Inclusive Radiative B-meson Decays at Belle

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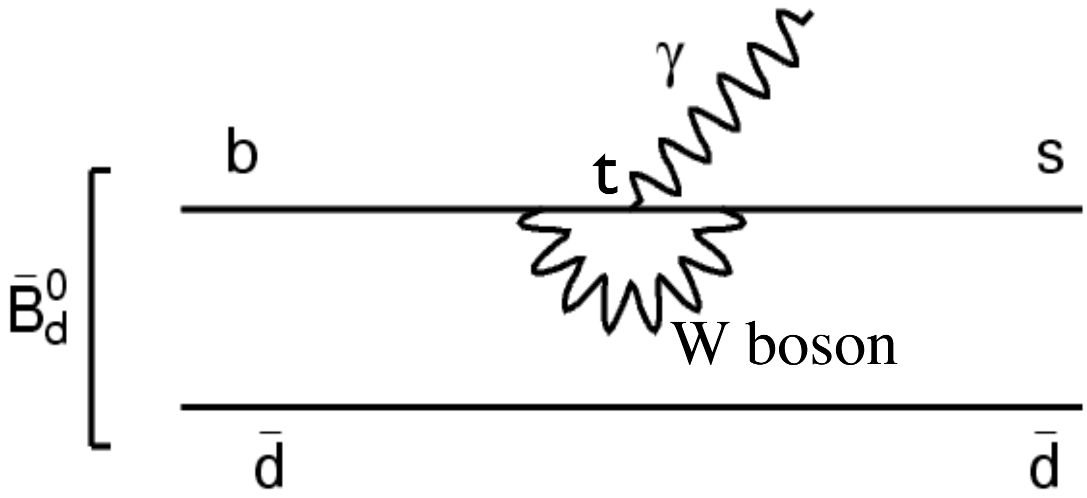
XLIII Recontres de Moriond

ELECTROWEAK INTERACTIONS &

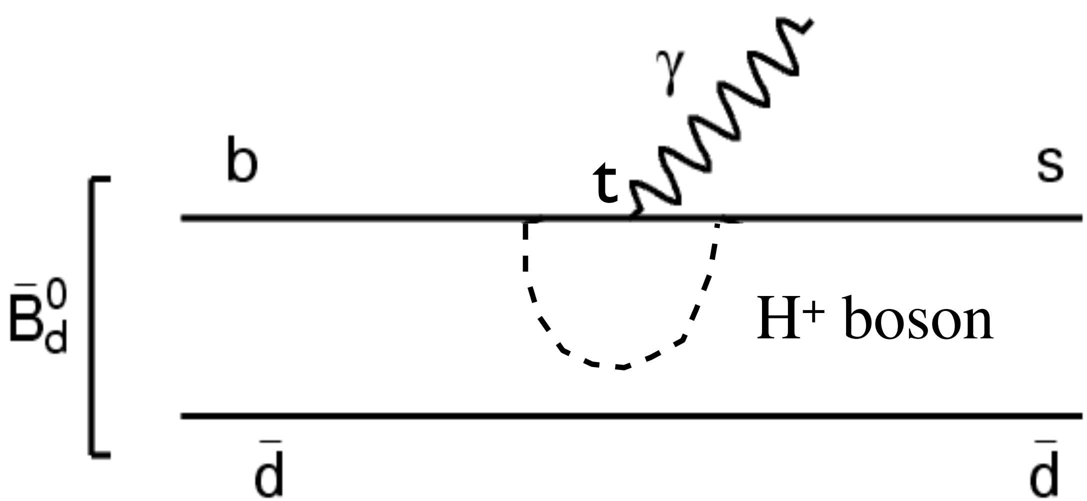
UNIFIED THEORIES

Motivation

Inclusive Radiative B-meson decays are a sensitive probe for physics beyond the standard model.

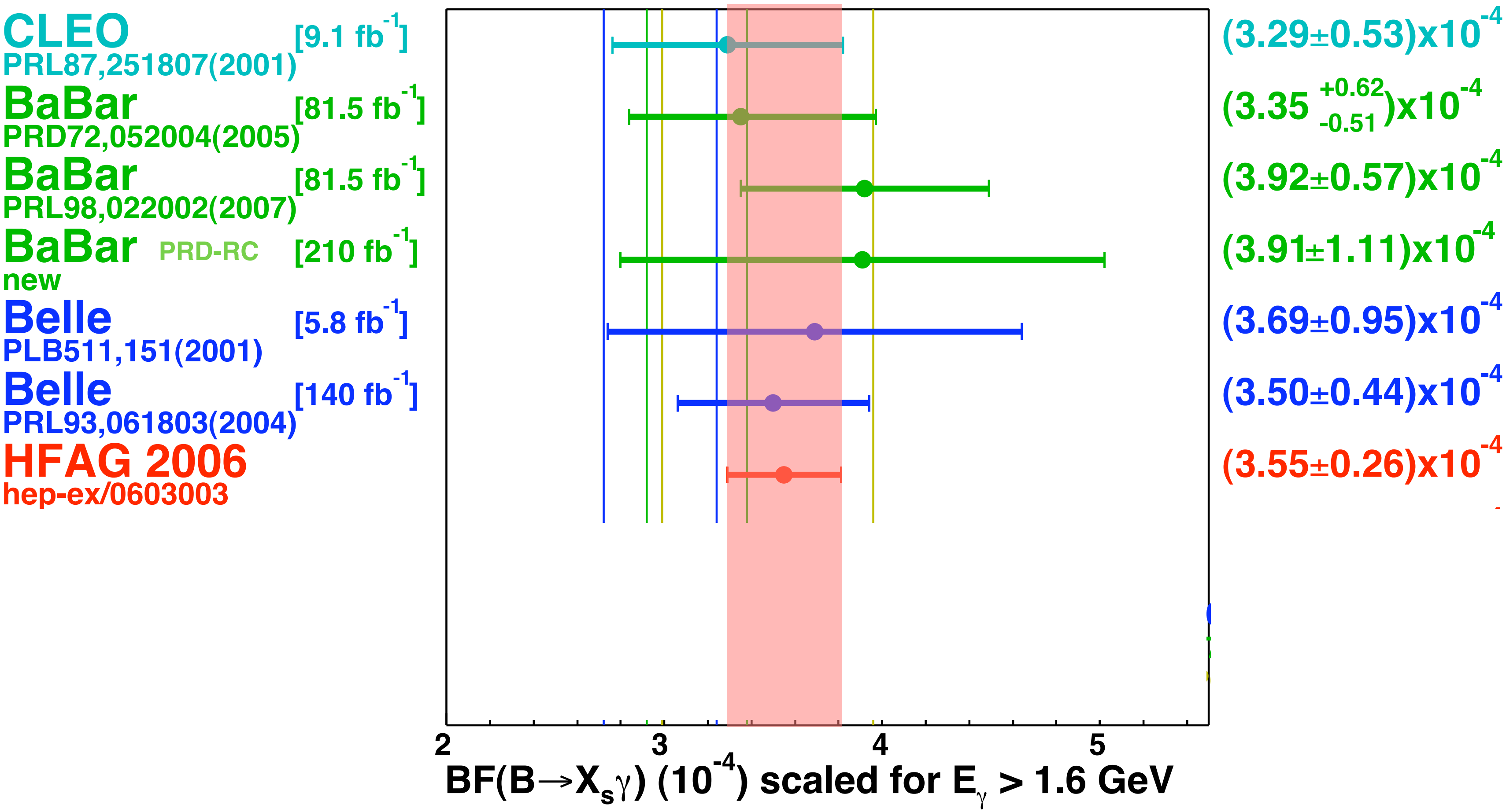


Motivation

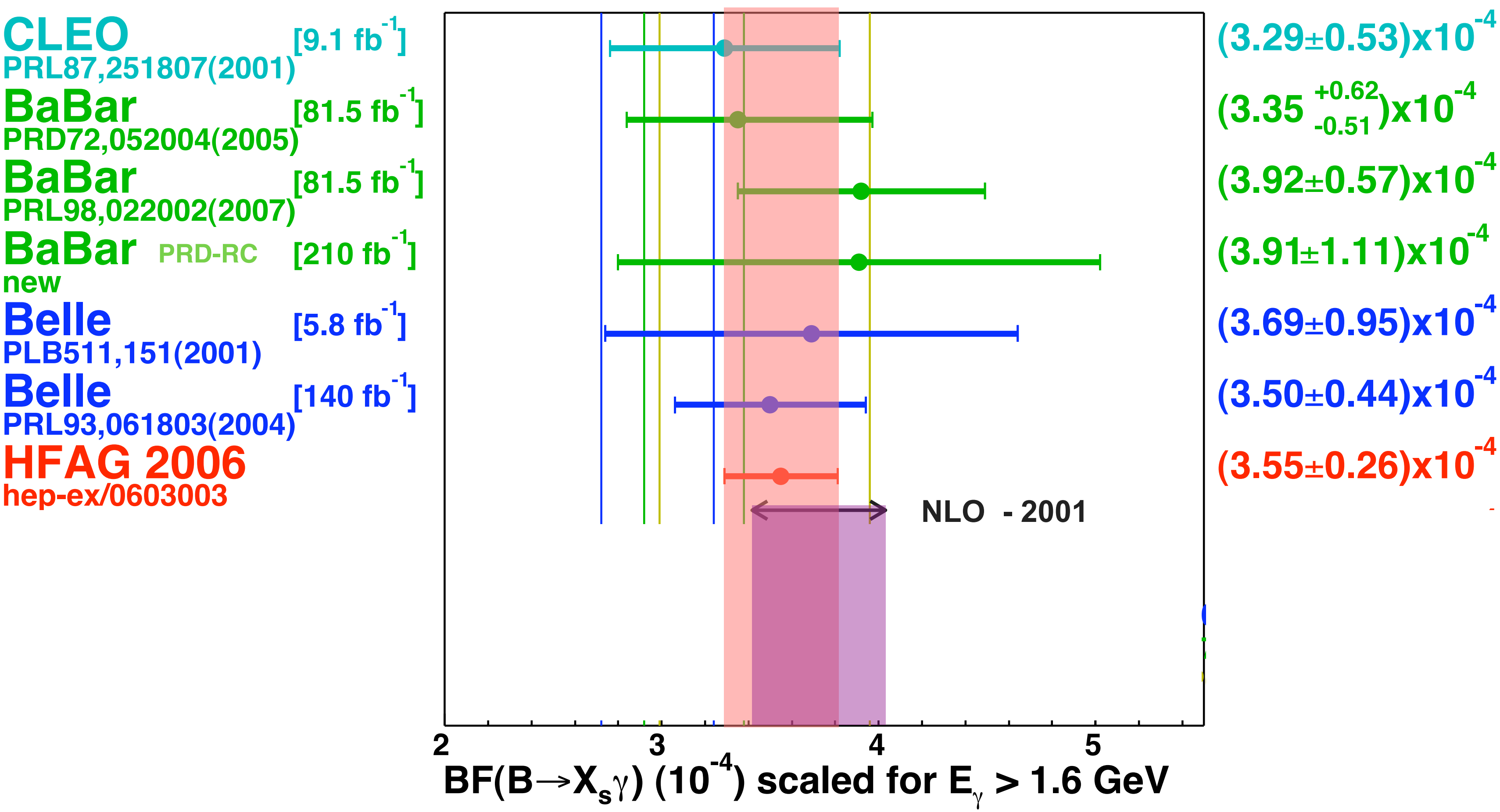


New physics may enter as new particles in the loop e.g heavier supersymmetric particles

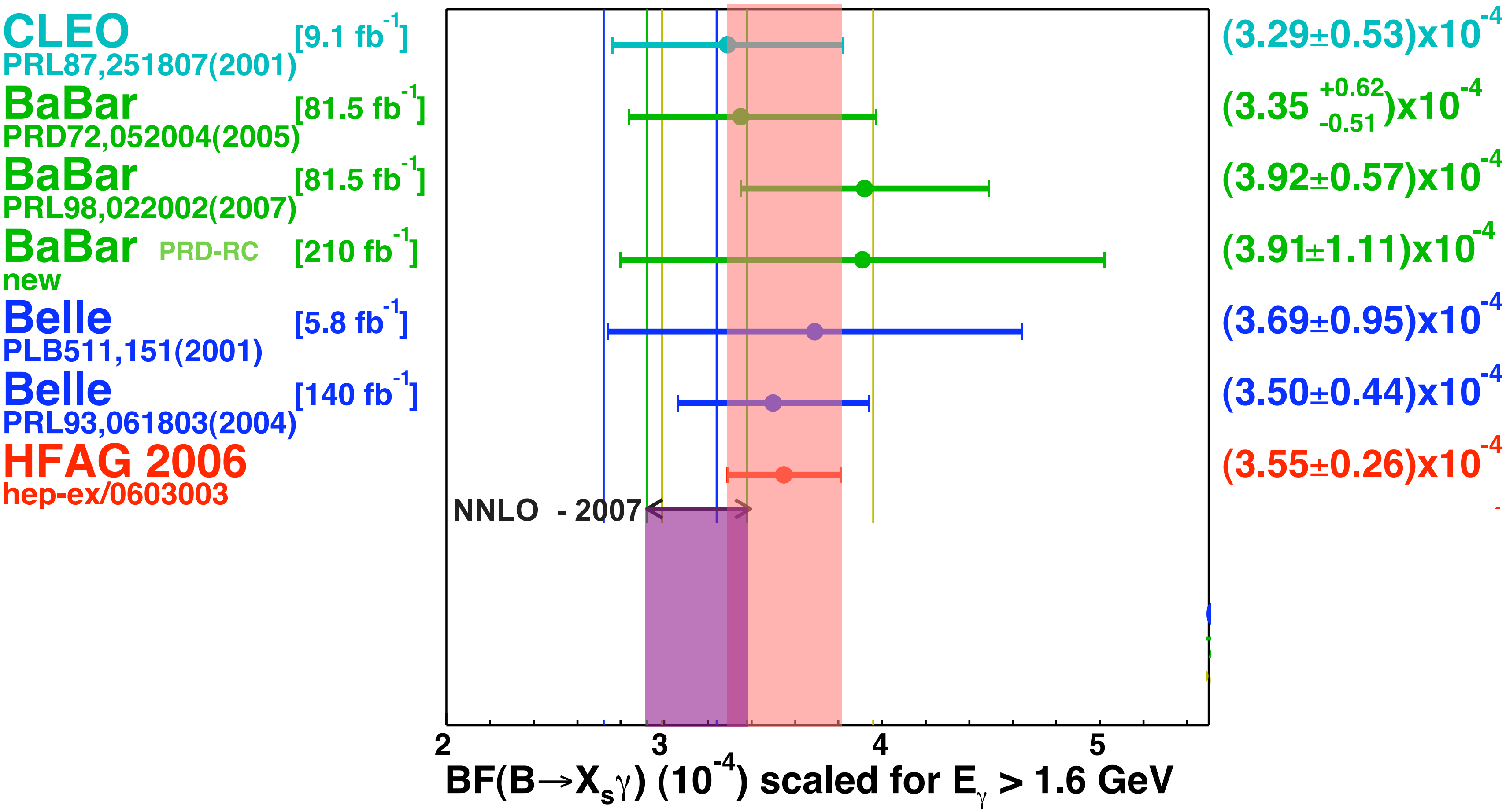
Branching Fraction $B \to X_s\gamma$



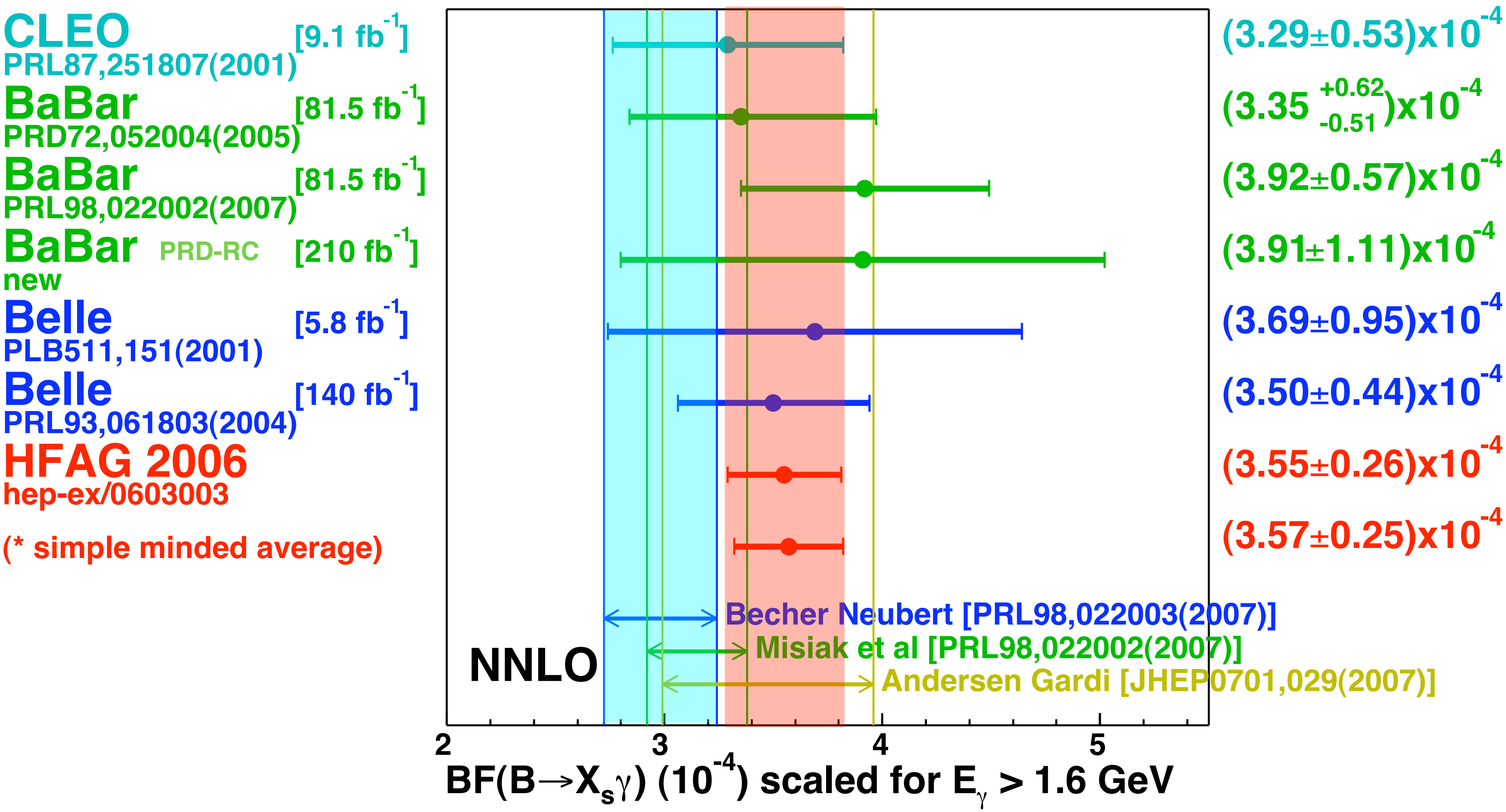
Branching Fraction $B \to X_s \gamma$



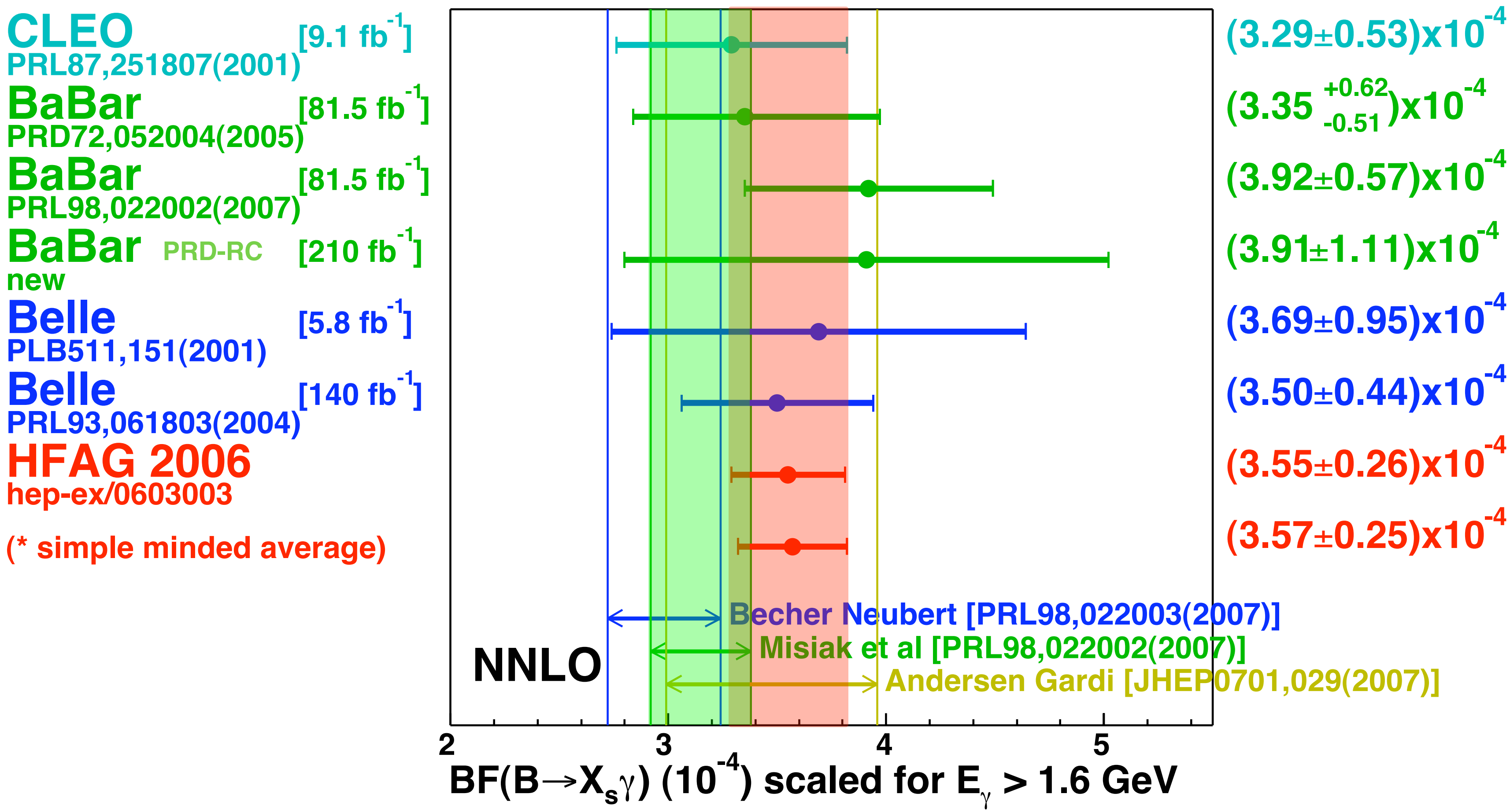
Branching Fraction $B \to X_s\gamma$



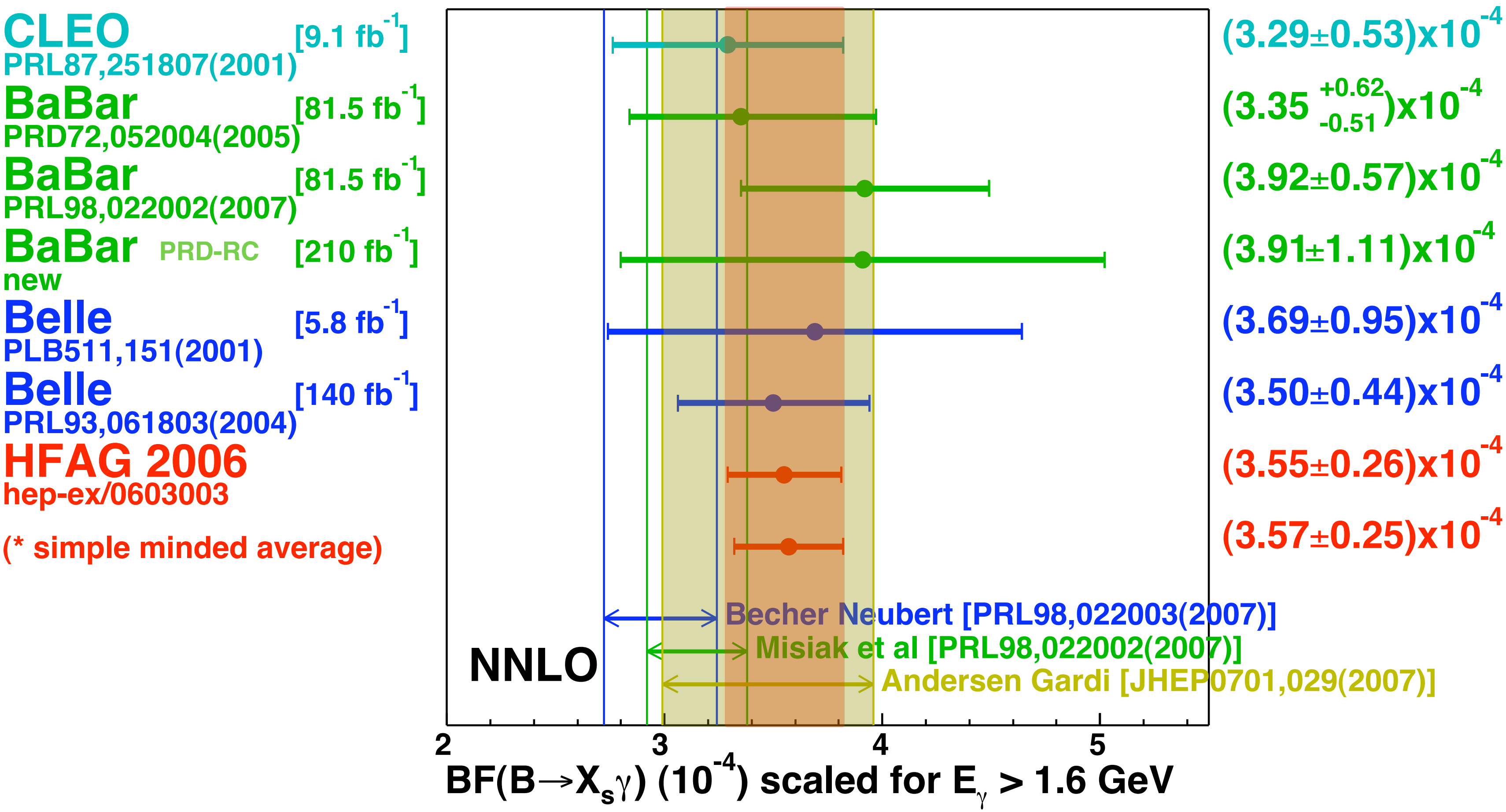
Branching Fraction $B \to X_s\gamma$



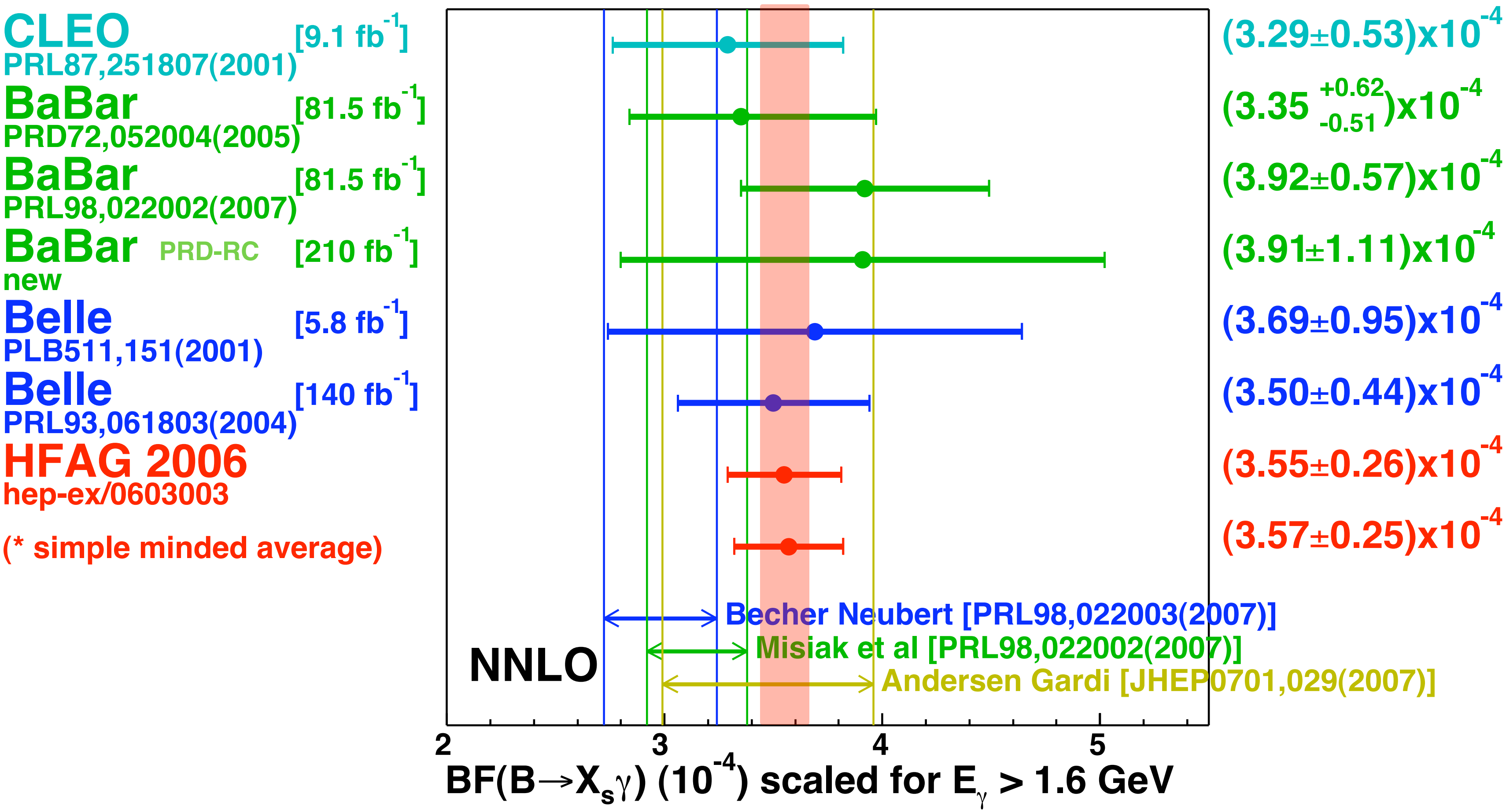
Branching Fraction $B \to X_s \gamma$



Branching Fraction $B \to X_s\gamma$

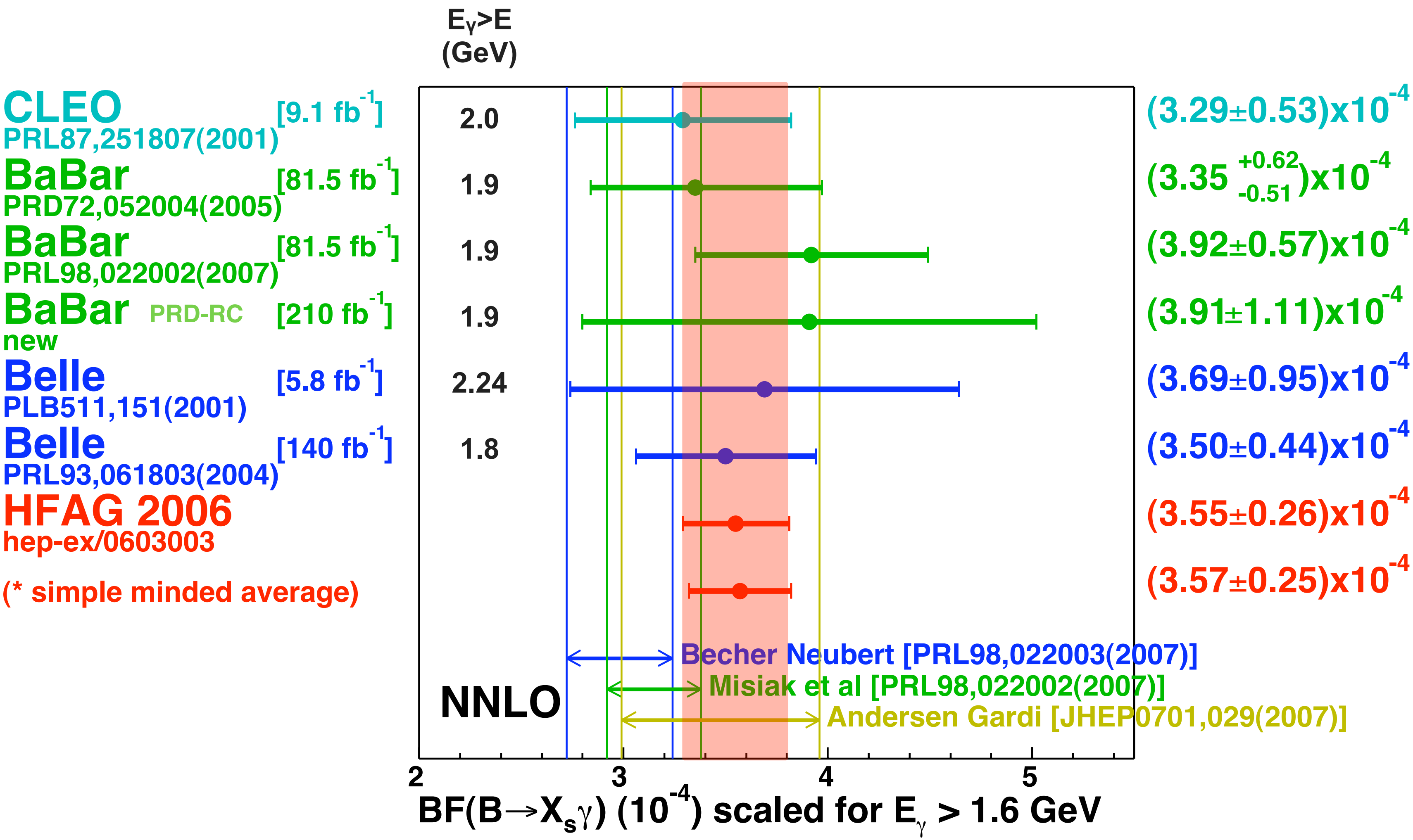


Branching Fraction $B \to X_s\gamma$



IMPERATIVE FOR EXPERIMENTS TO REDUCE UNCERTAINTY!

Branching Fraction $B \to X_s \gamma$



USE MORE DATA & TRY LOWER THE ENERGY CUT!

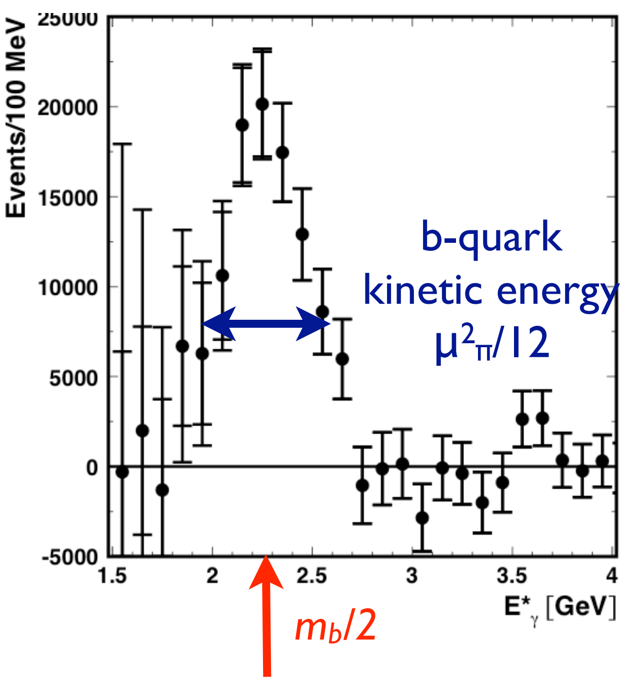
Unitarity Triangle

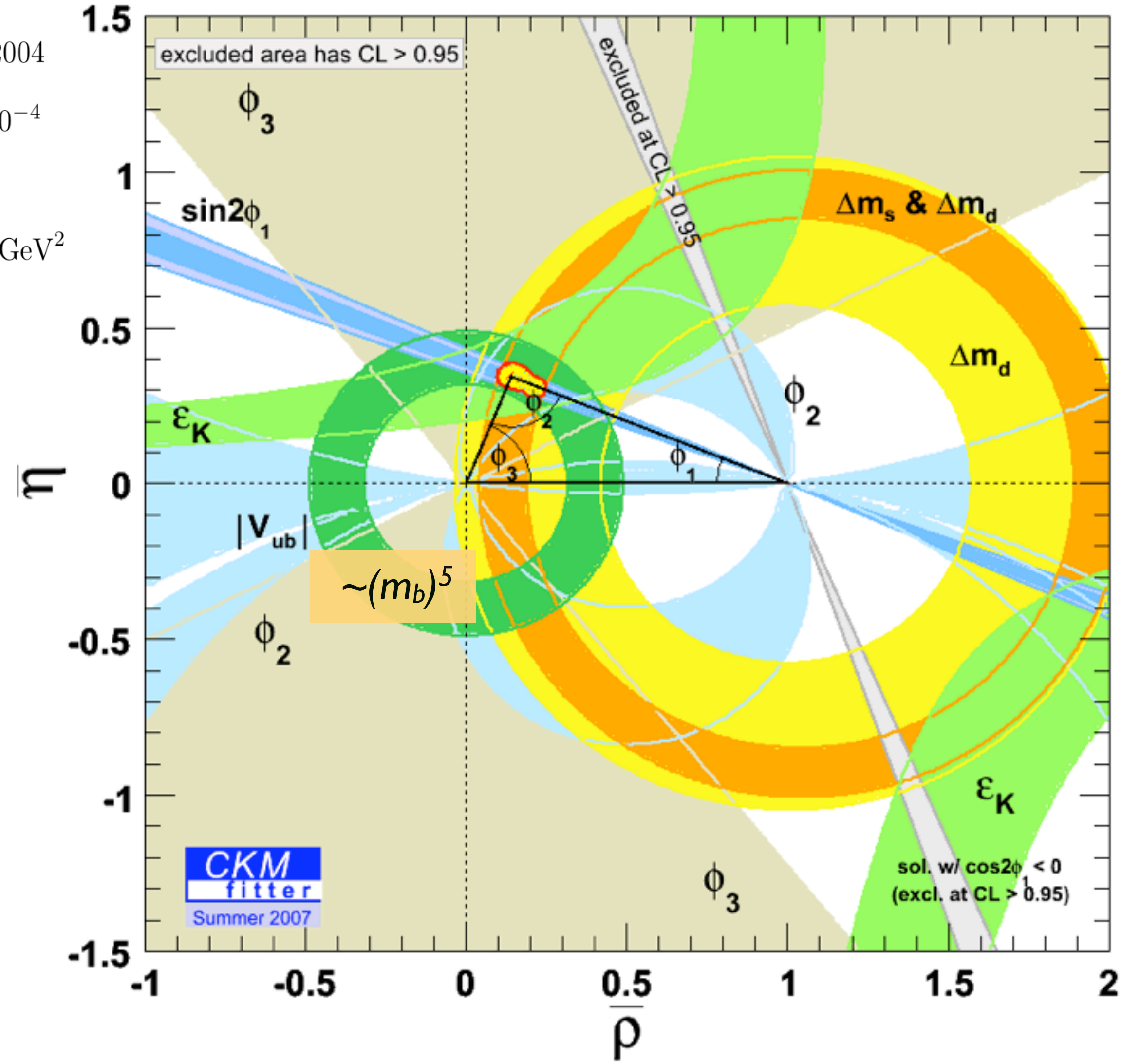
- P. Koppenburg et al (Belle) Phys.Rev.Lett.93:061803,2004

$$\mathcal{B}(b \to s\gamma) = (3.55 \pm 0.32^{+0.30+0.11}_{-0.31-0.07}) \times 10^{-4}$$

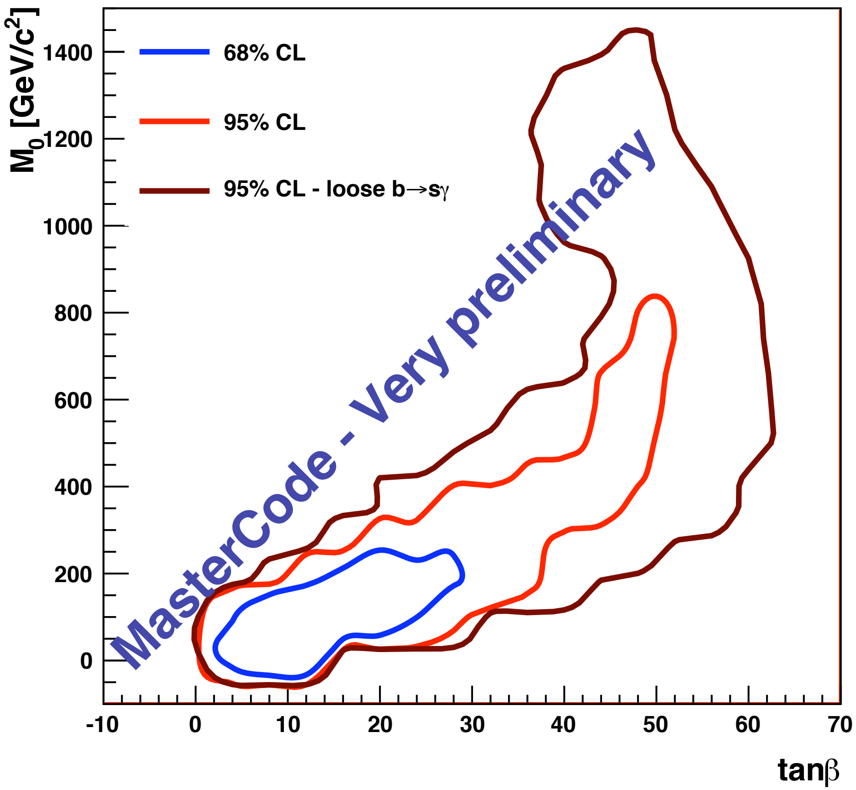
$$\langle E_\gamma \rangle = 2.292 \pm 0.026 \pm 0.034\,\text{GeV}$$

$$\langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2 = 0.0305 \pm 0.0074 \pm 0.0063\,\text{GeV}^2$$





CMSSM phase space



Ratio of BF(B -> $X_s\gamma$)
(Measurement/SM prediction)
Red : 1.127 +- 0.12
Brown : 1.127 +- 0.36

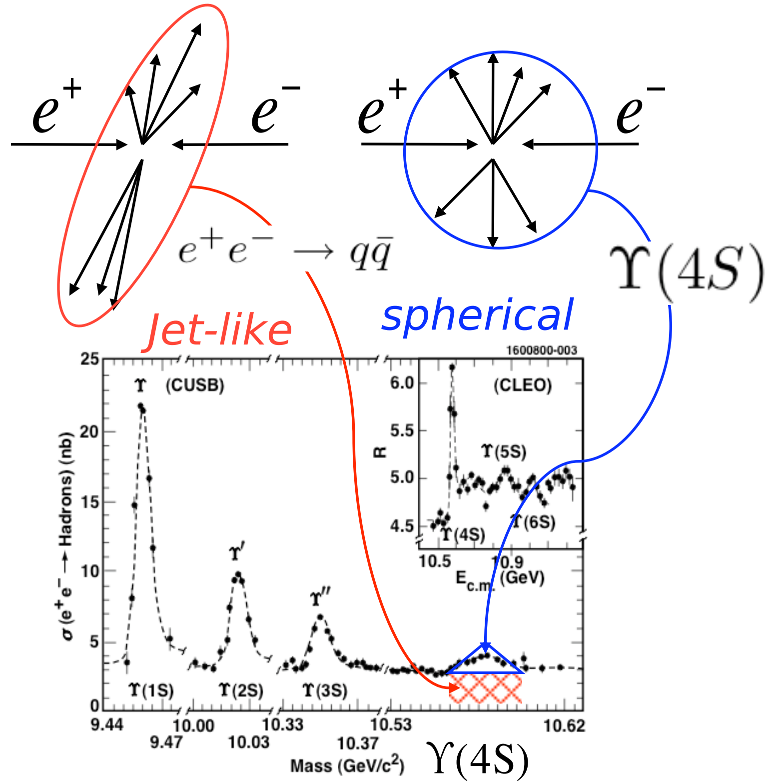
See talk by Frederic Ronga
" Prediction for the Lightest Higgs Boson Mass in the Framework of CMSSM"
Les Rencontres de Physique de la Vallée d'Aoste 2008

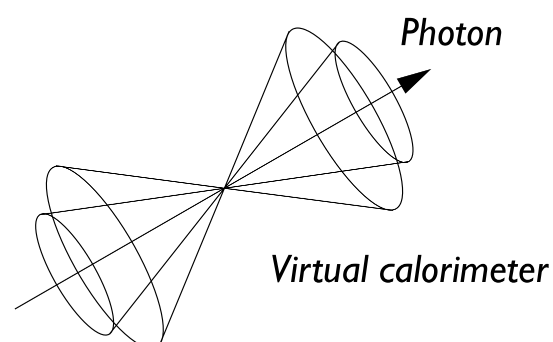
- Collaboration of interested theorists and experimentalists

Buchmüller, Oliver (CERN) – Exp.
De Roeck, Albert (CERN & Uni. Antwerpen) – Exp.
Heinemeyer, Sven (Santander) – Theo.
Olive, Keith (Uni. of Minnesota) – Theo.
Ronga, Frédéric (CERN) – Exp.
Weiglein, Georg (Durham) – Theo.
Cavanaugh, Richard (Uni. of Florida) – Exp.
Ellis, John (CERN) – Theo.
Isidori, Gino (INFN Frascati) – Theo.
Paradisi, Paride (Uni. of Valencia) – Theo.
Weber, Arne (Max Planck Inst. (Munich)) – Theo.

Inclusive Analysis

- Find isolated clusters in the ECL
  - High energy E* > 1.4 GeV
  - Veto γ from π, η & Bhabha
  - Use topological info to suppress continuum background
- Background is still very big!
  - Estimate continuum using OFF resonance data
  - Estimate B decays using "corrected" MC sample



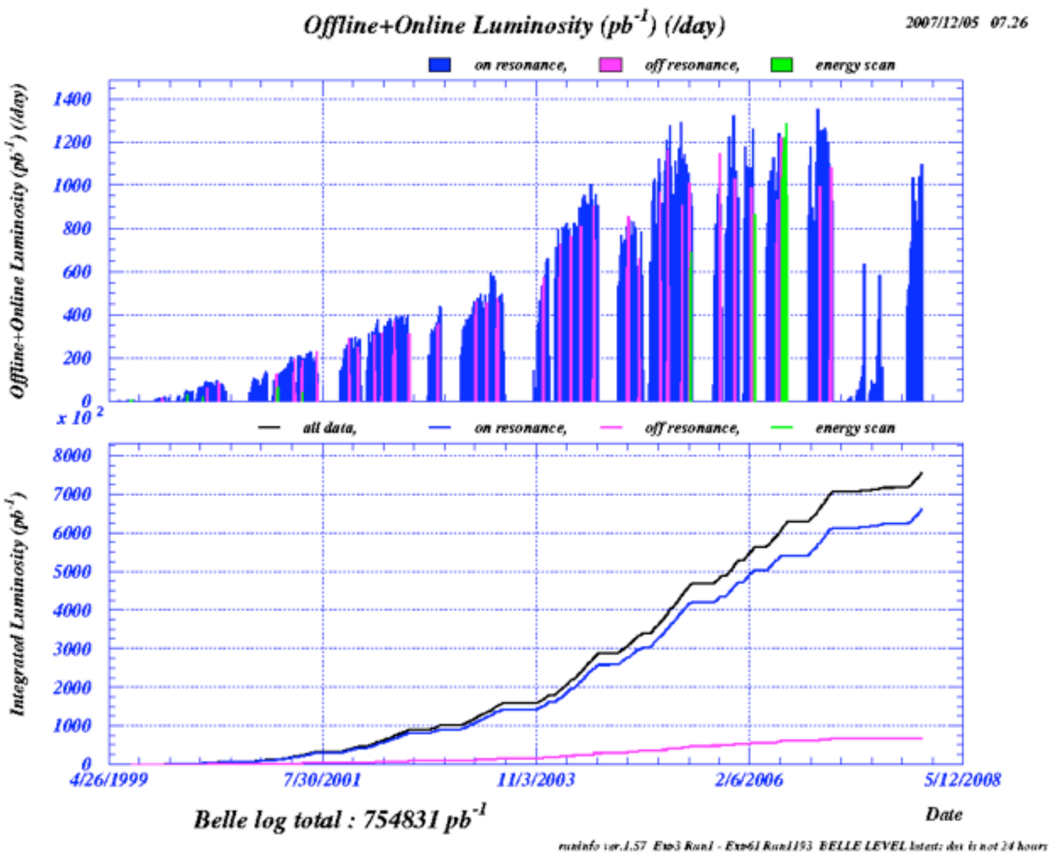


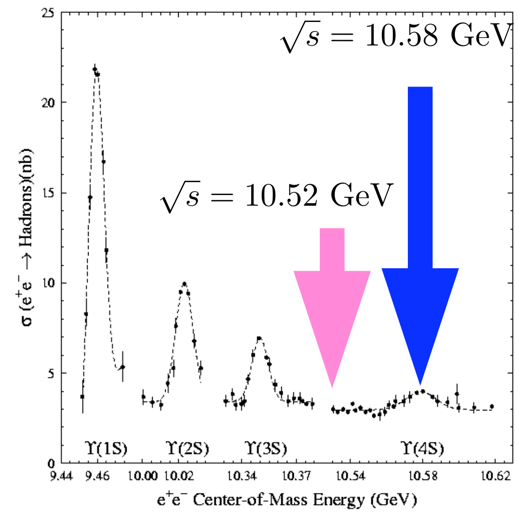
Continuum Scaling

$$N^{B\bar{B}}(E_\gamma^{*\mathrm{ON}}) = N^{\mathrm{ON}}(E_\gamma^{*\mathrm{ON}}) - c\alpha N^{\mathrm{OFF}}(F_E(E_\gamma^{*\mathrm{OFF}}))$$

Scaling OFF resonance data

$$N^{B\bar{B}}(E_\gamma^{*\mathrm{ON}}) = N^{\mathrm{ON}}(E_\gamma^{*\mathrm{ON}}) - c\alpha N^{\mathrm{OFF}}(F_E(E_\gamma^{*\mathrm{OFF}}))$$





$$\alpha = \frac{\int \mathcal{L}_{\mathrm{ON}} dt}{\int \mathcal{L}_{\mathrm{OFF}} dt} \cdot \frac{s_{\mathrm{OFF}}}{s_{\mathrm{ON}}} = \frac{604.633}{68.275} \frac{10.52^2}{10.58^2} = 8.7557(\pm 0.3\%)$$

Response to Selection

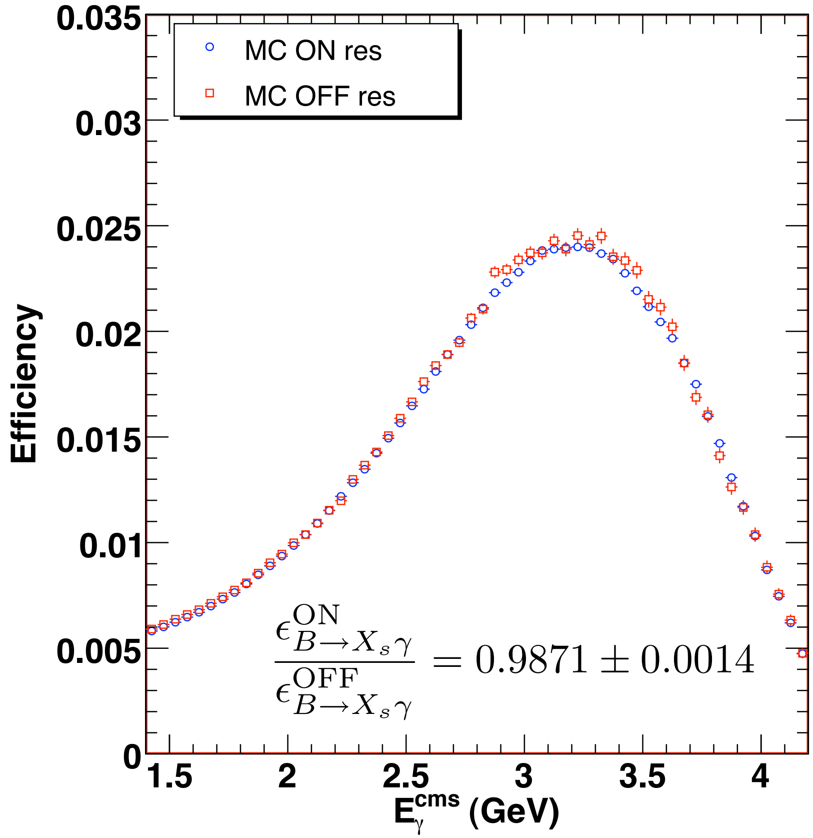
$$N^{B\bar{B}}(E_\gamma^{*\mathrm{ON}}) = N^{\mathrm{ON}}(E_\gamma^{*\mathrm{ON}}) - c\alpha N^{\mathrm{OFF}}(F_E(E_\gamma^{*\mathrm{OFF}}))$$

$$c = \frac{\epsilon^{\mathrm{ON}}_{\mathrm{HadB}}}{\epsilon^{\mathrm{OFF}}_{\mathrm{HadB}}} \cdot \frac{\epsilon^{\mathrm{ON}}_{\mathrm{B\to X_s\gamma}}}{\epsilon^{\mathrm{OFF}}_{\mathrm{B\to X_s\gamma}}} \cdot F_N$$

Efficiency of Hadronic Skim selection

$$\frac{\epsilon^{\mathrm{ON}}_{\mathrm{HadB}}}{\epsilon^{\mathrm{OFF}}_{\mathrm{HadB}}} = 0.9986 \pm 0.0001$$

Efficiency of the selection criteria

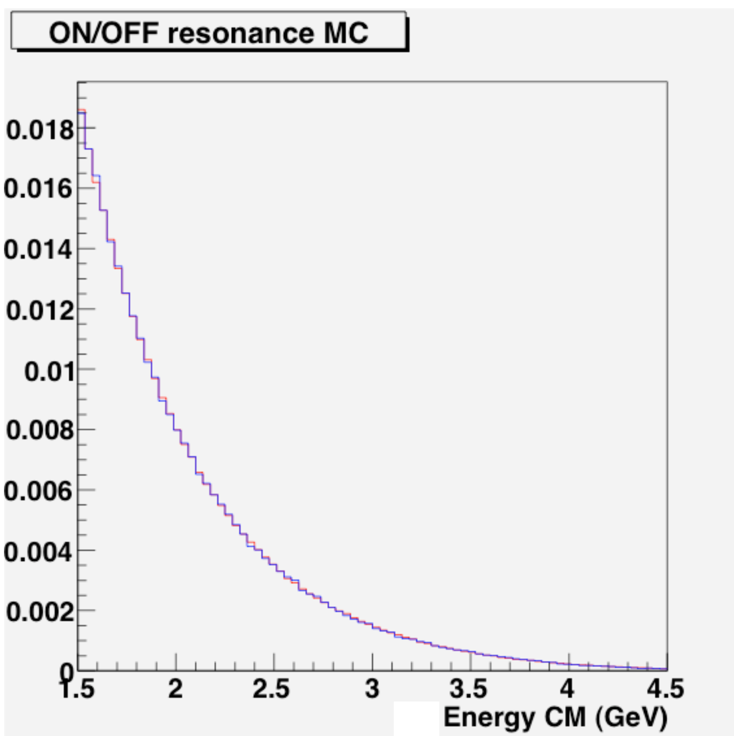


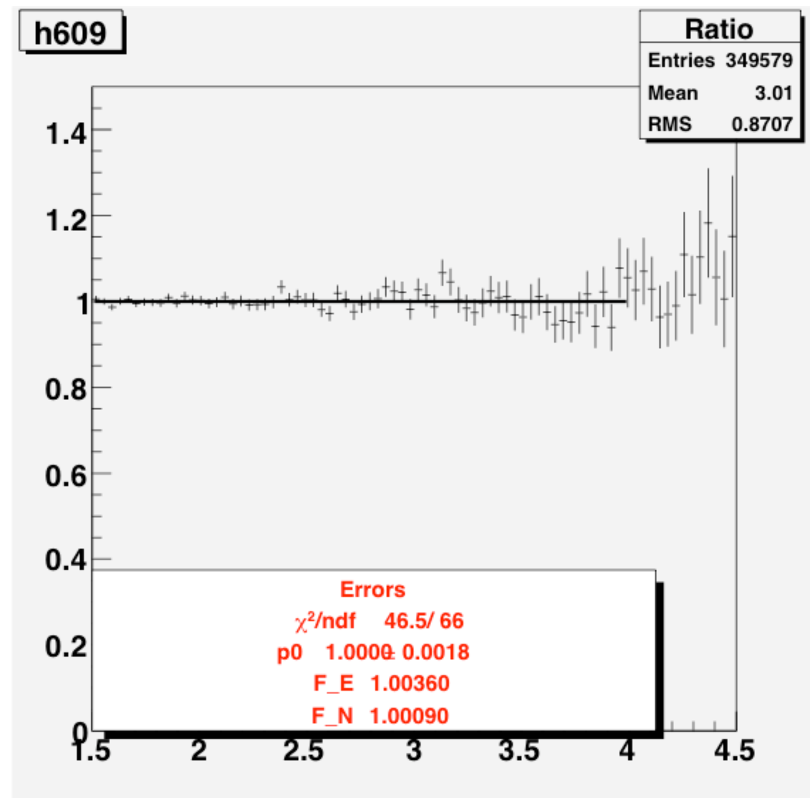
$$\frac{\epsilon^{\mathrm{ON}}_{B\to X_s\gamma}}{\epsilon^{\mathrm{OFF}}_{B\to X_s\gamma}} = 0.9871 \pm 0.0014$$

Energy (F_E) and Multiplicity (F_N) Scaling

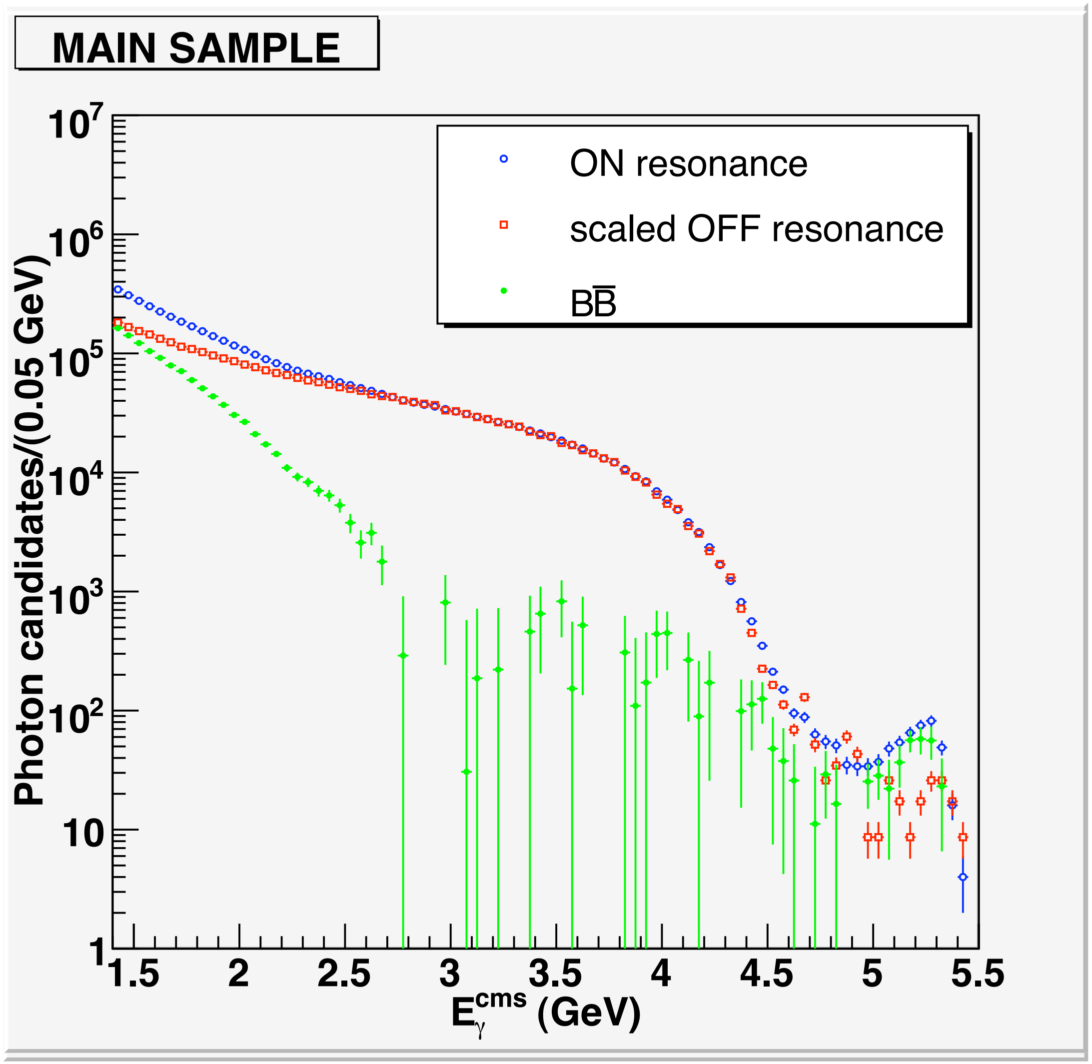
$$N^{B\bar{B}}(E_\gamma^{*\mathrm{ON}}) = N^{\mathrm{ON}}(E_\gamma^{*\mathrm{ON}}) - c\alpha N^{\mathrm{OFF}}(F_E(E_\gamma^{*\mathrm{OFF}}))$$

$$c = \frac{\epsilon_{\mathrm{HadB}}^{\mathrm{ON}}}{\epsilon_{\mathrm{HadB}}^{\mathrm{OFF}}} \cdot \frac{\epsilon_{\mathrm{B \to X_s \gamma}}^{\mathrm{ON}}}{\epsilon_{\mathrm{B \to X_s \gamma}}^{\mathrm{OFF}}} \cdot F_N$$

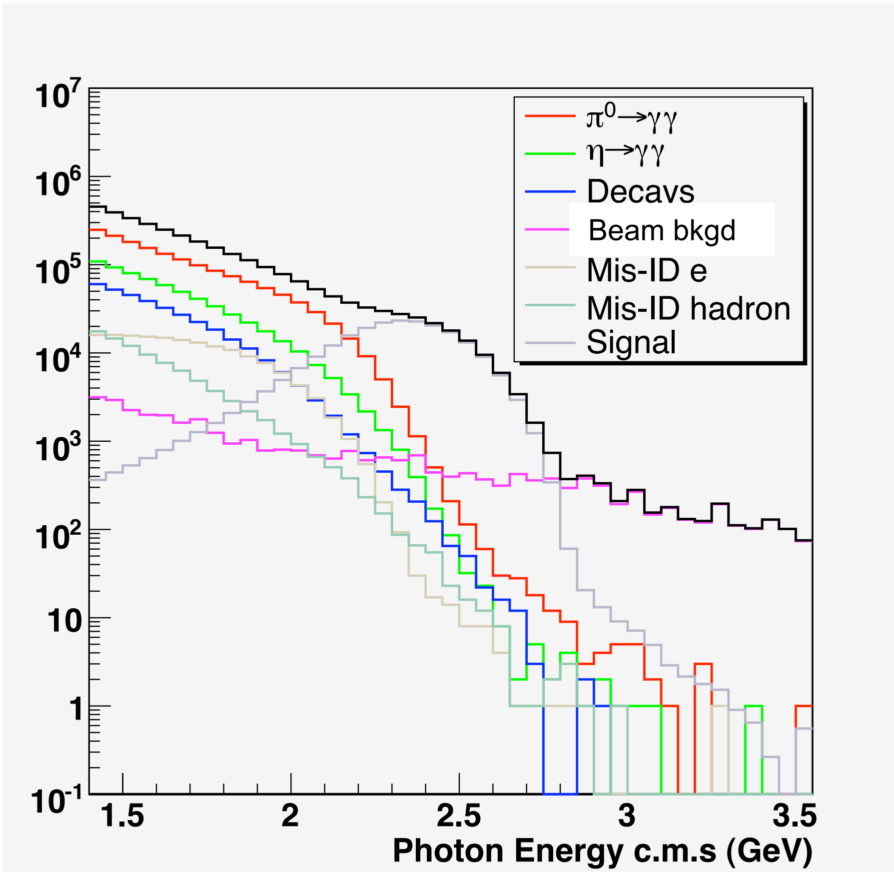




Scaled Continuum



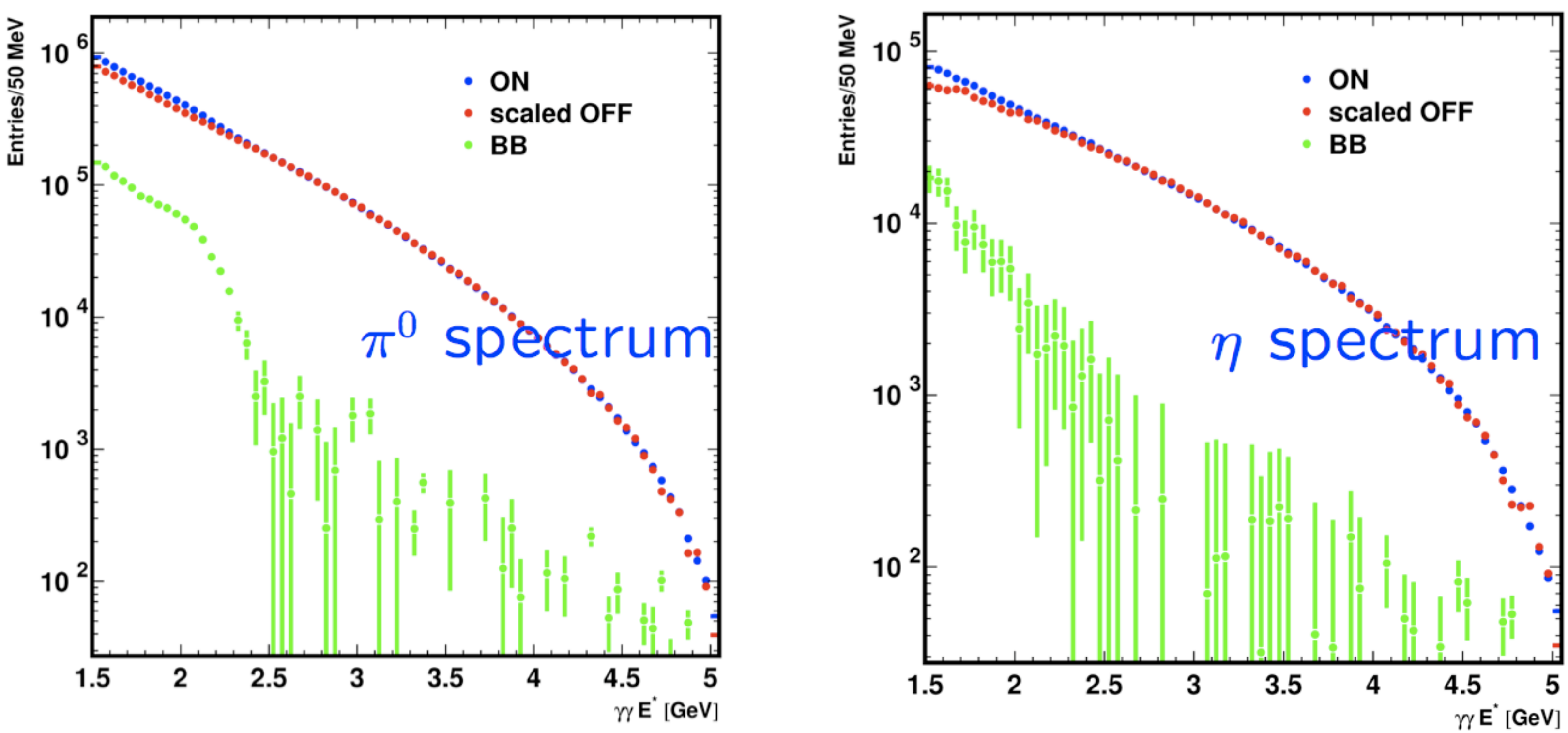
Photons from B-decays



	FRACTION
Signal	0.190
Decays of π^0	0.474
Decays of η	0.163
Decays of others	0.081
Mis-IDed electrons	0.061
Mis-IDed hadrons	0.017
Beam bkgd	0.013

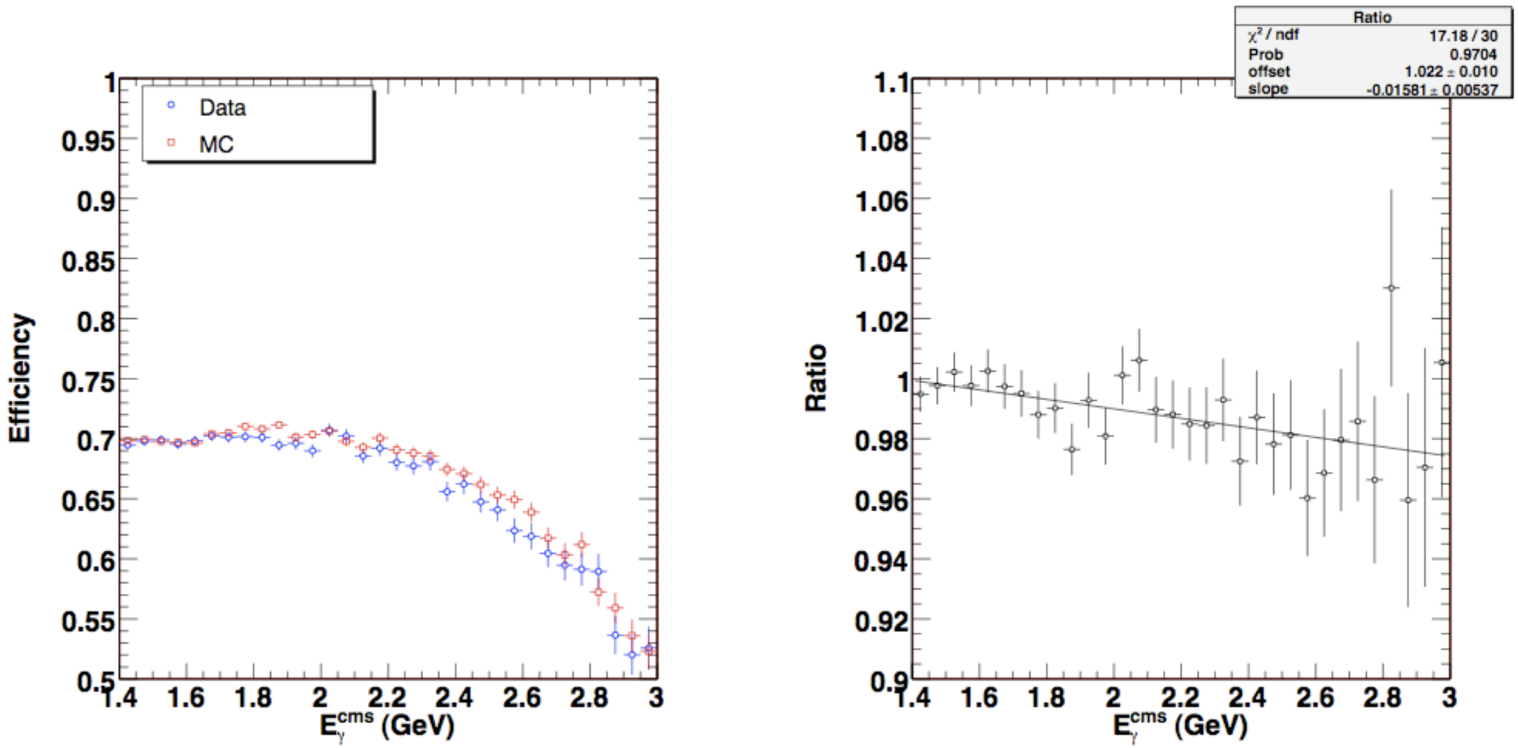
Pi0 and Eta from B-decays

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



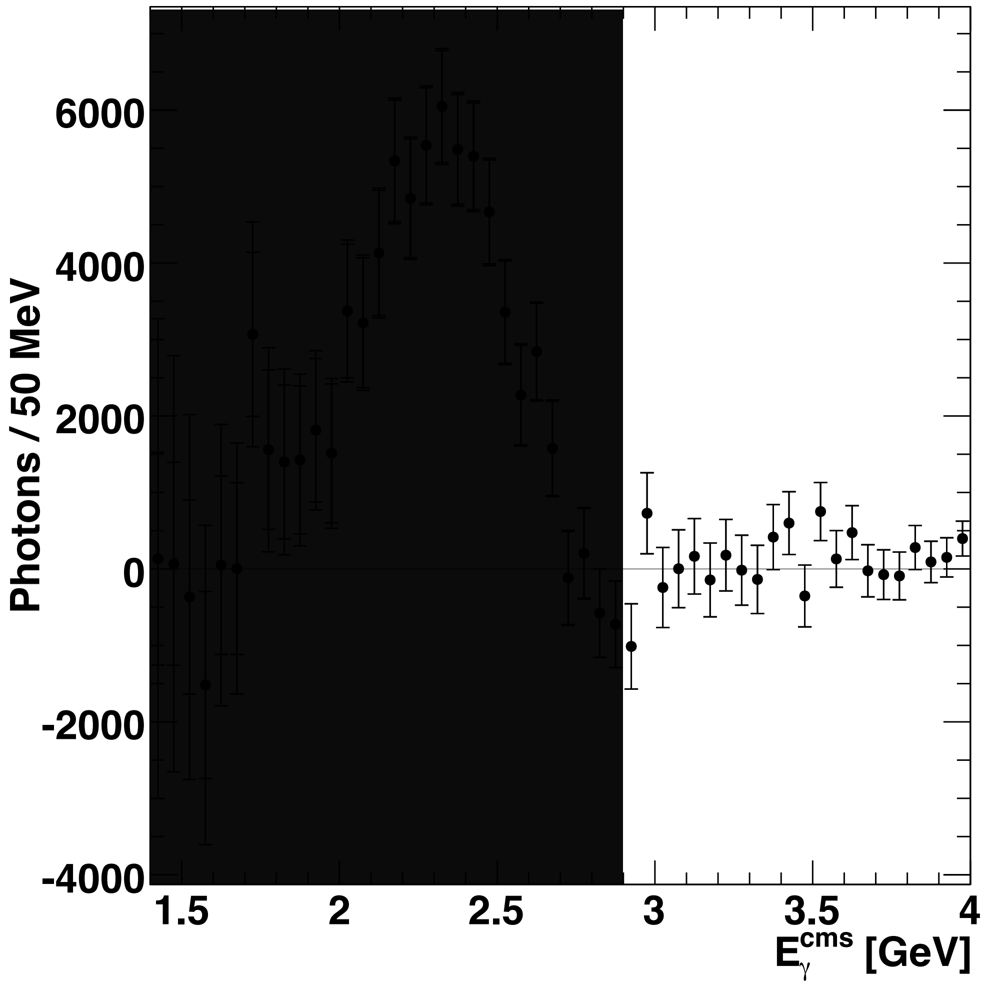
Efficiency corrections

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

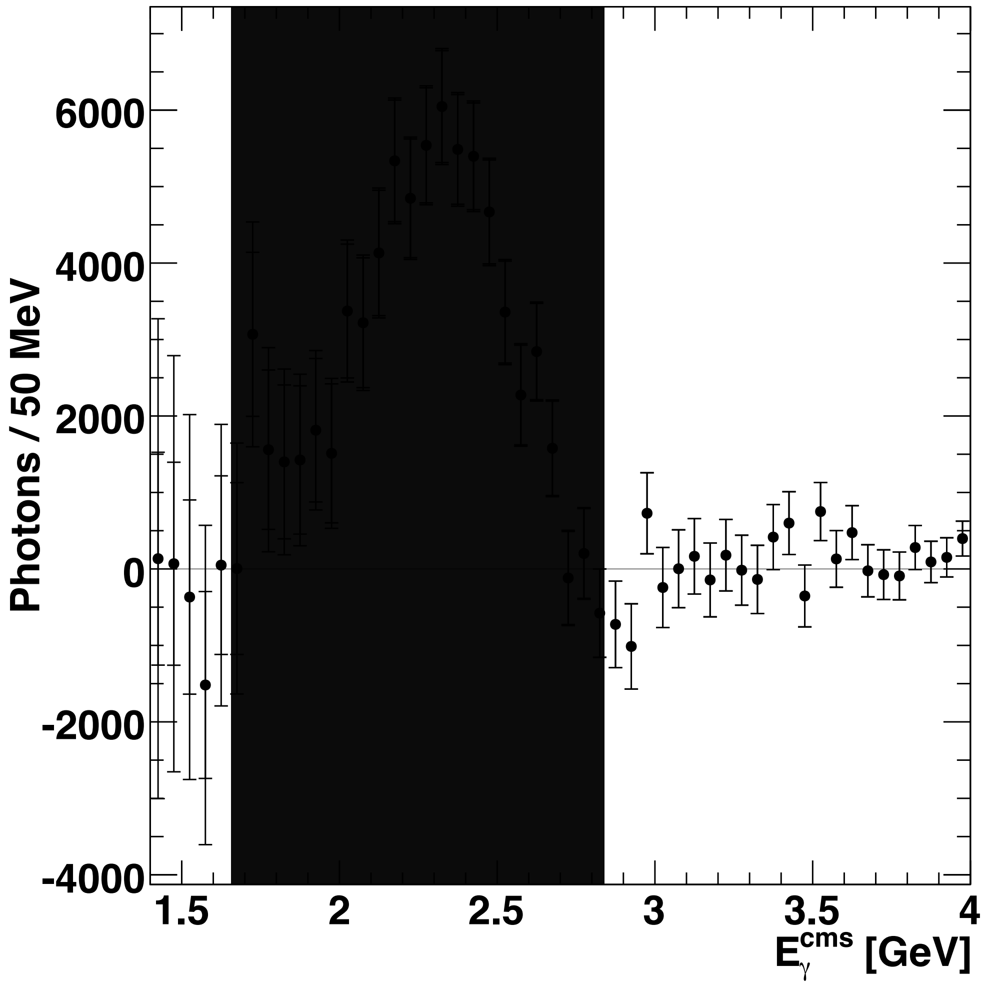
Spectrum (605/fb of data)



Did we properly subtract continuum and beam background?

Yield above endpoint for gamma from B-decay is consistent with zero

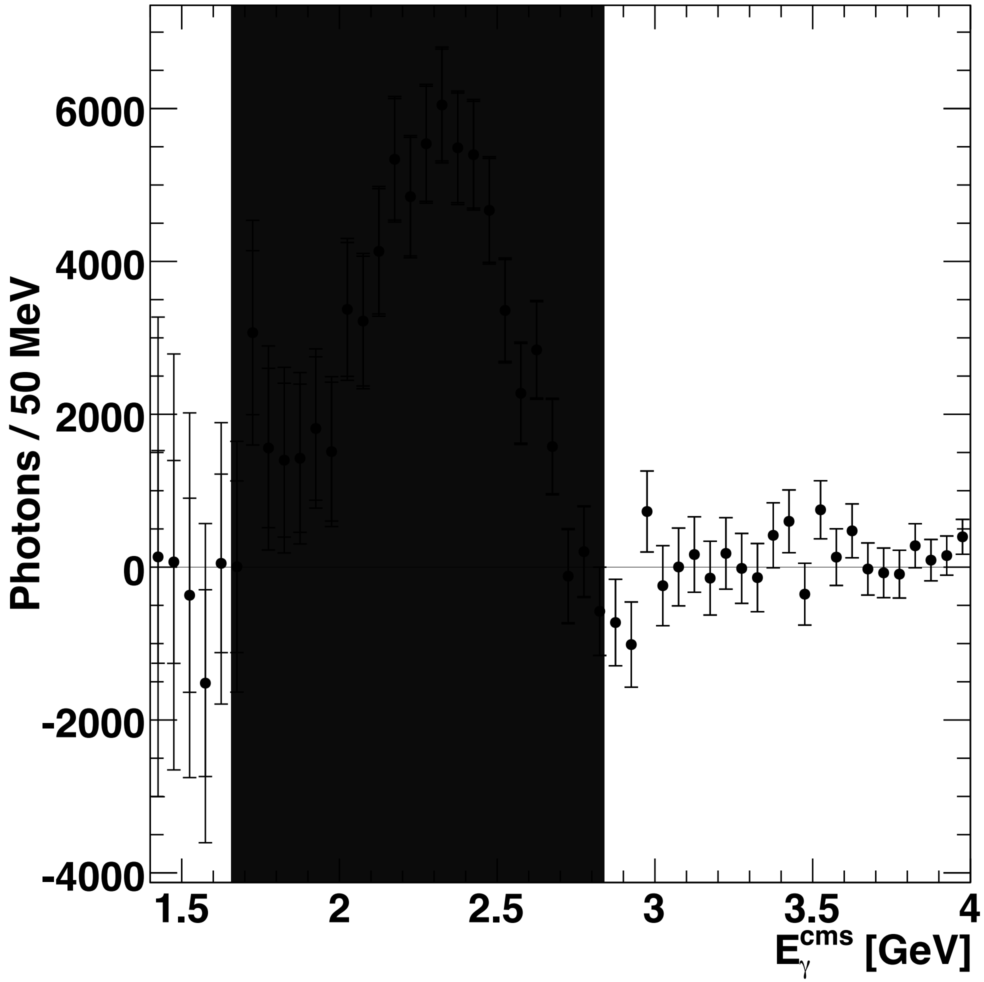
Spectrum (605/fb of data)



Did we properly estimate the the background from B-decays?

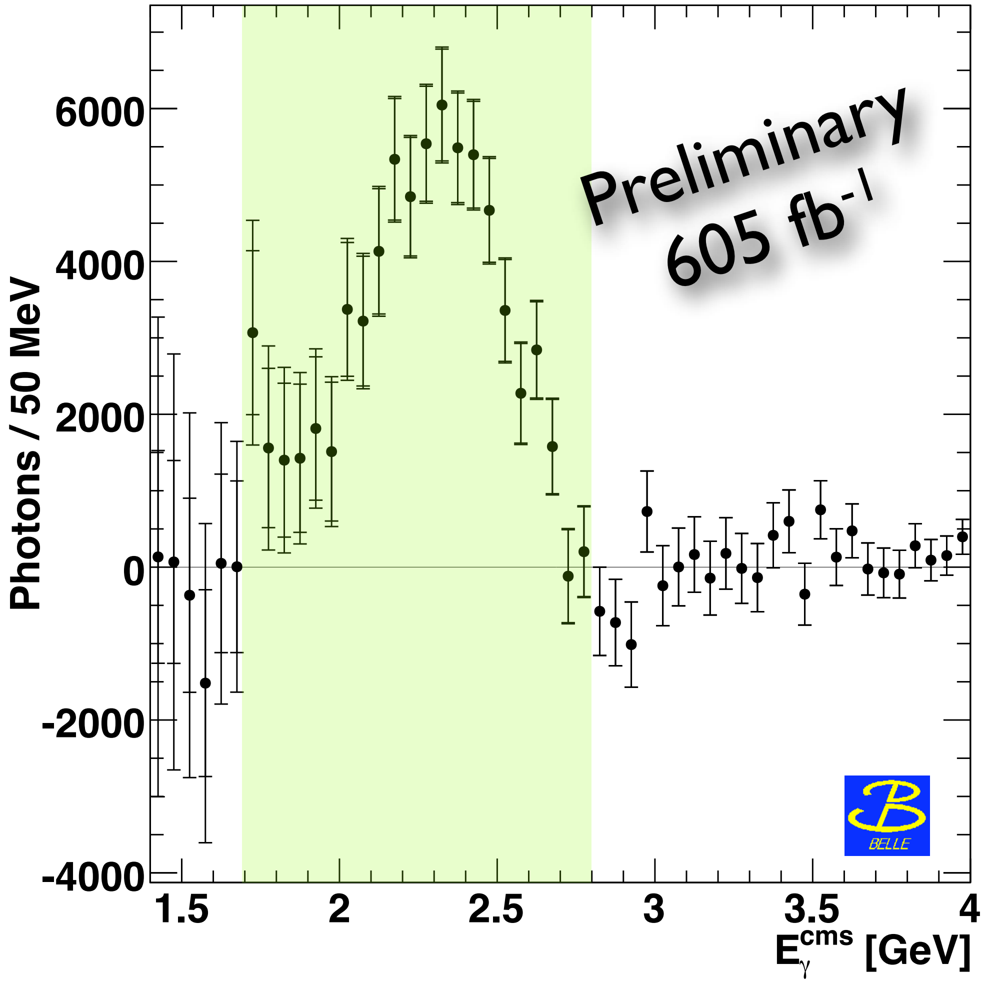
Yield where we expect very little signal is consistent with zero.

Spectrum (605/fb of data)



Before revealing the signal region, we first performed the analysis on the 140/fb sample (the same as used for our previous measurement) and found agreement with our published result.

Photon Energy Spectrum



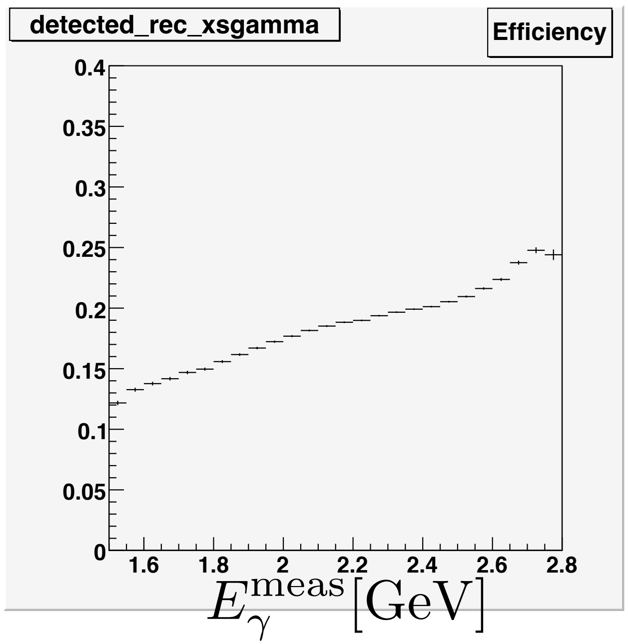
Peaks at half the mass of of the b-quark

Significant signal between 1.7< E(GeV) < 1.8

Acceptance Correction

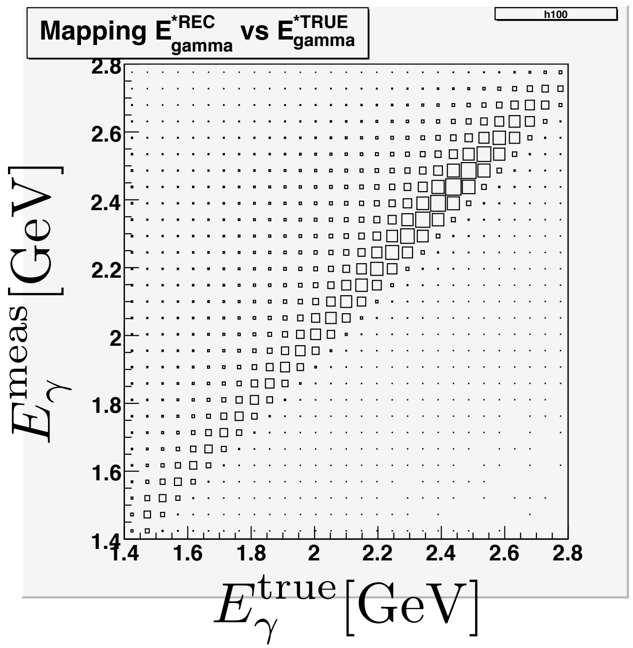
Selection Efficiency

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



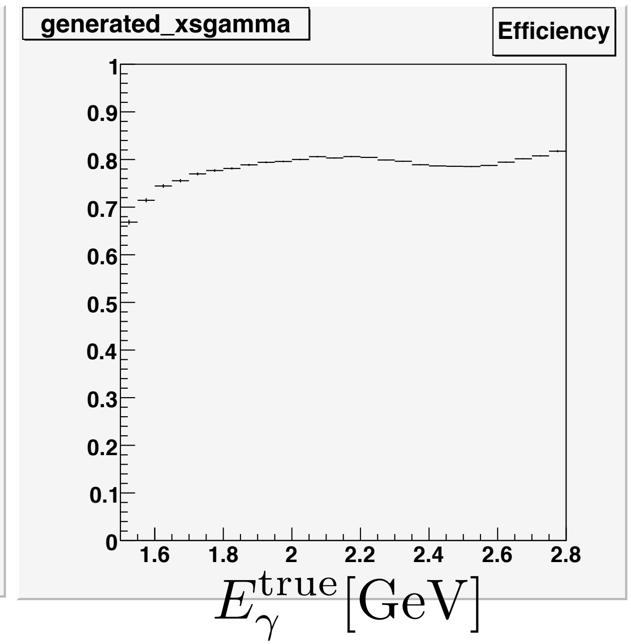
Unfolding

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



Detection Efficiency

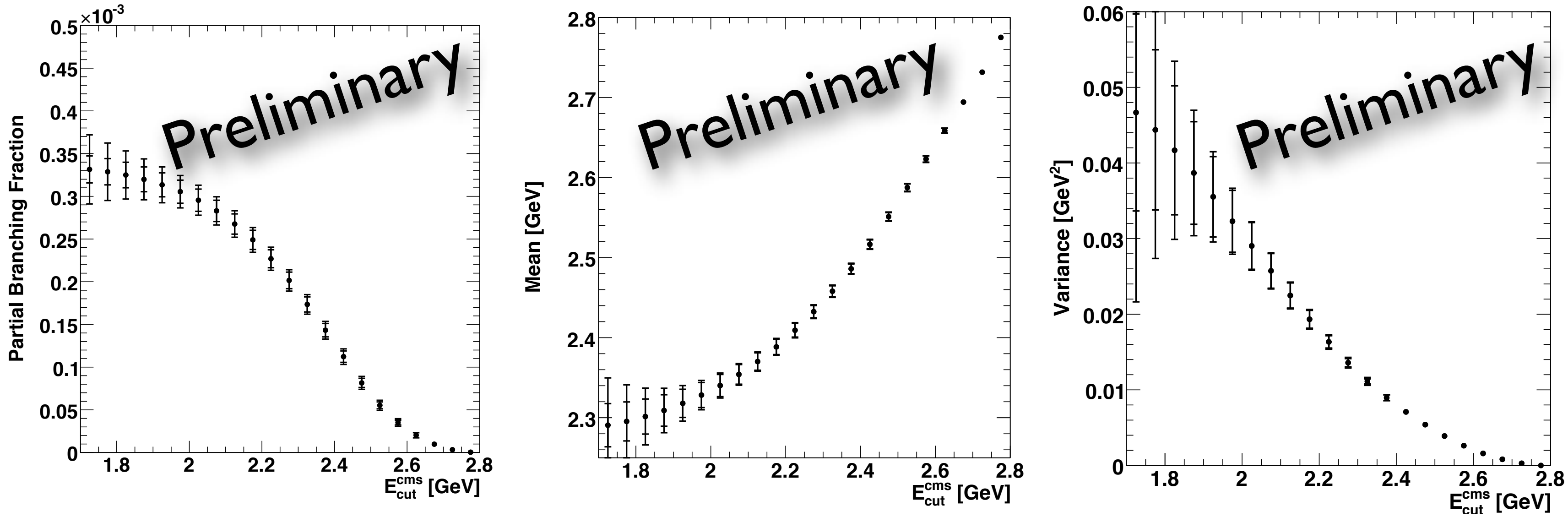
$$T(E_\gamma^{\mathrm{true}}) = \frac{M_{\mathrm{Unfolded}}}{\eta_{\mathrm{det}}}$$



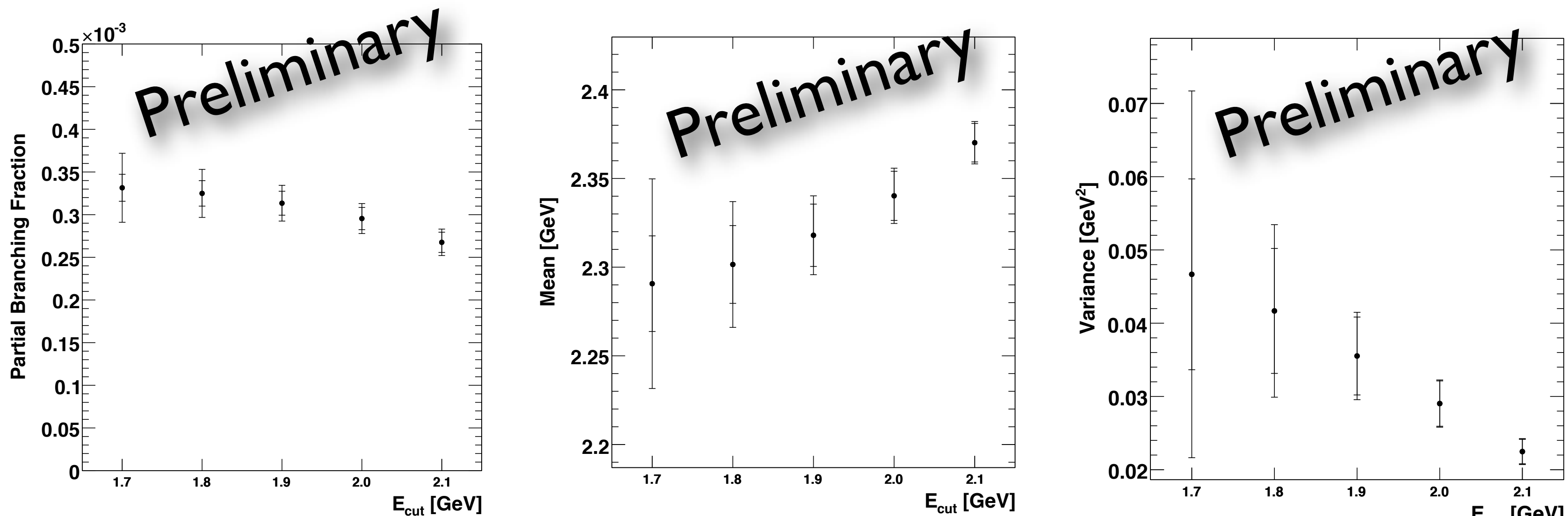
- ✤ Signal models include KN, DGE, BBU, BLNP and GG
- ✤The unfolding is done using Singular Value Decomposition (SVD).
- ✤The MC response of the ECL is calibrated to match DATA using a study of radiative mu-pair events

Results

Υ(4S)



B meson Frame



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 ± 0.16 ± 0.37	2.291 ± 0.027 ± 0.053	0.0467 ± 0.0130 ± 0.0214
1.80	3.25 ± 0.15 ± 0.24	2.302 ± 0.022 ± 0.028	0.0417 ± 0.0085 ± 0.0081
1.90	3.13 ± 0.14 ± 0.16	2.318 ± 0.018 ± 0.014	0.0355 ± 0.0053 ± 0.0027
2.00	2.95 ± 0.13 ± 0.12	2.340 ± 0.014 ± 0.007	0.0290 ± 0.0031 ± 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 ± 0.16 ± 0.37 ± 0.01	2.281 ± 0.027 ± 0.053 ± 0.002	0.0396 ± 0.0130 ± 0.0214 ± 0.0012
1.80	3.24 ± 0.15 ± 0.24 ± 0.01	2.290 ± 0.022 ± 0.028 ± 0.002	0.0350 ± 0.0085 ± 0.0081 ± 0.0005
1.90	3.12 ± 0.14 ± 0.16 ± 0.02	2.305 ± 0.018 ± 0.014 ± 0.004	0.0292 ± 0.0053 ± 0.0027 ± 0.0008
2.00	2.94 ± 0.13 ± 0.12 ± 0.02	2.326 ± 0.014 ± 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 +- 0.16 +- 0.37	(Belle 605/fb)	(12.2%)
1.80	3.24 +- 0.15 +- 0.24	(Belle 605/fb)	(8.7%)
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 $E_\gamma > 1.6$ GeV

FROM - Phys.Rev. D73 (2006) 073008
Buchmuller & Flacher

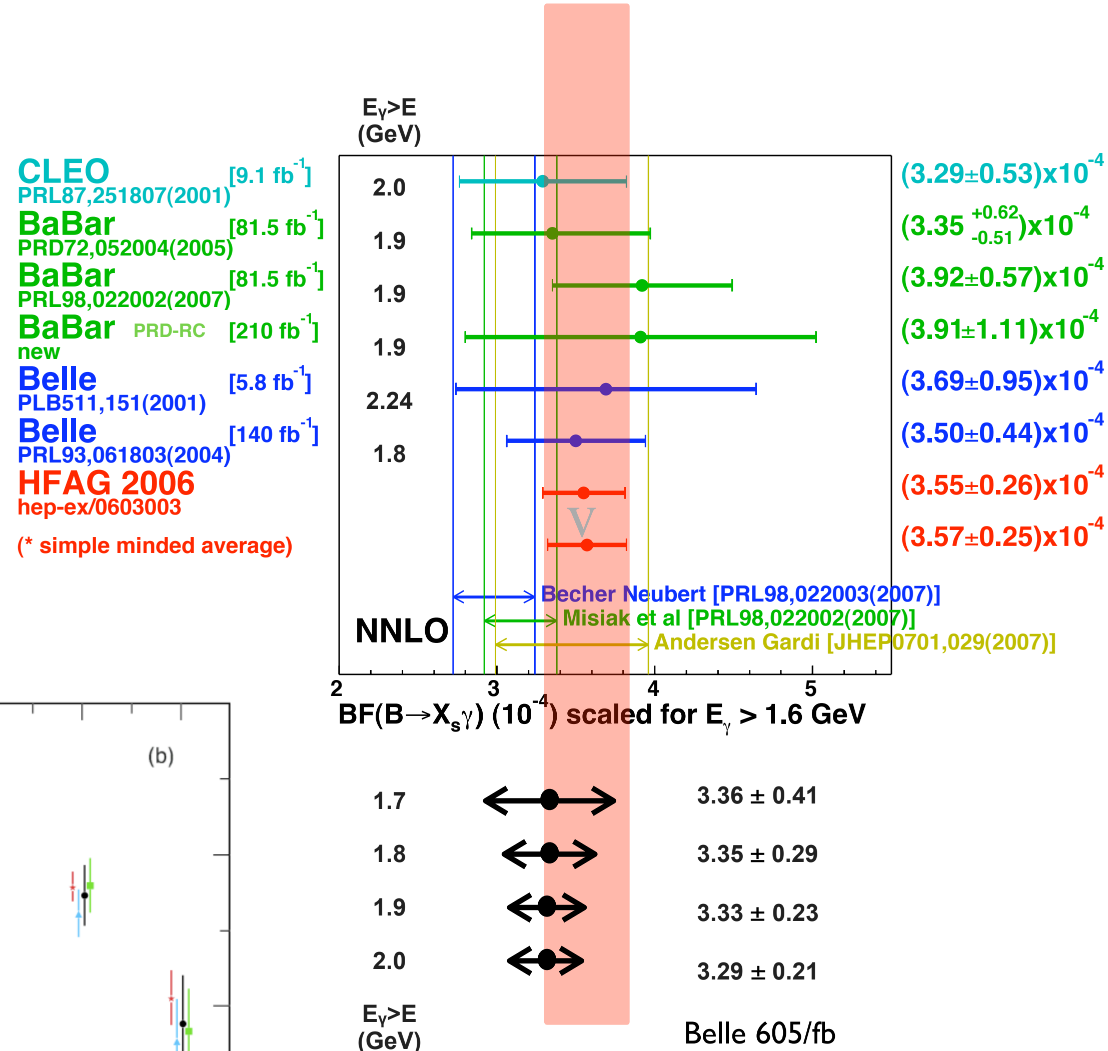
Eur.Phys.J.C7:5-27,1999 -
Kagan & Neubert (KN)

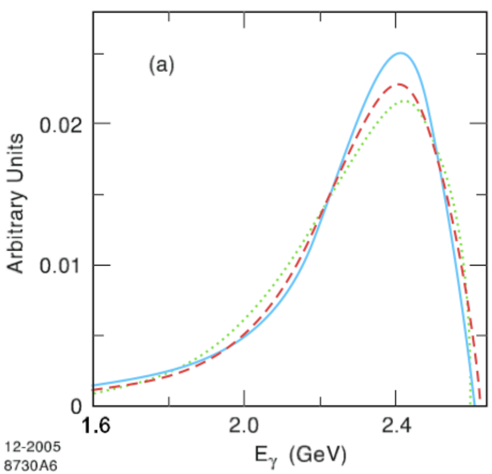
Nucl.Phys.B699:335-386,2004 -
Bosch, Lange,Neubert & Paz

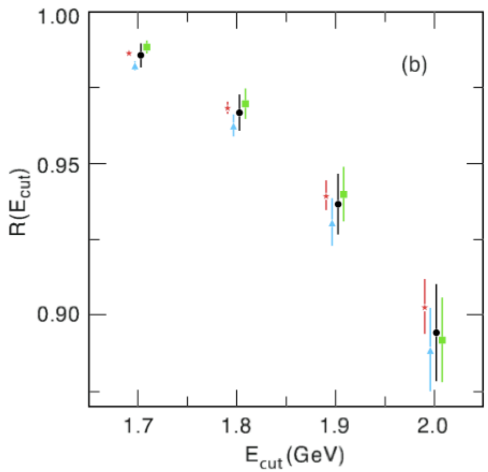
Nucl.Instrum.Meth.A462:152-155,2001 -
Lange, Neubert & Paz (BLNP)

Phys.Lett.B612:13-20,2005
Neubert

Nucl.Phys.B710:371-401,2005
Benson, Bigi & Uraltsev (BBU)







Conclusions

- The measurements of the branching fractions and moments are the most precise to date

Preliminary

$$\mathcal{B}(B \to X_s\gamma)|_{E\gamma>1.7\,\mathrm{GeV}} = (3.31 \pm 0.16 \pm 0.37 \pm 0.01) \times 10^{-4}$$

stat sys boost

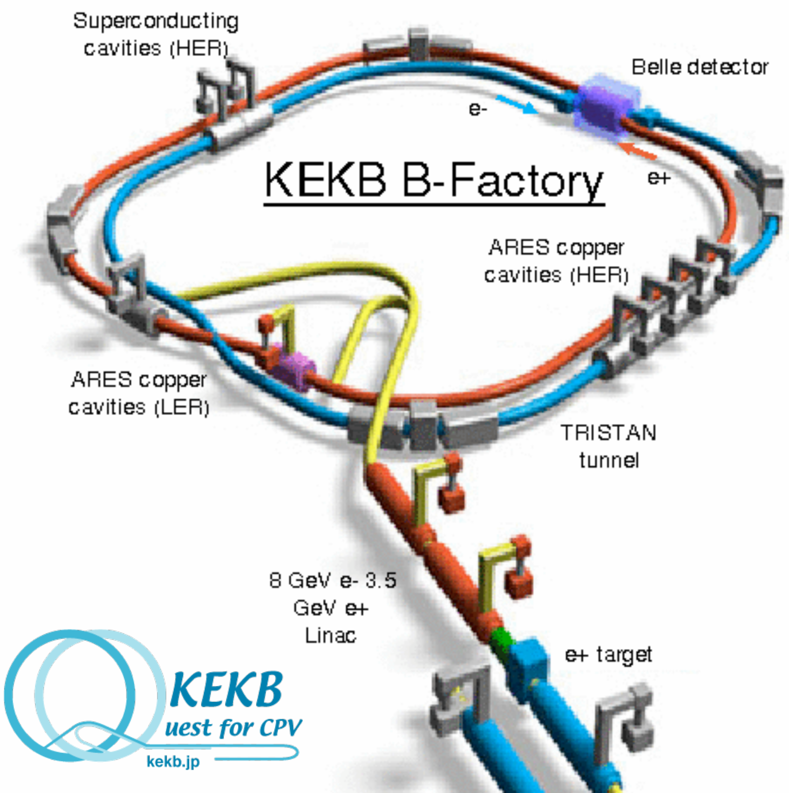
- Tighter constraints on new Physics

- Will reduce uncertainty on m_b thus improve our knowledge of a side of the Unitarity Triangle

- Inclusive measurements can only be done well at an e^+e^- machine.

Backup slides

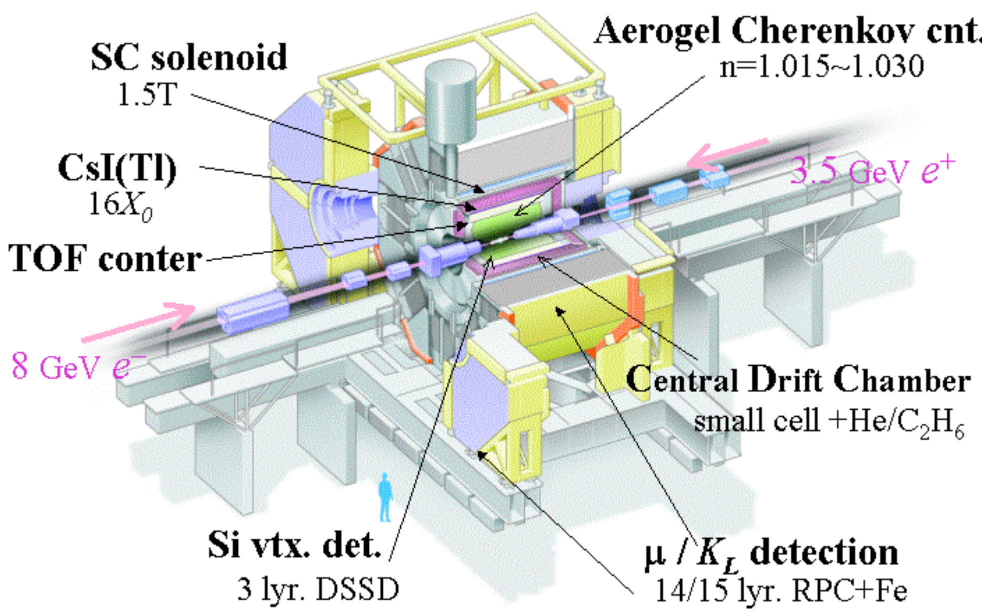
KEKB and Belle



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 ≥ 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

Signal Models

KN

Eur.Phys.J.C7:5-27,1999 - Kagan & Neubert (KN)

BLNP

Nucl.Instrum.Meth.A462:152-155,2001 -Lange, Neubert & Paz

BBU

Nucl.Phys.B710:371-401,2005 Benson, Bigi & Uraltsev

DGE

JHEP01(2007)029 Andersen & Gardi

GG

Gambino & Giordano - work in progress