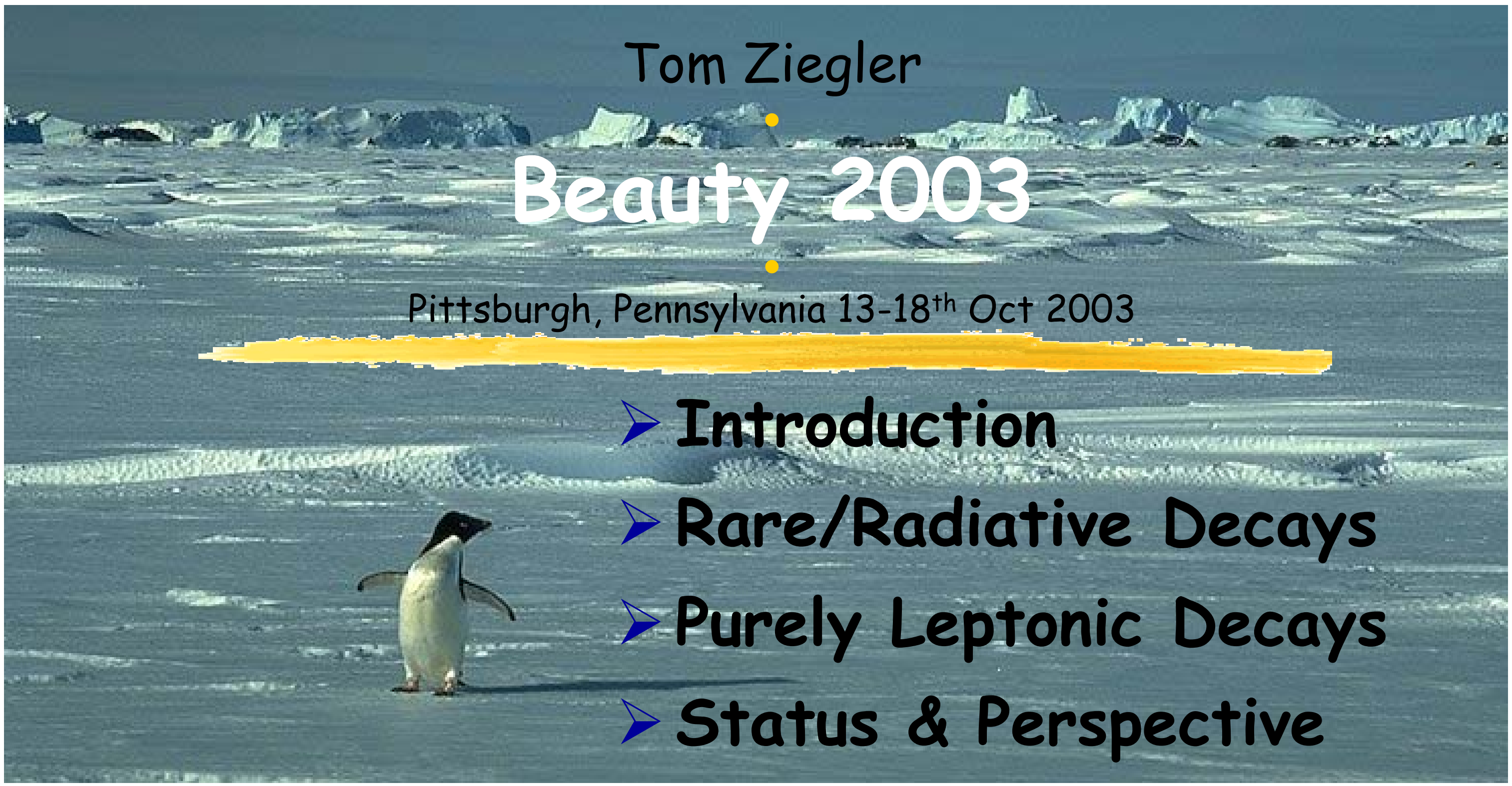
Radiative and EW Penguin B-Decays with the Belle Detector



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Beauty 2003

Pittsburgh, Pennsylvania 13-18th Oct 2003

- Introduction
- Rare/Radiative Decays
- Purely Leptonic Decays
- Status & Perspective

Introduction and Motivation

b -> sγ and b -> sl^+l^- decays proceed via

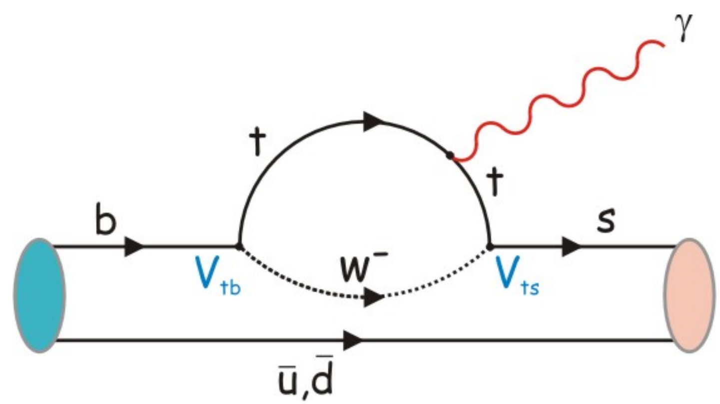
lflavour changing neutral current (FCNC)

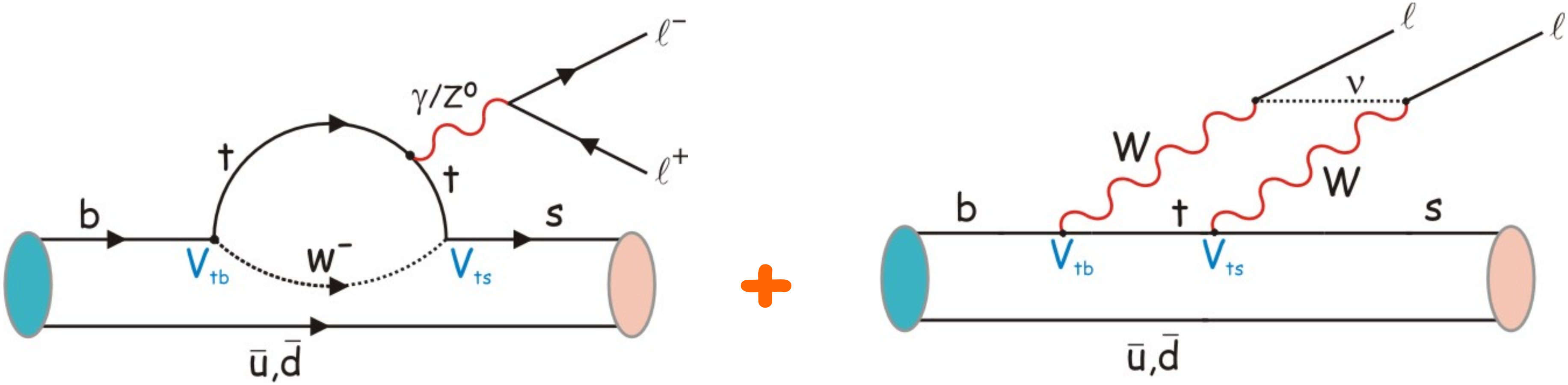
box and penguin diagrams

b -> sγ penguin:

$BR(b \to s\gamma) \approx 3.5 \times 10^{-4}$

Not so rare actually…



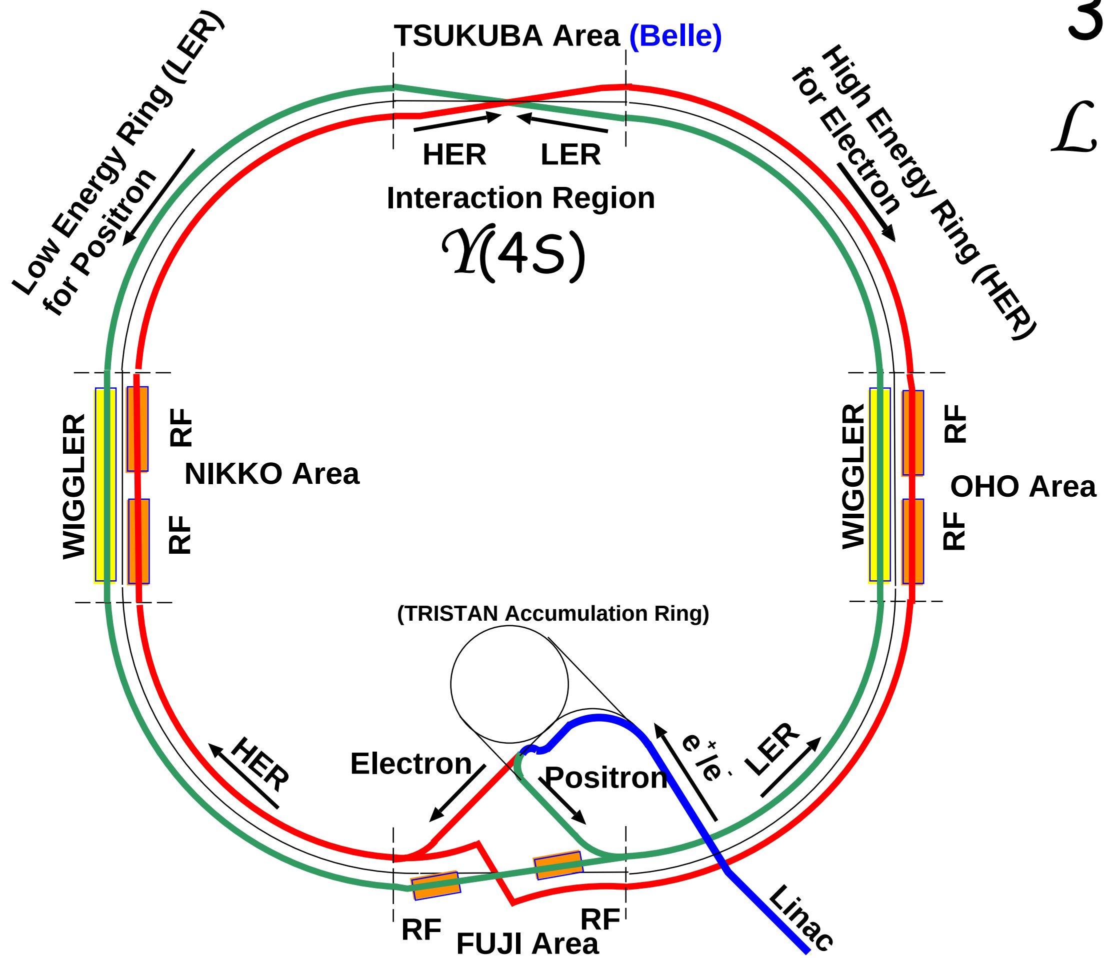


$BR(b\to sl^+l^-) \sim \alpha_{em}\cdot BR(b\to s\gamma) \approx 10^{-6}$!!!

New particles can/will contribute quite significantly to the decay rates and various asymmetries quite significantly via the loops!

=> Ideal testing ground for SM and extensions (2HDM, MSSM, GUT, ...?)

The KEK-B collider



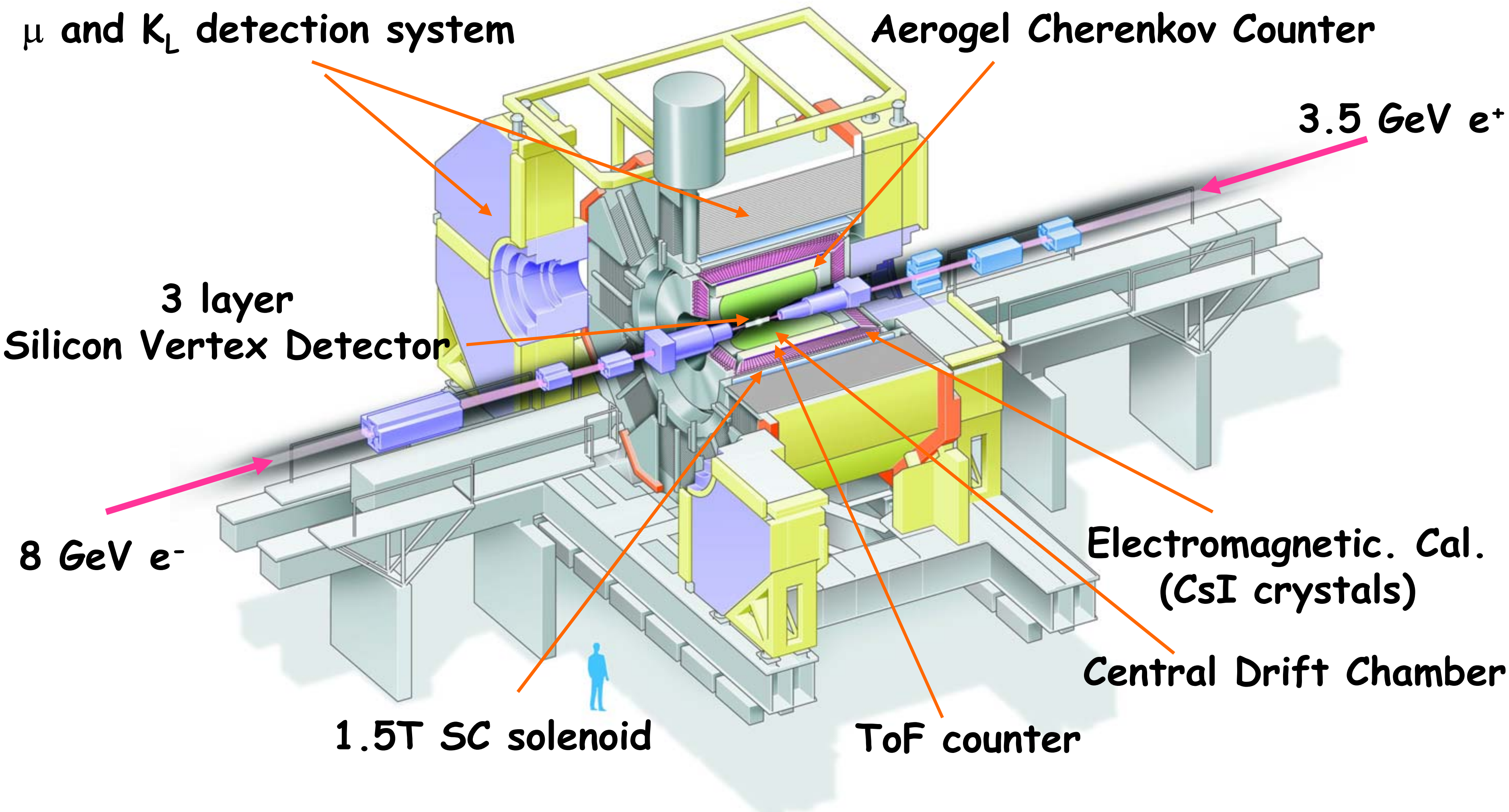
3.5 GeV e^+ on 8 GeV e^-

$\mathcal{L} > (1.0 \times 10^{34})/cm^2/sec$

$\int \mathcal{L}\, dt = 158\ fb^{-1}$

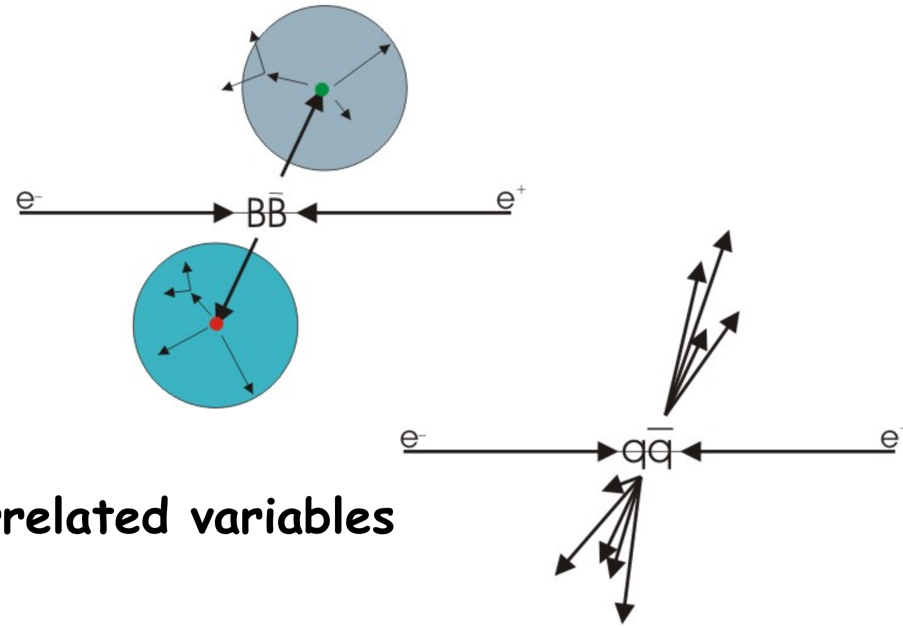
140 fb^{-1} on resonance!

The Belle Detector



Continuum suppression

BB and qq have different topologies!



Typical variables for Bkg suppression:

- **Modified Fox Wolfram moments**
- **Sphericity $\cos(\theta_{sph})$**
- **Thrust, $\cos(\theta_{thr})$**
- **…**

=> Build Fisher discriminant $\mathcal{F}$ for correlated variables

=> Form Likelihood for uncorrelated variables: $\mathcal{L}(\mathcal{F}, \cos\theta_B)$

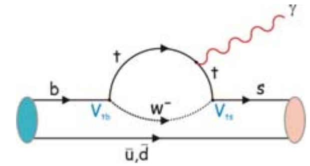
=> Build Likelihood ratio: LR = $\mathcal{L}_B / (\mathcal{L}_B + \mathcal{L}_{qq})$

Kinematic Variables:

$\Delta E = E^*_B - E^*_{beam}$

$M_{bc} = \sqrt{E^{*2}_{beam} - |p^*_B|^2}$

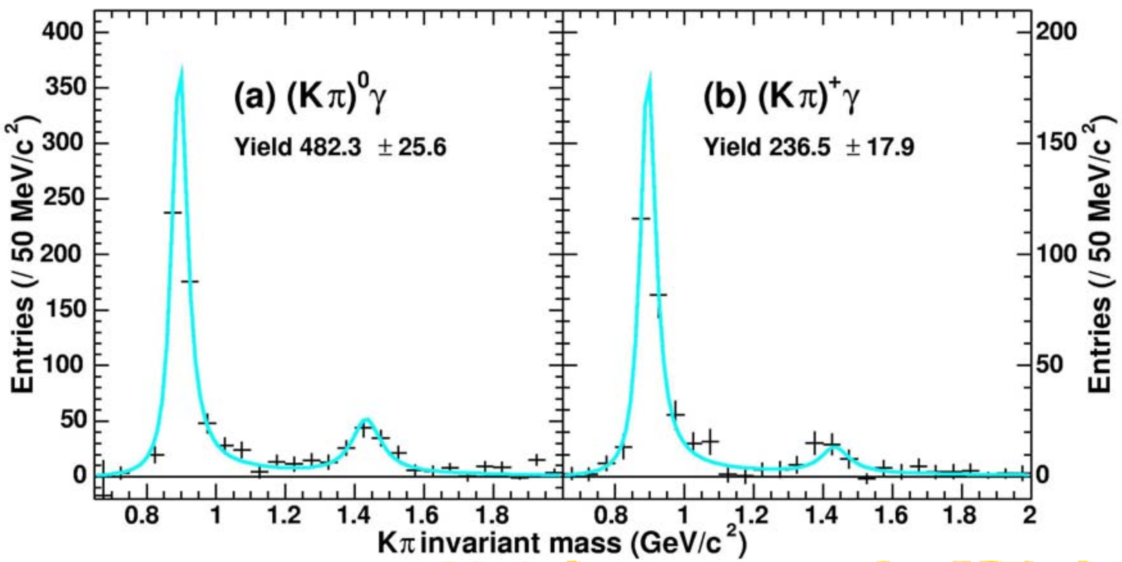
B -> $K^*\gamma$

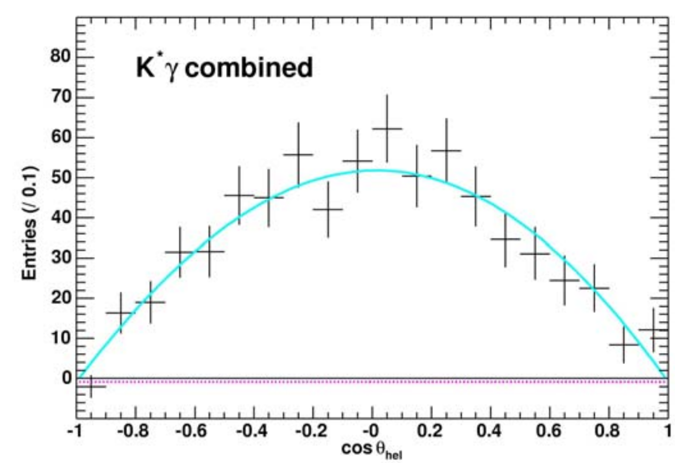


- Photon with $1.8 < E^*_\gamma < 3.4$ GeV, π^0/η veto
- K*(892) reconstructed in 4 final states:

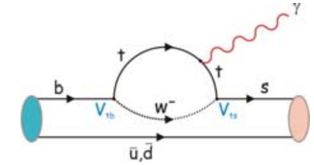
  $K^+\pi^-$, $K^0_s\pi^0$, $K^+\pi^0$, $K^0_s\pi^+$ with

  $|M(K\pi) - M(K^*)_r| < 75$ MeV/c^2
- BKG suppression against e^+e^- -> $qq(\gamma)$ -> LR(F,$\cos(\theta^*_B)$))



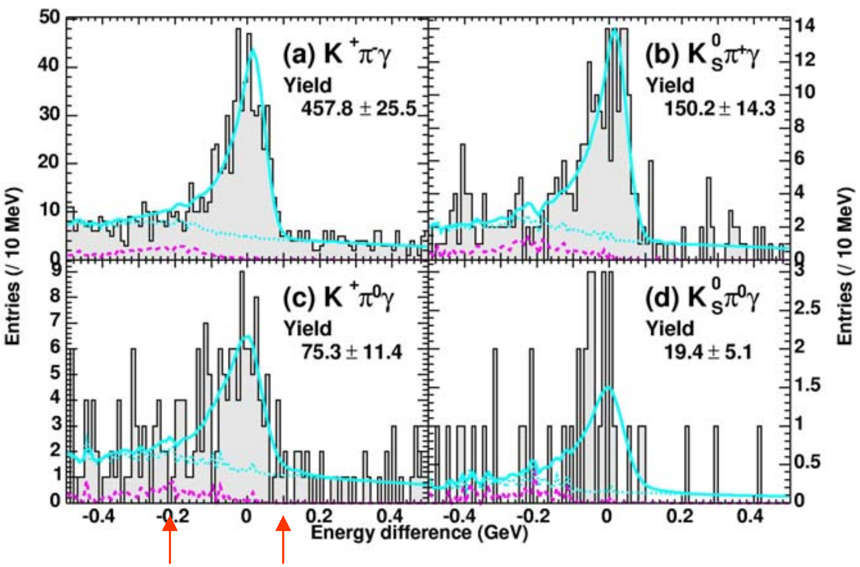


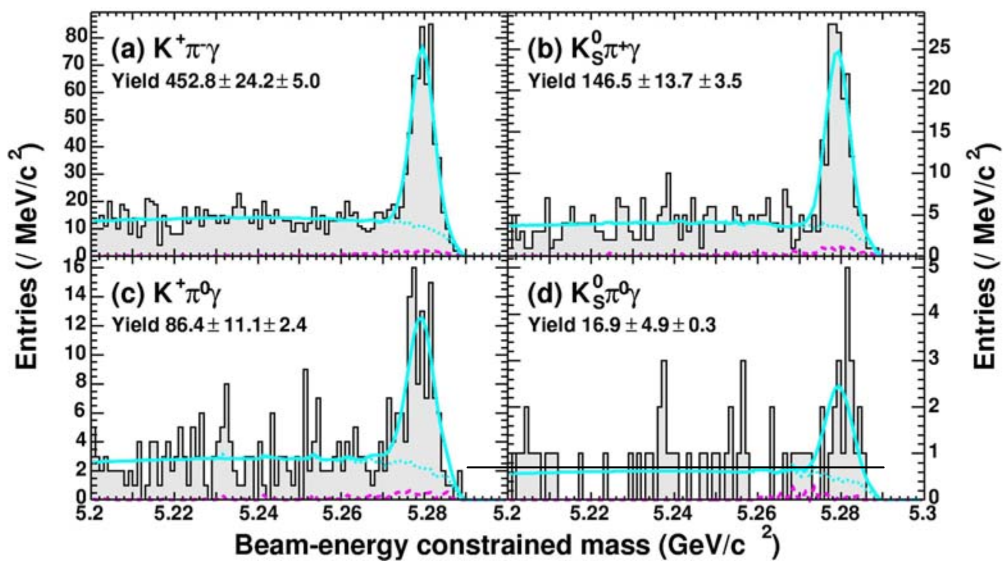
BR(B -> $K^*\gamma$)



$\Delta E = E^*_B - E^*_{beam}$

$M_{bc} = \sqrt{E^{*2}_{beam} - |p^*_B|^2}$



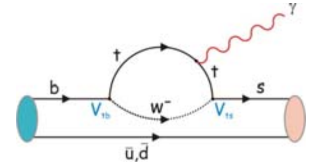


BR(B^0 -> $K^{*0}\gamma$) = $(40.9 \pm 2.1 \pm 1.9) \cdot 10^{-6}$ **SM $\approx (69 \pm 21) \cdot 10^{-6}$**

BR(B^+ -> $K^{*+}\gamma$) = $(44.0 \pm 3.3 \pm 2.4) \cdot 10^{-6}$ **SM $\approx (74 \pm 23\ ) \cdot 10^{-6}$**

Based on 78 fb^{-1} ($\simeq$ 85 M $B\bar{B}$-pairs)

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



Investigate Isospin asymmetry between B0 and B+:

$$\Delta_{0+} = \frac{\frac{\tau_{B^+}}{\tau_{B^0}}\, BR(B^0 \to K^{*0}\gamma) - BR(B^+ \to K^{*+}\gamma)}{\frac{\tau_{B^0}}{\tau_{B^+}}\, BR(B^0 \to K^{*0}\gamma) + BR(B^+ \to K^{*+}\gamma)}$$

$$\tau_{B^+}/\tau_{B^0} = 1.083 \pm 0.017 \quad \text{[PDG2002]}$$

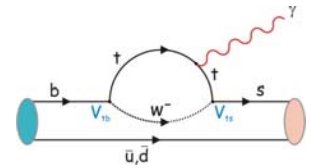
Assumes $f_+/f_0 = 1$!

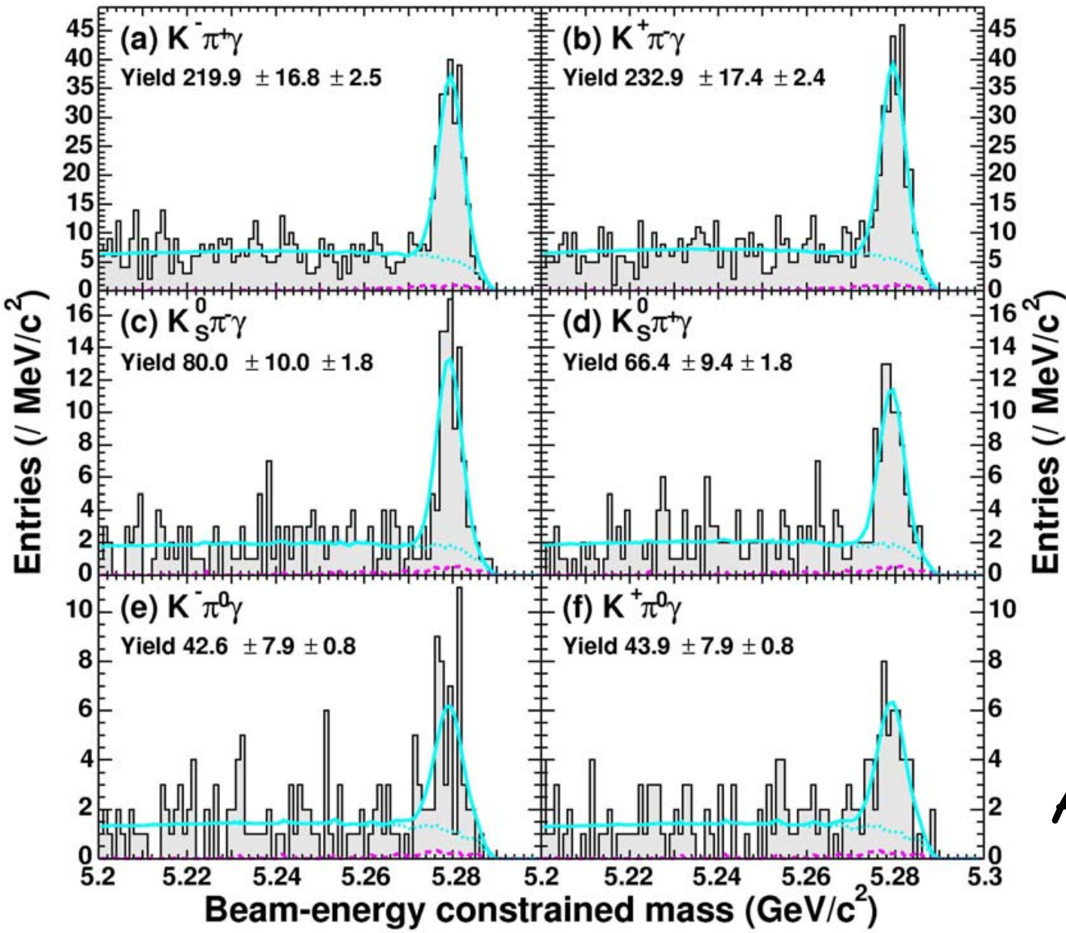
SM predicts +(5-10)%!

$f_+/f_0 = 1.072 \pm 0.057$
[PDG2002]

$$\Delta_{0+} = (+0.3 \pm 4.5 \pm 1.8)\%$$

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





$M_{bc} = \sqrt{E^{*2}_{beam} - |p^*_B|^2}$

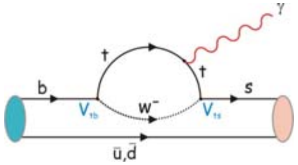
In SM A_{CP} should be smaller than 1% !

$$A_{CP} = 1/(1-2w) \times$$

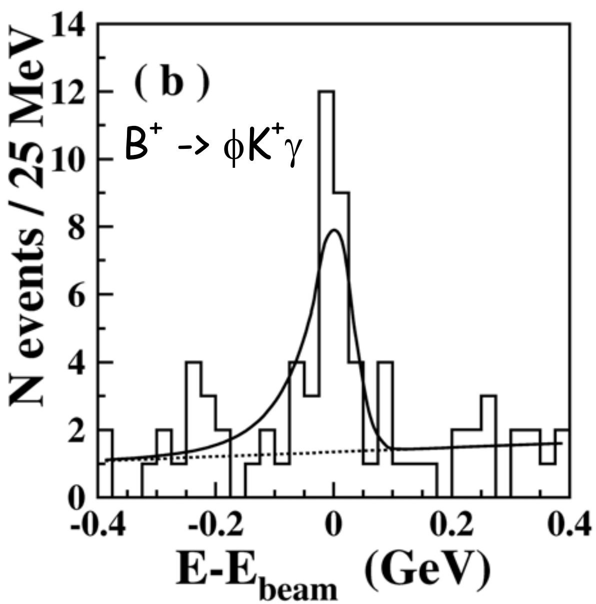
$$\frac{N(\bar{B} \to \bar{K}^*\gamma) - N(B \to K^*\gamma)}{N(\bar{B} \to \bar{K}^*\gamma) + N(B \to K^*\gamma)}$$

$$A_{CP} = (-0.1 \pm 4.4 \pm 0.8)\%$$

B -> φ K γ

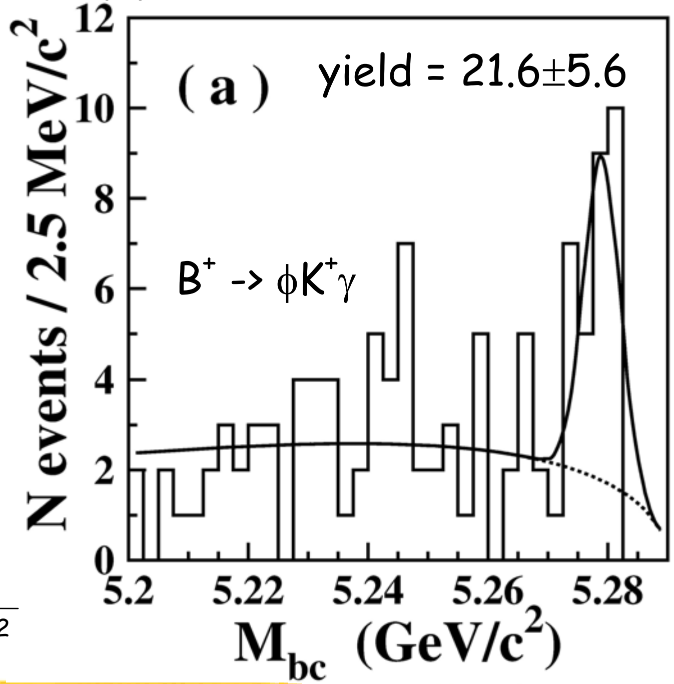


- Photon with 2.0 < E^*_γ < 2.7 GeV, π^0/η veto
- Select 2 charged K + charged/neutral K
- φ ID: |M(KK) – $M(\varphi)_r$| < 10 MeV/c²
- BKG suppression against e+e- -> qq(γ) -> LR(𝓕,cos(θ*B))

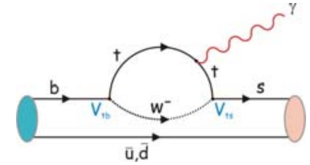


|ΔE|<400MeV

$M_{bc} = \sqrt{E^{*2}_{beam} - |p^*_B|^2}$



B -> φ K γ



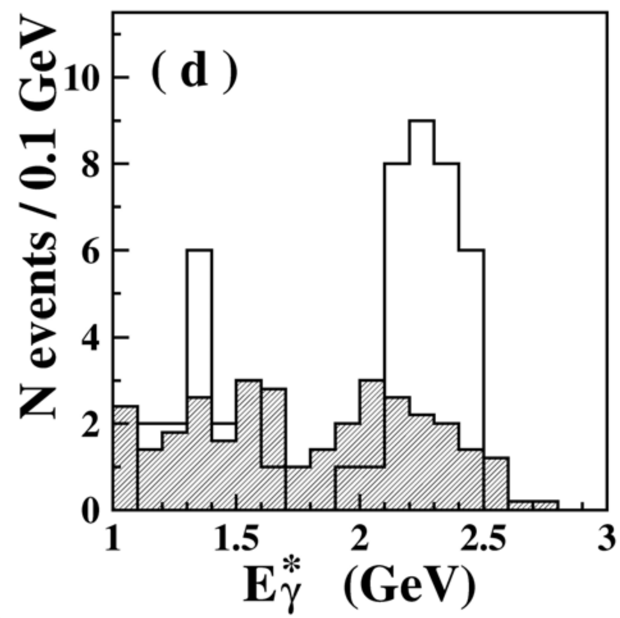
$BR(B^+ \to \varphi K^+\gamma) = (3.4 \pm 0.9 \pm 0.4) \cdot 10^{-6}$ -> **5.5σ**

$BR(B^0 \to \varphi K^0\gamma) = (4.6 \pm 2.4 \pm 0.6) \cdot 10^{-6}$ -> 3.3σ

< 8.3 ·10-6 (@90% C.L.)

$BR(B \to K^*\gamma) \approx 10 \times BR(B^+ \to \varphi K^+\gamma)$

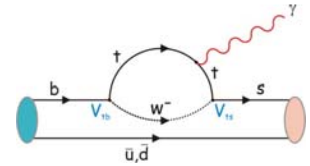
significance = $\sqrt{-2 \ln(\mathcal{L}_0/\mathcal{L}_{max})}$



$B^0 \to \varphi K^0 \gamma$ is around the corner! and is a very promising candidate for time-dependent CPV analysis!

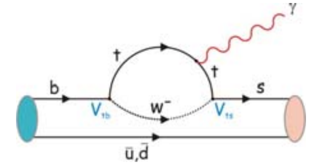
Based on $90 fb^{-1}$ (≅ 96 M BB-pairs)

Status of b->sγ in Belle

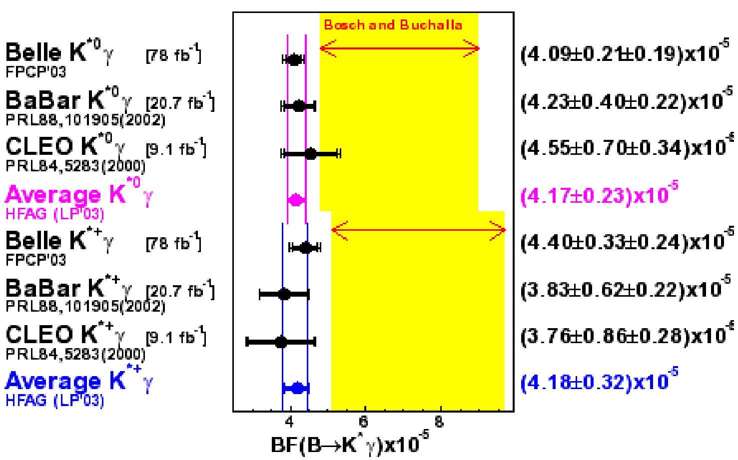


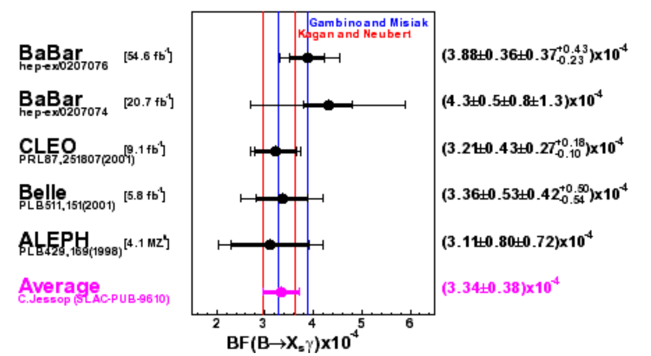
Channel	BR ($\cdot 10^{-6}$)	$\int \mathcal{L} dt$	Ref.
$B \to X_s \gamma$	$336 \pm 53 \pm 42$ +50/-54	6 fb^{-1}	[1]
$B^0 \to K^{*0} \gamma$	$40.9 \pm 2.1 \pm 1.9$	78 fb^{-1}	[2]
$B^+ \to K^{*+} \gamma$	$44.0 \pm 3.3 \pm 2.4$	78 fb^{-1}	[2]
$B^+ \to \phi K^+ \gamma$	$3.4 \pm 0.9 \pm 0.4$	90 fb^{-1}	[3]
$B^+ \to K^+ \pi^+ \pi^- \gamma$	24 ± 5 +4/-2	29 fb^{-1}	[3]
$B^0 \to K^{*0}_2(1430) \gamma$	$13 \pm 5 \pm 1$	29 fb^{-1}	[4]
$B^+ \to \rho^+ \gamma$	< 2.7 (@ 90% C.L.)	78 fb^{-1}	[5]
$B^0 \to \rho^0 \gamma$	< 2.6 (@ 90% C.L.)	78 fb^{-1}	[5]
$B^0 \to \omega(783) \gamma$	< 4.4 (@ 90% C.L.)	78 fb^{-1}	[5]

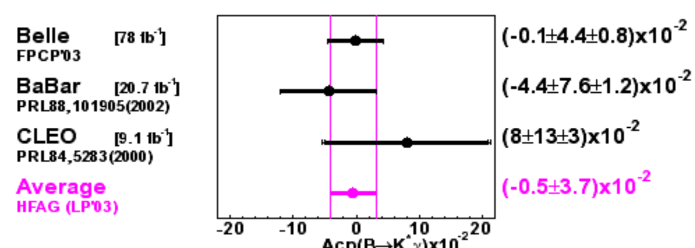
Status of b->sγ



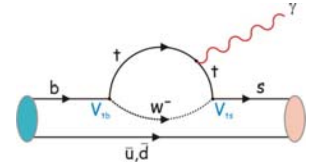
Channel	BR ($\cdot 10^{-6}$)	$\int \mathcal{L} dt$
B -> $X_s \gamma$	388 ± 36 ± 37 +43/-23	54.6 fb^{-1}
B^0 -> $K^{*0} \gamma$	42.3 ± 4.0 ± 2.2	20.7 fb^{-1}
B^+ -> $K^{*+} \gamma$	38.3 ± 6.2 ± 2.2	20.7 fb^{-1}
B^0 -> $K^{*0}_2(1430) \gamma$	12.2 ± 2.5 ± 1.1	81.4 fb^{-1}
B^+ -> $K^{*+}_2(1430) \gamma$	14.4 ± 4.0 ± 1.3	81.4 fb^{-1}

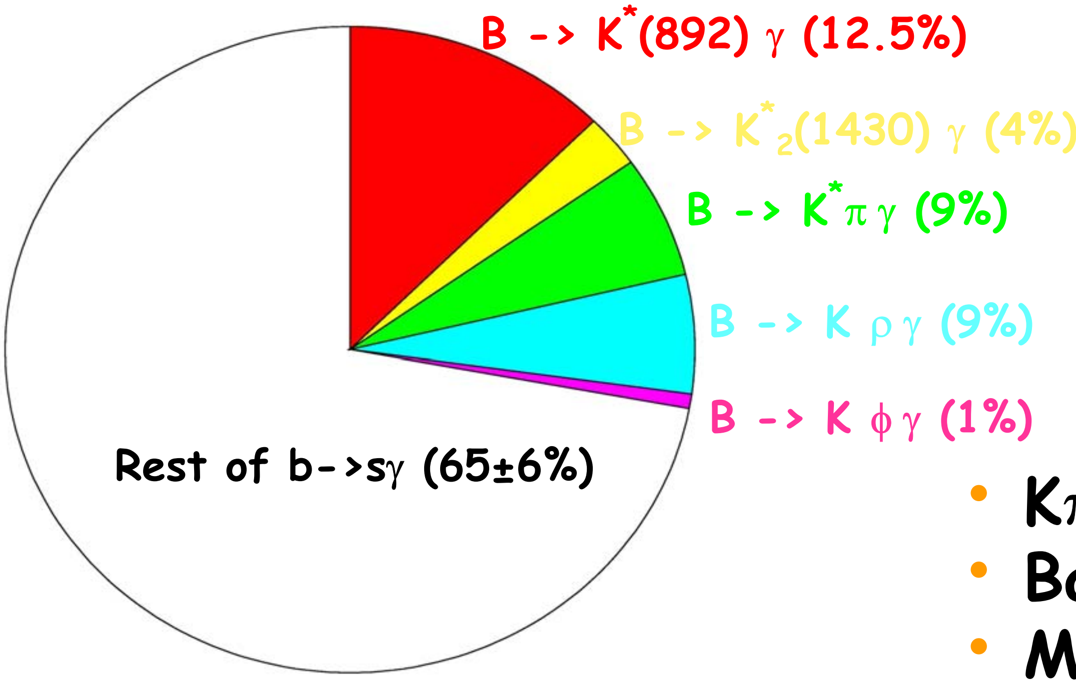






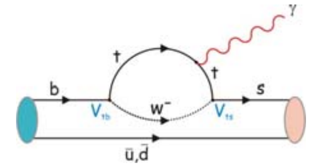
Status of BR(b->sγ)





- $K\pi^n\gamma$ (n>=3)
- Baryons + γ (≤13%)
- Mode with resonances, e.g. η, η'
- $KKK\pi^n\gamma$ (≠Kφγ)
- …

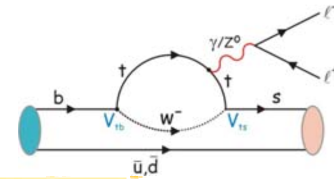
Future of b->sγ



Large theoretical uncertainties on BR!

- In ratios like A_{CP} or Isospin asymmetries systematic uncertainties are expected to cancel (th./exp.)
- Current measurements are statistically limited! Also more modes accessible with more data!
- e.g. $B^0 \to \phi K^0_S \gamma$ promising candidate for time-dependent CPV analysis!
- Energy spectrum analysis -> transition dynamics (CKM)
- b->dγ transitions not yet observed, large CPV effects could be expected!

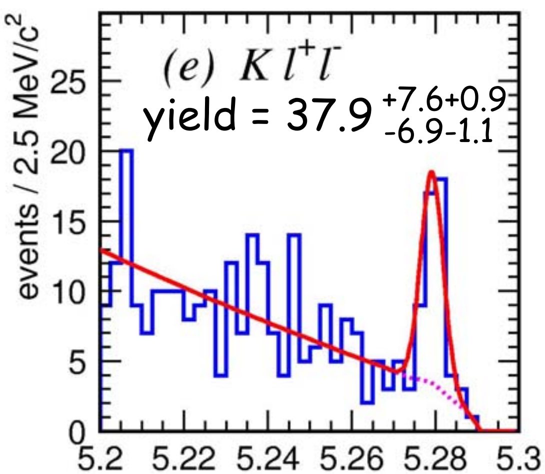
$B \to K\, l^+ l^-$ & $B \to K^* l^+ l^-$



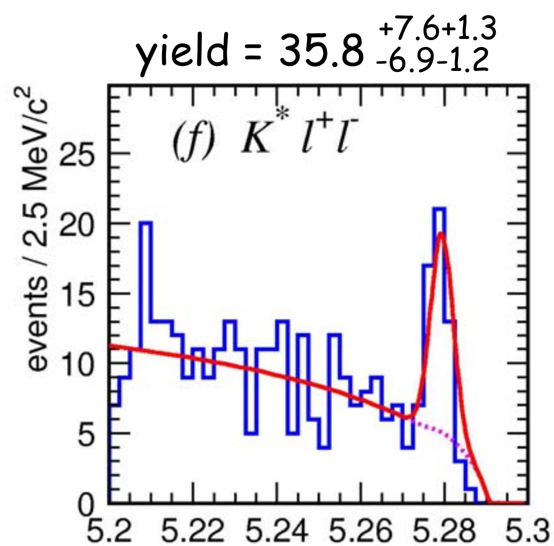
- K: charged or neutral
- K*: $K^+\pi^-$, $K^0_s\pi^+$, $K^+\pi^0$ with $|M(K\pi)-M(K^*)_r|<75$ MeV/c^2
- Lepton pair: e or μ

  $p(e)>0.4$ GeV/c, $p(\mu)>0.7$ GeV/c

  veto on J/Ψ, $\Psi(2S)$

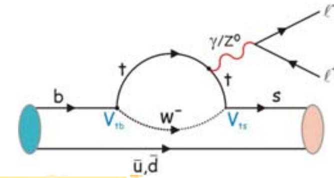


$M_{bc} = \sqrt{E^{*2}_{beam} - |p^*_B|^2}$



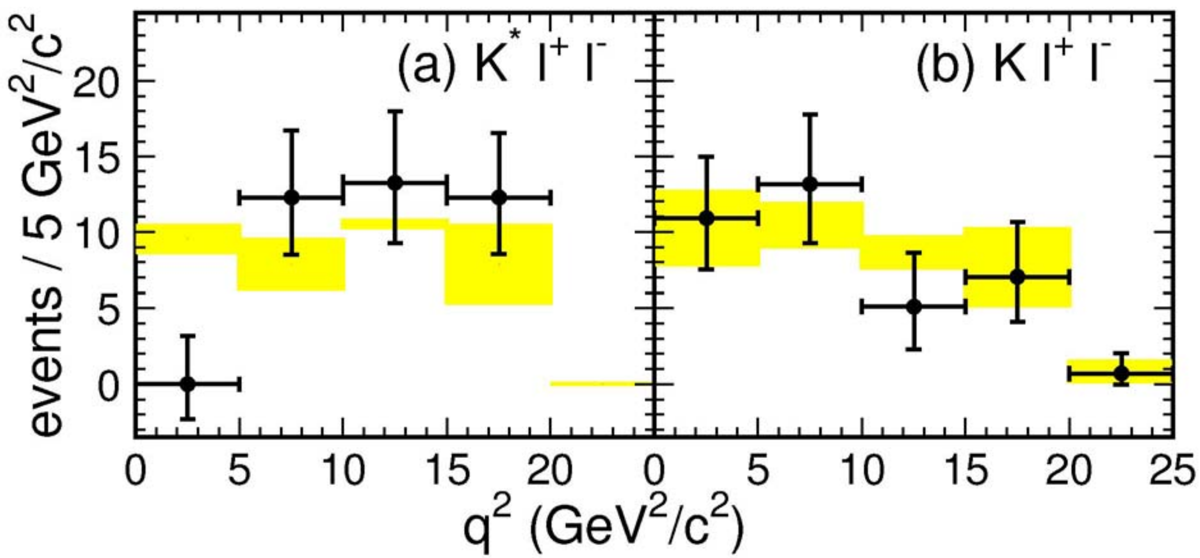
$M_{bc} = \sqrt{E^{*2}_{beam} - |p^*_B|^2}$

$B \to K\,l^+l^-$ & $B \to K^*l^+l^-$



$BR(B \to K l^+l^-) = (4.8\ {+1.0/-0.9} \pm 0.3 \pm 0.1) \cdot 10^{-7}$

$BR(B \to K^* l^+l^-) = (11.7\ {+2.6/-2.4} \pm 0.8 \pm 0.4) \cdot 10^{-7}$

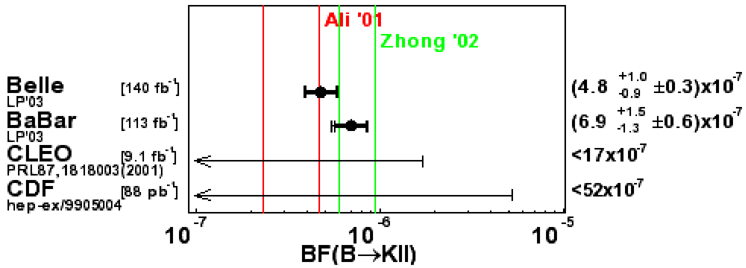


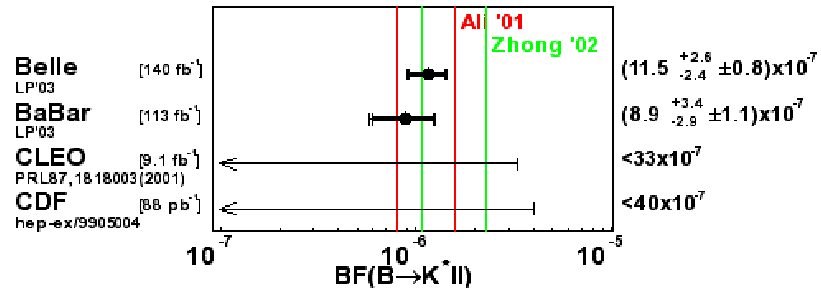
Based on 140 fb^{-1} (≅ 152 M BB-pairs)

Status of B -> s l^+l^-

Channel	BR ($\cdot 10^{-7}$)	$\int \mathcal{L}dt$	Ref.
Belle			
B -> $X_s ll$	61 ± 14 +14/-11	60 fb^{-1}	[6]
B -> Kll	4.8 +1.0/-0.9 ± 0.3 ± 0.1	140 fb^{-1}	[7]
B -> $K^* ll$	11.5 +2.6/-2.4 ± 0.8 ± 0.2	140 fb^{-1}	[7]
BaBar			
B -> $X_s ll$	63 ± 16 +18/-15	82 fb^{-1}	
B -> Kll	6.5 +1.4/-1.3 ± 0.4	113 fb^{-1}	
B -> $K^* ll$	8.8 +3.3/-2.9 ± 1.0	113 fb^{-1}	
B -> $K\nu\nu$	$< 7.0 \cdot 10^{-5}$ (@90% C.L.)	51/80 fb^{-1}	

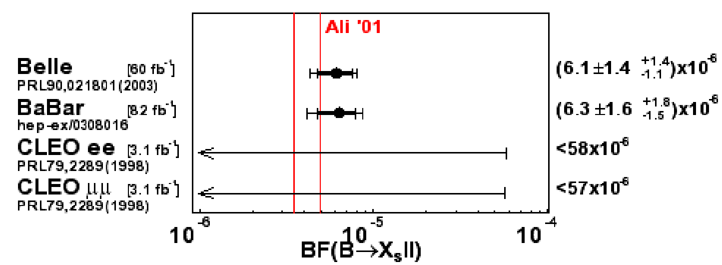
Status and Perspective: B -> s l^+l^-



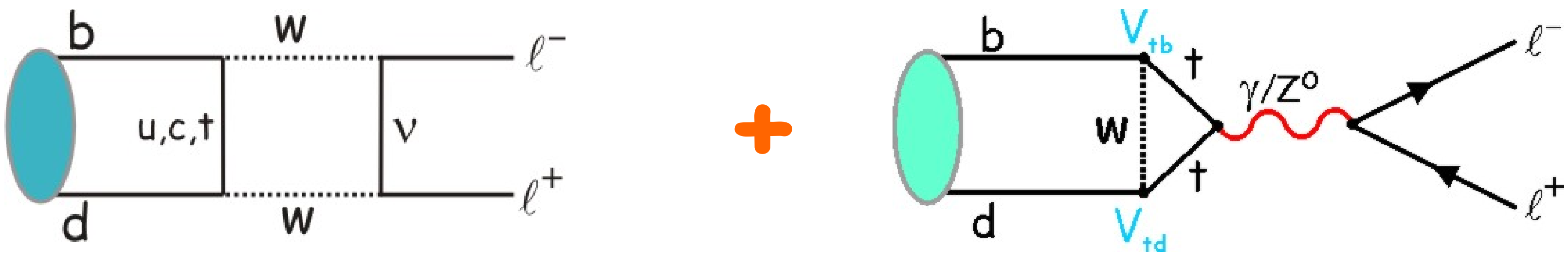


Next target:

- precise measurement of $X_s l^+l^-$
- increase precision in q^2
- A_{FB} measurement



$B^0 \rightarrow l^+l^-$



=> Helicity suppressed 2-body decay in SM

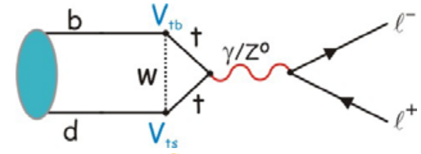
BR in SM: B->$\mu\mu$: $(1.00 \pm 0.14) \cdot 10^{-10}$

B->ee : $(2.34 \pm 0.33) \cdot 10^{-15}$

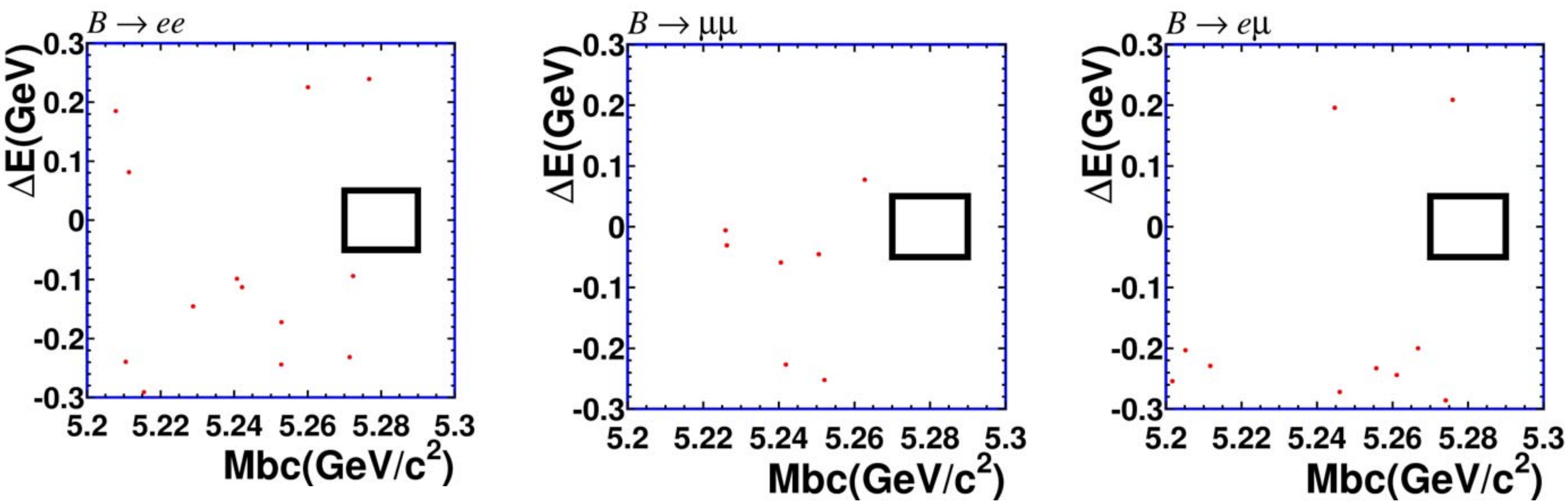
Not observable, but enhancement by 2-3 orders of magnitude in 2HDM or Z mediated FCNC models.

B->eμ forbidden in SM, but possible in SUSY or Lepto-Quark models!

$B^0 \to l^+l^-$



- Tight cut on leptons (e/μ): $\mathcal{L} > 0.9$
- BKG suppression with LR($\mathcal{F}$,$\cos(\theta^*_B)$)
- Signal box: $5.27 < M_{bc} < 5.29$ GeV/c^2, $|\Delta E| < 0.05$GeV

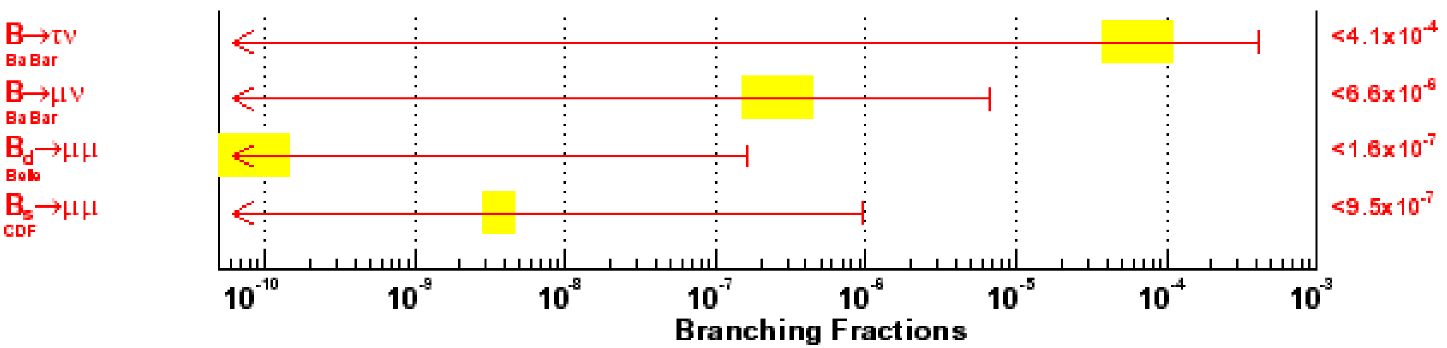


$\Delta E = E^*_B - E^*_{beam}$

$M_{bc} = \sqrt{E^{*2}_{beam} - |p^*_B|^2}$

Status of B → ll

Channel	BR (@90% C.L.)	$\int \mathcal{L} dt$	
B->ee	< $1.9 \cdot 10^{-7}$	78 fb^{-1}	Belle
B->μμ	< $1.6 \cdot 10^{-7}$	78 fb^{-1}	Belle
B->eμ	< $1.7 \cdot 10^{-7}$	78 fb^{-1}	Belle
B->μμ	< $2.5 \cdot 10^{-7}$	113 pb^{-1}	CDF
B_s->μμ	< $9.5 \cdot 10^{-7}$	113 pb^{-1}	CDF
B_s->μμ	< $16 \cdot 10^{-7}$	100 pb^{-1}	D0
B->eν	< $5.4 \cdot 10^{-6}$	60 fb^{-1}	Belle
B->μν	< $6.8 \cdot 10^{-6}$	60 fb^{-1}	Belle
B->μν	< $6.6 \cdot 10^{-6}$	81 fb^{-1}	Babar
B->τν	< $4.1 \cdot 10^{-4}$	81 fb^{-1}	Babar



Future? $B \to ll(\gamma)$

SM prediction for purely leptonic/radiative B-decays:

$B \to \tau\tau$	: $\approx 3 \cdot 10^{-8}$	$B \to \tau\tau\gamma$	: $> 3 \cdot 10^{-8}$
$B \to \mu\mu$	: $\approx 1 \cdot 10^{-10}$	$B \to \mu\mu\gamma$	: $\approx$ few $\cdot 10^{-10}$
$B \to ee$	: $\approx 3 \cdot 10^{-15}$	$B \to ee\gamma$	: $\approx$ few $\cdot 10^{-10}$

$B \to \tau\nu$	: $\approx 7 \cdot 10^{-5}$	$B \to \tau\nu\gamma$	: $> 7 \cdot 10^{-5}$
$B \to \mu\nu$	: $\approx 3 \cdot 10^{-7}$	$B \to \mu\nu\gamma$	: $\approx$ few $\cdot 10^{-6}$
$B \to e\nu$	: $\approx 7 \cdot 10^{-12}$	$B \to e\nu\gamma$	: $\approx$ few $\cdot 10^{-6}$

Any significant increase in these BR might give hint for new physics

Some of these modes should be accessible with the B-factories!

What have we achieved?

Radiative B-Decays in PDG 2000:

	charged modes	neutral modes
$K^{*}(892)\ \gamma$	$(5.7\pm3.3) \cdot 10^{-5}$	$(4.0\pm1.9) \cdot 10^{-5}$
$K_1(1270)\ \gamma$	$< 7.3 \cdot 10^{-3}$	$< 7.0 \cdot 10^{-3}$
$K^{*}_2(1400)\ \gamma$	$< 2.2 \cdot 10^{-3}$	$< 4.3 \cdot 10^{-3}$
$K^{*}_2(1430)\ \gamma$	$< 1.4 \cdot 10^{-3}$	$< 4.0 \cdot 10^{-4}$
$K^{*}(1680)\ \gamma$	$< 1.9 \cdot 10^{-3}$	$< 2.0 \cdot 10^{-3}$
$K^{*}_3(1780)\ \gamma$	$< 5.5 \cdot 10^{-3}$	$< 1.0 \cdot 10^{-2}$
$K^{*}_4(2045)\ \gamma$	$< 9.9 \cdot 10^{-3}$	$< 4.3 \cdot 10^{-3}$

Quite dramatic improvement in our knowledge of radiative B-decays

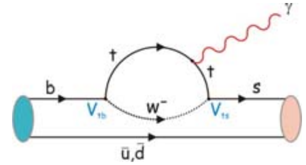
Summary

- Since last year new modes to $B \to X_s\gamma$ and $B \to X_s l^+ l^-$ added -> first observation of $B \to \phi K\gamma$ and $B \to K^* l^+ l^-$
- BR and asymmetries are in good agreement with SM, but many results are statistically limited
- We are entering the exciting phase of precision measurements (e.g. A_{FB}, q^2 dependence in $K^{(*)}ll$) just started
- Radiative Penguin decays are ideal testing ground for SM and new physics … but you knew that…
- Need more data to fix some of the important parameters in EW/radiative penguin transitions

Many interesting discoveries are still ahead…


There are lots of them…

List of References



[1] Phys.Lett. B511, 151 (2001)
[2] Abs.537, BELLE-CONF-0319 Preliminary
[3] Phys.Rev.Lett 98, 231801 (2002)
[4] Abs.542, BELLE-CONF-0322 Preliminary
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[6] PRL 90, 021801 (2003)
[7] hep-ex/0309032, submitted to PRL
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Low energy eff. Hamiltonian

$$\mathcal{H}_{\mathbf{eff}} \sim \sum^{10}_{i=1} C_i(\mu) O_i(\mu)$$

$$\Gamma(b \to s\gamma) = 1/32\pi^4 \, G^2_F \, \alpha_{em} \, m^5_b \, |V^*_{ts} V_{tb}|^2 \, (|C_7^{eff}|^2 + O(1/m_b, 1/m_c)))$$

=> Access to $|C_7|$

Low energy eff. Hamiltonian

$$\mathcal{H}_{eff} \sim \sum_{i=1}^{10} C_i(\mu) O_i(\mu)$$

$$\Gamma(b \to s\gamma) \sim |V^*_{ts}V_{tb}|^2 \; |C_7^{eff}|^2$$

=> Access to $|C_7|$

Interesting observables: BR, A_{CP}, γ spectrum

$$\Gamma(b \to s\ell^+\ell^-)/ds \sim |V^*_{ts}V_{tb}|^2 \; O(s,\ |C_7^{eff}|^2,\ |C_8^{eff}|^2,\ |C_{10}^{eff}|^2,\ C_7^{effR}Re(C_9^{eff}))$$

$$s = q^2/m^2_b = (M(\ell^+\ell^-)/m_b)^2$$

=> Access to $|C_7|$, $|C_9|$, $|C_{10}|$, $sgn(C_7)$

Interesting observables: BR, A_{FB}, q^2 distribution

Particle ID & Kinematic Variables

K/π separation:
- dE/dx from CDC
- light yield from ACC
- t from ToF

e ID:
- dE/dx from CDC
- light yield from ACC
- t from ToF
- CsI (ECL)

μ ID:
- hits in KLM

γ ID:
- $16X_0$ CsI (ECL)

Kinematic Variables:

$$\Delta E = E^*_B - E^*_{beam}$$

$$M_{bc} = \sqrt{E^{*2}_{beam} - |p^*_B|^2}$$