Search for invisible decay of a dark photon produced in e^+e^- collisions at BABAR

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On behalf of the *BABAR* Collaboration

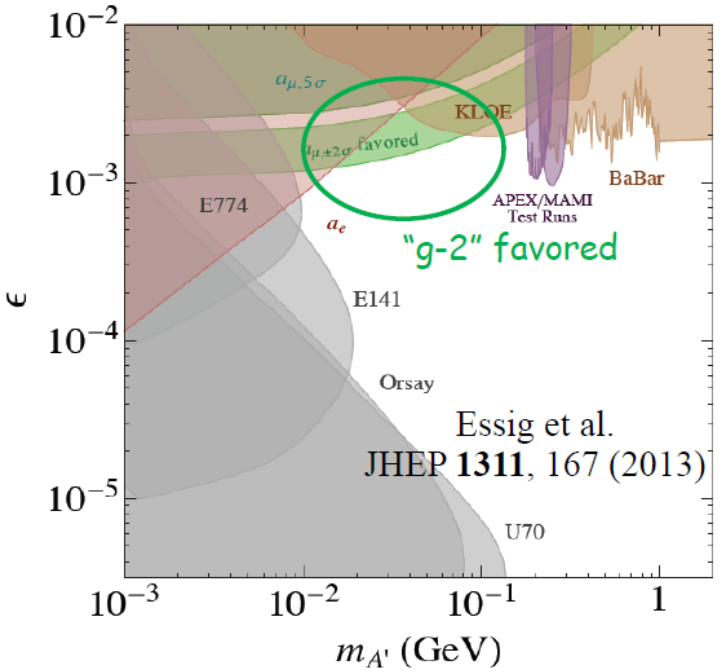
XIIIth Rencontres du Vietnam, Flavour Physics Conference
ICISE, Quy Nhon, Vietnam 13-19 August 2017

Outline

- Motivation for Dark Sector searches
- BABAR experiment
- Analysis details
- Interpretation of results
- Paper submitted to PRL (arXiv:1702.03327)

Motivation: the Dark Sector

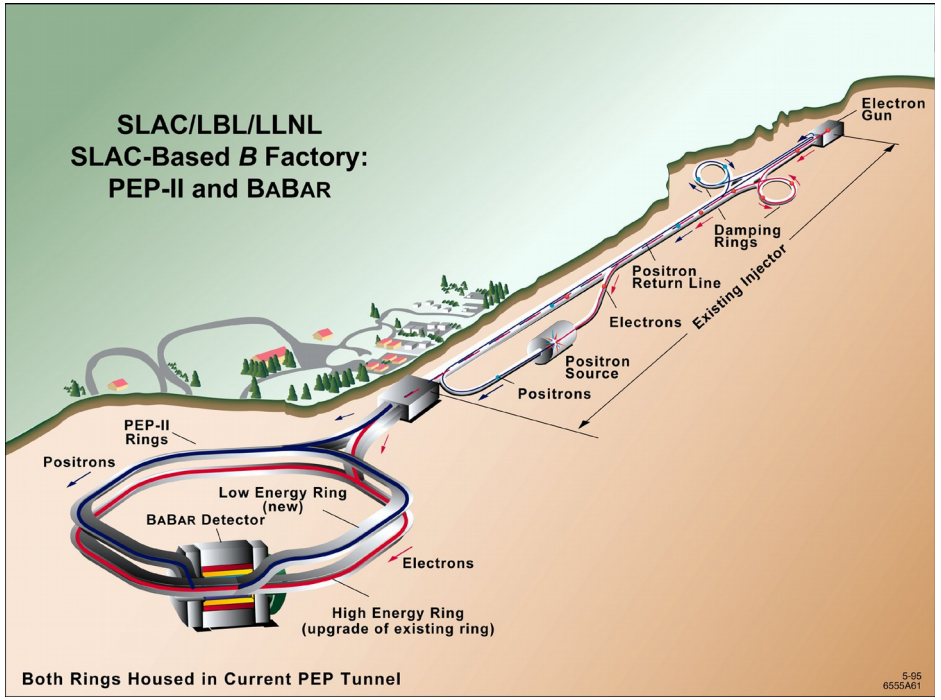
- Dark Matter could be part of the Dark Sector
- Dark sector includes particles that couple weakly to the SM
  - Theory motivated by BSMs, string theory, extra U(1) group
  - Dark force mediated by Dark U(1) photon(s), A’
- Astronomical observations & $(g–2)_\mu$ anomaly suggest dark photon mass to be in the MeV – GeV range
- Dark photon couples to SM fermion with a mixing strength expected to be as high as $\varepsilon \sim 10^{-3}$

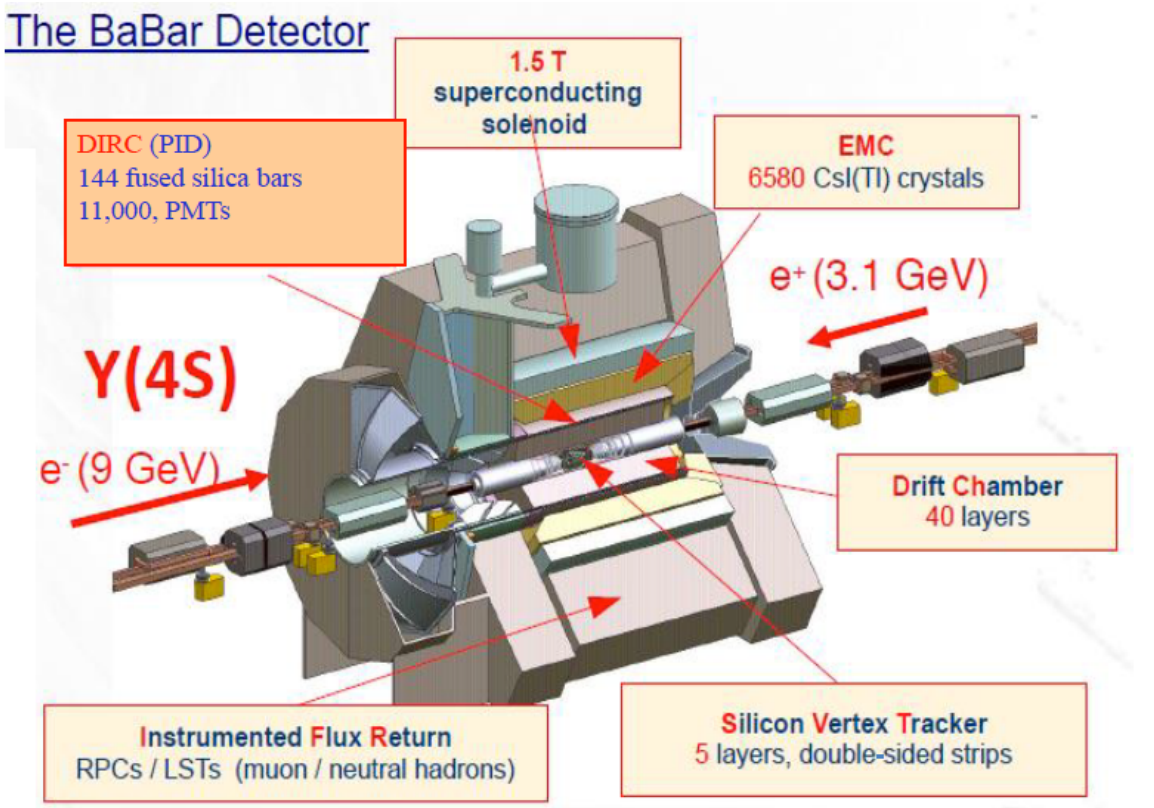


BABAR experiment

NIM A479, 1 (2002)
NIM A729, 615 (2013)

PEP-II asymmetric e^+e^- collider

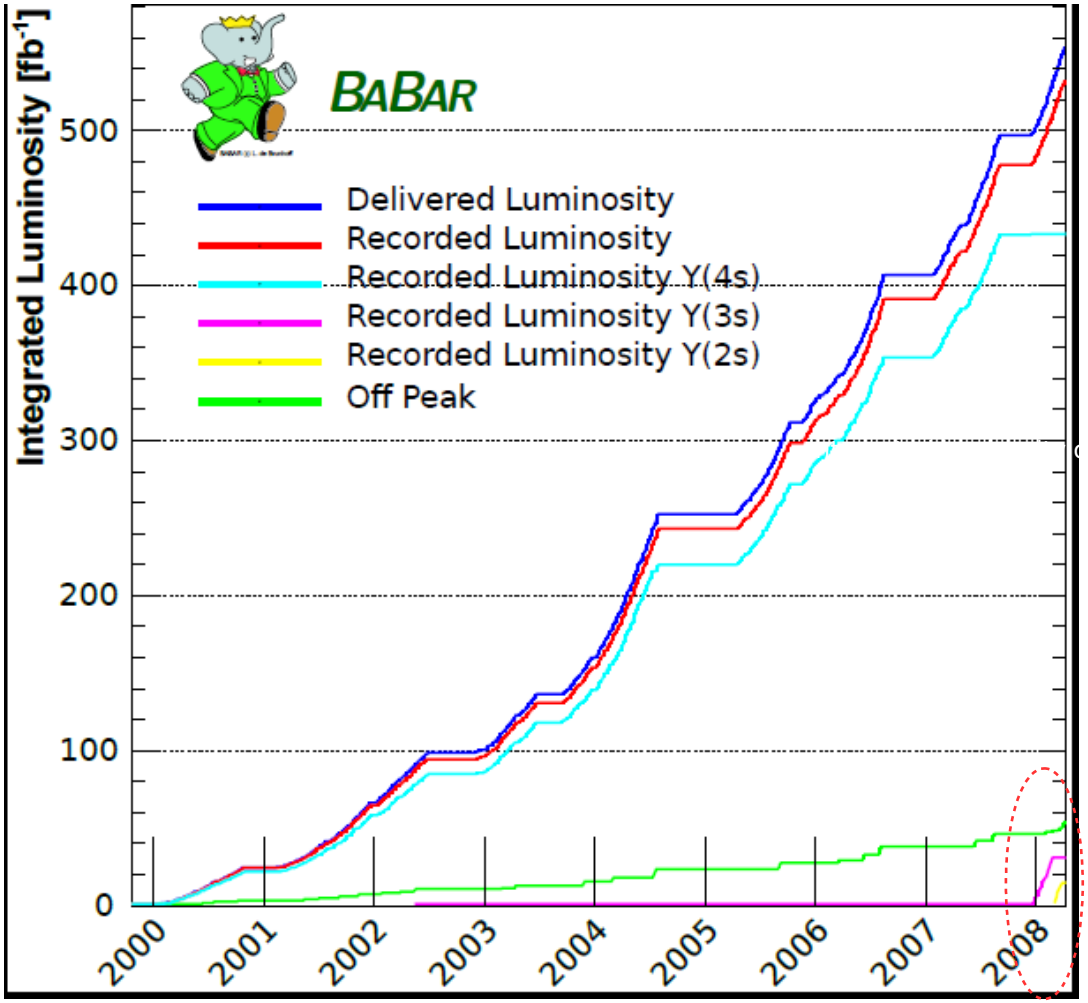




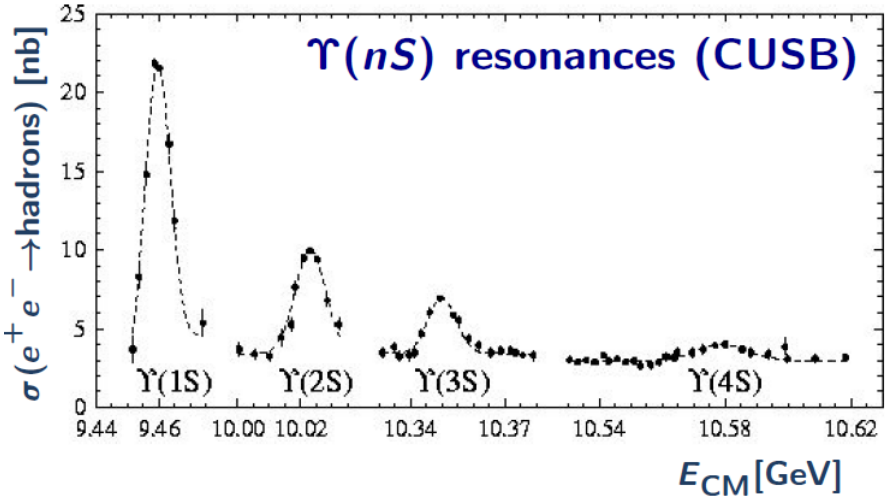
SVT, DCH: charged particle tracking: good vertex & momemtum resolution
EMC: Information related to $\gamma/e/\pi^0/\eta$
DIRC, IFR, DCH: charged particle ID on $\pi/\mu/K/p$
Efficient trigger for DS searches

Data samples

Integrated luminosity over time



Data-taking between 1999 and 2008



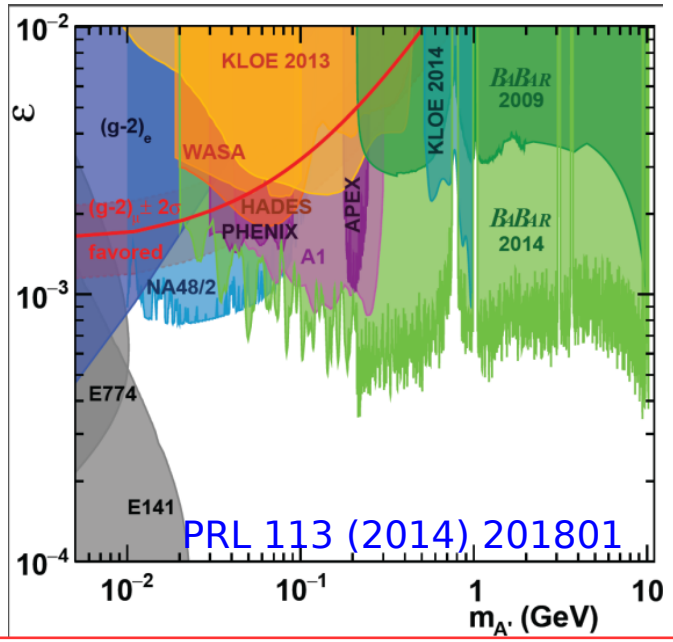
data samples (large and clean)

	$\mathcal{L}(\text{fb}^{-1})$	events
$\Upsilon(4S)$	424	$471 \cdot 10^6$
$\Upsilon(3S)$	28	$121 \cdot 10^6$
$\Upsilon(2S)$	14	$99 \cdot 10^6$
off-peak	48	
single-γ trigger $\Upsilon(4S, 3S, 2S)$	53	

Datasets used in this analysis, mostly at Y(2S) & Y(3S) energies collected during the last run period

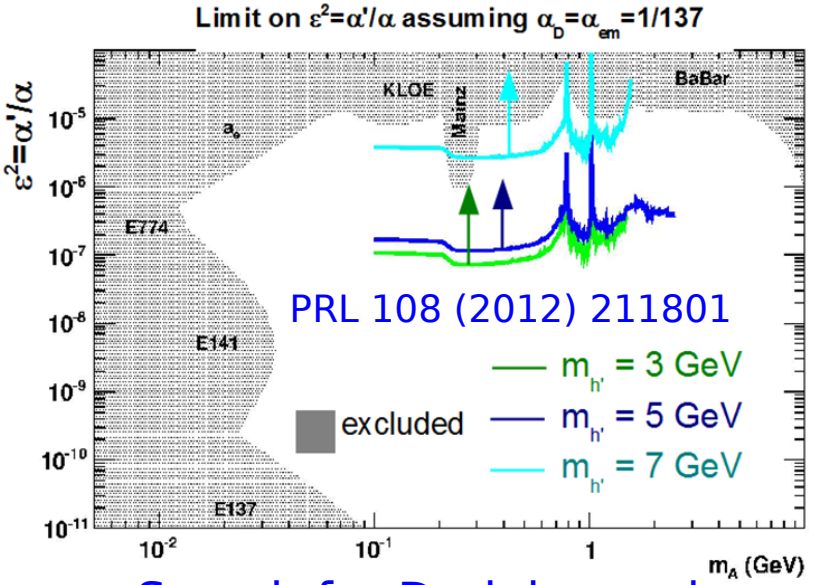
Previous BABAR Dark Sector searches

Search for visible Dark photon in $e^+e^- \to \gamma A'$, $A' \to e^+e^-$, $\mu^+\mu^-$



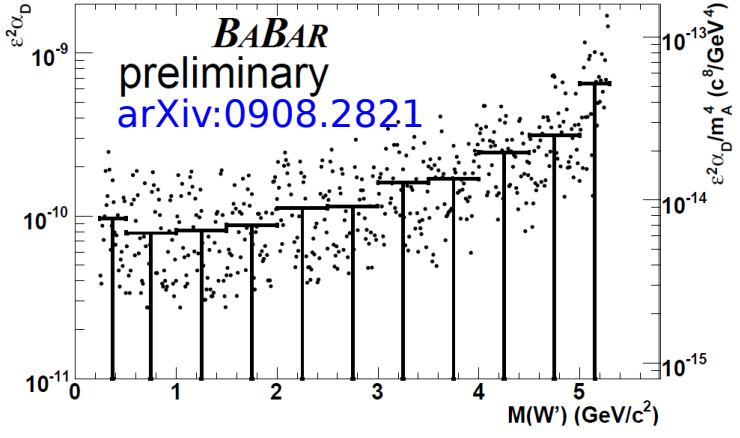
PRL 113 (2014) 201801

Search for Dark Higgs boson in $e^+e^- \to h'A'$, $h' \to A'A'$

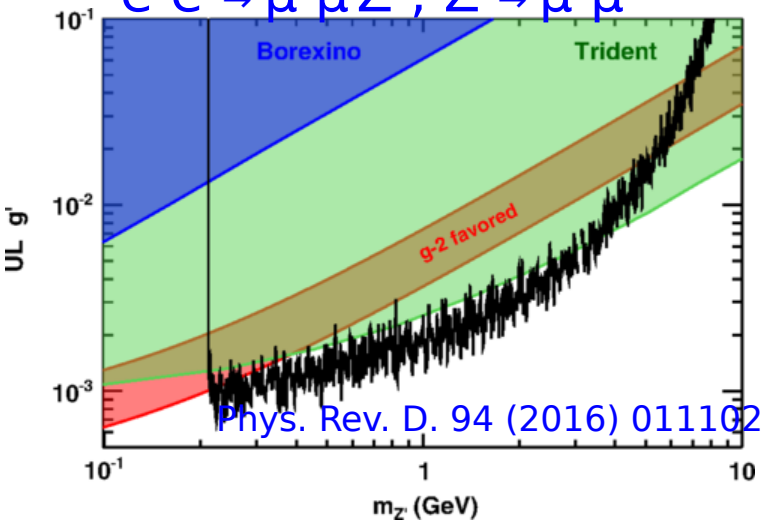


PRL 108 (2012) 211801

Search for Dark boson in $e^+e^- \to W'W' \to (\ell^+\ell^-)(\ell^+\ell^-)$



Search for Dark boson in $e^+e^- \to \mu^+\mu^- Z'$, $Z' \to \mu^+\mu^-$



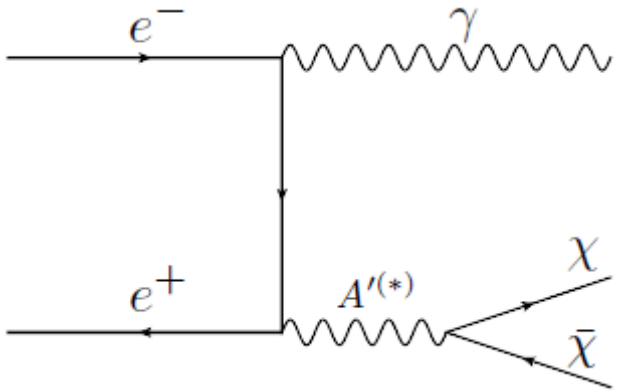
Phys. Rev. D. 94 (2016) 011102

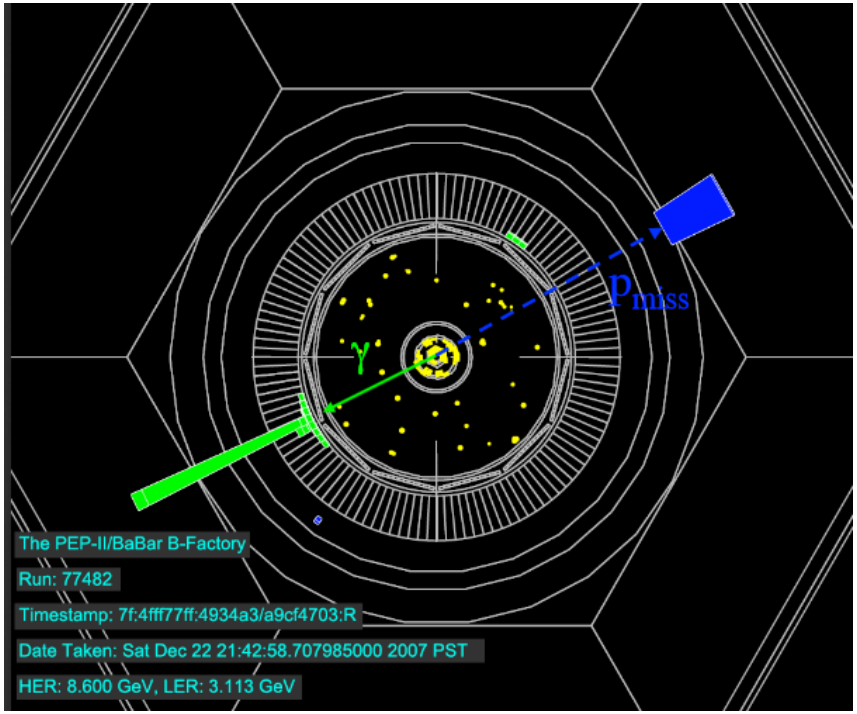
Search for invisible decay of a Dark photon (A')

- If exists, the Dark photon will decay invisibly
- At e^+e^- colliders, one can search for $e^+e^- \rightarrow \gamma A'$ with $A' \rightarrow$ invisible by tagging the recoil photon in "single photon" events
- The reconstructed A' mass from recoil photon (missing mass):

$$m_X^2 = s - 2\sqrt{s}\,E_\gamma^*$$

- **Analysis strategy**: scan $m^2_{A'}$ distribution, fitting bumps over background, compute significance





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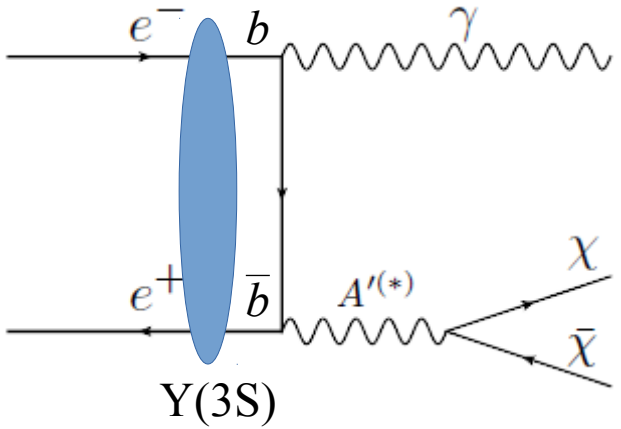
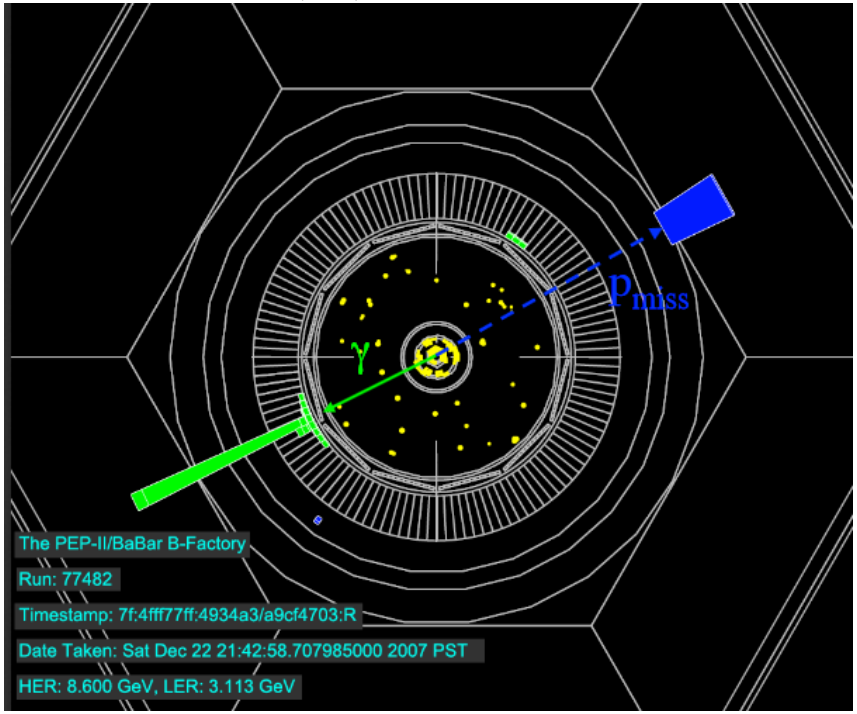




Analysis details

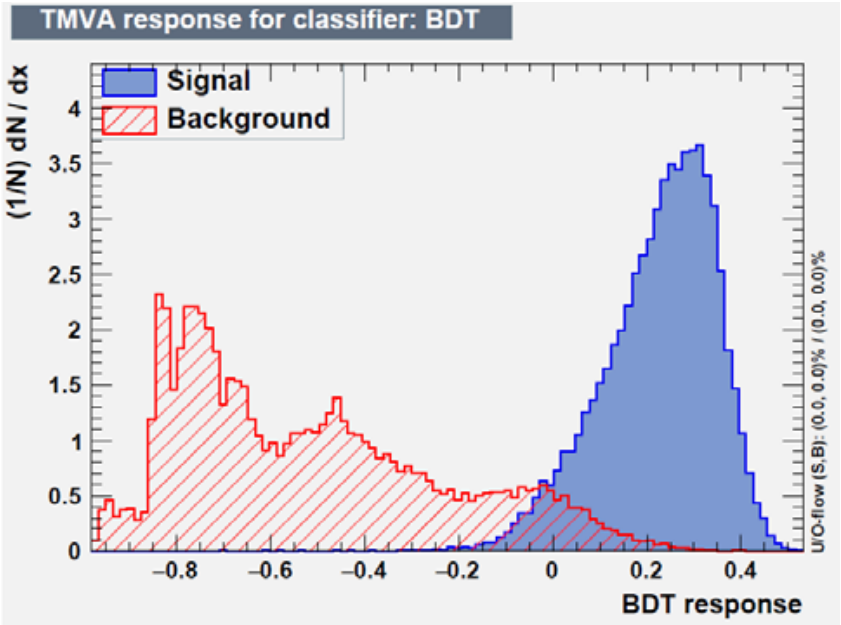
$$E^*_\gamma = \frac{s - m_X^2}{2\sqrt{s}}$$

- Single photon trigger during the final BABAR running period:
  - 35.9 fb^{-1} for high m_X (low E_γ), at Y(2S, 3S) resonances
  - 53 fb^{-1} for low m_X (high E_γ), mostly at Y(2S, 3S, 4S) resonances
  - Nominal trigger threshold at $E^*_\gamma > 1.5$ GeV
- Events with missing energy and momentum as signatures
- Looking for bumps in spectra of missing mass m_X or photon energy E^*_γ
- Background types:
  - $e^+e^- \to \gamma\gamma$, 1 γ not detected
    - Identical to signal for $m_X < 1.6$ GeV/c^2, poorly-quantified
  - $e^+e^- \to \gamma\gamma\gamma$,
  - $e^+e^- \to \gamma e^+e^-$
  - Beam background: photons can deposit energy in calorimeter for signal events

Event selection

- Selection criteria based on:
  - Photon quality
  - Small additional energy in the calorimeter
  - Number of tracks
  - Missing momentum 4-vector
- Data divided into two separate missing mass regions by photon triggers
  - **Low-mass (lowM)**: $-4 < m_X^2 < 36$ GeV^2
    - Residual background from $e^+e^- \to \gamma\gamma$ limits sensitivity
  - **High-mass (highM)**: $24 < m_X^2 < 69$ GeV^2
    - Smooth background, mainly $e^+e^- \to \gamma e^+e^-$
- Boosted Decision Tree (BDT) trained separately for lowM and highM for background suppression

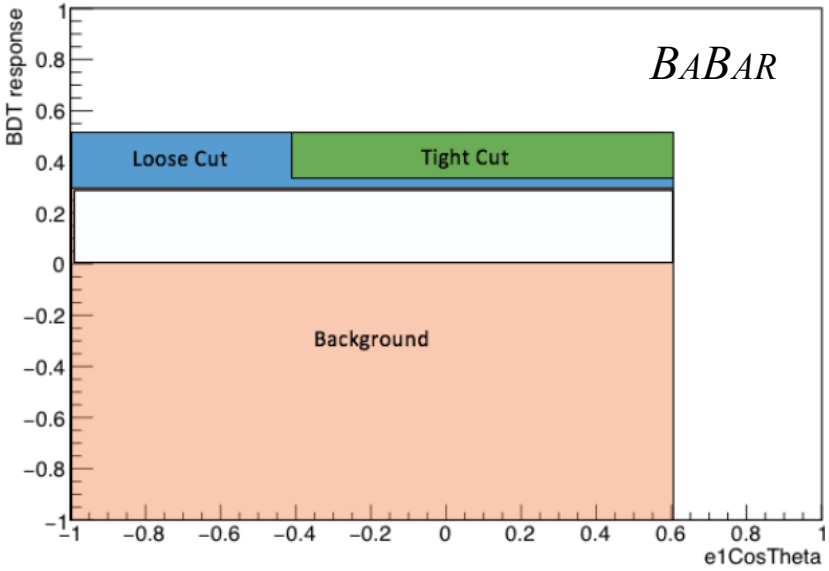
Event selection is optimized to minimize the expected upper limit on the $e^+e^- \to \gamma A'$ cross section

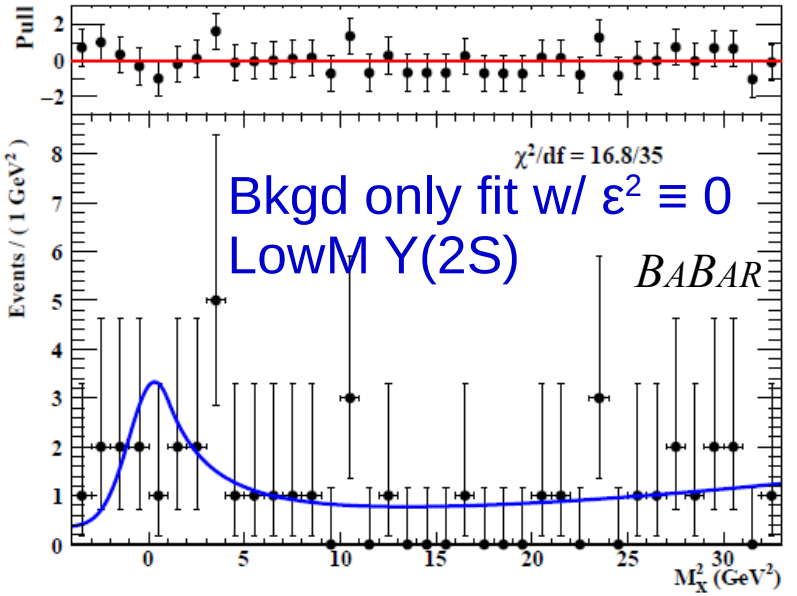


BDT Training samples:
- Simulated signals with uniformly distributed A' masses
- Background events from Y(3S) on-peak sample

Event selection

- Peaking contribution from $e^+e^- \to \gamma\gamma$ near $m_{A'} \sim 0$ needs to be further suppressed
- Signal regions defined in 2D, photon angle versus BDT output:
  - **Tight cut**: reduce $e^+e^- \to \gamma\gamma$ near $m_X \sim 0$
  - **Loose cut**: optimize for observation (smooth background)
  - **Background**: pure background region
- Data split into 4 non-overlapping regions for each dataset taken at different energies:
  - LowM + **Tight**, LowM + (**Loose** && !**Tight**), HighM + **Loose**, **Background**
- **Total**: 9 low-mass datasets (Y(2S,3S,4S)) and 4 high-mass datasets (Y(2S,3S)) for signal extraction

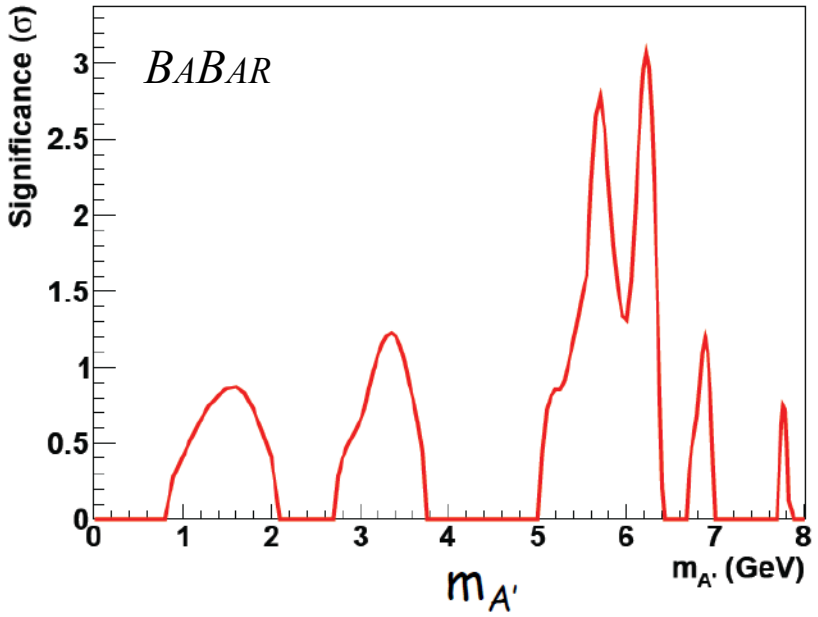




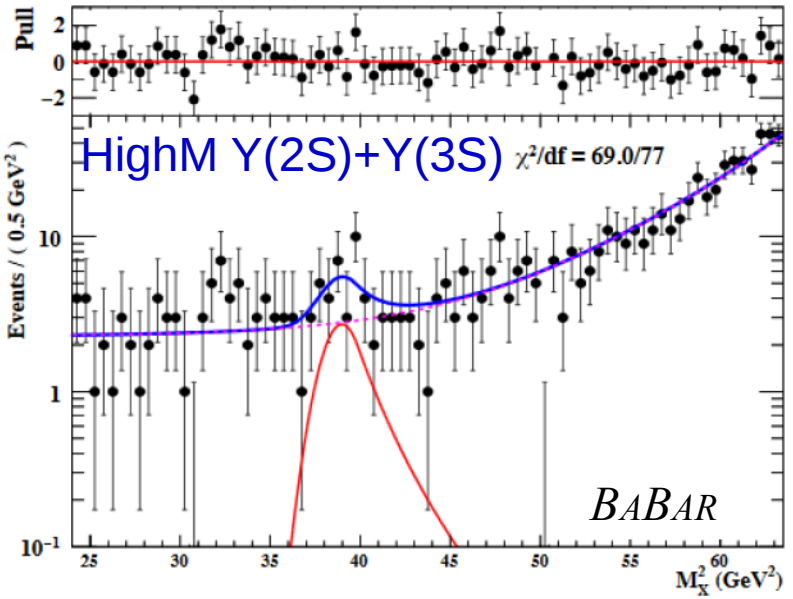
Signal extraction

- Signal yield extracted from simultaneous fit to the independent regions for each data set (Y(2S),Y(3S), Y(4S))
  - 166 mass hypotheses
- For each fit signal/background shape is fixed, signal yield, peaking and continuum backgrounds are floated

Local signal significance



Most significant fit, $m_{A'}$ = 6.22 GeV

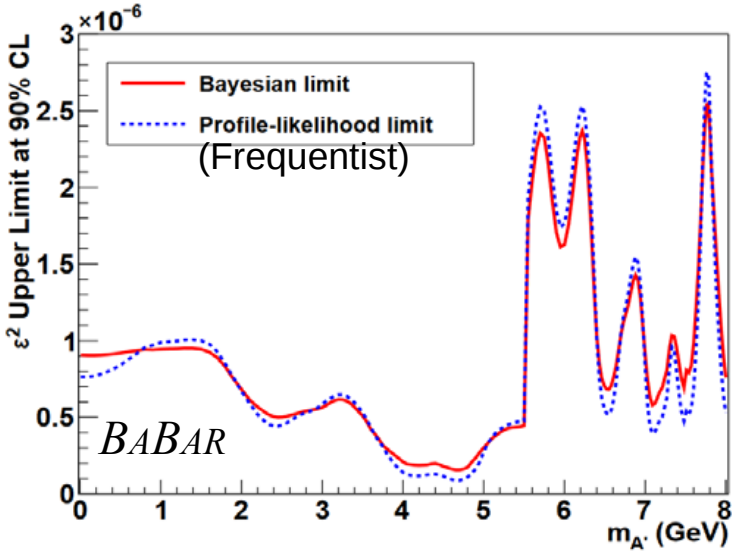


Local significance: 3.1σ
Global significance: 2.6σ
Global p-value ~ 1%

Final results

- Large improvement over previous measurements on constraining mixing parameters
- Entire region preferred by $(g-2)_\mu$ anomaly ruled out

90% CL on ε^2 vs $M_{A'}$



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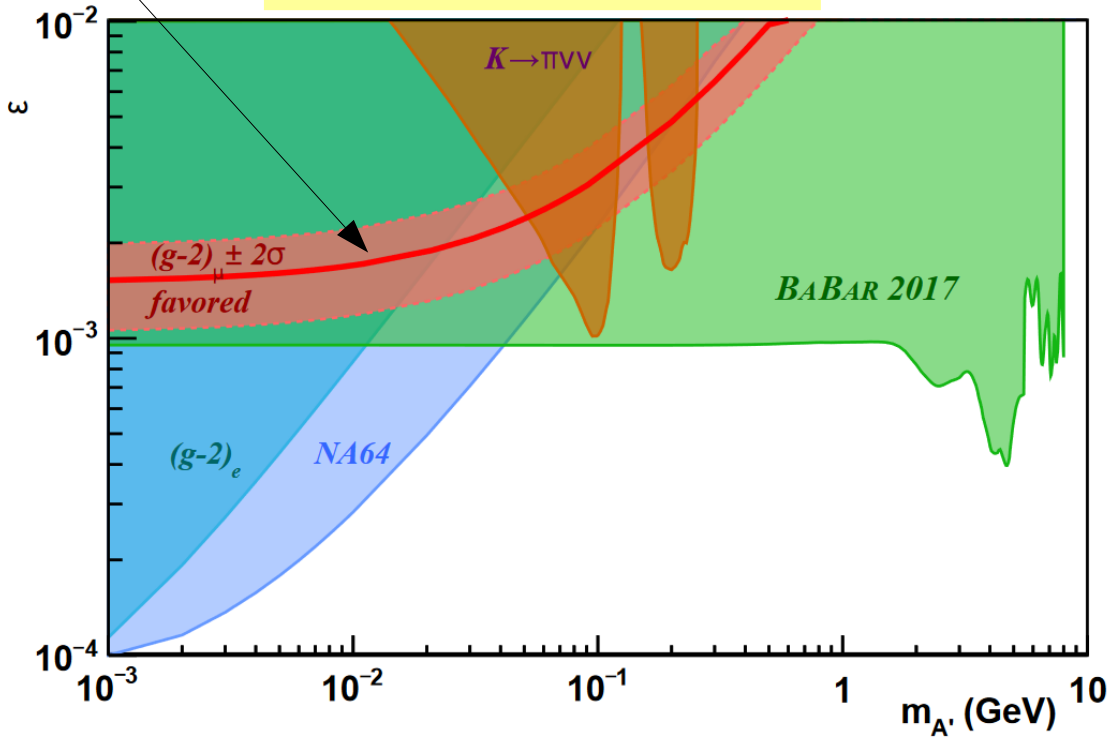

Summary

- Most sensitive search for Dark Photon decaying into an invisible final state
- No evidence for any signal
- The entire region preferred by (g-2)μ anomaly is ruled out
- Paper submitted to PRL

Backup Slides