Study of $e^+e^- \to p\bar{p}$ near threshold at $\sqrt{s}$ from 1.840 to 1.970 GeV

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Weekly Group Meeting

17th Feb. 2025

Outline

- **Motivation**
- **Data Sets and Event Selection**
  - Data and MC Samples
  - Strategy of the analysis
  - Validation of Signal MC
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- **Summary**
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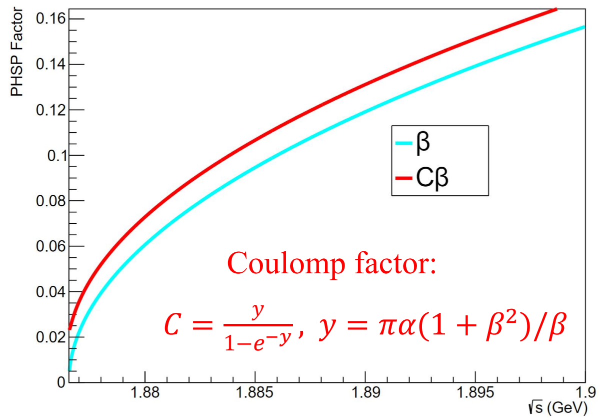
Motivation

- Nucleons' internal structure can be described in terms of the electromagnetic form factors, electric G_E and magnetic G_M, which are complex functions of the momentum transfer squared(q^2).
  - Connected to charge, current distribution.
  - Crucial testing ground for models of the nucleon internal structure.



$$\frac{d\sigma_{p\bar{p}}}{d\Omega} = \frac{\alpha^2\beta C}{4s}\left[|G_M(s)|^2(1+\cos\theta^2) + \frac{1}{\tau}|G_E(s)|^2\sin\theta^2\right], \quad \tau = \frac{s}{4m_B^2}$$

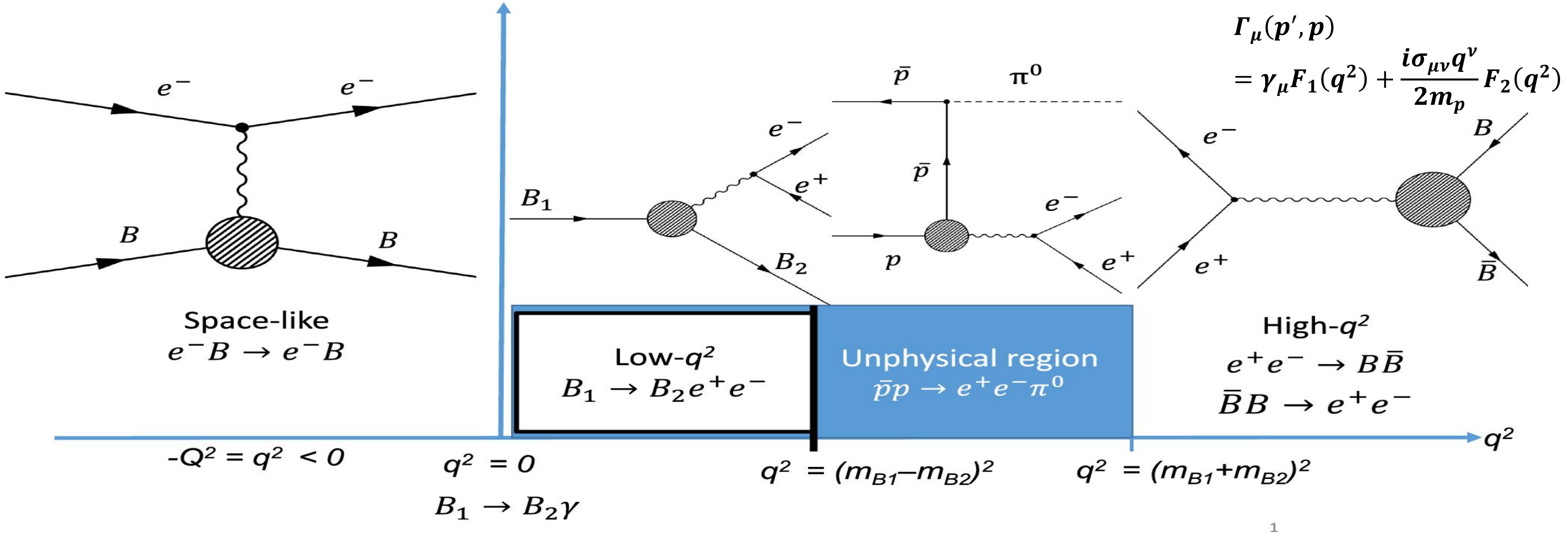
Integrated version: $\sigma(s) = \frac{4\pi\alpha^2\beta C}{3s}\left(1+\frac{1}{2\tau}\right)|G_{\text{eff}}|^2, \; |G_{\text{eff}}|^2 = \frac{2\tau|G_M(s)|^2+|G_E(s)|^2}{2\tau+1}$

- Interaction of final states, lead to a non-zero cross section for charged baryon at threshold.

Sachs FFs:

$G_E(q^2) = F_1(q^2) + \tau\kappa_p F_2(q^2)$,

$G_M(q^2) = F_1(q^2) + \kappa_p F_2(q^2)$



Motivation

- Various theoretical models describe TLFF in non-perturbative region: ChEFT, VMD, Relativistic CQM, parton model, pQCD etc.

Parametrization of TLFF:

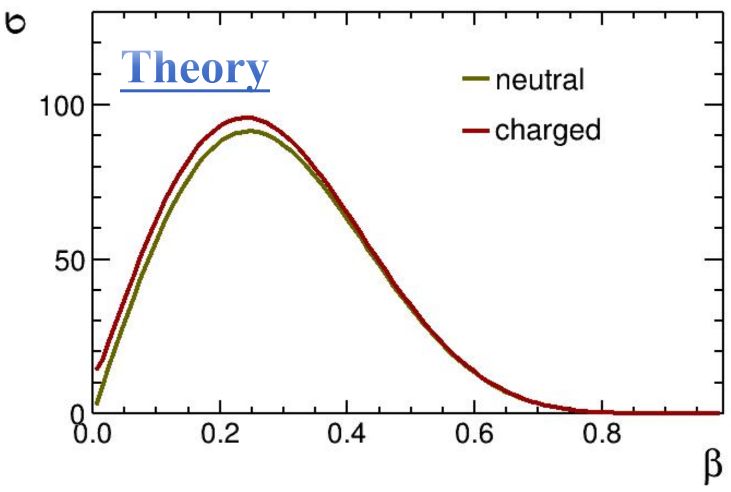
pQCD predicts continuous transition at high q^2, with the scaling behavior: $F_1 \propto q^{-4}, F_2 \propto q^{-6}$

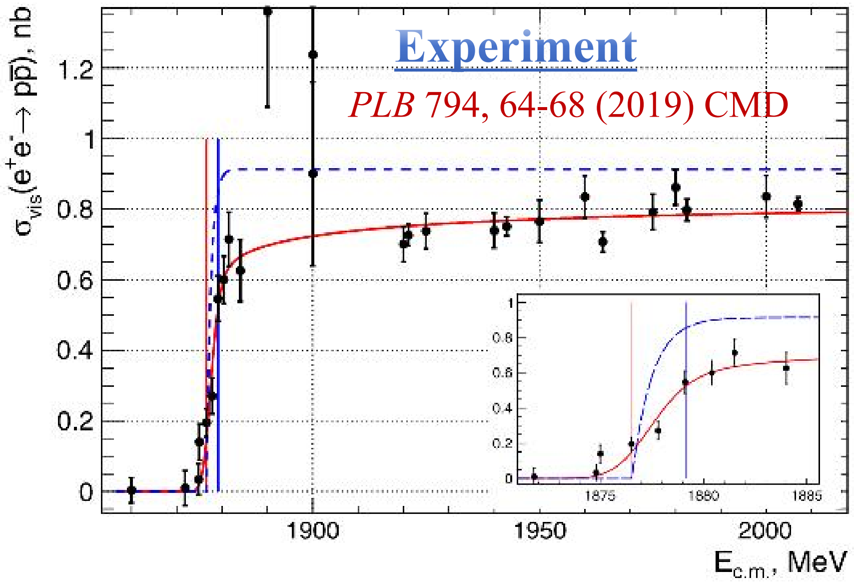
→

Modified scaling expression in nonperturbative region: $\frac{q^2 F_2}{F_1} \propto \ln(\frac{q^2}{\Lambda^2})$, with $\Lambda \approx 0.3$ GeV

→

VMD model described the effect of meson cloud
$|G_{\mathrm{eff}}| = \frac{\mathcal{A}}{q^4[\ln^2(\frac{q^2}{\Lambda^2})+\pi^2]}$ or
$|G_{\mathrm{eff}}| = \frac{\mathcal{A}}{(1+\frac{q^2}{m_a^2})[1-q^2/q_0^2]^2}$





- Cross section of $e^+e^- \rightarrow p\bar{p}$ near threshold shows very sharp step-like behavior.
- The plateau indicates **anomaly threshold effect** in the production cross section.

Data and MC samples

- Data: Boss 7.1.3

Requested $\sqrt{s}$(GeV)	Updated $\sqrt{s}$ (Preli.)(GeV)	Online Lumi.s(pb^{-1})	Run No.
1.840	1.844	1.502	81849-81970
1.870	1.874	2.003	81971-82104
1.872	1.876	2.014	82543-82656
1.874	1.878	2.019	82657-82783
1.875	1.879	1.485	82835-82909
1.876	1.880	2.035	82105-82203
1.877	1.881	1.341	82784-82834
1.878	1.882	2.021	82204-82261
1.882	1.886	2.033	82262-82310
1.886	1.890	2.031	82311-82358
1.900	1.904	2.022	82359-82404
1.940	1.944	2.040	82405-82462
1.970	1.974	2.229	82463-82530

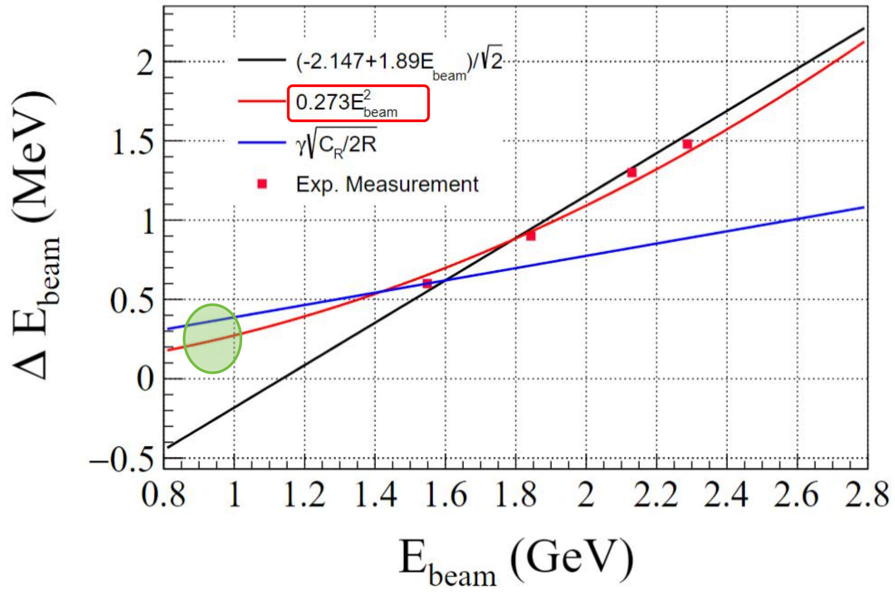
- MC:
  - $e^+e^- \to p\bar{p}$: 0.5M for each energy point higher than the threshold, generated by Phokhara, (will be iterated with energy spread and angular distribution) with **considering energy spread**.
  - $e^+e^- \to n\bar{n}$: 0.5M for each energy point higher than the threshold, generated by Phokhara.

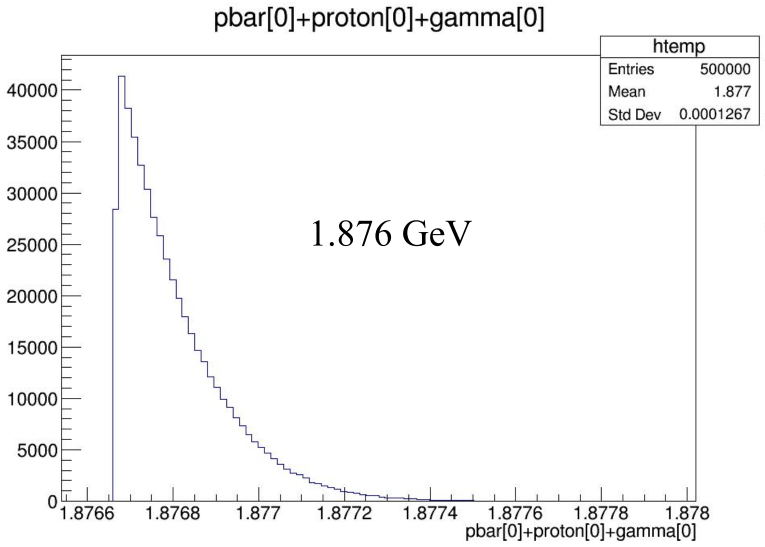
- Here we considered the preliminary results of the energy calibration and updated the ECM for each energy point.

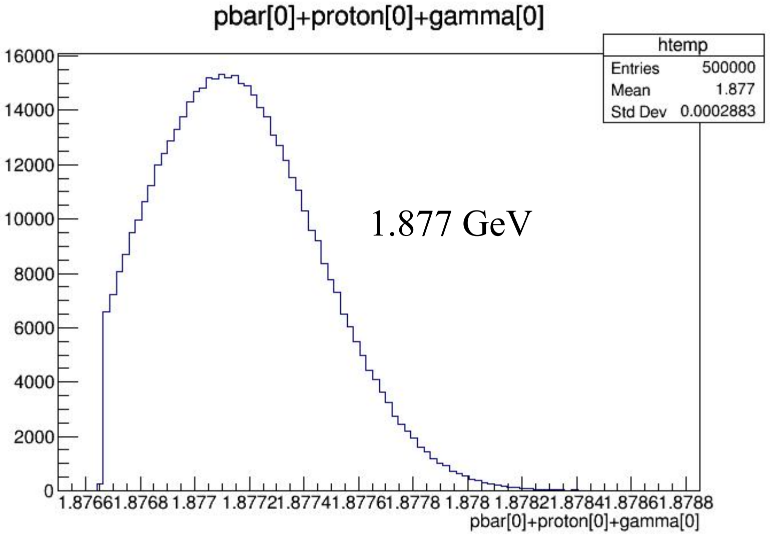
Data and MC samples

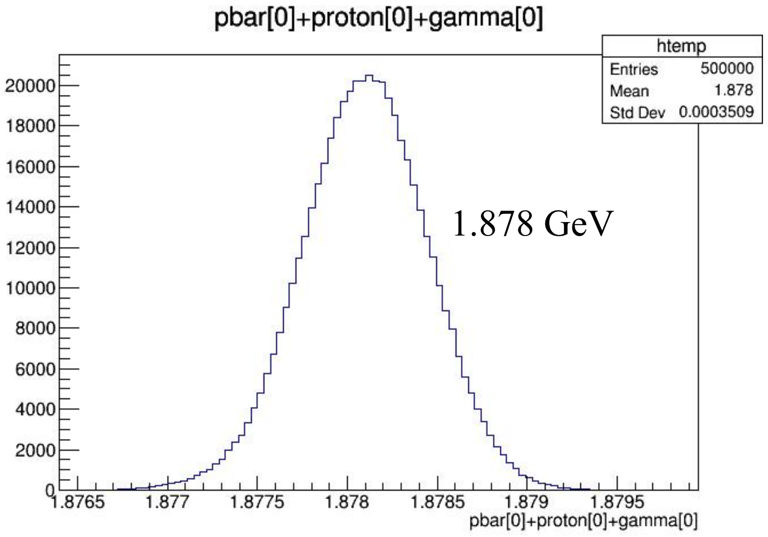
- Consider energy spread in Phokhara.

Before simulation, a Gaussian sampling is performed on the center-of-mass energy, only those greater than the ppbar threshold can enter the simulation.

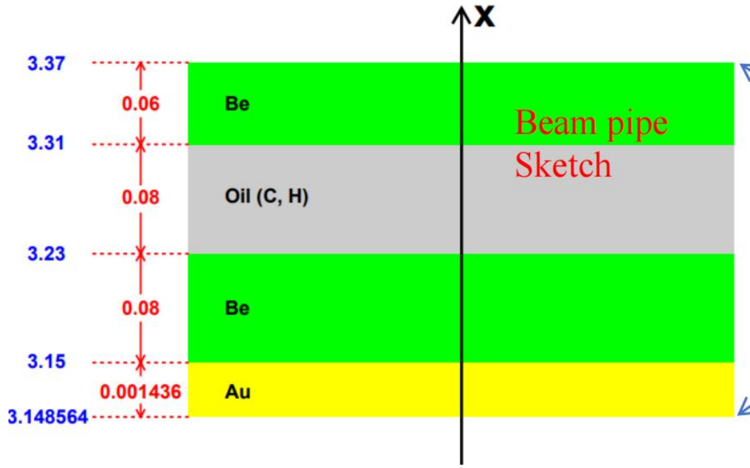


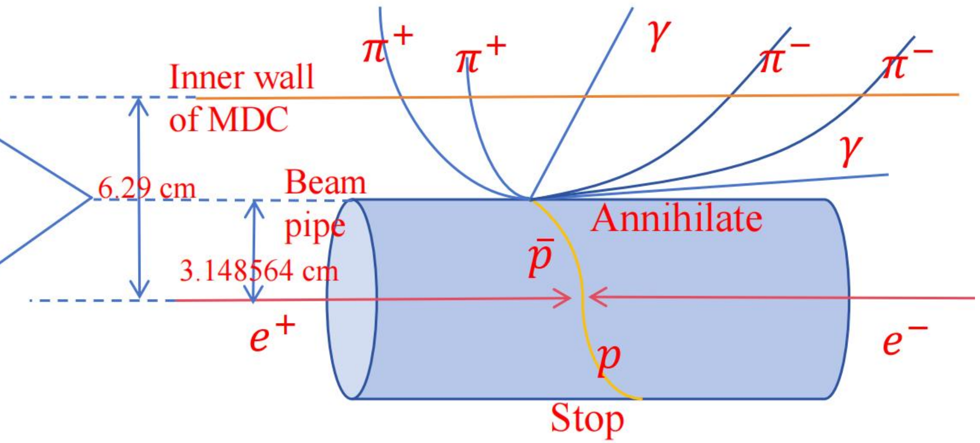






Strategy of the analysis



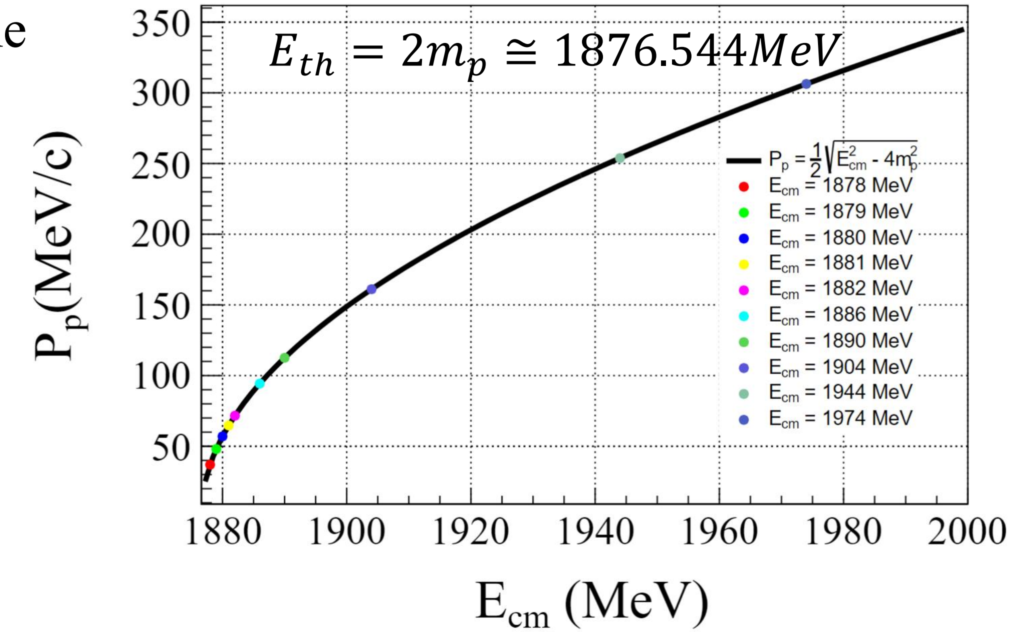


Decay Chain:

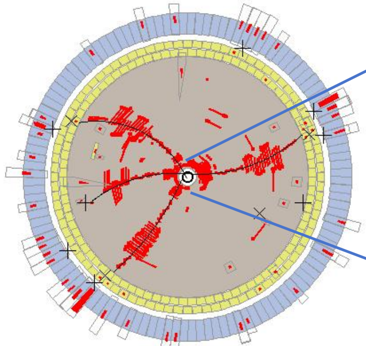
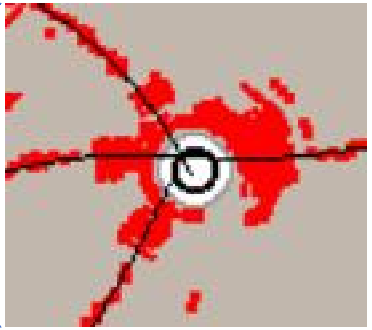
$$e^+e^- \to p\bar{p}$$

$$\bar{p}N \to anything$$

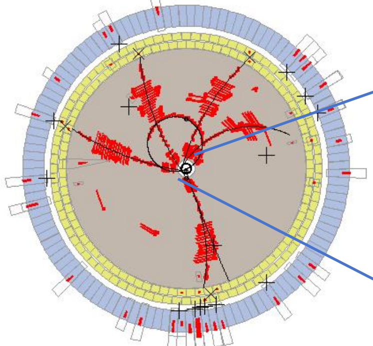
- Almost all the protons and antiprotons are ionized to rest at the beam pipe and the inner wall of the MDC. (P<200 MeV)
  - For antiproton, when stopped, it interacts with the nucleon in the detector matter, resulting in many higher energy secondary particles ($\pi, K, e, \ldots$).
  - For proton, it just stops, with no information left in the detector.



Strategy of the analysis

$P_{\bar{p}}$ = 100 MeV/c




From Single MC of $\bar{p}$

Annihilation frequencies of $\bar{p}p$ annihilation at rest in liquid H_2 into pionic final states (in units of 10^{-3}), from [2,48,216]

Physics Reports 413 (2005) 197 – 317

Final state	BNL	CERN	Crystal Barrel
All neutral	32 ± 5	41^{+2}_{-6}	35 ± 3
$2\pi^0$			0.65 ± 0.03
$3\pi^0$			7.0 ± 0.4
$4\pi^0$			3.1 ± 0.2
$5\pi^0$			9.2 ± 0.4
$6\pi^0$ (1)			0.12 ± 0.01
$7\pi^0$ (1)			1.3 ± 0.1
$8\pi^0$ (2)			0.012 ± 0.001
$9\pi^0$ (2)			0.025 ± 0.003
Non-multipion			15 ± 5
$\pi^+\pi^-$	3.2 ± 0.3	3.33 ± 0.17	3.14 ± 0.12
$\pi^+\pi^-\pi^0$	78 ± 9	69.0 ± 3.5	67 ± 10
$\pi^+\pi^-2\pi^0$			122 ± 18
$\pi^+\pi^-3\pi^0$			133 ± 20
$\pi^+\pi^-4\pi^0$			36 ± 5
$\pi^+\pi^-5\pi^0$ (1)			13 ± 2
$\pi^+\pi^-$MM	345 ± 12	358 ± 8	$65 \pm 20^*$
$2\pi^+2\pi^-$	58 ± 3	69 ± 6	56 ± 9
$2\pi^+2\pi^-\pi^0$	187 ± 7	196 ± 6	210 ± 32
$2\pi^+2\pi^-2\pi^0$			177 ± 27
$2\pi^+2\pi^-3\pi^0$			6 ± 2
$2\pi^+2\pi^-$MM	213 ± 11	208 ± 7	$30 \pm 15^*$
$3\pi^+3\pi^-$	19 ± 2	21.0 ± 2.5	40 ± 3^a
$3\pi^+3\pi^-\pi^0$	16 ± 3	8.5 ± 1.5	
$3\pi^+3\pi^-$MM	16 ± 3	3 ± 1	
Sum	954 ± 18	986 ± 6	970 ± 58

- Below 1.940 GeV, analysis strategy(Case 1):
  - ➢ Reconstruct the secondary particles produced by $\bar{p}N$ annihilation.
- Above 1.940 GeV, analysis strategy(Case 2):
  - ➢ Reconstruct $p\bar{p}$ directly.
- At 1.940 GeV, it can be used as an intermediate energy point to carry out two types of measurements.

Validation of Signal MC　　Control Sample of $\bar{p}$

- Anti-proton control sample is selected from $J/\psi \to p\bar{p}\pi^+\pi^-$ data, and here is the event selection:

➢ Good Charged Track:

$|\cos\theta| \leq 0.93$; $|V_{xy}| < 0.5$ cm; $|V_z| < 5.0$ cm; $3 \leq N_{\text{charged}} \leq 12$;

➢ PID: use dE/dx and TOF information

p: prob(p)>prob(π, K)

π: prob(π)>prob(p, K)

K: prob(K)>prob(π, p)

$N_p \geq 1$ and $N_{\pi^+} \geq 1$ and $N_{\pi^-} \geq 1$

➢ Vertex fit:

Loop all the $p\pi^+\pi^-$ tracks, and select the combination with minimum χ^2_{VF}

➢ Kinematic fit:

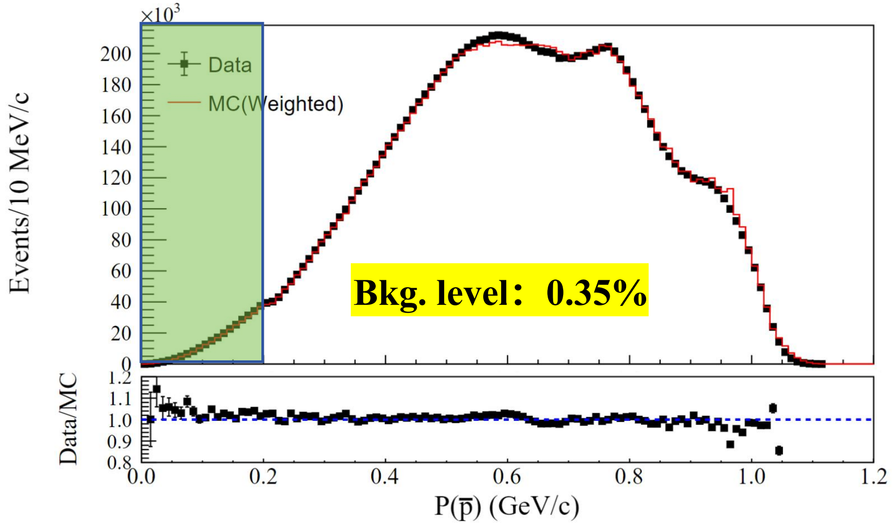
Missing 3-momentu of $\bar{p}$, do 1C kinematic fit, χ^2_{KF}

➢ Recoil $\bar{p}$:

$P_{\bar{p}} = P_{cms} - P_p - P_{\pi^+} - P_{\pi^-}$ with 4-mom before Kinematic fit

➢ Further Selection:

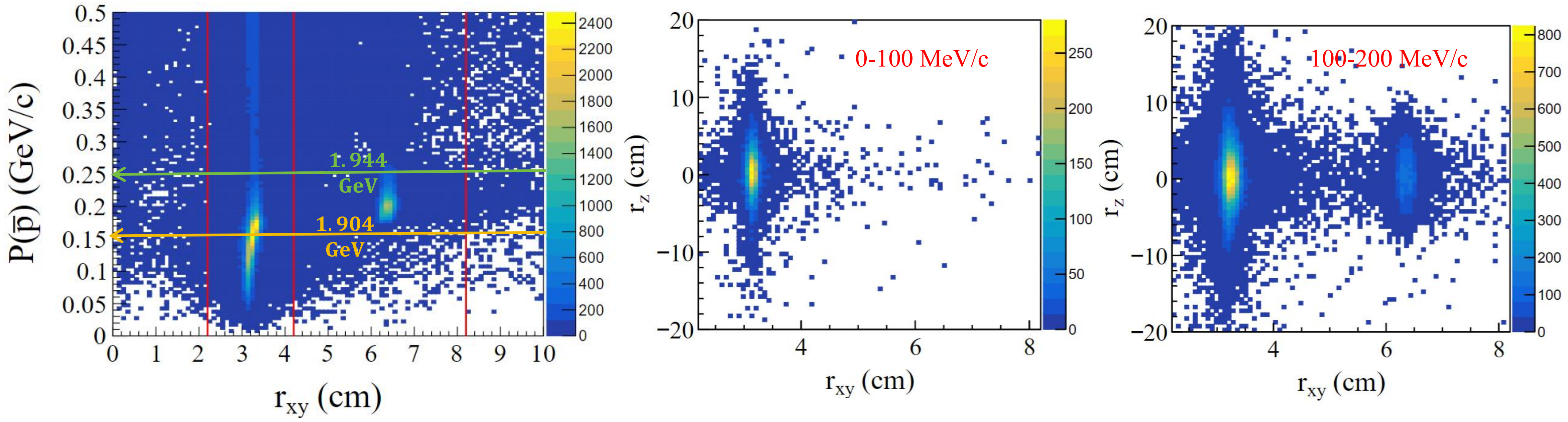
$0.92 < m_{\bar{p}} < 0.96$ GeV/c^2, $\chi^2_{VF} < 20$, $\chi^2_{KF} < 10$,
M($p\pi^-$) > 1.12 GeV/c^2 or M($p\pi^-$) < 1.11 GeV/c^2.



Almost 0.2 million antiproton with momentum less than 200 MeV/c obtained

Validation of Signal MC　　Control Sample of $\bar{p}$

- Remove the $p\pi^+\pi^-$ from $J/\psi \to p\bar{p}\pi^+\pi^-$, and then select the remain tracks, which we think they are the secondary tracks from $\bar{p}N$ interaction. Then a vertex fit is performed.



- ➢ From ppbar threshold to 1.904 GeV, almost all the antiproton interacts at the beam pipe region.
- ➢ At 1.944 GeV, one part of the antiproton interacts at the beampipe region and the other part interacts at the inner wall of MDC region. (Actually, major part can reach MDC)

Preliminary Event Selection for case 1

Decay Chain:

$\boldsymbol{e^+e^- \to p\bar{p}}$

$\boldsymbol{\bar{p}N \to anything}$

- **Good Charged Track:**

  $|\cos\theta| \leq 0.93$; $2 \leq N_{\text{charged}} \leq 9$;

- **Good Photon:**

  $E_{\text{barrel}} \geq 25$ MeV for $|\cos\theta| < 0.80$; $E_{\text{endcap}} \geq 50$ MeV for $0.86 < |\cos\theta| < 0.92$;

  $0 \leq TDC \leq 700$ ns.

- **PID: Only use dedx**

  p: prob(p)>0.001 and prob(p)>prob(π, K, e)

  π: prob(π)>0.001 and prob(π)>prob(p, K, e)

  K: prob(K)>0.001 and prob(K)>prob(p, π, e)

  e: prob(e)>0.001 and prob(e)>prob(p, π, K)

  Require: $N_{\pi^+} \geq 1$ and $N_{\pi^-} \geq 1$

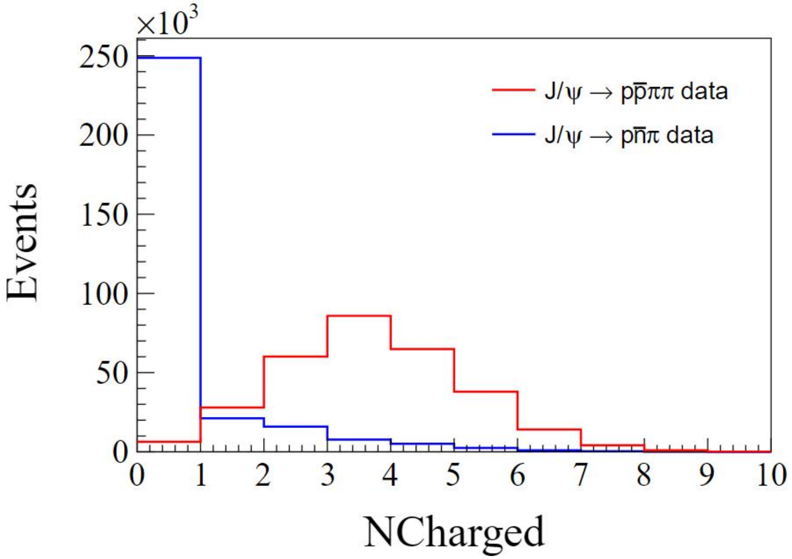
- **Further Selection:**
  - $\chi^2_{\text{vtx}} < 200$
  - $2.2 < R_{\text{xy}} < 4.2$ cm ($2.2 < R_{\text{xy}} < 8.2$ cm for 1.940 GeV)
  - $|R_{\text{z}}| < 10$ cm
  - $\text{Ang}_{\pi^+\pi^-} < 175°$

- **Vertexfit:**

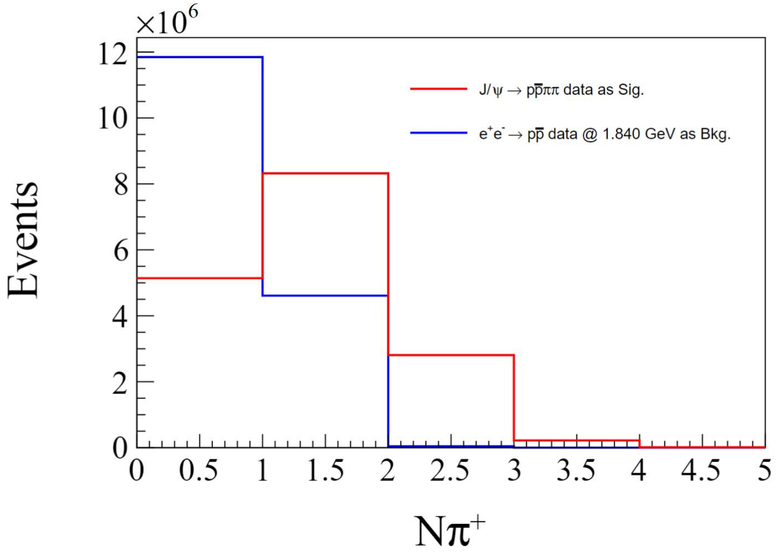
  A vertex fit is performed to all the selected charged tracks, and need to be successful. R_{xy}, R_z are obtained from vertex fit.

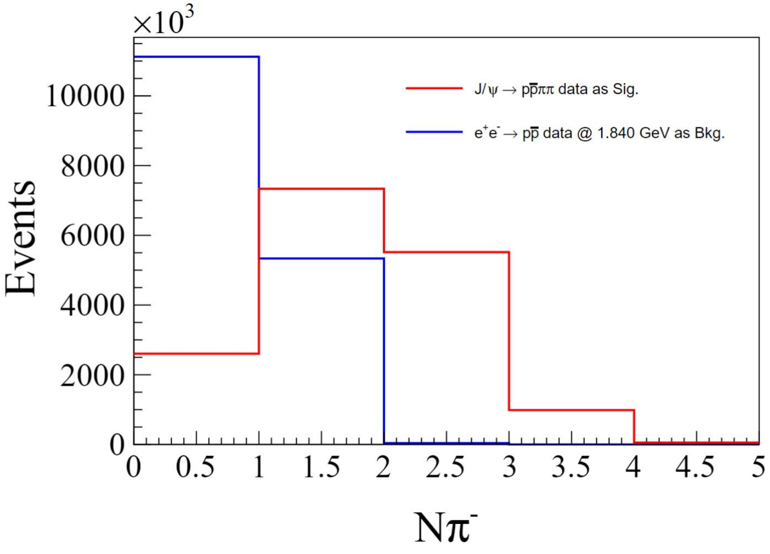
Preliminary Event Selection for case 1

- Charged tracks:



$2 \leq N_{charged} \leq 9$; In order to supress the $n\bar{n}$ background, and also satisfy the vertex fit requirement.

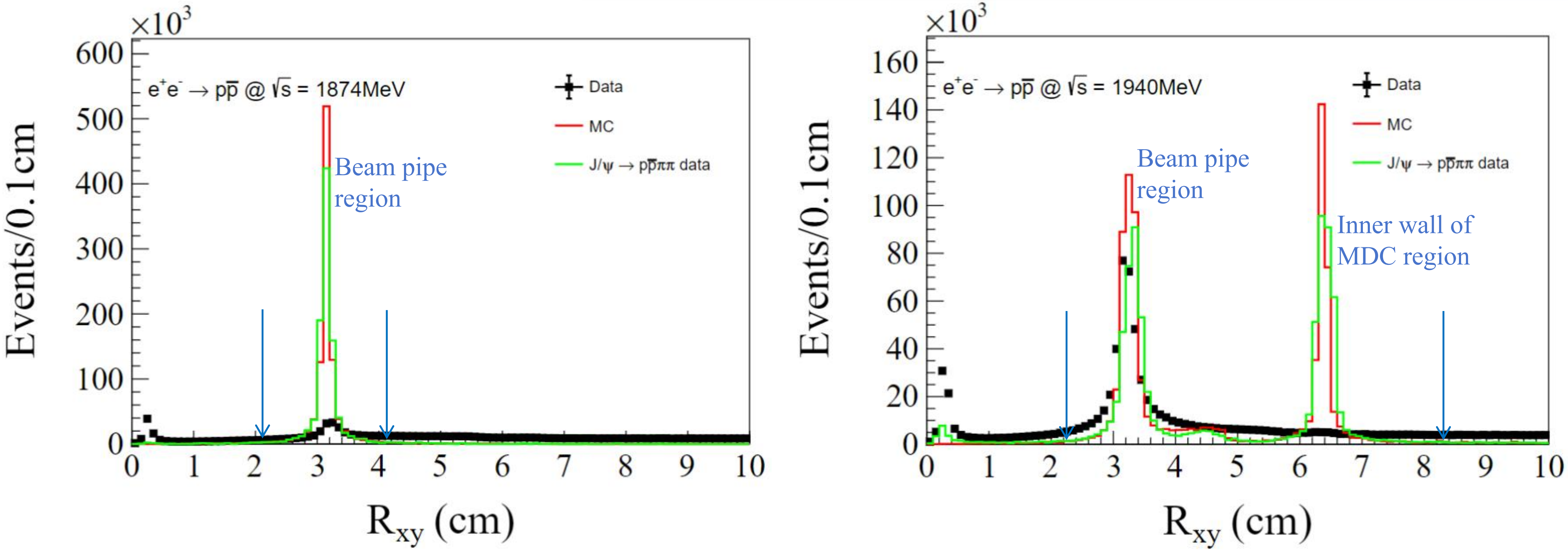




$N_{\pi^+} \geq 1$ and $N_{\pi^-} \geq 1$

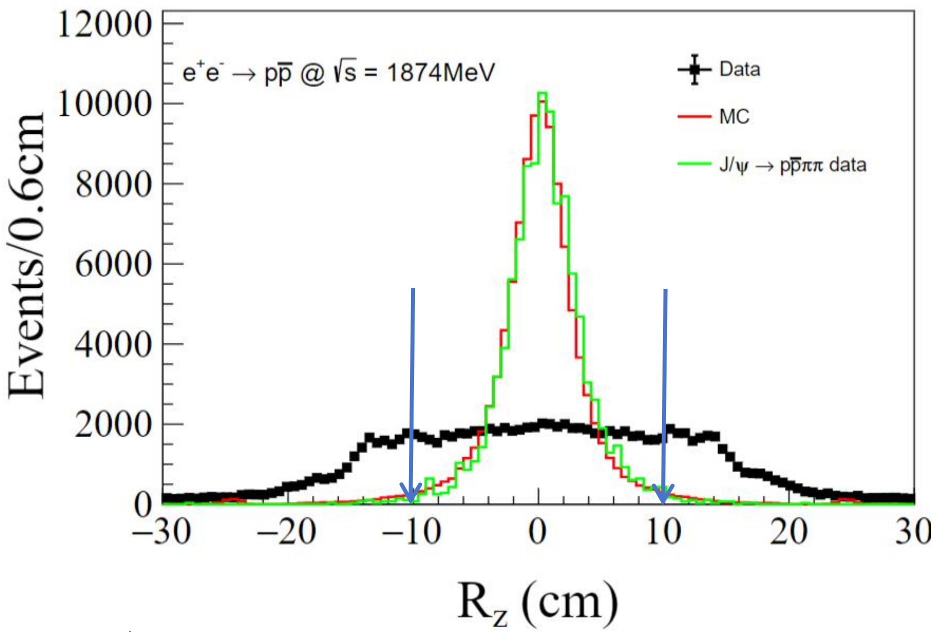
In order to supress the beam induced background.

Feature Variable R_{xy} from Vertex fit



- The signal region is determined to be $2.2 < R_{xy} < 4.2$ cm for energy points lower than 1.904 GeV; and $2.2 < R_{xy} < 8.2$ cm for 1.944 GeV.
- The physical background: $R_{xy} < 1$ cm.
- The main background is the beam-induecd background.
- The nnbar background is also very important.

Further Selection　　Compare Data,CS,MC

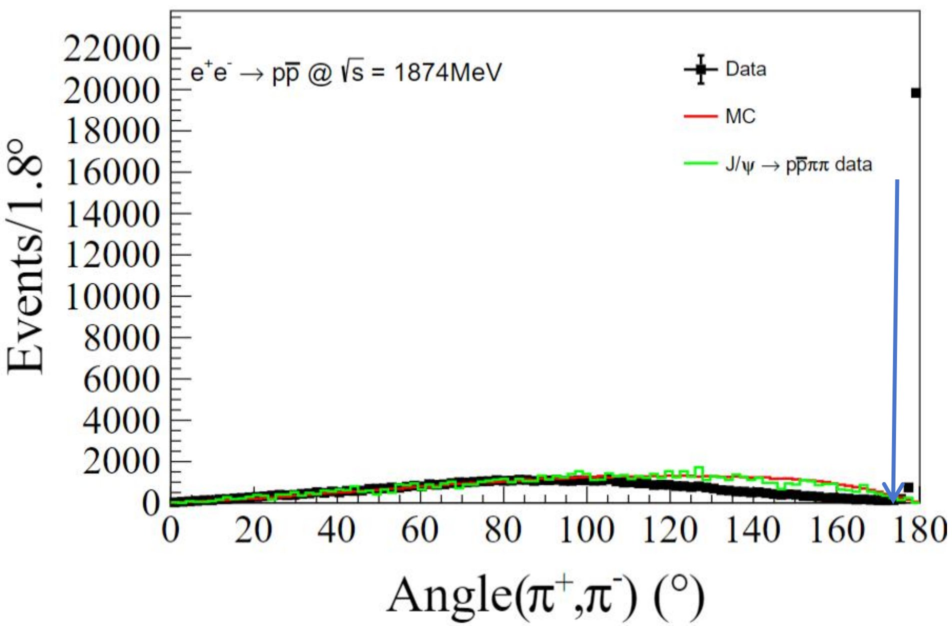


- R_z:

  The distance between the vertexfit point and the original point in z direction.

- Requirement:

  $|R_z| < 10$ cm



- $Ang_{\pi^+\pi^-}$:

  The angle between the most energetic two charged pions.

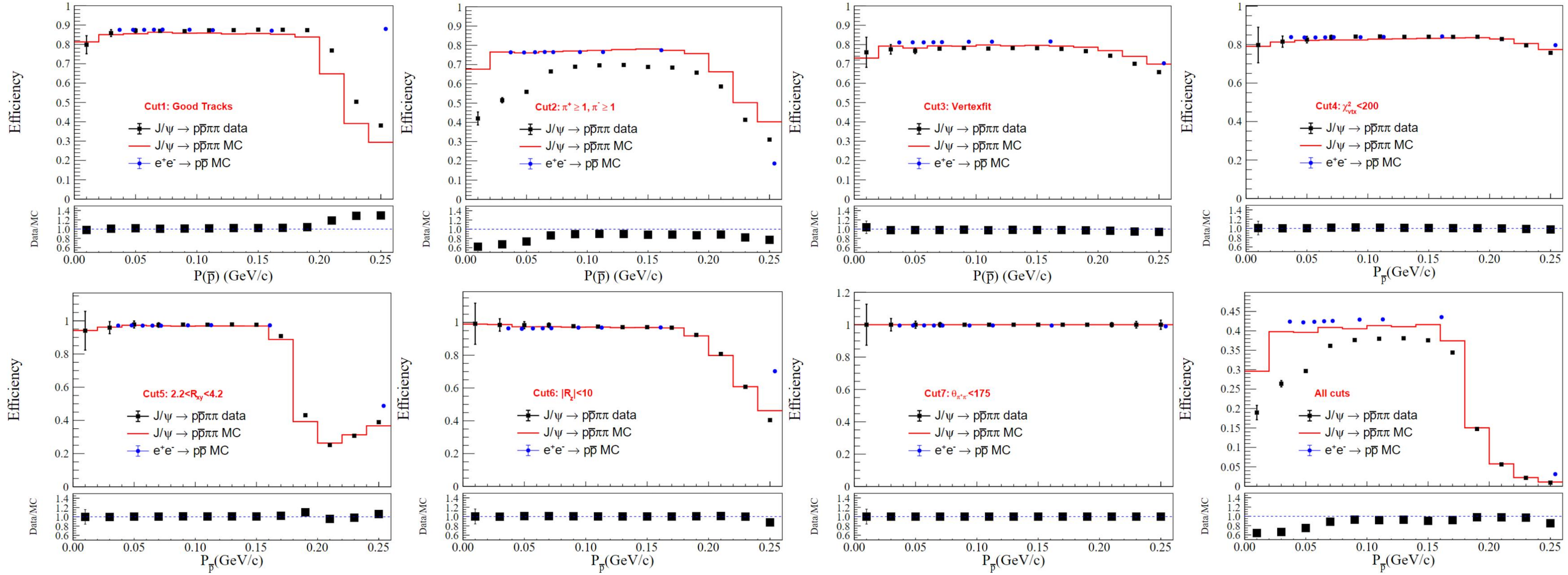
- The peak at 180° means the cosmic background.

- Requirement:

  $Ang_{\pi^+\pi^-} < 175°$

MC Efficiency before ML

- Compare the efficiency from $p\bar{p}$ MC and $J/\psi \to p\bar{p}\pi^+\pi^-$ control sample:

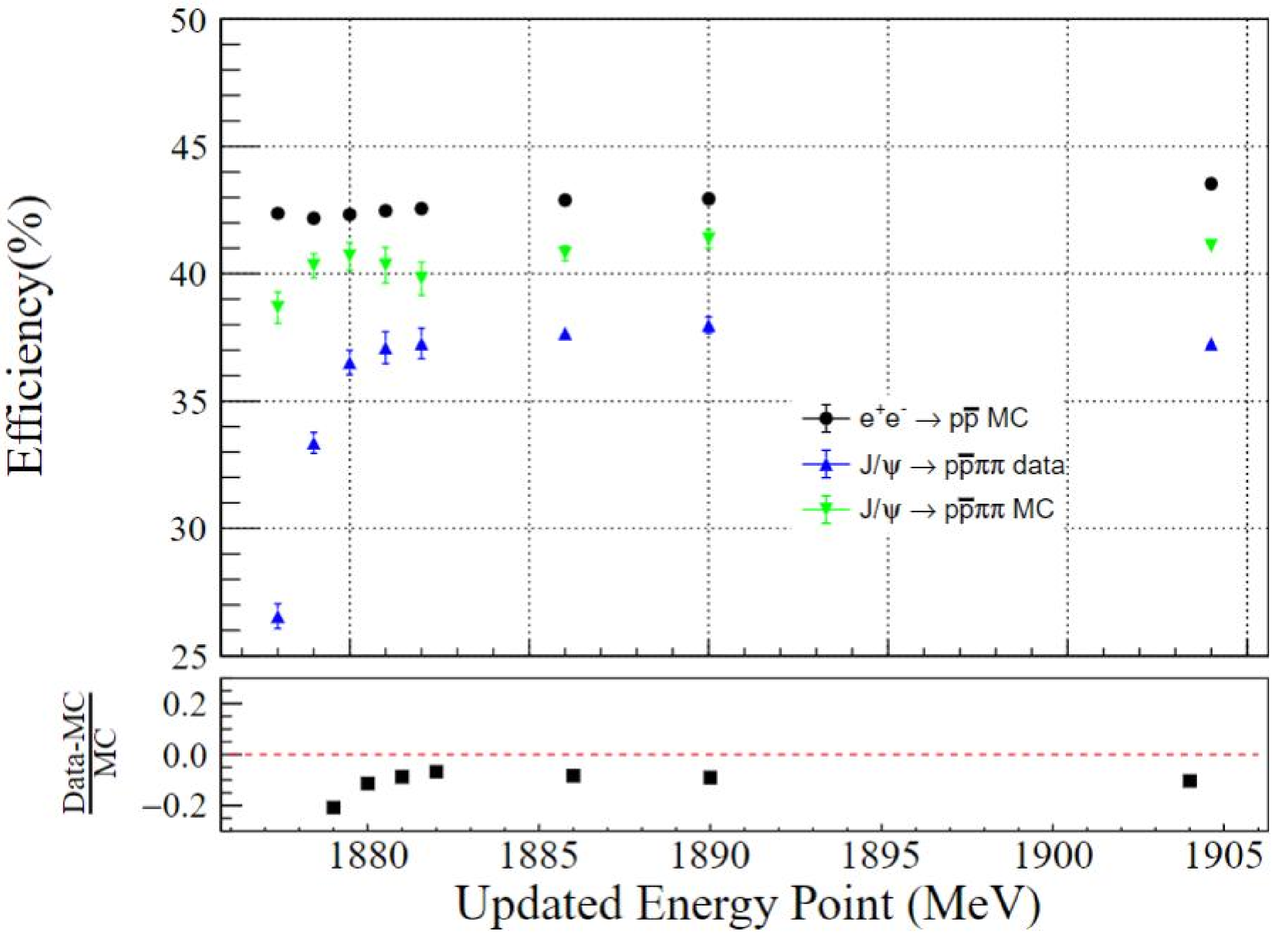


- There are significant differences between data and MC in some selection conditions, mainly in the low momentum region (mainly from the selection of $N_{\pi^+} \geq 1, N_{\pi^-} \geq 1$).

MC Efficiency before ML

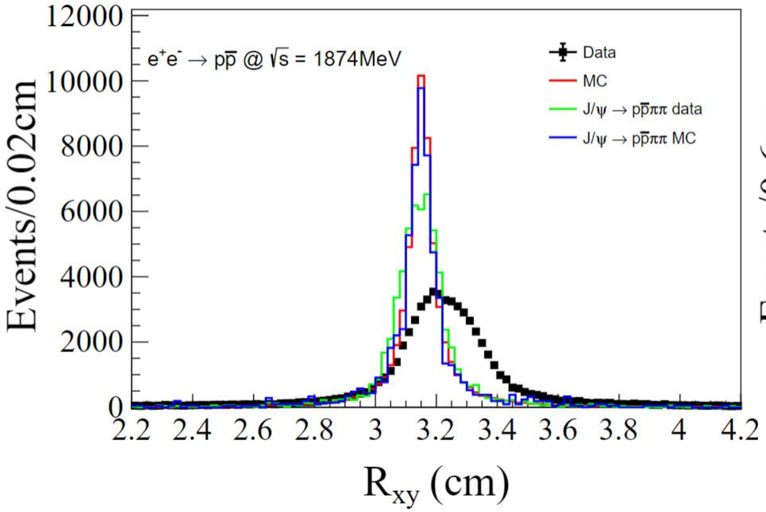
- Compare the efficiency from $p\bar{p}$ MC and $J/\psi \to p\bar{p}\pi^+\pi^-$ control sample:

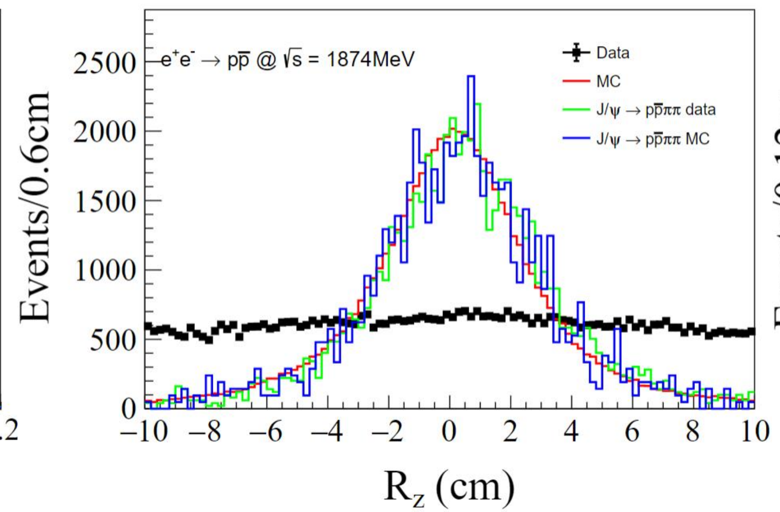
Updated $\sqrt{s}$ (Preli.)(GeV)	P_p(MeV/c)	CS Momentum Interval(MeV/c)
1.878	37	(0, 50)
1.879	48	(30,70)
1.880	57	(40, 80)
1.881	65	(45, 85)
1.882	72	(50, 90)
1.886	94	(80, 110)
1.890	113	(100, 120)
1.904	161	(155, 165)

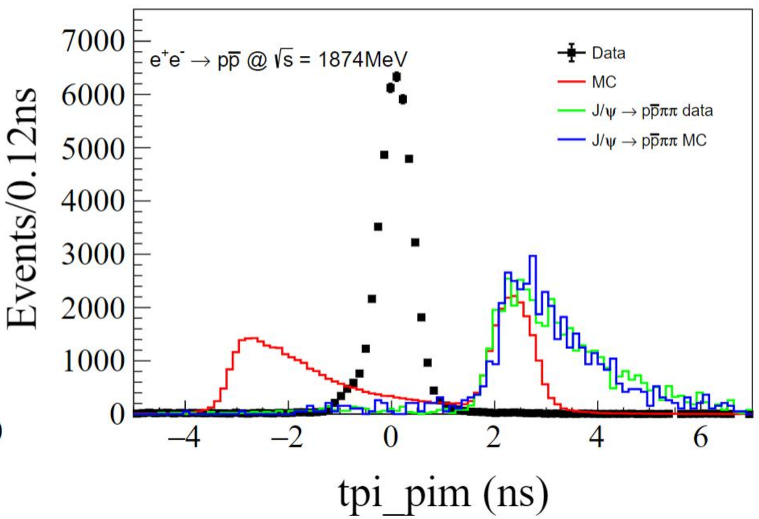


MC Efficiency before ML

- Some distributions after all the event selections:



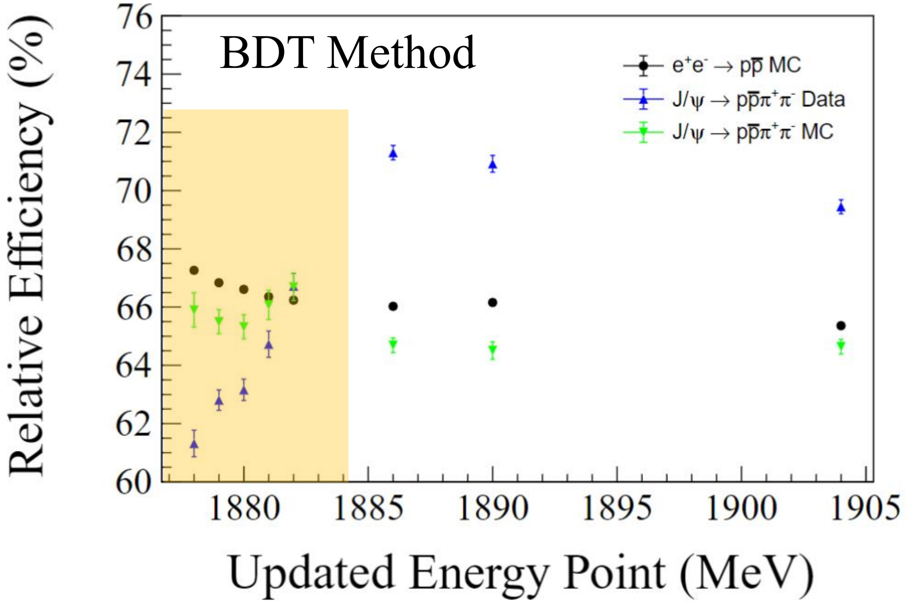


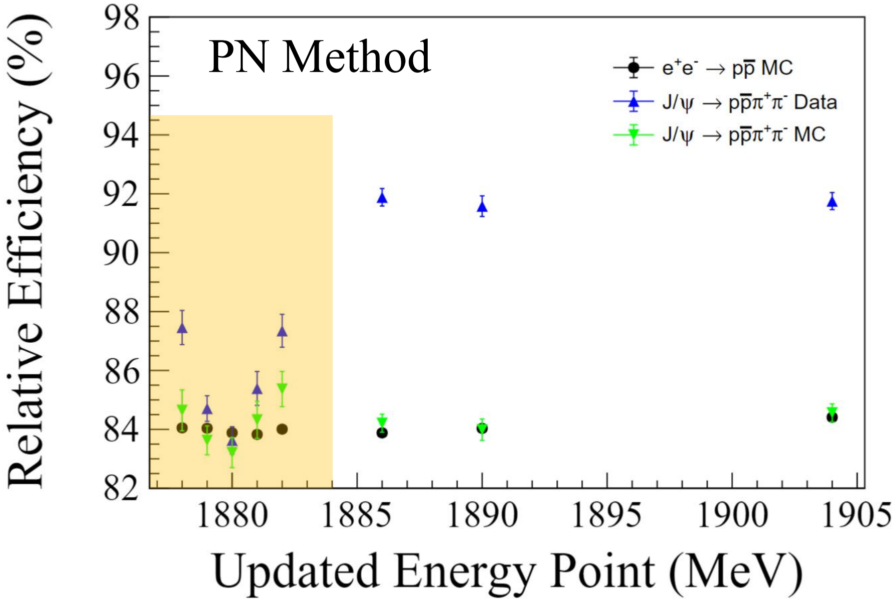


The background is still over a hundred times the signal (~60000:400), mainly from the beam background. Stronger methods for background removal are needed.

ML Method

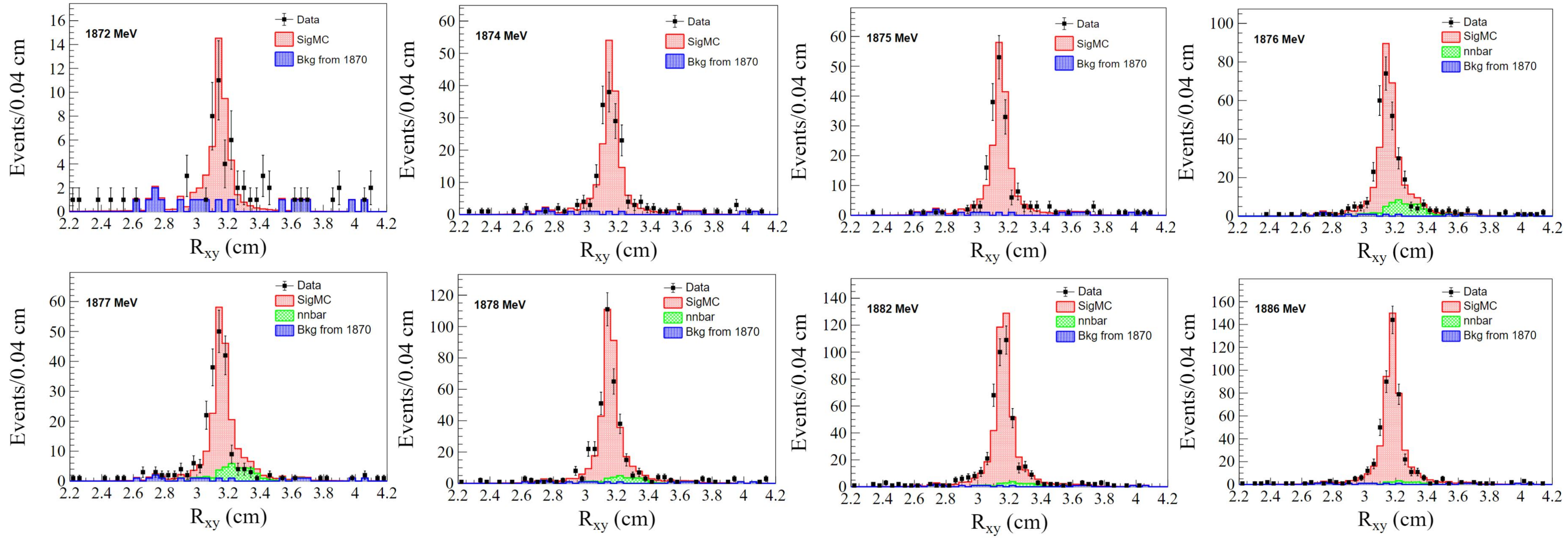
- Some ML methods are used to supress the backgrounds: MVA(BDT), GNN(Particle Net).
  - Training was conducted using data below the threshold (as background, 1.840, 1.870 GeV) and control sample data (as signal, with $P_{\bar{p}} < 0.1$ GeV), and the trained model was applied to all energy point data and MC.
  - Simply using the 1.870 GeV data and nnbar MC to estimate background events.
- Compare the ML relative efficiency given by $p\bar{p}$ MC and $J/\psi \to p\bar{p}\pi^+\pi^-$ control sample:





Rxy Distribution

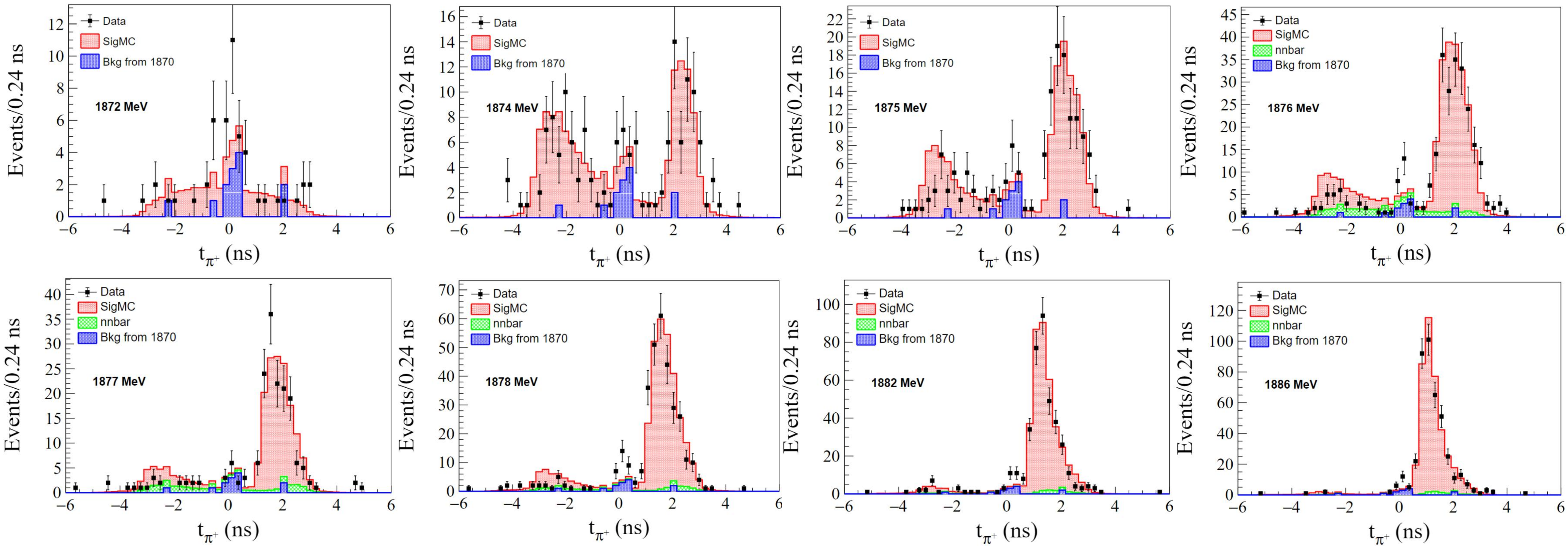
- After GNN veto (score_signal>0.98), use the updated ECM.



Updated $\sqrt{s}$ (Preli.)(GeV)	1.874	1.876	1.878	1.879	1.880	1.881	1.882	1.886	1.890	1.904
Survival Events	17	59	183	192	332	218	395	469	497	546

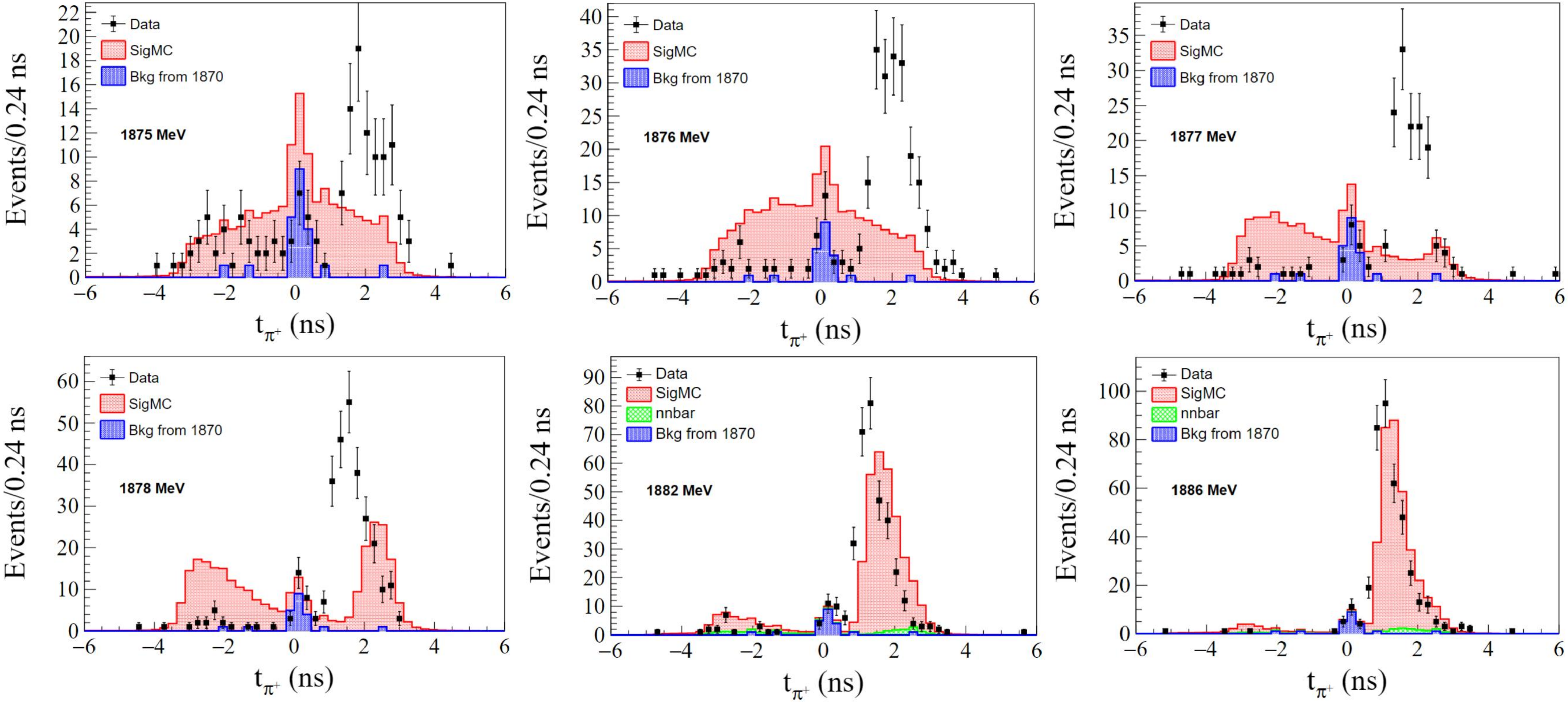
Time of flight of π

- After GNN veto (score_signal>0.98), use the updated ECM.



Time of flight of π

- After GNN veto (score_signal>0.98), use the requested ECM.



MC Efficiency Correction

- Due to the particularity of this process, which involves the complex interaction between antiprotons and the detector, the consistency between MC simulation and data needs to be verified.

Inconsistency between data and MC simulation of antiproton and detector interactions.

Inconsistency in T0 between the data and MC.

→ The inaccuracy of MC efficiency.

Using the $J/\psi \to p\bar{p}\pi^+\pi^-$ control sample to study the differences between data and MC caused by simulation of antiproton interaction.

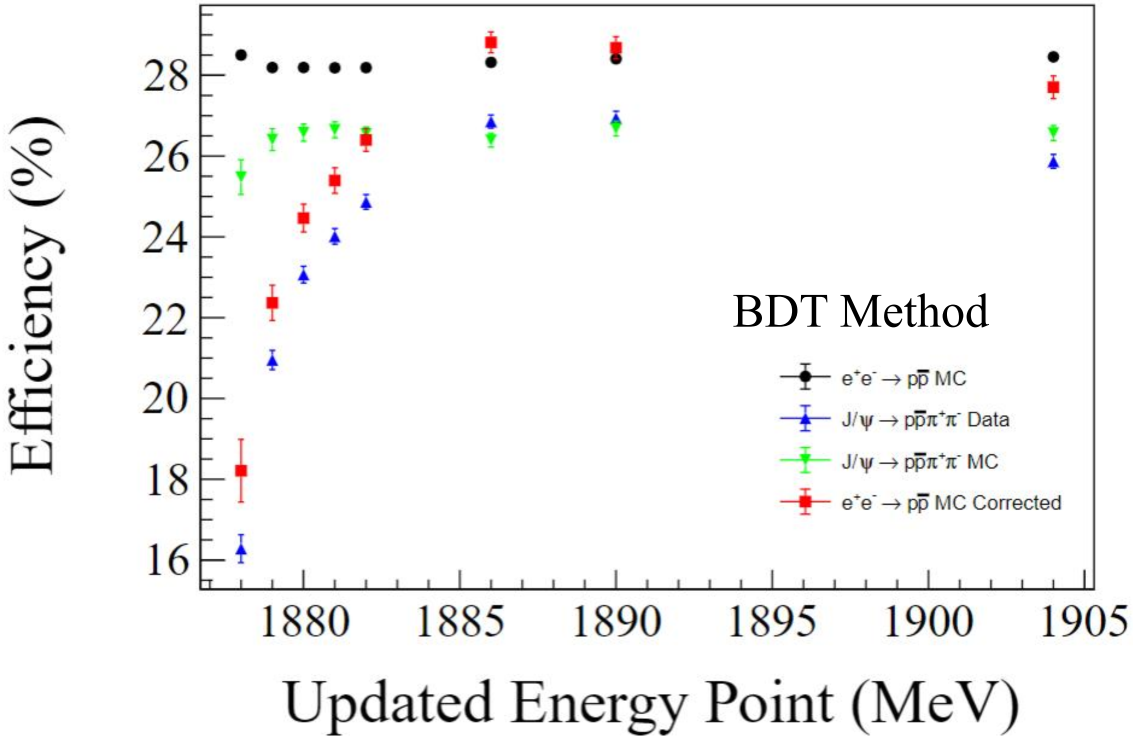
Study **as a systematic uncertainty**: By changing the bunchtime or adjusting the ECM, to achieve the goal of changing T0, indirectly.

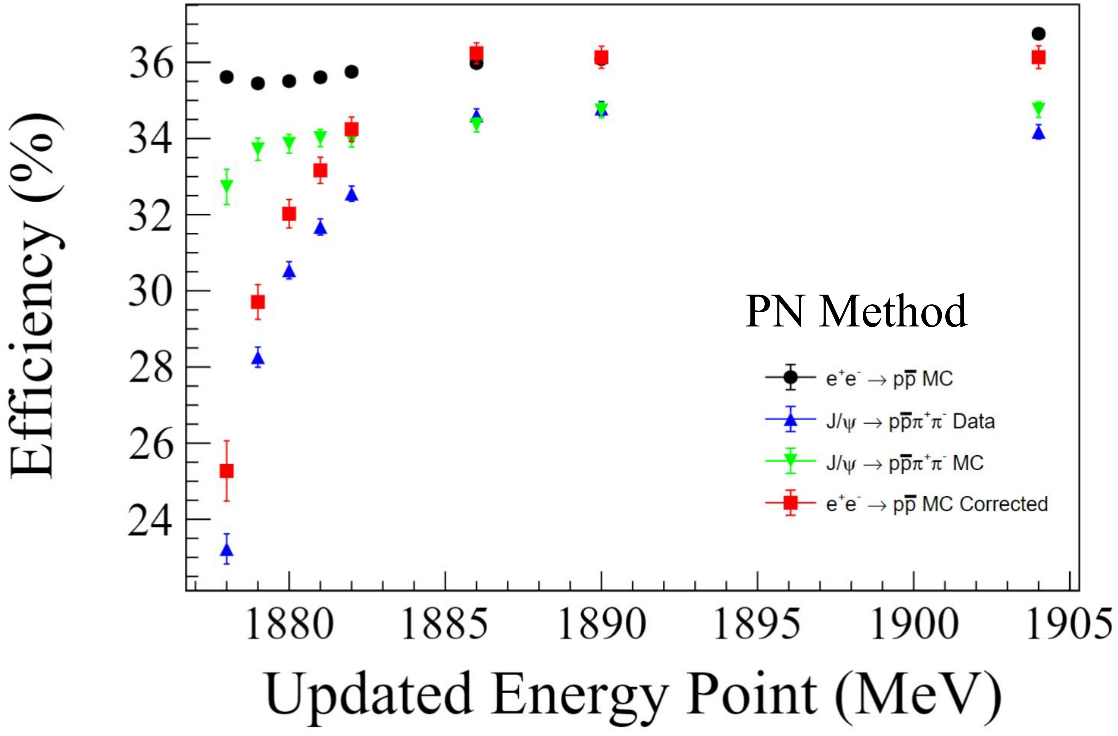
Do correction or **take the differences as systematic uncertainty.**

$$\frac{\varepsilon_{e^+e^-\to p\bar{p}\ data}}{\varepsilon_{e^+e^-\to p\bar{p}\ MC}} = \frac{\varepsilon_{J/\psi\to p\bar{p}\pi\pi\ data}}{\varepsilon_{J/\psi\to p\bar{p}\pi\pi\ data}}$$

MC Efficiency Correction

- Compare the finnal efficiency from $p\bar{p}$ MC and $J/\psi \rightarrow p\bar{p}\pi^+\pi^-$ control sample:



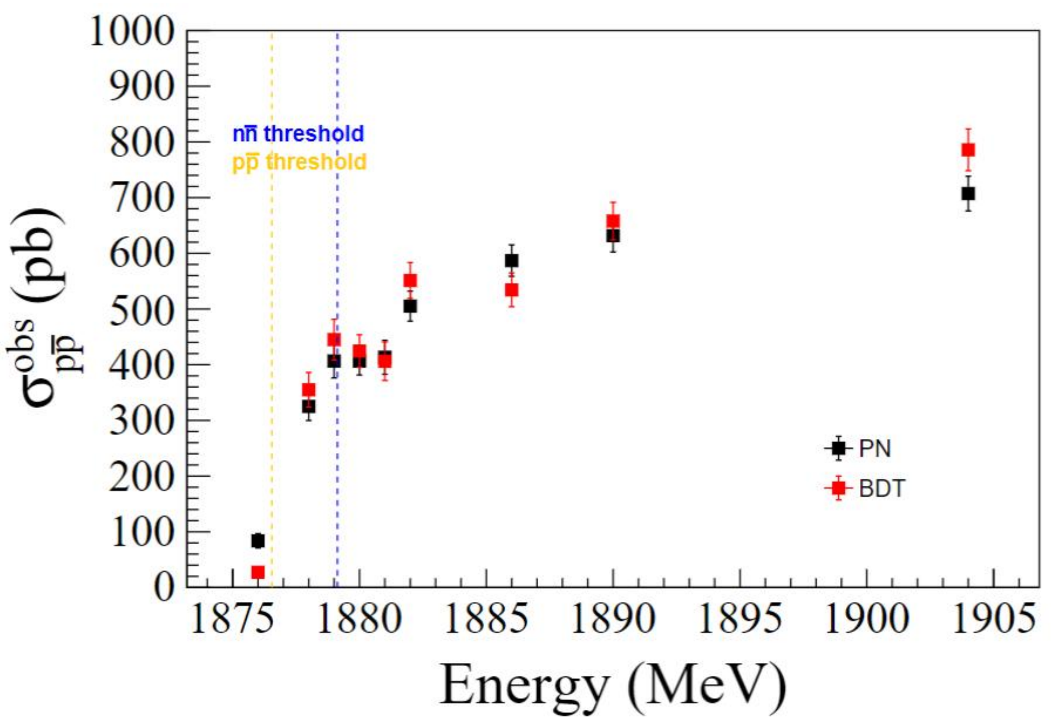


Preliminary cross-section results

- The cross section of $e^+e^- \to p\bar{p}$ can be calculated by:

$$\sigma_{p\bar{p}}^{obs} = \frac{N_{obs} - N_{bkg} - N_{n\bar{n}}}{L * \varepsilon_{cor}}$$

- Simply using the survival events of 1.870 GeV data and nnbar MC as N_{bkg} and $N_{n\bar{n}}$.
- ε_{cor} is the corrected MC efficiency by control sample.



- Particle Net:

Updated $\sqrt{s}$ (Preli.)(GeV)	1.874	1.876	1.878	1.879	1.880	1.881	1.882	1.886	1.890	1.904
Survival Events	17	59	183	192	332	218	395	469	497	546
MC Efficiency (%)	-	24.83	25.27	29.71	32.02	33.16	34.24	36.24	36.13	36.13
nnbar events	-	-	-	-	49	34	28	19	16	12
$\sigma_{p\bar{p}}^{obs}$(pb)	-	84 ± 13	325 ± 25	407 ± 30	406 ± 25	413 ± 30	505 ± 27	587 ± 28	632 ± 29	707 ± 31

Summary

- The preliminary cross-section results has been obtained, using the method of reconstructing the secondary particles produced by $\bar{p}N$ annihilation (lower 1.940 GeV).
- Next to do:
  - Analysis for Ecm larger than 1.940 GeV.
  - Angular distribution.
  - Selection criteria optimization.
  - GNN validation and systematic uncertainties.
  - ...

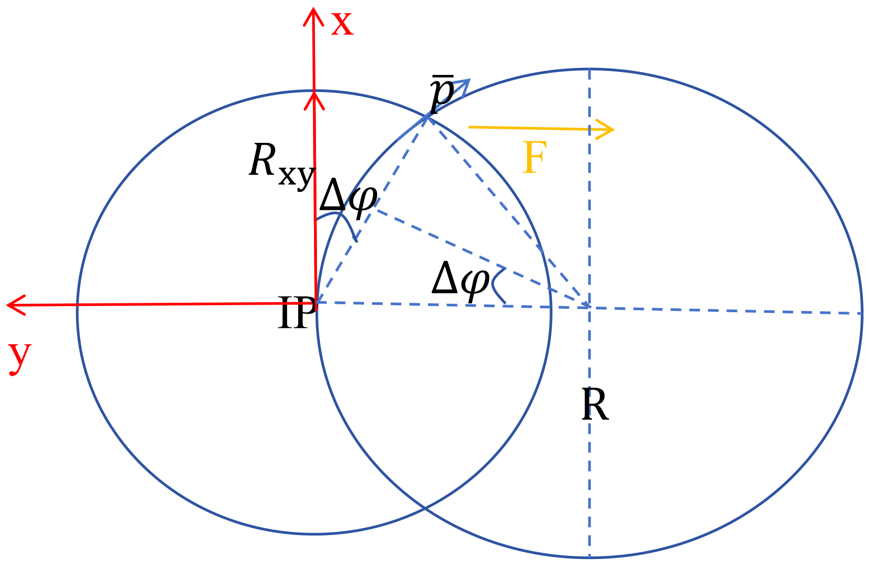
Thank you for attention!!!

Back Up

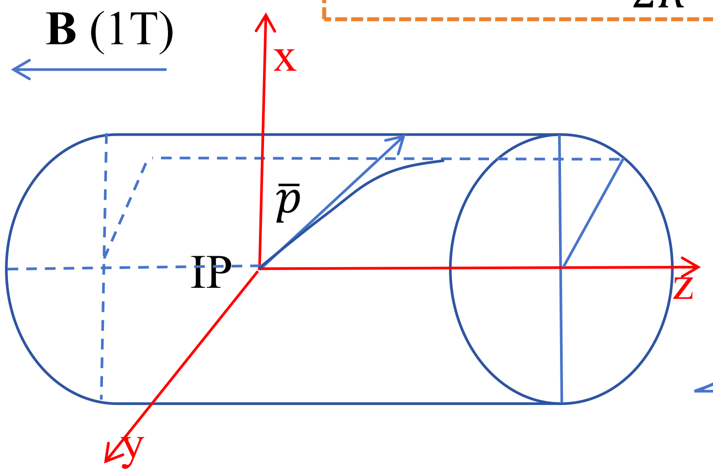
Back Up: Cut-flow before ML

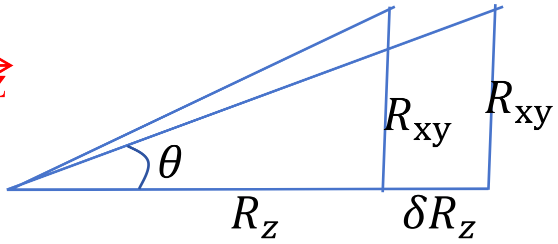
1874+4 MeV	MC Event Number	MC Efficiency	MC Relative Efficiency	Data Event Number	$p\bar{p}\pi\pi$ data Efficiency	$p\bar{p}\pi\pi$ MC Efficiency
Total	500000	100%	100%	147867603	100%	100%
Good Charged Track	437641	87.53%	87.53%	16743545	86.10%	84.96%
$N_{\pi^+} \geq 1, N_{\pi^-} \geq 1$	334227	66.85%	76.12%	2580182	44.46%	64.22%
Vertexfit	271112	54.22%	81.11%	2534787	34.25%	50.16%
$\chi^2 < 200$	227426	45.49%	83.89%	2485611	28.00%	40.81%
$2.2 < R_{xy} < 4.2$ cm	220838	44.17%	97.10%	284104	27.08%	39.47%
$\lvert R_z \rvert < 10$ cm	212860	42.57%	96.39%	81603	26.65%	38.82%
$Ang_{\pi^+\pi^-} < 175°$	211861	42.37%	99.53%	60857	26.55%	38.67%

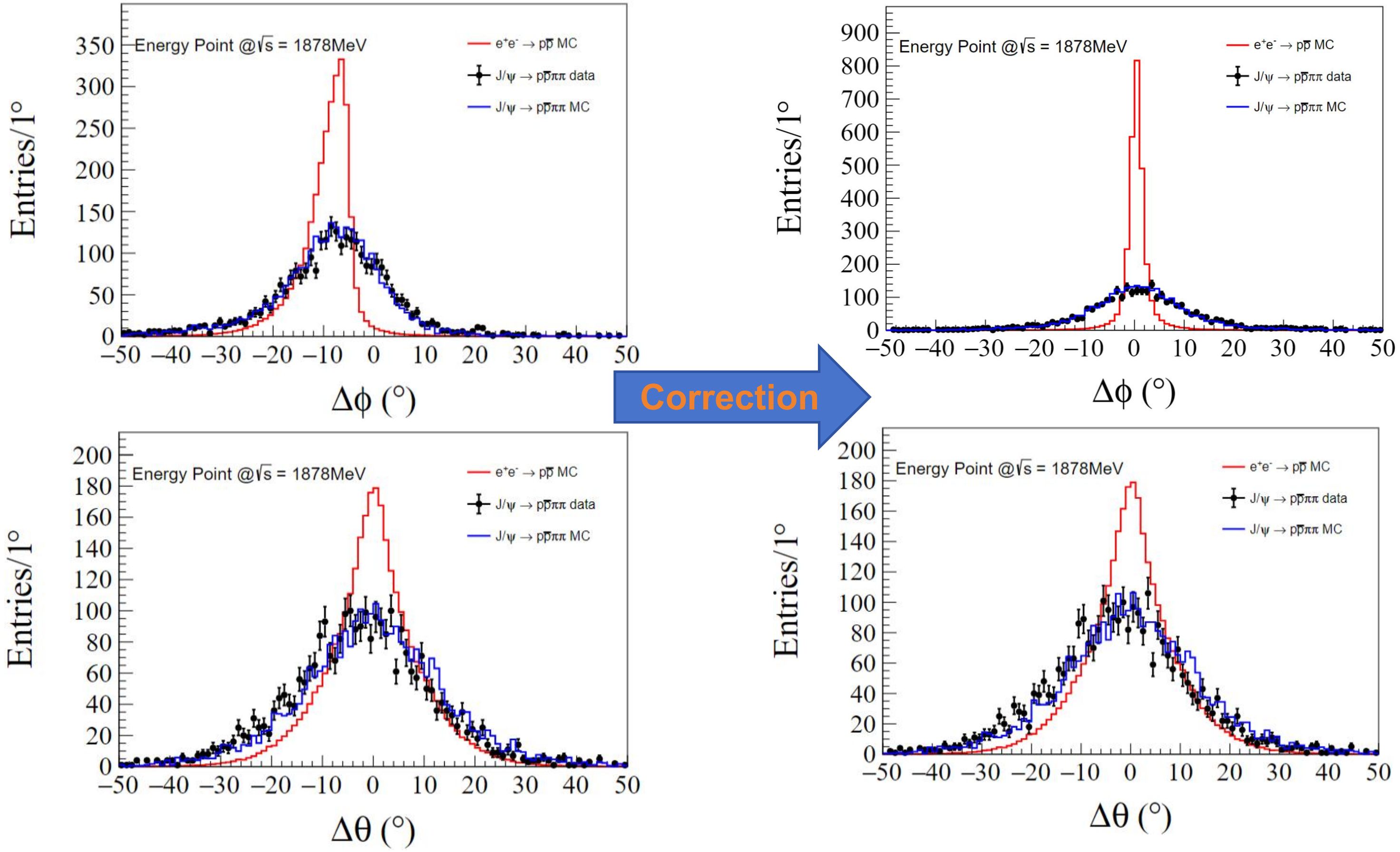
Angular Resolution



$$\Delta\varphi = sin^{-1}(\frac{R_{xy}}{2R})$$





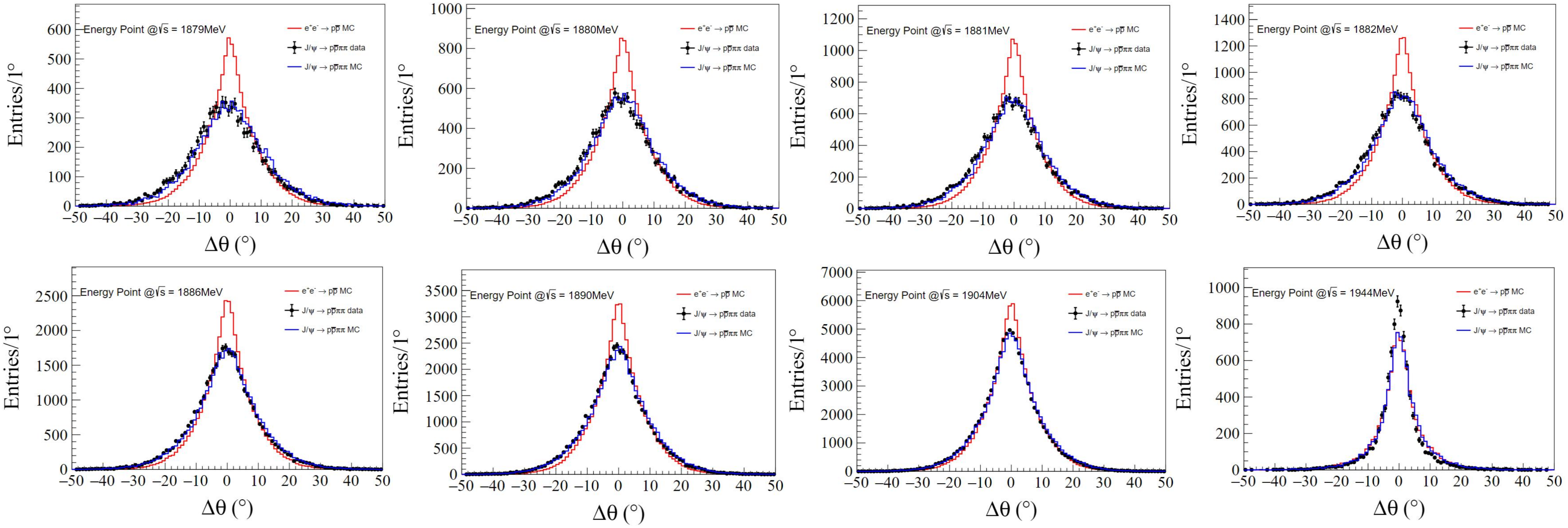


$$\delta = (\frac{2\Delta\varphi R - R_{xy}}{R_{xy}})$$

$$\Delta\theta = \frac{P_z}{|P_z|}[tan^{-1}(\frac{R_{xy}}{|R_z|}) - tan^{-1}(\frac{R_{xy}}{|R_z|(1+\delta)})]$$

Angular Resolution

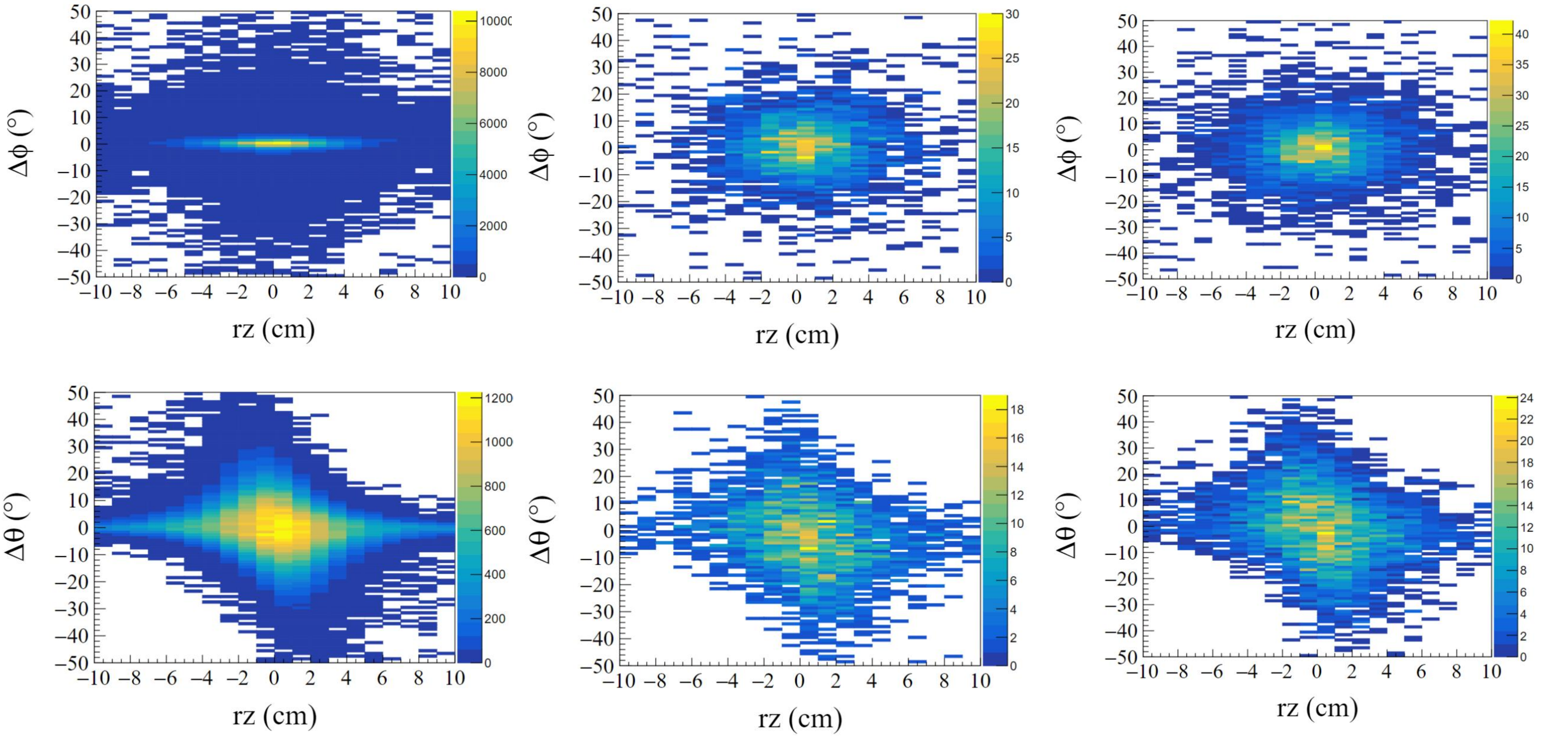
- Angular resolution at different energy points:



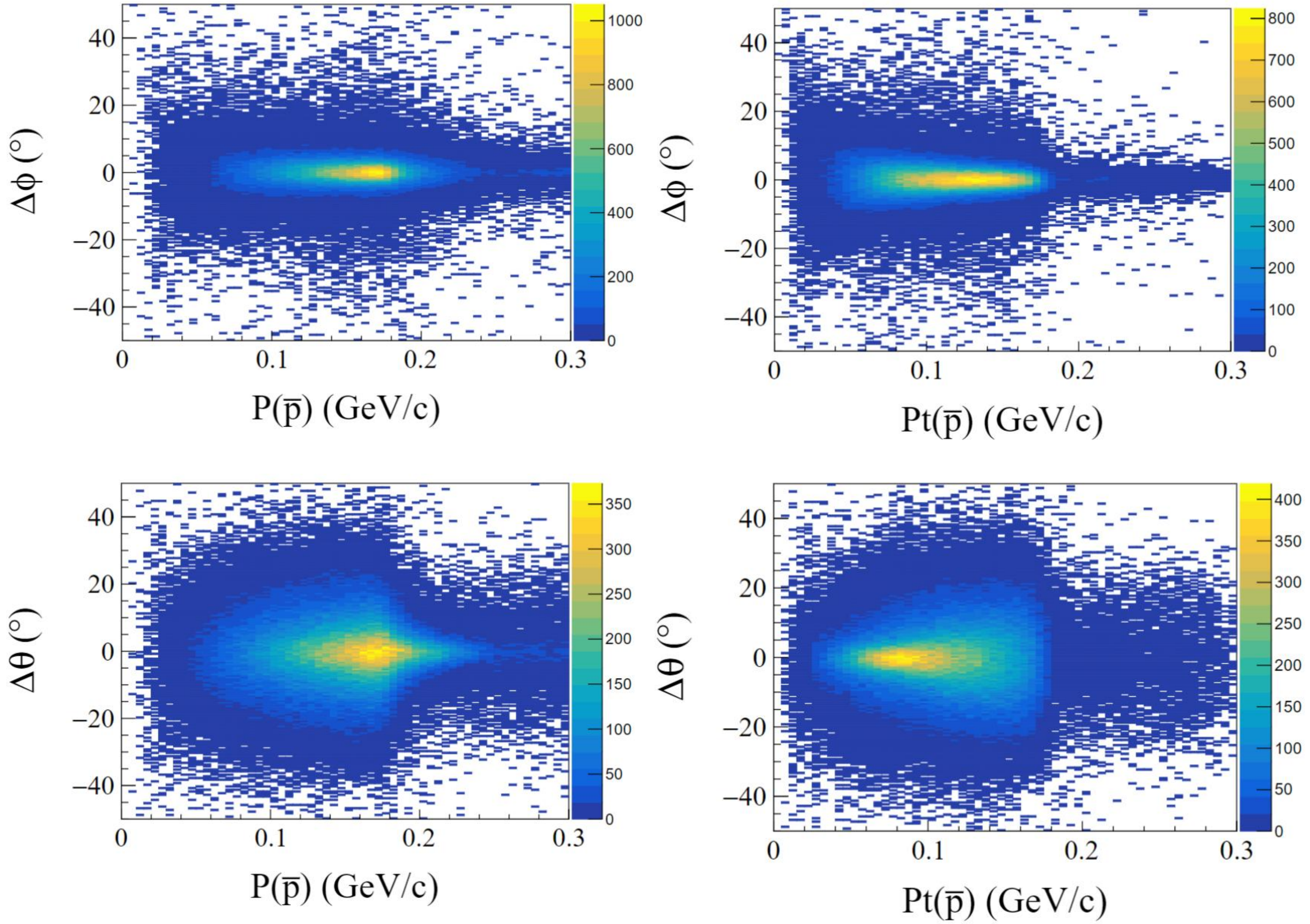
- With the increase of ECM, the anti-proton angular resolution improves.
- The angular resolution of $e^+e^- \rightarrow p\bar{p}$ MC better than $J/\psi \rightarrow p\bar{p}\pi^+\pi^-$ control sample at most energy points.

Angular Resolution

- 1.878 GeV:



Angular Resolution



Preliminary Event Selection for case 2

For energy points of 1.940 and 1.970 GeV

Decay Chain:

$$e^+e^- \to p\bar{p}$$

- **Good Charged Track:**

  $|\cos\theta| \leq 0.93$, $|V_z| < 1$ cm, $|V_{xy}| < 10$ cm; $N_{charged} = 2$;

- **PID: use Dedx and Tof information**

  p: prob(p)>prob(π, K)

  Require: $N_p = 1, N_{\bar{p}} = 1$.

- **Further Selection:**

  - For the proton candidate: $E/p < 0.5$, if the track can reach the EMC.
  - Momentum window cut for both tracks.

  - The opening angle $\theta_{p\bar{p}}$ between the two tracks in the rest frame of the e^+e^- CM system is required to be back-to-back.
  - $|T_{trk1} - T_{trk2}| < 4$ ns, where T_{trk1} and T_{trk2} are the time of flight meatured by Tof detector for the two tracks.

  Not used

Preliminary Event Selection for case 2

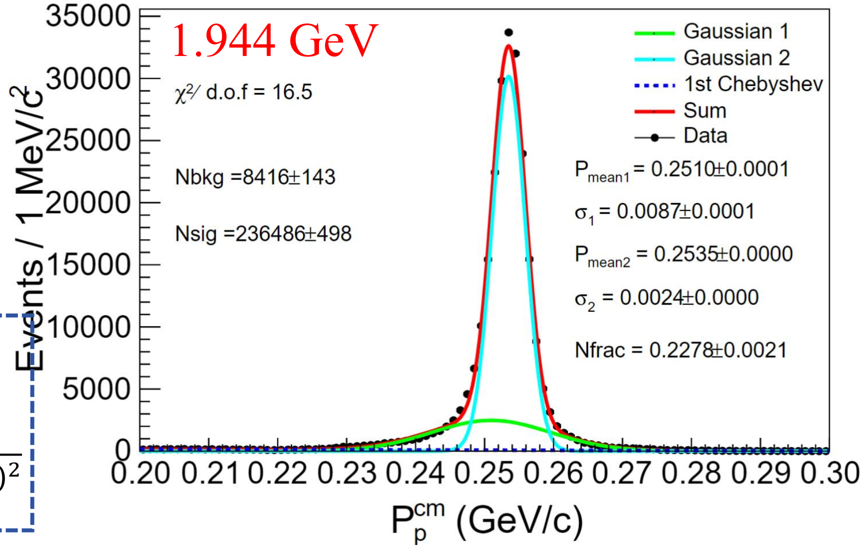
$$P_{mean} = \sqrt{f * P_1^2 + (1-f) * P_2^2}$$

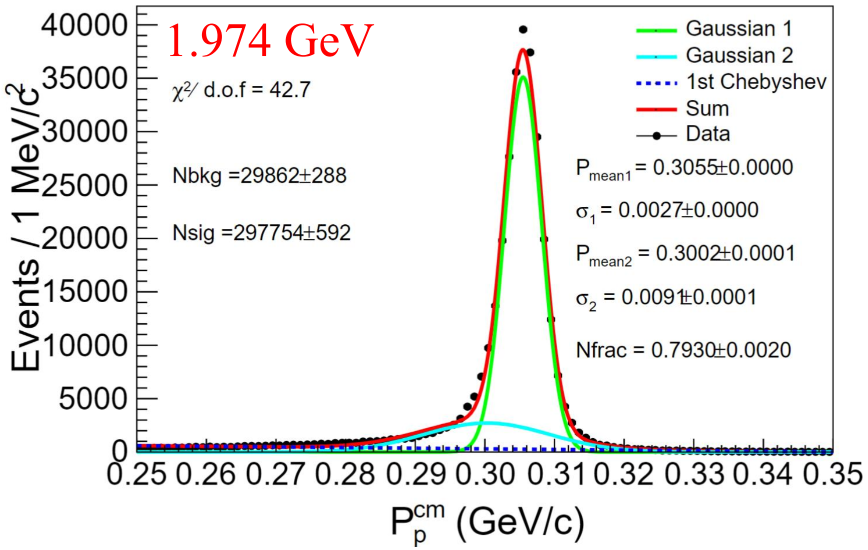
$$\sigma_P = \sqrt{f * \sigma_1^2 + (1-f) * \sigma_2^2 + f(1-f) * (P_1 - P_2)^2}$$

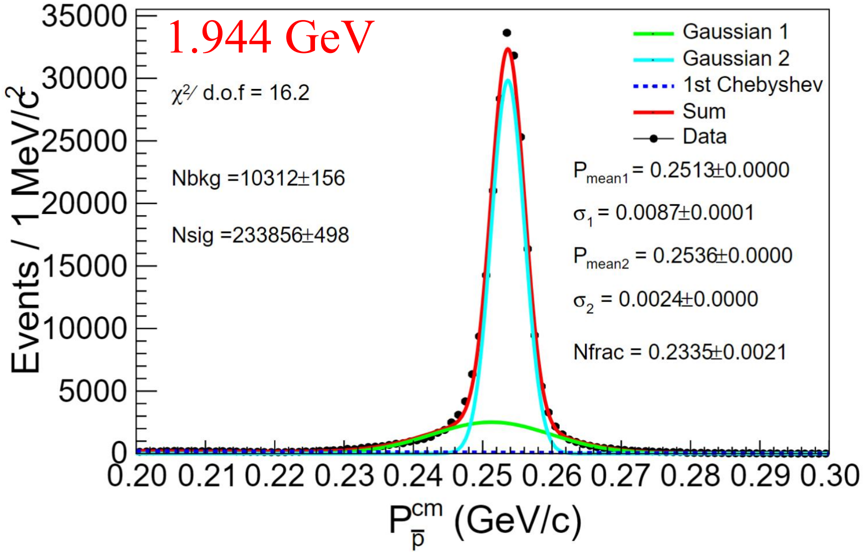
$$E_{cm} = \sqrt{P_1^2 + m_p^2} + \sqrt{P_2^2 + m_{\bar{p}}^2}$$

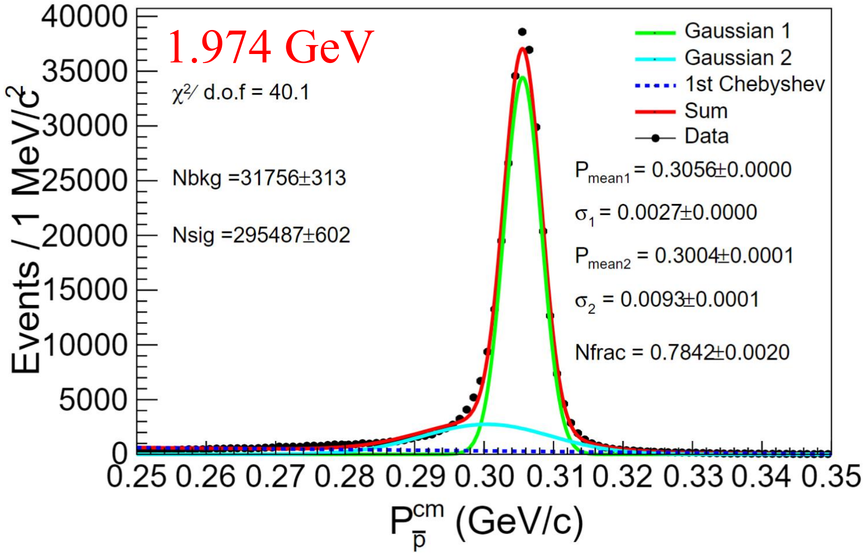
$E_{cm} = 1943.85$ MeV

$E_{cm} = 1973.54$ MeV









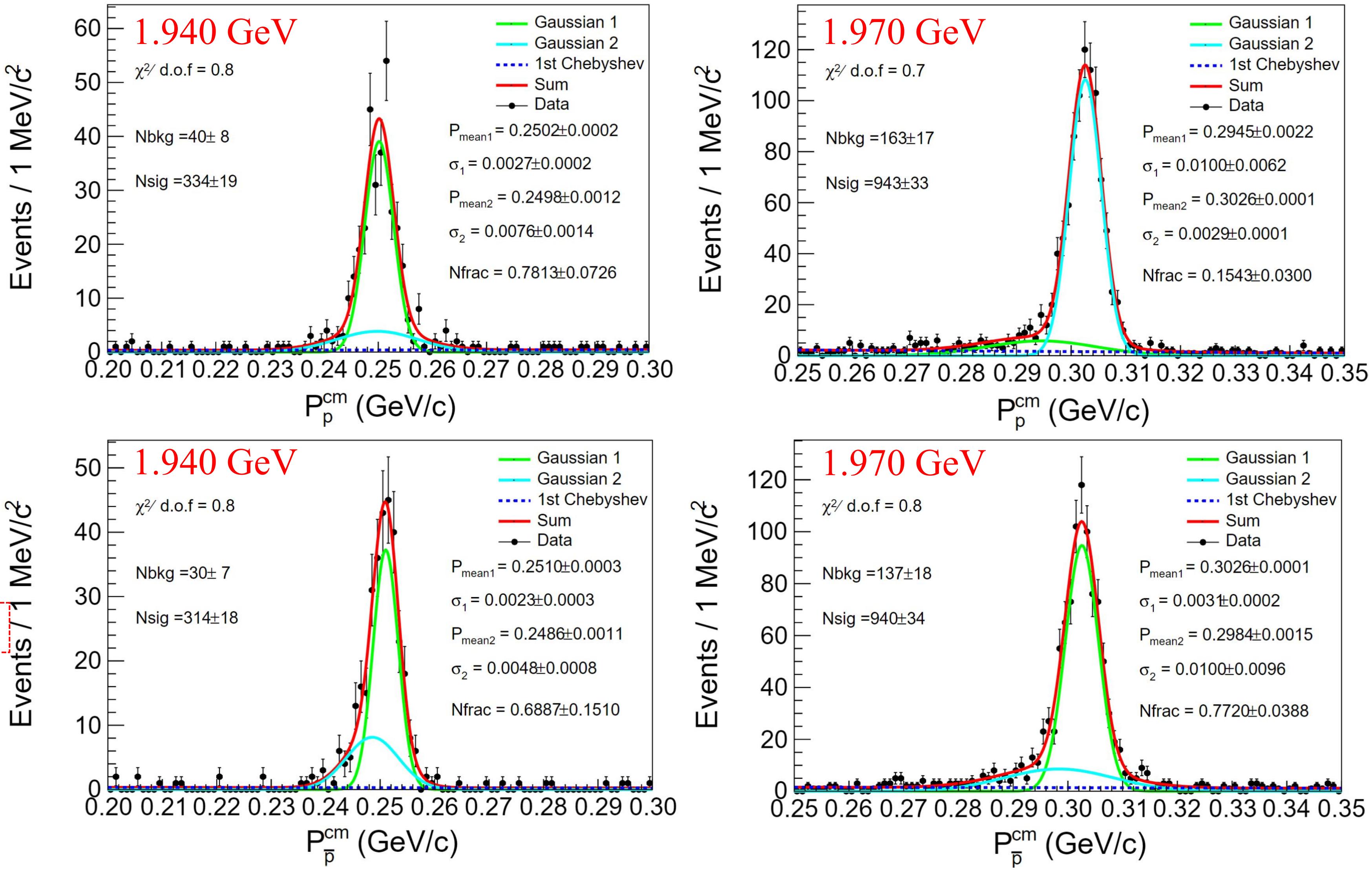
Preliminary Event Selection for case 2

$$E_{cm} = \sqrt{P_1^2 + m_p^2} + \sqrt{P_2^2 + m_{\bar{p}}^2}$$

$$E_{cm} = 1942.09 \text{ MeV}$$

$$E_{cm} = 1971.72 \text{ MeV}$$

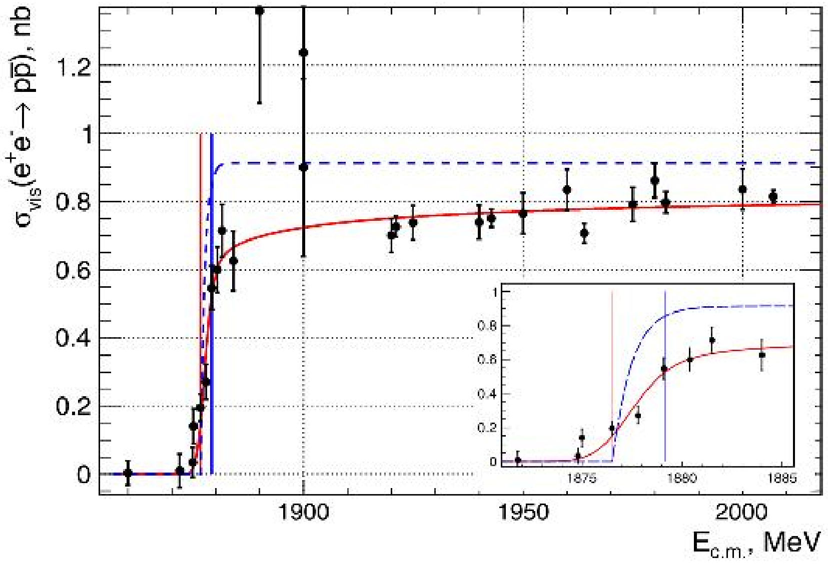
$$(P_{mean} - 4\sigma_P) < P < (P_{mean} + 3\sigma_P)$$

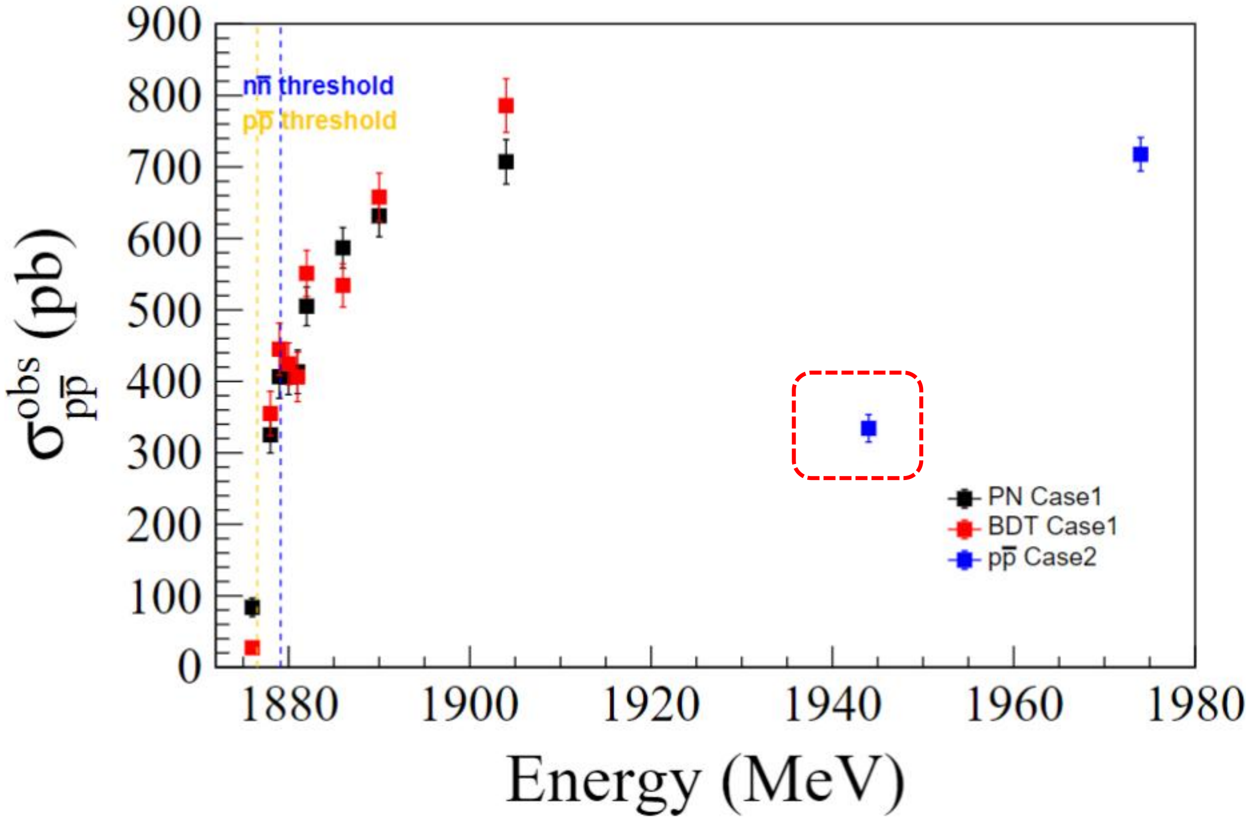


Preliminary Event Selection for case 2

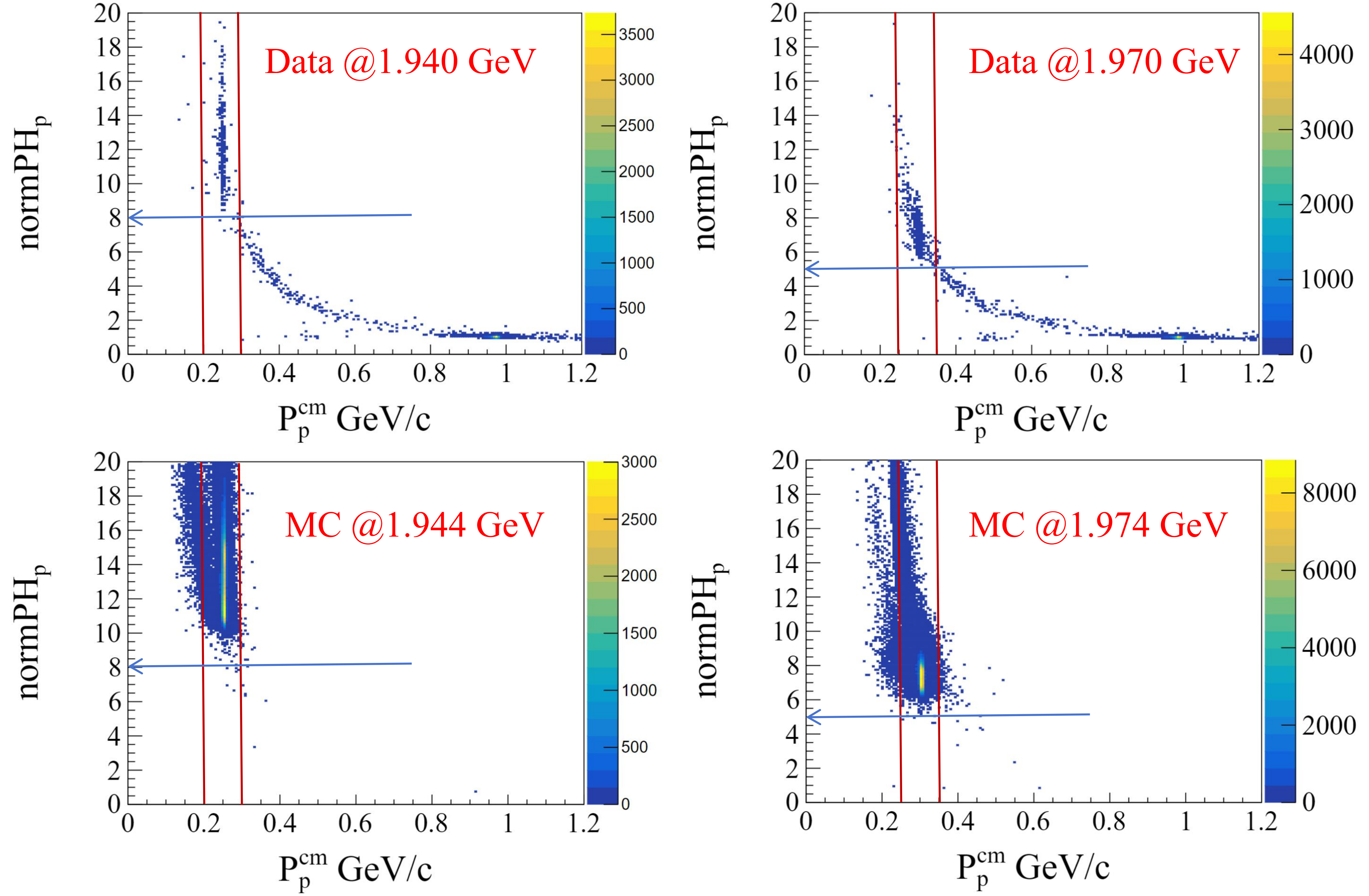
$$\sigma_{p\bar{p}}^{obs} = \frac{N_{obs}}{L * \varepsilon_{cor}}$$

Updated $\sqrt{s}$ (Preli.)(GeV)	1.940	1.970
Survival Events	306	936
MC Efficiency (%)	44.87	58.51
$\sigma_{p\bar{p}}^{obs}$(pb)	334 ± 19	718 ± 23

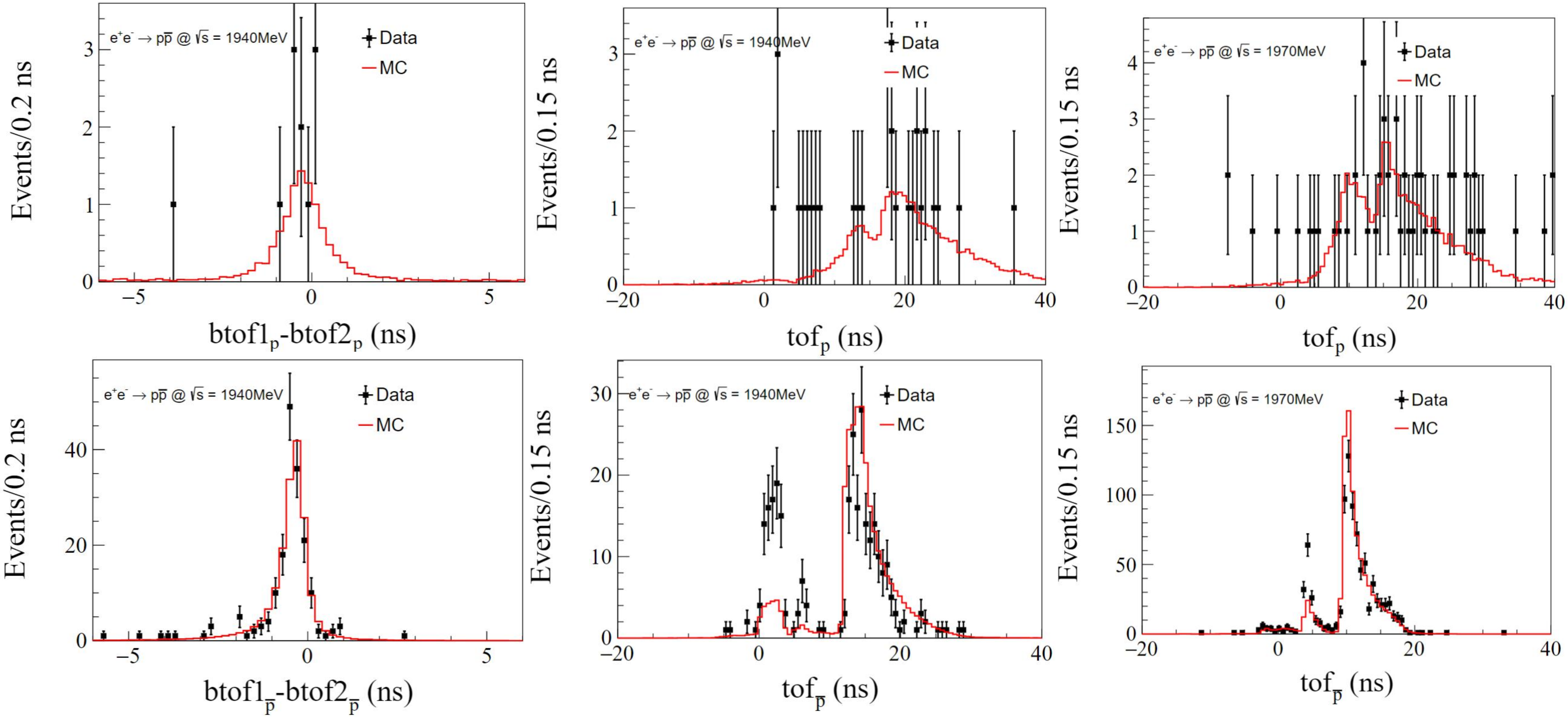




Preliminary Event Selection for case 2



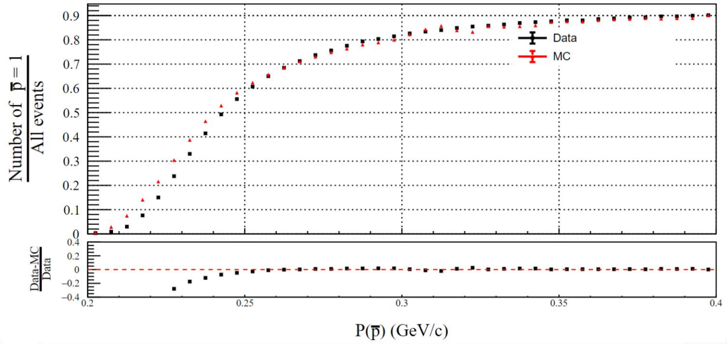
Preliminary Event Selection for case 2

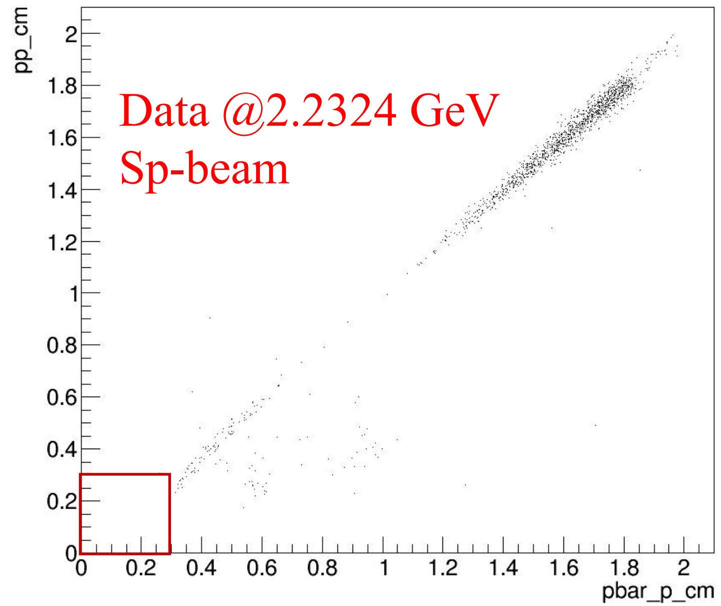


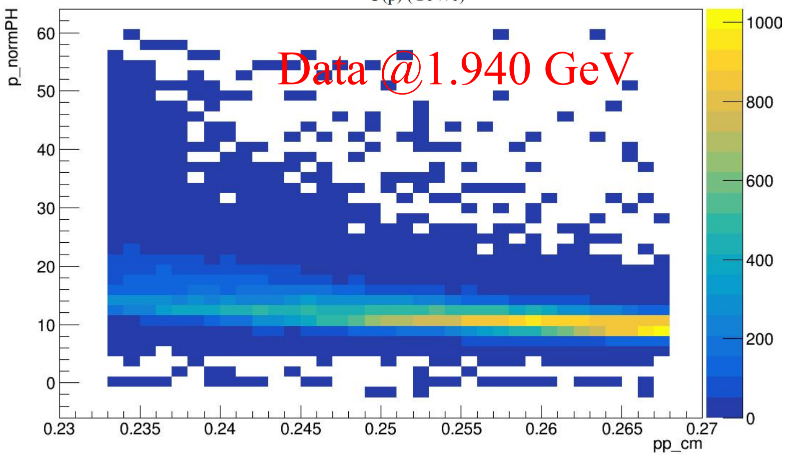
Preliminary Event Selection for case 2

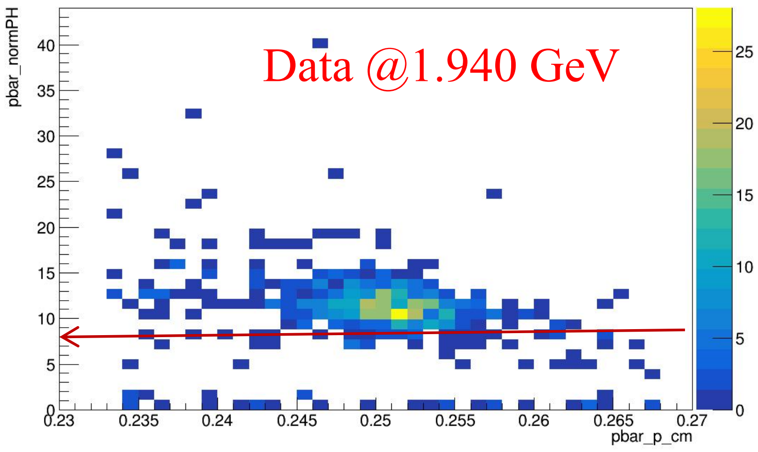
1.940 GeV	data	MC	qqbar MC	Bhabha MC	dimu MC	2.2324 sp-beam
ppbar	**306**	44.87%	2580/2580	0	0	8
only pbar	613→550	54.43%→54.42%	3378/3399→3378/3382	1→0	0	192
only p	60837→58521	58.17%→58.17%	3496/3713→3496/3668	5→5	0	68297

→: add the cut of normPH>8.



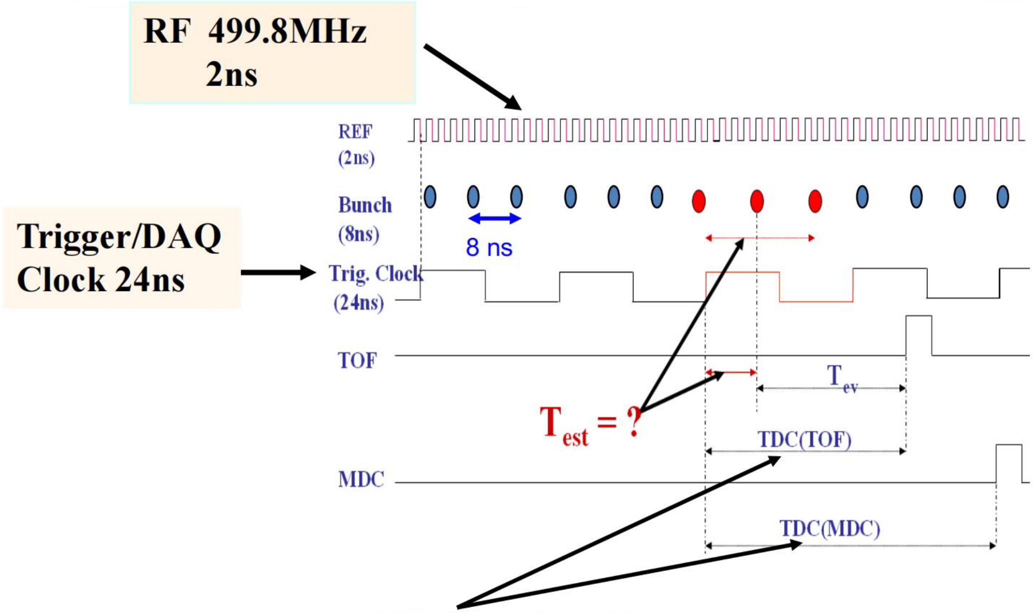






MC Efficiency T0 Determination

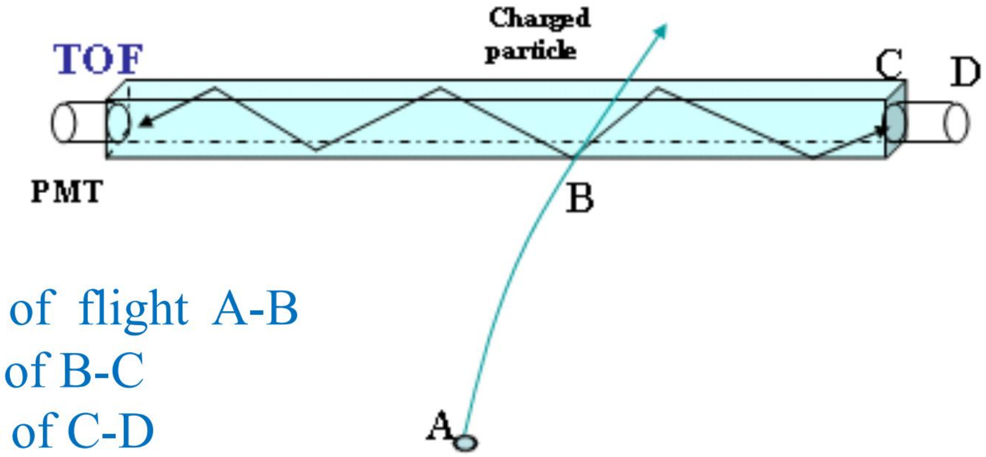
事例起始时间（Event Start Time T_{est}）



$TDC = T_{ev} + T_{est}$

$T_{est} = ?$ ← determined from offline data

利用TOF计算T_{est}



T_{tof}: Time of flight A-B
T_{pro}: Time of B-C
T_{pmt}: Time of C-D
T_{elc}: delay time at electronics

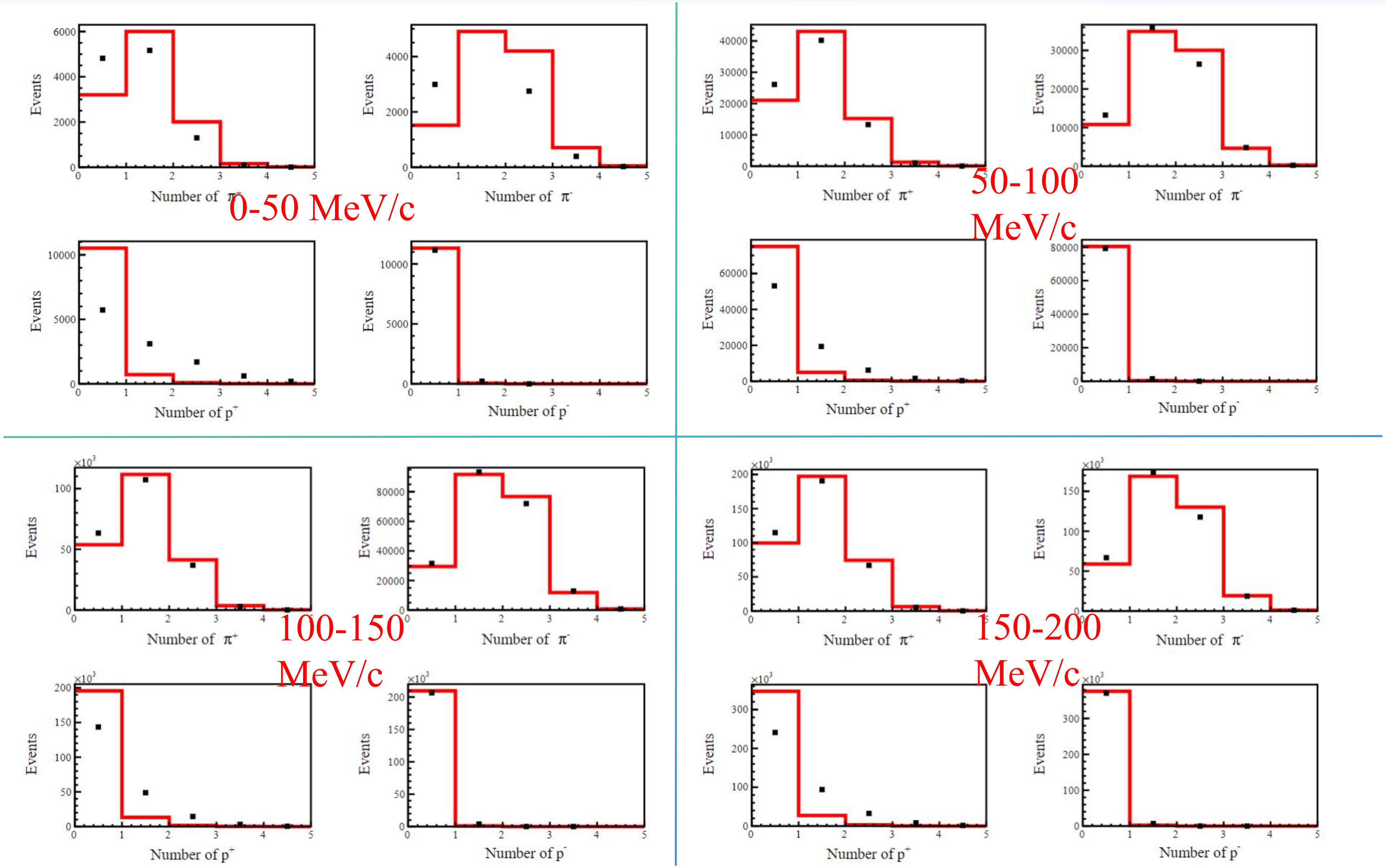
$$T_{est} = TDC - T_{ev}$$

$$T_{ev} = T_{tof} + T_{pro} + T_{pmt} + T_{elc}$$

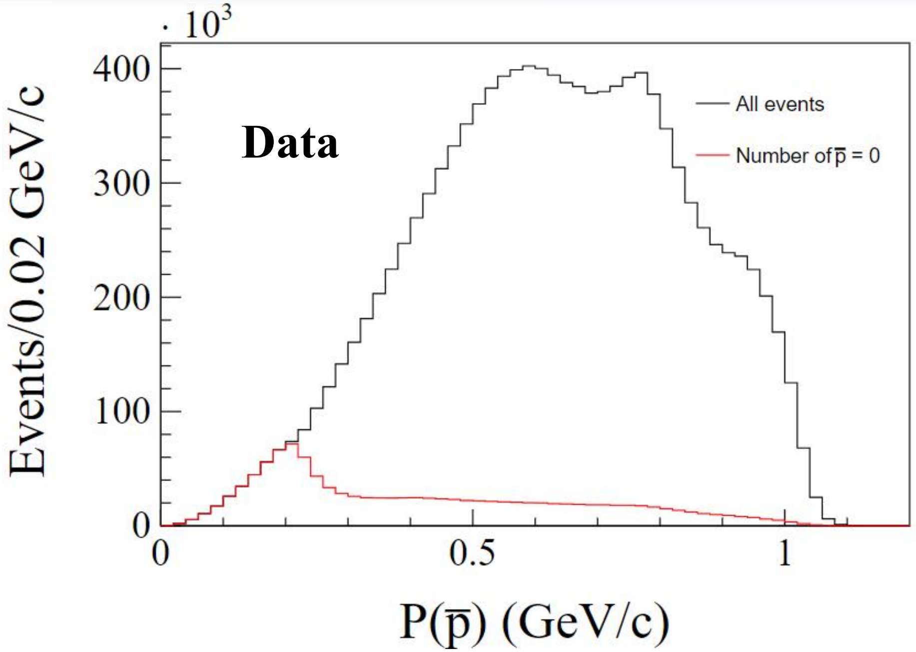
- Since the flight time of the low-energy antiproton is much greater than that of the pion, the flight time of the antiproton to the beam pipe is about 2ns. This causes Ttof to undercount by 2ns and Test to increase by 2ns, which ultimately results in an extra antiproton flight time forward when T0 is positioned.

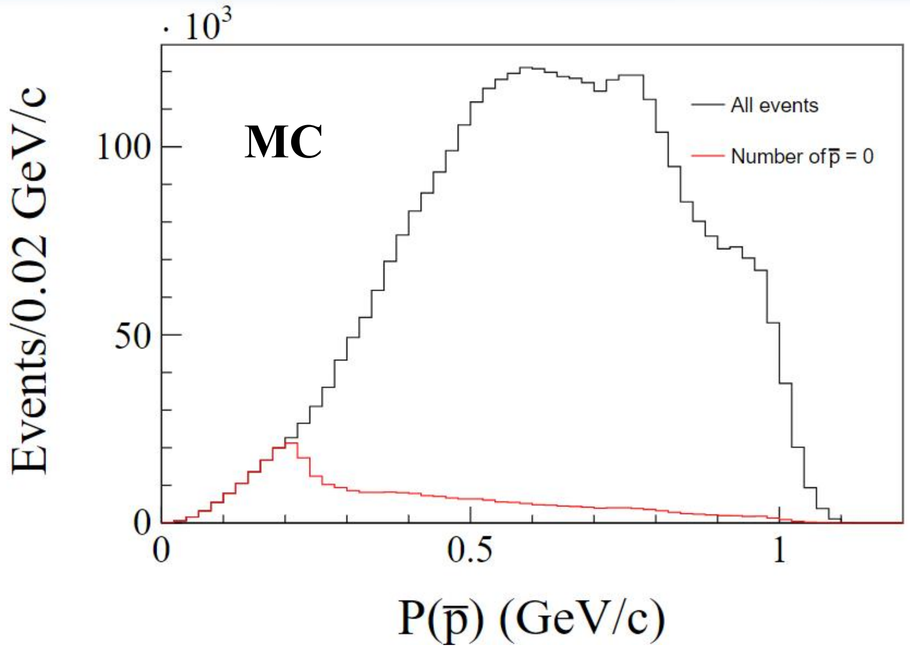
Compare Weight MC and Data $J/\psi \to p\bar{p}\pi^+\pi^-$

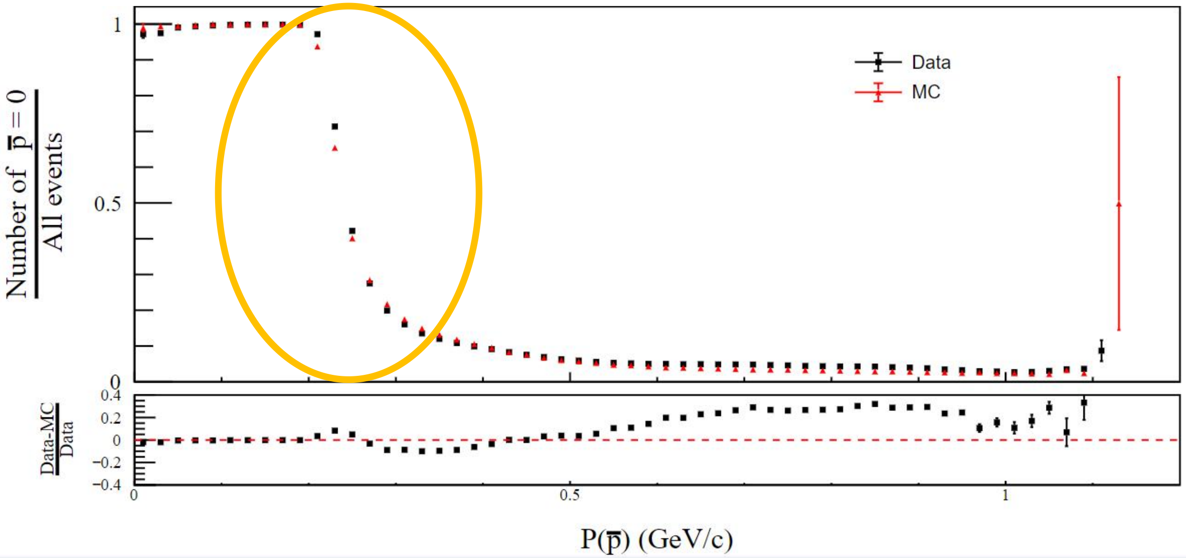
- The number of π can match well between data and MC.
- The number of p in data is more than it in MC.
- In the transition region (200-250 MeV/c), the simulation of $\bar{p}$ is not good.



BackUp: Features of $\bar{p}N$ interaction (inclusive)







More than 10M $\bar{p}$ sample within acceptance

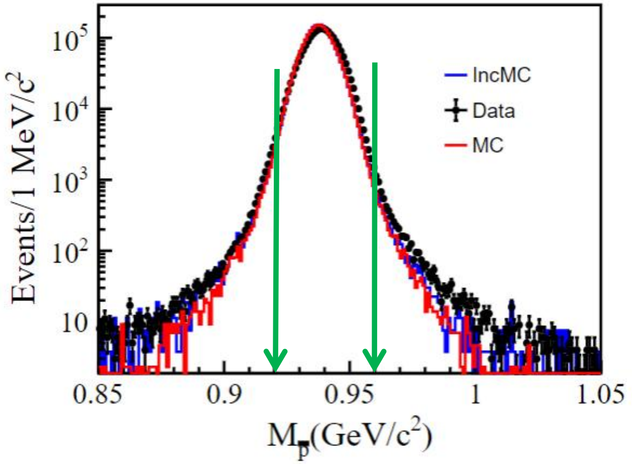
About 1.2M $\bar{p}$ didn't been observed ➔ interacted

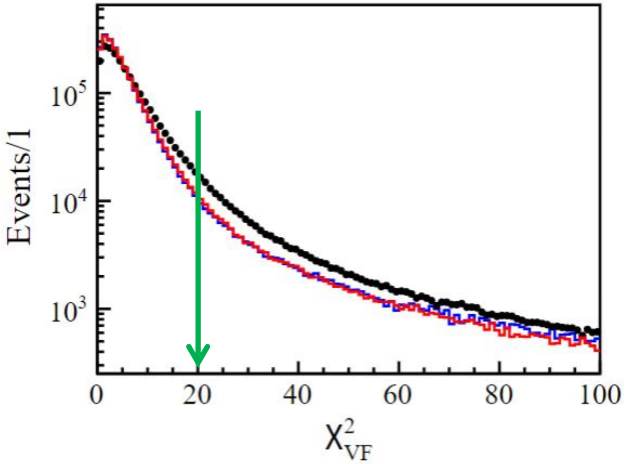
Below 200 MeV, almost 100% $\bar{p}$ interacted.

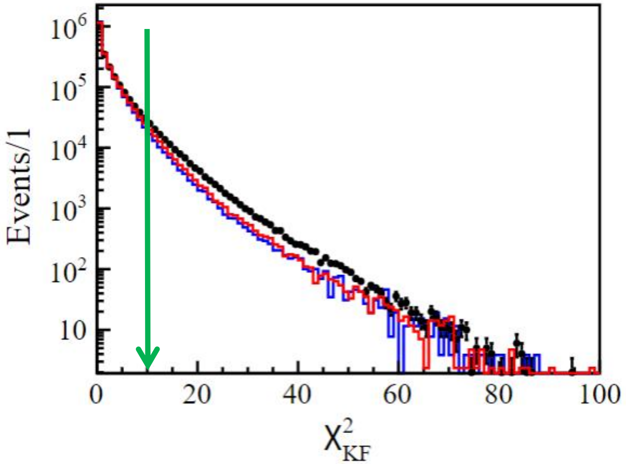
We focus on $P(\bar{p}) < 200$ MeV following

Back Up: Control Sample of $\overline{p}$

- Further Selection: $0.92 < m_{\bar{p}} < 0.96\ \mathrm{GeV/c^2}$, $\chi^2_{VF} < 20$, $\chi^2_{KF} < 10$.

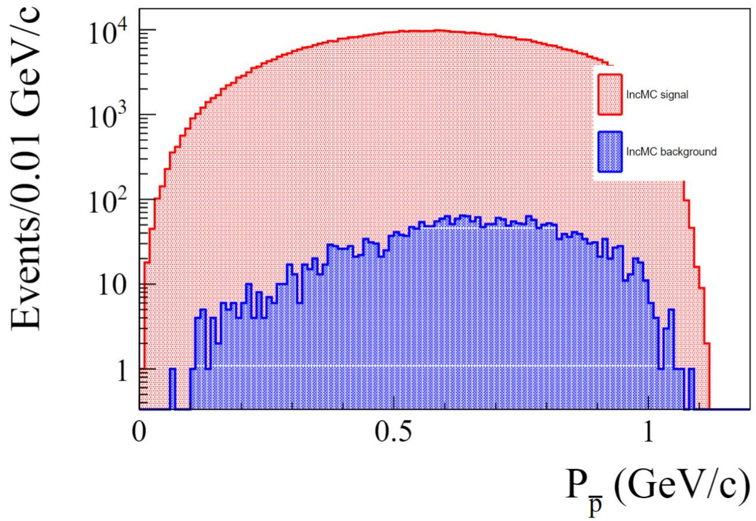






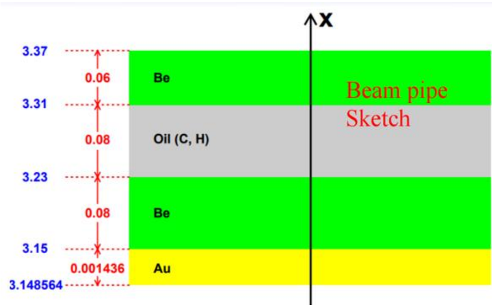
rowNo	decay initial-final states	iDcyIFSts	nEtr	nCEtr
1	$J/\psi \dashrightarrow \pi^+\pi^- p\bar{p}$	0	569168	569168
2	$J/\psi \dashrightarrow \pi^+\pi^- p\bar{p}\gamma^f$	3	747	569915
3	$J/\psi \dashrightarrow \pi^+\pi^+\pi^-\pi^- K^+K^-$	5	221	570136
4	$J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$	24	141	570277
5	$J/\psi \dashrightarrow \pi^0\pi^0\pi^+\pi^- K^+K^-$	22	136	570413
6	$J/\psi \dashrightarrow \pi^0 K^0_L\pi^+\pi^-\pi^- K^+$	12	114	570527
7	$J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^-\pi^-\pi^- K^+$	13	96	570623
8	$J/\psi \dashrightarrow \pi^0\pi^+\pi^- K^+K^-$	27	66	570689
9	$J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^-\pi^- K^+K^-$	10	54	570743
10	$J/\psi \dashrightarrow \pi^+\pi^- p\bar{p}$[illegible]	[illegible]	[illegible]	570796
11	$J/\psi \dashrightarrow \pi^0\pi^-\bar{n}p$	[illegible]	[illegible]	570841
12	$J/\psi \dashrightarrow \pi^0\pi^+\pi^+$[illegible]	15	44	570885
13	$J/\psi \dashrightarrow \pi^0\pi^0\pi^0\pi^+\pi^-\pi^- K^+$	48	43	570928
14	$J/\psi \dashrightarrow \pi^0\pi^+\pi^+\pi^-\pi^-$	19	41	570969
15	$J/\psi \dashrightarrow \pi^0 K^0_L\pi^+\pi^+\pi^- K^-$	37	40	571009
16	$J/\psi \dashrightarrow \pi^0\pi^0\pi^0\pi^+\pi^- K^+K^-$	2	35	571044
17	$J/\psi \dashrightarrow \pi^0\pi^0\pi^+\pi^+\pi^-\pi^-$	63	34	571078
18	$J/\psi \dashrightarrow \pi^+\pi^- p\bar{p}\gamma$	81	32	571110

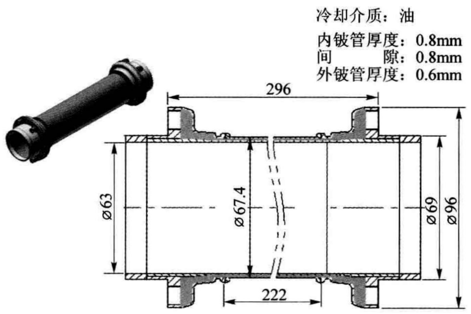
Bkg. level： 0.35%

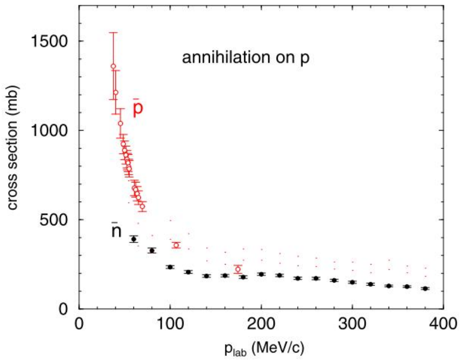


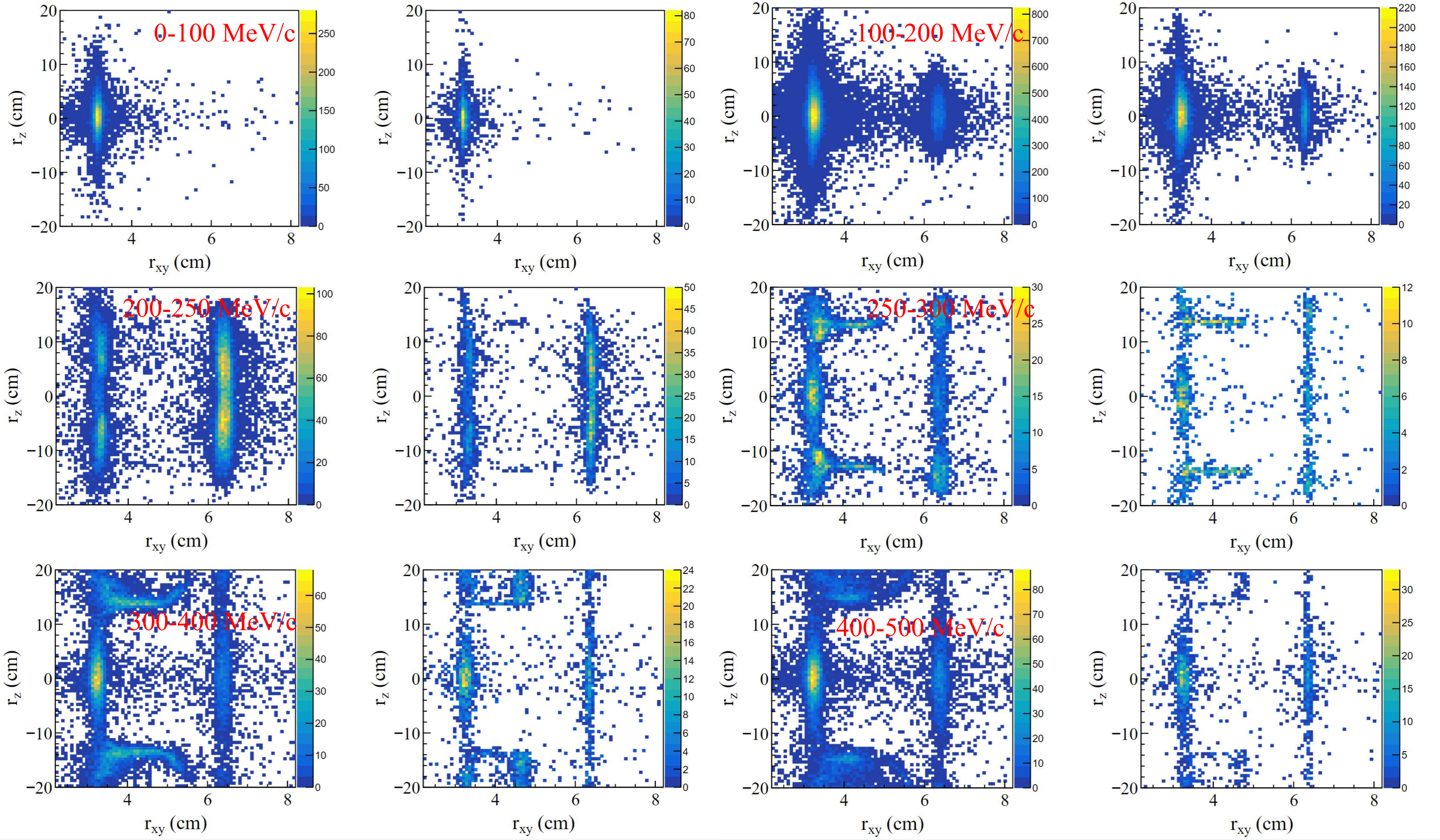
- Veto $\boldsymbol{J/\psi \to \Lambda\bar{\Lambda}}$ by requirement: $\mathrm{M}(p\pi^-) > 1.12\ \mathrm{GeV/c^2}$ or $\mathrm{M}(p\pi^-) < 1.11\ \mathrm{GeV/c^2}$

Back Up: Rxy and Rz from Vertexfit

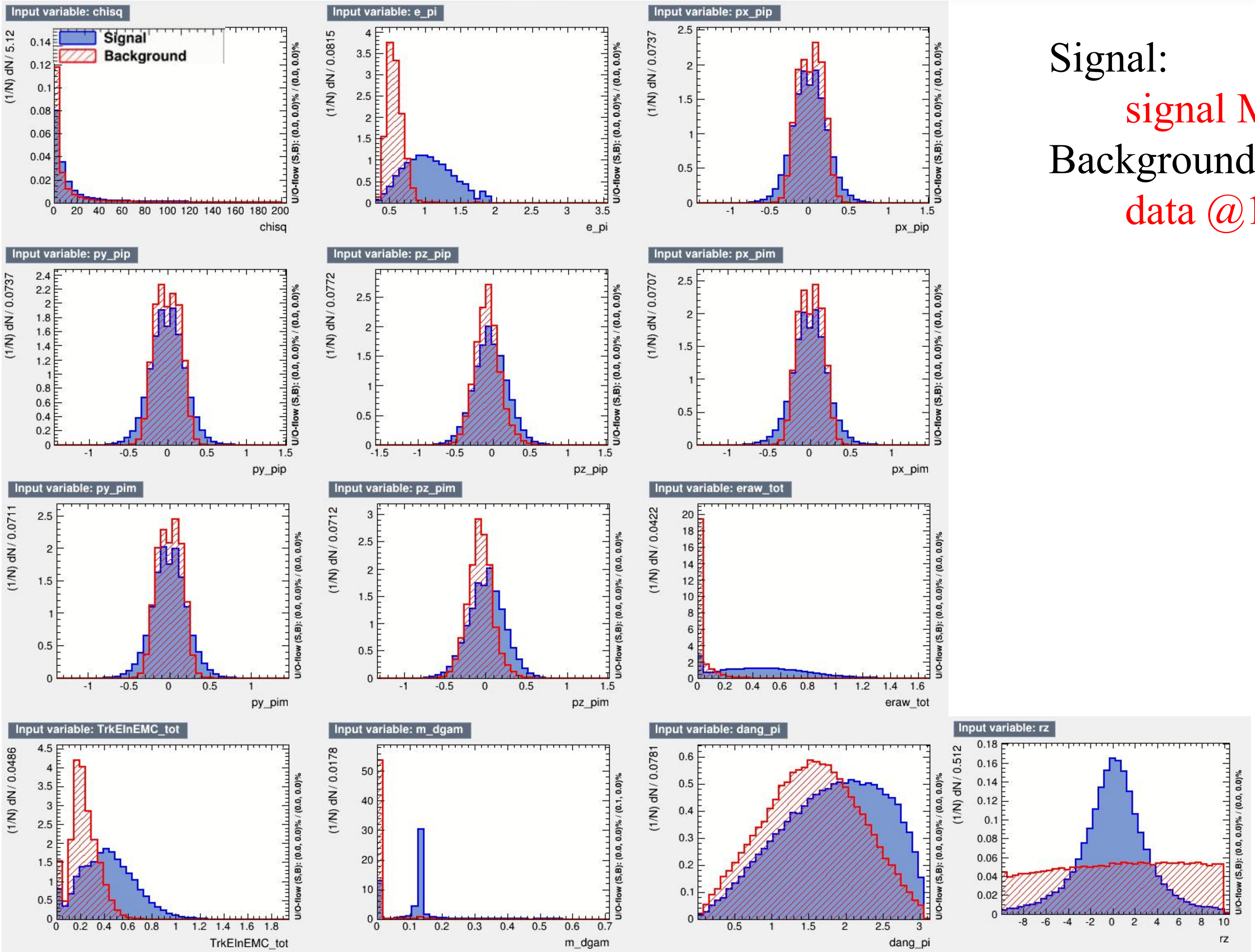








Method1:MVA-BDT Training



Signal:

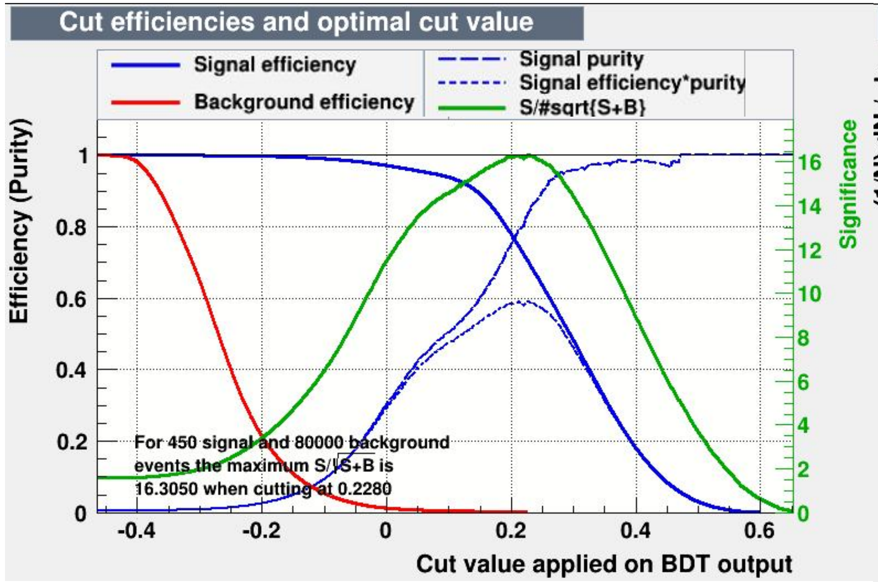
signal MC @1.878 GeV

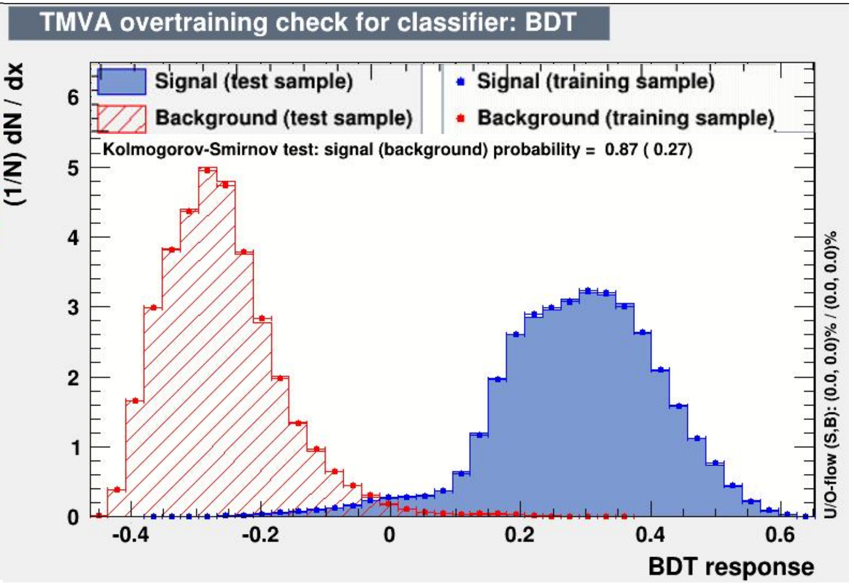
Background:

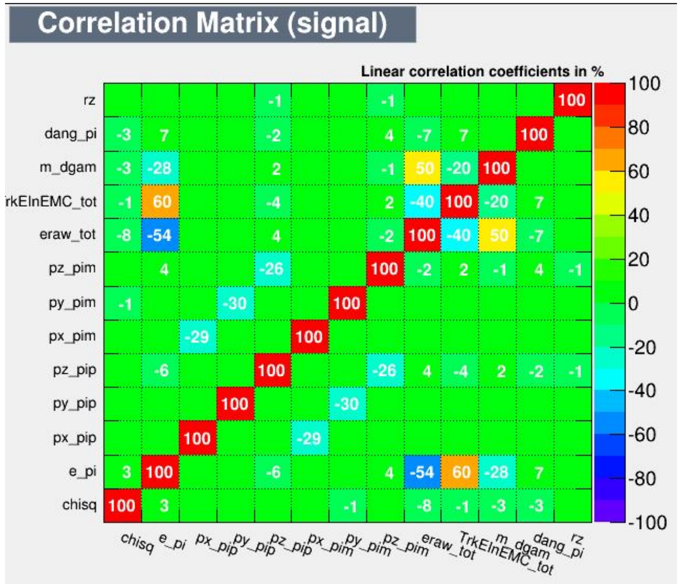
data @1.870 GeV and 1.840 GeV

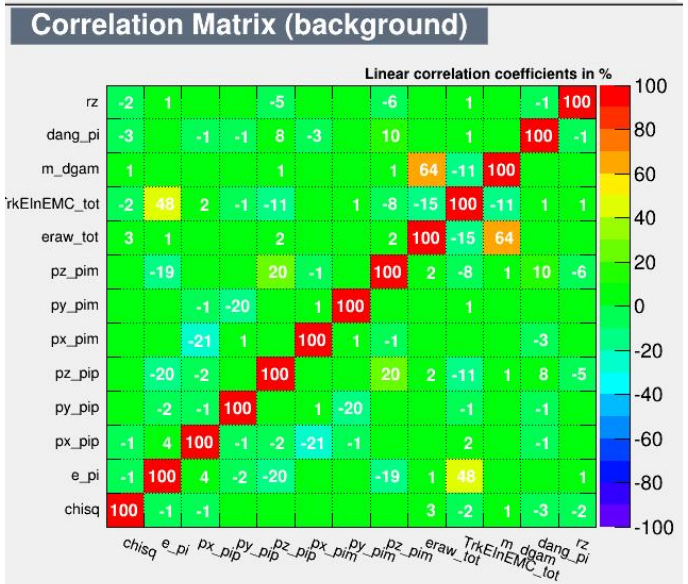
Method1:MVA-BDT Training

Classifier	(#signal, #backgr.)	Optimal-cut	S/sqrt(S+B)	NSig	NBkg	EffSig	EffBkg
BDT:	(450, 80000)	0.2280	16.305	314.8938	58.08896	0.6998	0.0007261



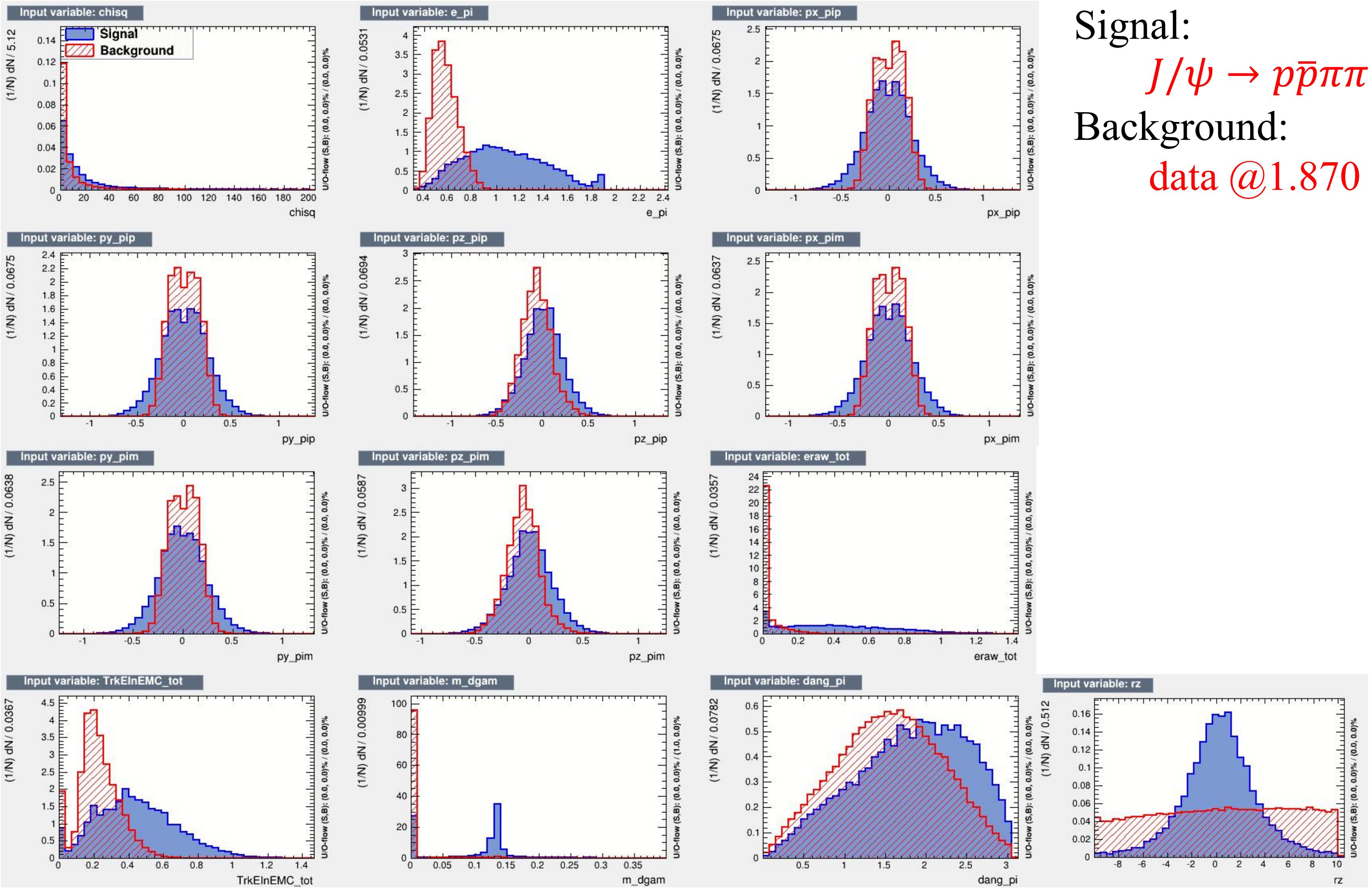






- Requirement: BDT>0.23

Method1:MVA-BDT Training



Signal:

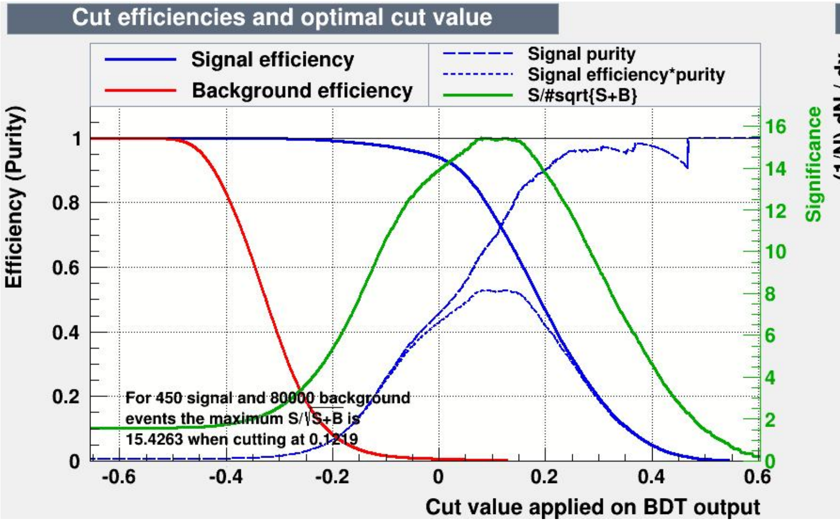
$J/\psi \to p\bar{p}\pi\pi$ data with $P_{\bar{p}} < 0.1$ GeV

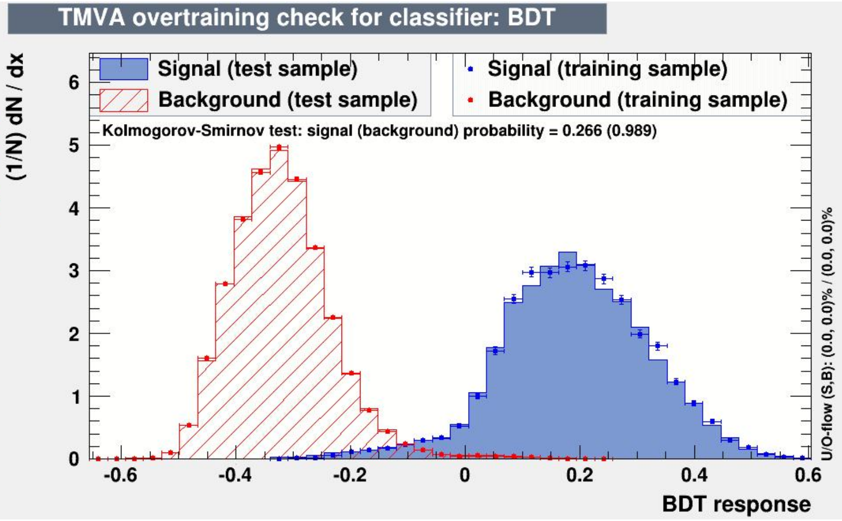
Background:

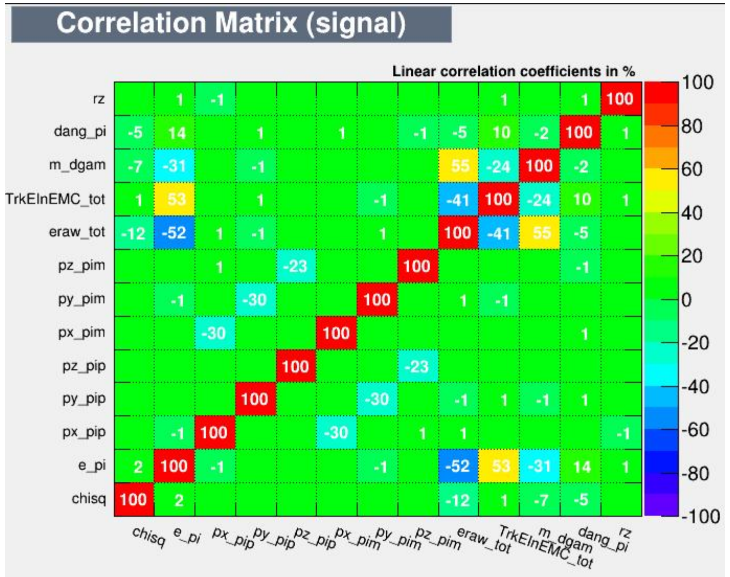
data @1.870 GeV and 1.840 GeV

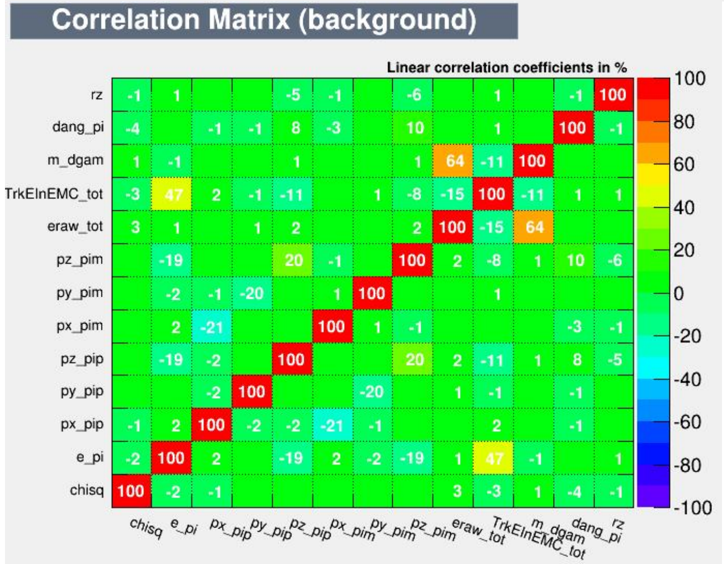
Method1:MVA-BDT Training

Classifier	(#signal,	#backgr.)	Optimal-cut	S/sqrt(S+B)	NSig	NBkg	EffSig	EffBkg
BDT:	(450,	80000)	0.1219	15.4263	319.0473	108.7011	0.709	0.001359









- Requirement: BDT>0.12

Method: Particle Transformer

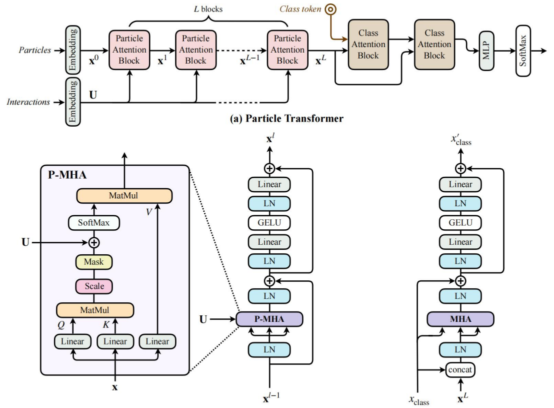
Features of Changed Tracks:

- **Azimuth angle:** ϕ and θ in lab frame.
- **Charge:** the charge of track.
- **Momentum:** the momentum of track. To achieve better resolution, this feature is obtained from `RecMdcKalTrack` after Kalman filter.
- **Helix parameters:** the five helix parameters $\left(d_\rho,\ d_z,\ \kappa,\ \phi_0,\ \lambda\right)$ describing the spatial trajectory of track.
- $\chi_{\mathrm{d}E/\mathrm{d}x}$**:** the four variables describing the divergence of $\mathrm{d}E/\mathrm{d}x$ measurement from its expected values under electron, pion, kaon and proton hypotheses, respectively.

Interaction of Tracks:

- **Four-momentum:** $(P_x\,, P_y\,, P_z\,, E)$

$$\Delta = \sqrt{(y_a - y_b)^2 + (\phi_a - \phi_b)^2},$$
$$k_\mathrm{T} = \min\left(p_{\mathrm{T},a},\ p_{\mathrm{T},b}\right)\Delta,$$
$$z = \min\left(p_{\mathrm{T},a},\ p_{\mathrm{T},b}\right) / \left(p_{\mathrm{T},a} + p_{\mathrm{T},b}\right),$$
$$m^2 = (E_a + E_b)^2 - \|\mathbf{p}_a + \mathbf{p}_b\|^2.$$



Features of Neutral Tracks:

- **Azimuth angle:** ϕ and θ in lab frame.
- **Energy:** the energy of this shower.
- **Hit Number:** the number of hitting crystals in EMC.
- **Time:** the time information of shower.
- E_{III} **and** E_V**:** the ratio of energy deposited in the 3×3 or 5×5 crystal around the center of the shower, respectively.
- A_{20} **moment and** A_{42} **moment:** the Zernike moment A_{nm} defined as

$$A_{n,m} = \left|\sum_i \frac{E_i}{E_{tot}} f_{n,m}(r_i/R_0) e^{im\phi}\right|, \tag{9}$$

  with $f_{2,0}(x) = 2x^2 - 1$ and $f_{4,2} = 4x^4 - 3x^2$. Here i denotes the different crystals, E_i is the energy deposited in the crystal and r_i is its distance from the shower center.
- **Secondary moment:** defined as $\sum_i E_i r_i^2 / \sum_i E_i$.
- **lateral moment:** defined as $\sum_{i=3}^n E_i r_i^2 / (E_1 r_0^2 + E_2 r_0^2 + \sum_{i=3}^n E_i r_i^2)$.

Method: Particle Net

Features of Changed Tracks:

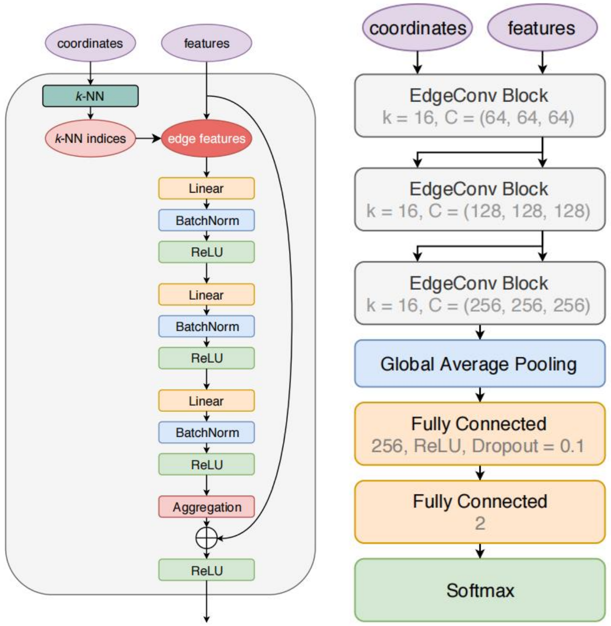
- **Azimuth angle:** ϕ and θ in lab frame.
- **Charge:** the charge of track.
- **Momentum:** the momentum of track. To achieve better resolution, this feature is obtained from `RecMdcKalTrack` after Kalman filter.
- **Helix parameters:** the five helix parameters $(d_\rho,\ d_z,\ \kappa,\ \phi_0,\ \lambda)$ describing the spatial trajectory of track.
- $\chi_{\mathbf{d}E/\mathbf{d}x}$**:** the four variables describing the divergence of dE/dx measurement from its expected values under electron, pion, kaon and proton hypotheses, respectively.

Points of Tracks:

- (θ, ϕ) as the position of particles.

$$\boldsymbol{x}_i' = \mathop{\square}_{j=1}^{k} \boldsymbol{h}_\Theta(\boldsymbol{x}_i, \boldsymbol{x}_{i_j}),$$

$$\boldsymbol{h}_\Theta(\boldsymbol{x}_i, \boldsymbol{x}_{i_j}) = \bar{\boldsymbol{h}}_\Theta(\boldsymbol{x}_i, \boldsymbol{x}_{i_j} - \boldsymbol{x}_i),$$



Features of Neutral Tracks:

- **Azimuth angle:** ϕ and θ in lab frame.
- **Energy:** the energy of this shower.
- **Hit Number:** the number of hitting crystals in EMC.
- **Time:** the time information of shower.
- $\boldsymbol{E_{III}}$ **and** $\boldsymbol{E_V}$**:** the ratio of energy deposited in the 3×3 or 5×5 crystal around the center of the shower, respectively.
- $\boldsymbol{A_{20}}$ **moment and** $\boldsymbol{A_{42}}$ **moment:** the Zernike moment A_{nm} defined as

$$A_{n,m} = \left| \sum_i \frac{E_i}{E_{tot}} f_{n,m}(r_i/R_0) e^{im\phi} \right|, \tag{9}$$

  with $f_{2,0}(x) = 2x^2 - 1$ and $f_{4,2} = 4x^4 - 3x^2$. Here i denotes the different crystals, E_i is the energy deposited in the crystal and r_i is its distance from the shower center.
- **Secondary moment:** defined as $\sum_i E_i r_i^2 / \sum_i E_i$.
- **lateral moment:** defined as $\sum_{i=3}^{n} E_i r_i^2 / (E_1 r_0^2 + E_2 r_0^2 + \sum_{i=3}^{n} E_i r_i^2)$.

BOSS Version Change

Upgrade of BOSS External Libraries

7.0.9		7.1.0-pre*		
OS: SLC6.9	→	OS: CentOS7	→	7.1.0
GCC:4.6.3		GCC:4.9.3		
LCG: 65a		LCG:84		
Gaudi:v23r9		Gaudi:v27r1		
ROOT:5.34		ROOT: 6.20.02		
CLHEP:2.0.4.5		CLHEP: 2.4.4.0		
Geant4:9.3		Geant4:10.7		

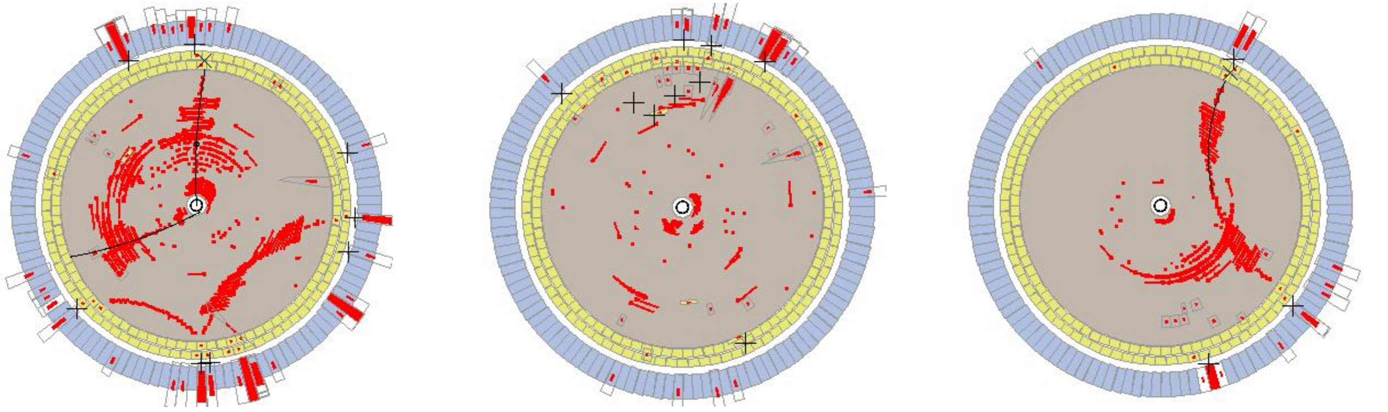
The changes about the upgrade of external libraries have been merged to CVS

- Take advantage of new CentOS 7.9
- More particle species and precise physics models
- More functionalities of ROOT, and support EOS
- For physics users, minimize the changes needed
  - Changes on Service and Algorithm interfaces, due to the upgrade of Gaudi
  - Changes due to upgrade of ROOT, C++, CLHEP

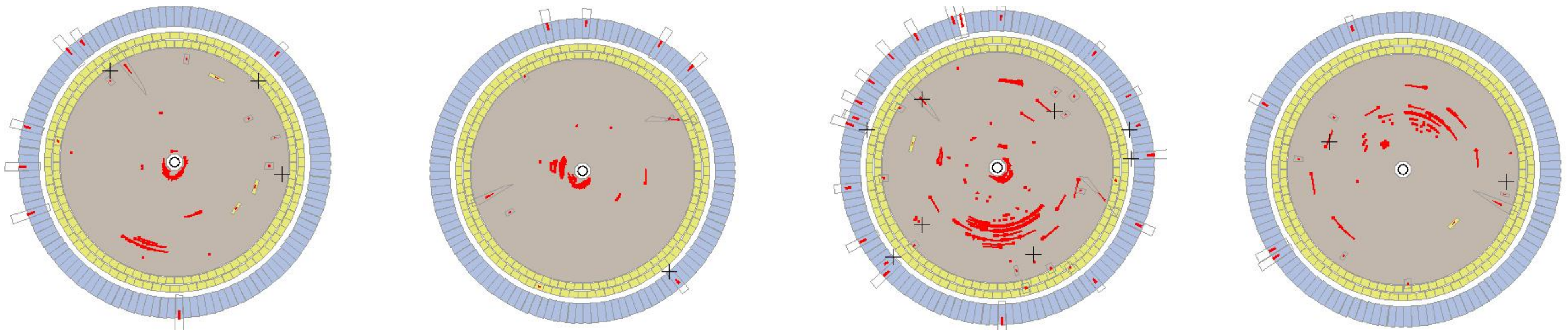
Back Up Single MC

$\bar{n}$:

$P = 100\ \mathrm{MeV/c}$



$p\ and\ n$:



Back Up $\bar{p}N \rightarrow Anything$

- $\bar{p}p \rightarrow Anything$

Pionic multiplicity distribution

	From Table 7	From [263]
2 pions	$0.38 \pm 0.03\%$	$0.38 \pm 0.03\%$
3 pions	$7.4 \pm 0.3\%$	$7.8 \pm 0.4\%$
4 pions	$18.1 \pm 1.8\%$	$17.5 \pm 3.0\%$
5 pions	$35.2 \pm 3.7\%$	$45.8 \pm 3.0\%$
6 pions	$23.3 \pm 2.8\%$	$22.1 \pm 1.5\%$
7 pions	$3.3 \pm 0.3\%$	$6.1 \pm 1.0\%$
8 pions		$0.3 \pm 0.1\%$

Final state	BNL	CERN
K^+K^-	1.10 ± 0.10	0.96 ± 0.08
$K_sK_s + K_lK_l$	$0.010^{+0.012}_{-0.010}$	0.008 ± 0.008
K_sK_l	0.71 ± 0.10	0.80 ± 0.05
$(K_sK_s + K_lK_l)\pi^0$	1.46 ± 0.20	1.56 ± 0.12
$K_sK_l\pi^0$	0.67 ± 0.07	0.67 ± 0.07
$(K_sK_s + K_lK_l)MM$	1.28 ± 0.16	1.42 ± 0.26
$K_sK^{\pm}\pi^{\mp}$	4.25 ± 0.55	4.25 ± 0.20
$(K_sK_s + K_lK_l)\pi^-\pi^+$	4.02 ± 0.52	3.90 ± 0.46
$K_sK_l\pi^-\pi^+$	2.41 ± 0.36	2.26 ± 0.45
$K^0K^{\pm}\pi^{\mp}\pi^0$	8.94 ± 1.06	9.38 ± 1.10
$(K_sK_s + K_lK_l)\pi^-\pi^+\pi^0$	2.98 ± 0.44	2.20 ± 0.28
$K^0K^{\pm}\pi^{\mp}\pi^-\pi^+$	0.59 ± 0.08	0.71 ± 0.07
$K^0K^{\pm}4\pi$	~ 0	~ 0
Sum	28.4 ± 1.5	28.1 ± 1.4

10^{-3}

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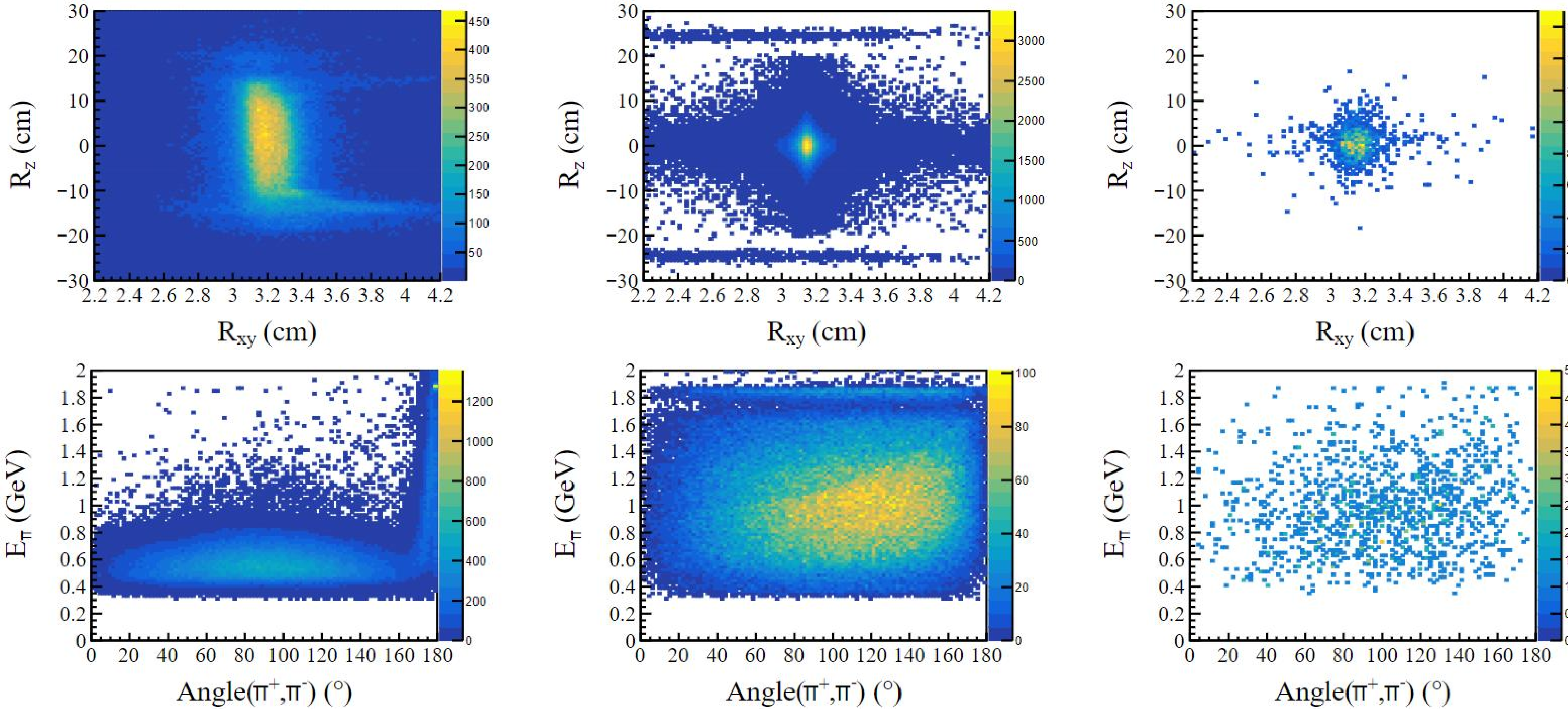
- $\bar{p}n \rightarrow Anything$

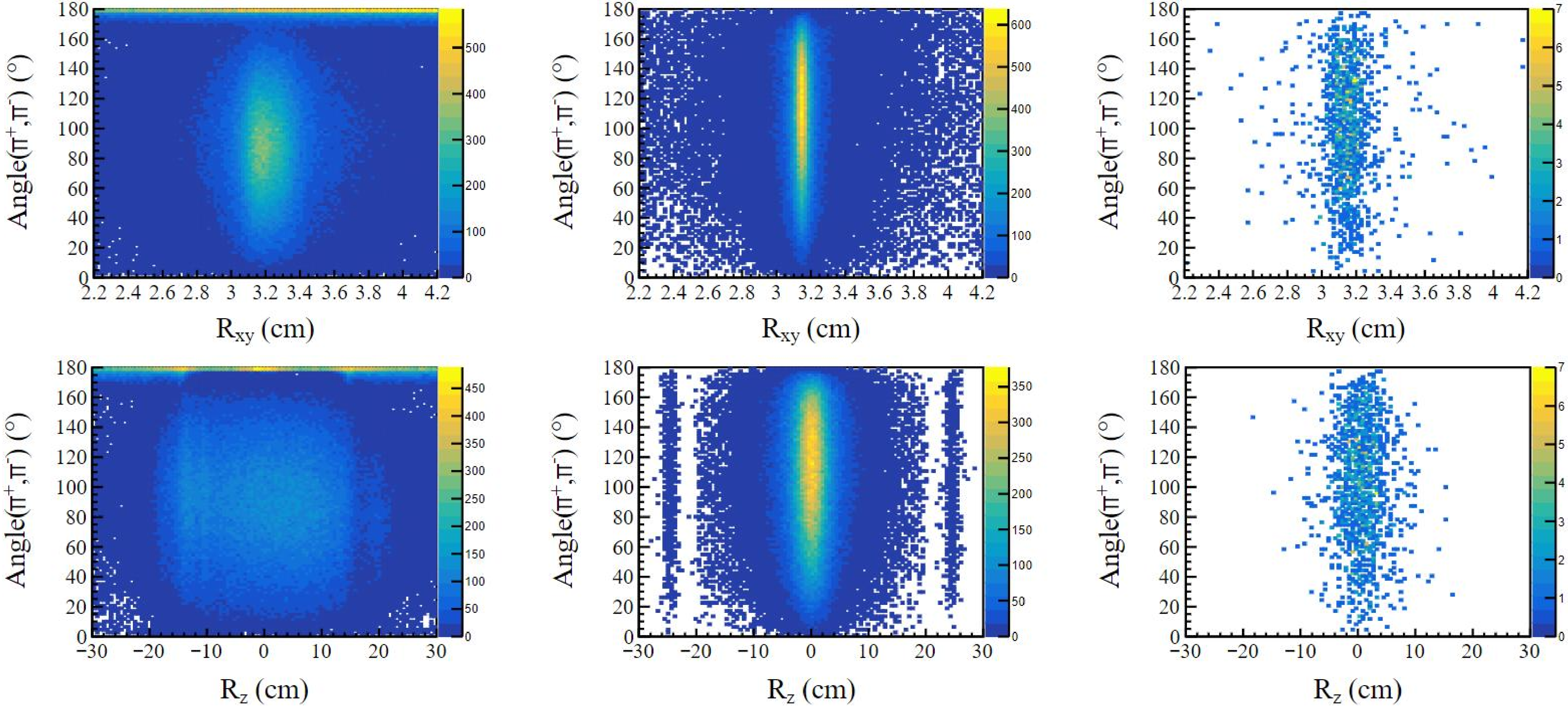
Final state	Frequency (in %)
$\pi^-n\pi^0$	16.4 ± 0.5
$\pi^-\pi^0$	0.40 ± 0.04
$\pi^-2\pi^0$	0.68 ± 0.07
$\pi^-4\pi^0$	1.32 ± 0.20
$2\pi^-\pi^+n\pi^0$	59.7 ± 1.2
$2\pi^-\pi^+$	1.57 ± 0.21
$2\pi^-\pi^+\pi^0$	21.8 ± 2.2
$2\pi^-\pi^+2\pi^0$	6.3 ± 1.1
$3\pi^-2\pi^+n\pi^0$	23.4 ± 0.7
$3\pi^-2\pi^+$	5.15 ± 0.47
$3\pi^-2\pi^+\pi^0$	15.1 ± 1.0
$4\pi^-3\pi^+n\pi^0$	0.39 ± 0.07
Sum	$95.5 \pm 1.5\%$

Final state	Frequency (in 10^{-4})
K^0K^-	14.7 ± 2.1
$K^0K^+\pi^-\pi^-$	36.0 ± 4.2
$K_sK_s\pi^-$	14.7 ± 2.0
$K_sK_l\pi^-$	21.2 ± 3.6
$K^0K^+\pi^-\pi^-$	24.8 ± 2.6
$K^0K^-\pi^+\pi^-$	34.2 ± 3.5
$K_sK_s\pi^-\pi^0$	25.6 ± 2.8
$K^0K^+\pi^-\pi^-\pi^0$	1.6 ± 0.9
$K_sK^-\pi^+\pi^-\pi^0$	33.6 ± 3.8
$K_sK^-\omega$	35.0 ± 5.2
$K_sK_s\pi^+\pi^-\pi^-$	2.8 ± 1.2
$K_sK_l\pi^+\pi^-\pi^-$	1.9 ± 1.2
Sum	$2.5 \pm 0.1\%$

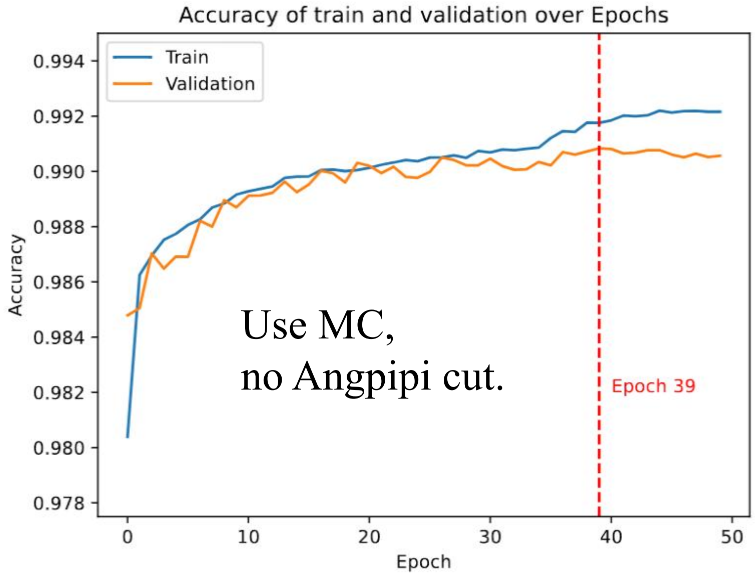
Back Up: 1.878 GeV before further selection

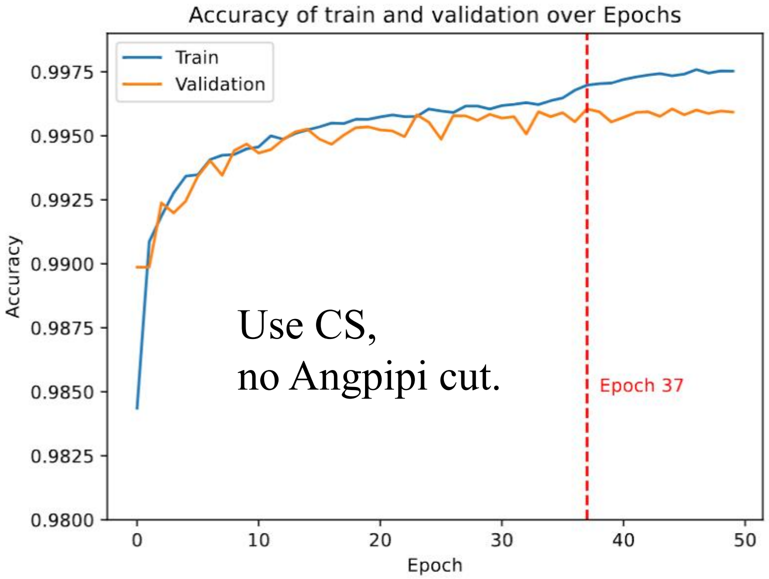


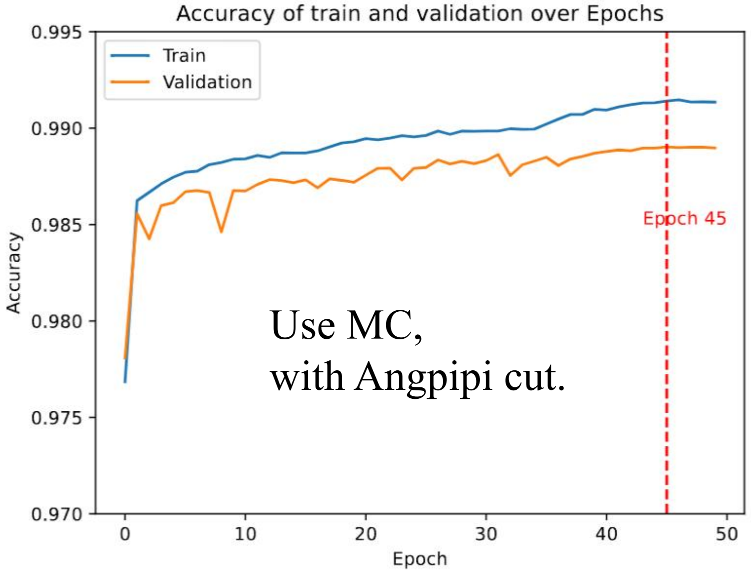
Back Up: 1.878 GeV before further selection

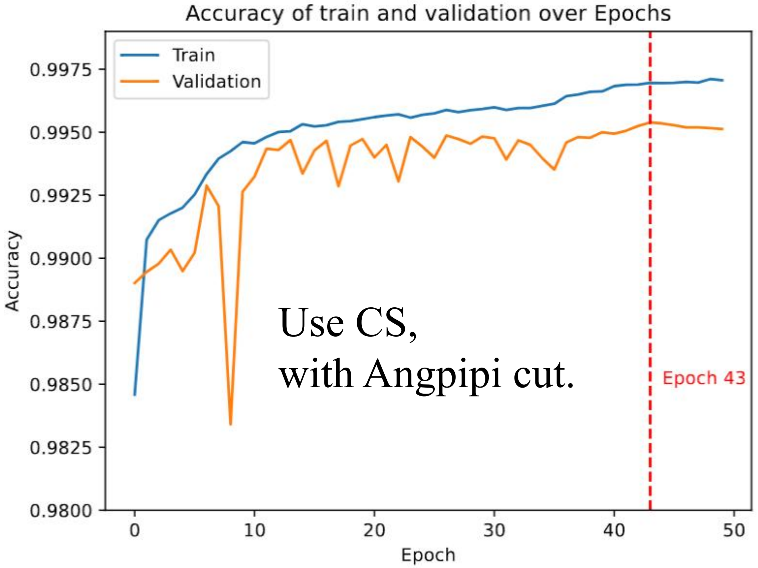


Back Up: GNN

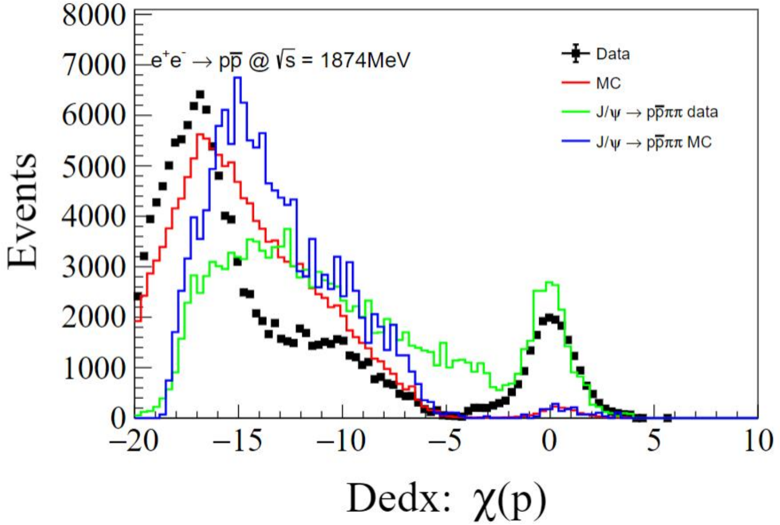

Accuracy of train and validation over Epochs
Train
Validation
Use MC,
no Angpipi cut.
Epoch 39
Accuracy
Epoch

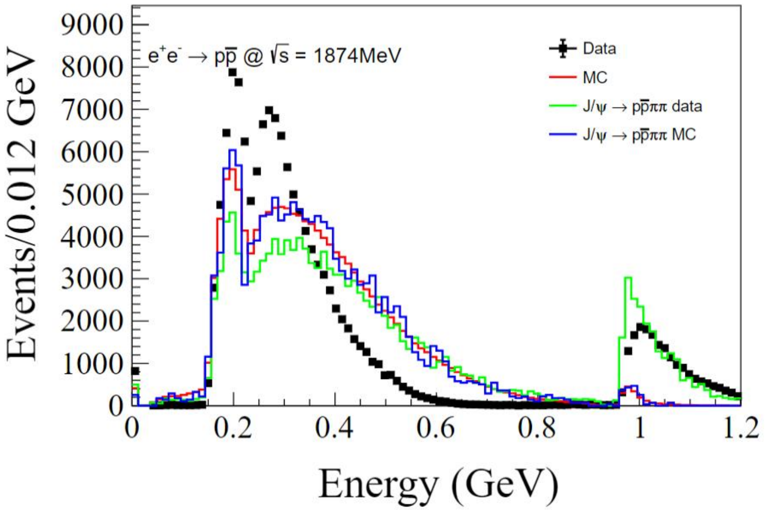

Accuracy of train and validation over Epochs
Train
Validation
Use CS,
no Angpipi cut.
Epoch 37
Accuracy
Epoch

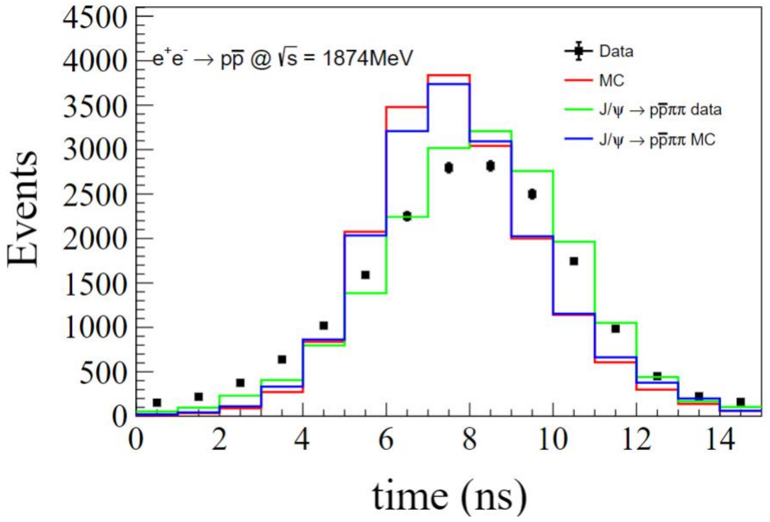

Accuracy of train and validation over Epochs
Train
Validation
Epoch 45
Use MC,
with Angpipi cut.
Accuracy
Epoch

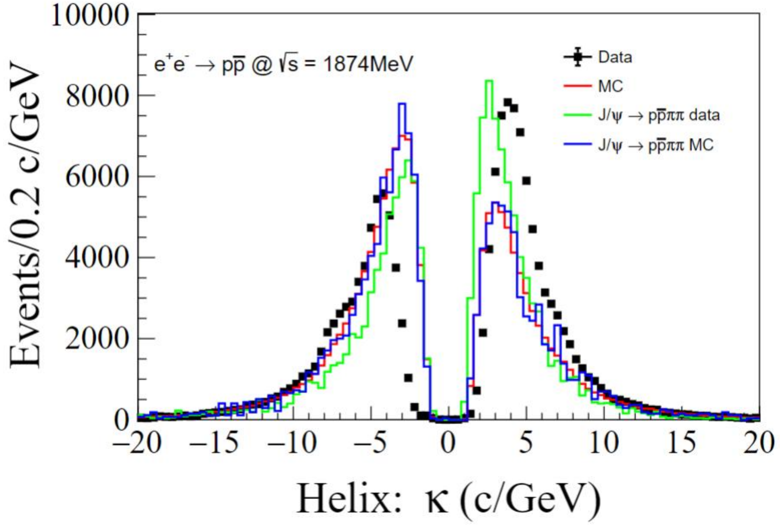

Accuracy of train and validation over Epochs
Train
Validation
Use CS,
with Angpipi cut.
Epoch 43
Accuracy
Epoch

Back Up: GNN variables



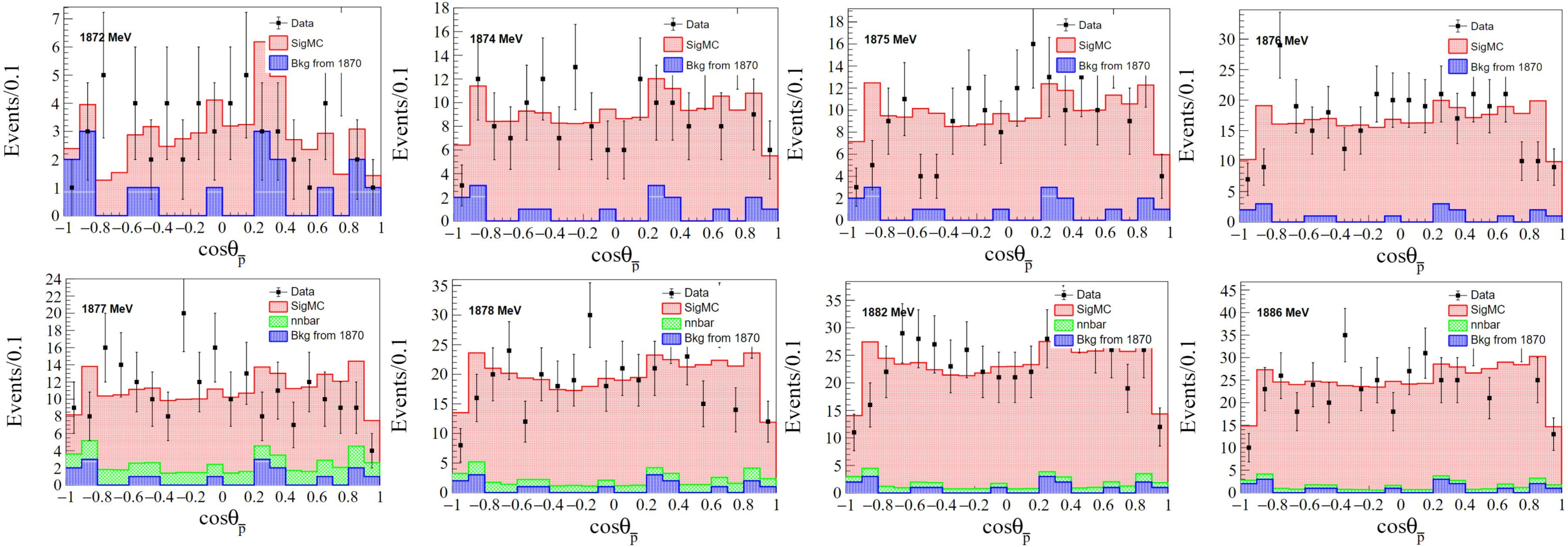






Back Up: Costheta of $\overline{p}$

- After GNN veto, but the Ecms of data all plus 4 MeV to match the Signal MC.



Back Up:

- The treatment of systematic errors about GNN in $\Lambda_c^+ \to p\pi^0$ and $\Lambda_c^+ \to ne^+\upsilon_e$:

$\Lambda_c^+ \to p\pi^0$

➢ Model uncertainty:

The uncertainties that is caused by limitations of the model, either by errors in the training procedure, an insufficient model structure, lack of knowledge due to unknown samples or a bad coverage of the training data set.

Using another ML model.

➢ Domain shift:

As a term from ML community describes the mismatch between the data distribution used for training and the data distribution which the model will be applied to in production.

Using control sample.

$\Lambda_c^+ \to ne^+\upsilon_e$

➢ Model uncertainty:

Repeat the analysis procedure for 100 times with exactly same inputs, where a random fluctuation is observed in their output signal BF results.

The number of channels C for each EdgeConv block are changed, repeat the analysis procedure for another 100 times.

➢ Domain shift:

Using control sample and perform IO check.