Search for CP violation in $D^+ \to \pi^+\pi^0$ *and* $\pi^+\eta$

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Outline

Introduction

A) Search for CP violation is very active in charm sector.

- ✓ Only CP violation in decay $D^+ \to K_S\pi^+$ is observed by **BABAR** [1], **Belle** [2].
- ✓ **LHCb** probed on $\Delta A_{cp} = A_{cp}(K^+K^-) - A_{cp}(\pi^+\pi^-)$ attracting lots of attention.
  $-0.82 \pm 0.21 \pm 0.11$, 2012 [3]
  $0.49 \pm 0.30 \pm 0.11$, 2013 [4]
  $0.14 \pm 0.16 \pm 0.08$, 2014 [5]
  $-0.10 \pm 0.08 \pm 0.03$, 2016 [6]

B) Recently: $A_{CP}(\pi^+\pi^0) = (2.31 \pm 1.24 \pm 0.23)\%$ **Belle** [7]

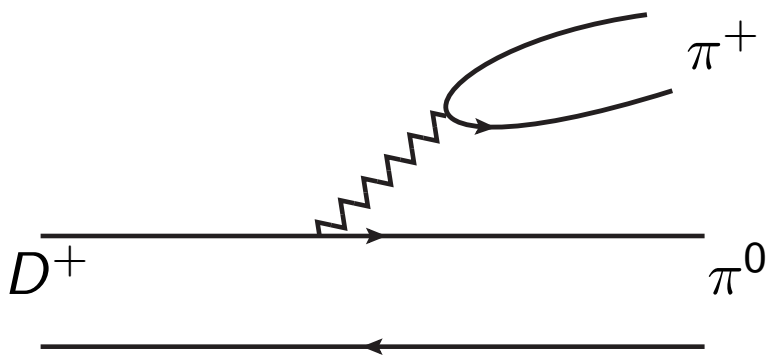
CP-violation in SM

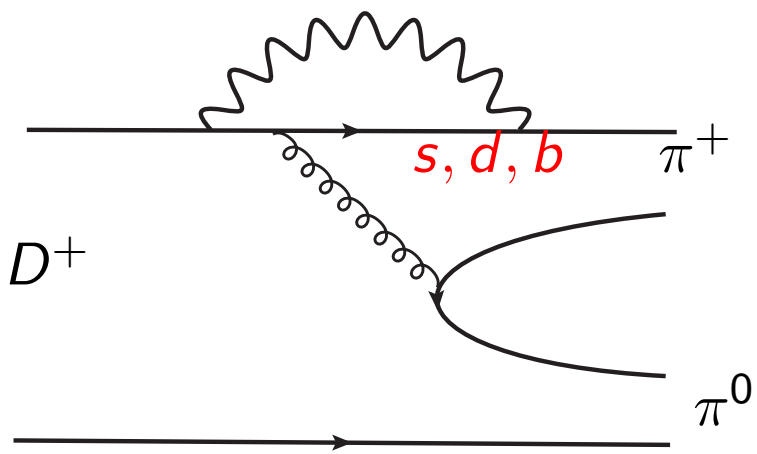
- ✓ Two typical amplitude

$$A(D^+ \to \pi^+\pi^0) = T_{tree} + T_{penguin}e^{i\delta_w+i\delta_I} \quad (1)$$
$$\bar{A}(D^+ \to \pi^+\pi^0) = T^*_{tree} + T^*_{penguin}e^{-i\delta_w+i\delta_I}$$

- ✓ CP-violation asymmetry:

$$\Delta A \sim sin\delta_w sin\delta_I \quad (2)$$





Beyond SM

A) The CP-violation in charm system is small(10^{-3}) within **SM** [8].

B) Yuval Grossman, Alexander L. Kagan and Jure Zupan suggest to probe violation in decay $D^+ \to \pi^+\pi^0$ [9].

- ✓ theoretical uncertainty is small
- ✓ provide strong signature for new physics (**NP**).

Method

A) Observable:

$$A_{raw} = \frac{N^{obs}(D^+ \to \pi^+\pi^0) - N^{obs}(D^- \to \pi^-\pi^0)}{N^{obs}(D^+ \to \pi^+\pi^0) + N^{obs}(D^- \to \pi^-\pi^0)} \tag{3}$$

B) Two parts: True CP-violation and efficiency asymmetry.

$$A_{raw} = A_{CP} + A_{\epsilon}^{\pi^{\pm}} \tag{4}$$

- ✓ The $A_{\epsilon}^{\pi^{\pm}}$ is obtained by control sample

$$D^+ \to K_S^0\pi^0$$

C) Mainly two sources of systematic uncertainties:

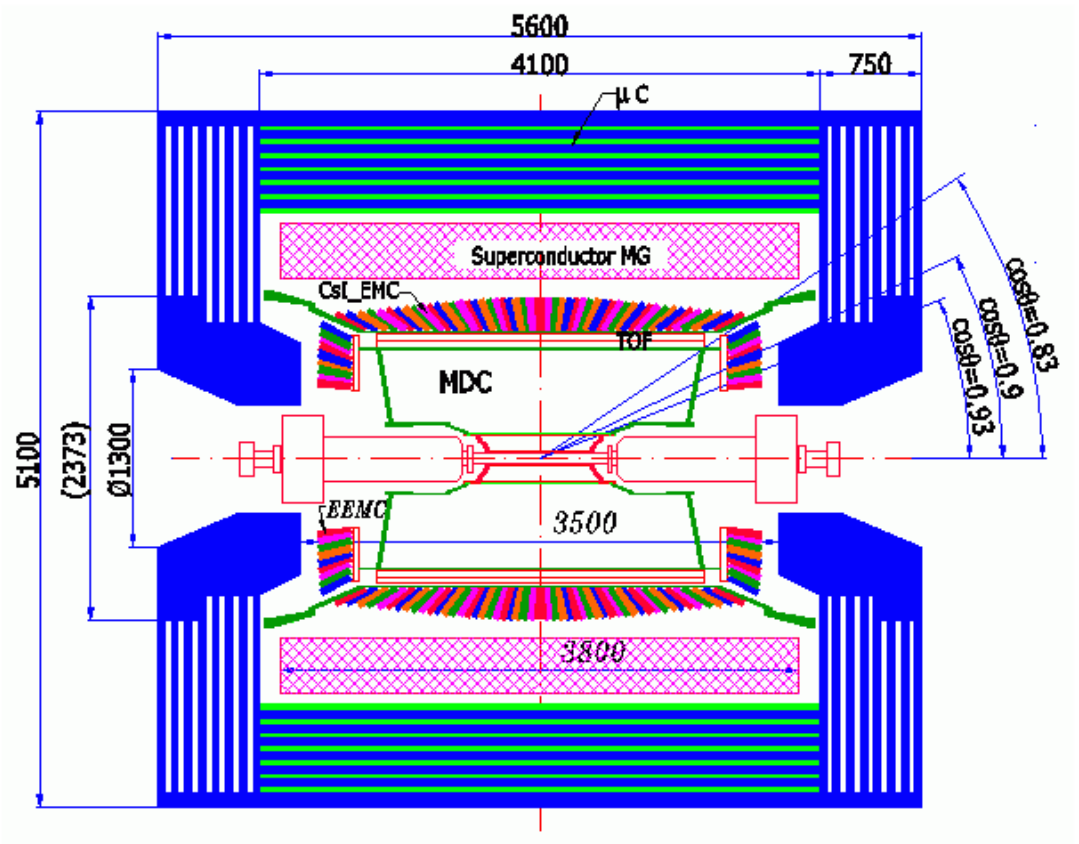
- ✓ efficiency asymmetry for pions mesons
- ✓ Fitting

D) Blind analysis method

- ✓ The event selection criteria, background study and systematic uncertainty are based on MC sample.

BESIII Detector

- ✓ momenta resolution: $0.32\% p_t \bigoplus 0.37\%/\beta$
- ✓ E_γ resolution: $2.3\%/\sqrt{E} \bigoplus 1\%$



Event Selection

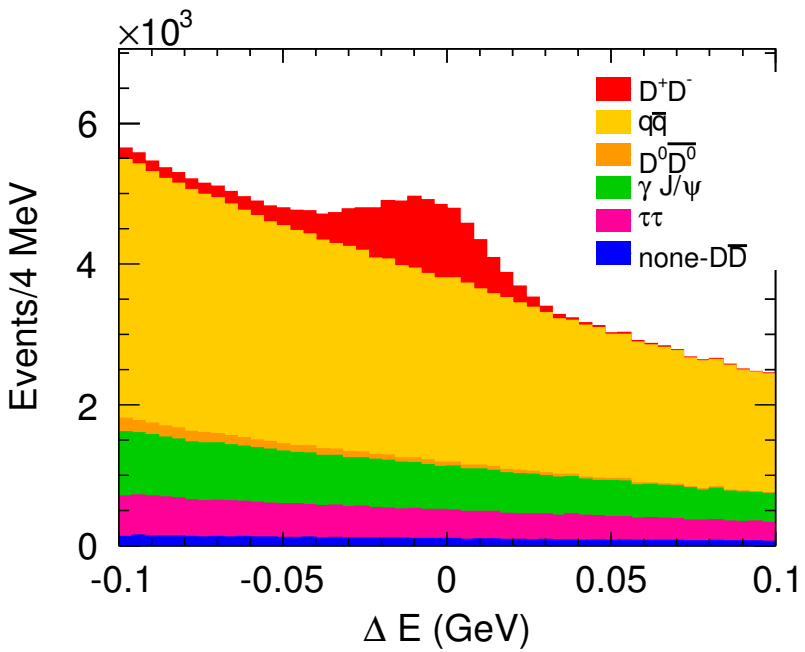
- ✓ Good charged track
  - ✓ Vertex: $V_r < 1\ cm$, $V_z < 10\ cm$
  - ✓ Polar angle: $cos\theta < 0.93$
- ✓ Good photons
  - ✓ Barrel: $cos\theta < 0.8$, $E_\gamma > 25$ MeV
  - ✓ End Cap: $0.86 < cos\theta < 0.92$, $E_\gamma > 50$ MeV
- ✓ pion candidates:
  - ✓ $prob(\pi) > 0$, $prob(\pi) > prob(K)$
- ✓ π^0 candidates
  - ✓ $\chi^2 < 200$
  - ✓ $[115, 150]$ MeV$/c^2$
- ✓ K_S candidates
  - ✓ $\chi^2_{vex} < 100$
  - ✓ mass: $[0.487, 0.511]$ GeV

Select Best candidate

- ✓ There may be more than one combinations $(\pi^+\pi^0)$ that fall into the signal region in one events.
- ✓ Select: $|\Delta E| = min$

$$\Delta E = E(D) - E(beam) \tag{5}$$

$$M_{BC} = \sqrt{E(beam)^2 - \vec{p}^2} \tag{6}$$



Study on $D^+ \to K_S\pi^+$

Introduction

A) Perfect control sample

- ✓ Angular distribution is same as the signal mode ($D^+ \to \pi^+\pi^0$).
- ✓ Momenta distribution is similarly as the signal mode.

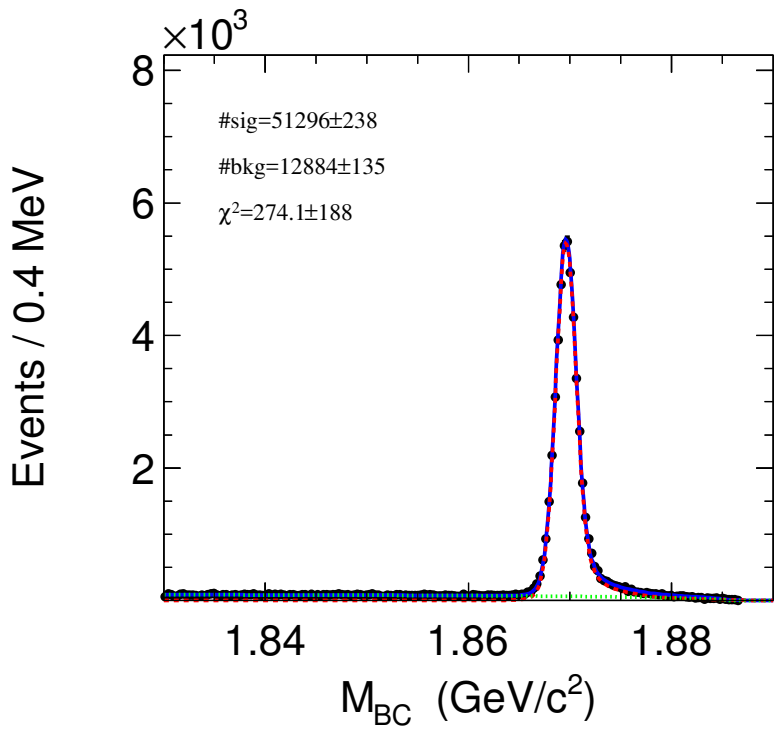
B) $A_{CP}(K_S\pi^\pm)$ is well measured

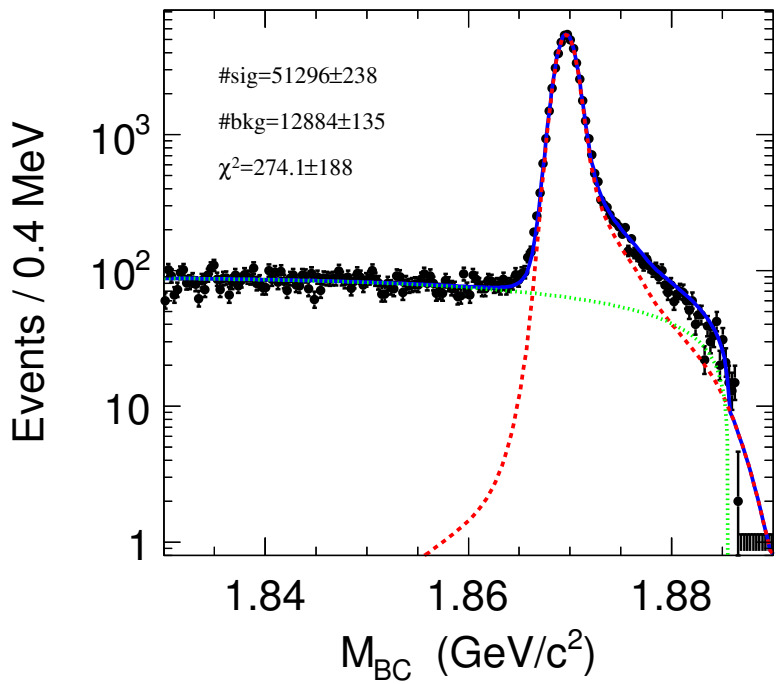
- ✓ BELL [2], CLEO [10], BABAR [1] and FOCS have measured $A_{cp}(K^0_S\pi^\pm)$
- ✓ The average value is [11]

$$A_{CP} = -0.41 \pm 0.09$$

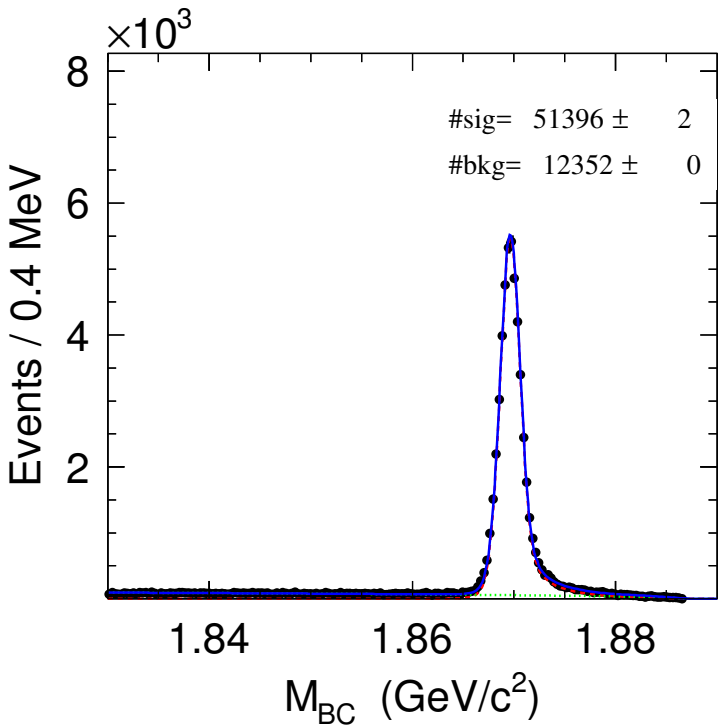
D^+ *Yields*

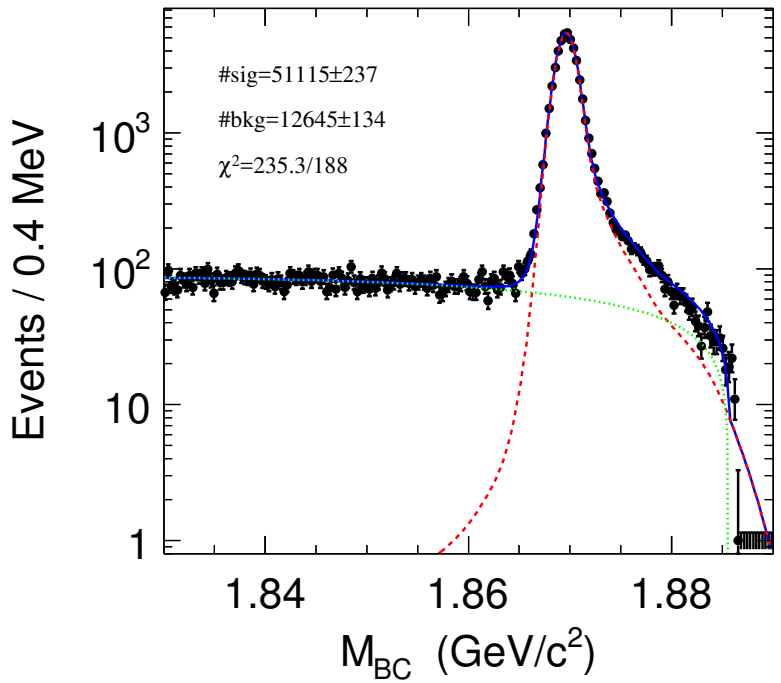
- ✓ Signal: MC shape $\otimes$ **Gaus**
- ✓ Background: Argus function





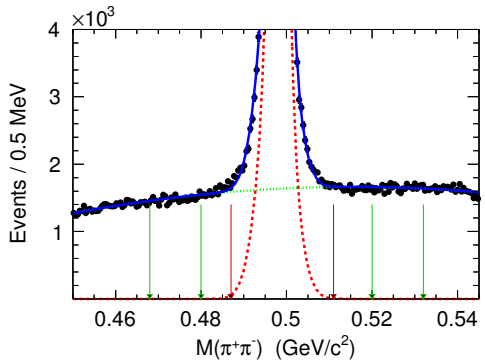
D^- Yields

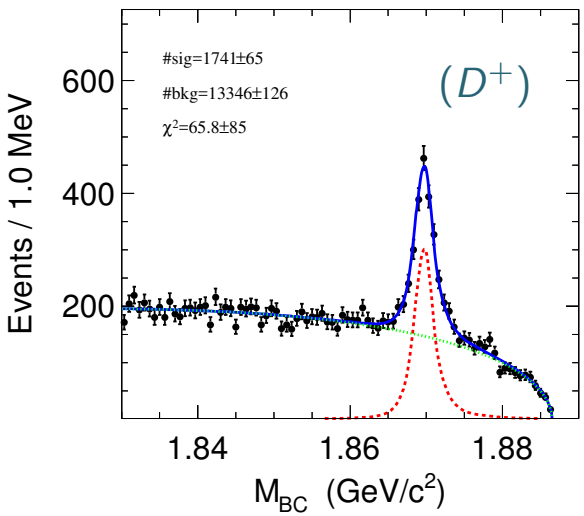

×10^3
8
6
4
2
#sig= 51396 ± 2
#bkg= 12352 ± 0
Events / 0.4 MeV
1.84
1.86
1.88
M_BC (GeV/c^2)

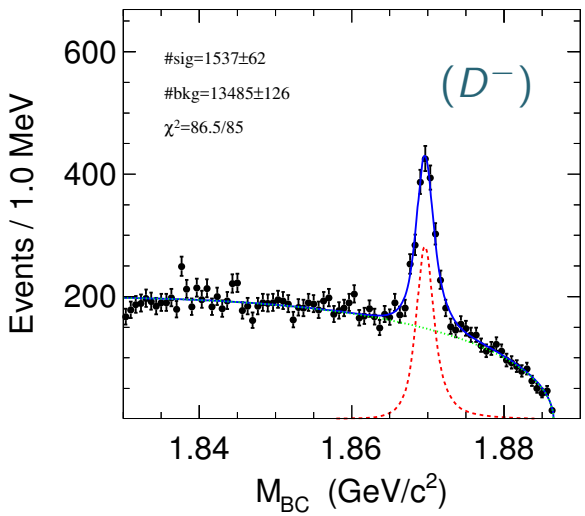

10^3
10^2
10
1
#sig=51115±237
#bkg=12645±134
χ^2=235.3/188
Events / 0.4 MeV
1.84
1.86
1.88
M_BC (GeV/c^2)

Peak background

✓ Peak from $D^+ \to 3\pi$







A) $A_\epsilon^{\pi^\pm}$ is determined by

$$A_{cp}^{raw}(K_S^0\pi^+) = A_{cp}(K_S^0\pi^+) + A_\epsilon^{\pi^\pm} \tag{7}$$

B) MC:

$$A_{epsilon}^{\pi^\pm} = (0.022 \pm 0.15)\% \tag{8}$$

C) Data:

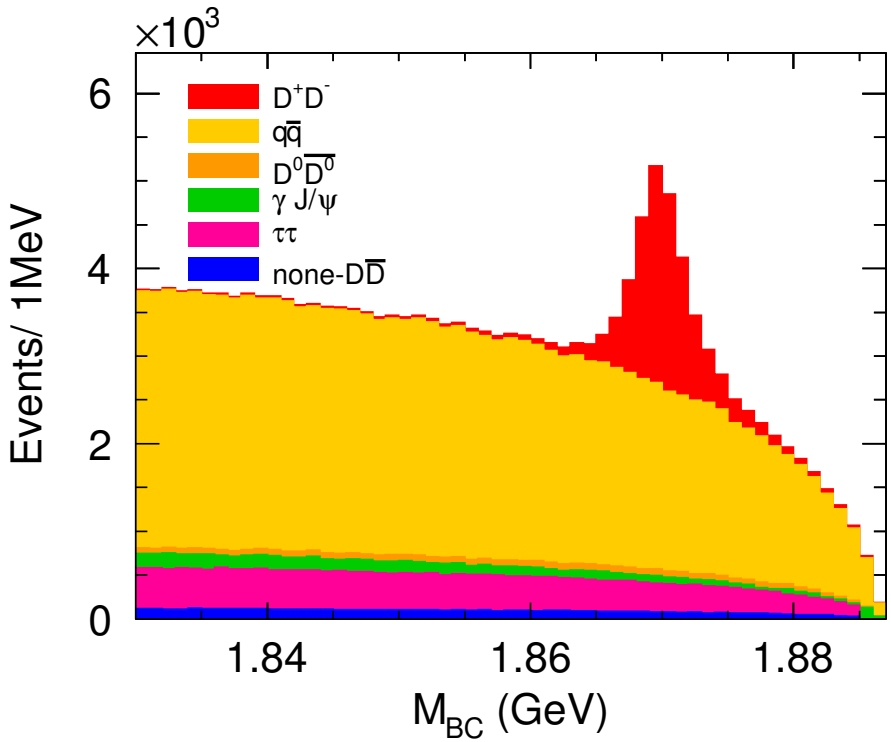
$$A_{raw}^{K\pi} = (0.09 \pm 0.33)\% \tag{9}$$

$$A_\epsilon^{\pi^+} = (-0.32 \pm 0.34)\% \tag{10}$$

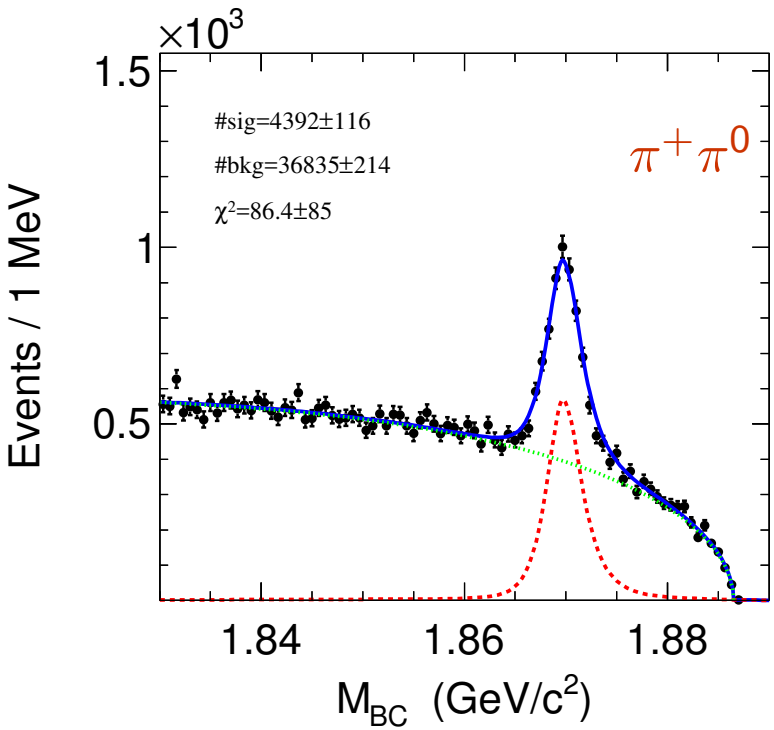
Study on $D^+ \to \pi^+\pi^0$ and $\pi^+\eta$

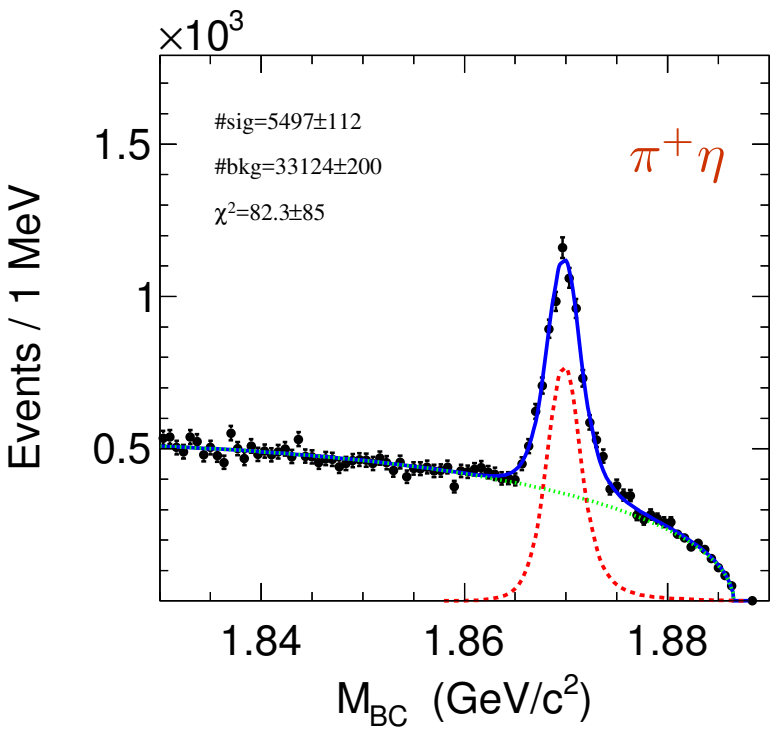
Background study

✓ No obvious peak background



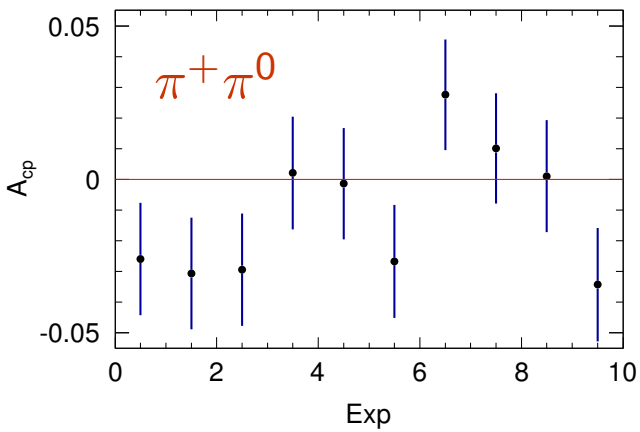
Some example of plots

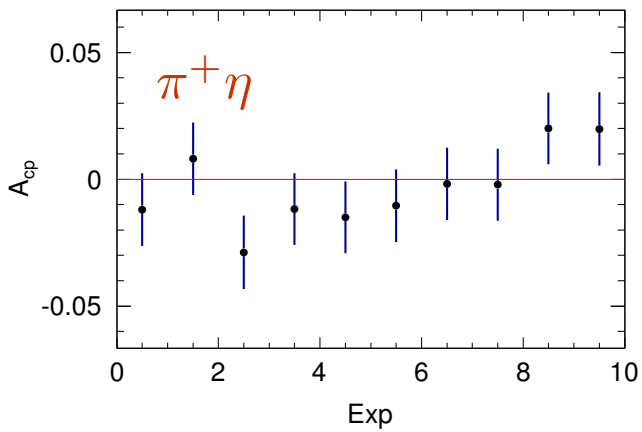




Study on MC sample

- ✓ Perform same procedure to the 10 MC samples.
- ✓ No obvious bias





Data

???

Summary

A) Efficiency asymmetry is determined to be:

$$A_{\epsilon}^{\pi^+} = (-0.32 \pm 0.34)\% \tag{11}$$

B) The sensitivity could reach 1.8% and 1.4% for $\pi^+\pi^0$ and $\pi^+\eta$ channels, respectively.

Thanks !

References I

[1] P. del Amo Sanchez et al., *Search for CP violation in the decay* $D^{\pm} \to K^0_S \pi^{\pm}$, , BaBar Collaboration, Phys. Rev. **D83** (2011) 071103, arXiv:1011.5477 [hep-ex].

[2] B. R. Ko et al., *Evidence for CP Violation in the Decay* $D^+ \to K^0_S \pi^+$, , Belle Collaboration, Phys. Rev. Lett. **109** (2012) 021601, arXiv:1203.6409 [hep-ex]. [Erratum: Phys. Rev. Lett.109,119903(2012)].

[3] R. Aaij et al., *Evidence for CP violation in time-integrated* $D^0 \to h^- h^+$ *decay rates*, , LHCb Collaboration, Phys. Rev. Lett. **108** (2012) 111602, arXiv:1112.0938 [hep-ex].

[4] R. Aaij et al., *Search for direct CP violation in D0 -¿ h- h+ modes using semileptonic B decays*, , LHCb Collaboration, Phys. Lett. **B723** (2013) 33–43, arXiv:1303.2614 [hep-ex].

References II

[5] R. Aaij et al., *Measurement of CP asymmetry in $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays*, , LHCb Collaboration, JHEP **07** (2014) 041, arXiv:1405.2797 [hep-ex].

[6] R. Aaij et al., *Measurement of the difference of time-integrated CP asymmetries in $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays*, , LHCb Collaboration, Phys. Rev. Lett. **116** (2016) no. 19, 191601, arXiv:1602.03160 [hep-ex].

[7] V. Babu et al., *Search for CP violation in the $D^+ \to \pi^+\pi^0$ decay at Belle*, , Belle Collaboration, Phys. Rev. **D97** (2018) no. 1, 011101, arXiv:1712.00619 [hep-ex].

[8] H.-n. Li, C.-D. Lu, and F.-S. Yu, *Branching ratios and direct CP asymmetries in $D \to PP$ decays*, , Phys. Rev. **D86** (2012) 036012, arXiv:1203.3120 [hep-ph].

References III

[9] Y. Grossman, A. L. Kagan, and J. Zupan, *Testing for new physics in singly Cabibbo suppressed D decays*, , Phys. Rev. **D85** (2012) 114036, arXiv:1204.3557 [hep-ph].

[10] G. Bonvicini et al., *Updated measurements of absolute D^+ and D^0 hadronic branching fractions and $\sigma(e^+e^- \to D\overline{D})$ at $E_{\rm cm} = 3774$ MeV*, , CLEO Collaboration, Phys. Rev. **D89** (2014) no. 7, 072002, arXiv:1312.6775 [hep-ex]. [Erratum: Phys. Rev.D91,no.1,019903(2015)].

[11] C. P. et al., *Review of Particle Physics*, , Chin. Phys. C **40** (2016) 100001.