DESY Seminar

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Electroweak Penguin Decays of B Mesons

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SCIPP

BABAR Collaboration

Penguins?!

The origin of penguins
Told by John Ellis:

http://www.symmetrymagazine.org/cms/?pid=1000424

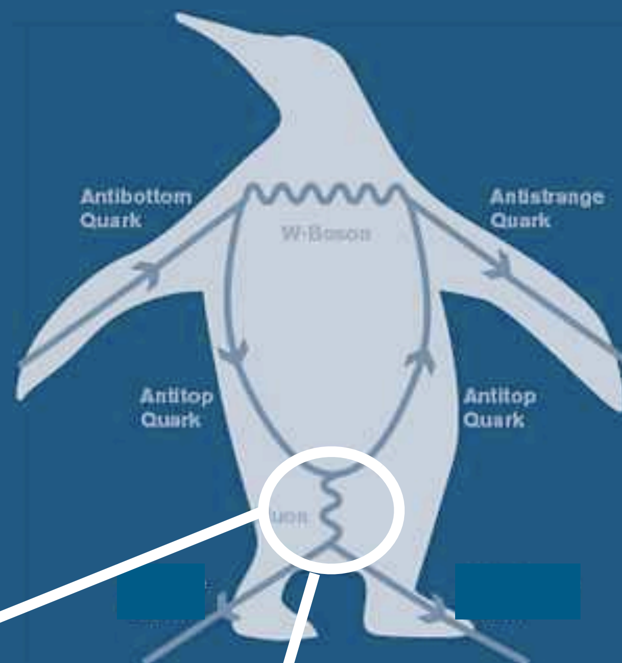
"Mary K. [Gaillard], Dimitri [Nanopoulos], and I first got interested in what are now called penguin diagrams while we were studying CP violation in the Standard Model in 1976… The penguin name came in 1977, as follows.

In the spring of 1977, Mike Chanowitz, Mary K. and I wrote a paper on GUTs [Grand Unified Theories] predicting the *b* quark mass before it was found. When it was found a few weeks later, Mary K., Dimitri, Serge Rudaz and I immediately started working on its phenomenology.

That summer, there was a student at CERN, Melissa Franklin, who is now an experimentalist at Harvard. One evening, she, I, and Serge went to a pub, and she and I started a game of darts. We made a bet that if I lost I had to put the word penguin into my next paper. She actually left the darts game before the end, and was replaced by Serge, who beat me. Nevertheless, I felt obligated to carry out the conditions of the bet.

For some time, it was not clear to me how to get the word into this *b* quark paper that we were writing at the time…. Later…I had a sudden flash that the famous diagrams look like penguins. So we put the name into our paper, and the rest, as they say, is history."

John Ellis in Mikhail Shifman's "ITEP Lectures in Particle Physics and Field Theory", *hep-ph/9510397*

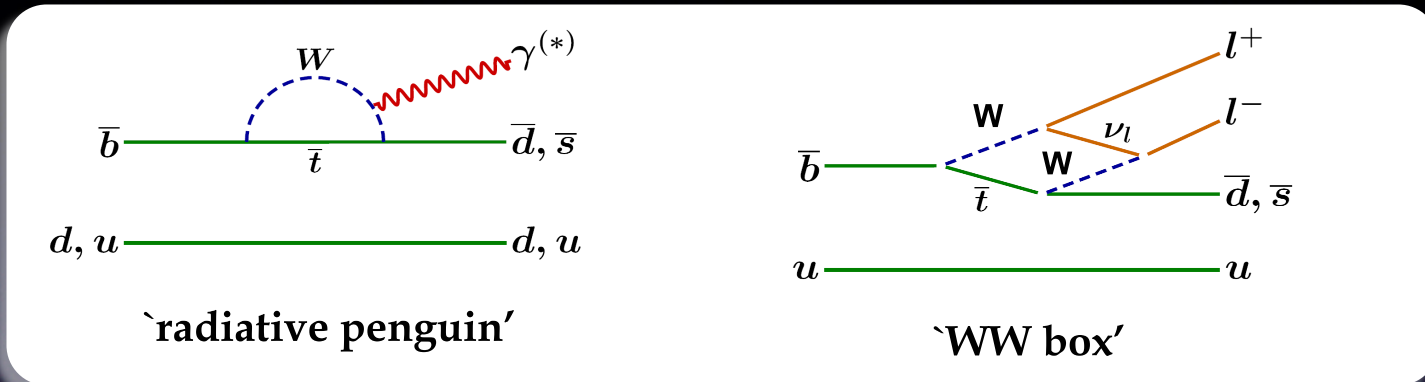


γ, Z: electroweak penguin [this talk]

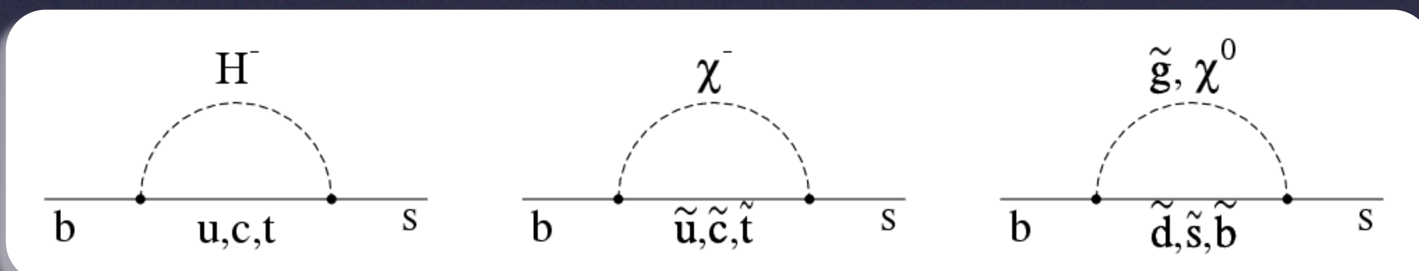
g: gluonic penguin [not today]

A Window to New Physics?

- $b \to s,d$ transitions with high-energy photon or lepton pair in the final state



- FCNC, forbidden at tree level: rare + sensitive to new physics at leading order



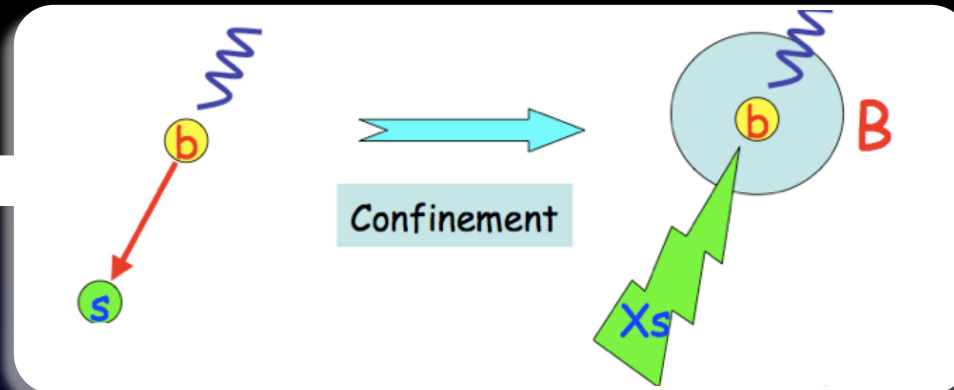
→ **low-energy access to the TeV scale!**

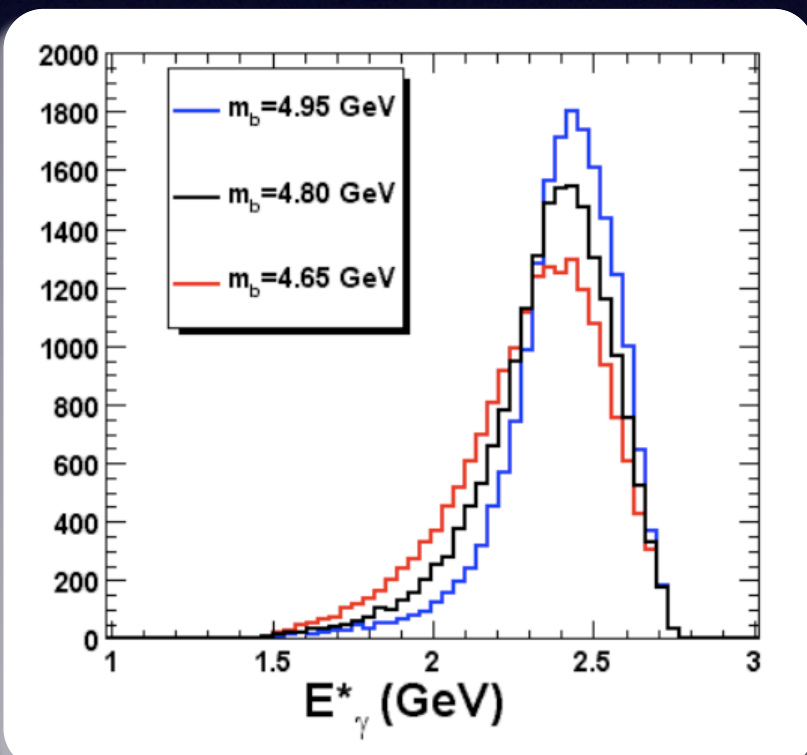
- relatively clean (only one hadronic current)

A Window Into The B Meson

quark level:

- two-body decay
- mono-energetic photon





hadron level:

- E_γ spectrum sensitive to internal B dynamics
- can extract HQE parameters, e.g.
  - quark mass: $m_b \sim E_\gamma/2$
  - Fermi motion: $\mu_\pi^2 \sim \langle E_\gamma^2 - \langle E_\gamma \rangle^2 \rangle$
- universal to (inclusive) B decays

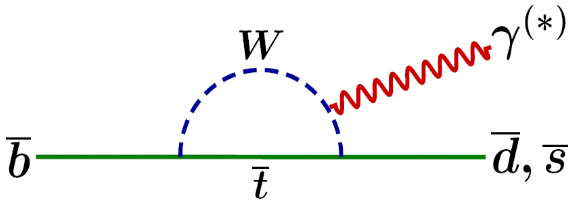
Operator Product Expansion

Local Operator: effective Lagrangian

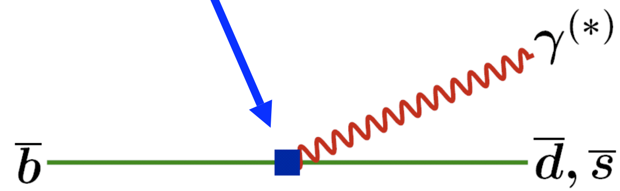
Heavy Quark Expansion in Λ / m_b

CKM

e.g.



$= \quad V_{tb} V_{td}^{*} \; \mathrm{x} \; C_7(m_b) \; \mathrm{x}$



Wilson coefficient(s):
short-distance physics;
calculated pertubatively

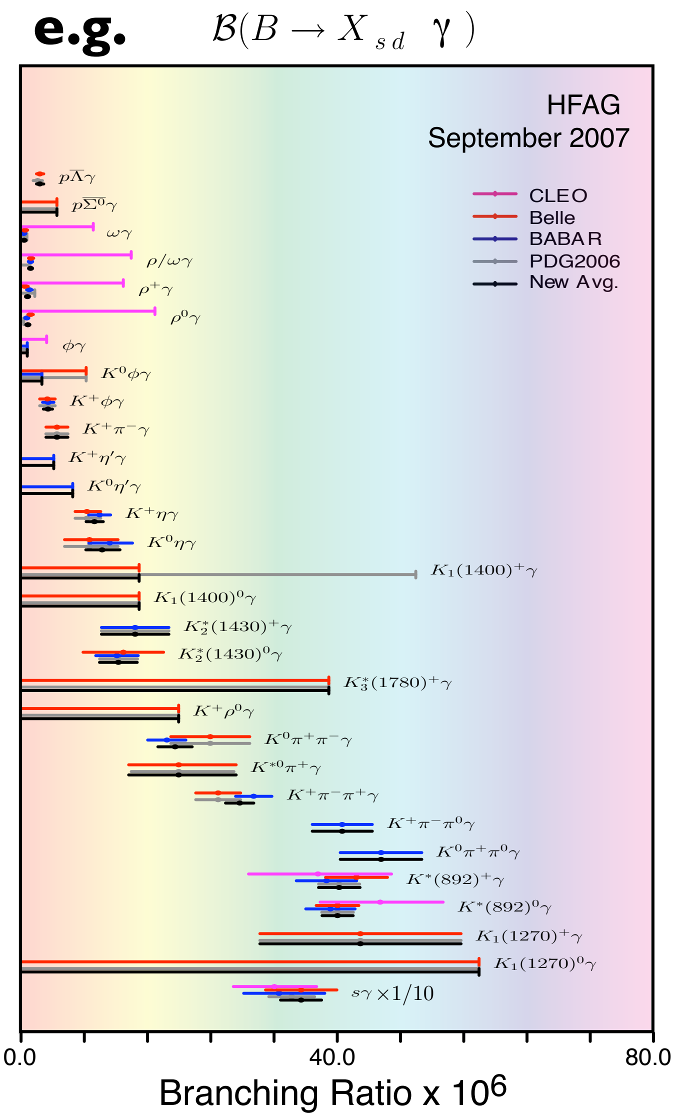
New Physics enters here

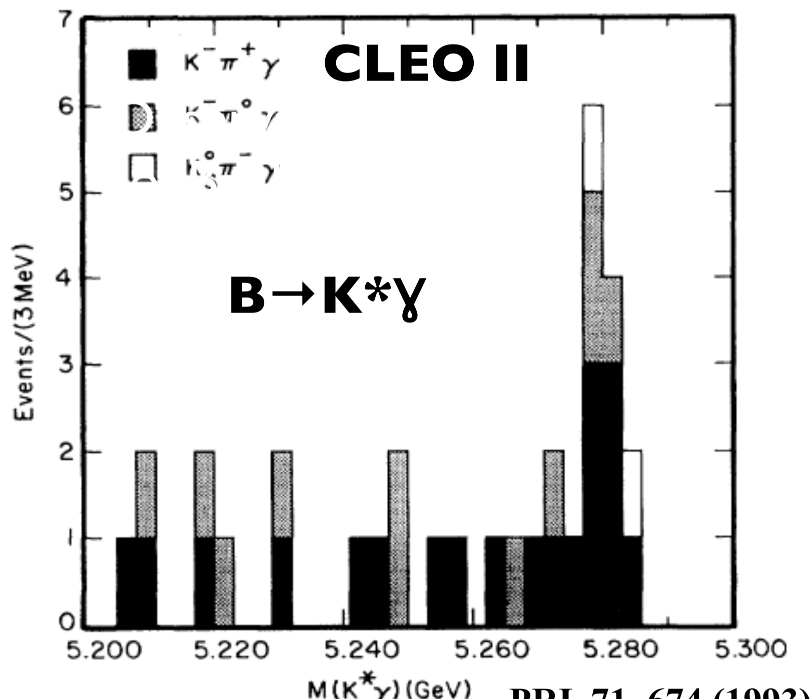
- modification of SM coefficients: $C_j = C_j^{SM} + \epsilon_j e^{i\theta_j}$
- addition of non-SM operators

PENGUINS – THEN AND NOW

2007

e.g. $\mathcal{B}(B \to X_{sd}\,\gamma)$





PRL 71, 674 (1993)

1993

Experimental Approaches

“experimentally clean”

fully inclusive
consider only photon spectrum
(use minimal opposite-side ‘tag’)

semi-inclusive
measure sum of exclusive final states

exclusive
measure specific decay mode(s)

“theoretically clean”

Observables

- Branching fractions
- CP asymmetry:

$$A_{CP} = \frac{\mathcal{B}(B \to X_{s,d}\,\gamma) - \mathcal{B}(\bar{B} \to X_{s,d}\,\gamma)}{\mathcal{B}(B \to X_{s,d}\,\gamma) + \mathcal{B}(\bar{B} \to X_{s,d}\,\gamma)}$$

- Isospin asymmetry:

$$\Delta_{0-} = \frac{\Gamma(\bar{B}^0 \to X_{s,d}\,\gamma) - \Gamma(B^- \to X_{s,d}\,\gamma)}{\Gamma(\bar{B}^0 \to X_{s,d}\,\gamma) + \Gamma(B^- \to X_{s,d}\,\gamma)}$$

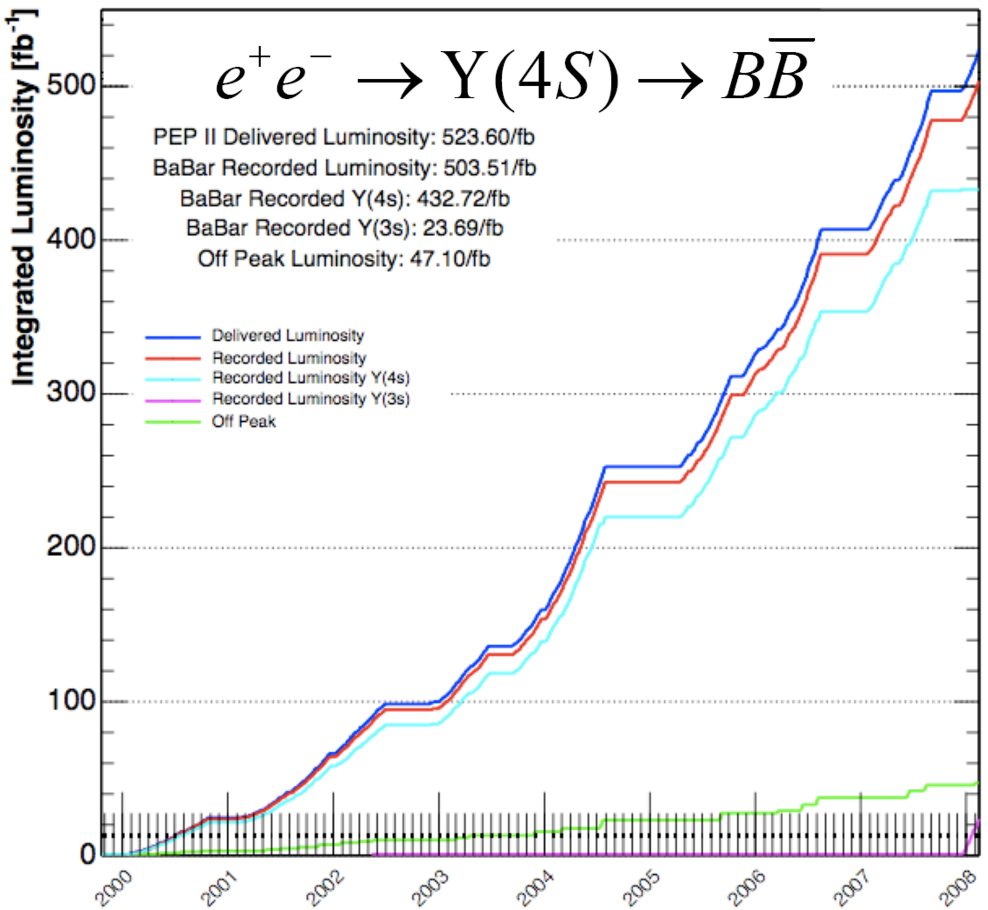
- Photon energy spectrum, q^2 ($|q|=m_{ll}$) spectrum
- Angular distributions (for di-lepton final states)
- ...

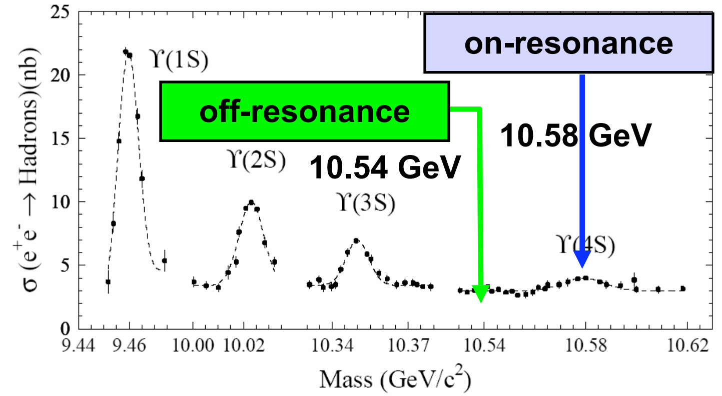
Selection For This Talk

- Inclusive $b \rightarrow s\gamma$ ('B tag'): BF, E_γ, A_{CP}, Δ_{0-} (384 million BB pairs); new BaBar publication [arXiv:0711.4889, to appear in PRD]
- Semi-inclusive $b \rightarrow s\gamma$: A_{CP} (383M BB); **new** BaBar **result** [preliminary, to be submitted to PRL]
- Exclusive $b \rightarrow d\gamma$: $B \rightarrow \rho/\omega\gamma$ BF, |Vtd/Vts|;
  - recent Belle results [preliminary, see LP07] (657M BB);
  - early-'07 BaBar publication [PRL 98,151802 (2007)] (347M BB)
- Semi-inclusive $b \rightarrow d\gamma$: (partial) BF (383M BB); recent BaBar result [preliminary, arXiv:0708.1652]
- Exclusive $b \rightarrow sl^+l^-$: angular analysis of $B \rightarrow K^*l^+l^-$;
  - **new** BaBar **result** [preliminary, to be submitted to PRL] (384M BB)
  - 2006 Belle publication [PRL 96, 251801 (2006)] (386M BB)

Need/Have Millions of B Mesons

NB: rare decays (BF of 10^{-4}-10^{-7})!

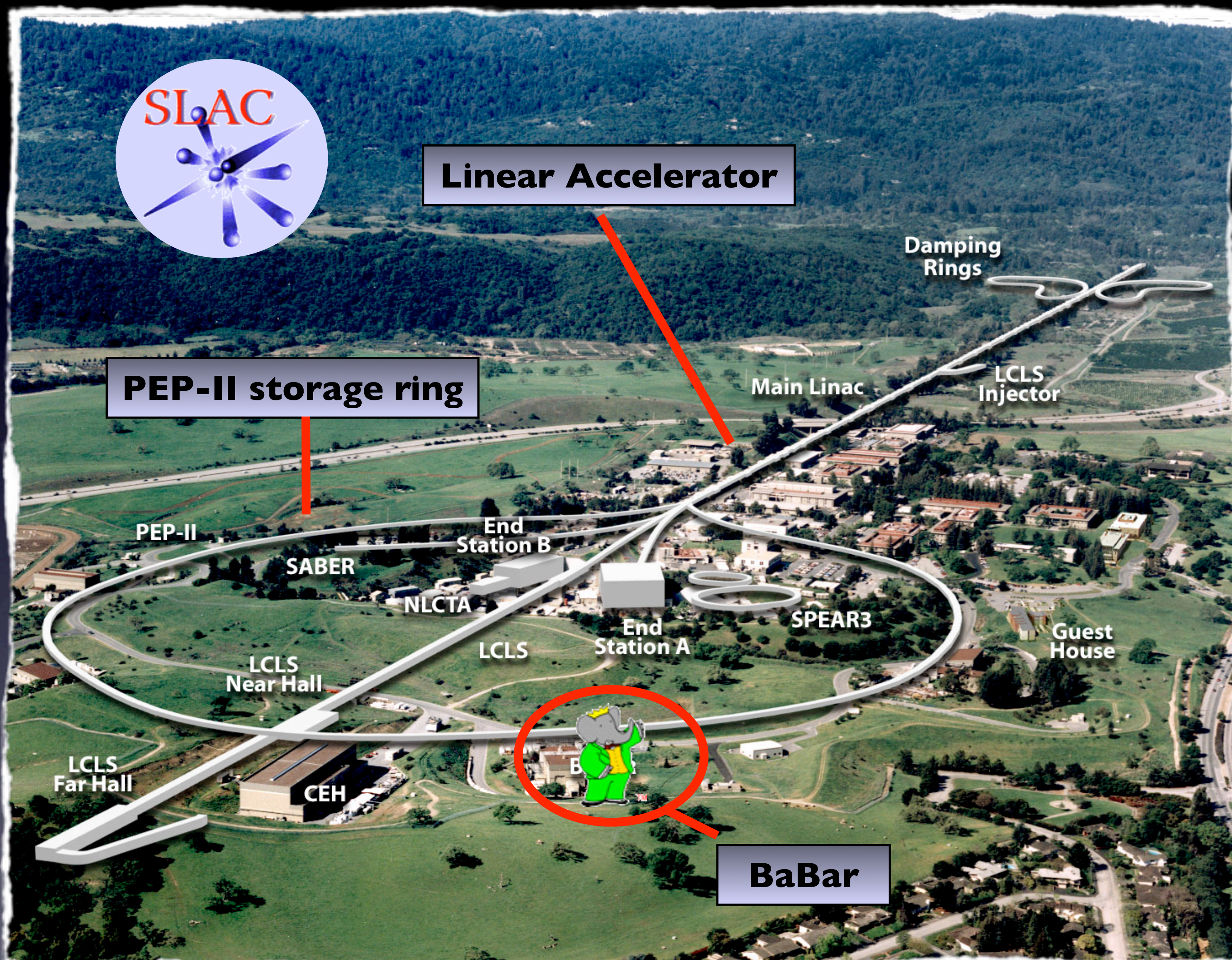




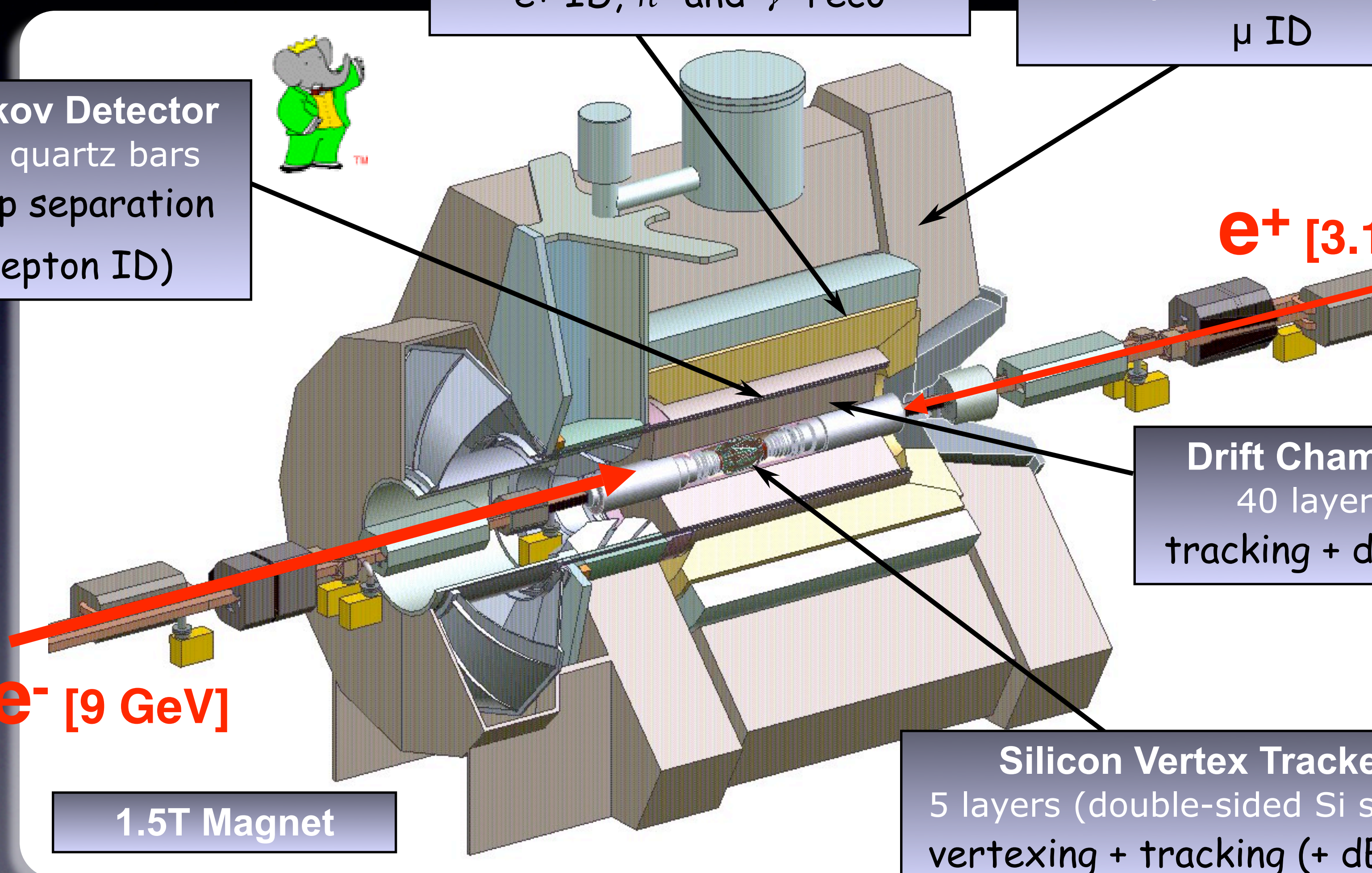
[~10% of data taken below the ϒ(4S)]

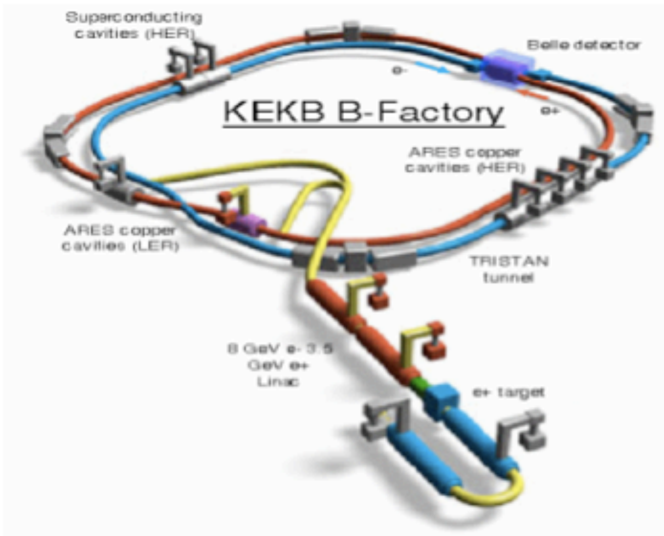
- ~430/fb →~480 million $B\bar{B}$
- most current results use ~380 million $B\bar{B}$
- now running on Y(3S) and Y(2S) to search for new low-mass particles

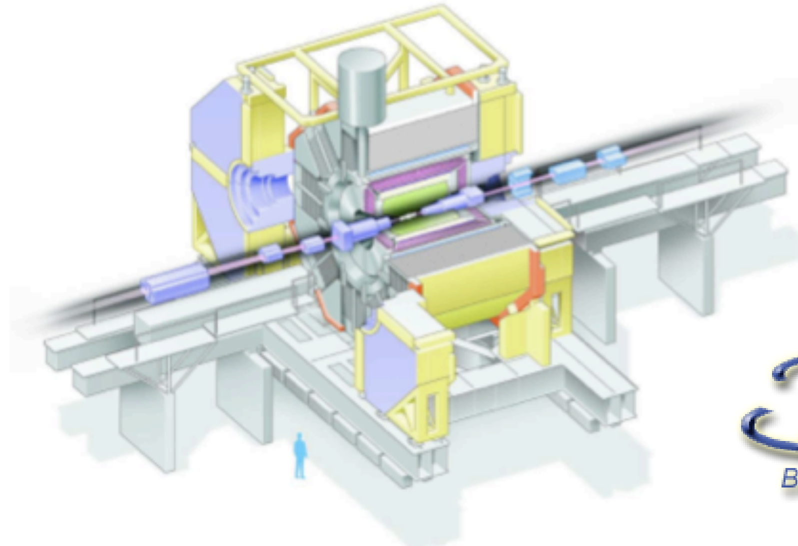
PEP-II and BaBar at SLAC



The BaBar Detector







- 3.5 GeV $e^+ \times$ 8.0 GeV e^-.
- $\mathcal{L}_{\text{max}} = 1.71 \times 10^{34} cm^{-2} s^{-1}$
- Continuous injection $\rightarrow >$ 1.2 fb^{-1}/day.
- $\int \mathcal{L} dt >$ 750 fb^{-1}

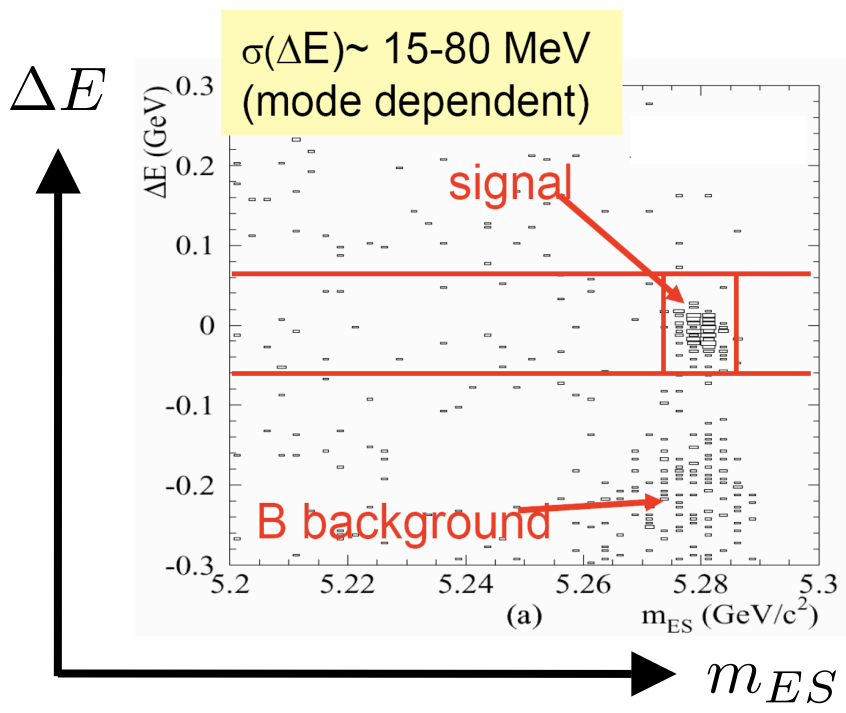
- Sil.VD: 3(4) layers DSSD
- CDC : small cells $He + C_2H_6$
- TOF counters.
- Aerogel CC:$n = 1.015 \sim 1.030$
- CsI(Tl) 16 X_0
- SC solenoid 1.5 T
- μK_L *detection* 14-15 layers RPC+Fe

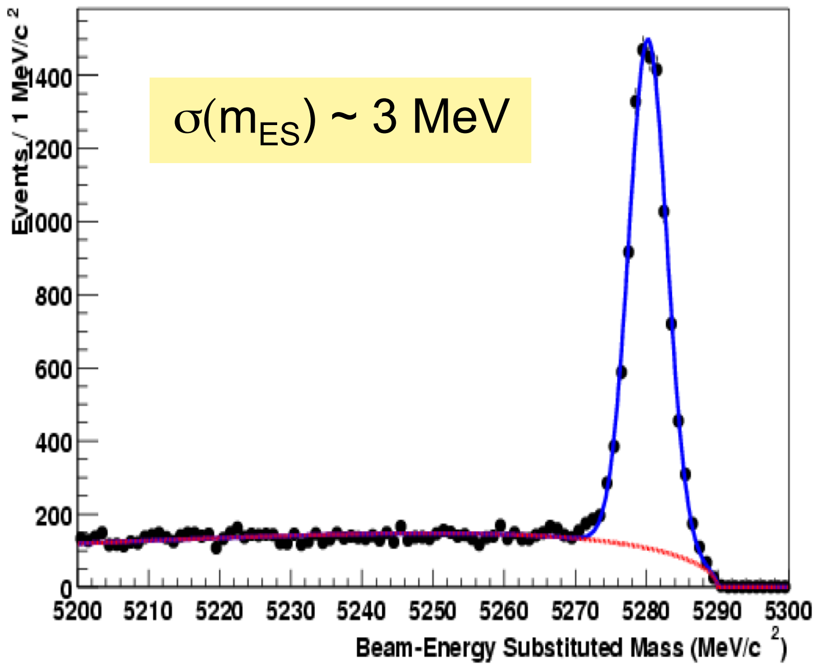
...and Tevatron!

B Meson Reconstruction

- e+e- collider: have precise knowledge of beam energy
- B selection via an energy difference and effective mass

$$\Delta E = E_B - E^*_{beam} \qquad m_{ES} = \sqrt{(E^*_{beam})^2 - P_B^2}$$

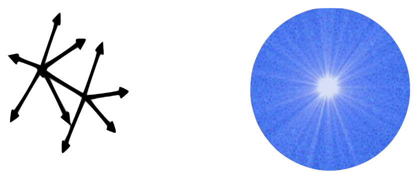




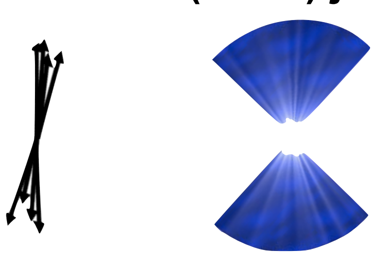
Continuum Suppression

- huge backgrounds, in particular from $e^+e^- \rightarrow q\bar{q}$ 'continuum' events (q=u,d,s)
- suppress using, e.g., event shape information

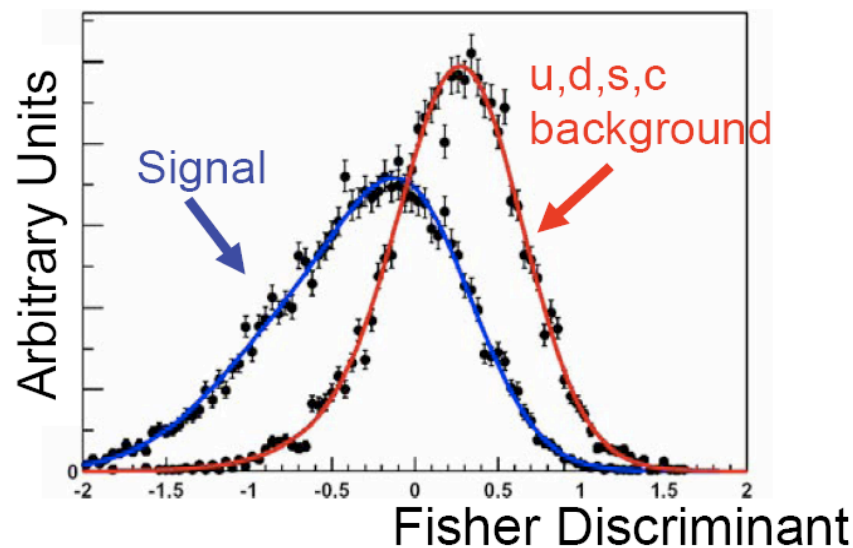
B decays: (more) isotropic



Continuum: (more) jet-like



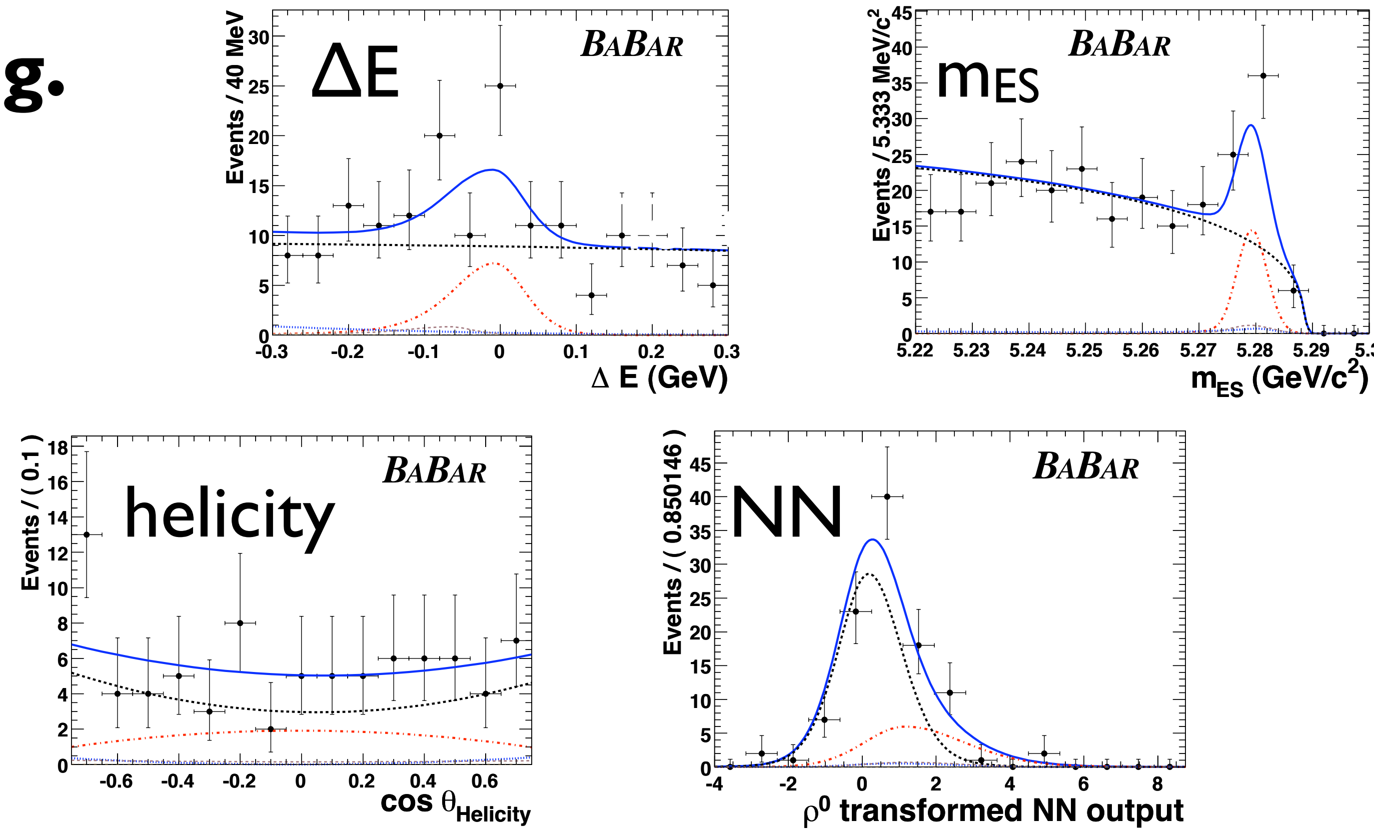
Combine various variables (in a Fisher Discriminant , Neural Network, Decision Tree, …) and use for cuts and/or fitting:



Signal Extraction

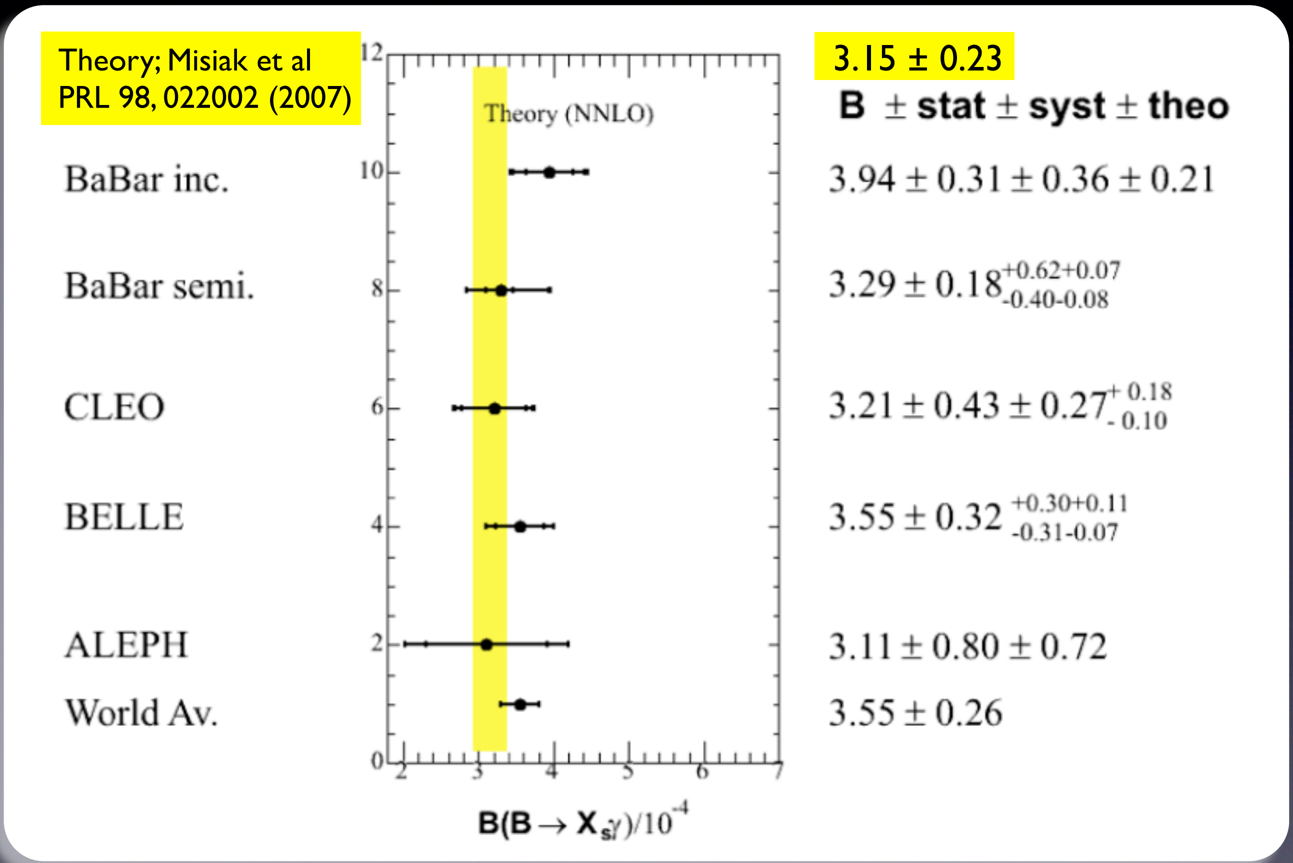
- ‘blind’ analysis: optimize procedure w/o looking at signal region
- validate analysis using control samples from real data
- perform multi-dimensional likelihood fits (or subtract background and count signal events)

e.g.



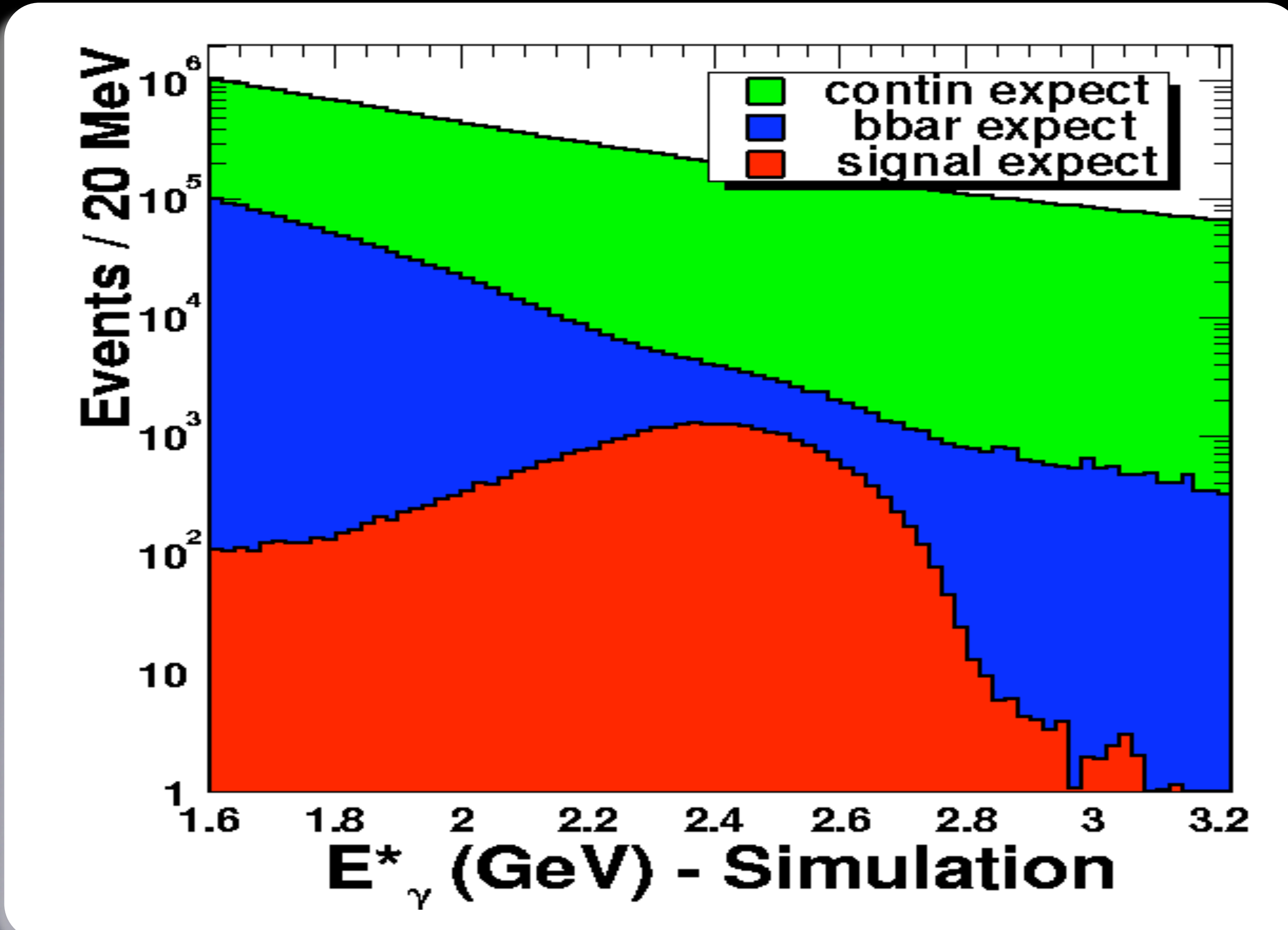
(Semi-)Inclusive $b \to s\gamma$: BF

Status of branching fraction measurements
(note theory breakthrough in 2006; can now compare to NNLO!):



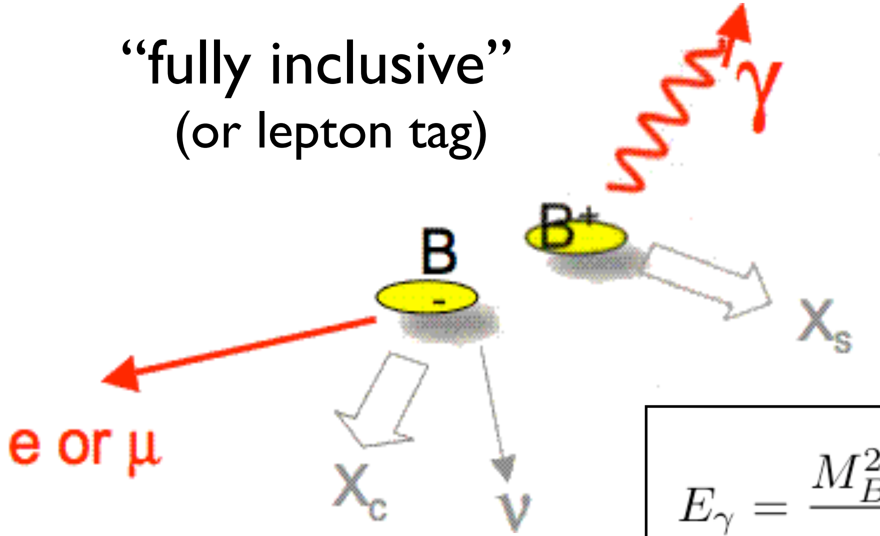
Measured BF are extrapolated down to $E^*_\gamma < 1.6$ GeV
(based on HQE fits to $b \to cl\nu$ and $b \to s\gamma$ moments)

Inclusive $b \to s\gamma$: The Challenge

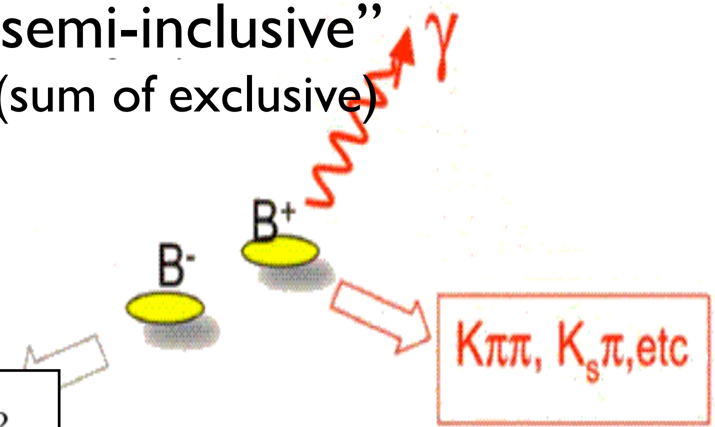


Incl. b → Sγ: Previous Methods

"fully inclusive"
(or lepton tag)



"semi-inclusive"
(sum of exclusive)



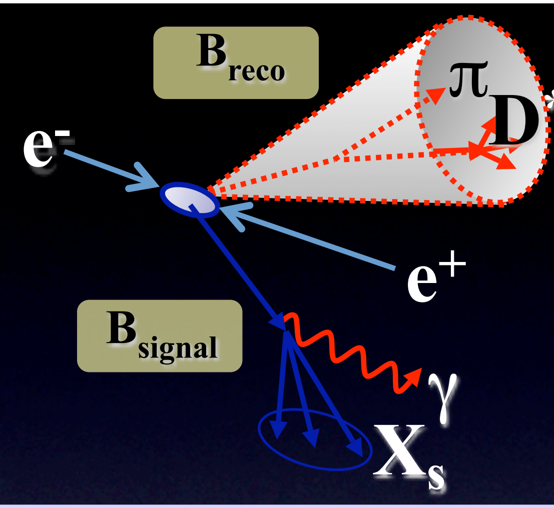
$$E_\gamma = \frac{M_B^2 - M(X_s)^2}{2M_B}.$$

- Measure only the γ (and tag lepton)
- Pros
  - no X_s fragmentation sensitivity
  - theoretically clean
- Cons
  - high background, no B constraint!
  - measure E_γ* in $\Upsilon(4s)$ frame

- Fully reconstruct X_s final states
- Pros
  - lower background
  - good E_γ resolution in B-frame
- Cons
  - missing X_s decay modes
  - X_s fragmentation systematic

Incl. $b \to s\gamma$: New Approach

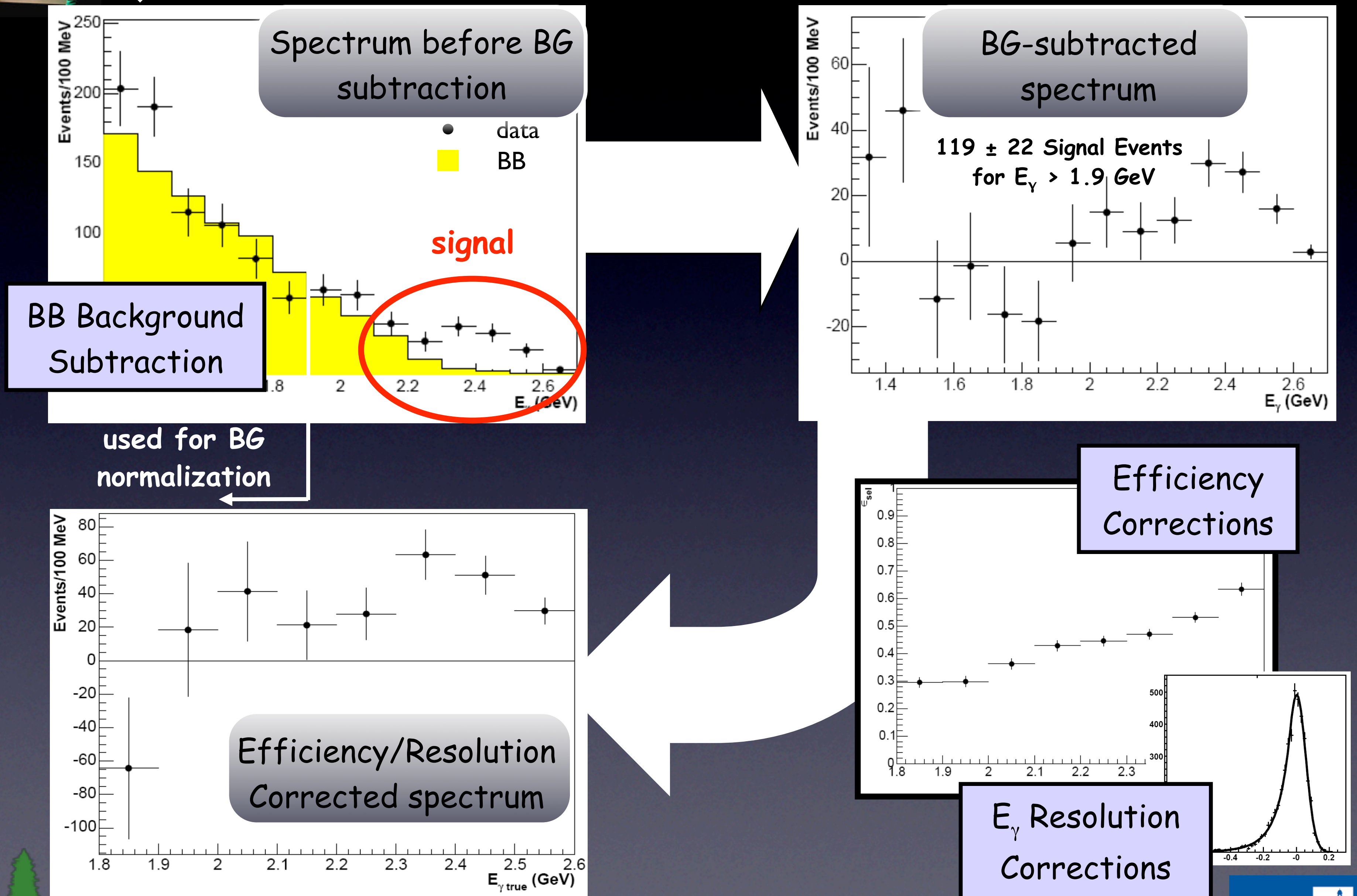
- Measure high-energy γ recoiling against a fully reconstructed hadronic B decay
- Photon energy spectrum is extracted from fits to m_{ES} in bins of E_γ



- Through full reconstruction of B_{reco} [and Υ(4S) momentum], flavor, charge and four-momentum of signal B are known
  - can measure photon energy in the B rest frame and CP asymmetry
- Fits to m_{ES} provide information on
  - total number of BB pairs → BF normalization
  - non-peaking background → continuum subtraction
- Independent of lepton-tagged sample used in previous analysis

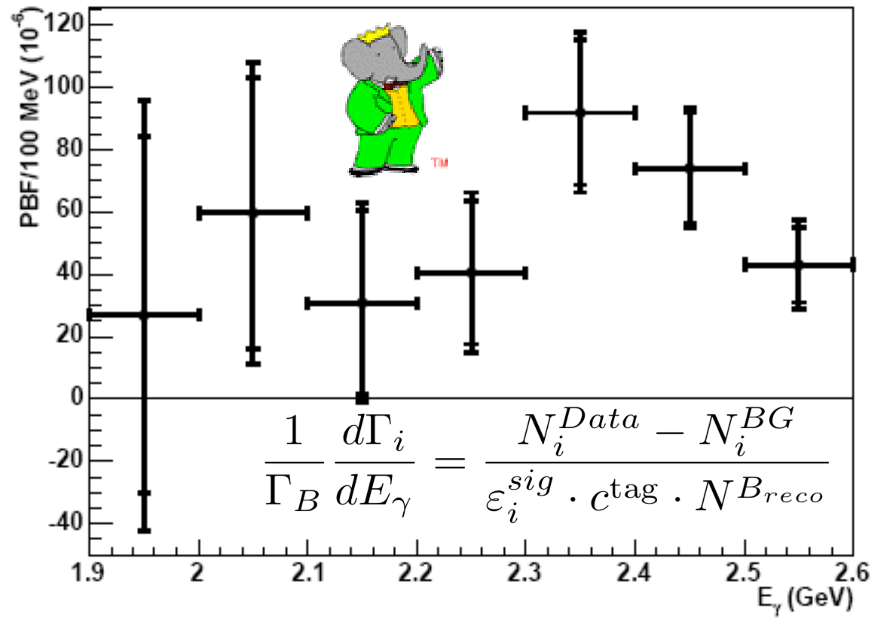
- **Downside:** small efficiency of B_{reco} tag (about 0.3%)

Inclusive $b \to s\gamma$: E_γ Spectrum



Incl. b→sγ: Branching Fraction

- Include systematics
- Normalize to entire tag sample



Integrate

BF(b→sγ) [E_γ > 1.9 GeV] = (3.66 ± 0.85 ± 0.60) x 10^{-4} ← measured

Extrapolate (using hep-ph/0507253)

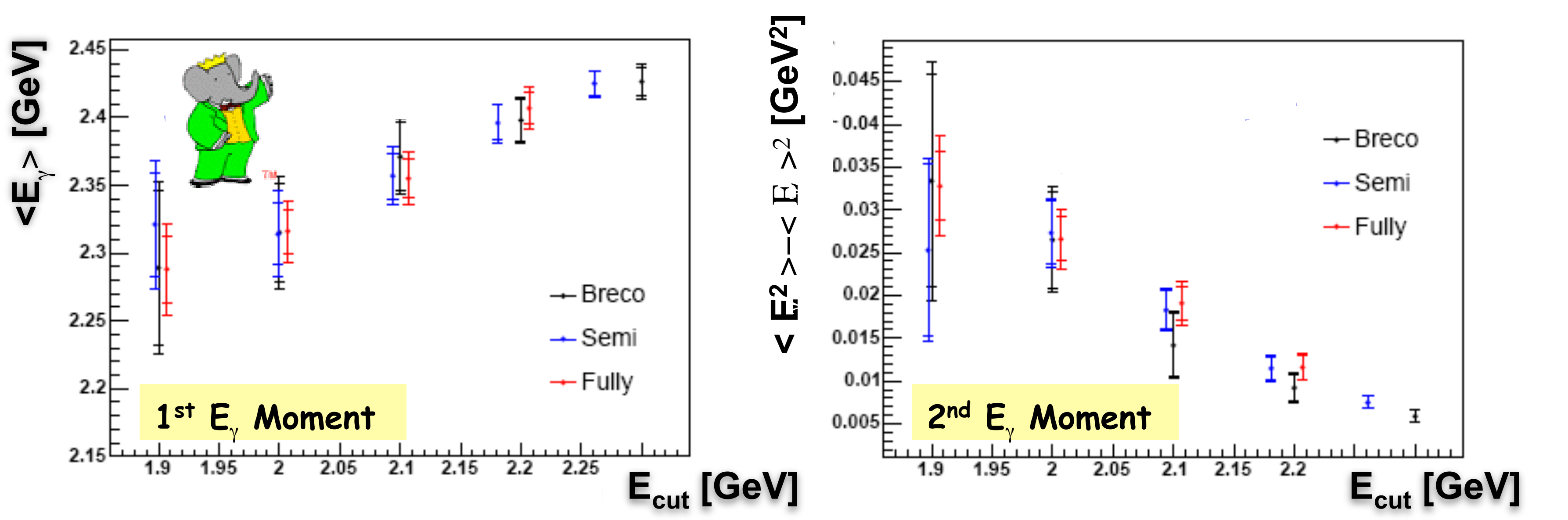
extrapolated

BF(b→sγ) [E_γ > 1.6 GeV] = (3.91 ± 0.91 ± 0.64) x 10^{-4}

[World average: (3.55 ± 0.26)x 10^{-4}]

Incl. $b \to s\gamma$: HQE Parameters

- Measure **photon energy moments** as a function of minimum E_γ
- Good agreement with previous results based on different methods and largely independent data samples



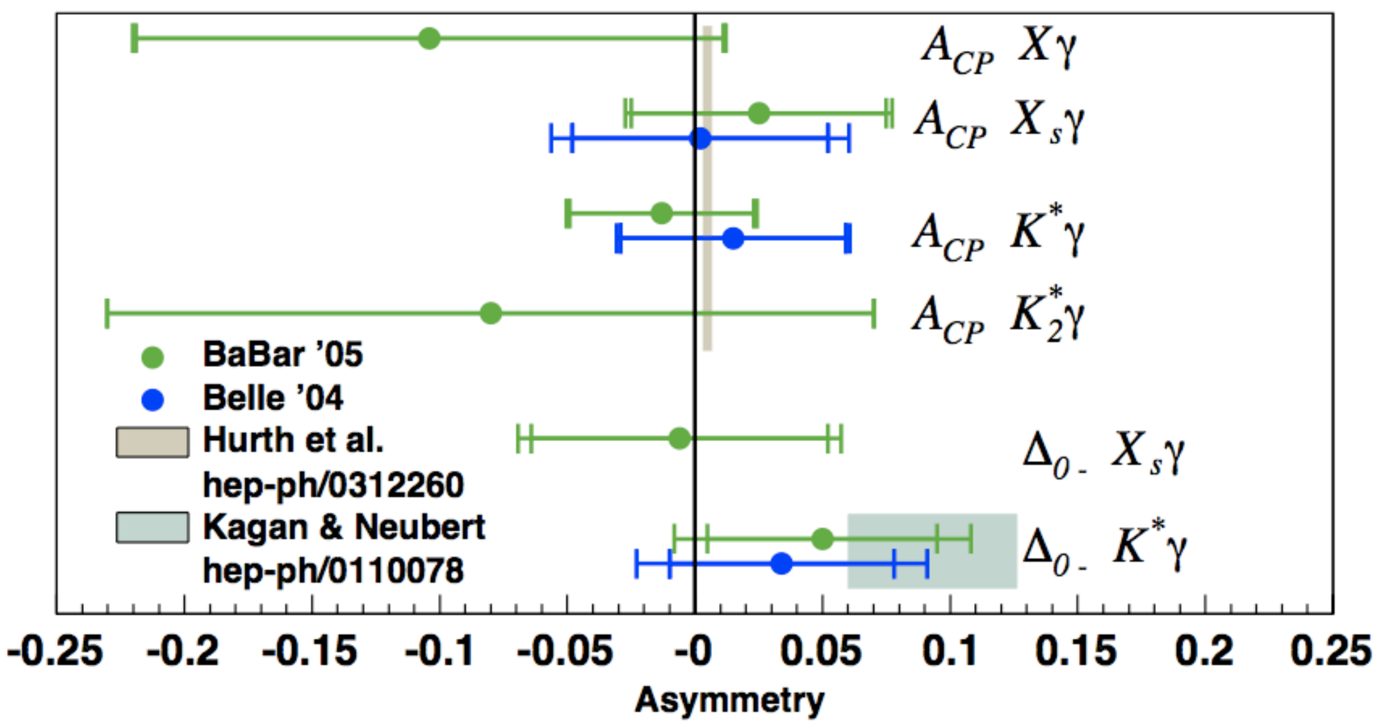
- **Extraction of HQE parameters:**

$m_b = 4.46^{+0.21}_{-0.23}\,\text{GeV};\ \mu_\pi^2 = 0.64^{+0.39}_{-0.38}\,\text{GeV}^2$

- **Also measure...**

$b \to s\gamma$: Asymmetries

- Isospin: $\Delta_{0-} = -0.06 \pm 0.15 \pm 0.07$ (recoil analysis)
- CP: $A_{CP} = +0.10 \pm 0.18 \pm 0.05$



- could be enhanced by new physics, e.g. A_{CP} to about 15%

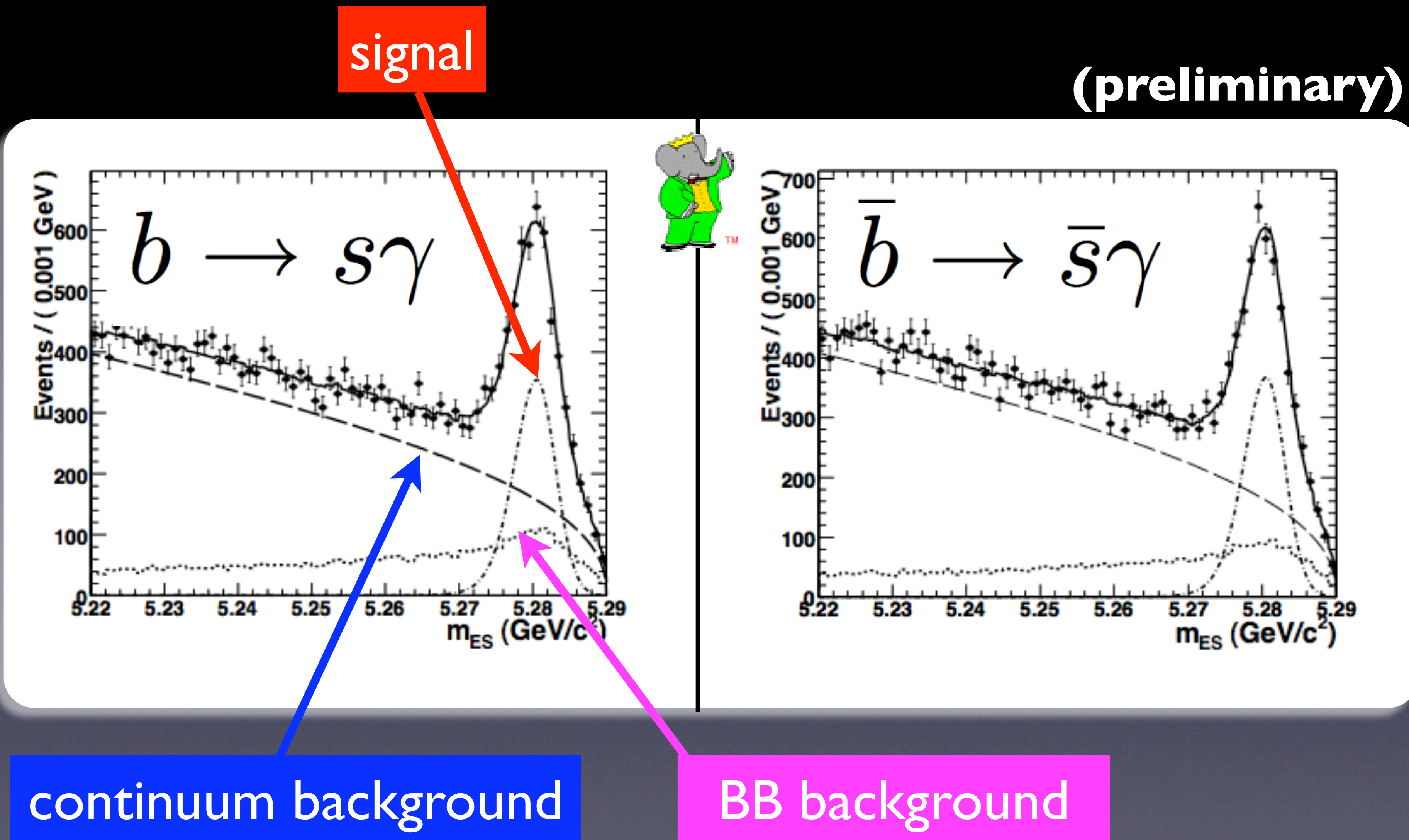
(T. Hurth, E. Lunghi hep-ph/0312260)

Semi-inclusive $b \rightarrow s\gamma$ (A_{CP})

- **New result** [preliminary; to be submitted to PRL]
- based on 383 million *BB* pairs
  [previous analysis: 83 million]
- reconstruct 16 exclusive, flavor ‘self-tagging’ final states
  [previous analysis: 13]
- $|\Delta E|<0.1\,GeV$
- select hadronic mass range $0.6< M(X_s)<2.8$ GeV;
  correponding to $E_\gamma > 1.9$ GeV

Semi-inclusive $b \to s\gamma$: Signals

(preliminary)



Semi-incl. $b \to s\gamma$: Systematics

$$A_{CP}^{true} = \left(A_{CP}^{measured} - \frac{\Delta D}{2}\right)\frac{1}{\langle D \rangle} - A_{CP}^{Detector}$$

signal+background shape modeling

differences in π^+ and π^- mistagging rates

detector reconstruction (charge asymmetry)

$\Delta D = \varpi - \omega$

$\langle D \rangle = 1 - \frac{(\varpi + \omega)}{2}$

MisID rate

$\omega : \pi^+ -> K^+$

$\varpi : \pi^- -> K^-$

Semi-incl. b → Sγ : Result

$$A_{CP}(b \to s\gamma) = -0.019 \pm 0.030 \pm 0.019$$

(preliminary) *stat.* *syst..*

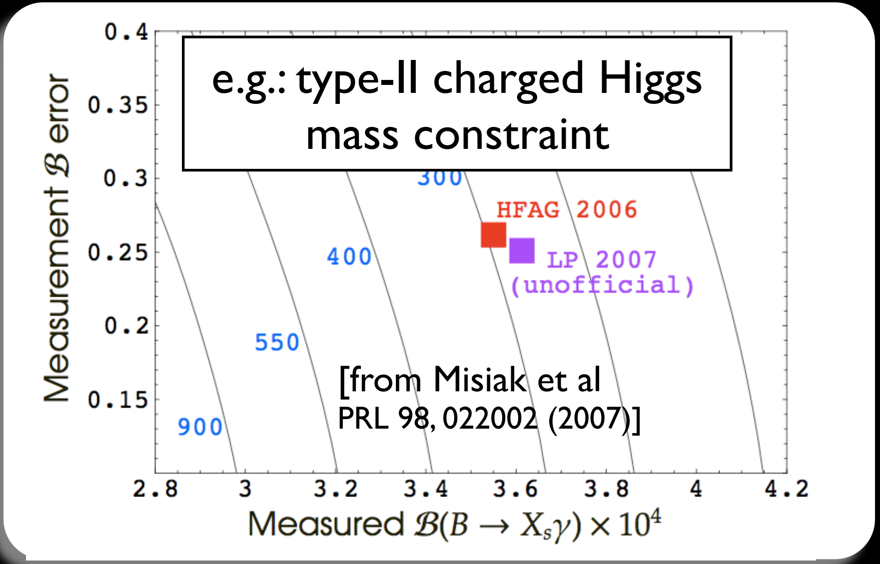
- previous results:

Experiment/Method	A_{CP}
CLEO/Inclusive (10M $B\overline{B}$)	$-0.079 \pm 0.108 \pm 0.022$
Belle/Pseudoreconstruction (140M $B\overline{B}$)	$0.002 \pm 0.050 \pm 0.030$
BaBar/Inclusive (89M $B\overline{B}$)	$-0.110 \pm 0.115 \pm 0.017$
BaBar/Semi (89M $B\overline{B}$)	$0.025 \pm 0.050 \pm 0.015$

- consistent with zero, uncertainties almost cut in half; **most precise measurement to date**

$b \to s\gamma$: Summary/Outlook

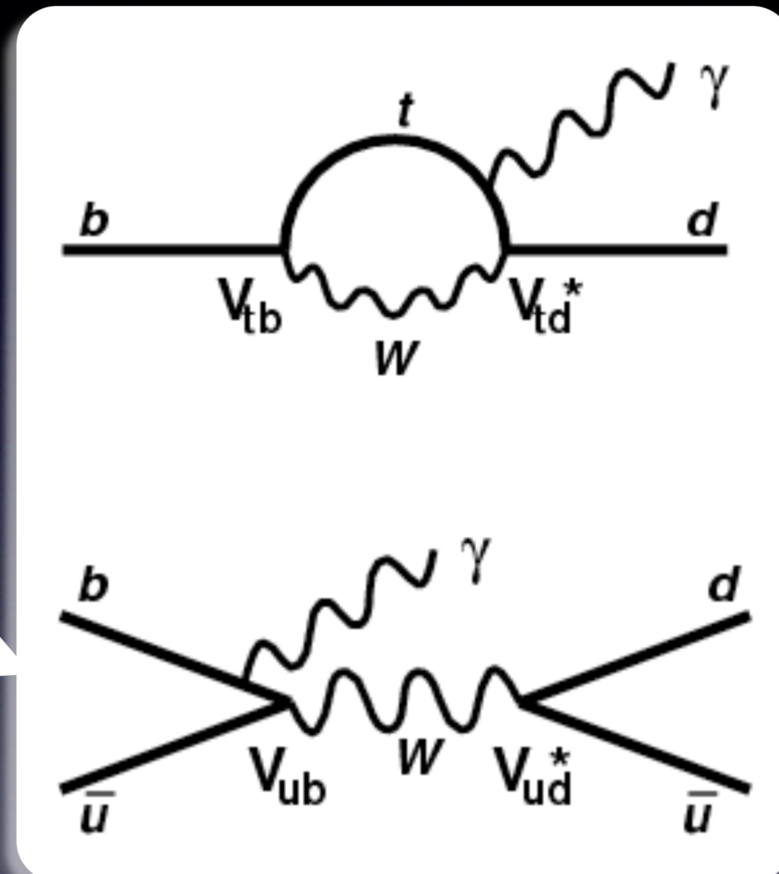
- one of *the* core B factory measurements; highly relevant within **and** outside 'B physics'
- a lot of recent activity (both experiment and theory); more to come soon
- no hint of new physics yet; agreement with SM poses severe constraints on BSM models
- essential to use (and eventually combine) all available methods and data to get best precision possible
- no way of knowing what's 'good enough'



Exclusive $b \to d\gamma$

i.e. $B \to (\rho^{\pm,0},\omega)\gamma$

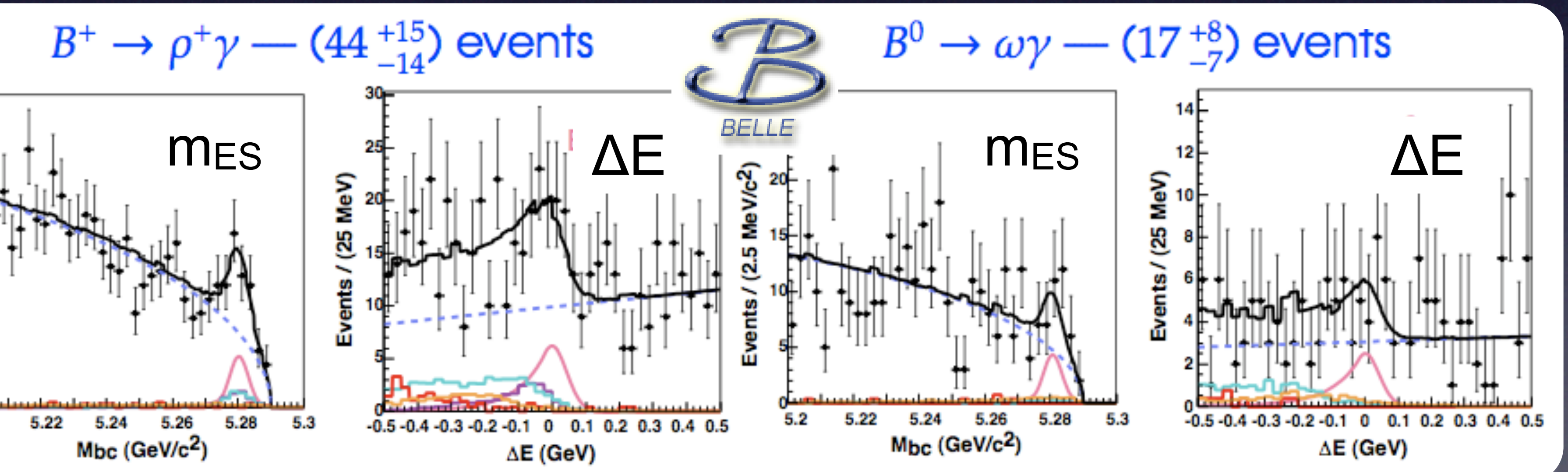
- SM **BF suppressed** by $|V_{td}/V_{ts}|^2 \sim 0.04$ w.r.t. $b \to s\gamma$
  - higher **NP sensitivity**
  - experimentally very **tough**!
- second sizable SM diagram
  - expect significant (~10%) SM A_{CP}
- **BF constrains $|V_{td}/V_{ts}|$** in SM **(similar to $\Delta m_d/\Delta m_s$)**



B → (ρ,ω)γ : Data Analysis

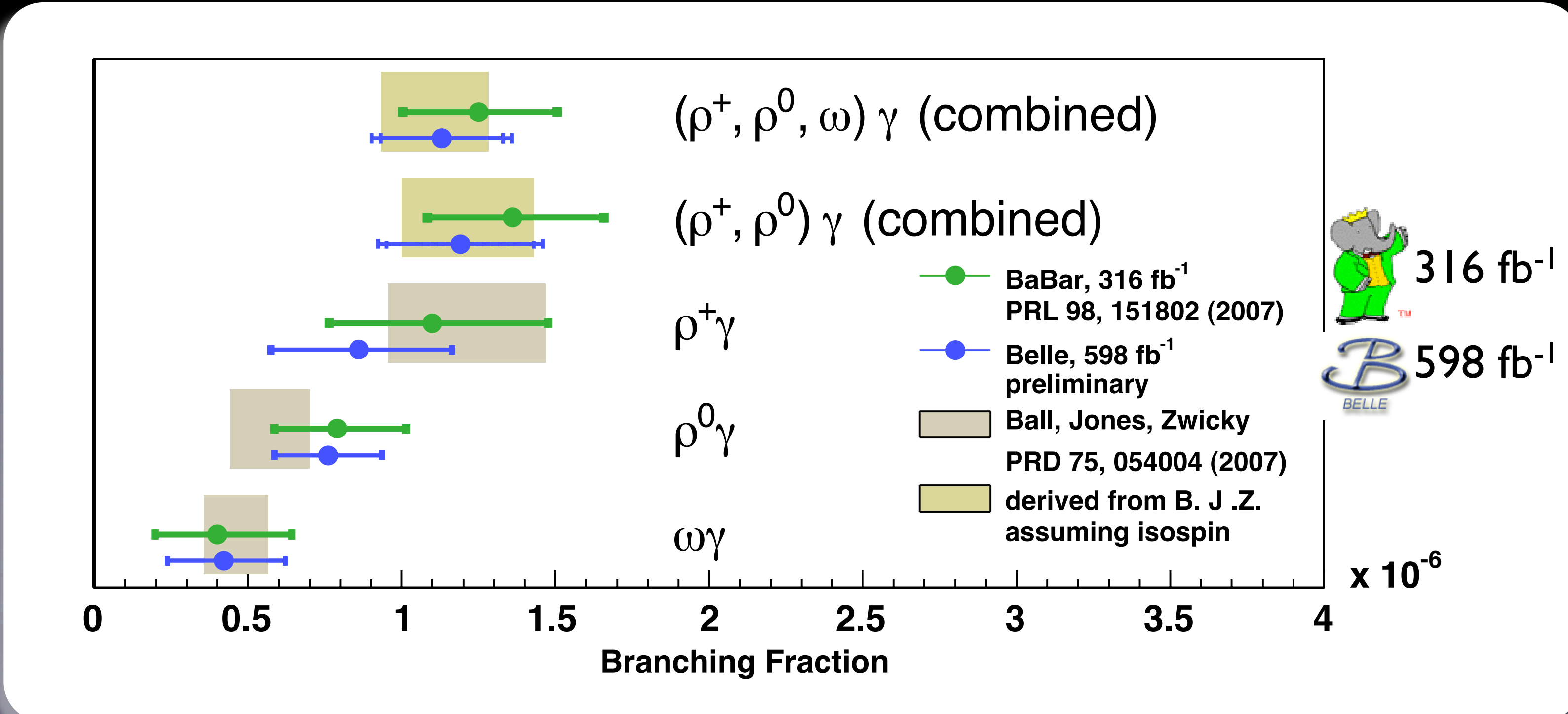
- **reconstruct** $\rho^{+/0} \rightarrow \pi^+\pi^{0/-}$, $\omega \rightarrow \pi^+\pi^-\pi^0$
- **background suppression**/discrimination is key:
  - continuum [Neural Net with event shape, 'B tagging' information, …]
  - $B \rightarrow K^*\gamma$ [particle ID]
  - $B \rightarrow (\rho^{\pm,0},\omega)(\pi^0,\eta)$ [veto and helicity angle]
- **perform** likelihood **fits**; Belle: 2D, BaBar 4/5D
  - m_{ES}, ΔE [+NN output, decay angles]

e.g.



(preliminary)

$B \rightarrow (\rho,\omega)\gamma$: BF Results



	Belle $\mathcal{B}$ (10^{-7})	Belle (Σ)	BaBar $\mathcal{B}$ (10^{-7})	BaBar (Σ)
$B^+ \rightarrow \rho^+\gamma$	$8.6\,^{+3.0}_{-2.8}\,^{+0.7}_{-0.8}$	(3.2σ)	$11.0\,^{+3.7}_{-3.3} \pm 0.9$	(3.8σ)
$B^0 \rightarrow \rho^0\gamma$	$7.6 \pm 1.7 \pm 0.6$	(4.9σ)	$7.9\,^{+2.2}_{-2.0} \pm 0.6$	(4.9σ)
$B^0 \rightarrow \omega\gamma$	$4.2\,^{+2.0}_{-1.8} \pm 0.4$	(2.6σ)	$4.0\,^{+2.4}_{-2.0} \pm 0.5$	(2.2σ)
$B \rightarrow \rho\gamma$	$11.9 \pm 2.4 \pm 1.2$	(5.5σ)	$13.6\,^{+2.9}_{-2.7} \pm 0.9$	(6.0σ)
$B \rightarrow (\rho,\omega)\gamma$	$11.3 \pm 2.0 \pm 1.1$	(5.9σ)	$12.5\,^{+2.5}_{-2.4} \pm 0.9$	(6.4σ)

B → (ρ,ω)γ : CKM Constraint

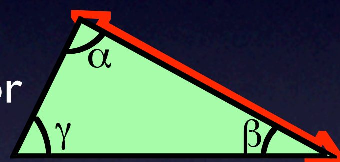
- together with $B \to K^*\gamma$, measures $|V_{td}/V_{ts}|$ within SM
- hadronic uncertainties partially cancel in ratio

see, e.g., Ali et al PLB 595, 323 (2004)

$$\frac{\mathcal{B}(B \to \rho/\omega\gamma)}{\mathcal{B}(B \to K^*\gamma)} = S_{\rho/\omega} \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m_{\rho/\omega}^2/m_B^2}{1 - m_{K^*}^2/m_B^2}\right)^3 \zeta^2 (1 + \Delta R)$$

well measured by B factories

isospin factor



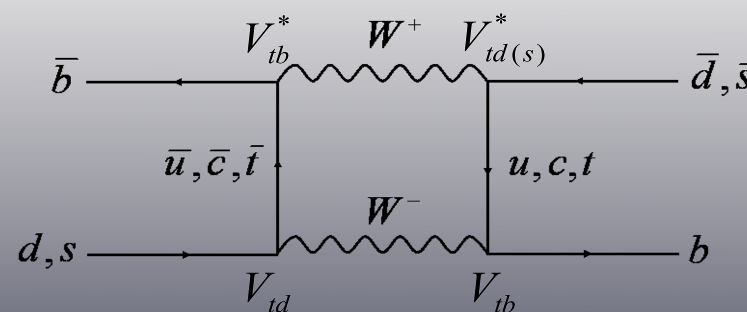
form factor ratio

accounts for decay dynamics differences

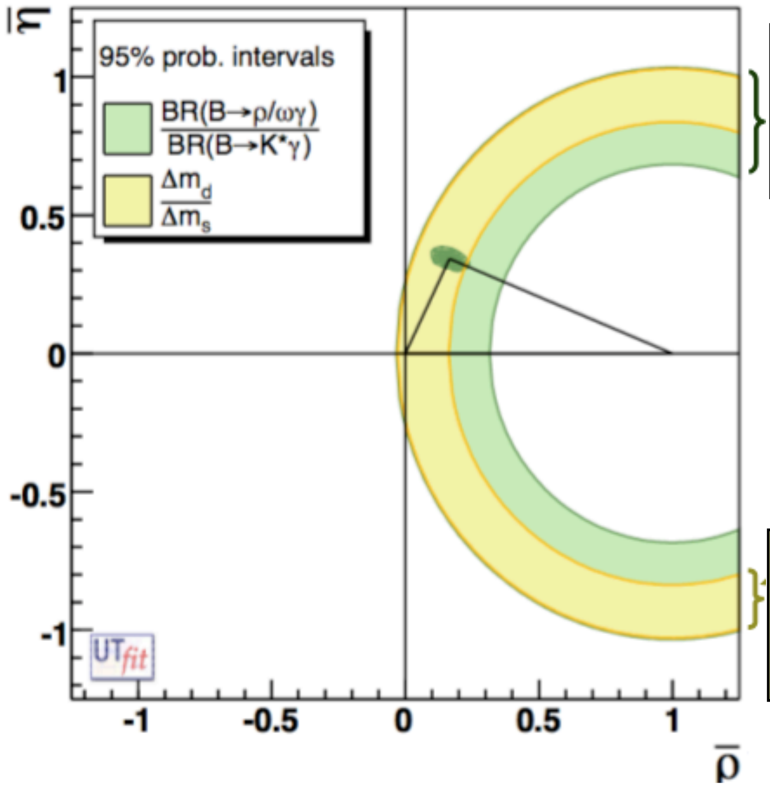
Compare with $|V_{td}/V_{ts}|$ from

B_s mixing (first observed in 2006)

$$\frac{\Delta m_d}{\Delta m_s} = \frac{1}{\xi^2} \frac{m_{B_s}}{m_{B_d}} \left|\frac{V_{td}}{V_{ts}}\right|^2$$

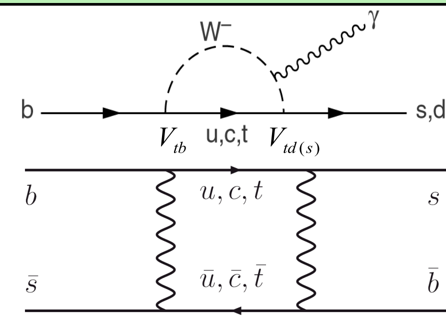


$B \rightarrow (\rho,\omega)\gamma$: CKM Result



$|V_{td}/V_{ts}|$ from $B \rightarrow \rho/\omega\gamma$

$0.202 \pm 0.017_{(exp)} \pm 0.015_{(theo)}$



$|V_{td}/V_{ts}|$ from B_s mixing

$0.2060 \pm 0.0007_{(exp)} \pm 0.008_{(theo)}$

PRL 97, 242003 (2006)

- independent physics providing same constraint within SM; new physics could enter two processes differently
- excellent agreement (within still sizable uncertainties)

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

$|V_{td}/V_{ts}|$ from $B \to \rho/\omega\gamma$

0.202±0.017 … 15*(theo)*

… $_{ts}|$ from B_s mixing

0.2060±0.0007*(exp)*±0.008*(theo)*

Where Do we Go From Here?

improve exclusive measurements and...

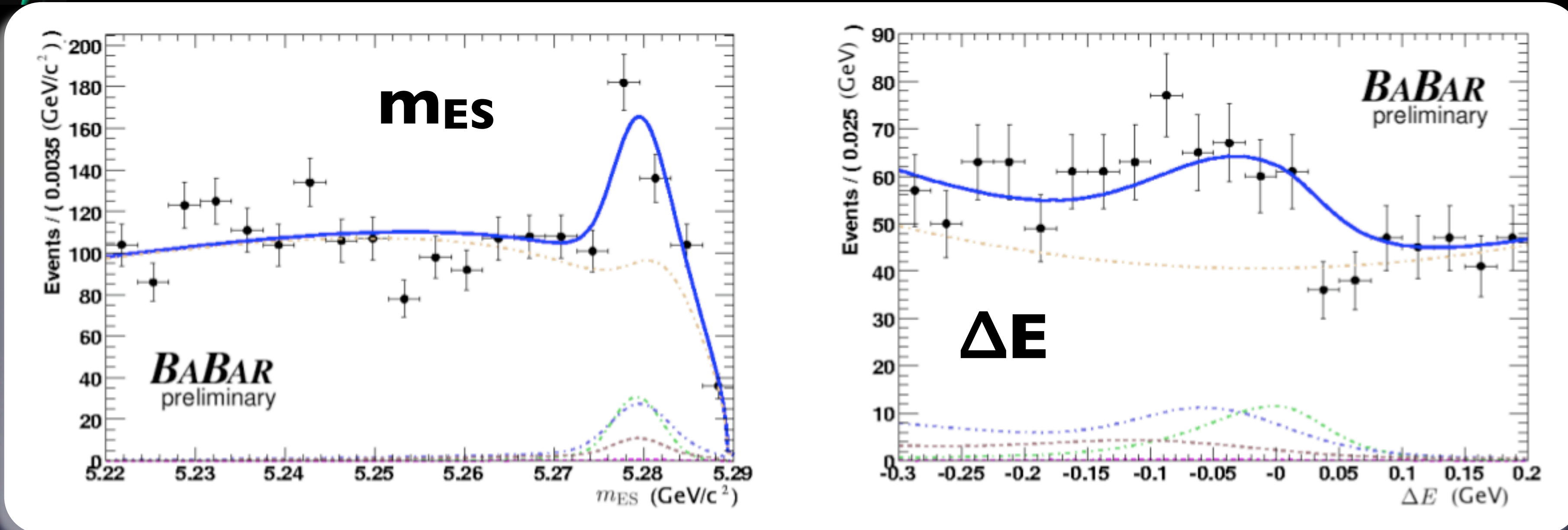
- indep… …ent physics providing same constraint within SM; new physics could enter two processes differently
- excellent agreement (within still sizable uncertainties)

SEMI-INCLUSIVE $B \to X_D \gamma$

- **LP07 result (preliminary)**
- based on **383 million BB pairs**
- reconstruct $B \to X_d \gamma$ in **seven exclusive decay modes** (acc. to MC, account for about 50% of decays in measured mass range)
- **two bins in** hadronic mass ***M(X_d)***:
  - [0.6..1.0] GeV: $B \to (\rho^{\pm,0},\omega)\gamma$ cross check (barely observed themselves!)
  - [1.0..1.8] GeV: analyis region

- $B^0 \to \pi^+\pi^-\gamma$
- $B^+ \to \pi^+\pi^0\gamma$
- $B^+ \to \pi^+\pi^-\pi^+\gamma$
- $B^0 \to \pi^+\pi^-\pi^0\gamma$
- $B^0 \to \pi^+\pi^-\pi^+\pi^-\gamma$
- $B^+ \to \pi^+\pi^-\pi^+\pi^0\gamma$
- $B^+ \to \pi^+\eta\gamma$

SEMI-INCL. B→$X_D\gamma$: VALIDATION



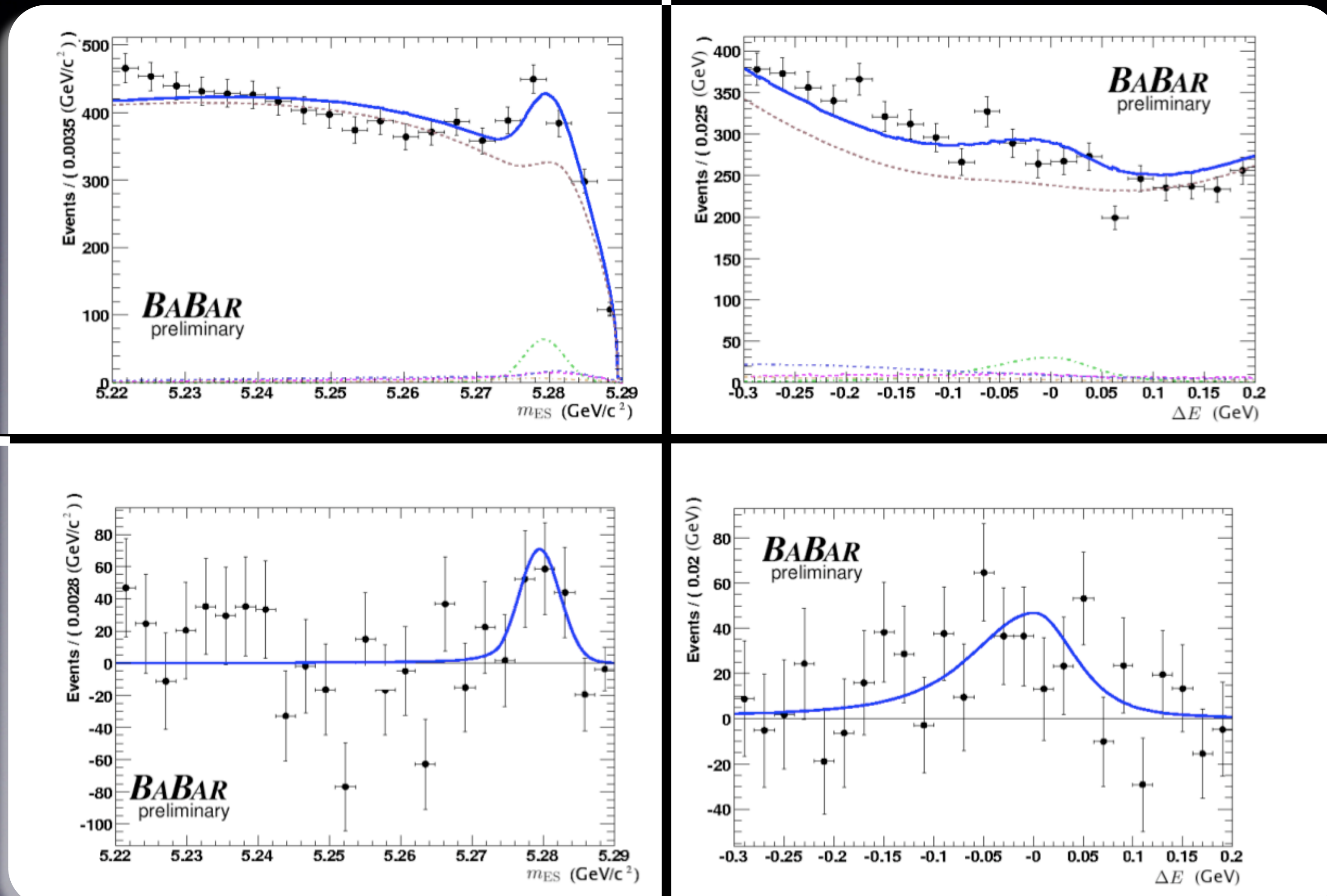
- to **validate procedure**, perform analysis in the mass range [0.6..1.0] GeV (dominated by ρ and ω resonances) and restrict to $\pi^+\pi^{-/0}\gamma$, and $\pi^+\pi^-\pi^0\gamma$ final states
- **expect 66±26 signal events** [from published B → $(\rho^{\pm,0},\omega)\gamma$ measurments]
- **find 73±25** (*stat.*) ✓

Semi-Incl. $B \to X_D \gamma$: Signal Fit

m_{ES} | ΔE

projection

background subtracted ('sPlot')



Semi-Incl. B→$X_D\gamma$: Result

$$\sum_{X_d=1}^{7} \mathcal{B}(B \to X_d\gamma)|_{1.0<M(X_d)<1.8GeV}$$
$$= [3.1 \pm 0.9(stat.) \pm 0.7(syst.)] \times 10^{-6}$$

(preliminary)

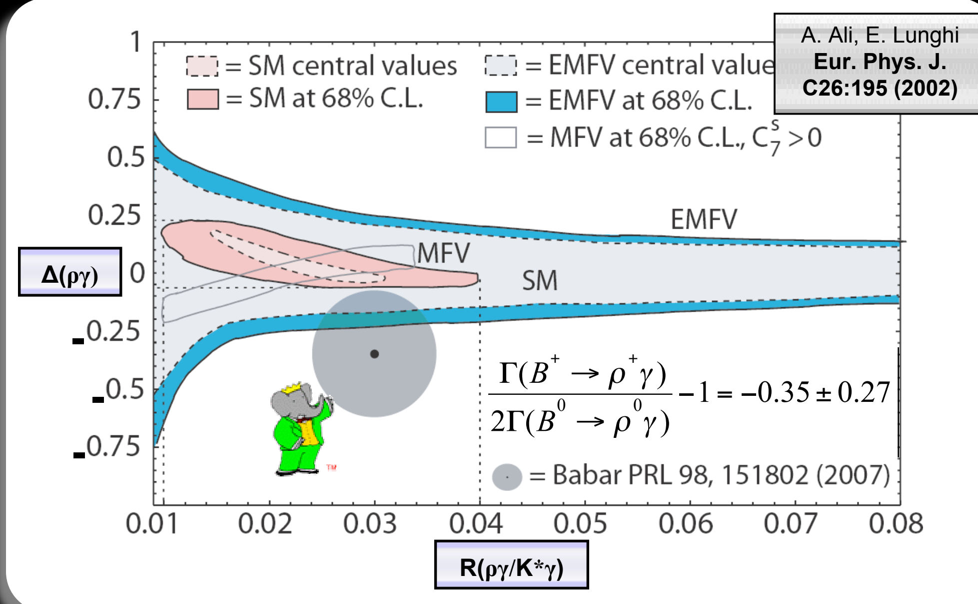
to do (in progress): **turn into inclusive b→dγ BF**

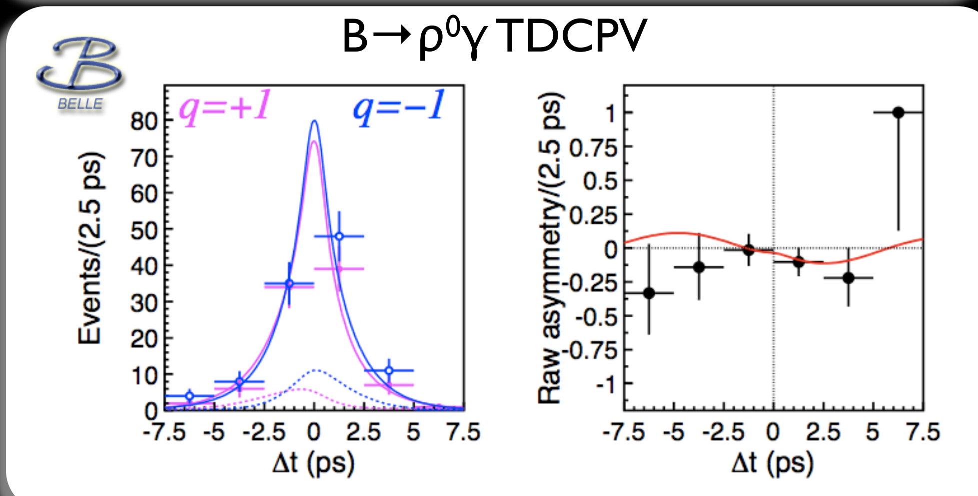
- extent measurement to low $M(X_d)$ range (for all 7 modes)
- correct for not reconstructed part of the X_d fragmentation
- extrapolate to full $M(X_d)$ range

then **use in measurement of $|V_{td}/V_{ts}|$**

b → dγ: Summary/Outlook

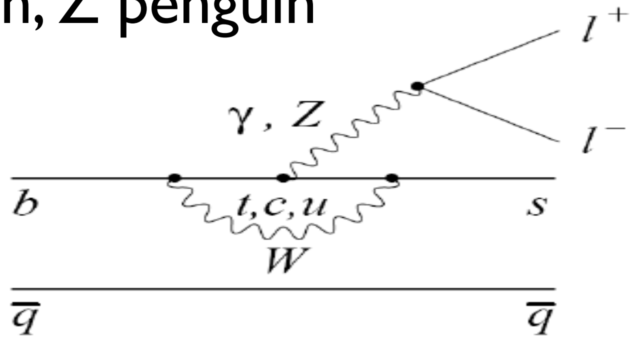
- exciting times!
- exclusive measurements have been moving from limits to observed signals
- now have precise SM reference from B_s mixing
- first evidence outside rho/omega mass region; proof of principle for semi-inclusive measurement
- keep pushing (and consider additional observables)



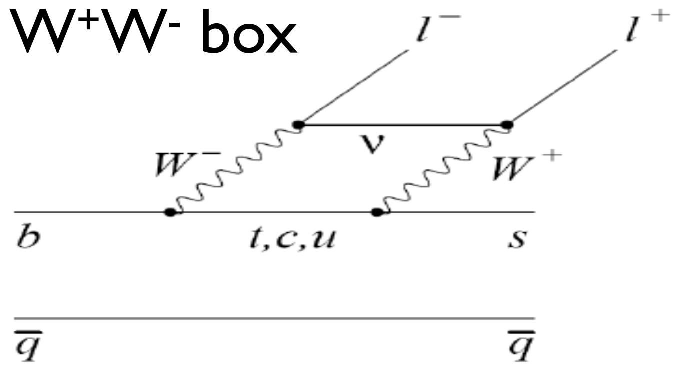


$B \rightarrow K^{(*)} \ell^+ \ell^-$

Photon, Z penguin



W+W- box

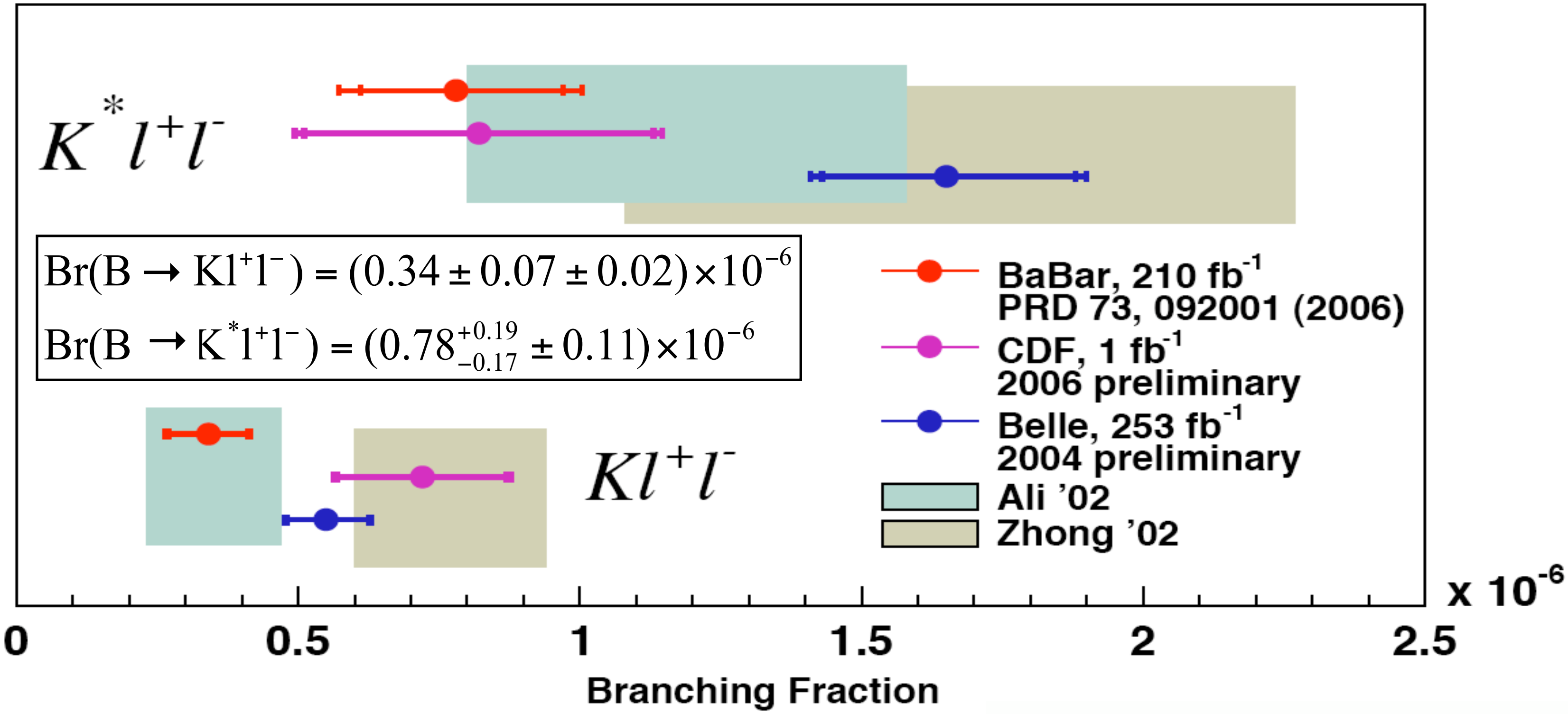


calculated at NNLO, see Ali *et al*., Phys.Rev. D66 (2002) 034002.

C_7 (γ penguin) C_9 (semileptonic vector) C_{10} (semileptonic axial-vector)

- Rich phenomenology for standard model tests:
  - additional scale: q^2 (di-lepton invariant mass squared)
  - additional degrees of freedom (angular distributions)
- SM BF prediction: $\mathrm{BF}\left(B \rightarrow K^{*} l^{+} l^{-}\right) \approx 10^{-6}$

$B \to K^{(*)} \ell^+\ell^-$: BF and A_{CP}



$$A_{CP} \equiv \frac{\Gamma(\overline{B} \to \overline{K}^{(*)}\ell^+\ell^-) - \Gamma(B \to K^{(*)}\ell^+\ell^-)}{\Gamma(\overline{B} \to \overline{K}^{(*)}\ell^+\ell^-) + \Gamma(B \to K^{(*)}\ell^+\ell^-)}$$

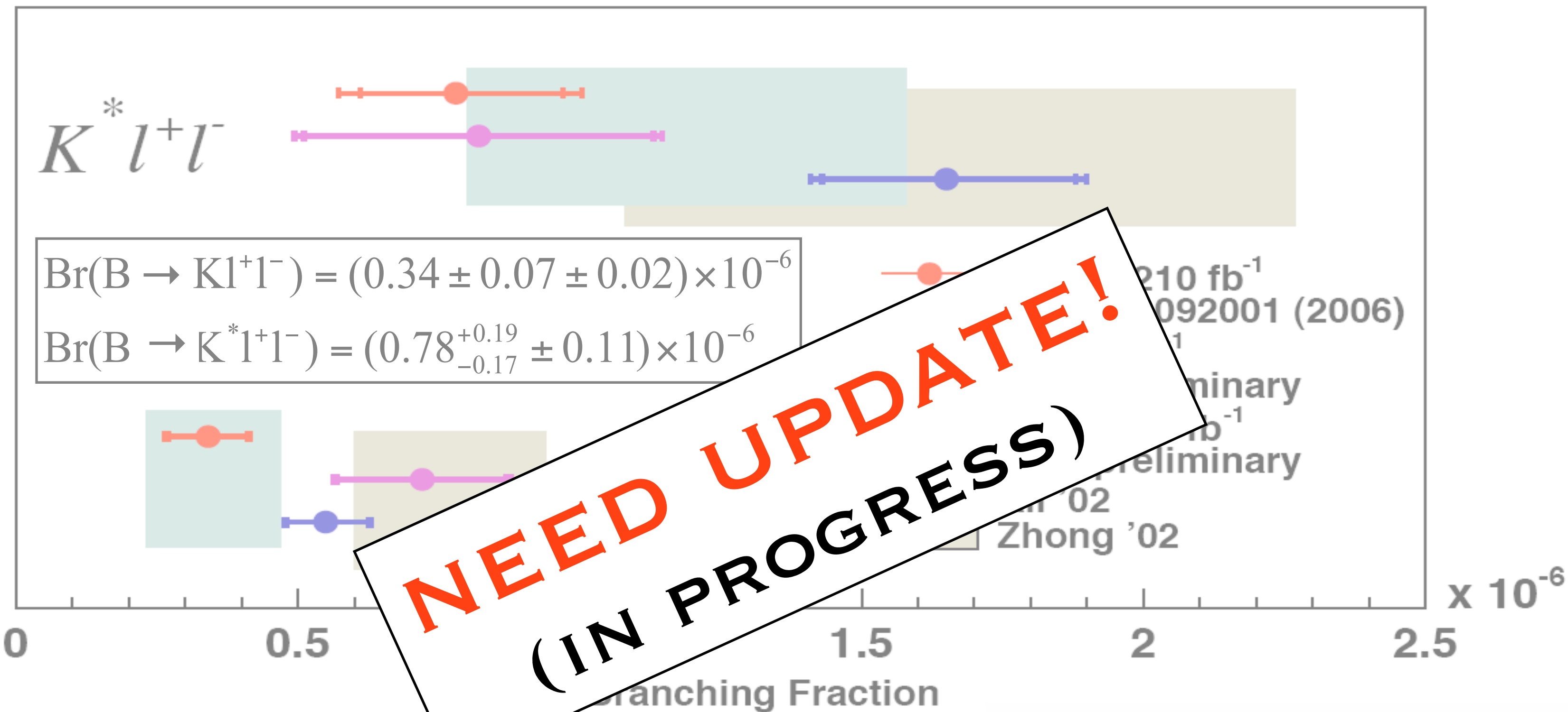
$$R_K \equiv \frac{\Gamma(B \to K\mu^+\mu^-)}{\Gamma(B \to K e^+ e^-)}$$

$A_{CP}(B^+ \to K^+ l^+ l^-) = -0.07 \pm 0.22 \pm 0.02$

$A_{CP}(B \to K^* l^+ l^-) = +0.03 \pm 0.23 \pm 0.03$

$R_K = 1.06 \pm 0.48 \pm 0.08$ SM : 1.0

$R_{K^*} = 0.91 \pm 0.45 \pm 0.06$ SM : 0.75



$Br(B \to K l^+ l^-) = (0.34 \pm 0.07 \pm 0.02) \times 10^{-6}$

$Br(B \to K^* l^+ l^-) = (0.78^{+0.19}_{-0.17} \pm 0.11) \times 10^{-6}$

$$A_{CP} \equiv \frac{\Gamma(\overline{B} \to \overline{K}^{(*)}\ell^+\ell^-) - \Gamma(B \to K^{(*)}\ell^+\ell^-)}{\Gamma(\overline{B} \to \overline{K}^{(*)}\ell^+\ell^-) + \Gamma(B \to K^{(*)}\ell^+\ell^-)}$$

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$R_K = 1.06 \pm 0.48 \pm 0.08$ SM : 1.0

$R_{K^*} = 0.91 \pm 0.45 \pm 0.06$ SM : 0.75

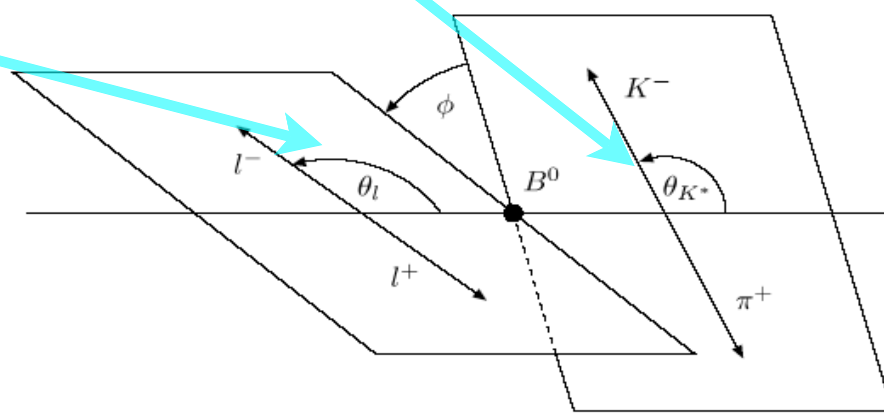
A_{FB} – forward-backward asymmetry of the l^+l^- helicity angle

F_L – longitudinal component of polarization

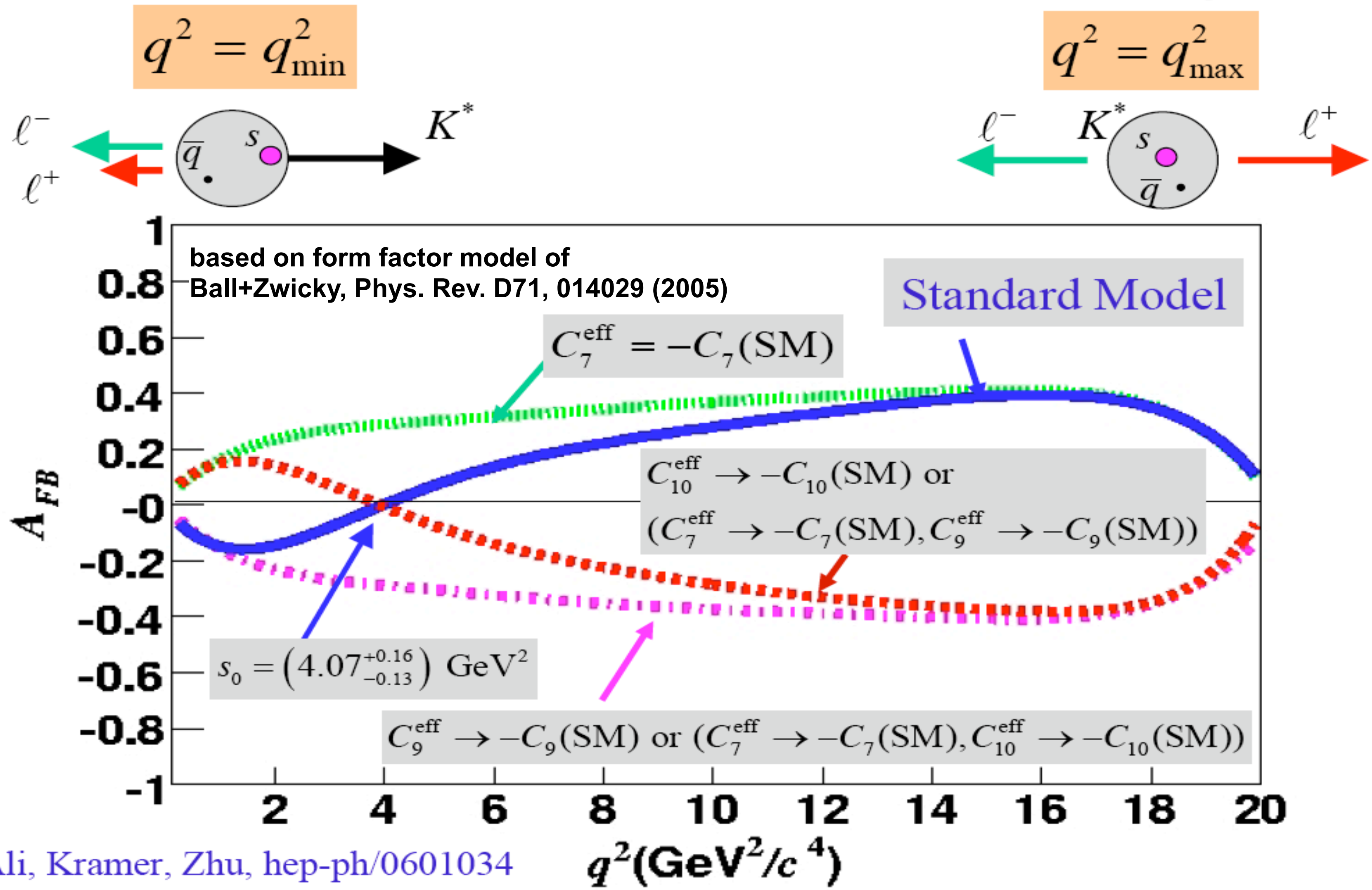
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_K} = \frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_l} = \frac{3}{4}F_L(1-\cos^2\theta_l) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_l) + A_{FB}\cos\theta_l$$

- Vector (C_7,C_9) and axialvector (C_{10}) contributions interfere
- Relative strength of V and A couplings varies with q^2
  → can test the magnitudes and signs of C_9 and C_{10}.

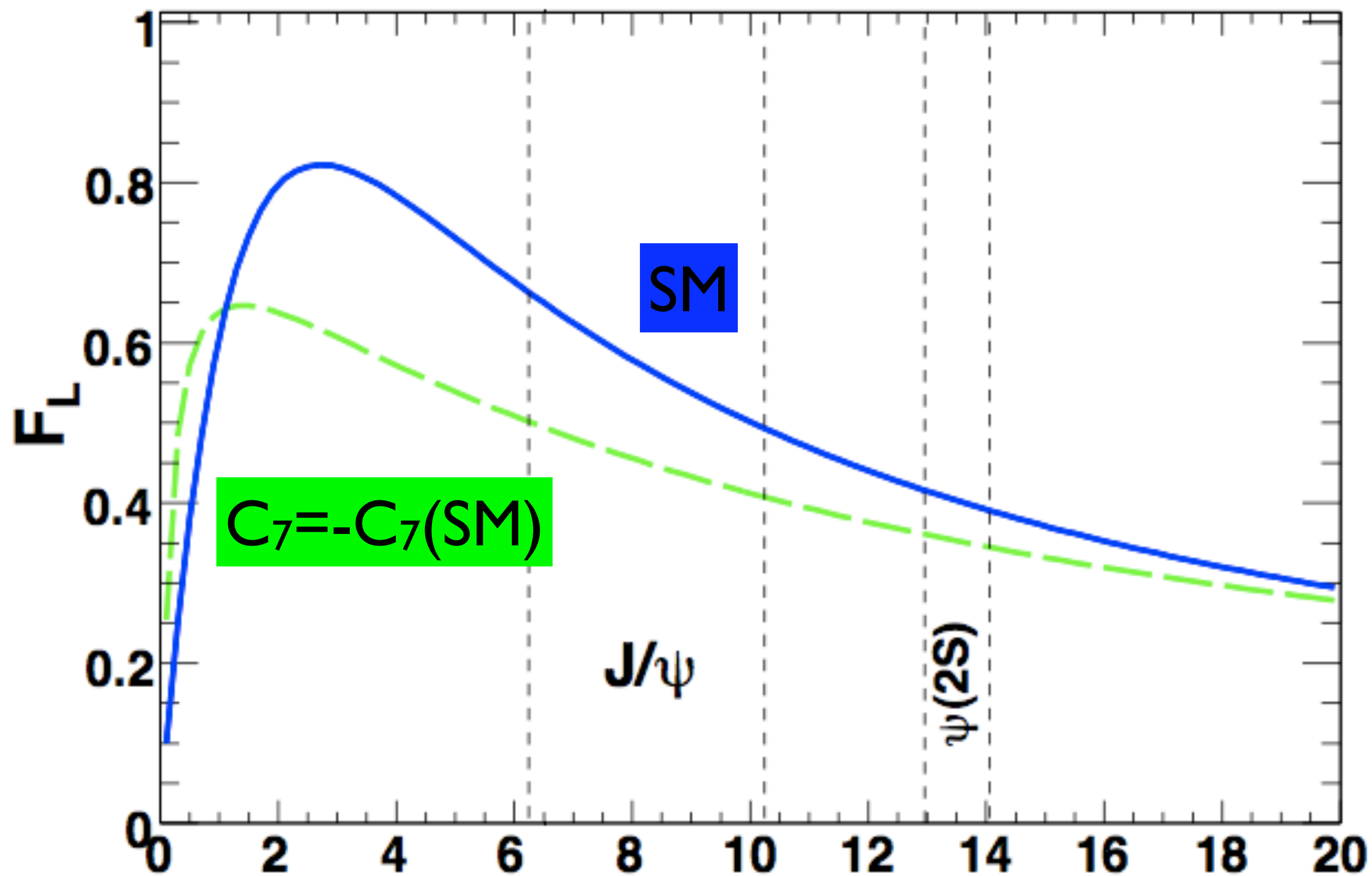


$B \rightarrow K^* \ell^+\ell^-$: (B)SM A_{FB}



s_0: Ali, Kramer, Zhu, hep-ph/0601034

$B \to K^* \ell^+\ell^-$: (B)SM F_L



$B \rightarrow K^* \ell^+\ell^-$: Analysis Overview

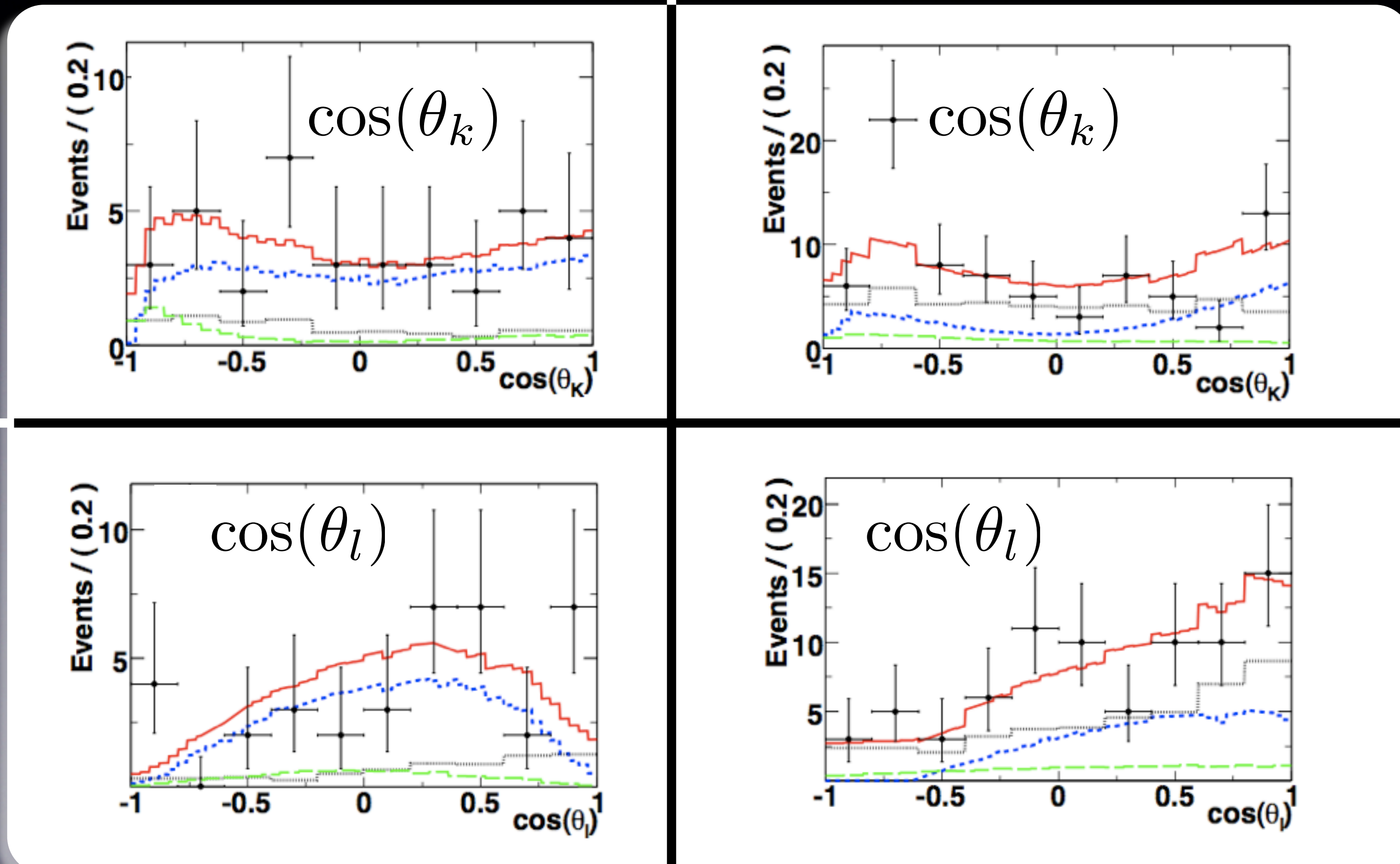
- **New results** [preliminary; to be submitted to PRL]
- based on 384 million BB pairs [previous analysis: 232 million]
- reconstruct $K^* \rightarrow K\pi$, $K\pi^0$, $K_S\pi$ plus e^+e^-, $\mu^+\mu^-$ pairs
- tight particle ID for K, e, μ
- ΔE + Neural Networks to suppress backgrounds
- veto charmonium resonances $B \rightarrow K^* J/\psi, K^*\psi'$ [BF~10^{-3}; powerful control sample to validate analysis]
- split data in two regions of the di-lepton mass $q^2<6.25$ GeV^2 and $q^2>10.24$ GeV^2
- extract F_L and A_{FB} from multi-stage fit (to m_{ES} and helicity angles)

$B \to K^{(*)} \ell^+\ell^-$: Fits

low q^2 | **high q^2**

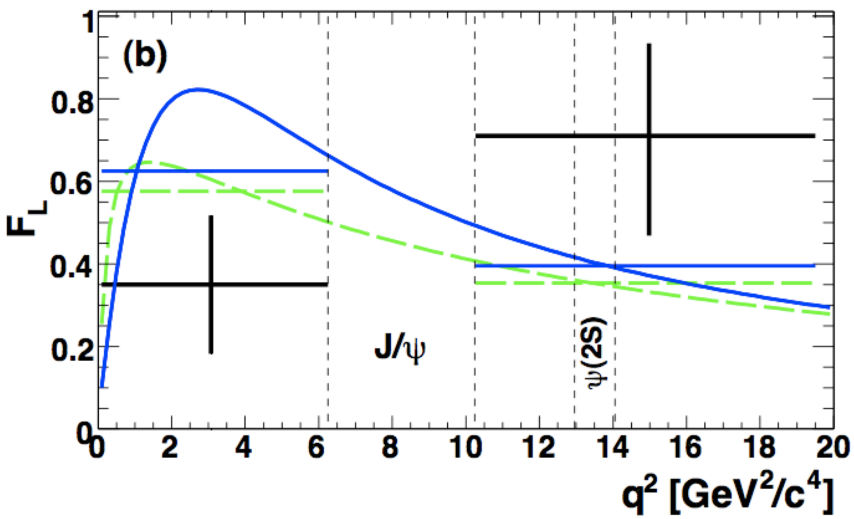
F_L

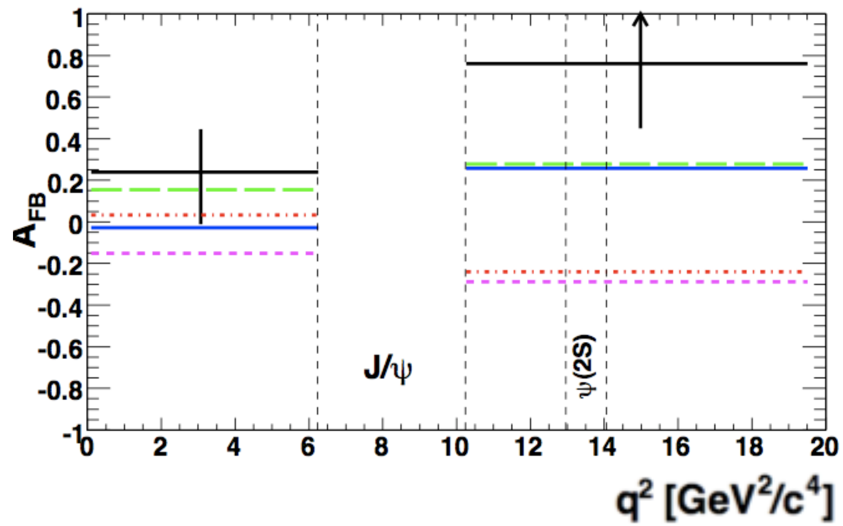
A_{FB}



$B \to K^{(*)} \ell^+\ell^-$: Results

F_L | A_{FB}

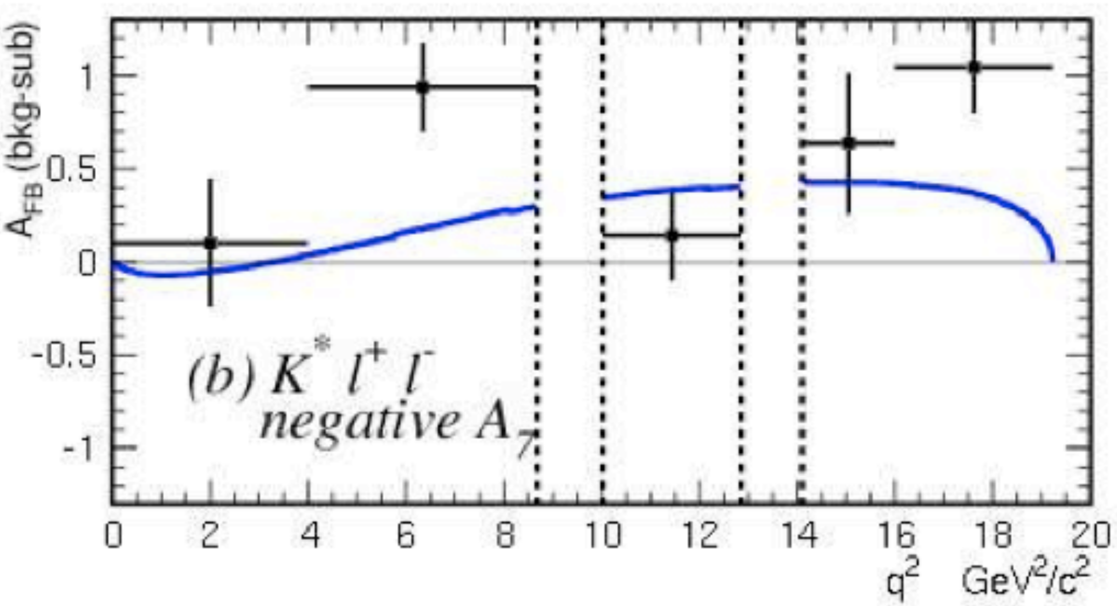




q^2	F_L	A_{FB}
low	$0.35 \pm 0.16 \pm 0.04$	$+0.24^{+0.18}_{-0.23} \pm 0.06$
high	$0.71^{+0.20}_{-0.22} \pm 0.05$	$+0.76^{+0.52}_{-0.32} \pm 0.07$

$B \to K^* \ell^+\ell^-$: Compare with Belle

Belle also see large positive forward-backward asymmetries:

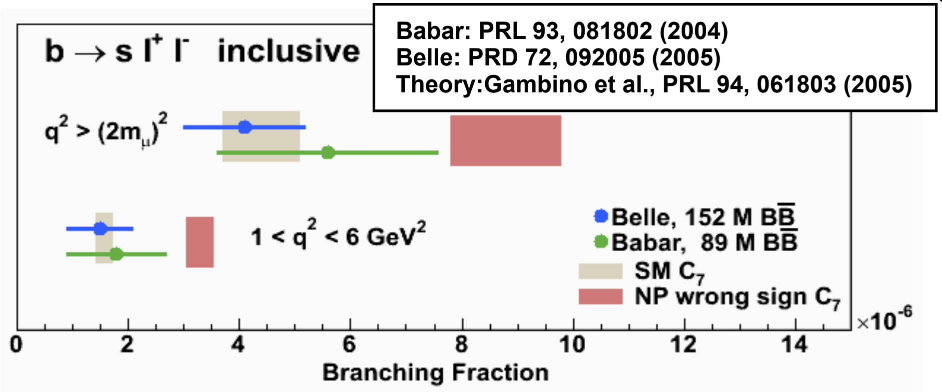


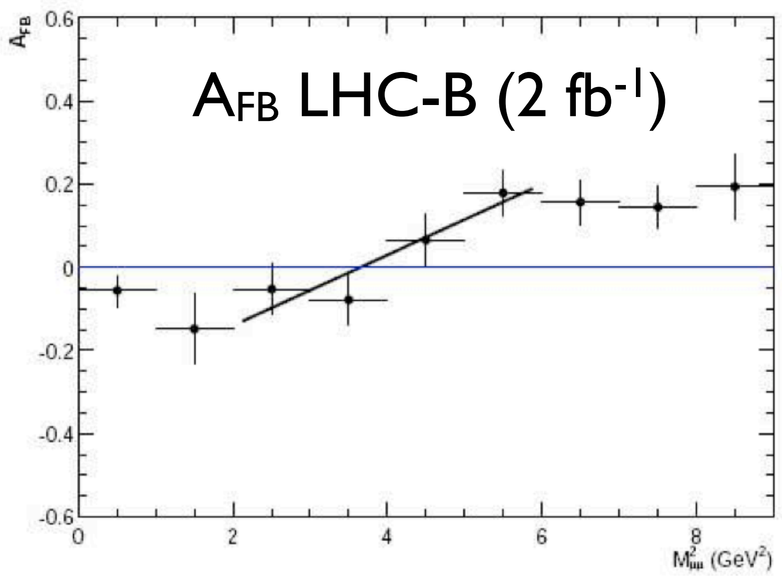
PRL 96, 251801(2006) - uses 386M $B\bar{B}$ pairs

Errors are comparable to BaBar results

B → K* ℓ⁺ℓ⁻ : Summary/Outlook

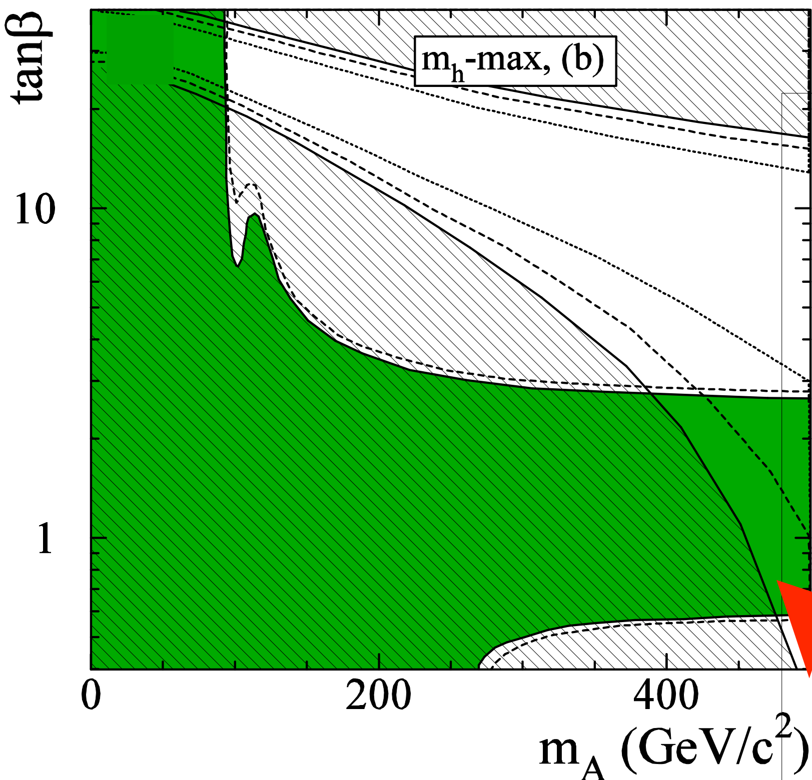
- all results statistics-limited
- angular analysis starting to probe SM
- future measurement might include more q^2 bins and additional observables
- also update exclusive BF + inclusive measurements
- for $B \to K^* \mu\mu$, can now compare to Tevatron (and LHC-B will join the game at some point)



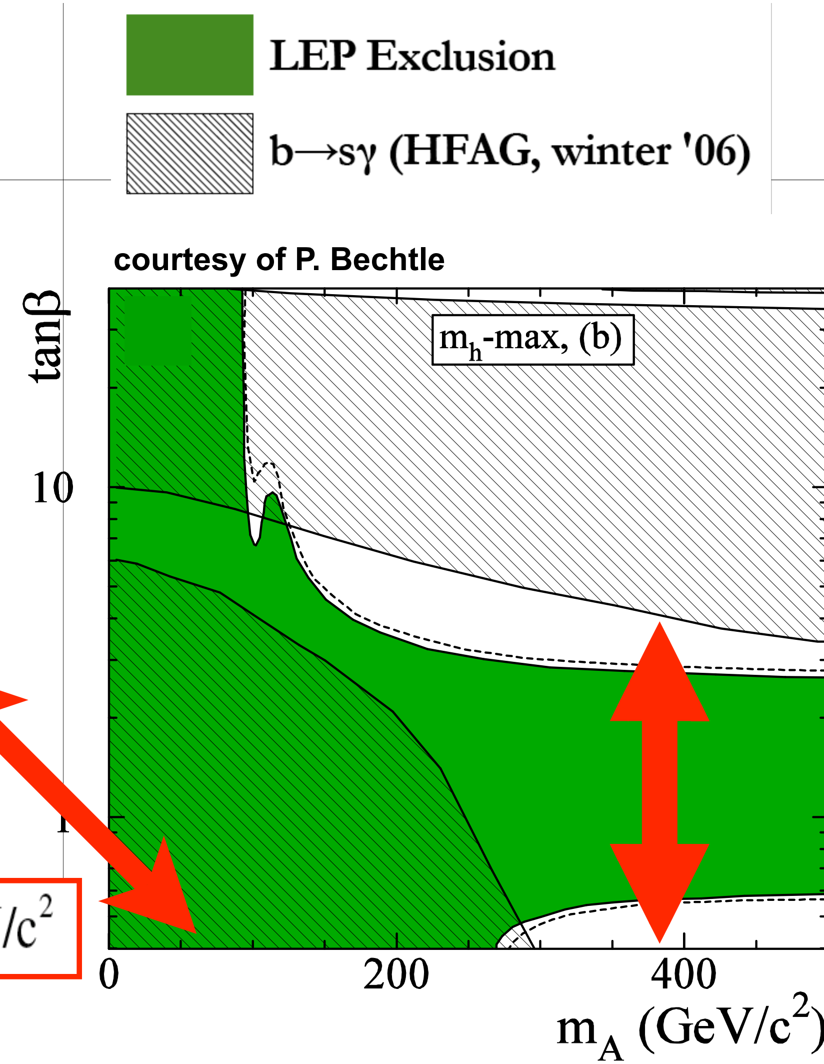


Interplay with LHC

e.g.: MSSM constraint



$$m_{\tilde{t}} = 1000\,\mathrm{GeV/c^2} \rightarrow m_{\tilde{t}} = 500\,\mathrm{GeV/c^2}$$



And There Is Much More...

- exclusive $b \to s\gamma$
- time-dependent CP violation
  [photon polarization?]
- exclusive $b \to dl^+l^-$
- B_s penguins
  [Belle Υ(5S) run]
- […]

Conclusions

- rich and active field
- window for direct NP observations is closing
- NP constraints will remain important
- BaBar running is ending; sizable part of data still to be analyzed
- will likely need continuation of B program - (Belle), superBxxx, LCH[-B], ?? - to make detailed sense of future discoveries

(from ICHEP06 talk by R. Barlow)