Imperial College London

The search for $B^{\pm} \rightarrow a_0^{\pm}\pi^0$ using the BaBar detector at SLAC

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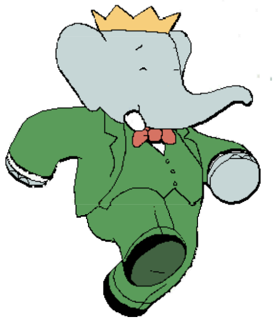


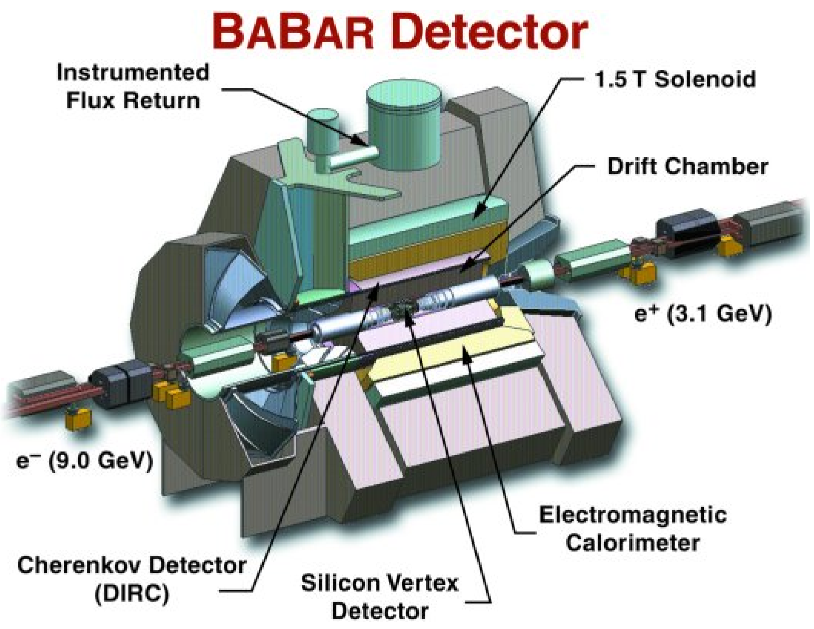
IoP HEPP Meeting, Warwick

April 2006

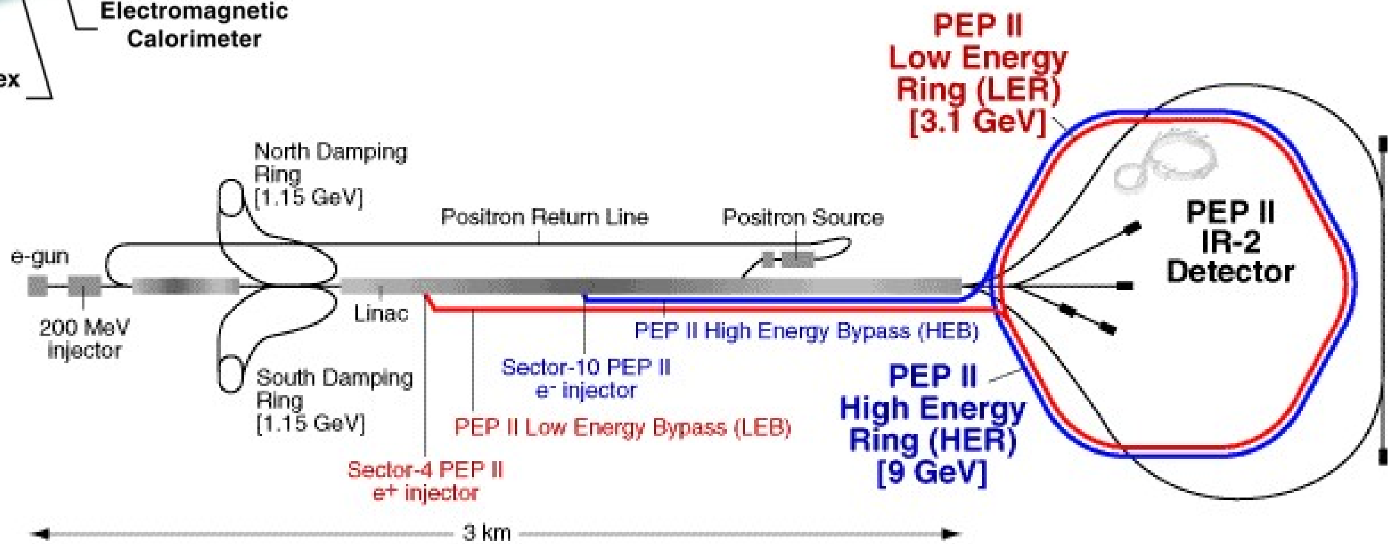
Overview

- The BaBar detector
- Physics Motivation
- Reconstruction & Background
  - Summary of potential background sources
  - Final state Dalitz plot
- Analysis techniques
  - Maximum Likelihood Fit
  - Fitting Variables
  - Signal and Continuum Background Models
  - Test fits to off-resonance data
- Analysis outlook

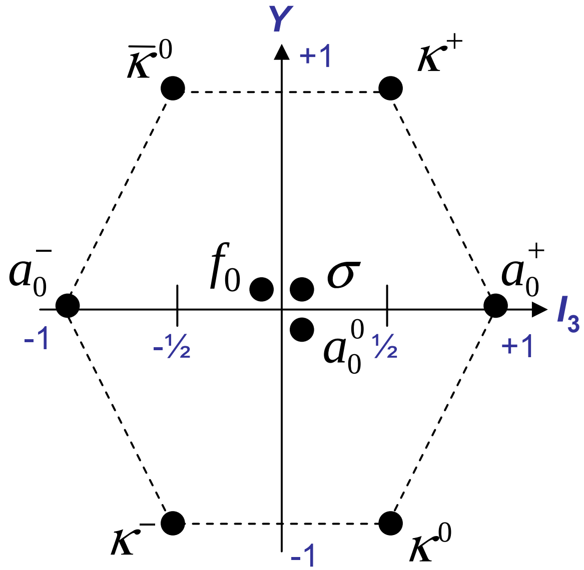
The BaBar Detector



- 2 mile long Linac feeds PEP-II storage ring
- Collide 9 GeV e^- and 3.1 GeV e^+ at a centre of mass energy of 10.58 GeV
- Produce $B\overline{B}$ pairs at the Y(4S) resonance
- 50% B^+B^- and 50% $B^0\overline{B}^0$ produced
- ~310fb^{-1} collected so far – 300M $B\overline{B}$ pairs

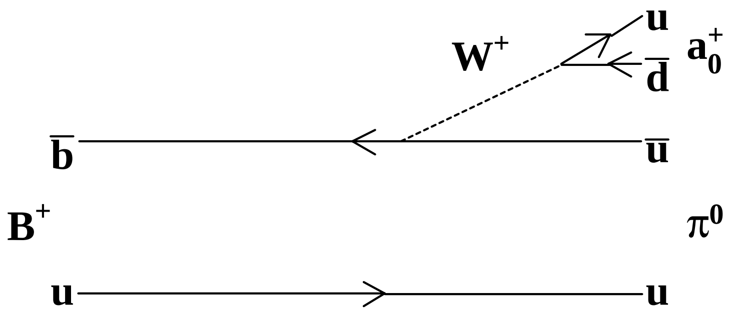


Physics Motivation



Scalar Meson Nonet

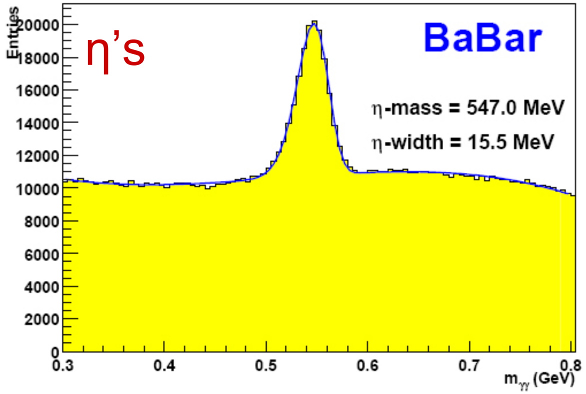
- Status of Theory
  - Scalar mesons generally poorly understood
  - 2 and 4 quark models exist
  - Also suggestion they could have substantial glueball or $K\overline{K}$ 'molecular admixture'
- Motivation for this analysis
  - Predicted 2 quark BF from QCD factorisation of ~2×10^{-7} (charmless decay therefore very rare). *(hep-ph/0501022)*

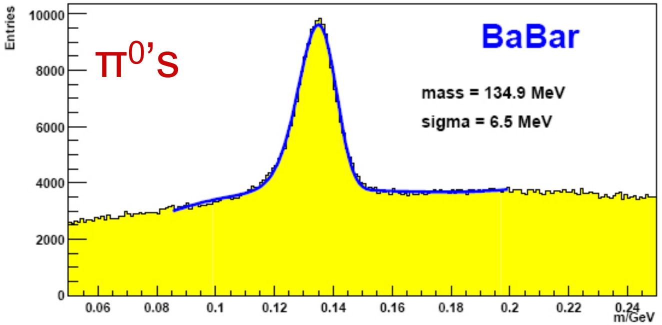


- In 4 quark model dominant tree amplitude suppressed giving a smaller branching fraction (predict up to a factor of 10 difference)
- Measurement of BF will be a test of credibility of these models.

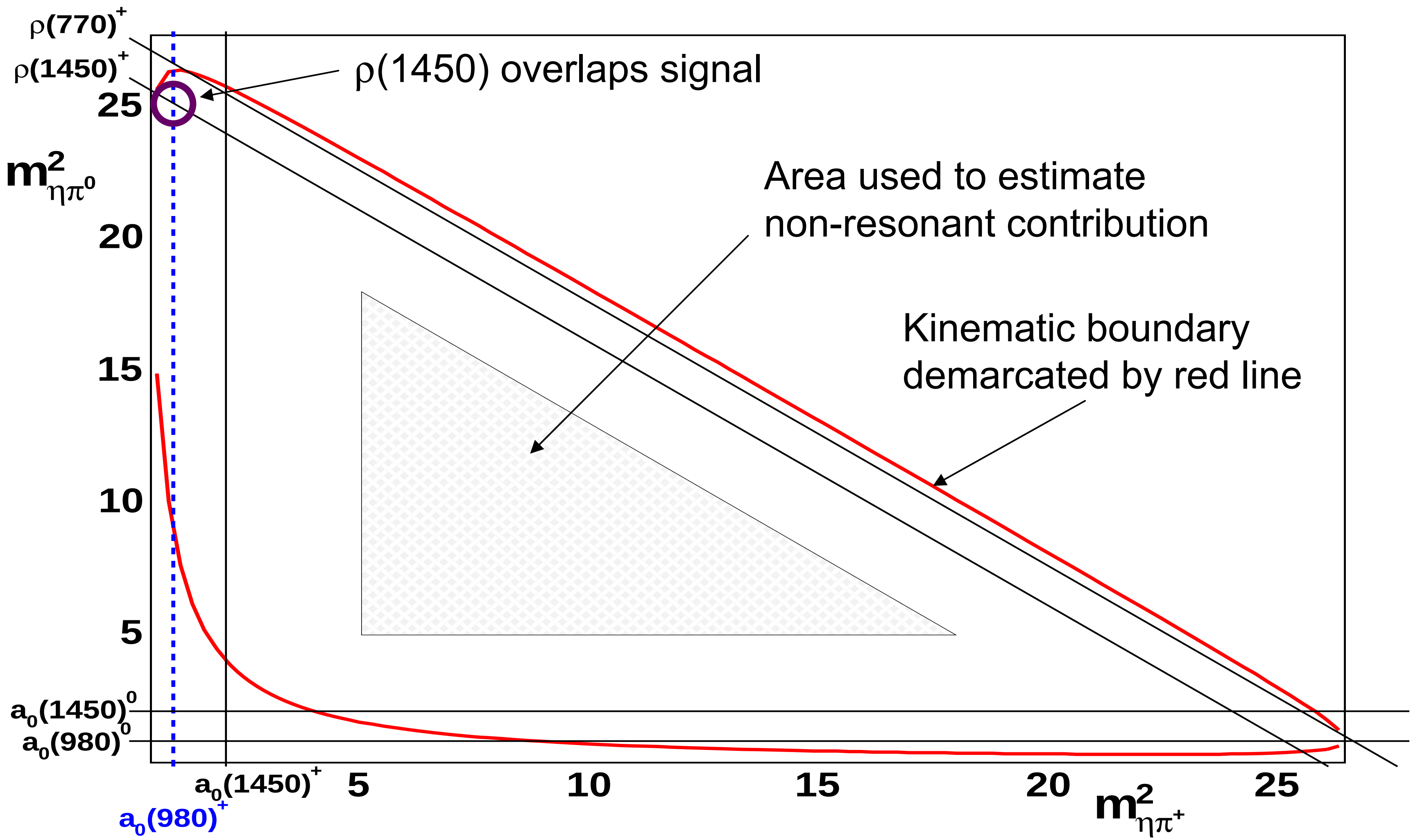
Reconstruction & Sources of Background

- Explicit decay chain:
  - $B^{\pm} \to a_0^{\pm}\pi^0(a_0^{\pm} \to \eta\pi^{\pm}, \eta \to \gamma\gamma)$
- Signal is composed of 1 charged track and 4 photons.
  - Large amount of combinatorial background is expected.
- 'Continuum' light quark ($u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c}$) production
  - Dominant background source
  - At BaBar (10.58 GeV) produced with σ = 3.39nb compared to 0.535nb for B^+B^-
  - Model using continuum Monte Carlo
- B decay background
  - B→charm component (non-peaking)
    - Using BaBar's generic 'cocktail' Monte Carlo containing known decays with latest Branching Fractions
  - Also a contribution from 'charmless' B decays
    - Potentially peaking backgrounds
    - Use specially generated Monte Carlo specific to each background mode





Dalitz Plot guide: charmless B backgrounds



Extended Maximum Likelihood fit

- The *Likelihood function* for *N* events

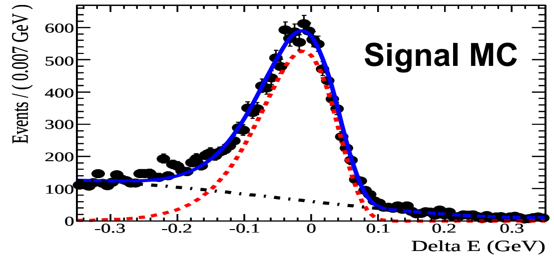
$$\mathcal{L} = \underbrace{\frac{e^{-\left(\sum n_j\right)}}{N!}}_{\text{'Extended' ML, } N \text{ varies according to a Poisson distribution}} \prod_{i=1}^{N} \underbrace{\left[\sum_{j=1}^{m} n_j \mathcal{P}_j(\mathbf{x}_i)\right]}_{\text{Likelihood for a given event '}i\text{'}}$$

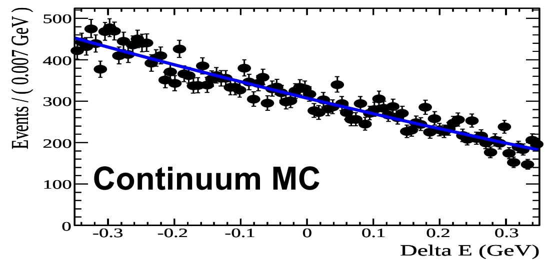
- Define hypothesis probability density functions (pdfs) for signal and background
- Each hypothesis has an associated yield
- Use *ROOFIT* package (now part of ROOT)

ML Fit Variables and PDFs - I

- Beam and B candidate energy difference

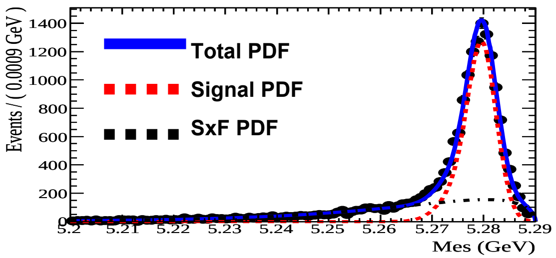
$$\Delta E = E_B^{cm} - \frac{1}{2}\sqrt{s}$$

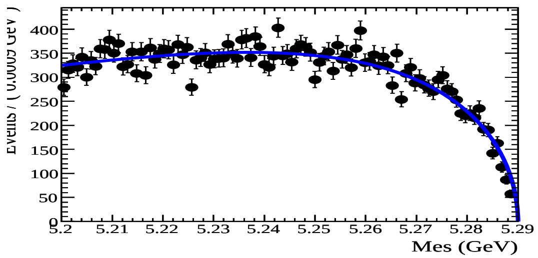




- Beam Energy Substituted Mass

$$m_{\mathrm{ES}} = \sqrt{\frac{1}{4}s - |\vec{p}_B|^2}$$

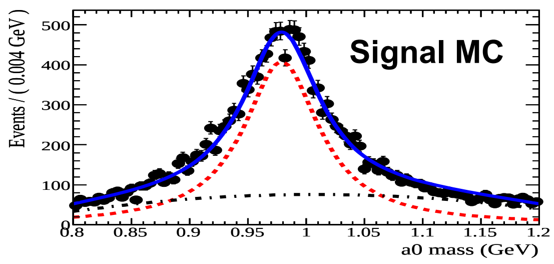


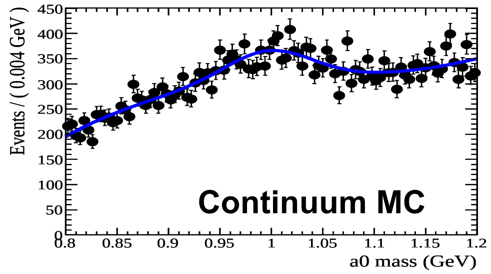


- ‘SxF’ refers to random combinations found in signal events
- Significant shape difference between signal and continuum
- B background shapes have both signal and continuum-like properties

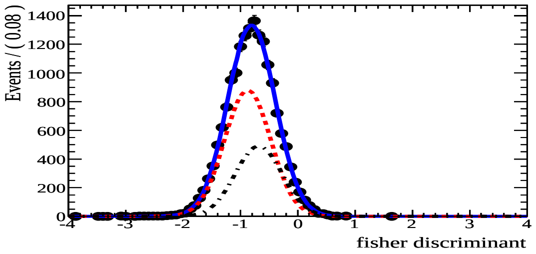
ML Fit Variables and PDFs - II

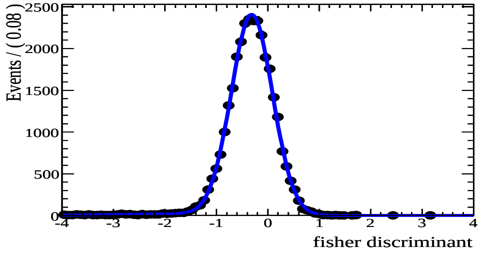
- Mass of a_0 candidate





- Linear Discriminant (Fisher)
  - Function optimised to maximise signal and continuum background separation
  - Constructed from Legendre Polynomials of energy flow and other event shape related quantities

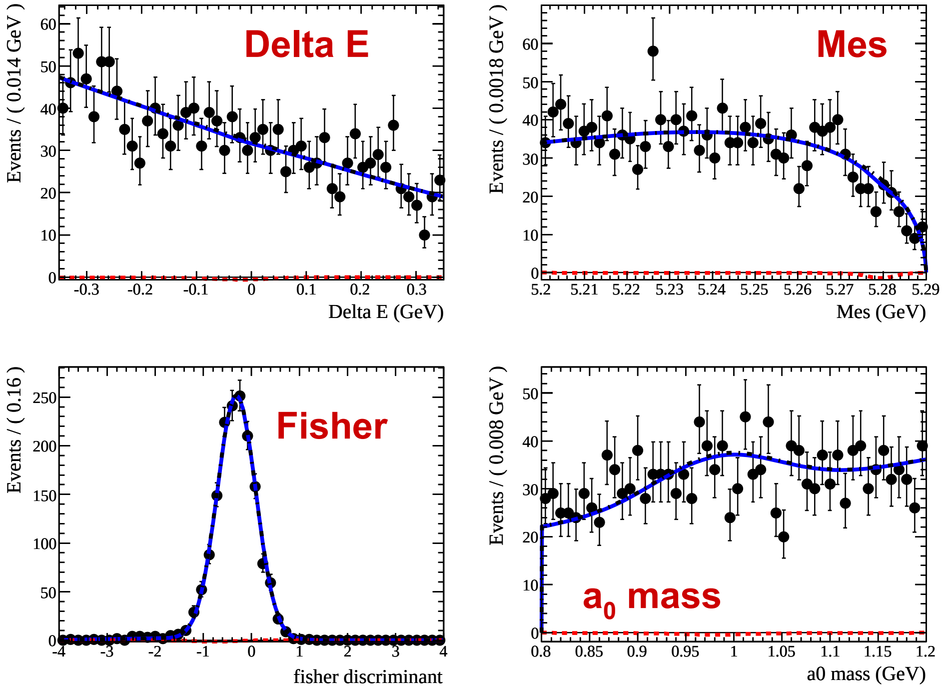




Other variables, not used in fit, have been used for event selection in order to optimise S/√B

Test fit to off-resonance data

- BaBar has collected ~20fb^{-1} at 40 MeV below the Y(4S)
  - Do not expect B meson production at this centre of mass energy
- Test fit by running it on this data
  - Yield = -8.7±4.1
  - Consistent with zero
- Estimating error when fitting to on-resonance data
  - 4.1x√9.7 = 13 events
  - Error on BF = 2x10^{-6}



Conclusion and Outlook

- Analysis still Blind
  - Not allowed to extract signal yield from on-resonance data
- Continuing the process of testing the fit
- Expect to be able to set an upper limit for the BF of this mode
- Currently extending analysis to cover both $\eta\rightarrow\gamma\gamma$ and $\eta\rightarrow\pi^+\pi^-\pi^0$ channels
  - $\eta\rightarrow\gamma\gamma$ (40%)
  - $\eta\rightarrow\pi^+\pi^-\pi^0$ (23%)
- Aim to include full 1999-summer 2006 dataset (~400fb^{-1})
  - Last new data available before I write my thesis!
- Eventually extend further to cover other resonances in the $\eta\pi^+\pi^0$ Dalitz plane.
  - Access to $a_0^0\pi^+$
  - Another test of the theories of scalar meson structure

Extra Slides

Categorising Charmless B backgrounds

- Modes which share our final state ($\eta\pi^{\pm}\pi^{0}$)
  - Understand further looking at Dalitz Plot (later)
- Modes sharing our final state + 1 particle
  - For example: a mode which decays to $\eta\pi^{\pm}\pi^{0}\pi^{0}$, but one π^{0} is not reconstructed
- Modes where an extra particle has been mis-reconstructed
  - For example: a mode with an $\eta\pi^{\pm}$ where a π0 is mis-resonstructed from background photons
- Modes with a mis-reconstructed η
  - For example: a mode with an $\pi^{\pm}\pi^{0}\pi^{0}$ final state, where one of the π0's is mis-reconstructed as an η
- Modes where particle ID algorithms incorrectly identify a Kaon as a Pion
  - For example: $K^{+}\eta\pi^{0}$

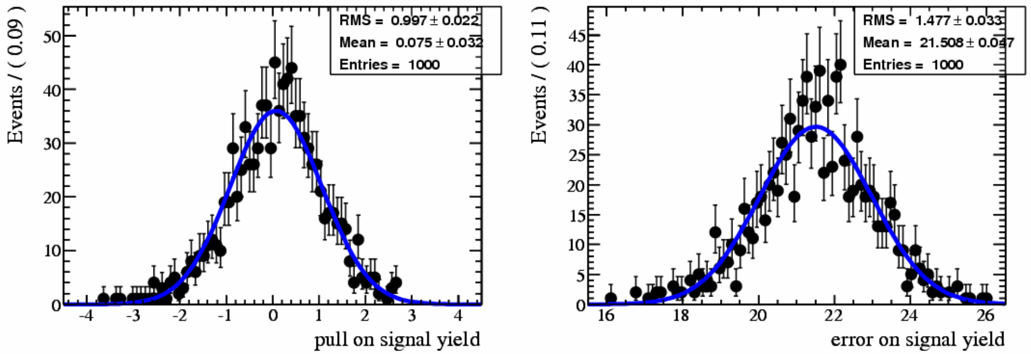
Background Model

Background type	ΔE Model	M_{es} Model	M_{a_0} Model	Fisher Model
udsc	2nd Order Poly	Argus	2nd Order Poly + Single Gauss	Double Gauss
Generic B^+B^-	3rd Order Poly	Argus	2nd Order Poly	Bifurcated Gauss
Generic B^0B^0bar	3rd Order Poly	Argus	2nd Order Poly	Bifurcated Gauss
$\rho^+\eta$	2D Keys		1st Order Poly	Bifurcated Gauss
$\rho(1450)^+\eta$	2D Keys		2nd Order Poly	Bifurcated Gauss
$a_0(1450)^+\pi^0$	2D Keys		2nd Order Poly	Bifurcated Gauss
$\eta\pi^+\pi^0$ (non-res)	1st Order Poly + Novosibirsk	Argus + Single Gauss	3rd Order Poly	Bifurcated Gauss
$a_0^+\rho^-$	2D Keys		Breit-Wigner	Bifurcated Gauss
$a_0^0\rho^-$	2D Keys		2nd Order Poly	Bifurcated Gauss
$\eta\pi^0$	2D Keys		1st Order Poly	Bifurcated Gauss
$\pi^+\pi^0\pi^0$ (non-res)	2D Keys		2nd Order Poly	Bifurcated Gauss
$\rho^+\pi^0$	2D Keys		2nd Order Poly + Breit-Wigner	Bifurcated Gauss
$X_S\gamma$ (combined)	2D Keys		2nd Order Poly	Bifurcated Gauss

Testing the fit: Toy Monte Carlo

- ‘Pure’ Toy Study
  - Test ML Fit by generating Monte Carlo events based on hypothesis PDFS
  - Re-fit this generated dataset with hypothesis PDFs
  - Shifts in measured quantities indicate a bias in the fit
- ‘Embedded’ Toy Study
  - Can add samples of signal and/or selected background modes into generated dataset
  - Correlations in variables will cause biases in the fit
  - Need to test if fit is robust against correlations

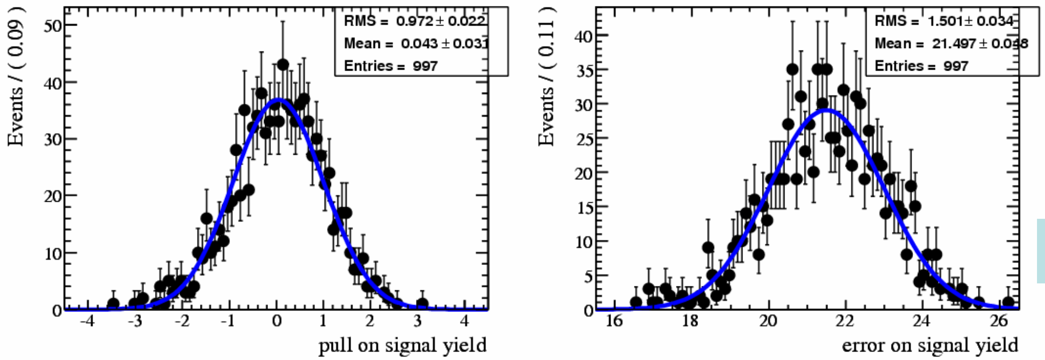
Toy MC Studies



← **Pure Toy**

Toy Type	Expected Signal	# of toy expts	Pull on yield	Error in yield	Bias (# cands)
Full Fit					
Pure toy	71	1000	0.075172	21.51	1.61695
Signal Embedded	71	997	0.043427	21.499	0.933637
Fully Embedded	71	998	0.011927	21.354	0.254689

Toy Type	Expected Continuum	# of toy expts	Pull on yield	Error in yield	Bias (# cands)
Full Fit					
Pure toy	20277	1000	0.005284	145.05	0.766372
Signal Embedded	20277	997	0.008485	145.45	1.234187
Fully Embedded	20277	998	-0.17496	144.93	-25.35695



← **Signal Embedded Toy**

Signal + B background Embedded Toy →