Analysis of the decay channel $B^0 \rightarrow \psi(2S)\pi^0$ with Belle

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- Physics Motivation
- Belle Experiment
- Study of the decay $B^0 \rightarrow \psi(2S)\pi^0$
- Summary and outlook

Max-Planck-Institut für Physik
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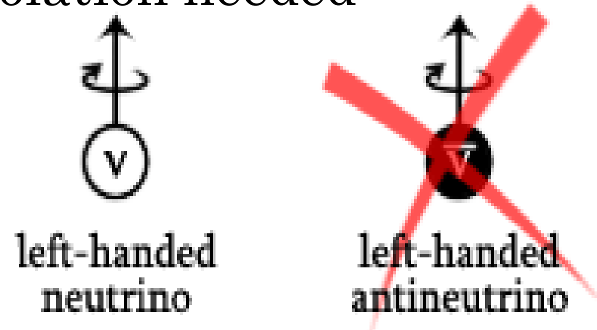
Physics Motivation

Standard Model is successful but not complete

- Cannot explain the **Dark Matter**
- Assumes massless **Neutrinos**
- Insufficient explanation of the **Matter-Antimatter Asymmetry**

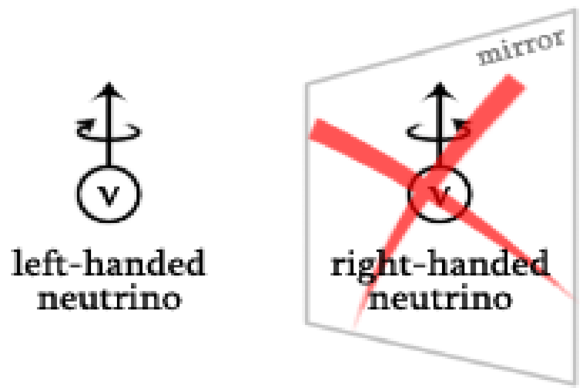
Matter-antimatter asymmetry ➡ **CP** Violation needed



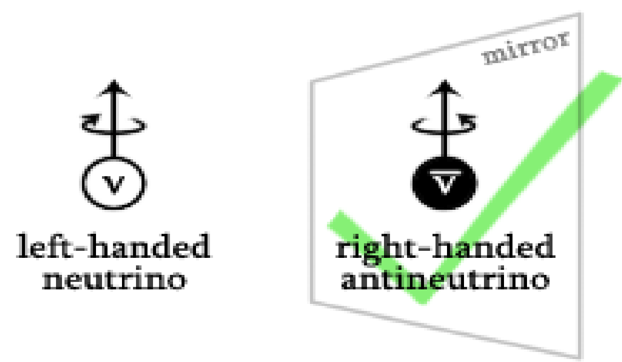
CP is a product of two symmetries

C (charge conjugation) and

P (parity)



CP transformation =
Charge Conjugation x **P**arity Transformation



CP Violation in the Standard Model

CP violation in the Standard Model ⇨ Cabibbo-Kobayashi-Maskawa (CKM)mechanism ⇨ relation between the weak and the mass eigenstates

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = V^{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

V_{ij} : quark flavor transition couplings

$$V^{CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & -A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

Wolfenstein parametrization

$\lambda = \sin\theta_C \approx 0.22 (Cabibbo \quad angle)$

4 free parameters:

- 3 real parameters
- 1 complex phase

CKM matrix is unitary

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

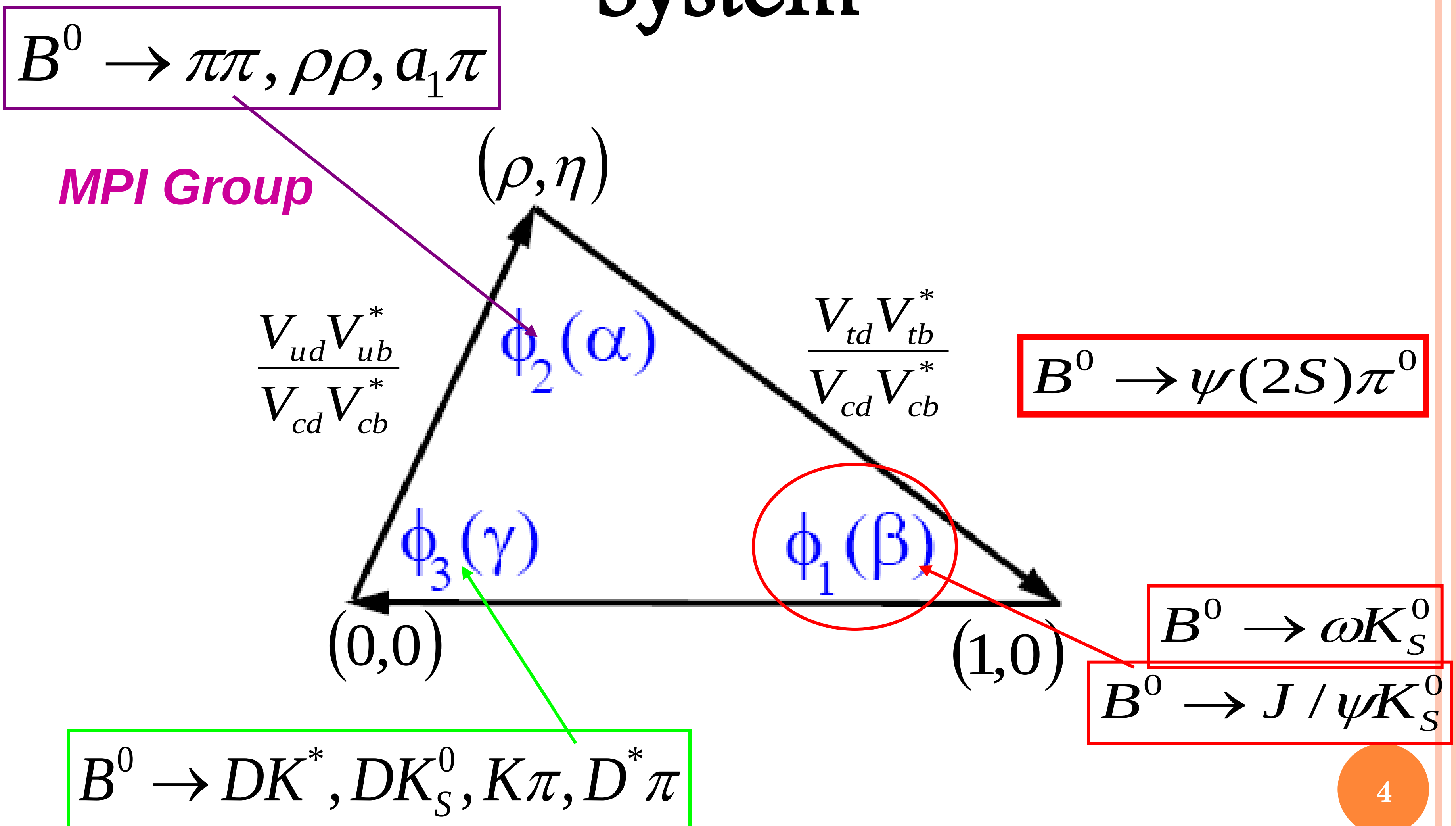
$O(\lambda^3)$ $O(\lambda^3)$ $O(\lambda^3)$

relevant for the B meson system

Sides with similar size ⟶ large angles

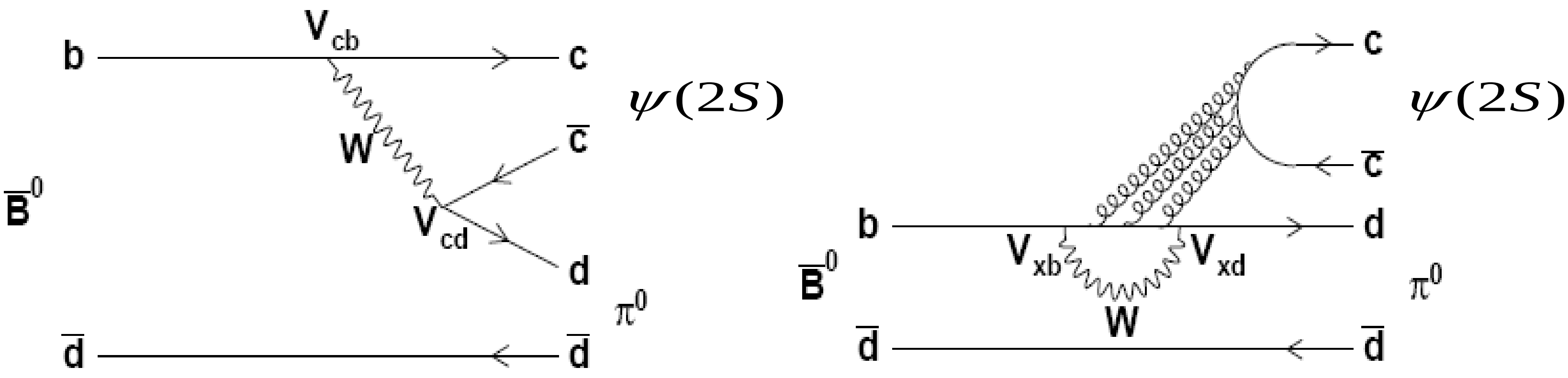
5 observables (2 sides, 3 angels)

Unitarity Triangle in the B Meson System



Confirm SM or hint for New Physics

$B^0 \to \psi(2S)\pi^0 \ (b \to (c\bar{c})d)$



$$M_{tree} \propto V_{cb} * V_{cd}^{*} \propto \lambda^2 * \lambda \propto \lambda^3 \qquad M_{penguin} \propto V_{tb} * V_{td}^{*} \propto \lambda^3 * 1 \propto \lambda^3$$

Matrix elements

Additional motivation to study charmonium $b \to (c\bar{c})d$

Using the result from $B^0 \to \psi(2S)\pi^0$ and SU(3) symmetry the penguin pollution to $B^0 \to \psi(2S)K_S^0$ can be estimated

For the tree amplitude

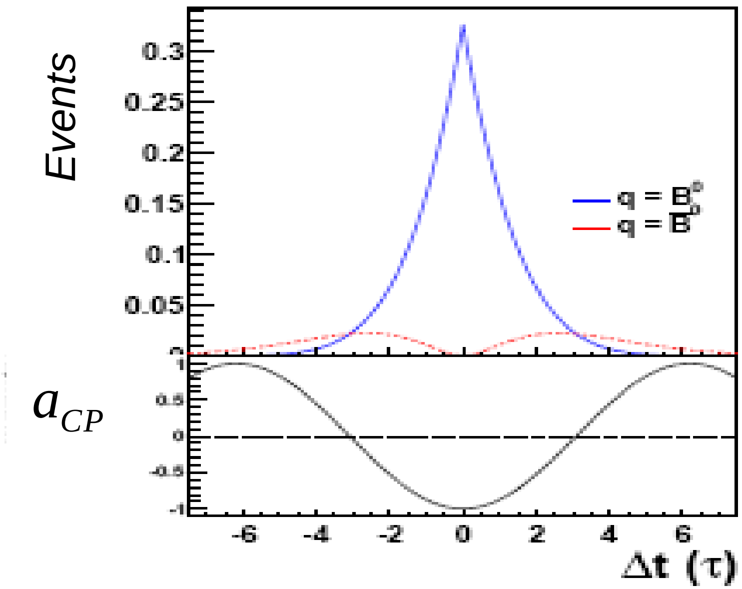
- $A_{CP} = 0$
- $S_{CP} = \sin 2\phi_1$

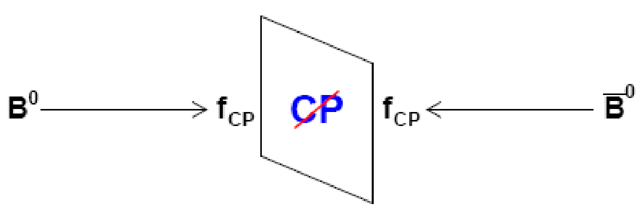
CP Violation in the B meson system

Time-dependent CP asymmetry

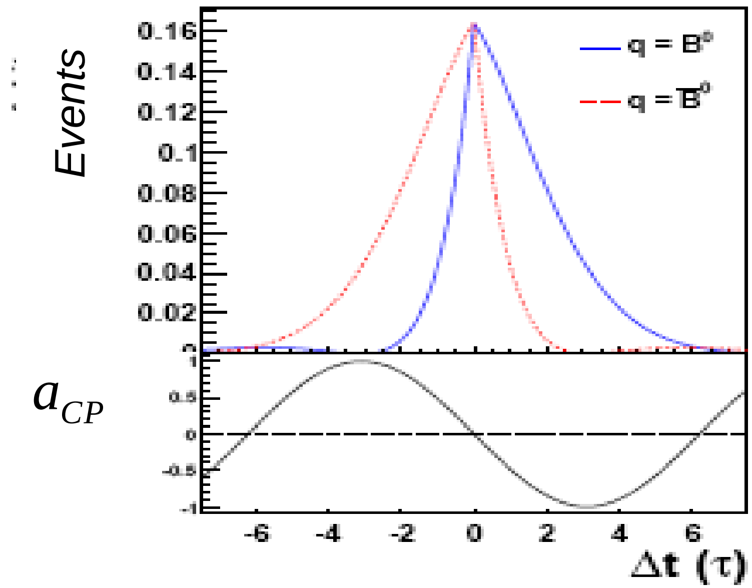
$$a_{CP}(\Delta t, f_{CP}) = \frac{N_{\bar{B}^0}(\Delta t, f_{CP}) - N_{B^0}(\Delta t, f_{CP})}{N_{\bar{B}^0}(\Delta t, f_{CP}) + N_{B^0}(\Delta t, f_{CP})} = A_{CP}\cos(\Delta m \Delta t) + S_{CP}\sin(\Delta m \Delta t)$$

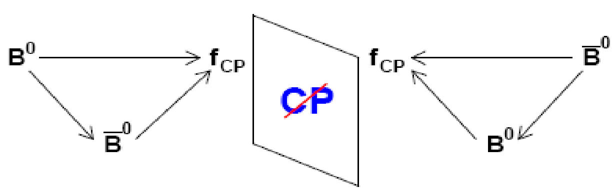
A_{CP} ➡ **direct** CP violation
different decay rates



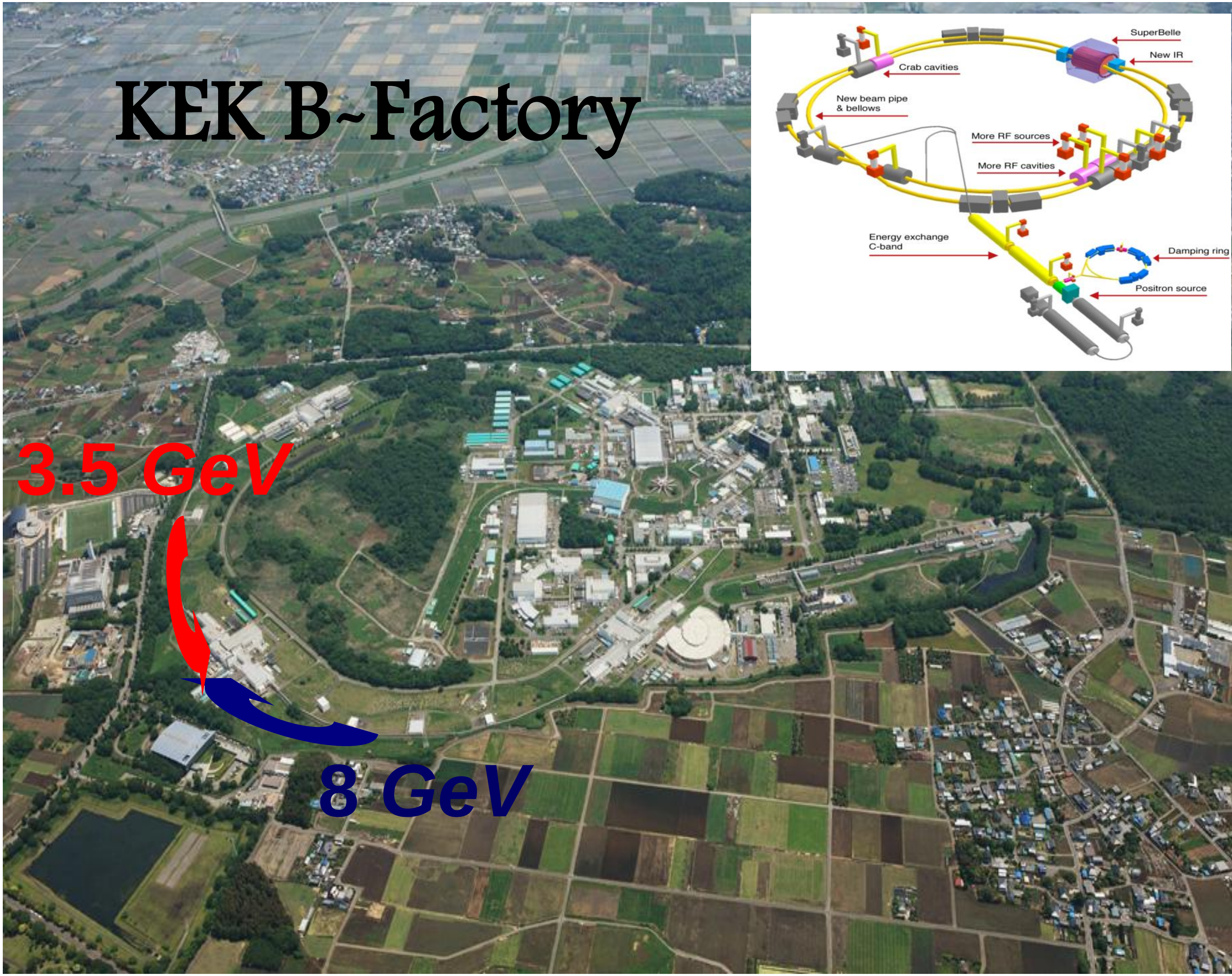


S_{CP} ➡ **indirect** CP violation
different time evolution

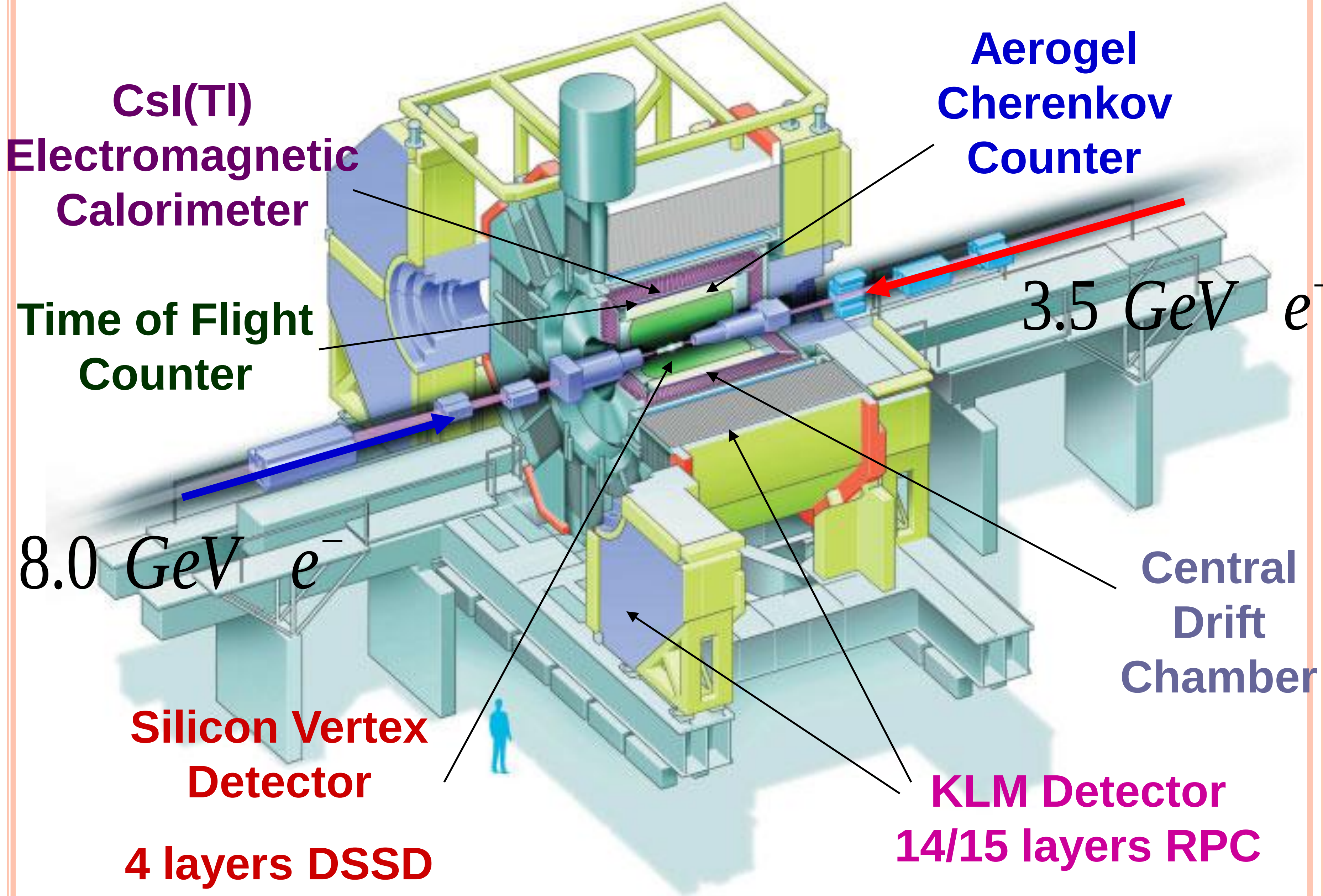




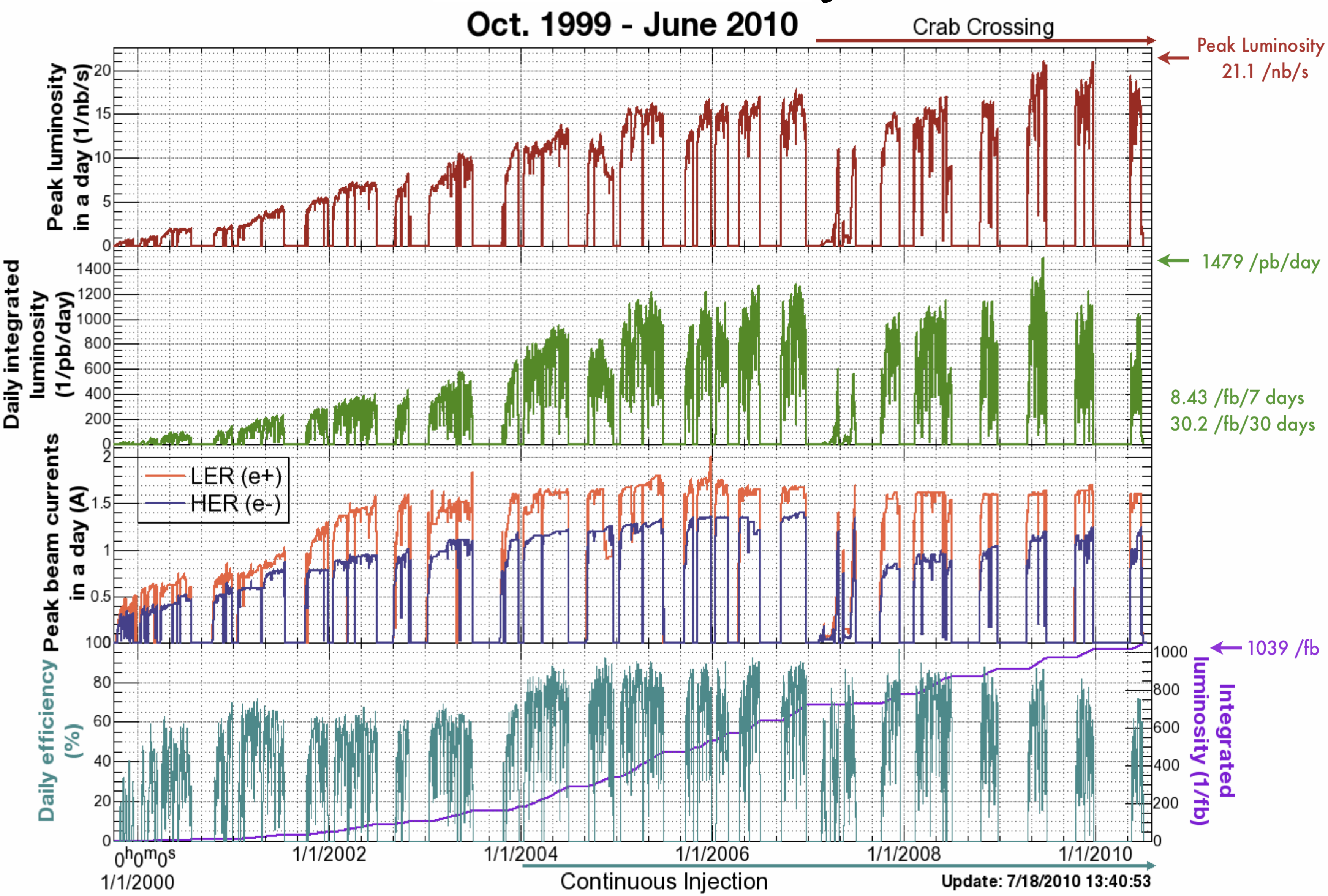
KEK B~Factory



Belle Detector



The development of the expected luminosity



B Meson Production

Υ(4S) resonance decays ➞ into $B\bar{B}$ pair

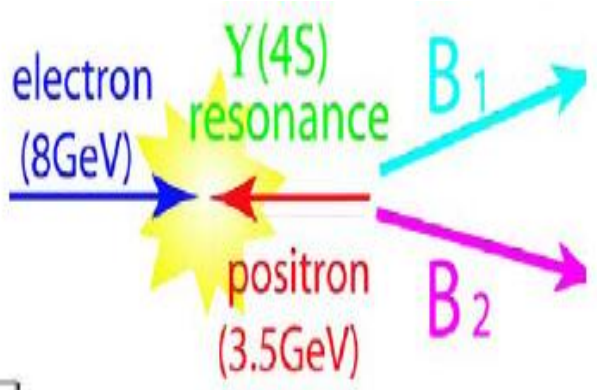
Υ(4S): $J^{PC} = 1^{--}$

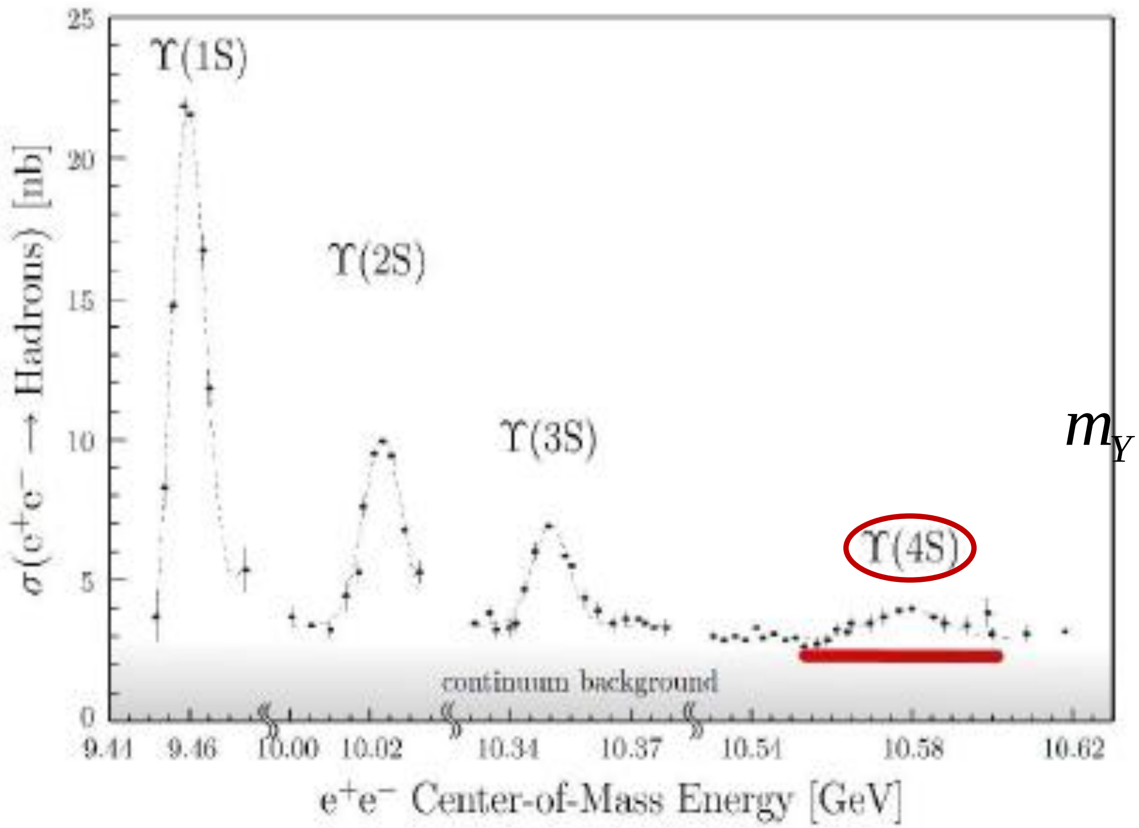
B: $J^{P} = 0^{-}$

➡ B meson pair in a p-wave

Asymmetric wave function

➡ B mesons have opposite flavor



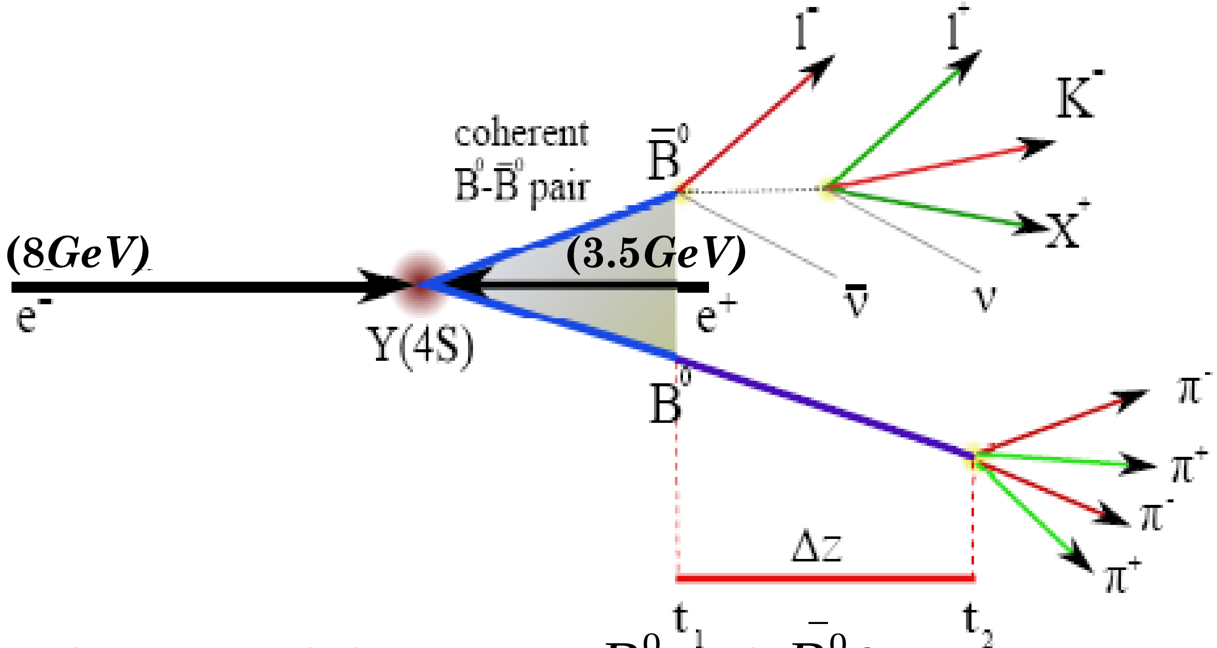


B meson pair in an entangled state

$$m_{Y(4S)} = 10.58 GeV/c^2 \approx 2 \times m_B$$

$$m_B = 5.28 GeV/c^2$$

CP Violation Measurement Principle



Tag side

CP side

How to distinguish between B^0 **and** $\bar{B}^0$ **?**

- if l^- ⟶ $\bar{B}^0$ on the Tag side
  ⟶ B^0 on the CP side
- if l^+ ⟶ B^0 on the Tag side
  ⟶ $\bar{B}^0$ on the CP side

Measurement of the time difference

$$\Delta t \approx \frac{\Delta z}{\langle \beta\gamma \rangle c}$$

Asymmetric beam energies at KEKB
⟶ boost of the center of mass system
Measure ⟶ $\Delta z \sim 100\mu m \Rightarrow \Delta t \sim ps$

Data Treatment

$$B^0 \rightarrow \psi(2S)\pi^0$$

$$\psi(2S) \rightarrow e^+e^-, \mu^+\mu^-, J/\psi\pi^+\pi^-$$

$$\pi^0 \rightarrow \gamma\gamma$$

$$J/\psi \rightarrow e^+e^-, \mu^+\mu^-$$

- Generate events

Blind:

- Develop an algorithm to reconstruct the decay
- Study the shape of the signal and the background
- Build a fit to discriminate the signal and the background
- Test the performance of the fit (bias?)

Data Treatment

Control Sample:

- Look at the data
- Choose a channel as close as possible to the decay in question
- Cross check the model developed for MC on data

Real Data:

- Look at the data
- Apply the model developed for MC on data
- Measure the branching fraction for $B^0 \to \psi(2S)\pi^0$

Signal Monte Carlo study

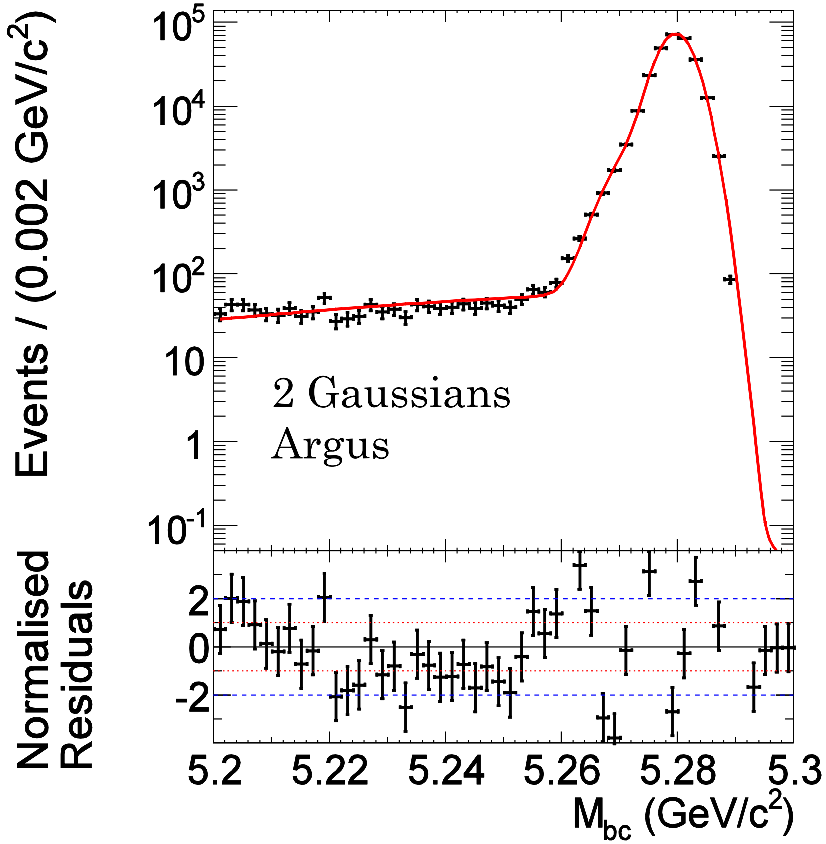
Reconstructed B mesons – described by:

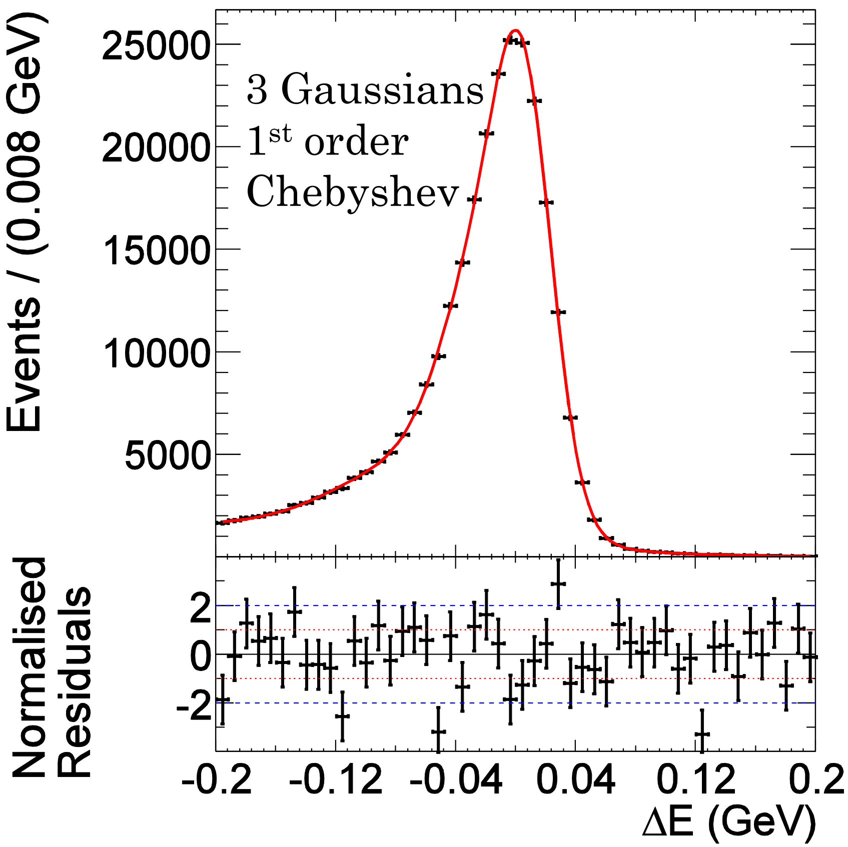
$$M_{BC} = \sqrt{(E_{beam}^{CMS})^2 - (p_B^{CMS})^2}$$

$$5.2 GeV/c^2 < M_{BC} < 5.3 GeV/c^2$$

$$\Delta E = E_B^{CMS} - E_{beam}^{CMS}$$

$$-0.2 GeV < \Delta E < 0.2 GeV$$

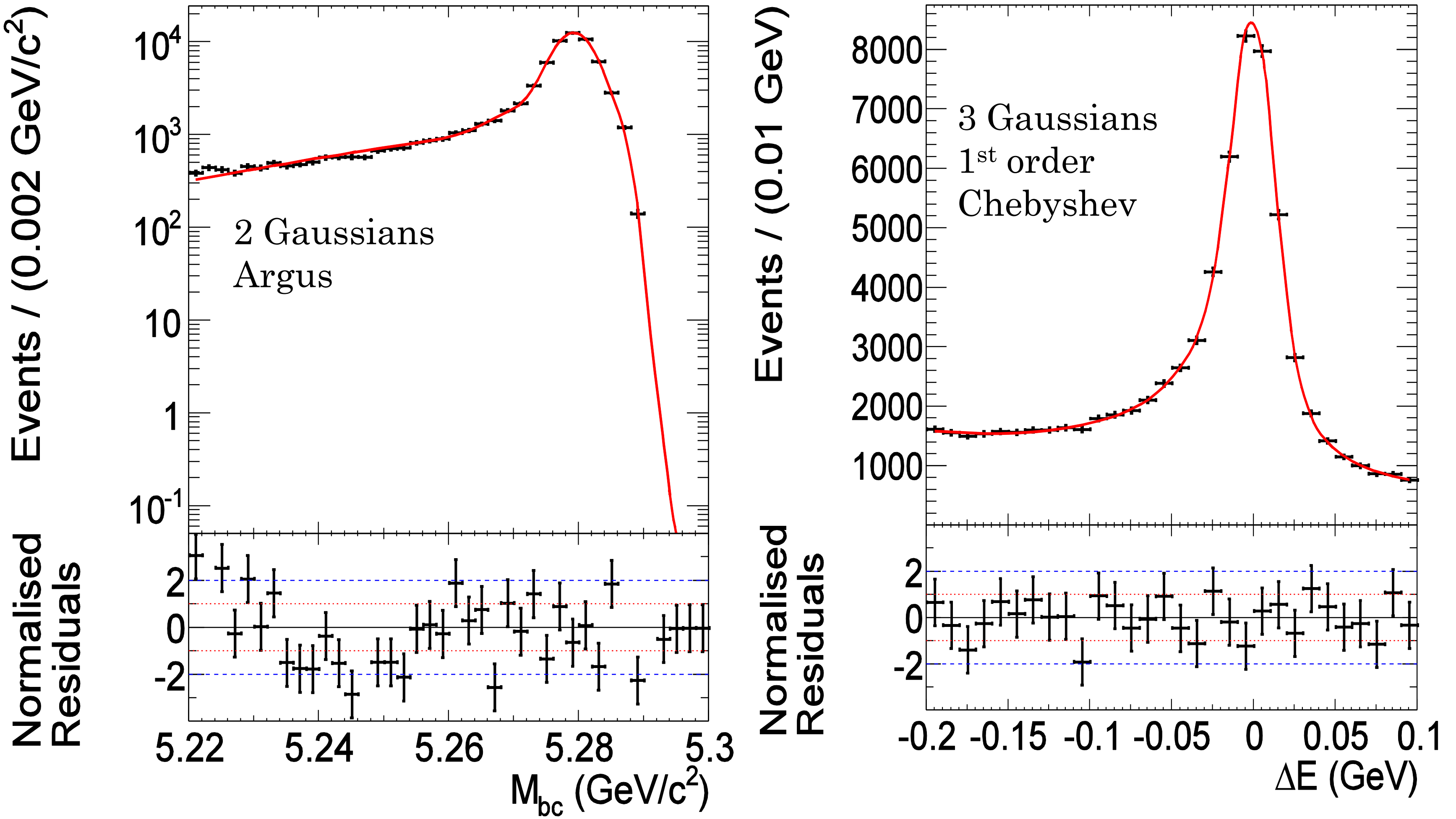




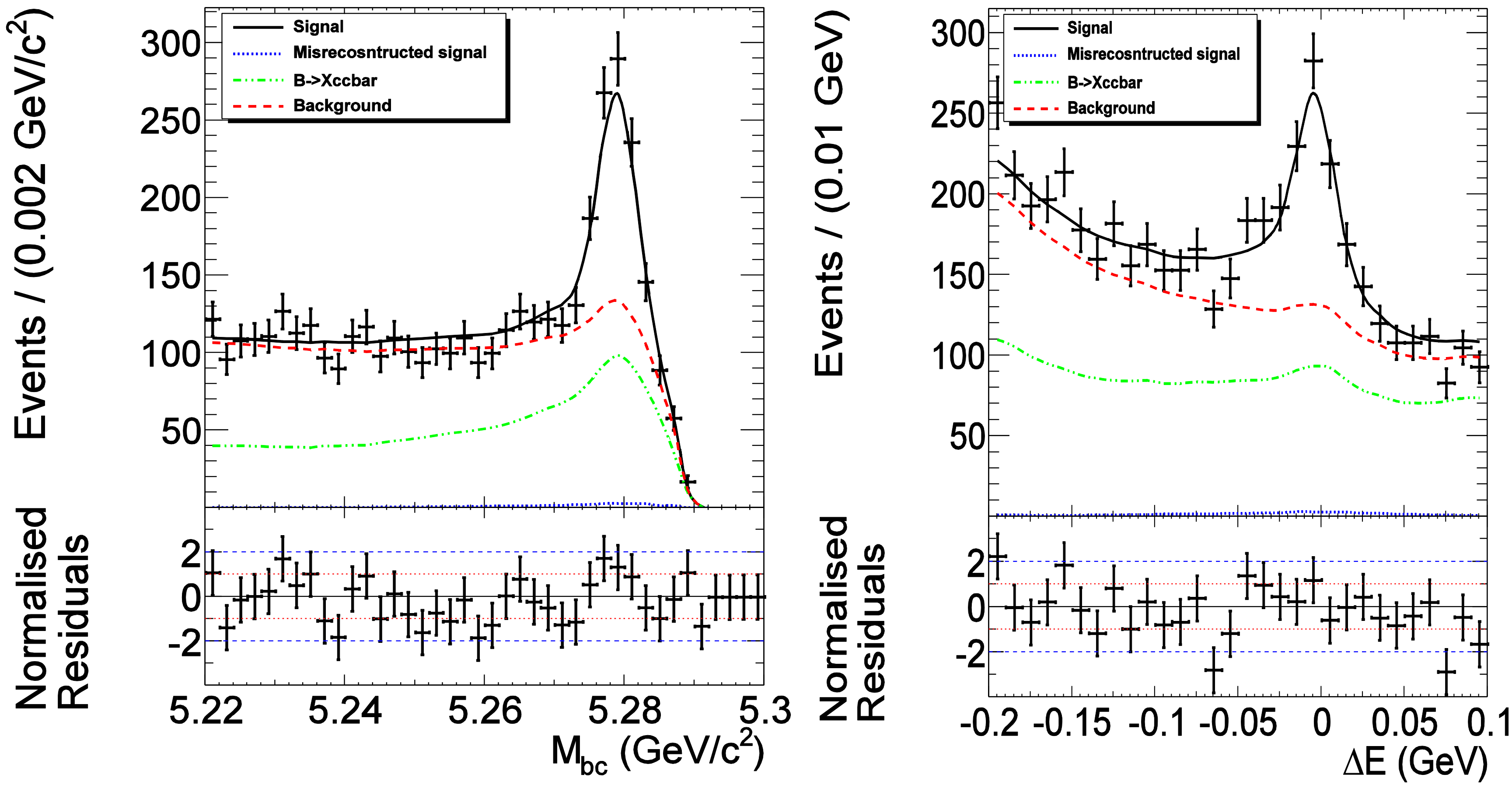
Control Sample

$$B^+ \to \psi(2S)K^{*+}$$

$$K^{*+} \to K^+\pi^0$$



Branching fraction – Control Sample



Measurement:

$$Br(B^{+} \to \psi(2S)K^{*+}) = (7.3 \pm 0.5) \times 10^{-4}$$

PDG:

$$Br(B^{+} \to \psi(2S)K^{*+}) = (6.1 \pm 1.2) \times 10^{-4}$$

Summary and outlook

- $B^0 \to \psi(2S)\pi^0$ helps to estimate the penguin pollution in $B^0 \to \psi(2S)K_S^0$, one of the “golden” modes
- Clean experimental signature and relatively small background
- Signal Monte Carlo studies
- Parametrise the distribution with functions
- Study the background from separate B decays
- Test the model with pseudo experiments
- Apply the model to the real data
- Measure the branching fraction
- World’s first measurement

Thank you for your attention

Backup

Reconstruction of $B^0 \to \psi(2S)\pi^0$

$$B^0 \to \psi(2S)\pi^0$$

$\psi(2S) \to e^+e^-, \mu^+\mu^-, J/\psi\pi^+\pi^-$; $\pi^0 \to \gamma\gamma$

$J/\psi \to e^+e^-, \mu^+\mu^-$

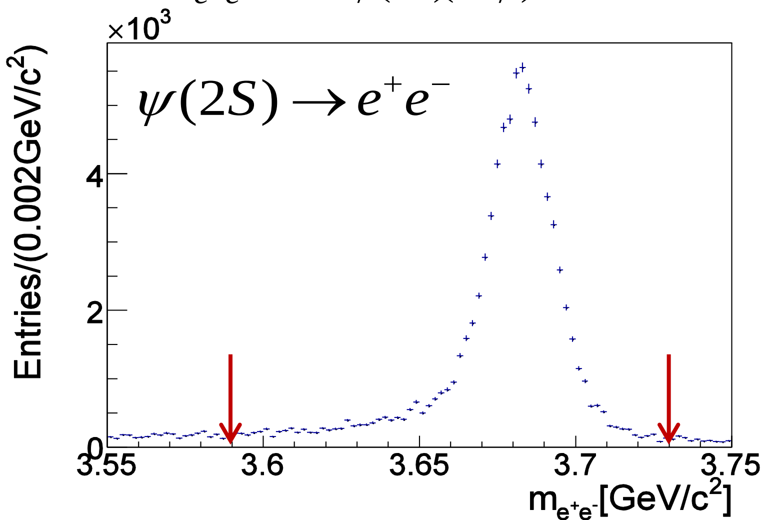
For the e^+e^- decay mode:

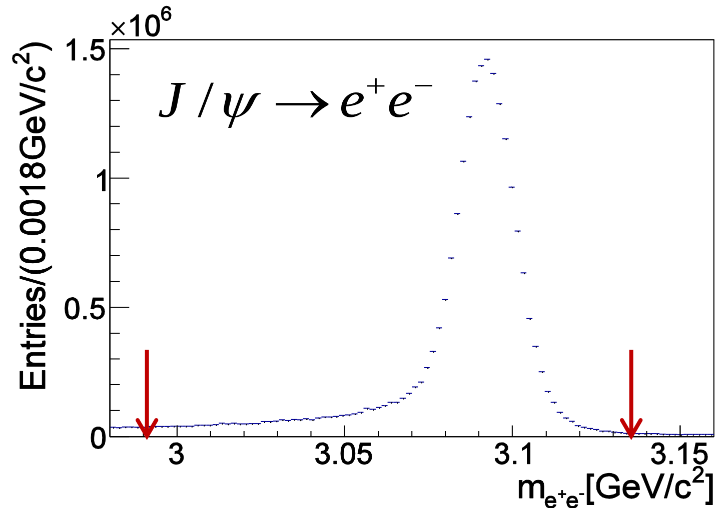
$eid.prob(3,-1,5) > 0.01$

$eid.prob(3,-1,5) > 0.01; \ eid.le\_eoverp() > 0.5 \,||\, eid.le\_dedx() > 0.5$

radiate photons – ECL clusters within 50 mrad of the e^+e^- tracks ➡ E< 3.5GeV

$-150 \le m_{e^+e^-} - m_{\psi(2S)(J/\psi)} \le 36 MeV/c^2$





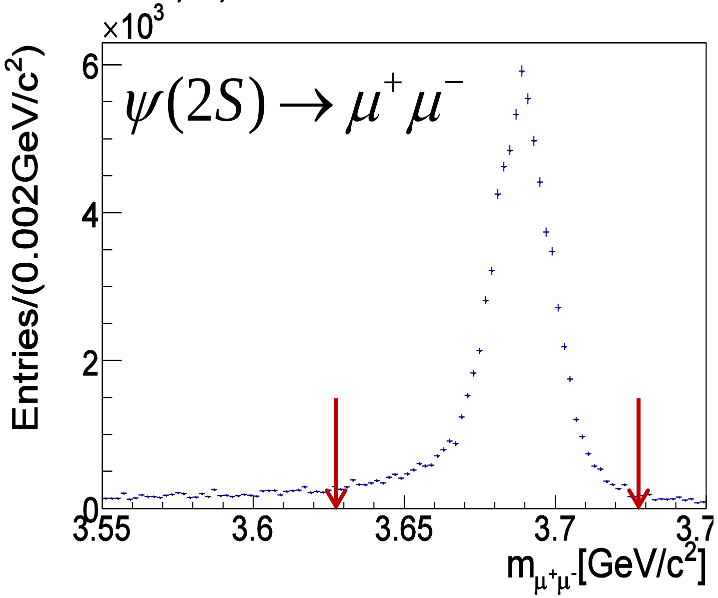
Reconstruction of $B^0 \to \psi(2S)\pi^0$

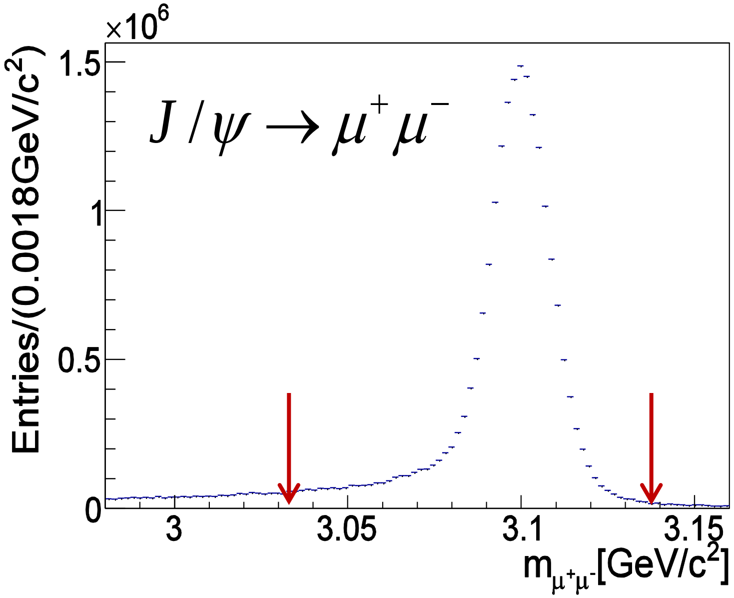
For the $\mu^+\mu^-$ decay mode:

$muid.Muon\_likelihood() > 0.1$

$muid.Muon\_likelihood() > 0.1;\ 0.1 < Energy(ECL) < 0.3GeV$

$-60 \le m_{\mu^+\mu^-} - m_{\psi(2S)(J/\psi)} \le 36MeV/c^2$



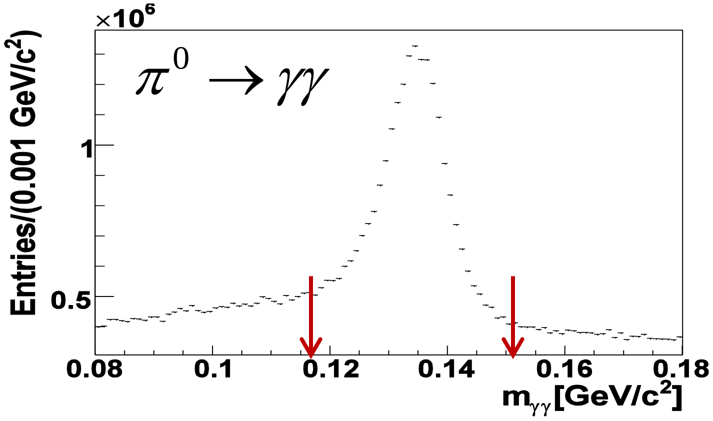


For the π^0 selection:

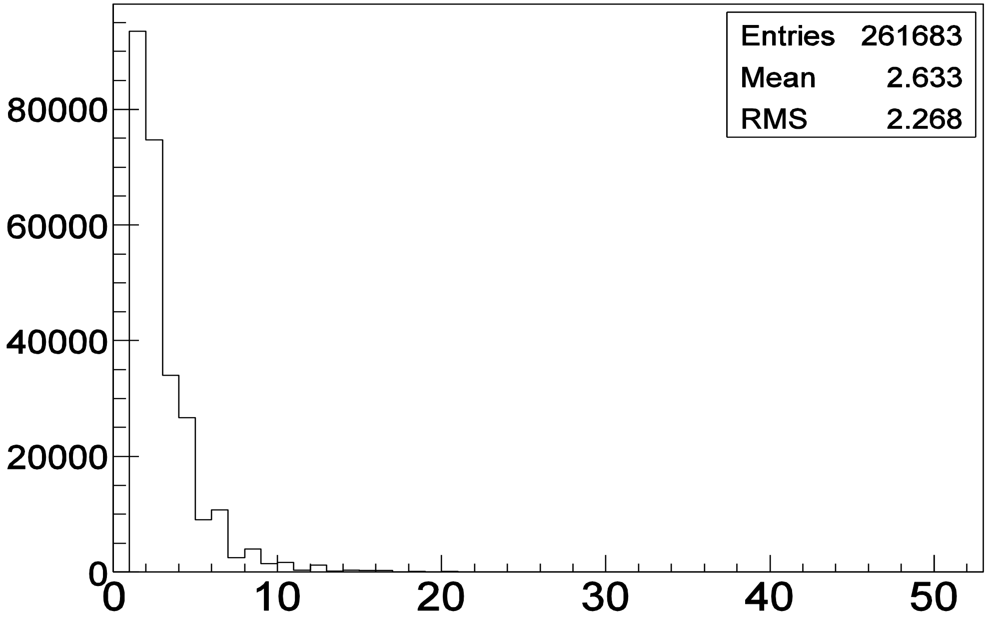
$E_\gamma > 0.05GeV\ (Barrel)$

$E_\gamma > 0.10GeV\ (Endcap)$

$0.118GeV/c^2 < m_{\gamma\gamma} < 0.150GeV/c^2$



Best B^0 selection



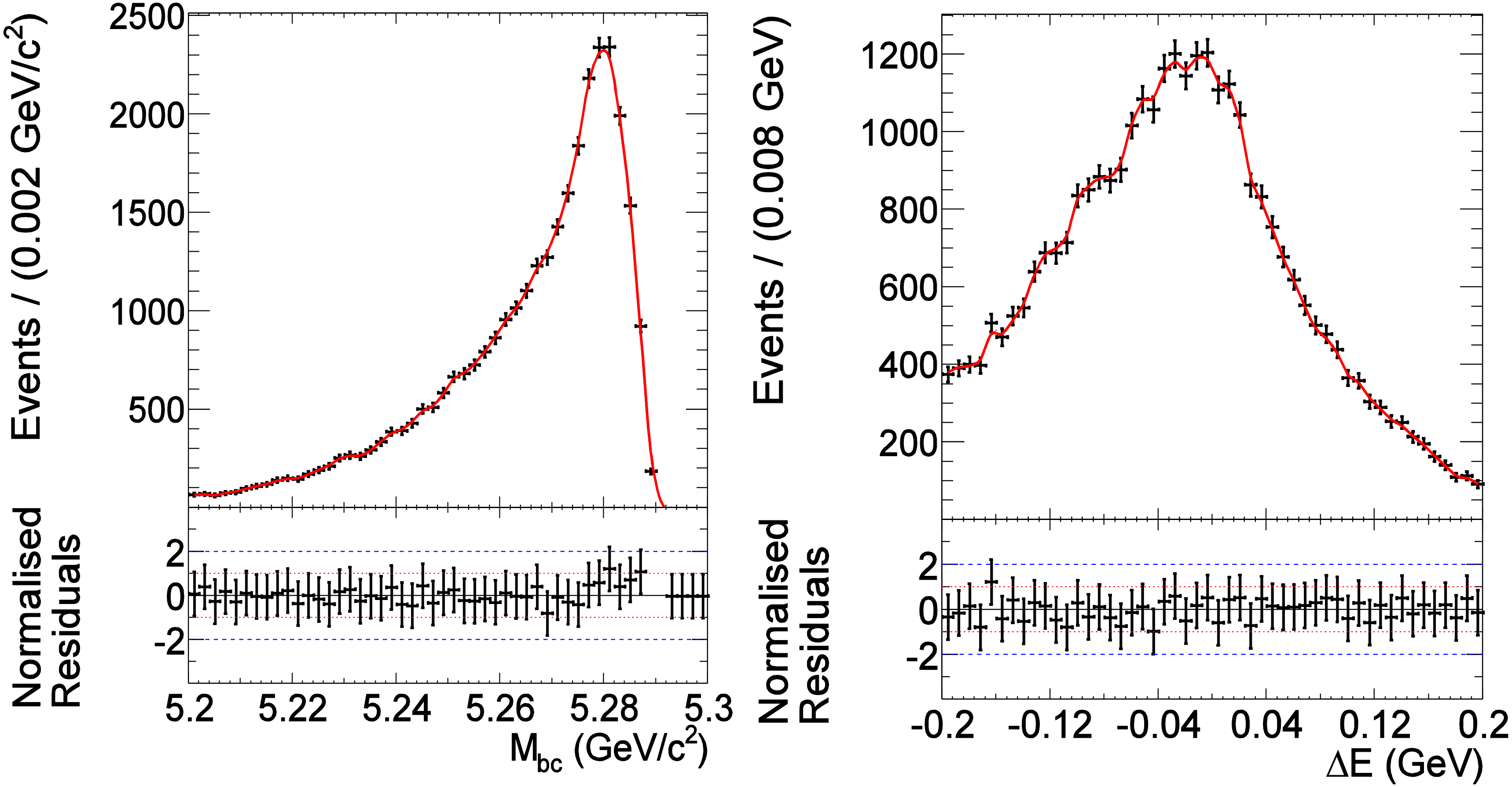
Number of B^0 per event = 2..6

$$\chi^2 = \left(\frac{m_{l^+l^-} - m_{\psi}}{\sigma_{l^+l^-}}\right)^2 + \left(\frac{m_{\gamma\gamma} - m_{\pi^0}}{\sigma_{\gamma\gamma}}\right)^2, \quad l = e, \mu$$

$$\chi^2 = \left(\frac{m_{\pi^+\pi^-} - (m_{\psi} - m_{J/\psi})}{\sigma_{\pi^+\pi^-}}\right)^2 + \left(\frac{m_{l^+l^-} - m_{J/\psi}}{\sigma_{l^+l^-}}\right)^2 + \left(\frac{m_{\gamma\gamma} - m_{\pi^0}}{\sigma_{\gamma\gamma}}\right)^2$$

- choose B meson with smallest χ^2

Misreconstructed Signal

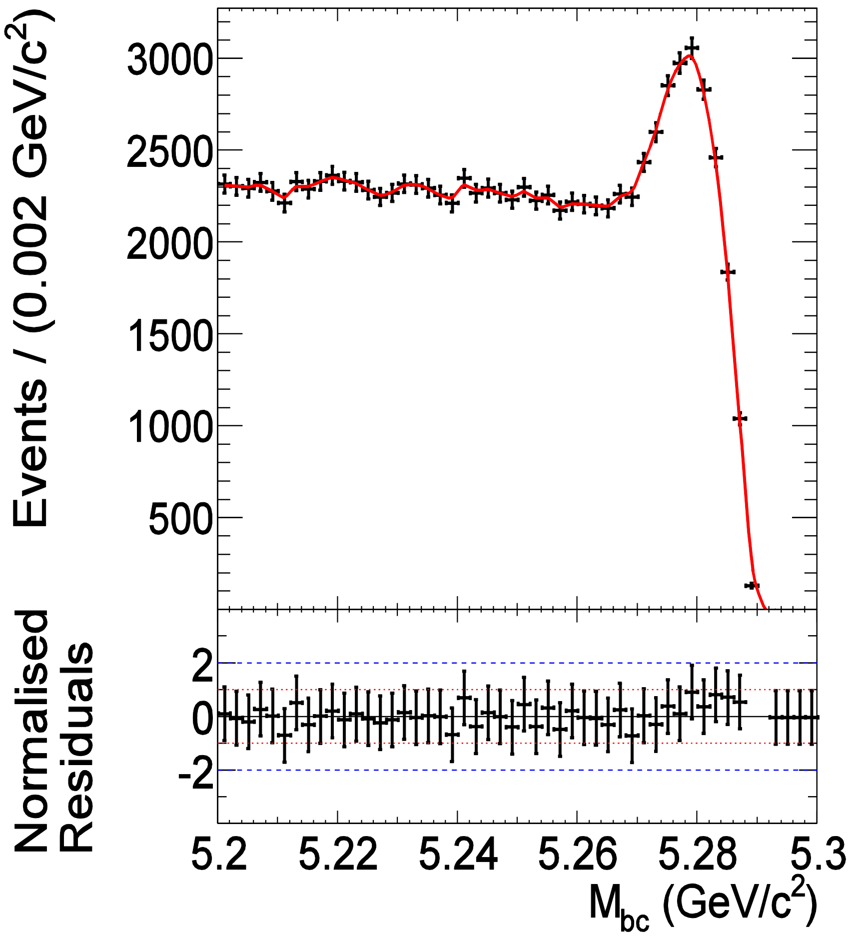


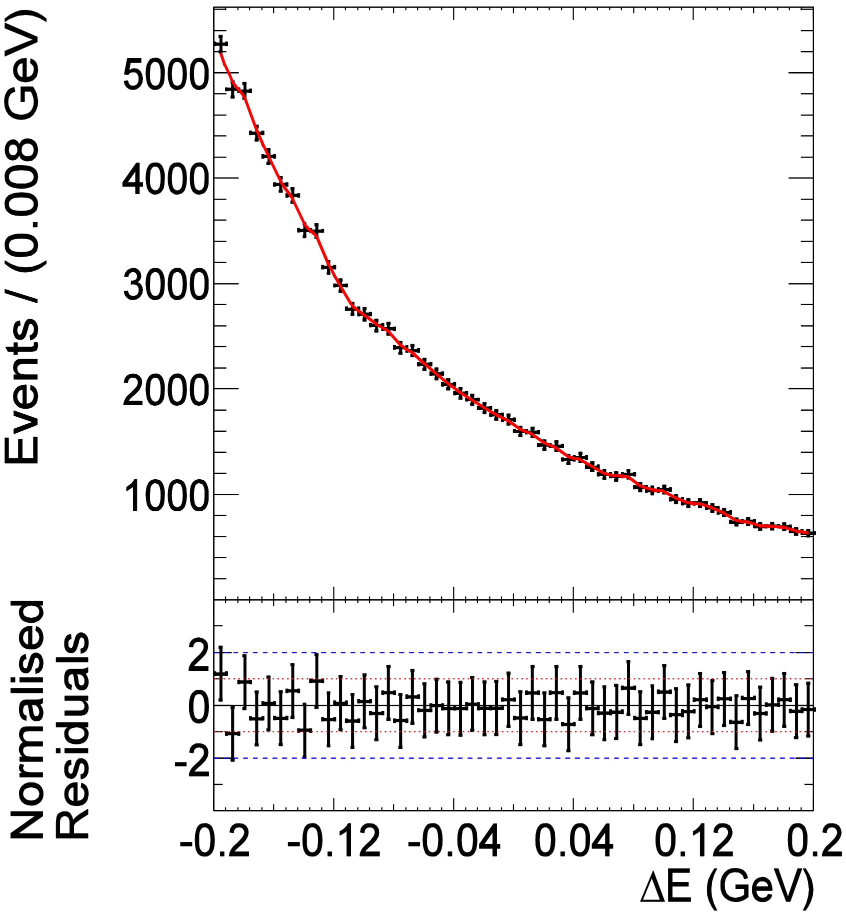
smoothed histogram PDFs

10 % misreconstructed particles

Background

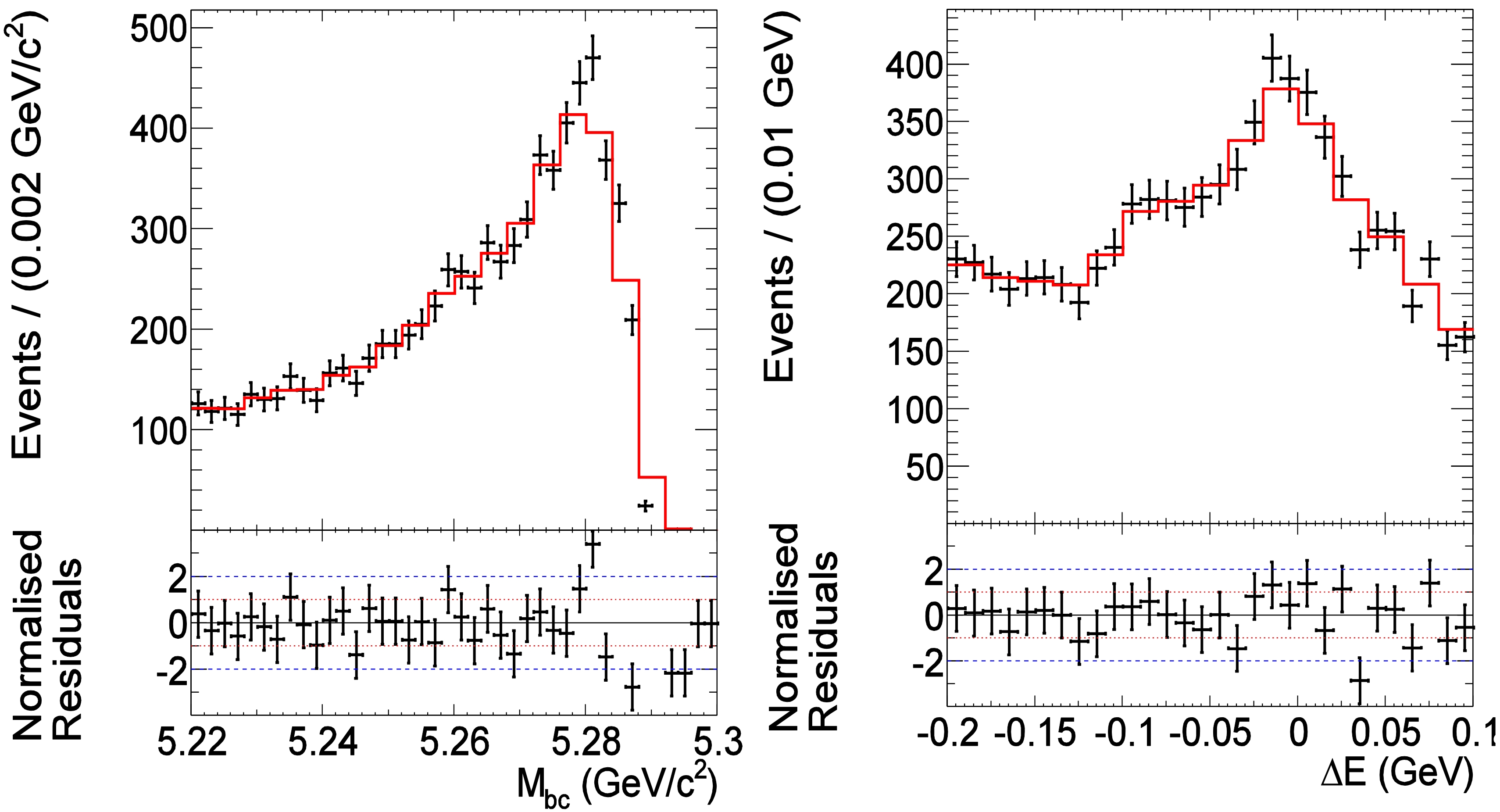
$B \rightarrow (c\bar{c})X$





smoothed histogram PDFs

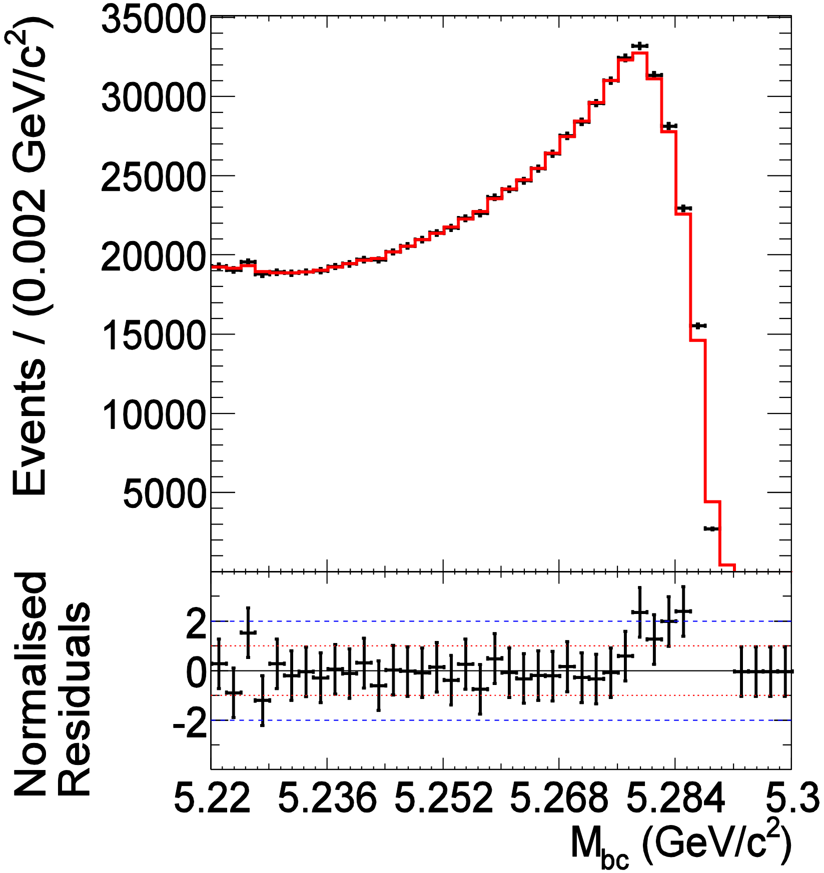
Control Sample~ Misreconstructed Signal

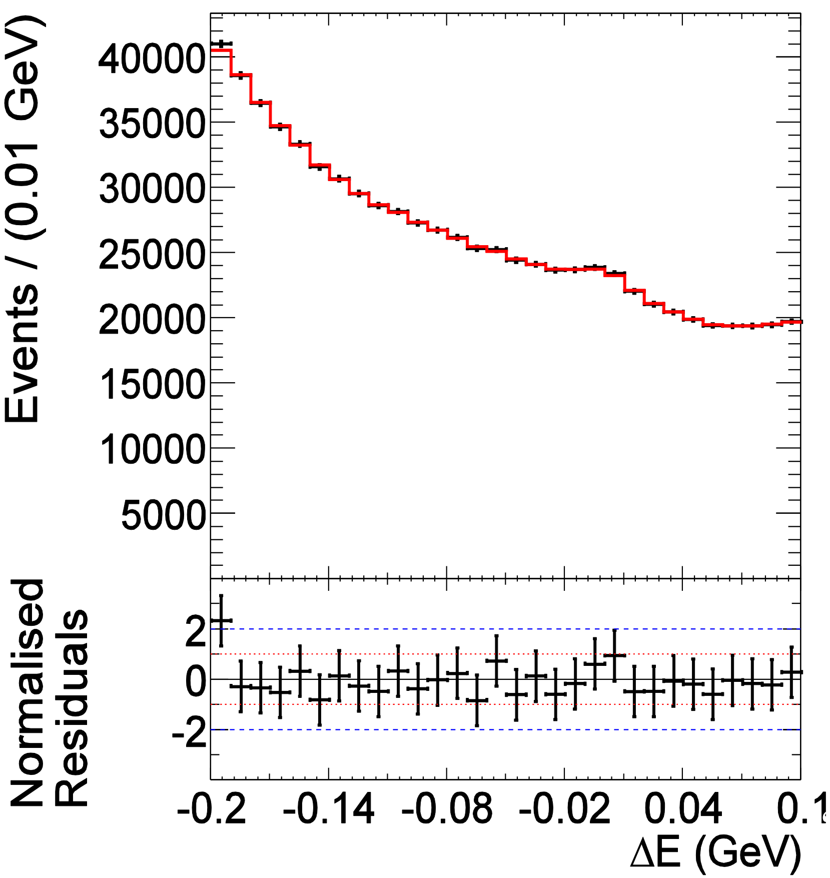


smoothed histogram PDFs

Control Sample ~Background

$B \rightarrow (c\bar{c})X$





smoothed histogram PDFs

Determination of the efficiency

$$B^0 \to \psi(2S)\pi^0$$

$\psi(2S) \to e^+e^-, \mu^+\mu^-, J/\psi\pi^+\pi^-$; $\pi^0 \to \gamma\gamma$

$J/\psi \to e^+e^-, \mu^+\mu^-$

Control Sample

$$B^+ \to \psi(2S)K^{*+}$$

$\psi(2S) \to e^+e^-, \mu^+\mu^-, J/\psi\pi^+\pi^-$; $K^{*+} \to K^+\pi^0$

$J/\psi \to e^+e^-, \mu^+\mu^-$

$SVD1:$

$$Eff\,(B^0 \to \psi(2S)\pi^0) = 0.0087 \pm 0.0003$$

$SVD2:$

$$Eff\,(B^0 \to \psi(2S)\pi^0) = 0.0106 \pm 0.0003$$

$SVD1:$

$$Eff\,(B^0 \to \psi(2S)K^{*+}) = 0.0018 \pm 3.36e-05$$

$SVD2:$

$$Eff\,(B^0 \to \psi(2S)K^{*+}) = 0.0024 \pm 4.17e-05$$