భారతీయ సాంకేతిక విజ్ఞాన సంస్థ హైదరాబాద్
भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

BELLE

Search for Radiative D_s Decays

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on behalf of Belle(II) collaboration | October 10, 2024

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Outline

1. Motivation
2. Belle experiment
3. Radiative D_s decays
   - $D_s^+ \to \rho^+\gamma$ & $D_s^+ \to K^{*+}\gamma$ study
   - Background suppression
   - Signal extraction
   - Control sample study
4. Summary

Motivation

- In the Standard Model (SM), the physics of charmed mesons faces certain challenges compared to strange and beauty mesons because the CP asymmetries and D^0 - $\bar{D}^0$ oscillations are small. (I. I. Bigi, Report No. CERN-TH.7370/94)
- Investigating weak decays of D mesons is complex due to significant final-state interactions.

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SM Predictions and NP Probes:

- The oscillations and $c \to u\gamma$ decays might have some contributions coming from the non-minimal supersymmetry (an NP scenario).
- NP would result in a deviation from the ratio of branching fractions

$$R_{\rho/\omega} \equiv \frac{\Gamma(D^0 \to \rho^0/\omega\gamma)}{\Gamma(D^0 \to \bar{K}^{*0}\gamma)} = \frac{tan^2\theta_c}{2}$$

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- A similar ratio for D_s^+ radiative decays offers a much better probe for an NP signal(Phys. Rev. D 54, 5883(1996)), as the latter

$$R_K \equiv \frac{\Gamma(D_s^+ \to K^{*+}\gamma)}{\Gamma(D_s^+ \to \rho^+\gamma)} = \tan^2\theta_c$$

is less sensitive to SM corrections and offers a more robust NP probe.

Recent Status:

- Long-distance(LD), non-perturbative processes dominate these decays, potentially enhancing BFs, basically to test the QCD based calculations of LD dynamics.[Phys. Rev. D 56, 4302]
- The BF of $D_s^+ \to \rho^+\gamma$ [$D_s^+ \to K^{*+}\gamma$] mode is expected to lie within the range of O(10^{-5}) − O(10^{-3})[O(10^{-8}) − O(10^{-4})], according to the predictions of different models [JHEP 08 (2017) 091 [arXiv:1701.06392]], which are quite divergent for the D_s decay mode.
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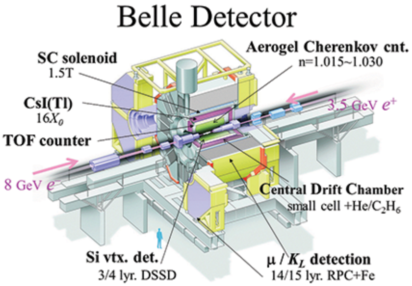
Presenting herein...

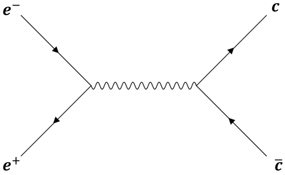
- Radiative decays $D_s^+ \to K^{*+}\gamma$ have not been observed experimentally.
- The first sensitivity study of radiative D_s meson decays with data collected by the Belle experiment.
- Predictions for branching fractions and comparisons with theoretical models.

Belle experiment at KEKB

- KEKB is an asymmetric-energy e^+e^- collider operating near $\Upsilon(4S)$ mass peak ($\sim$ 10.58 GeV/c^2, $>$ $B\bar{B}$ threshold).
- Belle detector has good performances on momentum/vertex resolution; particle identification, etc.
- Accumulated data set of $\sim$1 ab^{-1}: which provides a large $B\bar{B}$ sample (772 millions), and also a large charm sample to study charm physics.
- Fruitful Charm results are lasting to produce, although the accumulation of final data set finished $>$14 years ago.



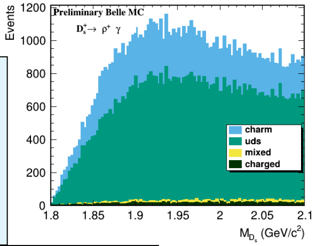
$e^+e^- \to$	Cross section [nb]
$\Upsilon(4S)$	1.05 ± 0.10
$c\bar{c}$	1.30
$s\bar{s}$	0.38
$u\bar{u}$	1.61
$d\bar{d}$	0.40
$\tau^+\tau^-(\gamma)$	0.919
$\mu^+\mu^-(\gamma)$	1.148
$e^+e^-(\gamma)$	300 ± 3



Analysis In a Nutshell

Challenges:

- Small signal rates, large background



1) Event Selection and Reconstruction

- Final state particle with good track selection, particle ID criteria etc.
- Forming D_s meson using final state particles.
- Simultaneous optimization using E_γ, $E9E25_\gamma$ and π^0 veto

Signal modes:

- $D_s^+ \to \rho^+\gamma, \rho^+ \to \pi^+\pi^0$
- $D_s^+ \to K^{*+}\gamma$

1. $K^{*+} \to K_s^0\pi^+$
2. $K^{*+} \to K^+\pi^0$

2) Background suppression

- Understand the background levels
- Cut on the output of MVA classifiers optimized and trained using simulated data

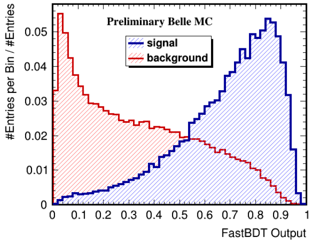
3) Signal Extraction

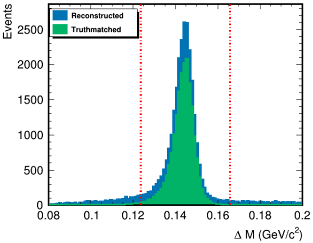
- Develop Fit model using simulation

4) Validation

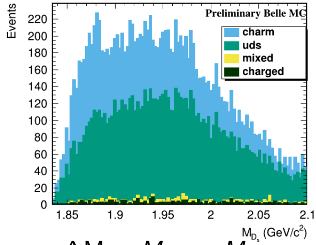
- Ensemble and control sample study

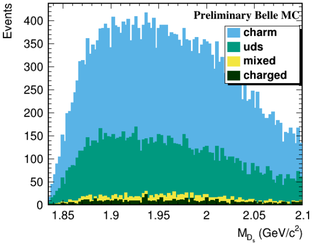
Background suppression





$D_s^+ \to \rho^+\gamma$ $\qquad$ $D_s^+ \to K^{*+}\gamma$





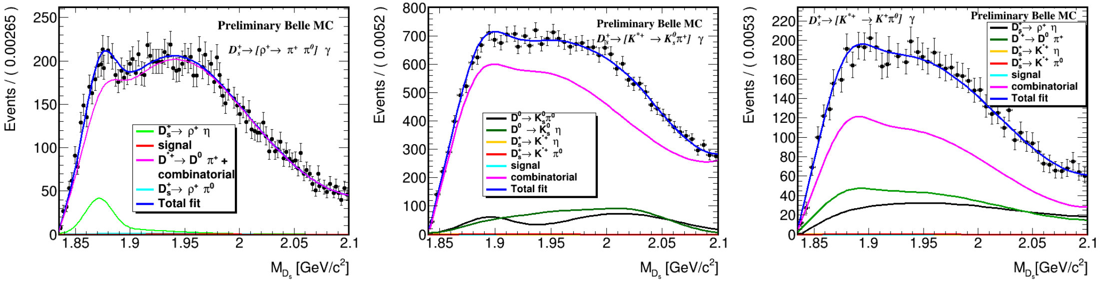
- $\Delta M = M_{D_s^{*+}} - M_{D_s^+}$

Decay mode	MVA cut	Bkg. Rej.	Sig. Ret.
$D_s^+ \to \rho^+\gamma$	>0.4	66 %	90 %
$D_s^+ \to K^{*+}\gamma$[1]	>0.5	74 %	78 %
$D_s^+ \to K^{*+}\gamma$[2]	>0.5	74 %	77 %

- Cut on the output of MVA classifiers optimized and trained using simulated data
- Expected around 80-100, 15-20 [1] and 8-10[2] events assuming Branching fraction 10^{-4} for $D_s^+ \to \rho^+\gamma$ and 10^{-5} for $D_s^+ \to K^{*+}\gamma$ using Belle data

Decay mode	efficiency(%)
$D_s^+ \to \rho^+\gamma$	0.47 ± 0.01
$D_s^+ \to K^{*+}\gamma$ [1]	3.09 ± 0.02
$D_s^+ \to K^{*+}\gamma$ [2]	0.79 ± 0.01

Signal extraction



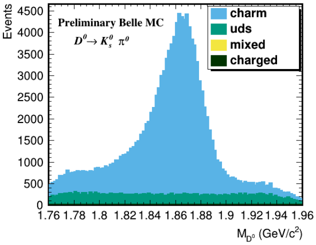
- ΔM signal window = [0.1237, 0.1660] GeV$/c^2$
- $M_{D_s} \in (1.835, 2.10)GeV/c^2$
- Performed 1D unbinned maximum likelihood fit to extract signal yield using 711 fb^{-1} of Belle MC sample taking peaking backgrounds into consideration.

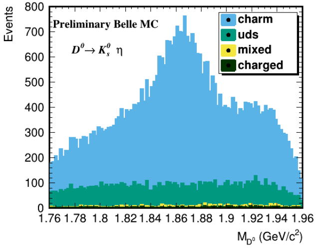
Validation

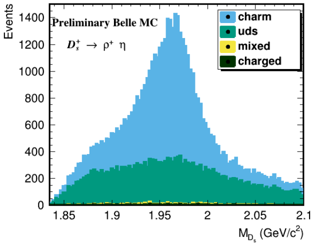
Control mode study:

- $D_s^+ \to \rho^+\eta, \rho^+ \to \pi^+\pi^0$
- $D^{*0} \to [D^0 \to K_s^0\pi^0]\gamma$
- $D^{*0} \to [D^0 \to K_s^0\eta]\gamma$

- To verify the signal extraction procedure and to calibrate the MC/Data resolution of our MC studies, we perform a control sample study on a decay channel.
- Similar cut applied including FastBDT output



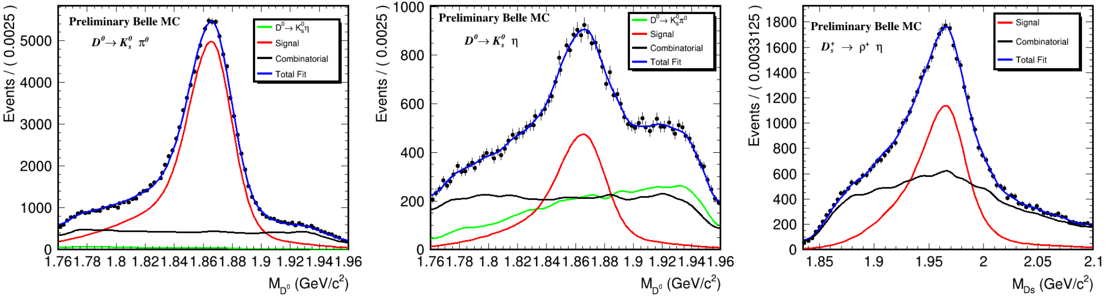




- $\Delta M = M_{D_s^{*+}} - M_{D_s}$
- $\Delta M = M_{D^{*0}} - M_{D^0}$
- $M_{D_s} \in (1.835, 2.10)\text{GeV}/c^2$
- $M_{D^0} \in (1.76, 1.96)\text{GeV}/c^2$

Decay mode	efficiency(%)
$D_s^+ \to \rho^+\eta$	0.43 ± 0.01
$D^0 \to K_s^0\pi^0$	3.37 ± 0.02
$D^0 \to K_s^0\eta$	3.15 ± 0.02

Crosschecks with MC



- Performed 1D unbinned maximum likelihood fit of M_{D_s} and M_{D^0} within the signal window of ΔM to extract signal yield using 711 fb^{-1} of Belle MC sample taking peaking backgrounds into consideration.

$$\text{ratio(R)} = \frac{B(D^0 \to K_s^0\pi^0)}{B(D^0 \to K_s^0\eta)}$$

- R as per MC (DECAY.DEC) = 2.91 (2.84)

Summary

Conclusion

- Belle is still producing new results.
- Performed MC Study with implementation of π^0/η veto and MVA training to get rid of the huge background for $D_s^+ \to \rho^+\gamma$ and $D_s^+ \to K^{*+}\gamma$ decay mode.
- Validated using control mode studies on $D_s^+ \to \rho^+\eta$, $D^0 \to {K_s}^0\eta$, $D^0 \to {K_s}^0\pi^0$. We will calculate of branching fraction or upper limit depending on the final observation.
- Expected around 80-100, 15-20 [1] and 8-10[2] events assuming branching fraction 10^{-4} for $D_s^+ \to \rho^+\gamma$ and 10^{-5} for $D_s^+ \to K^{*+}\gamma$ using Belle data.
- As a summary, I would like to say, "Our Belle is not only keeping alive but still keeping energetic with fruitful charm results, although its final full data set was achieved more than 14 years ago."

Please stay tuned!!!!



Thank you for your attention