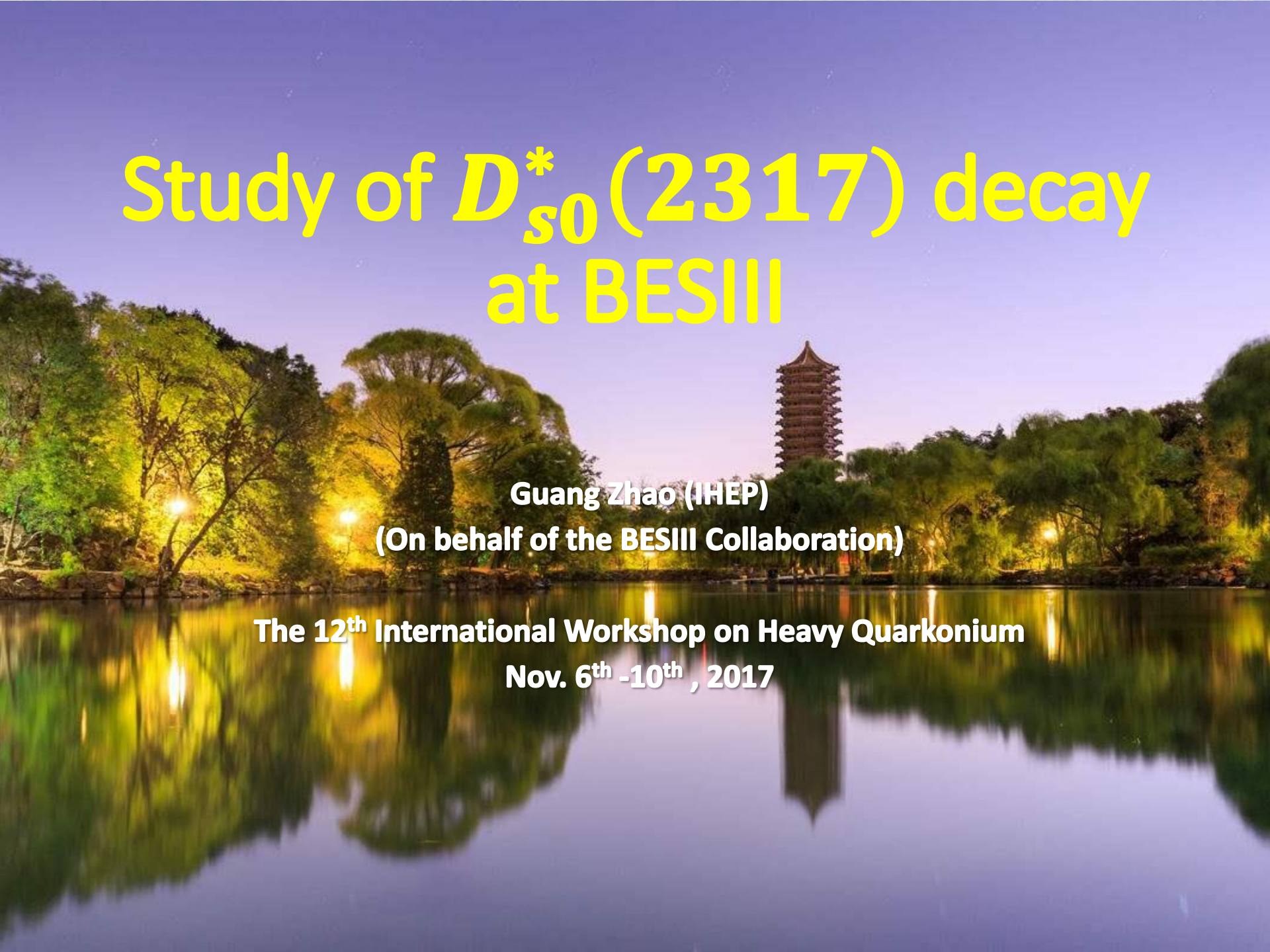
Study of $D_{s0}^{*}(2317)$ decay at BESIII



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(On behalf of the BESIII Collaboration)

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Motivation

- **The $D_{s0}^{*}(2317)^{-}$ meson**
  - was first observed at BABAR, confirmed by CLEO and Belle.
  - the measured mass is (2317.7 $\pm$ 0.6) MeV
  - is extremely narrow, and the upper limit of the width is 3.8 MeV @ 95% CL
  - the only known decay is $\pi^0 D_s^-$, but no measured branching fraction/partial decay width
  - is suggested to be the P-wave $\bar{c}s$ state with spin-parity $J^P = 0^+$.

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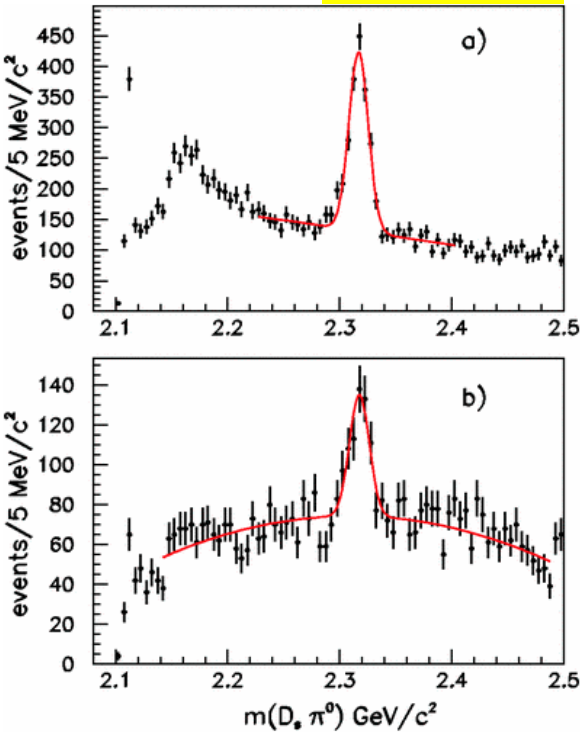


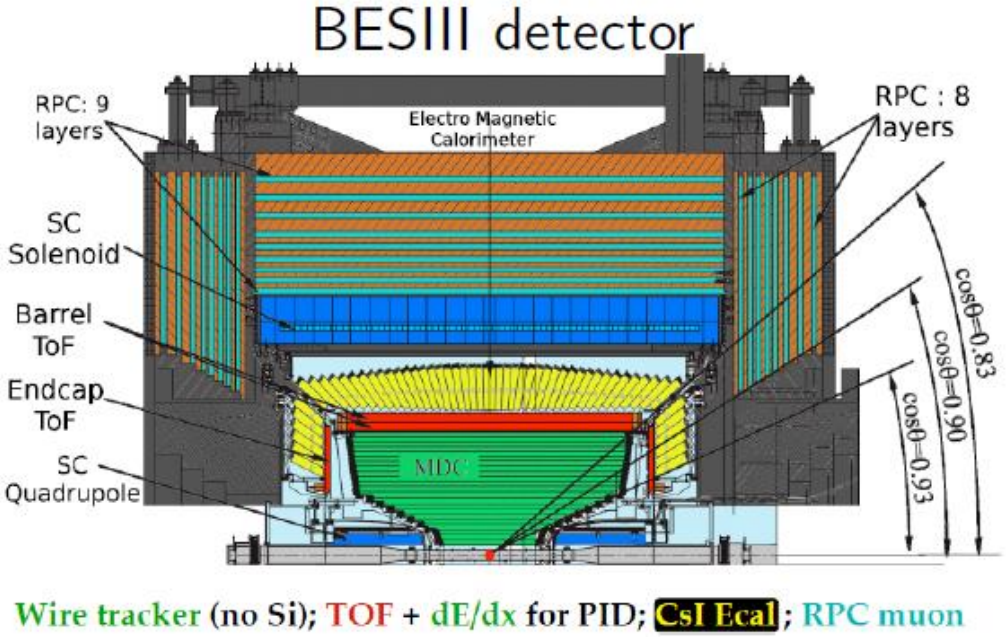
Motivation (cont.)

- **However…**
  - The measured mass (2317.7 ± 0.6) MeV is at least 150 MeV lower than the calculation of potential model and lattice QCD
  - As $D_{s0}^{*}(2317)^{-}$ is about 45 MeV below the DK threshold, it has been proposed as a good candidate of
    - DK molecule
    - a $\bar{c}sq\bar{q}$ tetraquark state
    - or a mixture of a $\bar{c}s$ meson and a $\bar{c}sq\bar{q}$ tetraquark.
  - Theoretical calculations give different values for the partial decay width $\Gamma(D_{s0}^{*}(2317)^{-} \to \pi^{0} D_{s}^{-})$
    - ~30 keV or even as low as a few keV if it is a pure $\bar{c}s$ state
    - can be enhanced by ~100 keV or even larger in the molecule picture due to the contribution of meson loop

- **So the partial decay width or the branching fraction of $D_{s0}^{*}(2317)^{-} \to \pi^{0} D_{s}^{-}$ is a key quantity to identify the nature of the $D_{s0}^{*}(2317)^{-}$**

Detector and data samples

Symmetric-energy e^+e^- collider



Sample for this work:

- 566.93 pb^{-1}, E_{cm} = 4.6 GeV taken at BESIII

Analysis strategy

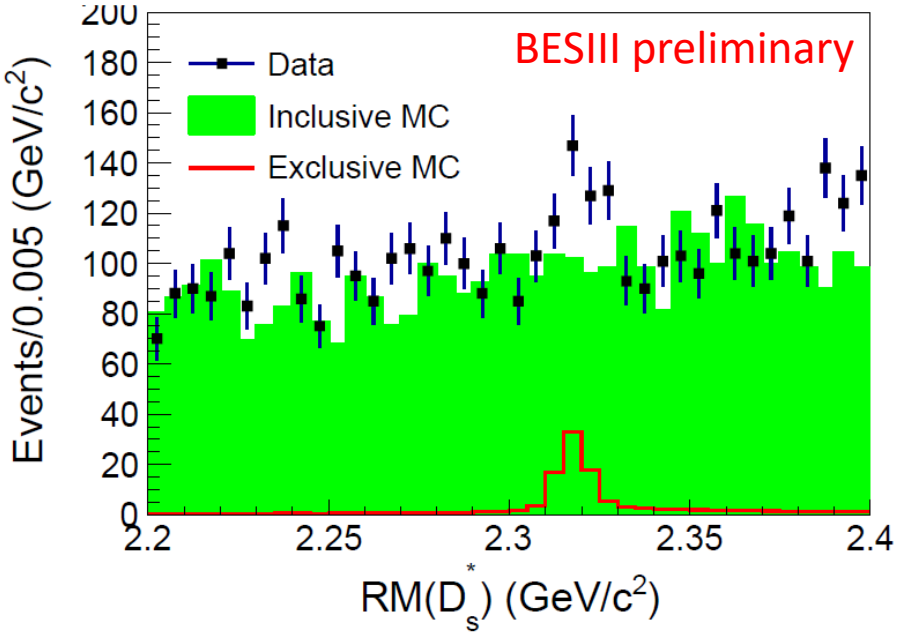
- **Topology**
  - $e^+e^- \to D_s^{*+} D_{s0}^*(2317)^-; D_{s0}^*(2317)^- \to \pi^0 D_s^-$

- **Strategy**
  - Tag $\boldsymbol{D_s^{*+}}$ with $\gamma D_s^+ \to \gamma K^+K^-\pi^+$
  - Search for $D_{s0}^*(2317)^-$ in the recoil mass of D_s^{*+}, and obtain the # of $D_{s0}^*(2317)^-$ events
  - Tag π^0 from $D_{s0}^*(2317)^-$ decay, and obtain the # of $\pi^0 D_s^-$ event
  - The absolute branching fraction of $D_{s0}^*(2317)^- \to \pi^0 D_s^-$ is calculable

Event selections of D_s^{*+} tag

- **Reconstruct $D_s^{*+} \to \gamma D_s^+ \to \gamma K^+ K^- \pi^+$ in $e^+e^- \to D_s^{*+} D_{s0}^*(2317)^-$**
  - At least 3 good charged tracks with vertex and PID requirements
  - At least 1 good photon
  - Make combinations of tracks/photos to form a D_s^+ and a D_s^{*+} candidate, and require
    - $|M(KK\pi) - M(D_s)| < 16$ MeV
    - $|M(\gamma KK\pi) - M(D_s^*)| < 11$ MeV
  - Perform 2C (constrain D_s^+ and D_s^{*+} mass) kinematic fit, and require $\chi^2 < 14$
  - (Event selections have been optimized based on MC)

Recoil mass of D_s^{*+}

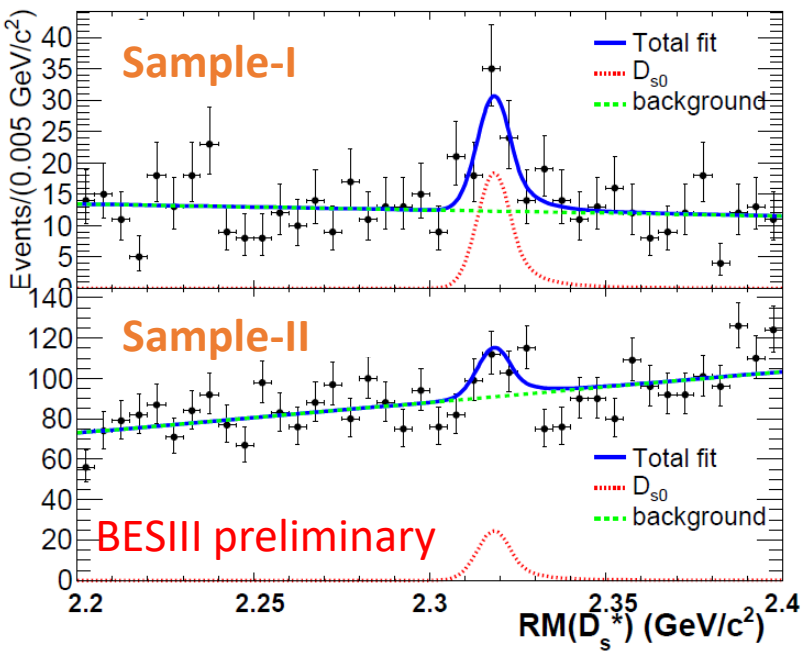


- Clear $D_{s0}^*(2317)^-$ peak
- Inclusive MC matches well with data background
- Backgrounds come from
  - non-D_s^* bkg: non-D_s^+ and mis-combined γD_s^+ events, cannot form a peak at 2317 MeV
  - real-D_s^* bkg: e.g. $D_s^* D_s^*$, $D_s^* D_s$. Their RM(D_s^{*+}) peak is distributed far away from 2317 MeV
  - Both of them cannot form peaking bkg

Event selections of π^0 tag

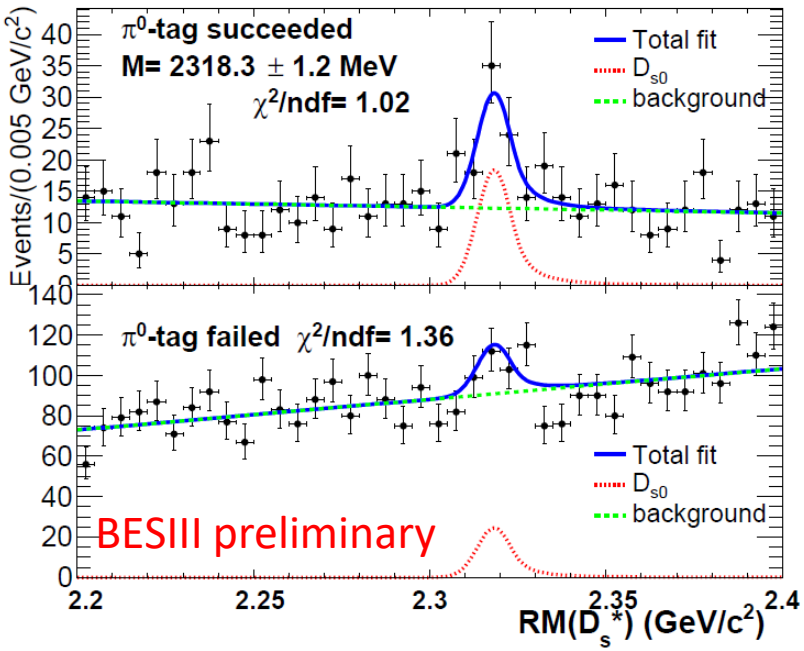
- **Due to the low statistics, we partially reconstruct the $D_{s0}(2317)^-$ from the particles not associated with the D_s^{*+} tag**
  - Reconstruct the π^0 from $D_{s0}(2317)^- \to \pi^0 D_s^-$, let D_s^- missing
  - If more than one π^0 exist, keep all combinations
  - Perform 4C kinematic fit (constrain M(D_s^+), M(D_s^{*+}), M(π^0) and M(D_s^-)$_{\text{miss}}$), require χ^2 < 36
  - (Event selections have been optimized based on MC)

Sample dividing based on π^0 tag



- **Divide the $e^+e^- \to D_s^{*+}D_{s0}^*(2317)^-$ events into 2 sub-samples:**
  - Sample-I: "π^0-tag succeeded"
    - at least one π^0 is tagged
  - Sample-II: "π^0-tag failed"
- **Will obtain better statistical precision if simultaneous fit these two sub-samples constraining the ratio of $\pi^0 D_s^-$ (or non-$\pi^0 D_s^-$) events in them be fixed by the MC efficiencies**

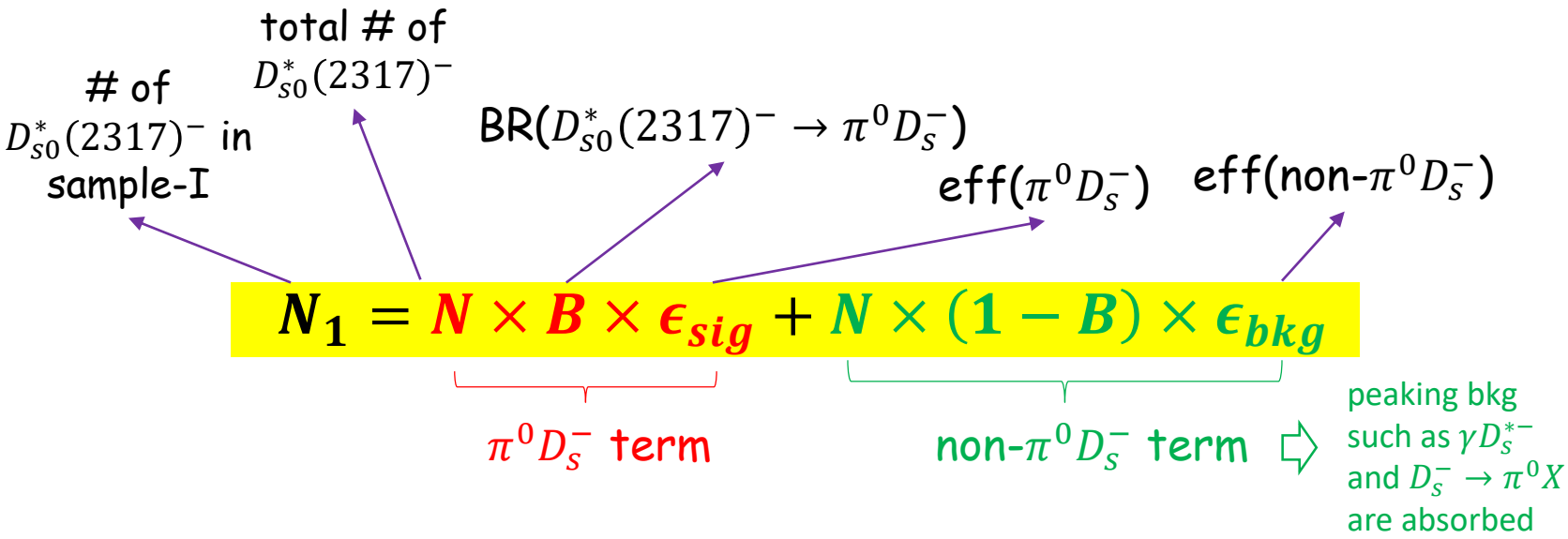
Simultaneous fit to RM(D_s^{*+})



- **Parametrization:**
  - Signal shape: Crystal ball (fixed by MC simulation except for mass) convolved a Gaussian (fixed by control sample: $D_s^{*+}D_s^{*-}$)
  - Background: 1-order polynomial
- **Fit results:**
  - # of $D_{s0}^*(2317)^-$ events: 115 ± 21
    - in sample-I: N1 = 46.8 ± 9.4
    - in sample-II: N2 = 68.2 ± 12.9
  - Mass of $D_{s0}^*(2317)$: (2318.3 ± 1.2) MeV

Statistical significance of the $D_{s0}^*(2317)^-$ signal is 5.8σ

BF measurements



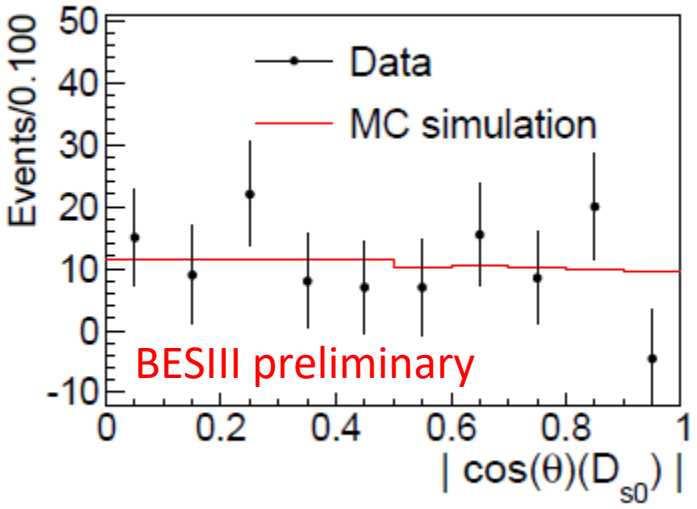
According to the formula above, the absolute branching fraction is measured as

$$\mathrm{BF}(D_{s0}^*(2317)^- \to \pi^0 D_s^-) = 1.00_{-0.14},$$

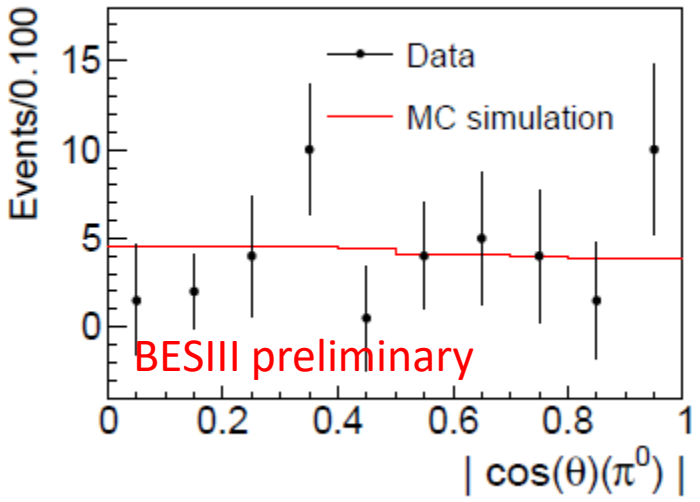
where the statistical error 0.14 is estimated by covering 68.3% confidence level from the likelihood distribution of the BF.

Angular distributions

$D_{s0}^{*}(2317)^{-}$ in the $e^{+}e^{-}$ c.m. system



π^{0} in the $D_{s0}^{*}(2317)^{-}$ c.m. system



If the J^{P} of $D_{s0}^{*}(2317)^{-}$ is 0^{+}, both the $D_{s}^{*+}D_{s0}^{*}(2317)^{-}$ and $\pi^{0}D_{s}^{-}$ systems could be in relative S-wave, and the angular distributions should be flat

Systematics for BF

For absolute branching fraction study, many sources of the systematics related to D_s^{*+} tag can be canceled

The remaining…

Source	Uncertainty (%)
π^0 reconstruction	0.7
Signal shape	5.0
Background shape	7.4
$\pi^0 D_s^-$ selections	3.1
Width of $D_{s0}^*(2317)^-$	5.3
Peaking backgrounds	8.5
Total	13.8

BESIII preliminary

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Due to the limited statistics, systematics related to $RM(D_s^{*+})$ fit dominate

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BESIII preliminary

The other major contribution…
Studied by simulating all the potential peaking backgrounds, including γD_s^{*-}, $\gamma\gamma D_s^-$ and $\pi^+\pi^- D_s^-$

Systematics for mass of $D_{s0}^{*}(2317)^{-}$

Source	Mass (MeV)
Mass calibration /c.m. energy determination	1.2
Signal shape	-
Background shape	-
Total	1.2

BESIII preliminary

Use control sample $e^+e^- \to D_s^{*+}D_s^{*-}$ at 4.6 GeV. Compare RM(D_s^{*+}) with PDG value. The difference 1.2 MeV is taken as systematic uncertainty

Summary

- We observe $D_{s0}^{*}(2317)^{-}$ signal via $e^{+}e^{-} \to D_{s}^{*+}D_{s0}^{*}(2317)^{-}$ using BESIII 4.6 GeV data (5.8σ)
- The mass of $D_{s0}^{*}(2317)^{-}$ is determined to be $(2318.3 \pm 1.2 \pm 1.2)$ MeV (preliminary)
- The branching fraction of $D_{s0}^{*}(2317)^{-} \to \pi^{0}D_{s}^{-}$ is measured as $1.00_{-0.14} \pm 0.14$ (preliminary) for the first time
- $D_{s0}^{*}(2317)^{-}$ tends to have a significantly smaller branching fraction to γD_{s}^{*-} than to $\pi^{0}D_{s}^{-}$, and this differs from the expectation of the conventional $\bar{c}s$ hypothesis but agrees well with the calculation in molecule picture
- The width of $D_{s0}^{*}(2317)^{-}$ could be measured in the future with more data, which may shed light on the nature of the $D_{s0}^{*}(2317)^{-}$.