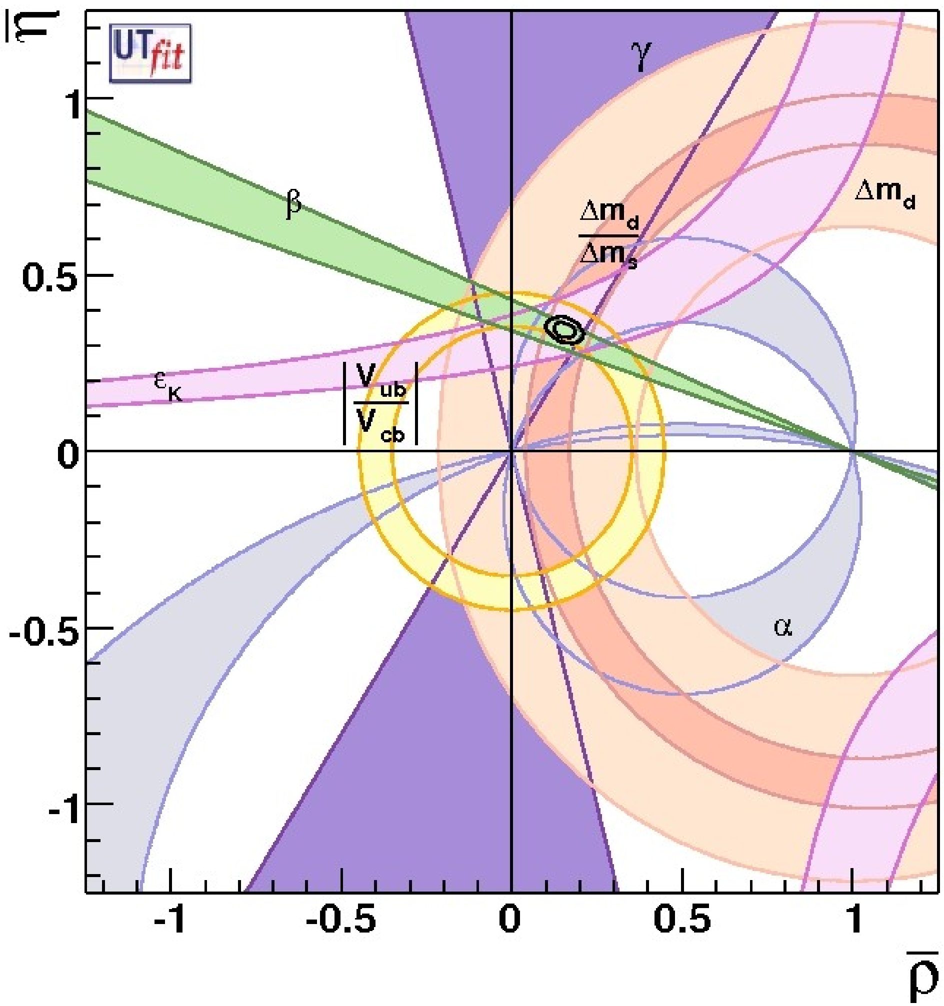
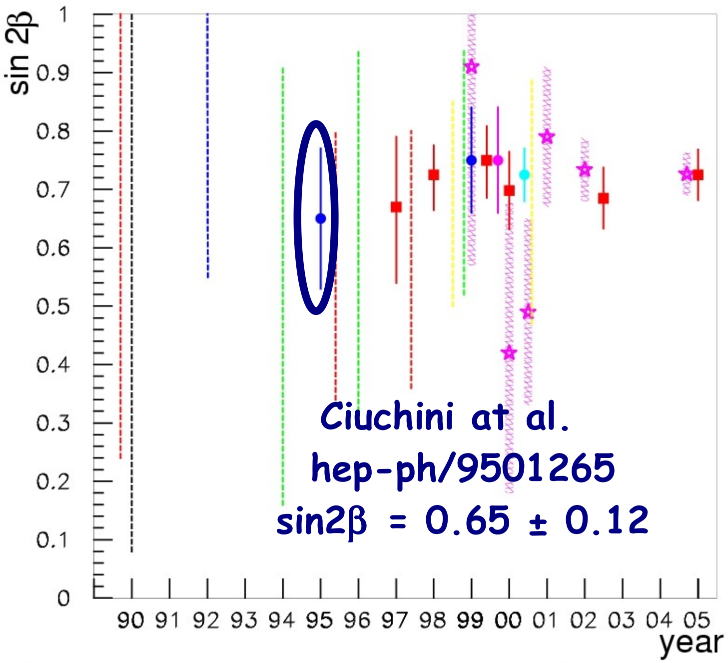
Measurements from BaBar

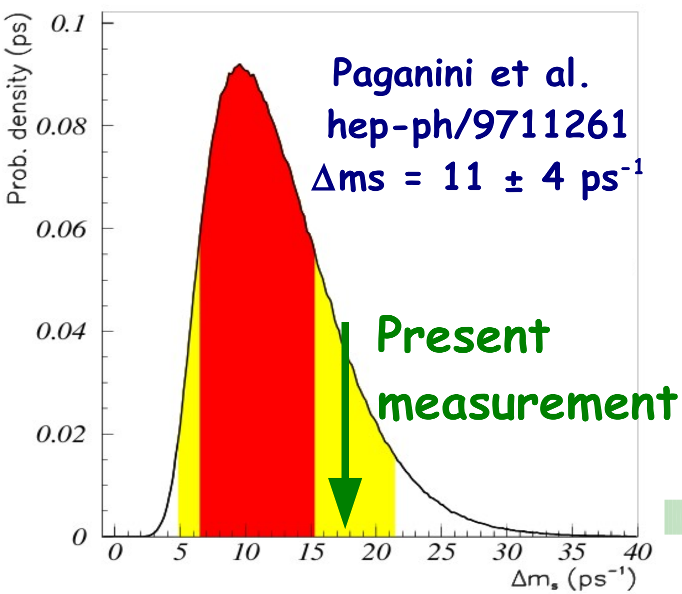
Maurizio Pierini
CERN-PH
on behalf of BaBar Collaboration

The consistency of the Standard Model

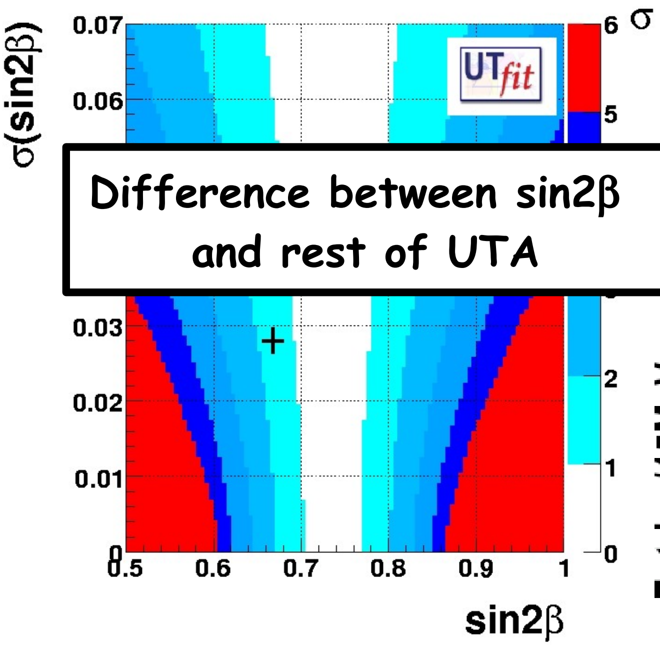
- The measurements of Bfactories & Tevatron have confirmed the prediction of the UTfit
- The CKM paradigm is established as the source of CP violation & flavor mixing in the SM



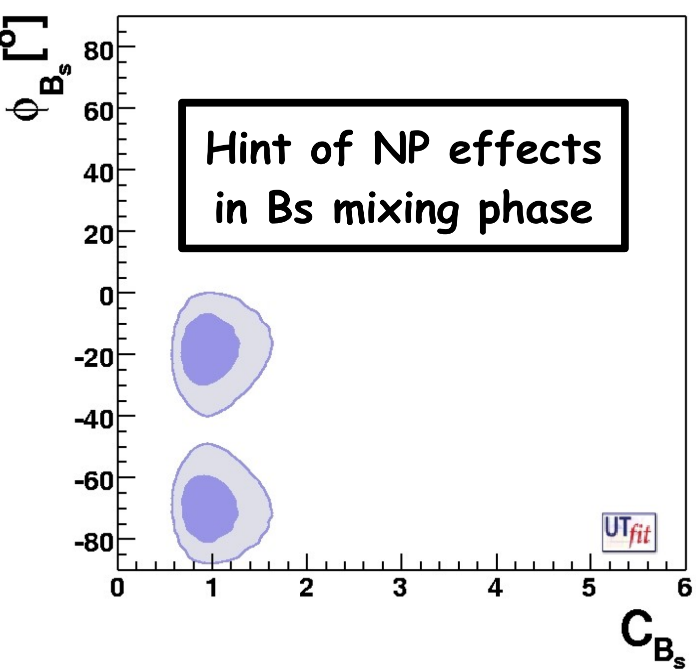




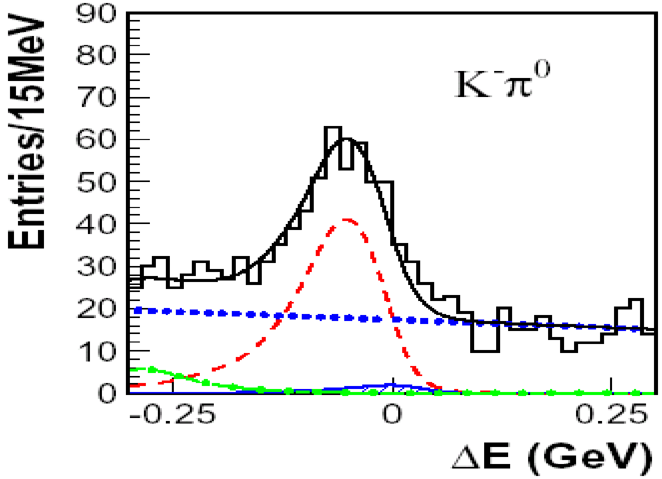
Some "tension" in the flavor land



Difference between sin2β and rest of UTA

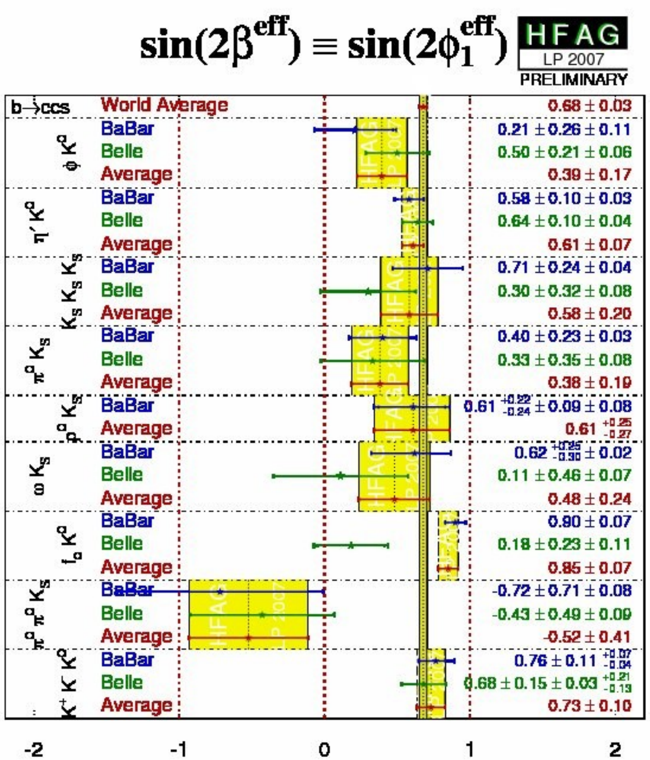


Hint of NP effects in Bs mixing phase

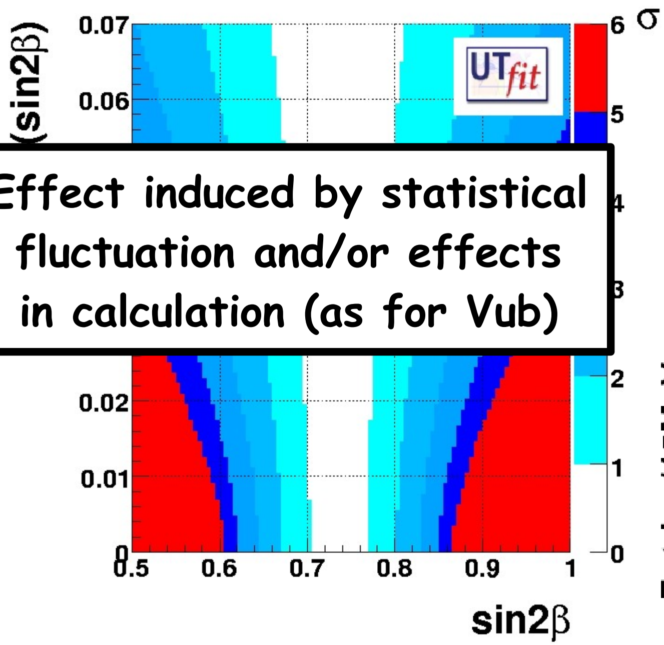


Large ACP difference in $B^0 \to K^+\pi^-$ and $B^+ \to K^+\pi^0$ decays

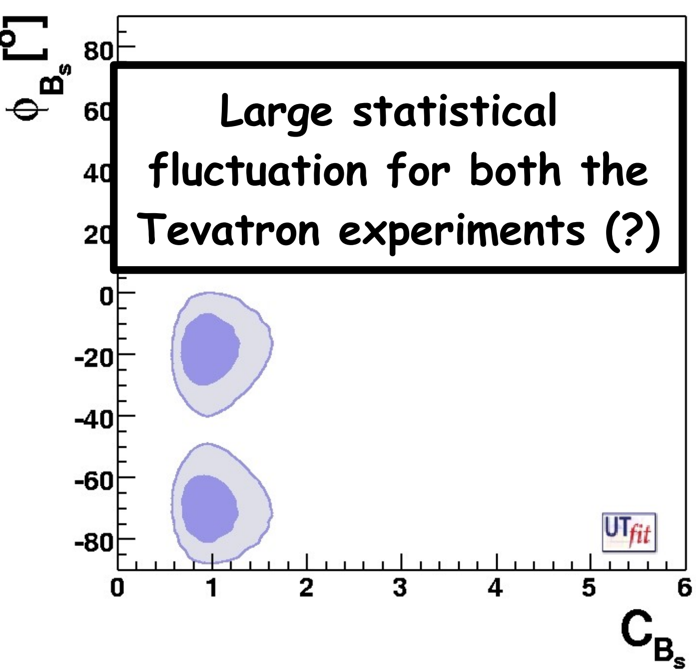
Negative Δ(s2β) in b→s penguins (vs mainly positive corrections expected by QCD effects in SM



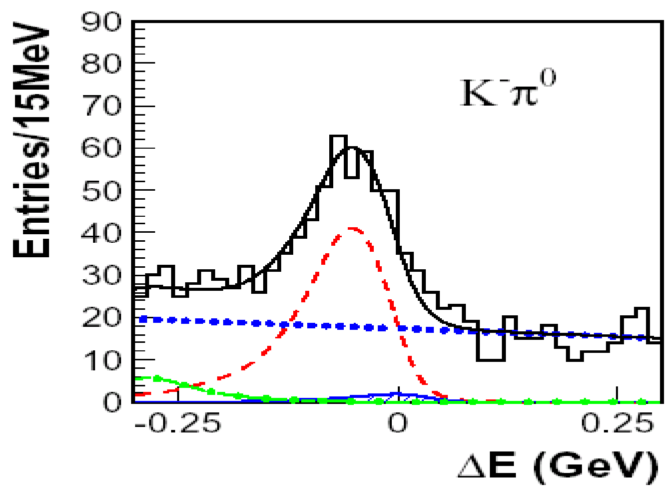
Possible Explanations in the SM



Effect induced by statistical fluctuation and/or effects in calculation (as for Vub)

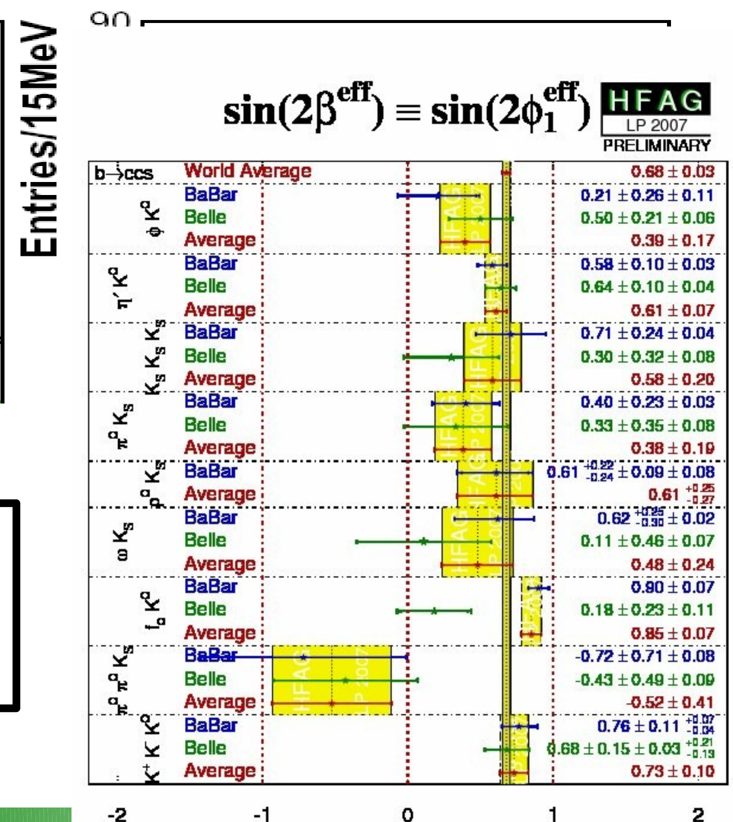


Large statistical fluctuation for both the Tevatron experiments (?)



Effect of Λ_{QCD}/m_β corrections (neglected in perturbative calculations)

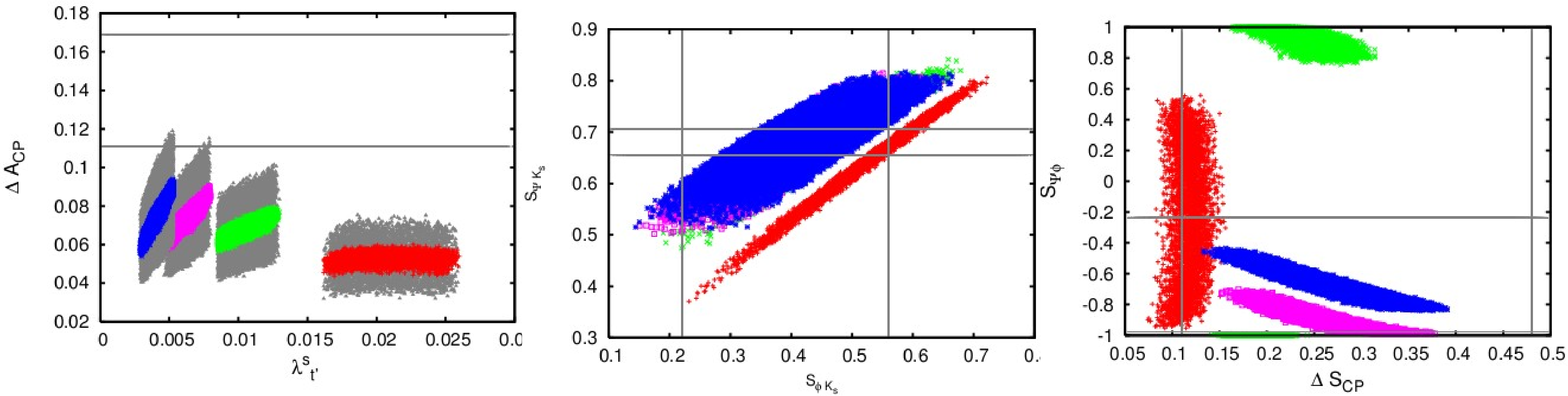
Statistical fluctuations (and indeed the differences are smaller than in the past)



4^{th} generation: An economical BSM explanation

A recent example: Soni et al arXiv:0807.1971

A fourth family of quarks with mt'>700 GeV provides a natural explanation of these effects



The measurements are a crucial ingredient, being the experimental errors a limiting factor to establish the deviation from the SM expectations. BaBar, Belle and a superB can play an important role in this scenario

BaBar & PEP-II

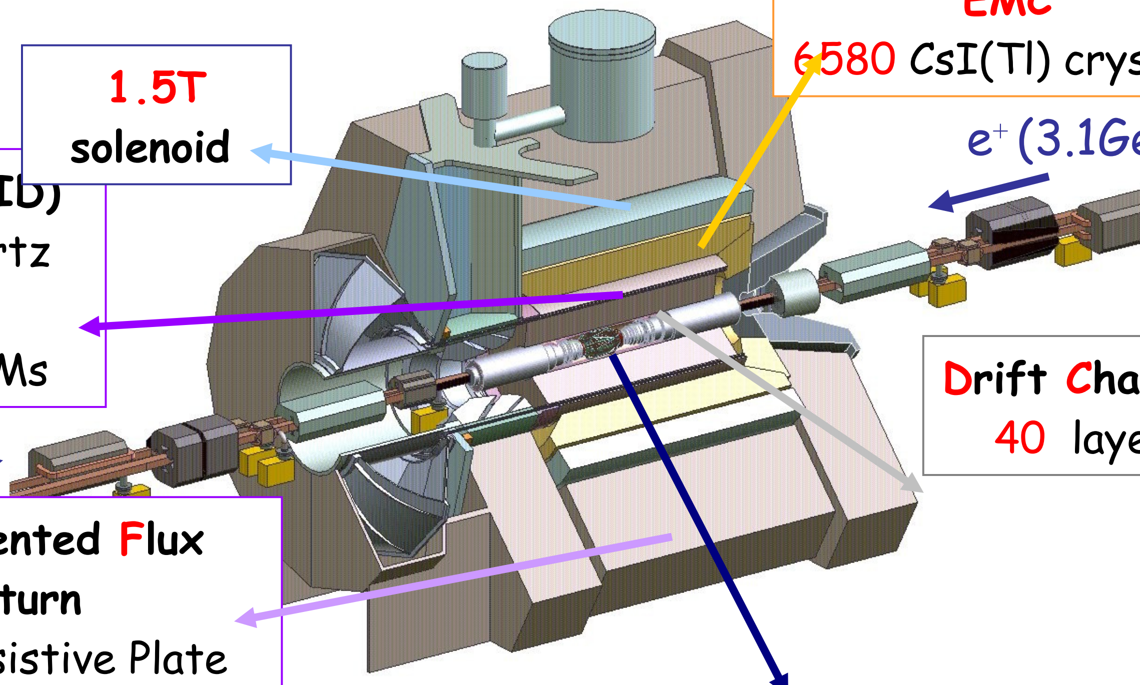
1.5T solenoid

DIRC (PID)
144 quartz bars
11000 PMs

EMC
6580 CsI(Tl) crystals

e^+ (3.1GeV)

e^- (9GeV)

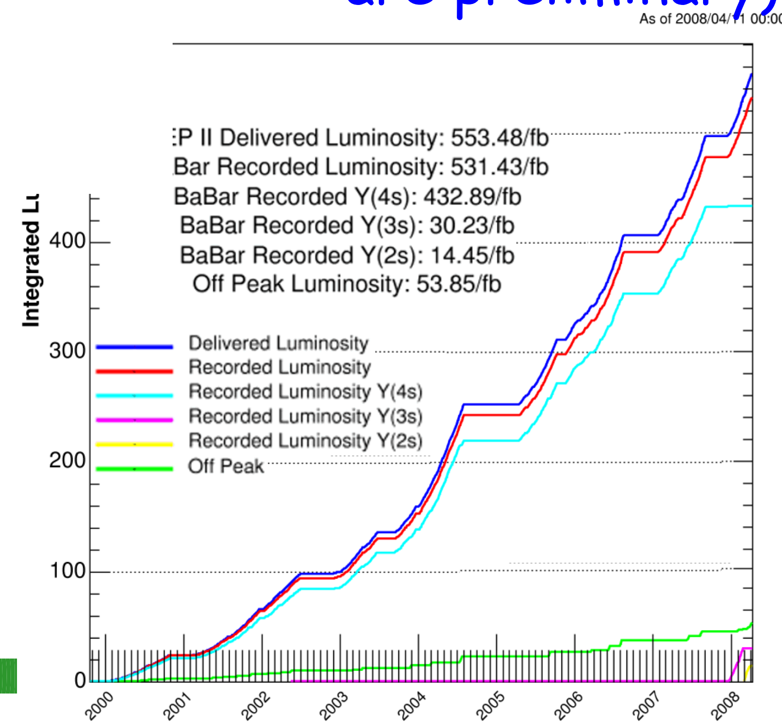


Drift Chamber
40 layers

Instrumented Flux Return
Iron / Resistive Plate Chambers or Limited Streamer Tubes
(muon / neutral hadrons)

Silicon Vertex Tracker
5 layers, double sided strips

Full Statistics
467 million $\Upsilon(4S)$
(All new results are preliminary)



The $B \to K\pi$ decays

Very rich phenomenology

- BR and direct CP asymmetries in a set of four isospin-conjugated states
- Time dependent analysis of $B^0 \to K^0\pi^0$ decays
- New results from BaBar for $K^+\pi^-$ and $K^0\pi^0$

One of the most rich and exiting parts of the physics program for the B factories

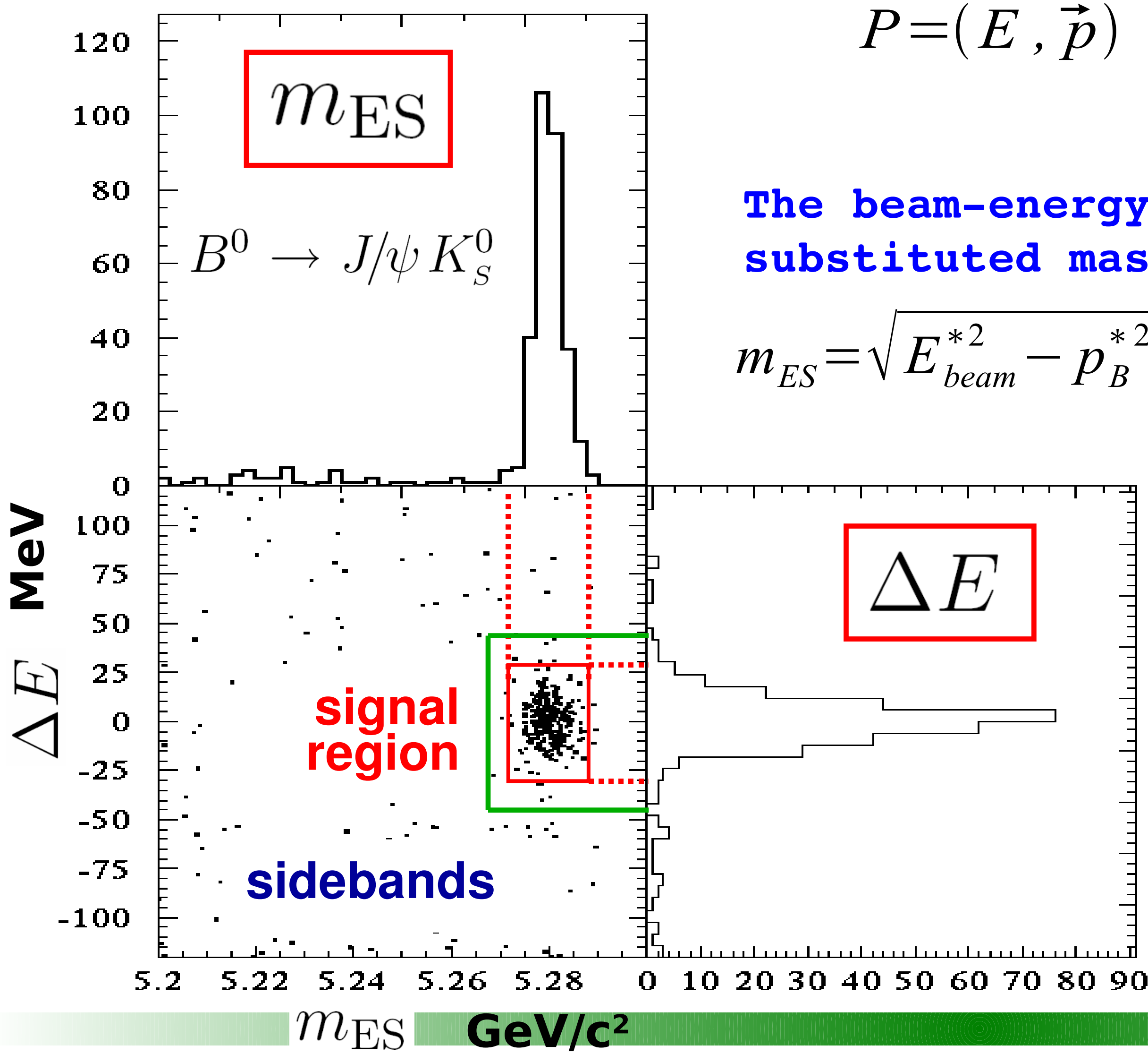
The experimental challenge:

- BR ~ 10^-5
- large contamination from $e^+e^- \to q\bar{q}$ events
- Possible cross-feed among the channels
- (for some of the channels) no charged track coming from the primary vertex

The experimental handles

- Closed kinematic
- Topological variables
- Use of the full decay chain
- Particle ID for K/π separation

"Closed" kinematics



Lab frame $P = (E, \vec{p})$ **Boost** → **CM frame** $P^* = (E^*, \vec{p}^*)$

The beam-energy substituted mass

$$m_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$$

The energy difference

$$\Delta E = E_{beam}^* - \sqrt{s}/2$$

Two independent analysis variables

$$\sigma_{m_{ES}} \approx 2.6\, MeV/c^2$$

dominated by beam energy spread

$$\sigma_{\Delta_E} \approx 10 \div 40\, MeV/c^2$$

dominated by energy resolution

Topological variables

Main source of background from $e^+e^- \to \bar{q}q$.

Difference in topology to reject them

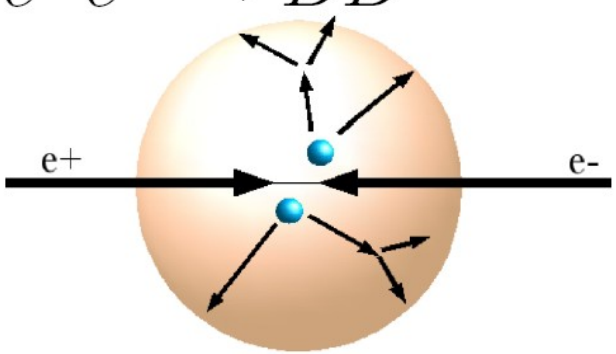
B produced ~ at rest

isotropic topology

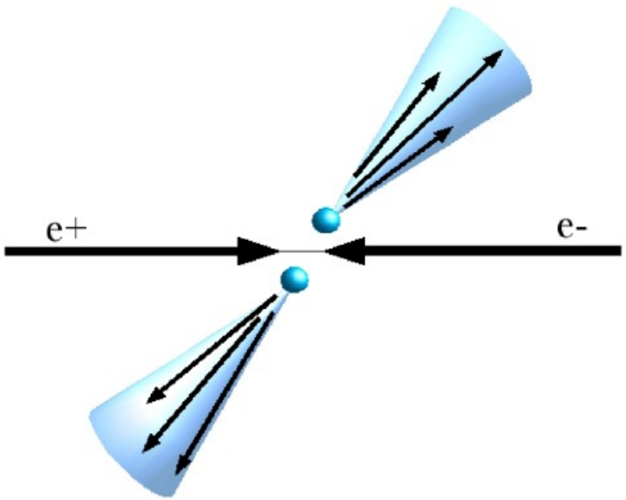
$\bar{q}q$ events decaying with large phase space

jet-like topology

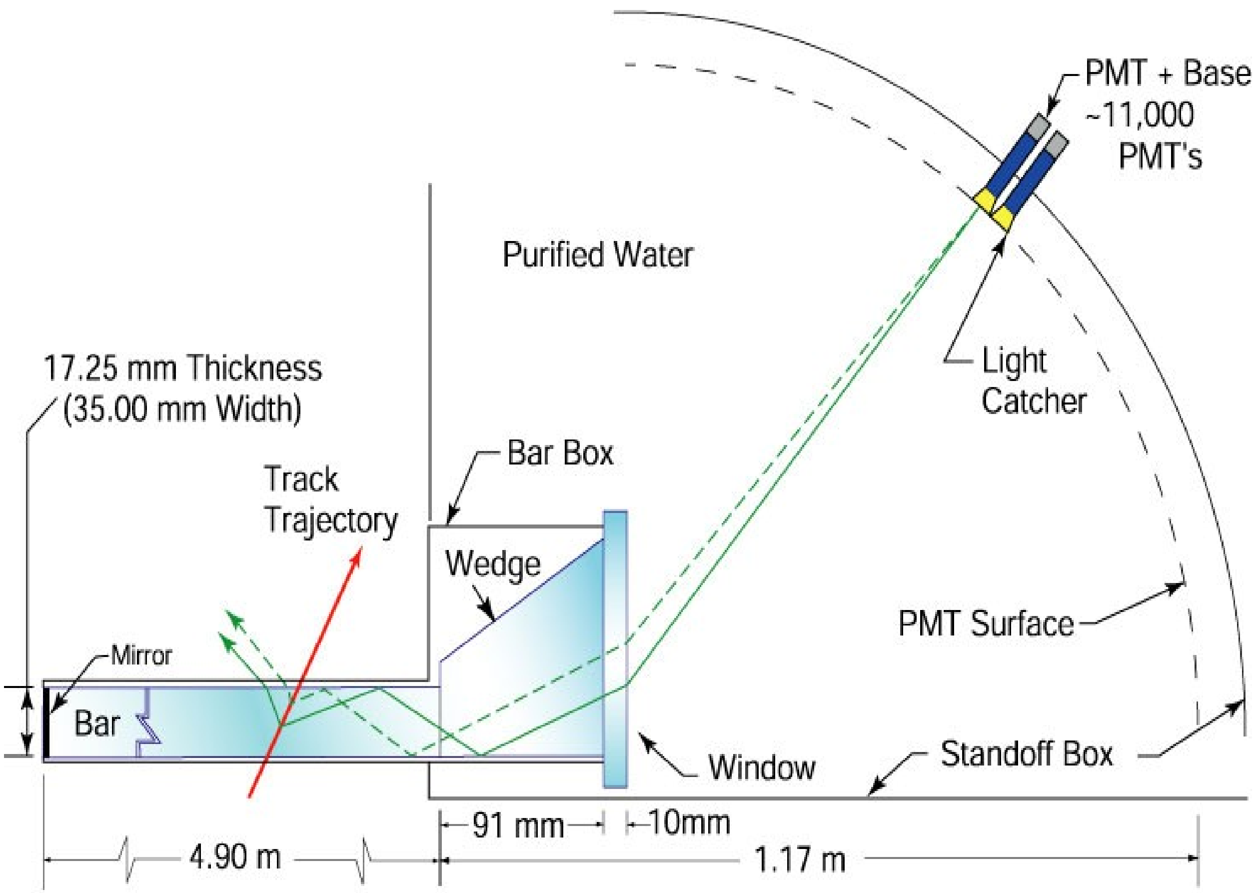
$$e^+e^- \to B\bar{B}$$

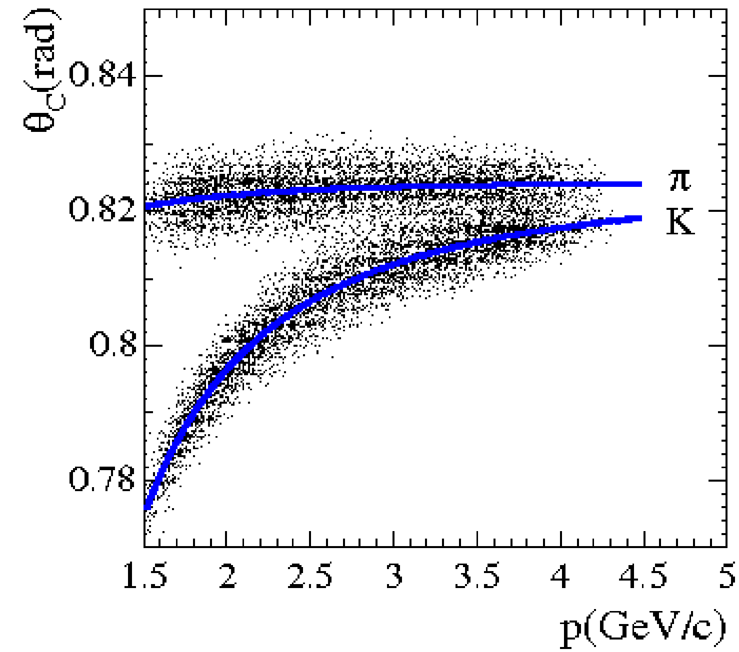


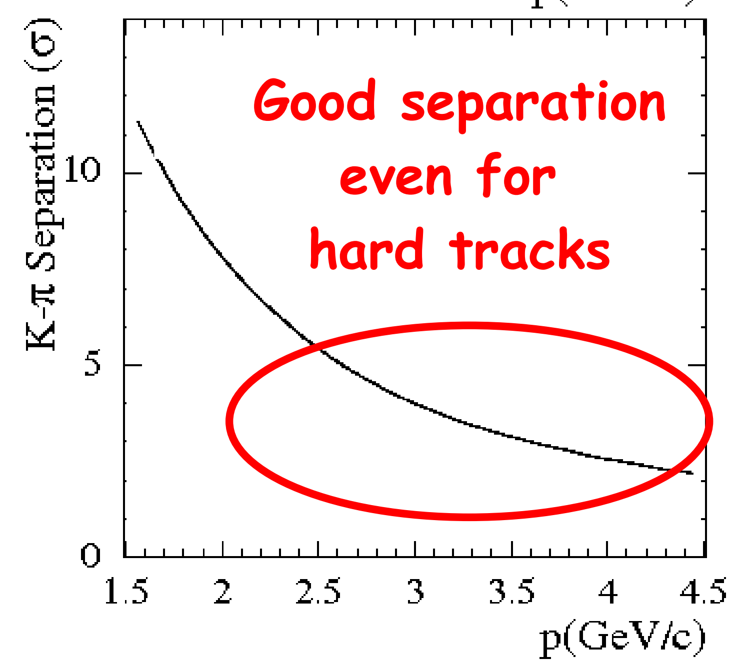
$$e^+e^- \to q\bar{q}$$



Particle ID for K/π separation





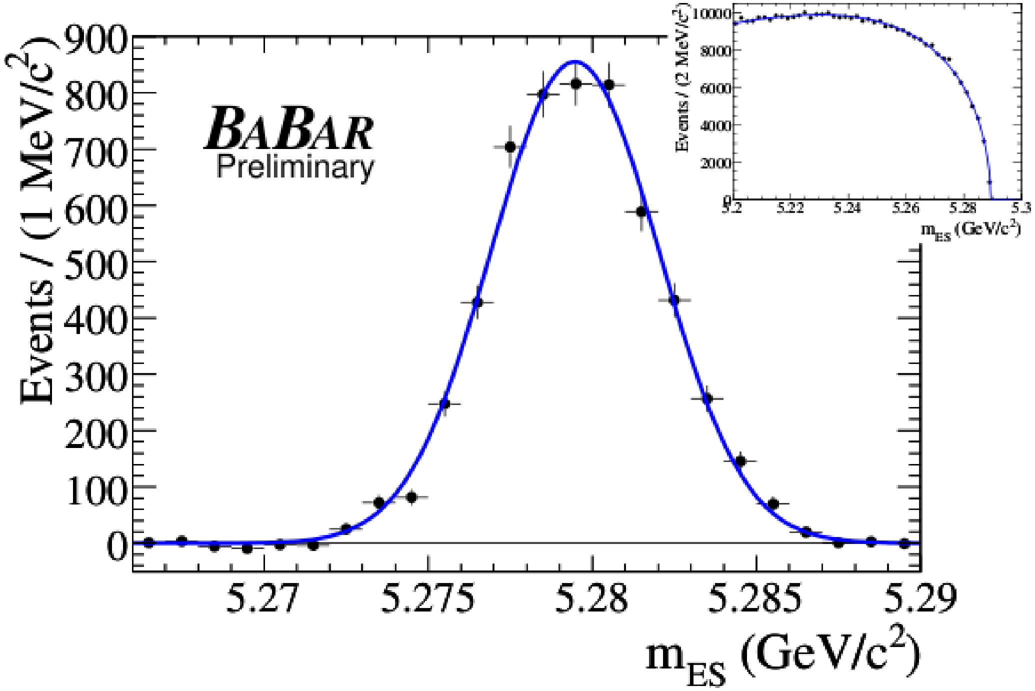


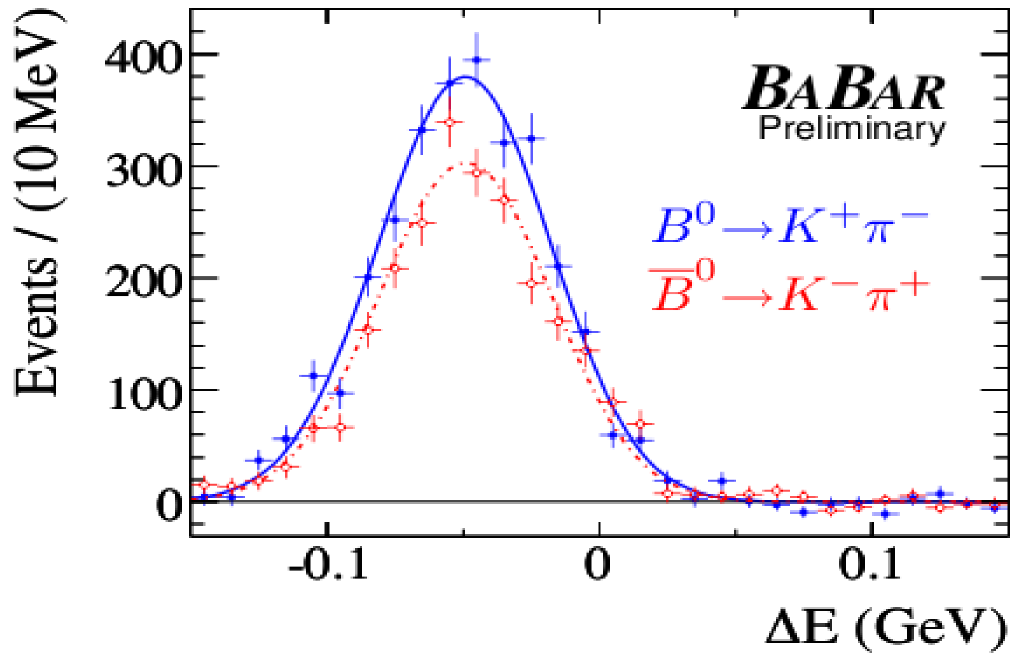
The pull of the measured Cherenkov angle is parameterized as a Gaussian with $m(\vec{p})$ and $\sigma(\vec{p})$ and used in the ML fit

A_{CP} of $B^0 \to K^+\pi^-$ decays (I)

ML Fit of kinematic variables, topology variables and Cherenkov angle

Kaon charge used to tag the B (i.e. no mistagging)





Preliminary e-Print: arXiv:0807.4226 [hep-ex]

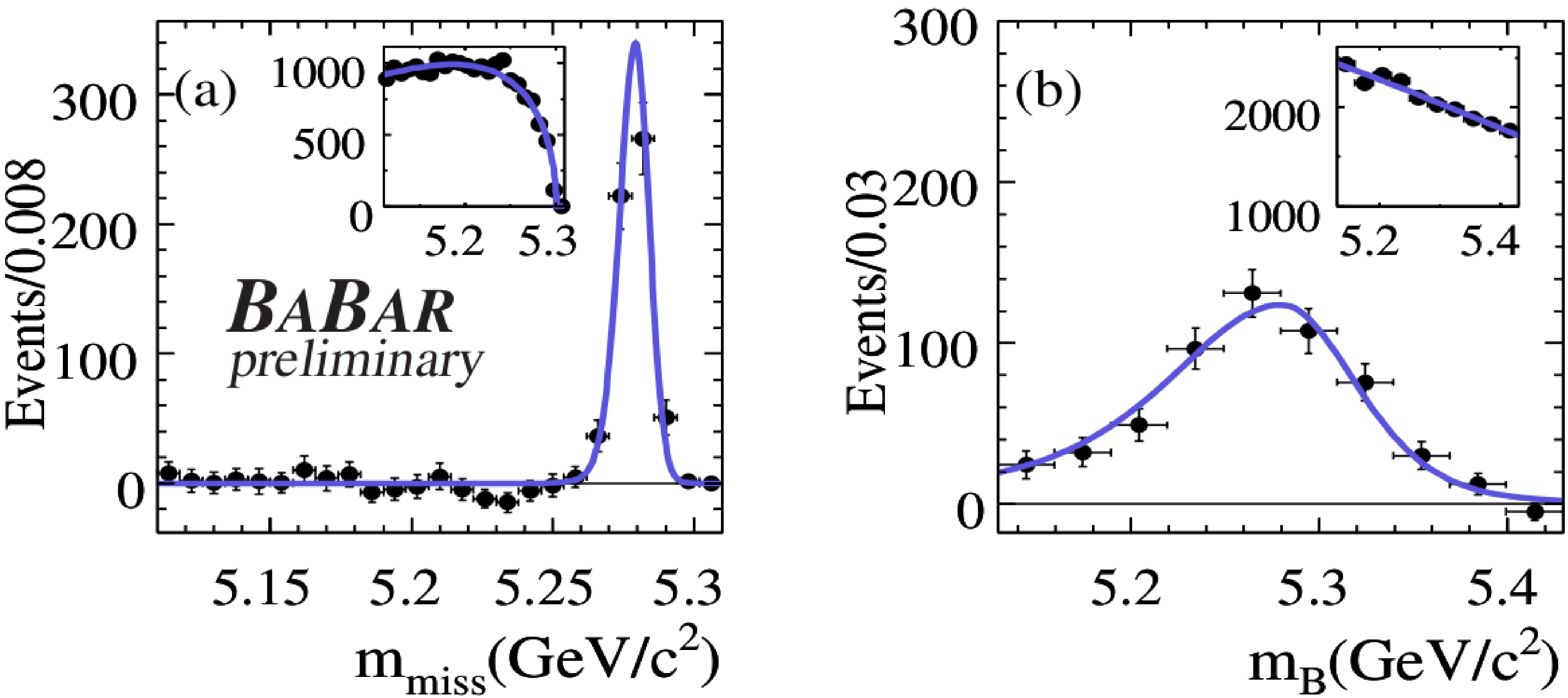
$$A_{CP}(B^0 \to K^+\pi^-) = \frac{N(\overline{B}^0) - N(B^0)}{N(\overline{B}^0) + N(B^0)} = -0.107 \pm 0.016 \, ^{+0.006}_{-0.004}$$

467 million Υ(4S)

BR of $B^0 \to K^0 \pi^0$ decays

Much more difficult than $K\pi$, due to the recontruction of the two composite mesons. m_{ES} and ΔE correlated because of π^0 energy resolution. Use m_B and m_{Miss} (lower correlation)

Preliminary
e-Print: arXiv:0807.4226 [hep-ex]



$BR(B^0 \to K^0 \pi^0) = (10.1 \pm 0.6 \pm 0.4) \times 10^{-6}$

467 million $\Upsilon(4S)$

--

The B→Kπ "puzzle"

L. Silvestrini Ann.Rev.Nucl.Part.Sc .57:405-440,2007.

	QCDF [50]	PQCD [54, 55]	SCET [58]	exp
$BR(\pi^- \bar{K}^0)$	$19.3^{+1.9}_{-1.9}{}^{+11.3}_{-7.8}{}^{+1.9}_{-2.1}{}^{+13.2}_{-5.6}$	$24.5^{+13.6}_{-8.1}$	$20.8 \pm 7.9 \pm 0.6 \pm 0.7$	23.1 ± 1.0
$A_{CP}(\pi^- \bar{K}^0)$	$0.9^{+0.2}_{-0.3}{}^{+0.3}_{-0.3}{}^{+0.1}_{-0.1}{}^{+0.6}_{-0.5}$	0 ± 0	< 5	0.9 ± 2.5
$BR(\pi^0 K^-)$	$11.1^{+1.8}_{-1.7}{}^{+5.8}_{-4.0}{}^{+0.9}_{-1.0}{}^{+6.9}_{-3.0}$	$13.9^{+10.0}_{-5.6}$	$11.3 \pm 4.1 \pm 1.0 \pm 0.3$	12.8 ± 0.6
$A_{CP}(\pi^0 K^-)$	$7.1^{+1.7}_{-1.8}{}^{+2.0}_{-2.0}{}^{+0.8}_{-0.6}{}^{+9.0}_{-9.7}$	-1^{+3}_{-5}	$-11 \pm 9 \pm 11 \pm 2$	4.7 ± 2.6
$BR(\pi^+ K^-)$	$16.3^{+2.6}_{-2.3}{}^{+9.6}_{-6.5}{}^{+1.4}_{-1.4}{}^{+11.4}_{-4.8}$	$20.9^{+15.6}_{-8.3}$	$20.1 \pm 7.4 \pm 1.3 \pm 0.6$	19.4 ± 0.6
$A_{CP}(\pi^+ K^-)$	$4.5^{+1.1}_{-1.1}{}^{+2.2}_{-2.5}{}^{+0.5}_{-0.6}{}^{+8.7}_{-9.5}$	-9^{+6}_{-8}	$-6 \pm 5 \pm 6 \pm 2$	-9.5 ± 1.3
$BR(\pi^0 \bar{K}^0)$	$7.0^{+0.7}_{-0.7}{}^{+4.7}_{-3.2}{}^{+0.7}_{-0.7}{}^{+5.4}_{-2.3}$	$9.1^{+5.6}_{-3.3}$	$9.4 \pm 3.6 \pm 0.2 \pm 0.3$	10.0 ± 0.6
$A_{CP}(\pi^0 \bar{K}^0)$	$-3.3^{+1.0}_{-0.8}{}^{+1.3}_{-1.6}{}^{+0.5}_{-1.0}{}^{+3.4}_{-3.3}$	-7^{+3}_{-3}	$5 \pm 4 \pm 4 \pm 1$	-12 ± 11

Only SCET includes a non-factorizable $O(\Lambda_{QCD}/mb)$ charming penguin

All these approaches neglect the CKM suppressed $O(\Lambda_{QCD}/mb)$ corrections

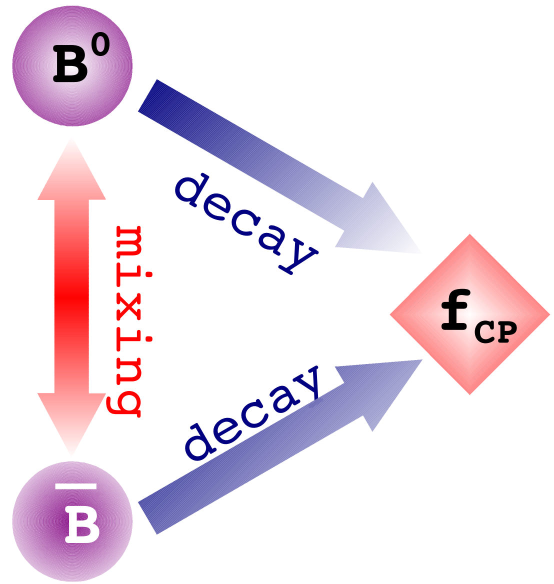
BSM physics not a must to explain the data

Time dependent measurements

decay

$$\lambda_{f_{CP}} = \frac{q}{p} \cdot \frac{\overline{A}_{f_{CP}}}{A_{f_{CP}}} = |\lambda_{f_{CP}}| \cdot e^{-2i\phi_{CP}}$$

mixing



$$\mathbf{A}_{f_{CP}} = \frac{\Gamma(\overline{B}^0_{phys}(t) \to f_{CP}) - \Gamma(B^0_{phys}(t) \to f_{CP})}{\Gamma(\overline{B}^0_{phys}(t) \to f_{CP}) + \Gamma(B^0_{phys}(t) \to f_{CP})}$$
$$= C_{f_{CP}} \cos(\Delta m_d \Delta t) + S_{f_{CP}} \sin(\Delta m_d \Delta t)$$

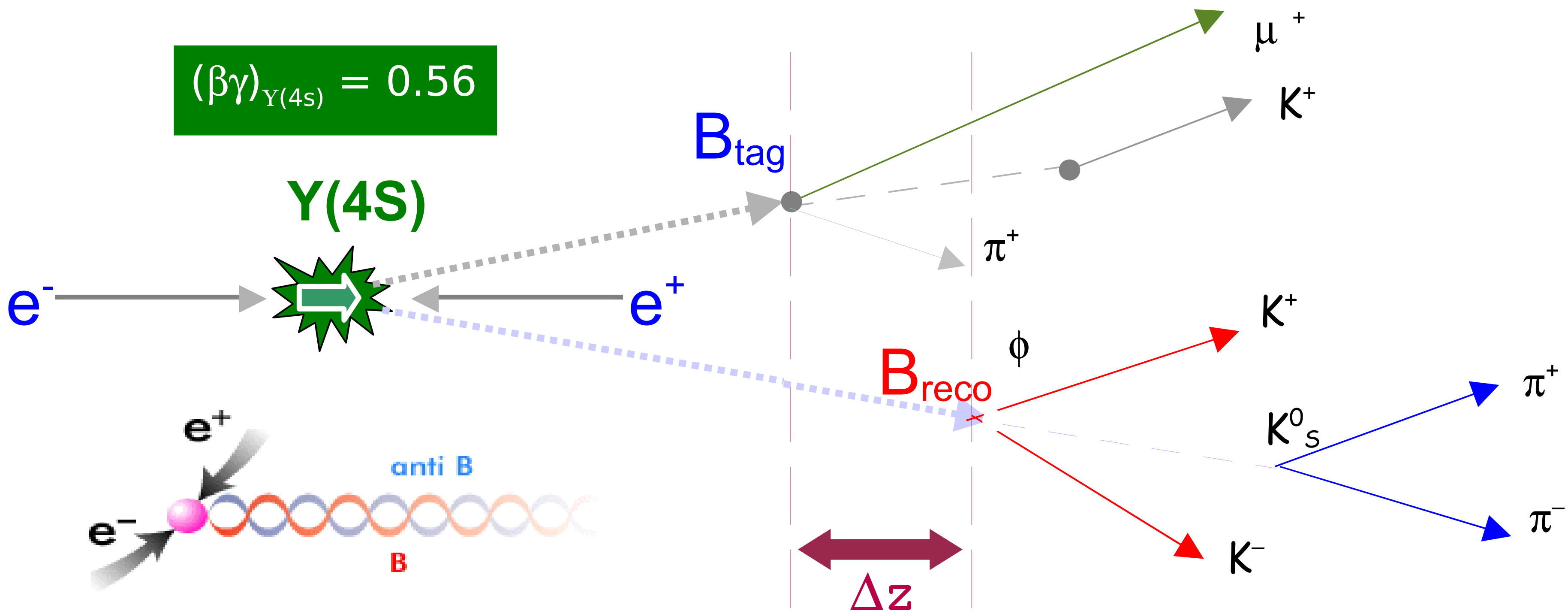
$$S_{f_{CP}} = -\frac{2\Im\lambda_{f_{CP}}}{1+|\lambda_{f_{CP}}|^2}$$

$$C_{f_{CP}} = \frac{1-|\lambda_{f_{CP}}|^2}{1+|\lambda_{f_{CP}}|^2}$$

With only one CKM term in the decay ($A = \overline{A}$)

$$C = 0 \quad ; \quad S = \sin(2\beta)$$

Vertex Reconstruction

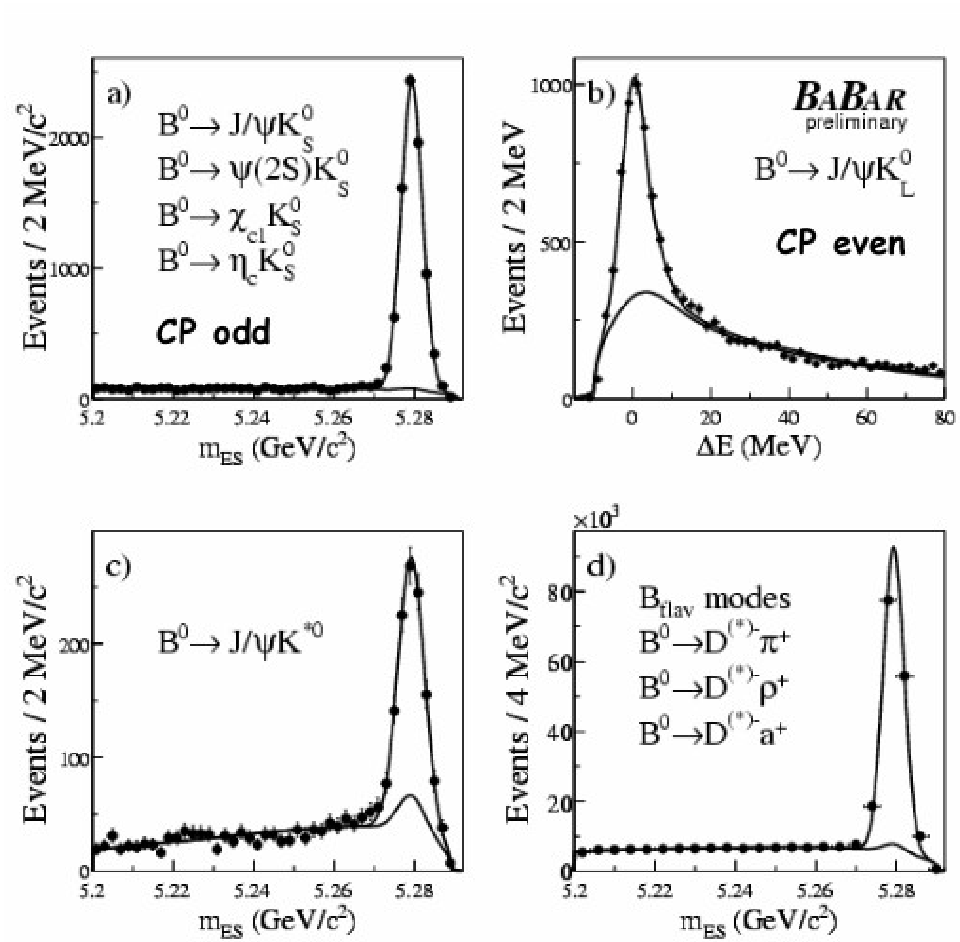


B mesons pair oscillating in a coherent state

$$< |\Delta z| > \sim 200\,\mu m$$

$$\Delta t \approx \frac{\Delta z}{<\beta\gamma> c}$$

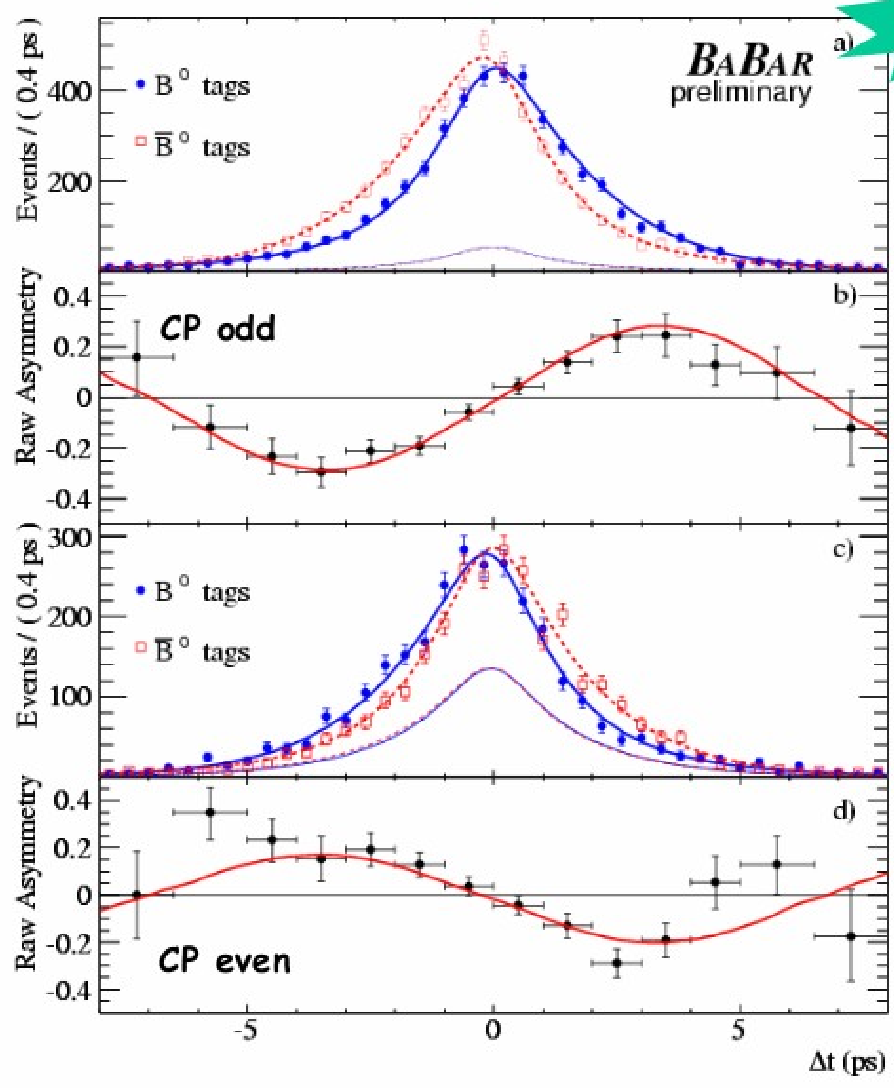
Measurement of sin2β from charmonium (I)



Sample	N_{tag}	$P(\%)$
Full CP sample	15481	76
$J/\psi K^0_S(\pi^+\pi^-)$	5426	96
$J/\psi K^0_S(\pi^0\pi^0)$	1324	87
$\psi(2S)K^0_S$	861	87
$\chi_{c1}K^0_S$	385	88
$\eta_c K^0_S$	381	79
$J/\psi K^0_L$	5813	56
$J/\psi K^{*0}$	1291	67
$J/\psi K^0$	12563	77
$J/\psi K^0_S$	6750	95
$\eta_f = -1$	8377	93

$$m_{ES} = \sqrt{(E^*_{beam})^2 - (\mathbf{p}^*_B)^2}$$
$$\Delta E = E^*_B - E^*_{beam}$$

Measurement of sin2β from charmonium (II)

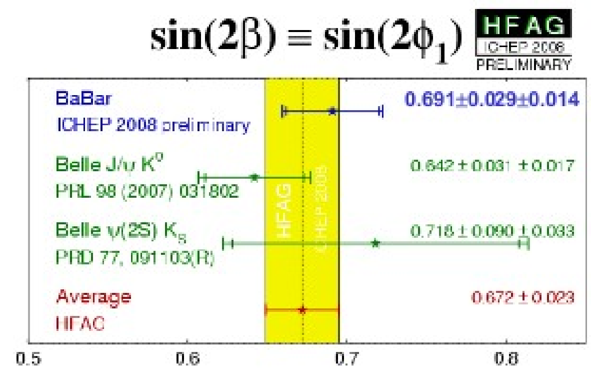


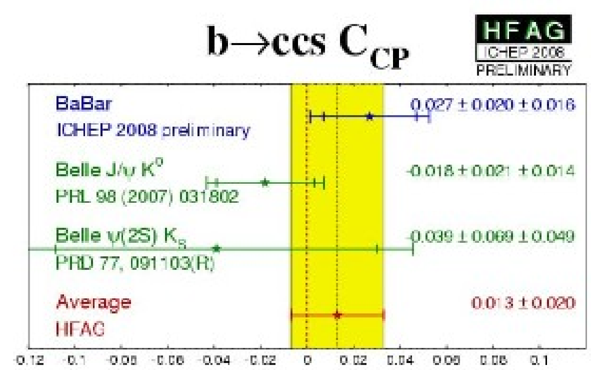
NEW!

467 million $\Upsilon(4S)$

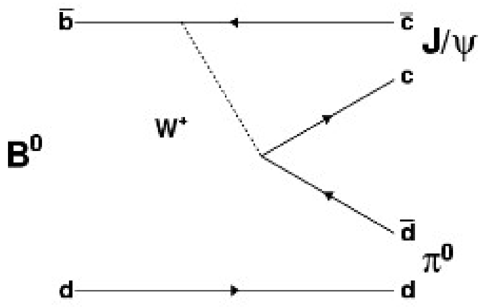
S=0.691±0.029(stat)±0.014(sys)
C=0.027±0.020(stat)±0.016(sys)

SM expectation: C=0, S=sin2β

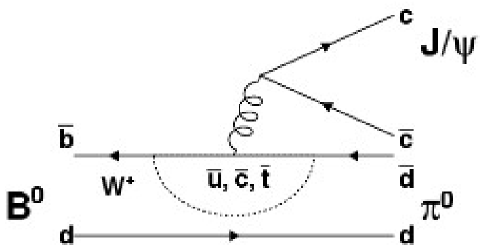


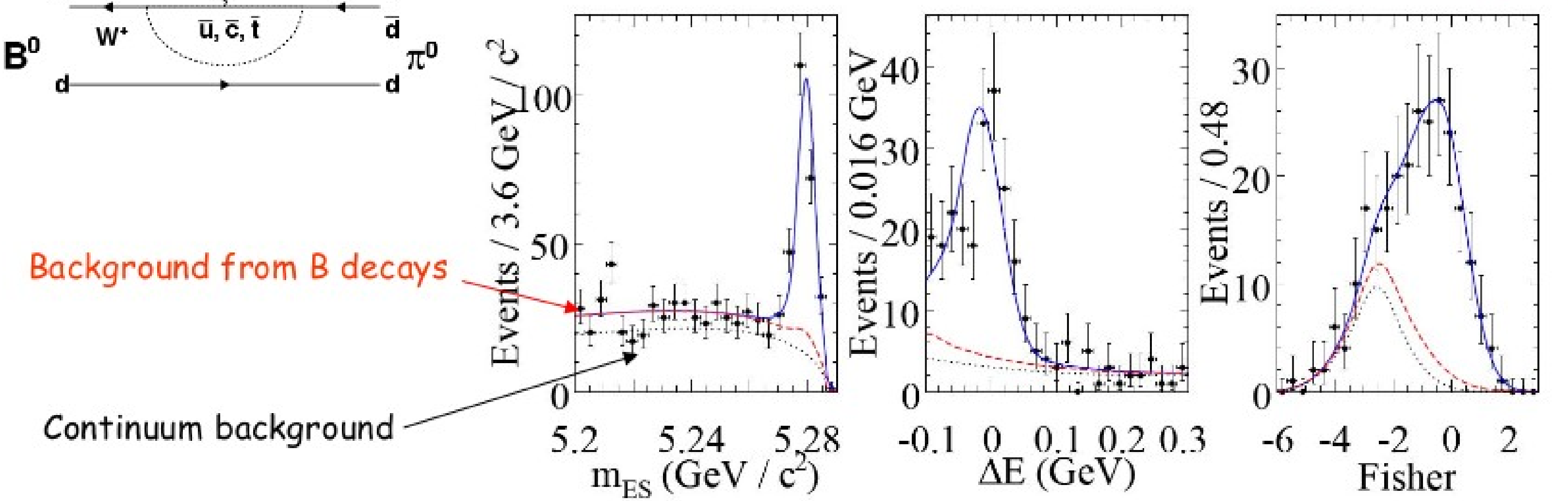


Measurement of $S(J/\psi\pi^0)$ (I)



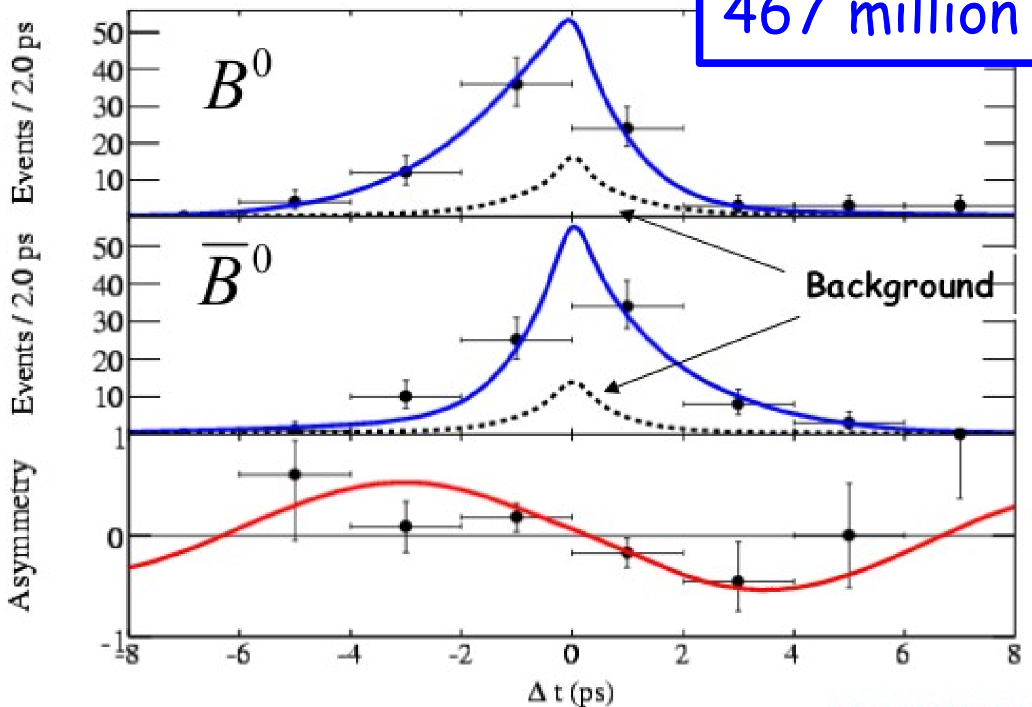
- Cabibbo suppressed decay,
- If no penguin contribution: C=0 and S=- sin2β
- A model independent approach to constrain penguin contribution in $J/\Psi K^0$ Golden modes: PRL95,221804 (2005)
- Maximum Likelihood fit on m_{ES}, ΔE, Fisher and Δt distributions:
  - ✓ Fisher: L_0,L_2 and $\cos\theta_H$
  - ✓ 184±15 signal events
  - ✓ Br=(1.69±0.14±0.07) $\times 10^{-5}$ PRL 101,021801 (2008)





Measurement of S($J/\psi\pi^0$) (II)

467 million $\Upsilon(4S)$

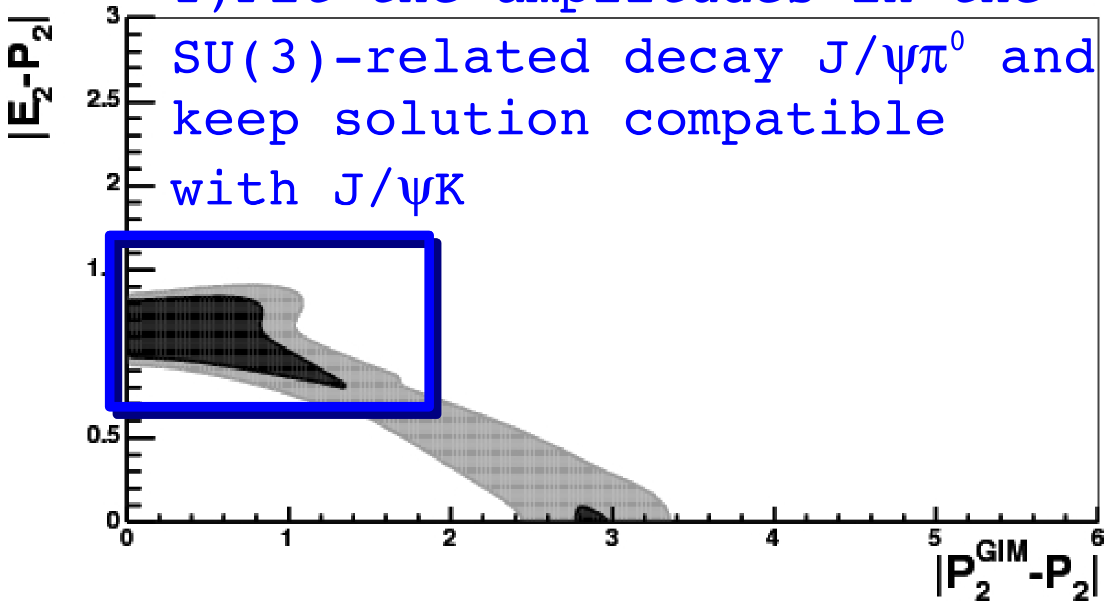


PRL 101,021801 (2008)

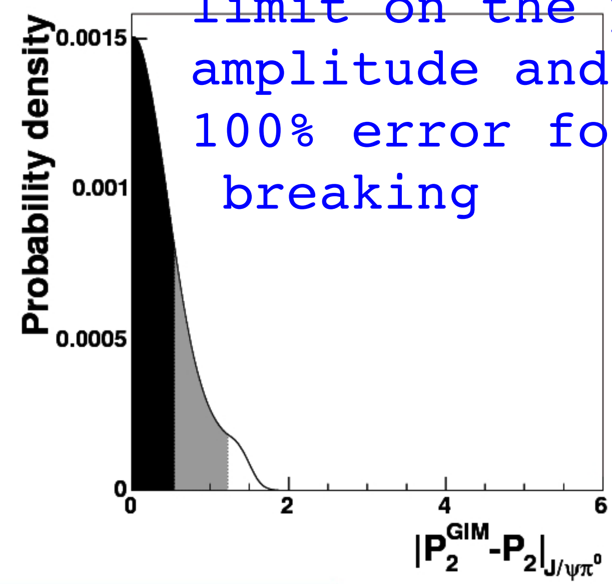
- $S = -1.23\pm0.21\pm0.04$ and $C = -0.20\pm0.19\pm0.03$
- Consistent with SM expectation for a tree-dominated transition
- Consistent with previous publication
- Significance of CP violation $> 4\sigma$

Theoretical error associated to sin2β

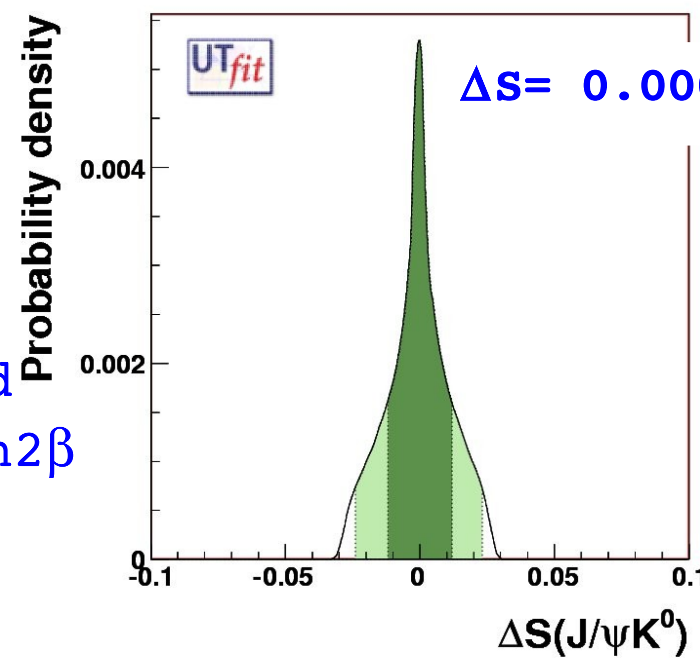
1) Fit the amplitudes in the SU(3)-related decay $J/\psi\pi^0$ and keep solution compatible with $J/\psi K$



2) Obtain the upper limit on the penguin amplitude and add 100% error for SU(3) breaking



3) Fit the amplitudes in $J/\psi K^0$ imposing the upper bound on the CKM suppressed amplitude and extract the error on sin2β



$\Delta S = 0.000 \pm 0.012$

Ciuchini, M.P. and Silvestrini hep-ph/0507290

S~sin2β in b→s penguin decays (I)

$$A(B^0\to K^0h^0) = V_{ts} V_{tb}^* \times P \left(1 + \frac{V_{us}V_{ub}^*}{V_{ts} V_{tb}^*} \frac{T+P^{GIM}}{P}\right)$$

We define

$r_F = |V_{us}V_{ub}|/|V_{ts} V_{tb}| \times (T+P^{GIM})/P$

ϕ_M = Bd mixing phase, i.e. β

βs = Bs mixing phase in the SM

$$S_F = \frac{\sin(2(\beta_s+\phi_M)) + |r_F|^2 \sin(2(\phi_M+\gamma)) + 2\,\mathrm{Re}\, r_F \sin(\beta_s + 2\phi_M + \gamma)}{1 + |r_F|^2 + 2\,\mathrm{Re}\, r_F \cos(\beta_s - \gamma)}$$

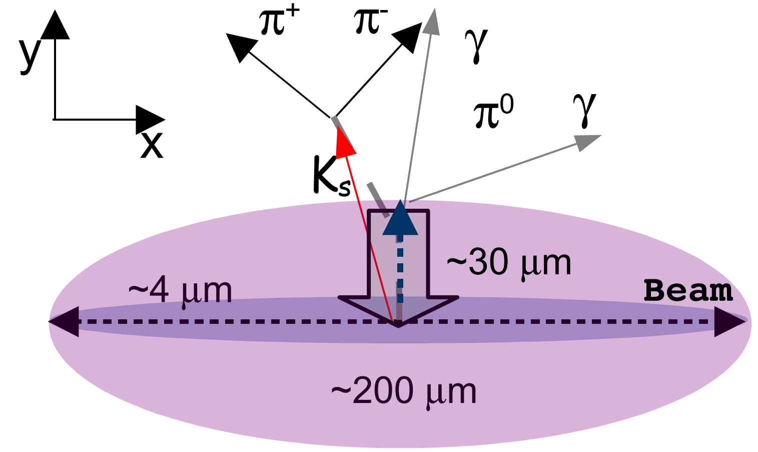
- In the SM and assuming a single amplitude ($r_F=0$) S= sin(2β+2βs), βs<< β
- BSM, S can deviates from sin2β if we have NP in Bd or Bs mixing
- A departure from sin2β in the SM can also be induced by hadronic effects ($r_F\neq0$)

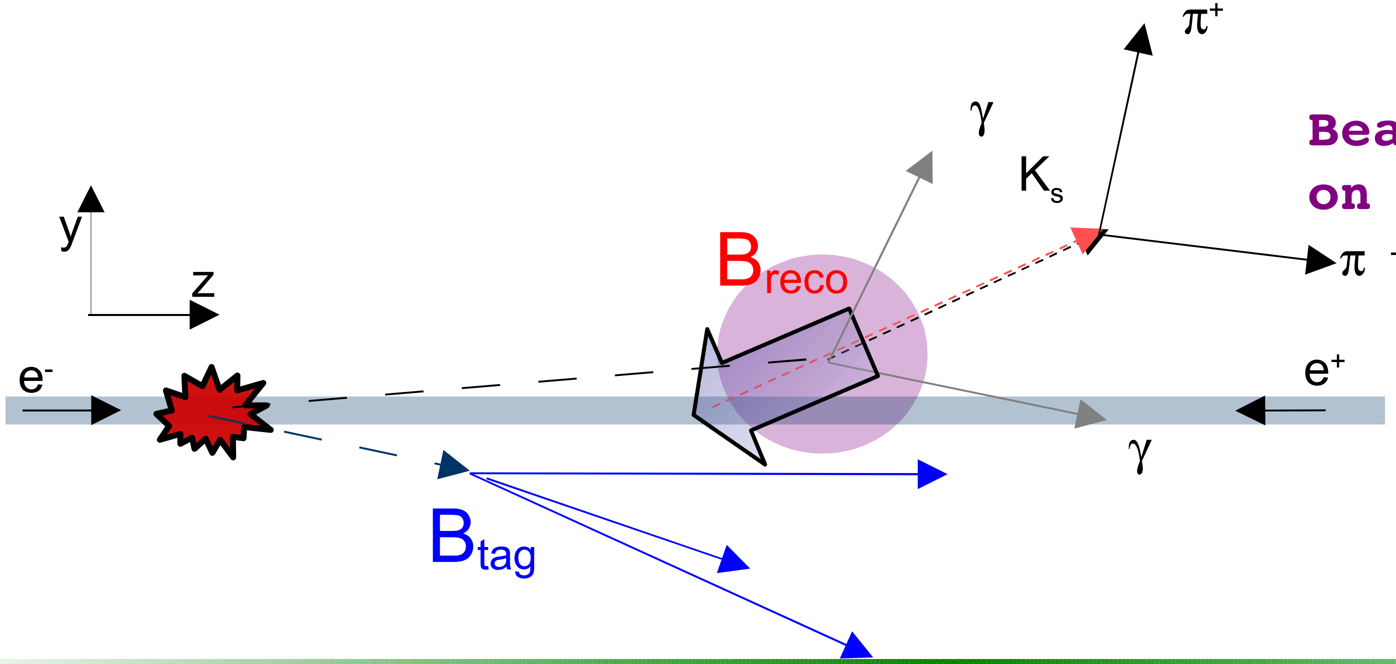
Experimental challenge: B vtx from Ks

No charged tracks from the B vertex.

Extrapolate back the K_S:

- Using the constraint of the beam spot on the transverse plane
- Requiring the K_S to decay in the inner part of the SVT

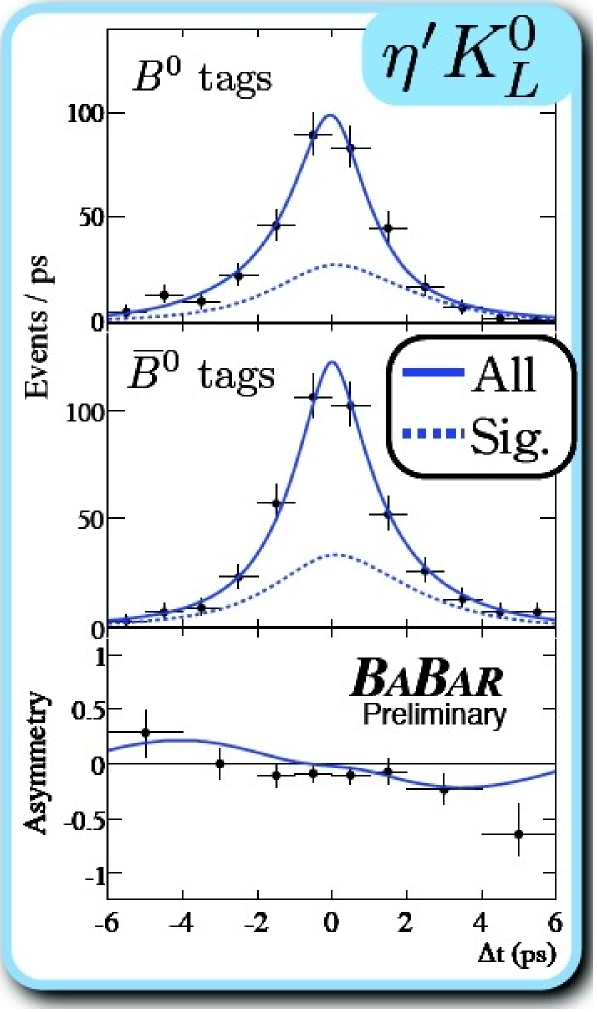


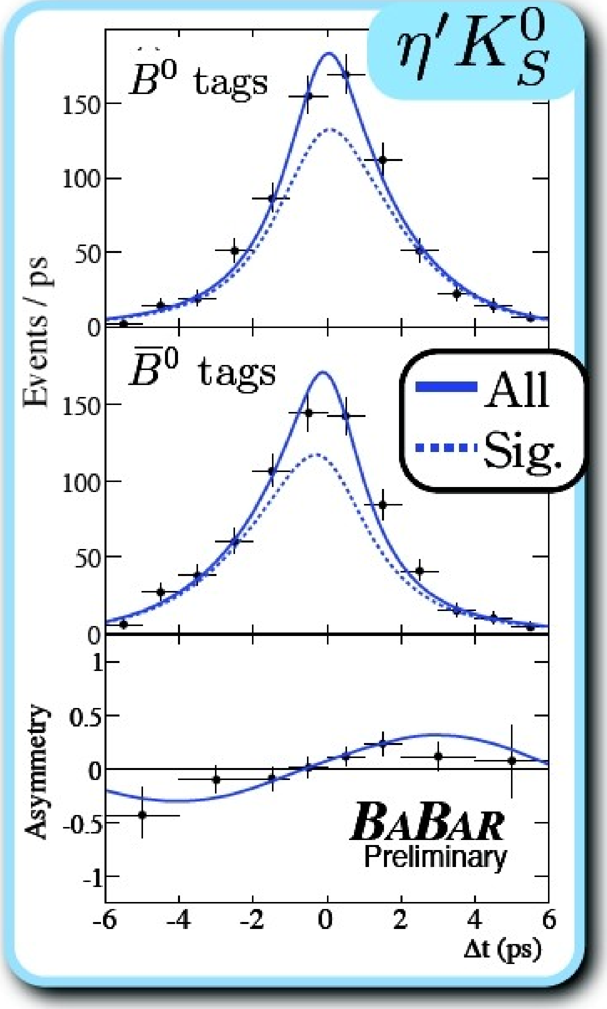


Beam spot constraint on transverse plane

BaBar updates Summer08 (I)

465 million $\Upsilon(4S)$



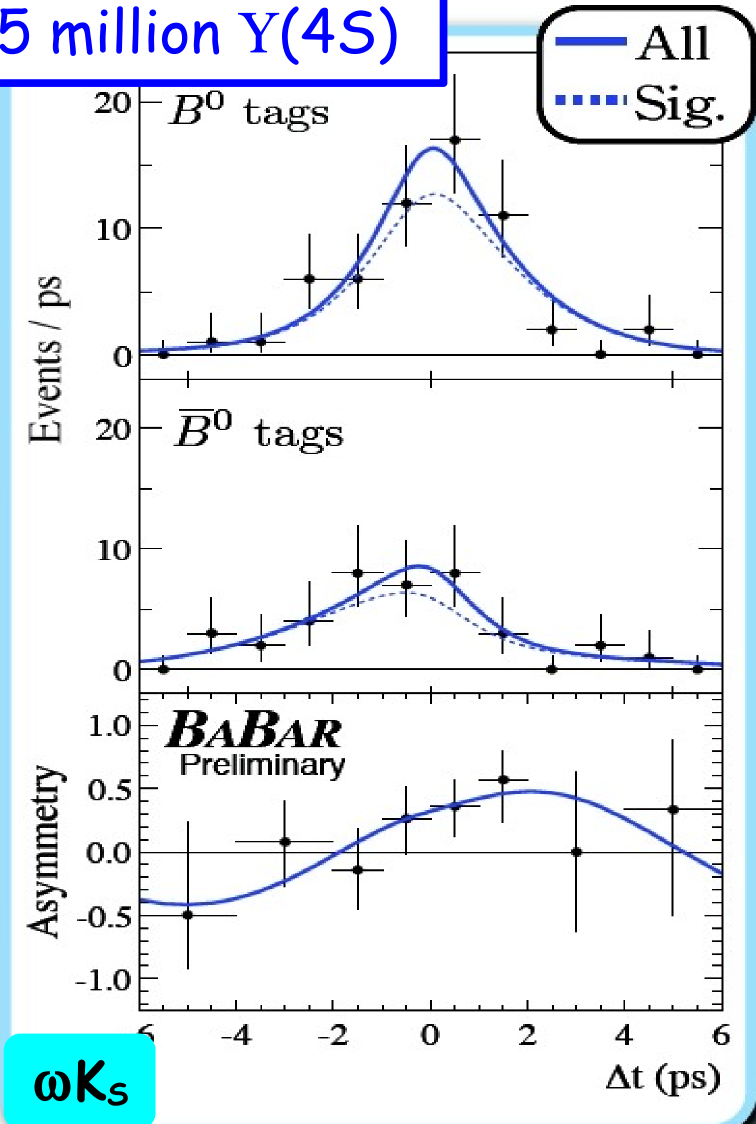


Mode	$-\eta_f S_f$
$\eta' K_S^0$	$0.53 \pm 0.08 \pm 0.02$
$\eta' K_L^0$	$0.82 \pm 0.19 \pm 0.02$
$\eta' K^0$	$0.57 \pm 0.08 \pm 0.02$

Mode	C_f
$\eta' K_S^0$	$-0.11 \pm 0.06 \pm 0.02$
$\eta' K_L^0$	$0.09 \pm 0.14 \pm 0.02$
$\eta' K^0$	$-0.08 \pm 0.06 \pm 0.02$

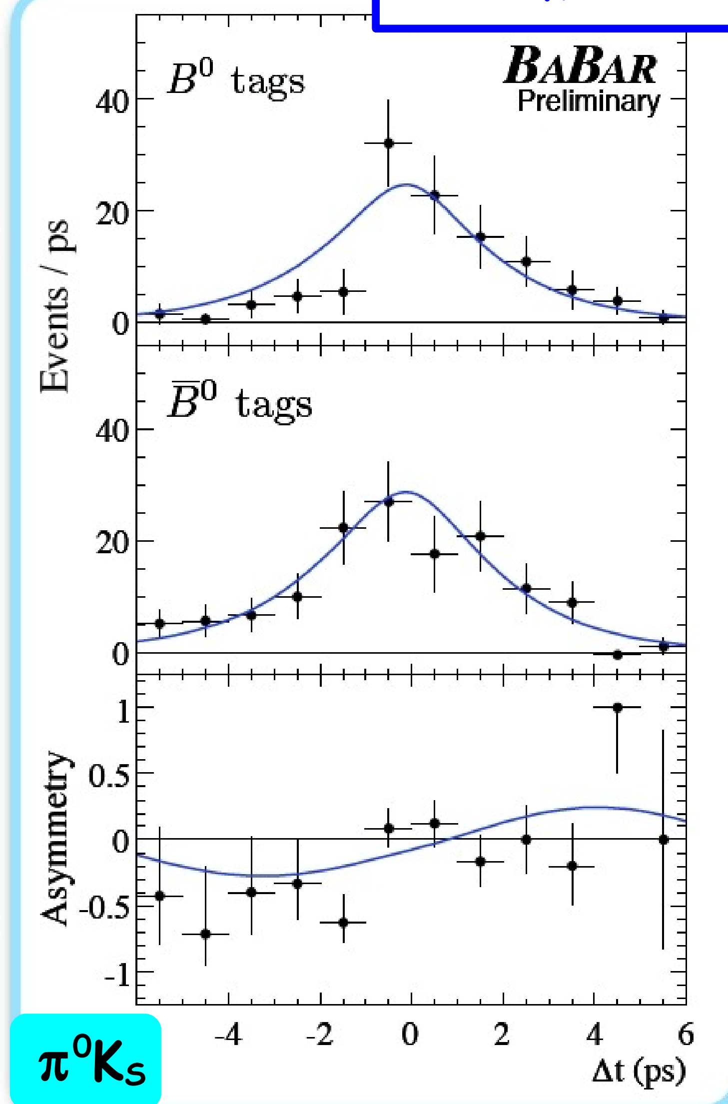
BaBar updates Summer08 (II)

465 million Υ(4S)



$$S = 0.55^{+0.26}_{-0.29} \pm 0.02$$
$$C = -0.52^{+0.22}_{-0.20} \pm 0.03$$

465 million Υ(4S)



$$S = 0.55 \pm 0.20 \pm 0.03$$
$$C = 0.13 \pm 0.13 \pm 0.03$$

BaBar updates Summer08 (III)

465 million $\Upsilon(4S)$

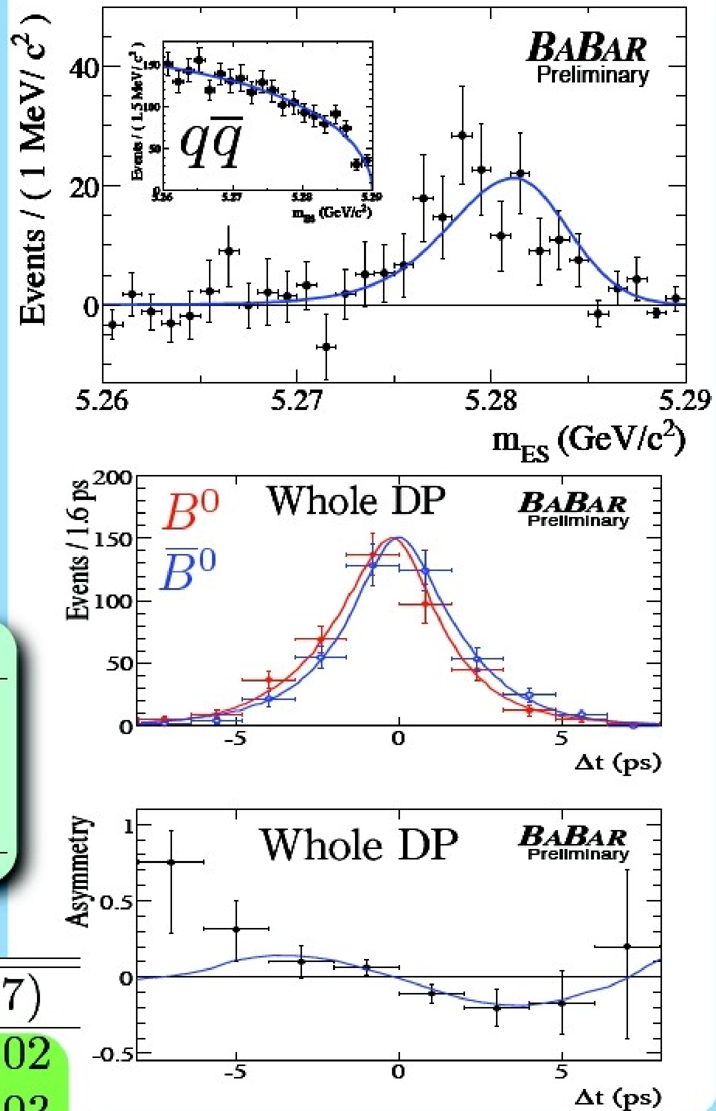
$B^0 \rightarrow K^+ K^- K^0_S$

- Reconstruct $K^0_S \rightarrow \pi^+\pi^-$ and $\pi^0\pi^0$.
- Model uses: ϕK^0_S, $f_0 K^0_S$ $X_0 K^0_S$, NR, $\chi_{c0} K^0_S$, D^+K^-, $D^+_s K^-$
- Fit entire Dalitz plot, then fit low-mass ($m_{K^+K^-} < 1.1$ GeV) and high-mass ($m_{K^+K^-} > 1.1$ GeV) regions.

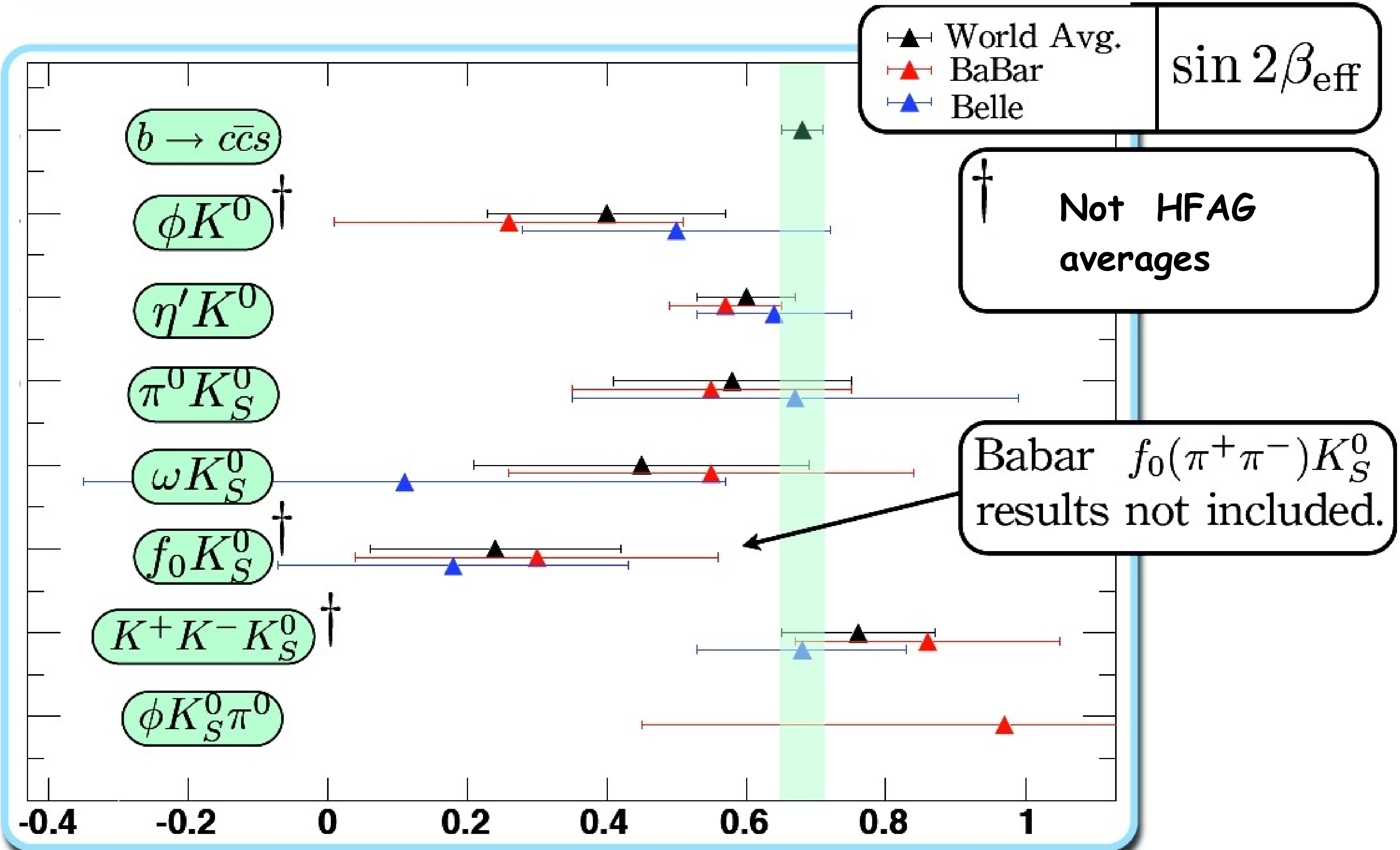
Fit	Signal yield
Whole DP	1428 ± 47
High-Mass	1011 ± 39
Low-mass	421 ± 25

$\frac{\pi}{2} - \beta$ ambiguity ruled out at 4.8σ.

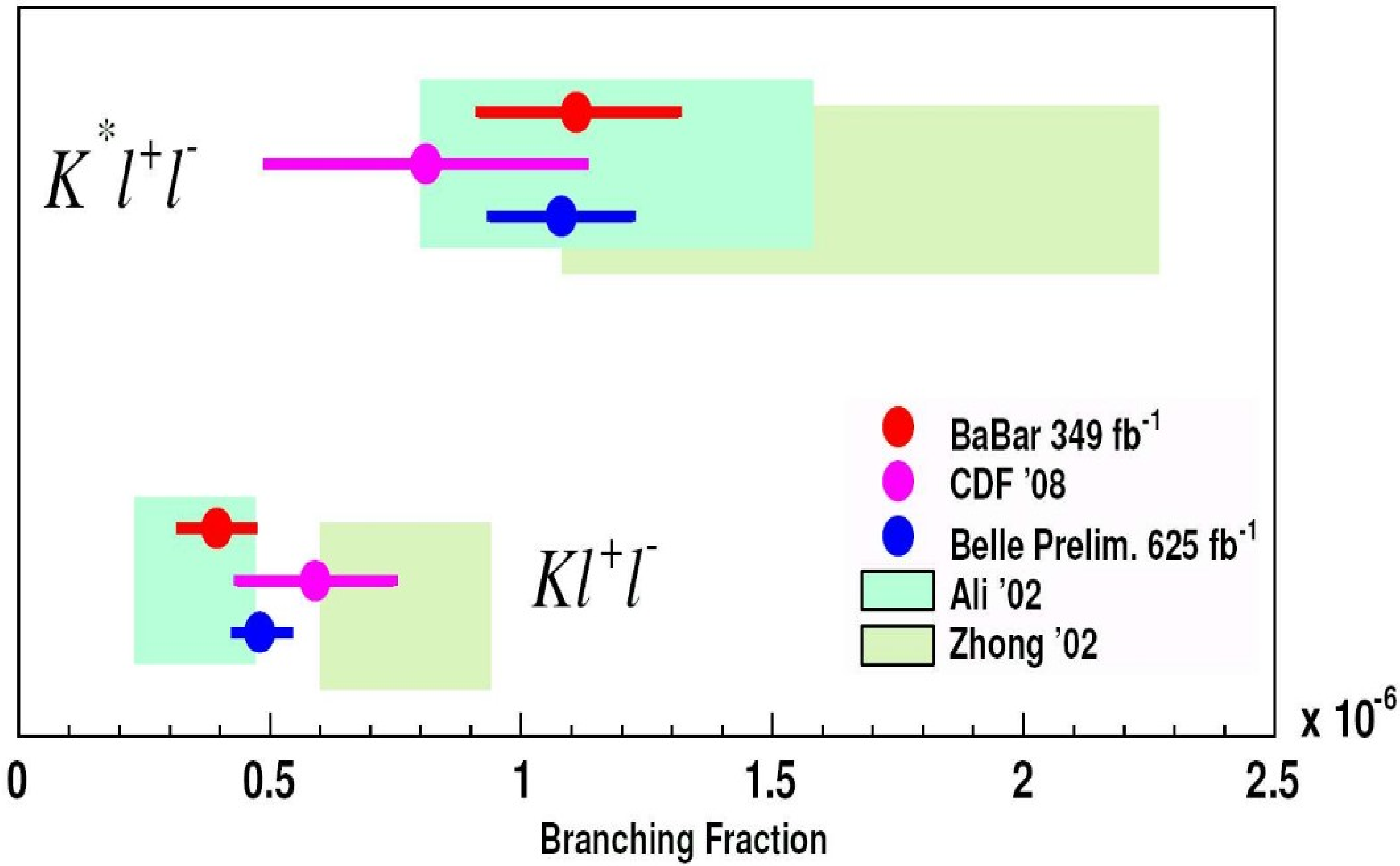
Fit	A_{CP} $(-C_f)$	$\beta_{\rm eff}$ $(\beta_{\rm SM} \simeq 0.37)$
Whole DP	$0.03 \pm 0.07 \pm 0.02$	$0.44 \pm 0.07 \pm 0.02$
High-Mass	$0.05 \pm 0.09 \pm 0.04$	$0.52 \pm 0.08 \pm 0.03$
ϕK^0_S	$0.14 \pm 0.19 \pm 0.02$	$0.13 \pm 0.13 \pm 0.02$
$f_0 K^0_S$	$0.01 \pm 0.26 \pm 0.07$	$0.15 \pm 0.13 \pm 0.03$



Summary of the results for ΔS



b→sll decays



Branching ratio in agreement with the theoretical predictions

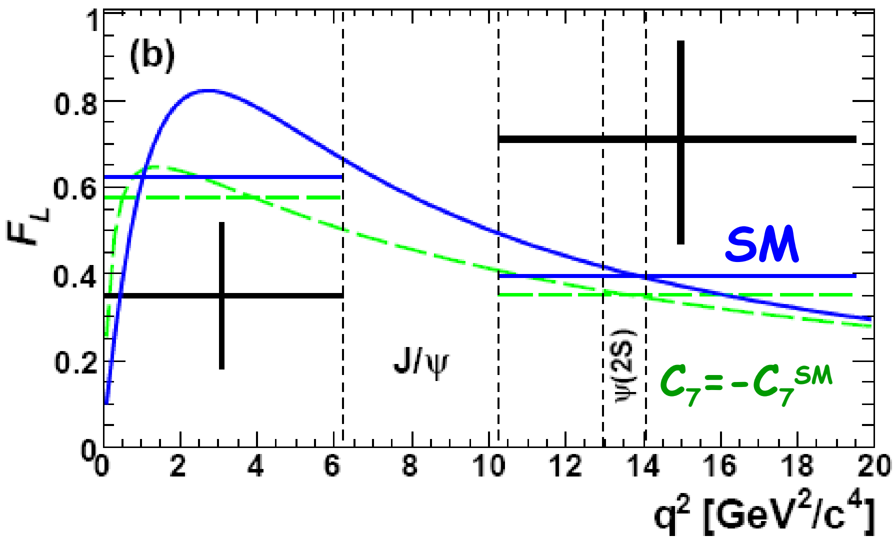
Rich phenomenology beyond the BR (isospin asymmetry, AFB, ...)

FL and AFB Results

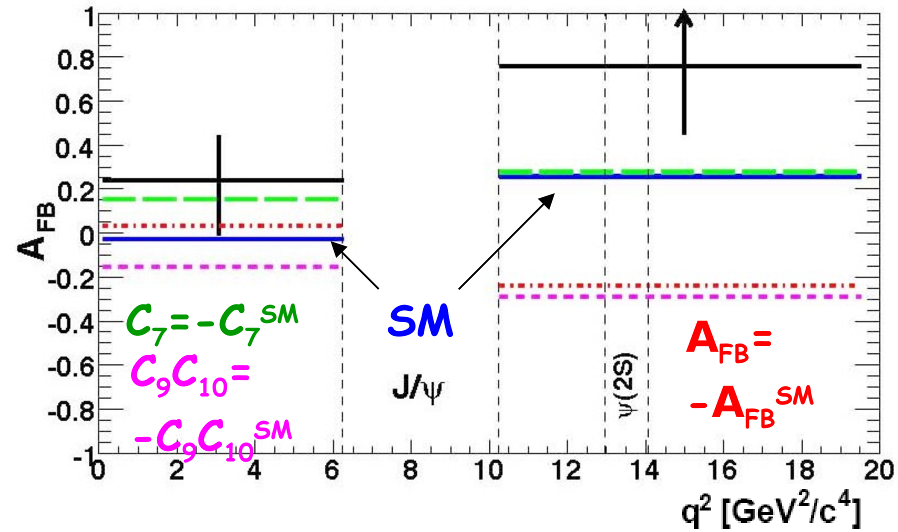
384 million Υ(4S)

ArXiv: 0804.4412
submitted to PRL

Longitudinal K* polarization



Lepton forward-backward asymmetry



$$F_L^{\text{low } s} = 0.35 \pm 0.16 \pm 0.04$$

$$F_L^{\text{high } s} = 0.71^{+0.20}_{-0.22} \pm 0.05$$

$$A_{FB}^{\text{low } s} = 0.24^{+0.18}_{-0.23} \pm 0.06$$

$$A_{FB}^{\text{high } s} = 0.76^{+0.52}_{-0.32} \pm 0.07$$

Isospin Asymmetry A_I

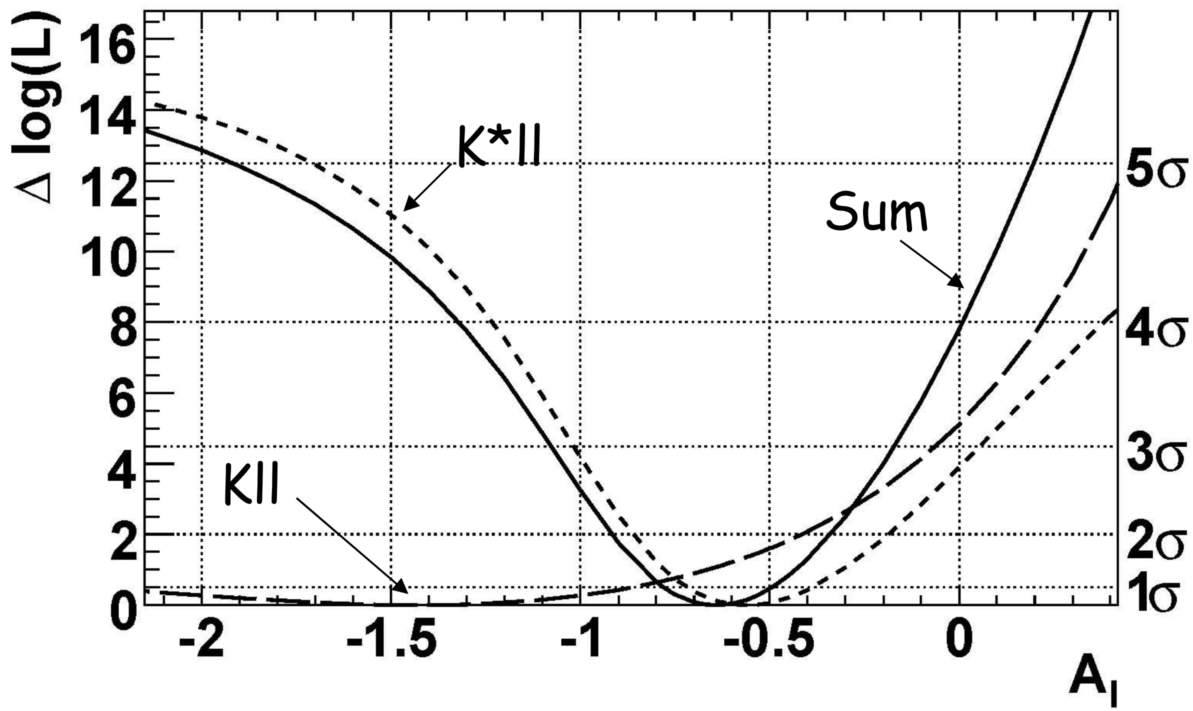
- No significant asymmetry observed in high mass region
- In low mass region, **significance to exclude A_I=0, including systematics**:
  - Kll: 3.2σ
  - K*ll: 2.7σ
  - K(*)ll: 3.9σ

arXiv:0807.4119
submitted to PRL

384 million Υ(4S)

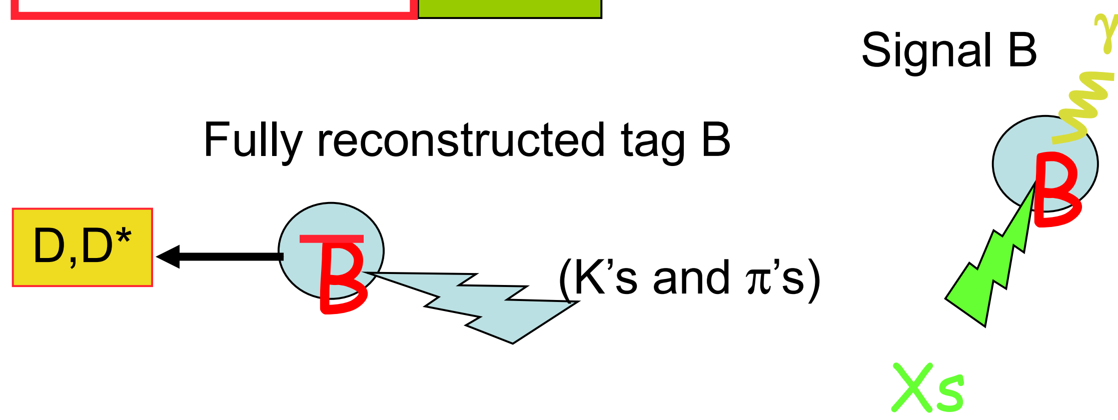
Mode	Low mass A_I
$K\mu^+\mu^-$	$-0.91^{+1.2}_{-\infty} \pm 0.18$
Ke^+e^-	$-1.41^{+0.49}_{-0.69} \pm 0.04$
$K\ell^+\ell^-$	$-1.43^{+0.56}_{-0.85} \pm 0.05$
$K^*\mu^+\mu^-$	$-0.26^{+0.50}_{-0.34} \pm 0.05$
$K^*e^+e^-$	$-0.66^{+0.19}_{-0.17} \pm 0.02$
$K^*\ell^+\ell^-$	$-0.56^{+0.17}_{-0.15} \pm 0.03$

Low mass A_I fit ΔlogL scans



Measuring $B \to X_s\gamma$ with recoil technique

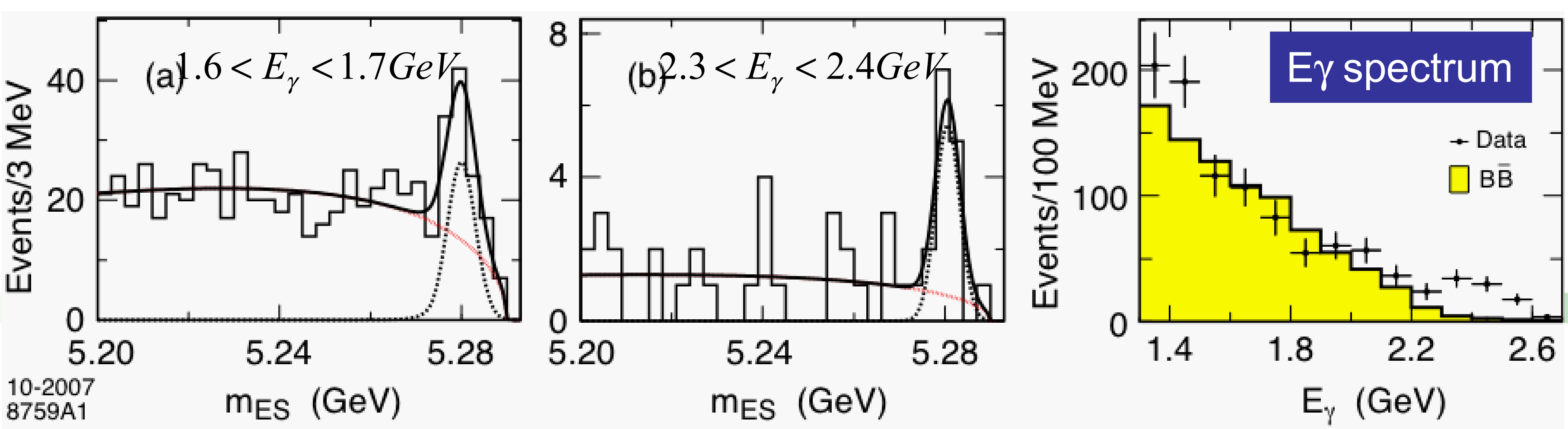
PRD 77:051103 2008 | $210 fb^{-1}$



$$B(B \to X_s\gamma, E_\gamma > 1.9 GeV) = 3.66 \pm 0.85(stat) \pm 0.60(sys) \times 10^{-4}$$

$$\langle E_\gamma \rangle (E_\gamma > 1.9 GeV) = 2.289 \pm 0.058 \pm 0.027 GeV$$

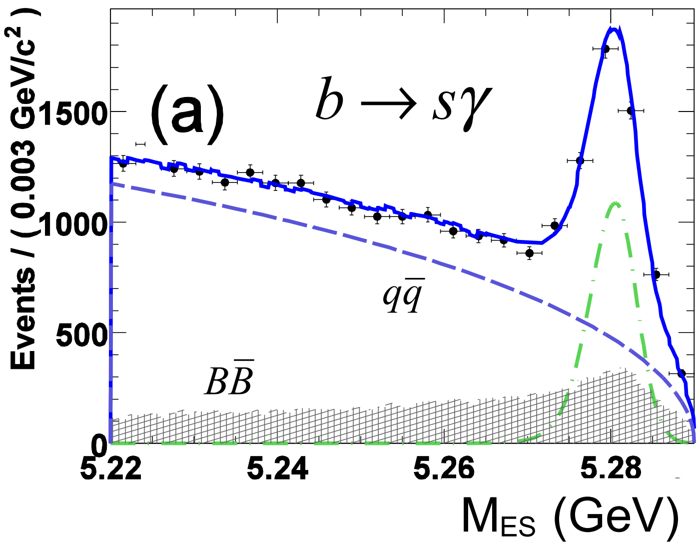
$$\langle (E_\gamma - \langle E_\gamma \rangle)^2 \rangle = 0.0334 \pm 0.0124 \pm 0.0062 GeV^2$$



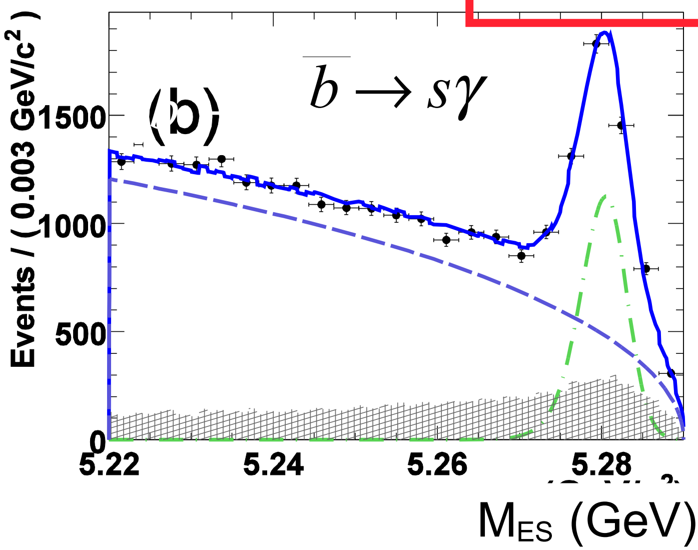
Time Integrated CP Asymmetry with $B \to X_s\gamma$

383 million $\Upsilon(4S)$

Preliminary



arXiv:0805.4796



Detector asymmetry A_{det}=-0.007 ± 0.005

$$A_{cp} = -0.011 \pm 0.030(stat) \pm 0.014(sys)$$

Most precise measurement to date of $A_{cp}(B \to X_s\gamma)$. Consistent with no CPV

Conclusions

The precision measurements at the B factories have confirmed that the CKM matrix is the source of flavor mixing and CP violation in nature

Some measurement shows a “tension” with respect to the global picture.

Some of these measurements are difficult to explain in the context of Standard Model

The presence of a 4th generation is an economical & attracting solution to these “puzzles”

The precision is limited by the experimental data

We gave a summary of the inputs from BaBar for this kind of analysis

Charmless hadronic B decays

Time Dependent measurements in the golden mode and measurement of sin2b

sin2b from penguin-dominated bs decays

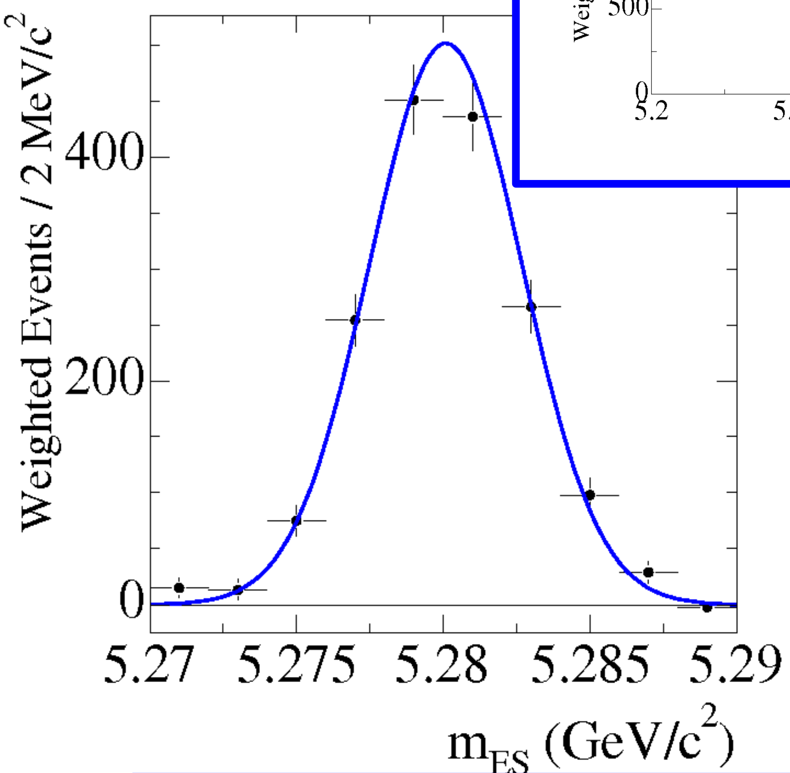
rare b decays (bsg and bsll)

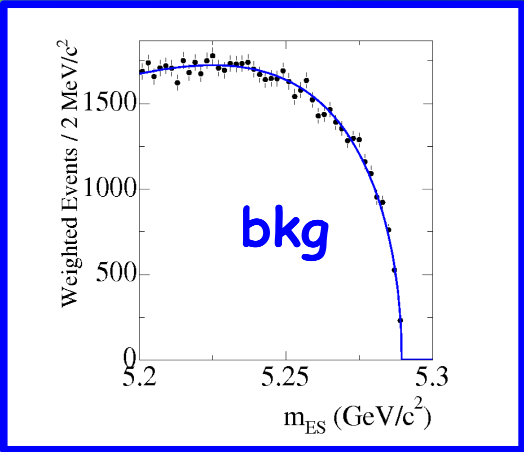
The systematic error dominates for the rates, but not for the CP asymmetries

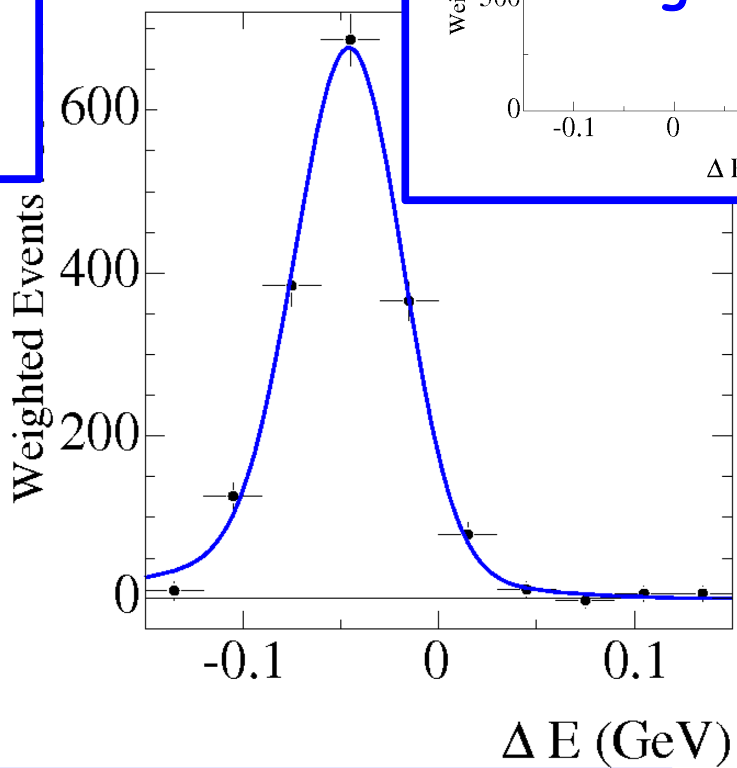
There is a lot of room for future experiments (LHCb and superB) to improve the precision of the constraints further

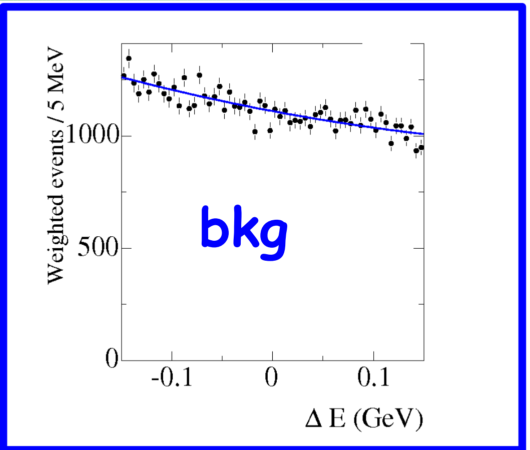
BR of $B^0 \to K^+\pi^-$ decays

Phys.Rev.D75:012008,2007
hep-ex/0608003







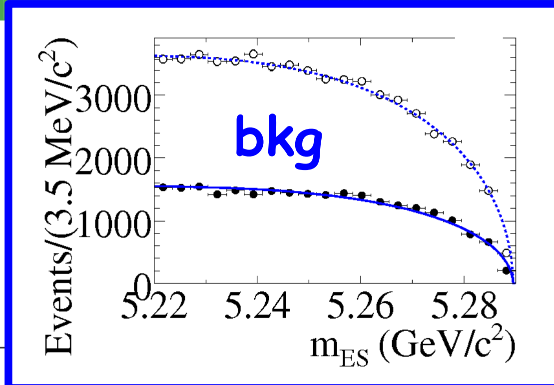


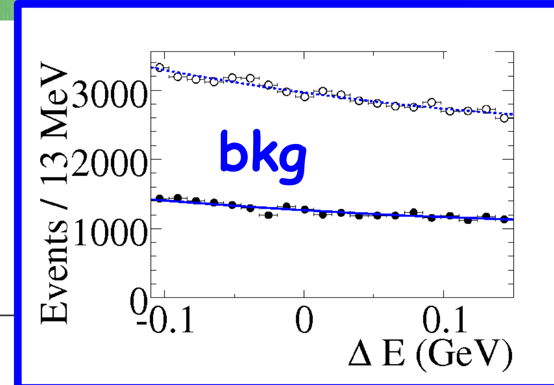
$BR(B^0 \to K^+\pi^-) = (19.1 \pm 0.6 \pm 0.6) \times 10^{-6}$

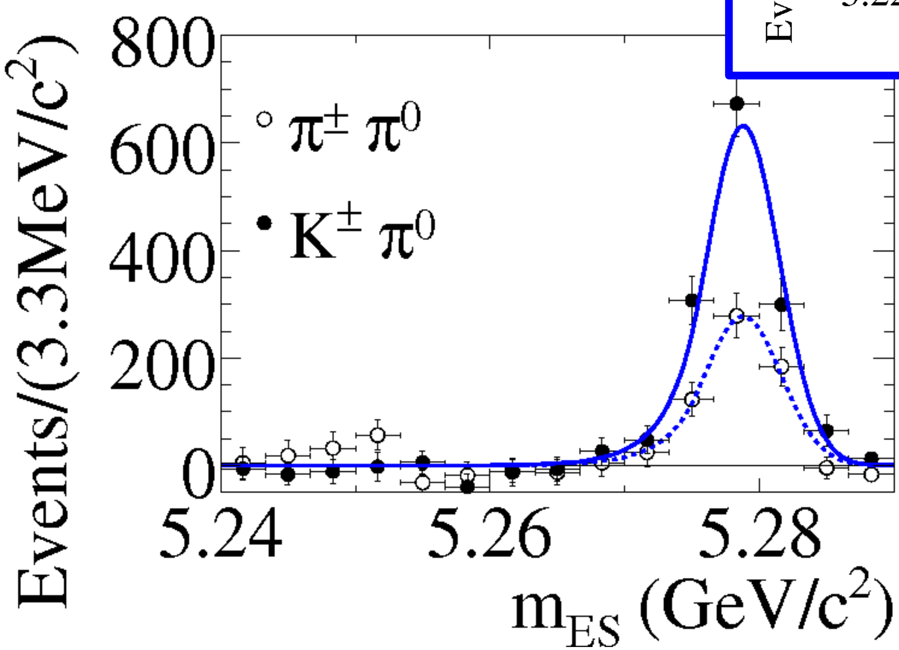
$BR(B^0 \to K^+\pi^-) = (18.1 \pm 0.6 \pm 0.6) \times 10^{-6}$ $\Gamma(E\gamma^{max}) = 0.947 \pm 0.005$

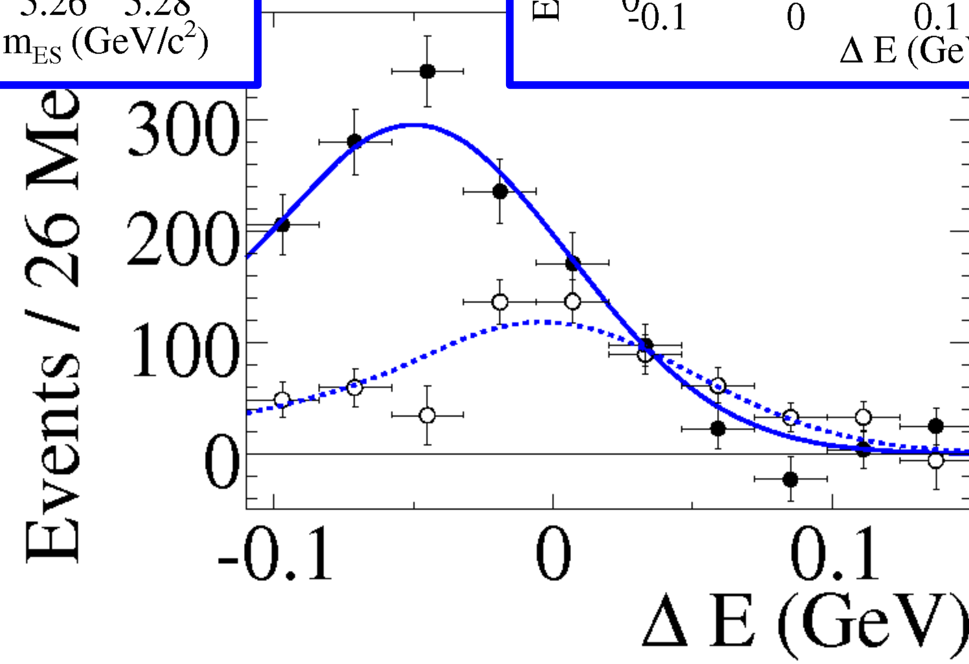
BR and A_{CP} of $B^+ \to K^+\pi^0$ decays

Phys.Rev.D76:091102,2007.
e-Print: arXiv:0707.2798
[hep-ex]







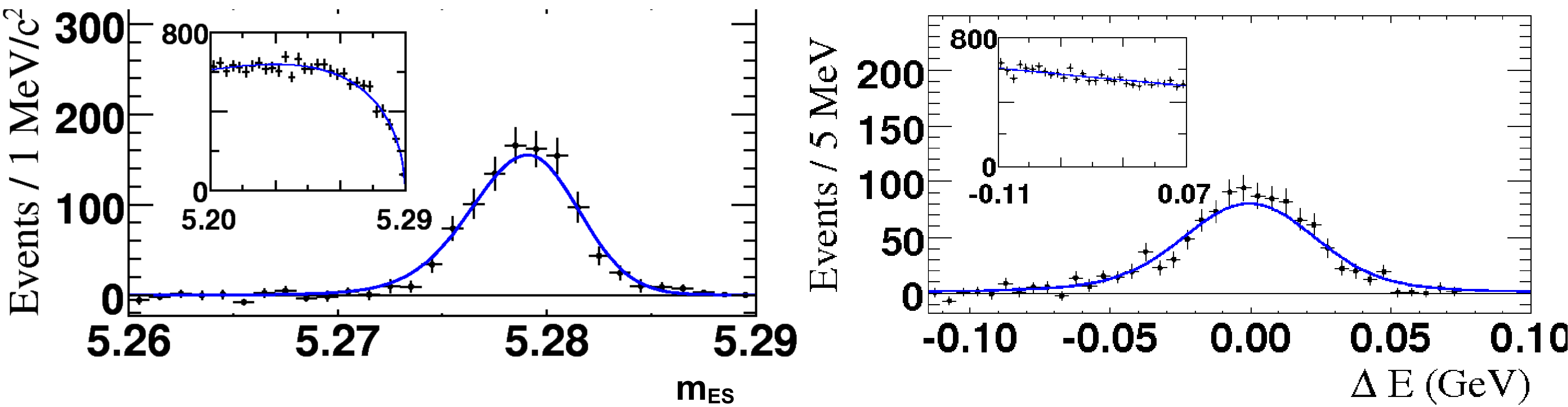


$BR(B^+ \to K^+\pi^0) = (13.6 \pm 0.6 \pm 0.7) \times 10^{-6}$

$A_{CP}(B^+ \to K^+\pi^0) = 0.030 \pm 0.039 \pm 0.010$

BR and A_{CP} of $B^+ \to K^0 \pi^+$ decays

Phys.Rev.Lett.97:171805,2006.
e-Print: hep-ex/0608036



$BR(B^+ \to K^0 \pi^+) = (23.9 \pm 1.1 \pm 1.0) \times 10^{-6}$

$A_{CP}(B^+ \to K^0 \pi^+) = -0.029 \pm 0.039 \pm 0.010$