BABAR™

Search for Low-Mass New Physics States at BaBar

EPS-HEP, Gent, July 12, 2019

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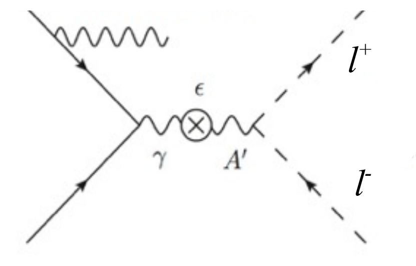
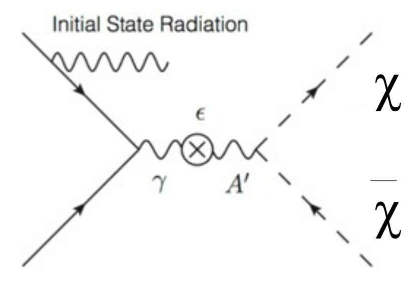
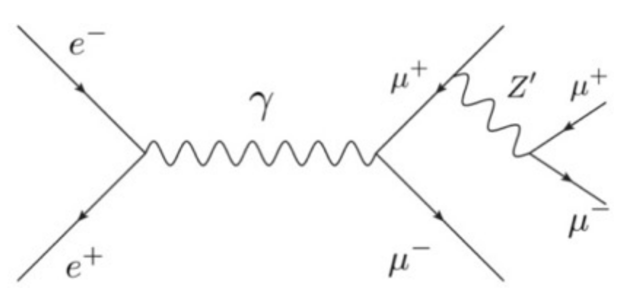
IN SUPREMÆ DIGNITATIS 1343

Outline

- Motivation for dark sector searches
- Visible dark photon decays
- Invisible dark photon decays
- Muonic force



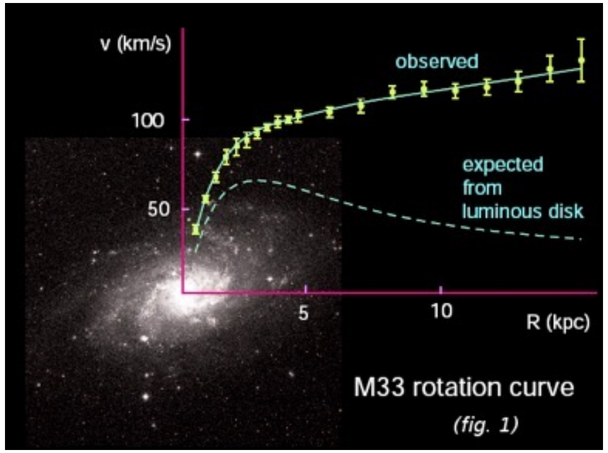


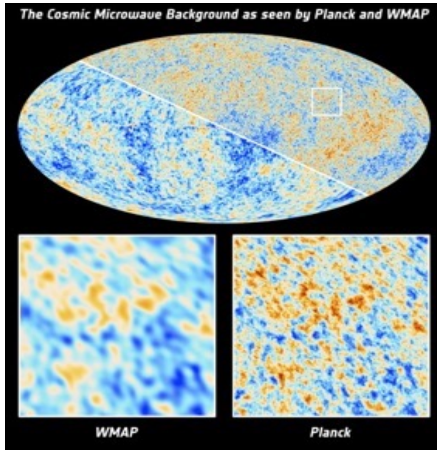


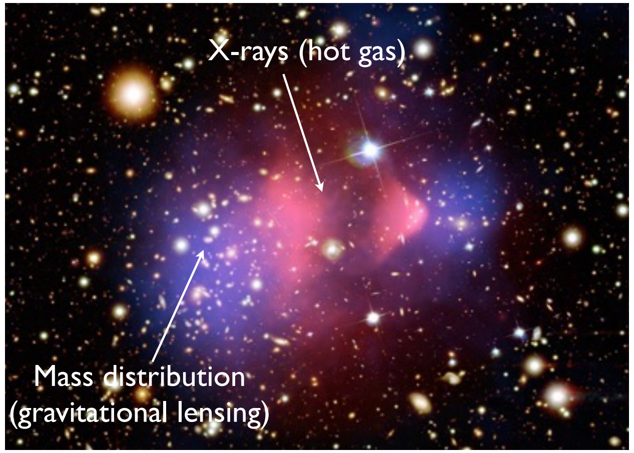
Dark Sector

Dark Matter exists, awaiting for discovery

H.Murayama, Granada European Strategy Meeting



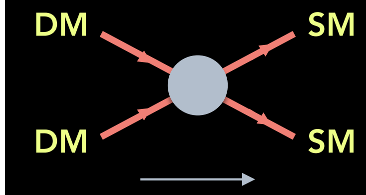




Search methods

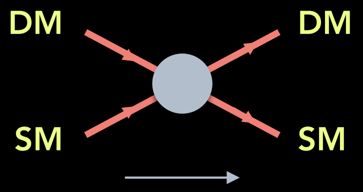
Annihilations

(Indirect Detection)



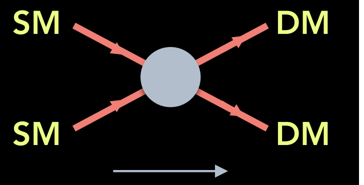
Scattering

(Direct Detection)



Production

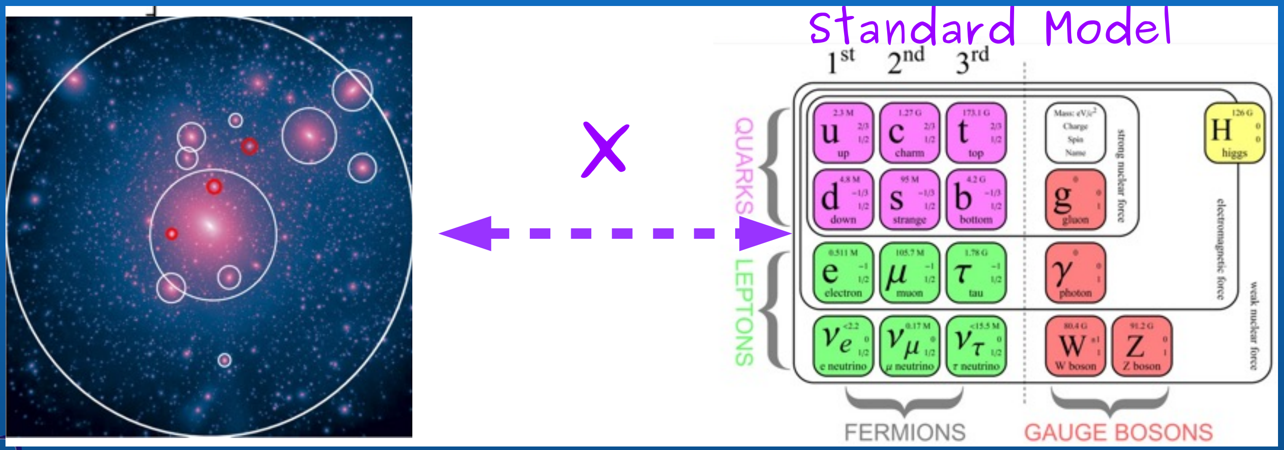
(Accelerators)



Portals

Anywhere door

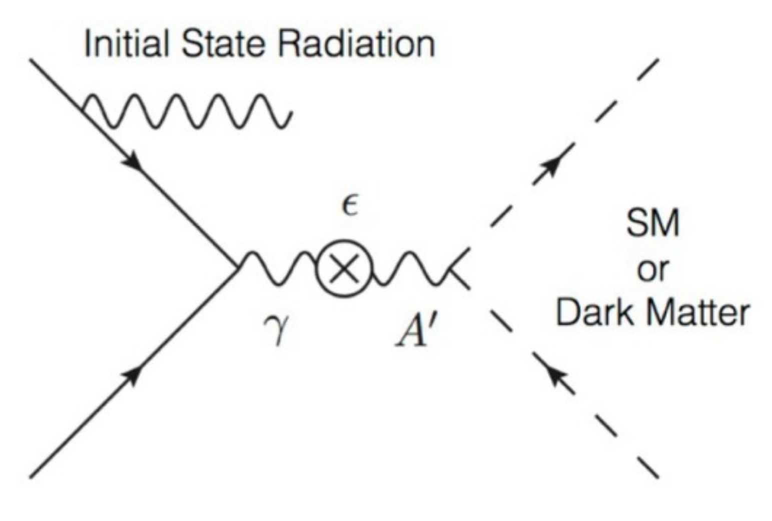
- Access to dark sector through "portals"
  - Possible sub-GeV scale scenario: *light dark sector* weakly coupled to SM through a light ***mediator X***
    - Vector portal → Dark Photon A'
    - Scalar portal → Dark Higgs/Scalars
    - Pseudo-scalar portal → Axion Like Particles (ALPs)
    - Neutrino portal → Sterile Neutrinos



P. Fayet, Phys. Lett. B 95, 285 (1980)
P. Fayet, Nucl. Phys. B 187, 184 (1981)
B. Holdom, Phys. Lett. B 166, 196 (1986)

Dark photon

- Minimal dark sector: add a new U(1) gauge symmetry → spin-1 "dark photon" A'
- Can mix with SM photon providing a "portal" to the dark sector.
- Kinetic mixing of strength ε
  - Could be as large as 10^{-2} with $m_{A'}$ in GeV range
- Lifetime ~ $1/(\varepsilon^2 m_{A'})$: prompt or displaced
- Also possible more complex scenarios, with richer phenomenology



$$\frac{1}{2}\epsilon F^{Y}_{\mu\nu} F'^{\mu\nu}$$

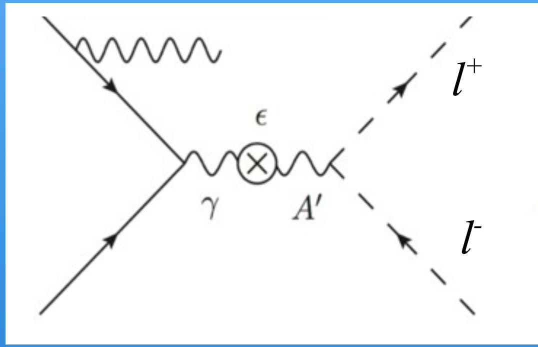
search for decay of $e^+e^- \to \gamma A'$ via $A' \to \chi\bar{\chi}$ or into SM particles

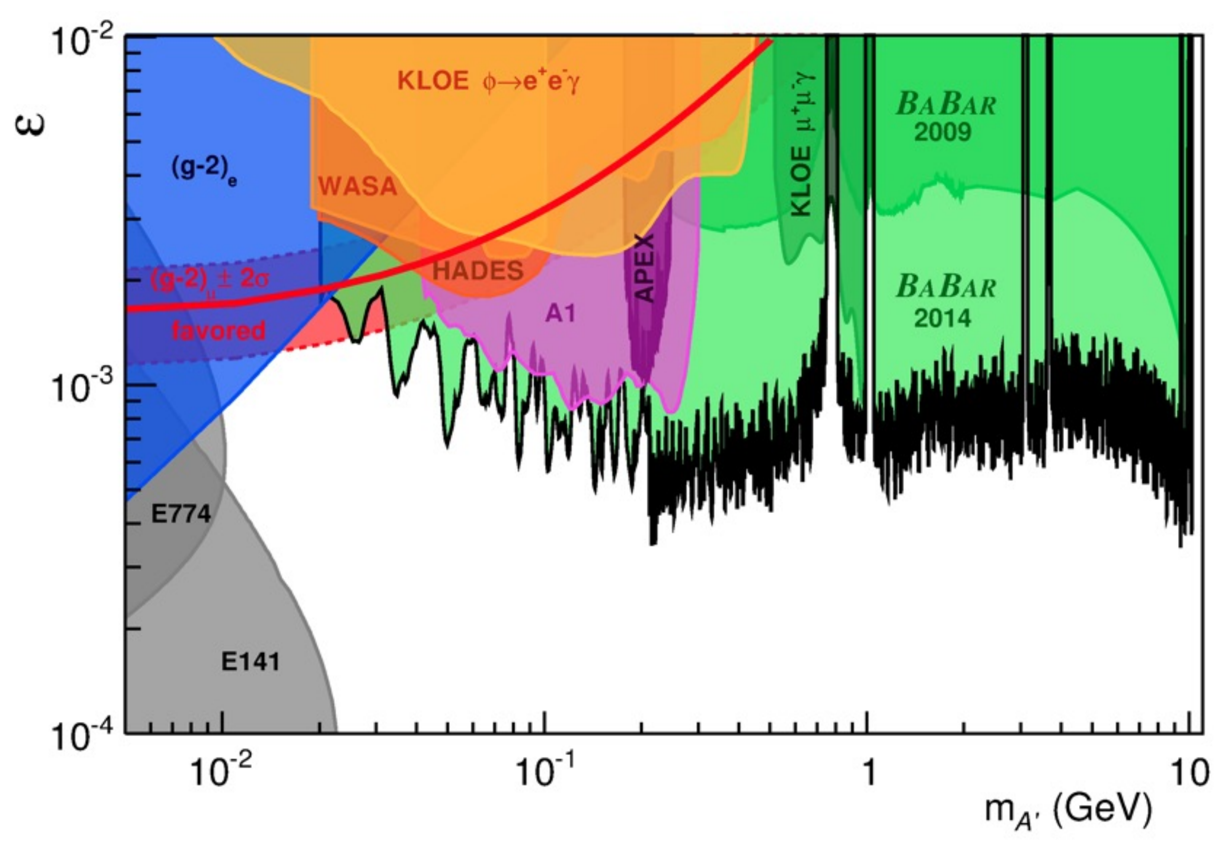
- "visible" $A' \to l^+l^-$, decaying promptly or with a displaced vertex
- "Invisible" A' decays, with A' mass determined from missing energy constraints

Visible dark photon decays

- Use 514fb^{-1} of data
  - All available CM energies
- Use simulation templates to model signal (small width)
- Scan di-lepton invariant mass in the range 0.02 GeV < $m_{A'}$ < 10.2 GeV
- Remove resonant background
- Obtain 90% C.L. upper limit on mixing strength ε as a function of $m_{A'}$

Phys. Rev. Lett. 113, 201801 (2014)
arXiv:1406.2980 [hep-ex]

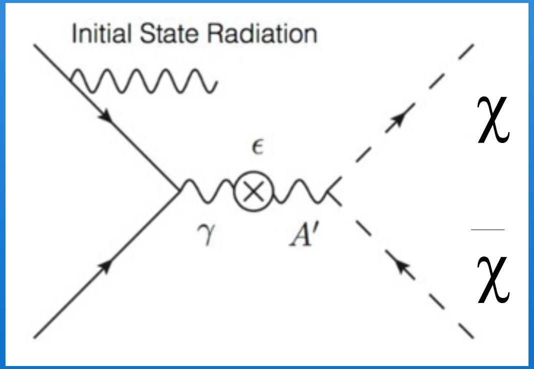




Invisible dark photon decays

Phys.Rev.Lett. 119, 131804 (2017)
arXiv:1702.03327 [hep-ex]

- B Factories provide an excellent environment for missing energy searches
  - Precisely known initial state
  - Hermetic detector
- Use 53fb^{-1} recorded with single γ trigger
  - Only in final running period
- Single isolated photon in the detector
  - Monochromatic for on-shell A’
- Optimize analysis and interpret as dark photon decaying invisibly
  - But no model dependence in analysis



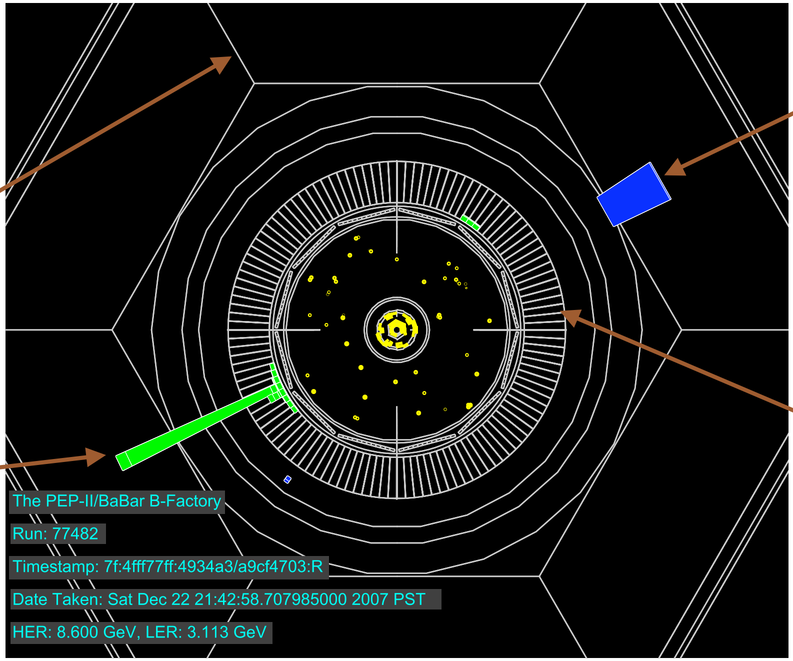
$$E^*_\gamma = E^*_{beam} - \frac{m^2_{A'}}{4E^*_{beam}}$$

Main backgrounds

- $e^+e^- \rightarrow \gamma\,\gamma$ event

photon shower detected in muon system. Inefficiency produces single photon events.

no efficiency in muon system near sector boundaries



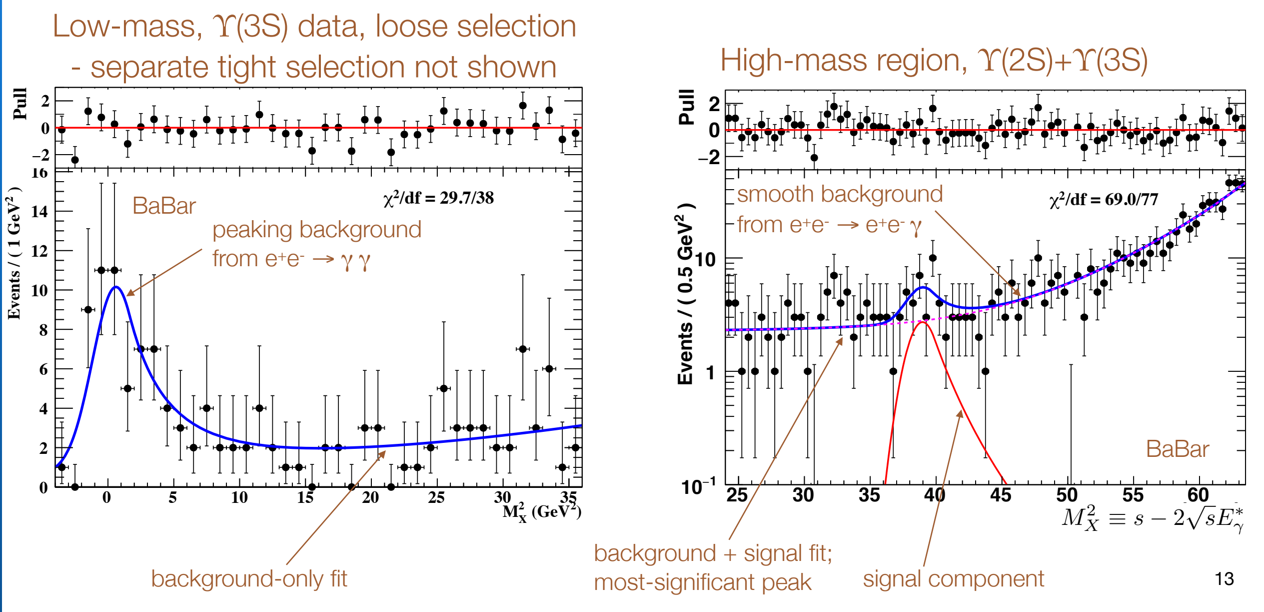
beam-energy photon shower

azimuthal gaps between crystals align with collision point

- Additional ISR down the pipe
- $e^+e^- \rightarrow e^+e^-\gamma$ where both electron and positron are lost

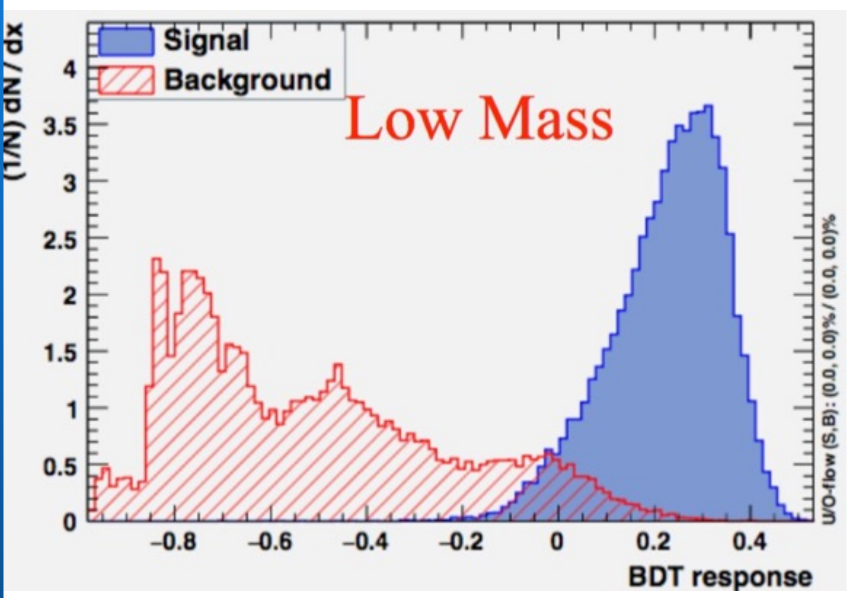
Invisible dark photon analysis

- Offline selection with Boosted Decision Tree
- Fit $m_X^2 = s - 2\sqrt{s}E_\gamma^*$ distribution: extract signal, peaking background, smooth background yields



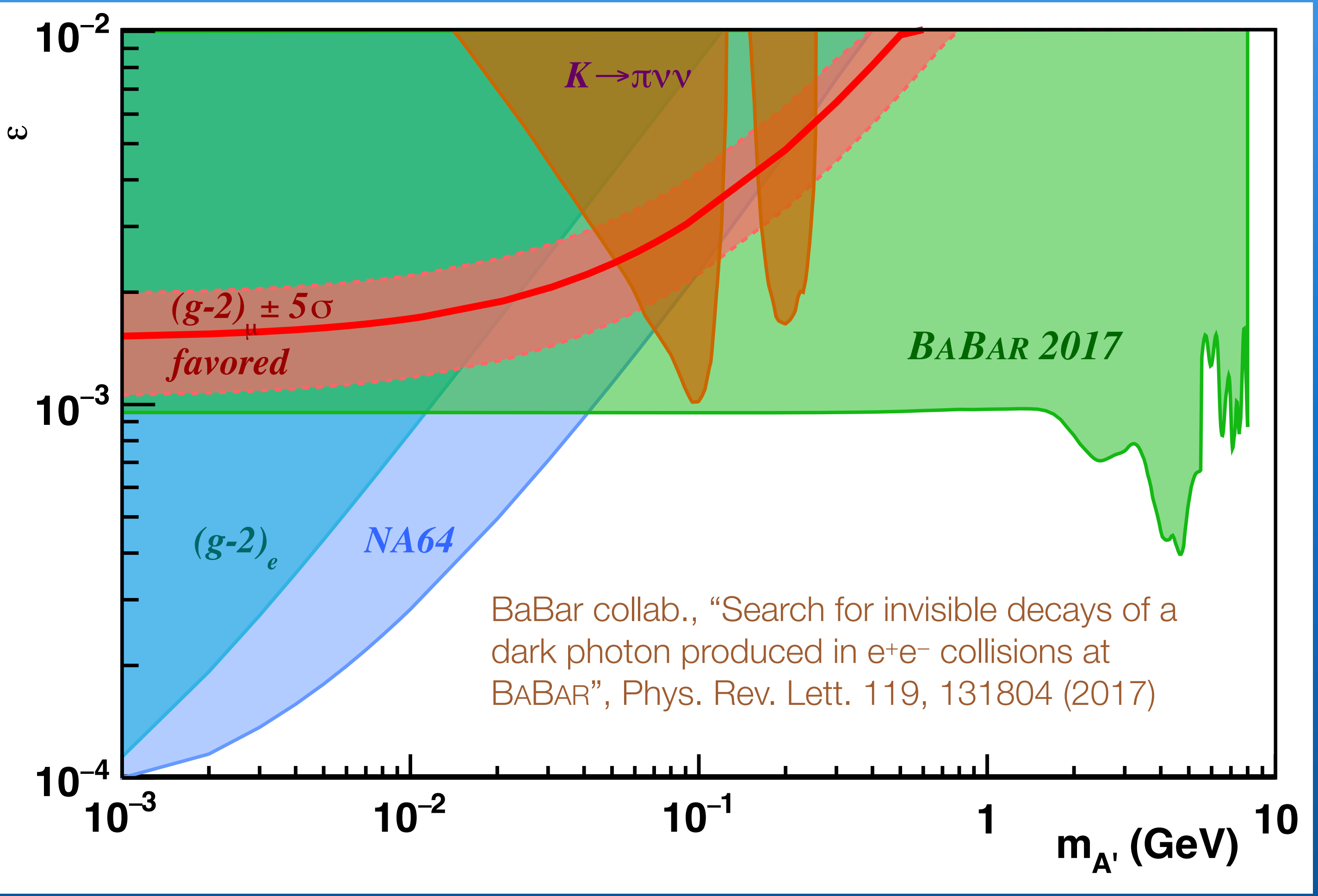
- Signal cluster shape parameters
- Additional calorimeter energy
- Properties of the second most energetic cluster: E*, θ*, ΔΦ*
- Properties of muon system cluster (E*, θ*, ΔΦ*) closest to the missing momentum direction

BDT



Invisible dark photon results

- No evidence of signal (in 116 mass hypothesis)
- Set limits in ε, A' plane
- Exclude region favored by g-2 measurement



Muonic dark force

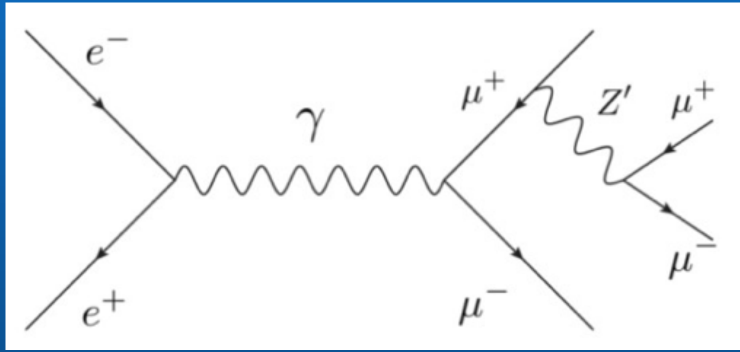
Phys. Rev. D94 011102 (2016)
arXiv:1606.03501 [hep-ex]

- Non-minimal dark sector models can permit additional interactions between dark boson and SM particles
  - e.g. Dark boson Z' which couples only to second and third generation leptons (L_μ-L_τ model)

He, Joshi, Lew, Volkas, Phys. Rev. D 43, R22 (1991)

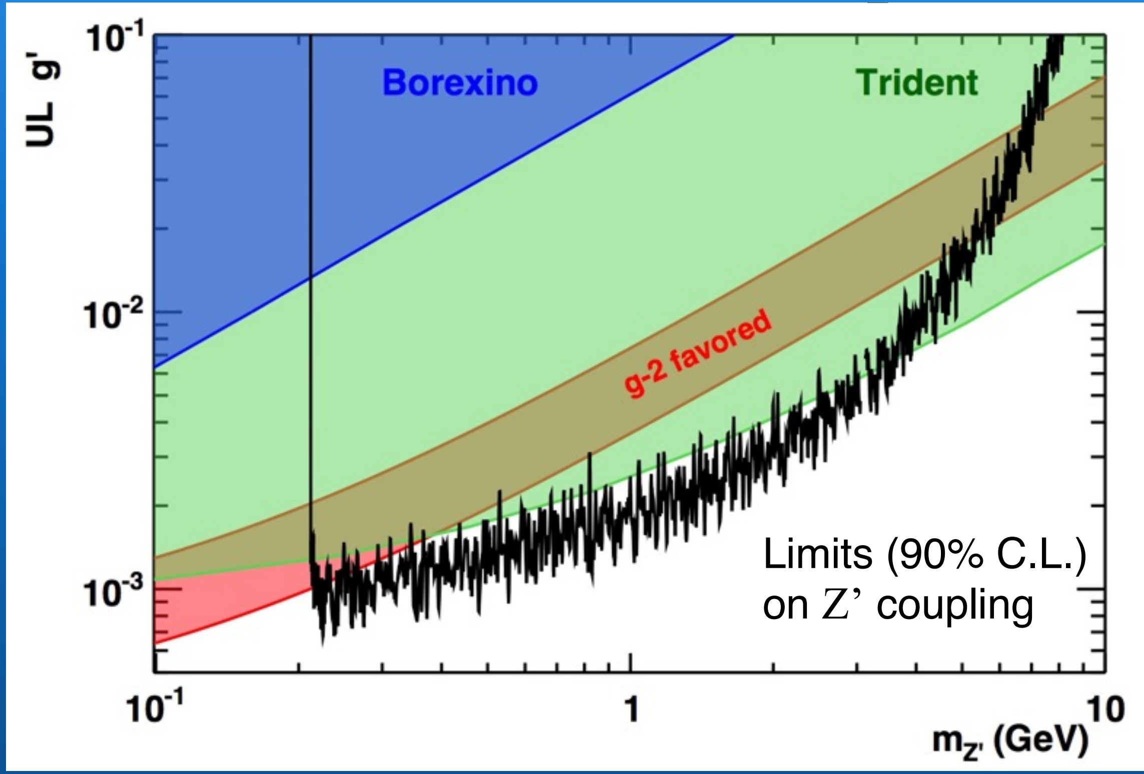
Shuve et al., arXiv:1403.2727

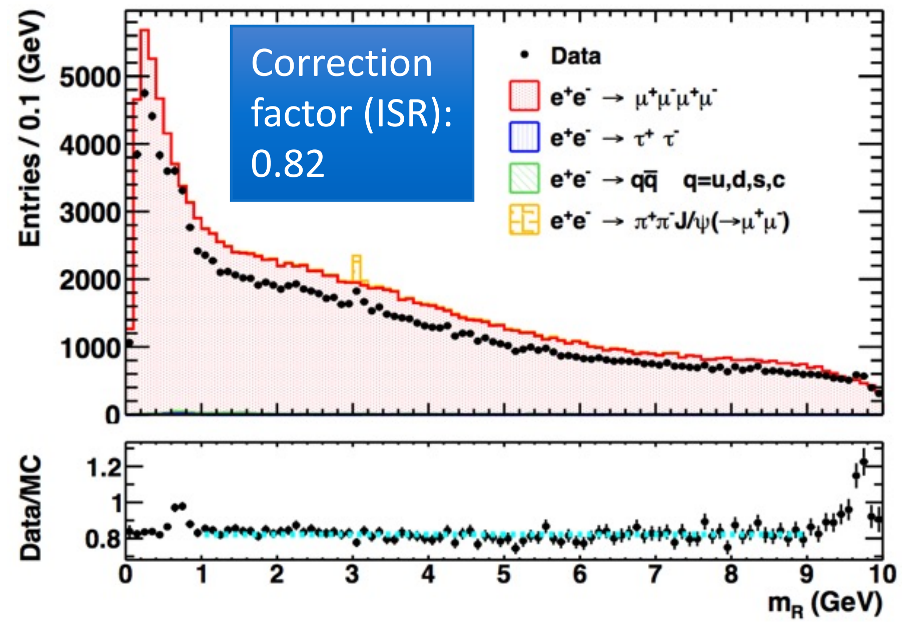
- Motivated by various anomalies observed in the muon sector
  - g-2 discrepancy
  - could also account for dark matter as sterile neutrinos by increasing their cosmological abundance via new interactions with SM neutrinos.
- "Z'-strahlung" production
  - Dark sector Z' in $e^+e^- \to \mu^+\mu^-$
- No specific model assumed in the analysis



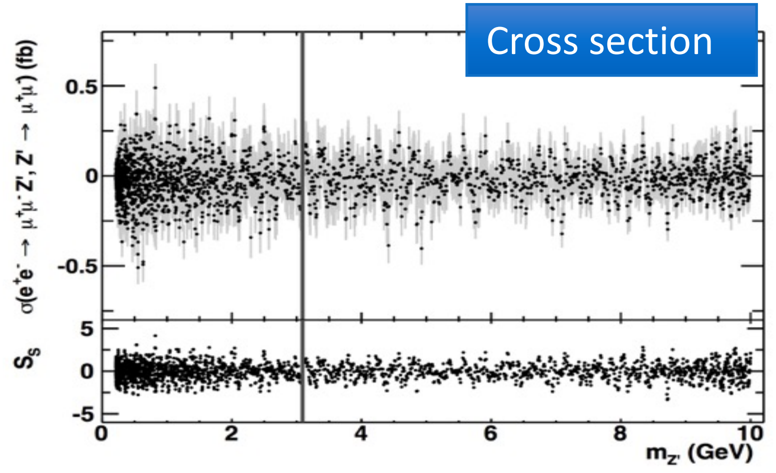
Muonic dark force search

- Search for a di-muon mass peak in $e^+e^- \to \mu^+\mu^-\mu^+\mu^-$
  - QED combinatorial backgrounds,
  - peaking backgrounds from $e^+e^- \to \pi^+\pi^- J/\psi$ and ρ
- First direct experimental limits on Z' coupling
- Excludes most of region favoured by g-2 results





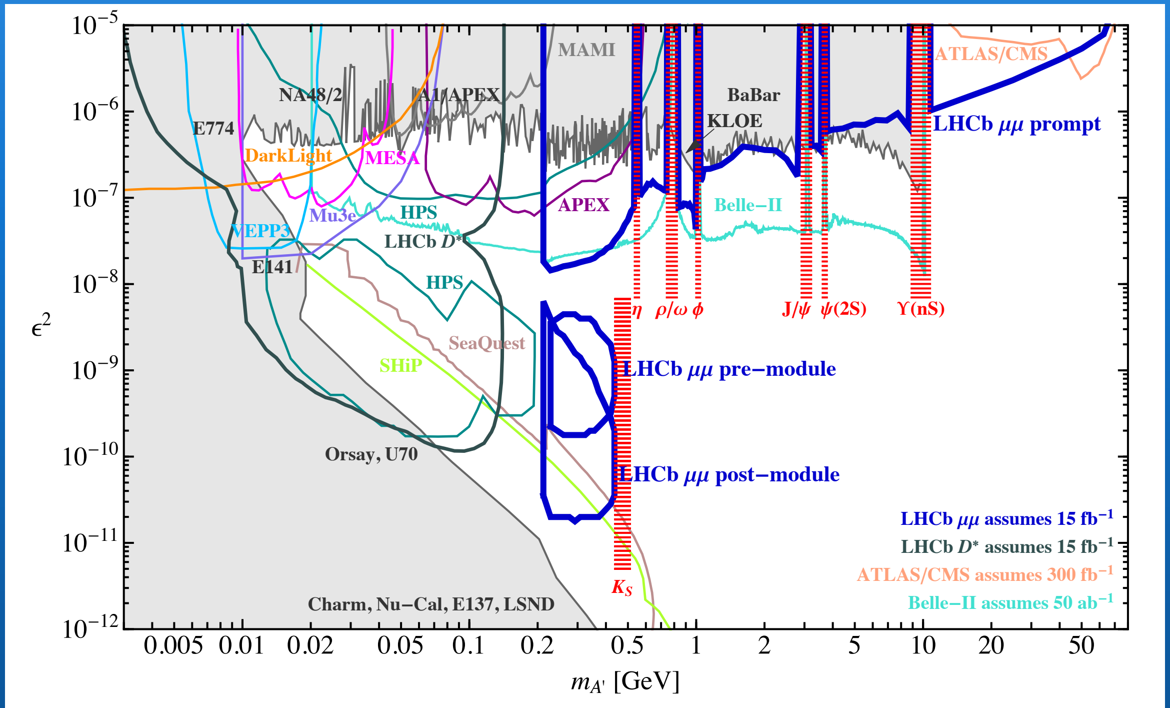
Di-muon reduced mass: $m_R = (m_{\mu\mu}^2 - 4m_\mu^2)^{1/2}$



The future

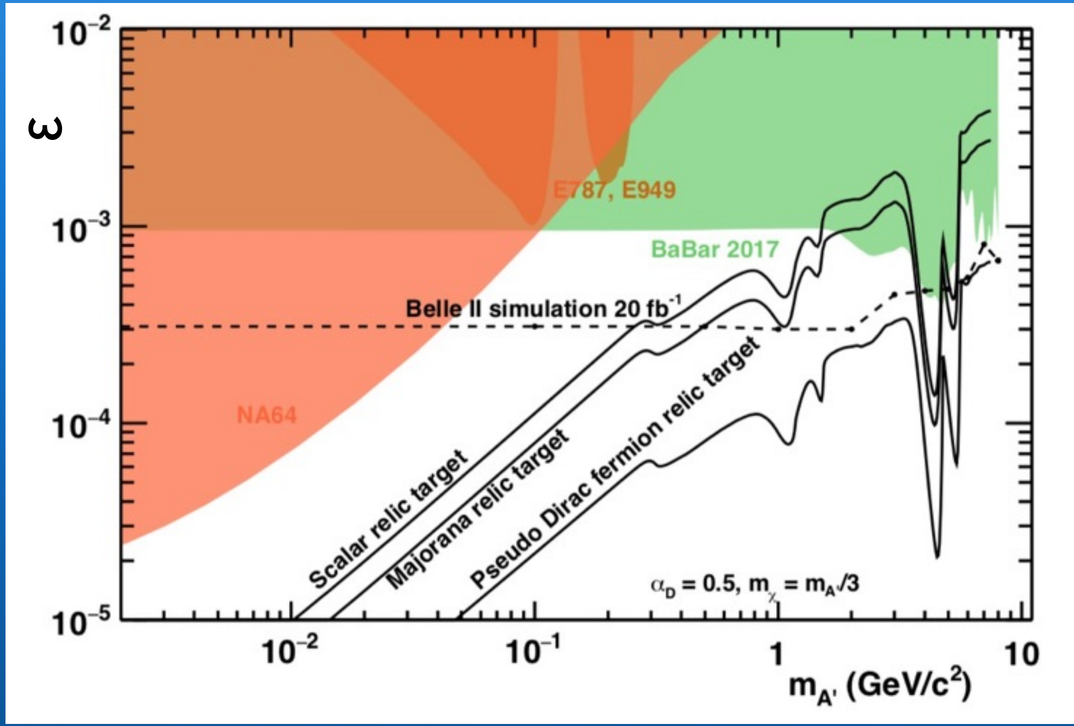
- Searches will continue at Belle II and LHCb in the coming years. For example, dark photon perspectives:

$A' \to \mu^+\mu^-$



arXiv:1603.08926

A'→ invisible



arXiv: 1808.10567

Conclusion and perspectives

- The ”dark sector” provides a still unexplored window on possible new physics at low masses
- Babar data still offer interesting analysis opportunities
  - Advantages of the clean environment of e+e- collider
- Search for Axion-like-particles on-going, to be presented soon.
- Larger data sets (Belle II, LHCb) will soon be available to improve the sensitivity of these analyses

Additional material

The BaBar experiment

SVT: 5 layers double-sided Si. Crucial for measuring Δt.

DCH: 40 layers in 10 super-layers, axial and stereo.

DIRC: Array of precisely machined quartz bars. Excellent Kaon identification.

EMC: Crystal calorimeter (CsI(Tl)) Very good energy resolution. Electron ID, π^0 and γ reco.

IFR: Layers of RPCs within iron. Muon and neutral hadron (K_L)