TECHNISCHE UNIVERSITÄT DRESDEN

iktp

Hadronic and Rare B decays with the BaBar and Belle Experiments

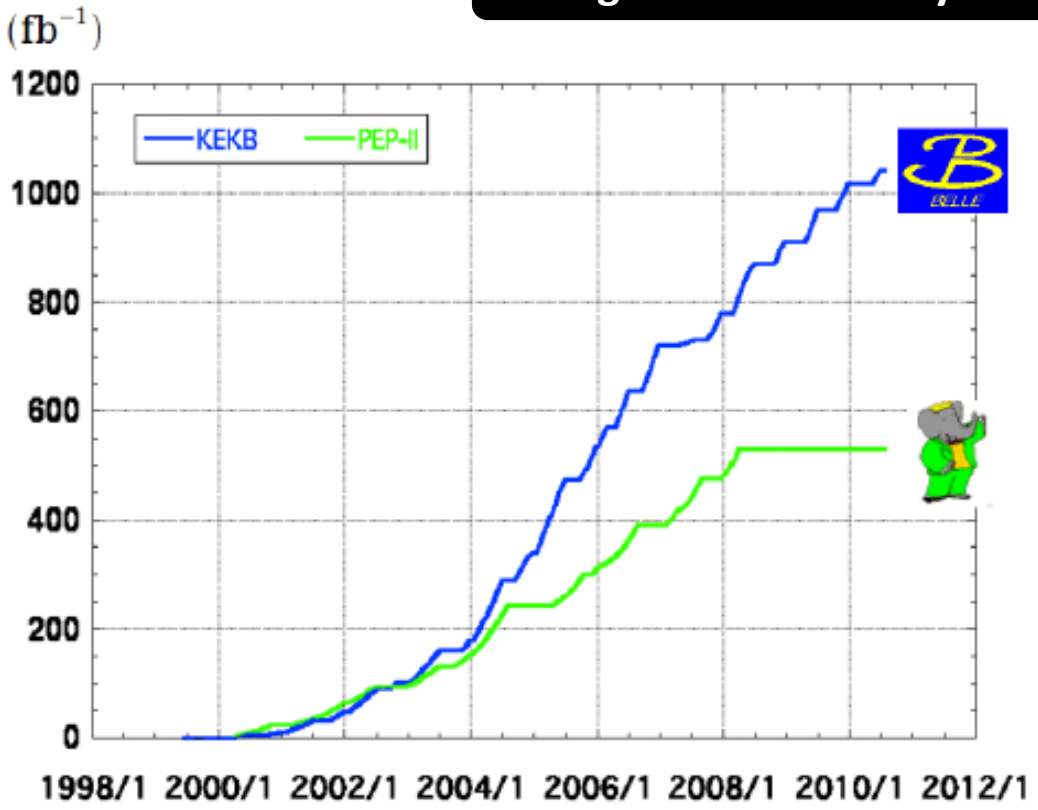
Xavier Prudent (IKTP, TU-Dresden)
On behalf of *BaBar* and Belle Collaboration

BABAR
Babar Characters TM & © Laurent de Brunhoff

BELLE

Cracow Epiphany Conference on Present and Future of B Physics - 2012

Integrated Luminosity of B Factories



> 1 ab^{-1}

On resonance:

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

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

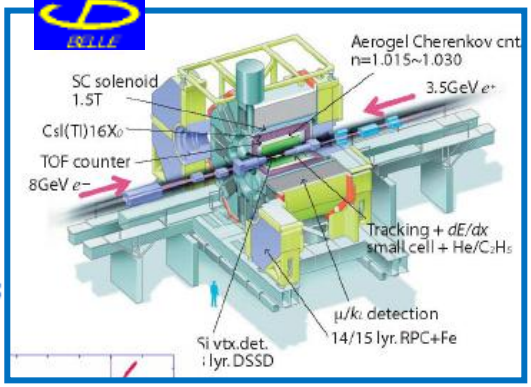
$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

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

Off reson./scan:

~ 100 fb^{-1}



~ 550 fb^{-1}

On resonance:

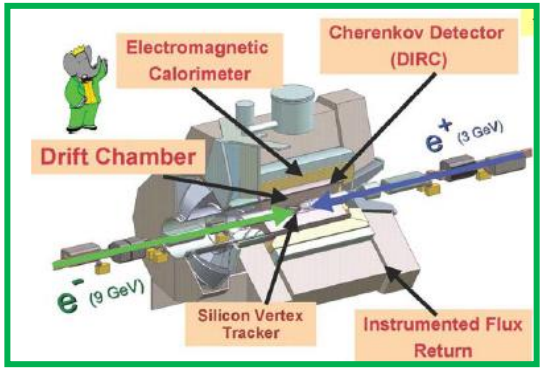
$\Upsilon(4S)$: 433 fb^{-1}

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

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

Off resonance:

~ 54 fb^{-1}



- World record of instantaneous luminosity

KEK: L = 2.11 .10^{34}cm^{-2}s^{-1}, **PEP-II: L = 1.21 .10^{34}cm^{-2}s^{-1}**

- Scan of Y resonances

- Total: > 10^{9} $B\bar{B}$ pairs

Comparison:

ARGUS experiment (1980-87) would have needed to run 10,000 years to achieve this luminosity

Reconstruction of B mesons at B Factories

Use of the 2-body kinematic of $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B^0\bar{B}^0$

Beam-energy substituted mass

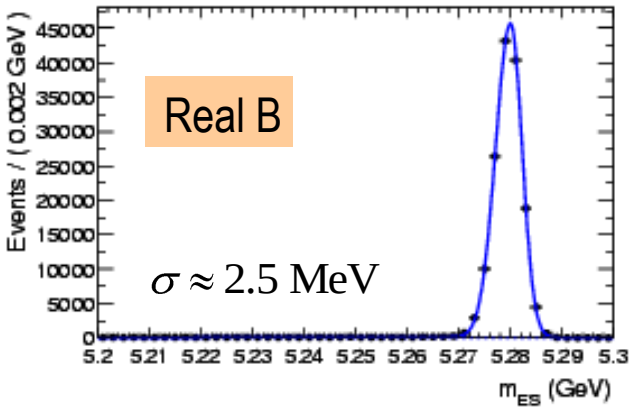
$$m_{ES} = \sqrt{E^{*}_{beam}{}^{2} - p^{*2}_{B}}$$

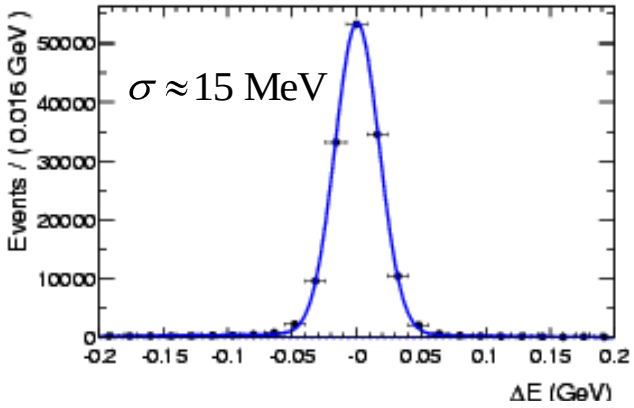
Energy difference

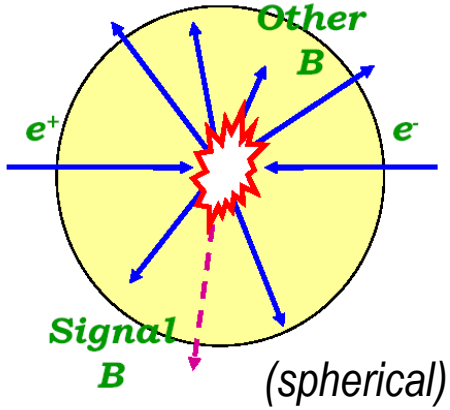
$$\Delta E = E^{*}_{B} - E^{*}_{beam}$$

Event *Topology*

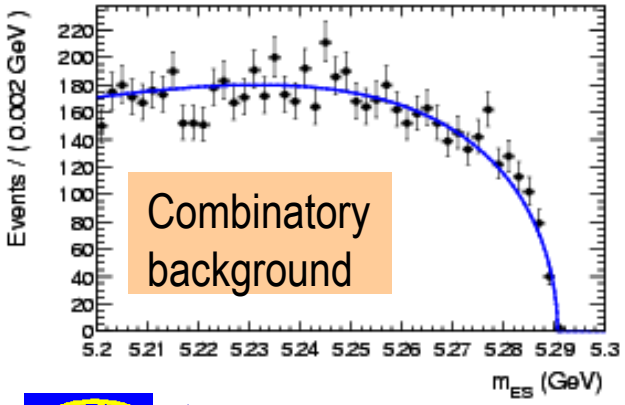
(multivariate method)

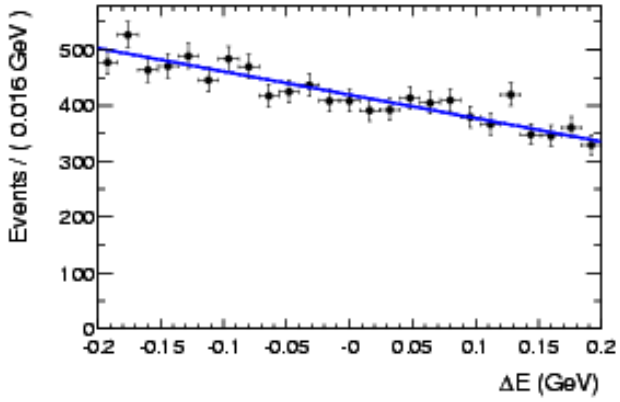


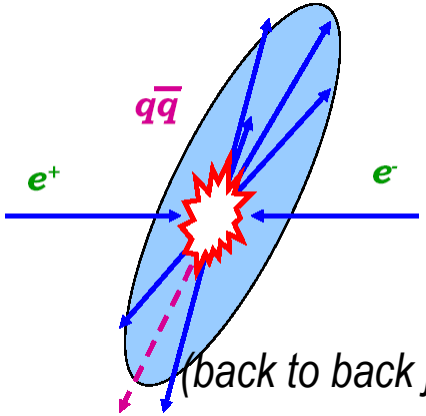




(spherical)







(back to back jets)

„beam constrained“m_{bc}

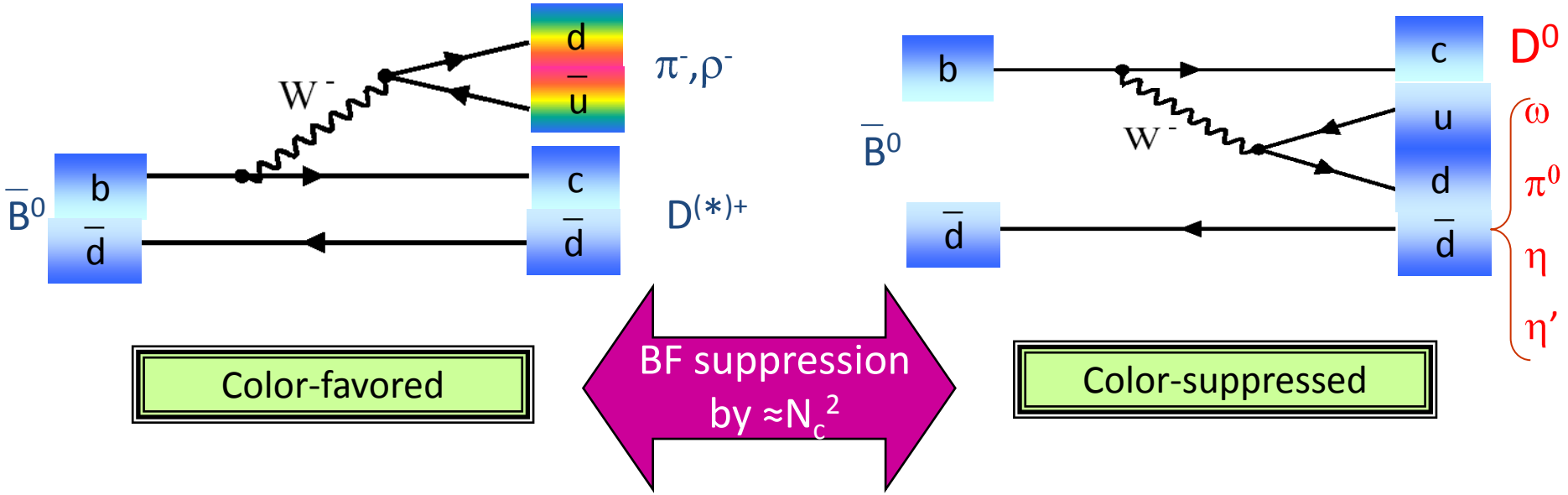
Color-Suppressed Decays $\bar{B}^0 \to D^{(*)0} h^0$, $h^0 = \pi^0, \eta, \eta', \omega$

Physics Motivation

Tree diagram of an hadronic 2-body decay

➔ 2 combinations depending on the spectator quark

➔ different constraints on the combining quarks (meson colorless)



Precise knowledge of QCD interactions in B decay pivotal for extraction of CKM parameters

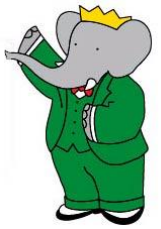
Factorisation of QCD final state interaction FSI successful description of color-favored decays

Nucl. Phys. B **591**, 313 (2000) Eur. Phys. Jour. C **22**, 677 (2002).

Color-suppressed: BF 4-5x higher than prediction… Phys. Rev. D**69**, 032004 (2004),

➔ Which model for the FSI ?

Color-Suppressed Decays $\bar{B}^0 \to D^{(*)0} h^0$, $h^0 = \pi^0, \eta, \eta', \omega$



The Analysis

$e^+e^- \to \Upsilon(4S) \to \bar{B}^0$

$\to$ $D^{(*)0}\pi^0$, $D^{(*)0}\eta$, $D^{(*)0}\omega$, $D^{(*)0}\eta'$

$D^{*0} \to D^0\pi^0$, $D^{*0} \to D^0\gamma$

$\pi^0 \to \gamma\gamma$

$\eta \to \gamma\gamma$

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

$\omega \to \pi^+ \pi^- \pi^0$

$\eta' \to \rho^0 \gamma$, $\rho^0 \to \pi\pi$

$\eta' \to \pi^+ \pi^- \eta \to \gamma\gamma$

$D^0 \to K^- \pi^+$

$D^0 \to K^- \pi^+ \pi^0$

$D^0 \to K^- \pi^+ \pi^- \pi^+$

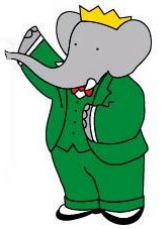
$D^0 \to K_s \pi^+\pi^-$, $K_s \to \pi^+\pi^-$

72 modes

Dataset: 454.10^6 BB

- Blind Optimization : only simulations and OffPeak data were used
- Use of high statistics/purity control samples
- Main Backgrounds:
  $e^+e^- \to q\bar{q}$: Fisher discriminant of topology variables
  Cross feed between signal modes: iterative fit
- Signal Extraction:Fit of ΔE

Color-Suppressed Decays $\bar{B}^0 \to D^{(*)0} h^0$, $h^0 = \pi^0, \eta, \eta', \omega$



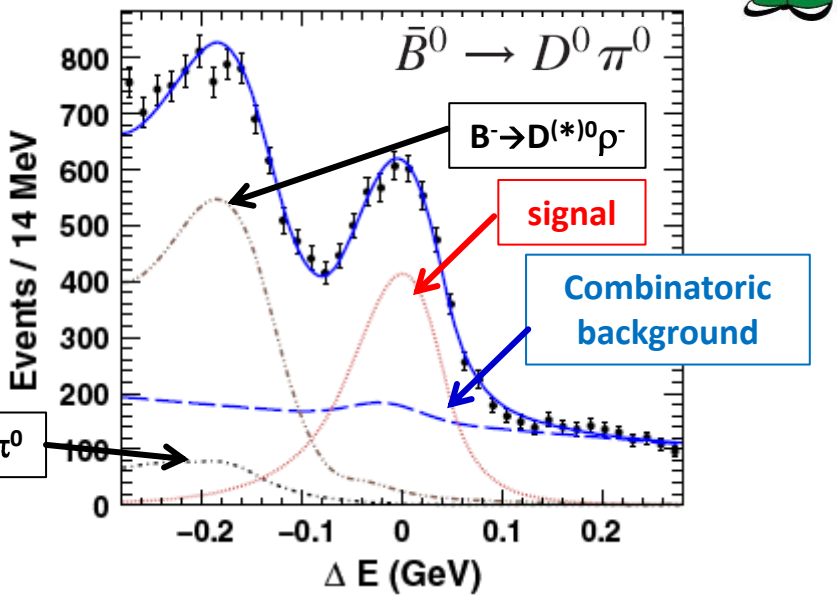
Clear signal in majority of channel

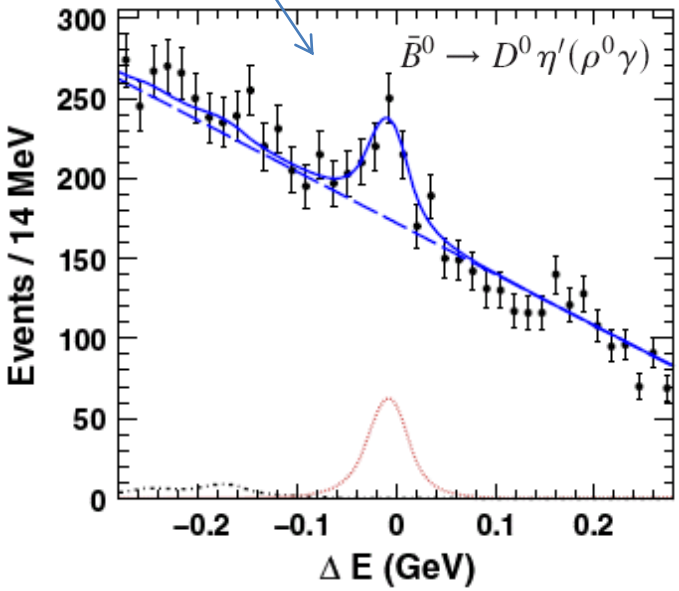
Good MC-data agreement

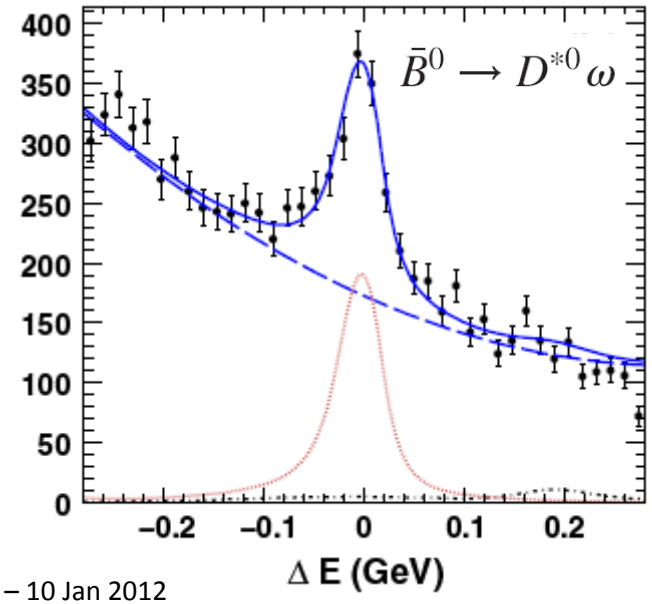
BF combined with **BLUE** method

L. Lyons *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A 270, 110 (1988);

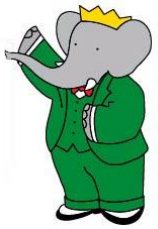
First observation of $\bar{B}^0 \to D^0 \eta'(\rho^0 \gamma)$





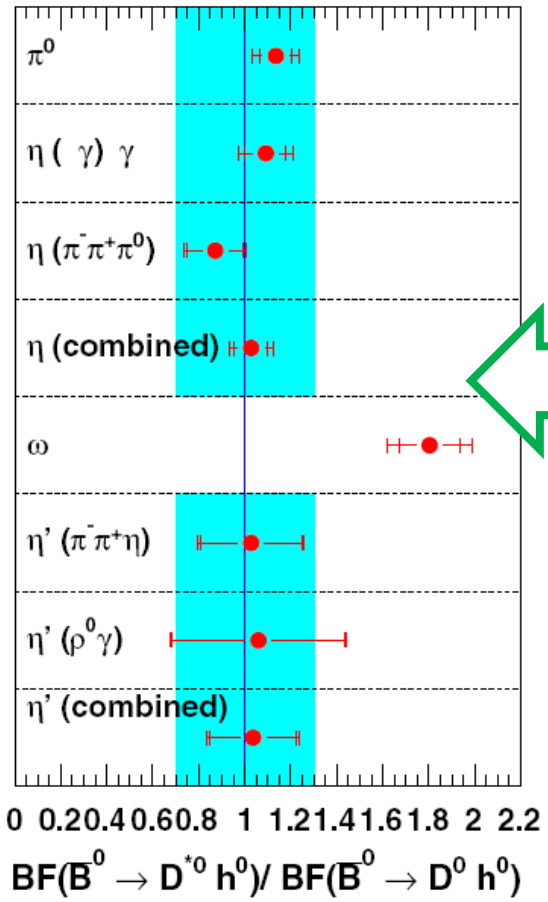


Color-Suppressed Decays $\bar{B}^0 \to D^{(*)0} h^0$, $h^0 = \pi^0, \eta, \eta', \omega$



Comparison to theoretical predictions from different QCD models

$\mathcal{B}(\bar{B}^0 \to)(\times 10^{-4})$	This measurement	Factorization	pQCD
$D^0\pi^0$	$2.69 \pm 0.09 \pm 0.13$	0.58 [16]; 0.70 [3]	2.3–2.6
$D^{*0}\pi^0$	$3.05 \pm 0.14 \pm 0.28$	0.65 [16]; 1.00 [3]	2.7–2.9
$D^0\eta$	$2.53 \pm 0.09 \pm 0.11$	0.34 [16]; 0.50 [3]	2.4–3.2
$D^{*0}\eta$	$2.69 \pm 0.14 \pm 0.23$	0.60 [3]	2.8–3.8
$D^0\omega$	$2.57 \pm 0.11 \pm 0.14$	0.66 [16]; 0.70 [3]	5.0–5.6
$D^{*0}\omega$	$4.55 \pm 0.24 \pm 0.39$	1.70 [3]	4.9–5.8
$D^0\eta'$	$1.48 \pm 0.13 \pm 0.07$	0.30–0.32 [50]; 1.70–3.30 [49]	1.7–2.6
$D^{*0}\eta'$	$1.48 \pm 0.22 \pm 0.13$	0.41–0.47 [49]	2.0–3.2



BF all significantly larger than factorisation prediction ➔ presence of FSI !

BF ratios compatible with „Soft Collinear Effective Theorie“ (SCET) expectation:

$$\frac{BF(B \to D^{*0} h^0)}{BF(B \to D^0 h^0)} \approx 1$$

Phys. Rev. D 65,054022 (2002).

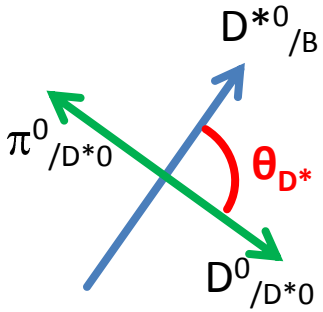
Published in Phys. Rev. D 84, 112007 (2011)

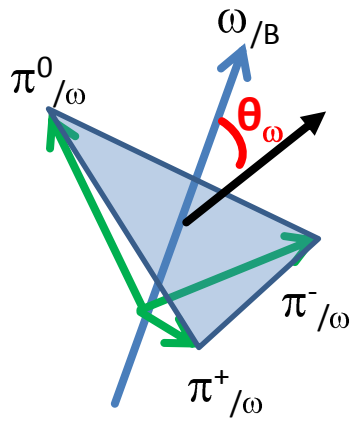
$\bar{B}^0 \to D^{*0}\omega$

Scalar → Vector Vector decay

Described by:

- 3 **amplitudes** H_+. H_-, H_0
- 3 **angles**: helicities θ_{D^*},θ_ω , azimuthal angle χ

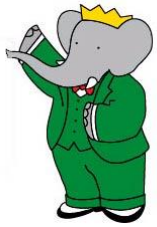




Polarisation never studied,

Simulations: assumed almost purely longitudinal (f_L~1) from HQET+factorisation would-be largest systematics in BF($\bar{B}^0 \to D^{*0}\omega$)

$$f_L = \frac{|H_0|^2}{|H_0|^2 + |H_+|^2 + |H_-|^2}$$

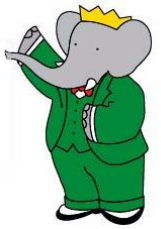


Study of $B \to K^*\phi$: measured longitudinal fraction $f_L \neq 1$
Would be interpreted in terms of New Physics

Phys. Rev. D 71, 094002 (2005).

Debate among SCET theorists:
QCD pinguin diagrams may enhance the transversal amplitude, leading to $f_L \neq 1$

Phys. Rev. Lett. 96, 141801 (2006).



The Measurement of the longitudinal fraction

Assume acceptance independent of angle χ

➔Data can be described by the **weighted sum 2 components**:

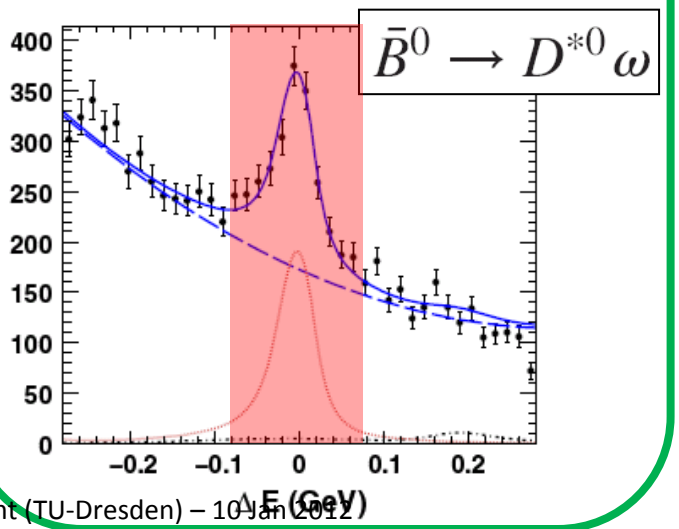
$(D^*\omega) = (1-\alpha)$. (purely transverse $D^*\omega$) + α . (purely longitudinal $D^*\omega$)

$$f_L = \frac{\alpha}{\alpha + (1 - \alpha - \gamma) \cdot \frac{\varepsilon_0}{\varepsilon_1}}.$$

Acceptance ratio of purely longitudinal/transverse $D^*\omega$ events➔ from MC simulation

Fraction of purely longitudinale $D^*\omega$

Background fraction fixed from the ΔE fit



Can be extracted with a 2D fit of the D^{*0}, ω, helicity angles

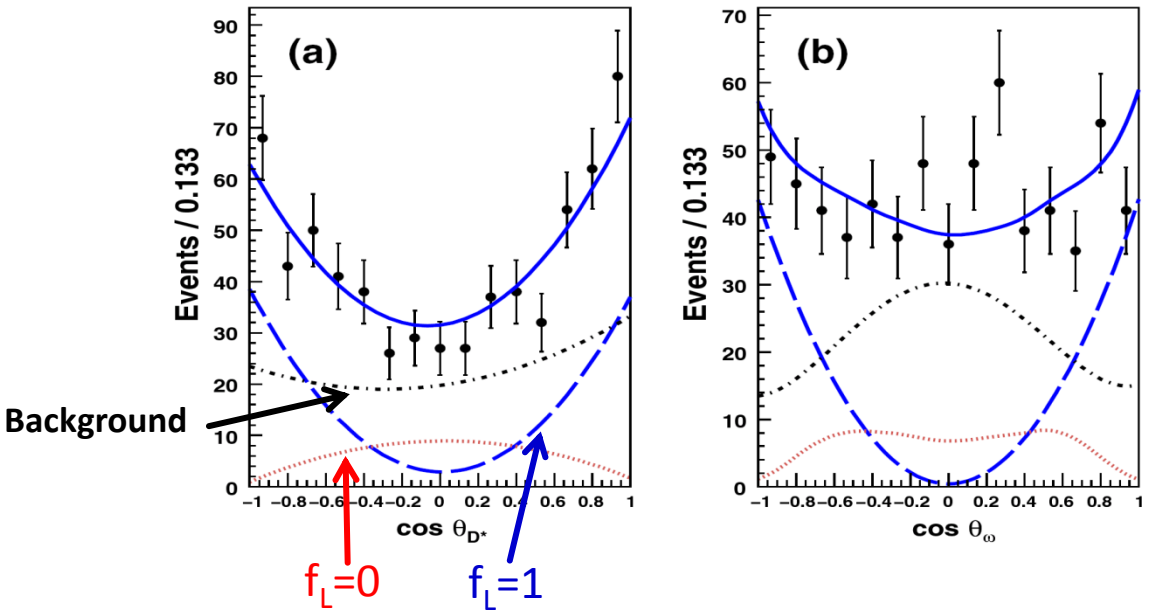
Measure only $\bar{B}^0 \to D^{*0}\omega$, $D^{*0} \to D^0\pi^0$
Fit applied to the 4 sub-modes of D^0

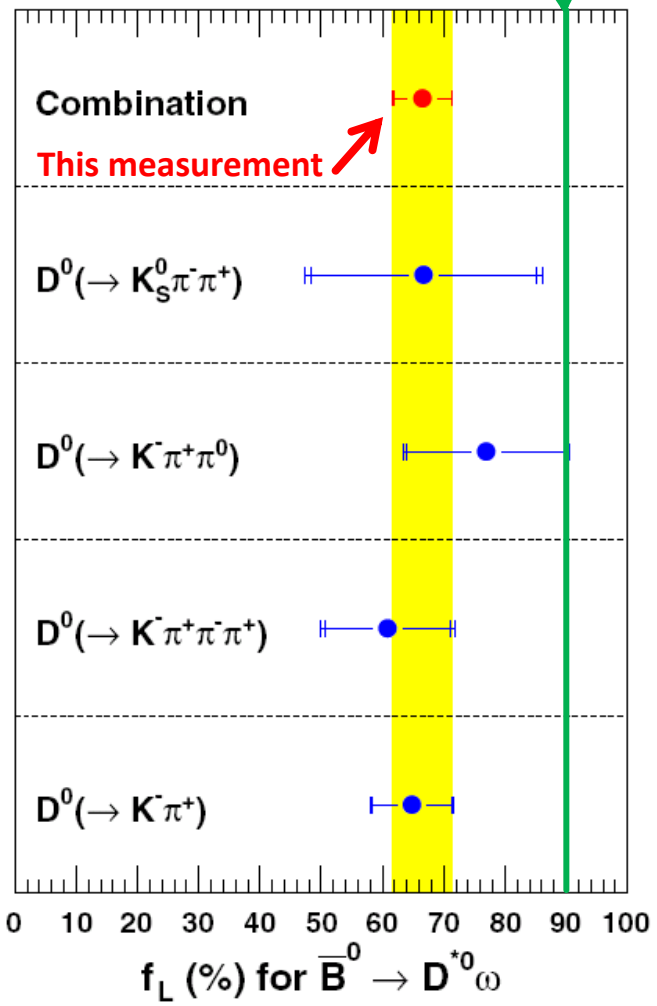
$\bar{B}^0 \to D^{*0}\omega$

Clear deviation from HQET prediction

$$f_L = (89.5 \pm 1.9)\%$$

2D fit for the sub-mode $D^0 \to K^-\pi^+$

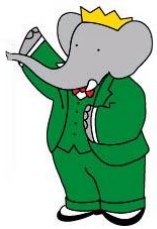




Measurements combined with BLUE

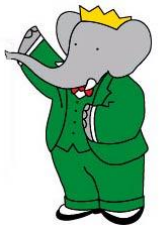
$$f_L = (66.5 \pm 4.7 \pm 1.5)\%$$

Supports the evidence of nontrivial long distance effect as predicted by SCET



Published in Phys. Rev. D 84, 112007 (2011)

Observation of $\bar{B}^0 \to \Lambda_c^+ \bar{\Lambda} K^-$



B decays to baryons ~ 6.8 % however very little known (fragmentation)
Investigate : exclusive reconstruction of $\bar{B}^0 \to \Lambda_c^+ \bar{\Lambda} K^-$

Dataset:

- 471.10^6 $B\bar{B}$
- MC simulation: non-resonant signal

Reconstruction modes:

- $\Lambda_c^+ \to pK^-\pi^+$
- $\bar{\Lambda} \to \bar{p}\pi^+$
- PID crucial :
- $\varepsilon_\pi(\pi)$=95%, ε_π (K) < 2%
- ε_K (K)=90%, $\varepsilon_K(\pi)$ = 5%

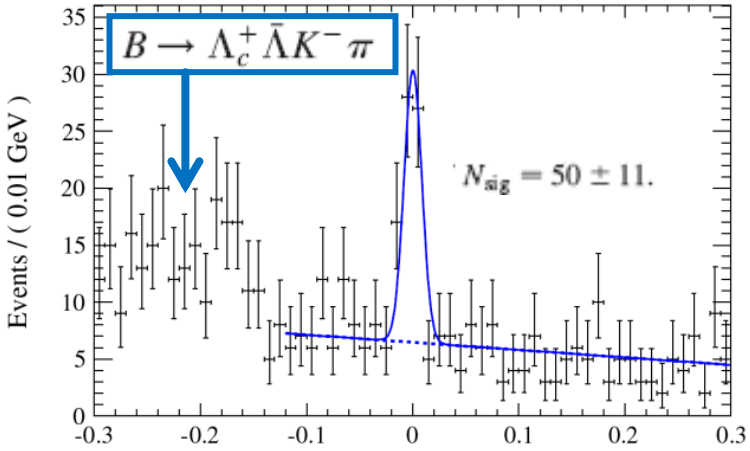
Published in PRD 84, 071102 (2011)

Main Backgrounds:

- $\bar{B}^0 \to \Lambda_c^+(\bar{p}\pi^+)K^-$
- Transverse flight length of $\Lambda > 0.4$cm
- $\bar{B}^0 \to \Lambda_c^+ \bar{\Sigma}^0 K^-$, $\bar{\Sigma}^0 \to \bar{\Lambda}\gamma$

Signal extraction:

- Fit of ΔE
- BF: signal not parametrized
- Signal = Data – Fitted background



Observation of $\bar{B}^0 \to \Lambda_c^+ \bar{\Lambda} K^-$

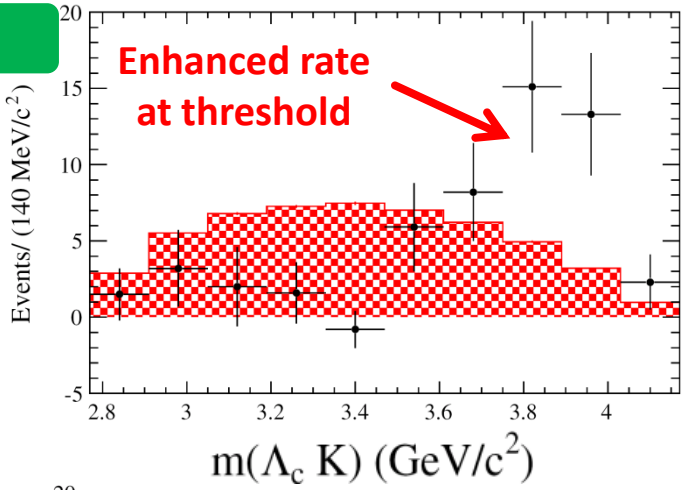
Search for resonance structure in 2-body spectrum

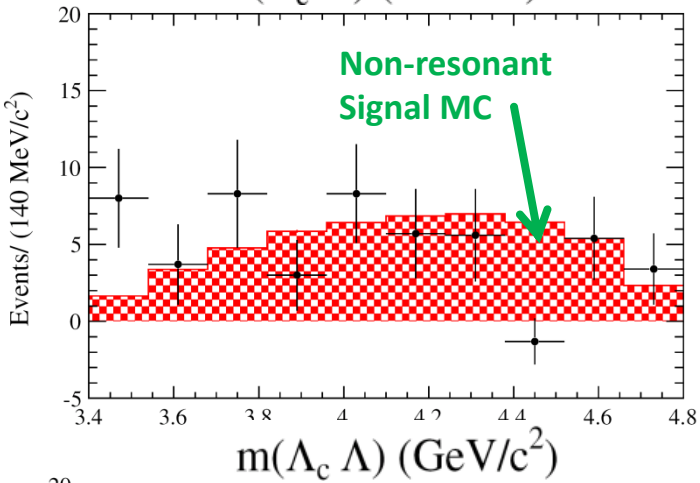
MC signal efficiency corrected with data

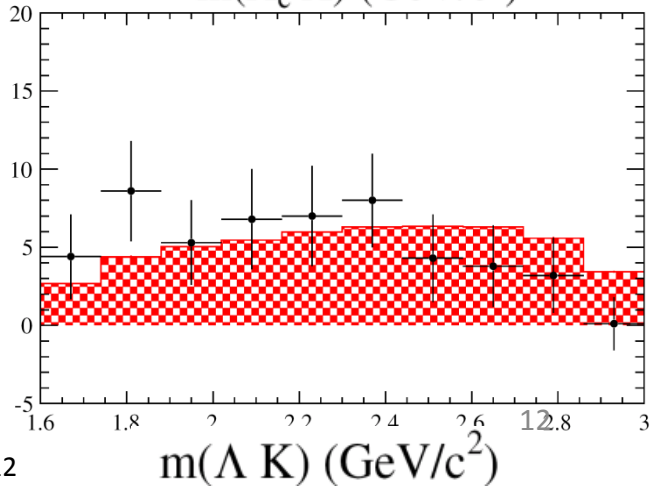
➔Iterative reweighting until reconstruction efficiency converges and data-MC agree within stat. unc.

Main systematics (%):

Particle identification	2.4
Baryonic background	2.1
ΔE background PDF	2.0
Total:	4.1







Results:

First observation of the baryonic decay $\bar{B}^0 \to \Lambda_c^+ \bar{\Lambda} K^-$ (>7σ)

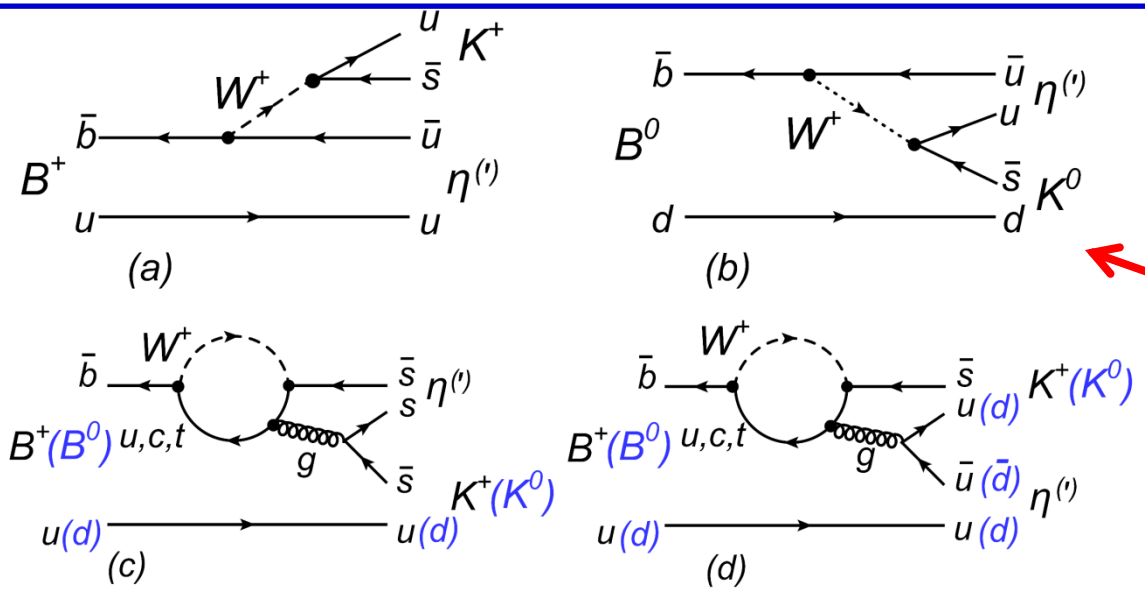
$$\mathcal{B}(\bar{B}^0 \to \Lambda_c^+ \bar{\Lambda} K^-) = (3.8 \pm 0.8_{\text{stat}} \pm 0.2_{\text{sys}} \pm 1.0_{\Lambda_c^+}) \times 10^{-5}$$

Resonant structure in $\Lambda_c^+ K^-$ mass

Published in PRD 84, 071102 (2011)

Charmless decay B→ η h± (h=π, K)

Charmless decays: **sensitive probes for CP violation**
Proceed through **tree & penguin** diagrams



Interference can lead to large direct CP asymmetry:

$$A_{CP} \equiv \frac{\Gamma[B^-(\overline{B}^0) \to \eta h^{-(0)}] - \Gamma[B^+(B^0) \to \eta h^{+(0)}]}{\Gamma[B^-(\overline{B}^0) \to \eta h^{-(0)}] + \Gamma[B^+(B^0) \to \eta h^{+(0)}]}$$

Large A_{CP} expected, but no clear prediction on A_{CP} sign…

BaBar PRD 80, 112002 (2009) : $A_{CP}(\eta K^+) = -0.36 \pm 0.11 \pm 0.03$.
Belle PRD 75, 071104 (2007) : $A_{CP}(\eta\pi^\pm) = -0.23 \pm 0.09(\text{stat}) \pm 0.02(\text{sys})$
$A_{CP}(\eta K^\pm) = -0.39 \pm 0.16(\text{stat}) \pm 0.03(\text{sys})$.

Now: 2.5x more data

Charmless decay B→ η h± (h=π, K)

Dataset:

- 772.10^6 $B\bar{B}$ (final Belle dataset)

Main Backgrounds:

- $e^+e^- \rightarrow q\bar{q}$
- Cross feed (MisID of π, K)

Reconstruction modes:

- $\eta \rightarrow \gamma\gamma$, $\pi^+\pi^-\pi^0$,
- $\pi^0 \rightarrow \gamma\gamma$
- $K_S \rightarrow \pi^+\pi^-$
- PID crucial: $\varepsilon_\pi(\pi)$=89-94% $\varepsilon_K(K)$=84%

Main systematics:

- MC's efficiency for η, π^0, K_S (1.8-4%)
- $n(B\bar{B})$ = 1.4 %
- Detector bias (0.8-1.4%)

Signal extraction:

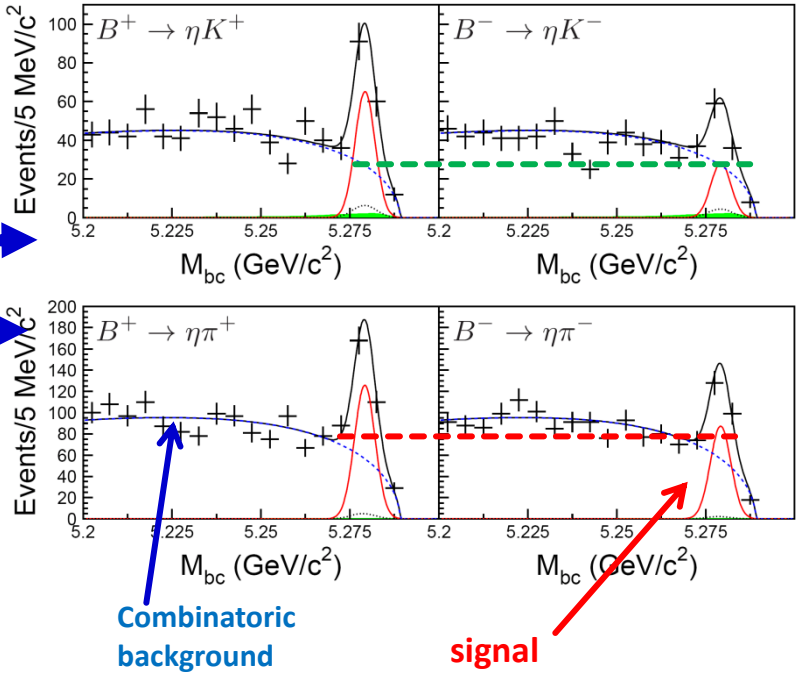
- 3D fit of { m_{bc}, ΔE, $\mathcal{L}$}
- $\mathcal{L}$ = likelihood with event topology variables
- → A_{CP} directly fitted for $B^\pm$

Charmless decay B→ η h± (h=π, K)

Results:

$$A_{CP}(B^{\pm} \to \eta K^{\pm}) = -0.38 \pm 0.11 \pm 0.01$$

$$A_{CP}(B^{\pm} \to \eta \pi^{\pm}) = -0.19 \pm 0.06 \pm 0.01.$$

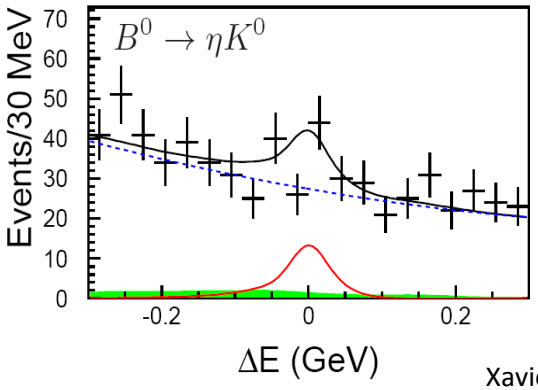


$$\mathcal{B}(B^0 \to \eta K^0) = (1.27^{+0.33}_{-0.29} \pm 0.08) \times 10^{-6}$$

$$\mathcal{B}(B^{\pm} \to \eta K^{\pm}) = (2.12 \pm 0.23 \pm 0.11) \times 10^{-6}$$

$$\mathcal{B}(B^{\pm} \to \eta \pi^{\pm}) = (4.07 \pm 0.26 \pm 0.21) \times 10^{-6}$$

First observation of $B^0 \to \eta K^0$ (5.4σ)



arXiv:1110.2000v1 [hep-ex], accepted by PRL

B→Kπ

Single diagram contribution *Nature 452, 332 (2008)*

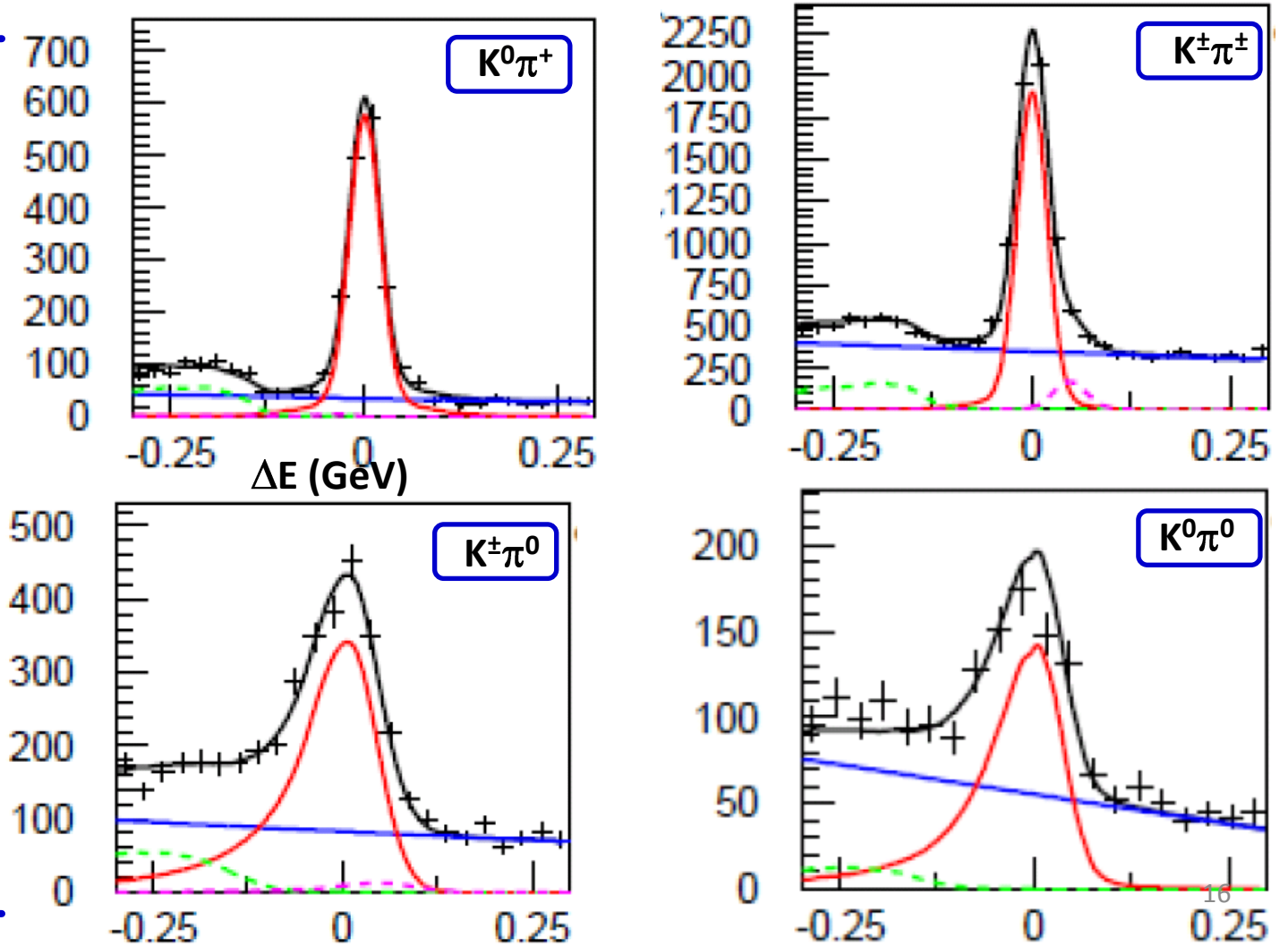
Previous measured **A_{CP} compatible with zero** (552.10^6 $B\bar{B}$)

Preliminary

Dataset: 772.10^6 $B\bar{B}$ (final Belle dataset) + Improved tracking

Similar analysis to B→ηh(h=π,K)

Fitted ΔE (GeV) distributions in data



B→Kπ

Preliminary

$K^{\pm}\pi^0$ BF = (12.62 ± 0.31 ± 0.56).10^{-6}
A_{CP} = 0.043 ± 0.024 ± 0.002

$K^{\pm}\pi^{\pm}$ BF = (20.00 ± 0.34 ± 0.63).10^{-6}
A_{CP} = -0.069 ± 0.014 ± 0.007

$K^0\pi^+$ BF = ($23.97^{+0.53}_{-0.52}$ ± 0.69).10^{-6}
A_{CP} = -0.014 ± 0.021 ± 0.006

$K^0\pi^0$ BF = (9.66 ± 0.46 ± 0.49).10^{-6}
A_{CP} needs time dependant fit

No evidence of direct CPV, as expected from a single dominant diagram

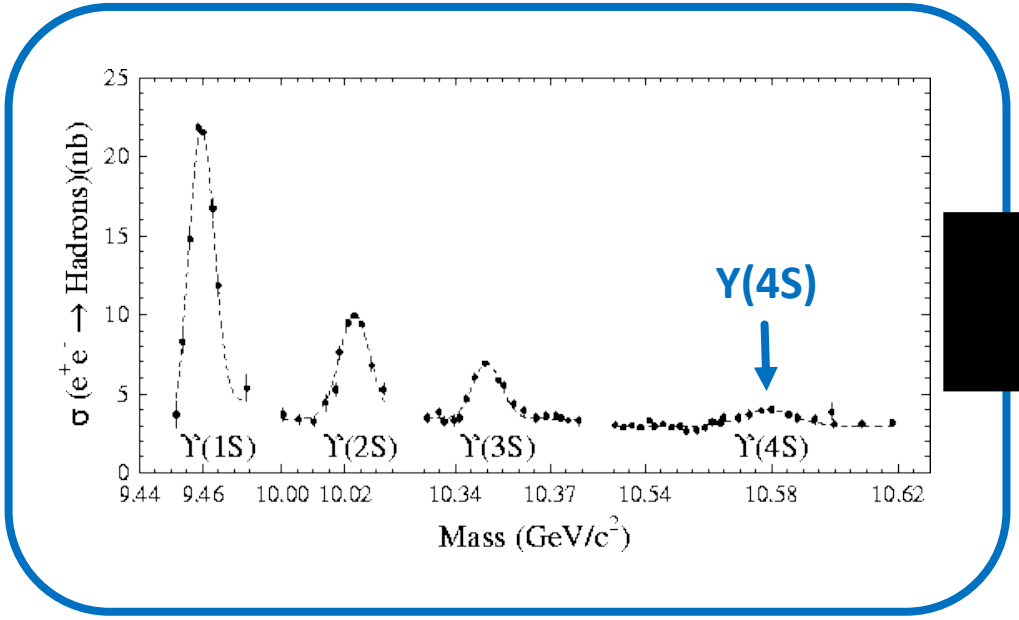
Consistent with results from BaBar, CDF, LHCb

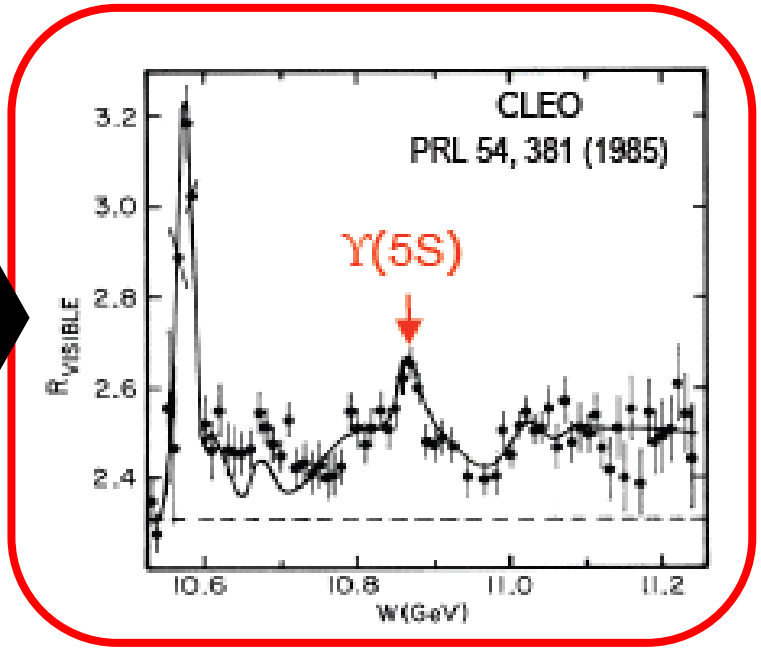
Width ratios can be compared to **SM predictions from SU(3) symmetry**

Buras et al. EPJC 45, 701 (2006)

Mode	Belle 2011	SM
$2\Gamma(K^+\pi^0)/\Gamma(K^0\pi^+)$	1.05 ± 0.03 ± 0.05	1.15 ± 0.05
$\Gamma(K^+\pi^-)/2\Gamma(K^0\pi^0)$	1.08 ± 0.08 ± 0.08	1.12 ± 0.05

Let‘s switch now to Y(5S) resonance and B_s mesons…





$B^0_s \to J/\Psi f_0$

$B \to c\bar{c}s$ ($B_s \to J/\Psi\phi$) have **large BF**
Used for measurement of **$\Delta\Gamma(B^0_s)$, CPV phase β_s**
Require angular analysis (**Scalar → Vector Vector**)

Promising channel: $B_s \to J/\Psi\ f_0$
No angular analysis required (**Scalar → Vector Scalar**)

Predicted BF (Leading order QCD): $(3.1 \pm 2.4).10^{-4}$
Ratio ($B_s \to J/\Psi\ f_0$) / ($B_s \to J/\Psi\ \phi$) expected in [0.2, 0.5] from $D_s \to f_0/\phi$

Dataset:
121.4/fb @Y(5S)(final Belle dataset)

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

87%
→ $\#(B_s^{*}\bar{B}_s^{*}) = (1.24 \pm 0.23)10^7$
Cut on m_{bc} rejects the others

$B^0_s \to J/\Psi f_0$

Reconstruction modes:

- $f_0 \to \pi^+\pi^-$
- $J/\Psi \to e^+e^-/\mu^+\mu^-$

  $\varepsilon(e,\mu)\sim 100\%$, $\varepsilon_{ID}(\pi)=96\%$

Main Backgrounds:

- $e^+e^- \to q\bar{q}$: event topology
- $B\bar{B}$: simulated sample of Y(5S)

Signal extraction:

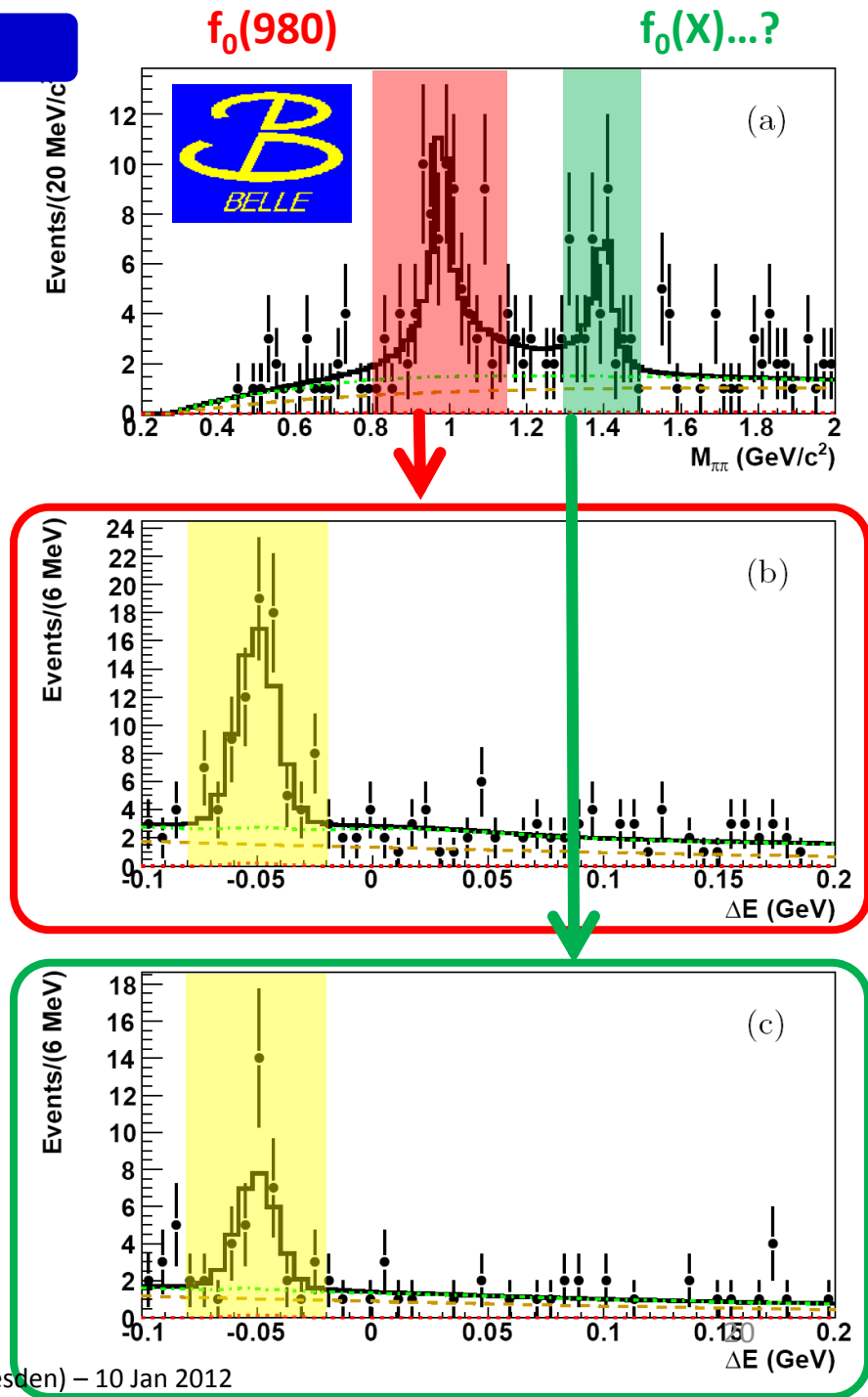
- 2D unbinned MLL fit of ΔE x $m(\pi^+\pi^-)$
- **$f_0(X)$: m = 1405 MeV, Γ = 54 MeV ➔ $f_0(1370)$?**

Possibility of another scalar resonance not excluded

Main systematics:

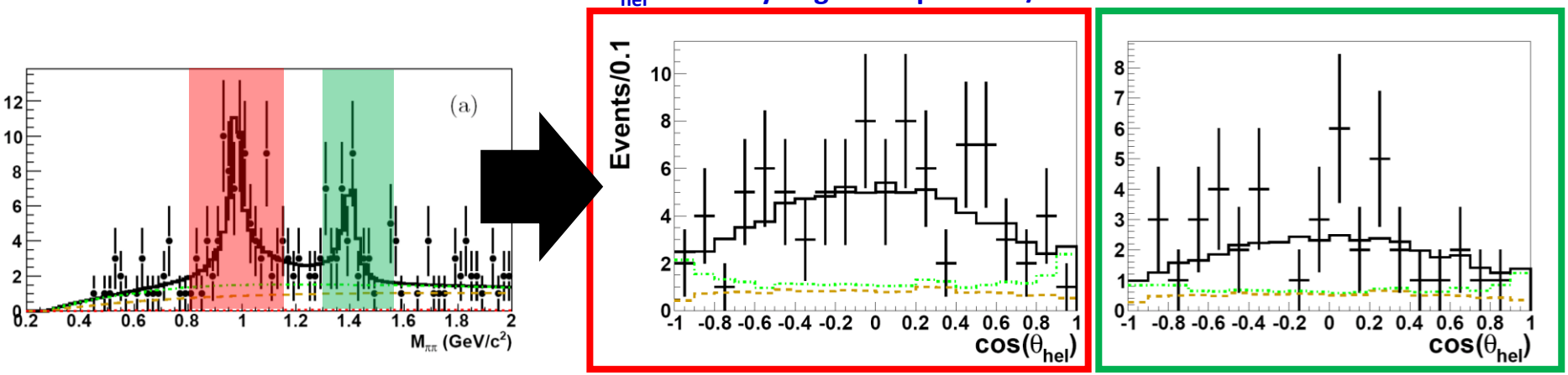
- fit PDF (0.4 – 14%)
- $\#(B_s^* B_s^*)$ -16 +22 %

Total: -17+26%



$B^0_s \to J/\Psi f_0$

θ_{hel} = Helicity angle of lepton in J/Ψ rest frame



Distribution compatible with scalar ππ resonances

Results:

First observation of $B^0_s \to J/\Psi f_0(980)$, *(LHCb: arXiv:1102.0206v2 [hep-ex])*

Evidence of $B^0_s \to J/\Psi f_0(1370)$

BF in agreement with theoretical expectation

Mode	Yield	Significance	$\mathcal{B}(B^0_s \to J/\psi F; F \to \pi^+\pi^-)$
$B^0_s \to J/\psi f_0(980)$	63^{+16}_{-10}	8.4σ	$(1.16^{+0.31}_{-0.19}(\text{stat.})^{+0.15}_{-0.17}(\text{syst.})^{+0.26}_{-0.18}(N_{B^{(*)}_s \bar{B}^{(*)}_s})) \times 10^{-4}$
$B^0_s \to J/\psi f_0(1370)$	19^{+6}_{-8}	4.2σ	$(0.34^{+0.11}_{-0.14}(\text{stat.})^{+0.03}_{-0.02}(\text{syst.})^{+0.08}_{-0.05}(N_{B^{(*)}_s \bar{B}^{(*)}_s})) \times 10^{-4}$

New CP channel for the study of B_s mixing properties

Published in PRL 106:121802,2011

And another CP eigenstate…

$B_s \to J/\Psi\, \eta$

Dataset:

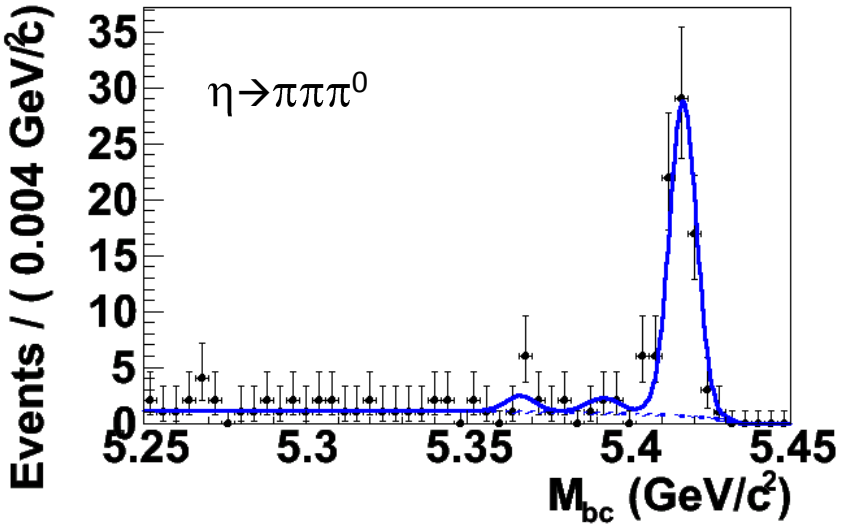
- 121.4/fb @Y(5S)(final Belle dataset)

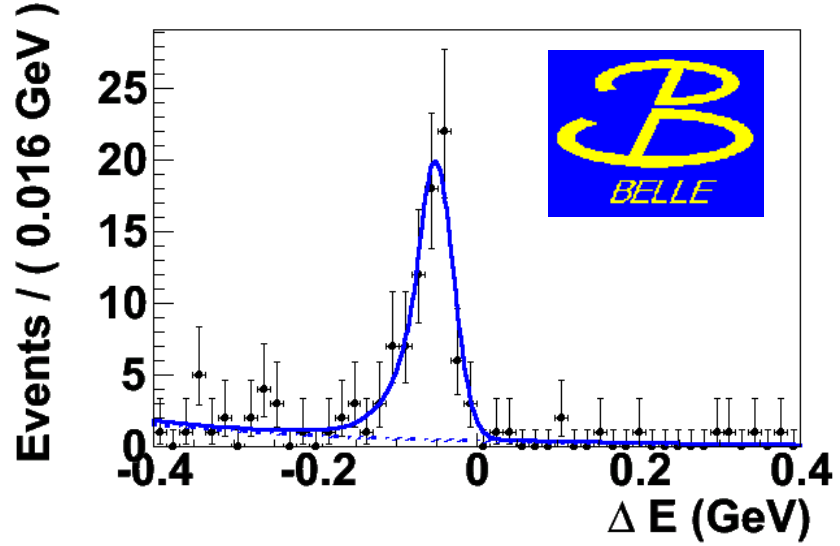
Reconstructed modes:

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

Signal extraction:

- 2D fit m_{bc} x ΔE





BF($B_s^0 \to J/\psi\eta$) =
(5.11 ± 0.50(stat.) ± 0.35(syst.) ± 0.68(f_s)) × 10^{-4}

Another *CP* eigenstate, whose time distribution can be used to measure directly the B_s^0 width difference $\Delta\Gamma_s$.

http://belle.kek.jp/results/summer11/Bs_JpsiEta/

Conclusion

Measurement of the BF of color-suppressed decays $\bar{B}^0 \to D^{(*)0} h^0$, $h^0 = \pi^0, \eta, \eta', \omega$

Presence of final state interaction not described by the QCD factorization

Data seems to favor SCET

First study of the $\bar{B}^0 \to D^{*0}\omega$ polarization

Clear deviation from HQET prediction for the longitudinal fraction

Non-trivial long distance effect ? Expected by SCET

Observation of $B^0 \to \bar{\Lambda}_c^+ \Lambda K^-$

Enhancement at phase space threshold

Charmless decay $B \to \eta h^{\pm}$ ($h = \pi, K$)

Measurements of BF

Large & negative direct CP asymmetry observed

First observation of $B^0 \to \eta K^0$ (5.4σ)

Charmless decay $B \to K\pi$

BF measured, ratios compatible with SU(3) expectations

Direct CP asymmetry compatible with zero as expected

Three new CP eigenstates for the study of Bs mixing properties :

$B^0_s \to J/\Psi f_0(980)$, $B^0_s \to J/\Psi f_0(1370)$, $B^0_s \to J/\Psi \eta$

➔ **B factories pave the way for LHC !**


Thank you for
your Attention