Recent Highlights from Belle

Beyond the CP violation measurements

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8th July 2003, 17h00 — DESY Seminar

KEKB

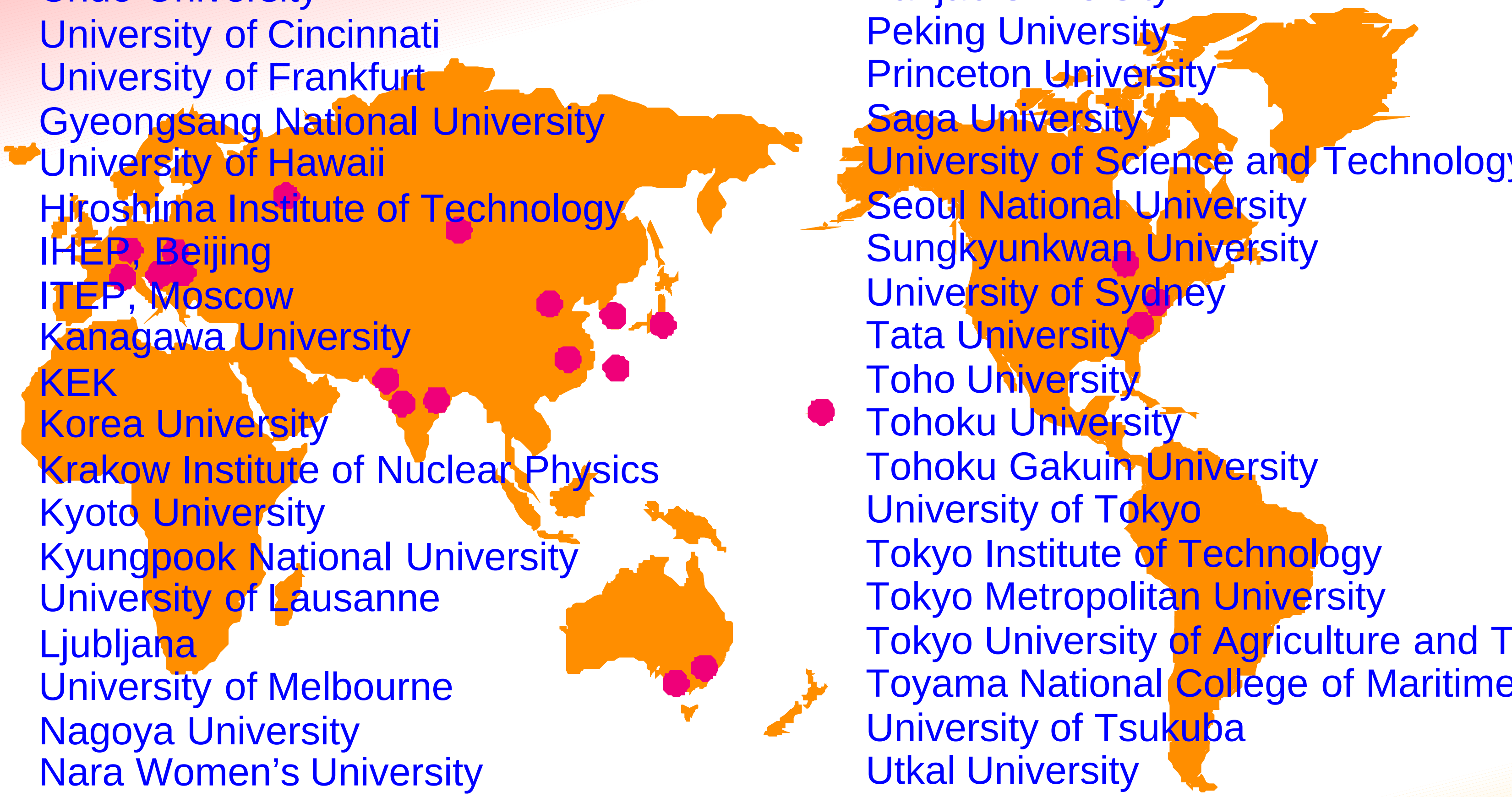
Quest for CPV

BELLE

The Belle Collaboration

~300 physicists from 13 regions, 53 institutions

Aomori University
Budker Institute of Nuclear Physics
Chiba University
Chuo University
University of Cincinnati
University of Frankfurt
Gyeongsang National University
University of Hawaii
Hiroshima Institute of Technology
IHEP, Beijing
ITEP, Moscow
Kanagawa University
KEK
Korea University
Krakow Institute of Nuclear Physics
Kyoto University
Kyungpook National University
University of Lausanne
Ljubljana
University of Melbourne
Nagoya University
Nara Women's University
National Central University
National Kaoshing Normal University
National Lien-Ho College of Technology
National Taiwan University
Nihon Dental College
Niigata Uniersity
Osaka University
Osaka City University
Panjab University
Peking University
Princeton University
Saga University
University of Science and Technology of China
Seoul National University
Sungkyunkwan University
University of Sydney
Tata University
Toho University
Tohoku University
Tohoku Gakuin University
University of Tokyo
Tokyo Institute of Technology
Tokyo Metropolitan University
Tokyo University of Agriculture and Technology
Toyama National College of Maritime Technology
University of Tsukuba
Utkal University
IHEP, Vienna
Virginia Polytechnic Institute and State University
Yokkaichi University
Yonsei University

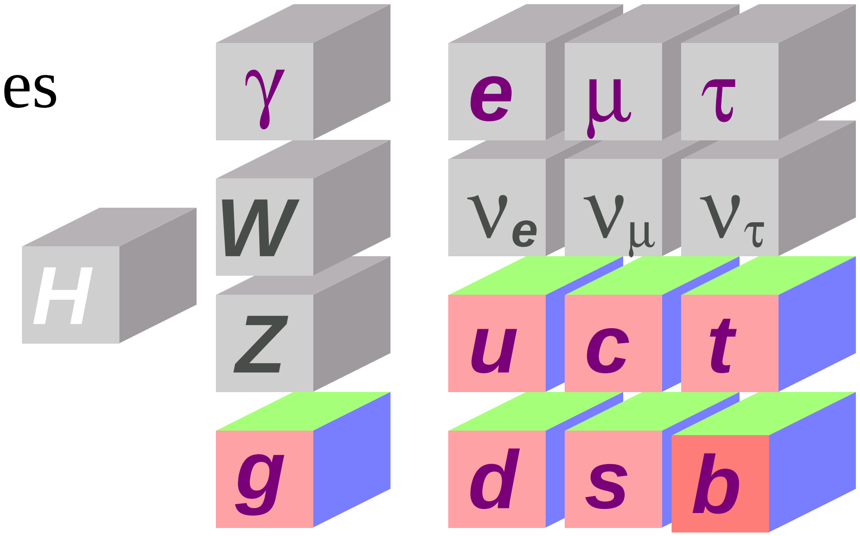


[= population of those who use ϕ_1, ϕ_2, ϕ_3 (instead of β, α, γ, sorry if you confused!)]

(Birthname given by A.I.Sanda) (Nickname given by somebody else)

Where we stand. . .

- Success of the Standard Model ($U(1) \otimes SU(2) \otimes SU(3)$ symmetry) hasn't been providing answers to our fundumental questions:
  - Baryogenesis
  - Grand unification of forces
  - Quark/lepton families?
- Higgs boson is the only missing piece in the SM
- What we wish is a theory (and experimental evidence) beyond SM (SUSY?)



"SM building blocks"

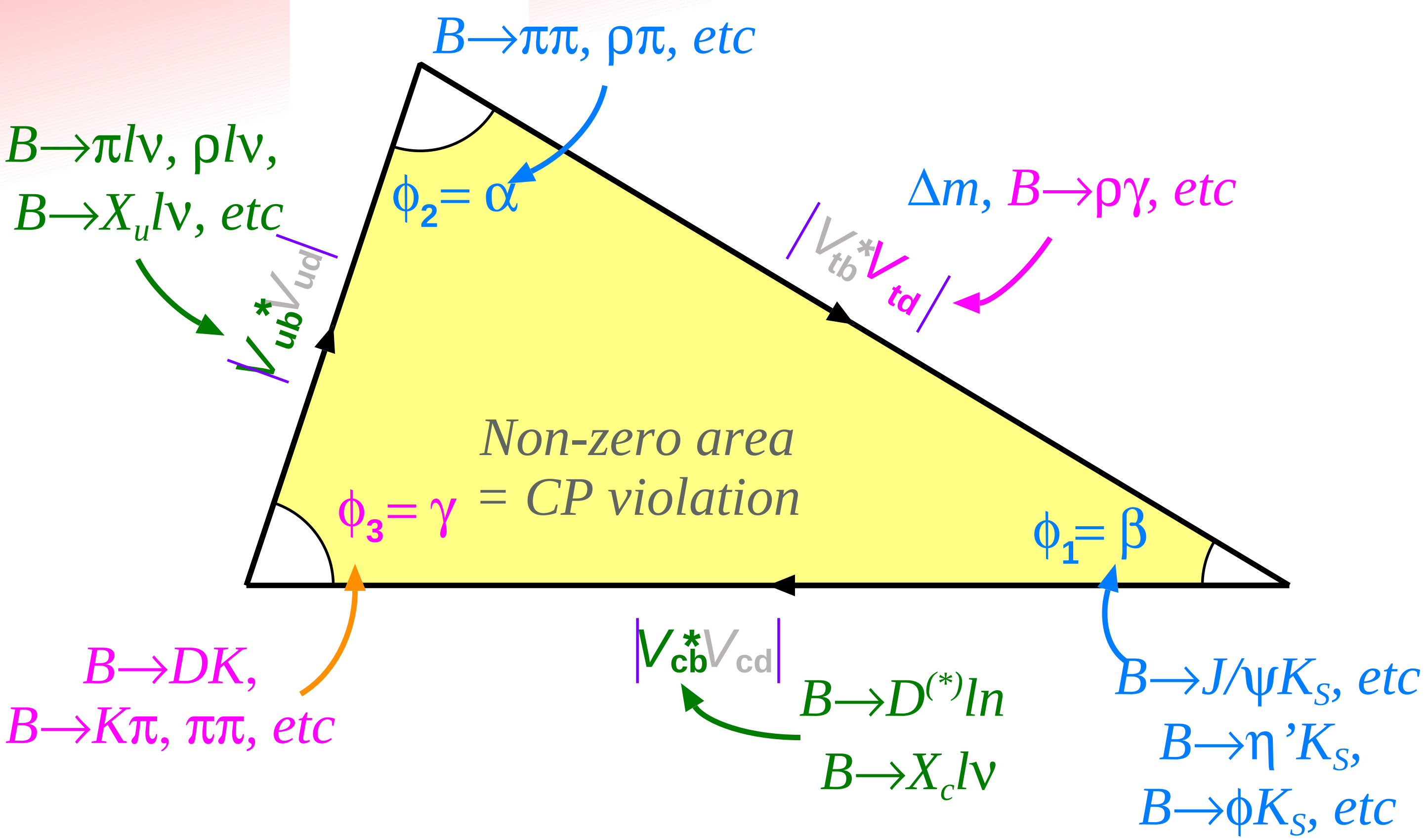
(Neutrino mixing is the only available piece of info beyond SM)

CPV in B decays — one more non-trivial test of the SM — has been discovered by two B-factories (KEK and SLAC).

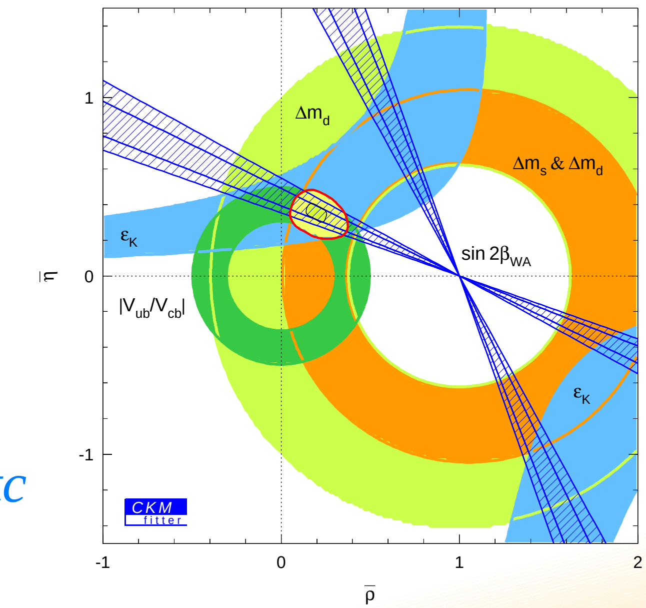
The aim is now to find any sign of new physics with more and more data.

Unitarity triangle

Unitarity of the CKM matrix $\Rightarrow V^*_{ub}V_{ud} + V^*_{cb}V_{cd} + V^*_{tb}V_{td} = 0$



UT is already over-constrained at the first round



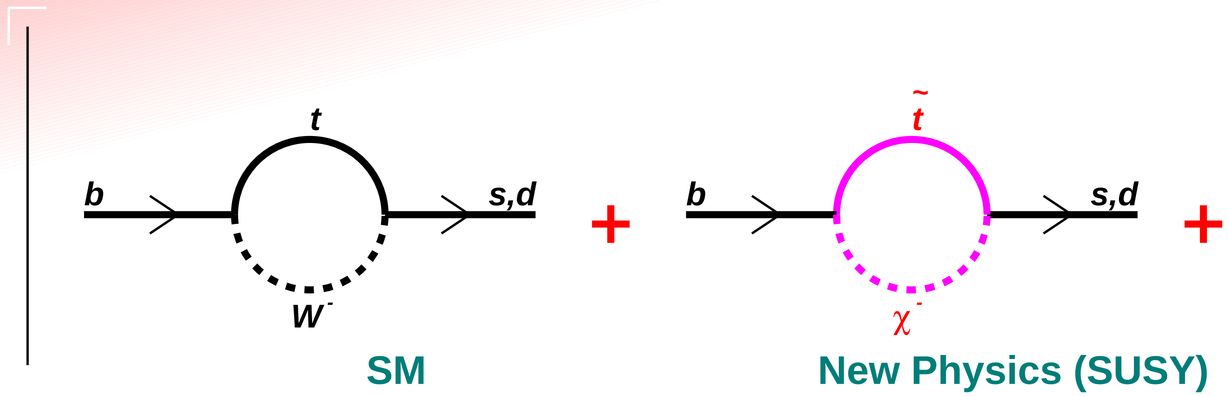
However, it is important to further shrink the errors.

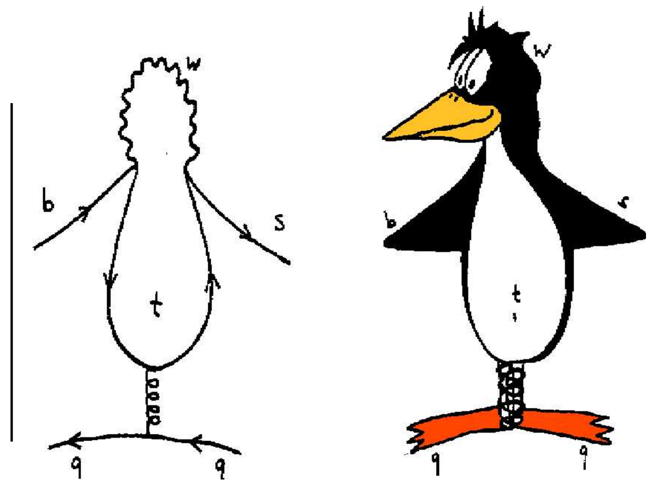
- Mixing for $\phi_1(=\beta)$, $\phi_2(=\alpha)$ and $|V_{td}|$
- Semileptonic decays for $|V_{cb}|$ and $|V_{ub}|$
- Rare decays for $\phi_3(=\gamma)$ and $|V_{td}|$

(All the sides and angles are measureable with B^0_d and B^+ decays)

Where to look for new physics

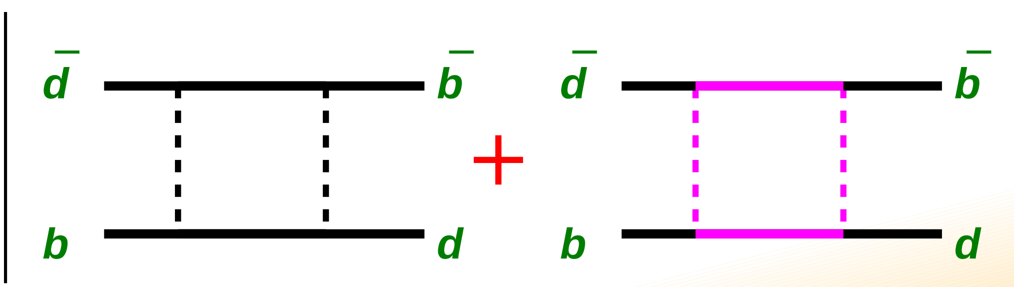
- Penguins



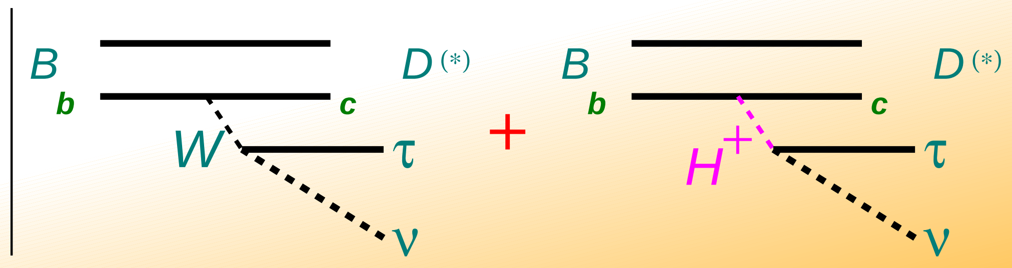


  - SM |Amplitude| may be modified
  - New phase? ⇒ ϕ_1, ϕ_2, ϕ_3 may differ, or direct CPV

- Mixing

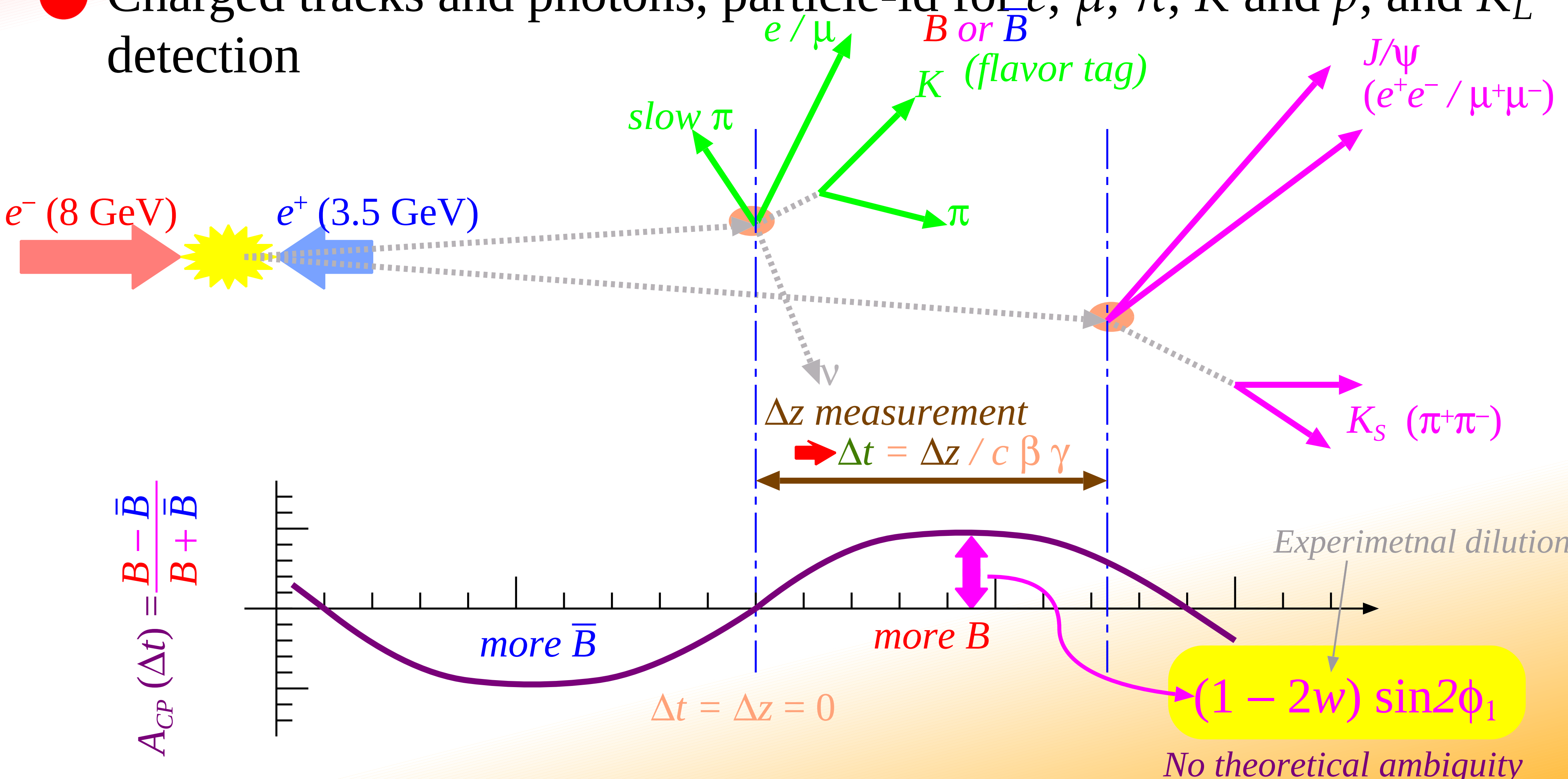


- Also in trees



How the B-factories designed

- Need huge luminosity (the single most important factor)
- Boosted CM frame, vertex detector for Δt measurement
- Charged tracks and photons, particle-id for e, μ, π, K and p, and K_L detection



Outline

- Introduction
- **Next** $\Rightarrow$ KEKB performance surpassing $\mathcal{L} = 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Approaches to go beyond SM
  - Search for new CP Violating B decays
  - Radiative/electroweak rare B decays
- Comments on the new D_{sJ} resonance

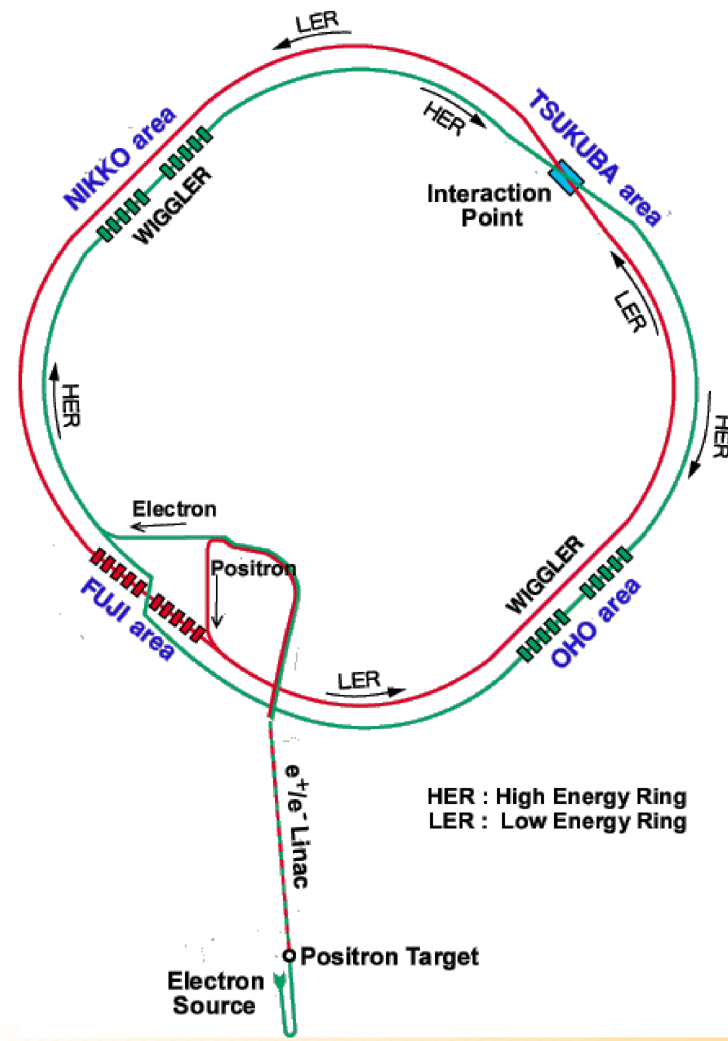
KEKB performance — a brief history

- 1989: KEKB Design started
- 1994: KEKB Construction started
- Jun. 1999: first physics run
- Apr. 2001: surpassed the PEP-II luminosity, $\mathcal{L} = 3.4 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Oct. 2002: Accumulated 100 fb^{-1}
- 9 May 2003, 07:26: Design luminosity $\mathcal{L} = 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ achieved!
- Jul. 2003: Accumulated 158 fb^{-1}

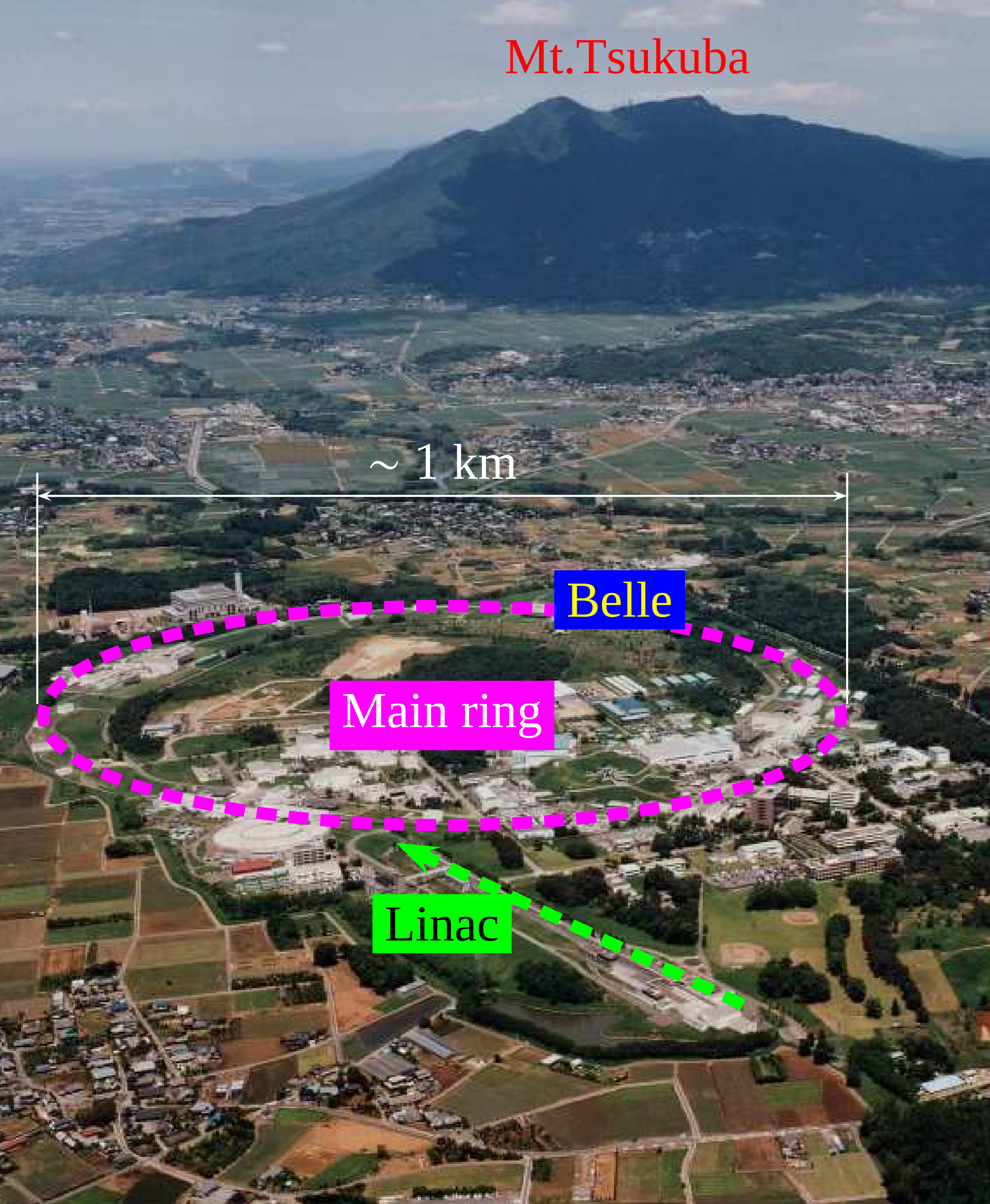
KEKB parameters

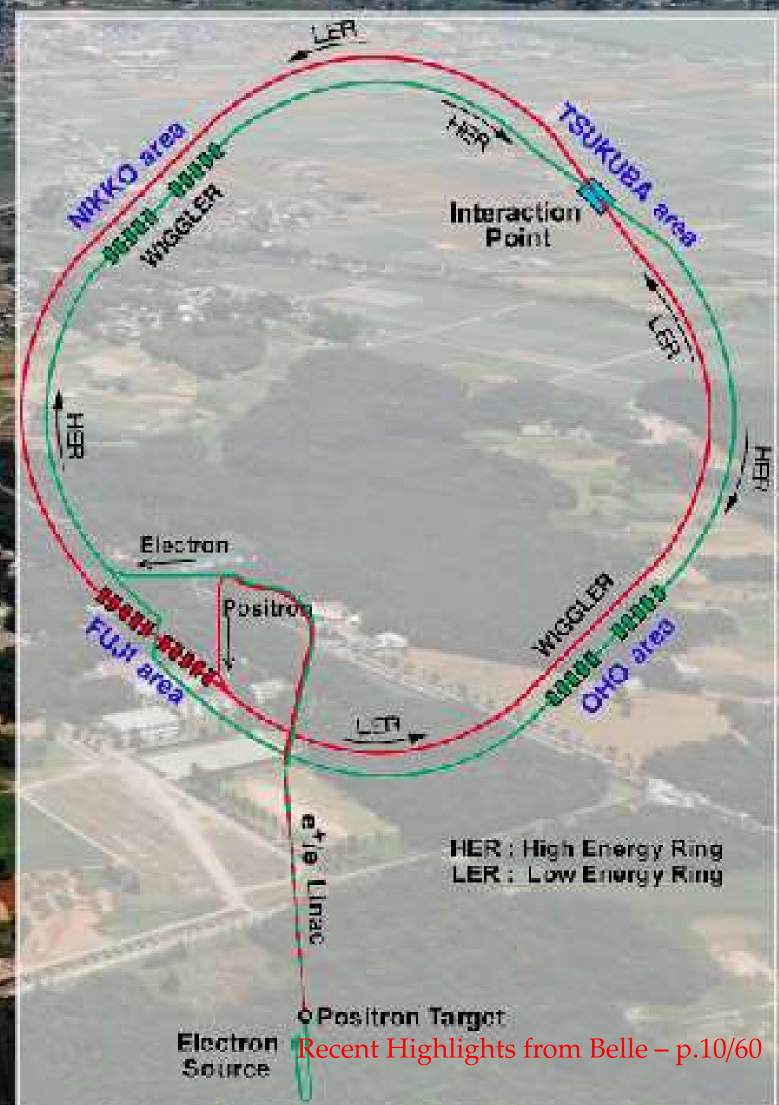
on 9 May, 2003

	LER(e^+)	HER(e^-)
Energy	3.5 GeV	8 GeV
Current	1.41 A	1.06 A
Number of bunches	1284 (/ 3 km)	
Crossing angle	22 mrad	
Beam lifetime	105 min	247 min
Peak luminosity	$1.031 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	



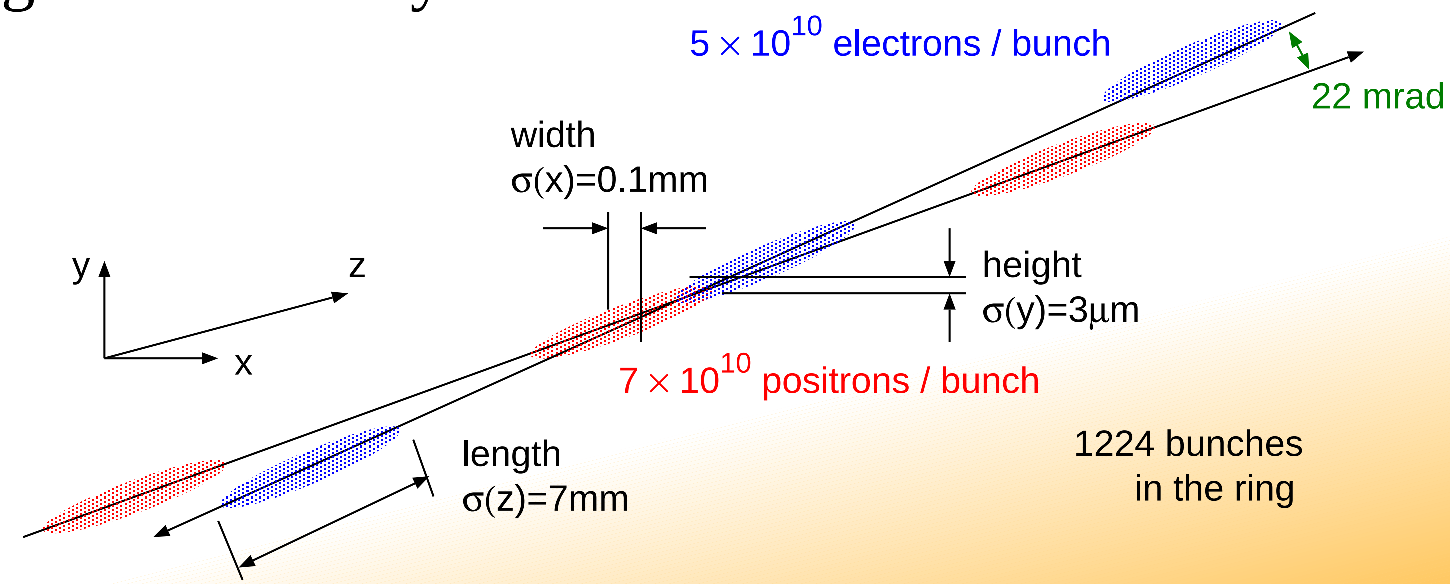
Most of the parameters are close to or better than the design values
— simulation did a good job for the accelerator design!


Mt.Tsukuba
~ 1 km
Belle
Main ring
Linac


LER
HER
TSUKUBA area
NIKKO area
WIGGLER
Interaction Point
Electron
Positron
FUJI area
OHO area
WIGGLER
e+/e- Linac
Positron Target
Electron Source
HER : High Energy Ring
LER : Low Energy Ring

How to get to the design

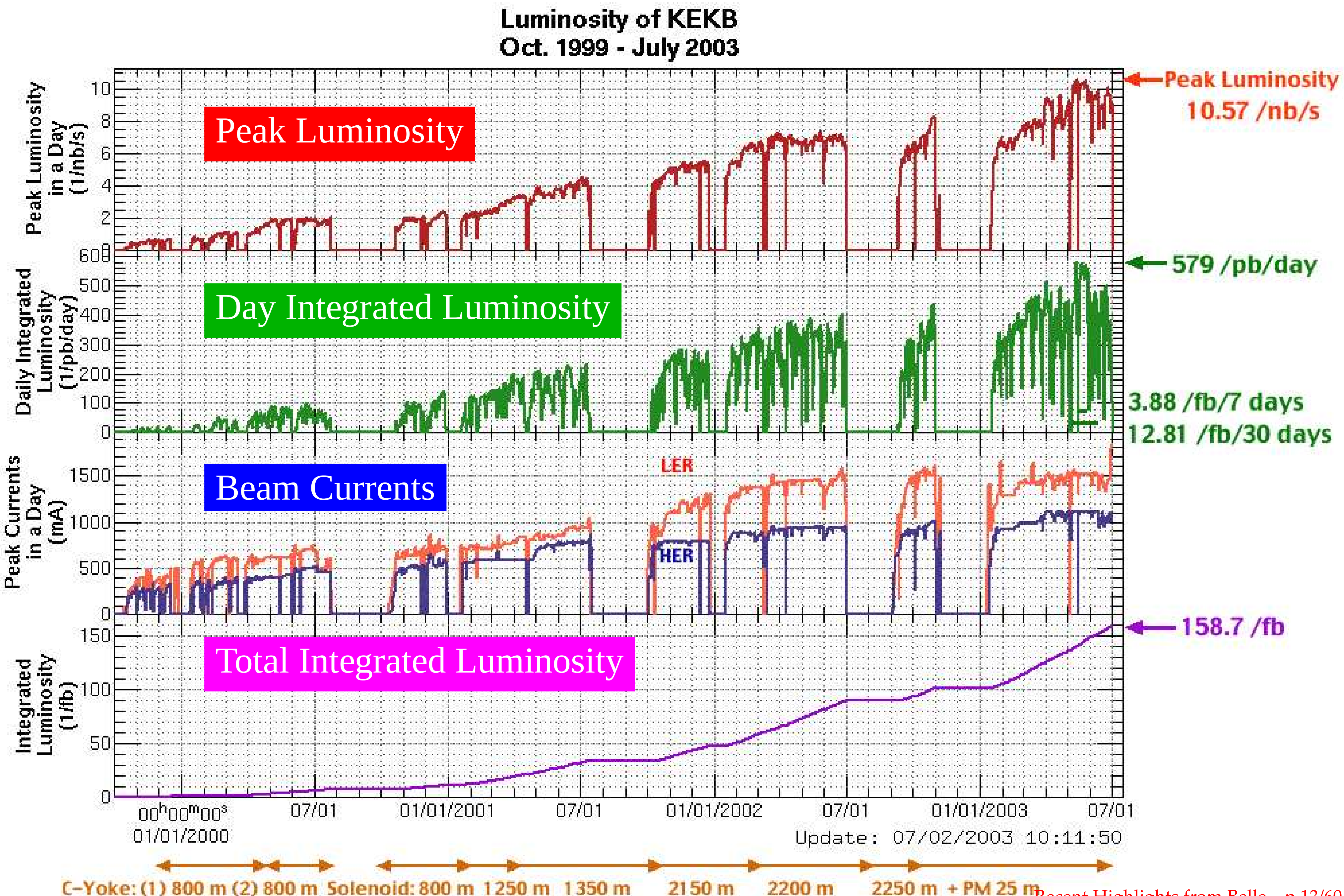
- Diligent efforts of KEKB crews!
  And joint-effort of KEKB-Belle members, too
- Excellent accelerator design
  - Infinite crossing angle — simpler IR, less background, heating
  - Large circumference — allows large freedom in the tuning space
- Flexible control software and quick feedback to the tuning knobs — good operation points are found in the "adiabatic" on-the-fly tuning during the luminosity runs



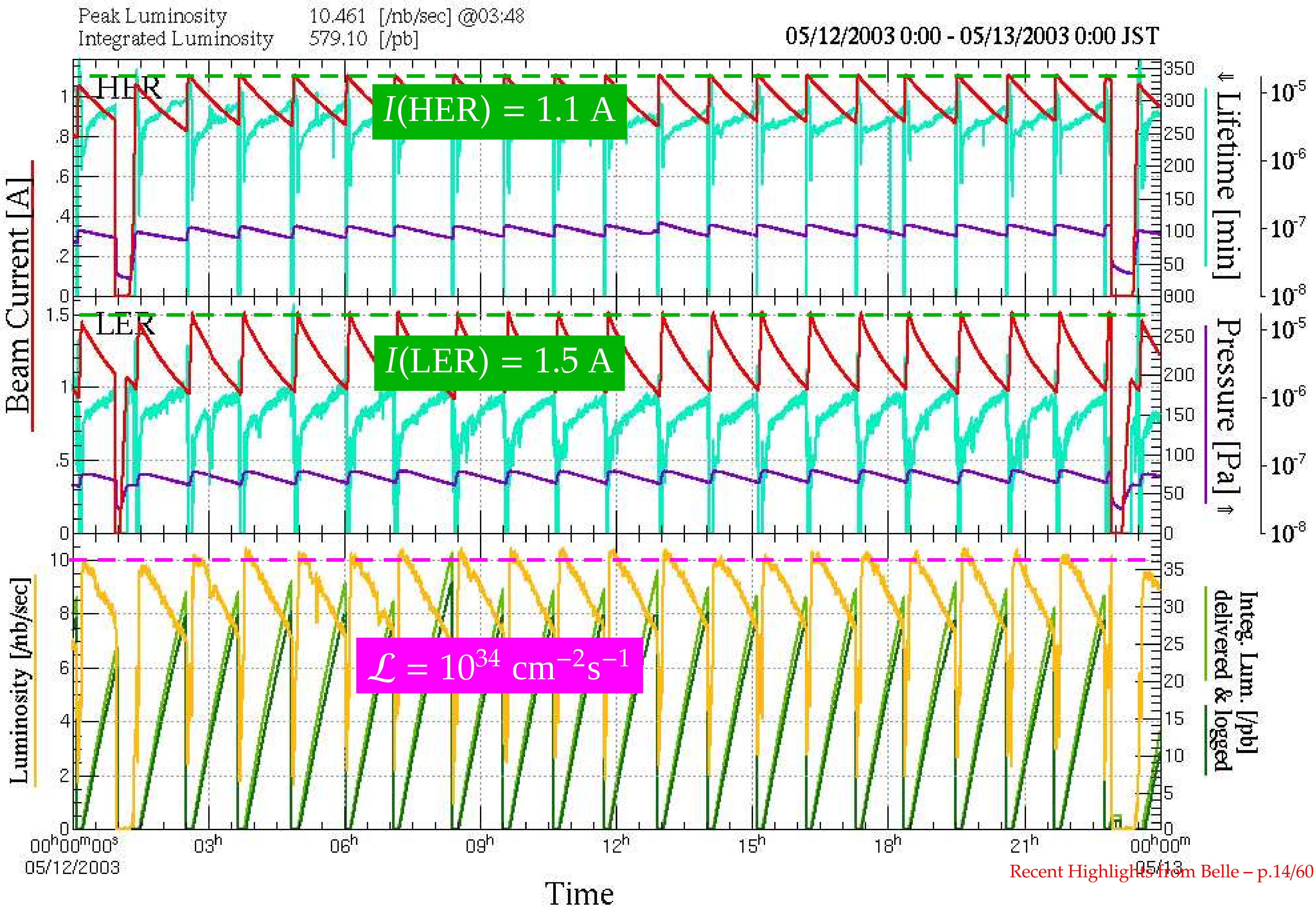
Solving many difficulties

- LER (e^+) photo-electron instability — beam size blows up by photo-electron clouds. We added solenoids around the beampipe all along the ring to effectively trap the photo-electrons.
- Heating and damaging — many components, such as the moveable beam-masks and bellows, have been damaged and replaced. When the beam (or synchrotron light) spots a single point, serious damages are made. We have been improving / replacing the components.

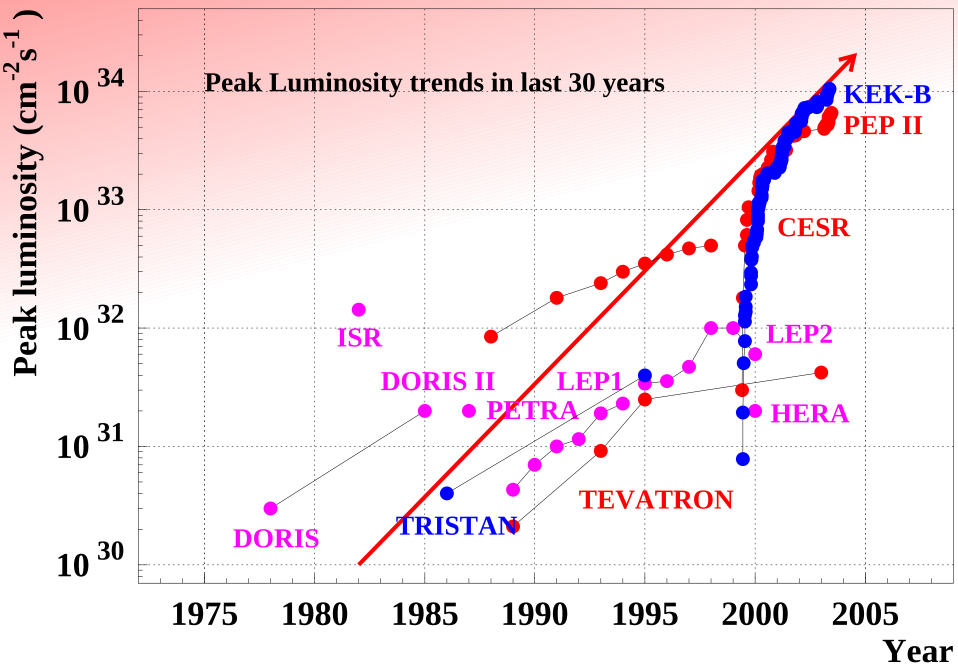
KEKB 4 year history

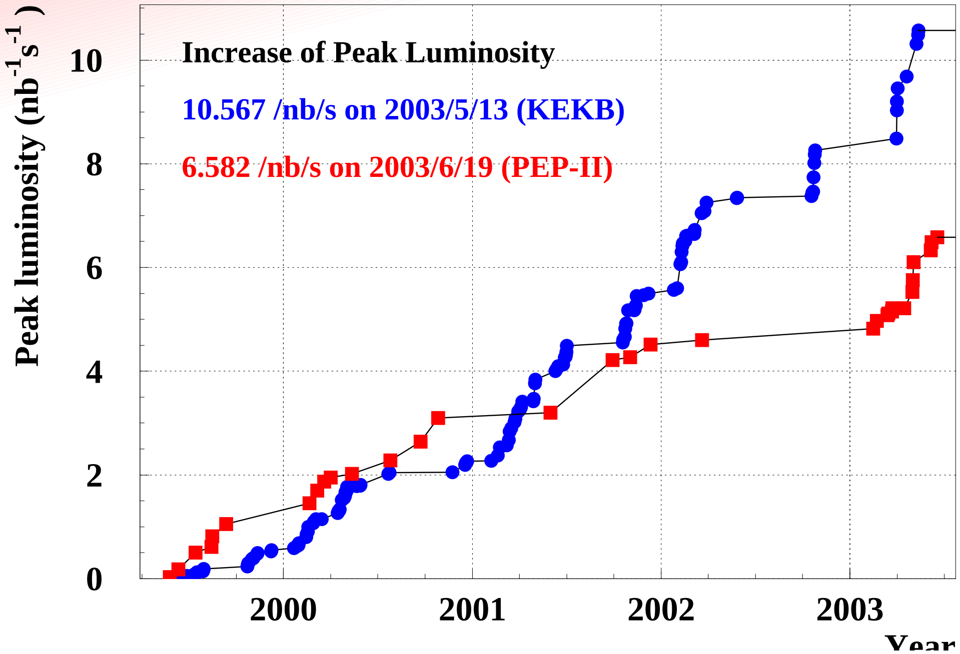


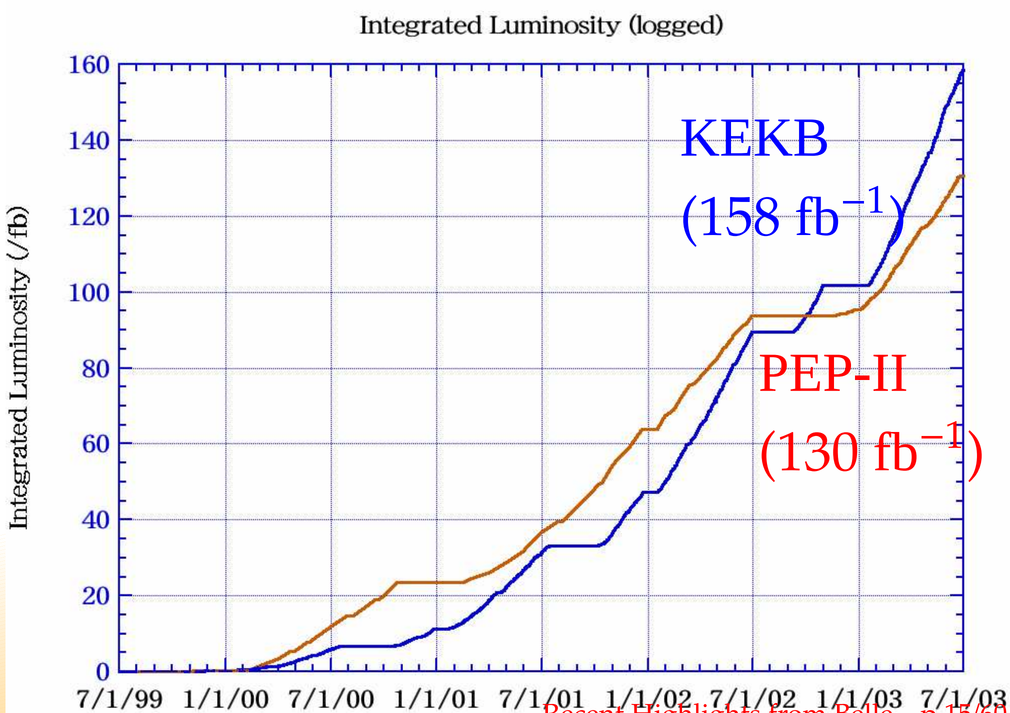
The best day — 12 May 2003 (0.579 fb^{-1}/day)



Luminosity race

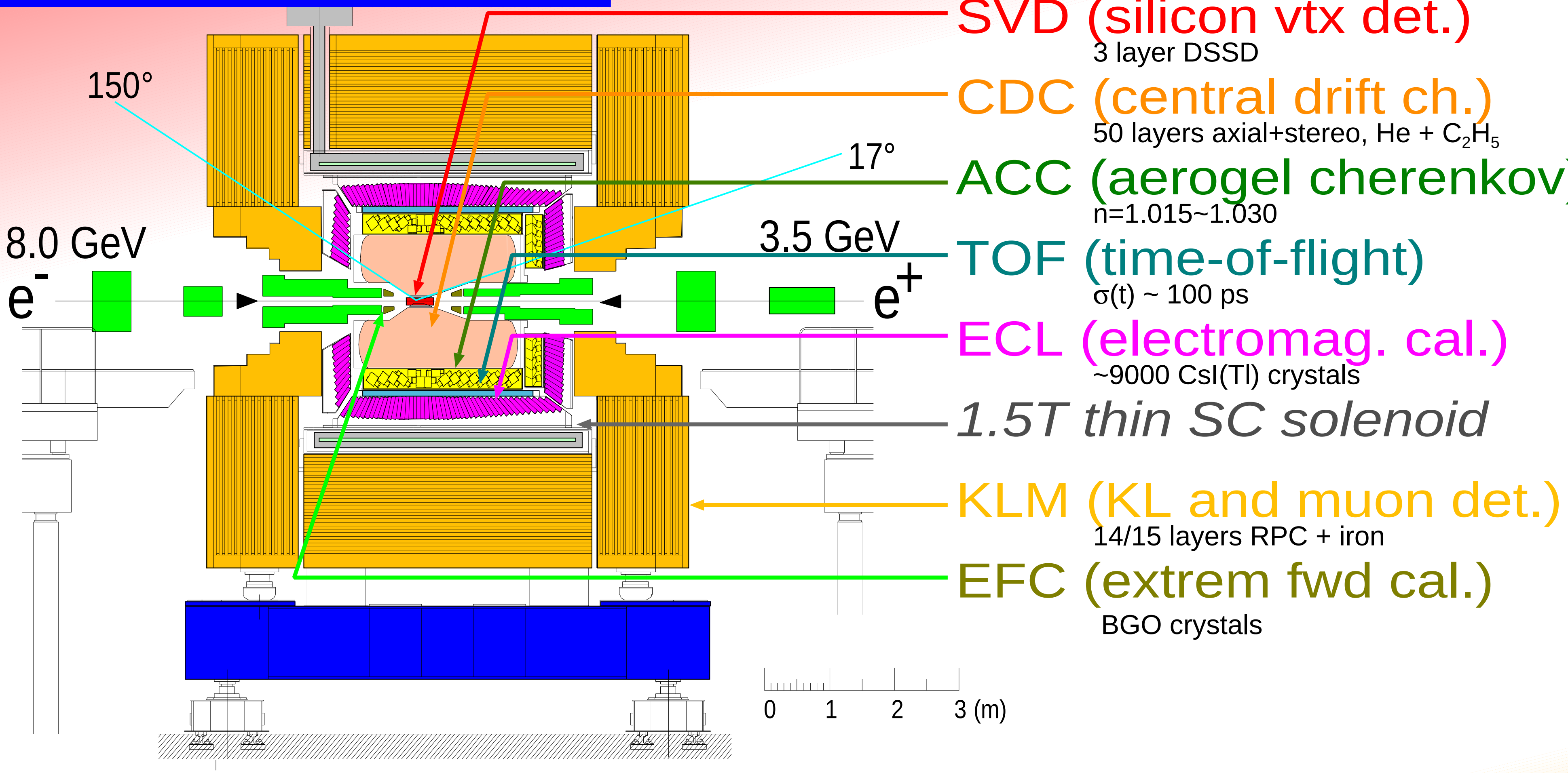






- 158 fb^{-1} collected (on resonance: 142 fb^{-1})
- 60–90 fb^{-1} used by analyses so far (most of them use 78 fb^{-1})
- First results from 142 fb^{-1} will be ready by LP03

Belle Detector



Vtx	$\sigma_{xy,z} \sim 55\mu m$ @ 1 GeV
Trk	$\sigma_{pt}/p_t = 0.19 p_t \oplus 0.34\%$
Cal	$\sigma_E/E \sim 1.8\%$ @ 1 GeV
K-id	$\epsilon \sim 90\%$, fake $\sim 6\%$ up to 3 GeV
e-id	$\epsilon > 90\%$, fake $\sim 0.3\%$ (> 0.5 GeV)
μ-id	$\epsilon > 90\%$, fake $< 2\%$ (> 1 GeV)

Belle Detector nicely works at $\mathcal{L} = 10^{34}$ cm^{-2}s^{-1}!

No signifi cant performance degradation

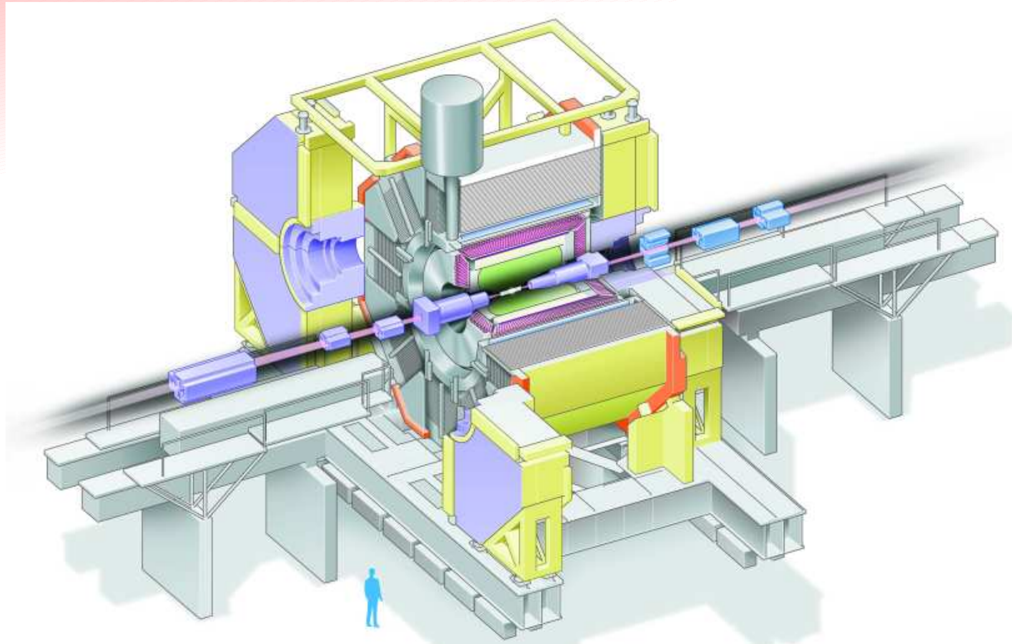
Trigger/DAQ works (500 Hz, $\epsilon(B\overline{B}) > 99\%$)

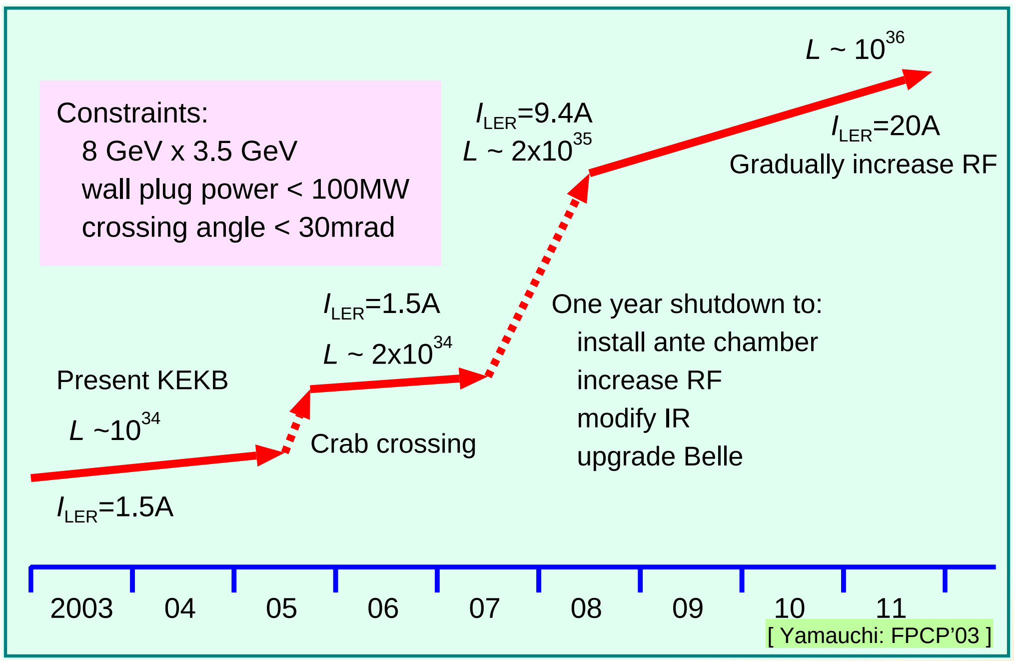
Probably OK up to a few $\times 10^{34}$ with minor changes

SuperKEKB

We need significantly more data, as discussed later.

Upgrade scenarios are seriously being studied, aiming for B physics at 10^{35} to 10^{36} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ luminosity



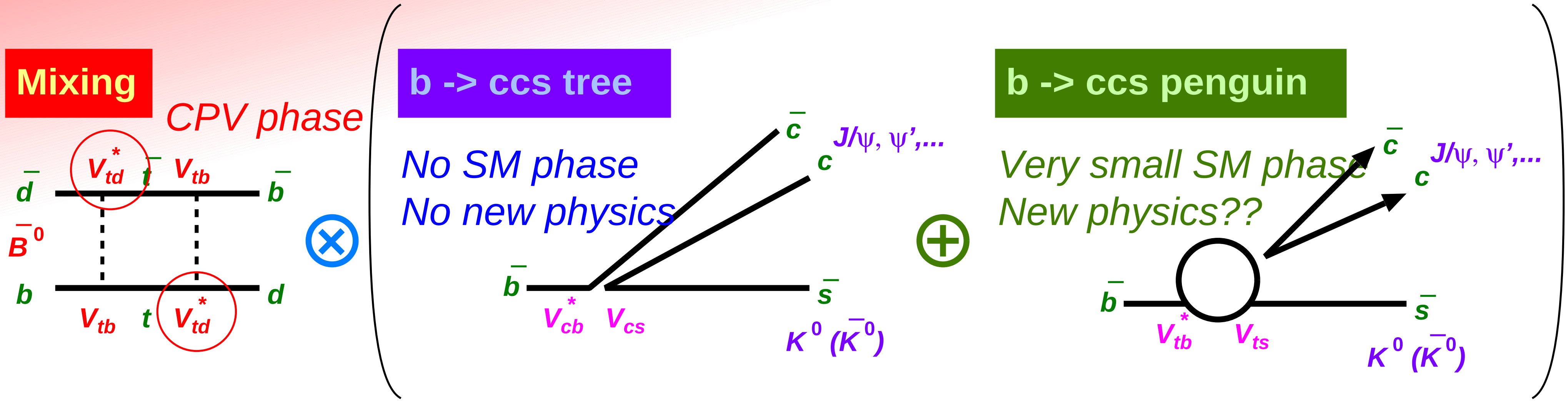


Vertexing: Pixel + DSSD
Particle-id: TOP + RICH
(Time Of Projection counter with quartz-bars)
Calorimeter: pure CsI for endcap
DAQ/trigger: full replacement
(R&D going on)

Outline

- Introduction
- KEKB performance surpassing $\mathcal{L} = 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  Summary — the world record luminosity is the result of the excellent design and enormous diligent efforts. But we do not stop here, aiming for 10^{35} *and more!*
- Approaches to go beyond SM
  - **Next** $\Rightarrow$ Search for new CP Violating B decays
  - Radiative/electroweak rare B decays
- Comments on the new D_{sJ} resonance

$b \to c\bar{c}s$ indirect CPV



- Now we know that $B \to J/\psi K_S^0$ and other $b \to c\bar{c}s$ indirect CPV gives the CP violating phase in $B\overline{B}$ mixing

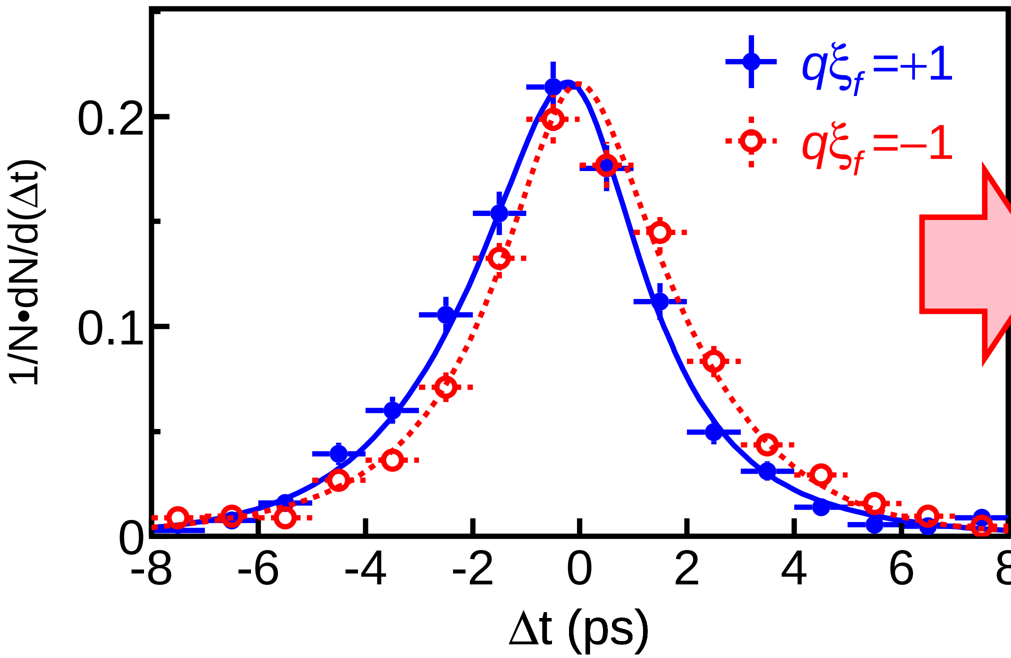
$$\frac{d\Gamma(\Delta t)}{d\Delta t} \propto \frac{e^{-|\Delta t|/\tau_B}}{2\tau_B}[1 - q\xi_f \sin 2\phi_1 \sin(\Delta m \Delta t)]$$

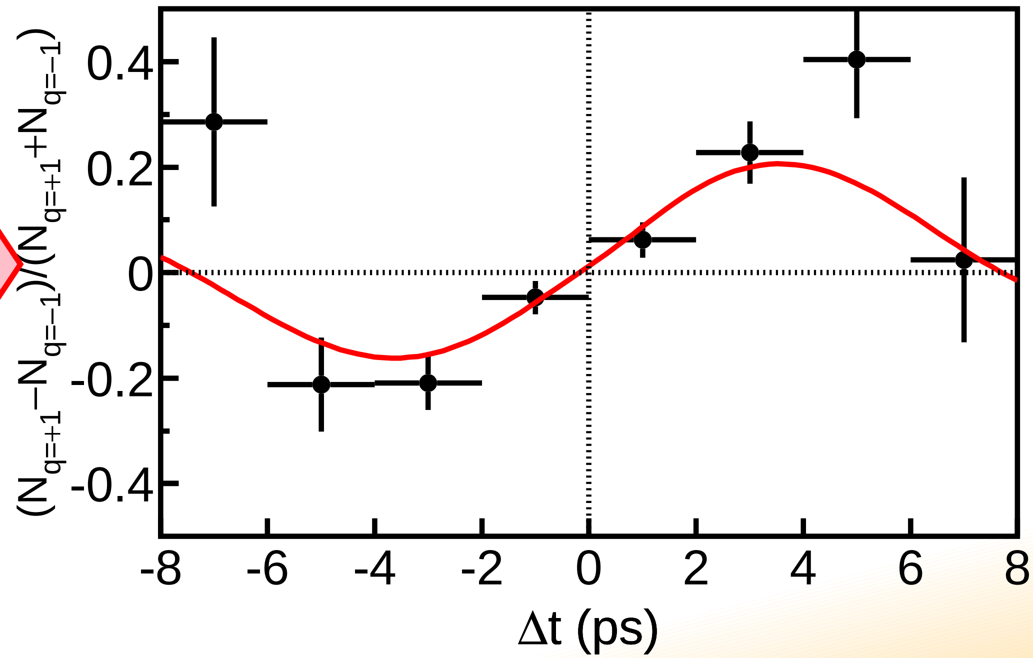
- Theoretically clean
  - SM $b \to s$ penguin: dominant t and c quark loops give the same phase; u quark loop is suppressed ($< 1\%$ effect)
  - New physics phase would be overwhelmed by the SM phase

$b \to c\bar{c}s$ indirect CPV in one page

Summer'02
Belle result

- 78 fb^{-1} data $\Rightarrow$ 2958 event (81% purity)
- Effective flavor tagging efficiency 28.8 ± 0.6%
- Δt resolution of 1.43 ps (τ_B = 1.55 ps)



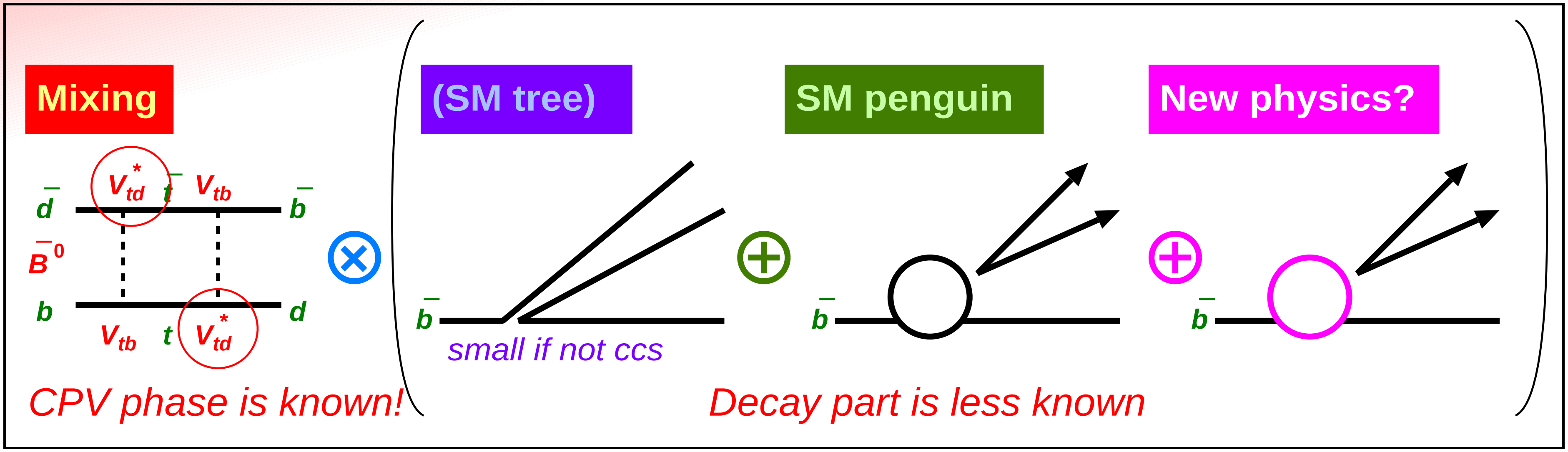


$$
\begin{aligned}
\sin 2\phi_1(\beta) &= 0.719 \pm 0.074 \pm 0.035 \text{ (Belle)} \\
&= 0.741 \pm 0.067 \pm 0.034 \text{ (BaBar)} \\
&= 0.734 \pm 0.055 \text{ (WA by HFAG)}
\end{aligned}
$$

Large CPV
in B decays

Any other indirect CPV?

- Testing ground for the CPV in decay into a CP eigenstate



$$\frac{d\Gamma(\Delta t)}{d\Delta t} \propto \frac{e^{-|\Delta t|/\tau_B}}{2\tau_B}[1 - q\xi_f\{S_f \sin(\Delta m \Delta t) + A_f \cos(\Delta m \Delta t)\}]$$

- Examples *(rare decays)*
  - $b \to c\bar{c}d$ — $J/\psi\pi^0$, $D^{*+}D^{*-}$ …
  - $b \to s\bar{s}s$ — $K_S^0\phi$, $K_S^0K^+K^-$, $K_S^0\eta'$ …
  - $b \to s\gamma$ — $K_1(1270)^0\gamma$, $K_S^0\phi\gamma$, …
  - $b \to u\bar{u}d$ — $\pi^+\pi^-$, $\rho^\pm\pi^\mp$ …

(Angular analysis can disentangle CP of a mixed state for VV and 3-body decays)

Analysis procedure

Please allow me to show this, although you might have already seen already more than 100 times.

Reconstructing CP decays

↓

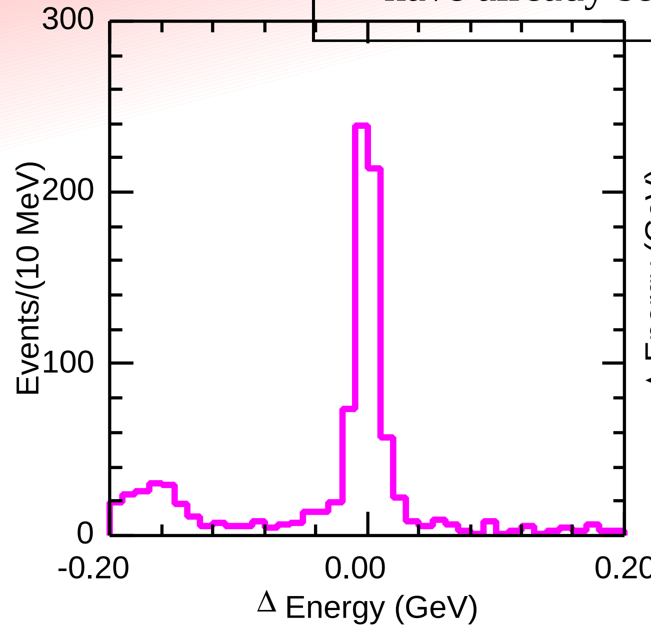
Background suppression

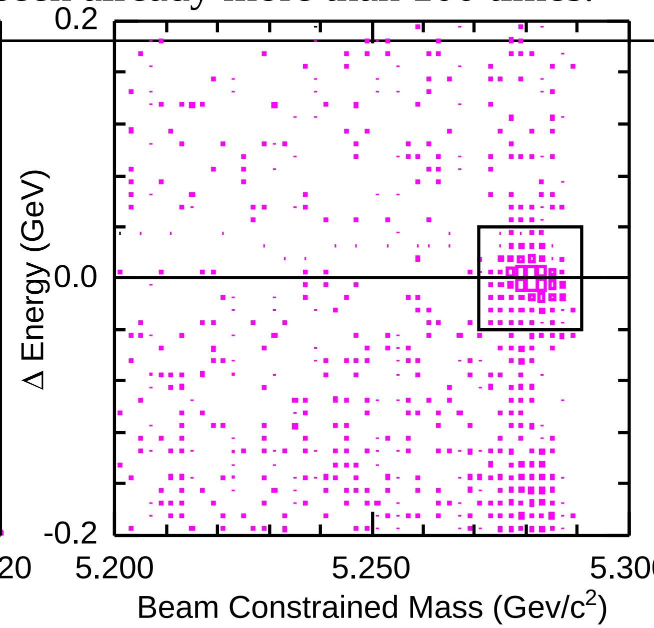
↓

Flavor tagging

↓

Δt from vertexing



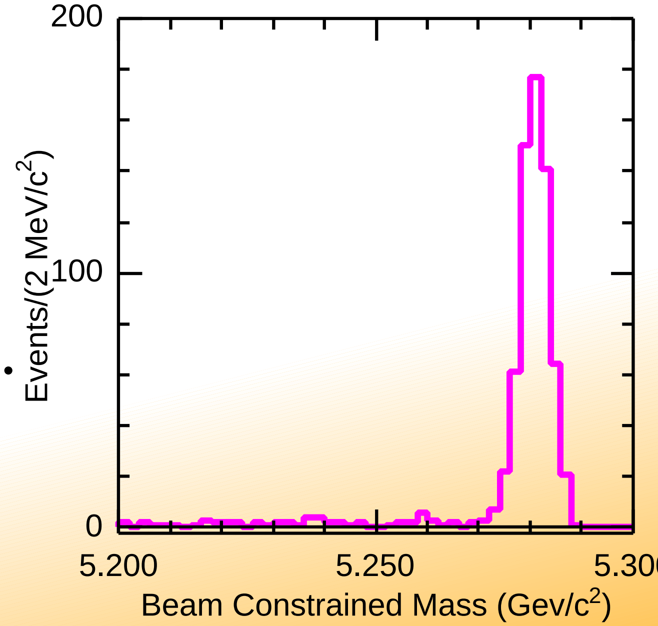


$$\Delta E = E^*_B - E^*_{\mathrm{beam}}$$

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

from e, μ, π, K id. and mom.

Very clean for $B \to J/\psi K^0_S$



Analysis procedure

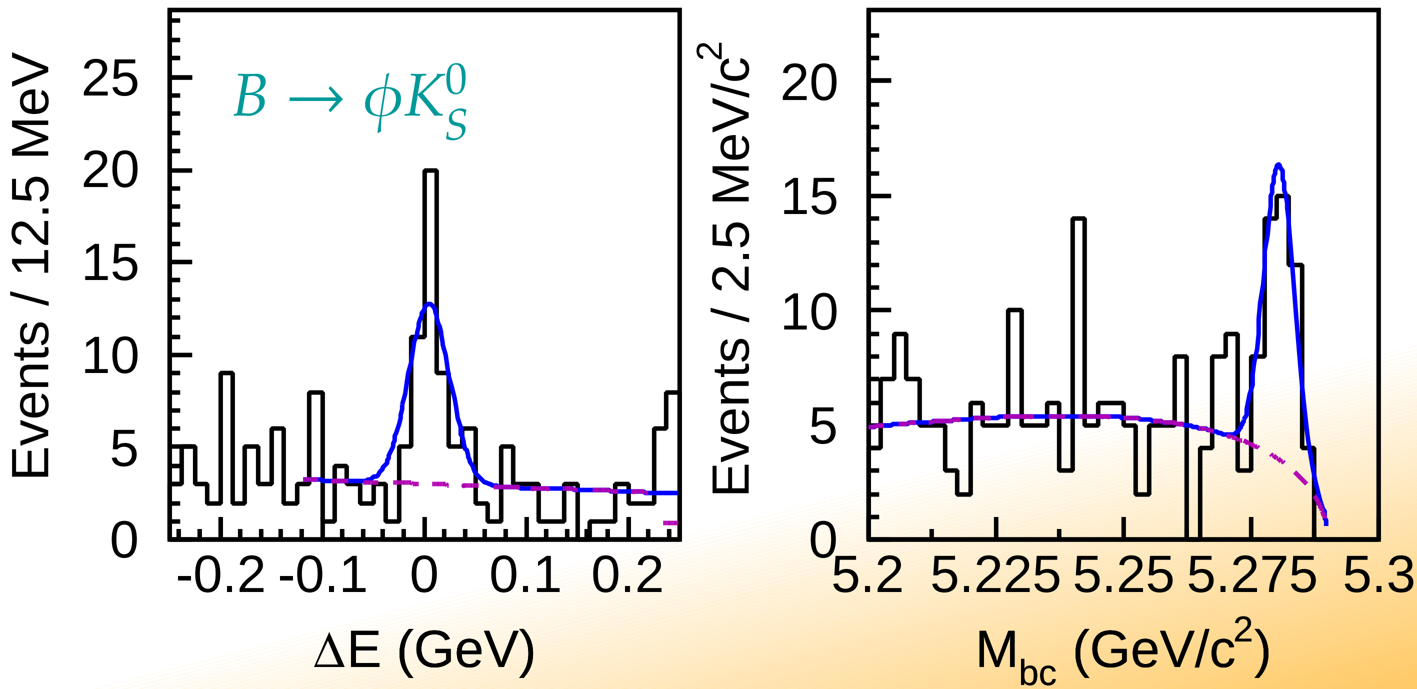
Reconstructing CP decays

Background suppression

Flavor tagging

Δt from vertexing

- Rare decays suffer from huge continuum background ($e^+e^- \to q\bar{q},\ q = u, d, s, c$)
  $\Leftrightarrow$ no abundant $c\bar{c}$ in continuum
- Need a background suppression
- Then ΔE, $M_{\rm bc}$ to reconstruct the signal



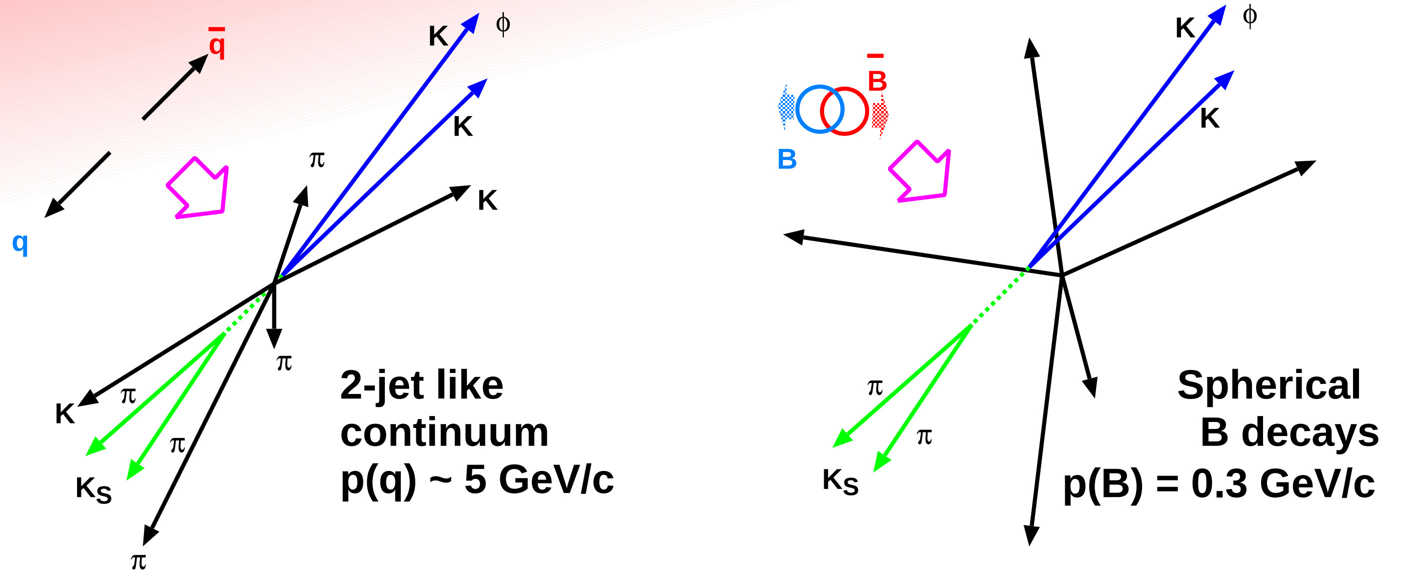
Analysis procedure

Reconstructing CP decays

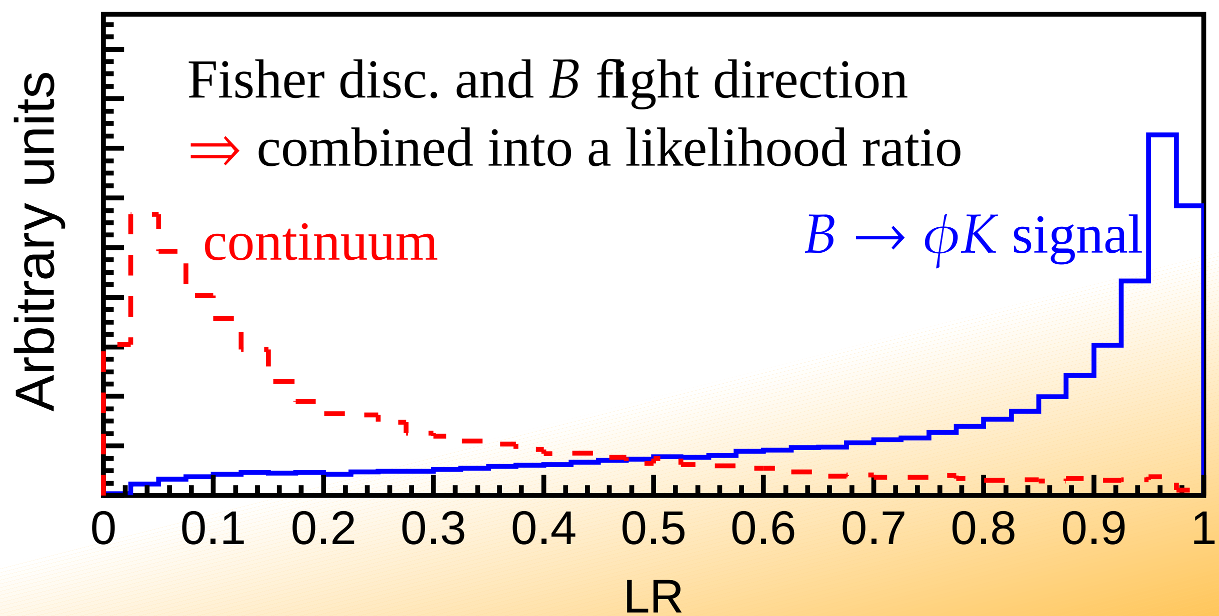
Background suppression

Flavor tagging

Δt from vertexing



- Event shape: moment of the event $\Rightarrow$ Fisher disc.



Analysis procedure

Reconstructing CP decays

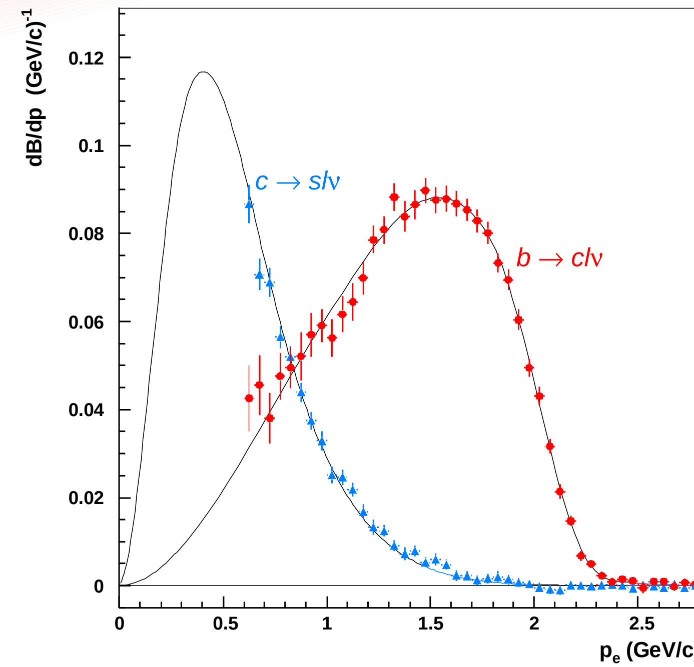
Background suppression

Flavor tagging

Δt from vertexing

- Leptons
  - High-p ℓ^+
  - Medium-p ℓ^-
- Hadrons
  - K^-
  - $\Lambda^0 \to p\pi^-$
  - High-p π^+
  - Low-p π^-

B^0 like signature



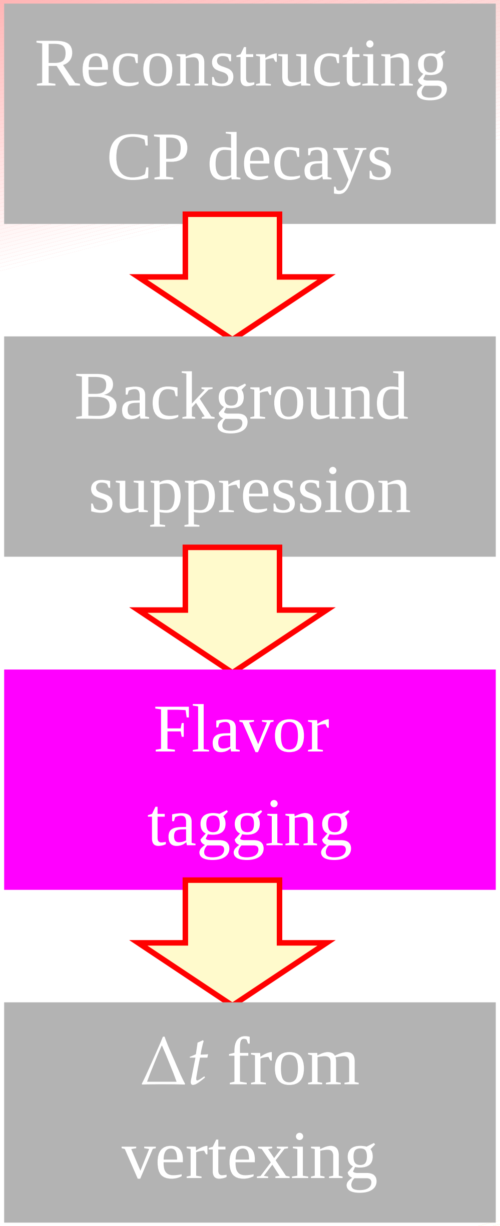
Combine all info using a look-up table into a single variable "r" ($0 < r < 1$) and assign $q = +1$

($\overline{B}^0$ like signature if opposite charges: $q = -1$)

$$\bar{b} \to \bar{c}\ell^+\nu, \quad \bar{c} \to \bar{s}\ell^-\bar{\nu}, \quad \bar{s} \to K^-, \Lambda^0, \quad \Lambda^0 \to p\pi^-$$

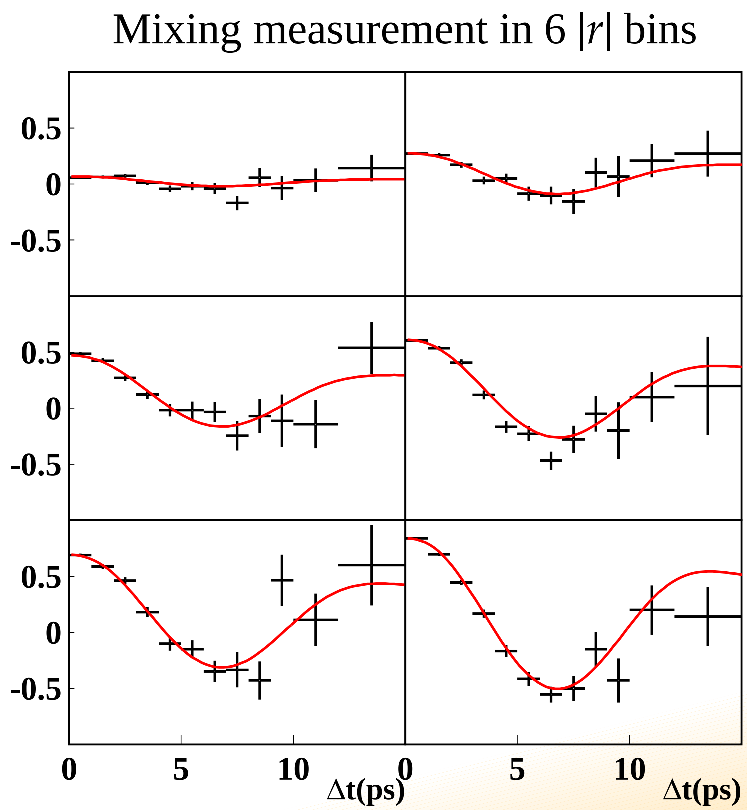
$$B^0 \to D^{*-}\pi^+, \quad \pi^+ \to \rho^+ \to \pi^+\pi^0, \quad D^{*-} \to \overline{D}^0\pi^-_{\mathrm{slow}}$$

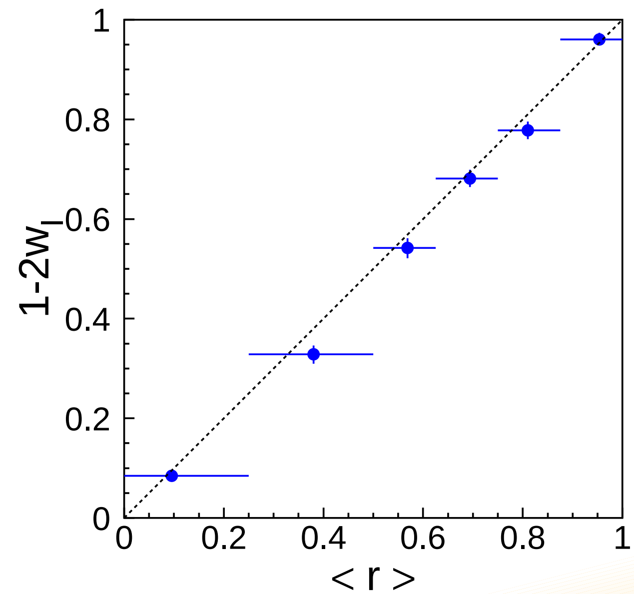
Analysis procedure



Variable r almost gives the wrong-tag fraction $1 - 2w$, which is measured with a control sample $B^0 \to D^{*-}\ell^+\nu$

$$\frac{N_{\mathrm{OF}} - N_{\mathrm{SF}}}{N_{\mathrm{OF}} + N_{\mathrm{SF}}} = \frac{1}{1-2w}\cos(\Delta m_d \Delta t)$$





Efficiency > 99.5%

$\epsilon_{\mathrm{effective}} = 28.8 \pm 0.5\%$

(exactly the same as $b \to c\bar{c}s$ CPV measurement)

Analysis procedure

Reconstructing CP decays

Background suppression

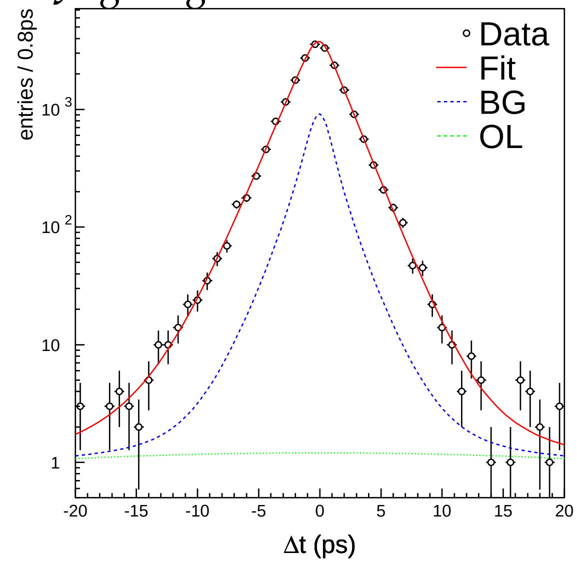
Flavor tagging

Δt from vertexing

Maximizing the likelihood to extract info out of Δt

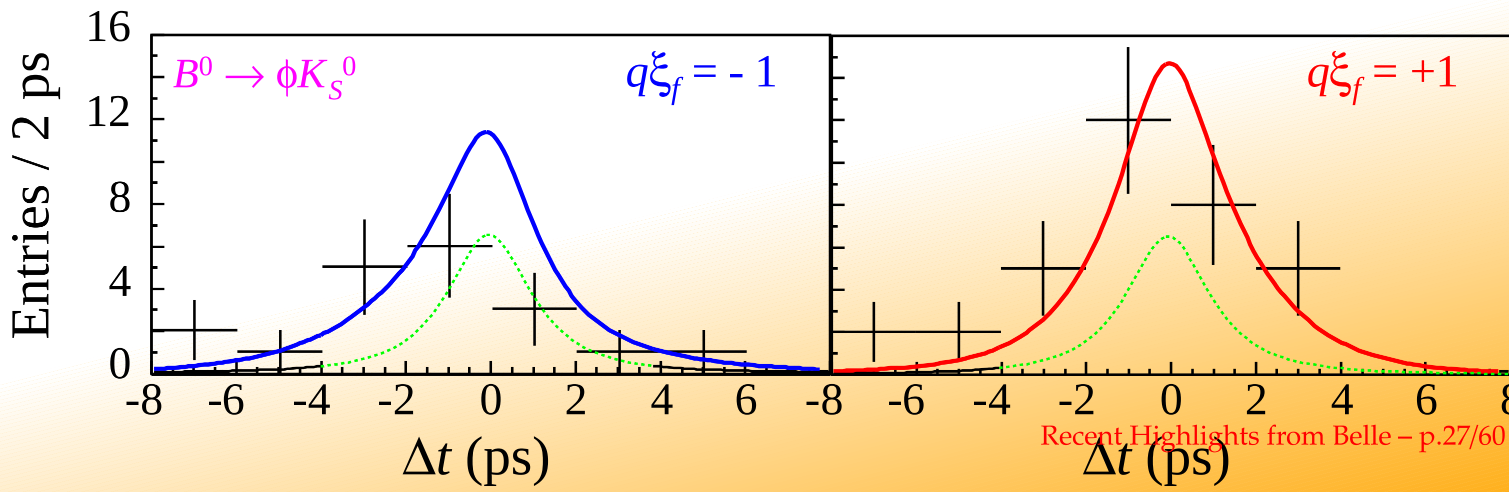
$$\prod_i \mathcal{L}_i = \int (1 - f_{\rm bg})\mathcal{P}_{\rm sig} R(\Delta t - \Delta t')d\Delta t' + f_{\rm bg}\mathcal{P}_{\rm bg}$$

Use $\mathcal{P}_{\rm sig} = \dfrac{e^{-|\Delta t|/\tau_B}}{2\tau_B}$ on non-CP events $\Rightarrow$ to get the 12 param. resolution function R (z_{CP}, $z_{\rm tag}$, $\tau_{\rm charm}$, p_B, outlier)



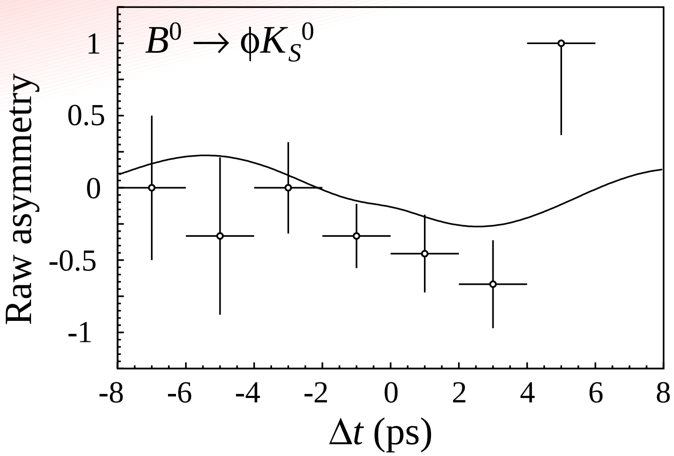
For the CP sample, use

$$\mathcal{P}_{\rm sig} = \frac{e^{-|\Delta t|/\tau_B}}{2\tau_B}[1 - \xi_f q(1 - 2w)\{S\sin(\Delta m\Delta t) + A\cos(\Delta m\Delta t)\}]$$



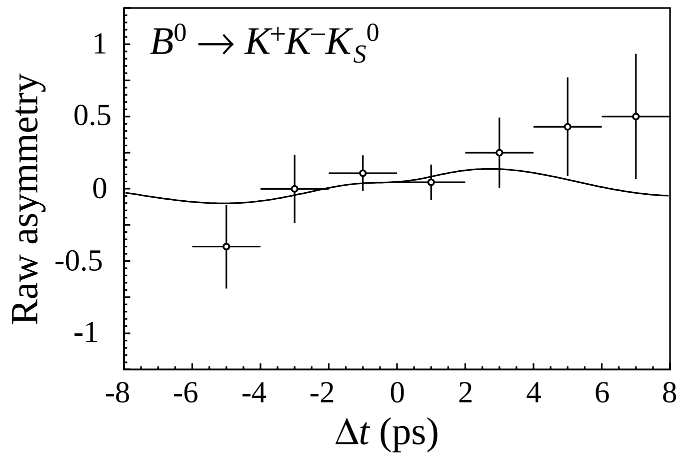
$b \to s\bar{s}s$ indirect CPV

ϕK_S^0
pure $b \to s$ penguin



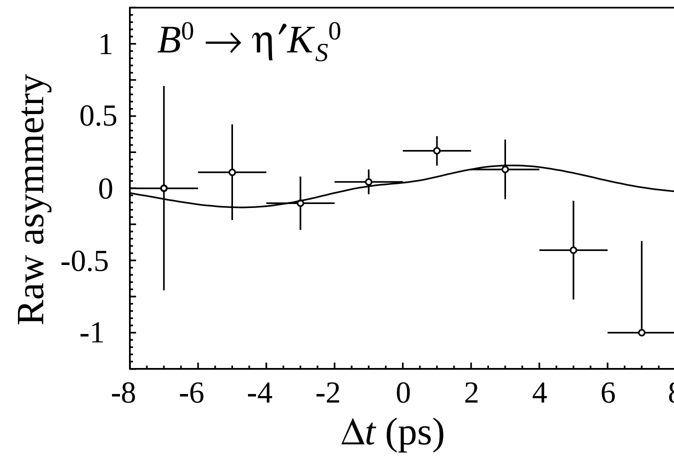
$S = -0.73 \pm 0.64 \pm 0.22$
$A = -0.56 \pm 0.41 \pm 0.16$

$K^+K^-K_S^0$
mixed CP state



$S = +0.49 \pm 0.43 \pm 0.11\,^{+0.33}_{-0.00}$
$A = -0.40 \pm 0.33 \pm 0.10\,^{+0.00}_{-0.26}$

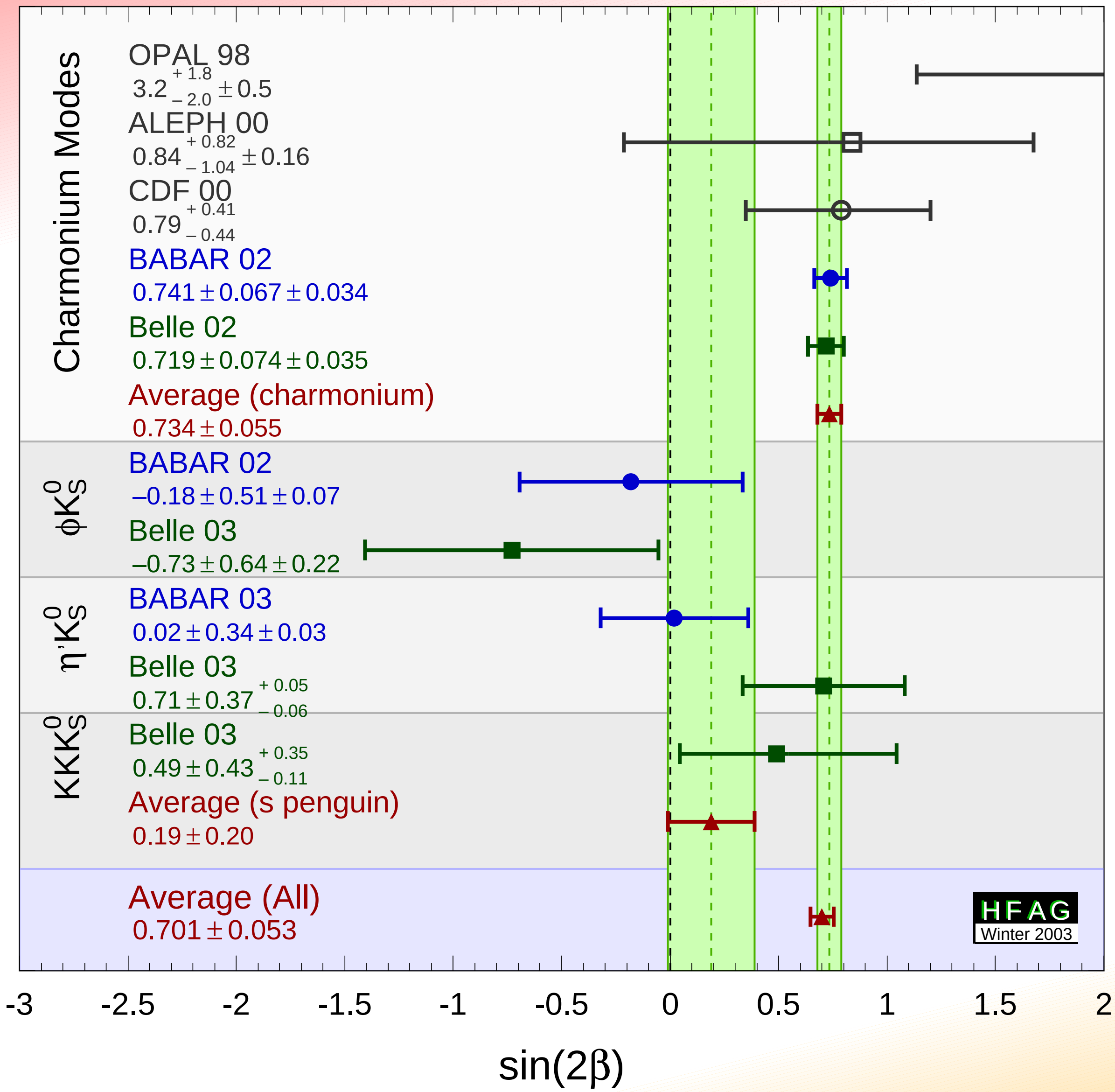
$\eta' K_S^0$
with small $u\bar{u}s$ and $d\bar{d}s$



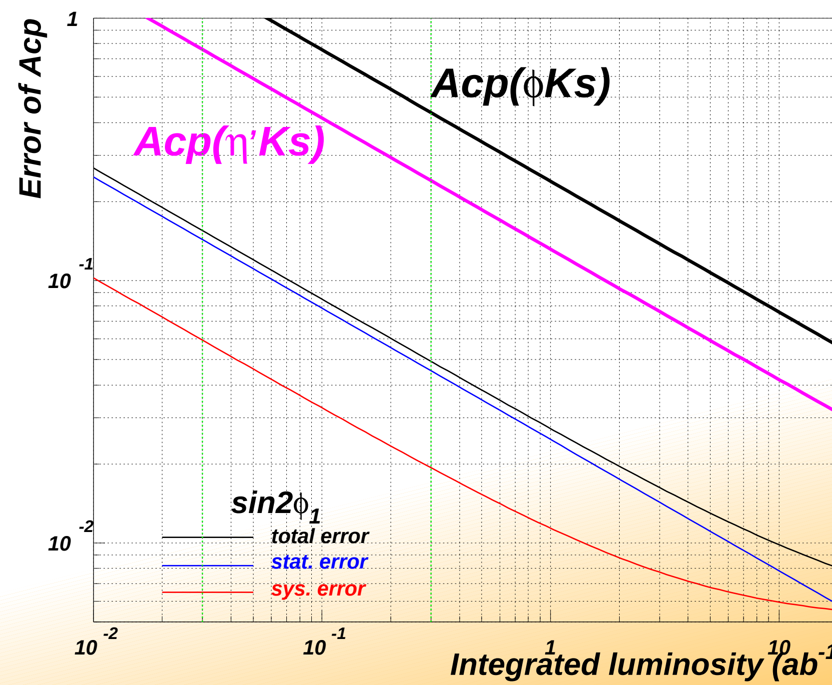
$S = +0.71 \pm 0.37\,^{+0.05}_{-0.06}$
$A = +0.26 \pm 0.22 \pm 0.03$
[PRD67,031102(R) (2003)]

- $B \to \phi K_S^0$ gives negative S ($S \neq \sin 2\phi_1$?)
- Other S are consistent with $\sin 2\phi_1$ ($S \sim \sin 2\phi_1$)
- no sign of non-zero A ($A \sim 0$)

$b \to s\bar{s}s$ comparison



Combined with BaBar, we may be seeing some difference between $b \to c\bar{c}s$ and $s\bar{s}s$.



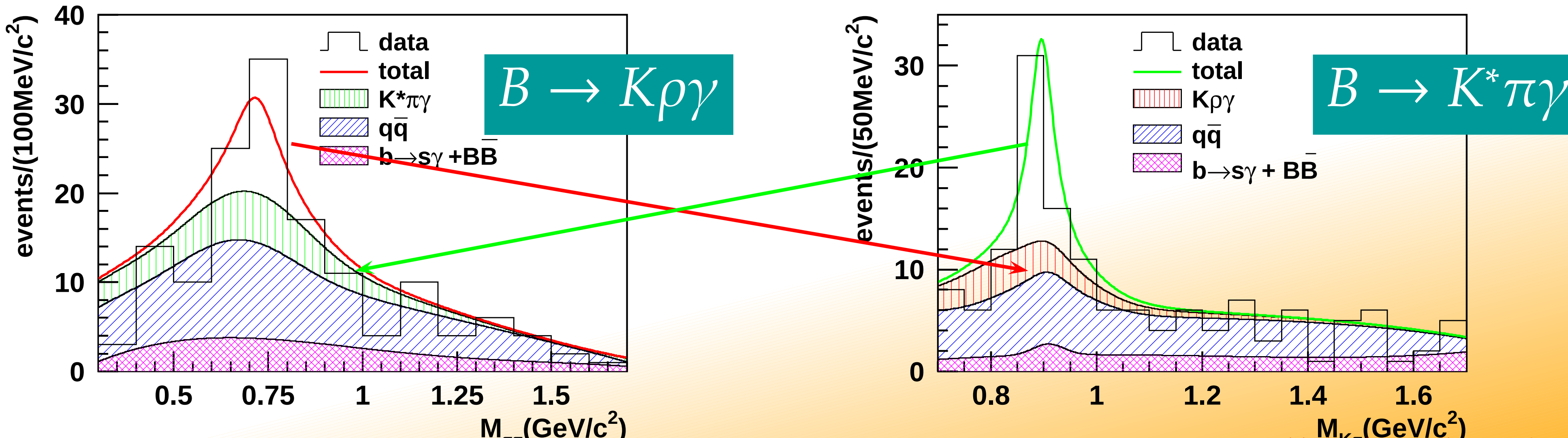
Indirect CPV in $b \to s\gamma$?

- Radiative decays provide a very (theoretically) clean environment to identify new physics in $b \to s$ penguins
- Unfortunately, $B^0 \to K^{*0}\gamma$, $K^{*0} \to K_S^0\pi^0$ has no precise vertex
- Proposed to use $B^0 \to K_1(1270)\gamma$, $K_1(1270) \to K_S^0\rho^0$, $\rho^0 \to \pi^+\pi^-$

[D.Atwood et al., PRL79,185(1997)]

- Our result on $B \to K\pi\pi\gamma$ shows that it is hard to disentangle $K\rho$ (CP) and $K^*\pi$ (non-CP) states.

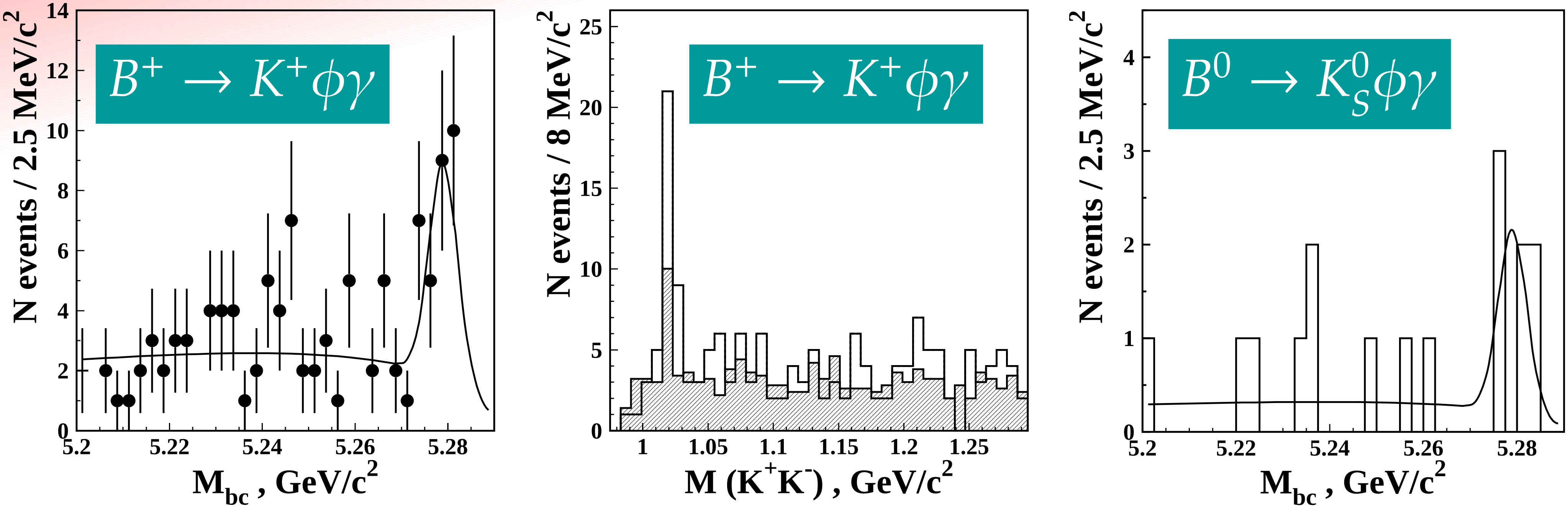
[Belle 29 fb^{-1}, PRL89,231801(2002)]



Possibility: indirect CPV in $B \to K\phi\gamma$

[Belle 90 fb^{-1} FPCP'03]

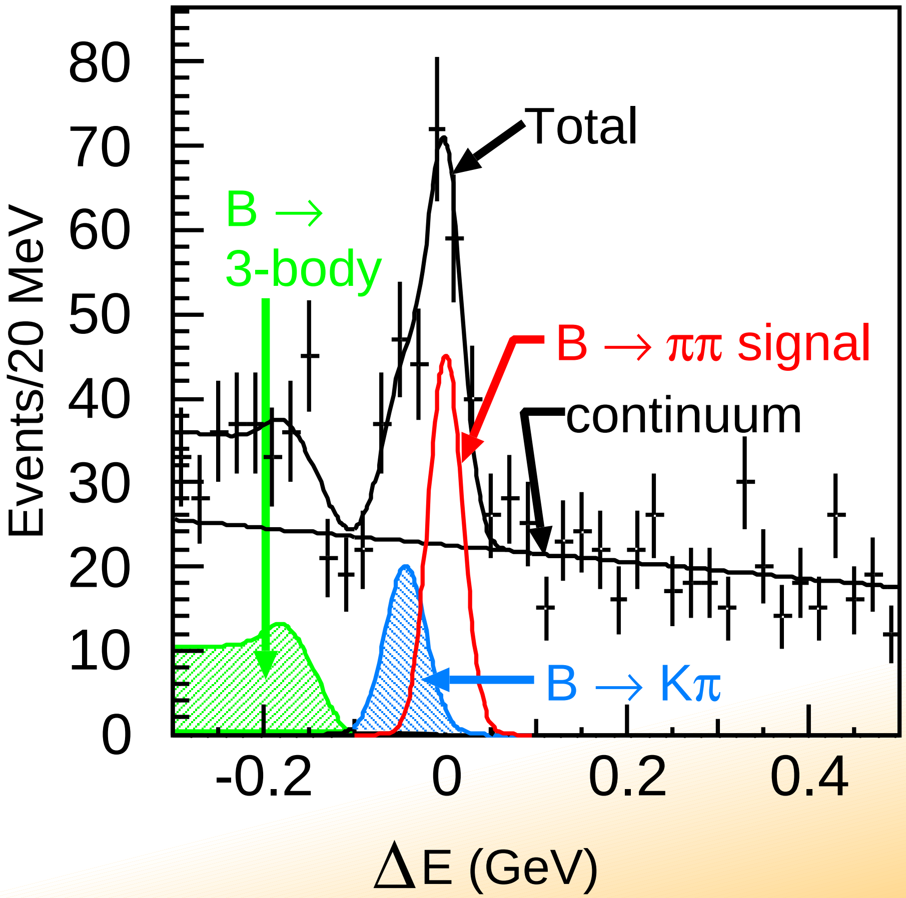
- New observation on $B^+ \to K^+\phi\gamma$ $(b \to s\bar{s}s\gamma)$ — very clear signal!

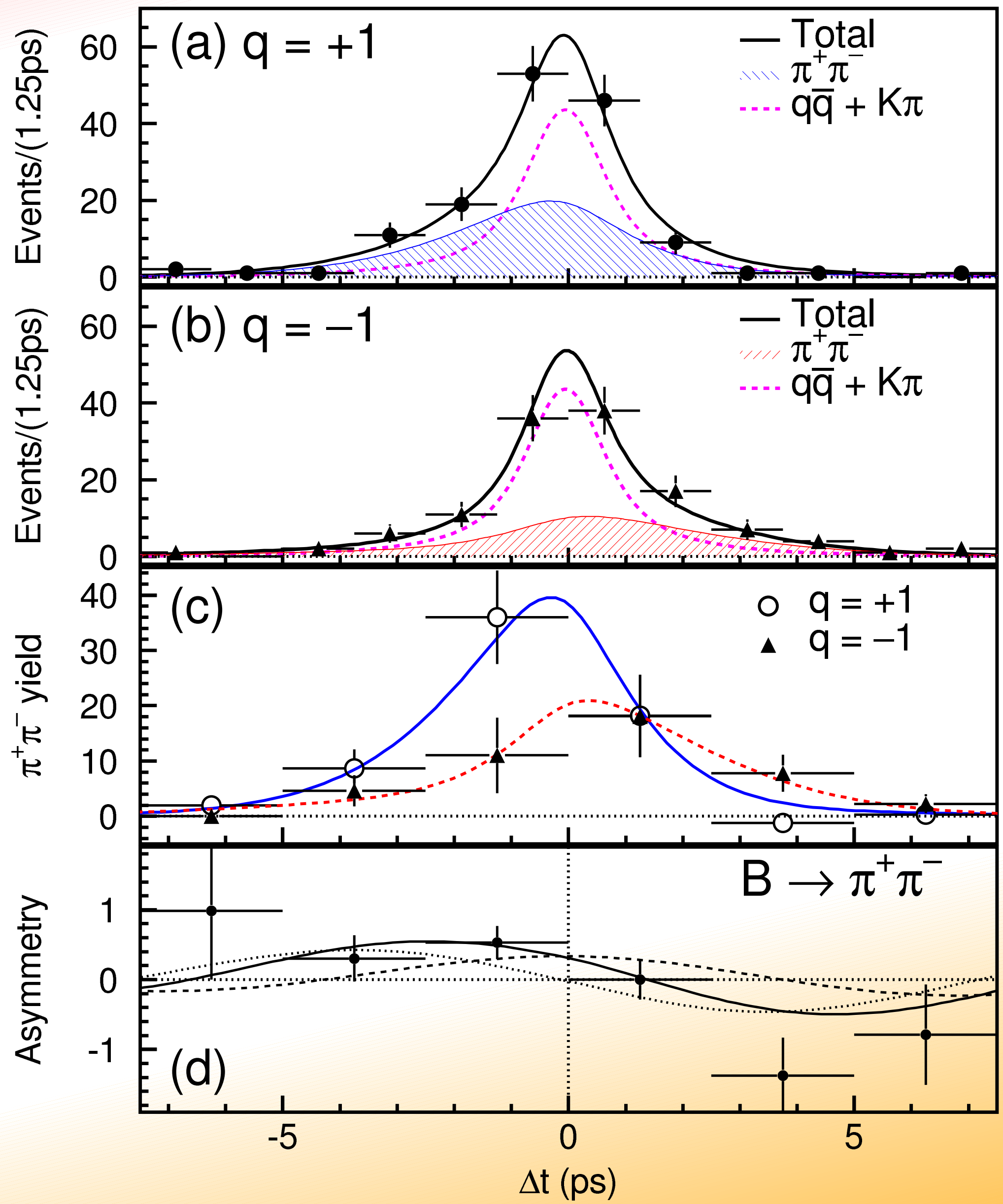


- $B^0 \to K^0_S\phi\gamma$ will be useful for indirect CPV
  - Not a CP eigenstate, but the CP content can be extracted from an angular analysis (a la $B^0 \to J/\psi K^{*0}$)
  - Need a few ab^{-1} for a meaningful result (but promissing)

$B \to \pi^+\pi^-$

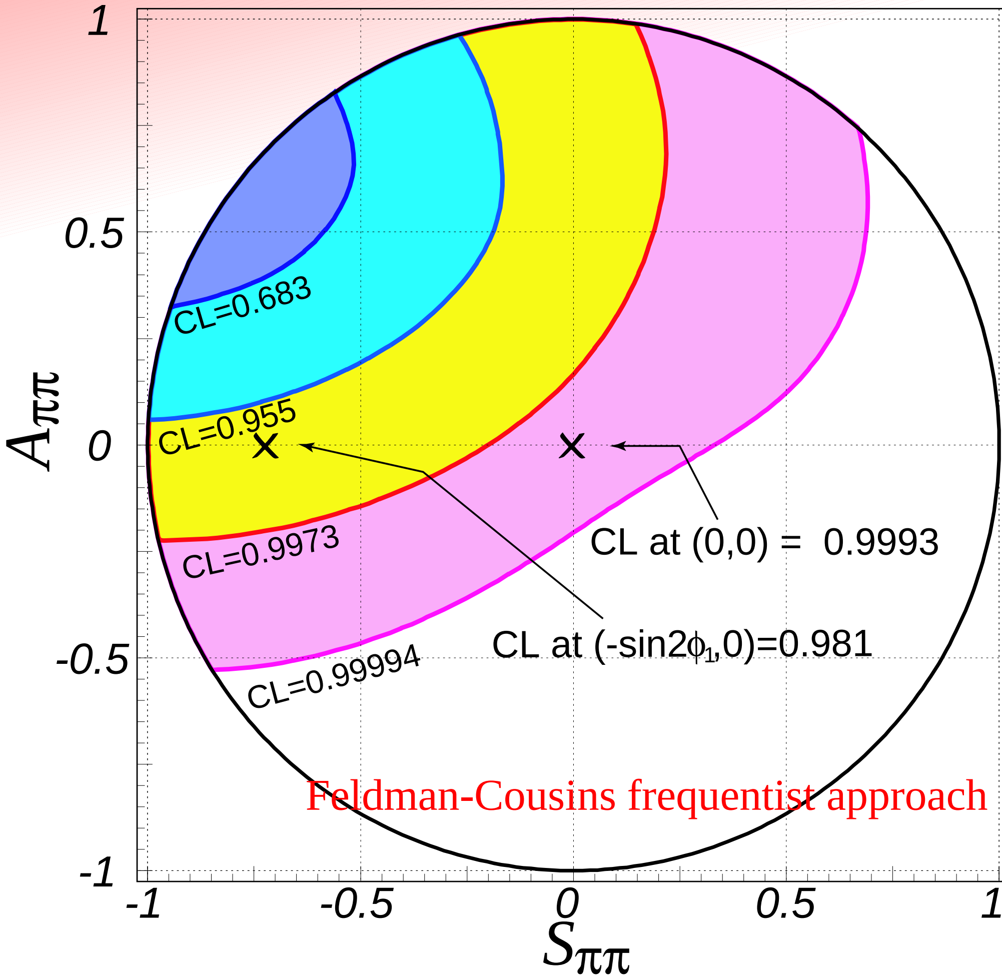
- PRL89, 071801 (2002) [45 fb^{-1}] has been updated [78 fb^{-1}] [hep-ex/0301032, to appear in PRD]
- Improved event selection, error evaluation



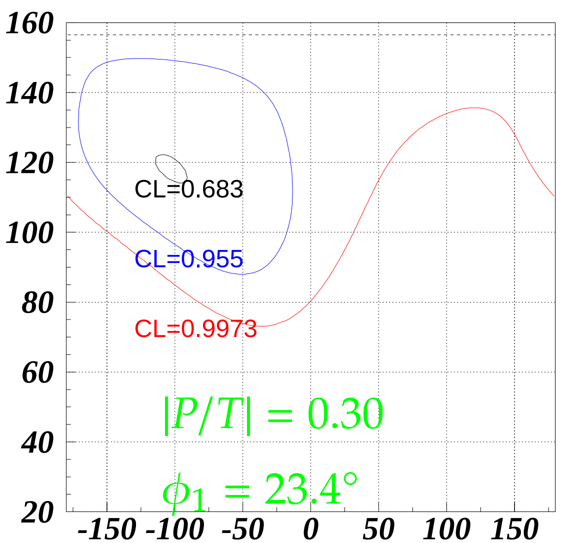


CPV in $B \to \pi^+\pi^-$

$S_{\pi\pi} = -1.23 \pm 0.41(\text{stat}) {}^{+0.08}_{-0.07}(\text{syst})$
$A_{\pi\pi} = +0.77 \pm 0.27(\text{stat}) \pm 0.08(\text{syst})$
$S = A = 0$ is excluded by 3.4σ
(another evidence for CPV in B decay)
2.2σ hint for direct CPV ($A_{\pi\pi} > 0$)?



Belle and BaBar disagree by 2.2σ:
$S_{\pi\pi} = +0.02 \pm 0.34 \pm 0.05$,
$A_{\pi\pi} = -C_{\pi\pi} = +0.30 \pm 0.25 \pm 0.04$

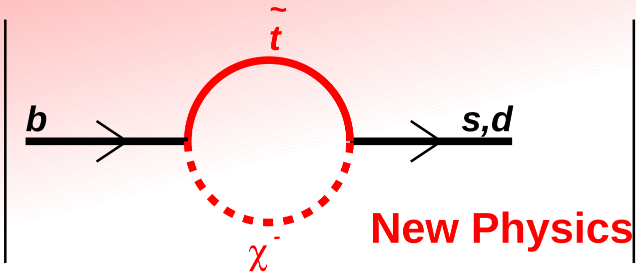


Constraints on ϕ_2

With a range of the Penguin/Tree amplitude ratio ($0.15 < |P|/|T| < 0.45$) [SM gives $|P|/|T| = 0.3$], and $\phi_1 = 23.5°$ (strong phase δ as free param.),

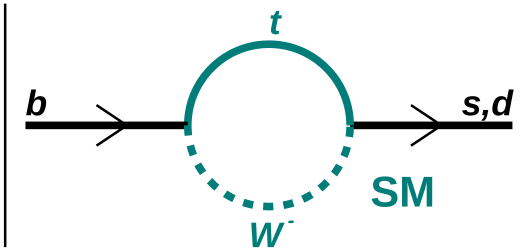
$\Rightarrow 78° < \phi_2 < 152°$ (95.5% C.L.)

Why not direct CPV in $b \to s$?



Similar size amplitudes

$A_{CP} \simeq$ (New Physics amplitude) / (SM amplitude $+ \left| NP/SM \right|^2$) $\times \sin(\phi_{SM}-\phi_{NP}) \times \sin(\delta_{SM}-\delta_{NP})$



(When |NP| < |SM|)

Weak phase difference

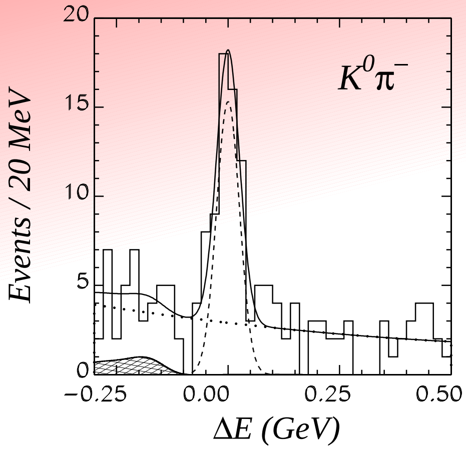
Strong phase difference

- Chances to see the direct CP asymmetry in the charged B decays
- Need also a strong phase difference (need a good luck)
- Pure $b \to s$ penguin examples: $B^+ \to \phi K^+$, $B^+ \to K^0_S \pi^+$, $B \to K^* \gamma$

  (Direct CPV is expected in the SM in many hadronic rare decays,
  where Tree and Penguin amplitudes interfere (like in $B \to \pi^+\pi^-$),
  but it is also interesting to see the first partial rate asymmetry in B decays,
  regardless SM or new physics)

$B^+ \to K^0_S \pi^+$ asymmetry

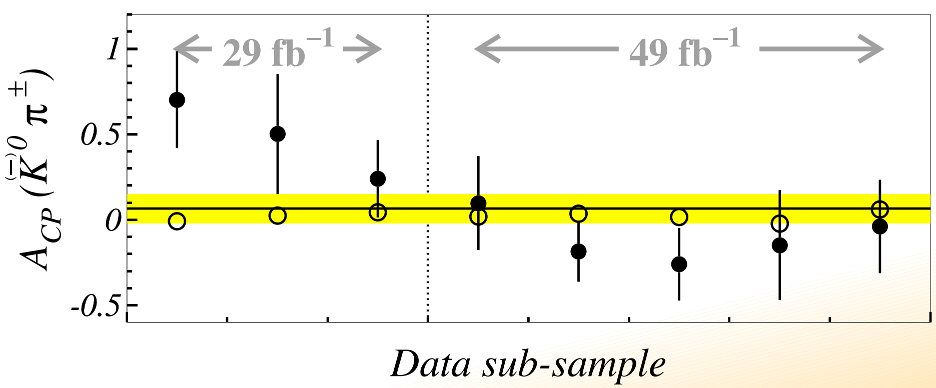
[Belle 29 fb^{-1} PRD66,092002(2002)]



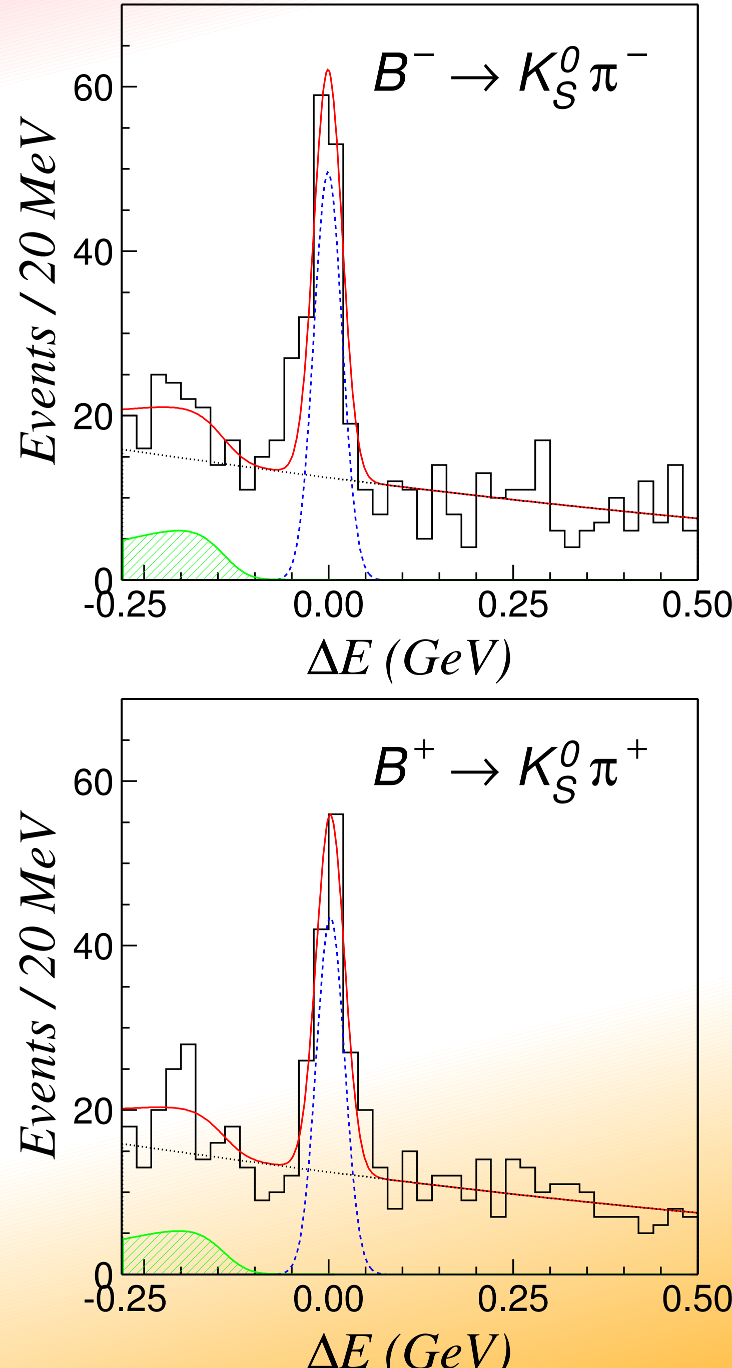
Pure penguin in SM, large A_{cp} was seen?!

Belle 2002	(29 fb^{-1})	$0.46 \pm 0.15 \pm 0.02$ (3σ)
Belle 2003	(78 fb^{-1})	$0.07^{+0.09}_{-0.08}{}^{+0.01}_{-0.03}$

But disappeared now (a good lesson!)

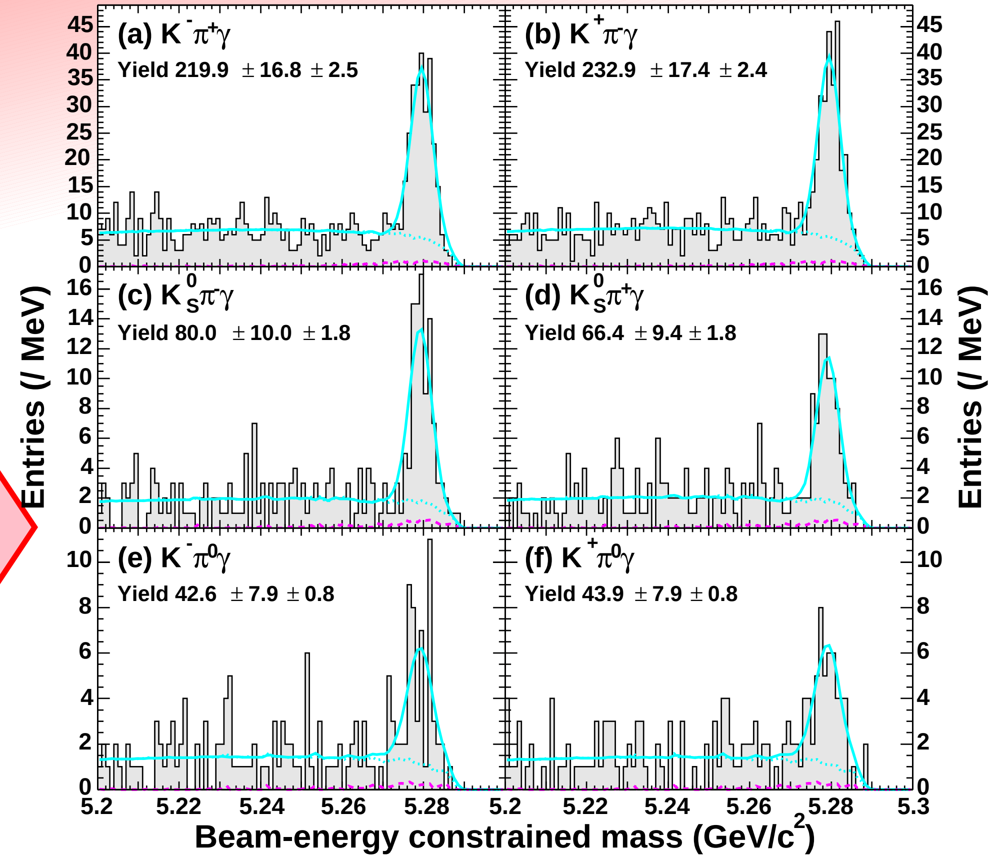


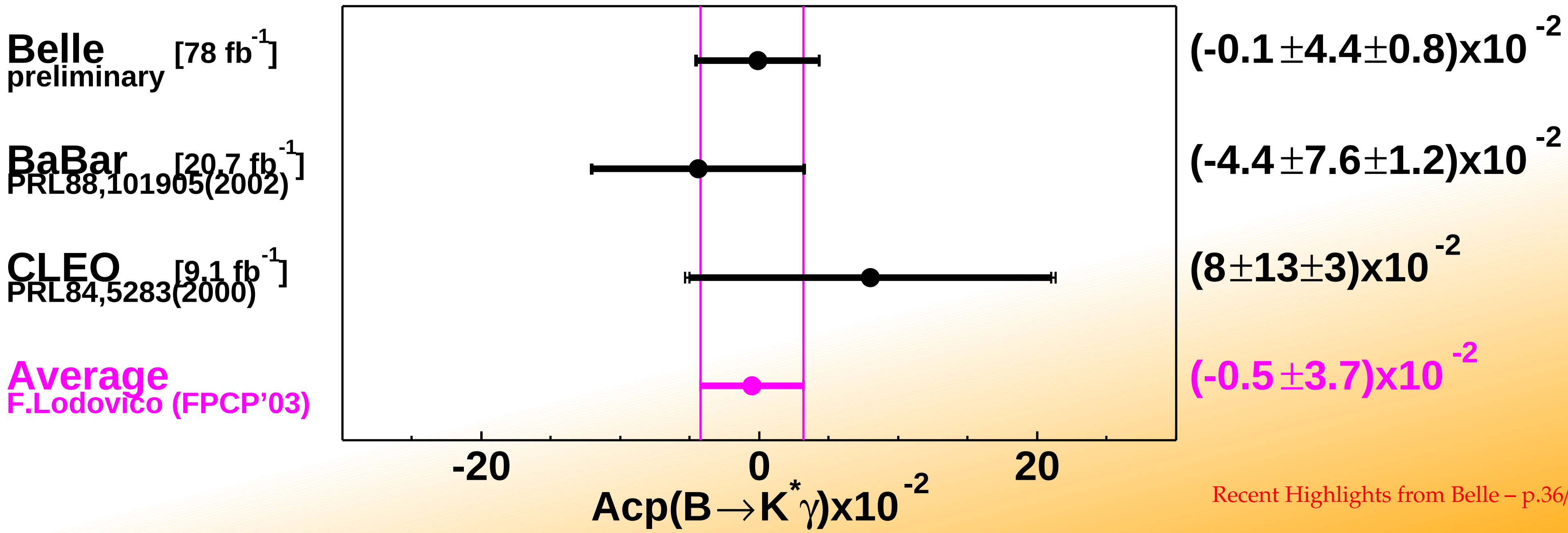
[Belle 78 fb^{-1} hep-ex/0304035,to appear in P



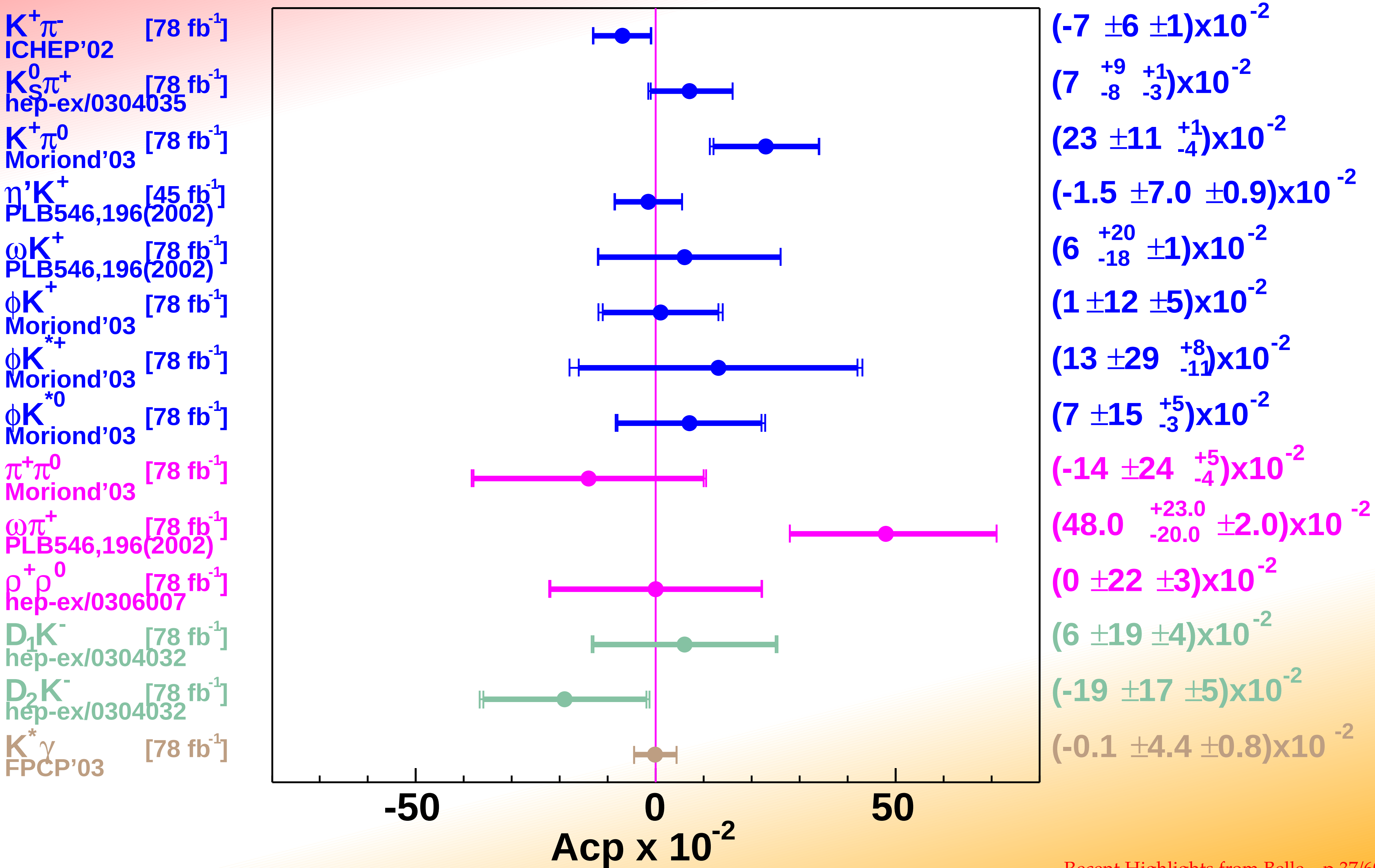
$B \to K^*\gamma$ asymmetry

- Very small SM A_{cp}, less than 1% is predicted
- A_{cp} is zero-consistent in data
- Systematic error is under good control, can go down to 1% with $\times 20$ data



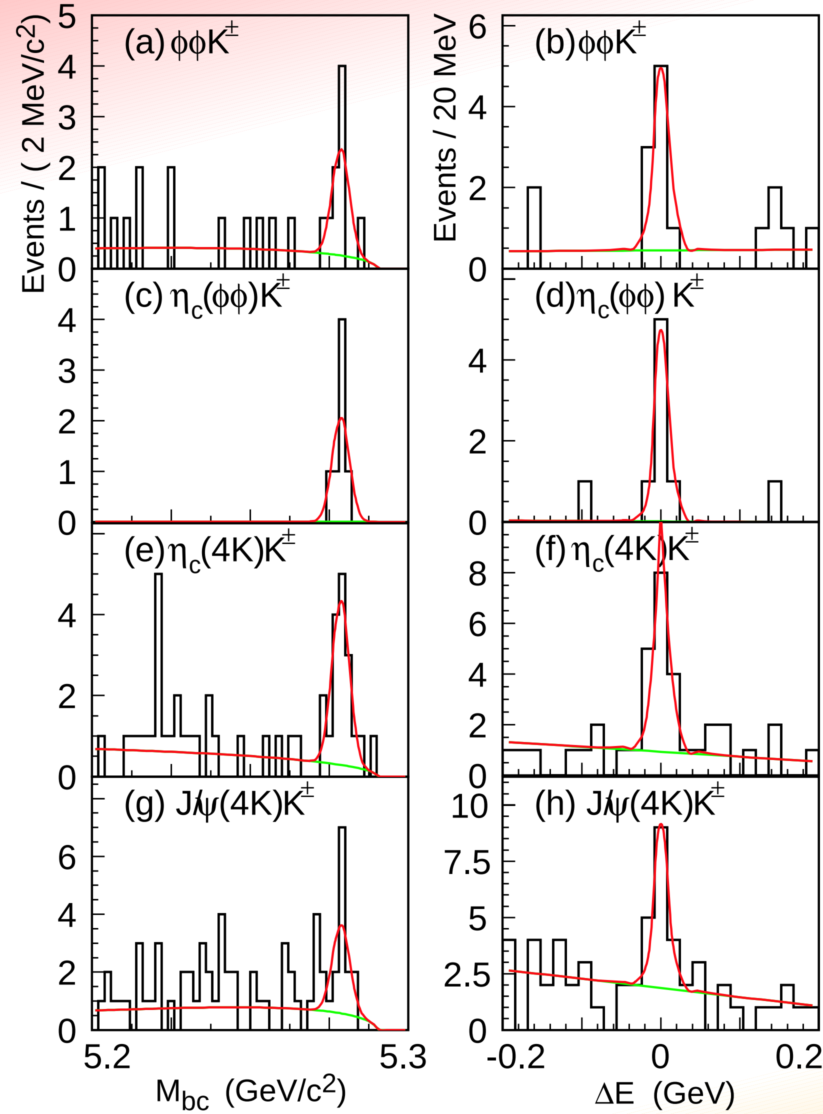


Direct CPV search (no evidence yet)



Possibility: $B \to K\phi\phi$

- 5 s-quark final state ($b \to s\bar{s}s\bar{s}s$)!
- $b \to s$ penguin $\Leftrightarrow$ $b \to (c\bar{c})s$ interfere, and strong phase from Breit-Wigner from $c\bar{c}$ resonance (16 MeV width for $\eta_c \to \phi\phi$)
- No SM weak phase difference — if new physics phase, seen as A_{cp}!
  (no need of luck for the strong phases!)



Belle 78 fb^{-1} [hep-ex/0305068]

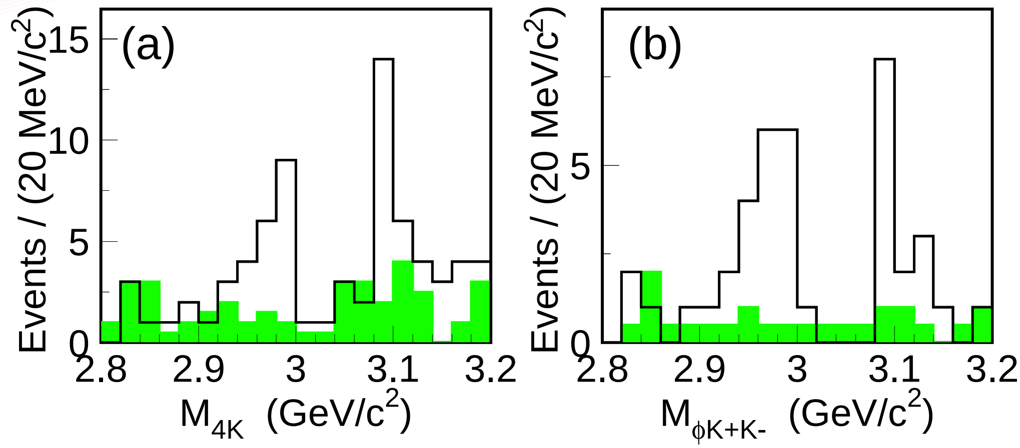
$$\mathcal{B}(B^- \to \phi\phi K^-;\ M_{\phi\phi} < 2.85\ \text{GeV}) = (1.8\,^{+0.8}_{-0.6} \pm 0.2) \times 10^{-6}$$

$$\mathcal{B}(B^- \to \eta_c K^-) \times \mathcal{B}(\eta_c \to \phi\phi) = (2.3\,^{+1.0}_{-0.7} \pm 0.5) \times 10^{-6}$$

First observations, at comparable rates!

More on $B \to 5$ kaons

$B^+ \to K^+K^-K^+K^-K^+$ decays provide a clean environment: we are updating some of the PDG J/ψ and η_c branching fractions by up to an order of magnitude!

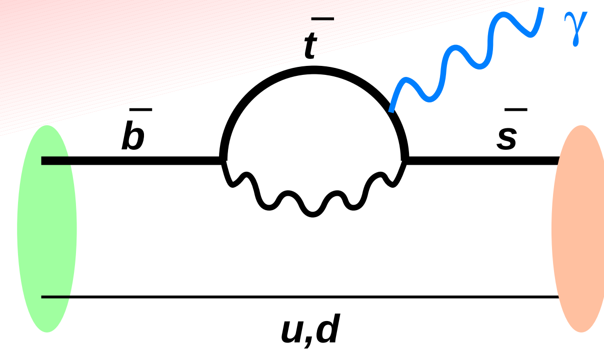


Decay mode	Branching fractions	
	Belle[hep-ex/0305068]	PDG2002
$\eta_c \to \phi\phi$	$(1.8^{+0.8}_{-0.6} \pm 0.7) \times 10^{-3}$	$(7.1 \pm 2.8) \times 10^{-3}$
$\eta_c \to \phi K^+K^-$	$(2.9^{+0.9}_{-0.8} \pm 1.1) \times 10^{-3}$	N.A.
$\eta_c \to 2(K^+K^-)$	$(1.4^{+0.5}_{-0.4} \pm 0.6) \times 10^{-3}$	$(21 \pm 12) \times 10^{-3}$ (!)
$J/\psi \to \phi K^+K^-$	$(2.4^{+1.0}_{-0.8} \pm 0.3) \times 10^{-3}$	$(0.74 \pm 0.11) \times 10^{-3}$
$J/\psi \to 2(K^+K^-)$	$(1.4^{+0.5}_{-0.4} \pm 0.2) \times 10^{-3}$	$(0.70 \pm 0.30) \times 10^{-3}$

Outline

- Introduction
- KEKB performance surpassing $\mathcal{L} = 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Approaches to go beyond SM
  - Search for new CP Violating B decays
    Summary — systematic search for CPV after $\sin 2\phi_1$ *has started, but no strong evidence for additional info yet. Many interesting modes with more data:* $B \to \phi K^0_S, K\phi\gamma, \pi^+\pi^-, K^*\gamma, K\phi\phi, \ldots$
  - **Next** $\Rightarrow$ Radiative/electroweak rare B decays
- Comments on the new D_{sJ} resonance

$b \to s\gamma$



$b\to s\gamma$ penguin

- Penguin diagram can accommodate heavy new particles (SUSY, H^+)

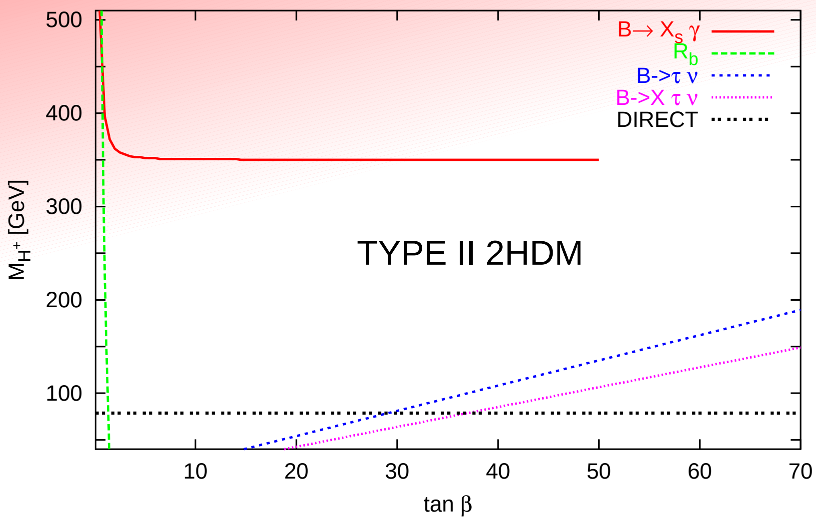
Branching fraction in an effective hamiltonian: $\mathcal{H}_{\text{eff}} \propto \sum_{i=1}^{10} C_i(\mu)O_i(\mu)$

$$\Gamma(b \to s\gamma) = \frac{G_F^2 \alpha_{\text{em}} m_b^5}{32\pi^4} |V_{ts}^* V_{tb}|^2 \left(|C_7^{\text{eff}}|^2 + 1/m_b,\ 1/m_c \text{ corrections}\right)$$

Normalized with $b \to c\ell\nu$: $(G_F^2 m_b^5 \left|V_{ts}^* V_{tb}\right|^2$ cancels by assuming $\left|V_{ts}^* V_{tb}\right| = |V_{cb}|)$

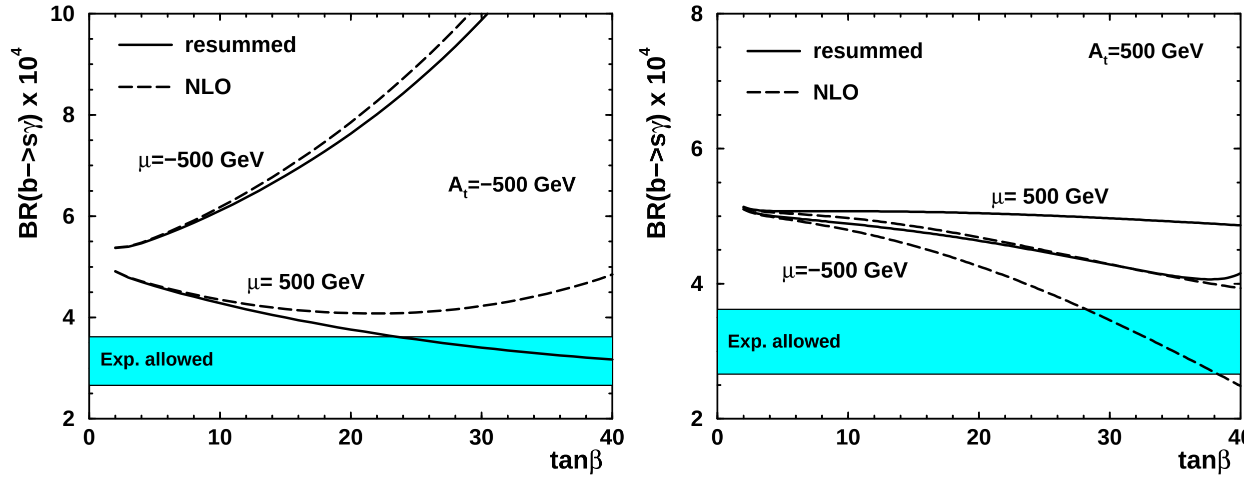
- Probe for new physics through Wilson coefficient $|C_7|$
  - Branching fraction $\sim 3.5 \times 10^{-4}$ (both in experiments and SM)
  - Calculation completed at NLO
- Tool for B-meson dynamics:
  - photon energy spectrum to understand lepton spectra for V_{ub}, V_{cb}

$b \to s\gamma$ examples



Lower bounds on type-II charged Higgs mass (w/o SUSY)

Gambino-Misiak, Nucl. Phys. B611, 338



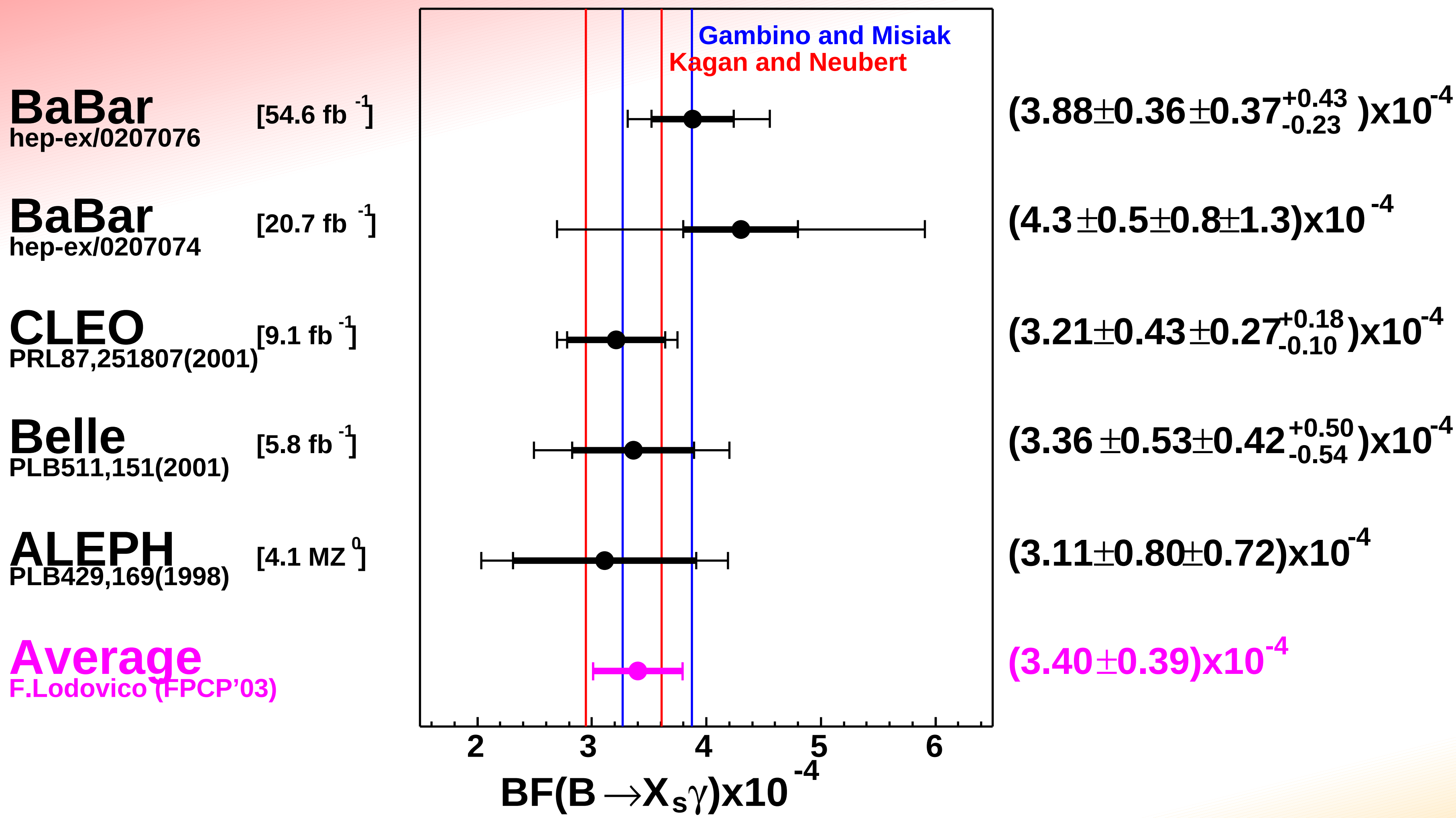
BF in particular MSSM scenario Carena et al., PLB499, 141

$m(H^+) = 200$ GeV, $m(\tilde{t}) = 250$ GeV, others 800 GeV

Type-II charged Higgs is very heavy, unless destructive SUSY contributions

type-I	both up and down quarks get their masses from the same Higgs doublet
type-II	up quark masses from Yukawa couplings to H_2, while down quarks get masses from couplings to H_1 (realized in MSSM).

$b \to s\gamma$



No deviation from SM — many constraints on new physics

$-0.37 < C_7^{\text{eff}} < -0.17$ or $+0.21 < C_7^{\text{eff}} < +0.43$ (exp.) $\Leftrightarrow$ $C_7^{\text{eff}} = -0.313$ (SM)

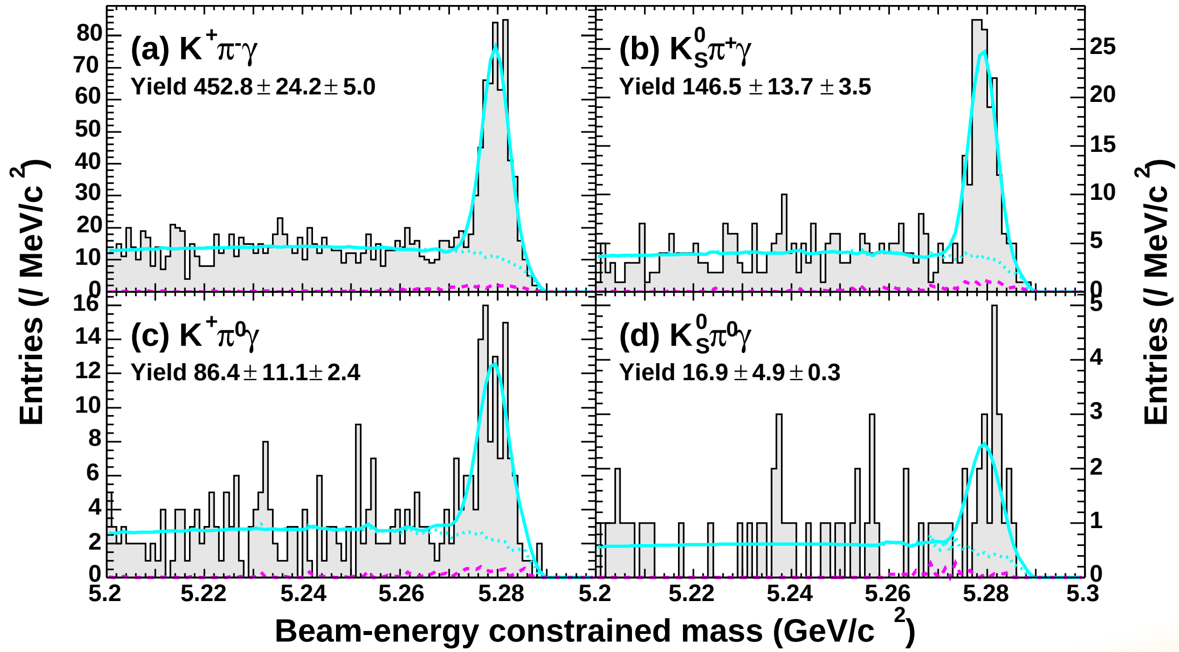
Need a better precision (experiments and theories) and/or search somewhere else

$B \to K^*\gamma$

Precision measurement 10 years after the first $B \to K^*\gamma$ by CLEO

- Large theoretical BF uncertainty to constrain new physics, but,
- Isospin asymmetry will tell the sign of C_6/C_7
  [Kagan-Neubert PLB539,227(2002)]
  SM gives +5 to 10% asymmetry

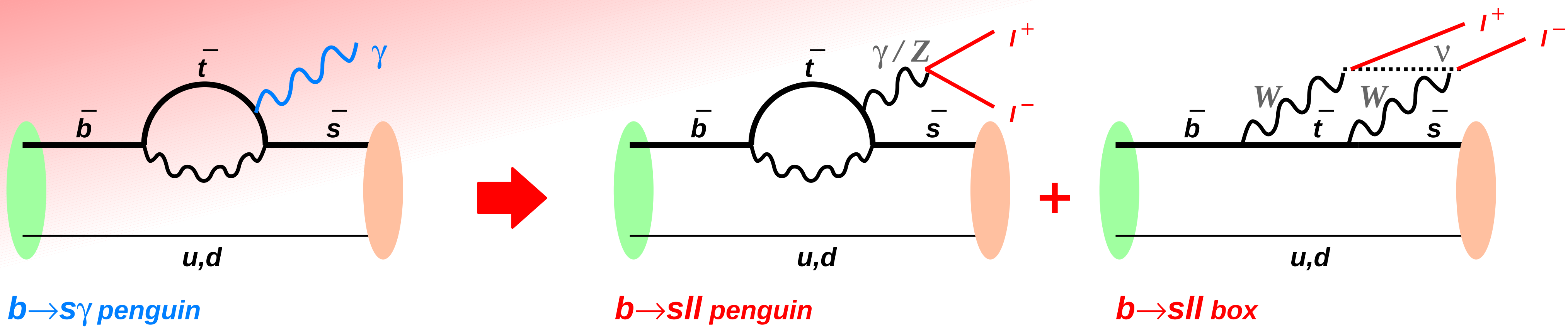
[FPCP'03 78 fb^{-1}]



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

$\Delta_{0+} = +0.003 \pm 0.045(\text{stat}) \pm 0.018(\text{syst})$ $\Rightarrow$ Need to revisit with more data.

$b \to s\ell^+\ell^-$



As it goes through virtual γ/Z, the decay rate is now a function of the virtuality, or $\hat{s} = s/m_b^2 = (M_{\ell^+\ell^-}/m_b)^2$

$$\frac{d\Gamma(b \to s\ell^+\ell^-)}{d\hat{s}} = \left(\frac{\alpha_{\rm em}}{4\pi}\right)^2 \frac{G_F^2 m_b^5 \left|V_{ts}^* V_{tb}\right|^2}{48\pi^3}(1-\hat{s})^2$$

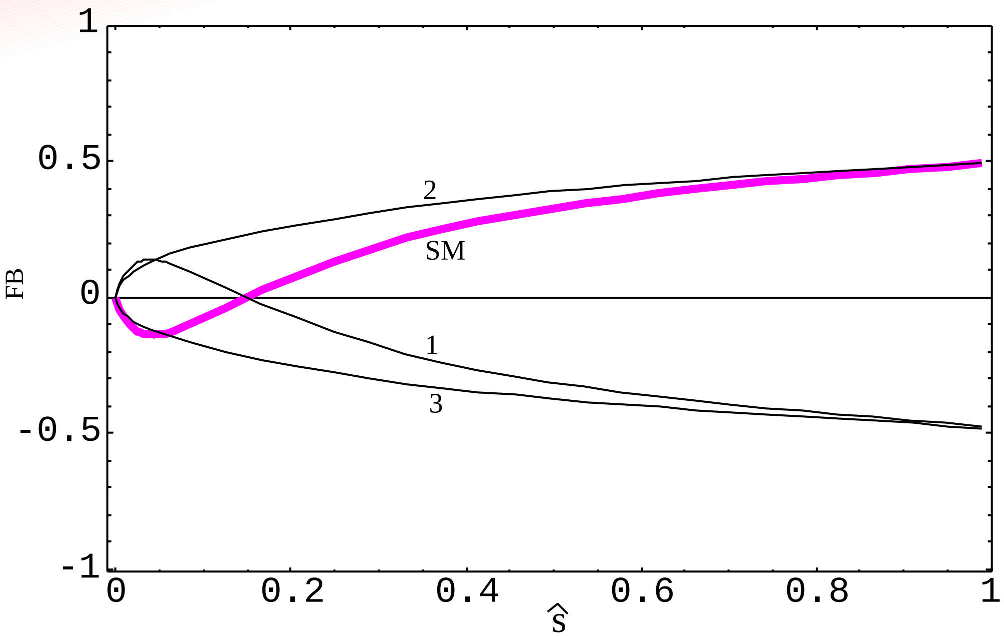
$$\times\left[(1+2\hat{s})\left(|C_9|^2+|C_{10}|^2\right)+4\left(1+\frac{\hat{s}}{2}\right)|C_7|^2+12\mathrm{Re}\left(C_7C_9\right)\right]+\text{corr.}$$

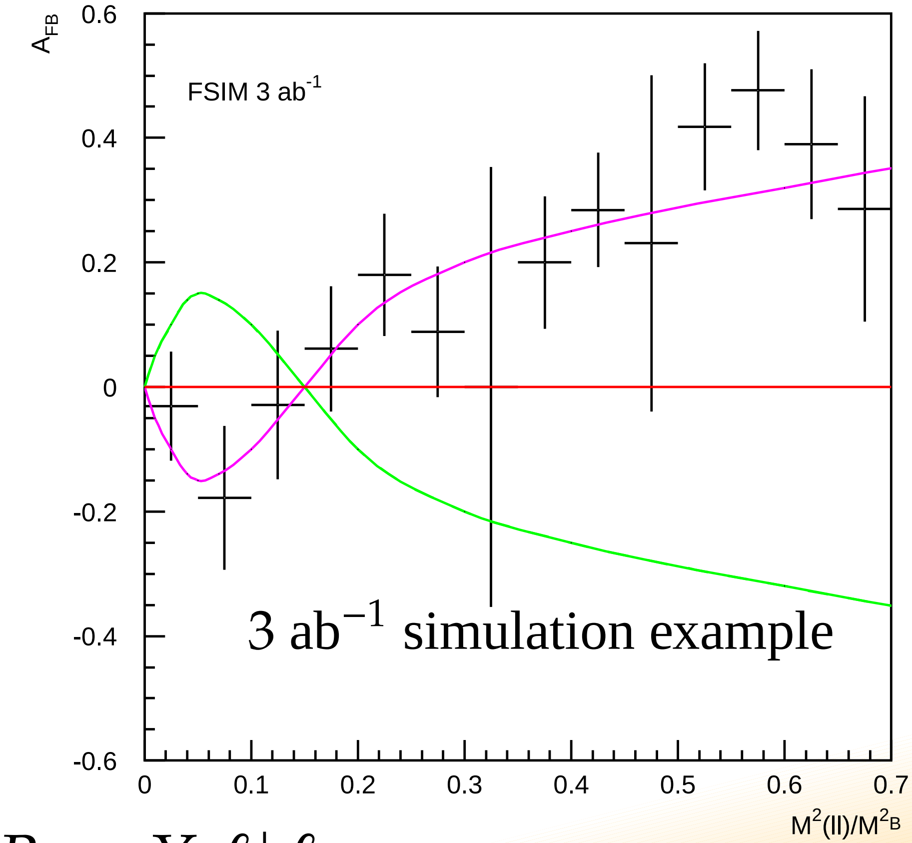
- Reliable NNLO calculation only up to $M_{\ell^+\ell^-} \sim 2.4$ GeV ($\hat{s} = 0.25$), calculation breaks down at resonances: $M_{\ell^+\ell^-} \sim M_{J/\psi}$ and above.
- There is large allowed space for C_9, C_{10} and the sign of C_7.
- Suppressed by $1/\alpha_{em}$, not seen before Belle/BaBar

Forward Backward Asymmetry

$A_{FB}$is one of the key observable to distinguish SUSY models.

Examples of A_{FB} with SUSY



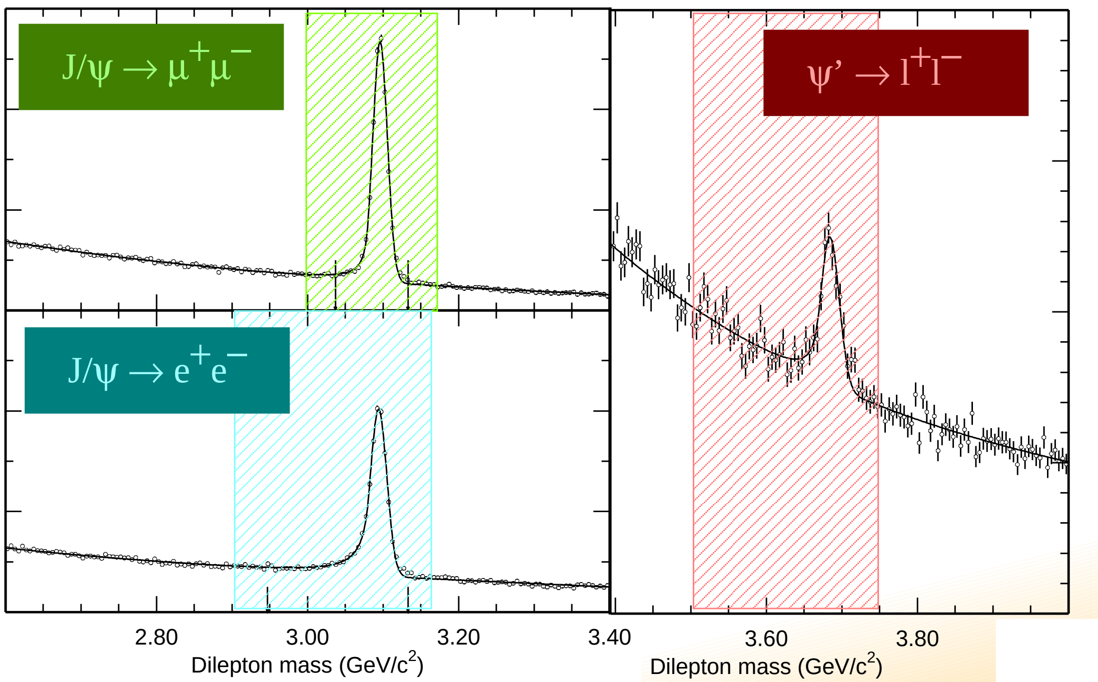


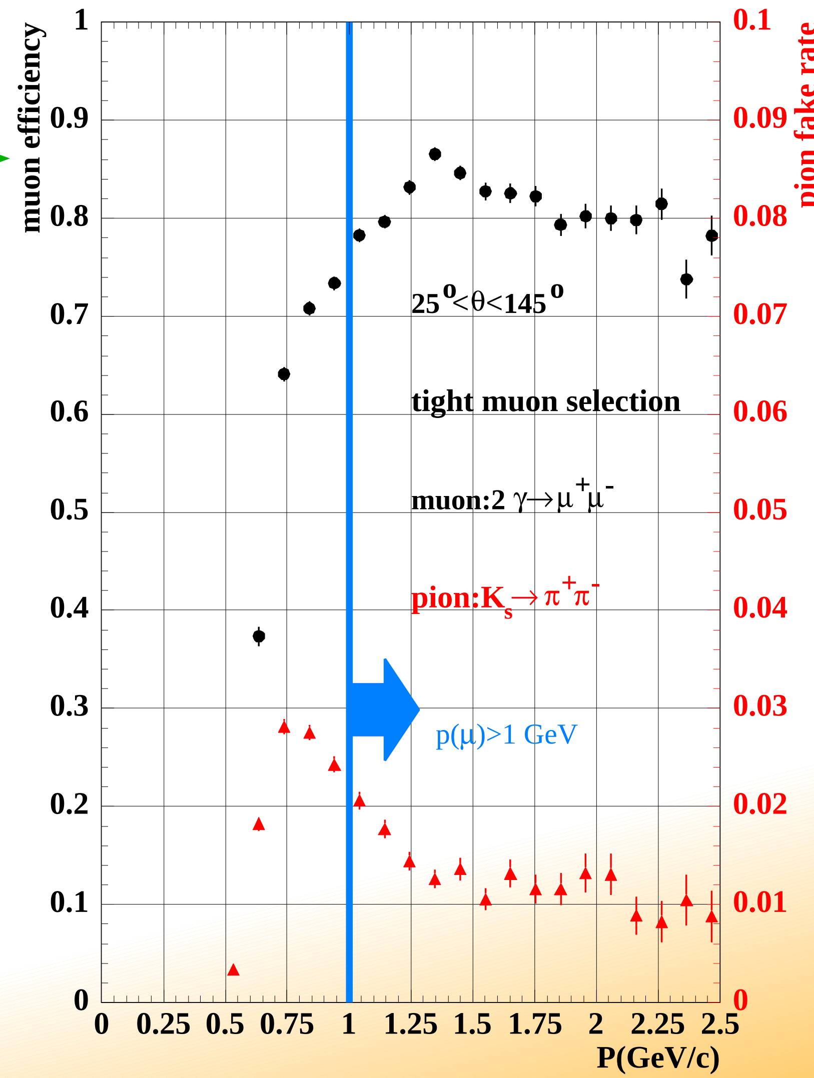
Either in $B \to K^* \ell^+ \ell^-$ or in inclusive $B \to X_s \ell^+ \ell^-$

[$B \to K \ell^+ \ell^-$ cannot be used. $B^0 \to K^0_S n(\pi^+\pi^-) m(\pi^0)$ requires flavor tagging]

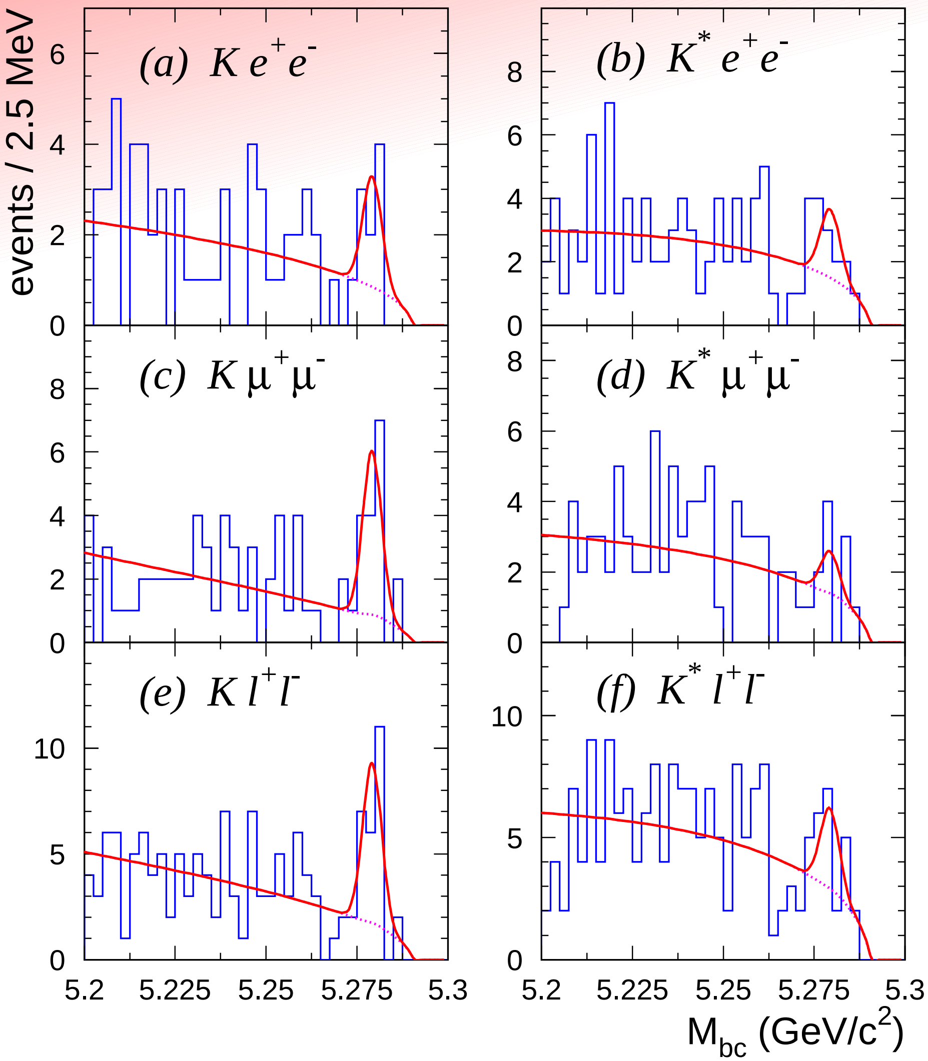
$B \to K\ell^+\ell^-$ analysis

- Kinematics close to abundant decays: $B \to J/\psi(\to \ell\ell)K^{(*)}$ or $D(\to K\pi)\pi$
- Fake $\pi \to \mu$ is not a problem
- J/ψ and ψ' are vetoed



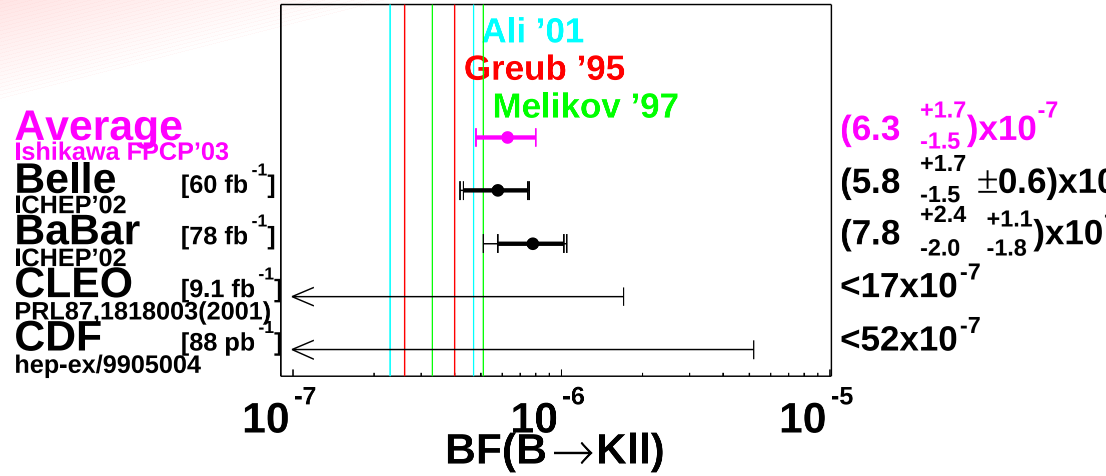


$B \to K\ell^+\ell^-$ signal

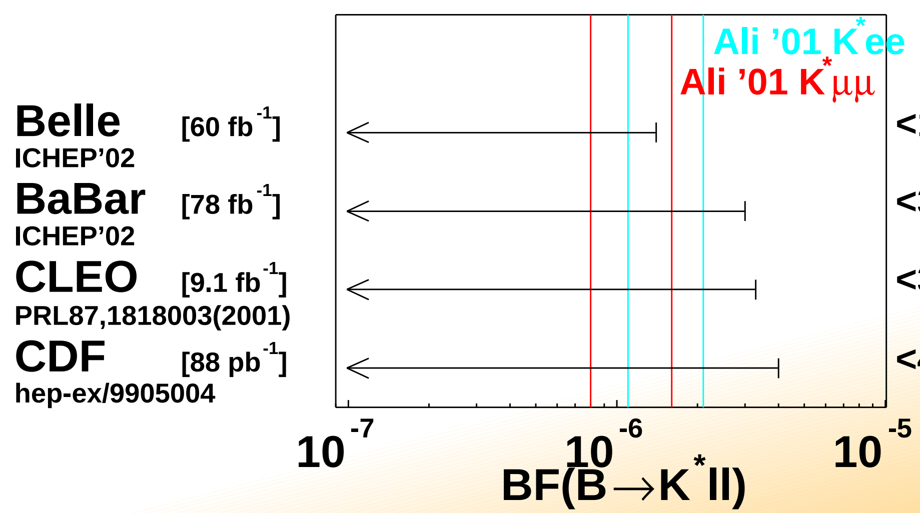


[Belle ICHEP'02 60 fb^{-1}]

(update of PRL88,021801(2002))



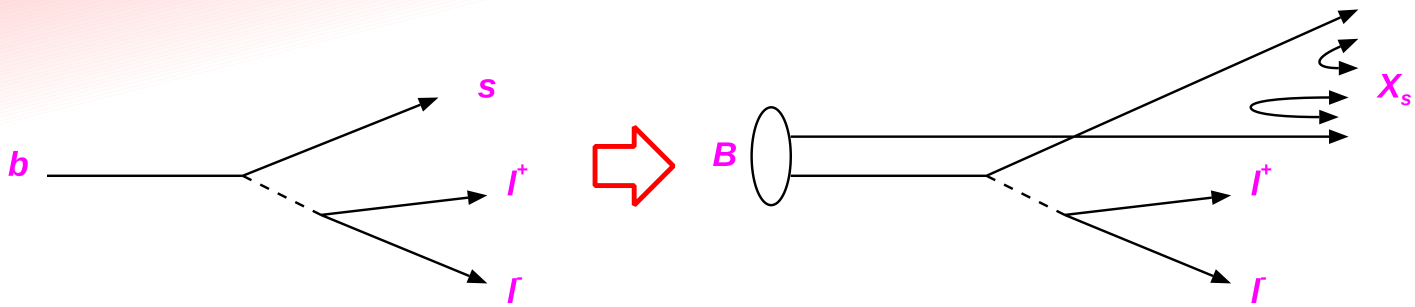
$B \to K\ell^+\ell^-$ signal is established



$B \to K^*\ell^+\ell^-$ will be there soon

$B \to X_s \ell^+ \ell^-$ analysis

Belle has performed a semi-inclusive analysis for $B \to X_s \ell^+ \ell^-$



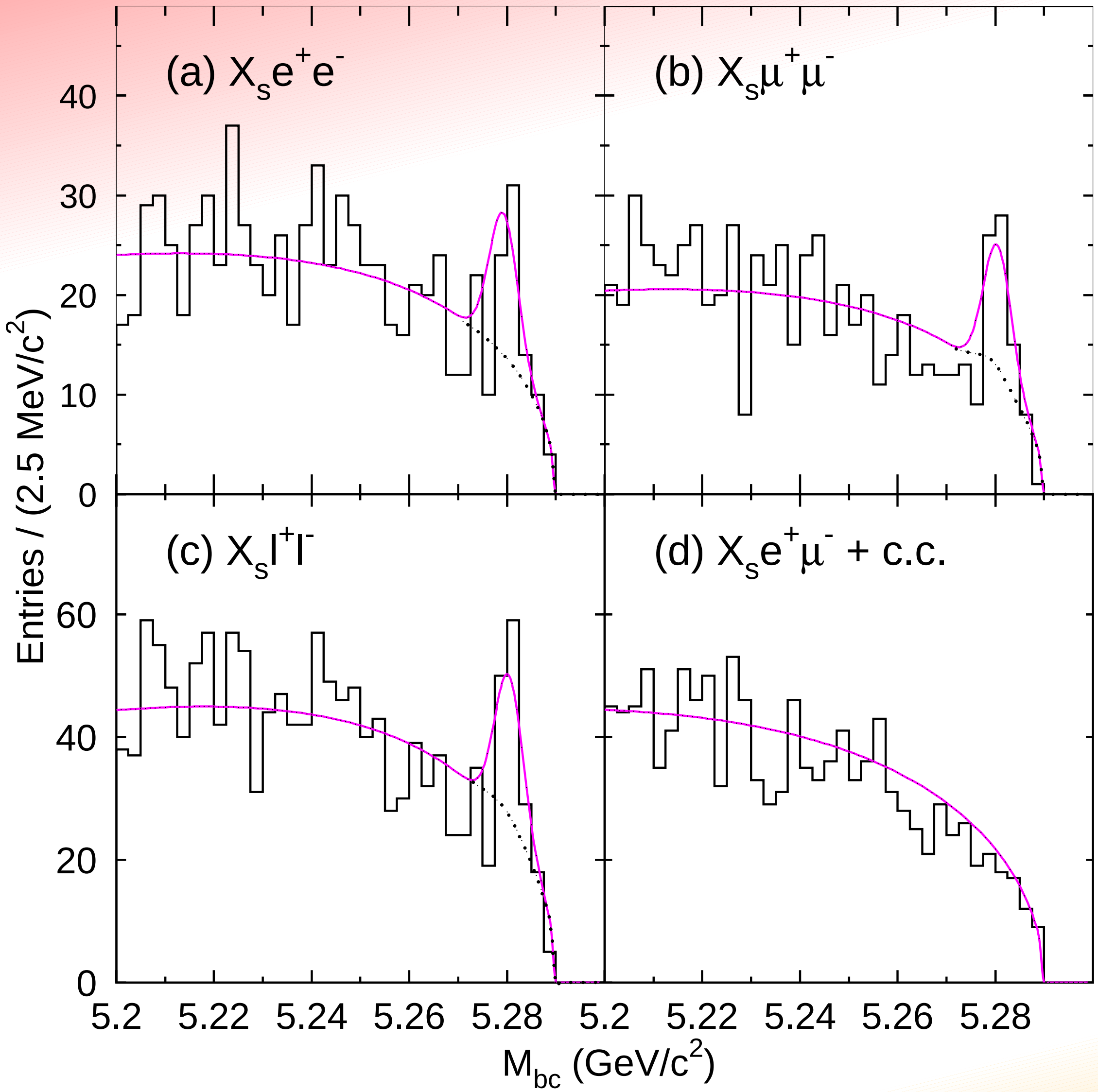
Reconstruction

- X_s = a kaon + 0 to 4 pion
  (covers $(82 \pm 2)\%$ of signal)
  kaon = $K^\pm$ or K_S^0
  pion = $\pi^\pm$ or π^0 (upto 1 π^0)
  $M_{X_s} < 2.1$ GeV
- lepton = e or μ
  $p(e) > 0.5$ GeV
  $p(\mu) > 1.0$ GeV
  $M_{\ell^+\ell^-} > 0.2$ GeV

Backgrounds

- $B \to J/\psi X_s$
- $B \to X_s \pi^+ \pi^-$
  (These are good control samples, too)
- $b \to c\ell\nu, c \to s\ell\nu$
- $b \to c\ell\nu, \bar{b} \to \bar{c}\ell\nu$
- $\pi^0 \to e^+ e^- \gamma$
- continuum background

$B \to X_s \ell^+ \ell^-$ branching fraction



Belle 60 fb^{-1} PRL90,021801(2003)

Clear signal (5.4σ)

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

Branching fractions in 10^{-6}

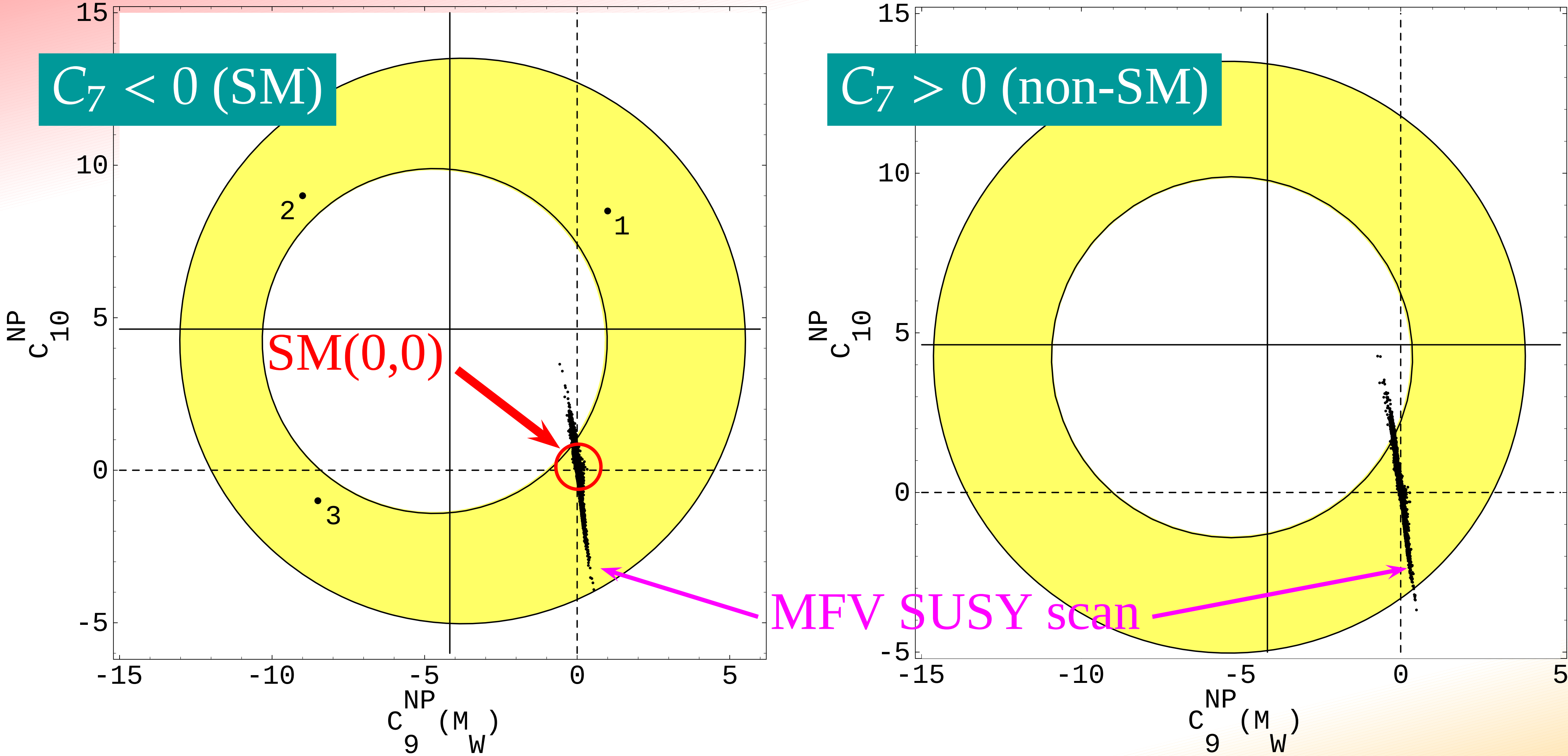
$B \to X_s e^+ e^-$	$5.0 \pm 2.3\,^{+1.3}_{-1.1}$
$B \to X_s \mu^+ \mu^-$	$7.9 \pm 2.1\,^{+2.1}_{-1.5}$
$\boldsymbol{B \to X_s \ell^+ \ell^-}$	$\mathbf{6.1 \pm 1.4\,^{+1.4}_{-1.1}}$

(for $M_{\ell^+\ell^-} > 0.2$ GeV)

(SM $(4.2 \pm 0.7) \times 10^{-6}$)

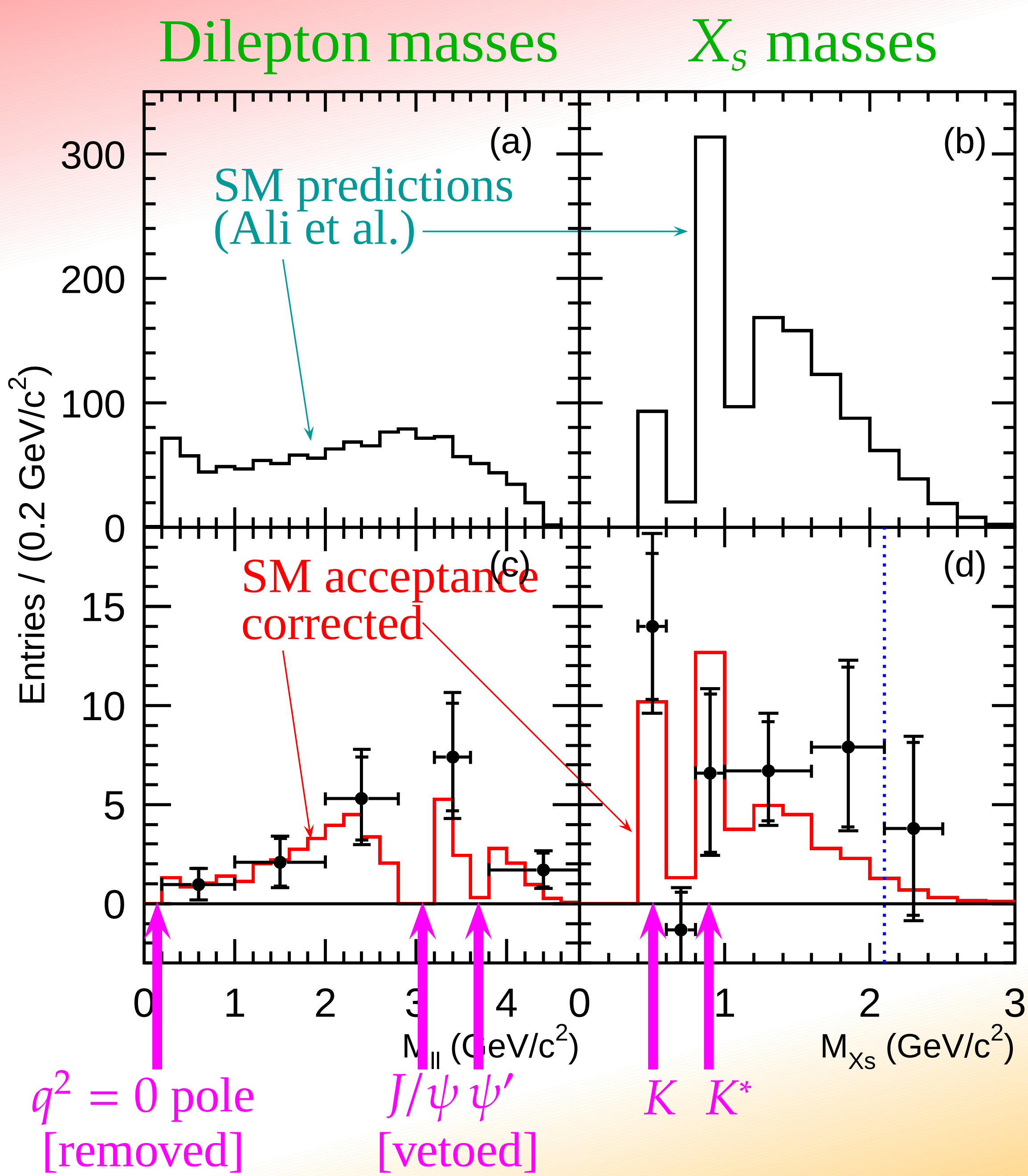
In agreement with SM (error is still large), constraint on Wilson coefficient C_9 and C_{10}

Constraints on C_9 and C_{10}



- Cutting out some non-SM C_9 and C_{10} space from $b \to s\ell^+\ell^-$ with a $|C_7|$ constraint from $b \to s\gamma$
- But sign of C_7 is not determined yet

$B \to X_s \ell^+ \ell^-$ distributions



Belle 60 fb^{-1}
PRL90,021801(2003)

From bin-by-bin fit to $M_{\rm bc}$

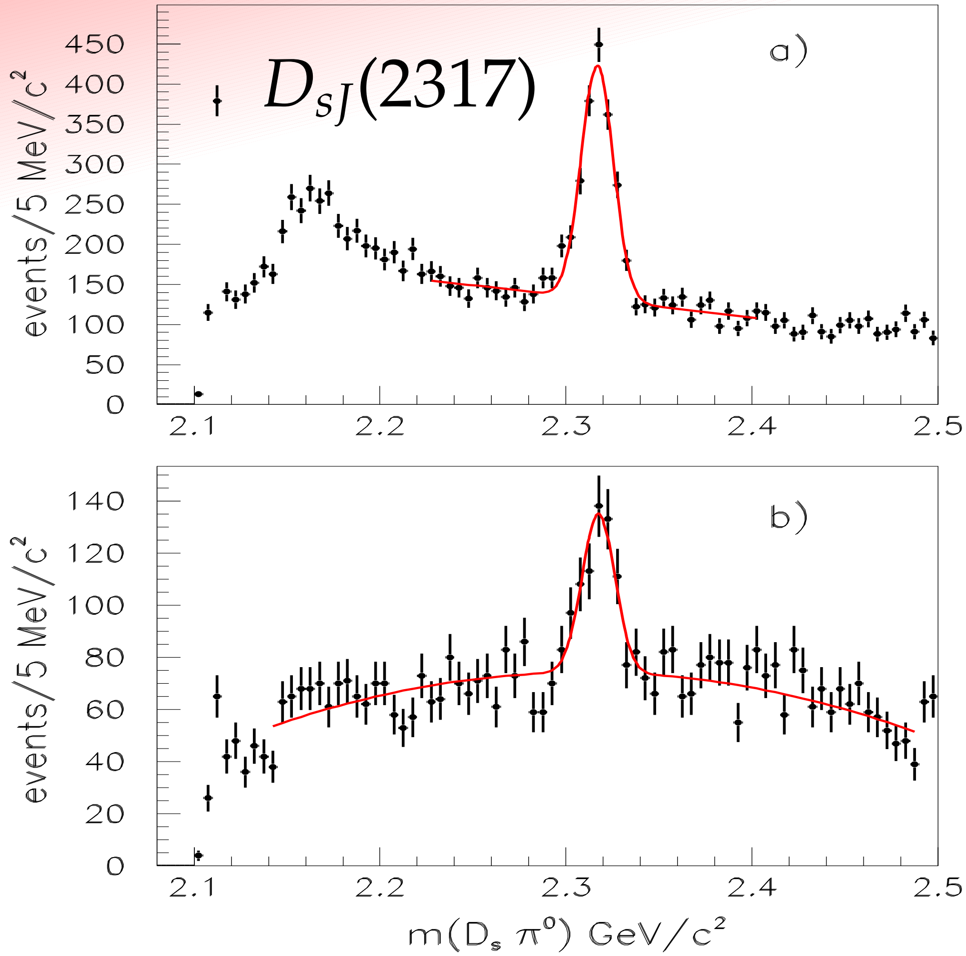
With more data, one can perform A_{FB} measuremts

Outline

- Introduction
- KEKB performance surpassing $\mathcal{L} = 10^{34}$ cm^{-2}s^{-1}
- Approaches to go beyond SM
  - Search for new CP Violating B decays
  - Radiative/electroweak rare B decays
    Summary — the first inclusive $b \to s\ell^+\ell^-$ has been measured by Belle. So far it does not conflict with SM, but it also demonstrates feasibilities for further studies. $b \to s\gamma$ will provide interesting results, too.
- **Next** $\Rightarrow$ Comments on the new D_{sJ} resonance

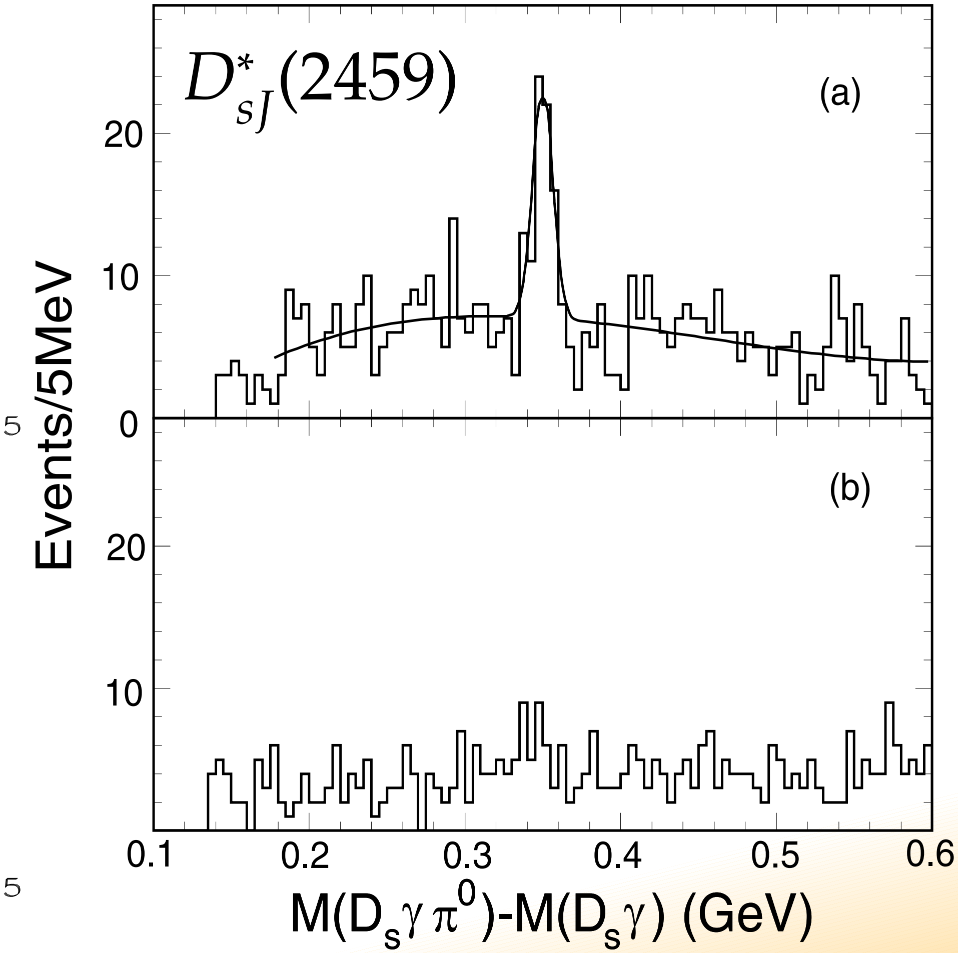
New D_{sJ} resonances

BaBar



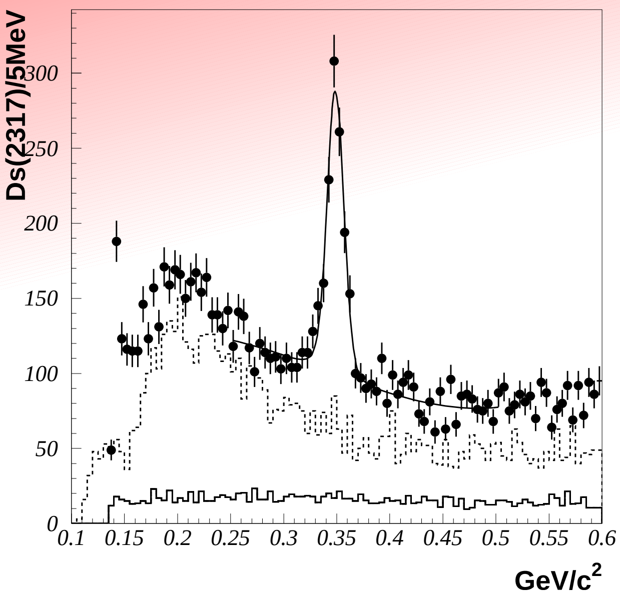
[hep-ex/0304021]

CLEO



[hep-ex/0305017]

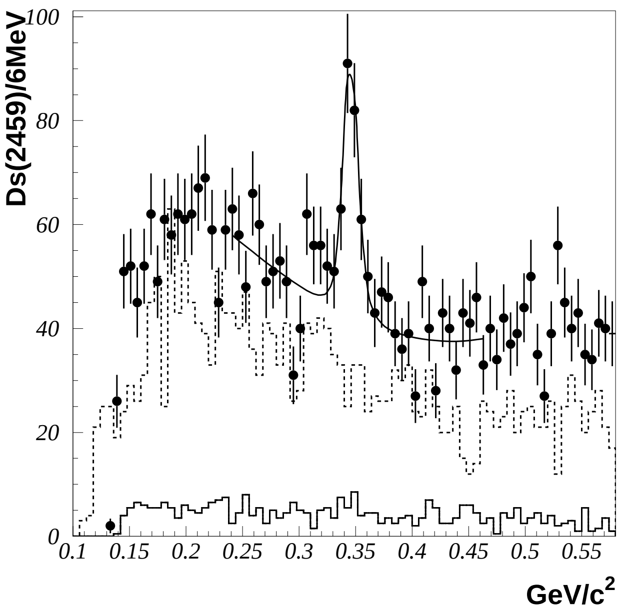
D_{sJ} at Belle



$D_{sJ}(2317) \to D_s^+ \pi^0$ (feed-across accounted)

- 643.2 ± 50.4 events
- $\delta M = M(D_{sJ}) - M(D_s^+) = 348.9 \pm 0.5$ MeV
- $M(D_{sJ}) = 2317.4 \pm 0.5$ MeV

Very close



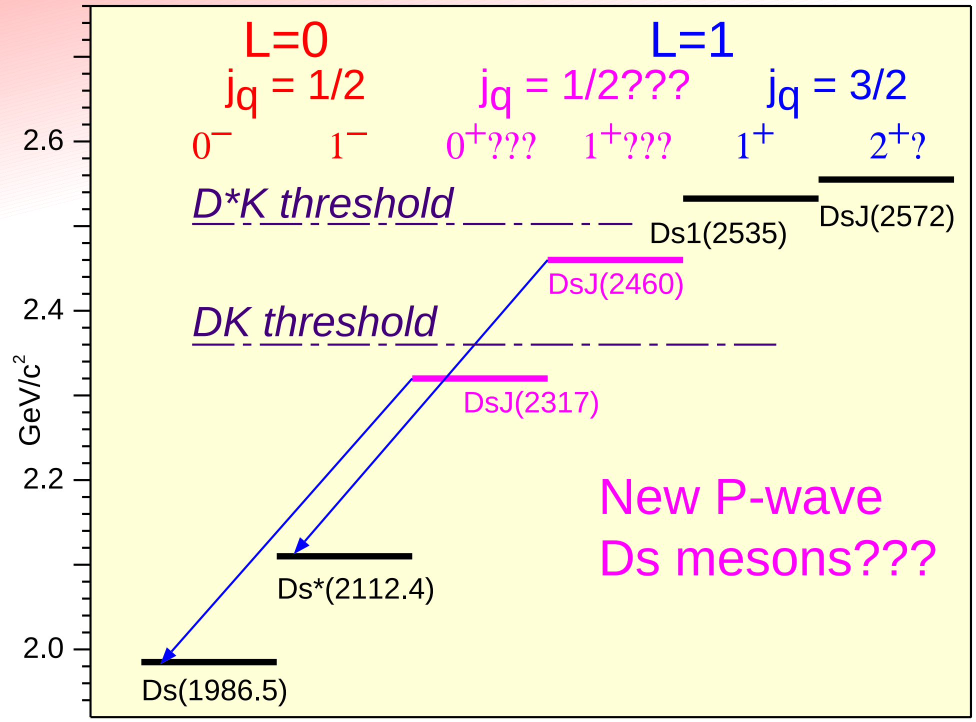
$D_{sJ}(2460) \to D_s^{*+} \pi^0$ (feed-across accounted)

- 79.1 ± 18.0 events
- $\delta M = M(D_{sJ}) - M(D_s^{*+}) = 345.4 \pm 1.3$ MeV
- $M(D_{sJ}) = 2457.8 \pm 1.4$ MeV

In agreement with BaBar and CLEO

D_{sJ} properties?

- D_{sJ} are below $D^{(*)}K$ threshold, and have to go through isospin violating channels $D_s^{(*)}\pi^0$
  ($D_{sJ}(2460)$ is not $0^+/1^-$ (no $D_{sJ}(2460 \to DK)$)
- Much lower D_{sJ} masses than expected for missing $J^P = 0^+, 1^+$

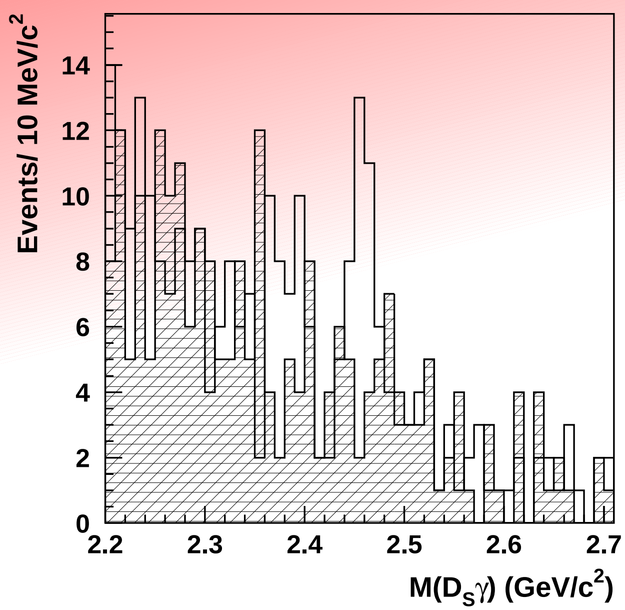


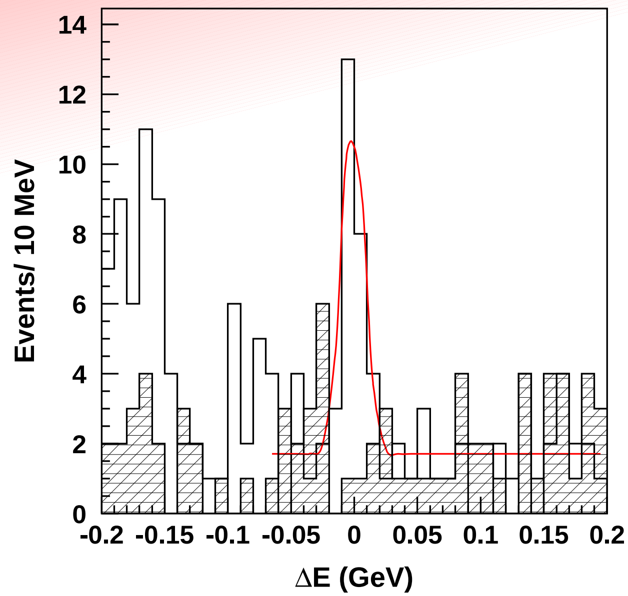
		BaBar	CLEO	Belle
$M(D_{sJ}(2317))$	(MeV)	2316.8 ± 0.4	—	2317.4 ± 0.5
$M(D_{sJ}(2317)) - M(D_s)$	(MeV)	—	$350.0 \pm 1.2 \pm 1.0$	348.9 ± 0.5
$M(D_{sJ}(2460))$	(MeV)	—	—	2457.8 ± 1.4
$M(D_{sJ}(2460)) - M(D_s^*)$	(MeV)	—	$351.2 \pm 1.7 \pm 1.0$	345.4 ± 1.3

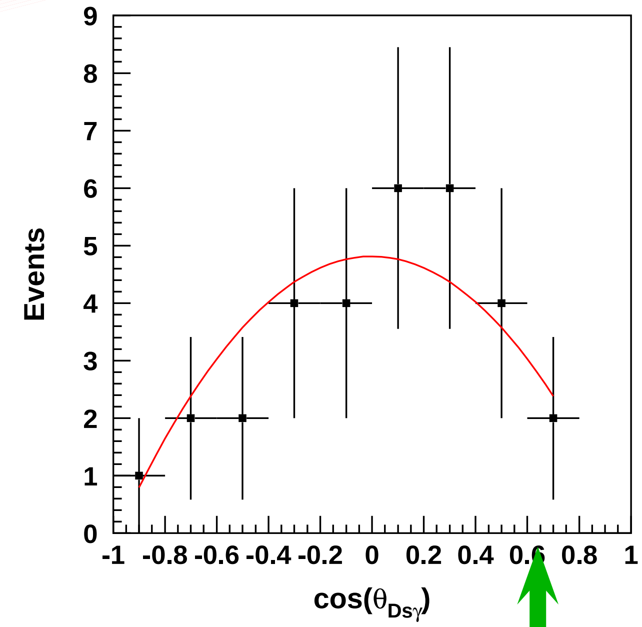
Mass splitting favors the 0^+ and 1^+ hypothesis [Bardeen-Eichten-Hill hep-ph/0305049]

CLEO found no signal in other D_{sJ} decays: $D_s^{(*)}\gamma$, $D_s\pi^+\pi^-$, $D_{sJ}(2317) \to D_s^*\pi^0$ and $D_{sJ}(2460) \to D_{sJ}(2317)\gamma$ (no evidence to disfavor 0^+ and 1^+)

Radiative D_{sJ} decays



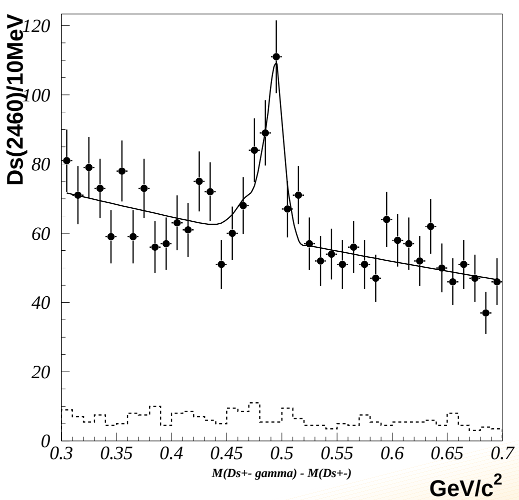




$D_{sJ}(2460) \to D_s\gamma$ is observed in $B \to DD_{sJ}(2460)$! ($D = D^0$ or D^+)

$J \neq 0$ for $D_{sJ}(2460)$, also $J^P \neq 1^-$ (no decay into DK) $\Rightarrow$ uniquely 1^+

(unless $J \geq 2$, also supported in the angular analysis: $\propto \sin^2\theta_{\rm hel}$)

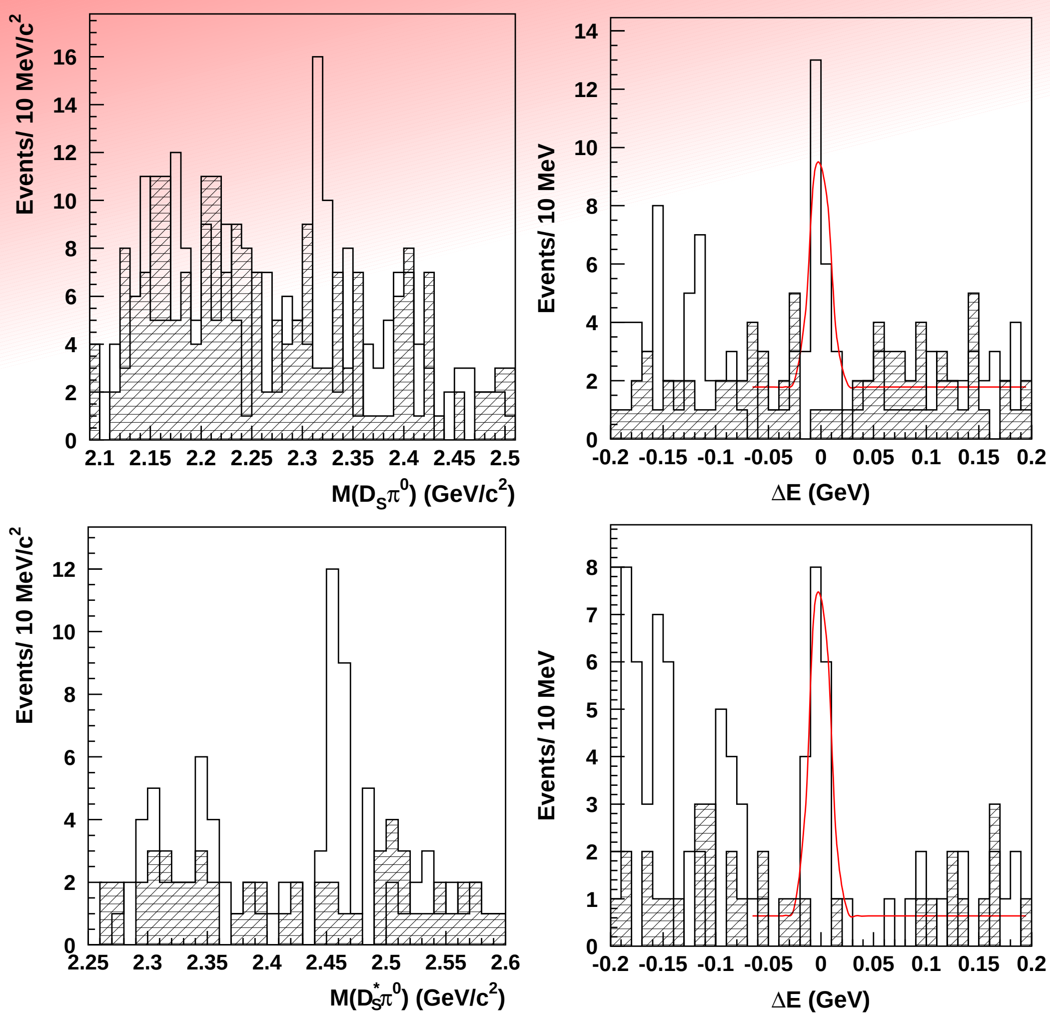


$$\mathcal{B}(B \to DD_{sJ}) \times \mathcal{B}(D_{sJ} \to D_s^+\gamma) = (5.3^{+1.4}_{-1.3} \pm 1.6) \times 10^{-4}$$

$\Leftarrow$ $D_{sJ}(2460) \to D_s\gamma$ is also observed in continuum

No $D_{sJ}(2317) \to D_s\gamma$ is found ($J = 0$ is likely $\Rightarrow 0^+$)

D_{sJ} from B decays



$B \to DD_{sJ}(2317)$, $D_{sJ}(2317) \to D_s^+\pi^0$

$18.8^{+5.4}_{-4.8}$ events (5.3σ signifi cance)

$\mathcal{B}(B \to DD_{sJ}) \times \mathcal{B}(D_{sJ} \to D_s^+\pi^0)$
$= (9.9^{+2.8}_{-2.5} \pm 3.0) \times 10^{-4}$

$B \to DD_{sJ}(2460)$, $D_{sJ}(2460) \to D_s^{*+}\pi^0$

$16.7^{+4.8}_{-4.1}$ events (6.0σ signifi cance)

$\mathcal{B}(B \to DD_{sJ}) \times \mathcal{B}(D_{sJ} \to D_s^+\pi^0)$
$= (25.8^{+7.0}_{-6.0} \pm 7.7) \times 10^{-4}$

$\mathcal{B}(D_s\gamma)/\mathcal{B}(D_s\pi^0) = 0.21 \pm 0.07 \pm 0.03$
is consistent with prediction for 1^+

[Bardeen-Eichten-Hill hep-ph/0305049]

Existence of $B \to DD_{sJ}$ for $j_q = 1/2$,
and non-existence for suppressed $j_q = 3/2$ (BaBar) also prefers $j_q = 1/2$ for new D_{sJ}

Many supports for ordinary $L = 0$, $j_q = 1/2$ states,
despite many theoretical speculations (4-quark state, . . .)

Outline

- Introduction
- KEKB performance surpassing $\mathcal{L} = 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Approaches to go beyond SM
  - Search for new CP Violating B decays
  - Radiative/electroweak rare B decays
- Comments on the new D_{sJ} resonance

  Summary — Belle constraints the properties of D_{sJ} using radiative decays and production in B decays. Most likely they are the missing 0^+ and 1^+ states, although their low mass remains to be a mystery.

Summary

- Some of the recent Belle highlights are discussed. There are many other topics that I could not cover today: semileptonic B decays (V_{ub}, V_{cb}), ϕ_3 measurement, hadronic rare B decays, τ and charm physics, …
- With more data (158 fb^{-1} this summer, more in the coming years), we will provide exciting results in CPV, radiative/electroweak decays, and many other modes.
- Plan is to improve KEKB and Belle, and go beyond 10^{35} cm^{-2}s^{-1} or more!