Belle
(recent and coming results)

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for the Belle collaboration

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HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION

Annecy , LAPP

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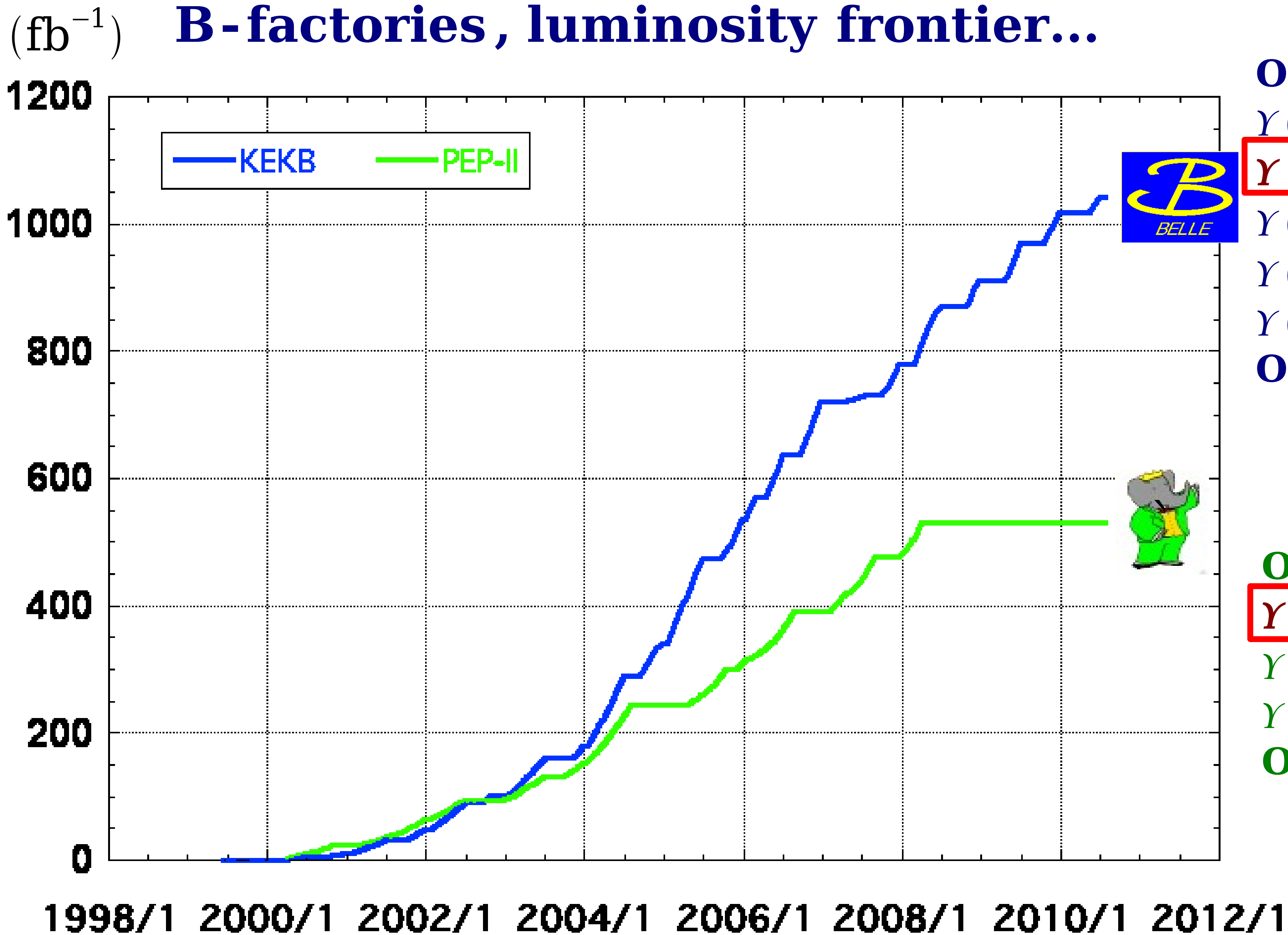
B-factories, luminosity frontier...



$\sim$ 1 ab^{-1}

On resonance:

$\Upsilon(5S)$: 121 fb^{-1}

$\boxed{\mathbf{\Upsilon(4S): 711\ fb^{-1}}}$

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 24 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan:

$\sim$ 100 fb^{-1}

$\sim$ 550 fb^{-1}

On resonance:

$\boxed{\mathbf{\Upsilon(4S): 433\ fb^{-1}}}$

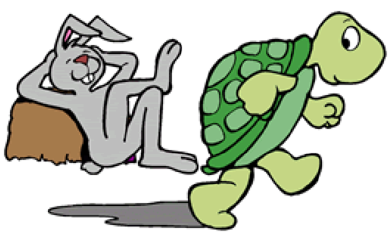
$\Upsilon(3S)$: 30 fb^{-1}

$\Upsilon(2S)$: 14 fb^{-1}

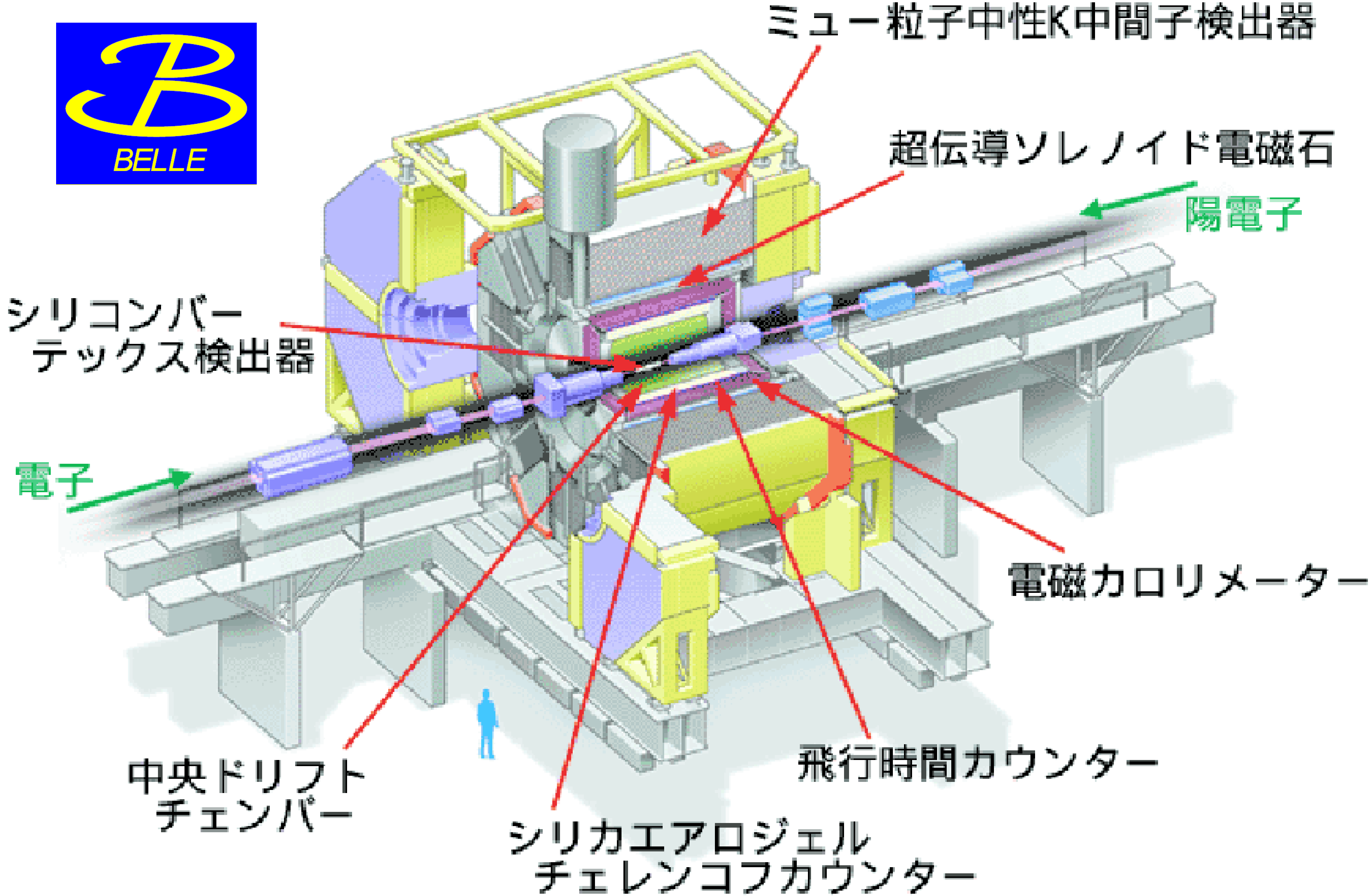
Off resonance:

$\sim$ 54 fb^{-1}

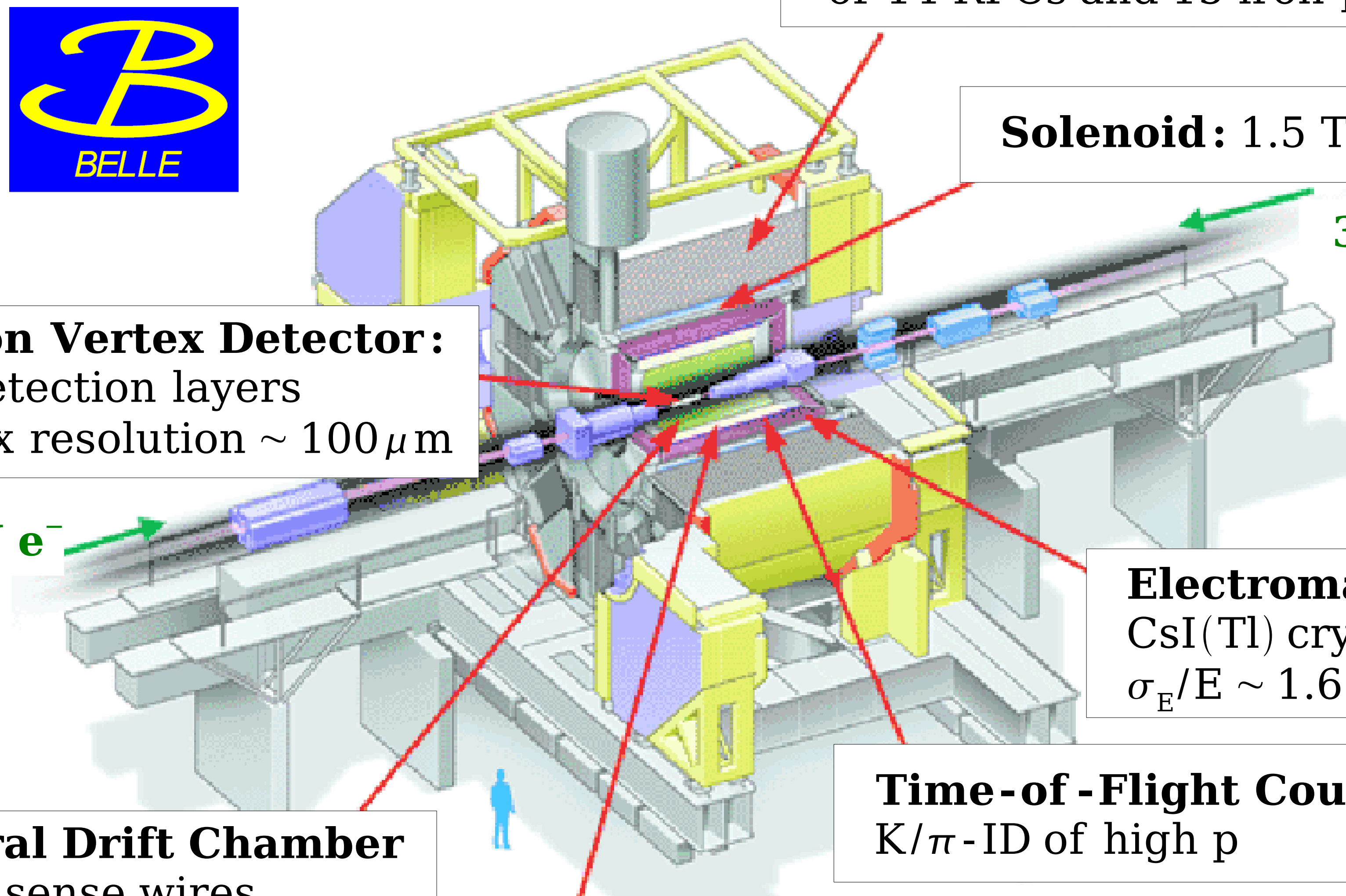
Rien ne sert de courir ; il faut partir a point.
Le Lievre et la Tortue en sont un temoignage.
Gageons, dit celle-ci, que vous n'atteindrez point
Si tot que moi ce but. Si tot ? Etes-vous sage ?
Repartit l'Animal leger...



Belle in a nutshell



Belle in a nutshell



very stable detector, good particle identification, (kaon, pion, electron, muon),

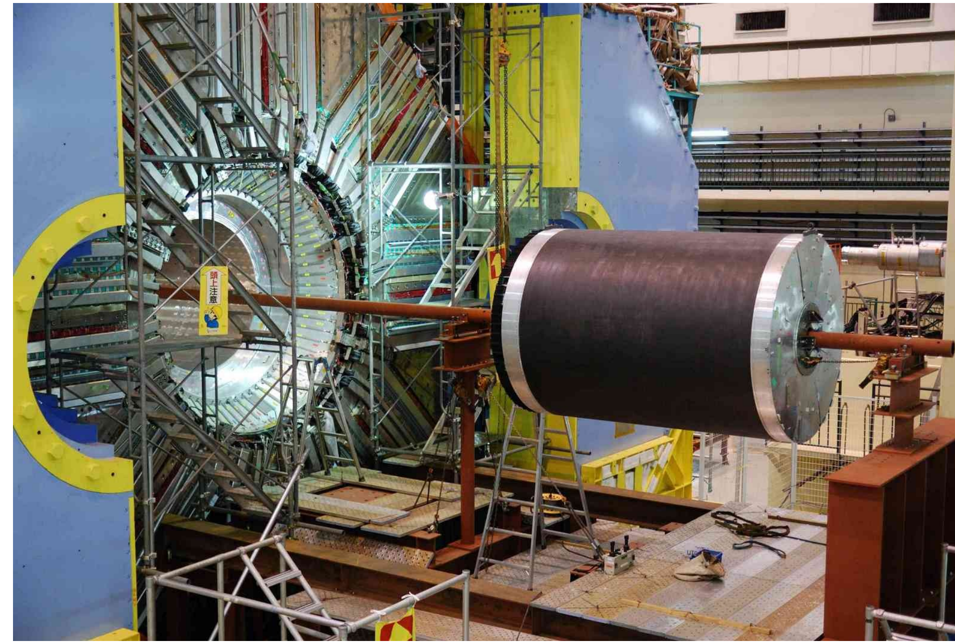
e^+e^- is a clean environment: excellent tracking, triggering, tagging...

Belle shutdown last June (2010)

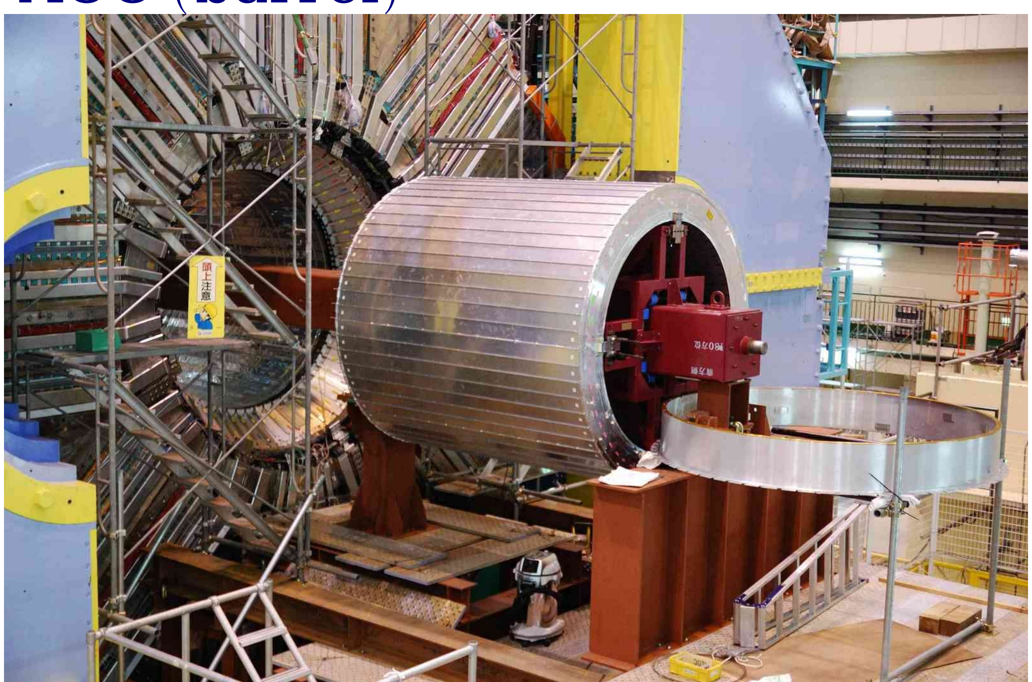
Belle these days...

ECL (backward endcap)

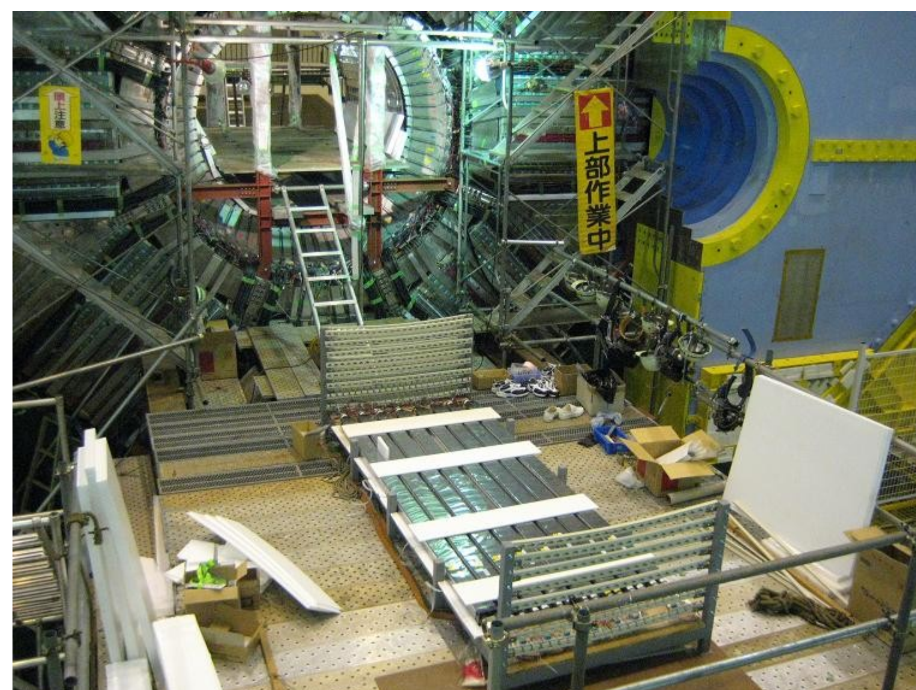
CDC



ACC (barrel)



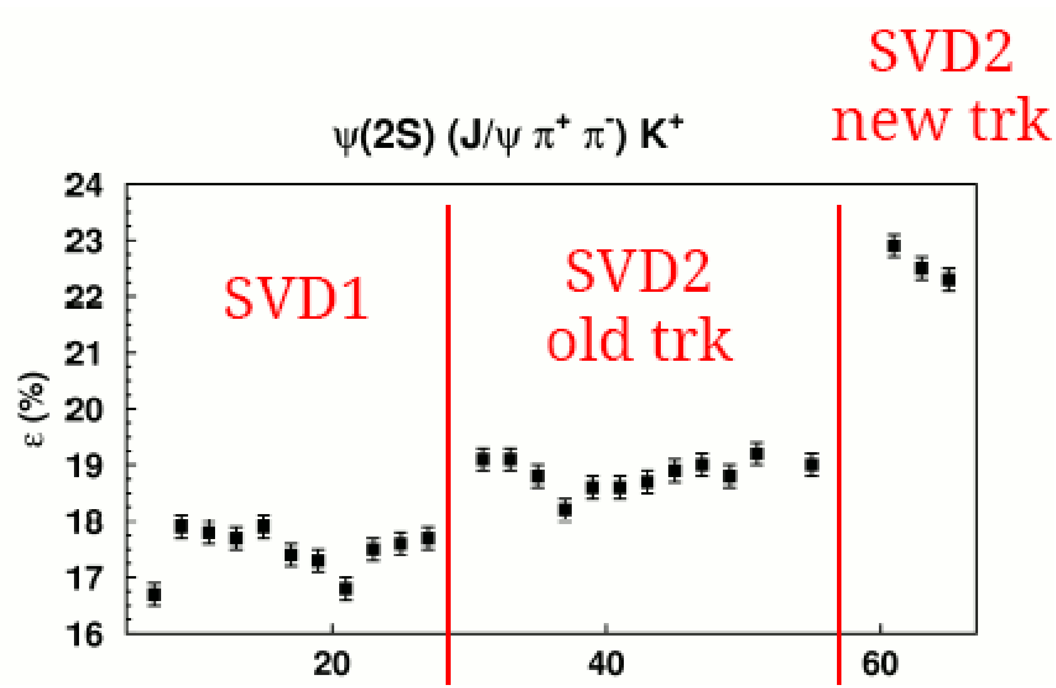
TOF



Toward the final Belle results...

- include the last part of the data ($> 100\ \mathrm{fb}^{-1}$, often much more...)
- reprocessed data ($\sim 2/3$ of the data, tracking efficiency increase $> 20\%$)

Efficiency for $B^+ \to \psi(2S)\,(J/\psi\,\pi\pi)\,K^+$



reconstruction systematics improved:

tracking efficiency systematics at high P_t

$1.2\% \to 0.34\%$ (update)

π^0: $4\% \to ??$

K_S: $4.5\% \to ??$

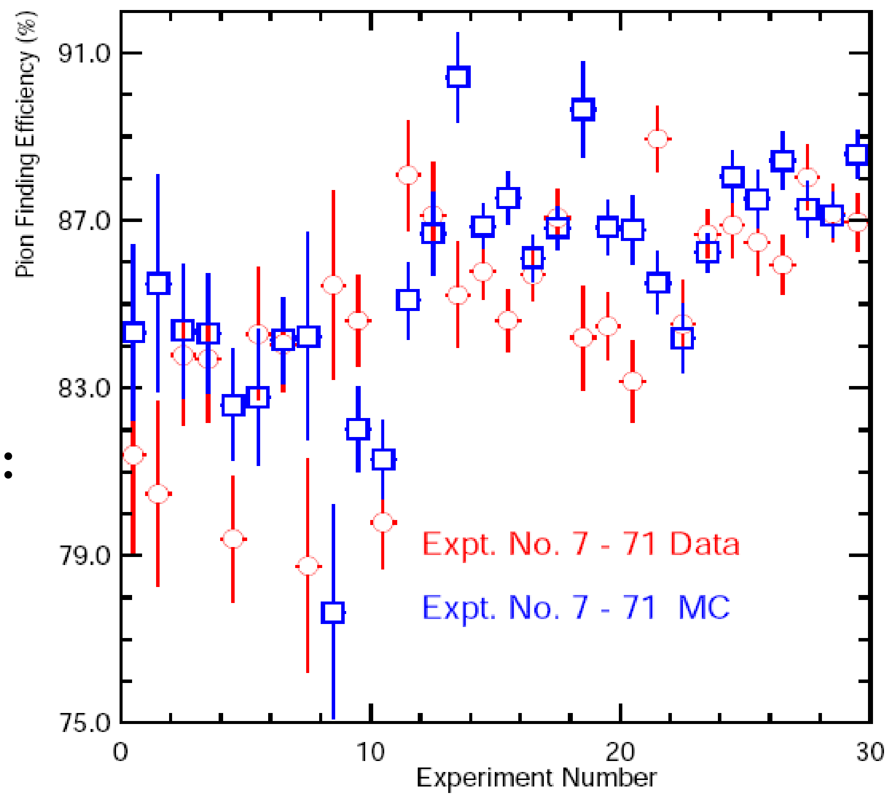
Example of $D \to K_S \pi\pi$

$0.5\,M$ signal candidates in $540\ \mathrm{fb}^{-1}$

PRL 99, 131803 (2007)

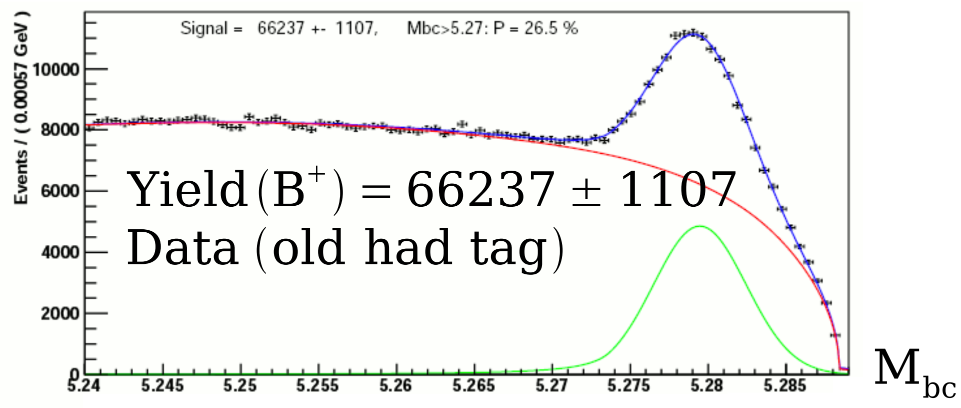
status of the update:

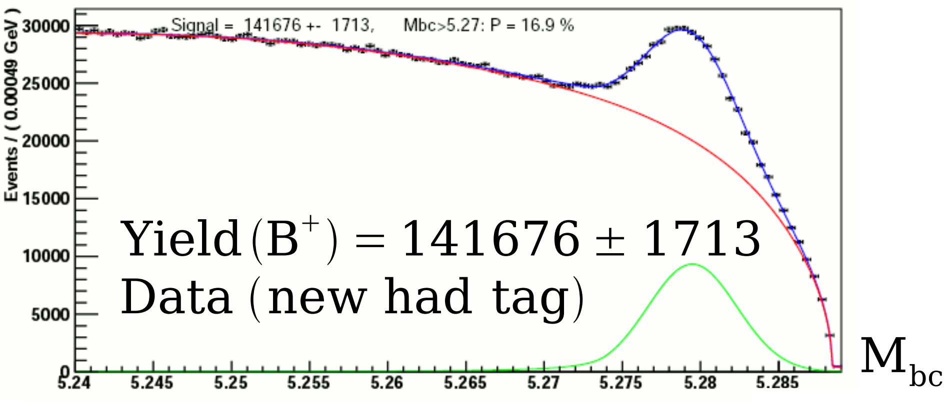
$1.1\,M$ signal candidates in $790\ \mathrm{fb}^{-1}$

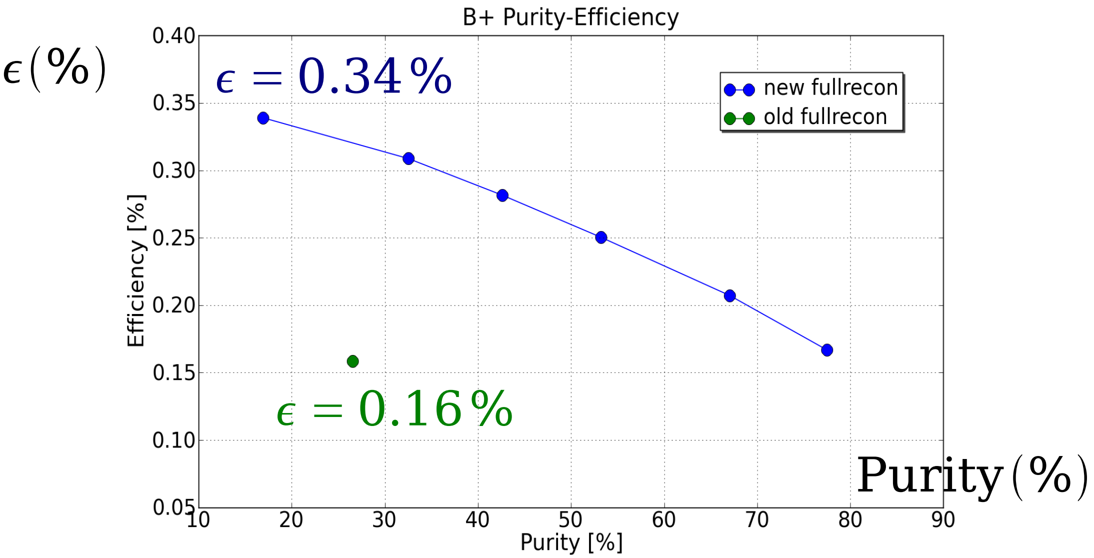


What else ?

- reprocessed data sample with improved tracking efficiency
- none of the results shown for rare B decays use full data sample yet
- **<u>had tag efficiency improved</u>: effective luminosity improved by factor $\sim \times 2$**



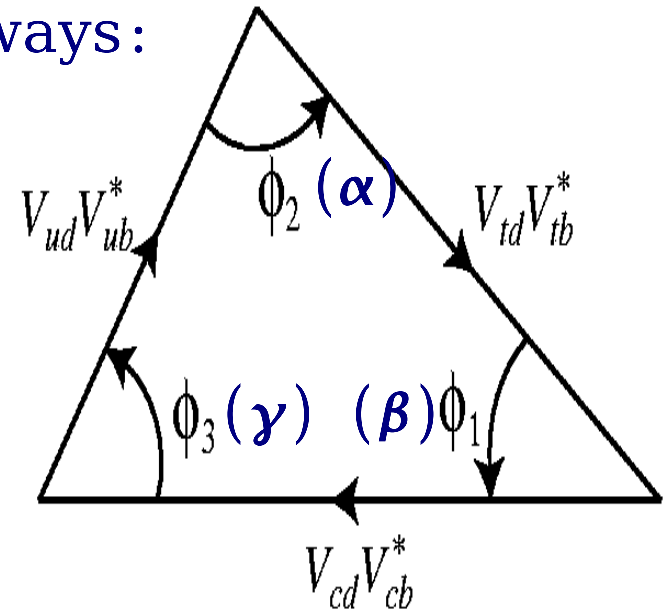




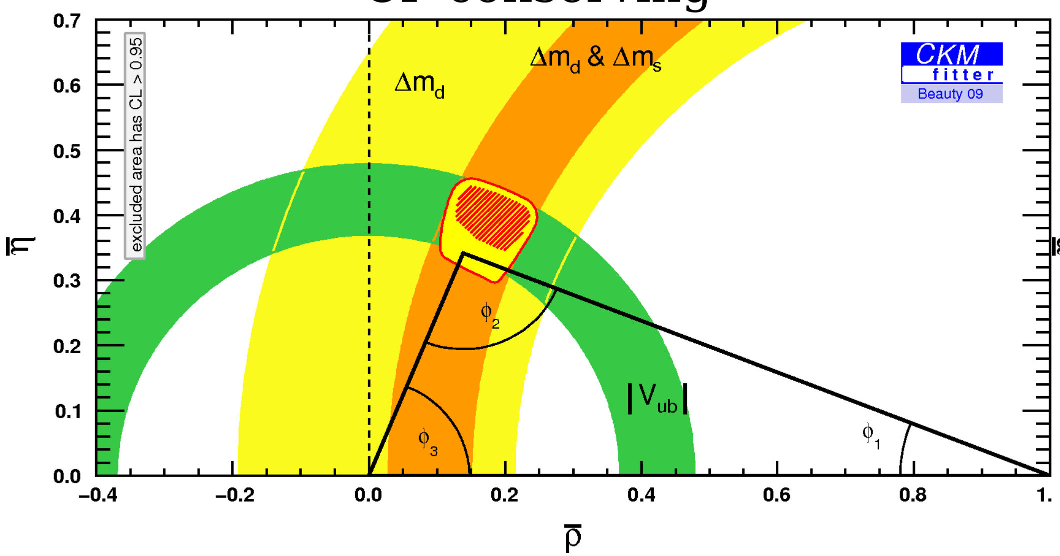
⇒ new results coming soon !
$B \to \tau\,\nu$, $\underline{\mu\,\nu}$, $K^{(*)}\nu\,\bar{\nu}$, ...

Main motivation…

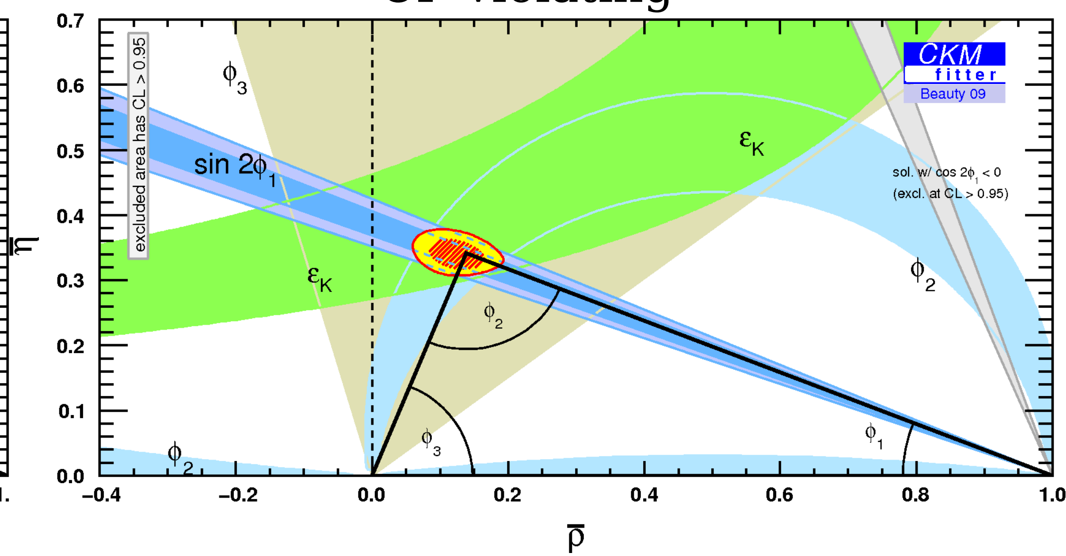
- Overconstrain the CKM matrix: measure fundamental parameters, constrain new physics effects
- Measure the 4 free paremeters in various ways:
  - CP conserving $\{|V_{us}|, |V_{cb}|, |V_{td}|, |V_{ub}|\}$
  - CP violating $\{\epsilon_K, \phi_s, \phi_1, \phi_3\}$
  - Tree level $\{\ldots, \ldots, |V_{ub}|, \phi_3\}$
  - Loop level $\{\ldots, \ldots, |V_{td}|, \phi_1\}$
  - …



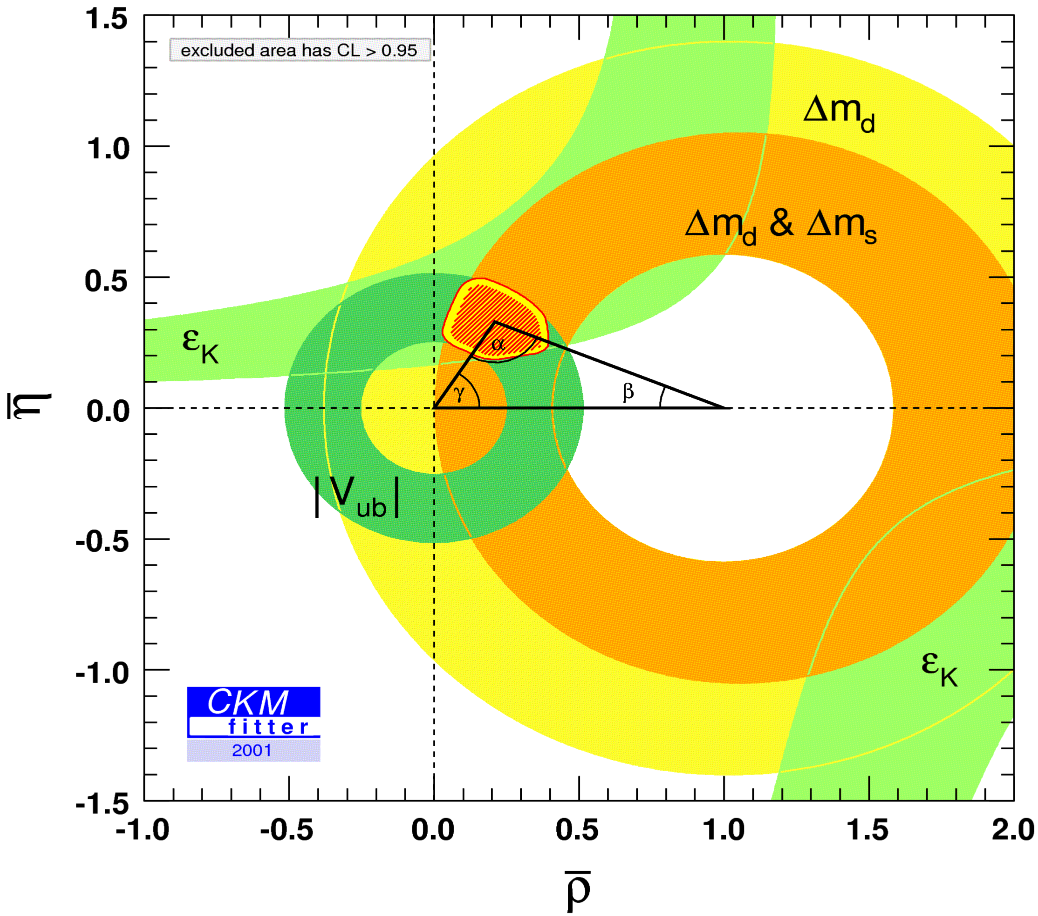
CP conserving

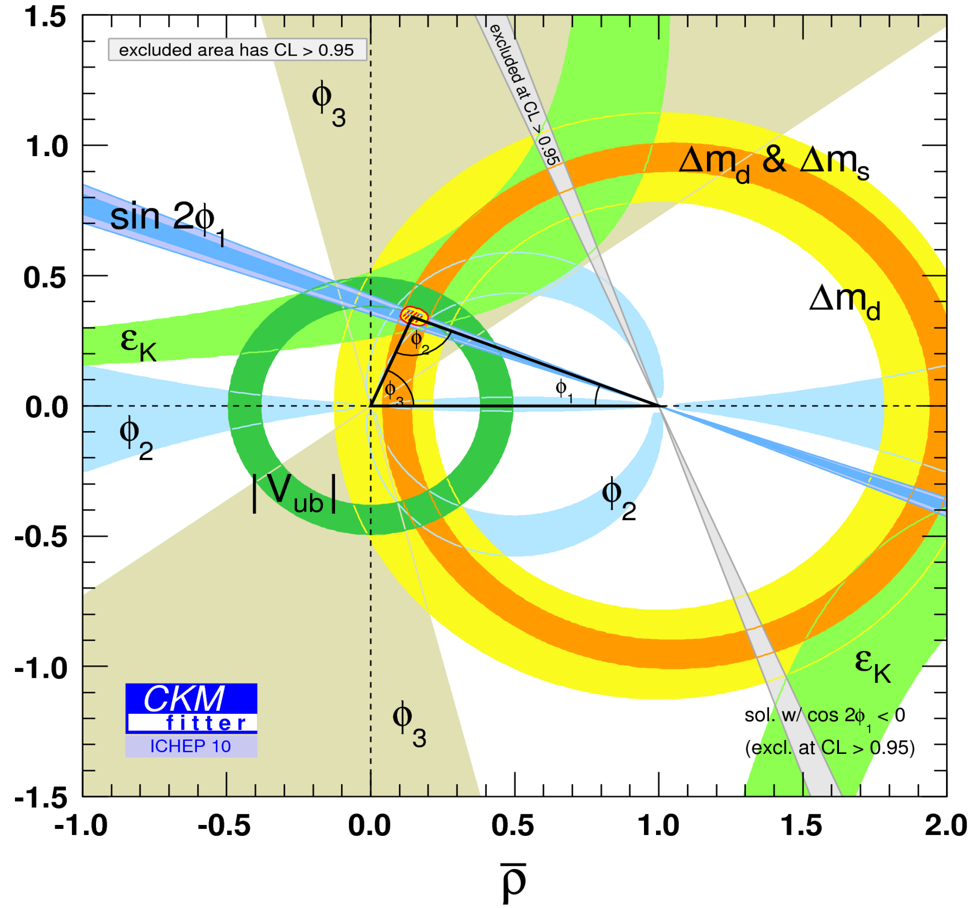


CP violating



from 2001… ...to today

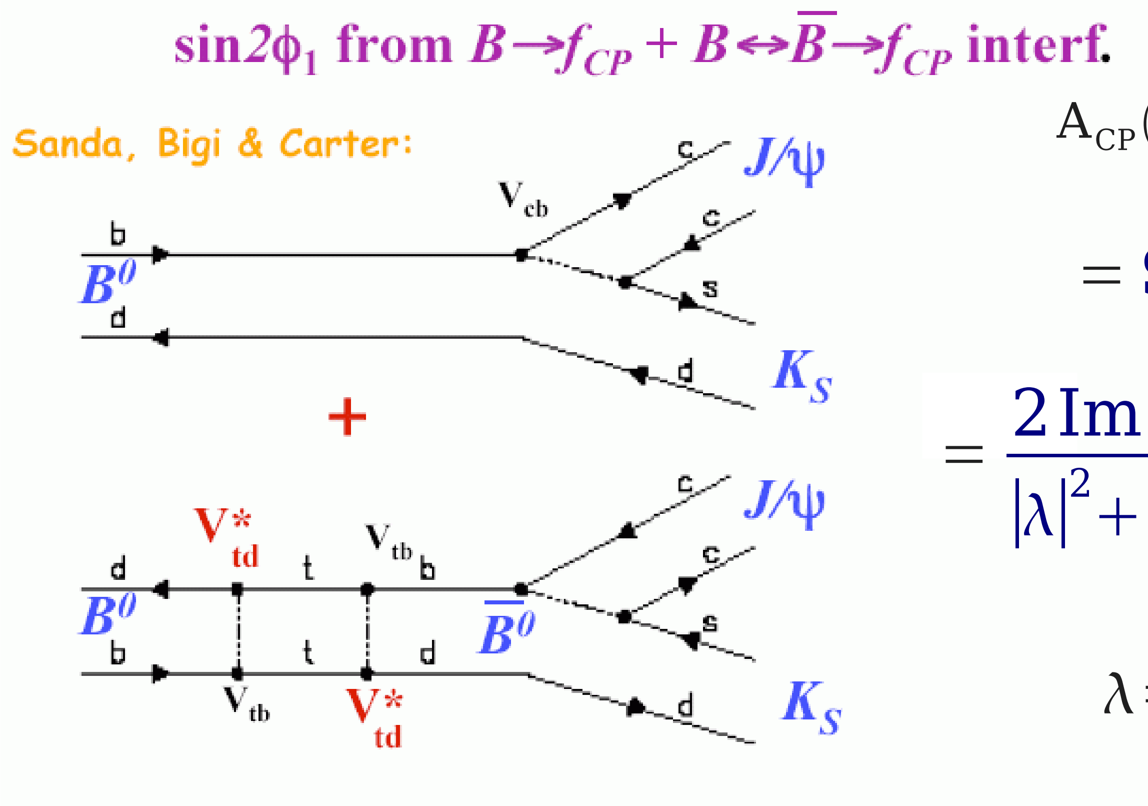




⇒ clear impact on B-factories (angles and sides) !

- **UT angles**
- **Rare B decays and NP**
- **B_s physics @ $\Upsilon(5S)$**

Time-dependent CP asymmetries in decays to CP eigenstates



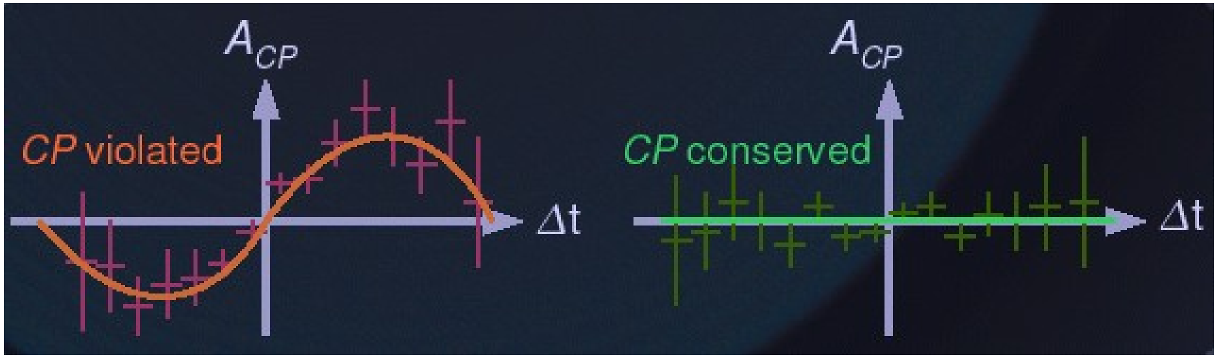
$$A_{CP}(f;t) = \frac{N(\overline{B}^0(t)\to f) - N(B^0(t)\to f)}{N(\overline{B}^0(t)\to f) + N(B^0(t)\to f)}$$

$$= \mathbf{S}\sin\Delta m_d t + \mathbf{A}\cos\Delta m_d t$$

$$= \frac{2\,\mathrm{Im}\,\lambda}{|\lambda|^2+1}\sin\Delta m_d t + \frac{|\lambda|^2-1}{|\lambda|^2+1}\cos\Delta m_d t$$

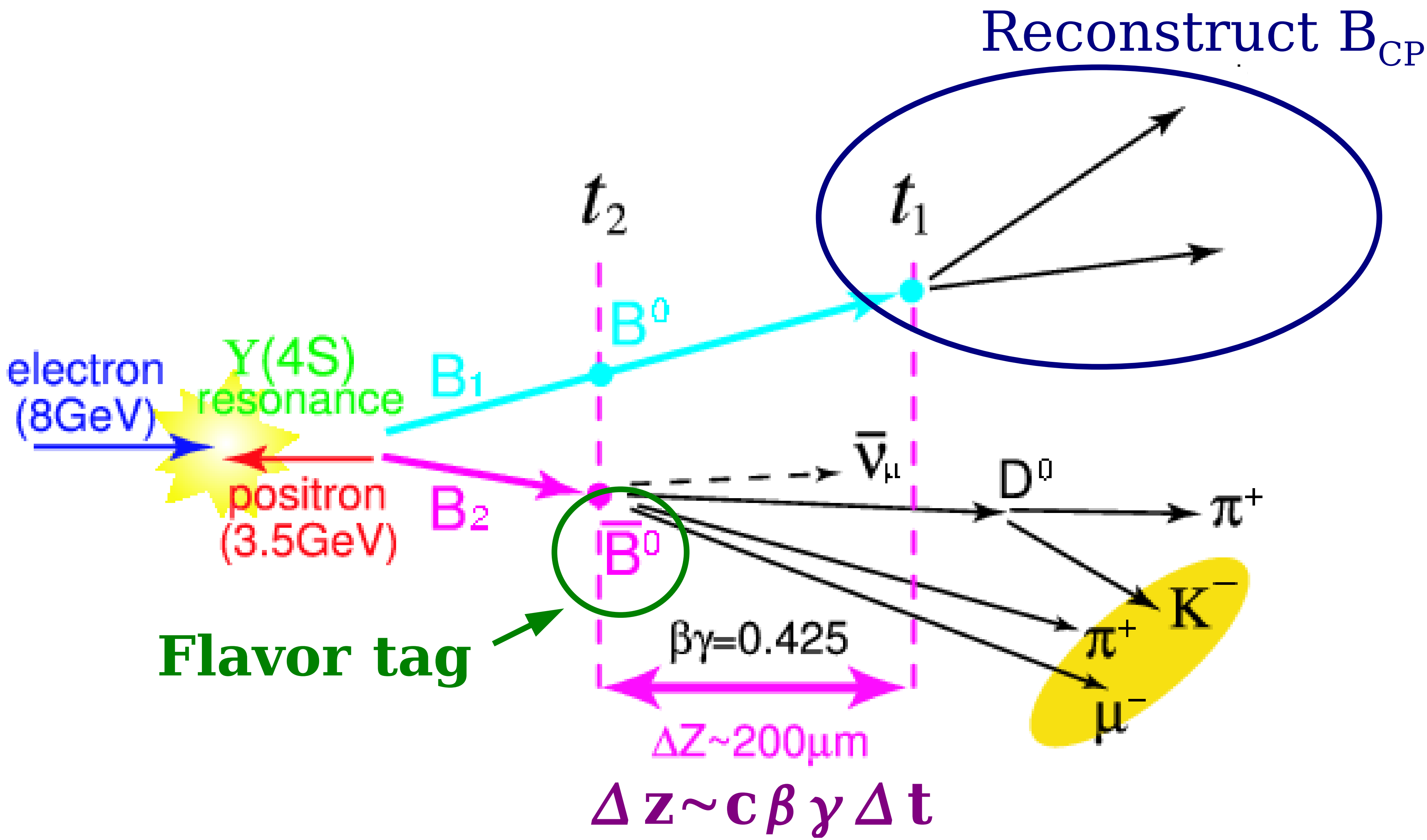
$$\lambda = \frac{q}{p}\frac{A(\overline{B}^0\to f)}{A(B^0\to f)} = e^{-i2\phi_i}\frac{\overline{A}_f}{A_f}$$

- $\mathbf{A} = 0$ and $\mathbf{S} = -\xi_f \sin 2\phi_1$ for $(c\bar{c})K_{S/L}$ $(\xi_f = \mp 1)$
- $\mathbf{A} = 0$ and $\mathbf{S} = \sin 2\phi_2$ for $\pi^+\pi^-$ (if tree only)



$\mathbf{C} = -\mathbf{A}$

Measuring the CP parameters **S** and **A**

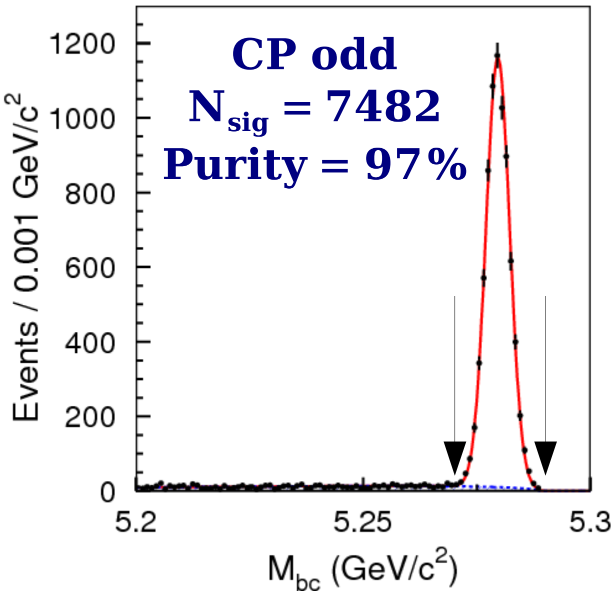


$$\frac{dP_{sig}}{dt}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B}\left(1 + q\left(S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)\right)\right)$$

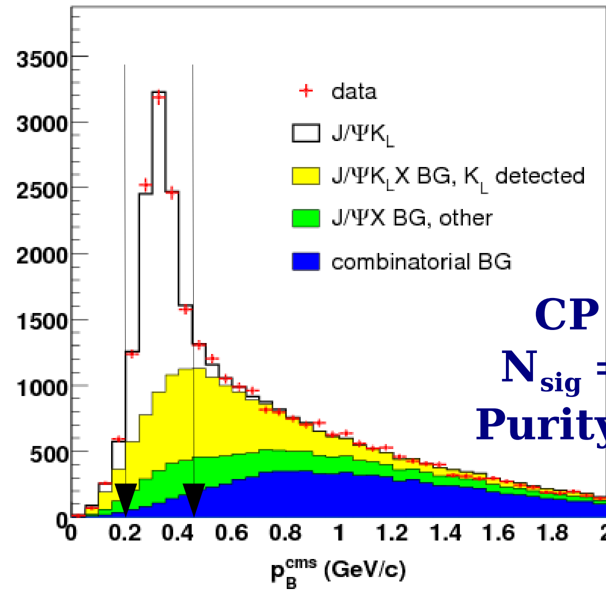
$J/\psi\ K_S$ and $J/\psi\ K_L$

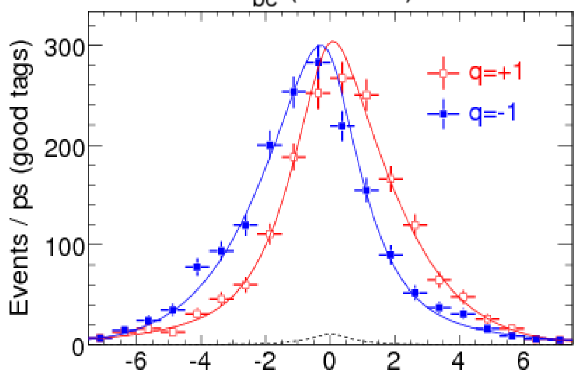
535×10^6 $B\overline{B}$ pairs
[PRL98 (2007) 031802]

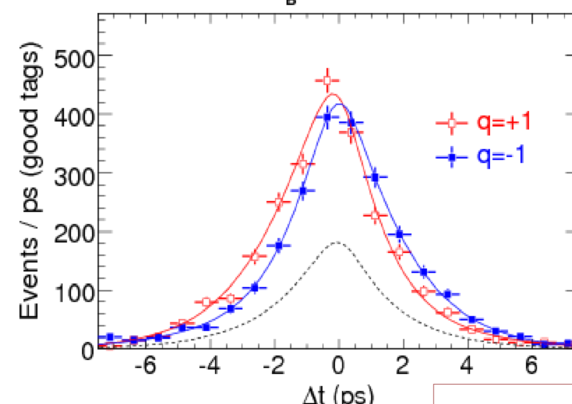
CP odd
N_{sig} = 7482
Purity = 97%



CP even
N_{sig} = 6512
Purity = 59%

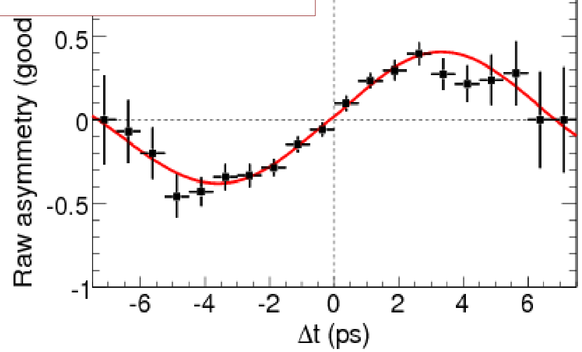


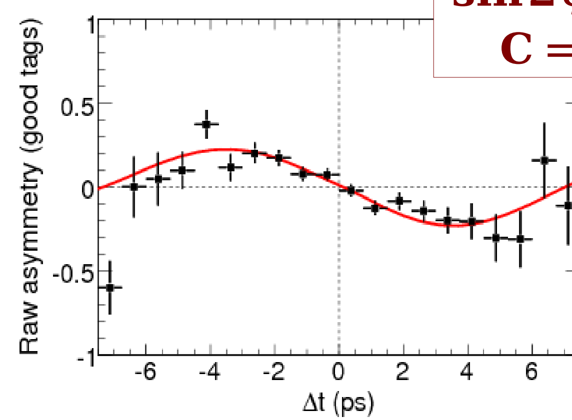




$\sin 2\phi_1 = 0.643 \pm 0.038$
$C = 0.001 \pm 0.028$

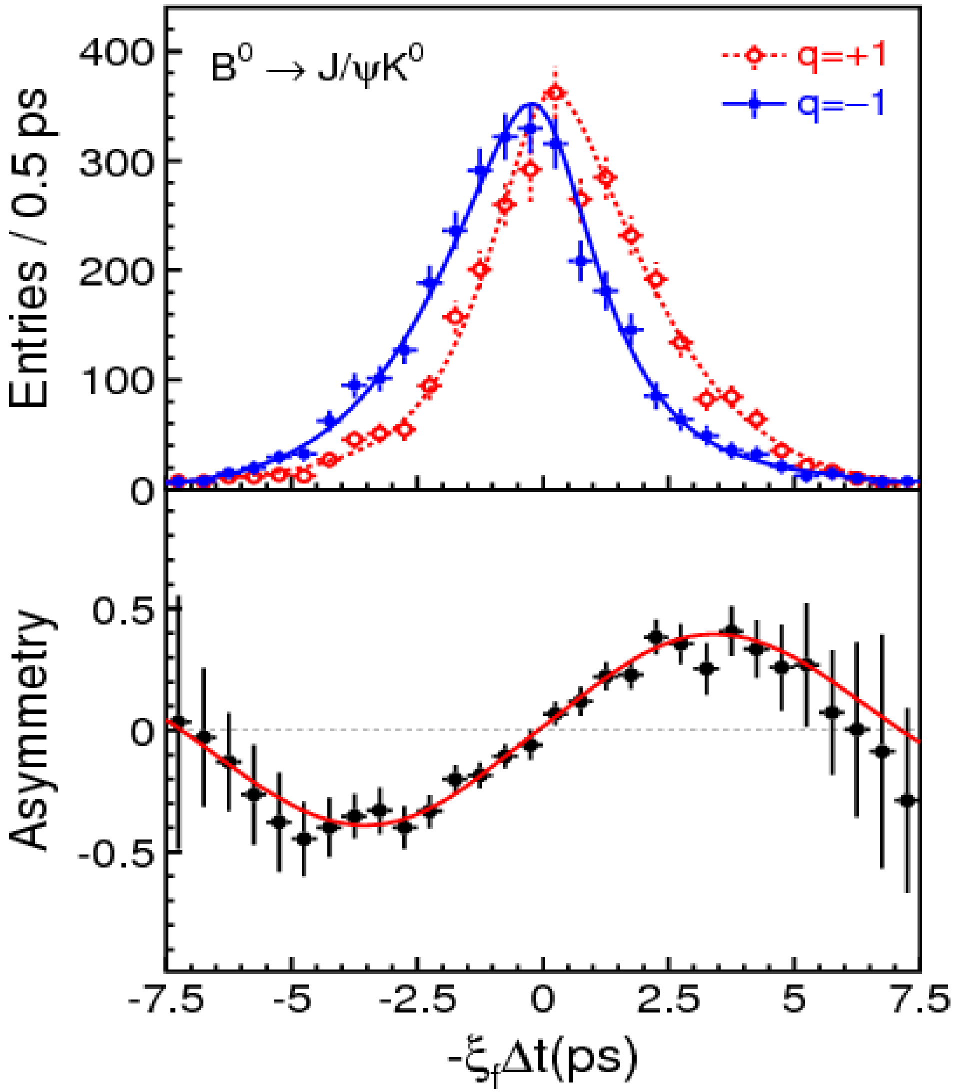
$\sin 2\phi_1 = 0.641 \pm 0.057$
$C = -0.045 \pm 0.033$





$\sin 2\beta$ in $J/\psi K^0$ ...

535×10^6 $B\bar{B}$ pairs
[PRL98 (2007) 031802]



$$\boxed{\begin{array}{c}\sin 2\phi_1 = 0.642 \pm 0.031 \pm 0.017 \\ C = -0.018 \pm 0.021 \pm 0.014\end{array}}$$

...and $\psi(2S)K_S$

$\sin 2\phi_1$ in $\psi(2S)K^0_S$

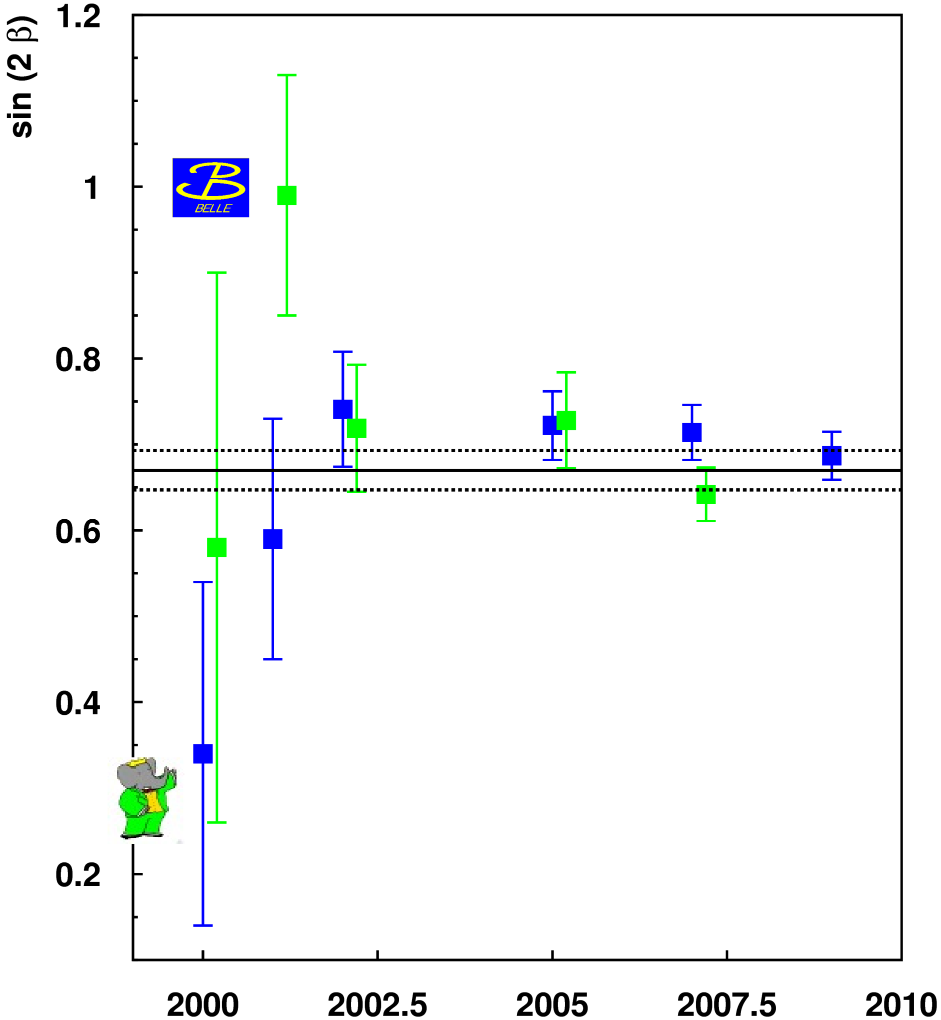
$\psi(2S)\to l^+l^-$
$\psi(2S)\to J/\psi\,\pi^+\pi^-$

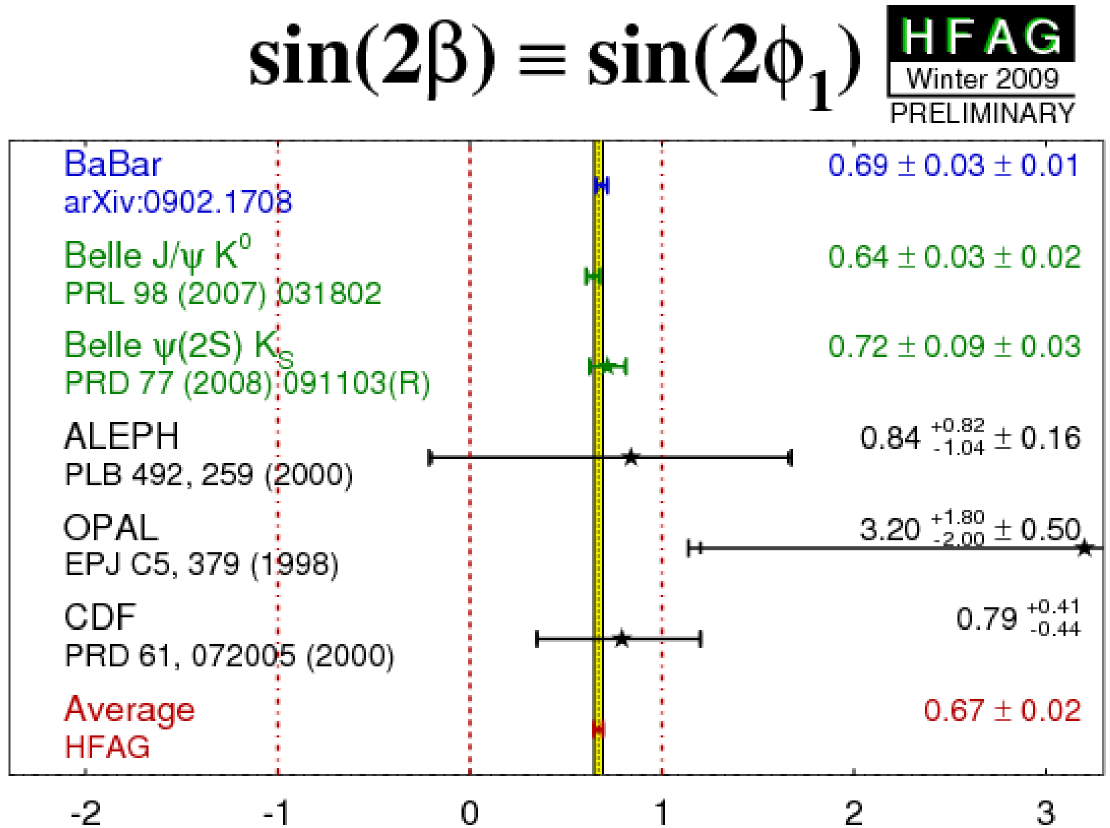
657×10^6 $B\bar{B}$ pairs
[PRD77 (2008) 091103]

$$\boxed{\begin{array}{c}\sin 2\phi_1 = 0.72 \pm 0.09 \pm 0.03 \\ C = -0.04 \pm 0.07 \pm 0.05\end{array}}$$

- anchor point of the SM
- still statistically limited !

La raison d'être of the B factories





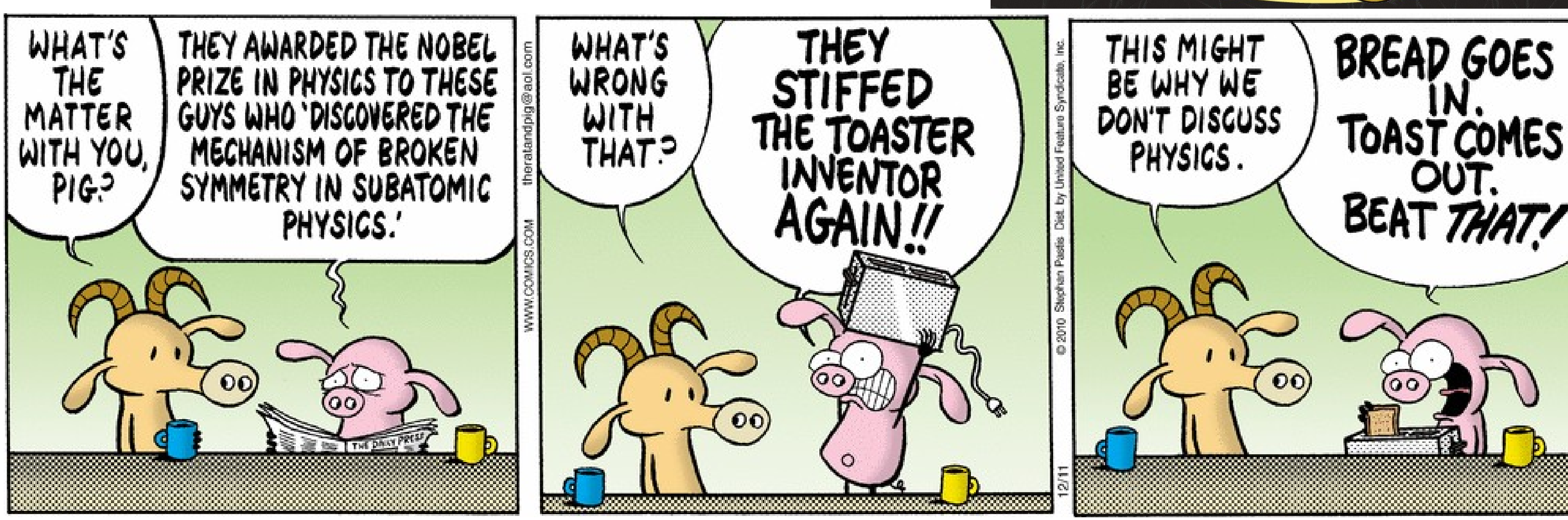
$$\beta = (21.0 \pm 0.9)^{\circ}$$

What is the source of CP violation ?

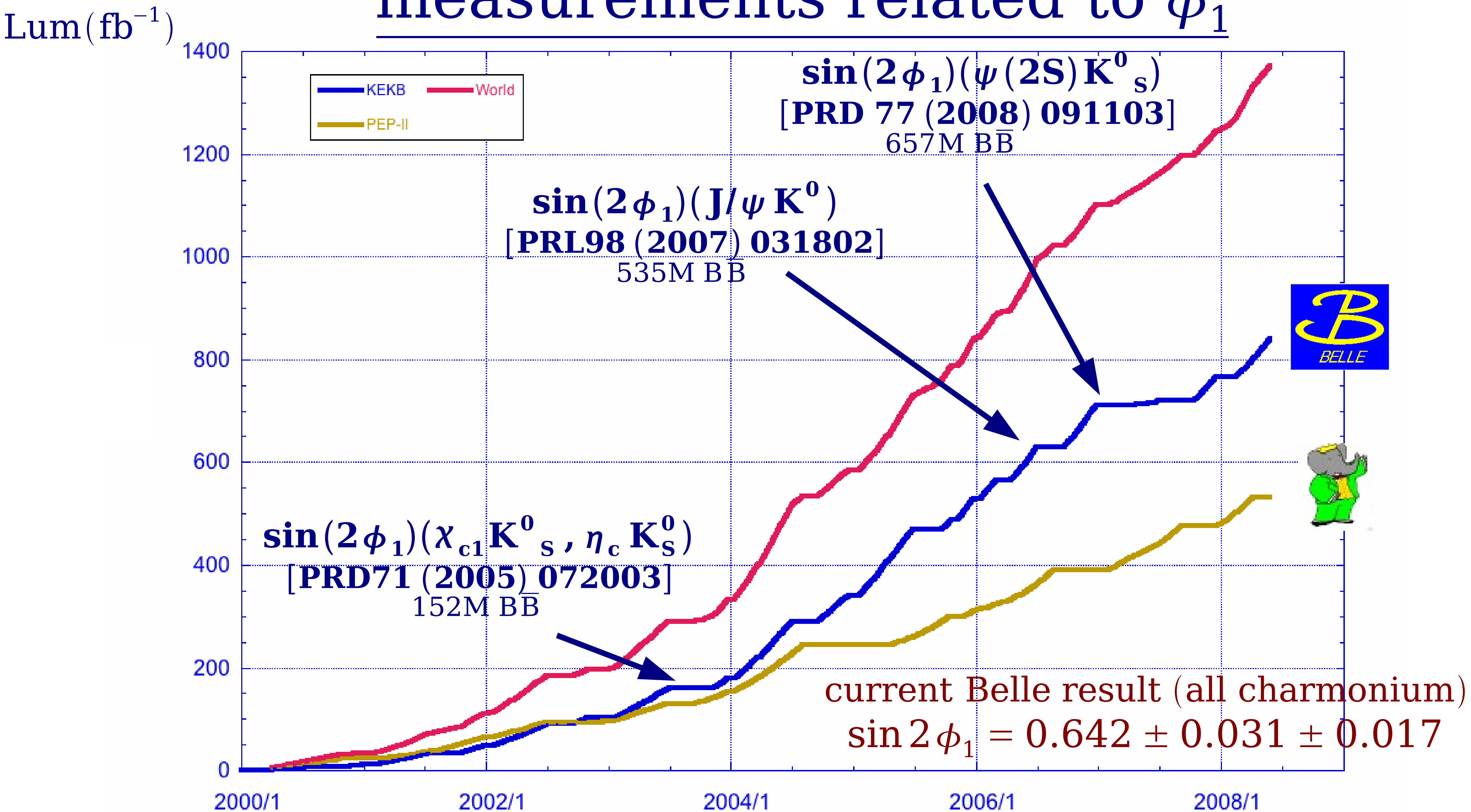
The Kobayashi-Maskawa phase is the source

Critical role of the B factories in the verification of the KM hypothesis

A single irreducible phase in the weak interaction matrix accounts for most of the CPV observed in kaons and B's



measurements related to ϕ_1

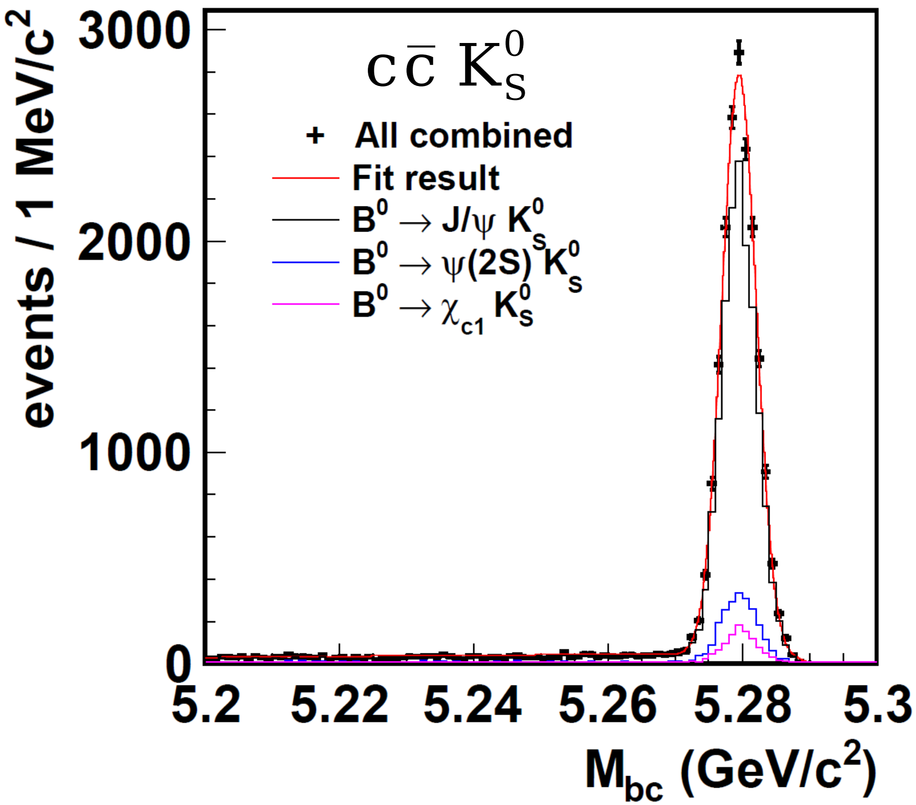


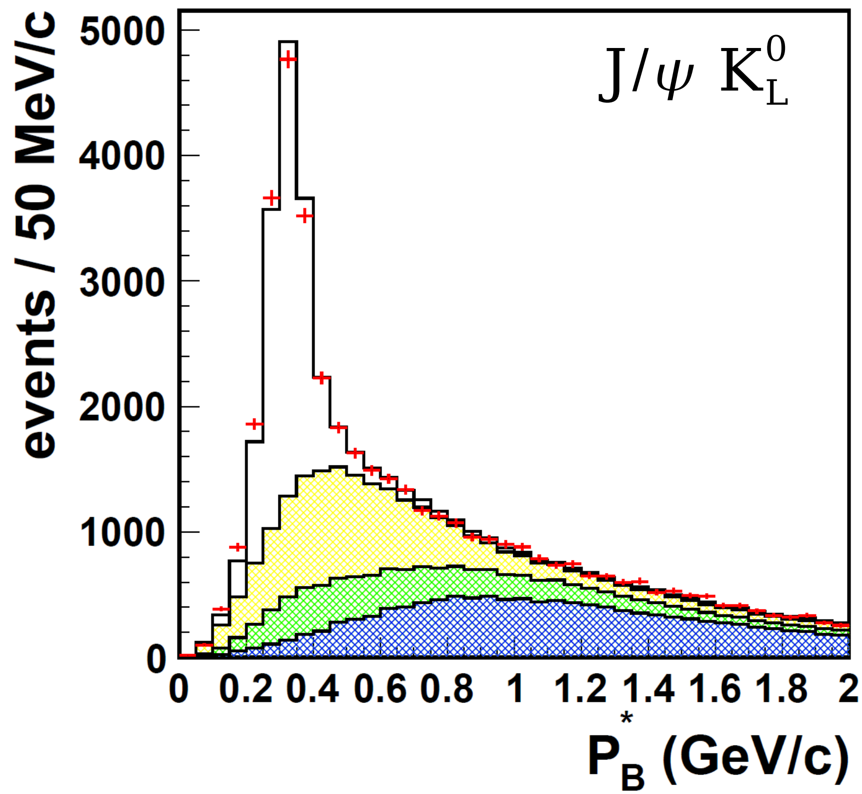
- update with full sample (770M $B\bar{B}$)and all charmonium modes
- additional improvements (rec. efficiency but also flavor tagging)

⇒ most precise measurement of ϕ_1 and...

...benchmark for all other TCPV measurements

$\sin 2\phi_1$ final update (using 772 M $B\bar{B}$)





	$J/\psi K_S^0$	$J/\psi K_L^0$	$\psi(2S)K_S^0$	$\chi_{c1}K_S^0$	N_{BB} (x 10^6)
Signal yield ('10)	12727±115	10087±154	1981±46	943±33	772
Purity ('10) [%]	97	63	93	89	
Signal yield ('06)	7484±87	6512±123	–	–	535
Purity ('06) [%]	97	59	–	–	

systematic error (2006)

Category	S	A
Vertex reconstruction	0.012	0.009
Δt resolution function	0.006	0.001
Signal fraction	0.006	0.002
Wrong tag fraction	0.004	0.003
Possible fit bias	0.007	0.004
Tag-side interference	0.001	0.009
Others	< 0.001	< 0.001

→ **winter 2011**

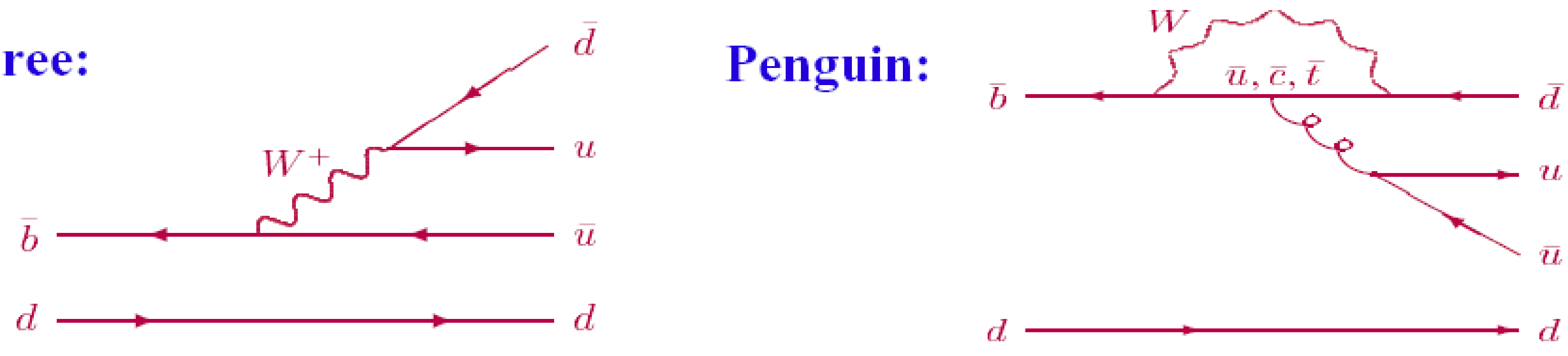
⇒ gain for the yields larger than $N_{B\bar{B}}$

⇒ stat error: $\sigma(S) \approx 0.024$

$\sigma(A) \approx 0.016$

ϕ_2 determination

Tree: Penguin:



$$A(B^0 \to \pi^+ \pi^-) = T^{+-} e^{i\gamma} + P$$

$$\begin{aligned} A(t) &= S_{\pi^+\pi^-} \sin(\Delta m t) - C_{\pi^+\pi^-} \cos(\Delta m t) \\ &= \sqrt{1 - C^2_{\pi^+\pi^-}} \sin 2\alpha_{\text{eff}} \sin(\Delta m t) - C_{\pi^+\pi^-} \cos(\Delta m t) \end{aligned}$$

from time dependent CP, we can measure $\boldsymbol{\phi_2^{\text{eff}}}$, but we want $\boldsymbol{\phi_2}$!

$$\mathbf{S}_{\pi^+\pi^-} = \mathbf{sin\,2}\boldsymbol{\phi_2} + 2r \cos\delta \sin(\phi_1 + \phi_2) \cos 2\phi_2 + O(r^2)$$

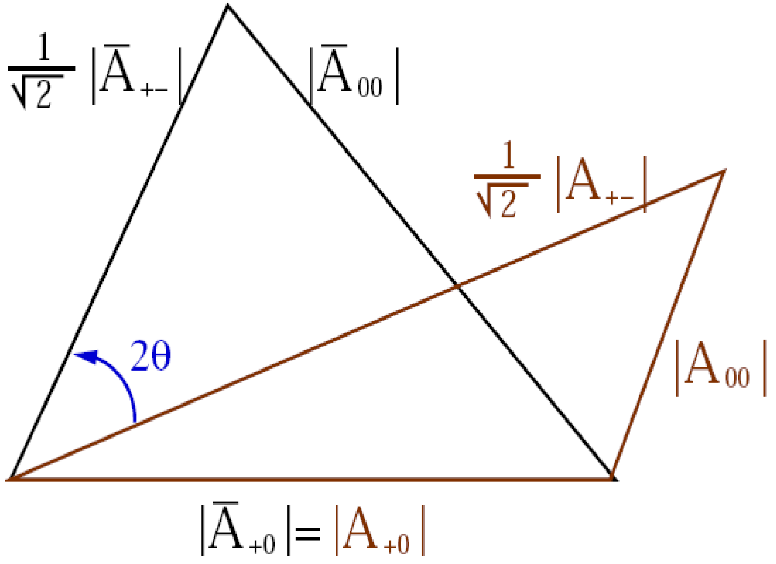
$$r = |P|/|T|$$

ϕ_2 determination with isospin analysis

[Gronau-London, PRL65, 3381 (1990)]

$$A_{+-} = A(B^0 \to \pi^+\pi^-) = e^{-i\phi_2}\, T^{+-} + P$$
$$\sqrt{2}\, A_{00} = \sqrt{2}\, A(B^0 \to \pi^0\pi^0) = e^{-i\phi_2}\, T^{00} + P$$
$$\sqrt{2}\, A_{+0} = \sqrt{2}\, A(B^+ \to \pi^+\pi^0) = e^{-i\phi_2}\, (T^{00} + T^{+-})$$

$$A_{+-} + \sqrt{2}\, A_{00} = \sqrt{2}\, A_{+0}$$
$$\overline{A}_{+-} + \sqrt{2}\, \overline{A}_{00} = \sqrt{2}\, \overline{A}_{+0}$$



- neglecting EWP $\Rightarrow$ A_{+0} pure tree
  $|A_{+0}| = |\overline{A}_{+0}|$

- Isospin breaking (d and u charges different, $m_u \neq m_d$)
- $\pi - \eta - \eta'$ and $\rho - \omega$ mixing

[J.Zupan, hep-ph/0701004]

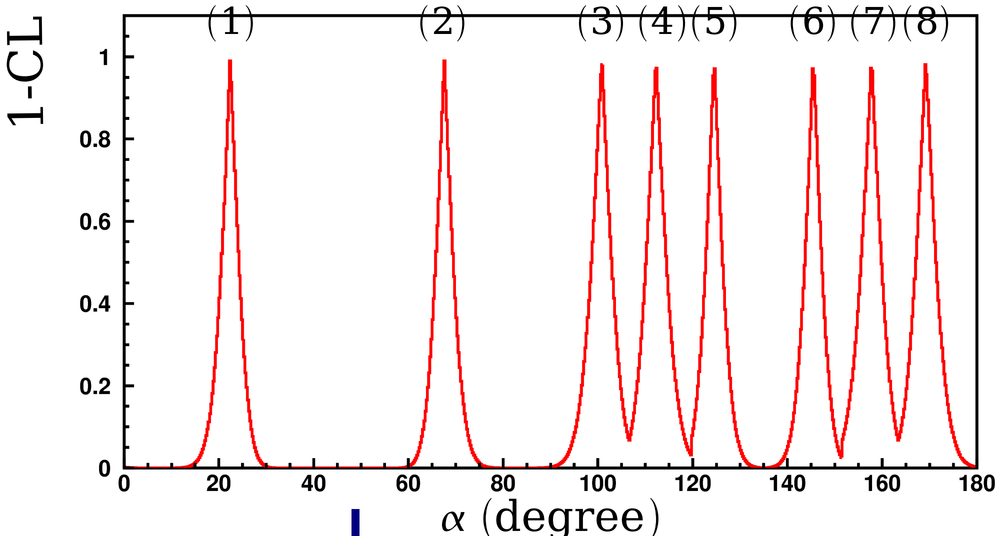
ϕ_2 can be resolved up to an 8-fold ambiguity ($\phi_2 \in [0, \pi]$)

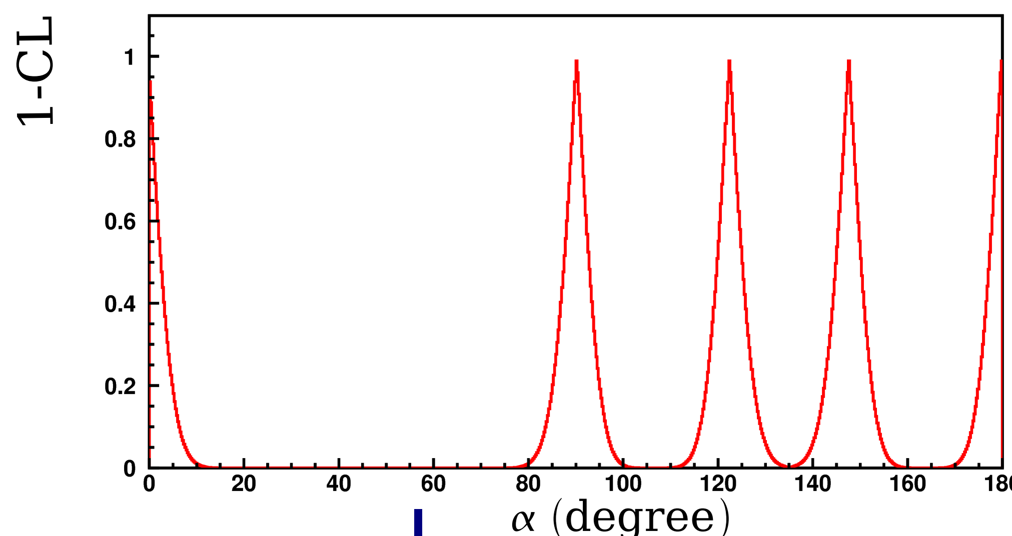
Some examples to illustrate ϕ_2 extraction

$Br(\pi^+\pi^-) = (5.0 \pm 0.2)\times 10^{-6}$
$Br(\pi^0\pi^0) = (1.5 \pm 0.1)\times 10^{-6}$
$Br(\pi^+\pi^0) = (3.5 \pm 0.2)\times 10^{-6}$
$C(\pi^+\pi^-) = -0.40 \pm 0.03$
$S(\pi^+\pi^-) = -0.50 \pm 0.04$
$C(\pi^0\pi^0) = -0.30 \pm 0.10$

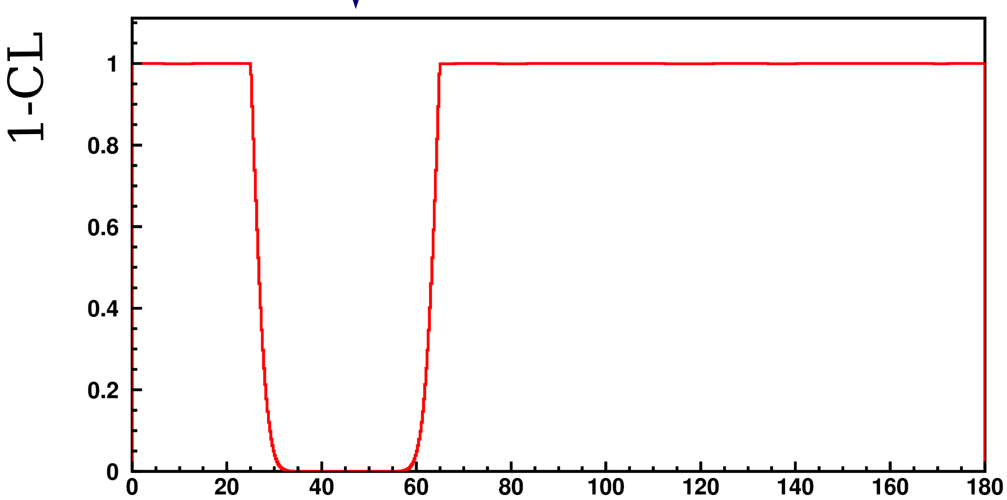
$\longrightarrow$

$\boxed{\begin{array}{l} Br(\pi^+\pi^-) = (2.0 \pm 0.2)\times 10^{-6} \\ Br(\pi^0\pi^0) = (0.5 \pm 0.1)\times 10^{-6} \end{array}}$
$Br(\pi^+\pi^0) = (3.5 \pm 0.2)\times 10^{-6}$
$C(\pi^+\pi^-) = -0.40 \pm 0.03$
$S(\pi^+\pi^-) = -0.50 \pm 0.04$
$C(\pi^0\pi^0) = -0.30 \pm 0.10$

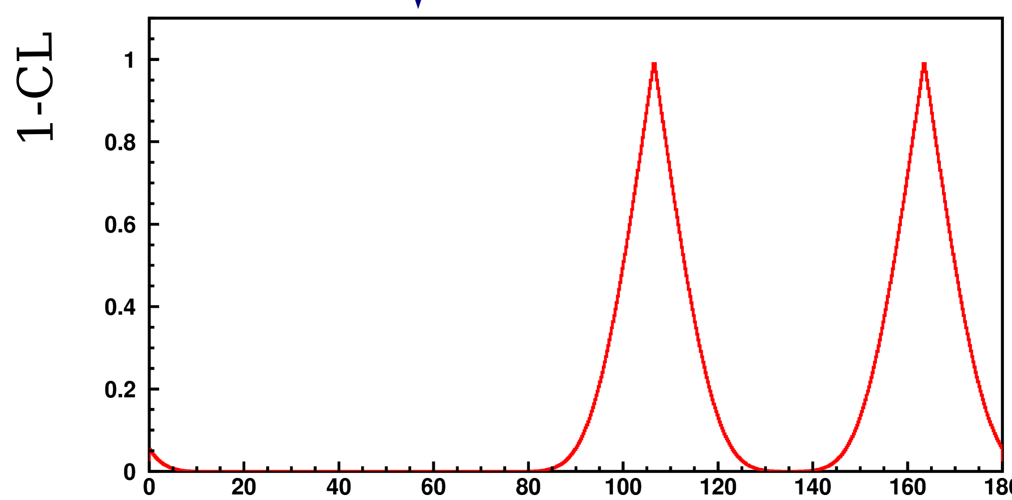




no $C(\pi^0\pi^0)$



no $C(\pi^0\pi^0)$



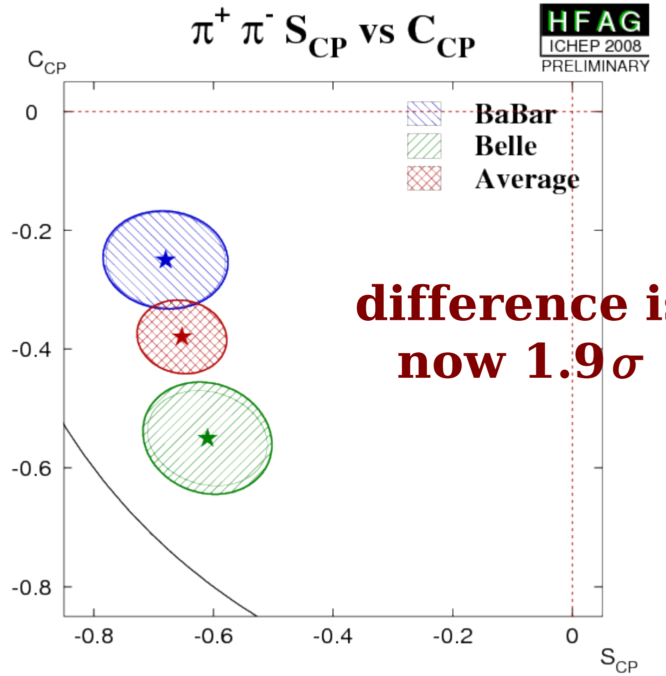
ϕ_2: $\pi\pi$ system

535×10^6 $B\overline{B}$ pairs
PRL98, 221801(2007)

$C = -0.55 \pm 0.08 \pm 0.05$

$S = -0.61 \pm 0.10 \pm 0.04$

direct CPV @ 5.5σ

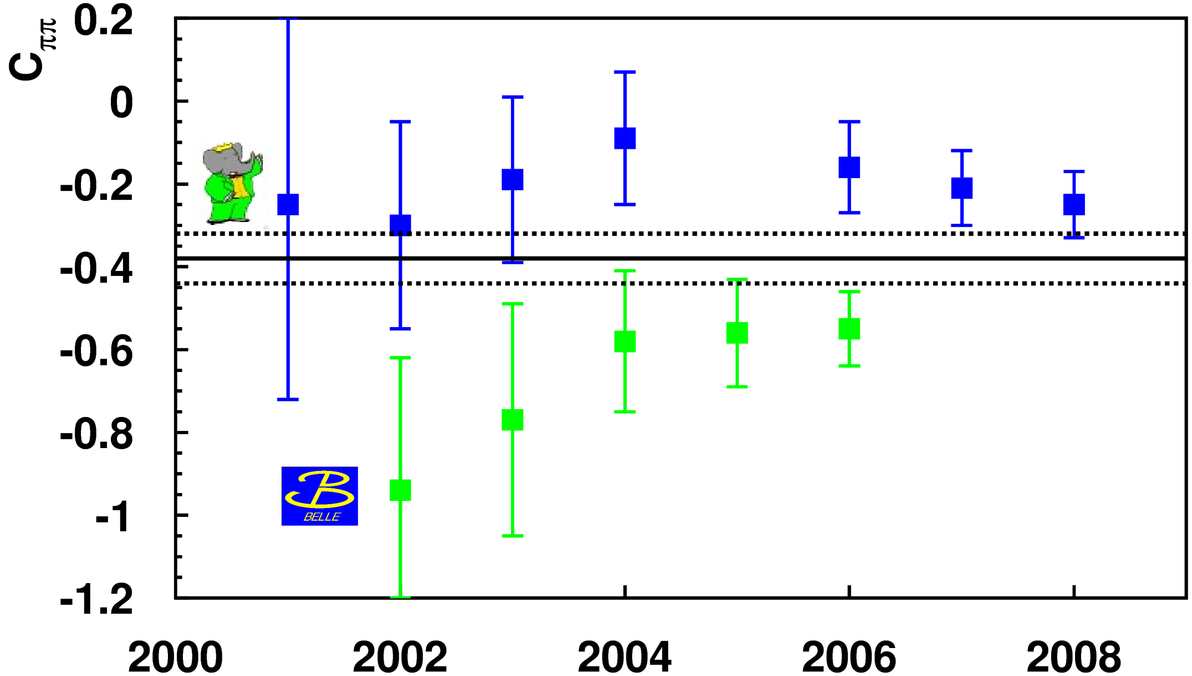


difference is now 1.9σ

467×10^6 $B\overline{B}$ pairs
ArXiv:0807.4226

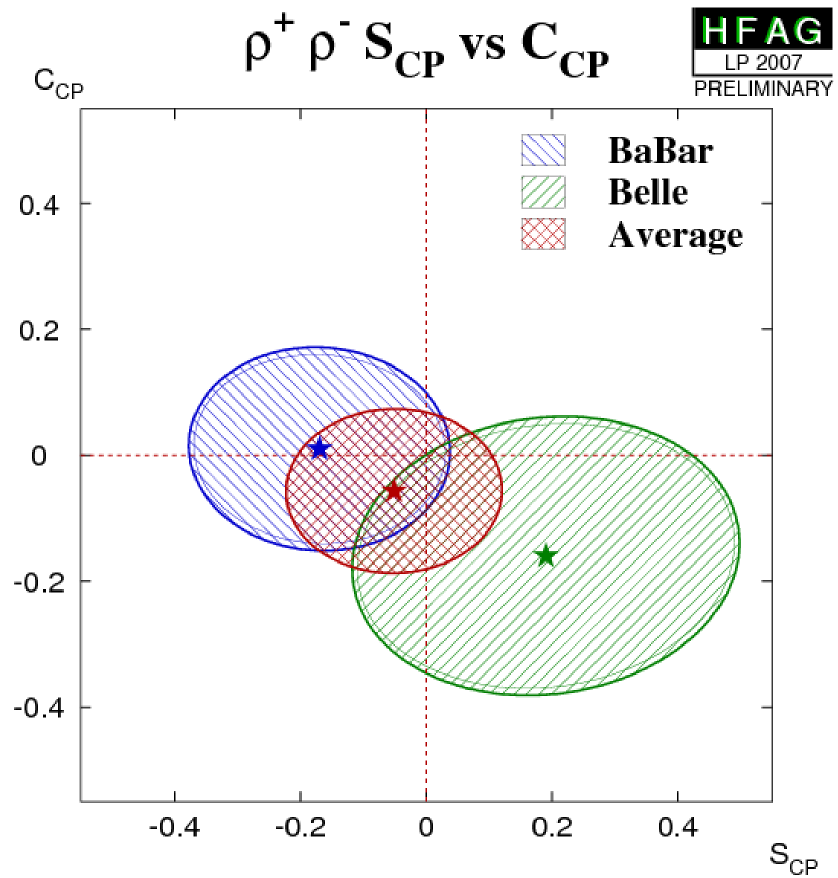
$C = -0.25 \pm 0.08 \pm 0.02$

$S = -0.68 \pm 0.10 \pm 0.03$



$\rho\rho$ system (5 observables for 6 parameters)

$(Br(B\to\rho^+\rho^-), S_{\rho^+\rho^-}, C_{\rho^+\rho^-}, Br(B\to\rho^+\rho^0), Br(B\to\rho^0\rho^0)) + f_L$



535×10^6 $B\overline{B}$ pairs
PRD76, 011104(R)(2007)

$C = -0.16 \pm 0.21 \pm 0.07$

$S = +0.19 \pm 0.30 \pm 0.07$

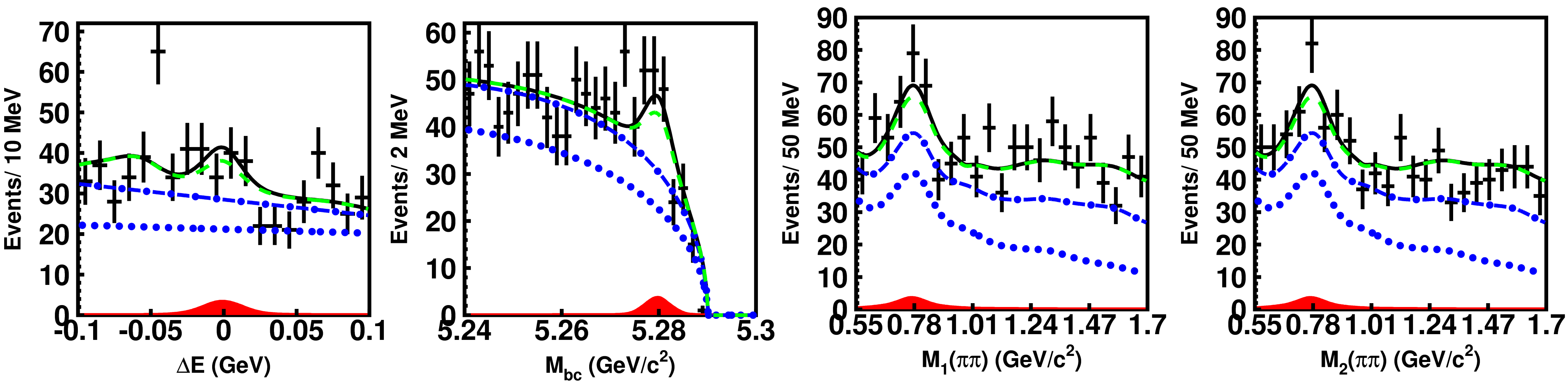
387×10^6 $B\overline{B}$ pairs
PRD76, 052007(R)(2007)

$C = +0.01 \pm 0.15 \pm 0.06$

$S = -0.17 \pm 0.20^{+0.05}_{-0.06}$

$\rho^0\rho^0$ mode

$657 \times 10^6\ B\overline{B}$ **pairs**
PRD78, 111102(R)(2008)



$$Br(B^0 \to \rho^0\rho^0) < 1.0 \times 10^{-6} \text{ @ } 90\%\text{C.L.}$$
$$= (0.4 \pm 0.4^{+0.2}_{-0.3}) \times 10^{-6}$$

$N_S(\rho^0\pi^+\pi^-) = 113^{+67}_{-66} \pm 52\ \ (\Sigma = 1.3\ \sigma)$

$Br(B^0 \to \rho^0\pi^+\pi^-) < 12.0 \times 10^{-6}$ @ 90%C.L.
$= (5.9^{+3.5}_{-3.4} \pm 2.7) \times 10^{-6}$

$N_S(4\pi^\pm) = 161^{+61}_{-59}{}^{+28}_{-25}\ \ (\Sigma = 2.5\ \sigma)$

$Br(B^0 \to 4\pi^\pm) < 19.3 \times 10^{-6}$ @ 90%C.L.
$= (12.4^{+4.7}_{-4.6}{}^{+2.1}_{-1.9}) \times 10^{-6}$

Br($\rho^0\rho^0$) is small ! SU(2) triangle even more squashed...

$\rho^0\rho^0$ mode

$465 \times 10^6\ B\bar{B}$ pairs
[PRD78, 071104(R)]

10-dim fit to extract yields, f_L, C_L^{00}, S_L^{00}:

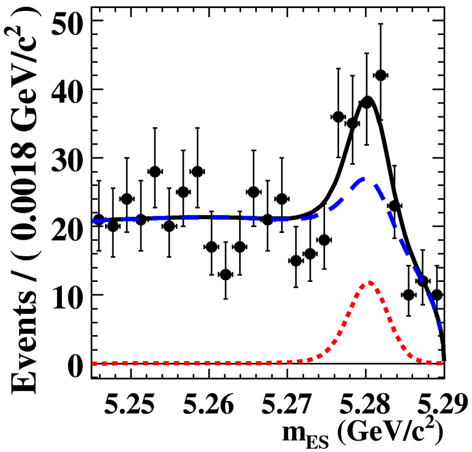
$N_S(\rho^0\rho^0) = 99^{+35}_{-34} \pm 15 \quad (\Sigma = 3.1\ \sigma)$

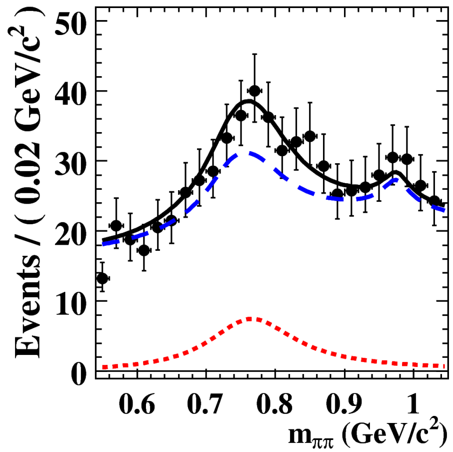
$N_S(\rho^0\pi^+\pi^-) = -12^{+39}_{-35} \pm 52$

$Br(B^0 \to \rho^0\pi^+\pi^-) < 8.7\times10^{-6}$ @ 90%C.L.

$N_S(4\pi^\pm) = 8^{+30}_{-25} \pm 6$

$Br(B^0 \to 4\pi^\pm) < 21.1\times10^{-6}$ @ 90%C.L.

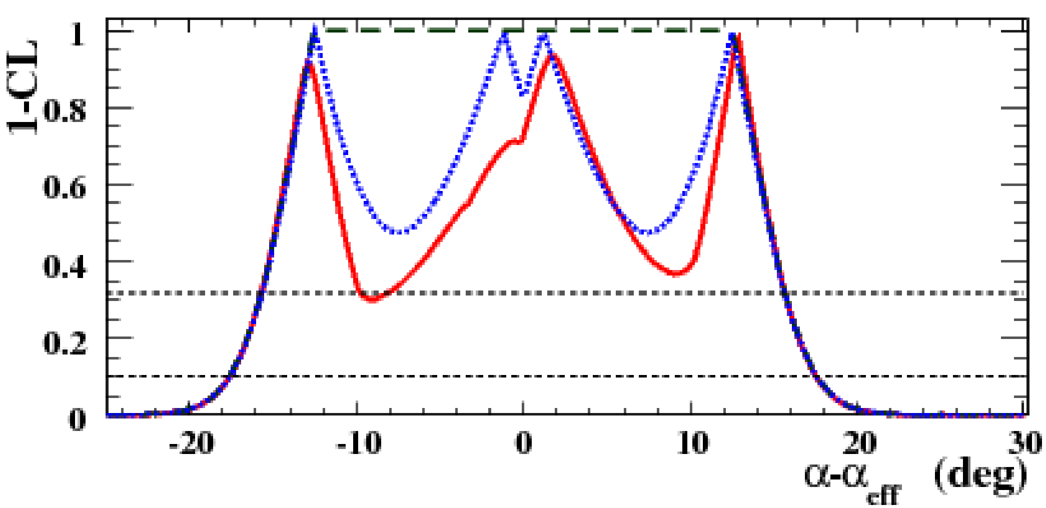




$$Br(B^0 \to \rho^0\rho^0) = (0.92 \pm 0.32 \pm 0.14) \times 10^{-6}$$

$$f_L = 0.75^{+0.11}_{-0.14} \pm 0.04$$

$$S_L^{00} = 0.3 \pm 0.7 \pm 0.2 \qquad C_L^{00} = 0.2 \pm 0.8 \pm 0.3$$

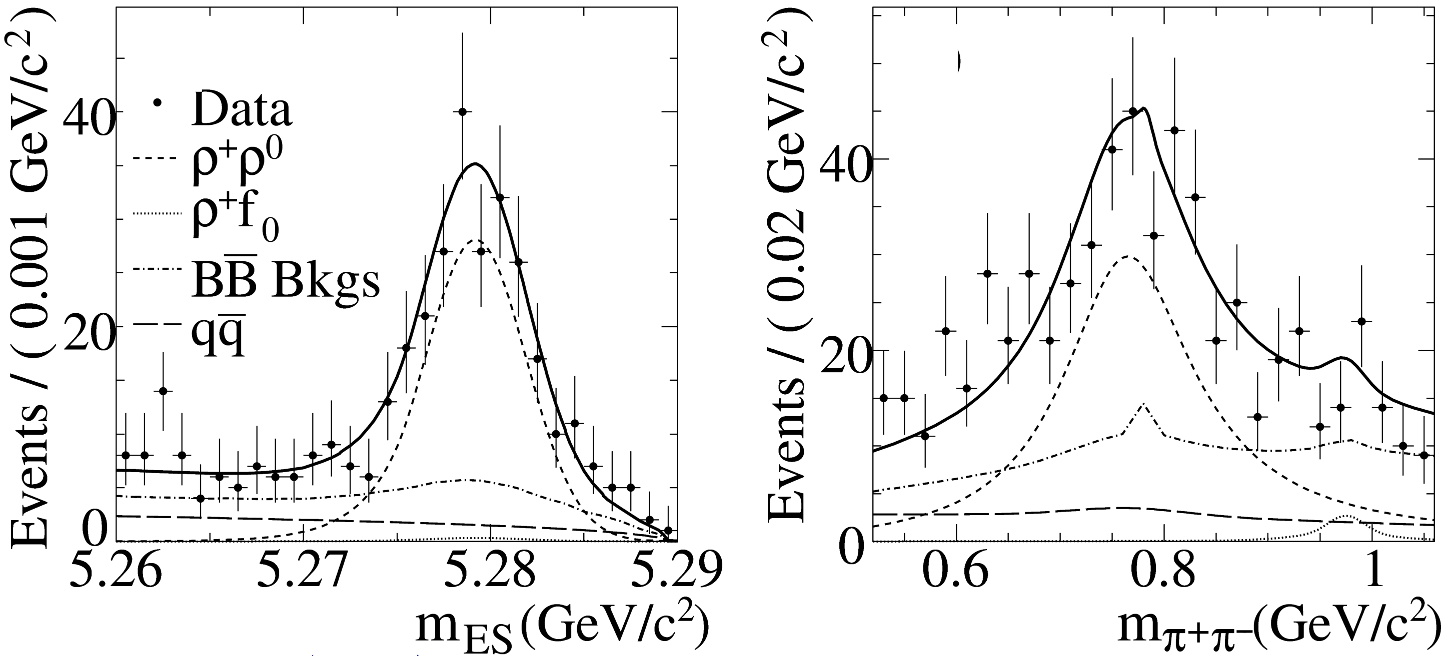


... C^{00}

... C^{00} & S^{00}

$\rho^+\rho^0$ mode

465×10^6 $B\bar{B}$ pairs
[ArXiv:0901.3522]



$N_S(\rho^+\rho^0) = 1122 \pm 63(\mathrm{stat})$

$$Br(B^+ \to \rho^+\rho^0) = (23.7 \pm 1.4 \pm 1.4) \times 10^{-6}$$

$$f_L = 0.950 \pm 0.015 \pm 0.006$$

Previous results:

232×10^6 $B\bar{B}$ pairs [PRL97, 261801 (2006)]

$Br(B^+ \to \rho^+\rho^0) = (16.8 \pm 2.2 \pm 2.3) \times 10^{-6}$

$f_L = 0.905 \pm 0.042\ ^{+0.023}_{-0.027}$

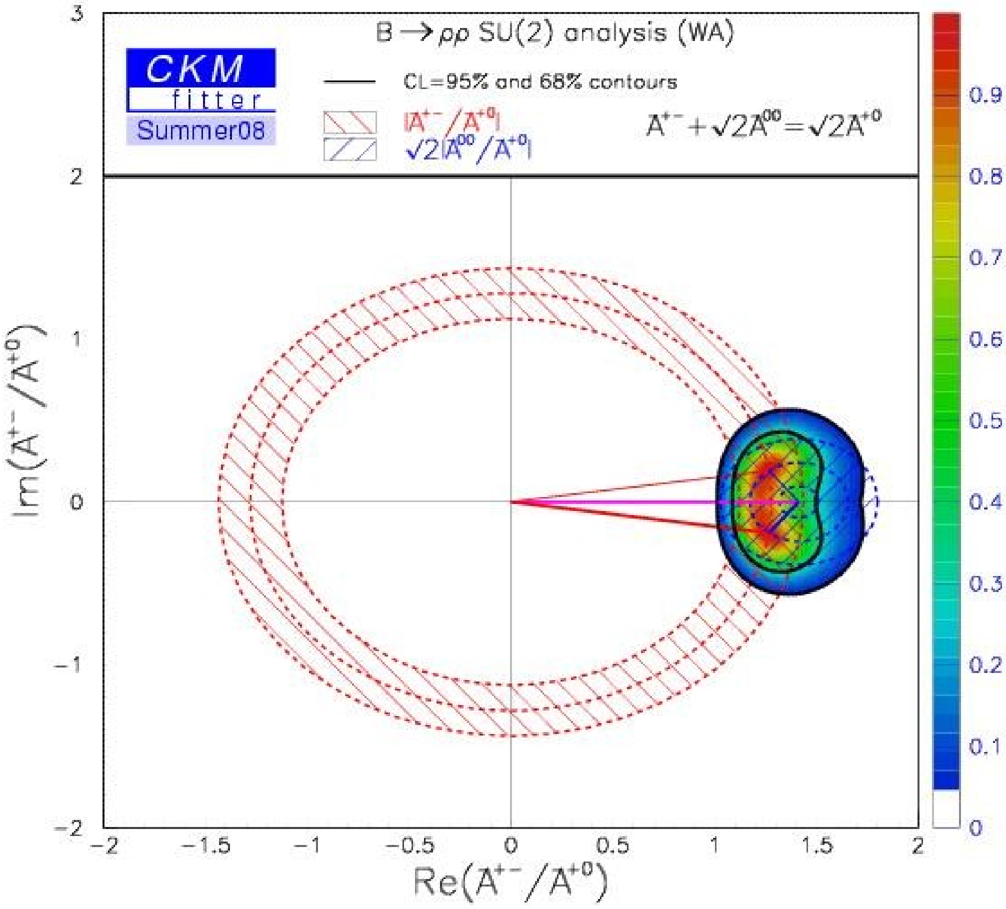
85×10^6 $B\bar{B}$ pairs [PRL91, 221801 (2003)]

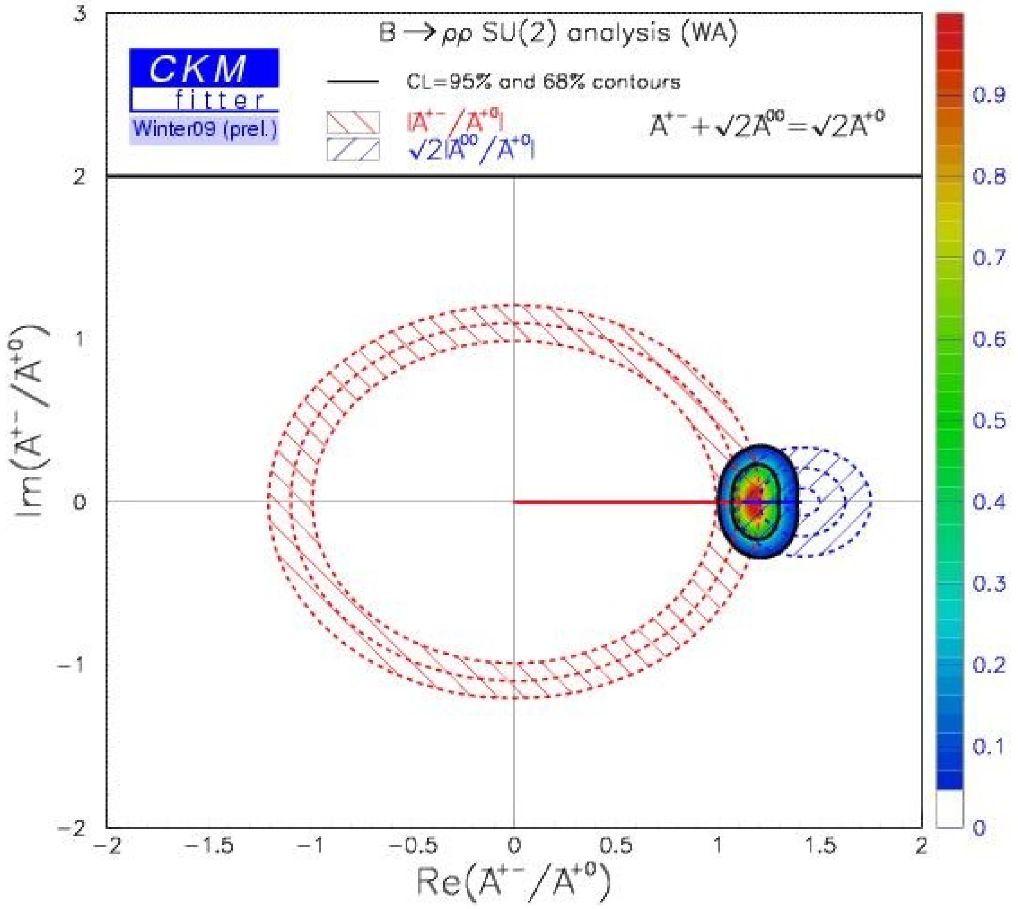
$Br(B^+ \to \rho^+\rho^0) = (31.7 \pm 7.1^{+3.8}_{-6.7}) \times 10^{-6}$

$f_L = 0.948 \pm 0.106\ \pm 0.021$

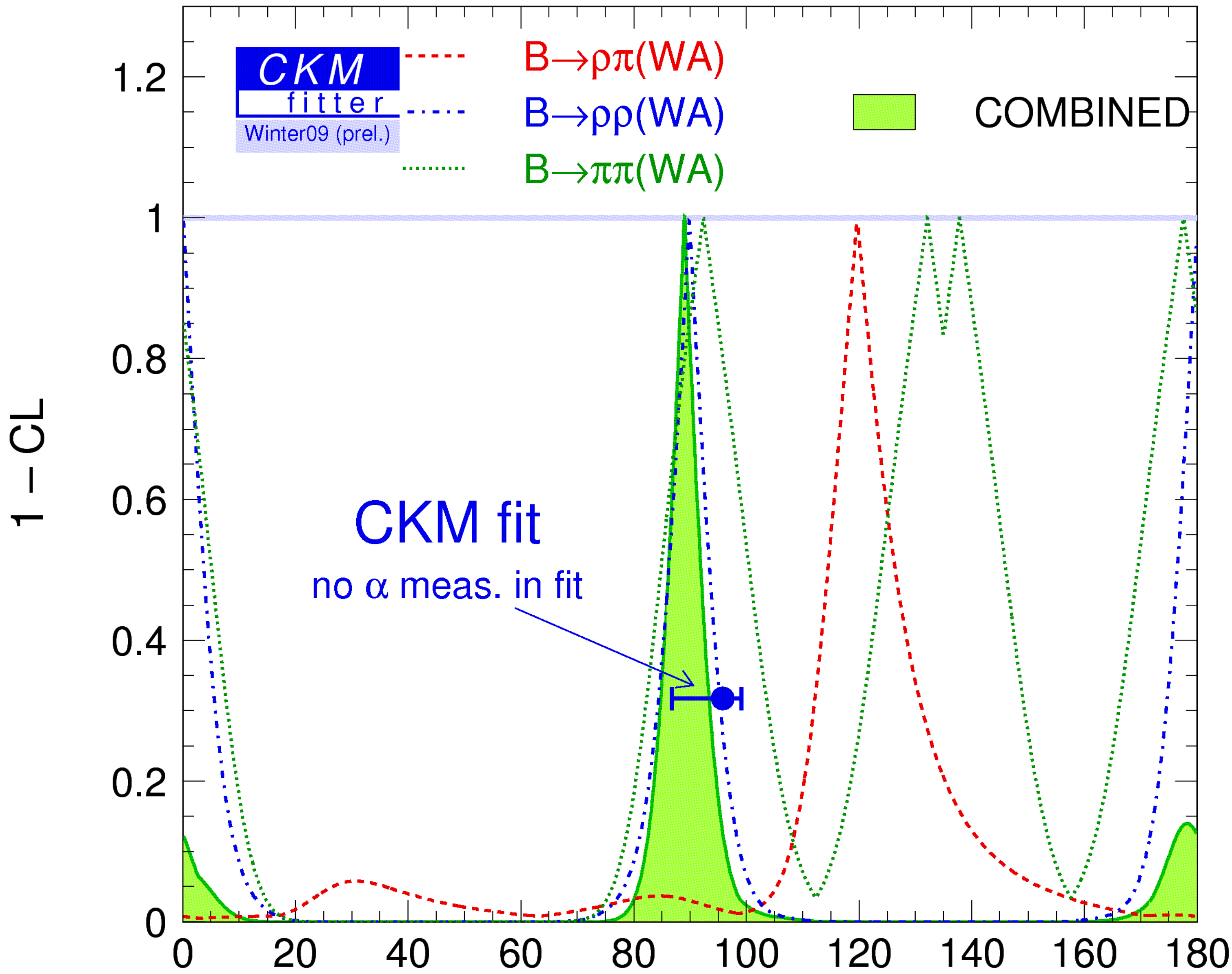
Isospin triangles (Summer 08 to Winter 09)

$B \to \rho\,\rho$ case



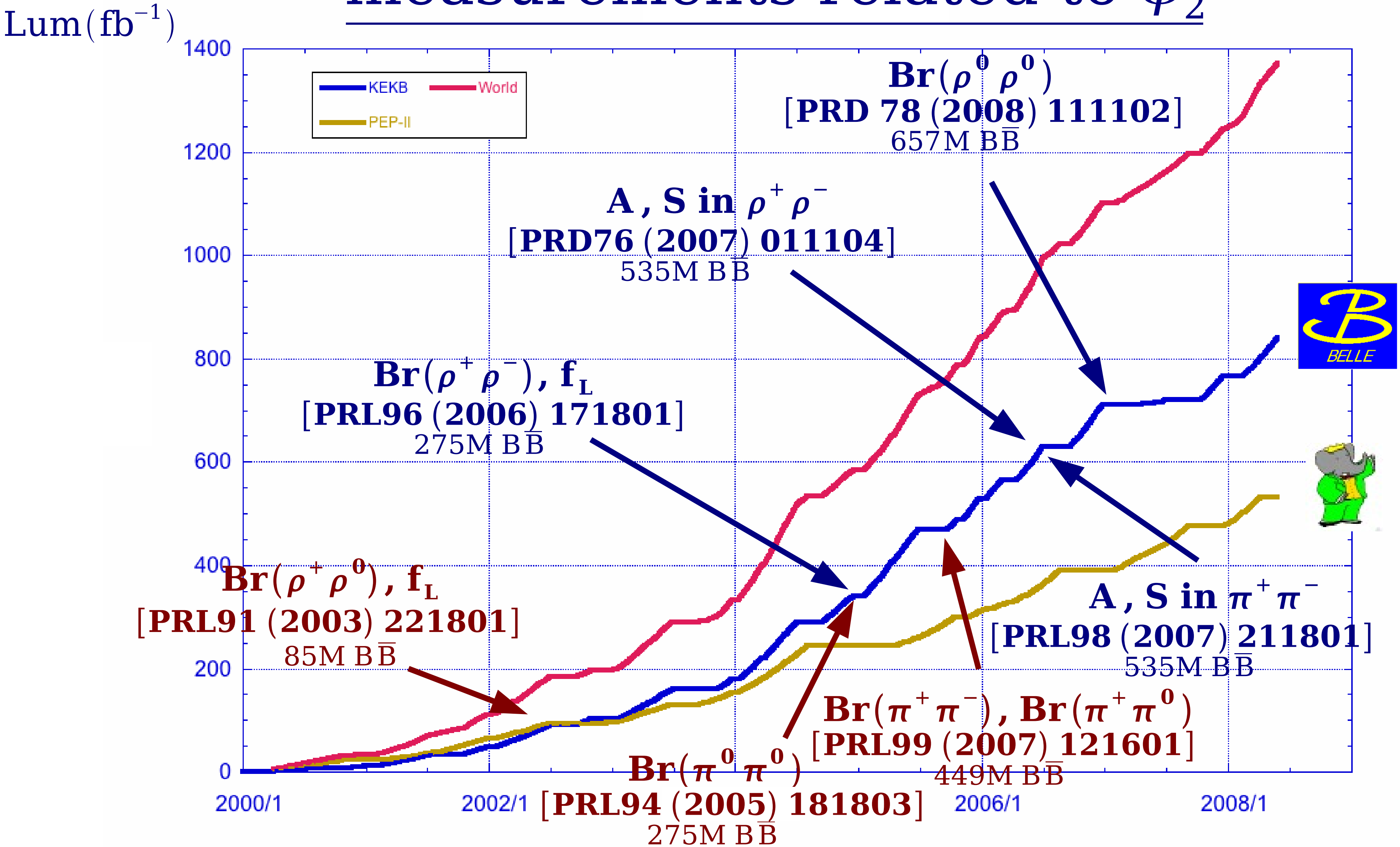


ϕ_2 determination



68% C.L. interval: $\alpha = (89.0^{+4.4}_{-4.2})^\circ$

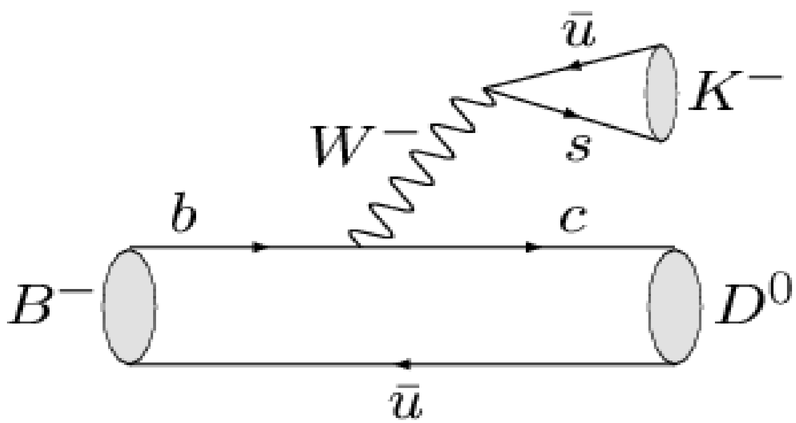
measurements related to ϕ_2



- $\rho^0\rho^0$ and $\rho^+\rho^0$: isospin triangles closing properly ?
- final Belle A($\pi^+\pi^-$), Br($\pi^0\pi^0$) (full advantage of reprocessing)
- first Belle measurement in $a_1^\pm\pi^\mp$ mode

ϕ_3 measurements from $B^{\pm} \rightarrow DK^{\pm}$

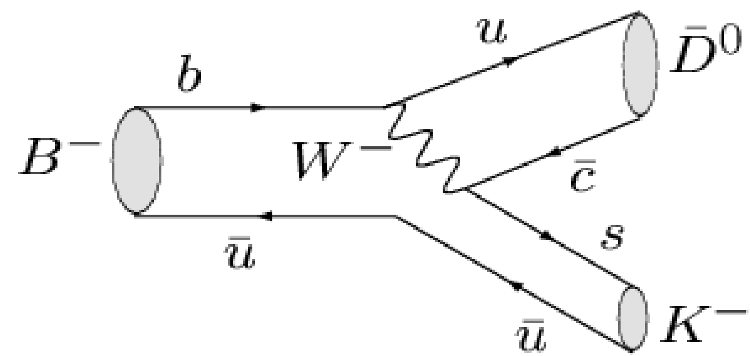
- Theoretically pristine $B \rightarrow DK$ approach
- Access ϕ_3 via interference between $B^- \rightarrow D^0 K^-$ and $B^- \rightarrow \bar{D}^0 K^-$



color allowed

$B^- \rightarrow D^0 K^- \sim V_{cb} V_{us}^*$

$\sim \mathbf{A\lambda^3}$



color suppressed

$B^- \rightarrow \bar{D}^0 K^- \sim V_{ub} V_{cs}^*$

$\sim \mathbf{A\lambda^3(\rho + i\eta)}$

relative magnitude of suppressed amplitude is r_B

$$\boxed{r_B = \frac{|A_{suppressed}|}{|A_{favoured}|} \sim \frac{|V_{ub} V_{cs}^*|}{|V_{cb} V_{us}^*|} \times [\text{color supp}] = 0.1\text{-}0.2}$$

relative weak phase is $\phi_{3,}$ relative strong phase is δ_B

ϕ_3 measurements from $B^{\pm} \to DK^{\pm}$

- Reconstruct D in final states accessible to both D^0 and $\overline{D}^0$
  - $D = D_{CP}$, CP eigenstates as K^+K^-, $\pi^+\pi^-$, $K_S\pi^0$

    GLW method (Gronau-London-Wyler)
  - $D = D_{sup}$, Doubly-Cabbibo suppressed decays as $K\pi$

    ADS method (Atwood-Dunietz-Soni)
  - Three-body decays as $D \to K_S\pi^+\pi^-$, $K_SK^+K^-$

    GGSZ (Dalitz) method (Giri-Grossman-Soffer-Zupan)

- Largest effects due to
  - charm mixing
  - charm CP violation

$\Big\}$ negligible

Y.Grossman, A.Soffer, J.Zupan
[PRD 72, 031501 (2005)]

- Different B decays (DK, D^*K, DK^*)
  - different hadronic factors (r_B, δ_B) for each

$B \to D^{(*)} K^{(*)}$ Dalitz analysis

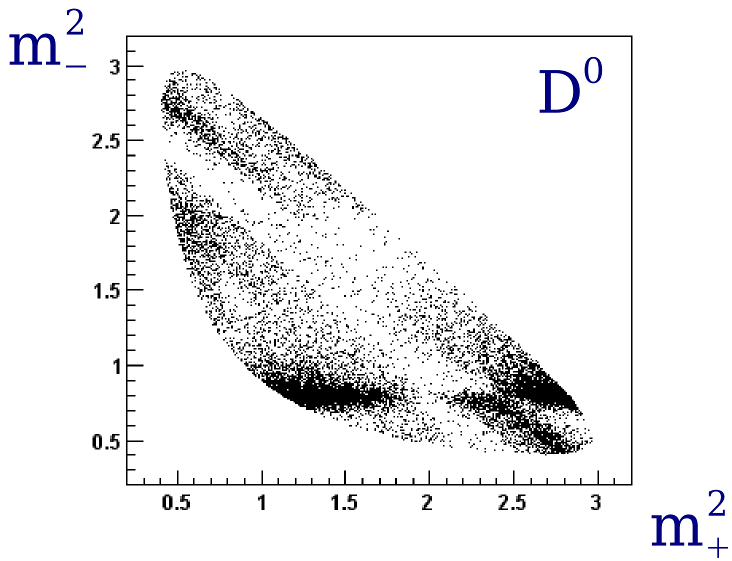
Reconstruction of three−body final states D^0, $\overline{D}^0 \to K_S \pi^+ \pi^-$

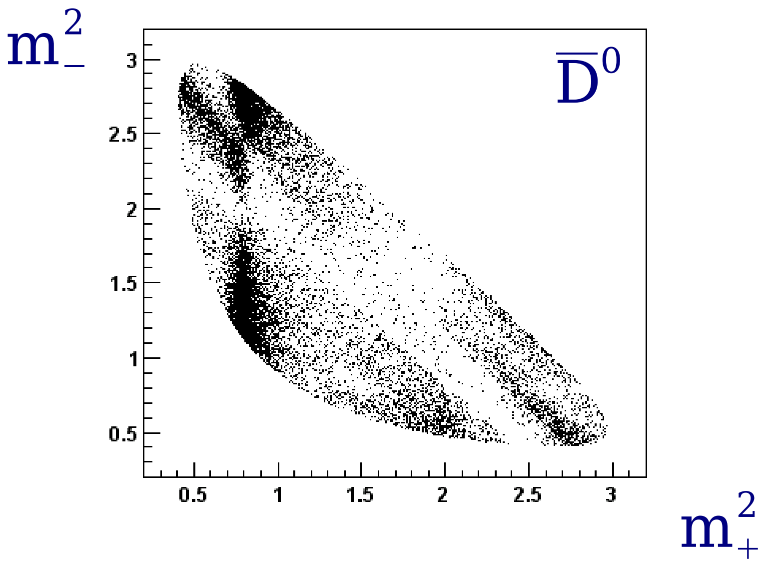
Amplitude for each Dalitz point is described as:

$$\overline{D}^0 \to K_S \pi^+ \pi^- \sim f(m_+^2, m_-^2)$$
$$D^0 \to K_S \pi^+ \pi^- \sim f(m_-^2, m_+^2)$$

$$B^+ \to (K_S \pi^+ \pi^-)_D K^+ : f(m_+^2, m_-^2) + r e^{i(\delta_B + \gamma)} f(m_-^2, m_+^2)$$

$m_- = M(K_S \pi^-)$
$m_+ = M(K_S \pi^+)$





$$B^- \to (K_S \pi^+ \pi^-)_D K^- : f(m_-^2, m_+^2) + r e^{i(\delta - \gamma)} f(m_+^2, m_-^2)$$

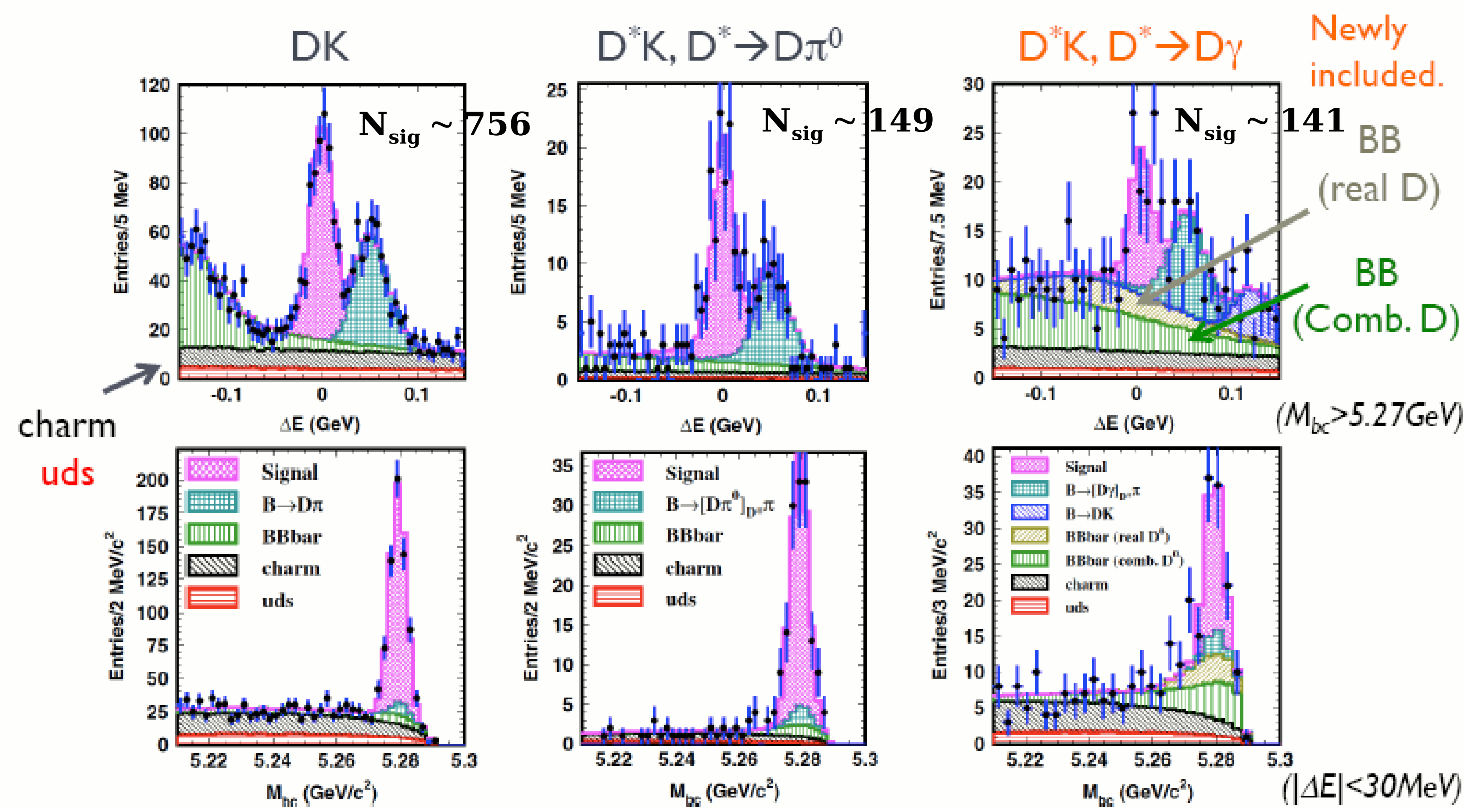
Simultaneous fit of B^+ and B^- to extract parameters r_B, ϕ_3 and δ_B

Note: 2 fold ambiguity on γ: $(\gamma, \delta_B) \to (\gamma + \pi, \delta_B + \pi)$

$B^- \to D^{(*)}(K_S\pi\pi)K^-$ Dalitz, ΔE and M_{bc} projections

$|\cos\theta_{thr}| < 0.8$ and $F > -0.7$

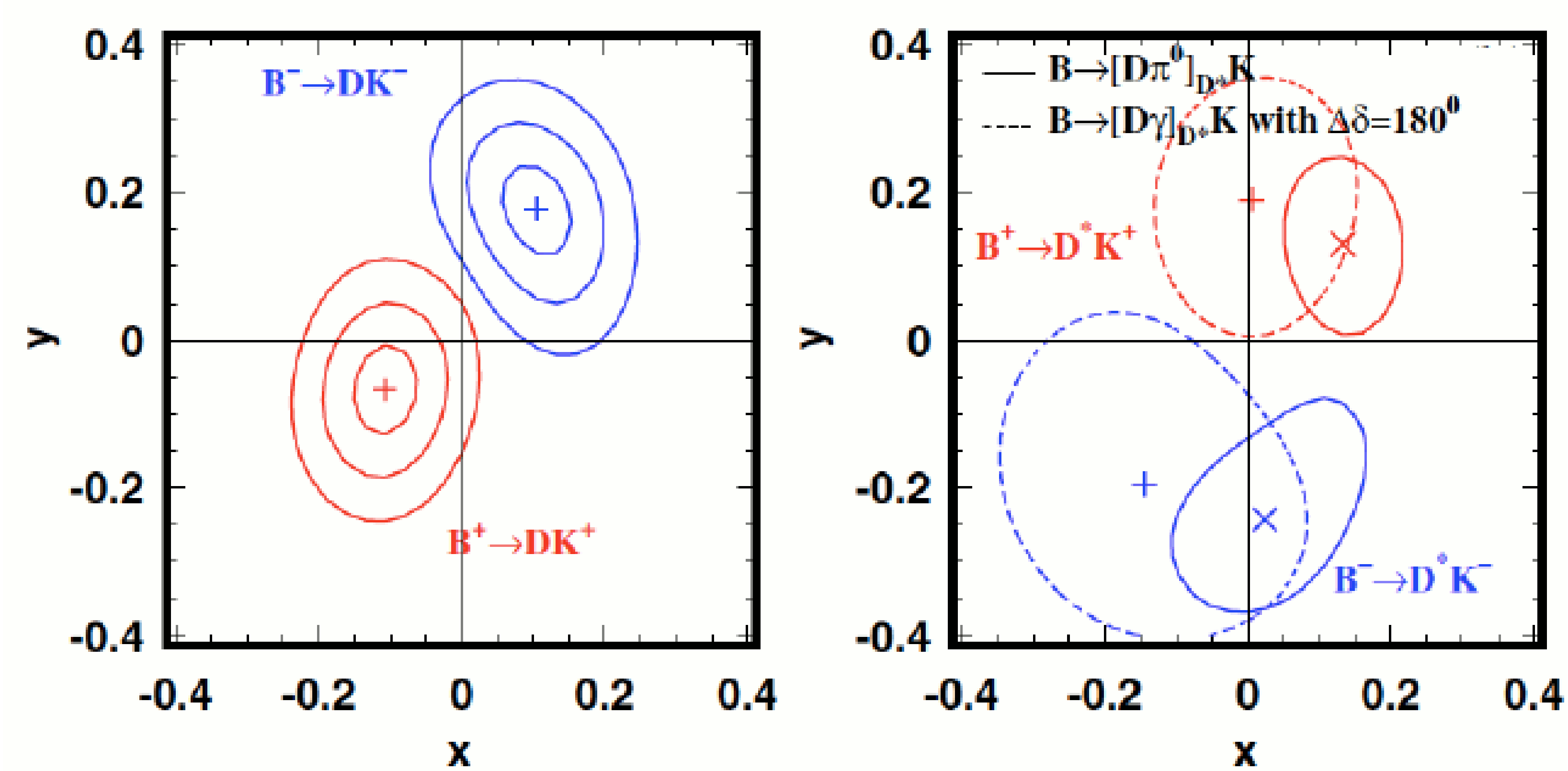
PRD 81, 112002 (2010)
657×10^6 $B\bar{B}$ pairs



ϕ_3 measurement with $B \to D(K_S\pi\pi)K$

PRD 81, 112002 (2010)
657×10^6 $B\overline{B}$ pairs

$x_\pm = r_B \cos(\delta_B \pm \phi_3)$, $y_\pm = r_B \sin(\delta_B \pm \phi_3)$

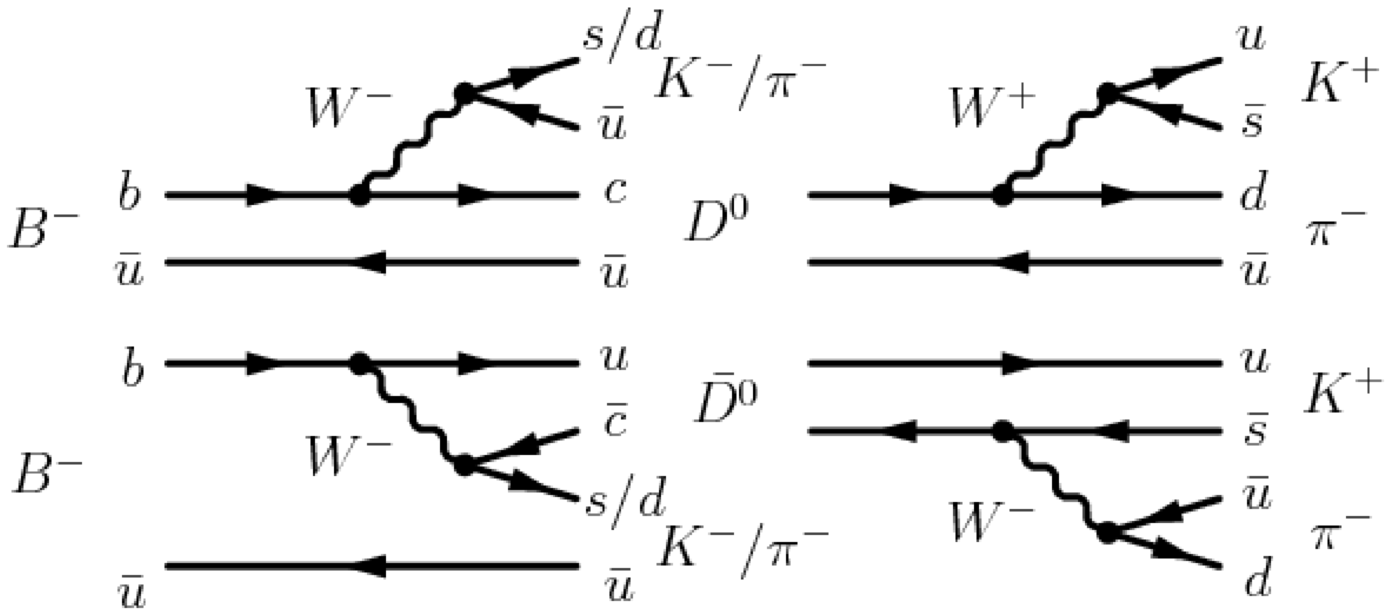


$\phi_3 = (80.8\,^{+13.1}_{-14.8} \pm 5.0 \pm 8.9)^\circ$	$\phi_3 = (73.9\,^{+18.9}_{-20.2} \pm 4.2 \pm 8.9)^\circ$
$r_B = 0.161\,^{+0.040}_{-0.038} \pm 0.011\,^{+0.050}_{-0.010}$	$r_B = 0.196\,^{+0.073}_{-0.072} \pm 0.013\,^{+0.062}_{-0.012}$
$\delta_B = (137.4\,^{+13.0}_{-15.7} \pm 4.0 \pm 22.9)^\circ$	$\delta_B = (341.7\,^{+18.6}_{-20.9} \pm 3.2 \pm 22.9)^\circ$

combining all modes (Dalitz): $\boldsymbol{\phi_3 = (78.4\,^{+10.8}_{-11.6} \pm 3.6 \pm 8.9)^\circ}$

CPV significance is 3.5 standard deviations

$B^- \to DK^-,\ D \to K^+\pi^-$ ADS



- interfering amplitudes are comparable
- introduce 2 new parameters: r_D, δ_D (but measured by CLEO ($\to$ BESIII))

Calibration Mode

$$\mathcal{R}_{Dh} \equiv \frac{\mathcal{B}(B^- \to [K^+\pi^-]_D h^-) + \mathcal{B}(B^+ \to [K^-\pi^+]_D h^+)}{\mathcal{B}(B^- \to [K^-\pi^+]_D h^-) + \mathcal{B}(B^+ \to [K^+\pi^-]_D h^+)}$$
$$= r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B + \delta_D)\cos\phi_3,$$

$$\mathcal{A}_{Dh} \equiv \frac{\mathcal{B}(B^- \to [K^+\pi^-]_D h^-) - \mathcal{B}(B^+ \to [K^-\pi^+]_D h^+)}{\mathcal{B}(B^- \to [K^+\pi^-]_D h^-) + \mathcal{B}(B^+ \to [K^-\pi^+]_D h^+)}$$
$$= 2 r_B r_D \sin(\delta_B + \delta_D)\sin\phi_3 / \mathcal{R}_{Dh},$$

$\boxed{h = K \text{ or } \pi}$

$B^- \to DK^-$, $D \to K^+\pi^-$ ADS

Main background is $e^+e^- \to q\bar{q}$ $(q=u, d, s, c)$ continuum

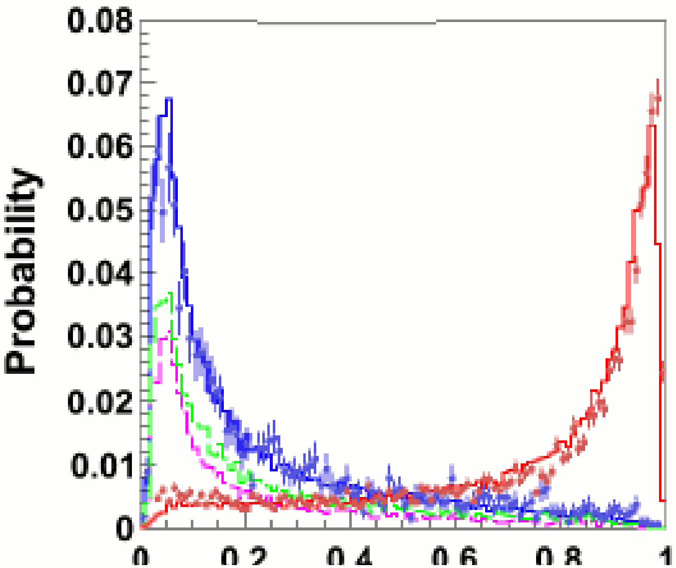
combine 10 variables with neural network

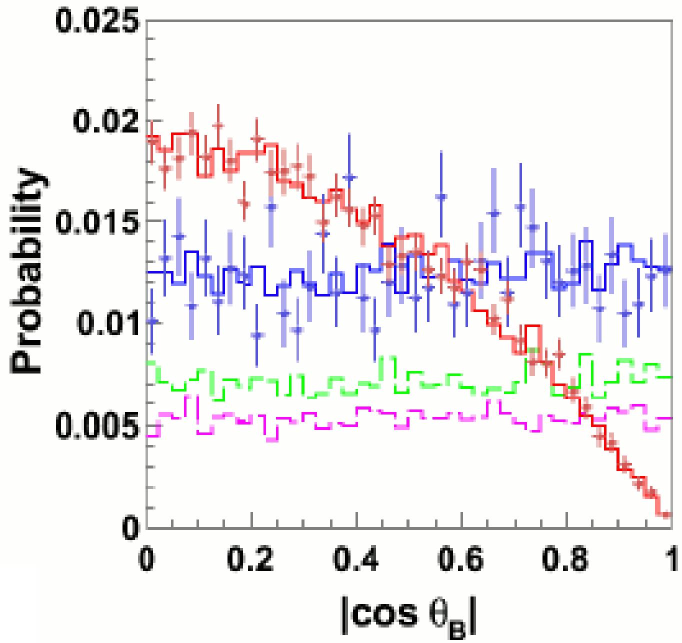
$B^- \to D\pi^-$
$\to K^-\pi^+$
M_{bc}-sideband

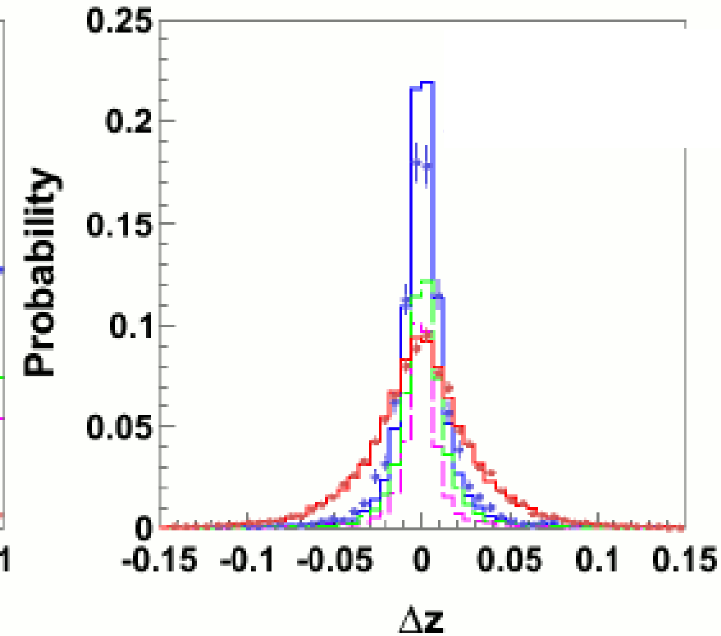
1. Variables

- Variables which have different distributions for signal and $q\bar{q}$ background are used.

histogram: MC, dots: data
signal
qq = charm + uds

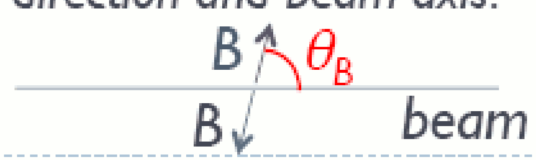




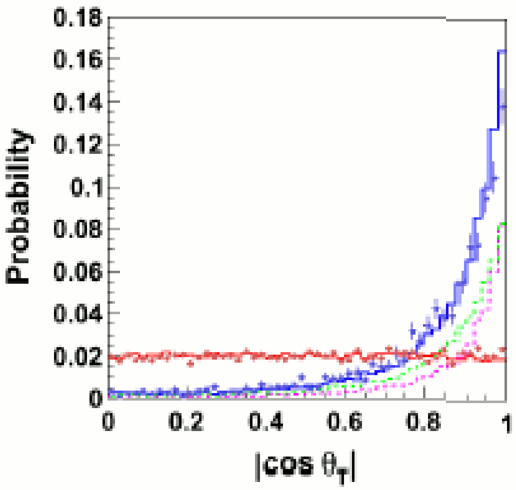


(Here, we use "old" package.)
(RooKSFW is also possible.)
Most powerful.

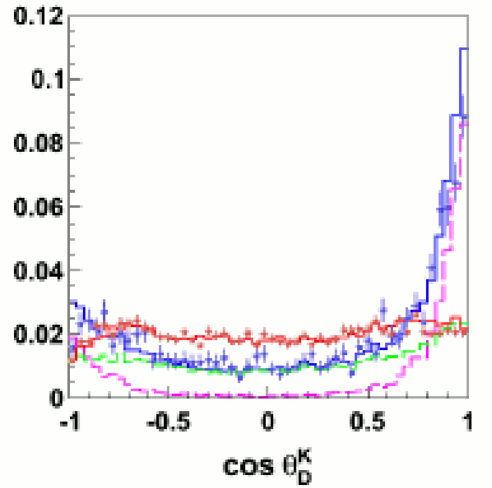
θ_B is angle between B-flight direction and beam axis.



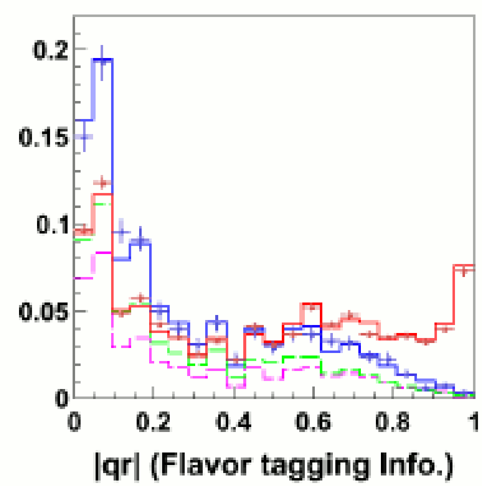
If tag is not possible, Δz = -999.
NB deals with as a δ-function.



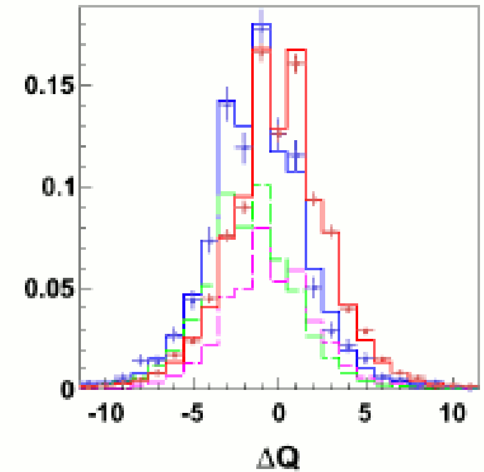
Angle between thrust axes of B decay and remainder.
No full correlation to LR(KSFW).



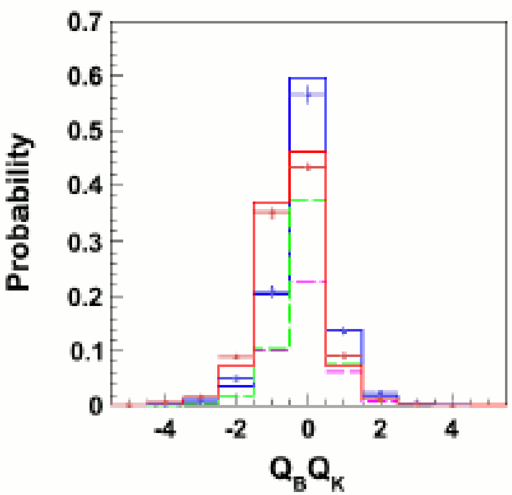
Decay angle of $D \rightarrow k\pi$.



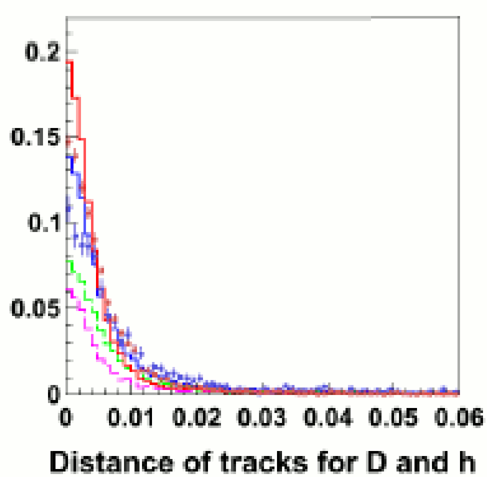
Flavor tagging Info. by MDLH. (NB possible.)



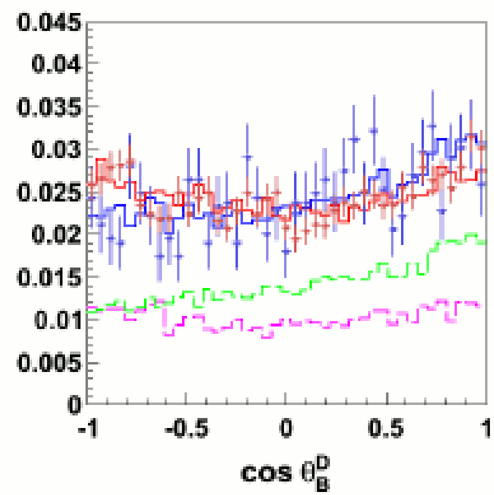
Difference of charges in D hemisphere and opposite hemisphere.



Product of charge of B and sum of charges for K not used in B reconstruction.



Distance of tracks for D and K.



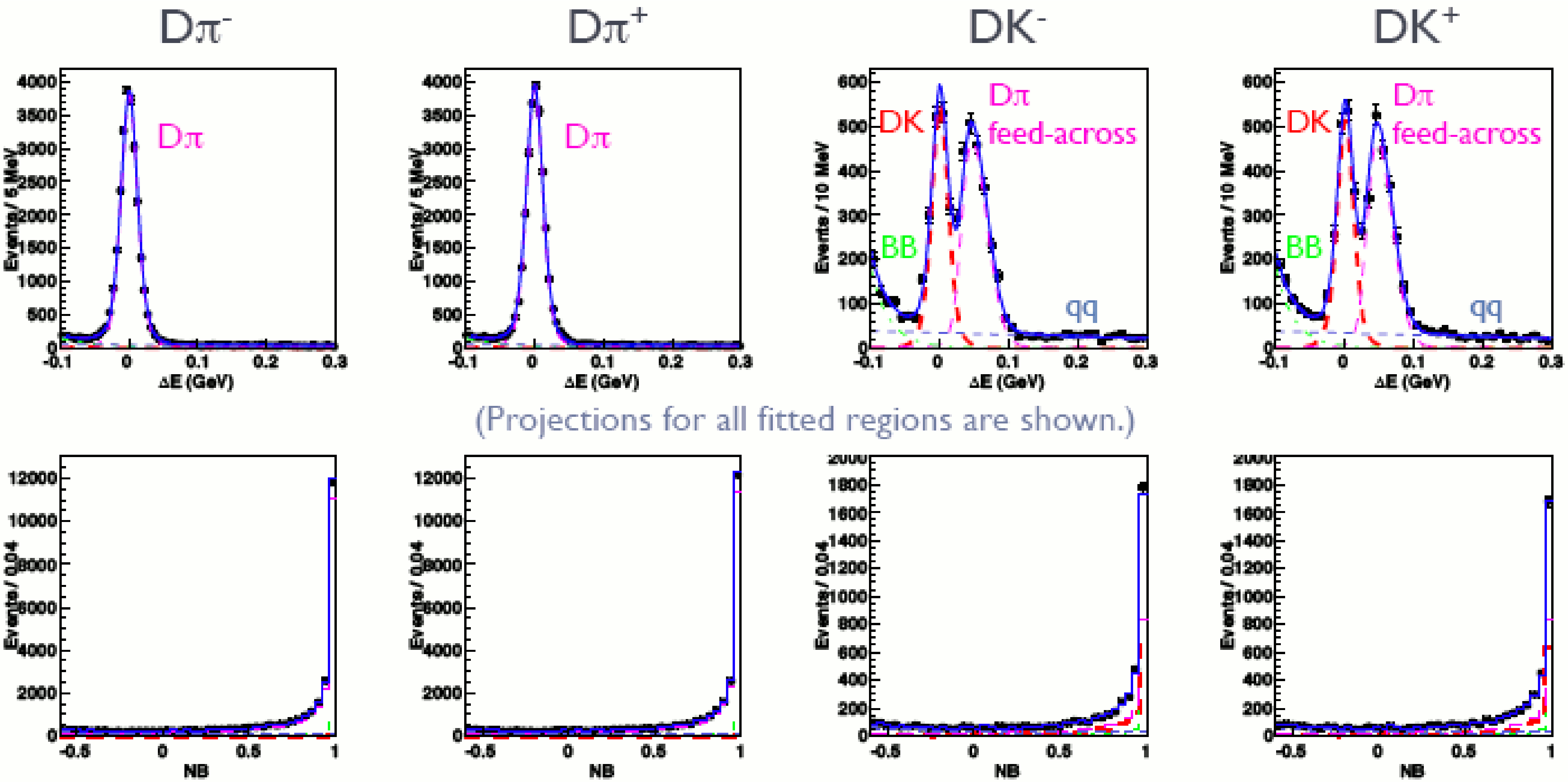
Decay angle of $B \rightarrow DK$.

10 variables are used in our analysis.

Simultaneous fit for $B^- \to [K^- \pi^+]_D h^-$ (calibration modes)

Preliminary results @ CKM2010

2D fit with ΔE and NB for $D\pi$ and DK



ΔE: Dh: 2 Gaussians (the same free shape for π/K).
$D\pi$ feed-across: 2 Asym. Gaussians (μ, $\sigma_{1,right}$ free).
BB: free exponential. qq: free linear.

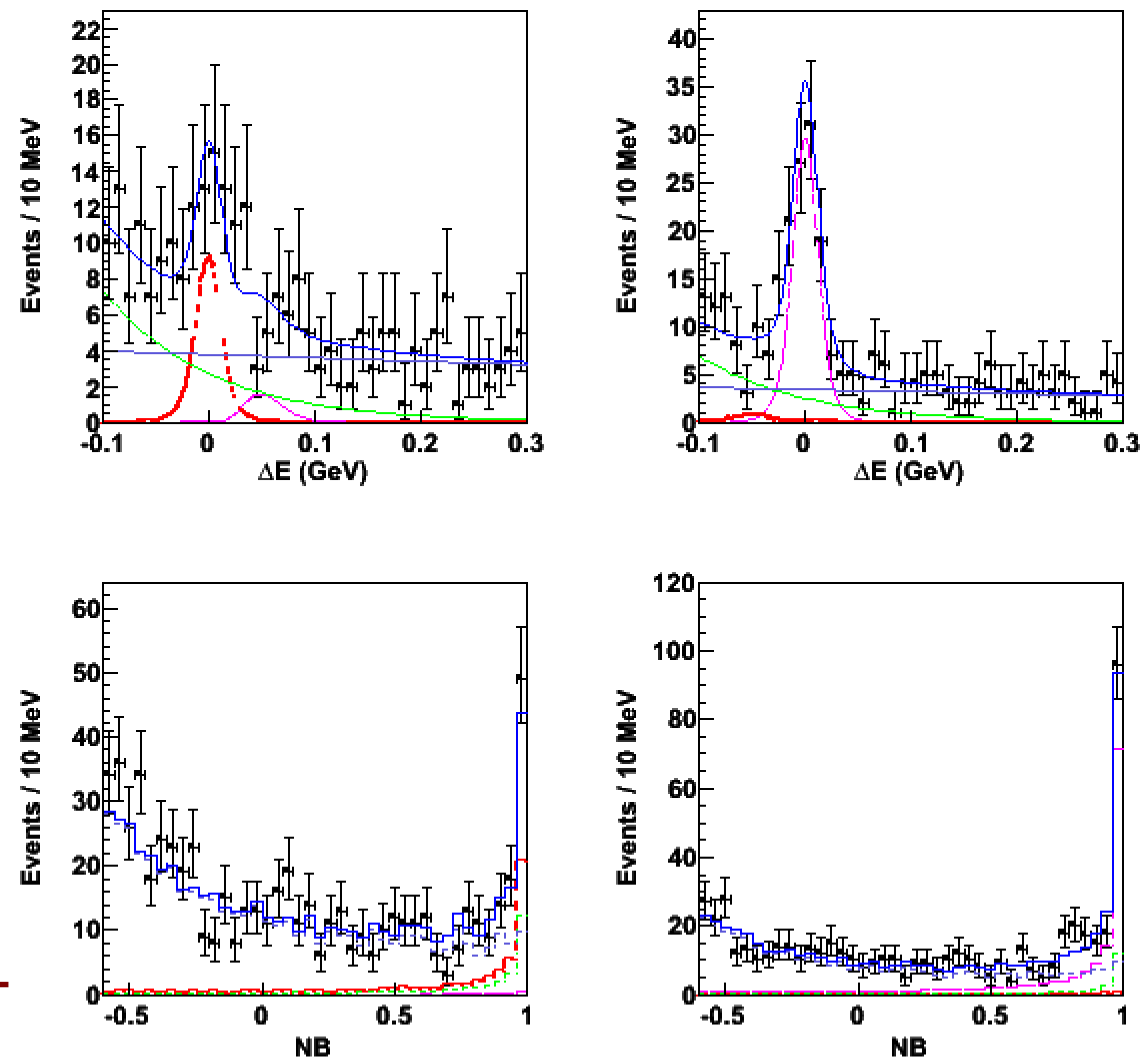
NB: Dh: Hist. from $|\Delta E|<10$ MeV. *Subtract qq.*
$D\pi$ feed-across: Hist. from $|\Delta E-50\ \mathrm{MeV}|<10$ MeV.
BB: Hist. from MC. qq: Hist. from M_{bc} sideband.

Simultaneous fit for $B^- \to [K^+\pi^-]_D h^-$ (signal modes)

Projections
shown here in signal regions:

- NB>0.9
- $|\Delta E| < 0.03$ GeV

DK $\qquad$ $D\pi$



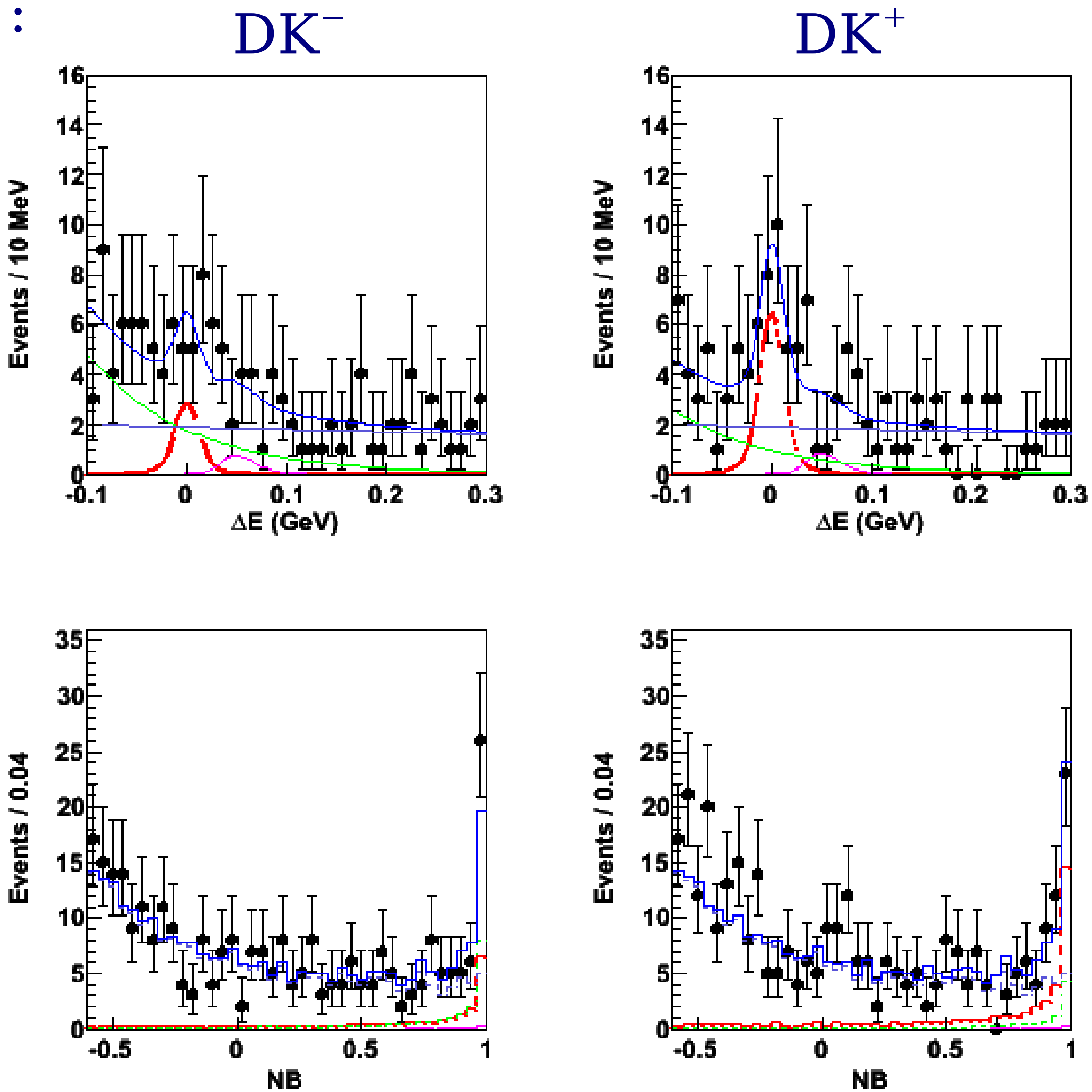
$$\mathbf{R_{DK} = (1.62 \pm 0.42\,^{+0.16}_{-0.19}) \times 10^{-2}}$$

**First evidence obtained
with a significance of 3.8σ
(including syst.)**

Simultaneous fit for $B^- \to [K^+\pi^-]_D h^-$ (signal modes)

Projections for h=K
shown here in signal regions:

- NB>0.9
- $|\Delta E| < 0.03$ GeV

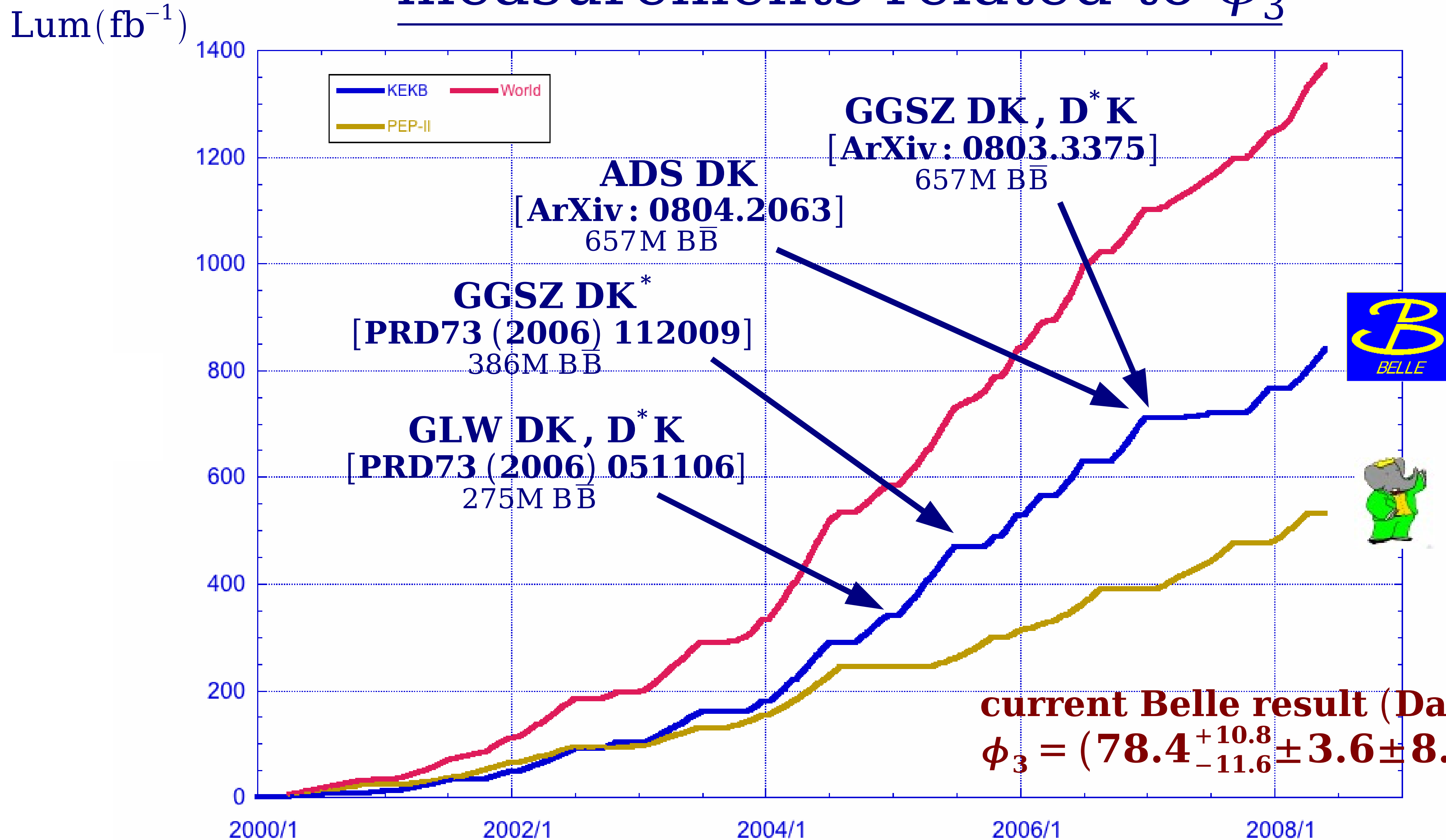


$$\mathbf{R_{DK} = (1.62 \pm 0.42\,^{+0.16}_{-0.19}) \times 10^{-2}}$$

$$\mathbf{A_{DK} = -0.39 \pm 0.26\,^{+0.06}_{-0.04}}$$

First evidence obtained with a significance of 3.8σ (including syst.)

measurements related to ϕ_3



current Belle result (Dalitz)

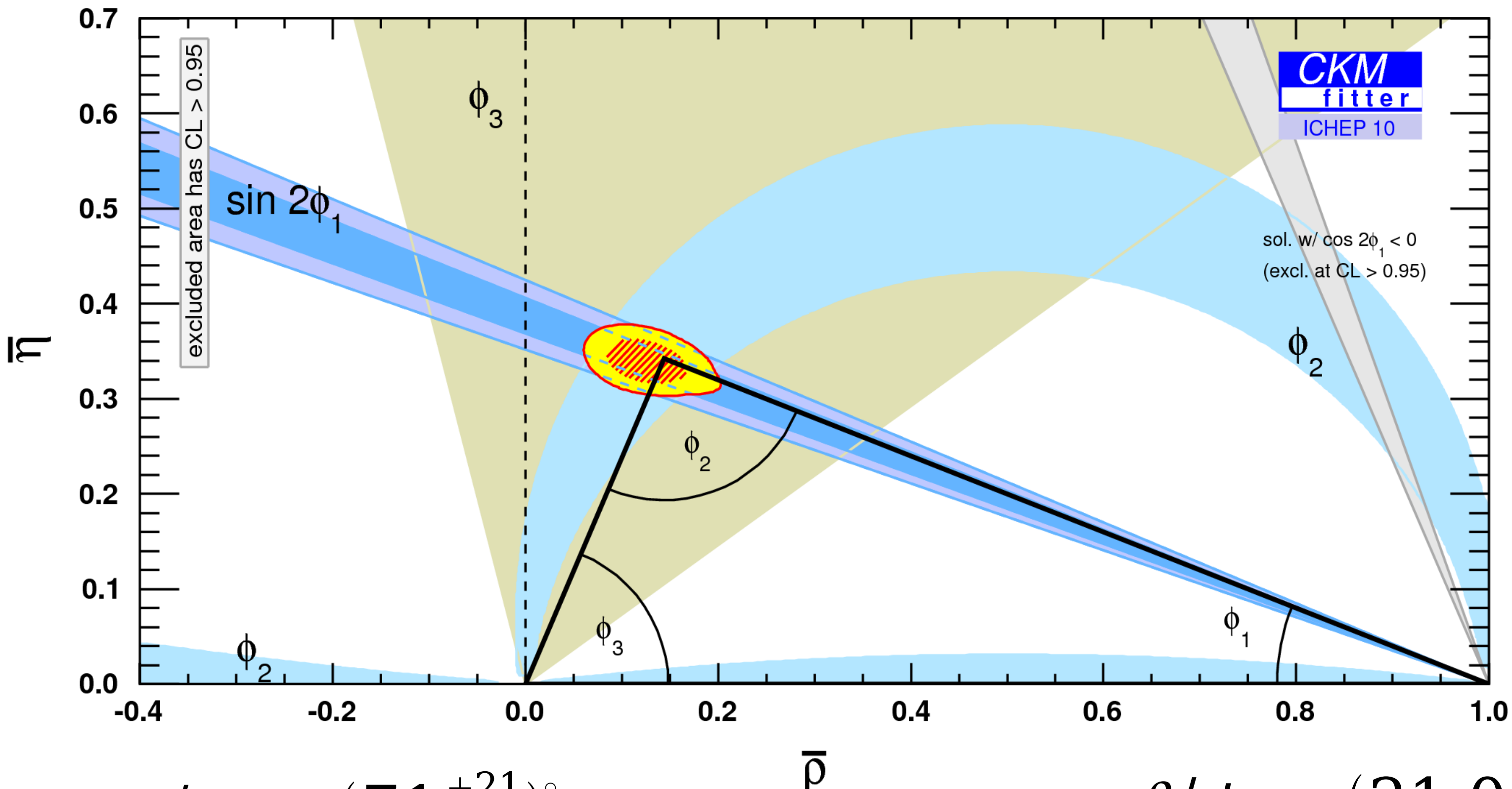
$$\phi_3 = (78.4^{+10.8}_{-11.6} \pm 3.6 \pm 8.9)^\circ$$

- first model independent $D(K_S\pi\pi)K$ result with final sample
  ~ statistical sensitivity, but no model error → **winter 2011**

- large stat in GLW modes ($\times 3$): clear evidence of charge asymmetries
- first ADS measurements in D^*K, DK^* modes

Summary on the angles

$$\alpha/\phi_2 = (89.0^{+4.4}_{-4.2})^\circ$$
(WA, CKMfitter, Winter09)



$$\gamma/\phi_3 = (71^{+21}_{-25})^\circ$$
(WA, CKMfitter, ICHEP10)

$$\beta/\phi_1 = (21.0 \pm 0.9)^\circ$$
(WA, HFAG, Winter09)

Radiative and Electroweak Penguin Decays

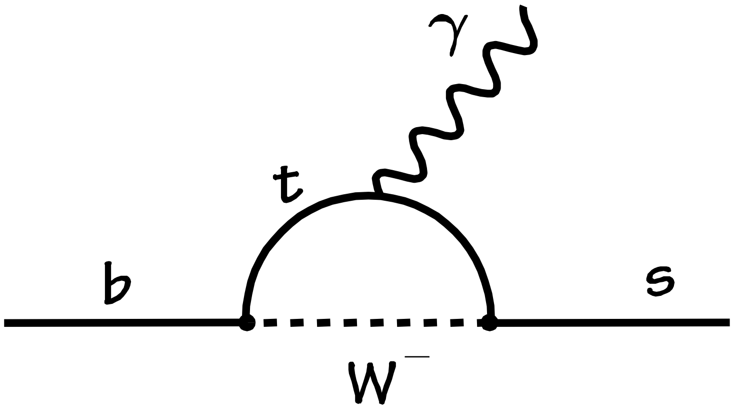
Radiative and Electroweak Penguin Decays are Flavor Changing Neutral Currents (FCNC) occuring in the Standard Model only at the **loop** level

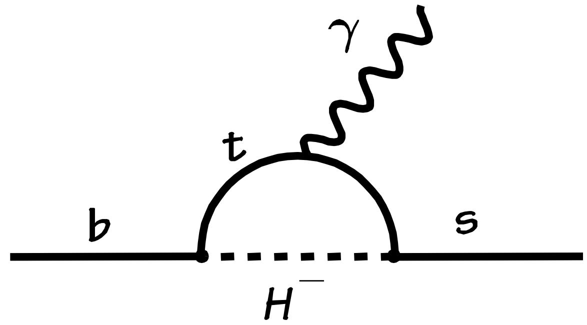
⇒ high sensitivity to **New Physics** (NP)
(can appear in the loop with size comparable to leading SM contributions)

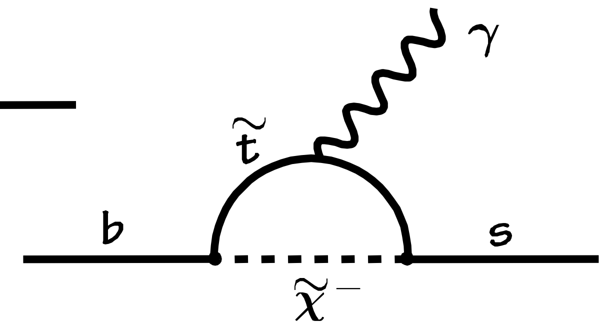
⇒ **Complementary** to the direct production of new particles expected at LHC

Huge datasets collected at the two B-factories, BaBar and Belle, have made it possible to explore precisely these decays in **exclusive** channels and **inclusive** measurements

$B \to X_s \gamma$







Sensitive to NP

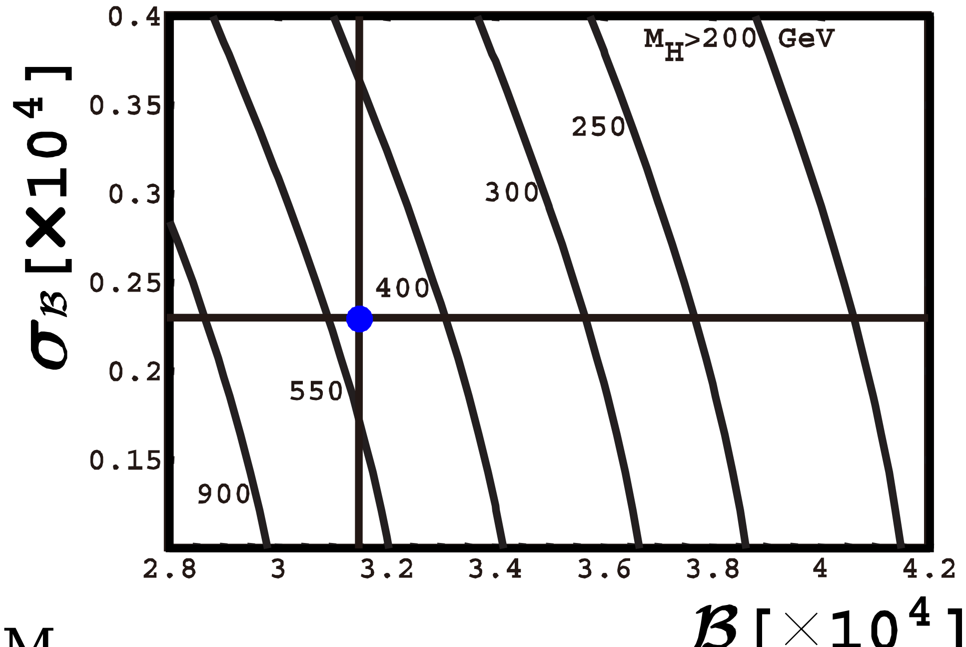
NNLO SM calculation:

$$B_{SM}(B \to X_s \gamma) = (3.15 \pm 0.23) \times 10^{-4}$$

(for $E_\gamma > 1.6$ GeV)

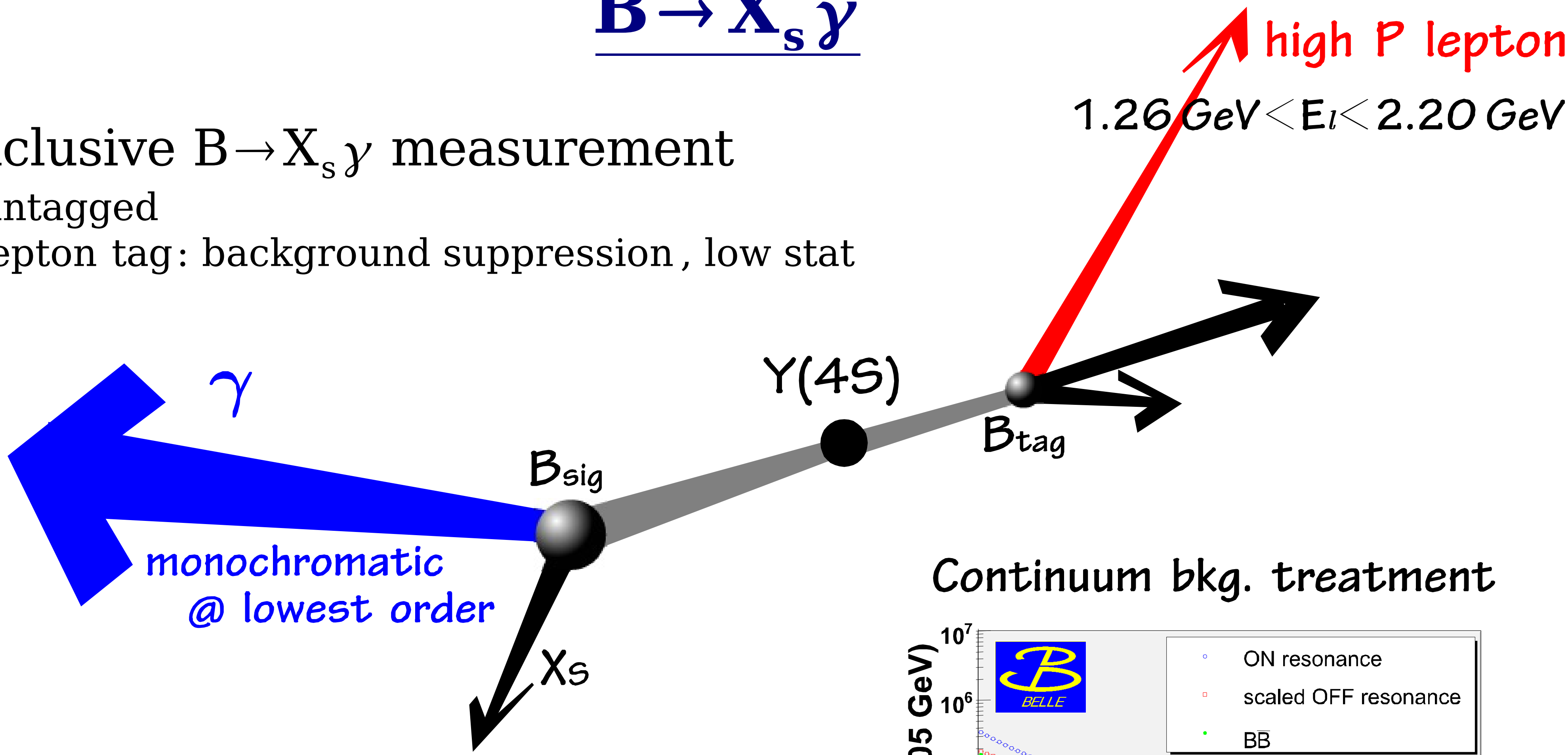
M.Misiak et al.
PRL 98, 022002 (2007)

Charged Higgs (2HDM Type II) bound



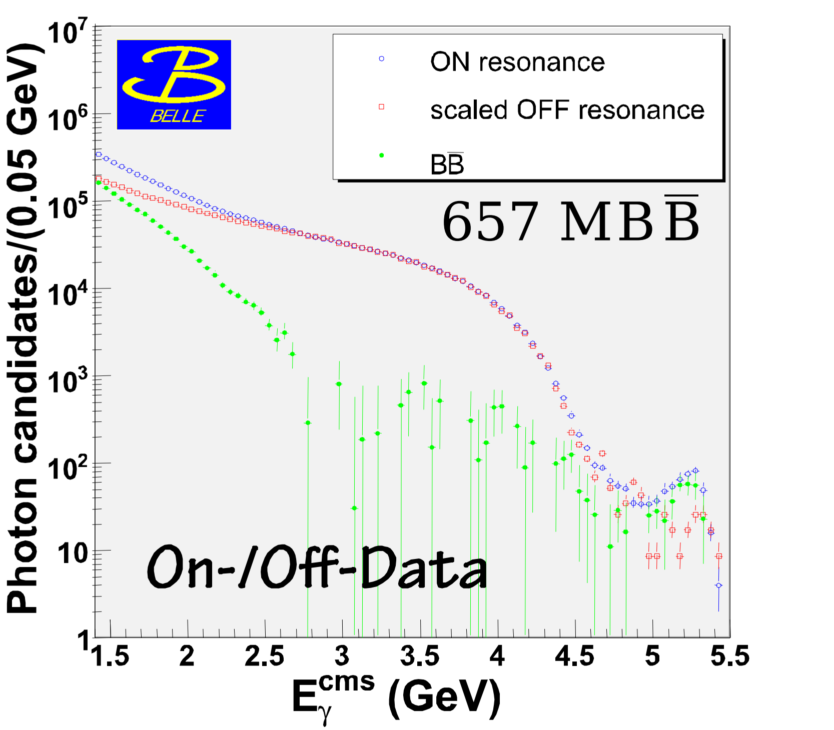
The lower γ energy threshold
the smaller the model uncertainties in SM,
but the larger background in measurement

$B \to X_s \gamma$



inclusive $B \to X_s \gamma$ measurement
untagged
lepton tag : background suppression , low stat

Continuum bkg. treatment



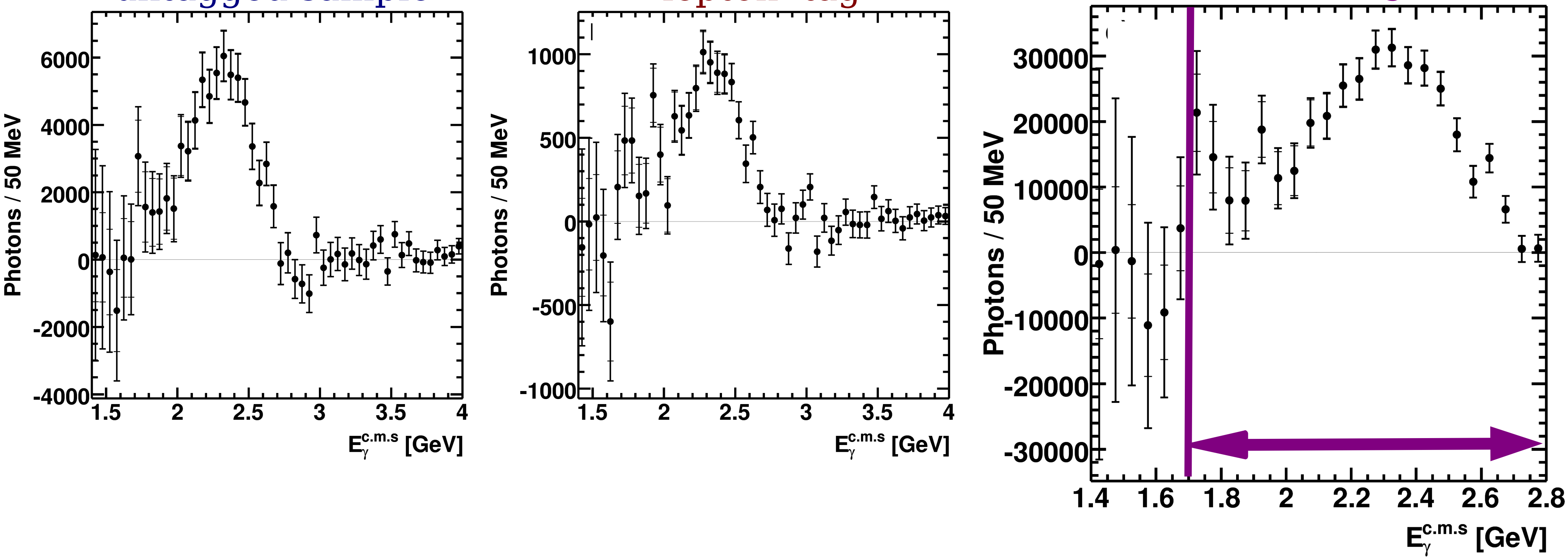
- No kinematic constraints
- Only a high energy photon measured in $\Upsilon(4S)$ rest frame
- Lower E_γ threshold (1.7 GeV)

$B \to X_s \gamma$ spectrum

PRL 103, 241801 (2009)

Background subtracted

untagged sample | lepton-tag | Efficiency corrected and averaged



$$\mathcal{B}(B \to X_s \gamma) = (3.45 \pm 0.15 \pm 0.40) \times 10^{-4} \quad (\text{for } E_\gamma > 1.7 \text{ GeV})$$

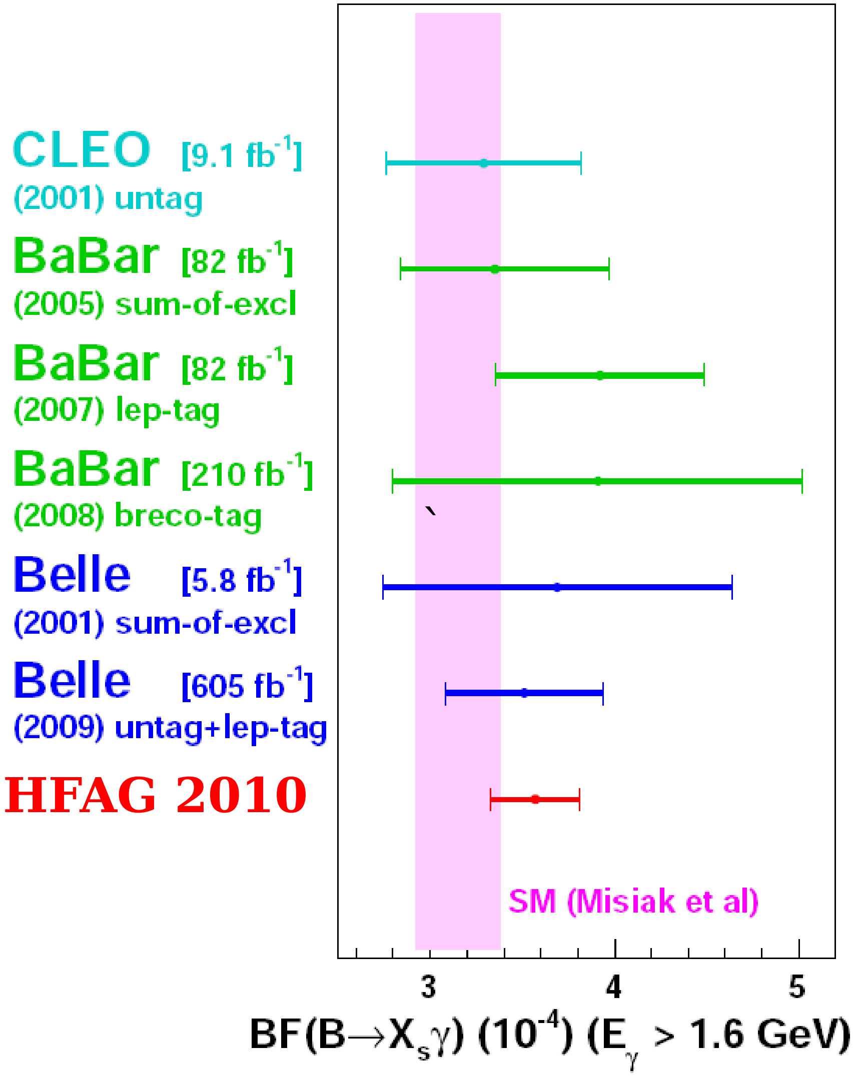
- Most precise measurement of $\mathcal{B}(B \to X_s \gamma)$ (lowest E_γ threshold)
- Crucial input for global fit to extract $|V_{ub}|$ and $B \to X_s \gamma$ decay rate
- $\mathcal{B}$ is given for E_γ thresholds: 1.7, 1.8, 1.9, 2.0 GeV
- Systematic error is dominated by off-resonance subtraction !

$\mathbf{B \to X_s \gamma}$

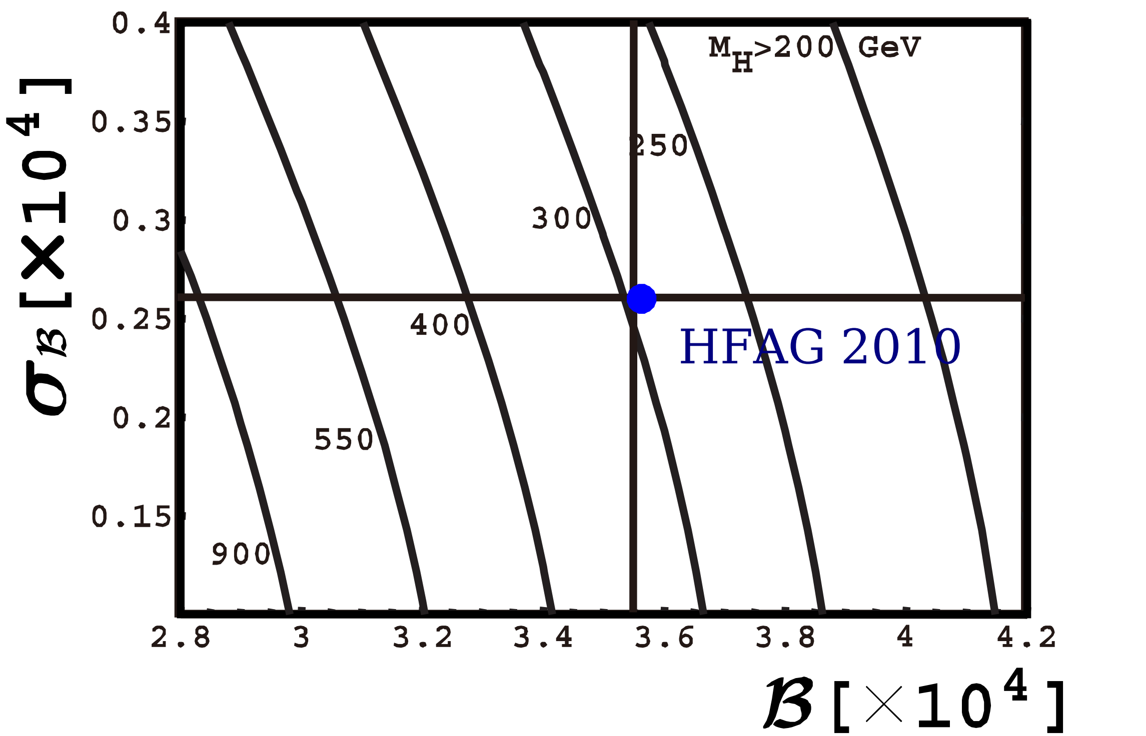
HFAG 2010: $\mathcal{B}(\mathrm{B} \to \mathrm{X_s}\gamma) = (3.55 \pm 0.26) \times 10^{-4}$ (for $E_\gamma > 1.6$ GeV)

vs

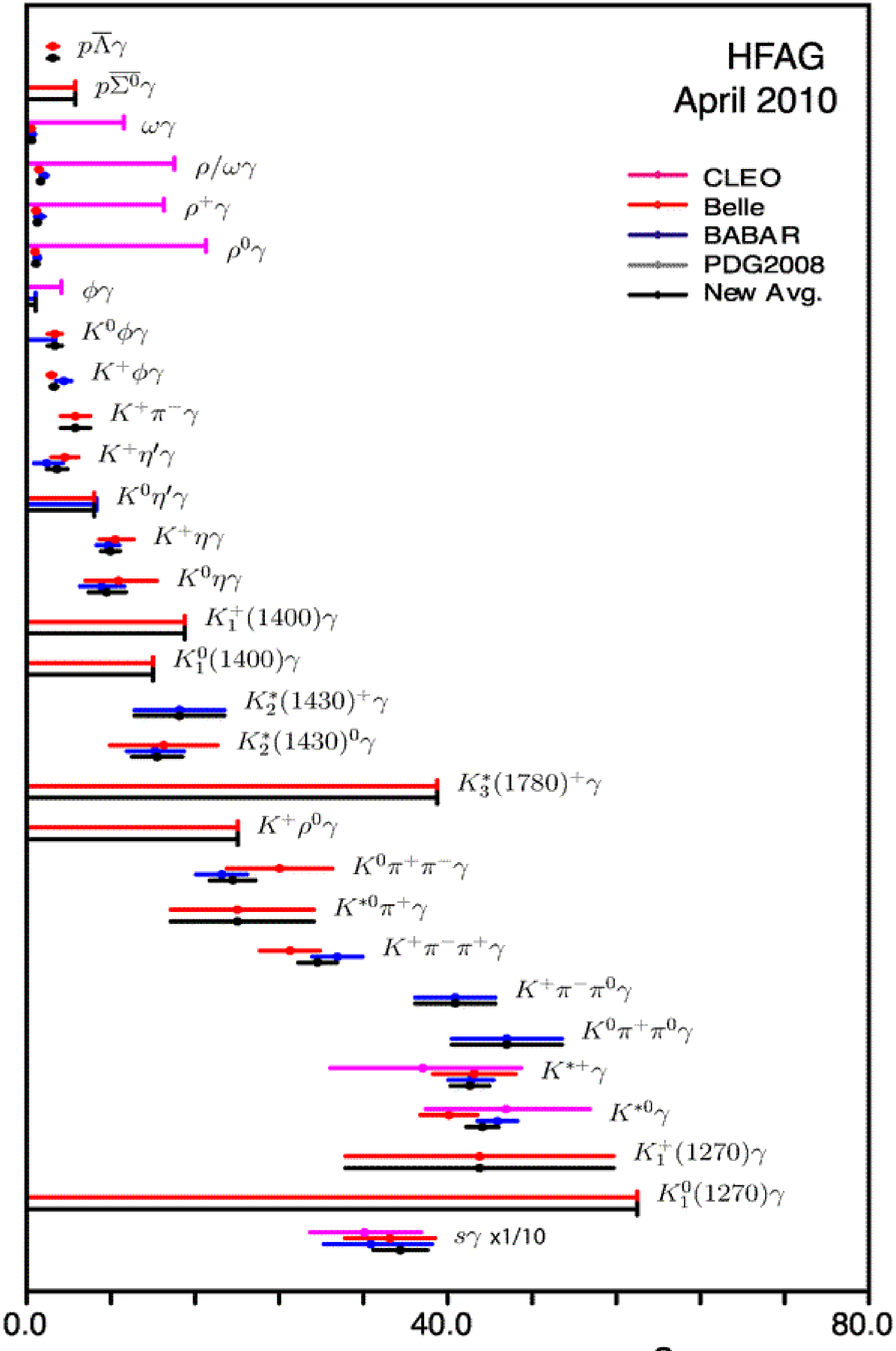
SM: $\mathcal{B}(\mathrm{B} \to \mathrm{X_s}\gamma) = (3.15 \pm 0.23) \times 10^{-4}$ (for $E_\gamma > 1.6$ GeV)



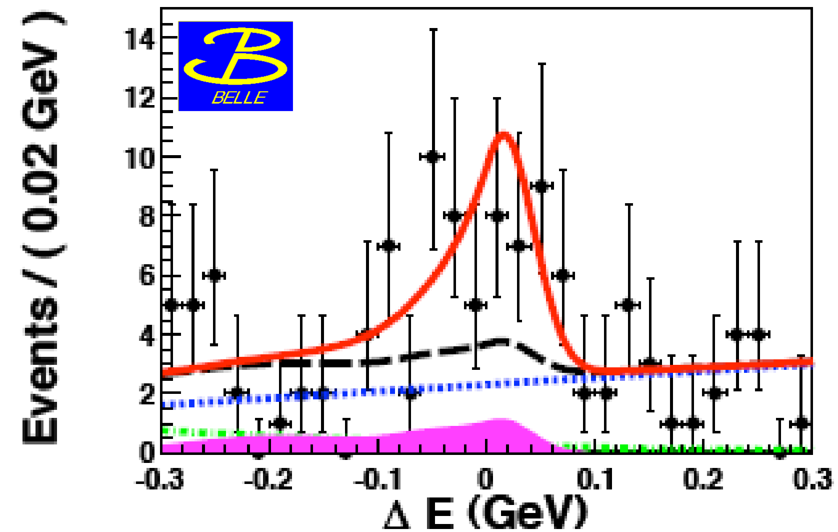
Charged Higss bound (2HDM TypeII)
$M_{H^+} > 300$ GeV



$B \to X_{s,d}\gamma$

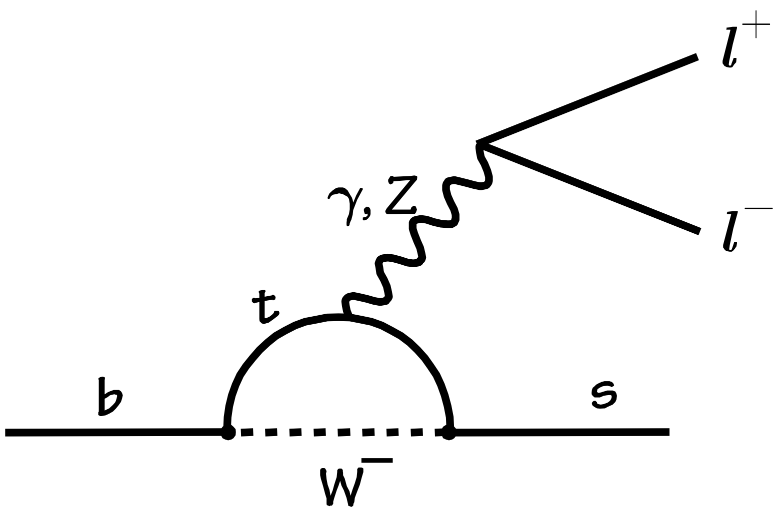


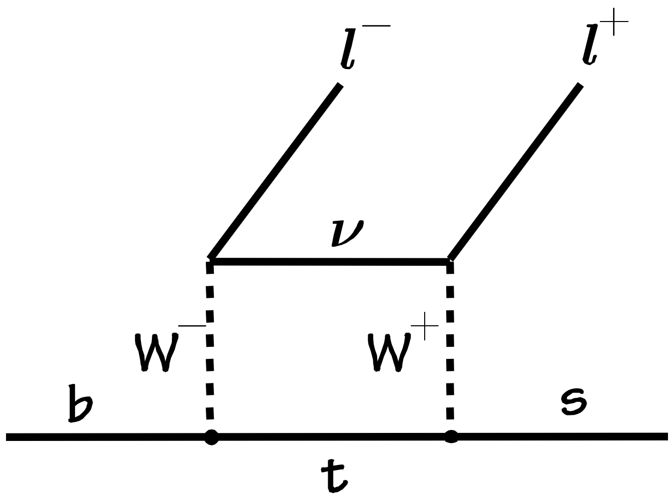
arXiv:0911.1779 $B \to \phi K_S \gamma$



$B(10^{-6})$

$\mathbf{b \to s\, l^+ l^-}$





$\Rightarrow$ 2 orders of magnitude smaller than $b \to s\gamma$ but rich NP search potential

Amplitudes from
- electromagnetic penguin: C_7
- vector electroweak: C_9
- axial-vector electroweak: C_{10}

may interfere w/ contributions from NP

Many observables:
- Branching fractions
- Isospin asymmetry (A_I)
- Lepton forward-backward asymmetry (A_{FB})

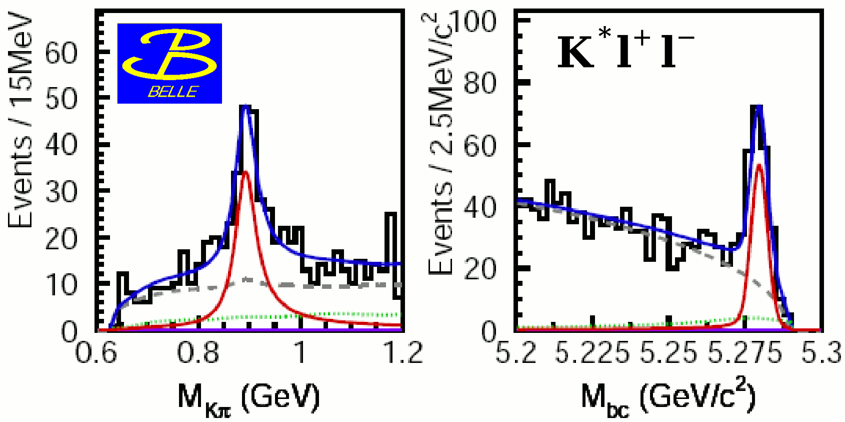
(many other observables: Tobias Hurth)

$\Rightarrow$ Exclusive ($B \to K^{(*)} l^+ l^-$), Inclusive ($B \to X_s\, l^+ l^-$)

Exclusive $B \to K l^+ l^-$ and $B \to K^* l^+ l^-$

$K = K^+$ or K_S^0, $K^* = K^{*0} \to K^+ \pi^-$, $K^{*+} \to K_S^0 \pi^+$, $K^+ \pi^0$, $l = e$ or μ

Various observables: Forward-backward asymmetry, F_L, isospin, lepton flavor...



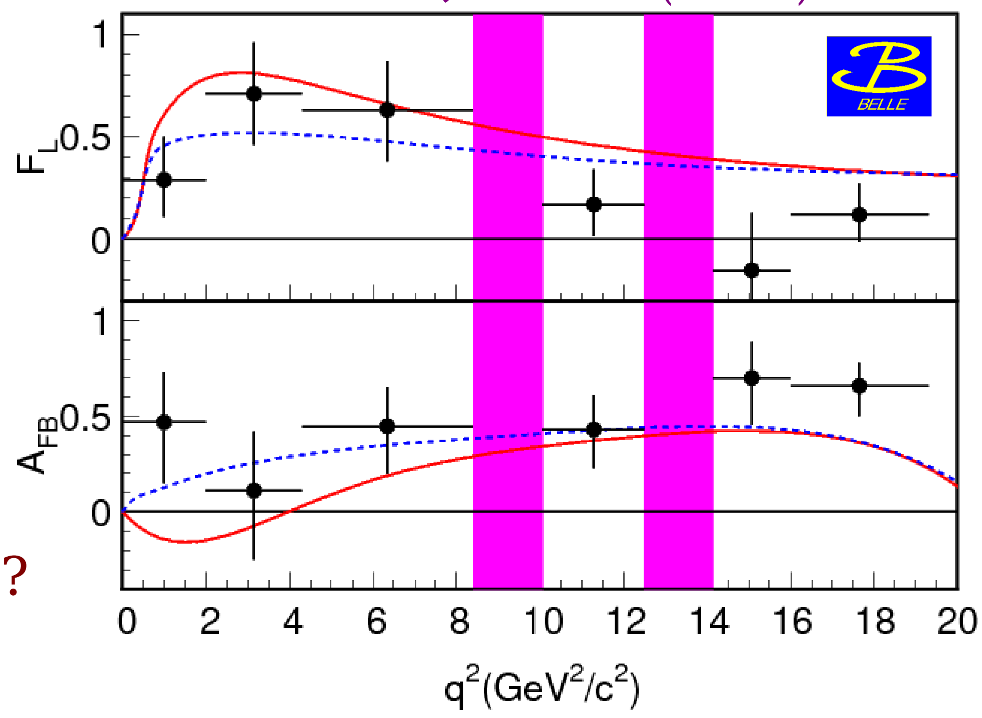
~ 250 $K^* l^+ l^-$ events

~ 160 $K l^+ l^-$ events

$$\boxed{A_{FB}(q^2) = -C_{10}^{eff}\, \xi(q^2) [\mathrm{Re}(C_9^{eff})\, F_1 + \frac{1}{q^2} C_7^{eff} F_2]}$$

$q^2 = m^2_{l^+l^-}$

PRL 103, 171801 (2009)



$C_7 = -C_7^{SM}$

SM

No crossing ?

opposite sign C_7 ?

Hints of anomalously large positive A_{FB} at low and high q^2

similar situation in CDF/BaBar's case

PRD 79, 031102 (2009)

$b \to s\gamma$, $s l^+ l^-$ and Wilson coefficients

NP effects can be parameterized as deviations from SM in Wilson coefficients C_7, C_9, C_{10}: $C_i = C_i^{SM} + C_i^{NP}$

$b \to s\gamma$ (sensitive to $|C_7|$ only)

$$B(b \to s\gamma) = \frac{G_F^2 \alpha_{em} m_b^5 |V_{ts}^* V_{tb}|^2}{32\pi^4} |\mathbf{C_7^{eff}}|^2 + \text{corr.}$$

$b \to s l^+ l^-$ (sensitive to C_7 sign, C_9, C_{10})

$$\frac{d\Gamma(b \to s l^+ l^-)}{d q^2} = \left(\frac{\alpha_{em}}{4\pi}\right)^2 \frac{G_F^2 m_b^5 |V_{ts}^* V_{tb}|^2}{48\pi^3} (1 - q^2)^2$$
$$\times [(1+2q^2)(|C_9^{eff}|^2 + |C_{10}^{eff}|^2) + 4(1 + \frac{2}{q^2})|\mathbf{C_7^{eff}}|^2 + 12\,\mathrm{Re}(\mathbf{C_7^{eff}} C_9^{eff})] + \text{corr.}$$

Inclusive differential branching fraction is sensitive to Wilson coefficients
(no form factor uncertainties of $B \to K^* l^+ l^-$)

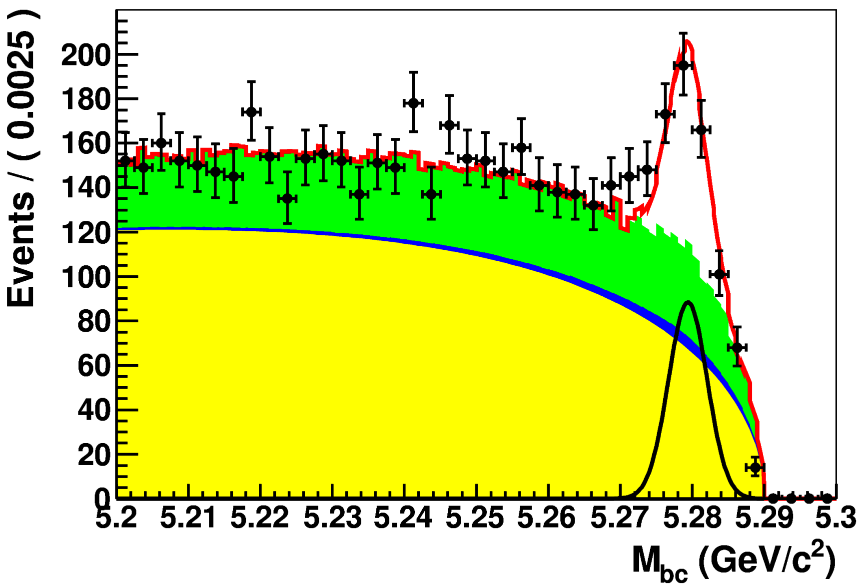
Opposite-sign C_7 makes the branching fraction larger
(in SM, $C_7 < 0$ and $C_9 > 0$)

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

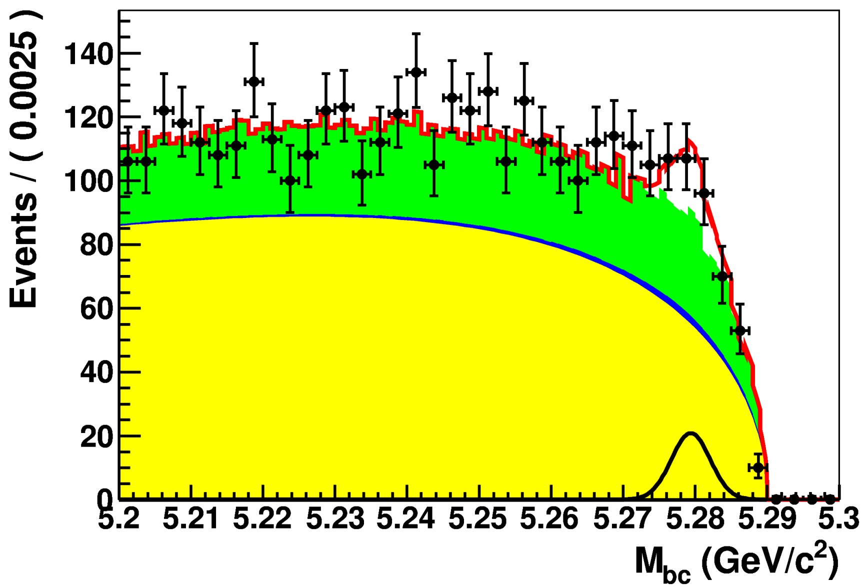
Full inclusive measurement is not feasible so far,
sum-of-exclusive technique has been used by Belle/BaBar

X_s reconstructed by: 1 ($K^\pm$ or K_S) + 4π's ($N\pi^0 \le 1$) (36 modes)

$\Rightarrow$ Belle (657 M$B\bar{B}$), preliminary (previous 152 M$B\bar{B}$)



10σ signal for entire M(X_s)



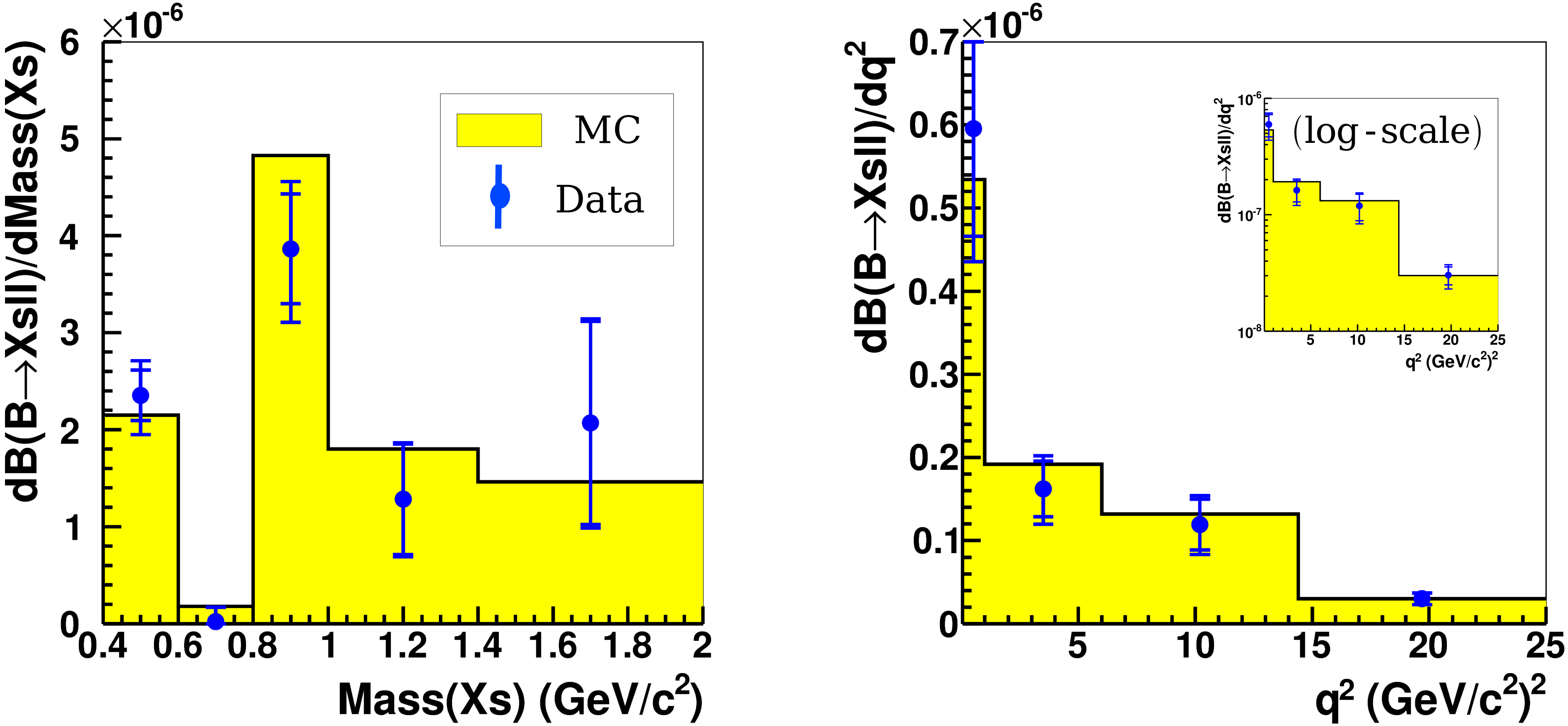
3σ signal for M(X_s)>1.0 GeV

Combinatorial BG (semi-leptonic B decays, continuum)

Self Cross-Feed

Peaking BG $B \to X_s \pi^+ \pi^-$ (double mis-id), leakage from J/ψ and ψ' veto,
charmonium higher resonances...

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



$$\mathcal{B}(B \to X_s l^+ l^-) = (3.33 \pm 0.80^{+0.19}_{-0.24}) \times 10^{-6}$$

[$q^2 > 0.2$ GeV^2/c^4 , extrapolated for J/ψ , ψ', and M(X_s)>2.0 GeV]

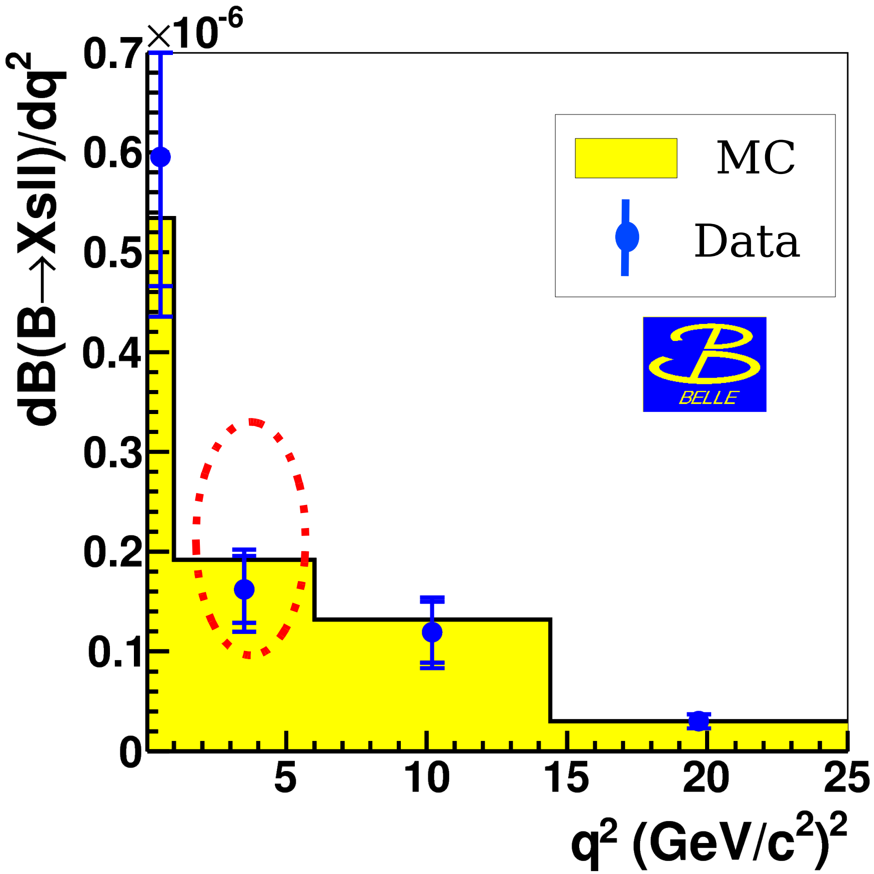
HFAG average: $\mathcal{B} = (3.66^{+0.76}_{-0.77}) \times 10^{-6}$

SM (Ali et al): $\mathcal{B}_{SM} = (4.2 \pm 0.7) \times 10^{-6}$

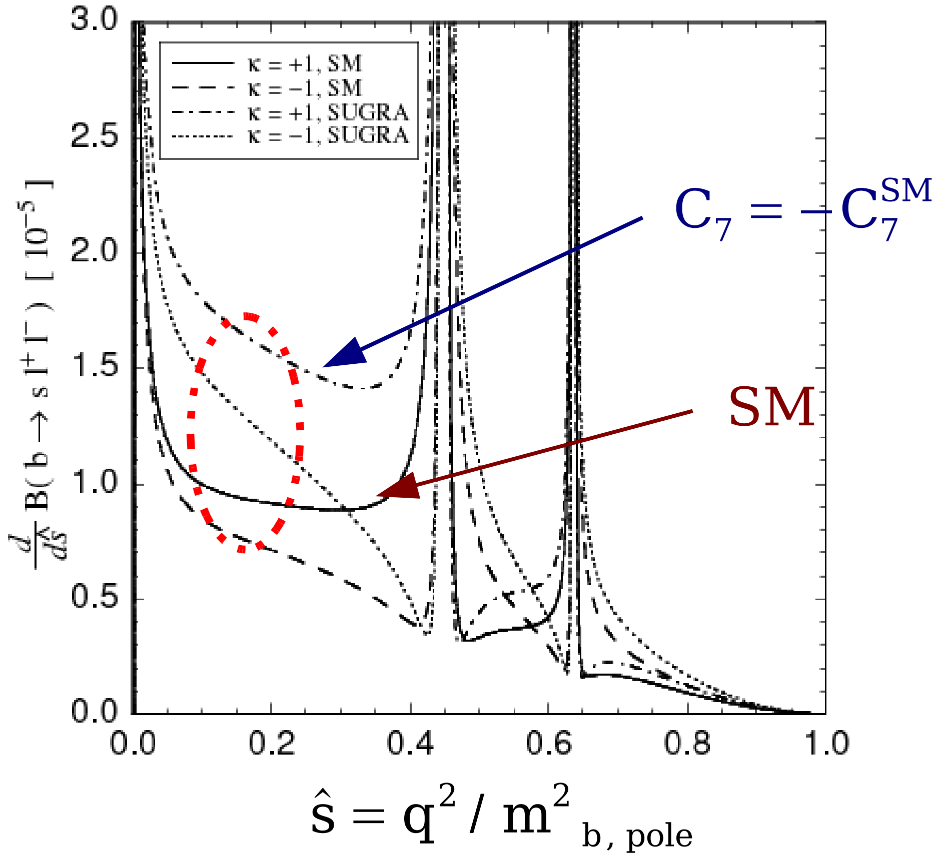
SM (Gambino et al): $\mathcal{B}_{SM} = (4.4 \pm 0.7) \times 10^{-6}$

PRL 94, 061803 (2005)

q^2 spectrum in $B \to X_s l^+ l^-$



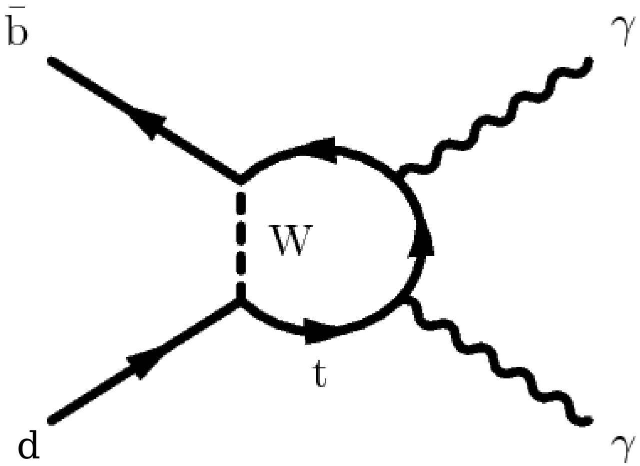
T.Goto et al
PRD 55, 4273 (1997)



$\Rightarrow$ No branching fraction enhancement in this region
strongly disfavor the case with the flipped sign of C_7
(other less extreme NP possibilities are still allowed)

More rare B decays to come...

an example...



$B_{SM} \sim 3\times10^{-8}$

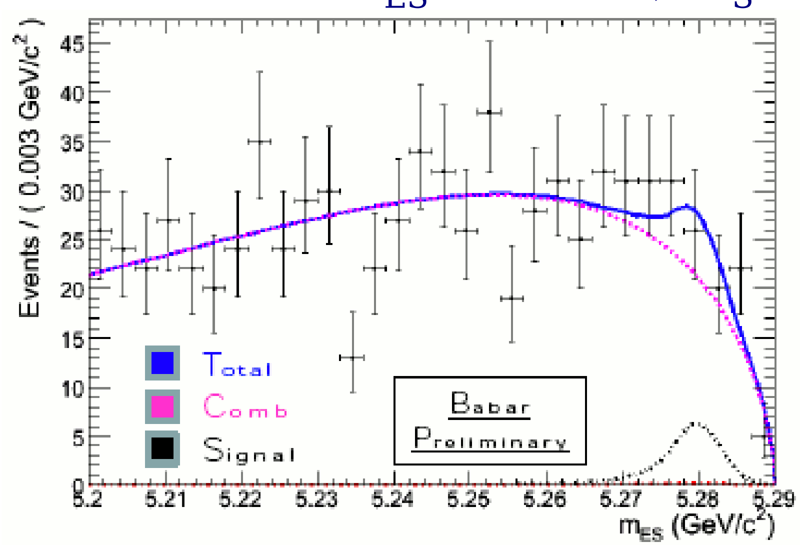
Bosch and Buchalla

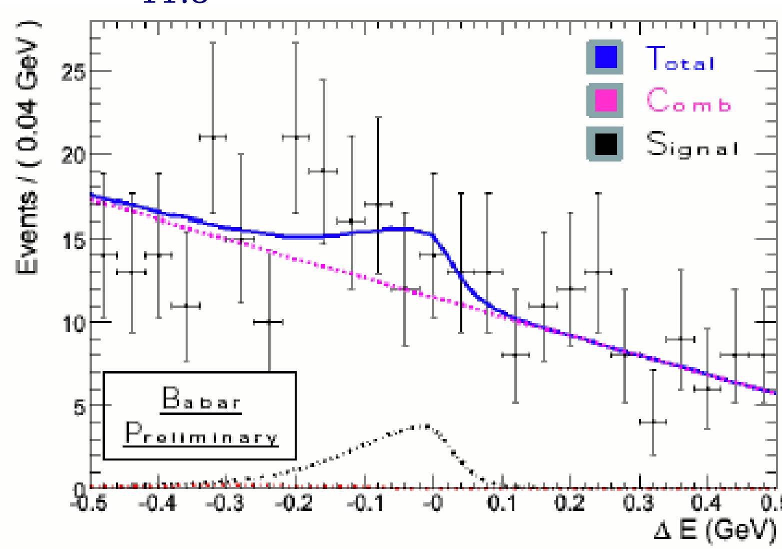
JHEP 0208:054 (2002)

$(B_{SM}(B_s \to \gamma\gamma) \sim 1\times10^{-6})$

after continuum background rejection and π^0 , η vetoes

2d fit to m_{ES} and ΔE, $N_S = 21.3^{+12.8}_{-11.8} \pm 1.4$

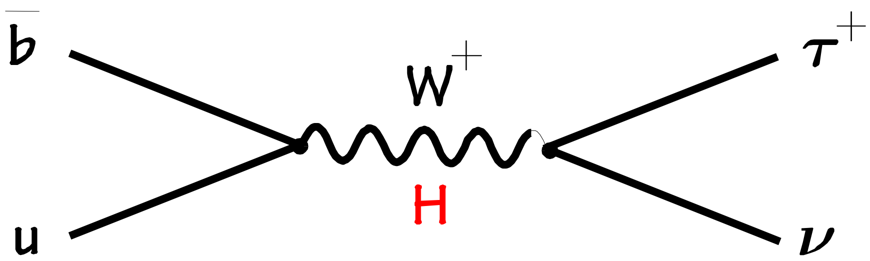


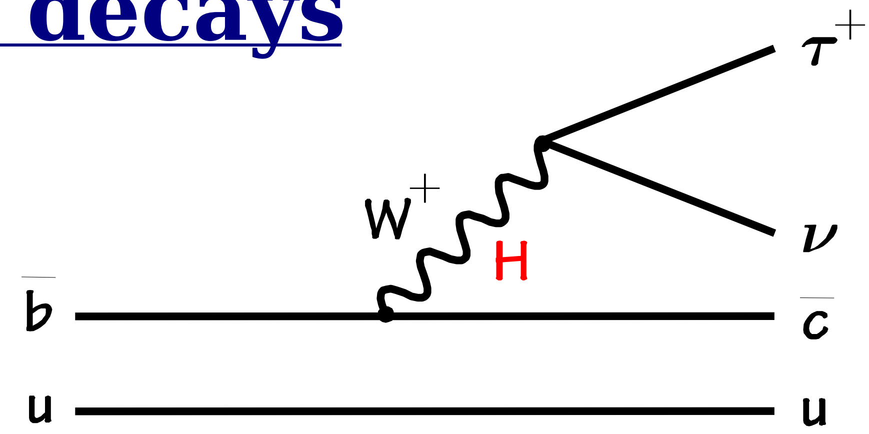


$B(B^0 \to \gamma\gamma) < 3.2 \times 10^{-7}$ @ 90% C.L.

$B(B^0 \to \gamma\gamma) < 6.1 \times 10^{-7}$ @ 90% C.L. (using 104 fb^{-1}) [PRD73, 051107 (2006)]

Tauonic B decays





$B \to \tau \nu$

$$\mathcal{B}_{SM}(B^+ \to \tau^+ \nu) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right) f_B^2 |V_{ub}|^2 \tau_B$$

$$\text{2HDM (type II)}: \mathcal{B}(B^+ \to \tau^+ \nu) = \mathcal{B}_{SM} \times \left(1 - \frac{m_B^2}{m_{H^+}^2}\tan^2\beta\right)^2$$

uncertainties from f_B and $|V_{ub}|$ can be reduced to B_B
and other CKM uncertainties by combining with precise Δm_d

$B \to D^{(*)} \tau \nu$

$$\text{2HDM (type II)}: \mathcal{B}(B \to D \tau^+ \nu) = G_F^2 \tau_B |V_{cb}|^2 f\left(F_V, F_S, \frac{m_B^2}{m_{H^+}^2}\tan^2\beta\right)$$

uncertainties from form factors F_V and F_S can be studied
with $B \to D l \nu$ (more form factors in $B \to D^* \tau \nu$)

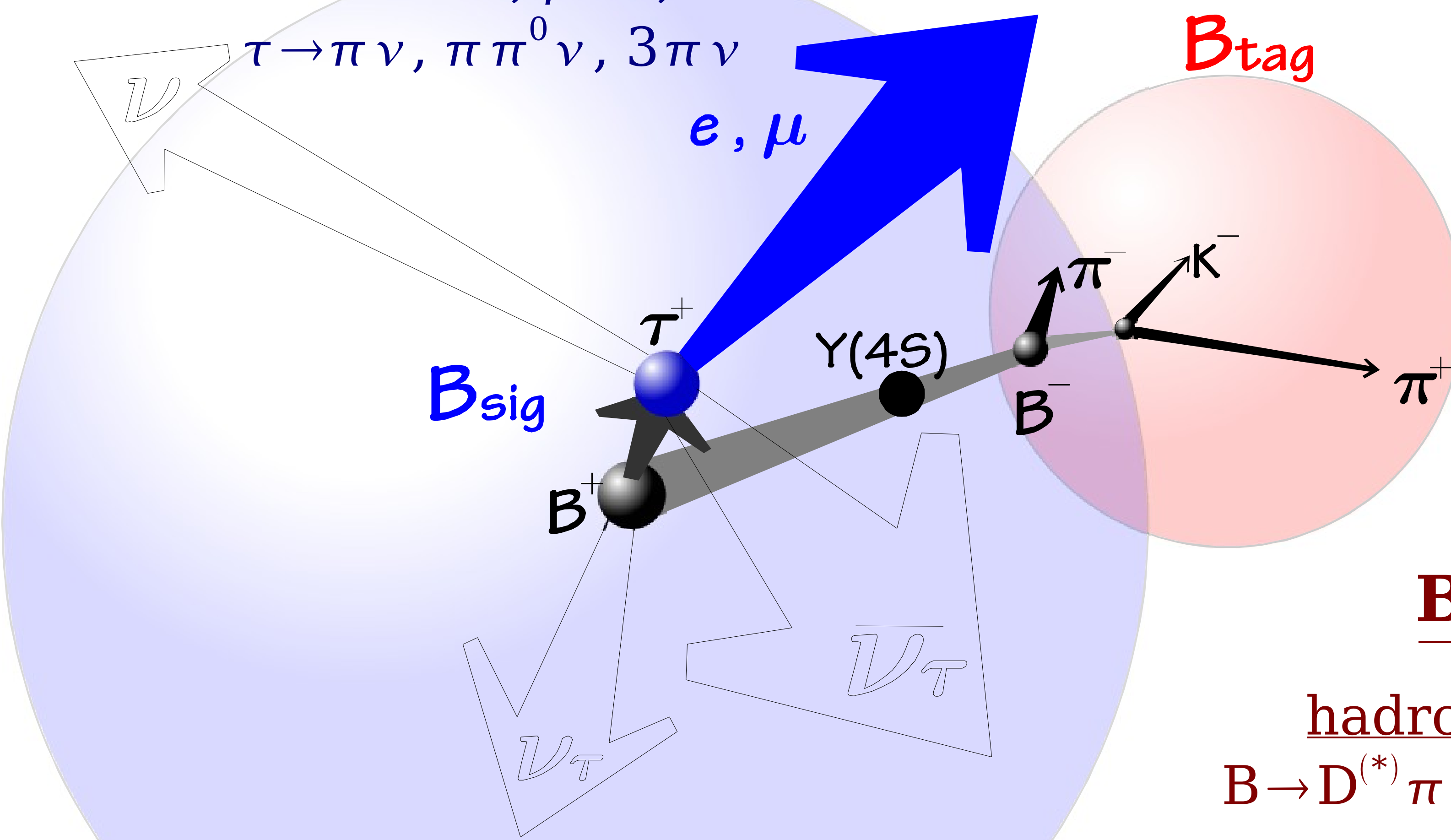
Event reconstruction in $B \to \tau \nu$

$B_{sig} \to \tau \nu$

(70 % of all τ decays)

$\tau \to e \nu \nu, \mu \nu \nu,$

$\tau \to \pi \nu, \pi \pi^0 \nu, 3\pi \nu$



Require no particle
and no energy left
after removing B_{tag}
and visible particles of B_{sig}

B_{tag}

hadronic tag

$B \to D^{(*)} \pi, D^{(*)} \text{rho}....$

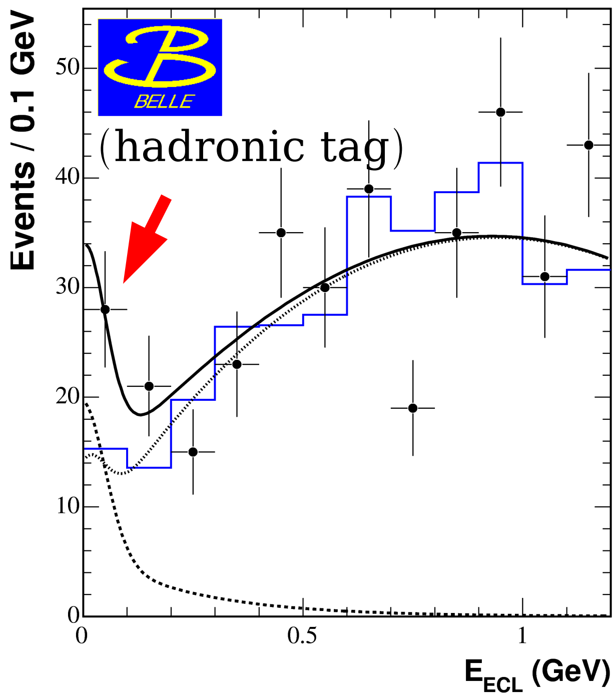
$\epsilon \sim 0.2\%$

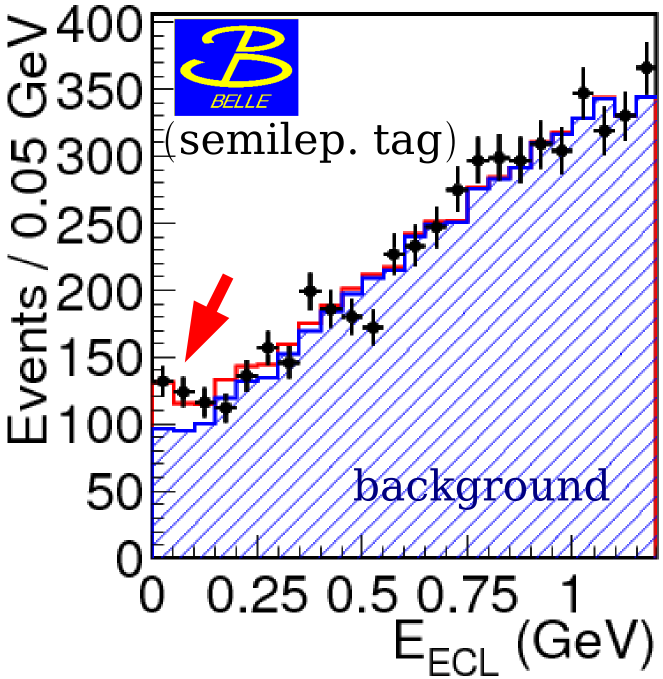
semileptonic tag

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

$B^+ \rightarrow \tau^+ \nu$ results

Extra calorimeter energy: $E_{ECL/extra}$ (GeV)





Belle	$N_{B\bar{B}}$	$\boldsymbol{B}\,(10^{-4})$	$\Sigma\,(\sigma)$	
Hadronic tag	(449 M)	$(1.79^{+0.56}_{-0.49}{}^{+0.46}_{-0.51})$	3.5	PRL97, 251802 (2006)
⇒ Semilep. tag	(657 M)	$(1.54^{+0.38}_{-0.37}{}^{+0.29}_{-0.31})$	3.6	PRD82, 071101(R)2010
BaBar				
Hadronic tag	(468 M)	$(1.80^{+0.57}_{-0.54} \pm 0.26)$	3.6	preliminary
Semilep. tag	(459 M)	$(1.7 \pm 0.8 \pm 0.2)$	2.3	PRD81, 051101 (2010)

$B^+ \to \tau^+ \nu$ results

World average: $\mathcal{B}(B^+ \to \tau^+ \nu) = (1.68 \pm 0.31) \times 10^{-4}$

2HDM (type II):

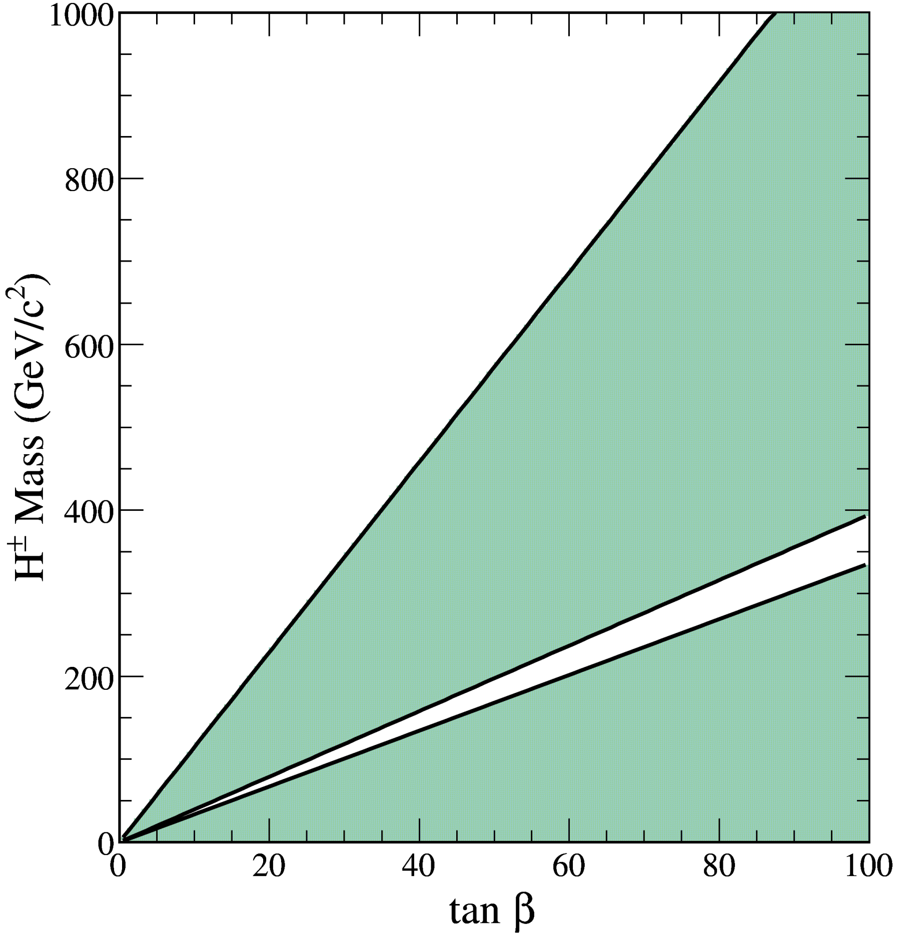
$$\mathcal{B}(B^+ \to \tau^+ \nu) = \mathcal{B}_{SM} \times \left(1 - \frac{m_B^2}{m_{H^+}^2} \tan^2 \beta\right)^2$$

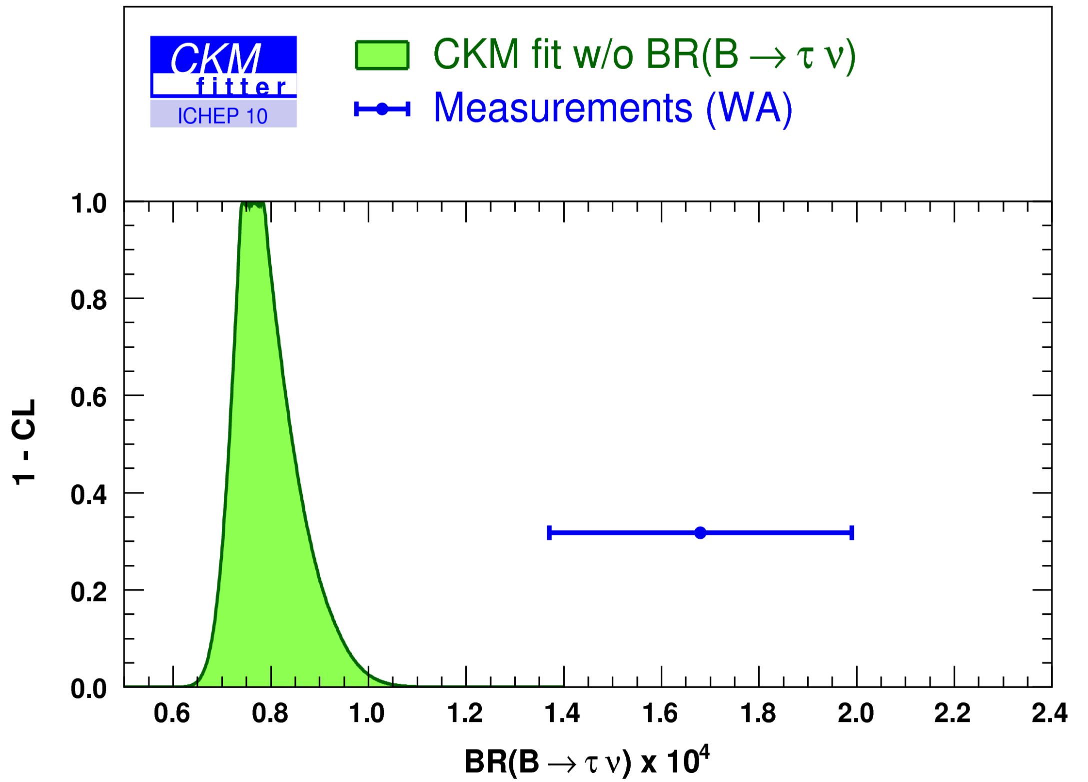
$$\mathcal{B}_{SM}(B^+ \to \tau^+ \nu) = (1.20 \pm 0.25) \times 10^{-4}$$

using f_B (HPQCD), $|V_{ub}|$ (HFAG)

$$\text{CKMfitter}: \mathcal{B}_{SM}(B^+ \to \tau^+ \nu) = (0.763^{+0.114}_{-0.061}) \times 10^{-4}$$

2.8σ difference



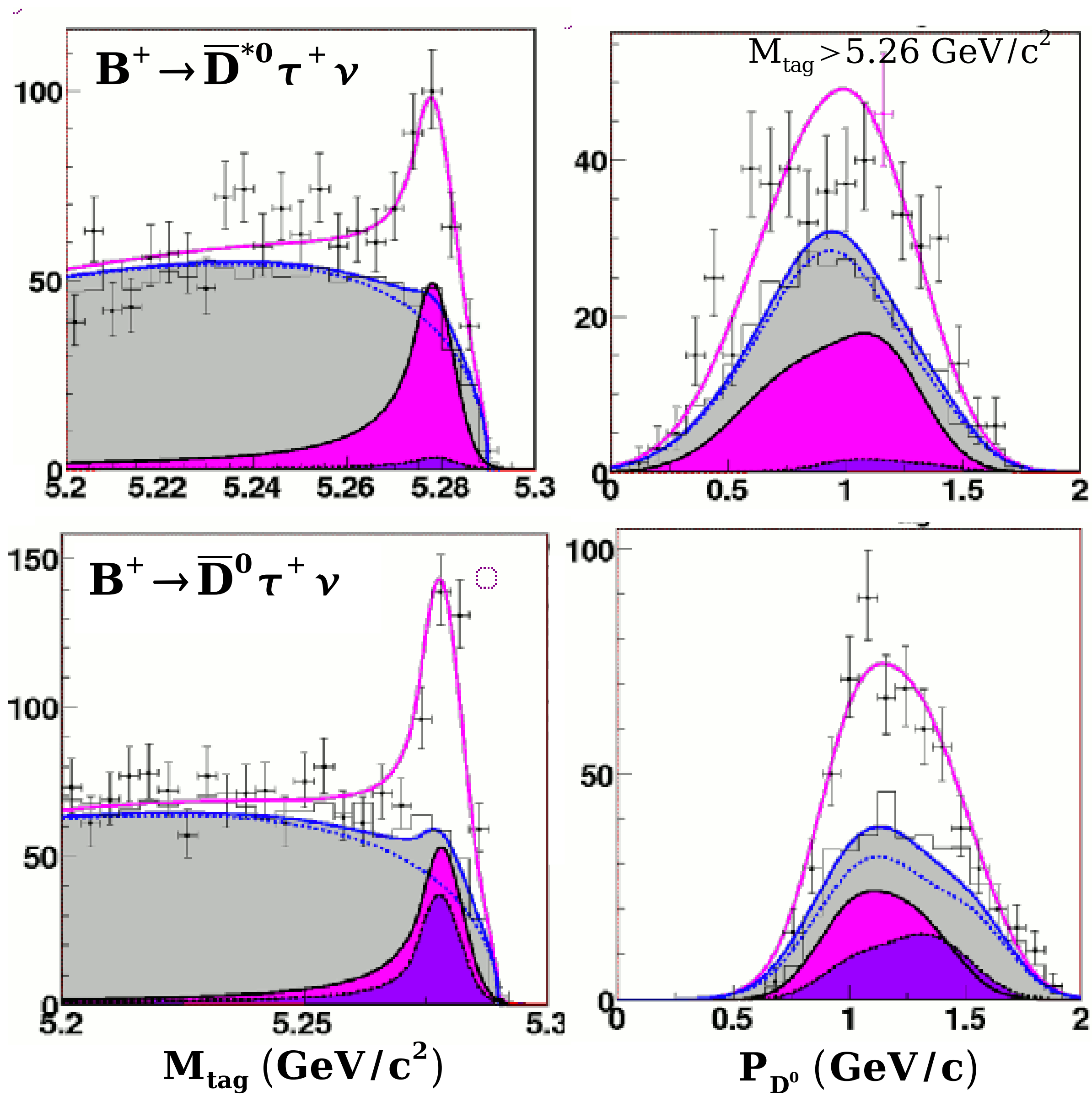


→ update this year, especially with hadronic tag

→ also $B^+ \to \mu^+ \nu$!!! $\mathcal{B}^{exp} \sim 6 \times 10^{-7}$, best U.L. (BaBar) $< 10^{-6}$ @ 90% C.L.

$B^+ \to D^{(*)} \tau^+ \nu$

arXiv:1005.2302, PRL



- 657M $B\overline{B}$
- same method than for $B^0 \to D^{*-} \tau^+ \nu$

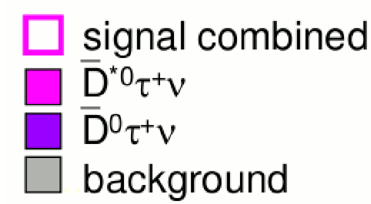
B_{sig}:

$D^0 \to K\pi,\ K\pi\pi^0$

$\tau^+ \to e^+ \nu_e \overline{\nu}_\tau,\ \mu^+ \nu_\mu \overline{\nu}_\tau,\ \pi^+ \overline{\nu}_\tau,\ \rho^+ \overline{\nu}_\tau$

13 different decay chains

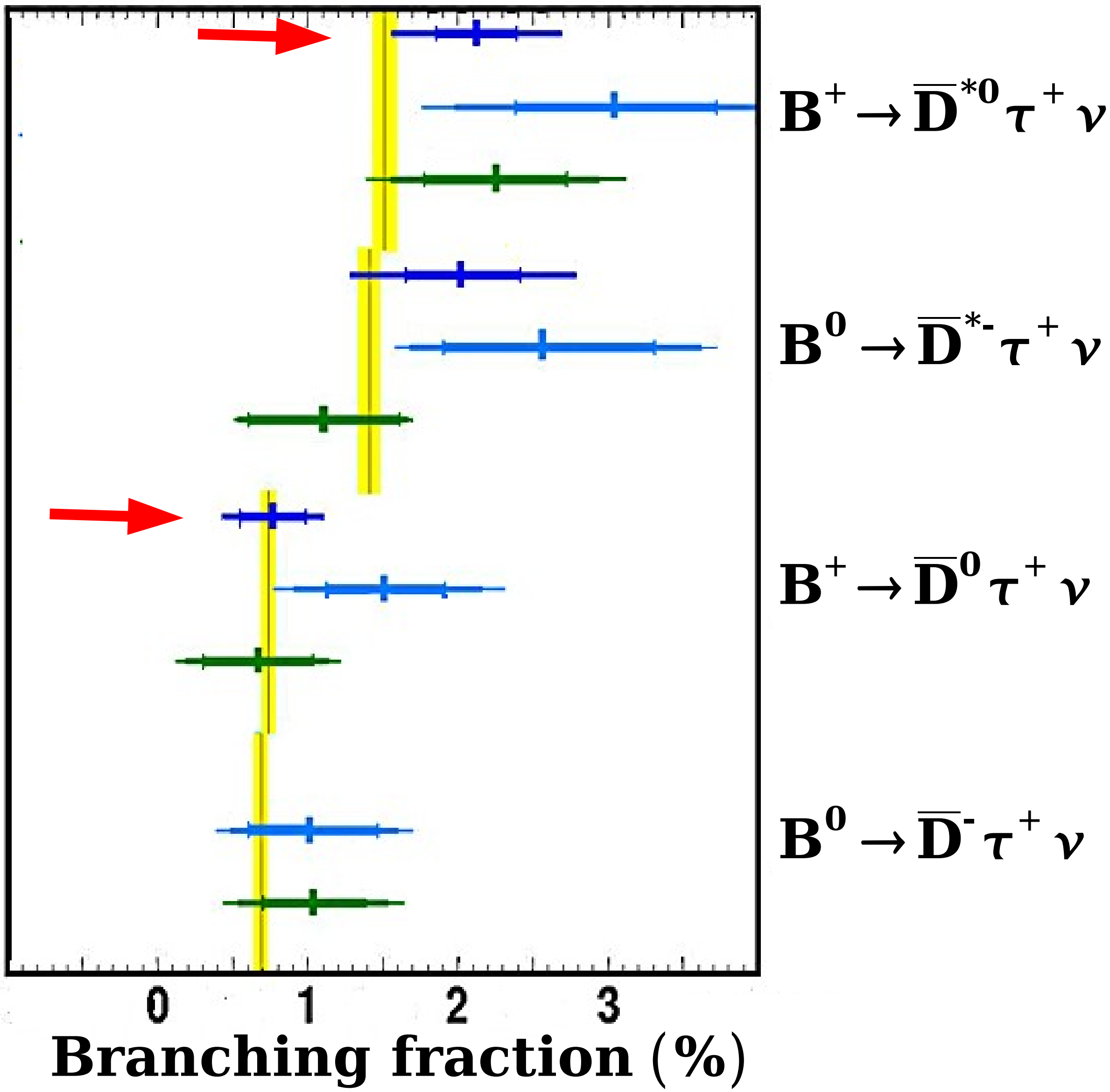
B_{tag}: all remaining particles

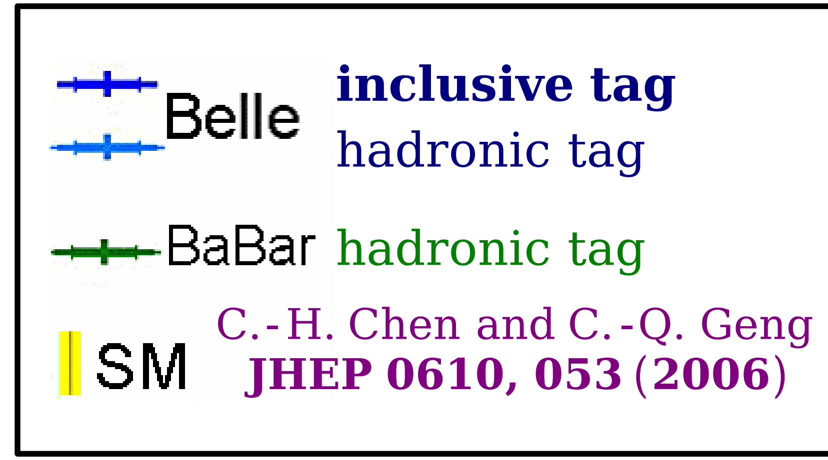


First $B^+ \to \overline{D}^0 \tau \nu$ evidence !

	N_S	$B(\%)$	$\Sigma(\sigma)$
$B^+ \to \overline{D}^{*0} \tau^+ \nu$	446^{+58}_{-56} (226)	$2.12^{+0.28}_{-0.27} \pm 0.29$	8.1
$B^+ \to \overline{D}^{0} \tau^+ \nu$	146^{+42}_{-41} (15)	$0.77 \pm 0.22 \pm 0.12$	3.5

$B^+ \to D^{(*)} \tau^+ \nu$ summary

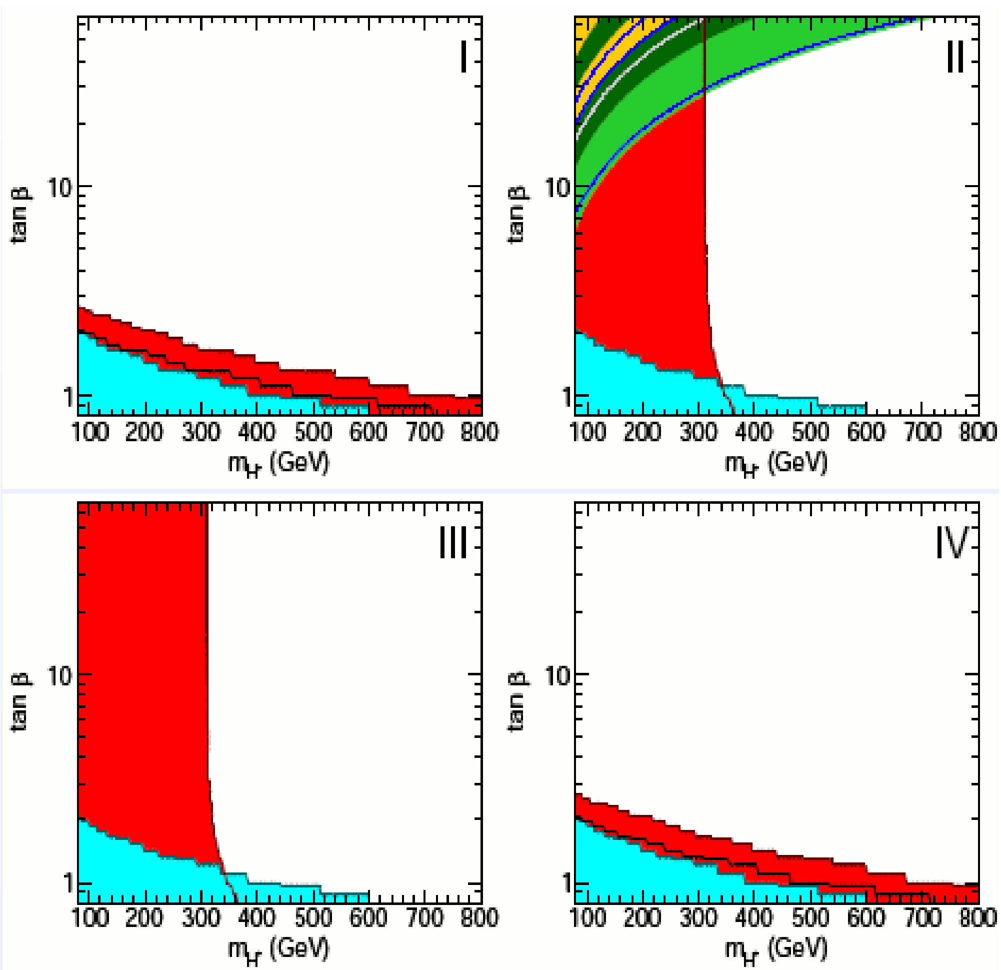




Belle inclusive tag
PRL99, 191807 (2007)
arXiv:1005.2302
Belle hadronic tag
arXiv:0910.4301
BaBar hadronic tag
PRL100, 021801 (2008)

Combined charged Higgs bound from B-factories

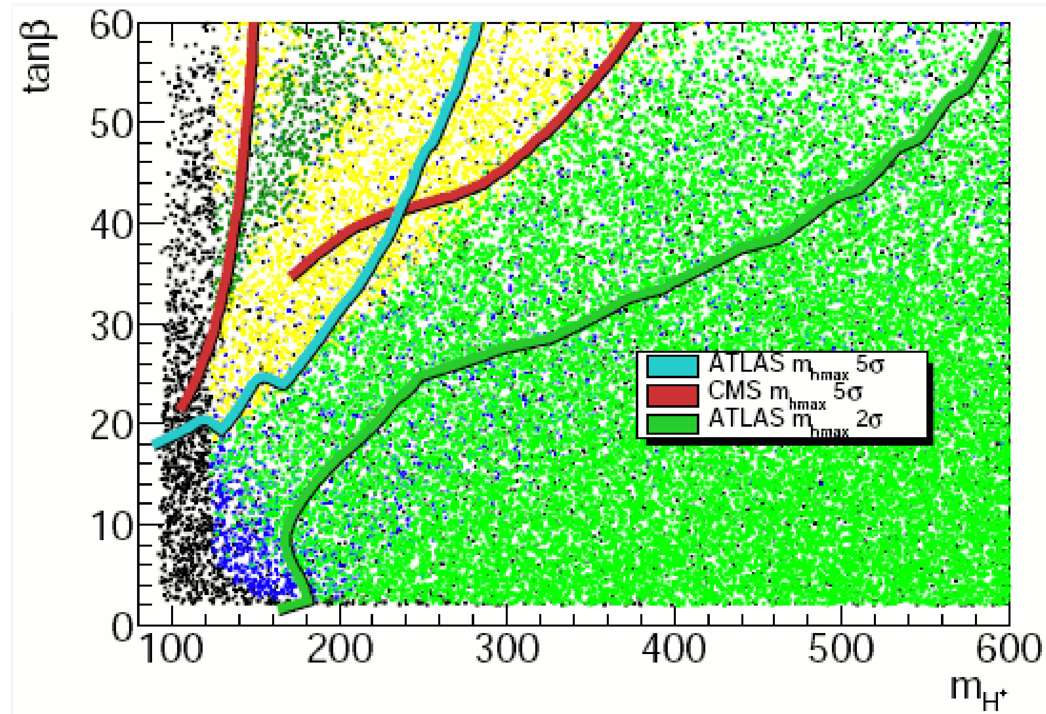
2HDM (Type I - IV)



$\mathcal{B}(B \to X_s \gamma)$ (red), $\mathcal{B}(B \to \tau \nu)$ (blue)
$\mathcal{B}(B \to D \tau \nu)$ (yellow)

F.Mahmoudi and O.Stal
PRD81, 035016 (2010)

NUHM scenario
(non-universal Higgs mass models)

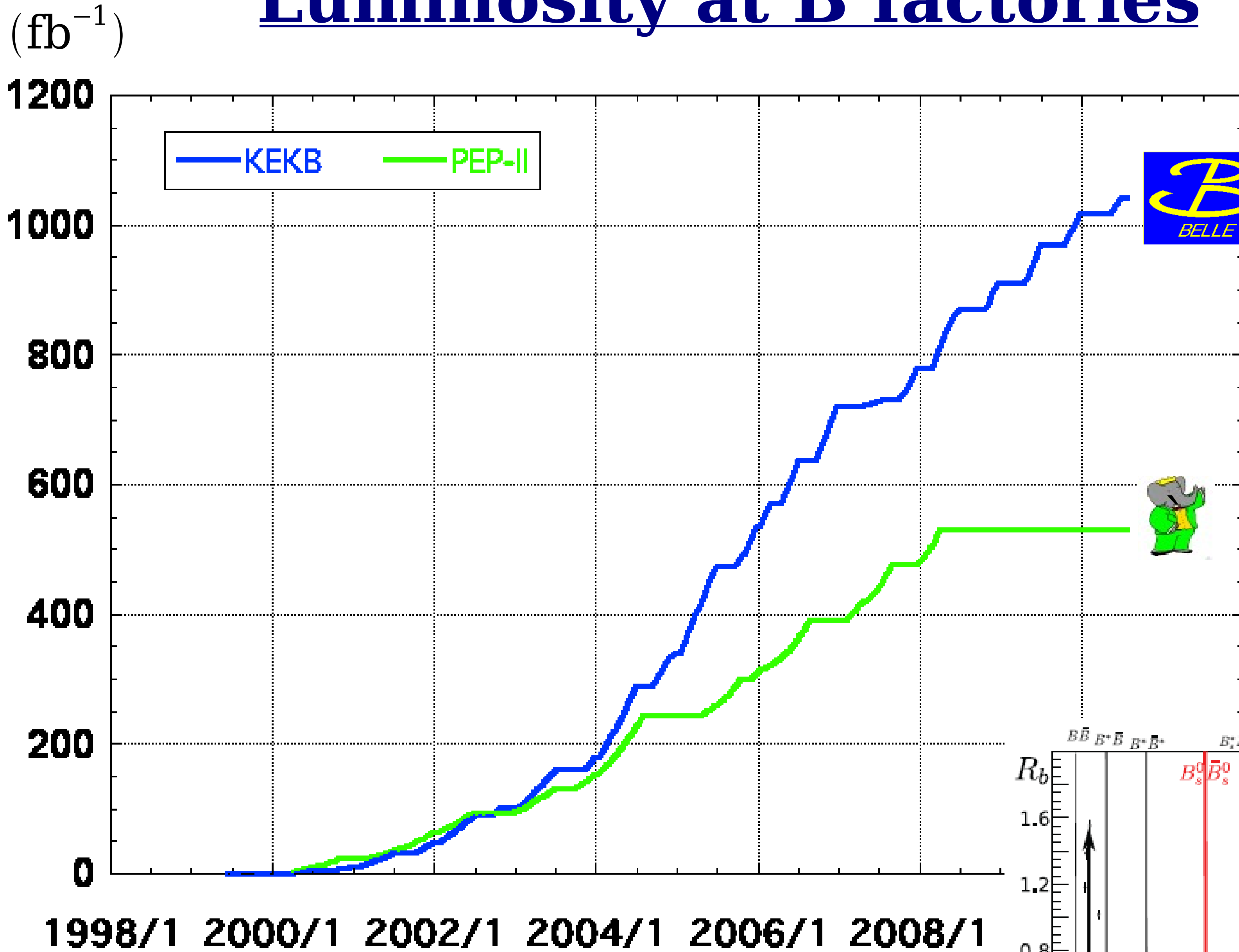


$\mathcal{B}(B \to X_s \gamma)$ (blue), $\mathcal{B}(B \to \tau \nu)$ (yellow)
$\mathcal{B}(B \to D \tau \nu)$ (dark green), allowed region (green)

D.Eriksson et al
JHEP, 0811 (2008)

see also: U.Haisch et al (arXiv:0805.2141), O.Deschamps et al (arXiv:0907.5135)...

Luminosity at B factories



> 1 ab^{-1}

On resonance:

Υ(5S): 121 fb^{-1}

Υ(4S): 711 fb^{-1}

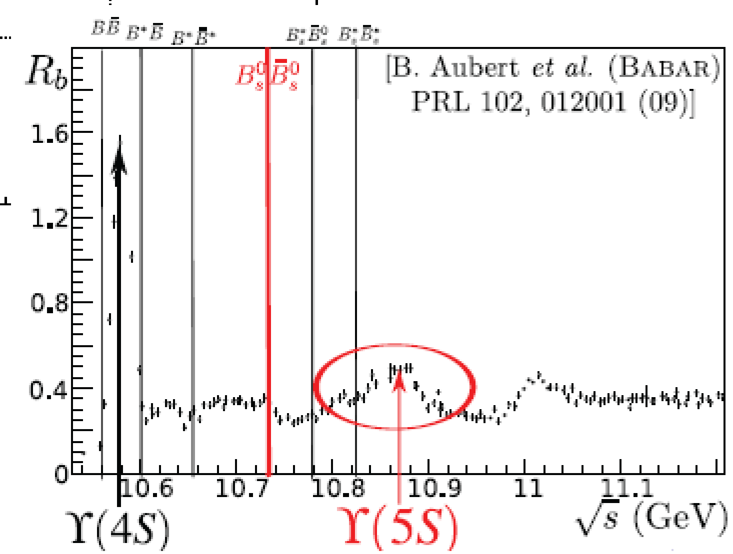
Υ(3S): 3 fb^{-1}

Υ(2S): 24 fb^{-1}

Υ(1S): 6 fb^{-1}

Off reson./scan:

~ 100 fb^{-1}



Data taken at Υ(5S) ($\sqrt{s}$ = 10867 ± 1 MeV)
results shown today with 23.6 fb^{-1}
(1/5 of the final 5S sample)

B_s production at $\Upsilon(5S)$

Hadronic $\Upsilon(5S)$ events $\rightarrow$ udsc continuum

Hadronic $\Upsilon(5S)$ events $\rightarrow$ $b\bar{b}$ events

$\sigma(b\bar{b}) = (302 \pm 14)$ pb

Cleo (PRD 75, 012002)

Belle (PRL 98, 052001)

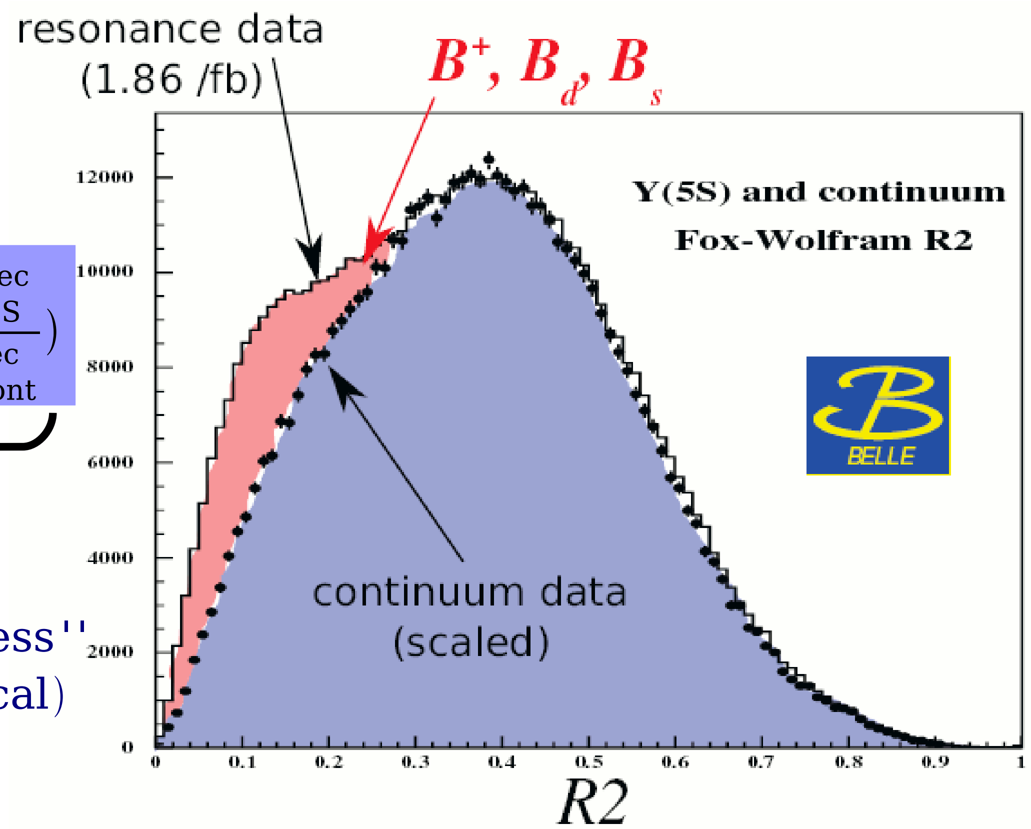
$b\bar{b}$ cross section : subtraction of taken below open-beauty threshold

$$\sigma(b\bar{b}) = \frac{N_{5S}^{b\bar{b}}}{L_{5S}}$$

$$= \frac{1}{L_{5S}} \frac{1}{\epsilon_{5S}^{b\bar{b}}} \Big(N_{5S}^{had} - \underbrace{N_{cont}^{had} \frac{L_{5S}}{L_{cont}} \frac{E_{cont}^2}{E_{5S}^2} \frac{\epsilon_{5S}^{rec}}{\epsilon_{cont}^{rec}}}_{\text{scaling factor}} \Big)$$

On resonance data

Continuum data below open-beauty threshold



R_2: 2nd Fox-Wolfram moment ~ event ''jettiness''

$\rightarrow$ smaller values for $B\bar{B}$ events (more spherical)

(measurement done with 1.86 fb^{-1})

B_s production at $\Upsilon(5S)$

udsc continuum

non $B\bar{B}$

$f_{\text{non } B} \geq (2.8 \pm 0.3)\%$
Belle (PRL 100, 112001)

Hadronic $\Upsilon(5S)$ events

B^0, B^+ events

$f(B^{+/0}) = (73.7 \pm 6.0)\%$
Belle (PRD 81, 112003)

$b\bar{b}$ events

$\sigma(b\bar{b}) = (302 \pm 14)$ pb
Cleo (PRD 75, 012002)
Belle (PRL 98, 052001)

$f_s = (20.2 \pm 3.6)\%$
HFAG (arXiv:1010.1589)

B_s^0 events

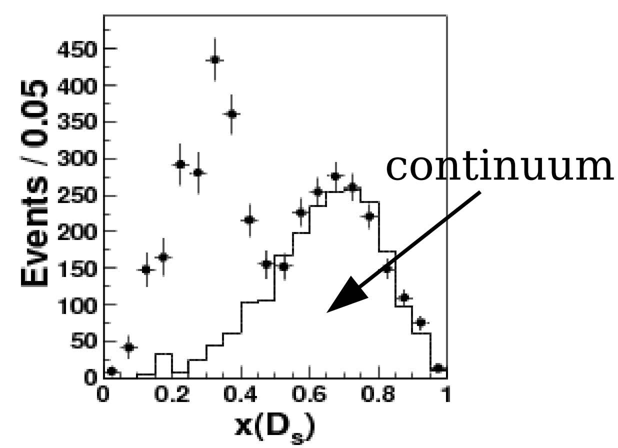
f_s = fraction of B_s. Inclusive measurements:

$$\underbrace{\frac{1}{2} B(\Upsilon(5S) \to D_s X)}_{\Upsilon(5S)\text{ data}} = f_s \times \underbrace{B(B_s \to D_s X)}_{\text{model-dependent estimate}} + (1 - f_s) \times \underbrace{B(B \to D_s X)}_{\Upsilon(4S)\text{ data}}$$

15% uncertainty, mainly due to model-dependent estimate

⇒ dominant systematics for our branching fractions

measurement with 1.86 fb^{-1}



In 23 fb^{-1} (today's dataset):
$N_{B_s^0} = 2\, L_{int} \,.\, \sigma(b\bar{b}) \,.\, f_s \approx 2.8 \times 10^6$

B_s production at $\Upsilon(5S)$

3 productions modes:

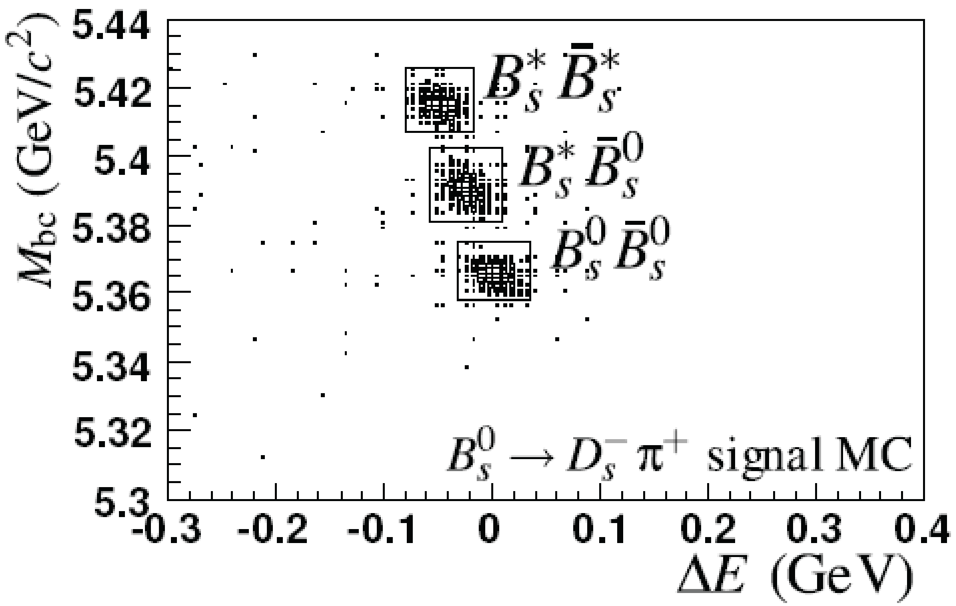
$$\Upsilon(5S) \to B_s^* \bar{B}_s^*,\ \Upsilon(5S) \to B_s^* \bar{B}_s^0,\ \Upsilon(5S) \to B_s^0 \bar{B}_s^0$$

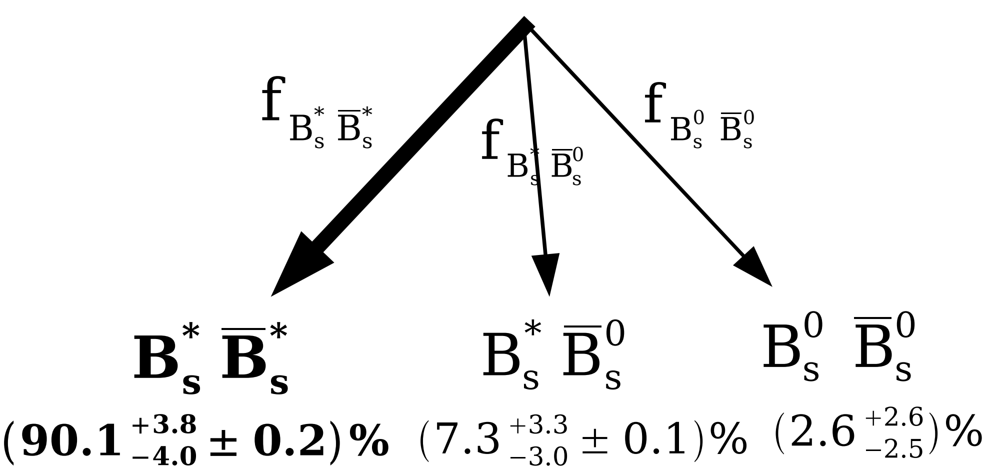
$B_s^* \to B_s^0 \gamma$ is not reconstructed (γ too soft)

Full reconstruction of the B_s^0 with observables: $(E_b^* = \sqrt{s}/2)$

- **Beam-constrained mass: $M_{bc} = \sqrt{E_b^{*2} - p_{B_s^0}^{*\,2}}$**
- **Energy difference: $\Delta E = E_{B_s^0}^* - E_b$**

$\Rightarrow$ B_s^0 candidates are in 3 signal regions

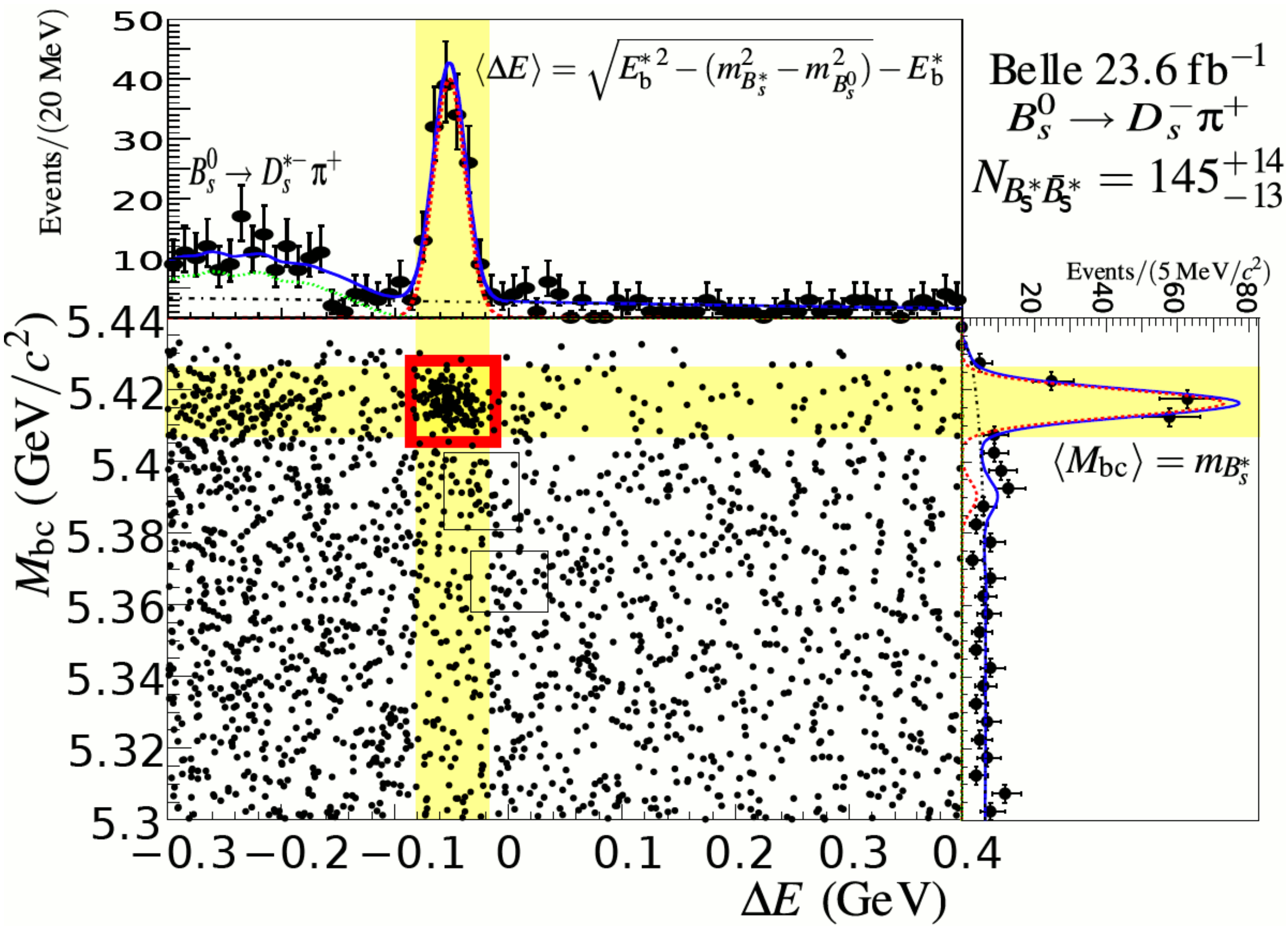




Belle (PRL 102, 021801)

Study of $B_s^0 \to D_s^- \pi^+$

Phys. Rev. Lett. **102,** 021801 (2009)



$$f_{B_s^* \bar{B}_s^*} = (90.1^{+3.8}_{-4.0} \pm 0.2)\%$$

$$m_{B_s^*} = (5416.4 \pm 0.4 \pm 0.5)\ \mathrm{MeV}/c^2$$

$$m_{B_s^0} = (5364.4 \pm 1.3 \pm 0.7)\ \mathrm{MeV}/c^2$$

$$\boxed{\mathcal{B}(B_s^0 \to D_s^- \pi^+) = (3.67\,^{+0.35}_{-0.33}\,^{+0.43}_{-0.42} \pm 0.49\,(f_s)) \times 10^{-3}}$$

- 20% uncertainties, f_s is a crucial source of systematics
- large $f_{B_s^* B_s^*}$ confirmed (1st Belle value: $(93^{+7}_{-9} \pm 1)\%$ [PRD 76, 012002 (07)])
- $m_{B_s^*}$ is 2.6σ larger than CLEO [PRL 96, 152001 (06)]
- $m_{B_s^*}$ (m_{B_s}) is the 1st (2nd) most precise measurement so far

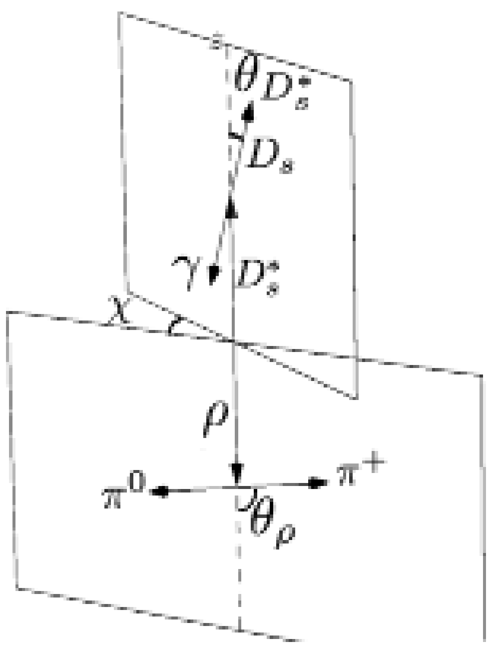
Study of $B_s^0 \to D_s^{*-} \rho^+$

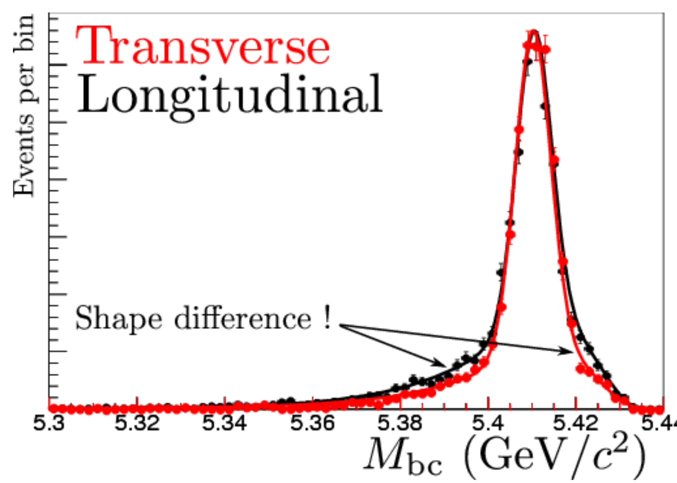
Phys. Rev. Lett. **104,** 231801 (2010)

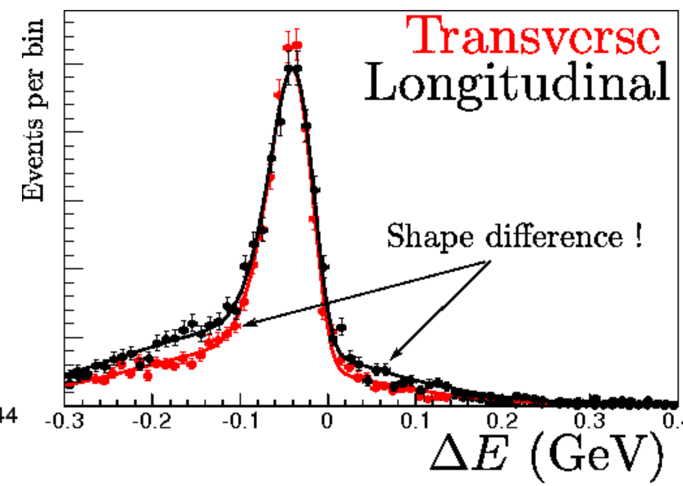
Scalar → Vector + Vector: Longitudinal and transverse polarizations are possible

$$\frac{d^2\Gamma}{d\cos\theta_{D_s^*}\, d\cos\theta_\rho} \propto 4 f_L \sin^2\theta_{D_s^*} \cos^2\theta_\rho + (1 - f_L)(1 + \cos^2\theta_{D_s^*}) \sin^2\theta_\rho$$

MC simulation

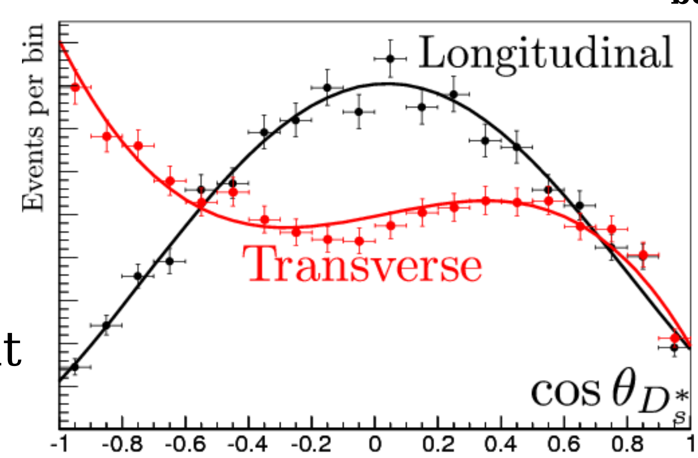


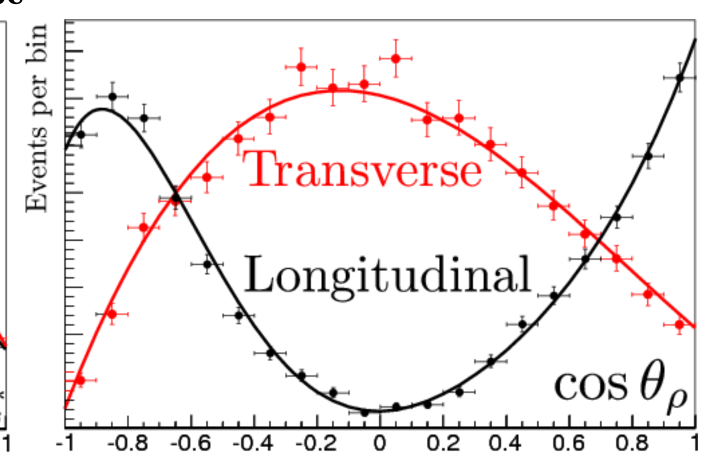




Longitudinal ($f_L = 1$) and tranverse ($f_L = 0$) events have different M_{bc}, ΔE distributions

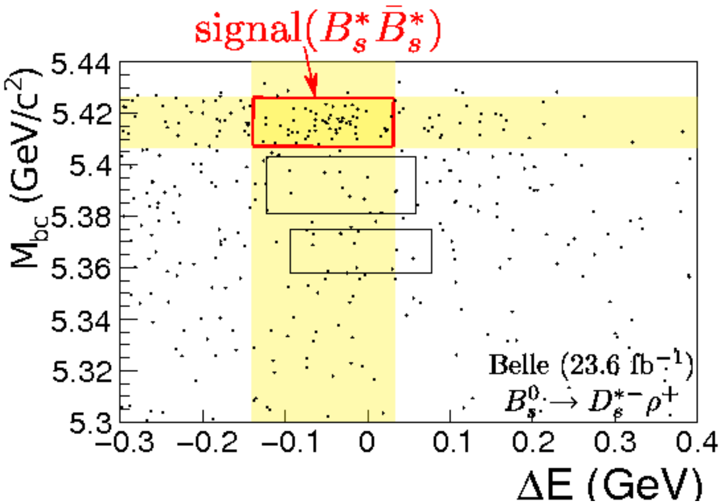
Simultaneous extraction of
$\mathcal{B}(B_s^0 \to D_s^{*-}\rho^+)$ and
$f_L(B_s^0 \to D_s^{*-}\rho^+)$ with
4D (M_{bc}, ΔE, $\cos\theta_{D_s^*}$, $\cos\theta_\rho$) fit

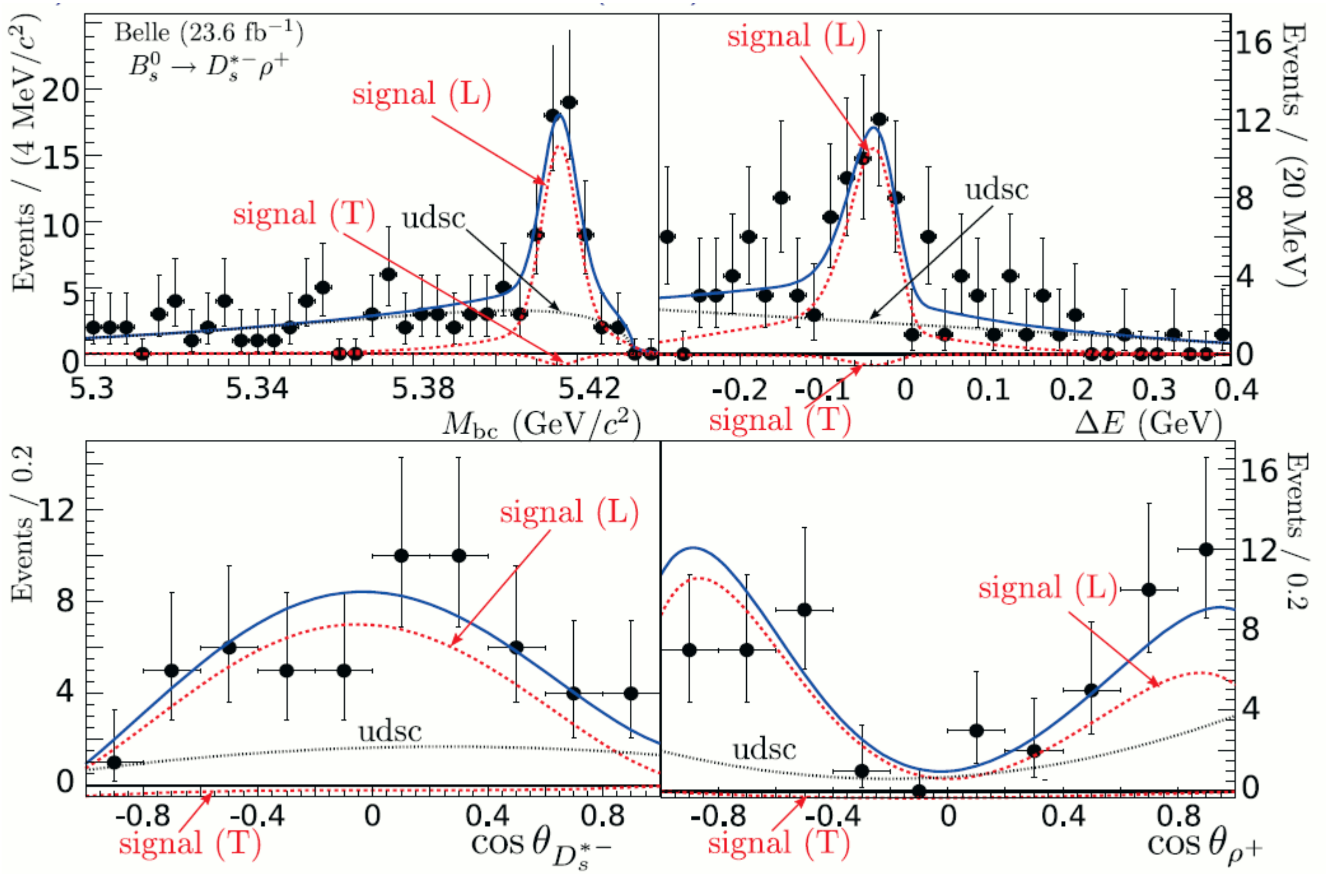




Observation of $B_s^0 \to D_s^{*-} \rho^+$

Phys. Rev. Lett. **104,** 231801 (2010)





- $N(B_s^* \bar{B}_s^*) = 77.8^{+14.5}_{-13.4} \pm 3.3$ (7.4σ significance)

$$\boldsymbol{\mathcal{B}(B_s^0 \to D_s^{*-}\rho^+) = (11.8^{+2.2}_{-2.0} \pm 1.7 \pm 1.8(f_s)) \times 10^{-3}}$$

$$\boldsymbol{f_L = 1.05^{+0.08}_{-0.10}{}^{+0.03}_{-0.04} \quad (\text{or } f_L \in [0.93, 1.00] \text{ at } 68\% \text{ C.L.})}$$

large longitudinal polarization as expected:

from theory: 83% [Li et al.. PRD 78, 014018]
comparable with $B^0 \to D^{*-}\rho^+$: 88.5 ± 2.0% [CLEO, PRD67, 112002]

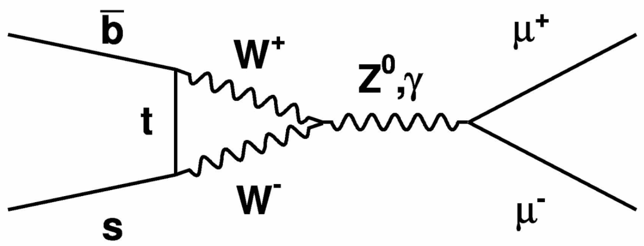
Motivation for BR measurements

- $B_s \to \mu^+ \mu^-$:

  sensitive probe to New Physics, very suppressed in SM:

$$\boldsymbol{B}(\mathbf{B_s} \to \boldsymbol{\mu^+ \mu^-}) = (\mathbf{3.35 \pm 0.32}) \times \mathbf{10^{-9}}$$

[M.Blanke et al, hep-ph/0604057]



- NP can lead to enhancement of the BR up to an order of magnitude

  (for example, constrained versions of the MSSM $\sim 20 \times 10^{-9}$)

$\Rightarrow$ **BUT could be "only" a factor 2 above SM value !!**

- Need normalization with BR of $B_{(s)}$ decays
  - for example, Tevatron experiments use $B^+ \to J/\psi K^+$
  - $\sigma_{\text{syst}} \sim 13\%$: dominant error from $\dfrac{f(B_s)}{f(B)}$

$\Rightarrow$ **not sufficient if $\boldsymbol{B}(\mathbf{B_s} \to \boldsymbol{\mu^+ \mu^-}) < \mathbf{10^{-8}}$**

- Need normalization mode meas with higher accuracy, preferably B_s mode

$\Rightarrow$ **measure $\mathbf{B_s}$ branching fraction in $\Upsilon(5S)$ decays !**

(for example $B_s \to J/\psi\,\phi$) so need to improve f_s

$B_s \to$ CP eigenstates decays and more...

- CP eigenstates:
  - $B_s \to KK$
  - $B_s \to J/\psi\,\phi$ (especially BR)
  - $B_s \to J/\psi\, f_0(980)$ (silver mode at LHCb to measure β_s)
  - $B_s \to J/\psi\,\eta$, $J/\psi\,\eta'$, $J/\psi\, K^0_S$ ...

⇒ the first step is to establish these modes !

⇒ decays with π^0 and/or γ are difficult for hadron-collider experiments

- $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ dominates $\Delta\Gamma_s$

$$\Delta\Gamma^{CP} = \Gamma(\text{CP-even}) - \Gamma(\text{CP-odd}) \approx \Gamma(B_s^0 \to D_s^{(*)+} D_s^{(*)-})$$

- CKM-favored and CP-even eigenstate (in heavy-quark limit)
- Dominates $\Delta\Gamma$ (this relation has few % theoretical uncertainty)

$$\frac{\Delta\Gamma_s^{CP}}{\Gamma_s} \approx \frac{2 \times \mathcal{B}(B_S^0 \to D_s^{(*)+} D_s^{(*)-})}{1 - \mathcal{B}(B_S^0 \to D_s^{(*)+} D_s^{(*)-})}$$

R.Aleksan et al., Phys. Lett. B 316, 567 (1993)

$B_s^0 \to K\,K$

Phys. Rev. D **82,** 072007 (2010)

- $B_s^0 \to K^+ K^-$ events and $B^0 \to \pi^+ \pi^-$ related by SU(3), probing NP by comparing CP asymmetries

Observation of $23.4^{+5.5}_{-6.3}$ $B_s^0 \to K^+ K^-$ events ($5.8\,\sigma$)

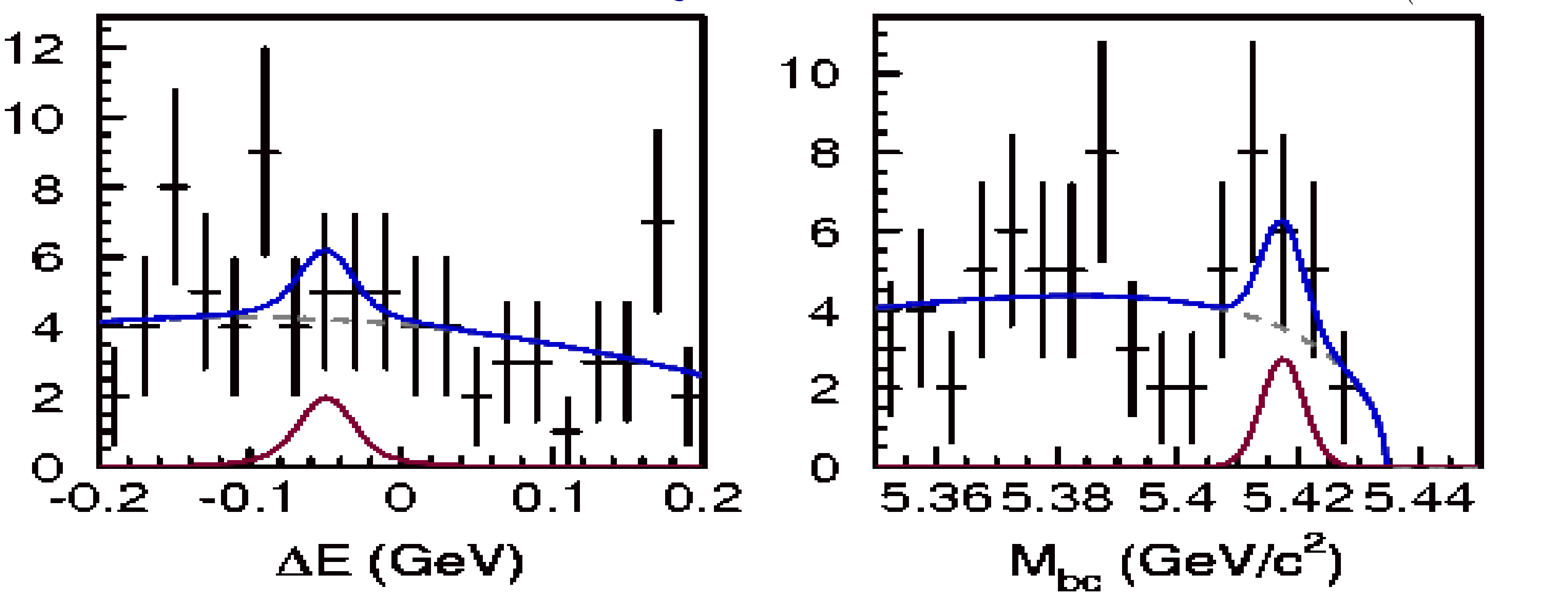
$$\boldsymbol{\mathcal{B}(B_s^0 \to K^+ K^-) = (3.8^{+1.0}_{-0.9} \pm 0.5 \pm 0.5\,(f_s)) \times 10^{-5}}$$

confirms CDF results (102 events): $(2.44 \pm 0.14 \pm 0.46) \times 10^{-5}$
[Nucl. Phys. B (Proc.Suppl) 170, 39 (07)]

- $B_s^0 \to K^0\,\overline{K}^0$ same BR but more challenging:

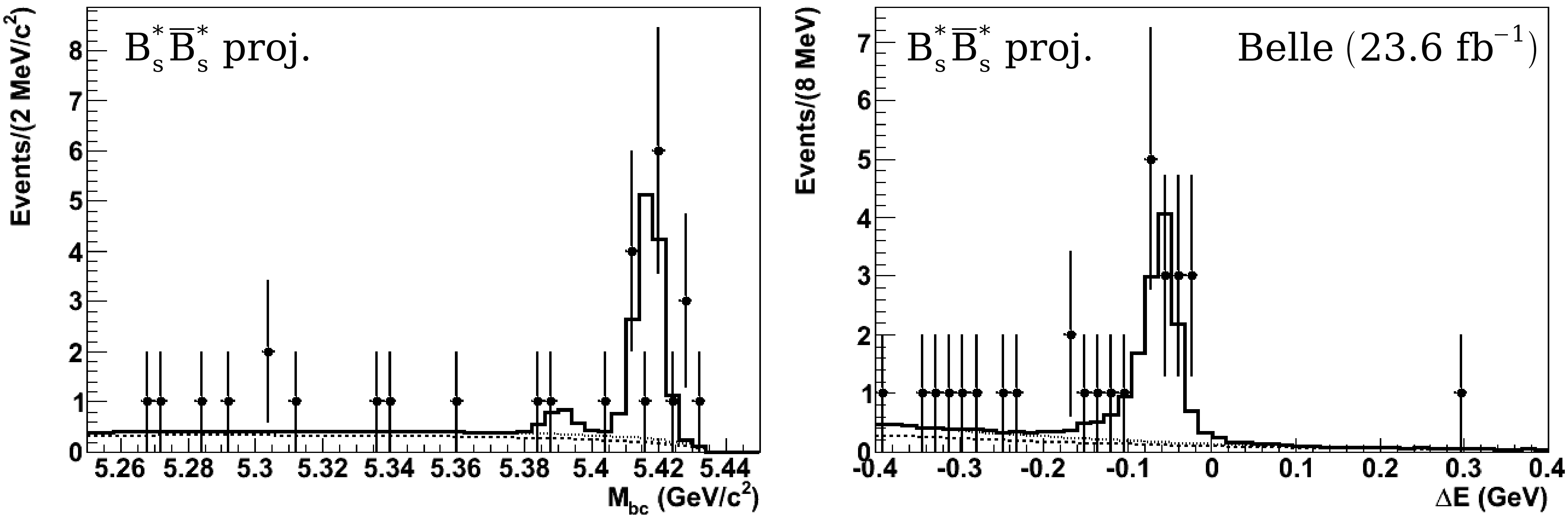
First limit on $\mathcal{B}(B_s^0 \to K^0\,\overline{K}^0) < 6.6 \times 10^{-5}$

Belle (23.6 fb^{-1})



Observation of $B_s^0 \to J/\psi\,\eta$

Belle-conf-0902, arXiv:0912.1434



- $\eta \to \gamma\gamma + \eta \to \pi^+\pi^-\pi^0$ channels
- First observation of 14.9 ± 4.1 events (7.3σ)

$$\boxed{\mathcal{B}(B_s^0 \to J/\psi\,\eta) = (3.32 \pm 0.87\,^{+0.32}_{-0.28} \pm 0.42\,(f_s))\times 10^{-4}}$$

...and also $B_s \to J/\psi\,\eta'$:

- 3 η' channels: $\eta' \to \eta(\to\gamma\gamma)\pi^+\pi^-$, $\eta\,(\to \pi^+\pi^-\pi^0)\pi^+\pi^-$ and $\eta' \to \rho^0\gamma$
- First evidence of 10.7 ± 4.6 events (3.8σ)

$$\boxed{\mathcal{B}(B_s^0 \to J/\psi\,\eta') = (3.1 \pm 1.2\,^{+0.5}_{-0.6} \pm 0.4\,(f_s))\times 10^{-4}}$$

Search for $B_s^0 \to J/\psi\, f_0(980)$

Contribution to FPCP 2010 (arXiv:1009.2605)

- Silver mode at LHCb to measure β_s (CP-violating phase in the B_s mixing)
- BR is smaller than $B_s \to J/\psi\,\phi$ but $B_s \to J/\psi\, f_0(980)$ is a pure CP-eigenstate
  - no angular analysis is required as in $B_s \to J/\psi\,\phi$
- CP-eigenstate (odd) mode with a final state with only 4 charged particles
- Expectations:
  - $\dfrac{B(B_s^0 \to J/\psi\ f_0)\ B(f_0 \to \pi^+\pi^-)}{B(B_s^0 \to J/\psi\ \phi)\ B(\phi \to K^+K^-)} \approx 0.2$ (Stone + Zhang [PRD 79, 074024])
  - $\dfrac{B(B_s^0 \to J/\psi\ f_0)\ B(f_0 \to \pi^+\pi^-)}{B(B_s^0 \to J/\psi\ \phi)\ B(\phi \to K^+K^-)} = 0.42 \pm 0.11$ (CLEO ($D_s \to f_0 e^+ \nu_e$) [PRD 80, 052009])

$$\rightarrow\ \boldsymbol{B(B_s^0 \to J/\psi\ f_0)\ B(f_0 \to \pi^+\pi^-) \approx (1.3 - 2.7) \times 10^{-4}}$$

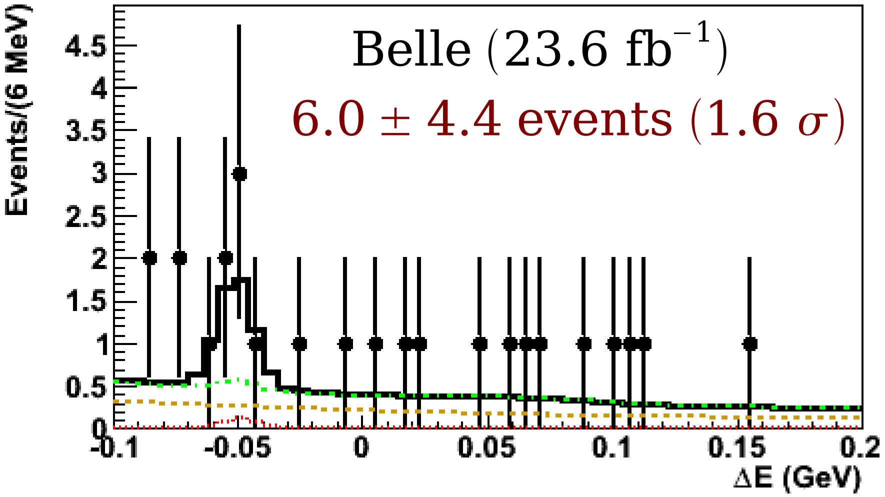
  - $B(B_s^0 \to J/\psi\ f_0) = (3.1 \pm 2.4) \times 10^{-4}$ QCD (LO) [PRD 81, 074001]
    with $B(f_0 \to \pi^+\pi^-) = (50^{+7}_{-9})\%$ BES data [CLEO, PRD 80, 052009]

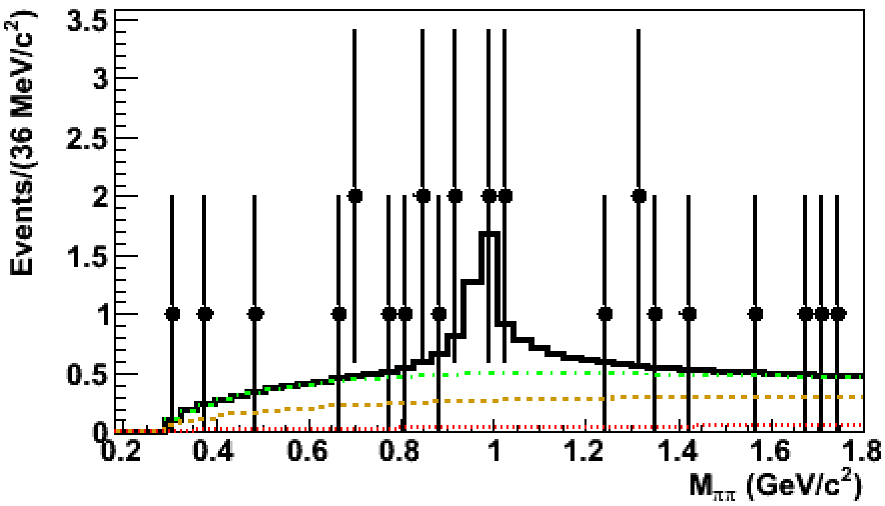
$$\rightarrow\ \boldsymbol{B(B_s^0 \to J/\psi\ f_0)\ B(f_0 \to \pi^+\pi^-) \approx (1.6 \pm 1.3) \times 10^{-4}}$$

Search for $B_s^0 \to J/\psi\, f_0(980)$

Contribution to FPCP 2010 (arXiv:1009.2605)

- $J/\psi \to e^+e^-$ or $\mu^+\mu^-$, $f_0 \to \pi^+\pi^-$
- $(\Delta E, M_{\pi^+\pi^-})$ 2D fit in -0.1 GeV $< \Delta E < 0.2$ GeV and $M_{\pi^+\pi^-} < 1.8$ GeV/c^2
- includes backgrounds from $B_s^0 \to J/\psi\,\pi^+\pi^-$ (peaks in ΔE) and other J/ψ modes





$$\boxed{\mathcal{B}(B_s^0 \to J/\psi\, f_0) \times \mathcal{B}(f_0 \to \pi^+\pi^-) < 1.6 \times 10^{-4} \text{ (at 90\% C.L.)}}$$

- We are sensitive to the region of interest !
- **More to come with 120 fb^{-1} <u>and</u> improved analysis...**

→ **winter 2011**

$\mathbf{B_s^0 \to D_s^{(*)+} D_s^{(*)-}}$ Analysis

Phys. Rev. Lett. **105,** 201802 (2010)

- CKM-favored and CP-even eigenstate (in heavy-quark limit)
- Dominates $\Delta\Gamma$ (this relation has few % theoretical uncertainty)

$$\frac{\Delta\Gamma_s^{CP}}{\Gamma_s} = \frac{2\times \mathcal{B}(B_s^0 \to D_s^{(*)+} D_s^{(*)-})}{1-\mathcal{B}(B_s^0 \to D_s^{(*)+} D_s^{(*)-})}$$

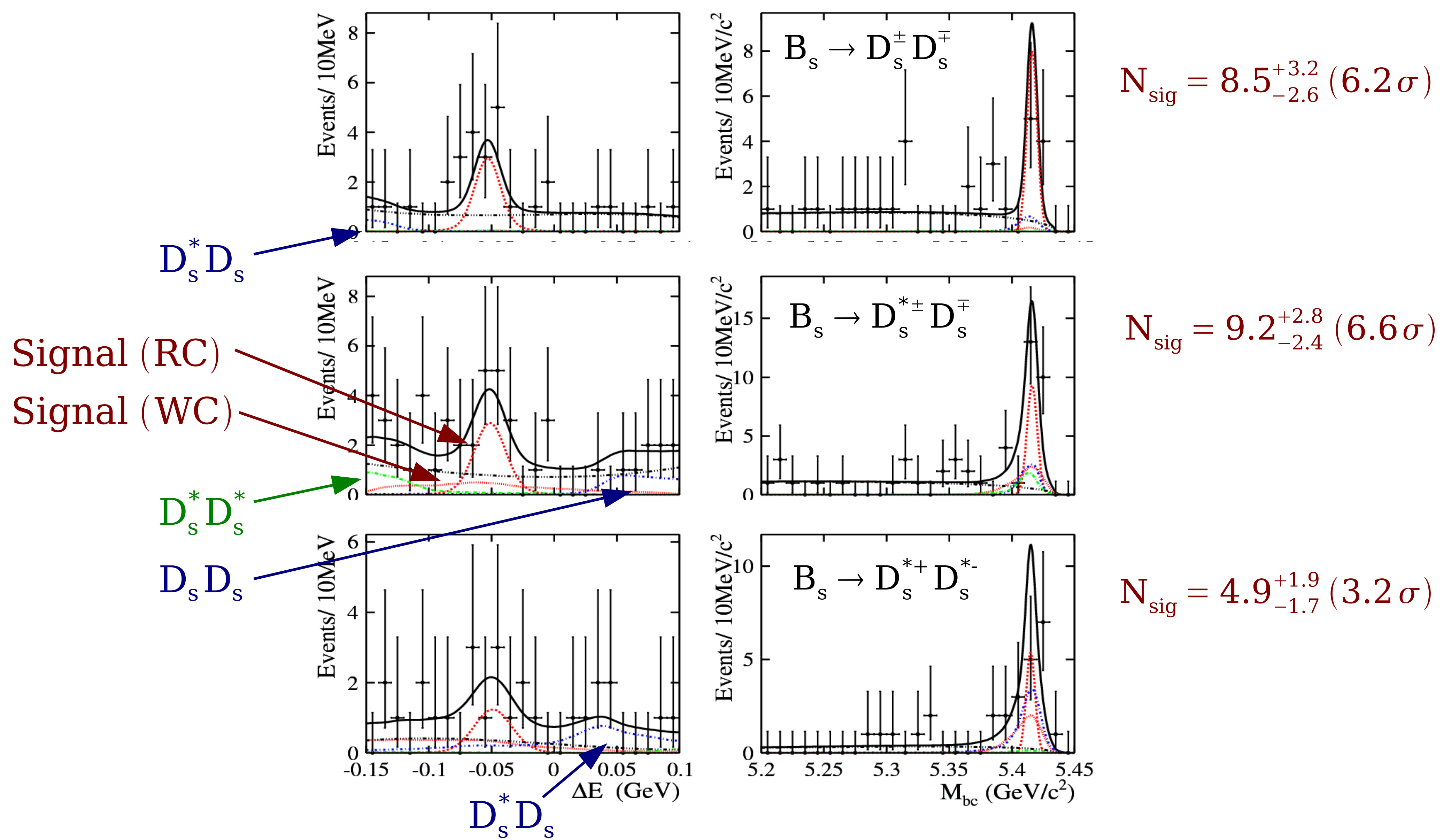
R.Aleksan et al., Phys. Lett. B 316, 567 (1993)

- Full reconstruction of $B_S^0 \to D_s^{(*)+} D_s^{(*)-}$
- Large B.R. $(\sim 10^{-2})$ but low efficiency $(\sim 10^{-4})$
- D_s^+ reconstructed in 6 final states: $\phi\pi^+$, $K_S^0 K^+$, $\overline{K}^{*0} K^+$, $\phi\rho^+$, $K_S^0 K^{*+}$ and $\overline{K}^{*0} K^{*+}$
- $D_s^{*+} \to D_s^+ \gamma$: photon energy is low $(E_\gamma < 150$ MeV$)$!
- Contamination between the 3 modes (cross feed) when a photon is missing or added by error

Observation of $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$

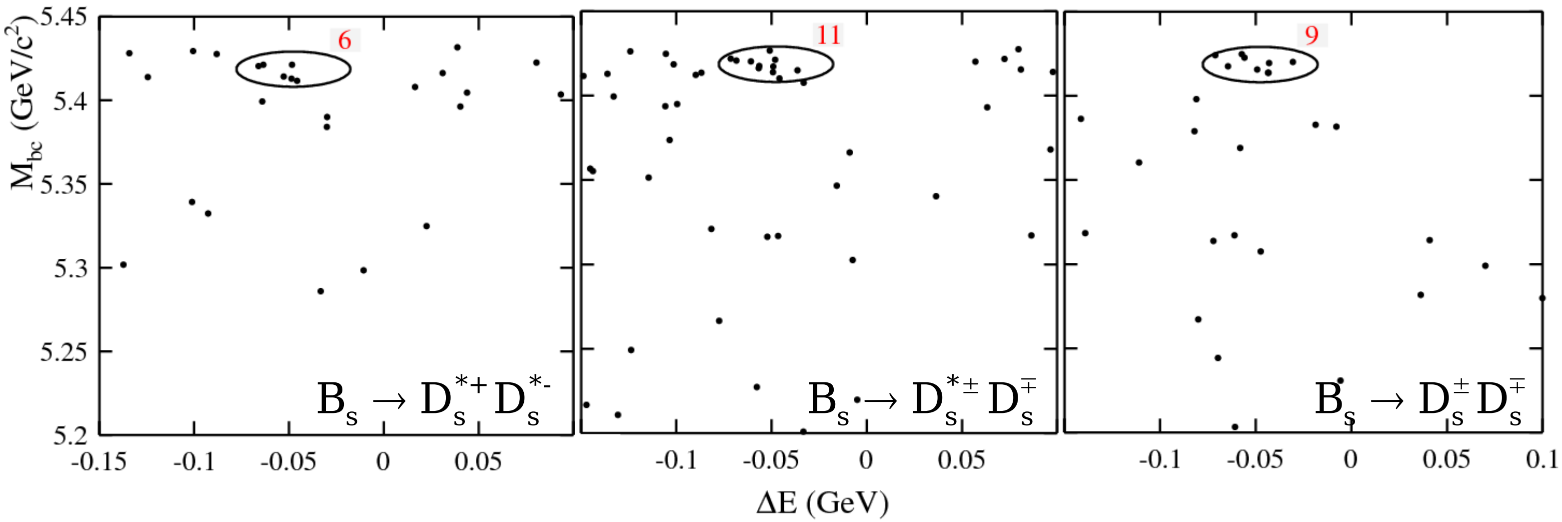
Phys. Rev. Lett. **105,** 201802 (2010)

- Simultaneous fit of the 3 modes. For each mode, cross feed from the 2 others is included
- Signal has 2 components: right and wrong combinations



Observation of $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$

Phys. Rev. Lett. **105,** 201802 (2010)



⇒ 3 modes are seen separately (22.6 signal events)

$$B\,(B_s^0 \to D_s^+ D_s^-) = (1.0\,^{+0.4}_{-0.3}\,^{+0.3}_{-0.2})\%$$

consistent with CDF [PRL 100, 021803]

$$B\,(B_s^0 \to D_s^{*\pm} D_s^{\mp}) = (2.8\,^{+0.8}_{-0.7} \pm 0.7)\%$$

first observation

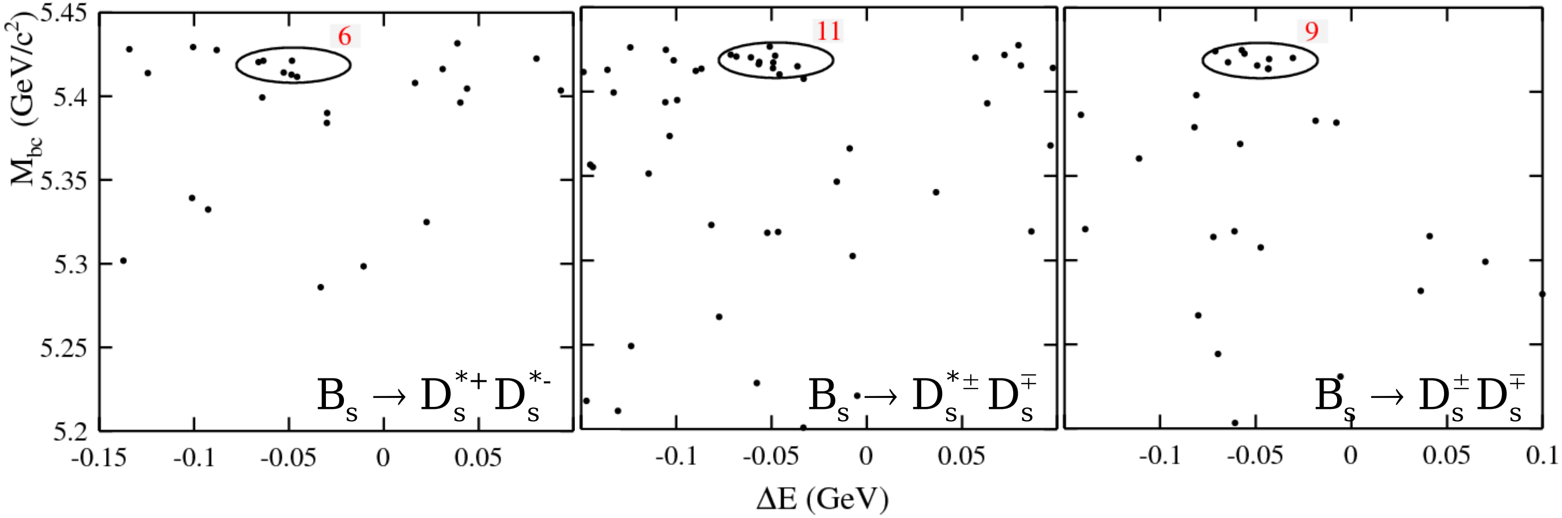
$$\Rightarrow \boldsymbol{B\,(B_s^0 \to D_s^{(*)+} D_s^{(*)-}) = (6.9\,^{+1.5}_{-1.3} \pm 1.9)\%}$$

$$B\,(B_s^0 \to D_s^{*+} D_s^{*-}) = (3.1\,^{+1.2}_{-1.0} \pm 0.8)\%$$

first evidence

Observation of $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$

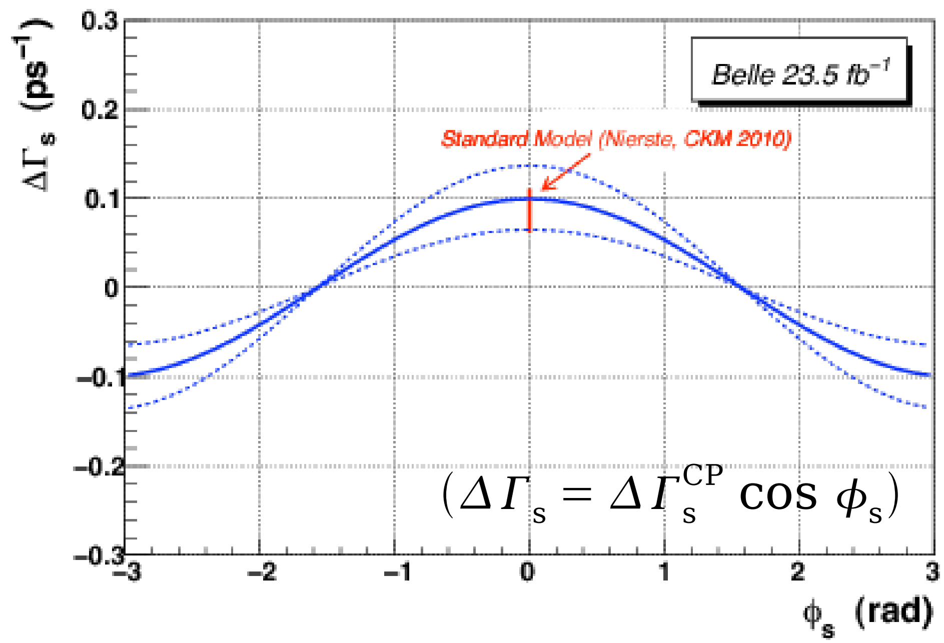
Phys. Rev. Lett. **105,** 201802 (2010)



$$\boldsymbol{B}\,(\mathbf{B_s^0} \to \mathbf{D_s^{(*)+}\,D_s^{(*)-}}) = (\mathbf{6.9^{+1.5}_{-1.3} \pm 1.9})\,\%$$

$$\frac{\Delta\Gamma_s^{CP}}{\Gamma_s} = (\mathbf{14.7}\,^{+3.6\,+4.4}_{-3.0\,-4.2})\,\%$$

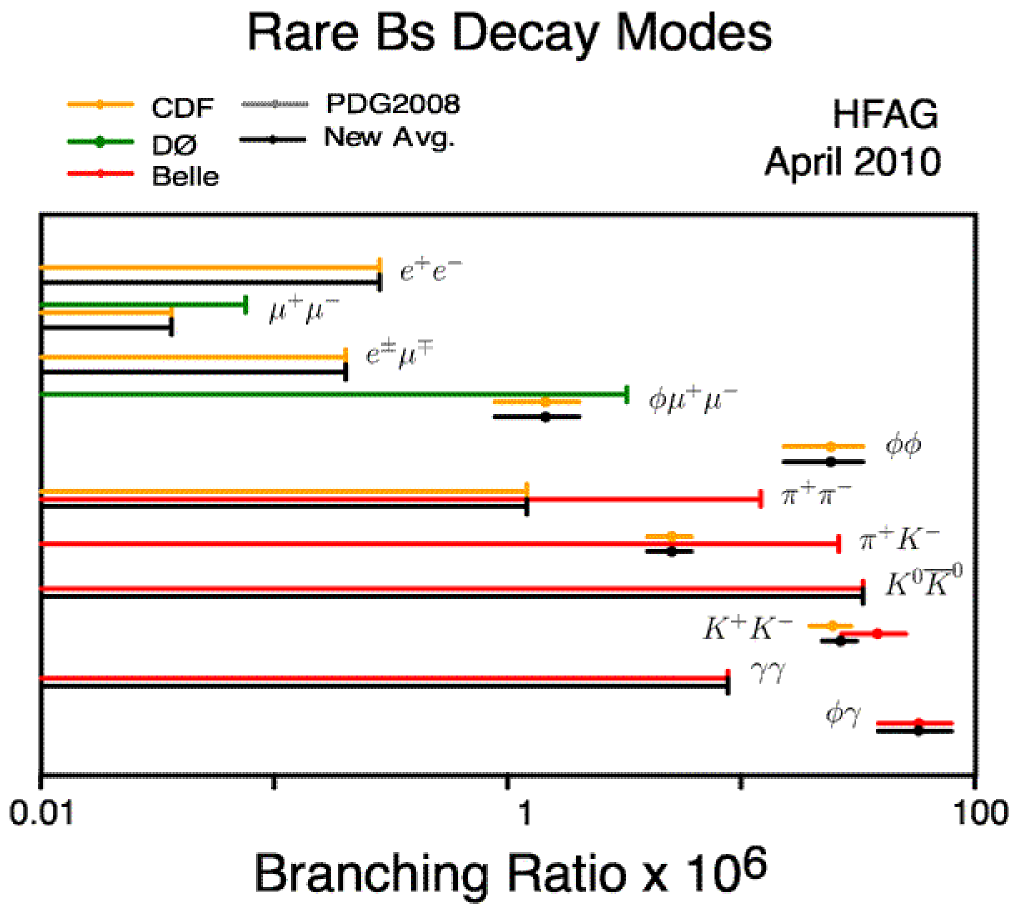
CDF: $(12 \pm 10)\%$ [PRL 100, 121803]
D0: $(7.2 \pm 3.0)\%$ [PRL 102, 091801]



$\Rightarrow$ competitive precision on $\Delta\Gamma/\Gamma$ with 23.6 fb^{-1}

Rare B_s decays

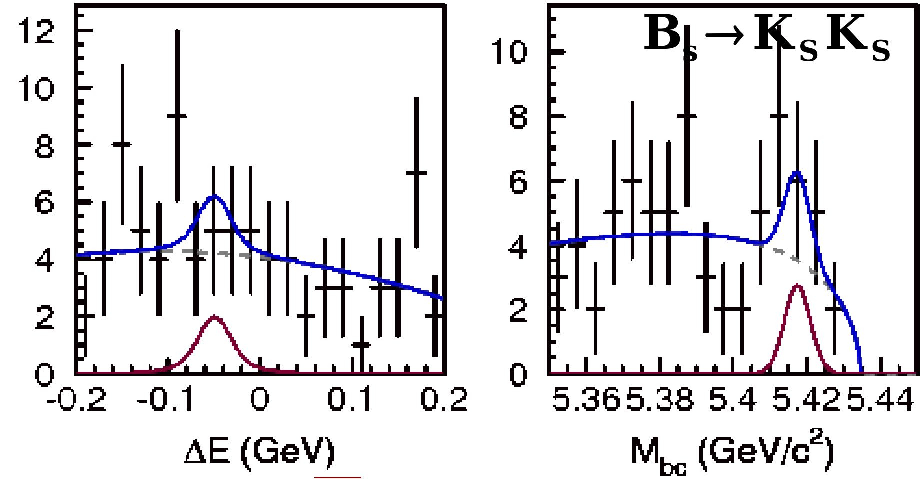
using 1/5 of the $\Upsilon(5S)$ data sample available



$\Rightarrow$ complementarity between B-factories and LHCb

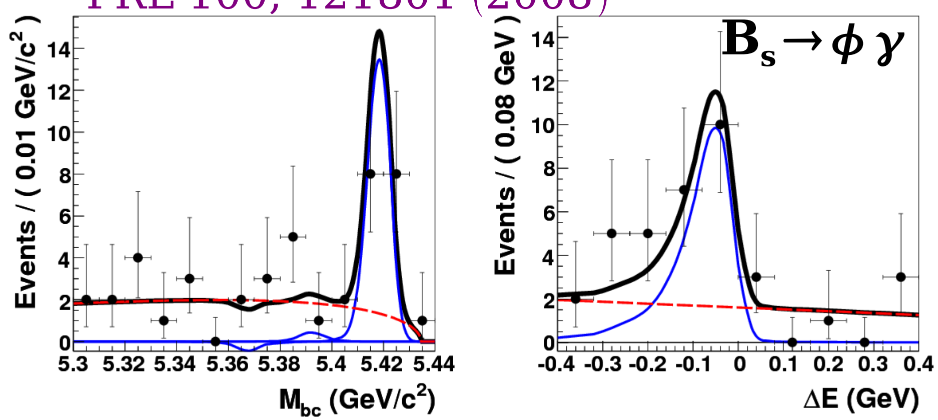
Belle can do neutrals, cleaner, but will have less statistics...

arXiv:1006.5115

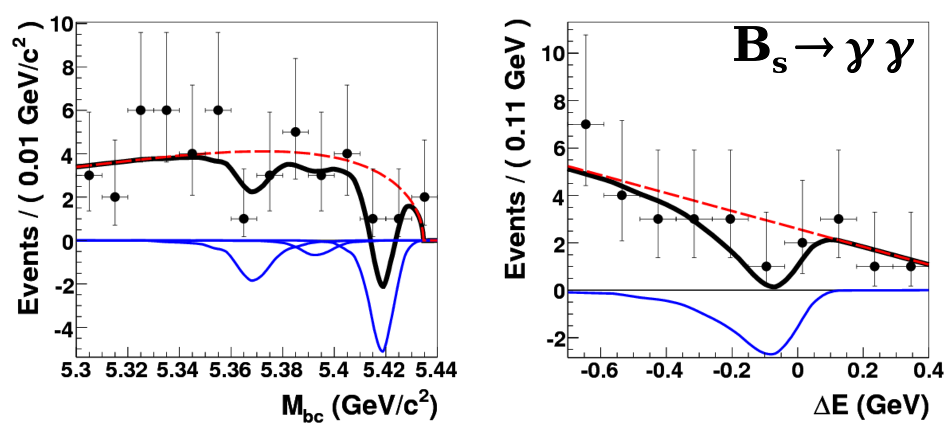


$B(B_s \to K^0 \overline{K^0}) < 6.6 \times 10^{-5}$ @ 90%C.L.

PRL 100, 121801 (2008)



$\boldsymbol{B(B_s \to \phi\gamma) = (57^{+18}_{-15}(\mathrm{stat})\ ^{+12}_{-11}(\mathrm{syst})) \times 10^{-6}}$

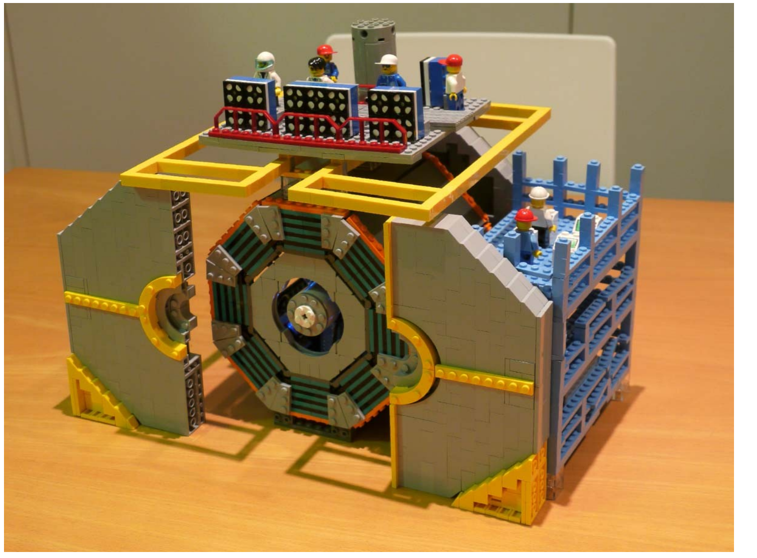


$B(B_s \to \gamma\gamma) < 8.7 \times 10^{-6}$ @ 90%C.L.

and then...

⇒ physics with $O(10^{10})$ B, τ, D....

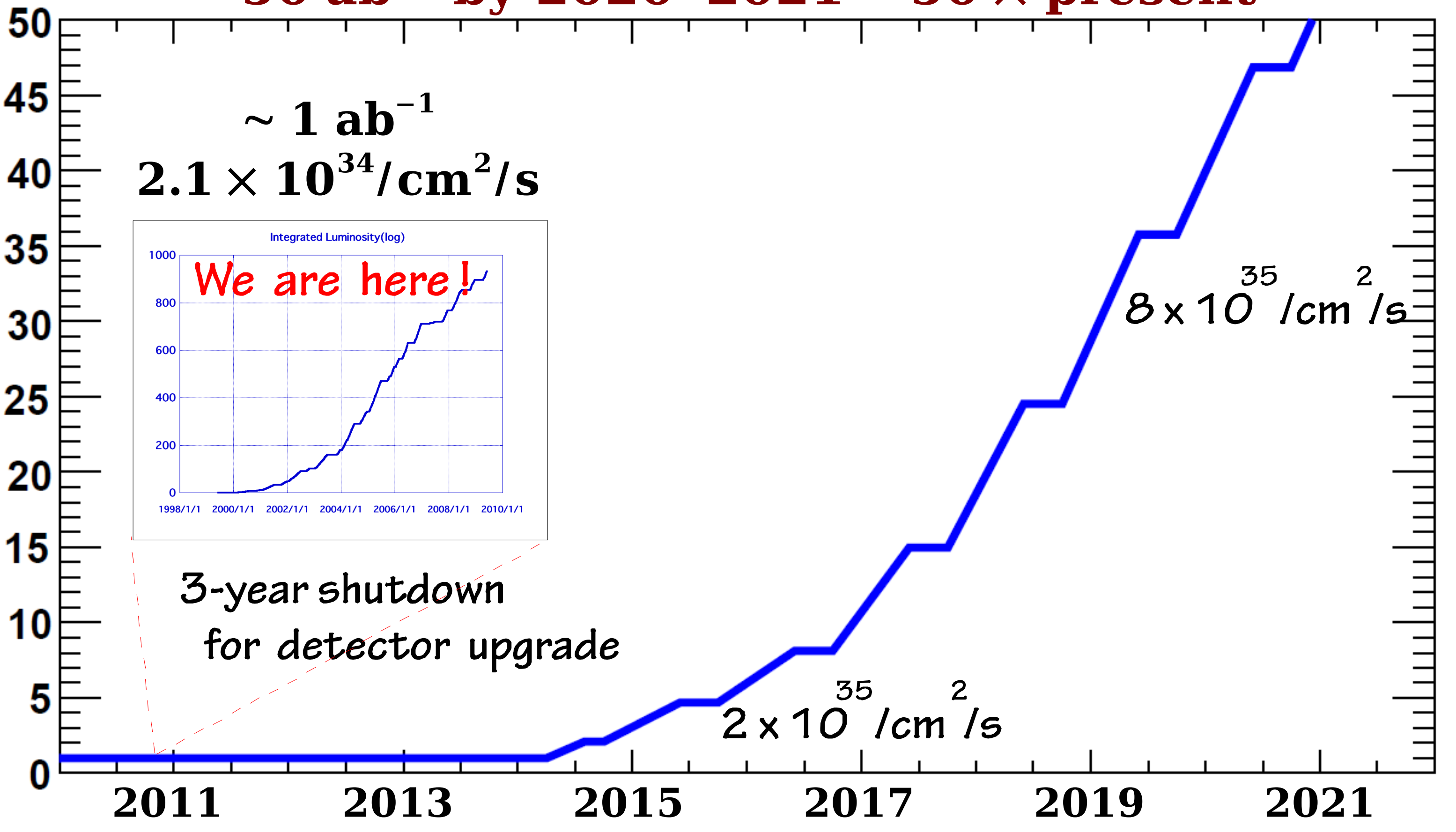
SuperKEKB/Belle II (in Japan)



⇒ KEKB upgrade has been approved

100 oku yen(*) for machine (FY 2010-2012)

50 ab^{-1} by 2020-2021 = 50 × present



(*) 100 oku yen ~ 88.6M euros (Jul 26, 2010)

Summary

$b \to s\gamma$, $b \to d\gamma$, $b \to s l^+ l^-$, $B^+ \to \tau\nu$, $B \to D\tau\nu$ ...

$\Rightarrow$ provide tests of SM predictions and interesting BSM constraints

- Charged Higgs bounds from $b \to s\gamma$, $B^+ \to \tau\nu$, $B^+ \to D\tau\nu$
- Constraints on Wilson coefficients C_7, C_9 and C_{10}
- Constraints on $|V_{td}|/|V_{ts}|$

$\Rightarrow$ Interesting signatures

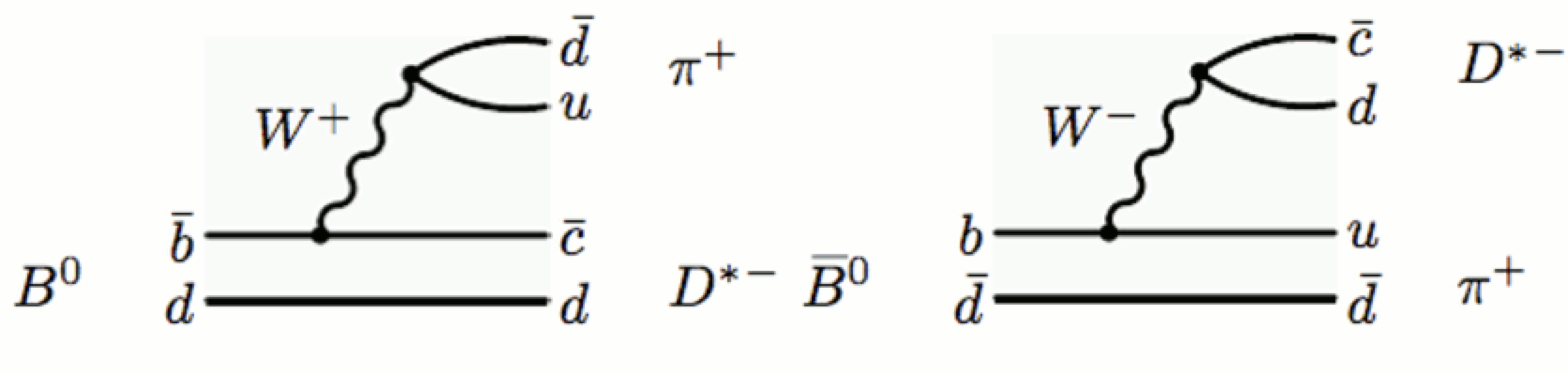
- $\mathcal{B}(B^+ \to \tau^+\nu)$ direct measurement versus CKM fit
- large forward-backward asymmetry of $K^* l^+ l^-$

Final Belle data sample is yet to be analyzed !

- **soon updated ϕ_1 measurement, and also on ϕ_2, ϕ_3 ...**
- **Rare B decays: $K^{(*)}\nu\bar{\nu}$, $l\nu$, $\gamma\gamma$, ...**
- **Results on B_s decays with $5\times$ more stat**
- **τ physics (lifetime, LVF decays), charm (mixing $K\pi$, KK, $K_S\pi\pi$), new particles (X, Y, Z), bottomonium...**

Even more interesting results at Super B factories with two orders of magnitude larger data samples !

$r \sin(2\phi_1+\phi_3)$ from $B^0 \to D^{(*)}\pi$ decay



Use B flavor tag, measure time-dependent decay rates

$$P(B^0 \to D^{(*)\pm}\pi^{\mp}) = \frac{1}{8\tau_B} e^{-|\Delta t|/\tau_B} [1 \mp \mathbf{C} \cos(\Delta m \Delta t) - \mathbf{S}^{\pm} \sin(\Delta m \Delta t)]$$

$$P(\overline{B}^0 \to D^{(*)\pm}\pi^{\mp}) = \frac{1}{8\tau_B} e^{-|\Delta t|/\tau_B} [1 \pm \mathbf{C} \cos(\Delta m \Delta t) + \mathbf{S}^{\pm} \sin(\Delta m \Delta t)]$$

$$\mathbf{S}^{\pm} = -2 r \sin(2\phi_1 + \phi_3 \pm \delta_{D^{(*)}\pi}) \qquad \mathbf{C} = \frac{1-r^2}{1+r^2} \approx 1 \qquad r \approx 0.02$$

$\Rightarrow$ large stat available, small CP violation effect

- partial reconstruction helps increase statistics
- lepton tag (50196±286 signal evts)

657×10^6 $B\overline{B}$ pairs
[ArXiv:0809.3203]

$r \sin(2\phi_1+\phi_3)$ from $B^0 \to D^{(*)}\pi$ decay

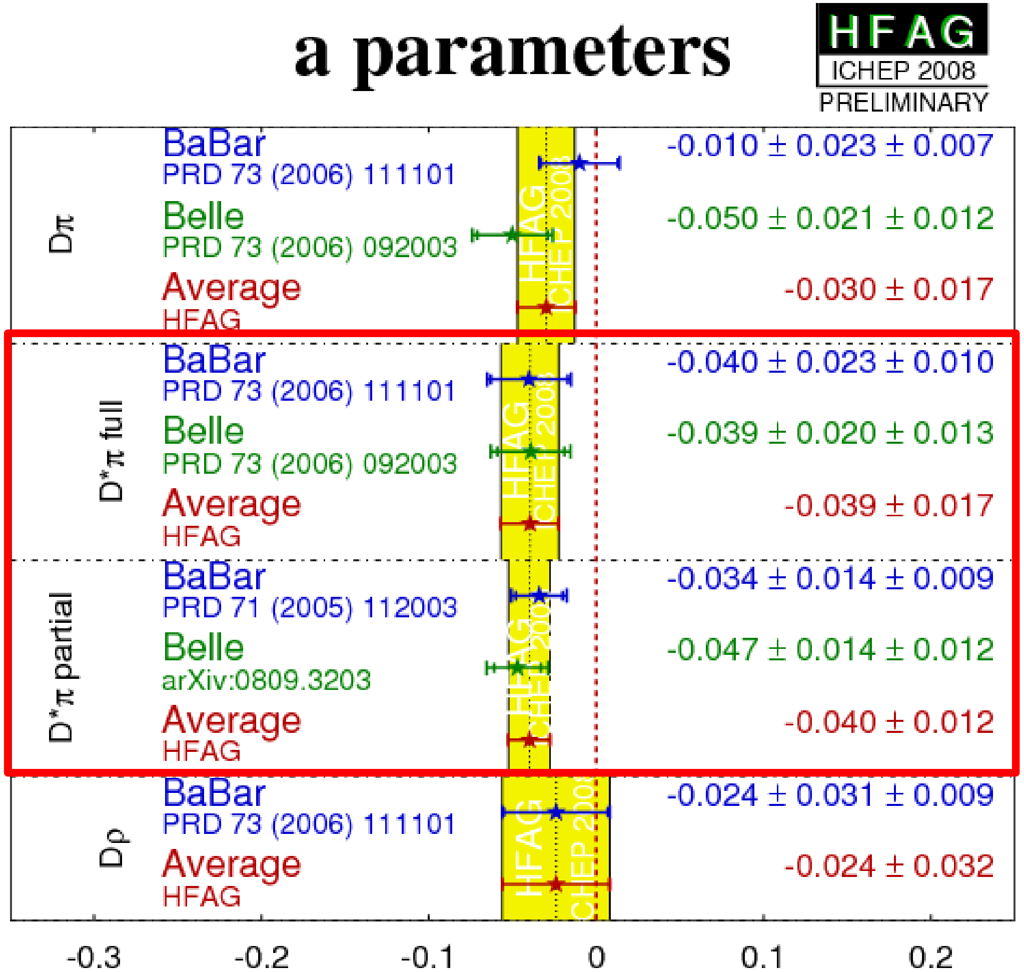
657×10^6 $B\bar{B}$ pairs
[ArXiv:0809.3203]

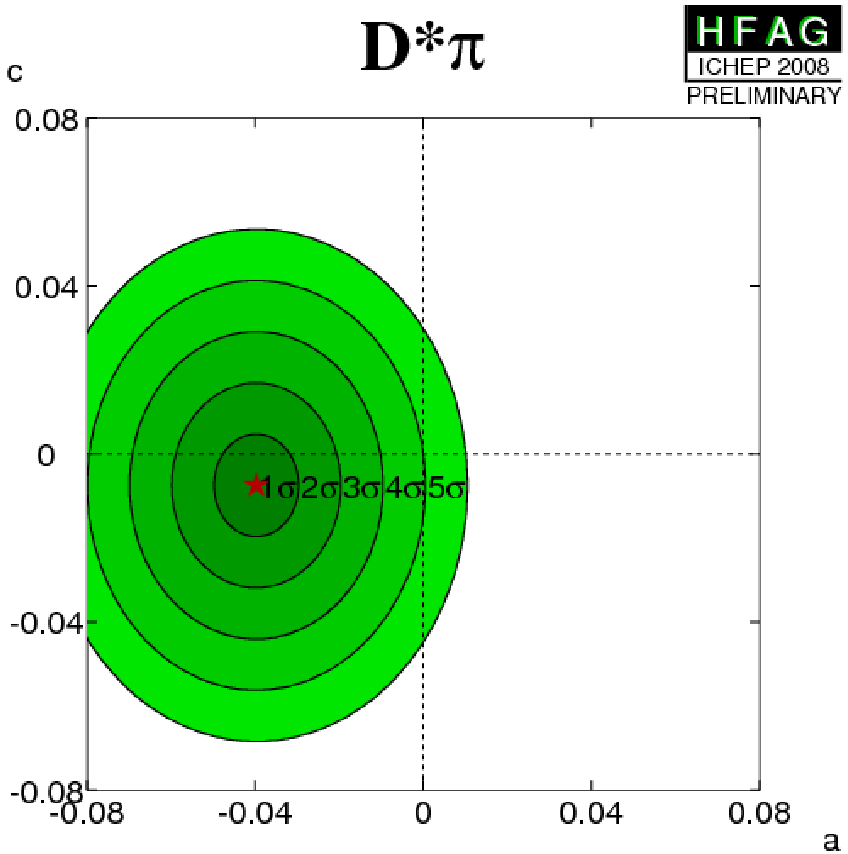
HFAG notation
$$a = -(S^+ + S^-)/2$$
$$c = -(S^+ - S^-)/2$$

$$\boxed{\begin{aligned} a &= -0.047 \pm 0.014 \pm 0.012 \\ c &= -0.009 \pm 0.014 \pm 0.010 \end{aligned}}$$

significance of CPV is 2.6σ

summary for all measurements (partial and full)



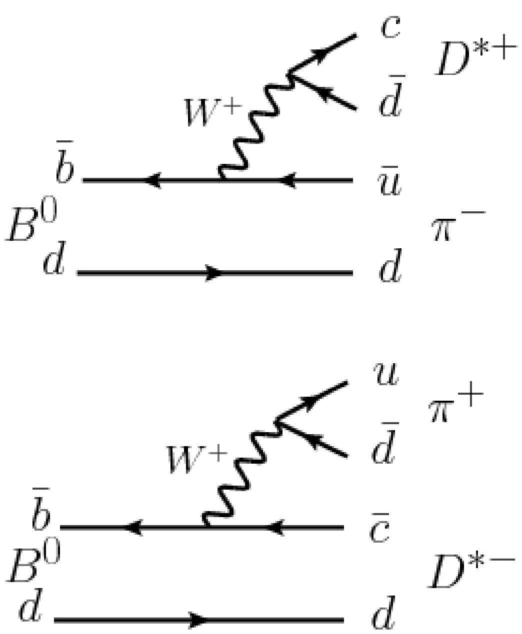


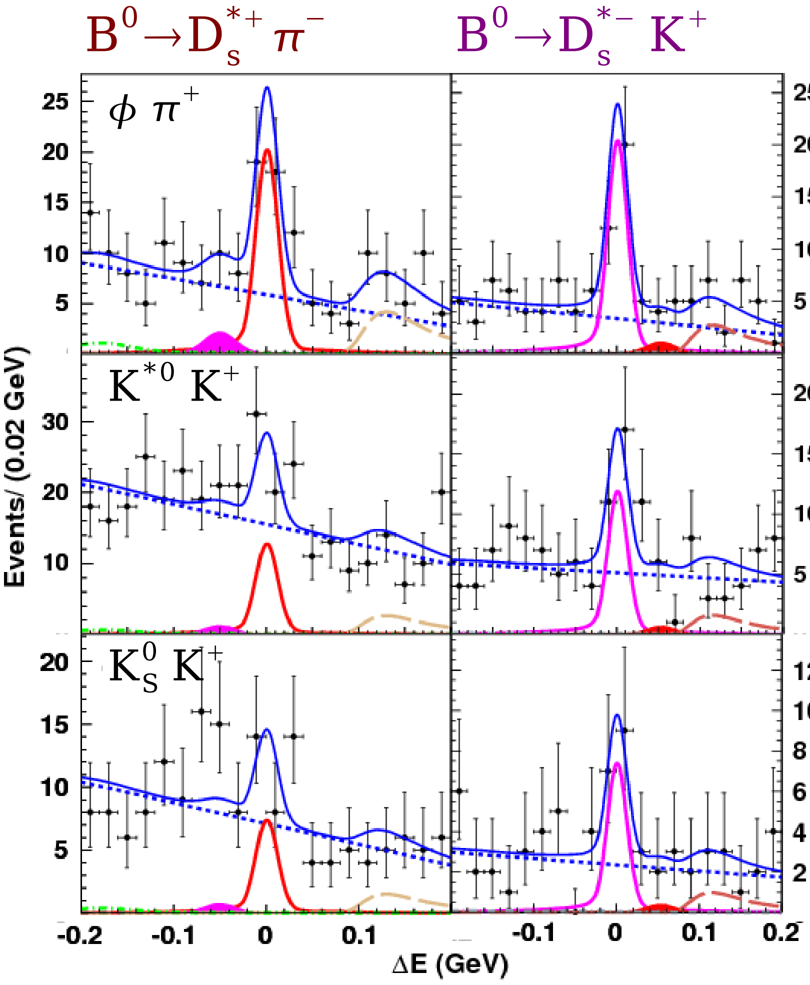
significance of CPV is ~4σ

r using $B^0 \to D_s^{*+} \pi^-$ decay

$657 \times 10^6 B\bar{B}$ pairs
[PRD 81, 031101 (2010)]

1^{st} measurement in Belle





$$r = \tan\theta_C \left(\frac{f_{D^*}}{f_{D_s^*}}\right) \sqrt{\frac{Br(B^0 \to D_s^{*+} \pi^-)}{Br(B^0 \to D^{*-} \pi^+)}}$$

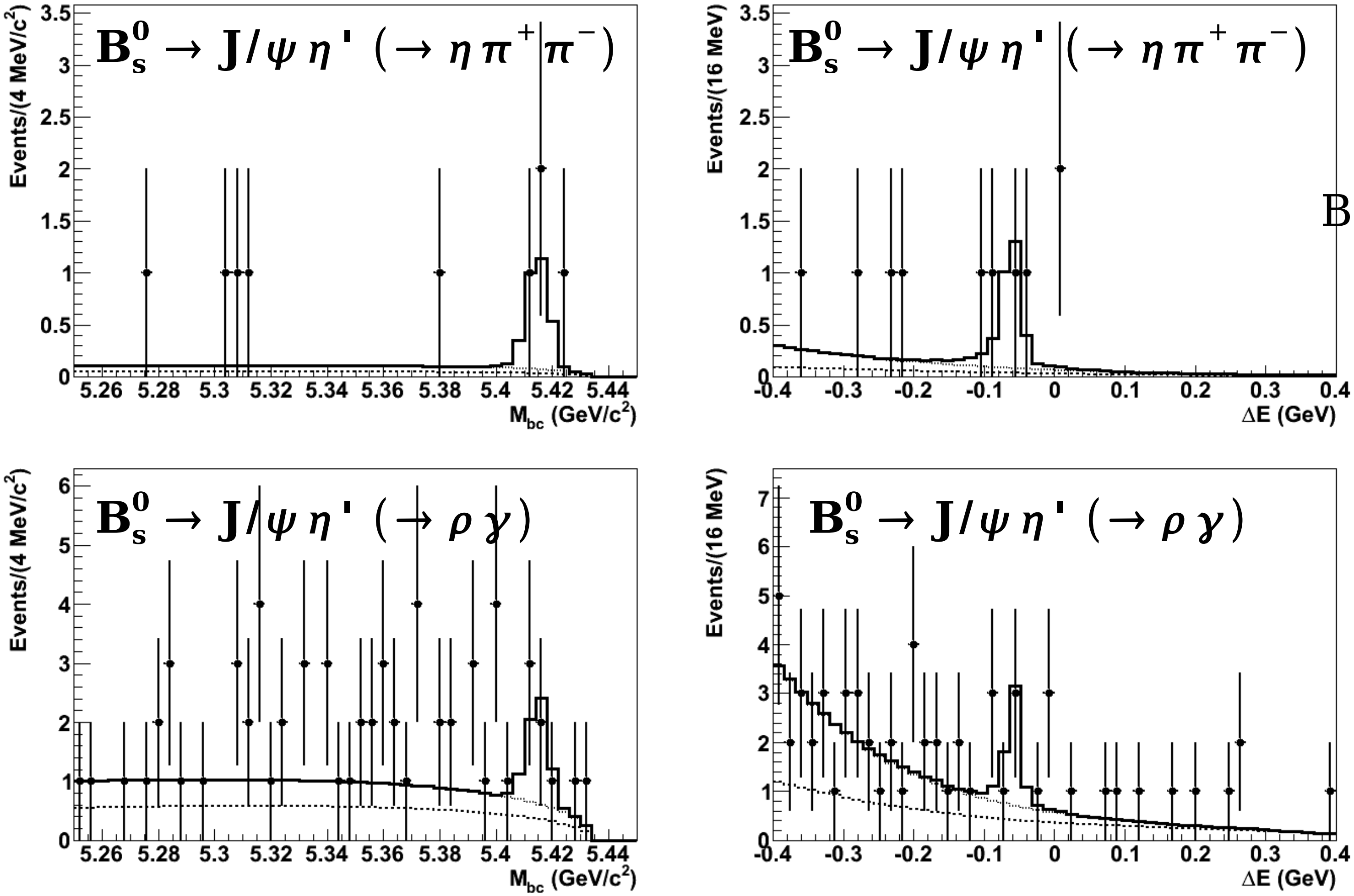
$\Sigma = 6.1\,\sigma$

$\mathbf{Br(D_s^{*+} \pi^-) = (1.75 \pm 0.34 \pm 0.17 \pm 0.10) \times 10^{-5}}$

$$\boxed{\mathbf{r = (1.58 \pm 0.15 \pm 0.10 \pm 0.03)\%}}$$

Observation of $B_s^0 \to J/\psi\,\eta'$

Belle-conf-0902, arXiv:0912.1434



Belle $(23.6\ \mathrm{fb}^{-1})$

- 3 η' channels: $\eta' \to \eta(\to\gamma\gamma)\pi^+\pi^-$, $\eta\,(\to \pi^+\pi^-\pi^0)\pi^+\pi^-$ and $\eta' \to \rho^0\gamma$
- First evidence of 10.7 ± 4.6 events (3.8σ)

$$\boxed{\mathcal{B}(B_s^0 \to J/\psi\,\eta') = (3.1 \pm 1.2\,^{+0.5}_{-0.6} \pm 0.4\ (f_s)) \times 10^{-4}}$$