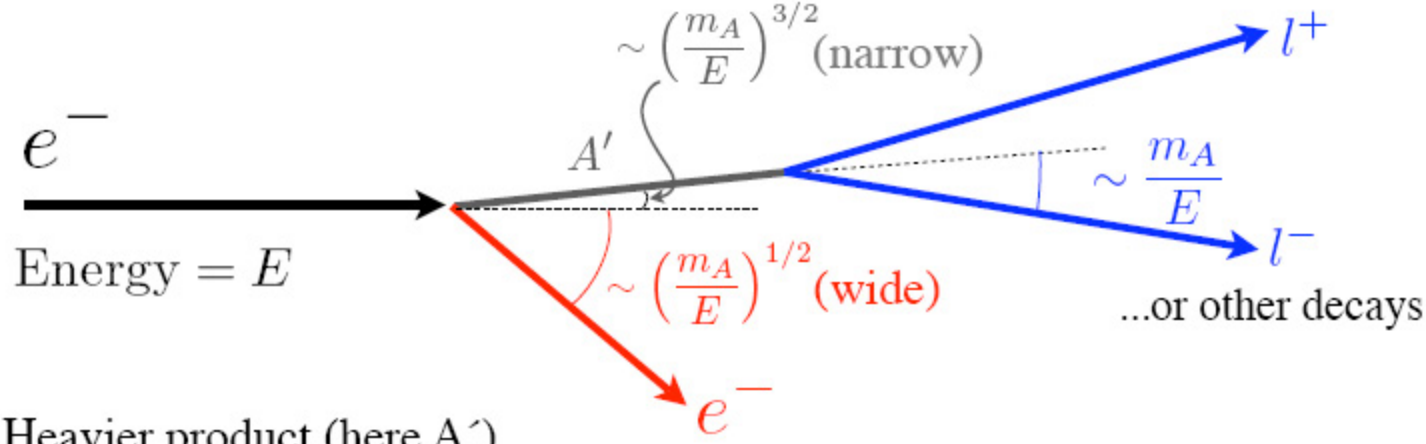
$$\begin{aligned} \sigma_{\gamma'} &\sim 100\ \text{pb} \left(\frac{\chi}{10^{-4}}\right)^2 \left(\frac{100\ \text{MeV}}{m_{\gamma'}}\right)^2 \\ \ell_d = \gamma c\tau &\sim 1\ \text{mm} \left(\frac{\gamma}{10}\right) \left(\frac{\chi}{10^{-4}}\right)^{-2} \left(\frac{100\ \text{MeV}}{m_{\gamma'}}\right)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

- Vary over many orders of magnitude in interesting parameter range

$\Rightarrow$ Multiple experimental approaches, with different strategies for constructing backgrounds

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

Kinematics and Geometry



Heavier product (here A´) takes most of beam energy:

$m_{A'} \gg m_e$ vs. $m_e \gg m_\gamma = 0$ for bremsstrahlung

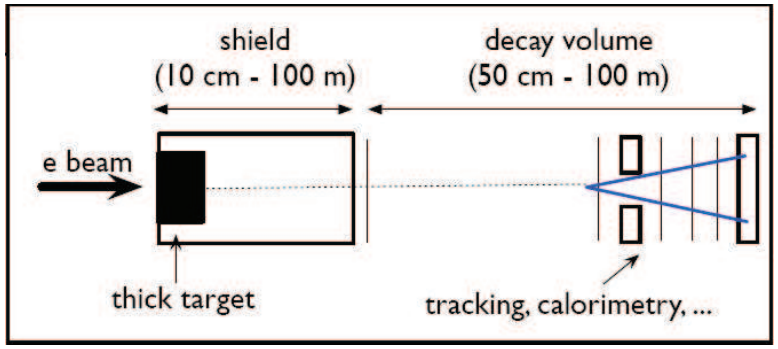
$E_{e^-} \simeq m_{A'}$ $E_{A'} \simeq E_{beam}$

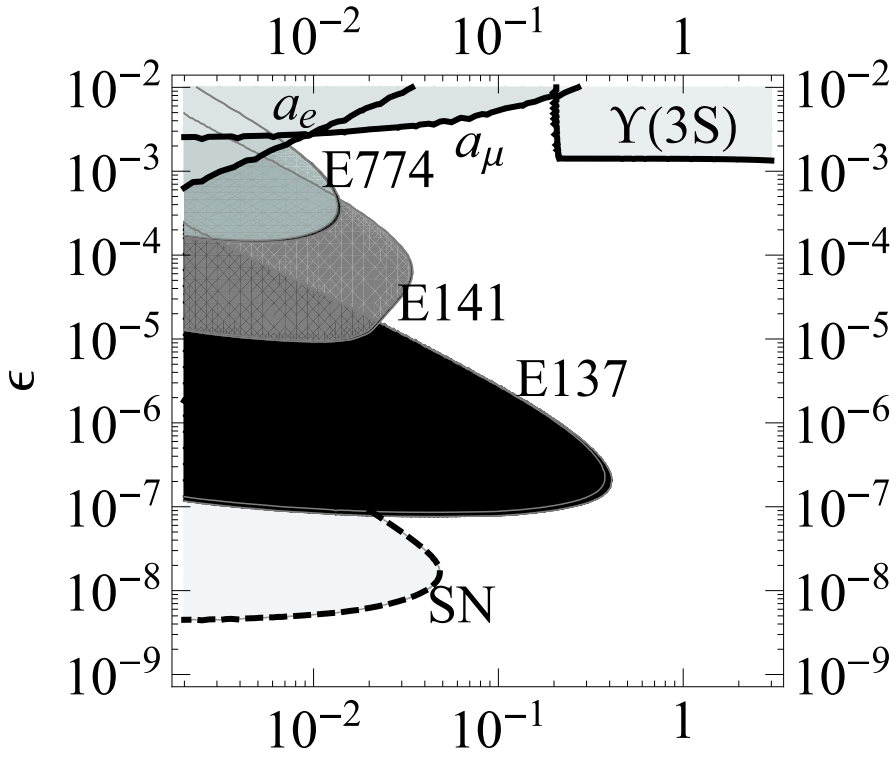
- Forward geometry allows small, purpose-built detector
- Limitation: Beam products also forward!

- **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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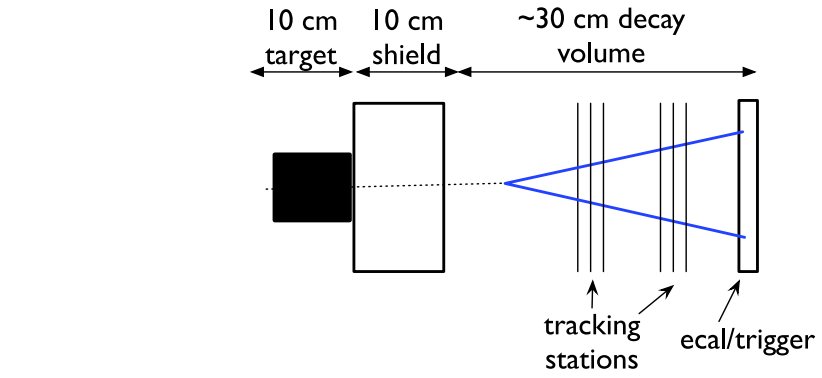
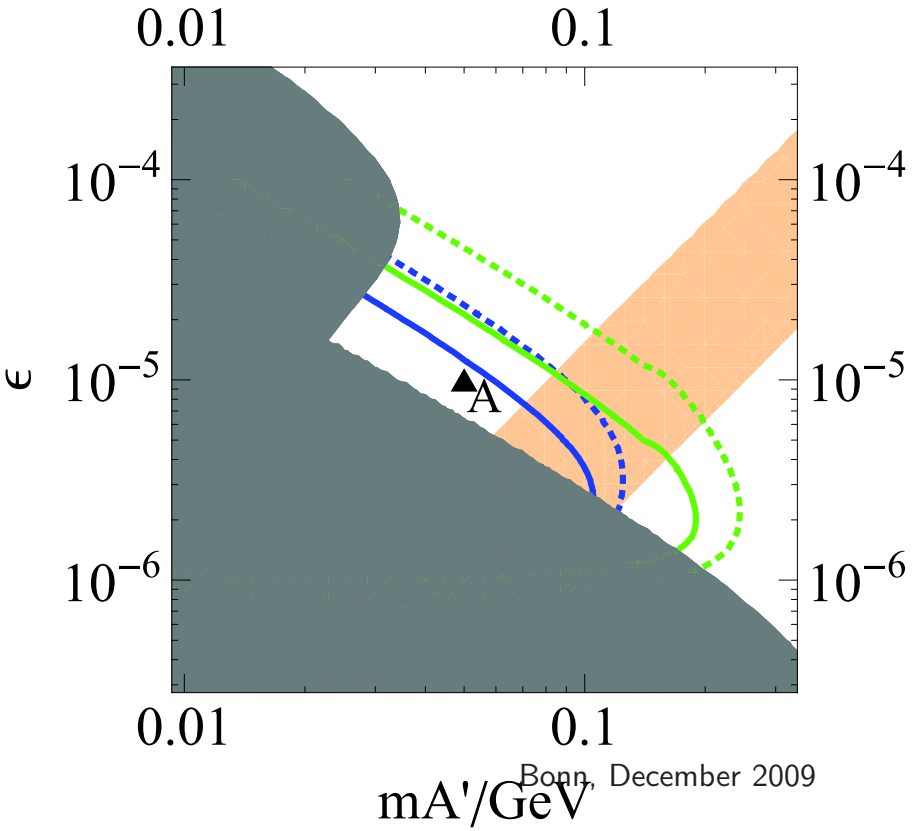
- **New beam dump suggested:**

[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

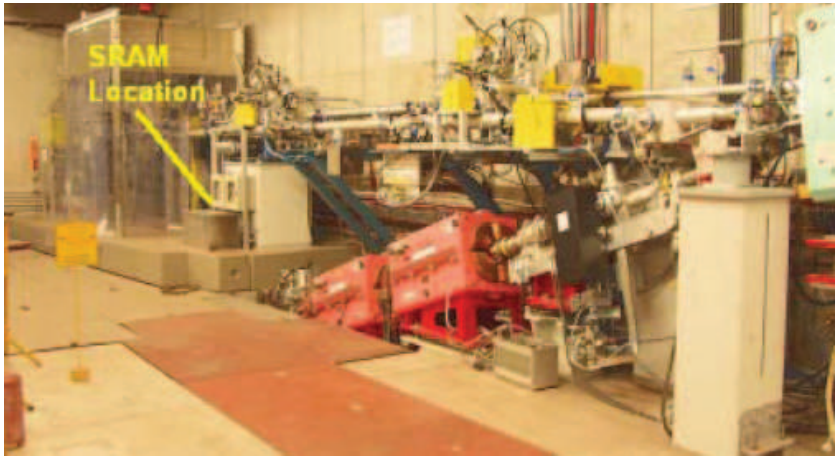
  ⇒ Opportunity at DESY, ELSA, MAMI?





- **New experiments at DESY?**
  - **Beam dump of FLASH?**
    - ∗ extremely high current
    - ∗ no space
    - ∗ no time

    ⇒ opportunity for new beam dump at FLASH II



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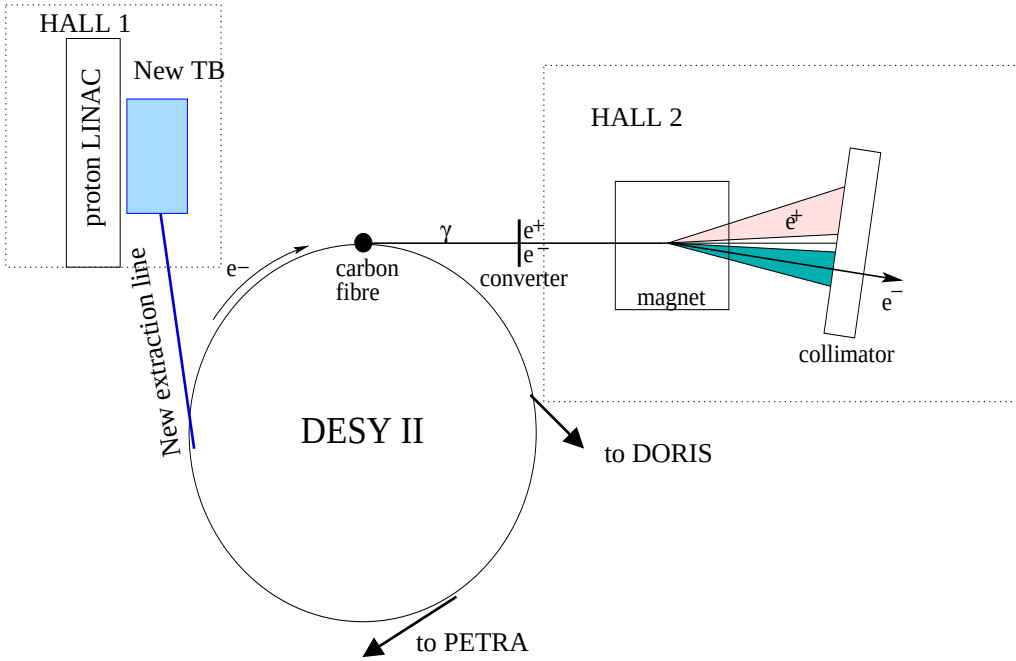
    - ∗ ∼ 10 nA with 0.45 - 7 GeV
    - ∗ new extraction line could be build within ∼ weeks



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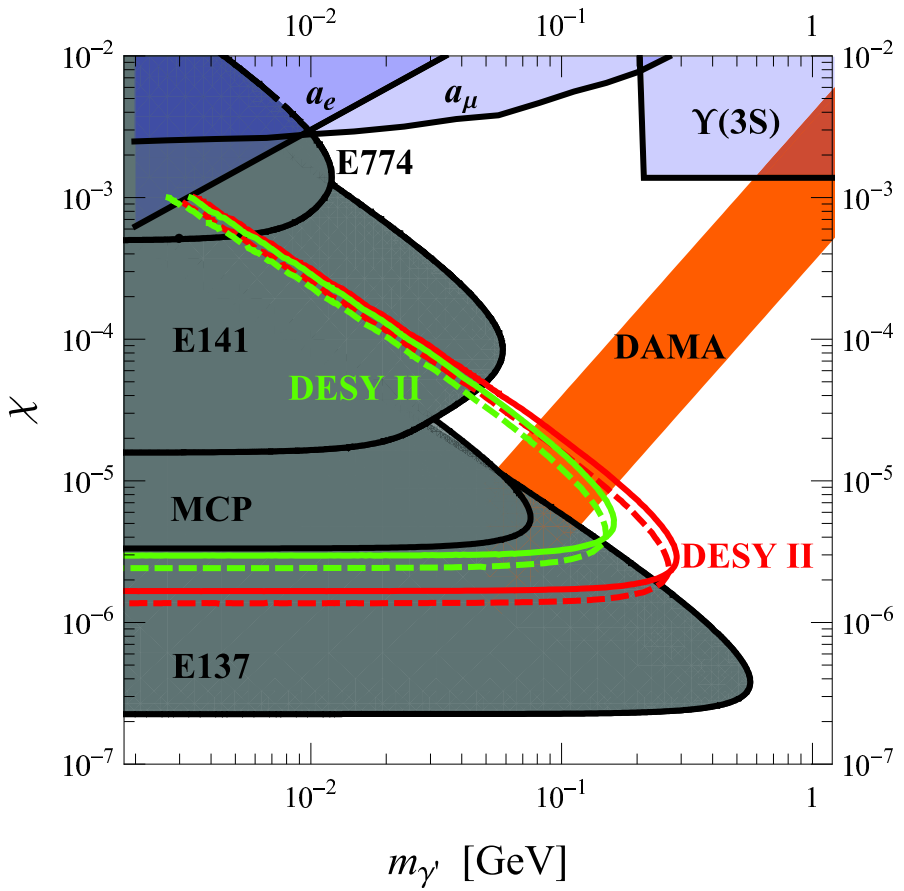
    - ∗ new extraction line could be build within ∼ weeks
    - ∗ first estimates of beam dump sensitivity
    - ∗ can be new user facility

    ⇒ discussions with directorate

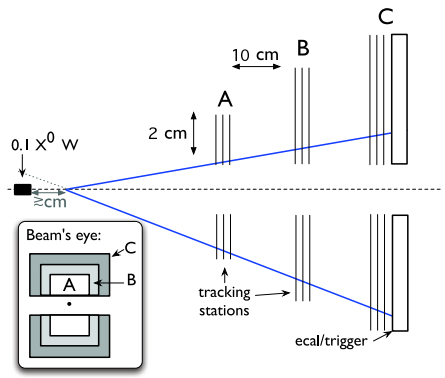


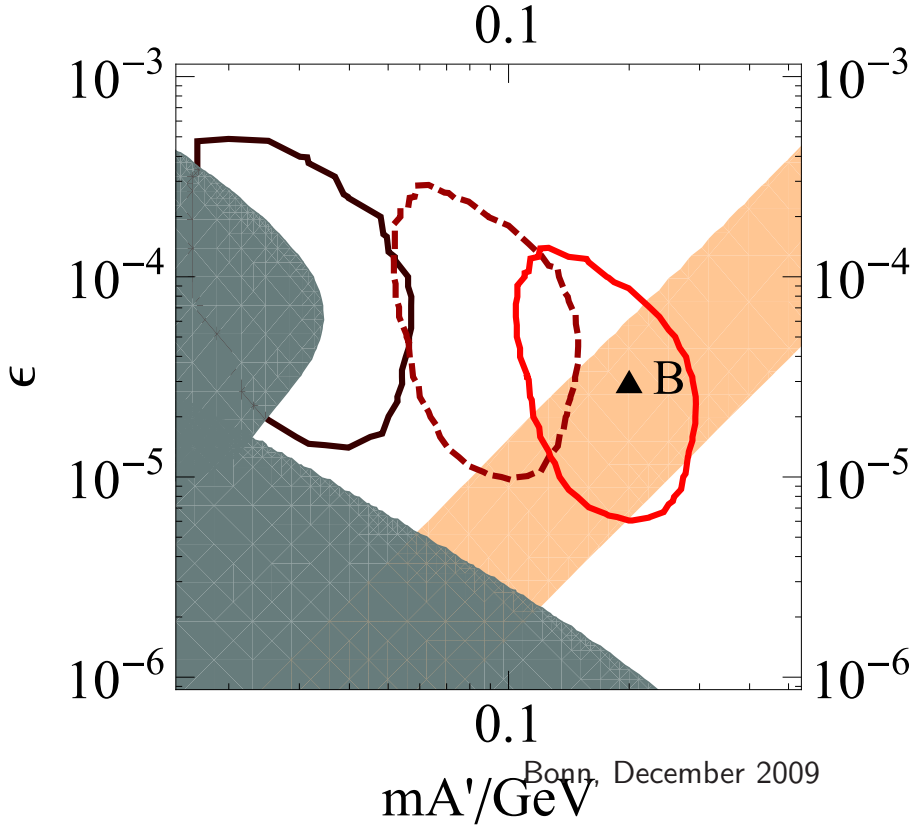
[Andreas,Bechtle,Ehrlichmann,Garutti,Gregor,Lindner,Meyners,Redondo,AR]

- **Fixed-target suggestions:**

  [Bjorken,Essig,Schuster,Toro '09]

  – Thin target, double arm spectrometer
  0.1 C, 6 GeV, 20-55 mrad





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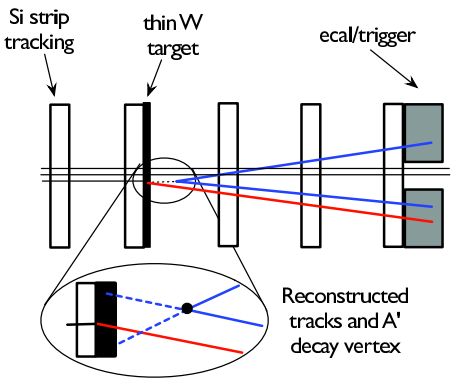

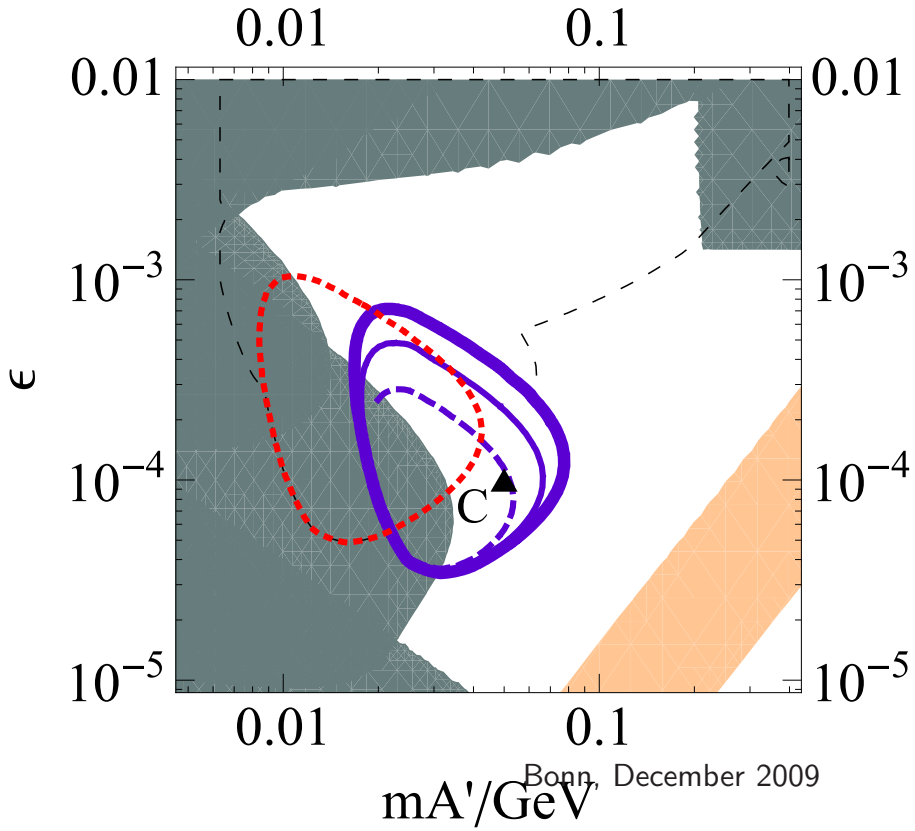

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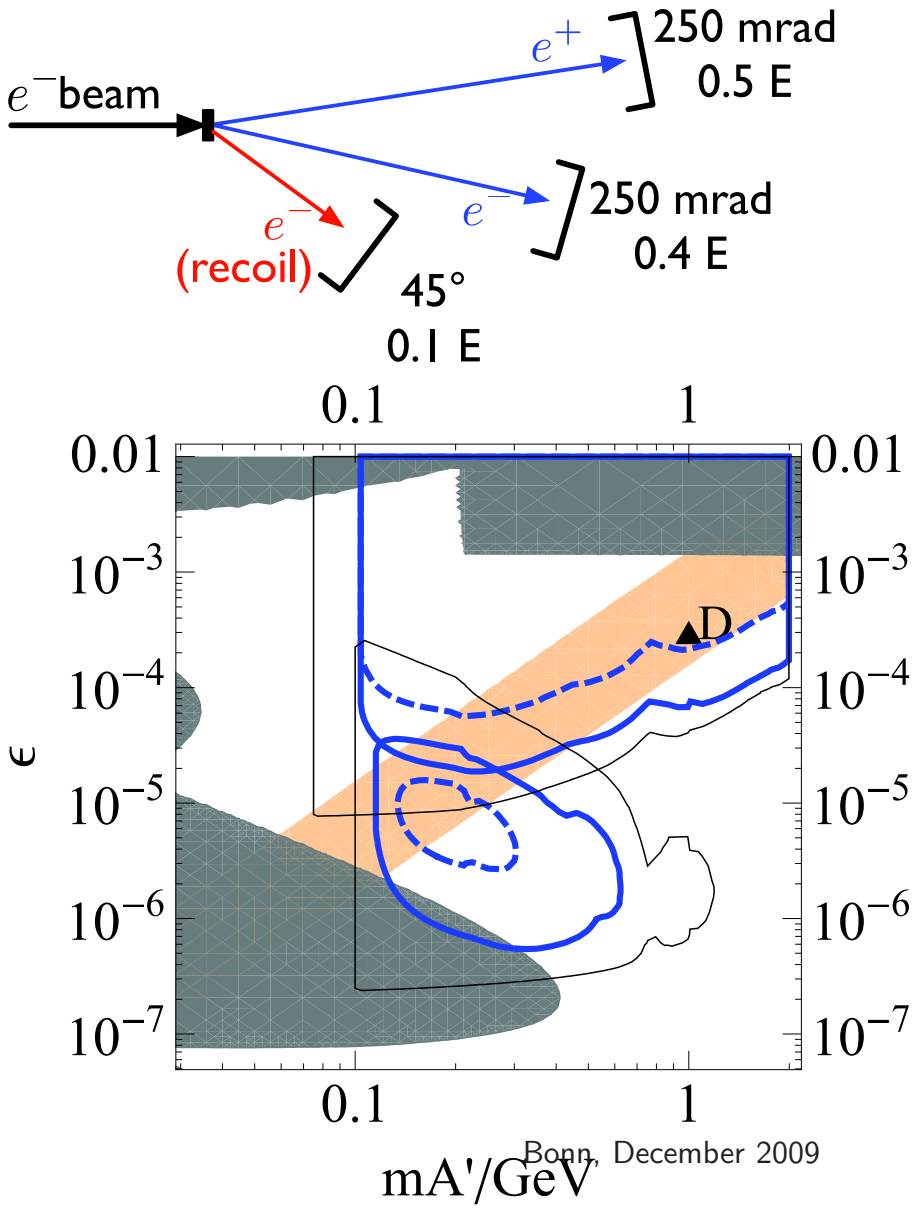
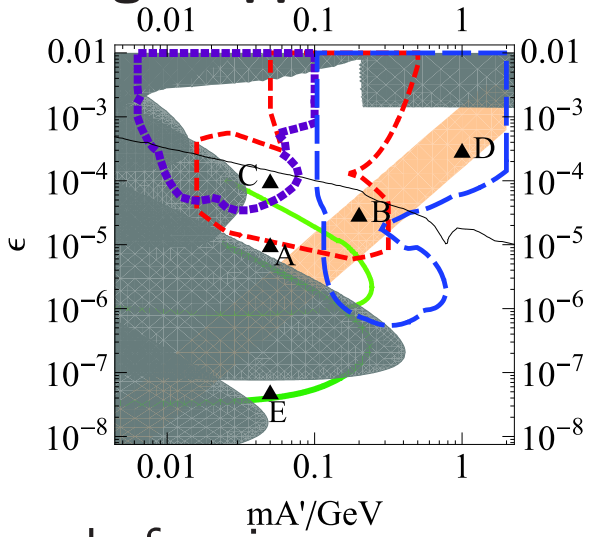
  - Thin target, double arm spectrometer
    0.1 C, 6 GeV, 20-55 mrad
  - Silicon strip layers in diffuse beam
    $\sim 10^8$ e/s for 10^6 s, 1 GeV
  - High resolution, high rate trident spectrometer
    ~ 100 μA, 6 GeV



- **Coverage of new fixed-target opportunities:**



- In US, collaborations already forming ... e.g.

  Heavy Photon Search working group for proposal to attack **B** at JLab

  SLAC: Field, Graham, Jaros (Chair), Kenney, Maruyama, Moffeit, Odian, Sheppard, Spencer; **JLab:** Stepanyan, Weinstein; **UOregon:** Frey

  Proposal to attack **D** with JLab wide angle spectrometers

  Bjorken, Deur, Wojtsekhowski (Chair),...

⇒ More info on webpages of Dark Forces Workshop, SLAC, Sept. 2009

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)

$\Rightarrow$ Opportunities for DESY, ELSA and MAMI!