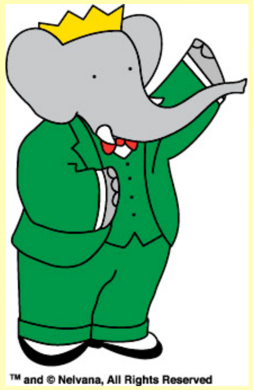
Search for Light Higgs at BABAR



Swagato Banerjee

University of Victoria | British Columbia Canada

Les Renconstres de Physique de la Vallee d'Aoste
La Thuile, Aosta Valley, Italy
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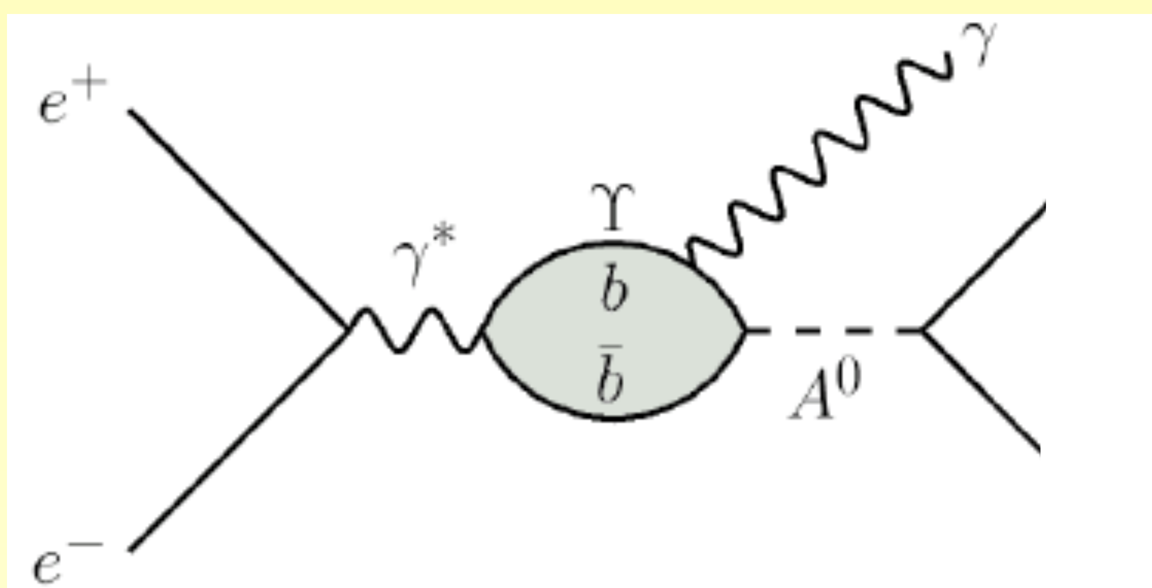
Light Higgs in Υ decays?

- Higgs Mechanism: Electroweak symmetry breaking
- Naturalness problem: Higgs mass unstable under radiative corrections in Standard Model
- Possible solution: Minimal Supersymmetric Standard Model (2 Higgs doublets → $h, H, A, H^{\pm}$)
- Hierarchy Problem: Fine tune the scale of Electroweak symmetry breaking
- Possible solution: Next-to-Minimal Supersymmetric Standard Model (introduce Higgs singlet)
- Mixing of singlet with MSSM-like Higgs doublet can produce low mass CP-odd Higgs (A^0)
- If mixing is small, coupling of A^0 to Z is suppressed: this evades most LEP limits, including those from model independent Higgs search using recoil mass against $Z \to e^+ e^-$ or $\mu^+ \mu^-$
- If BR($H \to A^0 A^0$) > 0.7, $m_{A0} < 2m_b$, LEP limits on *Higgs* → *bb, bbbb* channels can be evaded
- Interesting possibility of Higgs discovery in $\Upsilon \to \gamma A^0$ decays via the Wilczek mechanism



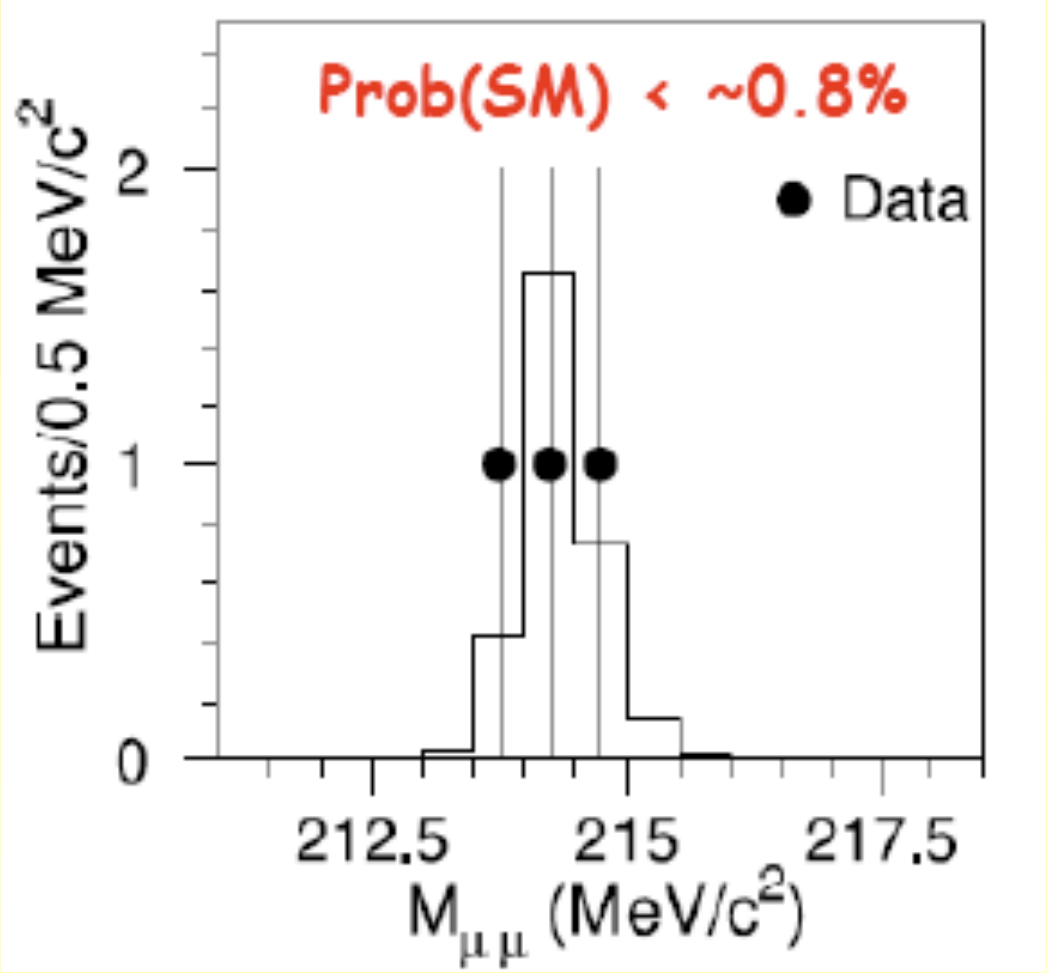
Depending on M(A^0), dominant decays are

- $A^0 \to$ *hadrons*
- $A^0 \to \tau^+ \tau^-$
- $A^0 \to \mu^+ \mu^-$ (*)
- $A^0 \to$ *invisible* (*)

(* In this talk)

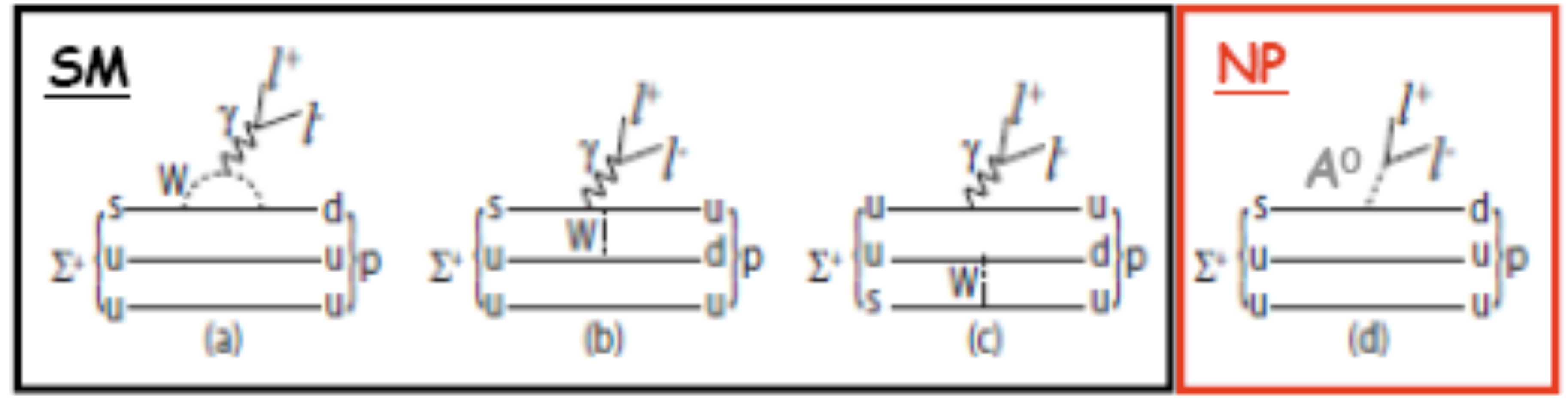
Can we solve the Dark Matter puzzle and illuminate the Higgs sector at the same time?

HyperCP excess events



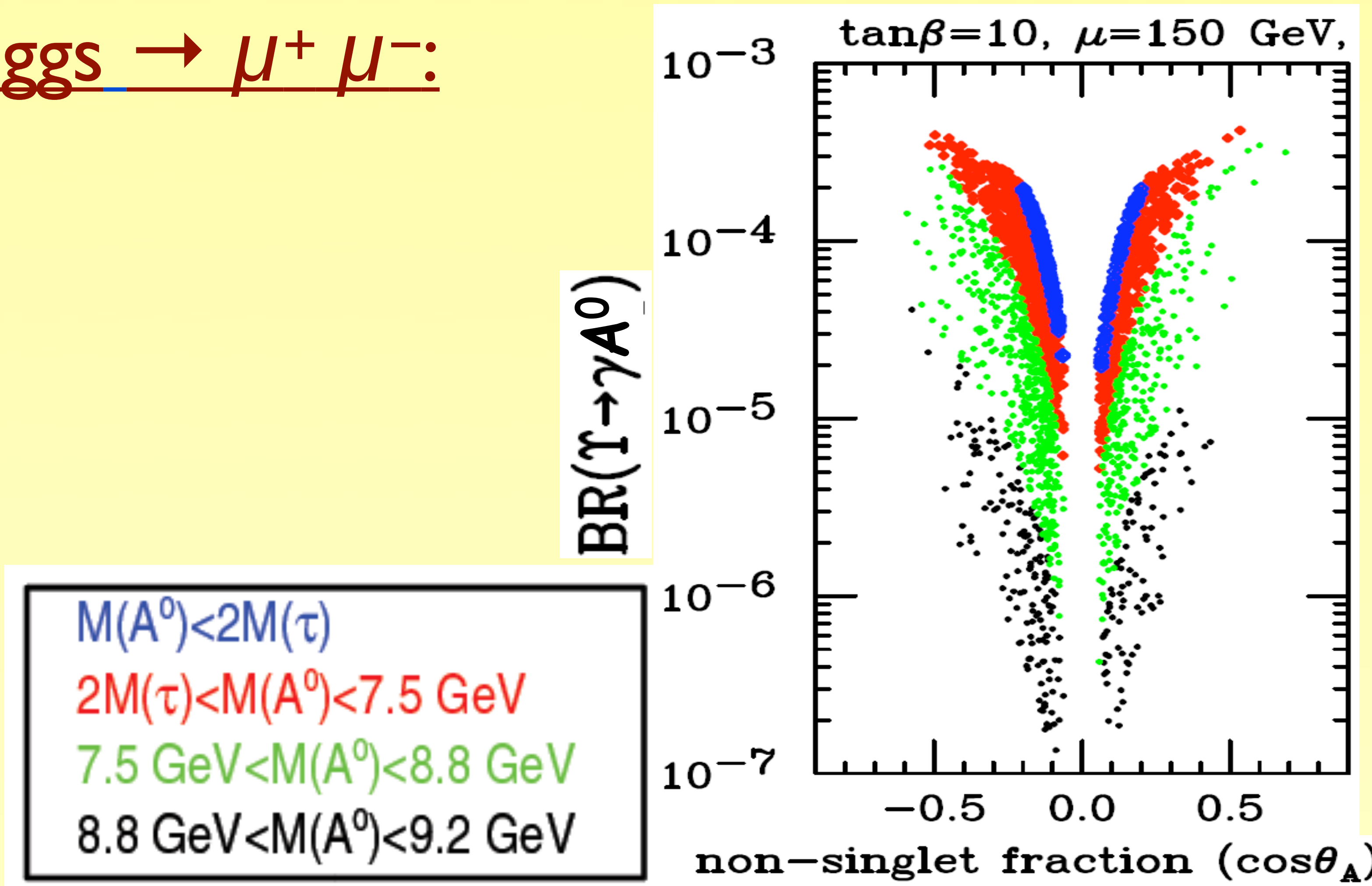
Phys. Rev. Lett. 94, 021801 (2005)

- HyperCP experiment observed resonance structure in $\Sigma \rightarrow p\mu^+\mu^-$ scattering, 3 events at $M_{\mu\mu}$=214 MeV/c^2 observed. Light scalar decaying to $\mu^+\mu^-$?



How small can the rate be?

Higgs → $\mu^+ \mu^-$:



Light Higgs $(A^0) = A_{MSSM} \cos\theta_A + A_{singlet} \sin\theta_A$

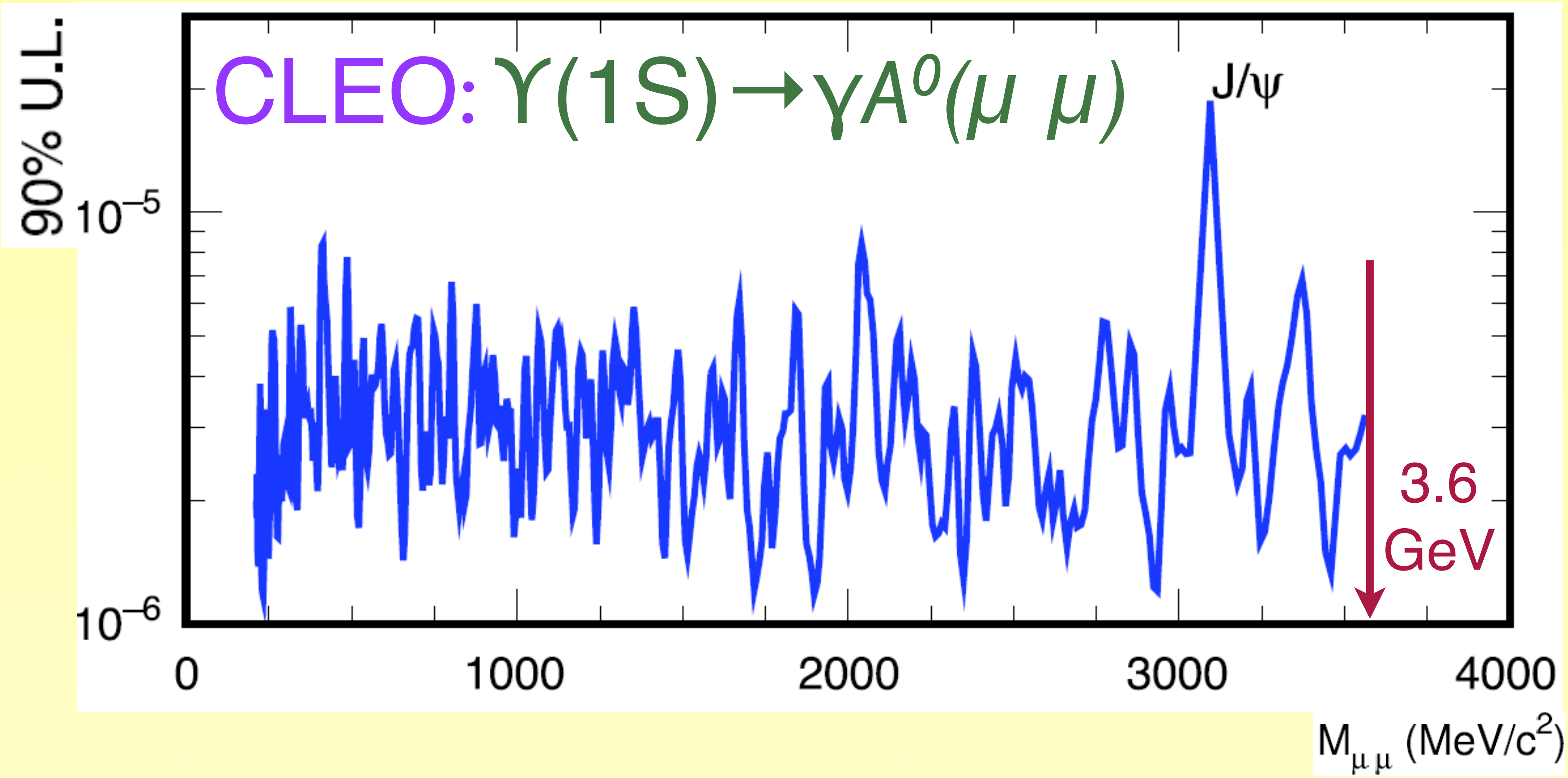
J. Gunion et. al.,
Phys. Rev. D76, 051105 (2007)

Axion → $\mu^+ \mu^-$: Motivated by the galactic positron excess seen by PAMELA and ATIC/PPB-BETS

"Dark Matter through the Axion Portal" may be realized in the mass range [360, 800] MeV for the axion decaying predominantly into di-muons with $BR(\Upsilon \to \gamma A^0) \sim 10^{-5} - 10^{-6}$

Y. Nomura and J. Thaler, arXiv: 0810.5397 [hep-ph]

How small is the rate known to be?



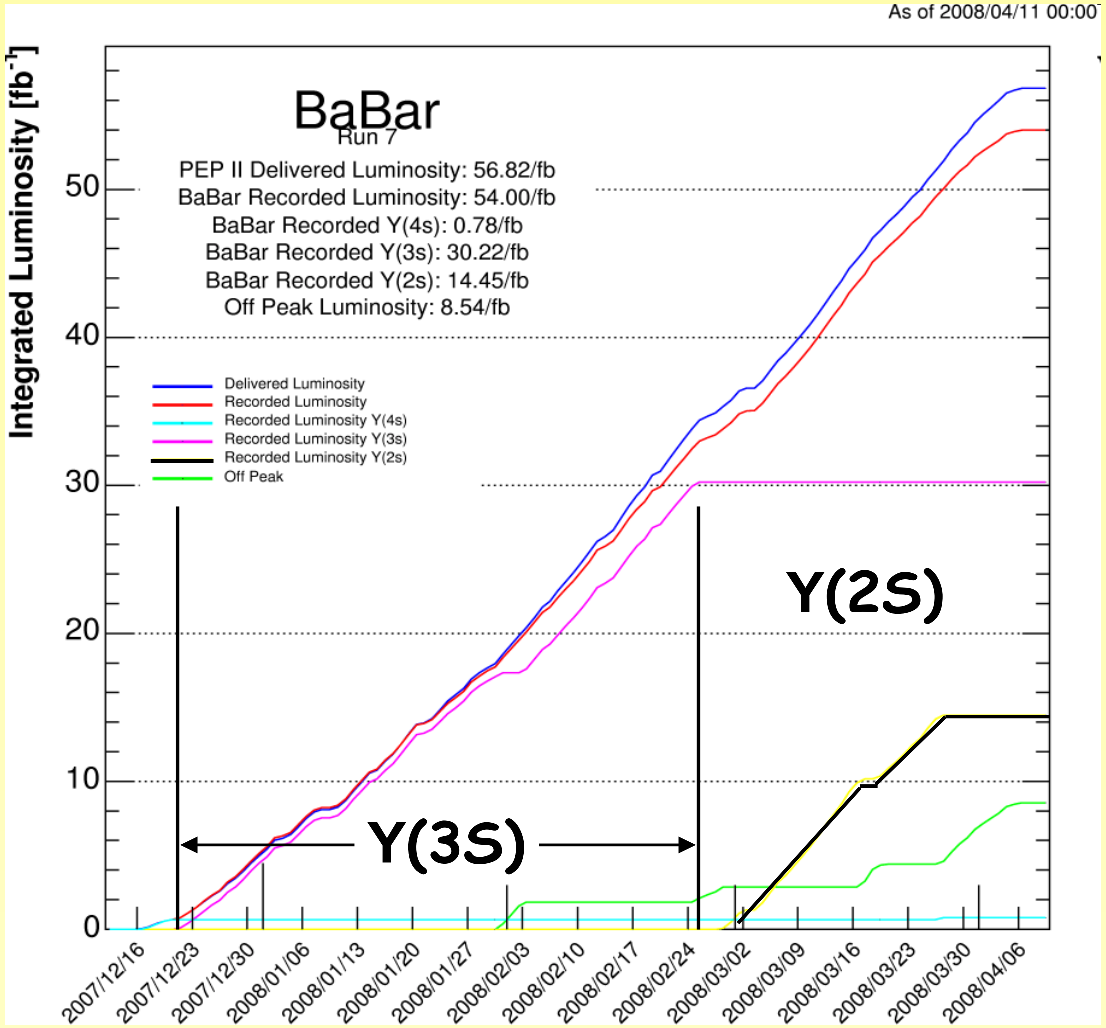
First upper limit from CLEO: $BF(\Upsilon(1S) \to \gamma A^0) \times BF(A^0 \to \mu^+\mu^-) < (1\text{-}20) \times 10^{-6}$

using 21.5M $\Upsilon(1S)$ mesons directly produced in e^+e^- annihilation

Phys. Rev. Lett. 101, 151802 (2008)

How small a rate can BABAR measure?

Between Dec 2007 - Apr 2008,
PEP II collected data below $\Upsilon(4S)$:
~ 30 fb^{-1} @ $\Upsilon(3S)$ (122 M decays)
~ 15 fb^{-1} @ $\Upsilon(2S)$ (100 M decays)



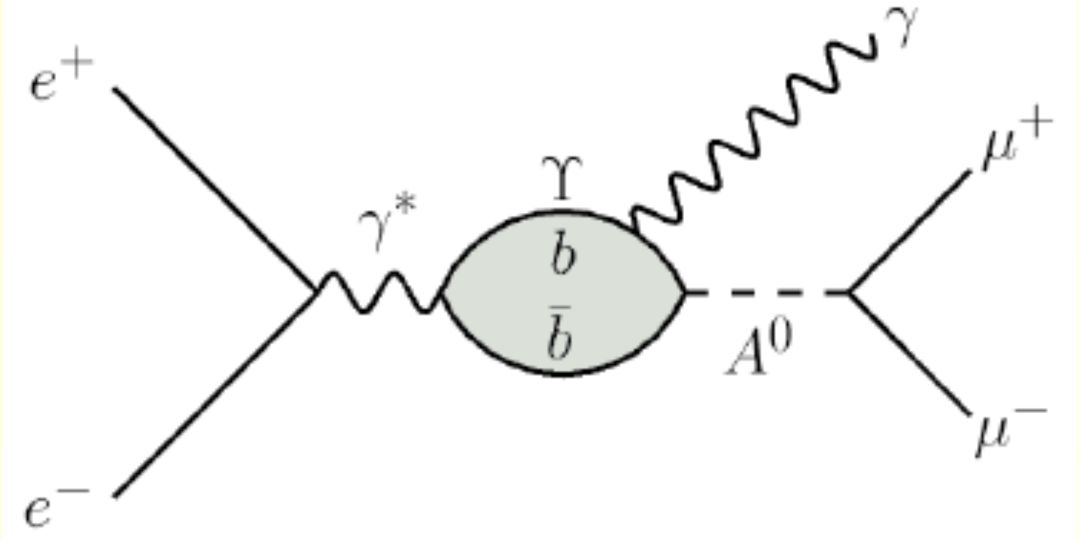
Dramatic increase in
sensitivity to rare decays:
$\Gamma_{\Upsilon(4S)} / \Gamma_{\Upsilon(nS)} \sim 10^3$

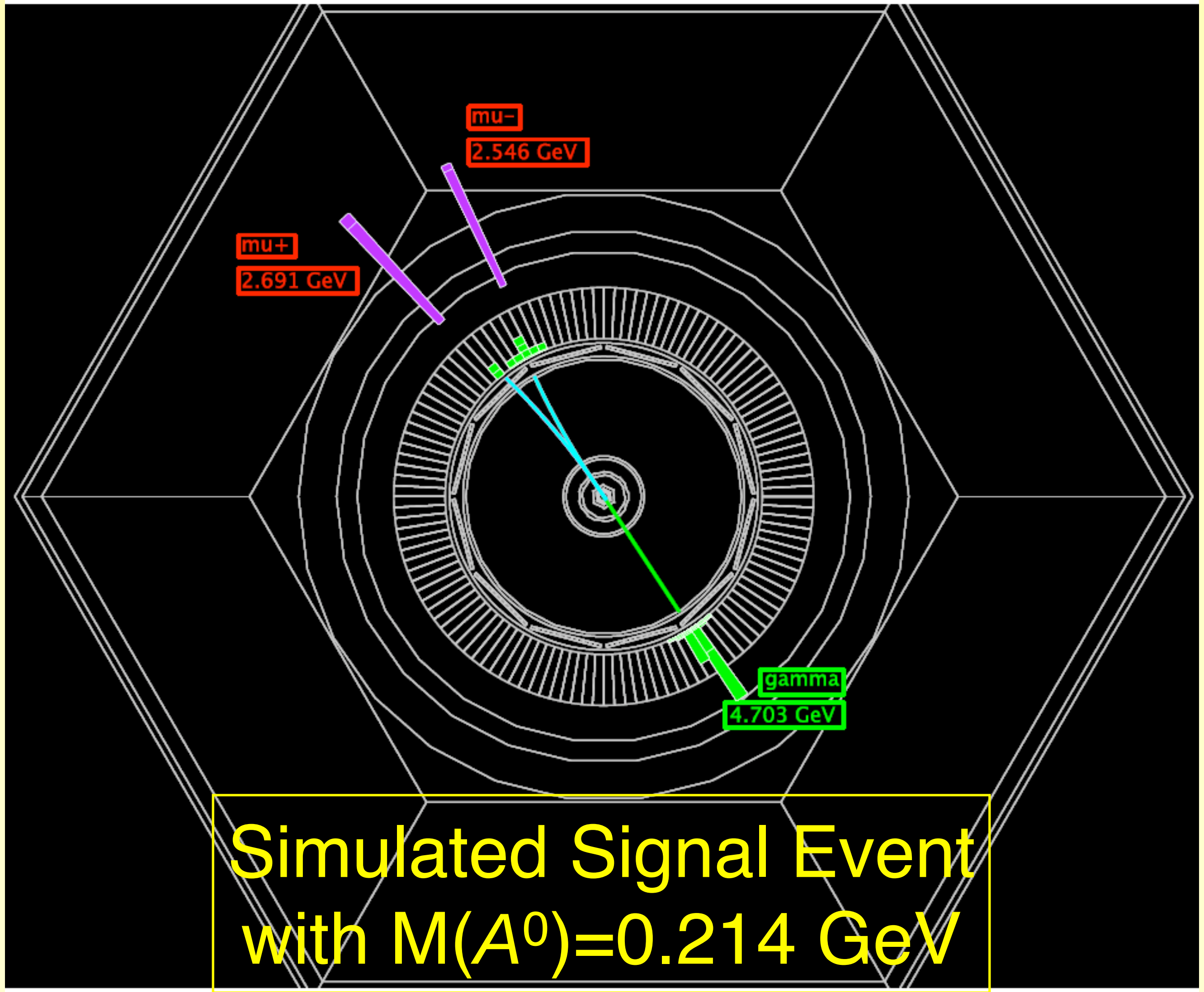
Sensitivity for Higgs discovery in Υ Decays:

$$\sigma(\mathcal{B}) = \frac{\sqrt{N_{\mathrm{bkg}}}}{\varepsilon N_{\Upsilon(3S)}}$$

Efficiency ~ 50-25 %; Estimate N_{bkg} within ± resolution ~ 3-10 MeV
~5 times more Υ decays ⇨ improve CLEO limits by factor of ~2

Event selection

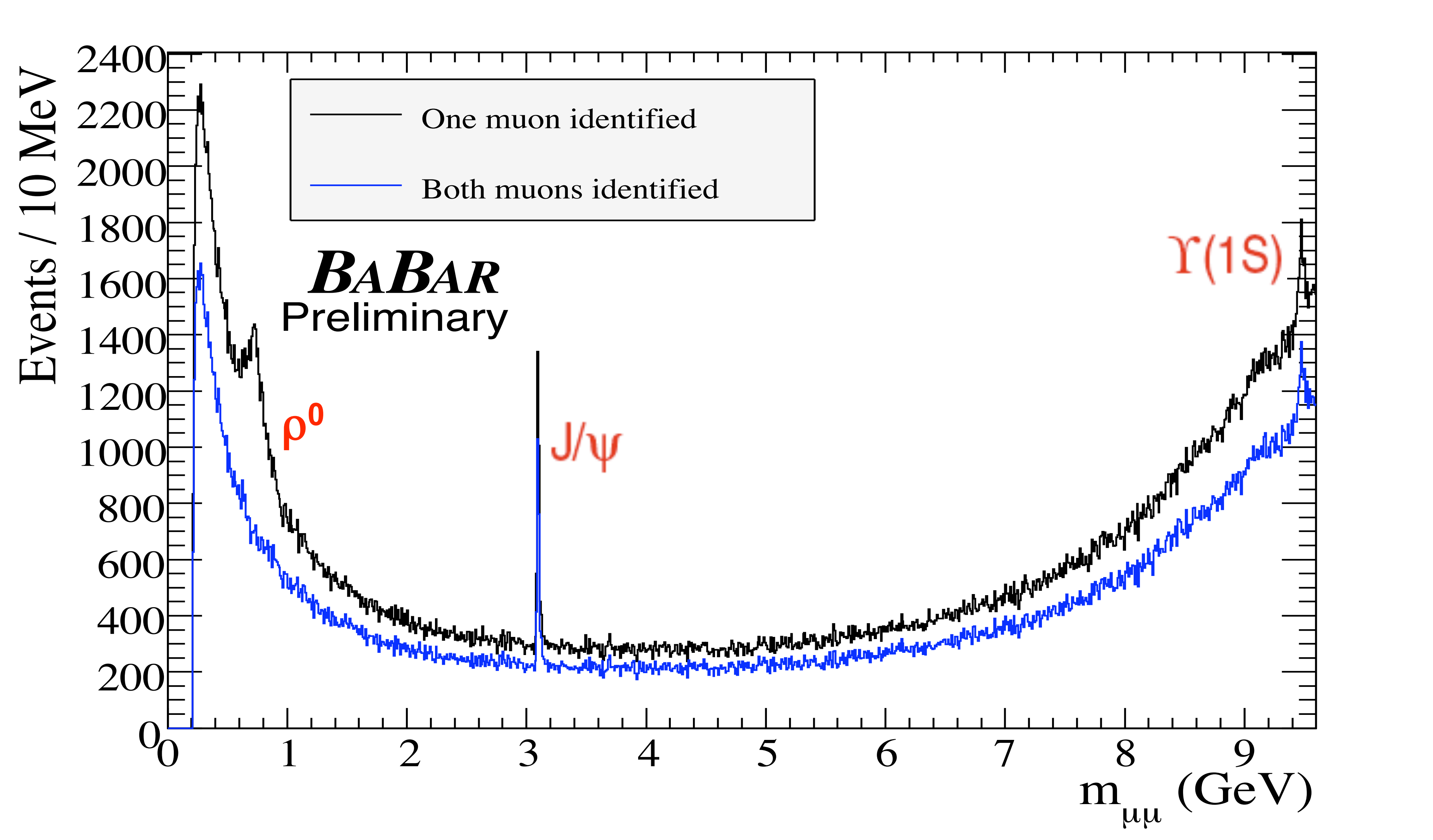




- Fully reconstruct final state from
  - two oppositely charged tracks
  - and a single energetic photon
- only one photon with
  - CM Energy > 0.5 GeV
- Kinematic ϒ(3S) fit with
  - Beam Energy Constraint
  - Beam Spot Constraint on di-muon vertex
  - Fit χ^2 probability > 10^{-6}
- Extra Mass:

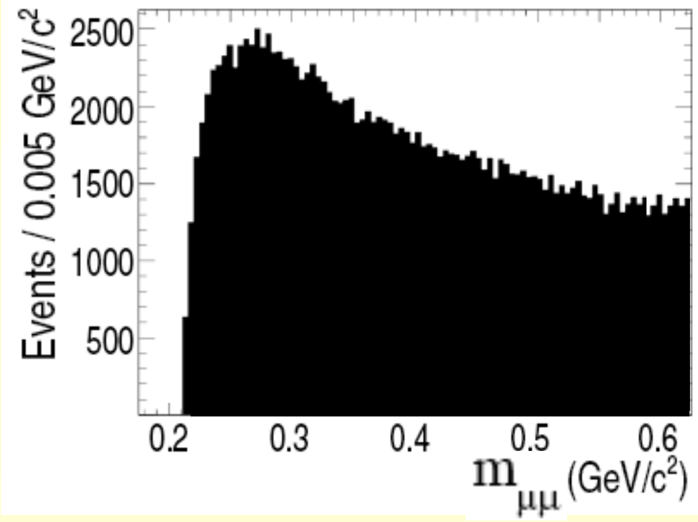
  $-0.07 < M_{beam} - M_{\Upsilon(3S)} < 2$ GeV
- Di-muon system back-to-back with photon

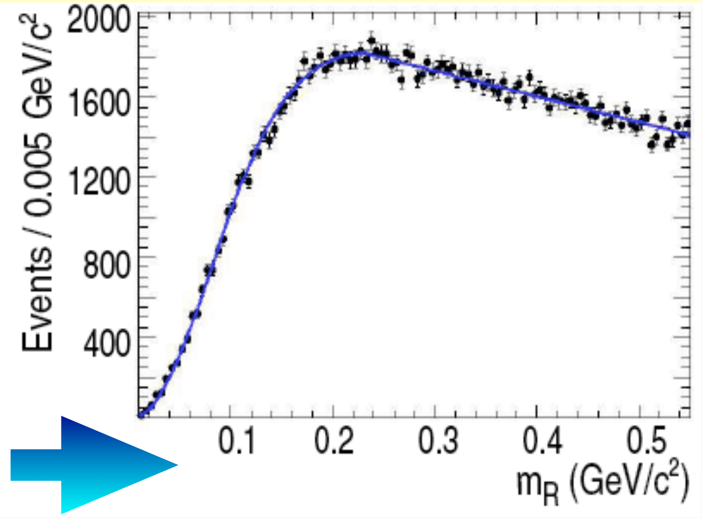
The di-muon mass spectrum



- Signal extraction: ML fit in slices of invariant mass
  - Variable of choice is "reduced mass"
  - Smooth threshold behavior

$$m_R = \sqrt{m_{\mu\mu}^2 - 4m_\mu^2} = 2|p_\mu^{A^0}|$$

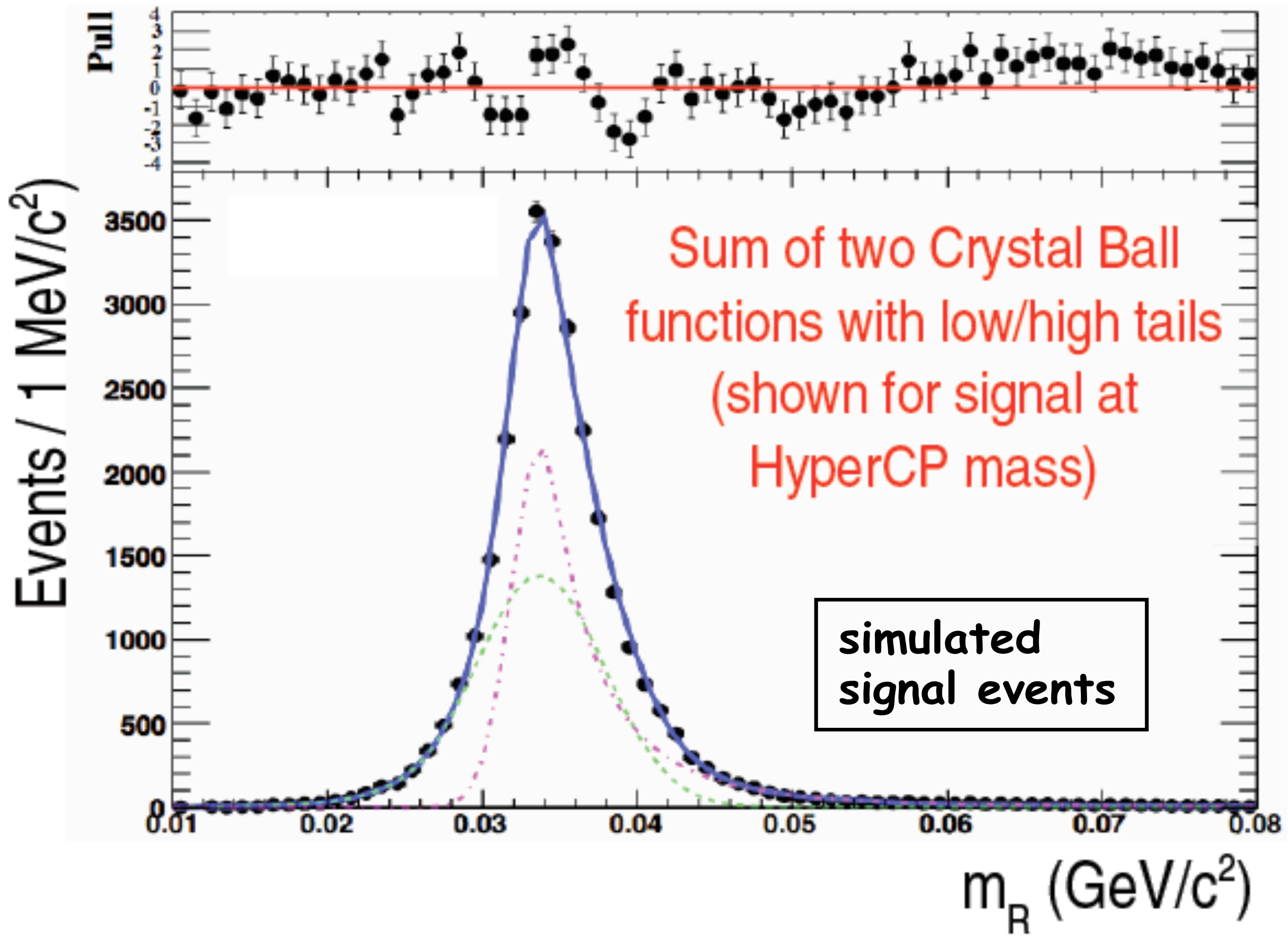




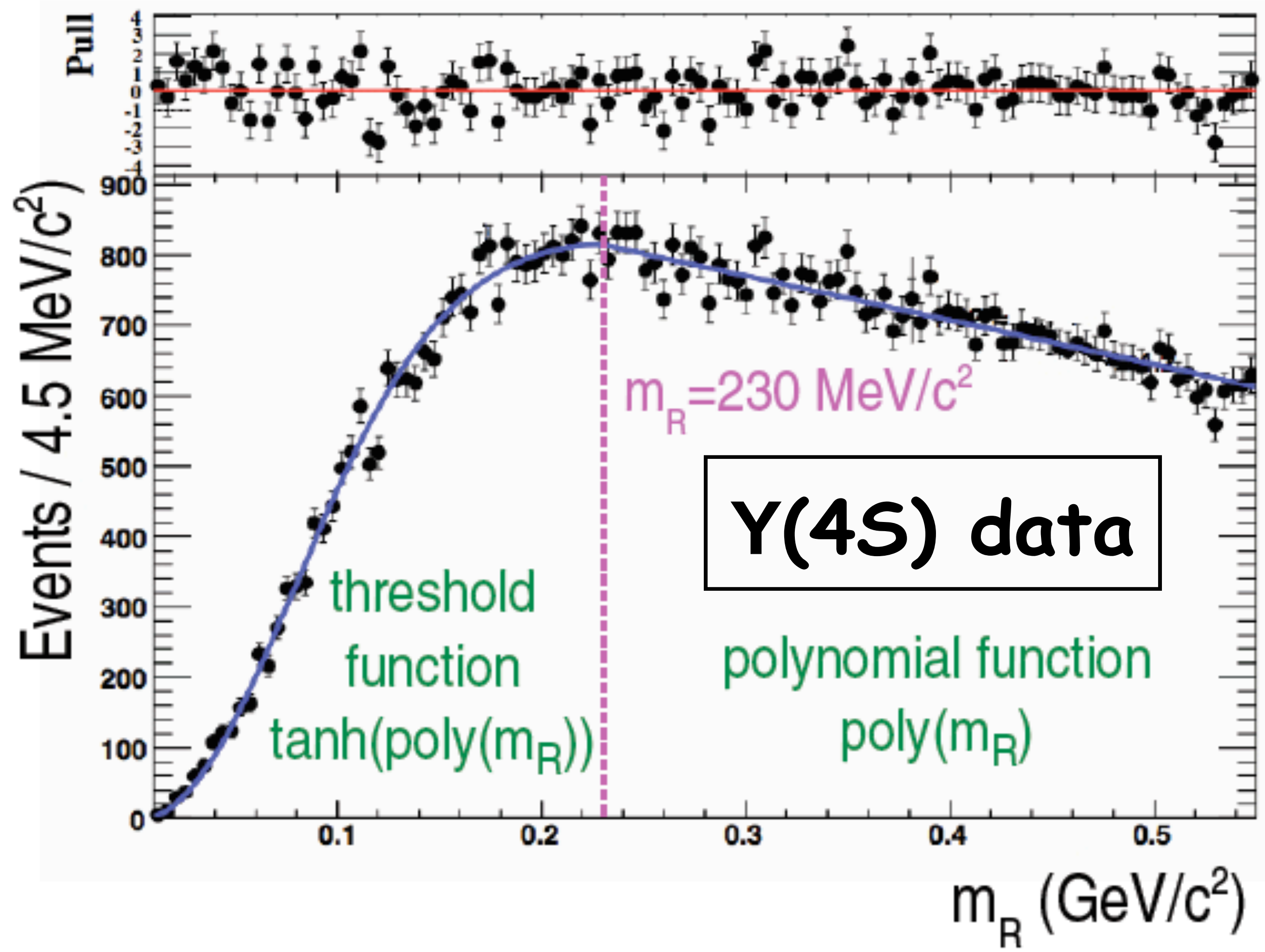
Signal and background shapes

- Signal PDF generated at 20 values between $0.212 < M(A^0) < 9.5$ GeV
  - Sum of two Crystal Balls
    - ☞ With opposite-side tails
- Background: smooth functions from fit to Υ(4S) data
  - Threshold function at low mass, linear above 0.23 GeV

Signal PDF



Background PDF

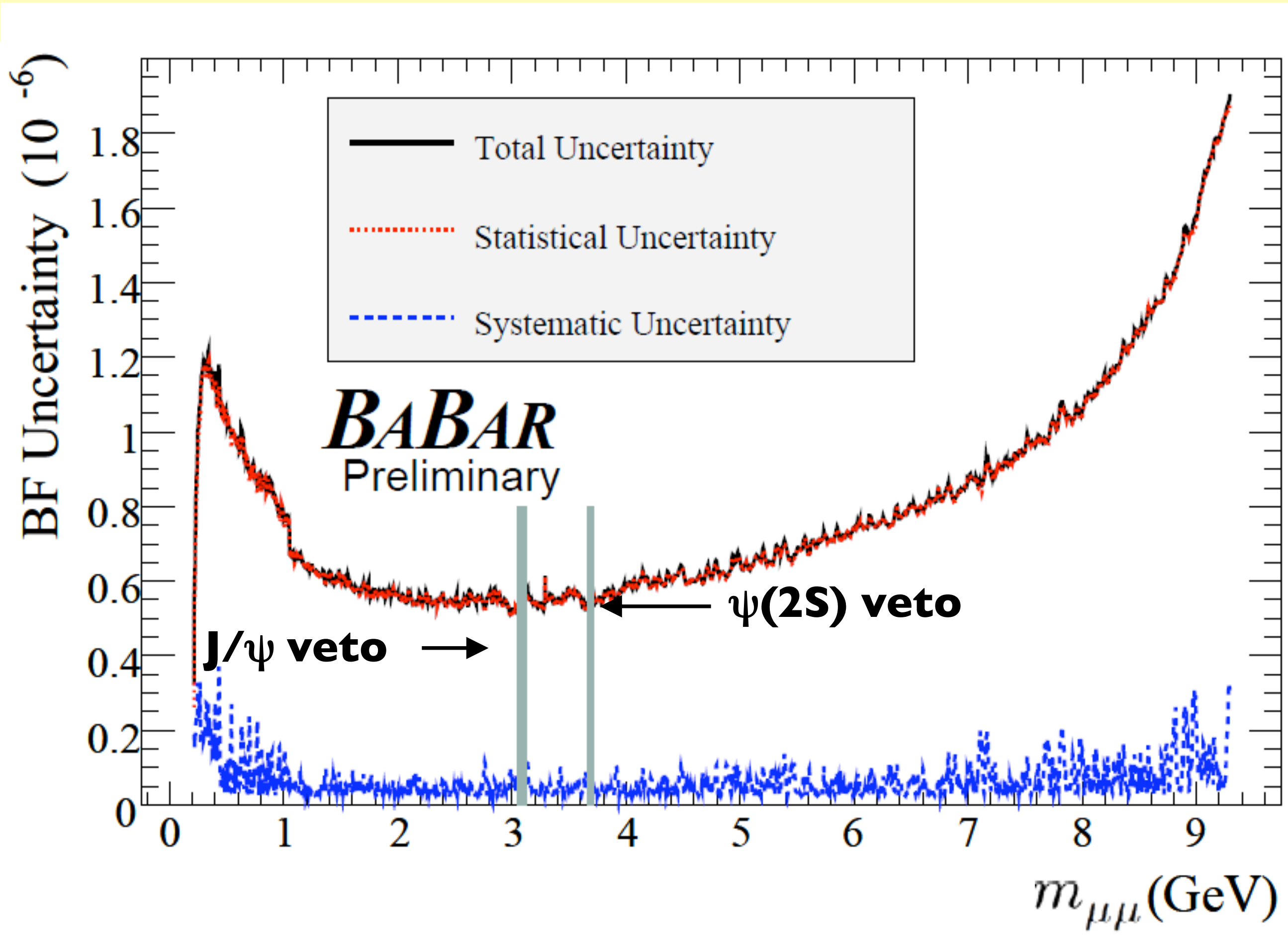


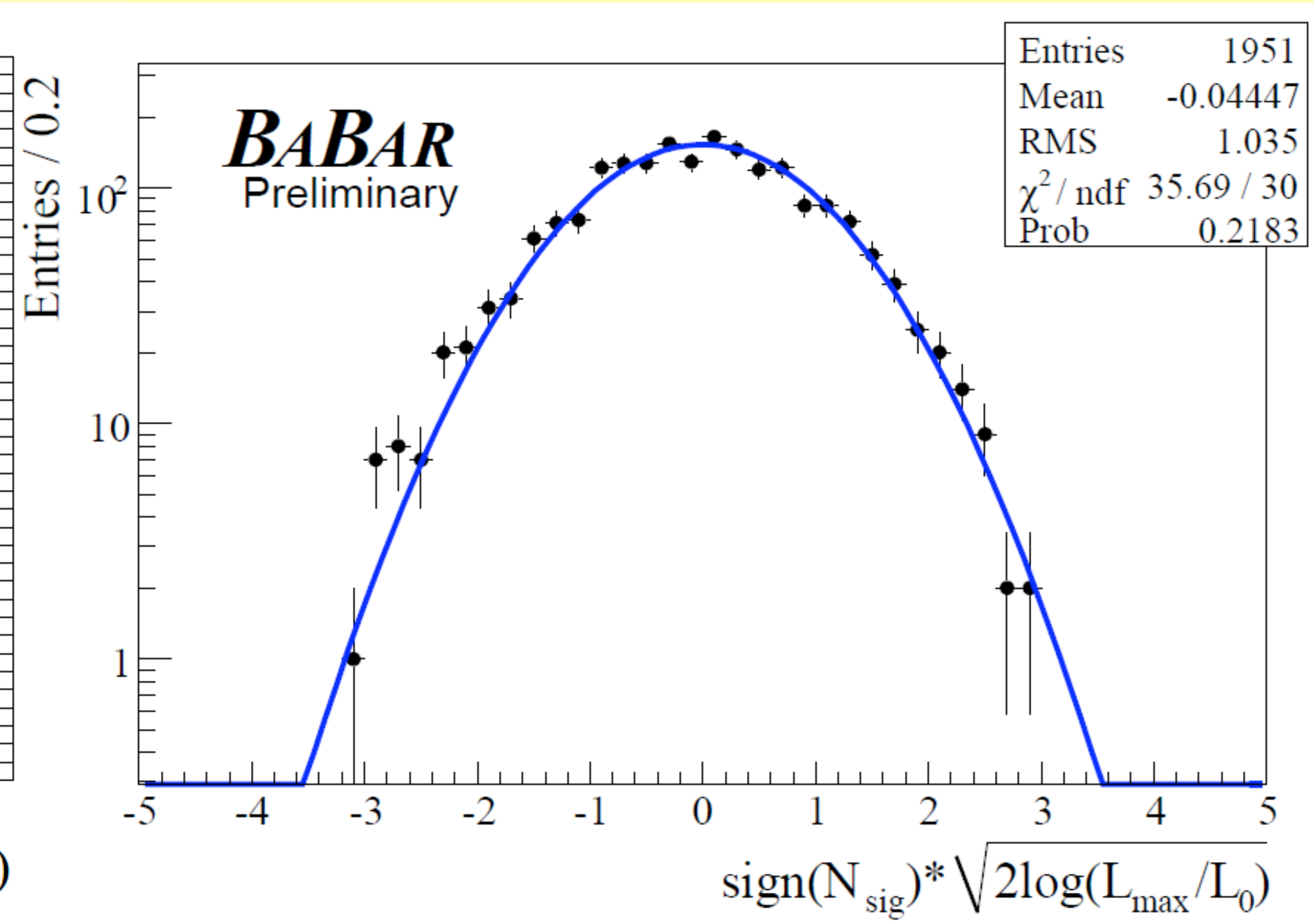
- ML Fit to ~ 2000 mass points scanned between $2M(\mu) < M(A^0) < 9.3$ GeV

Signal Significance

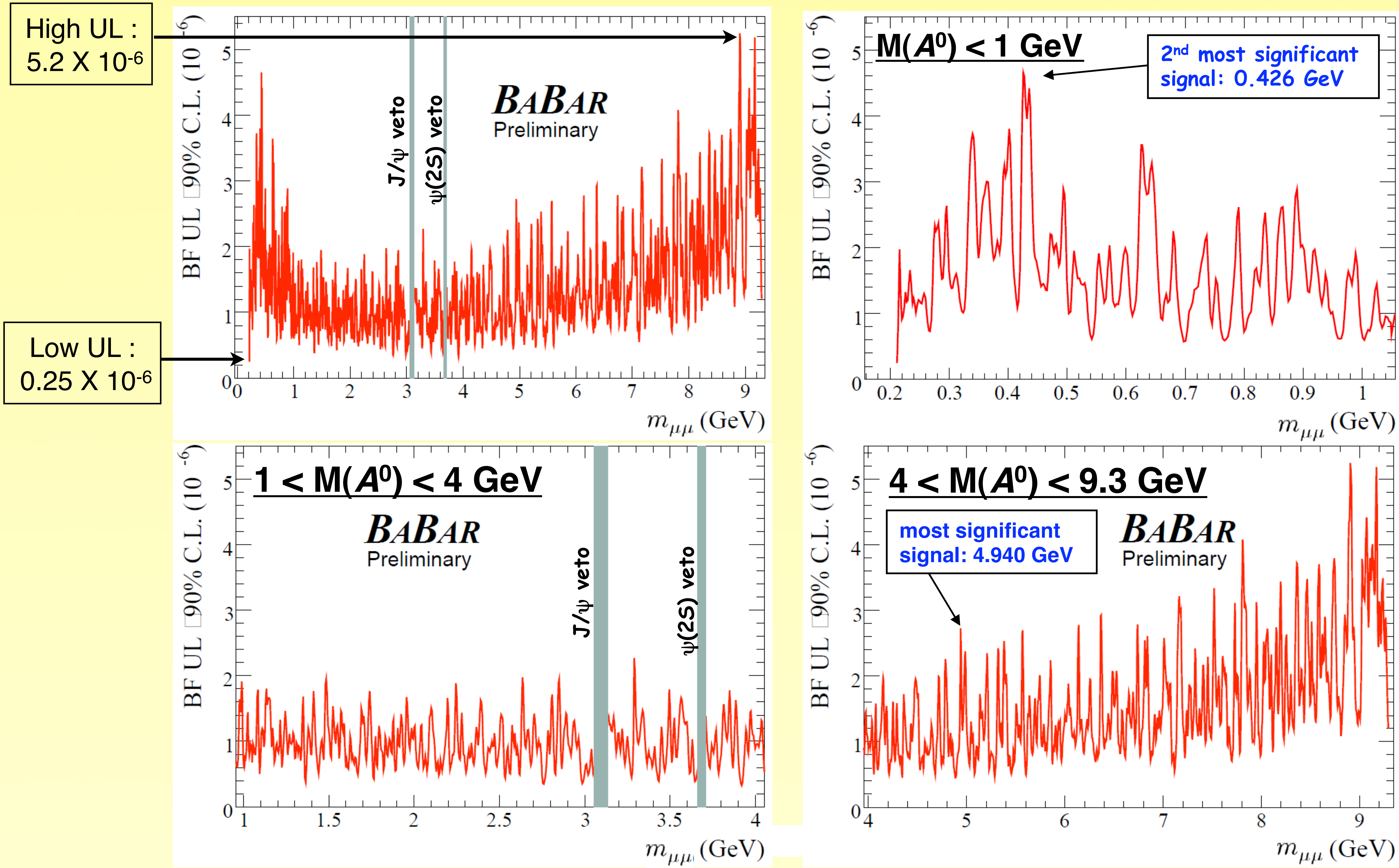
- PDF systematics
  - ±1σ PDF parameter variations
  - Signal width calibrated from J/ψ data/MC
  - Peaking background mean, width, tail
- Fit bias $\sigma_{BR} \sim 0.02 \times 10^{-6}$
- Efficiency corrections ~ 2-10%
- ϒ(3S) counting ~ 1%

- Signal significance distribution (stat+sys) in ϒ(3S) data shows no significant outliers
  - No excess signal events observed at HyperCP mass region ~214 MeV
  - Most significant upward fluctuations (~3σ) at 4.940 GeV and 0.426 GeV
  - ~80% probability to see one >3σ result for the number of points here





BF(Υ(3S)→γA^0(μ μ)) Upper Limits @ 90% CL



arXiv: 0902.2176 [hep-ex]

Most significant fit region ~ 4.940 GeV

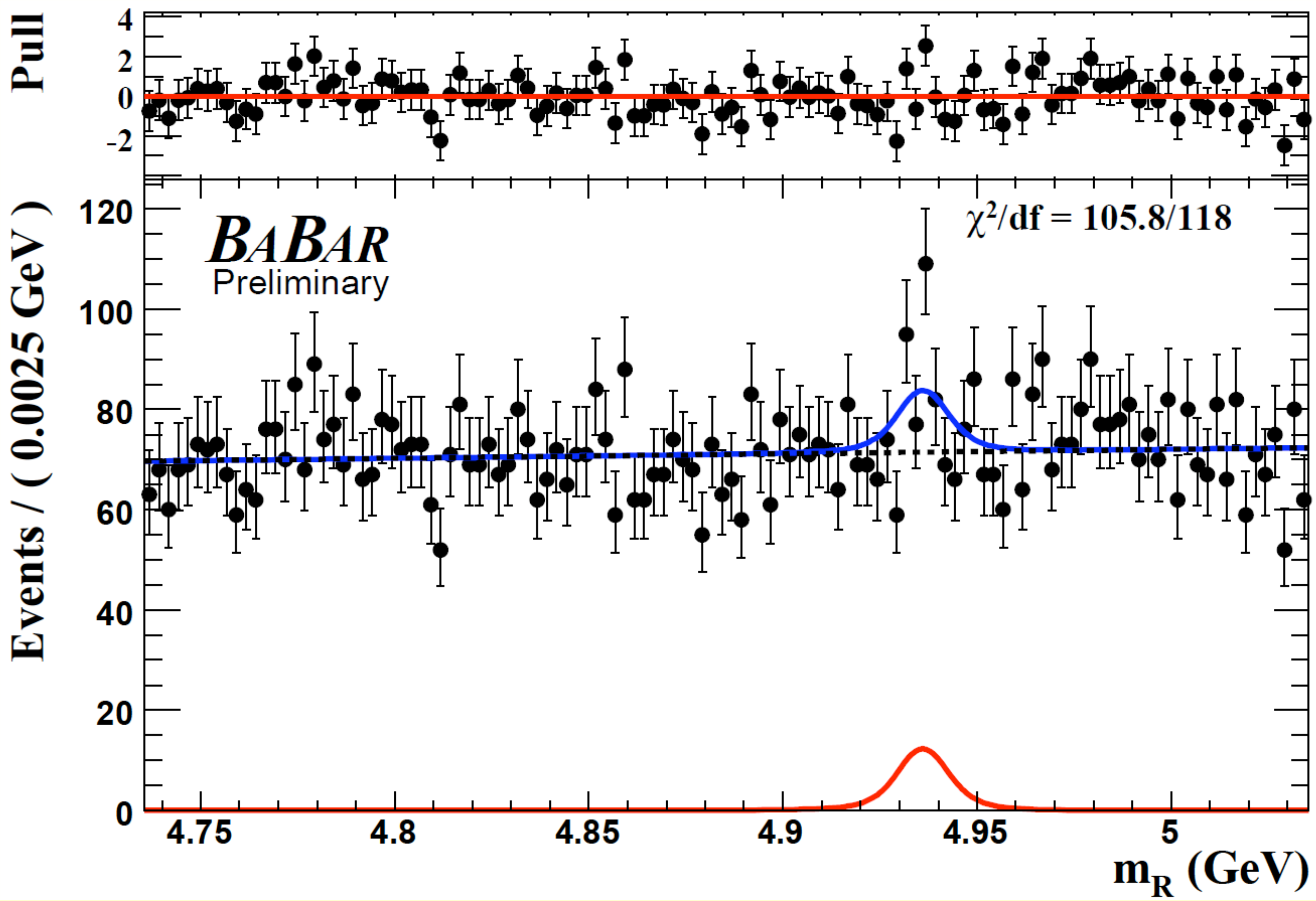
BF(4.940) = (1.9 ± 0.7 ± 0.1) × 10^{-6}

Significance = 3.0 σ (stat+sys)

Total fit

Background

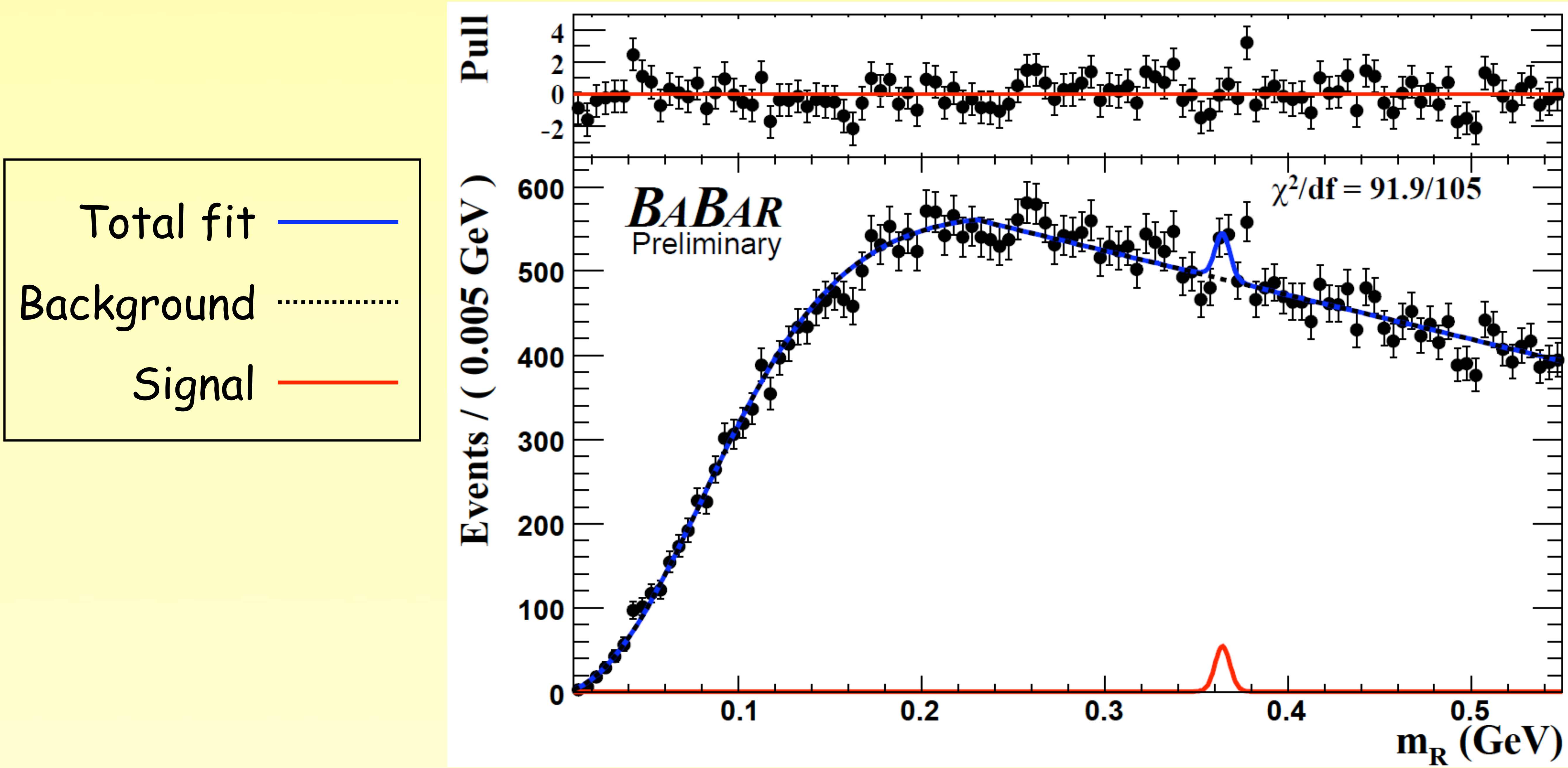
Signal



2nd most significant fit region ~ 0.426 GeV

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

Significance = 2.9 σ (stat+sys)

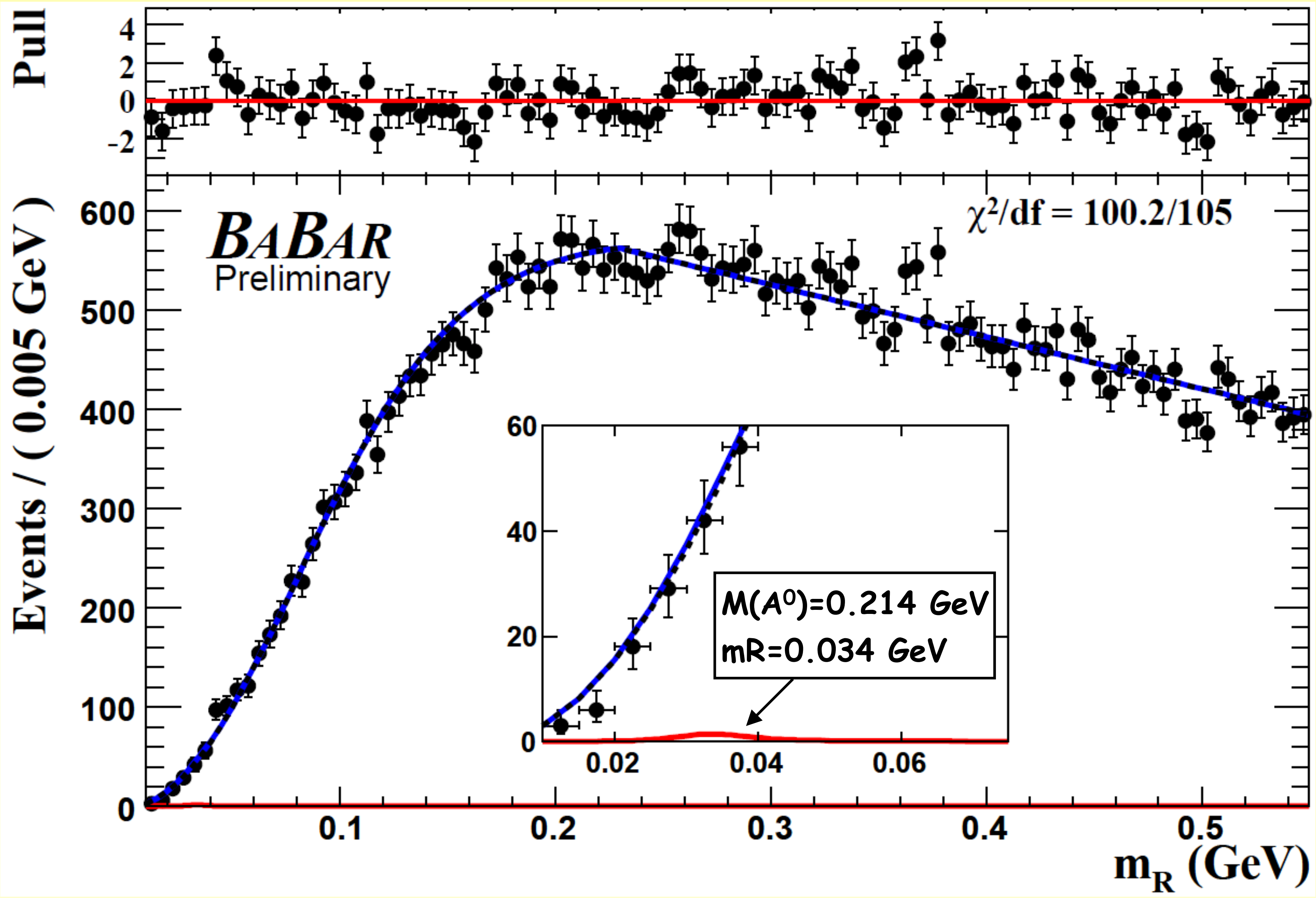


HyperCP mass region ~ 0.214 GeV

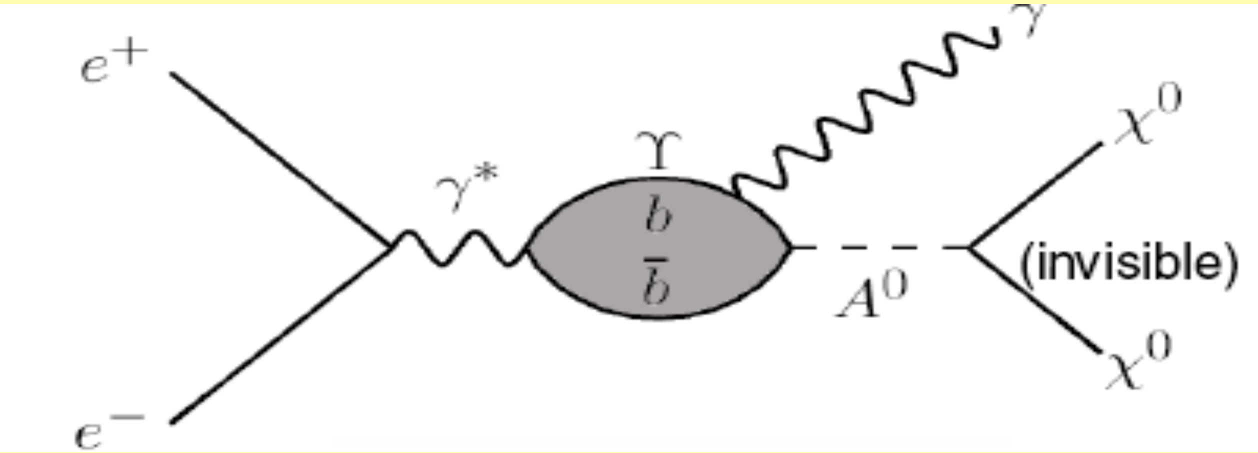
$$\mathrm{BF}(0.214) = (0.12\,^{+0.43}_{-0.41} \pm 0.17) \times 10^{-6}$$

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

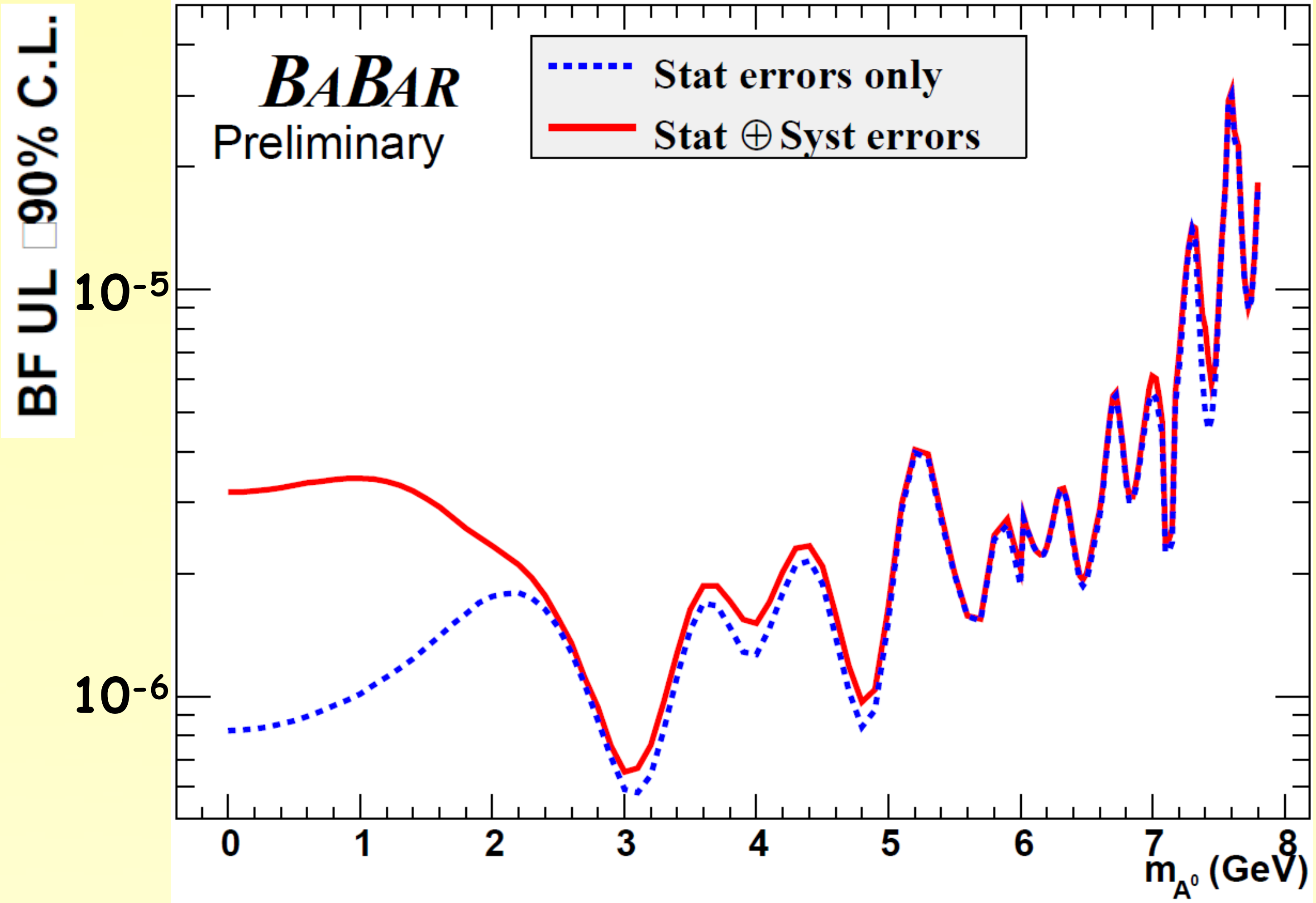
Total fit
Background
Signal



Search for Invisible Higgs Decay



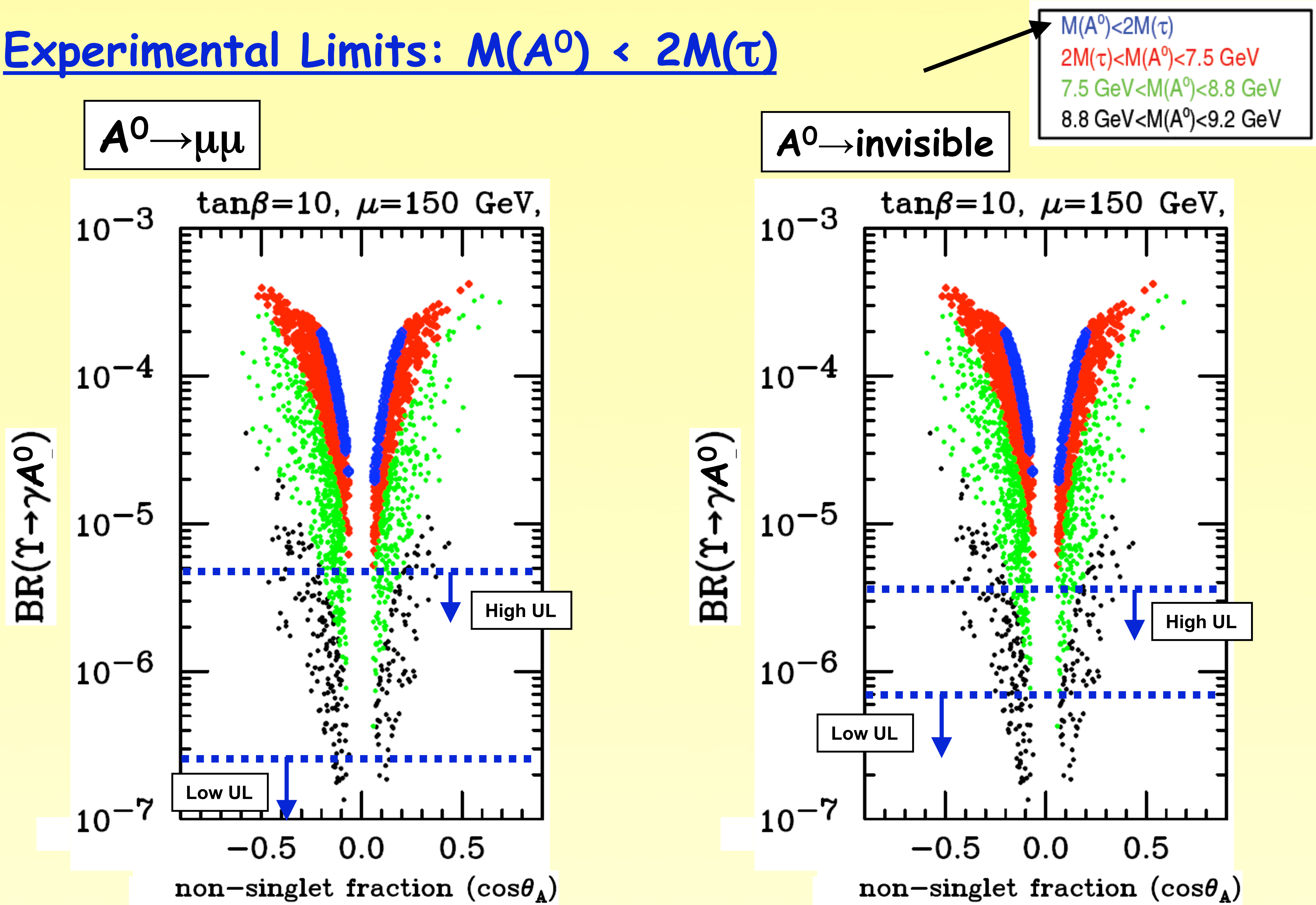
- No significant signal seen anywhere, limits similar to di-muon results



arXiv: 0808.0017 [hep-ex]

Summary of Light Higgs Search

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



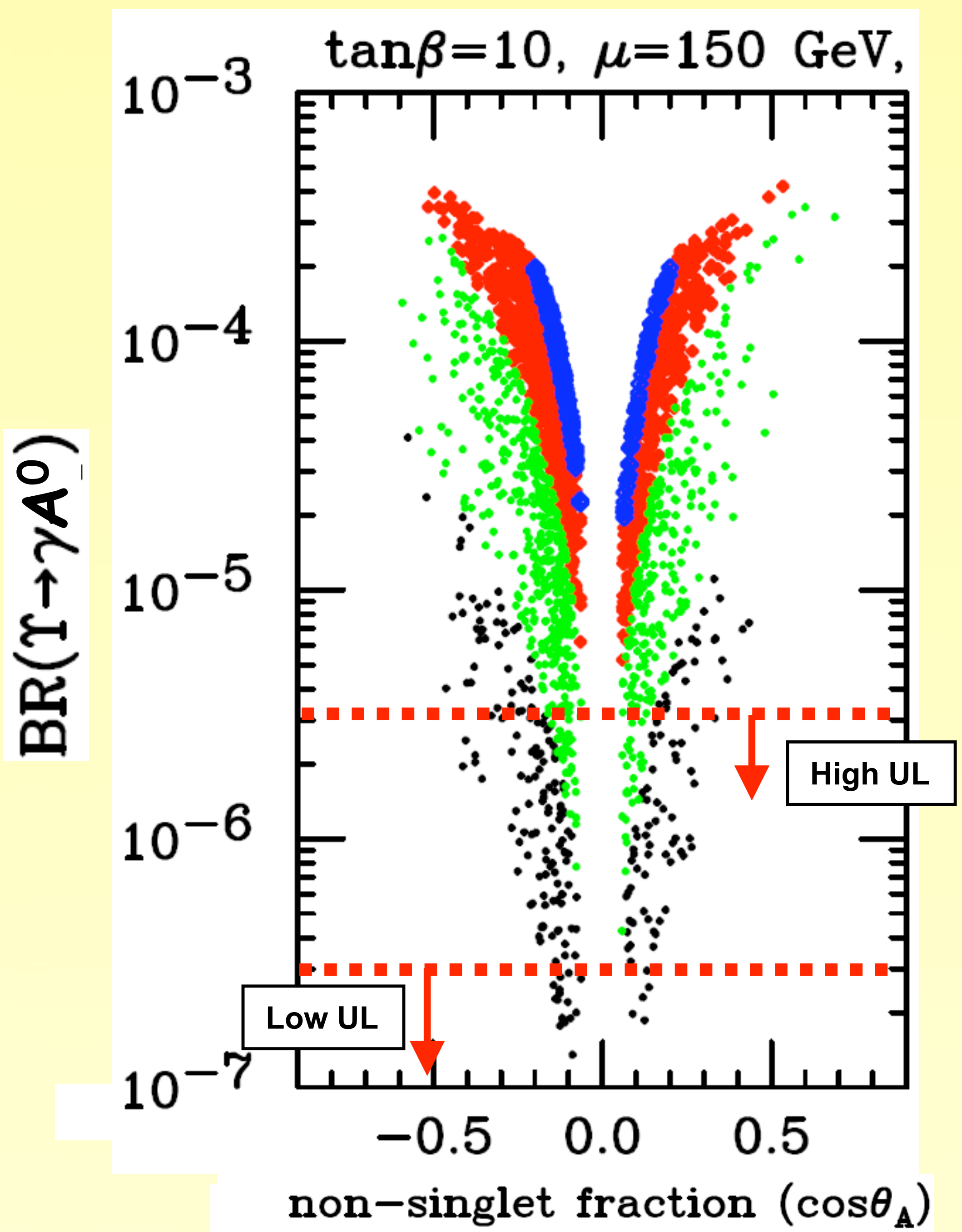
S. Banerjee
University of Victoria
British Columbia • Canada

Summary of Light Higgs Search

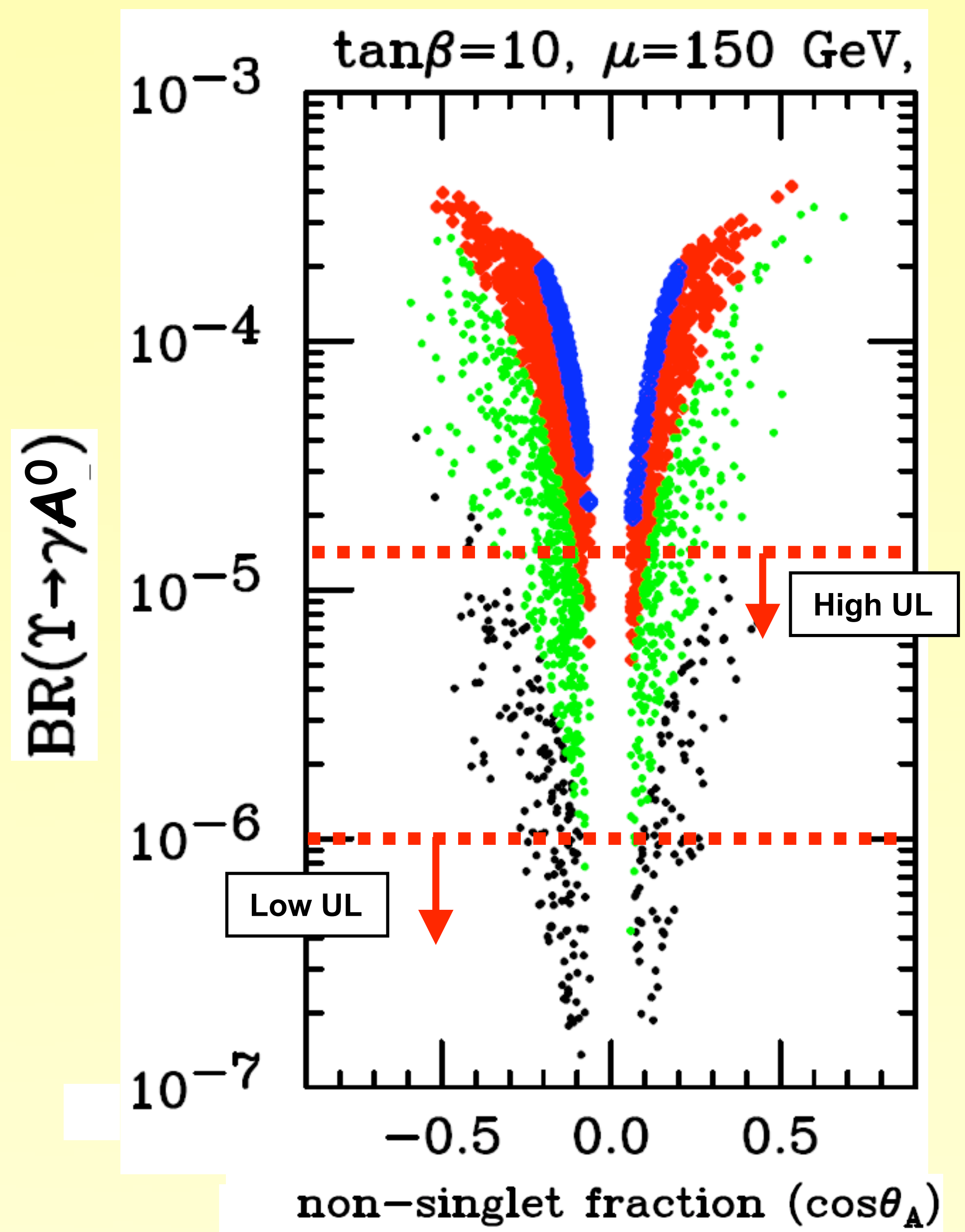
Experimental Limits: $2M(\tau) < M(A^0) < 7.5$ GeV

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

$A^0 \to \mu\mu$



$A^0 \to$ invisible

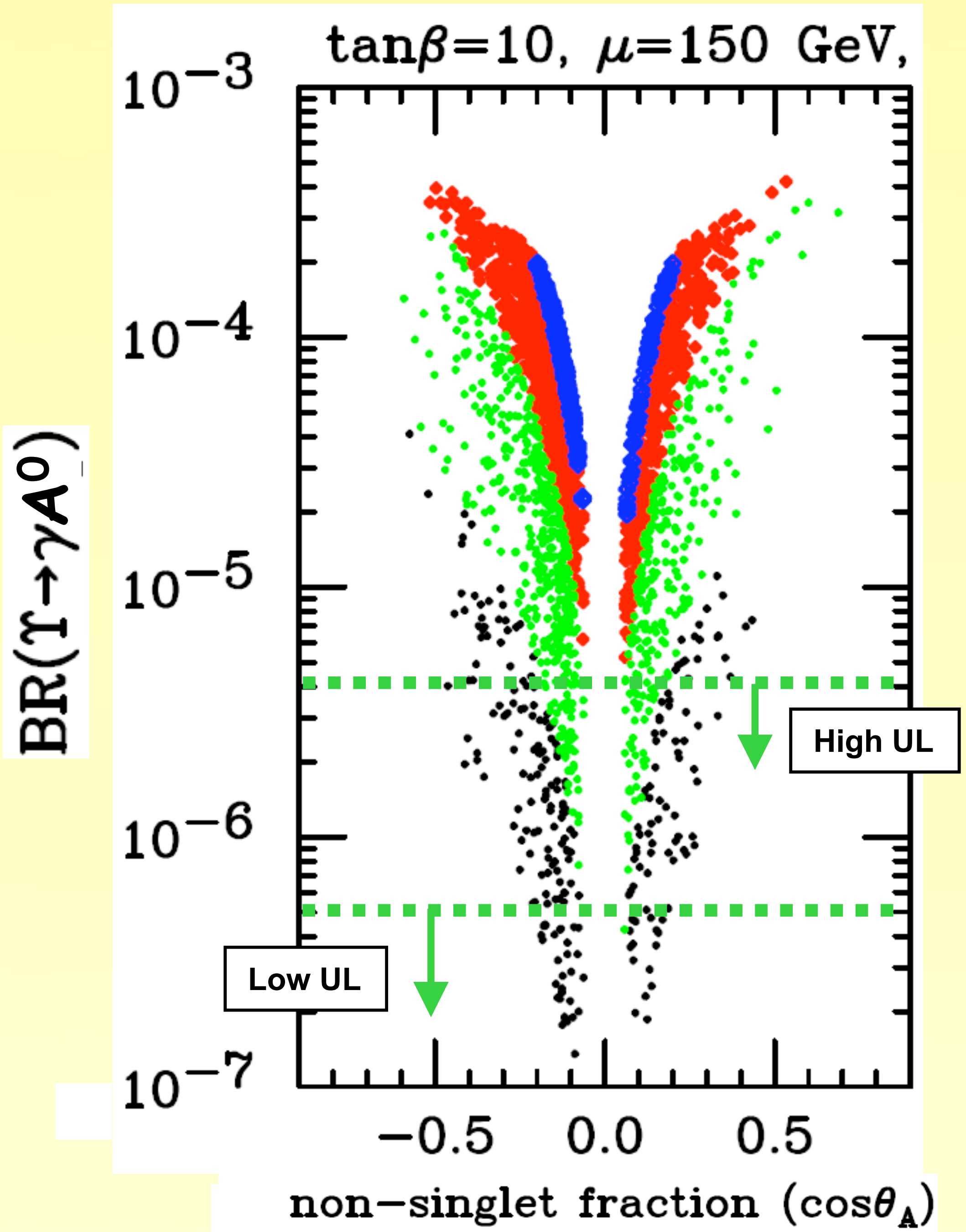


Summary of Light Higgs Search

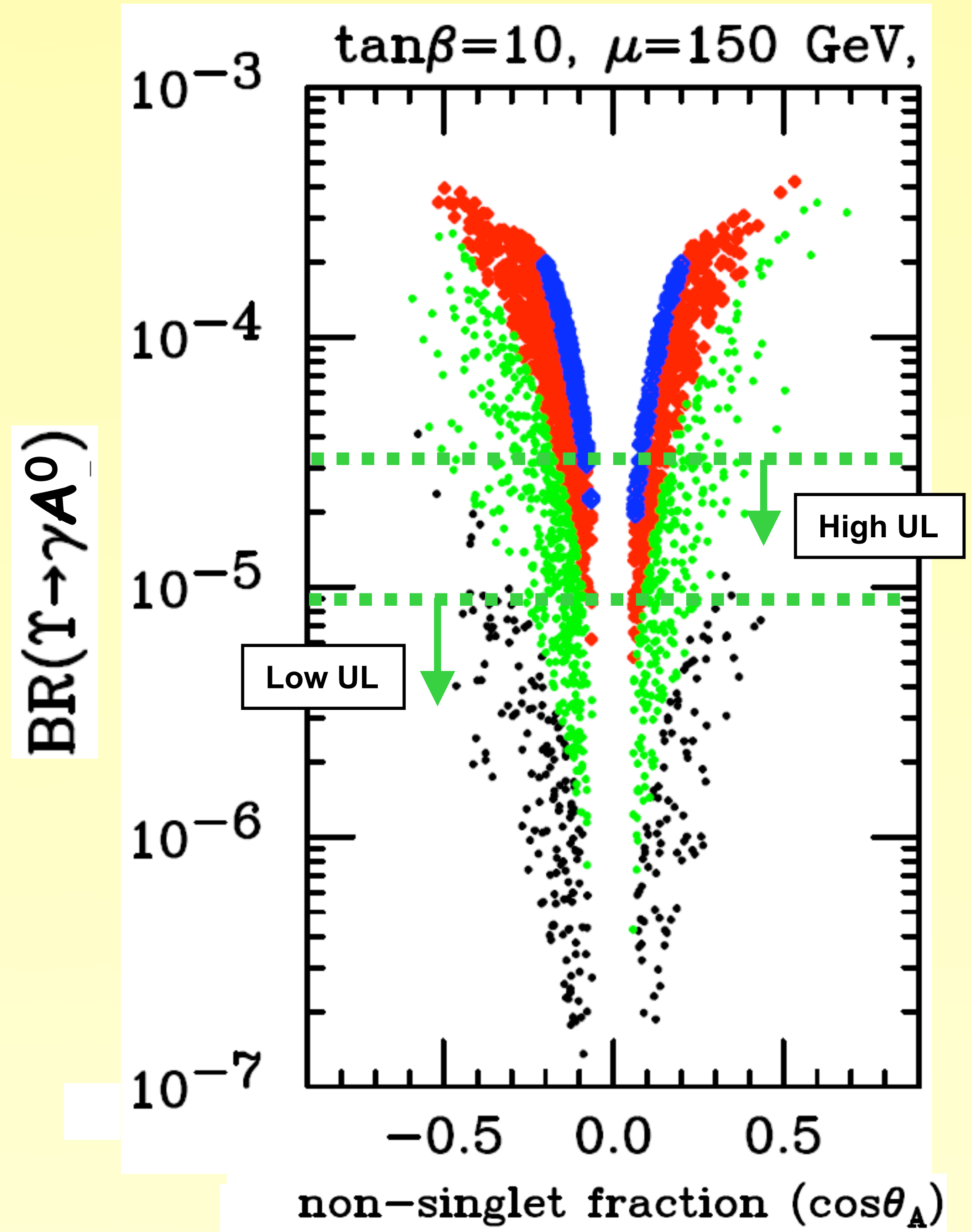
Experimental Limits: 7.5 < M(A⁰) < 8.8 GeV

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

$A^0\to\mu\mu$



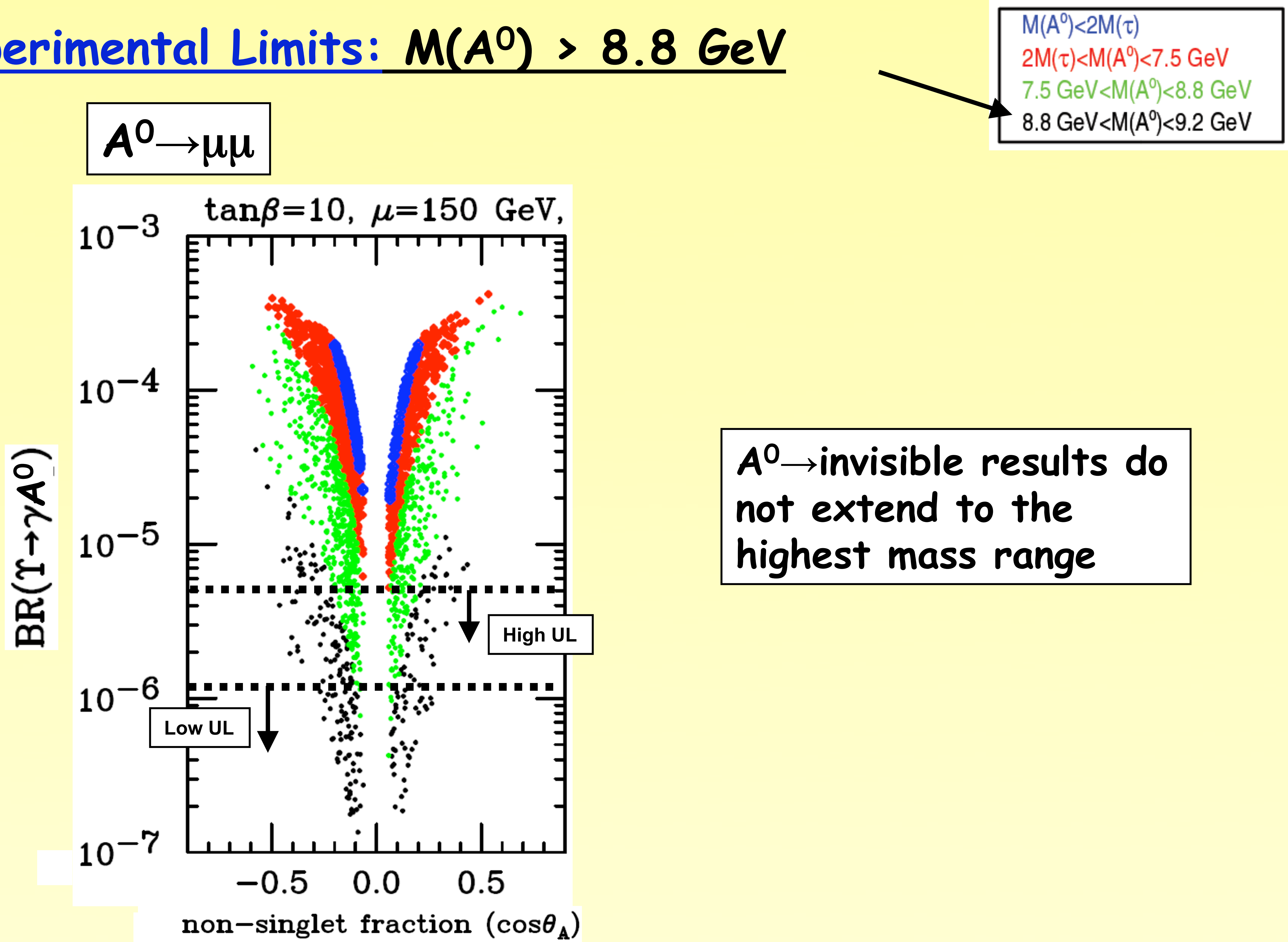
$A^0\to$invisible



Summary of Light Higgs Search

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

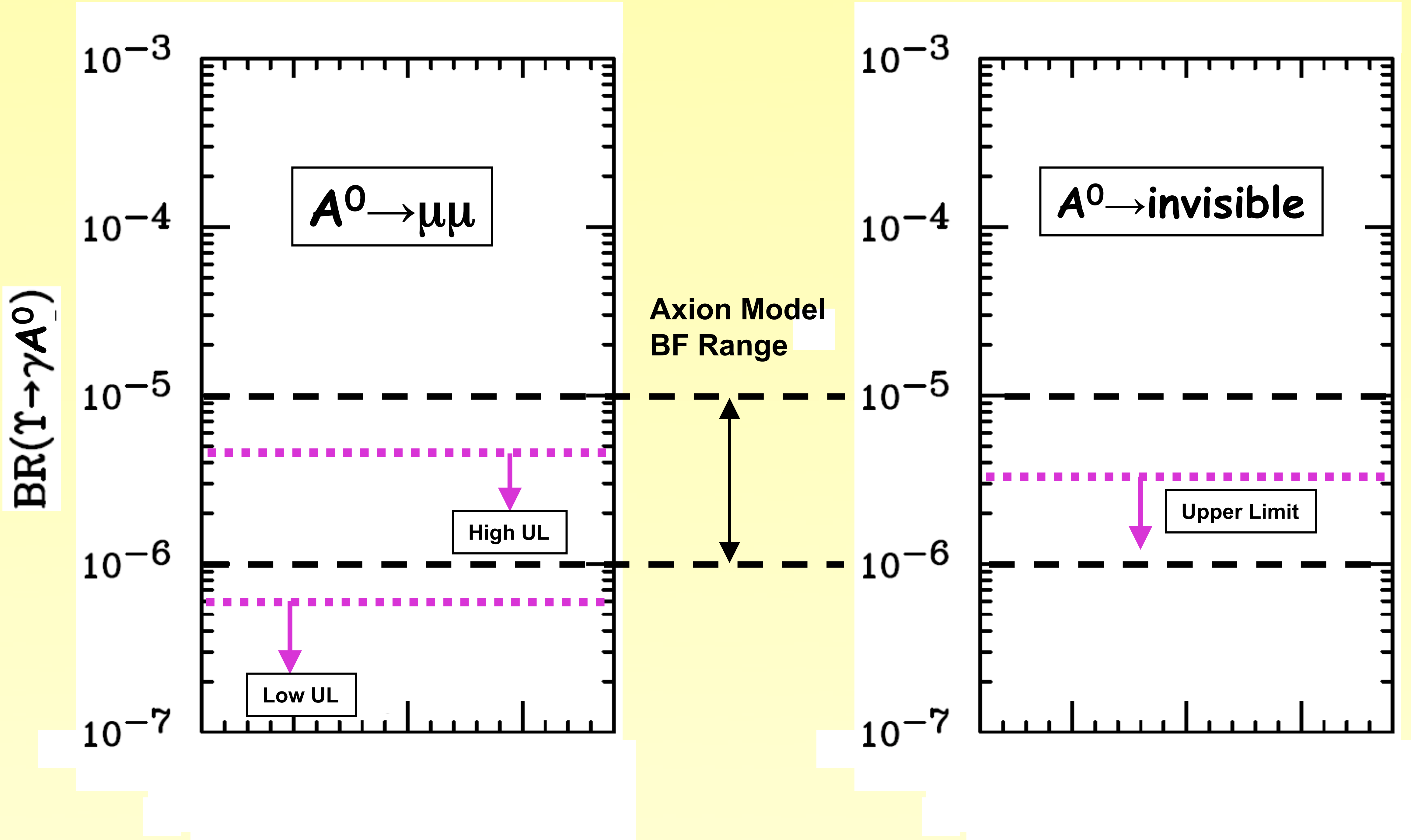
$A^0 \to \mu\mu$



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

Summary of Axion Search

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



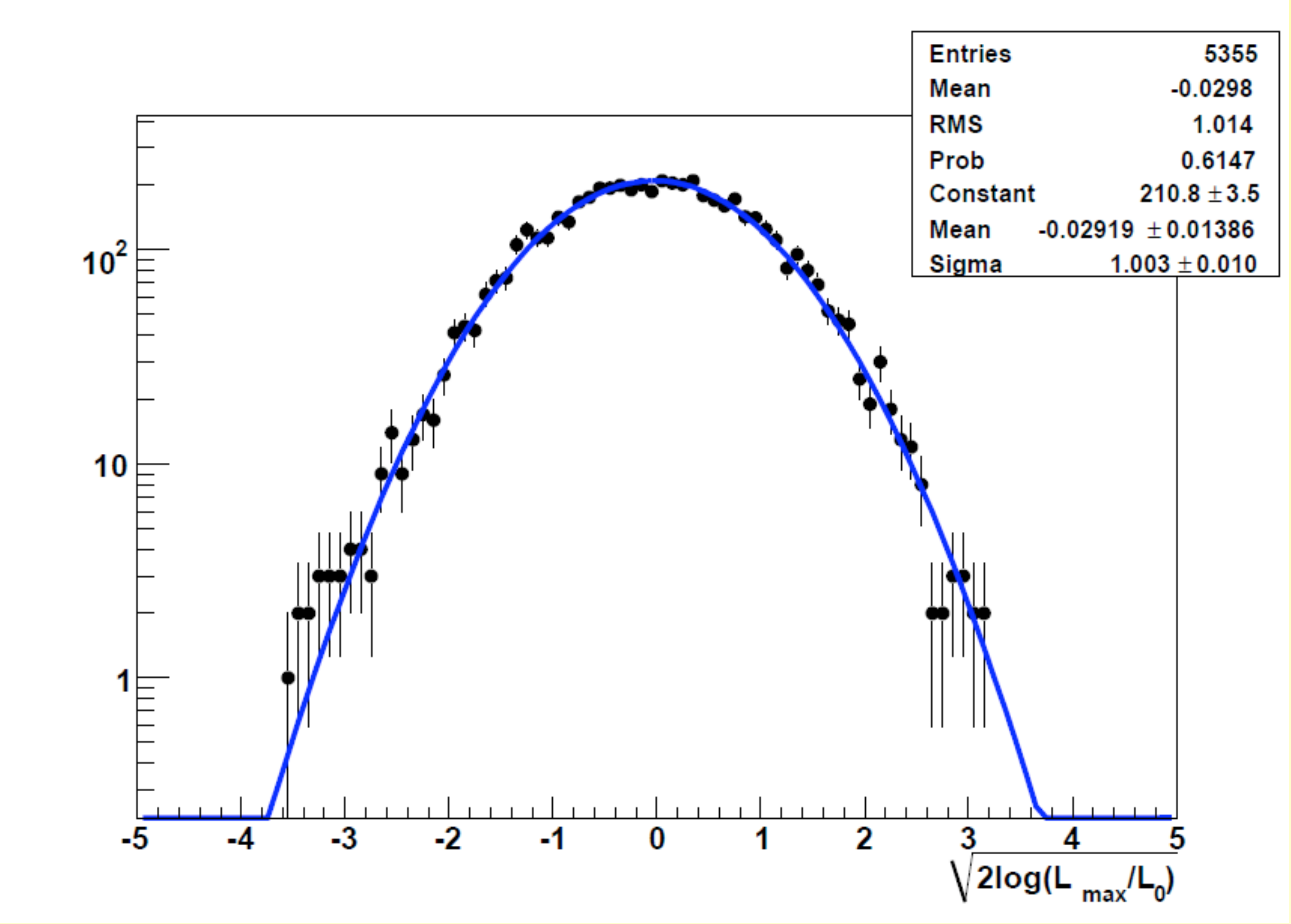
Conclusions

- 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 $(0.25\text{-}5.2) \times 10^{-6}$
  - Generally lower upper limits than CLEO by a factor of ~2
- No significant signal at HyperCP mass (di-muon threshold)
  - $BF[\Upsilon(3S) \to \gamma A^0(214)] < 0.8 \times 10^{-6}$ (90% CL)
- No evidence of $\eta_b \to \mu^+\mu^-$ decays
  - $BF[\eta_b \to \mu^+\mu^-] < 0.8\%$ (90% CL)
- $\Upsilon(3S) \to \gamma A^0$, $A^0 \to$ invisible UL $(0.7\text{-}31) \times 10^{-6}$ (90% CL)
  - ICHEP 2008 conference note at arXiv:0808.0017 [hep-ex]
- Other approaches to increase sensitivity for A^0 discovery:
  - $\Upsilon(2S) \to \gamma A^0$, $A^0 \to \mu^+\mu^-$
    - ~20% higher sensitivity than $\Upsilon(3S)$
  - $\Upsilon(2S, 3S) \to \gamma A^0$, $A^0 \to \tau^+\tau^-$
  - $\Upsilon(2S, 3S) \to \gamma A^0$, $A^0 \to$ *hadrons*
  - Search for non-universality (enhancement of $\tau^+\tau^-$ over $\mu^+\mu^-$): higher efficiency without directly tagging the photon increases sensitivity

Extra Slides ...

Fit to ϒ(4S) Data

- Signal Significances from mass fits on 78.5 fb-1 ϒ(4S) data are Gaussian distributed with no significant outliers



Fit near the η_b mass region

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