Search at Babar for a Light Higgs Using Radiative Upsilon Decays

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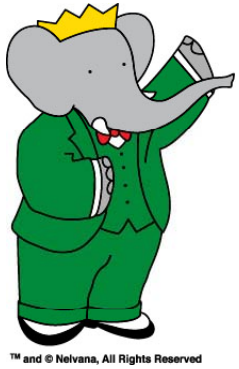
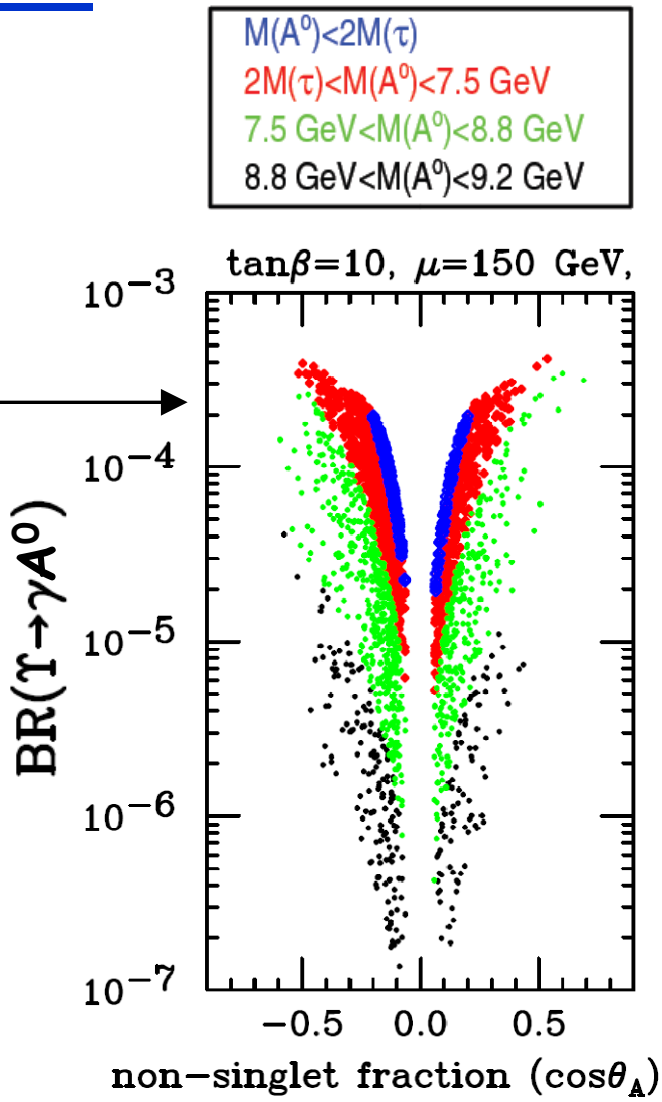


On behalf of the Babar Collaboration

THE UNIVERSITY of WISCONSIN MADISON

Why a Light Higgs?

- NMSSM introduces a singlet Higgs which mixes with CP-odd MSSM Higgs to produce a possibly low-mass CP-odd Higgs state A^0
- Scan of NMSSM parameter space for various A^0 mass ranges gives possible BR($\Upsilon \to \gamma A^0$) > ~10^{-4}
- Direct searches for $M(A^0) < 2m_b$ are possible at the B-factories
  - Depending on $M(A^0)$, dominant decays are
    - $A^0 \to \tau^+\tau^-$, $A^0 \to \mu^+\mu^-$, $A^0 \to$ invisible, $A^0 \to$ hadrons
- Recent model proposes axion-like state $360 < M(a) < 800$ MeV predominantly decaying to di-muons
  - BR($\Upsilon \to \gamma a$) ~ 10^{-5} - 10^{-6}
  - Nomura, Thaler arXiv:0810.5397 [hep-ph]

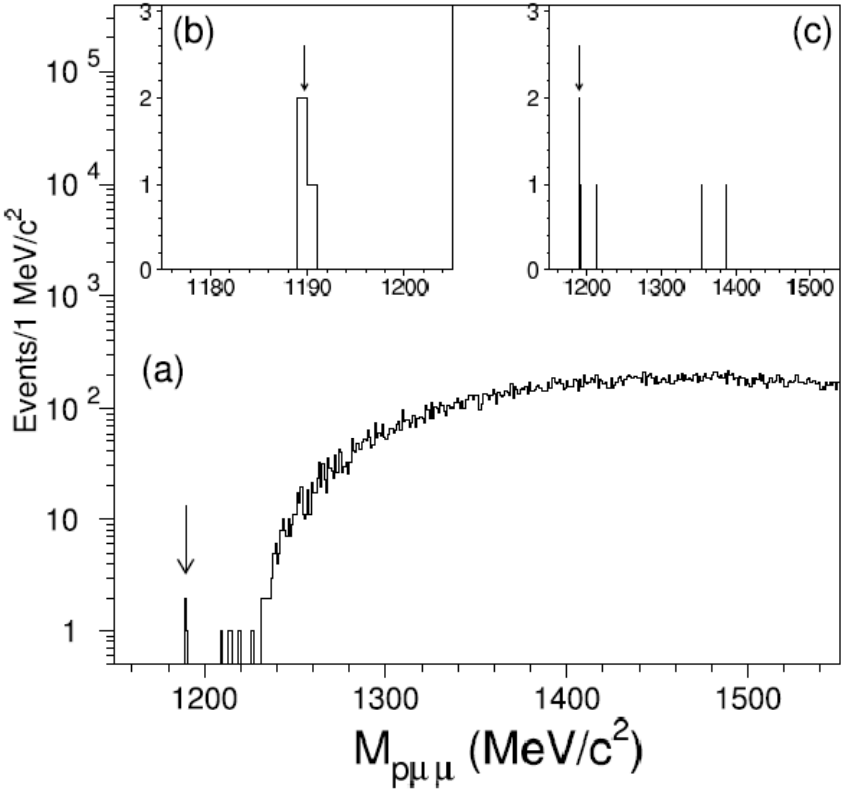


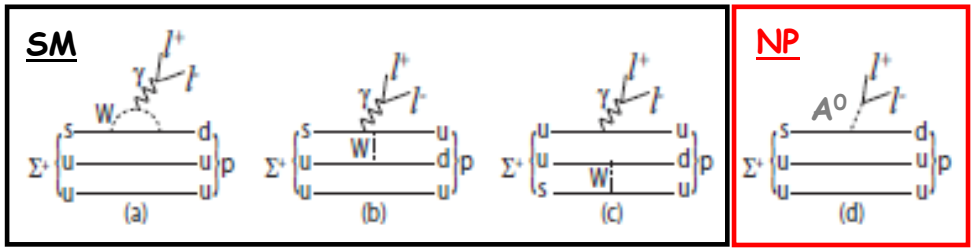
Gunion et al, Phys.Rev.D76:051105,2007

HyperCP Excess Events

PRL 94, 021801 (2005), hep-ex/0501014

$\Sigma^+ \rightarrow p\mu^+\mu^-$





$BF(\Sigma^+ \rightarrow pA^0,\ A^0 \rightarrow \mu^+\mu^-) = (3.1\ ^{+2.4}_{-1.9} \pm 1.5) \times 10^{-8}$

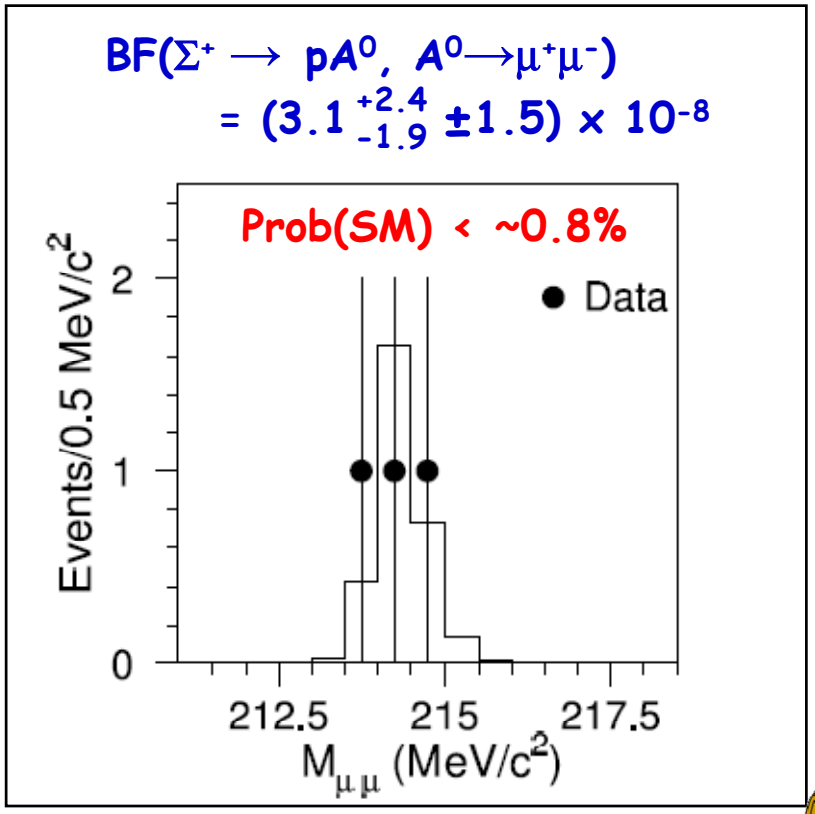
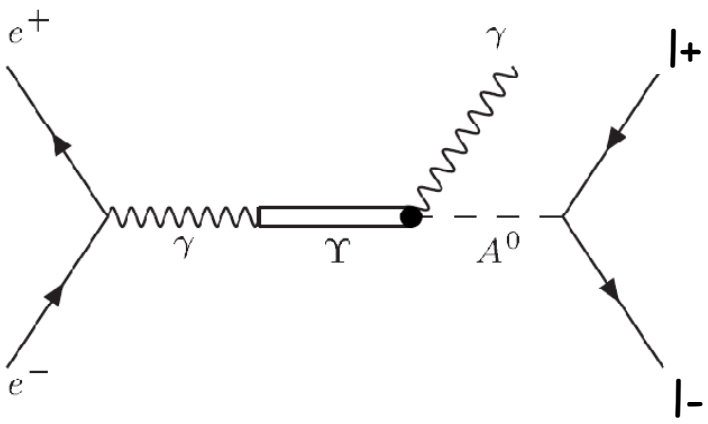


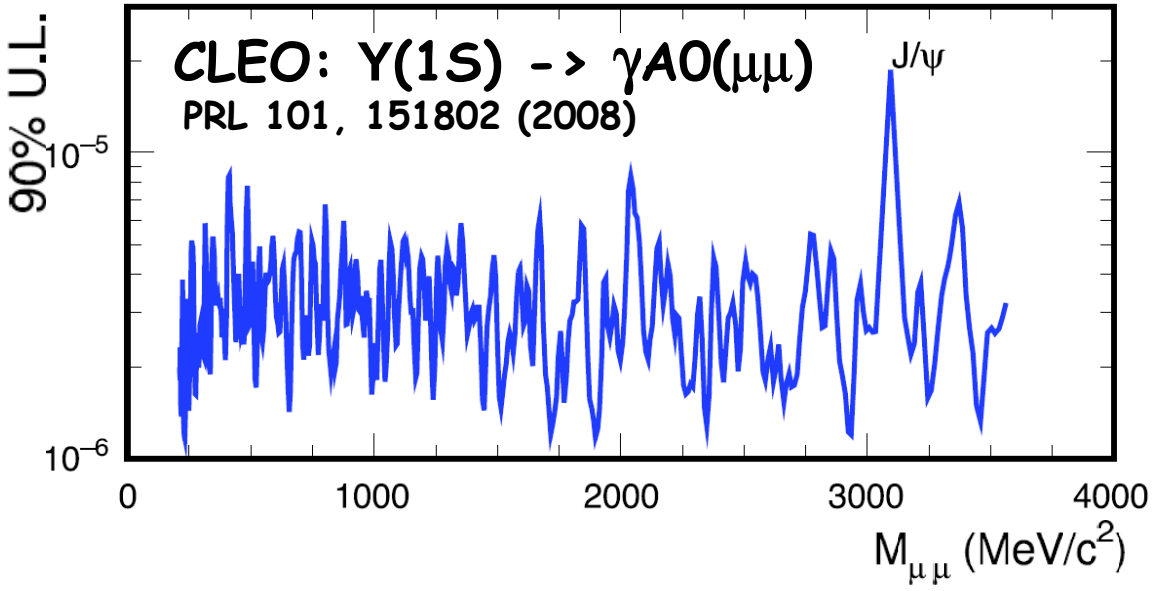
FIG. 3: $M_{p\mu\mu}$ distribution for the positive-secondary-beam data, (a) after the standard cuts, (b) within ± 15 MeV/c^2 of the Σ^+ mass, and (c) after the additional cuts. The arrow represents the Σ^+ mass.

Light Higgs At B-Factories

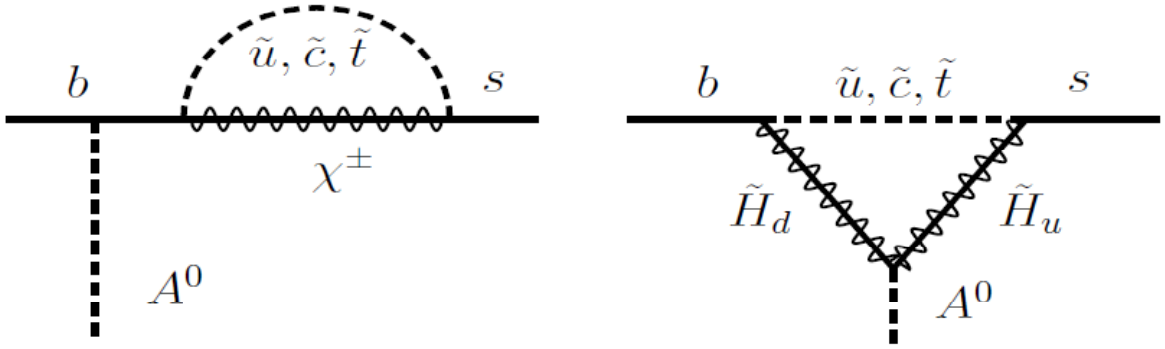
Radiative Upsilon Decays



Di-muon final state dominates for $M(A^0) < 2M(\tau)$



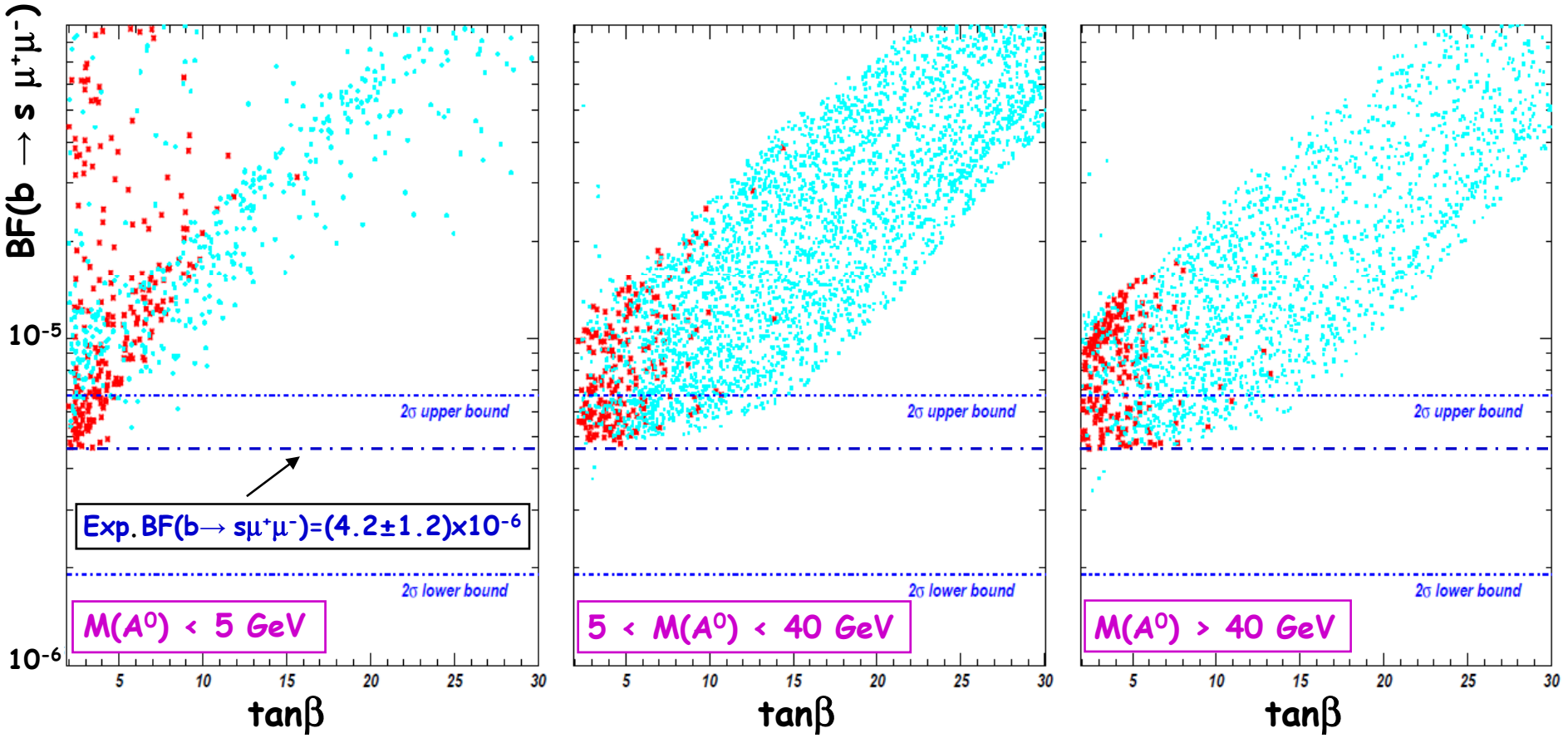
b -> A^0 s



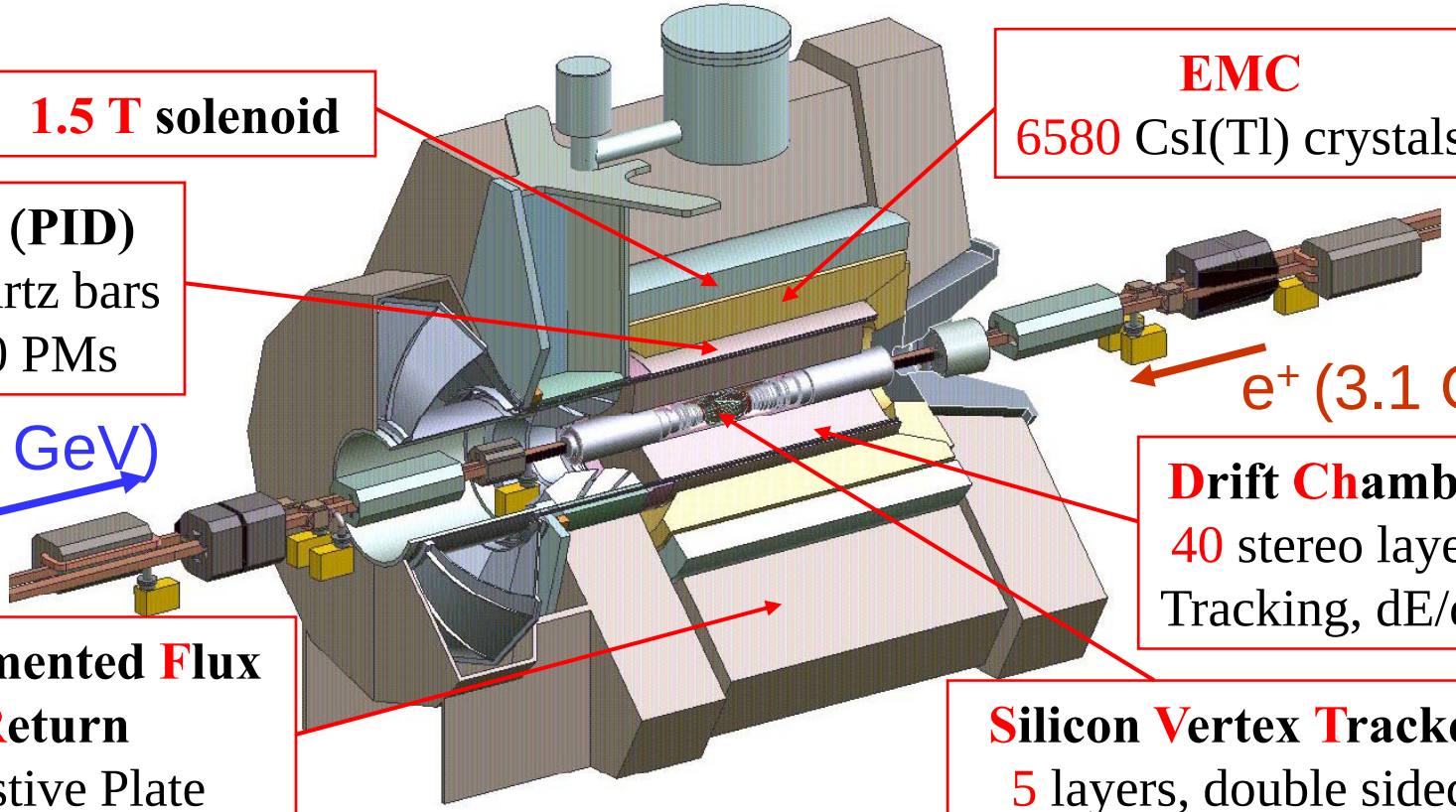
Indirect Effects

Heng et al, PRD 77, 095012 (2008), 0801.1169 [hep-ph]

- b -> sγ, b -> sμ⁺μ⁻ already constrain large tanβ, light A^0 scenarios
  - Points show scan of NMSSM parameter space on BF(b->sμ⁺μ⁻) vs tanβ plane
  - Red points allowed by experimental b->sγ BF result, blue points excluded



The Babar Detector



1.5 T solenoid

EMC
6580 CsI(Tl) crystals

DIRC (PID)
144 quartz bars
11000 PMs

e^+ (3.1 GeV)

e^- (8.5 GeV)

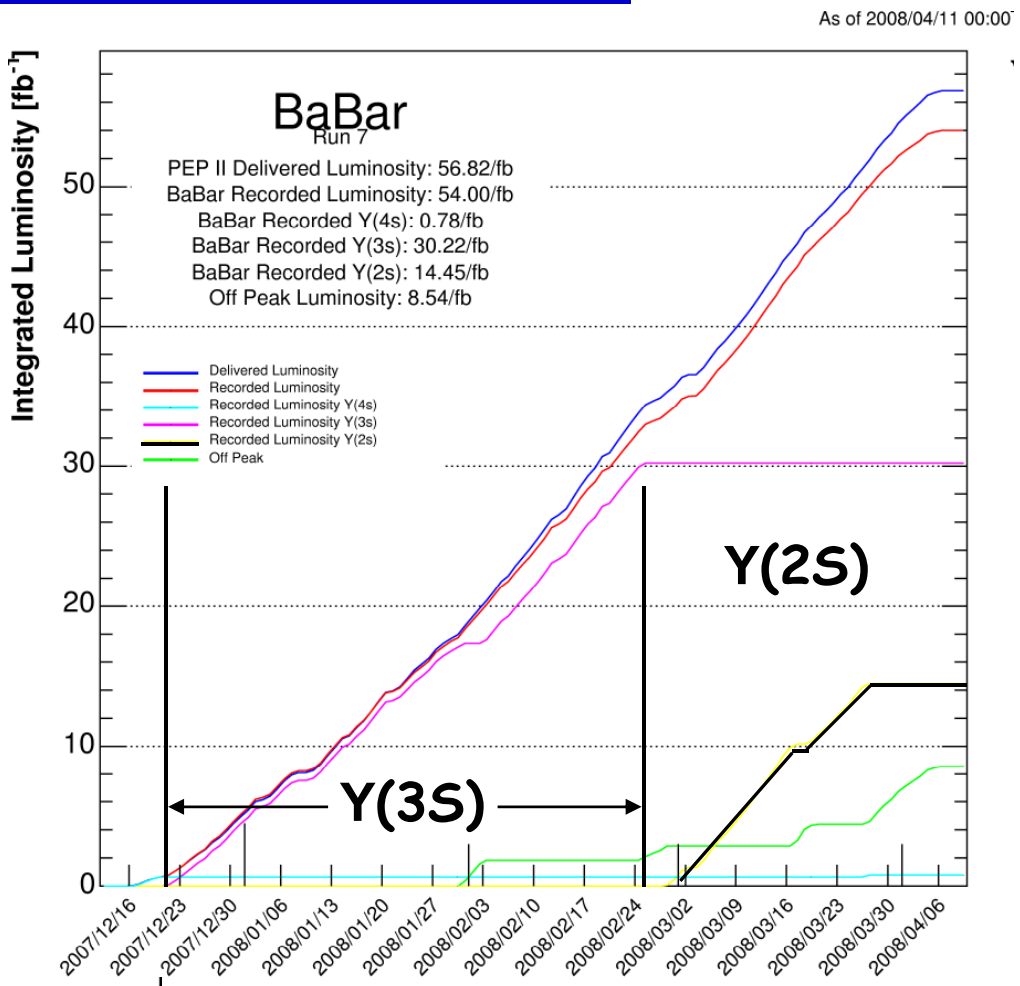
Drift Chamber
40 stereo layers
Tracking, dE/dX

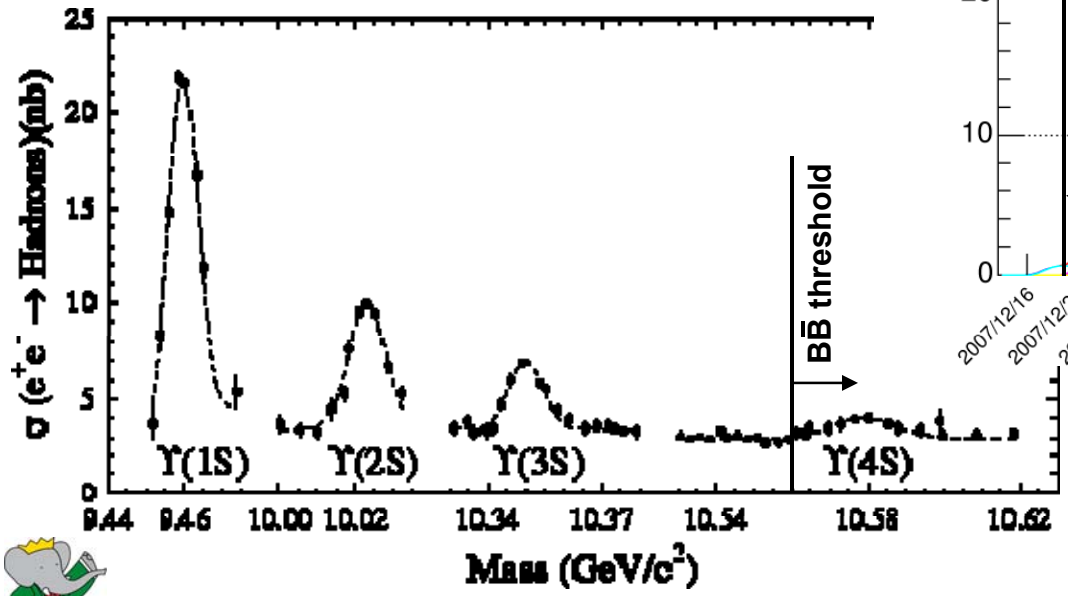
Instrumented Flux Return
Resistive Plate Chambers (Runs1-4)

Silicon Vertex Tracker
5 layers, double sided strips

Babar at the Y(3S) and Y(2S)

- PEP-II Y(2S,3S) running December 2007 - April 2008
  - **Y(3S) ~ 30 fb^{-1} (~122x10^6 decays)**
  - **Y(2S) ~ 15 fb^{-1} (~100x10^6 decays)**
- Initial Y(3S) results showed at ICHEP 2008
  - Observation of η_b
  - UL: Y(3S) -> γA^0, A^0 -> invisible

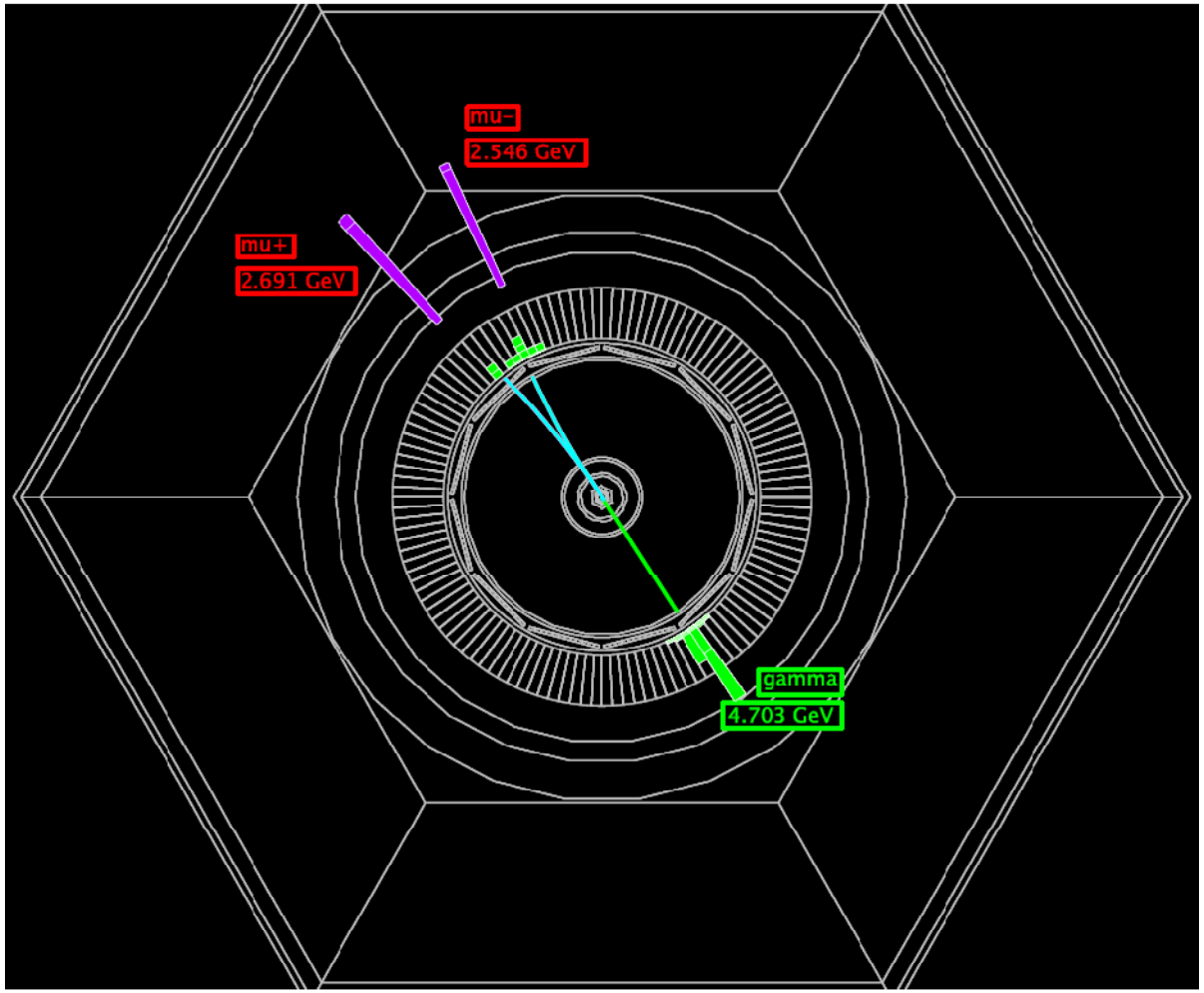


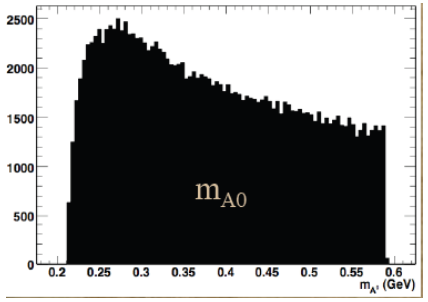


Analysis Strategy

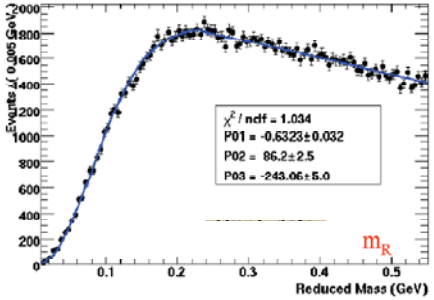
- Fully reconstruct final state from two oppositely charged tracks and a single energetic photon
  - only one E*(g) > 0.5 GeV
- Kinematic Υ(3S) fit
  - Beam-energy constraint
  - Beam spot constrained vertex
  - Fit chi2 probability > 10^{-6}
  - Doca in xy-plane < 2 cm
- $-0.07 < M_{beam} - M_{\Upsilon(3S)} < 2$ GeV
- Collinear di-muon, photon
- $10 < N_{crys} < 50$
- 1d fit to reduced mass m_R

$$m_R = \sqrt{m_{\mu\mu}^2 - 4m_\mu^2}$$





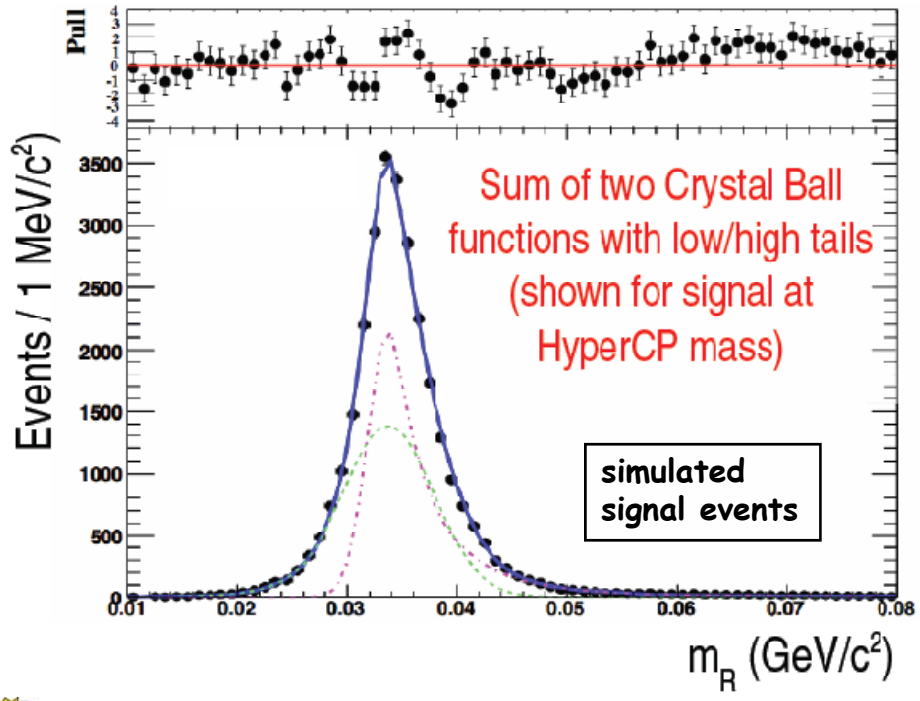
m_R



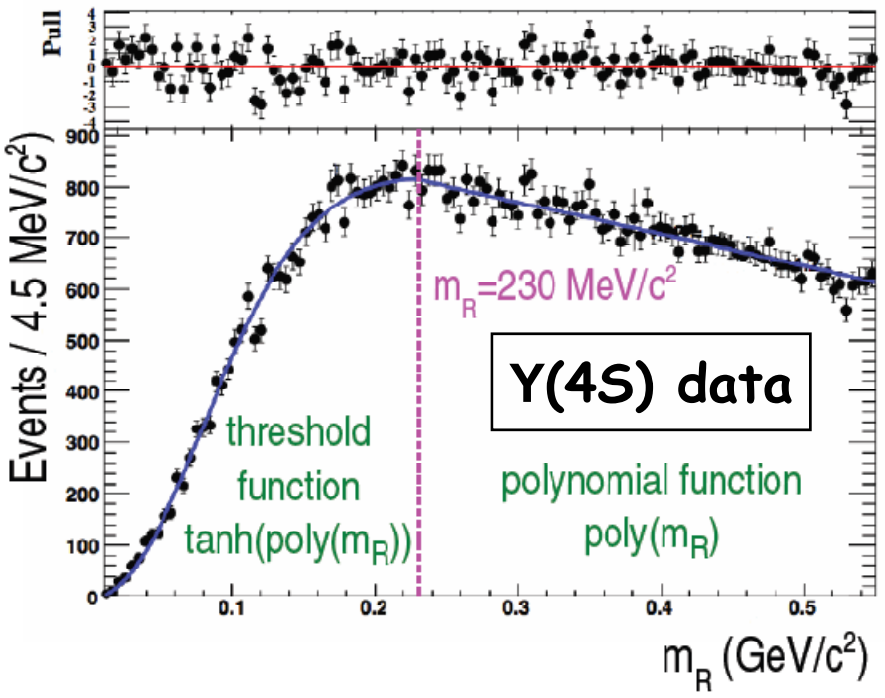
Signal and Background PDFs

- Signal m_R PDF from simulated signal events generated at many different mass points
  - PDF shape parameters interpolated between mass points
  - Simulation results calibrated using charmonium backgrounds
- Background m_R PDF determined from fit to Y(4S) data

Signal PDF

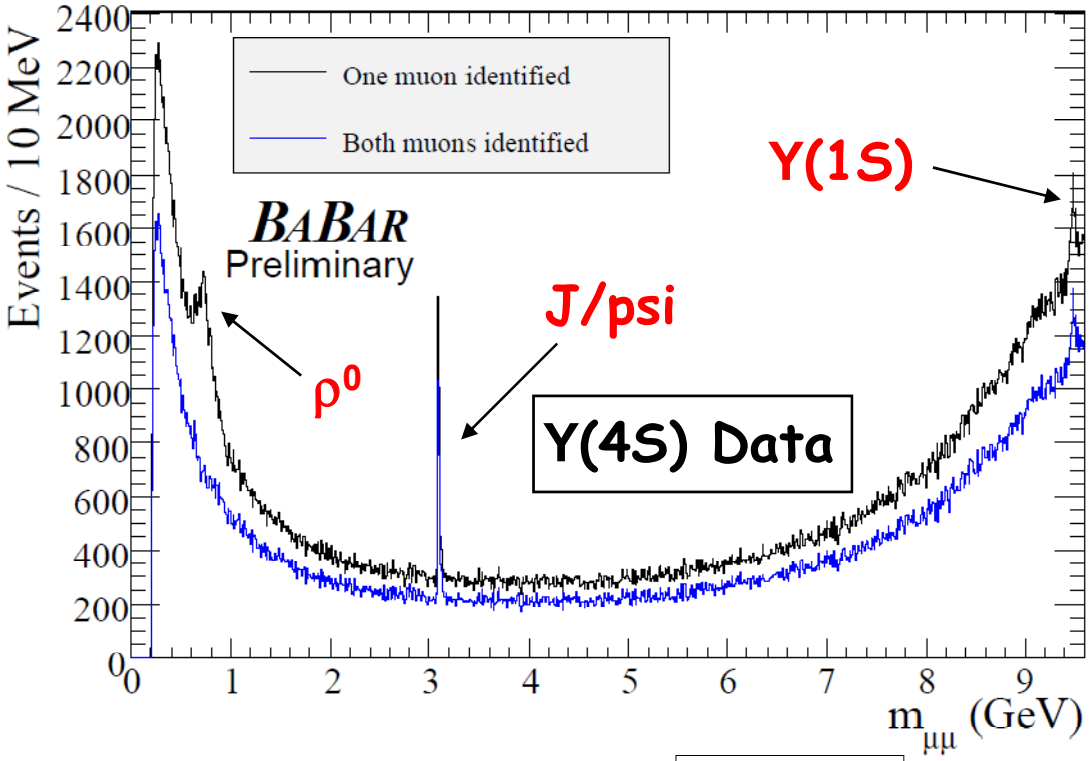


Background PDF

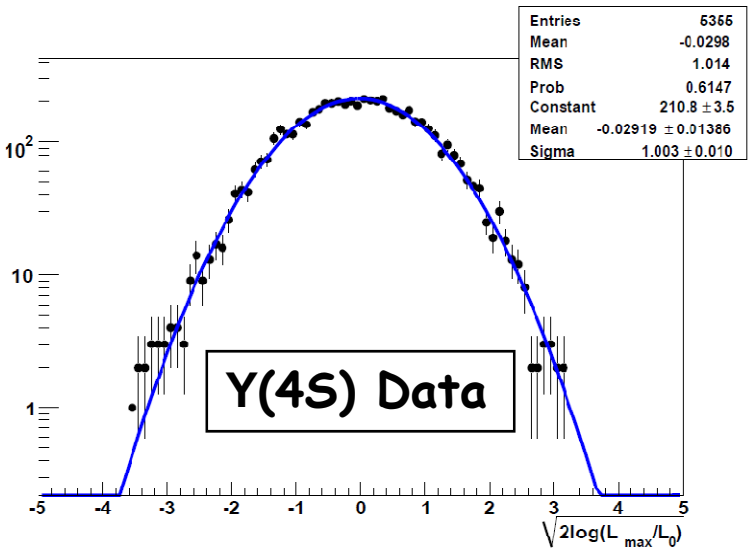


Mass Scan

- M(A^0) mass scan over ~2000 points
  - $2M(\mu) < M(A^0) < 9.3$ GeV
- Signal yield from ML fit in ~300 MeV m_R bins
- To suppress ρ^0 background, require two identified muons for $M(A^0) < 1.05$ GeV
  - Muon mis-id as pion ~ 5%

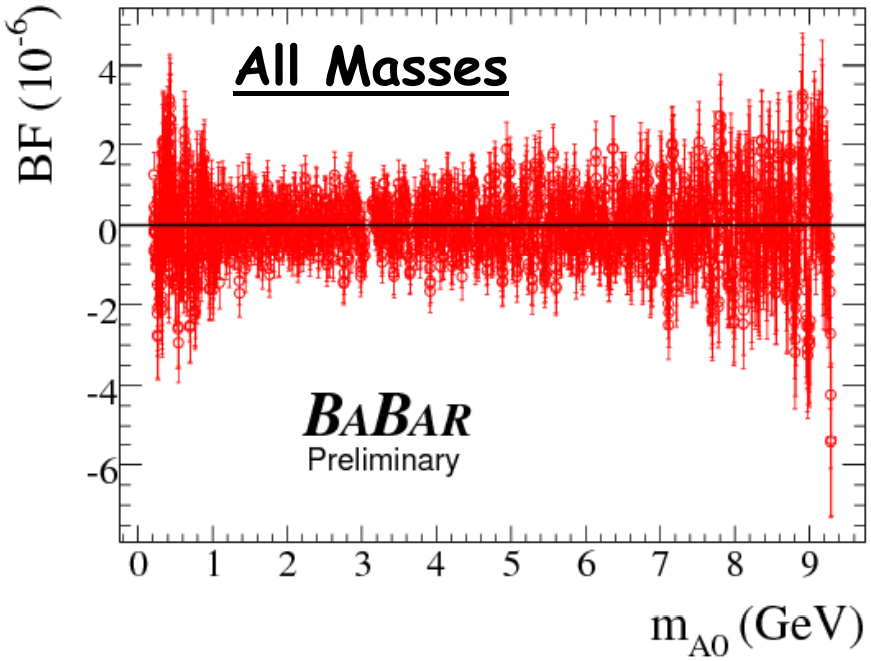


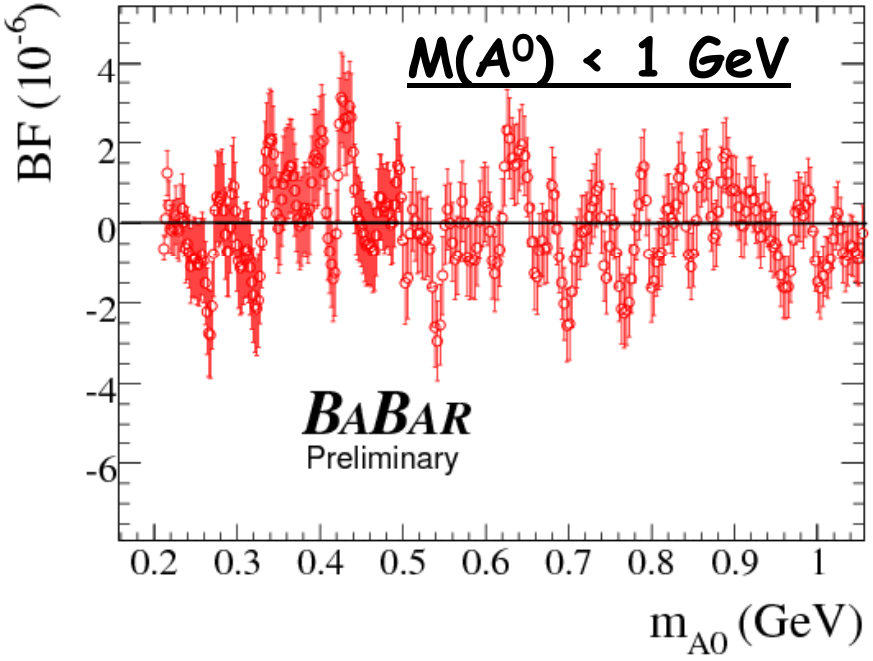
- Signal significances from mass fits on 78.5 fb^{-1} Y(4S) data control sample are Gaussian distributed with no significant outliers

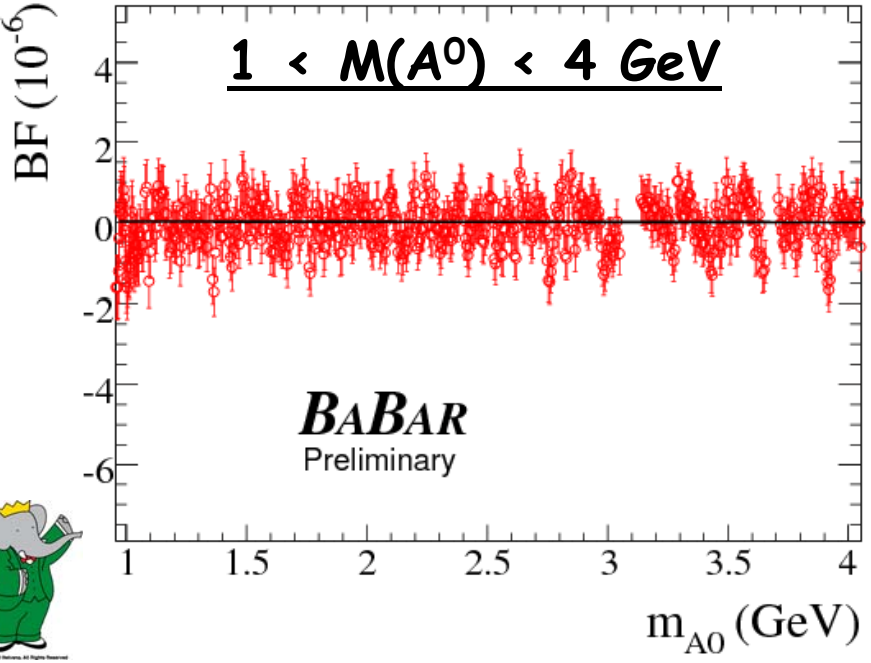


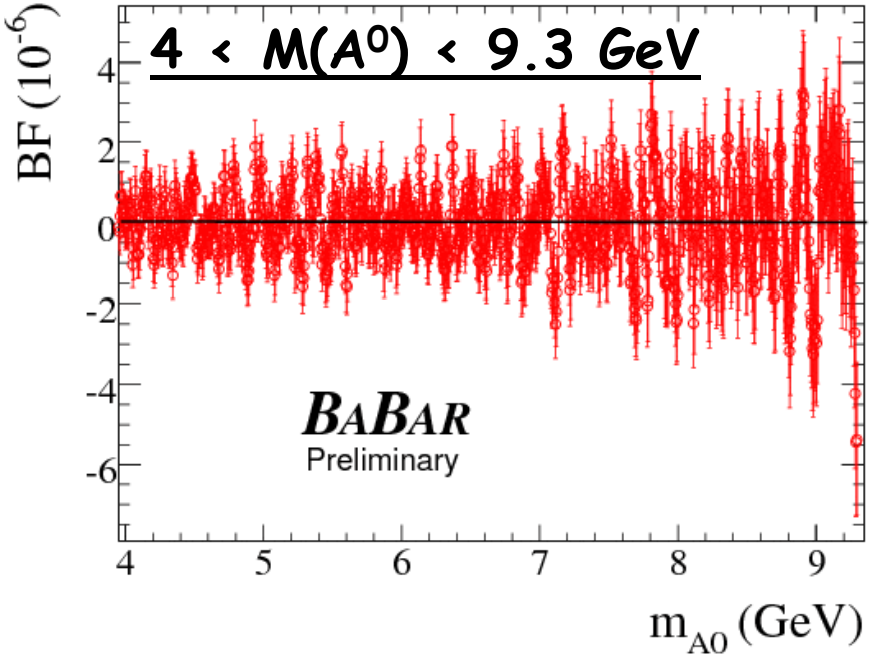
Υ(3S) Mass Scan Fit Results

arXiv:0902.2176





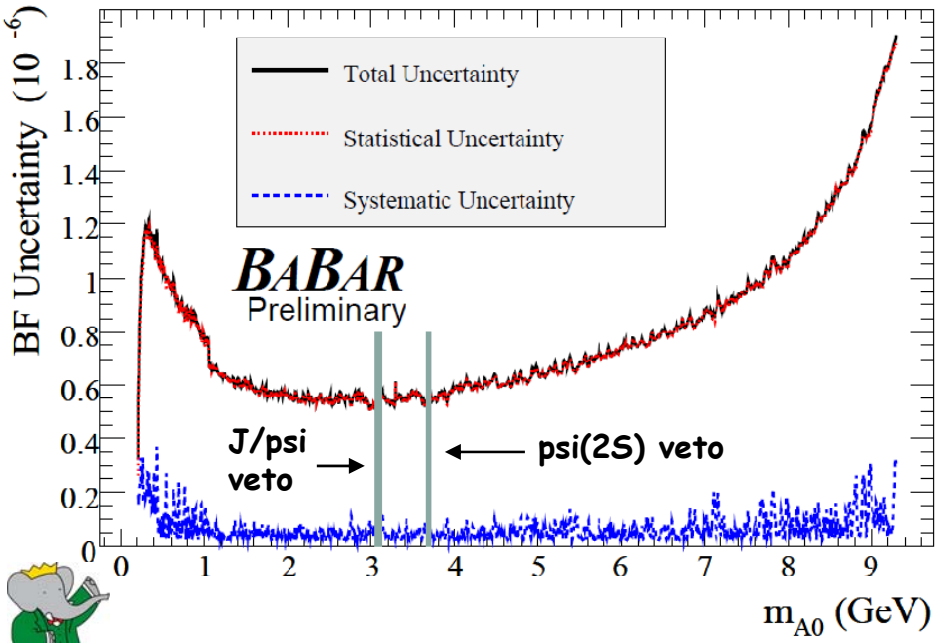


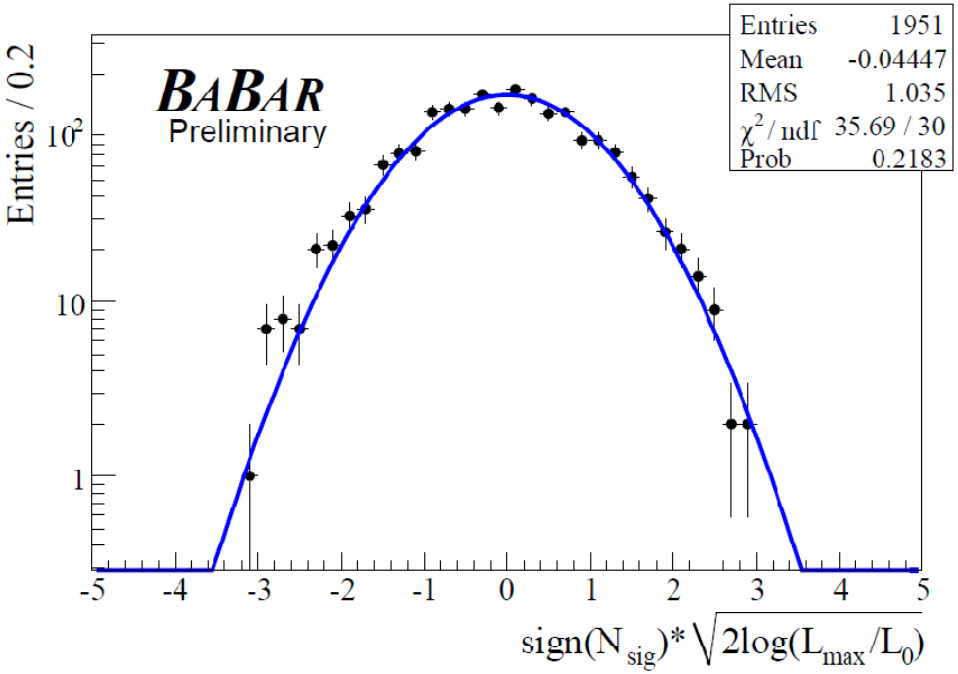


Sytematic Uncertainties and Significance

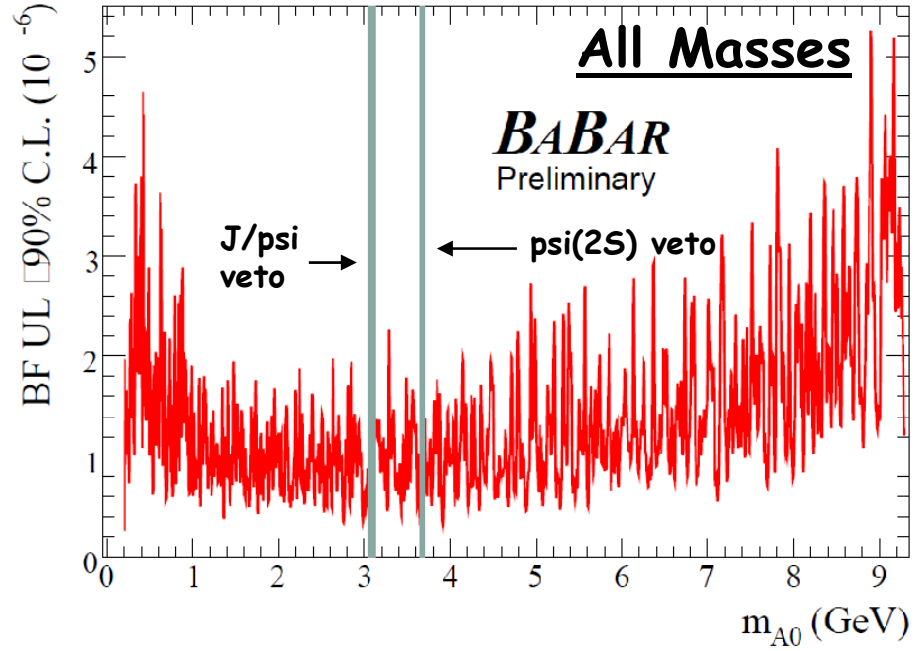
- PDF systematics
  - ± 1 sigma PDF parameter variations
  - Signal width correction
    - calibrated from J/psi data/MC
  - Peaking background mean, width, tail
- Fit bias σ_{BF} ~ 0.02 x 10^{-6}
- Efficiency corrections ~ 2-10%
- Y(3S) counting ~ 1%

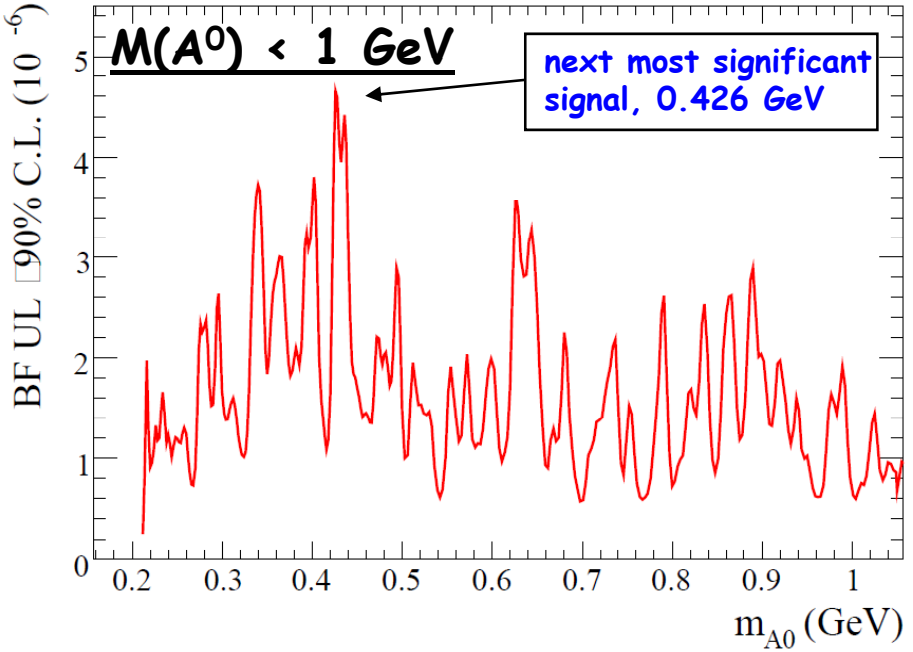
- **Signal significance distribution (stat+sys) in Y(3S) data shows no significant outliers**
  - **No excess signal events observed at HyperCP mass ~214 MeV**
  - **Most significant upward fluctuations (~3σ) at 4.94 GeV and 0.426 GeV**
  - **~80% probability to see one >3σ result for number of points here**

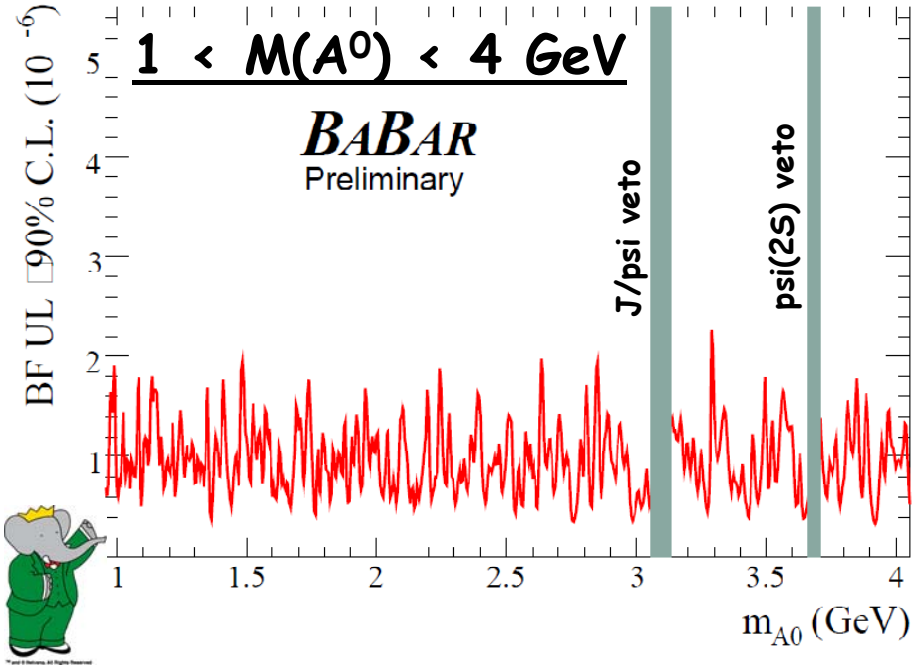


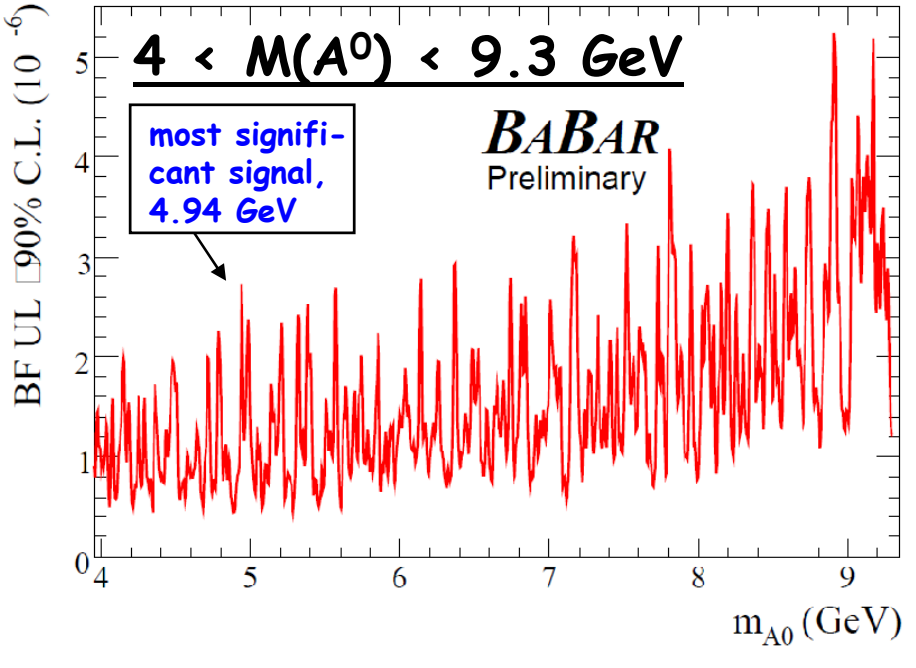


BF Upper Limits (90% CL, Stat+Sys)





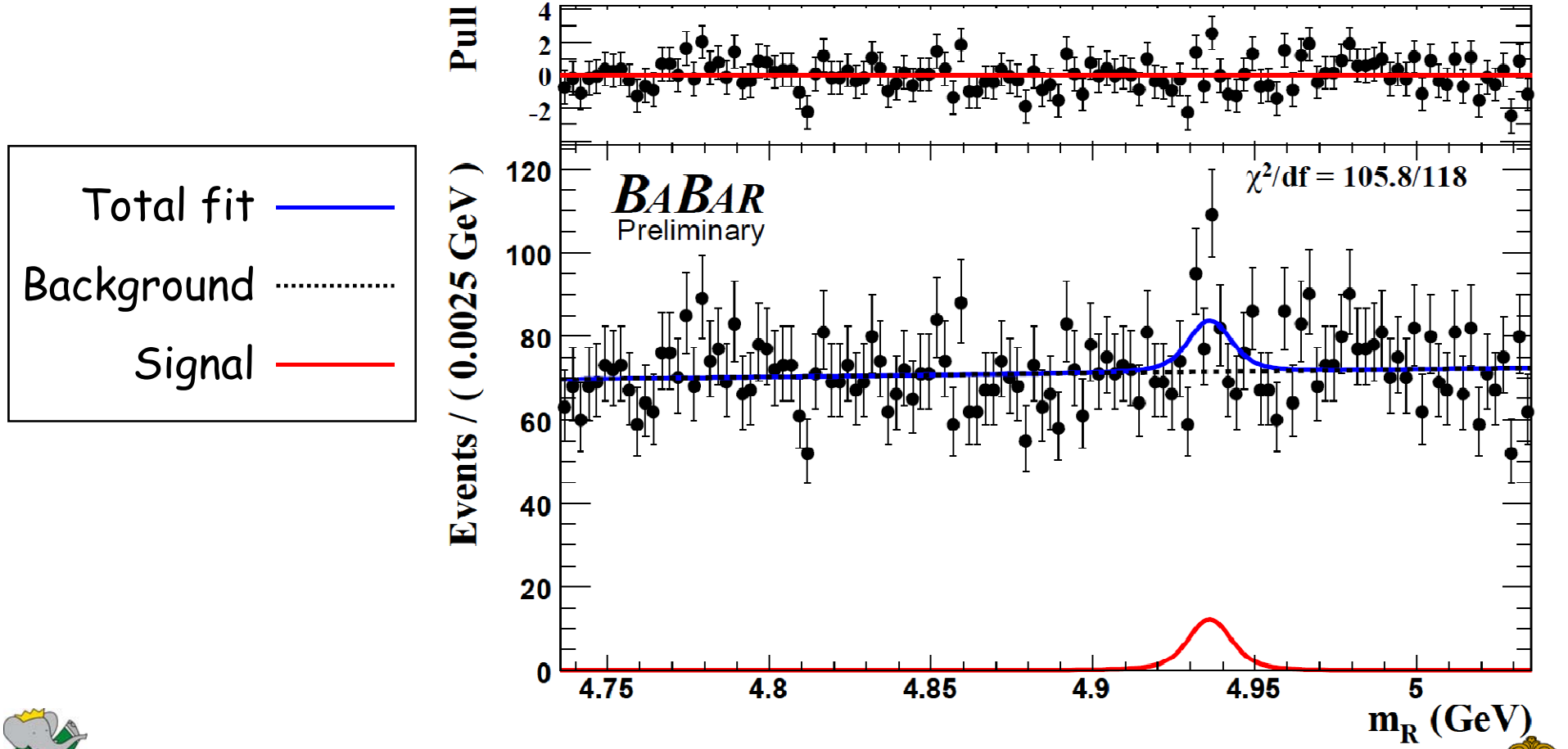




Most Significant Mass Region Fit (4.940 GeV)

BF(4.940) = (1.9 ± 0.7 ± 0.1) x 10^{-6}

Significance = 3.0 (stat+sys)



Second Most Significant Mass Region Fit (0.426 GeV)

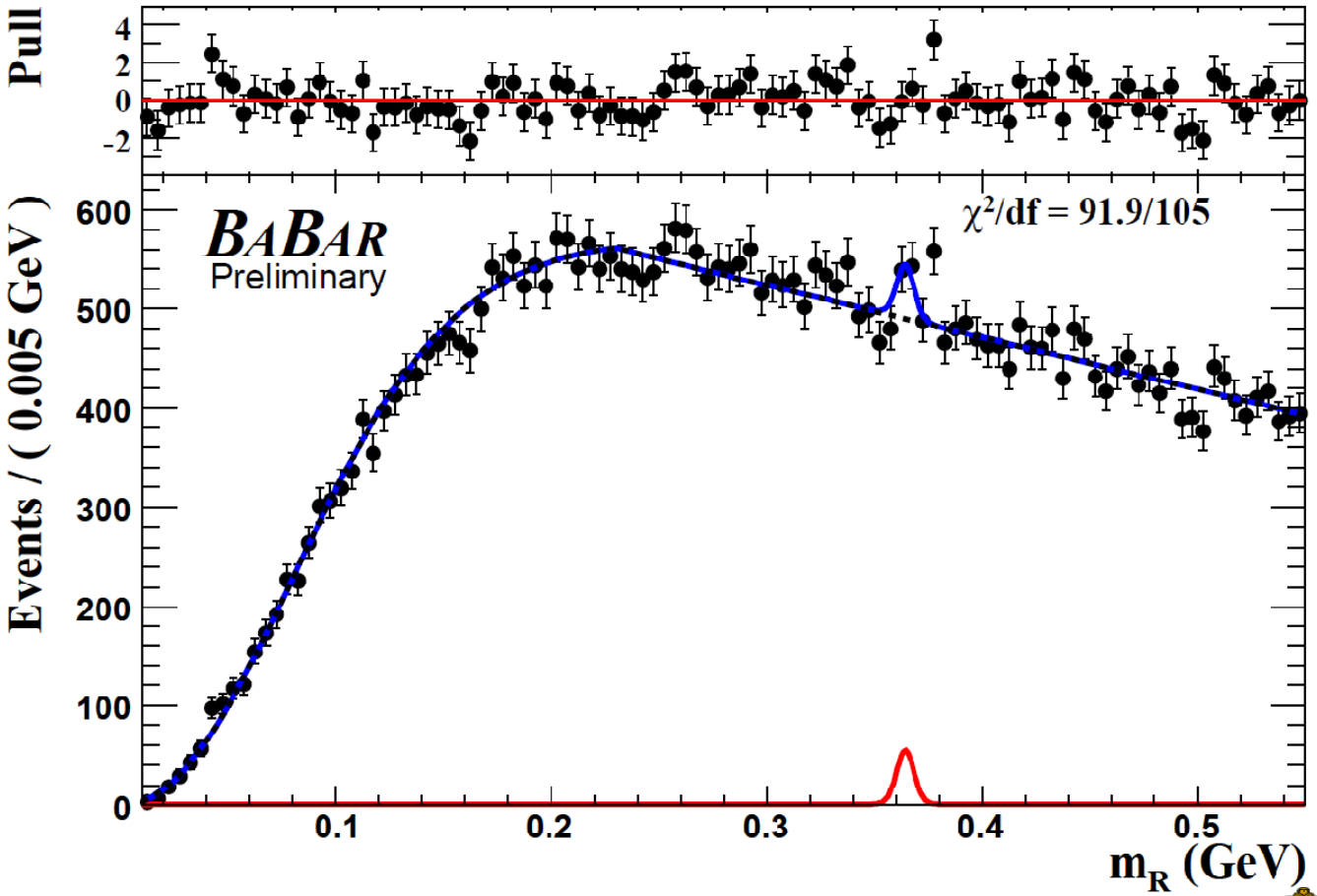
BF(0.426) = (3.1 ± 1.1 ± 0.3) x 10^{-6}

Significance = 2.9 (stat+sys)

Total fit

Background

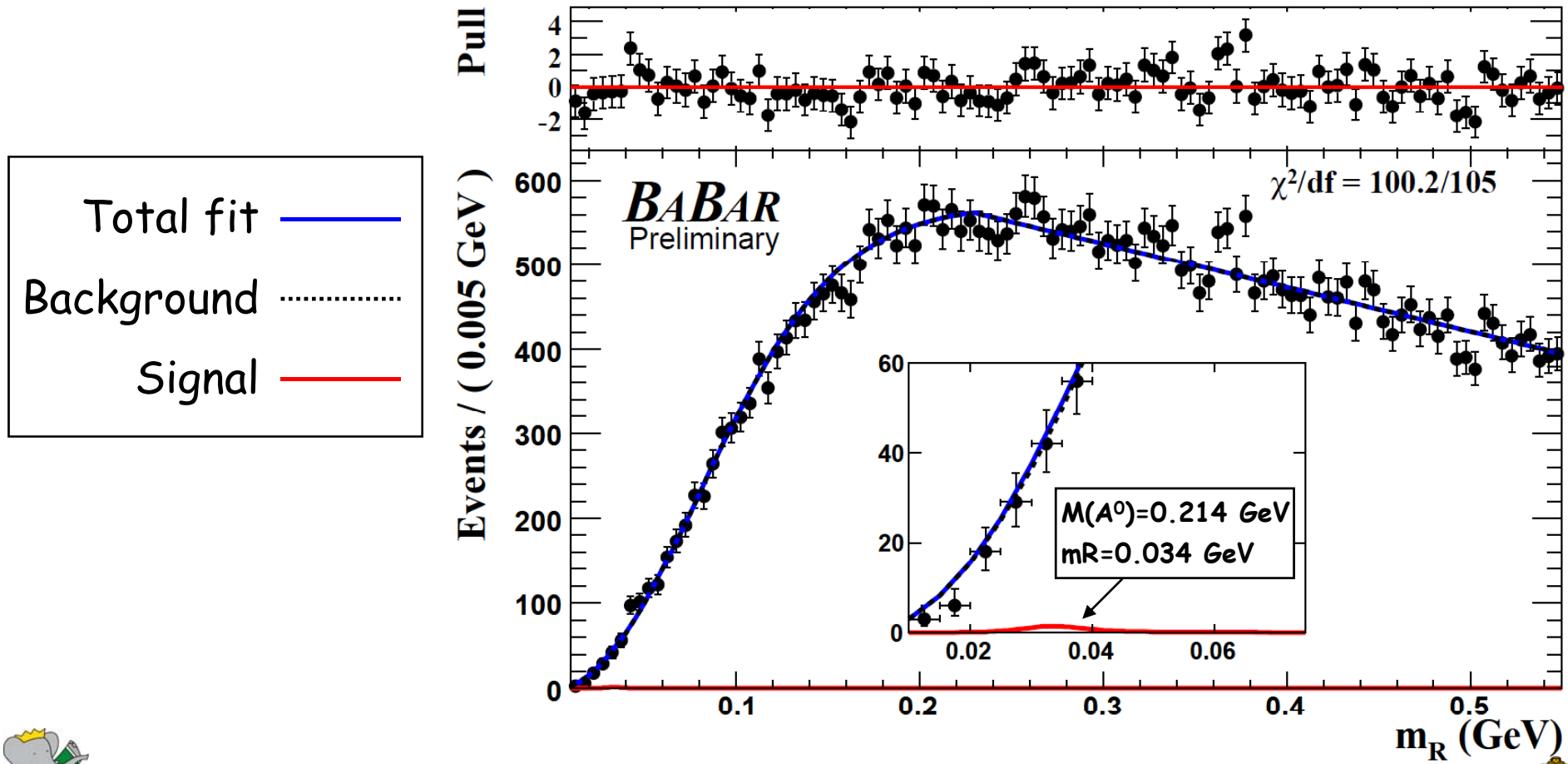
Signal



Mass Fit in the HyperCP Signal Region (0.214 GeV)

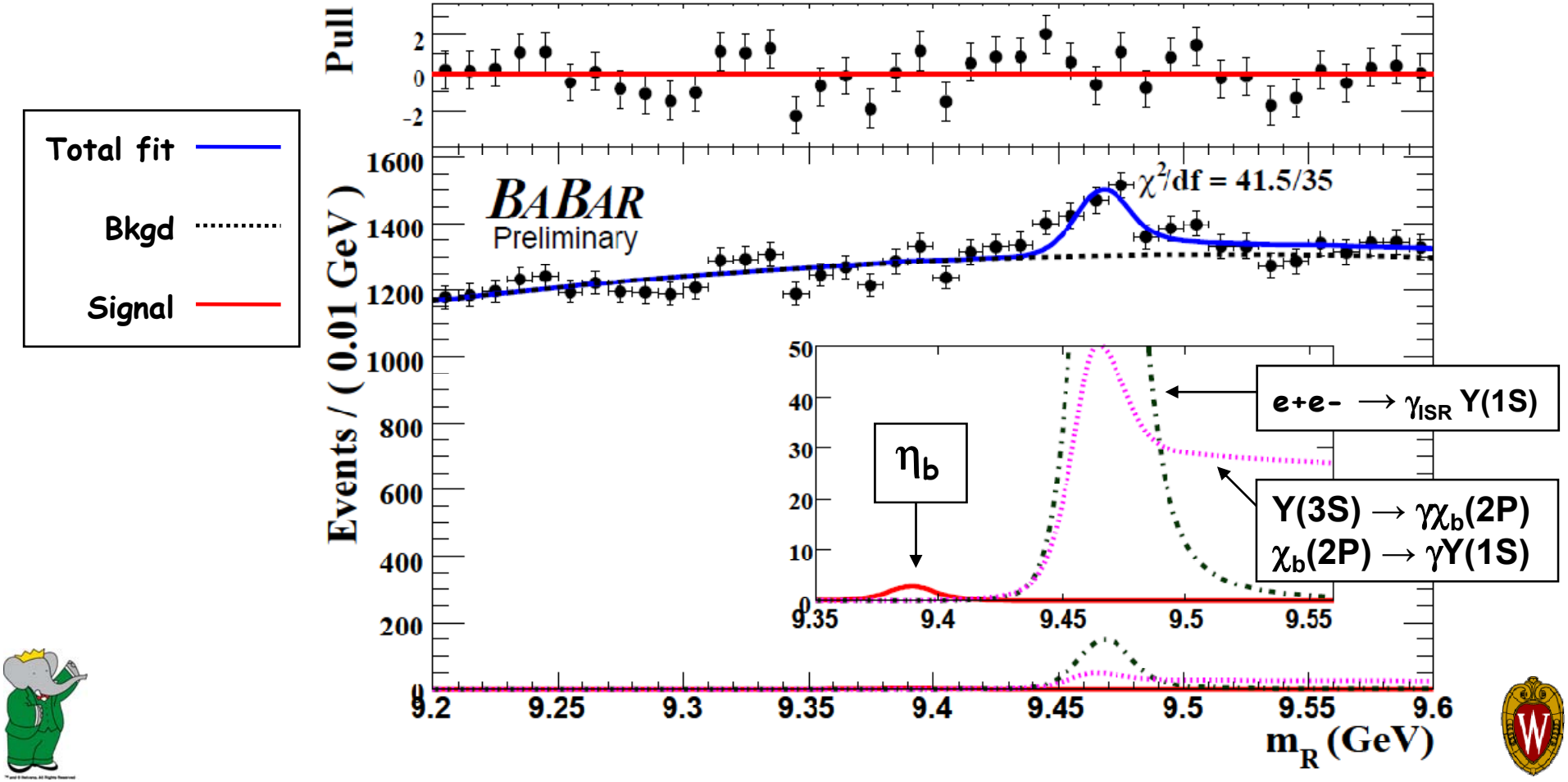
$BF(0.214) = (0.12\ ^{+0.43}_{-0.41} \pm 0.17) \times 10^{-6}$

$BF(0.214) < 0.8 \times 10^{-6}$ (90% CL)



η_b Mass Region Fit

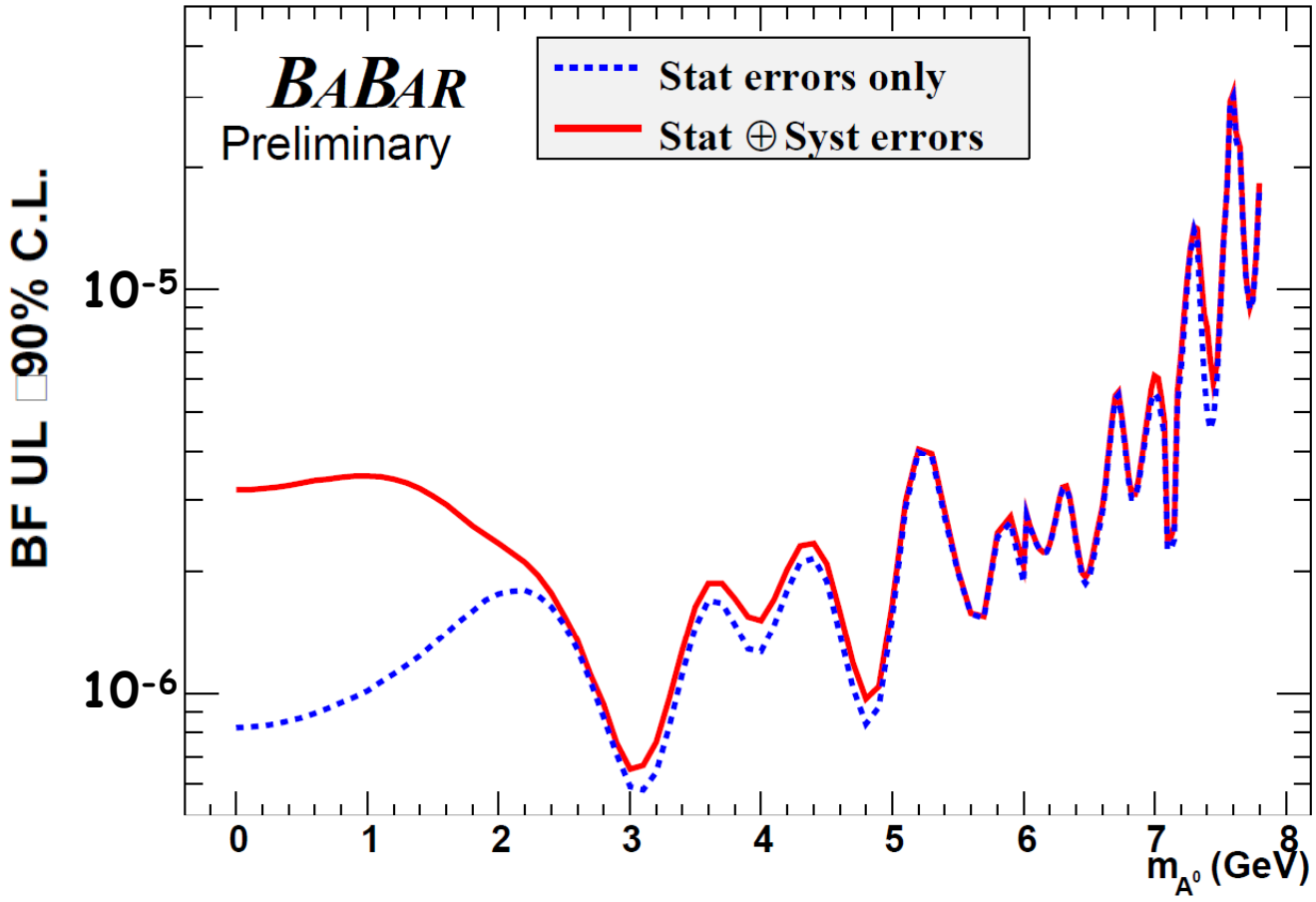
- No significant signal observed
- BF[$\Upsilon(3S) \to \gamma\eta_b$] x BF[$\eta_b \to \mu\mu$] = $(0.2 \pm 3.0 \pm 0.9) \times 10^{-6}$
- BF[$\eta_b \to \mu\mu$] = $(0.0 \pm 0.6 \pm 0.2) \times 10^{-2}$
  - BR[$\eta_b \to \mu\mu$] < 0.8% (90% CL)
  - Assuming Babar's measurement BR[$\Upsilon(3S) \to \gamma\eta_b$] = $(4.8 \pm 0.5 \pm 1.2) \times 10^{-4}$



$\Upsilon(3S) \rightarrow \gamma A^0,\ A^0 \rightarrow$ invisible

arXiv:0808.0017

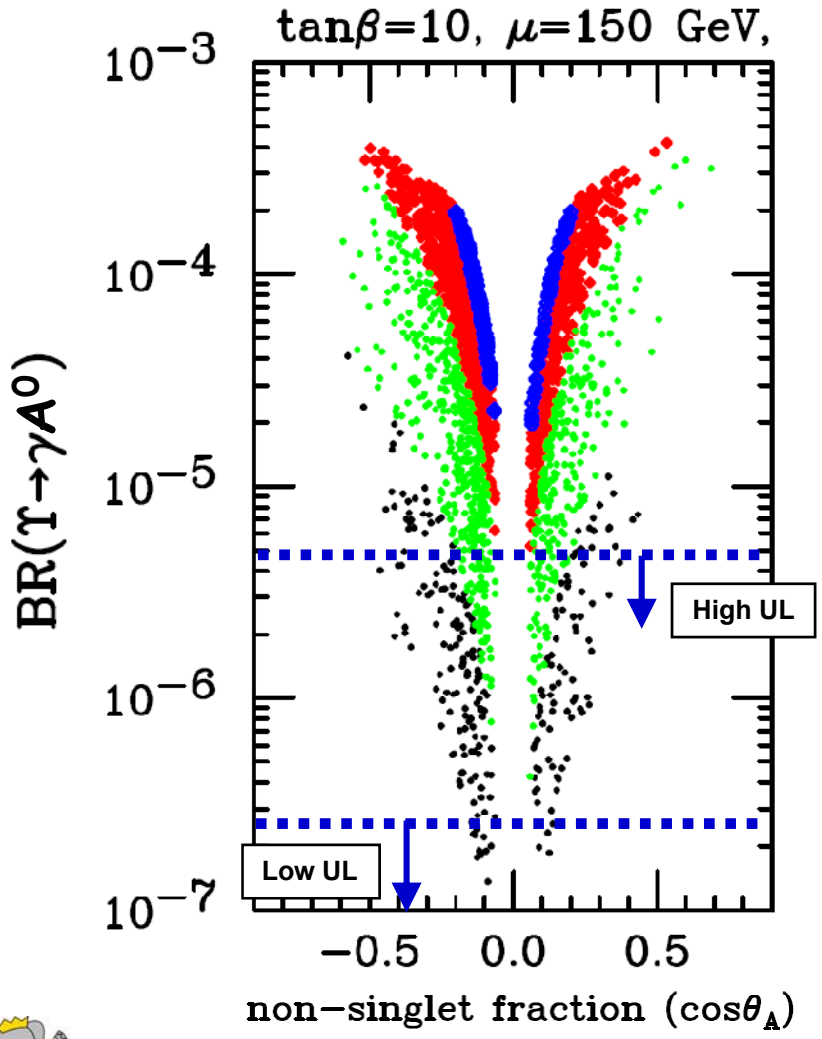
- Dominant A^0 decay mode may be invisible, e.g. to neutralino LSP pair
- Fit for missing mass in events with a high-energy photon with energy consistent with $0 < M(A^0) < 7.8$ GeV
- No significant signal seen anywhere, limits similar to di-muon results



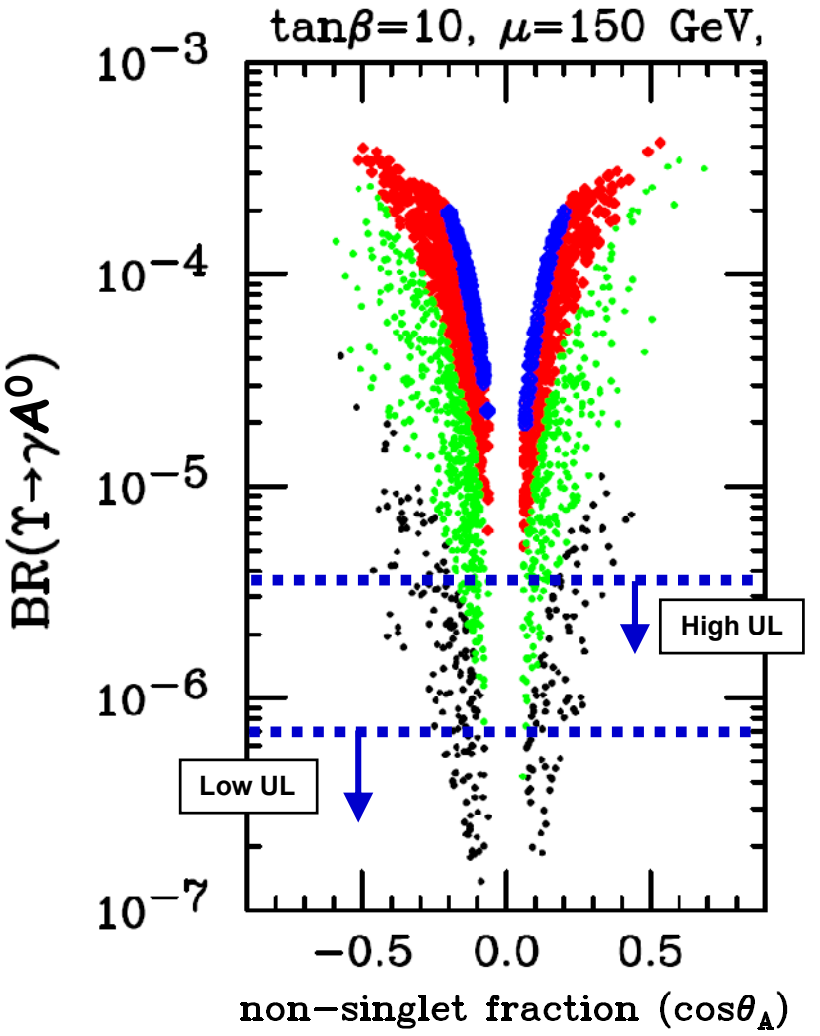
Experimental Limits: $M(A^0) < 2M(\tau)$

$M(A^0)<2M(\tau)$
$2M(\tau)<M(A^0)<7.5$ GeV
7.5 GeV$<M(A^0)<8.8$ GeV
8.8 GeV$<M(A^0)<9.2$ GeV

$A^0 \to \mu\mu$



$A^0 \to$ invisible



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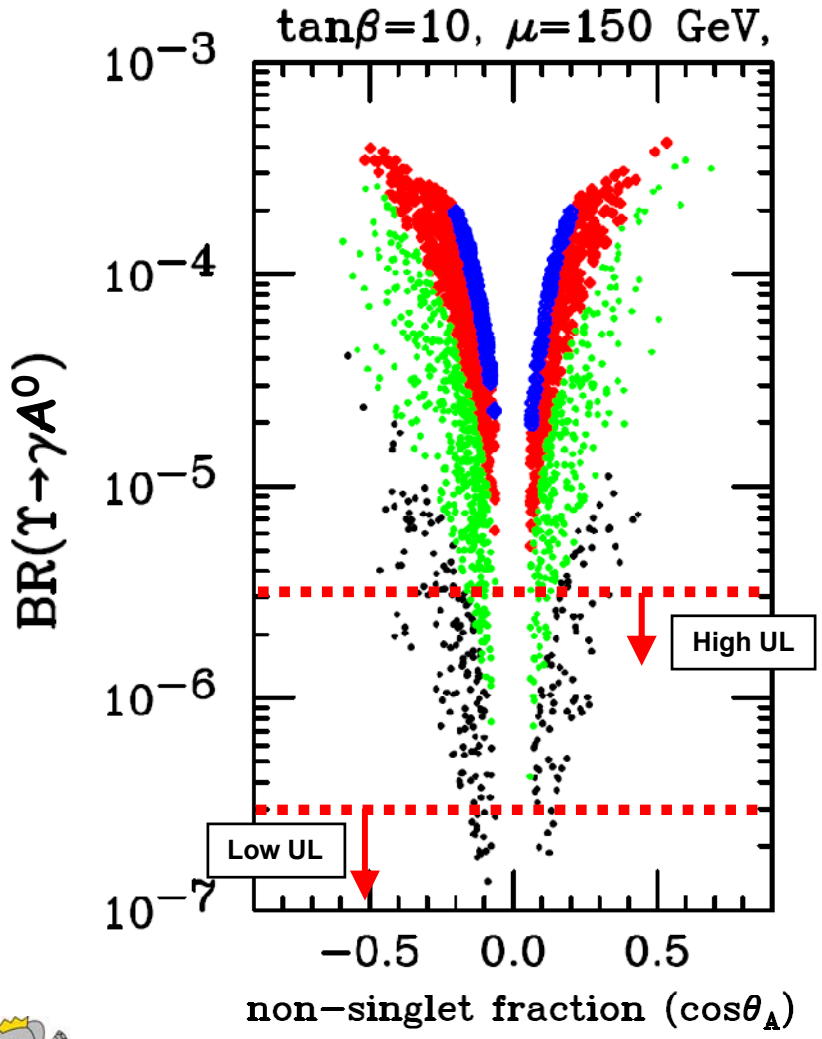
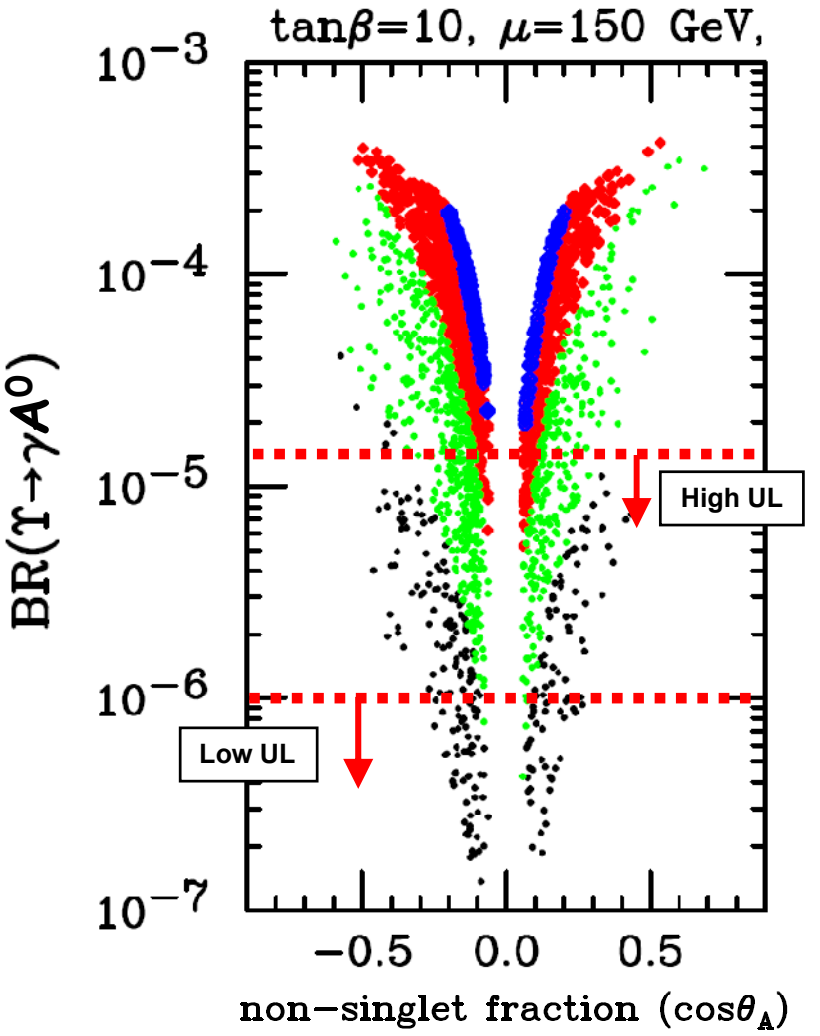
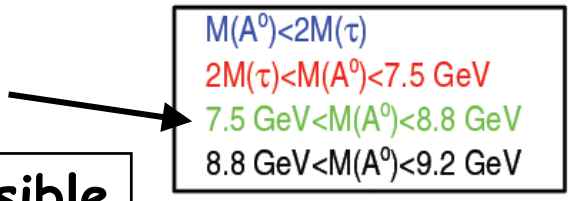
$A^0 \to \mu\mu$



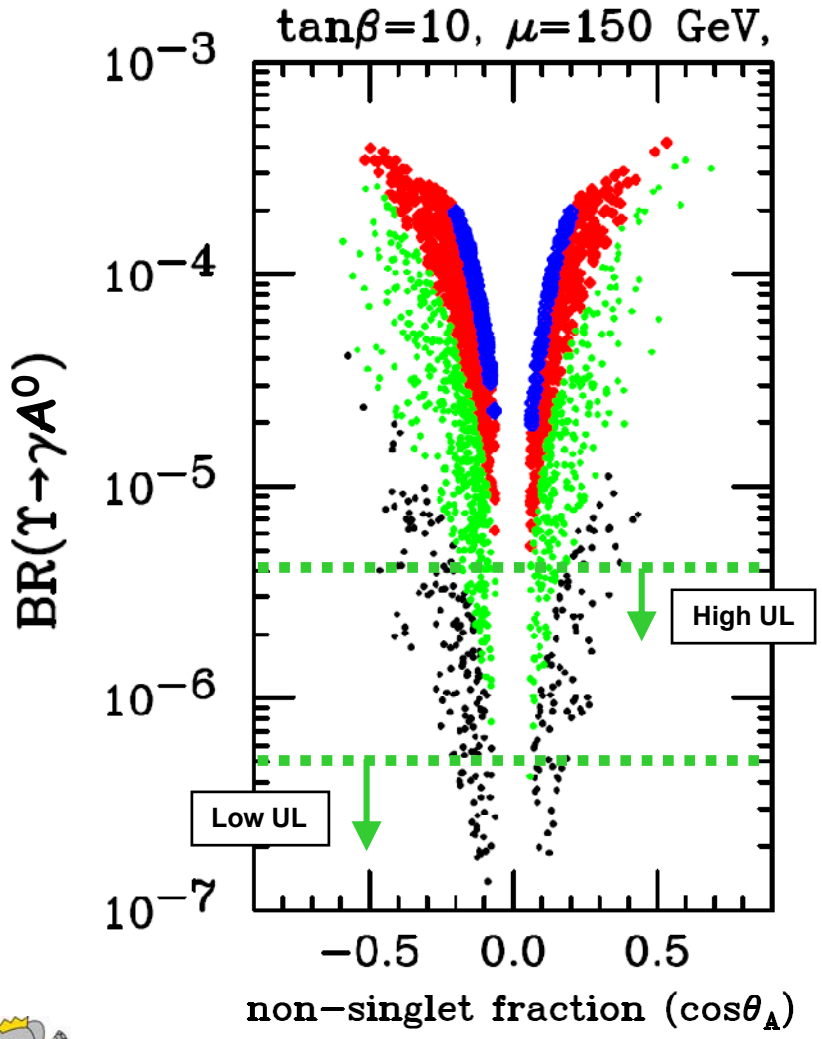
$A^0 \to$ invisible



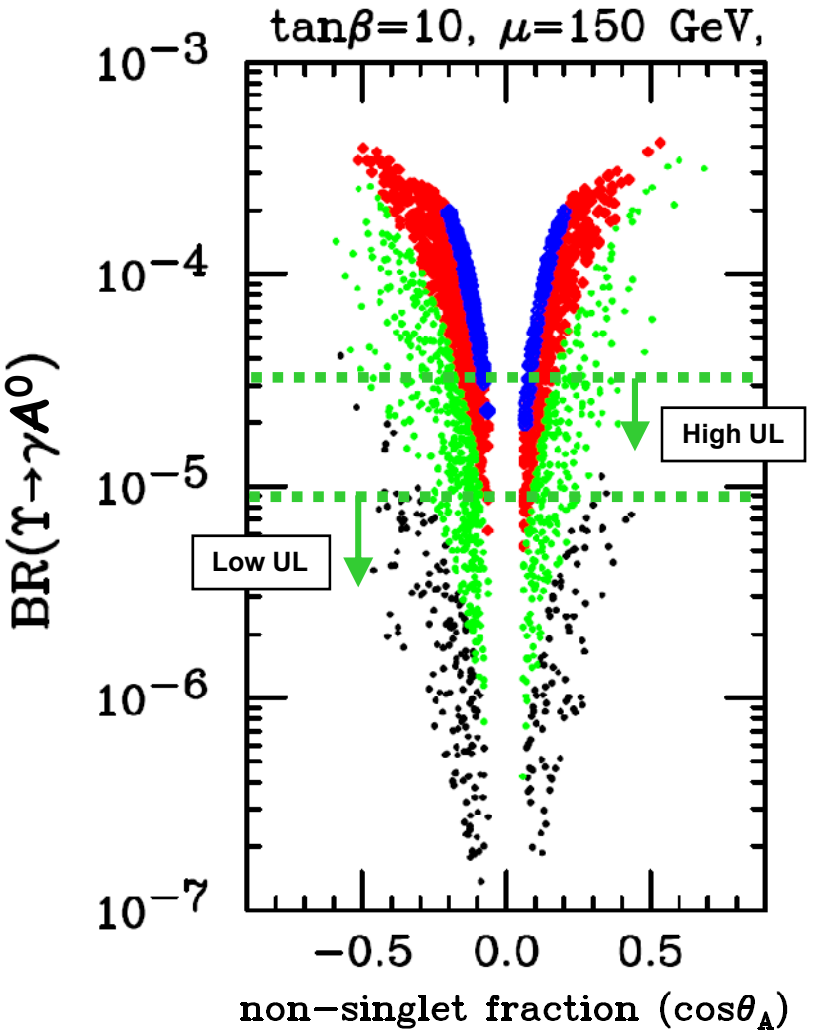
Experimental Limits: 7.5 < M(A^0) < 8.8 GeV



$A^0 \to \mu\mu$



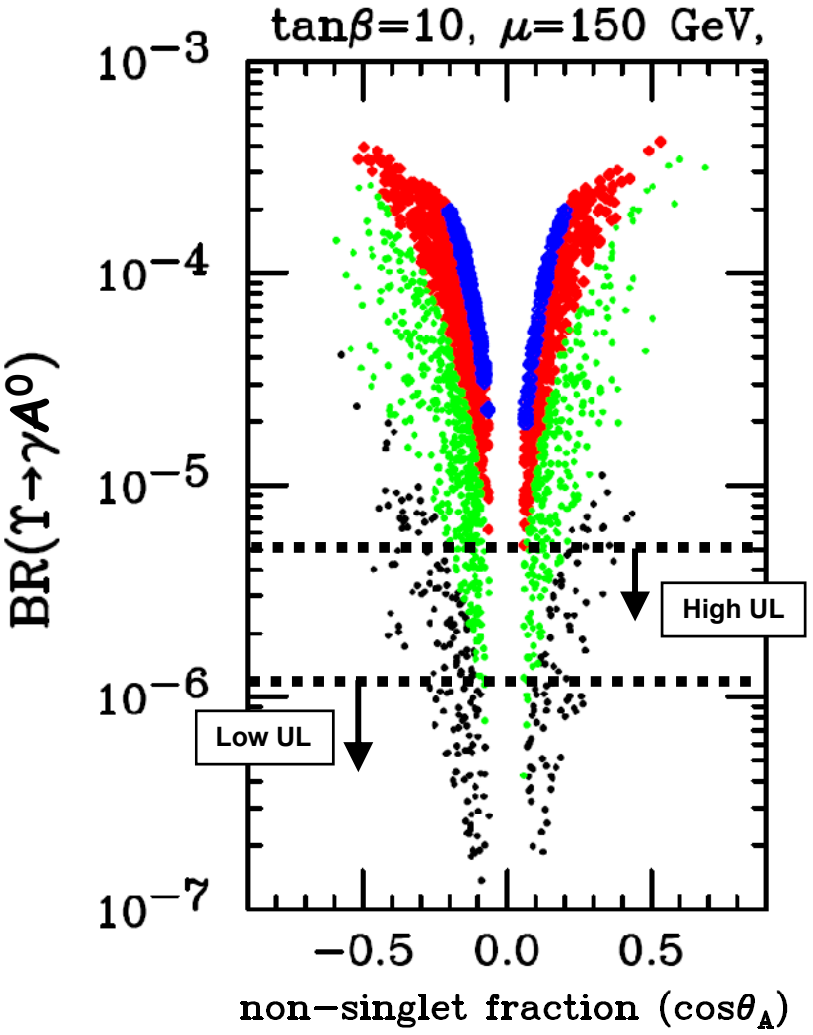
$A^0 \to$ invisible



Experimental Limits: $M(A^0) > 8.8$ GeV

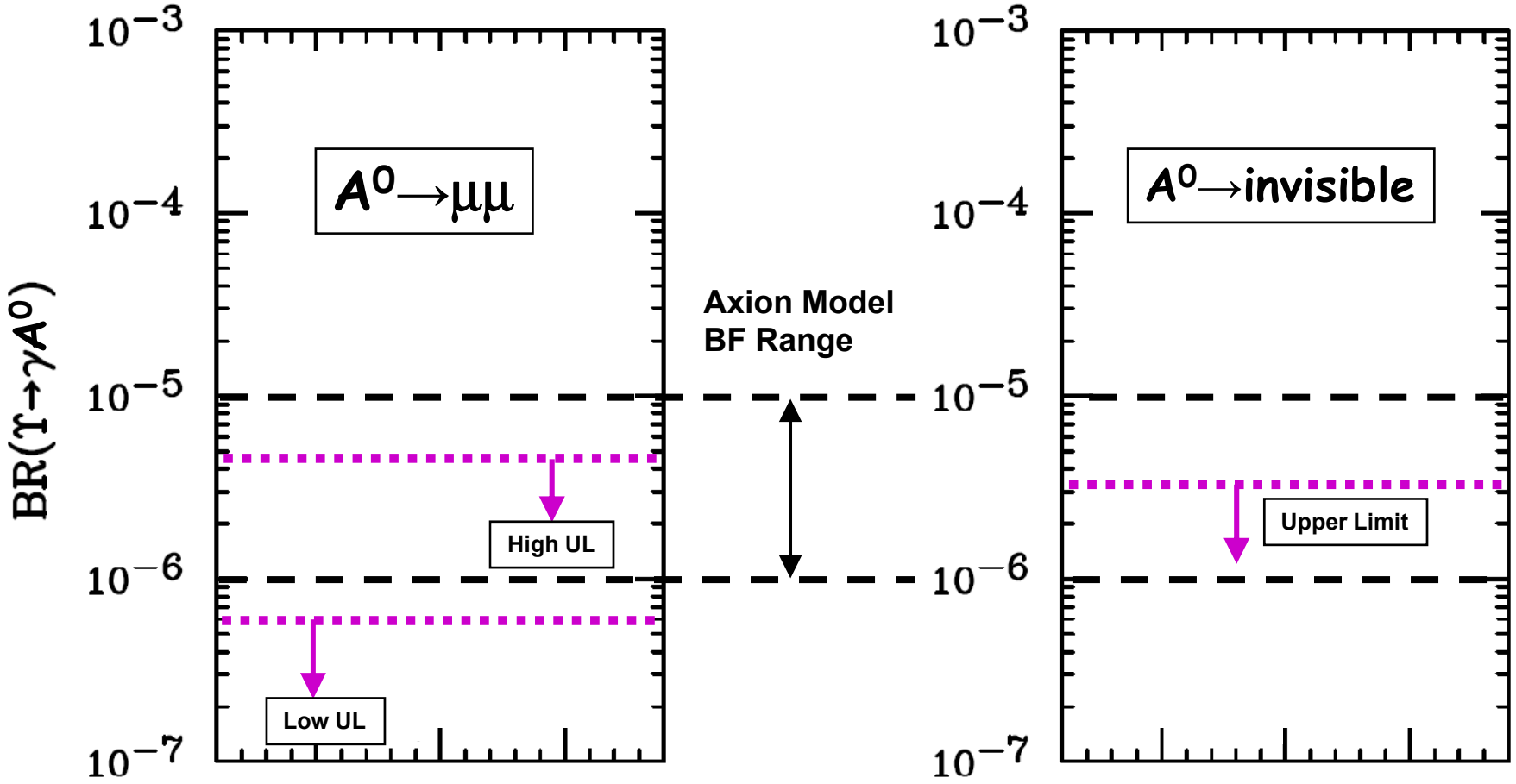
$M(A^0)<2M(\tau)$
$2M(\tau)<M(A^0)<7.5$ GeV
7.5 GeV$<M(A^0)<8.8$ GeV
8.8 GeV$<M(A^0)<9.2$ GeV

$A^0 \rightarrow \mu\mu$



$A^0 \rightarrow$ invisible results do not extend to the highest mass range

Experimental Limits: 0.36 < M(A0) < 0.8 GeV (Axion Model Mass Range)



Conclusions

- No significant $\Upsilon(3S) \to \gamma A^0$, $A^0 \to \mu\mu$ signal observed
  - ~2000 mass points $2m_\mu < M(A^0) < 9.3$ GeV
  - Conference note at arXiv:0902.2176 [hep-ex]
- Upper limits (90% CL) range from (0.25-5.2) x 10^{-6}
  - Generally lower upper limits than CLEO by a factor of ~2
- No significant signal at HyperCP mass (di-muon threshold)
  - BF[$\Upsilon(3S) \to \gamma A^0$ (214)] < 0.8 x 10^{-6} (90% CL)
- No evidence of $\eta_b \to \mu\mu$ decays
  - BR[$\eta_b \to \mu\mu$] < 0.8% (90% CL)
- $\Upsilon(3S) \to \gamma A^0$, $A^0 \to$ invisible UL (0.7-31) x 10^{-6} (90% CL)
  - ICHEP 2008 conference note at arXiv:0808.0017 [hep-ex]
- Other Babar searches for A^0 proceeding
  - **$\Upsilon(2S) \to \gamma A^0$, $A^0 \to \mu\mu$**
    - **~20% better sensitivity than Y(3S)**
  - $\Upsilon(2S, 3S) \to \gamma A^0$, $A^0 \to \tau\tau$
  - $\Upsilon(2S, 3S) \to \gamma A^0$, $A^0 \to$ hadrons
  - $b \to s A^0$, $A^0 \to \mu\mu$