Prospect of Measuring $D_{s}^{+} \rightarrow \pi^{+}\pi^{+}\pi^{-}\chi$ @ BESIII

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Motivation

- Measuring $R_{D^*}$ with decay $B^0 \rightarrow D^{*+}\tau^+\nu_\tau$ with $\tau$ lepton reconstructed from $\tau^+ \rightarrow \pi^+\pi^+\pi^-\nu_\tau$ in LHCb [arXiv:1708.08856, arXiv:1711.02505]

- Dominant double charm background: $B \rightarrow D^{*-}D_s(X)$ with 3 charged pions from $D_s$
  - $\text{Br} (D_s \rightarrow 3\pi+X)$ expected to be 25%, never measured directly

- The resonant structure of the 3$\pi$ system from $D_s$ is dominated by $\eta(\rho)$, different from that in the $\tau^+ \rightarrow 3\pi X$ final states

- LHCb uses $D_s$ enriched data to measure the inclusive $D_s \rightarrow 3\pi X$ decays

- These decays can be better understood using independent datasets from a different experiment
Beijing Electron Positron Collider (BEPCII)

Beam energy: 1.0 – 2.3 GeV

- 2004: started BEPCII upgrade, BESIII construction
- 2008: test run
- 2009 - now: BESIII physics physics run

- 1989-2004 (BEPC):
  \[ L_{\text{peak}} = 1.0 \times 10^{31} / \text{cm}^2 \text{s} \]
- 2009-now (BEPCII):
  \[ L_{\text{peak}} = 1.0 \times 10^{33} / \text{cm}^2 \text{(4/5/2016)} \]
BESIII detector

Muon Counter
8-9 layers RPC
$\Delta R\phi = 1.4 \text{ cm} \sim 1.7 \text{ cm}$

Super-conducting magnet
1.0 Tesla

93% coverage

Time of Flight (TOF)
$\sigma_t$: 90 ps Barrel
110 ps Endcap

Beryllium beam pipe

Drift Chamber (MDC)
$\sigma_p/p = 0.5\% \ (1 \text{ GeV})$
$\sigma_{dE/dx} = 6\%$

EMC (CsI)
$\sigma_{E/\sqrt{E}} = 2.5\% \ (1 \text{ GeV})$
$\sigma_{Z,\phi} = 0.5 - 0.7 \text{ cm}/\sqrt{E}$

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$3\sigma$ $K/\pi$ separation for $P < 0.9 \text{ GeV/c}$

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$\sigma_E/\sqrt{E} = 2.5\%$ (1 GeV)
$\sigma_{Z,\phi} = 0.5 - 0.7 \text{ cm}/\sqrt{E}$

Charm data sets at BESIII

- **D^{0(+)} data**
  - Taken @ $E_{cm} = 3.773$ GeV, $L_{int} = 2.93$ fb$^{-1}$
  - $e^+e^- \rightarrow D^0\bar{D}^0/D^+D^-$: 21 M $D^0$ and 16 M $D^+$ produced

- **$D_s^+$ data**
  - Taken @ $E_{cm} = 4.009$ GeV, $L_{int} = 0.482$ fb$^{-1}$
    - $e^+e^- \rightarrow D_s^+D_s^-$: 0.3 M $D_s^+$ produced
  - Taken @ $E_{cm} = 4.178$ GeV, $L_{int} = 3.19$ fb$^{-1}$
    - $e^+e^- \rightarrow D_s^+D_s^-$: 6 M $D_s^+$ produced
    - Accumulated in 2016

- **$\Lambda_c$ data**
  - Taken @ $E_{cm} = 4.599$ GeV, $L_{int} = 0.567$ fb$^{-1}$
  - $e^+e^- \rightarrow \Lambda_c^+\bar{\Lambda}_c^-$: 0.2 M $\Lambda_c$ produced

Most relevant for this study
Tagging method

Tag side: we have a fully reconstructed $D_s$ decay, $D_s^- \rightarrow K^+K^-\pi^-$ for example

Signal side: requiring three charged pion tracks $D_s^+ \rightarrow \pi^+\pi^+\pi^-X$

Photon emitted from $D_s^*$ could be either in the tag side or signal side

Possible tagging modes: $KK\pi$, $KK\pi\pi^0$, $\pi\pi\pi$, $K_sK$, $K_sK\pi^0$, $\eta(\gamma)\pi$, ...

$e^+ e^- \rightarrow D_s^{**} D_s^-$

$3.19 \text{ fb}^{-1} @ 4.178 \text{ GeV}$

For Tag side (reconstructed from $K^+K^-\pi^-$):

$$M_{\text{rec}} = \sqrt{(E_{\text{cm}} - \sqrt{m_{D_s^*}^2 + m_{D_s^-}^2})^2 - \left| -\vec{p}_{D_s^-}\right|^2}$$

$\sim 130K D_s^- \rightarrow K^+K^-\pi^-$ tag events collected

Major background: light qq
Some thoughts on this study

- Based on BESIII $D_sD_s^*$ datasets, we expect to collect a few tens of thousands $D_s \to 3\pi(X)$ events with $D_s$ tagged
- This could provide a unique opportunity for measuring the inclusive branching ratio, understanding the resonant structures, etc

- Challenges:
  - Efficiency determination
  - Backgrounds from $K/\pi$ & $\mu/\pi$ misID
    - Can be evaluated using data-driven methods
  - $K_s \to \pi\pi$ background
Plans

- For $D_s D_s^*$ events, fully reconstruct a tagged $D_s$
- In the signal side, collect three pions with total charge equal to the signal $D_s$
- Identifying the photon from $D_s^*$ helps to improve the background suppression, though not necessary
- Understanding background sources
- Efficiency determination from MC & validation
- Exploration of intermediate states in the $3\pi$ inclusive mode
Summary

- $D_s \rightarrow \pi\pi\pi X$ inclusive branching fraction and its $3\pi$ resonant structure important inputs for the LHCb $B \rightarrow D^*\tau\nu$ analysis

- Based on recently collected $3\text{fb}^{-1} \, D_s^*D_s$ data, BESIII is able to provide unique information on $D_s \rightarrow \pi\pi\pi X$ inclusive mode

- A large range of physics topics are accessible @ BESIII: $D_s \rightarrow N3\pi$, $D_s \rightarrow \eta\pi X$, $D_s \rightarrow \eta'\pi X$, $D_s \rightarrow \pi\pi\pi\pi\pi X$, $D_s \rightarrow \tau(\rightarrow \pi\pi\pi X)\nu$, etc.

- Expecting first status report during the BES-LHCb Workshop in February