Inclusive Production Of Charmonium Mesons above 4 GeV

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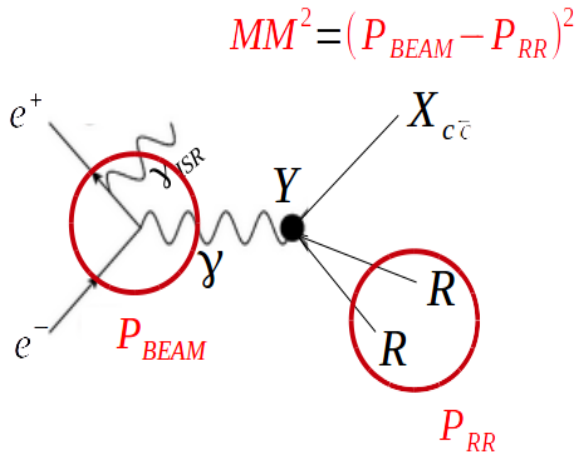
Motivation : The recoil mass technique

- Improve our understanding of the Y-Charmonium like states using the recoil mass technique



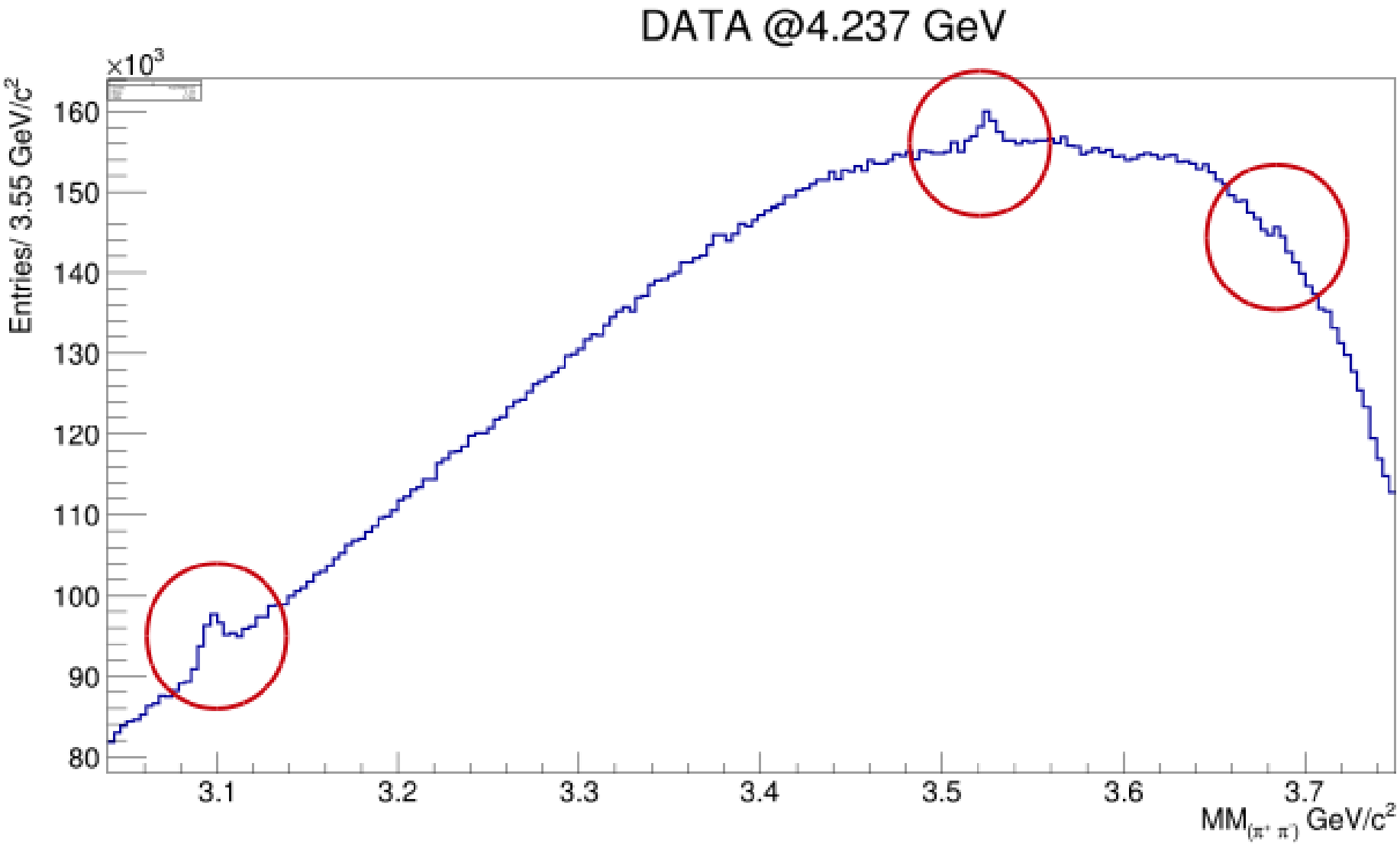
→ Different recoil systems are being investigated :

$\pi^+\pi^-$ $\pi^0\pi^0$ K^+K^- $\eta\eta$
K_sK_s $K^\pm\pi^\mp$ $K_s\pi^0$ η

- Analysis of $e^+e^- \to J/\psi\pi^+\pi^-$
- Analysis of $e^+e^- \to h_c\pi^+\pi^-$

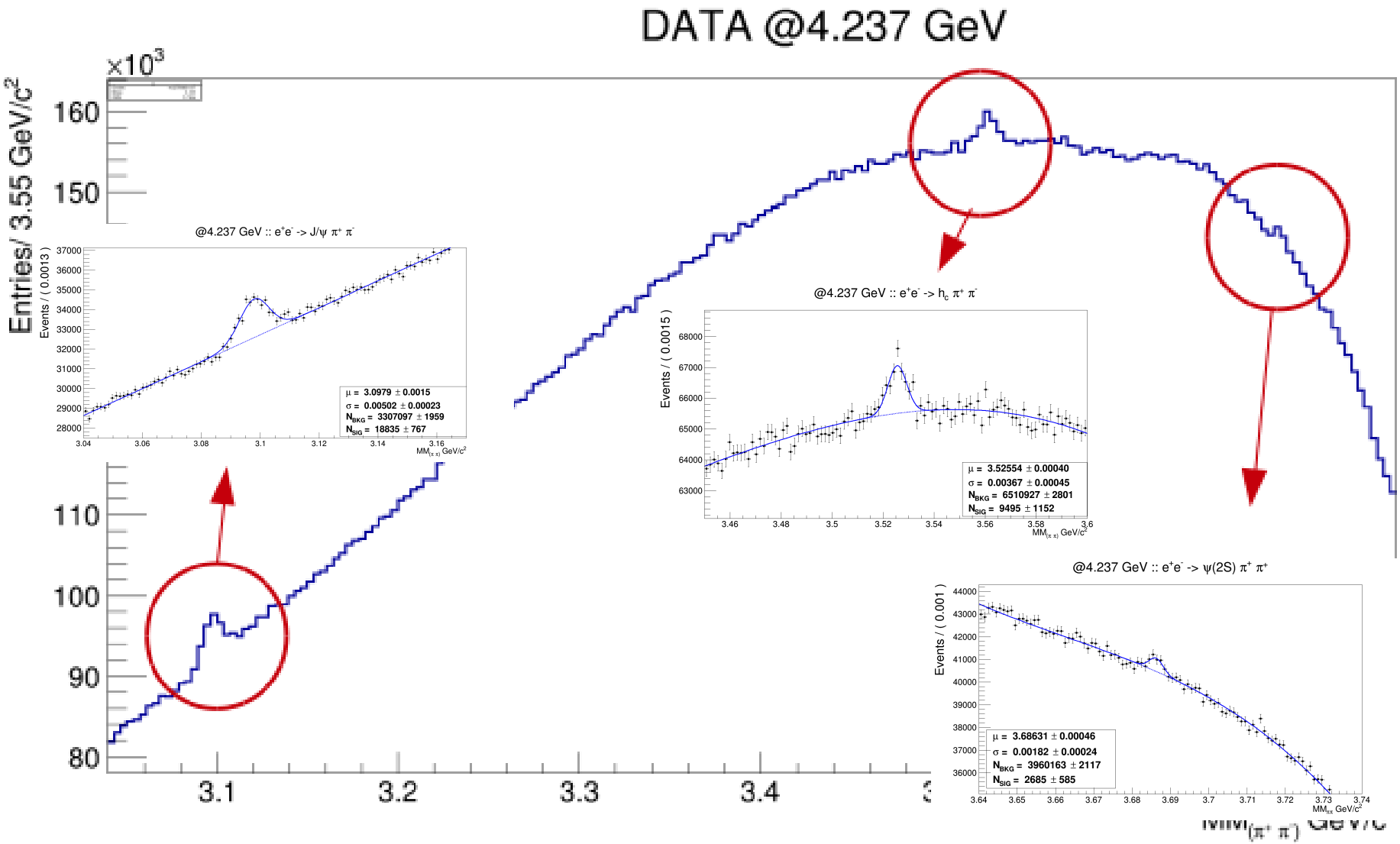
Reminder : Analysis of $e^+e^- \to X_{c\bar{c}}\pi^+\pi^-$

Observation of $J/\psi, h_c, \psi(2S)$ in the missing mass recoiling against $\pi^+\pi^-$



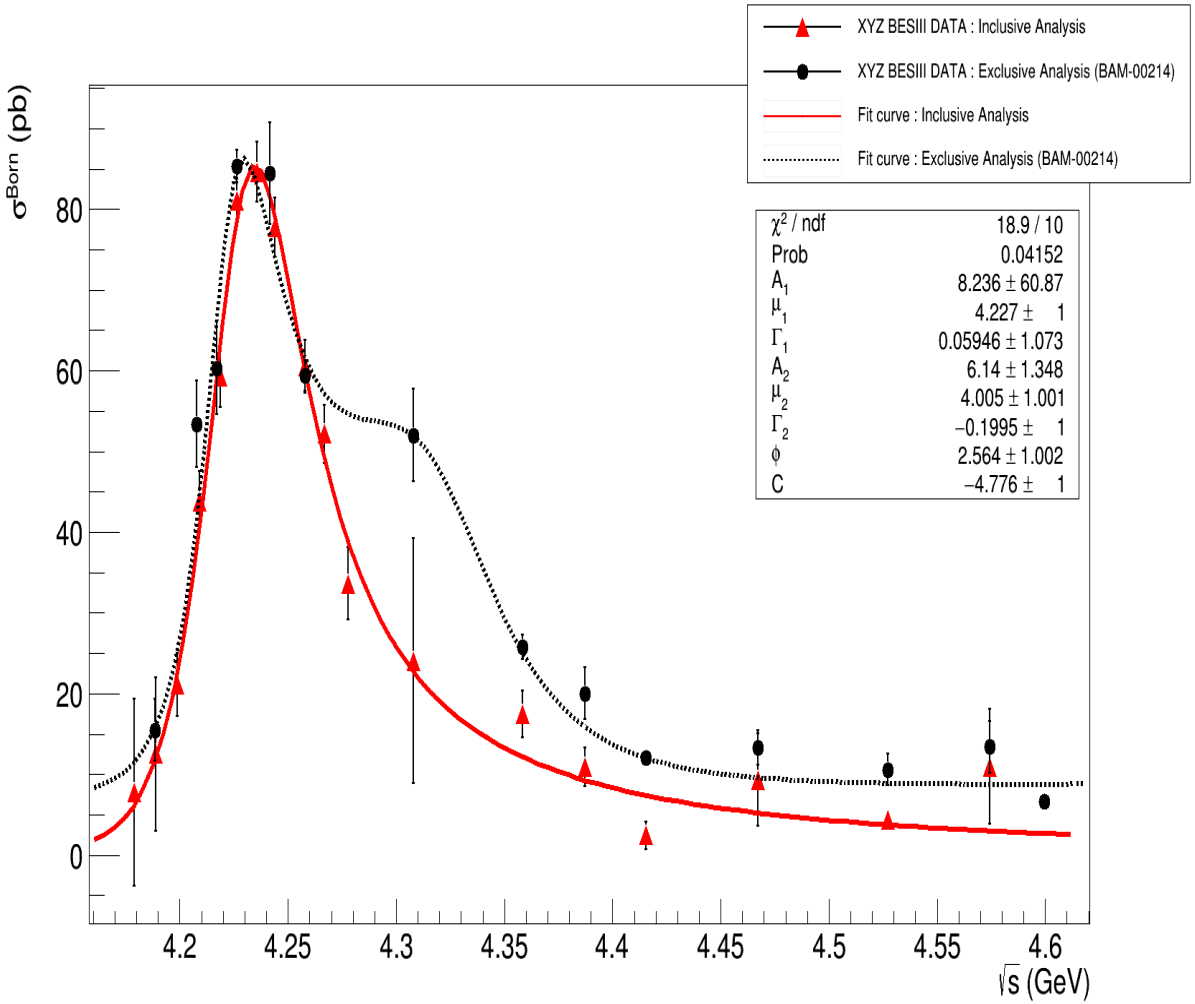
Reminder : Analysis of $e^+e^- \to X_{c\bar{c}}\pi^+\pi^-$

Observation of $J/\psi, h_c, \psi(2S)$ in the missing mass recoiling against $\pi^+\pi^-$



Reminder : Analysis of $e^+e^- \to J/\psi\pi^+\pi^-$

Two Resonant structures have been observed in the energy dependent born cross section of $e^+e^- \to J/\psi\pi^+\pi^-$



Exclusive Analysis-BAM 00214

$Y(4220)$

$\mu_{4220} = 4223.7 \pm 3.2 MeV/c^2$

$\Gamma_{4220} = 43.1 \pm 4.1 MeV$

$Y(4320)$

$\mu_{4320} = 4318.5^{+9.4}_{-10.2} MeV/c^2$

$\Gamma_{4320} = 95.7^{+22.7}_{-18.6} MeV$

Inclusive Analysis

$Y(4220)$

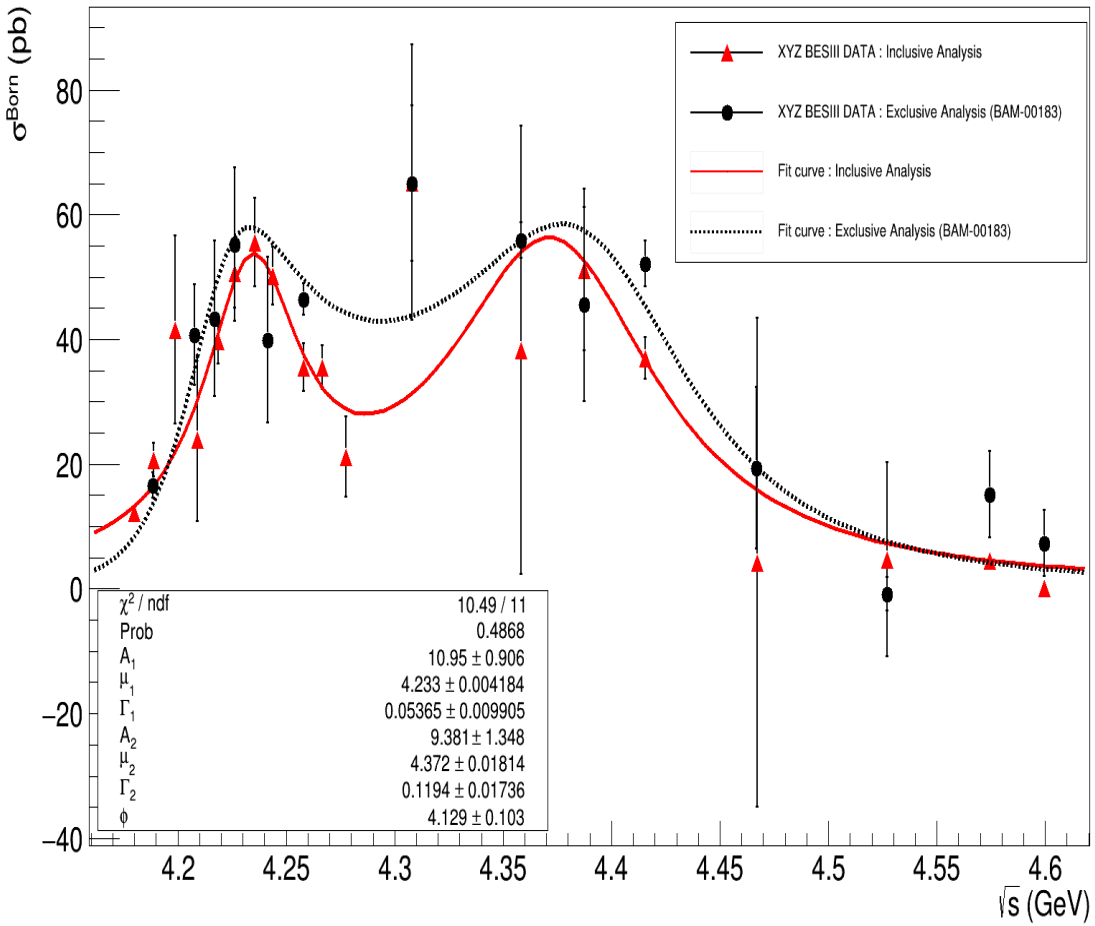
$\mu_{4220} = 4234.4 \pm 4.927 MeV/c^2$

$\Gamma_{4220} = 61.01 \pm 3.507 MeV$

with the assumption of a second Breight-Wigner around 4 GeV

Reminder : Analysis of $e^+e^- \to h_c\pi^+\pi^-$

Two Resonant structures have been observed in the energy dependent born cross section of $e^+e^- \to h_c\pi^+\pi^-$



Exclusive Analysis-BAM 00183

$Y(4220)$

$\mu_{4220} = 4218.4^{+5.5}_{-4.5} MeV/c^2$

$\Gamma_{4220} = 66.0^{+12.3}_{-8.3} MeV$

$Y(4390)$

$\mu_{4390} = 4319.5^{+6.3}_{-6.8} MeV/c^2$

$\Gamma_{4390} = 139.5^{+16.2}_{-20.6} MeV$

Inclusive Analysis

$Y(4220)$

$\mu_{4220} = 4233.4 \pm 4.18 MeV/c^2$

$\Gamma_{4220} = 53.65 \pm 9.90 MeV$

$Y(4390)$

$\mu_{4390} = 4372.5 \pm 18.14 MeV/c^2$

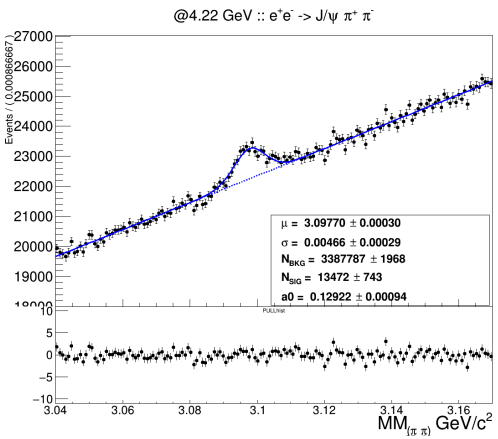
$\Gamma_{4390} = 119.4 \pm 17.32 MeV$

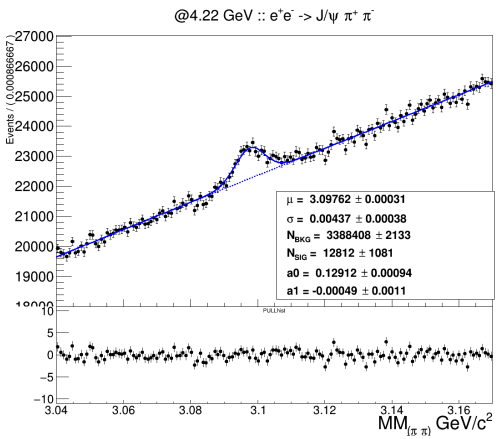
Systematics Uncertainties : $e^+e^- \to J/\psi\pi^+\pi^-$ $e^+e^- \to h_c\pi^+\pi^-$

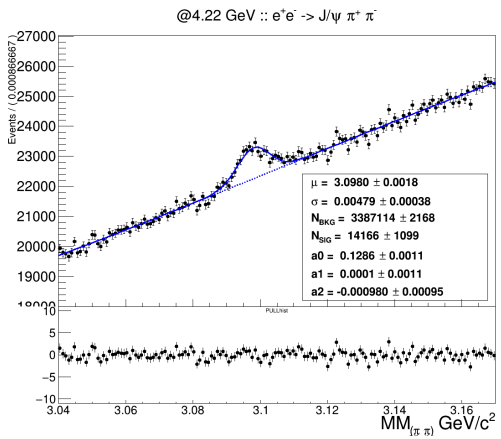
- Observation of J/ψ in 11 out of 19 Energy points :$4190, 4200, 4210, 4220, 4230, 4237, 4246, 4260, 4270, 4280, 4360$
- Observation of h_c in 13 out of 19 Energy points :$4180, 4190, 4200, 4210, 4220, 4230, 4237, 4246, 4260, 4270, 4280, 4360, 4420$
- For other energy points :$4310, 4390, 4470, 4530, 4575, 4600...$ $\to$ Extracting N_s and Err_{Sys} is more challenging
- Testing a new approach to improve the systematic errors.
  Subtract background $\to$ Fit signal only $\to$ fix signal parameters $\to$ re-fit original distribution

Systematics Uncertainties : $e^+e^- \to J/\psi\pi^+\pi^-$

- Background shape - order of polynomial
  Example : @4.22 GeV





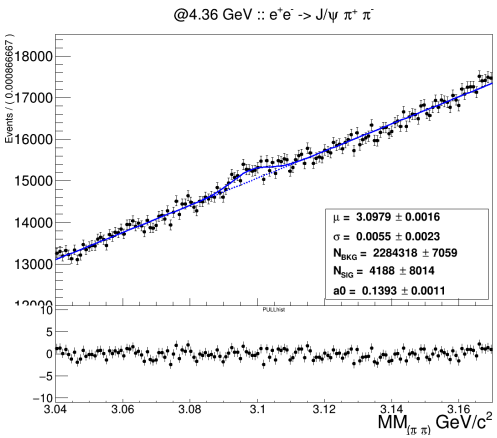


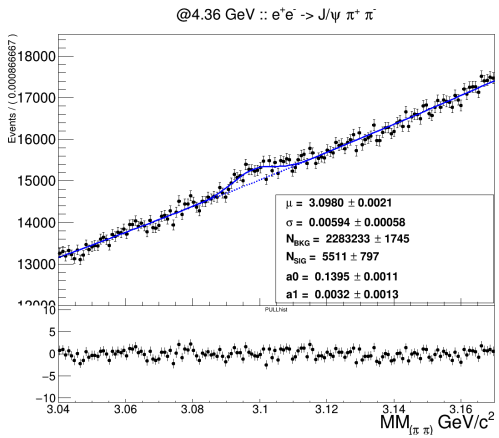
- $\Delta_{N_{pol}} = \frac{1}{n}\Sigma N_{S_0} - N_{S_i}$

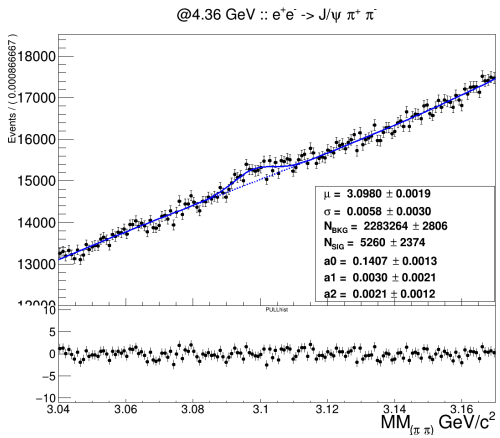
  $Err_{pol} = \frac{\Delta_{N_{pol}}}{N_{S_0}} = 5.2\%$

Systematics Uncertainties : $e^+e^- \to J/\psi\pi^+\pi^-$

- Background shape - order of polynomial
  Example : @4.36 GeV





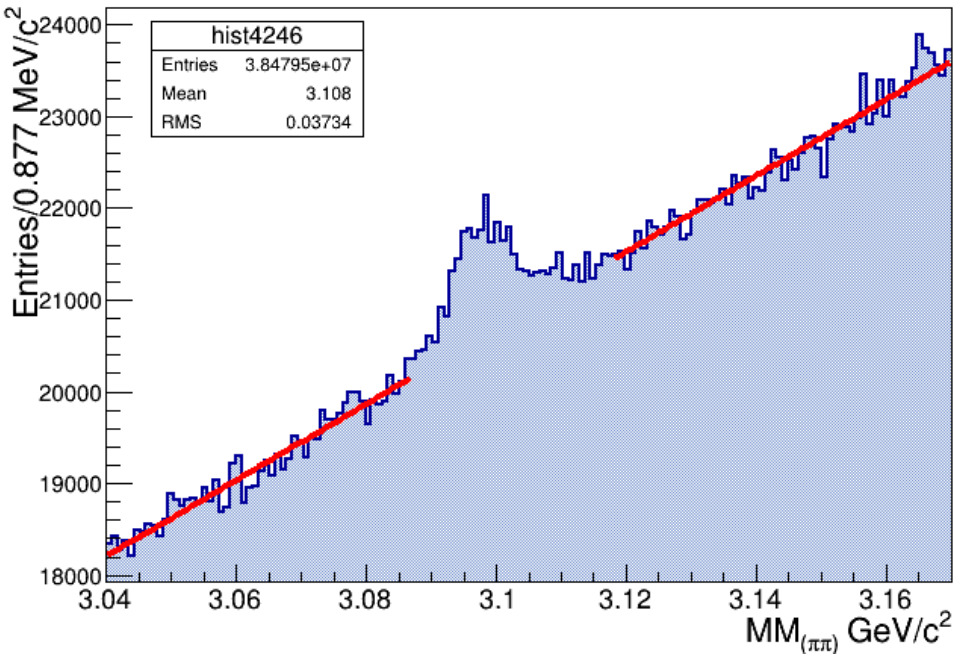


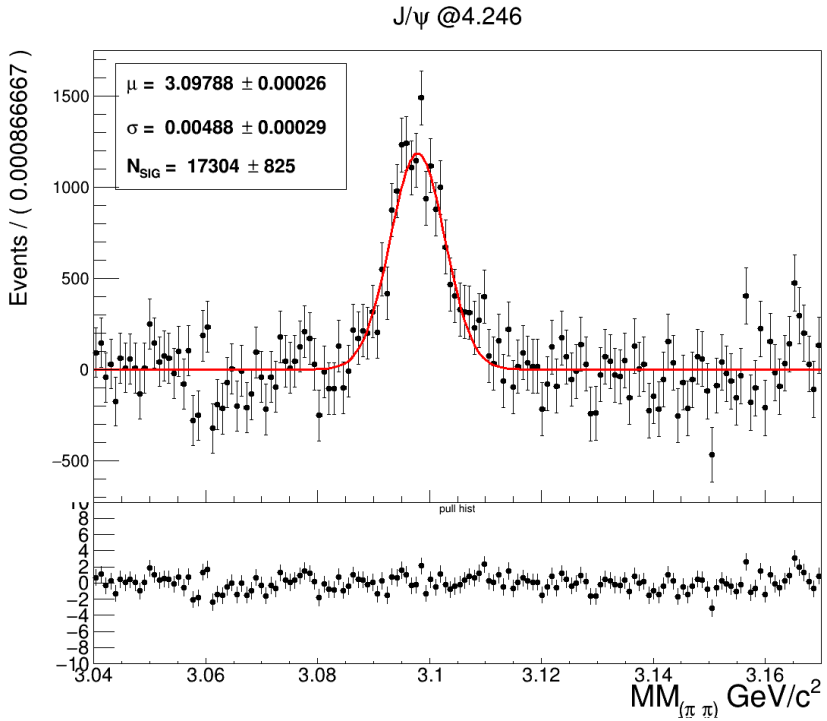
- $\Delta_{N_{pol}} = \frac{1}{n}\Sigma N_{S_0} - N_{S_i}$

  $Err_{pol} = \frac{\Delta_{N_{pol}}}{N_{S_0}} = 28.59\%$

Systematics Uncertainties : $e^+e^- \to J/\psi\pi^+\pi^-$

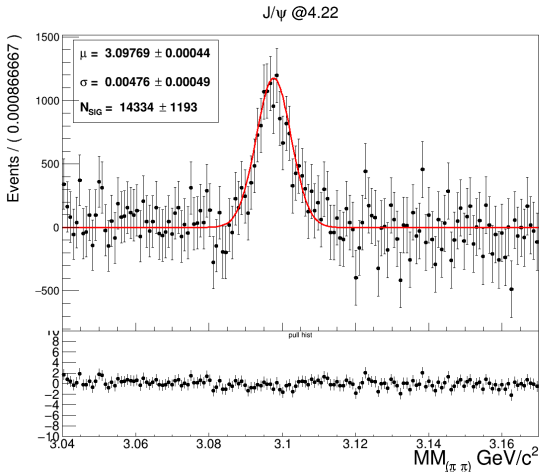
- Background shape - order of polynomial
  Example : @4.246 GeV

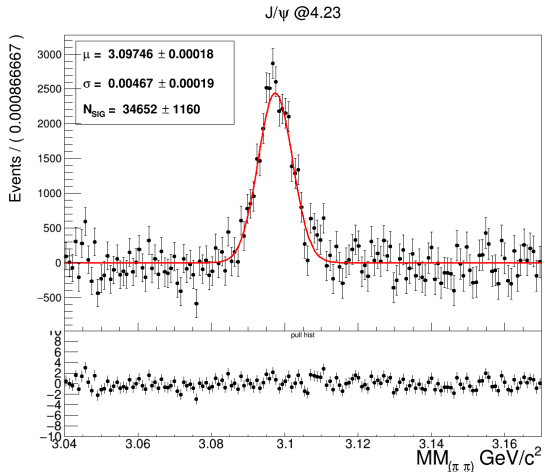


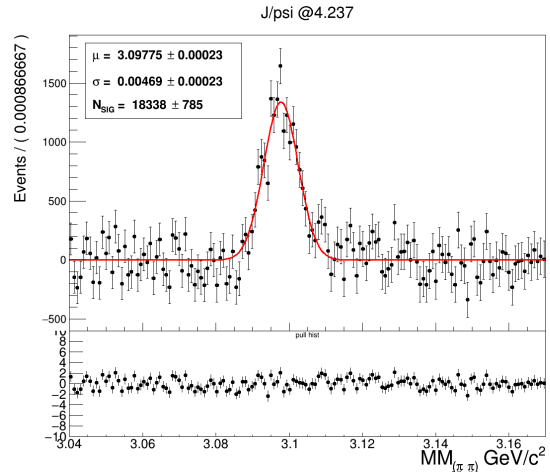


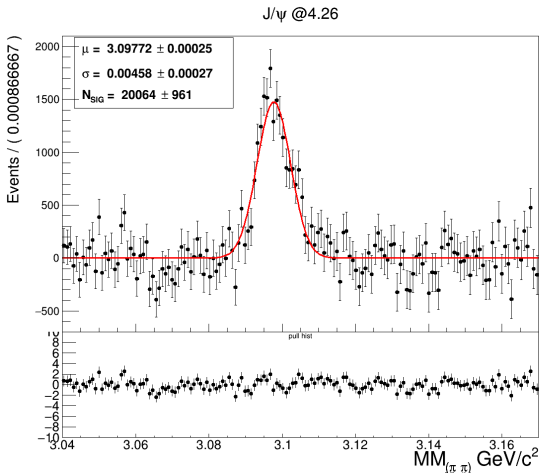
Systematics Uncertainties : $e^+e^- \to J/\psi\pi^+\pi^-$

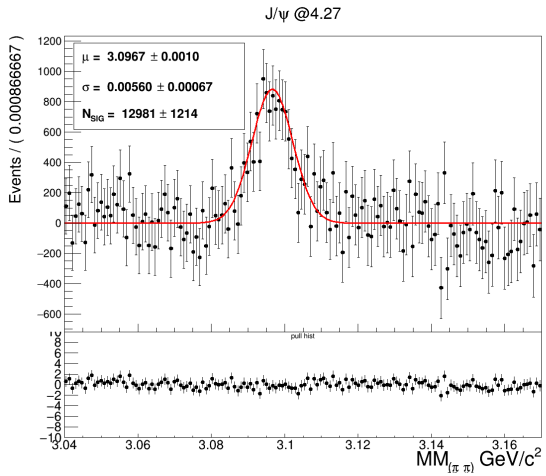
- Background Subtacted distributions for @4.22,@4.23,@4.237,@4.26, @4.27,@4.28

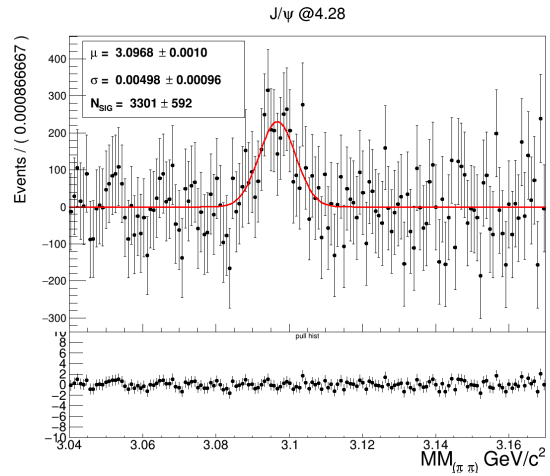






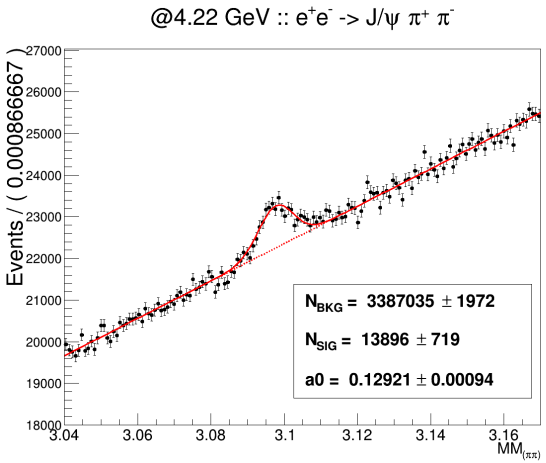


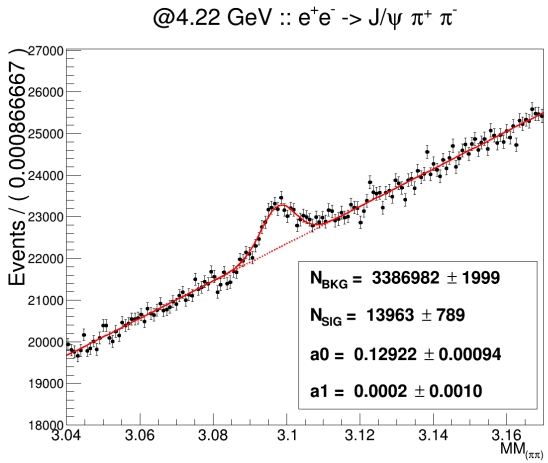


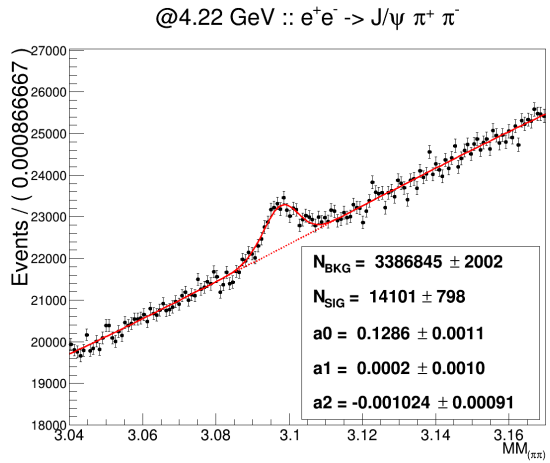


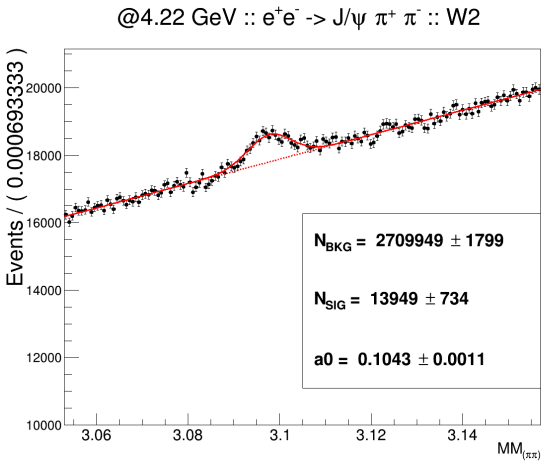
Systematics Uncertainties : $e^+e^- \to J/\psi\pi^+\pi^-$

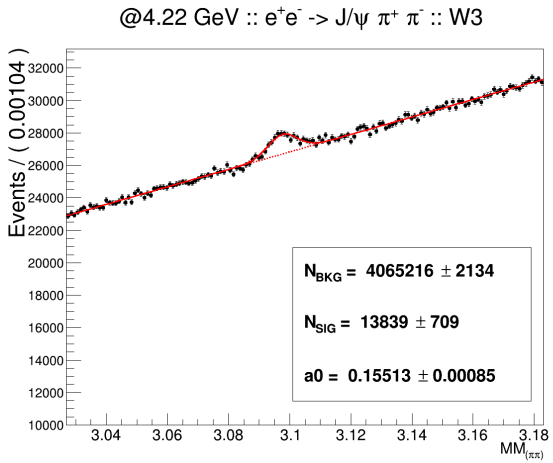
- Background shape - order of polynomial - fixed Signal shape
  Example : @4.22 GeV











- $\Delta_{N_{pol}} = \frac{1}{n}\Sigma N_{S_0} - N_{S_i}$; $Err_{pol} = \frac{\Delta_{N_{pol}}}{N_{S_0}} = 0.44\%$

Systematics Uncertainties : $e^+e^- \to J/\psi\pi^+\pi^-$

Order Of Polynomial and Fit Window

J/ψ	W1	W2	W3
P1	X		
P2	X		
P3	X		

$$W1 \to [3.04, 3.17]$$
$$W2 \to [3.053, 3.157]$$
$$W3 \to [3.027, 3.183]$$

DATAset	$N_{S_{W1P1}}$	$N_{S_{W1P2}}$	$N_{S_{W1P3}}$	Err_{sys}	$Err_{sys_{old}}$
4190	4223 ± 727	4671 ± 791	4909 ± 799	13.4 %	19.67%
4200	5539 ± 704	5816 ± 721	6094 ± 801	7.51%	4.2 %
4210	9898 ± 695	9976 ± 755	10010 ± 762	0.95%	11.75%
4220	13896 ± 719	13963 ± 789	14101 ±798	0.97%	5.2 %
4230	34953 ± 998	34913 ±1093	35802 ± 1106	0.24%	3.25 %
4237	18397 ± 693	18187 ± 759	18337 ± 767	0.73 %	6.59%
4246	17444 ± 705	17784 ± 776	17715 ± 785	1.75%	5.9%
4260	20177 ± 821	20529 ± 897	20632 ± 907	1.99%	6.2%
4270	12553 ± 725	12299 ± 811	12644 ± 826	1.37%	2.3%
4280	3312 ± 384	3559 ± 423	3566 ± 430	7.56 %	10.38 %
4360	4596 ± 649	5431 ± 730	5209 ± 740	15.75 %	28.59%

Systematics Uncertainties : $e^+e^- \to J/\psi\pi^+\pi^-$

Order Of Polynomial and Fit Window

J/ψ	W1	W2	W3
P1	X	X	X
P2			
P3			

$$W1 \to [3.04, 3.17]$$
$$W2 \to [3.053, 3.157]$$
$$W3 \to [3.027, 3.183]$$

DATAset	$N_{S_{W1P1}}$	$N_{S_{W2P1}}$	$N_{S_{W3P1}}$	Err_{sys}
4190	4223 ± 727	4534 ± 741	3953 ± 719	6.87 %
4200	5539 ± 704	5714 ± 711	5139 ± 720	5.19%
4210	9898 ± 695	10053 ± 708	10149 ± 738	2.05%
4220	13896 ± 719	13949 ± 734	13839 ±709	0.39%
4230	34953 ± 998	35051 ±1019	34438 ± 986	0.87%
4237	18397 ± 693	18458 ± 707	18106 ± 684	0.95 %
4246	17444 ± 705	17777 ± 721	17287 ± 696	1.40%
4260	20177 ± 821	20479 ± 838	20178 ± 811	1.75%
4270	12553 ± 725	12654 ± 744	12126 ± 713	2.10%
4280	3312 ± 384	3475 ± 393	3297 ± 378	2.68 %
4360	4596 ± 649	4770 ± 666	5386 ± 708	10.48 %

Systematics Uncertainties : $e^+e^- \to J/\psi\pi^+\pi^-$

Order Of Polynomial and Fit Window

J/ψ	W1	W2	W3
P1	X	X	X
P2	X	X	X
P3	X	X	X

$$W1 \to [3.04, 3.17]$$
$$W2 \to [3.053, 3.157]$$
$$W3 \to [3.027, 3.183]$$

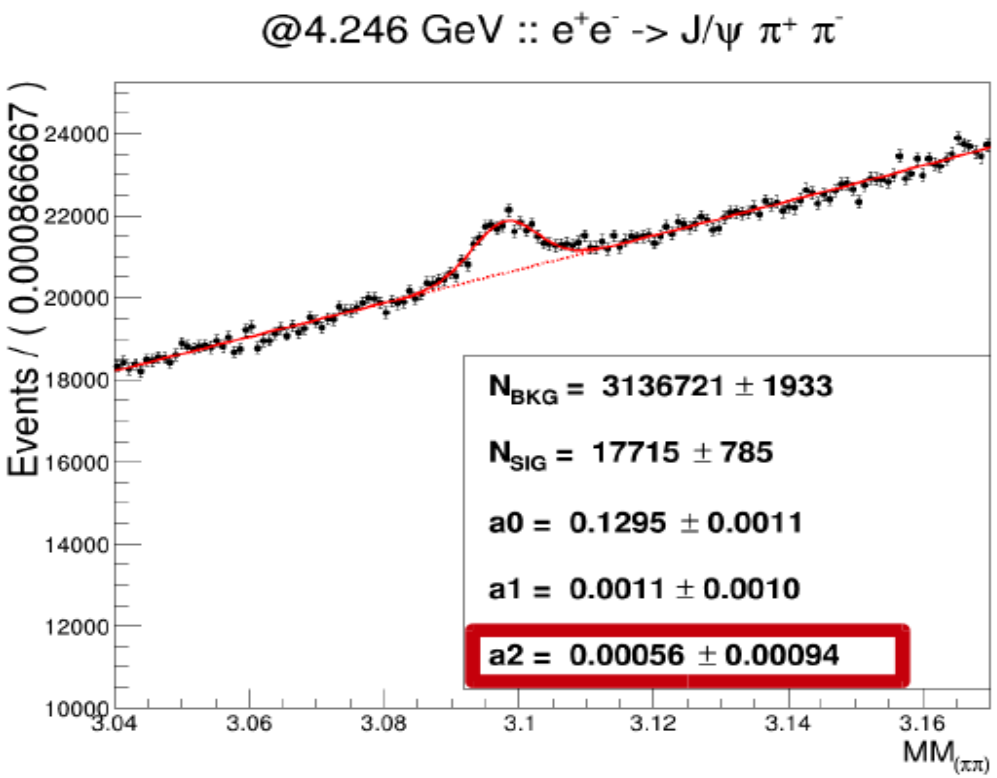
DATAset	$N_{S_{W2P2}}$	$N_{S_{W2P3}}$	$N_{S_{W3P2}}$	$N_{S_{W3P3}}$	Err_{pol}
4190	4622 ± 820	4915 ± 843	4729 ± 771	4849 ± 774	11.65 %
4200	6008 ± 824	6167 ± 849	6060 ± 770	6284 ± 775	8.50%
4210	9644 ± 785	9676 ± 802	10088 ± 735	10149 ± 739	1.90%
4220	14163 ± 826	14241 ±848	14070 ± 766	14110 ± 770	1.24%
4230	34378 ±1142	34458 ± 1175	35115 ± 1062	35353 ± 1068	0.86%
4237	18047 ± 793	18398 ± 814	18454 ± 737	18627 ± 741	0.85%
4246	17065 ± 813	17040 ± 836	17810 ± 753	17883 ± 757	1.92%
4260	20210 ± 937	20536 ± 961	20693 ± 872	20637 ± 877	1.53%
4270	11983 ± 856	12887 ± 896	12835 ± 782	13071 ± 789	2.56%
4280	3568 ± 443	3574 ± 460	3499± 410	3548± 413	6.11 %
4360	5130 ± 774	5083 ± 800	5449 ± 703	5386 ± 708	13.8 %

Systematics Uncertainties : $e^+e^- \to J/\psi\pi^+\pi^-$

Order Of Polynomial and Fit Window

J/ψ	W1	W2	W3
P1	X	X	X
P2	X	X	X
P3	X	X	X

$$W1 \to [3.04, 3.17]$$
$$W2 \to [3.053, 3.157]$$
$$W3 \to [3.027, 3.183]$$



Systematics Uncertainties : $e^+e^- \to J/\psi\pi^+\pi^-$

Order Of Polynomial and Fit Window

J/ψ	W1	W2	W3
P1	X	X	X
P2	X	X	X
P3			

$$W1 \to [3.04, 3.17]$$
$$W2 \to [3.053, 3.157]$$
$$W3 \to [3.027, 3.183]$$

DATAset	$N_{S_{W2P2}}$	$N_{S_{W3P2}}$	Err_{pol}
4190	4622 ± 820	4729 ± 771	9.15 %
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4270	11983 ± 856	12835 ± 782	2.60%
4280	3568 ± 443	3499± 410	5.24 %
4360	5130 ± 774	5449 ± 703	13.8 %

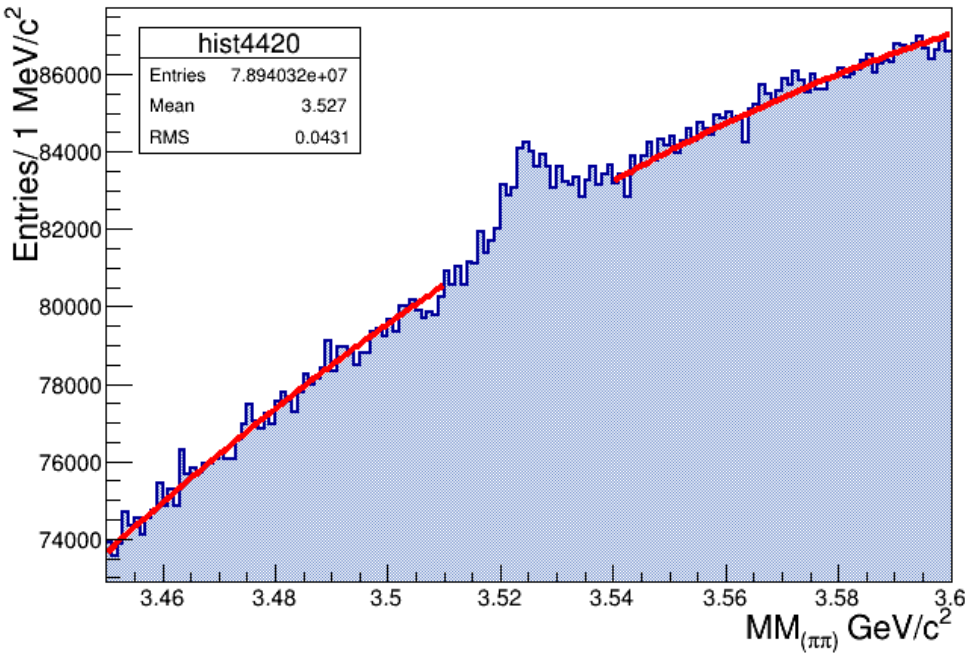
Systematics Uncertainties : $e^+e^- \to J/\psi\pi^+\pi^-$

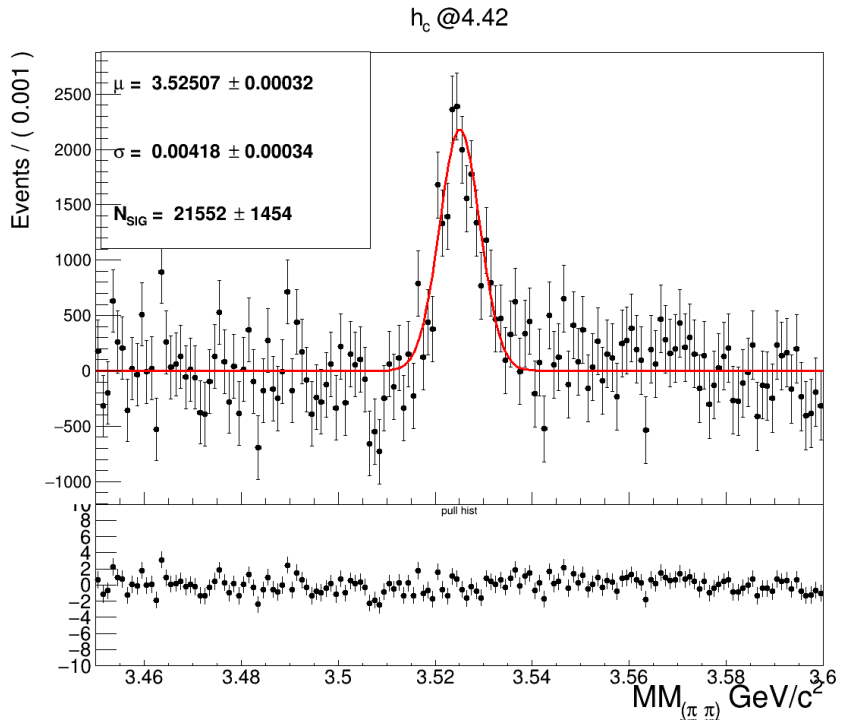
- Luminosty
- Tracking : 2 pions
- PID
- Background shape : Polynomial order
- Fit Window

DATAset	Luminosity	Tracking	PID	POL + W	TOTAL
4190	1%	2%	2%	9.15%	9.62%
4200	1%	2%	2%	6.65%	7.29%
4210	1%	2%	2%	1.87%	3.53%
4220	1%	2%	2%	0.88%	3.12%
4230	1%	2%	2%	0.79%	3.10%
4237	1%	2%	2%	1.05%	3.17%
4246	1%	2%	2%	1.80%	3.49%
4260	1%	2%	2%	1.19%	3.22%
4270	1%	2%	2%	2.60%	3.96%
4280	1%	2%	2%	5.24%	6.03%
4360	1%	2%	2%	13.86%	14.18%

Systematics Uncertainties : $e^+e^- \to h_c\pi^+\pi^-$

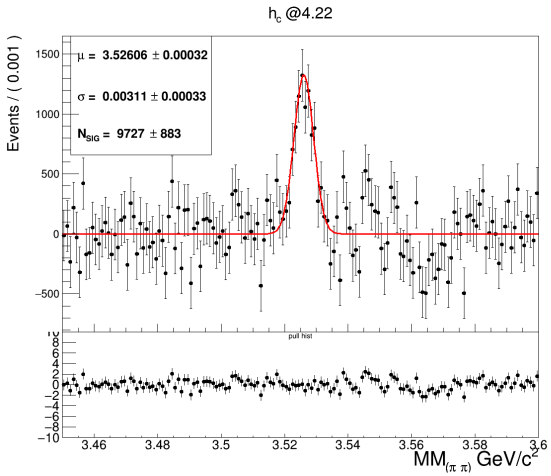
- Background shape - order of polynomial
  Example : @4.42 GeV

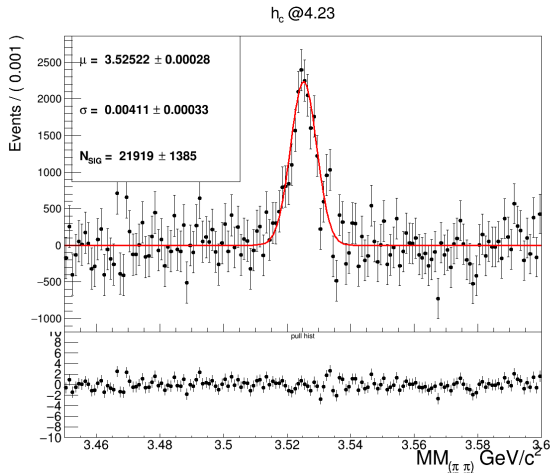


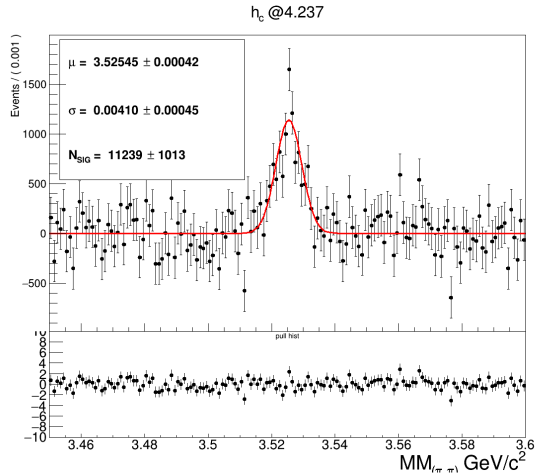


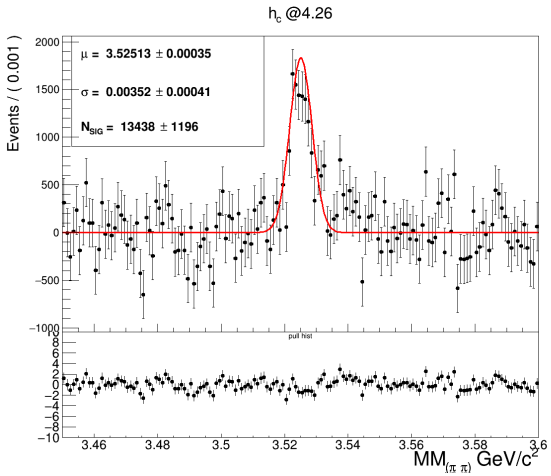
Systematics Uncertainties : $e^+e^- \to h_c\pi^+\pi^-$

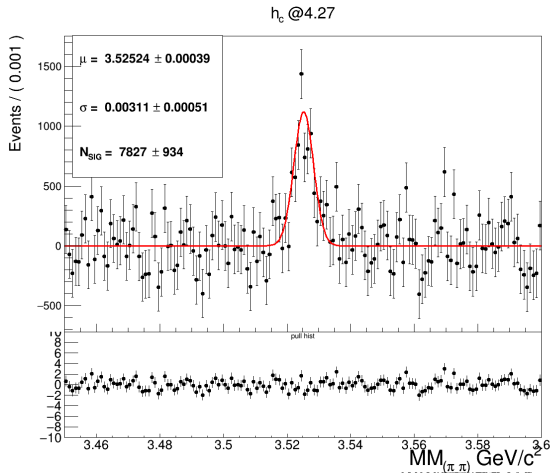
- Background Subtacted distributions for @4.22,@4.23,@4.237,@4.26, @4.27,@4.36

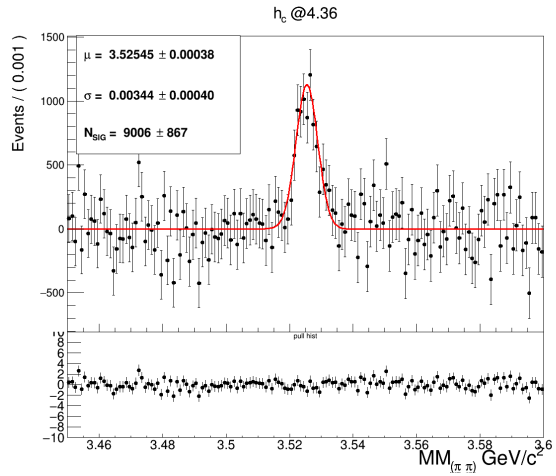












Systematics Uncertainties : $e^+e^- \to h_c\pi^+\pi^-$

Order Of Polynomial and Fit Window

h_c	W1	W2	W3
P2	X	X	X
P3	X	X	X
P4			

$W1 \to [3.45, 3.6]$
$W2 \to [3.465, 3.585]$
$W3 \to [3.435, 3.615]$

DATAset	$N_{S_{W1P2}}$	$N_{S_{W2P2}}$	$N_{S_{W3P2}}$	$N_{S_{W1P3}}$	$N_{S_{W2P3}}$	Err
4180	10761 ±1611	11562 ± 1638	11001 ± 1594	11893± 1625	12351 ± 1673	15.01 %
4190	3729 ± 683	3925 ± 697	3321 ± 675	3694 ± 683	3961 ± 715	6.47%
4200	7136 ± 1025	6979 ± 1071	6732 ± 996	7063 ± 1025	6713 ± 1135	3.67%
4210	5271 ± 699	5226 ± 715	5275 ± 690	5284 ± 700	5047 ± 735	0.41%
4220	7950 ± 731	7741 ±750	7866 ± 720	7968 ± 731	7382 ± 774	1.46%
4230	21658 ±1228	21305 ± 1271	22631 ± 1201	21645 ± 1215	20900 ± 1315	2.43%
4237	9928 ± 881	9878 ± 881	10246 ± 833	9914 ± 881	10146 ± 978	1.54%
4246	9161 ± 761	9107 ± 782	9269 ± 748	9154 ± 761	9121 ± 810	0.75%
4260	11619 ± 949	11580 ± 977	12045 ± 932	11622 ± 949	11386 ± 1013	1.61%
4270	7144 ± 704	7344 ± 722	7087 ± 693	7142 ± 704	7292 ± 745	1.43%
4280	2177 ± 444	2087 ± 457	2142± 436	2174± 444	1860 ± 475	2.42 %
4310	1950 ± 482	2320 ± 511	2330 ± 502	1924 ± 482	2272 ± 553	11.67 %
4360	8548 ± 730	8559 ± 750	8798 ± 717	8252 ± 730	8393 ± 775	1.21 %
4420	20306± 1258	20449 ± 1303	20701 ±1230	20235 ± 1258	20767 ± 1364	0.91 %

Systematics Uncertainties : $e^+e^- \to h_c\pi^+\pi^-$

- Luminosty
- Tracking : 2 pions
- PID
- Background shape : Polynomial order
- Fit Window

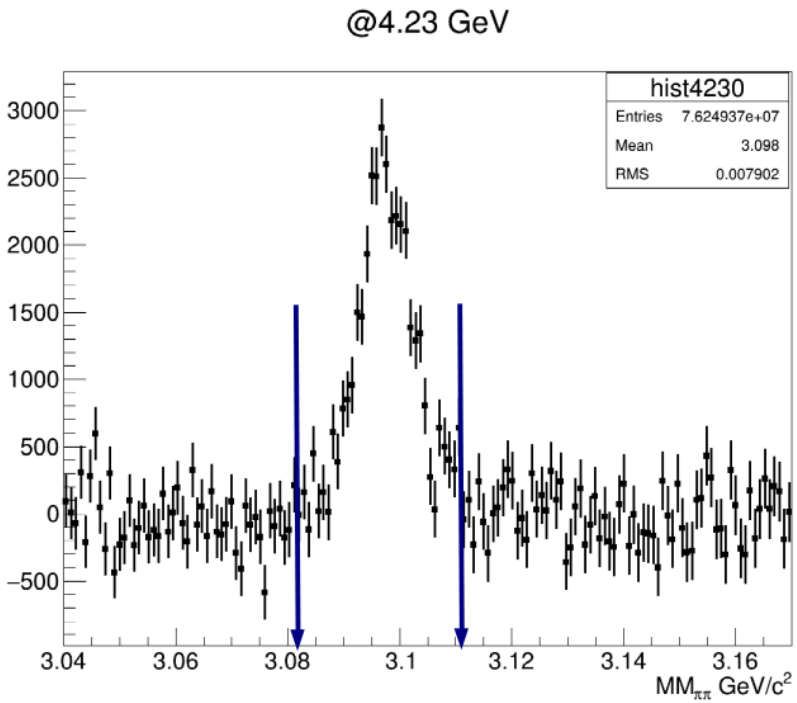
DATAset	Luminosity	Tracking	PID	POL + W	TOTAL
4180	1%	2%	2%	15.10%	15.39%
4190	1%	2%	2%	6.47%	7.13%
4200	1%	2%	2%	3.67%	4.74%
4210	1%	2%	2%	0.41%	3.02%
4220	1%	2%	2%	1.46%	3.33%
4230	1%	2%	2%	2.43%	3.86%
4237	1%	2%	2%	1.54%	3.72%
4246	1%	2%	2%	0.75%	3.09%
4260	1%	2%	2%	1.61%	3.40%
4270	1%	2%	2%	1.43%	3.32%
4280	1%	2%	2%	2.42%	3.85%
4310	1%	2%	2%	11.67%	12.04%
4360	1%	2%	2%	1.21%	3.23%
4420	1%	2%	2%	0.91%	3.13%

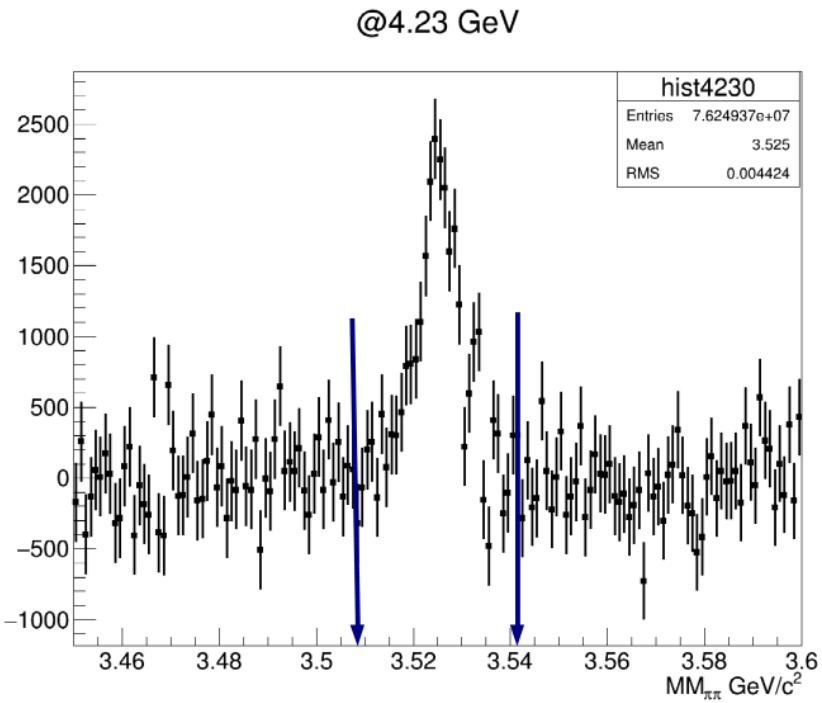
To-do list

- Improving and finalising systematic errors for h_c and J/ψ
- Have more consistent results with the exclusive analysis of $e^+e^- \to J/\psi\pi^+\pi^-$
  New energy points around 4.31 GeV ?

Backup I - Counting approach

- Another approach → Events counting (No Signal shape definition)





Backup I - Counting approach

- Another approach → Events counting (No Signal shape definition)

DATAset	$N_{J\psi}$
4190	4019
4200	5119
4210	9914
4220	13836
4230	35689
4237	18207
4246	18271
4260	20672
4270	12772
4280	2984
4360	4474

DATAset	N_{hc}
4180	11448
4190	4290
4200	8097
4210	6447
4220	9797
4230	22818
4237	11606
4246	9630
4260	13517
4270	8684
4280	2432
4310	2087
4360	9275
4420	21714

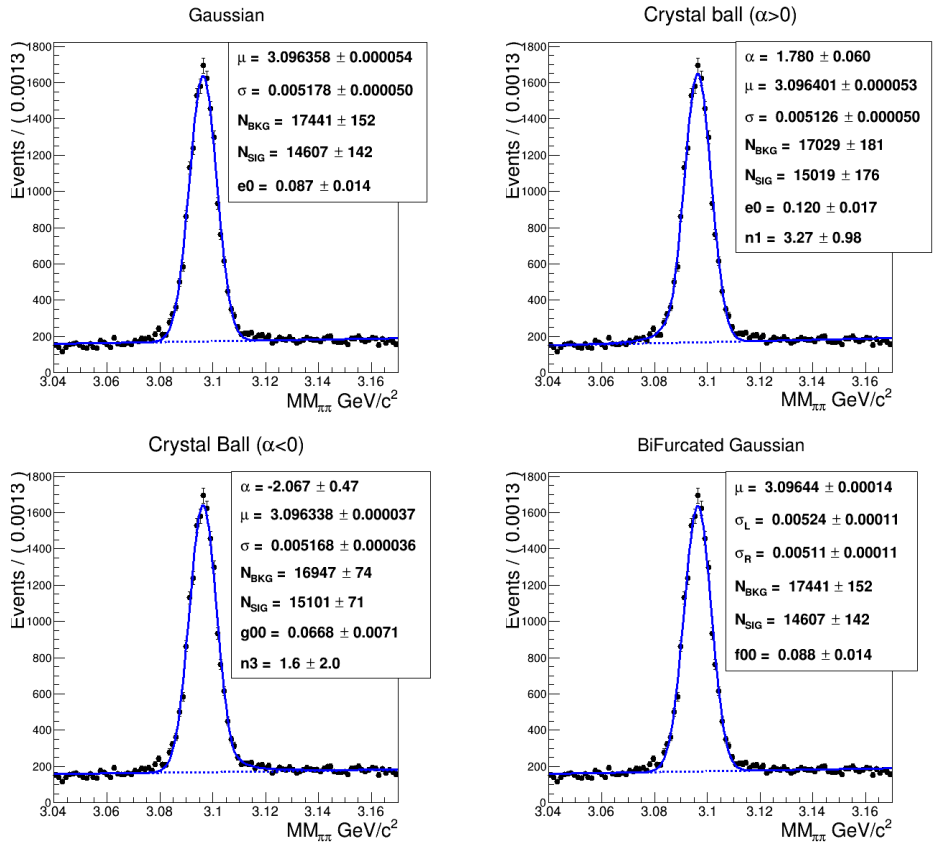
BACKUP I- MC Signal

Additional Systematics ?

- Monte Carlo Signal Shape

  Gaussian Vs Crystal Ball

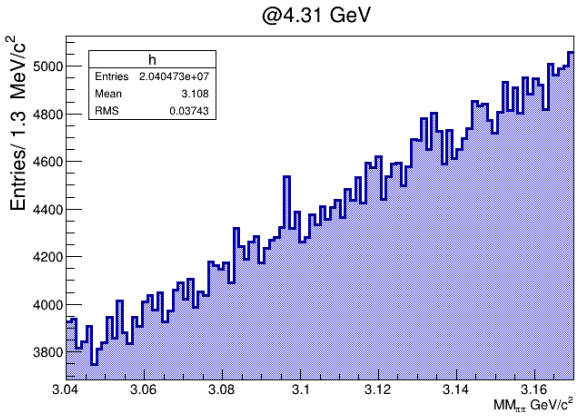
  Efficiency difference 2%

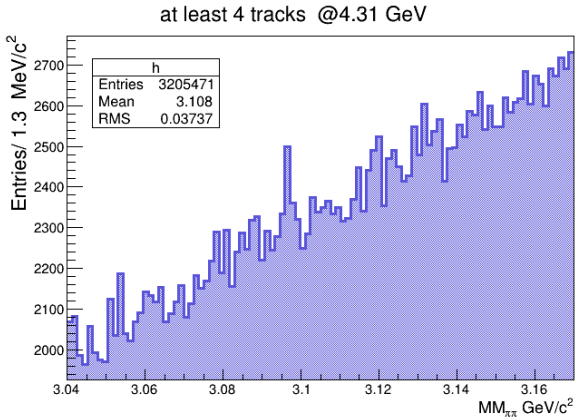


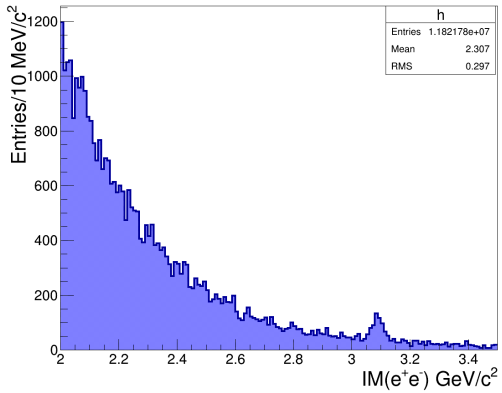
- Systematic error from ISR correction

BACKUP III- @4.31 GeV

- Fig 1 : Missing Mass recoiling against $\pi\pi$ @4.31GeV
- Fig 2 : At least 4 good tracks are required
- Fig 3 : Two electrons are reconstructed $\rightarrow$ J/ψ appears in the IM(ee)

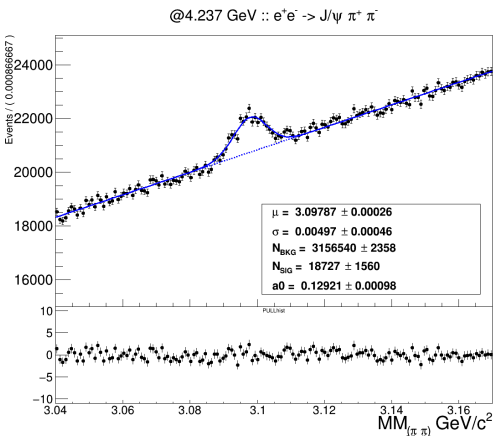


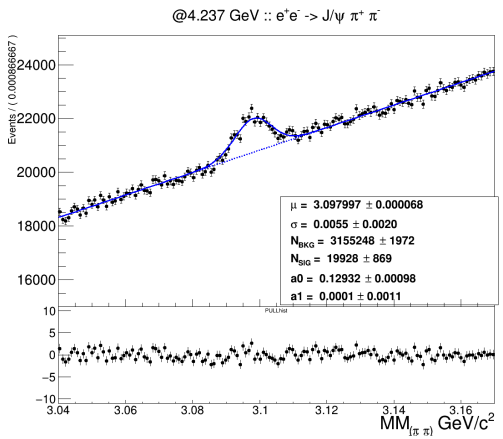


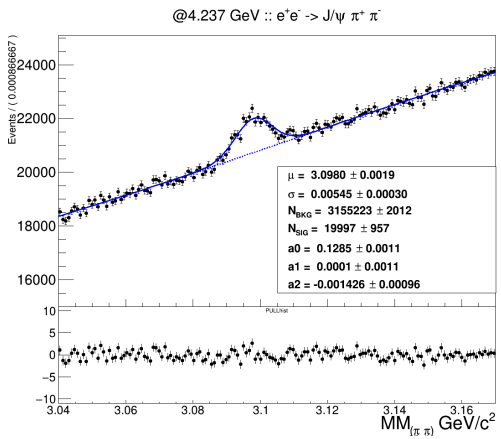


BACKUP IV

- Background shape - order of polynomial
  Example : @4.237 GeV





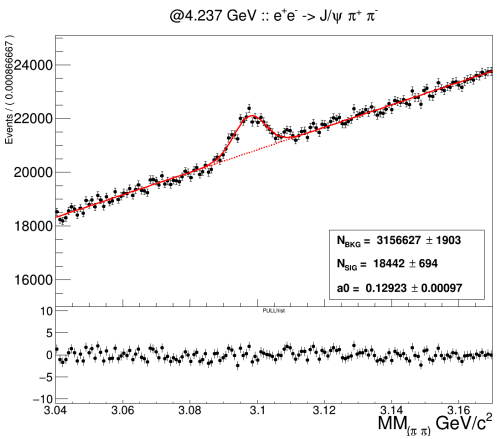


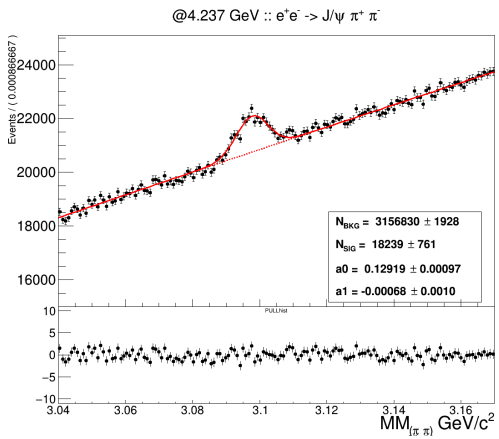
- $\Delta_{N_{pol}} = \frac{1}{n}\Sigma N_{S_0} - N_{S_i}$

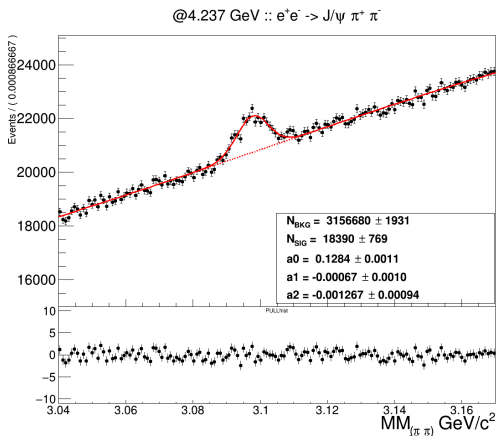
  $Err_{pol} = \frac{\Delta_{N_{pol}}}{N_{S_0}} = 6.59\%$

BACKUP IV

- Background shape - order of polynomial - fixed Signal shape
  Example : @4.237 GeV







- $\Delta_{N_{pol}} = \frac{1}{n}\Sigma N_{S_0} - N_{S_i}$

  $Err_{pol} = \frac{\Delta_{N_{pol}}}{N_{S_0}} = 0.6\%$