MesonNet Meeting

chaired by Andrzej Kupsc (Uppsala University), Simona Giovannella (LNF)

from Monday, 29 September 2014 at **09:00** to Wednesday, 1 October 2014 at **14:30** (Europe/Rome)
at **INFN - Laboratori Nazionali di Frascati (Auditorium B. Touschek)**
Via E. Fermi, 40 00044 Frascati ITALY

Description

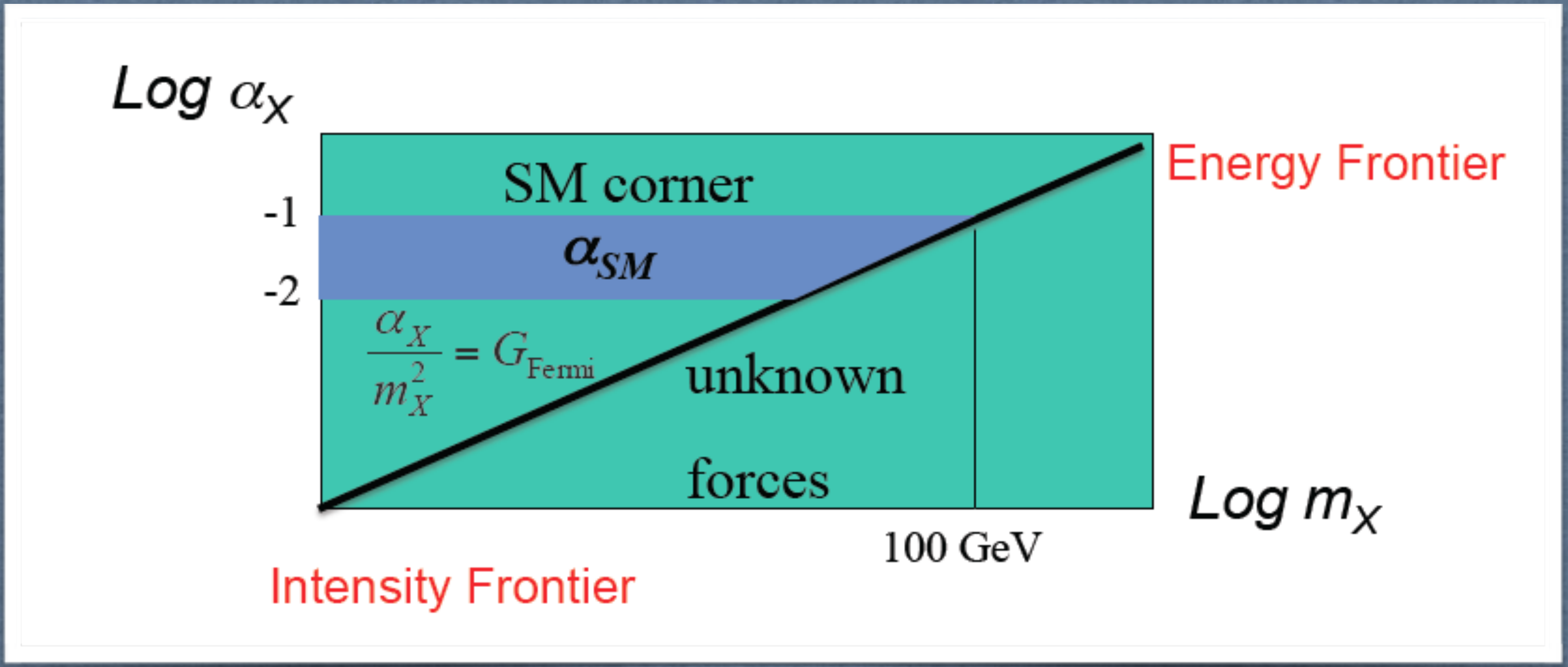
MesonNet Meeting
September 29th - October 1st
INFN - Laboratori Nazionali di Frascati

Status of dark photon searches

M.Battaglieri
INFN-GE, Italy

- Physics case (top-down)
- Experimental evidence (bottom-up)
- Today: latest results in Heavy [Dark] Photon search
- Tomorrow: hunting HP invisible decays

How to look for new physics



LHC range: m_x~1TeV, $\alpha_x \sim \alpha_{SM}$

First results show no hints of new strongly-interacting states or new heavy EW bosons (other than Higgs)

What about if: m_x~1GeV, $\alpha_x < 10^{-6}$?

Important progress in neutrino physics, dark matter sensitivity, precise frontier measurements

Precise experiments at low/moderate energy!

Forces in nature

4 fundamental interactions known so far: strong, electromagnetic, weak and gravitational

Are there other interactions? how could we know about?
what could be their properties?

Particles, interactions and symmetries

Known particles & new force-carriers

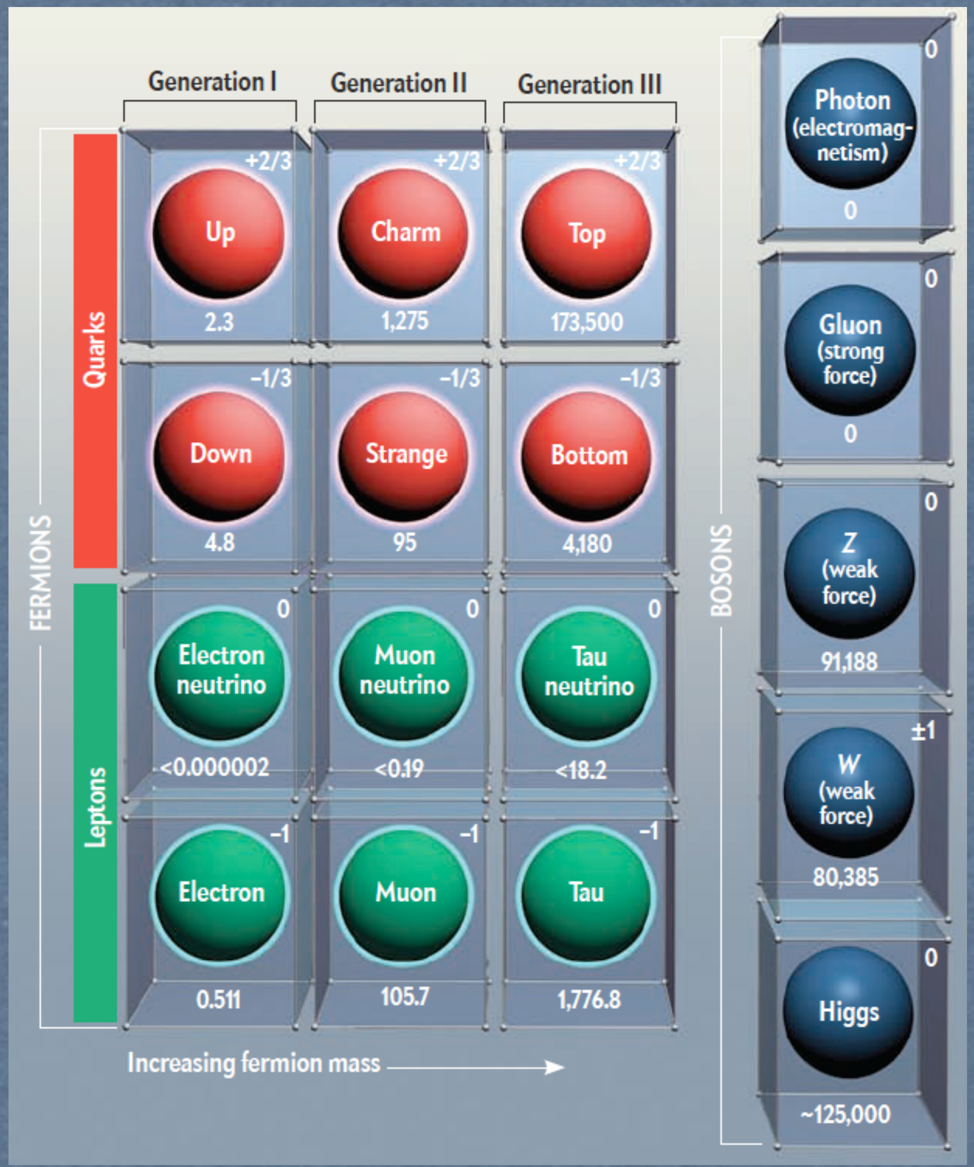
Particles:
quarks, leptons

Force-carriers:
gluons, γ, W, Z, graviton (?), Higgs, ...

New particles & new force-carriers

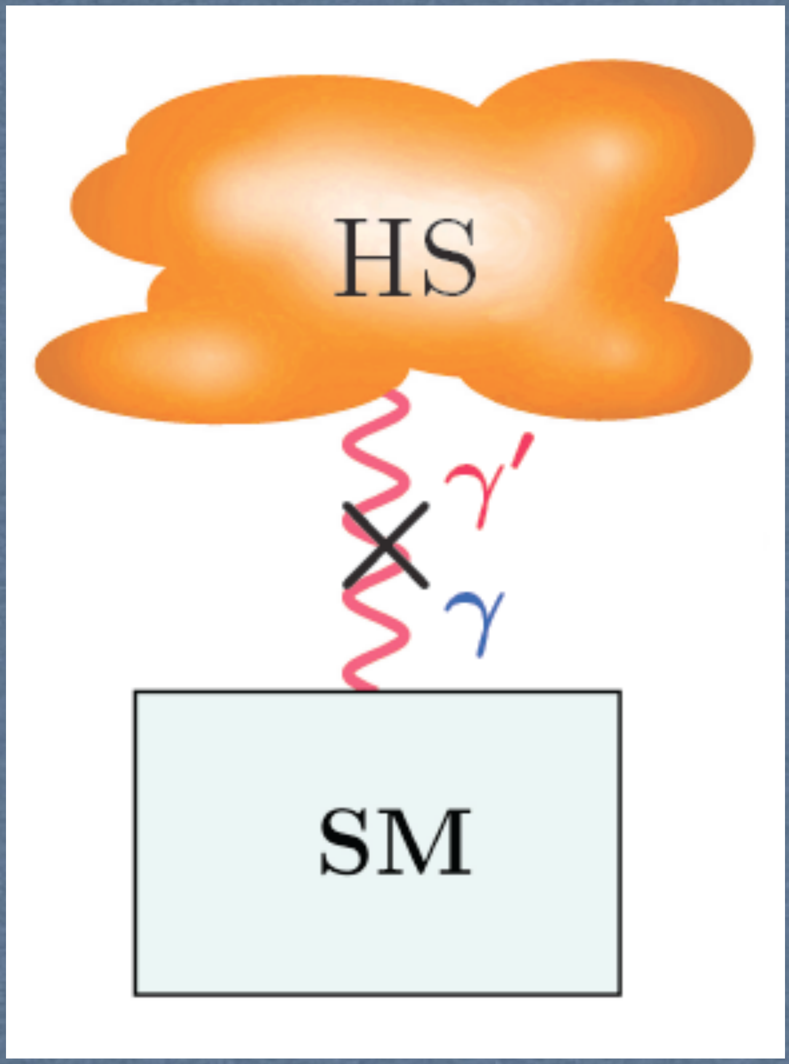
Dark Matter

Spin-1: U bosons ('hidden' or 'dark' photons)
Spin-0: Axions (or axion-like particles)
Spin-0 (scalars): Higgs-like



New bosons are expected to mediate new interactions

Neutral doors (*Portals*) to include DM in the SM



- There are (many) possible ways to include the DM into the SM
- Some of them can be tested directly (e.g. rare B-decays)

A simple way to go beyond the SM (not yet excluded!):

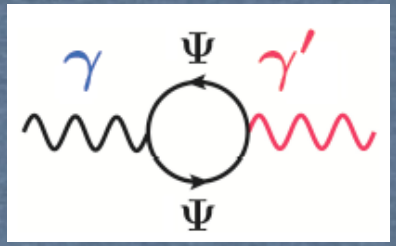
$SU(3)_C$ x $SU(2)_L$ x $U(1)_Y$ **x extra U(1)**

Color | Electroweak | Hypercharge | Hidden sector

- Hidden sector (HS)
  present in string theory and super-symmetries
- HS not charged under SM gauge groups (and v.v.)
  no direct interaction between HS and SM
  HS-SM connection via messenger particles

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

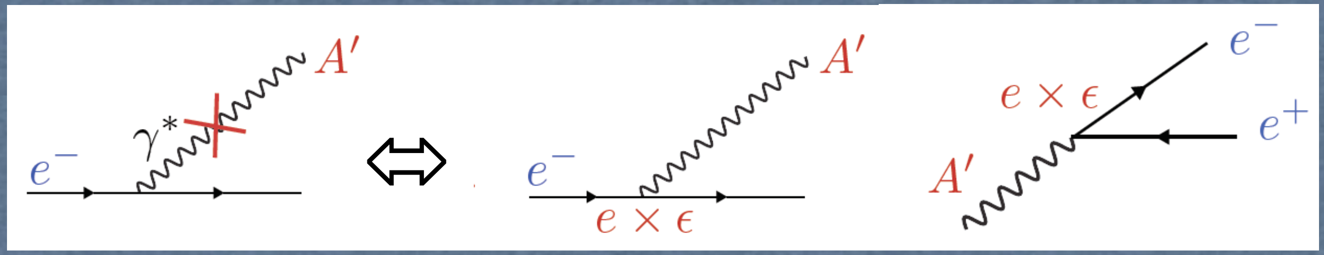
($X_{\mu\nu}$: Hidden; $F^{\mu\nu}$: Visible)



Ψ can be a huge mass scale particle (M~1EeV) coupling to both SM and HS

γ'/A' couples to SM via electromagnetic current (kinetic mixing)

→ $A_\mu \rightarrow A_\mu + \varepsilon a_\mu$ $\chi = \varepsilon \sim 10^{-6}$-$10^{-2}$ ($\alpha^{\rm DarkPhoton} = \varepsilon^2 \alpha_{\rm em}$)



Neutral doors (*Portals*) to include DM in the SM

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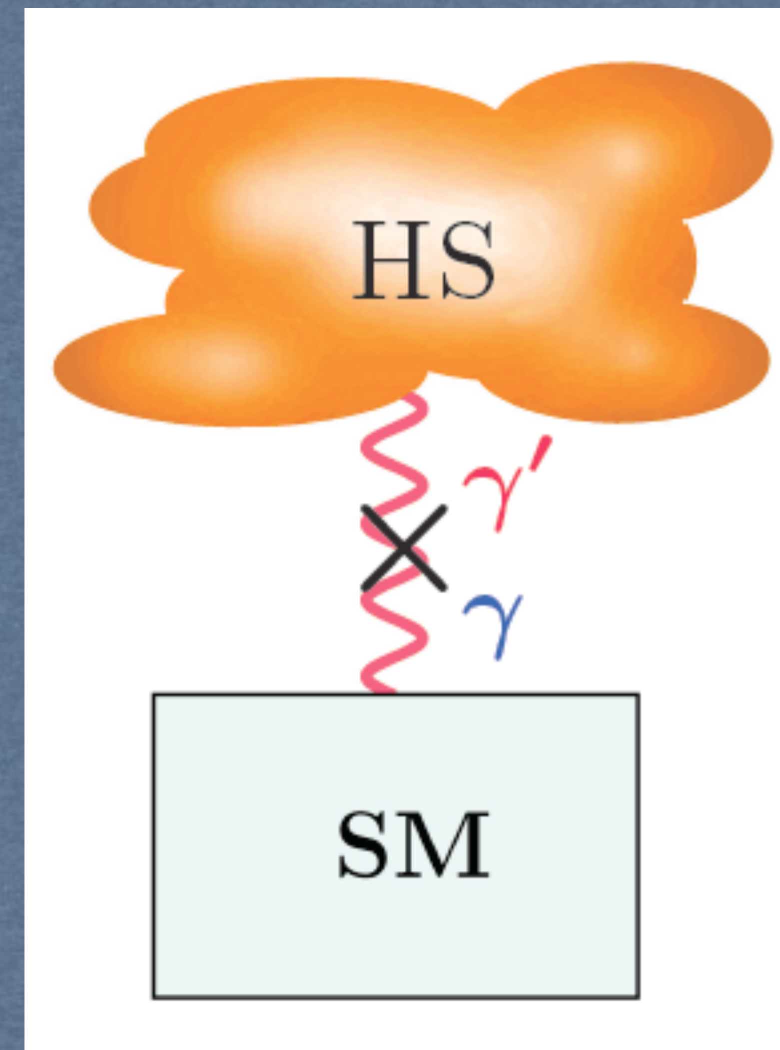

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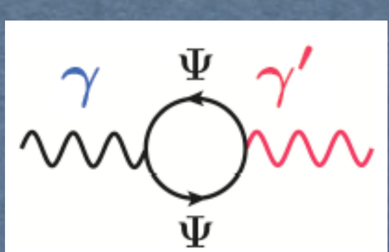

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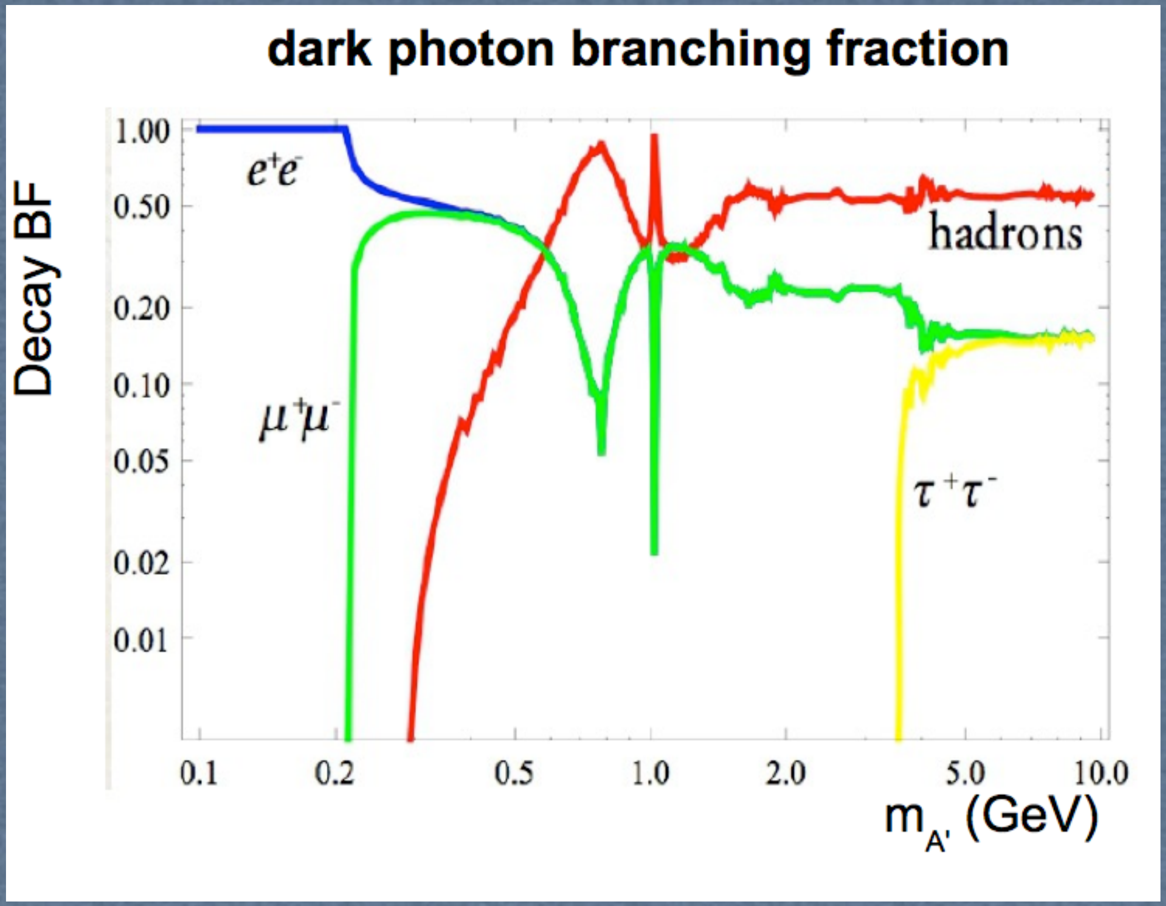
γ'/A' mass depends on the model

→ $m^2_{\gamma'} \sim \chi M^2_{EW}$ (M_Z or TeV) ~ **MeV - GeV scale**

Consequences



Assumptions:
$M_{A'}$>1 MeV and no light dark fermions

- γ'/A' decay back to SM particles
- Prompt decay
- BF (A'→hadrons/A'→leptons) ~ M^2(A')

Above 1.2 GeV hadronic decays dominate

γ'/A' decays in leptons

→ **abundance of e^+e^- in Universe**

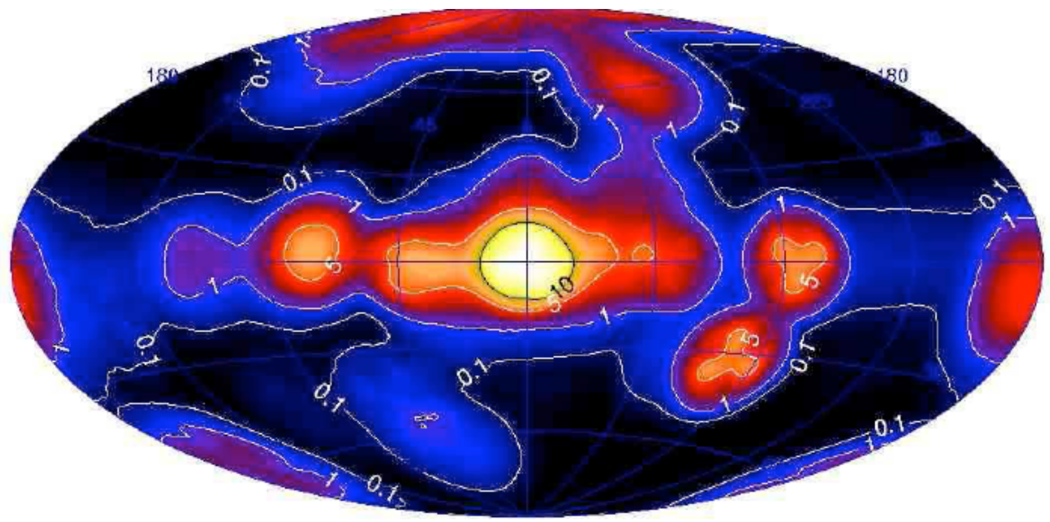
γ'/A' couples to SM via electromagnetic current (kinetic mixing)

→ **short range modification of EM interaction**

γ'/A' couples weakly to SM particles

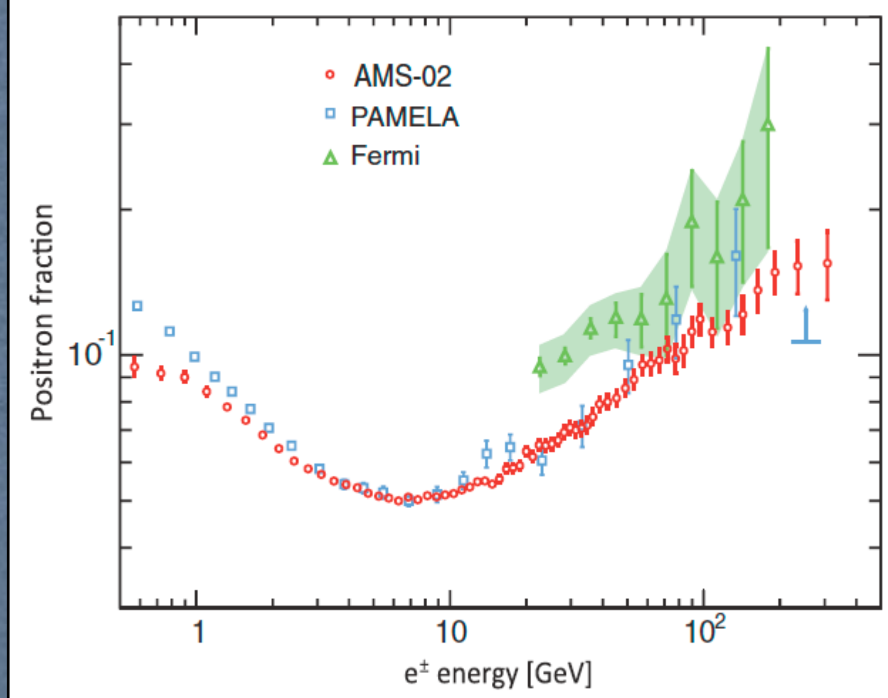
→ **long lived states**

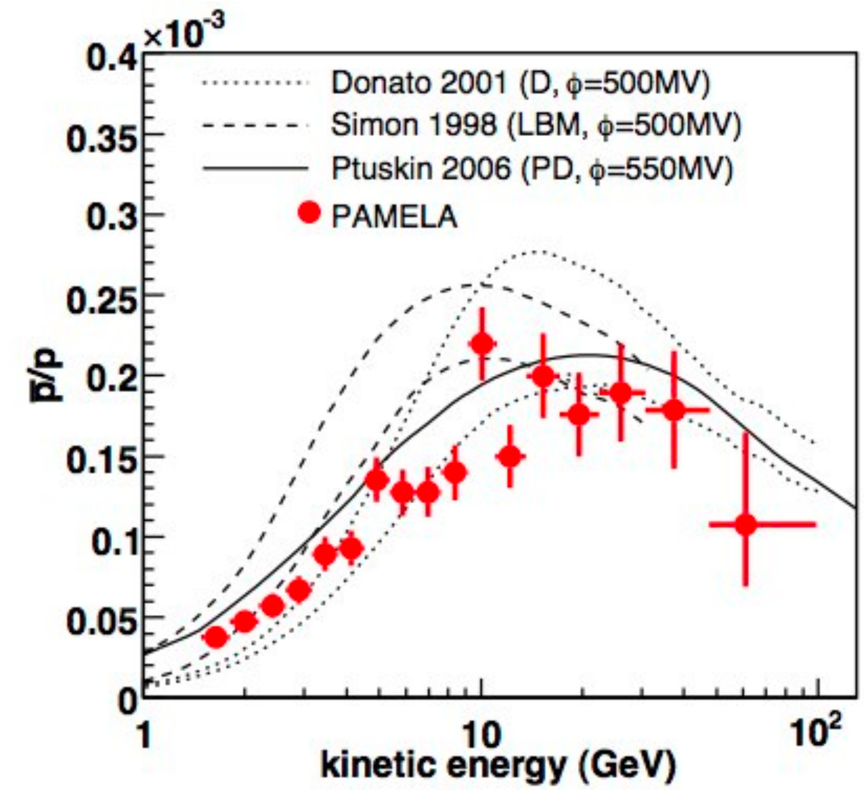
Astrophysical motivation: the 511γ keV line



511 keV line map from GRAL/SPI data

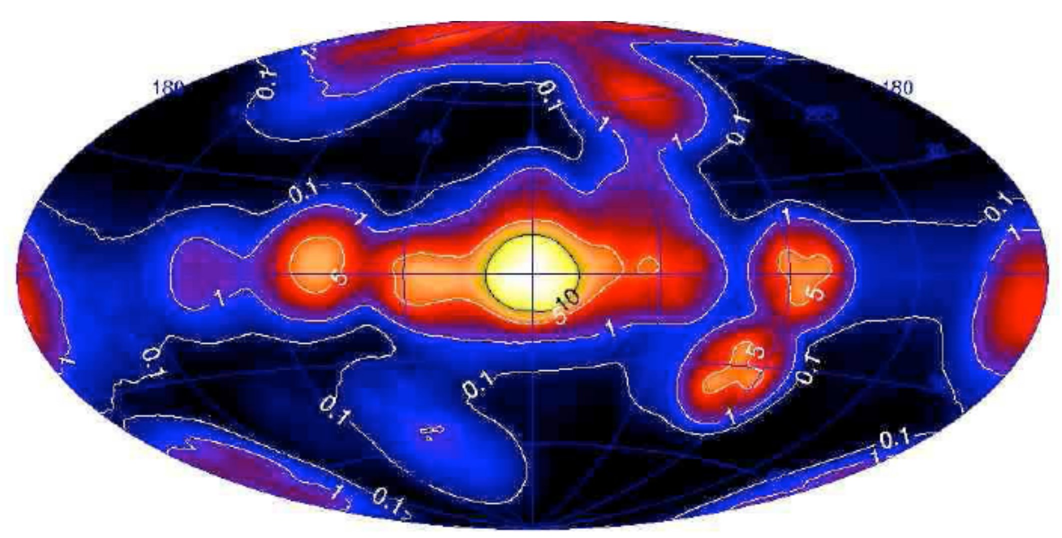
Positron and antiproton abundance from PAMELA/AMS





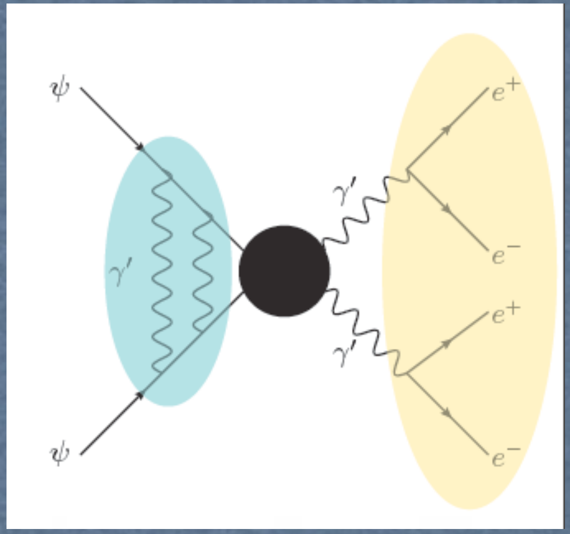
- ✳ Unexplained concentration of 511 keV line from the galactic center
- ✳ Diffuse emission of e+ e- annihilation (?)
- ✳ Increasing fraction of e+/e- measured by PAMELA
- ✳ No surprise with antiprotons (sub GeV mass gauge boson?)
- ✳ It is very difficult to explain PAMELA results with standard DM (WIMPS): needs a boost of 100-1000

Astrophysical motivation: the 511γ keV line



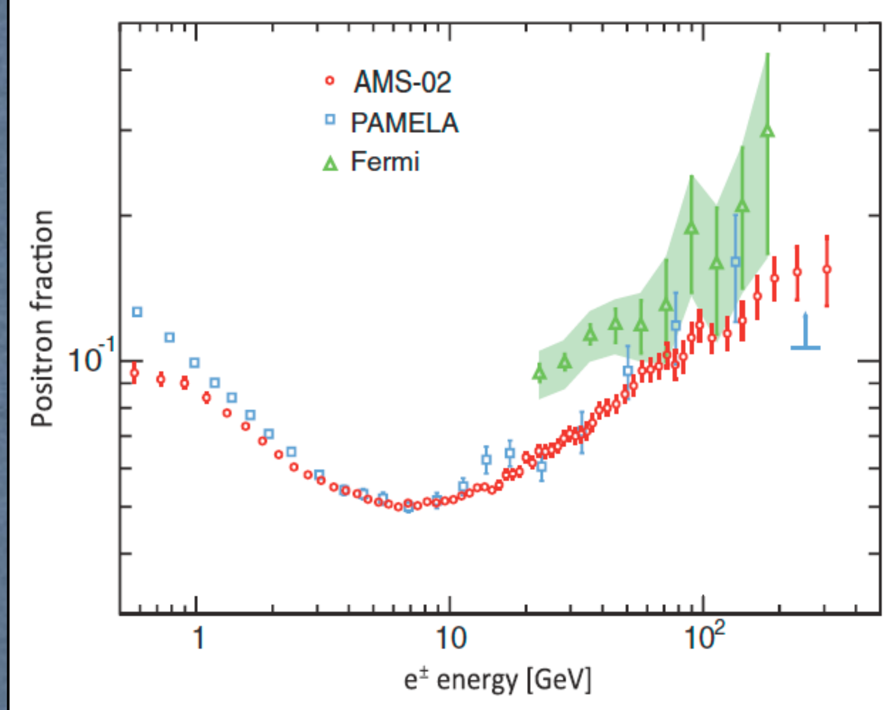
511 keV line map from GRAL/SPI data

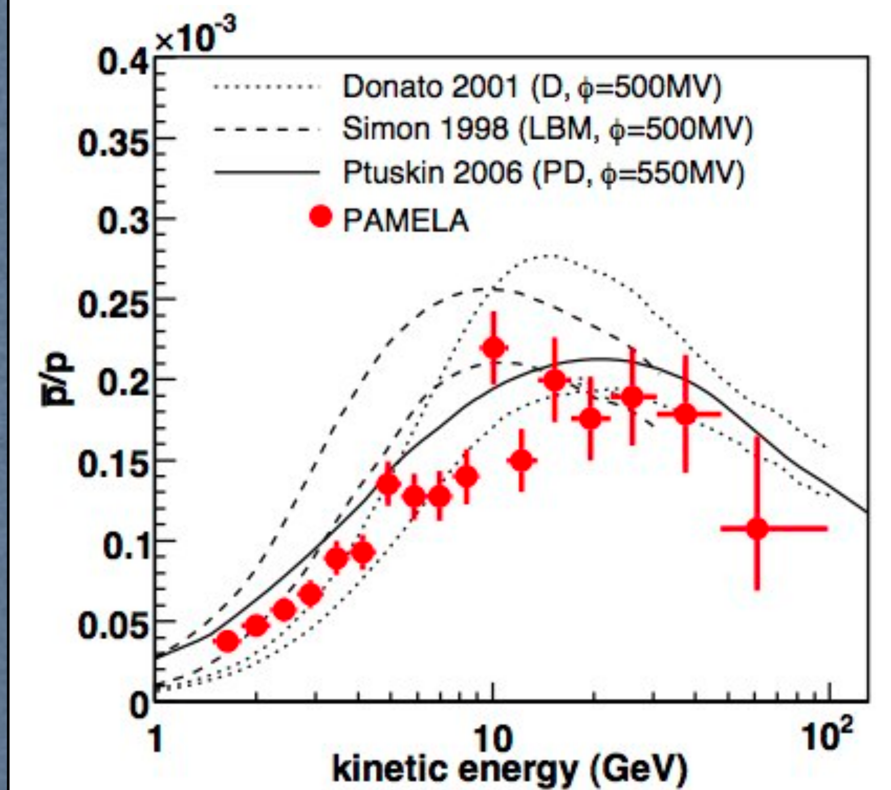
Dark forces may explain it by
DM annihilation in A' ➜ decay to e+e-



1) enhancement in e+ yield
2) hard e+ spectrum
3) no anti-p excess if $M_{A'} < 2\,M_p$

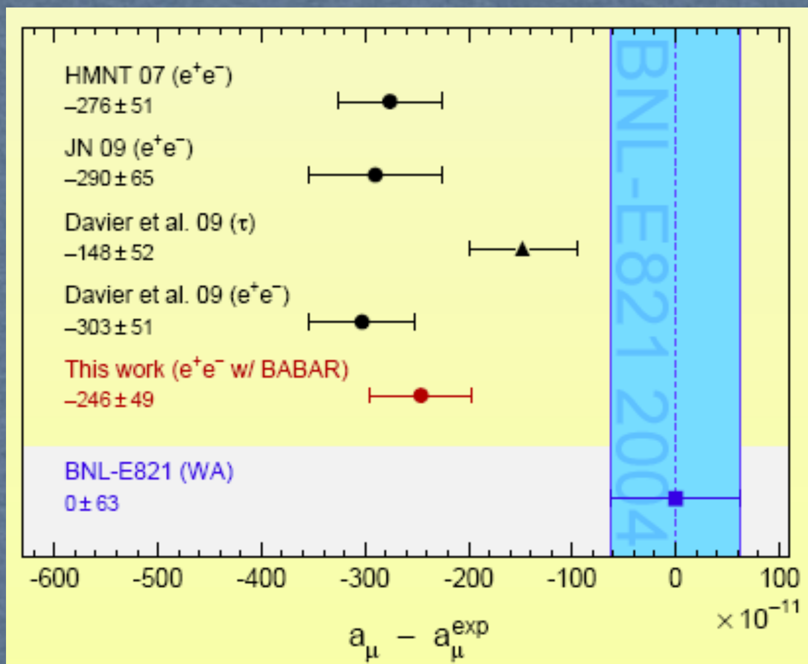
Positron and antiproton abundance from PAMELA/AMS





Modification of EM

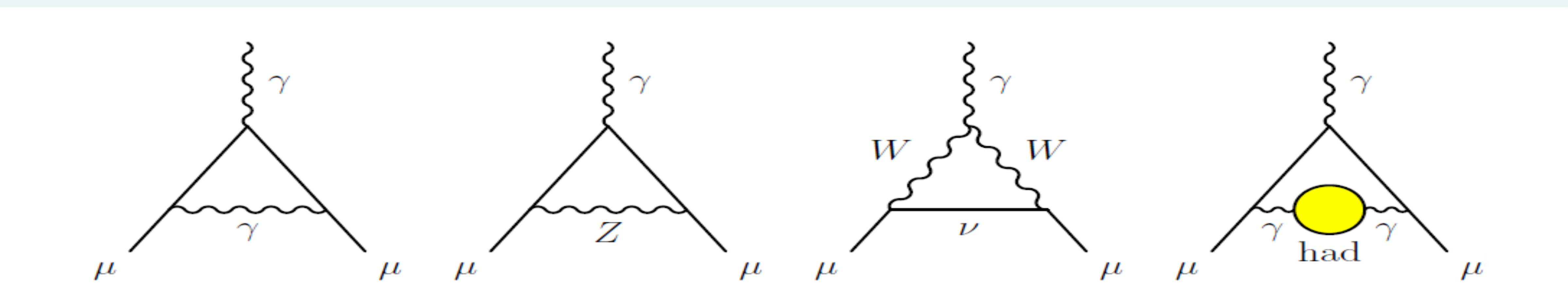
g-2 of muon



- ✳ g-2 is expected to be 0
- ✳ Discrepancy >3σ
- ✳ Some (complicated) strong interaction dynamic?
- ✳ New physics?

Standard Model Prediction

$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{Hadronic}$$



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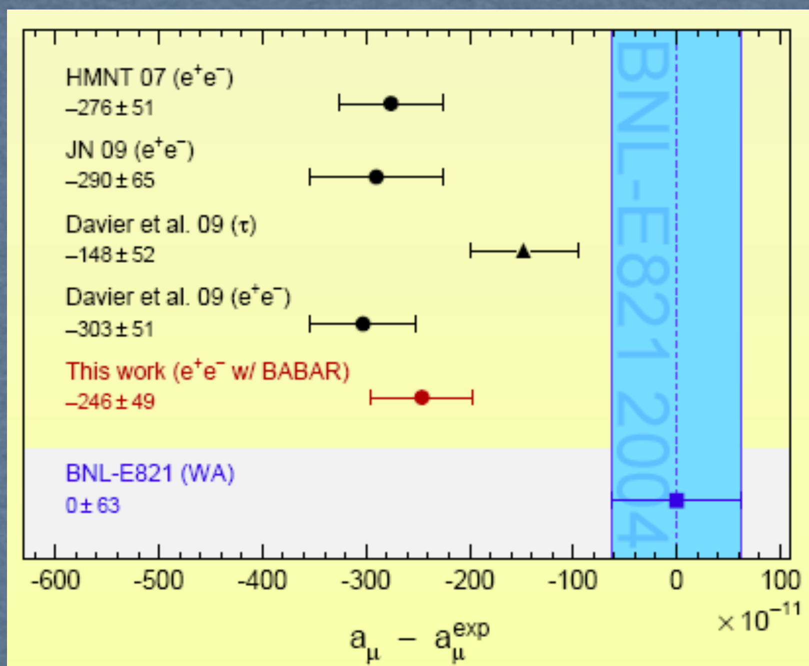
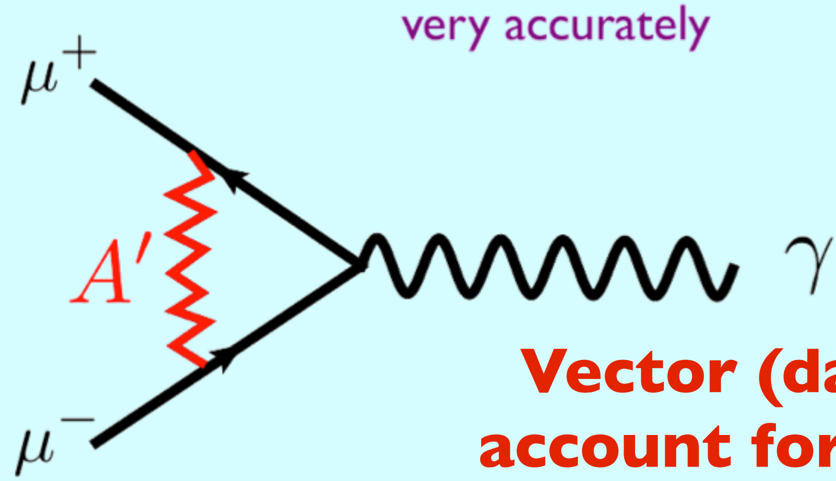


magnetic dipole moment $\vec{\mu} = g_s \left(\frac{q}{2m}\right) \vec{s}$ ← spin

can be measured very accurately



$g_s \neq 2$

Vector (dark) force could account for the discrepancy

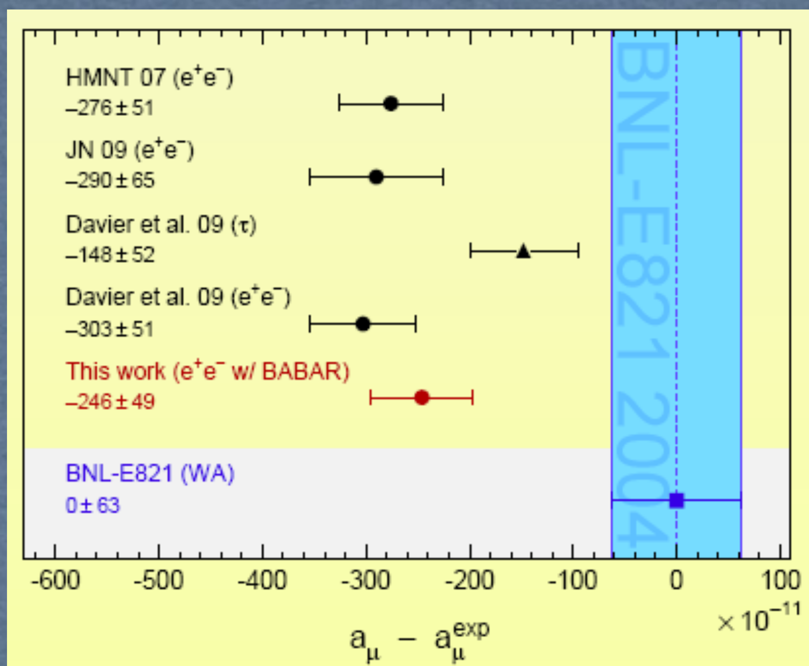
Contribution to g-2 from dark photon

$$a_\mu^{\text{dark photon}} = \frac{\alpha}{2\pi}\varepsilon^2 F(m_V/m_\mu)\,, \quad (17)$$

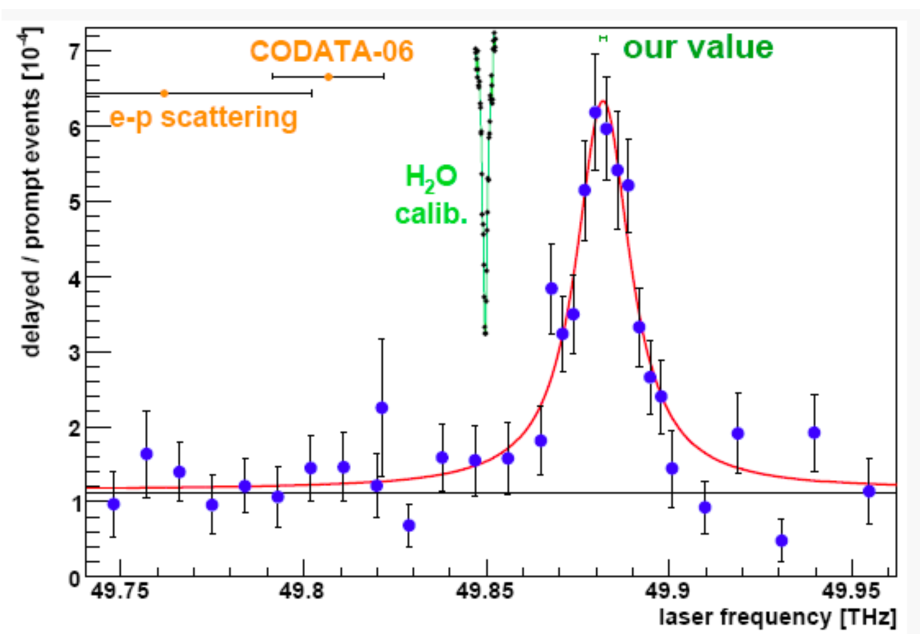
where $F(x) = \int_0^1 2z(1-z)^2/[(1-z)^2 + x^2 z]\,dz$. For values of $\varepsilon \sim 1$–$2 \cdot 10^{-3}$ and $m_V \sim 10$–$100\,\text{MeV}$, the dark photon, which was originally motivated by cosmology, can provide a viable solution to the muon $g-2$ discrepancy. Searches for the dark

Modification of EM

g-2 of muon



muonic hydrogen Lamb shift



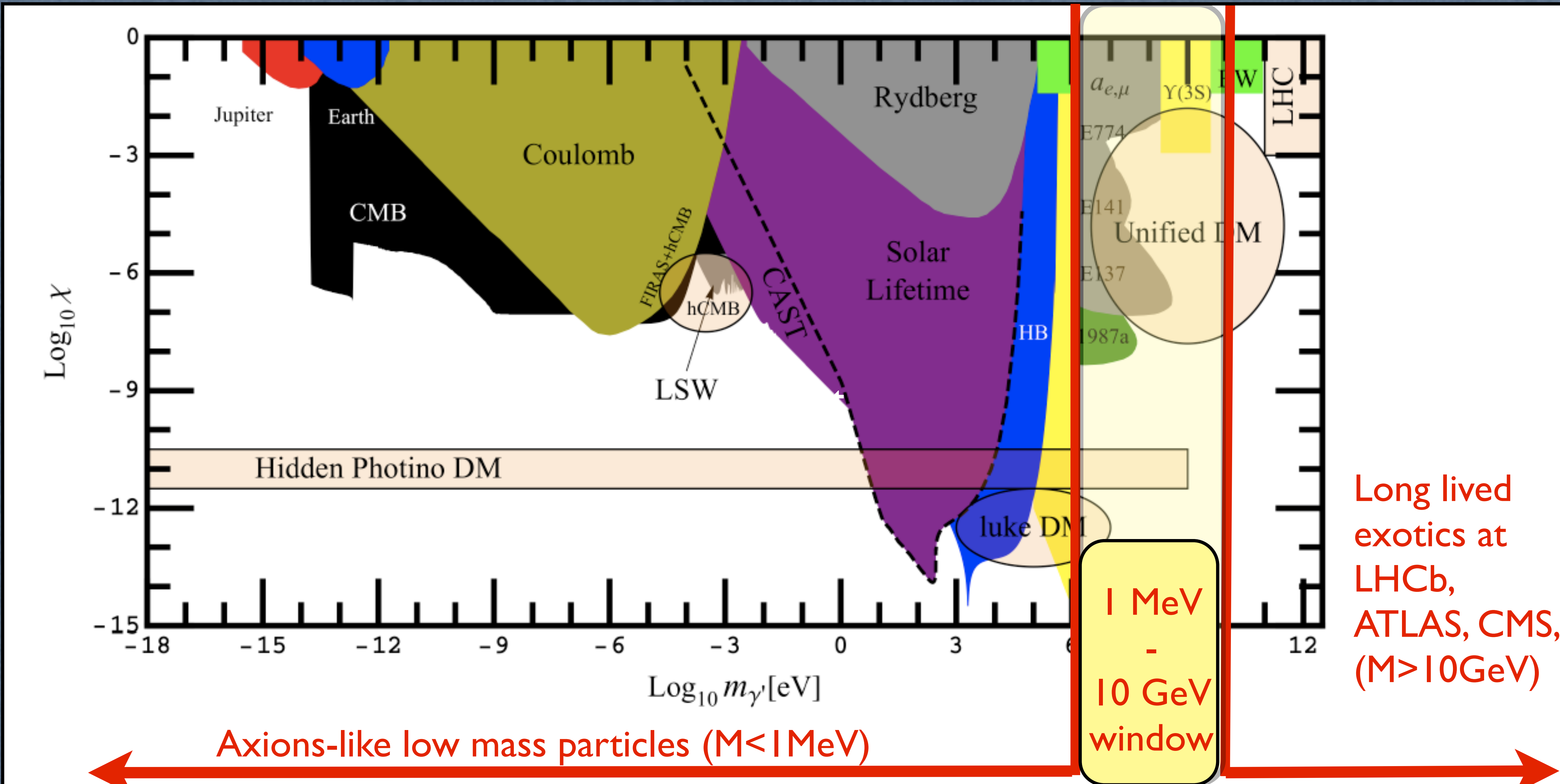
$$r_p = 0.84184(67) \text{ fm} \qquad u_r^{th} = 8 \times 10^{-4}$$

CODATA 2006: $r_p = (0.8768 \pm 0.0069)$ fm, from H

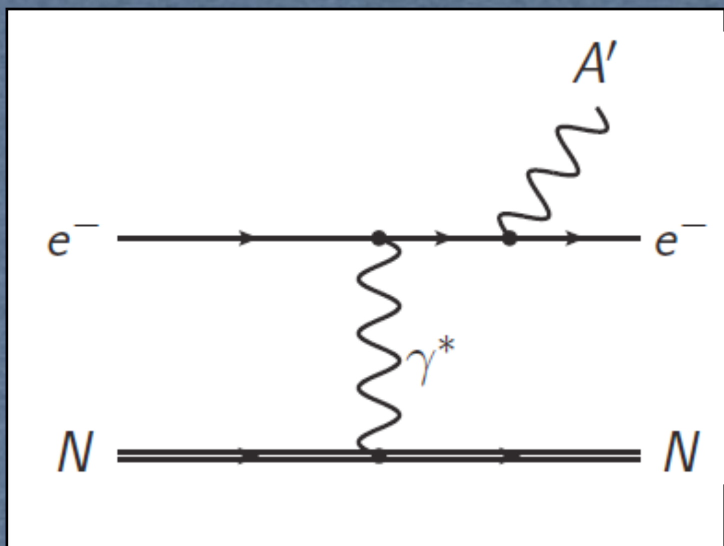
e-p scattering: $r_p = (0.895 \pm 0.018)$ fm (2%)

- ✳ muon 200 times closer to p (w.r.t. hydrogen)
- ✳ New forces for muon?

Where to look for?

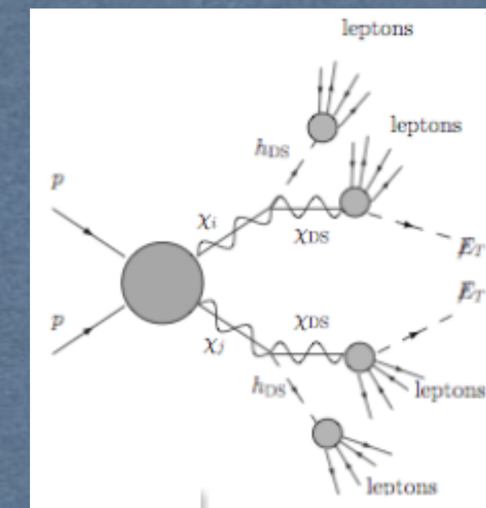


Particle physics search of A’/γ’ (hidden photon)

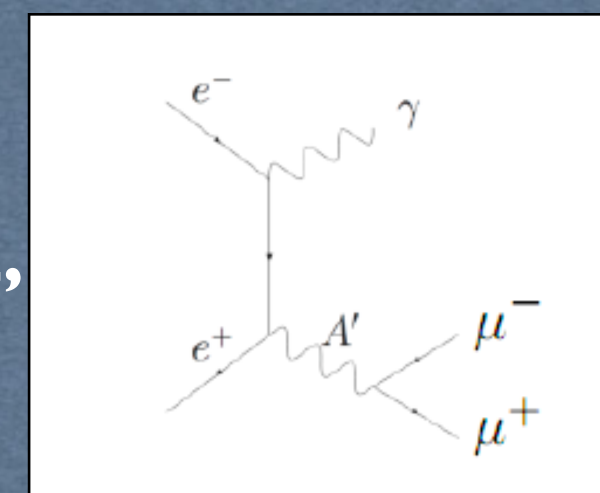


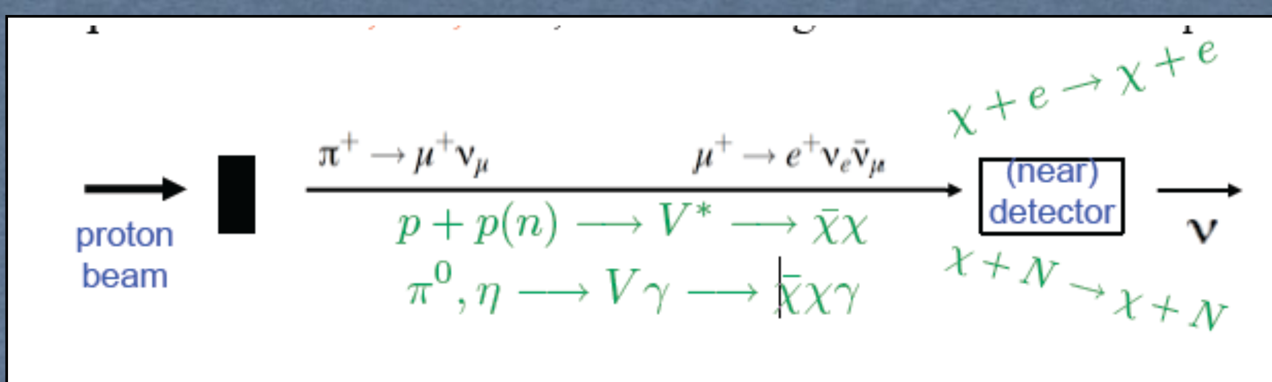
Fixed target:
e N →N γ’→ N Lepton Lepton+
→ **JLAB, MAINZ**

High Energy
Hadron Colliders:
pp → lepton jets
→ **ATLAS, CMS, CDF&D0**



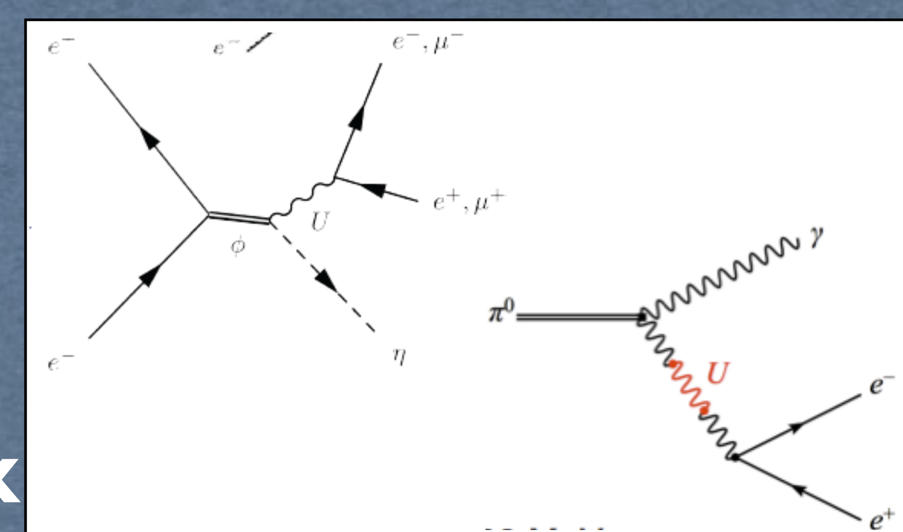
Annihilation:
e+e- → γ’ γ → μμ γ
→ **BABAR, BELLE, KLOE, CLEO**





Fixed target:
p N →N γ’→ p Lepton Lepton+
→ **FERMILAB, SERPUKHOV**

Meson decays:
π^0, η, η’, ω,’ → γ’ γ (M)
→Lepton Lepton + γ (M)
→ **KLOE, BES3, WASA-COSY, PHENIX**



Particle physics search of A'/γ' (hidden photon)

Fixed target: e N →N γ'→ N Lepton⁻ Lepton⁺
→ **JLAB, MAINZ**

Fixed target: p N →N γ'→ p Lepton⁻ Lepton⁺
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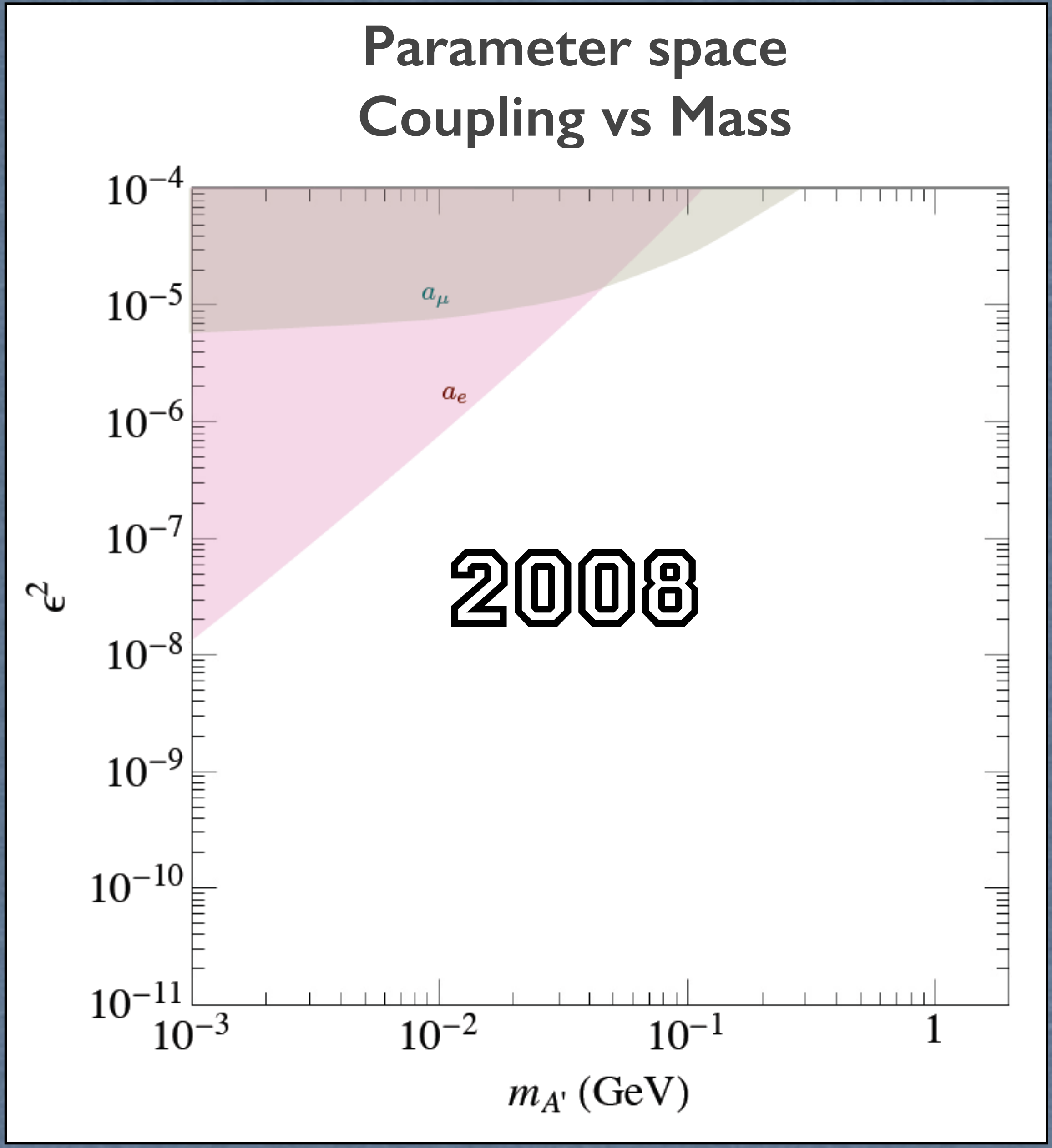

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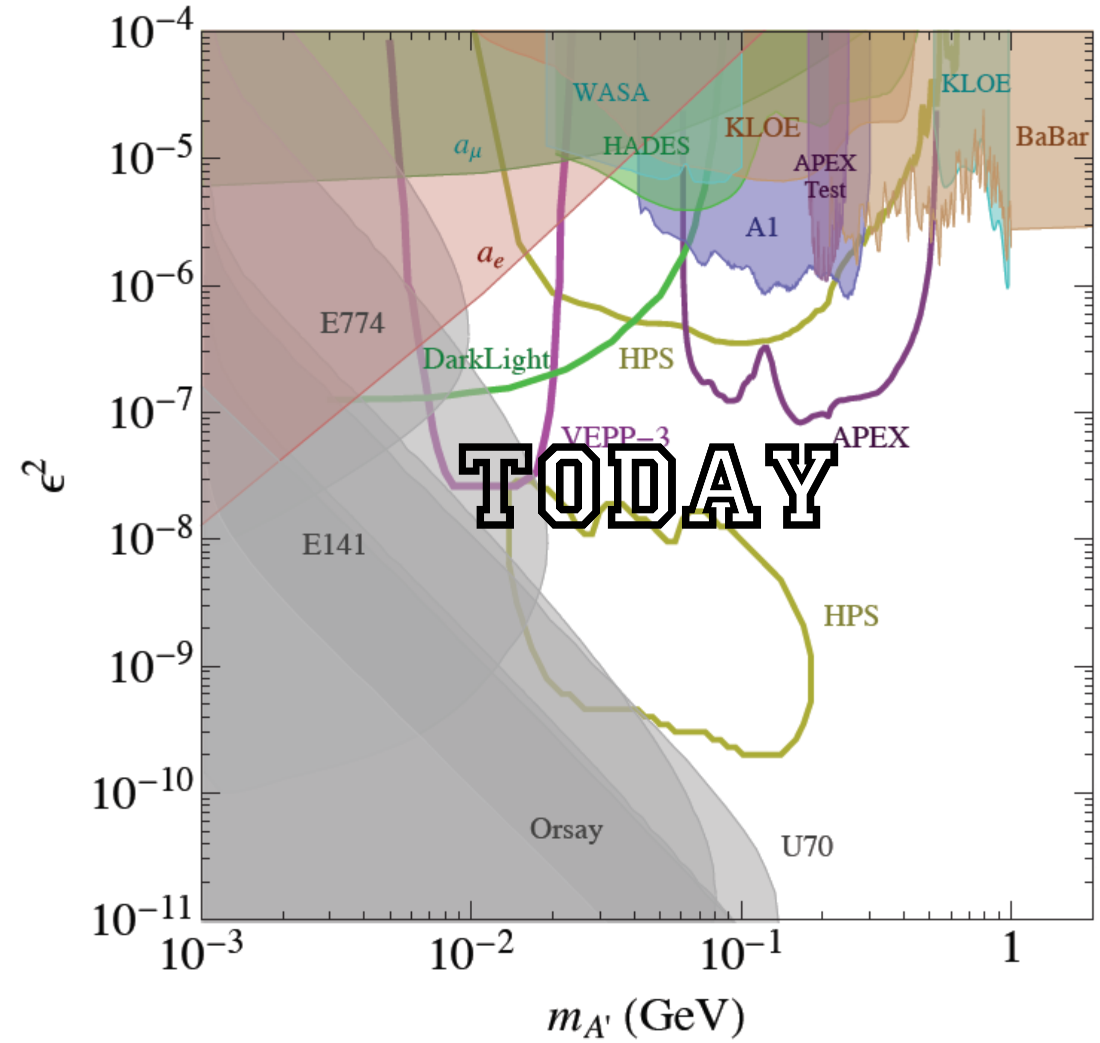
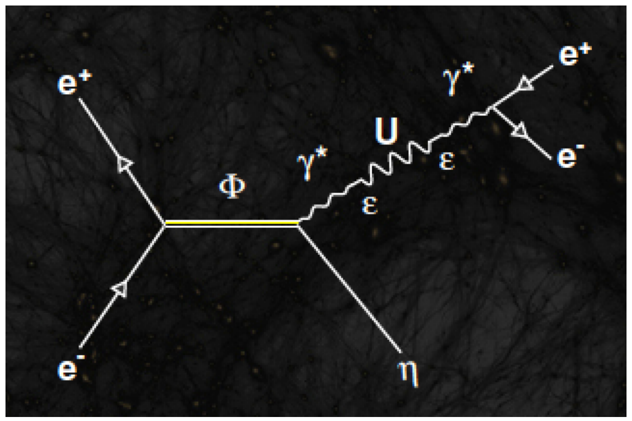
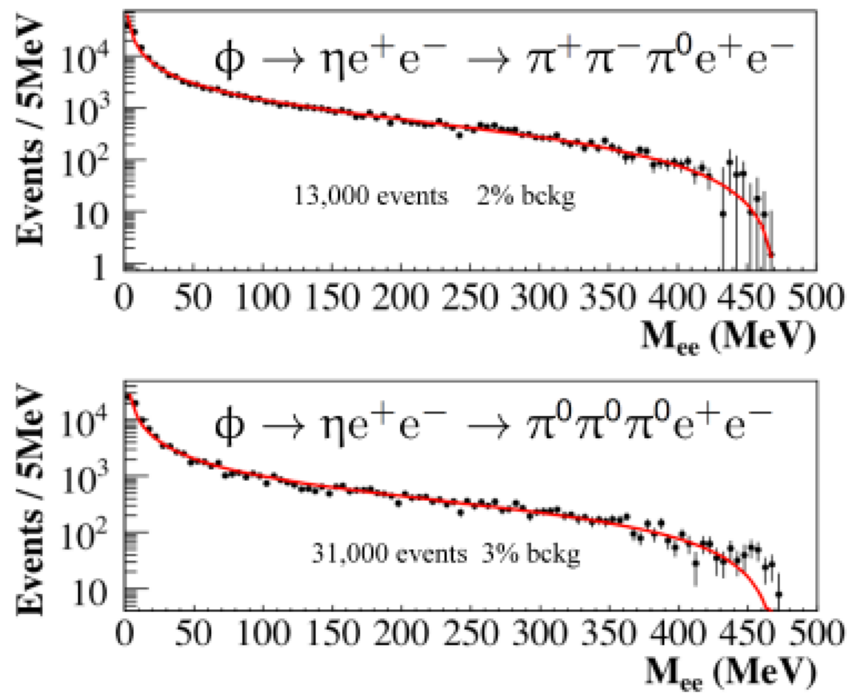
No positive signal (so far) but limits in parameter space coupling vs mass

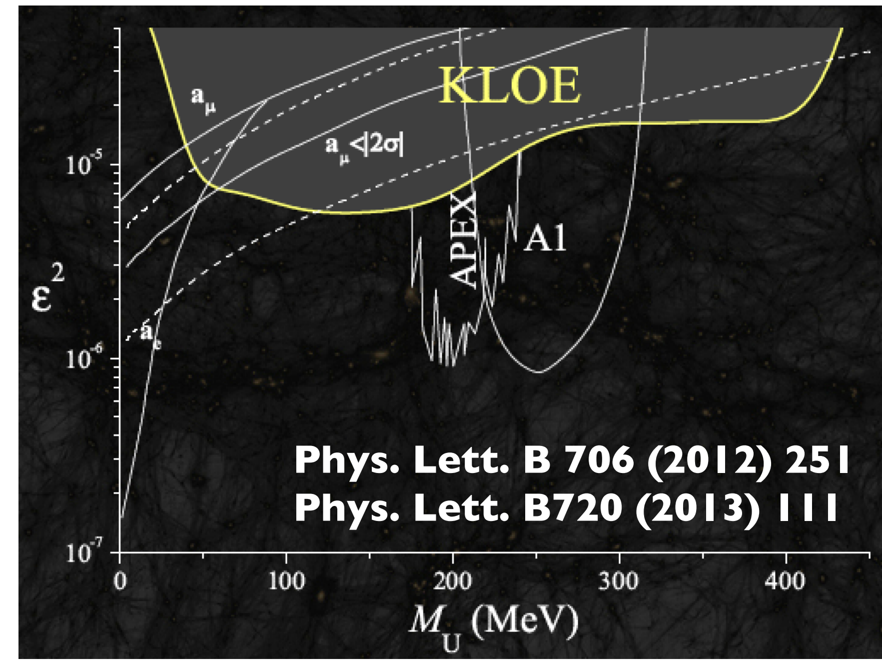
Parameter space
Coupling vs Mass



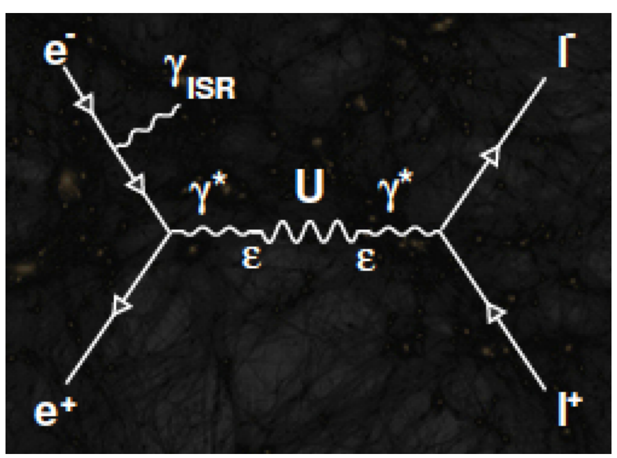
e+e- Colliders - Recent Results

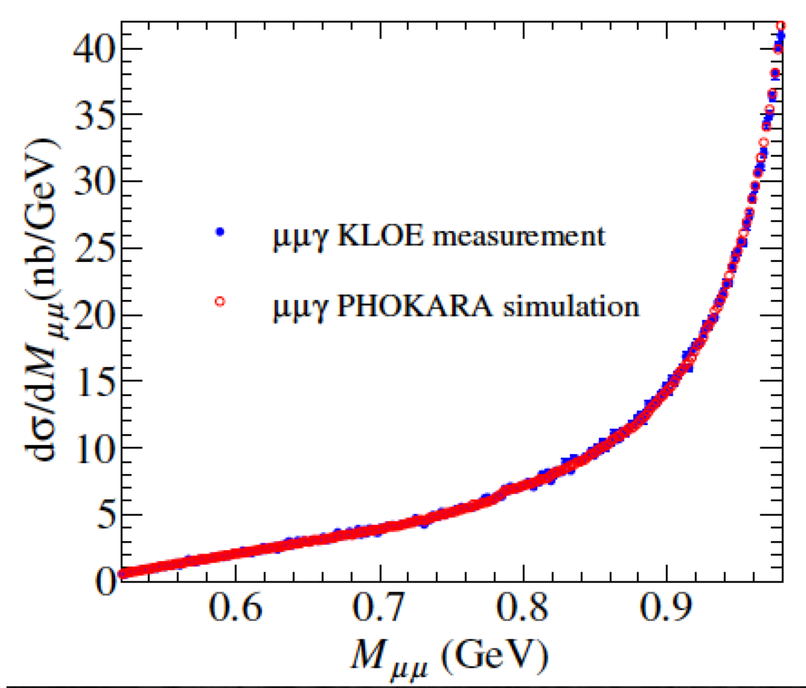


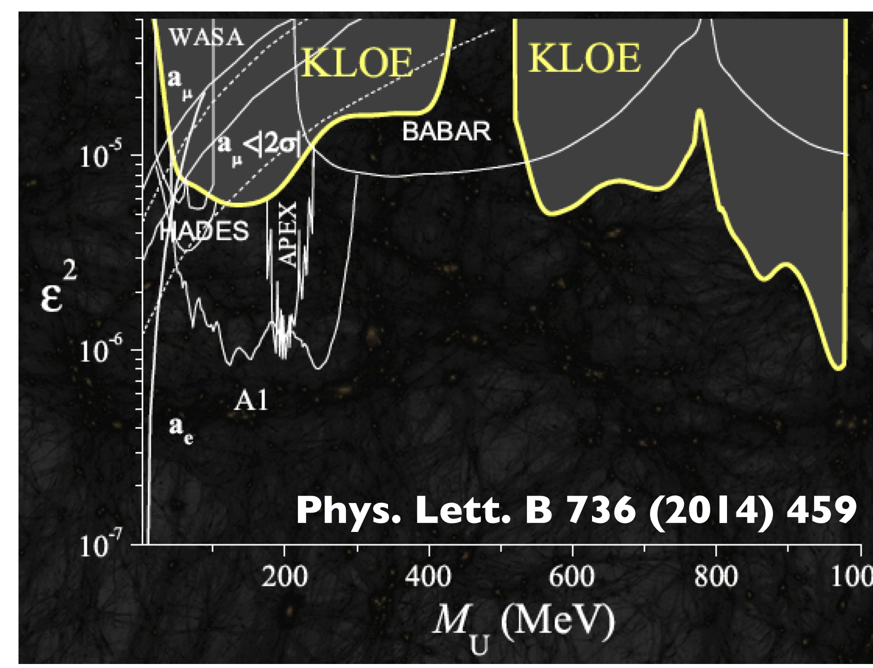




- Events with e+e- detected
- L~1.5 - 1.7 fb^{-1}







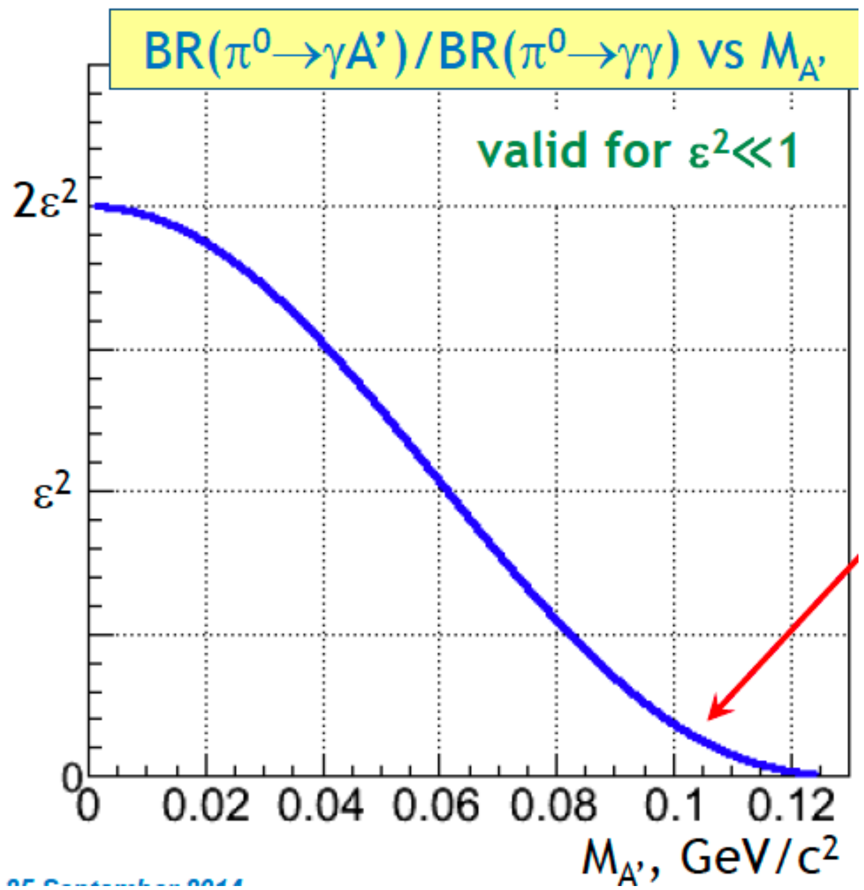
- Events with μ+μ- detected
- L~ 240 pb^{-1}

Meson Decay - Recent Results

$\pi^0 \rightarrow \gamma A'$

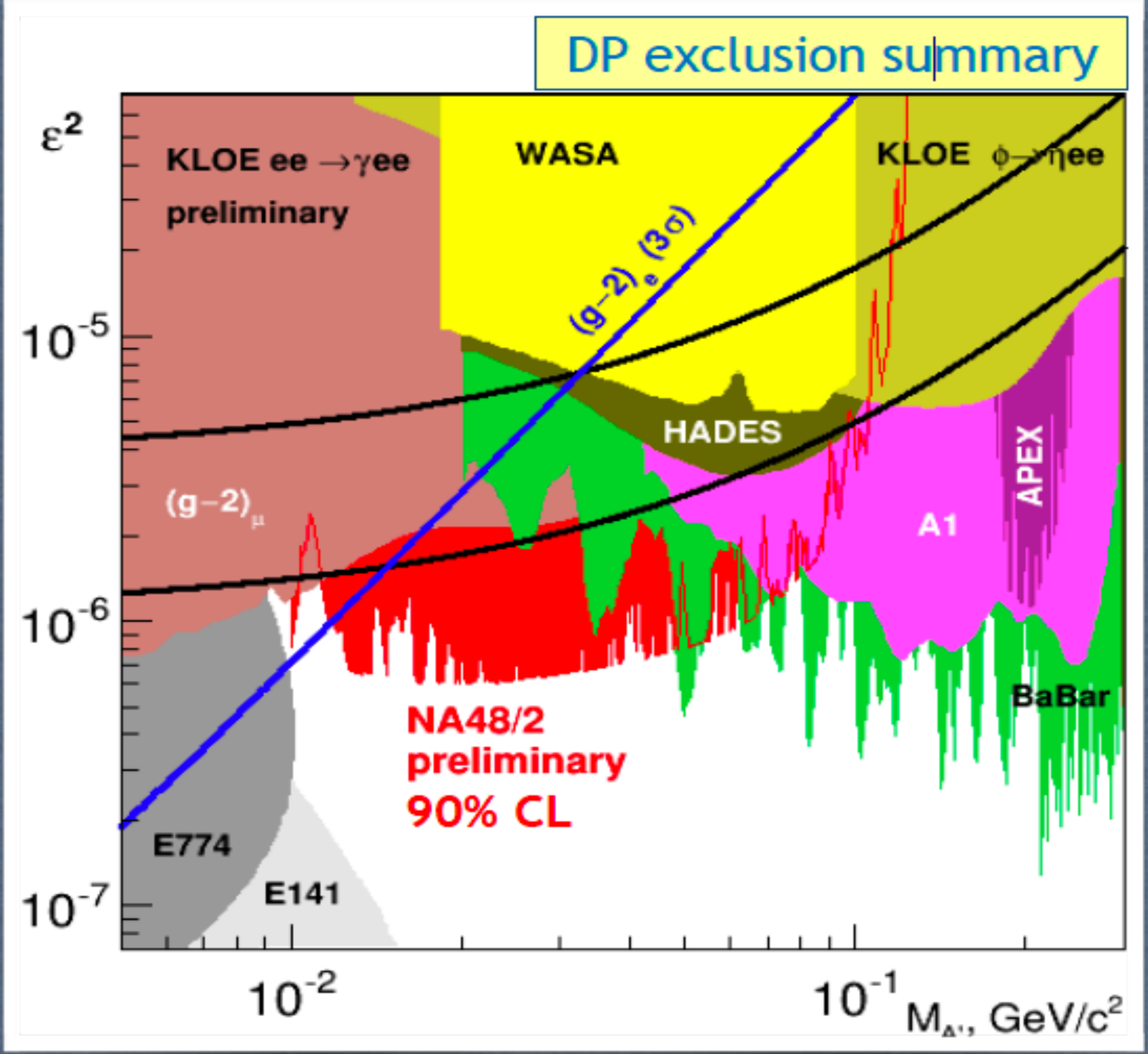
$K^\pm \rightarrow \pi^\pm \pi^0$, $\pi^0 \rightarrow \gamma A'$, $A' \rightarrow e^+e^-$

- 4×10^{10} π^0
- Acceptance ~ 2.5%
- δM ~ 1% Mee

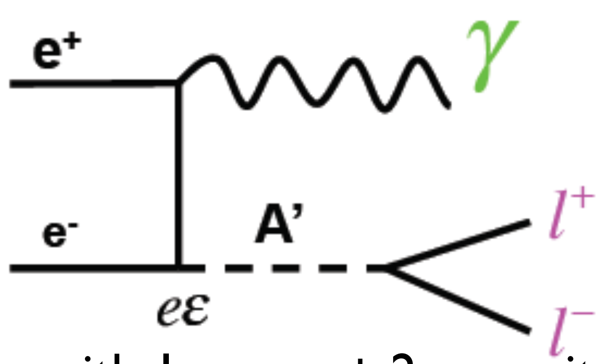


NA48/2

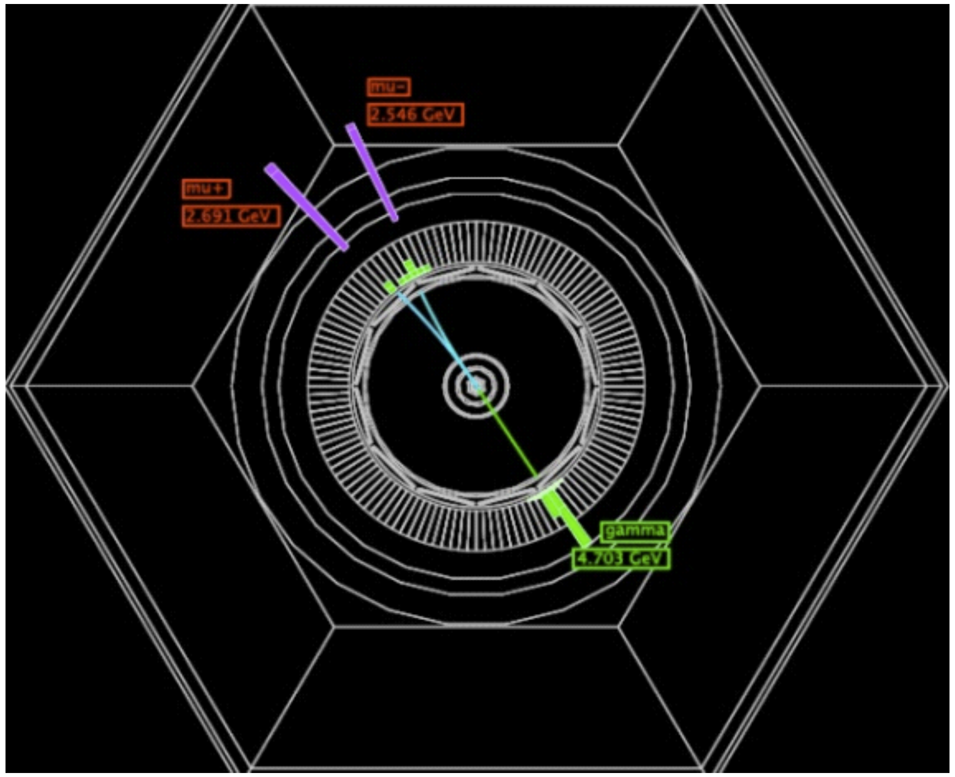
E. Goudzovski
Messina, 25 September 2014



e+e- Colliders - Recent Results

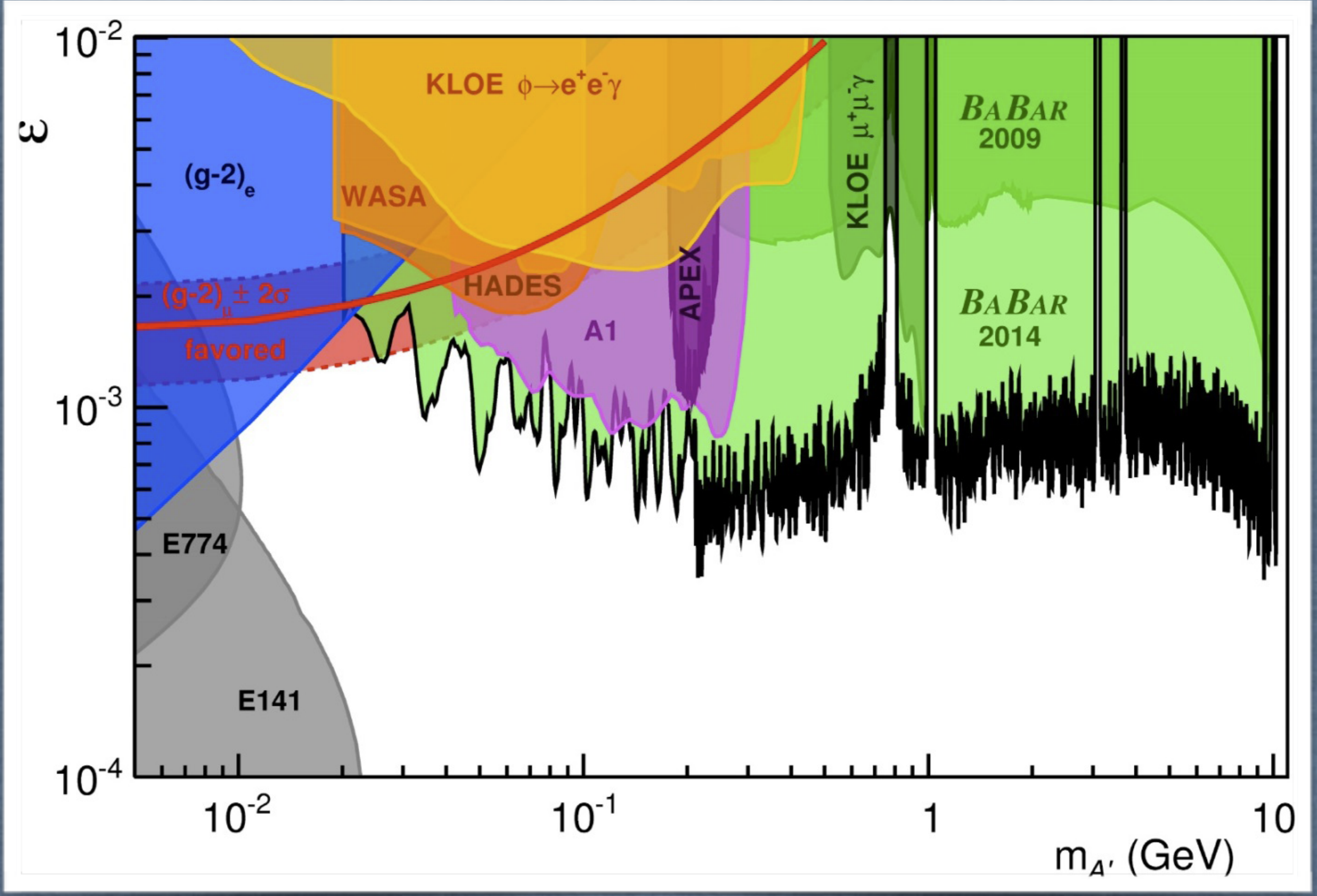


- Events with 1gamma + 2 opposite leptons
- Di-lepton mass fit to a bg (all res included)
- Mass resolution: 1.5 MeV - 8 MeV
- Int (L) = 514 fb^{-1}



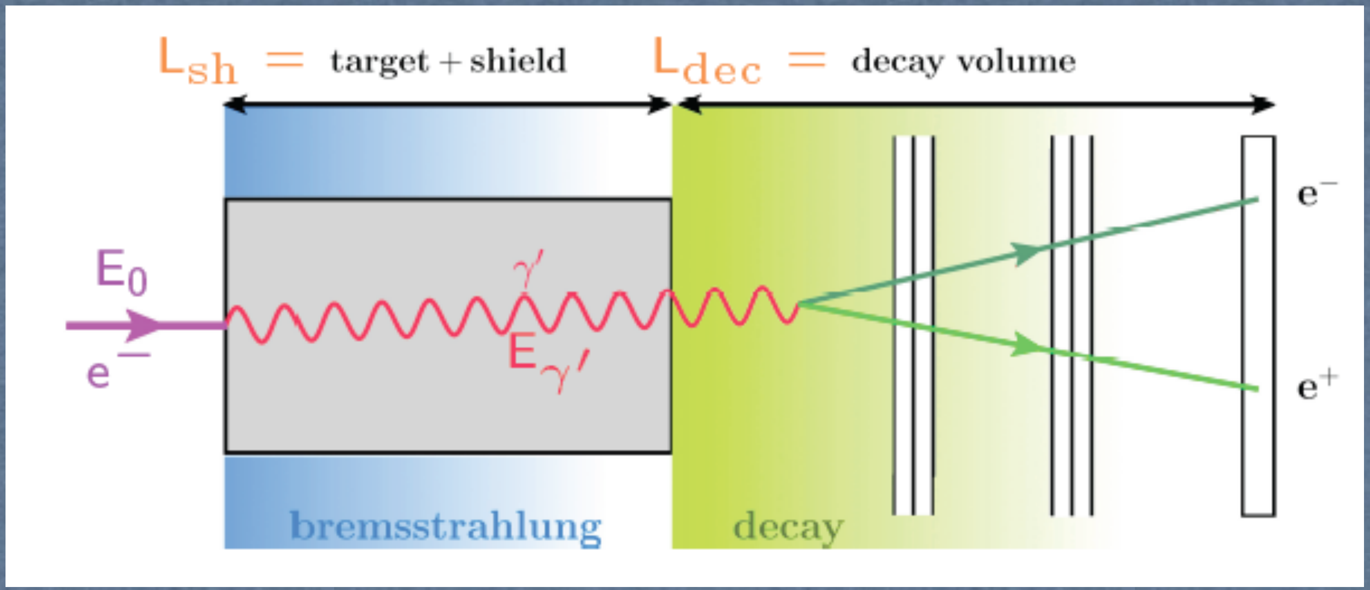
BABAR

J.P. LEEs et al. (The BABAR Collaboration)
arXiv:1406.2980 [hep-ex]

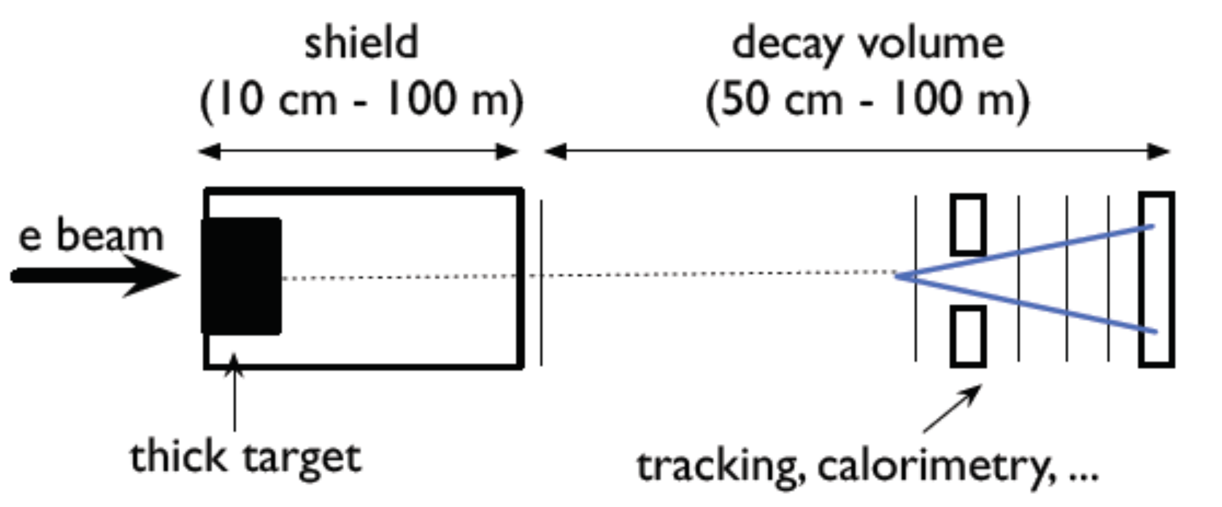


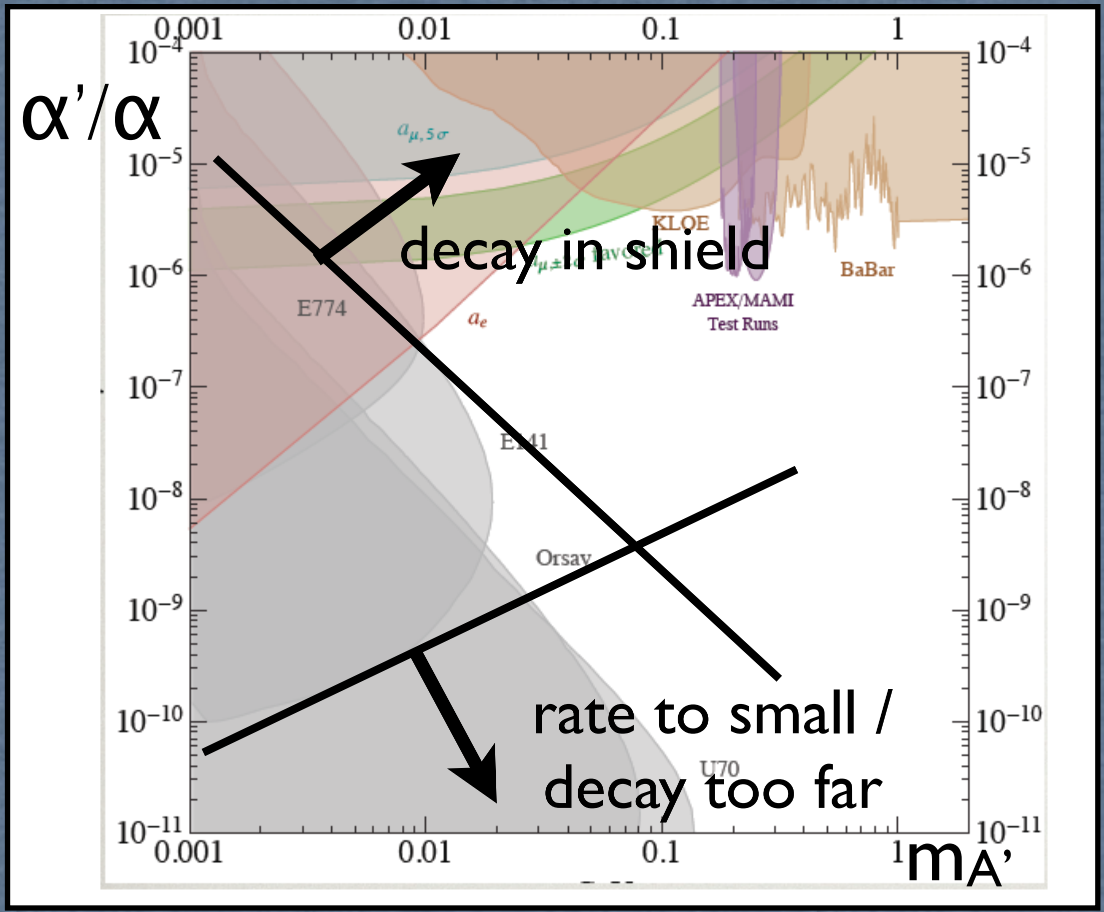
Ist generation fixed target exp: beam dump

- e- beam incident on thick target
- A' is produce in a process similar to ordinary Bremsstrahlung
- A' carries most of the beam energy
- A' emitted forward at small angle
- A' decays before the detector



$$\gamma c\tau \approx 1\ \mathrm{mm}\,(\gamma/10)\,\left(10^{-8}\alpha/\alpha'\right)$$
$$\times\,(100\ \mathrm{MeV}/m_{A'})$$





Current generation fixed target exp: thin target JLab and Mainz

JLab

✳ DARK LIGHT (FEL)

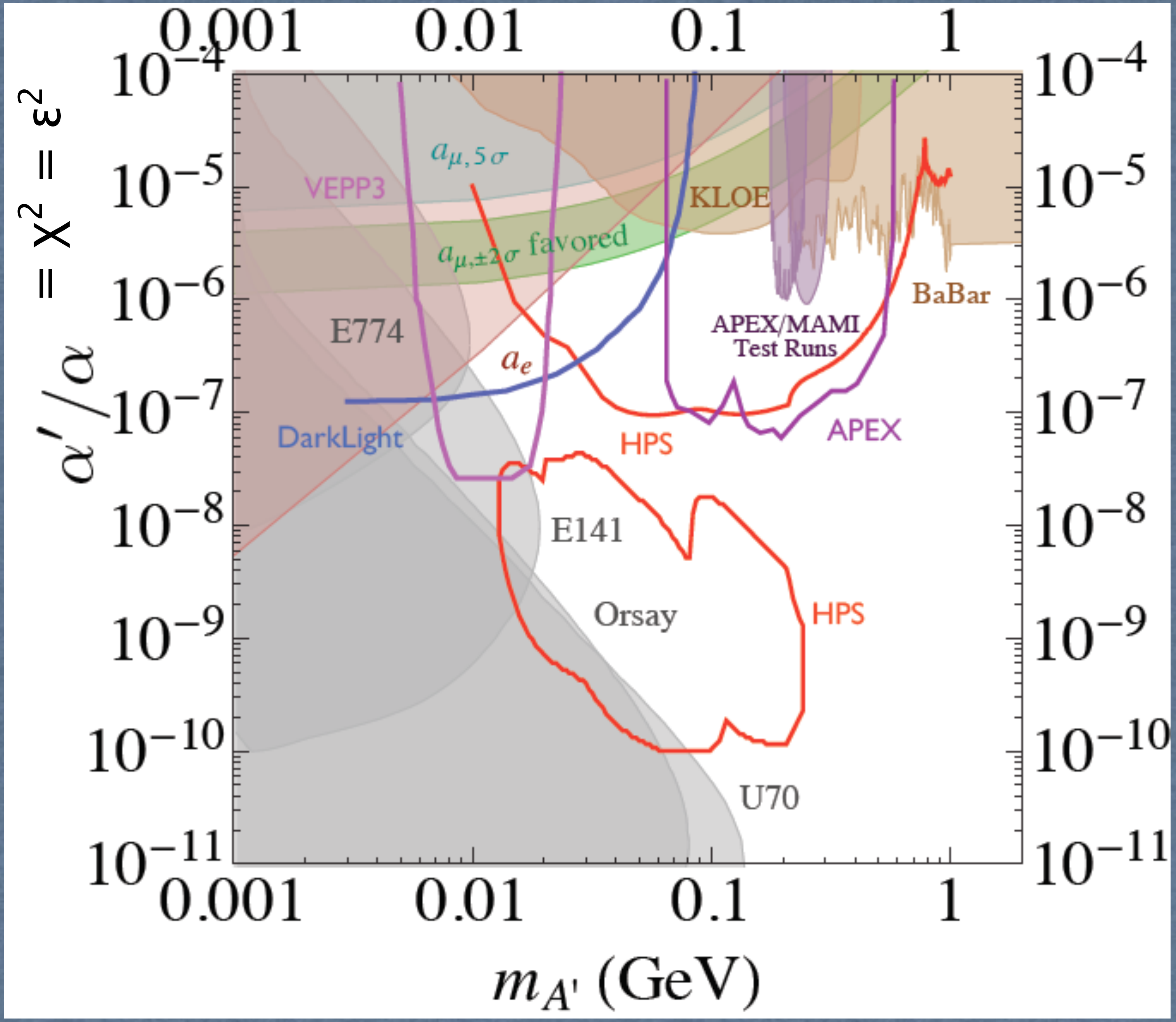
✳ APEX (Hall-A)

✳ HPS (Hall-B)

- Unconventional use of the CEBAF
- PAC approval (max rating conditioned to technical feasibility)
- Positive run-tests
- Experiments begin: 2015-16

Mainz

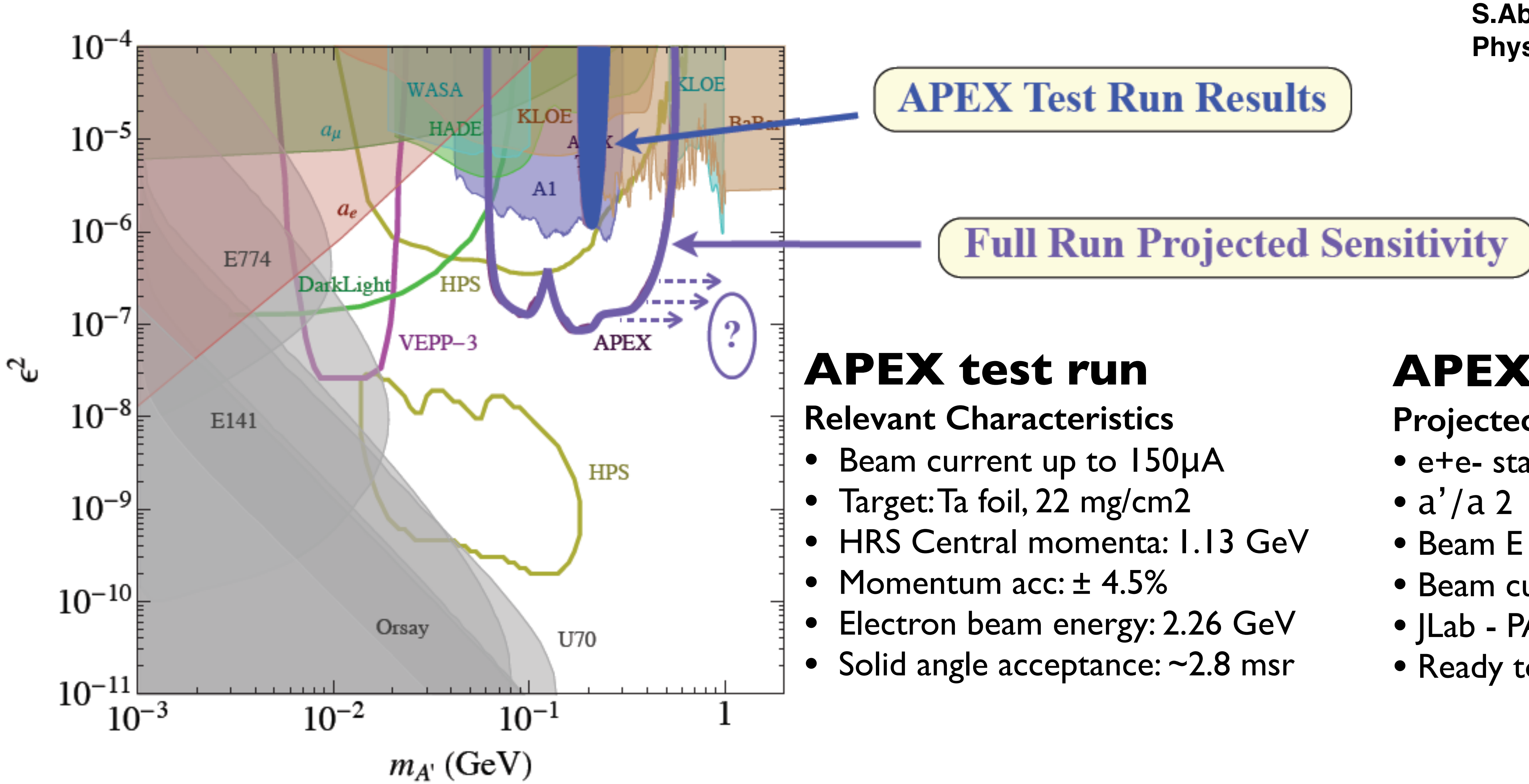
- Magnetic spectrometers (A1)
- Pilot run in 2012
- Full analysis published in 2014
- Future plans



JLab experiments
APEX (A-Prime EXperiment)

- Dark photon search in fixed target experiment in Hall-A at Jefferson Lab
- Looking for a small, narrow bump on top of a smooth histogram of QED processes
- Excellent mass resolution required (~ 0.85 - 1.1MeV)

S.Abrahamayan et al.,
Phys. Rev. Lett. 107 (2011) 191804



APEX test run

Relevant Characteristics

- Beam current up to 150μA
- Target: Ta foil, 22 mg/cm2
- HRS Central momenta: 1.13 GeV
- Momentum acc: ± 4.5%
- Electron beam energy: 2.26 GeV
- Solid angle acceptance: ~2.8 msr

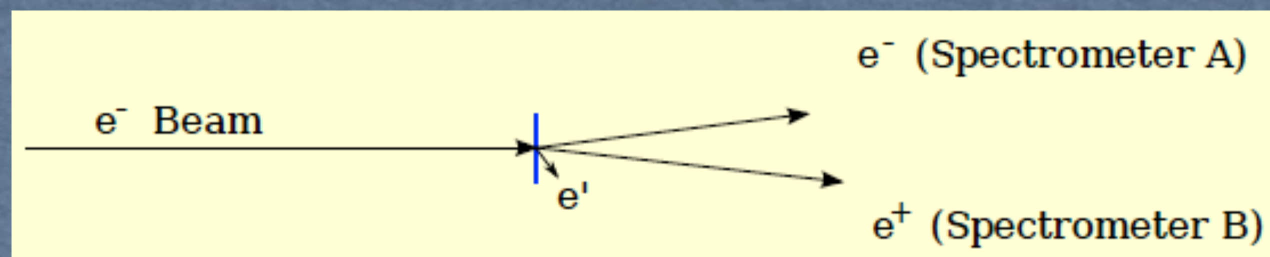
APEX full run

Projected sensitivity

- e+e- statistics 200x
- a'/a 2 100x below current limits
- Beam E from 1.1 GeV to 4.4 GeV
- Beam current: 60-100 μA
- JLab - PAC41 High impact rate
- Ready to run in 2015

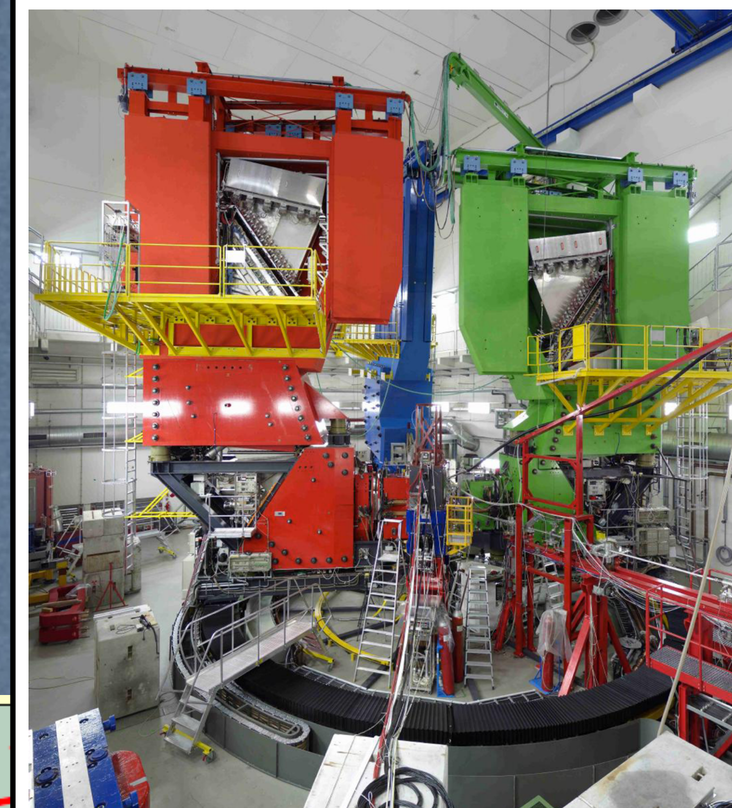
A' search at MAINZ
Full data analysis

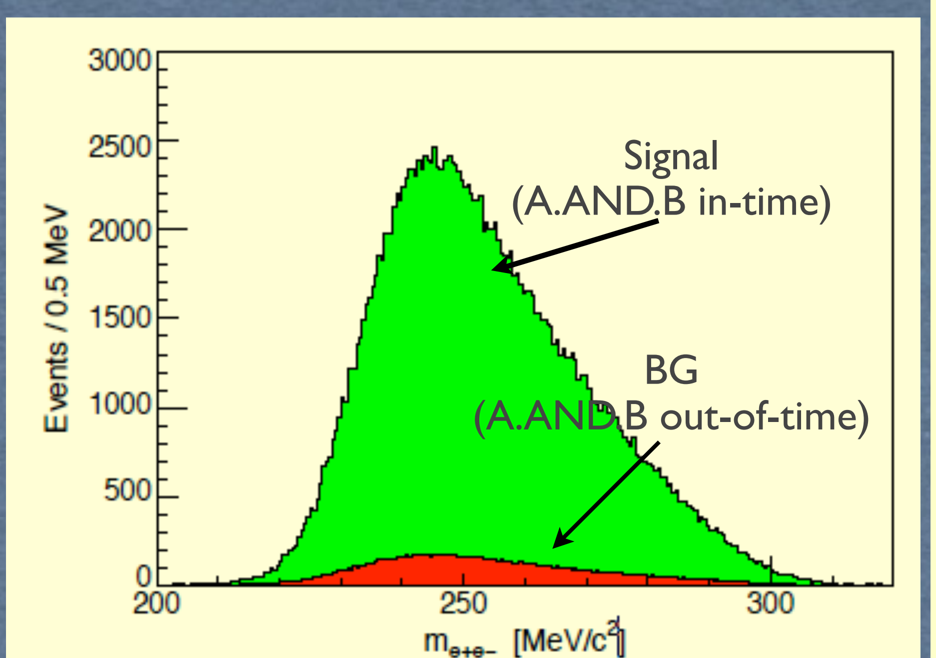
- E=855 MeV
- I=100uA
- Ta target

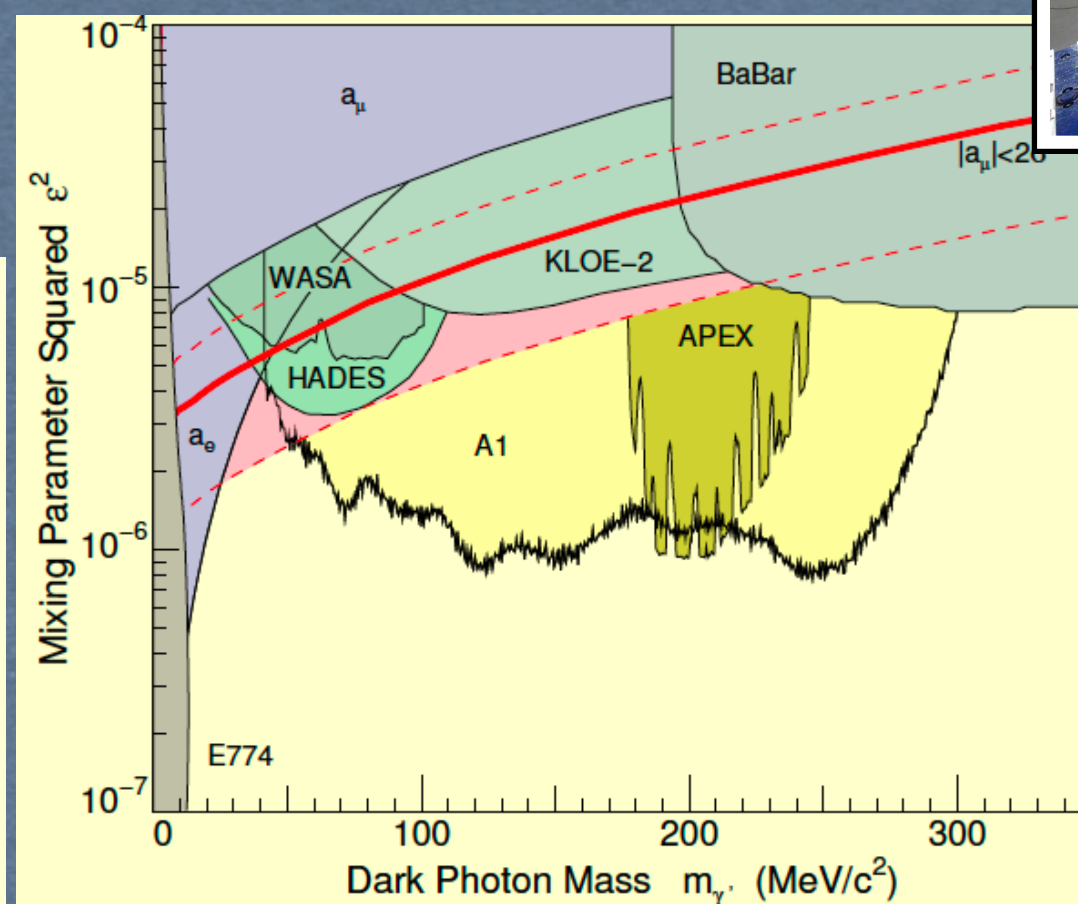


- Spectrometer A (red): p_{e-} 338 MeV/c J_{e-}=22.8°
- Spectrometer B (blue): p_{e+} 470 MeV/c J_{e+}=15.2°

A1 spectrometers @ MAMI

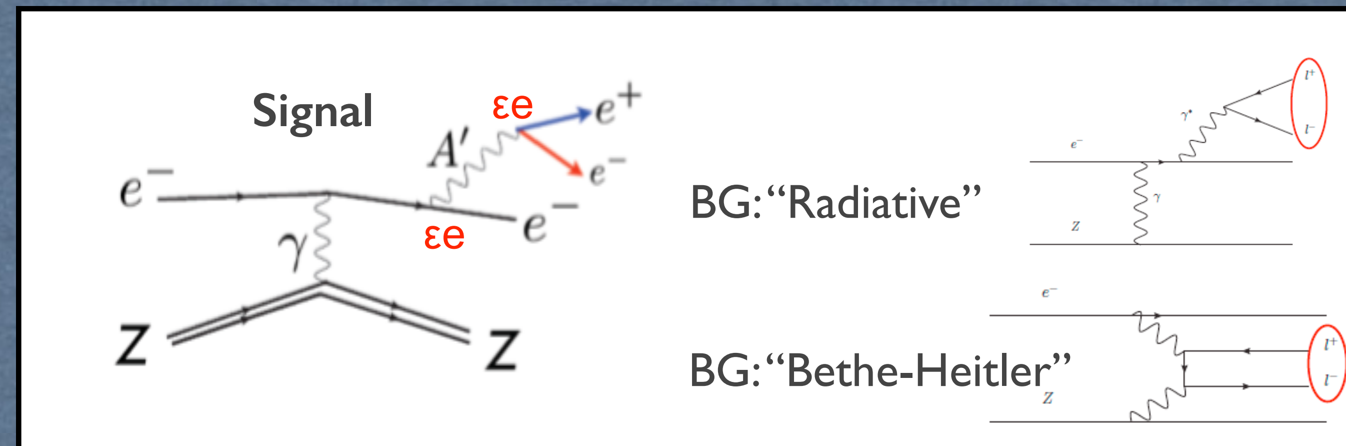


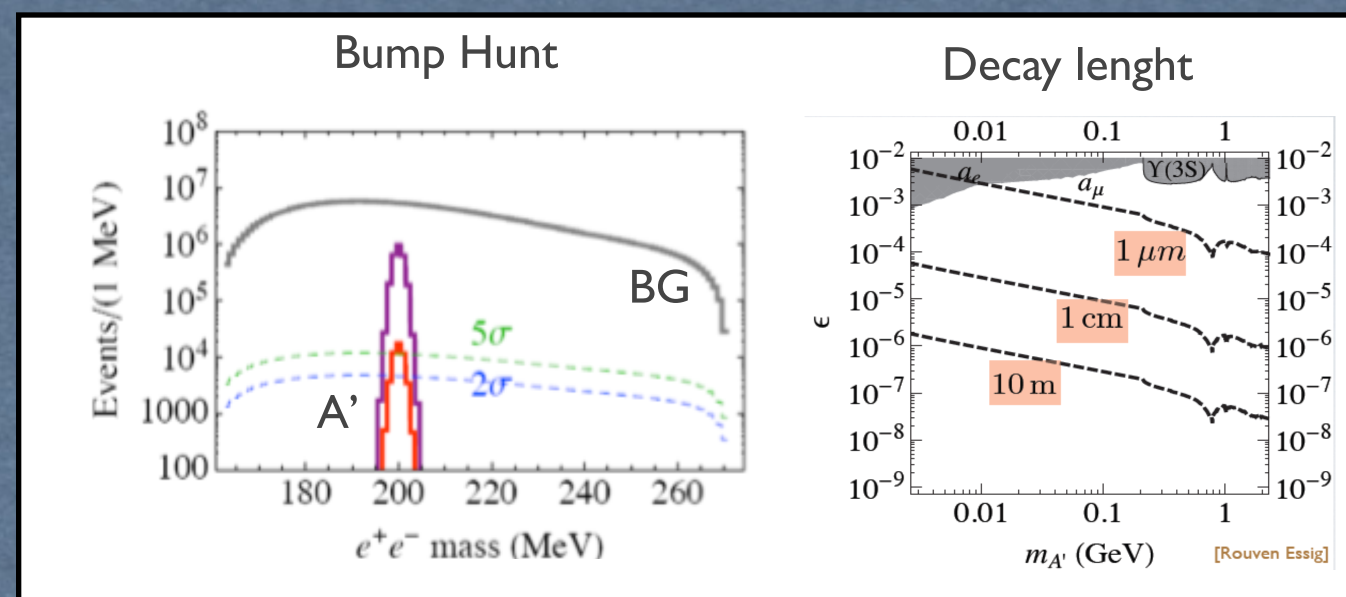




H. Merkel et al.,
Phys. Rev. Lett. 112 (2014) 015032

HPS@JLab
Heavy Photon Search





Heavy photon signatures in HPS

1) Bump Hunting (BH)

Narrow e+e-resonance over a QED background

➥ good mass resolution: $\sigma_{A'mass}$~1 MeV

2) Secondary decay vertex (vertexing)

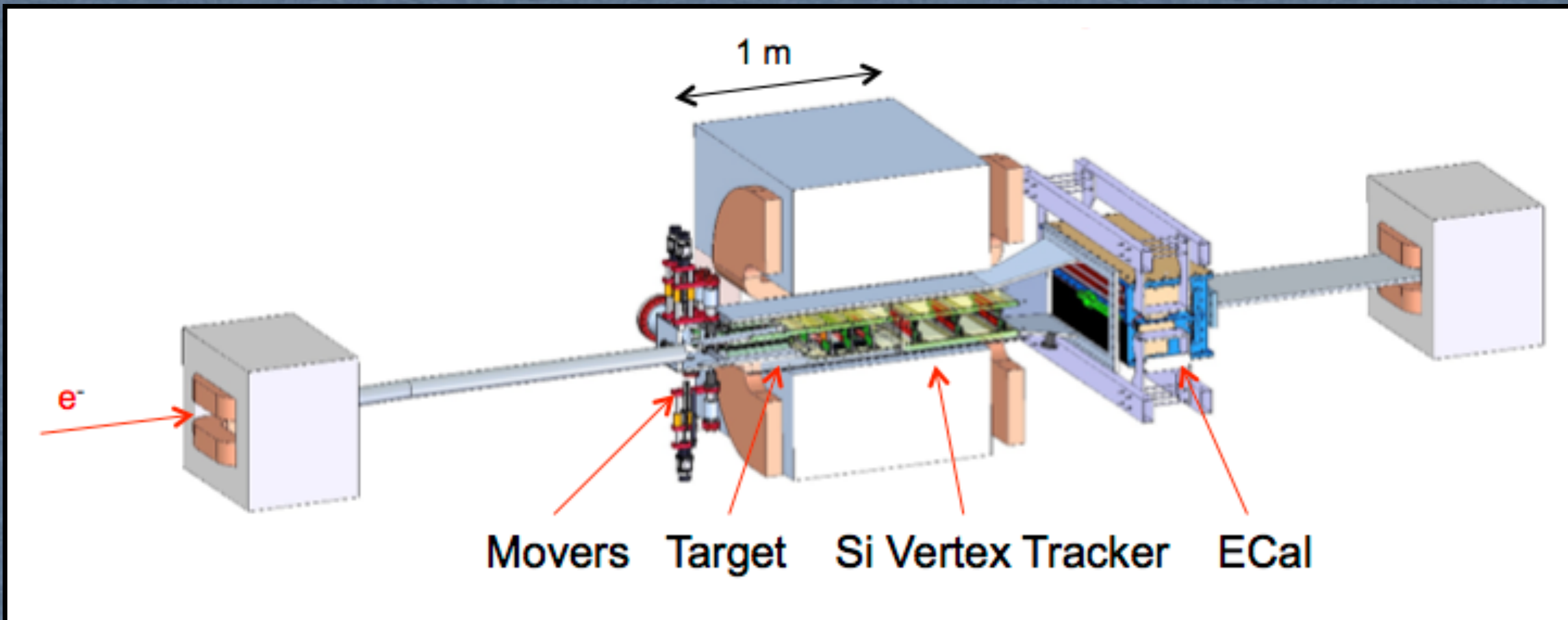
Detached vertex from few mm to tens cm

➥ good spacial resolution: σ_{vertex}~1mm

BH + Vertexing = enhanced experimental reach

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

The HPS Experiment



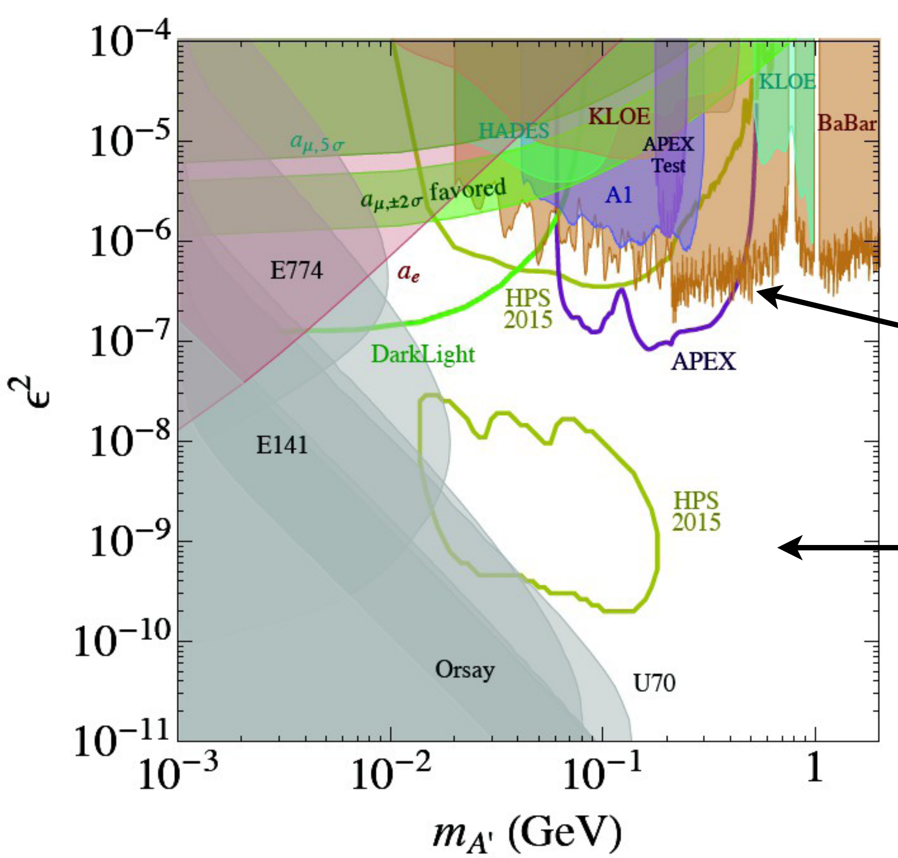
Requirements:

- forward angles coverage
- good spacial resolution:
  σ_{vertex}~1mm (vertexing)
- good mass resolution:
  $\sigma_{A'mass}$~1 MeV (bump hunting)

Experimental set-up

- B field to bend e+/e- pairs
- Si TRCK for vertexing
- EM cal for triggering

Projected results



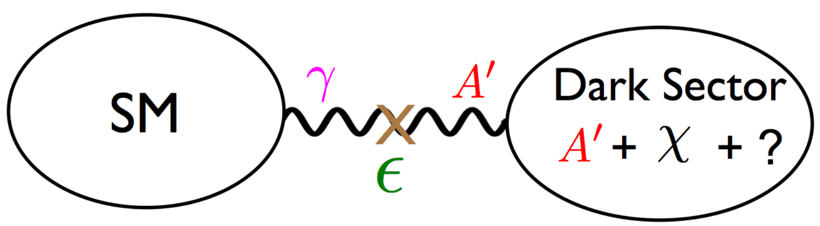
Bump hunting

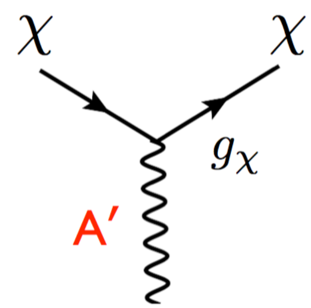
Bump hunting + vertexing

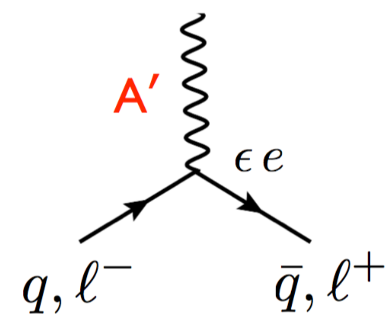
1 week 1.1 GeV 1 week 2.2 GeV 2 weeks 4.4 GeV	Phase I 2014/15
few months 2.2 GeV few months 4.4 GeV few months 6.6 GeV	Phase II 2017 -2019

JLab - PAC41 High impact rate

Dark forces and dark matter
(Light WIMP - light mediators)



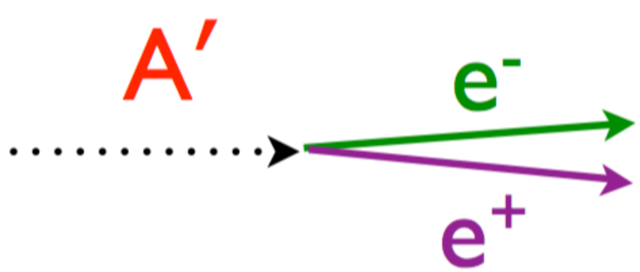




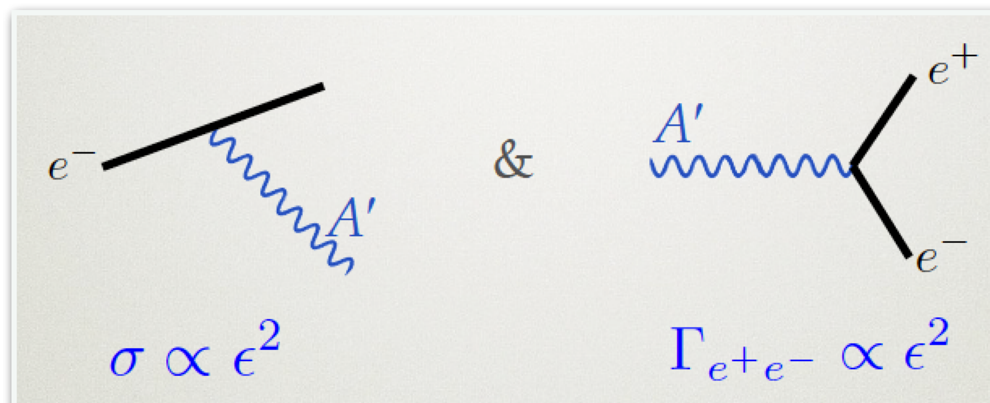
4 parameters: $m_\chi, m_{A'}, \epsilon, g_\chi$

$m_\chi \sim m_{A'} \sim \text{MeV} - 5\text{ GeV}$

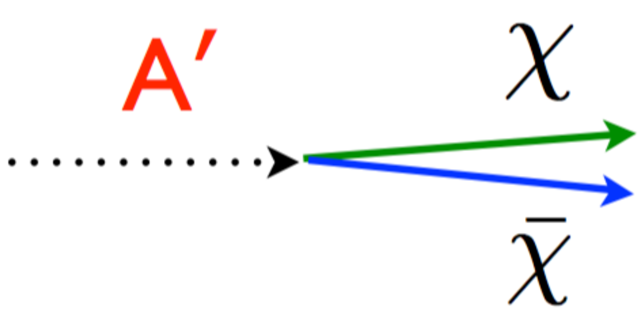
Visible



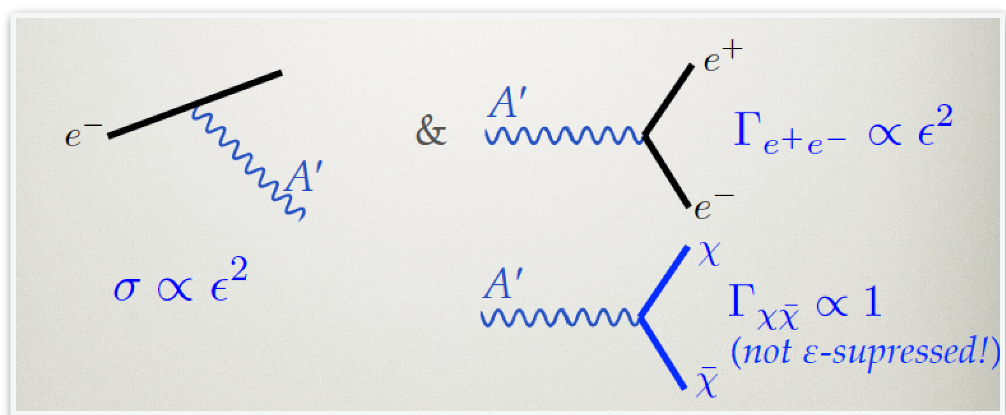
- *Minimal* decay
- Decay regulated by ε^2
- Independent on m_χ
- Requires $m_{A'} < 2m_\chi$



Invisible



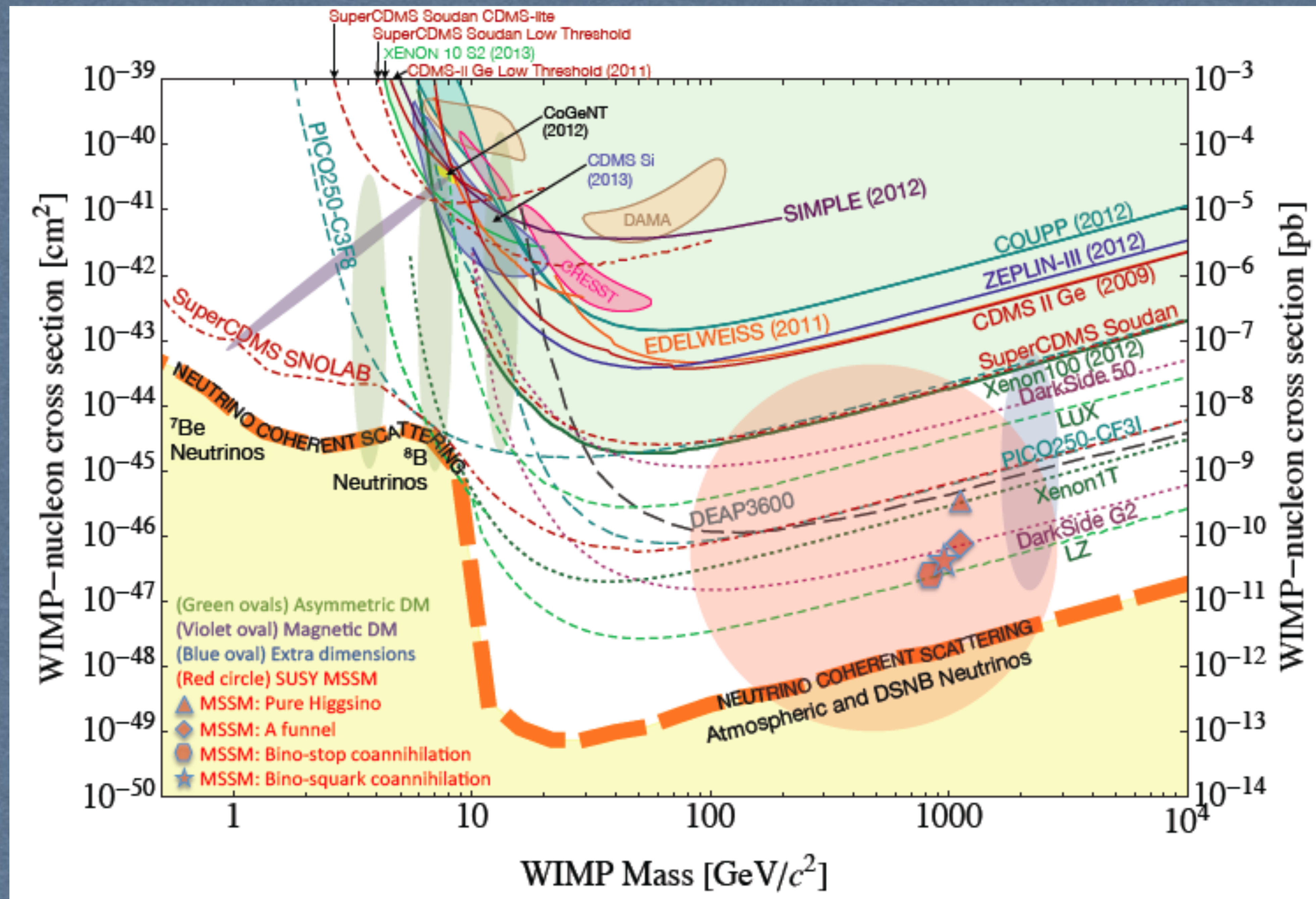
- $m_\chi < 2m_{A'}$
- i) stable and invisible
- ii) decays to SM particles
- Independent on ε



Dark Matter search - Direct measurements

Dark matter (DM) direct search mainly focused in the mass region 10 GeV -10 TeV

- WIMP: weakly interacting massive particles with weak scale mass provides the correct DM relic abundance
- No signal in direct detection

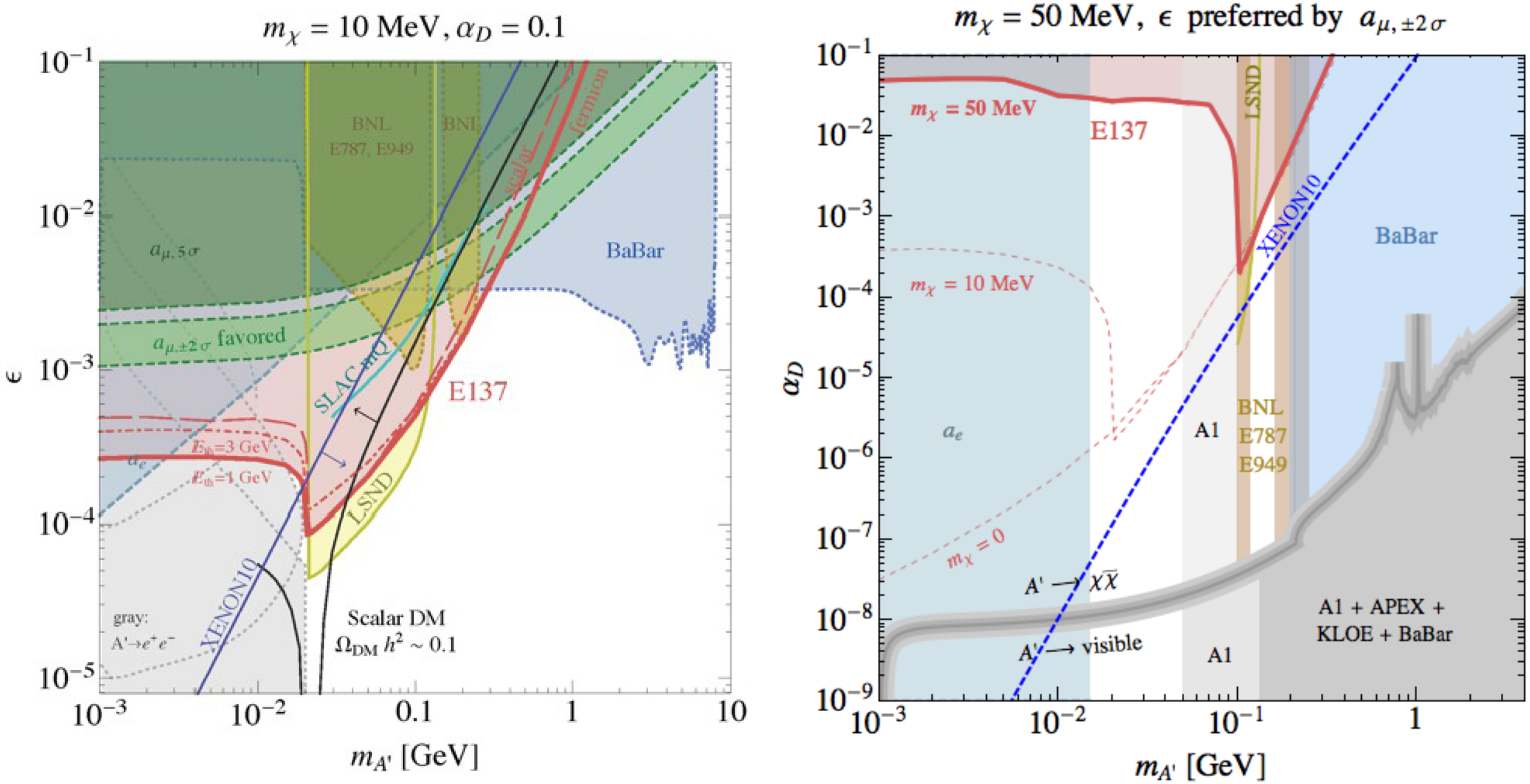


DM detection by measuring the (heavy) nucleus recoil of slow moving cosmological DM

→ no experimental sensitivity to light DM (<1 GeV)

Visible vs Invisible: complementarity $(g-2)_\mu$

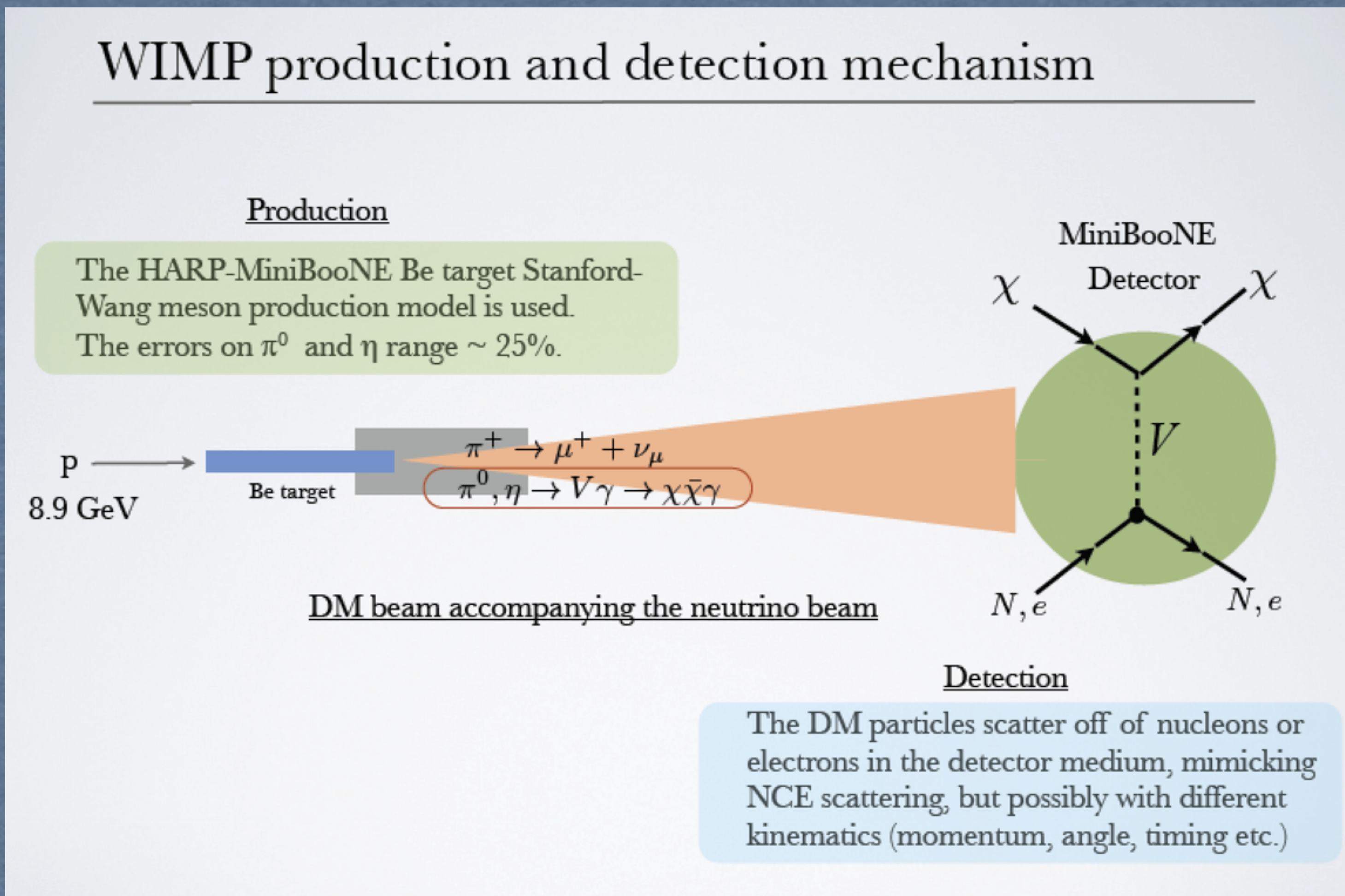
Invisible only | **Visible + Invisible**



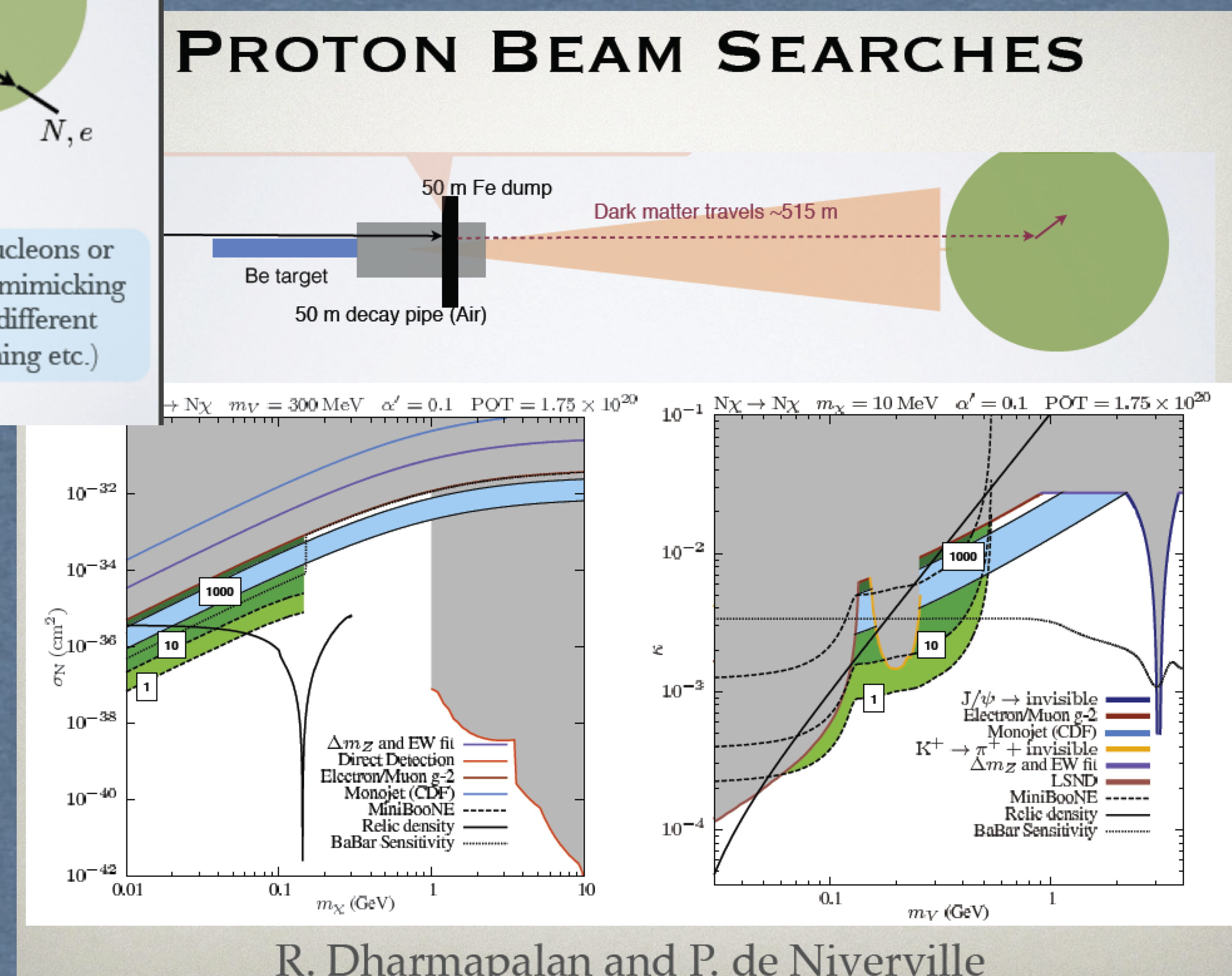
Strong Constraints on Sub-GeV Dark Matter from SLAC Beam Dump E137
http://arxiv.org/abs/1406.2698 Brian Batell, Rouven Essig, Ze'ev Surujon

- Reinterpretation of existing data are ruling out *(g-2)*$_\mu$ favoured region
- Exclusion limits are model dependent: if invisible decay is included limits do not hold!

MiniBooNE

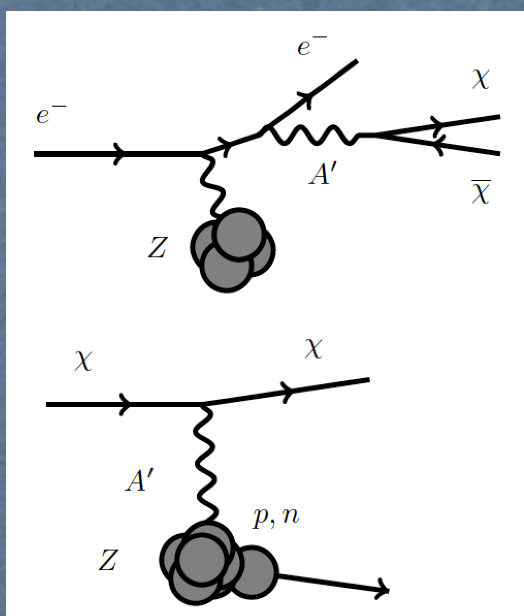


Tests Run just ended!



BDX - Dark matter search in a Beam Dump eXperiment at JLab

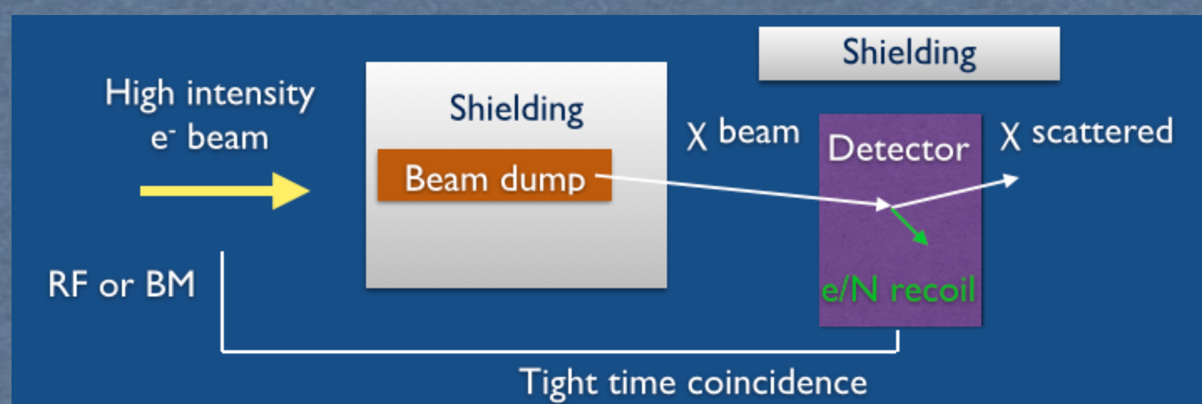
Beam dump (e^-) experiments can provide unprecedented sensitivity to light dark matter Jefferson Lab can play a significant role in light DM search

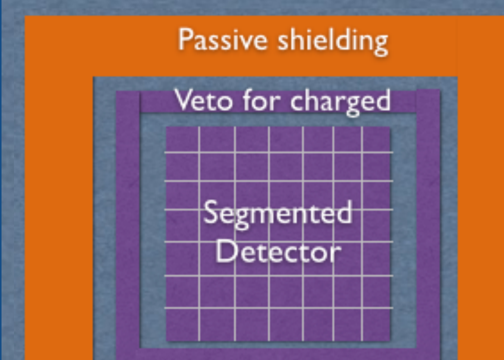


Two steps process:

I) An electron irradiates an A' and the A' pormptly decays to a χ (DM) pair

II) The χ elastically scatters on a e^-/nucleon in the detector producing a visible recoil (GeV/MeV)





~1 m^3 segmented plastic scintillator + small rl crystals

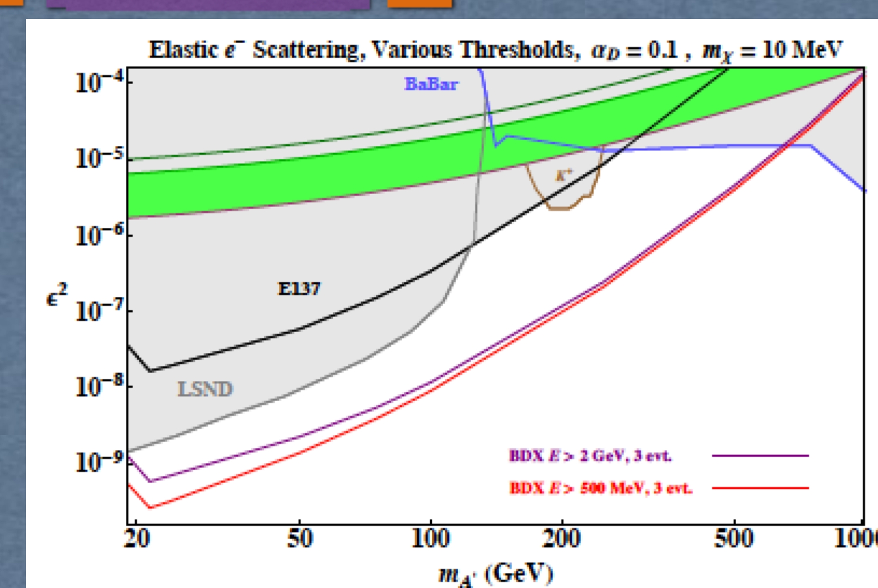
Key issue: bg rejection

BDX@JLab reach

- 1m3 detector (~9 m x 0.4x0.4 m2)
- 10^{22} EOT (100 uA for 6 months, full parasitic)
- realistic estimates of cosmogenic and beam-related background

At least, two orders of magnitudes better than any previous experiments

- BDX@LNF reach evaluation in progress



PADME at LNF

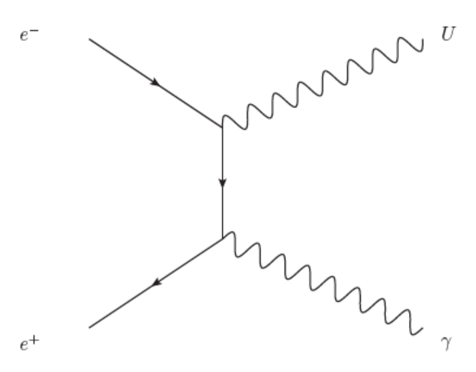
Present BTF

- E_{e+} = 550 MeV
- EOT ~ 10^{13} - 10^{14} year^{-1}
- 1 year experiment

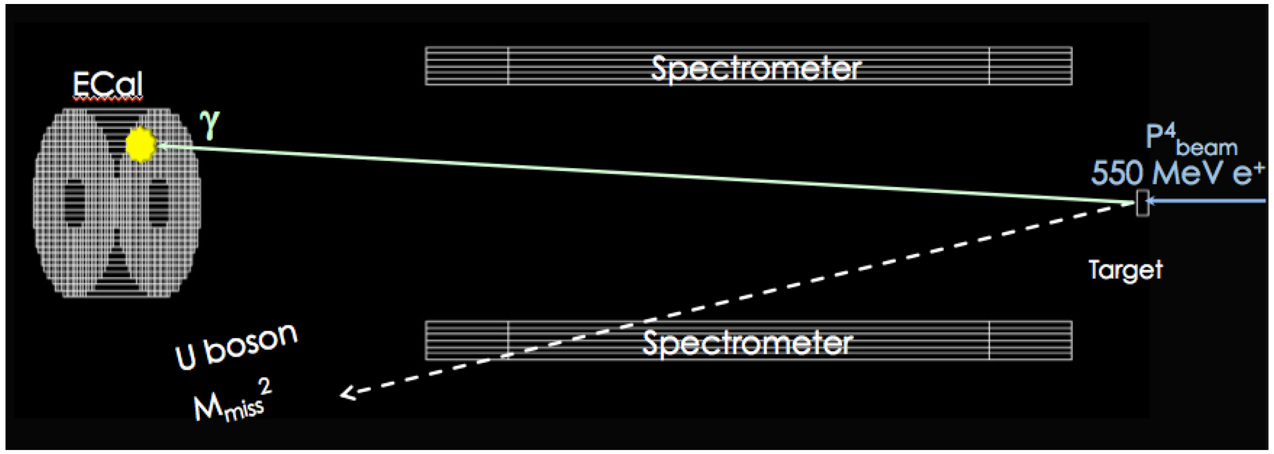
Future Upgrade

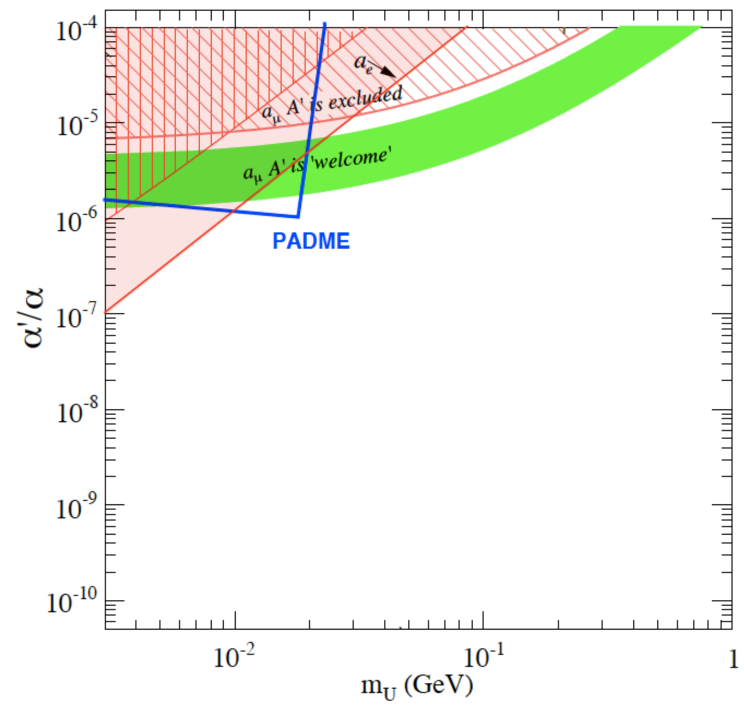
- E_{e-} = 1.250 GeV
- EOT ~ 10^{19} - 10^{20} year^{-1}
- LINAC + BTF beam-dump (BDX@LNF)

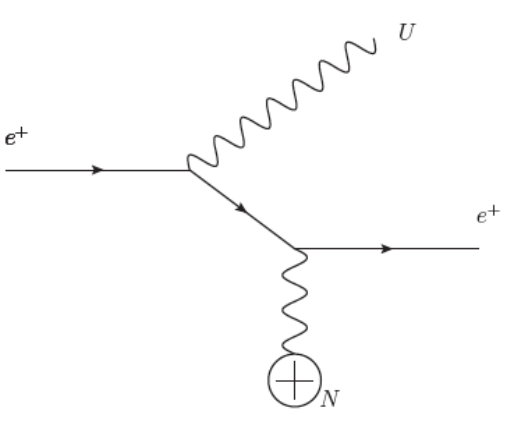
M. Raggi, V. Kozhuharov Advances in High Energy Physics Vol. 2014 ID 959802



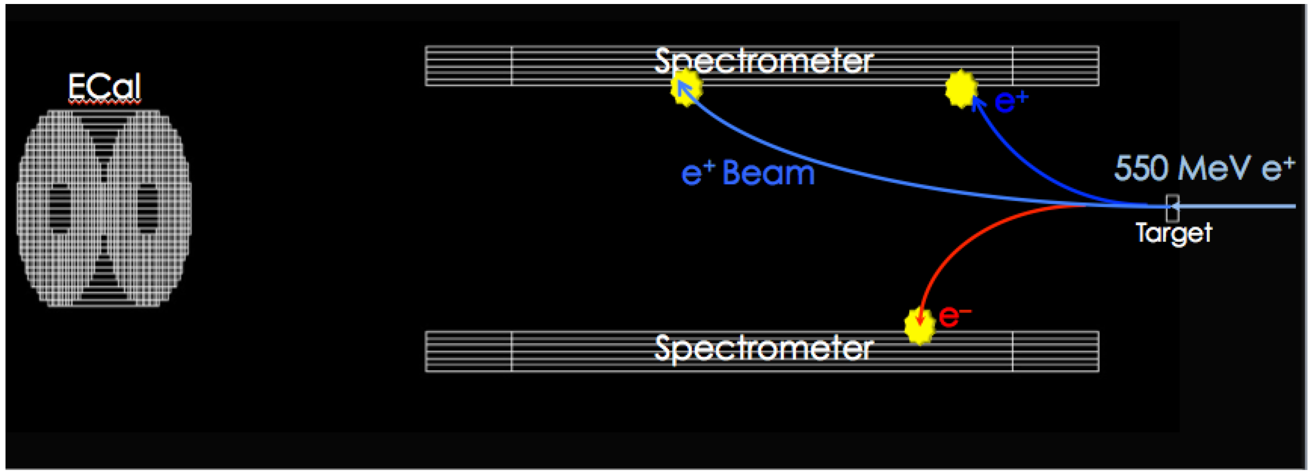
Annihilation

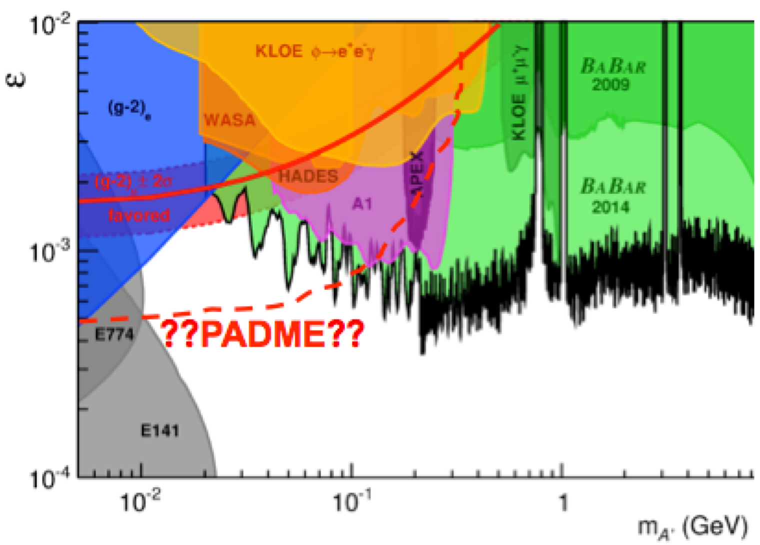




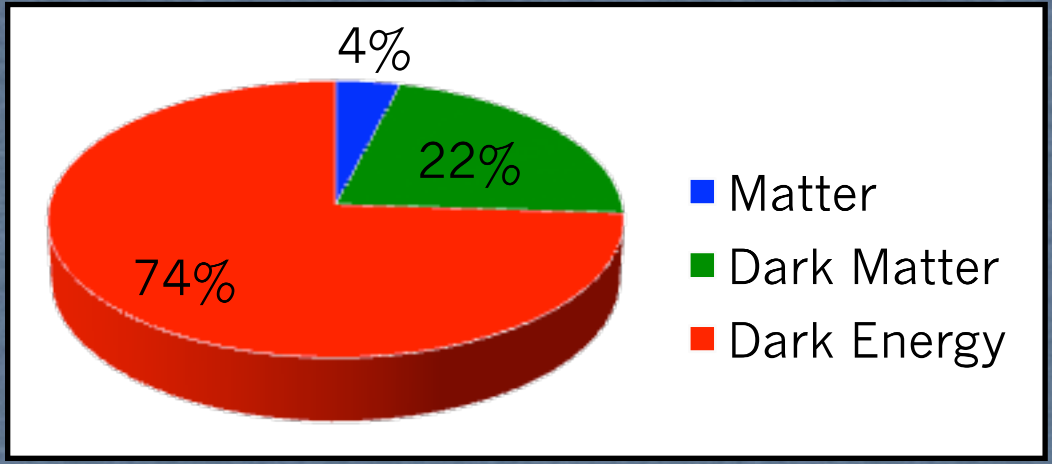


Bremsstrahlung





Conclusions



✳ It seems established that hadronic matter only accounts for the 4% of the total mass in the Universe

✳ Strong physics motivation for the possible existence of GeV-scale hidden/ dark photons:

- top-down: extra U(1)s in string models
- bottom-up: anomalies associated with dark matter (PAMELA, FERMI) and $(g-2)_\mu$

✳ Dark Photon searches are excluding a significant part of parameters space

✳ Light Dark Matter could explain null results resetting experimental limits

✳ Active and vibrant field, with new results coming shortly!