Recent Results in Semileptonic B Decays with *BABAR*

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2011 Meeting of the Division
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American Physical Society

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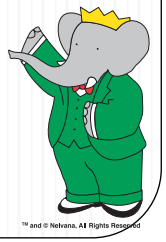
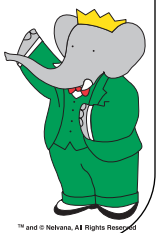


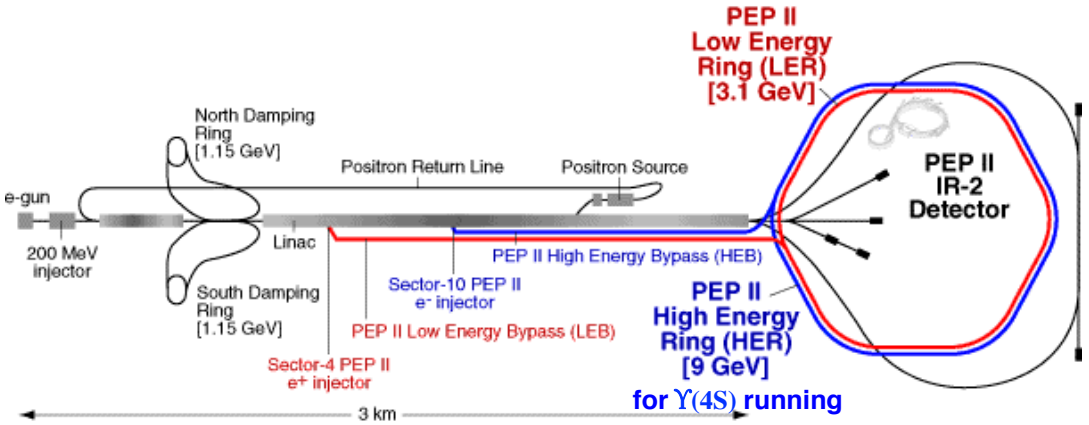
Outline

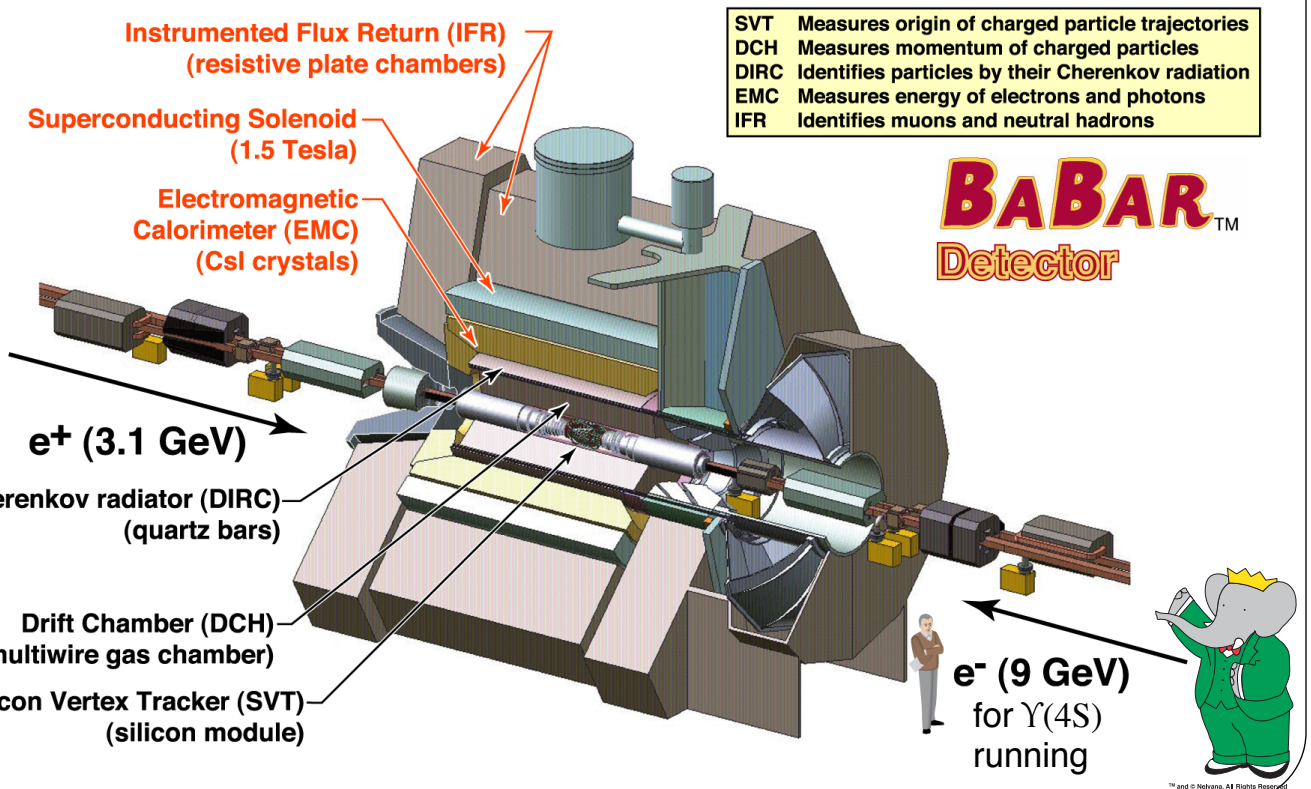
- Brief introduction to the ***BABAR*** experiment
- $\overline{B} \to D^{(*)} \tau^- \nu_\tau$ measurements
  - Event Reconstruction
  - Fit Structure
  - Results
- B_s production near the $\Upsilon(5S)$ and $\mathcal{B}(B_s \to l\nu X)$
  - Technique
  - Results
- Latest $|V_{ub}|$ results (time permitting)



BABAR at SLAC's PEP-II e^+e^- collider

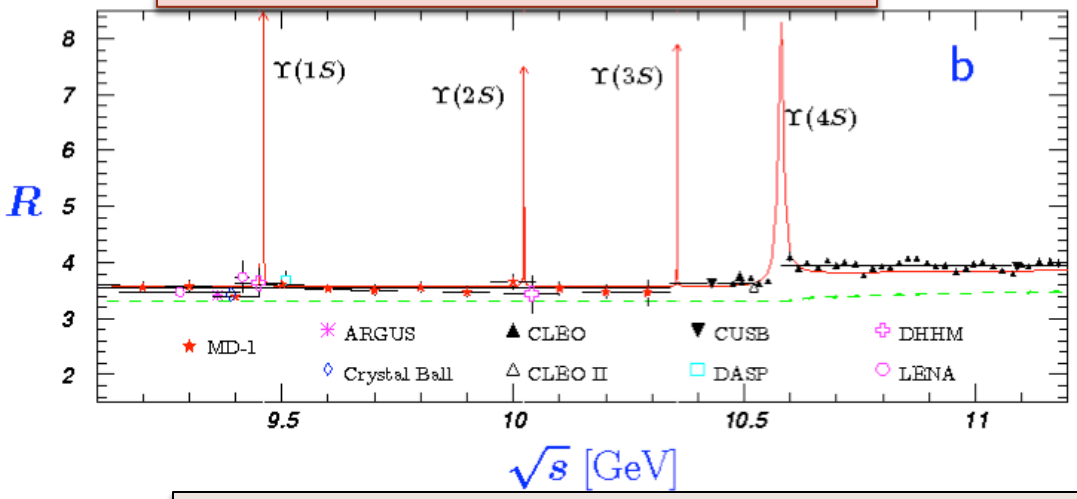
- 5-layer Silicon Vertex Tracker and 40-layer Drift Chamber in a 1.5-Tesla B-field provide measurements of track parameters
- Particle ID via measurements of specific ionization (dE/dx) and Cherenkov angle
- CsI(Tl) crystal calorimeter measures photon energies and assists in PID





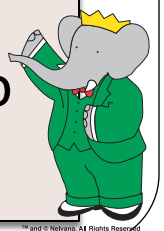
The Complete *BABAR* Dataset

Nakamura *et al.* (Particle Data Group), J. Phys. G **37**, 075021 (2010)



- $\sigma(e^+e^- \to \Upsilon(4S)) \approx 1.1$ nb
- $\mathcal{B}(\Upsilon(4S) \to B\bar{B}) > 96\%$ with Q-value ≈ 20 MeV

- 432.89 fb^{-1} $\Upsilon(4S)$
- 30.23 fb^{-1} $\Upsilon(3S)$
- 14.45 fb^{-1} $\Upsilon(2S)$
- 53.85 fb^{-1} off-resonance
  - below resonance for each on-resonance point
  - Scan above the $\Upsilon(4S)$ [10.56 GeV (open B threshold) to 11.2 GeV (short of Λ_b threshold at 11.24)]



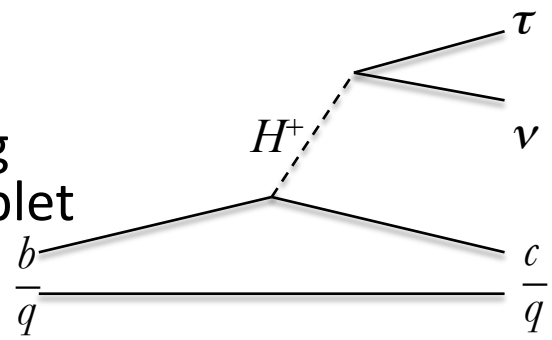
$\bar{B} \to D^{(*)} \tau^- \nu_\tau$

$\bar{B} \to D^{(*)} \tau^- \nu_\tau$

- B semileptonic decays to τ not as well-measured as to e, μ
  - Compare (PDG2010):

$$\mathcal{B}(\bar{B} \to D l^- \nu) = (2.23 \pm 0.11)\%$$
$$\mathcal{B}(\bar{B} \to D \tau^- \nu) = (0.77 \pm 0.25)\%$$

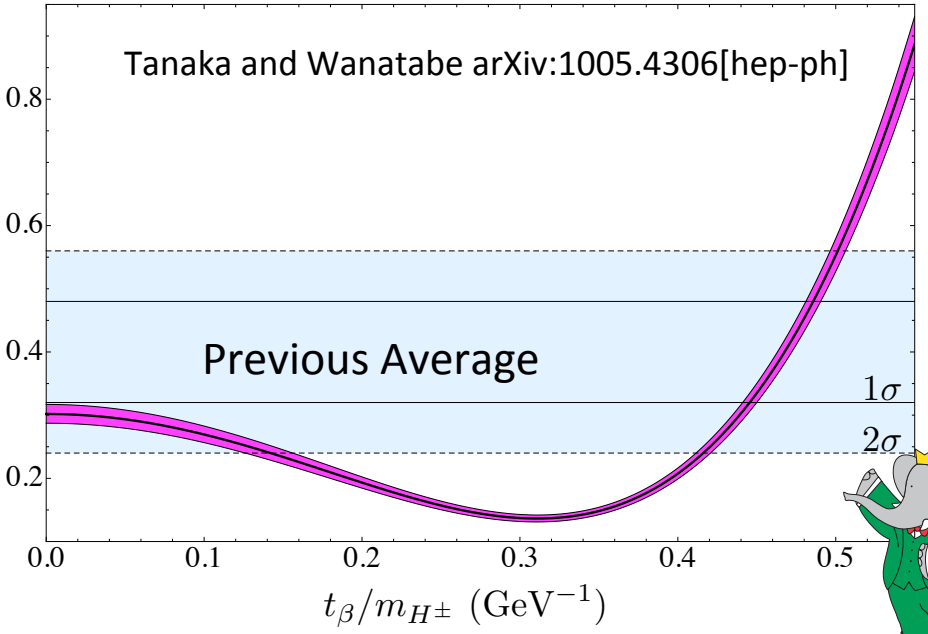
- New physics can easily effect the branching fraction to tau – for example, the two-doublet models of Higgs sector predict differences at tree level due to charged Higgs interactions



- A clean quantity to measure (in terms of systematic and theory uncertainty) is the ratio of semileptonic decays:

$$R(D^{(*)}) \equiv \frac{\mathcal{B}(B \to D^{(*)} \tau \nu)}{\mathcal{B}(B \to D^{(*)} \ell \nu)}$$

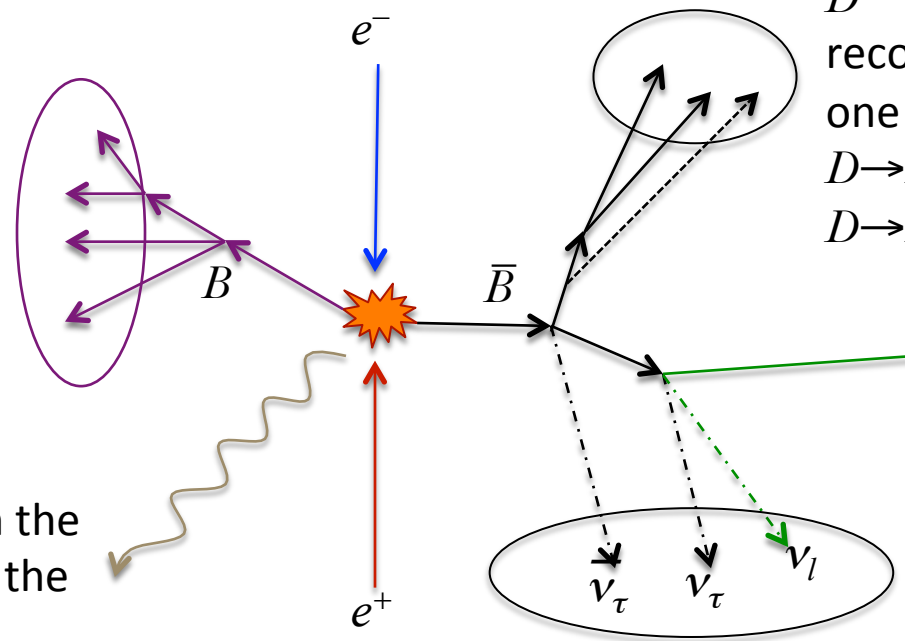
SM predicts $R(D)=0.31\pm0.02$, $R(D^*)=0.25\pm0.02$ (Nierste, Trine, Westoff, Phys. Rev. D **78** 015066 (2008))



Event Reconstruction

Improved "Tag side" candidate reconstruction from one of 1000+ hadronic B decay modes.

- Cut on $\Delta E = E^* - E^*_{beam}$ and $m_{ES} = (E^{*2}_{beam} - \mathbf{p}^{*2})^{1/2}$



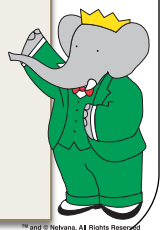
$D^{(*)}$ candidate reconstructed in one of 11 modes $D \to KK^+$ or $D \to Kn\pi$, n=1,2,3

e or μ (improved PID)

Energy deposits present in the calorimeter but unused in the reconstruction distinguish different ways to reconstruct an event

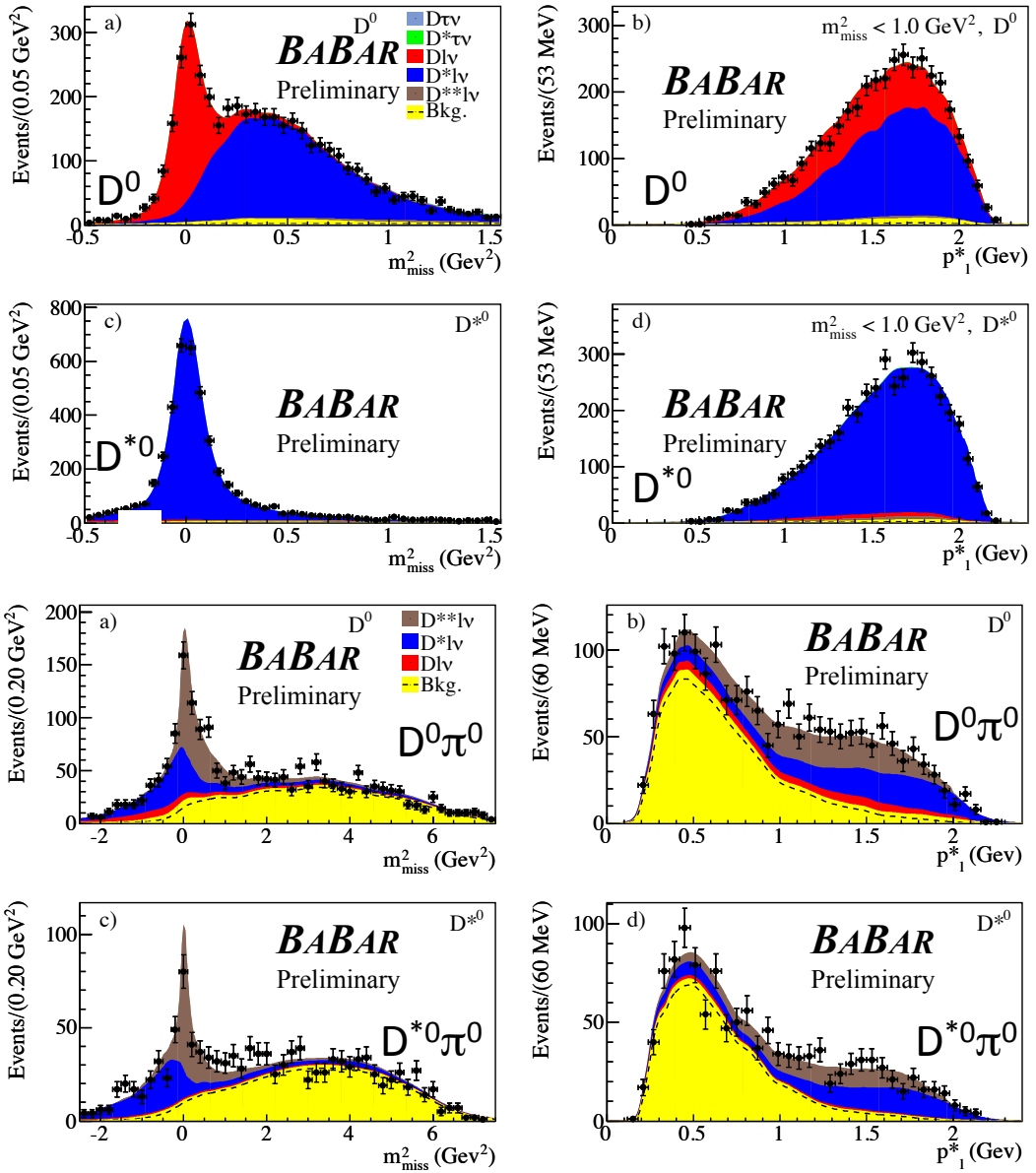
m^2_{miss} = invariant mass of missing E and **p** in event. "True" value in decays to e and μ is ≈0

- $q^2 = (E_{miss} + E_l)^2 - (\mathbf{p}_{miss} + \mathbf{p}_l)^2$ is used to discriminate against e and μ semileptonic decays. Signal region is $q^2 > 4$ GeV^2, normalization is $q^2 < 4$ GeV^2
- Boosted Decision Tree (BDT) used to suppress combinatoric and continuum $e^+e^- \to q\bar{q}$ backgrounds
- Improvements: Higher $\int \mathcal{L} dt$, 2.3×more B_{tag}, BDT

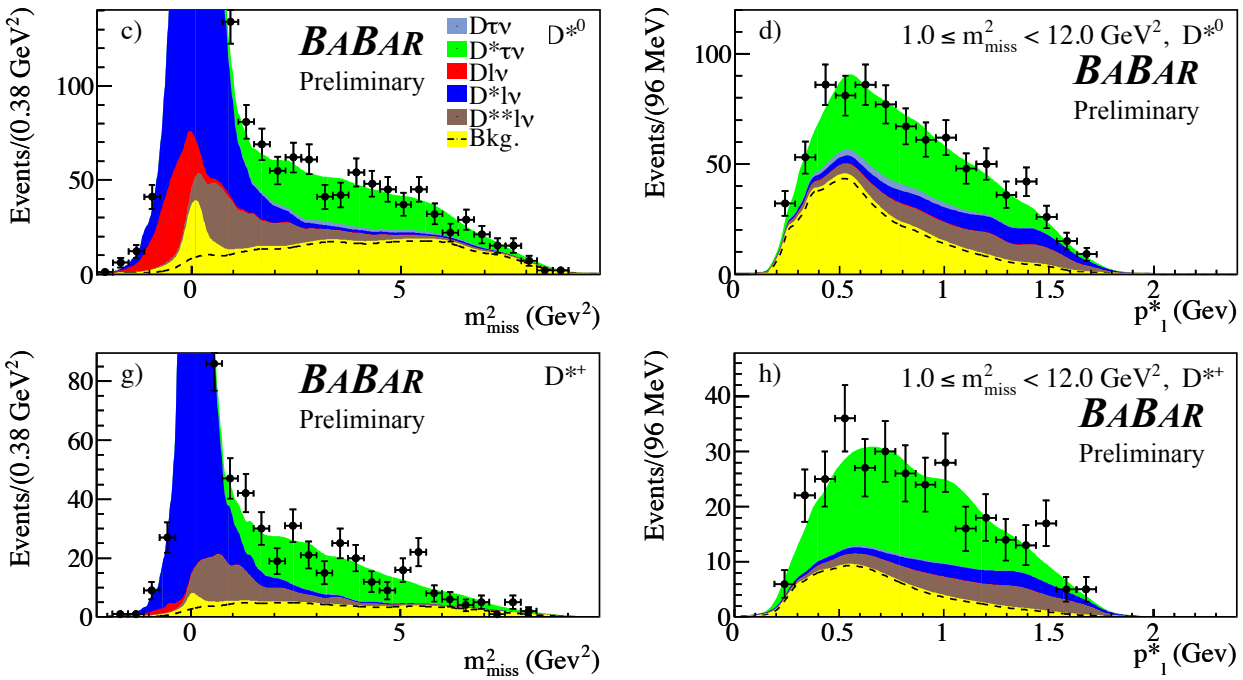


Fit in m^2_{miss} vs p^*_l

- 4 main channels: D^0, D^+, D^{*0}, and D^{*+}, plus D^{**}-enriched $D\pi^0$ samples
- Simulation used to fix:
  - Relative yields of continuum, B combinatoric and charge cross-feed backgrounds
  - Feed-down across different modes (e.g. so that D* feed-down in D sample is determined by yield in D* sample)
- Additional sample with π^0 candidates reconstructed and added to $D^{(*)}$ candidates used to enrich B to D^{**} decays and determine feed-down
- 10 Parameter fit to 4 signal channels+12 parameter fit to 4 π^0 control channels



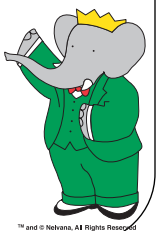
$D^* l\nu$ sample



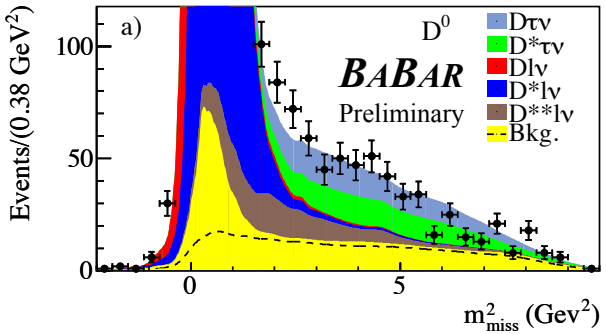
- Both charged and neutral modes reconstructed with high significance
- Consistent with SM at 1.8σ

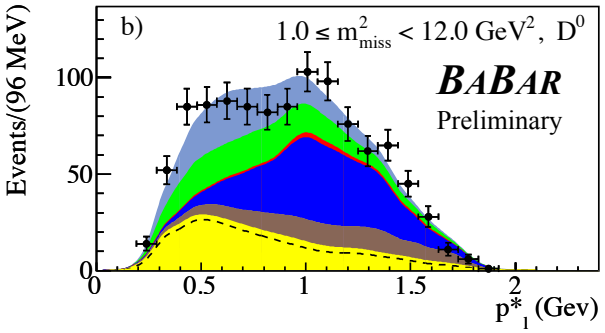
	Nsig	B(B→D*τν)(%)	R(D*)
D*0	511±48	1.79±0.17±0.14	0.341±0.030±0.028
D*+	220±23	1.82±0.19±0.17	0.356±0.038±0.032
Constrained	730±50	1.79±0.13±0.17	0.325±0.023±0.027

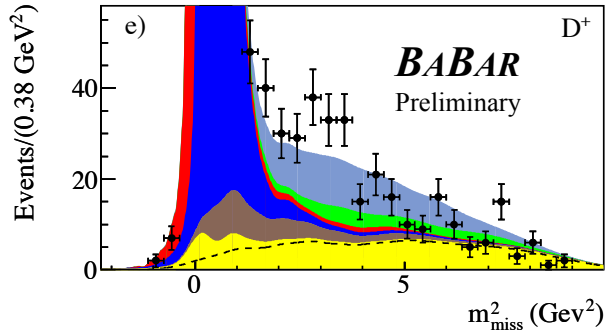
BABAR
Preliminary

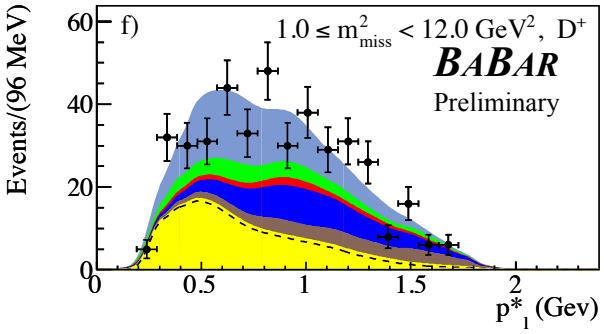


$D l \nu$ sample





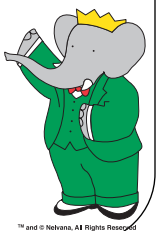




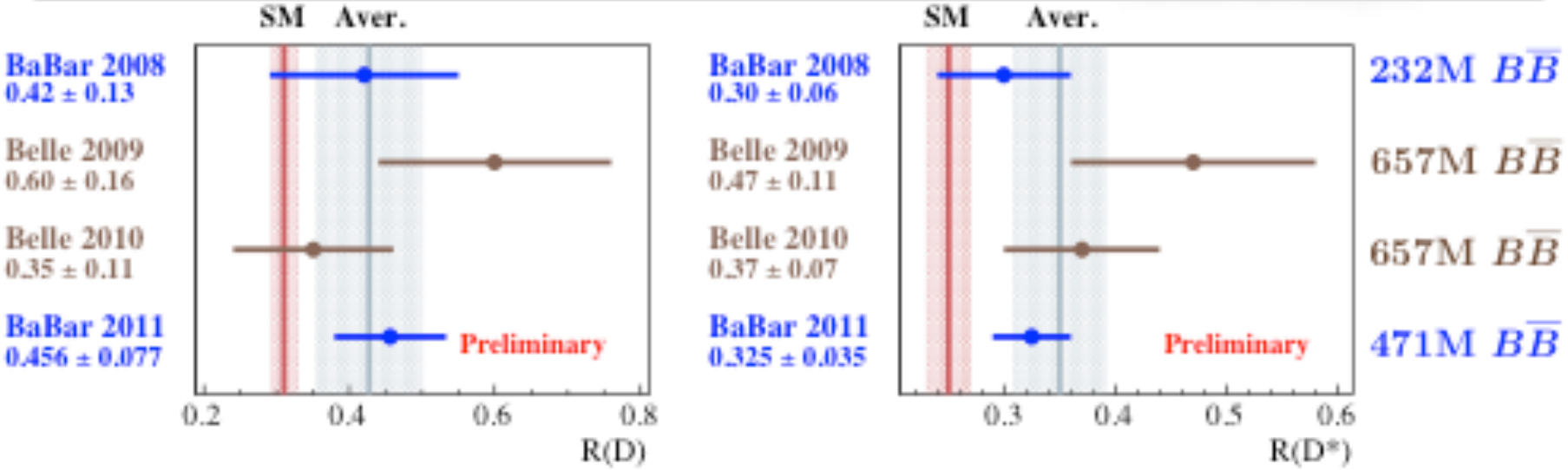
- First measurement of these modes at >5σ
- These modes also 1.8σ above SM

	Nsig	B(B→Dτν)(%)	R(D)
D0	226±39	0.96±0.17±0.14	0.422±0.074±0.059
D+	139±21	1.08±0.19±0.15	0.513±0.081±0.067
Constrained	368±42	1.04±0.12±0.14	0.456±0.053±0.056

BABAR Preliminary



Results (Continued)



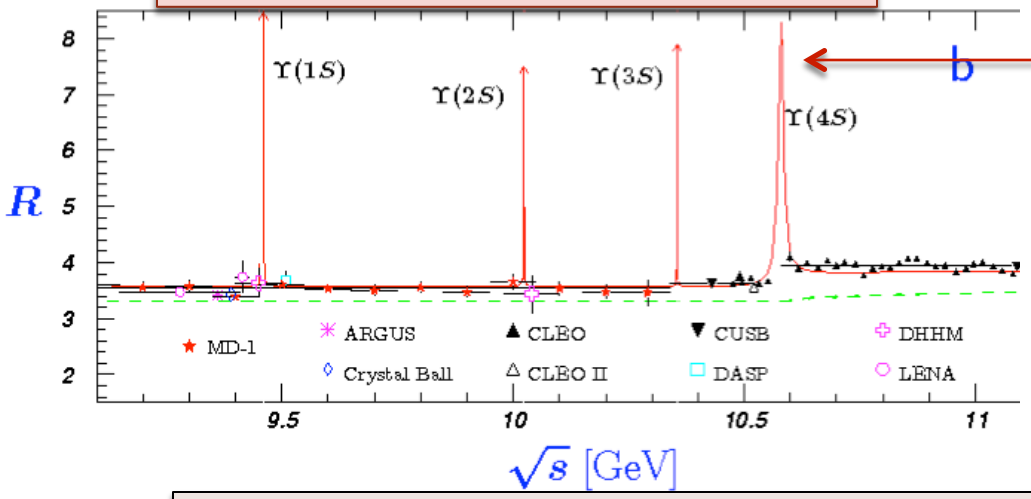
Figures from Manuel Sevilla's EPS talk

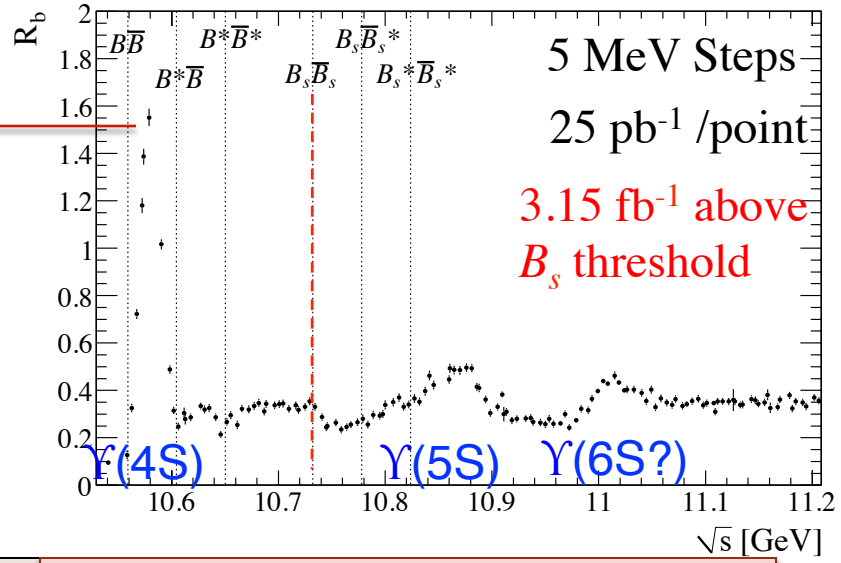
- Results compare well with previous average
- Improvement over previous BaBar result is better than luminosity scaling alone

B_s Production and Semileptonic Decay

The Complete *BABAR* Dataset

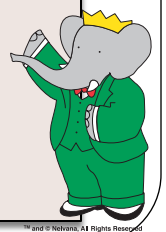
Nakamura *et al.* (Particle Data Group), J. Phys. G **37**, 075021 (2010)





- Scan above the Υ(4S) [10.56 GeV (open *B* threshold) to 11.2 GeV (short of Λ_b threshold at 11.24)]
  - ≈140 points, most 25 pb^{-1}, 8 100 pb^{-1}
  - ≈4.15 fb^{-1} total

The Scan above the Υ(4S)
BABAR Collaboration
Phys. Rev. Lett. **102**, 012001 (2009)



Inclusive ϕ(+lepton) as a probe of B_s decay

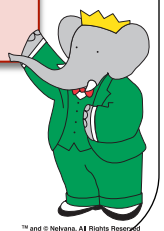
- ϕ yield from B_s large compared to $B_{u/d}$ decays:
  - $\mathcal{B}(B_s \to D_s X) \times \mathcal{B}(D_s \to \phi X) \approx 15\%$ (PDG2010)
  - **vs** $\mathcal{B}(B \to \phi X) \approx 3.43\%$ (PDG2010)

- ϕ+lepton:
  - $B_s \to D_s l\nu X_1 \to \phi l\nu X_2 \approx 1.3\%$ (same B_s)
  - **vs** $B \to D l\nu X_1 \to \phi l\nu X_2 \approx 0.1\%$ (same B)

  - $B_s \to l\nu X_1$ & $B_s \to \phi X_2 \approx 1.4\%$ (different B_s)
  - **vs** $B \to l\nu X_1$ & $B \to \phi X_2 \approx 0.4\%$ (different B)

➔ *Inclusive yields of* ϕ & ϕ+lepton can be used to measure both B_s production rate ($B_s B_s / B\bar{B}$) and its semileptonic branching fraction

- Backgrounds sources: Continuum $e^+e^- \to q\bar{q}$ & $B_{u/d}\bar{B}_{u/d}$



Analysis Method

- Measure number of events, ϕ yield, and ϕ yield in correlation with a high-momentum lepton as a function of CM energy

- Use below $B\bar{B}$ threshold data to subtract continuum $e^+e^- \to q\bar{q}$ (q=u,d,s,c) contributions. Schematically:
  - B hadron events:

$$R_b \left[f_s \epsilon_{1s} + (1 - f_s) \epsilon_1 \right]$$

  - Inclusive ϕ rate:

$$R_b \left[f_s P(B_s \bar{B}_s \to \phi \mathrm{X}) \epsilon_{2s} + (1 - f_s) P(B\bar{B} \to \phi \mathrm{X}) \epsilon_2 \right]$$

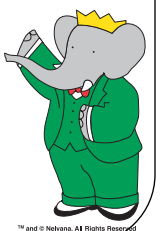
  - Inclusive ϕ+lepton rate:

$$R_b \left[f_s P(B_s \bar{B}_s \to \phi \ell \nu \mathrm{X}) \epsilon_{3s} + (1 - f_s) P(B\bar{B} \to \phi \ell \nu \mathrm{X}) \epsilon_3 \right]$$

- With
  - $f_s \equiv \dfrac{\#\ B_s \text{ events}}{\text{all } B \text{ hadron events}}$

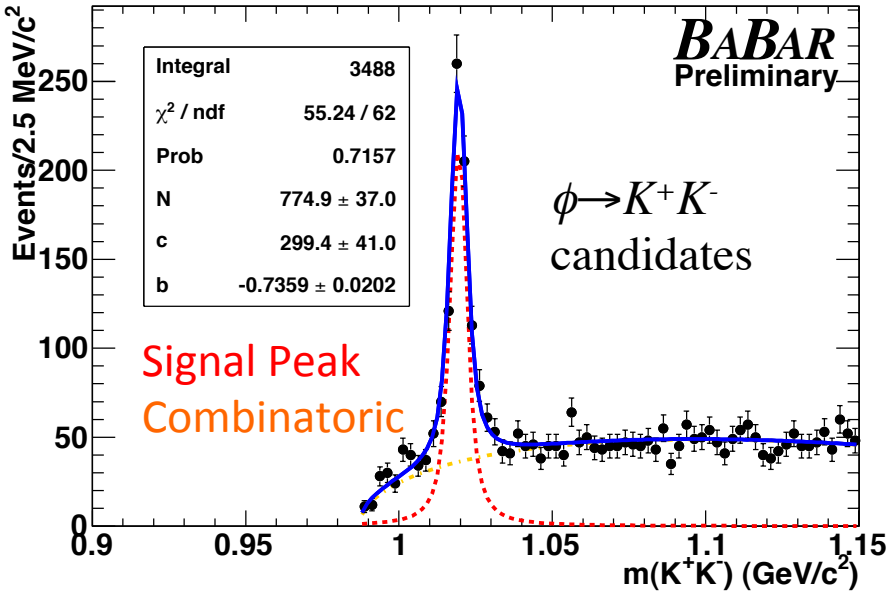
and ε_i representing the corresponding efficiencies.

- $P(B_sB_s \to \phi l\mathrm{X})$ contains info on $\mathcal{B}(B_s \to l\nu\mathrm{X})$

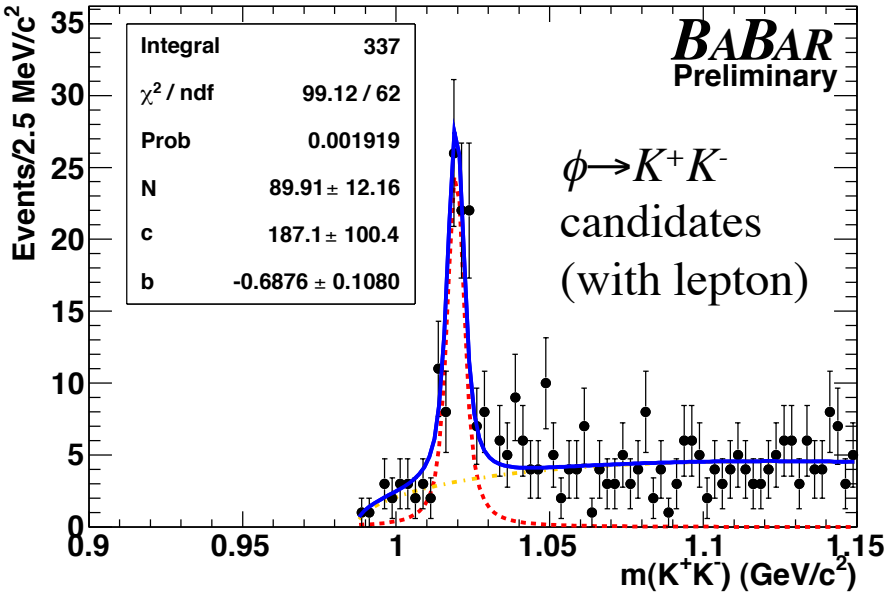


Measurement

ϕ candidate mass ($\sqrt{s}$=10.835 GeV)

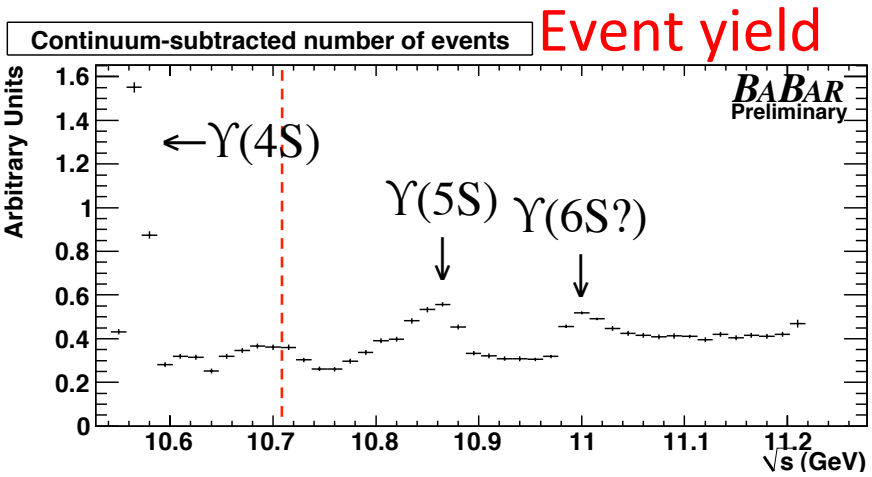


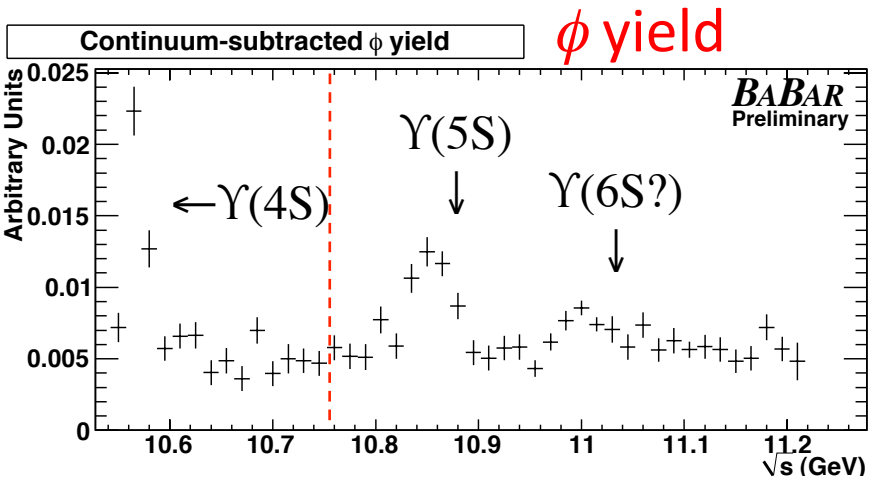
ϕ candidate mass ($\sqrt{s}$=10.835 GeV) (with lepton)

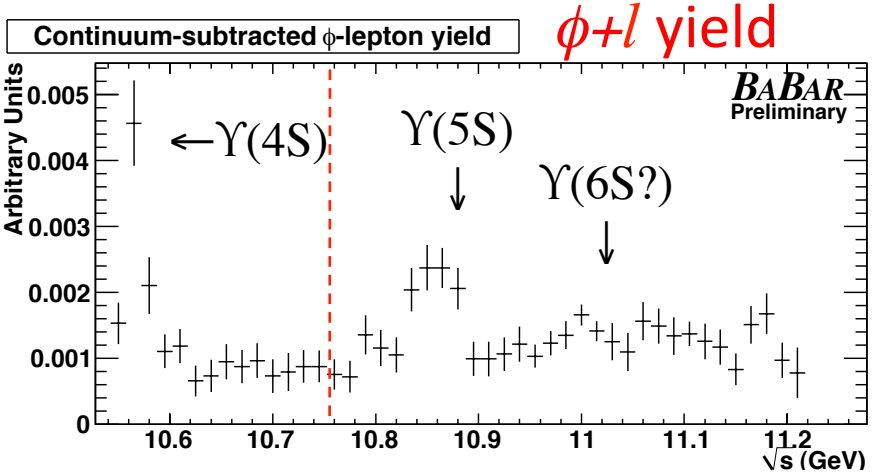


- Mass plots for inclusive ϕ and ϕ with lepton at $10.8225 < E_{CM} < 10.8475$ GeV (other points are similar)
  - (At same energy, so right plot is subset of events on left)

Measurement







Relative yields as a function of energy (15 MeV bins) after continuum $e^+e^- \to q\bar{q}$ subtraction

Events selected which pass multi-hadron event filters and have 2nd Fox-Wolfram moment < .2 (selecting more spherical events)

Simultaneous Extraction of Br($B_s \to l\nu X$)&f_s

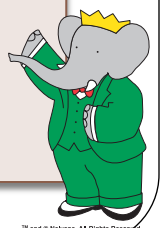
➢Continuum-subtracted rates given by:

$$\text{Event rate} = R_b\left[f_s\epsilon_{1s} + (1-f_s)\epsilon_1\right]$$

$$\phi \text{ rate} = R_b\left[f_s P(B_s\bar{B}_s \to \phi X)\epsilon_{2s} + (1-f_s)P(B\bar{B} \to \phi X)\epsilon_2\right]$$

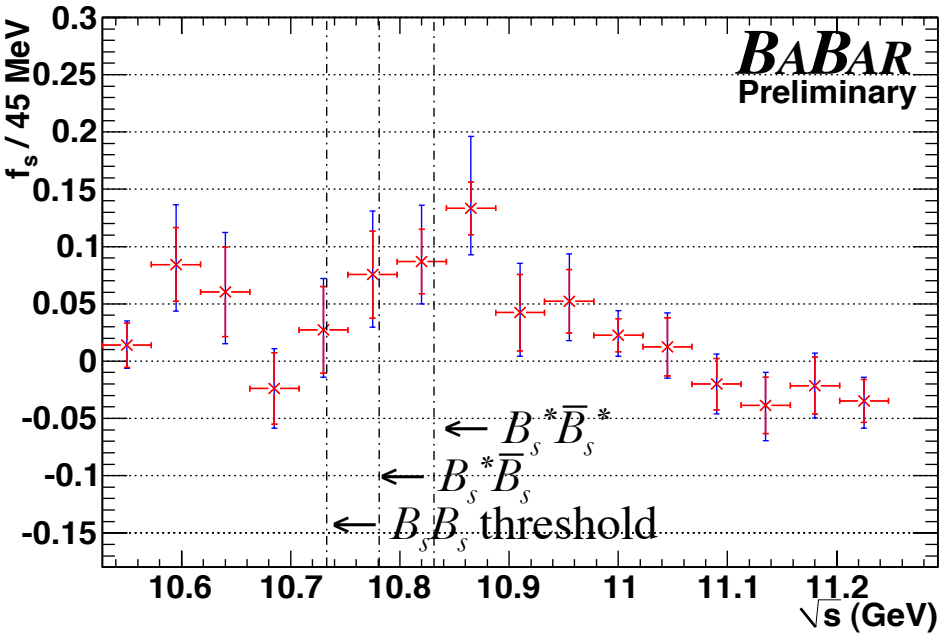
$$\phi-\ell \text{ rate} = R_b\left[f_s P(B_s\bar{B}_s \to \phi\ell\nu X)\epsilon_{3s} + (1-f_s)P(B\bar{B} \to \phi\ell\nu X)\epsilon_3\right]$$

- $B_{u/d}$ contributions are measured in data taken at $\Upsilon(4S)$
- f_s extracted at each energy point from number of events and ϕ yield
- B_s contributions depend on:
  - $\mathcal{B}(B_s \to D_s X_i)$ (PDG), $\mathcal{B}(B_s \to l\nu X_j)$, $\mathcal{B}(D_s \to l\nu X_k)$ (PDG), $\mathcal{B}(D_s \to \phi X_m)$ (PDG), $\mathcal{B}(D_s \to \phi l\nu X_n)$ (PDG) and others
- A χ^2 fit is performed to the measured yields to extract $\mathcal{B}(B_s \to l\nu X)$



Results

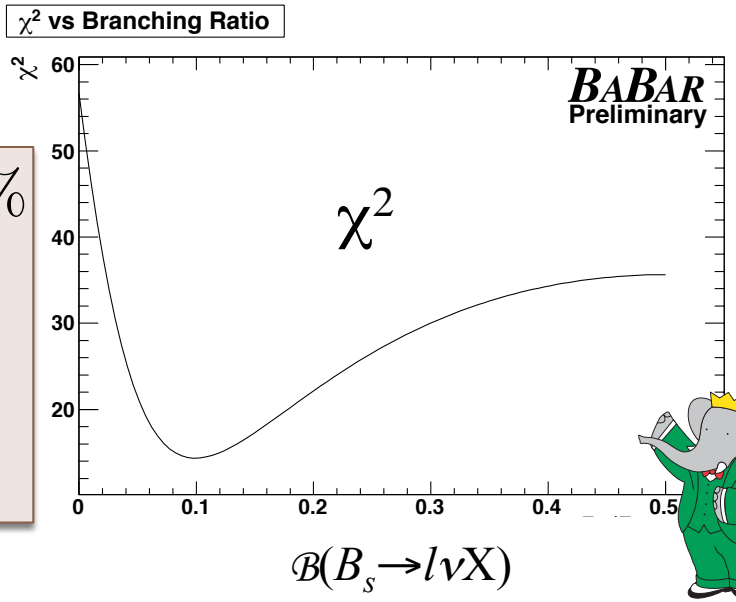
f_s in 45 MeV bins



Previous f_s results at $\Upsilon(5S)$ peak

- Belle: (19.3 ±2.9)%
  Phys. Rev. D **76**, 012002 (2007)
- CLEO: $(16.8 \pm 2.6^{+6.7}_{-3.4})\%$
  Phys. Rev. D **75**, 012002 (2007)

- $\mathcal{B}(B_s \to l\nu X) = \left(9.9^{+2.6}_{-2.1}(\text{stat})^{+1.3}_{-2.0}(\text{syst})\right)\%$
- Dominant systematic is from inclusive D_s yield per B_s = .93 ±.25 (PDG2010) (Belle & LEP)



Other Semileptonic Results of Note

- $|V_{ub}|$ measured using inclusive decays with the entire ***BABAR*** dataset
  - Hadronic B reconstruction plus lepton ID with 2D fit in q^2 and M_X (invariant mass of B daughters)
  - Extraction based on 4 QCD calculations (BLNP, DGE, GGOU, ADFR)
  - (Preliminary) average $|V_{ub}|_{incl}=(4.31\pm0.25\pm0.16)\times10^{-3}$
    - (Compare with 4.27±0.38 from 2010 PDG review on CKM elements)
  - To be submitted to PRD

- $|V_{ub}|$ measured in the in the exclusive $B\to\pi l\nu$ channel
  - No "tag B" reconstruction for this analysis. Instead, a fit in DE and m_{ES} of lepton-pion-missing energy/momentum system is used.
  - BF extracted in bins of q^2 and LQCD prediction used to extract $|V_{ub}|$
  - $|V_{ub}|_{excl}=(3.13\pm0.14\pm0.27)\times10^{-3}$
    - (Compare with 3.38±0.36 from 2010 PDG review on CKM elements)
  - Phys. Rev. D **83**, 032007 (2011) and Phys. Rev. D **83**, 052011 (2011)

  - Tension in inclusive vs exclusive measurements persists
    - See Manuel Sevilla's talk at EPS for more detail