Charmless B Decays at Babar

$B^0 \rightarrow K^{*0}\gamma$ and $B^0 \rightarrow \pi^+\pi^-, K^+\pi^-, K^+K^-$

Mark Convery

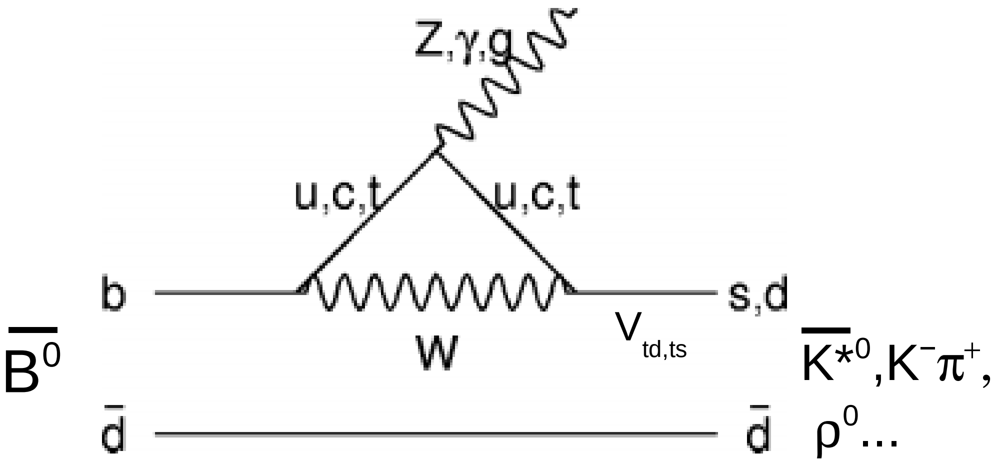
Stanford Linear Accelerator Center

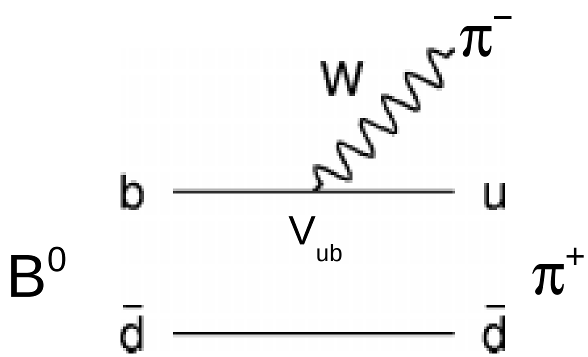
A national laboratory funded by the Department of Energy

Outline

- Theory and Motivation
- PEP−II
- BaBar Detector
- Backgrounds
- Kinematic Variables
- $B^0 \rightarrow K^{*0}\gamma$ Analysis (Branching fraction and A_{CP})
- $B^0 \rightarrow \pi^+\pi^-, K^+\pi^-, K^+K^-$ Analysis (Branching fraction)
- Conclusions

Theory and Motivation

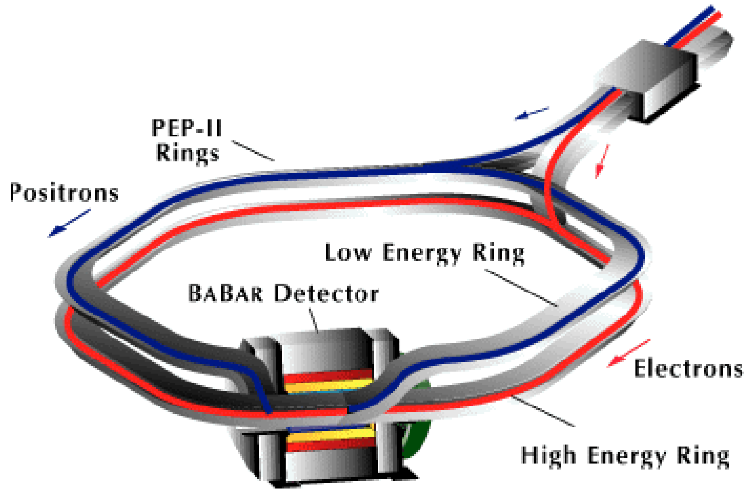




- Top quark dominates "penguin" diagrams
  - Low energy access to high mass phenomena (V_{td})
  - Possibility of non−SM physics, e.g. H+
  - Possible direct CP violation
- Tree diagram potentially very useful
  - CP−eigenstate with $M \propto V_{ub}$
  - Time−dependent CP−asymmetry to measure α
  - Unless $b \rightarrow dg$ spoils it
  - Particle ID to distinguish π from K

The PEP−II B Factory

- Asymmetric collider $e^+e^- \to \Upsilon(4s) \to B\bar{B}$
  $E_{e^-} = 9.0\,GeV,\ E_{e^+} = 3.1\,GeV$
- "Run 1" from Nov '99 − Oct '00
- Peak luminosity $L = 3.3 \times 10^{33} / cm^2\,sec$
  - Already at design
  - 4x higher than previous best (CESR)
- Integrated Luminosity
  - $\approx$ 21 fb^{-1} on resonance
    $\Rightarrow$ $(22.7 \pm 0.4) \times 10^6$ BB pairs
  - $\approx$ 3 fb^{-1} off resonance

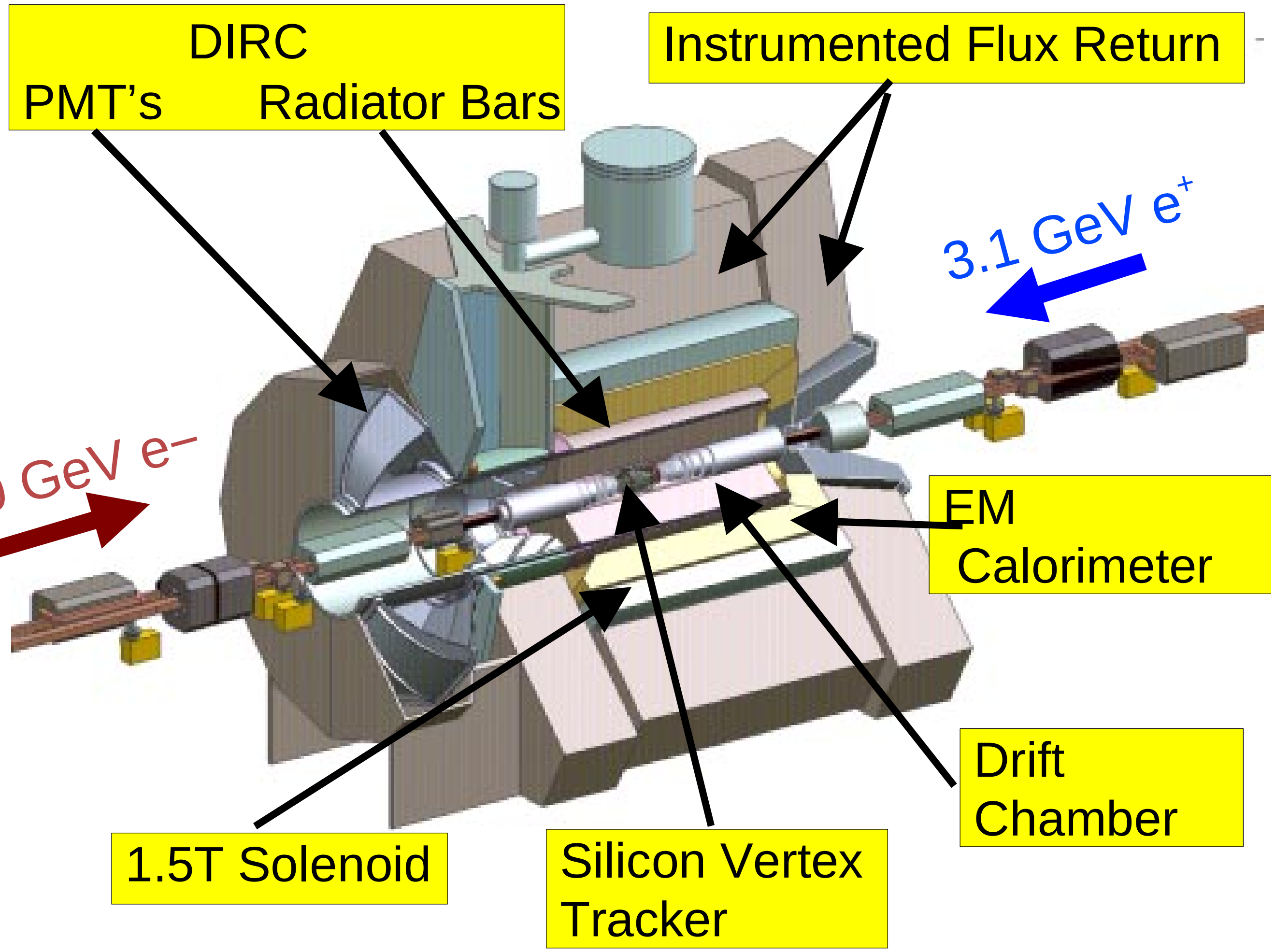


- Asymmetric energies required for time dependent CP asymmetries
- Bit of a nuisance for charmless BR's

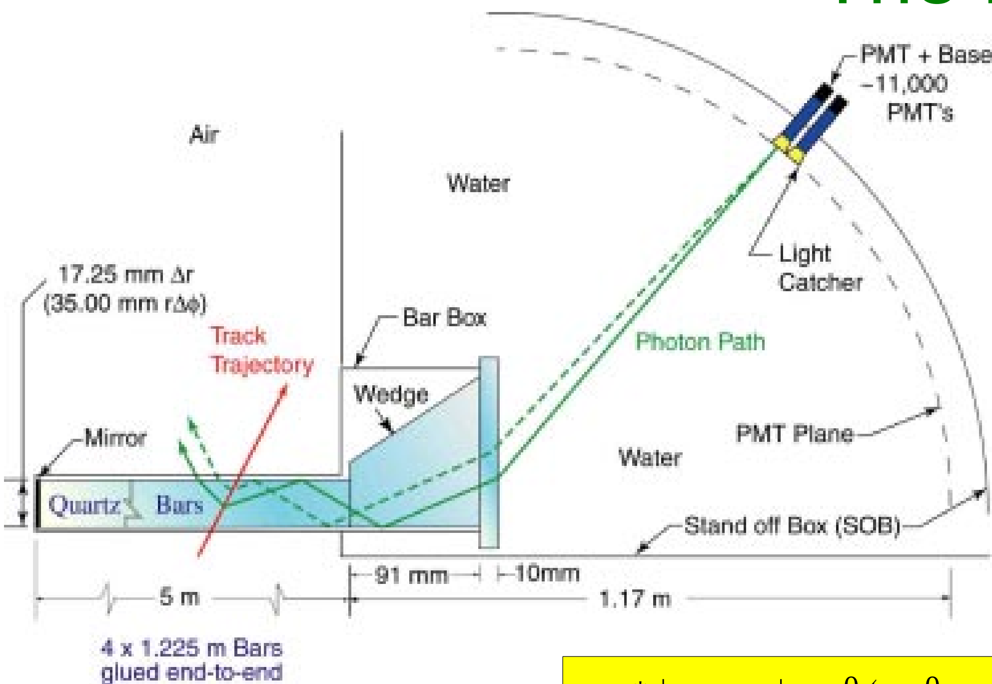
$$2.4\,GeV < p_{2-body,CMS} < 2.8\,GeV$$
$$2\,GeV < p_{2-body,lab} < 4\,GeV$$

BaBar Detector

- 5 Layer Vertex Detector
- 40 Layer Drift Chamber
- DIRC Cherenkov Counter
- CsI Electromagnetic Calorimeter
- Flux Return instrumented with RPC's
- Super−conducting Solenoid

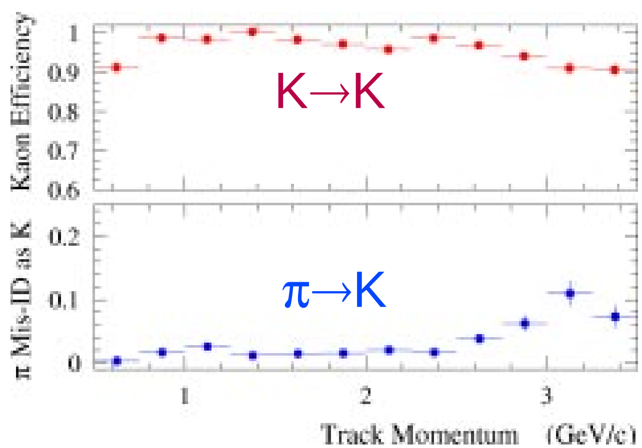


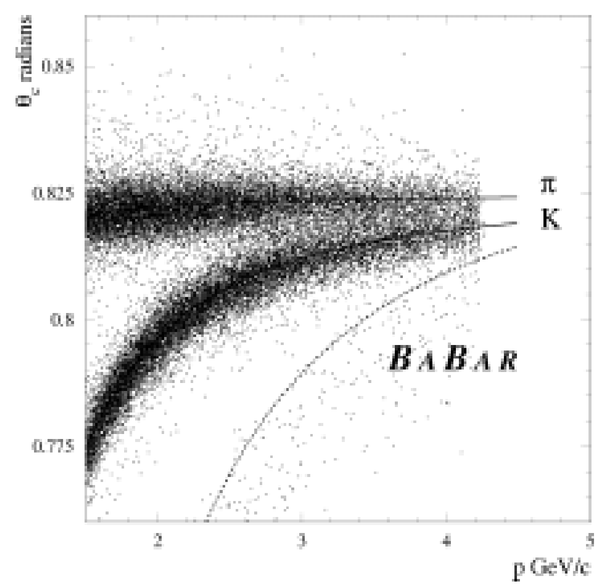
The DIRC



- Detector of Internally Reflected Cherenkov uses light trapped in radiator bar
- Light detected by an array of 11,000 PMT's
- Provides excellent π/K separation

$$D^{*+} \rightarrow \pi^{+} D^{0} (D^{0} \rightarrow K^{-} \pi^{+})$$





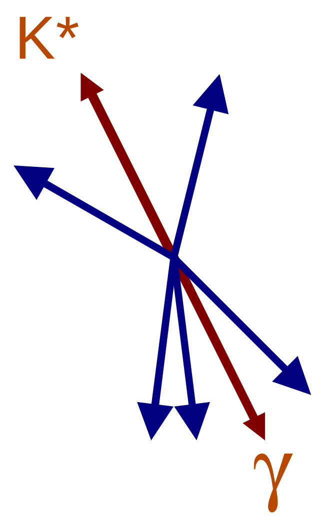
Analysis Procedure

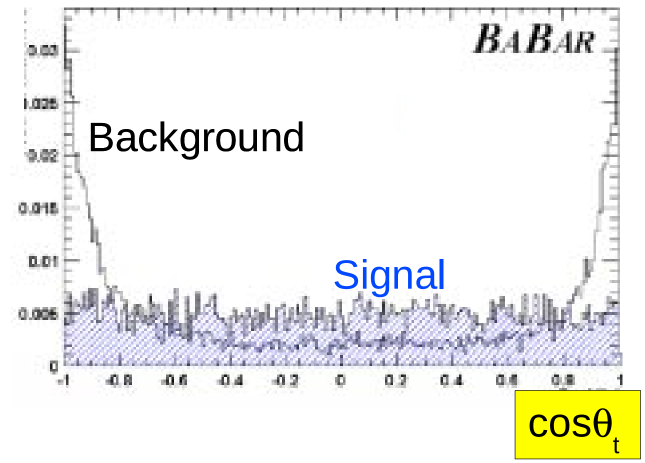
- Similar procedure for $B^0 \to K^{*0}\gamma$
  and for $B^0 \to \pi^+\pi^-, K^+\pi^-, K^+K^-$
- Compose B candidates from selected tracks, photons, π^0's
- Reject background using event shape variables.
- Measure background levels using off−resonance data, or on−resonance sidebands
- Fit for N_{sig} using ML Fit to kinematic variables
- Calculate signal efficiency in Monte Carlo. Adjust for tracking eff., etc.

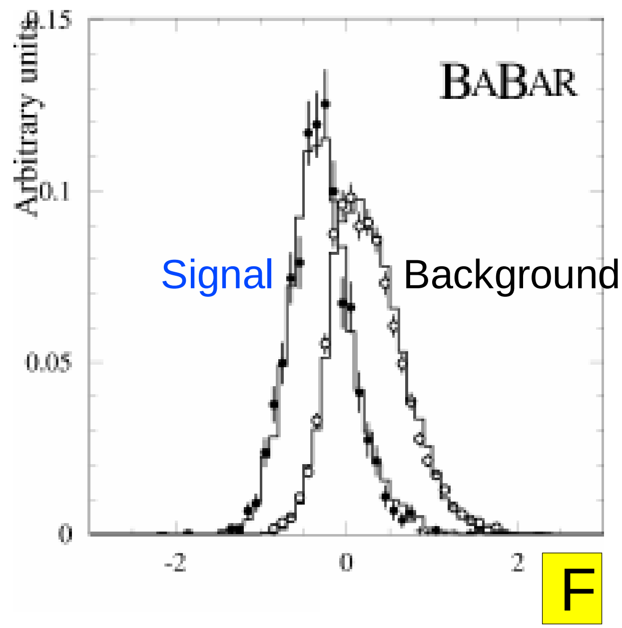
Background Suppression

- $\sigma(e^+e^- \to q\bar{q}) \approx 3\sigma(e^+e^- \to B\bar{B})$
  background mostly continuum
- Can be distinguished by "jetty" shape versus spherical BB shape
- Can simply use angle between candidate axis and thrust of remainder of event ($\cos\theta_t$)
- Or, more sophisticated, measure energy in 9 concentric cones (x_i) around candidate axis and adjust coefficients (α_i) to optimize separation in Fisher Discriminant (CLEO)

$$F = \sum_{i=1}^{9} \alpha_i x_i$$

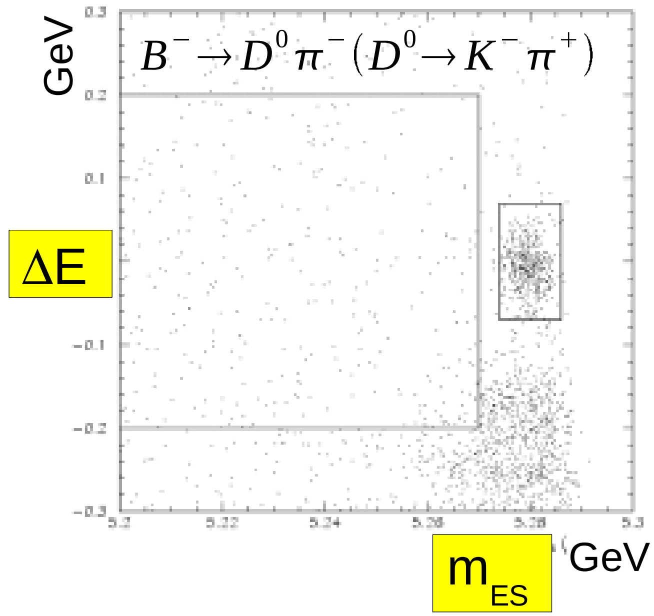


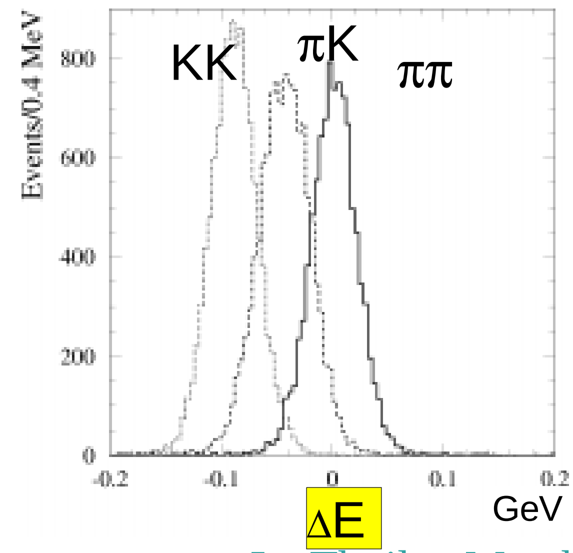




Kinematic Variables

- In symmetric collider, use
  - $m_B = \sqrt{E_{beam}^2 - p_B^2}$
  - $\Delta E = E_B - E_{beam}$ assume m_π
    - shifts due to daughter mass
- For asymmetric collider, want to avoid assigning masses to daughters
  - Define $m_{ES} = \sqrt{\left(\frac{1}{2}s + \vec{p}_0 \cdot \vec{p}_B\right)^2 / E_0^2 - p_B^2}$
    - Uses only lab quantities
    - Identical to m_B when evaluated in CM frame
  - $\Delta E = E_B^* - \sqrt{s}/2$ assume m_π
    - also has shifts due to true daughter mass

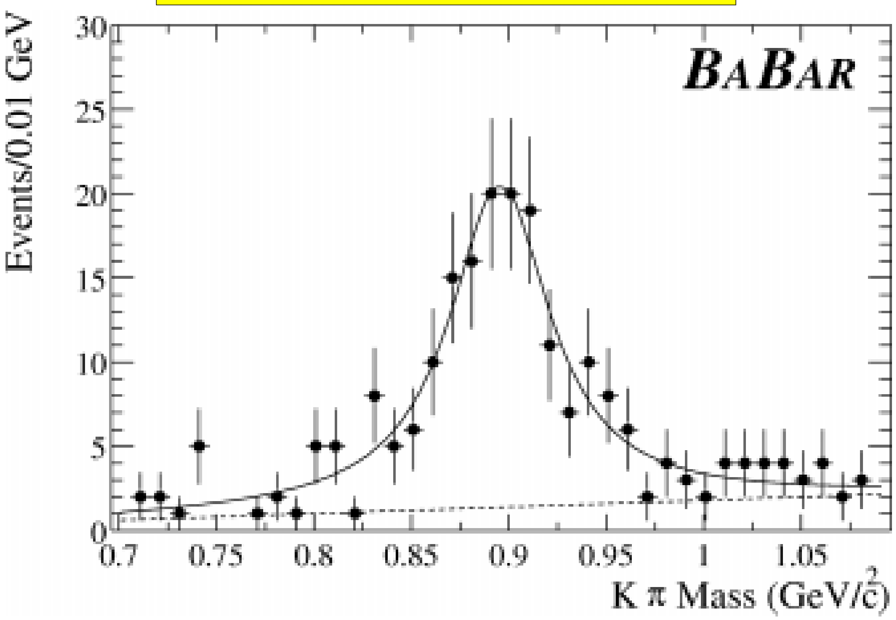




$B^0 \to K^{*0}\gamma$ Candidates

- Photon selection ($\varepsilon_\gamma = 0.77$)
  - 2.3 Gev < E_{cms} < 2.8 GeV
  - $-0.73 < \cos\theta_{lab} < 0.9$
  - Reject π^0's
    - with shower shape cuts
    - $m_{\gamma\gamma} \neq m_{\pi 0}$
- $K^{*0} \to K^+\pi^-$ selection ($\varepsilon_{K^*} = 0.56$)
  - Dirc PID
  - 0.796 GeV < $m_{K\pi}$ < 0.996 GeV
  - $|\cos\theta_{helicity}(K^*,K^+)| < 0.75$

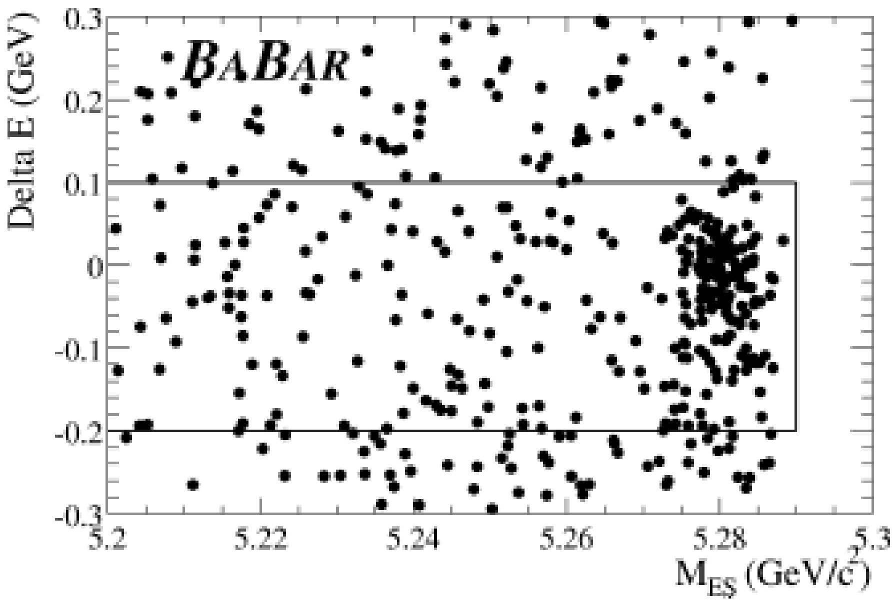
Breit−Wigner fit to $m_{K\pi}$ distribution in final $B^0 \to K^{*0}\gamma$ sample

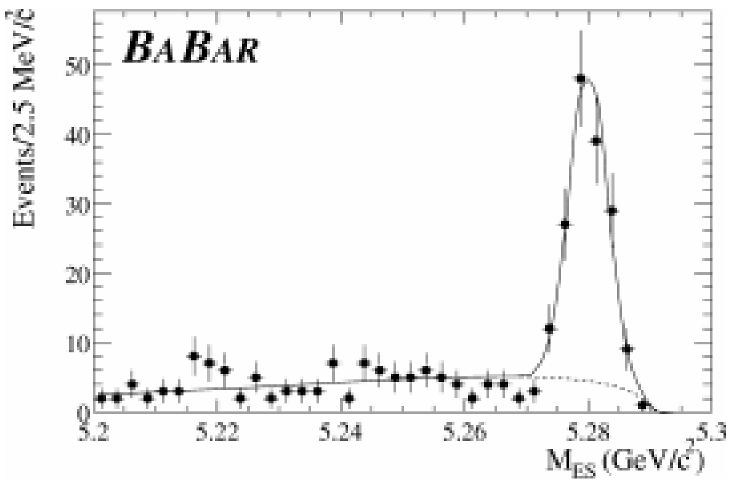


$B^0 \to K^* \gamma$ Mass Fit

- Cuts
  - $-200\ \text{MeV} < \Delta E^* < 100\ \text{MeV}$
  - $|\cos\theta_t^* < 0.8|$
  - $|\cos\theta_B^* < 0.75|$ (polar angle of B candidate)
- Fit to m_{ES} distribution
  - "Argus" Function for background. Shape taken from off−peak data
  - Gaussian for signal with floating mean, sigma and signal fraction

$N_{sig} = 139.2 \pm 13.1$ events





$B^0 \to K^{*0}\gamma$ Branching Ratio and Asymmetry

- Efficiency calculated in Monte Carlo with corrections for
  - Tracking efficiency
  - Photon efficiency
  - PID efficiency
- $\varepsilon = 0.209 \pm 0.013_{syst}$
- $$BR(B^0 \to K^{*0}\gamma) = \frac{N_{signal}}{(N_{B\bar{B}} * \epsilon * B_{K*})}$$
- Systematics mostly from data−derived efficiency corrections

$BR(B^0 \to K^{*0}\gamma)$ = $(4.39 \pm 0.41_{stat} \pm 0.27_{syst}) \times 10^{-5}$
BaBar Preliminary

- Asymmetry defined as

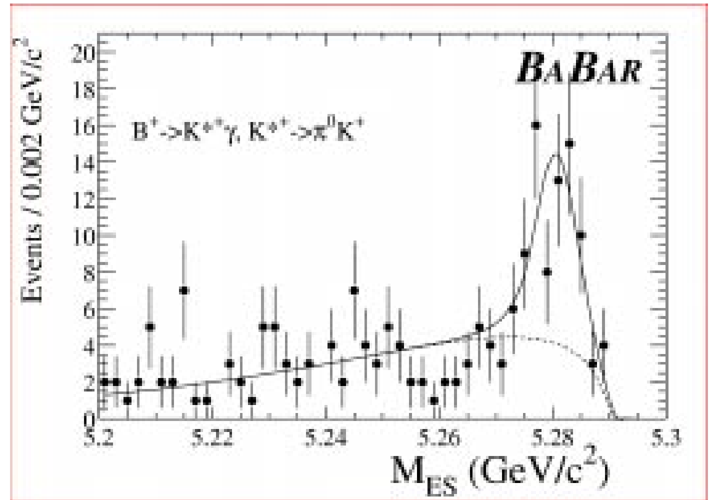
$$A_{CP} = \frac{N(\bar{B}^0 \to \bar{K}^{*0}\gamma) - N(B^0 \to K^{*0}\gamma)}{N(\bar{B}^0 \to \bar{K}^{*0}\gamma) + N(B^0 \to K^{*0}\gamma)}$$

$A_{cp} = -0.035 \pm 0.094 \pm 0.022$
BaBar Preliminary

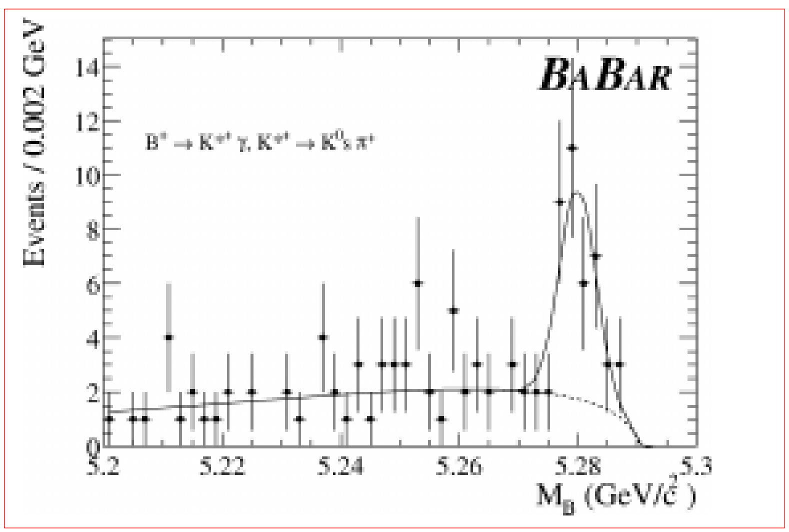
Other $B \rightarrow K^* \gamma$ Modes

Signals have been observed in three other $B \rightarrow K^* \gamma$ modes

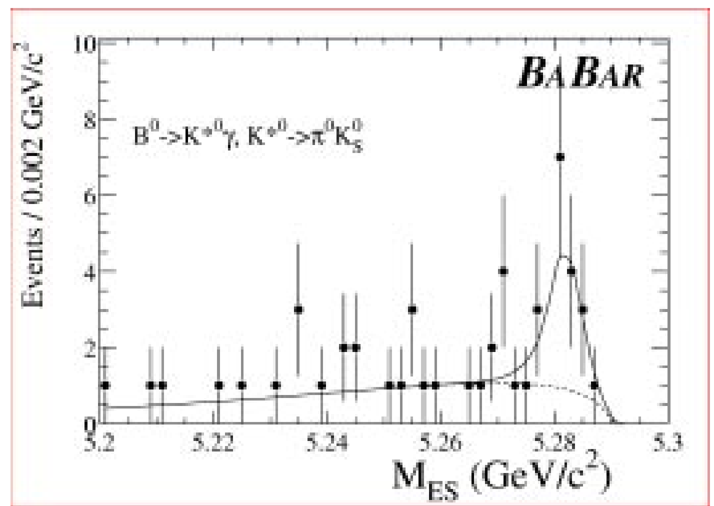
$B^+ \rightarrow K^{*+} \gamma, K^{*+} \rightarrow K^+ \pi^0$



$B^+ \rightarrow K^{*+} \gamma, K^{*+} \rightarrow K_s^0 \pi^+$



$B^0 \rightarrow K^{*0} \gamma, K^{*0} \rightarrow \pi^0 K_s^0$



$B^0 \to h^+ h'^-$ Candidates

- Selection of candidates
  - Sphericity angle, $\cos(\theta_s)<0.9$, almost identical to $\cos(\theta_t)$, defined earlier
  - Fox−Wolfram moment R2 < 0.95
  - Sphericity > 0.01
  - Track quality cuts
  - DIRC quality cuts
  - $5.2 < m_{ES} < 5.3$ GeV
  - $-0.15 < \Delta E < 0.15$ GeV
- 26404 selected ($\varepsilon_{\pi\pi,MC} \approx 0.45$) candidates used in Maximum Likelihood Fit

$B^0 \to h^+ h'^-$ Likelihood Fit

- Fit Parameters
  - $N_{\pi\pi}$ number of $B^0 \to \pi^+ \pi^-$
  - $N_{K\pi}$ number of $B^0 \to K^+ \pi^-$
  - $A_{K\pi}$ asymm. in $B^0 \to K^+ \pi^-$
  - N_{KK} number of $B^0 \to K^+ K^-$
  - $N_{b\pi\pi}$ background $\pi\pi$
  - $N_{bK\pi}$ background $K\pi$
  - $A_{bK\pi}$ asymm in bkg. $K\pi$
  - N_{bKK} background KK

- Fit Variables
  - m_{ES}
  - ΔE
  - F Fisher output for cone−based shape
  - $\theta_{c,+}$ DIRC Cherenkov Angle for positive track
  - $\theta_{c,-}$ DIRC Cherenkov Angle for negative track

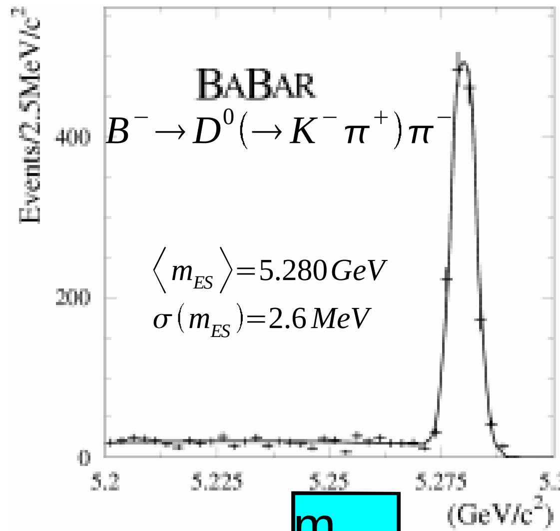
Event PDF $P^{hypo}_{event} = P^{hypo}_{m_{ES}} P^{hypo}_{\Delta E} P^{hypo}_{F} P^{hypo}_{\vartheta_{C,+}} P^{hypo}_{\vartheta_{C,-}}$

hypo $=\pi\pi, K\pi, KK, b\pi\pi, bK\pi, bKK$

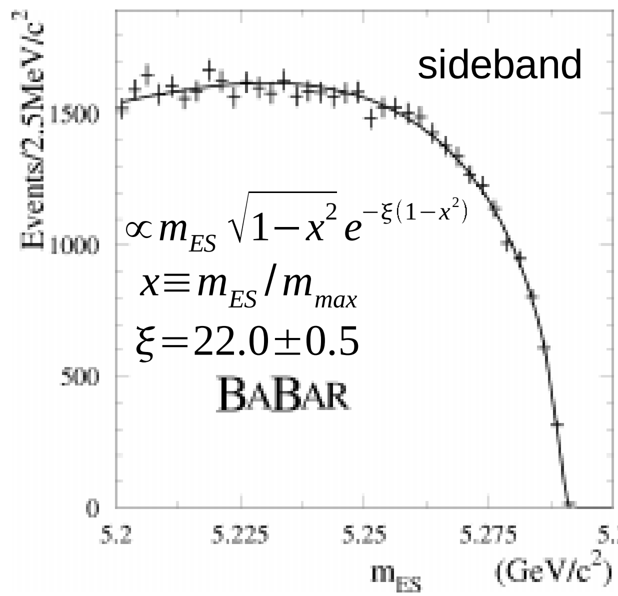
Calibration of PDF's

Crucially important that PDF's for signal and background are properly modelled

- m_{ES}
  - Signal σ dominated by beam energy spread. Taken from $B^- \rightarrow D^0(\rightarrow K^- \pi^+)\pi^-$
  - Background shape from ΔE sideband
  - Checked with offpeak and cont. MC
- ΔE
  - Signal σ dominated by tracking
  - $\sigma_{D^0\pi^-,MC} = 15\,MeV, \sigma_{D^0\pi^-,Data} = 19\,MeV$
  - $\sigma_{h^+h'^-,MC} = 21\,MeV \Rightarrow \quad \sigma_{h^+h'^-,PDF} = 26 \pm 5\,MeV$
  - Background from ΔE sideband



m_{ES}



Calibration of PDF's −II

- F
  - Signal from MC $B^0 \to \pi^+\pi^-, K^+\pi^-, K^+K^-$
  - Checked with $B^- \to D^0(\to K^-\pi^+)\pi^-$
  - Background from m_{ES} sideband
  - Checked with off−resonance and continuum MC
- $\theta_{c,1}$, $\theta_{c,2}$
  - π,K shapes taken from $D^{*+} \to \pi_s^+ D^0(D^0 \to K^-\pi^+)$
  - Includes $\cos\theta_{dip}$−dependent $<\theta_c>$ and $\sigma_{\theta c,}$ and small "satellite" peaks

$B^0 \to \pi^+\pi^-, K^+\pi^-, K^+K^-$ Fit Result

- Systematics calculated by varying PDF shape parameters
  - Within statistical errors
  - To cover disagreement between Data and MC
- Traditional "cut and count" analysis also done. Gives consistent results, lower sensitivity.

BaBar Preliminary

Decay Mode	$N_{signal} \pm \sigma_{stat} \pm \sigma_{syst}$	BR BaBar ($\times 10^{-6}$)	BR CLEO ($\times 10^{-6}$)
$\pi^+\pi^-$	$41 \pm 10 \pm 7$	$4.1 \pm 1.0 \pm 0.7$	$4.3 \pm^{+1.6}_{-1.4} \pm 0.5$
$K^+\pi^-$	$169 \pm 17^{+12}_{-17}$	$16.7 \pm 1.6^{+1.2}_{-1.7}$	$17.2^{+2.5}_{-2.4} \pm 1.2$
K^+K^-	$8.2^{+7.8}_{-6.4} \pm 3.3$	< 2.5 (90% CL)	< 1.9 (90 % CL)

Summer 2000 Results

Based on 7.7 fb^{-1}. Preliminary results, to be updated soon!

Decay Mode	BR BaBar ($\times 10^{-6}$)	Method
$K^{*0}\pi^+$	< 28 (90% CL)	cut & count
$\rho^0 K^+$	< 29 (90% CL)	cut & count
$K^+\pi^-\pi^+$	< 54 (90% CL)	cut & count
$\rho^0\pi^+$	< 39 (90% CL)	cut & count
$\pi^+\pi^-\pi^+$	< 22 (90% CL)	cut & count
$\rho^\pm\pi^\mp$	$49 \pm 13^{+6}_{-5}$	cut & count
ωh^+	< 24 (90% CL)	cut & count
ωK^0	< 14 (90% CL)	cut & count
$\eta' K^+$	$62 \pm 18 \pm 8$	cut & count
$\eta' K^0$	< 112 (90% CL)	cut & count

Conclusions

- Based on a first year sample of 22.4×10^6 BB pairs, BaBar has preliminary measurements of
  - $BR(B^0 \to K^{*0}\gamma) = (4.39 \pm 0.41_{stat} \pm 0.27_{syst}) \times 10^{-5}$
  - $A_{CP}(B^0 \to K^{*0}\gamma) = -0.035 \pm 0.094_{stat} \pm 0.022_{syst}$
  - $BR(B^0 \to K^+\pi^-) = (16.7 \pm 1.6_{stat}{}^{+1.2}_{-1.7}{}_{syst}) \times 10^{-6}$
  - $BR(B^0 \to \pi^+\pi^-) = (4.1 \pm 1.0_{stat} \pm 0.7_{syst}) \times 10^{-6}$
- Lots more modes and precision to come from BaBar charmless decays!