Cross Section measurement of $e^+e^- \rightarrow D_s^+ D_s^{*-}$

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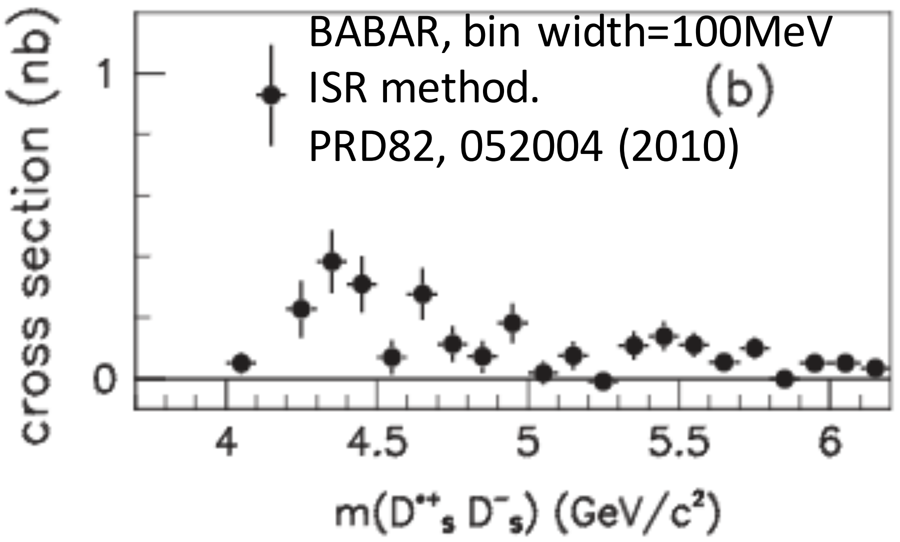
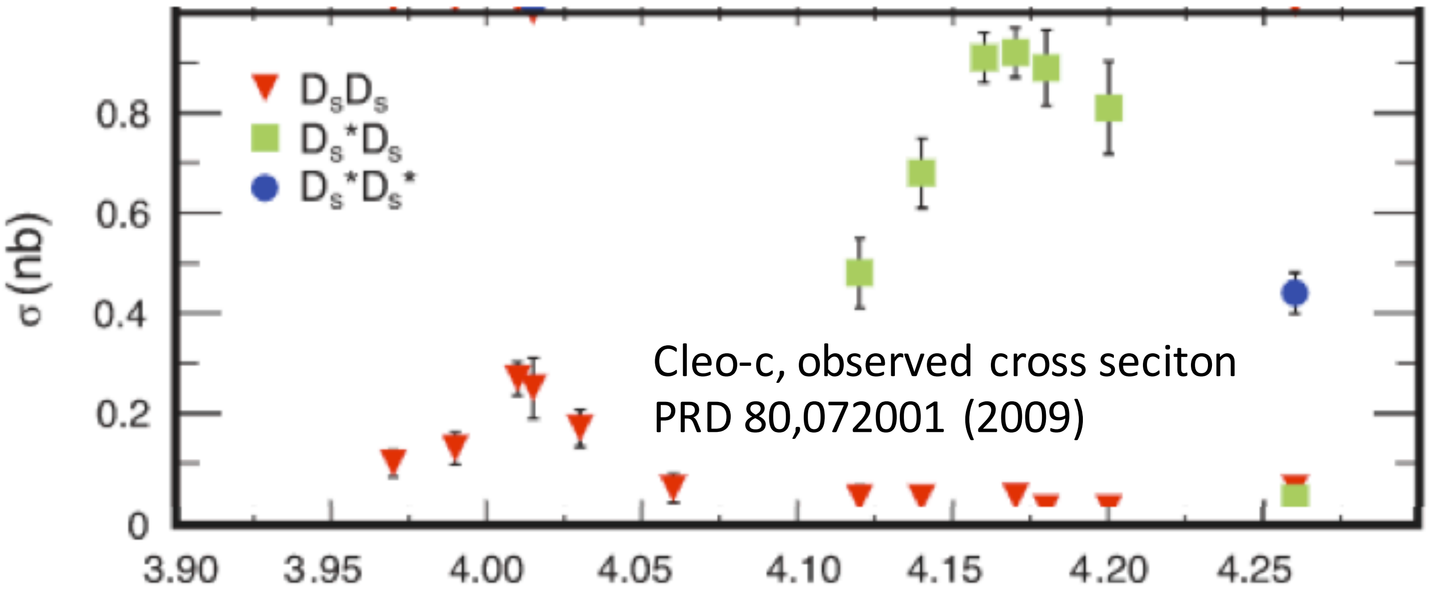
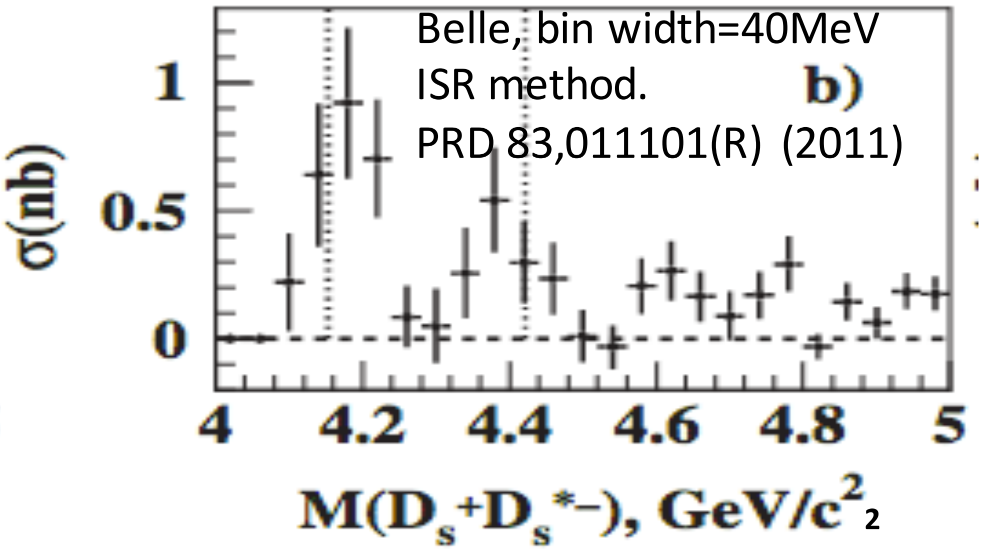
Introduction

- BABAR, Belle, CLEO-c have measured the cross section of $e^+e^- \rightarrow D_s^+ D_s^{*-}$ before, but the precision is not enough.







Introduction

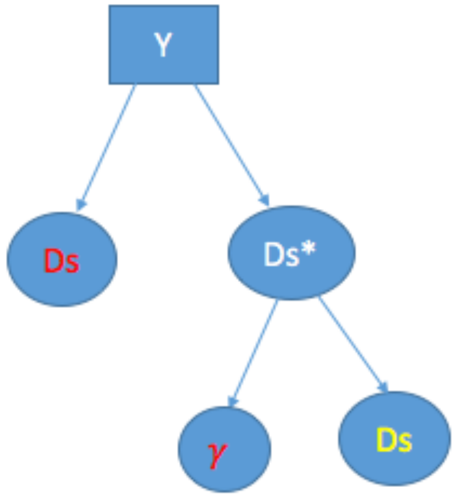
- There are abounded ψ and Y states between 4.0 and 4.6GeV, the cross section of their decay width to the open charm process is important to distinguish their property.

Table 2. $^3P_0$ model predictions for the partial and total widths (MeV) of known charmonium states above DD threshold. This assumes SHO wavefunctions with a width parameter $\beta = 0.5$ GeV, a pair production strength $\gamma = 0.4$, and the usual spectroscopic assignments $\psi(3770) = 1^3D_1$, $\psi(4040) = 3^3S_1$, $\psi(4159) = 2^3D_1$ and $\psi(4415) = 4^3S_1$.

arXiv: hep-ph/0412057

State	DD	DD*	D*D*	D_sD_s	$D_sD_s^*$	$D_s^*D_s^*$	DD_1	DD_1'	DD_2^*	Γ_{tot} [expt.]
$\psi(3770)$	43.									43. [23.6 ± 2.7]
$\psi(4040)$	0.1	33.	33.	7.8						74. [52 ± 10]
$\psi(4159)$	16.	0.4	35.	8.0	14.					74. [78 ± 20]
$\psi(4415)$	0.4	2.3	16.	1.3	2.6	0.7	31.	1.0	23.	78. [43 ± 15]

Event Selection



- The strategy is tag one Ds and one photon, miss the other Ds
- Reconstruct Ds^+ with BesDChain

➢ $Ds^+ = K^+list * K^-list * \pi^+list$, all combinations kept

➢ $|m(Ds^+)-m(Ds\_PDG)|<85$ MeV

- Reconstruct one γ
- 3C Kinematic Fit to all combinations of ($K^+K^-\pi^+$ & γ & missing Ds^-), with both $K^+K^-\pi^+$ and missing Ds fixed to Ds' PDG mass.
- The combination with minimum χ^2(3C) is chosen as nominate combination and χ^2(3C) <30 is required.

Signal channel MC

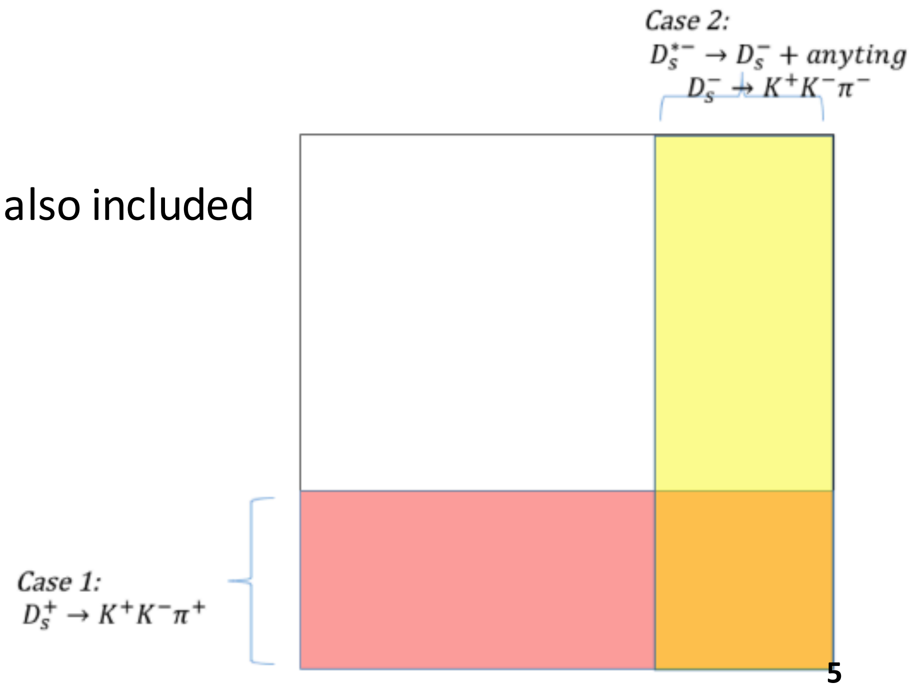
- There are two cases for signal channel, depending on which Ds is tagged

- Signal Case 1: $e^+e^- \to D_s^+ D_s^{*-}$, $D_s^+ \to K^+K^-\pi^+$, $D_s^{*-} \to anything$.
- Signal Case 2: $e^+e^- \to D_s^+ D_s^{*-}$, $D_s^+ \to anyting$, $D_s^{*-} \to anything + D_s^-$, $D_s^- \to K^+K^-\pi^-$.

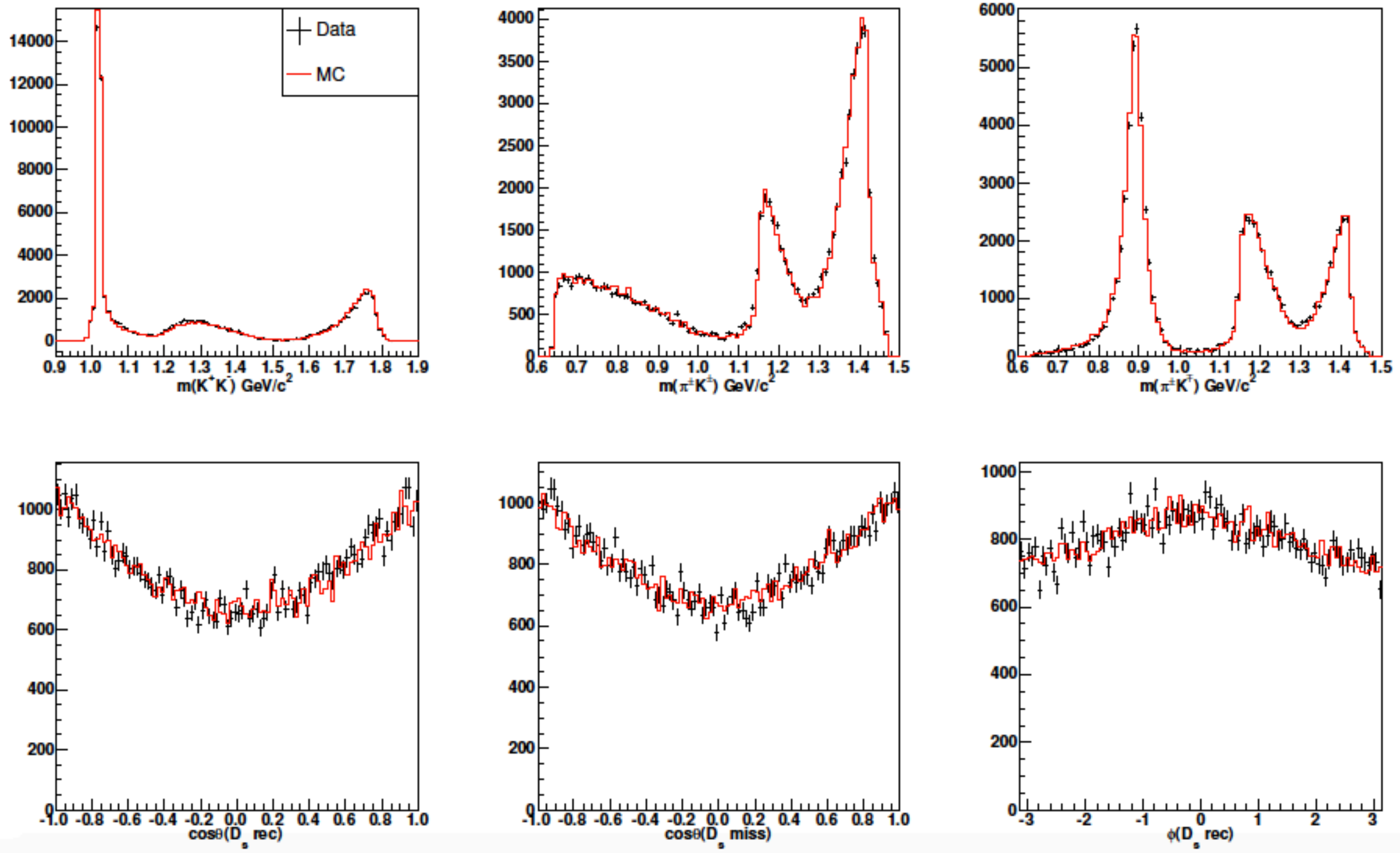
From PDG, we know there are three decay mode for D_s^{*-},

- $D_s^{*-} \to \gamma D_s^-$, $(93.5 \pm 0.7)\%$
- $D_s^{*-} \to \pi^0 D_s^-$, $(5.8 \pm 0.7)\%$
- $D_s^{*-} \to e^+e^- D_s^-$, $(6.7 \pm 1.6) \times 10^{-3}$

This two Ds* decay modes are also included
In signal MC



Comparison between Data and signal MC

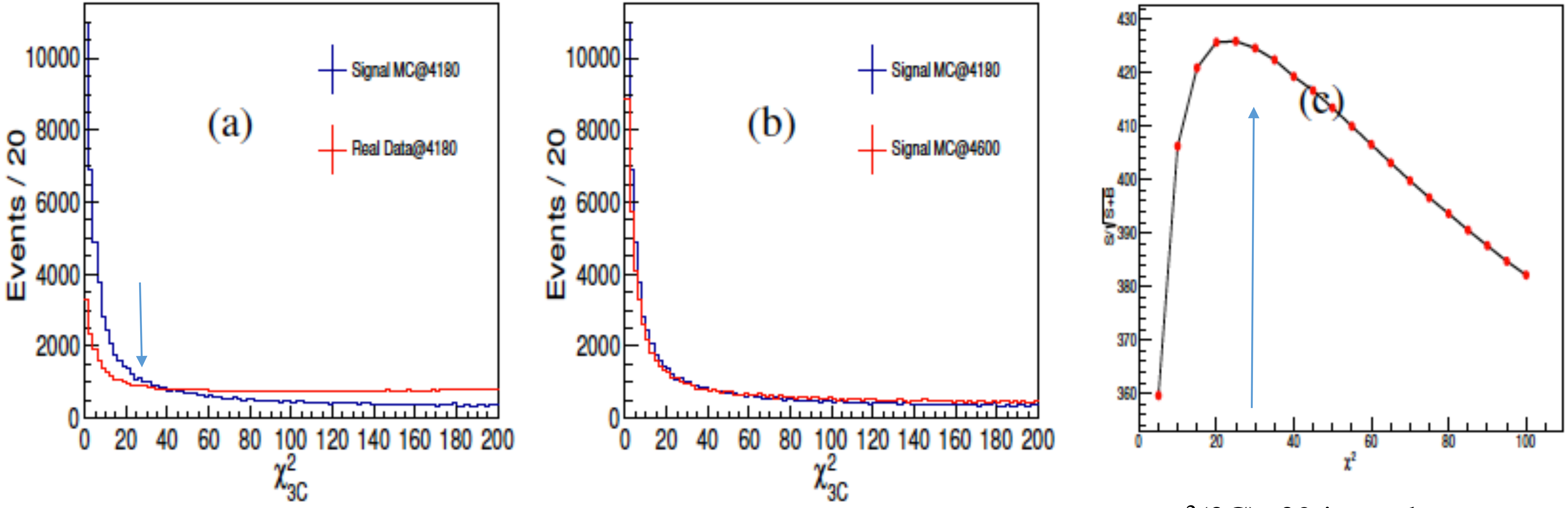


$e^+e^- \rightarrow D_s^+D_s^{*-}$ is generated with HelAmp
Ds→KKπ mode is generated with D_DALITZ

We can see the invariant mass And angular distribution agree very well between data and MC.

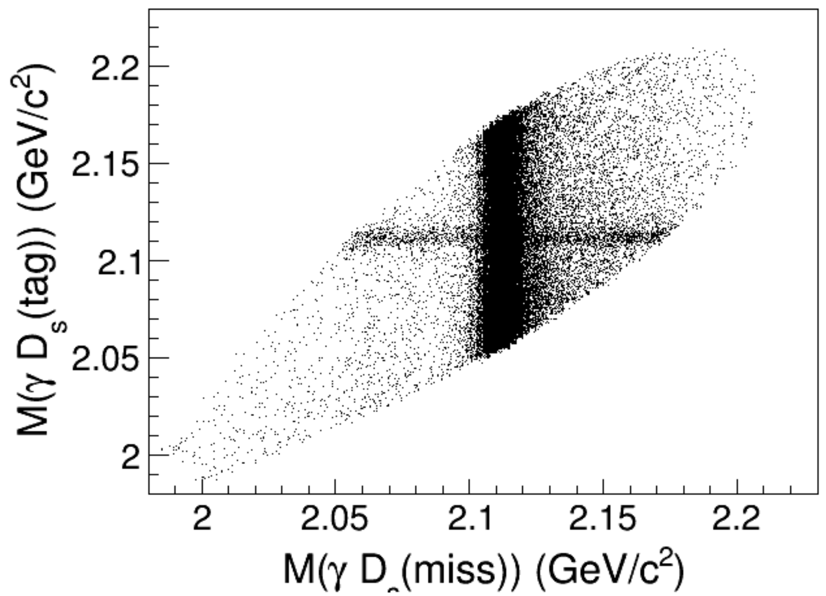
χ^2(3C) optimization

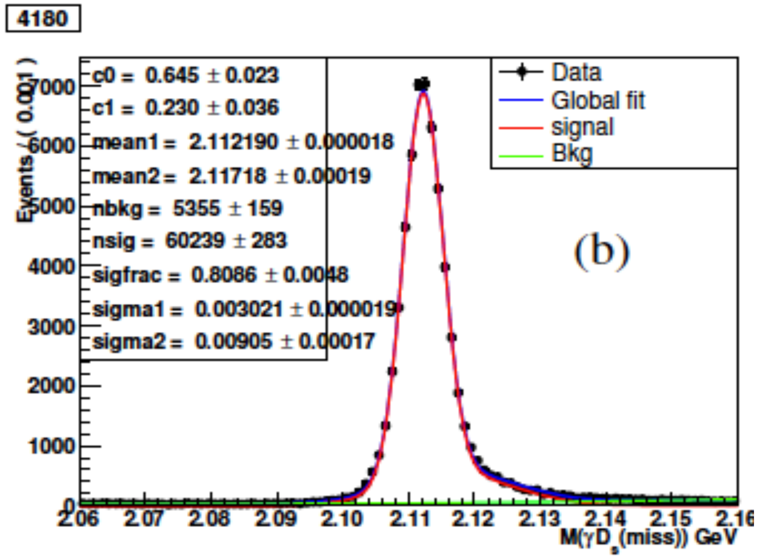
- χ^2(3C) is optimized using the inclusive MC @4.18GeV



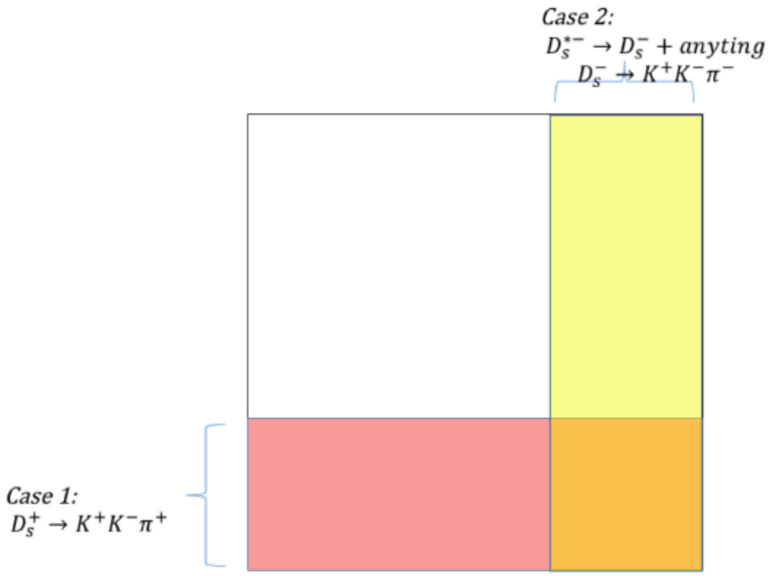
χ^2(3C)<30 is used

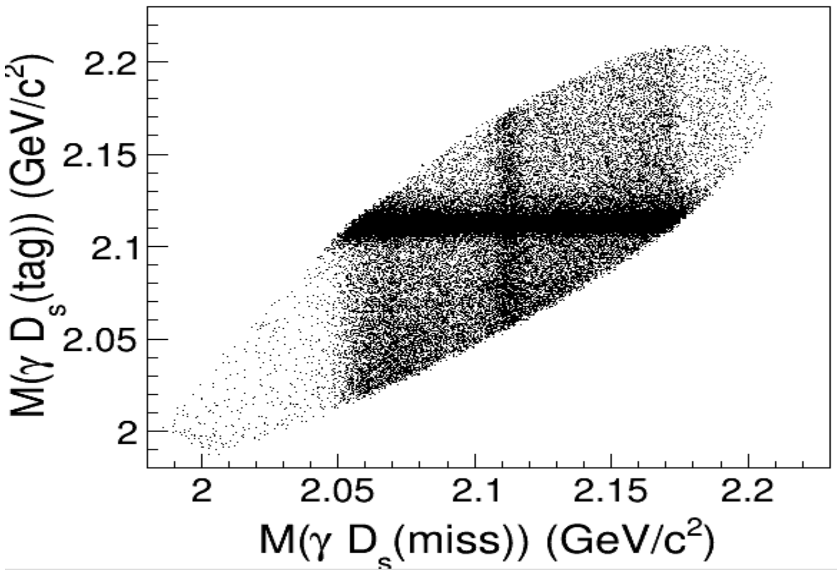
where to get the signal event number

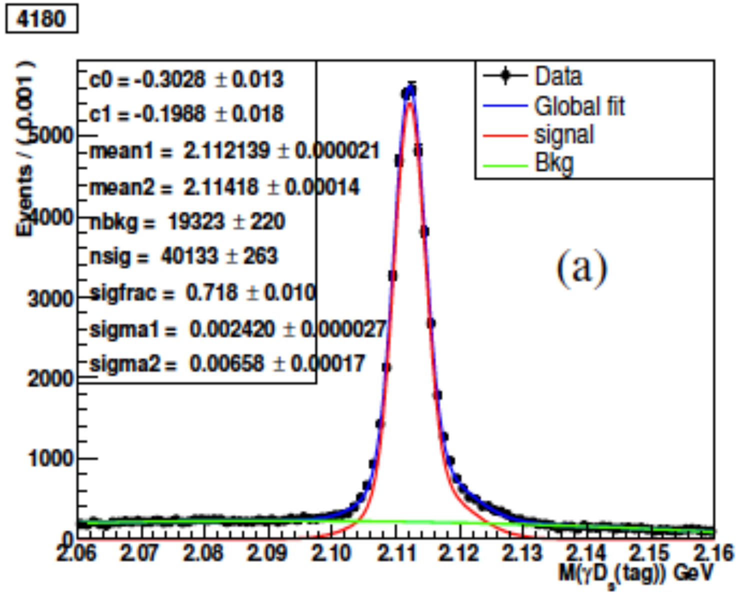




For case 1: we only count the signal event number on M(γDs(miss))



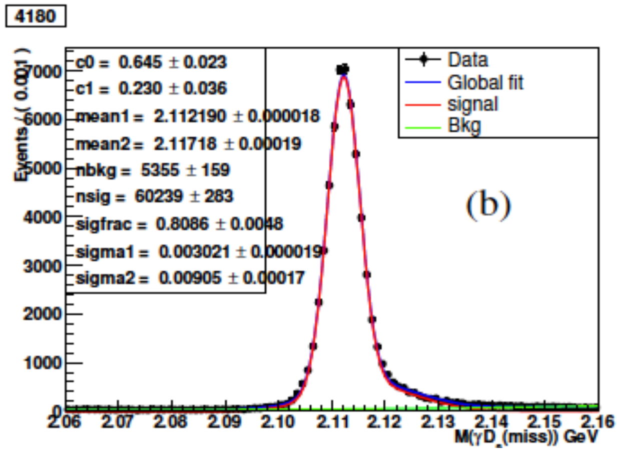


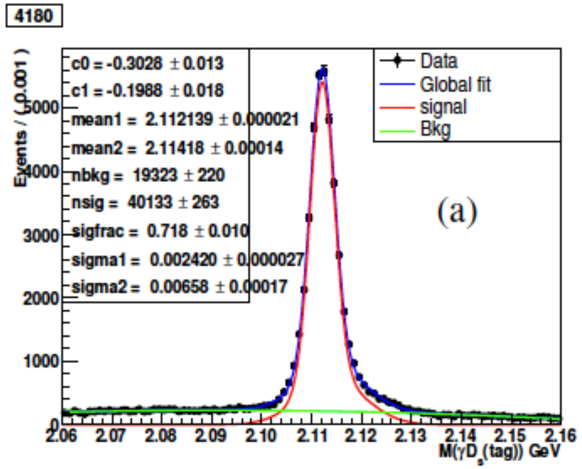


For case 2: we only count the signal event number on M(γDs(tag))

Then we can avoid the double double counting on the brown area.

How to get the cross section





Case1:

$$\epsilon_1 = \frac{N_{mc1}}{N_{gen1}}$$

$$\sigma(e^+e^- \to D_s^+ D_s^{*-}) = \frac{N_{re1}}{\mathscr{L} \cdot \epsilon_1 \cdot Br(D_s^+ \to K^+K^-\pi^+) \cdot (1+\delta_{ISR}) \cdot \delta_{VP}}$$

Case2:

$$\epsilon_2 = \frac{N_{mc2}}{N_{gen2}}$$

$$\sigma(e^+e^- \to D_s^+ D_s^{*-}) = \frac{N_{re2}}{\mathscr{L} \cdot \epsilon_2 \cdot Br(D_s^+ \to K^+K^-\pi^+) \cdot (1+\delta_{ISR}) \cdot \delta_{VP}}$$

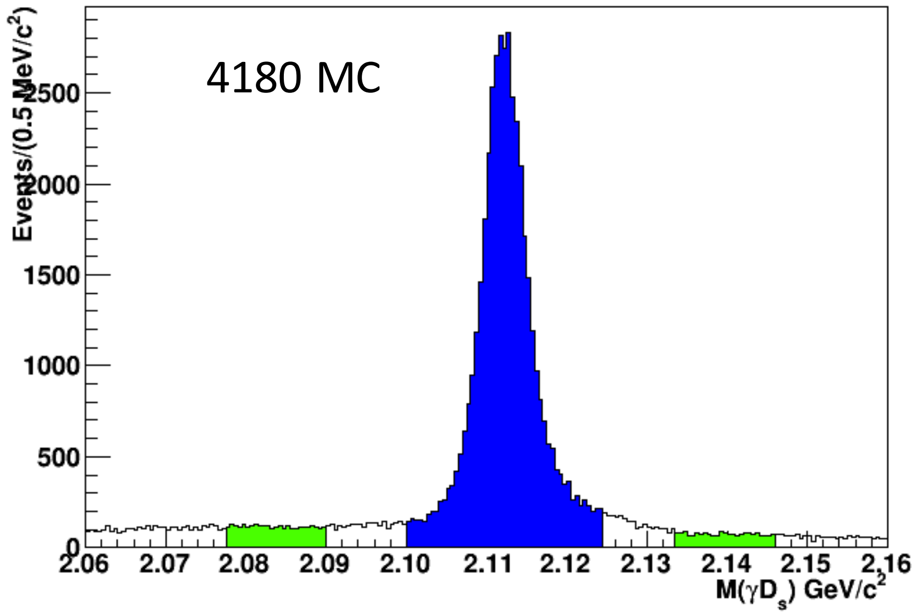
Combine:

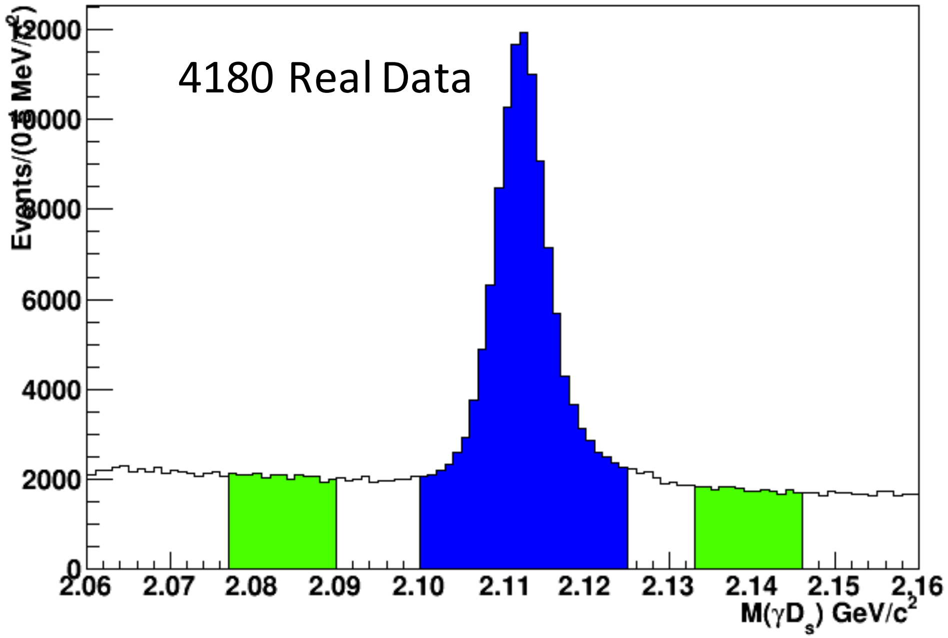
$$\sigma(e^+e^- \to D_s^+ D_s^{*-}) = \frac{N_{re1}+N_{re2}}{\mathscr{L} \cdot (\epsilon_1+\epsilon_2) \cdot Br(D_s^+ \to K^+K^-\pi^+) \cdot (1+\delta_{ISR}) \cdot \delta_{VP}}$$

$$= \frac{N_{re1}+N_{re2}}{\mathscr{L} \cdot \frac{N_{mc1}+N_{mc2}}{N_{gen}} \cdot Br(D_s^+ \to K^+K^-\pi^+) \cdot (1+\delta_{ISR}) \cdot \delta_{VP}}$$

We'll only show the combined result in the following analysis

Counting method to get the signal event number

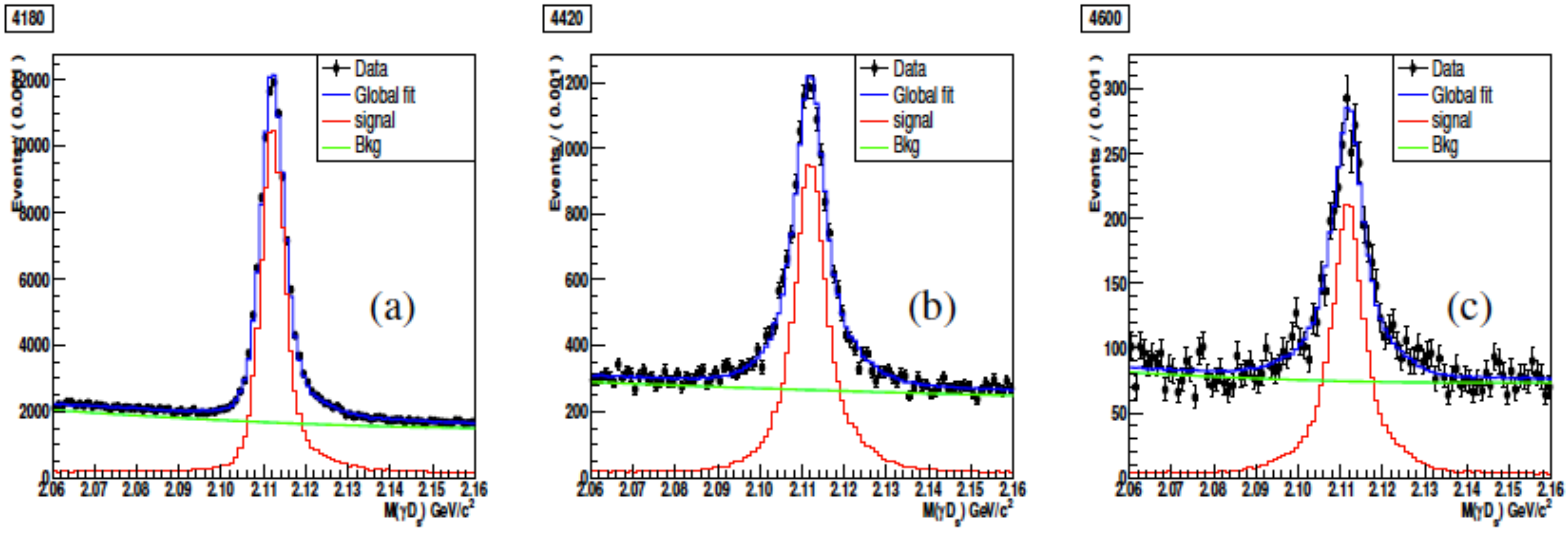




The event number in signal range [2.10, 2.124] GeV is Ns.
The event number in sideband range is [2.078, 2.09] & [2.134, 2.146] GeV is Nb.

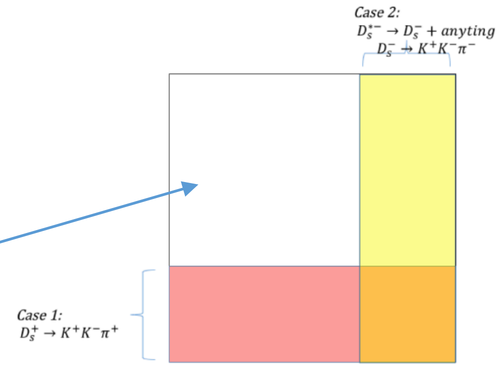
The signal event number Nsig= Ns-Nb.
The event number in most energy points is large enough, σ(Nsig)=$\sqrt{N_s + N_b}$

No bias for the signal peak position



The dots are realdata,
The red histogram is signal MC shape.
We can see the peak position are almost same for data and MC.

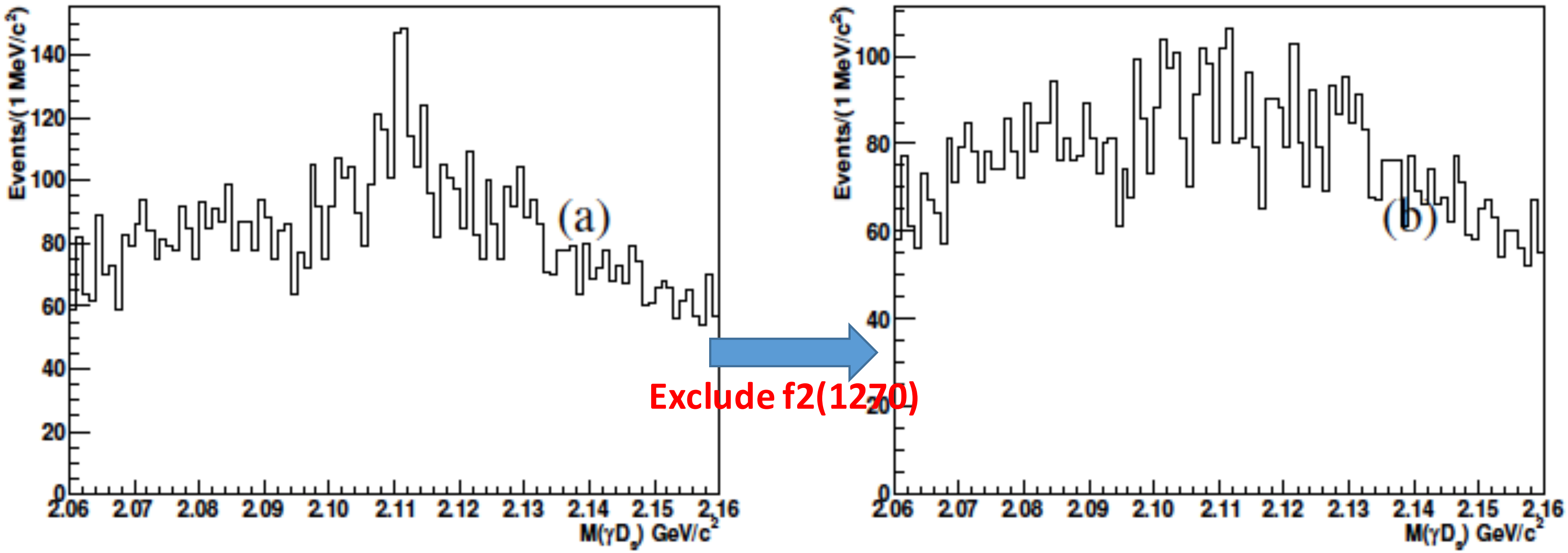
Background analysis



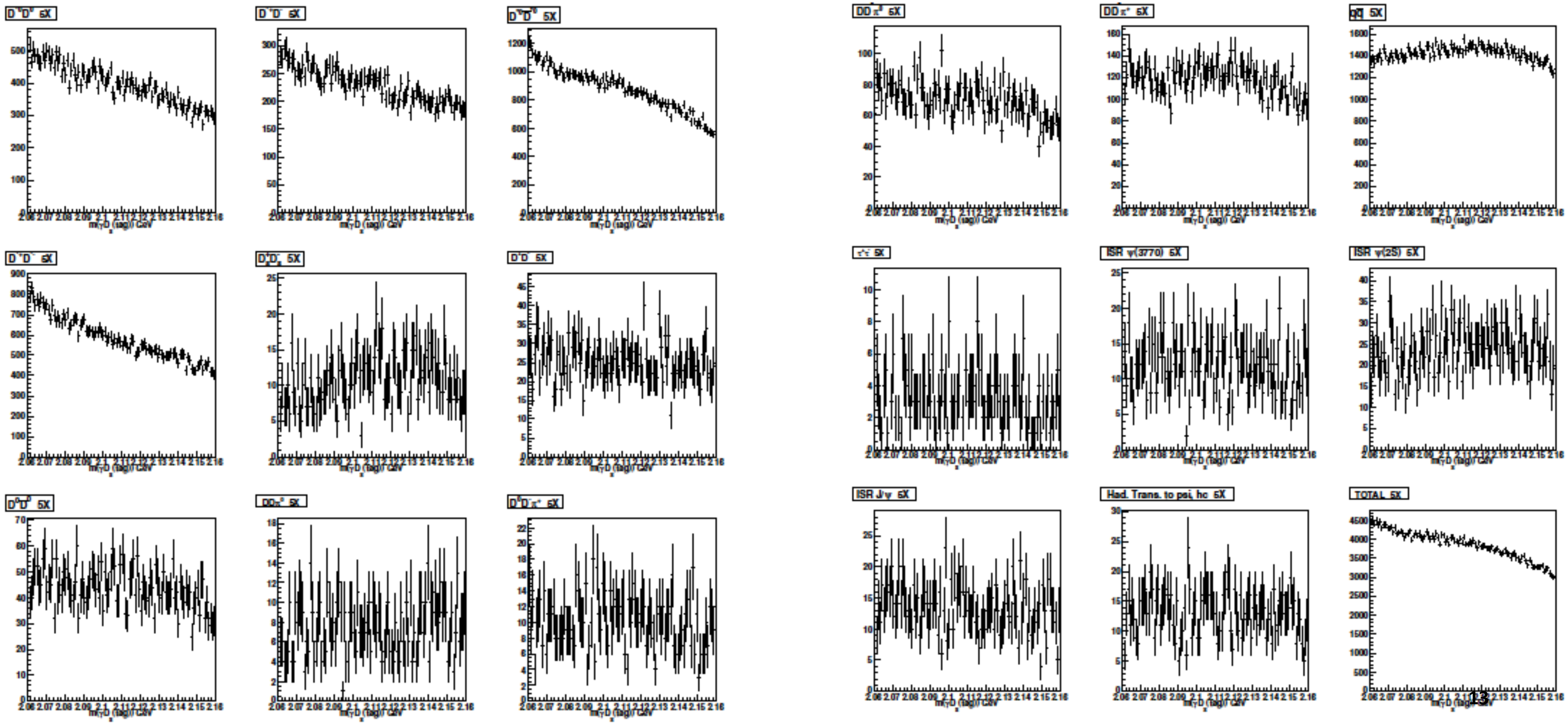
- **1. No peaking background from other Ds decay mode.**
- 8 Million $e^+e^- \to D_s^+ D_s^{*-}$ with Ds decay to anything but $K^+K^-\pi^+$ mode are generated.

This peak comes from

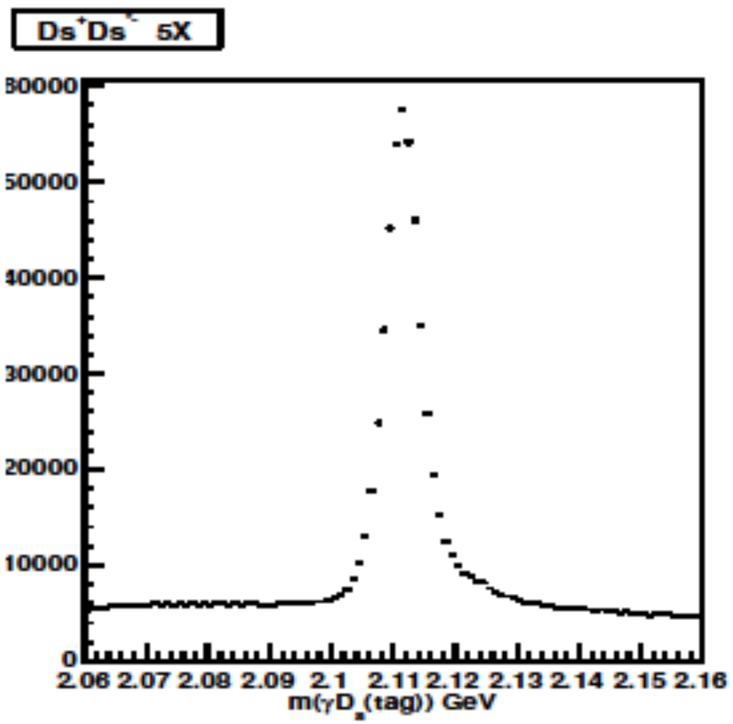
$$e^+e^- \to D_s^{*+}D_s^-, D_s^- \to \pi^- f_2(1270), f_2(1270) \to K^+K^-.$$

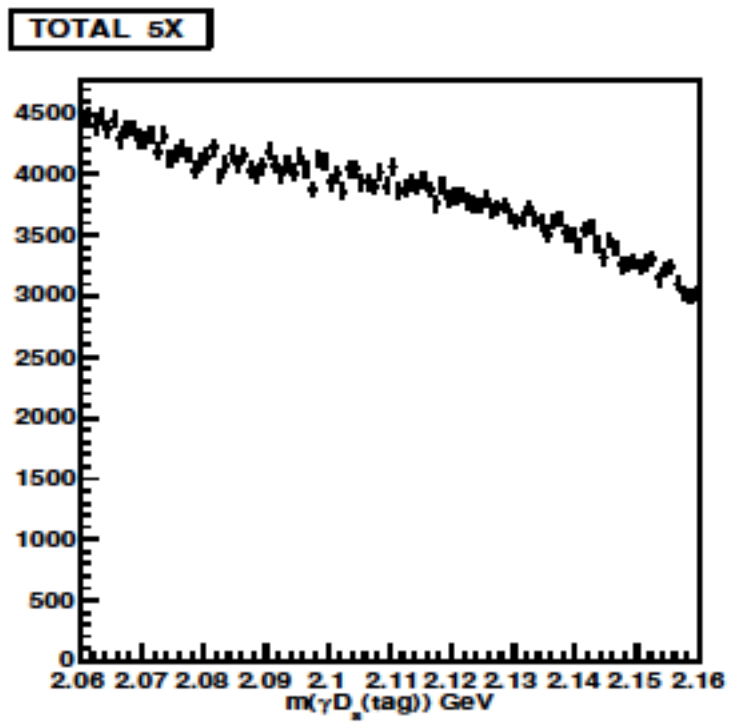


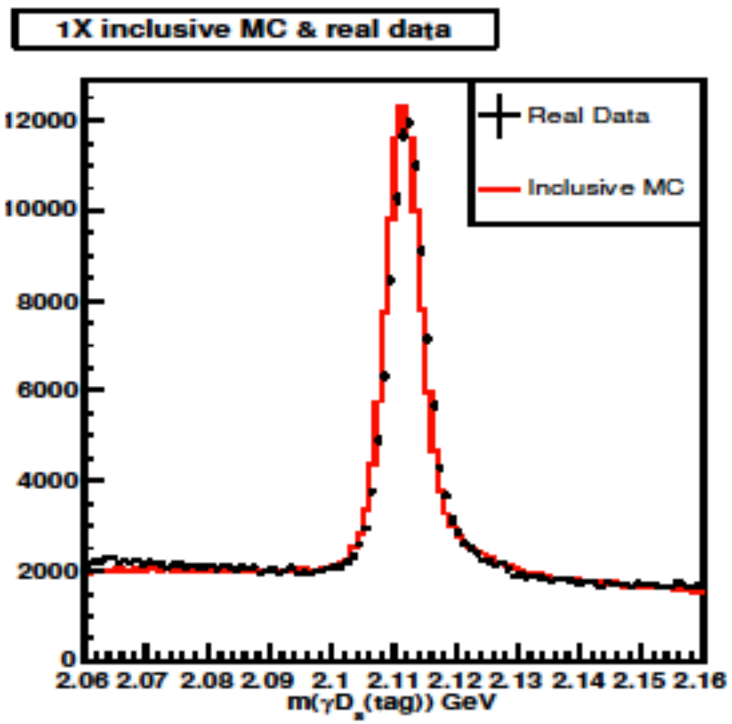
Background analysis with inclusive MC@4180



Background analysis with inclusive MC@4180







$e^+e^- \rightarrow D_s^+ D_s^{*-}$
About 5 times of luminosity @4180

The sum of all the inclusive Background events, 5times of luminosity@4180

The background is generally flat

Comparison between data and The inclusive MC.

Agreement is good.

Background analysis for exclusive channels

- **Although the inclusive background is generally flat, some exclusive channels have non-flat distribution at some energy points.**

➢ **The first channel is** $e^+e^- \rightarrow D_s^+ D_s^{*-}$, $D_s^{*-} \rightarrow \pi^0 D_s^-$

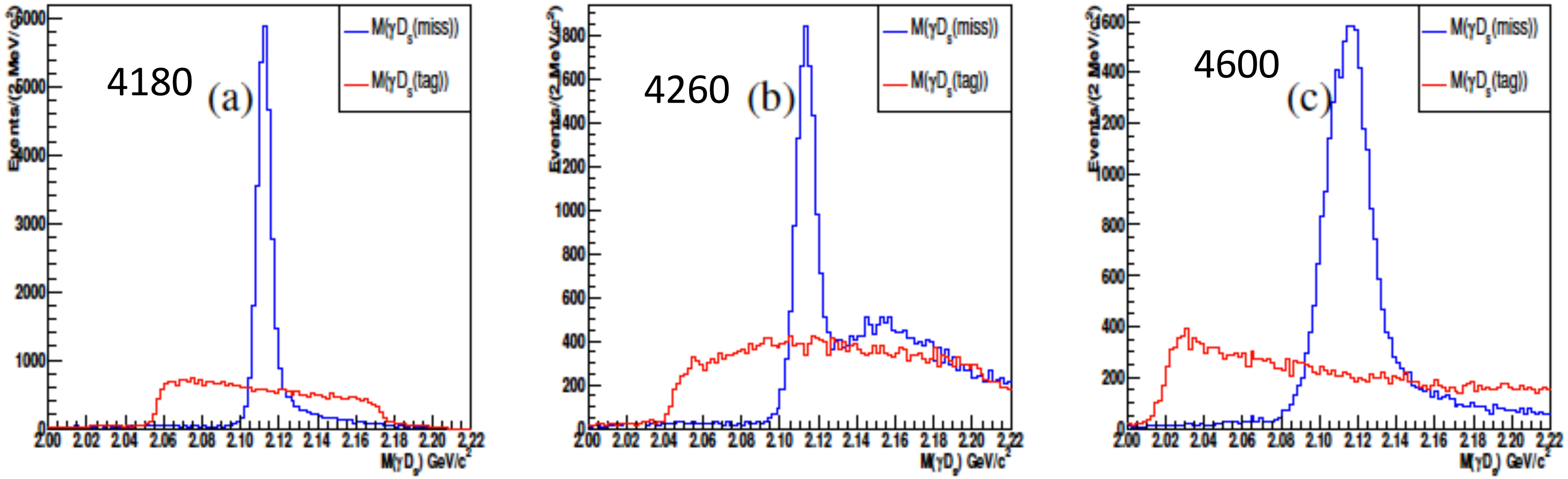


Figure 7: $e^+e^- \rightarrow D_s^+ D_s^{*-}$, $D_s^{*-} \rightarrow \pi^0 D_s^-$, with $D_s^+ \rightarrow K^+K^-\pi^+$ being tagged.

Case 1:
$e^+e^- \rightarrow D_s^+ D_s^{*-}$,
$D_s^{*-} \rightarrow \pi^0 D_s^-$
D_s^+ is tagged

When the D_s^+ is tagged, we can see M(γDs(miss)) will form a Ds* signal peak, that's why we include the $D_s^{*-} \rightarrow \pi^0 D_s^-$ into signal MC.

Background caused by $e^+e^- \rightarrow D_s^+D_s^{*-}$, $D_s^{*-} \rightarrow \pi^0 D_s^-$

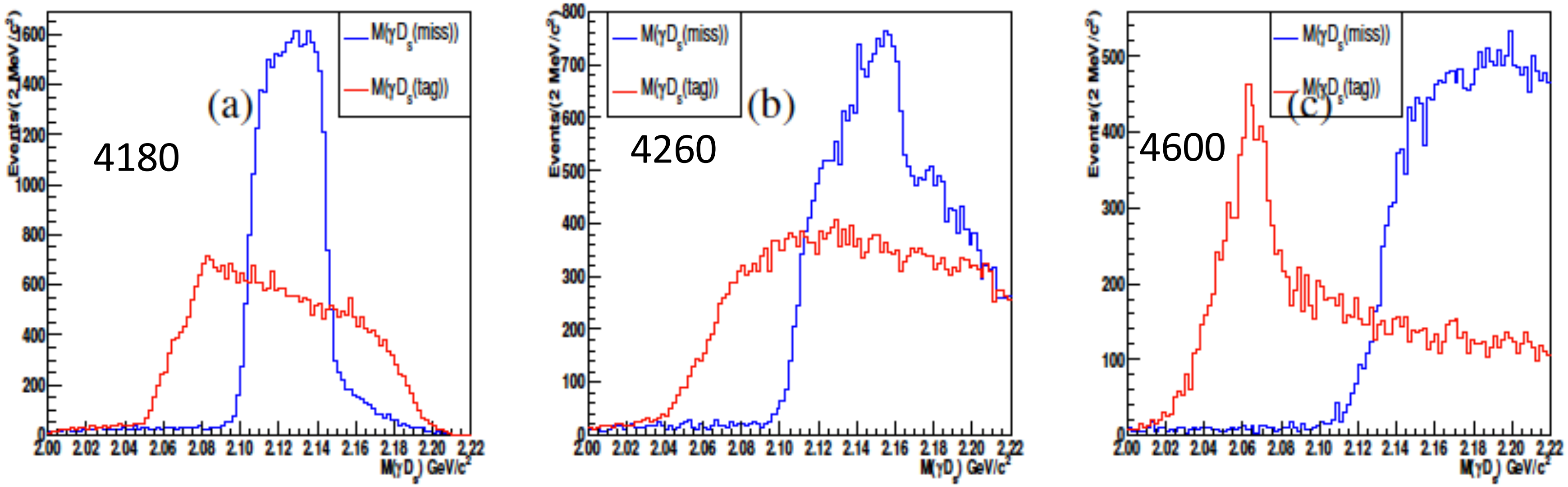


Figure 8: $e^+e^- \to D_s^+ D_s^{*-}$, $D_s^{*-} \to \pi^0 D_s^-$, with $D_s^- \to K^+K^-\pi^-$ being tagged.

Case 2:

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

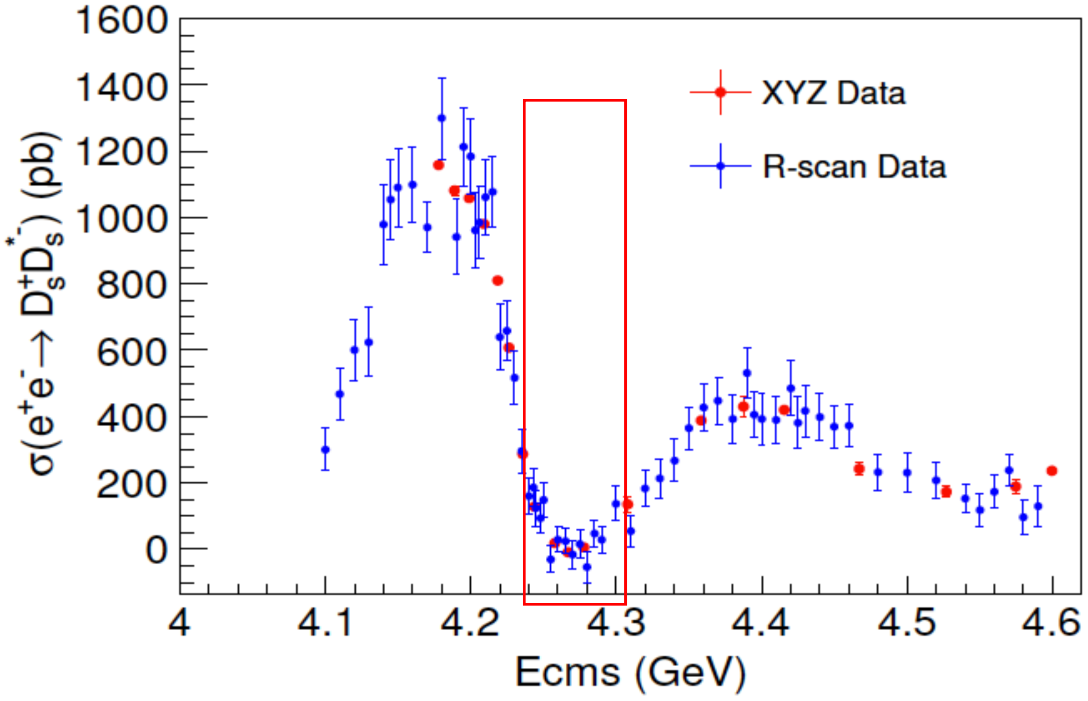
$D_s^{*-} \rightarrow \pi^0 D_s^-$

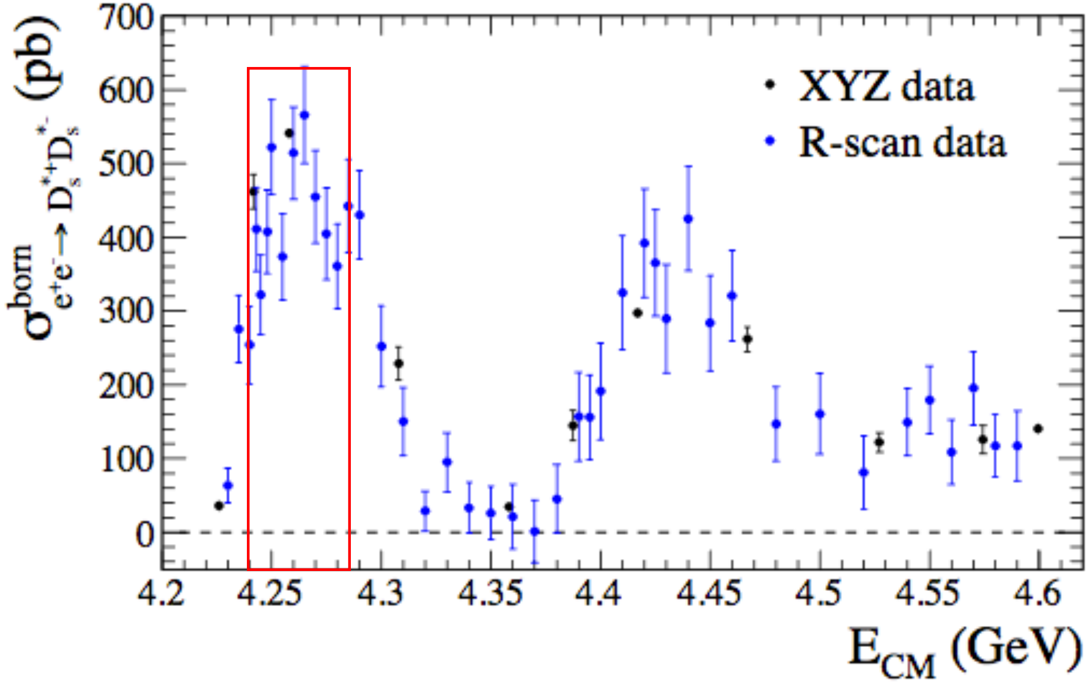
D_s^- is tagged

For case 2 MC, the blue line which is M(γDs(miss)) is not counted in getting signal MC but will be counted in data, This will cause some bias to the efficiency.

Since the fraction of $D_s^{*-} \rightarrow \pi^0 D_s^-$ is only 5.8% and the selection efficiency is much lower compere with $D_s^{*-} \rightarrow \gamma D_s^-$. largest bias occurs at 4180 which is 0.34%.

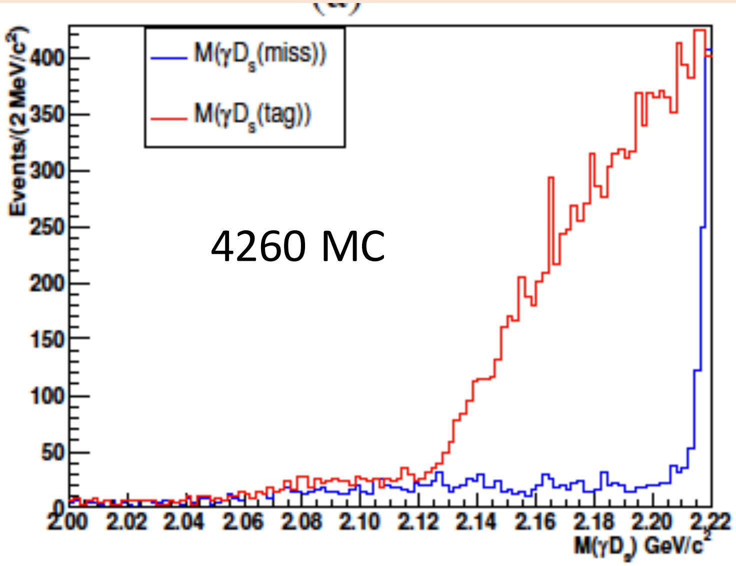
Background caused by $e^+e^- \rightarrow D_s^{*+}D_s^{*-}$

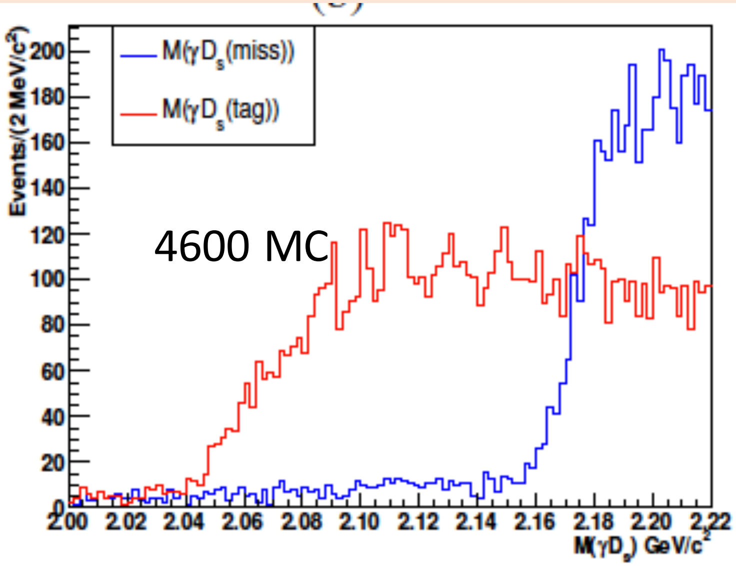




From the preliminary cross section, we can see around 4.26GeV, the cross section of $e^+e^- \rightarrow D_s^+D_s^{*-}$ almost vanish. While $e^+e^- \rightarrow D_s^{*+}D_s^{*-}$ arrive at the peak.

Background caused by $e^+e^- \rightarrow D_s^{*+}D_s^{*-}$



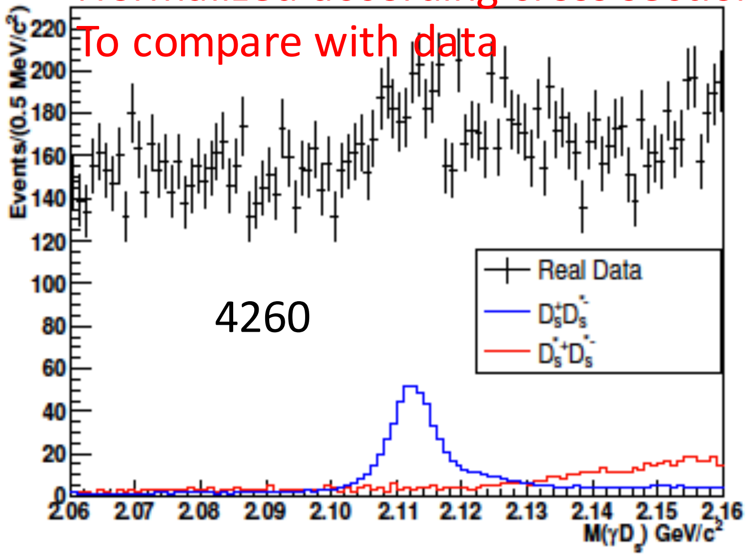


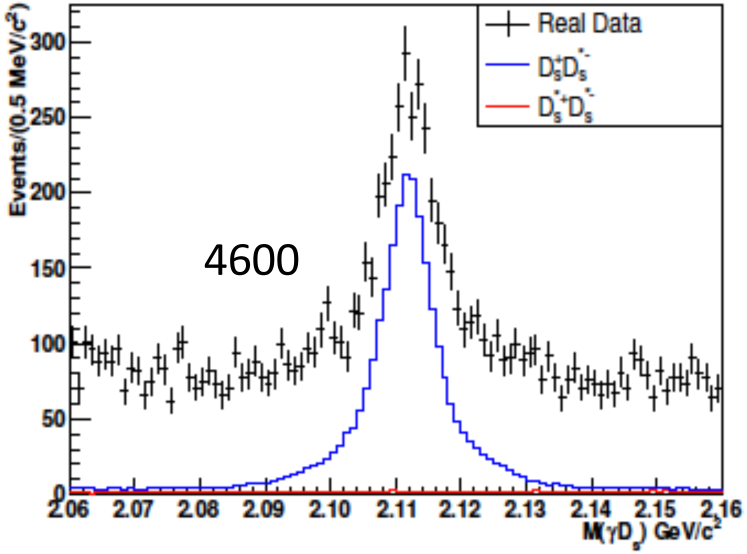
We can see at 4260, the influence of Ds*Ds* background is significant, Causing bias about 17%.

At other energy points where DsDs* and Ds*Ds* has comparable cross section, The bias is about 0.3%.

Figure 5: $e^+e^- \rightarrow D_s^{*+}D_s^{*-}$

Normalized according cross section
To compare with data

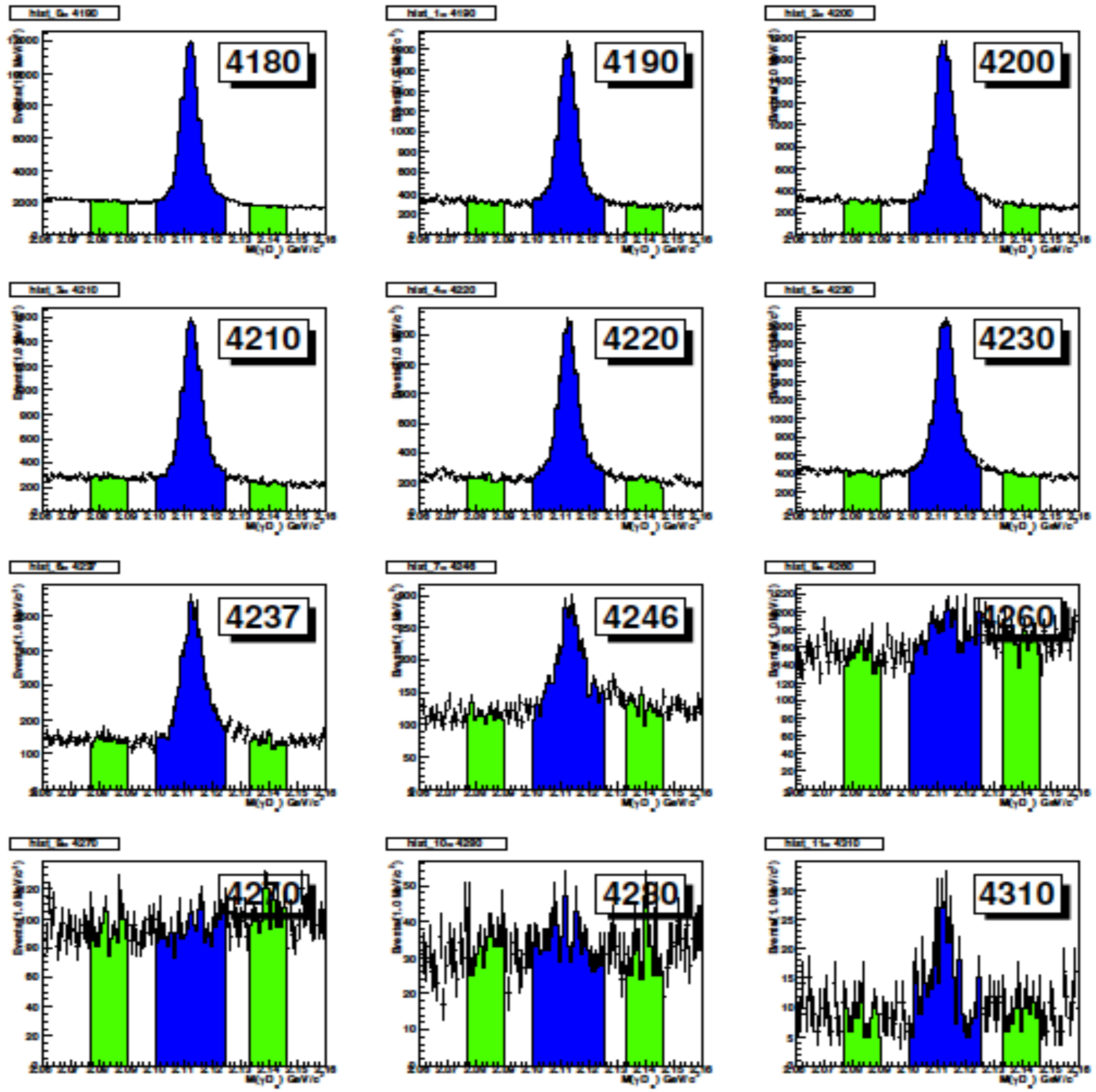


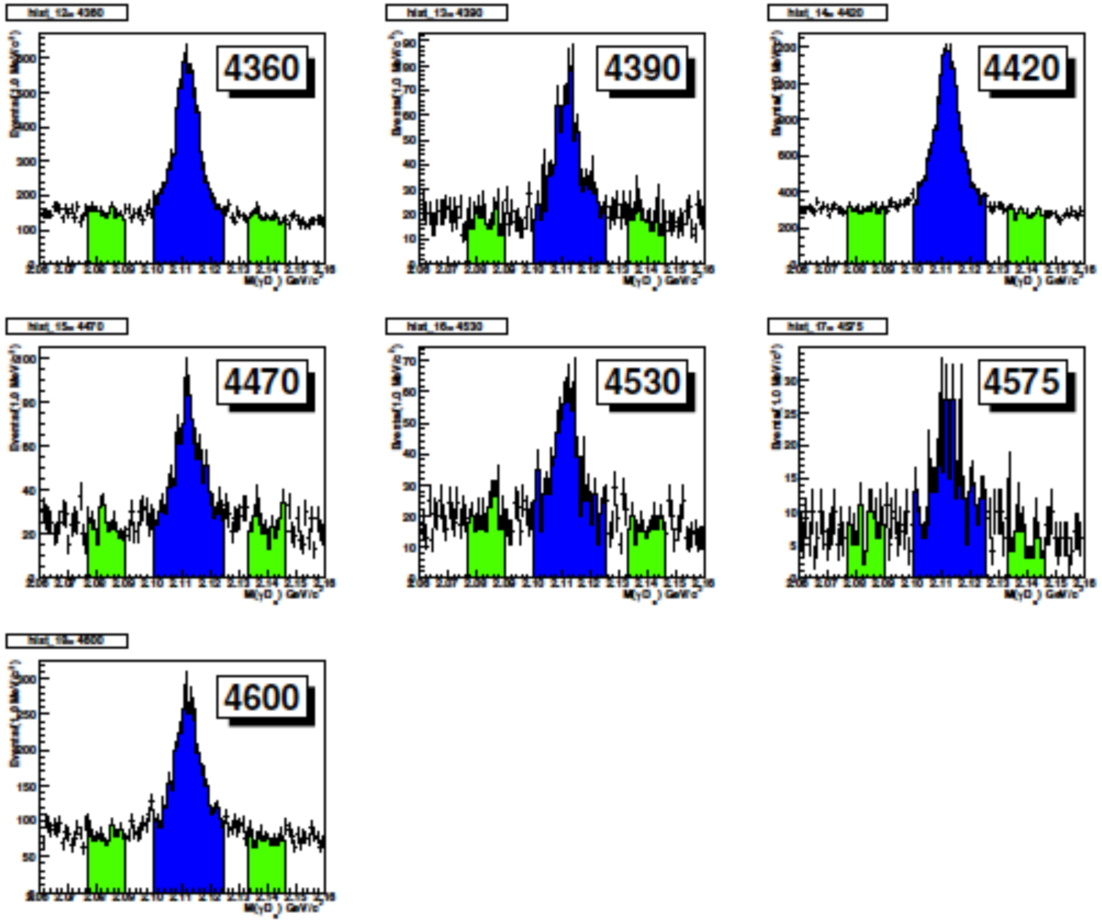


But what we care should be the combined Contribution of all the background.

We can't generate inclusive MC at all energy Points. So we can only check this with realdata.

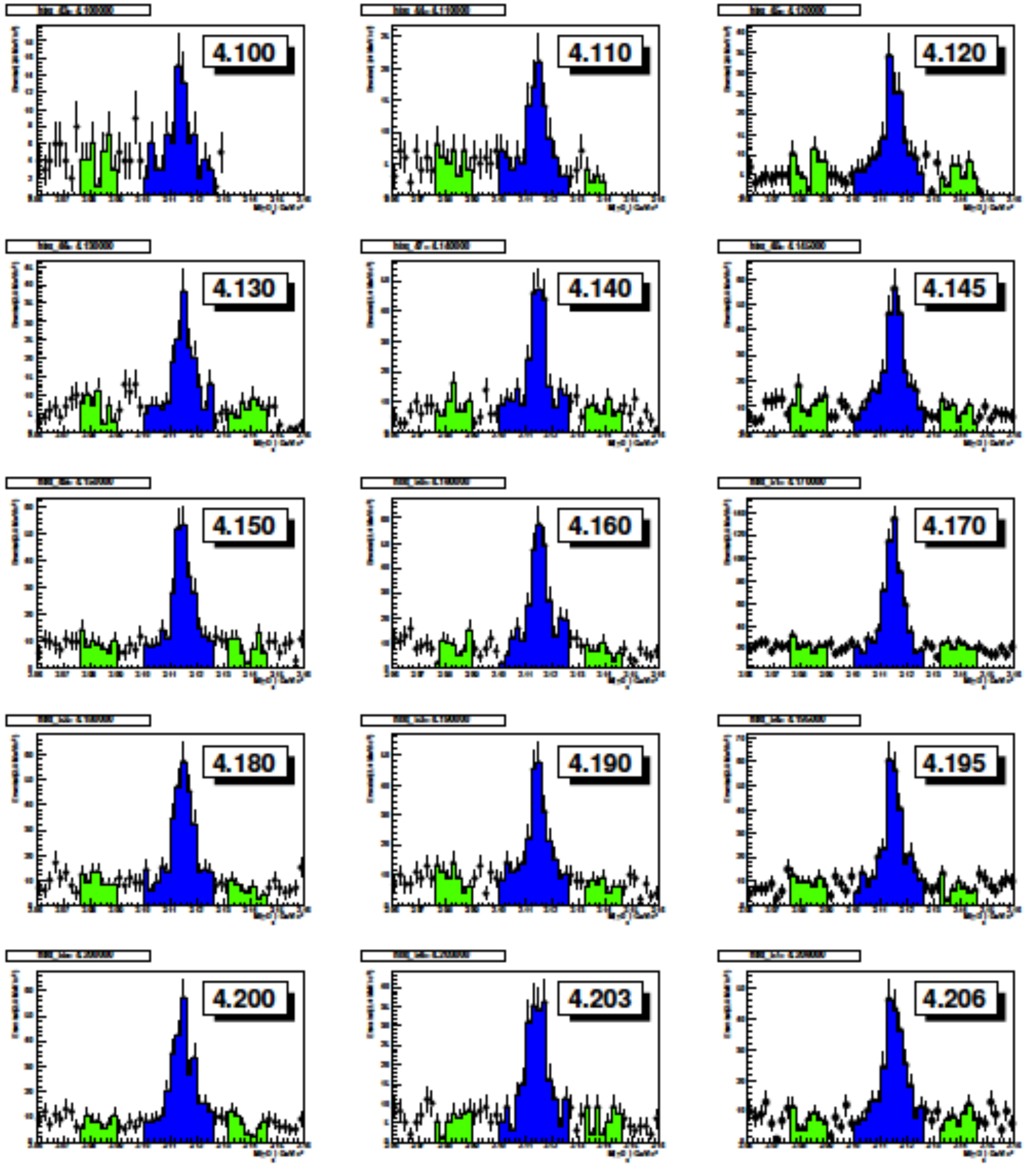
M(γDs) @XYZ data points

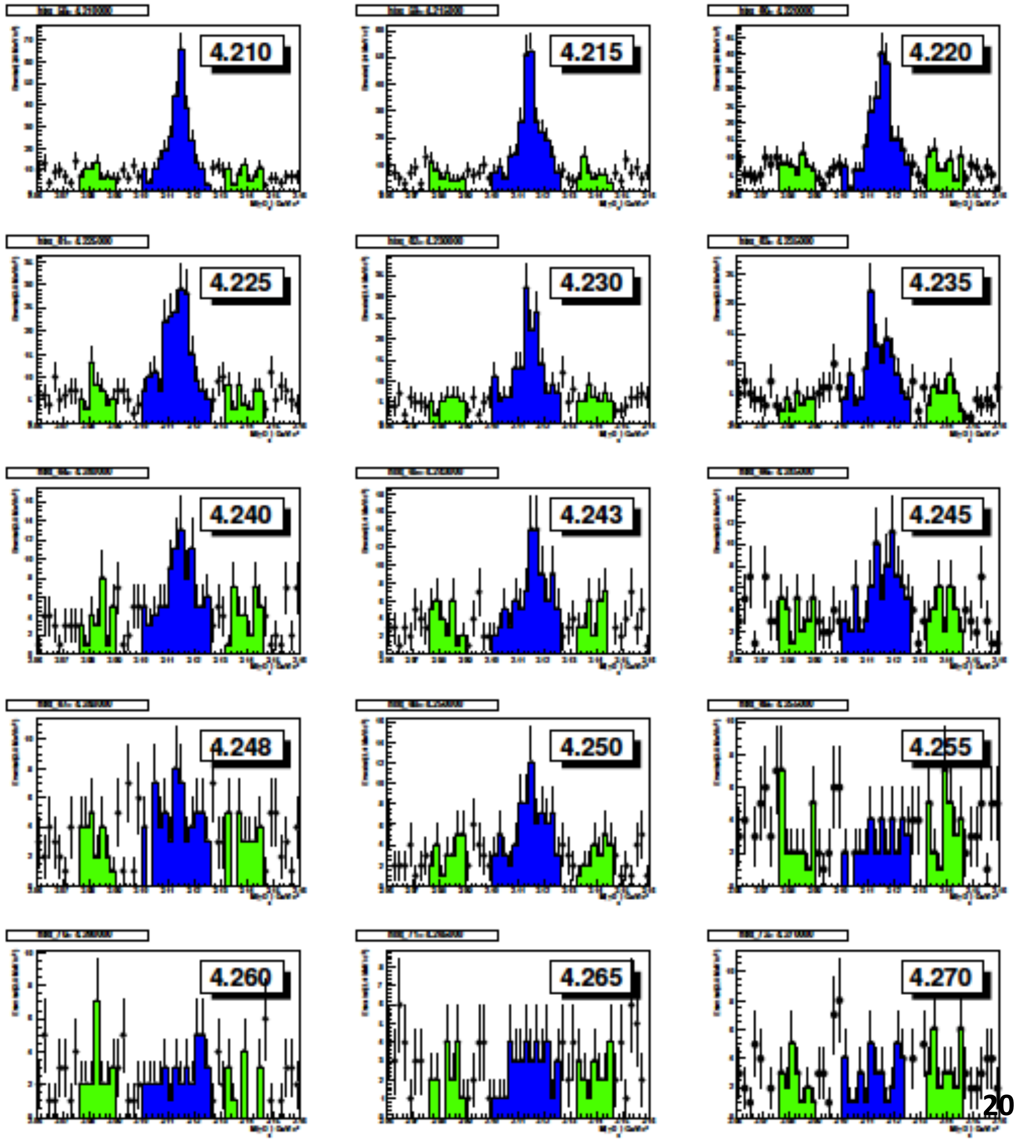




At most of the energy points the signal event number is Large enough and the background is flat.

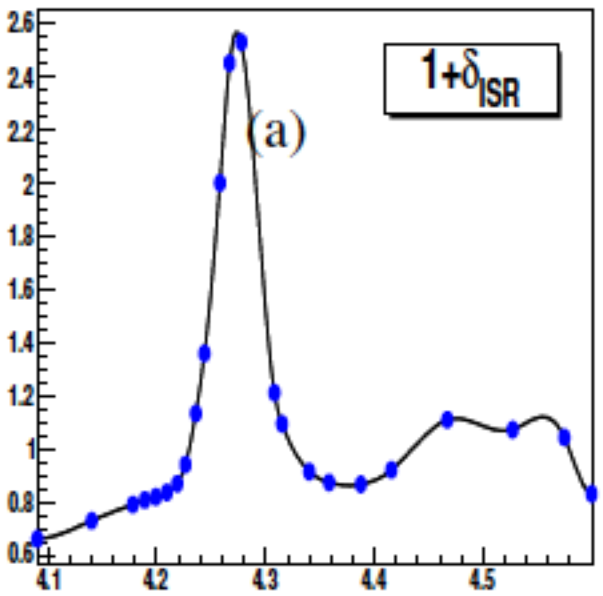
M(γDs) @R-scan data points (part)

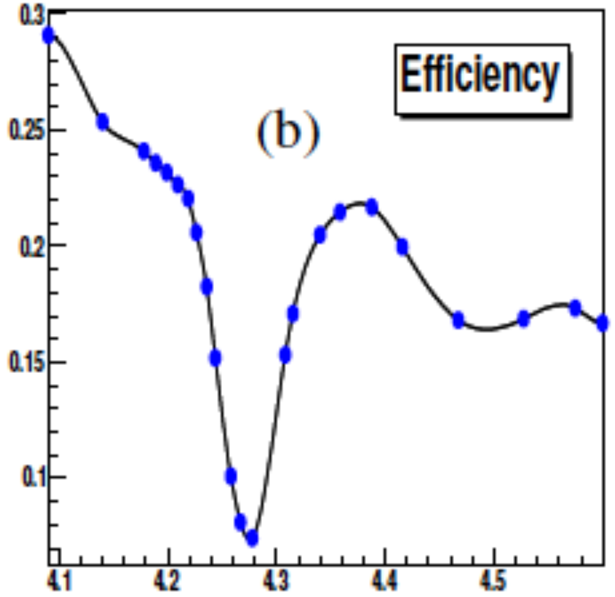


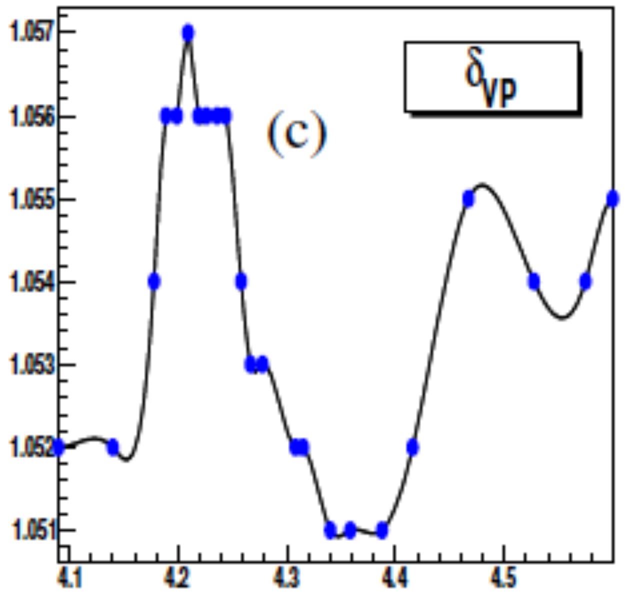


Interpolate for R-scan data

- We only generate MC samples at XYZ data points.
- We didn't generate MC samples for R-scan data, the needed ISR correction factor, efficiency, and vacuum polarization factor are gotten by Cubic Spline Interpolation. Besides the XYZ data points, we also generate MC at 4.09, 4.14, 4.315, 4.340GeV as reference nodes to reduce the distance between adjacent nodes.







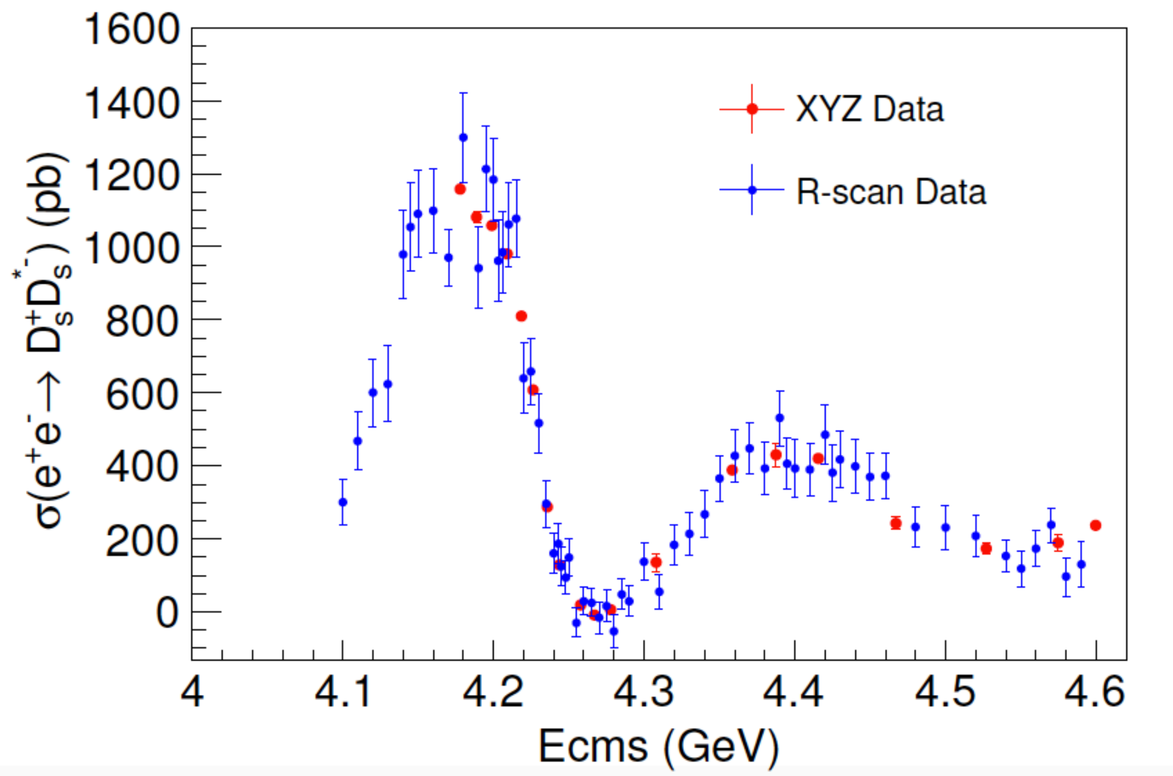
The cross section for XYZ data

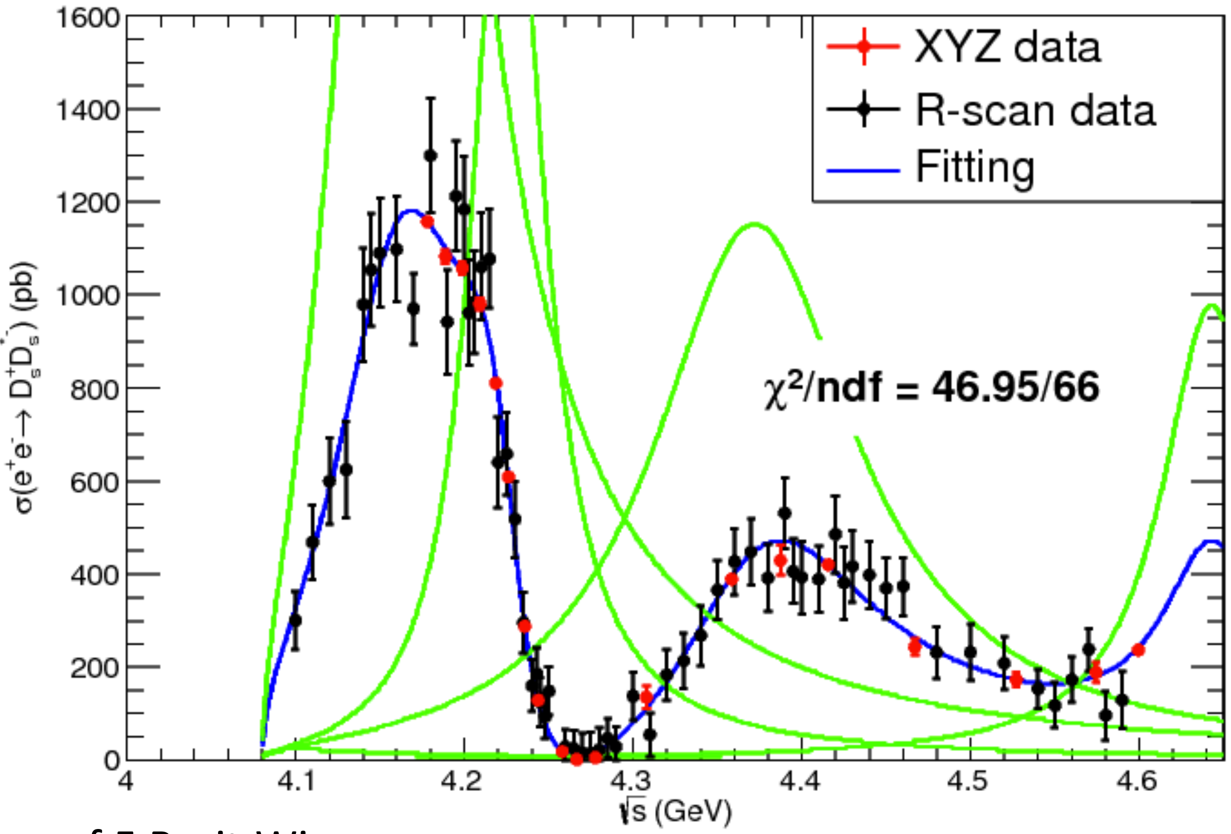
$E_{cms}(GeV)$	Luminosity(pb^{-1})	N_{sig}	Efficiency	$1+\delta_{ISR}$	δ_{VP}	$\sigma(D_sD_s^*)pb$
4.178	3160	40052±207	0.241	0.791	1.054	1157.98±5.98
4.1888	524.6	6217±81.5	0.236	0.807	1.056	1081.95±14.18
4.1989	526	6077.5±80.5	0.232	0.819	1.056	1057.87±14.01
4.2092	518	5548.5±76.5	0.227	0.837	1.057	980.78±13.52
4.2187	514.6	4596±70	0.220	0.869	1.056	810.04± 12.34
4.22626	1100.94	7470.5±92.5	0.206	0.941	1.056	608.50± 7.53
4.2357	530.3	1816.5±51	0.183	1.133	1.056	287.60± 8.07
4.2438	538.1	822±43	0.152	1.36	1.056	128.55± 6.72
4.25797	828.4	183.5±44.5	0.101	2.001	1.054	19.10± 4.63
4.2668	531.1	-54±33.5	0.081	2.454	1.053	-8.92± 5.53
4.2777	175.7	10.5±19.5	0.074	2.531	1.053	5.55±10.30
4.30789	45.08	65±12	0.153	1.212	1.052	135.48± 25.01
4.35826	543.9	2271.5±53	0.215	0.874	1.051	388.72± 9.07
4.3874	55.57	257±19	0.217	0.866	1.051	430.09± 31.80
4.41558	1090.7	4825.5±76.5	0.200	0.921	1.052	419.76± 6.65
4.46706	111.09	289.5±20.5	0.168	1.109	1.055	243.14± 17.22
4.52714	112.12	202±18	0.169	1.073	1.054	173.23± 15.44
4.5745	48.93	96±11	0.173	1.044	1.054	188.83± 21.64
4.59953	586.9	1110.5±38	0.167	0.831	1.055	237.37± 8.12

With statistical uncertainty only

The cross seciton for R-scan data can be Found in backup slides

The Born cross section for $e^+e^- \rightarrow D_s^+ D_s^{*-}$





A very preliminary fit to the cross section with coherent sum of 5 Breit-Wigner.

$\psi(4040)$ and Y(4660) are fixed to PDG mass and width. Parameters of the other 3 are free in the fit.

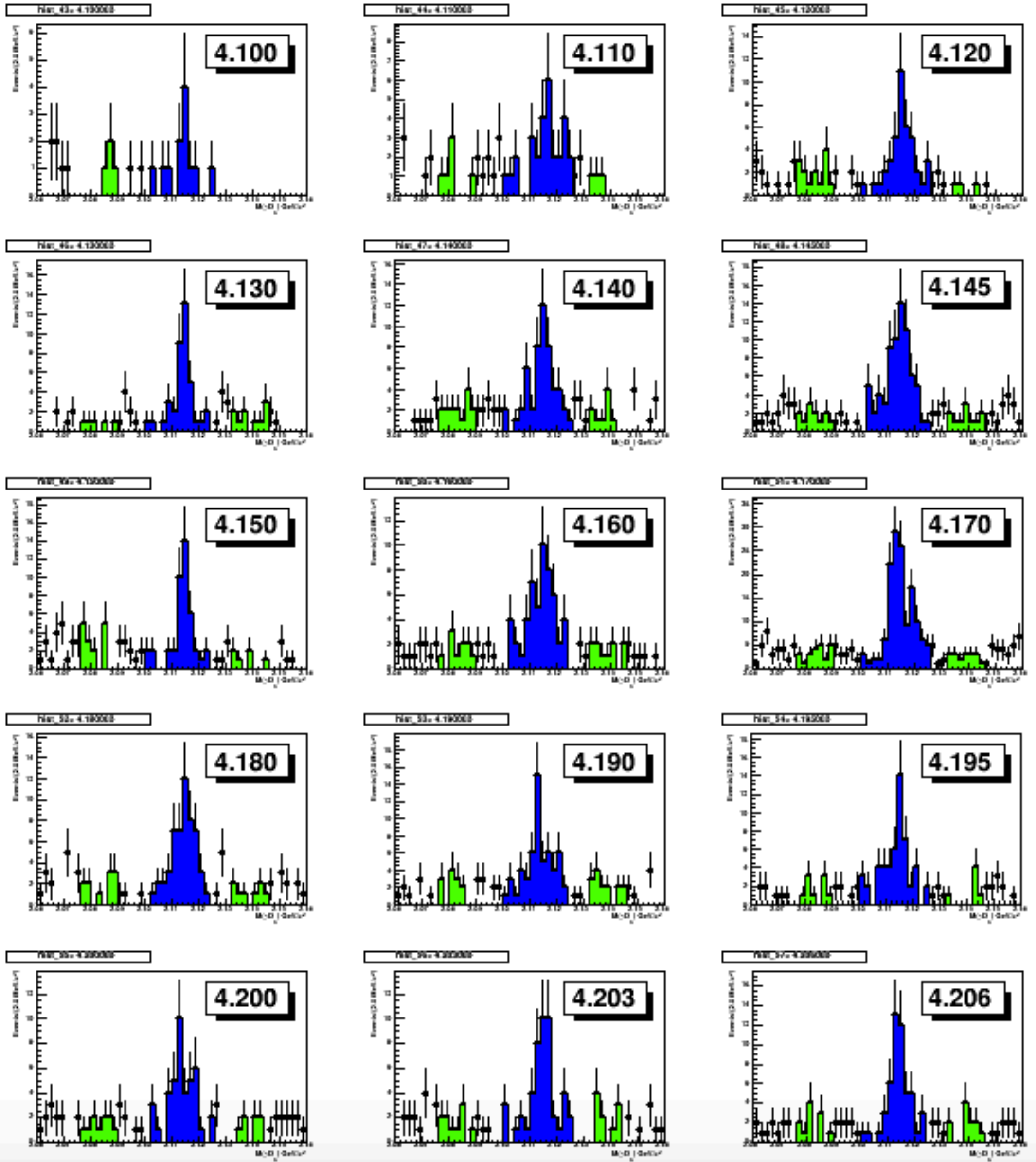
M1=4160.3$\pm$1.8 MeV, Γ1=94.7$\pm$2.3 MeV

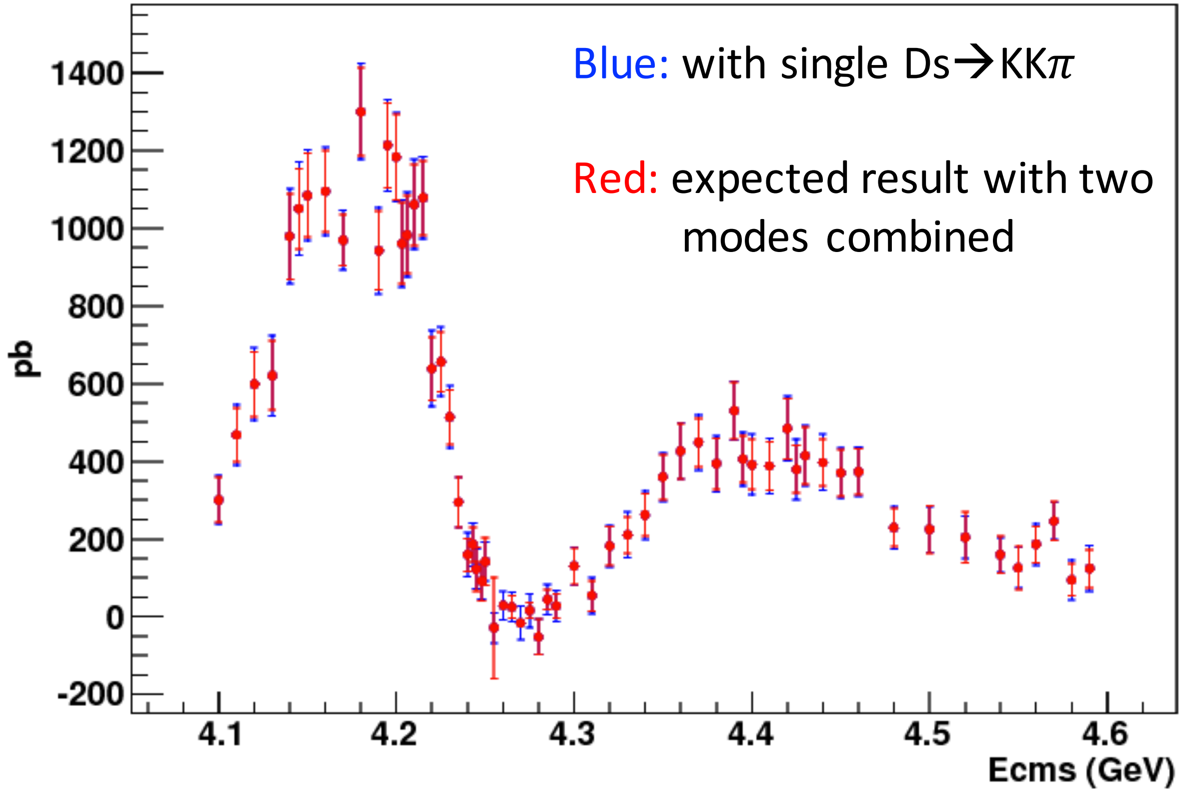
M2=4225.0$\pm$0.6 MeV, Γ2=49.2$\pm$1.3 MeV

M3=4369.2$\pm$2.7 MeV, Γ3=146.7$\pm$5.9 MeV

Other Ds decay mode?

Real data for r-scan data for $D_s^+ \to K^+ K_s^0$



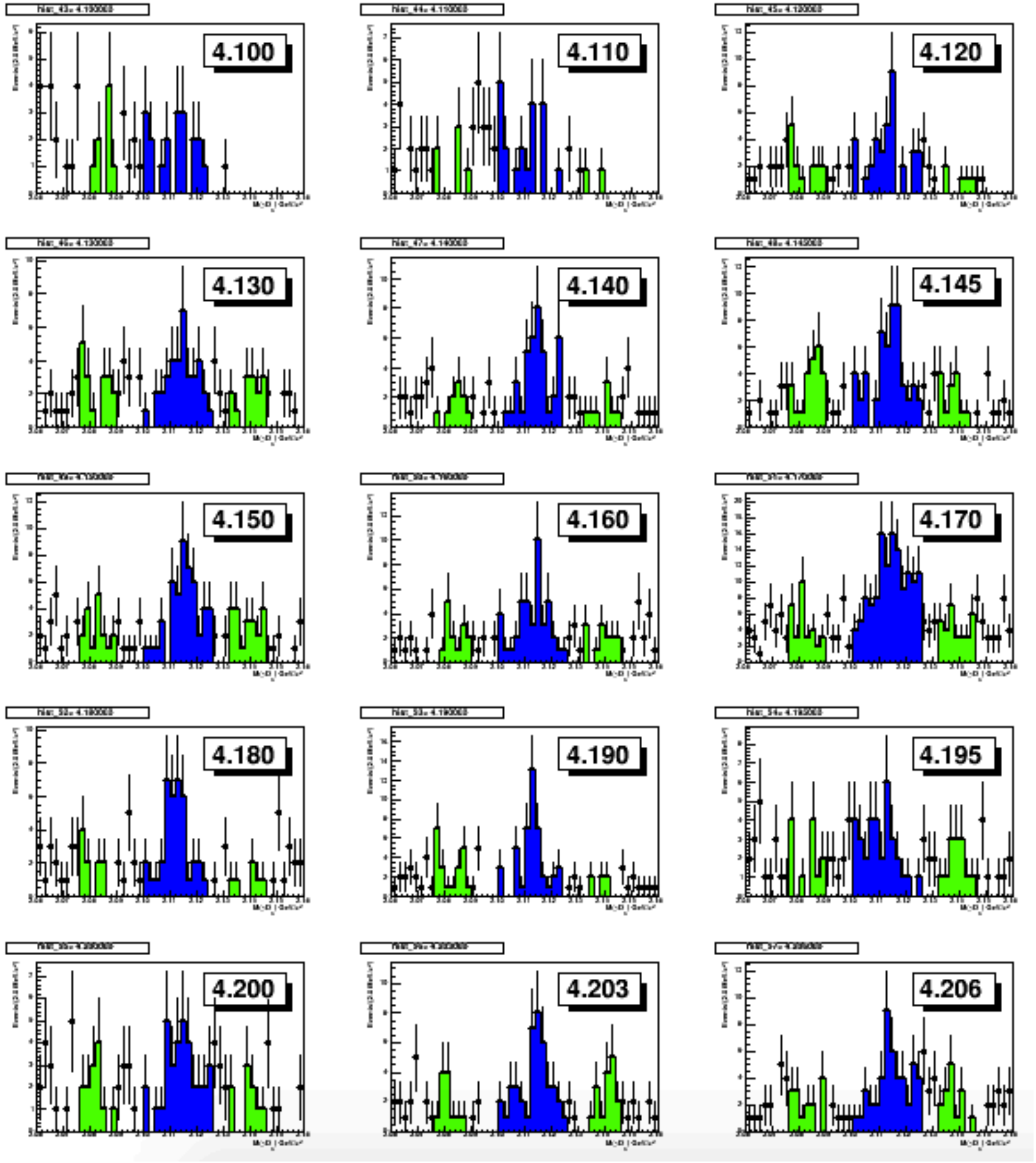


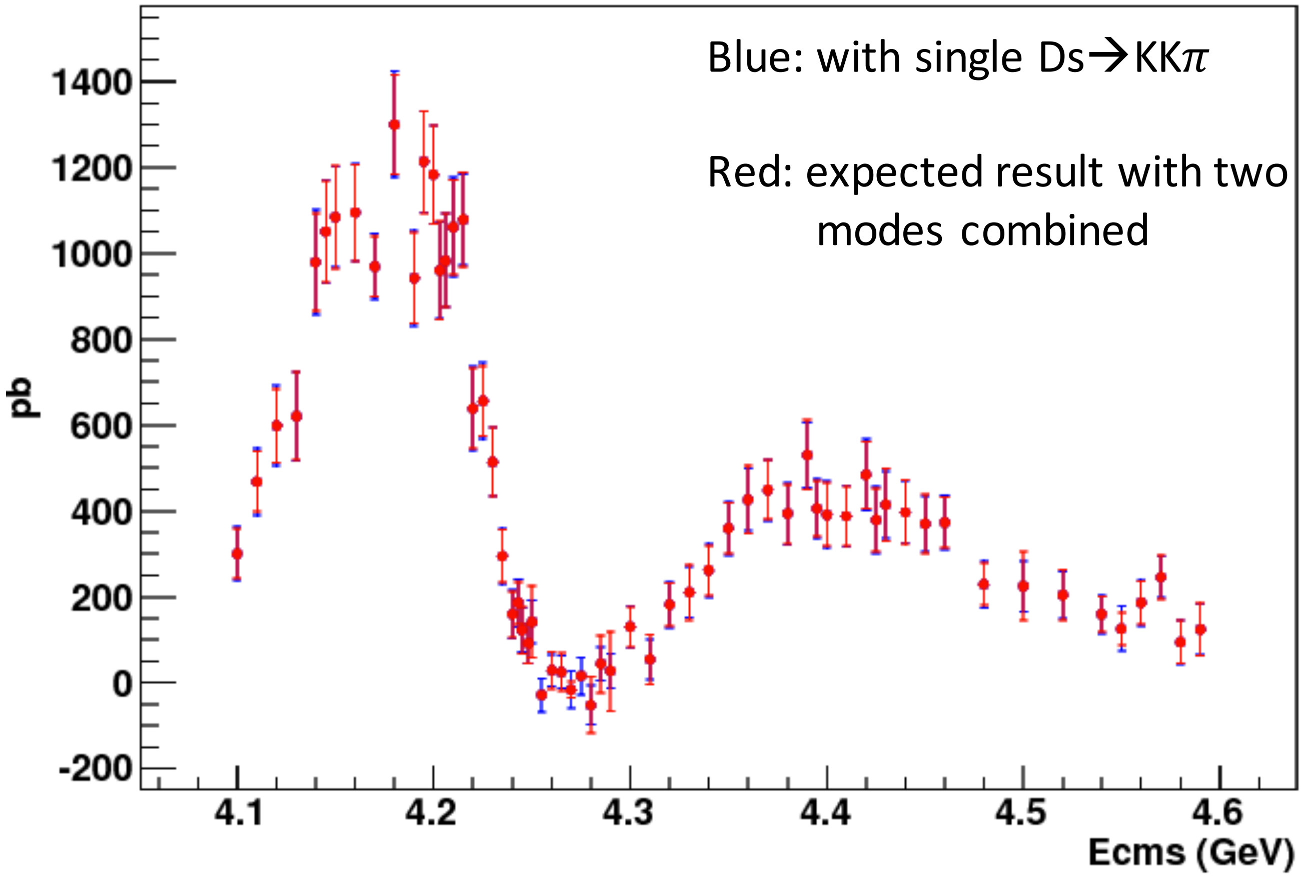
$D_s^+ \to K^+ K_s^0$ has about 25% statistical of the Ds→KKπ

Combining the two channels would reduce the relative uncertainty by ~10%.
Currently, we didn't consider this mode

$D_s^+ \to K_S^0 K^- \pi^+ \pi^+$

Real data for r-scan data





The statistical is too low, background is too high.
Including this mode don't have significant improvement
To the uncertainty

Summary

- We have finished the event selection and background analysis, and get the preliminary cross section.
- Next to do

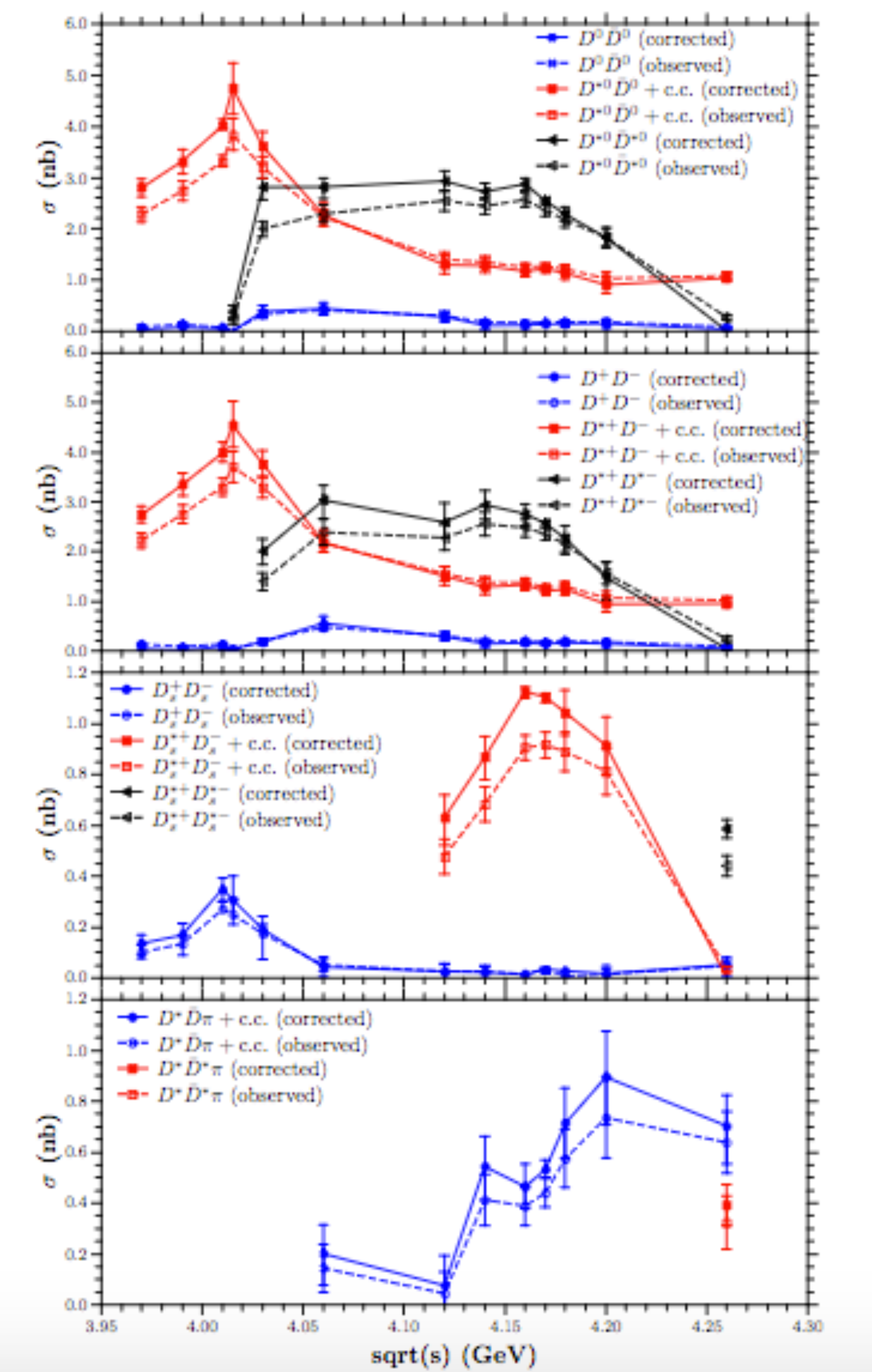
➢Systematic uncertainty

  - Kinematic fit uncertainty
  - Non-flat background(try use fitting instead of counting?)

➢Include new XYZ data taken@2019

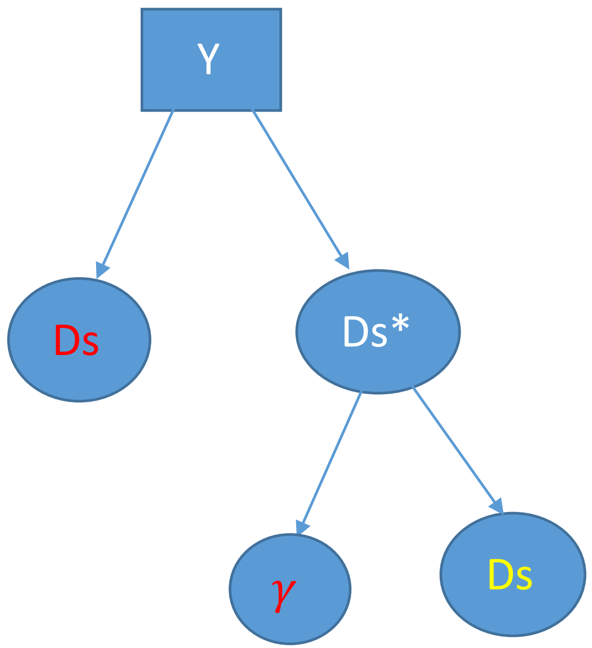
The born cross section @ R-scan data

Ecms	crosssection	uncertainty
4.1	300.744	62.655
4.11	468.382	78.8435
4.12	600.214	93.3352
4.13	624.21	104.035
4.14	979.034	121.471
4.145	1053.89	120.529
4.15	1090.56	117.532
4.16	1098.52	113.905
4.17	969.795	76.307
4.18	1299.04	123.336
4.19	942.186	111.692
4.195	1212.65	118.318
4.2	1183.85	114.92
4.203	961.758	112.339
4.206	984.292	109.687
4.21	1060.69	115.241
4.215	1077.63	106.392
4.22	639.87	97.6258
4.225	658.539	89.1667
4.23	517.27	81.0498
4.235	295.266	65.1936
4.24	160.118	56.3763
4.243	186.219	55.4428
4.245	124.239	52.8267
4.248	94.199	47.2948
4.25	148.543	52.4009
4.255	-29.7635	40.2999
4.26	29.1528	37.0035
4.265	25.2057	38.7217
4.27	-15.7156	43.5145
4.275	16.1638	44.1022
4.28	-52.9845	46.1908
4.285	47.1846	41.6129
4.29	29.2719	41.9678
4.3	137.484	51.2676
4.31	54.7997	47.1405
4.32	183.205	53.5589
4.33	213.819	59.5247
4.34	267.642	64.6783
4.35	365.784	63.4335
4.36	426.89	71.589
4.37	447.671	71.1819
4.38	392.278	72.137
4.39	530.683	75.6967
4.395	406.13	69.6507
4.4	392.694	77.9917
4.41	389.428	71.689
4.42	485.582	83.4243
4.425	381.761	77.9264
4.43	416.827	77.3596
4.44	398.495	71.7579
4.45	369.763	65.5675
4.46	373.032	62.6017
4.48	231.995	55.6305
4.5	231.378	60.889
4.52	207.84	55.8914
4.54	153.186	42.2201
4.55	117.707	48.8198
4.56	173.027	49.5569
4.57	237.701	46.5791
4.58	96.0864	52.3539
4.59	129.439	61.8597



Arxiv:1711.07311

Derived born cross section from CLEO-c measurement.


Y
Ds
Ds*
γ
Ds