Inclusive $B \to X_s \gamma$ Decays

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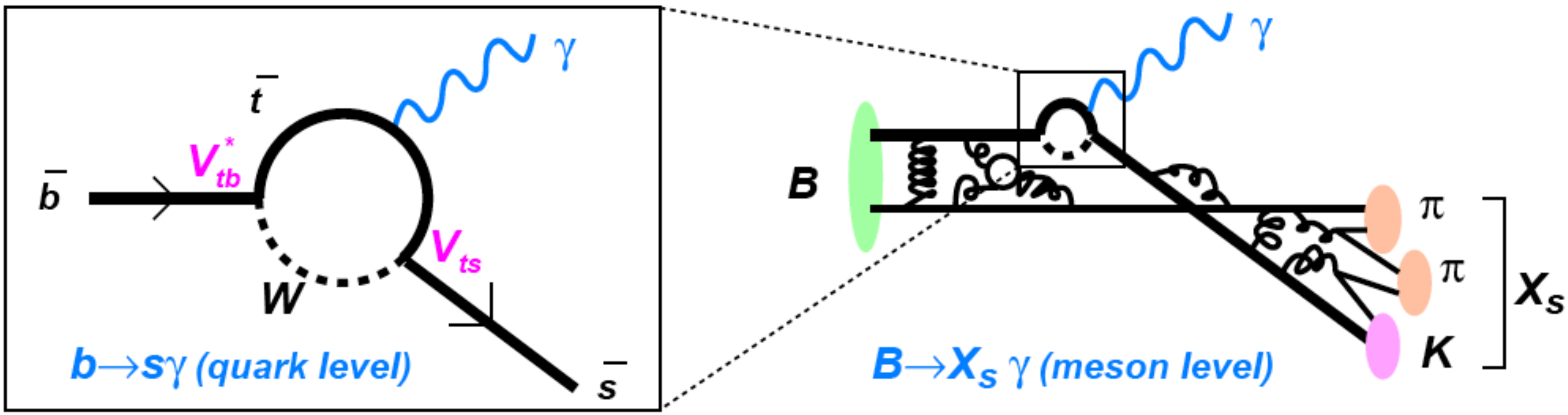
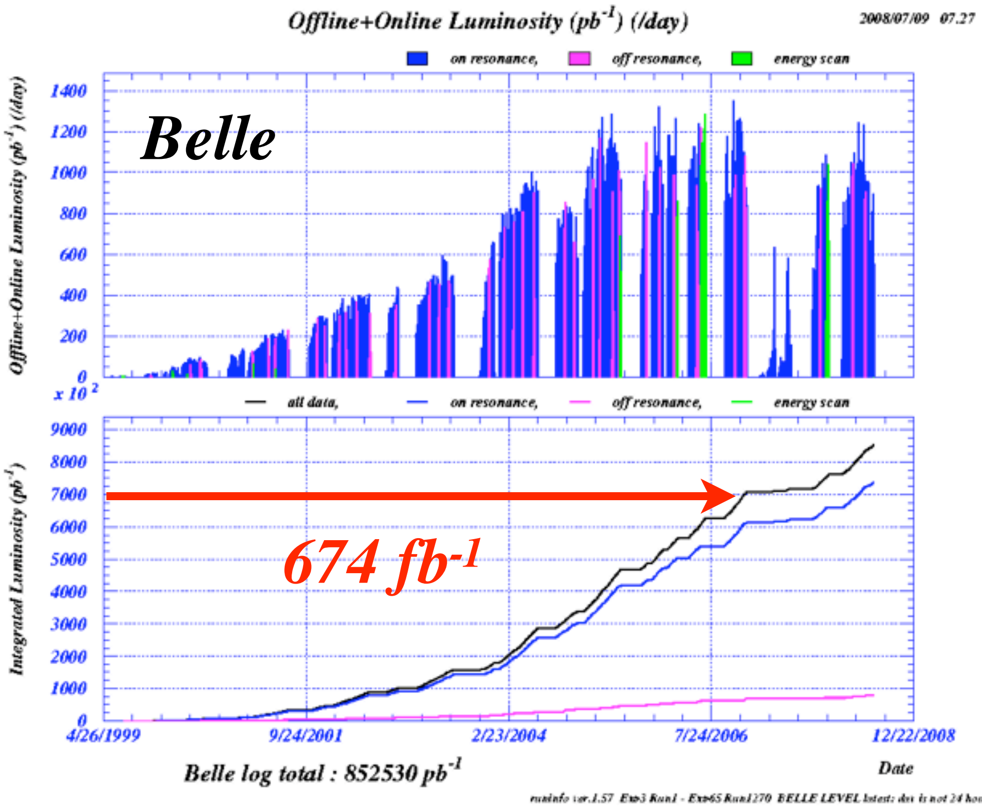
Motivation

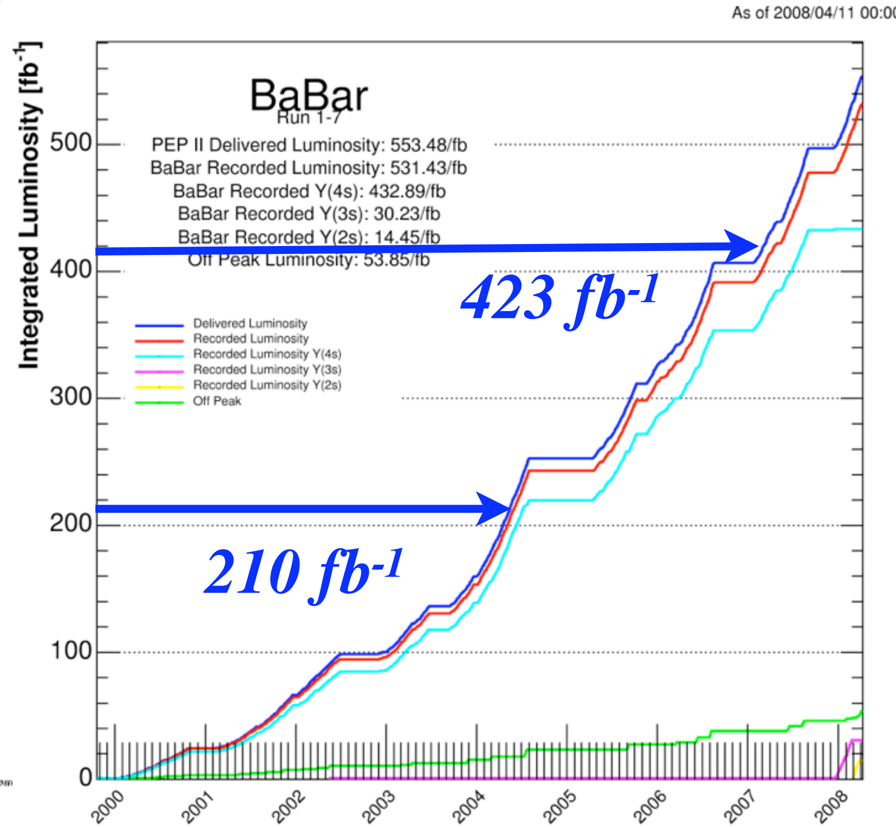


◉ Total Decay rate and CP Asymmetry : Probe for the New Physics e.g. charged Higgs, SUSY, LR models

◉ Differential Decay rate : Photon as a messenger of the dynamics of the b-quark properties e.g mass needed for V_{ub} and V_{cb}

Data set for new measurements





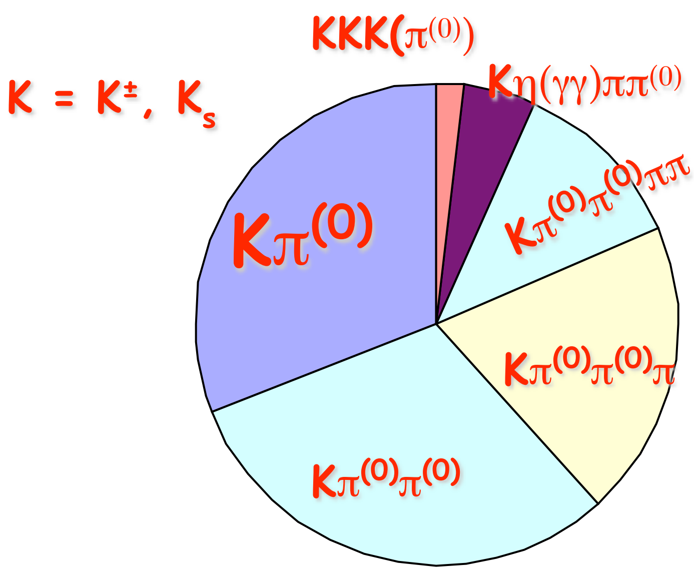
Time integrated CP Asymmetry

$$A_{CP} = \frac{\Gamma(\bar{B} \to \bar{X}_s\gamma) - \Gamma(B \to X_s\gamma)}{\Gamma(\bar{B} \to \bar{X}_s\gamma) + \Gamma(B \to X_s\gamma)}$$

- A_{CP} < 1% due to CKM & GIM suppression in SM
- Models with non-minimal Flavor violation (e.g SUSY) A_{CP} ~10%-15%

Wolfenstein & Wu PRL73 2809(1994)
Asatrian & Ioannisian PRD54, 5642 (1996)
Ciuchini, Gabrielli, Giudice PLB388 353 1996
Kagan and Neubert PRD 98 094012

Reconstructed Final States



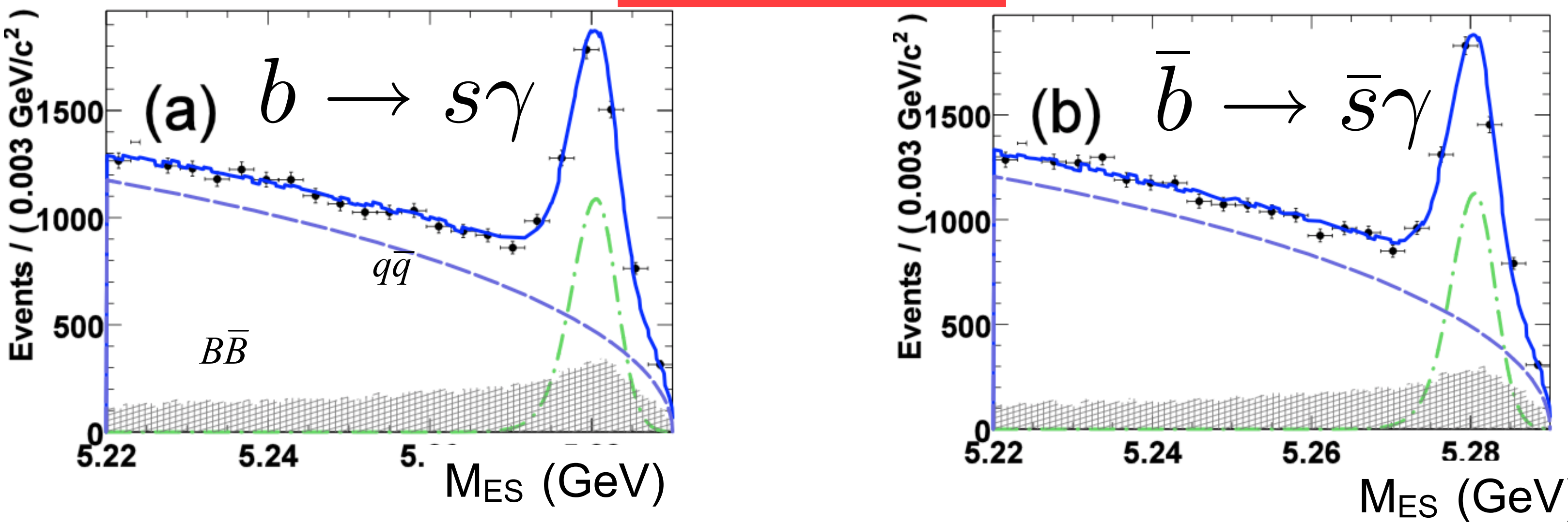
Exclusively Reconstruct 16 final states of X_s :

Covers ~55% of possible Xs states

Self-tagging

Results@423 fb^{-1}

arXiv:0805.4796 preliminary



Detector asymmetry A_{det}=-0.007±0.005

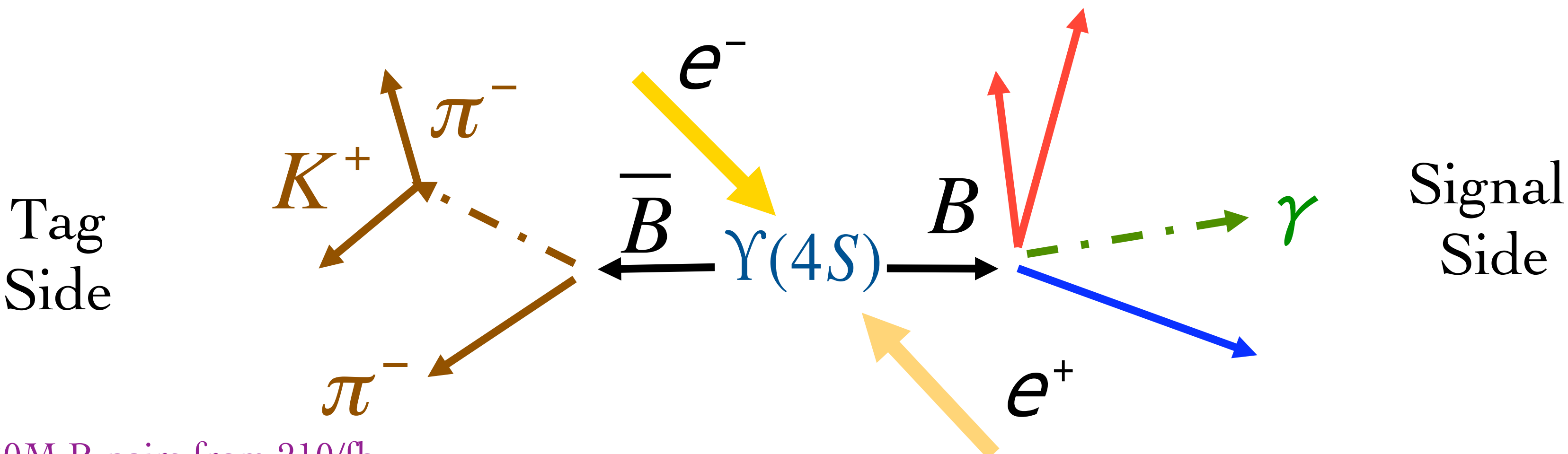
$$A_{CP} = -0.011 \pm \underbrace{0.030}_{\text{stat}} \pm \underbrace{0.014}_{\text{sys}}$$

$$0.6 < M_{X_s}/(\mathrm{GeV}/c^2) < 2.8$$

Most precise measurement to date of $A_{CP}(B \to X_s\gamma)$. Consistent with no CPV

B-recoil Method

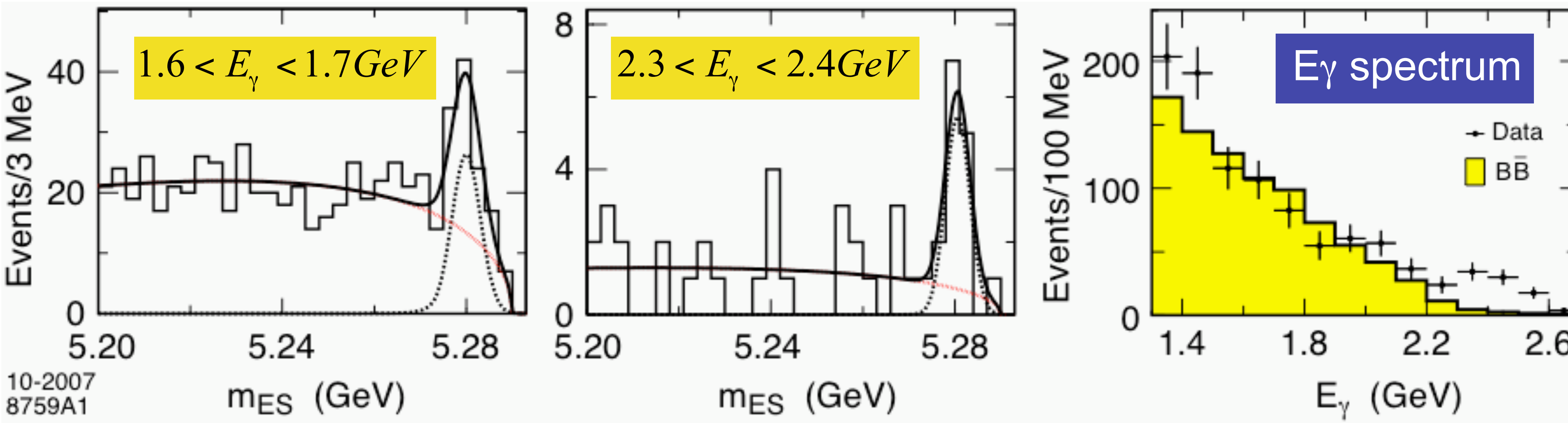
- Tag B is fully reconstructed in a hadronic mode
- Search for an isolated photon from the rest of the event



680M B-pairs from 210/fb
1114 modes ~about 5% of the total width of B decays

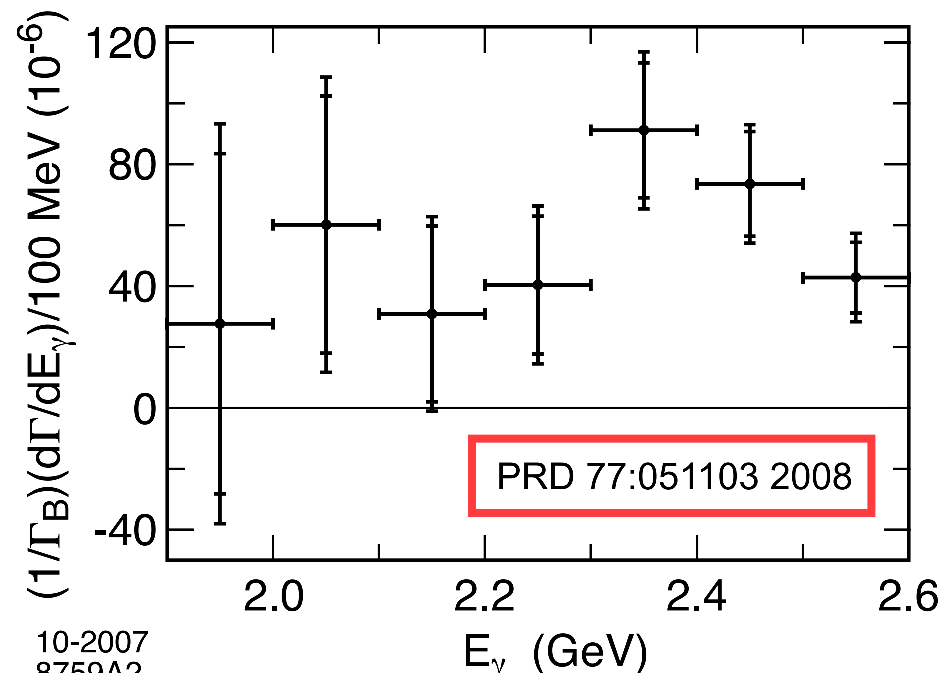
- Advantages
  - Rest frame of the B, negligible continuum background
  - Access to B flavour, charge and momentum
- Disadvantages
  - Low efficiency for fully reconstructing B (~0.3%)

Photon Spectrum



$$\frac{1}{\Gamma_B}\frac{d\Gamma_i}{dE_\gamma} = \frac{N_i - b_i}{\varepsilon_i N_B}$$

$$\varepsilon_i = \frac{N_{\mathrm{found},i}/N_{\mathrm{sim}}}{N_{\mathrm{true},i}/N_{\mathrm{gen}}} C_{\mathrm{tag}}$$



Results@210 fb^{-1}

$$\mathcal{B}(B \to X_s\gamma, E_\gamma > 1.9\,\mathrm{GeV}) = (3.66 \pm \underbrace{0.85}_{\text{stat}} \pm \underbrace{0.60}_{\text{sys}}) \times 10^{-4}$$

$$\langle E_\gamma \rangle|_{E_\gamma > 1.9\,\mathrm{GeV}} = 2.289 \pm 0.058 \pm 0.027\,\mathrm{GeV}$$

$$\left(\langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2\right)|_{E_\gamma > 1.9\,\mathrm{GeV}} = 0.0334 \pm 0.0124 \pm 0.0062\,\mathrm{GeV}^2$$

$$\begin{aligned}\Delta_{0-} &= \frac{\Gamma(\overline{B}^0 \to X_{s,d}\gamma) - \Gamma(B^- \to X_{s,d}\gamma)}{\Gamma(\overline{B}^0 \to X_{s,d}\gamma) + \Gamma(B^- \to X_{s,d}\gamma)} \\ &= -0.06 \pm 0.15_{\text{stat}} \pm 0.07_{\text{stat}}\end{aligned}$$

$$E_\gamma > 2.2\,\mathrm{GeV}$$

$$A_{CP} = 0.10 \pm 0.18_{\text{stat}} \pm 0.05_{\text{stat}}$$

$$m_b = 4.46^{+0.21}_{-0.23}\,\mathrm{GeV}/c^2$$

$$\mu_\pi^2 = 0.64^{+0.39}_{-0.38}\mathrm{GeV}^2/c^2$$

- Consistent with previous measurements and the SM prediction
- First look at the future : expect more from Super-B factory
- Both statistical and systematic uncertainties to decrease with more statistics

Fully Inclusive

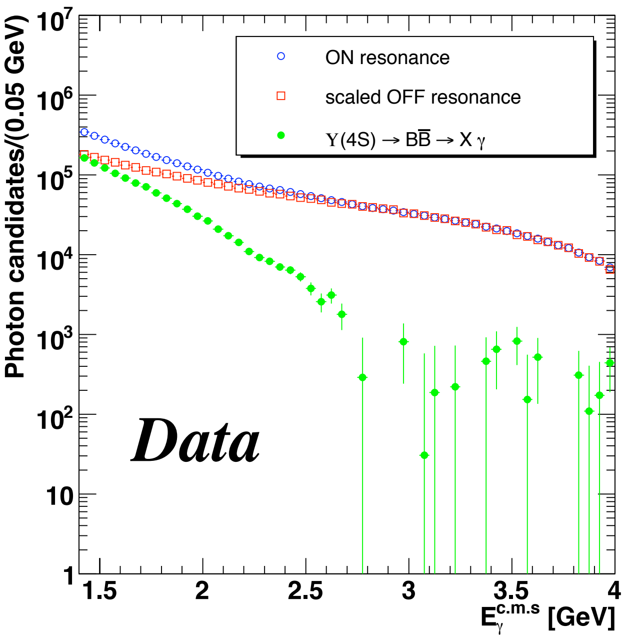
Find isolated clusters in the EM calorimeter

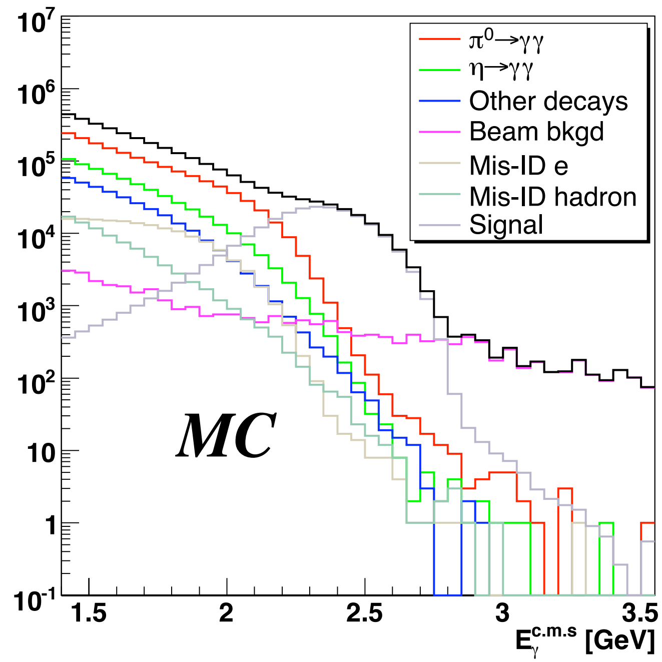
High energy E(c.m.s) > 1.4 GeV

Veto γ from π, η & Bhabha and use event topology to suppress continuum

Estimate continuum using OFF resonance data

Estimate B decays using "corrected" MC sample : Measure B→X (η/π^0)





Continuum Subtraction

$$N^{B\bar{B}}(E_\gamma^{\text{c.m.s.(ON)}}) = N^{\text{ON}}(E_\gamma^{\text{c.m.s.(ON)}}) - \alpha \cdot \beta \cdot \gamma \cdot F_N \cdot N^{\text{OFF}}(F_E E_\gamma^{\text{c.m.s.(OFF)}})$$

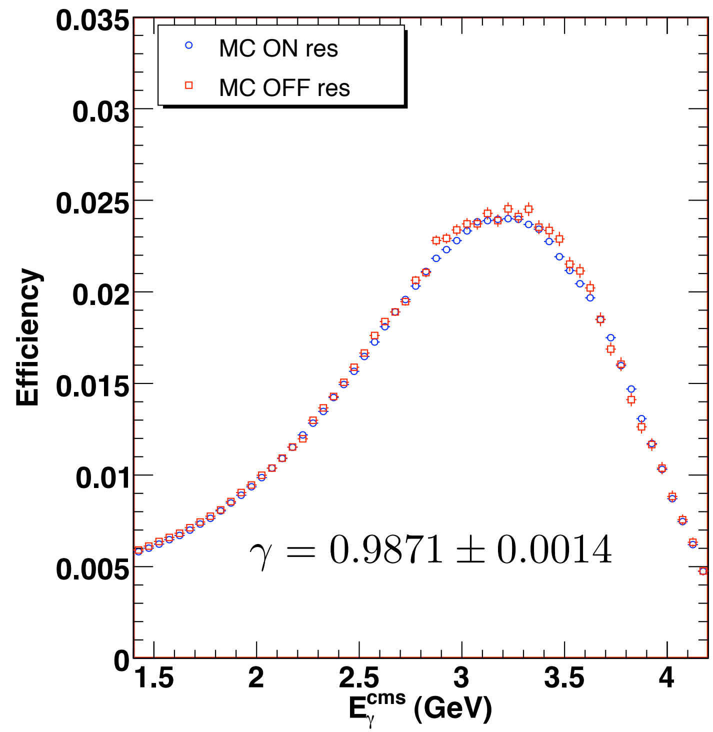
$$\alpha = \frac{\int \mathcal{L}_{\text{ON}} dt}{\int \mathcal{L}_{\text{OFF}} dt} \cdot \frac{s_{\text{OFF}}}{s_{\text{ON}}}$$

$$\beta = \frac{\epsilon^{\text{ON}}_{\text{Hadronic}}}{\epsilon^{\text{OFF}}_{\text{Hadronic}}}$$

$$\gamma = \frac{\epsilon^{\text{ON}}_{B \to X_s \gamma}}{\epsilon^{\text{OFF}}_{B \to X_s \gamma}}$$

$$\alpha = 8.7557(\pm 0.3\%)$$

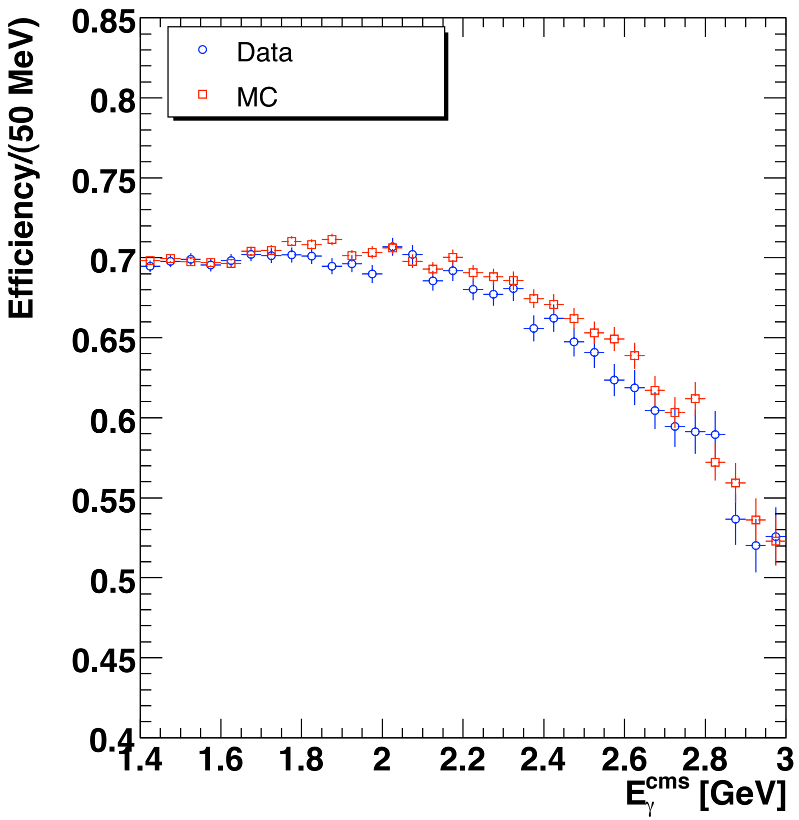
$$\beta = 0.9986 \pm 0.0001$$

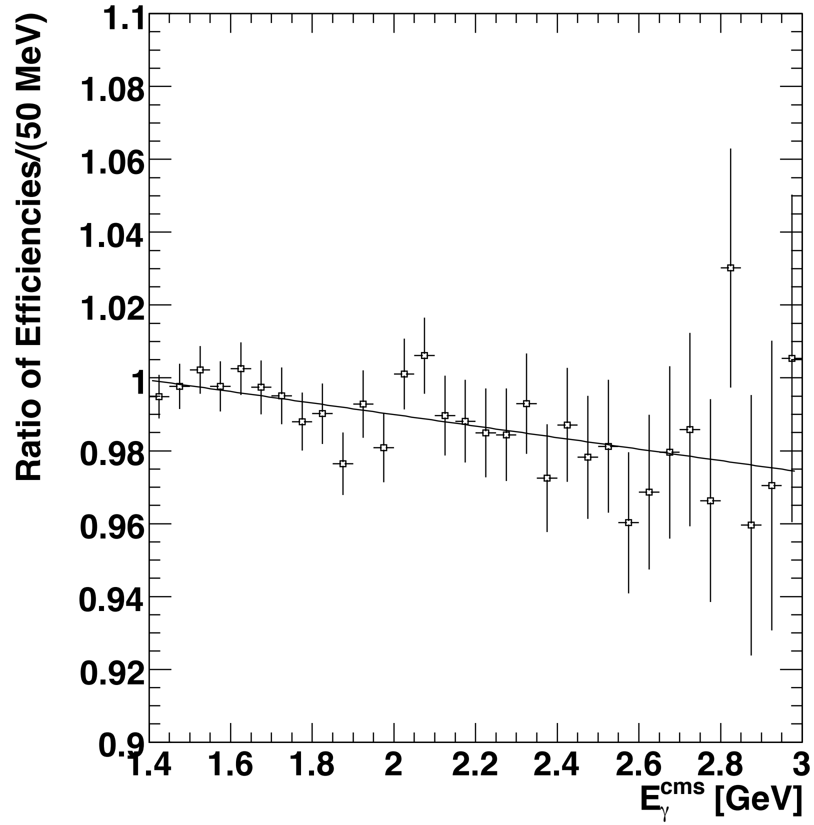


F_N= 1.0009 accounts for the difference in photon multiplicity
F_E= 1.0036 " " in photon mean energy

Efficiency Corrections

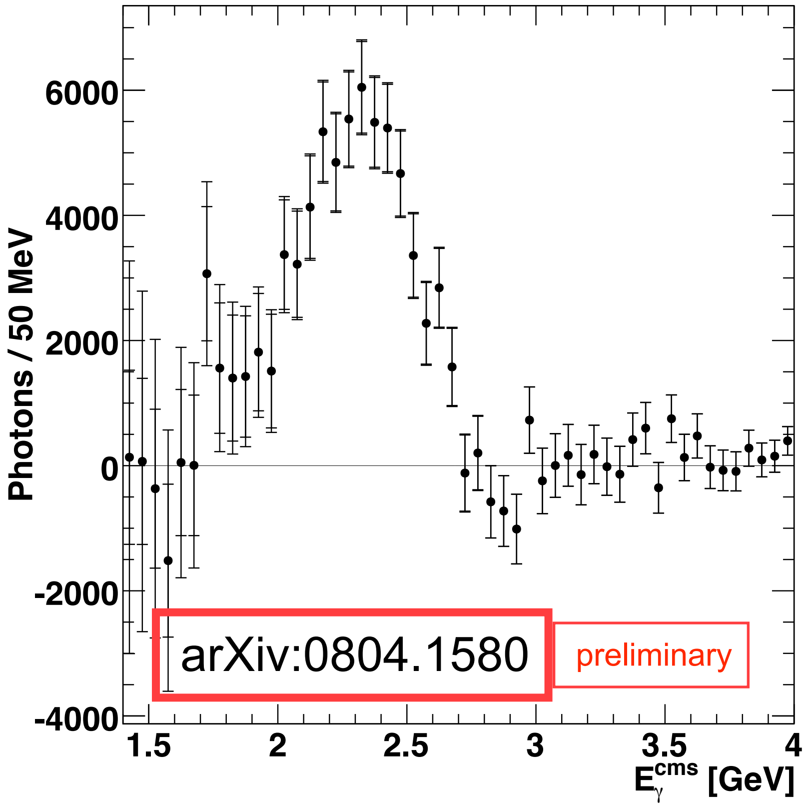
Get selection efficiency in MC and data in control samples
e.g the π^0 Veto efficiency in a sample of partially reconstructed $D^* \to D \to K\pi\pi^0,\ \pi^0 \to \gamma(\gamma)$





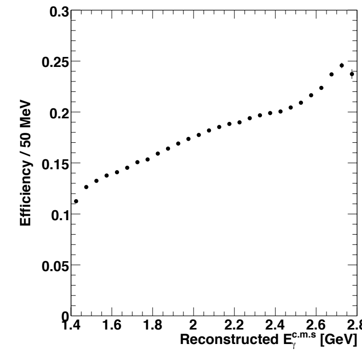
All selection criteria are investigated in a similar fashion

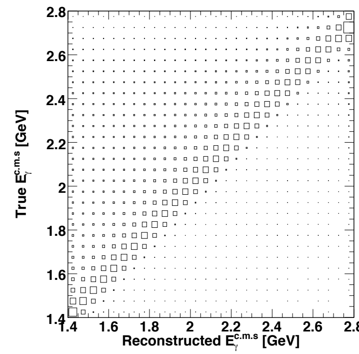
Photon Energy Spectrum



Step One.
Selection Efficiency

$$R(E_\gamma^{\rm meas}) = \frac{N_{\rm Rec}}{\eta_{\rm sel}}$$



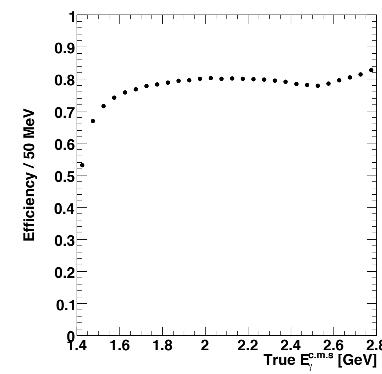


Step Two.
Unfold (SVD)

$$M(E_\gamma^{\rm true}) = A^{-1} R(E_\gamma^{\rm meas})$$

Step Three.
Detection Efficiency

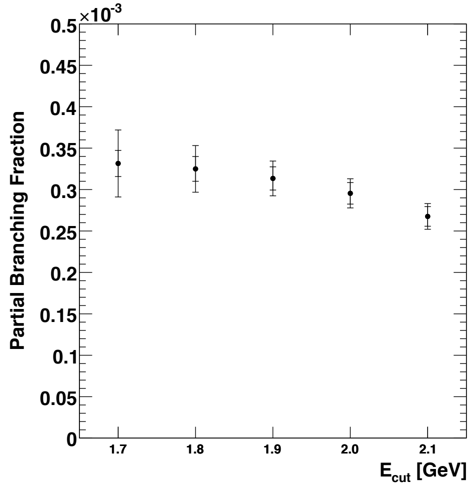
$$T(E_\gamma^{\rm true}) = \frac{M_{\rm Unfolded}}{\eta_{\rm det}}$$

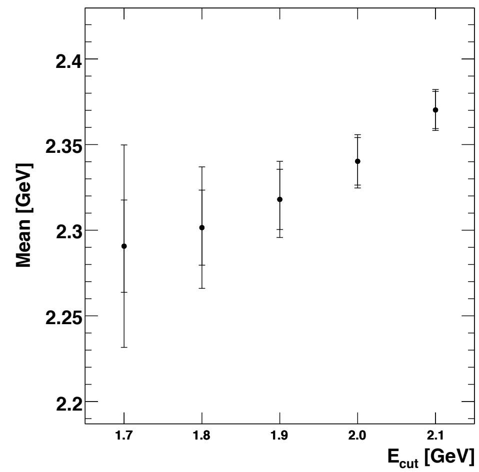


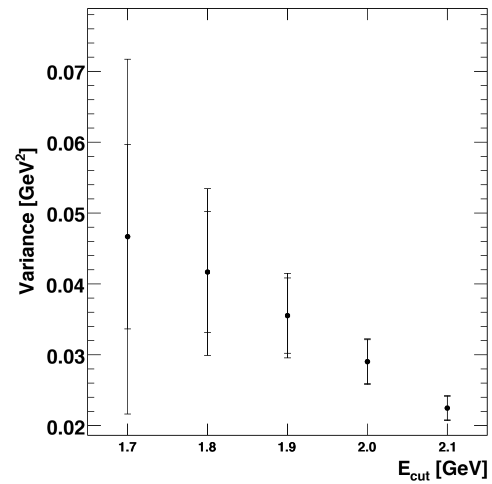
- Signal models: {KN, DGE, BBU, BLNP, GG}
- The MC response of the EM calorimeter is calibrated to match DATA using a study of radiative mu-pair events

Preliminary Results@ 605 fb^{-1}

B meson Frame



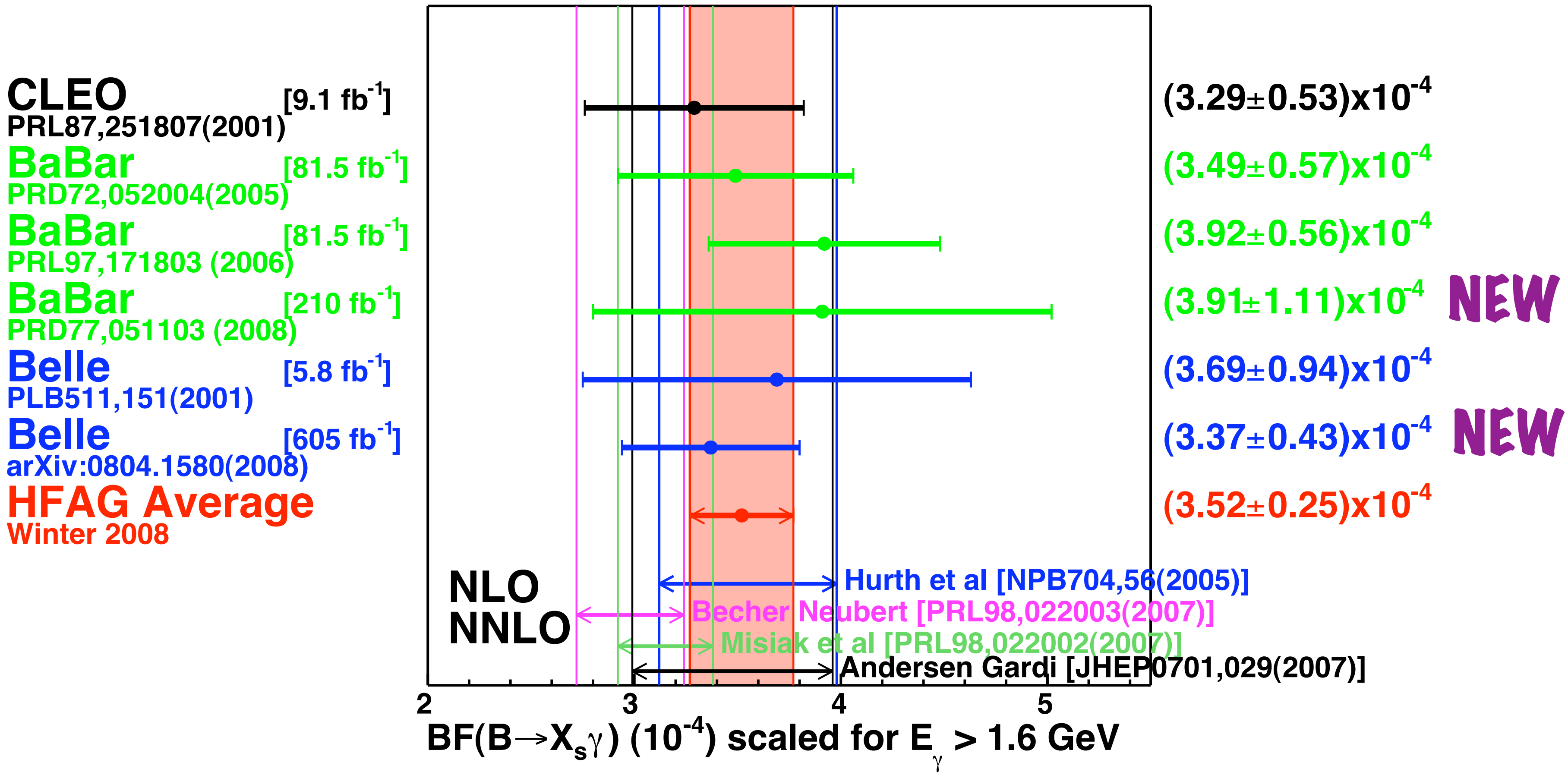




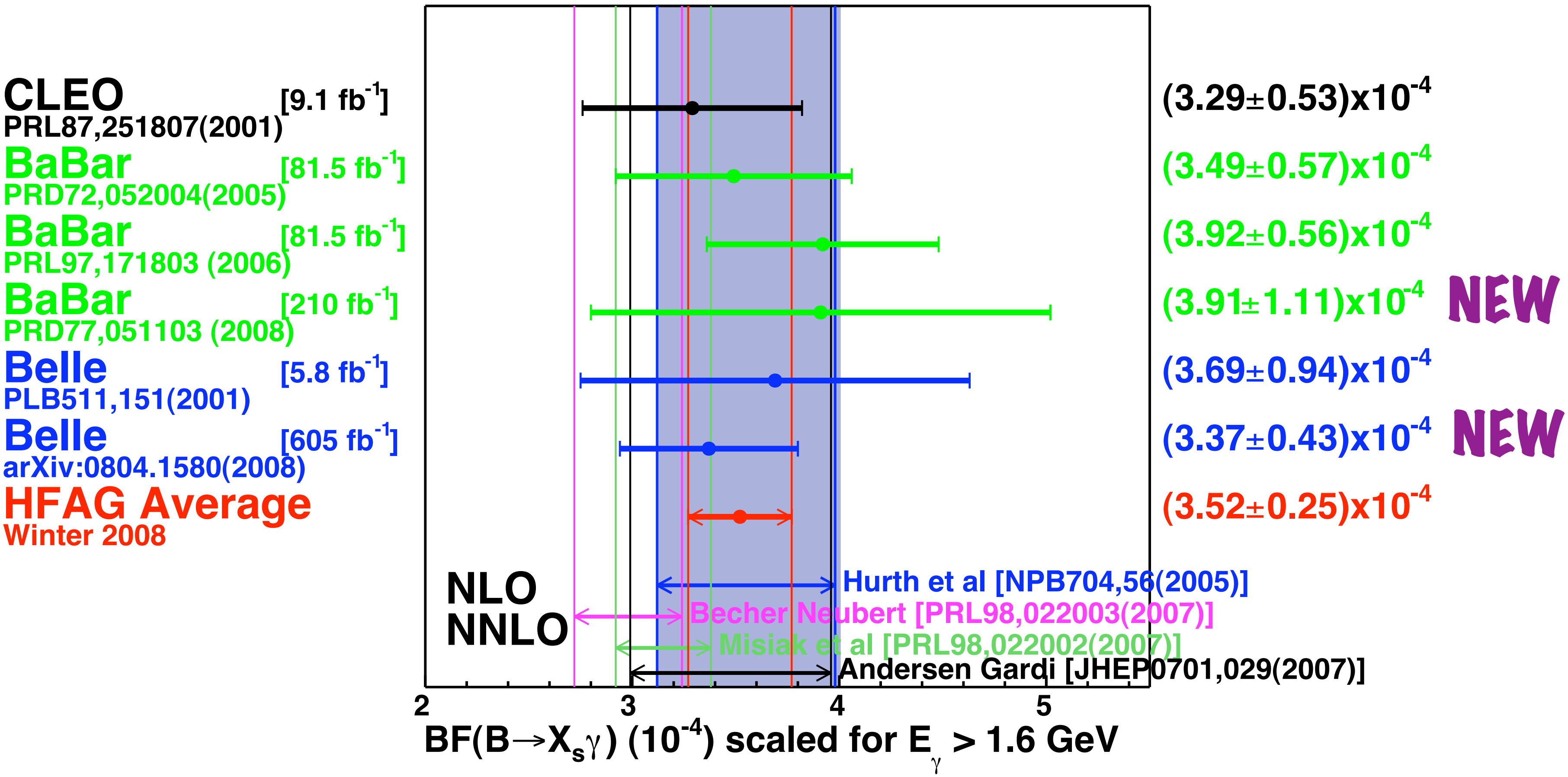
E(cut) [GeV]	PBF [10^{-4}]	Analysis	Relative Error
1.70	3.31 +- 0.19 +- 0.37	(Belle 605/fb)	(12.6%)
1.80	3.24 +- 0.17 +- 0.24	(Belle 605/fb)	(9.1%)
1.80	3.38 +- 0.31 +- 0.30	(Belle 140/fb)	(12.5%)

Systematic	PBF[10^{-4}] 1.7 GeV	1.8 GeV
other B - background	0.24	0.13
Selection Criteria	0.20	0.15
Continuum Background	0.17	0.12
pi0/eta background	0.06	0.05
Beam background	0.02	0.02
Energy resolution	0.01	0.01
Unfolding	0.01	0.01
Signal model	0.03	0.02
Photon detection	0.05	0.03
b-> d gamma	0.01	0.01
B-meson boost	0.01	0.01
Total	0.37	0.24

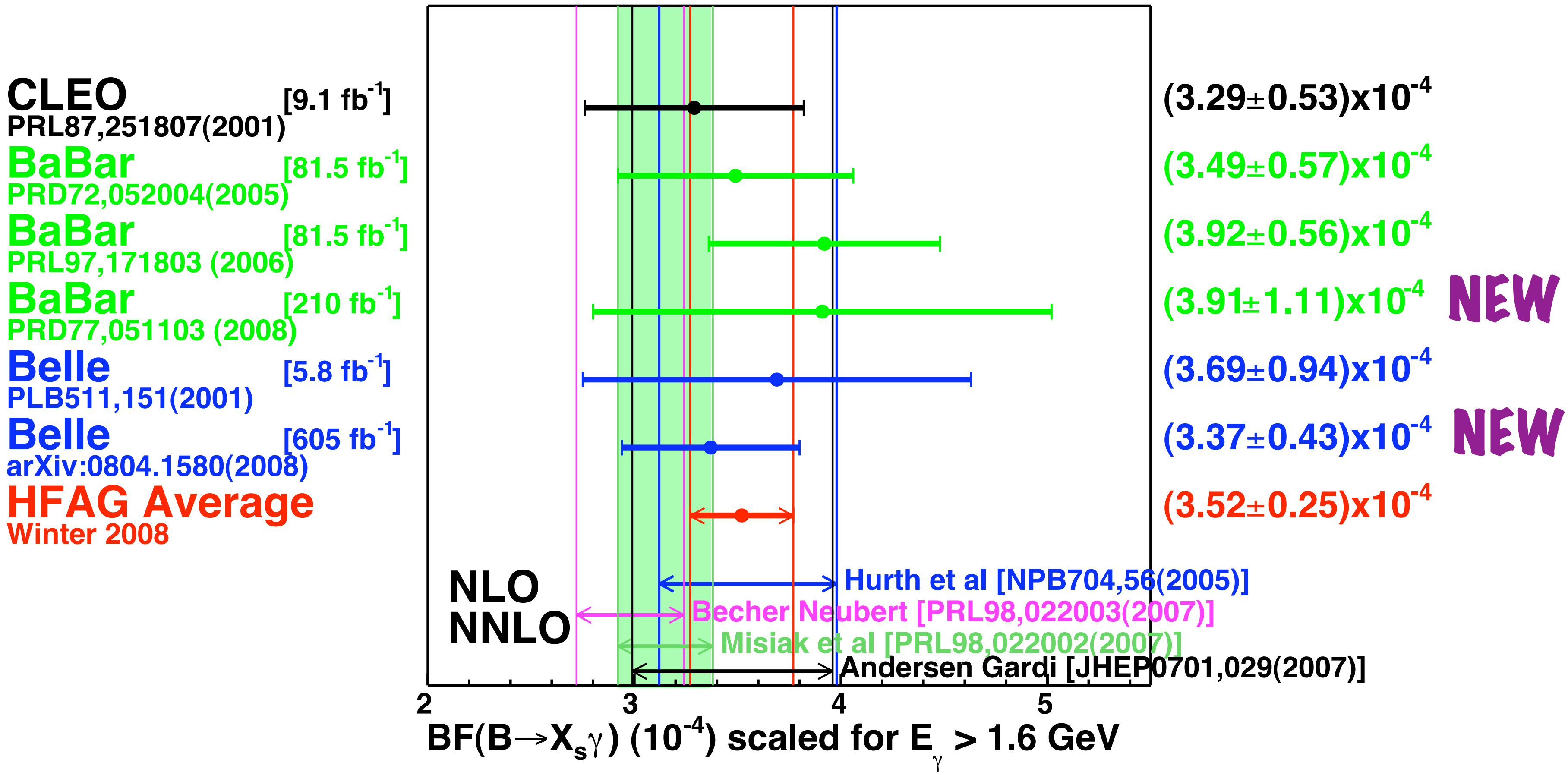
Branching fraction (Exp)



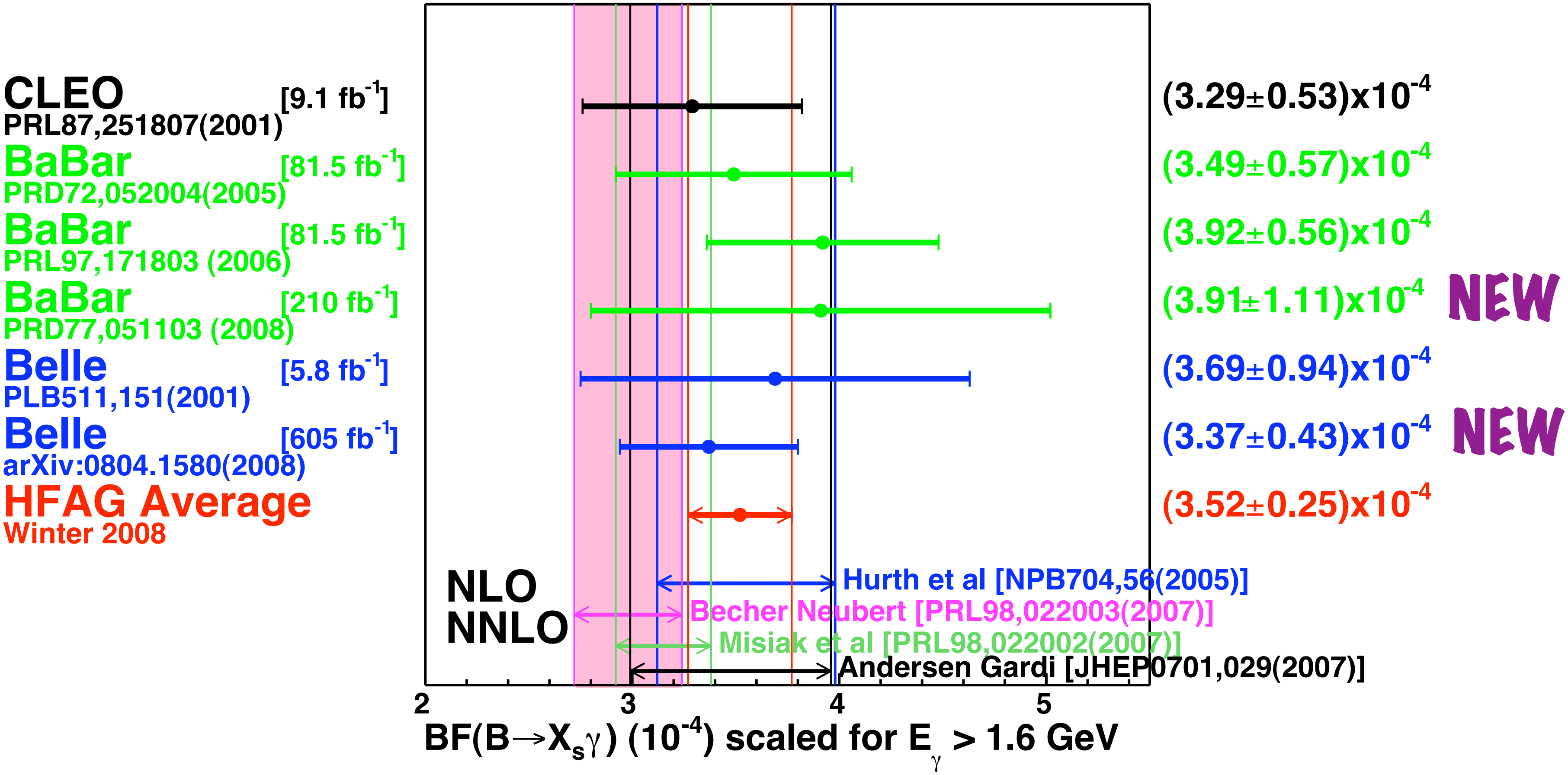
Branching fraction (NLO)



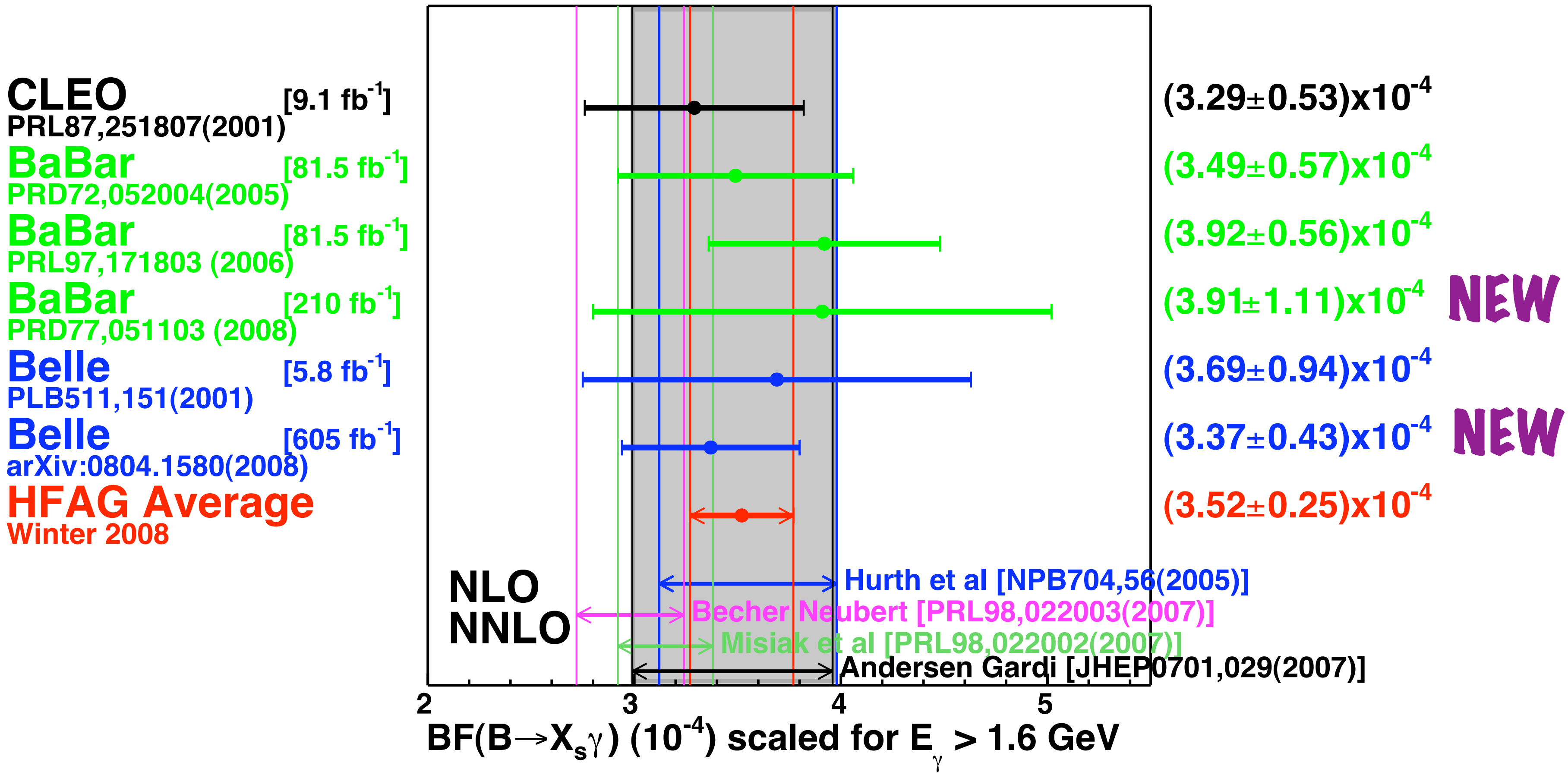
Branching fraction (NNLO)



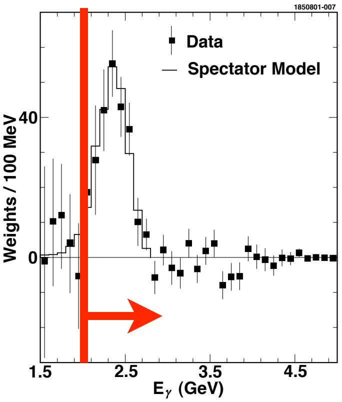
Branching fraction (NNLO)



Branching fraction (NNLO)

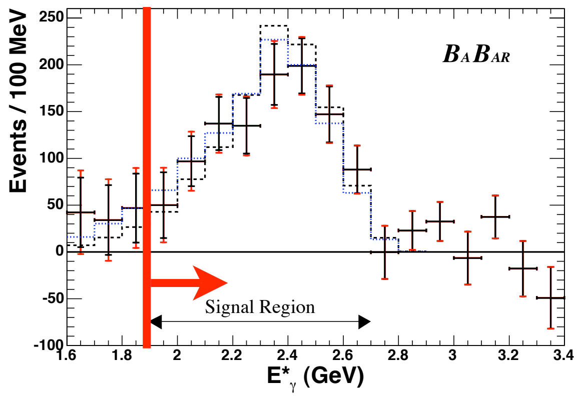


Summary of Fully Inclusive



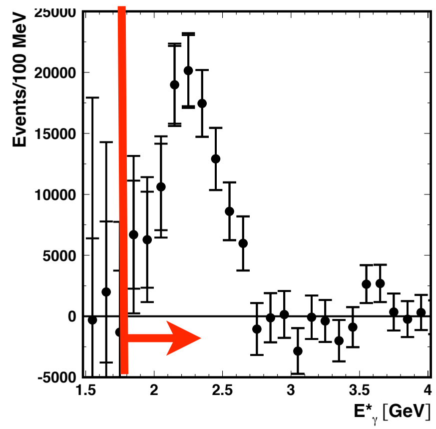
CLEO
9.1/fb ON
4.4/fb OFF
$E_\gamma > 2.0$ GeV

PRL87, 251807 (2001)



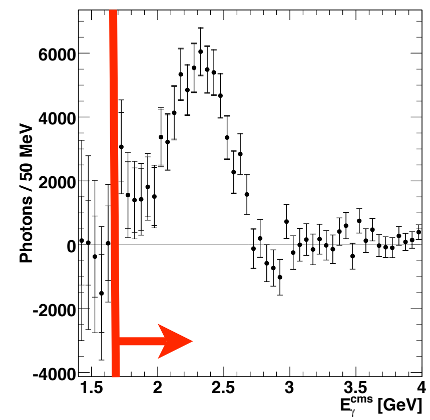
BABAR
81.5/fb ON
9.6/fb OFF
$E_\gamma > 1.9$ GeV

PRL97, 171803 (2006)



Belle
140/fb ON
15/fb OFF
$E_\gamma > 1.8$ GeV

PRL93, 061803 (2004)

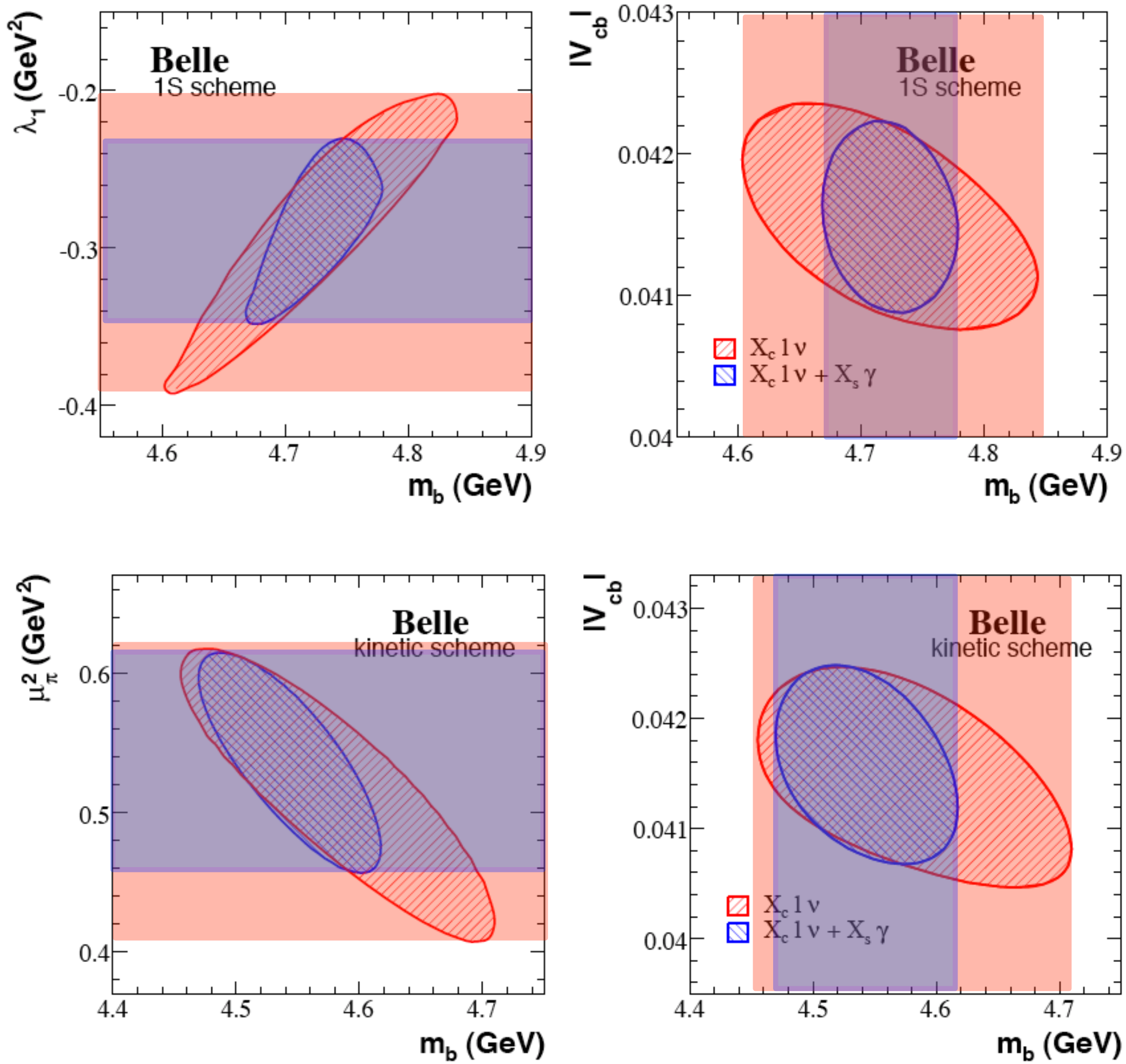


Belle
605/fb ON
68/fb OFF
$E_\gamma > 1.7$ GeV

arXiv:0804.1580 (2008)

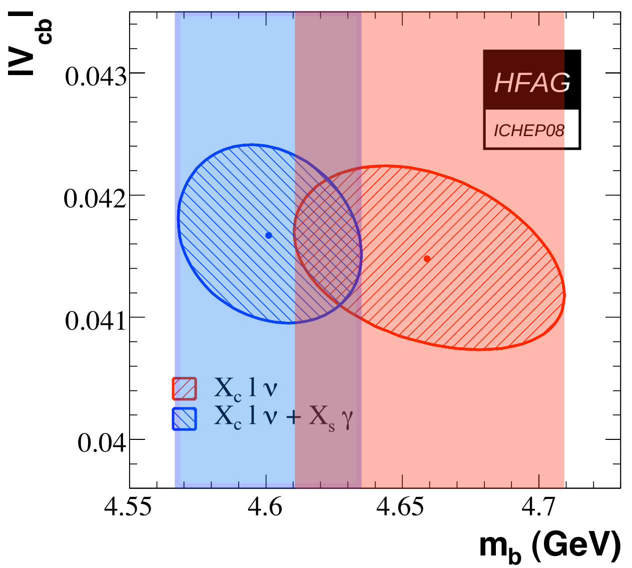
More data, lower the photon energy cut

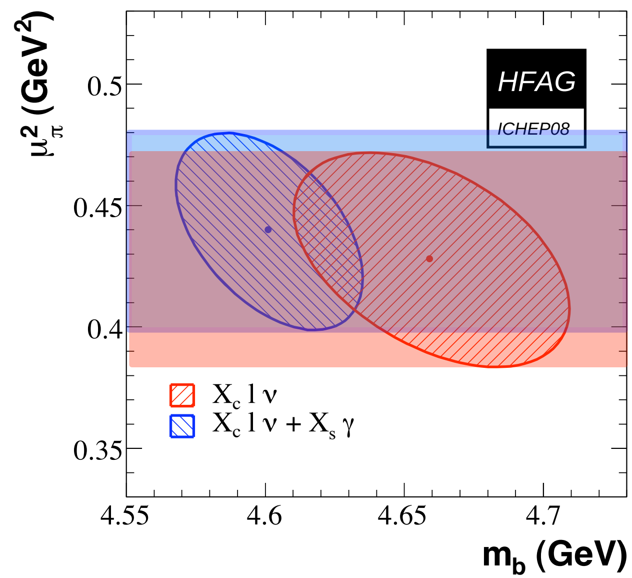
Moments : Global Fit



Belle 140/fb data

Global Fit (all Data)





Input	$\lvert V_{cb}\rvert$ (10^{-3})	m_b^{kin} (GeV)	mu^2_{pi} (GeV^2)
all moments ($X_c$lnu and $X_s$gamma)	41.67 +/- 0.43(fit) +/- 0.08(tau_B) +/- 0.58(th)	4.601 +/- 0.034	0.440 +/- 0.040
$X_c$lnu only	41.48 +/- 0.47(fit) +/- 0.08(tau_B) +/- 0.58(th)	4.659 +/- 0.049	0.428 +/- 0.044

Since CKM2006@Nagoya

- The branching fraction measurement uncertainty has reduced by about 5% to yield a total uncertainty of 7%, comparable to the theoretical uncertainty

- As yet no hint of new physics, CP asymmetry and BF consistent with the SM

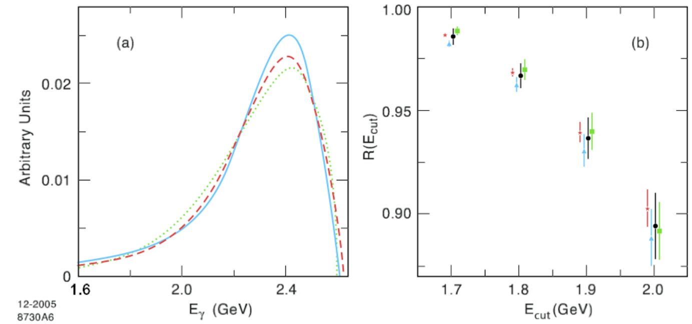
- First report of a measurement using a fully reconstructed B sample by BaBar, most promising avenue for improving the measurement ---> Super B factory

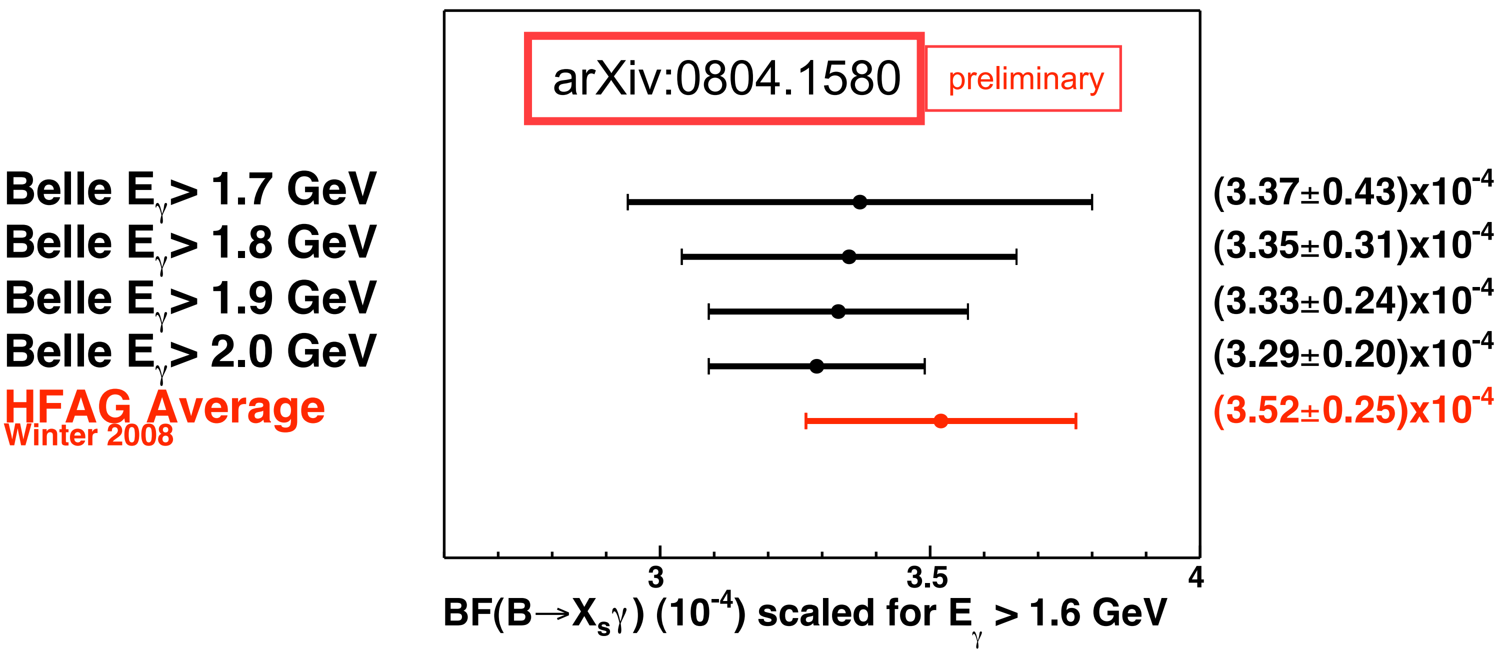
- $B \to X_s\gamma$ continues to play an important, albeit controversial, role in the determination of the CKM matrix elements V_{ub} and V_{cb}

Which is the best cut to use?

Extrapolation factors used by HFAG
from Buchmuller & Flacher PRD73 073008 (2006)

Scheme	$E_\gamma < 1.7$	$E_\gamma < 1.8$	$E_\gamma < 1.9$	$E_\gamma < 2.0$	$E_\gamma < 2.242$
Kinetic	0.986 ± 0.001	0.968 ± 0.002	0.939 ± 0.005	0.903 ± 0.009	0.656 ± 0.031
Neubert SF	0.982 ± 0.002	0.962 ± 0.004	0.930 ± 0.008	0.888 ± 0.014	0.665 ± 0.035
Kagan-Neubert	0.988 ± 0.002	0.970 ± 0.005	0.940 ± 0.009	0.892 ± 0.014	0.643 ± 0.033
Average	0.985 ± 0.004	0.967 ± 0.006	0.936 ± 0.010	0.894 ± 0.016	0.655 ± 0.037

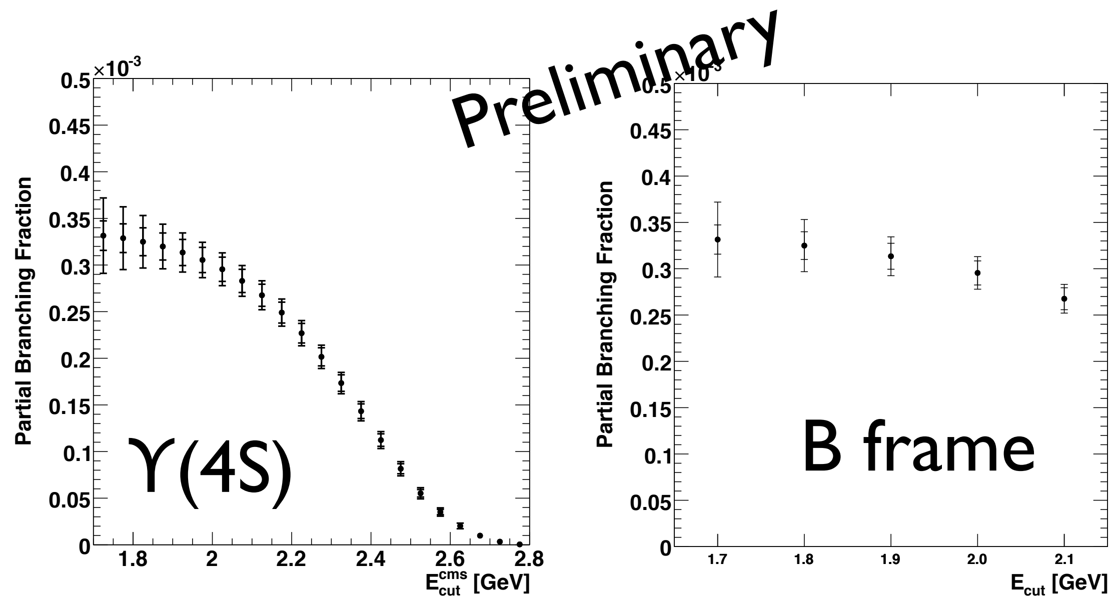




Much lower uncertainty if E>2.0 GeV cut is used!

Υ(4S) frame to B frame

- Fully inclusive measurements are out most precise to date, but necessarily restricted to the Υ(4S) frame. A correction is needed to go to the rest frame of the B.
- Correction is model dependent, moreover grows quickly, as the lower threshold energy cut is raised.



Υ(4S) rest frame
B rest frame

E(cut) [GeV]	PBF [10^{-4}]	Mean [GeV]	Variance [GeV^2]
2.00	2.95 ± 0.14 ± 0.12	2.340 ± 0.015 ± 0.007	0.0290 ± 0.0033 ± 0.0009
2.00	2.94 ± 0.14 ± 0.12 ± 0.02	2.326 ± 0.015 ± 0.007 ± 0.005	0.0227 ± 0.0031 ± 0.0009 ± 0.0009
2.10	2.68 ± 0.12 ± 0.10	2.370 ± 0.011 ± 0.005	0.0225 ± 0.0017 ± 0.0006
2.10	2.62 ± 0.12 ± 0.10 ± 0.05	2.350 ± 0.011 ± 0.005 ± 0.006	0.0170 ± 0.0017 ± 0.0006 ± 0.0012

- Can we make better use of all our data

Global fit of $B \to X_s\gamma$ data?

As is done with V_{cb}. m_b, other HQET parameters, is it time we performed a simultaneous fit to all the $B \to X_s\gamma$ data?

- Partial branching fraction, first moment (Mean), second central moment (Variance) and third central moment (Kurtosis).

To yield

- The full branching fraction (E>1.6 GeV or wherever)
- The b-quark mass m_b
- The mean momentum squared of the b-quark $(\mu_\pi)^2$

Parametric/Model errors

Parameter error Δm_b
"Signal model error"
used for acceptance correction

Systematic error on PBF, mean, variance

Fit of mean and variance to get m_b

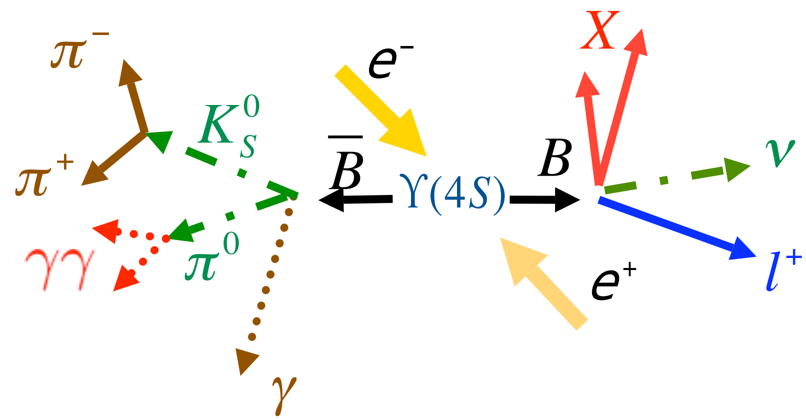
Initial error Δm_b propagates to the new determination of m_b. The effort to precisely determine m_b is undermined i.e. we don't allow the data to speak for itself.

At the moment we are necessarily choosing values for m_b and $(\mu_\pi)^2$ to extract the branching fraction and the moments, are we ready to allow our data simultaneously decide the value of these parameters?

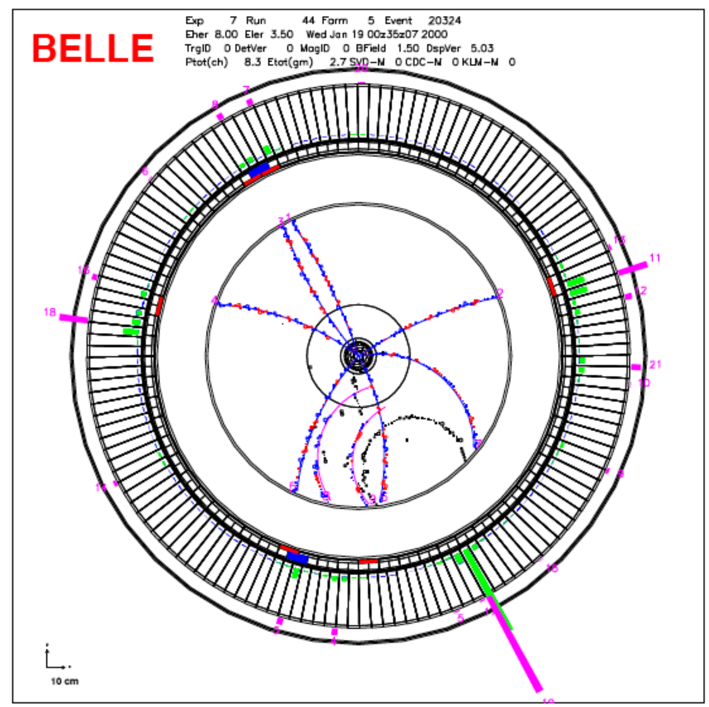
Backup Slides

Three methods

- Fully inclusive
  - Isolated photon
  - Big continuum background
  - Smeared by B-boost

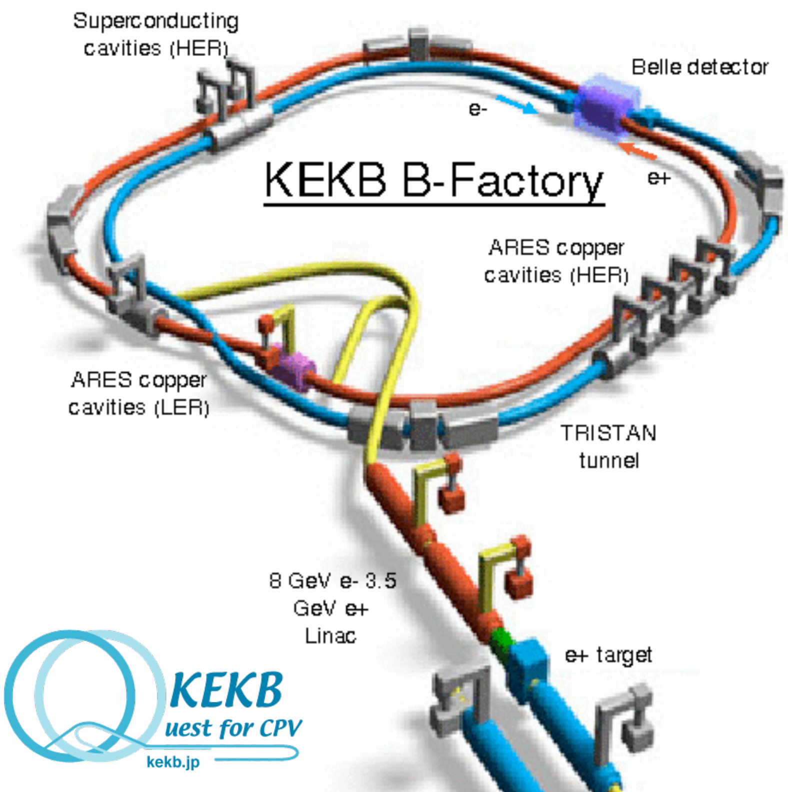


- Semi-inclusive
  - B reconstruction $M_{bc(ES)}$-ΔE
  - Sum up many modes ~55%
  - B-rest frame
  - Excellent γ energy resolution



- B-Recoil
  - Isolated photon
  - B-rest frame

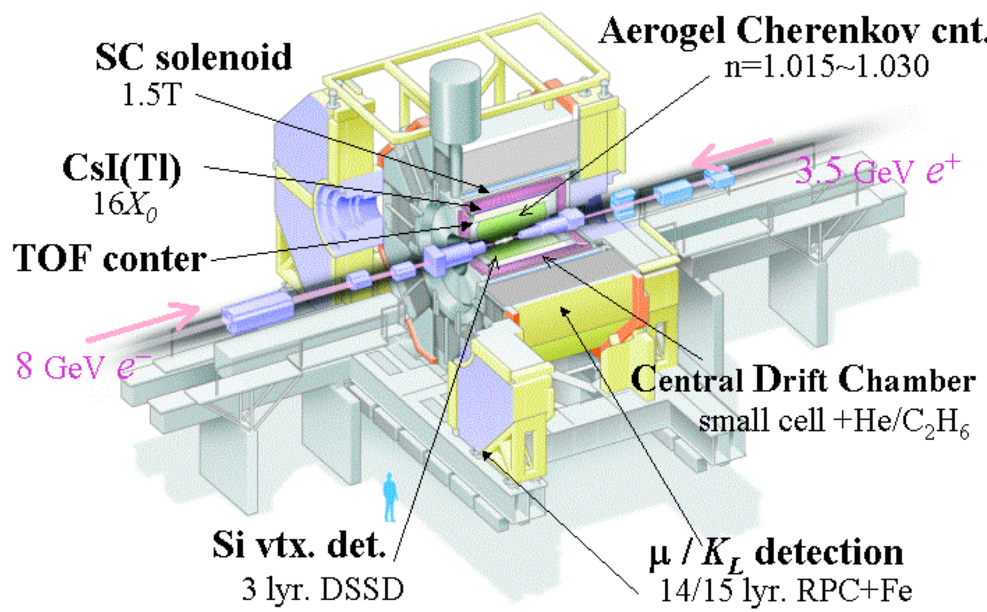
KEKB and Belle



Luminosity	KEKB
Peak	>16.5x10^{33} /cm^2/s
Total Integrated	>700/fb

Solid angle coverage	~92%
Particle ID	e m p K p

Belle Detector



Selection Criteria

γ polar angle	$\cos\theta$	$\in$	$[-0.35, 0.70]$
π^0 probability	$\mathcal{P}_{\pi^0}$	$\leq$	0.10
η probability	$\mathcal{P}_{\eta}$	$\leq$	0.20
Distance to closest charged	d_T	$\geq$	3 cm
Distance to closest charged with $P > 1\,\mathrm{GeV}$	d_{HT}	$\geq$	50 cm
Distance to closest γ	d_γ	$\geq$	30 cm
Angle to closest e	α_e	$\geq$	0.3
Angle to closest μ	α_μ	$\geq$	0.3
γ E_9/E_{25}	E_9/E_{25}	$\geq$	0.95
Second Fox Wolfram moment	R_2	$\leq$	0.5
Angle between γ and EM cluster $(-\pi)$	Θ	$\in$	$[0, 0.2]$
OFF time cut (Exp $\geq$ 39)	s_tdc	$\in$	$[9000, 11000]$
		OR	
	$mcsi\_bb$	$\in$	$[7500, 9300]$

MAIN stream

Virtual calorimeter central energy	E_C	$\geq$	3.0 GeV
Virtual calorimeter Fisher discriminant	F_{VC}	$\leq$	2.0 GeV
Event shapes Fisher Discriminant	F_{ES}^{MAIN}	$\leq$	-0.28

Table of Results for Belle

	$\mathcal{B}(B \to X_s\gamma)$ (10^{-4})					$\langle E_\gamma \rangle$ (GeV)					$\Delta E_\gamma^2 \equiv \langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2$ (GeV^2)				
E_γ^{B} [GeV]	1.7	1.8	1.9	2.0	2.1	1.7	1.8	1.9	2.0	2.1	1.7	1.8	1.9	2.0	2.1
Value	3.31	3.24	3.12	2.94	2.62	2.281	2.290	2.305	2.326	2.350	0.0396	0.0350	0.0292	0.0227	0.0170
±statistical	0.19	0.17	0.15	0.14	0.12	0.032	0.025	0.019	0.015	0.011	0.0156	0.0096	0.0058	0.0033	0.0017
±systematic	0.37	0.24	0.16	0.12	0.10	0.053	0.028	0.014	0.007	0.005	0.0214	0.0081	0.0027	0.0009	0.0006
±boost	0.01	0.01	0.02	0.02	0.05	0.002	0.002	0.004	0.005	0.006	0.0012	0.0005	0.0008	0.0009	0.0012
Systematic Uncertainties															
Continuum	0.18	0.11	0.08	0.07	0.07	0.030	0.016	0.008	0.004	0.002	0.0101	0.0040	0.0012	0.0004	0.0004
Selection	0.20	0.15	0.11	0.08	0.06	0.023	0.012	0.006	0.003	0.001	0.0114	0.0039	0.0014	0.0005	0.0001
π^0/η	0.07	0.05	0.04	0.02	0.01	0.012	0.006	0.003	0.002	0.001	0.0075	0.0023	0.0007	0.0003	0.0001
Other B	0.24	0.13	0.06	0.02	0.01	0.033	0.016	0.007	0.002	0.000	0.0124	0.0051	0.0017	0.0004	0.0000
Beam	0.02	0.02	0.01	0.01	0.01	0.001	0.001	0.000	0.000	0.000	0.0006	0.0003	0.0001	0.0000	0.0000
resolution	0.01	0.01	0.02	0.02	0.03	0.006	0.005	0.005	0.004	0.004	0.0009	0.0006	0.0005	0.0004	0.0004
Unfolding	0.01	0.00	0.00	0.01	0.01	0.002	0.001	0.001	0.001	0.002	0.0014	0.0008	0.0006	0.0003	0.0001
Model	0.03	0.02	0.01	0.00	0.00	0.005	0.003	0.002	0.001	0.000	0.0014	0.0006	0.0002	0.0000	0.0000
γ Detection	0.03	0.02	0.01	0.00	0.00	0.005	0.003	0.002	0.001	0.000	0.0014	0.0006	0.0002	0.0000	0.0000
$B \to X_d\gamma$	0.01	0.01	0.01	0.01	0.01	0.000	0.000	0.000	0.000	0.000	0.0001	0.0000	0.0000	0.0000	0.0000

Signal Models

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