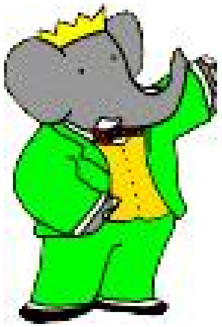

# $B \to X_s \gamma$ at BaBar

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*CERN/Royal Holloway*

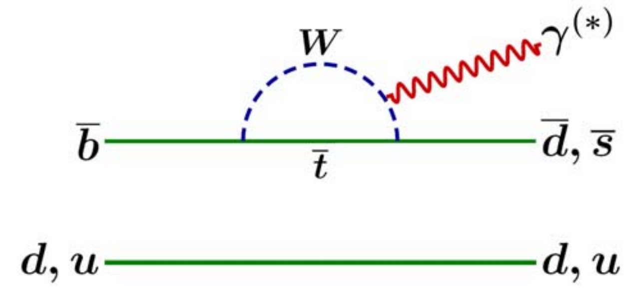
*for the BaBar Collaboration*


19 July 2007

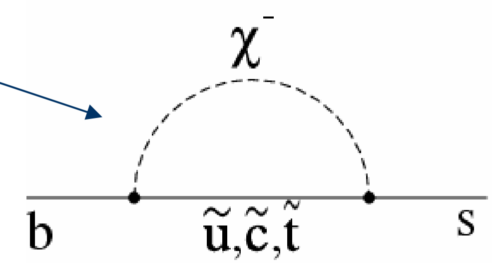
EPS Manchester

# The radiative decay $b \to s\gamma$

- $b \to s\gamma$ transition is a FCNC
- only occurs at loop level in SM
- Possibility of non-SM particles entering in the loop



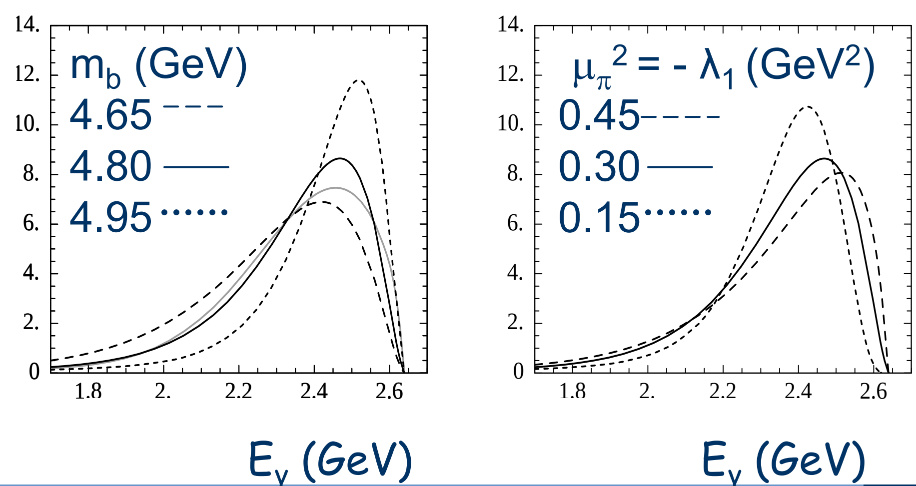

`radiative penguin'




BF measurement can constrain parameter space for many SUSY models
→ interesting in light of LHC

## The photon energy spectrum:

- sensitive to HQ parameters
- $m_b \sim E_\gamma/2$
- $\mu_\pi^2 \sim \langle E^2 - \langle E\rangle^2\rangle$
- quark mass interesting as SM parameter
- knowledge of HQ parameters important input to $|V_{ub}|$



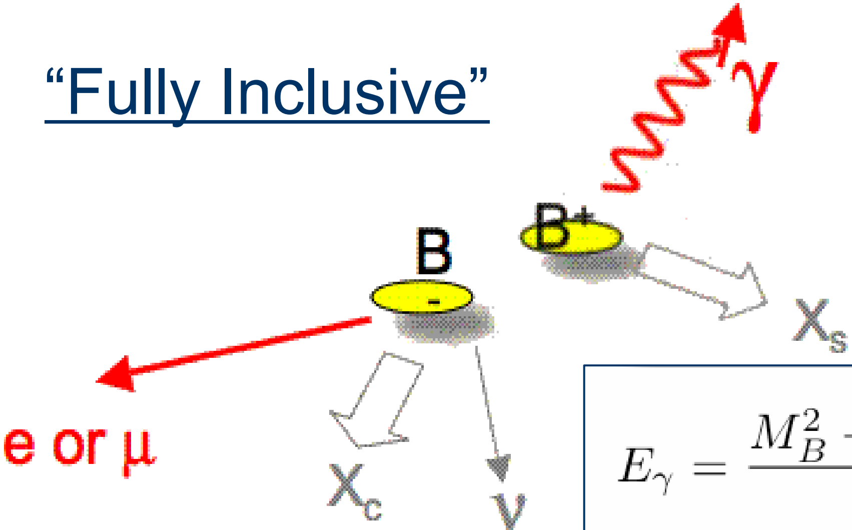

Eur.Phys.J.C7:5-27,1999

# Theoretical Predictions

- 3 NNLO calculations for Branching Fraction appeared in late 2006:
  - Misiak et al. hep-ph/0609232
    - **$BF(B \to X_s\gamma) = (3.15 \pm 0.23)\ 10^{-4}$ for $E_\gamma > 1.6$ GeV**
    - dedicated error analysis resulting in 7% error
  - Becher et al. hep-ph/0610067
    - **$BF(B \to X_s\gamma) = (2.98 \pm 0.26)\ 10^{-4}$ for $E_\gamma > 1.6$ GeV**
    - larger perturbative uncertainty resulting in 9% error
  - Andersen et al. hep-ph/0609250
    - **$BF(B \to X_s\gamma) = (3.47 \pm 0.48)\ 10^{-4}$ for $E_\gamma > 1.6$ GeV**
    - 11% uncertainty from variation of renormalisation scale
- Compare with:
  - NLO calculations:
    - **$(3.3\text{-}3.6) \times 10^{-4}$** with ~10% uncertainty
  - Experimental HFAG average:
    - **$(3.55 \pm 0.26) \times 10^{-4}$** 7% uncertainty

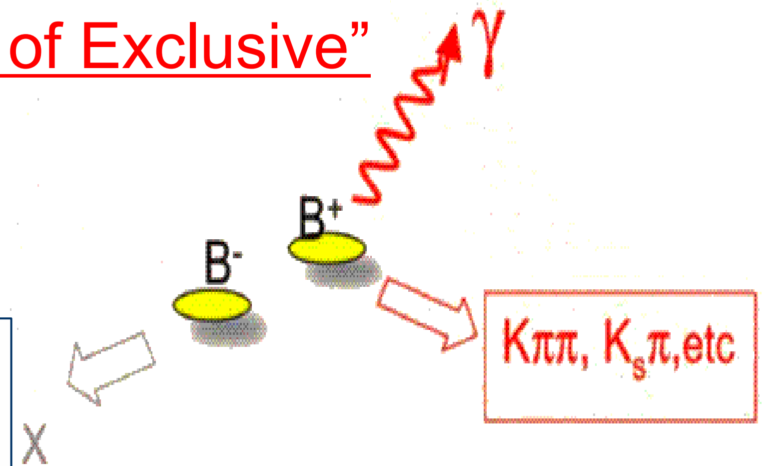
# Experimental Strategies for $B \to X_s\gamma$

## "Fully Inclusive"




$$E_\gamma = \frac{M_B^2 - M(X_s)^2}{2M_B}.$$

## "Sum of Exclusive"

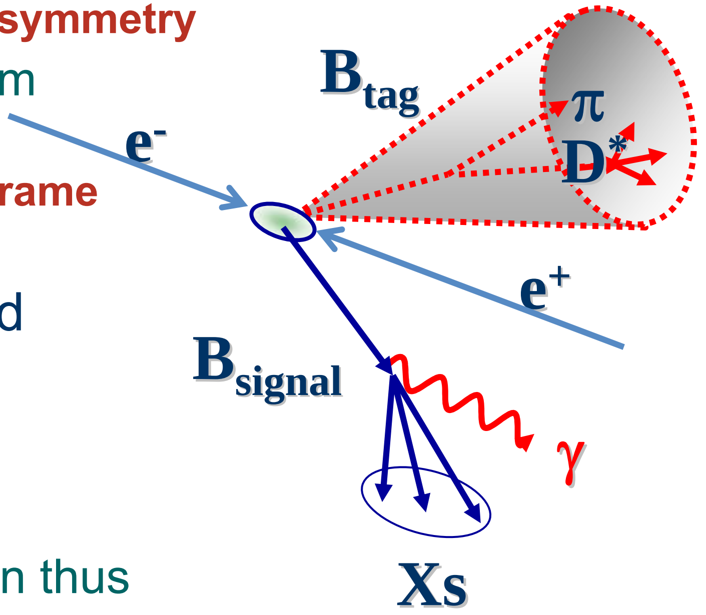



- Ignore $X_s$ system
- Reconstruct only the $\gamma$
- Pros
  - No $X_s$ fragmentation sensitivity
  - theoretically clean
- Cons
  - High background
  - Measure $E_\gamma$* in Y(4S) frame

- Fully reconstruct subset of $X_s$ final states
- Pros
  - Lower background
  - Good $E_\gamma$ resolution in B-frame
- Cons
  - $X_s$ fragmentation systematic
  - Missing $X_s$ decay modes

# New Approach: Full reconstruction tag

- Hadronic decay of one B meson is fully reconstructed
  - 4-momentum, charge and flavour determined
    - **Enables measurement of Isospin and CP Asymmetry**
  - With 4-momentum of Υ(4S), also 4-momentum of decaying B is known
    - **Photon energy can be measured in B rest frame**




- Signal and BB background yields determined from fit to $M_{ES}$ in bins of photon energy

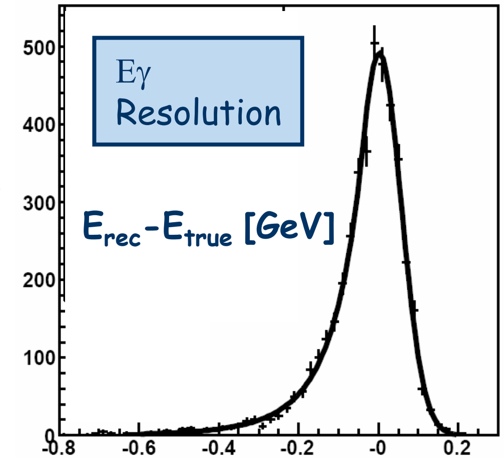
$$m_{ES} = \sqrt{(E^*_{beam})^2 - P^2_{B_{reco}}}$$

  - Continuum events do not peak in $M_{ES}$ and can thus be subtracted
  - Normalisation for branching fraction is determined from number of Bs in full reconstruction sample
  - Small efficiency extrapolation

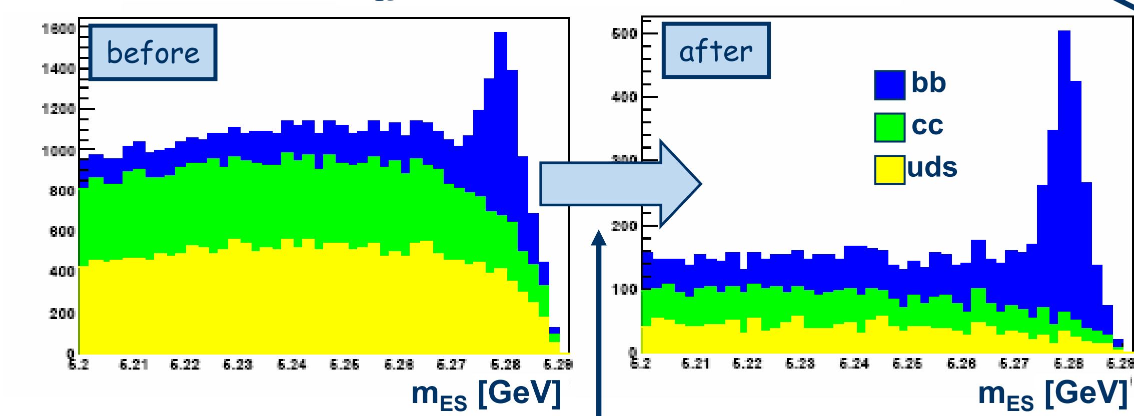
- Disadvantage: small B reconstruction efficiency of ~0.3%

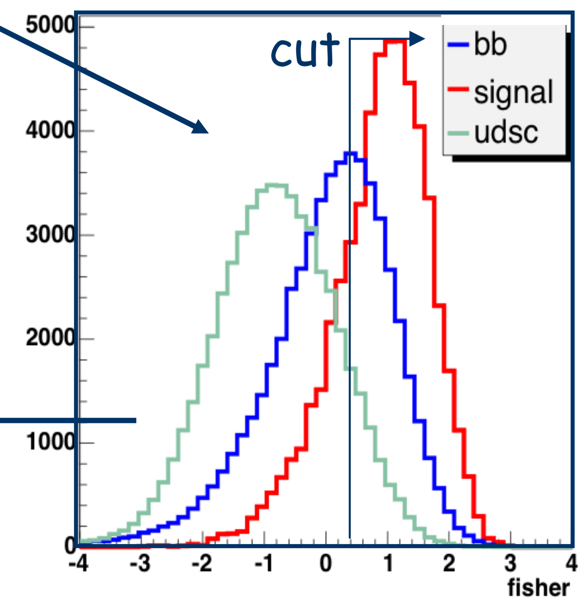
# Event Selection

- $B_{reco}$ sample: well-measured $B \to D^{(*)}X$ decays
  (X: relevant combinations of $\pi^\pm, \pi^0, K^\pm, K_S^0$ with $|\Sigma q|=1$)
- Select well-reconstructed high-energy photons
  ($E_\gamma > 1.3$GeV in the $B_{signal}$ rest frame)
- Veto photons compatible with $\pi^0$, $\eta$, $\rho$ decays
- Suppress continuum using Fisher discriminant
  (12 inputs, mostly based on event shape)




$m_{ES}$ distribution (from MC simulation)




- Selection optimized to maximize $S^2/(S+B)$
- Remaining background mainly from $\pi^0$ and $\eta$

# $B \to X_s\gamma$ : $m_{ES}$ Fits

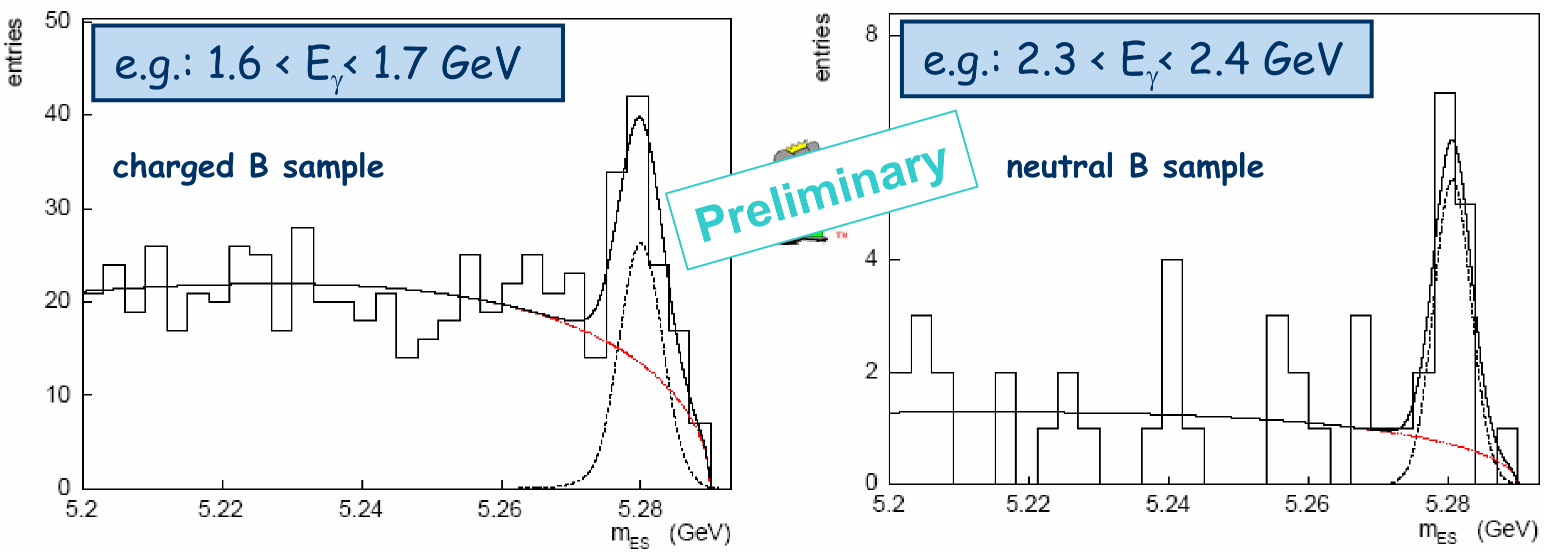
- Determine Partial Branching Fraction in bins of photon energy:

$$\frac{1}{\Gamma_B}\frac{d\Gamma_i}{dE_\gamma} = \frac{N_i^{Data} - N_i^{BG}}{\varepsilon_i^{sig} \cdot c^{\mathrm{tag}} \cdot N^{B_{reco}}}$$

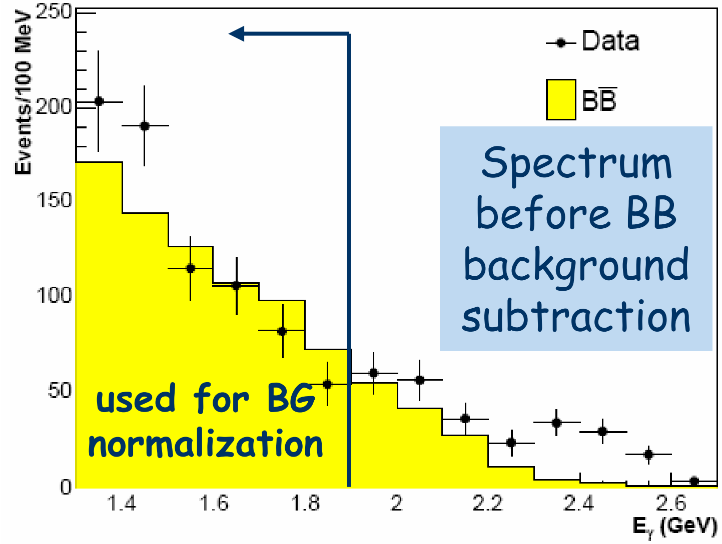
Selection efficiency, also correcting for resolution

Correction factor accounting for $B \to X_s\gamma$ final state affecting the probability to find a tag B.

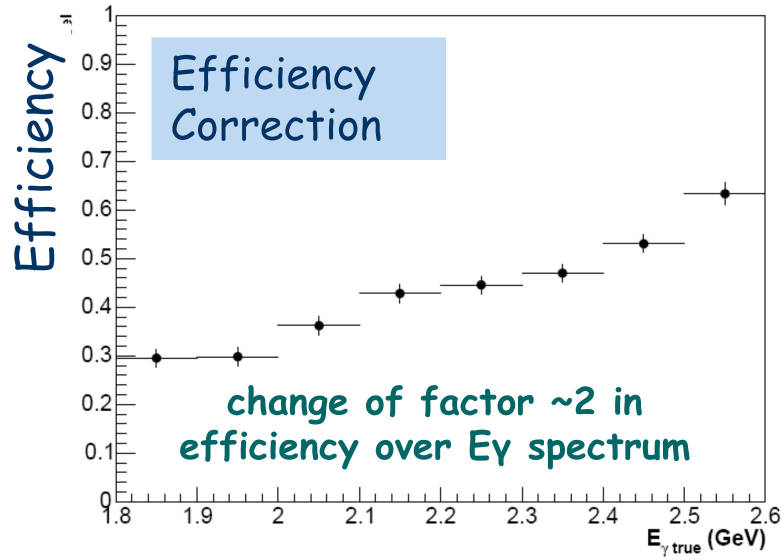
- All numbers determined from fits to $m_{ES}$

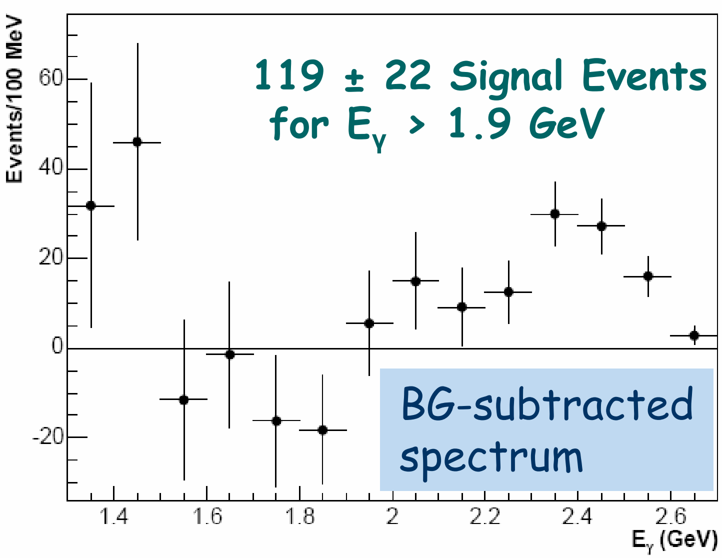


# $B \rightarrow X_s \gamma$ : $E_\gamma$ Spectrum



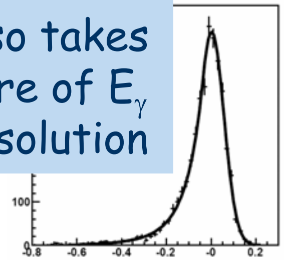

Preliminary

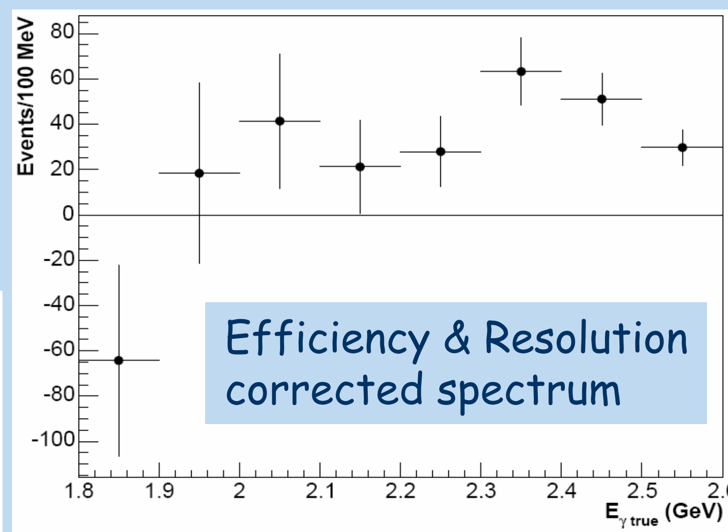



efficiency correction

also takes care of $E_\gamma$ resolution

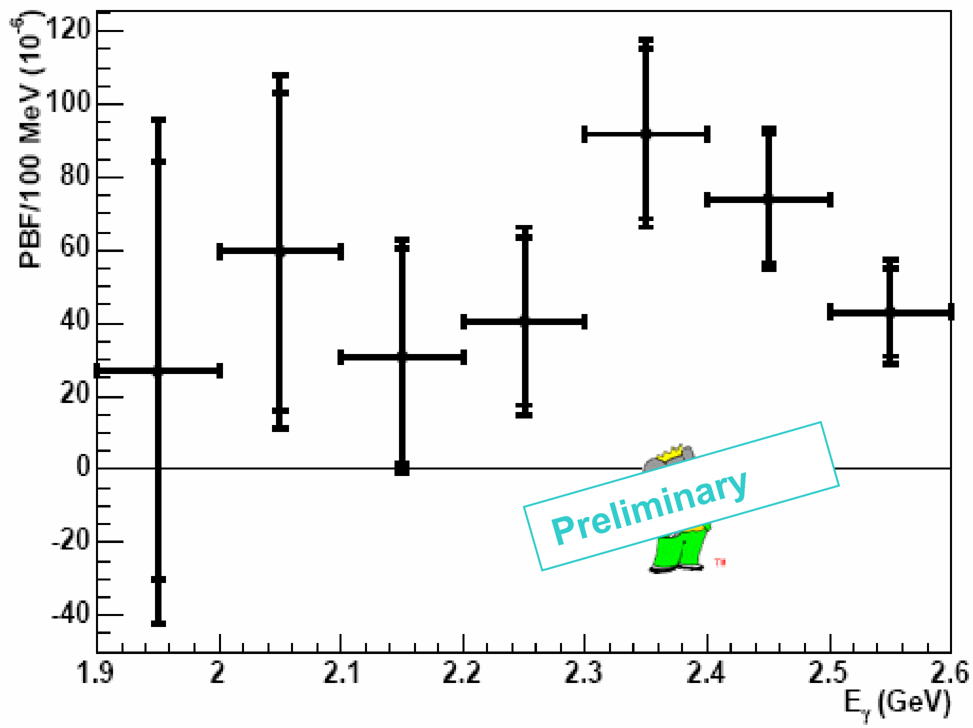




# $B \to X_s\gamma$ : Partial Branching Fractions

## Partial Branching Fractions:

- Statistical errors dominant
- main systematic errors will get reduced with larger dataset and higher statistics control samples




## Integrated Branching Fraction above $E_{cut}$:

| $E_{cut}$ (GeV) | $BF[E_\gamma > E_{cut}]/10^{-6}$ Value | $\sigma_{stat}$ | $\sigma_{syst}$ |
|---|---|---|---|
| 1.9 | 366 | ± 85 | ± 59 |
| 2.0 | 339 | ± 64 | ± 47 |
| 2.1 | 278 | ± 48 | ± 34 |
| 2.2 | 248 | ± 38 | ± 26 |
| 2.3 | 207 | ± 30 | ± 19 |

## Dominant Systematic Errors:

- **Mes Fit Parameterisation 12%**
- **BB Background Modelling 10%**
- **Detector Response 4%**

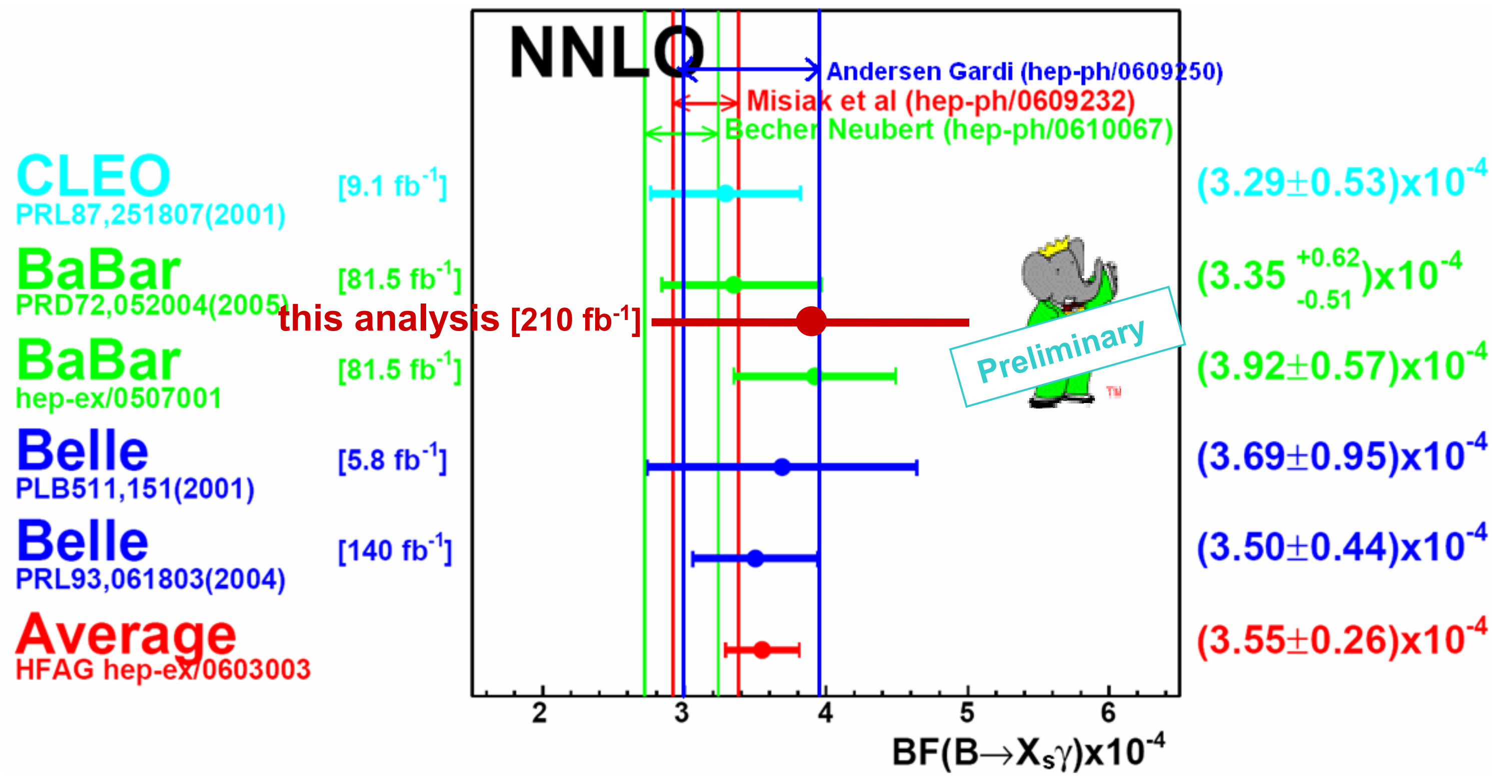
# $B \rightarrow X_s\gamma$ : Branching Fractions

Measured:

$BF(B \rightarrow X_s\gamma)\ [E_\gamma > 1.9\ \text{GeV}] = (3.66 \pm 0.85 \pm 0.59) \times 10^{-4}$

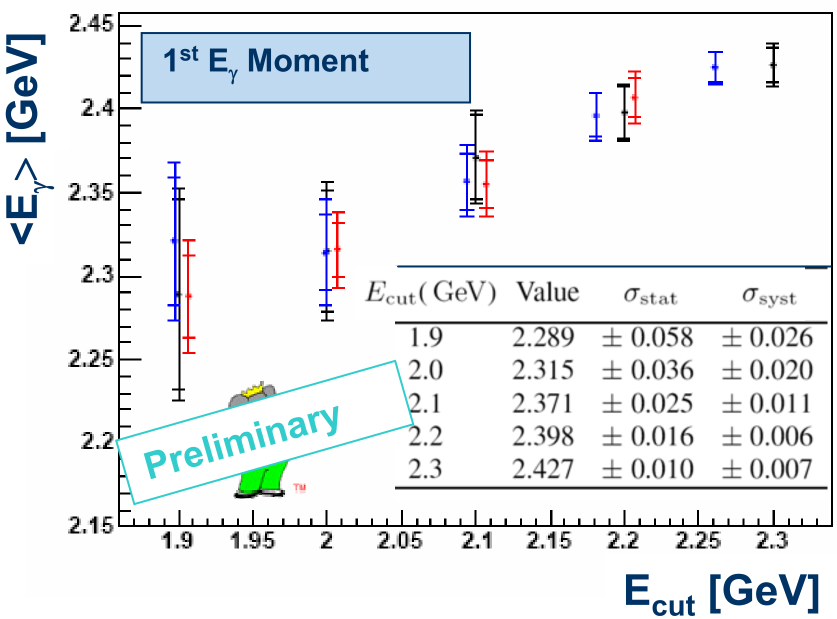
Extrapolated:
(using PRD 73,073008(2006))

$BF(B \rightarrow X_s\gamma)\ [E_\gamma > 1.6\ \text{GeV}] = (3.91 \pm 0.91 \pm 0.63) \times 10^{-4}$

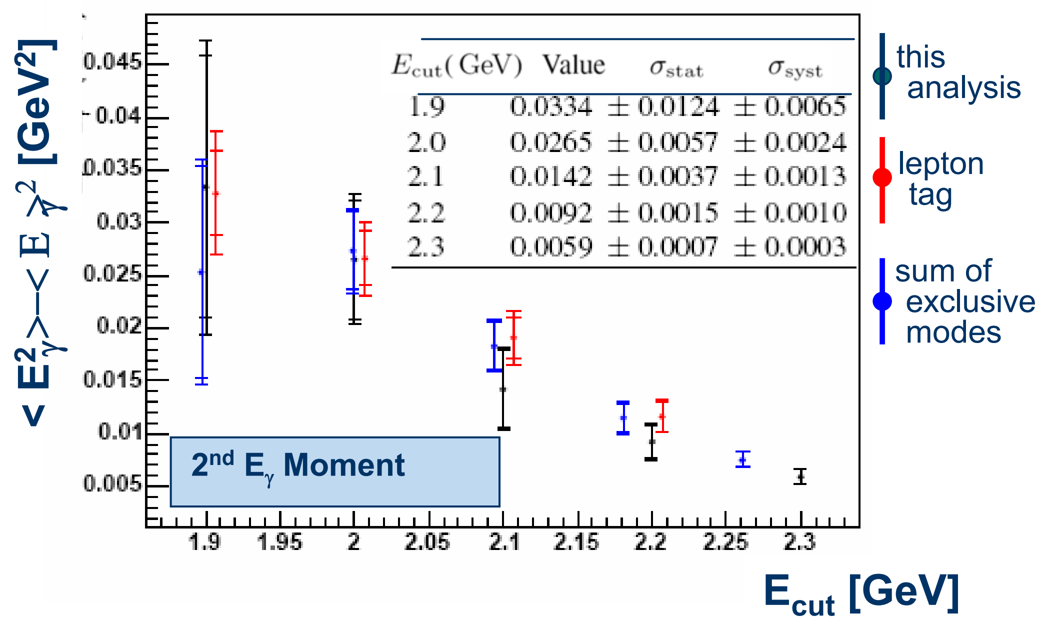


# $B \to X_s\gamma$ : $E_\gamma$ Moments

- Measurement of photon energy moments as a function of minimum energy
- Good agreement with previous results based on different methods and independent data samples




| $E_{cut}$(GeV) | Value | $\sigma_{stat}$ | $\sigma_{syst}$ |
|---|---|---|---|
| 1.9 | 2.289 | ± 0.058 | ± 0.026 |
| 2.0 | 2.315 | ± 0.036 | ± 0.020 |
| 2.1 | 2.371 | ± 0.025 | ± 0.011 |
| 2.2 | 2.398 | ± 0.016 | ± 0.006 |
| 2.3 | 2.427 | ± 0.010 | ± 0.007 |




| $E_{cut}$(GeV) | Value | $\sigma_{stat}$ | $\sigma_{syst}$ |
|---|---|---|---|
| 1.9 | 0.0334 | ± 0.0124 | ± 0.0065 |
| 2.0 | 0.0265 | ± 0.0057 | ± 0.0024 |
| 2.1 | 0.0142 | ± 0.0037 | ± 0.0013 |
| 2.2 | 0.0092 | ± 0.0015 | ± 0.0010 |
| 2.3 | 0.0059 | ± 0.0007 | ± 0.0003 |

Still to come:

- Isopin and CP asymmetries
- Use moments for HQ parameter extraction / combine with other measurement

# Conclusions

- Recent progress in studying $B \rightarrow X_s \gamma$ from both theory and experiment
  - very good agreement between different experimental approaches
- New measurement of $B \rightarrow X_s \gamma$ photon energy spectrum using hadronic B tag
  - photon spectrum is measured in B rest frame

$$BF(B \rightarrow X_s \gamma)\ [E_\gamma > 1.9\ GeV] = (3.66 \pm 0.85 \pm 0.59) \times 10^{-4}$$

    - still statistically limited ~23%
    - systematic uncertainties will be reduced with larger data sample!

  - Method will be used to measure Isospin and CP asymmetries
  - Complimentary to lepton tagged and semi-inclusive analysis

- full benefit of method to be exploited with full dataset!

# BACKUP

# Comparison of Exp. Methods

- Inclusive full reconstruction tag
  - 119 ± 22 signal events
  - stat. uncertainty ~23% with 210 $fb^{-1}$
  - $M_{es}$ fit parameterisation ~ 12%
  - BB Background ~9%

Will be reduced with improved statistics

- Inclusive lepton tag
  - 758 ± 66 signal events
  - stat. uncertainty 8% with 81$fb^{-1}$
  - model dependence ~8%
  - BB background ~6%

Can be reduced with improved statistics

- Sum of exclusive modes
  - 1513 ± 85 signal events
  - stat. uncertainty 6% with 81$fb^{-1}$
  - missing fraction of $X_s$ modes ~10%
  - fragmentation of $X_s$ ~6%

difficult to improve on more data helps