New physics through $b \to s\gamma$

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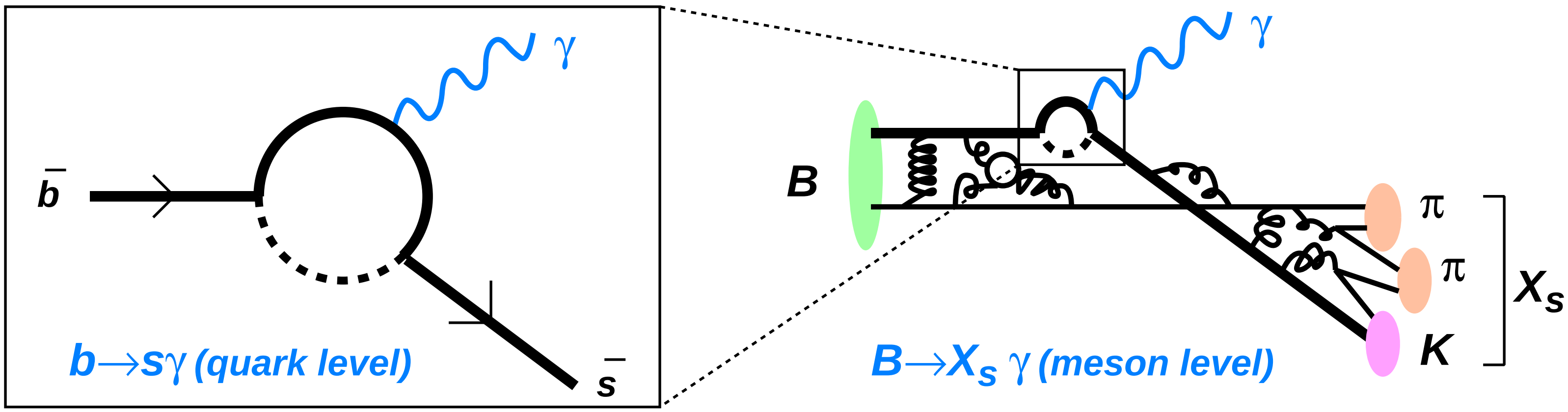
January 19, 2004

SuperB Workshop in Hawai'i

Physics cases at 5 and 50 ab^{-1}

Outline

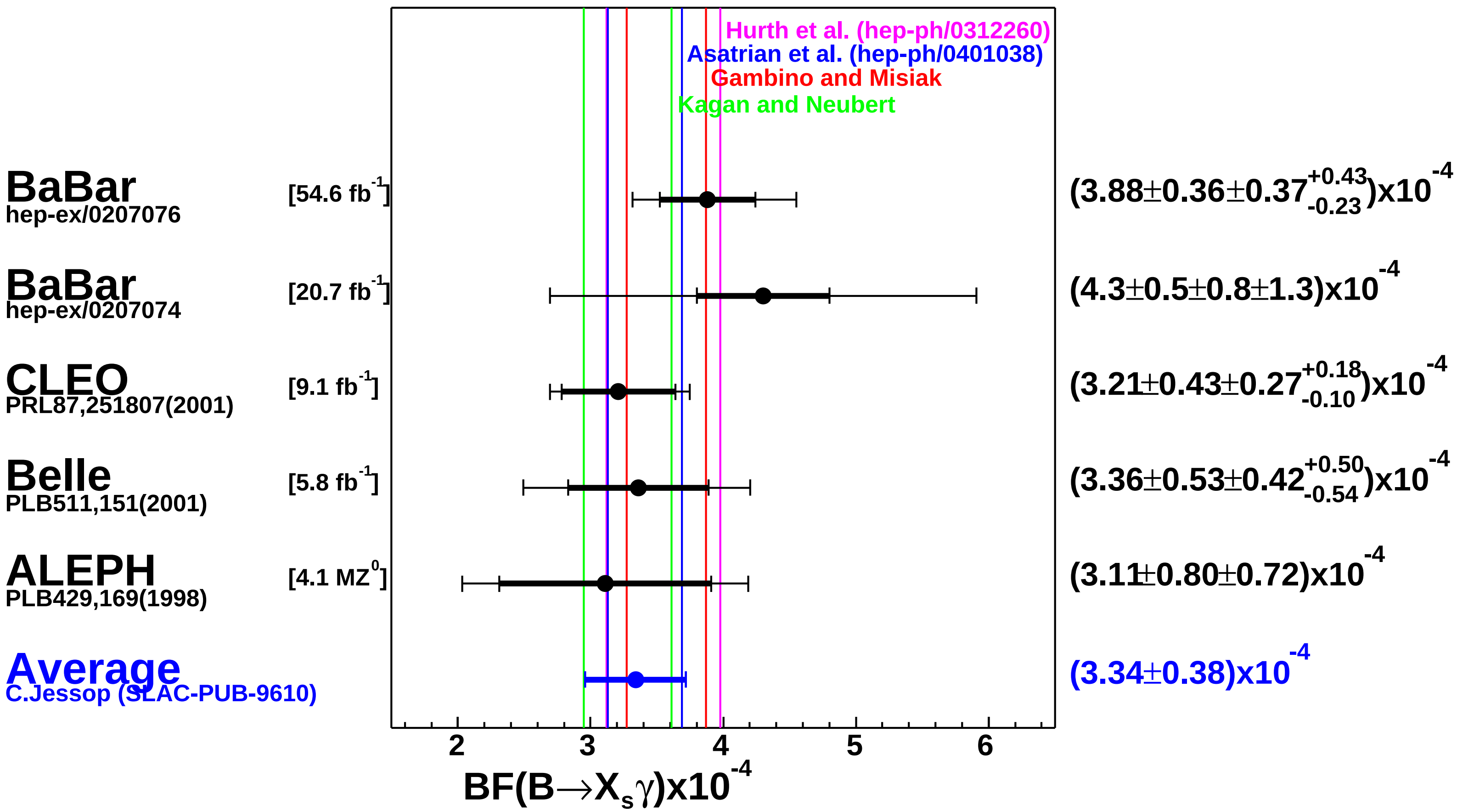
$B \to X_s\gamma$ has been the best mode — giving tightest constraints



- Inclusive $B \to X_s\gamma$ branching fraction
- Sign of C_7
- Mixing induced CP asymmetry
- Direct CP asymmetry
- (Not much on $b \to d\gamma$)

No new physics hint from $b \to s\gamma$, yet — hope is to find with Super-B

$B \to X_s\gamma$ branching fractions



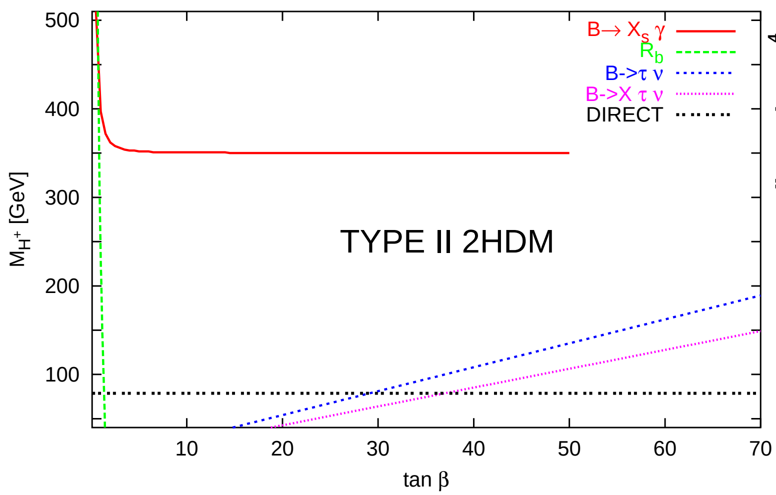
Measured: $\mathcal{B}(B \to X_s\gamma) = (3.34 \pm 0.38) \times 10^{-4}$ [world average]

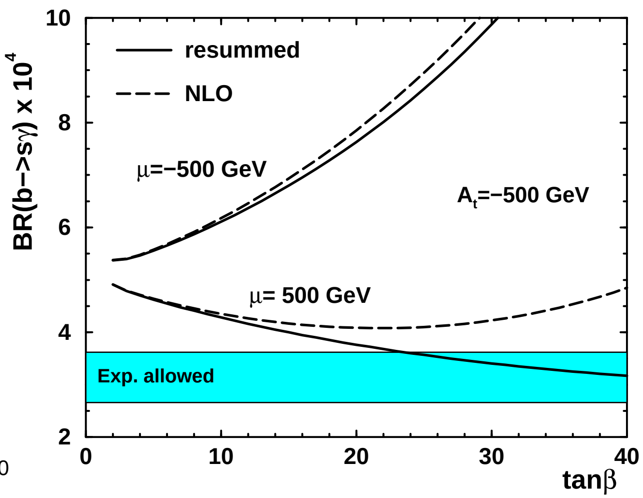
Predicted: $\mathcal{B}(B \to X_s\gamma) = (3.61\,^{+0.37}_{-0.49}) \times 10^{-4}$ [Hurth et al., hep-ph/031260]

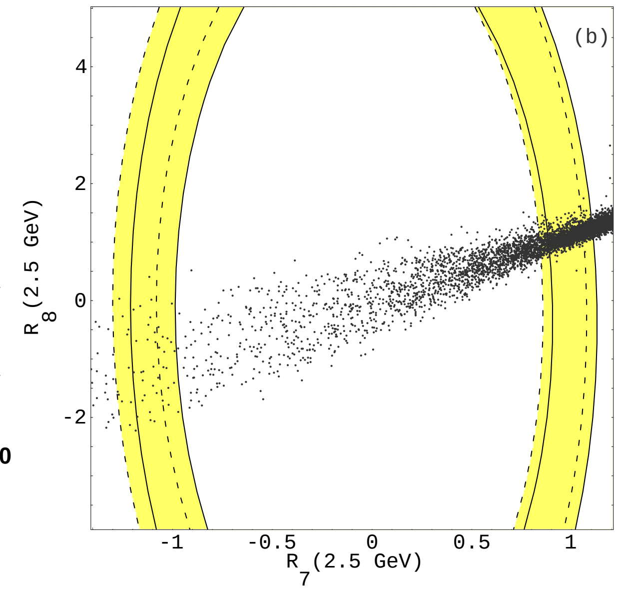
Very good agreement within 11–12% error

Many constraints

- Sensitive to charged Higgs, SUSY, ...
  but many dramatic senarios have been already excluded
- NP effect may be small (10–20%) or hidden in a tiny corner
  (SM like senarios (e.g. minimal flavor violating SUSY) are favored)







Hard to find a small NP effect, but

- $|C_7|$ needed for C_9, C_{10} from $B \to X_s \ell^+\ell^-$, $A_{FB}(B \to K^*\ell^+\ell^-)$
- $\langle E_\gamma \rangle$ and $\langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2$ needed for V_{ub} and $M(X_s)$ of $B \to X_s \ell^+\ell^-$

$B \to X_s\gamma$ backgrounds

Continuum background

off-resonance subtraction

$B \to \pi^0 X$

π^0 spectrum can be measured

$B \to \eta X$

η spectrum can be measured

other $B \to X(= \eta' \ldots) \to \gamma$

small and less harmful

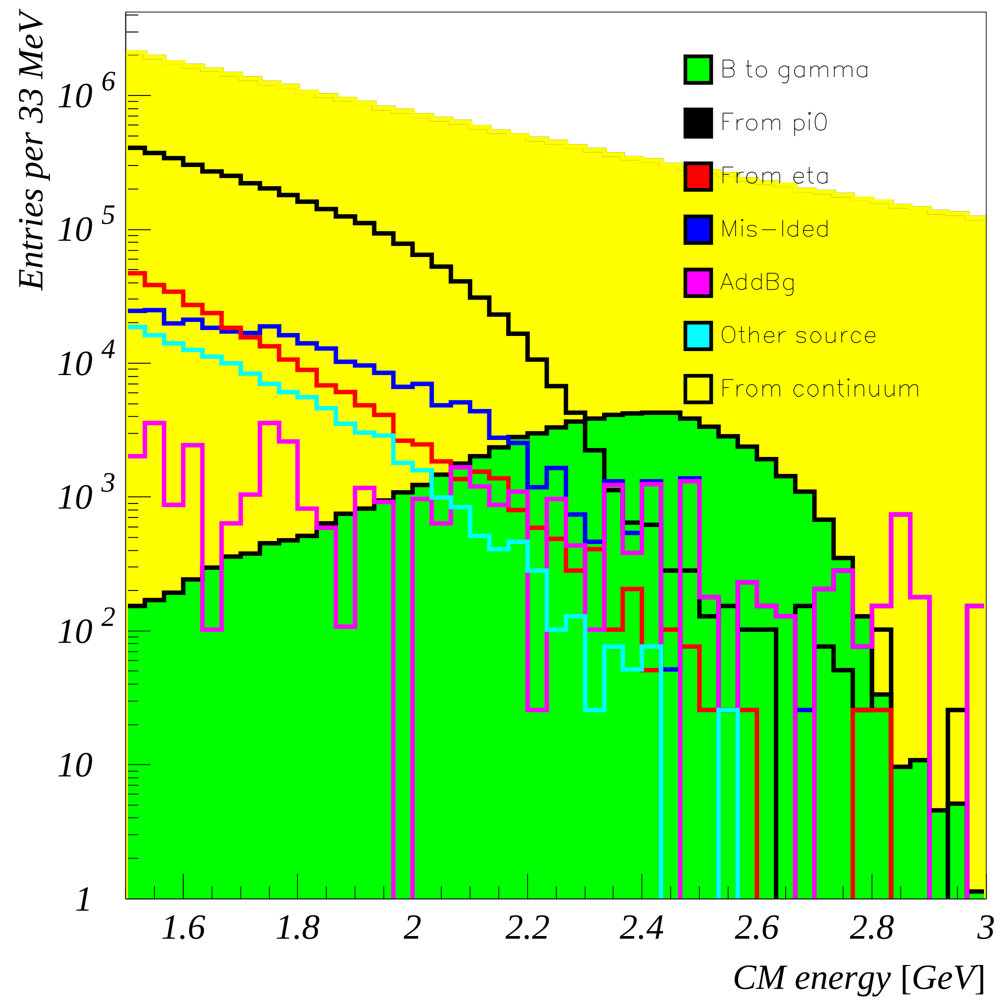
$B \to$ **hadronic shower (mis-id.)**

Poorly simulated (by GEANT)

No good control sample!

Beam background

subtracted with off-data



Roughly ×2 background when $E_\gamma^{\min}$ lowered by 0.1 GeV

Analysis techniques

	Full inclusive (γ (+ℓ-tag)) CLEO(01), BaBar(ICHEP02)	Sum of exclusive($K + n\pi\gamma$) Belle(01), BaBar(ICHEP02)
$q\bar{q}$ backg.	off-resonance subtraction	fit to the M_{bc}-ΔE signal peak
$B \to \pi^0 X, \eta X$	use measured data	complicated peaking b.g., need MC ($D^0\pi^0$, $D^0\rho^-$ etc)
other b.g.	Monte Carlo	less problematic
S/N	poor	good
Coverage	$E_\gamma > E_\gamma^{min}$ (90–95%)	~50% of X_s (or 70% with K_L^0)
Advantage	small theory error	clear signal
Disadvantage	**tough analysis**, constraints and control samples limited, $b \to d\gamma$ unknown	irreducible model uncertainties ($M(X_s)$, hadronization), **large syst. error**
Next step	lower E_γ^{min}, **main method**	include η, 5π, $2\pi^0$, $3K$, Λ...

Beam backgrounds

Two worries, if we have **20 times** more beam backgrounds!

Fake photon from beam

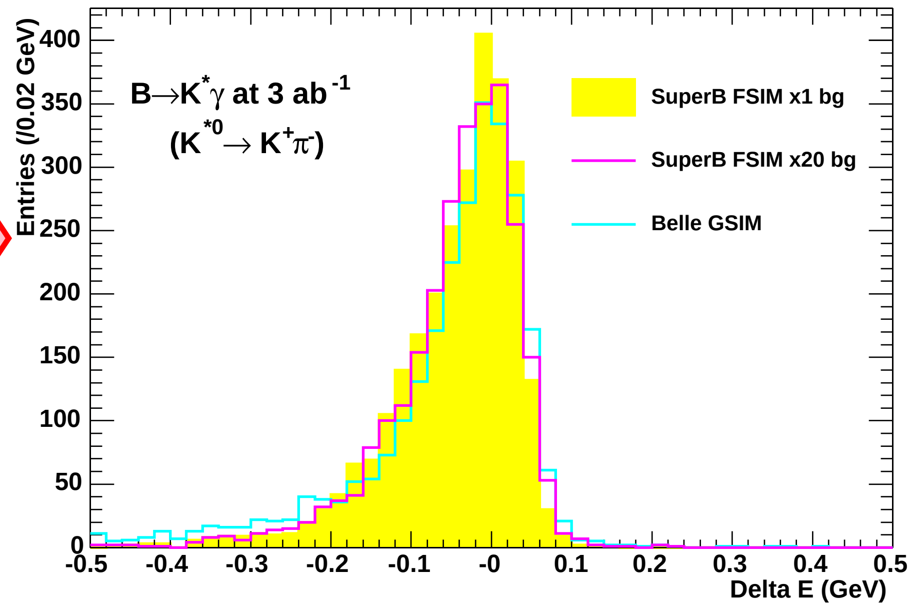
Should be correctly subtracted with off-resonance, but careful watching is necessary to avoid large systematics.

Efficiency / Resolution

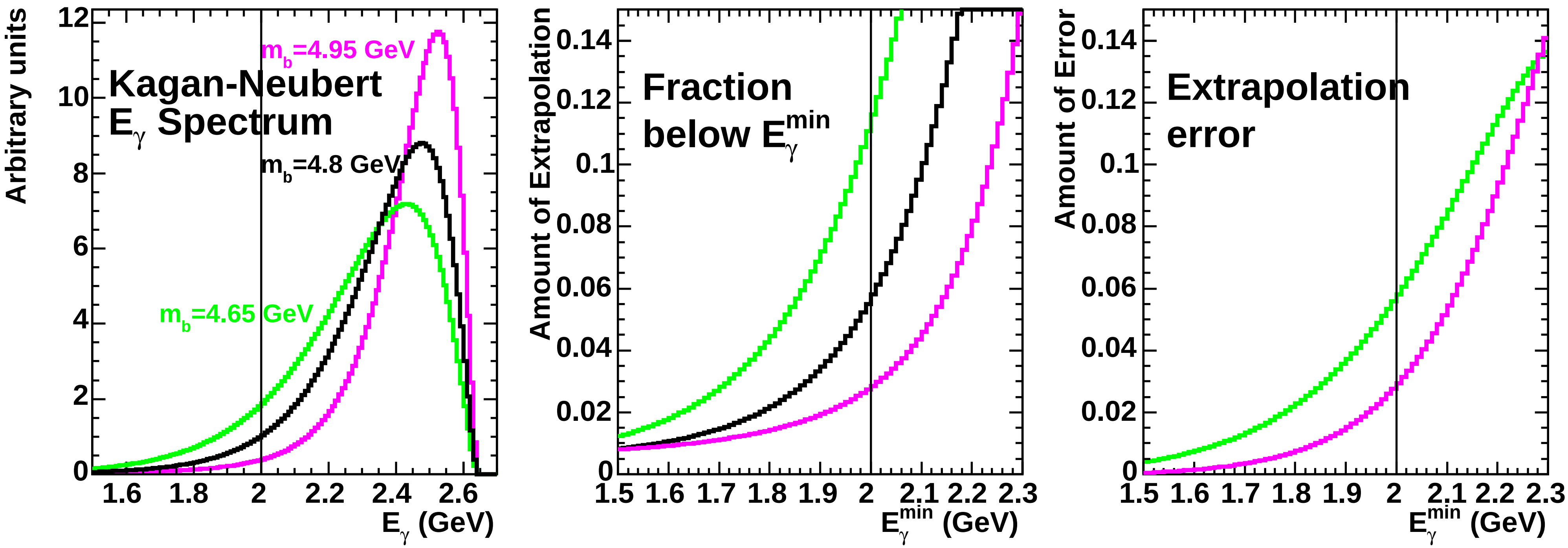
So far (for Belle update design), it won't be a serious problem. Loss is compensated by thinner PID material and waveform sampled digitization.

No big change in the photon energy response and efficiency even with 20 times background.

(In $B \to K^*\gamma$ ΔE distribution)

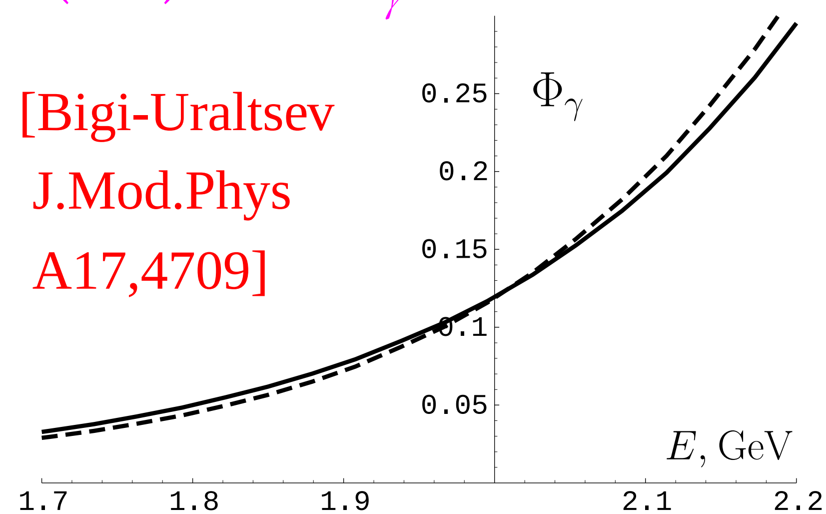


$B \to X_s\gamma$ model errors



- $\mathcal{O}(5\%)$ error with $E_\gamma^{\rm min} = 2.0$ GeV $\Rightarrow$ $\mathcal{O}(2\%)$ with $E_\gamma^{\rm min} = 1.8$ GeV
  (Kagan-Neubert)
- But more ambiguity?
  Fraction below $E_\gamma^{\rm min}$ may be larger
  can be checked only with lower $E_\gamma^{\rm min}$

[Bigi-Uraltsev J.Mod.Phys A17,4709]



$B \to X_s\gamma$ systematic errors

Some errors scale with (off-resonance) luminosity

- $B \to \pi^0/\eta X$ background subtraction
- Energy correction for off-resonance
- Hadronic shower fake rate (K_L from $e^+e^- \to \phi\gamma$, etc)

Some errors are reduced more slowly

- Photon efficiency (from $e^+e^- \to e^+e^-\gamma$, τ decays, ...)
- Shape variable efficiency (need a better $M(X_s)$ understanding)
- $b \to d\gamma$ subtraction ($|V_{td}/V_{ts}|$?, E_γ for $b \to d\gamma$?)

Wild guess: 60% of stat. error $\oplus$ *3%*?

Tag the rest of particles

- From the rest of particles, one can tag X_s and X_d with “some” mis-tag fraction $\Rightarrow$ $B \to X_d\gamma$ measurement!

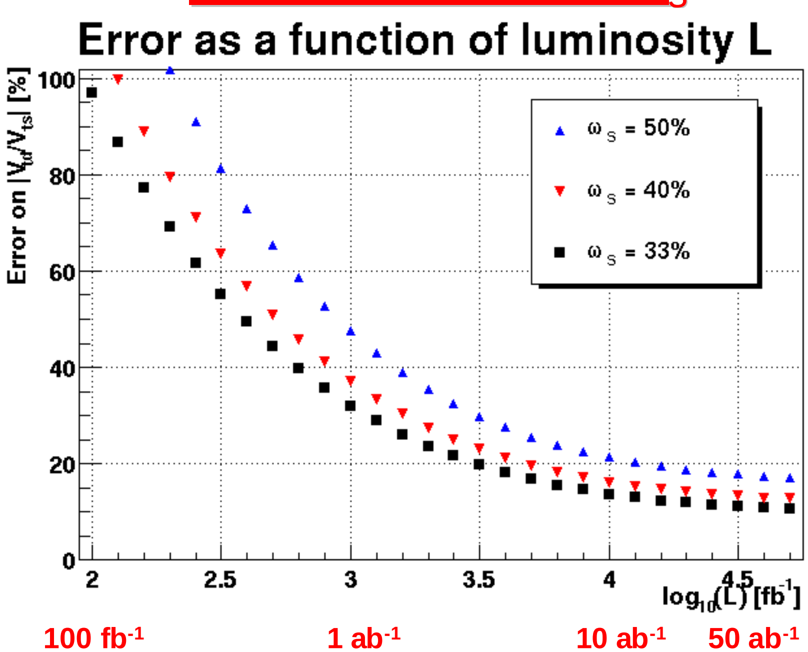
[$s \to d$] w_s = 33 to 50%, mainly due to missing K_L^0 and $K_S^0 \to \pi^0\pi^0$

[$d \to s$] w_d = 5 to 20%, mainly due to mis-PID

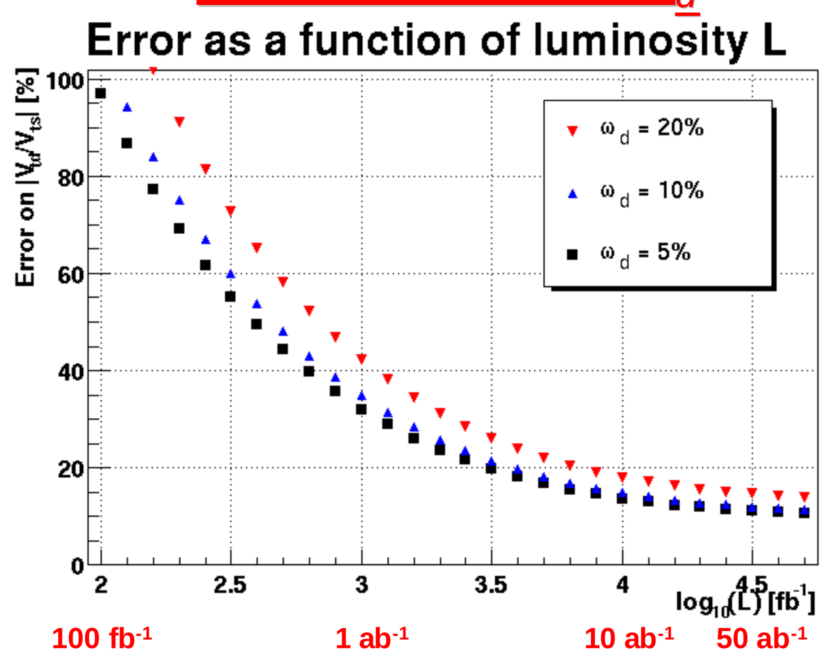
(optimistic? how about other B?)

C.Jessop, 1st SLAC SuperB WS

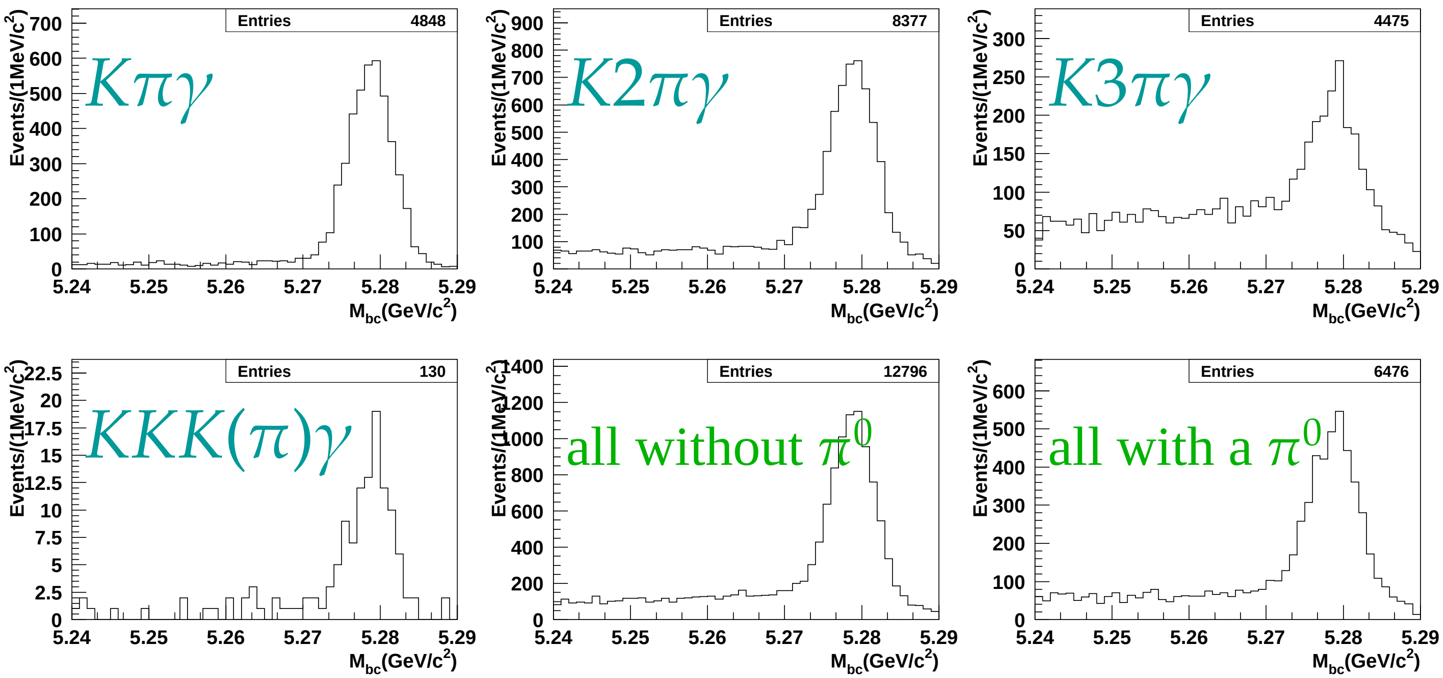
Variation with ω_s



Variation with ω_d



Sum of exclusive method

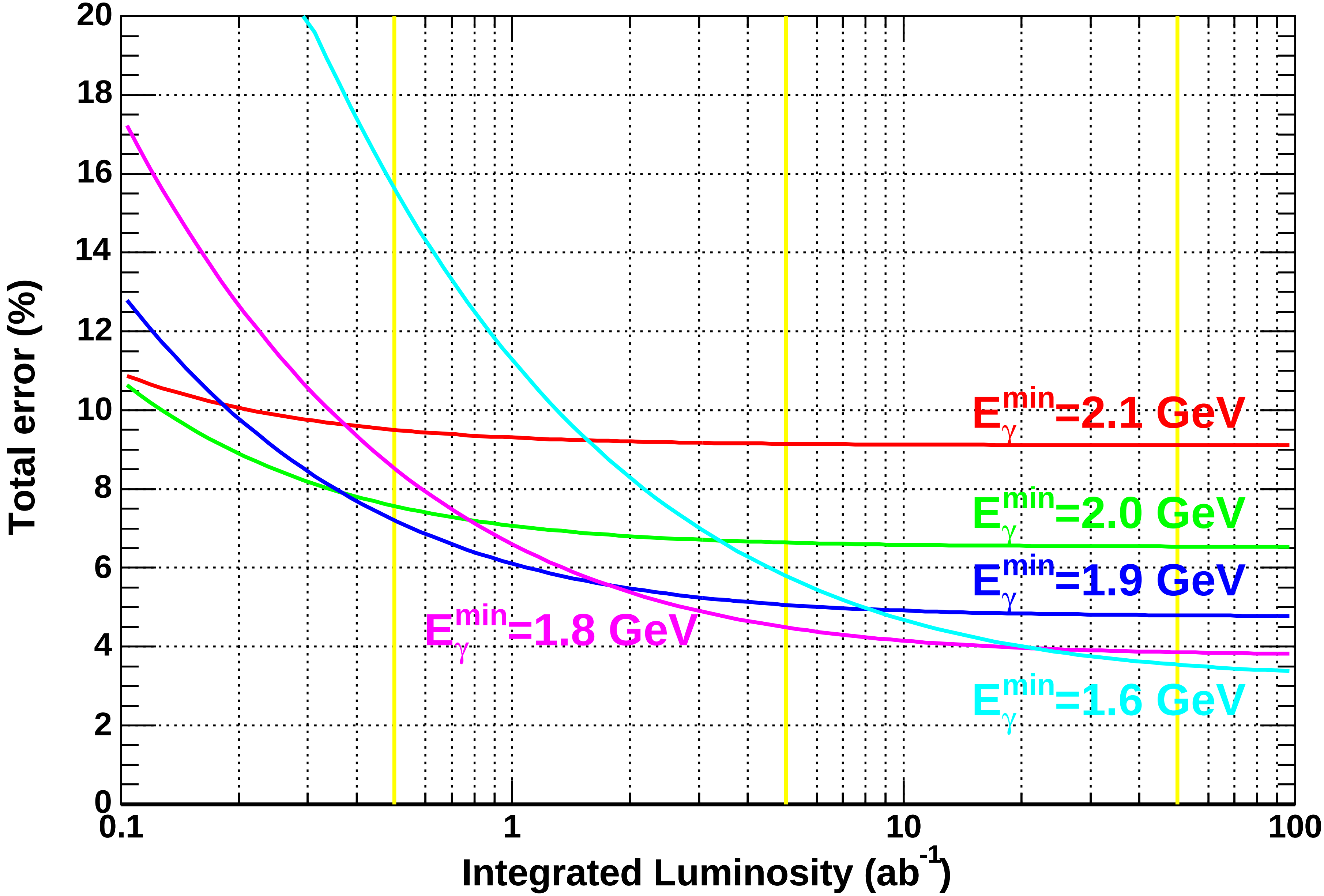


Expected signal at 5 ab^{-1}

- JETSET is not reliable, need to measure the break-down
- Cannot measure all modes even at 5 ab^{-1}, huge cross-feeds, model error would be still VERY large
- Essential input for fully inclusive $b \to s\gamma$
  - Systematic error due to $M(X_s)$ and multiplicity modeling
  - Also for $B \to X_s \ell^+ \ell^-$ (fully inclusive study would be tough)

$B \to X_s\gamma$ error extrapolation

Belle/BaBar 30 + 3 fb^{-1} (On:Off = 10:1) = CLEO 9.1 + 4.4 fb^{-1}



$B \to X_s\gamma$ prospects

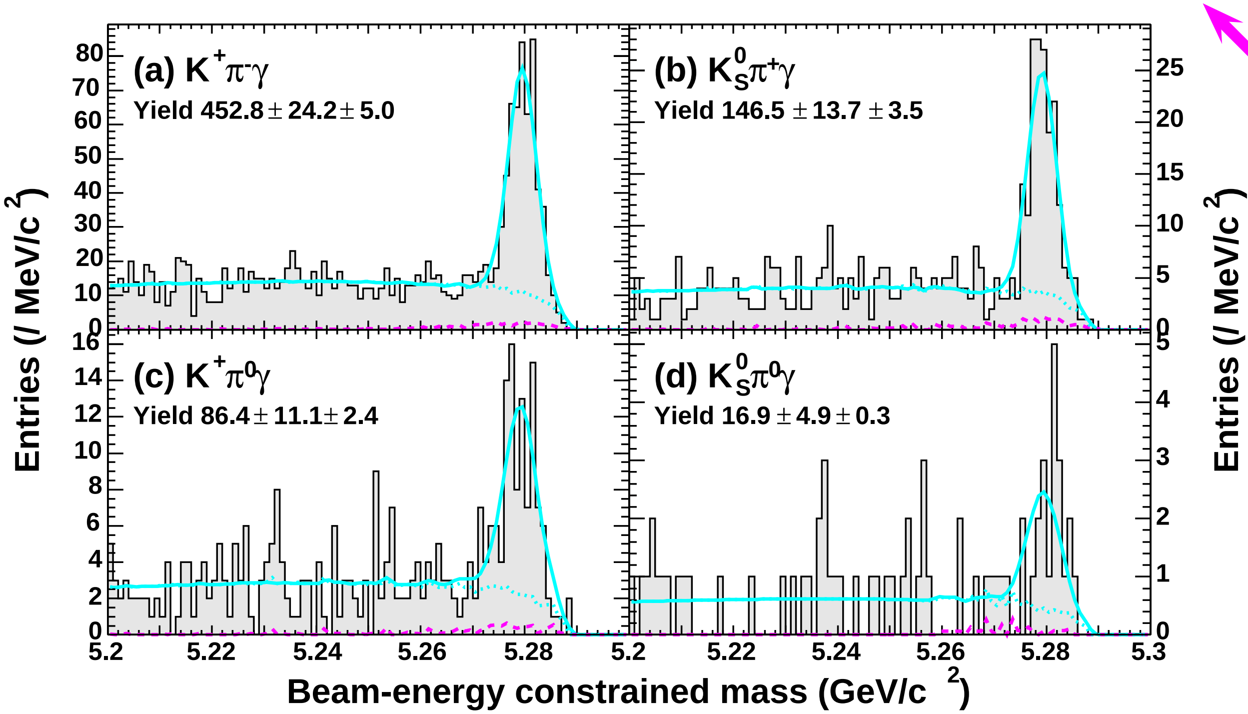
- 4–5 % measurement error is possible
  (Comparable error would be expected for NNLO prediction, too)
- No big chance to see the new physics effect in the rate itself
- Pursue other measurements:
  - Sign of C_7, from $b \to s\ell^+\ell^-$, $B \to K^*\gamma$ isospin asymmetry or $B \to \rho\gamma$
  - Photon polarization from mixing induced CP, $B \to K\pi\pi\gamma$ angular analysis, low q^2 end of $B \to K^*e^+e^-$
  - Direct CP violation: $A_{CP}(B \to K^*\gamma)$, $A_{CP}(B \to X_s\gamma)$
  - More with $b \to d\gamma$

$B \to K^*\gamma$ isospin asymmetry

$$\Delta_{+0} \equiv \frac{(\tau_{B^+}/\tau_{B^0})\mathcal{B}(B^0 \to K^{*0}\gamma) - \mathcal{B}(B^+ \to K^{*+}\gamma)}{(\tau_{B^+}/\tau_{B^0})\mathcal{B}(B^0 \to K^{*0}\gamma) + \mathcal{B}(B^+ \to K^{*+}\gamma)}$$

is sensitive to sign(C_6/C_7) [Kagan-Neubert PLB539,227(2002)]

$$\Delta_{+0} = (+0.003 \pm 0.045 \pm 0.018) \times (1.022 \pm 0.025) \text{ [Belle 78 fb}^{-1}\text{]}$$



$f_+/f_0 = 1.044 \pm 0.050$
from HFAG

Δ_{+0} prospects

- SM predicts +5 to 10% asymmetry ⇔ ~2% error is needed

- Stat. error will become negligible 1.8% at 500 fb^{-1}, 0.5% at 5 ab^{-1}
- Syst. error from K^+/K^0_S and π^+/π^0 eff. difference 1.8% will decrease slowly
- f_+/f_0 is already very crucial $\left[\delta(\Delta_{+0}) = \frac{1}{2}\delta(f_+/f_0)\right]$
  2.5% error in Δ_{+0} will decrease slowly (systematics limited)

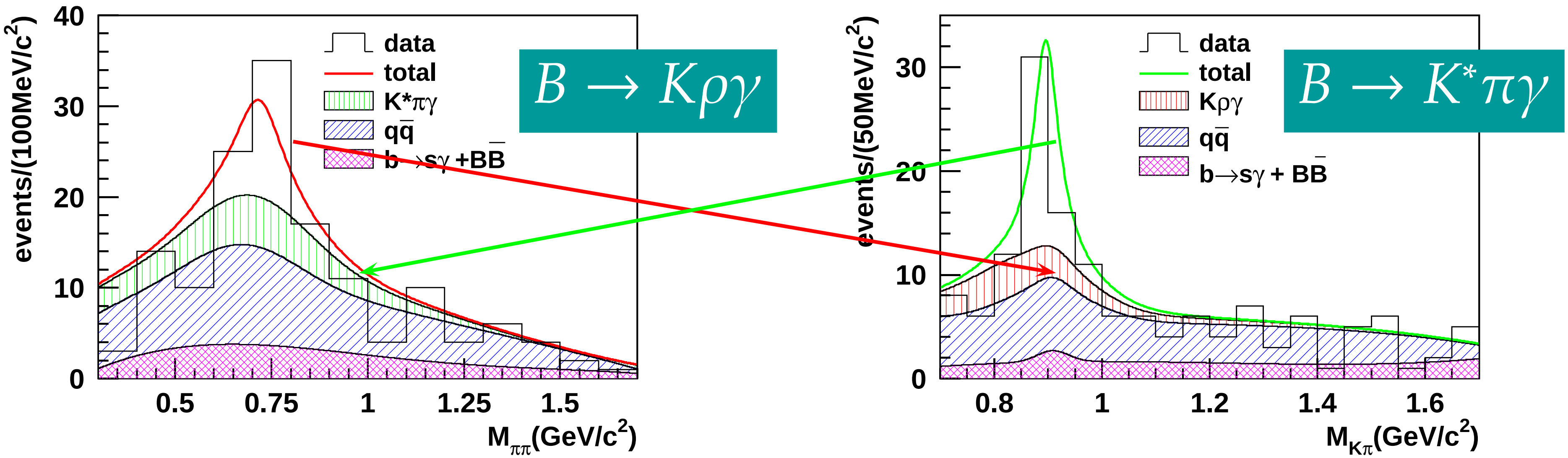
CLEO	$D^*\ell\nu$ partial recon.	$f_+/f_0 = 1.041 \pm 0.054 \pm 0.050$	[PRD66,052003]
Belle	dilepton	$f_+/f_0 = 1.01 \pm 0.03 \pm 0.09$	[PRD67,052004]
BaBar	charmonium	$f_+/f_0 = 1.10 \pm 0.06 \pm 0.05$	[PRD65,032001]

Sooner or later it becomes systematic error dominant,
but if 2% level is feasible with $\mathcal{O}(1\ ab^{-1})$, no need to wait A_{FB}!

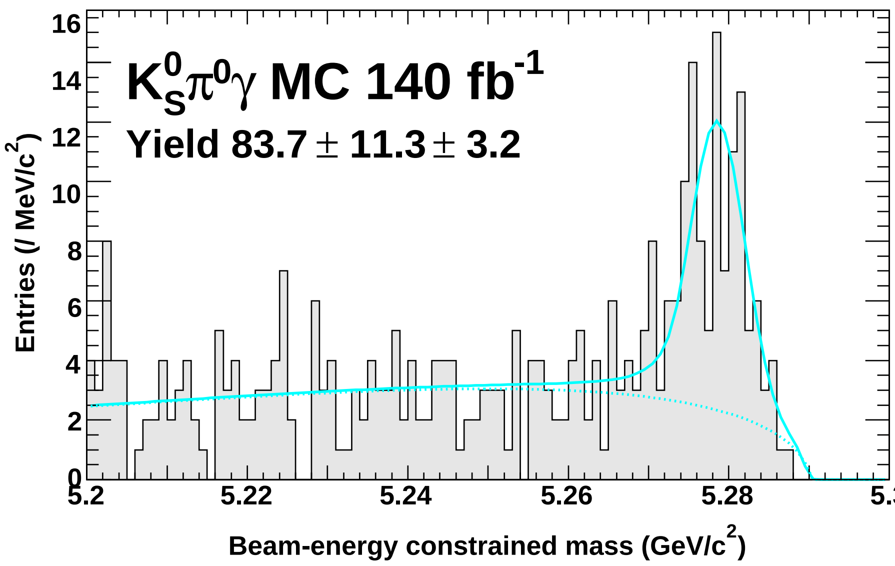
Mixing induced CPV

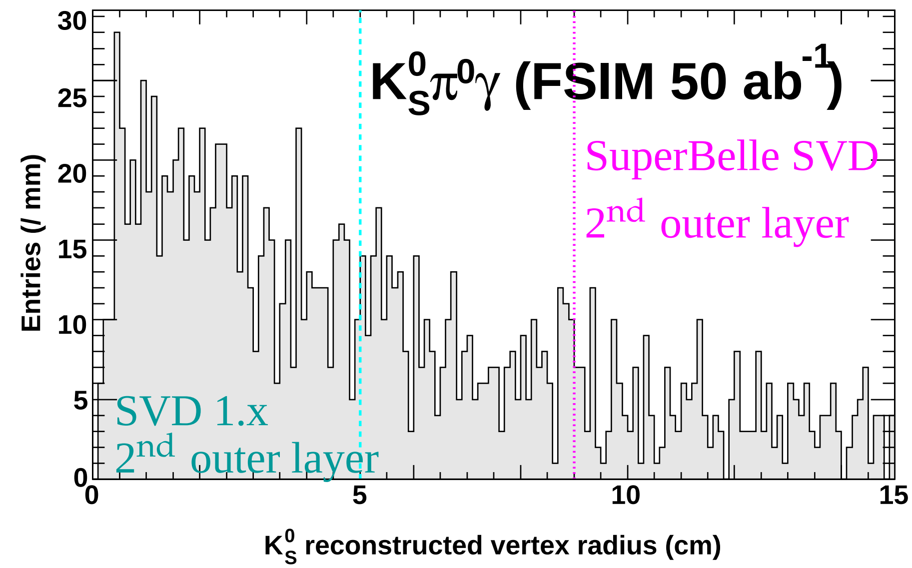
- $B^0 \to K^{*0}\gamma \to K_S^0\pi^0\gamma$
- $B^0 \to K_S^0\phi\gamma$
  - ➡ Next slides
- $B \to K\pi\pi\gamma$
  - $B \to K_1(1270)^0\gamma \to K_S\rho^0\gamma$
  - Triple momentum correlation in $B \to K_1(1400)\gamma$
  - ➡ Dalitz analysis is necessary, no technique available yet

[Belle 29 fb^{-1}]



$B^0 \to K_S^0 \pi^0 \gamma$

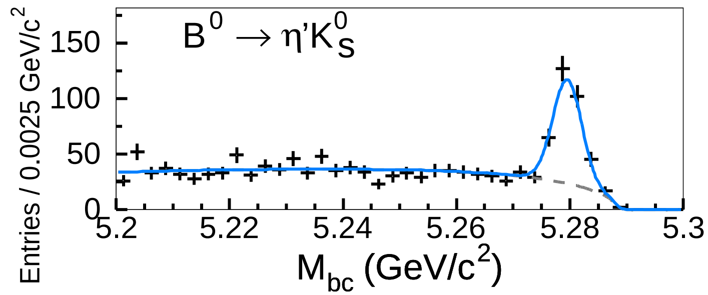




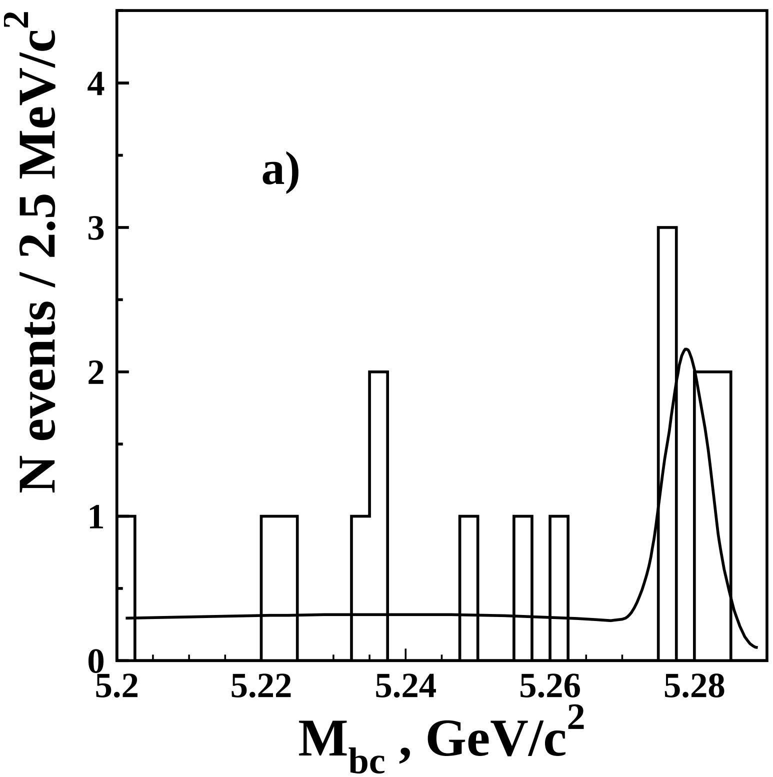
- Technique developed by BaBar ($B \to K_S^0 \pi^0$ mixing CPV)
- 50% useful with current SVD / 70% with SuperBelle SVD
- Sensitivity is similar to $B \to \eta' K_S^0$ ($\delta S_{\eta' K_S^0} = 0.27$ for 421 event)

5 ab^{-1} ➡ 2000 events $\delta S = 0.12$

50 ab^{-1} ➡➡ 20000 events $\delta S = 0.04$



$B^0 \to K_S^0 \phi\gamma$



- Vertex from ϕ as precise as J/ψ
- Very clean $B^0 \to K_S^0 \phi\gamma$ signal
- Mixed CP state $\Rightarrow$ angular analysis
  $J/\psi K^*$ technique is applicable

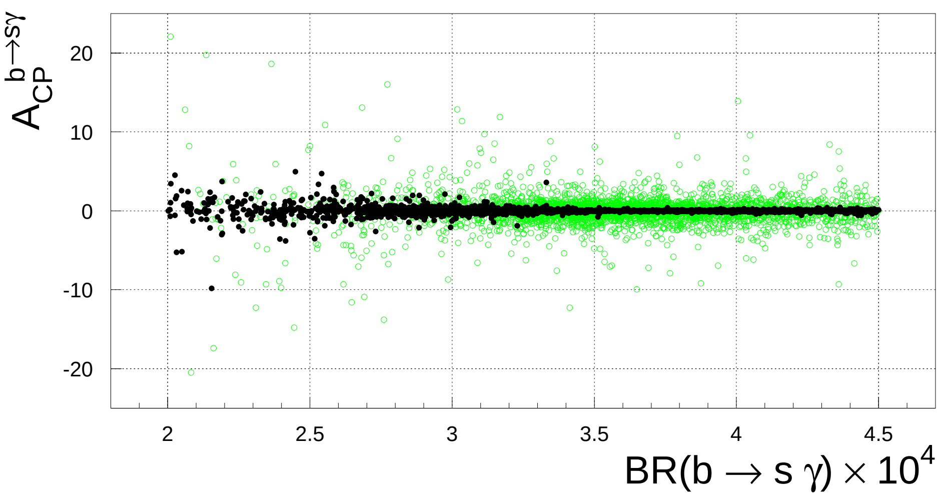
3σ hint at 90 fb^{-1}
(should be there as $B^+ \to K^+\phi\gamma$ is seen at 5σ)

- $\sim$ 160 event at 5 ab^{-1} to get started, with $\delta S \sim 0.5$
  cf. 89 event of $B^0 \to J/\psi K^{*0}$ event $\Rightarrow$ $\sin 2\phi_1 = 0.04 \pm 0.63$
- at 50 fb^{-1}, $\delta S \sim 0.15$

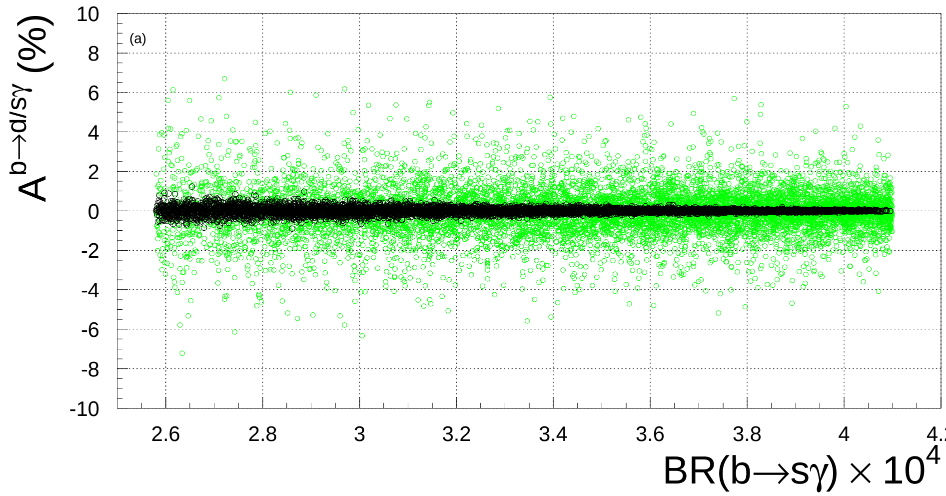
Direct CPV in $b \to (s,d)\gamma$

- Very small in SM ($0.42\,^{+0.17}_{-0.12}\%$) [T.Hurth et al hep-ph/0312260]
- Even smaller for untagged: $A_{CP}(B \to X_{s+d}\gamma)$, even in various SUSY scenarios
- With EDM constraint, almost no asymmetry is possible for naive SUSY scenarios ⇒ Sensitive to exotic new physics

Tagged [Bartl et al. PRD64,076009]



Untagged [Hurth et al. hep-ph/0312260]



$A_{CP}(B \to X_{s+d}\gamma)$

- Lepton flavor tag for inclusive photon
  - Can't select X_s only (tagging X_s/X_d will be difficult)
- Mistag due to mixing and cascade $b \to c \to s\ell\nu$,
  Still wrong tag fraction $w = 0.13$ is not a serious problem.
- Systematic error under very good control (statistics dominant)
- $X_s\gamma$ and $X_{s+d}\gamma$ have different new physics sensitivity

[J.Libby 2nd SLAC SuperB WS]

0.1 ab^{-1}	± 0.1(stat)	± 0.01(syst)
1 ab^{-1}	± 0.03(stat)	± 0.003(syst)
10 ab^{-1}	± 0.01(stat)	(model error?)

$A_{CP}(B \to X_s\gamma)$

Need "sum of exclusive" method to tag X_s
Known large systematic error are:

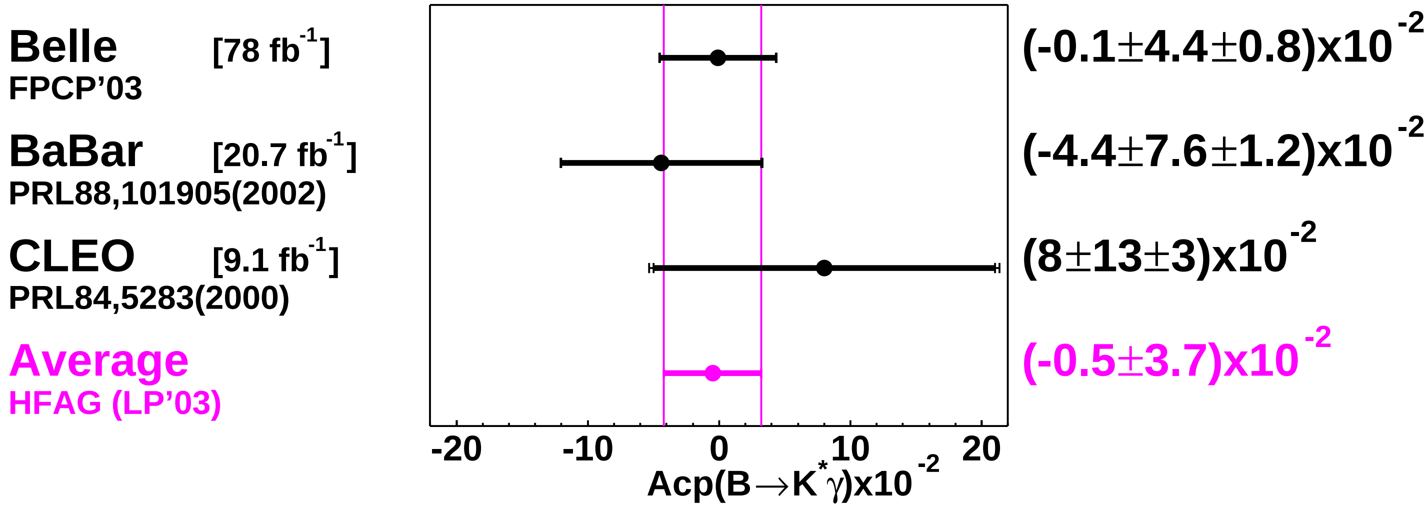
- Signal shape ($\sim 0.8\%$ at 140 fb^{-1}) —
  - $M(X_s)$ spectrum — model error should be reduced from fully inclusive $b \to s\gamma$ measurement
  - Multiplicity distribution — scale with statistics
- A_{CP} in Rare B ($\sim 2\%$ at 140 fb^{-1}) —
  - Now, up to 100% asymmetry is allowed
  - Will significantly reduce by using measured limits
- Charge asymmetry in the cuts ($\sim 2.9\%$ at 140 fb^{-1})
  - Limited by the control sample, scale with statistics

5 ab^{-1} ➡ ± 0.009(stat) ± 0.006(syst)

50 ab^{-1} ➡➡ ± 0.003(stat) ± 0.002(syst) ± 0.003(model)

[extrapolated from Belle LP03 result]

$A_{CP}(B \to K^*\gamma)$

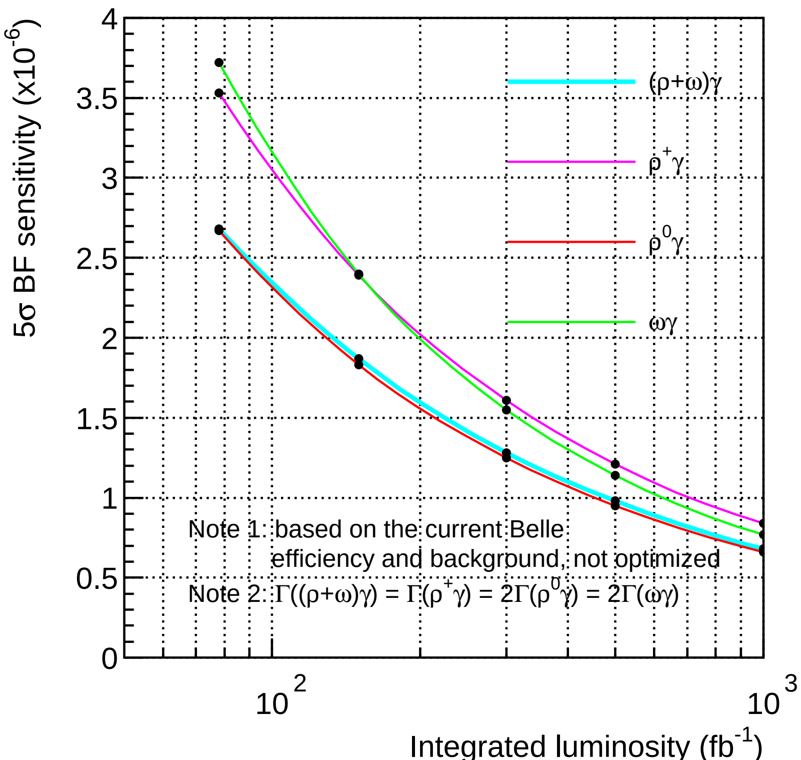


- No deviation from zero: $A_{CP}(B \to K^*\gamma) = (-0.5 \pm 3.7)\%$
- No serious systematic error source, error just scales with luminosity
  $\Rightarrow$ 1.8% at 0.5 ab^{-1}, 0.6% at 5 ab^{-1}, 0.2% at 50 ab^{-1}
- Is it as sensitive as inclusive for new physics?

A few words on $b \to d\gamma$

- Still need to observe the signal in $B \to \rho\gamma, \omega\gamma$ — a few hundred fb^{-1}?
- BF, $\Gamma(\rho\gamma/K^{*}\gamma)$, A_{CP}, isospin asymmetry, mixing induced CPV, . . . possible only at SuperB
- Inclusive — need a serious study to find ω_s and ω_d — in inclusive and sum-of-exclusive methods

[Belle extrapolation]



[BaBar extrapolation, Eigen CKM WS'03]

Luminosity	signifi cance	$(\sigma_{\mathcal{B}}/\mathcal{B})_{exp}$	$\sigma(V_{td}/V_{ts})$
100 fb^{-1}	$1.9 - 2.8\sigma$	0.38-0.53	0.19-0.27
200 fb^{-1}	$2.7 - 3.9\sigma$	0.28-0.38	0.14-0.19
300 fb^{-1}	$3.3 - 4.8\sigma$	0.23-0.31	0.12-0.15
400 fb^{-1}	$3.9 - 5.5\sigma$	0.20-0.27	0.1-0.14
500 fb^{-1}	$4.3 - 6.2\sigma$	0.18-0.25	0.09-0.13
1000 fb^{-1}	$6.0 - 8.7\sigma$	0.14-0.18	0.07-0.09

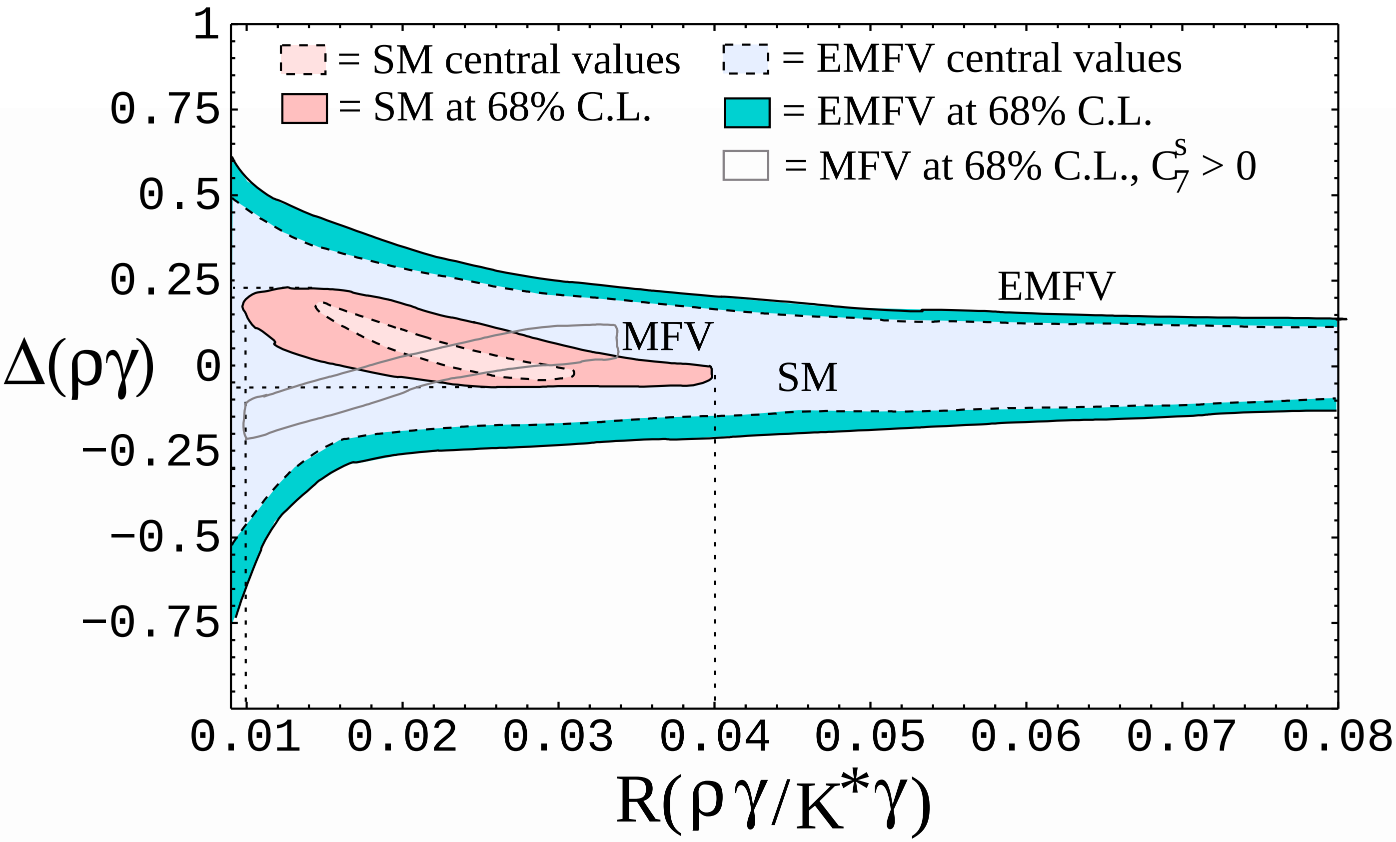
Summary

	0.5 ab^{-1}	5 ab^{-1}	50 ab^{-1}
Branching fraction			
$\mathcal{B}(B \to X_s\gamma)$	<10%	"5%"	still 5%
$\mathcal{B}(B \to X_d\gamma)$	—	—	possible?
Sign of C_7			
$\Delta_{0+}(B \to K^*\gamma)$	4%	2%	no better
$\Delta_{0+}(B \to \rho\gamma)$	possible?	reasonable	precise
Mixing CPV			
$S(K_S^0\pi^0\gamma)$	—	0.12	0.05
$S(K_S^0\phi\gamma)$	—	0.5	0.15
$S(K_1(1270)\gamma)$	—	difficult?	possible?
Direct CPV			
$A_{CP}(B \to X_s\gamma)$ inclusive	4.5%	1.4%	0.5%
$A_{CP}(B \to X_s\gamma)$ sum-of-excl.	3%	1%	0.5%
$A_{CP}(B \to K^*\gamma)$	1.8%	0.6%	0.2%

End

sign(C_7) from $B \to \rho\gamma$

[Hurth-Lunghi hep-ph/0307142]



- One can do the same thing using $B \to \rho\gamma$ isospin asymmetry
  Maybe a better test since expected asymmetry is larger
- However, it will demand $\sim 0.5\ \mathrm{ab}^{-1}$ for $B \to \rho\gamma$ observation.
  especially where $R(\rho\gamma/K^*\gamma)$ is small.