Measurements of the ratio of partial widths: $\Gamma(D_s^{*+} \to D_s^+ \pi^0)/\Gamma(D_s^{*+} \to D_s^+ \gamma)$

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Introduction

- $D_s^{*+} \to D_s^+\gamma$ only observed radiative decay mode of D_s^{*+} meson and $D_s^{*+} \to D_s^+\pi^0$ is only kinematically allowed decay.
- $D_s^{*+} \to D_s^+\pi^0$ violates isospin symmetry but theoretically(PhysRevD.49.6228) suggested $D_s^{*+} \to D_s^+\pi^0$ proceed via $\pi^0 - \eta$ mixing to conserve isospin.
- Theoretically estimated ratio of partial widths: $\Gamma(D_s^{*+} \to D_s^+\pi^0)/\Gamma(D_s^{*+} \to D_s^+\gamma) \simeq 0.01 - 0.10$
- Previous measurements of $\Gamma(D_s^{*+} \to D_s^+\pi^0)/\Gamma(D_s^{*+} \to D_s^+\gamma)$:
  - $0.062^{+0.020}_{-0.018}$(stat.) $\pm$ 0.022(syst.) CLEO using 3.75 fb^{-1} data
  - 0.062 ± 0.005(stat.) $\pm$ 0.006(syst.) BABAR using 90.4 fb^{-1} data
- Higher statistics in Belle II can improve existing measurements
- Early measurements will give a better understanding of the Belle II performance
- With neutrals, Belle II can perform better than LHCb

Data Samples and Decay mode

We will use following decay modes of D_s^+

Decay Mode	Effective Branching Ratio
$D_s^+ \to K^+\bar{K}^{*0}$, $\bar{K}^{*0} \to K^-\pi^+$	2.58%
$D_s^+ \to \phi\pi^+$, $\phi \to K^+K^-$	2.24%

Generic MC samples: MC 15 run independent samples, corresponds to an integrated luminosity of 400 fb^{-1}

Official Generated Signal Samples:$\sim$ 1 Million for each decay mode

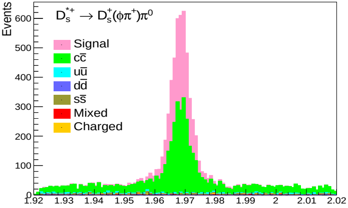
Selection criteria for $D_s^{*+} \to D_s^+ \pi^0$

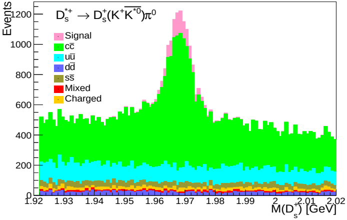
Objects	Selection cuts
Tracks	$\lvert dr \rvert < 1$ cm $\lvert dz \rvert < 3$ cm
K^+	KaonID > 0.4
π^+	PionID > 0.4
γ	$E_\gamma^{barrel} > 30$ MeV $E_\gamma^{forward} > 120$ MeV $E_\gamma^{backward} > 80$ MeV clusterE1E9 > 0.4 $0.5 <$ clusterTheta < 2.6180 clusterNHits > 1.5
π^0	$0.121 < M(\gamma\gamma) < 0.142$ $-1.2 < \Delta\phi < 1.2$ daughterAngle(0,1) < 1 Mass Fit
D_s^+	$1.922 < M < 2.02$ GeV/c^2
D_s^{*+}	$0.135 < \Delta M(M(D_s^{*+}) - M(D_s^+)) < 0.16$ GeV/c^2 $p^*(D_s^{*+}) > 2.5$ Gev/c

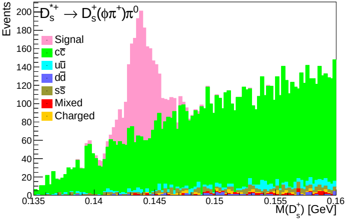
Signal and background is selected using **isSignal** variable

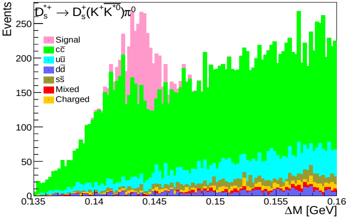
M(D_s^+) & ΔM distributions for $D_s^{*+} \to D_s^+ \pi^0$ decay mode

ΔM is within signal region $1.96 < M(D_s^+) < 1.98$ but no ΔM on M(D_s^+) distributions









Purity(Signal Region: $1.96 < M(D_s^+) < 1.98$ and $0.14 < \Delta M < 0.15$)

$D_s^+ \to \phi\pi^+$:∼ 45% and $D_s^+ \to \bar{K}^{*0} K^+$: ≃ 21%

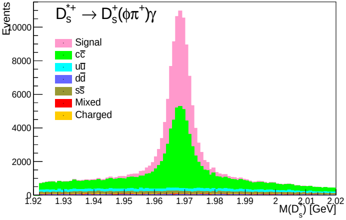
Selection criteria for $D_s^{*+} \to D_s^+ \gamma$

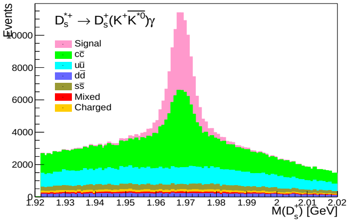
Objects	selection cuts
Tracks	$\lvert dr \rvert < 1$ cm $\lvert dz \rvert < 3$ cm
K^+	KaonID $\frac{\mathcal{L}_K}{\mathcal{L}_\pi + \mathcal{L}_K} > 0.4$
π^+	PionID $\frac{\mathcal{L}_\pi}{\mathcal{L}_\pi + \mathcal{L}_K} > 0.4$
γ	E > 300 MeV
D_s^+	$1.922 < M(K^+K^-\pi^+) < 2.02$ GeV/c^2
D_s^{*+}	$0.06 < \Delta M < 0.18$ GeV/c^2 $2.06 < M(D_s^{*+}) < 2.16$ GeV/c^2 $p^*(D_s^{*+}) > 2.5$ Gev/c

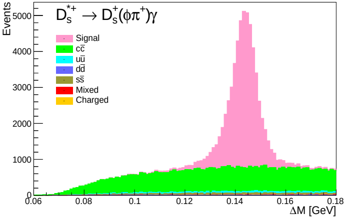
Additional π^0 veto is applied to reduce background from π^0

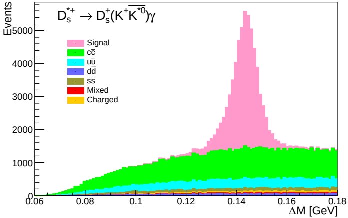
M(D_s^+) & ΔM distributions for $D_s^{*+} \to D_s^+\gamma$ decay mode

ΔM is within signal region $1.96 < M(D_s^+) < 1.98$ but no ΔM on M(D_s^+) distributions







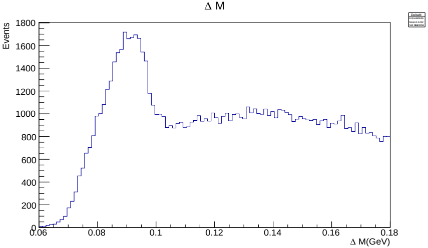


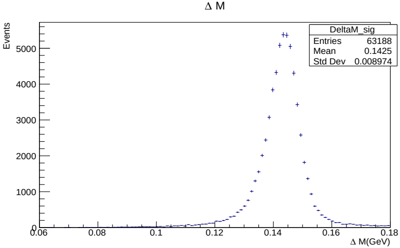
Purity (Signal Region: $1.96 < M(D_s^+) < 1.98$ and $0.12 < \Delta M < 0.16$)

$D_s^+ \to \phi\pi^+$:∼ 84% and $D_s^+ \to \bar{K}^{*0}K^+$: ∼ 60%

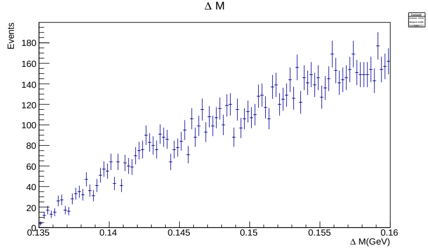
Crossfeed Plots

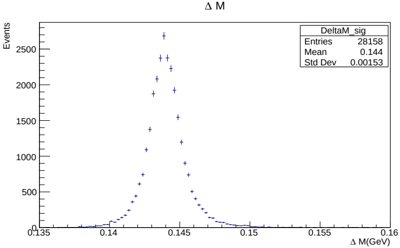
Background of $D_s^{*+} \to D_s^+(\phi\pi^+)\pi^0$ in $D_s^{*+} \to D_s^+(\phi\pi^+)\gamma$





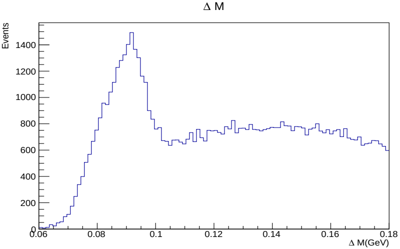
Background of $D_s^{*+} \to D_s^+(\phi\pi^+)\gamma$ in $D_s^{*+} \to D_s^+(\phi\pi^+)\pi^0$

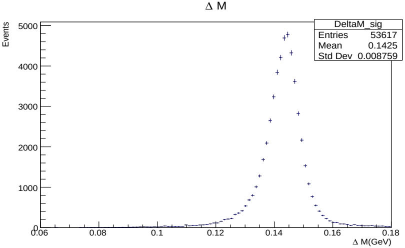




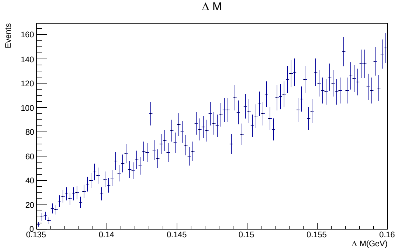
Crossfeed Plots

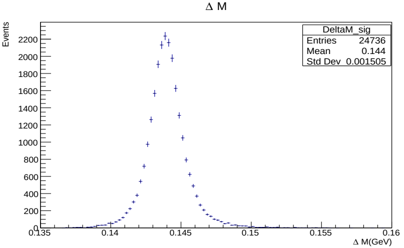
Background of $D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\pi^0$ in $D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\gamma$





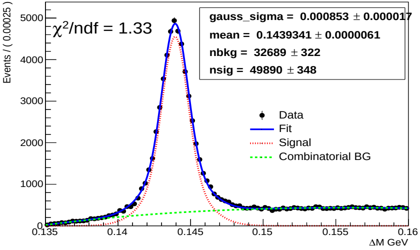
Background of $D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\gamma$ in $D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\pi^0$



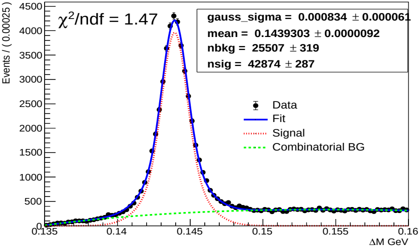


Efficiency for $D_s^{*+} \to D_s^+ \pi^0$ decay mode

$D_s^+ \to \phi\pi^+$



$D_s^+ \to \bar{K}^{*0} K^+$



$$Efficiency = \frac{Number\ of\ Reconstructed\ D_s^{*+} \to D_s^+ \pi^0\ candidates}{Total\ Number\ of\ D_s^{*+}\ candidates}$$

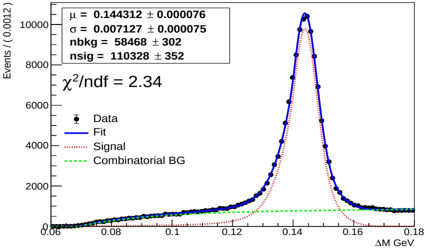
Process	Efficiency(%)
$D_s^+ \to \phi\pi^+$	2.5 ± 0.017(Stat.)
$D_s^+ \to \bar{K}^{*0} K^+$	2.1 ± 0.014(Stat.)

Signal PDF: Double Gaussian Function

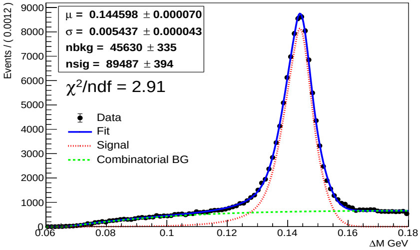
Background PDF: Threshold Function

Efficiency for $D_s^{*+} \to D_s^+ \gamma$ decay mode

$D_s^+ \to \phi\pi^+$



$D_s^+ \to \bar{K}^{*0} K^+$



$$Efficiency = \frac{Number\ of\ Reconstructed\ D_s^{*+} \to D_s^+ \gamma\ candidates}{Total\ Number\ of\ D_s^{*+}\ candidates}$$

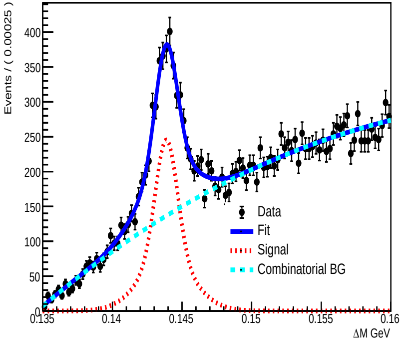
Process	Efficiency(%)
$D_s^+ \to \phi\pi^+$	5.5 ± 0.017(Stat.)
$D_s^+ \to \bar{K}^{*0} K^+$	4.5 ± 0.019(Stat.)

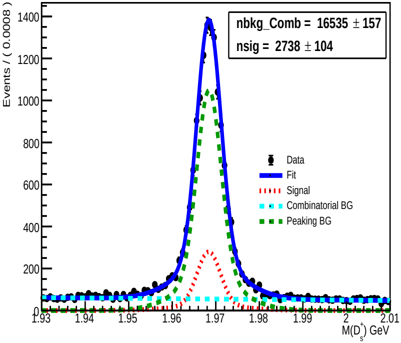
Signal PDF: Double Gaussian + Crystal Ball Function

Background PDF: Threshold Function

$D_s^{*+} \to D_s^+(\phi\pi^+)\pi^0$ 2D fit

To extract the signal yield from we 2D fit ΔM and $M(D_s^+)$ distribution of all the 4 decays



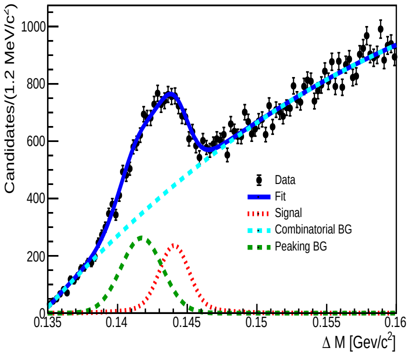


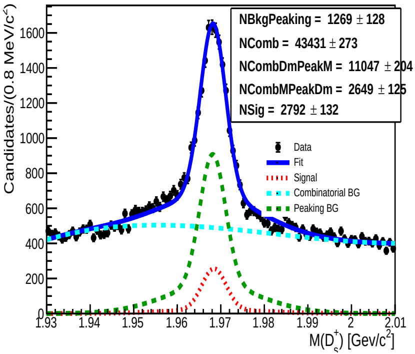
Signal Pdf: Double Gaussian Function
Combinatorial bkg: Threshold function

Signal Pdf: Double Gaussian
Combinatorial bkg: 3^{rd} order polynomial
Peaking bkg: Double Gaussian

Signal Candidates from Truth matching: 2696

$D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\pi^0$ 2D fit



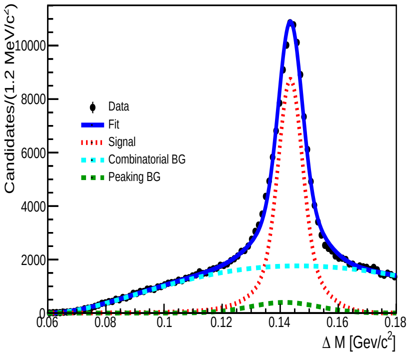


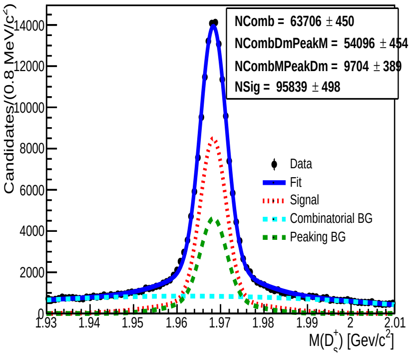
Signal Pdf: Double Gaussian Function
Combinatorial bkg: Threshold function
Peaking bkg: Gaussian Function

Signal Pdf: Double Gaussian
Combinatorial bkg: 3^{rd} order polynomial
Peaking bkg: Double Gaussian

Signal Candidates from Truth matching: 2674

$D_s^{*+} \to D_s^+(\phi\pi^+)\gamma$ 2D fit



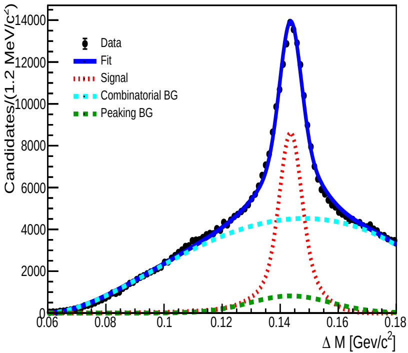


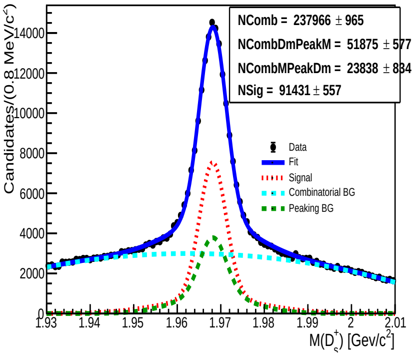
Signal Pdf: Crystall Ball + Double Gaussian Function
Combinatorial bkg: Threshold function
Peaking bkg: Gaussian

Signal Pdf: Double Gaussian
Combinatorial bkg: 2^{nd} order polynomial
Peaking bkg:Double Gaussian

Signal Candidates from Truth matching: 98501

$D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\gamma$ 2D fit





Signal Pdf: Crystall Ball + Double Gaussian Function
Combinatorial bkg: Threshold function
Peaking bkg: Gaussian

Signal Pdf: Double Gaussian
Combinatorial bkg: 2^{nd} order polynomial
Peaking bkg: Double Gaussian

Signal Candidates from Truth matching: 94670

Measurement of $\Gamma(D_s^{*+} \to D_s^+\pi^0)/\Gamma(D_s^{*+} \to D_s^+\gamma)$

$$\mathrm{N}_1 = \epsilon_1(D_s^{*+} \to D_s^+(\phi\pi^+)\pi^0) \times N(D_s^{*+}) \times BR(D_s^{*+} \to D_s^+\pi^0) \times Eff.BR(D_s^+ \to \phi\pi^+)$$

$$\mathrm{N}_2 = \epsilon_2(D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\pi^0) \times N(D_s^{*+}) \times BR(D_s^{*+} \to D_s^+\pi^0) \times Eff.BR(D_s^+ \to K^+\bar{K}^{*0})$$

$$\mathrm{N}(D_s^{*+} \to D_s^+\pi^0) = \mathrm{N}_1 + \mathrm{N}_2$$

$$\Gamma(D_s^{*+} \to D_s^+\pi^0) = \frac{N(D_s^{*+} \to D_s^+\pi^0)}{N(D_s^{*+})(\epsilon_1 \times Eff.BR(D_s^+ \to \phi\pi^+)) + (\epsilon_2 \times Eff.BR(D_s^+ \to K^+\bar{K}^{*0}))}$$

$$\Gamma(D_s^{*+} \to D_s^+\gamma) = \frac{N(D_s^{*+} \to D_s^+\gamma)}{N(D_s^{*+})(\epsilon_3 \times Eff.BR(D_s^+ \to \phi\pi^+)) + (\epsilon_4 \times Eff.BR(D_s^+ \to K^+\bar{K}^{*0}))}$$

$$\frac{\Gamma(D_s^{*+} \to D_s^+\pi^0)}{\Gamma(D_s^{*+} \to D_s^+\gamma)} = \frac{N(D_s^+\pi^0) \times (\epsilon_3 \times Eff.BR(D_s^+ \to \phi\pi^+)) + (\epsilon_4 \times Eff.BR(D_s^+ \to K^+\bar{K}^{*0}))}{N(D_s^+\gamma) \times (\epsilon_1 \times Eff.BR(D_s^+ \to \phi\pi^+)) + (\epsilon_2 \times Eff.BR(D_s^+ \to K^+\bar{K}^{*0}))}$$

Measurement of $\Gamma(D_s^{*+} \to D_s^+\pi^0)/\Gamma(D_s^{*+} \to D_s^+\gamma)$

Quantity	Value(Generic MC)
$\epsilon_1(D_s^{*+} \to D_s^+(\phi\pi^+)\pi^0)$	0.025 ± 0.00017
$\epsilon_2(D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\pi^0)$	0.021 ± 0.00014
$\epsilon_3(D_s^{*+} \to D_s^+(\phi\pi^+)\gamma)$	0.055 ± 0.00017
$\epsilon_4(D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\gamma)$	0.045 ± 0.00019
$Eff.BR(D_s^+ \to \phi\pi^+)$	0.0224
$Eff.BR(D_s^+ \to K^+\bar{K}^{*0})$	0.0258
$N(D_s^{*+} \to D_s^+\pi^0)$	5530 ± 168
$N(D_s^{*+} \to D_s^+\gamma)$	187270 ± 747
$\frac{\Gamma(D_s^{*+} \to D_s^+\pi^0)}{\Gamma(D_s^{*+} \to D_s^+\gamma)}$	0.064 ± 0.003(Stat.)

Experiment	Previous Results
BABAR	0.062 ± 0.005(stat.) ± 0.006(syst.)
CLEO	$0.062^{+0.020}_{-0.018}$(stat.) ± 0.022(syst.)

- Initial measurements from MC is consistant with expectations.
- There is about 50% reduction in statistical uncertainty as compared to previous best measurements

- Working on the measurements of the ratio of partial widths: $\Gamma(D_s^{*+} \to D_s^+ \pi^0)/\Gamma(D_s^{*+} \to D_s^+ \gamma)$ with Belle II data.
- Presented results with Generic MC
- To do:
  – Look at the data, understand various correction factors, robustness of fitting setup, and systematic uncertainties
  – We are also planning to measure the width of $D_s^{*+}(\Gamma(D_s^{*+}))$

Thank you !!

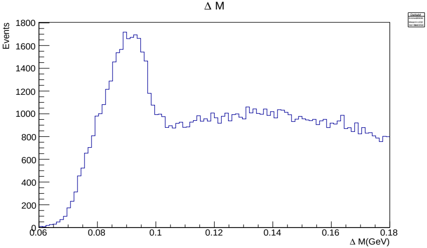
Backup slides

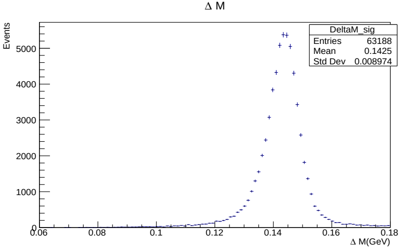
Multiplicity and BCS Efficiency

Process	Multiplicity(%)	Efficiency(%)
$D_s^{*+} \to D_s^+(\phi\pi^+)\pi^0$	0.04	100
$D_s^{*+} \to D_s^+(\phi\pi^+)\gamma$	0.08	98
$D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\pi^0$	0.07	100
$D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\gamma$	0.05	89

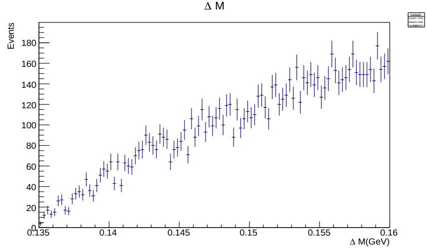
Crossfeed Plots

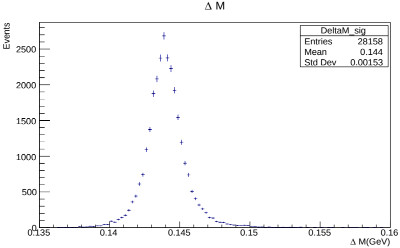
Background of $D_s^{*+} \to D_s^+(\phi\pi^+)\pi^0$ in $D_s^{*+} \to D_s^+(\phi\pi^+)\gamma$





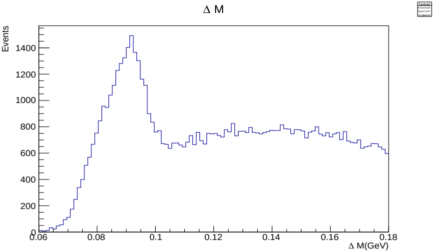
Background of $D_s^{*+} \to D_s^+(\phi\pi^+)\gamma$ in $D_s^{*+} \to D_s^+(\phi\pi^+)\pi^0$

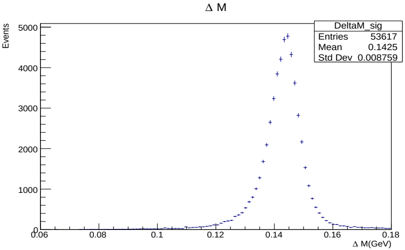




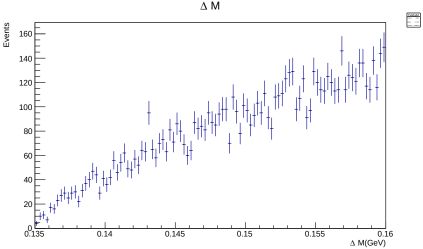
Crossfeed Plots

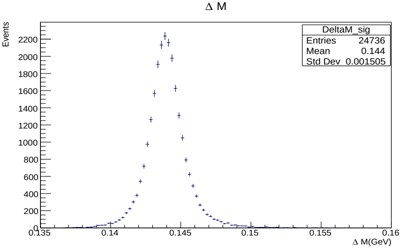
Background of $D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\pi^0$ in $D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\gamma$





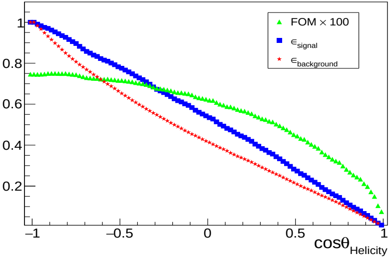
Background of $D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\gamma$ in $D_s^{*+} \to D_s^+(K^+\bar{K}^{*0})\pi^0$

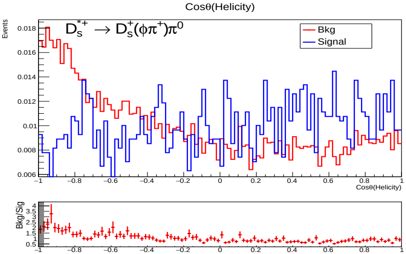




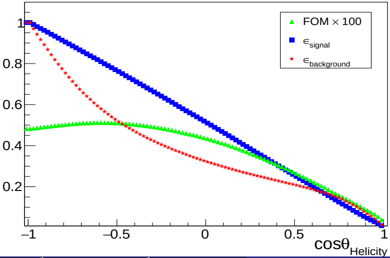
CosθHelicity

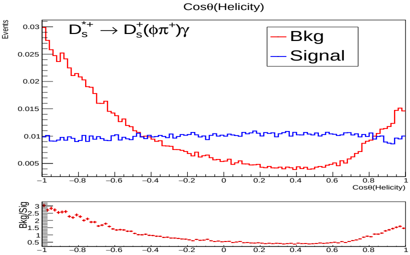
$$D_s^{*+} \rightarrow D_s^+(\phi\pi^+)\pi^0$$





$$D_s^{*+} \rightarrow D_s^+(\phi\pi^+)\gamma$$





Systematics from previous studies

Sources	Relative Uncertainty(%)
Background Shape	4.8
Monte carlo statistics	5.0
Signal model	3.6
p^* dependance	6.8
Quadrature Sum	10.2

Method of applying π^0 veto

We apply π^0 veto cut to reduce the background from π^0, Following is the method

- Reconstruct the decay mode $D_s^{*+} \to D_s^+ \gamma$
- Create Rest of Event
- Combine γ used in the reconstruction of D_s^{*+} with all other γs in the event with energy > 50 MeV to reconstruct π^0 candidate

- π^0 mass window is selected as 80 MeV $<$ M $<$ 200 MeV
- Best π^0 candidate is selected
- Obtained χ^2 variable for π^0
- Optimized the χ^2 distribution and applying $\chi^2 > 0.2$ cut will reduce 67% of background from π^0.