

Charmless hadronic B-decays from Belle



(<https://sfde16.0x1115.org/images/du-lich-quy-nhon-01.jpg>)

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School of Physics
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August 14, 2017

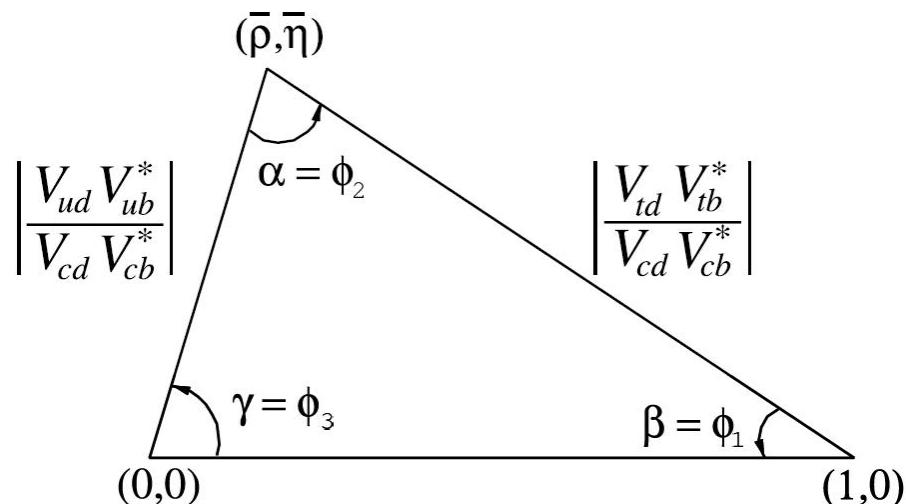
M. Sevior, Flavour Physics, ICISE,
Quy Nhon, Vietnam

Slide 1

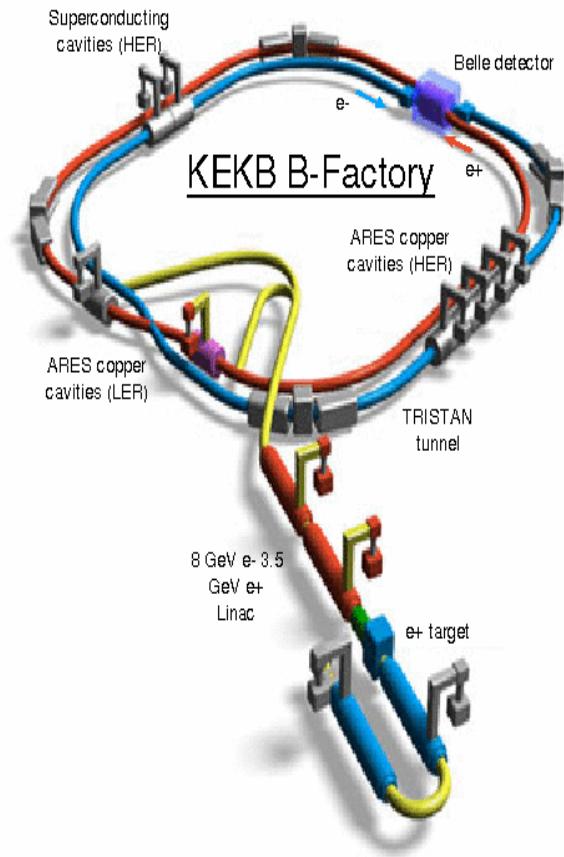
Outline

- $B^\pm \rightarrow K^+K^-\pi^\pm$, Branching Fraction, (\mathcal{B}), A_{CP}
- $B \rightarrow \pi^0\pi^0$ - $\mathcal{B}, A_{CP}, \phi_2$

$$A_{CP} = \frac{\mathcal{B}(B^- \rightarrow K^+K^-\pi^-) - \mathcal{B}(B^+ \rightarrow K^+K^-\pi^+)}{\mathcal{B}(B^- \rightarrow K^+K^-\pi^-) + \mathcal{B}(B^+ \rightarrow K^+K^-\pi^+)}$$

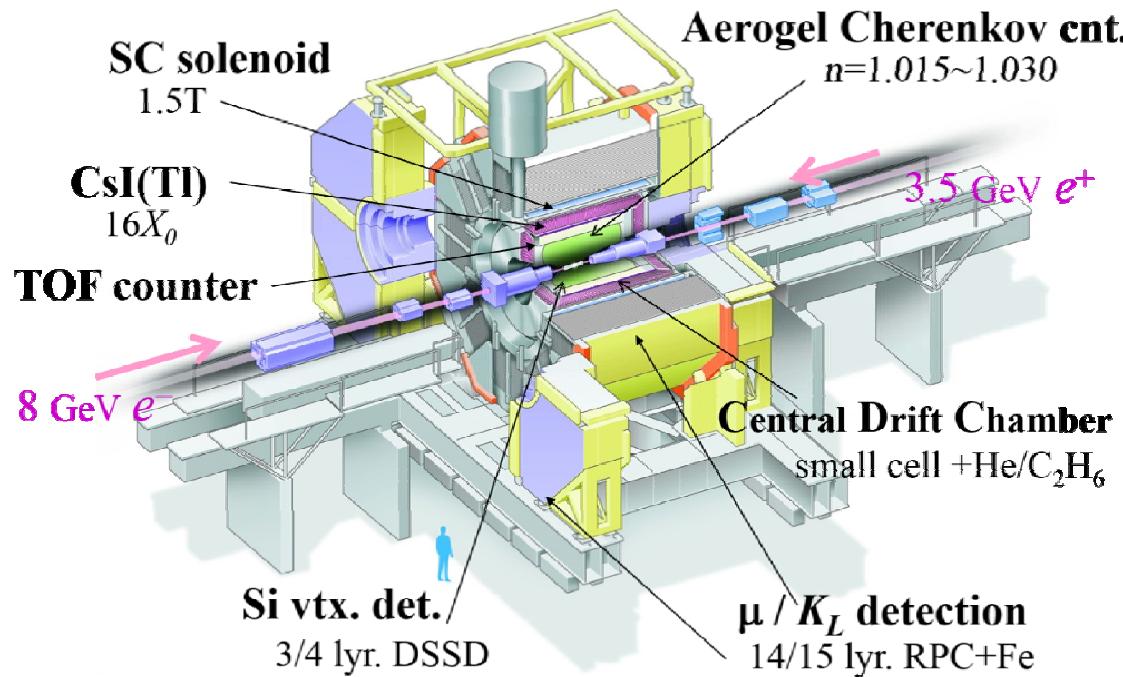


KEKB -Worlds most intense collider

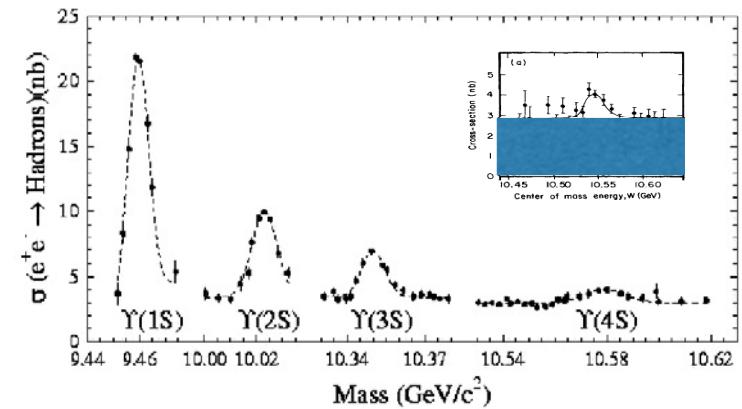
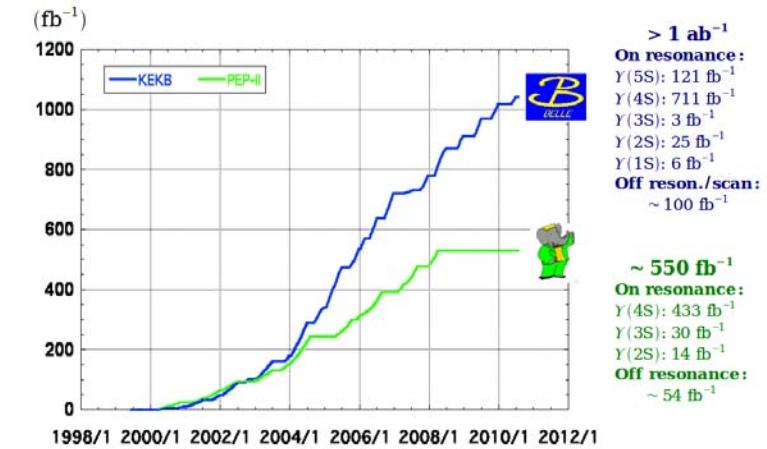


Maximum Luminosity $2.1 \times 10^{34} \text{ cm}^2 \text{s}^{-1} \Rightarrow 21 \text{ B-pairs/sec}$

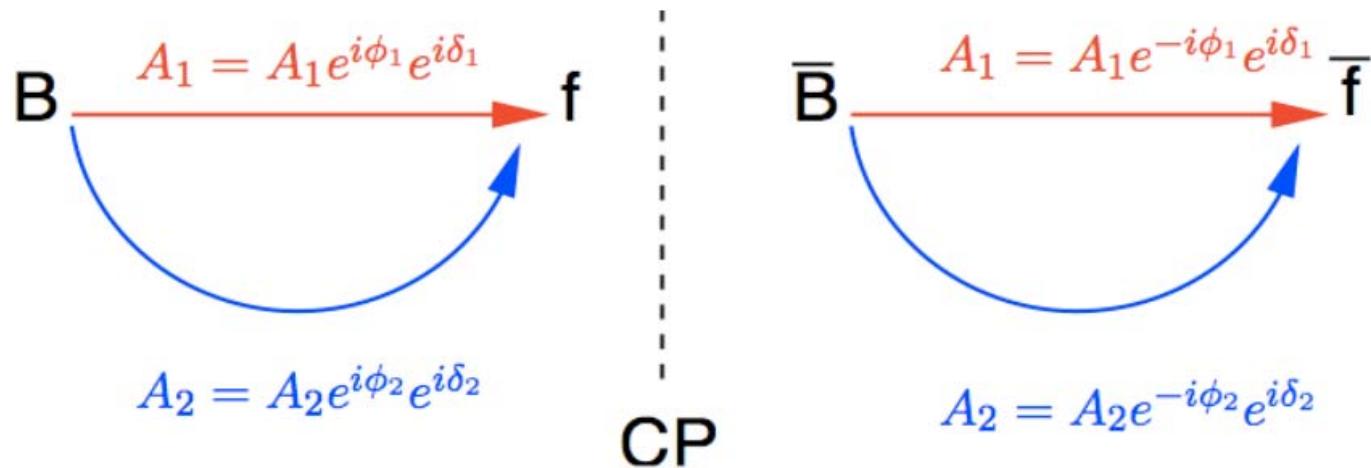
The Belle Experiment



Integrated luminosity of B factories

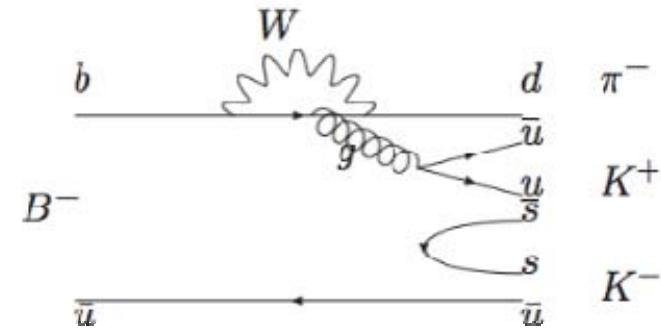
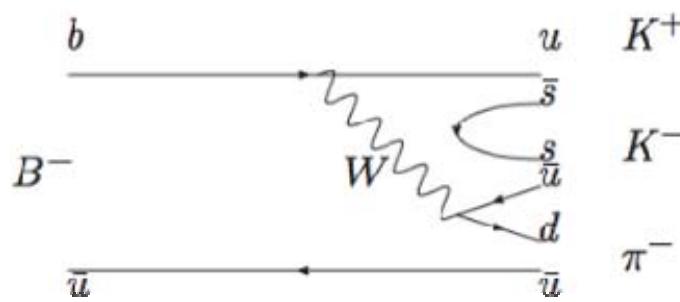


Direct CP Violation



$$|A|^2 = A_1^2 + A_2^2 + 2A_1 A_2 \cos(\Delta\delta + \Delta\phi)$$

$$|\bar{A}|^2 = A_1^2 + A_2^2 + 2A_1 A_2 \cos(\Delta\delta - \Delta\phi)$$



- Requires Interference of multiple Feynman diagrams.
- For non-zero DCPV, A_1 and A_2 need to have **different weak phases Φ** and **different CP invariant (e.g. strong) phases δ** .

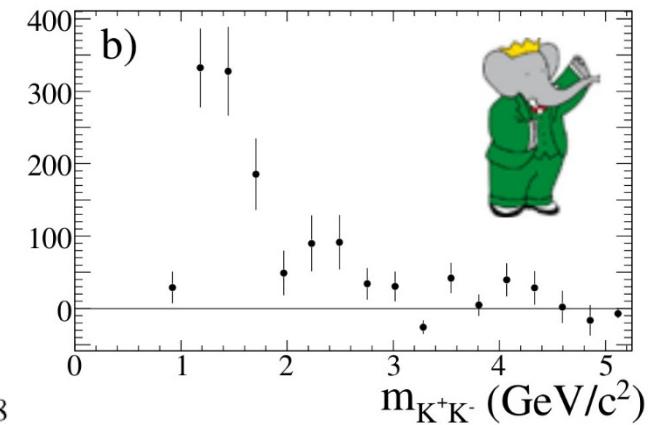
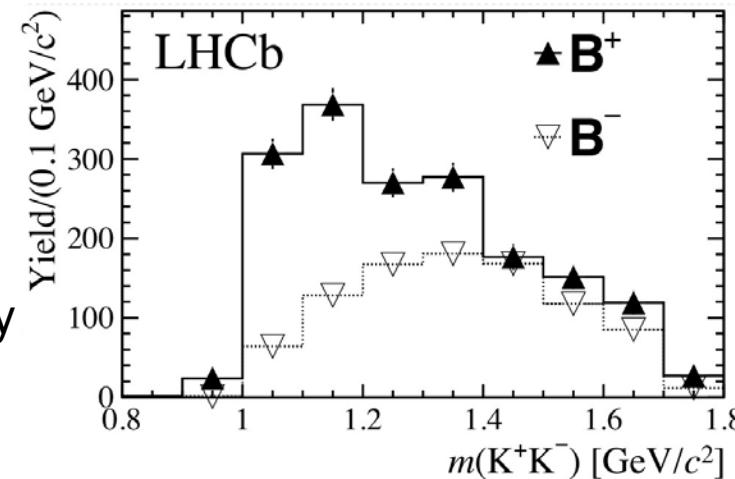
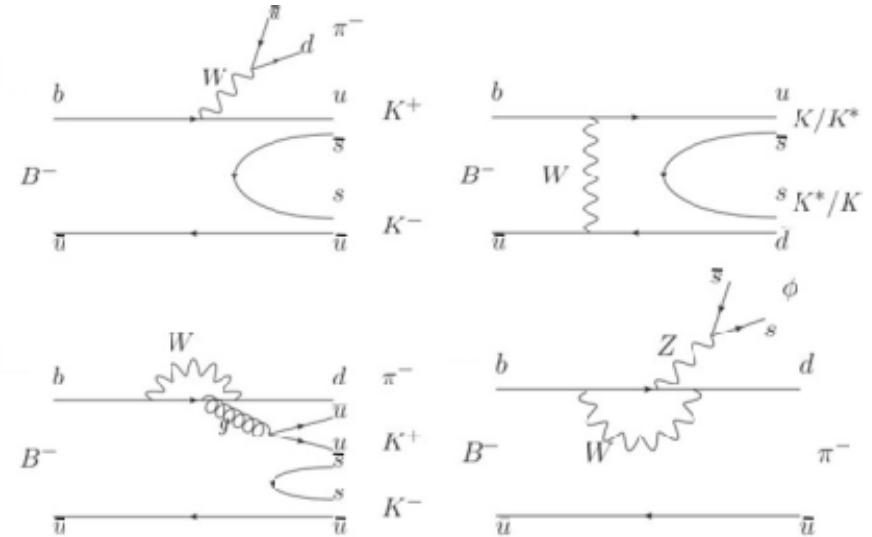
$\text{Br and } A_{CP} \text{ for } B^\pm \rightarrow K^+ K^- \pi^\pm$

Cabibbo and color suppressed tree
 And Penguin diagrams

$\text{Br}(B^\pm \rightarrow K^- K^+ \pi^\pm) = (5.0 \pm 0.5 \pm 0.5) \times 10^{-6}$
 PRL 99, 221801 (2007) BaBar

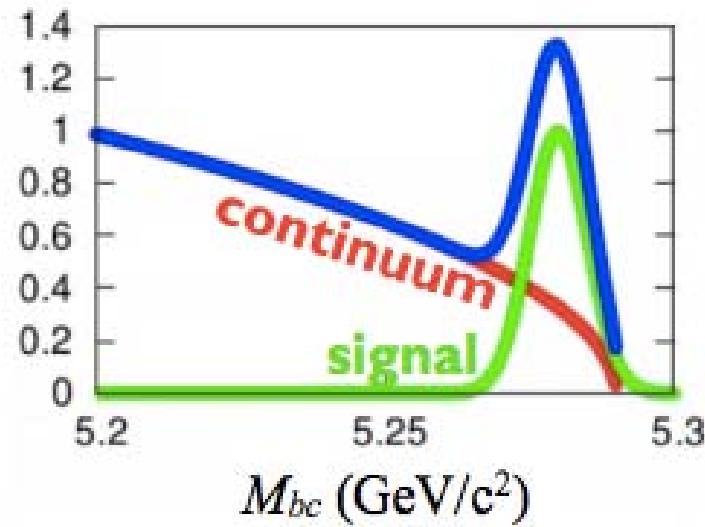
$A_{CP} = 0.123 \pm 0.017 \pm 0.012 \pm 0.007$
 PRD 90, 112004 (2014) LHCb

Unquantified:
 Large enhancement
 Large A_{CP} at low M_{KK}
 Investigate and quantify
 At Belle

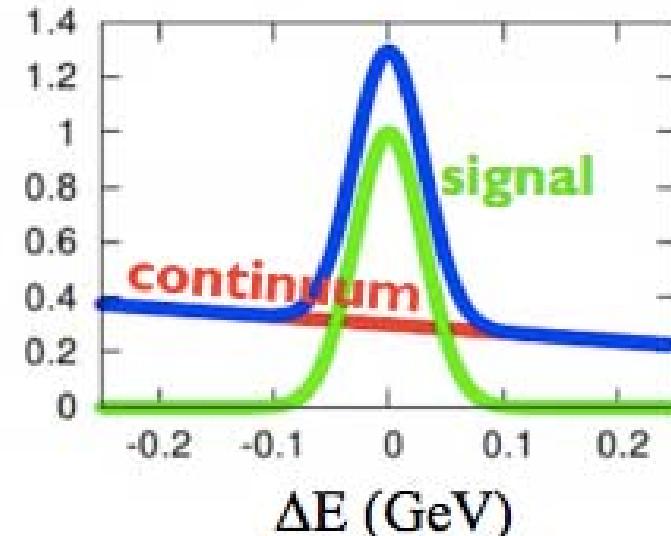


Kinematic Variables in B-Factory measurements

$$M_{bc} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$$



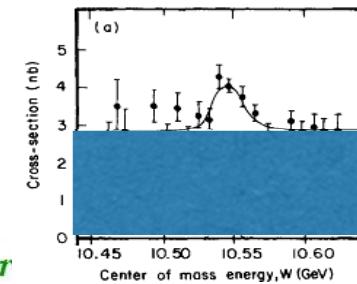
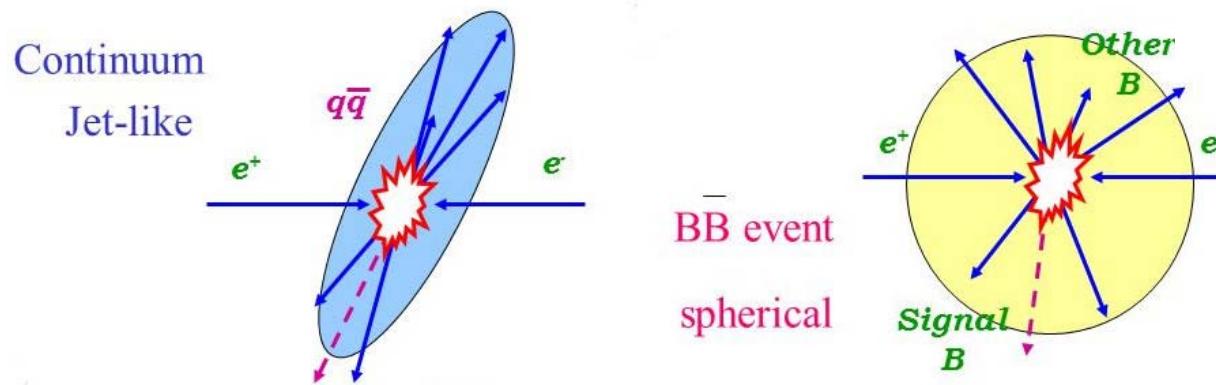
$$\Delta E = E_B^* - E_{beam}^*$$



M_{bc} peaks at B mass for fully reconstructed signal
 ΔE peaks at zero for fully reconstructed signal

Continuum Background

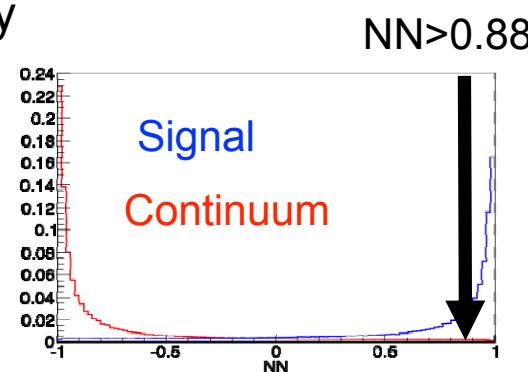
- Continuum background($e^+e^- \rightarrow q\bar{q}(u,d,s,c)$):
 - Dominant background
 - Event topology differs from BB decays



- Combined variables describing the event topology in an artificial neural network.
- Selection criteria is determined by optimizing figure of merit:

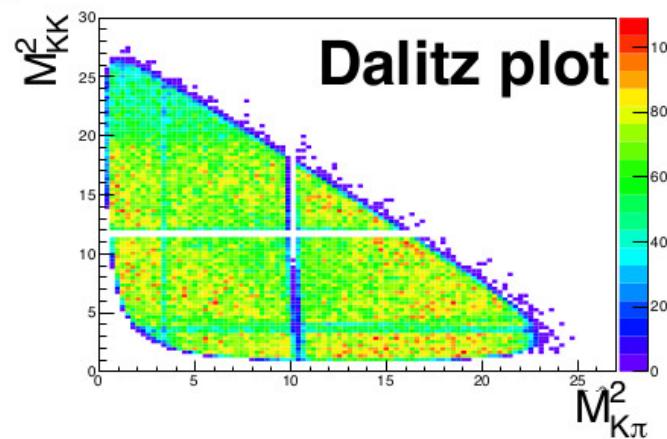
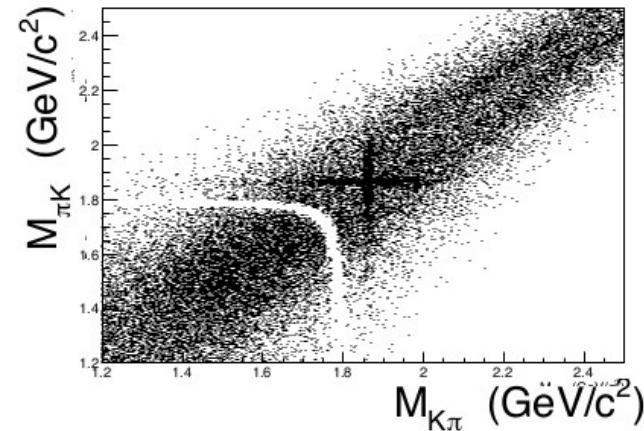
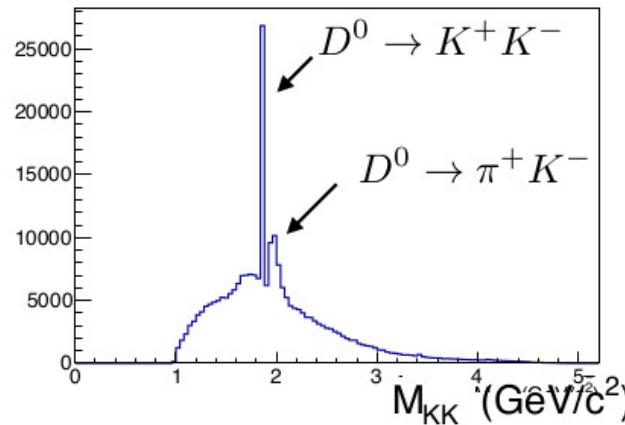
$$F.O.M = \frac{N_{sig}}{\sqrt{N_{sig} + N_{bck}}}$$

NN>0.88, rejects 99% of background



$B^\pm \rightarrow K^+ K^- \pi^\pm$ Backgrounds

- Background from other B decays
 - Same final state particles from charmful B decays
 - Misidentified tracks from either charmful or charmless B decays

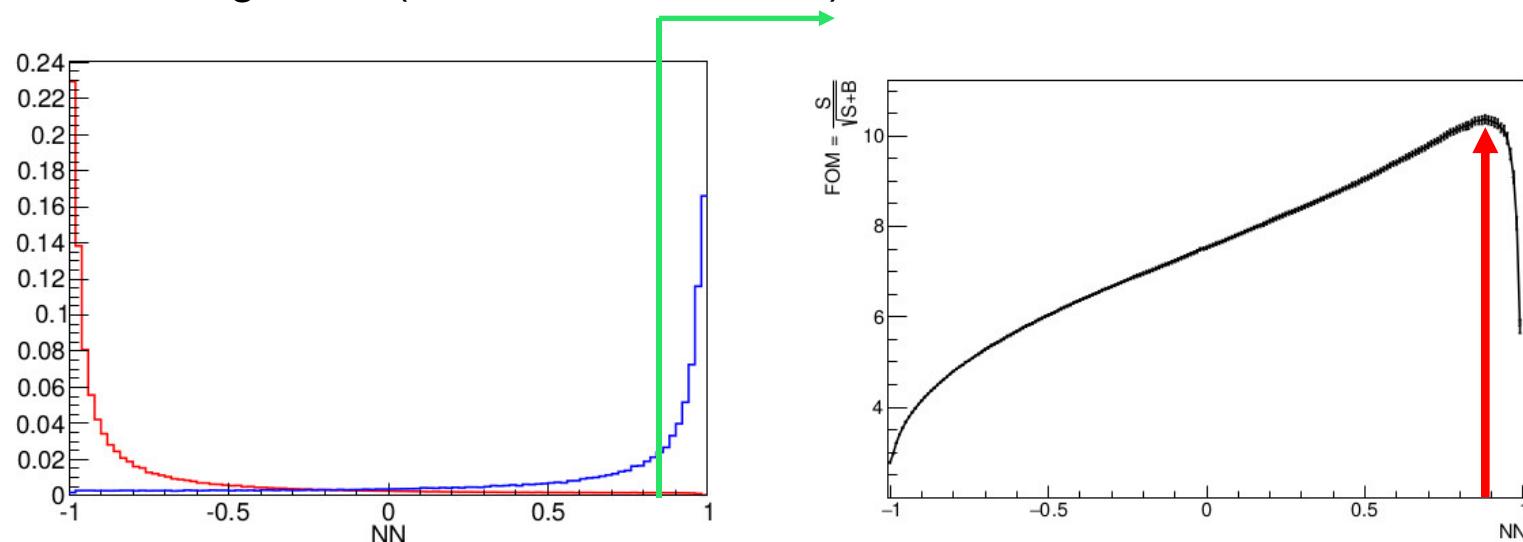


Analysis strategy

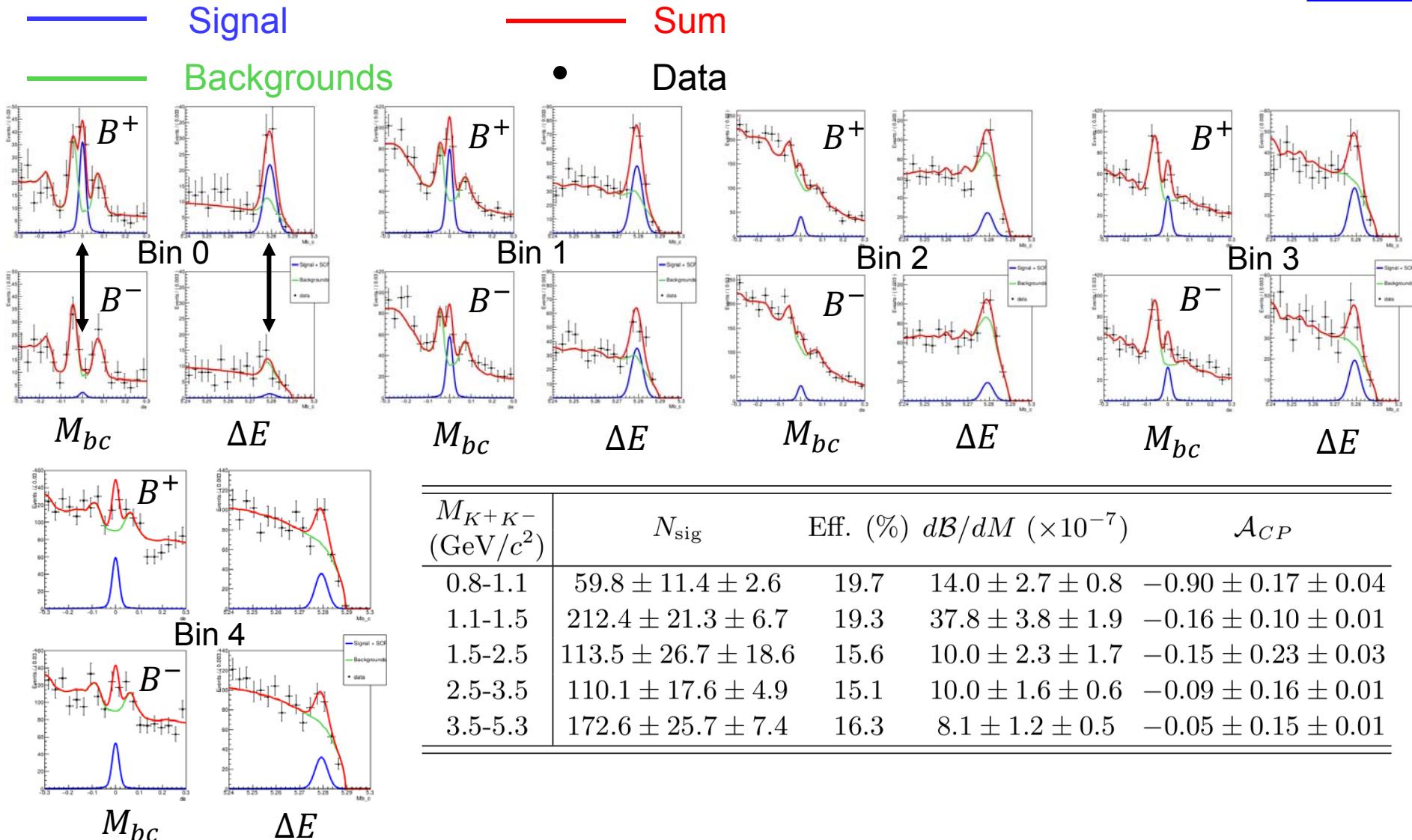
- Continuum suppression KSFW moments, $\text{Cos}\theta_B$, $\text{Cos}\theta_{thr}$, ΔZ , q.r => NeuroBayes
- Place cut on continuum suppression variable from NeuroBayes
- Cut charm backgrounds
- 2D fit for Signal yield and A_{CP} in M_{bc} and ΔE in bins of M_{KK}

Other fit components

- Continuum background
- Generic $B\bar{B}$ background
- $B \rightarrow KKK$ background (K misidentified as π)
- $B \rightarrow K\pi\pi$ background (π misidentified as K)



Fit for $B^\pm \rightarrow K^+ K^- \pi^\pm$ in M_{KK} Bins

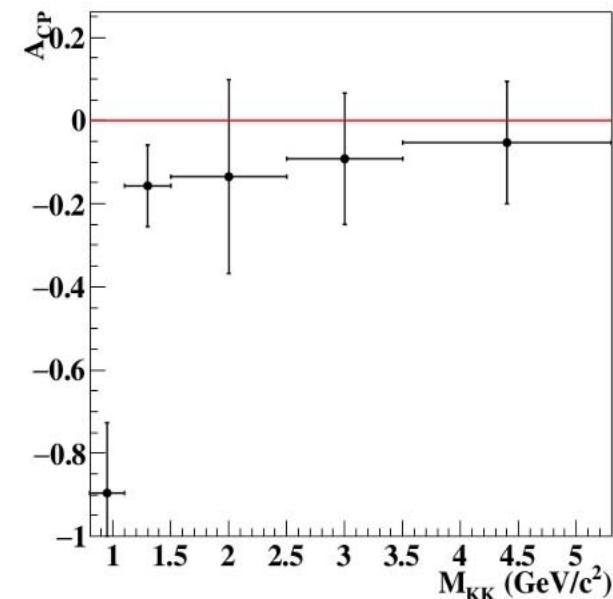
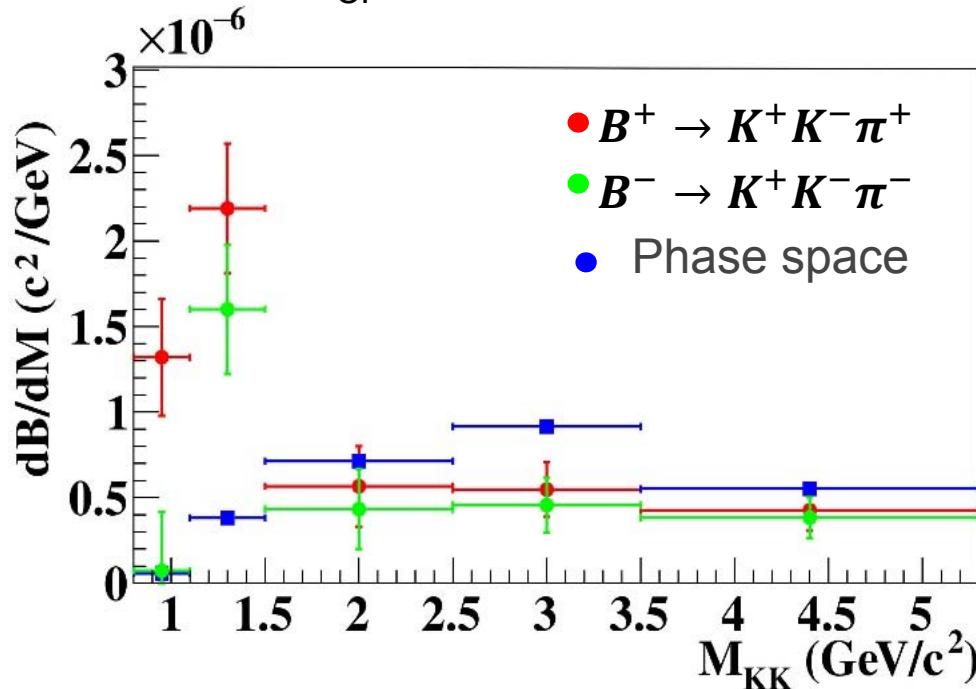


$B^\pm \rightarrow K^+K^-\pi^\pm$

Total $\mathcal{B} = (5.38 \pm 0.40 \pm 0.35) \times 10^{-6}$

$A_{CP} = -0.170 \pm 0.073 \pm 0.017$

To be published in PRD(RC)
 arXiv:1705.02640



$$|A|^2 = A_1^2 + A_2^2 + 2A_1A_2 \cos(\Delta\delta + \Delta\phi)$$

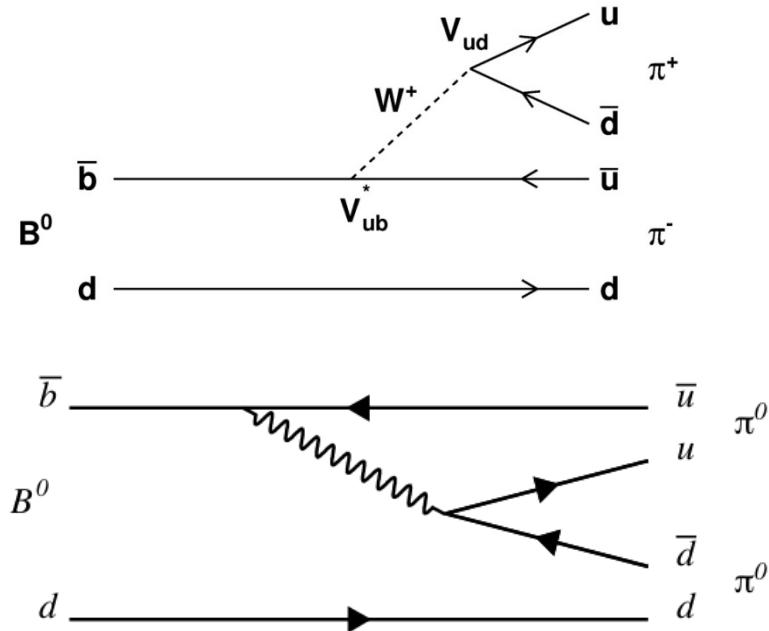
$$|\bar{A}|^2 = A_1^2 + A_2^2 + 2A_1A_2 \cos(\Delta\delta - \Delta\phi)$$

Unusual dynamics showing a large enhancement and very large direct CP-violation

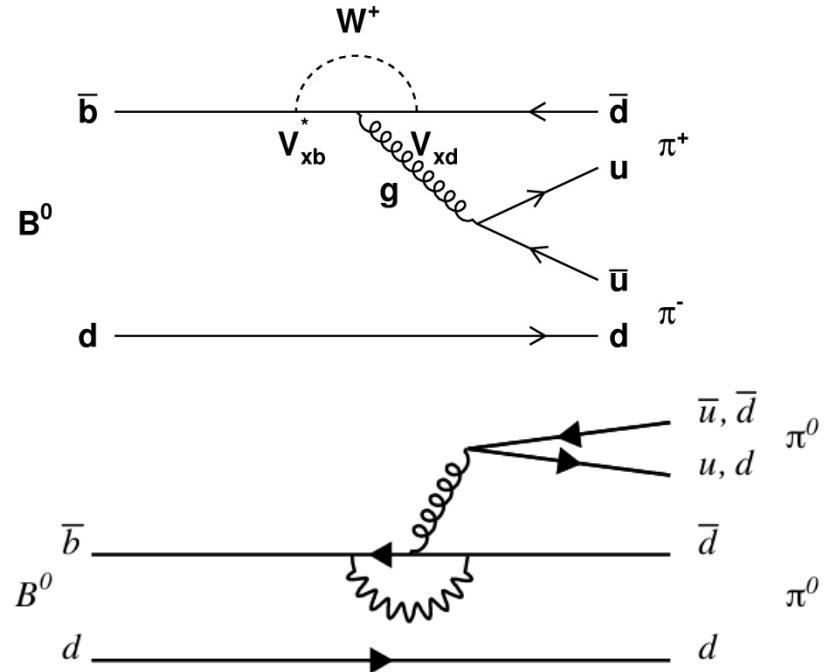
$A_{CP} = -0.9 \pm 0.17 \pm 0.03$ at $M_{KK} < 1.1 \text{ GeV}$ (4.8σ)

Hard to make a model do both.

Br and Acp for $B^0 \rightarrow \pi^0\pi^0$



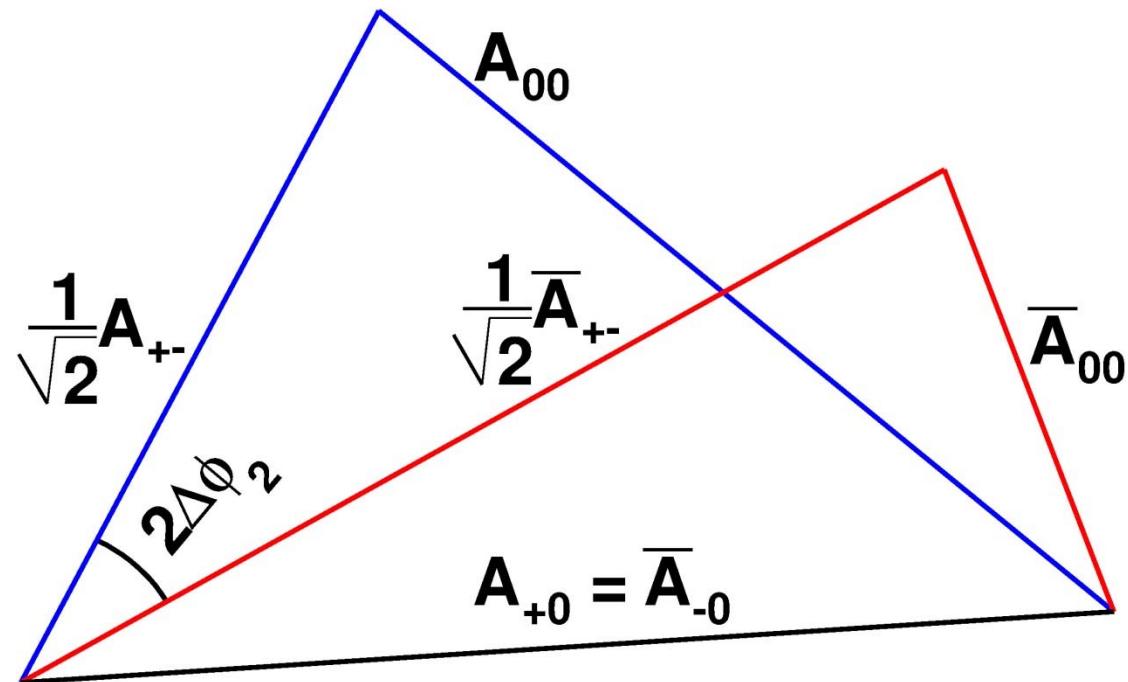
Time dependent measurements
of $B \rightarrow \pi^-\pi^+$ are sensitive to Φ_2



Contribution of penguin diagram which
gives rise to direct CPV
“Penguin Pollution”
 $B^0 \rightarrow \pi^0\pi^0$ vital to unravel these effects

$B \rightarrow \pi^0 \pi^0$

Penguin pollution can be isolated via an isospin analysis
 (M. Gronau and D. London, PRL 65, 3381 (1990))



$$\begin{aligned}
 A^\pm &= B^0 \rightarrow \pi^+ \pi^- \\
 \bar{A}^\pm &= \bar{B}^0 \rightarrow \pi^+ \pi^- \\
 A^0 &= B^0 \rightarrow \pi^0 \pi^0 \\
 \bar{A}^0 &= \bar{B}^0 \rightarrow \pi^0 \pi^0 \\
 A^{+0} &= B^+ \rightarrow \pi^+ \pi^0 \\
 A^{-0} &= B^- \rightarrow \pi^- \pi^0
 \end{aligned}$$

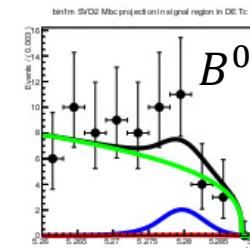
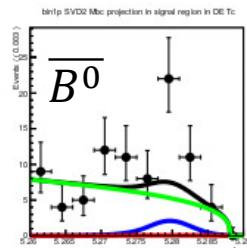
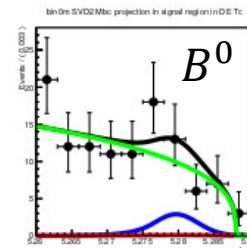
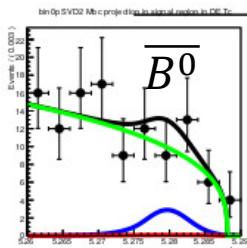
Fit Components $B^0 \rightarrow \pi^0\pi^0$



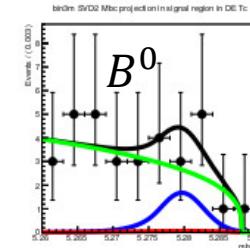
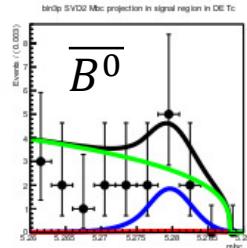
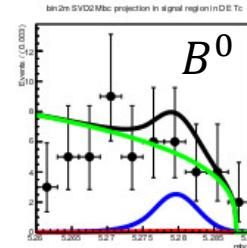
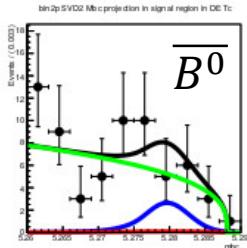
- For $B \rightarrow \pi^0\pi^0$ we have 4 components to fit to M_{bc} , ΔE and T_C (Continuum suppression variable)
 - Signal
 - Continuum
 - $B \rightarrow \rho^+\pi^0$ (rho-pi)
 - Other rare charmless (rare)
- Simultaneous fit to 14 bins in flavor tag q.r for SVD1 (2)
- T_C Fisher Discriminant of KSFW Likelihood, $\cos\theta_B$, $\cos\theta_{thrust}$
- T_C PDF obtained from analytic anzatz fit to Full Detector simulation for Signal MC and off-resonance for Continuum
- M_{bc} and ΔE for signal obtained with analytic function which accounts for correlation due to energy leakage

Results $B^0 \rightarrow \pi^0\pi^0$

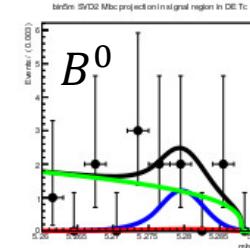
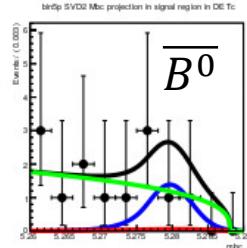
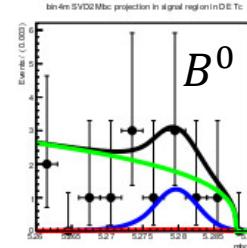
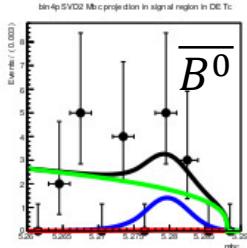
$0.0 < |q.r| < 0.1$



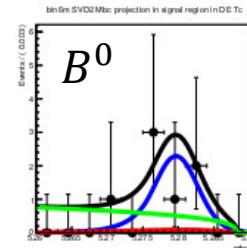
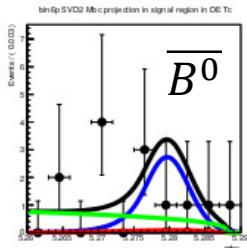
$0.25 < |q.r| < 0.5$



$0.625 < |q.r| < 0.75$



$0.875 < |q.r| < 1.0$



$M_{bc} (GeV)$

$M_{bc} (GeV)$

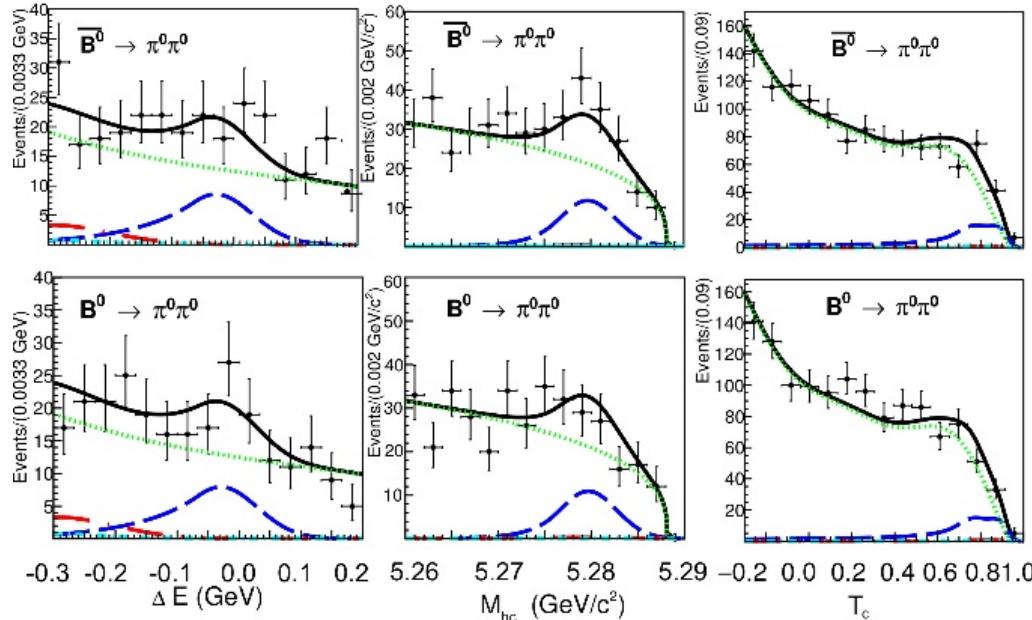
Full sum
Signal
Continuum
 $\rho\pi$ Background

$M_{bc} (GeV)$

$M_{bc} (GeV)$

M. Sevior, Flavour Physics, ICISE,
Quy Nhon, Vietnam

Results $B^0 \rightarrow \pi^0\pi^0$



$$\mathcal{B} = (1.31 \pm 0.19 \pm 0.19) \times 10^{-6}$$

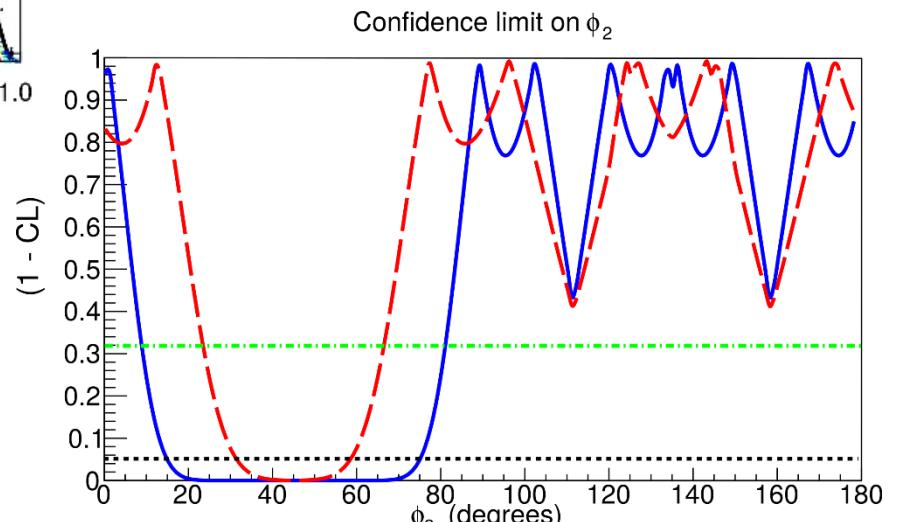
$$A_{CP} = 0.14 \pm 0.36 \pm 0.10$$

ϕ_2 excluded from the range:

$$15.5^\circ < \phi_2 < 75.0^\circ \text{ at } 2\sigma$$

— Full sum
 — Signal
 - - Continuum
 - · - $\rho\pi$ Background

Accepted for publication in PRD
 arXiv:1705.02083



Belle only $B \rightarrow \pi\pi$ data

Summary



- $B^\pm \rightarrow K^+ K^- \pi^\pm$ arXiv:1705.02640 (PRD(RC))
- $\mathcal{B} = (5.38 \pm 0.40 \pm 0.35) \times 10^{-6}$
- $A_{CP} = -0.170 \pm 0.073 \pm 0.017$
- $A_{CP} = -0.9 \pm 0.17 \pm 0.03$ at $M_{KK} < 1.1$ GeV (4.8σ)
- $B^0 \rightarrow \pi^0 \pi^0$ arXiv:1705.02083 (PRD)
- $\mathcal{B} = (1.31 \pm 0.19 \pm 0.19) \times 10^{-6}$
- $A_{CP} = 0.14 \pm 0.36 \pm 0.10$
- ϕ_2 excluded from the range (Belle data):
 $15.5^\circ < \phi_2 < 75.0^\circ$ at 2σ



Thank you!

Backup

Theory for BR $B^0 \rightarrow \pi^0\pi^0$

- Besides determination of $\Phi_2\dots$
- $\text{BR } (B \rightarrow \pi^0\pi^0) < \text{BR}(B \rightarrow \rho^0\rho^0)$ (Hsiang-nan Li and Satoshi Mishima.
Phys.Rev.D73:114014,2006)
- Same diagrams and stronger coupling to ρ^0
- At most $\text{BR } (B \rightarrow \pi^0\pi^0) < 1 \times 10^{-6}$ (H.L. & SM Phys.Rev.D83:034023,2011)
- Previously published results
- Belle PRL 94, 181803(2005) = $(2.32 +0.4-0.5(\text{stat})) \times 10^{-6}$
 (253 fb^{-1})
- BABAR PR D87 052009 $(1.83 \pm 0.21 \pm 0.13) \times 10^{-6}$
- PDG Average $(1.62 \pm 0.31) \times 10^{-6}$

=> Update to full Belle Data Set

Signal Shape

- Energy Leakage from ECL causes correlation between M_{bc} and ΔE
- Account with 2D M_{bc} and ΔE anstanz

$$CB_{\Delta E}(f(\Delta E), \mu_{\Delta E}, \sigma_{\Delta E}, \alpha_{\Delta E}, n_{\Delta E})$$

$$CB_{M_{bc}}(M_{bc}, \mu_{M_{bc}}, \sigma_M, \alpha_M, n_{M_{bc}})$$

where

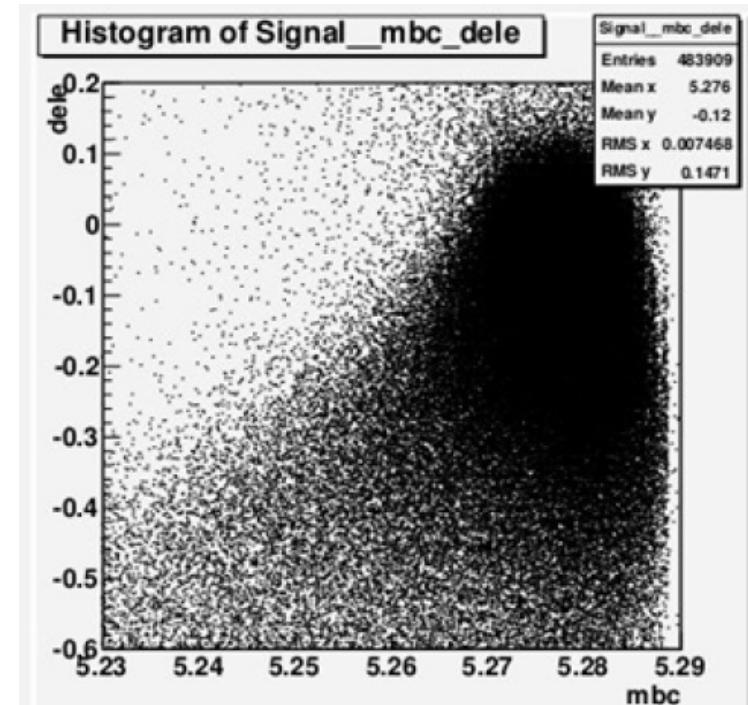
$$\sigma_M = \sigma_{M_{bc}} + A\Delta E$$

$$\alpha_M = \alpha_{M_{bc}} + Be^{\frac{-1}{2}(\frac{\Delta E}{C})^2}$$

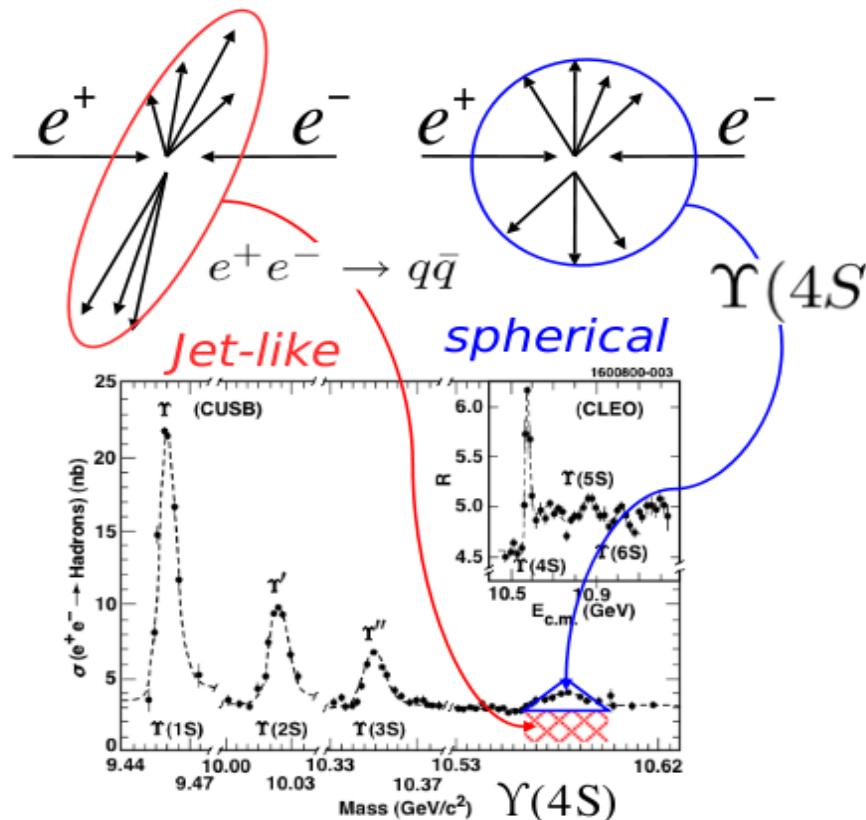
$$f(\Delta E) = \Delta E + \mu_{\Delta E} + Ce^{\frac{-1}{2}(\frac{\mu_{M_{bc}} - \mu_M}{D})^2}$$

$$PDF(M_{bc}, \Delta E) = CB_{\Delta E}CB_{M_{bc}}$$

Where CB = “Crystal Ball function”



Backgrounds - Continuum

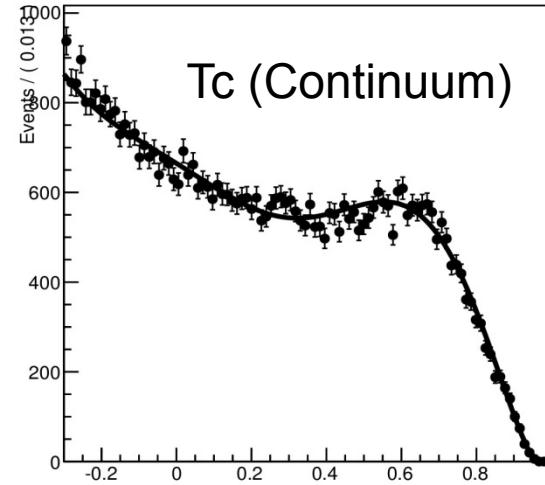


$e^+ e^- \rightarrow q\bar{q}$ "Continuum" background

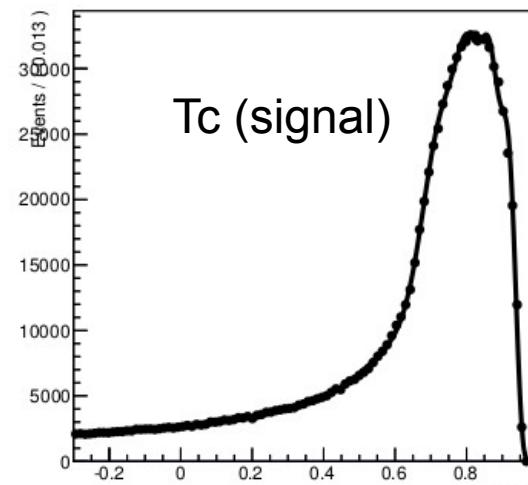
Fisher Discriminant of KSFW Likelihood,
 $\cos\theta_B, \cos\theta_{\text{thrust}} = \text{Tc}$

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Fisher
Discriminant
Continuum
 $5.24 < M_{bc} < 5.26$



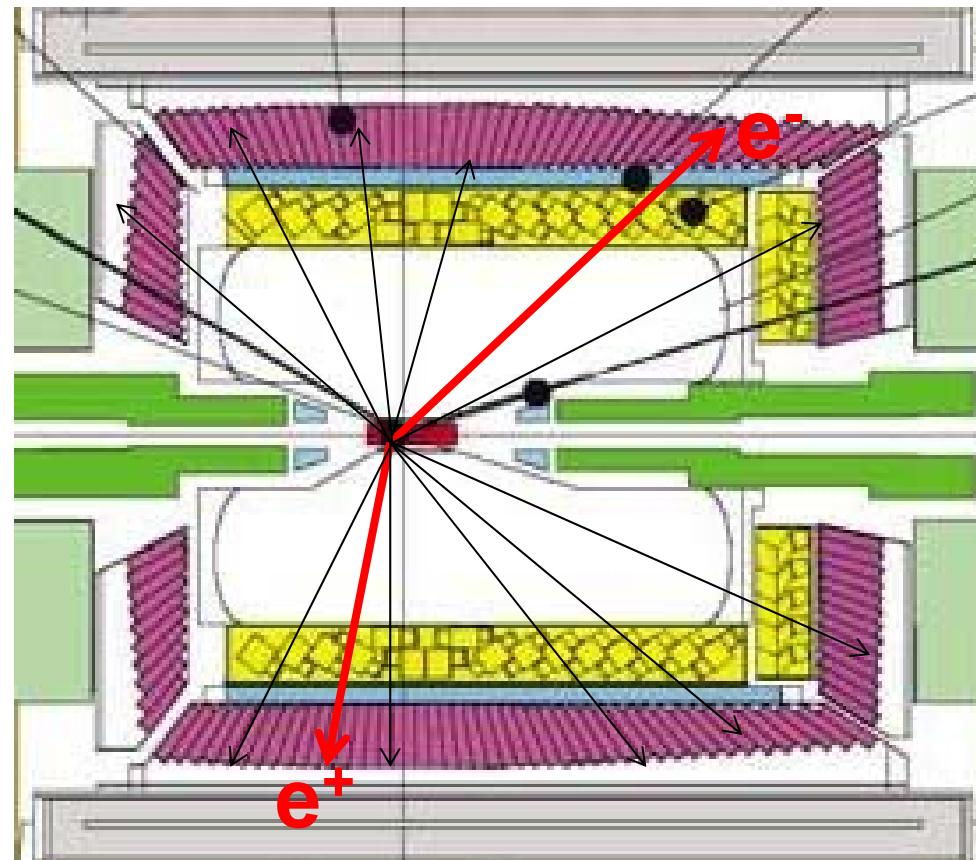
Fisher
Discriminant
Simulated
Signal

Slide 23

Out of time ECL background

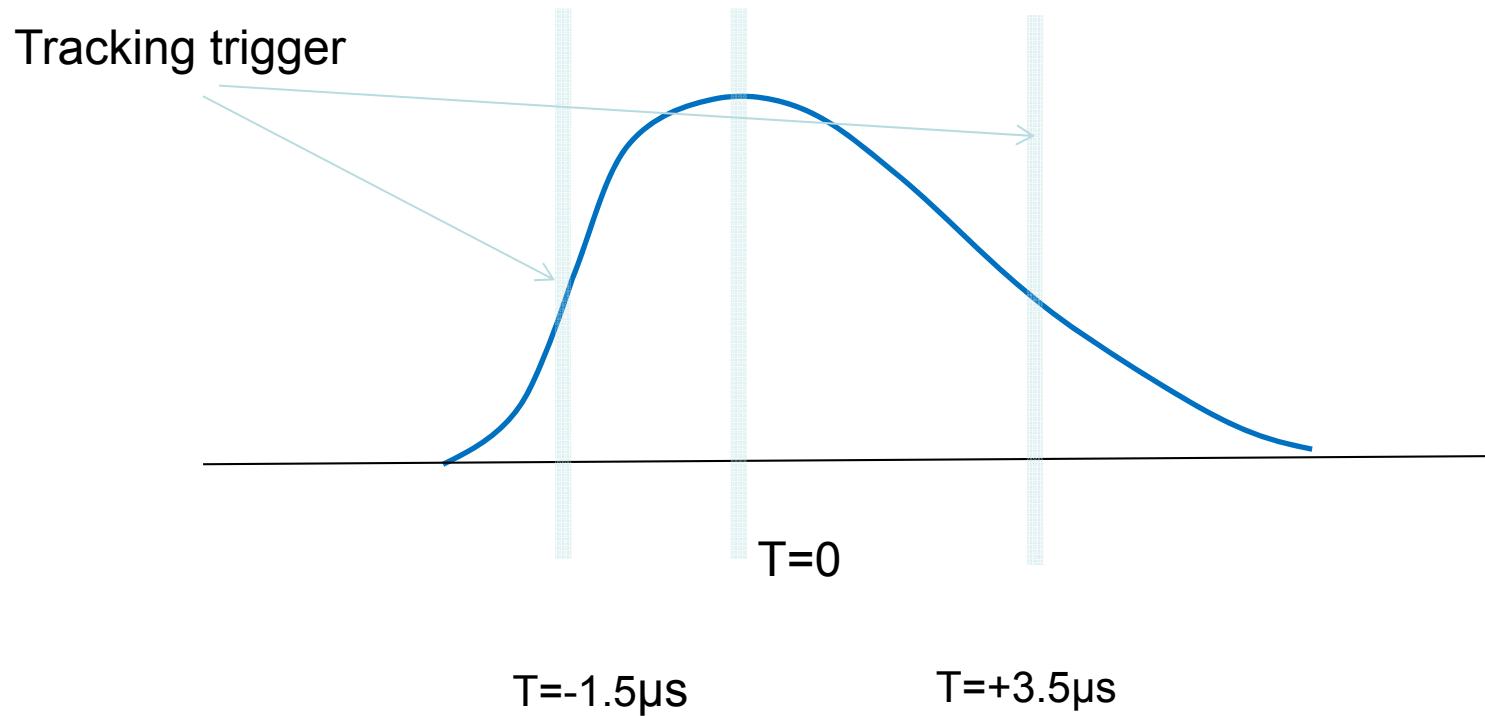
- “Pile-up” from $e^+e^-(\gamma)$ scatter within a few microseconds of $e^+e^- \rightarrow B\bar{B}$ event.

$e^+e^-(\gamma)$ scatter is
Back-to-back
In CM



Out of time ECL background

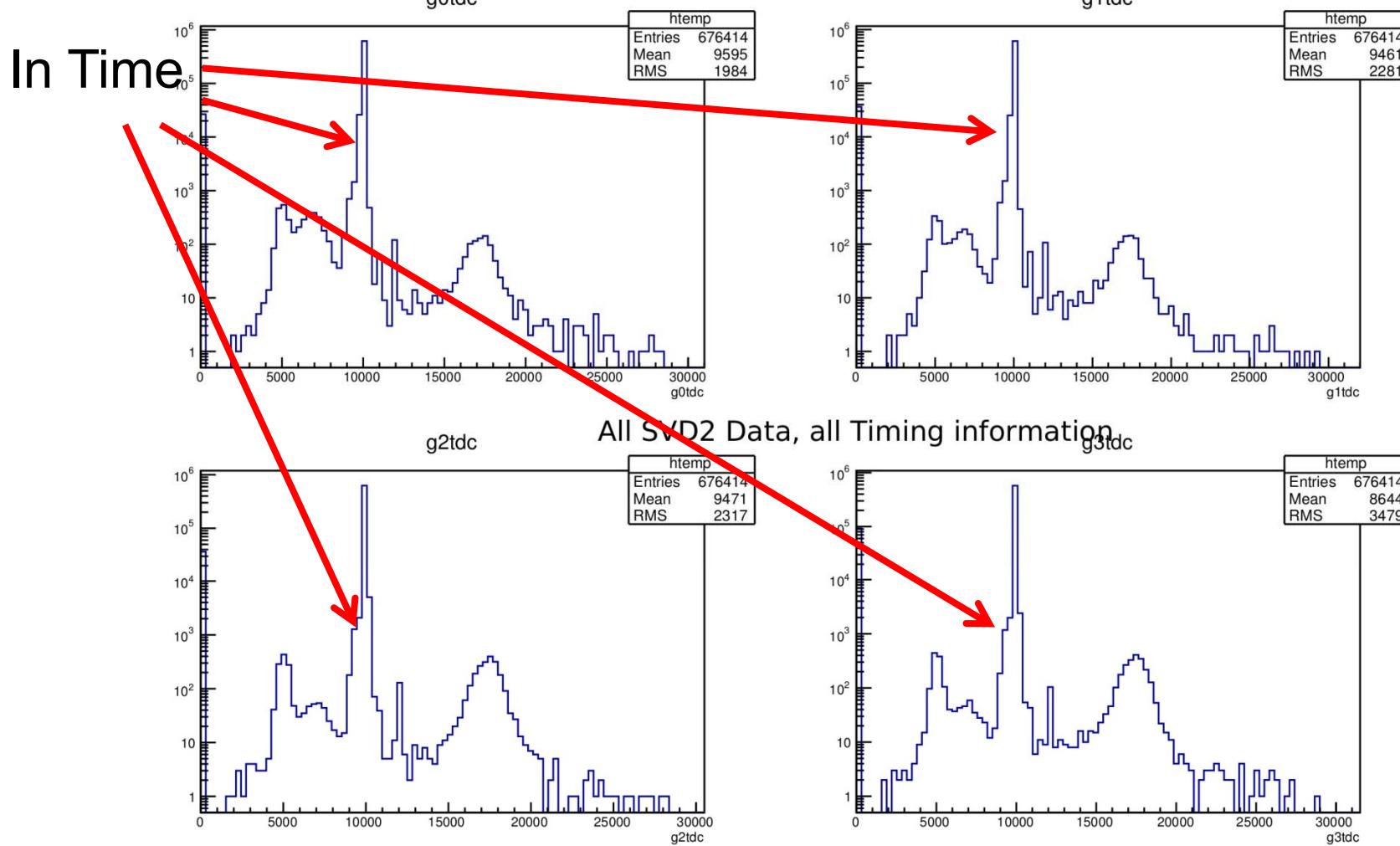
Output of CsI crystals is processed with 1 μ sec shaping time



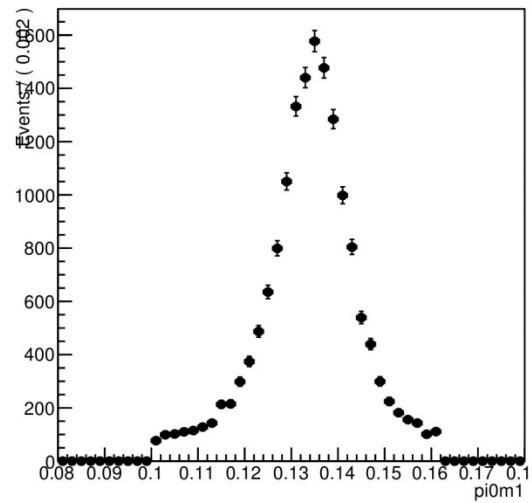
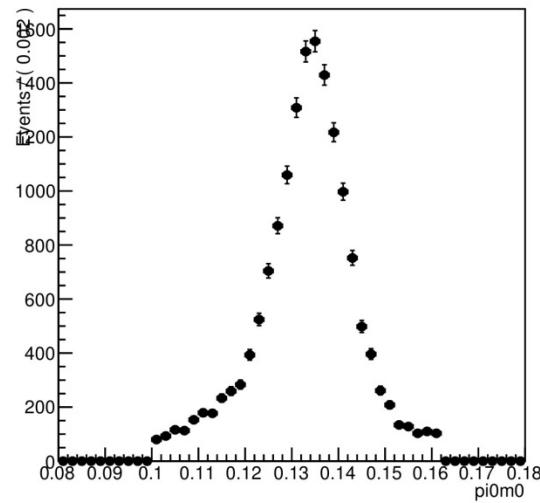
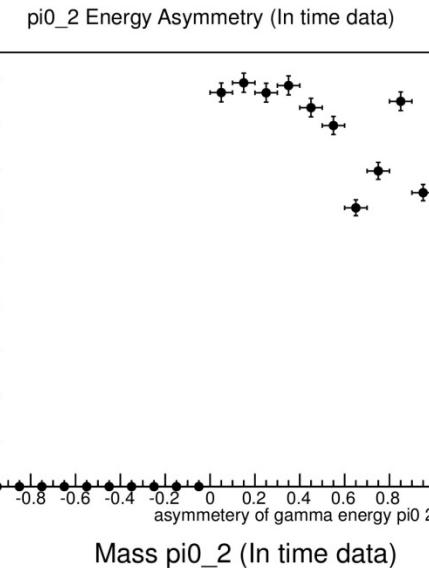
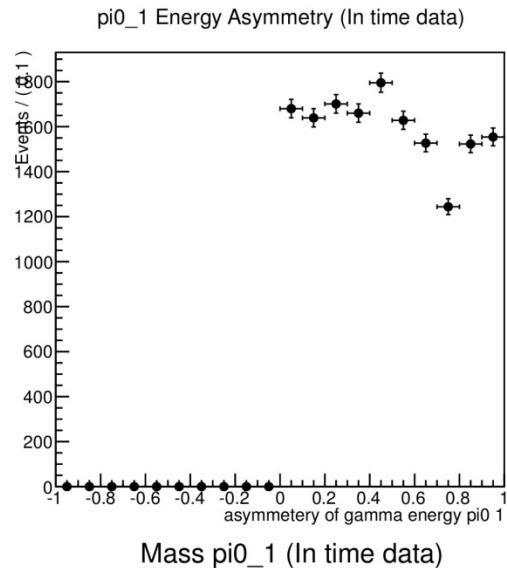
Trigger from $B\bar{B}$ event within a few microseconds samples non-peak part of ECL.
 Shows up as high energy photons located back-to-back in ECL.
 Photons pick up low energy photon from rest of BB-bar event to form fake π^0 's
 Momentum dominated by high energy deposits. Vector sum ~ 0 So $M_{bc} \sim B_{mass}$

Out of time ECL background

Logarithmic plots of 4γ 's from $B^0 \rightarrow \pi^0(\gamma_0, \gamma_1)\pi^0(\gamma_2, \gamma_3)$



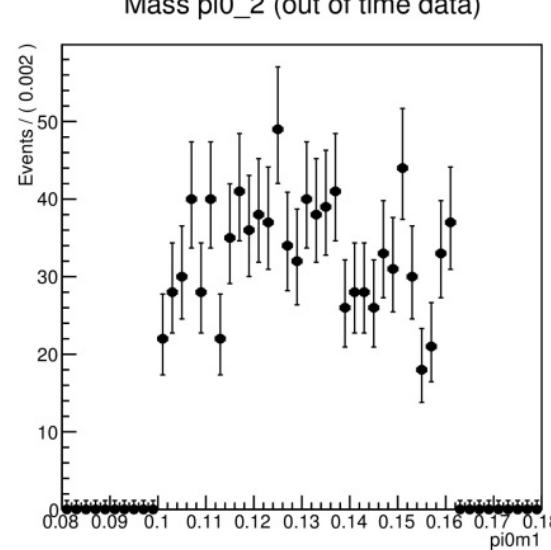
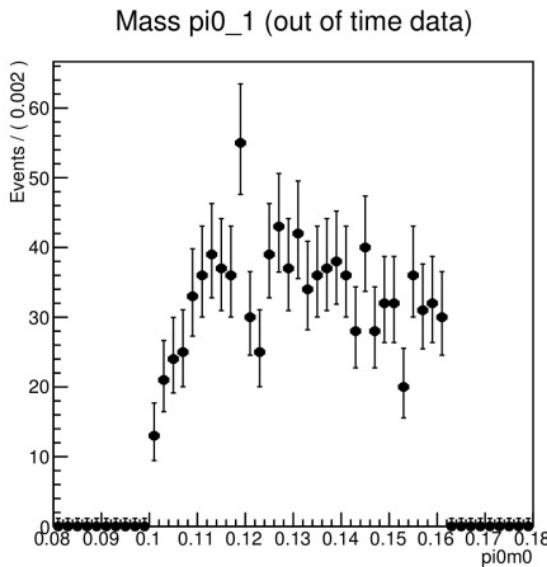
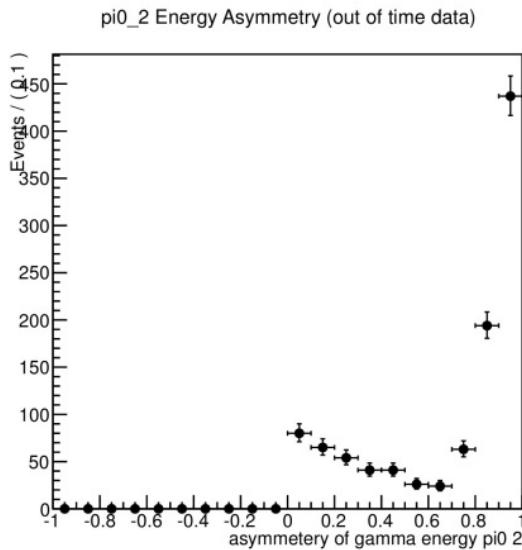
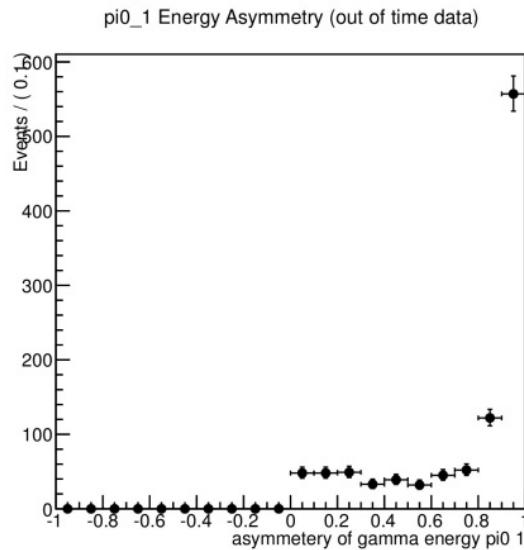
Data with timing cuts



$$\frac{E_{\gamma 1} - E_{\gamma 2}}{E_{\gamma 1} + E_{\gamma 2}}$$

π^0 Invariant
mass

Out of time Data

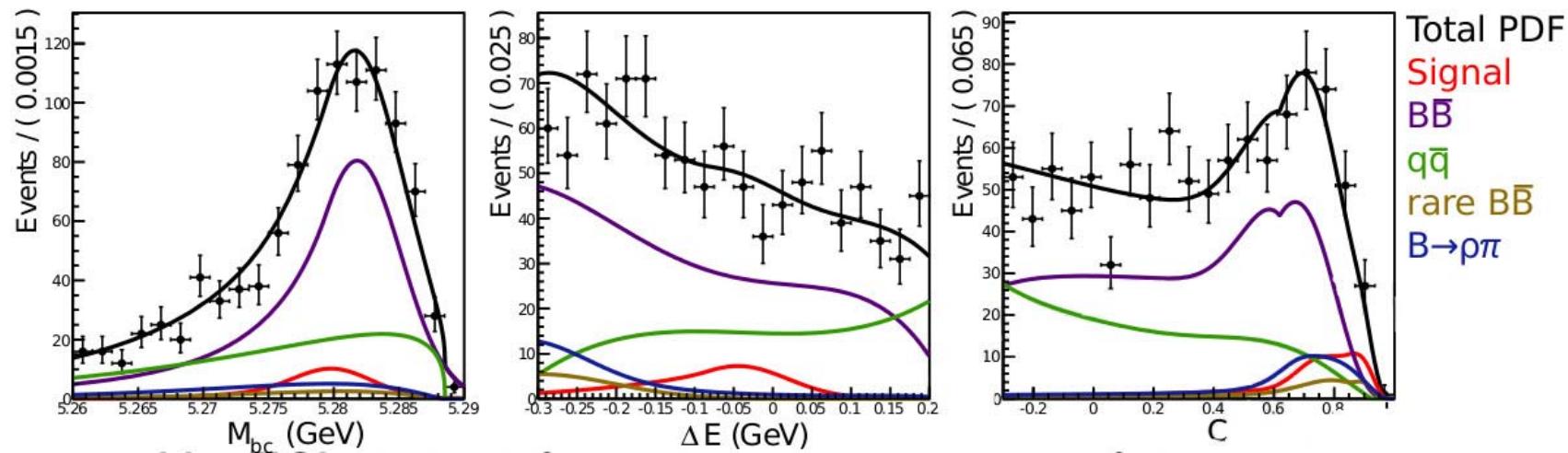


$$\frac{E_{\gamma 1} - E_{\gamma 2}}{E_{\gamma 1} + E_{\gamma 2}}$$

π^0 Invariant mass

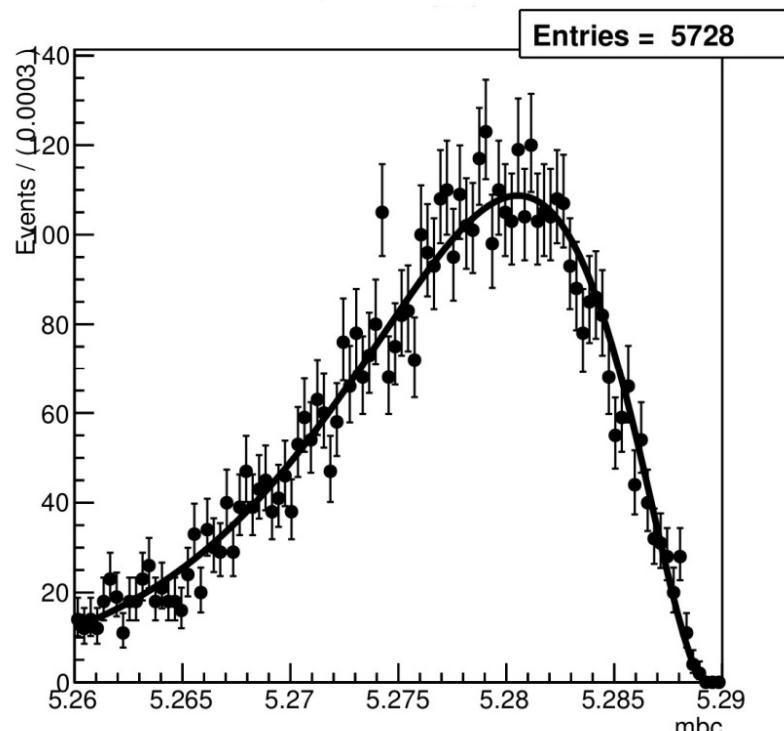
$B^0 \rightarrow \pi^0\pi^0$ - Out of time Background

- substantial background from out of time showers in the electromagnetic calorimeter ($\tau_{ECL} = 1.5\mu s$) (Pileup)
- out of time ECL hit + BB event \rightarrow peaking background

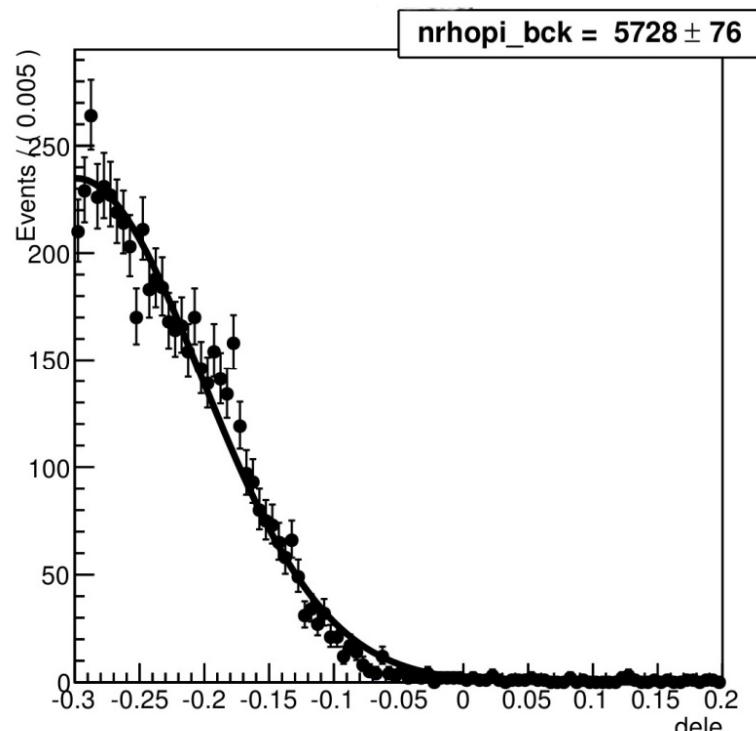


Timing cut on ECL Trigger crystals removes 99% of the background and keeps 99% of the signal

Backgrounds - $B \rightarrow \rho\pi$



M_{bc}



ΔE

Background from other charmless B-decays

