Control sample for $e^+e^- \to n\bar{n}$ study

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on behalf of $n\bar{n}$ analysis team

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Tau-QCD group meeting
28th May.2025

Outline

- Motivation
- Strategy of the analysis
  - Data and MC samples
- Control Sample of $\overline{n}$ in EMC
  - Control Sample of $\overline{n}$ from $J/\psi \to p\overline{n}\pi^-$
  - Control Sample of $\overline{n}$ from $J/\psi \to p\overline{n}\pi^-\pi^+\pi^-$
- Control Sample of $\overline{n}$ in MDC and BeamPipe
- Summary and to do list

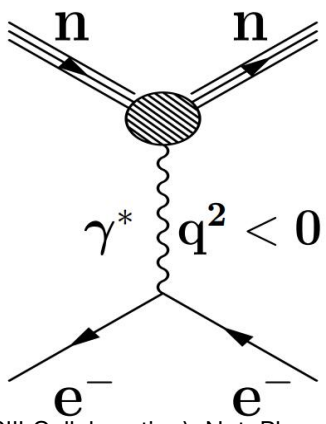
Motivation

- The e^+e^- annihilation to neutron-antineutron pairs depends on two factors: electric G_E and magnetic G_M, which also can describe the neutron's internal structure.
  - A testing ground for the understanding of QCD at low momentum transfer q^2

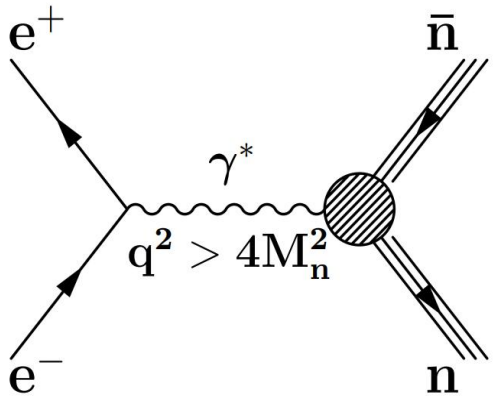
$$\frac{d\sigma(n\bar{n})}{d\Omega} = \frac{\alpha^2\beta}{4s}\left[|G_M(s)|^2(1+\cos^2\theta) + \frac{1}{\gamma^2}|G_E(s)|^2\sin^2\theta\right],\ \gamma = \sqrt{\frac{s}{4m_n^2}}$$ [1]

Integrated cross section: $\sigma(s) = \frac{4\pi\alpha^2\beta}{3s}(1+\frac{1}{2\gamma})|G_{eff}|^2,\ |G_{eff}|^2 = \frac{2\gamma^2|G_M(s)|^2+|G(E)|^2}{2\gamma^2+1}$

Space Like (SL) process



Time Like (TL) process



[1]

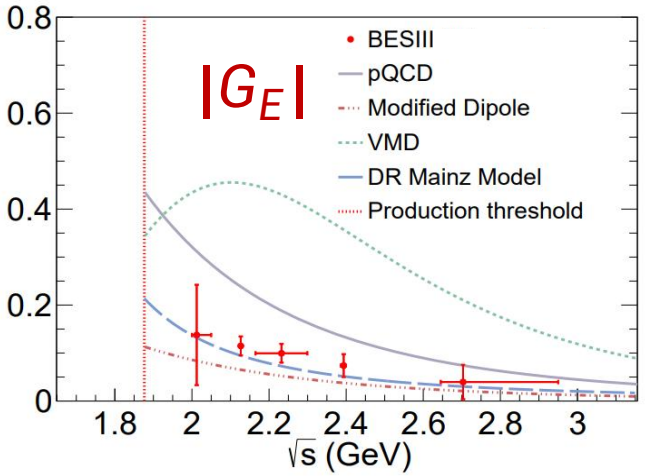
The gray circle represents the internal nucleon structure parameterized by the electromagnetic form factors [2]

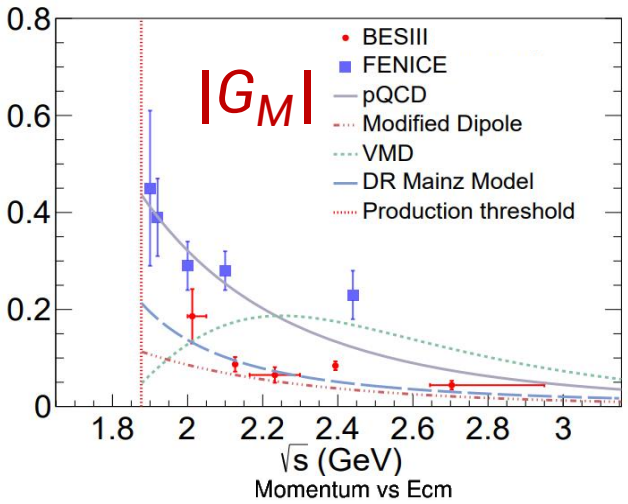
[1]M. Ablikim *et al.* (BESIII Collaboration), Nat. Phys. **17**, 1200 (2021).
[2]M. Ablikim *et al.* (BESIII Collaboration), Phys. Rev. Lett. **130**, 151905 (2023)

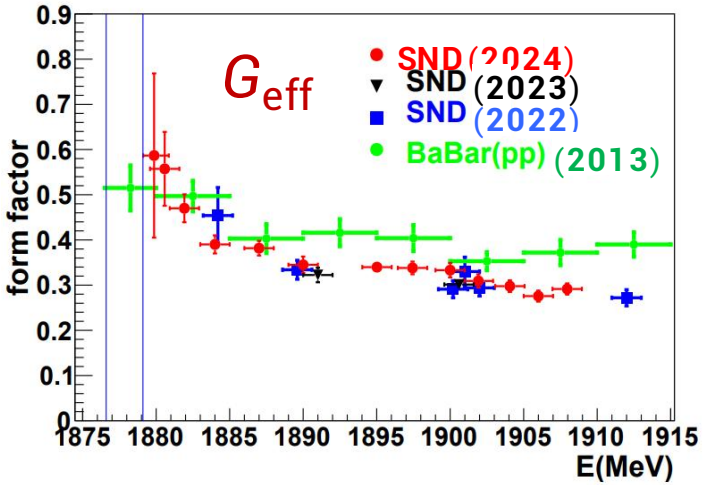
Motivation

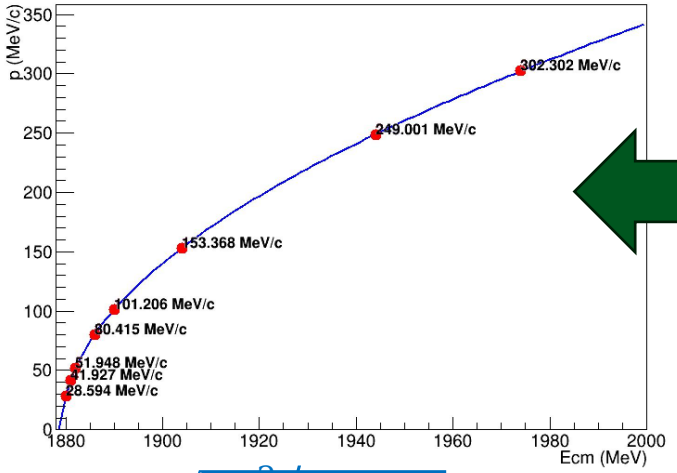
- Data: Boss 7.1.3

Previous work









E^{nom}(MeV)	Lumi.(pb^{-1})	E^{cor}(MeV)
1840	1.502	1844.138 ± 0.083
1870	2.003	1874.137 ± 0.084
1872	2.014	1876.035 ± 0.079
1874	2.019	1878.002 ± 0.084
1875	1.485	1879.139 ± 0.099
1876	2.035	1880.073 ± 0.080
1877	1.341	1880.925 ± 0.101
1878	2.021	1882.185 ± 0.089
1882	2.033	1886.032 ± 0.081
1886	2.031	1890.160 ± 0.083
1900	2.022	1903.824 ± 0.080
1940	2.040	1943.686 ± 0.088
1970	2.229	1973.483 ± 0.092

$P_n = \sqrt{\sqrt{s}^2/4 - m_n^2}$; $E_{th} = 2m_n$~2*939.565 = 1879.138 MeV

Strategy of the analysis

◆ Decay channel:

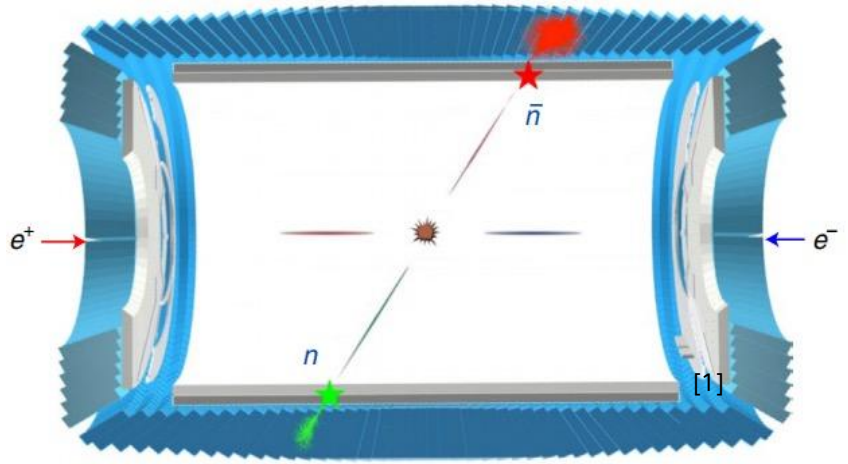
$e^+e^- \rightarrow n\bar{n}$

$\bar{n}N \rightarrow$ angthing

◆ Data and MC samples

- Data:
  - 1 billion J/ψ data collected in 2012 (EMC)
  - 10 billion J/ψ data collected in 2009-2019 (MDC and pipe)
- MC Sample:
  - 1 billion J/ψ inclusive MC (EMC)
  - PHSP MC (EMC)
  - 10 billion J/ψ inclusive MC (MDC and pipe)
  - DIY MC based on PWA

EMC



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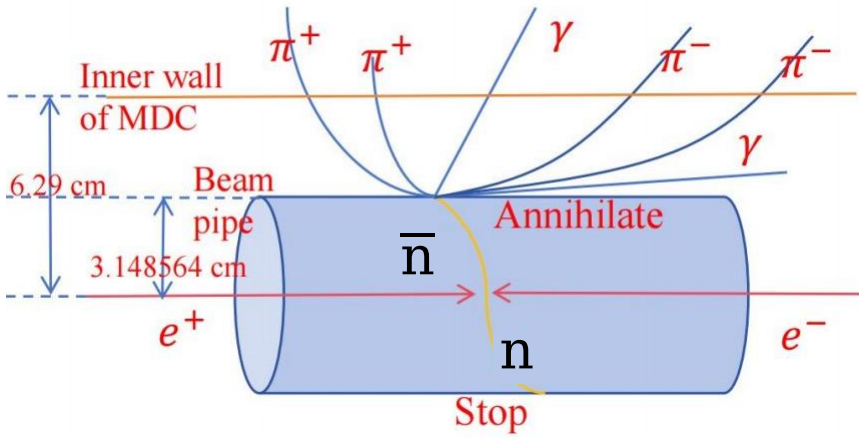

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Control Sample of $\bar{n}$ from $J/\psi \to p\bar{n}\pi^-$

- Boss Version: 708

✓ Charged Track

- $|\cos\theta| < 0.93$; $|V_{xy}| < 0.5$ cm; $|V_z| < 5$ cm;
- QCharge=0 && nGoodCharge=2

✓ PID: use tof and dE/dx info

- prob > 0.001 & highest prob
- $N_p \geq 1$ & $N_{\pi^-} \geq 1$

✓ Vertex Fit:

- Loop all the p, π^- tracks, and select the combination with minimum $\chi^2_{\text{vertex fit}}$
- IPVxy<1 cm; IPVz<5 cm
- $\chi^2_{\text{vertex fit}} < 5$

✓ Addtional track:

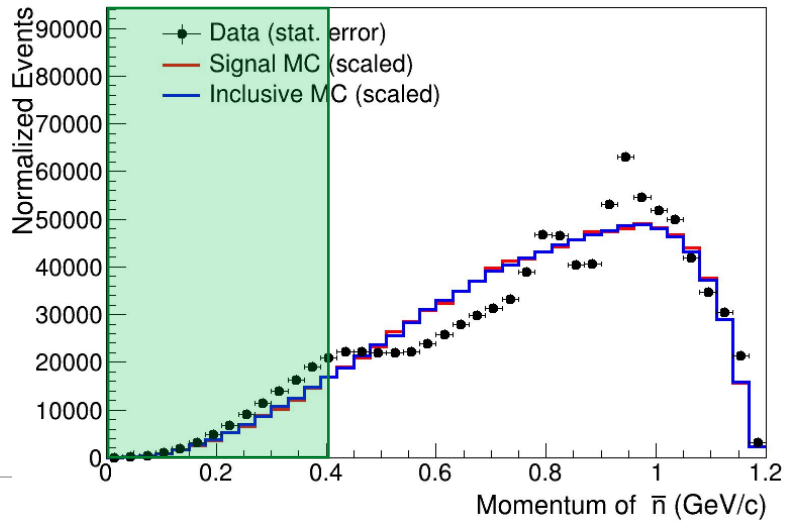
- No requirement for V_{xy}、V_z
- nremaintrack = 0

✓ Recoil $\bar{n}$:

- $P_{\bar{n}} = P_{J/\psi} - P_p - P_{\pi^-}$
- $0.92\ \text{GeV} < M^{\text{recoil}}_{p\pi^-} < 0.96\ \text{GeV}$

✓ EMC

- Time: [0, 700] ns
- Barrel: $E_n > 25$ MeV ($|\cos\theta| < 0.80$)
- Endcap: $E_n > 50$ MeV($0.86 < |\cos\theta| < 0.92$)
- nGoodShw >0
- θrecoil_leadingshw < 30^0



9.33%

Control Sample of $\bar{n}$ from $J/\psi \to p\bar{n}\pi^-$

- Background Rate

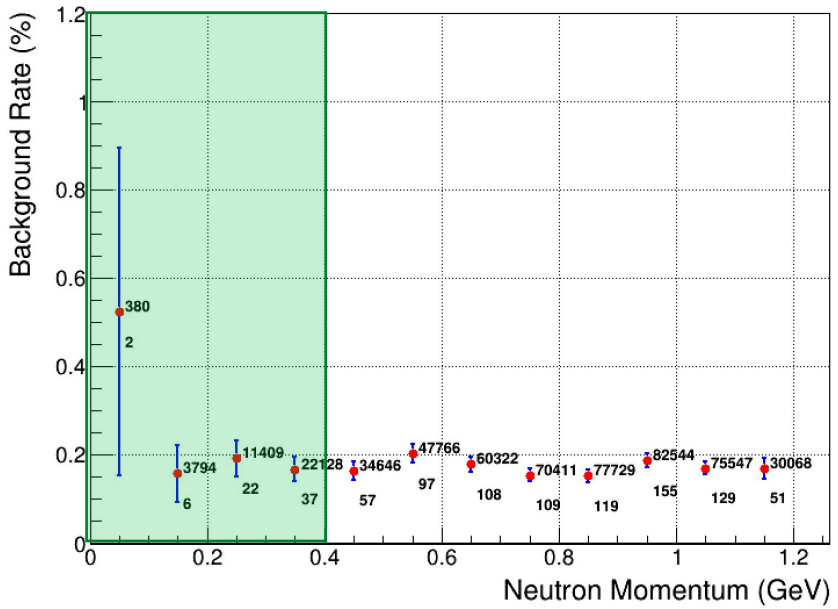


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Table 1: Decay trees and their respective final states.

rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$J/\psi \to \pi^- \bar{n} p$	$\pi^- \bar{n} p$	0	515241	515241
2	$J/\psi \to \eta_c \gamma, \eta_c \to \pi^- \bar{n} p$	$\pi^- \bar{n} p \gamma$	1	700	515941
3	$J/\psi \to \pi^- \bar{n} p \gamma^f$	$\pi^- \bar{n} p \gamma^f$	2	648	516589
4	$J/\psi \to \bar{n}\Delta^0, \Delta^0 \to \pi^- p$	$\pi^- \bar{n} p$	3	400	516989
5	$J/\psi \to p\bar{\Delta}^+, \bar{\Delta}^+ \to \pi^- \bar{n}$	$\pi^- \bar{n} p$	4	370	517359
6	$J/\psi \to \pi^- \bar{n} p \gamma^F$	$\pi^- \bar{n} p \gamma^F$	7	83	517442
7	$J/\psi \to \pi^- \bar{n}\Delta^+, \Delta^+ \to \pi^0 p$	$\pi^0 \pi^- \bar{n} p$	11	26	517468
8	$J/\psi \to \pi^- \bar{\Delta}^0 p, \bar{\Delta}^0 \to \pi^0 \bar{n}$	$\pi^0 \pi^- \bar{n} p$	16	15	517483
9	$J/\psi \to \pi^0\pi^0\pi^0\pi^+\pi^-$	$\pi^0\pi^0\pi^0\pi^+\pi^-$	9	13	517496
10	$J/\psi \to \pi^0 \pi^- \bar{n} p$	$\pi^0 \pi^- \bar{n} p$	22	13	517509
11	$J/\psi \to e^+ e^- \gamma^f \gamma^f$	$e^+ e^- \gamma^f \gamma^f$	17	7	517516
12	$J/\psi \to \Lambda\bar{\Lambda}, \Lambda \to \pi^- p, \bar{\Lambda} \to \pi^0 \bar{n}$	$\pi^0 \pi^- \bar{n} p$	12	6	517522
13	$J/\psi \to \pi^0 \pi^- K_S^0 K^+, K_S^0 \to \pi^0\pi^0$	$\pi^0\pi^0\pi^0\pi^- K^+$	29	6	517528
14	$J/\psi \to \Sigma^+\bar{\Sigma}^-, \Sigma^+ \to \pi^0 p, \bar{\Sigma}^- \to \pi^- \bar{n}$	$\pi^0 \pi^- \bar{n} p$	18	4	517532
15	$J/\psi \to \eta'\gamma, \eta' \to \pi^+\pi^-\gamma^F$	$\pi^+\pi^-\gamma^F\gamma$	25	4	517536
16	$J/\psi \to \pi^+\pi^-\eta\gamma^F, \eta \to \gamma\gamma$	$\pi^+\pi^-\gamma^F\gamma\gamma$	26	4	517540
17	$J/\psi \to e^+ e^- \gamma^f$	$e^+ e^- \gamma^f$	28	4	517544
18	$J/\psi \to \pi^0\pi^0 h_1(1170), h_1(1170) \to \pi^-\rho^+, \rho^+ \to \pi^0\pi^+$	$\pi^0\pi^0\pi^0\pi^+\pi^-$	20	4	517548
19	$J/\psi \to K^+\bar{K}_1^{'-}, \bar{K}_1^{'-} \to \pi^0 K^{*-}, K^{*-} \to \pi^-\bar{K}^0, \bar{K}^0 \to K_L^0$	$\pi^0 K_L^0 \pi^- K^+$	30	4	517552
20	$J/\psi \to \eta\omega, \eta \to \pi^0\pi^0\pi^0, \omega \to \pi^0\pi^+\pi^-$	$\pi^0\pi^0\pi^0\pi^0\pi^+\pi^-$	19	3	517555
21	$J/\psi \to K^+\bar{K}_1^{'-}, \bar{K}_1^{'-} \to \pi^0 K^{*-}, K^{*-} \to \pi^-\bar{K}^0, \bar{K}^0 \to K_S^0, K_S^0 \to \pi^0\pi^0$	$\pi^0\pi^0\pi^0\pi^- K^+$	45	3	517558
22	$J/\psi \to \pi^0\pi^0\pi^+\pi^-\gamma^F$	$\pi^0\pi^0\pi^+\pi^-\gamma^F$	66	3	517561
23	$J/\psi \to \pi^0 K_S^0 K^*, K_S^0 \to \pi^0\pi^0, K^* \to \pi^- K^+$	$\pi^0\pi^0\pi^0\pi^- K^+$	35	2	517563
24	$J/\psi \to \pi^0 K^+ K^{*-}, K^{*-} \to \pi^-\bar{K}^0, \bar{K}^0 \to K_L^0$	$\pi^0 K_L^0 \pi^- K^+$	38	2	517565
25	$J/\psi \to \pi^-\bar{K}^* K^{*+}, \bar{K}^* \to \pi^0\bar{K}^0, K^{*+} \to \pi^0 K^+, \bar{K}^0 \to K_L^0$	$\pi^0\pi^0 K_L^0 \pi^- K^+$	40	2	517567
26	$J/\psi \to \pi^- K_2^{*0} K^+, K_2^{*0} \to \pi^0\bar{K}^0, \bar{K}^0 \to K_L^0$	$\pi^0 K_L^0 \pi^- K^+$	41	2	517569
27	$J/\psi \to \pi^+\pi^-\eta\gamma^F, \eta \to \pi^0\pi^0\pi^0$	$\pi^0\pi^0\pi^0\pi^+\pi^-\gamma^F$	10	2	517571
28	$J/\psi \to \pi^0 h_1(1170), h_1(1170) \to \pi^0\rho^0, \rho^0 \to \pi^+\pi^-$	$\pi^0\pi^0\pi^+\pi^-$	49	2	517573
29	$J/\psi \to \pi^0\pi^0 h_1(1170), h_1(1170) \to \pi^0\rho^0, \rho^0 \to \pi^+\pi^-$	$\pi^0\pi^0\pi^0\pi^+\pi^-$	50	2	517575
30	$J/\psi \to p\bar{\Delta}^+, \bar{\Delta}^+ \to \pi^-\bar{n}\gamma^f$	$\pi^-\bar{n}p\gamma^f$	59	2	517577
31	$J/\psi \to \Delta^0\bar{\Delta}^0, \Delta^0 \to \pi^- p, \bar{\Delta}^0 \to \pi^0\bar{n}$	$\pi^0\pi^-\bar{n}p$	34	2	517579
32	$J/\psi \to K^*\bar{K}^*\gamma, K^* \to \pi^- K^+, \bar{K}^* \to \pi^0\bar{K}^0, \bar{K}^0 \to K_S^0, K_S^0 \to \pi^0\pi^0$	$\pi^0\pi^0\pi^0\pi^- K^+\gamma$	70	2	517581

Control Sample of $\bar{n}$ from $J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$

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- QCharge=0 && nGoodCharge=4

✓ PID: use tof and dE/dx info

- prob>0.001 & highest prob
- $N_p \geq 1$ & $N_{\pi^-} \geq 2$ &$N_{\pi^+} \geq 1$

✓ Vertex Fit:

- Loop all the p, π^-、π^-、π^+ tracks, and select the combination with minimum $\chi^2_{\text{vertex fit}}$
- IPVxy<1 cm; IPVz<5 cm
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✓ Addtional track:

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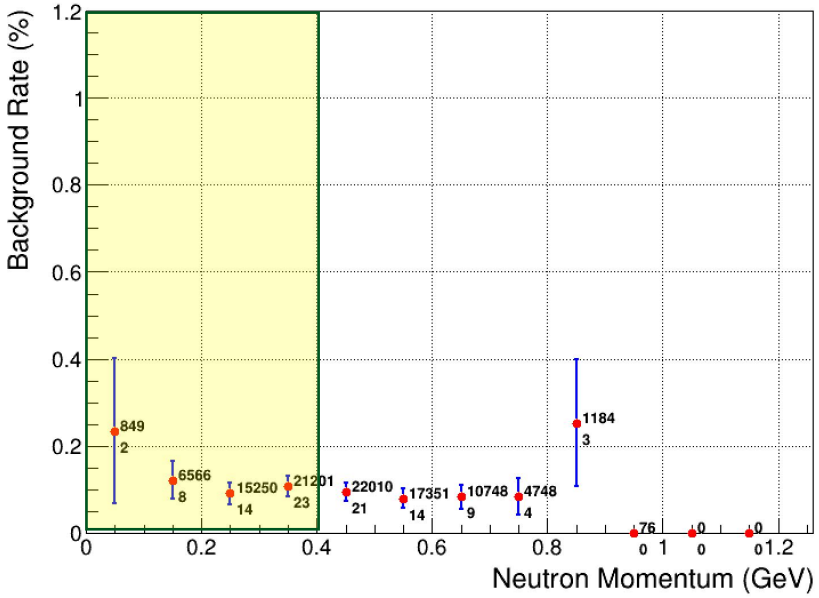
✓ Recoil $\bar{n}$:

- $P_{\bar{n}} = P_{J/\psi} - P_p - P_{\pi^-} - P_{\pi^-} - P_{\pi^+}$
- 0.92 GeV < $M^{\text{recoil}}_{p\pi^-\pi^+\pi^-}$ < 0.96 GeV

✓ EMC

- Time: [0, 700] ns
- Barrel: E_n > 25 MeV ($|\cos\theta| < 0.80$)
- Endcap: E_n > 50 MeV($0.86 < |\cos\theta| < 0.92$)
- nGoodShw >0; θrecoil_leadingshw < 30^0



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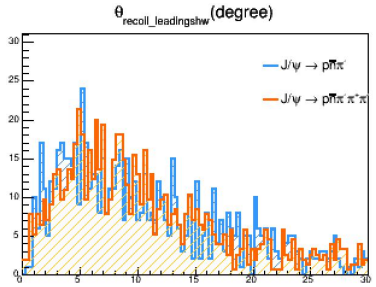
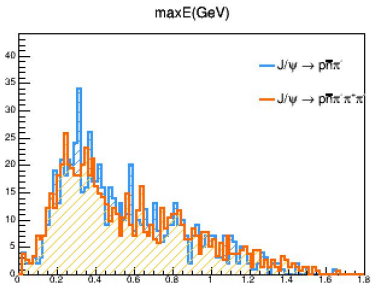
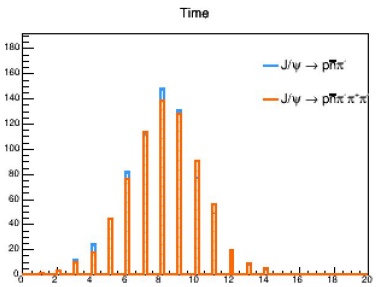
Comparison of $\bar{n}$ properties

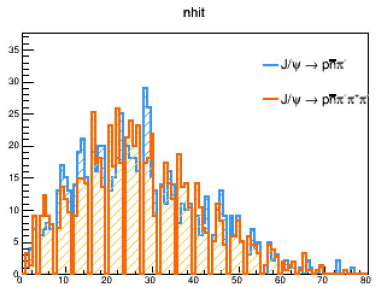
- Comparing $\bar{n}$ with $J/\psi \to p\bar{n}\pi^-$ and $J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$

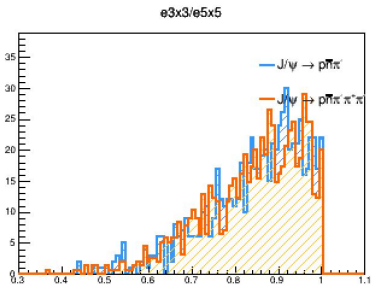
$0 < p_{\bar{n}} < 100$ MeV

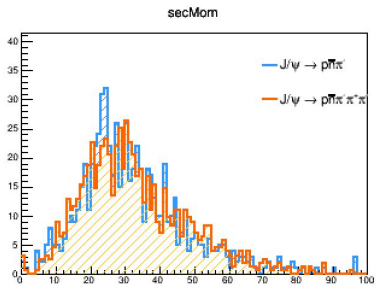


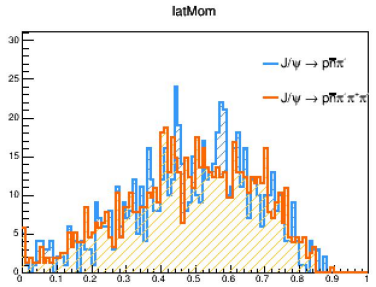


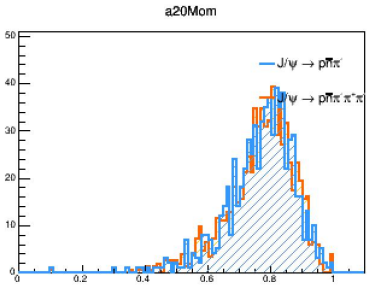


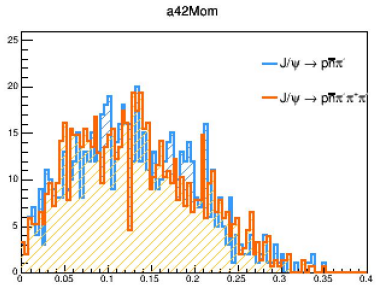




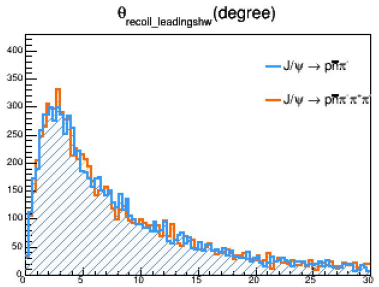


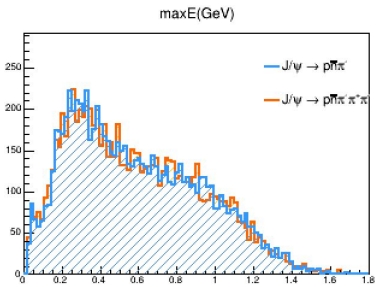


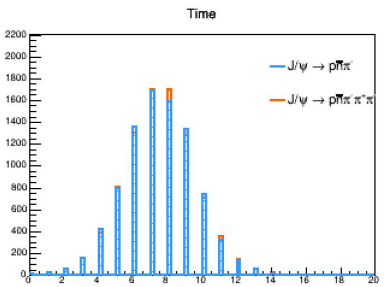


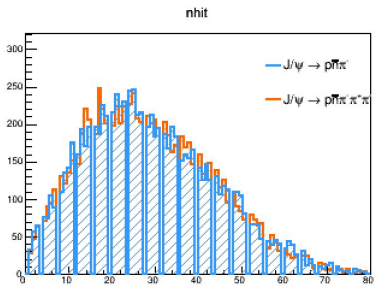


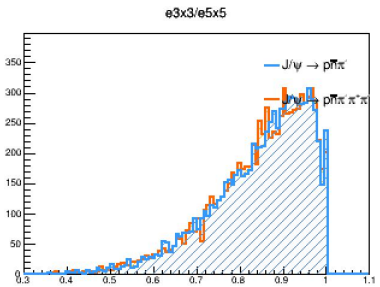
$100 < p_{\bar{n}} < 200$ MeV

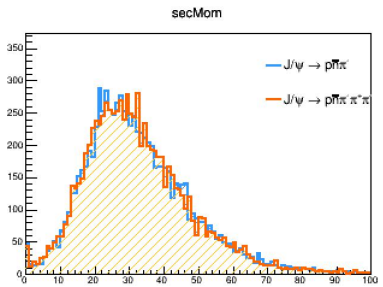


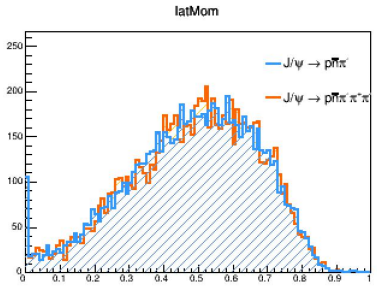


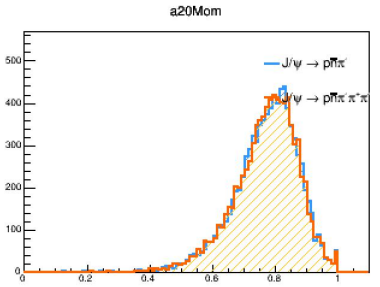


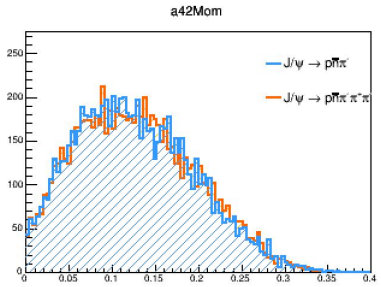












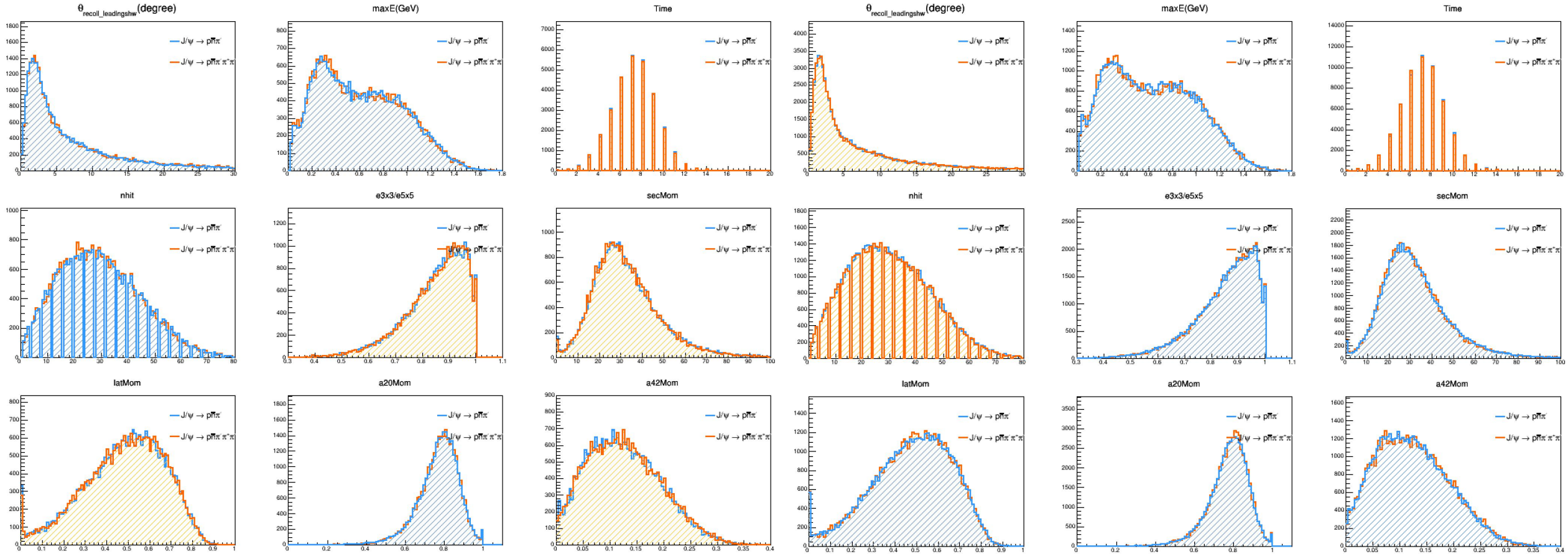
Almost identical !

Comparison of $\bar{n}$ properties

- Comparing $\bar{n}$ with $J/\psi \to p\bar{n}\pi^-$ and $J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$

$200 < p_{\bar{n}} < 300$ MeV

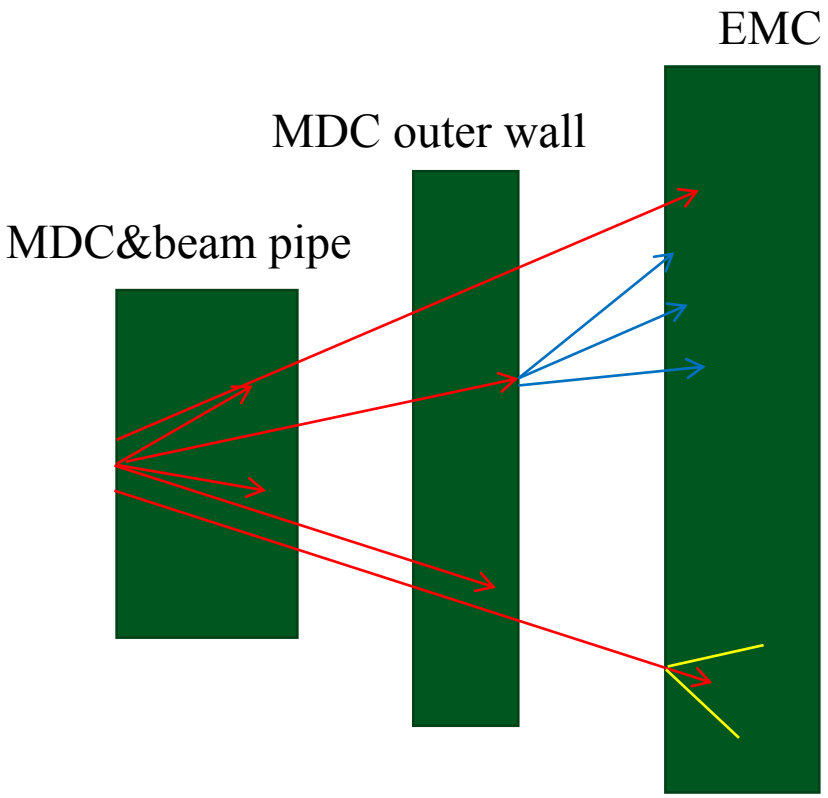
$300 < p_{\bar{n}} < 400$ MeV



Almost identical ! Consider combining $J/\psi \to p\bar{n}\pi^-$ and $J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$ as control sample.

Reaction rate in EMC

- Reaction Rate = Ncut/Nall



$J/\psi \to p\bar{n}\pi^-$

› Nall:
- QCharge=0 & nGoodCharge=2
- $N_p \geq 1$ & $N_{\pi^-} \geq 1$
- $\chi^2_{\text{vertex fit}} < 5$
- 0.92 GeV < $M^{\text{recoil}}_{p\pi^-}$ < 0.96 GeV

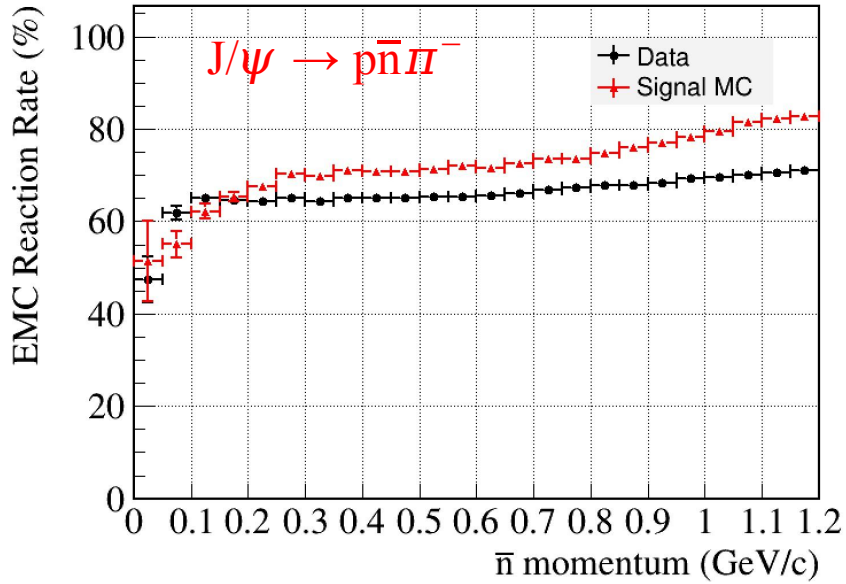
› Ncut:
- nremaintrack = 0
- nGam > 0
- θrecoil_leadingshw < 30^0

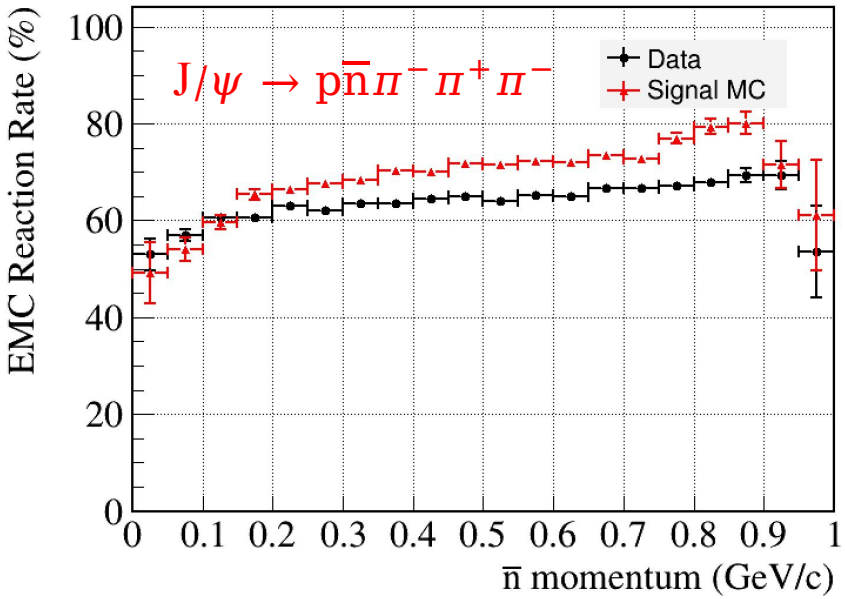
$J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$

› Nall:
- QCharge=0 & nGoodCharge=4
- $N_p \geq 1$ & $N_{\pi^-} \geq 2$ & $N_{\pi^+} \geq 1$
- $\chi^2_{\text{vertex fit}} < 5$
- 0.92 GeV < $M^{\text{recoil}}_{p\pi^-\pi^+\pi^-}$ < 0.96 GeV

› Ncut:
- nremaintrack = 0
- nGam > 0
- θrecoil_leadingshw < 30^0

Reaction rate in EMC





_x001A_E^{cor}(MeV)	Lumi.(pb^{-1})	Estimated results (from $p\bar{n}\pi^-$)	Estimated results (from $p\bar{n}\pi^-\pi^+\pi^-$)
1879.139 ± 0.099	1.485	-	-
1880.073 ± 0.080	2.035	372	416
1880.925 ± 0.101	1.341	245	274
1882.185 ± 0.089	2.021	482	443
1886.032 ± 0.081	2.033	485	446
1890.160 ± 0.083	2.031	510	475
1903.824 ± 0.080	2.022	503	472
1943.686 ± 0.088	2.040	506	496
1973.483 ± 0.092	2.229	553	545

Outline

- Motivation
- Strategy of the analysis
  - Data and MC samples
- Control Sample of $\overline{n}$ in EMC
  - Control Sample of $\overline{n}$ from $J/\psi \to p\overline{n}\pi^-$
  - Control Sample of $\overline{n}$ from $J/\psi \to p\overline{n}\pi^-\pi^+\pi^-$
- Control Sample of $\overline{n}$ in MDC and BeamPipe
- Summary and to do list

Control Sample of $\overline{n}$ from $J/\psi \to p\overline{n}\pi^-$

✓ Charged Track

- $V_r < 0.5$cm, $V_z < 5$cm
- $N_c \geq 2$; $|\cos\theta| < 0.93$

✓ PID: use tof and dE/dx info

- Prob> 0.001 highest prob
- $N_p \geq 1, N_{\pi^-} \geq 1$

✓ Additional Charged tracks:

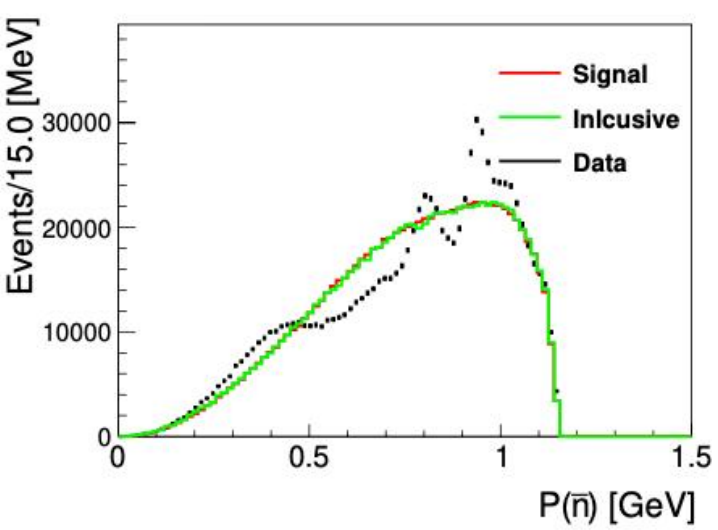
- $0.5 < V_r < 10$cm, $V_z < 30$cm
- $|\cos\theta| < 0.93$

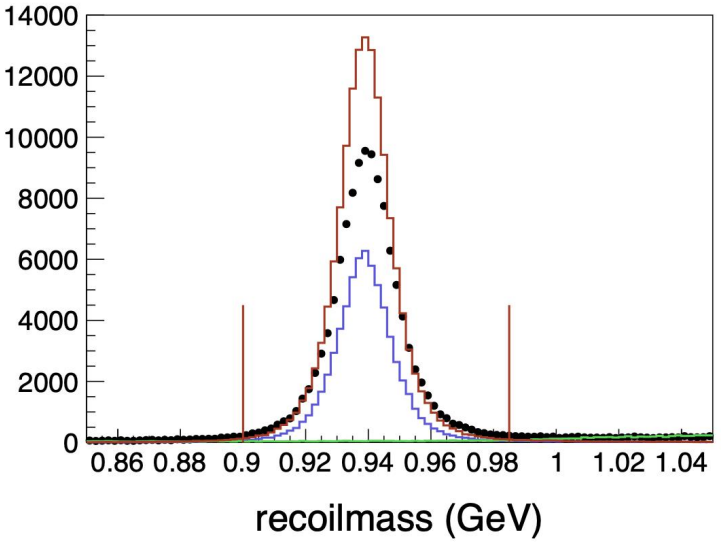
✓ VertexFit for p, π^-

- $\chi^2_{vf} < 5$

✓ VertexFit for all additional tracks

- $\theta_{\overline{n}-recoil} < 10°$





Further Selection:

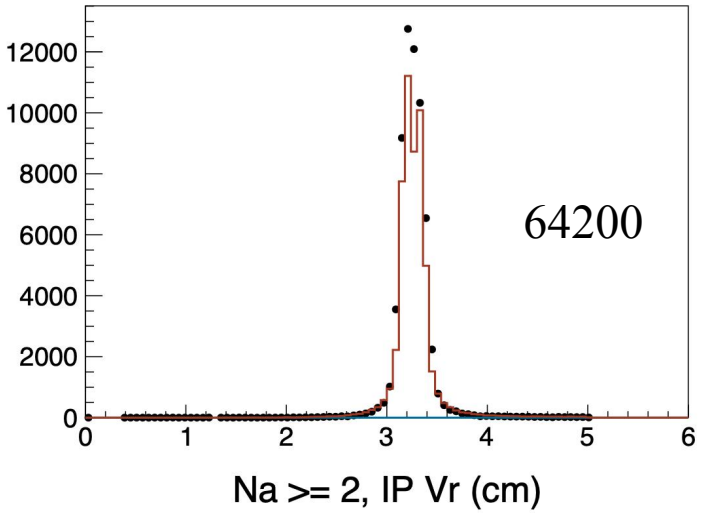
Signal region: $0.9 < M_{recoil} < 0.985$GeV

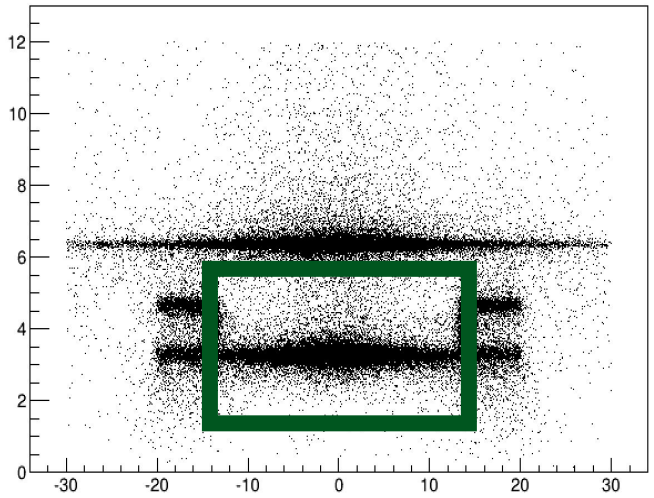
$V_r < 5, |V_z| < 10$ (select $\overline{n}$ interact with BP)

$5.8 < V_r < 7, |V_z| < 30$ (select $\overline{n}$ interact with MDC inner wall)

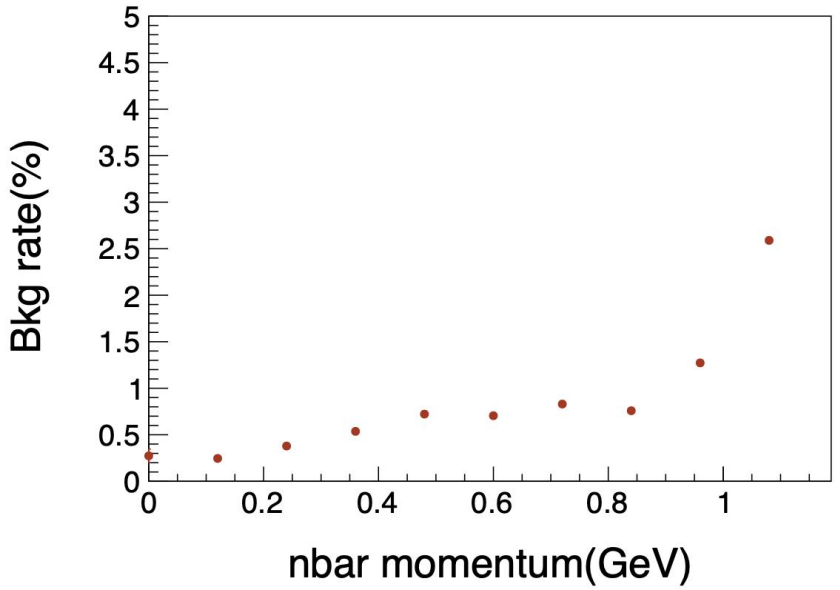
Control Sample of $\overline{n}$ from $J/\psi \to p\overline{n}\pi^-$

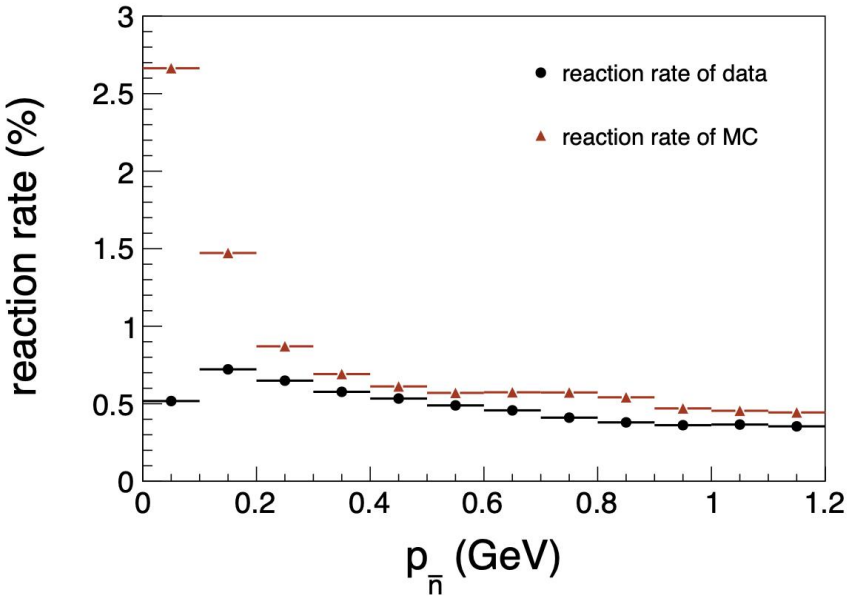
- $V_r < 5, |V_z| < 10$ (select $\overline{n}$ interact with BP)





- ✓ reaction rate $= \frac{N_{react}}{N_{recoil}}$
- N_{react}: at least 2 additional tracks
- N_{recoil}: recoiled $\overline{n}$ candidates

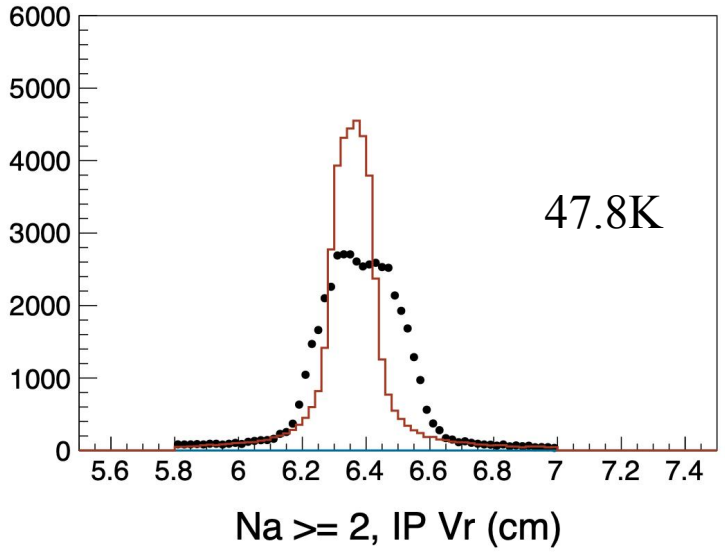


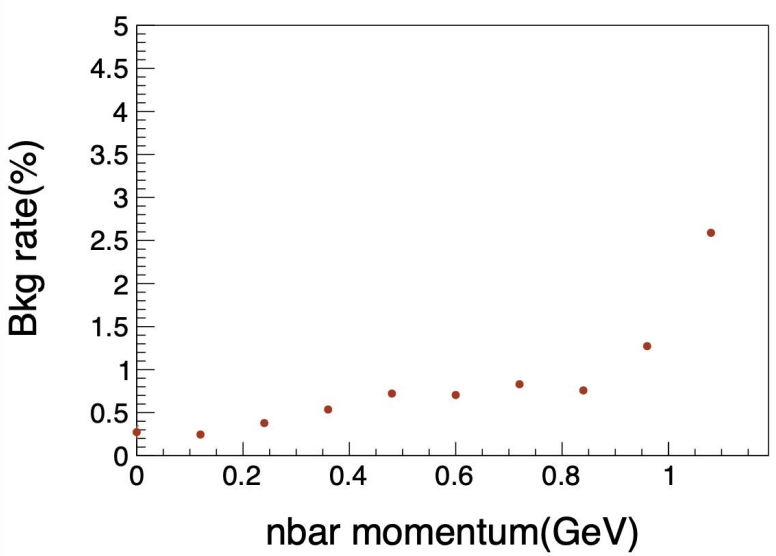


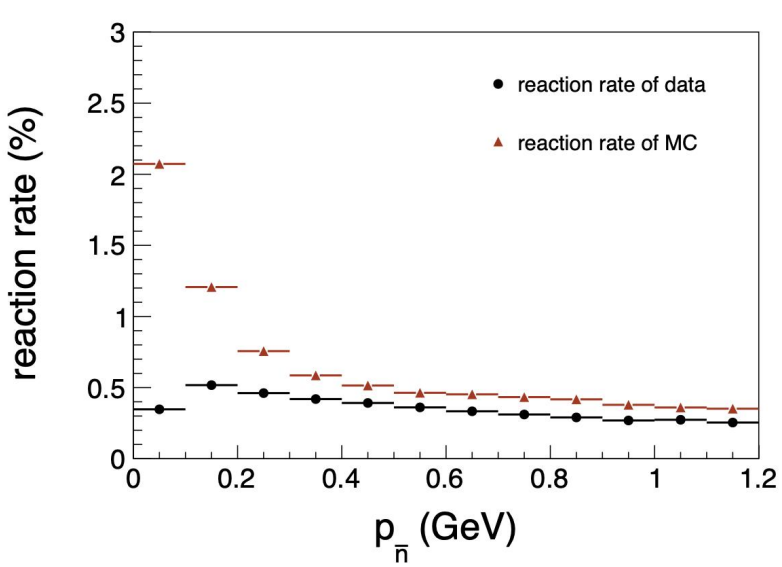
Ecor(GeV)	1.880	1.881	1.882	1.886	1.890	1.904	1.944	1.974
nEvent	4	3	4	4	5	5	5	5

Control Sample of $\bar{n}$ from $J/\psi \to p\bar{n}\pi^-$

- $5.8 < V_r < 7, |V_z| < 30$ **(select $\bar{n}$ interact with MDC inner wall)**







Ecor(GeV)	1.880	1.881	1.882	1.886	1.890	1.904	1.944	1.974
nEvent	3	2	3	3	4	4	4	4

Control Sample of $\bar{n}$ from $J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$

✓ Charged Track
- $V_r < 0.5$cm, $V_z < 5$cm
- $N_c \geq 4$; $|\cos\theta| < 0.93$

✓ PID: include tof and dE/dx info
- Prob> 0.001 highest prob
- $N_p \geq 1, N_{\pi^-} \geq 2, N_{\pi^+} \geq 1$

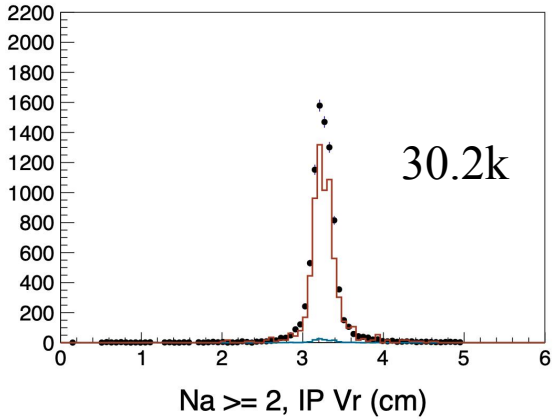
✓ Additional Charged tracks:
- $0.5 < V_r < 10$cm, $V_z < 30$cm
- $|\cos\theta| < 0.93$

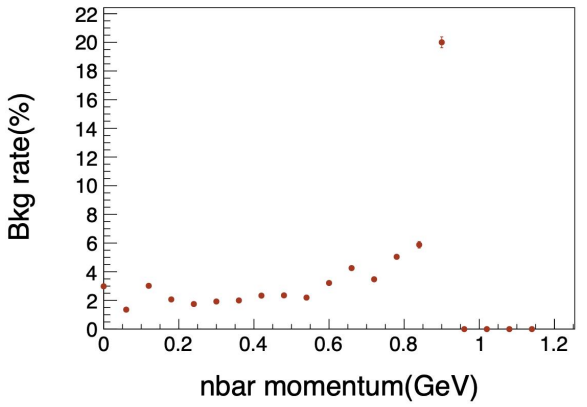
✓ VertexFit for p, π^+, π^-, π^-
- $\chi^2_{vf} < 5$

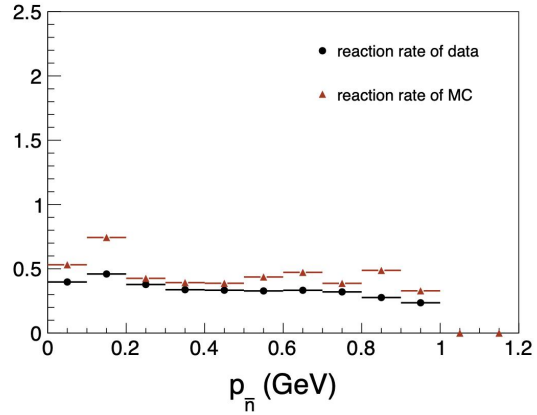
✓ VertexFit for all additional tracks
- $\theta_{\bar{n}-recoil} < 10°$

✓ Signal region:
- $0.92 < M_{\text{recoil}} < 0.96$GeV

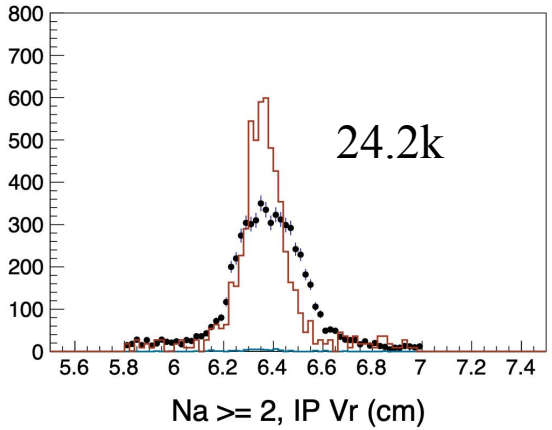
- $V_r < 5, |V_z| < 10$ (select $\bar{n}$ interact with BP)

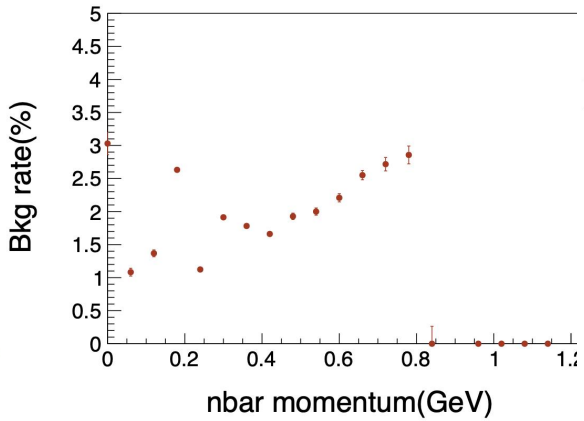


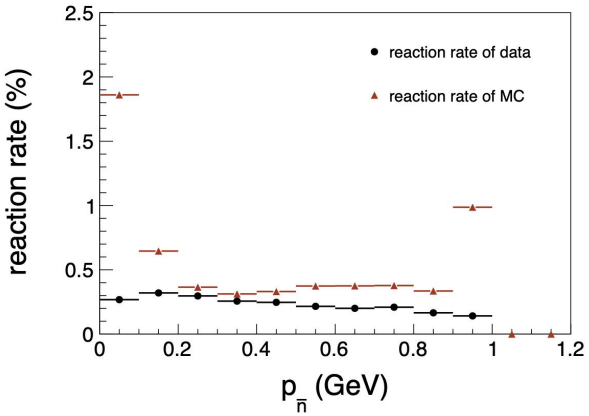




- $5.8 < V_r < 7, |V_z| < 30$ (select $\bar{n}$ interact with MDC inner wall)







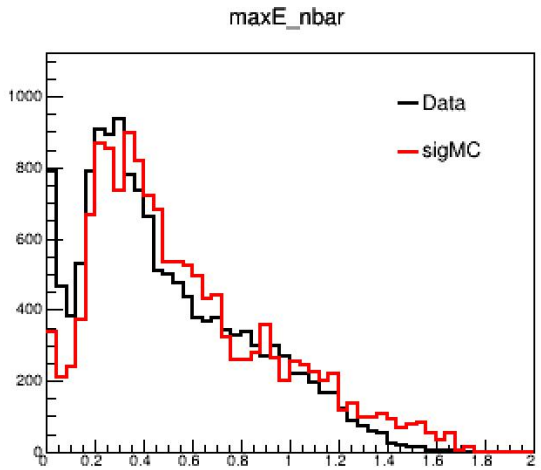
Summary and To do list

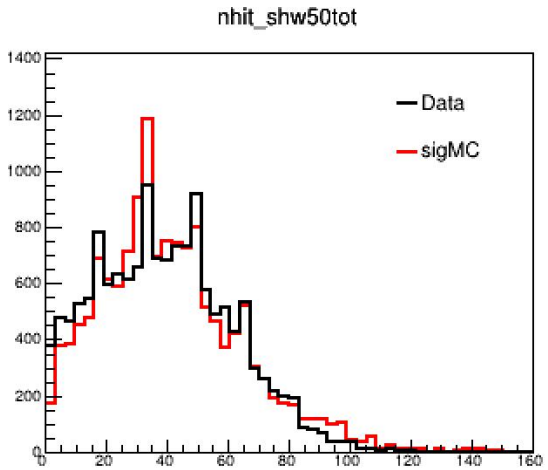
- The reaction rate in MDC and BP is very low, and it is difficult to use this part to reconstruct antineutrons. Our focus is currently on finding the signal process on EMC.
- Currently in progress: Event selection.

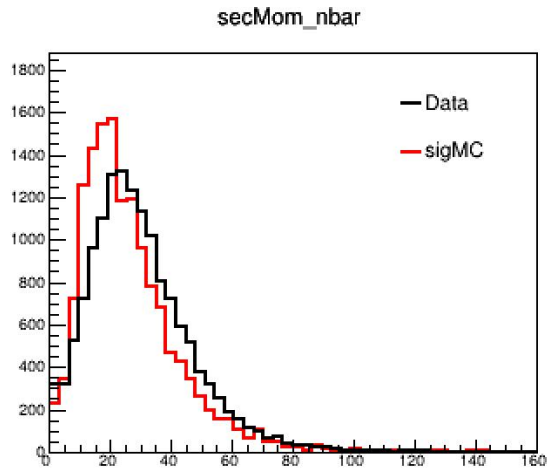
Thank You for your Attention ! ;)

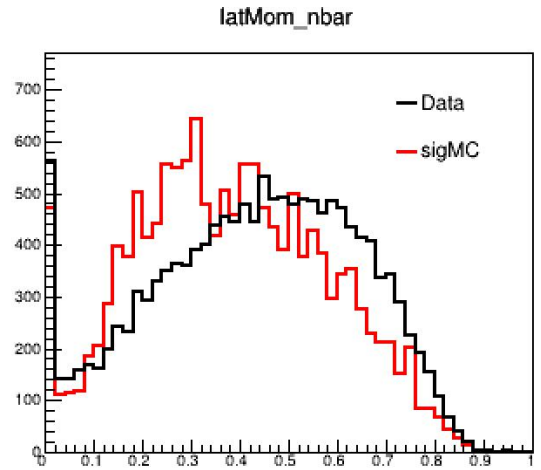
Back up

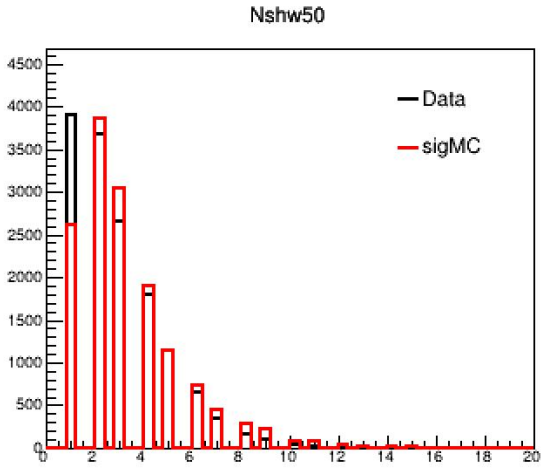
Data vs MC of $J/\psi \to p\bar{n}\pi^-$ in 0~200 MeV

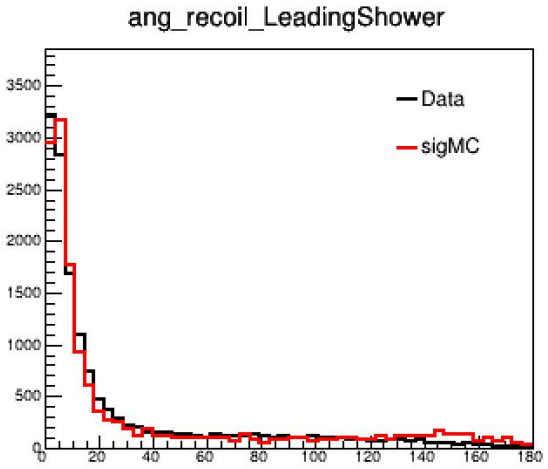


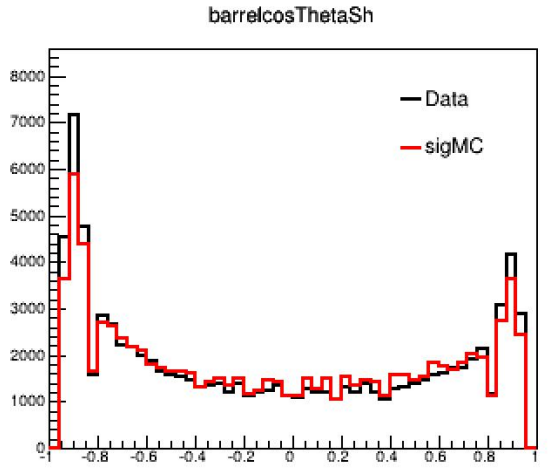


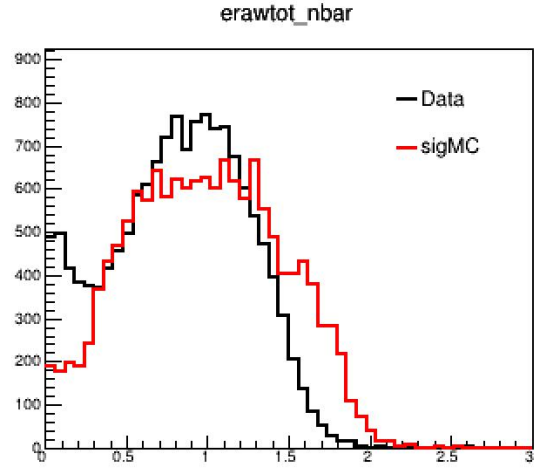




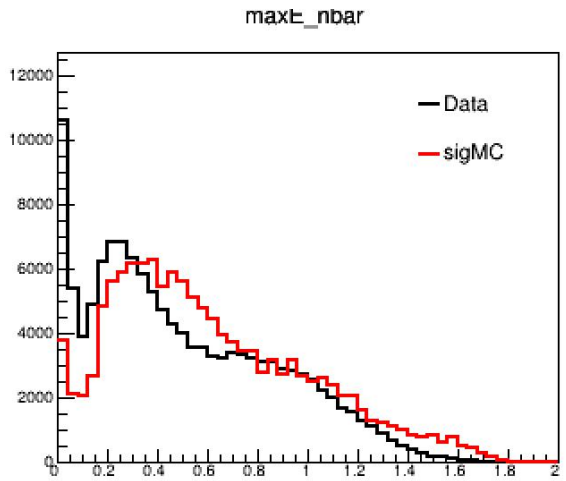


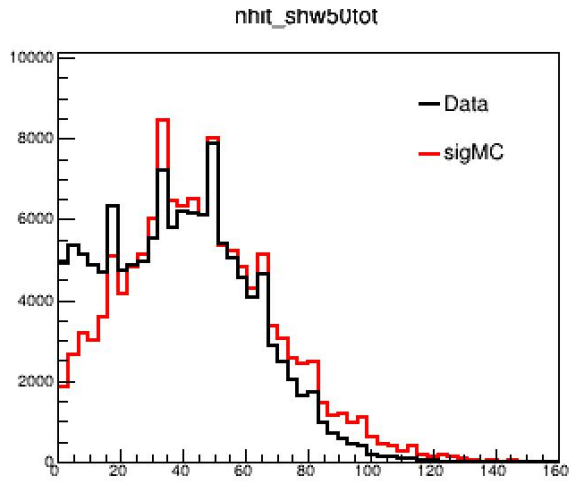


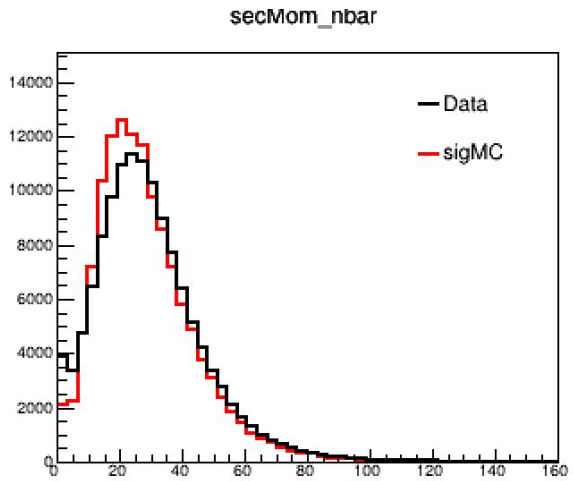


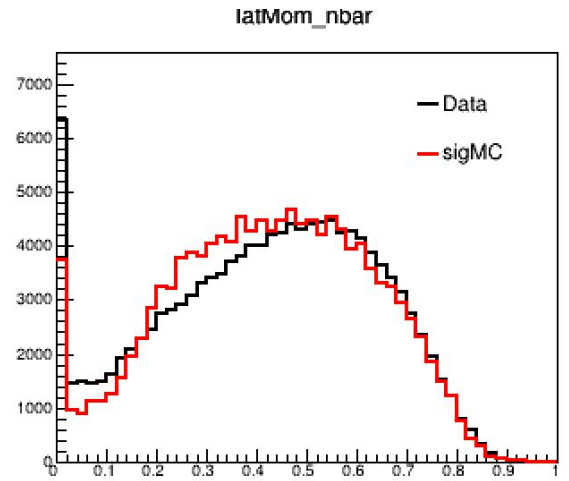


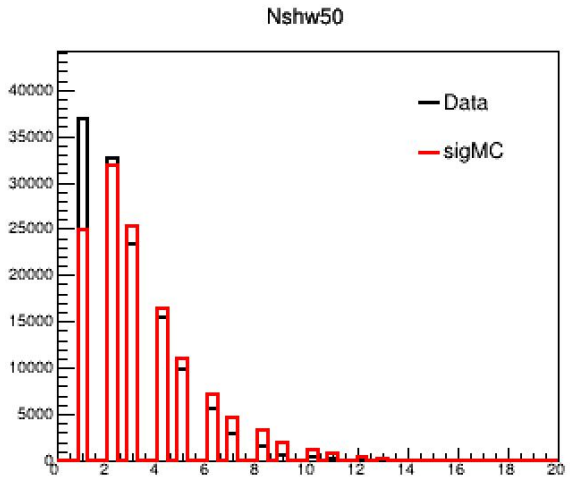
Data vs MC of $J/\psi \to p\bar{n}\pi^-$ in 200~400 MeV

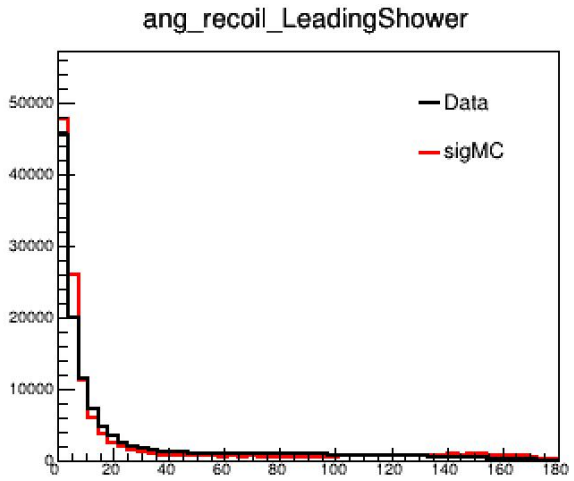


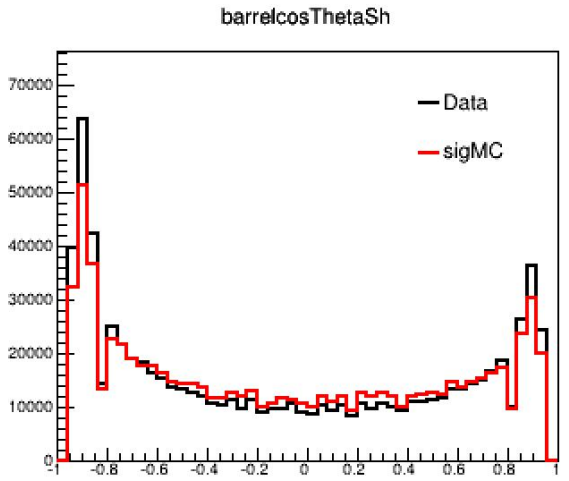


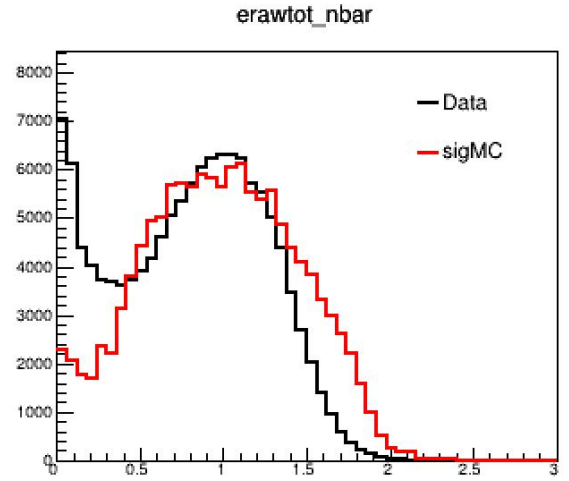




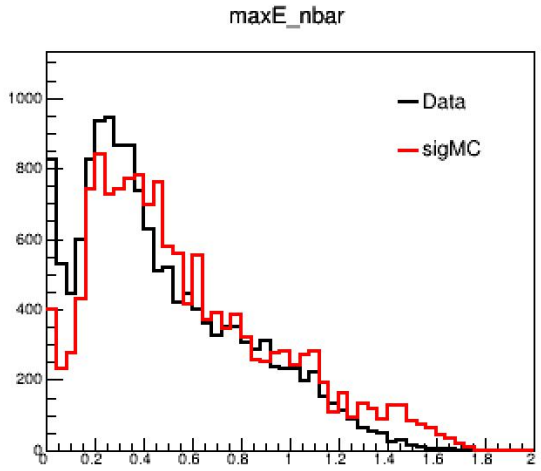


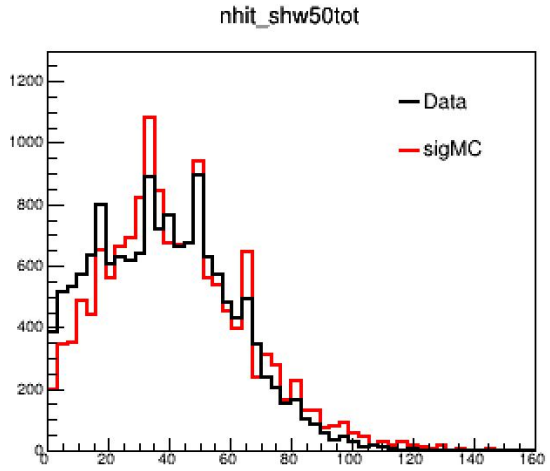


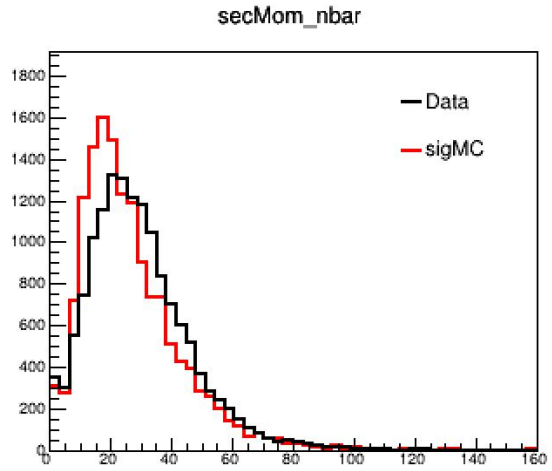


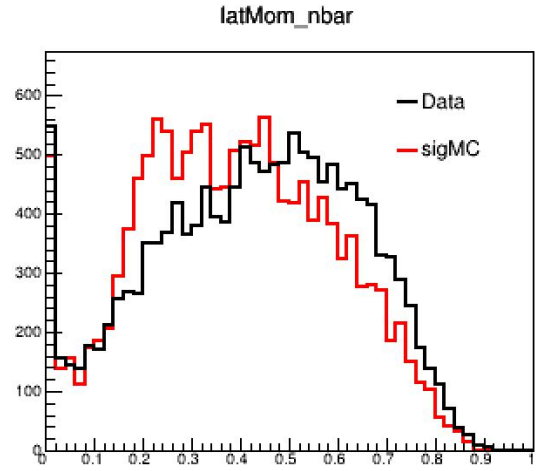


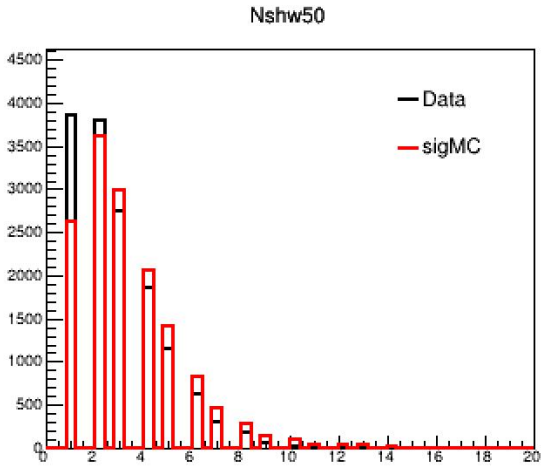
Data vs MC of $J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$ in 0~200 MeV

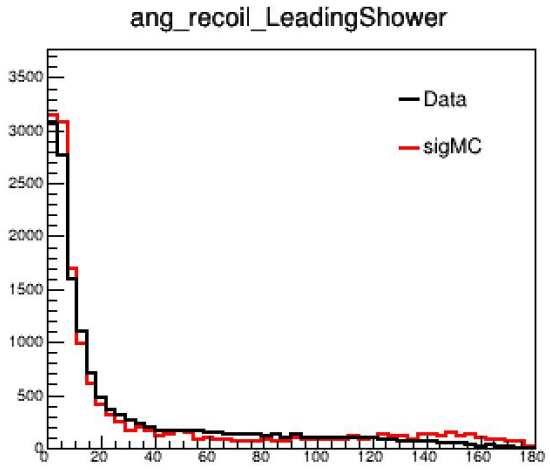


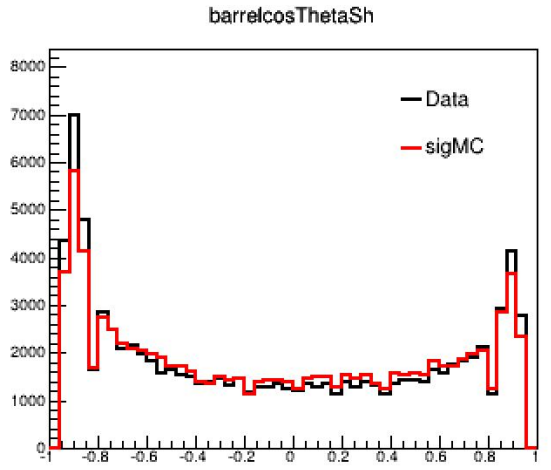


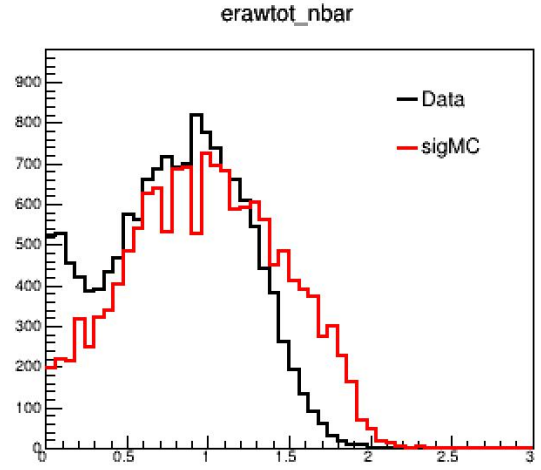




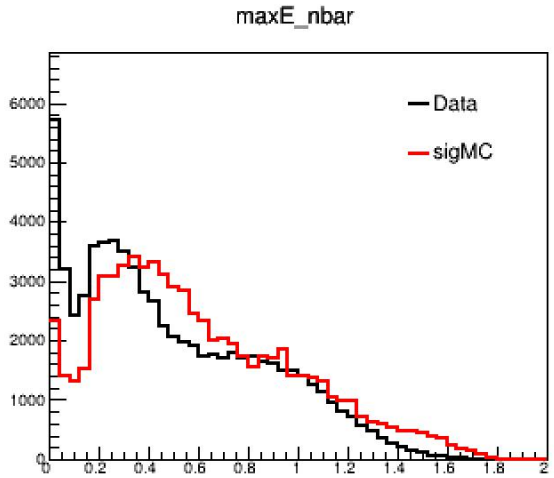


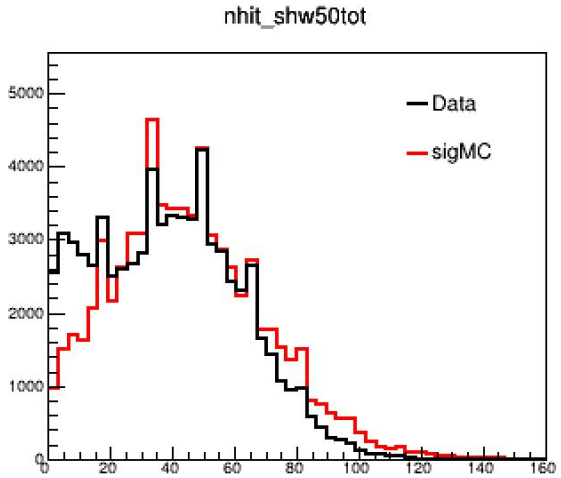


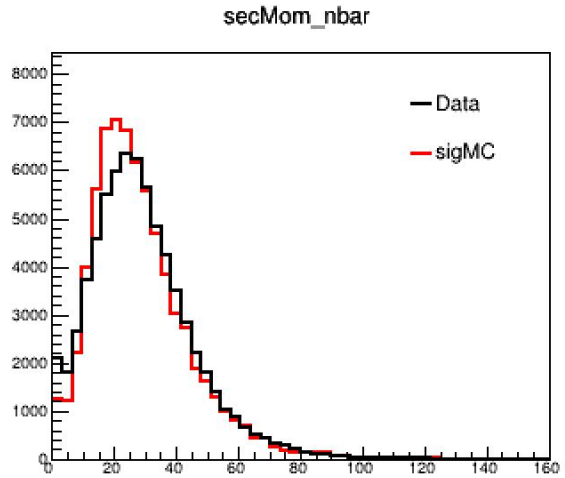


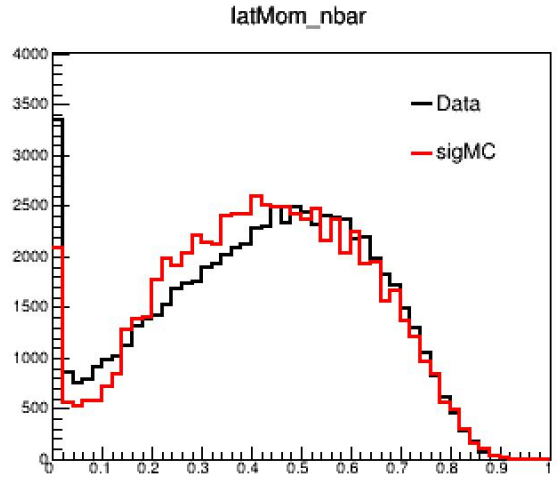


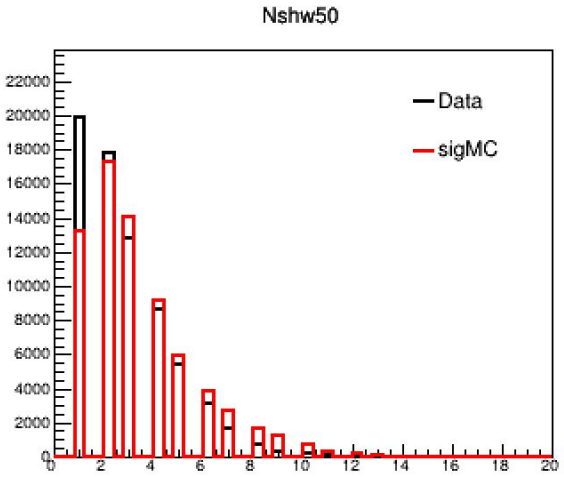
Data vs MC of $J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$ in 200~400 MeV

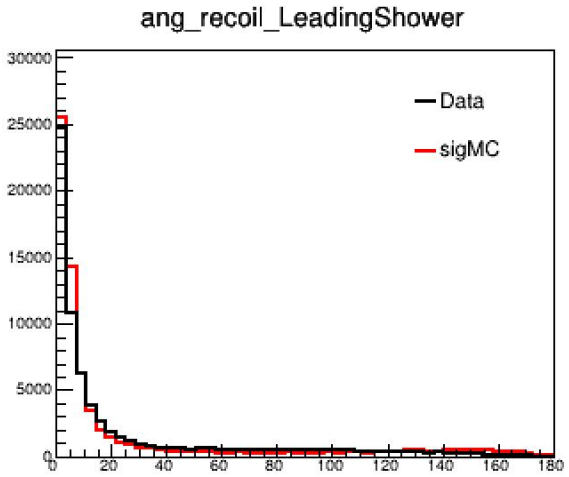


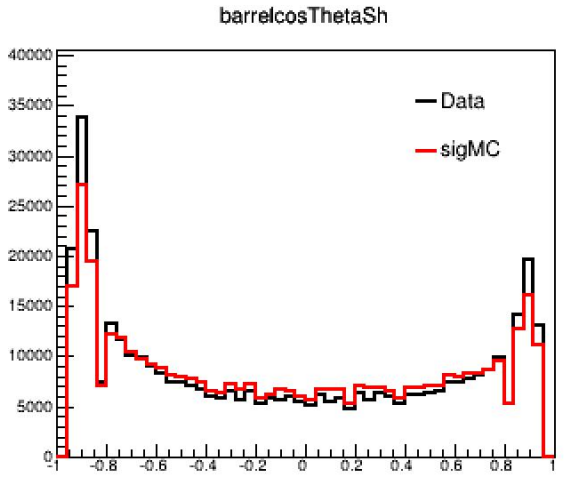


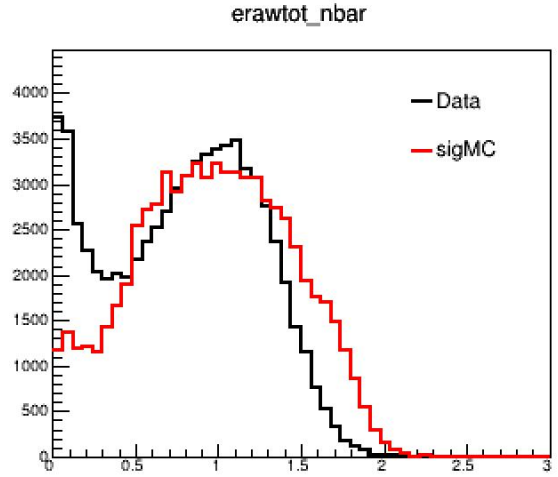




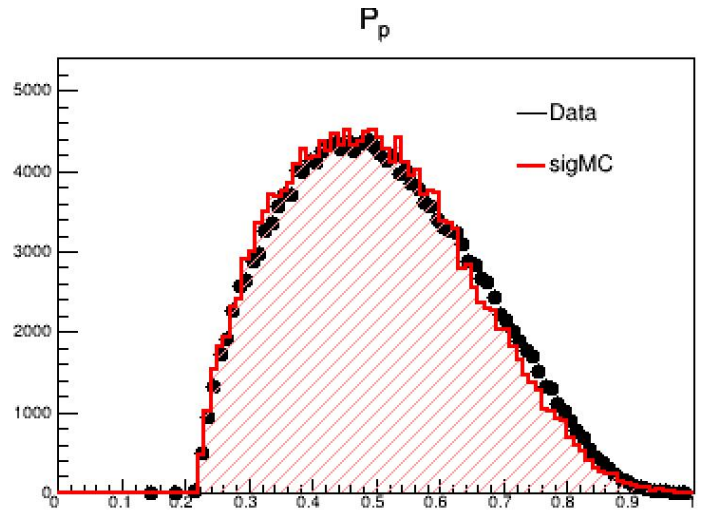


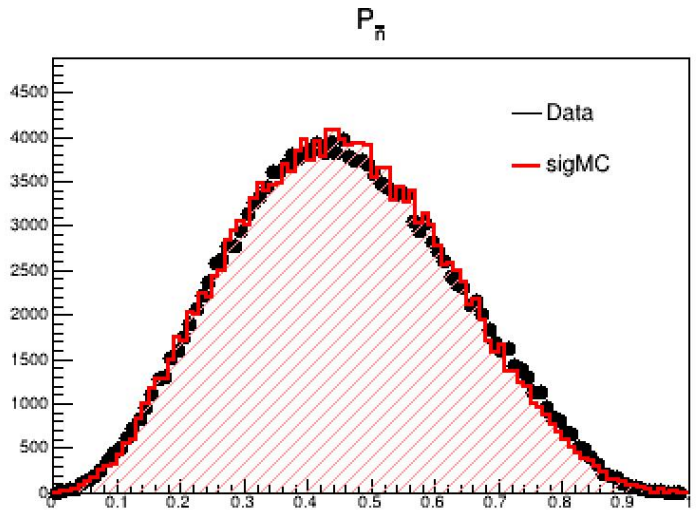


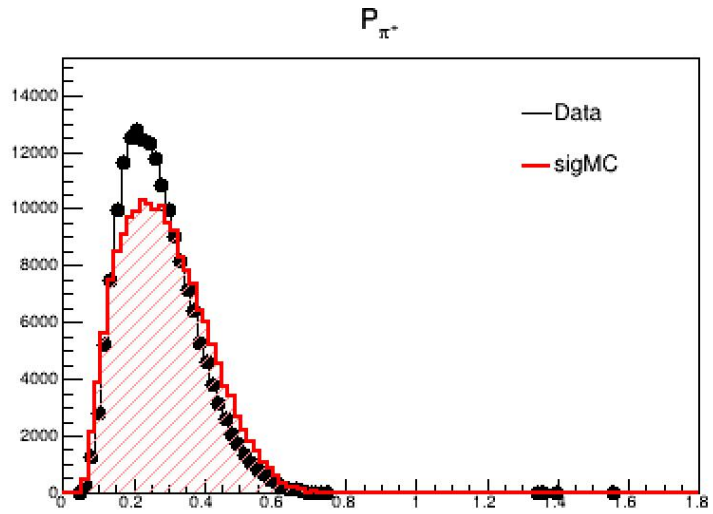


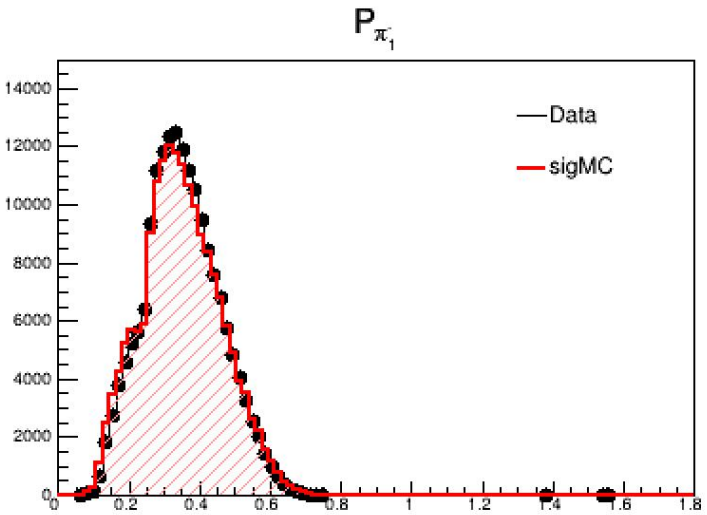


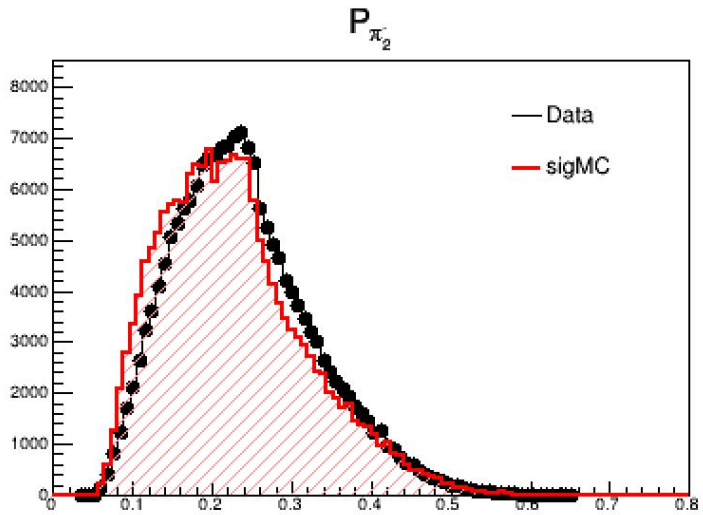
$J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$











$J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$

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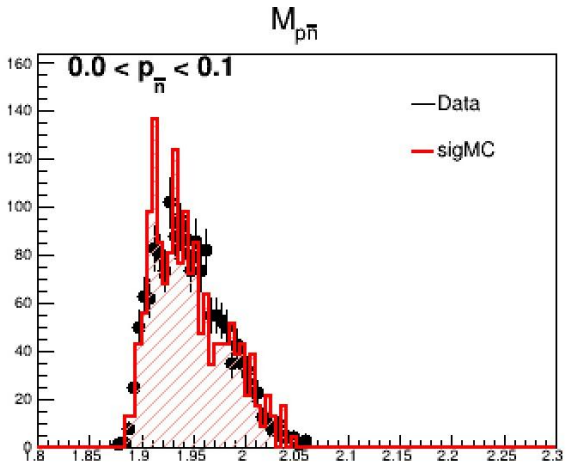
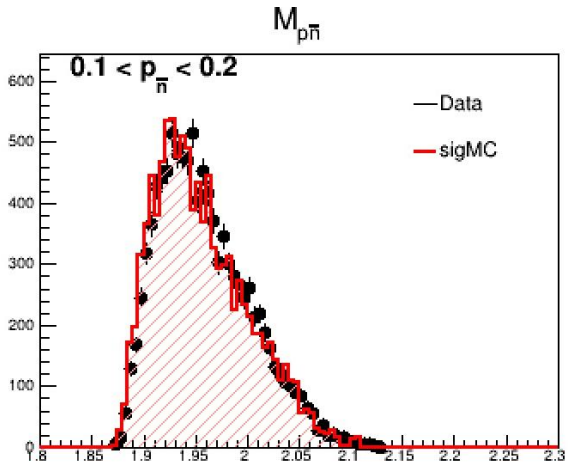
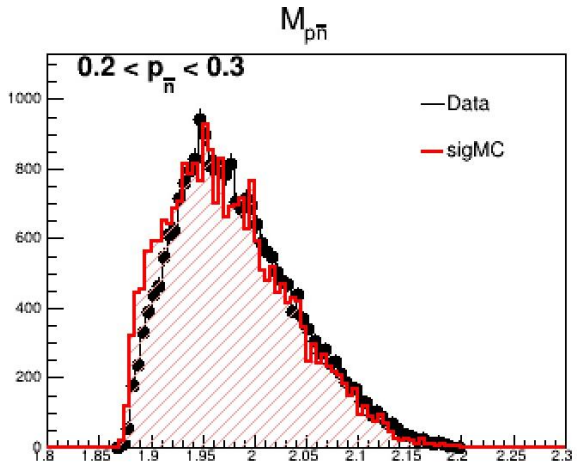
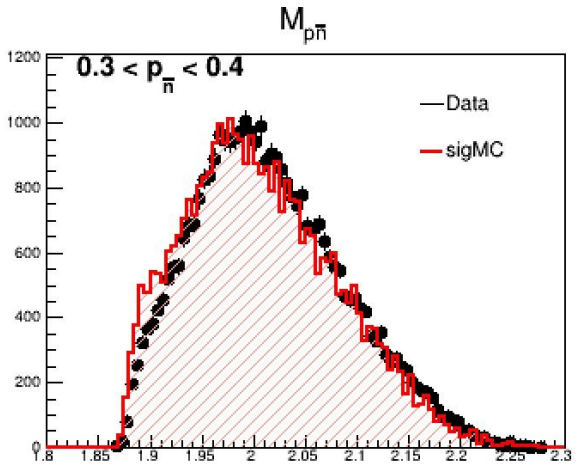
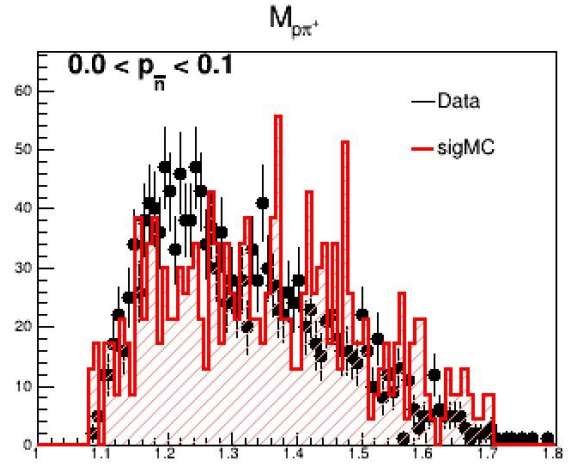
Two final particles merge:

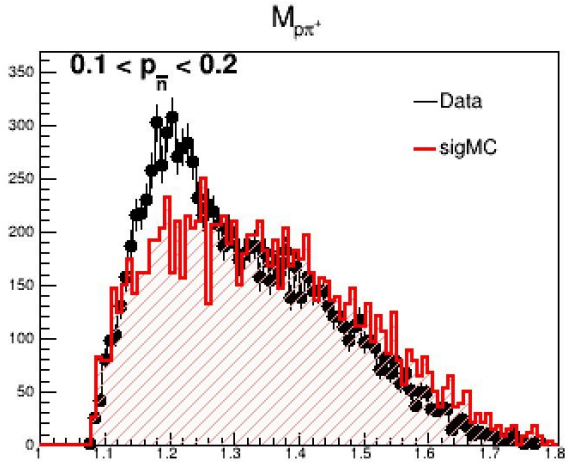


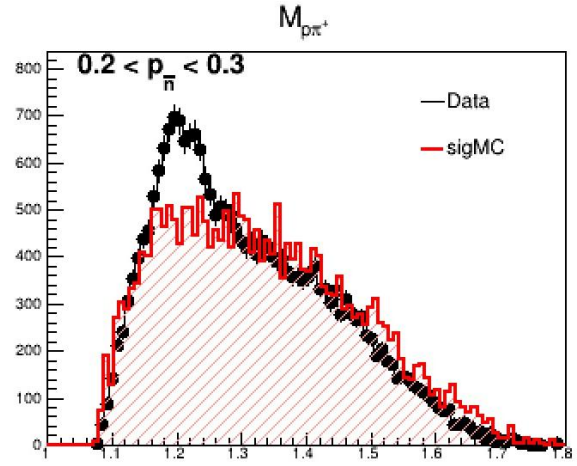


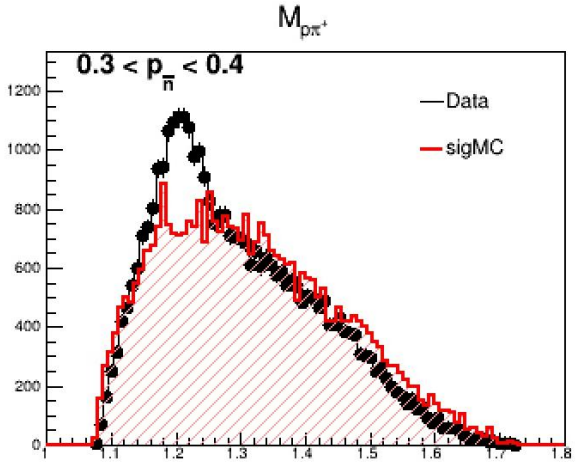




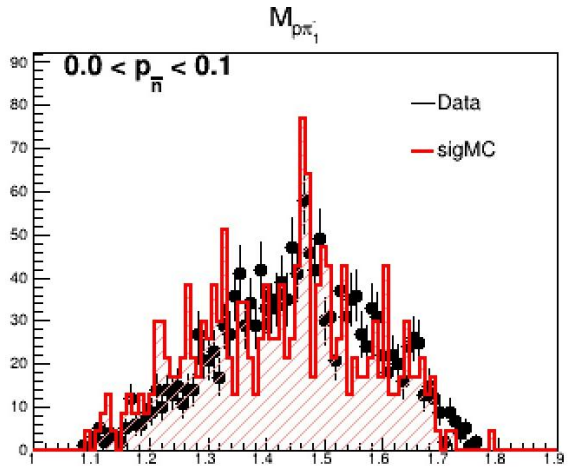


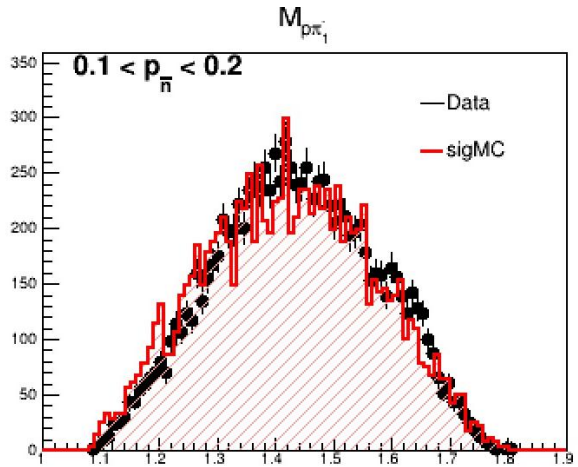


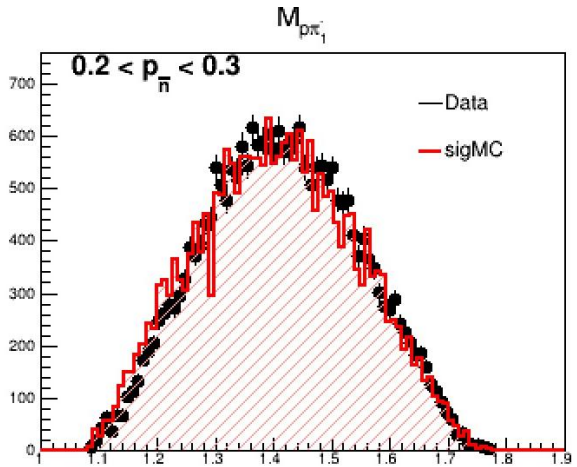


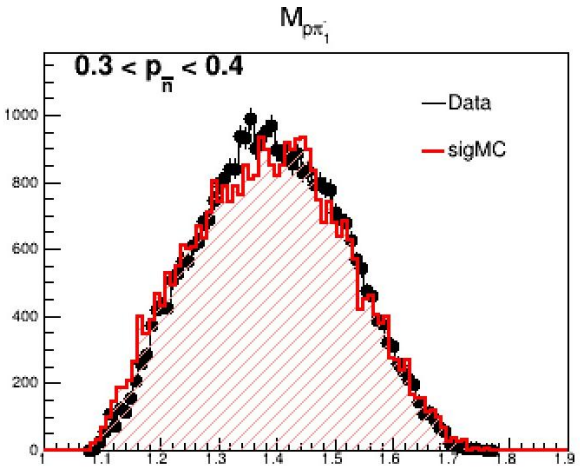


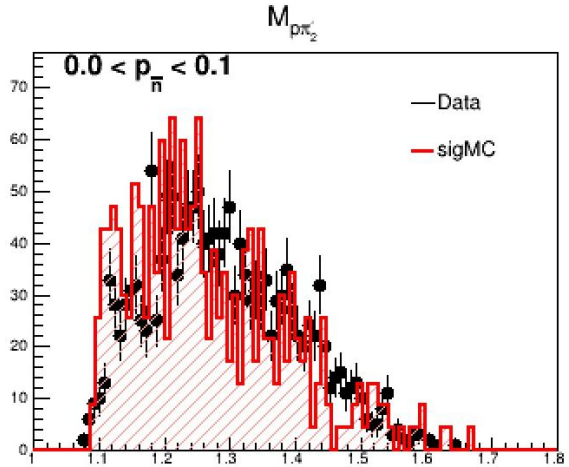
$J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$

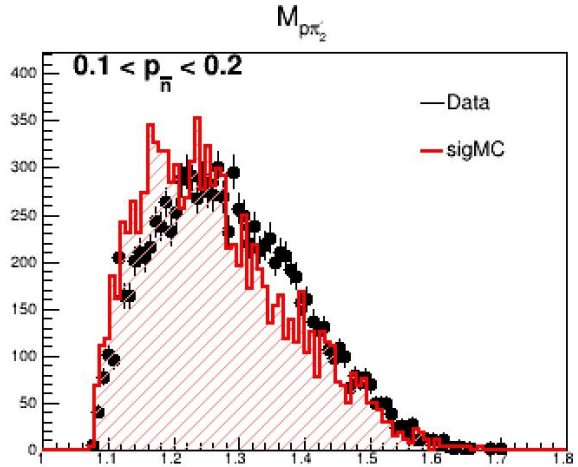


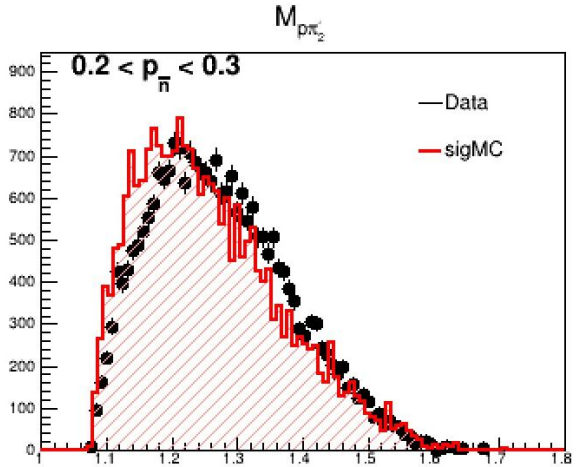


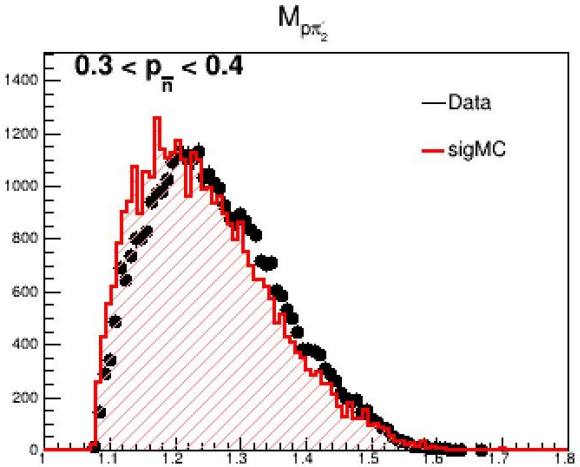




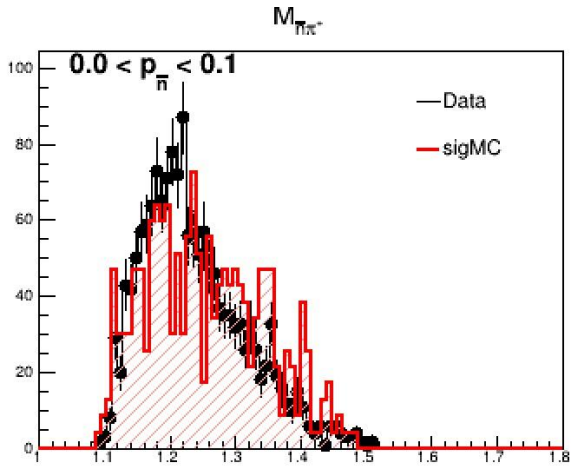


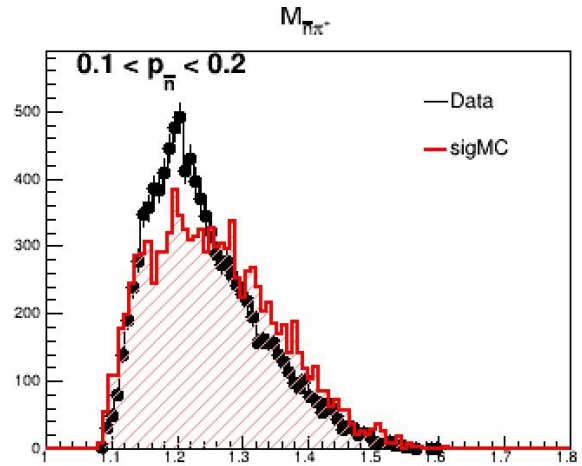


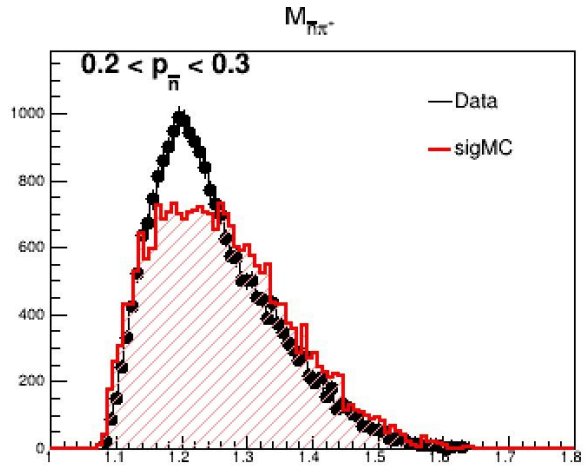


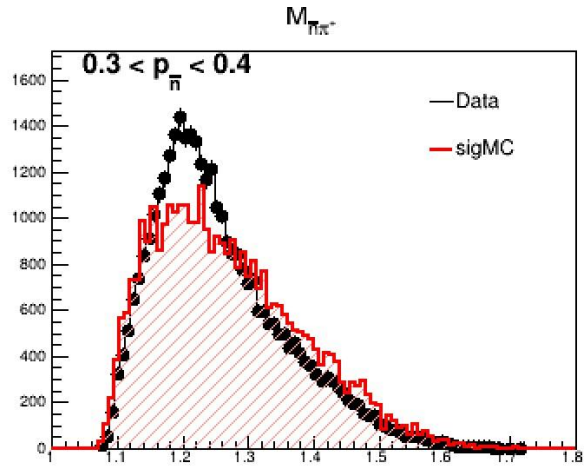


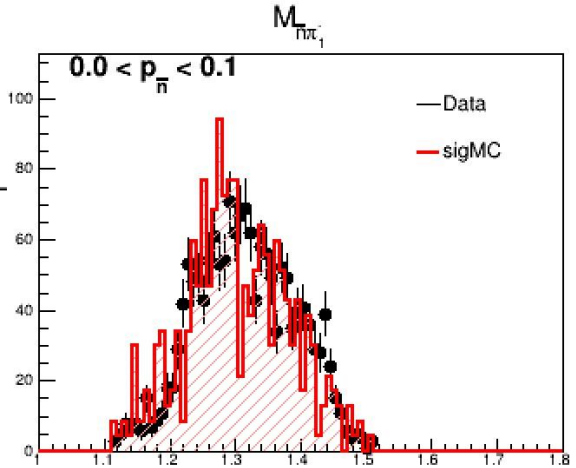
$J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$

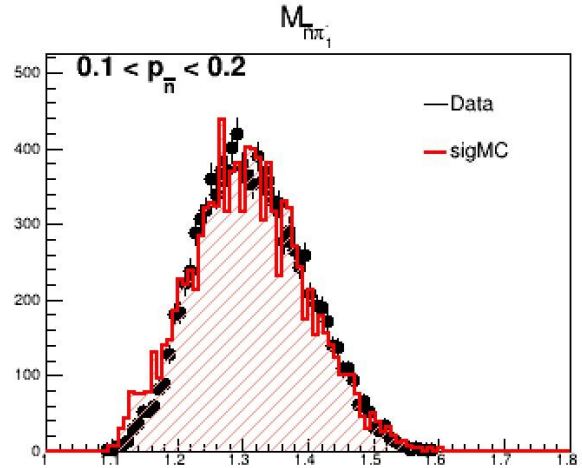


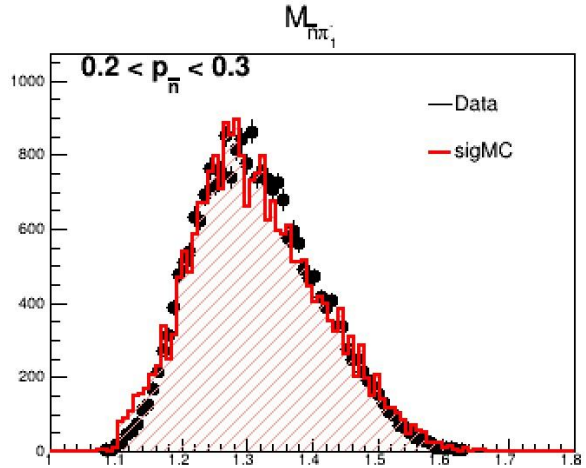


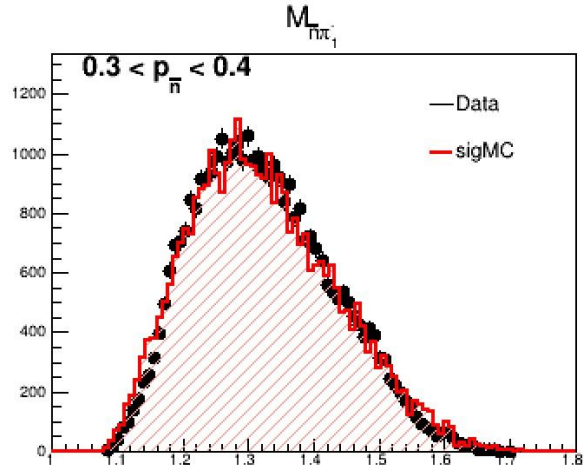




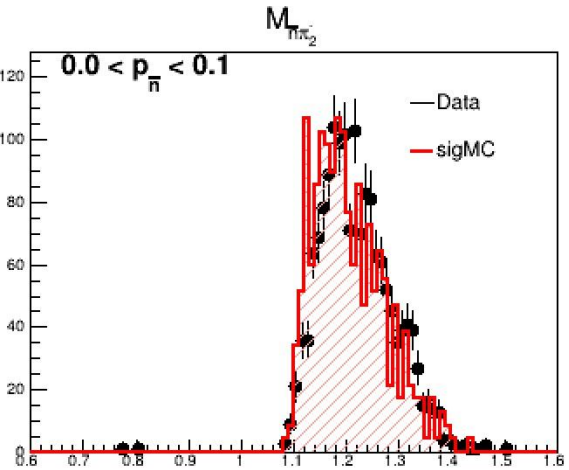


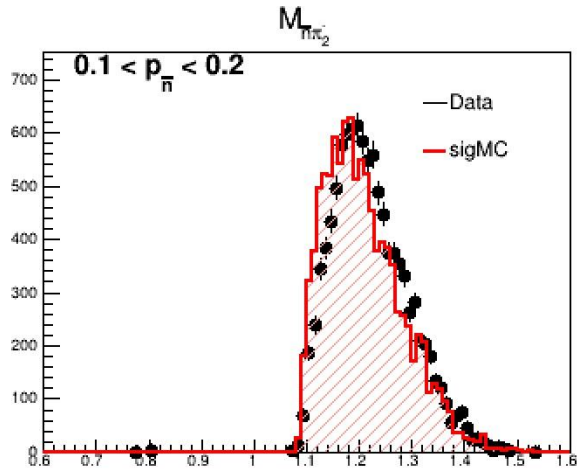


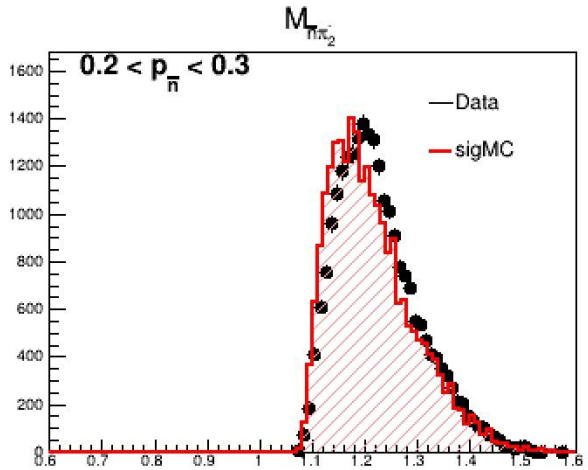


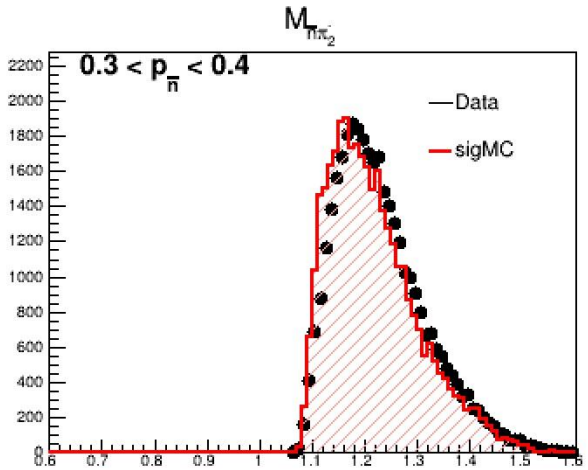


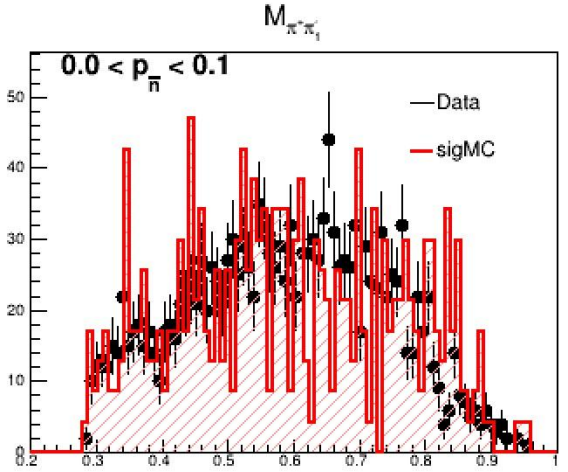
$J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$

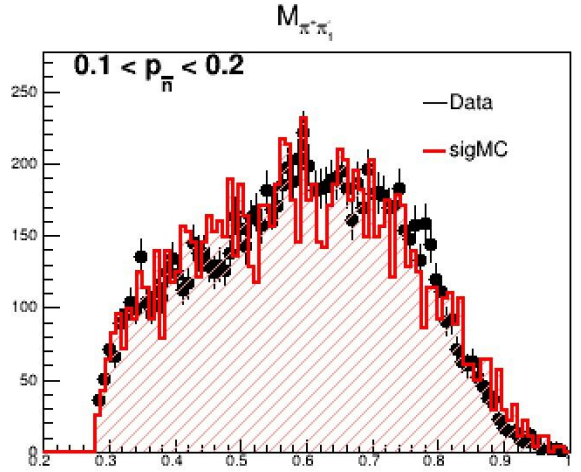


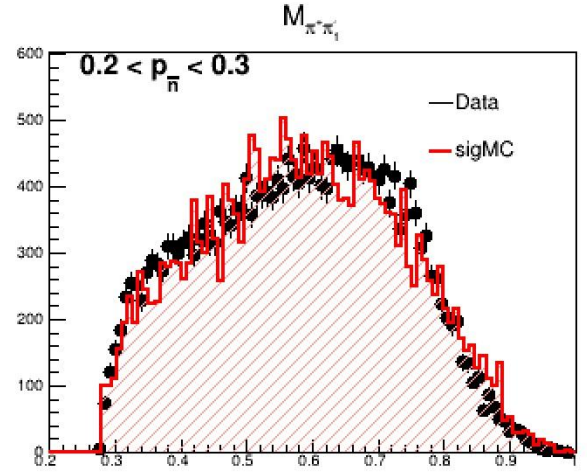


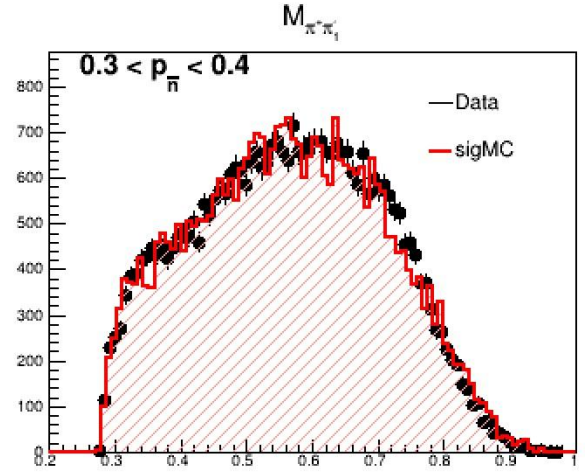




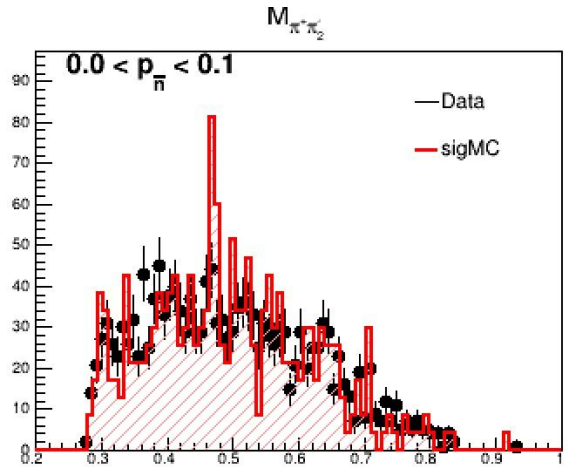


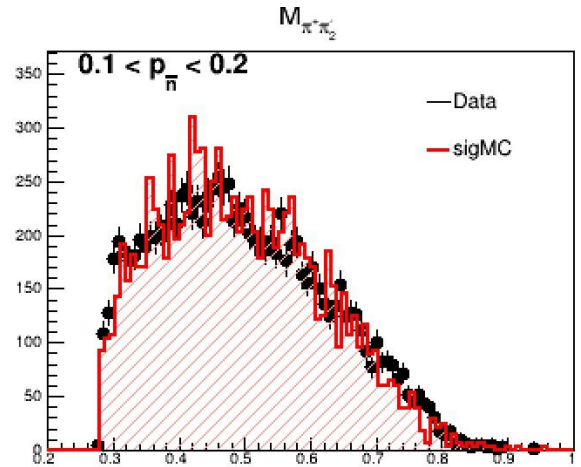


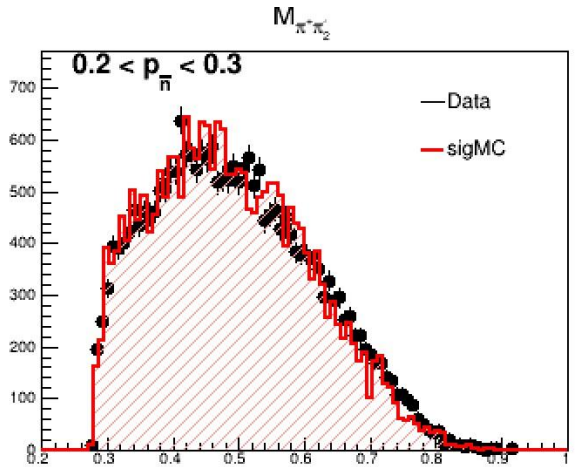


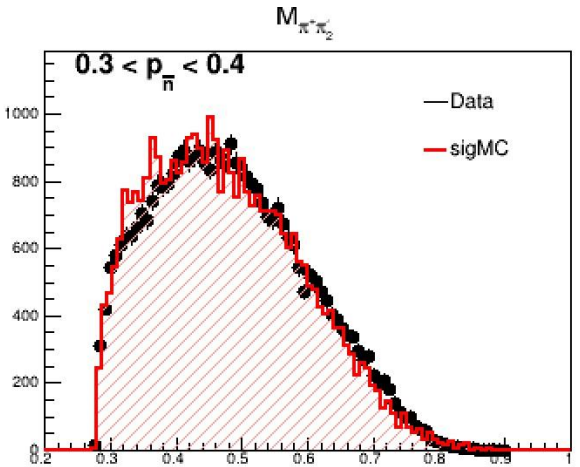


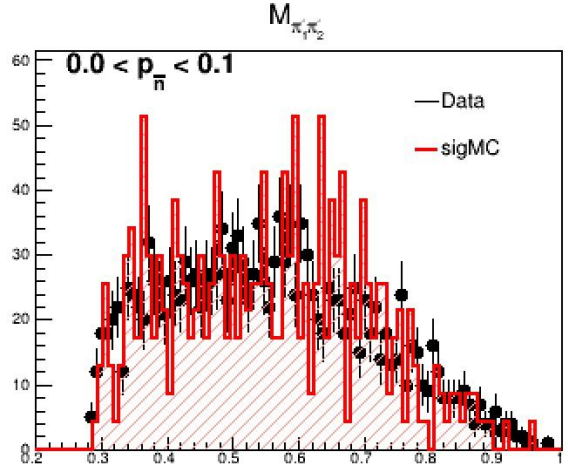
$J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$

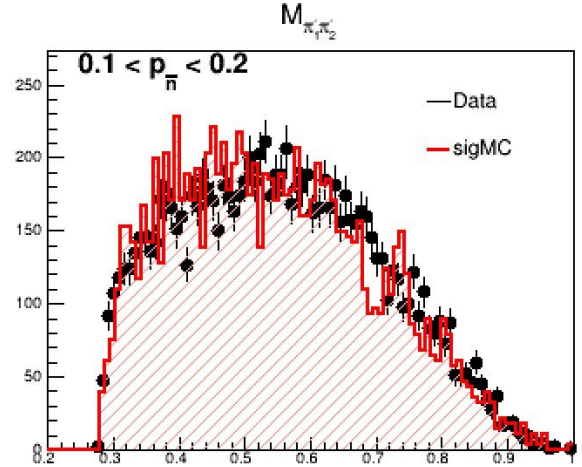


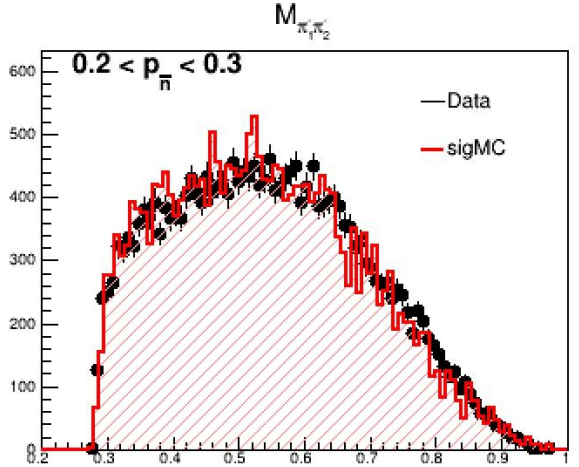


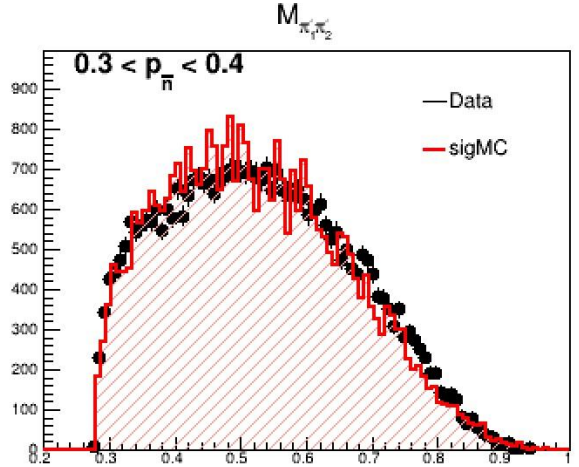








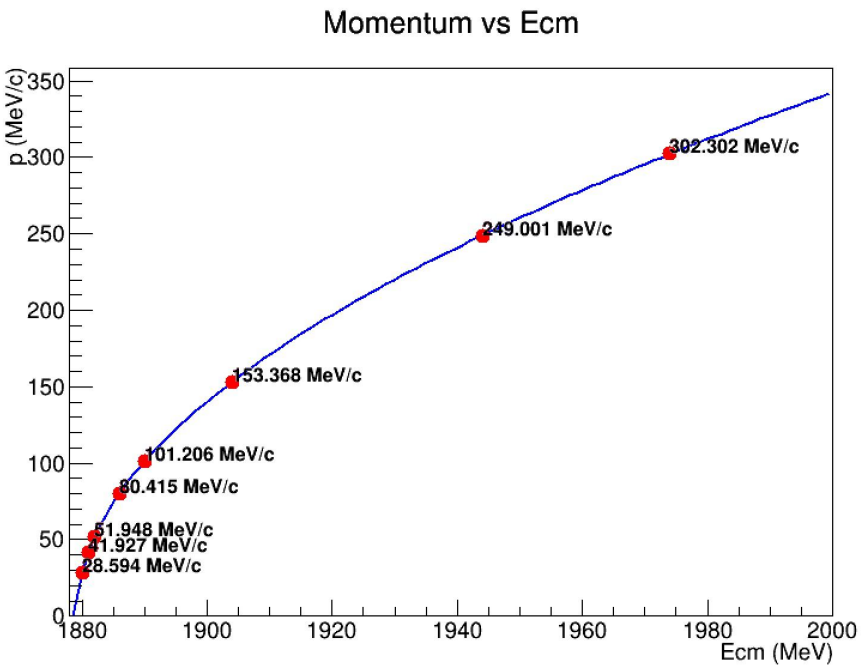




Energy points vs $\bar{n}$ Momentum

- Data: Boss 7.1.3

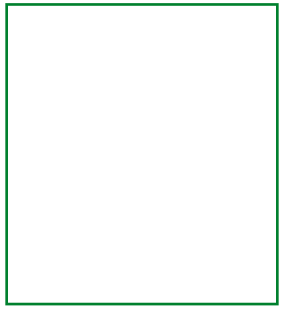
E^{nom}(MeV)	Lumi.(pb^{-1})	Run No.	E^{cor}(MeV)
1840	1.502	81849-81970	1844.138 ± 0.083
1870	2.003	81971-82104	1874.137 ± 0.084
1872	2.014	82543-82656	1876.035 ± 0.079
1874	2.019	82657-82783	1878.002 ± 0.084
1875	1.485	82835-82909	1879.139 ± 0.099
1876	2.035	82105-82203	1880.073 ± 0.080
1877	1.341	82784-82834	1880.925 ± 0.101
1878	2.021	82204-82261	1882.185 ± 0.089
1882	2.033	82262-82310	1886.032 ± 0.081
1886	2.031	82311-82358	1890.160 ± 0.083
1900	2.022	82359-82404	1903.824 ± 0.080
1940	2.040	82405-82462	1943.686 ± 0.088
1970	2.229	82463-82530	1973.483 ± 0.092



$$P_n = \sqrt{\sqrt{s}^2/4 - m_n^2}$$

$E_{th} = 2m_n$~2*939.565 = 1879.138 MeV

Purity of $J/\psi \to p\bar{n}\pi^-\pi^+\pi^-$



sig: 55324/64904 = 85.23%
bkg: 89/170=52.35%
bkg rate ↓

all sig: 553240

Table 1: Decay trees and their respective final states.

rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$J/\psi \to \pi^-\bar{\Delta}^+\Delta^{++}, \Delta^+ \to \pi^-\bar{n}, \Delta^{++} \to \pi^+p$	$\pi^+\pi^-\pi^-\bar{n}p$	3	37721	37721
2	$J/\psi \to \pi^-\bar{\Delta}^-\Delta^0, \bar{\Delta}^- \to \pi^+\bar{n}, \Delta^0 \to \pi^-p$	$\pi^+\pi^-\pi^-\bar{n}p$	1	37334	75055
3	$J/\psi \to \pi^+\Delta^0\bar{\Delta}^+, \Delta^0 \to \pi^-p, \bar{\Delta}^+ \to \pi^-\bar{n}$	$\pi^+\pi^-\pi^-\bar{n}p$	2	13863	88918
4	$J/\psi \to \pi^-\pi^-\bar{\Delta}^-p, \bar{\Delta}^- \to \pi^+\bar{n}$	$\pi^+\pi^-\pi^-\bar{n}p$	0	3399	92317
5	$J/\psi \to \pi^-\pi^-\bar{n}\Delta^{++}, \Delta^{++} \to \pi^+p$	$\pi^+\pi^-\pi^-\bar{n}p$	4	3226	95543
6	$J/\psi \to \pi^+\pi^-\bar{n}\Delta^0, \Delta^0 \to \pi^-p$	$\pi^+\pi^-\pi^-\bar{n}p$	7	784	96327
7	$J/\psi \to \pi^+\pi^-p\bar{\Delta}^+, \bar{\Delta}^+ \to \pi^-\bar{n}$	$\pi^+\pi^-\pi^-\bar{n}p$	11	782	97109
8	$J/\psi \to \rho^0\bar{n}\Delta^0, \rho^0 \to \pi^+\pi^-, \Delta^0 \to \pi^-p$	$\pi^+\pi^-\pi^-\bar{n}p$	9	479	97588
9	$J/\psi \to \rho^0\pi^-\bar{n}p, \rho^0 \to \pi^+\pi^-$	$\pi^+\pi^-\pi^-\bar{n}p$	5	479	98067
10	$J/\psi \to \rho^0p\bar{\Delta}^+, \rho^0 \to \pi^+\pi^-, \bar{\Delta}^+ \to \pi^-\bar{n}$	$\pi^+\pi^-\pi^-\bar{n}p$	8	450	98517
11	$J/\psi \to \pi^+\pi^-\pi^-\bar{n}p$	$\pi^+\pi^-\pi^-\bar{n}p$	12	442	98959
12	$\to \pi^+\Lambda\bar{\Sigma}^-, \Lambda \to \pi^-p, \bar{\Sigma}^- \to \pi^-\bar{n}$	$\pi^+\pi^-\pi^-\bar{n}p$	10	219	99178
13	$J/\psi \to K_S^0\bar{n}\Lambda, K_S^0 \to \pi^+\pi^-, \Lambda \to \pi^-p$	$\pi^+\pi^-\pi^-\bar{n}p$	19	112	99290
14	$J/\psi \to \pi^-\bar{\Delta}^-\Delta^0, \bar{\Delta}^- \to \pi^+\bar{n}, \Delta^0 \to \pi^-\gamma^f$	$\pi^+\pi^-\pi^-\bar{n}p\gamma^f$	15	93	99383
15	$J/\psi \to \pi^-\bar{\Delta}^+\Delta^{++}, \bar{\Delta}^+ \to \pi^-\bar{n}\gamma^f, \Delta^{++} \to$ p	$\pi^+\pi^-\pi^-\bar{n}p\gamma^f$	23	82	99465
16	$J/\psi \to \pi^-\bar{\Delta}^-\Delta^0, \bar{\Delta}^- \to \pi^+\bar{n}\gamma^f, \Delta^0 \to \pi^-p$	$\pi^+\pi^-\pi^-\bar{n}p\gamma^f$	18	63	99528
17	$J/\psi \to \bar{\Sigma}^+\Sigma^{*-}, \bar{\Sigma}^+ \to \pi^+\bar{n}, \Sigma^{*-} \to \pi^-\Lambda, \Lambda \to \pi^-p$	$\pi^+\pi^-\pi^-\bar{n}p$	27	60	99588
18	$J/\psi \to \pi^-\bar{\Delta}^+\Delta^{++}, \bar{\Delta}^+ \to \pi^-\bar{n}, \Delta^{++} \to \pi^+p\gamma^f$	$\pi^+\pi^-\pi^-\bar{n}p\gamma^f$	16	50	99638
19	$J/\psi \to \omega p\bar{\Delta}^+, \omega \to \pi^+\pi^-, \bar{\Delta}^+ \to \pi^-\bar{n}$	$\pi^+\pi^-\pi^-\bar{n}p$	6	42	99680
20	$J/\psi \to \bar{\Sigma}^-\Sigma^{*+}, \bar{\Sigma}^- \to \pi^-\bar{n}, \Sigma^{*+} \to \pi^+\Lambda, \Lambda \to \pi^-p$	$\pi^+\pi^-\pi^-\bar{n}p$	21	39	99719
21	$J/\psi \to \pi^-\bar{\Delta}^+\Delta^{++}\gamma^f, \bar{\Delta}^+ \to \pi^-\bar{n}, \Delta^{++} \to \pi^+p$	$\pi^+\pi^-\pi^-\bar{n}p\gamma^f$	34	39	99758
22	$J/\psi \to \pi^+\Delta^0\bar{\Delta}^+, \Delta^0 \to \pi^-p\gamma^f, \bar{\Delta}^+ \to \pi^-\bar{n}$	$\pi^+\pi^-\pi^-\bar{n}p\gamma^f$	20	37	99795
23	$J/\psi \to \omega\bar{n}\Delta^0, \omega \to \pi^+\pi^-, \Delta^0 \to \pi^-p$	$\pi^+\pi^-\pi^-\bar{n}p$	32	31	99826
24	$J/\psi \to \pi^-\bar{\Delta}^-\Delta^0\gamma^f, \bar{\Delta}^- \to \pi^+\bar{n}, \Delta^0 \to \pi^-p$	$\pi^+\pi^-\pi^-\bar{n}p\gamma^f$	35	27	99853
25	$J/\psi \to K^0\bar{n}\Lambda, K^0 \to K_S^0, \Lambda \to \pi^-p, K_S^0 \to \pi^+\pi^-$	$\pi^+\pi^-\pi^-\bar{n}p$	13	26	99879
26	$J/\psi \to a_2^-\bar{n}p, a_2^- \to \rho^0\pi^-, \rho^0 \to \pi^+\pi^-$	$\pi^+\pi^-\pi^-\bar{n}p$	28	25	99904
27	$J/\psi \to \pi^+\Delta^0\bar{\Delta}^+, \Delta^0 \to \pi^-p, \bar{\Delta}^+ \to \pi^-\bar{n}\gamma^f$	$\pi^+\pi^-\pi^-\bar{n}p\gamma^f$	14	25	99929
28	$J/\psi \to \pi^+\Delta^0\bar{\Delta}^+\gamma^f, \Delta^0 \to \pi^-p, \bar{\Delta}^+ \to \pi^-\bar{n}$	$\pi^+\pi^-\pi^-\bar{n}p\gamma^f$	31	19	99948
29	$J/\psi \to \pi^-\omega\bar{n}p, \omega \to \pi^+\pi^-$	$\pi^+\pi^-\pi^-\bar{n}p$	39	19	99967
30	$J/\psi \to \pi^0\pi^-\bar{n}p, \pi^0 \to e^+e^-\gamma^F$	$e^+e^-\pi^-\bar{n}p\gamma^F$	30	14	99981
31	$J/\psi \to \bar{n}pb_1^-, b_1^- \to \pi^-\omega, \omega \to \pi^+\pi^-$	$\pi^+\pi^-\pi^-\bar{n}p$	17	8	99989
32	$J/\psi \to \rho^0\bar{n}\Delta^0, \rho^0 \to \pi^+\pi^-\gamma^f, \Delta^0 \to \pi^-p$	$\pi^+\pi^-\pi^-\bar{n}p\gamma^f$	41	8	99997