Selected Results On
Rare Decays of Beauty and Charm

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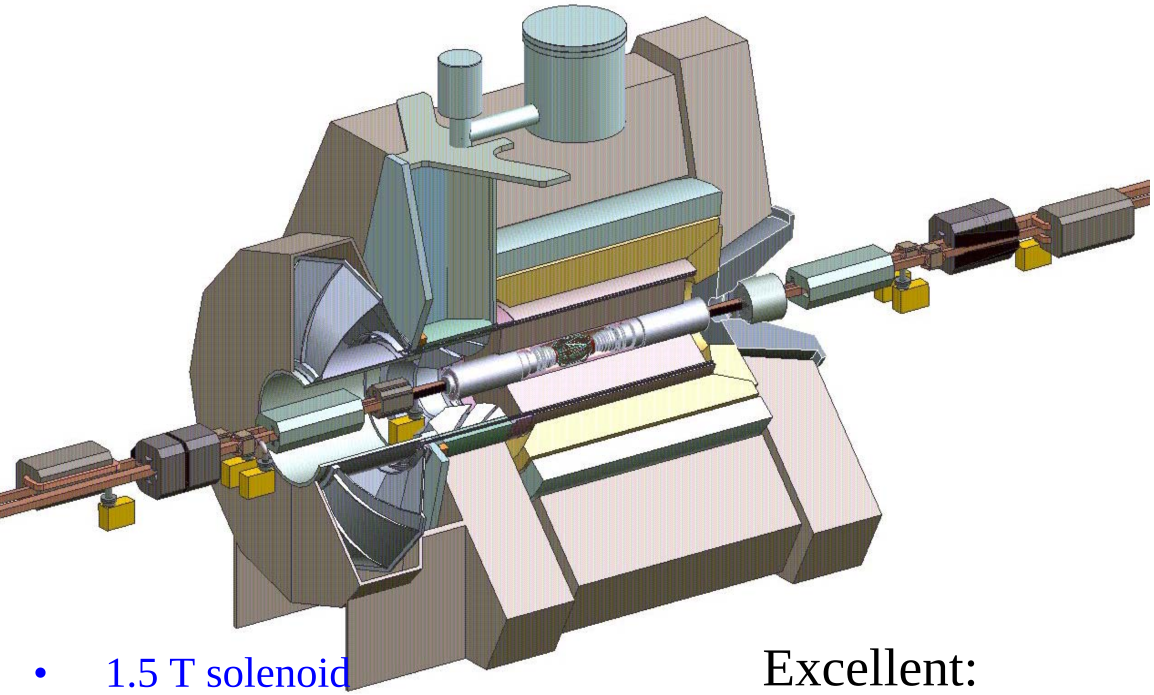
Outline of This Talk

- The Luminosity Frontier in Heavy Flavor Physics
- Penguin decays of Beauty : Rates and Asymmetries
  - $b \to s\,\gamma$ and $b \to d\,\gamma$
  - $b \to s\, l^+ l^-$ *and* $b \to d\, l^+ l^-$
  - $b \to s\, \upsilon\, \underline{\upsilon}$
- Leptonic B meson decays : $B^+ \to \tau^+ (\mu^+) \upsilon$, $B^0 \to l^+ l^-$
- Charmless Hadronic decays of Beauty: Rates & Asymmetries
  - Highlights & Summary only (See Bonder, Mir's talk)
- Rare Charm Decays
  - $D \to \phi\,\gamma$ (Belle)
  - $D^+ \to \mu^+\, \upsilon$ (CLEO-c)
  - Summary and Prospects

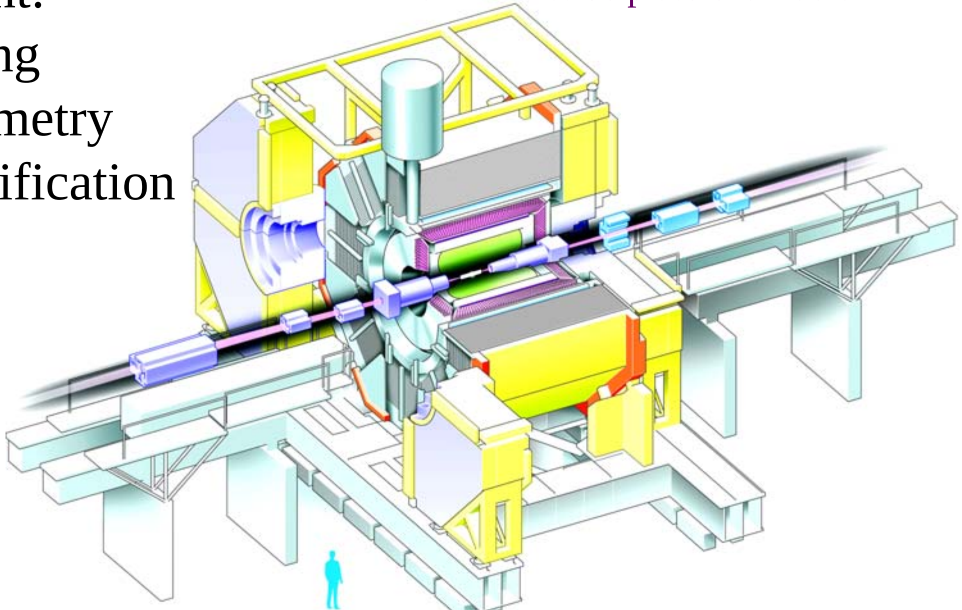
BaBar and Belle : Collecting Data since 1999



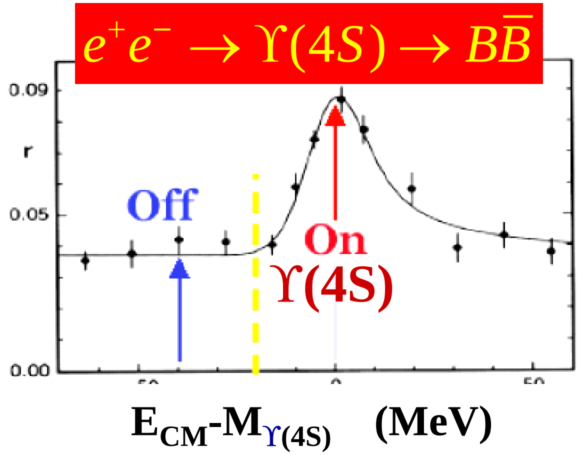
- 1.5 T solenoid
- Silicon vertex tracker
  - 5 layer, double-sided
- Drift chamber
  - Tracking + dE/dx
  - 40 stereo layers
- DIRC particle ID
  - Quartz bars, 11000 PMTs
- CsI(Tl) calorimeter
  - 6580 crystals
- Instrumented Flux Return
  - Iron + resistive plate chambers

Excellent:
Tracking
EM calorimetry
Particle Identification

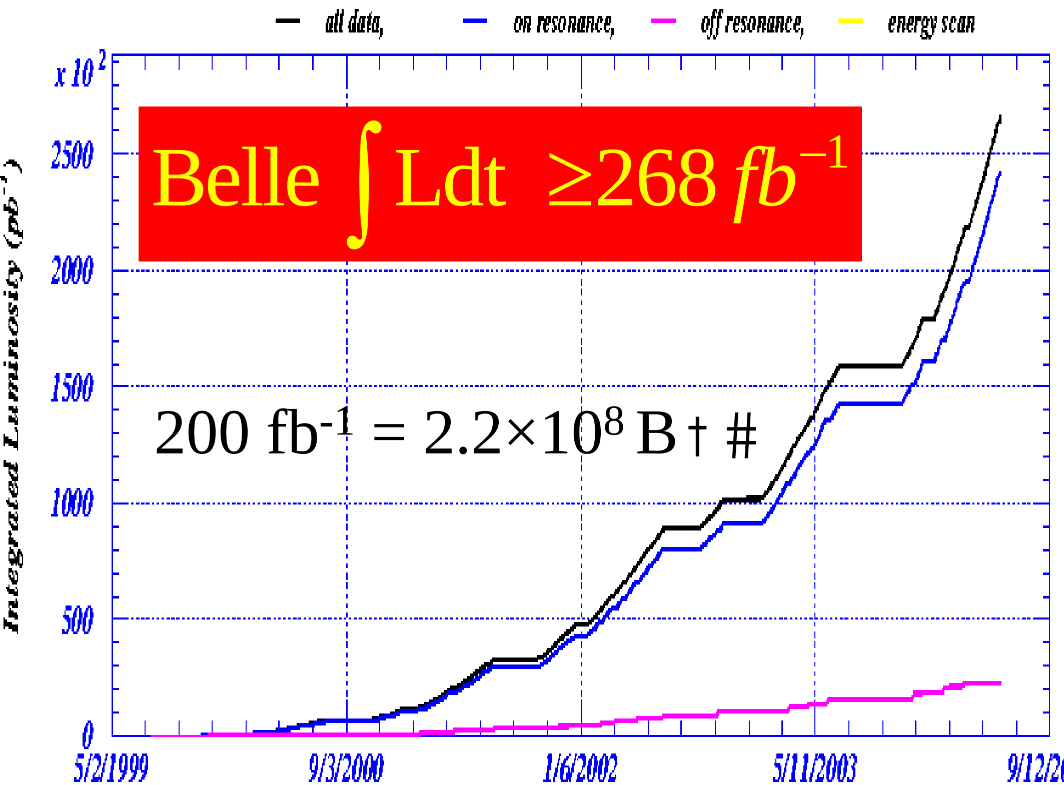
- 1.5 T solenoid
- Silicon vertex tracker
  - 4 layer, double-sided
- Drift chamber
  - Tracking + dE/dx
  - 50 layers
- Particle ID
  - Time-of-flight
  - Aerogel
- CsI(Tl) calorimeter
  - 8736 crystals
- Muon/K_L detector
  - Iron + resistive plate chambers

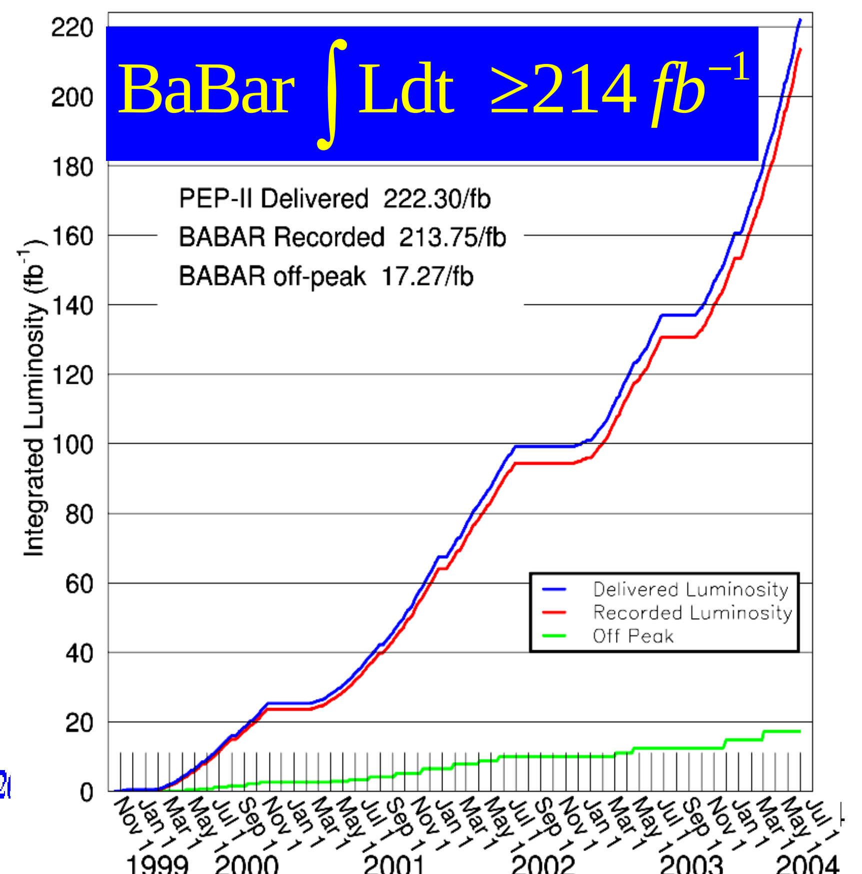


The Joy of Luminosity at $\Upsilon(4S)$!



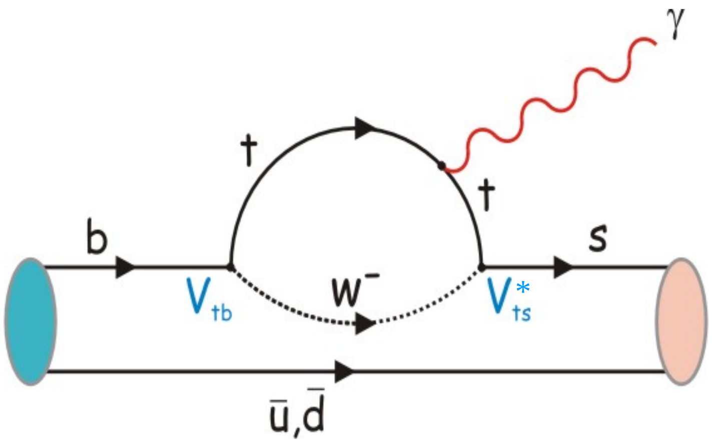
Luminosity is the most important attribute in searching for rare phenomena





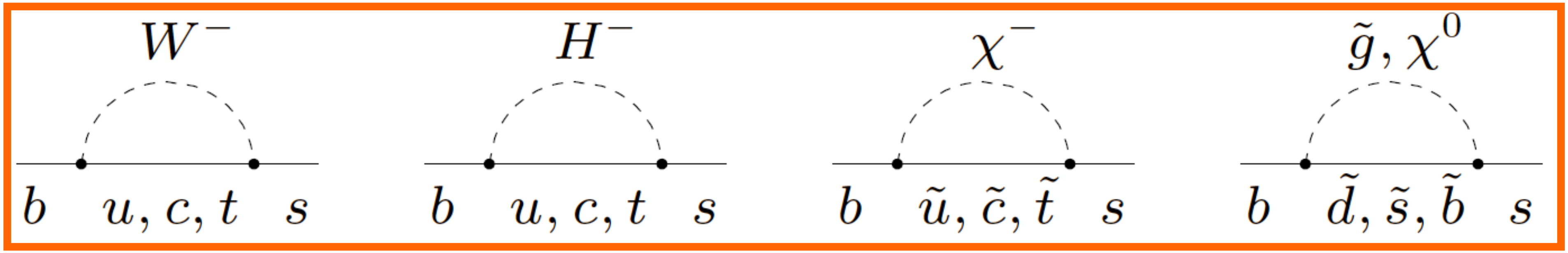
Radiative and Electroweak Penguin Decays of B Mesons

$b \to s\gamma$



- Forbidden at Tree level, occur only thru induced loop effects
- Probe the underlying fundamental theory at quantum level $\Rightarrow$ sensitive to masses much higher than b quark (e.g. t quark)
  - Enable measurement of CKM elements V_{tb}, V_{td} and V_{ts}
- In Beyond SM scenarios, FCNC processes sensitive to loop effects of new particles such as Higgs, Chargino, Squarks and Neutralinos
  - NP contribution to **rate** or **CP asymm**. comparable or much larger than SM
- Provide ideal situation to develop and test theoretical tools for HF
  - Provide insight into non-trivial aspects of effective theory for heavy-light hadronic transitions (factorization, ….shape function etc)

FCNC Via Electroweak Loops & New Physics



Effective Interaction Hamiltonian: $H_{\text{eff}} = -\frac{4G}{\sqrt{2}} (V_{tb} V_{ts}^*) \sum_{i=1}^{10} C_i(\mu) O_i(\mu)$

Information about heavy particles and new physics encoded in short distance (Wilson) coeff C_i

C_7 most important for $b \to s\gamma$; C_7, C_9 (Z), C_{10} (W) important for $b \to s\ell^+\ell^-$

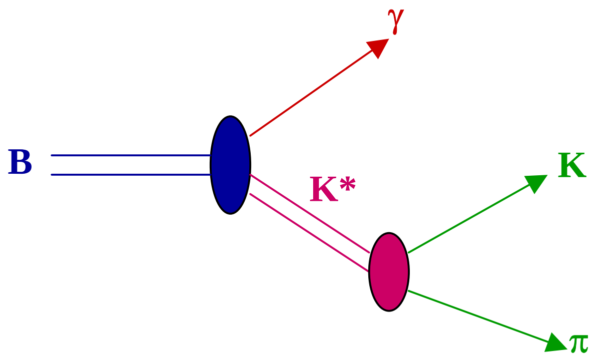
Hadronic matrix elements of operators O_i contain all long-distance QCD interaction effects

Long-distance $\Rightarrow$ expansion in powers of (Λ_{QCD}/m_b), Heavy Quark Effective Theory, QCD-factorization, Lattice...etc

Experimentally probed via measurements of decay Rate and Asymmetry

"Common" & Critical Analysis Elements In Belle & BaBar

•Exclusive B Decay Reconstruction

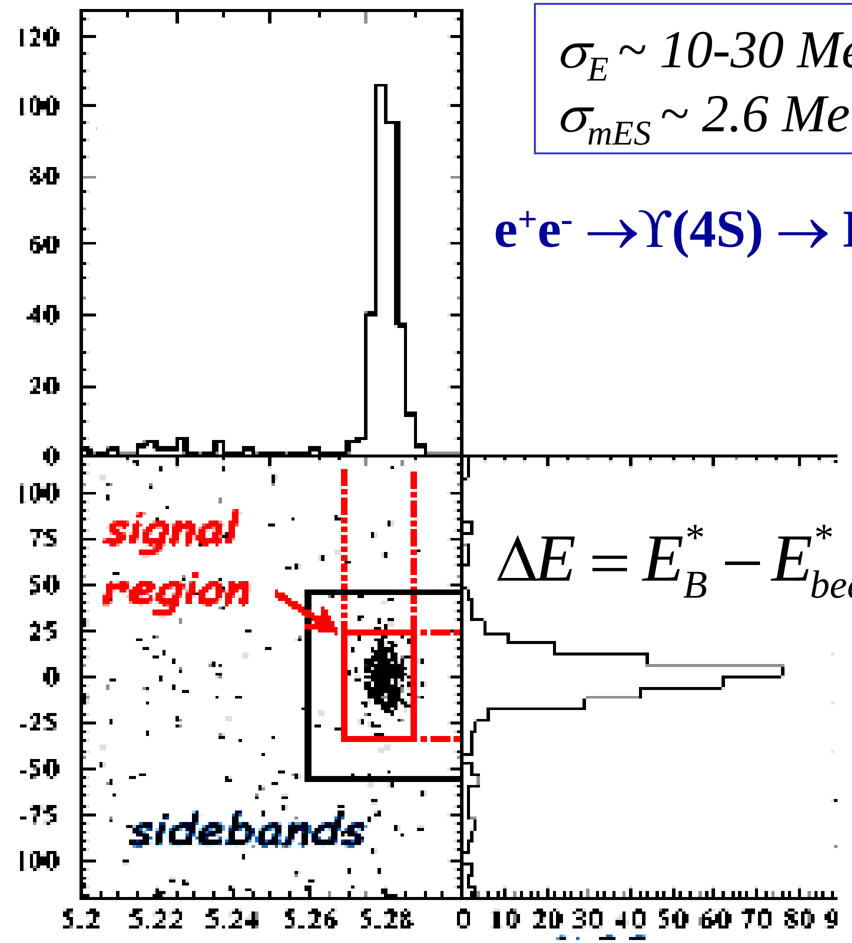


Use e,K, μ,γ,π PID & mass and energy constraints: m_{ES}, ΔE

$$m_{ES} = \sqrt{\left(E_{beam}^2 - P_B^2\right)}$$

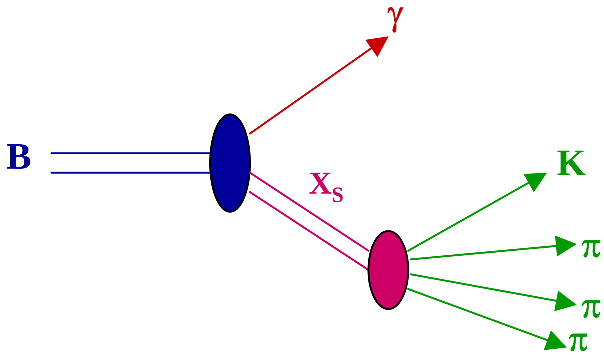
$\sigma_E \sim 10\text{-}30\ MeV$
$\sigma_{mES} \sim 2.6\ MeV$

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$



$$\Delta E = E_B^* - E_{beam}^*$$

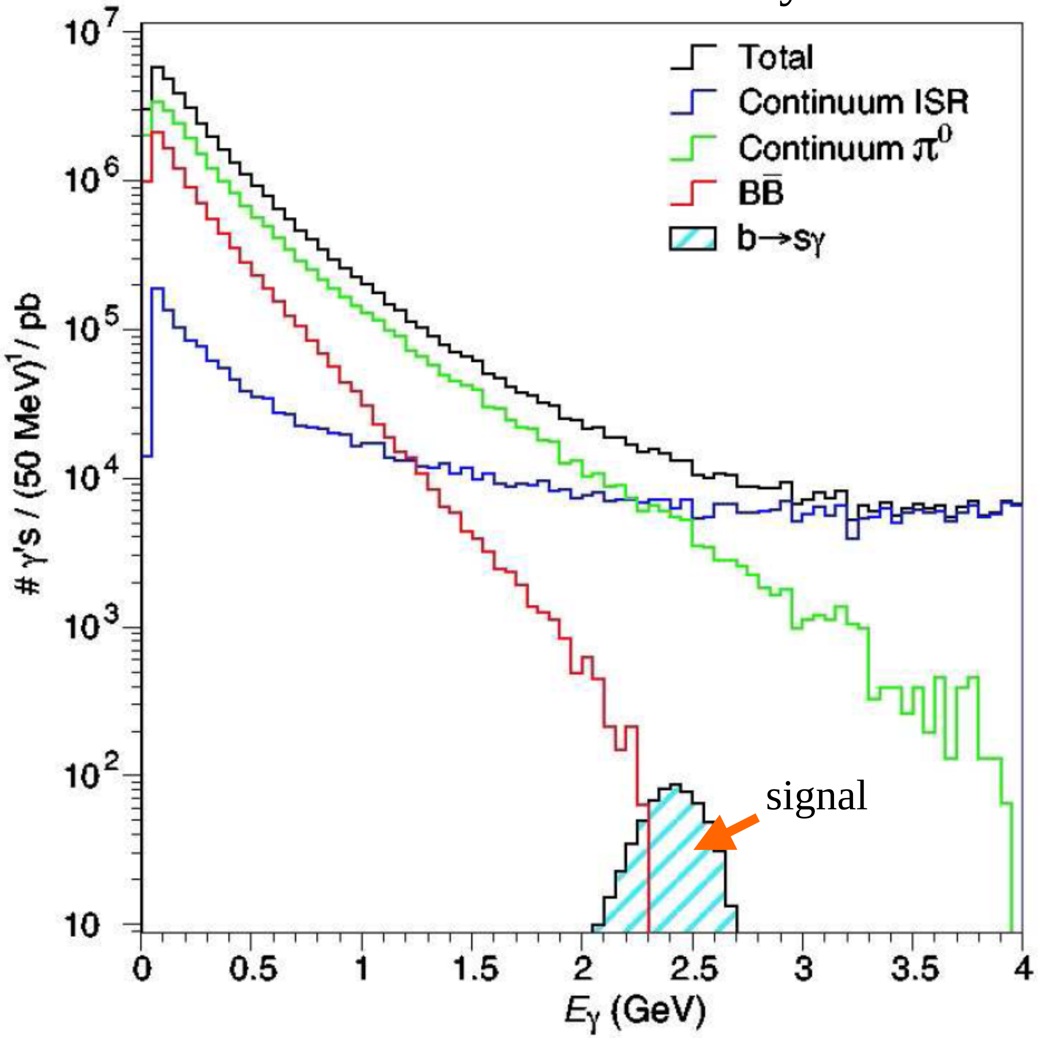
•Semi-Inclusive Reconstruction

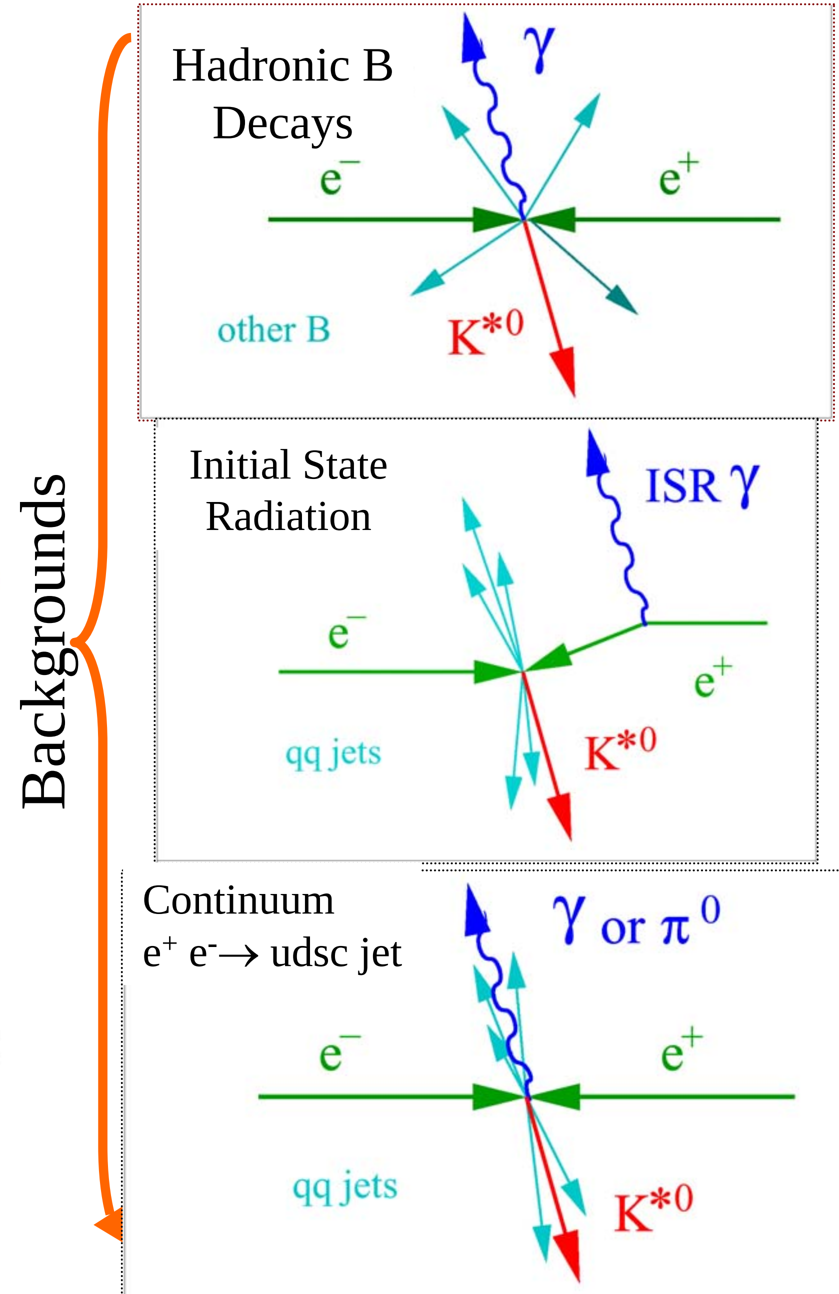


Intermediate mass states not reconstructed

$b \to s\gamma$: Signal and Backgrounds

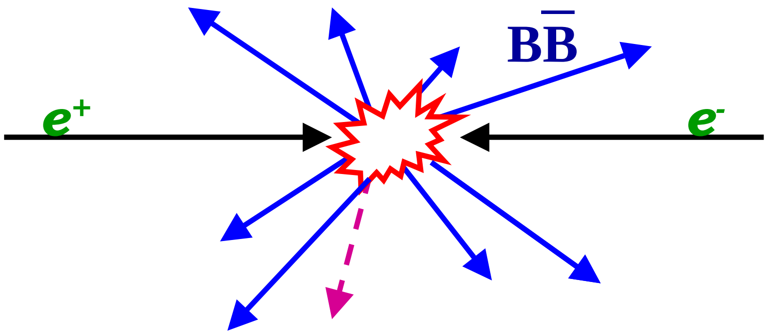
Proverbial Needle in a Hay Stack !



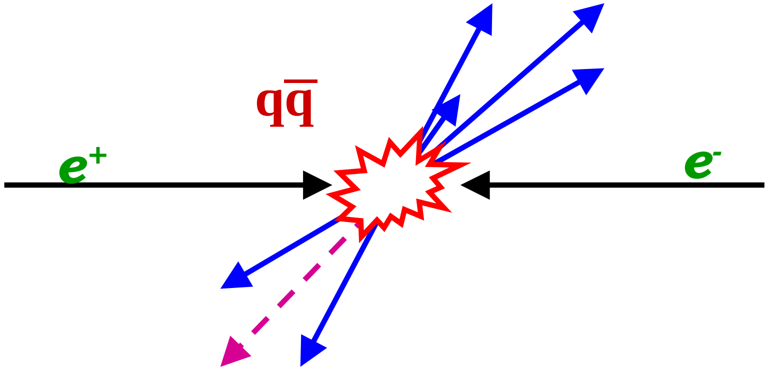


Continuum (udsc) Background Suppression Critical

B decays: Isotropic

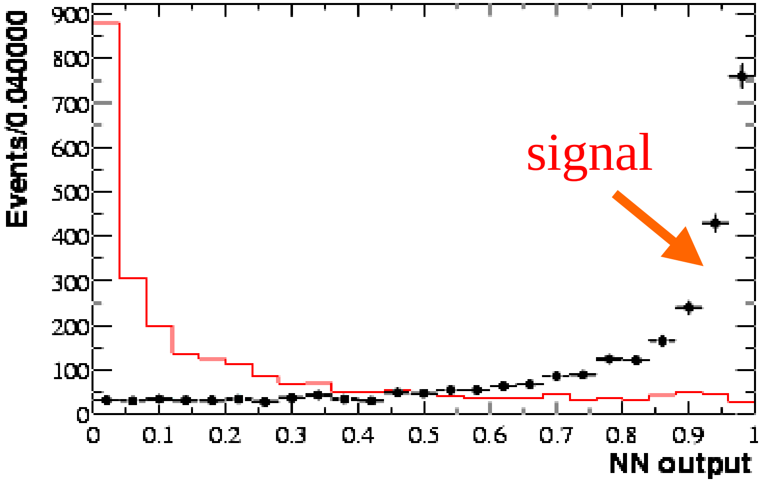


Continuum (u,d,s,c): Jet-like



Topological variables combined into a Fisher Discriminant or Neural Network:

- **Thrust axes, Fox-Wolfram moments**
- **Energy flow pattern**

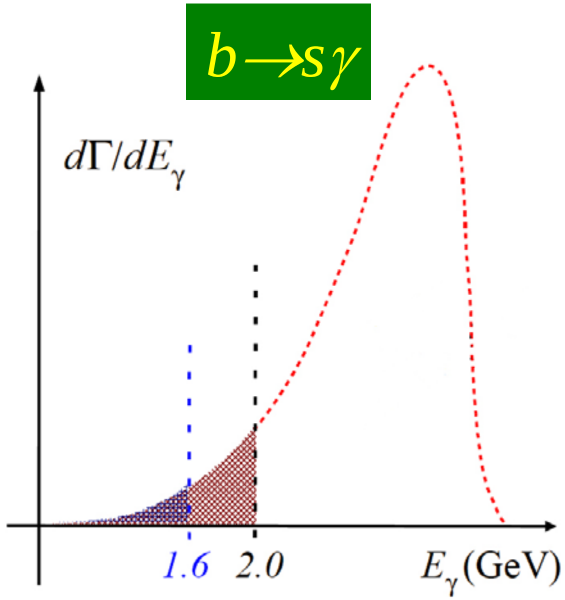


(a) $K^{*0} \rightarrow K^+\pi^-$ network

Issue Of Convenience : Inclusive Vs Exclusive Rates

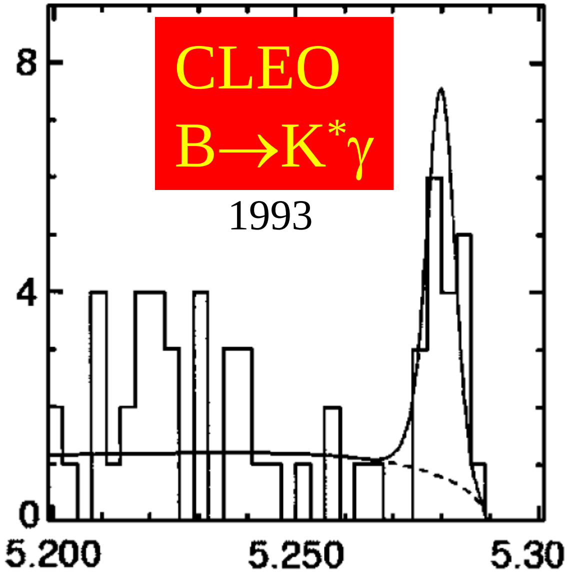
Inclusive Spectrum:

- Theory Picture: dominated by short-distance (perturbative) interactions, can be reliably and "precisely" calculated
- Experiment: Measurement of full spectrum challenging due to (e.g. in $b \to s\gamma$)
  - large final state multiplicity and horrific "continuum" background from udsc and ISR
  - "wall of γ " from B decays to energetic π^0, η etc

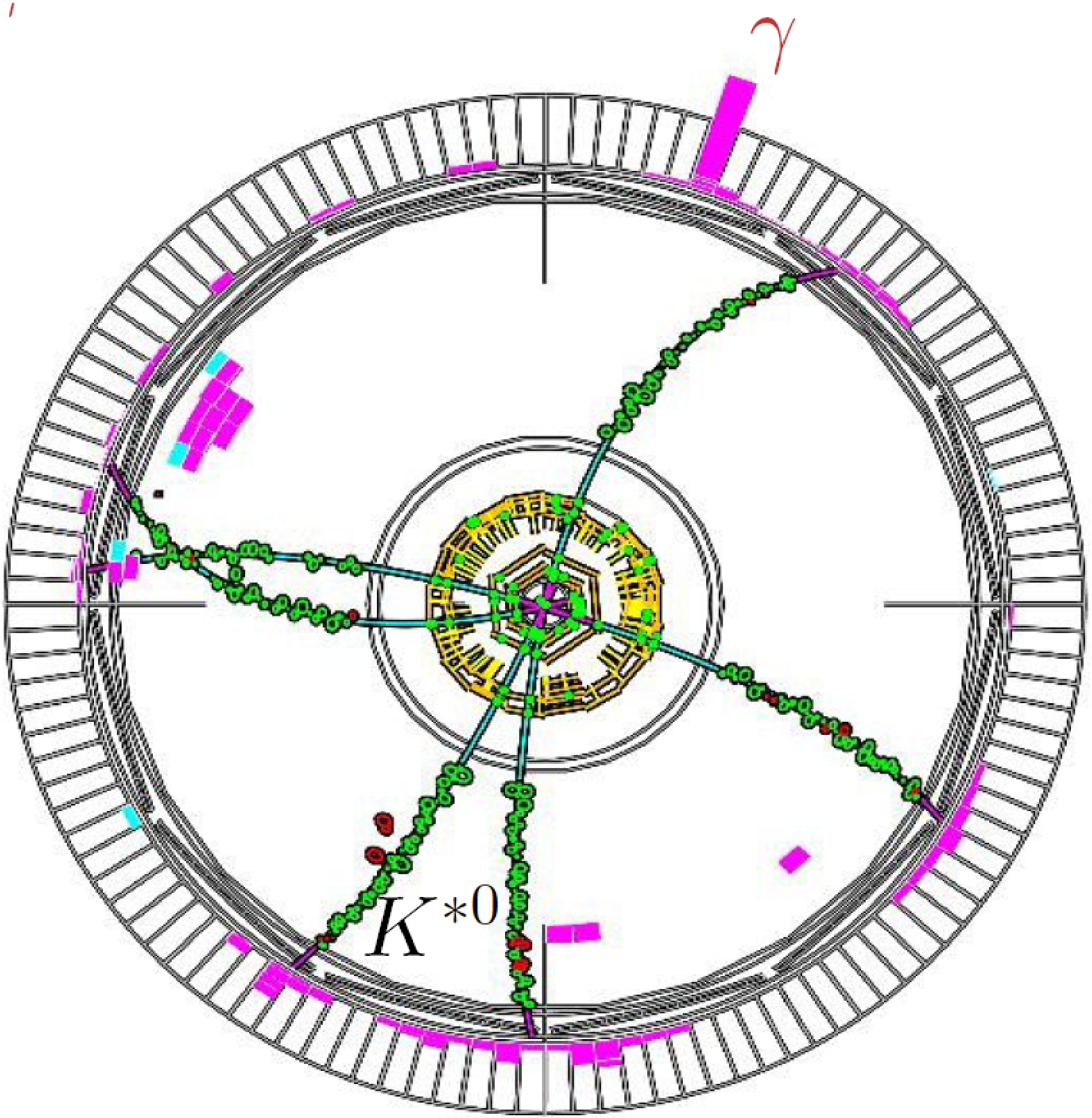


Exclusive Final States:

- Theory: Uncertainty in hadronization process (form factors) limits estimates from first principles
- Experiment: Always easier to find when you know exactly the final state you are looking for.
- Finding energetic photon or l^+l^- easier/cleaner

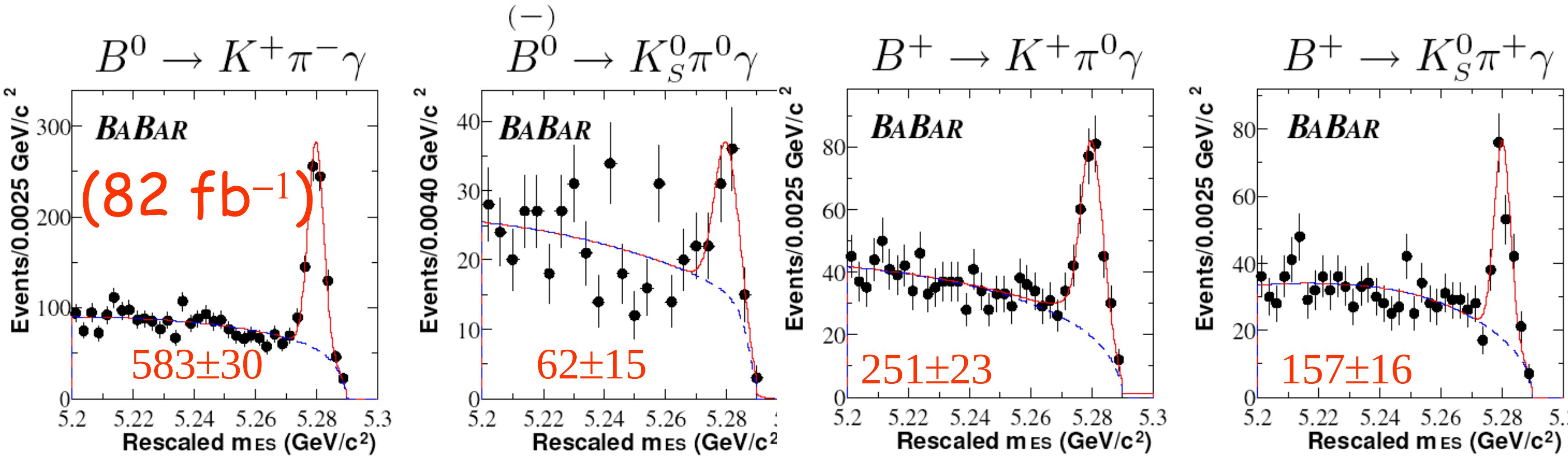


A b→sγ Event In BaBar



- The γ candidate:
  - ▷ *A high energy isolated cluster in the electromagnetic calorimeter*
  - ▷ *Shape consistent with single photon hypothesis*
  - ▷ *Veto on γ from π^0, η*
- Complete reconstruction of the hadronic system:
  - ▷ *One identified charged kaon or one K_S^0 reconstructed in $\pi^+ \pi^-$*
  - ▷ *One or more pions*

$B^0 \to K^{*0}(892)\,\gamma$ and $B^+ \to K^{*+}(892)\,\gamma$



~1000 events !

No longer a "rare" Decay in 2004

Exptal errors smaller than Theory Estimates

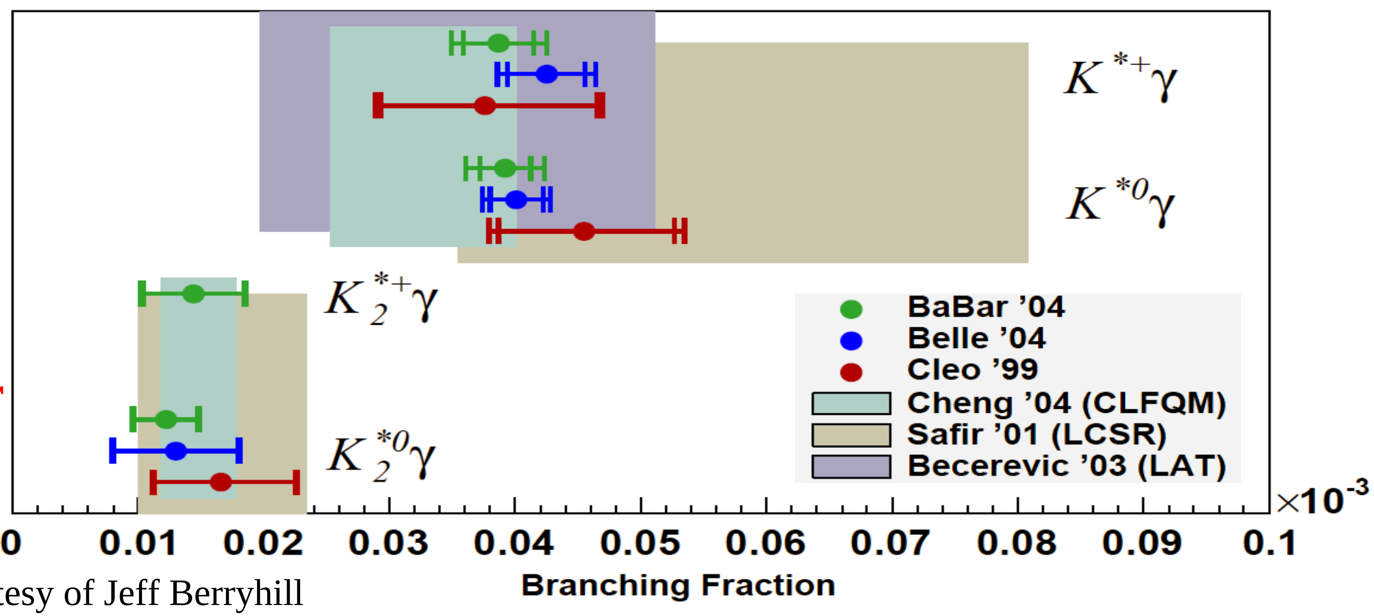
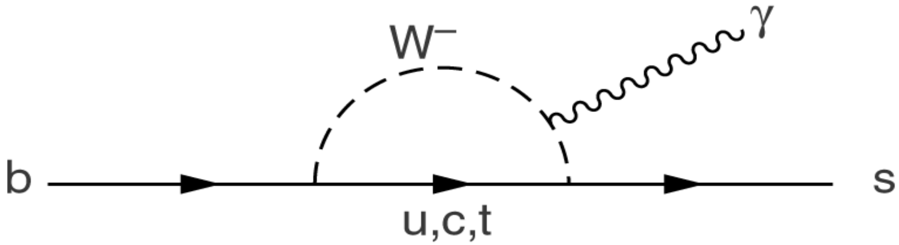


Figure courtesy of Jeff Berryhill

Inclusive $b \to s\gamma$ Decay Rate

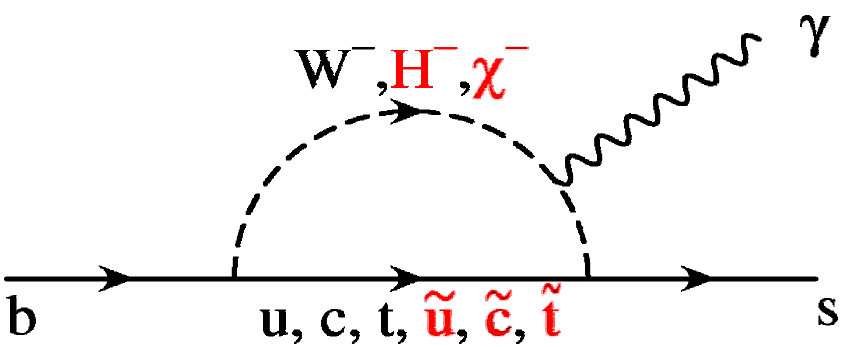


Not so rare, but important test of SM, Constrains parameters of beyond SM phenomena

- Touted as "standard Candle of flavor physics" since theory robust

$B(B \to X_s\gamma) = (3.60 \pm 0.30) \times 10^{-4}$ [SM, (NLO)]

Misiak and Gambino Nucl. Phys B611,338(2001)



?

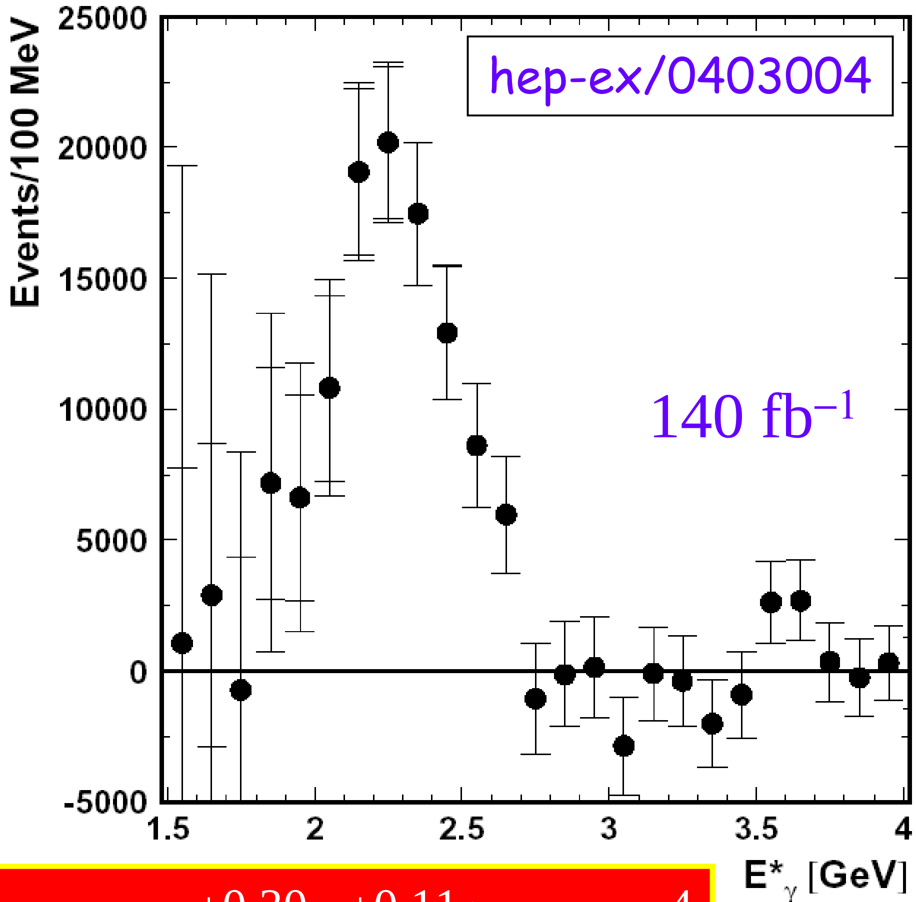
• Sensitive to Re(C_7), New Physics can modify sign/phase of C_7 leading to measurable rate enhancement, CPV and Isospin breaking effects

• Experimental challenge is to sample as much of the photon spectrum as possible and understand background sources and rates

Inclusive $b \to s\gamma$ Decay Rate

Best Measurement from Belle

- $E_\gamma > 1.8$ GeV
  - veto π^0, η
  - subtract $q\bar{q}$ bkg using off-resonance data
  - subtract $B\bar{B}$ bkg using MC scaled to data



$$B(b \to s\gamma) = (3.59 \pm 0.32 \,^{+0.30}_{-0.31} \,^{+0.11}_{-0.07}) \times 10^{-4}$$

Leaves little room for drastic new physics in FCNC processes based on b→sγ

HQ Engineering Numbers From $b \rightarrow s\gamma$

- E_γ spectrum insensitive to NP effects (2 body decay)
  - reflects *b* quark's mass, Fermi motion and gluon bremsstrahlung
- Shape of Eγ spectrum provides important engineering numbers for theory of SL B decays

Belle

Moments: $\langle E_\gamma \rangle = 2.289 \pm 0.026 \pm 0.034\,\text{GeV}$

$\langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2 = 0.0311 \pm 0.0073 \pm 0.0063\,\text{GeV}^2$ (for $1.8 < E_\gamma < 2.8$ GeV)

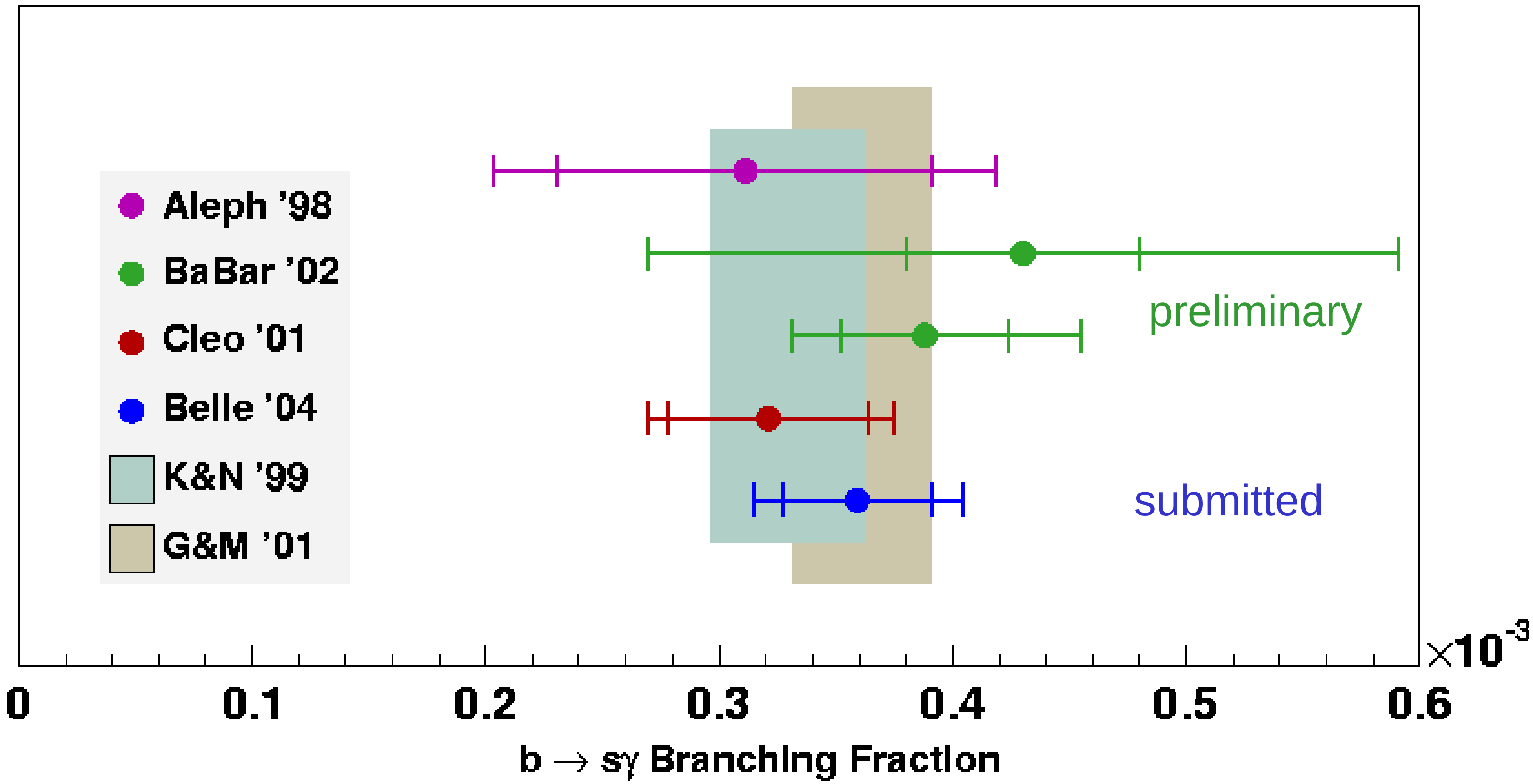
Helps:

$\Rightarrow$ improve $b \rightarrow ul\,\upsilon$ measurement of $|V_{ub}|$

$\Rightarrow$ determine heavy quark parameters for $|V_{cb}|$ from $b \rightarrow cl\upsilon$

Neubert, hep-ph/02102360

Summary of $B \to X_s \gamma$ Rate Measurements



- Measurements consistent with SM theory calculations
- Experimental errors comparable in size with theory errors

Figure Courtesy of Jeff Berryhill

Direct CP Asymmetries in Inclusive & Excl. $b \to s\gamma$

Direct CP Asymmetry: $A_{CP} = \dfrac{\Gamma(b \to s\gamma) - \Gamma(\bar{b} \to \bar{s}\gamma)}{\Gamma(b \to s\gamma) + \Gamma(\bar{b} \to \bar{s}\gamma)}$

Time independent

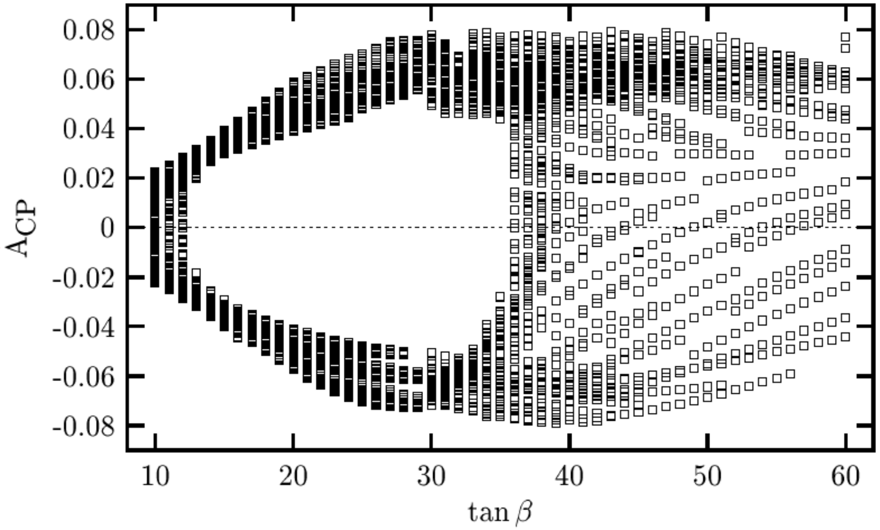
$A_{CP}^{SM}(B \to X_s\gamma) \approx$ Strong phase $\times$ CKM suppres $\times$ GIM suppress $\approx 0.5\%$

$\Rightarrow$ Small SM "background"

Large A_{CP} ($\approx$ 10%) possible in many beyond SM scenarios [with new CP violating couplings entering Wilson coeffs] **without affecting the decay rate** measurements

$A_{CP} \approx [1.3\ \mathrm{Im}(C_2/C_7) - 9.5\ \mathrm{Im}(C_8/C_7)]\%$ [Kagan & Neubert. '98]

Direct CPV in a SUSY model with Minimal flavor violation but explicit CP violation [Boz & Pak, ph/0201199]



CPV in exclusive modes can be enhanced over net inclusive rate $\Rightarrow$ good place to look

Direct CP Asymmetries in Inclusive $b \to s\gamma$

- S/N consideration requires BaBar & Belle to build an inclusive sample by summing over many "semi-exclusive" final states
- sum of several final states with identified K (about 50% of all X_s)
- sign of charged K provides "self-flavor tag"
- removes small (1/20) $b \to d\gamma$ (A_{CP} larger (20) and opposite sign)
- some theory error since quark-hadron duality not exact for semi-inclusive samples

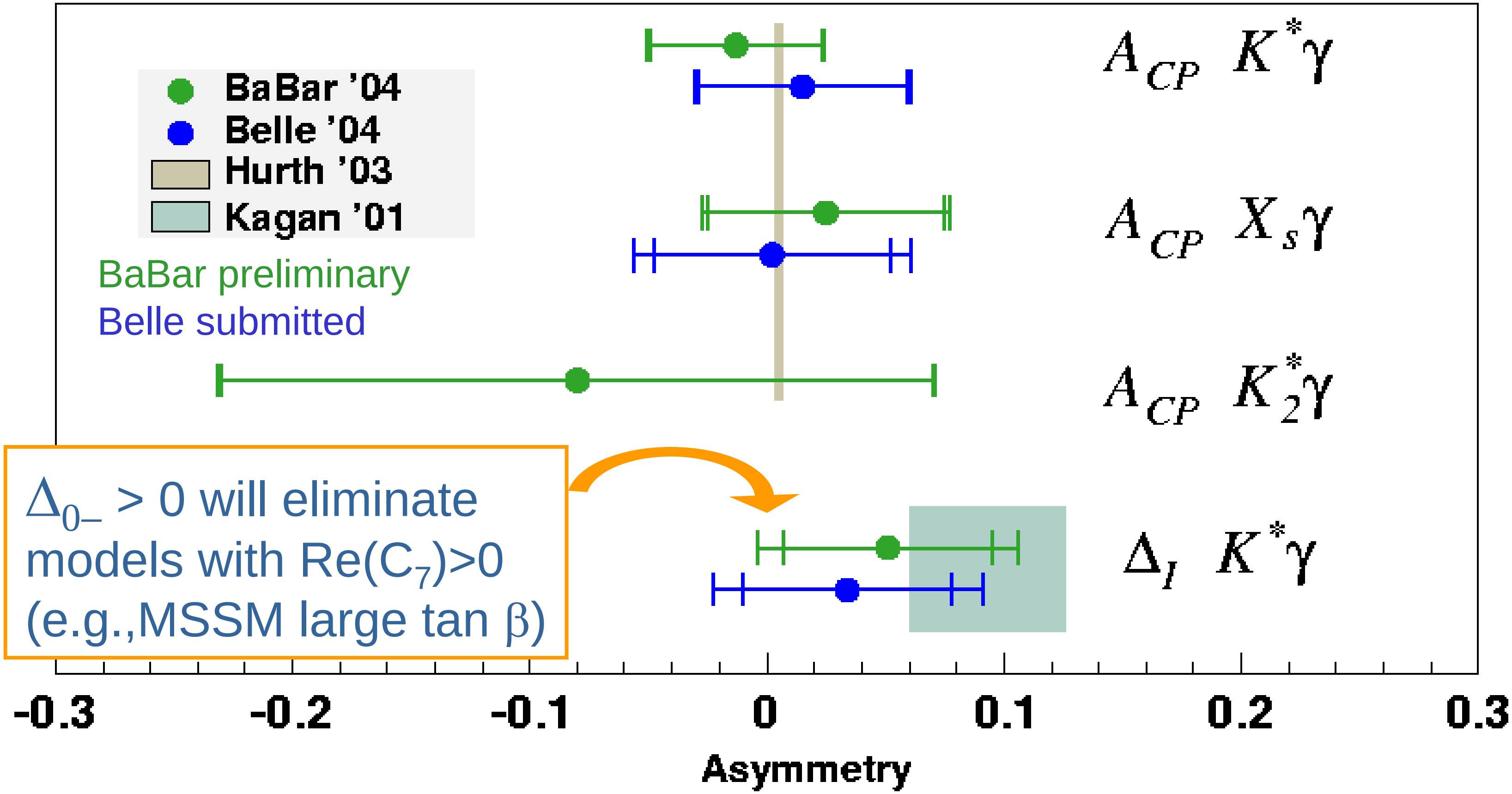
BaBar (82 fb^{-1})
hep-ex/0403035

$$A_{CP} = 0.025 \pm 0.050(\text{stat}) \pm 0.015(\text{syst})$$
$$-0.06 < A_{CP} < 0.11 \ (90\%\text{CL})$$

Belle (140 fb^{-1})
hep-ex/0308038

$$A_{CP} = 0.002 \pm 0.050(\text{stat}) \pm 0.030(\text{syst})$$
$$-0.093 < A_{CP} < 0.096 \ (90\%\text{CL})$$

Summary of Direct Asymmetries In $b \to s\,\gamma$

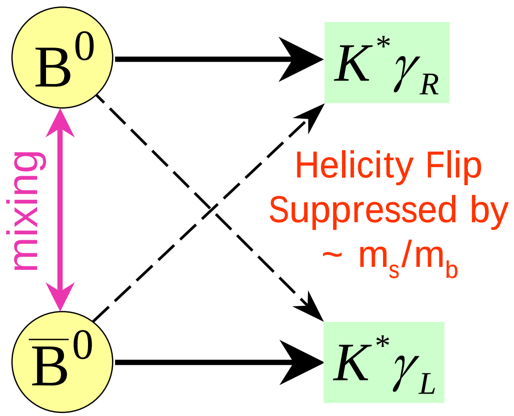


- Measurements consistent with theory so far
- Experimental errors can be IMPROVED with more data

Searches For Time-dependent CP asymmetry In $B^0 \to s\gamma$

- Atwood,Gronau,Soni [PRL,79,185(1997)]
  - Photon in $b \to s\gamma$ predominantly ($\approx m_s/m_b$) lefthanded. B^0-oscillation induced CPV suppressed [$A_{CP} \propto 2(m_s/m_b)\sin 2\beta \approx 4\%$]
  - In SM extensions (LRSM, SUSY, SU(2) ×U(1) with exotic fermions) ⇒ amplitude of right handed photon grows with virtual heavy fermion masses
    - **Can lead to large CPV asymmetries ~ 50% or larger without affecting decay rates**
    - **If there is new physics contribution in $B^0 \to \phi K_s$ one may see it also in $B^0 \to s\gamma$**

- Subsamples of 2-body $B^0 \to s\gamma$ with common B^0 final states can be probed



$$A_{CP}(t) = \frac{\Gamma(\overline{B}^0 \to K_S\pi^0\gamma) - \Gamma(B^0 \to K_S\pi^0\gamma)}{\Gamma(\overline{B}^0 \to K_S\pi^0\gamma) + \Gamma(B^0 \to K_S\pi^0\gamma)} = S\sin(\Delta m t) - C\cos(\Delta m t)$$

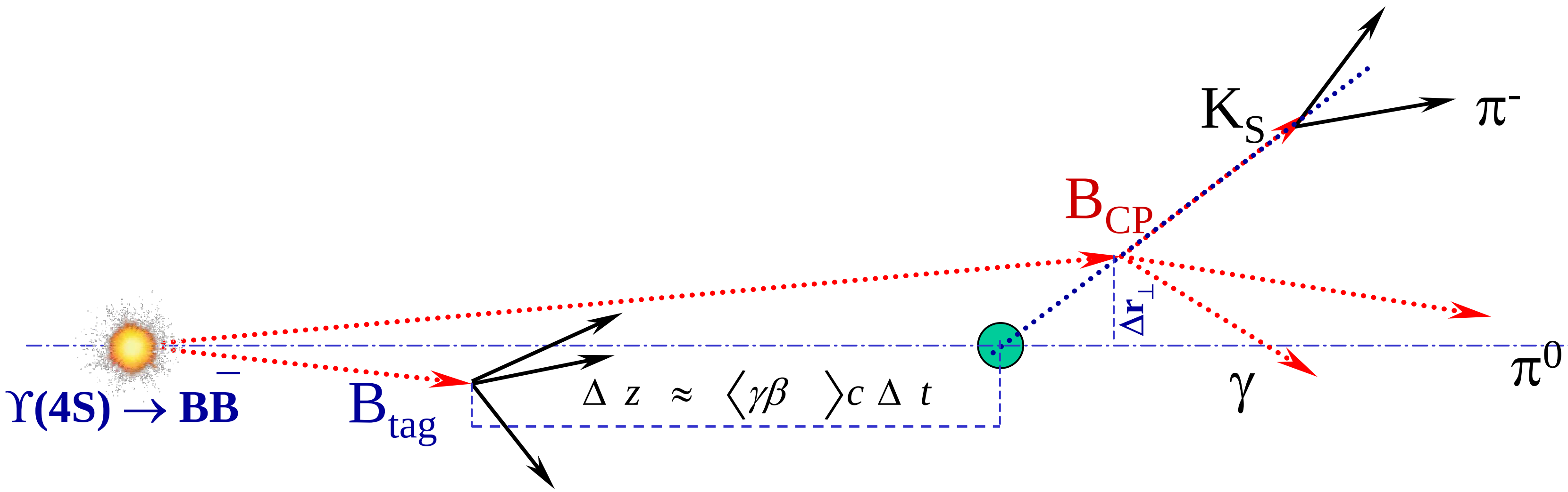
Mixing Induced

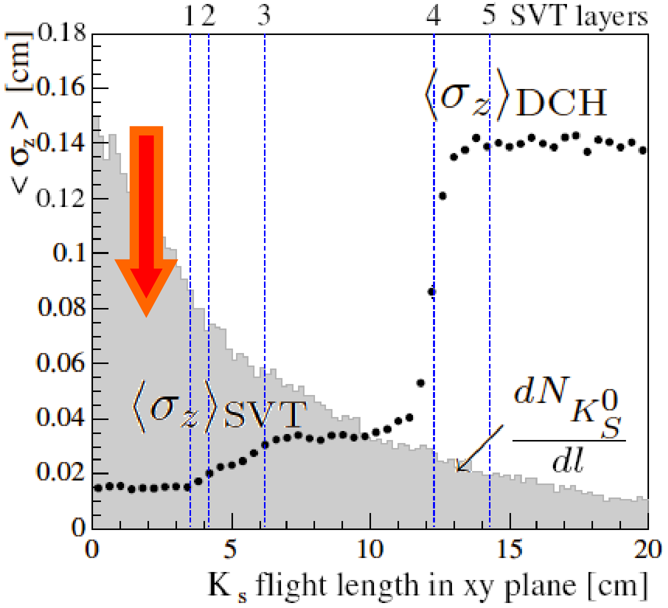
Direct CPV

Decay distance $\Delta Z \propto \Delta t$ measurement tricky since no charged track originates from $B_{K^*\gamma}$ decay point.

Innovation from BaBar: Use $Ks \to \pi^+\pi^-$ decay in silicon detector to estimate $B_{K^*\gamma}$ decay point [$\langle\beta\gamma c\tau\rangle_{Ks}$ is small]

Time-dependent CP Asymmetry In $B^0 \to K^{*0}\gamma \to (K_s\pi^0)\gamma$



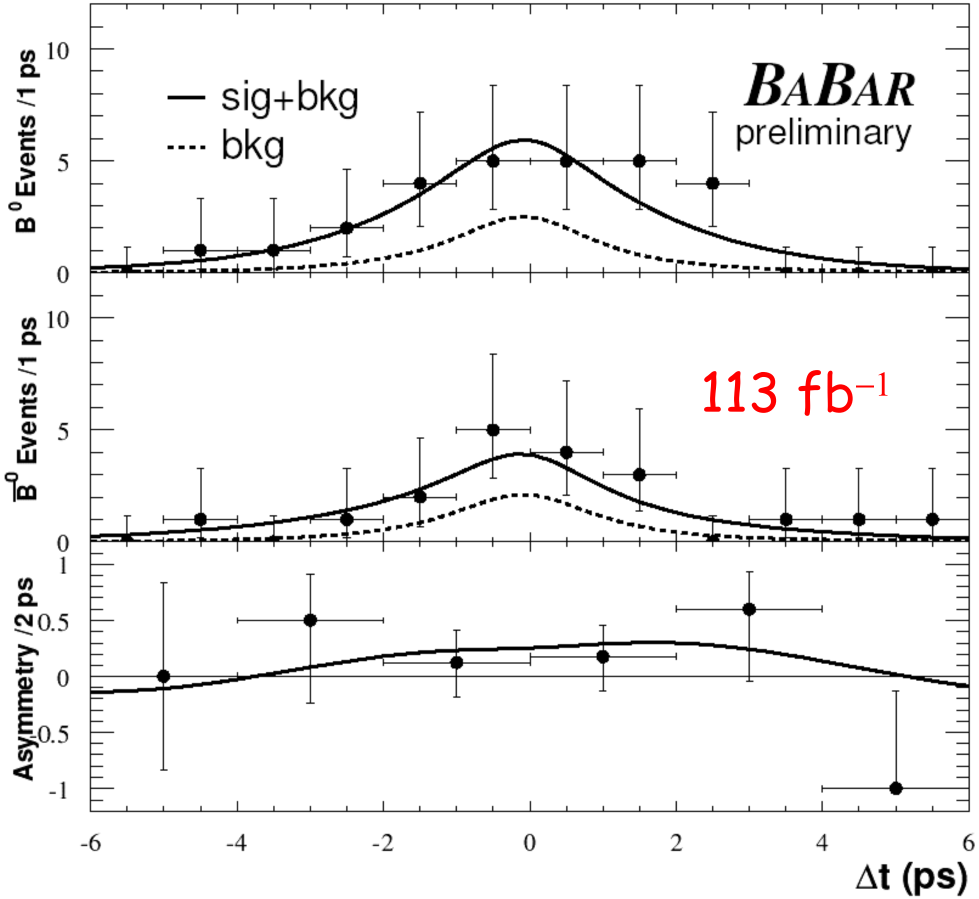


B Flight decay path: $\Delta Z \sim 260\mu$ >> $\Delta r_{xy} \sim 30$mm

- B_{CP} decay vertex position reconstructed using
  - ▷ K^0_S *reconstructed vertex and momentum*
  - ▷ *beam-line position and direction*
- SVT position measurement of the pions from K^0_S decay is sufficient to obtain a good resolution on Δz.

ΔZ measurement dominated by B_{tag} vertex error (180μ)

Time-dependent CP Asymmetry In $B^0 \rightarrow (K_s\pi^0)\,\gamma$



First measurement – BaBar preliminary

$S_{K^{*0}\gamma} = 0.25 \pm 0.65 \pm 0.14$ for $C_{K^{*0}\gamma} = 0$

Imprecise but First $A_{CP}(t)$ measurement for a radiative penguin totally statistics limited ! → Extend to more modes.
A new tool in probing Penguin properties

Rate of $b \to d\gamma$

- Decay CKM suppressed ($|V_{td}/V_{ts}|$) w.r.t. $b \to s\gamma$; *measures* $|V_{td}|$
- Inclusive measurements background challenged !
  - *$b \to s\gamma \Rightarrow \times 20$ background ! Needs K^+,K_S and K_L veto*
- Exclusive processes are current exptal target: $B \to \rho(\omega)\gamma$
  - Theor. Estimate imprecise $B(B \to \rho(\omega)\gamma) \approx (0.5\text{-}2.0)\times 10^{-6}$
  - Ratio $R(\rho\gamma/K^*\gamma)$ reduces theory error, estimates $|V_{td}/V_{ts}|$

$$\frac{B(B\to\rho\gamma)}{B(B\to K^*\gamma)} \propto \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{\xi_\perp^{\rho}(0)}{\xi_\perp^{K^*}(0)}\right)^2 (1+\Delta R)$$

Long distance corrections ?

Form factor at $q^2=0$
SU(3) breaking corrections ?

Past Searches

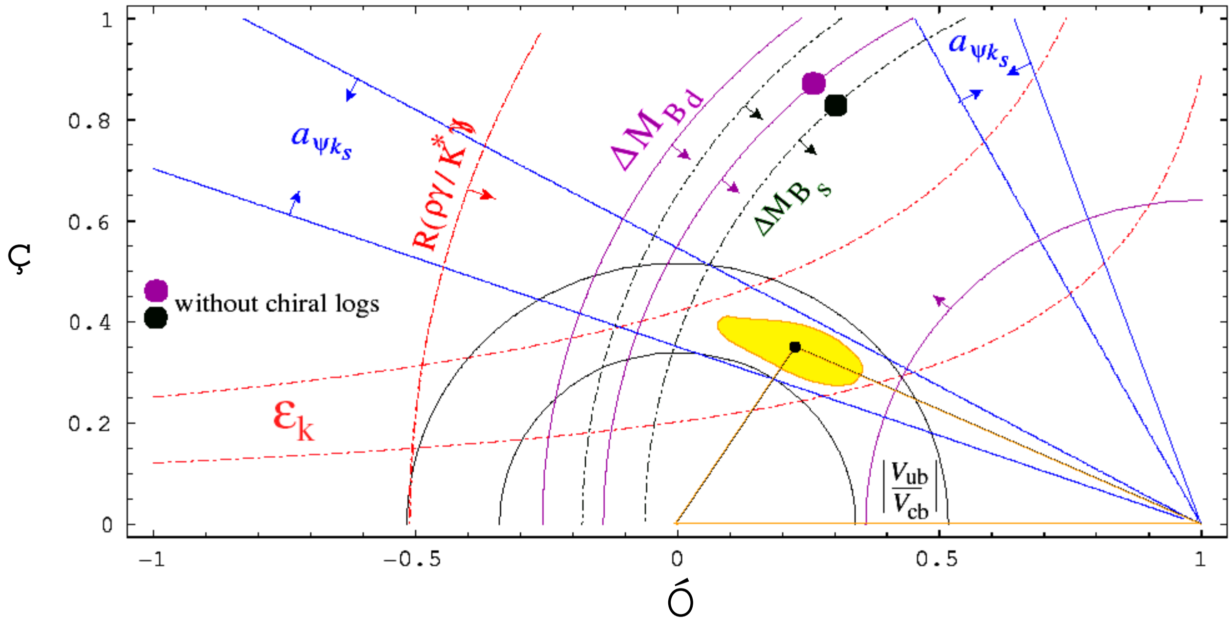
	CLEO	Belle	BaBar
$B^+ \to \rho^+\gamma$:	$< 13 \times 10^{-6}$	$< 2.7 \times 10^{-6}$	$< 2.1 \times 10^{-6}$
$B^0 \to \rho^0\gamma$:	$< 17 \times 10^{-6}$	$< 2.6 \times 10^{-6}$	$< 1.2 \times 10^{-6}$
$B^0 \to \omega\gamma$:	$< 9.2 \times 10^{-6}$	$< 4.4 \times 10^{-6}$	$< 1.0 \times 10^{-6}$

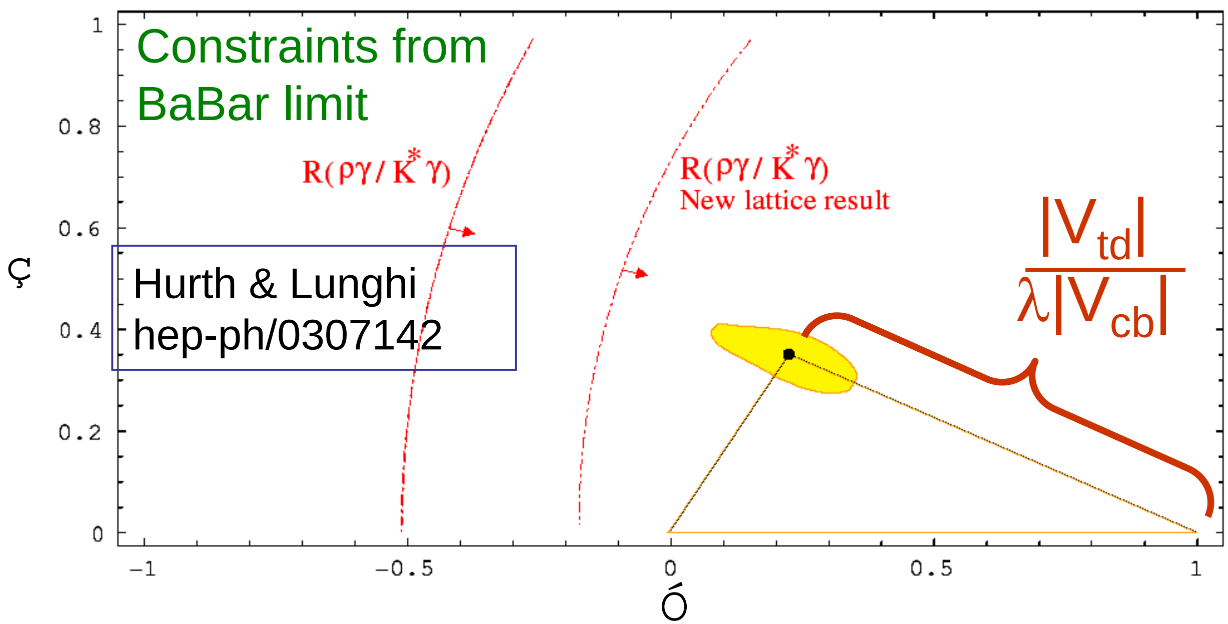
Three Roads to $|V_{td}|$

- $B(K^+ \rightarrow \pi^+$¥Ÿ)
- $\Delta M_s / \Delta M_d$
- $R(\rho\gamma / K^*\gamma)$

$\Rightarrow$ measurement of $B \rightarrow \rho\gamma$ of will provide an annular constraint centered at (Ó,Ç)= (1,0)

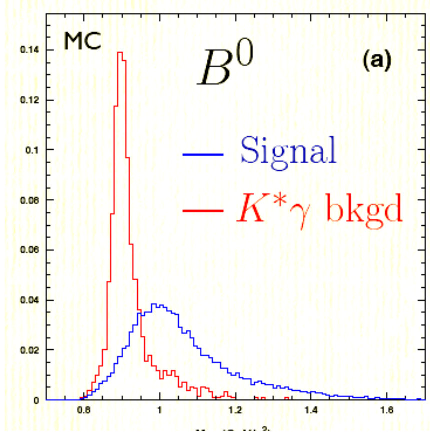
Significance will depend on precision of Theory ability to intrepret expt. Result



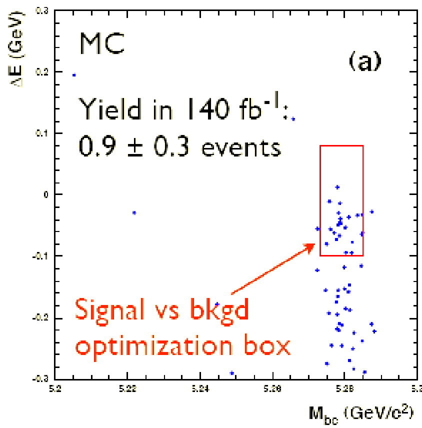


$B \to \rho\gamma, \omega\gamma$: Belle (140 fb^{-1}, Preliminary)

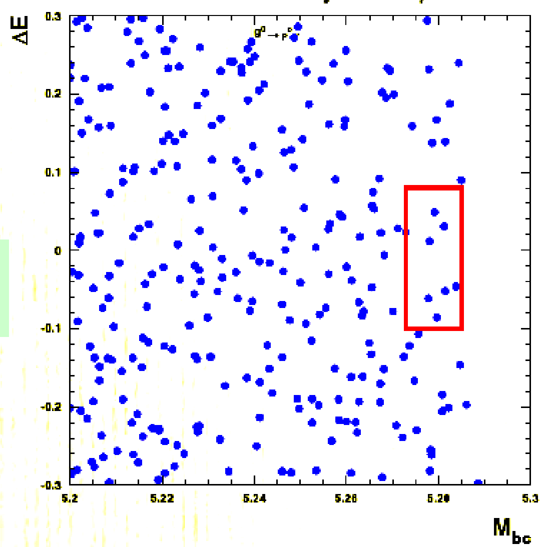
- New result reported at Moriond04 (Iwasaki), Pheno04 (Piilonen)
- All out effort to beat back background from
  - Continuum suppression
  - $B \to K^*\gamma$
  - $B \to (\rho/\omega)\,\pi^0$



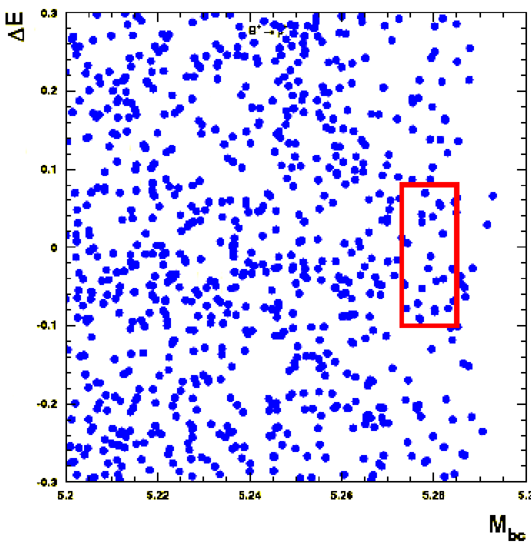
$B^0 \to \rho^0 \pi^0$



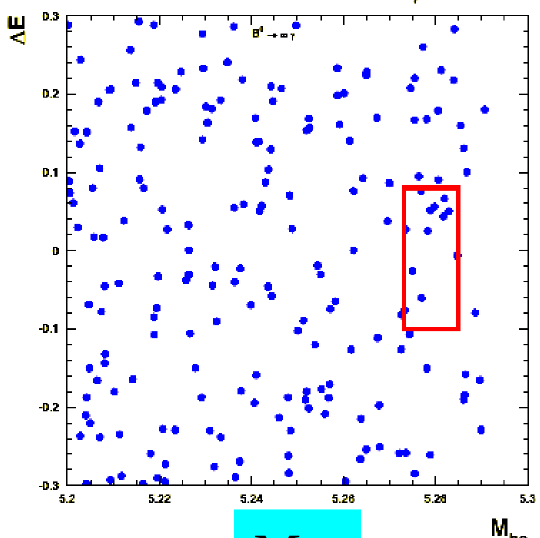
$B^0 \to \rho^0 \gamma$



$B^+ \to \rho^+ \gamma$



$B^0 \to \omega \gamma$



ΔE

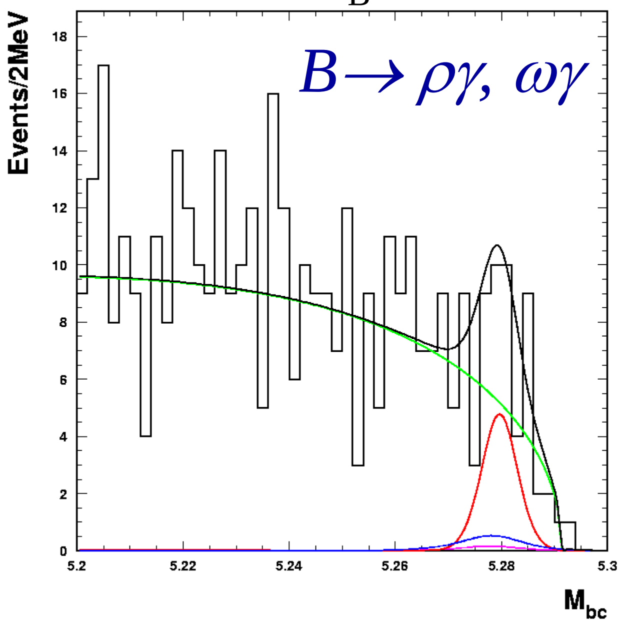
M_{ES}

$B \to \rho\gamma, \omega\gamma$: Belle (140 fb^{-1}, Preliminary)

L = 140 fb^{-1} Fit region: $m_{bc} > 5.2$ GeV, $|\Delta E| < 0.3$ GeV

Claim first evidence for $b \to d\gamma$

Combined M_B distribution



	$B^0 \to \rho^0\gamma$	$B^+ \to \rho^+\gamma$	$B^0 \to \omega\gamma$
Observed Yield:	280	749	197
Signal Yield:	6.3	15.2	5.9
Significance:	3.5σ including systematic uncertainties		
Signal Efficiency:	0.0502 ± 0.0033	0.0588 ± 0.0042	0.0468 ± 0.0046

Use $B(B \to \rho/\omega\gamma) = B(B^+ \to \rho^+\gamma)$

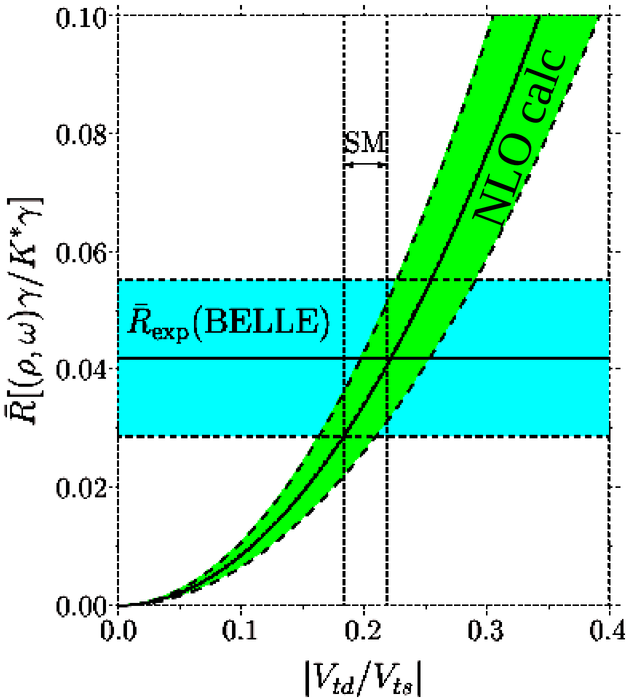
$$= 2\frac{\tau^+}{\tau^0} B(B^0 \to \rho^0\gamma) = 2\frac{\tau^+}{\tau^0} B(B^0 \to \omega\gamma)$$

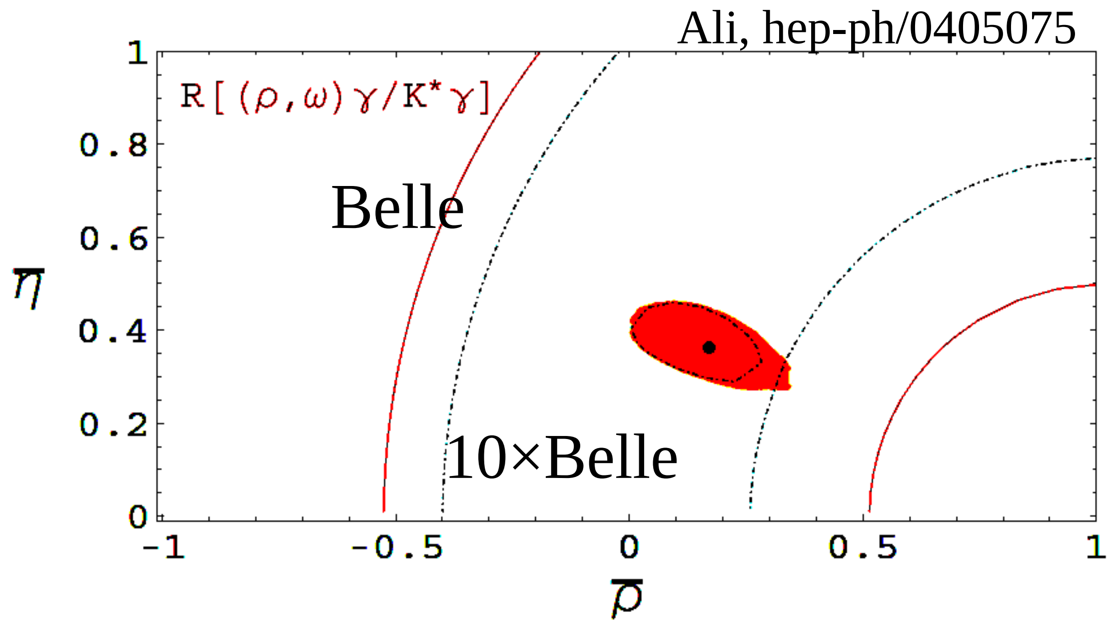
Belle $B(B \to \rho/\omega\gamma) = (1.8\ ^{+0.6}_{-0.5} \pm 0.1) \times 10^{-6}$ favors large $|V_{td}|$

BaBar's comparable limit: $B(B \to \rho\gamma) < 1.9 \times 10^{-6}$ (90% CL)

Both experiments have much more data, so picture will become clearer soon

Impact of B→ργ On Unitarity Triangle

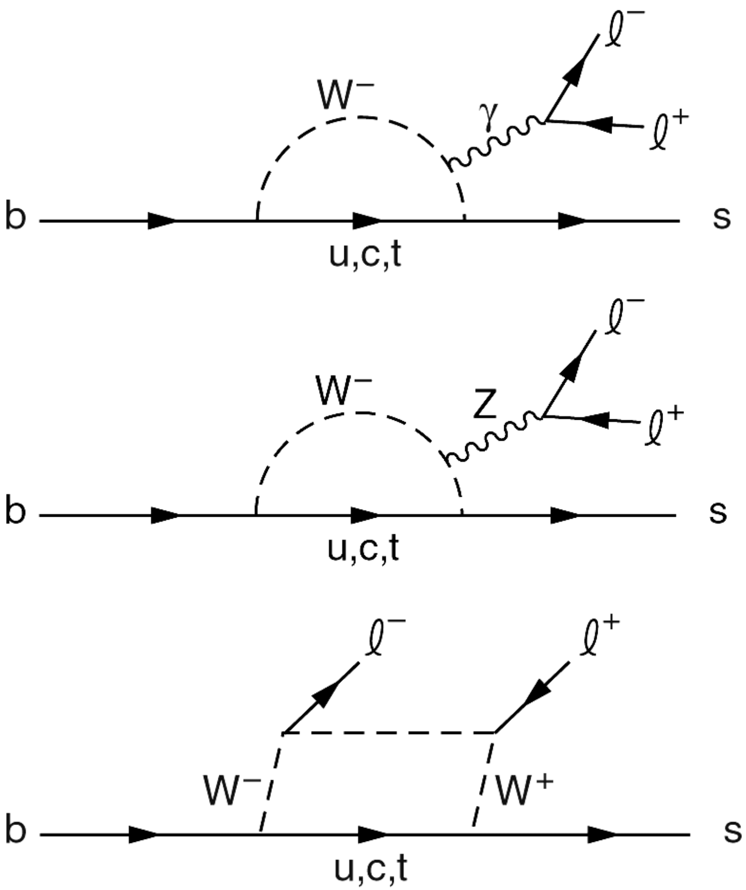




Belle measurement in comfortable agreement with fits for UT from all other observables. Due to large theory and expt. Error impact of this Measurement on UT fit is small.

For B→ργ measurement to make a significant impact in future, the estimate of theory errors must decrease by > ×2 (Lattice ?)

The Decay Rate of $b \to s\, l^+ l^-$



- More complex than $b \to s\,\gamma$
  - W-box and Z-penguin amplitudes important
  - c ª resonances in dilepton spectrum (removed by cuts on M_{ll})

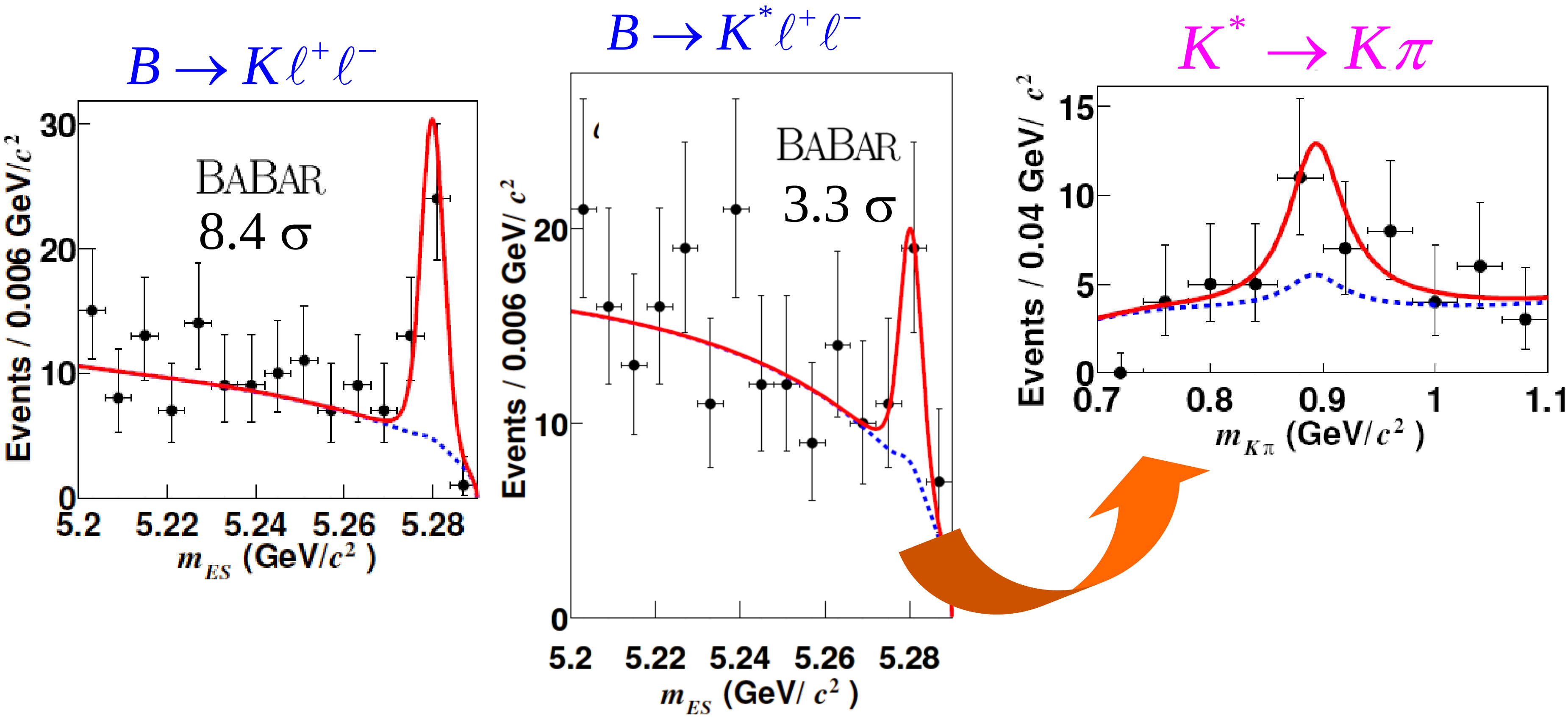
- More observables
  - dilepton mass spectrum ($q^2 = M_{ll}^2$)
  - forward-backward asymmetry (A_{FB})

- BR expectation in NNLO SM:
  - $B(B \to X_S\, e^+ e^-) = (6.9 \pm 1.0) \times 10^{-6}$
  - $B(B \to X_S\, \mu^+ \mu^-) = (4.2 \pm 0.7) \times 10^{-6}$

  [Ali et al., Phys. Rev D66,034002(2002)]

First Steps → Exclusive Final States: $B \to K^{(*)} l^+ l^-$

- Sum over ee and μμ channels, remove $J/\psi \to l^+ l^-$ regions

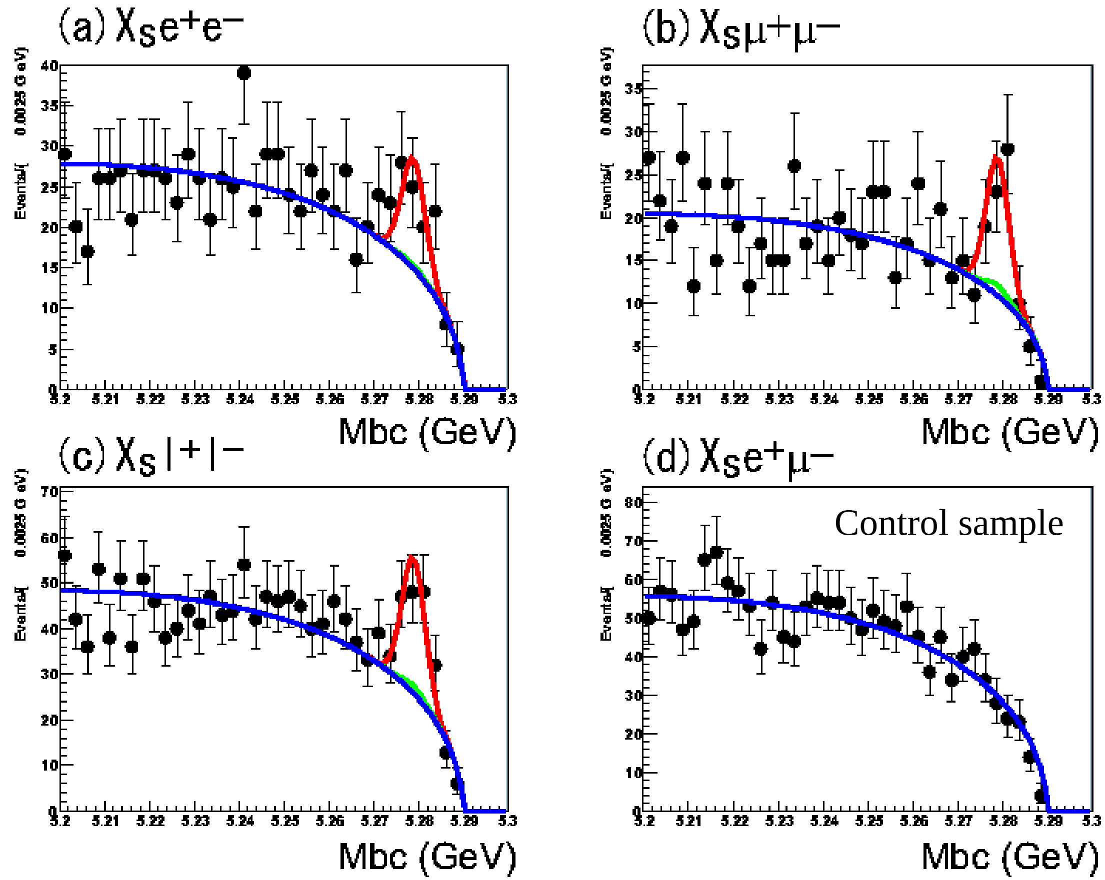


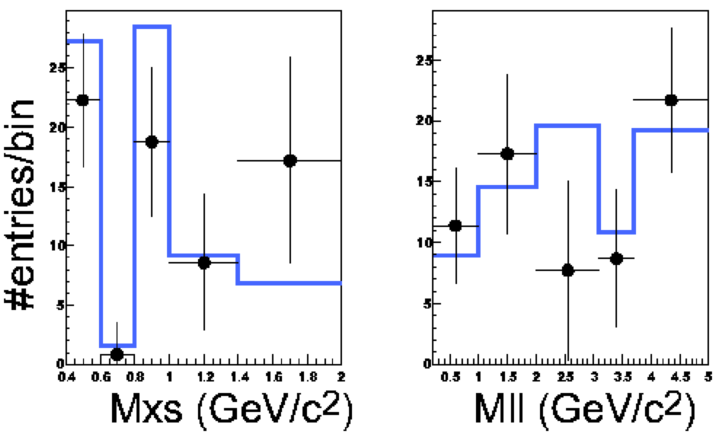
Mode	BaBar(113fb^{-1})	Belle(140fb^{-1})	SM Theory (Ali et al)
$B(B \to K\ell^+\ell^-)$	$(6.5^{+1.4}_{-1.3} \pm 0.4)\times 10^{-7}$	$(4.8^{+1.0}_{-0.9} \pm 0.3)\times 10^{-7}$	$(3.5 \pm 1.2)\times 10^{-7}$
$B(B \to K^*\ell^+\ell^-)$	$(8.8^{+3.3}_{-2.9} \pm 1.0)\times 10^{-7}$	$(11.5^{+2.6}_{-2,4} \pm 0.8)\times 10^{-7}$	$(16_{ee}(12_{\mu\mu}) \pm 5.0)\times 10^{-7}$

$B \to X_s l^+ l^-$ Rate

Belle, 140 fb^{-1} Prelim
(Moriond, Iwasaki)

Semi-exclusive measurement:
Xs = K or K_s + 0-4π (0,1 π^0)
72 signal above BG, 6.2 σ





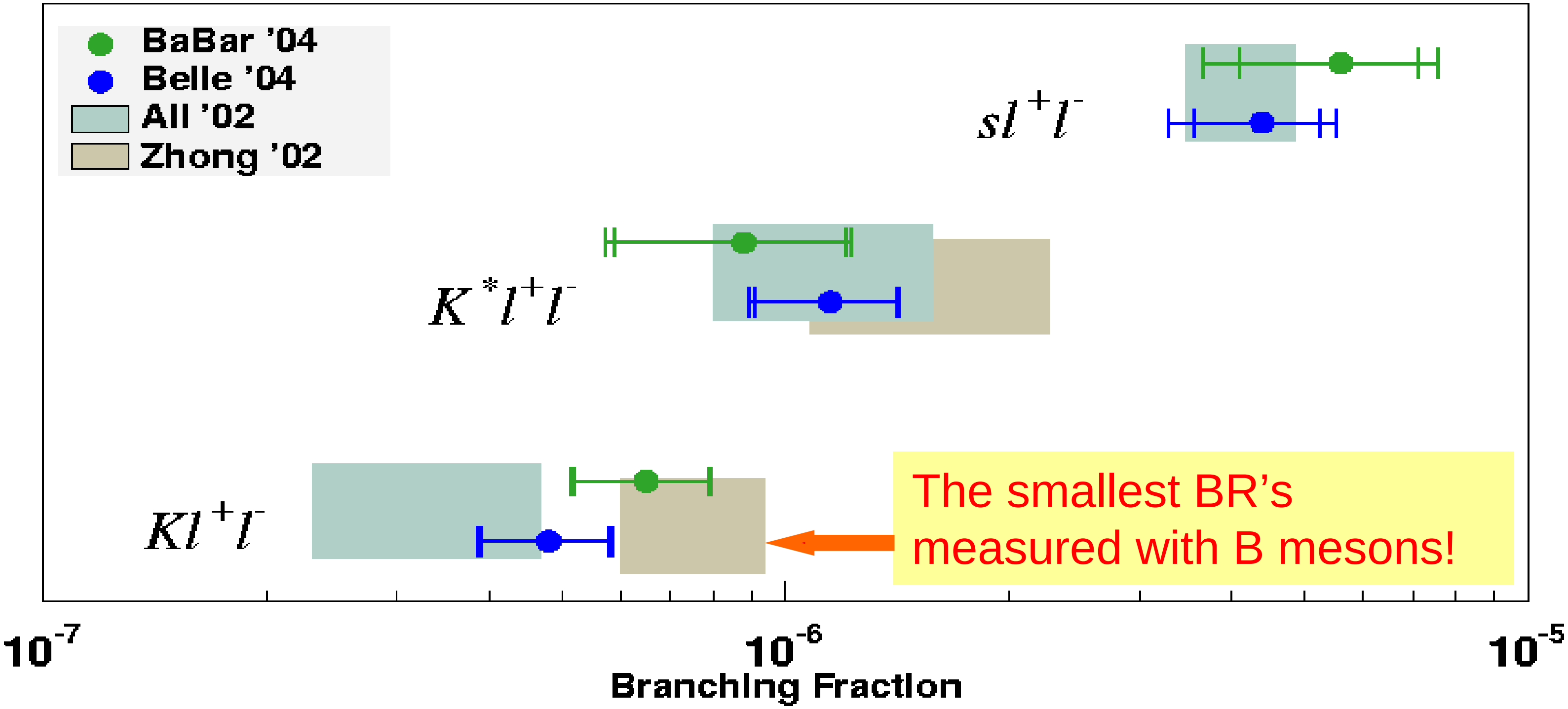
$$B(B \to X_s e^+ e^-) = (4.45 \pm 1.32 \ {}^{+0.84}_{-0.79}) \times 10^{-6}$$

$$B(B \to X_s \mu^+ \mu^-) = (4.31 \pm 1.06 \ {}^{+0.74}_{-0.70}) \times 10^{-6}$$

$$B(B \to X_s l^+ l^-) = (4.39 \pm 0.84 \ {}^{+0.78}_{-0.73}) \times 10^{-6}$$

($M_{ll} > 0.2$ GeV)

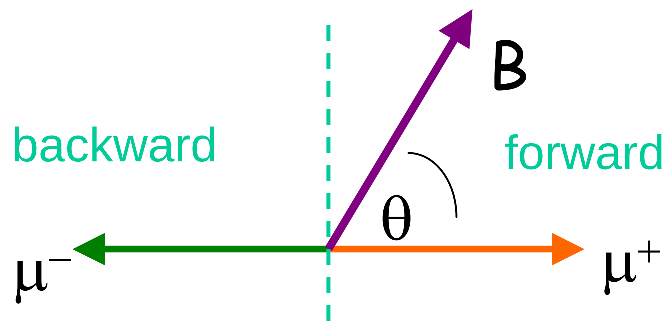
Summary of $b \to s\, l^+ l^-$ Measurements



- Measurements consistent with SM theory expectation
- Experimental errors are down to size of theory errors
- Next level of SM tests expected from asymmetries

FB Asymmetry in $b \to s l^+ l^-$ As Probe of New Physics

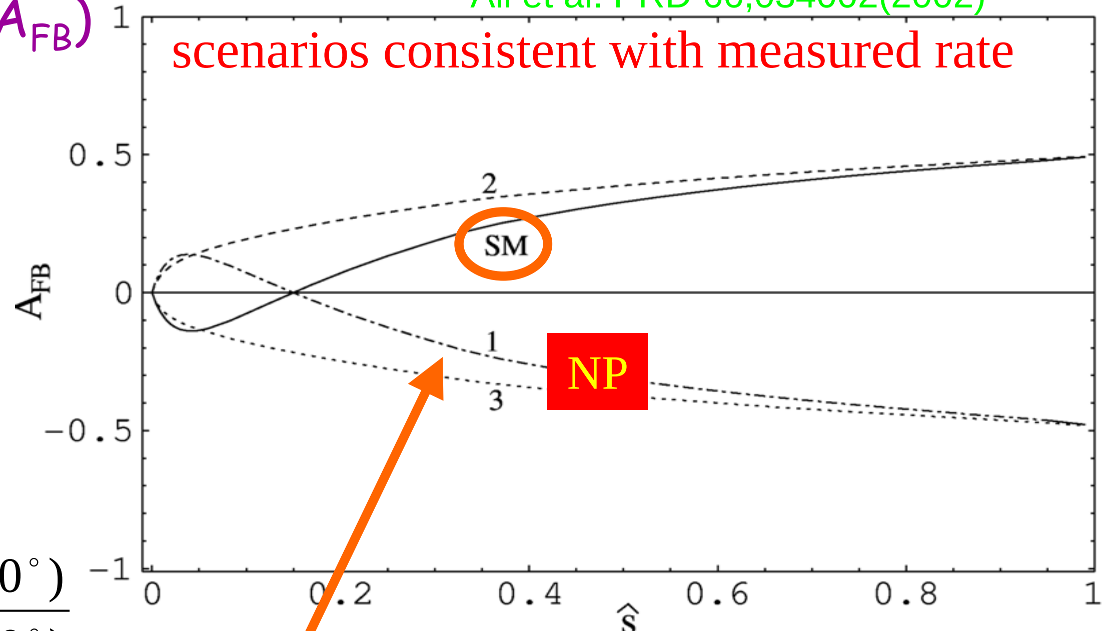
Forward-backward asymmetry (A_{FB})



Lepton pair CM

$$A_{FB}(\hat{s} = \frac{q^2}{m_b^2}) = \frac{N(\theta < 90^\circ) - N(\theta > 90^\circ)}{N(\theta < 90^\circ) + N(\theta > 90^\circ)}$$

Ali et al. PRD 66,034002(2002)



A_{FB} sensitive to relative signs of Wilson coefficients : measurably large

$A_{FB} \to -A_{FB}$ under CP: *Sensitive* to New Physics through Non-SM CPV phases

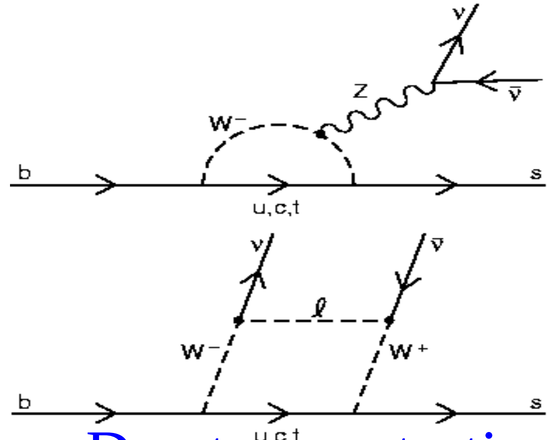
$$BaBar \Rightarrow \quad A_{CP} = -0.22 \pm 0.26(\text{stat}) \pm 0.02(\text{syst})$$

Consistent with SM theory but Data limited

Potential to rule out some NP scenarios (where A_{FB} is of opposite sign w.r.t SM) with $\approx 500\ \text{fb}^{-1}$

$$A_{FB}^{CP}(q^2) = \frac{A_{FB}\{B\} - A_{FB}\{\bar{B}\}}{A_{FB}\{B\} + A_{FB}\{\bar{B}\}} \cong 10^{-3} \text{ in SM}$$

Search For b→s ¥Ÿ & B→K ¥Ÿ



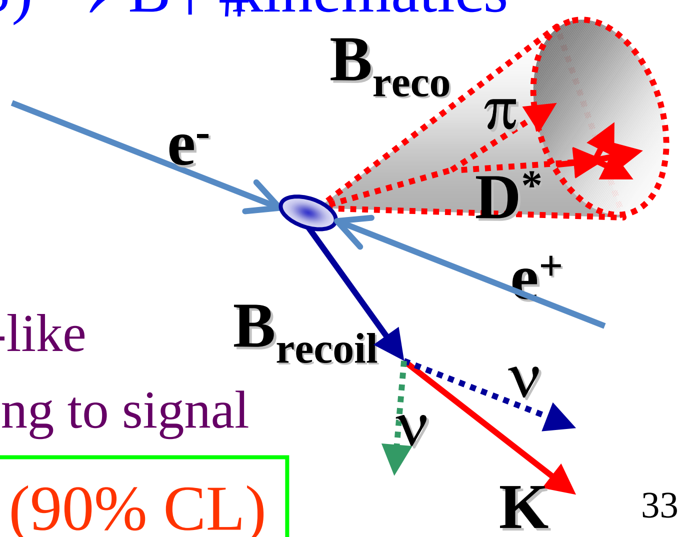
$B(b \to s$ ¥Ÿ$) \approx 4 \times 10^{-5}$
$B(B \to K$ ¥Ÿ$) \approx 4 \times 10^{-6}$

SM Predictions

Free of long-distance effects

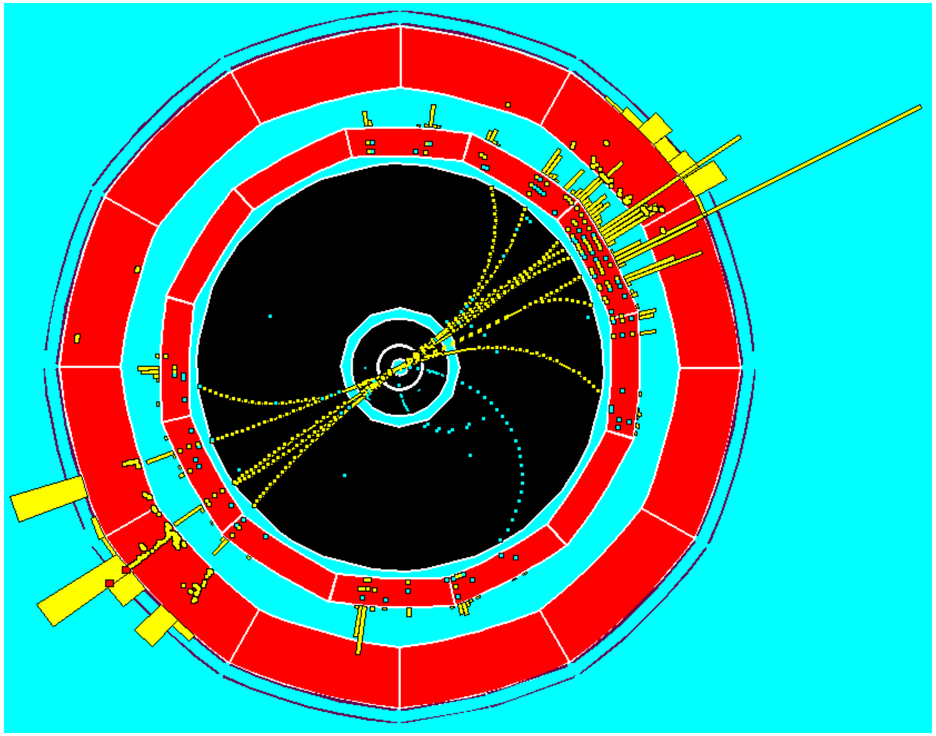
Only published limit from CLEO: $< 2.4 \times 10^{-4}$

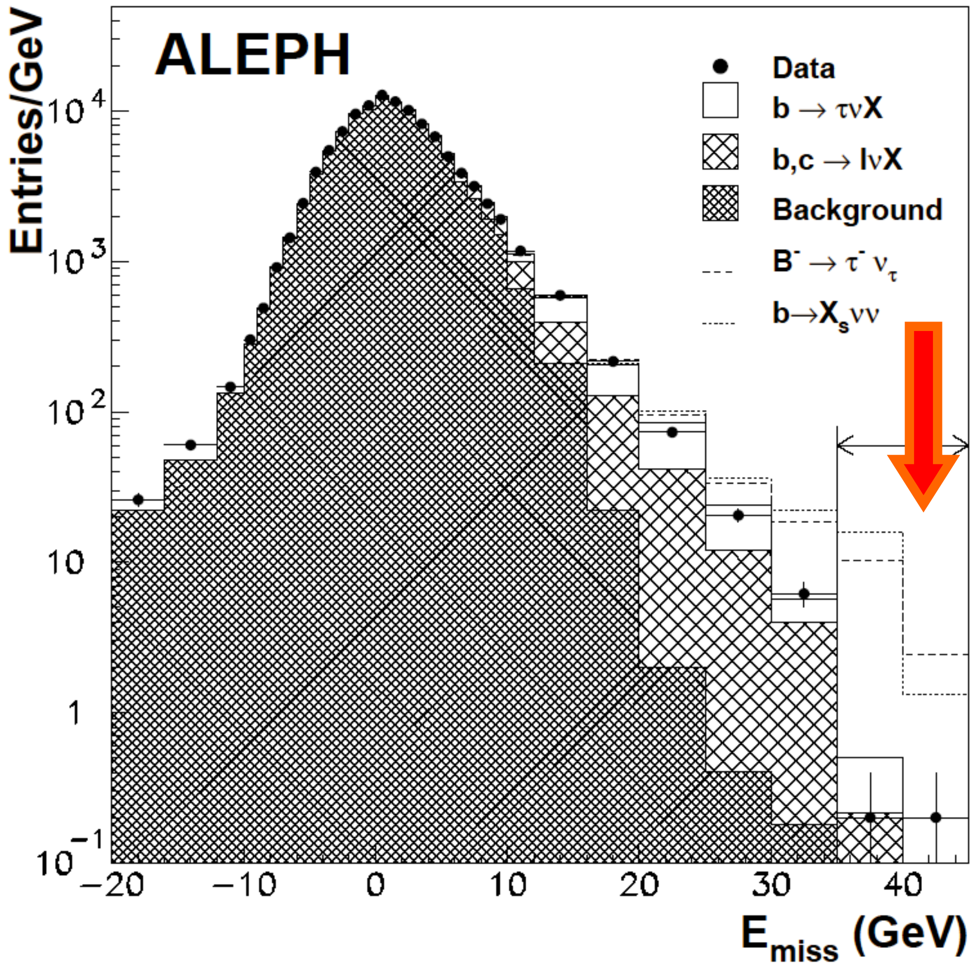
- Due to penetration of machine within detector, BaBar (and Belle) are not hermatic detectors, measurement of missing energy hard !
- "Neutrino reconstruction" inefficient and imprecise
- Analysis strategy takes advantage of $\Upsilon(4S) \to$ B† ‡kinematics
  - Reconstruct One B "completely" $\Rightarrow B_{reco}$
    - **Complete knowledge of 4-vector of other B**
      - and missing energy if B→sυυ
    - **DRASTIC continuum background reduction**
  - Require remaining event topology to be signal-like
  - Cherenkov device to identify K track conforming to signal



BaBar (81 fb^{-1}): $B(B \to K$ ¥Ÿ$) < 7.0 \times 10^{-5}$ (90% CL)

Nostalgia : Missing Energy Spectrum in Z→bÆ at LEP-I





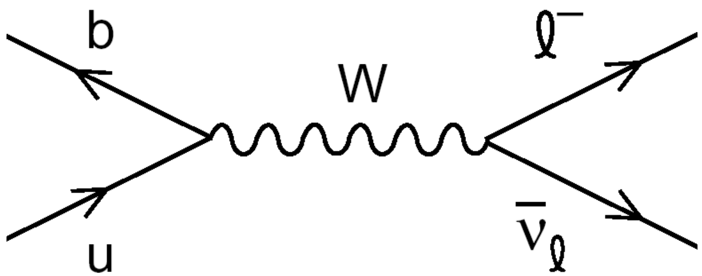
B jets naturally separated by hadronization
Excellent Granularity of Calorimeters

$$\text{ALEPH}: \quad Br(b \to s\nu\bar{\nu}) < 6.4\times10^{-4} \text{ at 90\% CL}$$

$$\text{Theory}: \quad Br(b \to s\nu\bar{\nu}) \approx 4.0 \times10^{-5}$$

Best Limit even 10 years later ⇒ Still an order of magnitude to conquer !

Search For $B^{\pm} \rightarrow l^{\pm}$ ¥



Depends on $f_B\,|V_{ub}|$

- if $|V_{ub}|$ come from $b \rightarrow ul$ ¥ then measures f_B

$$\mathcal{B}(B^+ \rightarrow \ell^+ \nu_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_{B^+}$$

Enhancements up to current limits possible (e.g., MSSM charged Higgs)

mode	SM theory*	90% CL limit
τ^+ ¥	8×10^{-5}	4.1×10^{-4} (BaBar-CONF-03/005)
μ^+ ¥	4×10^{-7}	6.6×10^{-6} (BaBar PRL accepted) 6.8×10^{-6} (Belle-CONF-0247)
e^+ ¥	9×10^{-12}	5.4×10^{-6} (Belle-CONF-0247)

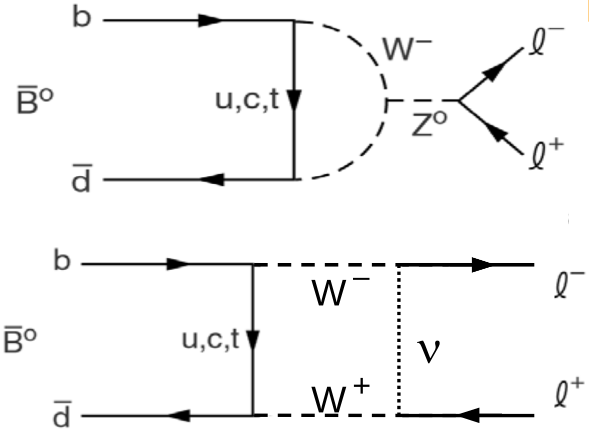
82 fb^{-1}

81 fb^{-1}

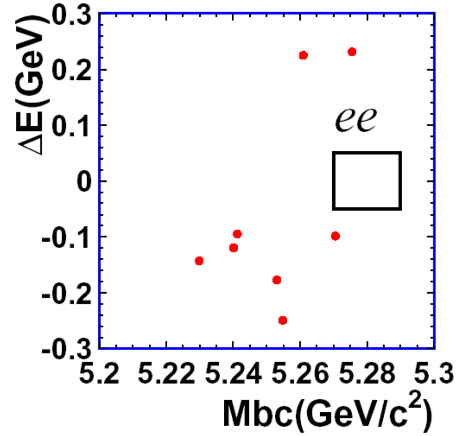
60 fb^{-1}

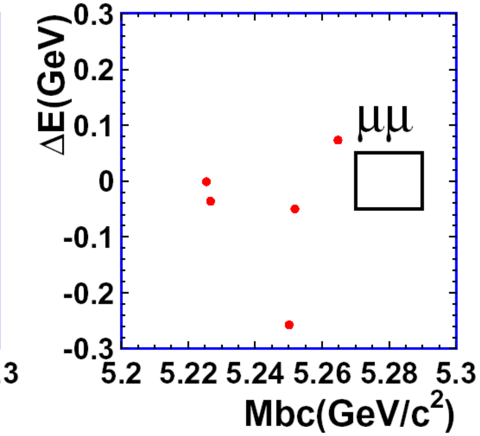
* - assumes f_B = 198 MeV, $|V_{ub}|$ = 0.0036

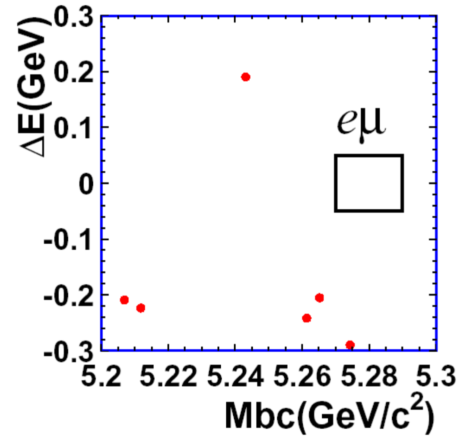
$B^0 \to l^+ l^-$



Belle







Very small in Standard Model

- $B(B^0 \to \tau^+\tau^-) \approx 3 \times 10^{-8}$
- μ and e modes helicity suppressed
- possible large enhancement from non-SM scalar currents (e.g., MSSM)
- important window for New Physics

Best published Limit:
Belle (78 fb^{-1}) PRD 68,111101(2003)

$$B(B^0 \to \mu^+\mu^-) < 1.6 \times 10^{-7} \text{ (90\% CL)}$$
$$B(B^0 \to e^+ e^-) < 1.9 \times 10^{-7} \text{ (90\% CL)}$$
$$B(B^0 \to \mu\, e) < 1.7 \times 10^{-7} \text{ (90\% CL)}$$

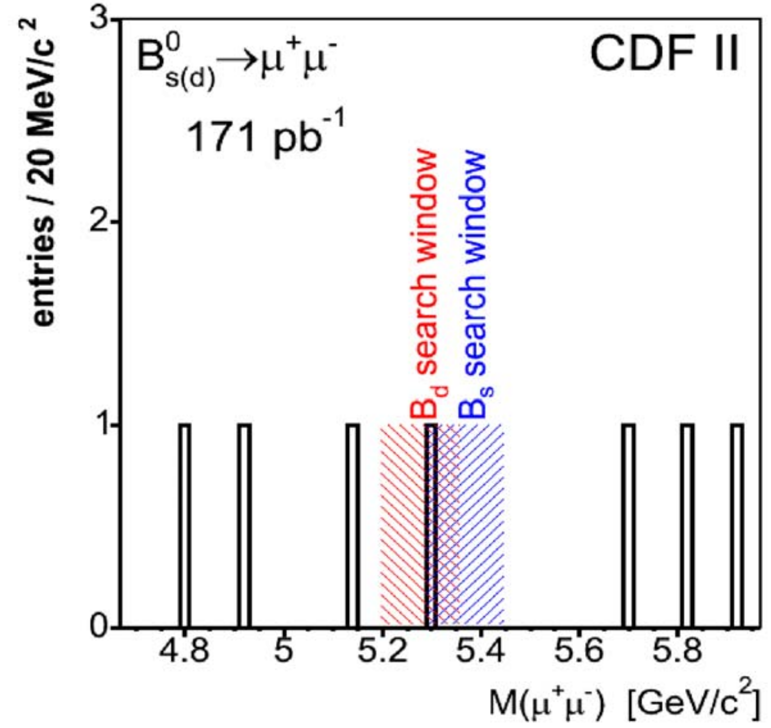
CDF preliminary
171 pb^{-1} (hep-ex/0403032)

$$B(B^0 \to \mu^+\mu^-) < 1.5\times10^{-7} \text{ (90\% CL)}$$

Search For $B_s \to \mu^+ \mu^-$

An important decay mode where hadron colliders will dominate.

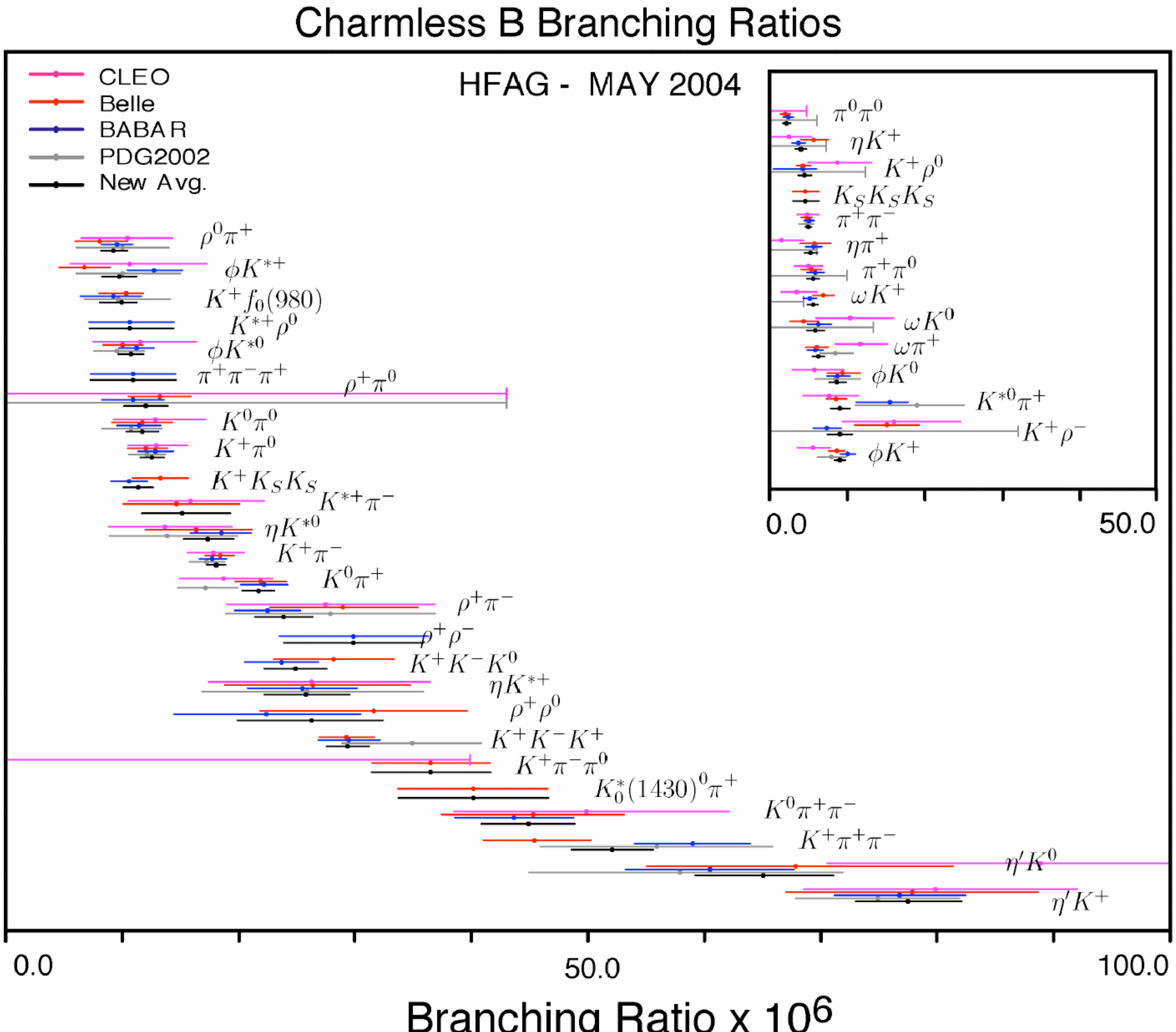
- in SM, $B(B_S \to \mu^+\mu^-) = (3.4 \pm 0.5) \times 10^{-9}$ leaving room for New Physics to appear
- in MSSM models, significant scalar FCNCs at large tan β ⇒ can constrain tan β from above



Recent preliminary limit from CDF
171 pb^{-1} (hep-ex/0403032)

$$B(B_s^0 \to \mu^+\mu^-) < 5.8 \times 10^{-7} \text{ (90\% CL)}$$

Charmless Hadronic Decays Are Not So Rare !



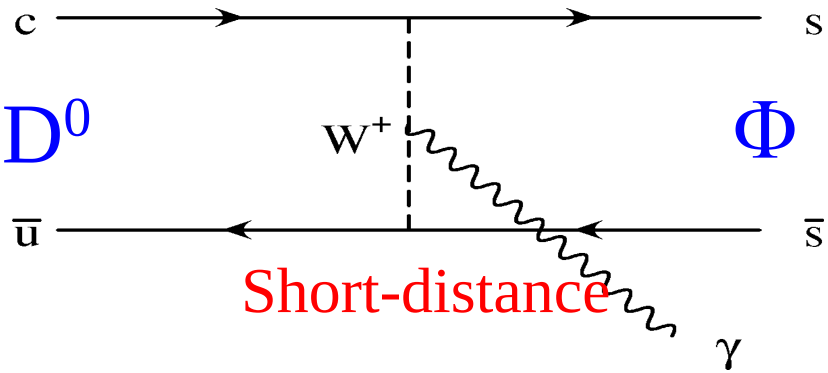
Results being digested in the HF theory community

Two Quick (!) Topics in Rare D Decays

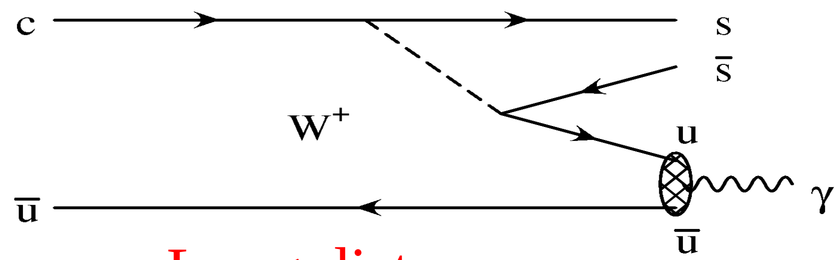
$D^0 \rightarrow \varphi\gamma$ (Belle)

$D^+ \rightarrow \mu^+\upsilon_\mu$ (CLEO-c)

First Observation of $D^0 \to \varphi\gamma$

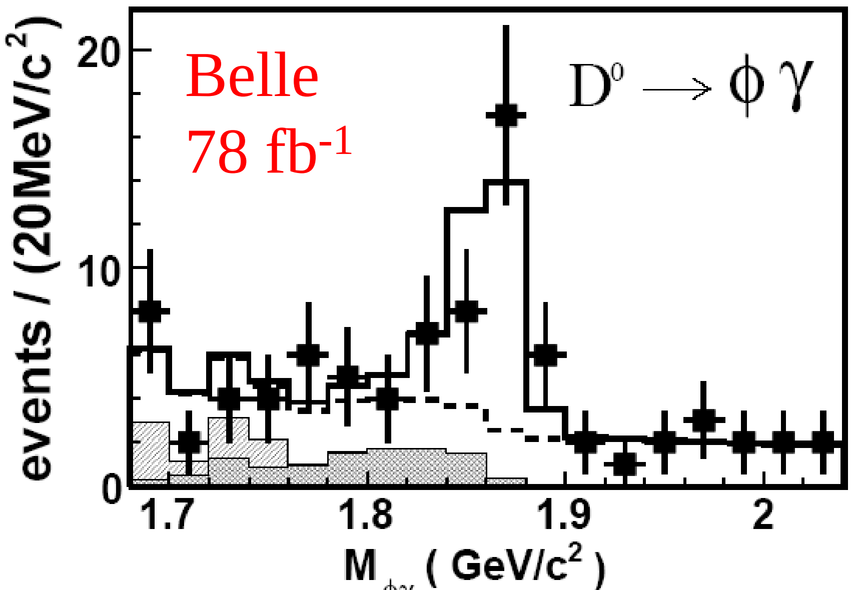


Short-distance



Long distance

- In SM, short distance contribution negligible ($< 10^{-8}$)
- Long-distance contribution due to vector meson dominant [Burdman95, Fajfer97]
- Rate predicted in range [$(0.04\text{-}3.4)\times 10^{-5}$], 90% CL limit from CLEO $<1.9 \times 10^{-4}$
- Reality check when considering long-distance effects in $b \to d\gamma$ for determing V_{td}



Observe $27.6^{+7.4}_{-6.5}(stat)^{+0.5}_{-1.0}(syst)$ events

Significance is 5.4σ !

$$B(D^0 \to \Phi\gamma) = [2.60^{+0.70}_{-0.61}\ (stat)\ ^{+0.15}_{-0.17}]\times 10^{-5}$$

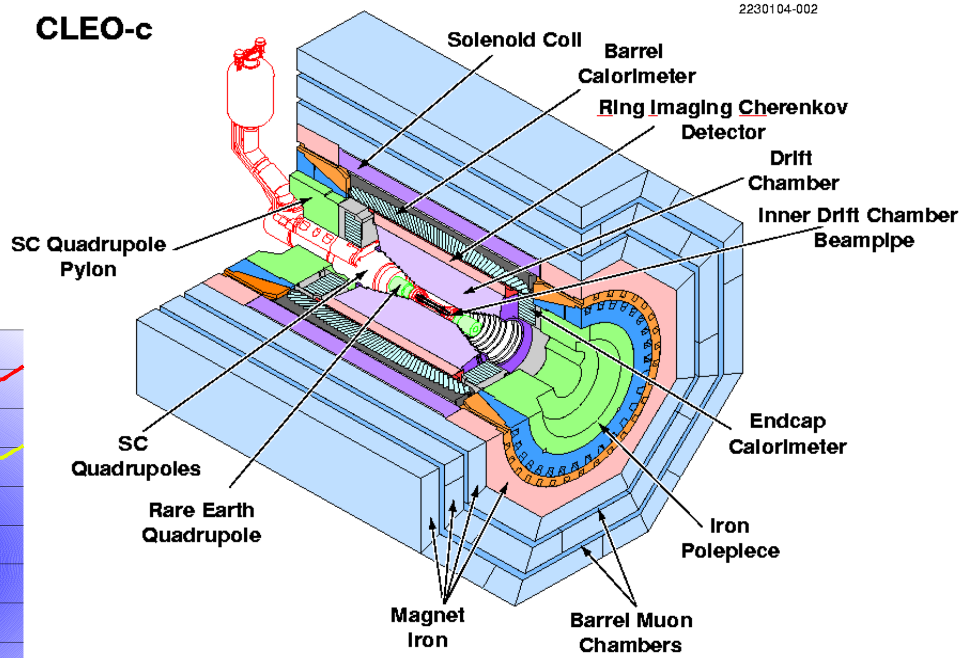
" An anchor for future development of non-perturbative QCD"

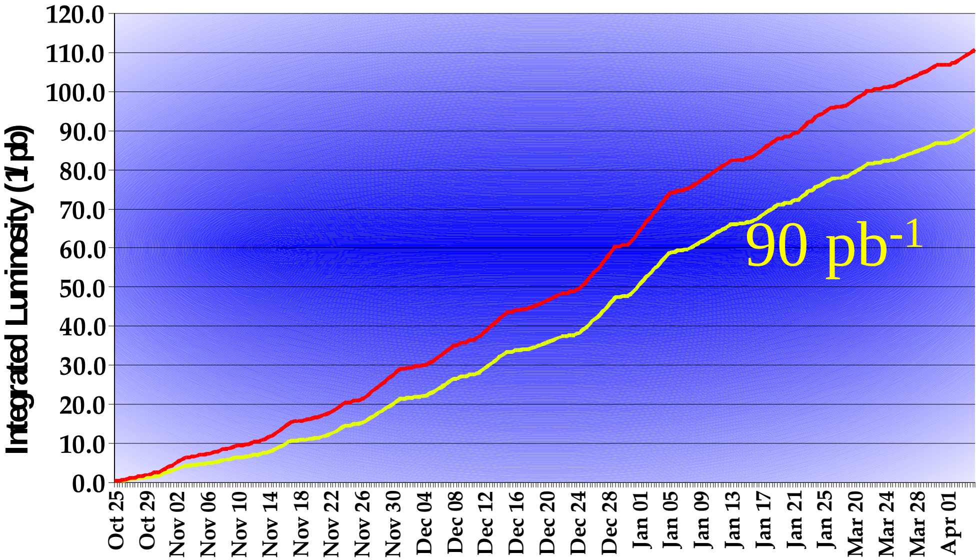
The Return of Cleo !

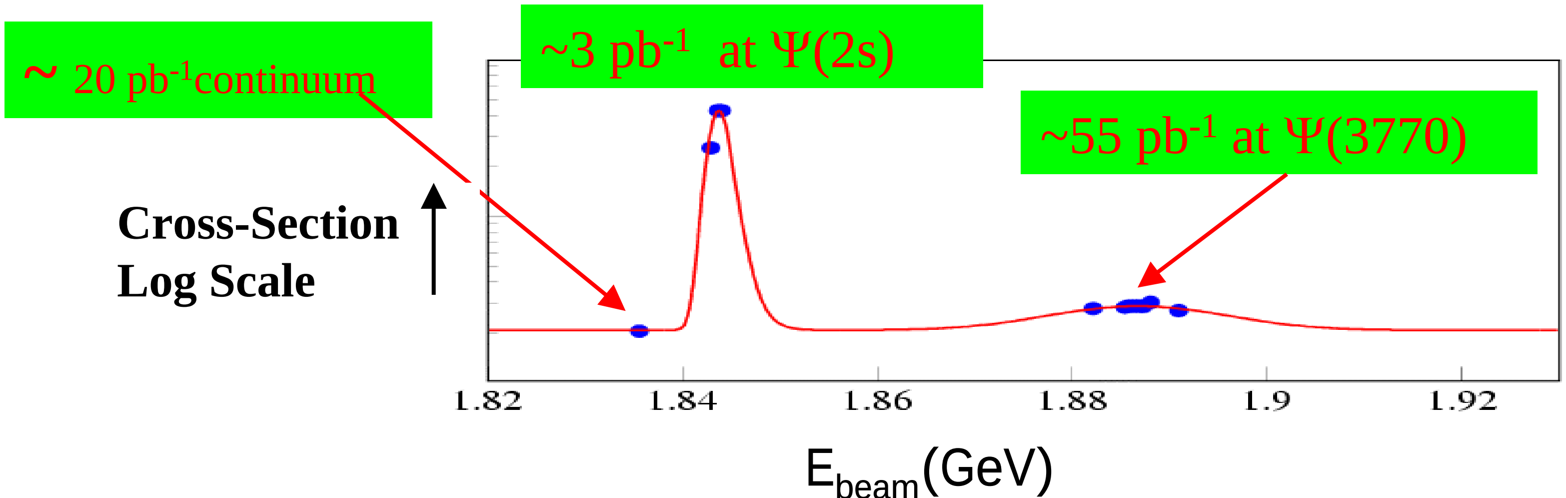
CESR with 6 Wiggler running L ~ 5×10^{31} cm^{-2} s^{-1}

On target!

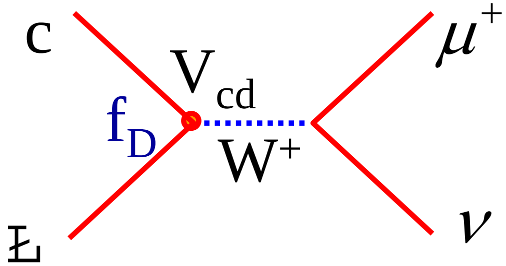
Design Luminosity, 12 Wigglers, ~ 3×10^{32} cm^{-2}s^{-1}





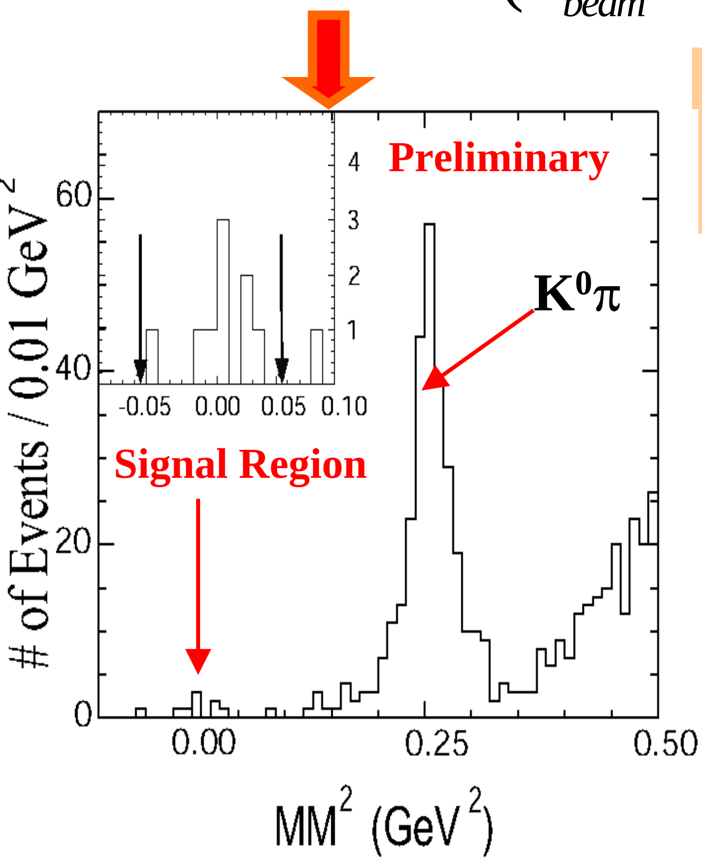


Observation of $D^+ \to \mu^+\upsilon_\mu$ (CLEO-c)



$$\Gamma(M \to l\nu) = \frac{1}{8\pi} G_F^2 f_M^2 m_l^2 M_M \left(1 - \frac{m_l^2}{M_M^2}\right)^2 |V_{qq'}|^2$$

Calculate $MM^2 = (E_{beam} - E_\mu)^2 - (-\overrightarrow{P_{D^+}} - \overrightarrow{P_\mu})^2$ recoiling against recoed D



9 events in 2σ window (-0.056<MM²<0.056 GeV²) , 0.67 ±0.24 estimated background

$B(D^+ \to \mu^+\nu_\mu) = (4.57 \pm 1.66 \pm 0.41) \times 10^{-4}$

$\Rightarrow f_{D^+} = (230 \pm 42 \pm 10) MeV$ [Prelim]

This is just the begining

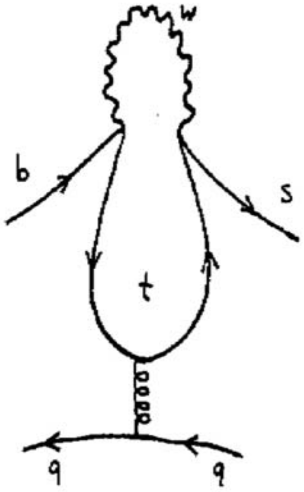
Expect $\times 60$ data at $\psi(3770)$ soon

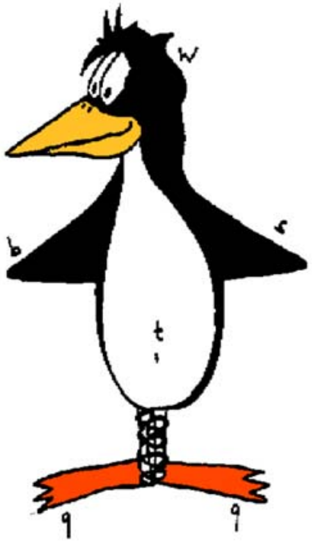
New era in charm physics is here !

Summary & Outlook

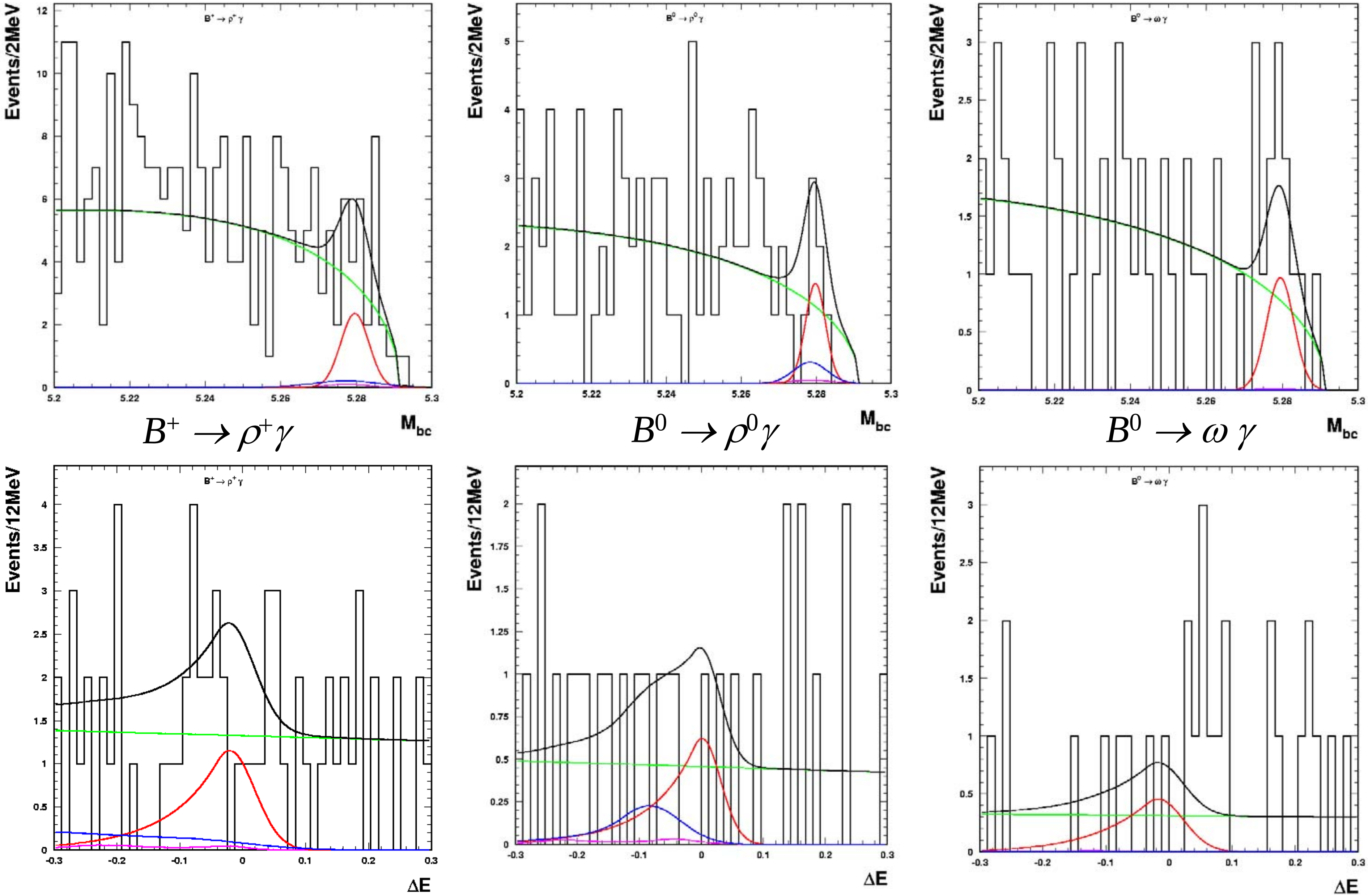
- First round of experimental goal of establishing $b \to s \gamma$ and $b \to s l^+ l^-$ decays (more-or-less) achieved
  - Branching fractions are so far consistent with the SM expectations
  - Measurement accuracy beginning to rival theoretical precision
- The Future is in Asymmetry measurements which will improve substantially with projected large (500 fb^{-1}) data sets
  - Isospin, direct CP violation & CP(t) in $b \to s \gamma$
  - Forward-backward (and FBCP) in $b \to s\, l^+ l^-$
    - $\Rightarrow$ **windows for New Physics with small SM background**
- Evidence for $B \to \rho\, \gamma$ from Belle, favors large V_{td}
- Leptonic decays searches not yet testing SM
- Radiative FCNC in Charm system finally observed in $D \to \Phi \gamma$
- CLEO-c off to an excellent start with first results on $D^+ \to \mu \upsilon$

Backup Slides

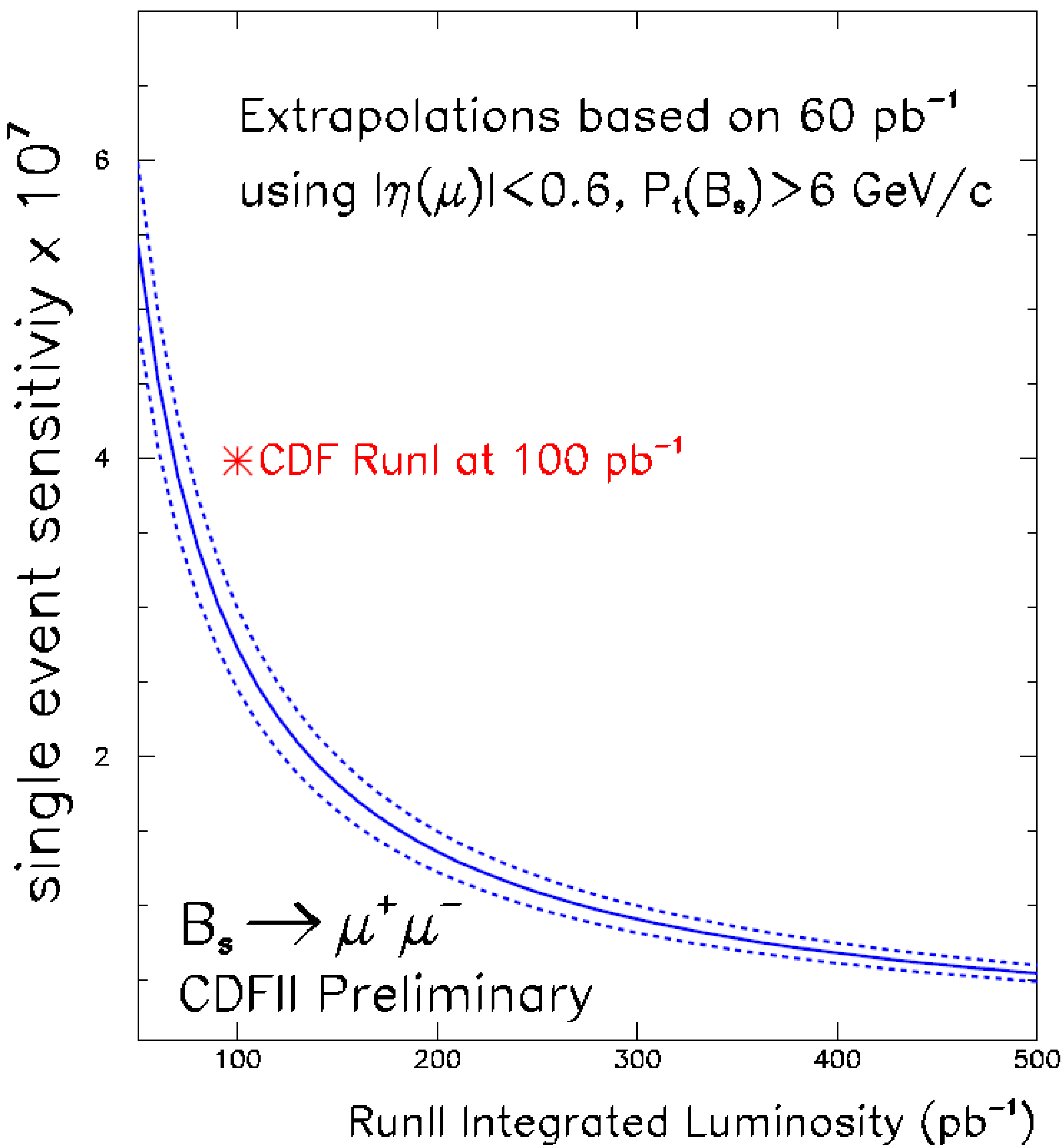




black = total, red = signal, green = cont. bkg, blue = $K^*\gamma$ bkg, purple = $(\rho/\omega)\pi^0$



Fits shown are simultaneous in M_{bc} and ΔE assuming isospin


Extrapolations based on 60 pb^{-1}
using $|\eta(\mu)|<0.6$, $P_t(B_s)>6$ GeV/c
✳CDF RunI at 100 pb^{-1}
$B_s \rightarrow \mu^+\mu^-$
CDFII Preliminary
single event sensitiviy x 10^7
RunII Integrated Luminosity (pb^{-1})
6
4
2
100
200
300
400
500

CLEO-c Run Plan

Main change for CESR to become CESR-c is the installation of 12 wigglers (6 completed, 6 more being installed).

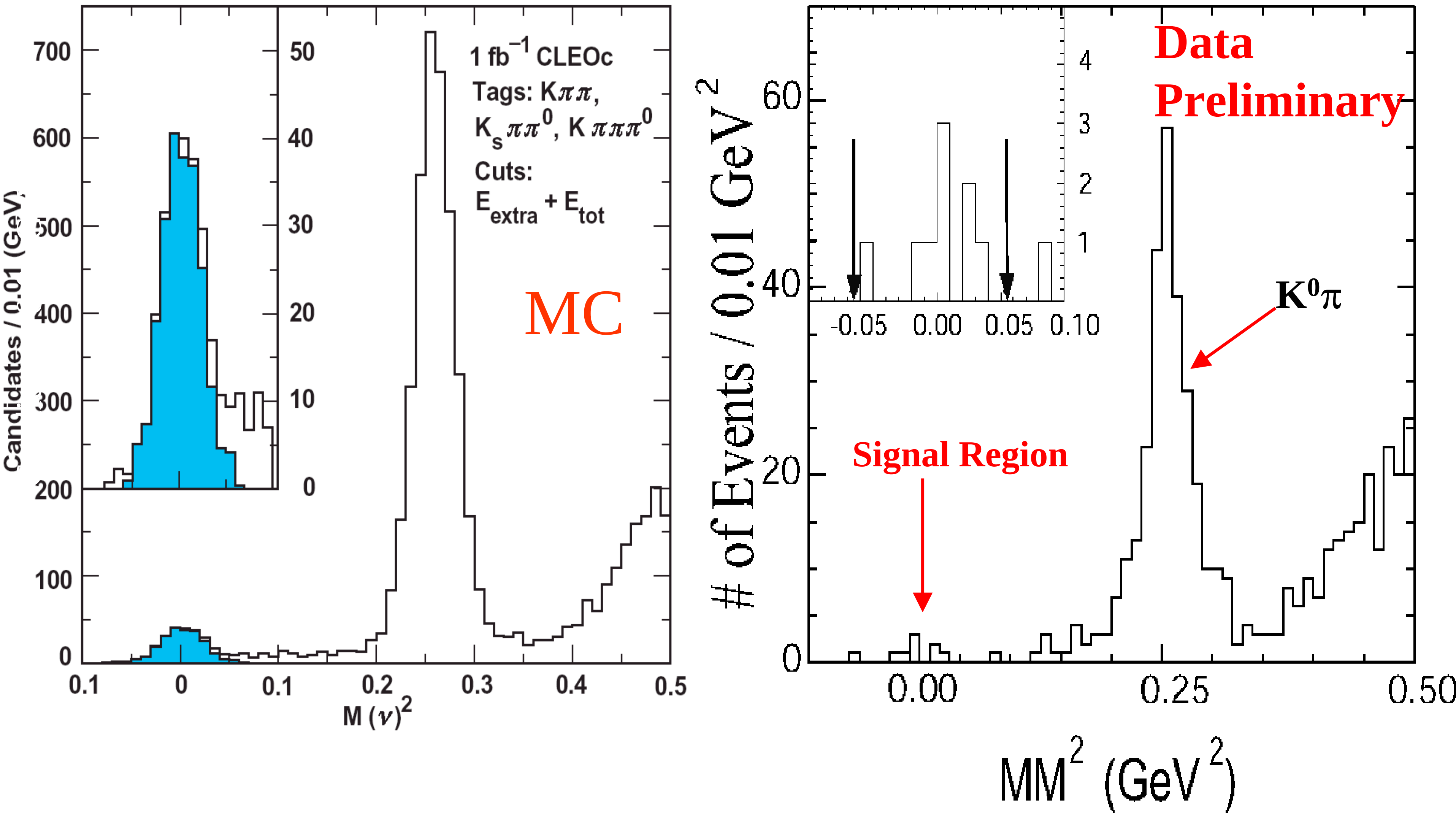
Spring and Fall 2004, we hope for 3 fb^{-1} at and around the $\Psi(3770)$. This corresponds to ~18,000,000 $D\bar{D}$ decays, and maybe 3,600,000 *tagged* D decays (310 x MARKIII, 170xBES)

Fall 2005, E=4140 MeV, we hope for 3 fb^{-1} giving 1,500,000 D_sD_s events, 300 ,000 *tagged* D_s decays (480 x MARK III, 130 x BES)

Fall 2006 we may run at E=3100 MeV, 1 fb^{-1}, giving 1,000,000,000 J/ Ψ decays (170 x MARKIII, 20 x BES II)

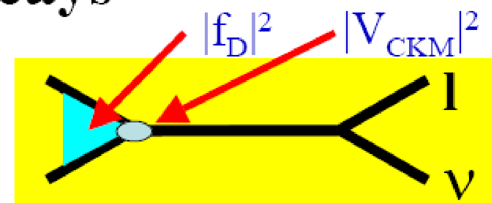
Run plan subject to change, in particular it is dependent on the physics results from the early running.

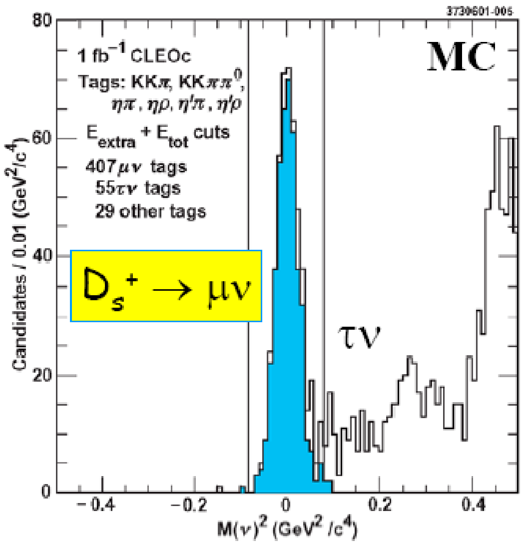
MM² Distribution

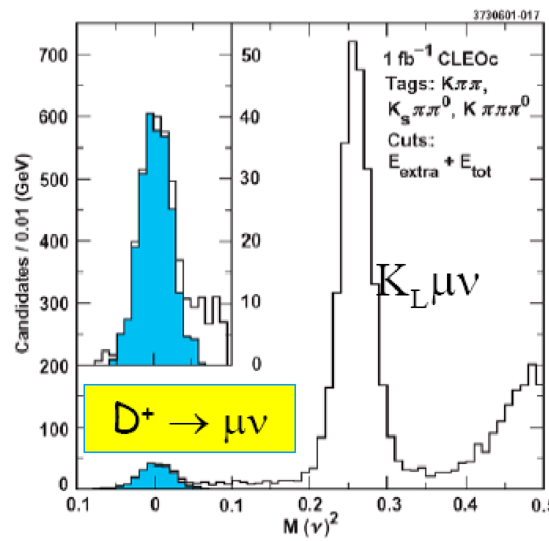


f_{Dq} from Leptonic Decays

$$\Gamma(D_q \rightarrow l\nu) \propto |f\_Dq|^2 \; |V\_cq|^2$$



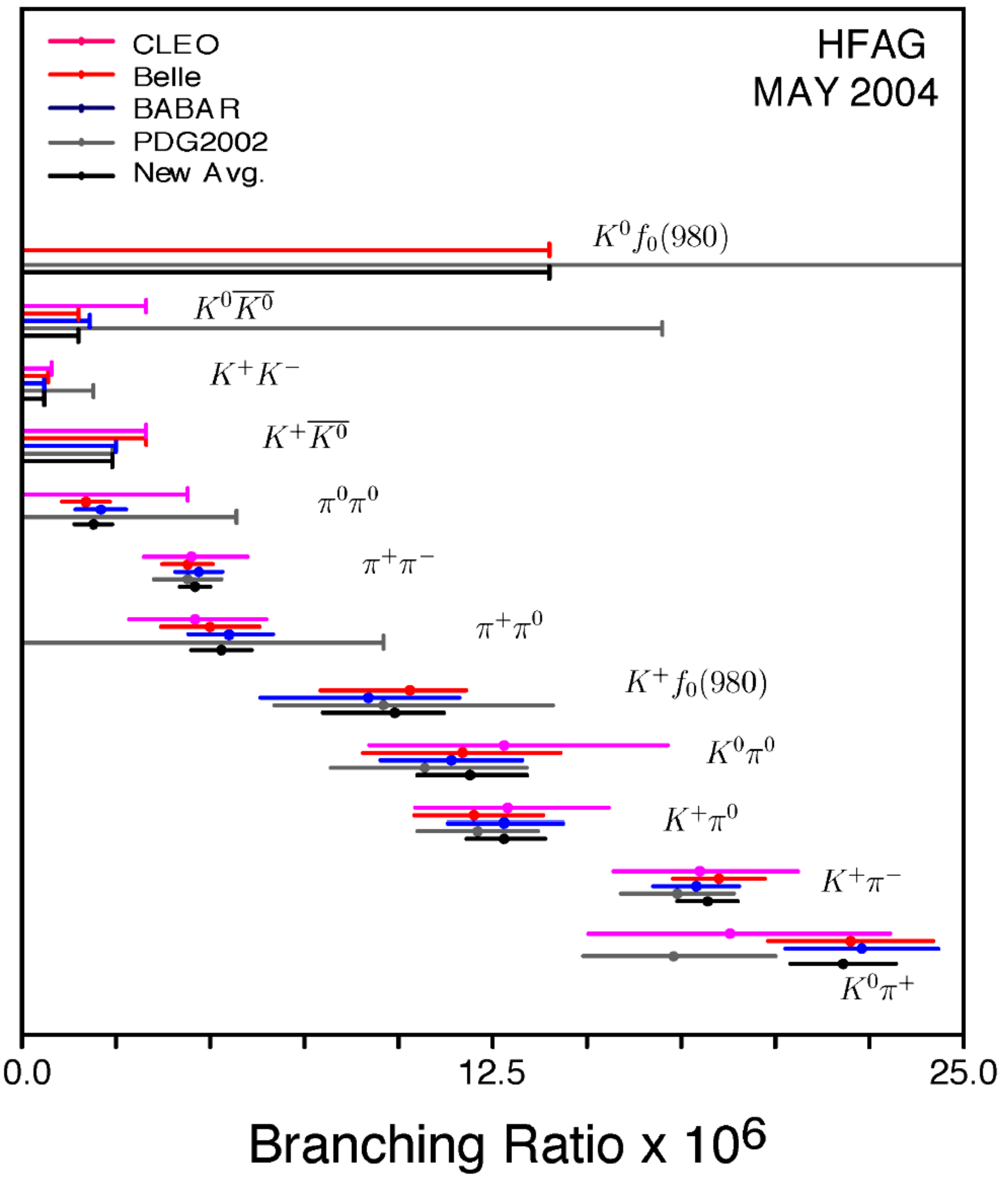




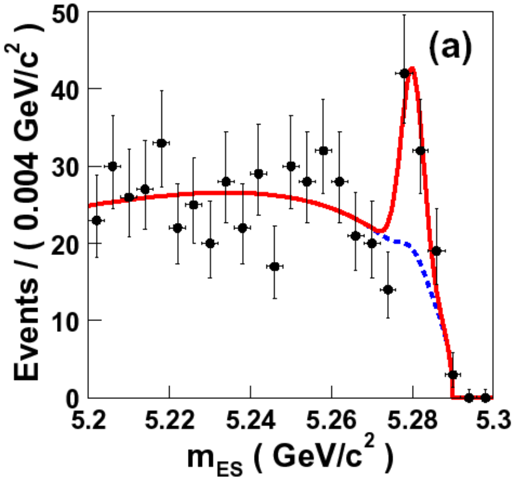
w/ 3 fb-1 & 3-gen CKM unitarity:

Decay Constant	Reaction	PDG δf/f	CLEO-c δf/f
f_{Ds}	$D_s^+ \rightarrow \mu\nu$	17%	1.9%
f_{Ds}	$D_s^+ \rightarrow \tau\nu$	33%	1.6%
f_D	$D^+ \rightarrow \mu\nu$	UL	2.3%

$\mathcal{B}(B \to K\pi,\ \pi\pi,\ KK,\ Kf_0)$



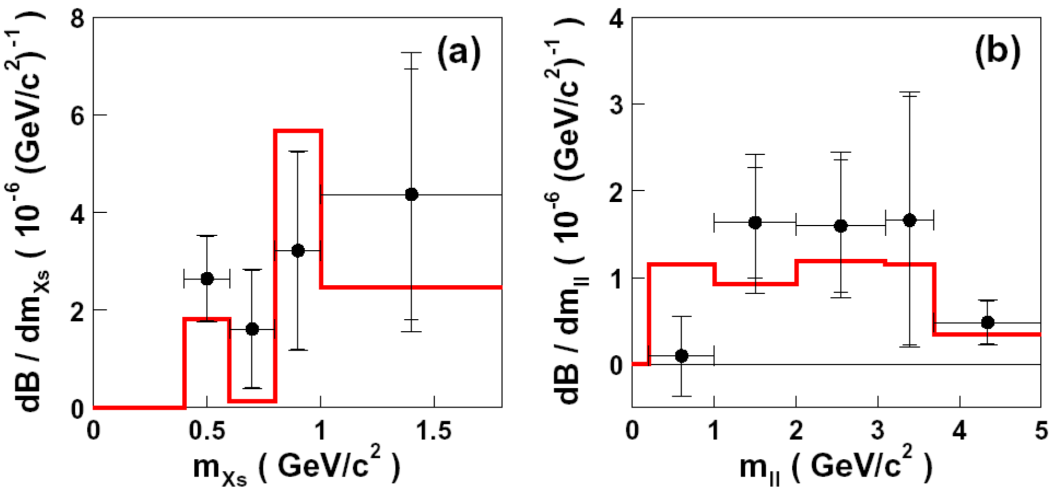
$B \to X_s l^+ l^-$



82 fb^{-1}

X_S = K or K_s + 0-2π (0,1 π^0)
(≈75% of all if K_L=K_S)
40 signal above BG, 4.3 σ

Submitted to PRL
hep-ex/0404006



$$B(B \to X_s e^+ e^-) = (6.0 \pm 1.7 \pm 0.7 \pm 1.1) \times 10^{-6}$$

$$B(B \to X_s \mu^+ \mu^-) = (5.0 \pm 2.8 \pm 0.6 \pm 1.0) \times 10^{-6}$$

$$B(B \to X_s l^+ l^-) = (5.6 \pm 1.5 \pm 0.6 \pm 1.1) \times 10^{-6}$$

(M_{ll} > 0.2 GeV)

★ $A_{CP} = -0.22 \pm 0.26(\text{stat}) \pm 0.02(\text{syst})$
consistent with SM theory

Isospin and Direct CP Asymmetries in $B \to K^* \gamma$

Hadronic uncertainties which affect exclusive rate calculation, mostly cancel in asymmetries:

Isospin:
$$\Delta_{0-} = \frac{\Gamma(\overline{B^0} \to \overline{K^{*0}}\gamma) - \Gamma(B^- \to K^{*-}\gamma)}{\Gamma(\overline{B^0} \to \overline{K^{*0}}\gamma) + \Gamma(B^- \to K^{*-}\gamma)}$$

$\Delta_{0-} \cong (8\pm3)\%$ in SM; deviation test of New Physics [Kagan et.al, Phys.Lett.B539,227(2002)

Direct CP:
$$A_{CP} = \frac{\Gamma(\overline{B} \to \overline{K^*}\gamma) - \Gamma(B \to K^*\gamma)}{\Gamma(\overline{B} \to \overline{K^*}\gamma) + \Gamma(B \to K^*\gamma)} \cong 0$$

BaBar (82 fb^{-1}) preliminary →

$\Delta_{0-} = 0.051 \pm 0.044 \pm 0.023 \pm 0.024(+/0)$

$-0.039 < \Delta_{0-} < 0.141$ (90% CL)

$A_{CP} = -0.013 \pm 0.036$ (stat) ± 0.010 (syst)

$-0.074 < A_{CP} < 0.049$ (90% CL)

Belle (78 fb^{-1}) hep-ex/0402042 →

$\Delta_{0-} = 0.034 \pm 0.044 \pm 0.026 \pm 0.025(+/0)$

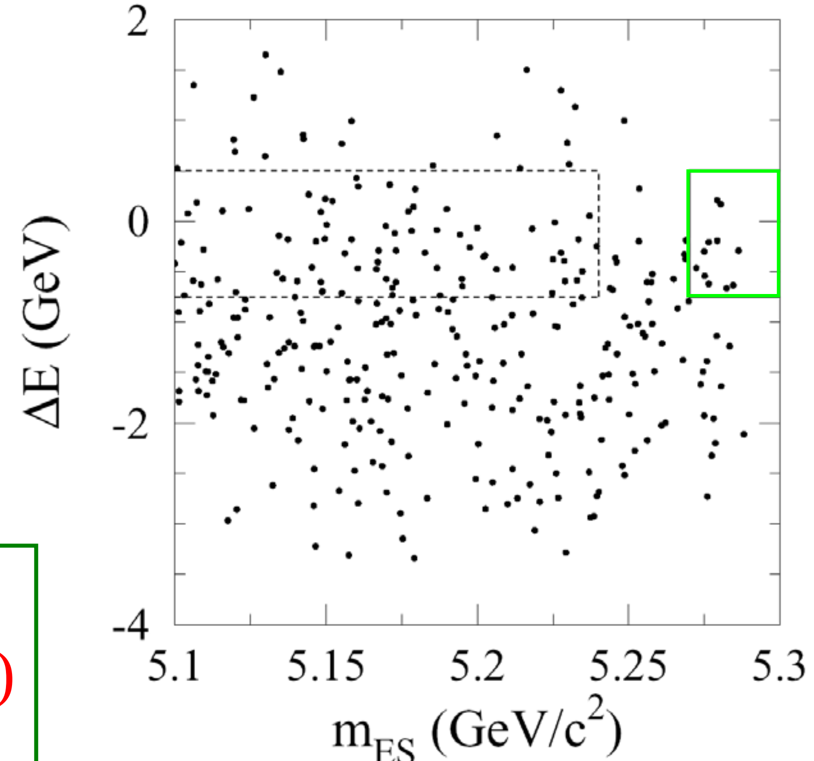
$A_{CP} = -0.015 \pm 0.044$ (stat) ± 0.012 (syst)

$B^{\pm} \to \mu^{\pm}$ ¥

Best published limit from CLEO: $< 2.1 \times 10^{-5}$ (90% CL)

BaBar: 81 fb^{-1}

- Good muon: $2.25 < p_{\mu} < 2.95$ GeV
  all other tracks and EM clusters assigned to companion B
  $\Rightarrow \quad M_{ES}, \Delta E$
- Missing momentum points inside detector
- Shape cuts to suppress continuum

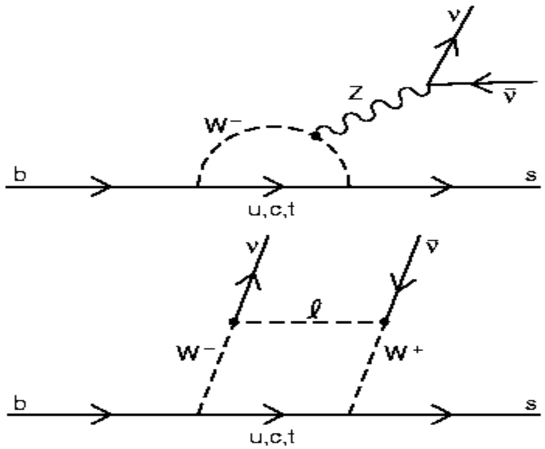


New BaBar

$B(B^{+} \to \mu^{+}$ ¥$) < 6.6 \times 10^{-6}$ (90% CL)

hep-ex/0401002, accepted for PRL

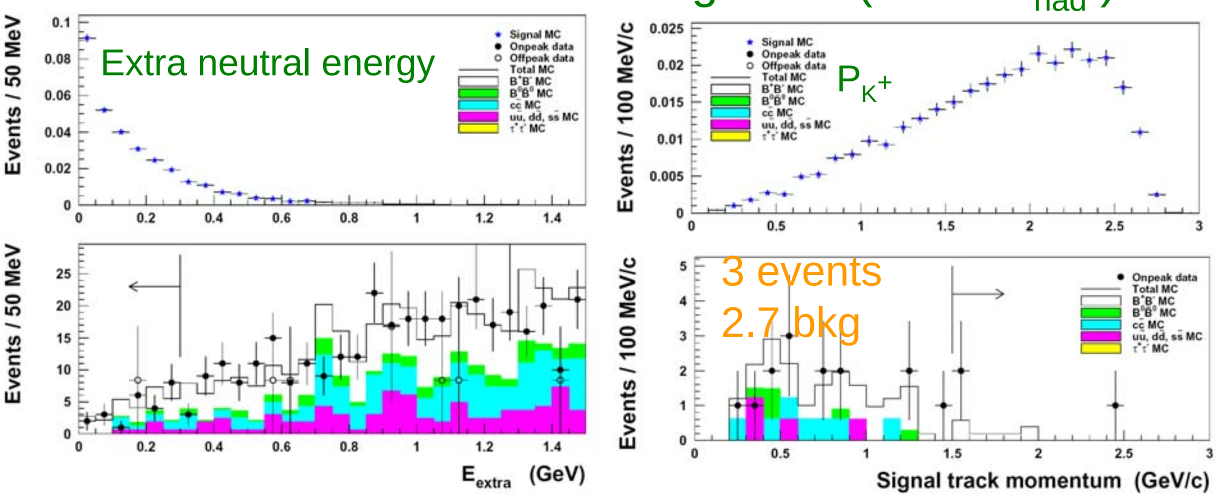
$B \to K \nu\bar{\nu}$



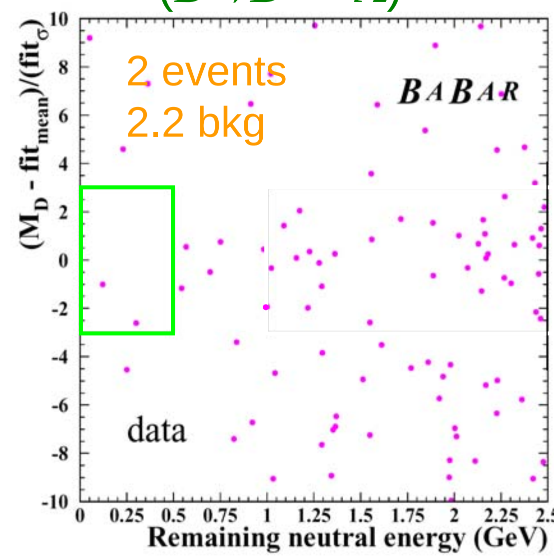
SM
$B(b \to s\ \nu\bar{\nu}) \approx 4 \times 10^{-5}$
$B(B \to K\ \nu\bar{\nu}) \approx 4 \times 10^{-6}$
Free of long-distance effects

Only published limit from CLEO: $< 2.4 \times 10^{-4}$

Full reconstruction of the tag B: $(B \to D^0 X_{had})$



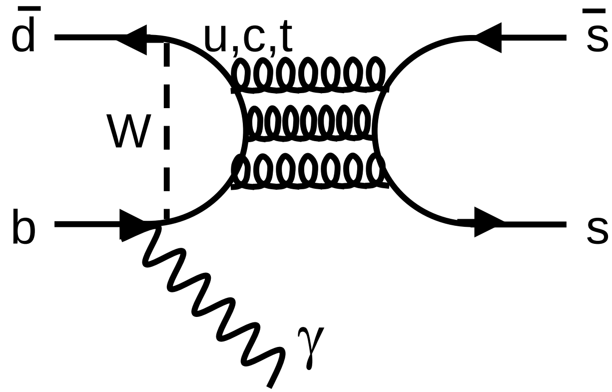
$(B \to D^{0(*)}\, l\, \nu)$

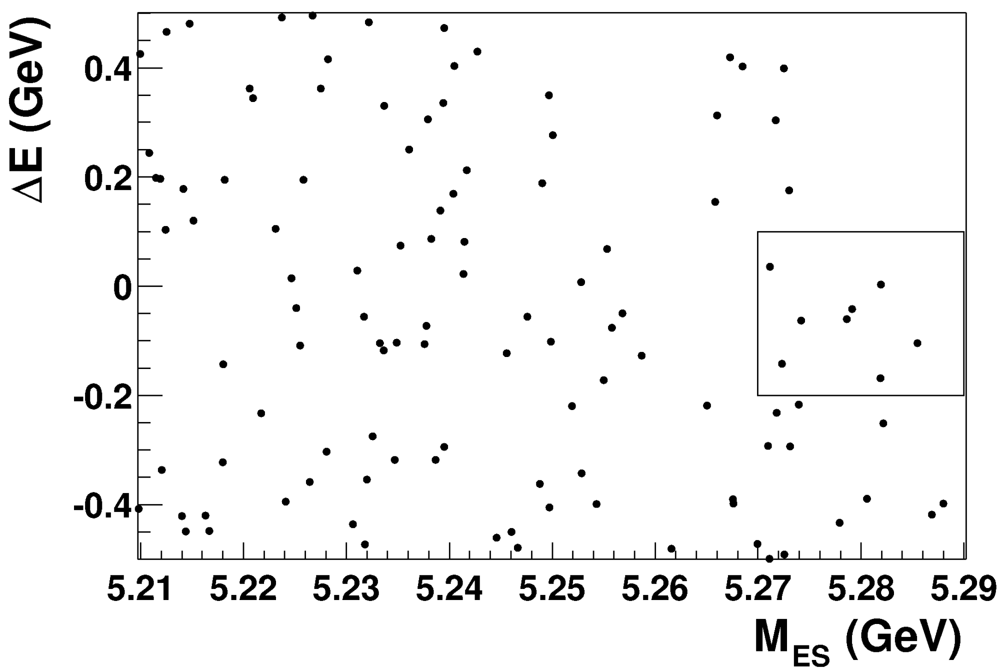


Combined result of two independent analyses

BaBar (81 fb–1) $B(B \to K \nu\bar{\nu}) < 7.0 \times 10^{-5}$ (90% CL)

$B \to \varphi\, \gamma$





SM expectation

- $B(B^0 \to \varphi\gamma) \cong 3.6 \times 10^{-12}$

  [Li et al., hep-ph/0305283]

- up to 10^{-8} in some SUSY scenarios (R-parity vio)

Prior limit

- $B(B^0 \to \varphi\gamma) < 3.3 \times 10^{-6}$

from CLEO

BaBar preliminary (113 fb^{-1})

$B(B^0 \to \varphi\, \gamma) < 9.4 \times 10^{-7}$ (90% CL)