Search for Invisible Decays of the $\Upsilon(1S)$

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For the BABAR Collaboration

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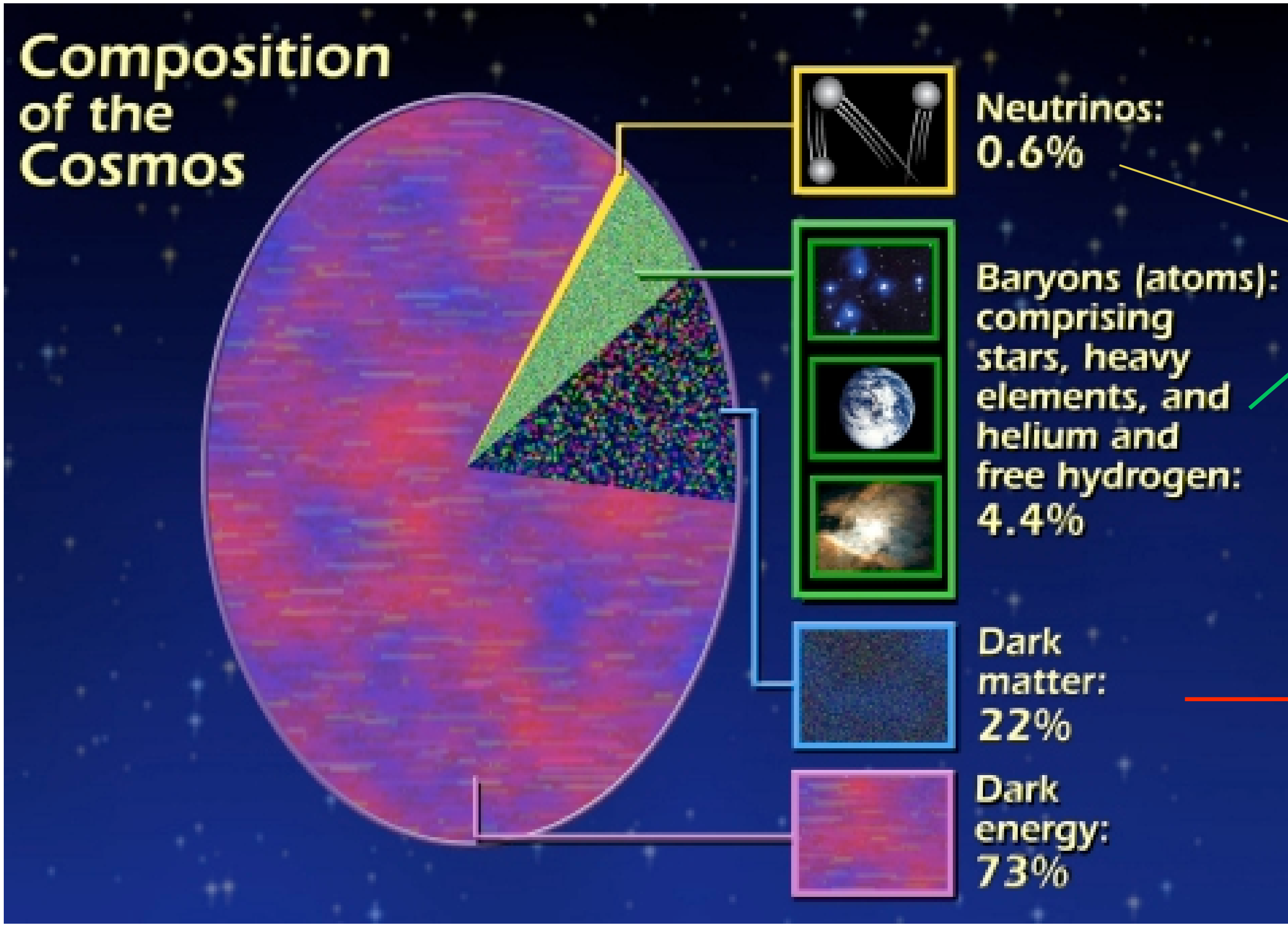
Motivation

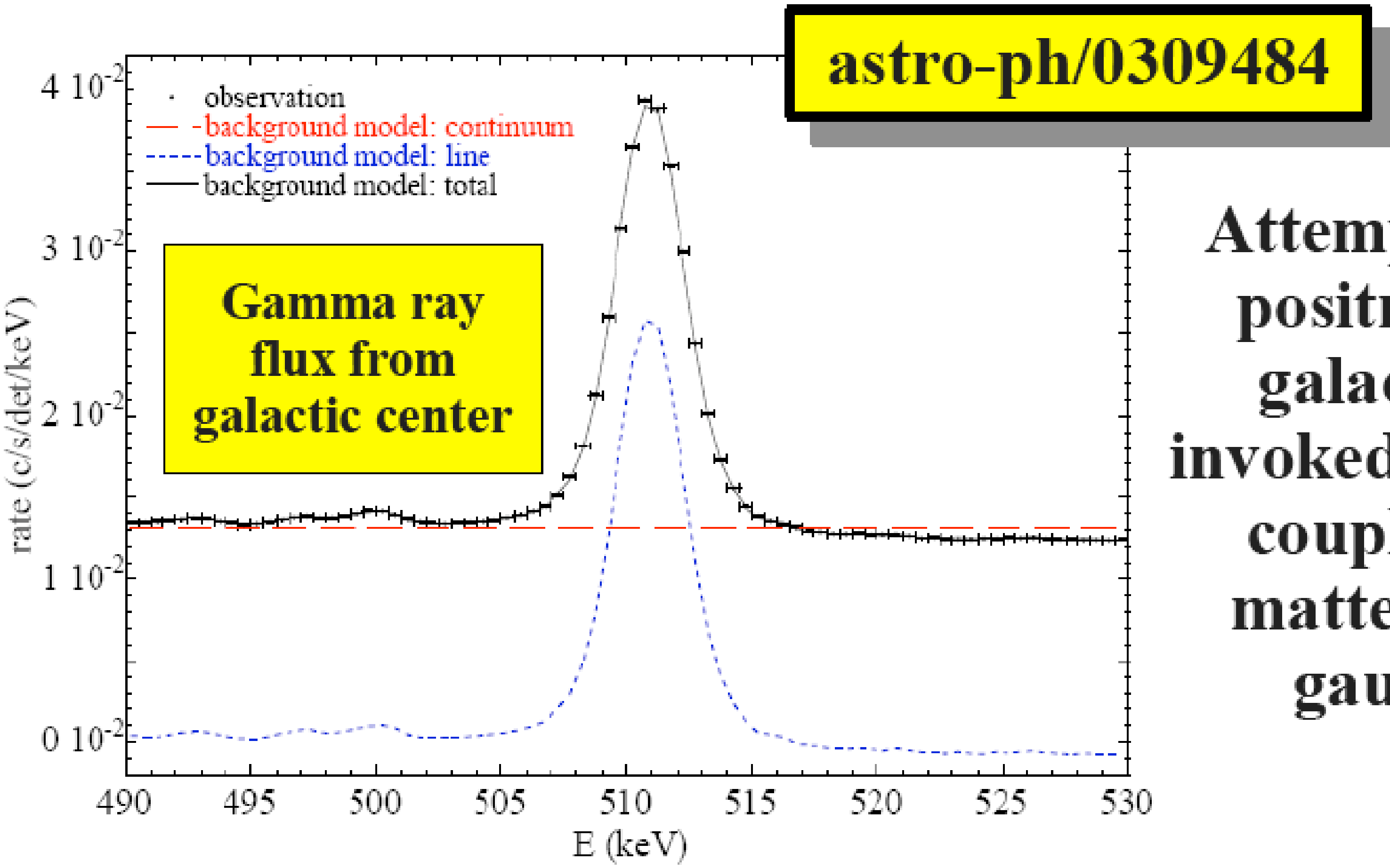


If this spectrum is complex…

Why should this be simple ?

Astrophysically-motivated models include light dark matter/invisible components

INTEGRAL Anomaly



Attempts to explain the positron excess at the galactic center have invoked light dark matter coupling to ordinary matter via a new U(1) gauge interaction

Examples of models with collider signatures:

McElrath, PRD**72**, 103508 (2005), arXiv:0712.0016

Borodatchenkova et al, PRL**96**, 141802 (2006)

G. Yeghiyan @ DPF09

With apologies to others

Invisible Upsilon Decays

- Upsilon system is a particularly nice place to look for the light dark matter component
  - ☞ Higgs-like sector couples preferentially to 3rd generation
  - ☞ Rich spectroscopy tagging of invisible decays

Region of interest within experimental reach:

Standard Model Prediction: $BR(\Upsilon \to \nu\bar{\nu}) \approx 1\times10^{-5}$

Below current experimental sensitivity...

Light Dark Matter:

(McElrath, arXiv:0712.0016 and Phys.Rev. D72 (2005) 103508)

p-wave annihilation in early universe:

$$BR(\Upsilon \to \text{invisible}) < 2\times10^{-3}$$

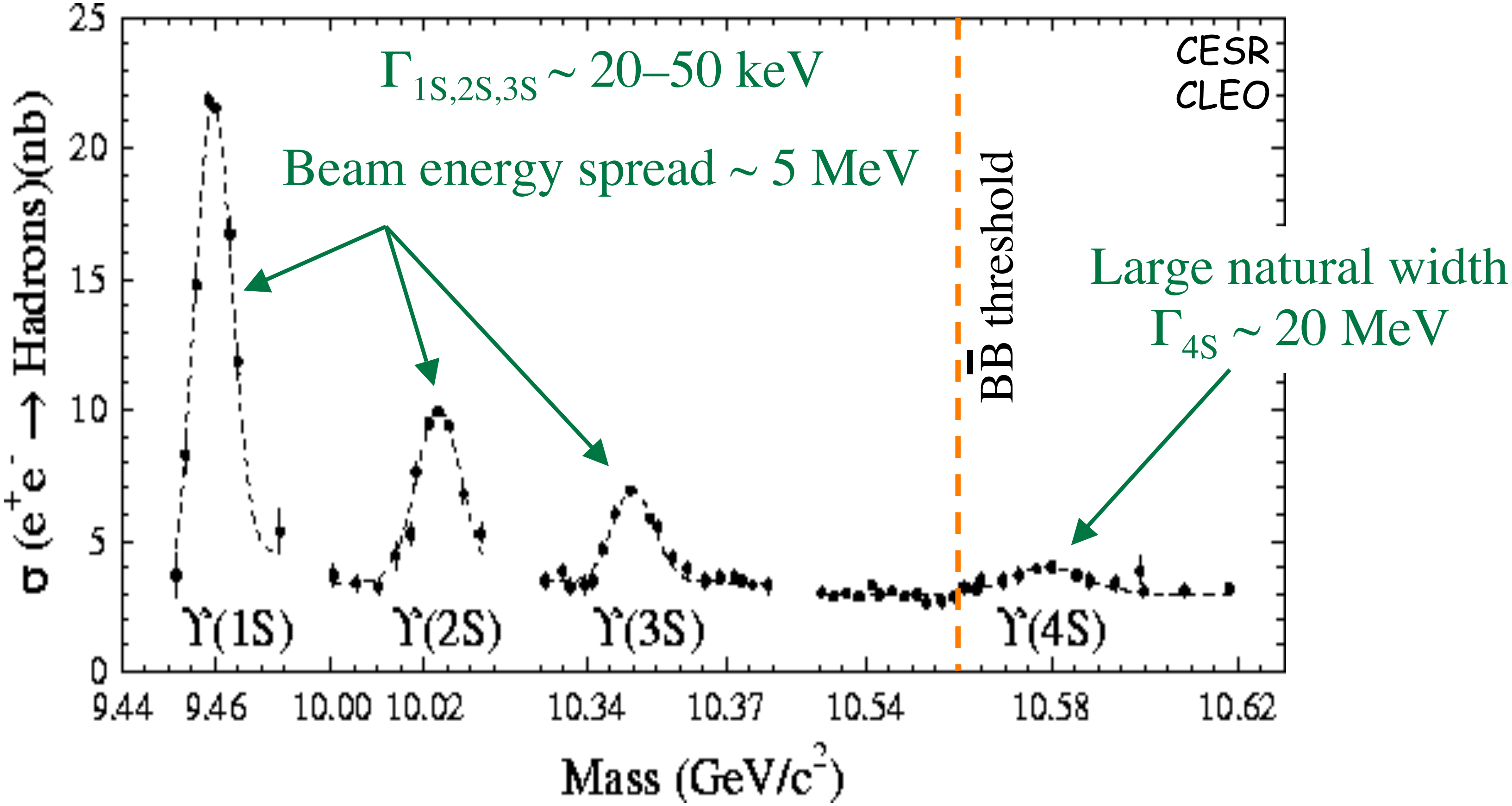
s-wave annihilation in early universe:

$$BR(\Upsilon \to \text{invisible}) < 5\times10^{-4}$$

Best Experimental Constraint (Belle): $BR(\Upsilon \to \text{invisible}) < 2.5\times10^{-3}$

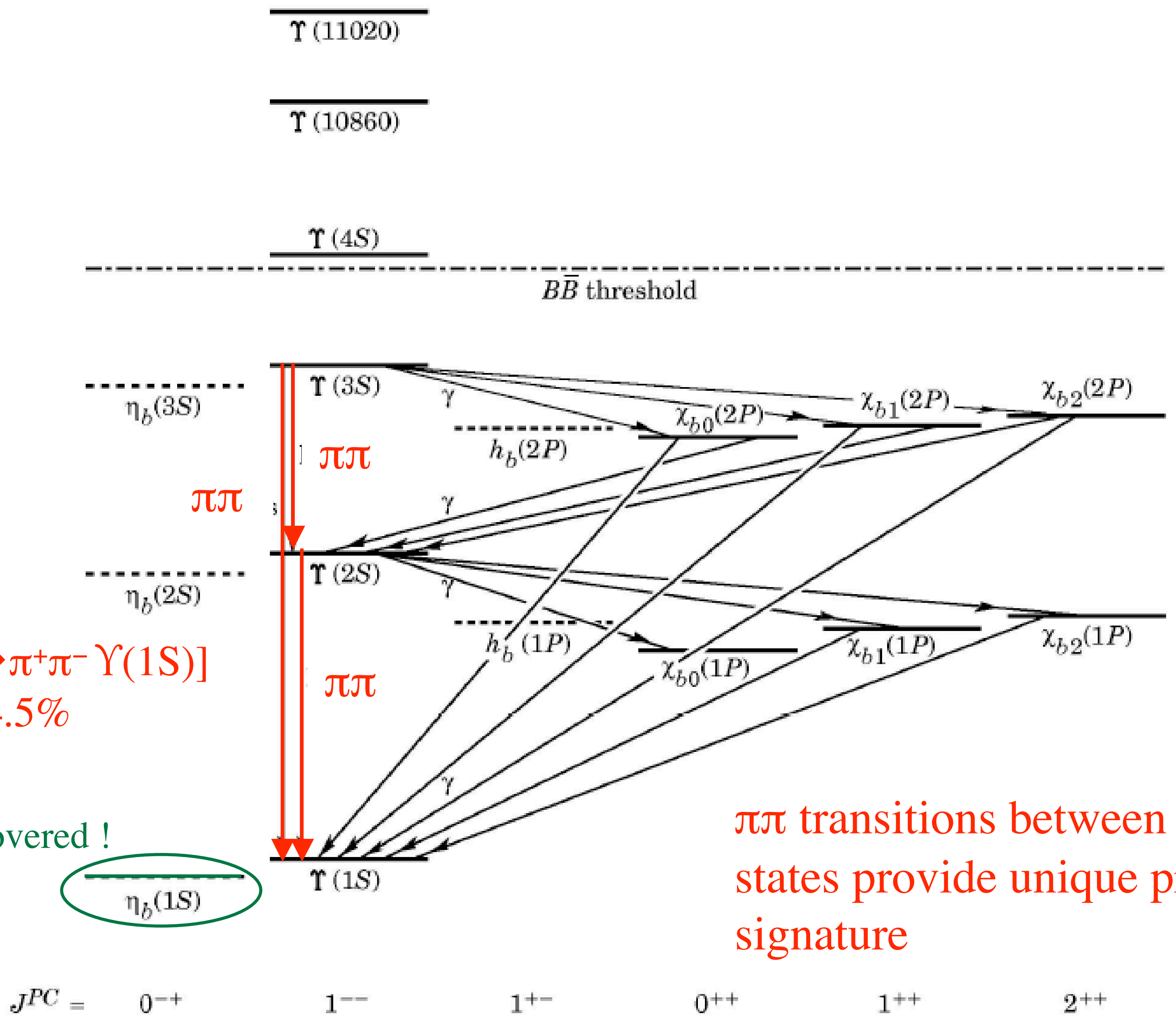
Upsilon Resonances

- Electron-Positron collider: $e^+e^- \to \gamma^* \to \Upsilon(nS)$



For any bottomonium process $BF_{nS}=\Gamma_{nS}/\Gamma_{tot} >> BF_{4S}$, n=1,2,3
Significantly better sensitivity to new physics @ narrow resonances

Upsilon Spectroscopy

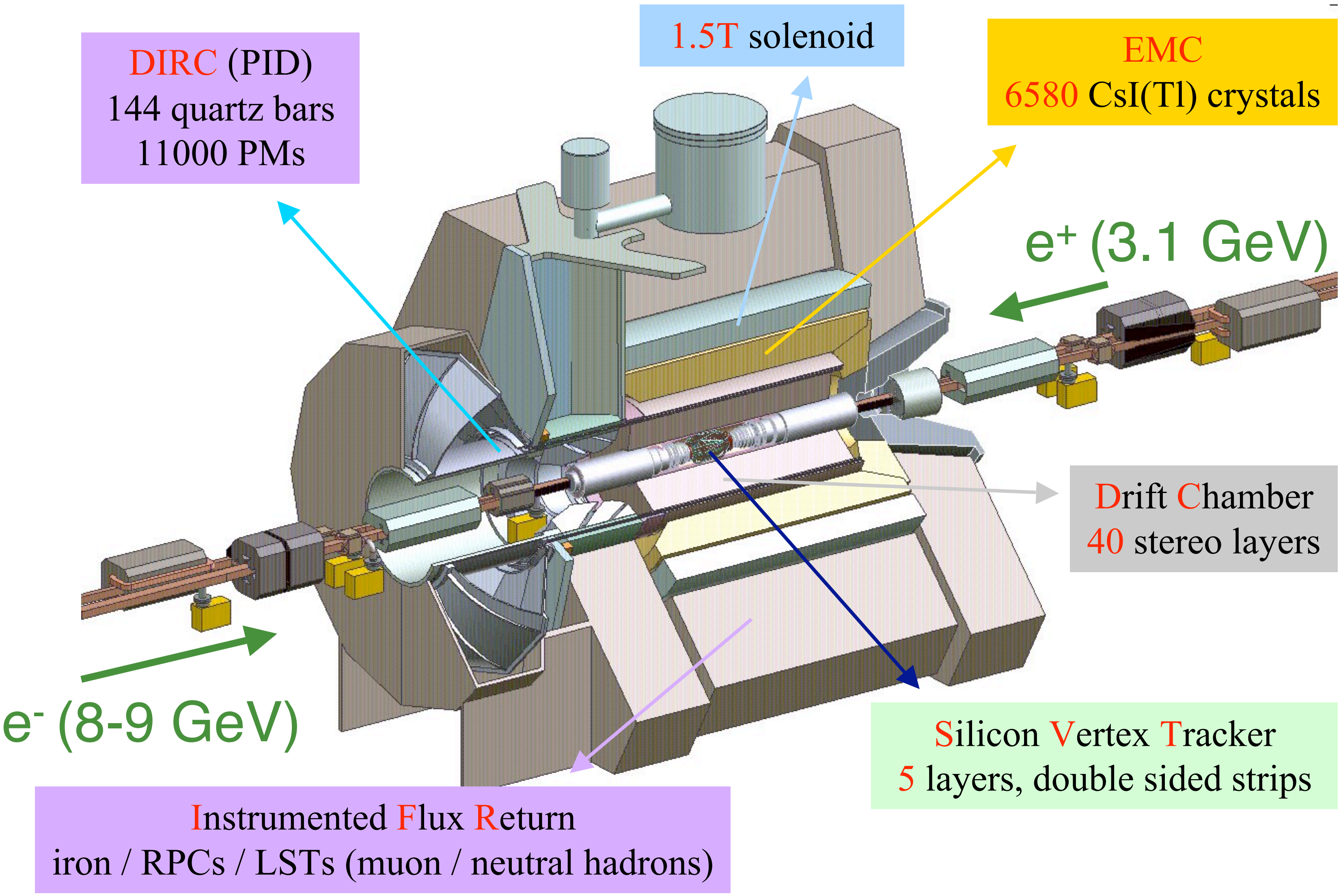


BR[ϒ(3S)→$\pi^+\pi^-$ ϒ(1S)] ≈ 4.5%

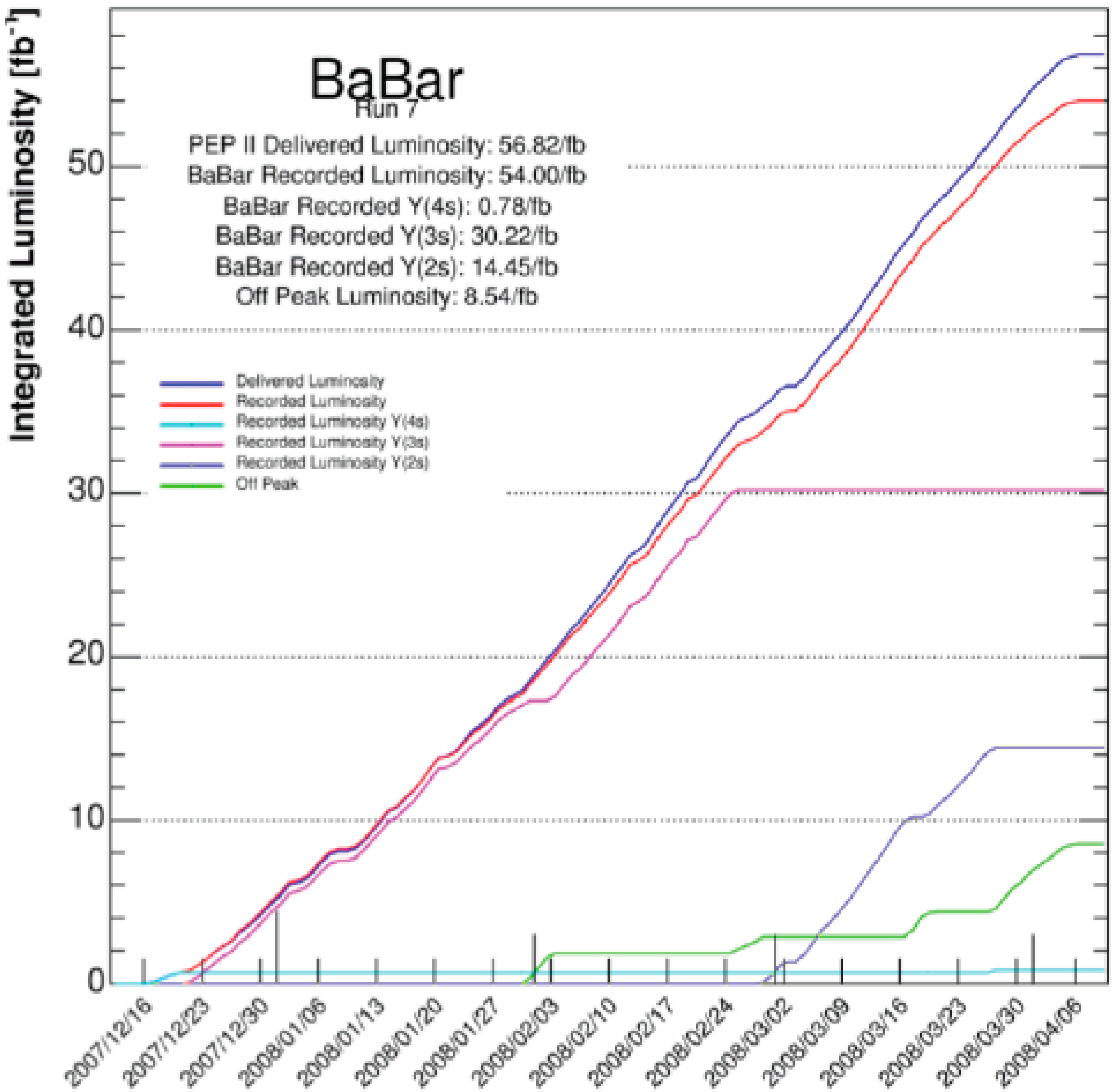
Recently discovered !

ππ transitions between Upsilon states provide unique production signature

BaBar Detector



BaBar 2008 Dataset



Dec. 2007 - Apr. 2008

Dedicated run on Υ(3S) and Υ(2S), cross section scan above Υ(4S)

122M Υ(3S) decays

Sample used in this search

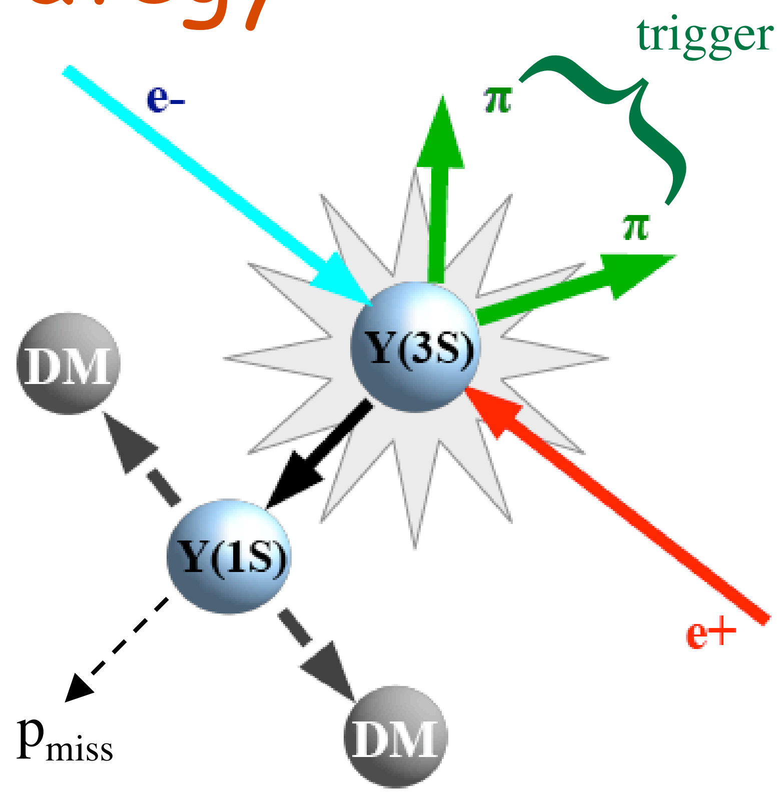
99M Υ(2S) decays

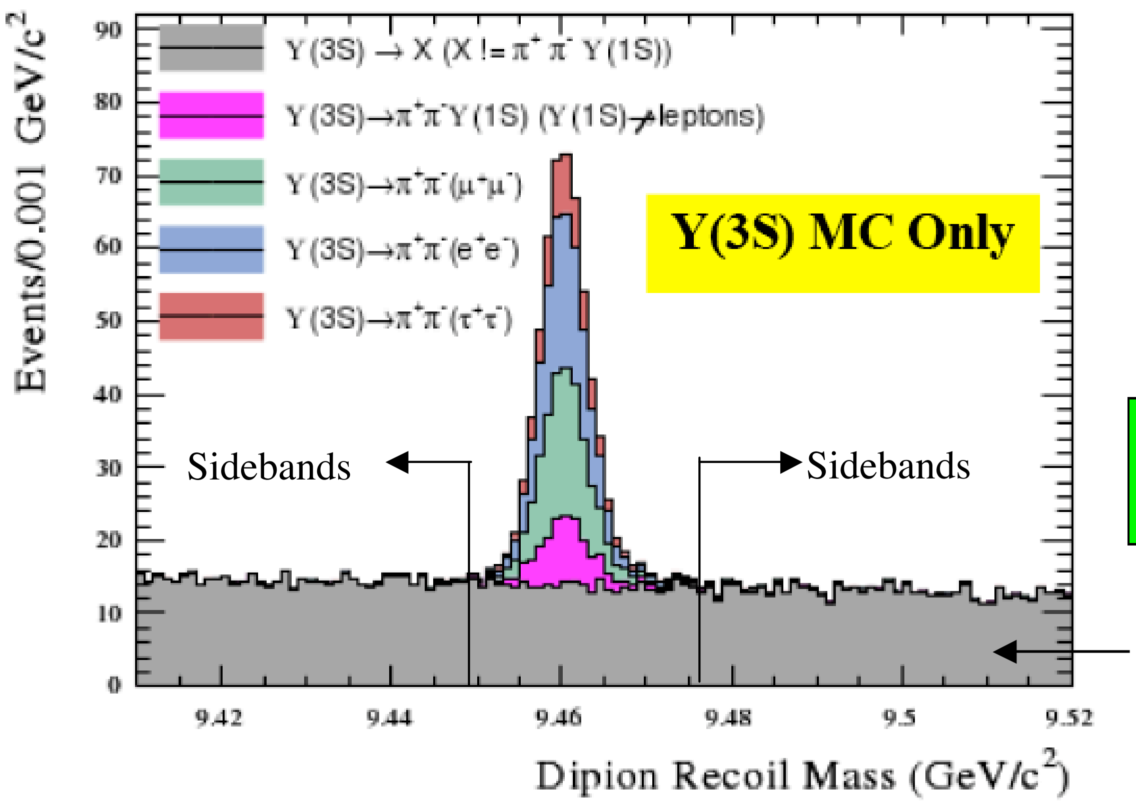
Other experiments

Exp	Υ(1S)	Υ(2S)	Υ(3S)
CLEO	20M	9M	6M
Belle	100M	50M	11M

Analysis Strategy

Leverage the charged dipion transition to the Υ(1S) (4.48%) to suppress background



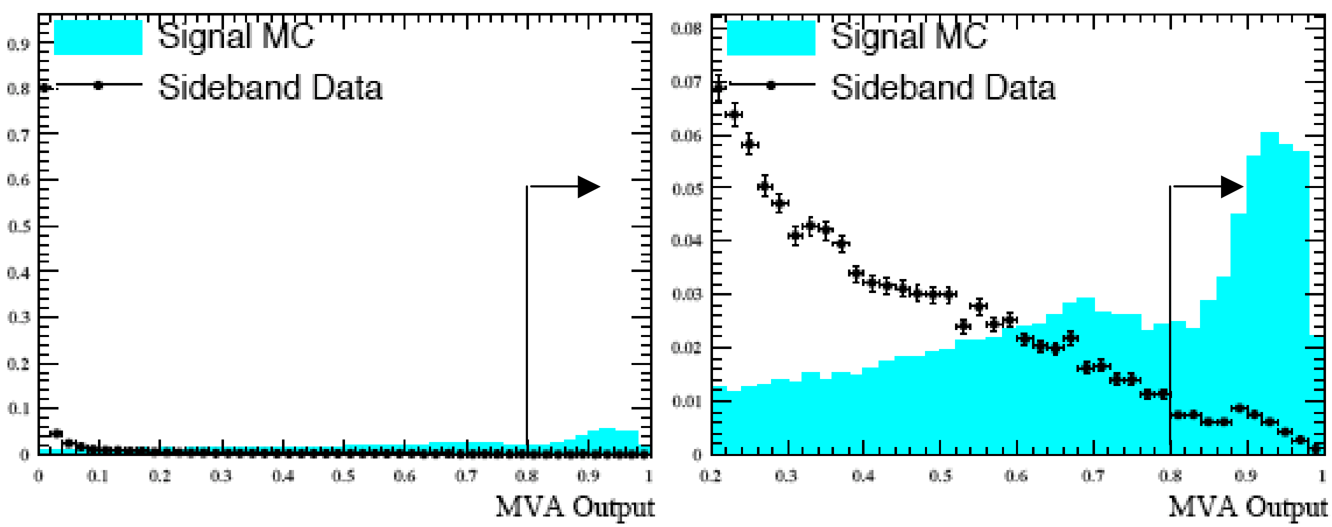


$$m^2_{recoil} = s + m^2_{\pi\pi} - 2E_{\pi\pi}\sqrt{s}$$

Additional non-peaking backgrounds from $e^+e^- \to \gamma^*\gamma^* \to e^+e^-\pi^+\pi^-$ not included

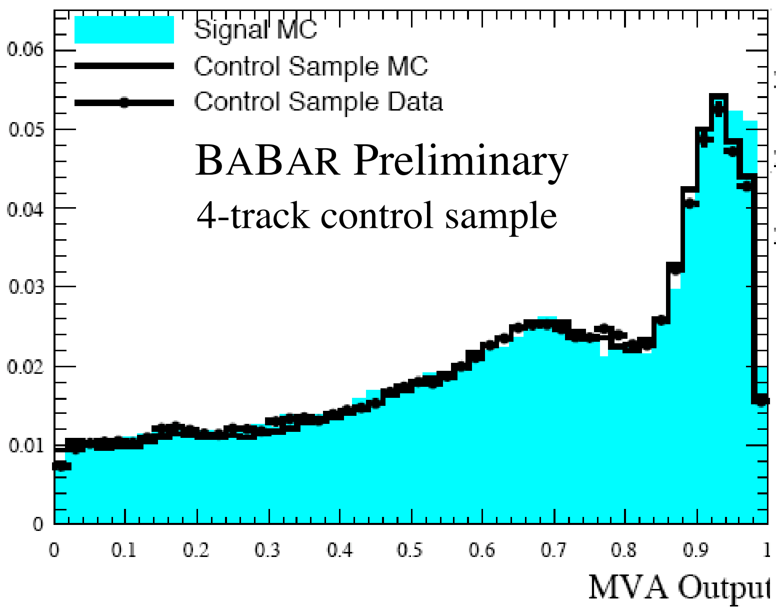
Event Selection

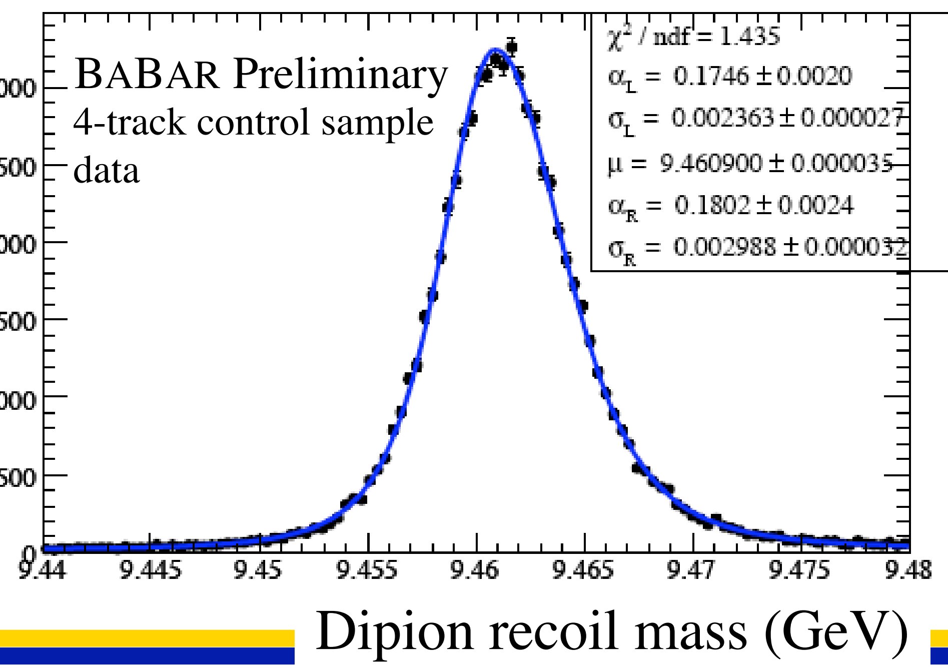
- "Invisible sample":
  - Select events with two low-momentum charged tracks and little additional activity in the detector
    - ☞ Di-pion kinematics specific to $\Upsilon(3S)\rightarrow\pi^+\pi^-\Upsilon(1S)$ transition (C.C.D. Cronin-Hennessy et al., PRD**76**, 072001 (2007))
    - ☞ Implement a MultiVariate Analyzer (MVA) as a *random forest of boosted decision trees*
    - ☞ Train on signal Monte Carlo and sideband data
    - ☞ Suppresses the non-peaking background by more than a factor of 1000
    - ☞ Signal efficiency: 18%



"Visible" Calibration Samples

- In addition, select events with 1 or 2 additional high-momentum tracks in the final state
  - Dominated by $\Upsilon(3S)\rightarrow\pi^+\pi^-\Upsilon(1S)$, $\Upsilon(1S)\rightarrow l^+l^-$
    - Check di-pion selection, including MVA
    - Calibrate detection efficiency
    - Calibrate BR for $\Upsilon(3S)\rightarrow\pi^+\pi^-\Upsilon(1S)$
    - Calibrate recoil mass distribution





Signal Extraction

Maximum likelihood fit to 2-track "invisible" sample

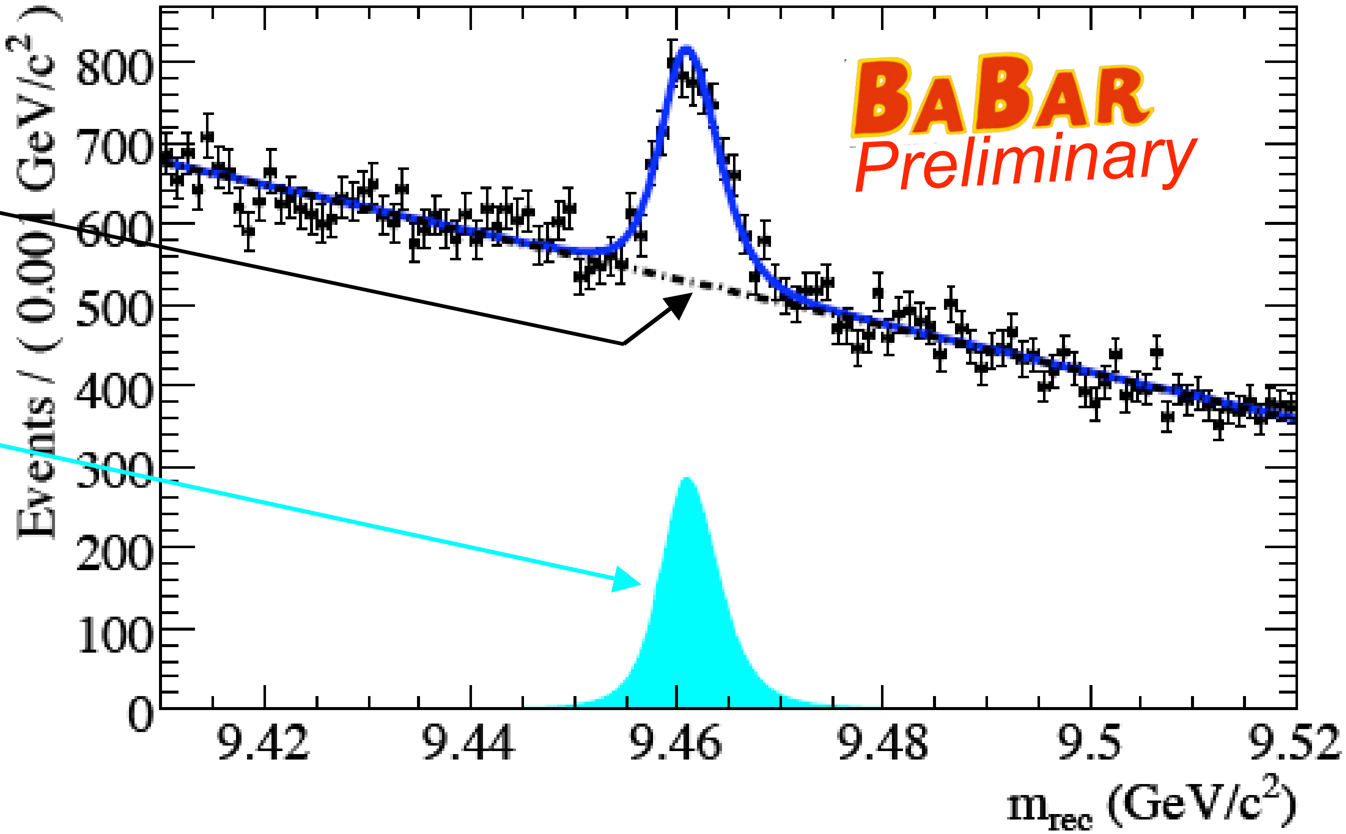
Non-peaking background:

✔ Float all parameters and yield

Peaking Component:

✔ Fix shape, float yield

Contains peaking background and signal



Fit Results: N_{peak} = 2326 ± 105 (stat.) events

Peaking background estimate, calibrated against control sample data:

N_{bkg} = 2444 ± 123 (syst.) events

Υ(1S)→invisible yield: –118 ± 105 (stat.) ± 124 (syst.)

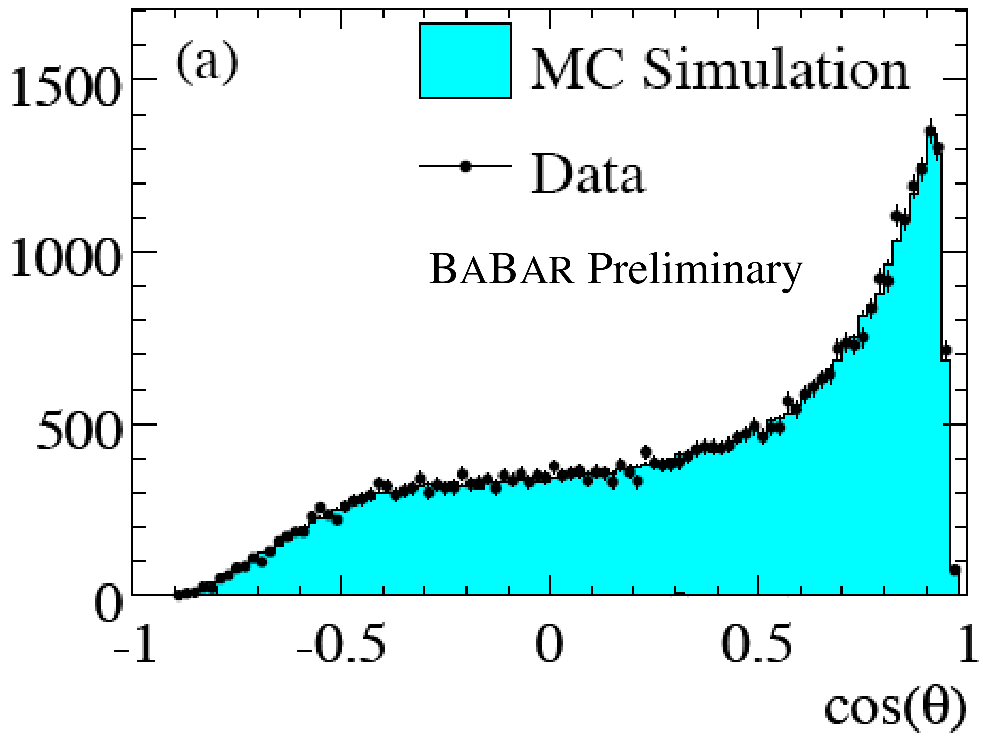
Systematics

- Most systematic uncertainties are derived from comparison between the Monte Carlo simulation and the control samples
  - 3- and 4-track samples $\Upsilon(3S)\to\pi^+\pi^-\Upsilon(1S)$, $\Upsilon(1S)\to l^+l^-$
  - Measure series of multiplicative corrections to MC
    - Reconstruction efficiency times BR($\Upsilon(3S)\to\pi^+\pi^-\Upsilon(1S)$): correction of 1.088±0.012
    - BR for $\Upsilon(1S)\to l^+l^-$ in calibration: ±2.5%
    - Software trigger efficiency: 0.997±0.009
    - Hardware trigger efficiency: ±2.2%
    - MVA selection efficiency: ±4%
  - Additive peaking background uncertainty
    - Non-leptonic peaking background: ±15 events (0.6%)
    - Total peaking background uncertainty is ±41 events
- Most of these apply to both signal efficiency and peaking background yield: correlated corrections

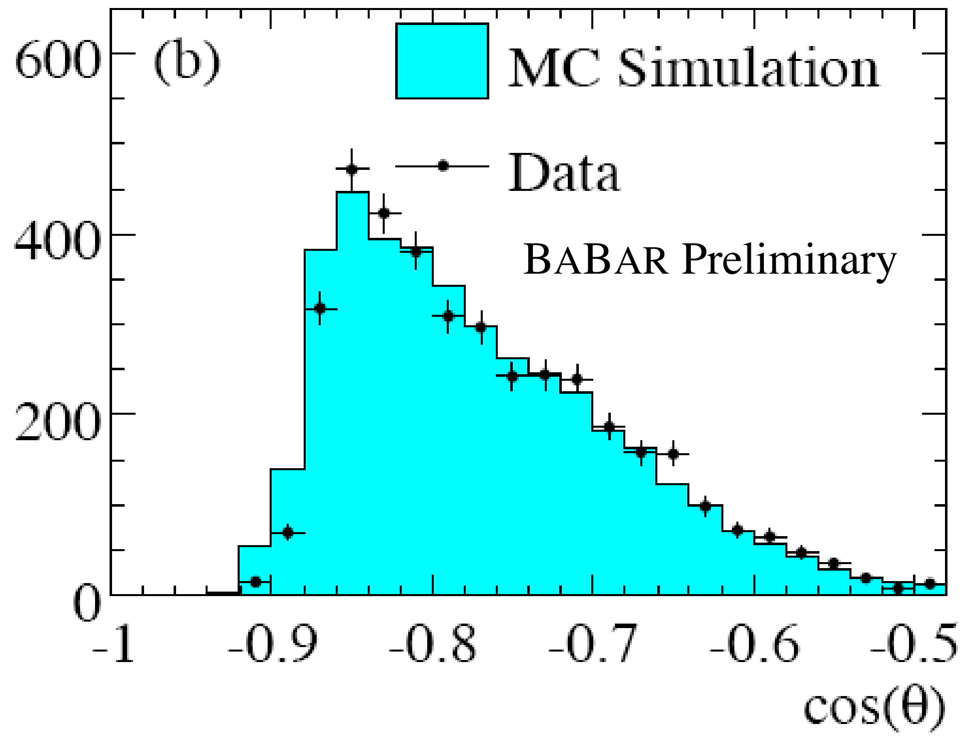
Corrections and Systematics

Geometric acceptance and efficiency for visible events

4-track sample



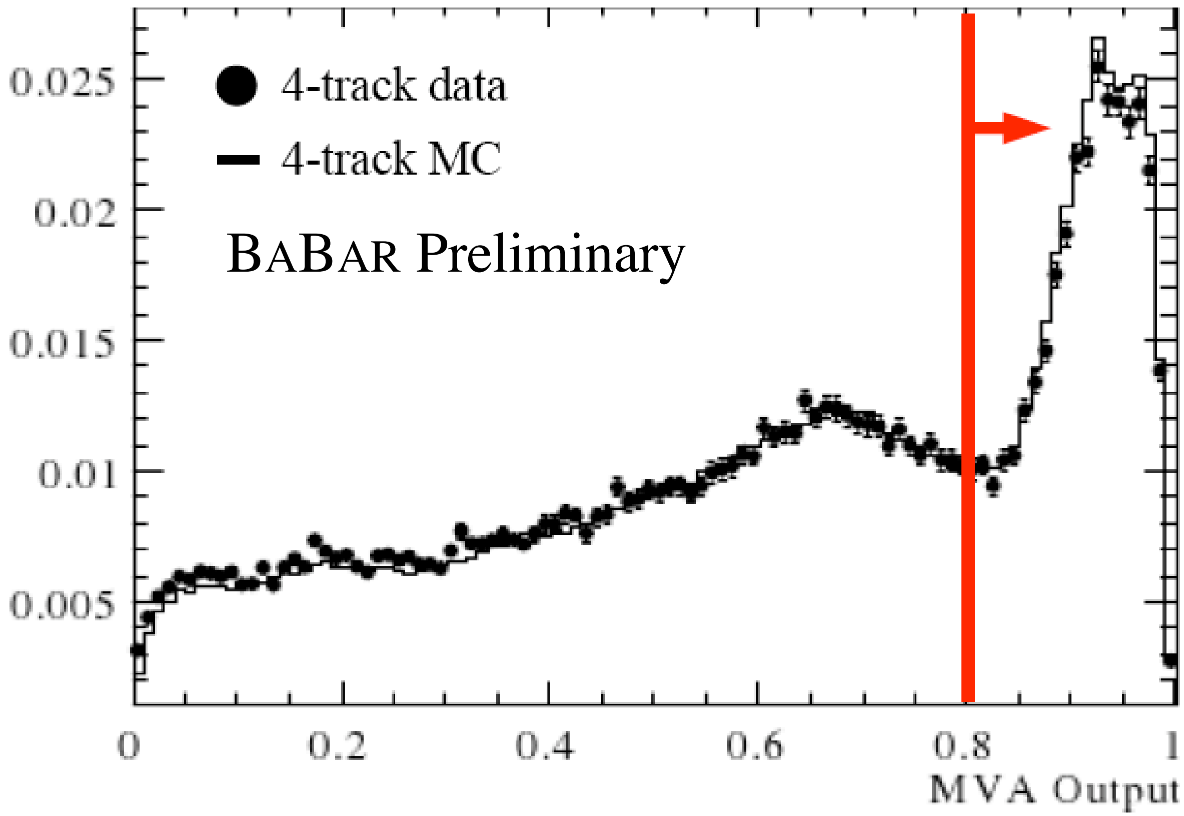
3-track sample: one track missing in forward direction



Use data distributions in the polar angle to re-weight the simulated events, recompute efficiency. Plots shown after re-weighting. Correction of 1.088±0.012 (applies to the product of efficiency and BR($\Upsilon(3S) \rightarrow \pi^+\pi^- \Upsilon(1S)$))

Systematic Checks

MVA selection efficiency



4% systematic uncertainty

Computing the Branching Ratio

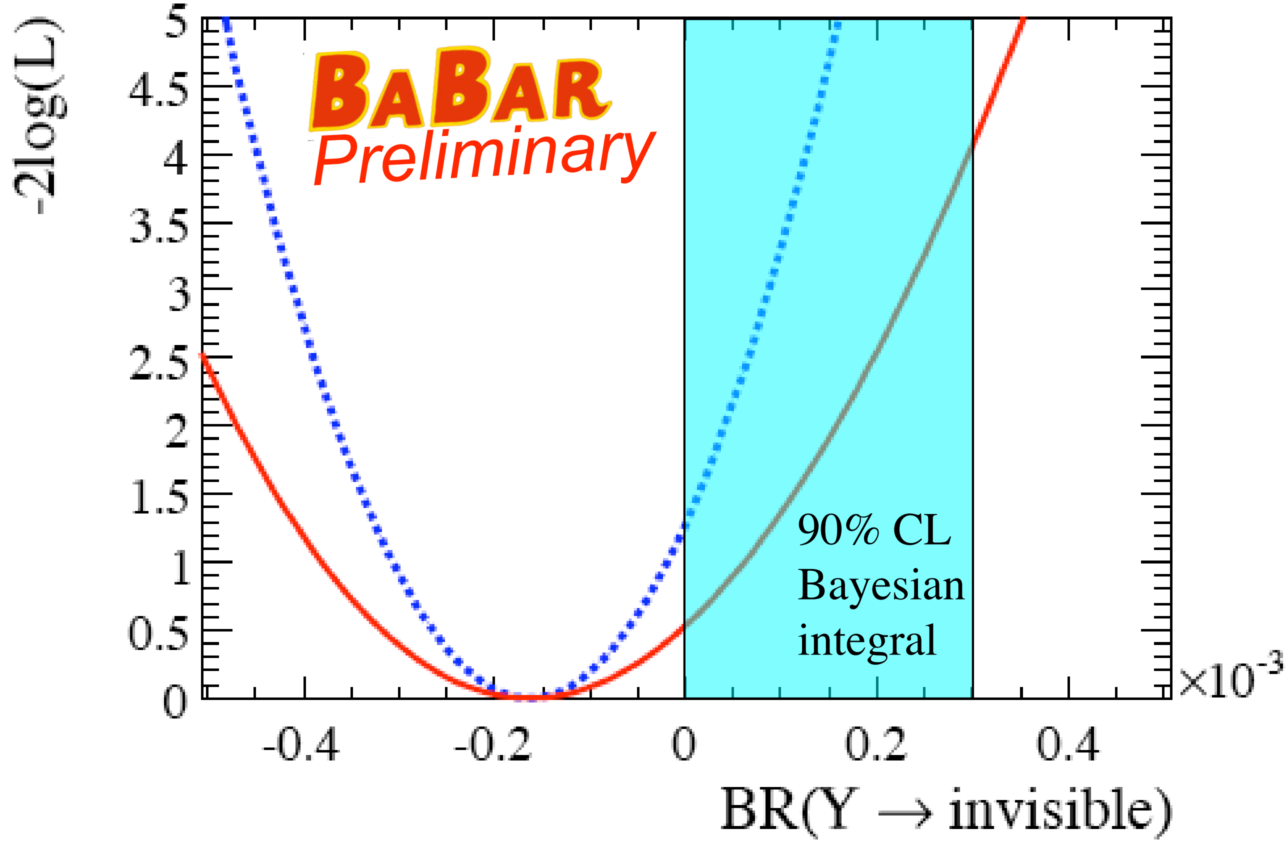
$$BR(\Upsilon \rightarrow \text{invisible}) = \frac{N_{\text{fit}} - N_{\text{peaking bkg.}}}{N_{\Upsilon(3S)} \times BF(\Upsilon(3S) \rightarrow \pi^+\pi^-\Upsilon(1S)) \times \varepsilon_{\text{sig}}}$$

$N_{\Upsilon(3S)}$=91.4M
BR($\Upsilon(3S) \rightarrow \pi^+\pi^- \Upsilon(1S)$)=4.48%
Signal efficiency ε=17.8%

Most control sample corrections appear twice (marked with *): in the signal efficiency and peaking background yield
Assume 100% correlated

Source	Correction	Uncertainty
Background Estimate		
1-lepton correction	N/A	38.3 out of 2448.0 events (1.6%)
hadronic peaking backgrounds	N/A	15.7 out of 2451.4 events (0.6%)
2-lepton scaling correction [*]	1.088	1.1%
L1 Trigger [*]	1.000	2.1%
L3 Trigger [*]	0.997	0.9%
MVA [*]	1.000	4.0%
Total (uncorrelated with Signal efficiency)	41.4 events out of 2444.0 (1.7%)	
Total (correlated with Signal efficiency) [*]	116.2 events out of 2444.0 (4.8%)	
Signal Efficiency		
L1 Trigger [*]	1.000	2.1%
L3 Trigger [*]	0.997	0.9%
MVA [*]	1.000	4.0%
Total (uncorrelated with Peaking Bkg.)	0.0%	
Total (correlated with Peaking Bkg.) [*]	4.6%	
$N_{\Upsilon(3S)} \cdot \mathcal{B}(\Upsilon(3S) \rightarrow \pi^+\pi^-\Upsilon(1S)) \cdot \varepsilon_{\text{sig}}$		
2-lepton scaling correction	1.088	1.1%[*] ± 2.5%
Total (uncorrelated with Peaking Bkg.)	2.5%	
Total (correlated with Peaking Bkg.) [*]	1.1%	
Additive Uncertainties		
Signal Shape Parameters	N/A	17.7 events out of 2325.8 (0.8%)

Final Results



BR(ϒ(1S)→invisible) = [–1.6 ± 1.4 (stat.) ± 1.6 (syst.)]$\times 10^{-4}$

BR(ϒ(1S)→invisible) < 3.0×10^{-4} @ 90% C.L.

Brand-new result, submitted to PRL

Conclusions

- No evidence for invisible decays of $\Upsilon(1S)$
  - Set an upper limit
    - ☞ $BR(\Upsilon(1S)\rightarrow invisible) < 3.0\times10^{-4}$ @ 90% C.L.
  - Improvement by a factor of 8 over the previous best measurement (Belle)
  - Significant constraints on the models of light dark matter
    - ☞ Predicted range 5×10^{-4}–3×10^{-3} for one typical model
- Analysis systematics-dominated
  - Difficult to expect significant improvements from the current generation of experiments
  - SuperB and/or SuperBelle: will require improvements in hermeticity and understanding of the peaking backgrounds

Related Talks at DPF2009

- Searches for Light Higgs in BaBar
  - ☞ YGK, Higgs Session (Tue, 7/28)
- Lepton Universality in Upsilon Decays
  - ☞ Elisa Guido, LE-BSM Session (Thu, 7/30)
- Lepton Flavor Violation Searches in Tau and Upsilon Decays
  - ☞ Swagato Banerjee, LE-BSM Session (Fri, 7/31)