Hadronic *B* Decays at *BaBar*

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Summary

- A selection of recent results from *BABAR*
  - $B \to \phi K^*$
  - $B \to p \overline{p} h$
  - $B \to \eta_c K^*,\ \eta_c \gamma K^{(*)}$
- All results are preliminary.

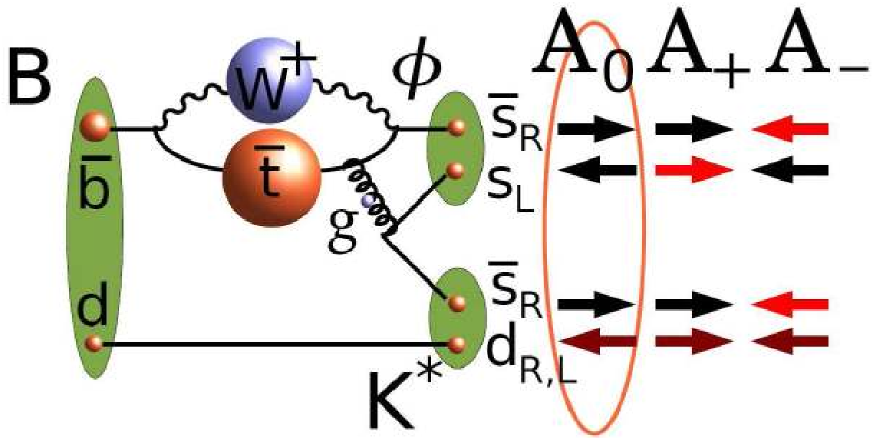
More hadronic B-decay results from BABAR in the other BABAR talks.

Amplitude Analysis of $B \rightarrow \phi K^*$

384×10^6 $B\overline{B}$ pairs

arXiv:0705.0398 [hep-ex], submitted to Phys. Rev. D
arXiv:0705.1798 [hep-ex], submitted to Phys. Rev. Lett.

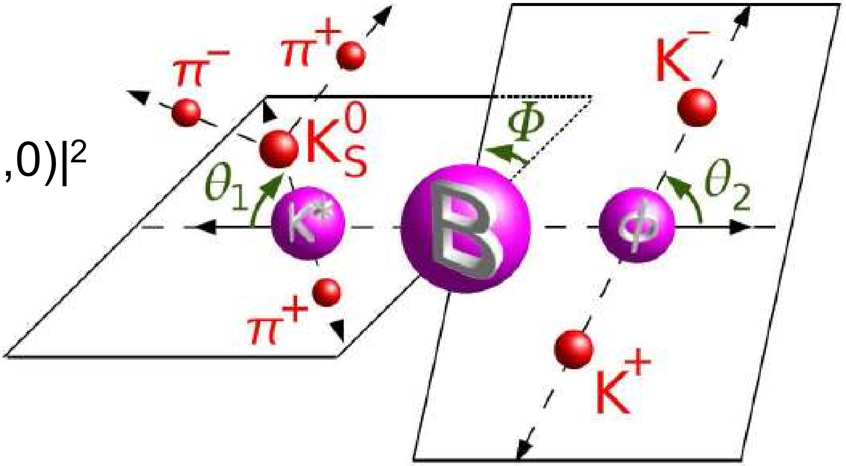
- Full amplitude analysis of $B \rightarrow \phi K^*$ decays:
  - test of SM expectations.

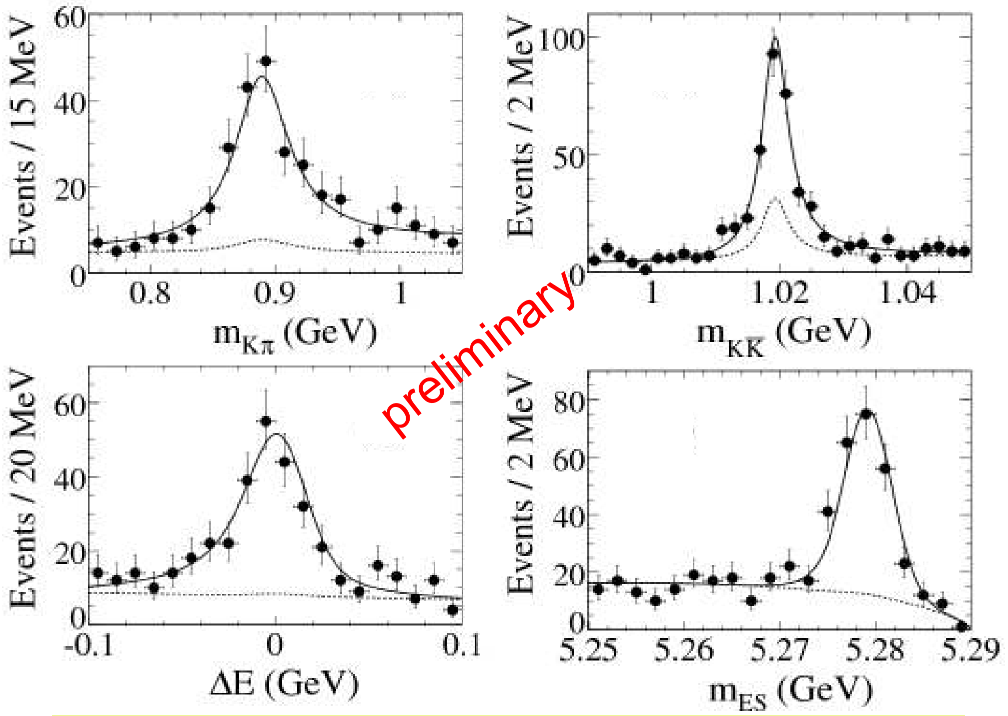


– Expectation from weak interaction V–A structure, helicity conservation and *s*-quark spin filp suppression in penguin decays: **$|A_0|^2 >> |A_+|^2 >> |A_-|^2$**

$$\frac{d^3\Gamma}{d\cos\theta_1\, d\cos\theta_2\, d\phi} \propto \left|\sum_{\lambda=0,+,-} A_\lambda \times Y_1^{\lambda}(\theta_1,\phi) \times Y_1^{-\lambda}(\pi-\theta_2,0)\right|^2$$

$$A_\pm = |A_{||} \pm A_\perp| / \sqrt{2}$$





- Reconstruction and selection of $B^{\pm} \to \phi K^{*\pm}$ candidates:

$K^{*\pm} \to K^{\pm}\pi^{0}, K_{s}\pi^{\pm}$; $\phi \to K^{+}K^{-}$

$\Delta E = (E_{Y}E_{B} - \mathbf{p}_{Y}\mathbf{p}_{B} - s/2) / \sqrt{s}$

$m_{ES} = [(s/2 + \mathbf{p}_{Y}\mathbf{p}_{B})^{2} / E_{Y}^{2} - \mathbf{p}_{B}^{2}]^{1/2}$

$N(\phi K^{*\pm} \to K^{+}K^{-}\pi^{\pm} K_{s}) = 102 \pm 13 \pm 6$

$N(\phi K^{*\pm} \to K^{+}K^{-} K^{\pm}\pi^{0}) = 117 \; ^{+15}_{-16} \; \pm 7$

$\to$ BR($B^{+} \to \phi K^{*\pm}$)= $(11.2 \pm 1.0 \pm 0.9) \times 10^{-6}$

- Measurement of 12 polarization-related quantities. Also allowed for CP violation (6 quantities):
  - $f_{L} = |A_{0}|^{2} / \Sigma|A_{\lambda}|^{2} = 0.49 \pm 0.05 \pm 0.03$ $\Rightarrow$ $|A_{0}|^{2} \sim |A_{+}|^{2} + |A_{-}|^{2}$
  - $f_{\perp} = |A_{\perp}|^{2} / \Sigma|A_{\lambda}|^{2} = 0.21 \pm 0.05 \pm 0.03$
  - $\phi_{||} - \pi = \arg(A_{||} / A_{0}) - \pi = -0.67 \pm 0.20 \pm 0.07$ rad
  - $\phi_{\perp} - \pi = \arg(A_{\perp} / A_{0}) - \pi = -0.45 \pm 0.20 \pm 0.03$ rad

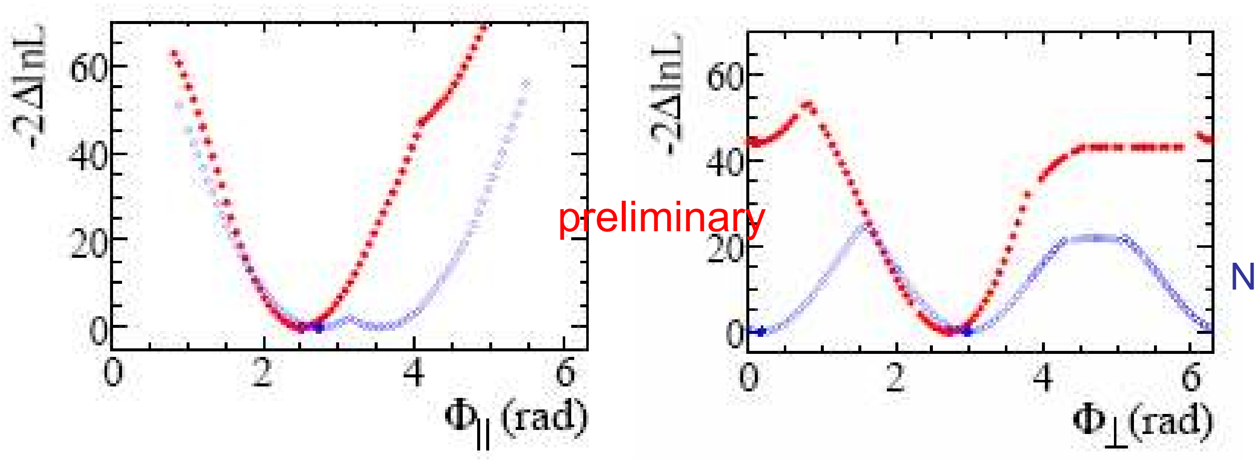
  $\Rightarrow$ $\arg(A_{+}) \neq \arg(\pm A_{0})$
  - No evidence of CP violation.

- Two possible solutions would be equally plausible:

I) $\phi_\perp \cong \phi_{||} - \pi$ $A_\perp \cong -A_{||}$ $|A_+|^2 << |A_-|^2$

II) $\phi_\perp \cong \phi_{||}$ $A_\perp \cong A_{||}$ $|A_+|^2 >> |A_-|^2$

- To solve the ambiguity we can use interference between P-wave K*(892) and S-wave $(K\pi)^*_0$
  - the fit finds N($\phi(K\pi)_0^{*\pm}$) = 57^{+14}_{-13}



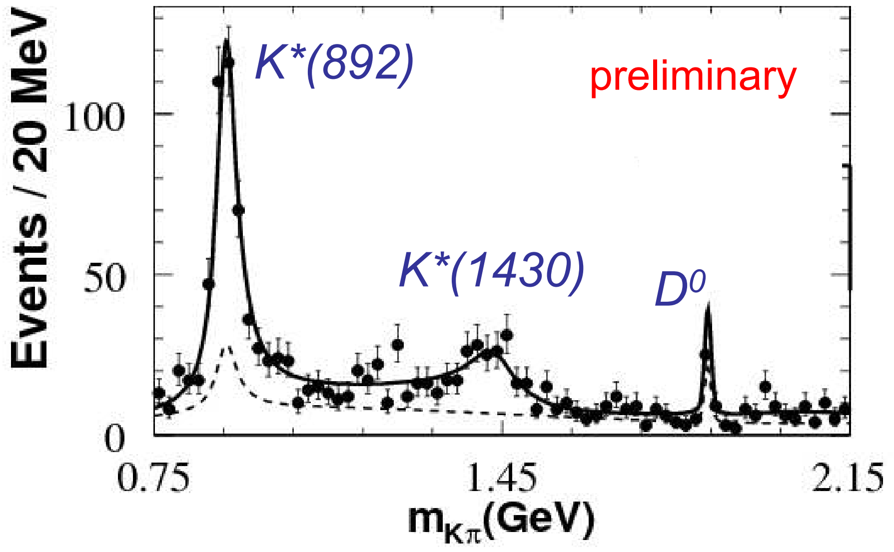
L = fit likelihood

Including P-S-wave interference

Not including P-S-wave interference

→ Only solution II is acceptable! $|A_+|^2 >> |A_-|^2 \rightarrow |A_0|^2 \sim |A_+|^2$

- Study of $B \to \phi\,(K\pi)$ decays with large $K\pi$ invariant mass.



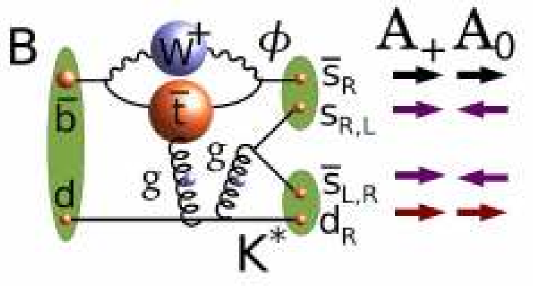
- Vector – Tensor: $|A_0| >> |A_\pm|$
  - – To be understood why different from Vector – Vector case.

J^P	B decay	BR (× 10^6)	f_L
0^+	$\phi K^*_0(1430)^0$	4.6 ± 0.7± 0.6	
1^-	$\phi K^*(892)^0$	9.2 ± 0.7± 0.6	0.51 ± 0.04± 0.02
1^-	$\phi K^*(892)^+$	11.2 ± 1.0± 0.9	0.49 ± 0.05± 0.03
1^-	$\phi K^*(1680)^0$	< 3.5, 90 % C.L.	
2^+	$\phi K^*_2(1430)^0$	7.8 ± 1.1± 0.6	$0.85\,^{+0.06}_{-0.07} \pm 0.04$
3^-	$\phi K^*_3(1780)^0$	< 2.7, 90 % C.L.	
4^+	$\phi K^*_4(2045)^0$	< 15.3, 90 % C.L.	

Also: $BR(B^0 \to \phi\,\overline{D^0}) < 11.6 \times 10^{-6}$, 90 % C.L.

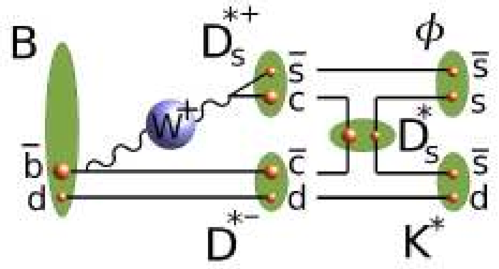
- Possible explanations of the excess of A_+ within SM:
  - annihilation mechanism

    e.g. Phys. Lett. B 601, 151

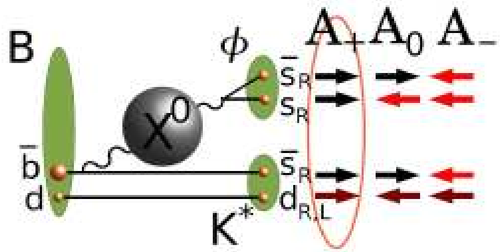


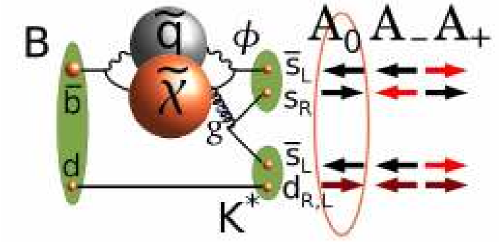
  - QCD rescattering

    e.g. Phys. Rev. D 70, 054015



  - others….





- Explanations outside SM?
  - scalar interaction ?

    current $\bar{q}(1+\gamma^5)q$

  - supersymmetry ?

    current $\bar{q}\gamma^\mu(1+\gamma^5)q$

  - others ??

Study of $B \to p \bar{p} h$ Decays

232×10^6 $B\bar{B}$ pairs

arXiv:0707.1648 [hep-ex], submitted to Phys. Rev. D

- Study of $B^0 \to p\bar{p}K_s$, $p\bar{p}K^{*0}$ and $B^+ \to p\bar{p}\pi^+$, $p\bar{p}K^{*+}$:
  - $B^+ \to p\bar{p}K^+$ already published in Phys. Rev. D72, 051101.
  - 3-body decay: dominant diagrams:
    - $B^+ \to p\bar{p}\pi^+$: external and internal W-emission tree diagram;
    - $B^0 \to p\bar{p}K^{(*)0}$: virtual loop penguin process $b \to sg$;
    - $B^+ \to p\bar{p}K^{(*)+}$: penguin and doubly CKM suppressed W-emission tree.
  - CP violation studies
    - Direct CP violation: different weak and strong phases between tree and penguin diagrams
      - 20% asymmetry foreseen in $B^+ \to p\bar{p}K^{*+}$ (Phys. Rev. Lett. 98, 011801).

- Other interesting results from $B \to p\bar{p}h$ decays: 2-body and quasi-2-body decays
  - Search for $B^0 \to \Theta^+(1540)\,\bar{p}$, $\Theta^+(1540) \to p\,K_s$.
    - Pentaquark candidate seen by several experiments
  - Search for $B \to f_J(2220)\,h$, $f_J(2220) \to p\,\bar{p}$.
    - Glueball candidate seen in $K\bar{K}$ by MarkIII and in $K\bar{K}$, $\pi\pi$, $p\bar{p}$ by BES.
  - Study of low $p\bar{p}$ mass enhancement:
    - observed in B (Belle, CLEO, BABAR) and J/ψ decays (BES), also in modes other than $p\bar{p}$;
    - short-range correlation between p and $\bar{p}$?
    - maybe the $X(1835)$ observed by BES?
  - Study of $B \to \eta_c\,h$ and $B^0 \to \Lambda^+_c\,\bar{p}$.

- Results and comparison with Belle and with mesonic *B* decays. $BR \times 10^6$:

h	BABAR $B\to p\bar{p}h$	Belle $B\to p\bar{p}h$ **PRL92,131801** **arXiv:0705.0398 [hep-ex]**	$B\to\pi^0 h$ **PDG 2007**	$B\to\rho^0 h$ **PDG 2007**
K^+	$6.7 \pm 0.5 \pm 0.4$ **PRD72,051101**	$5.98^{+0.29}_{-0.27} \pm 0.39$	12.1 ± 0.8	$5.0^{+0.7}_{-0.8}$
K^0	$3.0 \pm 0.5 \pm 0.3$	$2.40^{+0.64}_{-0.44} \pm 0.28$	11.5 ± 1.0	$5.4^{+0.9}_{-1.0}$
K^{*+}	$5.3 \pm 1.5 \pm 1.3$	$10.3^{+3.6}_{-2.8}\,^{+1.3}_{-1.7}$	6.9 ± 2.4	11.0 ± 4.0
K^{*0}	$1.5 \pm 0.5 \pm 0.4$ **First evidence**	< 7.6, 90 % C.L.	< 3.5, 90 % C.L.	5.6 ± 1.6
π^+	$1.7 \pm 0.3 \pm 0.3$	$1.68^{+0.26}_{-0.22} \pm 0.12$	5.5 ± 0.6	8.7 ± 1.1

- From isospin symmetry one expects $BR(B^+\to p\bar{p}K^+)$ / $BR(B^0\to p\bar{p}K^0)$ ~ 1 (as for the mesonic decays).
  - The observed ratio is ~ 2: is this due to the absense of the tree diagram for $p\bar{p}K^0$? Then why $BR(B^+\to p\bar{p}\pi^+)$ is that smaller?
- $BR(B^+\to p\bar{p}K^{*+})$ larger than $BR(B^0\to p\bar{p}K^{*0})$, similarly to the mesonic cases.
- $BR(B\to p\bar{p}K^*)$ smaller than $BR(B\to p\bar{p}K)$, similarly to $\pi^0\,h$ but not $\rho^0\,h$.

- Results for charmonium modes. All consistent with PDG
  - First evidence of $B^+ \to \eta_c K^{*+}$: $BR(B^+ \to \eta_c K^{*+}) \times BR(\eta_c \to p\bar{p}) = (1.57^{+0.56}_{-0.45}\,{}^{+0.46}_{-0.36}) \times 10^{-6}$

- Result for $\Lambda^+_c \bar{p}$. Consistent with Belle measurement:
  - $BR(B^0 \to \Lambda^+_c \bar{p}) = (21.0\,{}^{+6.7}_{-5.5}\,\mathrm{stat}\,{}^{+6.7}_{-6.2}\,\mathrm{syst}\,{}^{+2.1}_{-1.7}\,\mathrm{br}_1\,{}^{+7.4}_{-4.3}\,\mathrm{br}_2) \times 10^{-6}$

$$\frac{BR(\Lambda^+_c \to pK^{(*)})}{BR(\Lambda^+_c \to pK_s\pi)} \qquad BR(\Lambda^+_c \to pK_s\pi)$$

- Results for search for $\Theta^+(1540)$:
  - No evidence: $BR(B^0 \to \Theta^+(1540)\,\bar{p}) < 9.2 \times 10^{-7}$, 90% C.L., assuming $BR(\Theta^+ \to pK_s)=0.25$.

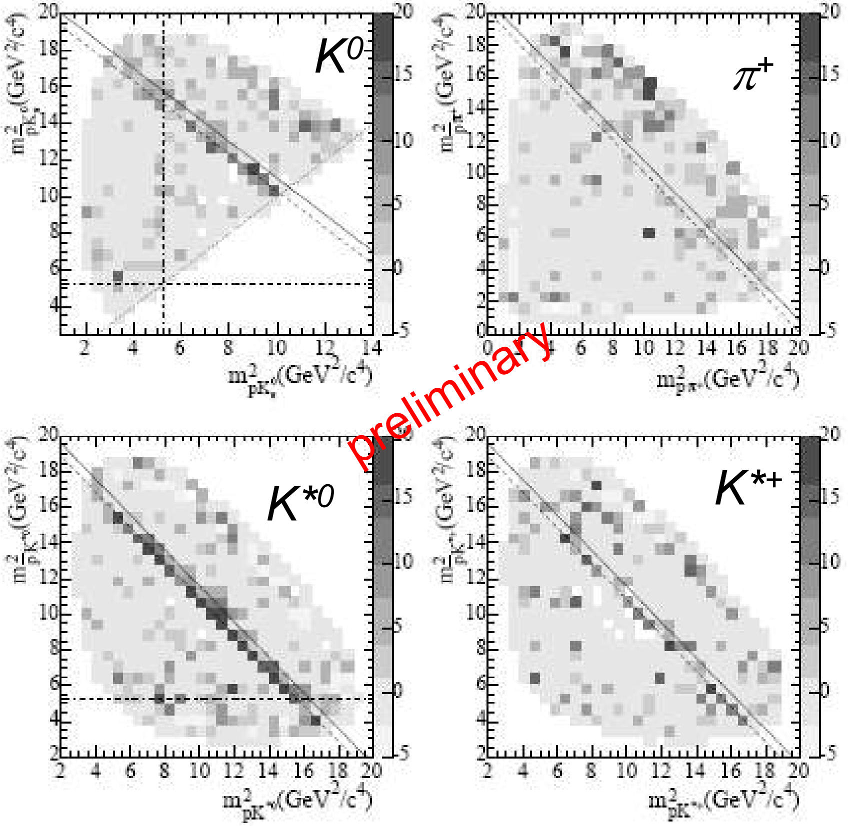
- Results for search for $f_J(2220)$:
  - No evidence. Assuming $\Gamma(f_J(2220)) < 30$ MeV:
    - $BR(B^0 \to f_J(2220)\,K^0) \times BR(f_J(2220) \to p\bar{p}) < 4.5 \times 10^{-7}$, 90% C.L.
    - $BR(B^0 \to f_J(2220)\,K^{*0}) \times BR(f_J(2220) \to p\bar{p}) < 1.5 \times 10^{-7}$, 90% C.L.
    - $BR(B^+ \to f_J(2220)\,K^{*+}) \times BR(f_J(2220) \to p\bar{p}) < 7.7 \times 10^{-7}$, 90% C.L.

- Result for search for direct CP violation:
  - All CP-violating charge asymmetry measurements are consistent with 0.

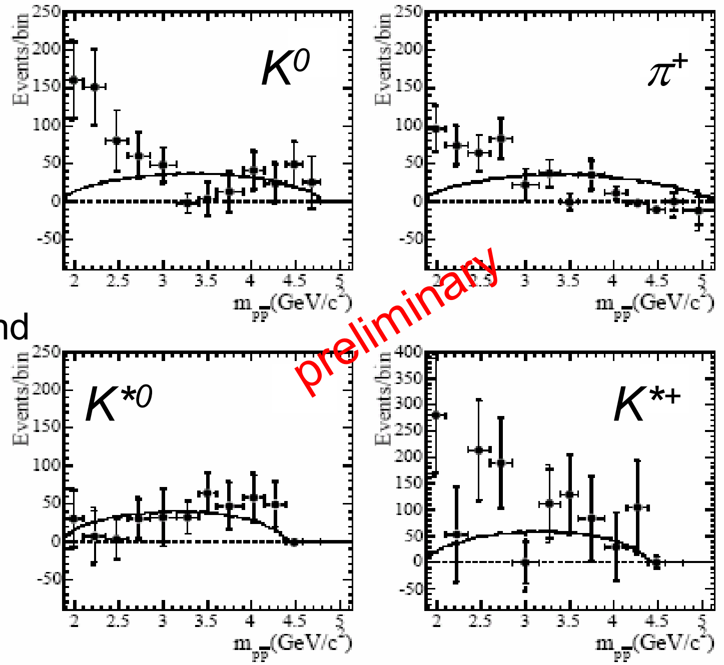
- Study of the decay dynamics.

Dalitz plots for signal events

— η_c ⋯⋯ J/ψ -·- Λ_c



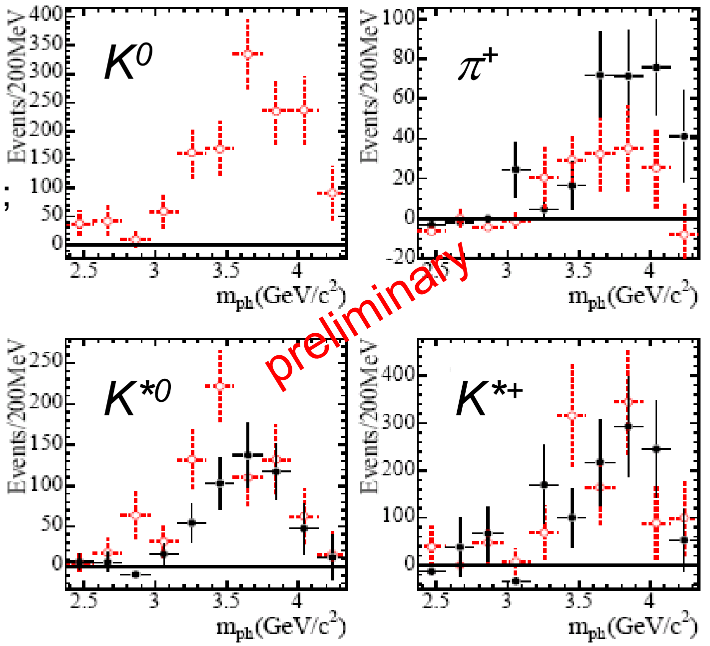
$m_{p\bar{p}}$: efficiency corrected, background and charmonium subtracted.



m_{ph} for signal;

○ $m_{ph} > m_{\bar{p}h}$;

• $m_{ph} < m_{\bar{p}h}$



- The $p\bar{p}$ enhancement is prominent in $p\bar{p}K^0$, $p\bar{p}\pi^+$.
- Dalitz plot expected symmetric for a resonance: $p\bar{p}\pi^+$ seems not. More data are needed…

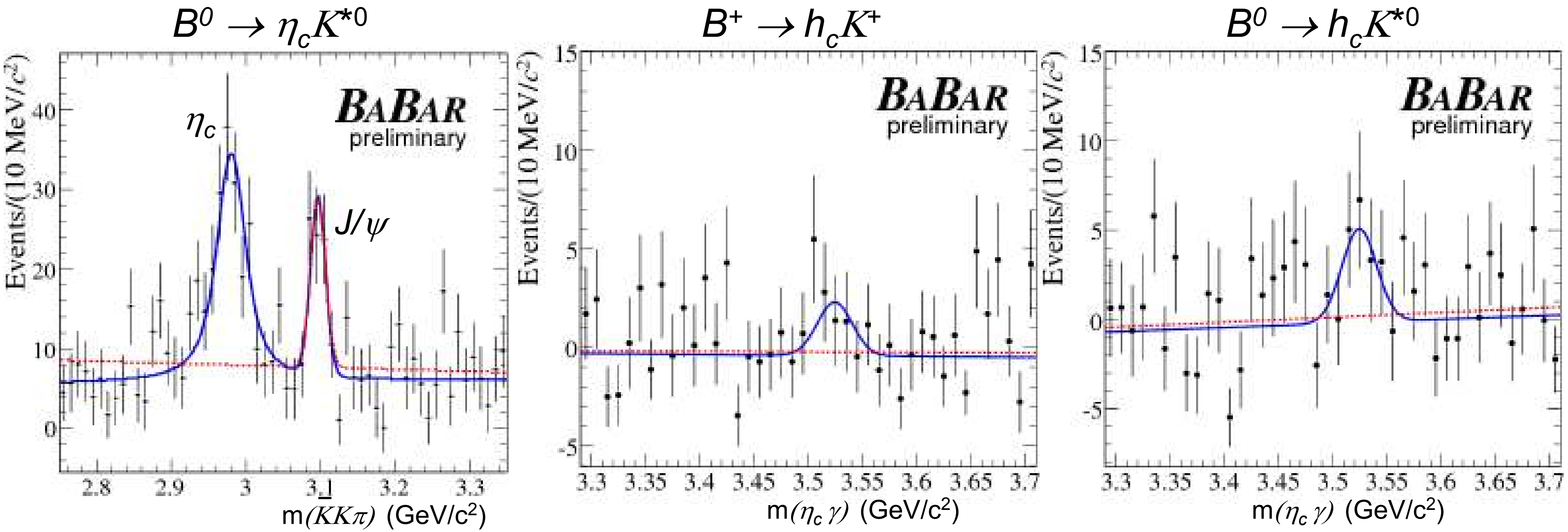
B Decays to $\eta_c K^*$ and $\eta_c \gamma K^{(*)}$

384×10^6 $B\overline{B}$ pairs

arXiv:0707.2843 [hep-ex]

- *B* decays to singlet states of charmonium are still more poorly known wrt *B* decays to triplet states.
- Here focus on **$B^0 \to \eta_c K^{*0}$, $B^+ \to h_c K^+$** and **$B^0 \to h_c K^{*0}$** with $h_c \to \eta_c \gamma$ and $\eta_c \to K_s(\pi^+\pi^-)K^+\pi^-$ and $K^+K^-\pi^0$.
- *B* decays to P-wave states (χ_c and h_c) foreseen in NR-QCD (PRD 51, 1125) to occur all at similar rates:
  - $B \to \chi_{c1} K(^*)$ and $B \to \chi_{c0} K$ indeed observed with $BR \sim 10^{-4}$.
  - Current limits on $B^{0,+} \to \chi_{c2} K(^*)$ and $B^+ \to h_c K^+$ are much smaller (few 10^{-5}): why?
- h_c recently discovered by CLEO (PRD 72, 092004) and confirmed by E835 (PRD 72, 032001).
- To suppress most uncertainties, we reconstruct also $B^+ \to \eta_c K^+$ and measure ratios of branching fractions with respect to it.

- m$(K\bar{K}\pi(\gamma))$ spectra after subtraction of background from m_{ES} sideband.



$B^0 \to \eta_c K^{*0}$ $B^+ \to h_c K^+$ $B^0 \to h_c K^{*0}$

- Clear signal for $\eta_c K^{*0}$:
  - $BR(B^0 \to \eta_c K^{*0}) = (6.1 \pm 0.8 \pm 1.1) \times 10^{-4}$: improved precision over world average by a factor 2.
- No evidence for $h_c K^{(*)}$:
  - $BR(B^+ \to h_c K^+) \times BR(h_c \to \eta_c \gamma) < 5.2 \times 10^{-5}$, 90% C.L., consistent with Belle limit.
  - $BR(B^0 \to h_c K^{*0}) \times BR(h_c \to \eta_c \gamma) < 2.41 \times 10^{-4}$, 90% C.L., first limit.

  → confirmation of h_c suppression in B decays.

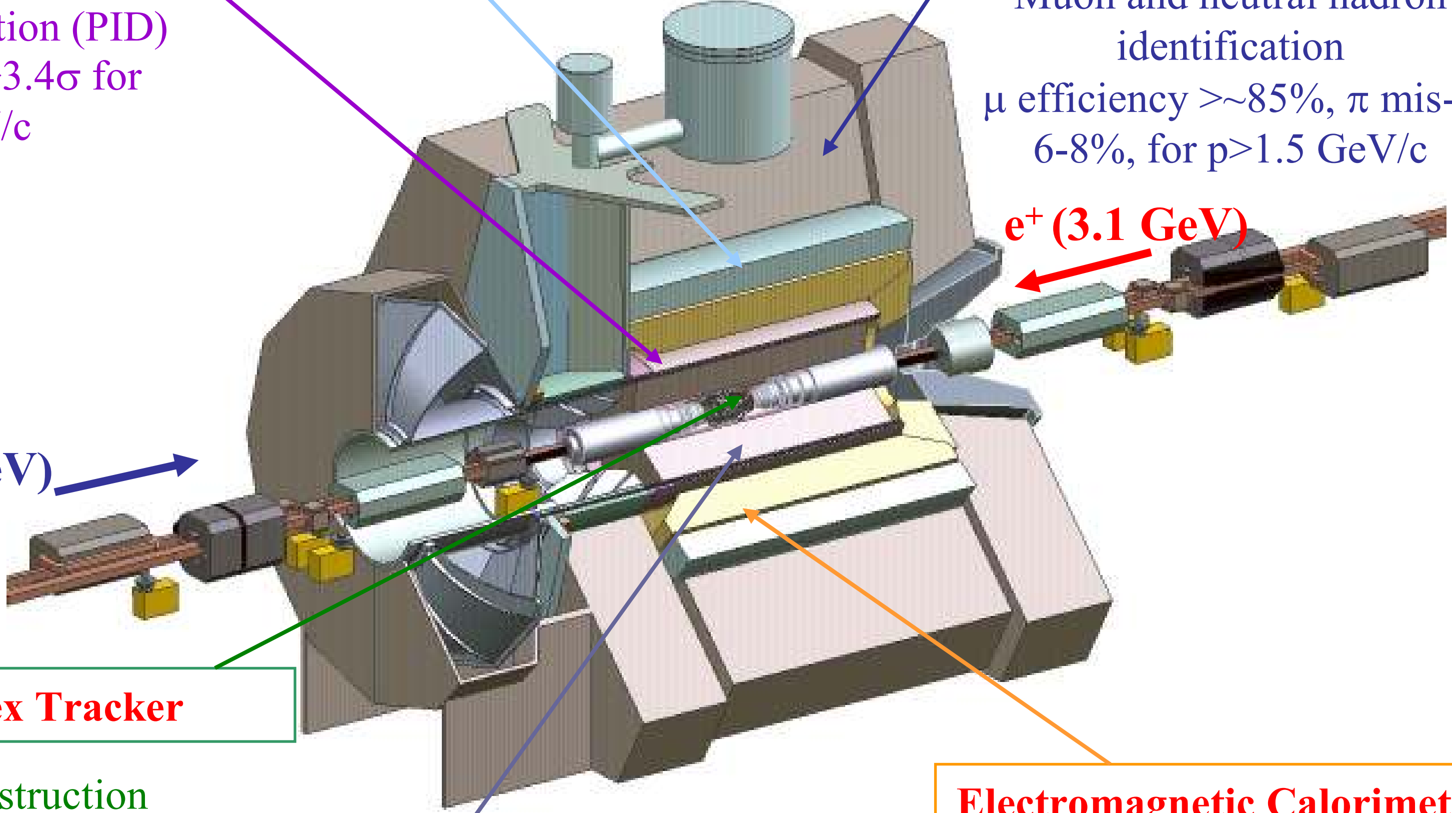
Conclusions

- Many new results from *B*A*B*AR. All results are preliminary.
- Amplitude analyses in $B \to \phi K^*$:
  - – results difficult to accommodate within the SM.
- Several new branching ratio measurements of *B* decays to $p\overline{p}h$ with study of intermediate states and decay dynamics.
  - – first evidence of $B^0 \to p\overline{p}K^{*0}$ and $B^+ \to \eta_c K^{*+}$.
- More results on *B* decays to singlet charmonium states:
  - – no sign of h_c yet.

→ More hadronic *B*-decay results from *B*A*B*AR in the other *B*A*B*AR talks.

Back-up Slides

The *BABAR* Detector



Cherenkov Detector

Particle identification (PID)
K-π separation $>3.4\sigma$ for
$p<3.5$GeV/c

Solenoid 1.5T

Instrumented Flux Return

Muon and neutral hadron
identification
μ efficiency $>\sim 85\%$, π mis-id
6-8%, for $p>1.5$ GeV/c

e^+ (3.1 GeV)

e^- (9 GeV)

Silicon Vertex Tracker

Vertex reconstruction
and tracking + dE/dx.
Efficiency ~ 97%

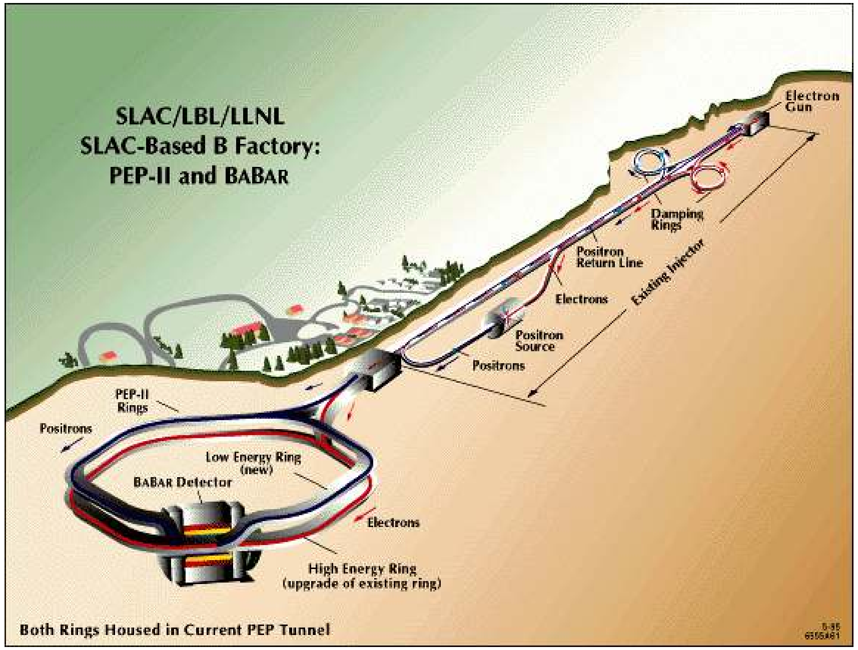
Drift Chamber

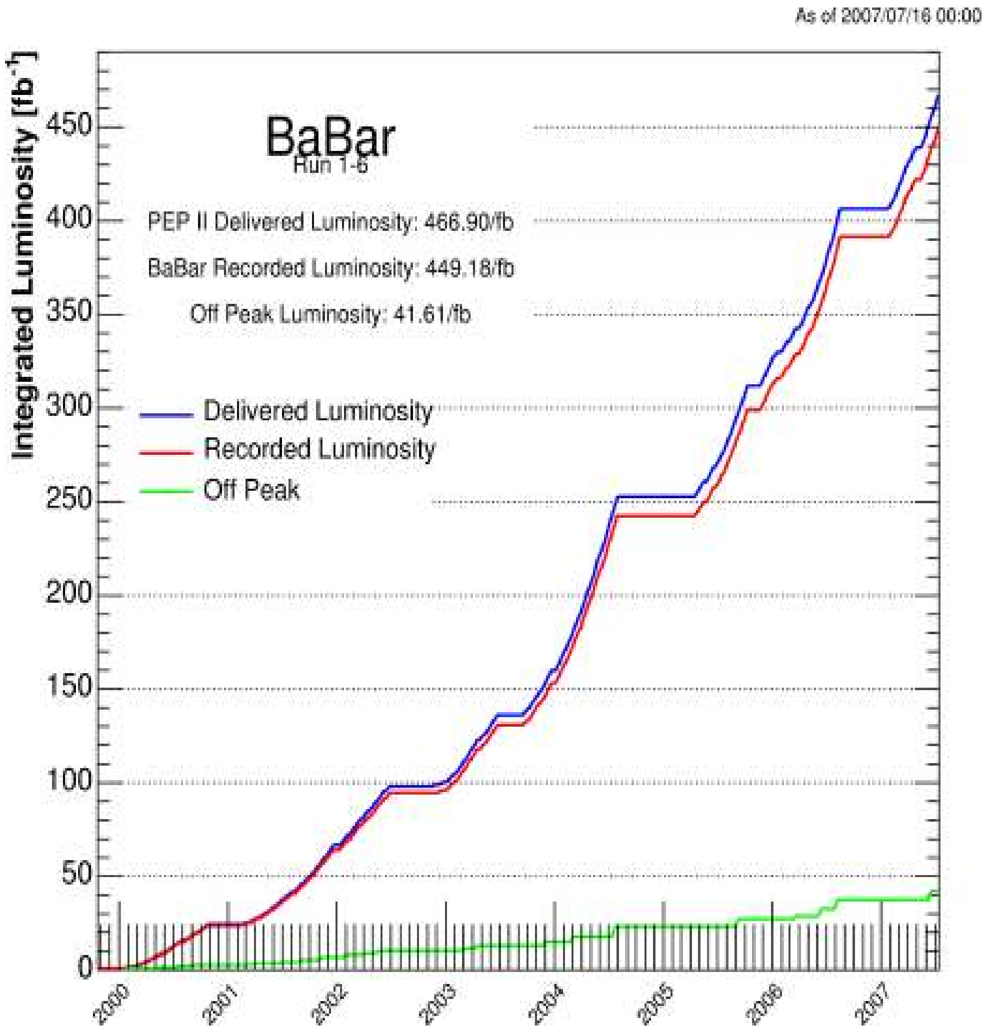
Momentum measurement for
charged particles + dE/dx.
$\sigma(p_T)/p_T=0.13\%p_T\oplus0.45\%$

Electromagnetic Calorimeter

Electron and photon energy
measurement.
$\sigma(E)/E=1.33\%E^{-1/4}\oplus2.1\%$

- Beam energies: 9 GeV e^- / 3.1 GeV e^+
- Instantaneous luminosity:
  $L_{peak} \approx 12 \times 10^{33}\ cm^{-2}\ s^{-1}$
- Boost: $\beta\gamma \sim 0.56$





Current data sample

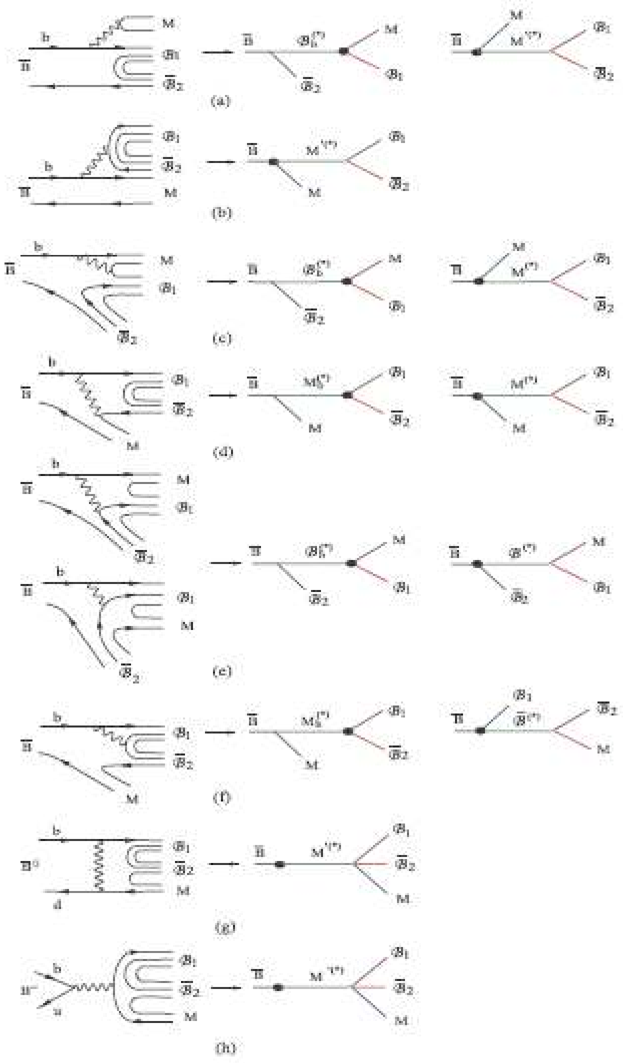


FIG. 2. Quark and pole diagrams for three-body baryonic B decay $\overline{B} \to \mathcal{B}_1\overline{\mathcal{B}}_2M$, where the symbol • denotes the weak vertex. Figs. 2(a) and 2(b) correspond to factorizable external W-emission contributions, Figs. 2(c) and 2(d) to factorizable internal W-emission, Figs. 2(e) and 2(f) to nonfactorizable internal W-emission, Fig. 2(g) to W-exchange and Fig. 2(h) to W-annihilation. Penguin contributions are obtained from Figs. 2(c)-2(g) by replacing the $b \to u$ tree transition by the $b \to s(d)$ penguin transition.

Diagrams for $B \to p\bar{p}h$ decays, from PRD 66, 014020