Constraining Light Dark Matter with Low-Energy e^+e^- Colliders

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In collaboration with

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arXiv: 1305.xxxx

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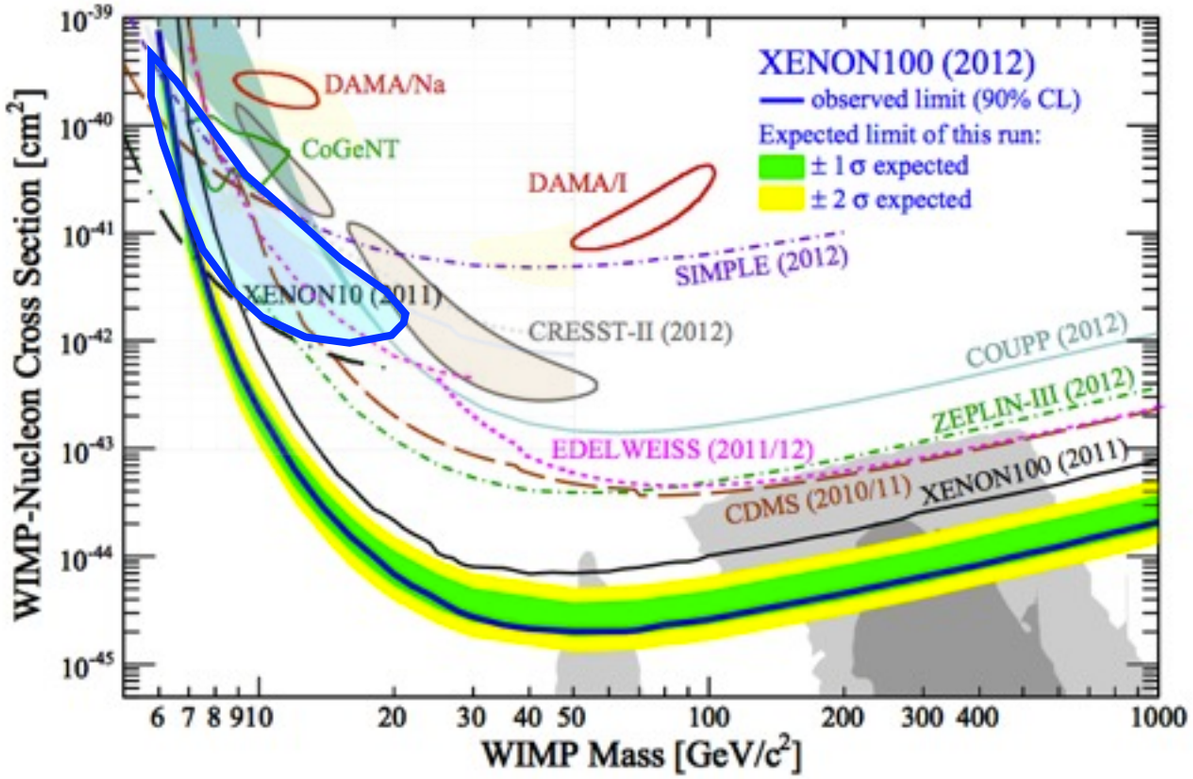
Outline

- Introduction
- Searches for light dark matter (LDM) at BaBar
- Summary and prospects

Going beyond WIMPs

Weakly Interacting Massive Particles (WIMPs) are popular DM candidates and received much attention from collider/direct/indirect detection



XENON100, 1207.5988;
CDMS Collaboration

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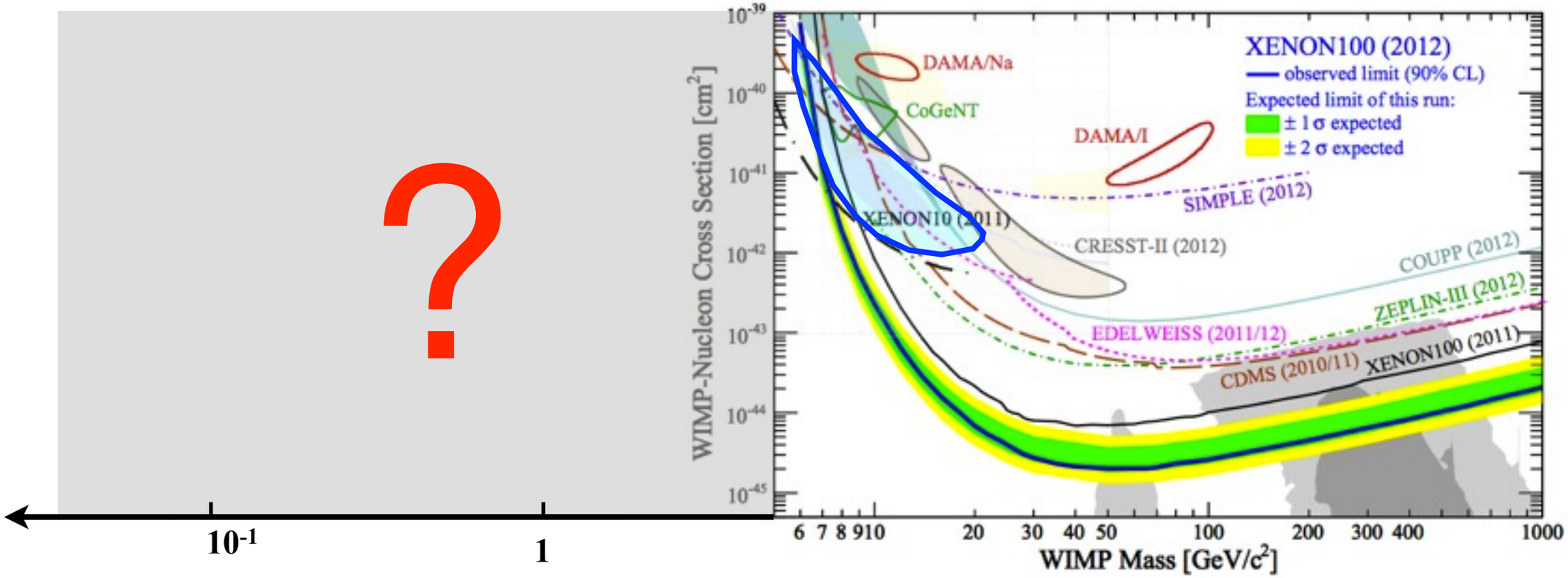

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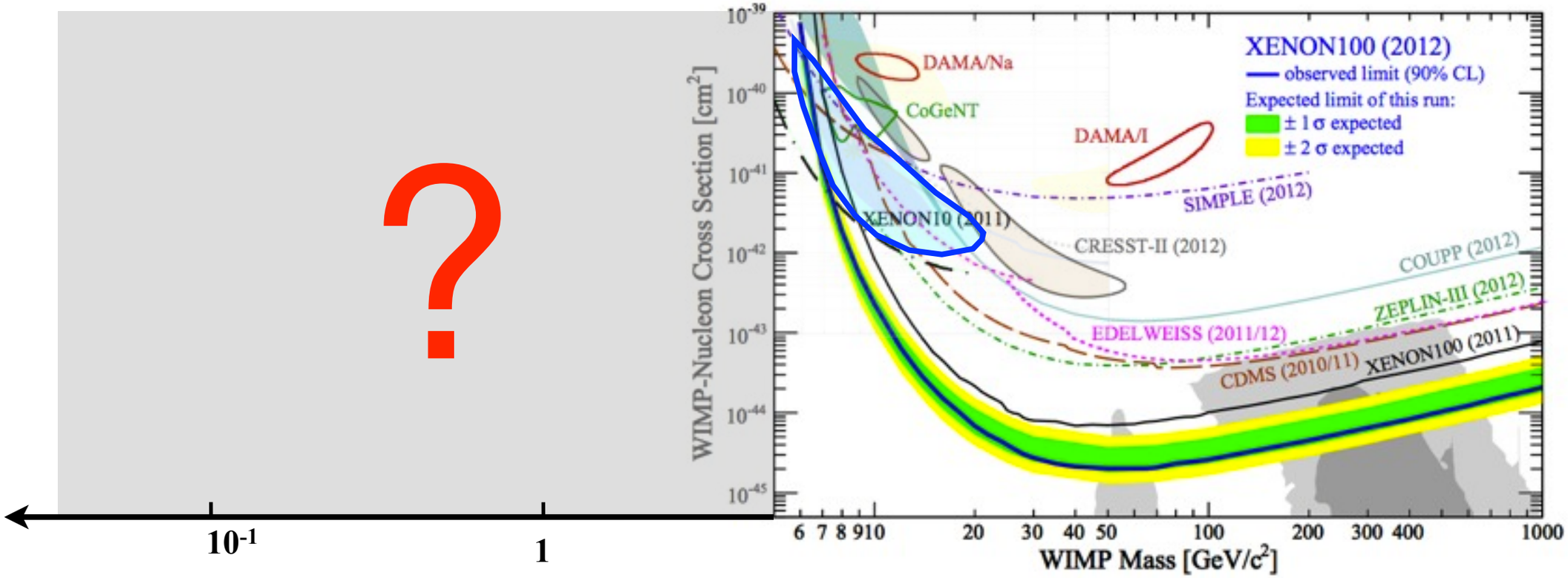
Going beyond WIMPs

Weakly Interacting Massive Particles (WIMPs) are popular DM candidates and received much attention from collider/direct/indirect detection

LDM can be also probed by these experiments



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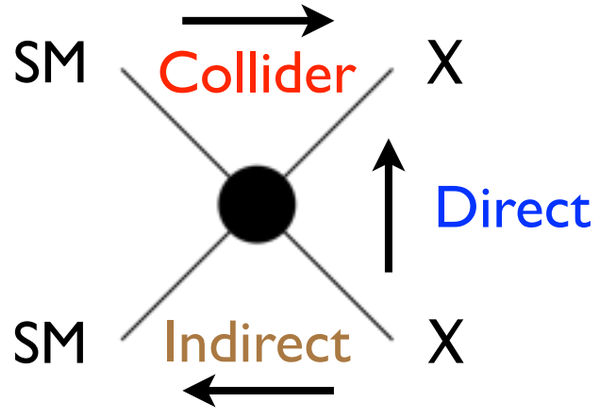
4. Translate bounds on Λ to bounds on direct/indirect detections



Look at BaBar

BarBar is the B-factory

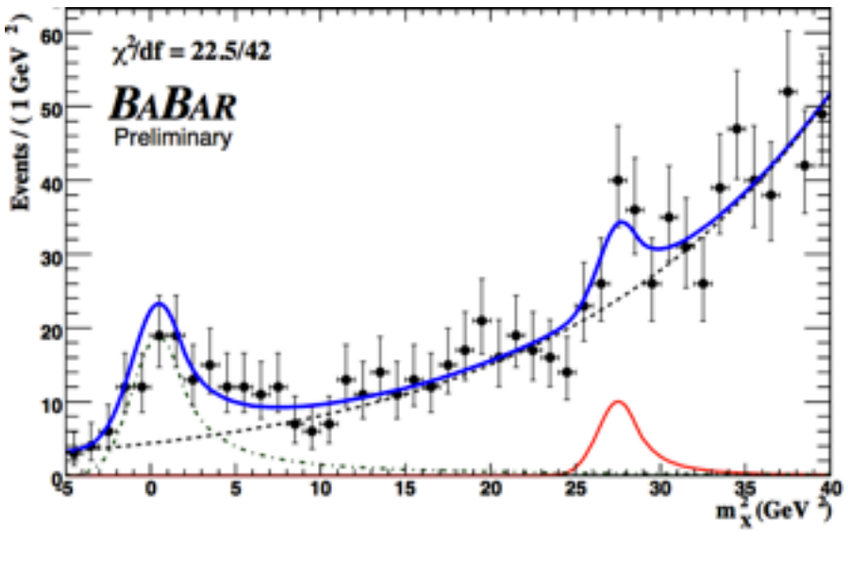
at SLAC, 1999-2008

BaBar is an ideal place for LDM search:

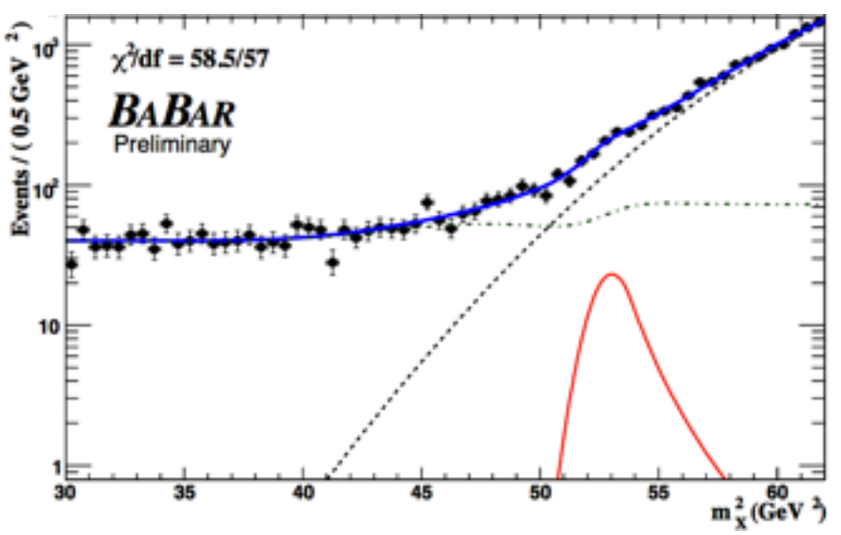
1. Low energy e^+e^- collision with $\sqrt{s}$=10.58 GeV
2. Sensitive to both DM-quark/gluon and DM-electron couplings
3. BaBar in total has ~500/fb data. But data with mono-photon trigger is only 30/fb (122×10^6 $\Upsilon(3S)$ decays). Still a lot!

BaBar's Results

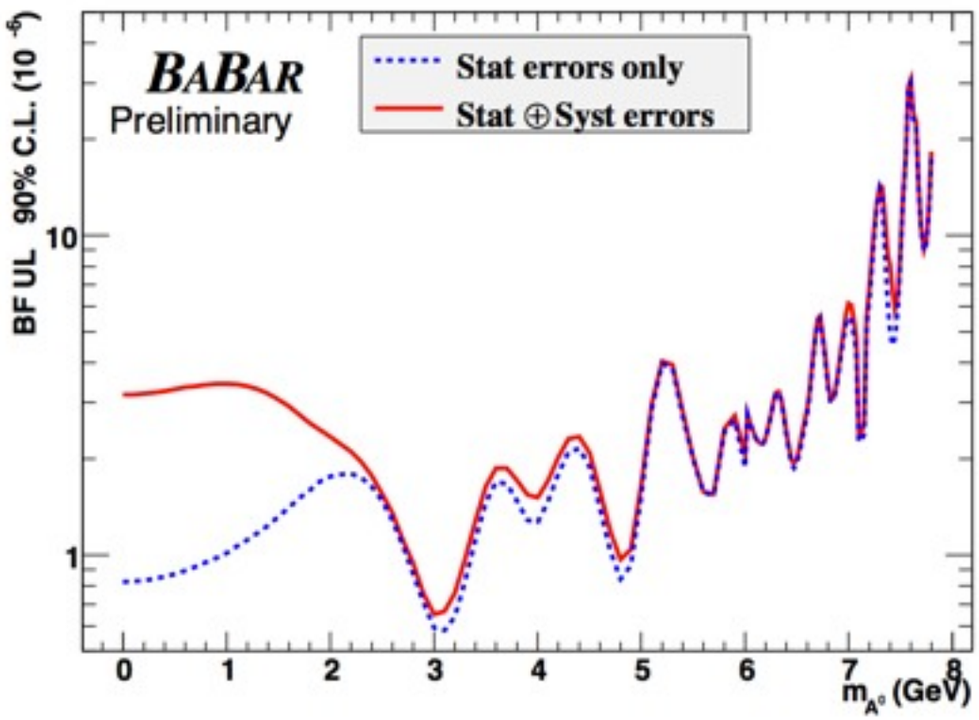
BaBar searched for $\Upsilon(3S) \rightarrow \gamma A^0 \rightarrow \gamma$+invisible.
No significant excess of events in the search range
($2.2 < E_\gamma < 5.5$ GeV)



Mono-photons at high E_γ region (3.2~5.5 GeV)



Mono-photons at low E_γ region (2.2~3.7 GeV)

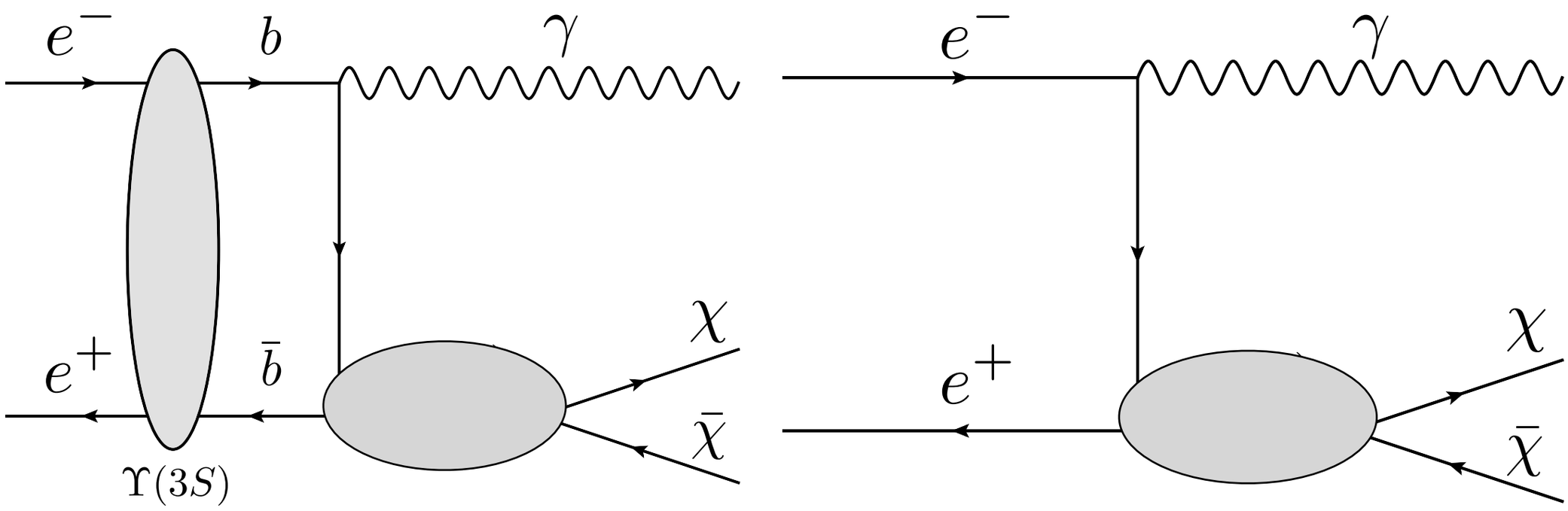


Upper limits of BR of $\Upsilon(3S) \rightarrow \gamma A^0 \rightarrow$ invisible
BaBar, 0808.0017

How to Produce DM at BaBar

Two ways:

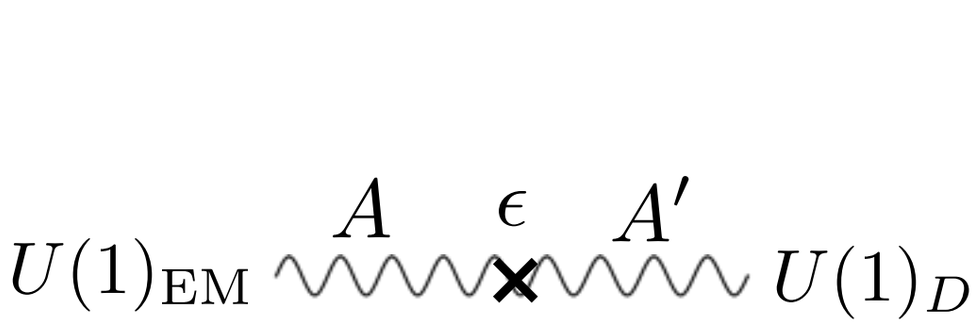
1. Through $\Upsilon(3S)$ decays (BaBar, 0808.0017; Yeghiyan, 0909.4919, 0910.2071)
2. Through direct e^+e^- collisions (New)

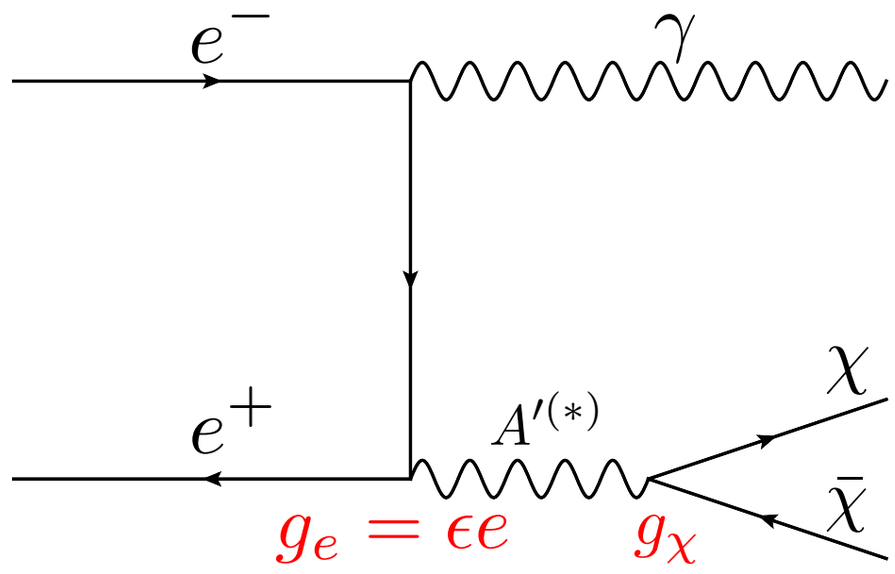


Search Strategy

Consider decay with a mediator to be a vector/ pseudo-vector/scalar/pseudo-scalar

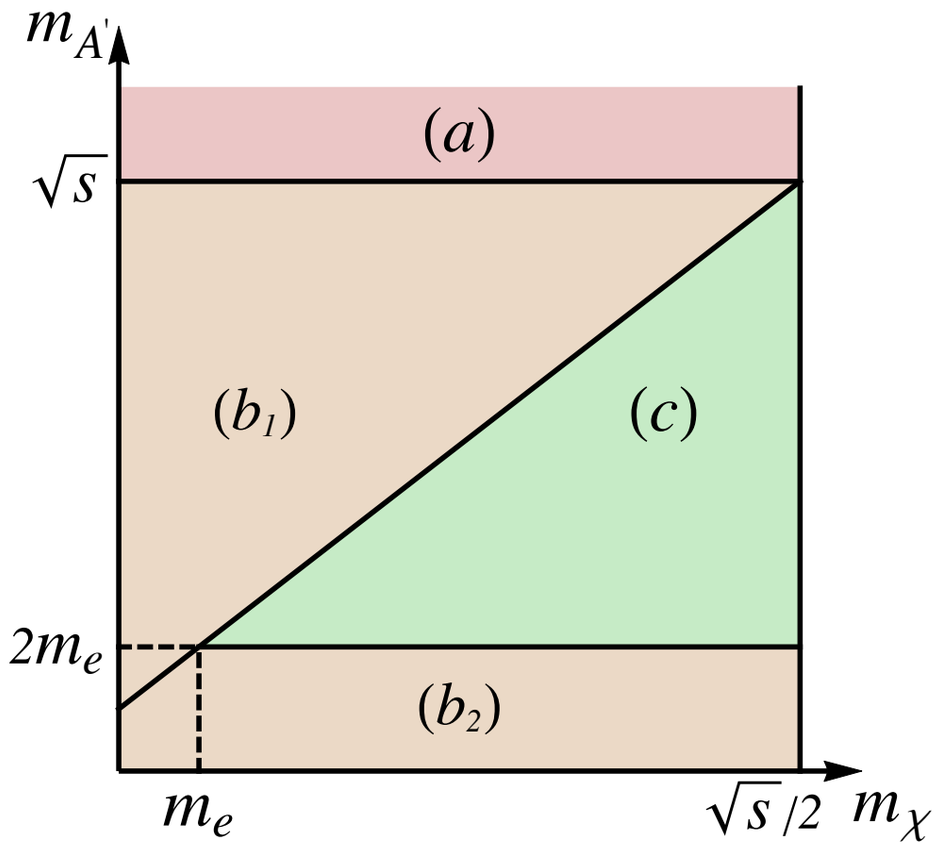
e.g. vector mediator: apply the hidden photon model





Integrating out a heavy mediator provides an effective contact term

Search Strategy



(a) Off-shell heavy mediator

(b) On-shell light mediator

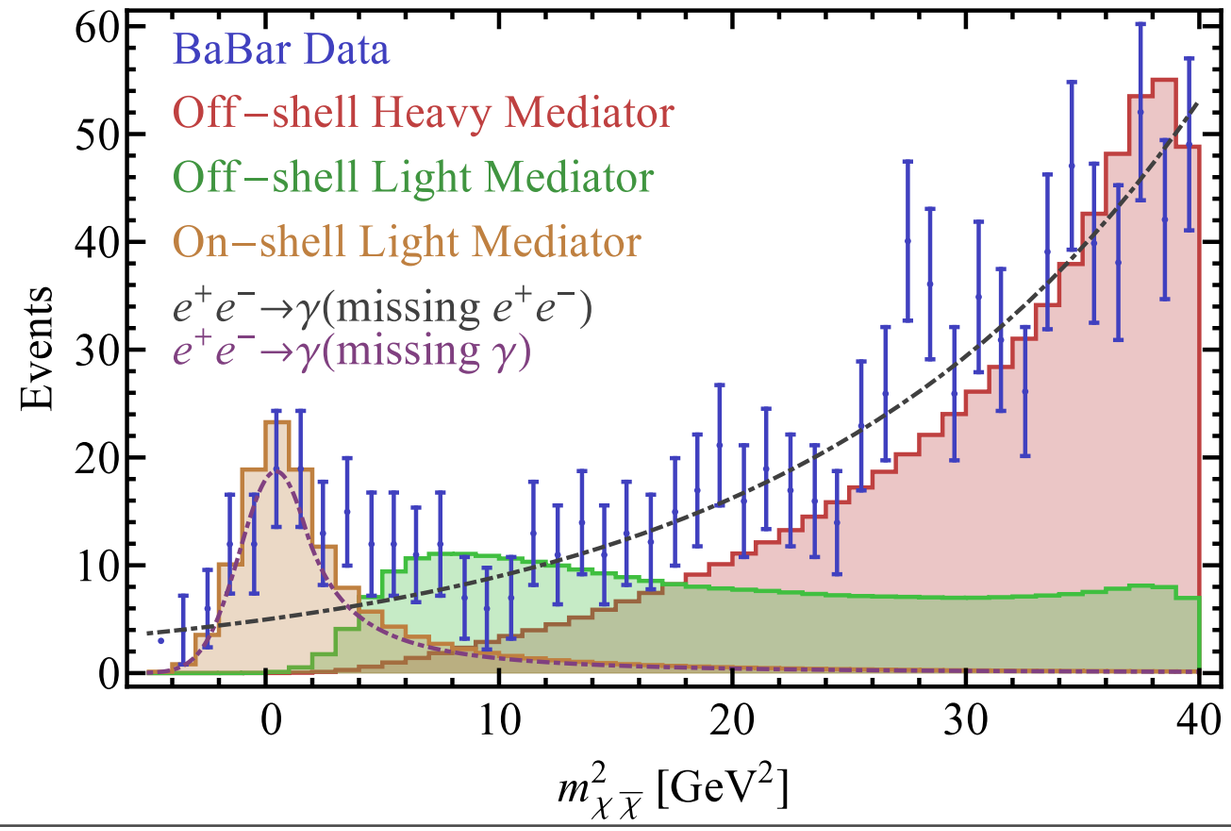
(b1) A′ on-shell decays to DM

(b2) A′ is long-lived

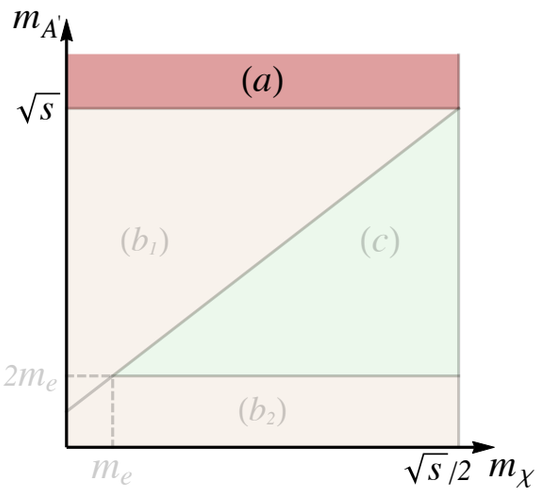
(c) Off-shell light mediator

Generate signals with Madgraph 5

e.g. vector mediator:



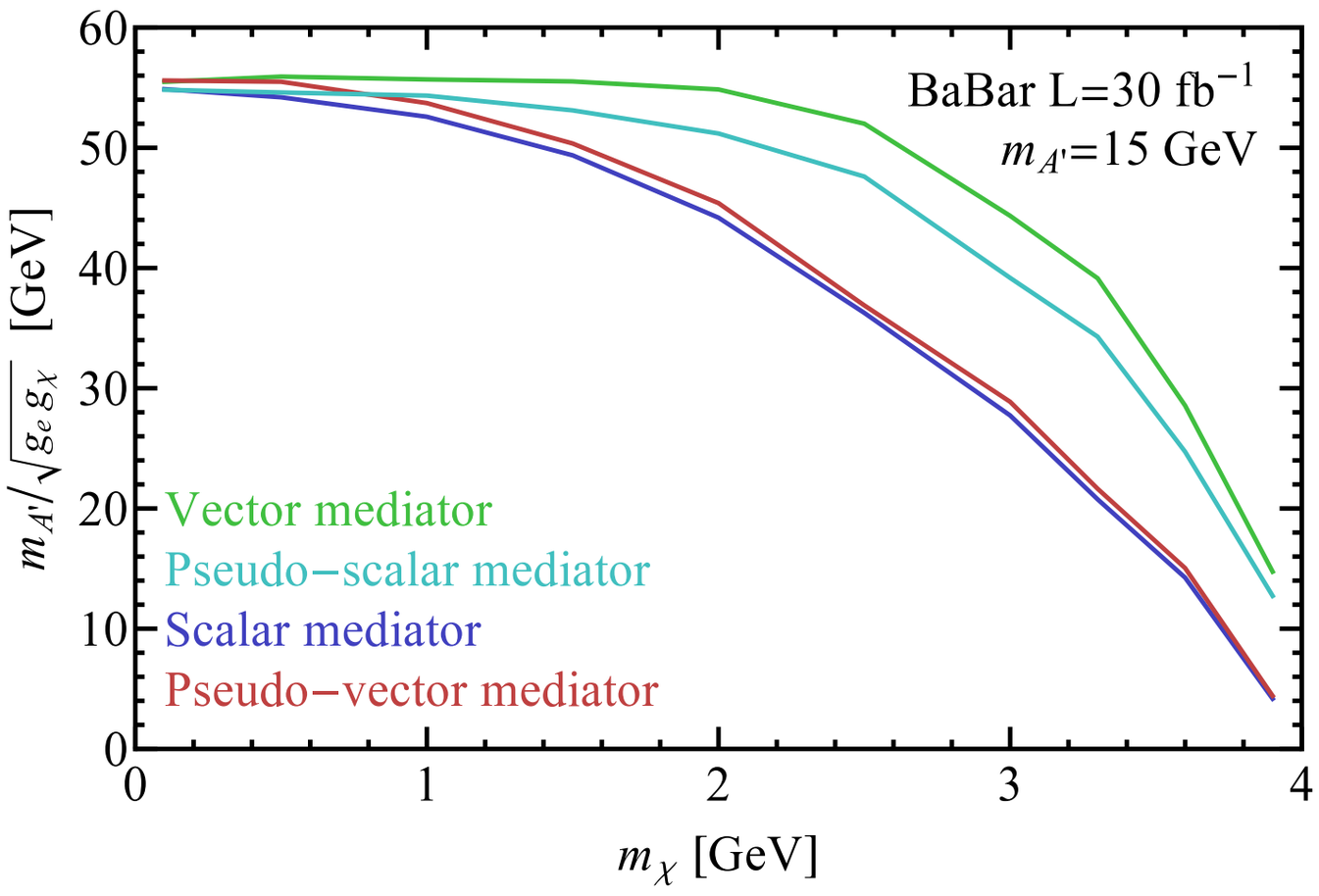
(a) Off-shell Heavy Mediators



$m_{A'} > \sqrt{s} = 10.58$ GeV, A′ is off-shell

Choose $m_{A'} = 15$ GeV. Place bounds on $m_{A'}/\sqrt{g_e g_\chi}$

Bounds are insensitive to changes of $m_{A'}$



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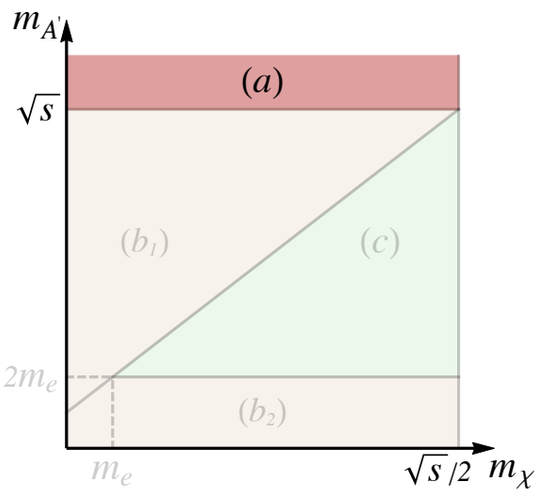


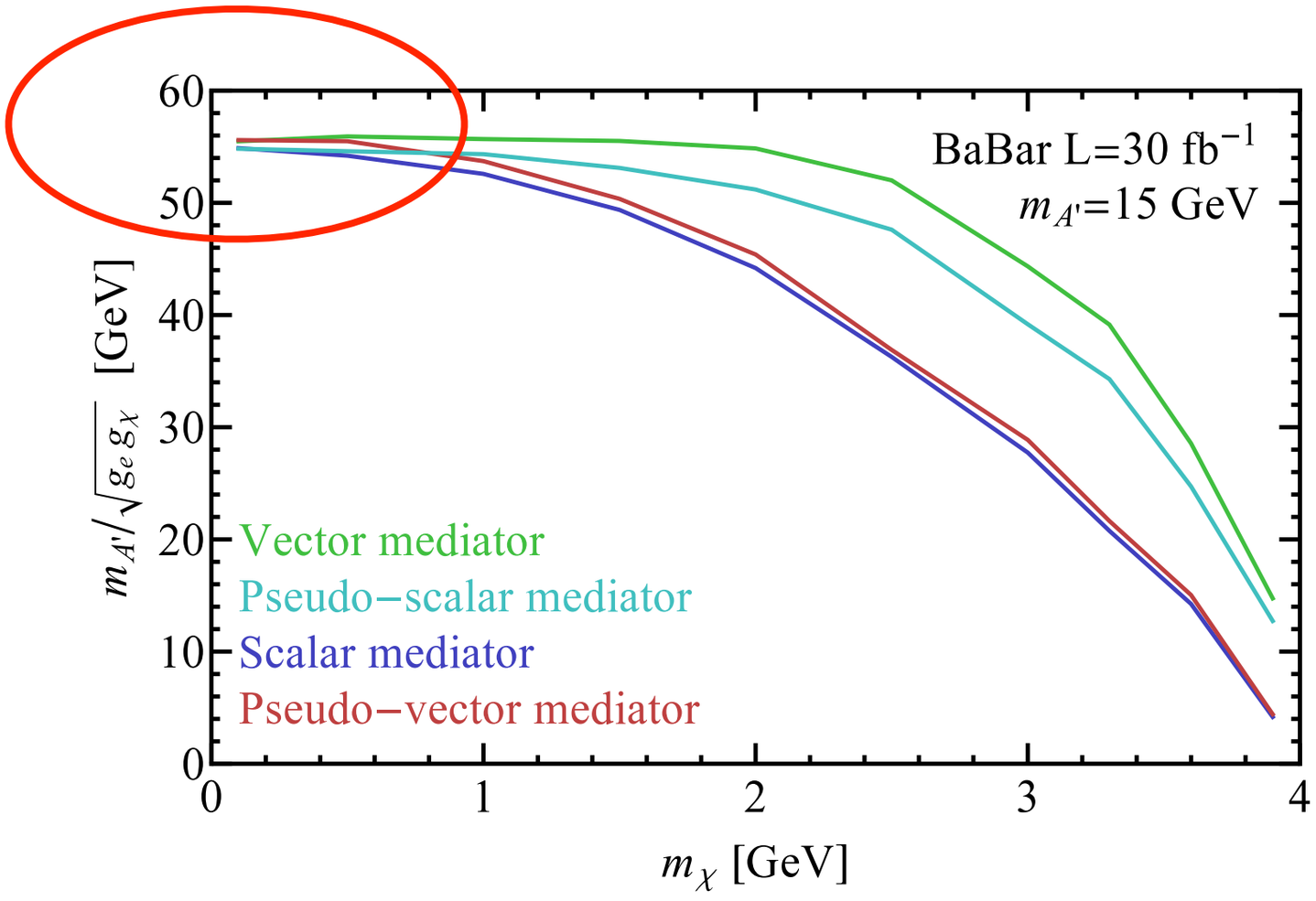
$m_{A'} > \sqrt{s} = 10.58$ GeV, A′ is off-shell

Choose $m_{A'}$ =15 GeV. Place bounds on $m_{A'}/\sqrt{g_e g_\chi}$

For light DM,

$$\frac{m_{A'}}{\sqrt{g_e g_\chi}} \gtrsim 55\,\mathrm{GeV}$$

Bounds are insensitive to changes of $m_{A'}$



Are Those Bounds Competitive?

For a hidden photon A′, ϵ is a small coupling and constrained by various experiments already

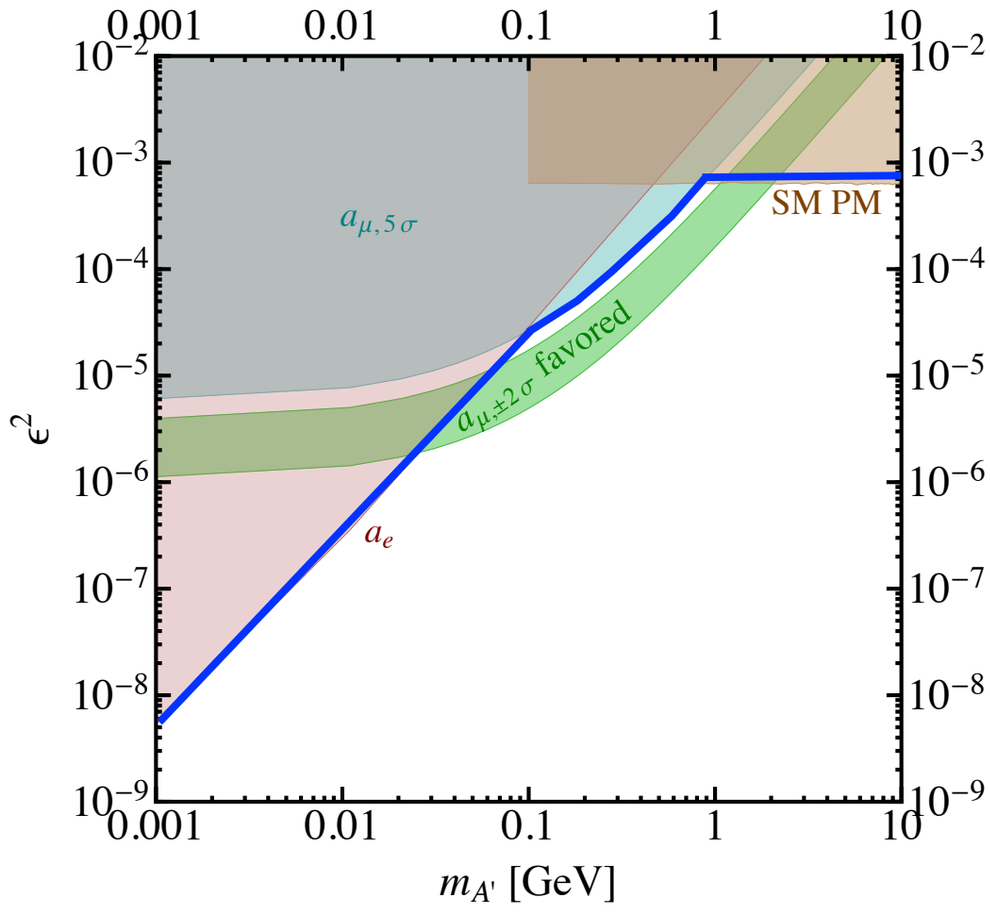
Define the "ϵ+perturbativity" bound:
$\alpha_X \leq 1$ & ϵ is constrained by SM precision measurements and anomalous magnetic moment of μ^- and e^-

For $m_{A'}$=15 GeV, ϵ<0.026

(Hook et al,1006.0973)

$$\Rightarrow \frac{m_{A'}}{\sqrt{g_e g_\chi}} \gtrsim 88.6\,\mathrm{GeV}$$

Stronger than BaBar



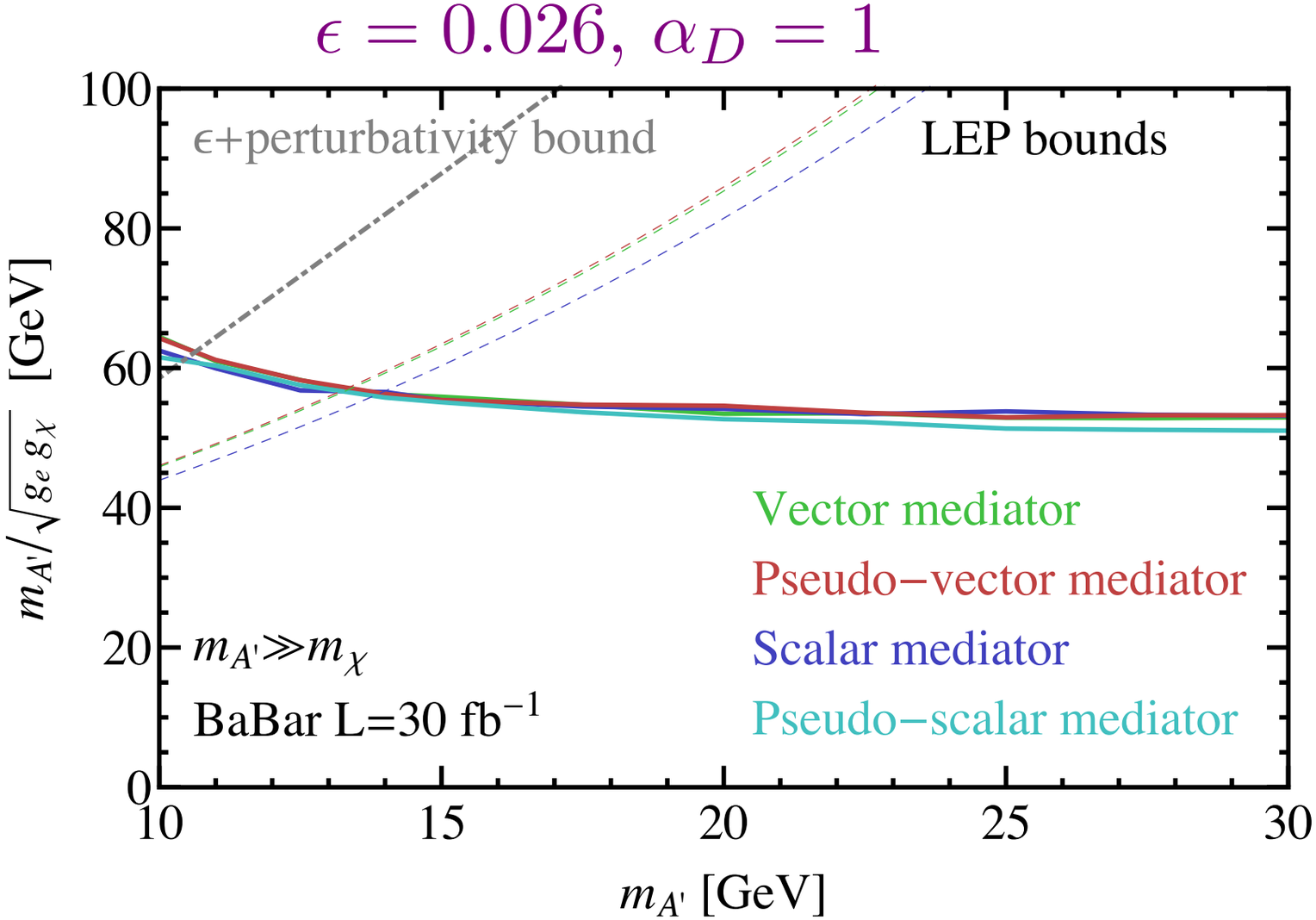
Are Those Bounds Competitive?

Fix m_X to be light and vary $m_{A'}$

Competitive with
ϵ+perturbativity bound:
$m_{A'} \lesssim 10.8$ GeV

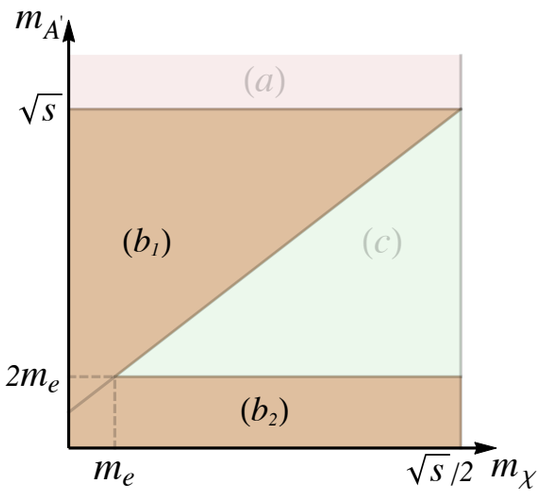
Competitive with
LEP bounds:
$m_{A'} \lesssim 13$ GeV

For a light mediator,
BaBar has better constraints



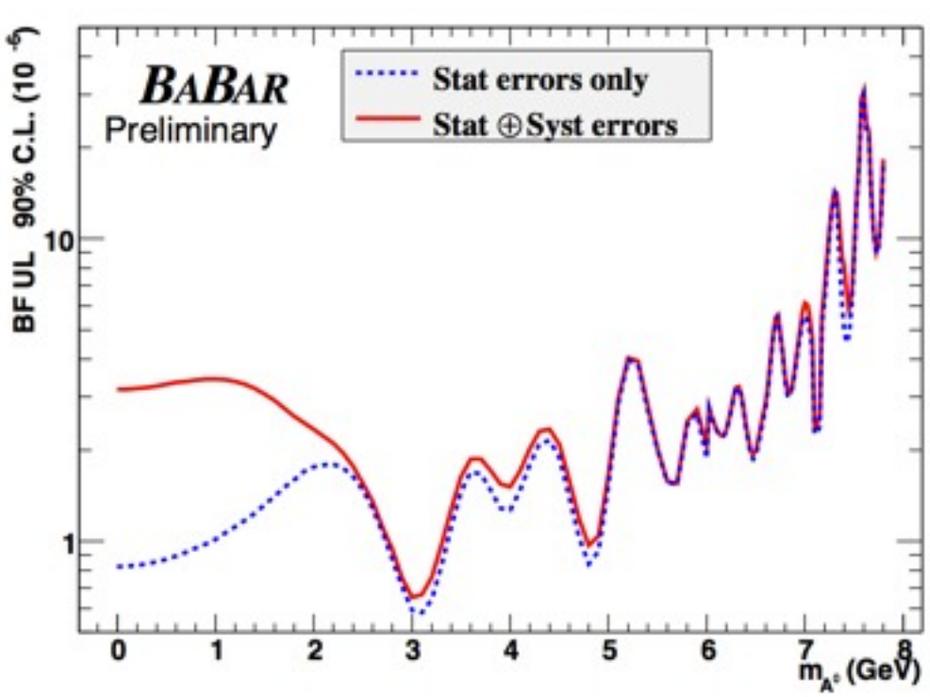
LEP bounds are obtained by interpolating limits on cut-off scales from Fox et al, 1103.0240

(b) On-Shell Light Mediators



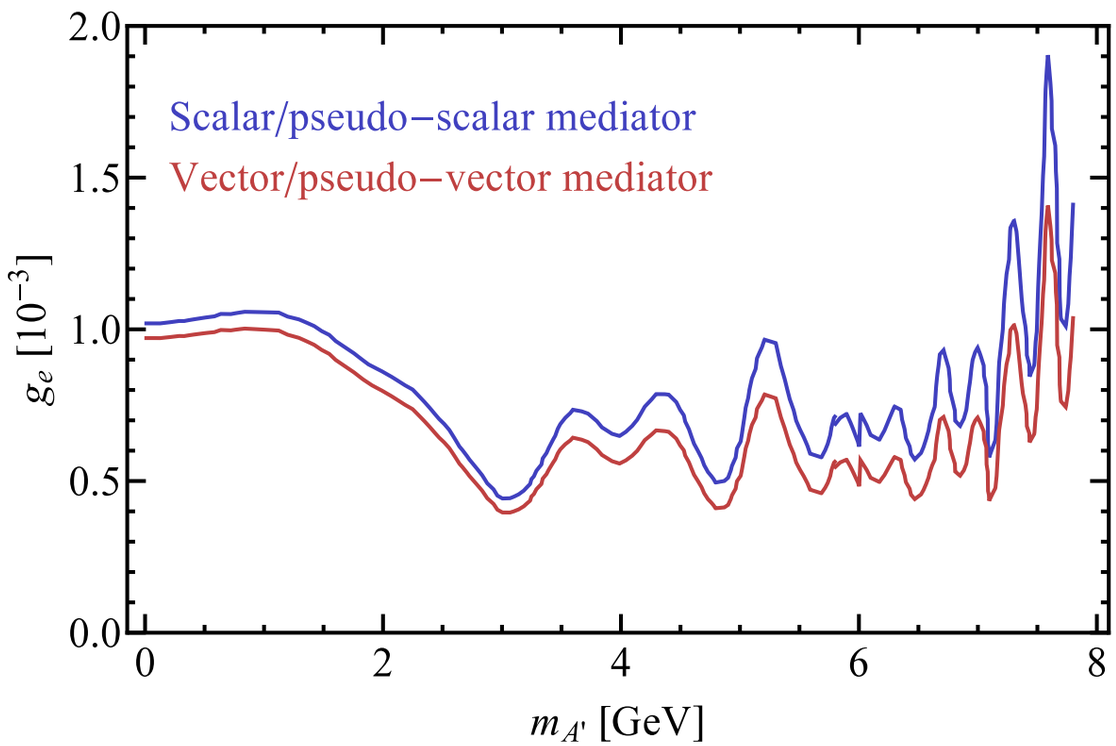
$2m_\chi < m_{A'} < \sqrt{s}$ or $m_{A'} < 2m_e$, $m_{A'} < 2m_\chi$, A′ is produced on-shell and decays to invisible

Use BaBar's upper limits on branching ratio to constrain g_e



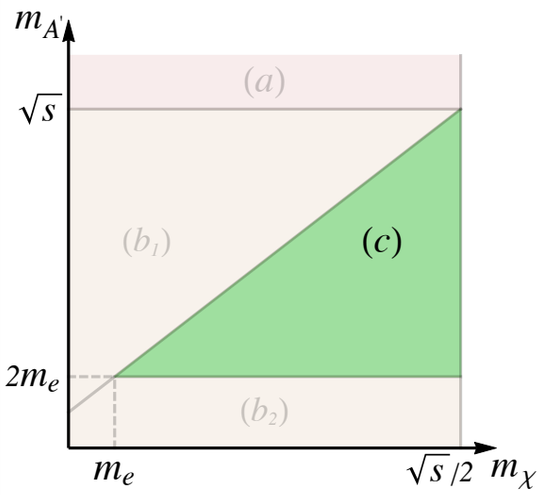
90% CL upper limits of BR of $\Upsilon(3S) \to \gamma A^0 \to$ invisible

BaBar, 0808.0017



Upper limits of g_e w. r. t. A′ mass for various types on-shell A′

(c) Off-Shell Light Mediators



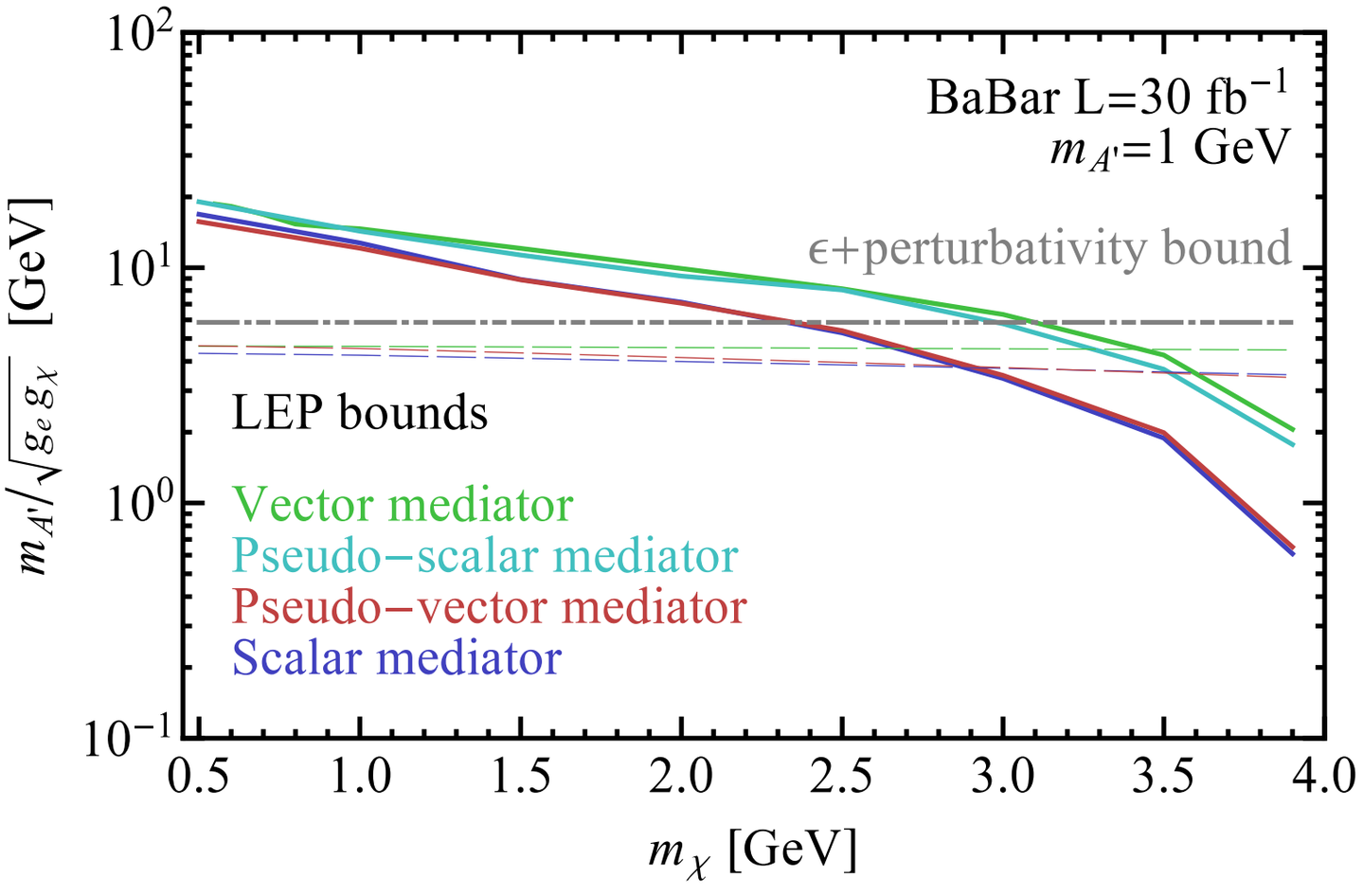
MeV<$m_{A'}$< 2m_χ, produce DM pairs via off-shell A′

Bounds on $m_{A'}/\sqrt{g_e g_\chi}$ depends on g_e g_χ, $m_{A'}$, m_χ

Competitive with
ϵ+perturbativity bound
$m_\chi \lesssim 3.1$ GeV

Competitive with
LEP bounds:
$m_\chi \lesssim 2.9$ GeV

For a light mediator,
BaBar has even better
constraints

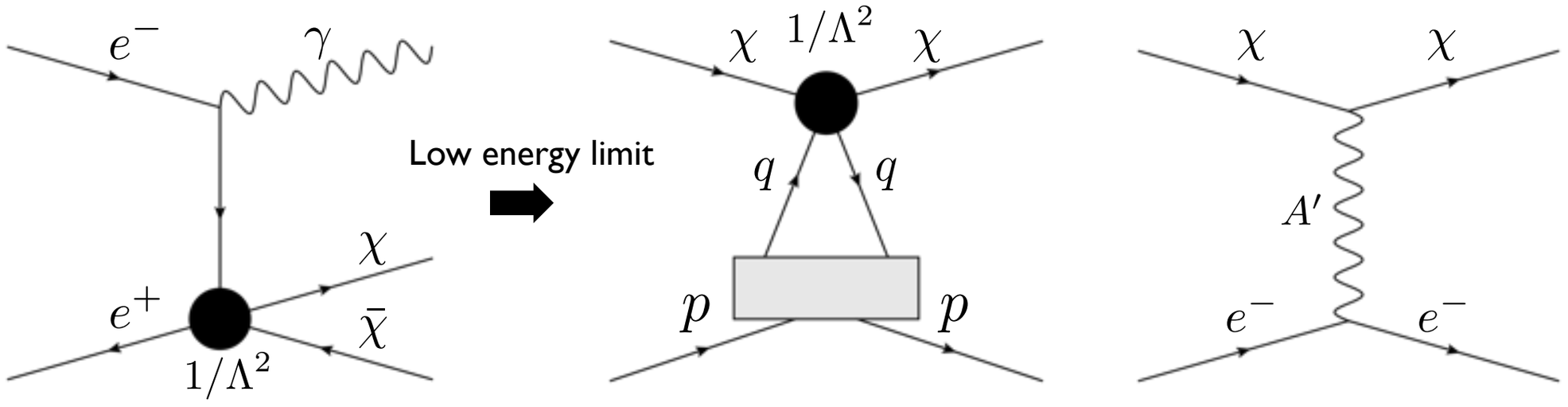


Translate to Direct Detection

In direct detections, DM-nucleon/electron scattering takes place with a very low recoil energy. Effective contact terms are valid.

$$\Lambda = m_{A'}/\sqrt{g_e g_\chi}$$

Translate vector/pseudo-vector/scalar coupling bounds into direct detection limits



DM-proton scattering

DM-electron scattering

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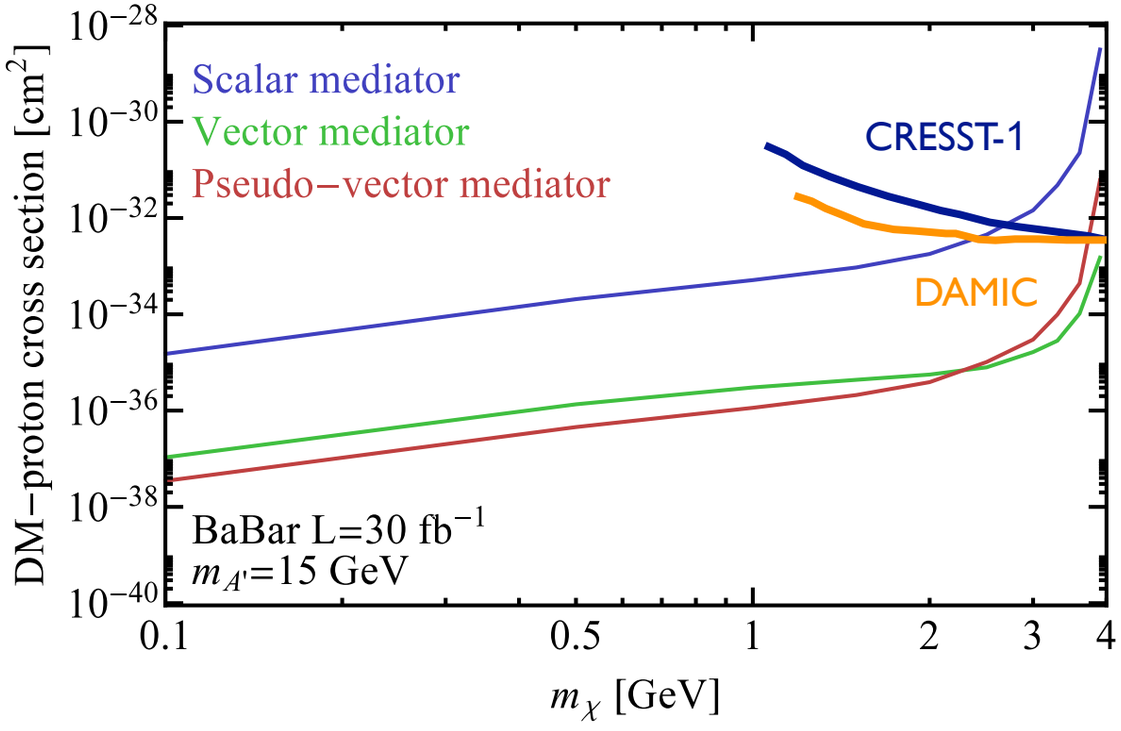

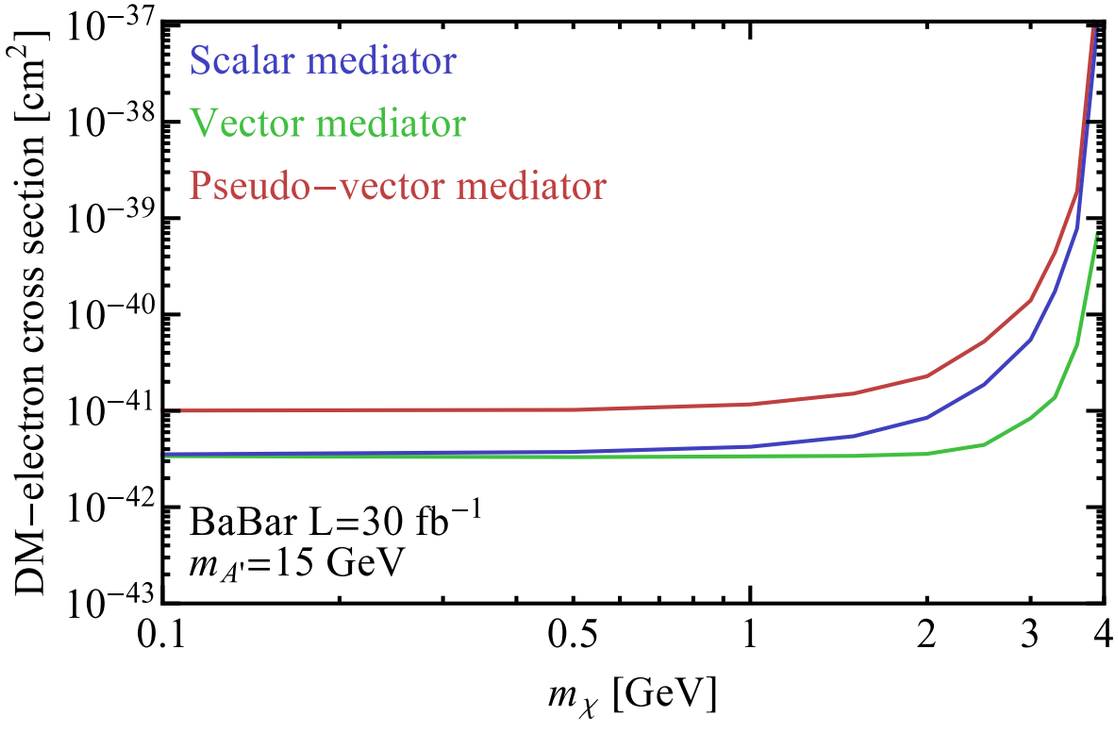

Summary and Prospects

To search LDM with a ~GeV mediator, low-energy e^+e^- colliders are more competitive than high energy colliders.

High luminosity is more helpful for small signal huntings

Future B-factories, like Belle-II, will obtain 50 /ab data by 2021, 100 times more than BaBar data

A mono-photon trigger will be very helpful for LDM/hidden mediator huntings!