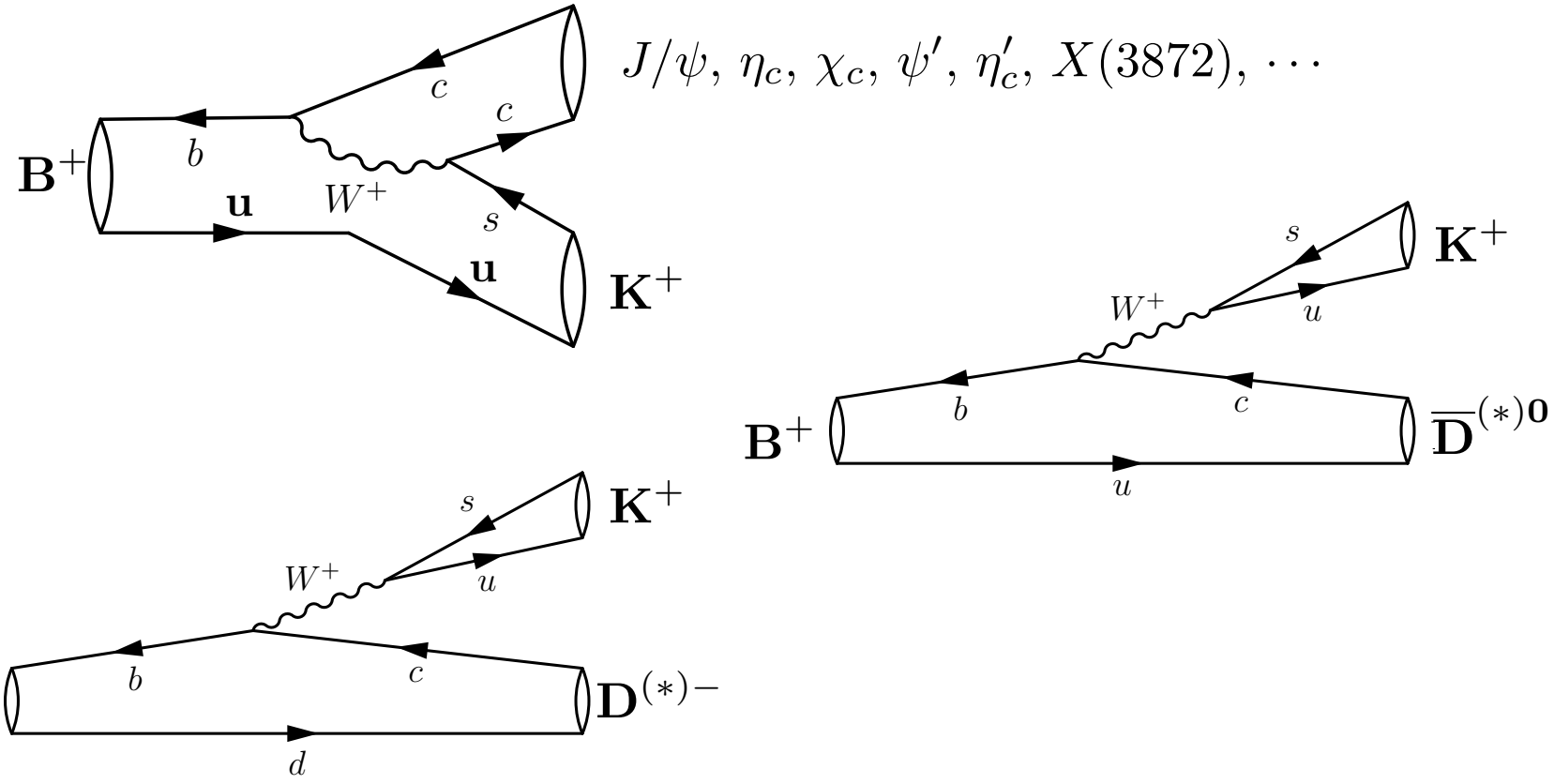
Measurements of charmonium states inclusive production in the two body decays B → X_{cc} + K, and more.

Michael D. Sokoloff
University of Cincinnati
on behalf of the BABAR Collaboration

Fully reconstructing a $\bar{B}$ in e^+e^- → $\Upsilon(4S)$ allows one to study the recoil (missing mass) spectrum of B → K,X decays (charge conjugation implicit). This provides measurements absolute B → (K,charmonium) branching fractions. In addition to probing charmonium production, the same technique allows one to study exclusive B → K,$D^{(*)}$ production. Results from BaBar's 424 fb^{-1} sample are reported. In particular, we observe production of a $D^{**0}(2680)$ resonance.

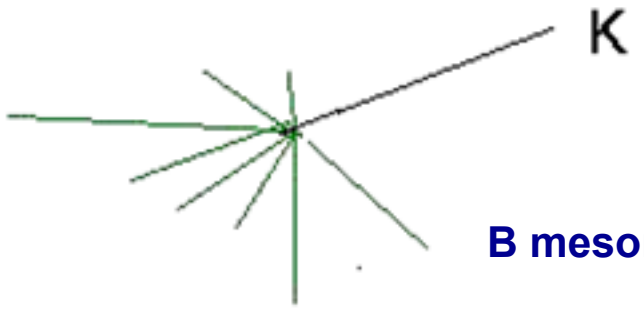
UNIVERSITY OF Cincinnati

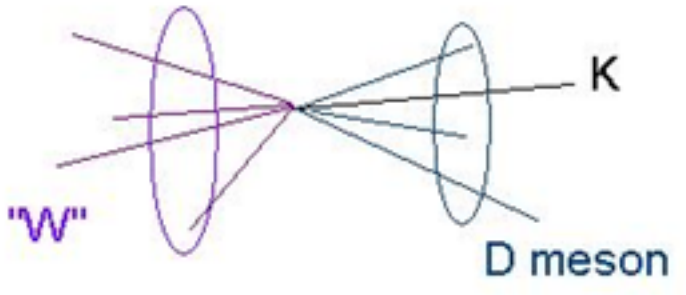
Feynmann Diagrams for the Amplitudes



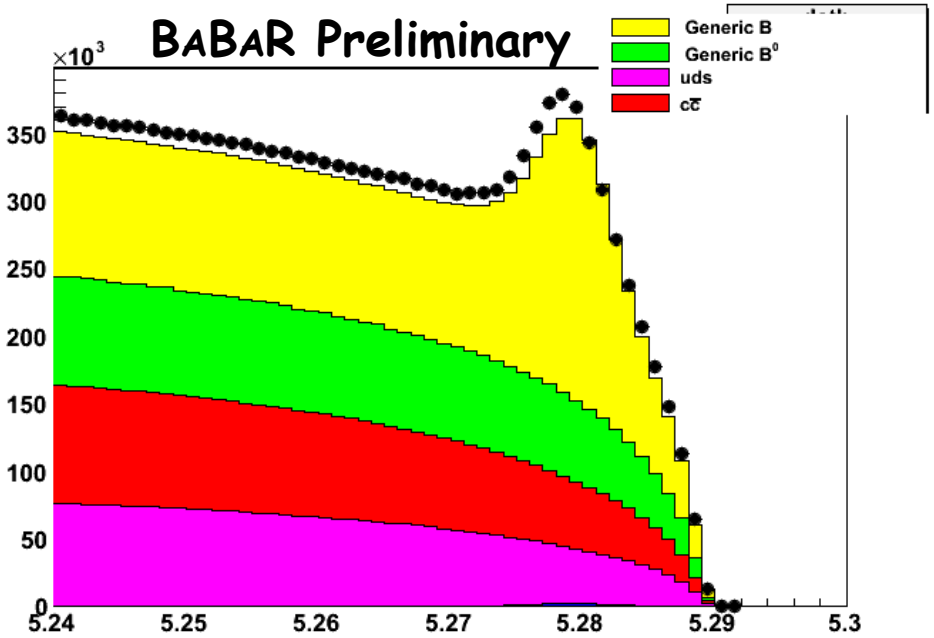
Some Key Ideas

- Recoil (missing mass) spectra measure "inclusive" B → K,X branching fractions. They are democratic as they do not depend on the decays of their daughters.
- Alternatively, exclusive B → K,X final states can be fully reconstructed for specific decays, including specific final states for the daughter states. For example X = X(3872) → $J/\psi,\pi^-,\pi^+$.
- B → K,X daughter kaons characteristically differ from B → D,X; D → K,Y kaons:





Inclusive B^+ Sample



m_{ES} (GeV)

$$m_{ES} = \sqrt{E_{CM}^2/4 - p_B^2}$$

- 1.67 M ± 4230 $B^{\pm}$
- Train a neural net to accept 80% of signal, remove 90% of bkgd.
- Remaining sample is ~1.3 M $B^{\pm}$ (shown on left)

Selecting Kaons from B → K,X

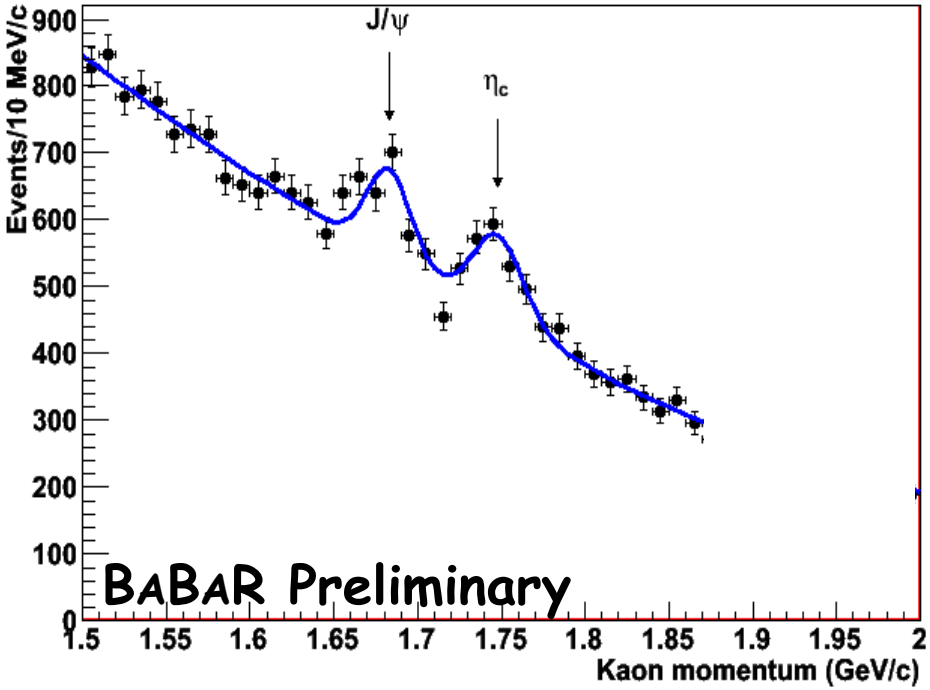
- Most kaons produced in B-decays are daughters of D-mesons, not daughters of the B-mesons themselves.
- Another neural net is trained to discriminate between daughter and grand-daughter kaons:
  - Use MC to avoid bias;
  - Train separately for 1 GeV < p_K < 1.5 GeV and for 1.5 GeV < p_K < 2.0 GeV;
  - 15 discriminating variables chosen carefully not to depend on particular decay topology of recoil system.

"Combination" Neural Nets

- The separate B and K neural nets are combined to further optimize $S^2/(S+B)$
- This "super-NN" is trained separately for $1.5\ GeV < p_K < 1.8\ GeV$ and for $1.2\ GeV < p_K < 1.5\ GeV$ (higher charmonium mass)
- These optimized super-NNs retain 55% of signal and reject background 3x in the X(3872) region, 2.5x in the J/ψ region.

$B^- \to K^-, X^0$

Lower Mass Charmonium Region

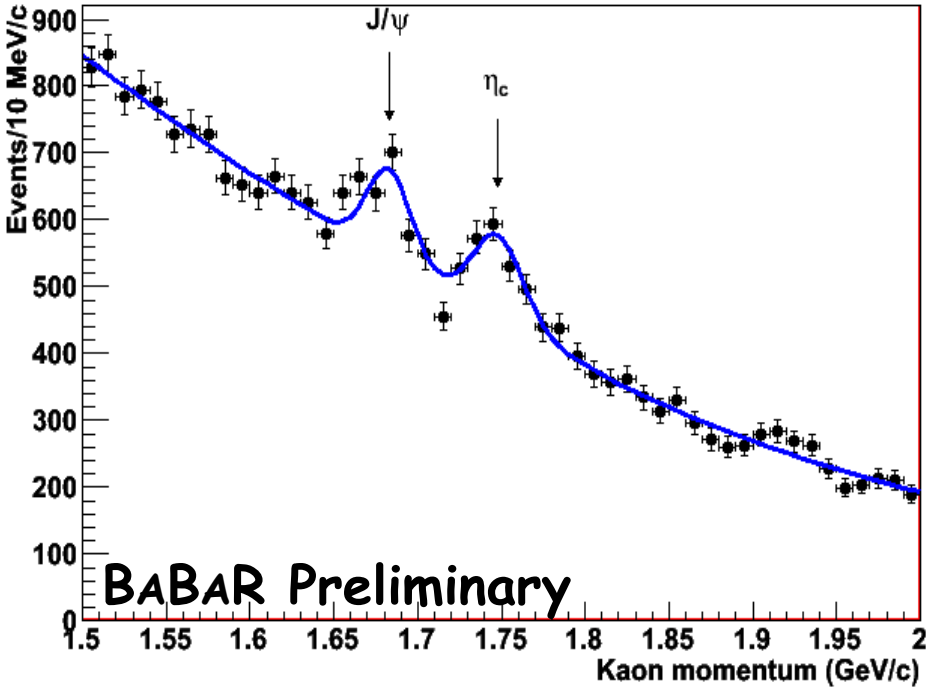


$p(K^-)$ from $B^- \to K^-, X^0$

$B \to K^-, \eta_c$ BF not sensitive to unknown η_c decay BFs.

$B^- \to K^-, X^0$

Lower Mass Charmonium Region

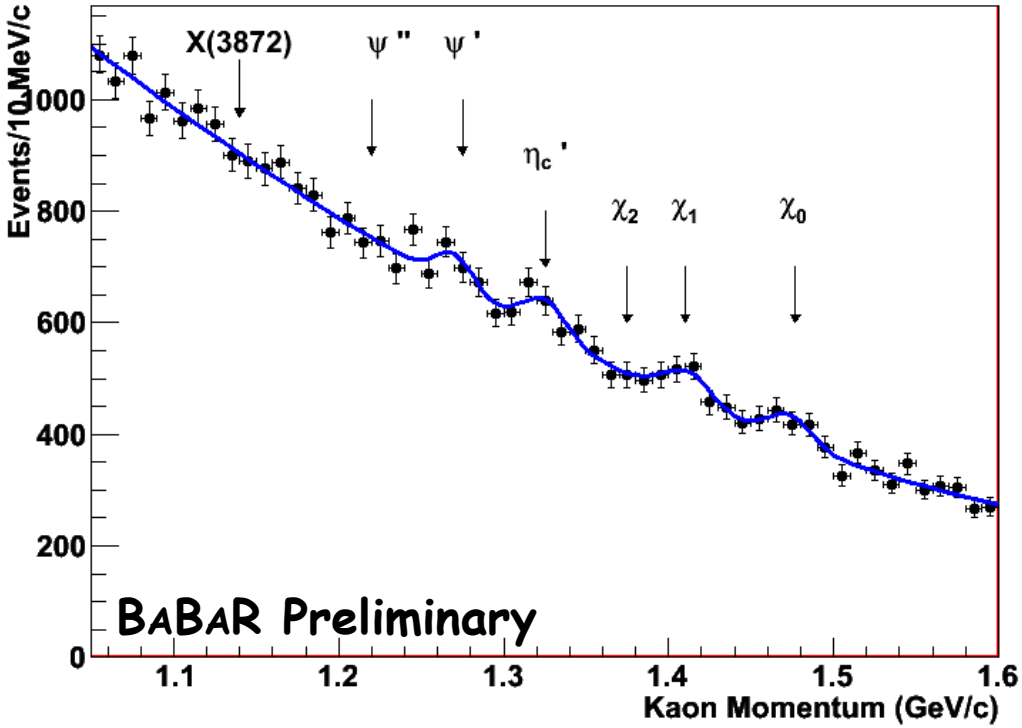


$p(K^-)$ from $B^- \to K^-, X^0$

$B \to K^-, \eta_c$ BF not sensitive to unknown η_c decay BFs.

$B^- \to K^-, X^0$

Higher Mass Charmonium Region

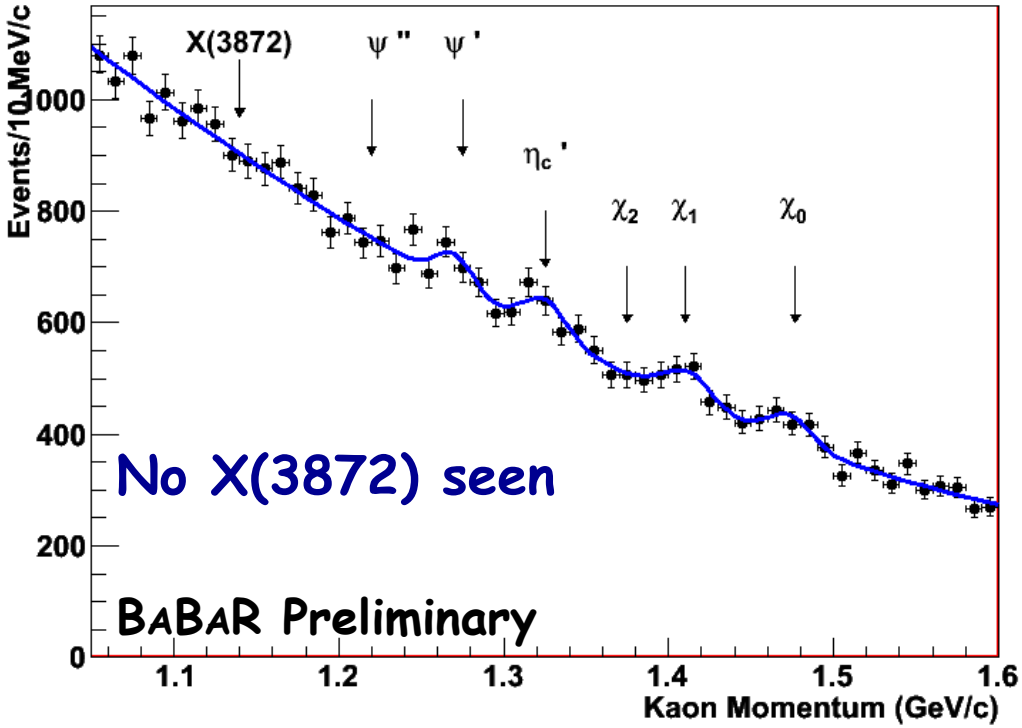


$p(K^-)$ from $B^- \to K^-, X^0$

Spectrum is fit with PDG widths convoluted with detector resolution for 8 signal peaks [that labeled χ_1 is a combination of χ_{c1} and h_c] and a third degree polynomial background shape.

$B^- \to K^-, X^0$

Higher Mass Charmonium Region

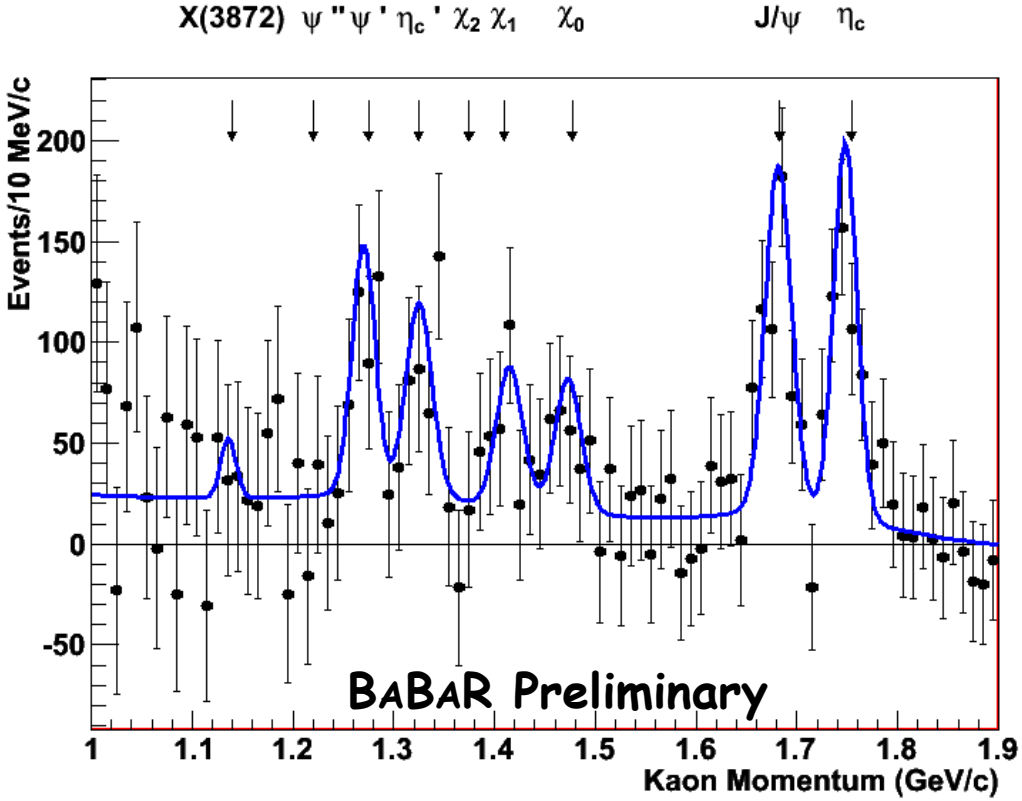


$p(K^-)$ from $B^- \to K^-, X^0$

Spectrum is fit with PDG widths convoluted with detector resolution for 8 signal peaks [that labeled χ_1 is a combination of χ_{c1} and h_c] and a third degree polynomial background shape.

$B^- \to K^-, X^0$

Full Charmonium Mass Region

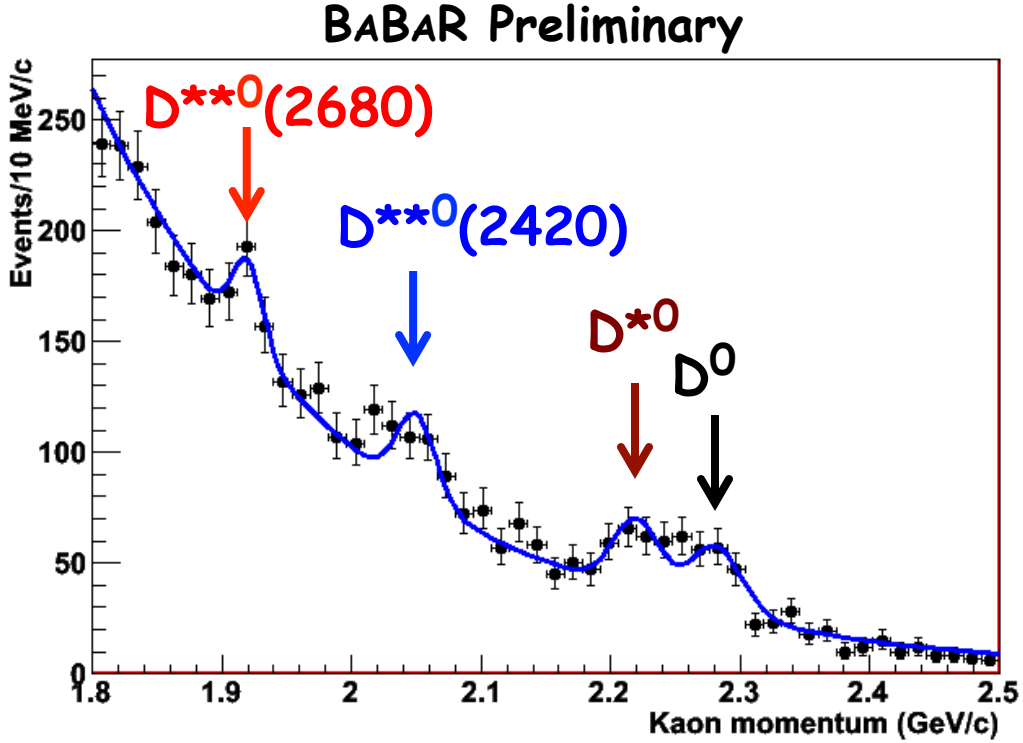


$p(K^-)$ from $B^- \to K^-, X^0$

Spectrum is fit with PDG widths convoluted with detector resolution for 10 signal peaks, after background subtraction. (BF tables will be presented later.)

$B^- \to K^-, X^0$

Lower Mass, Neutral $D^{(*)}$, Recoil Region

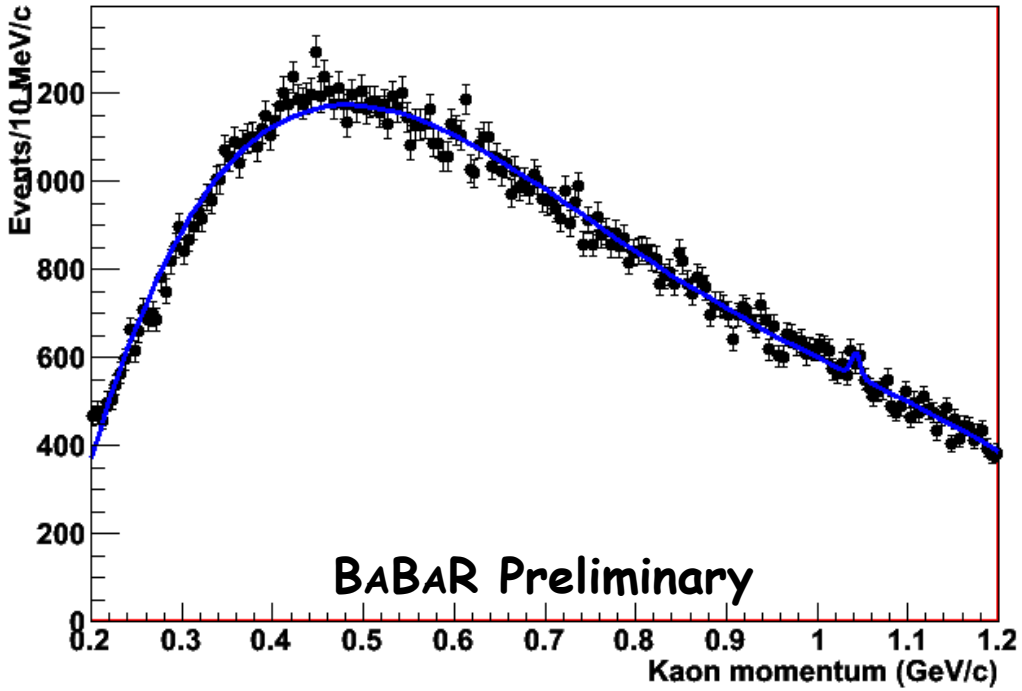


$p(K^-)$ from $B^- \to K^-, X^0$

The statistical significance of the $D^{**0}(2680)$ ~ 3.3σ. Its mass is measured to be (2.680 ± 0.003) GeV. The K^-, D^0 and K^-, D^{*0} branching fractions are consistent with PDG 2014 values.

$B^- \to K^-, X^0$

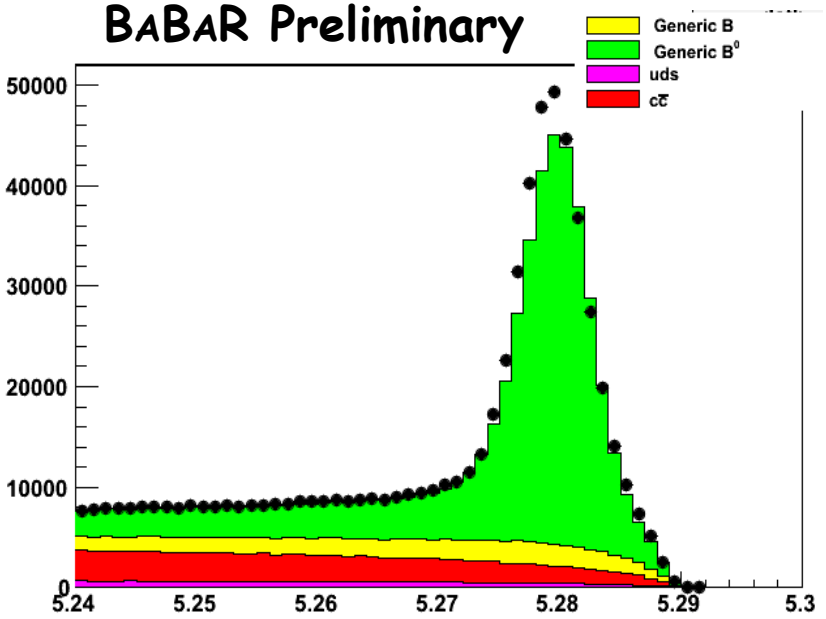
Very High Mass Charmonium Region



$p(K^-)$ from $B^- \to K^-, X^0$

Sensitive to narrow peaks (Γ < 20 MeV). The only structure "observed" (p_K = 1.0425 GeV, m_{recoil} = 3.990 GeV) has a statistical significance < 3σ when considering the "look elsewhere" effect. Not sensitive to Y(4260) due to its width (Γ ~ 100 MeV)

Inclusive B^0 Sample

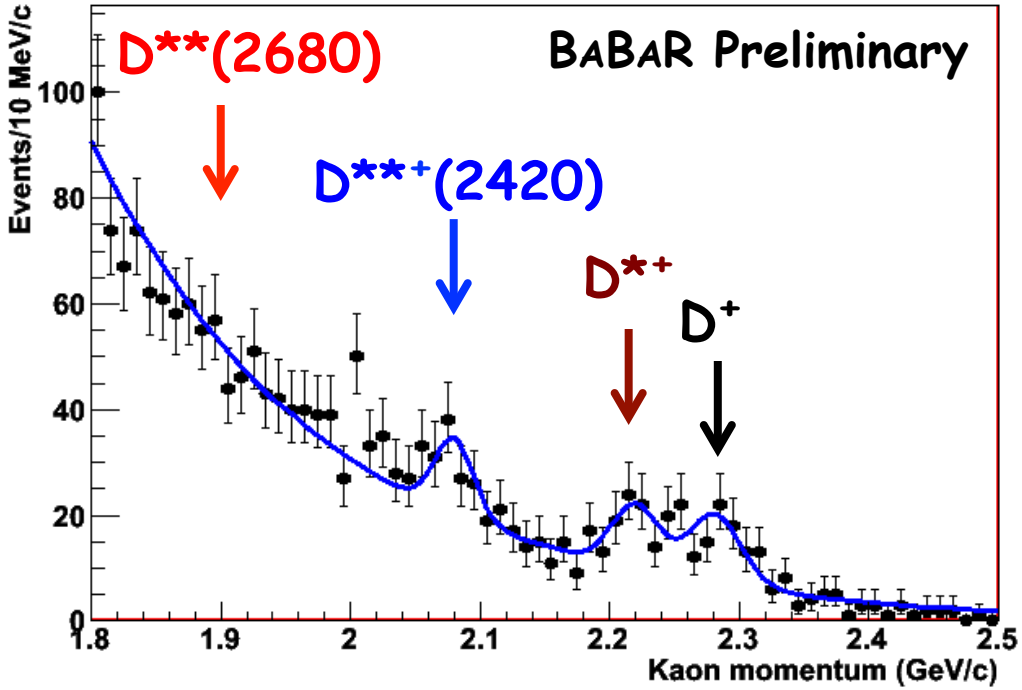


- 372,597 ± 775 B^0
- Only very clean tagging B^0-decays, and tighter cuts than for $B^\pm$, so fewer events and better S:B.

$$m_{ES} = \sqrt{E_{CM}^2/4 - p_B^2}$$

$B^0 \to K^-, X^+$

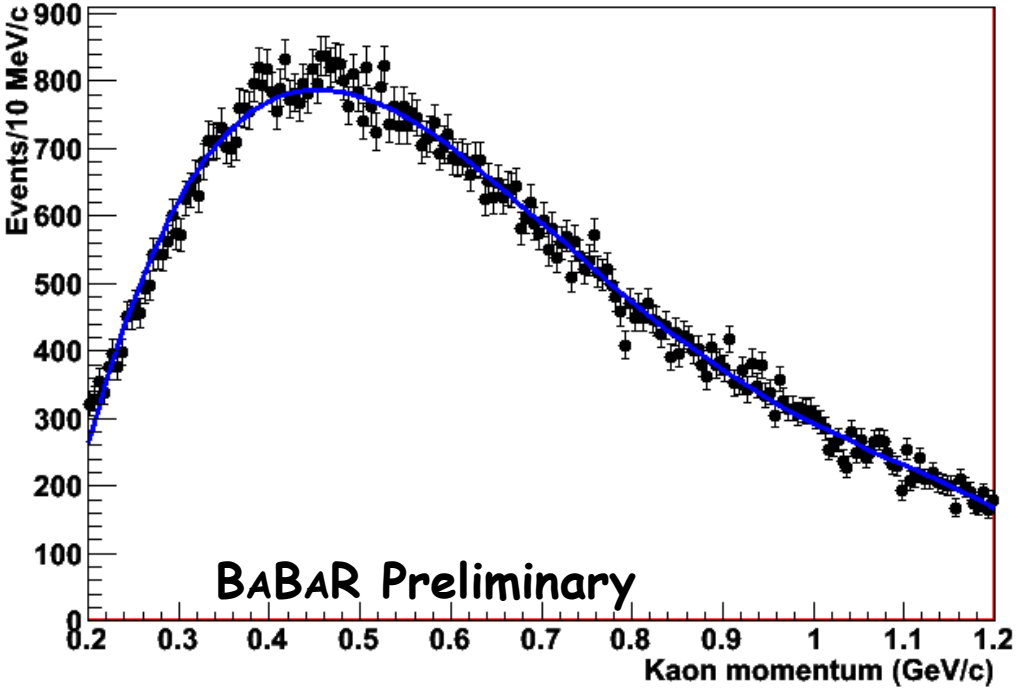
Lower Mass, Charged $D^{(*)}$, Recoil Region



$p(K^-)$ from $B^0 \to K^-, X^+$

No evidence for a $D^{**+}(2680)$ although D^+, D^{*+}, and D^{**+} signals are seen. The K^-, D^+ and K^-, D^{*+} branching fractions are consistent with PDG 2014 values.

Higher Mass, Charged Recoil Region



$p(K^-)$ from $B^0 \to K^-, X^+$

Sensitive to narrow peaks (Γ < 20 MeV).
No structures evident. Sensitivity to BF's
~ (3 – 5) x 10^{-4}.

Charmonium Results

BABAR Preliminary

Particle	Yield	Peak Position	Width	BF(10^{-4})
J/ψ	516±67			9.6±1.2(sta)±0.8(sys)
η_c	655±77	2982±5	<43	13.3±1.8(stat)±0.4(sys)±0.3(ref)
χ_{c0}	218±76			4.4±0.9
χ_{c1}	192±35			7.0±1.3(stat)±1.0(sys)
χ_{c2}	0±32			<1.2
η_c (2S)	283±94	**3632 ± 7**	<33	6.0±2.1(stat)±0.4(sys)
ψ'	293±90			6.2±2(stat)±0.6(sys)
$\psi(3770)$	0±49			<2.0
X(3872)	75±81			1.4±1.5 or < 4.4

Results from the fits of the K momentum spectrum in the charmonium mass region for 1.67 M reconstructed $B^{\pm}$ events. (Peak positions and widths in MeV; upper limits are 90% CL)

D-meson Results

BABAR Preliminary

Particle	Yield	Peak Position	BF(10^{-4})	PDG 2014
D^0	126±20		3.5±0.5(sta)±0.3(sys)	3.7±0.17
D^{*0}	126±21		3.5±0.5(stat)±0.3(sys)	4.2±0.34
D^{**0}	97±25		2.1±0.5(stat))±0.3(sys)	-
$D^{**0}(2680)$	95±29	2.68±0.003	2.1±0.6(stat)±0.3(sys)	-
$D^{\pm}$	44±10		3.3±0.8(sta)±0.3(sys)	2.0±0.21
$D^{*\pm}$	40±10		3.0±0.8(stat)±0.3(sys)	2.1±0.16
D**$(2420)^{\pm}$	52±13		3.9±1.0(stat))±0.3(sys)	-

Results from the fits of the K momentum spectra in the D region mass, performed for $B^{\pm}$ and B^0 samples of 1.67 M and 0.8 M reconstructed B events, respectively. (Peak position reported in GeV)

Summary and Outlook

- BABAR has measured exclusive B → K,X final state branching fractions for a series of X = charmonium and $D^{(*)}$ channels.
- Because these measurements are inclusive, they can be used in conjunction with exclusive final state measurements to determine absolute charmonium and $D^{(*)}$ branching fractions, particularly for the η_c and $\eta_c(2S)$.They also provide lower bounds for observed X(3872) modes. With the 100x statistics anticipated from Belle-II, the precision of BF measurements will become a few percent.
- We observe a new D^{**0} at a mass of (2680 ± 3) MeV with 3.3σ significance. We do not observe the charged analogue.