Production and Electromagnetic Structure Studies of the Δ Resonance in Proton-Proton Collisions at 4.5 GeV with HADES

FAIRNESS 2024

Saket Kumar Sahu[1],Johan Messchendorp[3] and James Ritman[1,2,3]

[1]Ruhr University Bochum (RUB)

[2]Forschungszentrum Jülich, Jülich, Germany

[3]GSI Helmholtzzentrum fur Schwerionenforschung GmbH, Darmstadt, Germany

Table of Contents

- Physics Motivation
- Analysis Details
  - PID Procedure
- Dalitz Plot of $np\pi^+$
  - Kinfit Missing Mass Constraint
- Outlook

Motivation

- The study of **electromagnetic currents** in hadronic processes and baryon decays via their **dilepton decay** channels is still not fully understood.

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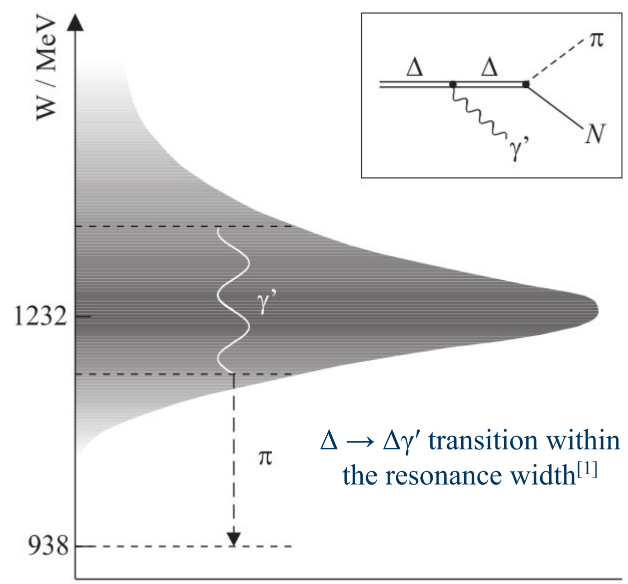
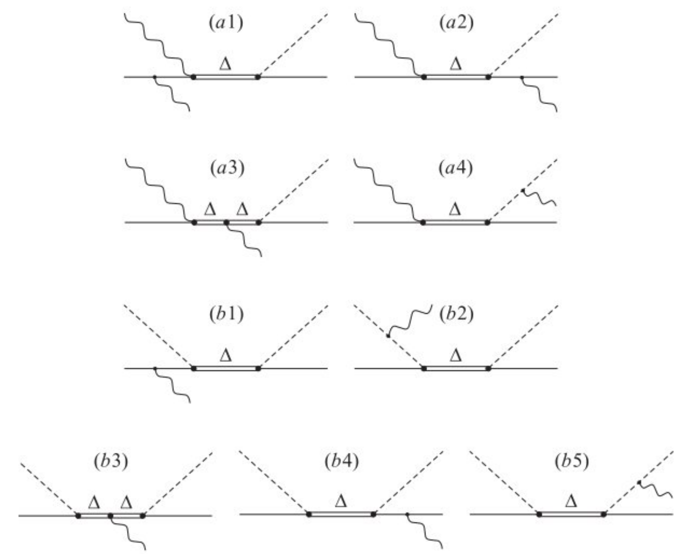
- The electromagnetic structure of the lowest lying excitation of the nucleon, the Δ **resonance**, remains of particular interest.
- This is accessible via radiative transitions such as $\Delta \rightarrow \Delta\gamma$ with real or, preferably, virtual photons .



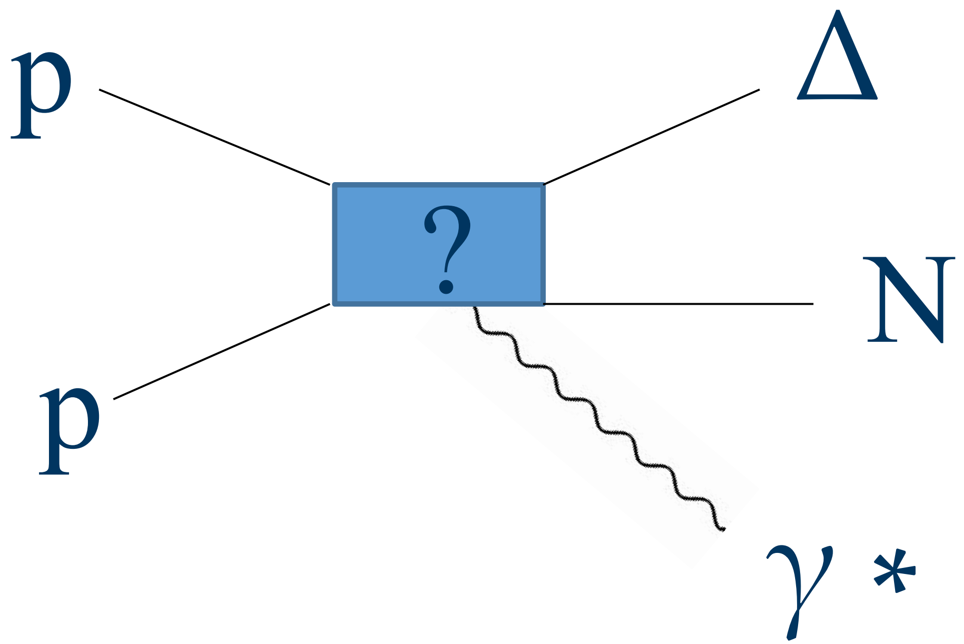
Δ → Δγ′ transition within the resonance width[1]



1. S. Schumann et al. (The European Physical Journal A 43.3 (2010), pp. 269–282).

Motivation

- The first challenge is to understand the **production mechanism** and **reaction dynamics** of different N and Δ states in pp $\rightarrow$ NNπ.



Motivation

- The first challenge is to understand the **production mechanism** and **reaction dynamics** of different N and Δ states in $pp \rightarrow NN\pi$.
- The second challenge lies in the **identification of (mostly) low-mass dilepton pairs.**
- The main aim of the analysis presented in this talk is to extract **differential cross-sections** for the exclusive Δ channels in proton-proton collisions at 4.5 GeV.

$$p + p \rightarrow p\Delta^{+} \rightarrow pn\pi^{+}$$
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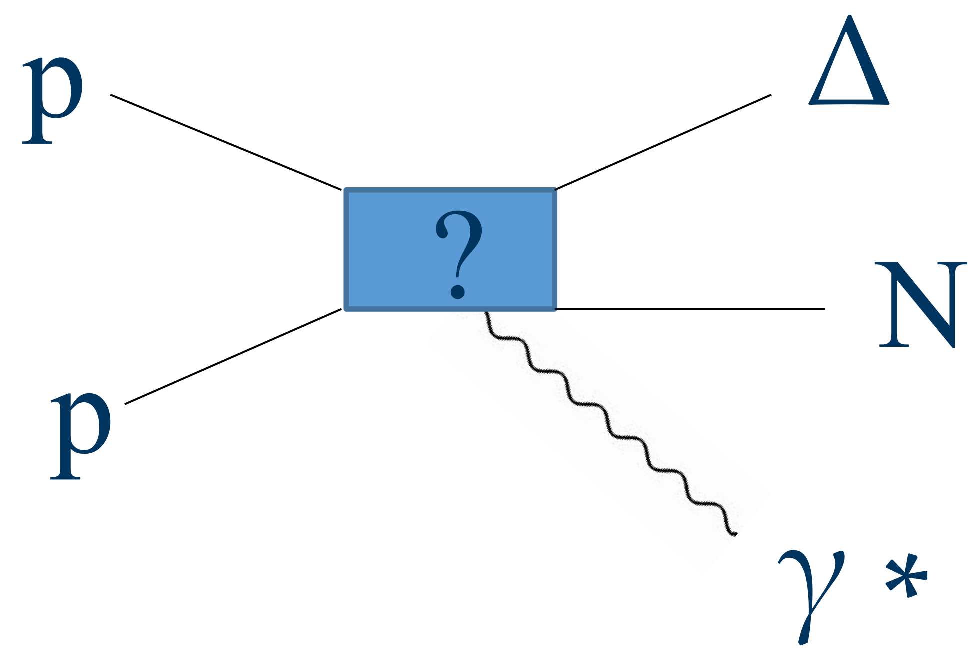

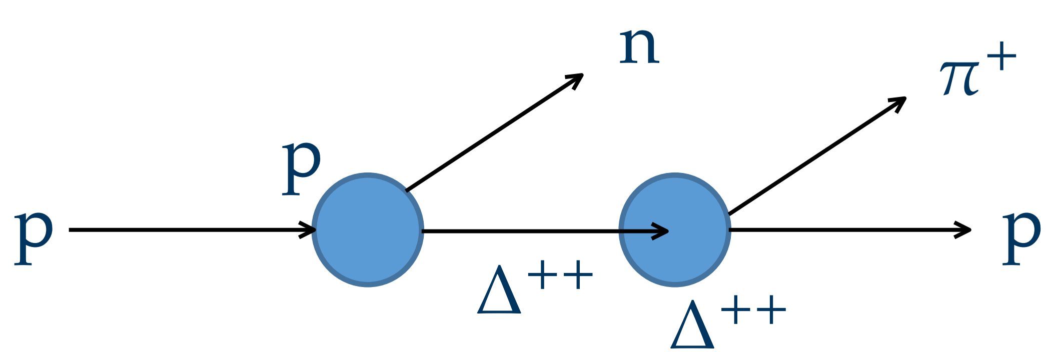

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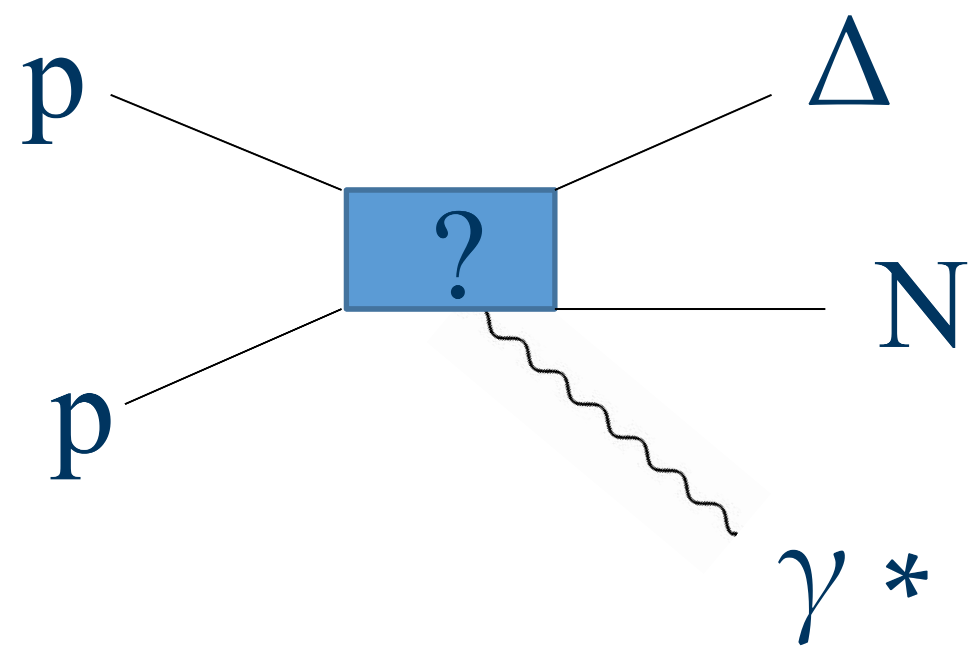
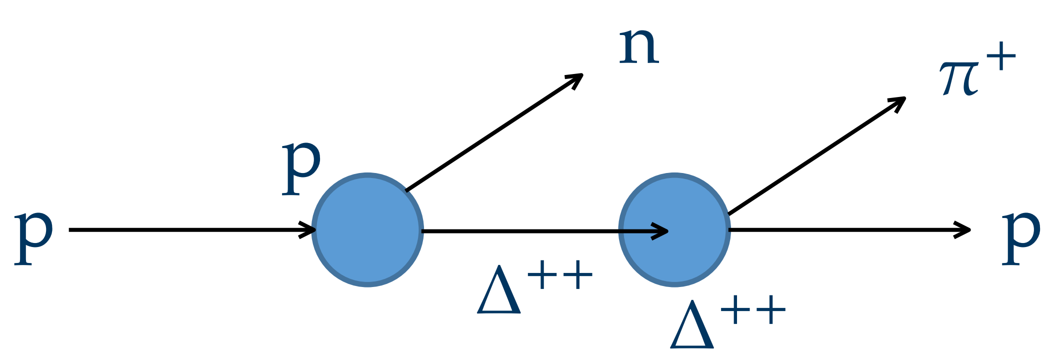
- Good basis to **compare with theory** for understanding the internal structure through radiative transitions.

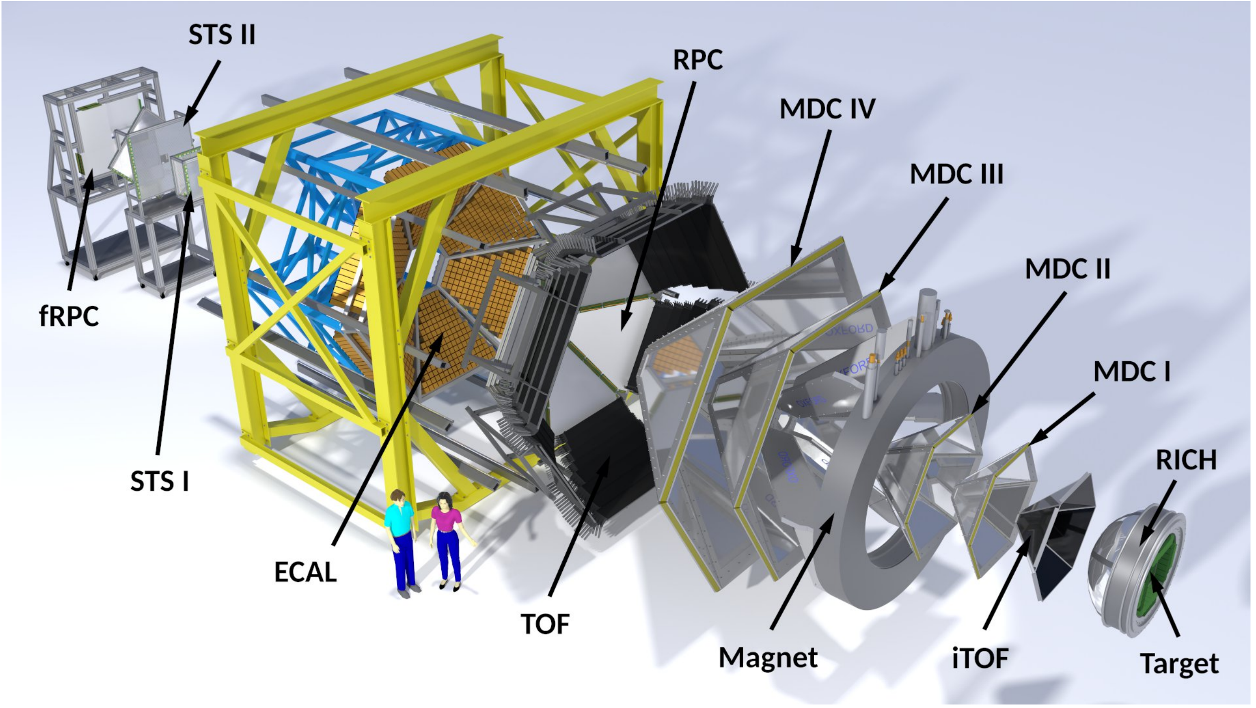
- Also as reference to **heavy ion reactions**.





HADES-High Acceptance DiElectron Spectrometer

- **Versatile magnetic spectrometer** located at GSI Darmstadt.
- Can measuring wide range of charged particle final states, has **excellent e^+/e^- reconstruction**.
- Data used in analysis is **1/30** of full statistics collected in **pp at T=4.5 GeV**.



Analysis Details

- Only **Tracks in HADES**, no Forward Detector used.
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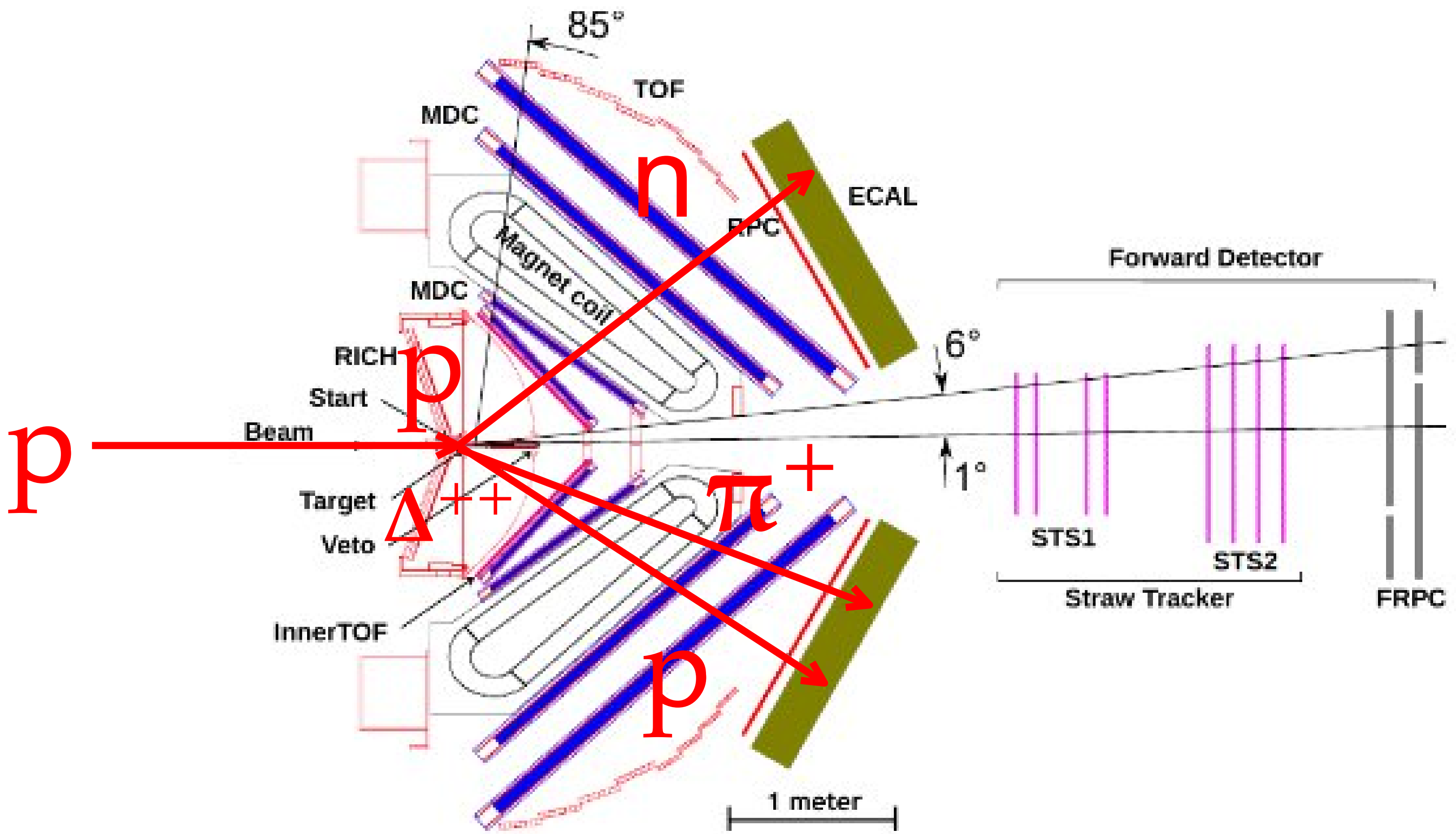

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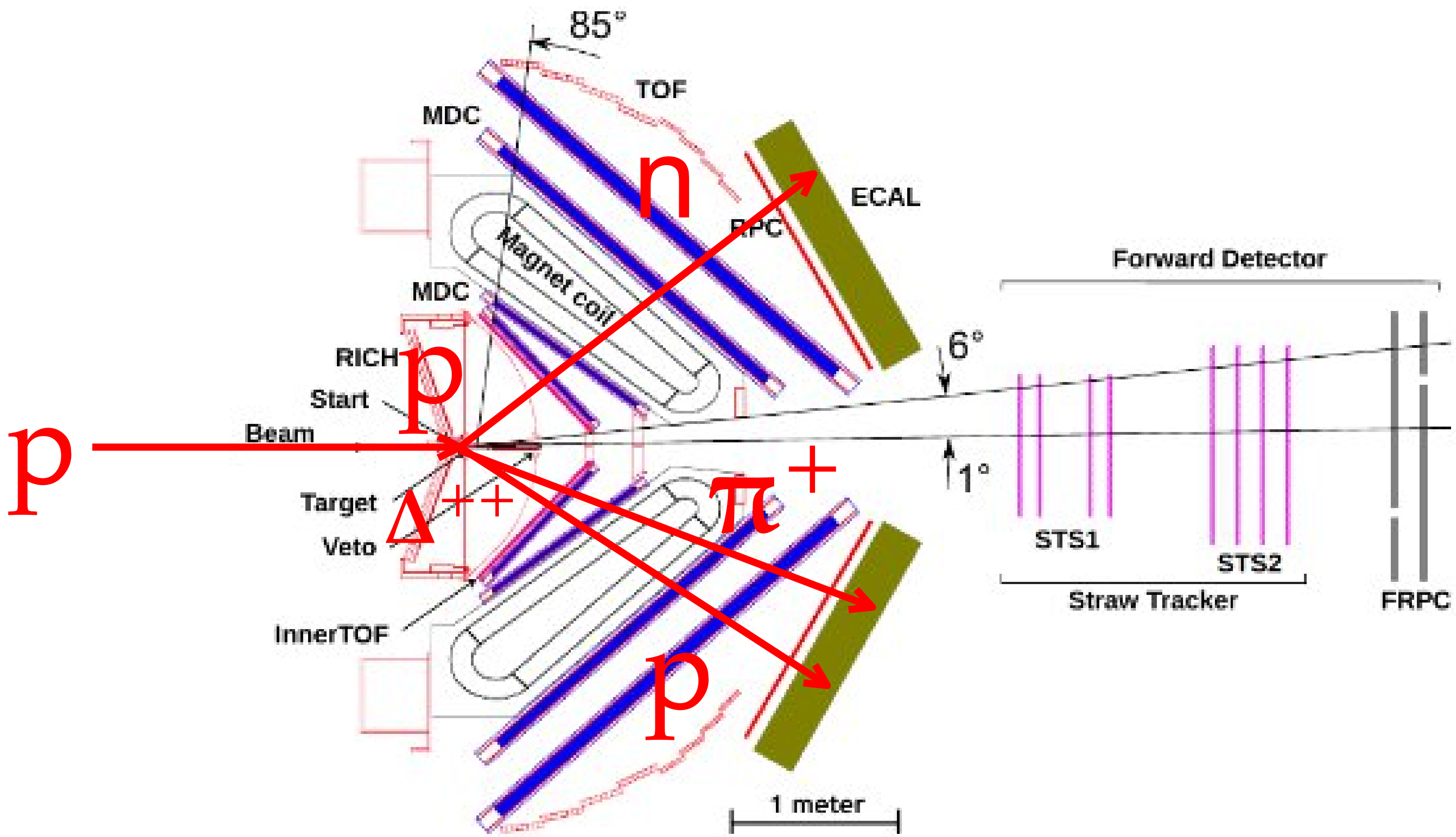

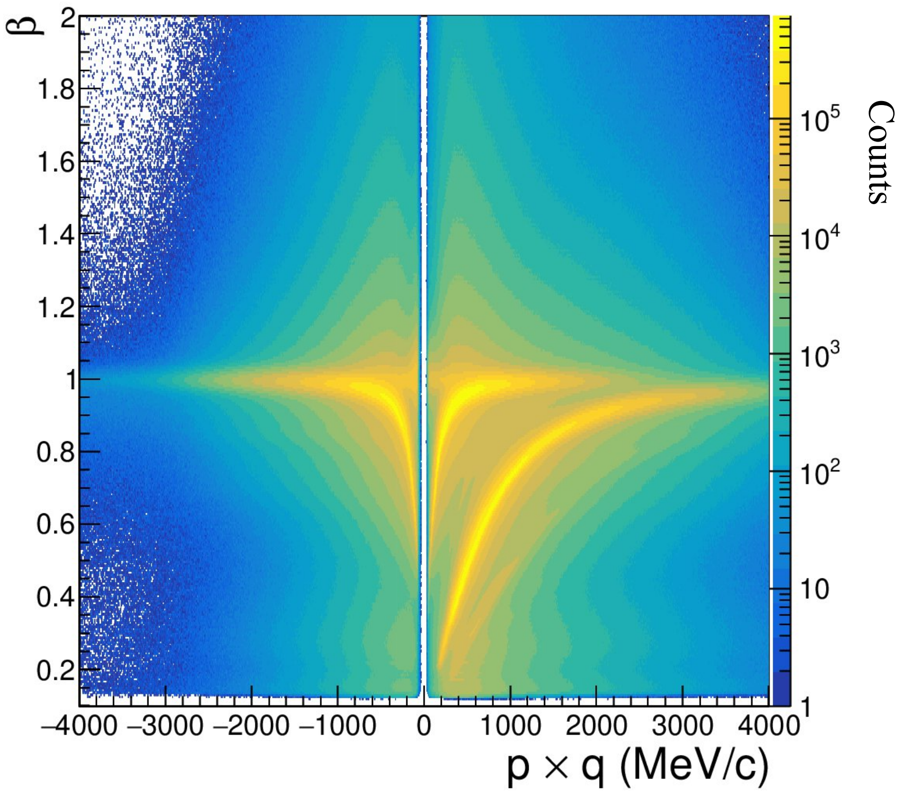

PID Procedure

- For each event, four track combinations are evaluated:

  pp, $p\pi^+$, π^+p, $\pi^+\pi^+$

- Relative Time Difference (ΔT) = rel_{tof_track1} - rel_{tof_track2} ,

  where $rel_{tof} = tof_{measured} - tof_{expected}$ taking proton,pion mass.

- For each event, four ΔT values are calculated corresponding to the four possible track combinations.

- The track combination with the smallest absolute value of ΔT is chosen to identify the PID of the two tracks.
- Optimum cut value on ΔT found by comparing the statistical significance for the missing neutron peak, which is found to be $|\Delta T| < 3.2$ ns.

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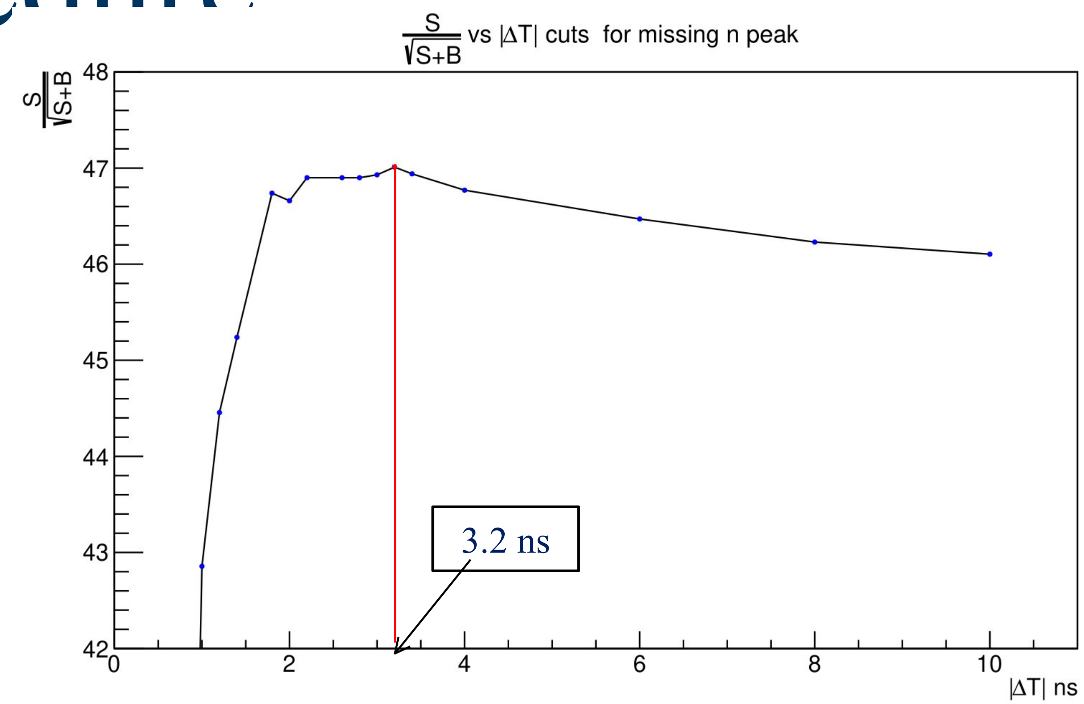
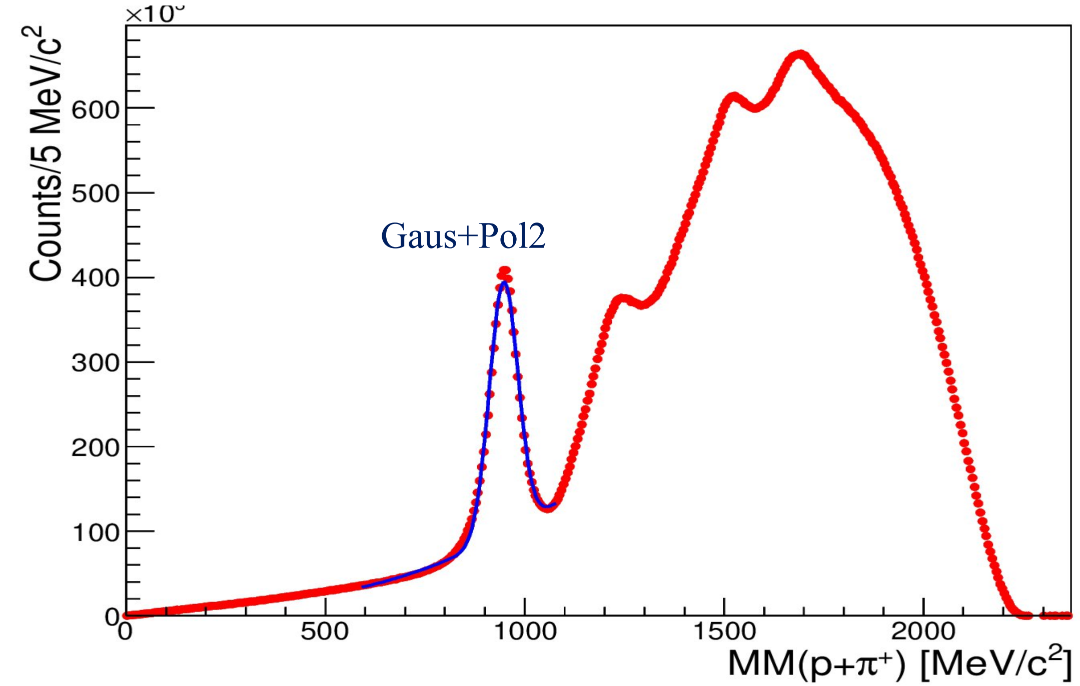
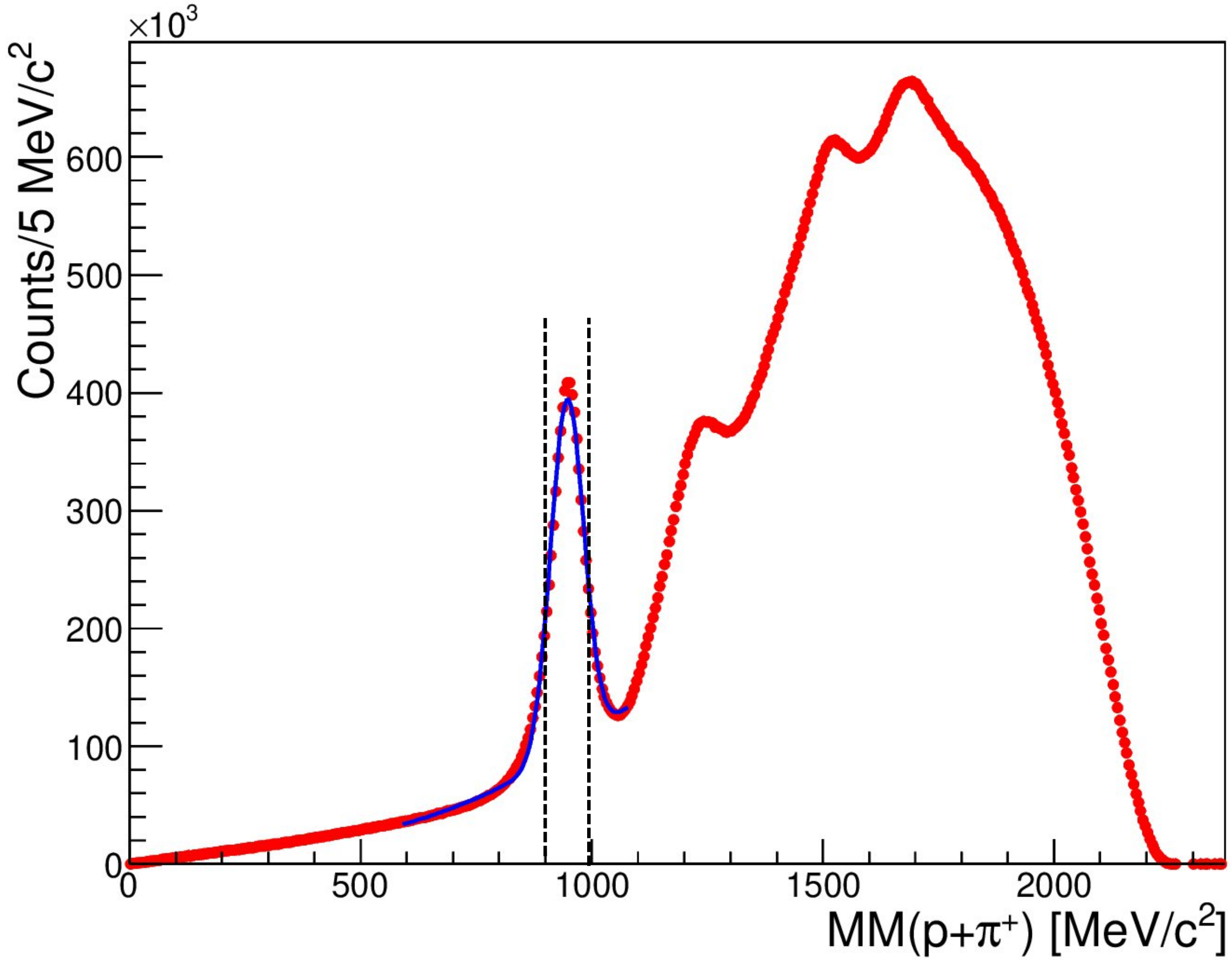




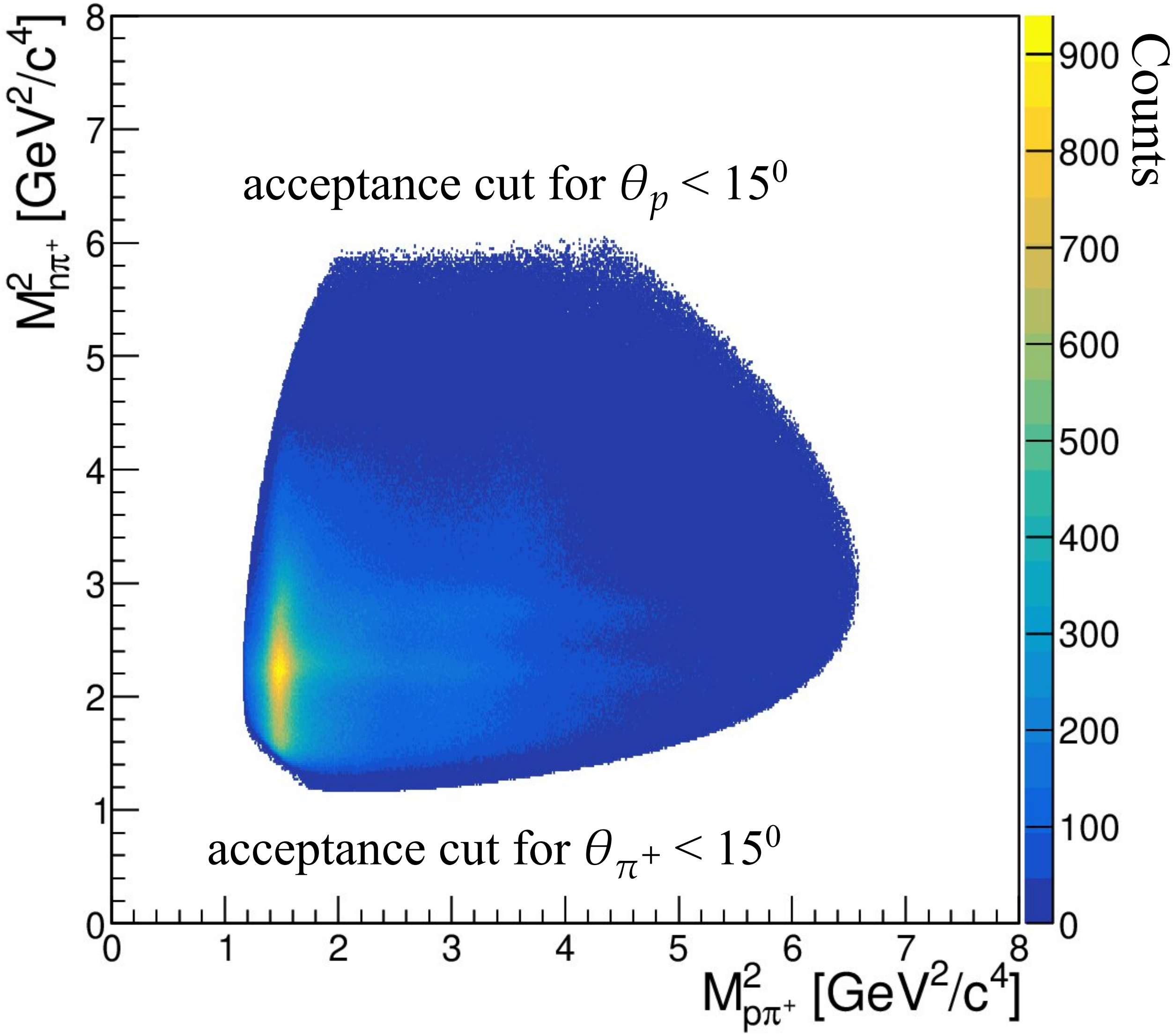
Neutron Selection



Select **missing neutron** by applying mass window of 900<MM($p + \pi^+$) <1000 MeV/c^2 for Dalitz plot

Dalitz Plot

- Dalitz plot for **npπ^+ final state** between $M^2 p\pi^+$ vs $M^2 n\pi^+$.
- count rate, **without correcting for acceptance** and **background subtraction.**



Dalitz Plot

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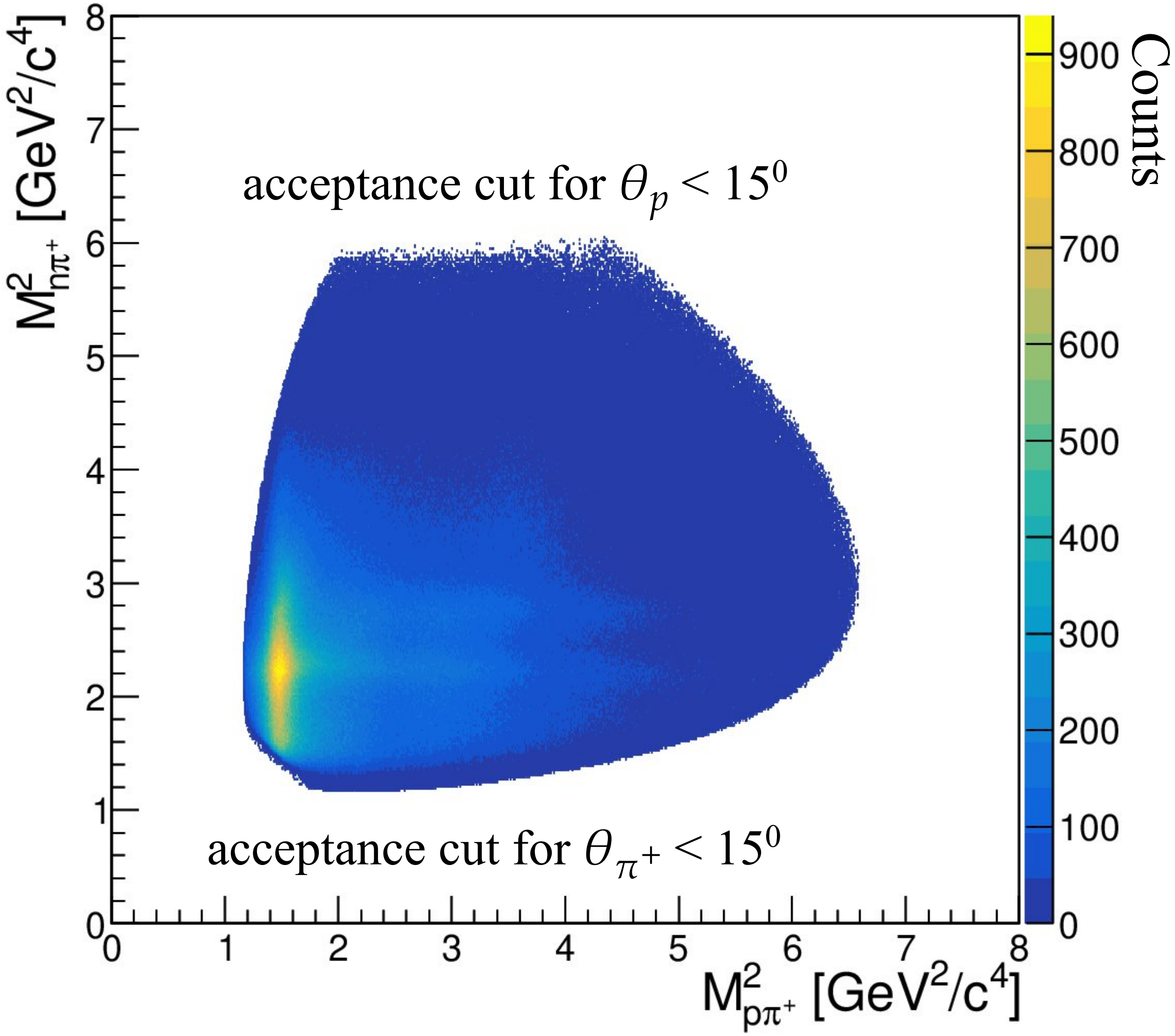
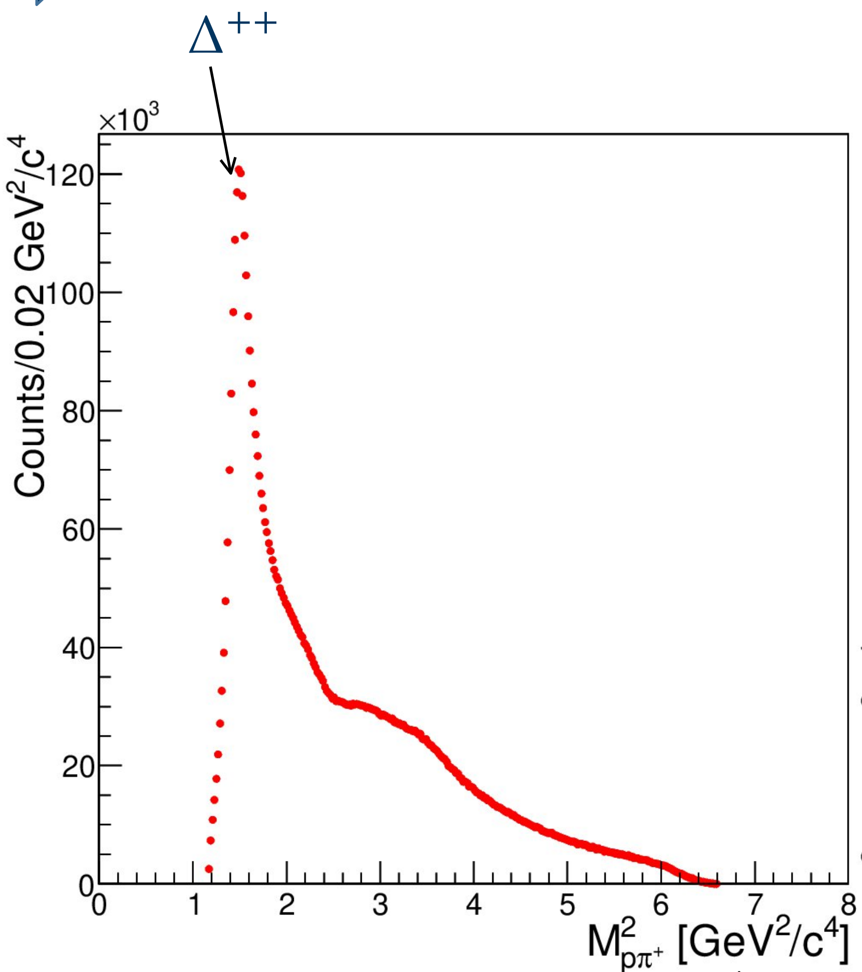
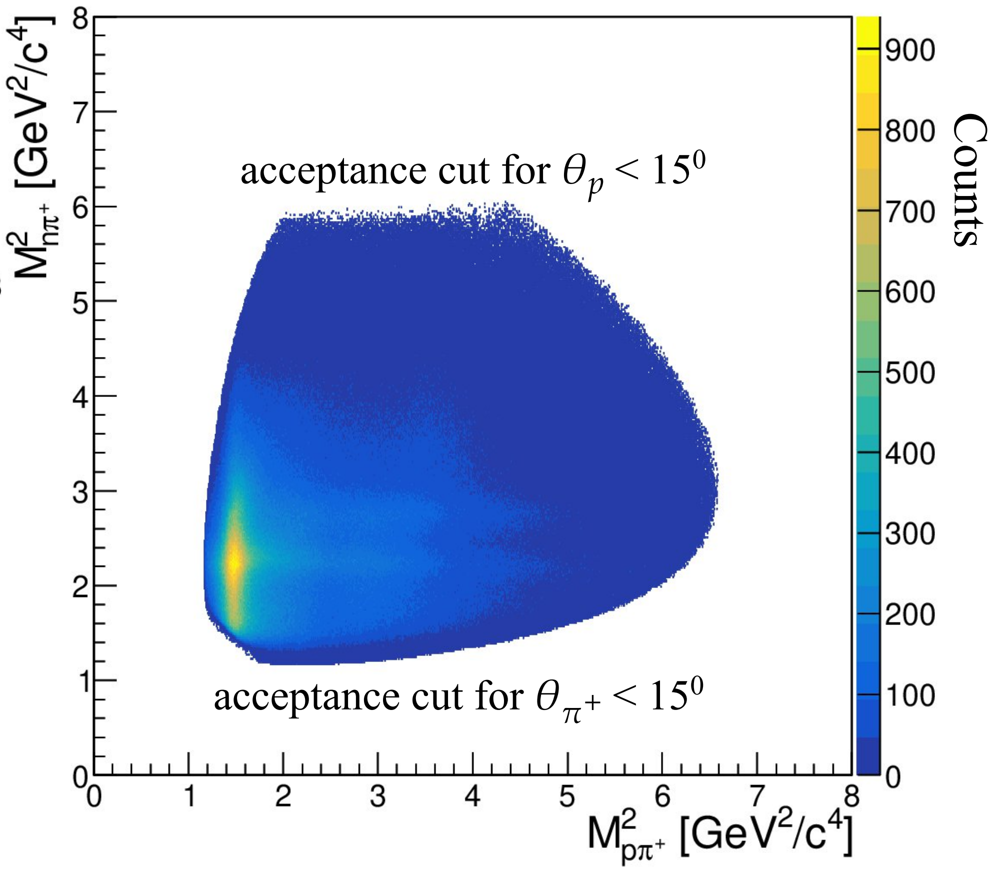


observe lots of "dynamics" involving various baryon resonances (N and Δ)

Dalitz Plot



X projection



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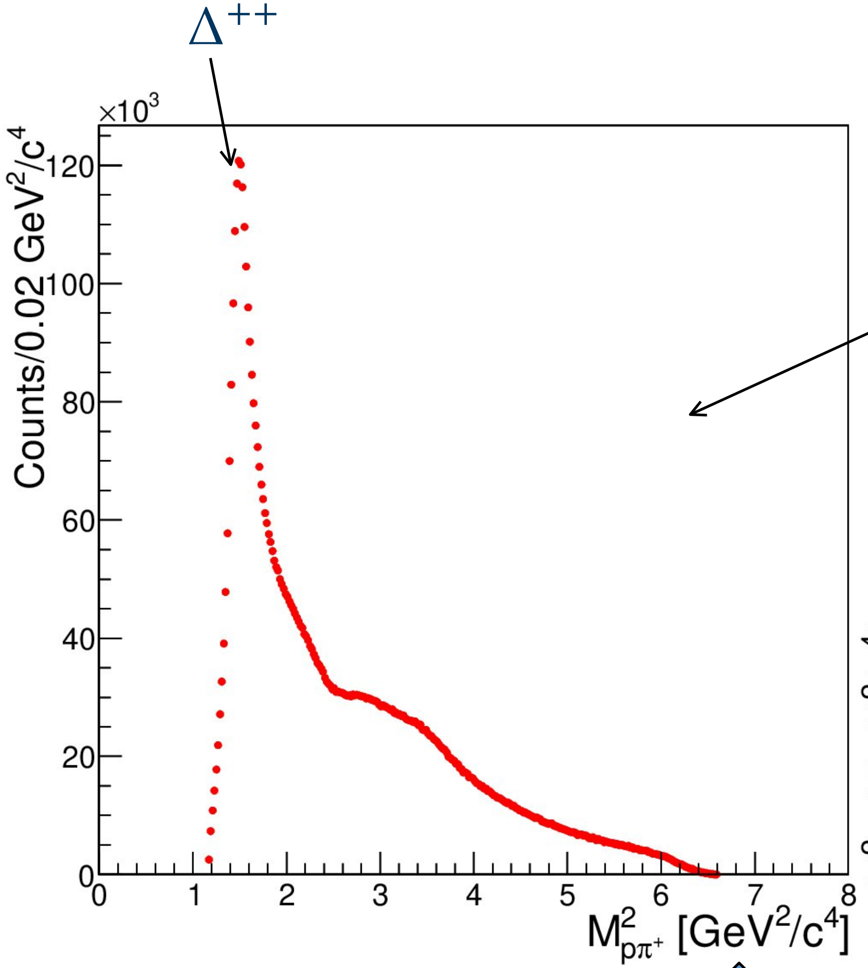
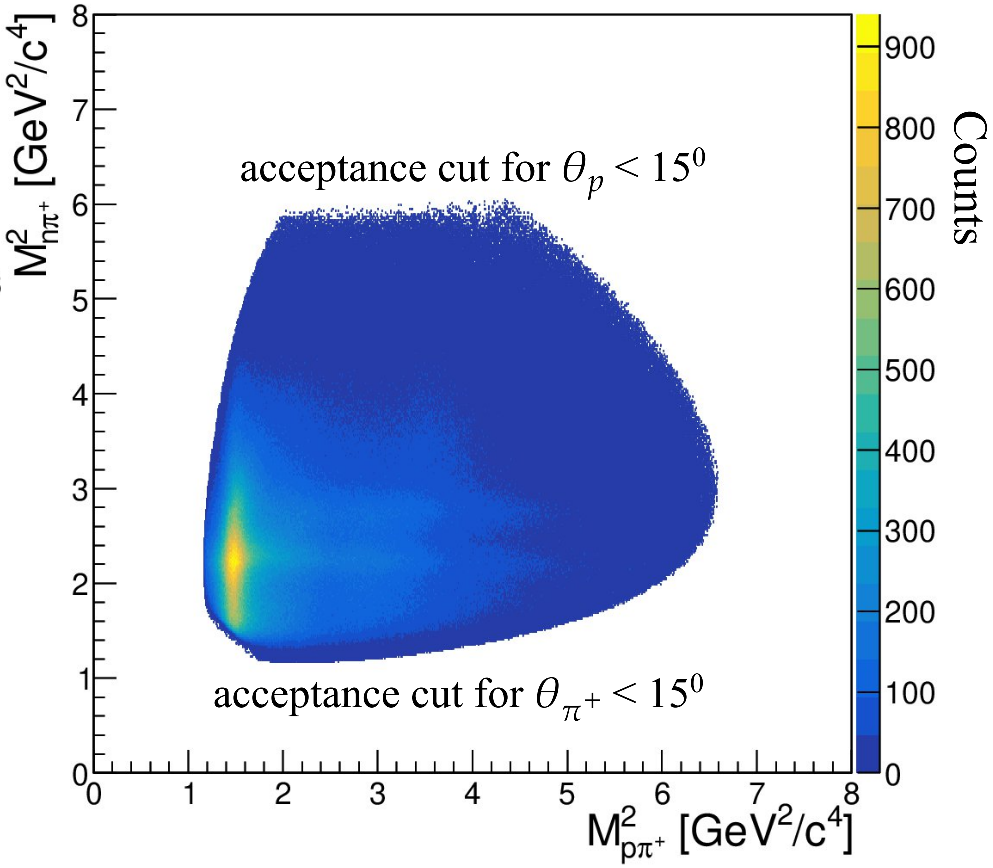


X projection

This is the I=3/2 spectrum and is much cleaner since it does not involve N* resonances



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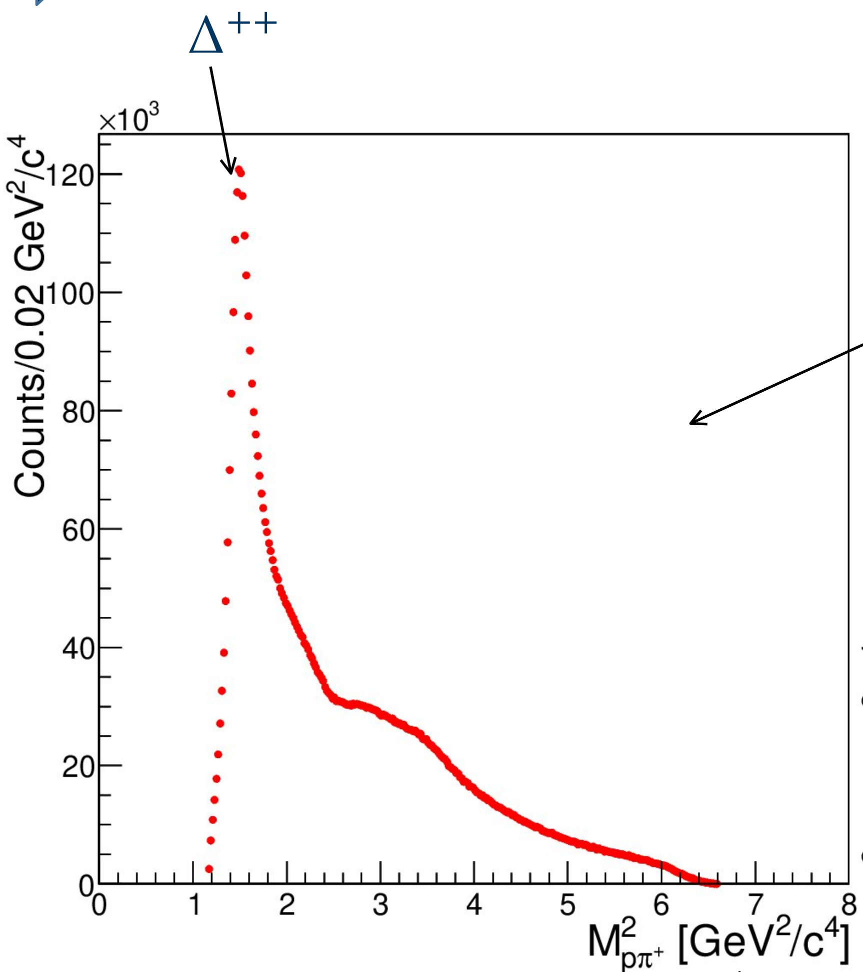

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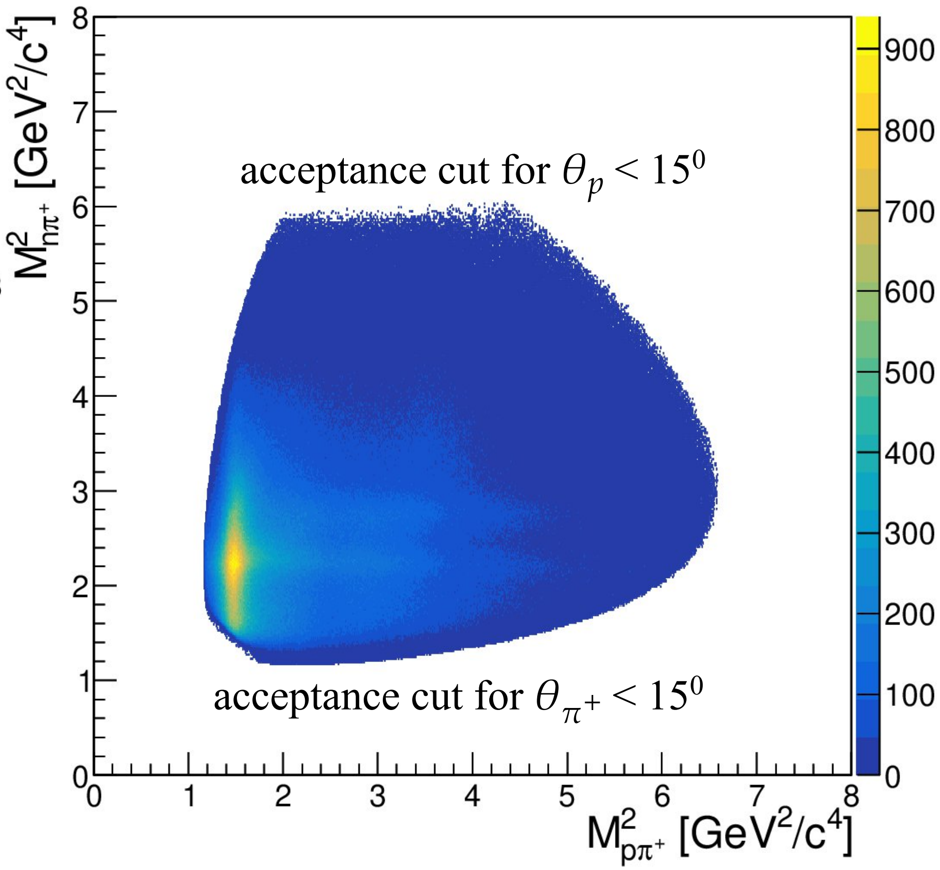
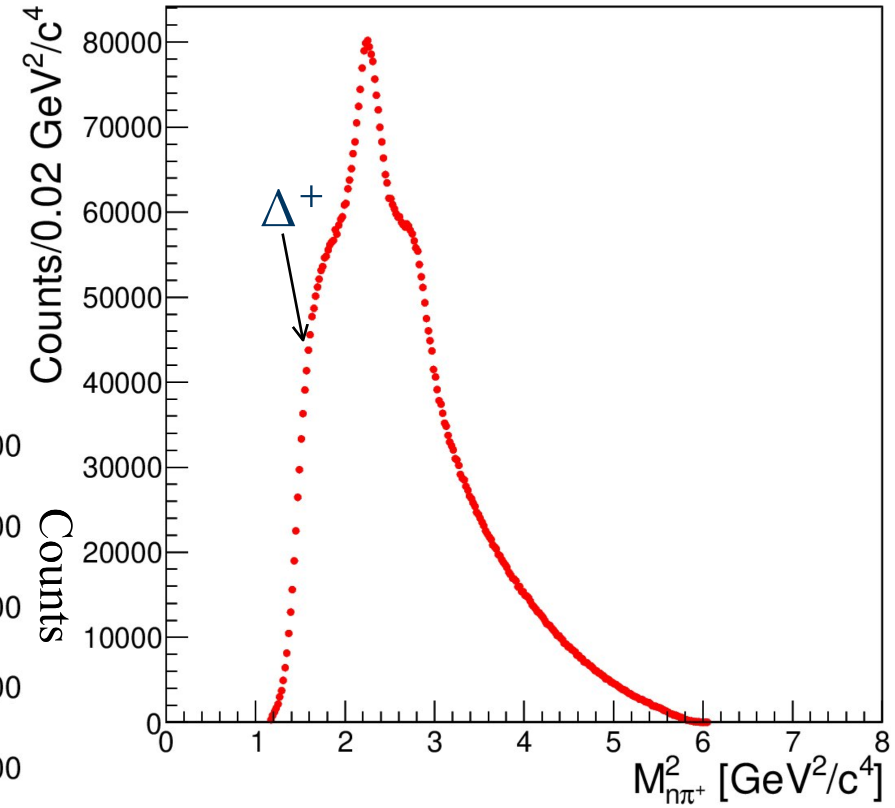


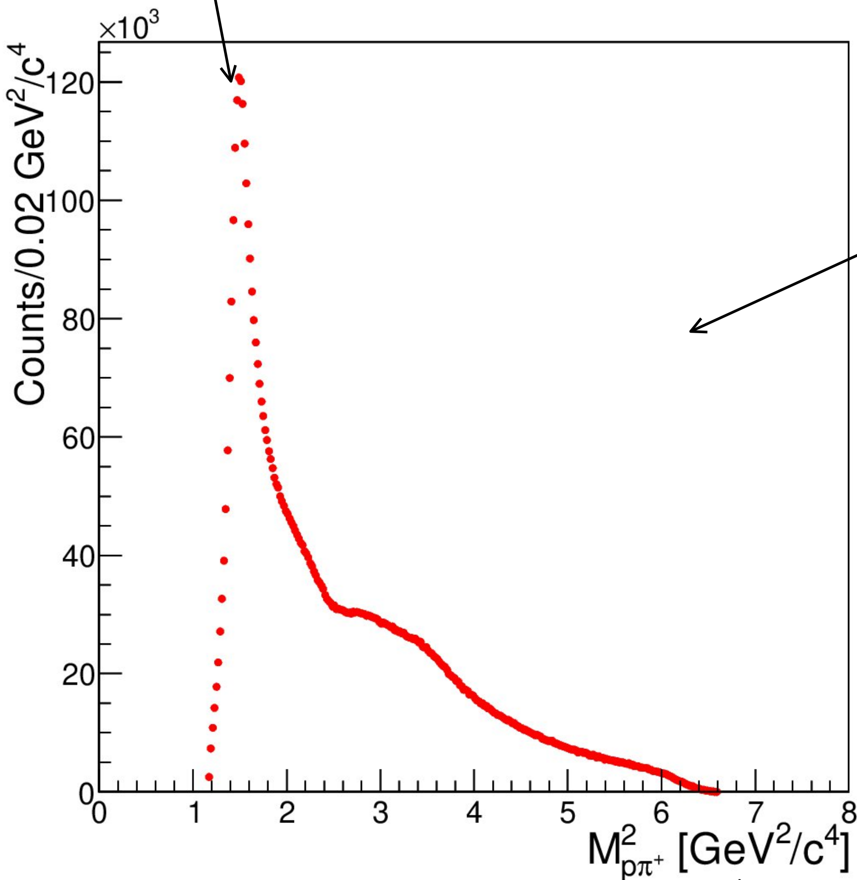
Resonant N and Δ states



Y projection

Dalitz Plot

Δ^{++}



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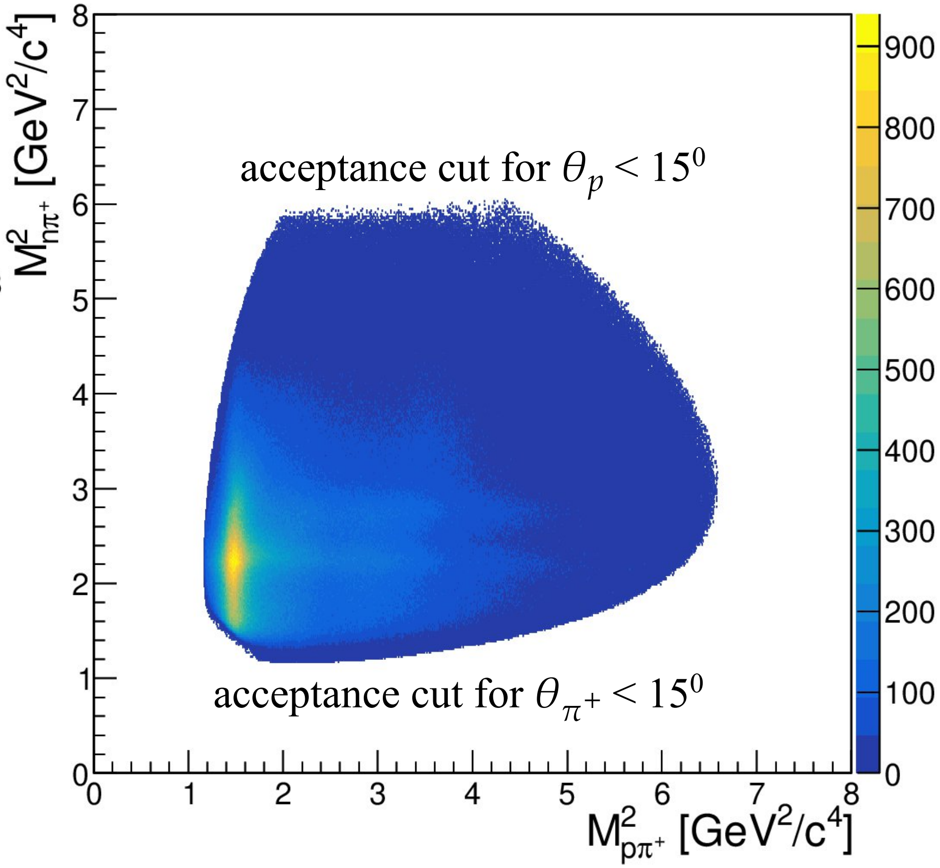

Suppression of Δ^+ ?

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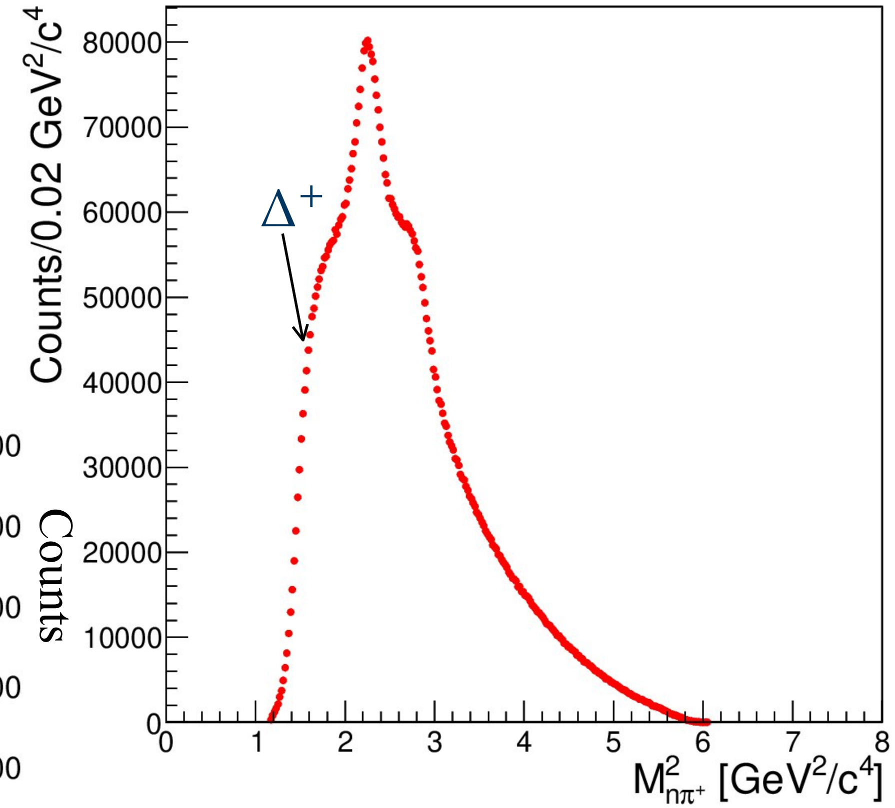

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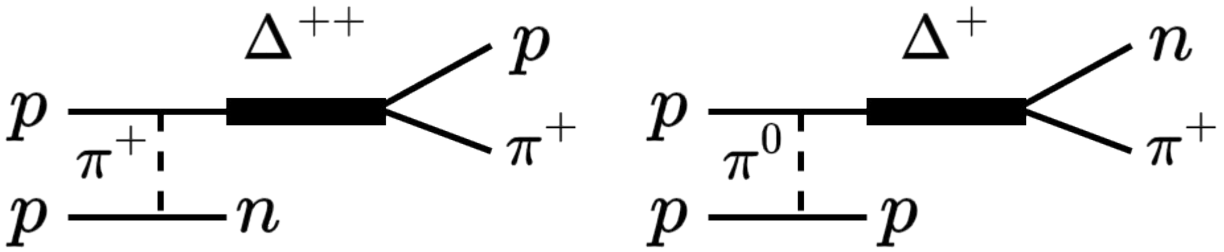

$p\pi^+n : C_{iso} = \sqrt{\frac{2}{3}}$ $\quad$ $p\pi^+\Delta^{++} : C_{iso} = 1$ $\quad$ $\Delta^{++}p\pi^+ : C_{iso} = 1$

$p\pi^0p : C_{iso} = -\sqrt{\frac{1}{3}}$ $\quad$ $p\pi^0\Delta^+ : C_{iso} = \sqrt{\frac{2}{3}}$ $\quad$ $\Delta^+n\pi^+ : C_{iso} = \sqrt{\frac{1}{3}}$

So expected $\frac{\Delta^{++}}{\Delta^+} = 9$

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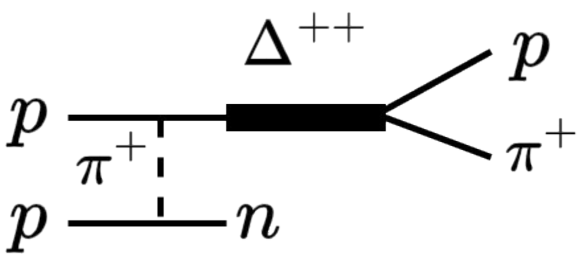

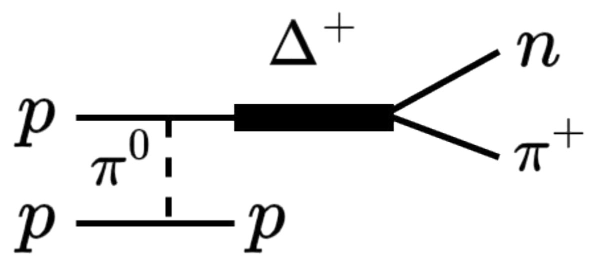

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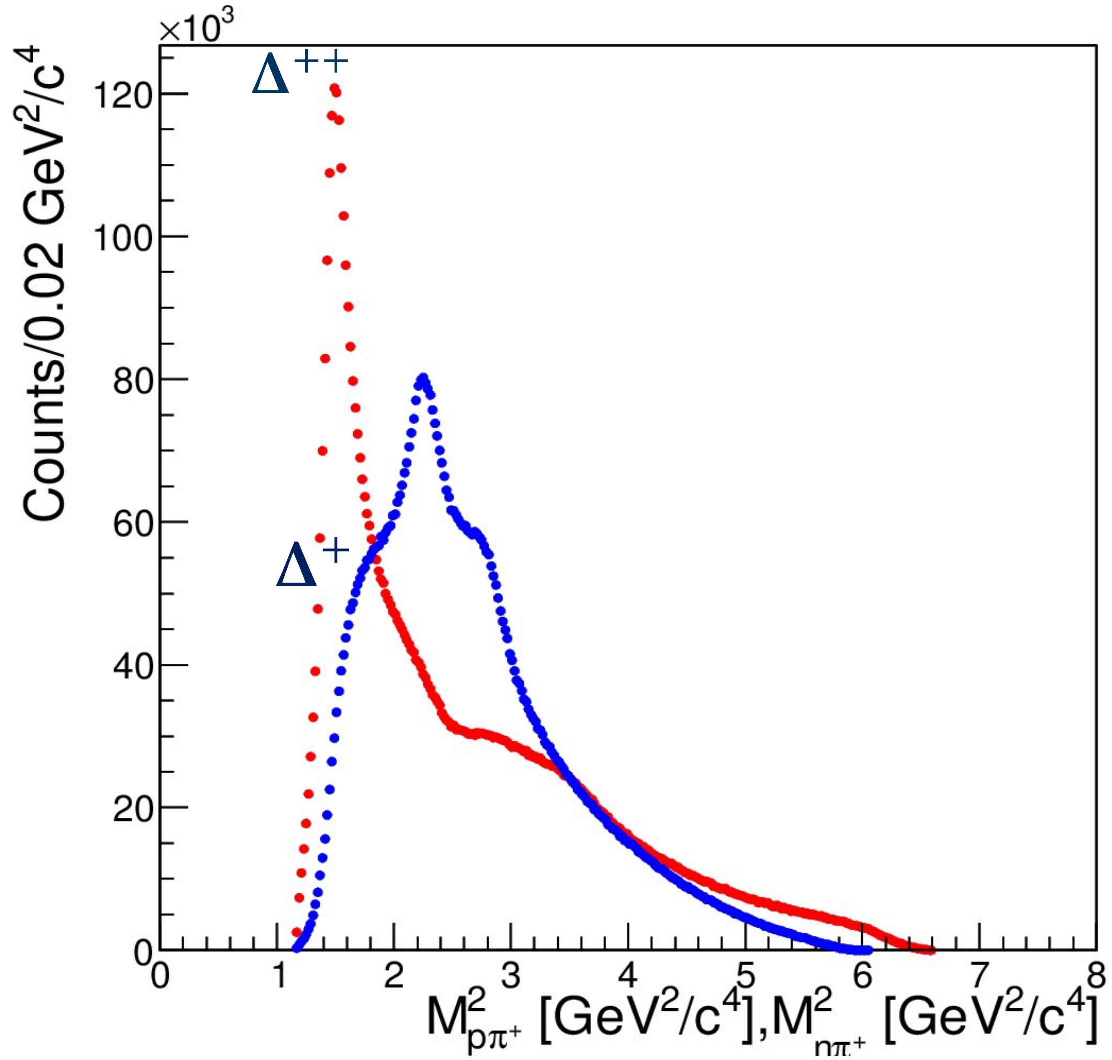
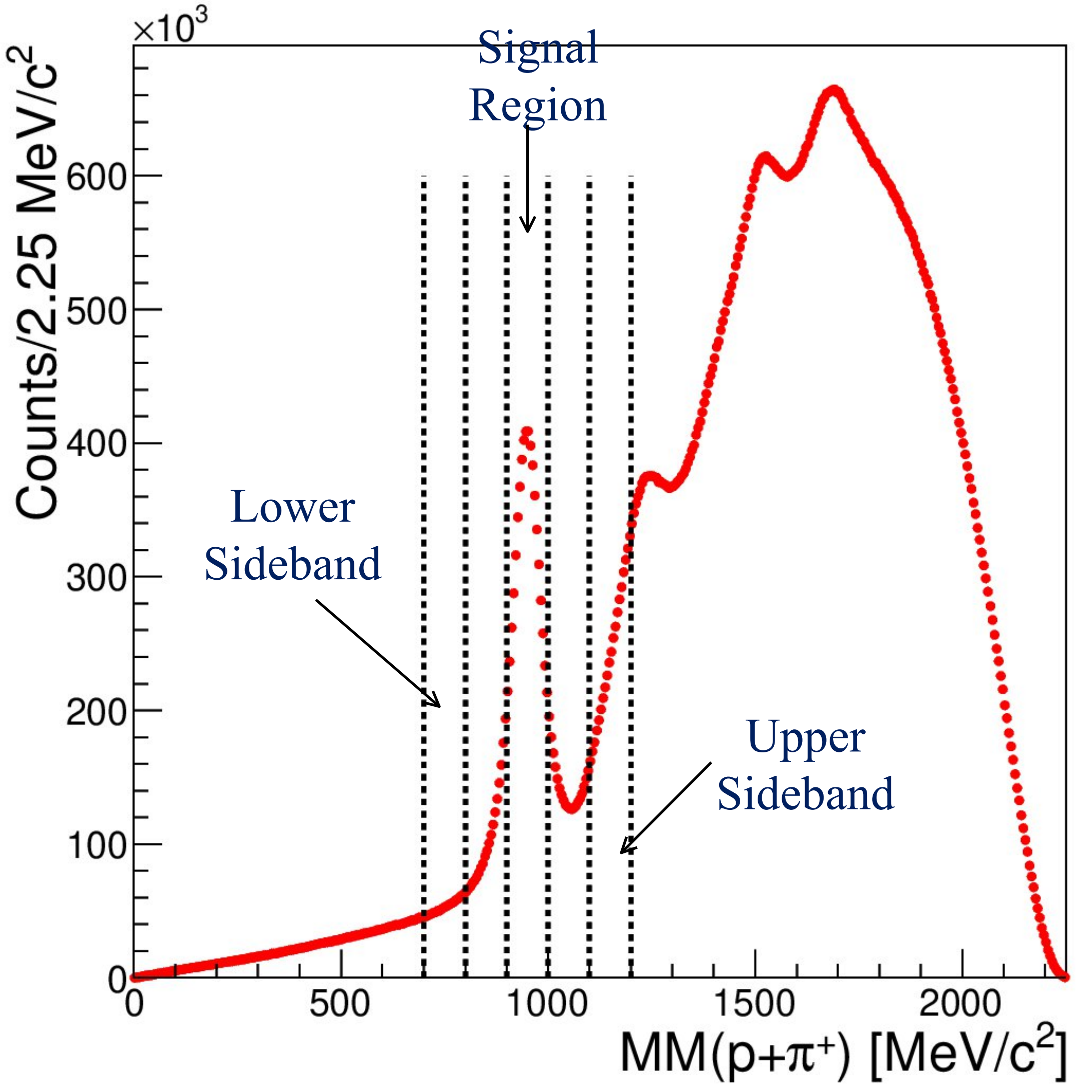


Sideband Analysis of the Dalitz Plot

- Take sideband around missing neutron mass.



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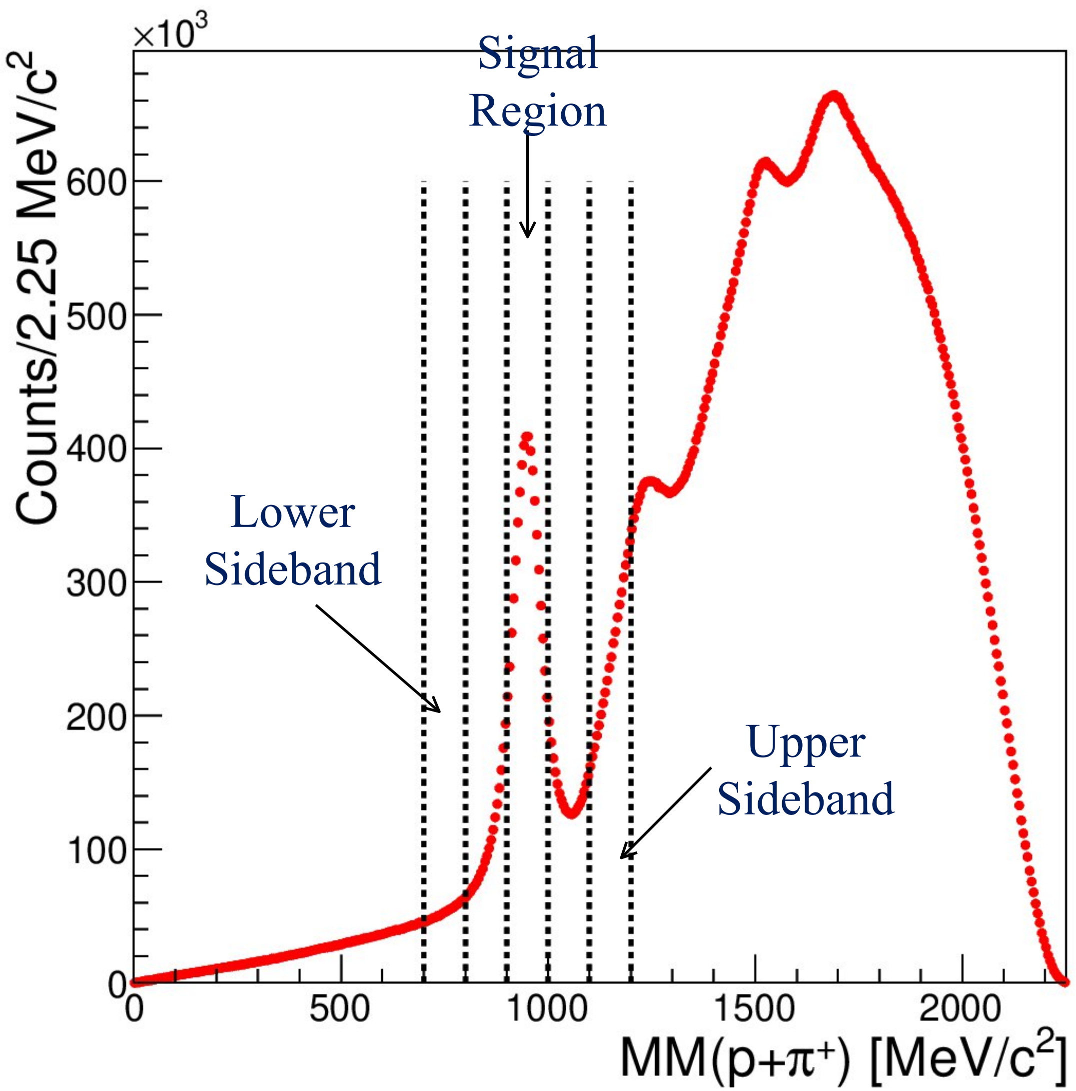
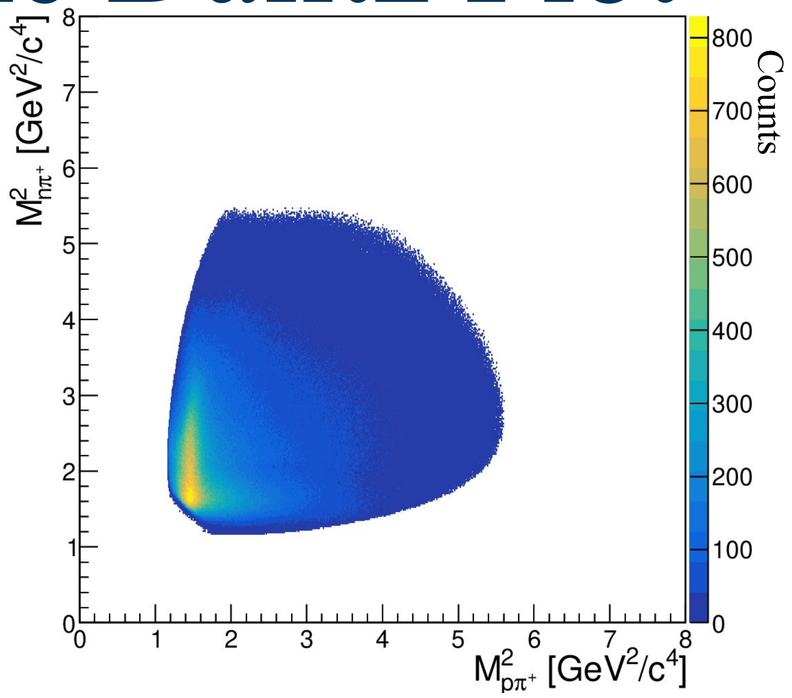


Upper Sideband



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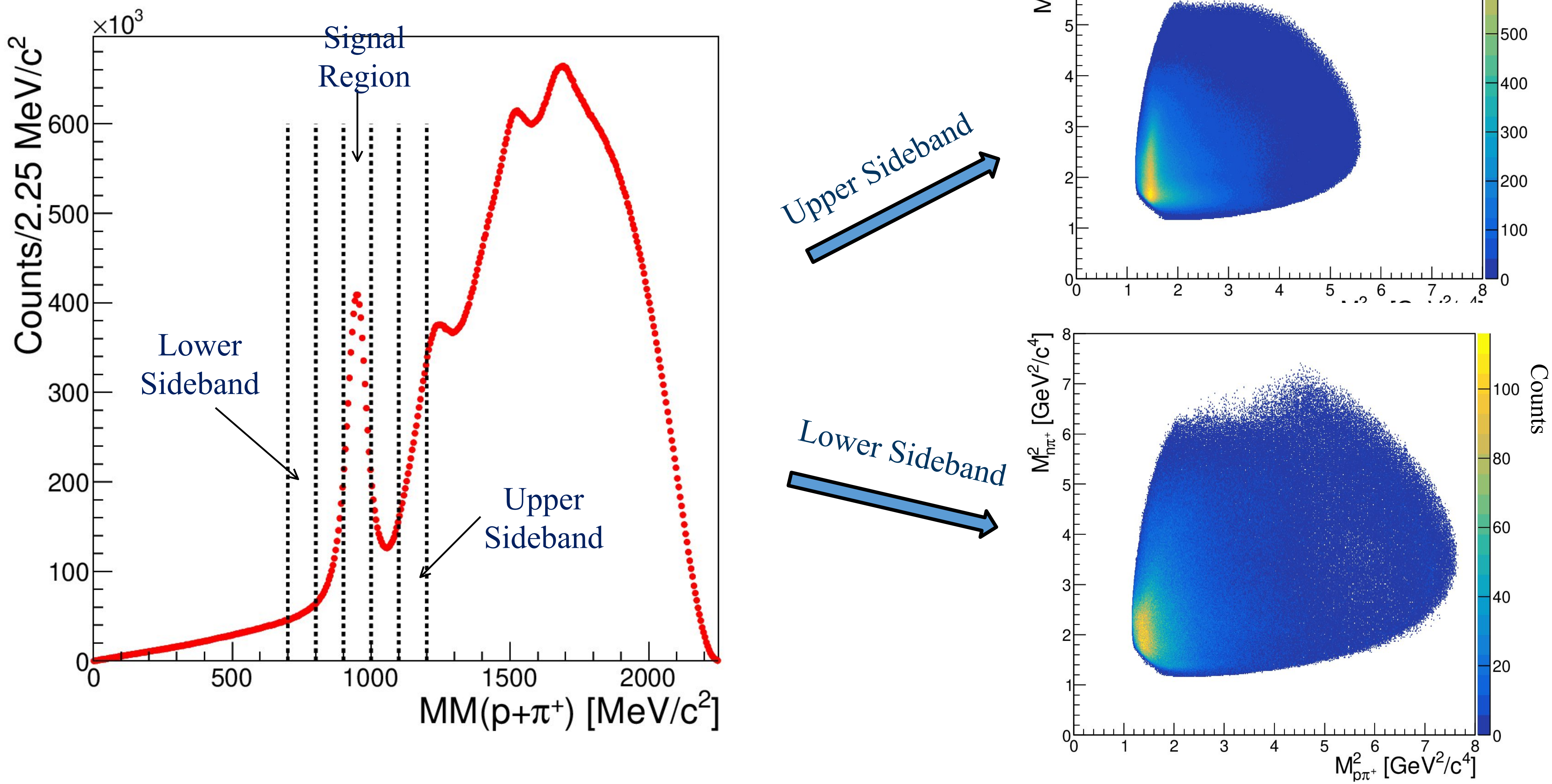

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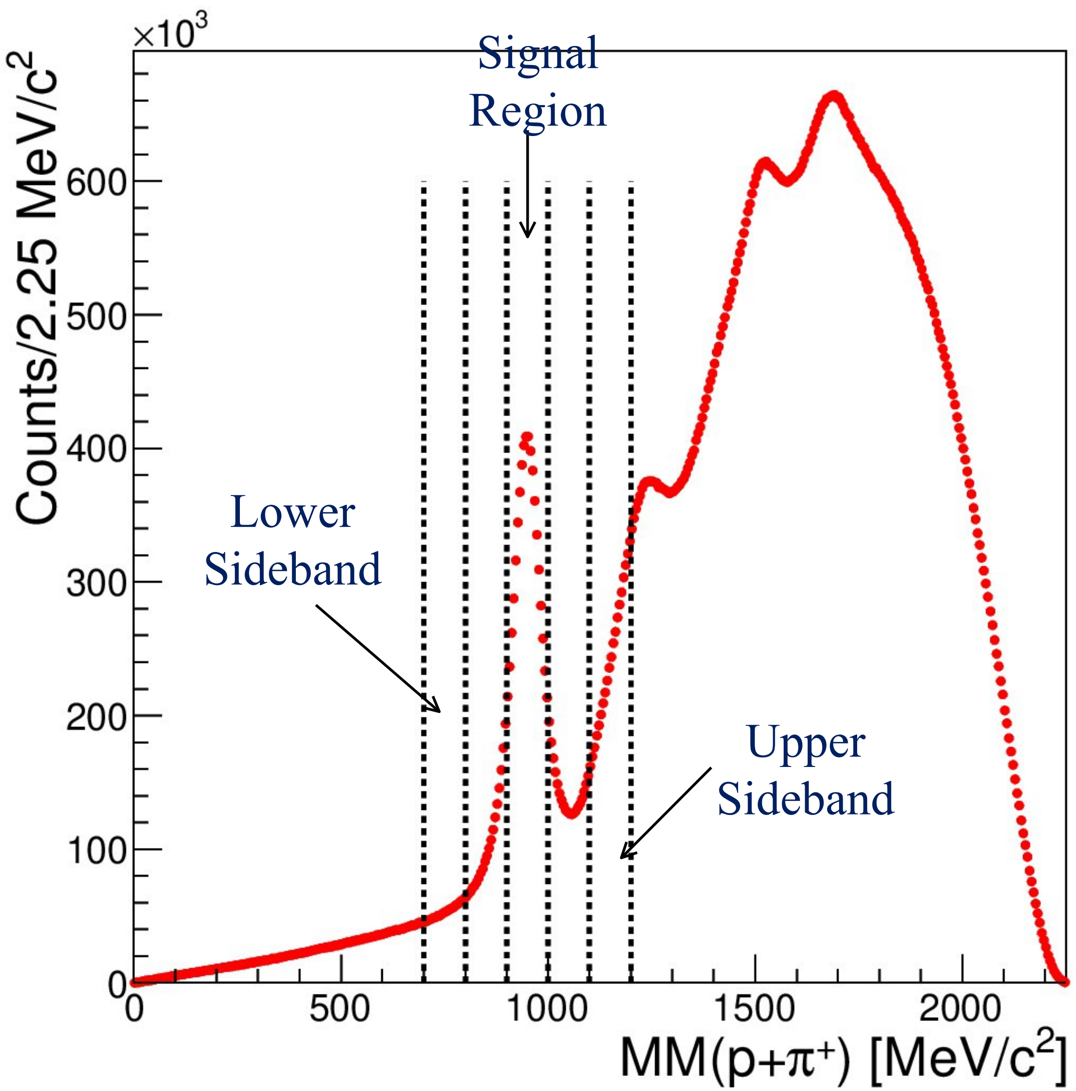
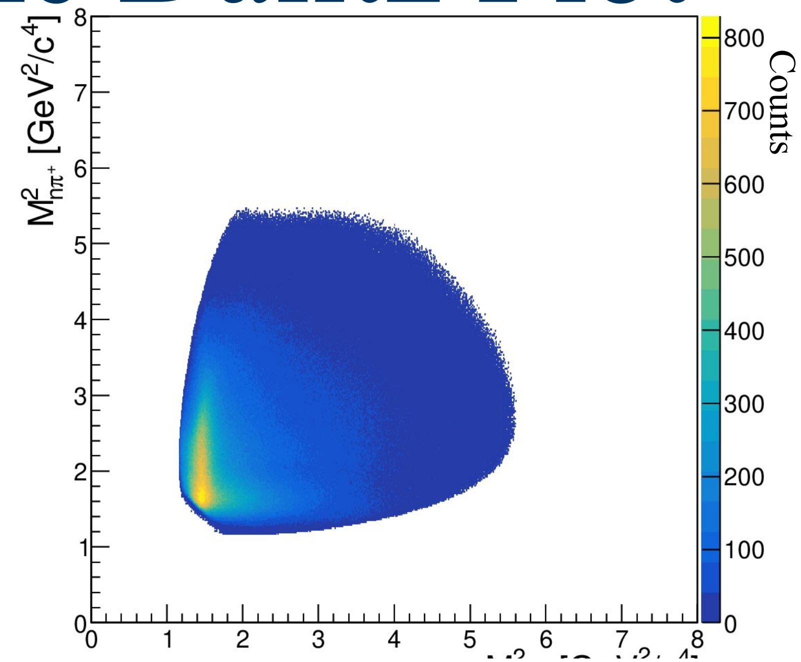
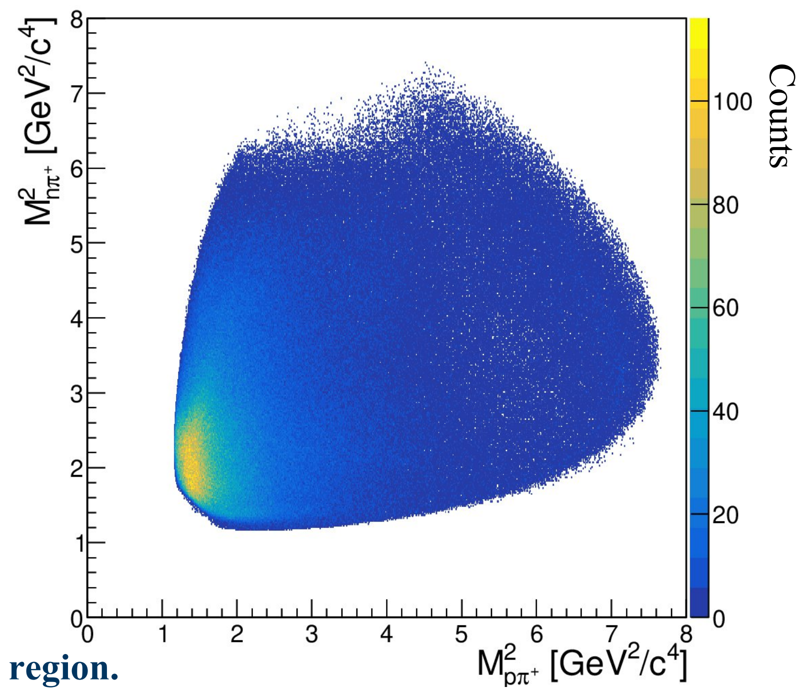


Upper Sideband



Lower Sideband



The momenta of the particles of the sideband data are not properly scaled to those within the signal region.

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- KinFit- a kinematic fitting package based on Lagrange Multiplier technique.

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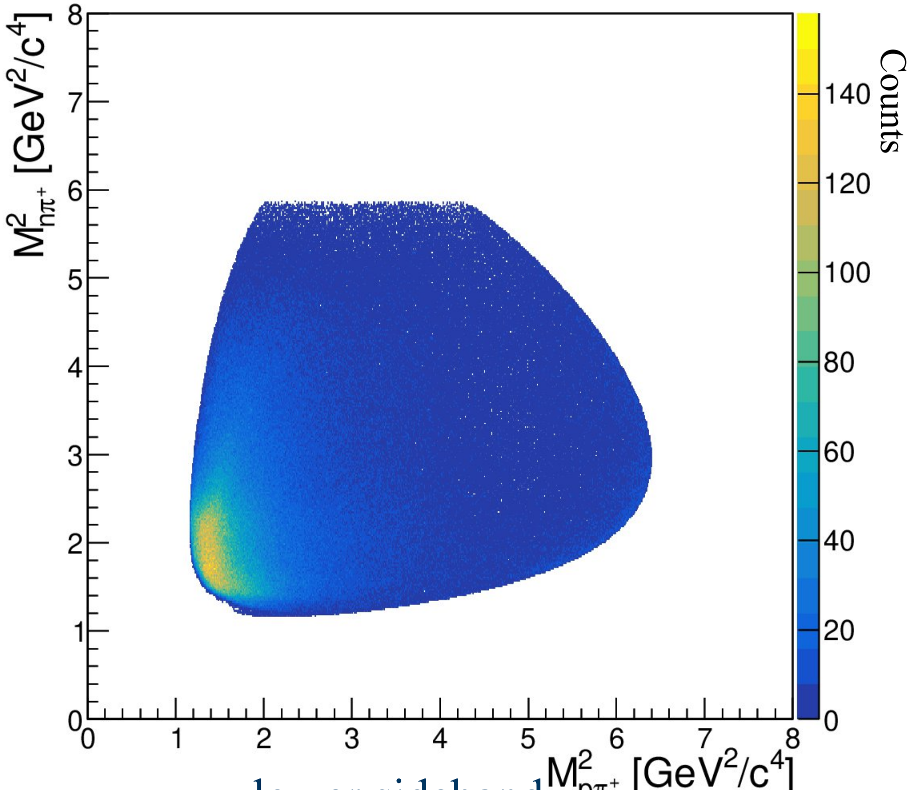
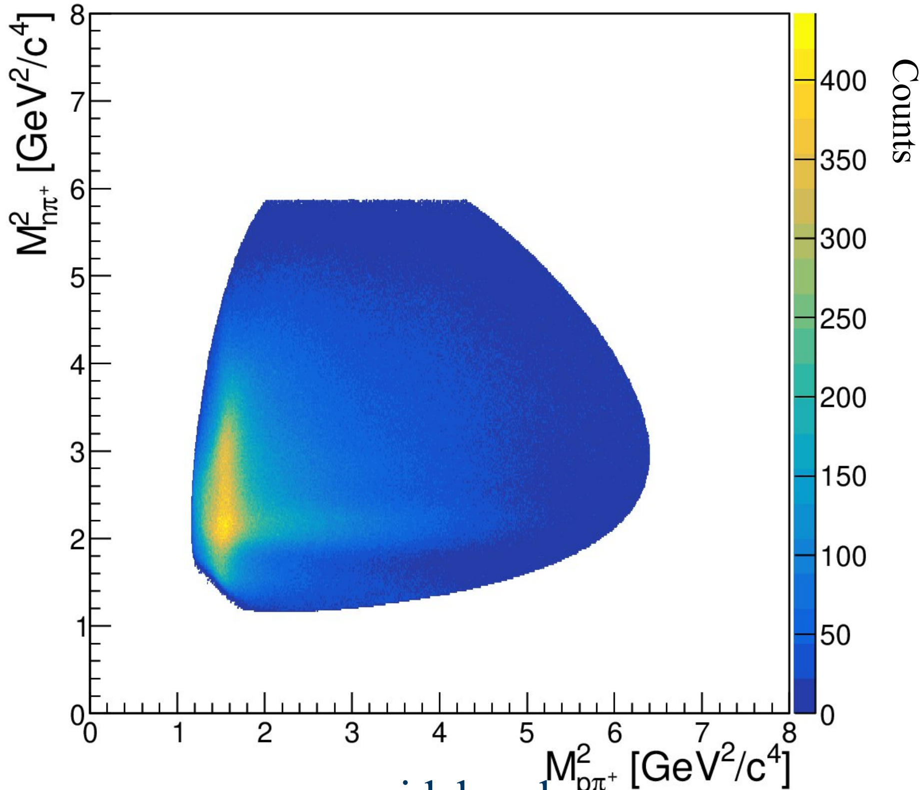


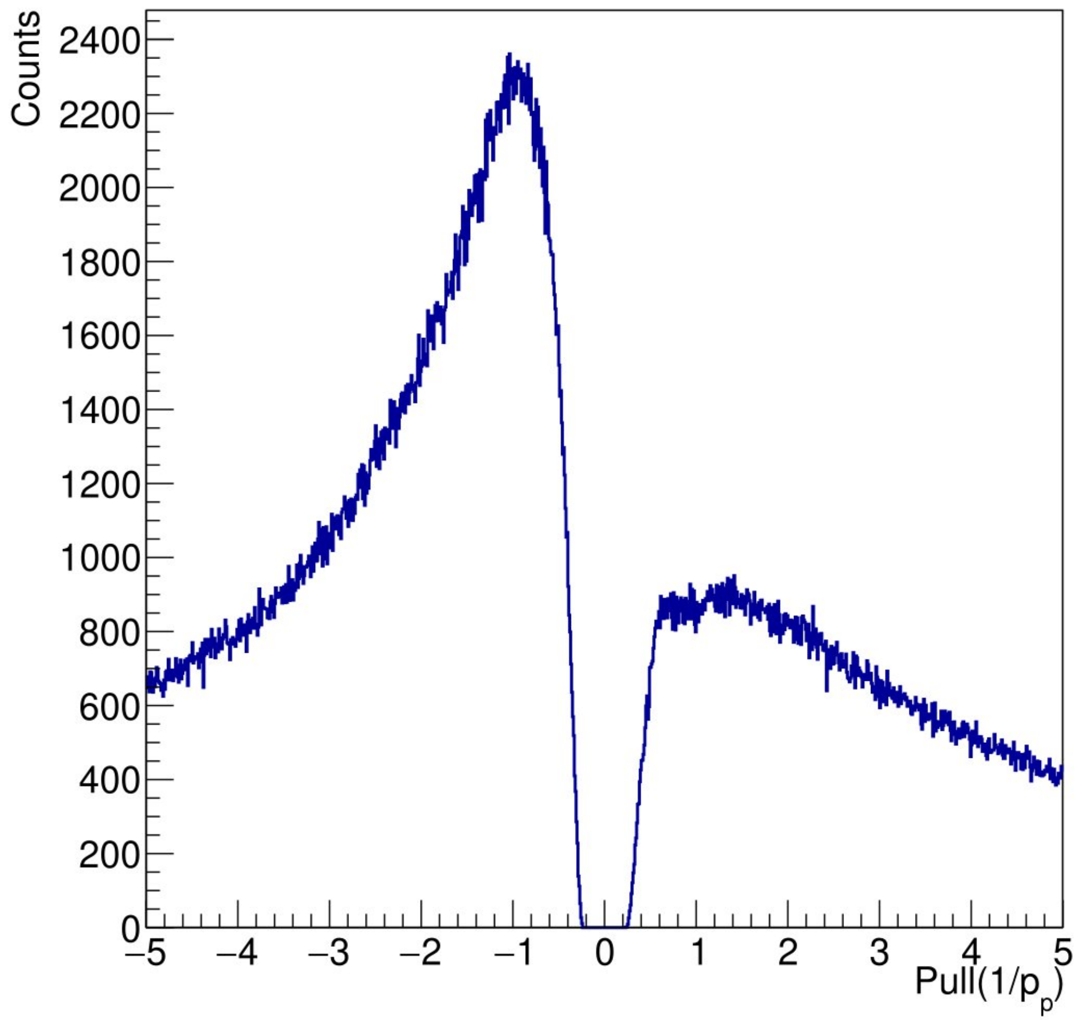
lower sideband



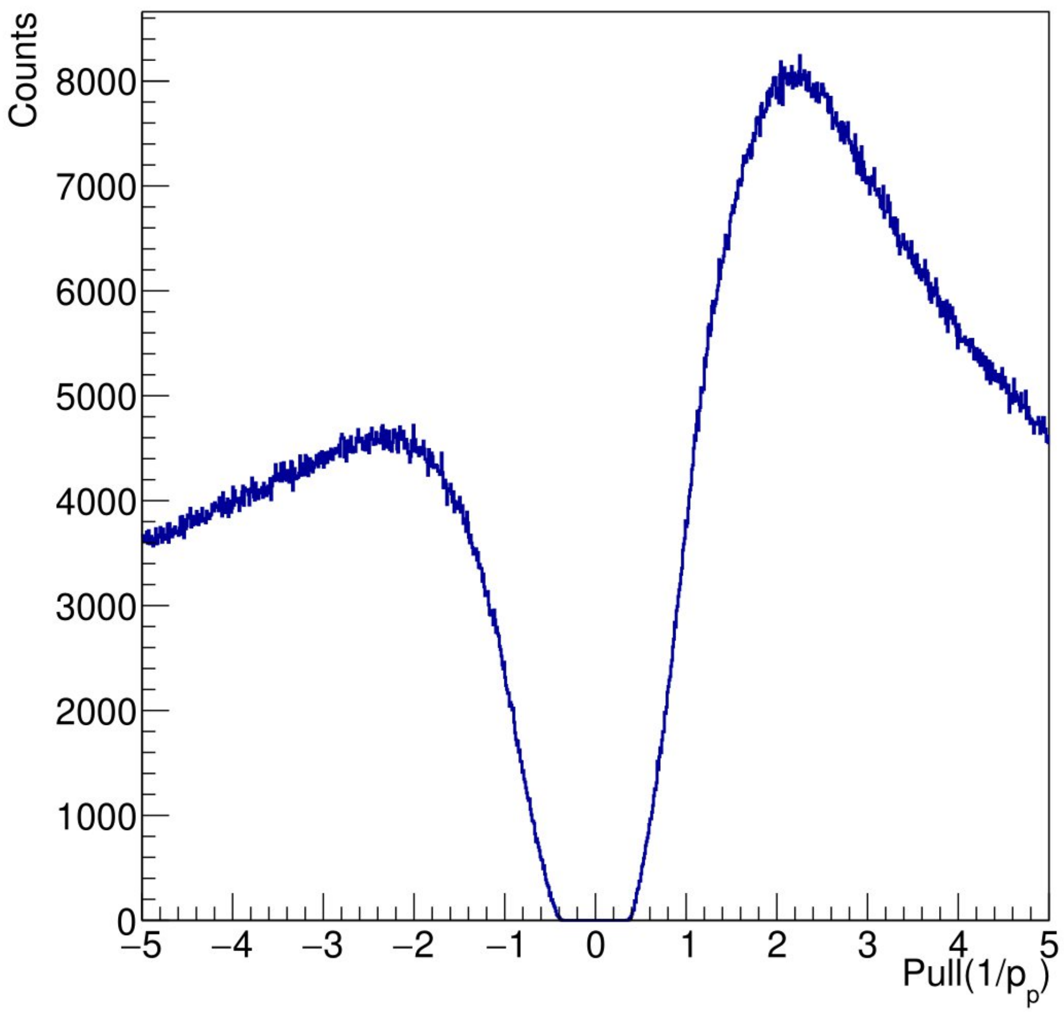
upper sideband

Kinfit Missing Mass Constraint

Can be thought as the 1C fit is shrinking the momentum of lower sideband to lower values and stretching the momentum of the upper sideband to higher values.



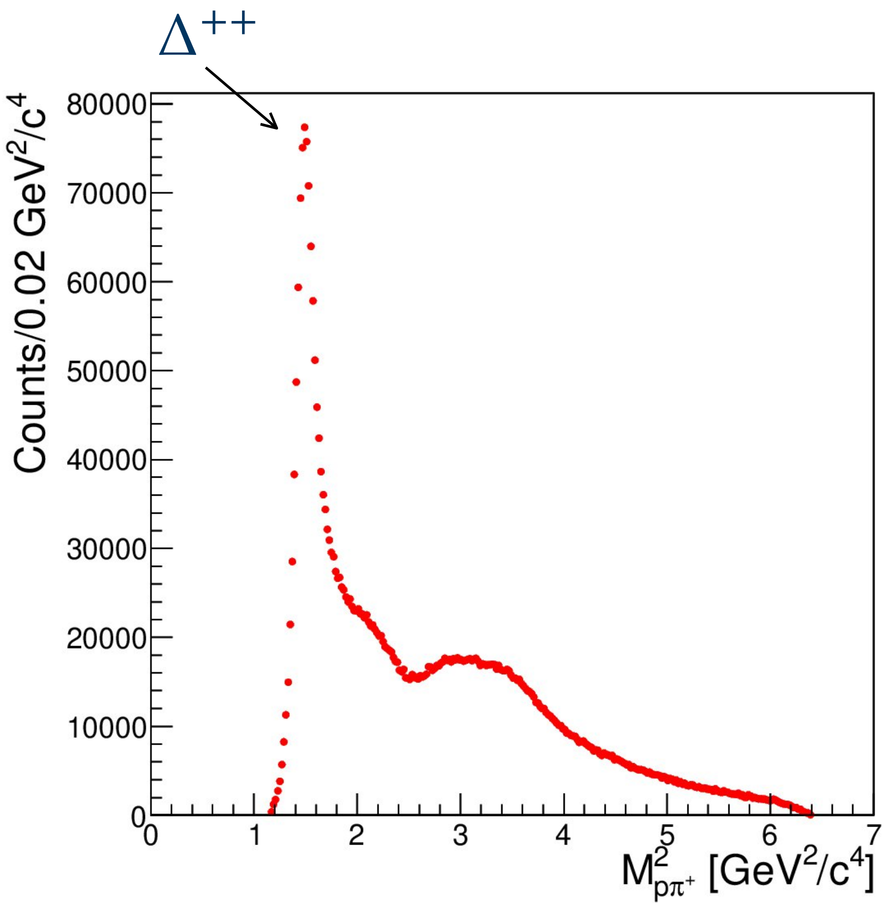
lower sideband



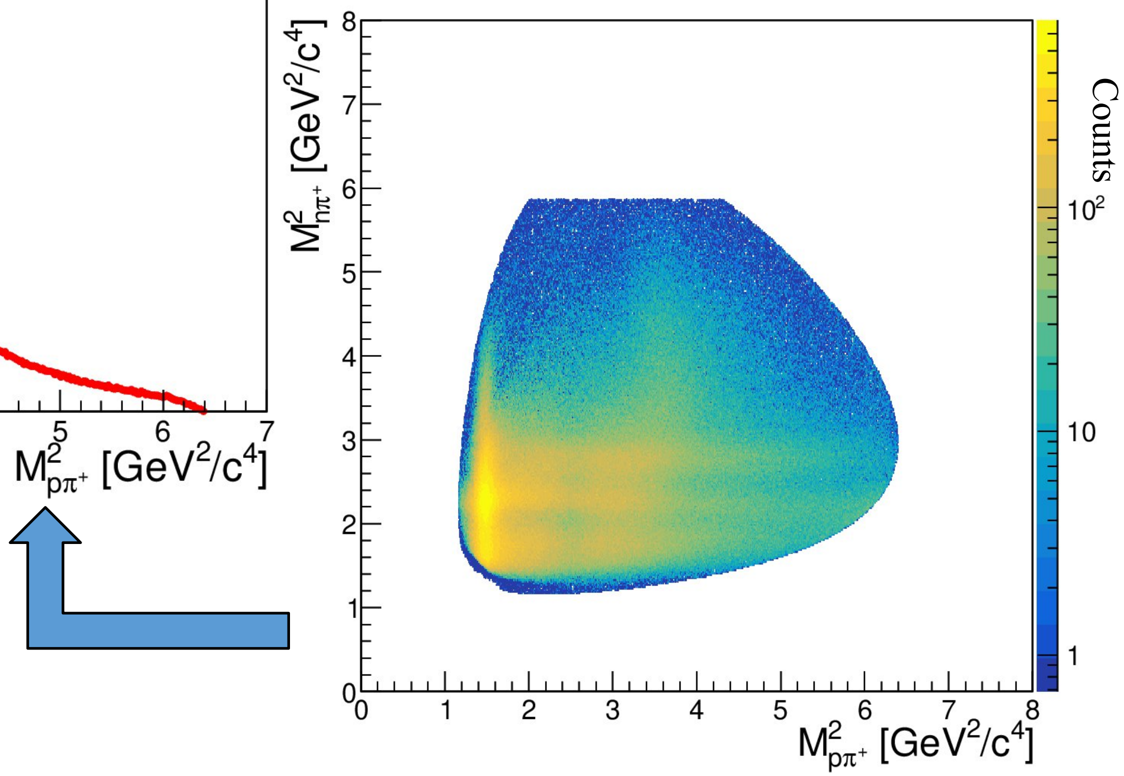
upper sideband

Kinfit Missing Mass Constraint

- Sideband Subtracted $np\pi^+$ final state Dalitz plot.



X projection



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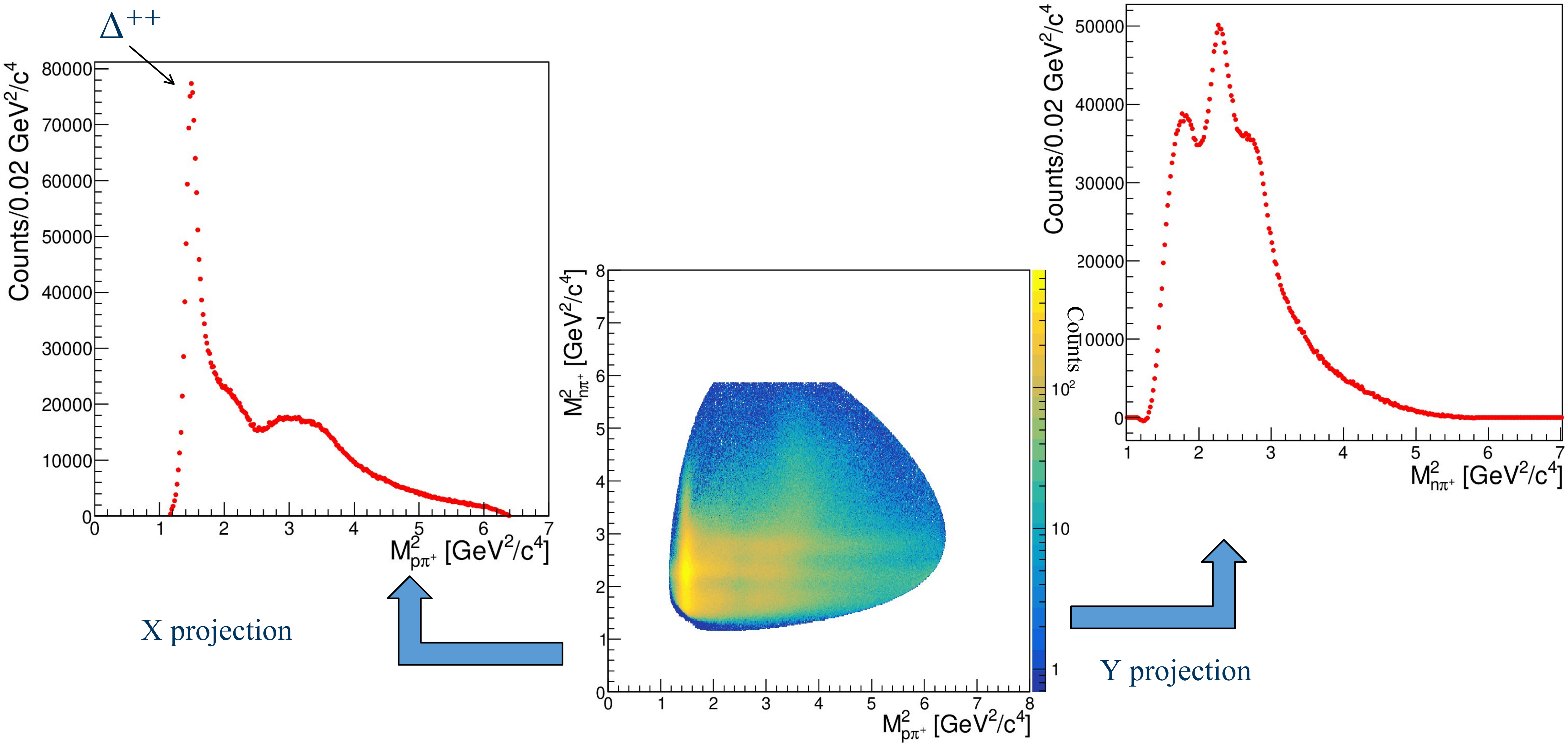
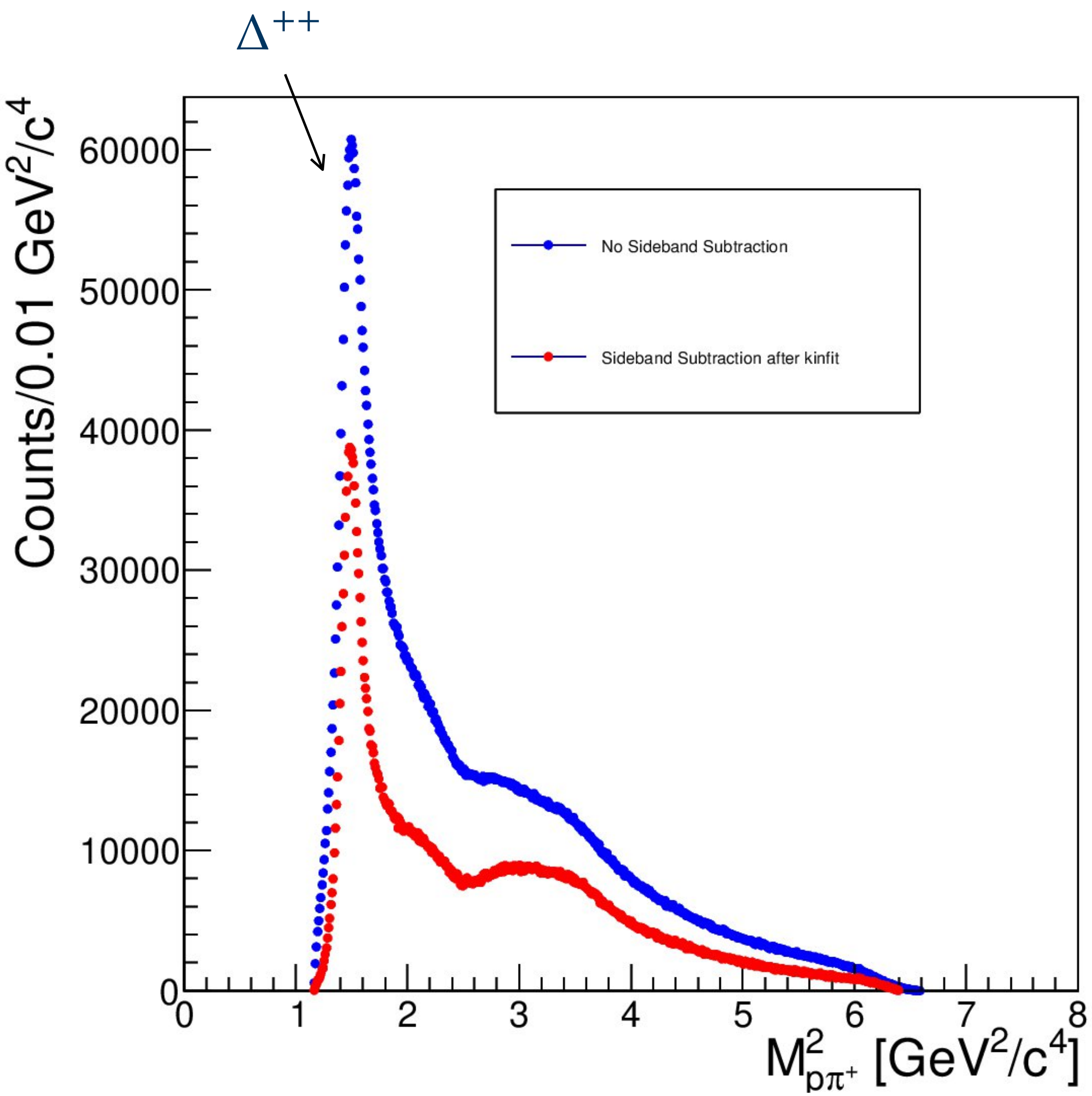
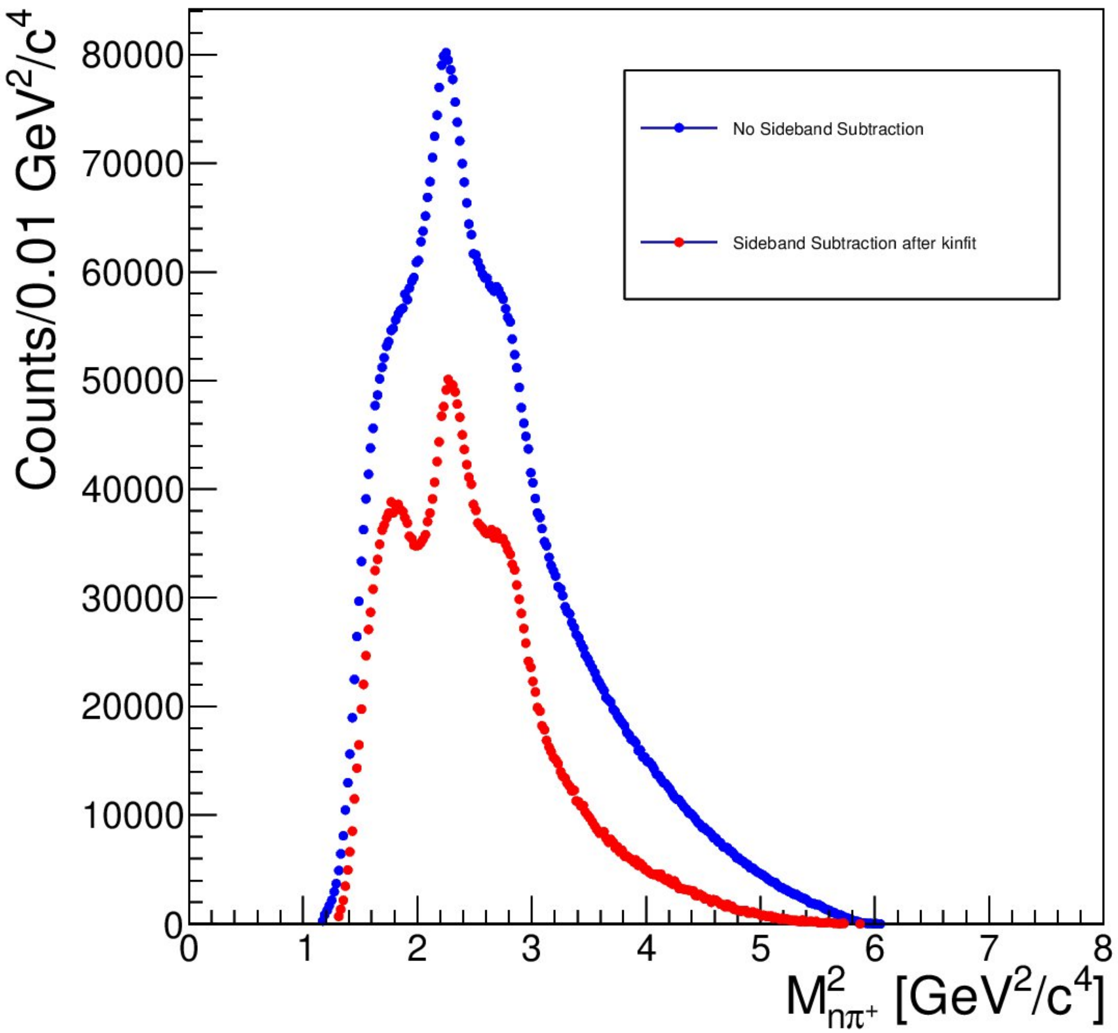


Before and After





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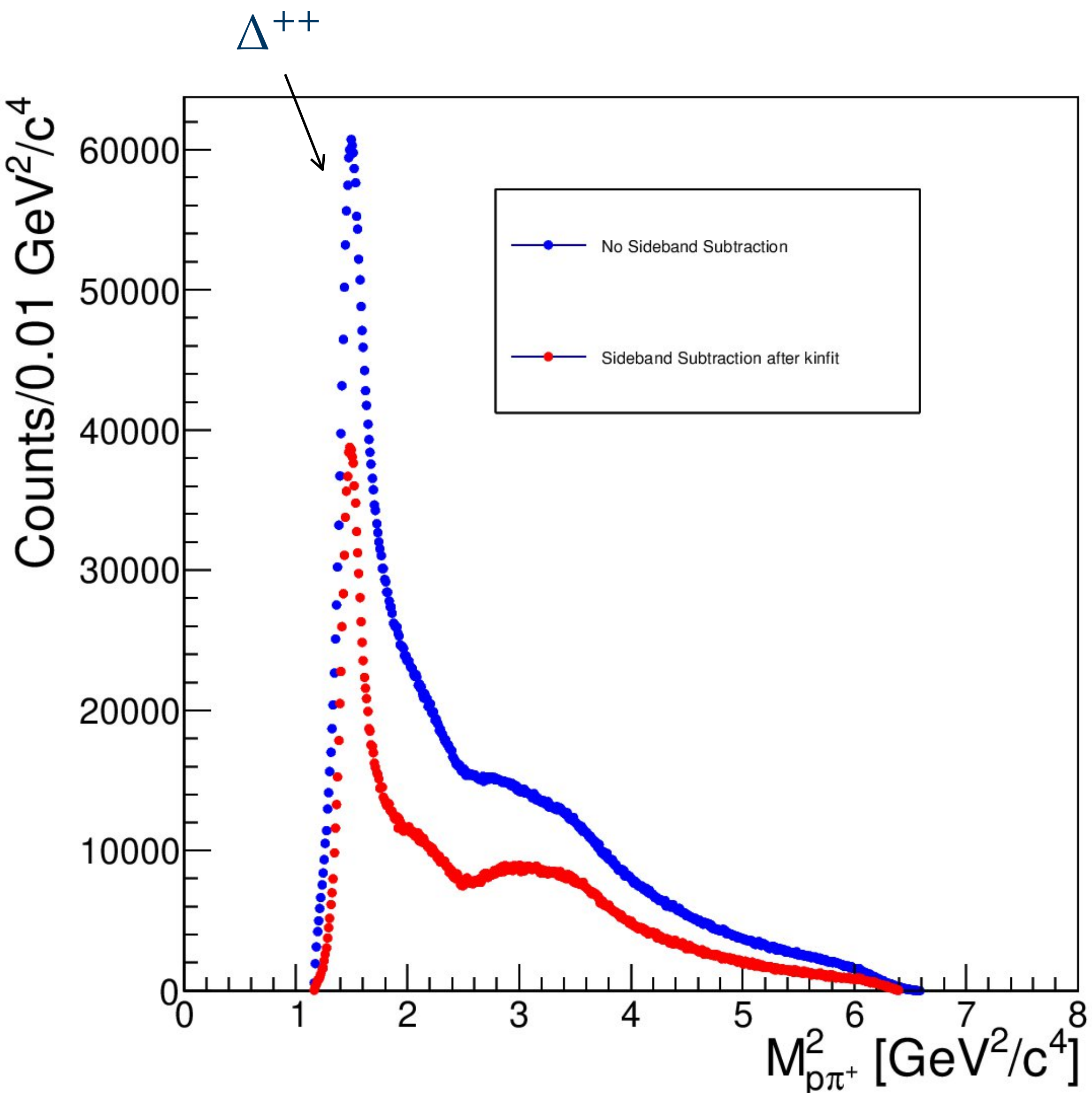
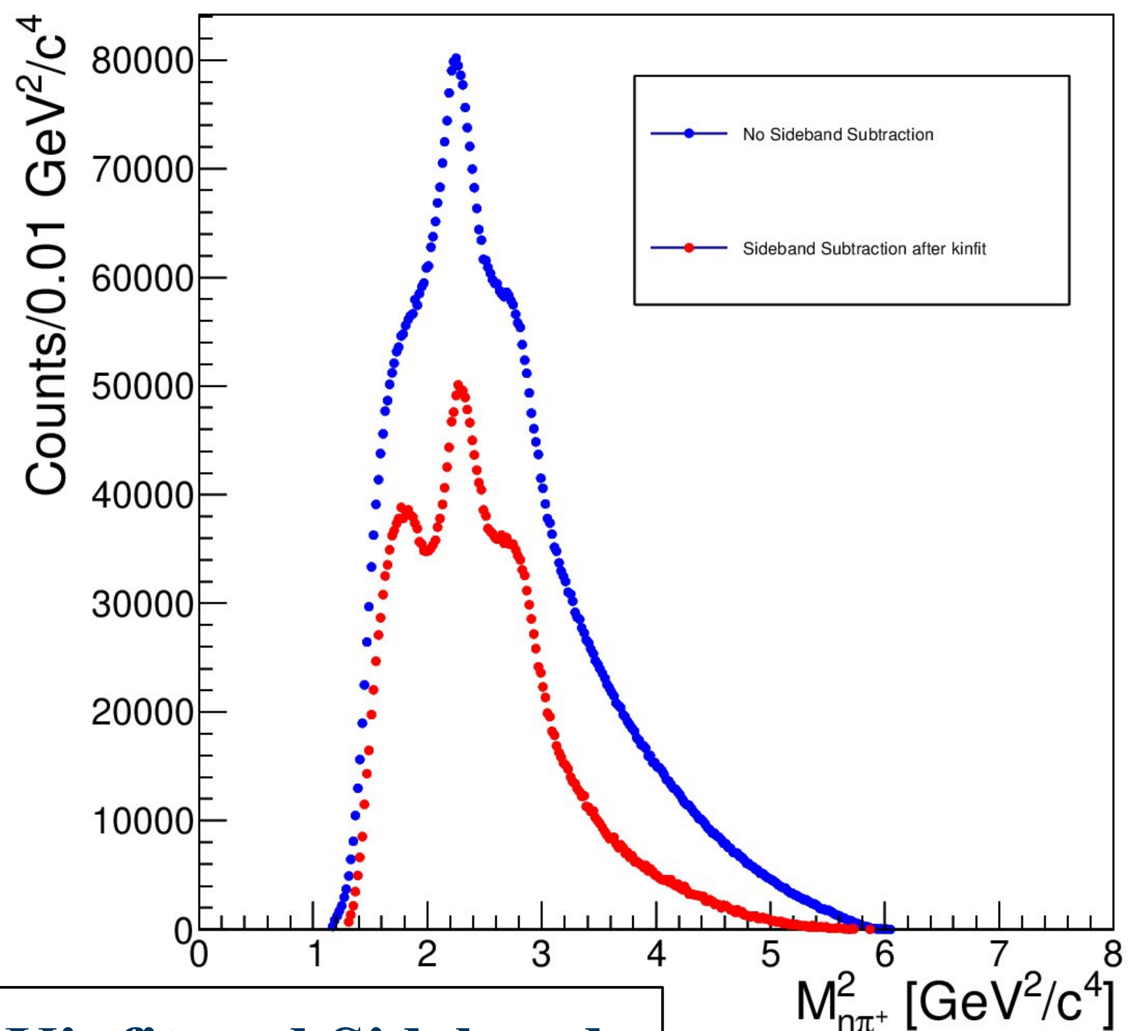
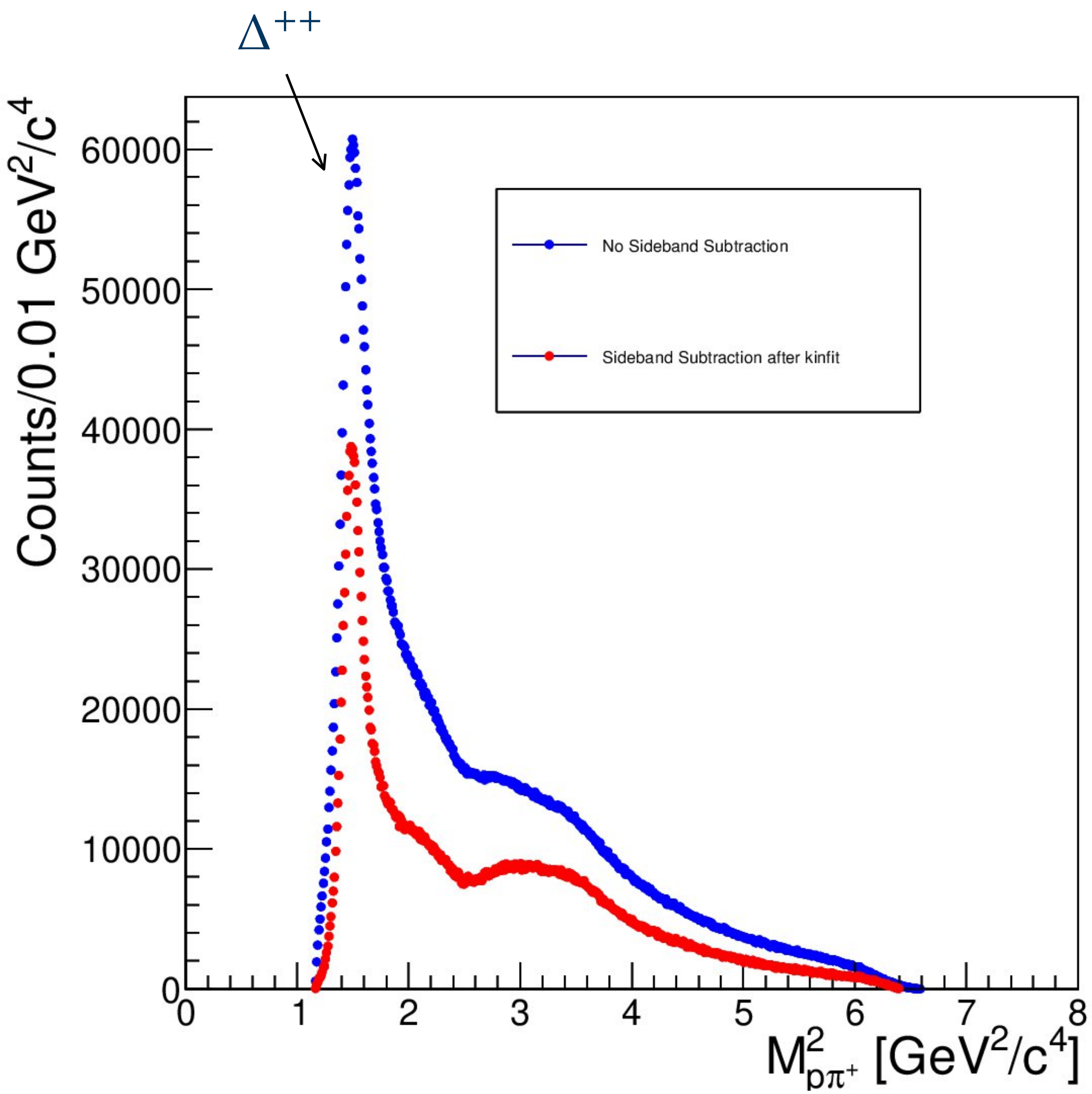
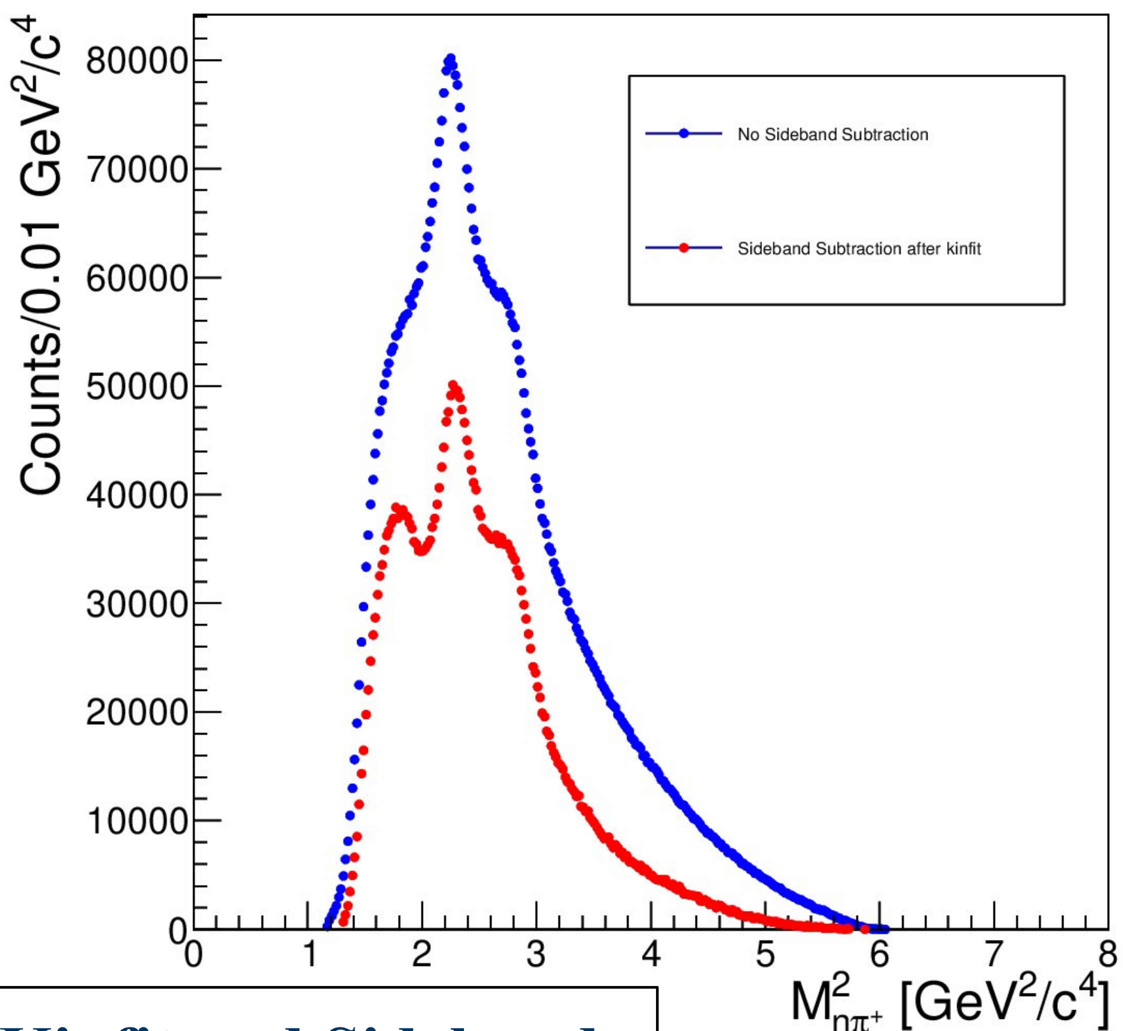




Kinfit and Sideband Subtraction needed

Before and After





Kinfit and Sideband Subtraction needed

Conclusion and Outlook

- Clear identification of exclusive three-body channel: $pp \rightarrow pn\pi^+$ with very high statistics, good S/B ratio.
- Kinfit and Sideband Subtraction was tested.
- Work on optimisation of the sideband windows.
- Study MC simulations of the reaction to get a measure of acceptances and efficiencies.
- Use Forward Detector to cover even the missing pieces in the Dalitz plot.
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Δ Thank You Δ

Backup

√

.15
.27

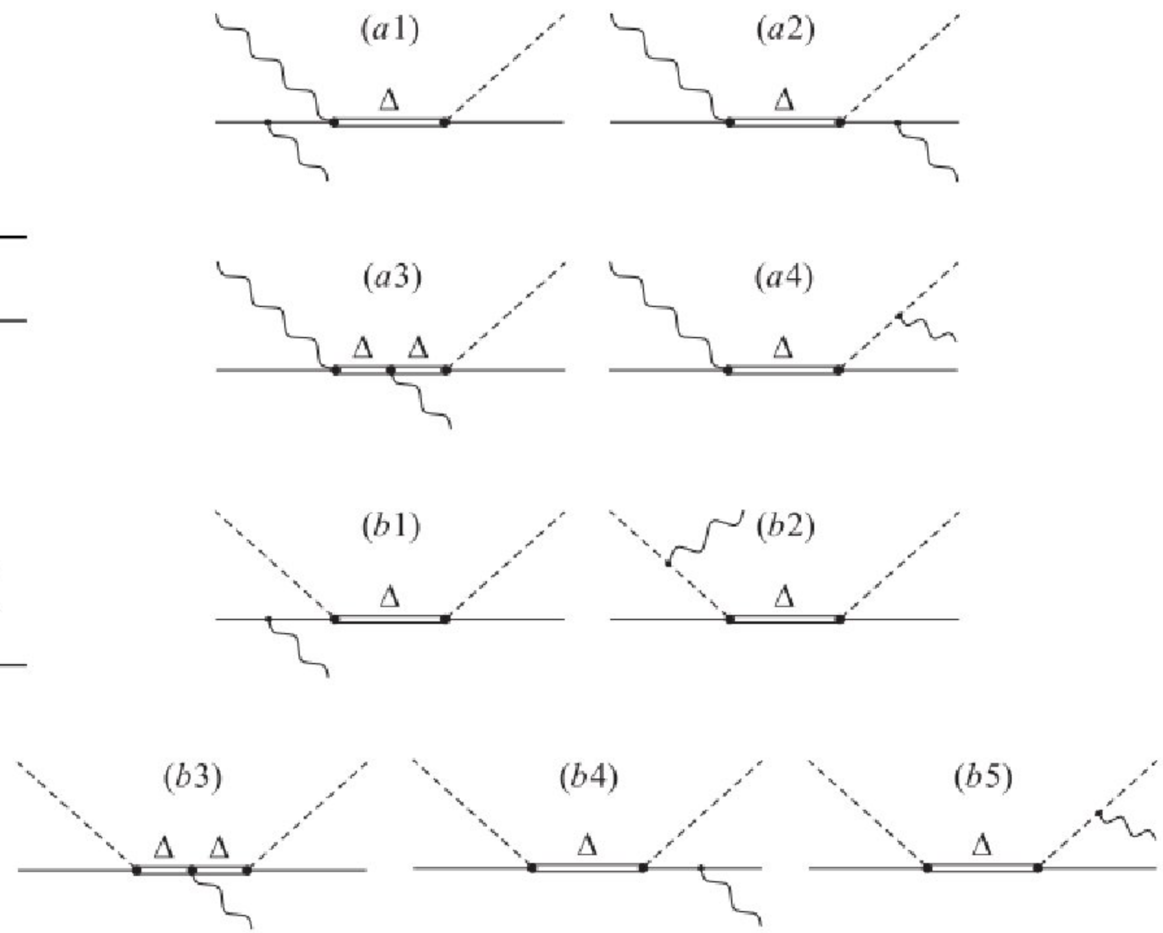


Fig. 2. Bremsstrahlung and Δ-resonant contributions to $N\pi\gamma'$ final states for pion photoproduction (a) and pion scattering (b). Only diagrams $(a3)$ and $(b3)$ are sensitive to the magnetic dipole moments μ_Δ.

Backup

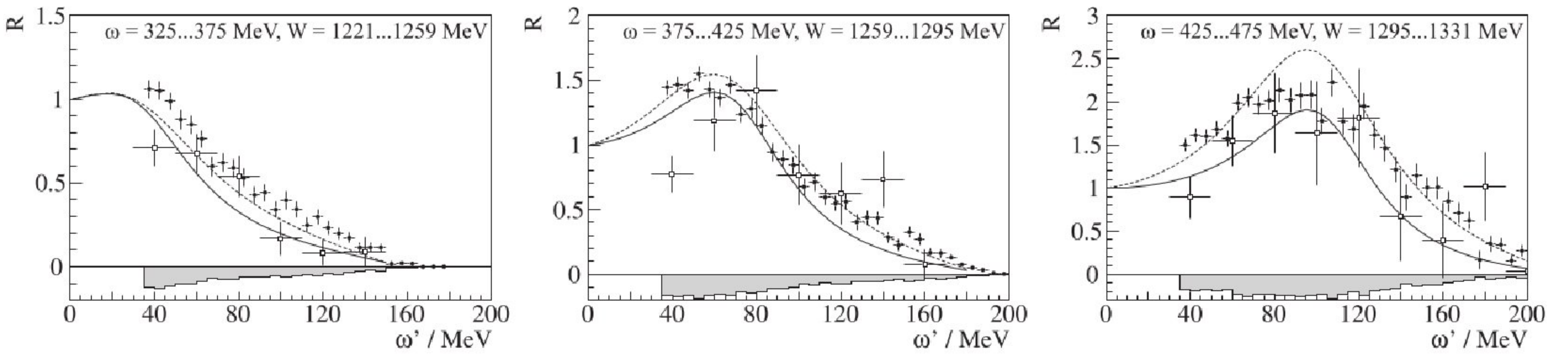


Fig. 18. Cross section ratio R at different ranges for beam energy ω and total c.m. energy W, respectively. Black points represent Crystal Ball / TAPS results, white squares are results from ref. [19]. Error bars denote statistical errors, grey shaded bands show absolute systematic uncertainties. Black lines are theoretical predictions (using $\kappa_{\Delta^+} = 2.6$) of the unitary model from ref. [33] (dashed line) and the χEFT calculation from ref. [35] (solid line).

Backup

Appendix D: U-NET

- U-NET is an image segmentation algorithm which was originally designed for **biomedical uses** in the ISBI challenge for segmentation of neuronal structures in electron microscopic stacks[6].
- The architecture relies heavily on the use of **data augmentation** and is strong with training on **small datasets.**
- Segmentation of a 512x512 image takes **less than a second** on a recent GPU.

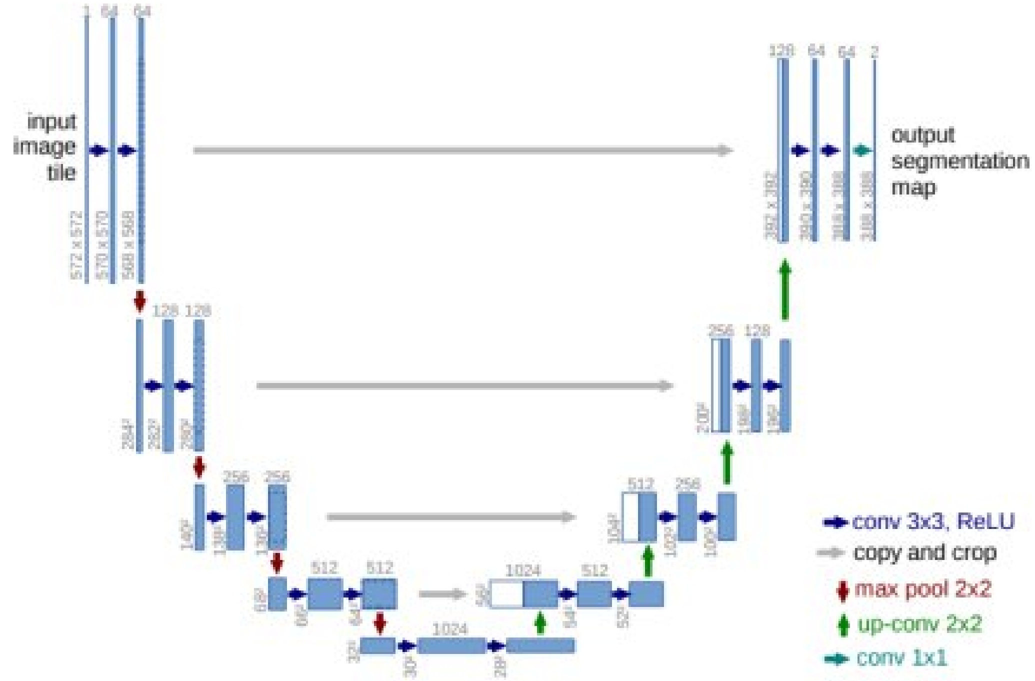
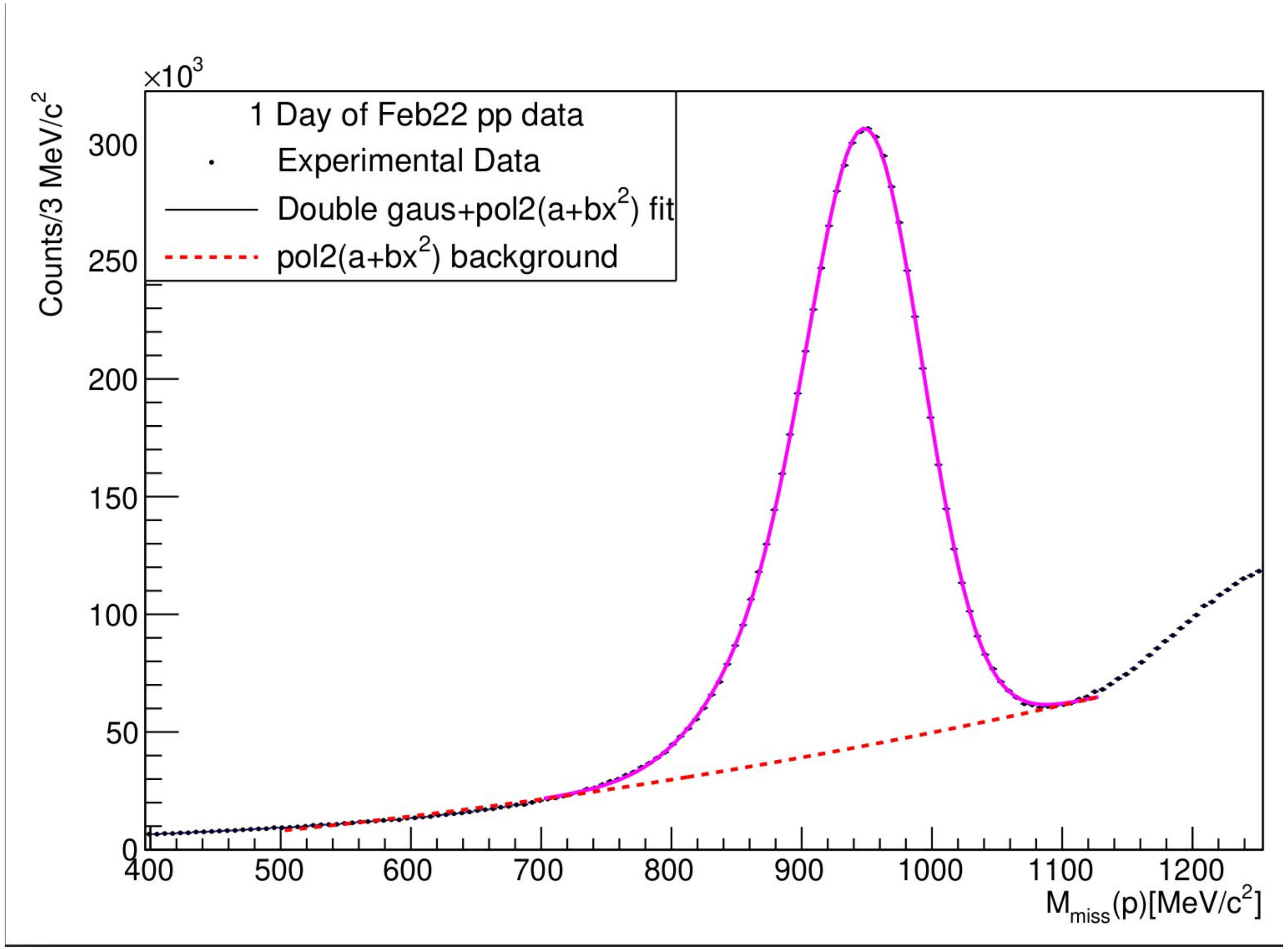


Figure 8:U-net architecture (example for 32x32 pixels in the lowest resolution). Each blue box corresponds to a multi-channel feature map. The number of channels is denoted on top of the box. The x-y-size is provided at the lower left edge of the box. White boxes represent copied feature maps. The arrows denote the different operations. Image and caption sourced from Ref [9].

[9] U-Net: Convolutional Networks for Biomedical Image Segmentation, arXiv:1505.04597, Last accessed 02-07-2024.

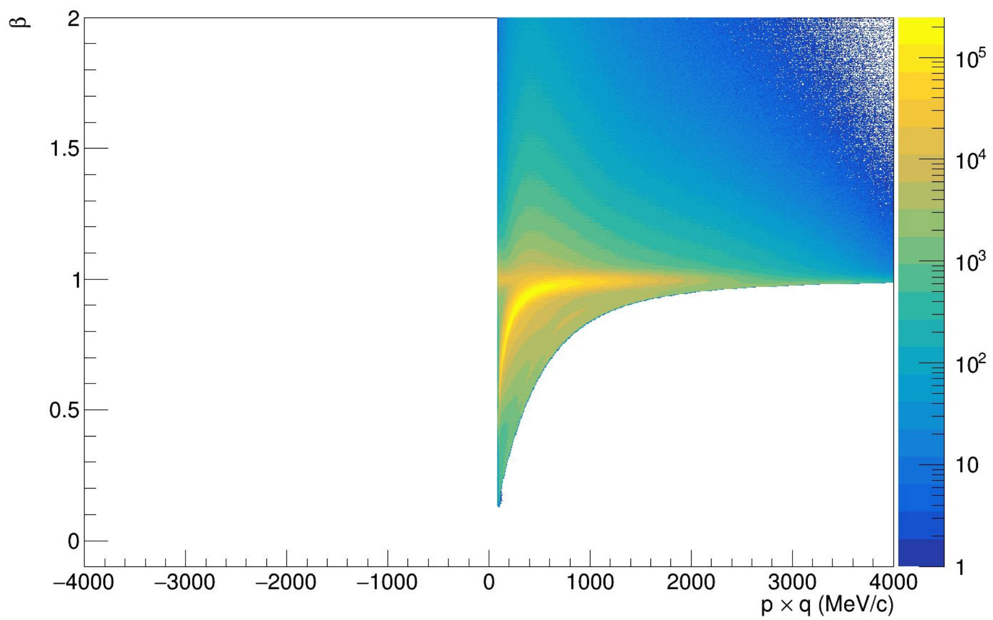
Backup

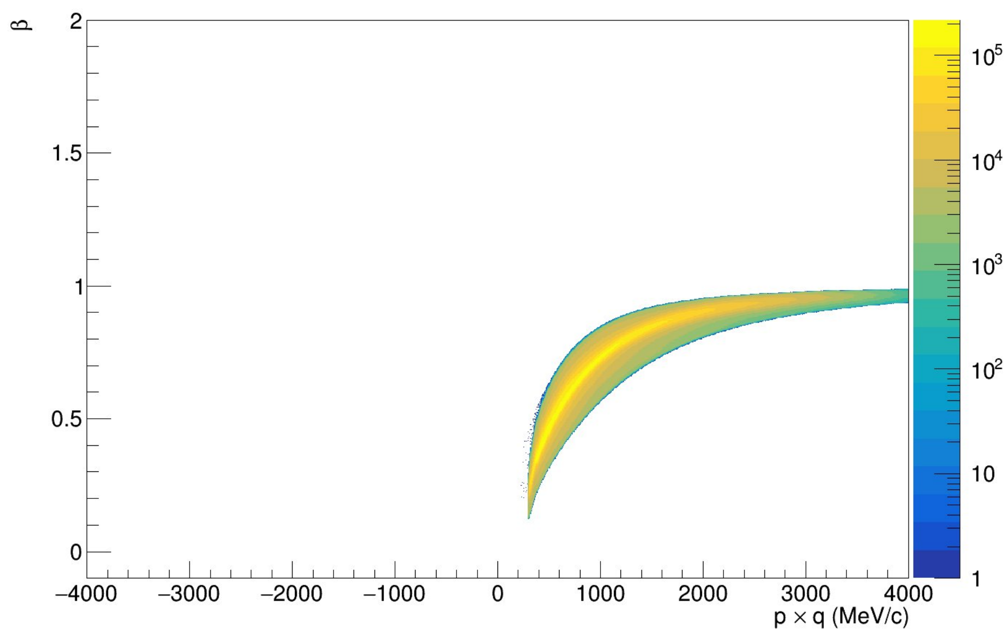


×10³
Counts/3 MeV/c²
1 Day of Feb22 pp data
Experimental Data
Double gaus+pol2(a+bx²) fit
pol2(a+bx²) background
300
250
200
150
100
50
0
400
500
600
700
800
900
1000
1100
1200
M_miss(p)[MeV/c²]

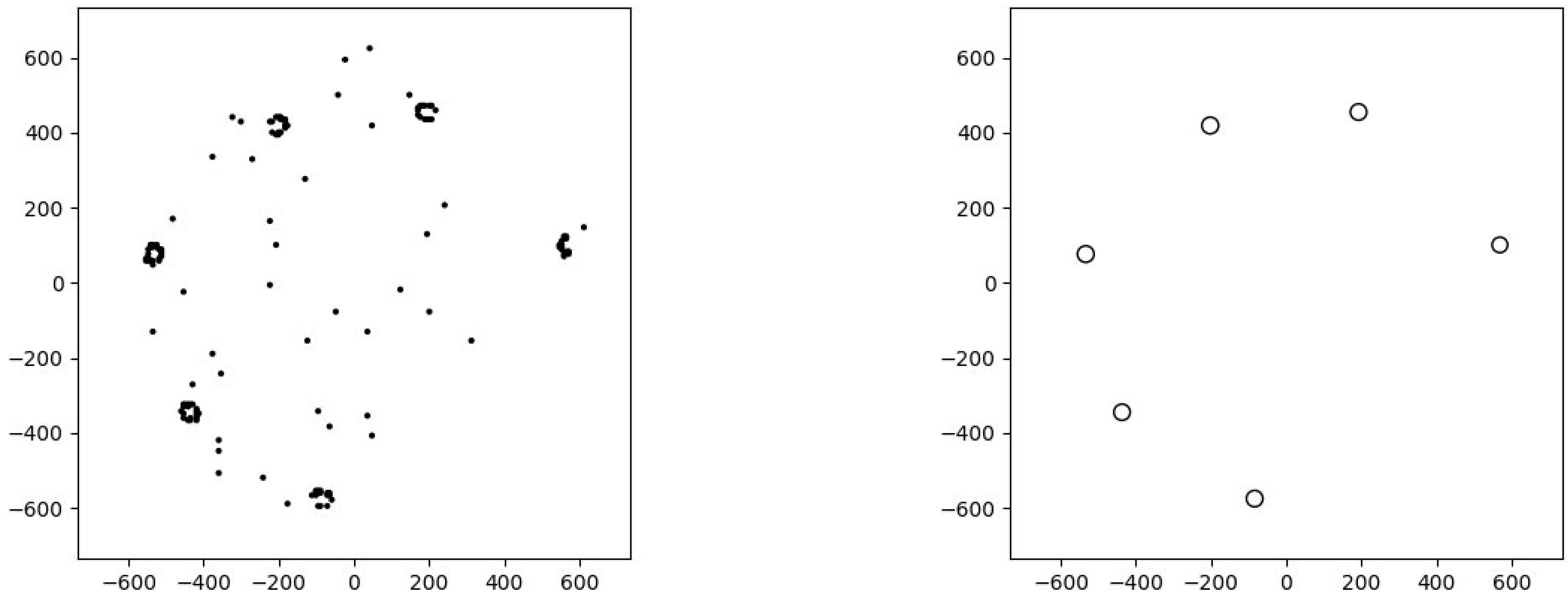
Backup

Branching Ratio for $\Delta^+ \rightarrow pe^+e^-$ is 4.2×10^{-5}





Backup

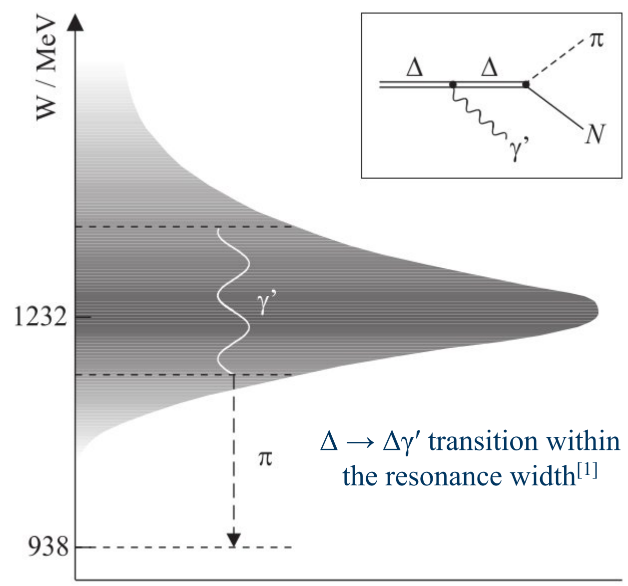

600
400
200
0
−200
−400
−600
−600 −400 −200 0 200 400 600
600
400
200
0
−200
−400
−600
−600 −400 −200 0 200 400 600

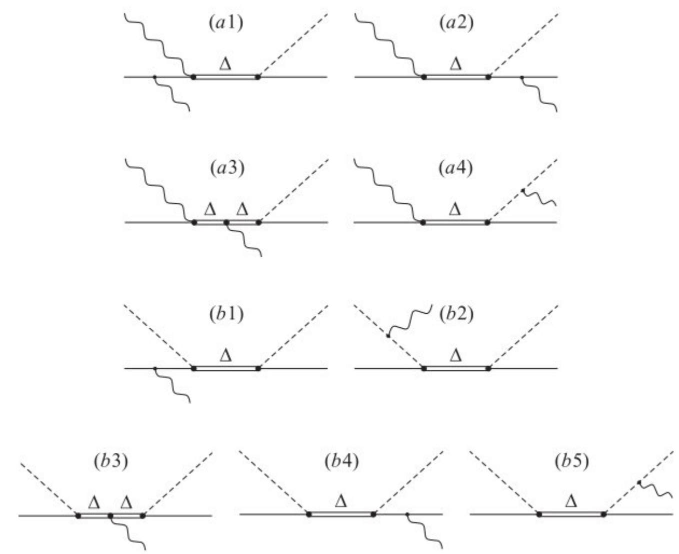
Motivation

- The main long term aim of the analysis is to do a **feasibility study** of the **radiative transitions** of the Δ as they provide insights into their electromagnetic structure.

- The magnetic moment of the Δ^+, $\mu_{\Delta^+} = 2.7^{+1.0}_{-1.3}$ (stat) ± 1.5 (syst) ± 3.0 (theo) μ_N [1] has **large theoretical uncertainty** due to model ambiguities.

- **Virtual photon (dilepton)** transitions may provide a less model dependent extraction of the magnetic moment exploiting a measurement of the **spin-density matrix elements (SDME)**.

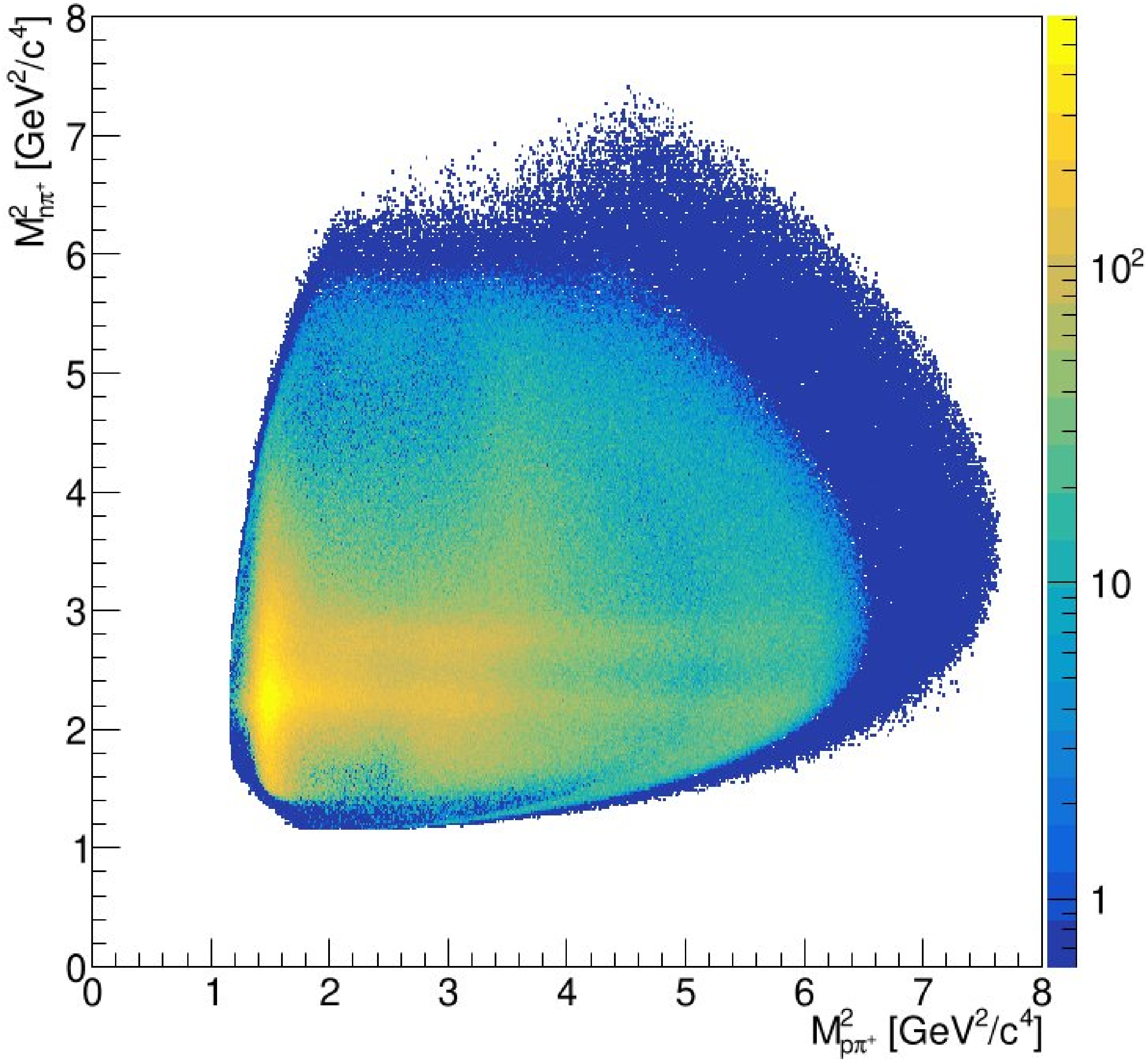




1. S. Schumann et al. (The European Physical Journal A 43.3 (2010), pp. 269–282).

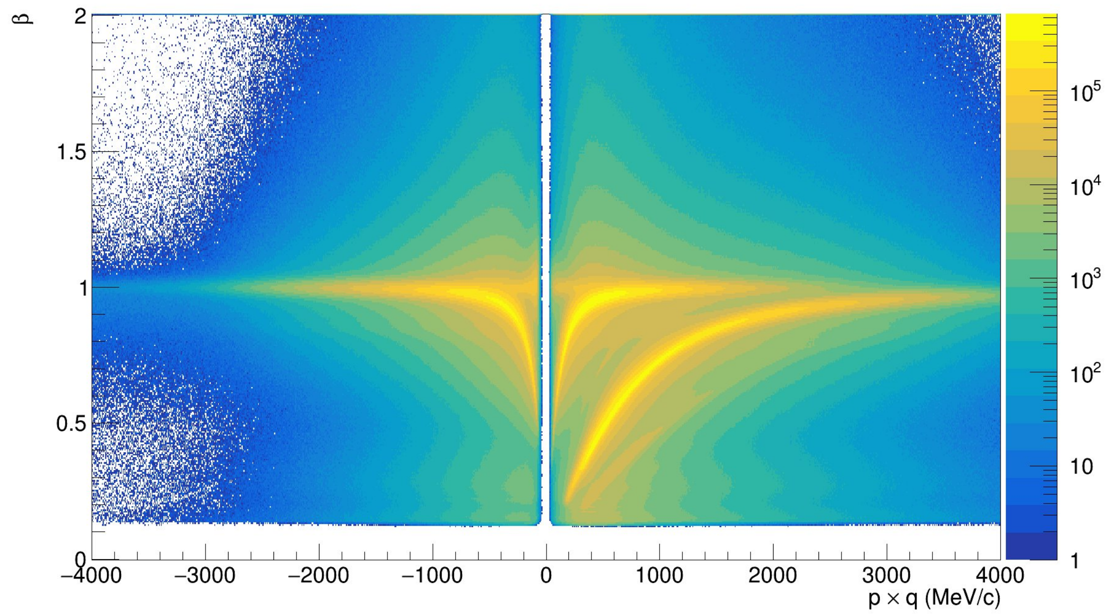
Backup

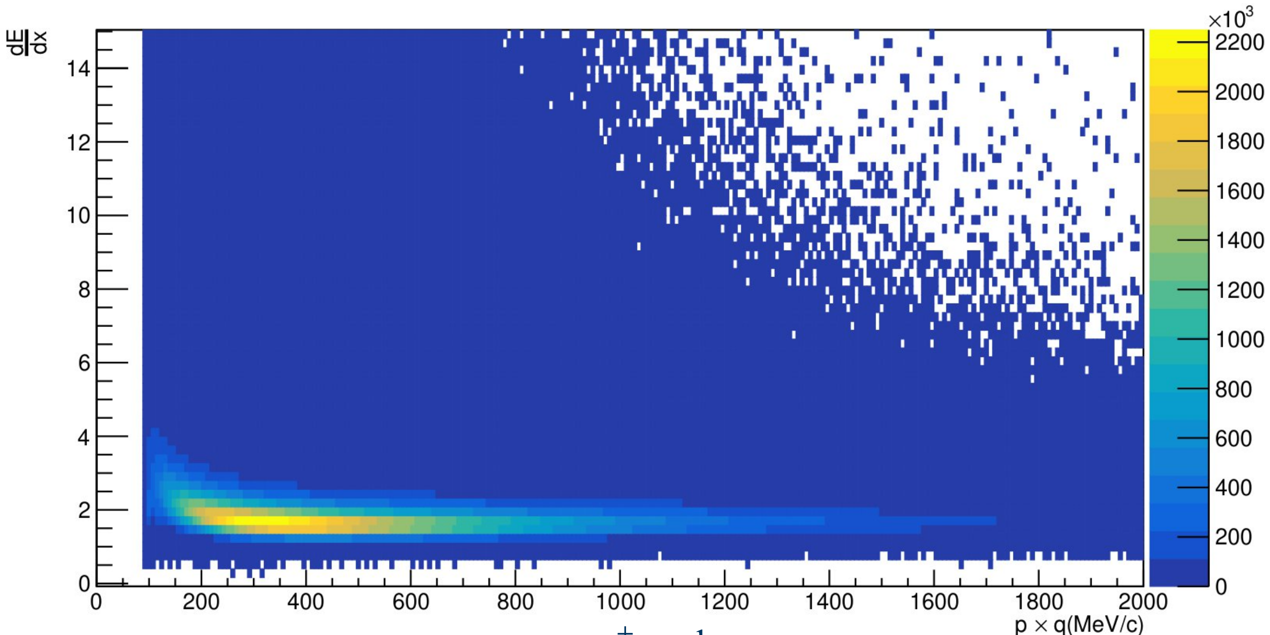
Sideband subtracted
without kinfit



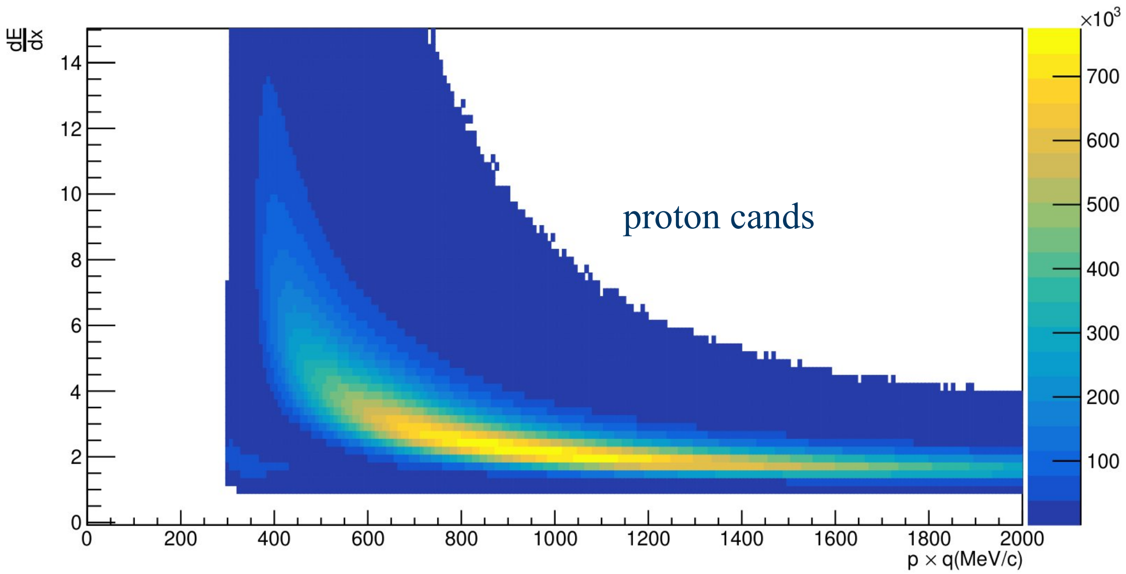
Backup

- First calculate $rel_{tof} = tof_{measured} - tof_{expected}$ taking proton,pion and deuteron mass where $tof_{expected} = \frac{L}{c} \cdot \frac{\sqrt{p^2 + M_{PDG}{}^2}}{p}$
- For each event find the least value of rel_{tof} and compare it with the $tof_{expected}$ for each particle.
- The matching rel_{tof} for that event is assigned the corresponding particle PID.





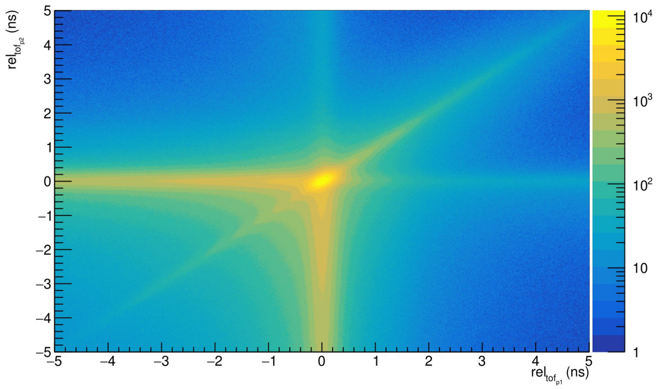
π^+cands



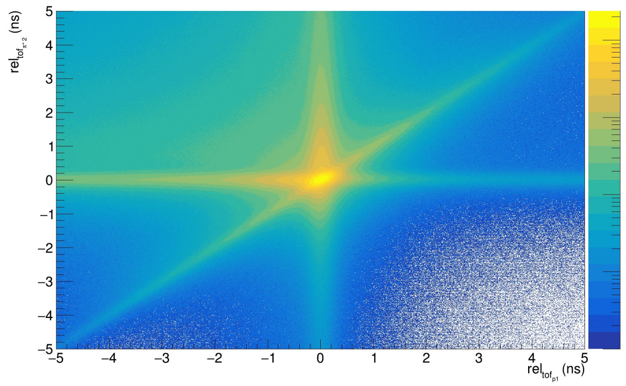
Backup

- Plotting $\mathrm{rel}_{\mathrm{tof\_track1}}$ vs $\mathrm{rel}_{\mathrm{tof\_track2}}$ for the 4 cases.

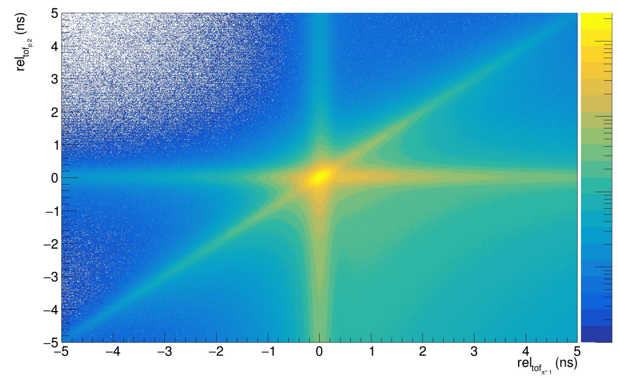
pp



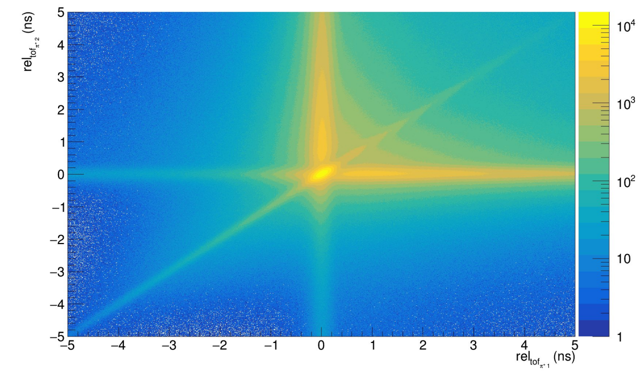
$p\pi^+$



$\pi^+ p$



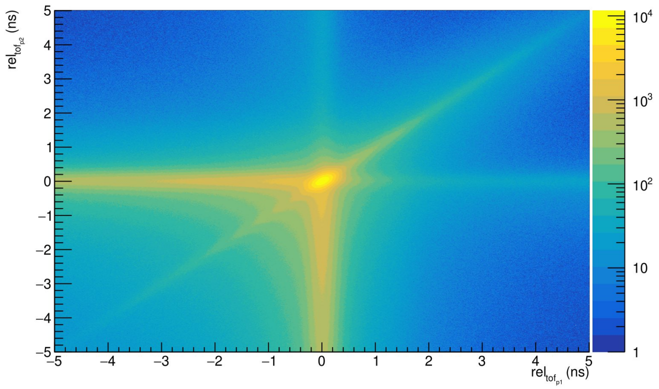
$\pi^+\pi^+$



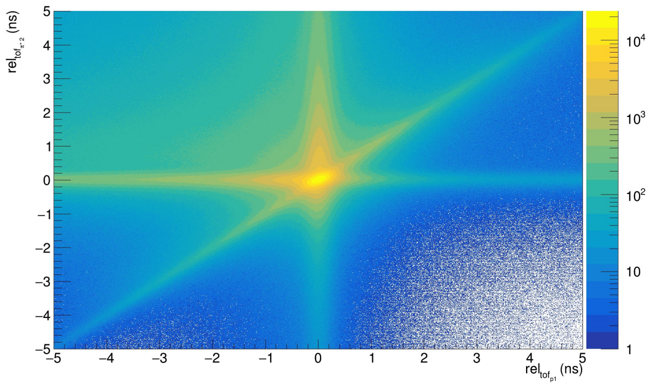
Backup

- Plotting rel_{tof_track1} vs rel_{tof_track2} for the 4 cases.

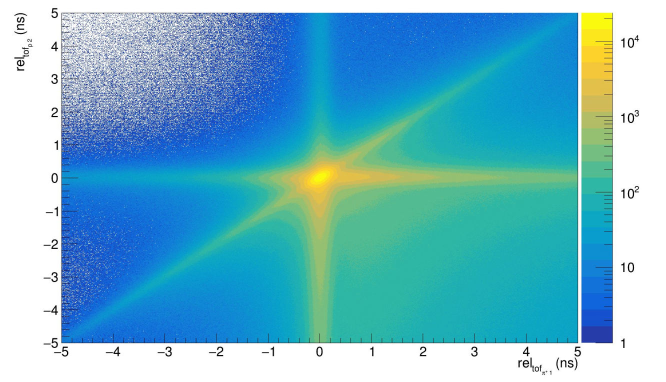
pp



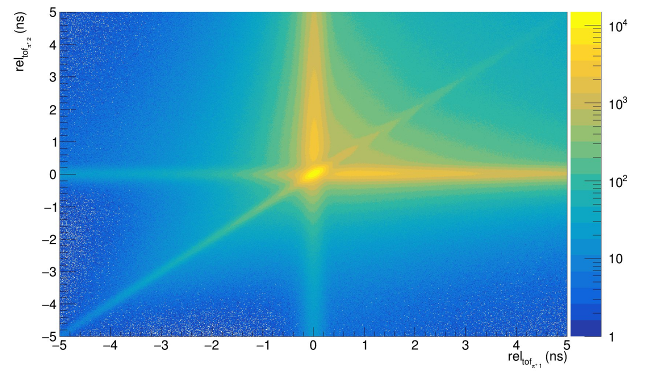
$p\pi^+$



π^+p



$\pi^+\pi^+$

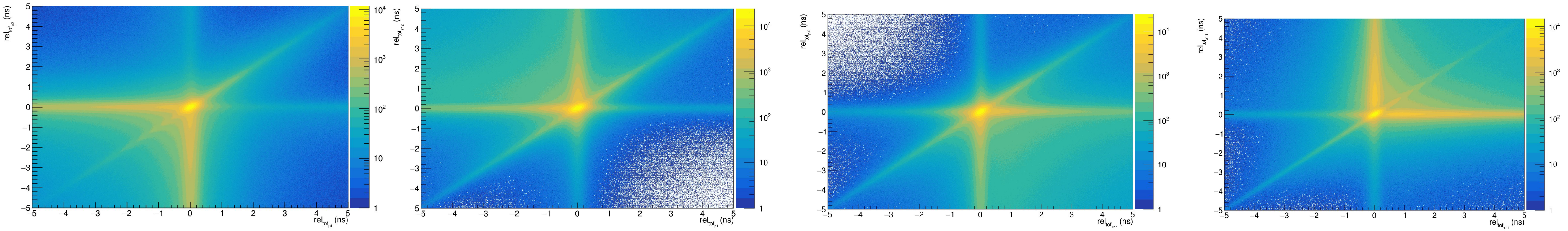


After applying $\Delta T| < 3.2$ ns cut

Backup

- Plotting rel_{tof_track1} vs rel_{tof_track2} for the 4 cases.

pp | $p\pi^+$ | π^+p | $\pi^+\pi^+$



After applying ΔT| < 3.2 ns cut