Inclusive and Exclusive $b \rightarrow s/d\ \gamma$

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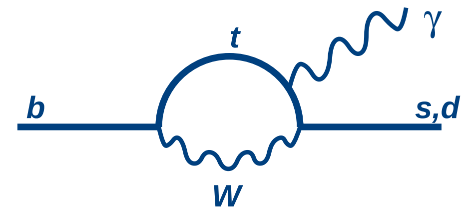
Outline

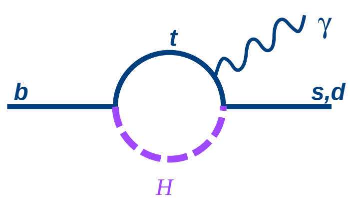
- *Introduction*
- *b → s γ*
  – Branching fraction of inclusive B → Xs γ
  – Direct CP violation for inclusive B → Xs γ
- *b → d γ*
  – Exclusive B → ργ, ωγ
  – CP asymmetry for B → ρ γ
  – Sum of exclusive modes

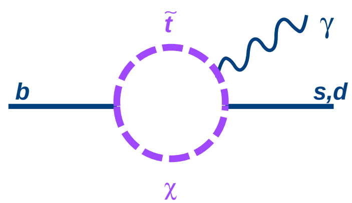
Introduction

- *b → s,d transitions*



- FCNC in the SM
  – b → s,d transitions are forbidden at tree level
- Probe for New physics effects
  – New particles in the loops can give effects at the same order





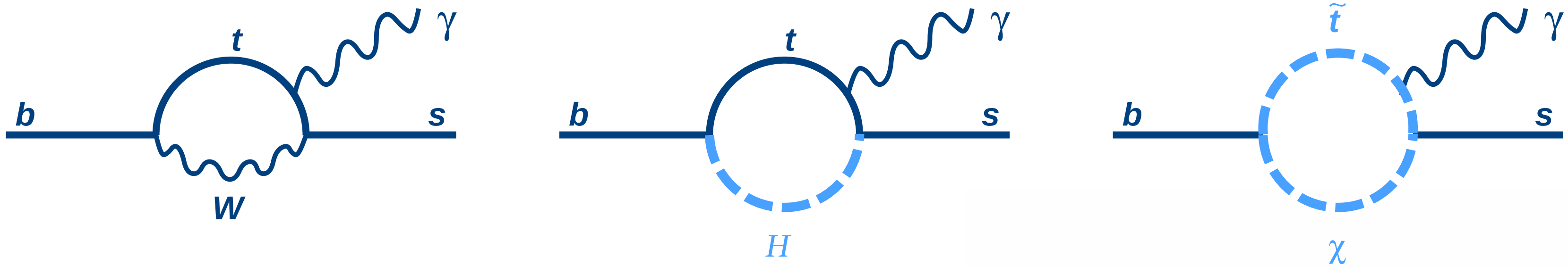
- Measurement of $|V_{td}/V_{ts}|^2$
  – From B.F($B \to \rho\gamma$)/B.F($B \to K^*\gamma$)

Analysis technique

- Large clean sample of $\Upsilon(4S) \rightarrow B^+B^-$ and $B^0\overline{B}^0$
  - Inclusive analysis of radiative decays
- Continuum suppression technique with event shape variables
- Continuum subtraction with off-resonance data
- Exclusive *B* reconstruction with

  $\Delta E = E_B^* - E_{beam}^*$ and $(M_{bc})^2 = (M_{ES})^2 = (E_{beam}^*)^2 - |\vec{p}_B^*|^2$

$b \rightarrow s\,\gamma$



Most powerful mode to constrain new physics

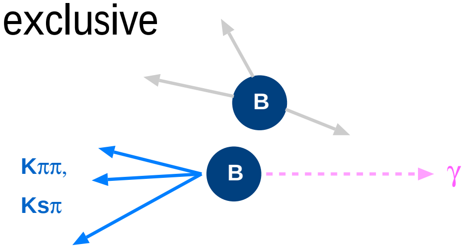
Inclusive branching fraction measurement agree with SM

$B \to X_s\gamma$ inclusive measurements

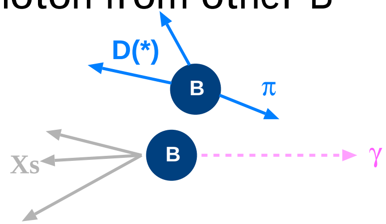
- Branching fraction can be accurately predicted at NNLO
- $E\gamma$ distribution depends on the b-quark mass and the fermi motion of the b quark
  - Can be used to reduce the model dependent error on $|V_{ub}|$ and $|V_{cb}|$
- Direct CP asymmetry ~ 0.4 % in SM
  - Can be up to ~ 10% in some new physics models

$B \to X_s\gamma$: methods

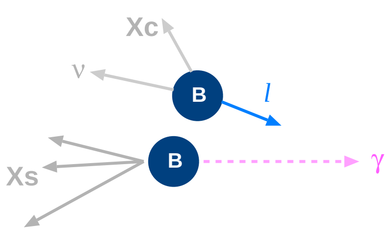
- Semi-inclusive
  - Sum of exclusive

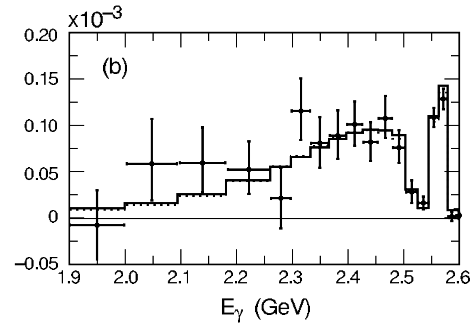


- B recoil
  - Fully reconstruct one B
  - Measure photon from other B

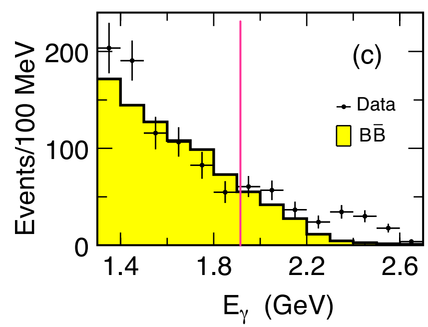


- Inclusive
  - Reconstruct only the photon
  - Reduce background with lepton tag

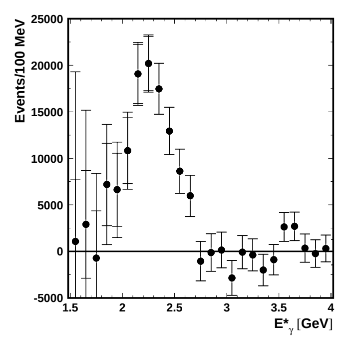




BaBar
81.5/fb
$E_\gamma > 1.9$ GeV, semi-inclusive
(PRD72, 052004 (2005))

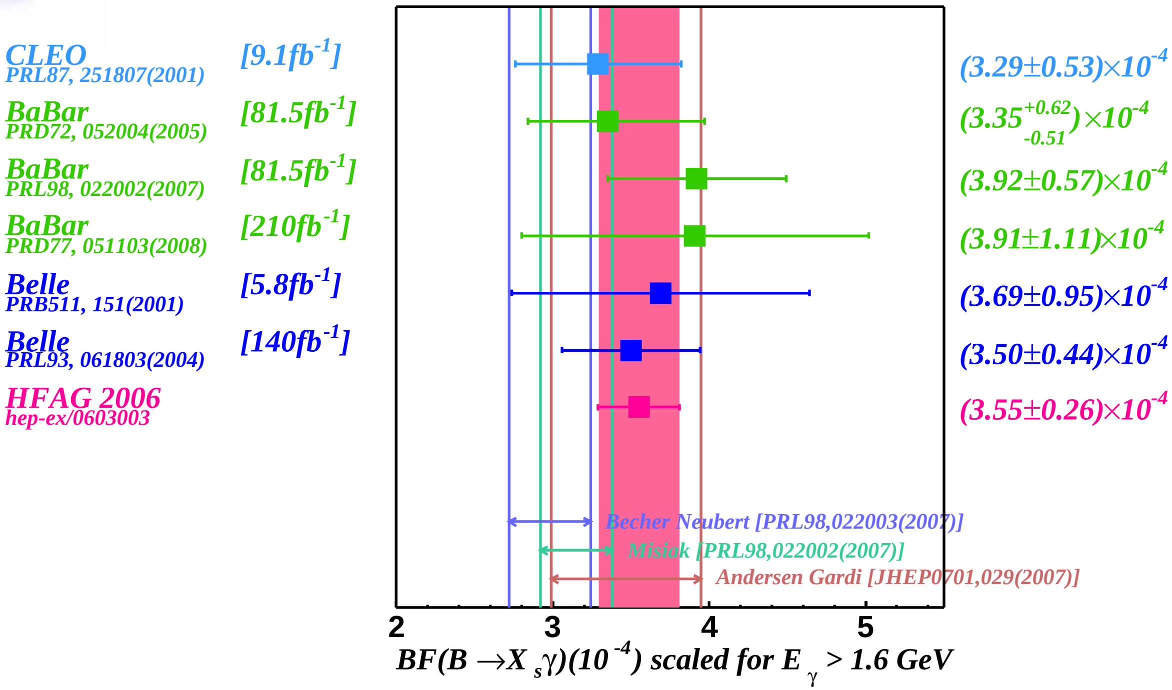


BaBar
81.5/fb
$E_\gamma > 1.9$ GeV, B recoil
(PRD77, 051103(2008))



Belle
140/fb
$E_\gamma > 1.8$ GeV, inclusive
(PRL93, 061803(2004))

$B.F(B \rightarrow X_s\gamma)$ comparison

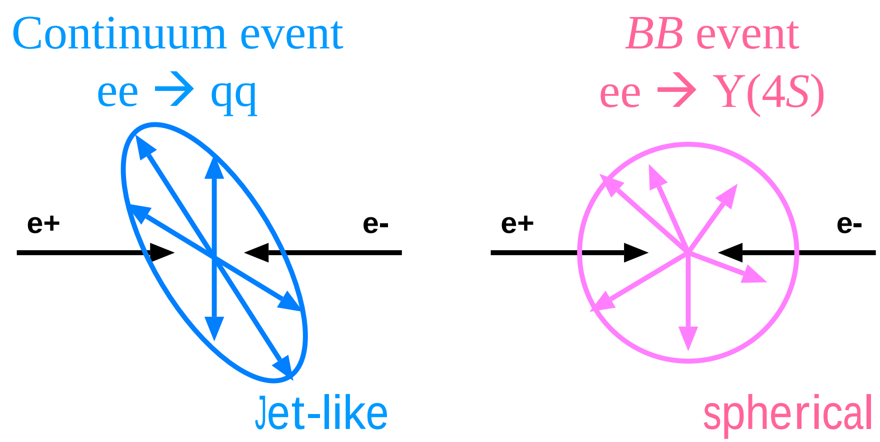


- Calculations up to NNLO
  - Agreement between experiment and theory has been degraded
- Need to improve the precision in the experimental measurement

More data and lower energy cut

New $B \rightarrow X_s\gamma$ *by Belle*

- Inclusive analysis
  - 605/fb, 4.3 times more data than previous analysis
  - Improvements in the analysis technique
- Find isolated clusters in the ECL
  - High energy $E^*_\gamma > 1.4$ GeV
  - Veto γ from π^0, η & Bhabha
  - Use topological information to suppress continuum background



- Background subtraction
  - Estimate continuum event using OFF resonance data
  - Estimate B decays using “corrected” MC sample

Continuum scaling

$$N^{B\overline{B}}(E_\gamma^{*ON}) = N^{ON}(E_\gamma^{*ON}) - \alpha\,\varepsilon\,F_N\,N^{OFF}(F_E\,E_\gamma^{*OFF})$$

Continuum scaling

$$N^{B\bar{B}}(E_\gamma^{*ON}) = N^{ON}(E_\gamma^{*ON}) - \alpha\,\varepsilon\,F_N\,N^{OFF}(F_E\,E_\gamma^{*OFF})$$

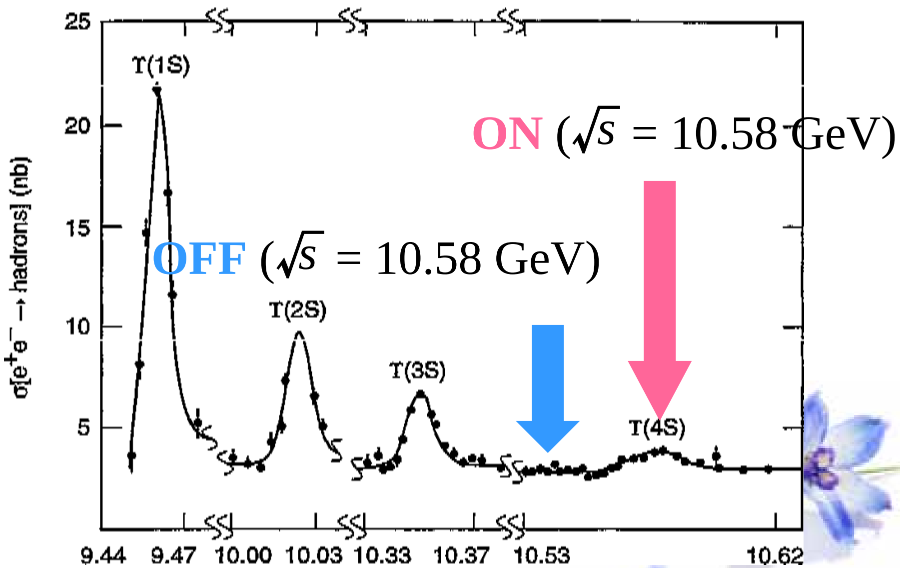
Scaling OFF resonance data

$$N^{B\bar{B}}(E_\gamma^{*ON}) = N^{ON}(E_\gamma^{*ON}) - \boxed{\alpha}\, \varepsilon\, F_N\, N^{OFF}(F_E\, E_\gamma^{*OFF})$$

- The ratio of ON to OFF resonance integrated luminosity corrected for the energy difference

$$\alpha = \frac{\int L_{ON}\, dt}{\int L_{OFF}\, dt} \times \frac{s^{OFF}}{s^{ON}} = \frac{604.633}{68.275} \times \frac{10.52^2}{10.58^2}$$

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



Response to Selection

$$N^{B\overline{B}}(E_\gamma^{*ON}) = N^{ON}(E_\gamma^{*ON}) - \alpha \varepsilon F_N N^{OFF}(F_E E_\gamma^{*OFF})$$

- Combined efficiency of hadronic selection and analysis selection criteria ($B \rightarrow X_s \gamma$) for either ON-resonance and OFF-resonance beam energies

$$\varepsilon = \frac{\varepsilon^{ON}_{Hadronic}}{\varepsilon^{OFF}_{Hadronic}} \times \frac{\varepsilon^{ON}_{B\to X_s\gamma}}{\varepsilon^{OFF}_{B\to X_s\gamma}}$$

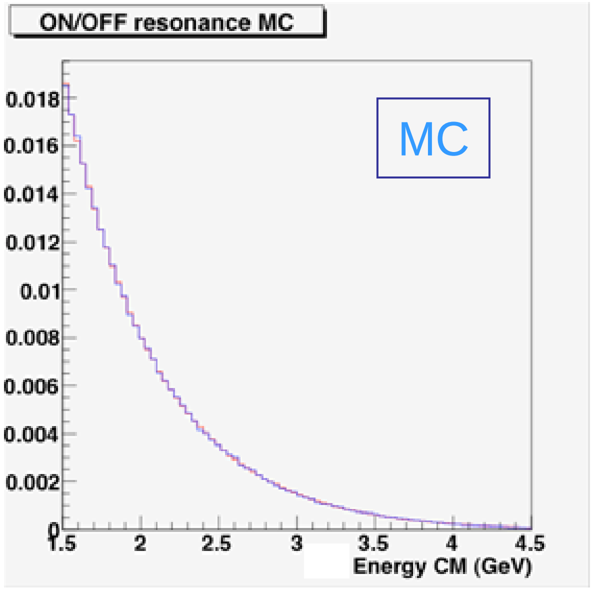
$$= (0.9986 \pm 0.0001) \times (0.9871 \pm 0.0014)$$

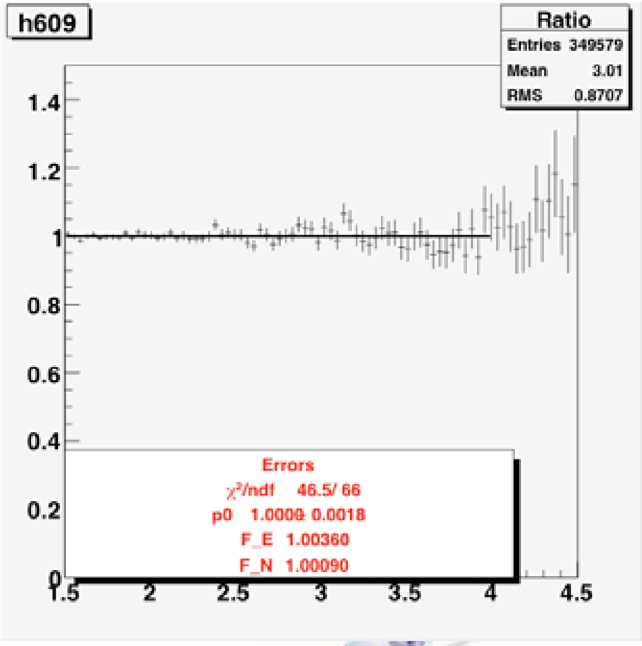
Energy (F_E) and Multiplicity (F_N) Scaling

$$N^{B\bar{B}}(E_\gamma^{*ON}) = N^{ON}(E_\gamma^{*ON}) - \alpha\,\varepsilon\, F_N N^{OFF}(F_E E_\gamma^{*OFF})$$

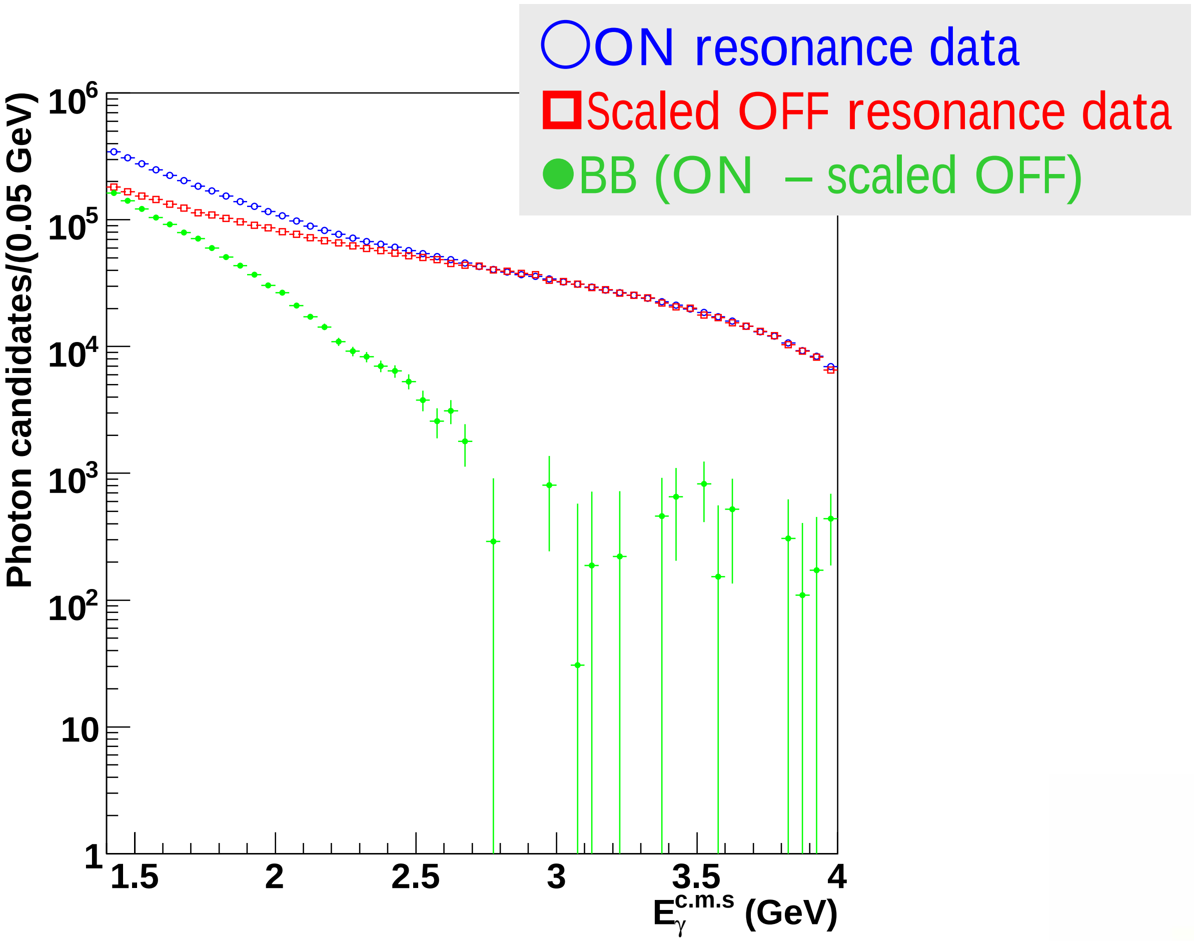
- Compensation for slightly lower mean energy and multiplicity of particles in OFF compared to ON events

$$F_N = (1.0009 \pm 0.0001)$$
$$F_E = (1.0036 \pm 0.0001)$$



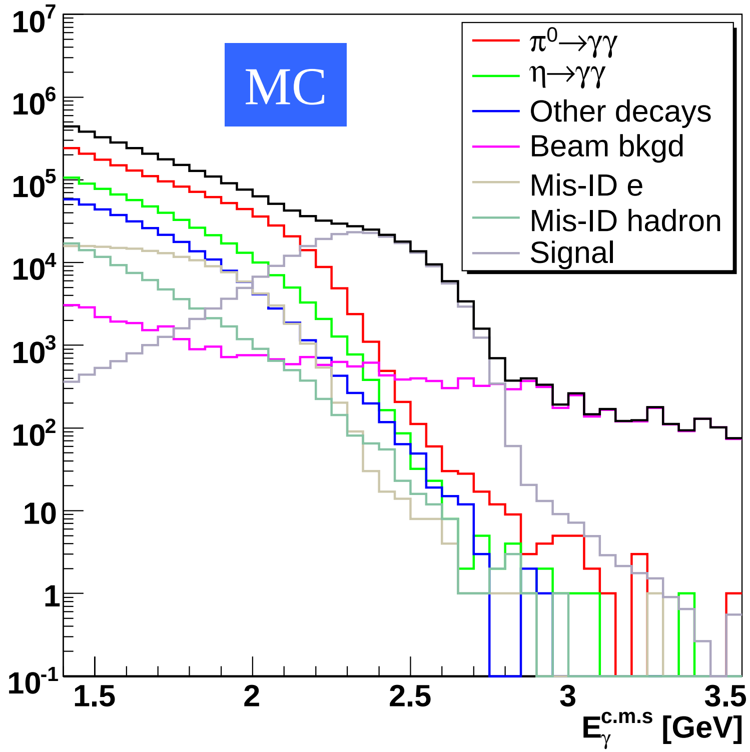


Scaled continuum



background sources from B decays

- Photons from B decays
  - Six background categories



	fraction
Signal	0.190
Decays of π^0	0.474
Decays of η	0.163
Decay of others	0.081
Mis-IDed electrons	0.061
Mis-IDed hafrons	0.017
Beam background	0.013

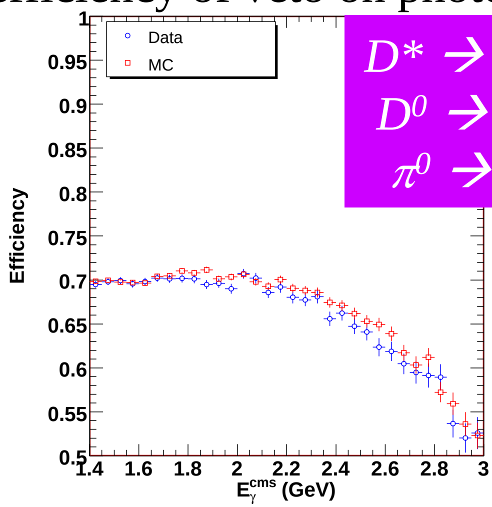
Subtraction of the background from B decays

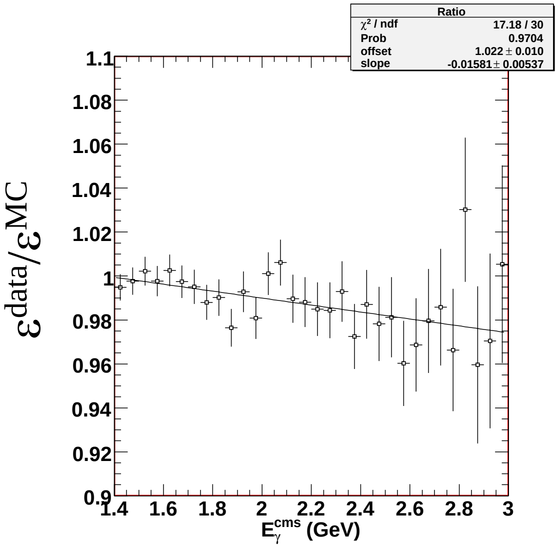
For all six background categories, (if possible),

- Determine E_γ-dependent selection efficiency using control sample
  - OFF-subtracted ON data (ε^{data})
  - MC (ε^{MC})
- Scale MC background sample according to the ratio of these efficiencies

The efficiency of veto on photons from π^0s

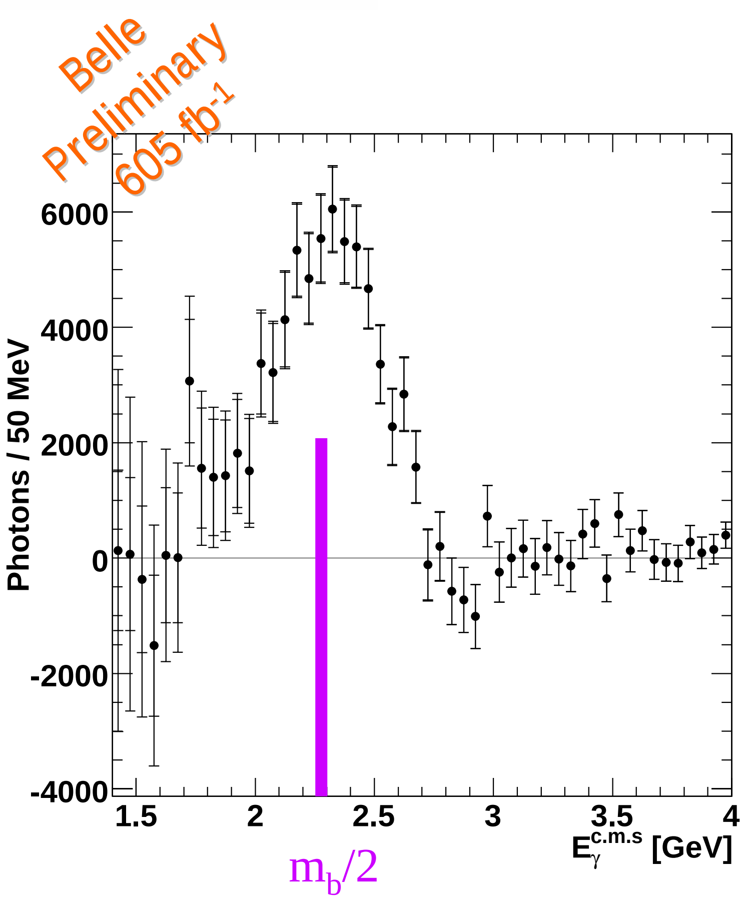
$D^* \to D^0\pi,$
$D^0 \to K\pi\pi^0,$
$\pi^0 \to \gamma(\gamma)$





All selection criteria are investigated in a similar fashion

Photon energy spectrum



- Yield above endpoint for photon from B decay is consistent with zero
  - Background are properly subtracted
- Peaks at half the mass of the b-quark
- Significant signal between $1.7 < E_\gamma < 2.8$ GeV

For $E_\gamma > 1.7$ GeV

$$B.F(B \to X_s\gamma) = (3.31 \pm \underset{\text{(Stat.)}}{0.19} \pm \underset{\text{(Syst.)}}{0.37} \pm \underset{\text{(Boost.)}}{0.01}) \times 10^{-4}$$

$$\langle E_\gamma \rangle = 2.281 \pm 0.032 \pm 0.053 \pm 0.002\ \text{GeV}$$

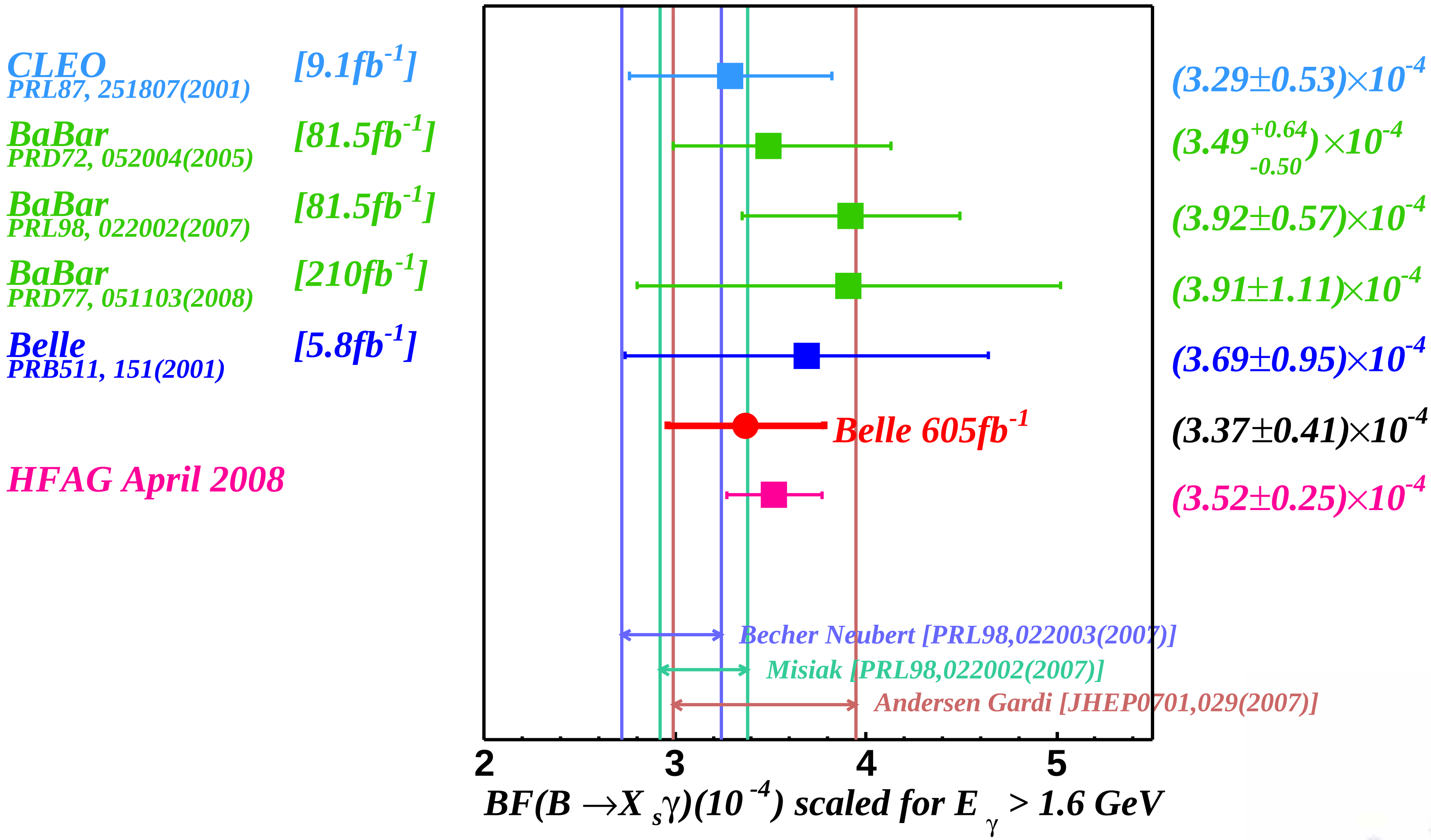
$$\langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2 = 0.0396 \pm 0.0156 \pm 0.0214 \pm 0.0012\ \text{GeV}^2$$

E_γ cut extended down to 1.7 GeV

The most precise measurements to date

FPCP 08, Taipei, Taiwan
N. Taniguchi

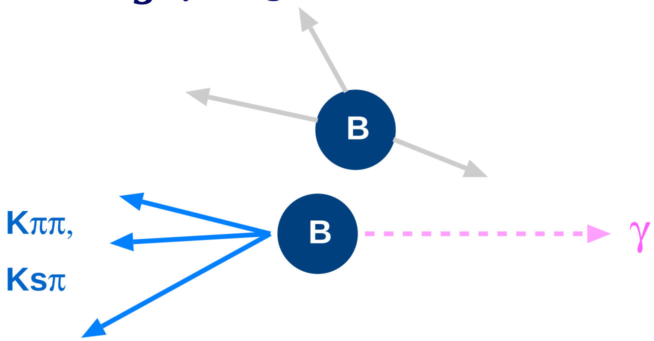
B.F($B \rightarrow X_s\gamma$) summary



Measurement of direct CP violation in $b \to s\gamma$ by BaBar

SM predicts very tiny CP violation ~ 0.4%

Direct CP Violation for $B \to X_s \gamma$ by Babar

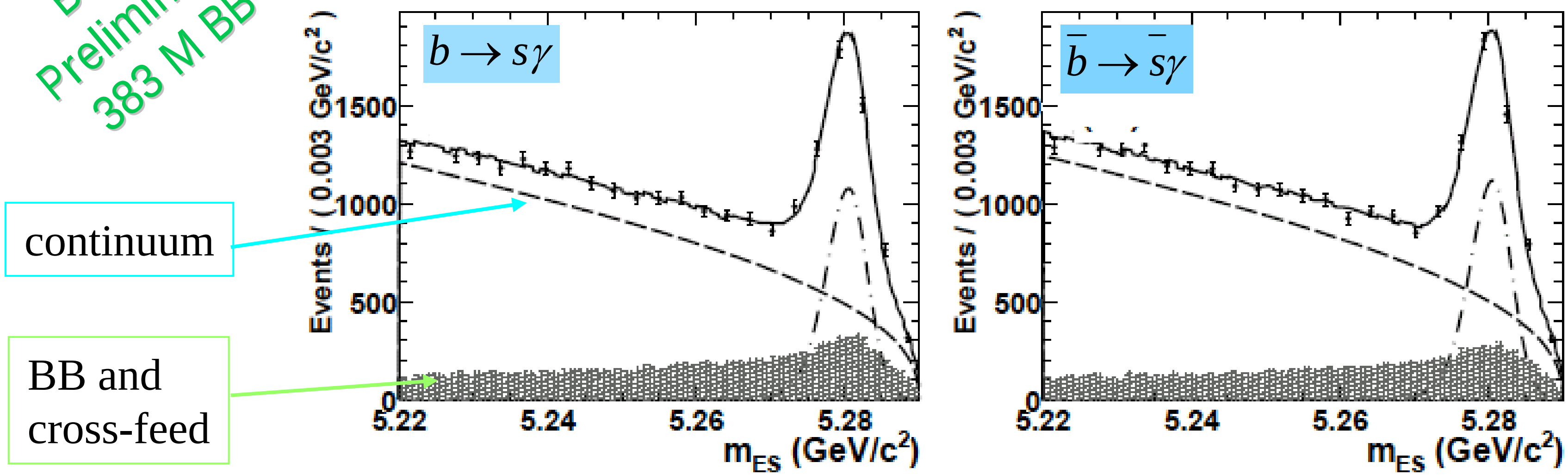


- Sum of exclusive modes
- Fully reconstruct $B \to X_s\gamma$ in 16 exclusive modes
  - Xs = K and up to 3π, 3K and 0 or 1π, Kη(π), 3K(π)
- Main background: π^0 and η from continuum, ISR
  - Veto photons which form good π^0 or η
- Extract yield from M_{ES} fit to signal region
  - Background shapes from MC
- Sidebands and $B \to X_s\pi^0$ control sample used for:
  - Detector bias (different interaction cross sections for K+ and K-)
  - BB background shape uncertainty
  - Continuum shape uncertainty

$$A_{CP} = \frac{N_{b\to s\gamma} - N_{\bar{b}\to\bar{s}\gamma}}{N_{b\to s\gamma} + N_{\bar{b}\to\bar{s}\gamma}}$$

Direct CP Violation for $B \to X_s \gamma$

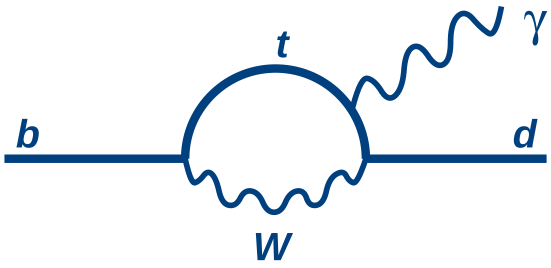
BaBar Preliminary 383 M BB

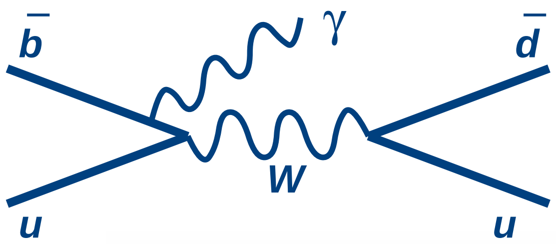


Select candidates with $|\Delta E| < 0.10$ GeV

- $A_{cp} = -0.012 \pm 0.030(stat) \pm 0.019(syst)$ [*preliminary*]
  - $0.6 < M(X_s) < 2.8$ GeV/c^2 corresponding to $E\gamma > 1.9$ GeV
- Most accurate measurement of A_{cp} to date

$b \rightarrow d\,\gamma$





Sensitive probe for physics beyond the standard model

Similar to $b \rightarrow s\gamma$ in SM, could be different in new physics

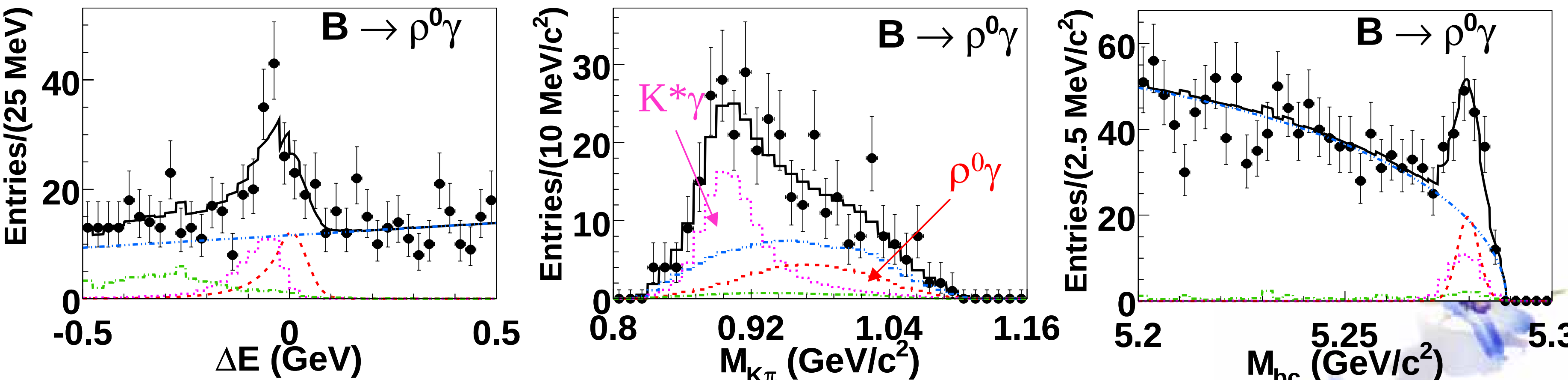
Suppressed by $|V_{td}/V_{ts}|$

Belle, arXiv:0804.4770 , 657M BB
Submitted to PRL

Update B → ργ, ωγ by Belle

- B → K*γ is significant background
  - (Mis-id rate for kaon) x B.F(B → K*γ) > B.F(B → ργ)
- $M_{K\pi}$ now in the fit for $B^0 \to \rho^0\gamma$ (M_{bc}-ΔE-$M_{K\pi}$ fit)
  - $M_{K\pi}$: invariant mass of ππ with kaon mass assignment for one pion
- good separation of signal from background

$$N(B^0 \to \rho^0\gamma) = 75.7^{+16.8}_{-16.0}$$

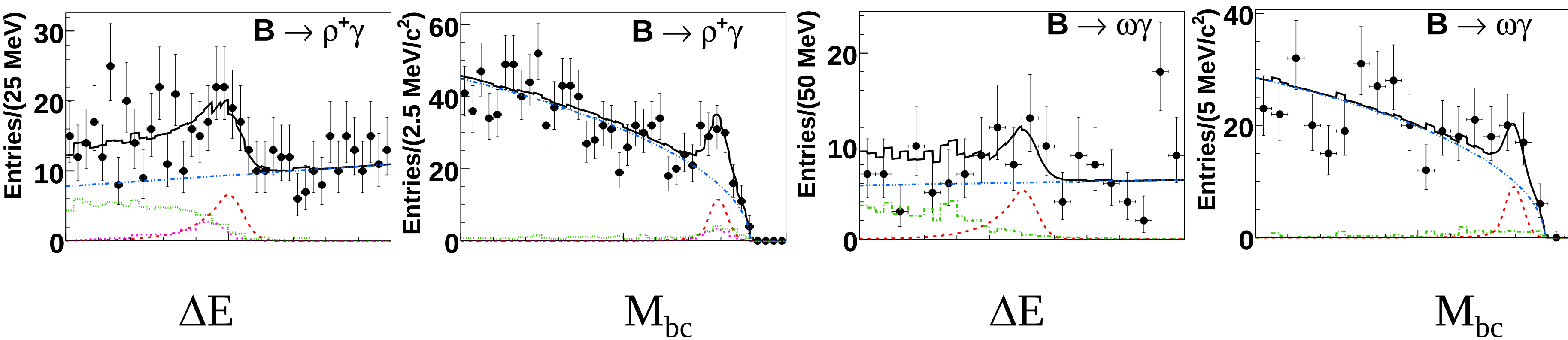


N. Taniguchi
FPCP 08, Taipei, Taiwan

Measurements of branching fraction for $B \rightarrow \rho\gamma, \omega\gamma$

$$N(B^+ \rightarrow \rho^+\gamma) = 45.8^{+15.2}_{-14.5}$$

$$N(B^0 \rightarrow \omega\gamma) = 17.5^{+8.2}_{-7.4}$$



$$B.F(B^+ \rightarrow \rho^+\gamma) = (8.7^{+2.9+0.9}_{-2.7-1.1}) \times 10^{-7}$$

$$B.F(B^0 \rightarrow \omega\gamma) = (4.0^{+1.9}_{-1.7} \pm 1.3) \times 10^{-7}$$

$$B.F(B^0 \rightarrow \rho^0\gamma) = (7.8^{+1.7+0.9}_{-1.6-1.0}) \times 10^{-7}$$

Belle, arXiv:0804.4770 , 657M BB
BaBar PRL98, 151802 (2007), 347M BB

Comparison

	Belle $B(10^{-7})$	Belle (Σ)	Babar $B(10^{-7})$	Babar (Σ)
$B^+ \to \rho^+\gamma$	$8.7^{+2.9\ +0.9}_{-2.7\ -1.1}$	(3.3σ)	$11.0^{+3.7}_{-3.3} \pm 0.9$	(3.8σ)
$B^0 \to \rho^0\gamma$	$7.8^{+1.7\ +0.9}_{-1.6\ -1.0}$	(5.0σ)	$7.9^{+2.2}_{-2.0} \pm 0.6$	(4.9σ)
$B^0 \to \omega\gamma$	$4.0^{+1.9}_{-1.7} \pm 1.3$	(2.6σ)	$4.0^{+2.4}_{-2.0} \pm 0.5$	(2.2σ)
$B \to \rho\gamma$	$12.1^{+2.4}_{-2.2} \pm 1.2$	(5.8σ)	$13.6^{+2.9}_{-2.7} \pm 0.9$	(6.0σ)
$B \to (\rho,\omega)\gamma$	$11.4 \pm 2.0^{+1.0}_{-1.2}$	(6.2σ)	$12.5^{+2.5}_{-2.4} \pm 0.9$	(6.4σ)

$B \to (\rho,\omega)\gamma$: CKM constraint

Form factor ratio

$$R = \frac{B.F(B \to (\rho,\omega)\gamma)}{B.F(B \to K^*\gamma)} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \frac{(1-m_{(\rho,\omega)}^2/m_B^2)^3}{(1-m_{K*}^2/m_B^2)^3} \varsigma^2 [1+\Delta R]$$

[Ali, Lunghi, Parkhomenko, PLB 595, 323 (2004)]

Annihilation amplitude corrections

$$R = \frac{B.F(B \to (\rho,\omega)\gamma)}{B.F(B \to K^*\gamma)} = 0.0263 \pm 0.0047^{+0.0022}_{-0.0025}$$

Using Ball, Jones, Zwicky, PRD 75 054004 (2007)

$$|V_{td}/V_{ts}| = 0.195^{+0.020}_{-0.019}(\text{exp.}) \pm 0.015(\text{theo.})$$

CP Asymmetry of B → ργ by Belle

First CPV in $b \to d\gamma$

- Time-dependent CPV in $B \to \rho^0\gamma$ $A_{cp}(\Delta t) = S\sin\Delta m\Delta t + A\cos\Delta m\Delta t$
- S ~ zero in SM   *Time-dependent CP asymmetry*
  - Weak phase cancelation: $\arg(V_{td})$ in mixing ←→ $\arg(V_{td})$ in decay
  - Suppression due to photon polarization
- A could be non-zero in SM   *Direct CP asymmetry*
- Charge asymmetry in $B^+ \to \rho^+\gamma$ *Direct CP asymmetry*
  - Simultaneous fit to M_{bc} and ΔE of $B^+ \to \rho^+\gamma$ and $B^- \to \rho^-\gamma$
- Asymmetries in the other background sources
  - Fixed to zero in the nominal fit
  - Included in the systematic error
- $B \to D\pi$ control sample used for:
  - Detector bias

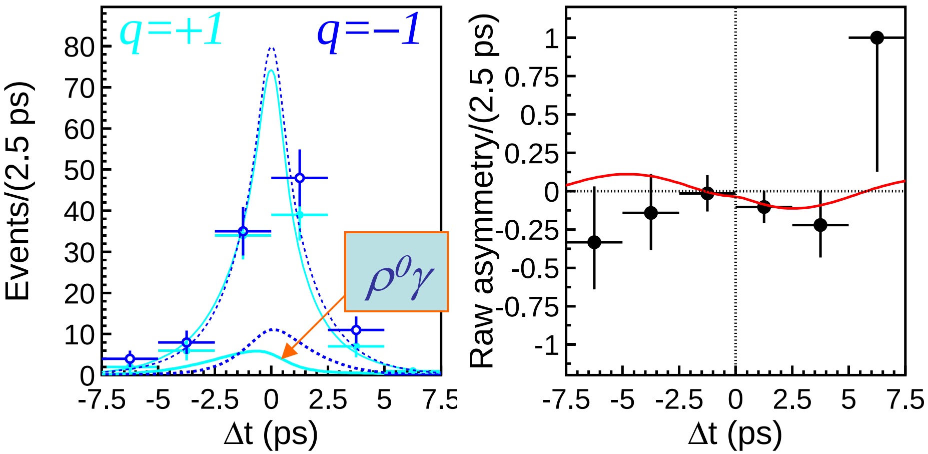
$$A(B^+ \to \rho^+\gamma) = \frac{N(B^- \to \rho^-\gamma) - N(B^+ \to \rho^+\gamma)}{N(B^- \to \rho^-\gamma) + N(B^+ \to \rho^+\gamma)}$$

Belle, PRL100, 021602 (2008), 657M BB

arXiv:0804.4770 , 657M BB

CP Asymmetry of $B \rightarrow \rho\gamma$

PRL **100**, 021602 (2008)

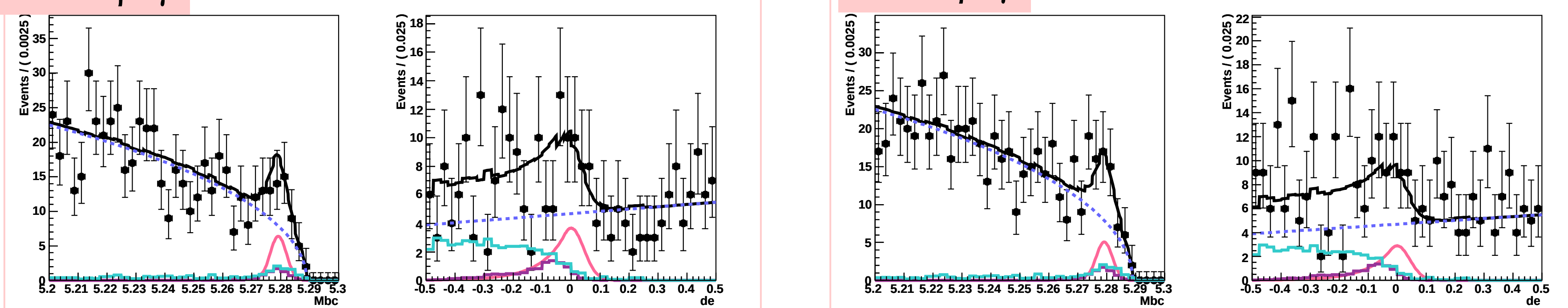


$$S_{\rho^0\gamma} = -0.83 \pm 0.65(stat) \pm 0.18(sys)$$

$$A_{\rho^0\gamma} = -0.44 \pm 0.49(stat) \pm 0.14(sys)$$

$B^+ \rightarrow \rho^+\gamma$

$B^- \rightarrow \rho^-\gamma$



M_{bc} ΔE M_{bc} ΔE

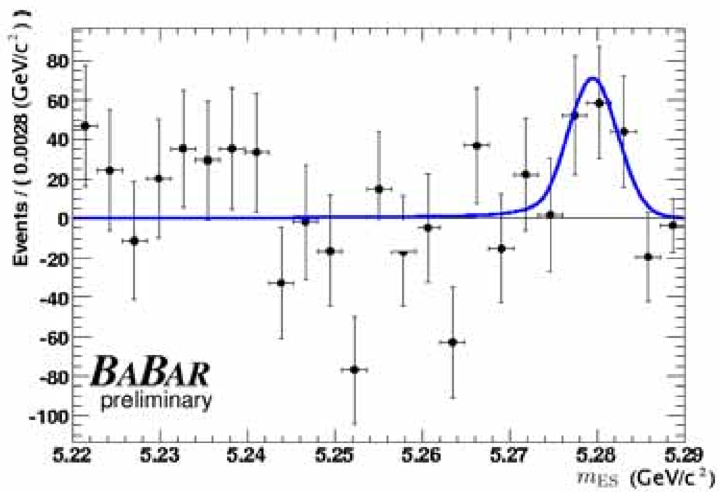
$$A(B^+ \rightarrow \rho^+\gamma) = -0.11 \pm 0.32(stat) \pm 0.09(sys)$$

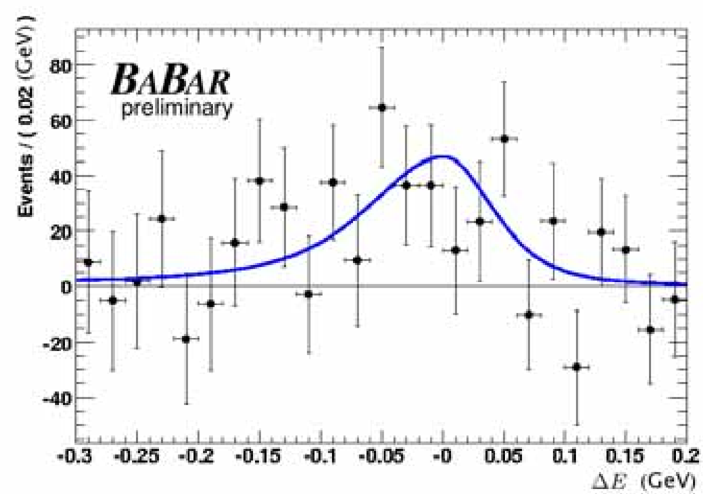
Babar, arXiv:0708.1652, 383M BB

Measurement of branching fraction for B → $X_d\gamma$ by BaBar

- Sum of 7 exclusive final state for study of inclusive b → dγ
- B → X_d γ ($X_d = \pi^+\pi^-, \pi^+\pi^0, \pi^+\pi^-\pi^+, \pi^+\pi^-\pi^0, \pi^+\pi^-\pi^+\pi^-, \pi^+\pi^-\pi^+\pi^0, \pi^+\eta$)
- 1.0 < M(X_d) < 1.8 GeV (B → ργ and ωγ are not included)
- Partial branching fraction B → X_d γ = $(3.1\pm0.9\pm0.7)\times10^{-6}$
  - Promising method for a improved $|V_{td}/V_{ts}|$ determination

383 M BB pairs





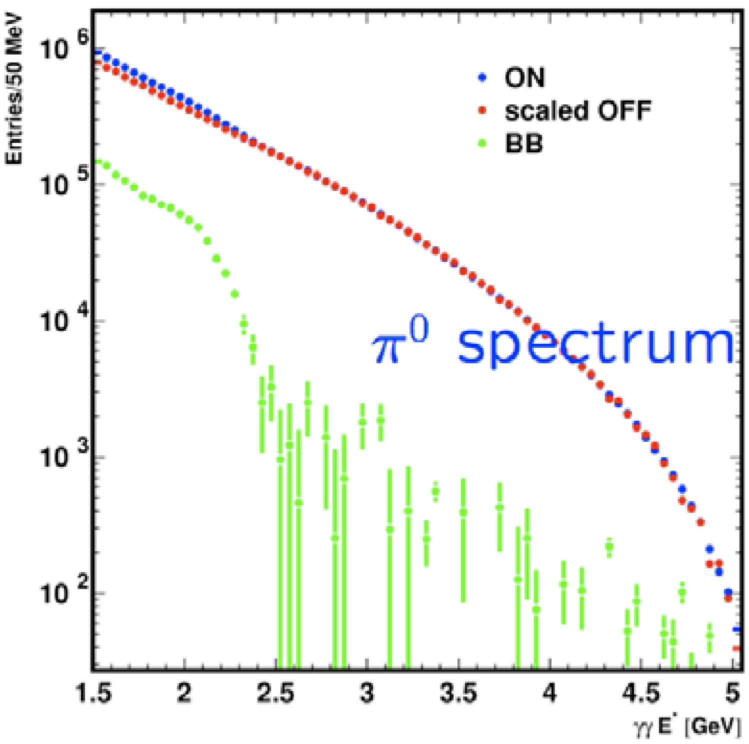
Summary

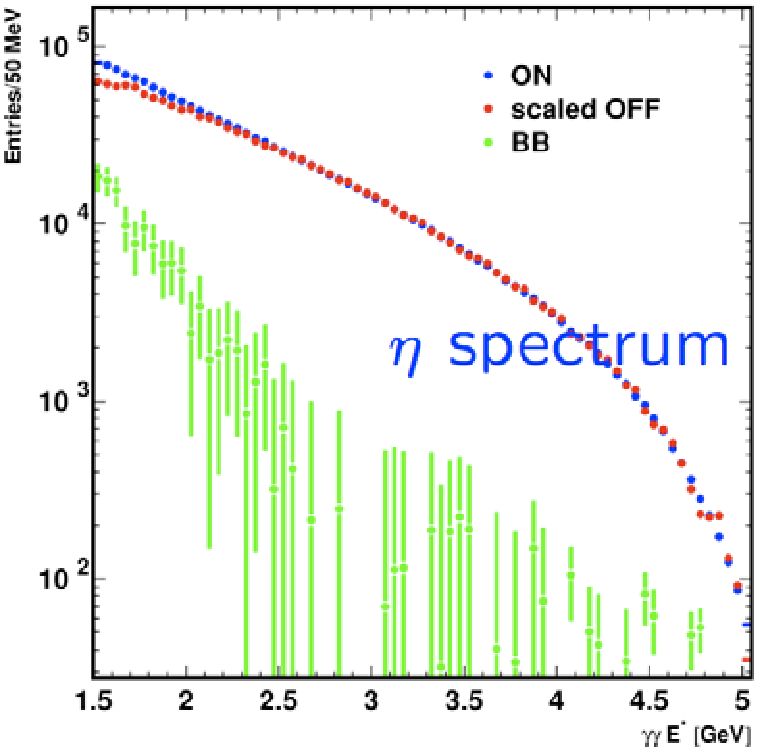
- Precise measurement of $b \to s\gamma$
  - Branching fraction with $E\gamma$ cut = 1.7 GeV
  - CP asymmetry with $0.6 < M(X_s) < 2.8$ GeV/c^2
- Measurement of $b \to d\gamma$
  - New measurement of exclusive modes with a larger sample
  - First measurement of the CP asymmetry of $B \to \rho\gamma$
  - First Evidence for $B \to X_d\gamma$ with $1.0 < M(X_d) < 1.8$ GeV/c^2

Backup slides

Pi0 and Eta from B-decays

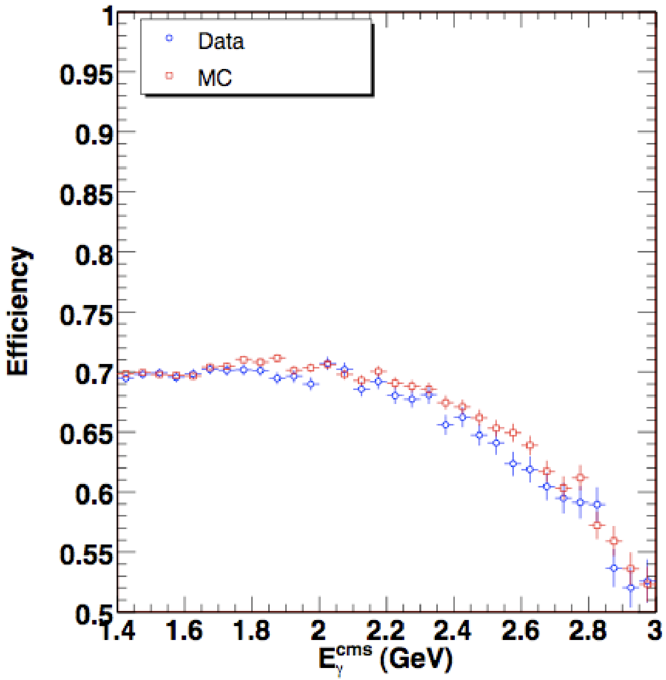
- Measure major backgrounds in data and MC independently and correct our analysis sample MC

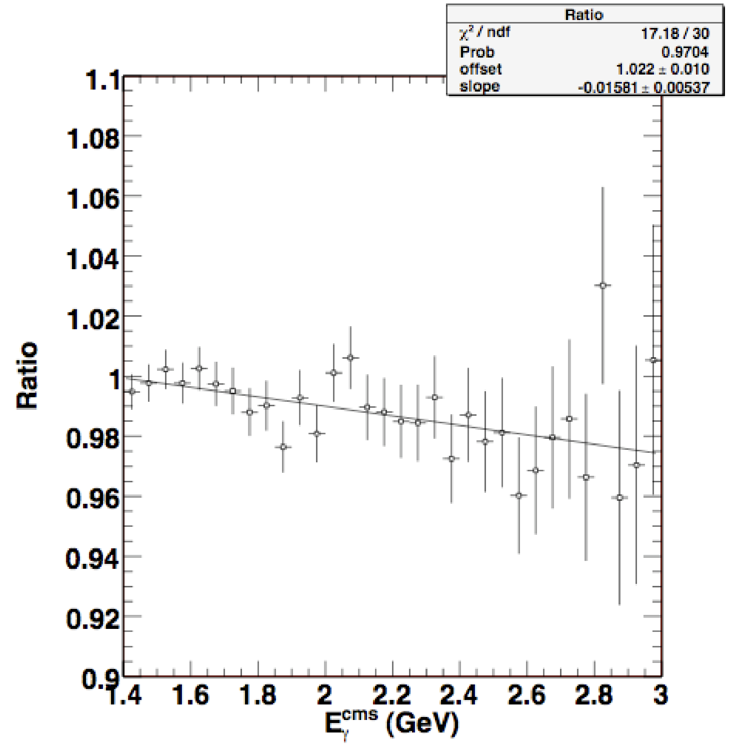




Efficiency corrections

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



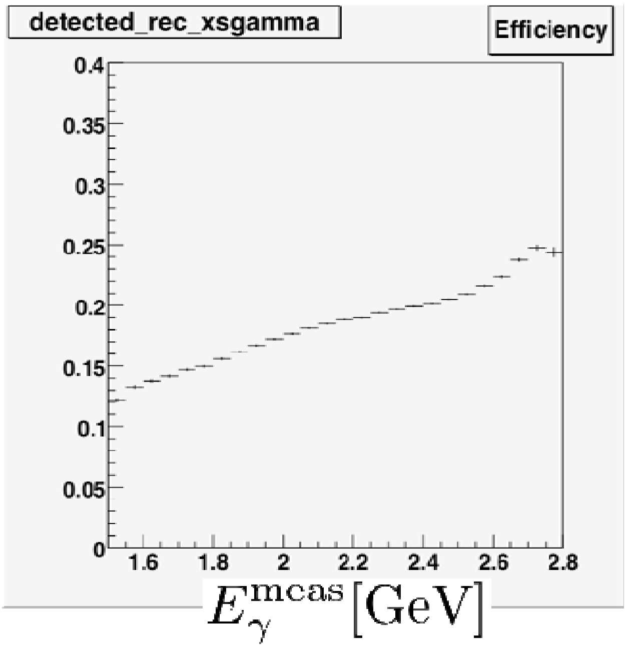


All selection criteria are investigated in a similar fashion

Acceptance Correction

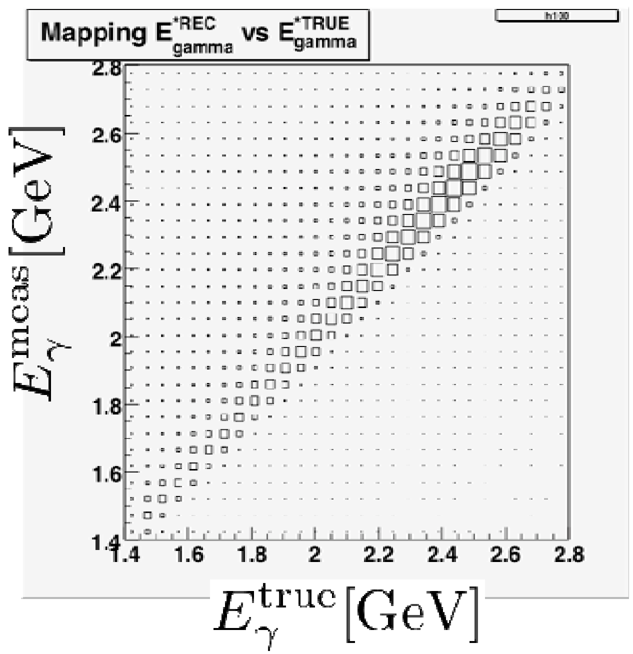
Selection Efficiency

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



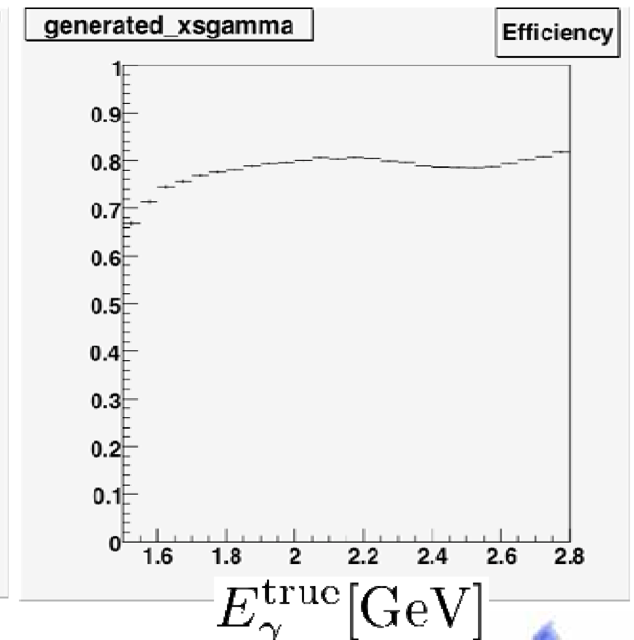
Unfolding

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



Detection Efficiency

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



- Signal models include KN, DGE, BBU, BLNP and GG
- The unfolding is done using Singular Value Decomposition (SVD).
- The MC response of the ECL is calibrated to match DATA using a study of radiative mu-pair events

First at E(cut)=1.7 GeV

Preliminary

Y(4S) rest frame

E(cut) [GeV]	PBF [10^-4]	Mean [GeV]	Variance [GeV^2]
1.70	3.32 ± 0.19 ± 0.37	2.291 ± 0.032 ± 0.053	0.0467 ± 0.0156 ± 0.0213
1.80	3.25 ± 0.17 ± 0.24	2.302 ± 0.025 ± 0.028	0.0417 ± 0.0096 ± 0.0081
1.90	3.13 ± 0.15 ± 0.16	2.318 ± 0.019 ± 0.014	0.0355 ± 0.0058 ± 0.0027
2.00	2.95 ± 0.14 ± 0.12	2.340 ± 0.015 ± 0.007	0.0290 ± 0.0033 ± 0.0009
2.10	2.68 ± 0.12 ± 0.10	2.370 ± 0.011 ± 0.005	0.0225 ± 0.0017 ± 0.0006

Preliminary

B-meson rest frame
(additional uncertainty due to models needed to calculate correction from Y(4S) to B frame)

E(cut) [GeV]	PBF [10^{-4}]	Mean [GeV]	Variance [GeV^2]
1.70	3.31 ± 0.19 ± 0.37 ± 0.01	2.281 ± 0.032 ± 0.053 ± 0.002	0.0396 ± 0.0130 ± 0.0213 ± 0.0012
1.80	3.24 ± 0.17 ± 0.24 ± 0.01	2.290 ± 0.025 ± 0.028 ± 0.002	0.0350 ± 0.0085 ± 0.0081 ± 0.0005
1.90	3.12 ± 0.15 ± 0.16 ± 0.02	2.305 ± 0.019 ± 0.014 ± 0.004	0.0292 ± 0.0053 ± 0.0027 ± 0.0008
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	2.62 ± 0.12 ± 0.10 ± 0.05	2.350 ± 0.011 ± 0.005 ± 0.006	0.0170 ± 0.0017 ± 0.0006 ± 0.0012

Systematics

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	PBF[10^{-4}] 1.8 GeV
Continuum Background	0.17	0.12
Selection Criteria	0.20	0.15
pi0/eta background	0.06	0.05
other B - background	0.24	0.13
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

Preliminary

Extrapolation to E γ>1.6 GeV

FROM - Phys.Rev. D73 (2006) 073008
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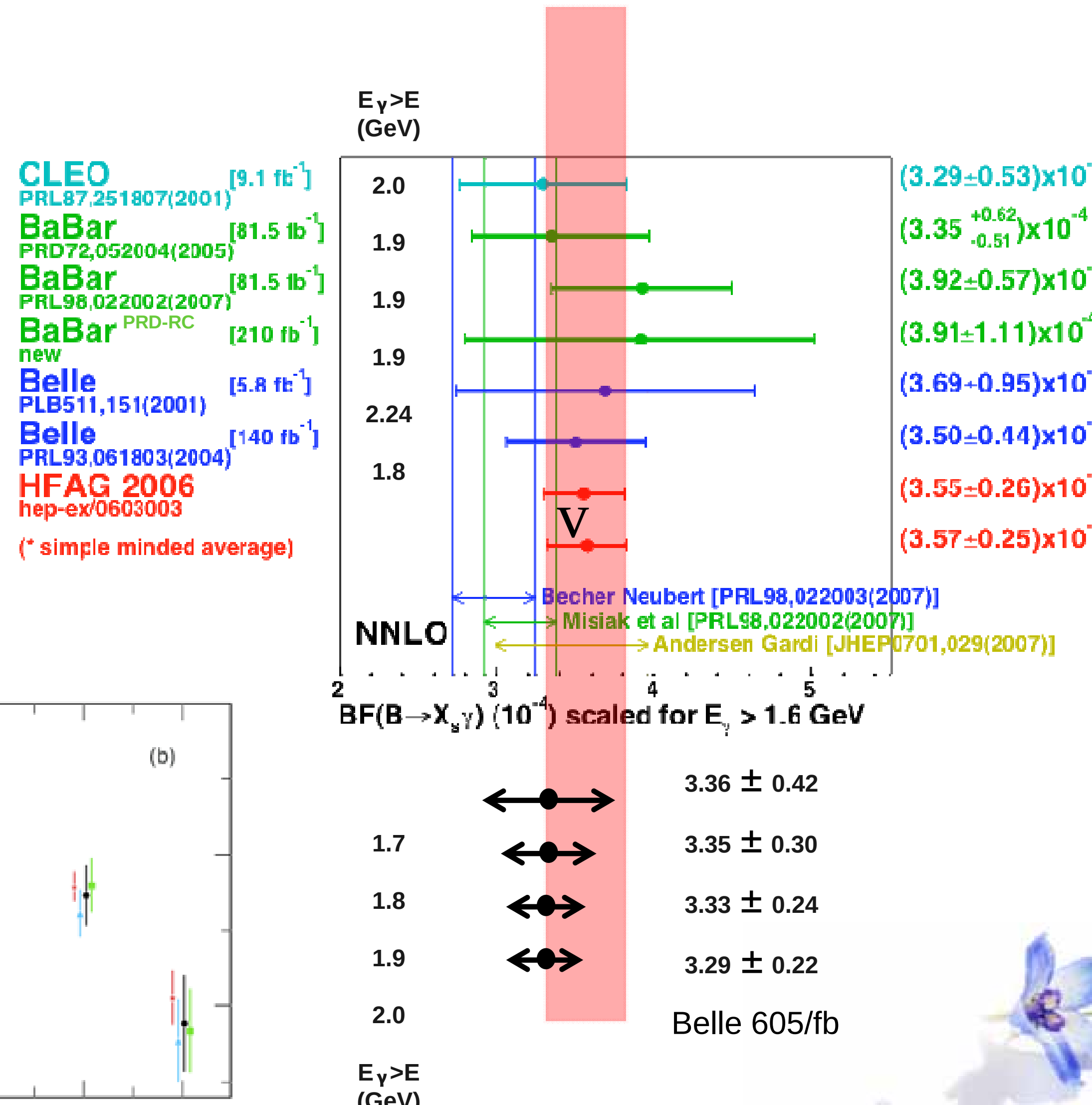

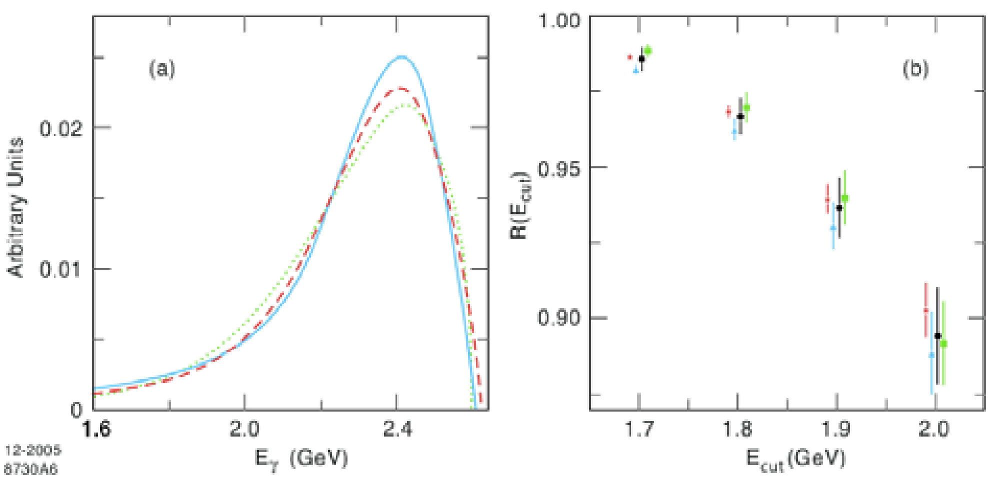

p.38

Taiwan

Signal Models

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DGE
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GG
Gambino & Giordano - work in progress