Evidence for $b \rightarrow d\gamma$ Transitions Using a Sum of Exclusive Final States

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On behalf of the BaBar Collaboration

IoP Annual HEP Conference, 31st March 2008

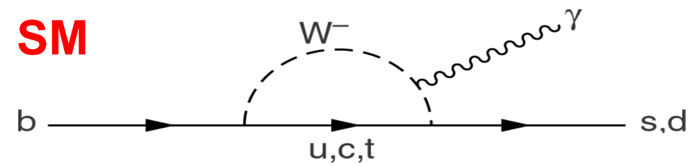
Outline

- Theoretical Motivation
- The BaBar Experiment
- Analysis Overview
- Backgrounds
- Fit Strategy
- Results
- Summary and Future Work

Motivation

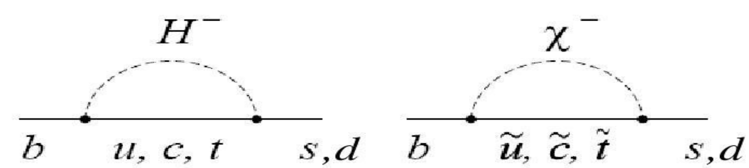
- b→dγ and b→sγ are FCNC forbidden at tree level in SM
- Leading order processes are one-loop electroweak penguin diagrams

SM



- SM motivation
  - Ratio of *Br*(b→dγ)/*Br*(b→sγ) can lead to constraint on CKM elements $|V_{td}/V_{ts}|$

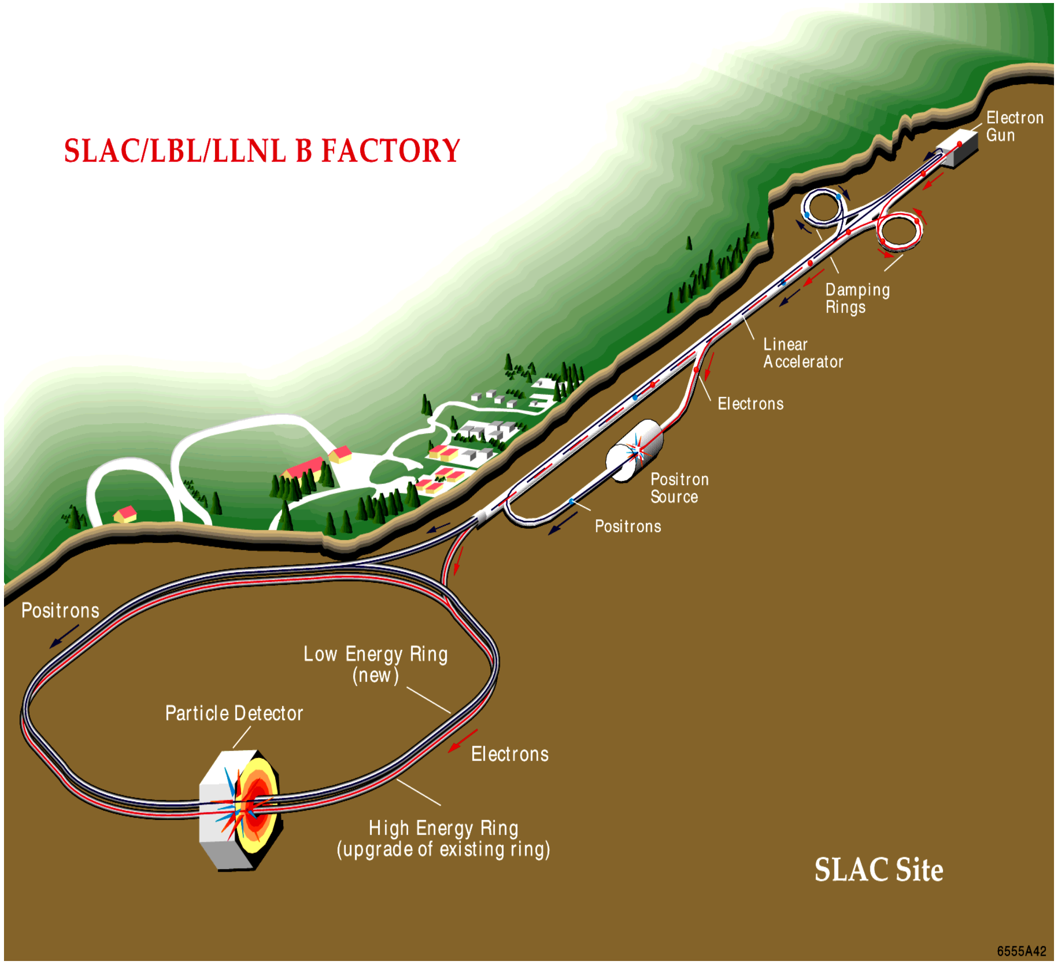
SUSY



- NP motivation
  - New virtual particles may contribute to the loop (eg. charged Higgs or chargino and squarks in SUSY)
  - SM *Br*(b→dγ) is smaller than *Br*(b→sγ) due to CKM suppression; could evidence for NP be seen here?

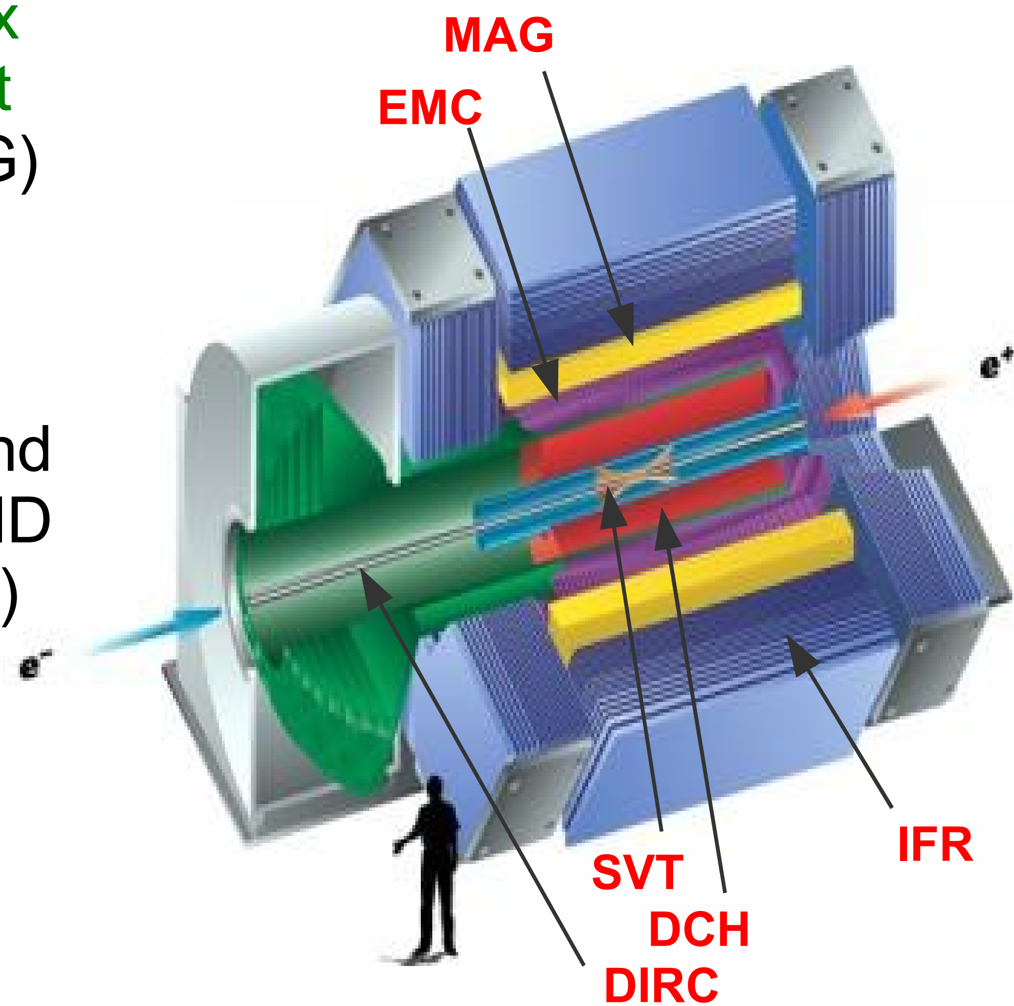
PEP II B Factory

- Asymmetric e^+e^- collider
- Tuned to Υ(4S) resonance
  - $\sqrt{s}$ = 10.58GeV
  - 3.1GeV e^+; 9.0GeV e^-
- Nearly continuous bunch crossing at ~5ns spacing
- ~0.5ab^{-1} delivered data
  - 460M BB pairs recorded
- Instantaneous luminosity record ~1.2x10^{34}cm^{-2}s^{-1}



BaBar Detector

- Charged tracks from 5 layer vertex tracker (SVT) and 40 layer He drift chamber (DCH) in 1.5T field (MAG)
- Photons from CsI(TI) crystal EM calorimeter (EMC)
- Pion/kaon PID from DCH dE/dx and Cerenkov detector (DIRC), muon ID from instrumented flux return (IFR)
- Trigger on DCH hits and EMC clusters
  - L1 (hardware) ~2500Hz
  - L3 (software) ~300Hz



Analysis Overview

- Reconstruct 7 exclusive $B \rightarrow X_d \gamma$ final states
- Use 2 hadronic mass bins
  - Low mass region dominated by ρ, ω resonances
    - $0.6 \leq M(X_d) < 1.0$ GeV
  - High mass bin
    - $1.0 \leq M(X_d) \leq 1.8$ GeV
- Reconstruct corresponding $B \rightarrow X_s \gamma$ final states
  - Reverse PID requirements from pion to kaon on one track
  - Same selection criteria for X_d and X_s $\Rightarrow$ many uncertainties cancel in ratio

- $B^0 \rightarrow \pi^+ \pi^- \gamma$
- $B^+ \rightarrow \pi^+ \pi^0 \gamma$
- $B^+ \rightarrow \pi^+ \pi^- \pi^+ \gamma$
- $B^0 \rightarrow \pi^+ \pi^- \pi^0 \gamma$
- $B^0 \rightarrow \pi^+ \pi^- \pi^+ \pi^- \gamma$
- $B^+ \rightarrow \pi^+ \pi^- \pi^+ \pi^0 \gamma$
- $B^+ \rightarrow \pi^+ \eta \gamma$

all $\pi^0 \rightarrow \gamma\gamma$, $\eta \rightarrow \gamma\gamma$

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- $B^0 \to K^+ \pi^- \gamma$
- $B^+ \to K^+ \pi^0 \gamma$
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- $B^0 \to K^+ \pi^- \pi^+ \pi^- \gamma$
- $B^+ \to K^+ \pi^- \pi^+ \pi^0 \gamma$
- $B^+ \to K^+ \eta \gamma$

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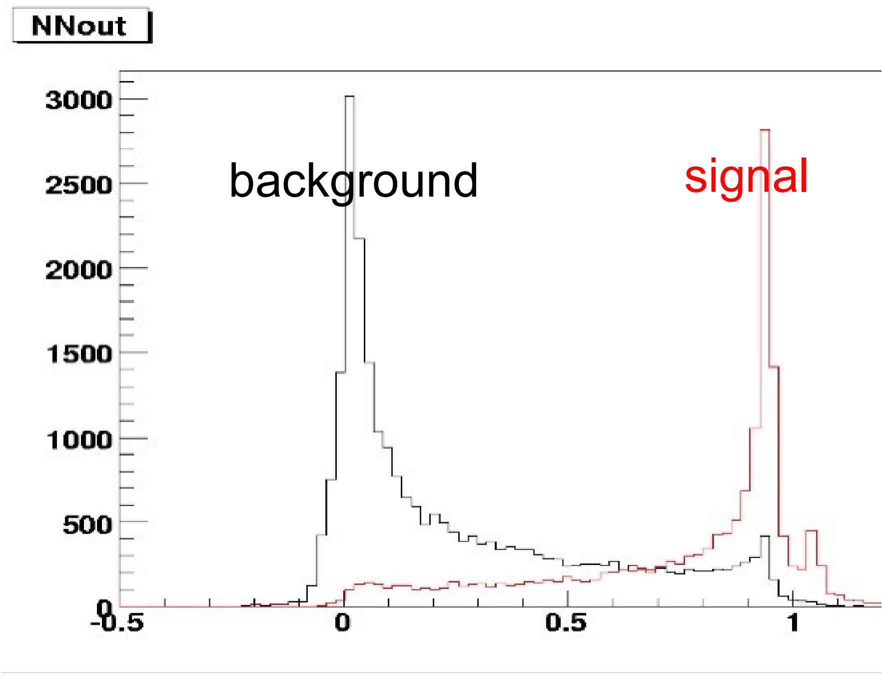
Backgrounds

- Contributions from generic B and continuum (udsc) backgrounds
- Generic B events with high energy (HE) photon from asymmetric π^0/η decay
  - Veto events where the HE photon used in B reco can make a π^0/η with any other photon in the event
- Continuum backgrounds (dominant)
  - Arise from any HE photon, eg. ISR or π^0/η decay
  - Combine event shape and 'tag B' information variables (eg. Lepton content of rest of the event) in Neural Net to discriminate between BB and udsc events



Fit Strategy

- Common BaBar reco B kinematic variables
  - Beam energy substituted mass (m_{ES}) of reco B; peaks at B mass for signal

$$m_{ES} = \sqrt{\frac{1}{4}s - |p_B^*|^2}$$

* Denotes CM frame

  - Difference in beam energy and energy of reco B (ΔE); peaks at 0 for signal

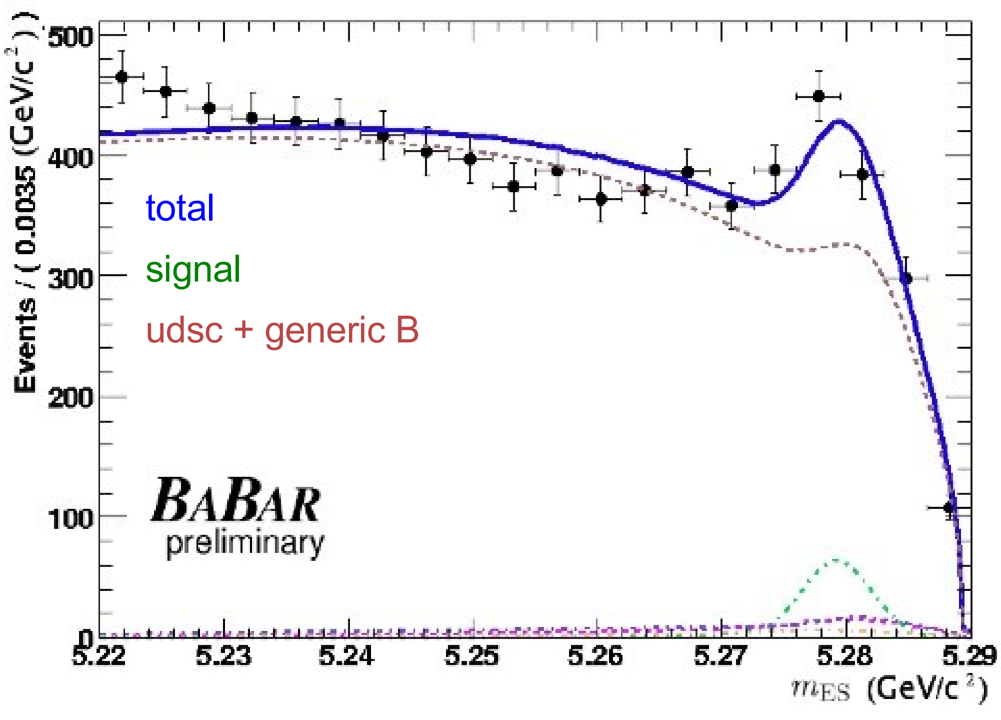
$$\Delta E = E_B^* - \frac{1}{2}\sqrt{s}$$

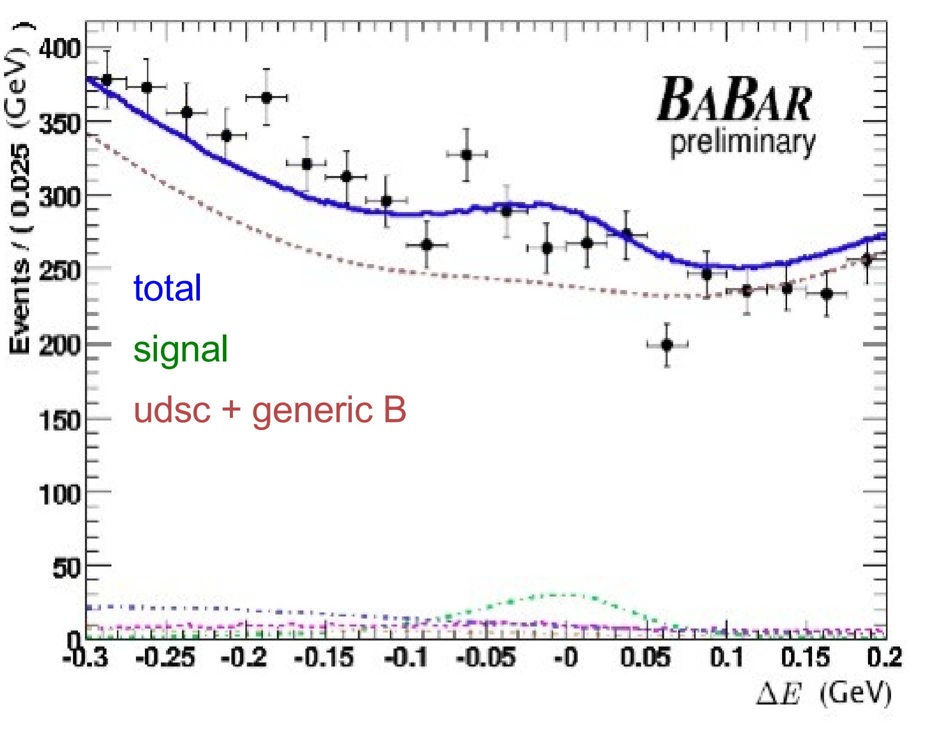
- Signal yield is extracted from a 2D Maximum Likelihood Fit to ΔE and m_{ES} distributions
- PDF shapes are optimised on signal and generic MC samples and then fit to data – blind analysis

Results

- Preliminary result for the 1.0-1.8GeV mass bin for $B \to X_d \gamma$ final states were presented at LP '07 (arXiv:0708.1652v1)

$$\sum_{i=1}^{7} Br(B \to X_d^i \gamma)_{1.0 < m_{X_d} < 1.8 GeV} = 3.1 \pm 0.9(stat.)^{+0.6}_{-0.5}(sys.) \pm 0.5(model) \times 10^{-6}$$





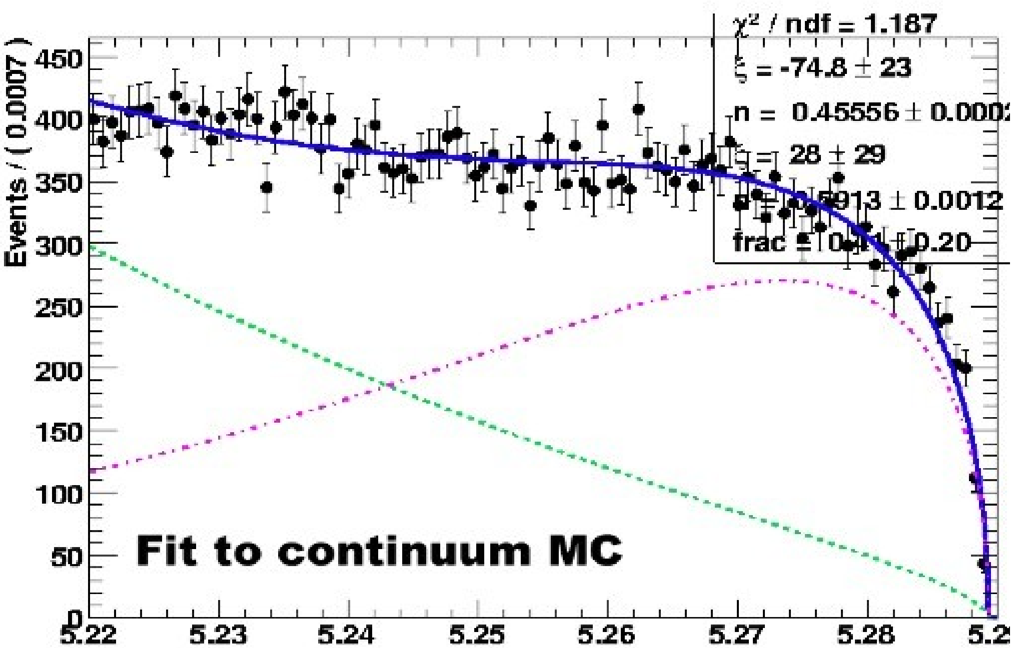
Summary and Future Work

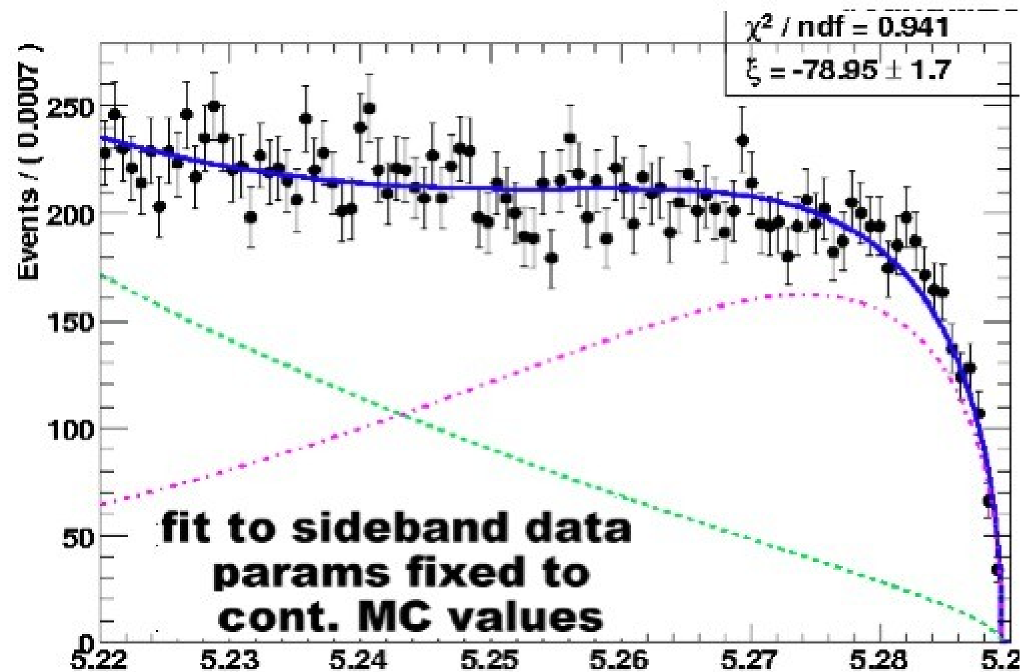
- LP result is first evidence for non-resonant hadronic $b \rightarrow d\gamma$ transitions
- Above results only uses 380M BB pairs, final round of analysis will move to the full dataset
- Analysis is re-blinded and parameterisation being re-optimised
  - Improved continuum PDF for m_{ES}
- Plan to increase hadronic mass upper limit to 2.2GeV
- Looking at possibility of including some $2\pi^0$ modes
  - $B^+ \rightarrow \pi^+\pi^0\pi^0\gamma$; $B^0 \rightarrow \pi^+\pi^-\pi^0\pi^0\gamma$
- Considering how to extrapolate measurement to fully inclusive value and obtain limit on $|V_{td}/V_{ts}|$

Backup Slides

Continuum Fit

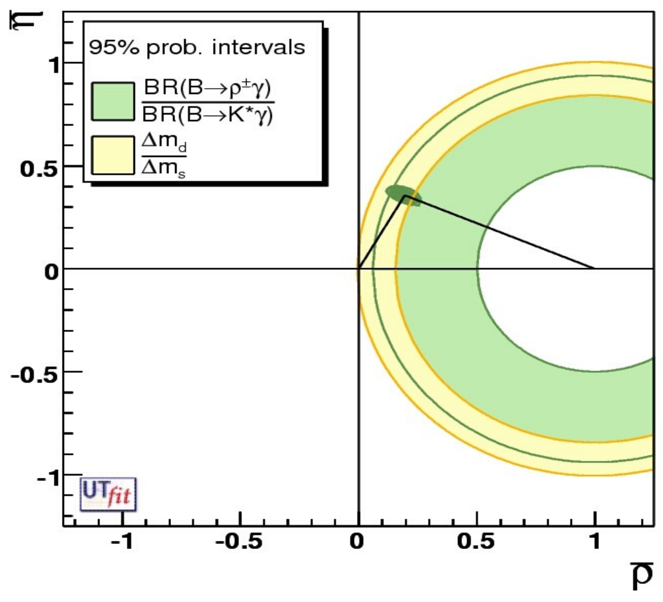
- LP result showed poor fit to the continuum background
- Now used a revised fit strategy – 2 argus for udsc instead of one
- udsc MC and data sidebands show how fit has improved

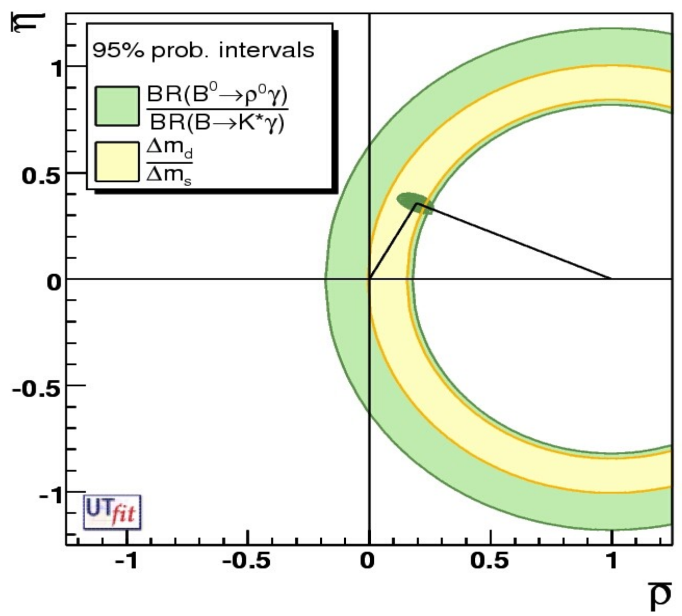




Motivation

- $|V_{td}/V_{ts}|$ can be extracted from the ratio of inclusive BFs
- Currently constrained by exclusive modes $B \to (\rho,\omega)\gamma$ $B \to K^*\gamma$ and neutral B mixing results





- In SM A_{cp} for $b \to d\gamma$ ~10% compared to ~1% in $b \to s\gamma$; any deviations due to new physics may be more evident in $b \to d\gamma$ A_{cp}

Event Selection

- Current analysis uses ~80% of total $\Upsilon(4S)$ dataset
- Initial skim rejects ~98% of total data by looking for events with
  - At least 1 neutral EMC deposit with $1.15 < E^* < 3.5$ GeV (* denotes $\Upsilon(4S)$ frame)
  - At least 2 reco tracks with $|p_T|>0.1$GeV, >11 DCH hits, (x,y) DOCA to IR <1.5cm, |DOCA(z)|<10cm
  - Ratio of 2nd FW moment to 0th <0.9 in $\Upsilon(4S)$ frame
- Remaining backgrounds
  - Continuum with HE photon (eg. ISR or π^0/η decay)
  - Generic B decays with HE photon from π^0/η decay

Candidate Reconstruction

- Quality cuts minimise combinatoric backgrounds
- High Energy Photon has energy $1.15<E^*<3.5$GeV in CM frame and EMC deposit >4 crystals
- π^0 (η) candidates constructed from photon pairs with invariant mass $117<m_{\gamma\gamma}<145$MeV ($470<m_{\gamma\gamma}<620$MeV) required to have $|p_{lab}|>0.3$GeV
- Tracks require $|p_{lab}|>0.3$GeV
  - X_d candidates all tracks must pass pion PID
  - X_s candidates one track must pass kaon PID and all others pass pion PID

Candidate Reconstruction

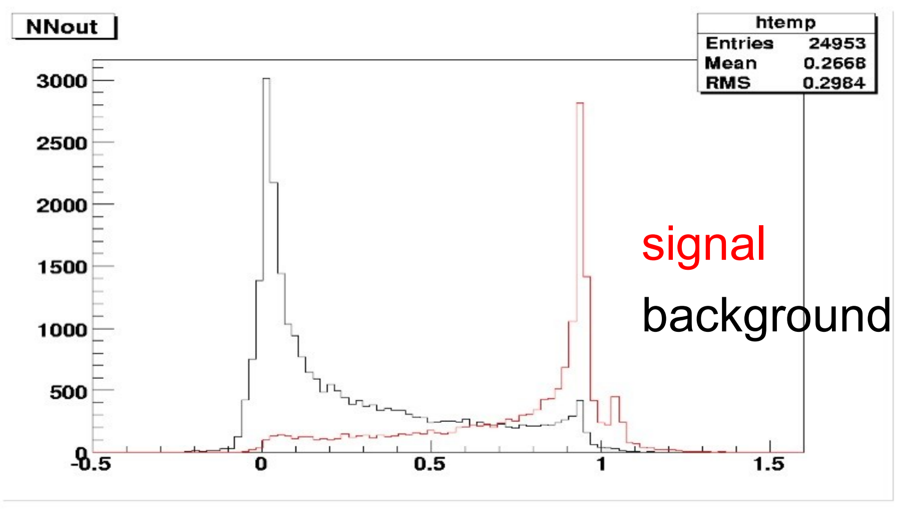
- X_d candidate required to have mass $0.6<M(X_d)<1.8$GeV
- B candidate cuts use common BaBar kinematic variables
  - $\Delta E = E_B^* - ½ \sqrt{s}$; peaks at 0 for signal
  - $m_{ES}=\sqrt{(¼s - |p_B^*|^2)}$; peaks at B mass for signal
- Require $|\Delta E|<0.3$GeV and $m_{ES}>5.22$GeV
- In events with multiple B candidates the candidate with the closest π^0/η mass to PDG is used
  - Candidates without neutral X_d daughter highest vertex χ^2 candidate chosen

Background Suppression

- Continuum background
  - Dominates for this analysis
  - Event shape variables can help reduce this
    - $\theta_B{}^*$ – B-meson production angle wrt beam axis (CM frame)
    - θ_T – Angle between photon and trust axis of ROE (ROE are all tracks and neutrals not used to reconstruct the B)
    - Legendre moments
  - Tag information from ROE
    - Lepton/Kaon content

Background Suppression

- Continuum background
  - To discriminate continuum from background MVA techniques widely used at BaBar
  - We use 12 event shape and tag variables and combine them in a NN with 2 hidden layers
  - NN is trained on MC to find optimum combination of variables which maximises $S/\sqrt{(S+B)}$
  - Cut >0.83 on NN output



Signal Efficiency

- Efficiency of cuts on signal X_d MC for 1.0-1.8GeV mass bin

Cut	Value	Efficiency	Cumulative
Mass Region	1.0-1.8GeV	100	100
γ 2^{nd} Moment	<0.002	98.9	98.9
γ No Crystals	>4	100	98.9
γ dist to nearest EMC deposit	>25cm	98.3	97.1
γ No dead/noisy EMC crystals	none	100	97.1
Vertex $\chi 2$ prob	>0.02	89	86.5
$\pi 0$ mass	117-145MeV	82	85.4
Track momentum	>0.3GeV	92.4	77.3
$\pi 0$ momentum	>0.3GeV	98.3	73.9
$\lvert\cos\theta_T\rvert$	<0.8	95	69.2
γ $\pi 0$ veto	105-155MeV	89.5	62.1
γ η veto	500-590MeV	94.7	58.9
pion PID	passes	81	43.7
NN output	>0.83	51.4	20.6
ΔE^*	-0.3-0.2GeV	89.2	16.3
mES	>5.22GeV	92.9	15.7

Measured quantity:

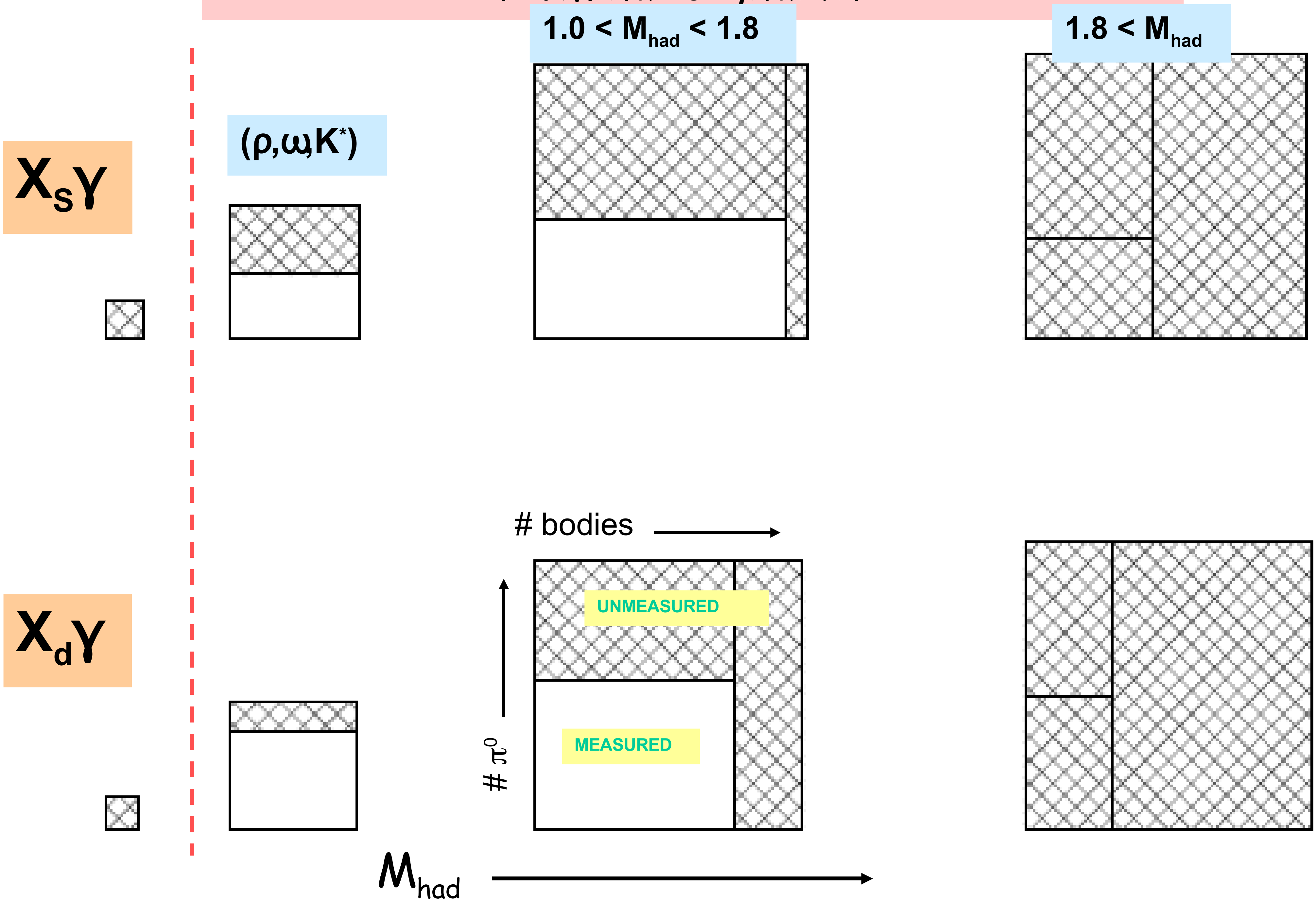
$$R_{obs} = \frac{\sum_{i=1}^{7} Br(B \to X_d^i \gamma)}{\sum_{i=1}^{7} Br(B \to X_s^i \gamma)}$$

Electroweak quantity

$$R_{EW} = \frac{\Gamma(b \to d\gamma)}{\Gamma(b \to s\gamma)} = \kappa \frac{\sum_{i=1}^{7} Br(B \to X_d^i \gamma)}{\sum_{i=1}^{7} Br(B \to X_s^i \gamma)}$$

How well can we determine κ ?

Breakdown of Measured/Unmeasured Width
Nominal Signal MC



Initial plans:

- $X_s\gamma$ fragmentation has been measured well, and correction factors derived. We can apply those correction factors to $X_d\gamma$ and see how *K* changes.

- Alternative $X_s\gamma$ model based on $R_S\,\gamma$ for ~10 resonances developed; simulate corresponding $R_d\gamma$ and see how *K* changes.