भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

BELLE

Belle II

Study Of Radiative D_s Decays In Belle

Belle Analysis Workshop, 2022

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2. **Decay Modes of Interest**
3. **Analysis Strategy for signal modes**
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   - $D_s^+ \rightarrow K^{*+}\ \gamma$
4. **Control Mode Study**
   - ${D_s}^+ \rightarrow \rho^+ \eta$
   - $D^0 \rightarrow {K_s}^0 \pi^0$
   - $D^0 \rightarrow {K_s}^0 \eta$
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Motivation

- In SM, the physics of charm meson is not expected to have NP discovery potential because CP asymmetries and D^0-$\bar{D}^0$ oscillations are small.
- The weak decays of D mesons are also difficult to investigate due to the strong final state.
- It has been pointed that the oscillations and c$\rightarrow$ uγ decays might have some contributions coming from the non-minimal supersymmetry which is NP scenario.
- Therefore, one can search for NP using c$\rightarrow$ uγ transitions. It was suggested that NP will result in deviation from

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

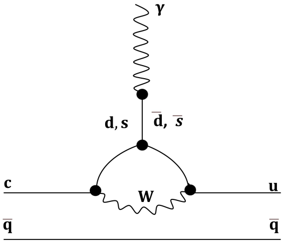
- B. Bajc et al [PhysRevD.54(9).5883 (1996)] studied Cabibbo suppressed D^0, D^+, D_S^+ radiative weak decays in order to find the best mode to test c$\rightarrow$ uγ decay.
- They calculated the ratios between various Cabibbo suppressed and Cabibbo allowed charm meson radiative weak decays, as predicted by the SM. After analysing them they noticed that the previous equation can be violated already in the SM framework , while a similar relation for D_S^+ radiative decays offers a much better test for c$\rightarrow$ uγ

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

Theoretical Point of View

S. Fajfer,P. Singer et al. [doi:10.1103/PhysRevD.56.4302]

- The analysis of the D→V γ transitions was done using a model which combines heavy quark effective theory and the chiral Lagrangian approach and includes symmetry breaking.
- They notice that in addition to the s-channel annihilation and t-channel W exchange, there is a long- distance penguin like c→u γ contribution in the Cabibbo-suppressed modes.
- Although smaller in magnitude, the penguin like contribution would lead to sizable effects in case of cancellations among the other contributions to the amplitude. Thus, it may invalidate suggested tests for beyond the standard model effects in these decays.
- They also indicated the range of expectations for the branching ratios of various D→V γ modes.



Decay Mode	Branching Fraction
$D_s^+ \to \rho^+\gamma$	(3-5) * 10^{-4}
$D_s^+ \to K^{*+}\gamma$	(2.1-3.2) * 10^{-5}

Decay Mode

Decay Mode of Interest

- $D_s^+ \rightarrow \rho^+ \gamma$ where $\rho^+ \rightarrow \pi^+ \pi^0$
- $D_s^+ \rightarrow K^{*+} \gamma$ where $K^{*+} \rightarrow \pi^+ K_S^0$

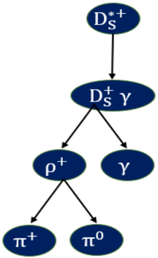
Branching Fraction

- $\rho^+ \rightarrow \pi^+ \pi^0$ BF=100%
- $K^{*+} \rightarrow K_S^0 \pi^+$ BF=66 %

Control Modes

- ${D_s}^+ \rightarrow \rho^+ \eta$ where $\eta \rightarrow \gamma\gamma$
- $D^0 \rightarrow K_s^0 \pi^0$ where $K_s^0 \rightarrow \pi^+ \pi^-$, $\pi^0 \rightarrow \gamma\gamma$
- $D^0 \rightarrow K_s^0 \eta$ where $K_s^0 \rightarrow \pi^+ \pi^-$,$\eta \rightarrow \gamma\gamma$

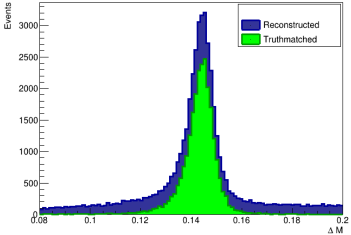
$D_s^+ \rightarrow \rho\ \gamma$



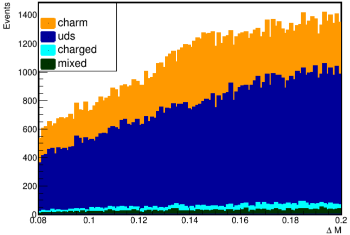
Selection Criteria
ΔM ϵ [0.12, 0.16] GeV/c^2
M_{D_s} ϵ [1.90, 2.01] GeV/c^2
$M_{D_s^{*+}}$ ϵ [2.05, 2.15] GeV/c^2
M_{π^0} ϵ [0.120, 0.150] GeV/c^2
M_ρ ϵ [0.7, 0.9] GeV/c^2
$\theta_\gamma(\pi^0)$ ϵ [0.54, 2.28]
abs(d0) $<$ 0.5 cm
abs(z0) $<$ 2.5 cm

Optimized by Punzi FOM
$p_{D*} > 3$
$E_{asym} < 0.80$
$E_\gamma(D_s^*) > 0.17$ GeV
$E_\gamma(D_s) > 0.9$ GeV
$E_\gamma(\pi^0) > 0.2$ GeV
Pi0-Veto $<$ 0.85
E9E25 $>$ 0.95
$(cos\theta_{hel}) < 0.8$
xp $>$ 0.6

SMC



GMC

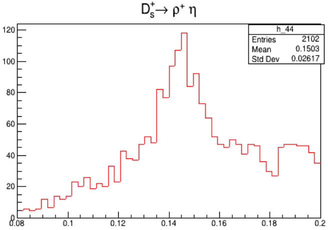


Framework used	B2BII
Generated Sample	5M
Generic Sample	1 stream of Belle data

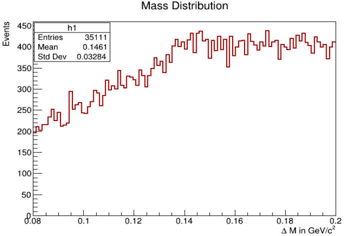
- BCS criteria $\chi^2{}_{D_s*}$
- BCS efficiency 73.5%
- Multiplicity 25.2 %
- Expected yield = 400-800 events assuming 10^{-4} Branching fraction using Belle data

Continued....

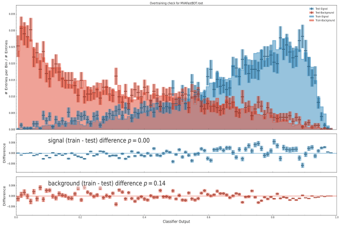
Peaking Background

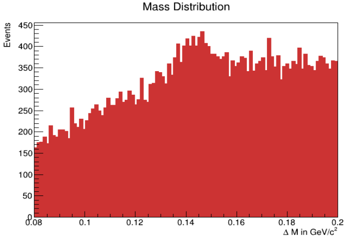


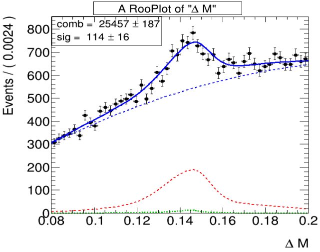
After removing the peaking



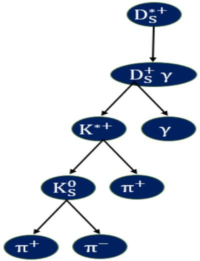
MVA Training







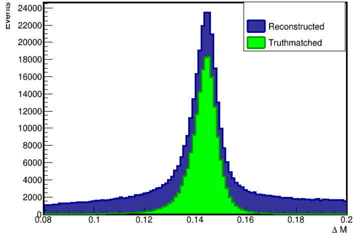
- Used GenMCTag tool to identify the peaking background. Most of the peaking background comes from $D_s \to \rho\eta$ decay mode.
- Plan to use $D_s \to \rho\eta$ as control mode.
- Applied FastBDT cut $> 0.4 \to 64\%$ of background loss in the cost of 10% signal loss.



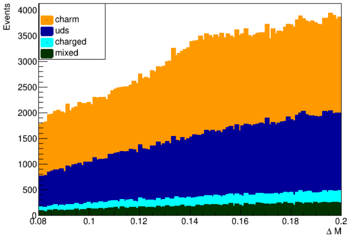
Selection Criteria
$\Delta M \in [0.12, 0.16]$ GeV/c^2
$M_{D_s} \in [1.90, 2.01]$ GeV/c^2
$M_{D_s^{*+}} \in [2.05, 2.15]$ GeV/c^2
$M_{K_S^0} \in [0.45, 0.55]$ GeV/c^2
$M_{K^{*+}} \in [0.8, 1.0]$ GeV/c^2
abs(d0) $<$ 0.5 cm
abs(z0) $<$ 2.5 cm

Optimized by Punzi FOM
$p_{D*} > 3$
$E_\gamma(D_s^*) > 0.17$ GeV
$E_\gamma(D_s) > 0.9$ GeV
Pi0-Veto < 0.85
E9E25 > 0.95
$(cos\theta_{hel}) < 0.8$
xp > 0.6

SMC



GMC

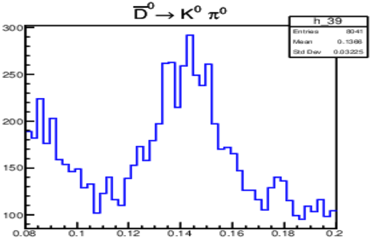


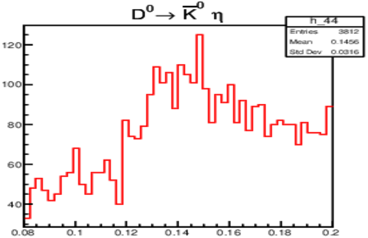
Framework used	B2BII
Generated Sample	5M
Generic Sample	1 stream of Belle data

- BCS criteria $\chi^2{}_{D_s}$
- BCS efficiency 70%
- Multiplicity 26%
- Expected yield = 20-30 events assuming 10^{-5} Branching fraction using Belle data

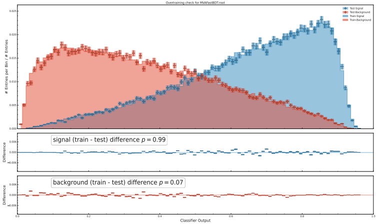
Continued...

Peaking Background

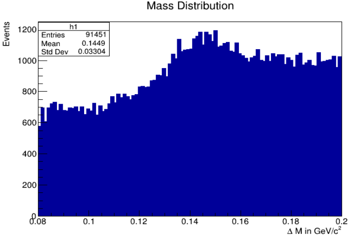




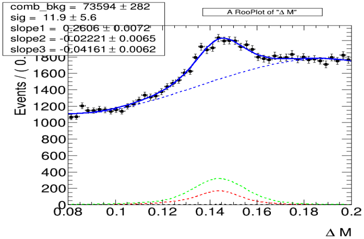
MVA Training



After applying FastBDT

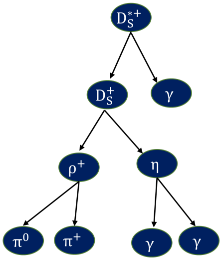


Signal Extraction



- Most of the peaking background coming from $D^0 \to K^0\eta$ and $D^0 \to K^0\pi^0$.
- Plan to use$D^0 \to K^0\eta$ and $K^0\pi^0$ as control modes.
- Applied FastBDT cut $> 0.4 \to$ 74% of background loss in the cost of 22% signal loss.

$D_s^+ \to \rho^+ \eta$ control mode



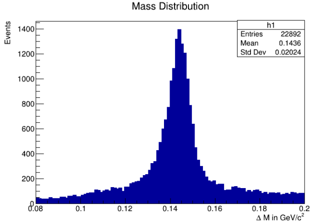
Selection Criteria
$\Delta M \; \epsilon \; [0.12, 0.16]$ GeV/C^2
$M_{D_s} \; \epsilon \; [1.98, 2.02]$ GeV/C^2
$M_{D_s^{*+}} \; \epsilon \; [2.05, 2.15]$ GeV/C^2
$M_\eta \; \epsilon \; [0.50, 0.58]$ GeV/C^2
$M_\rho \; \epsilon \; [0.7, 0.9]$ GeV/C^2
abs(d0) $<$ 0.5 cm
abs(z0) $<$ 2.5 cm
$E_{asym} < 0.80$
$E_\gamma(D_s^*) > 0.17$ GeV
$p_{D*} > 3$

$E_\gamma(\pi^0) > 0.2$ GeV
Pi0-Veto < 0.85
$(cos\theta_{hel}) < 0.8$
xp > 0.6

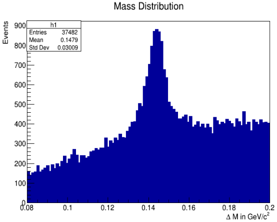
Signal sample = 2M
GMC sample = stream 10
Efficiency = 0.8 %

Peaking part investigated by GenMC Tag tool, mostly coming from signal decay

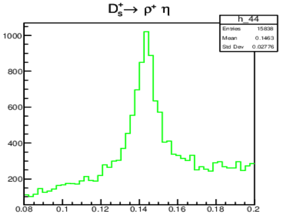
Signal MC Distribution



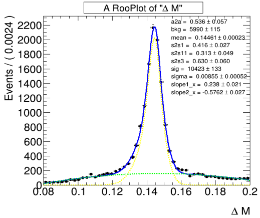
Background Distribution



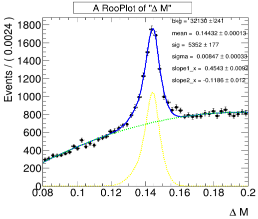
peaking background



SMC

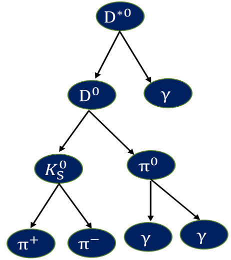


Signal Extraction



Expected yield around 150k events assuming 10^{-2} Branching fraction using Belle data.

$D^0 \to K_s{}^0\pi^0$ control mode



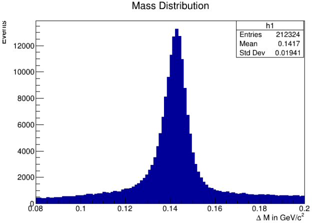
Selection Criteria
$\Delta M \; \epsilon \; [0.12,\ 0.16]\ GeV/C^2$
$M_{D*0} \; \epsilon \; [1.98\ ,\ 2.02] GeV/C^2$
$M_{D0} \; \epsilon \; [1.75\ ,\ 2.05] GeV/C^2$
$M_{K^0_S} \; \epsilon \; [0.45\ ,\ 0.55] GeV/C^2$
$p_{D*} > 2.5\ GeV/C$
abs(d0) $<$ 0.5 cm
abs(z0) $<$ 2.5 cm
$E_\gamma(D^{*0}) > 0.17$ GeV

Pi0-Veto < 0.85
xp > 0.5
MVA > 0.5

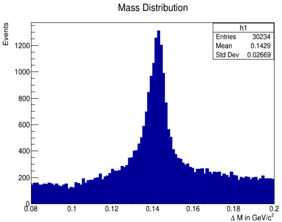
Signal sample = 2M
GMC sample = stream 10
Efficiency = 10.6 %

Peaking part investigated by GenMC Tag tool, mostly coming from signal decay

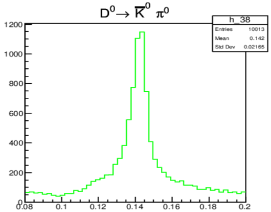
Signal MC Distribution



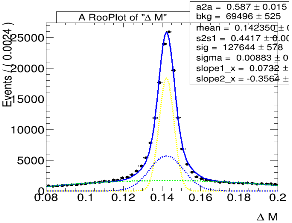
Background Distribution



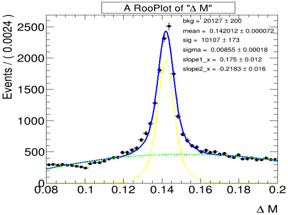
Peaking Contribution



SMC

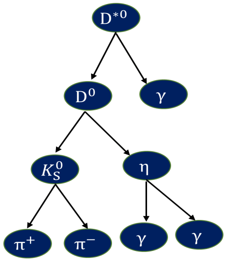


Signal Extraction



Expected yield around 350k events assuming 10^{-2} Branching fraction using Belle data.

$D^0 \to K_s{}^0 \eta$ control mode



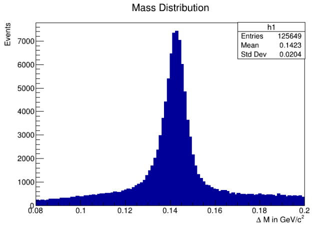
Selection Criteria
$\Delta M \in [0.12, 0.16]$ GeV/c^2
$M_{D^{*0}} \in [1.9 , 2.01]$GeV/$c^2$
$M_{D^0} \in [1.75 , 2.05]$GeV/$c^2$
$M_{K_S^0} \in [0.45 , 0.55]$GeV/$c^2$
$p_{D*} > 2.5$ GeV/C
abs(d0) $<$ 0.5 cm
abs(z0) $<$ 2.5 cm
$E_\gamma(D^{*0}) > 0.17$ GeV

Pi0-Veto $<$ 0.85
xp $>$ 0.5
MVA $>$ 0.5

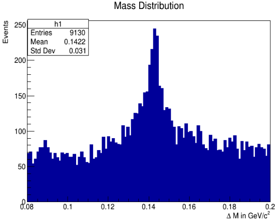
Signal sample = 2M
GMC sample = stream 10
Efficiency = 6.28 %

Peaking part investigated by GenMC Tag tool, mostly coming from signal decay

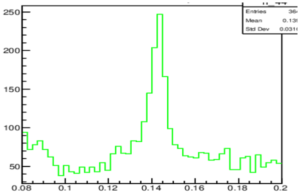
Signal MC Distribution



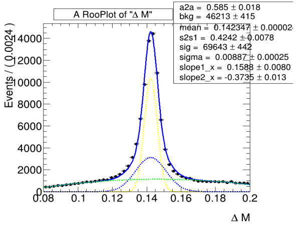
Background Distribution



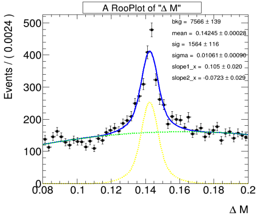
Peaking Background



SMC



Signal Extraction



Expected yield around 52k events assuming 10^{-3} Branching fraction using Belle data.

Summary and Future Plan

- Performed MC Study using B2BII Framework.
- We have implemented Koppenburg π^0/η veto to get rid of the huge background coming from π^0 decays.
- We have performed MVA training to get rid of the uds background.
- The best candidate selection has been performed using ${\chi^2}_{D_s{}^*}$ and ${\chi^2}_{D_s}$ respectively.
- We then carried out the unbinned maximum likelihood fit on the variable ΔM taking peaking background into consideration.
- Control mode studies on $D_s \to \rho\eta$, $D^0 \to {K_s}^0\eta$, $D^0 \to {K_s}^0\pi^0$ are going on.
- Plan to test the robustness of the fit with toy MC study.
- Plan to Calculate of branching fraction or upper limit depending on the final observation.


Շնորհակալություն
Teşekkür ederim
Terima kasih
Merci
ขอบคุณ
Gratiam ago
Cảm ơn
Grazie
ধন্যবাদ।
شكرًا
Спасибо
நன்றி
Mulţumesc
多謝
To-siā
Danke
धन्यवाद।
Asante
Děkuji
Ďakujem
Dankie
naŋri
Köszönöm
Tak
Gràcies
Thank you
Tack
唔該
Dankon
謝謝
Hvala
Takk
Diolch
dhanyavaad
감사합니다
Kiitos
谢谢
Faleminderit
Obrigado
Paldies
Bedankt
Dziękujemy
Mèsi
ありがとう
Ви благодарам
Gracias
Lóo-lát
Σας ευχαριστούμε