Charmless Branching Fraction Studies of $B^0 \rightarrow K^0_S \pi^+ \pi^-$ at *BABAR*

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The *BABAR* Collaboration

Outline

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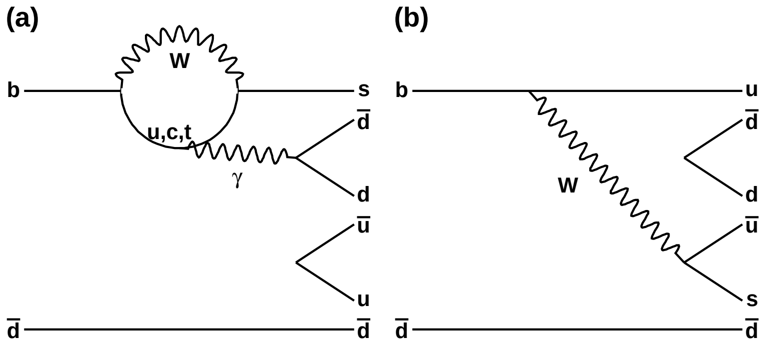
- Method - Inclusive BF
  - Variables & Cuts
  - Calibration Channel $B^0 \to D^-\pi^+, D^- \to K^0_S\pi^-$
  - Model (Signal, Continuum Background, B Background)
  - Fit Tests & Systematics
  - Results & Branching Fraction
- Quasi 2 Body Modes
- Conclusions and Future

Physics Motivation

- The decay mode $B^0 \to K^0_S \pi^+\pi^-$ is mediated by a combination of tree and penguin amplitudes, of comparable magnitudes. Fig (a) represents the penguin diagram, fig (b) represents the tree.
- Measurements of $B^0 \to K^0_S \pi^+\pi^-$final states, along with other $K\pi\pi$ modes, can help to yield the CKM angle γ . arXiv:hep-ph/0207257
- Inclusive and quasi 2 body BFs needed, as well as time dependent analyses of $\rho^0 K^0_S$ and $f^0 K^0_S$.
- The quasi-two-body intermediate states $K^{*+}\pi^-$, $\rho^0 K^0_S$, $f^0 K^0_S$, $K^+_X(1430)\pi^-$, higher $f_X K^0_S$, and higher $K^{*^+}\pi^-$ all interfere with each other in the Dalitz plot, allowing their relative phases to be determined by amplitude analysis, when statistics allow.



Discriminating Variables

- m_{ES} - Energy Substituted Mass of the event:

$$m_{ES} = \sqrt{E_x^2 - p^2}, \text{ where } E_x = \frac{E_{beam}^2 - p_{beam}^2 + 2p_{beam} \cdot p}{E_{beam}}$$

- ΔE - difference between the energy of the reconstructed B and the expected B decay energy.

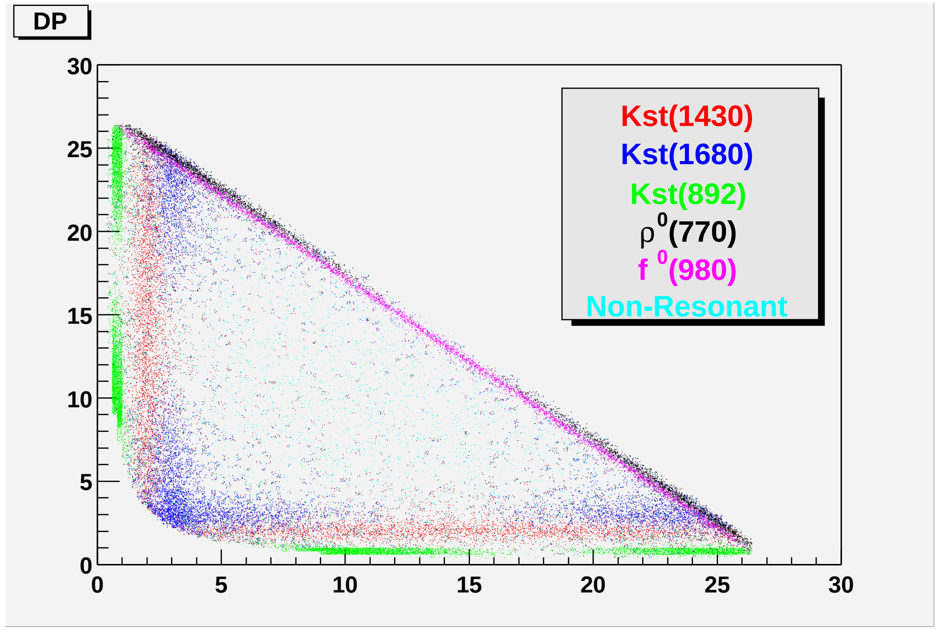
$$\Delta E = E_x - E_{Bcand}$$

- Fisher - the Cornelius (CLEO) Fisher uses 9 cones of different size around the direction of the B candidate (CMS frame). Discriminates between jet-like $q\overline{q}$ events and spherical B events. The coefficients of the cones maximise the separation between the two types of events.
- $\cos(\theta_{thrust})$ - angle between the thrust axis (direction which maximises the sum of the longitudinal momenta of the particles in the event) and the momenta of the B candidate. Again tests event topology.
- K_S^0 lifetime significance $= c\tau/\sigma_{c\tau}$
- $\cos\theta_{K_S^0}$ - angle between the line of flight of the K_S^0 and its momentum vector.
- $\cos\theta_{hel}$ - Angle between the momentum vectors of one of the daughter particles from the resonance and the spectator particle, in the resonance's rest frame.

Selection Criteria

- Require each candidate to have 4 tracks, 2 of which make the K^0_S candidate.
- GoodTracksLoose: Charged Tracks, $0.1 < p_t < 10$ GeV, > 20 DCH Hits, Maximum Distance of Closest Approach (DOCA) in xy = 1.5cm, DOCA in z axis < 10cm
- $5.22 < \mathrm{m_{ES}}(\mathrm{GeV}) < 5.29$
- $q_{\pi_1} * q_{\pi_2} = -1$
- Particle Identification: π_1 and π_2 should fail electron and kaon selectors
- $0.483 < m_{K^0_S}(\mathrm{GeV}) < 0.513$
- $\mid \cos\theta_{thrust} \mid < 0.9$
- Lifetime significance: $c\tau_{K^0_S}/\sigma_{c\tau} > 5$ cm
- $\cos\theta_{K^0_S} > 0.999$

Inclusive BF measurement Method



Dalitz plot contains many charmless modes:

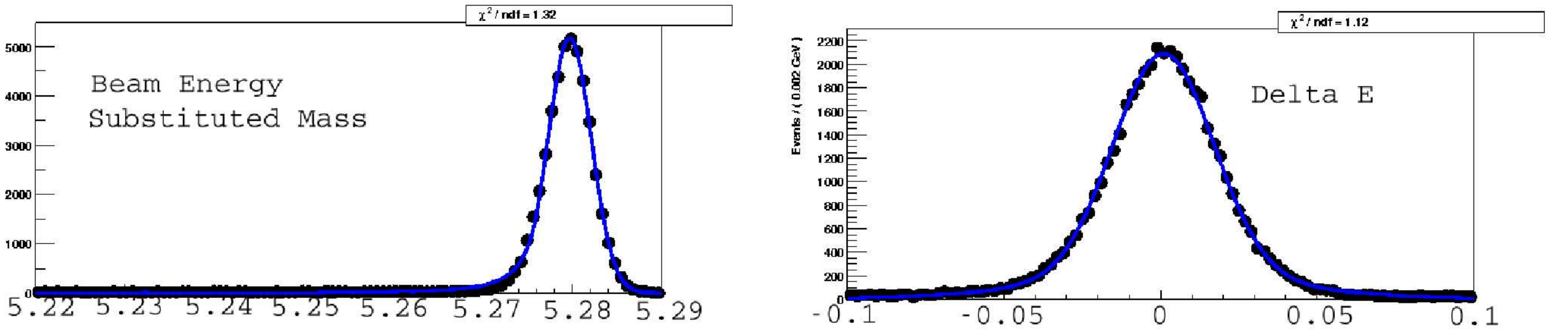
$K^{*+}\pi^-, K^{*+}(1410)\pi^-, K^{*+}(1680)\pi^-,\ K^{*+}_{0,2}(1430)\pi^-,\ \rho^0 K^0_S,\ f^0 K^0_S,\ higher\, f^0 K^0_S ...$

The ultimate aim would be to achieve a full Dalitz Plot analysis - but more data is needed first. (This analysis is on $81\,\mathrm{fb}^{-1}$).

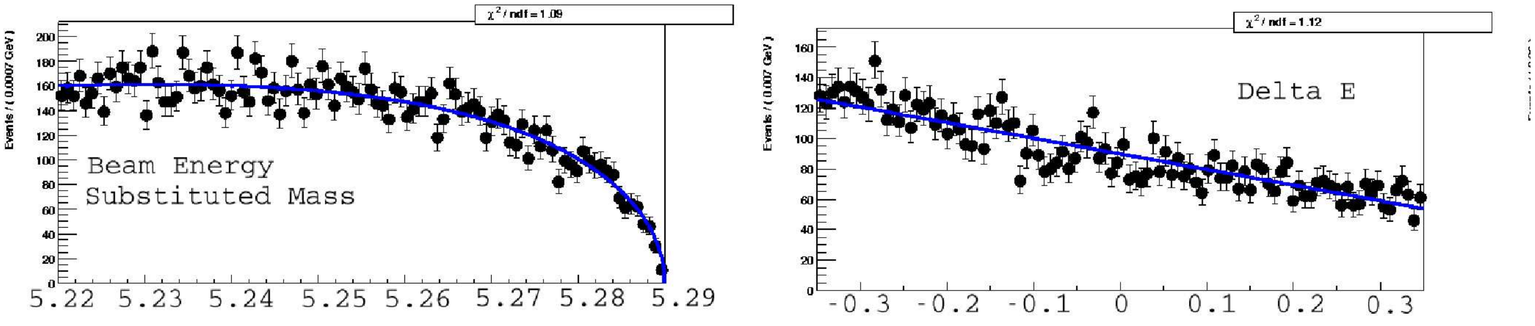
This is an ML analysis, fitting to m_{ES}, ΔE and Fisher.

Model for the Inclusive Measurement

- The signal is modelled using non-resonant $B^0 \to K^0_S \pi^+ \pi^-$MC.



- The background is modelled using a ΔE sideband in on-resonance data (taken at $\sqrt{s} = \Upsilon(4S)$) for m_{ES} and Fisher and off-resonance data for ΔE (taken 40MeV below $\sqrt{s} = \Upsilon(4S)$).

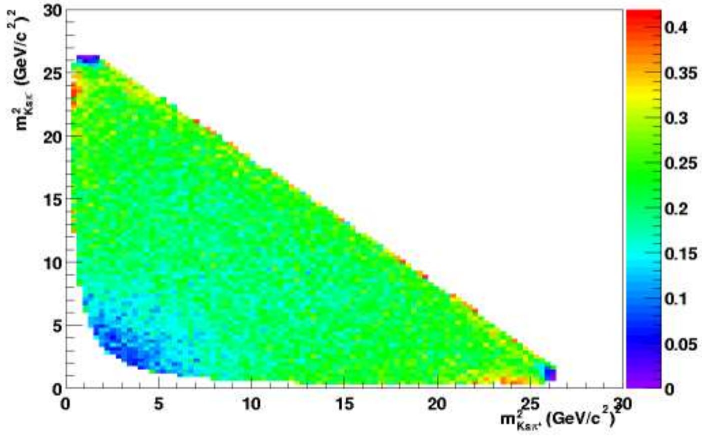


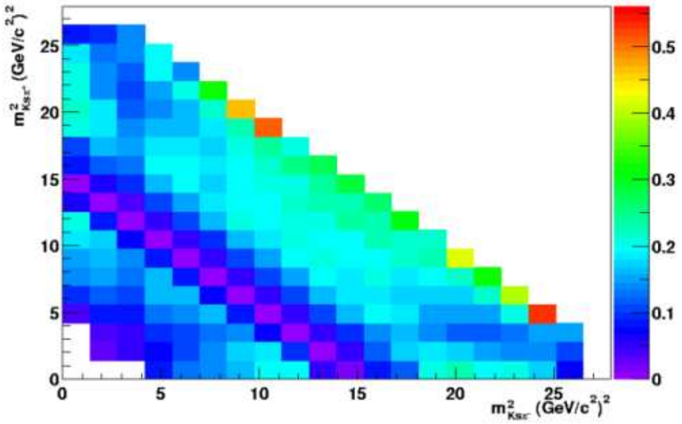
- The major charmed backgrounds
  $B^0 \rightarrow D^- \pi^+ (D^- \rightarrow K^0_S \pi^-)$,
  $B^0 \rightarrow J/\psi K^0_S (J/\psi \rightarrow \mu^+\mu^- \text{or } \pi^+\pi^-)$,
  $B^0 \rightarrow \psi(2S) K^0_S (\psi(2S) \rightarrow \mu^+\mu^- \text{or } \pi^+\pi^-)$,
  $B^0 \rightarrow \chi_{0c} K^0_S (\chi_{0c} \rightarrow \pi^+\pi^-)$
  are vetoed in a 5σ band about the mean of their distribution.

- In addition to signal and background PDFs, the model also includes PDFs for these B backgrounds:
  - $B^0 \rightarrow D^- \pi^+, D^- \rightarrow K^0_S \pi^-$
  - $B^0 \rightarrow \eta' K^0_S, \eta' \rightarrow \pi^+\pi^-\gamma$
  - $B^0 \rightarrow D^- \rho^+, D^- \rightarrow K^0_S \pi^-$
  - $B^0 \rightarrow D^- \pi^+, D^- \rightarrow K^0_S K^-$
  - $B^+ \rightarrow D^{*0} \pi^+, D^{*0} \rightarrow D^0 \gamma, D^0 \rightarrow K^0_S \pi^0$
  - $B^+ \rightarrow D^{*0} \pi^+, D^{*0} \rightarrow D^0 \pi^0, D^0 \rightarrow K^0_S \pi^0$

- Expect 0 cross-feed from $B^0 \rightarrow K^0_S K^+ K^-$, < 6 events from $B^0 \rightarrow K^0_S K^+ \pi^-$ (dependent on UL of BF)

- We tested > 35 B backgrounds for possible contamination
- Efficiency binned within the Dalitz plot. Corrections for tracking, PID and K_S^0 are also applied to calculate the efficiency in each bin.





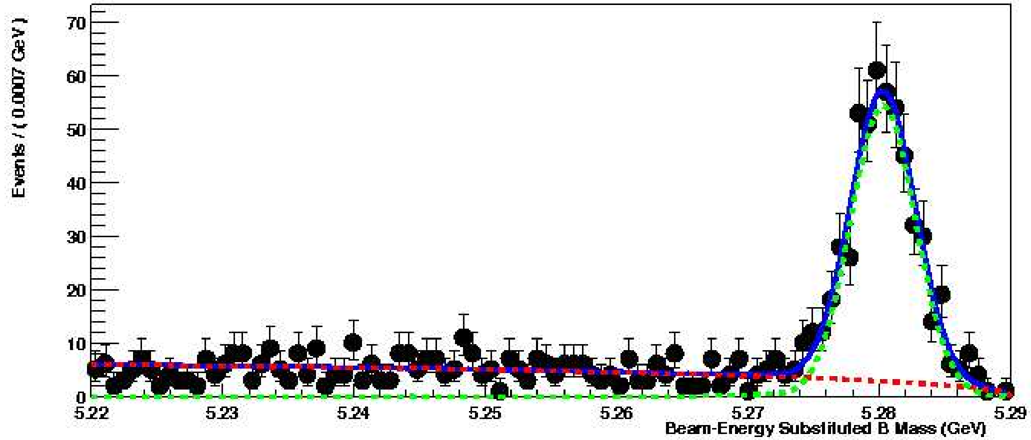
- Thorough fit testing of the model completed.

Calibration Channel - $B^0 \to D^-\pi^+, D^- \to K^0_S\pi^-$

- PDG: $\mathcal{B} = 41.7 \pm 6.2 \times 10^{-6}$
- Use additional mass cut to select the $D\pi$ channel:

$$1.847 < m_{D^\pm} < 1.887$$

- No significant B background expected
- Float all parameters to check for discrepencies with MC
- Signal Yield = 484.7 ± 23.2
- $\mathcal{B} = 43.9 \pm 2.1 \pm 2.2 \times 10^{-6}$



Systematics

Systematic Consideration	BF Uncertainty %
Particle Identification	1.90
Tracking	1.70
K_S^0 efficiency	4.18
Fit Bias	4.11
PDF parameterisation	1.46
B background	0.37
Dalitz plot Efficiency	3.50
B counting	1.1
TOTAL	7.5

Unblinded Yields

Signal Yield = 309.74 +/- 27.132

(Background Yield = 21980 +/- 149.54)
which yields a

$$\mathcal{B}(B^0 \to K^0_S \pi^+\pi^-) = 21.9 \pm 1.9(\text{stat}) \times 10^{-6}$$

We choose to quote the BF without $K^0 \to K^0_S$:

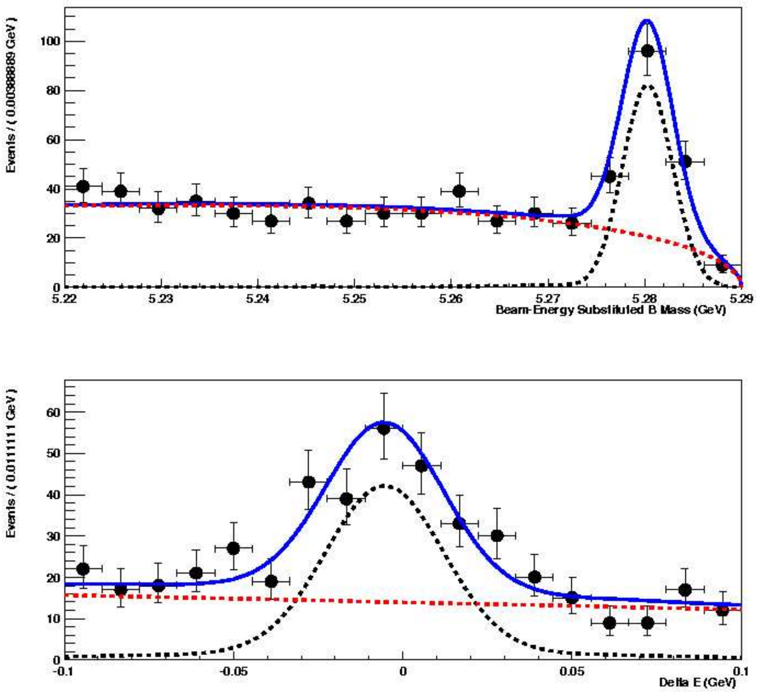
$$\mathcal{B}(B^0 \to K^0 \pi^+\pi^-) = 43.8 \pm 3.8(\text{stat}) \pm 3.4(\text{syst}) \times 10^{-6}$$

Belle's BF = 41.7 $\pm$ 7.2 $\times 10^{-6}$ (arXiv:hep-ex/0207003)
CLEO's BF = 50.0 $\pm$ 12.2 $\times 10^{-6}$ (arXiv:hep-ex/0206024)

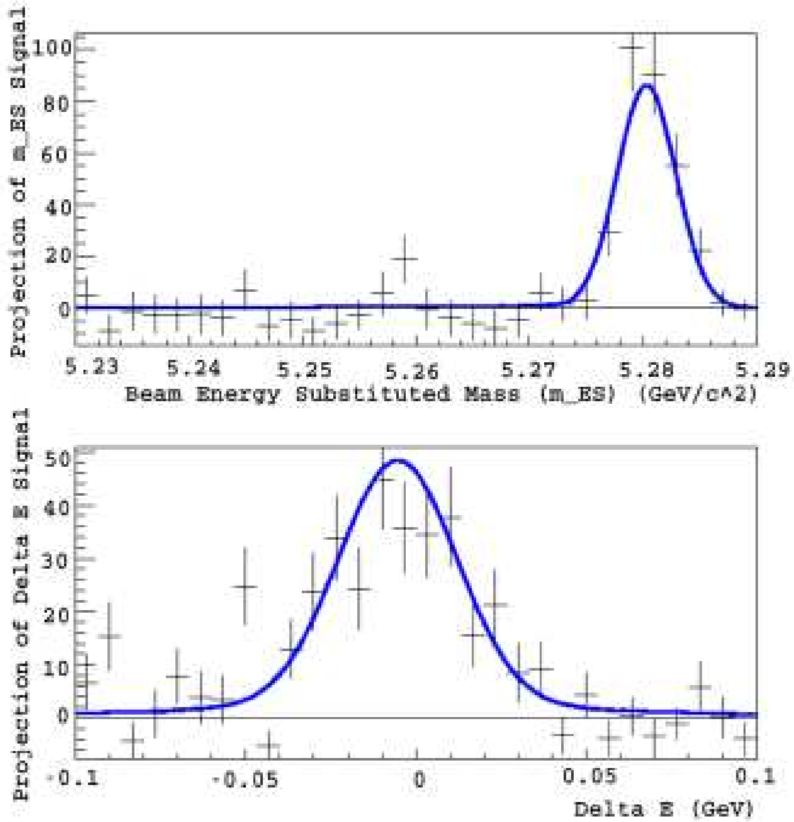
Projection Plots

Top - m_{ES}, Bottom - ΔE

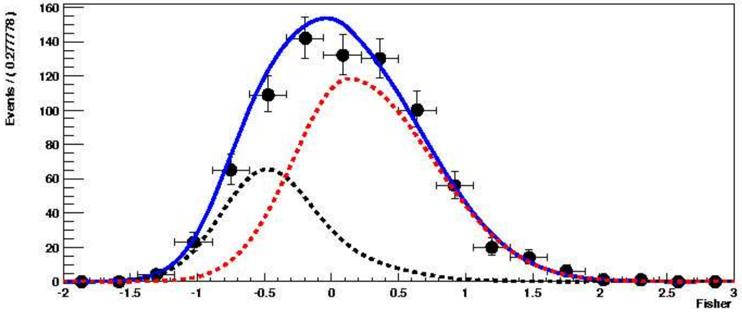
Likelihood plots ($\mathcal{L} > 0.8$)

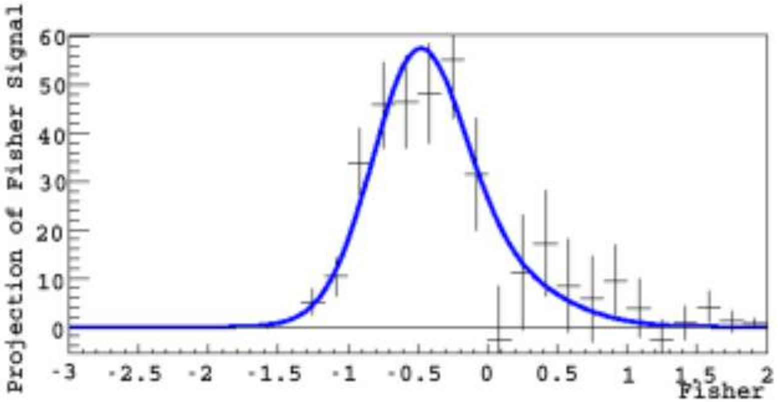


$_s$Plots (arXiv:physics/0402083)

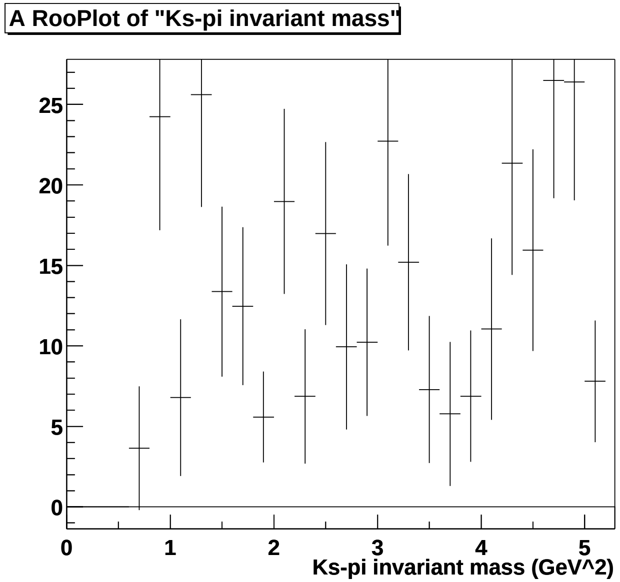


Fisher

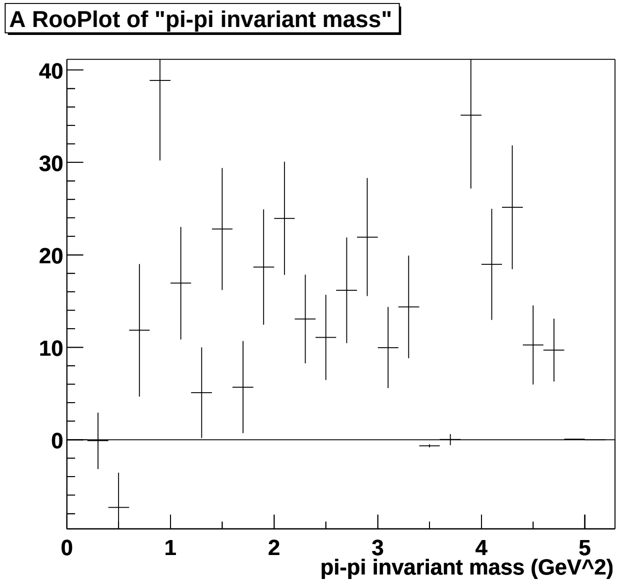




$m_{K^0_S\pi^+}$ $_s$Plot Projection



$m_{\pi^+\pi^-}$ $_s$Plot Projection



Quasi Two Body Modes

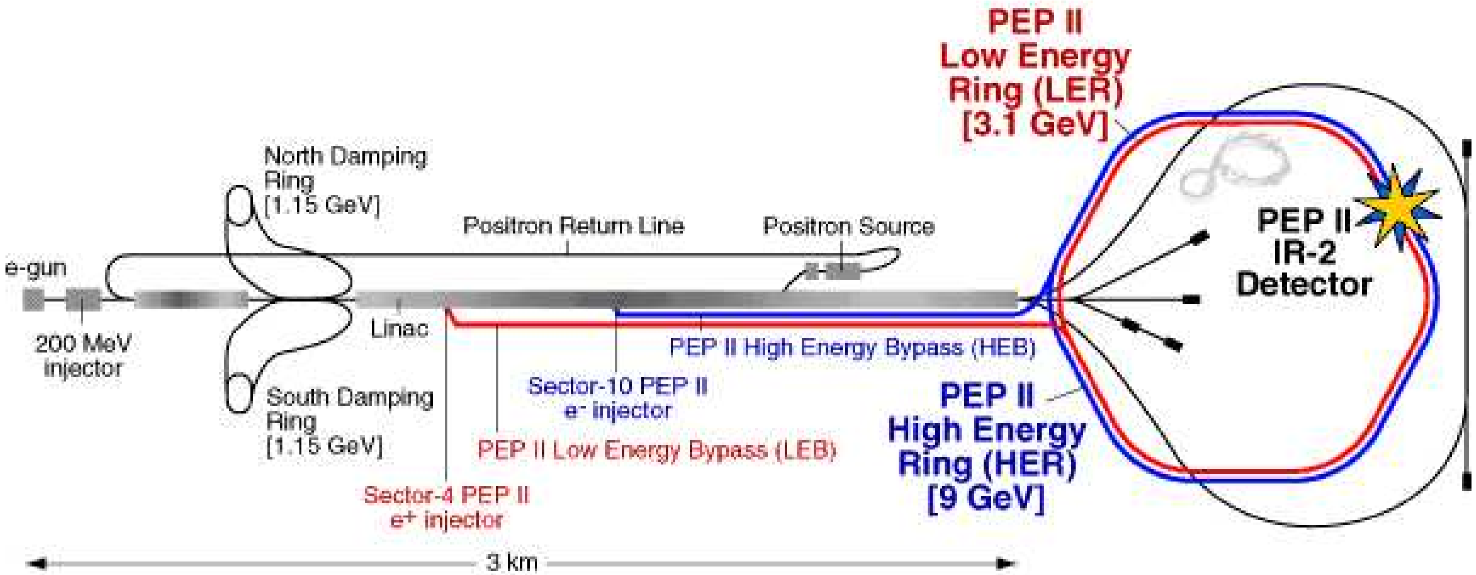
Currently looking at ${K^*}^{\pm}\pi^{\mp}$, $\rho^0 K^0_S$, $f^0 K^0_S$. We use the same selection but for

- A mass cut of 3σ about the resonance:
  - ${K^*}^{\pm}$ - $0.792 < m_{K^{*\pm}} < 0.992$
  - f^0 - $0.875 < m_{f^0} < 1.075$
  - ρ^0 - $0.53 < m_{\rho^0} < 0.91$
- A helicity cut for the $\rho^0 K^0_S$:
  - $0.53 < \cos\theta_{hel} < 0.91$
- Fit testing is done.
- B background studies done.
- Working on final interference systematics.

Conclusions & Future

- $\mathcal{B}(B^0 \rightarrow K^0\pi^+\pi^-) = 43.8 \pm 3.8(\text{stat}) \pm 3.4(\text{syst}) \times 10^{-6}$ on $81\,\text{fb}^{-1}$ of data at *BABAR*
- $\mathcal{B}(B^0 \rightarrow D^{\mp}\pi^{\pm}, D^{\mp} \rightarrow K^0_S\pi^{\mp}) = 43.9 \pm 2.1 \pm 2.2 \times 10^{-6}$
- These measurements went to Moriond EW
- Need to finish systematics on quasi two body modes
- Write Paper
- Summer update of all modes on maximum available sample (hopefully around $200\,\text{fb}^{-1}$)
- We intend to do a full Dalitz plot analysis, when statistics allow

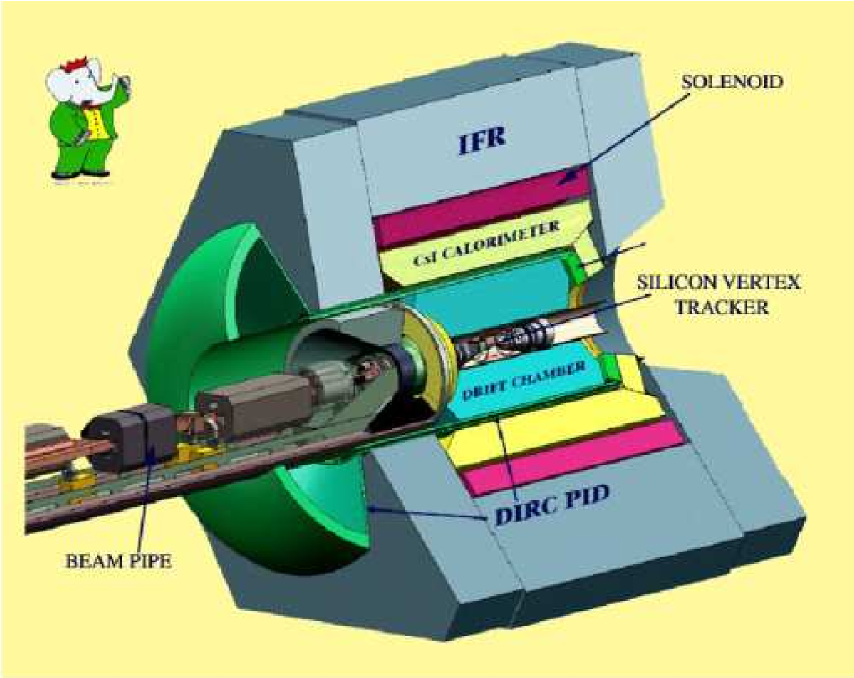
SLAC and PEP-II

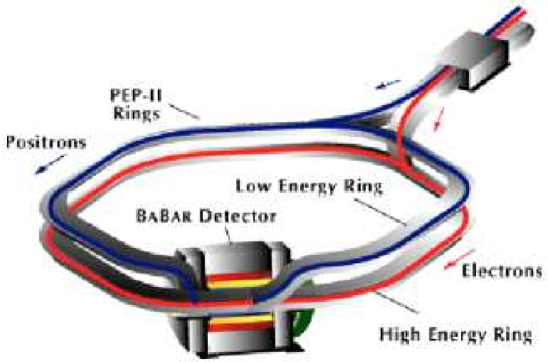


- SLAC runs the PEP-II accelerator
- Delivers asymmetric beams of electrons and positrons
- HER - 9 GeV, LER - 3.1 GeV
- Interaction Region is inside the *BABAR* detector
- Running the *B* Factory since 1999.

the BABAR Experiment

- SVT - tracking + vertexing
- DCH - tracking
- EMC - neutrals, energy measurements
- DIRC - PID
- IFR - muon seperation
- Magnet
- Trigger





Maximum Likelihood Method

For each event x_i, the likelihood is defined as:

$$\mathcal{L}_i = \sum_{j=1}^{k} N_j \mathcal{P}_j(x_i)$$

where N_j is the number of events associated with the j^{th} hypothesis (signal, bg, etc). $\mathcal{P}_j(x_i)$ is the probability of the fit evaluated for that event, i:

$$\mathcal{P}_j(x_i) = \mathcal{S}_j(m_{ES\,i}) \cdot \mathcal{T}_j(\mathcal{F}_i) \cdot \mathcal{U}_j(\Delta E_i)$$

For N events, this becomes:

$$\mathcal{L} = \frac{\exp\left(-\sum_j N_j\right)}{N!} \prod_i^N \mathcal{L}_i$$

where the coefficient takes poissonian fluctuations for the observed number of events into account.

Fit Tests

We conduct several tests of our fitting procedure to see: Can we get back what we put in?

- Toy tests of full model, and with varying amounts of signal.
- Embedded fits - use toy data for continuum background, MC for signal and B bgs. - here we observe a small bias of $+4.1\%$, which is included as a systematic.
- Mock Data Set tests - use a full data set constructed purely from MC, subjected to our selection criteria
- Negative Log Likelihood tests

sPlots - a BRIEF Explanation

In order to calculate the BF, and provide clean signal plots, we use the sPlot method (arXiv:physics/0402083)

The description is very involved, although implementation is relatively simple.

For each species in your fit (signal, continuum bg etc.), you can define an sWeight (a "covariance-weighted weight") for each event

$$ {}_s\mathcal{P}_n(y_e) = \frac{\Sigma_{j=1}^{N_s} \mathbf{V}_{nj} f_j(y_e)}{\Sigma_{k=1}^{N_s} N_k f_k(y_e)} $$

where $\mathbf{V}$ is the covariance matrix of the fit, and f is the value of the species pdf for that event e.
To calculate the branching fraction for the inclusive measurement, and take into account the variation of efficiency over the Dalitz plane, we need to weigh each event by its efficiency.

$$ \mathcal{B} = \frac{\sum_{e=1}^{N} \frac{{}_s\mathcal{P}_n(y_e)}{\epsilon(x_e)}}{N_{B\overline{B}}} $$