

# Measurement of charm production cross sections in $e^+e^-$ annihilation

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# Motivation

- $e^+e^-$  hadronic cross sections to final states with charm meson pairs are of special interest because they provide information on the spectrum of  $J^{PC} = 1^{--}$  charmonium states above the open-charm threshold, which is poorly understood. [Phys. Rev. D 72, 017501 \(2005\)](#).
- Y states, such as Y(4008), Y(4260), Y(4360), Y(4630), Y(4660), have been reported in initial state radiation process  $e^+e^- \rightarrow \gamma_{ISR}\pi^+\pi^-J/\psi$   
[Phys. Rev. Lett. 95, 142001 \(2005\)](#).
- A study of the production cross section of the charm meson pairs which considers radiative correction could help us understand the structure of these charmoniumlike states well.

# BOSS version and data samples

- Boss version : 6.6.4.p01 and 6.6.5.p01
- BESIII experimental data:
  - using data samples taken at 23 center-of-mass energies from 3900 to 4390MeV
- Inclusive MC : DD @4.26GeV with boss version 6.6.4.p01

# Event selection



- Charged tracks:

$$|R_{xy}| < 1.0\text{cm}; |Z_0| < 10.0\text{cm}; |\cos \theta| < 0.93; \text{nGood} \geq 2;$$

- PID:

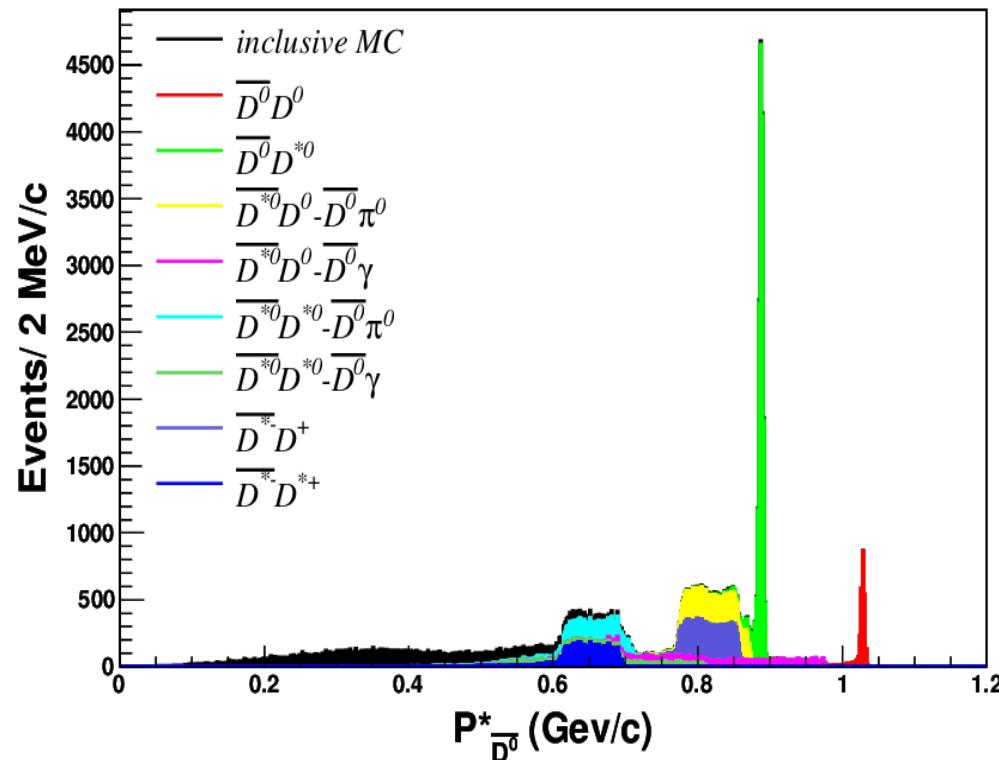
$$\pi: prob(\pi) > prob(K) > prob(p) > 0.1\%$$

$$K: prob(K) > prob(\pi) > prob(p) > 0.1\%$$

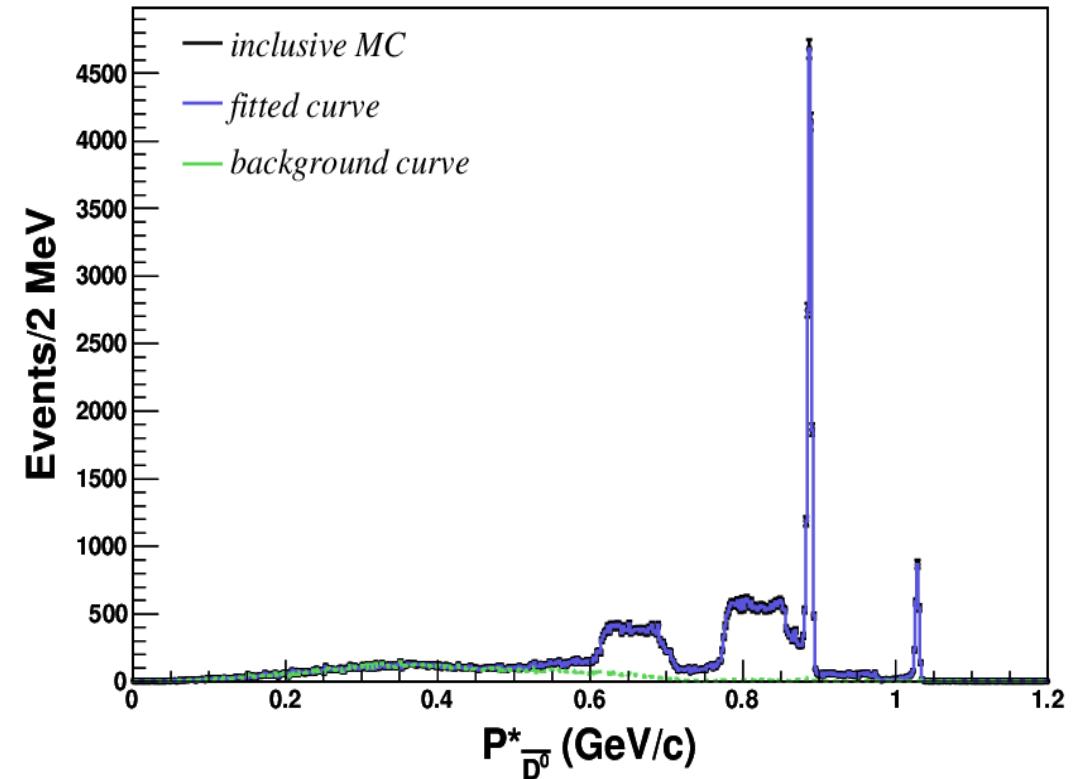
- Vertex fit is required to be successful

# Input-Output check

Momentum spectra in inclusive MC at 4260MeV for  $\bar{D}^0 \rightarrow K^+ \pi^-$

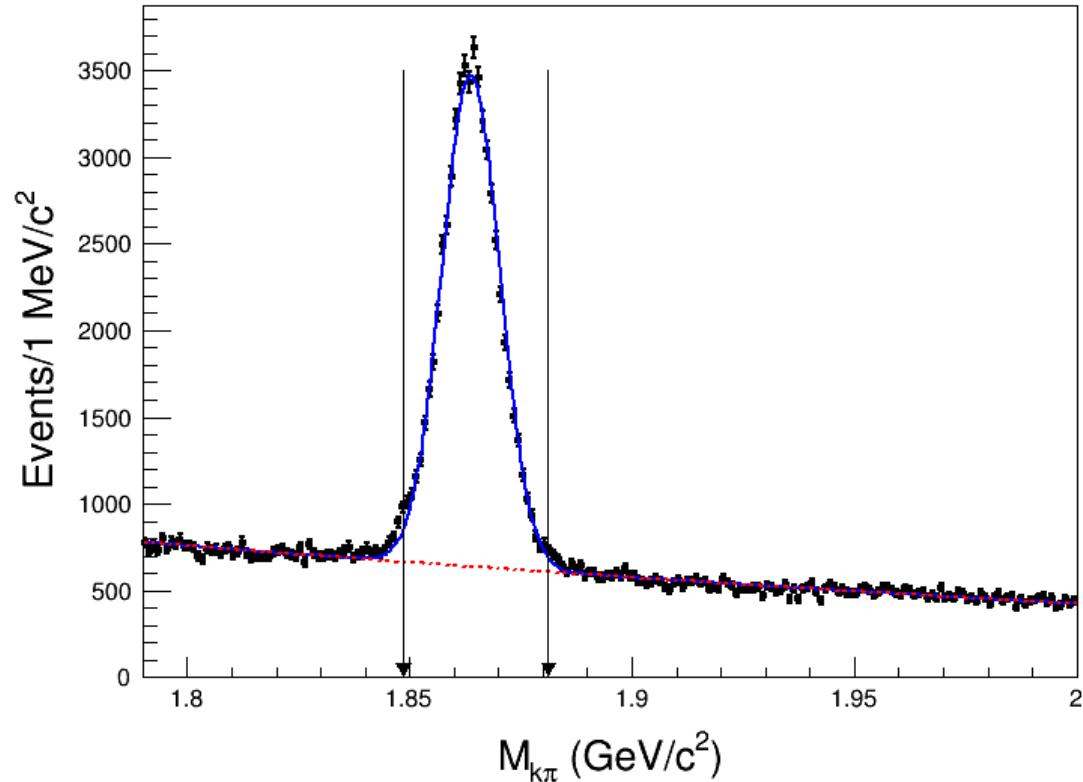


Use MC truth to read all charm meson pairs events

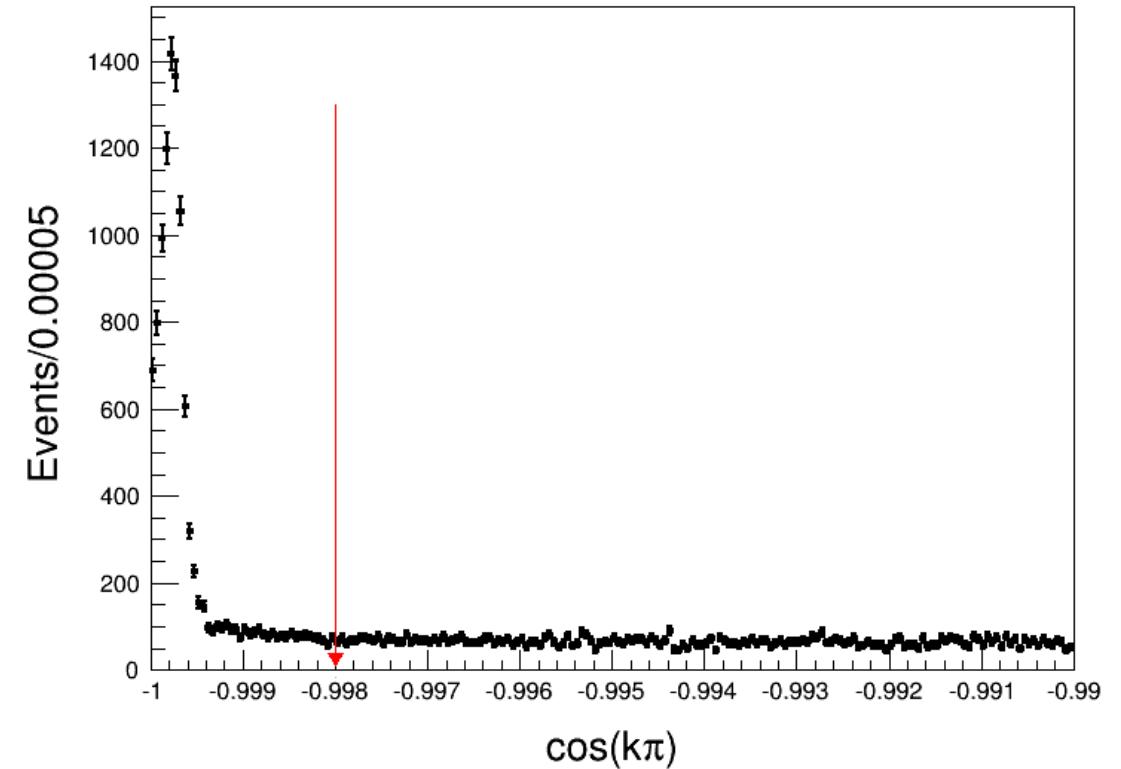


The reliability of fit is confirmed by difference between fit results and MC truth results within one standard deviation.

# Some distributions of observable quantity in data

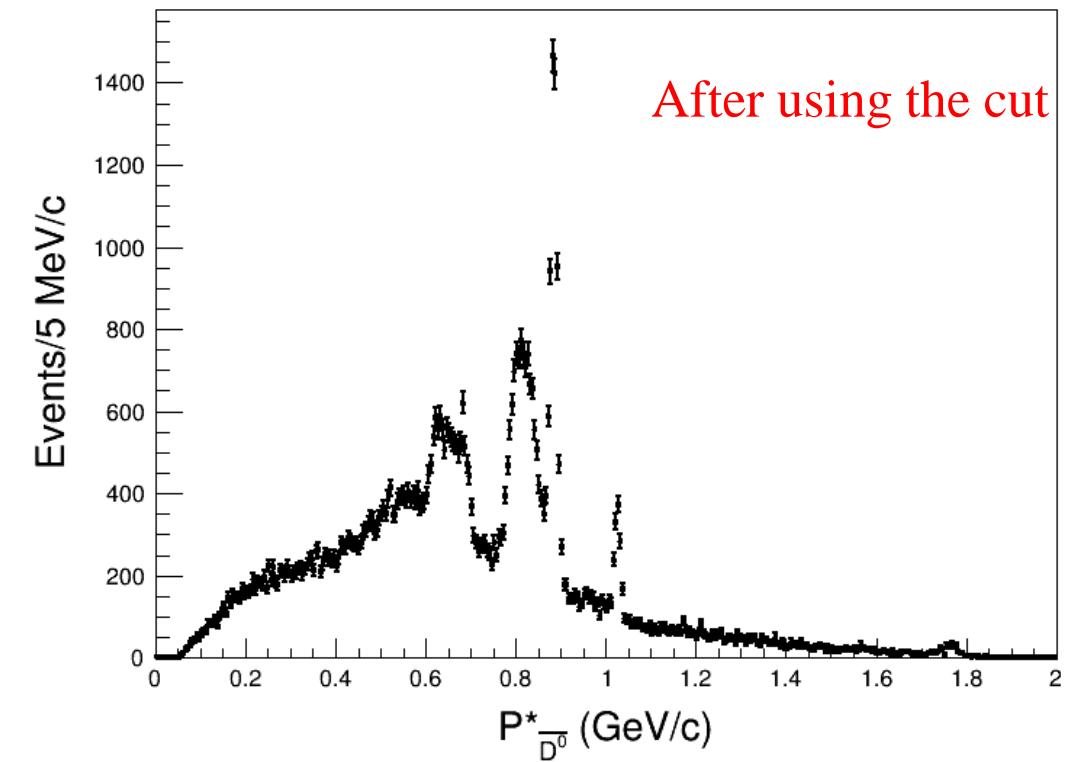
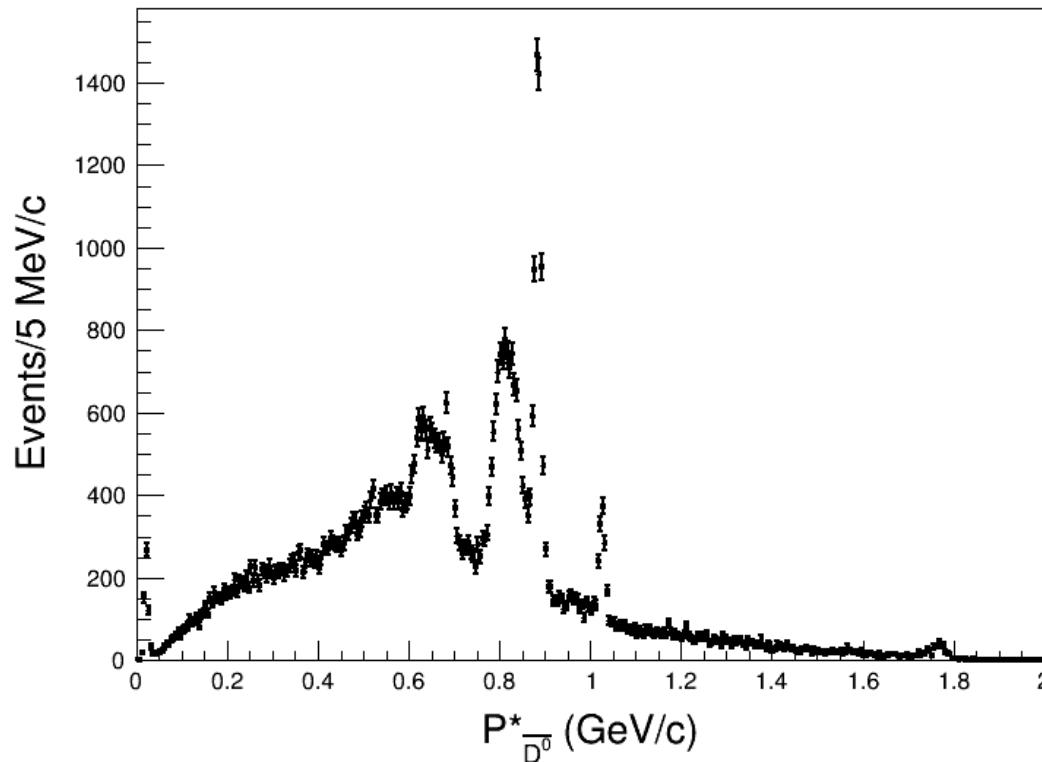


Invariant mass spectra in data at 4260MeV for  $\bar{D}^0 \rightarrow K^+\pi^-$



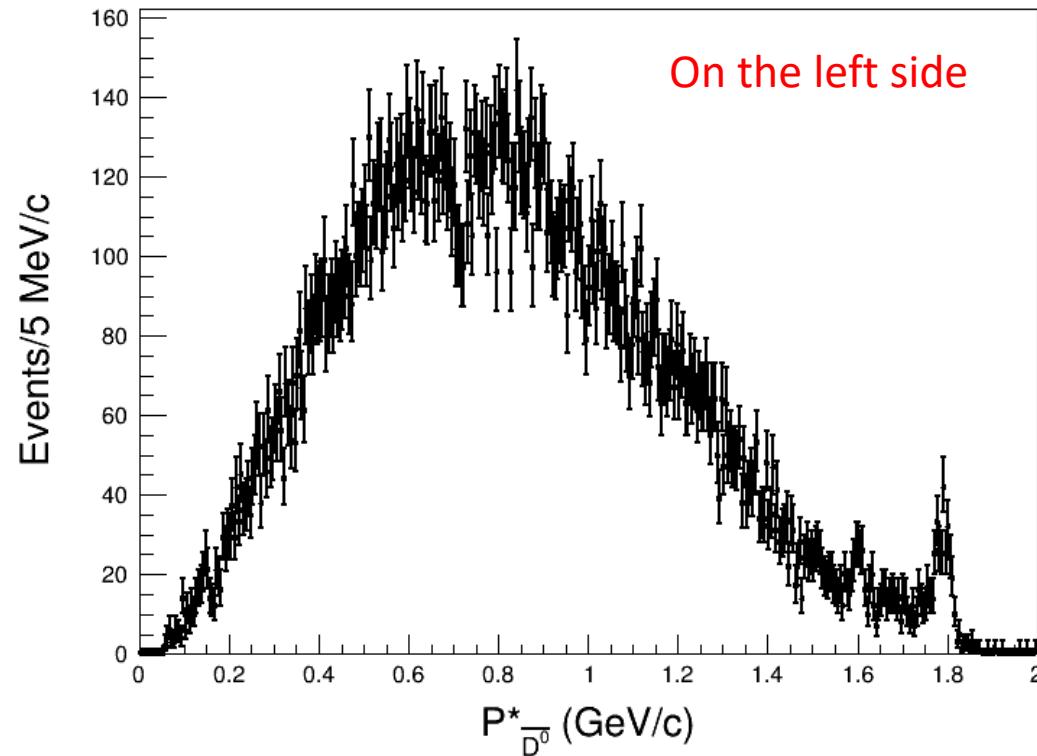
Cosine of angle between  $K^+$  and  $\pi^-$  in data at 4260MeV

Use the cut that cosine of angle between  $K^+$  and  $\pi^-$  greater than -0.998 to remove the peak events around 0.02GeV/c. the cut efficiency is 96.56%

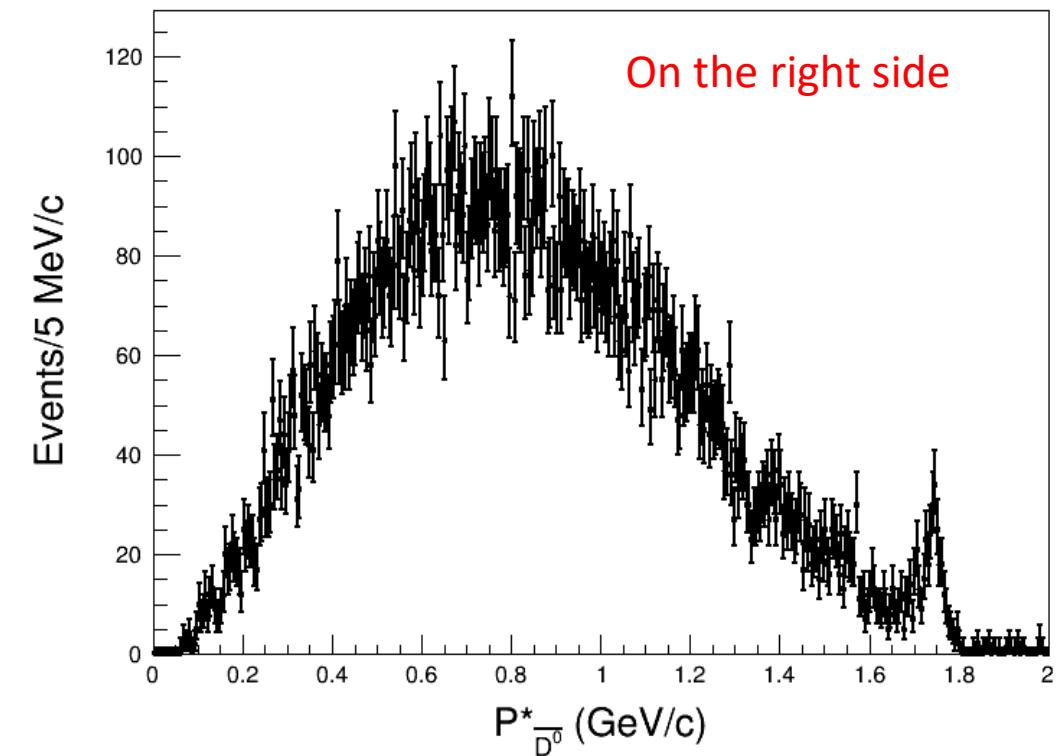


Momentum spectra in data at 4260MeV for  $\bar{D}^0 \rightarrow K^+ \pi^-$  with invariant masses within 16MeV of the nominal value

Having used the cut that cosine of angle between  $K^+$  and  $\pi^-$  greater than -0.998



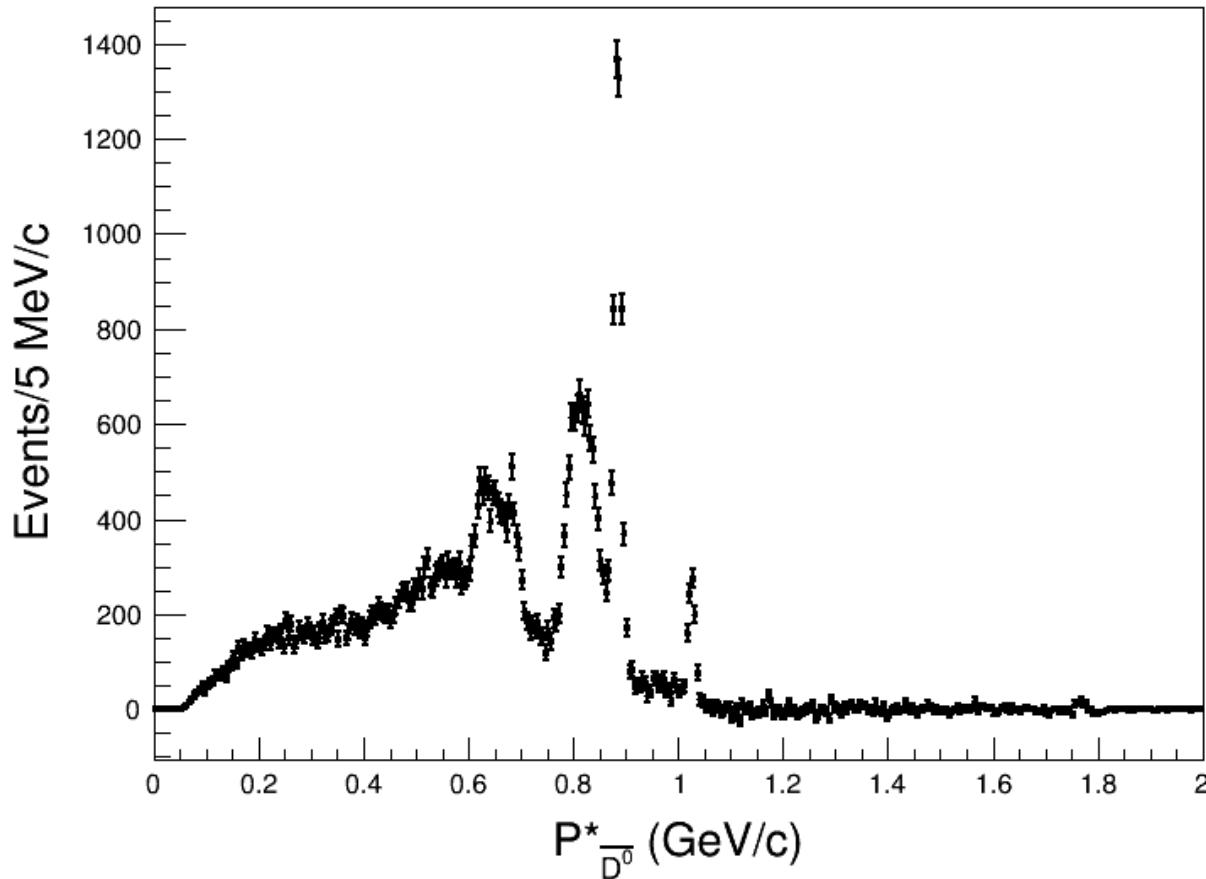
On the left side



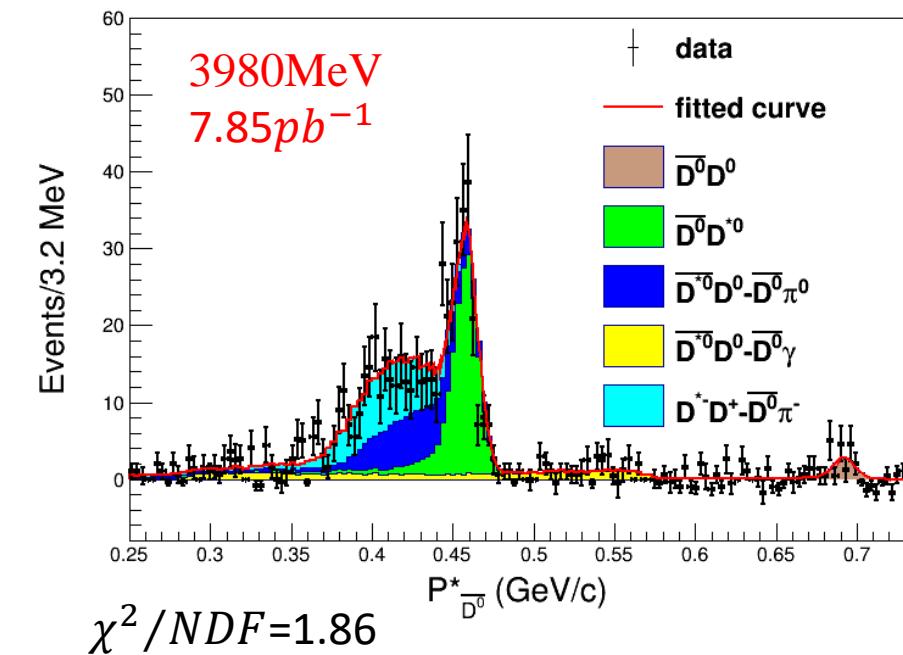
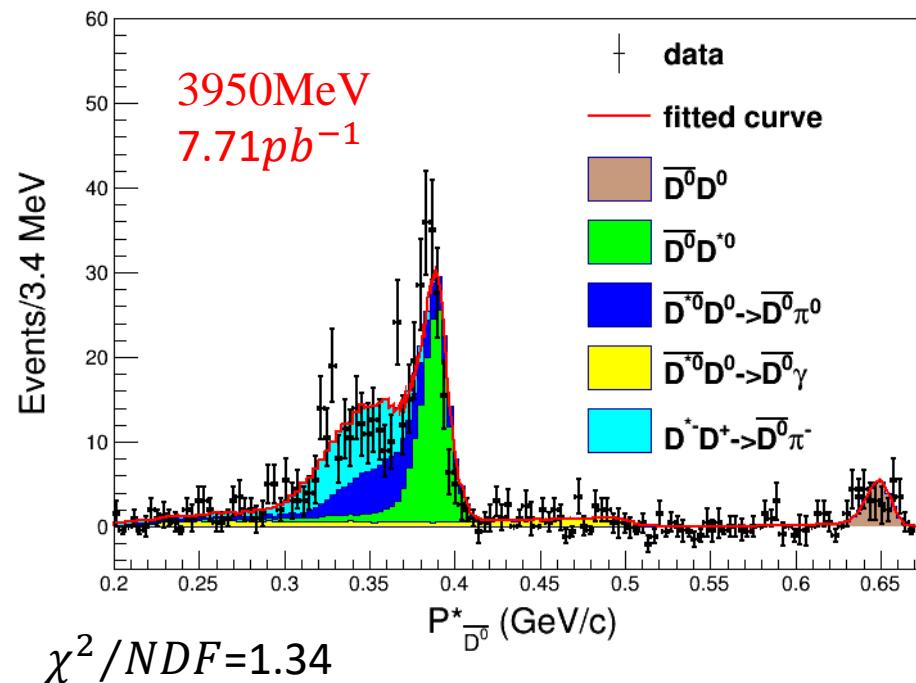
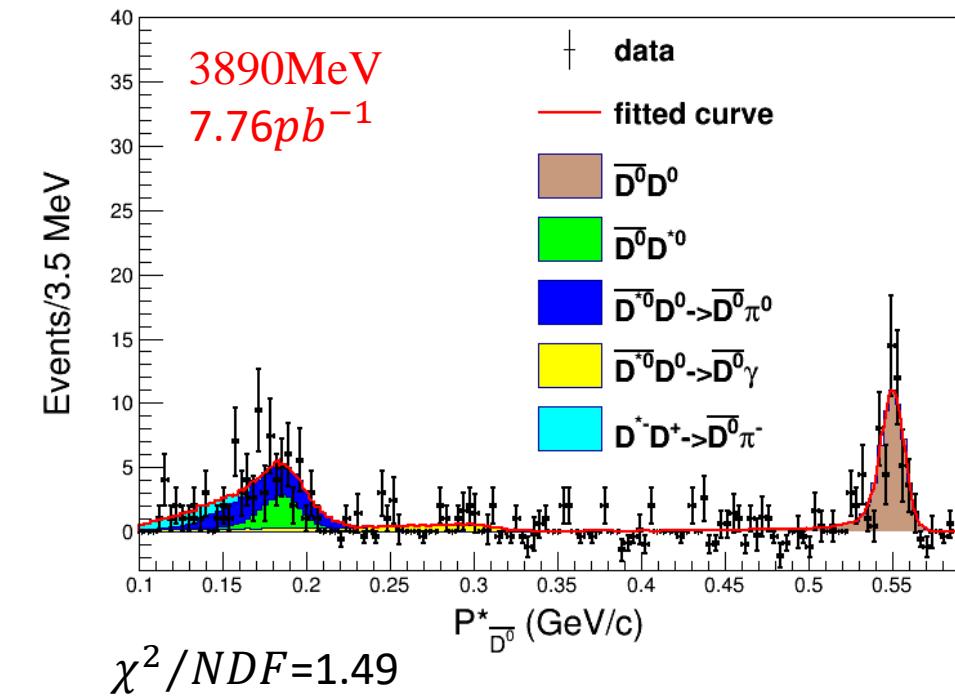
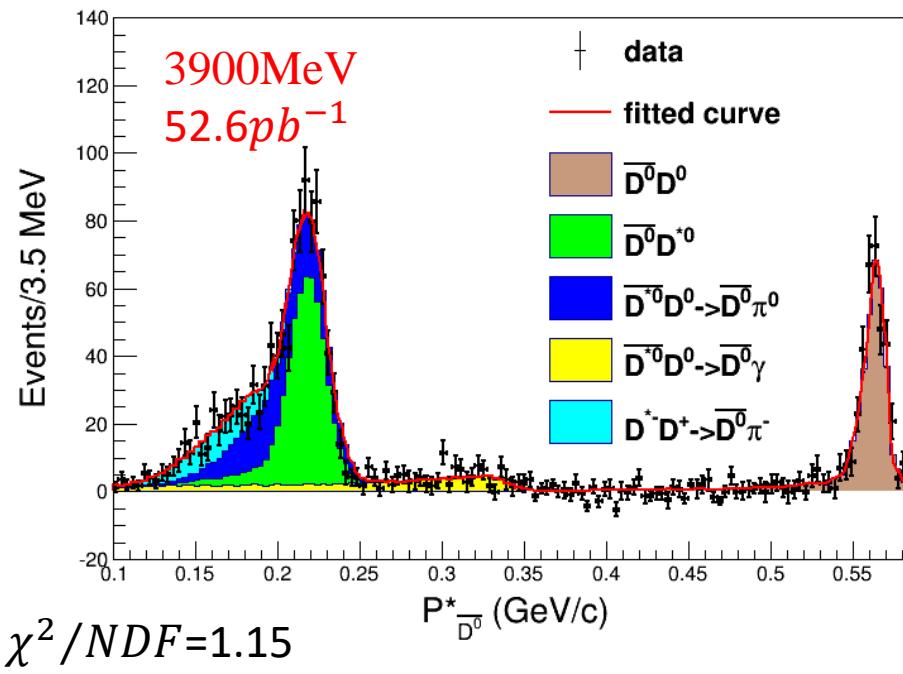
On the right side

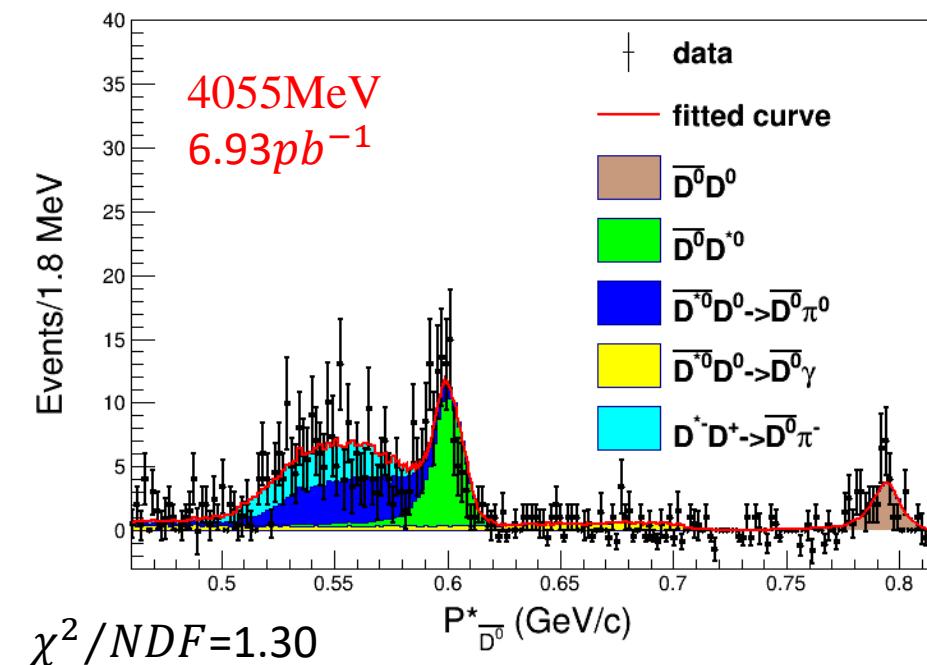
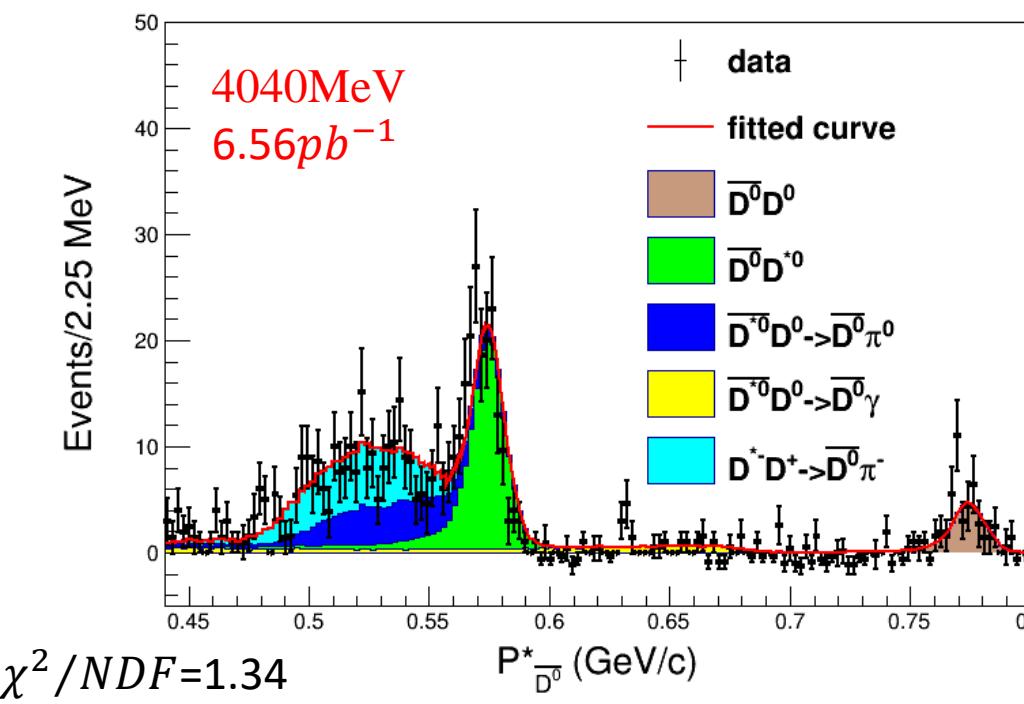
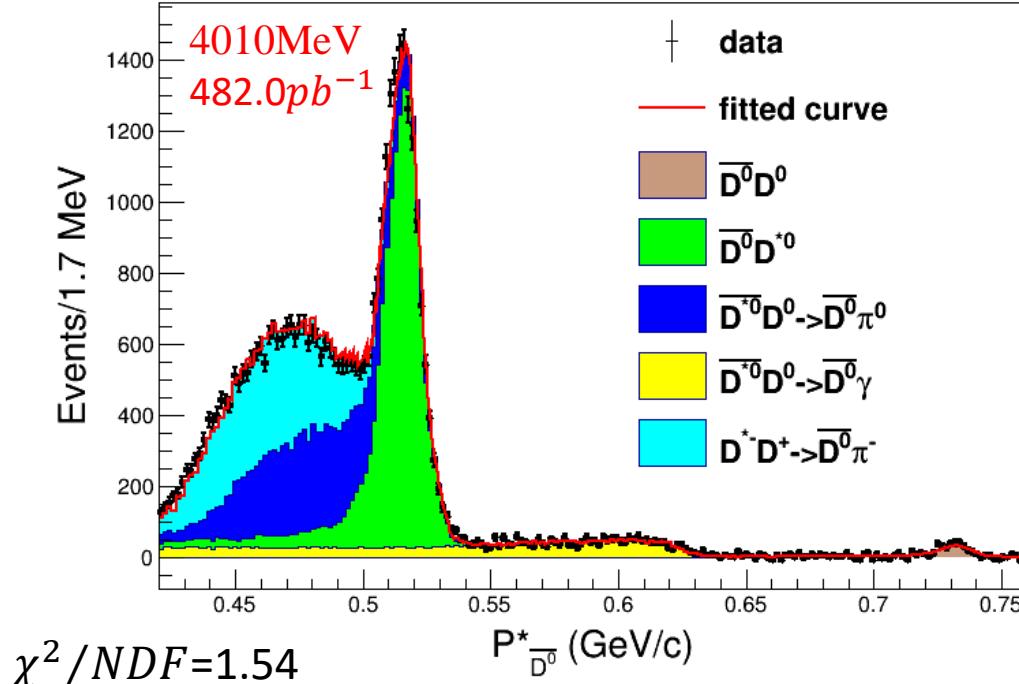
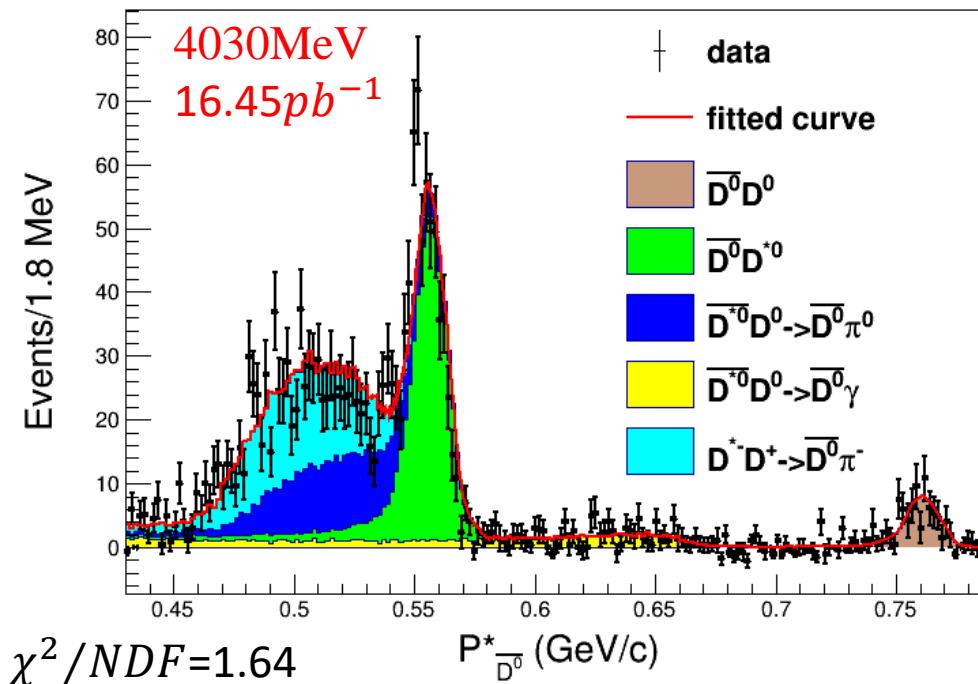
Sideband regions are taken on both sides of the expected signal

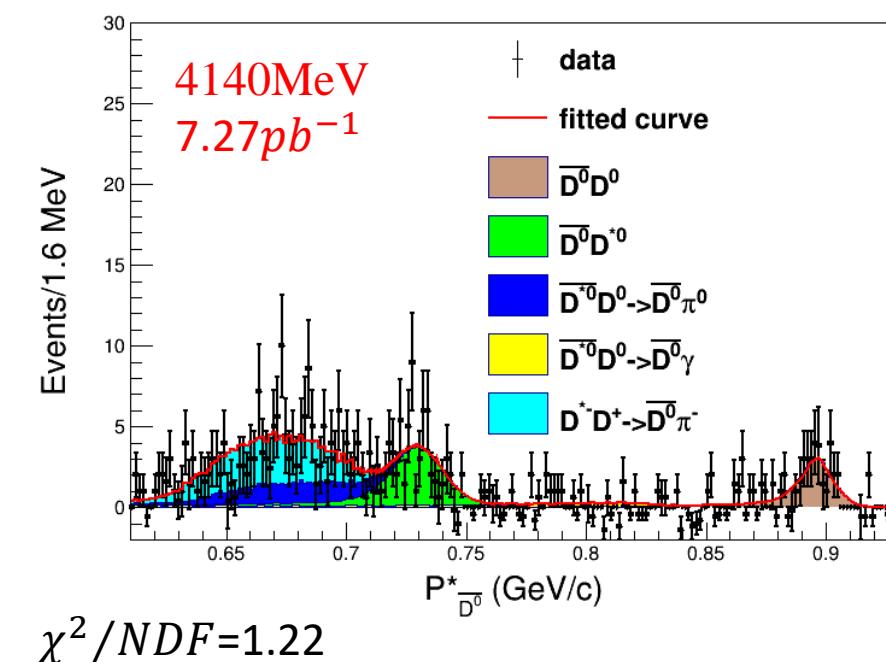
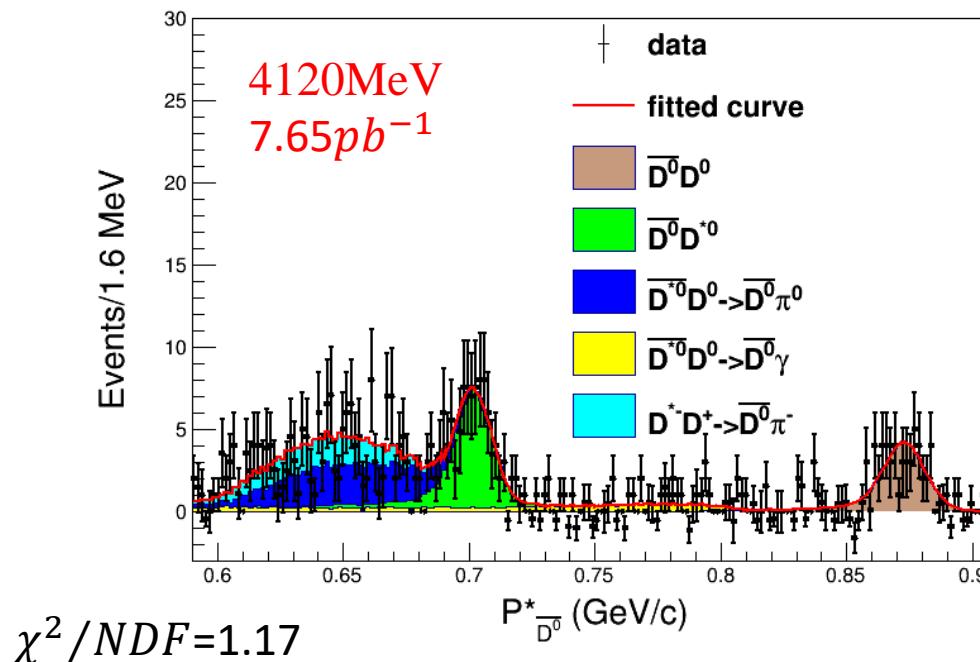
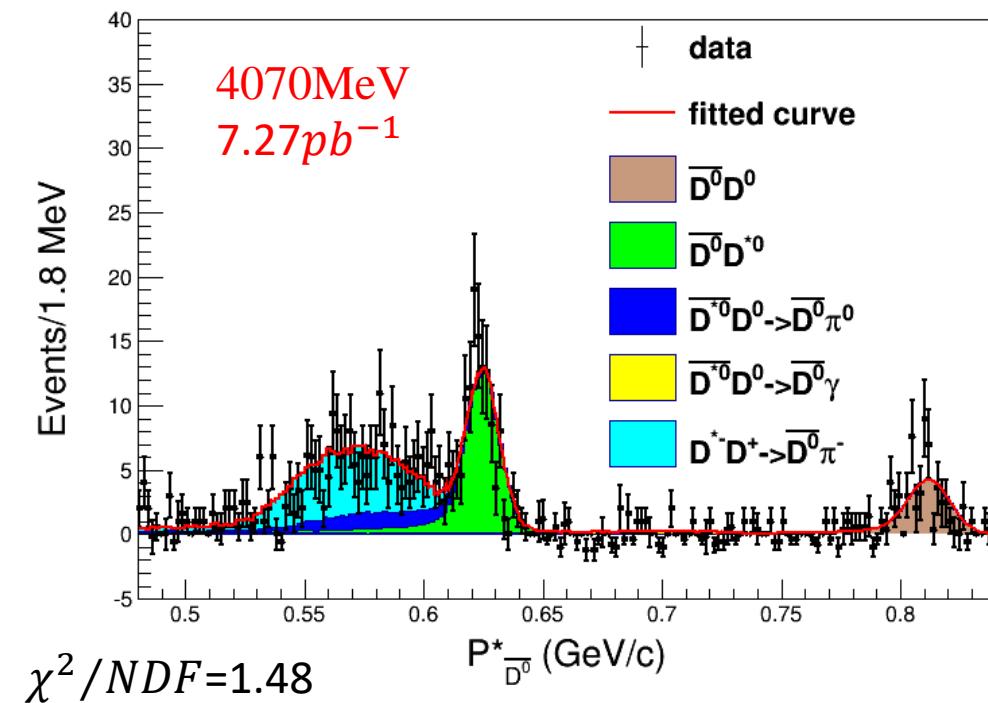
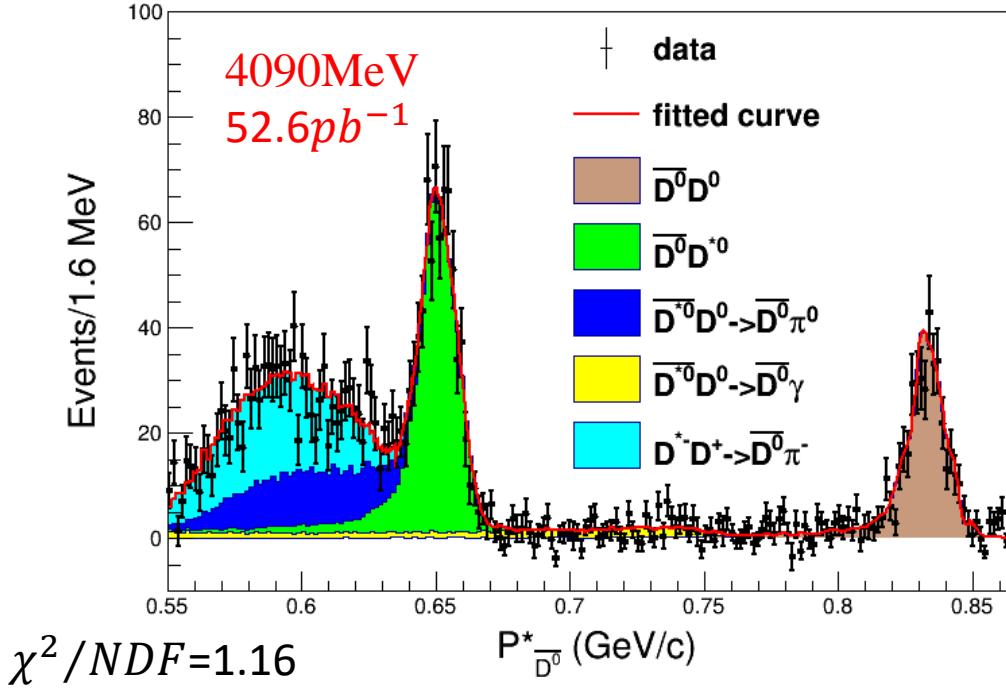
Backgrounds are estimated with a sideband technique

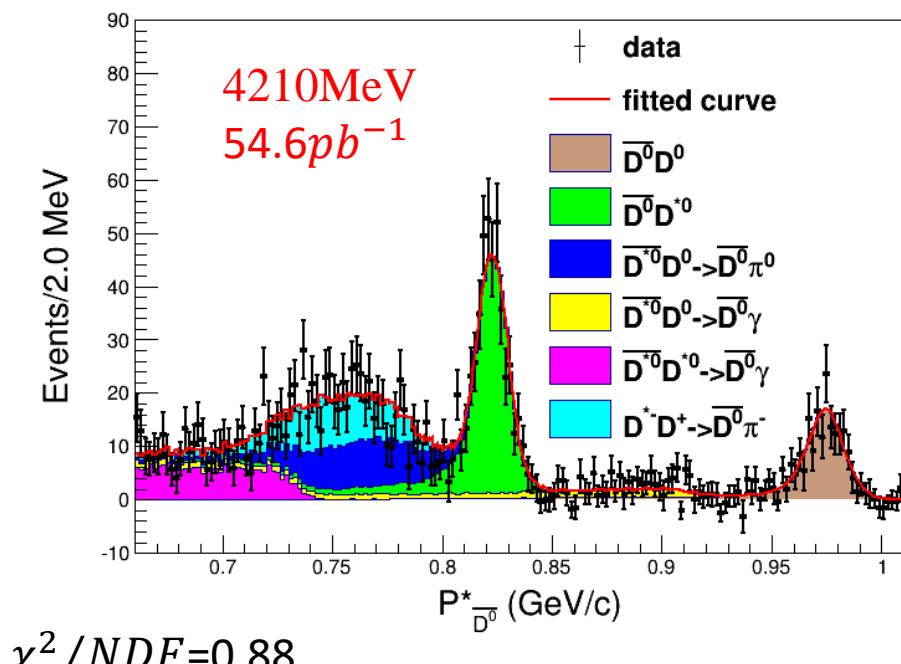
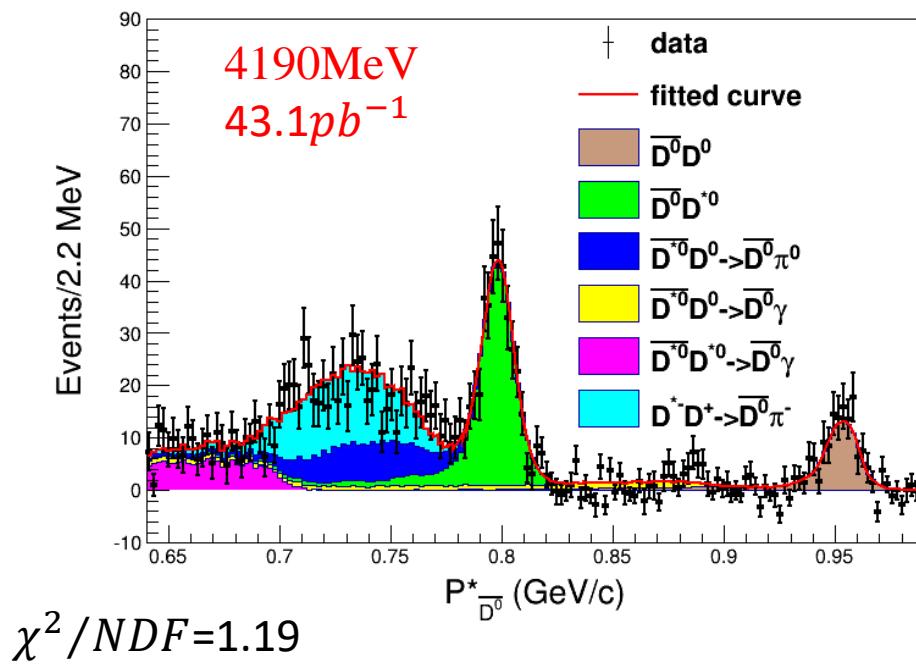
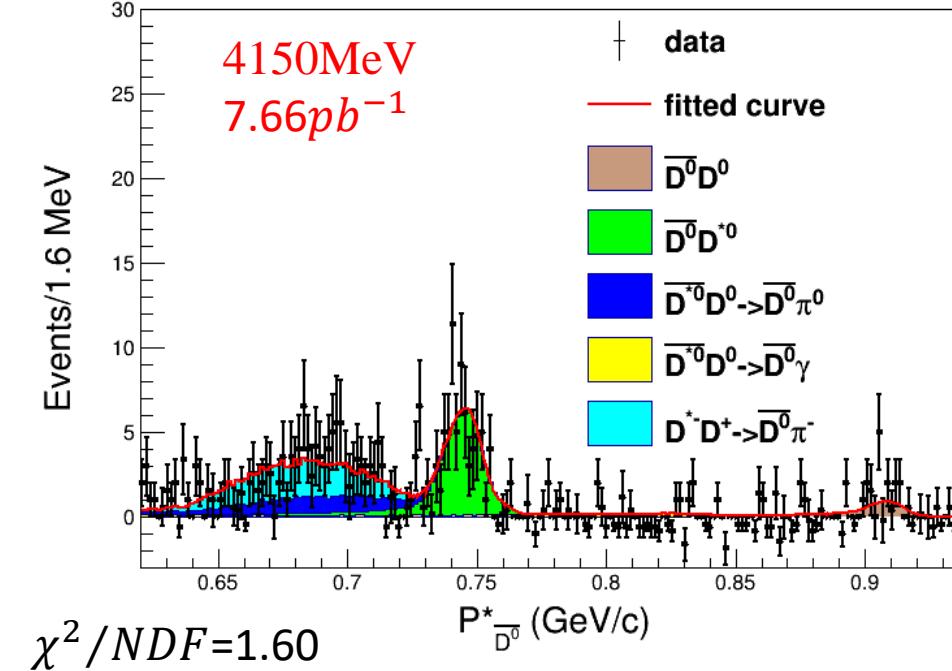
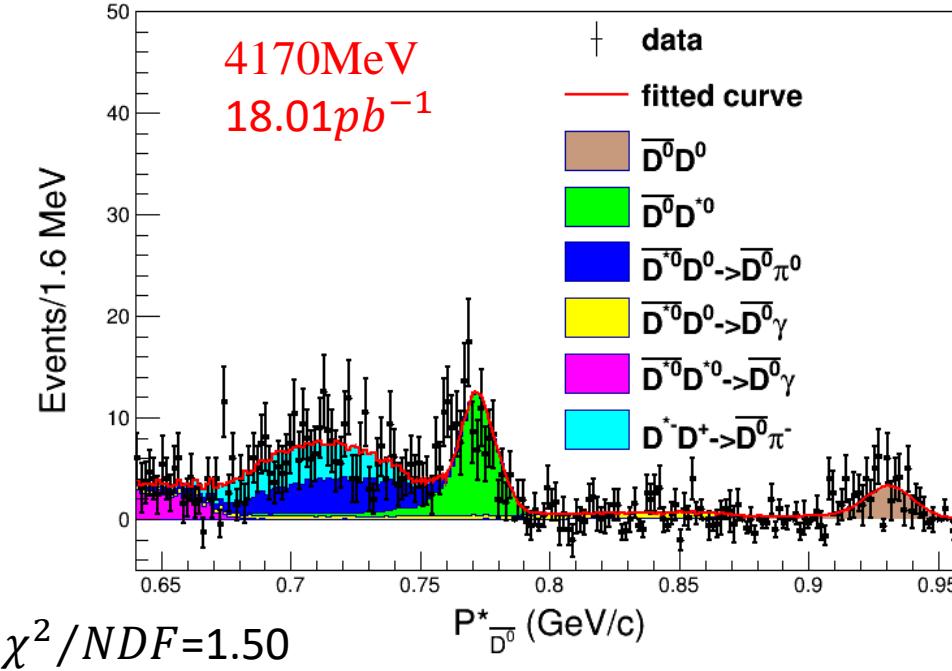


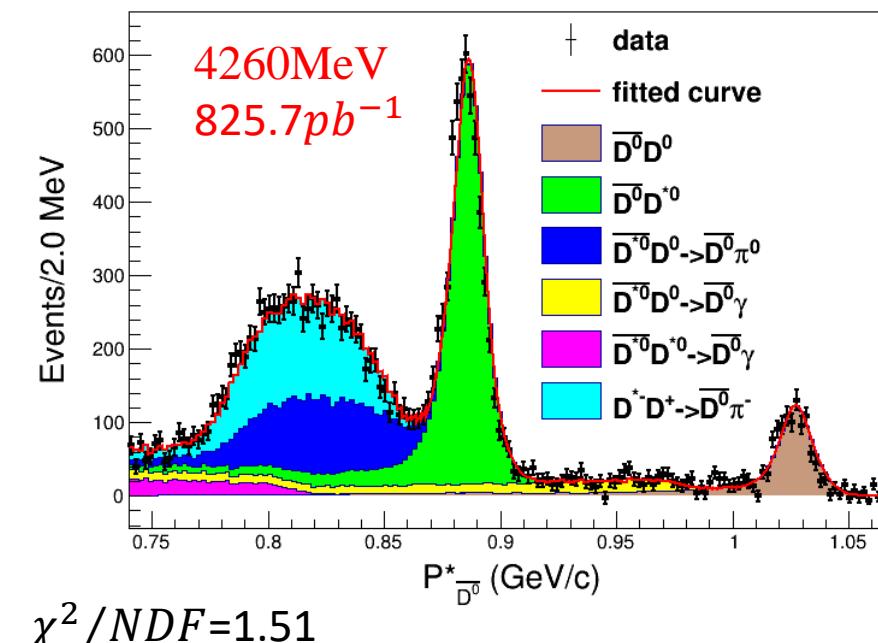
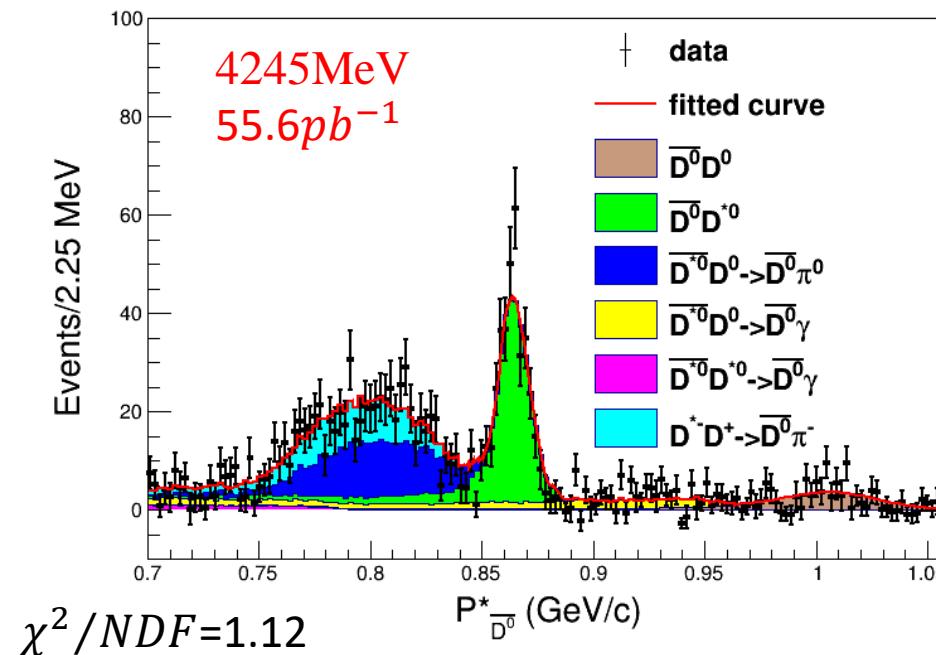
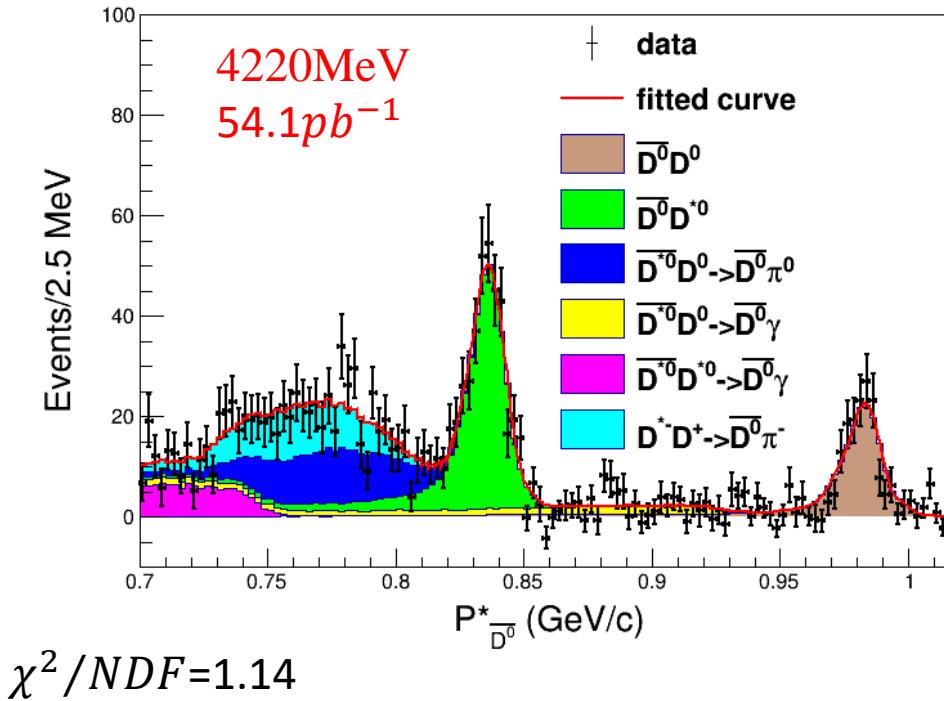
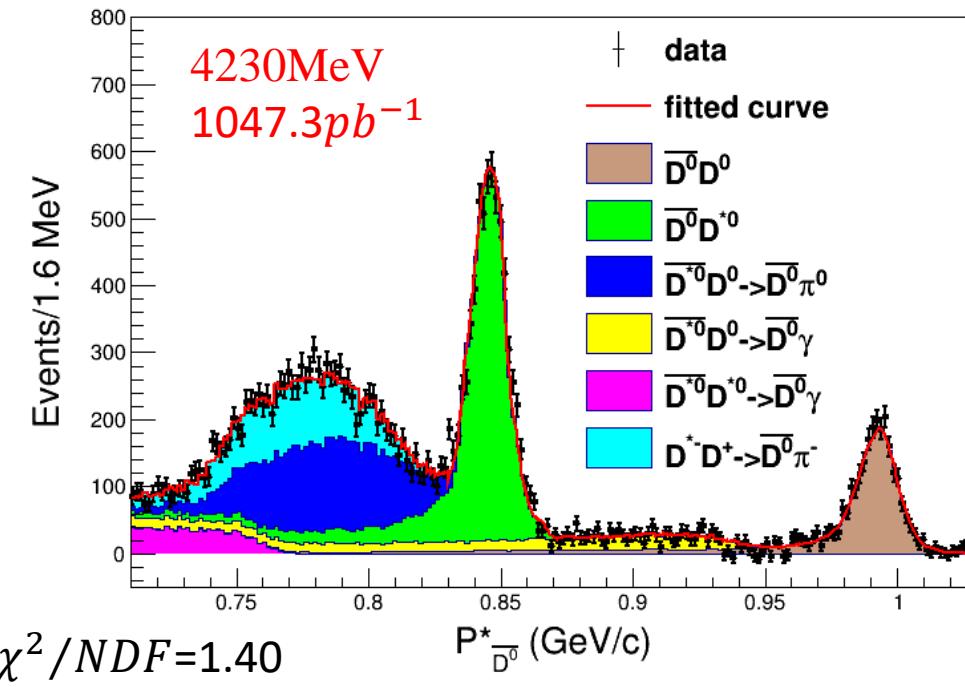
Momentum spectra in data at 4260MeV for  $\bar{D}^0 \rightarrow K^+ \pi^-$  with invariant masses within 16MeV of the nominal value

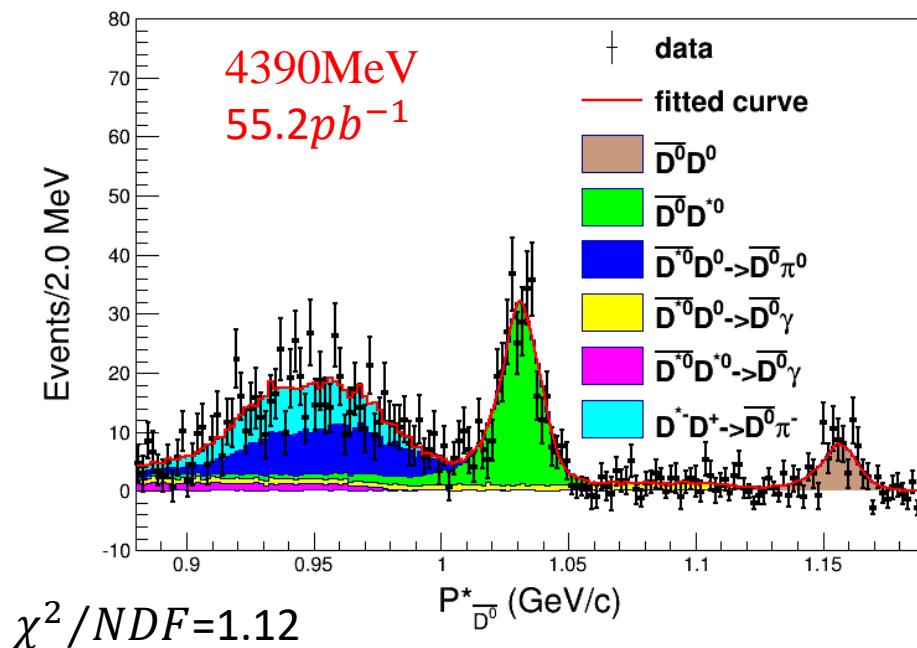
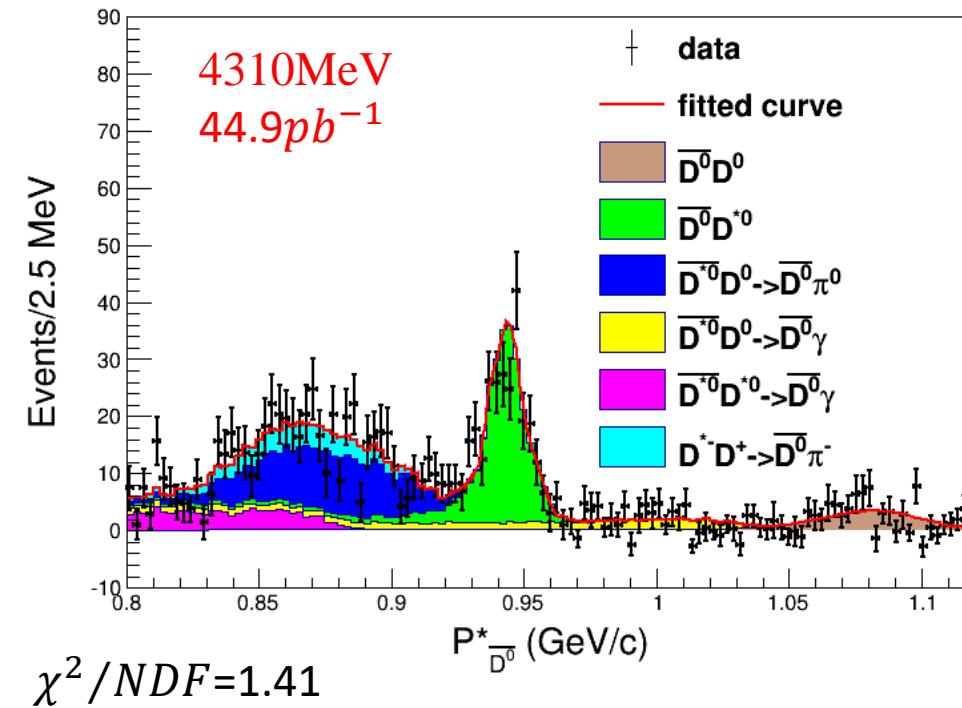
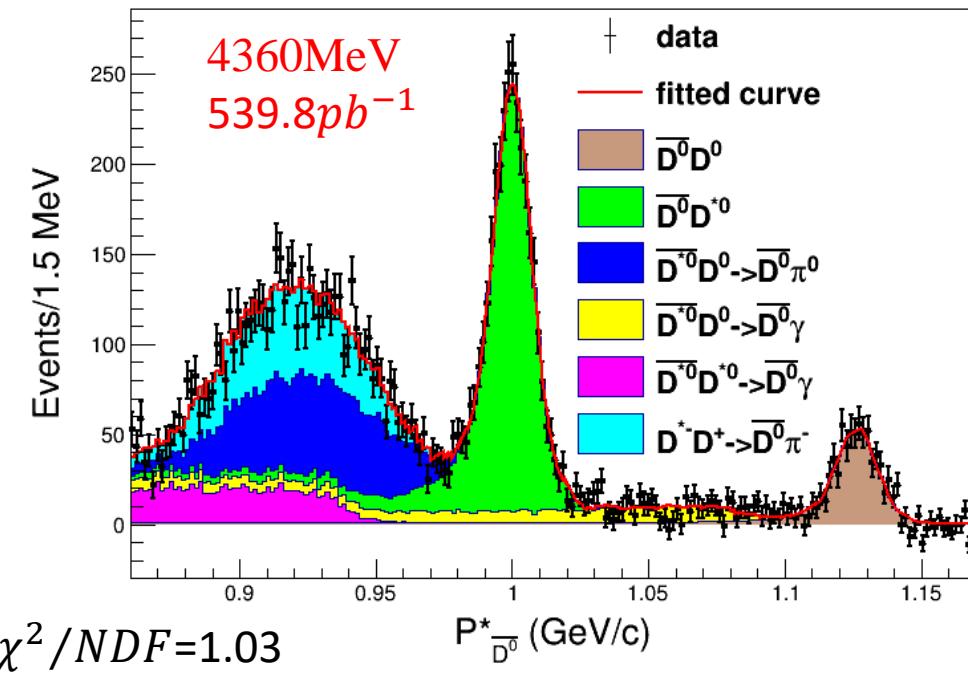












# The Born cross section of $e^+e^- \rightarrow \overline{D^0}D^0$ channel

| $\sqrt{s}(GeV)$ | $\mathcal{L}(pb^{-1})$ | $N^{sig}$      | $\epsilon$ | $\frac{1}{ 1 - \Pi(s) ^2}$ | $1 + \delta$ | $\mathcal{B}(\overline{D^0} \rightarrow K^+\pi^-)$ | $\sigma^{Born}$ |
|-----------------|------------------------|----------------|------------|----------------------------|--------------|--|-----------------|
| 3.890           | 7.76                   | 69.0 +- 8.38   | 59.6%      | 1.052                      | 0.875        | 3.93%  | 412.1 +- 50.06  |
| 3.900           | 52.6                   | 389.5 +- 20.02 | 59.7%      | 1.052                      | 0.880        | 3.93%  | 340.4 +- 17.49  |
| 3.950           | 7.71                   | 36.3 +- 6.09   | 58.8%      | 1.052                      | 0.925        | 3.93%  | 209.3 +- 35.15  |
| 3.980           | 7.85                   | 19.3 +- 4.48   | 57.9%      | 1.052                      | 0.950        | 3.93%  | 108.1 +- 25.11  |
| 4.010           | 482.0                  | 490.3 +- 24.01 | 56.4%      | 1.052                      | 0.973        | 3.93%  | 44.7 +- 2.19    |
| 4.030           | 16.45                  | 91.3 +- 9.80   | 57.0%      | 1.052                      | 0.992        | 3.93%  | 237.4 +- 25.50  |
| 4.040           | 6.56                   | 42.8 +- 6.70   | 56.6%      | 1.052                      | 1.000        | 3.93%  | 276.6 +- 43.59  |
| 4.055           | 6.93                   | 41.2 +- 6.56   | 56.1%      | 1.052                      | 1.012        | 3.93%  | 253.3 +- 40.32  |
| 4.070           | 7.27                   | 62.3 +- 8.03   | 56.0%      | 1.052                      | 1.024        | 3.93%  | 360.5 +- 46.49  |
| 4.090           | 52.6                   | 463.5 +- 22.0  | 56.4%      | 1.052                      | 1.037        | 3.93%  | 364.2 +- 17.29  |
| 4.120           | 7.65                   | 64.7 +- 8.35   | 56.1%      | 1.052                      | 1.066        | 3.93%  | 342.5 +- 44.19  |

| $\sqrt{s}(GeV)$ | $\mathcal{L}(pb^{-1})$ | $N^{sig}$       | $\varepsilon$ | $\frac{1}{ 1 - \Pi(s) ^2}$ | $1 + \delta$ | $\mathcal{B}(\bar{D}^0 \rightarrow K^+ \pi^-)$ | $\sigma^{Born}$ |
|-----------------|------------------------|-----------------|---------------|----------------------------|--------------|--|-----------------|
| 4.140           | 7.27                   | 42.3 +- 6.70    | 55.0%         | 1.052                      | 1.083        | 3.93%  | 236.2 +- 37.44  |
| 4.150           | 7.66                   | 16.7 +- 4.14    | 55.1%         | 1.052                      | 1.091        | 3.93%  | 87.7 +- 21.75   |
| 4.170           | 18.01                  | 68.0 +- 8.80    | 54.1%         | 1.052                      | 1.107        | 3.93%  | 152.4 +- 19.72  |
| 4.190           | 43.1                   | 153.7 +- 13.43  | 54.6%         | 1.056                      | 1.123        | 3.93%  | 140.2 +- 12.25  |
| 4.210           | 54.6                   | 232.6 +- 16.69  | 54.3%         | 1.057                      | 1.139        | 3.93%  | 165.8 +- 11.89  |
| 4.220           | 54.1                   | 212.7 +- 15.82  | 54.5%         | 1.057                      | 1.147        | 3.93%  | 151.3 +- 11.25  |
| 4.230           | 1047.3                 | 3046.0 +- 60.57 | 53.8%         | 1.056                      | 1.154        | 3.93%  | 112.7 +- 2.24   |
| 4.245           | 55.6                   | 118.4 +- 12.85  | 53.4%         | 1.056                      | 1.167        | 3.93%  | 82.3 +- 8.94    |
| 4.260           | 825.7                  | 1732.8 +- 48.47 | 52.7%         | 1.054                      | 1.182        | 3.93%  | 81.2 +- 2.27    |
| 4.310           | 44.9                   | 87.8 +- 9.90    | 50.1%         | 1.052                      | 1.222        | 3.93%  | 76.2 +- 8.58    |
| 4.360           | 539.8                  | 914.4 +- 33.99  | 49.6%         | 1.051                      | 1.263        | 3.93%  | 65.3 +- 2.42    |
| 4.390           | 55.2                   | 111.9 +- 12.09  | 49.0%         | 1.051                      | 1.287        | 3.93%  | 77.8 +- 8.40    |

# The Born cross section of $e^+e^- \rightarrow \overline{D^0}D^0{}^*$ channel

| $\sqrt{s}(GeV)$ | $\mathcal{L}(pb^{-1})$ | $N^{sig}$         | $\varepsilon$ | $\frac{1}{ 1 - \Pi(s) ^2}$ | $1 + \delta$ | $\mathcal{B}(\overline{D^0} \rightarrow K^+\pi^-)$ | $\sigma^{Born}$  |
|-----------------|------------------------|-------------------|---------------|----------------------------|--------------|--|------------------|
| 3.890           | 7.76                   | 22.7 +- 10.80     | 61.4%         | 1.052                      | 0.573        | 3.93%  | 201.6 +- 95.78   |
| 3.900           | 52.6                   | 535.3 +- 36.44    | 61.6%         | 1.052                      | 0.587        | 3.93%  | 680.0 +- 46.30   |
| 3.950           | 7.71                   | 167.8 +- 18.47    | 61.2%         | 1.052                      | 0.708        | 3.93%  | 1215.2 +- 133.78 |
| 3.980           | 7.85                   | 196.4 +- 18.98    | 60.4%         | 1.052                      | 0.767        | 3.93%  | 1305.7 +- 126.16 |
| 4.010           | 482.0                  | 15042.2 +- 154.45 | 56.9%         | 1.052                      | 0.817        | 3.93%  | 1621.9 +- 16.65  |
| 4.030           | 16.45                  | 582.3 +- 30.55    | 56.9%         | 1.052                      | 0.853        | 3.93%  | 1761.7 +- 92.42  |
| 4.040           | 6.56                   | 179.1 +- 16.55    | 56.8%         | 1.052                      | 0.868        | 3.93%  | 1326.5 +- 122.68 |
| 4.055           | 6.93                   | 112.2 +- 13.91    | 56.8%         | 1.052                      | 0.890        | 3.93%  | 774.3 +- 96.01   |
| 4.070           | 7.27                   | 143.2 +- 14.36    | 57.1%         | 1.052                      | 0.911        | 3.93%  | 916.3 +- 91.94   |
| 4.090           | 52.6                   | 787.5 +- 32.78    | 55.7%         | 1.052                      | 0.929        | 3.93%  | 698.8 +- 29.08   |
| 4.120           | 7.65                   | 95.2 +- 11.76     | 55.7%         | 1.052                      | 0.968        | 3.93%  | 557.9 +- 68.92   |

| $\sqrt{s}(GeV)$ | $\mathcal{L}(pb^{-1})$ | $N^{sig}$        | $\varepsilon$ | $\frac{1}{ 1 - \Pi(s) ^2}$ | $1 + \delta$ | $\mathcal{B}(\bar{D}^0 \rightarrow K^+ \pi^-)$ | $\sigma^{Born}$ |
|-----------------|------------------------|------------------|---------------|----------------------------|--------------|--|-----------------|
| 4.140           | 7.27                   | 69.5 +- 10.34    | 55.5%         | 1.052                      | 0.987        | 3.93%  | 422.6 +- 62.86  |
| 4.150           | 7.66                   | 83.07 +- 10.63   | 55.1%         | 1.052                      | 0.996        | 3.93%  | 478.1 +- 61.18  |
| 4.170           | 18.01                  | 161.1 +- 27.10   | 54.1%         | 1.052                      | 1.011        | 3.93%  | 395.8 +- 66.57  |
| 4.190           | 43.1                   | 447.5 +- 24.95   | 54.3%         | 1.056                      | 1.022        | 3.93%  | 451.13 +- 25.15 |
| 4.210           | 54.6                   | 508.1 +- 26.06   | 54.1%         | 1.057                      | 1.032        | 3.93%  | 400.7 +- 20.56  |
| 4.220           | 54.1                   | 434.9 +- 24.38   | 53.1%         | 1.057                      | 1.036        | 3.93%  | 352.1 +- 19.72  |
| 4.230           | 1047.3                 | 7511.2 +- 103.22 | 52.3%         | 1.056                      | 1.039        | 3.93%  | 317.8 +- 4.36   |
| 4.245           | 55.6                   | 420.3 +- 24.00   | 53.2%         | 1.056                      | 1.044        | 3.93%  | 327.8 +- 18.72  |
| 4.260           | 825.7                  | 6303.6 +- 92.69  | 51.6%         | 1.054                      | 1.047        | 3.93%  | 341.2 +- 5.01   |
| 4.310           | 44.9                   | 291.0 +- 67.84   | 49.7%         | 1.052                      | 1.046        | 3.93%  | 301.4 +- 70.26  |
| 4.360           | 539.8                  | 3552.0 +- 68.60  | 49.5%         | 1.051                      | 1.029        | 3.93%  | 312.5 +- 6.03   |
| 4.390           | 55.2                   | 399.4 +- 23.53   | 48.1%         | 1.051                      | 1.012        | 3.93%  | 359.4 +- 21.17  |

# The Born cross section of $e^+e^- \rightarrow \overline{D^0}^* D^0$ channel

| $\sqrt{s}(GeV)$ | $\mathcal{L}(pb^{-1})$ | $N^{sig}$         | $\varepsilon$ | $\frac{1}{ 1 - \Pi(s) ^2}$ | $1 + \delta$ | $\mathcal{B}(\bar{D}^0 \rightarrow K^+ \pi^-)$ | $\sigma^{Born}$  |
|-----------------|------------------------|-------------------|---------------|----------------------------|--------------|--|------------------|
| 3.890           | 7.76                   | 63.5 +- 14.39     | 58.1%         | 1.052                      | 0.708        | 3.93%  | 480.9 +- 108.87  |
| 3.900           | 52.6                   | 524.3 +- 45.14    | 59.8%         | 1.052                      | 0.713        | 3.93%  | 564.8 +- 48.62   |
| 3.950           | 7.71                   | 170.0 +- 29.77    | 60.7%         | 1.052                      | 0.757        | 3.93%  | 1158.9 +- 202.96 |
| 3.980           | 7.85                   | 211.1 +- 33.24    | 59.6%         | 1.052                      | 0.781        | 3.93%  | 1395.3 +- 219.68 |
| 4.010           | 482.0                  | 14353.1 +- 279.13 | 50.4%         | 1.052                      | 0.804        | 3.93%  | 1775.9 +- 34.53  |
| 4.030           | 16.45                  | 582.0 +- 57.89    | 52.3%         | 1.052                      | 0.822        | 3.93%  | 1990.3 +- 197.98 |
| 4.040           | 6.56                   | 157.4 +- 32.74    | 53.5%         | 1.052                      | 0.829        | 3.93%  | 1352.3 +- 272.22 |
| 4.055           | 6.93                   | 186.1 +- 32.85    | 52.9%         | 1.052                      | 0.842        | 3.93%  | 1457.8 +- 257.28 |
| 4.070           | 7.27                   | 65.9 +- 31.57     | 53.4%         | 1.052                      | 0.854        | 3.93%  | 481.3 +- 230.43  |
| 4.090           | 52.6                   | 574.0 +- 64.13    | 49.0%         | 1.052                      | 0.866        | 3.93%  | 621.6 +- 69.45   |
| 4.120           | 7.65                   | 141.1 +- 28.73    | 49.4%         | 1.052                      | 0.894        | 3.93%  | 1009.1 +- 205.5  |

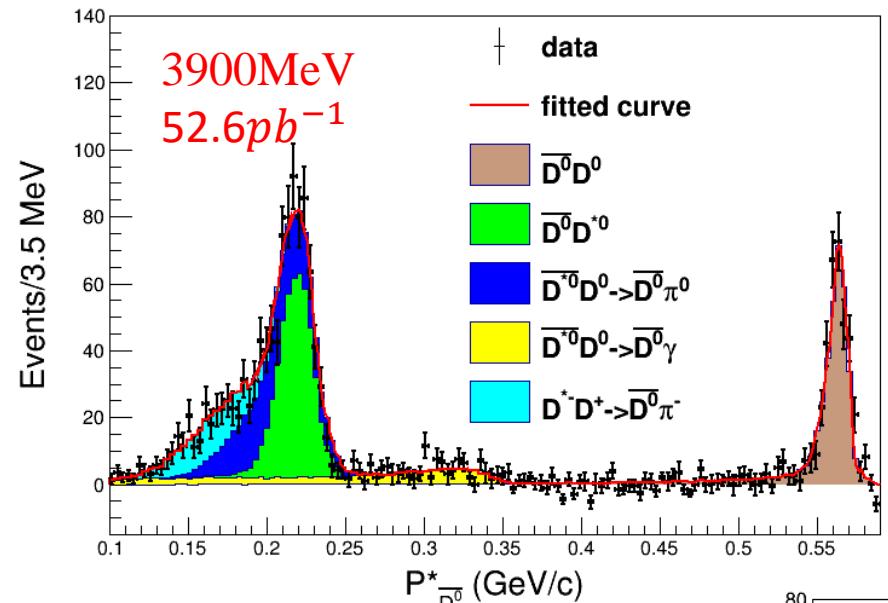
| $\sqrt{s}(GeV)$ | $\mathcal{L}(pb^{-1})$ | $N^{sig}$        | $\varepsilon$ | $\frac{1}{ 1 - \Pi(s) ^2}$ | $1 + \delta$ | $\mathcal{B}(\bar{D}^0 \rightarrow K^+ \pi^-)$ | $\sigma^{Born}$ |
|-----------------|------------------------|------------------|---------------|----------------------------|--------------|--|-----------------|
| 4.140           | 7.27                   | 73.7 +- 26.28    | 49.5%         | 1.052                      | 0.911        | 3.93%  | 543.9 +- 193.99 |
| 4.150           | 7.66                   | 58.8 +- 26.46    | 47.1%         | 1.052                      | 0.918        | 3.93%  | 429.5 +- 193.12 |
| 4.170           | 18.01                  | 197.0 +- 82.45   | 49.0%         | 1.052                      | 0.934        | 3.93%  | 577.6 +- 241.75 |
| 4.190           | 43.1                   | 325.7 +- 62.65   | 50.2%         | 1.056                      | 0.949        | 3.93%  | 382.0 +- 73.46  |
| 4.210           | 54.6                   | 445.9 +- 60.90   | 50.5%         | 1.057                      | 0.965        | 3.93%  | 403.1 +- 55.04  |
| 4.220           | 54.1                   | 399.3 +- 58.27   | 47.4%         | 1.057                      | 0.973        | 3.93%  | 385.8 +- 55.92  |
| 4.230           | 1047.3                 | 7993.4 +- 249.89 | 47.4%         | 1.056                      | 0.980        | 3.93%  | 395.8 +- 12.37  |
| 4.245           | 55.6                   | 492.7 +- 61.16   | 49.5%         | 1.056                      | 0.993        | 3.93%  | 434.7 +- 53.96  |
| 4.260           | 825.7                  | 4922.2 +- 221.64 | 46.1%         | 1.054                      | 1.007        | 3.93%  | 310.1 +- 13.96  |
| 4.310           | 44.9                   | 391.3 +- 80.86   | 45.4%         | 1.052                      | 1.046        | 3.93%  | 443.7 +- 91.68  |
| 4.360           | 539.8                  | 3422.2 +- 173.23 | 43.4%         | 1.051                      | 1.086        | 3.93%  | 325.2 +- 16.46  |
| 4.390           | 55.2                   | 407.2 +- 59.29   | 43.0%         | 1.051                      | 1.110        | 3.93%  | 374.1 +- 54.46  |

# The Born cross section of $e^+e^- \rightarrow D^{*-}D^+$ channel

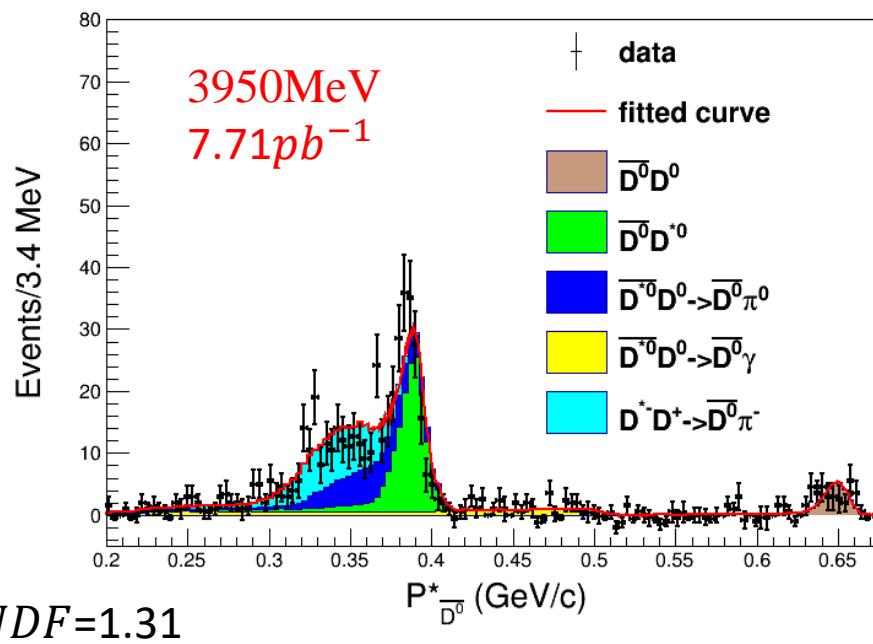
| $\sqrt{s}(GeV)$ | $\mathcal{L}(pb^{-1})$ | $N^{sig}$        | $\varepsilon$ | $\frac{1}{ 1 - \Pi(s) ^2}$ | $1 + \delta$ | $\mathcal{B}(\bar{D}^0 \rightarrow K^+\pi^-)$ | $\sigma^{Born}$  |
|-----------------|------------------------|------------------|---------------|----------------------------|--------------|---|------------------|
| 3.890           | 7.76                   | 14.1 +- 5.99     | 54.3%         | 1.052                      | 0.662        | 3.93%   | 183.9 +- 77.99   |
| 3.900           | 52.6                   | 153.4 +- 23.02   | 59.4%         | 1.052                      | 0.669        | 3.93%   | 265.7 +- 39.89   |
| 3.950           | 7.71                   | 139.6 +- 23.33   | 60.5%         | 1.052                      | 0.736        | 3.93%   | 1471.9 +- 245.95 |
| 3.980           | 7.85                   | 155.7 +- 26.63   | 59.8%         | 1.052                      | 0.774        | 3.93%   | 1553.1 +- 265.57 |
| 4.010           | 482.0                  | 11250.8 +- 230.2 | 54.6%         | 1.052                      | 0.808        | 3.93%   | 1916.8 +- 39.22  |
| 4.030           | 16.45                  | 532.2 +- 48.77   | 55.3%         | 1.052                      | 0.836        | 3.93%   | 2538.2 +- 232.59 |
| 4.040           | 6.56                   | 149.5 +- 27.83   | 55.7%         | 1.052                      | 0.848        | 3.93%   | 1702.6 +- 325.46 |
| 4.055           | 6.93                   | 100.5 +- 26.61   | 56.0%         | 1.052                      | 0.867        | 3.93%   | 1084.2 +- 286.98 |
| 4.070           | 7.27                   | 169.7 +- 28.79   | 56.4%         | 1.052                      | 0.885        | 3.93%   | 1694.4 +- 287.44 |
| 4.090           | 52.6                   | 677.2 +- 55.90   | 52.9%         | 1.052                      | 0.904        | 3.93%   | 975.3 +- 80.51   |
| 4.120           | 7.65                   | 63.4 +- 23.68    | 53.9%         | 1.052                      | 0.947        | 3.93%   | 588.9 +- 219.81  |

| $\sqrt{s}(GeV)$ | $\mathcal{L}(pb^{-1})$ | $N^{sig}$        | $\varepsilon$ | $\frac{1}{ 1 - \Pi(s) ^2}$ | $1 + \delta$ | $\mathcal{B}(\bar{D}^0 \rightarrow K^+ \pi^-)$ | $\sigma^{Born}$  |
|-----------------|------------------------|------------------|---------------|----------------------------|--------------|--|------------------|
| 4.140           | 7.27                   | 107.5 +- 23.49   | 54.3%         | 1.052                      | 0.972        | 3.93%  | 1015.9 +- 221.96 |
| 4.150           | 7.66                   | 78.9 +- 24.01    | 54.0%         | 1.052                      | 0.984        | 3.93%  | 702.8 +- 213.64  |
| 4.170           | 18.01                  | 139.4 +- 57.37   | 53.4%         | 1.052                      | 1.009        | 3.93%  | 521.4 +- 214.47  |
| 4.190           | 43.1                   | 408.9 +- 52.38   | 54.2%         | 1.056                      | 1.032        | 3.93%  | 612.3 +- 78.43   |
| 4.210           | 54.6                   | 303.1 +- 53.08   | 52.3%         | 1.057                      | 1.056        | 3.93%  | 362.4 +- 63.45   |
| 4.220           | 54.1                   | 259.3 +- 53.06   | 49.3%         | 1.057                      | 1.068        | 3.93%  | 328.0 +- 66.82   |
| 4.230           | 1047.3                 | 4016.1 +- 228.57 | 48.1%         | 1.056                      | 1.078        | 3.93%  | 266.7 +- 15.18   |
| 4.245           | 55.6                   | 255.1 +- 55.02   | 50.0%         | 1.056                      | 1.099        | 3.93%  | 301.6 +- 65.04   |
| 4.260           | 825.7                  | 4241.7 +- 194.23 | 48.7%         | 1.054                      | 1.121        | 3.93%  | 340.6 +- 15.59   |
| 4.310           | 44.9                   | 101.3 +- 14.17   | 45.2%         | 1.052                      | 1.180        | 3.93%  | 153.4 +- 21.45   |
| 4.360           | 539.8                  | 2035.9 +- 183.73 | 45.0%         | 1.051                      | 1.242        | 3.93%  | 244.8 +- 22.09   |
| 4.390           | 55.2                   | 265.6 +- 60.91   | 43.7%         | 1.051                      | 1.278        | 3.93%  | 312.8 +- 71.73   |

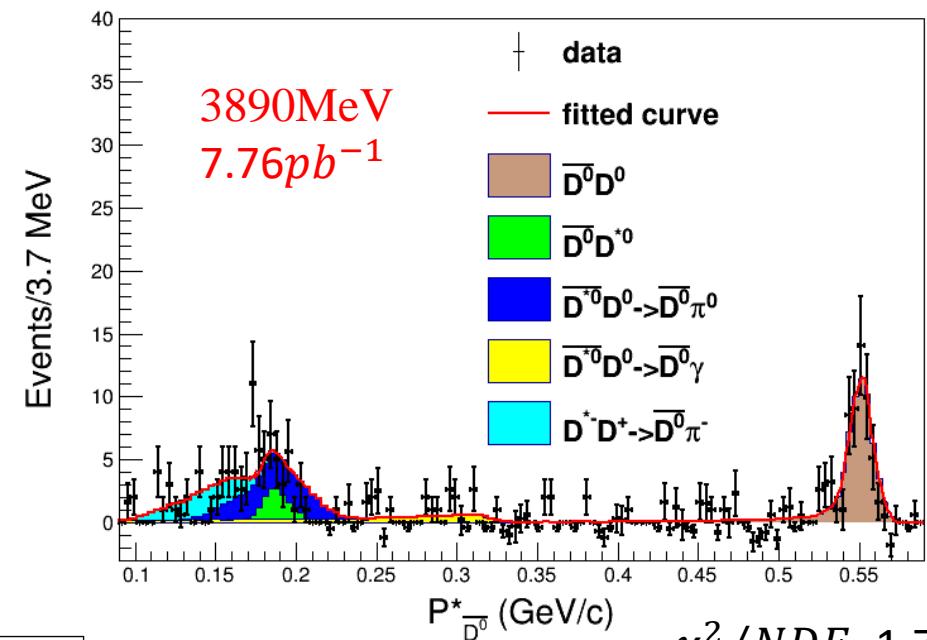
# The first iteration results



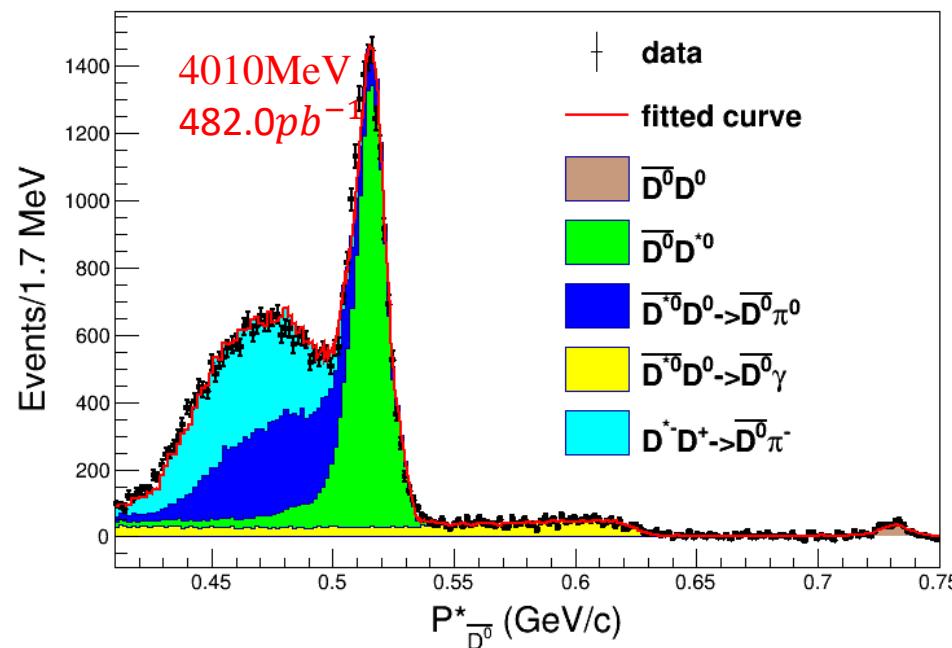
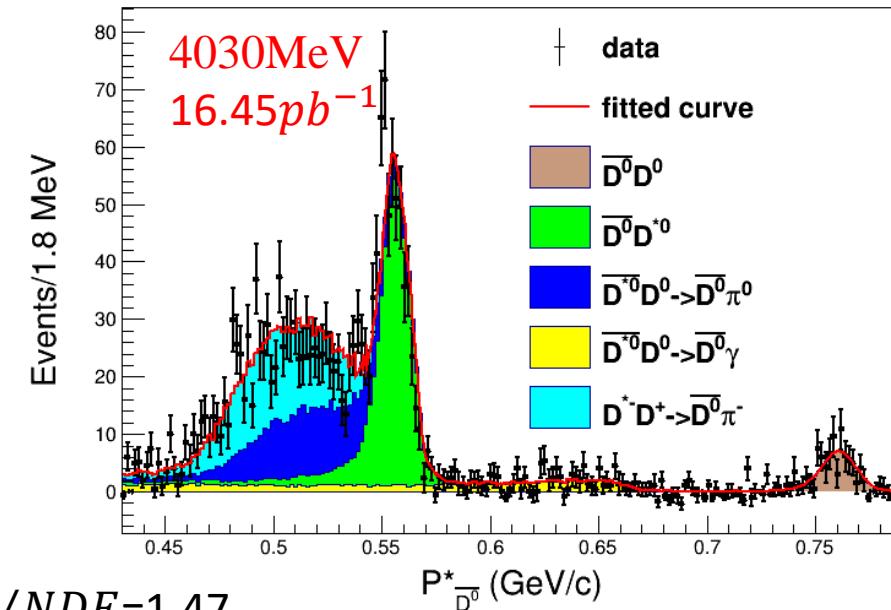
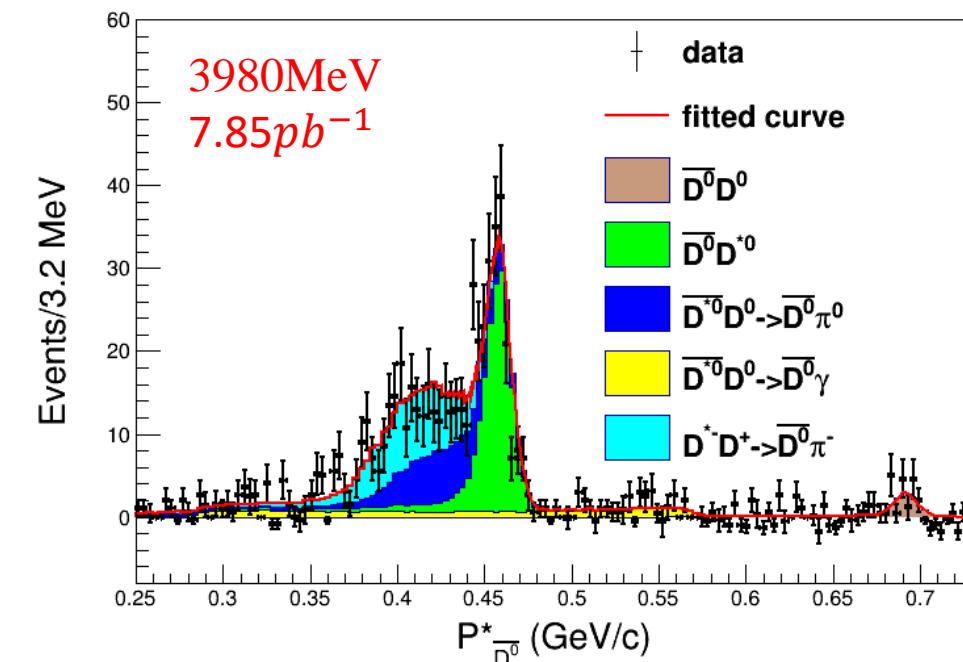
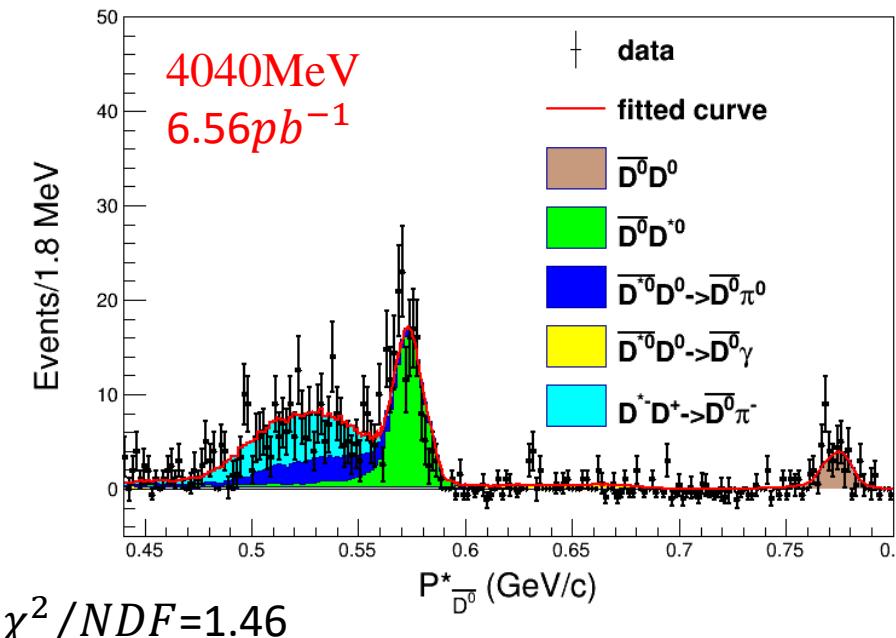
$\chi^2/NDF=1.13$

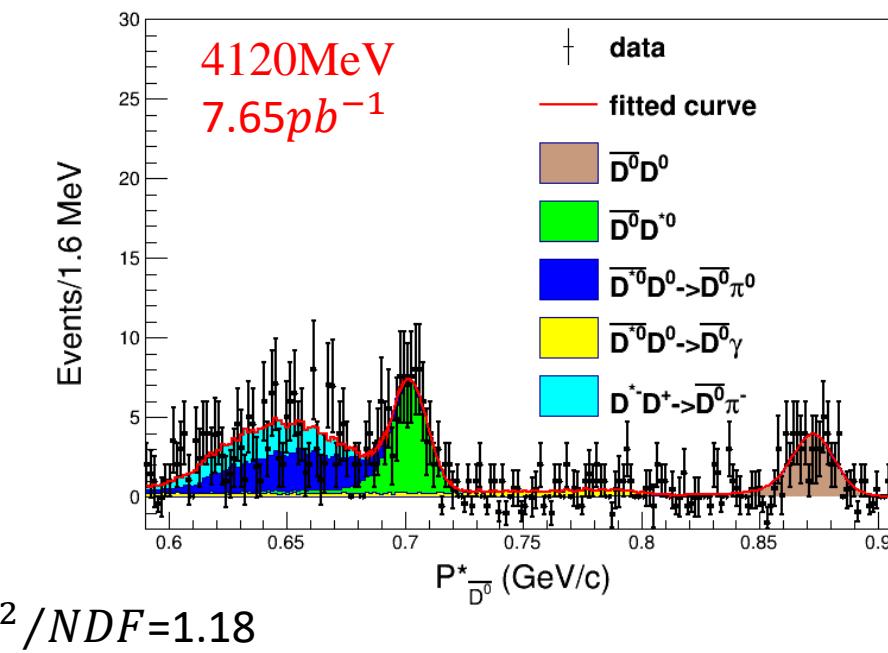
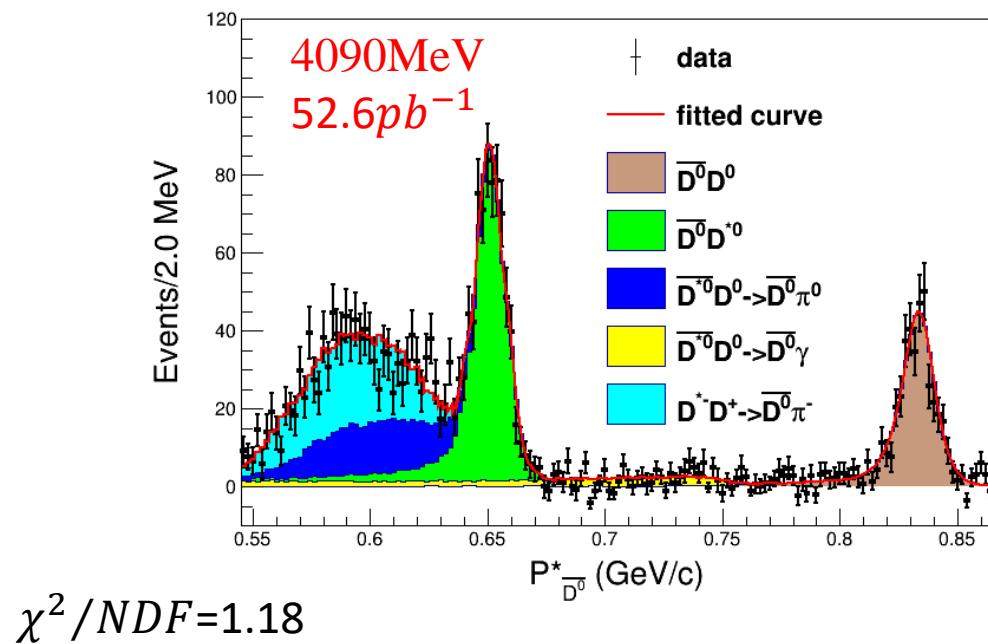
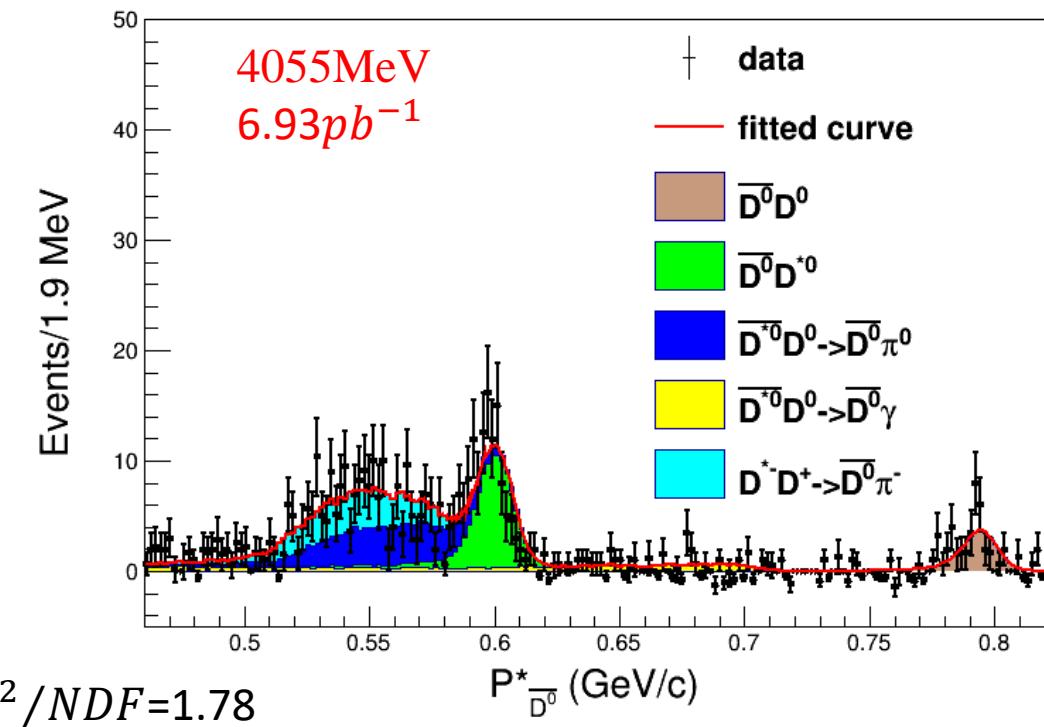
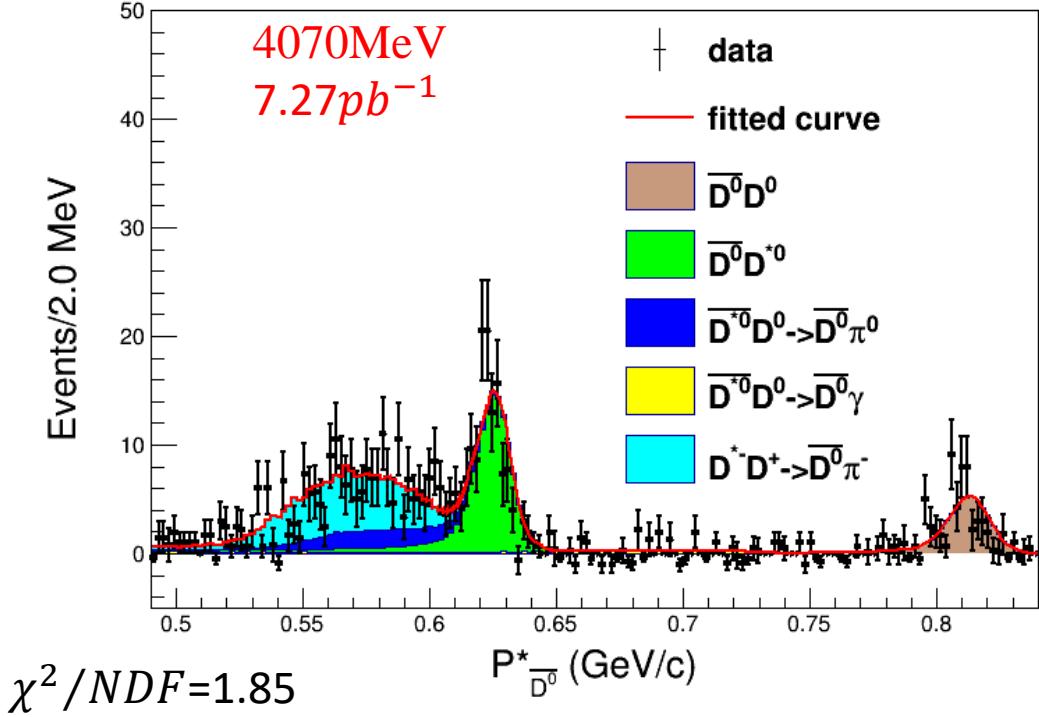


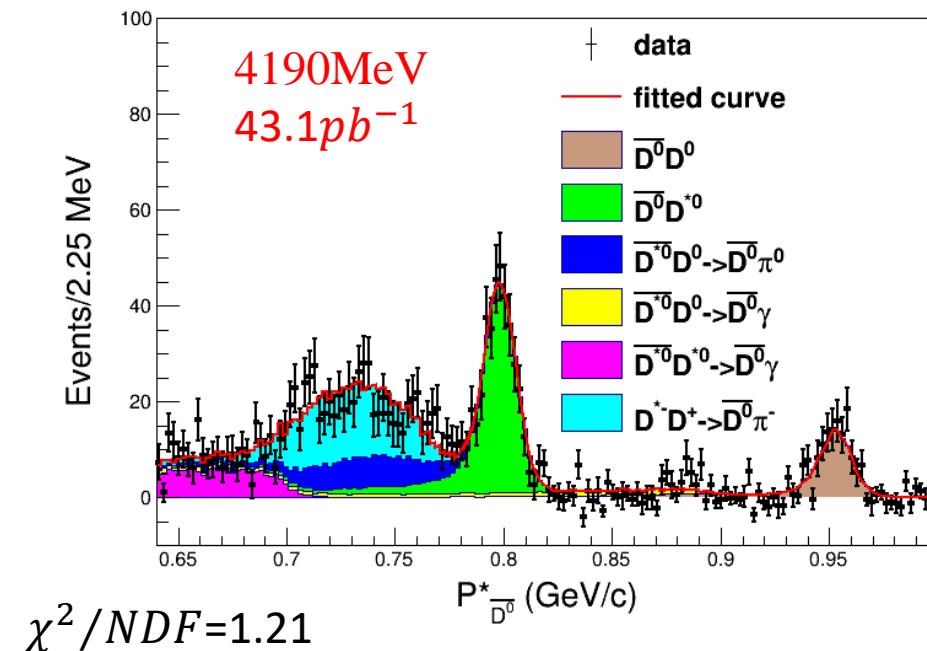
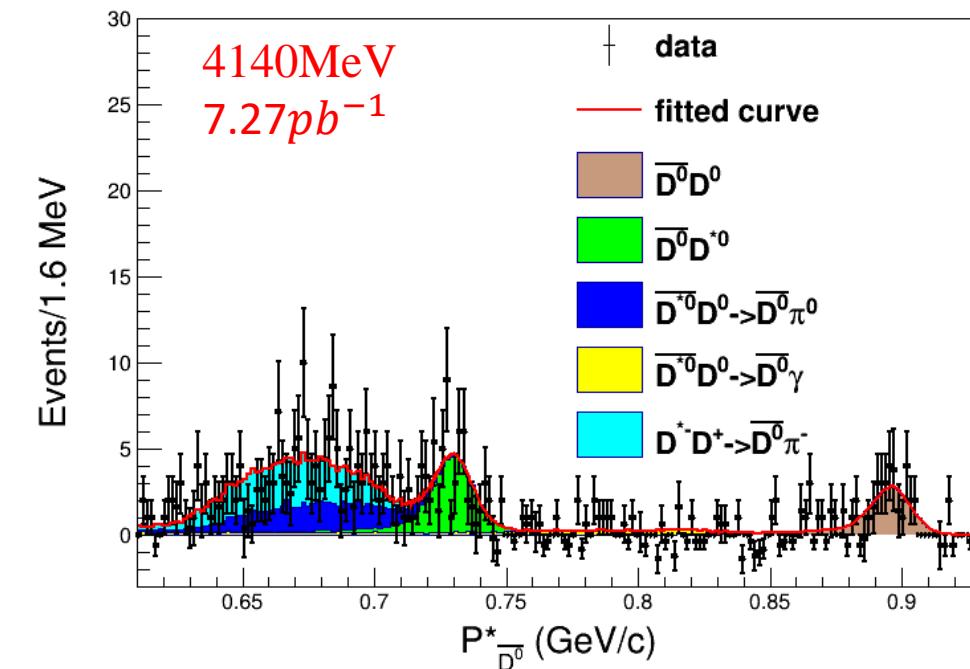
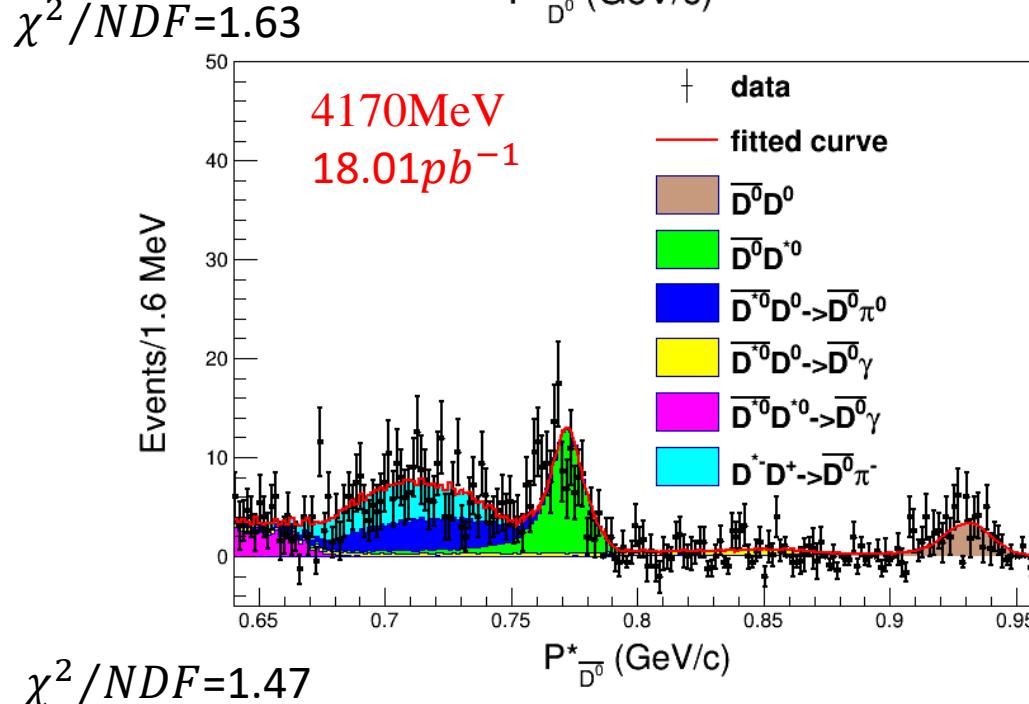
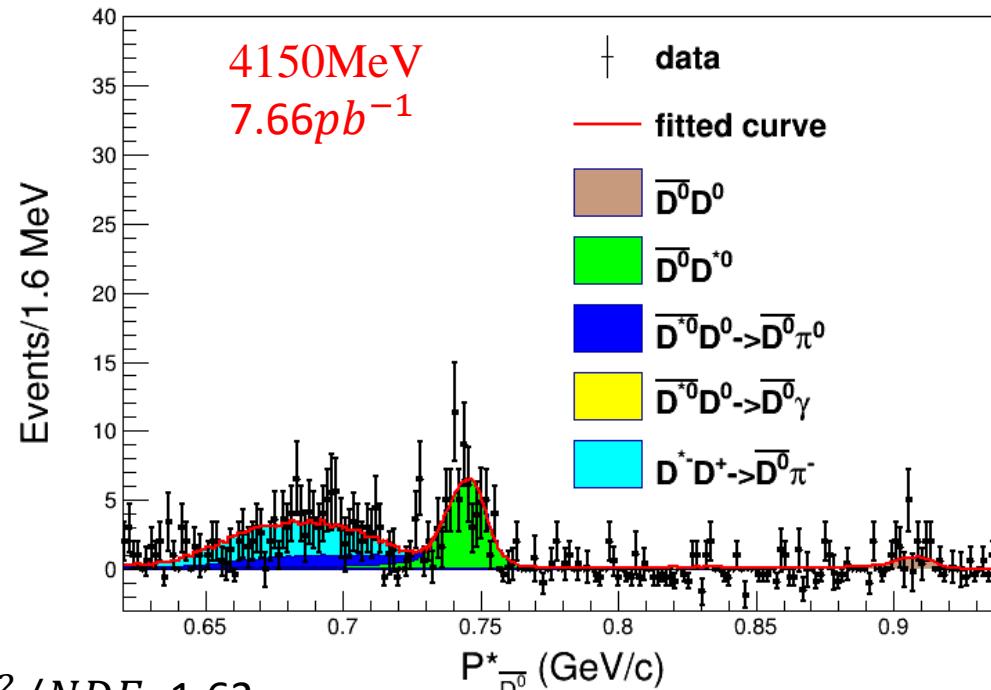
$\chi^2/NDF=1.31$

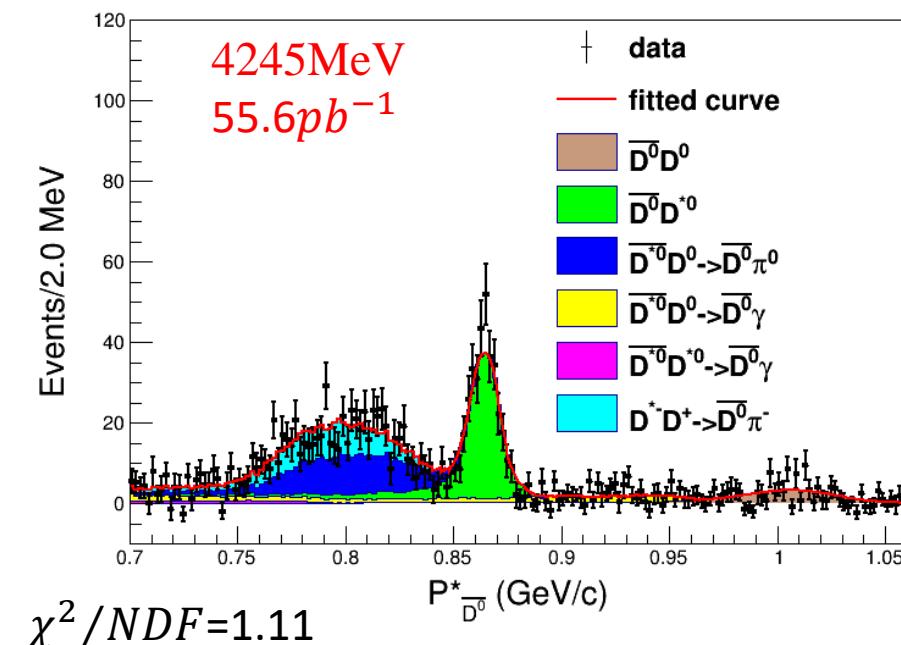
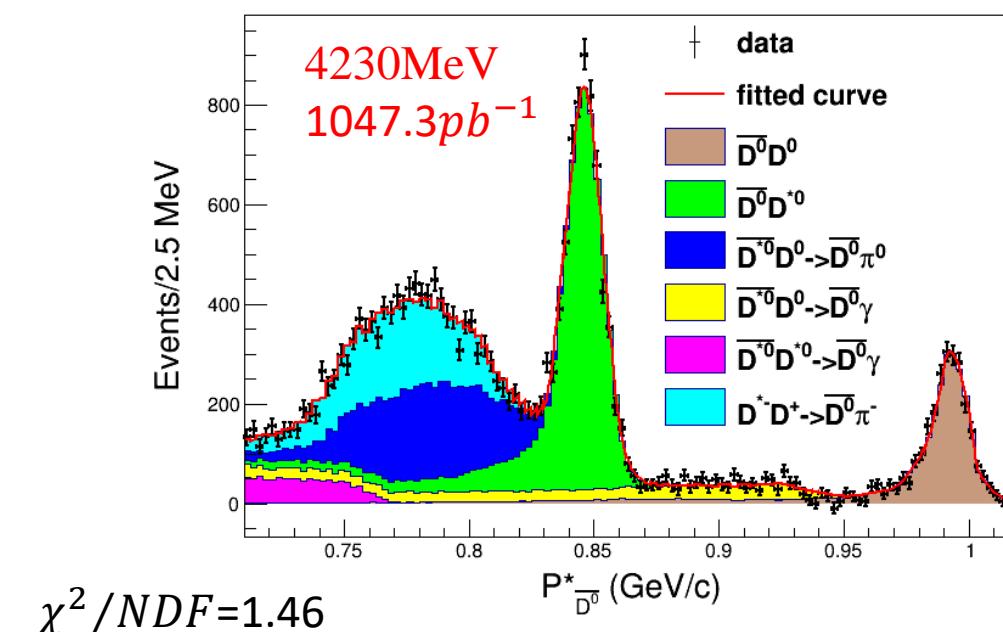
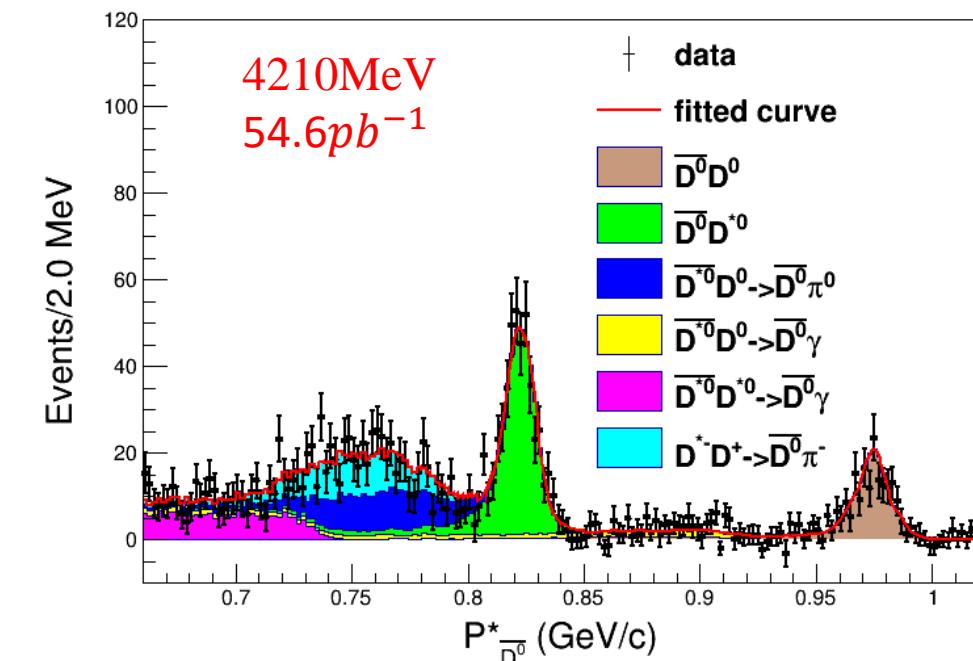
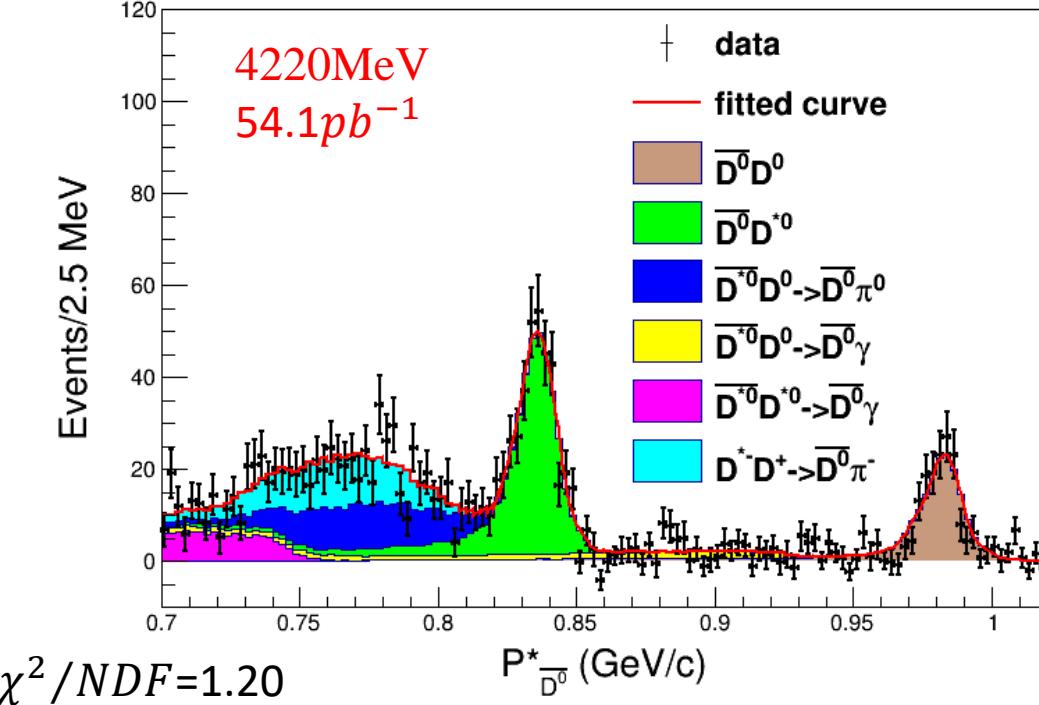


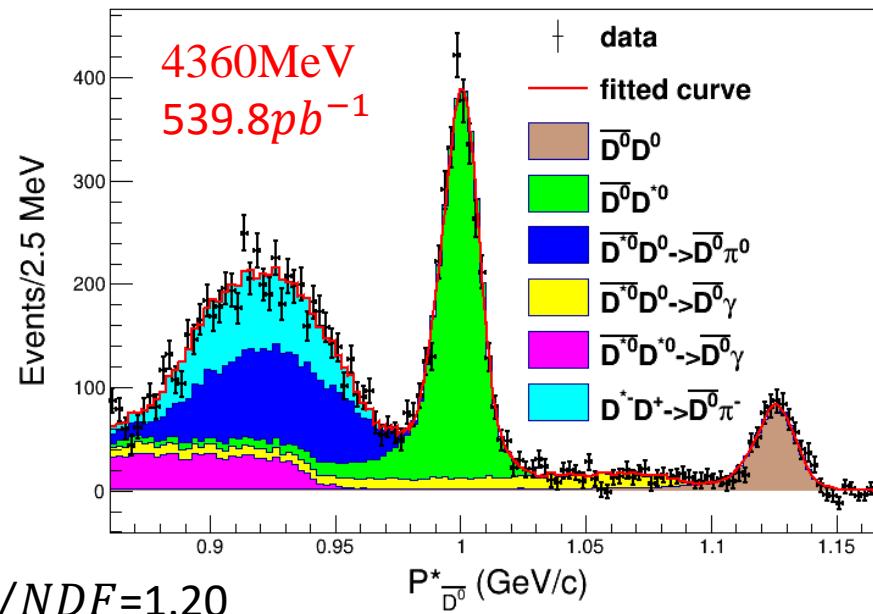
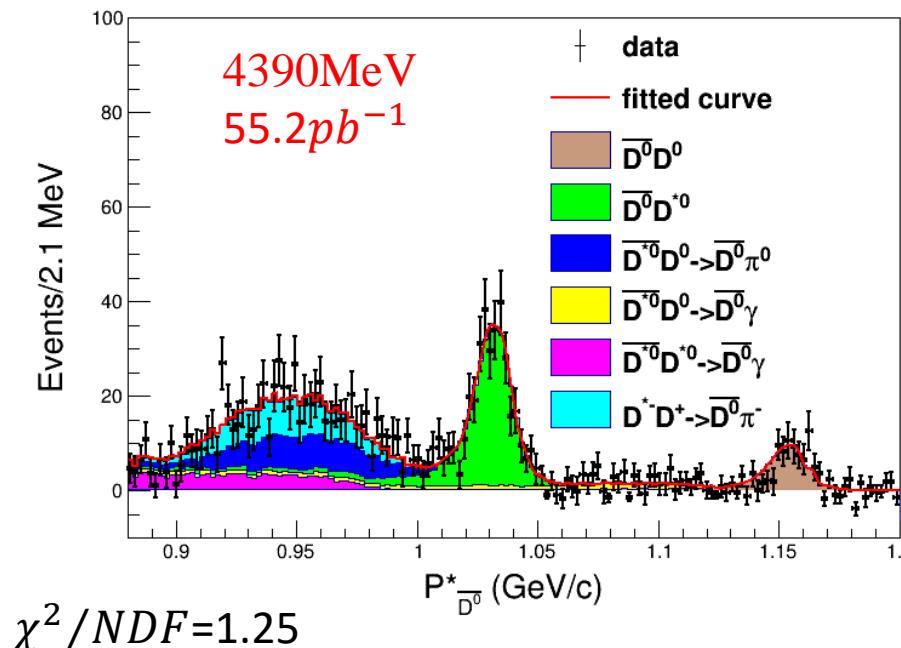
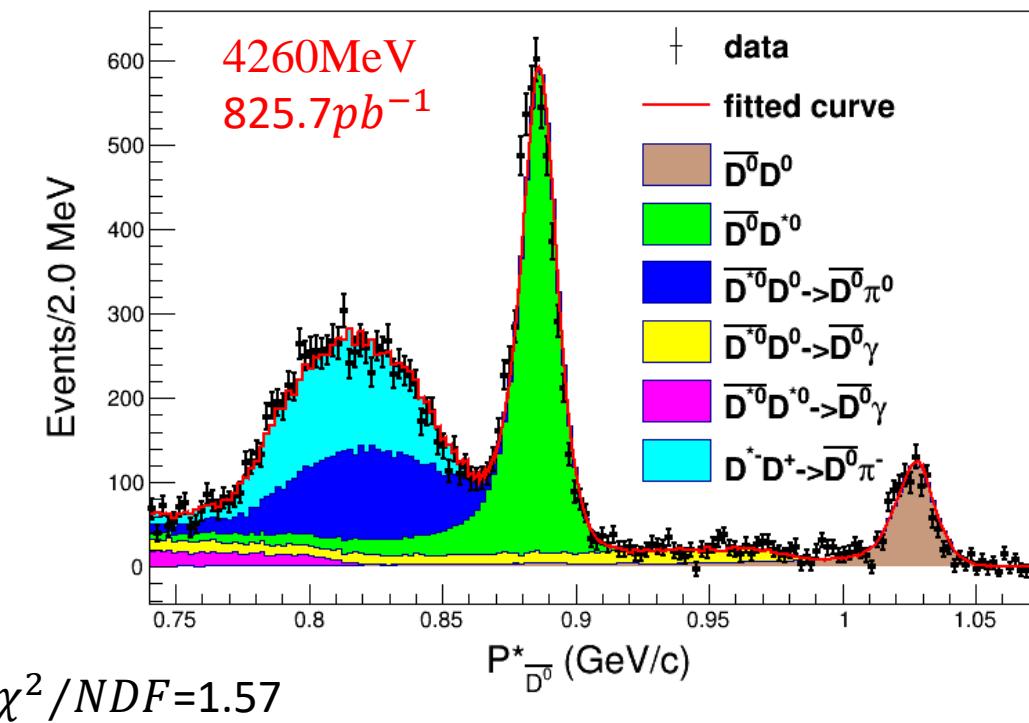
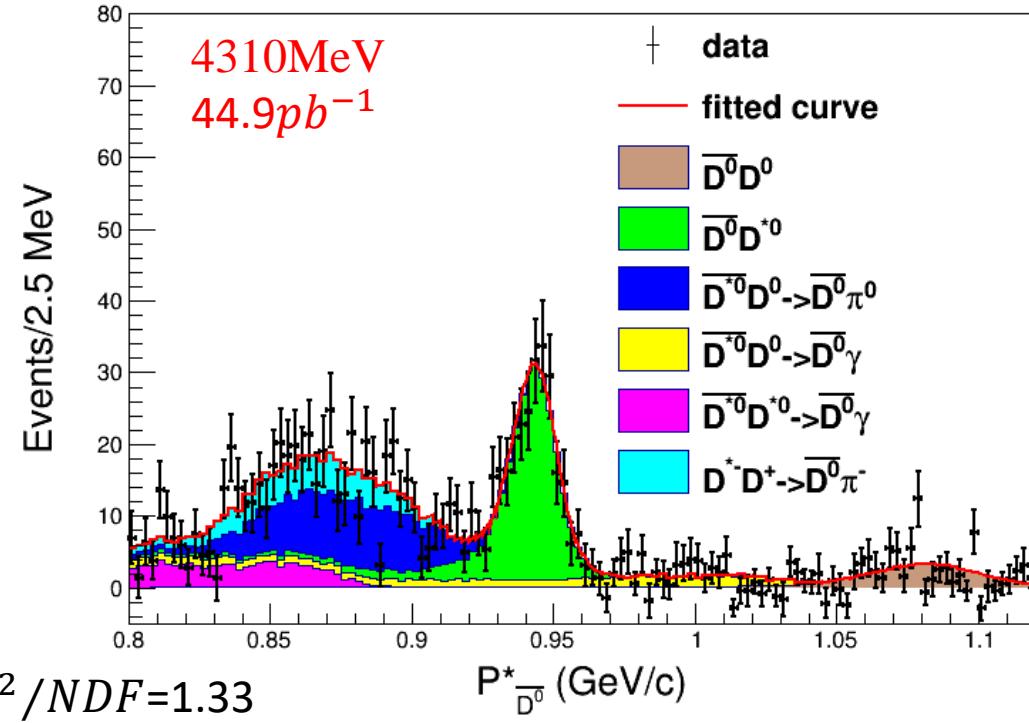
$\chi^2/NDF=1.76$


 $\chi^2/NDF = 1.73$ 

 $\chi^2/NDF = 1.47$ 

 $\chi^2/NDF = 1.81$ 

 $\chi^2/NDF = 1.46$





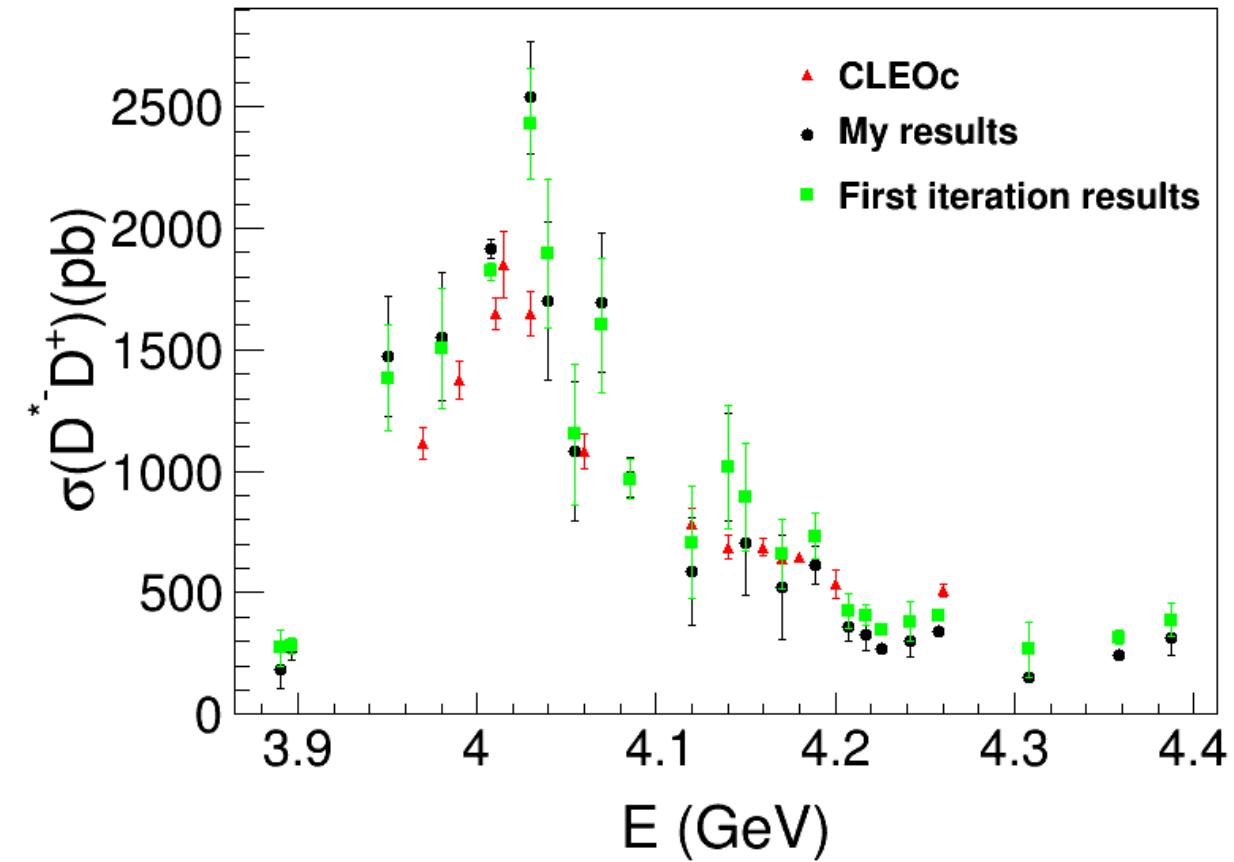
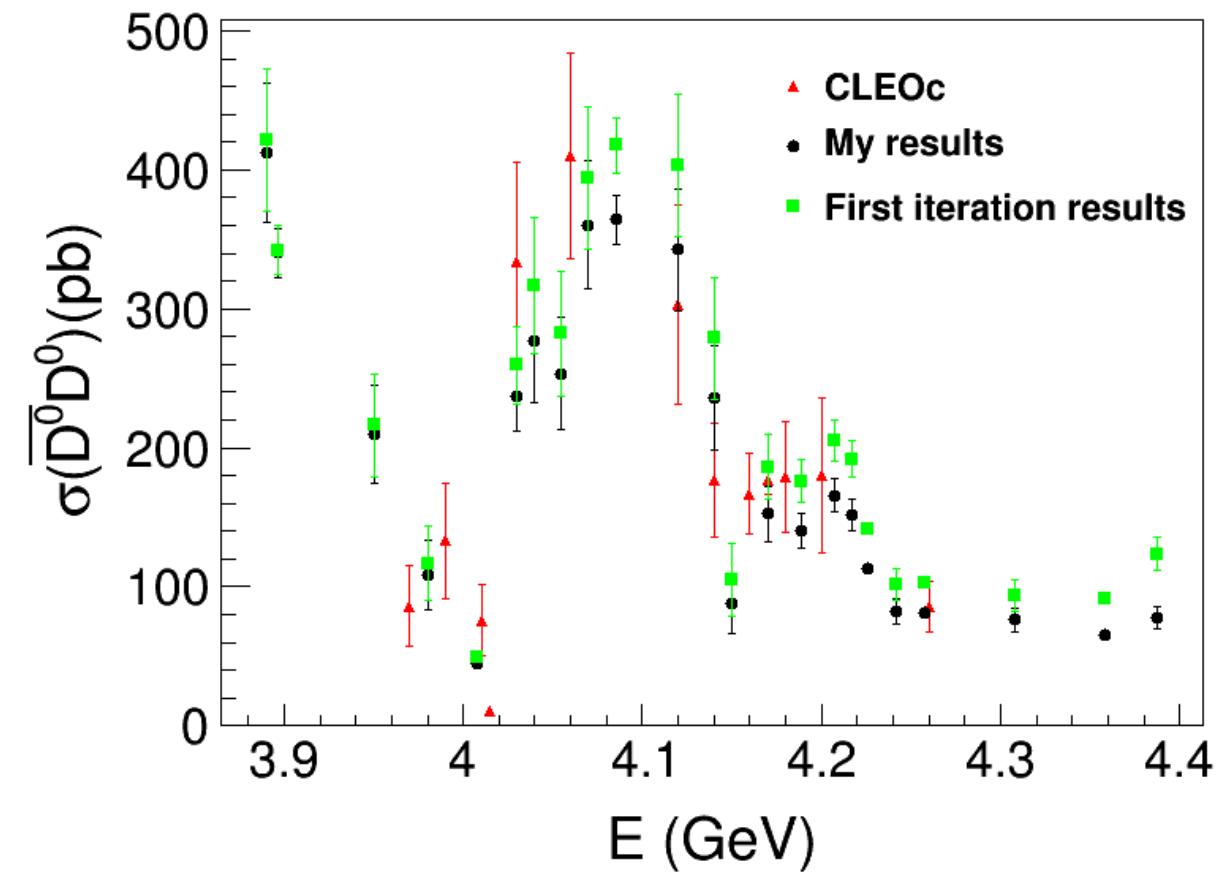


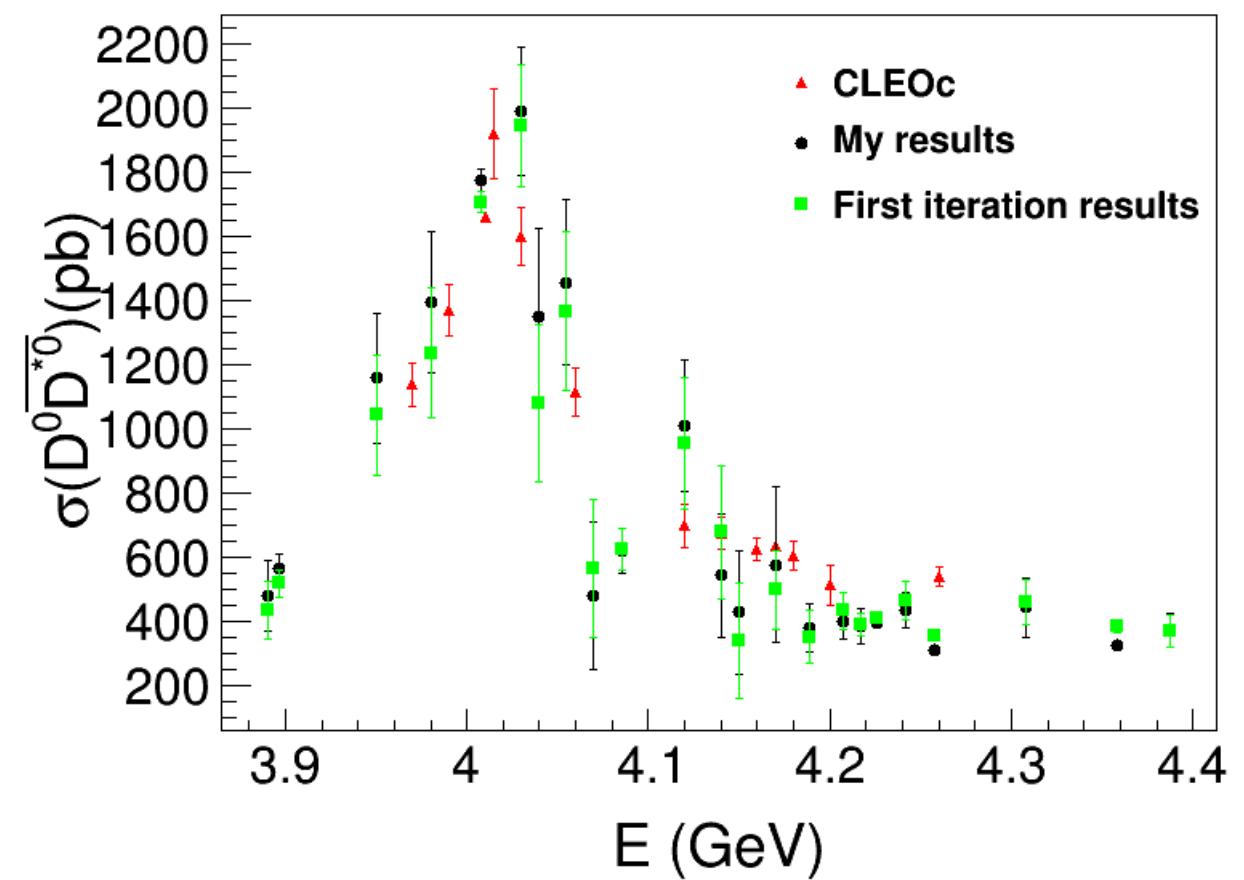
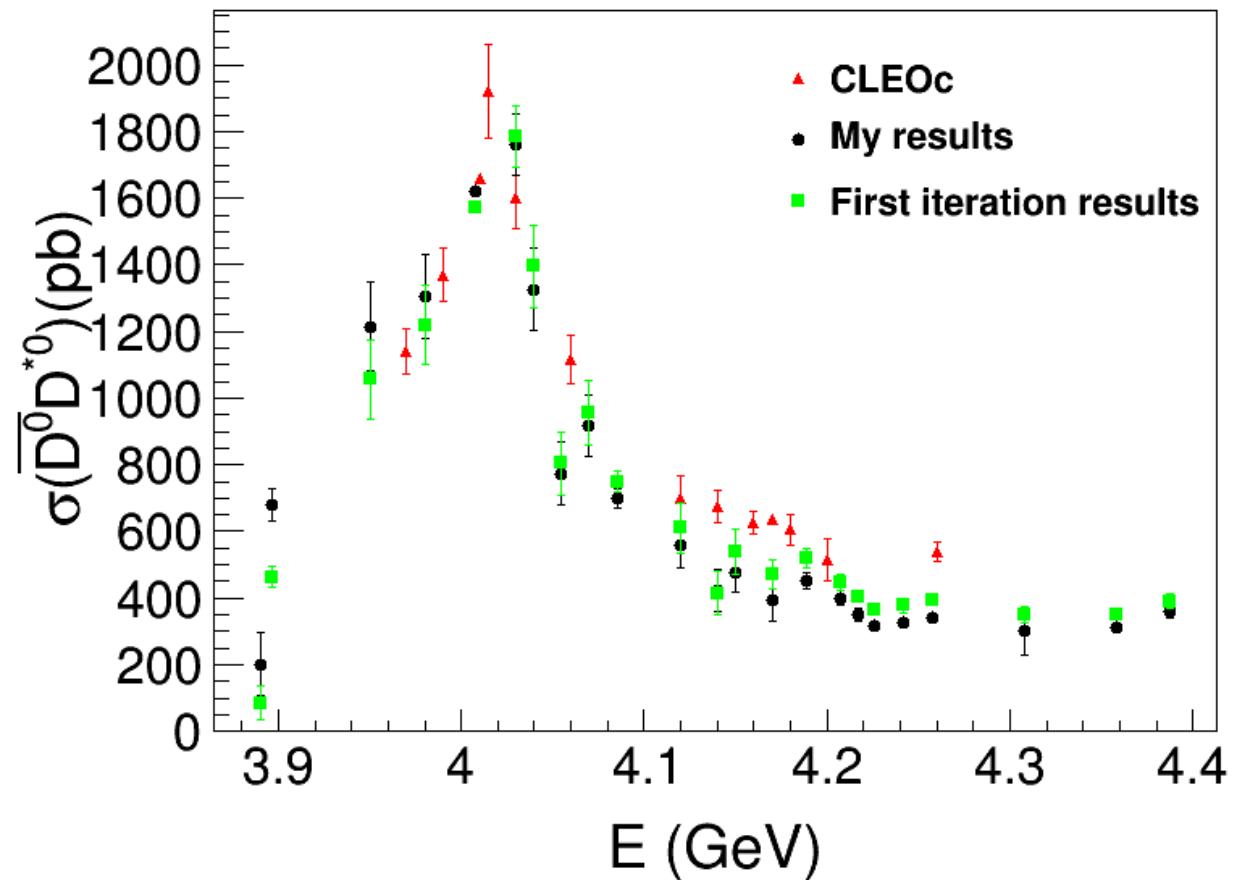


# Compare CLEOc results with mine

My results: we first use the published cross section as input, then measure the  $e^+e^- \rightarrow \overline{D}^0 D^0$ ,  $\overline{D}^0 D^{0*}$  and  $D^{*-} D^+$  with our own data.

First iteration results: iterate the first measurement results





# Next to do

- Run other XYZ and R-scan data samples.
- Iterate the radiative correction procedure with our own measurement until this procedure converges.
- $D^0 \rightarrow K^- \pi^+$  will also be included later

**Thanks for your attention**