FIU FLORIDA INTERNATIONAL UNIVERSITY

clas CEBAF Large Acceptance Spectrometer

Proton Antiproton Electroproduction off Protons at CLAS12

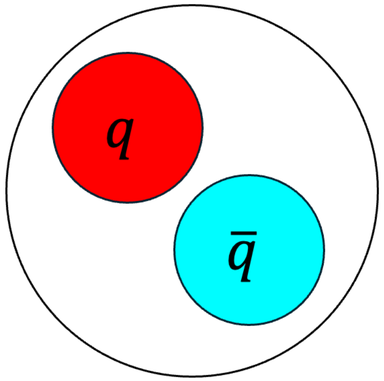
Cross Sections and other Preliminary Results

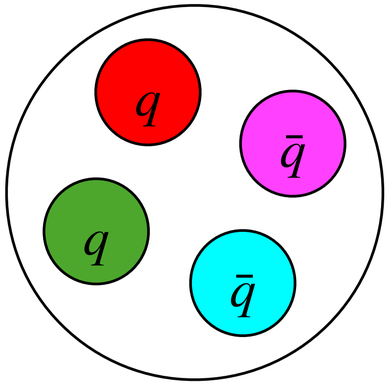
Leonel Martinez 11/18/26

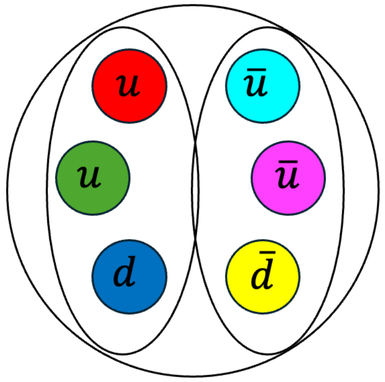
lmart470@fiu.edu

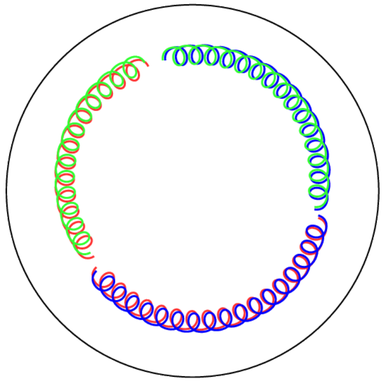
Why?

- How $p\bar{p}$ pairs are produced is not well understood
  - Through an intermediate state, or directly (exchange, rescattering)?
- Recent theories suggest non-conventional intermediate state
  - Baryonium[1, 2]: bound nucleon-anti nucleon
  - Glueball[3]: bound gluons
  - Tetraquark: 4 quark state ($qq\bar{q}\bar{q}$)
- Electroproduction adds Q^2









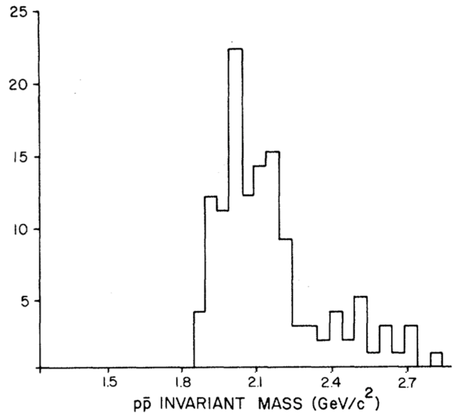
[1] S. Wycech, J.P. Dedonder, and B. Loiseau. "Baryonium, a common ground for atomic and high energy physics".
[2] Mu-Lin Yan et al. "Baryonium with a phenomenological Skyrmion-type potential".
[3] N. Kochelev, "X(1835) as the Lowest Mass Pseudoscalar Glueball and Proton Spin Problem,"

Previous Experiments

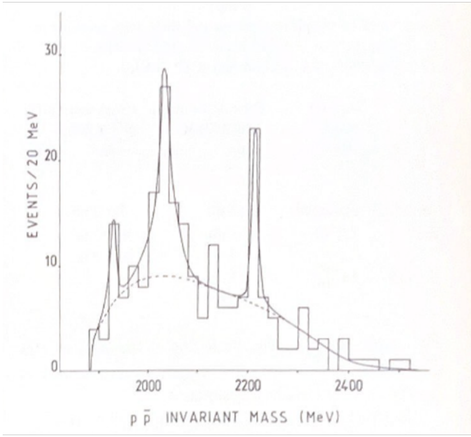
$p\bar{p}$ Production Experiments

$\gamma p \rightarrow pp\bar{p}$ [4]|| $ep \rightarrow epp\bar{p}$ [5]|| $\pi^- p \rightarrow \pi^- pp\bar{p}$[6]

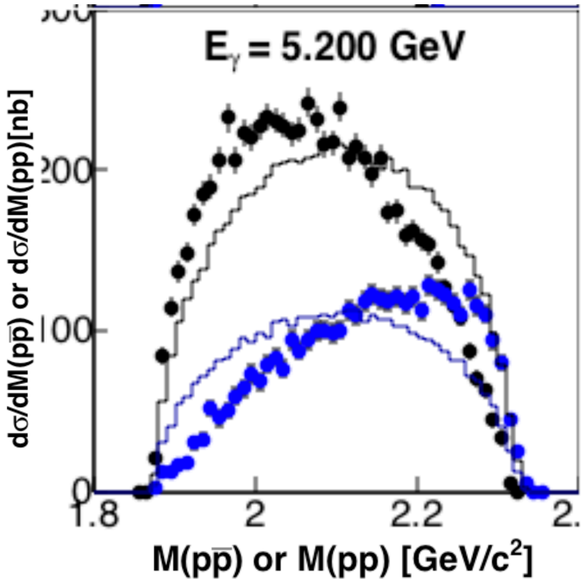
- Observed narrow resonances in $M(p\bar{p})$ system
- Limited statistics prevented firm conclusions on underlying production mechanism
- Recent high statistics photoproduction experiments have found no evidence of narrow resonances
- Narrow states remain uncorroborated by high statistic experiments

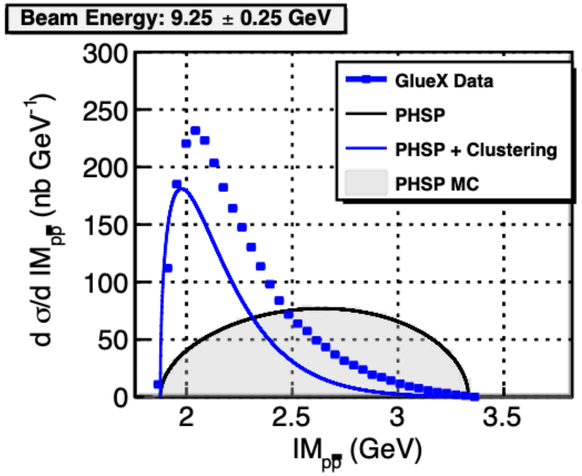


$M(p\bar{p})$ from the reaction $ep \rightarrow epp\bar{p}$



$M(p\bar{p})$ from the reaction $\pi^- p \rightarrow \pi^- pp\bar{p}$



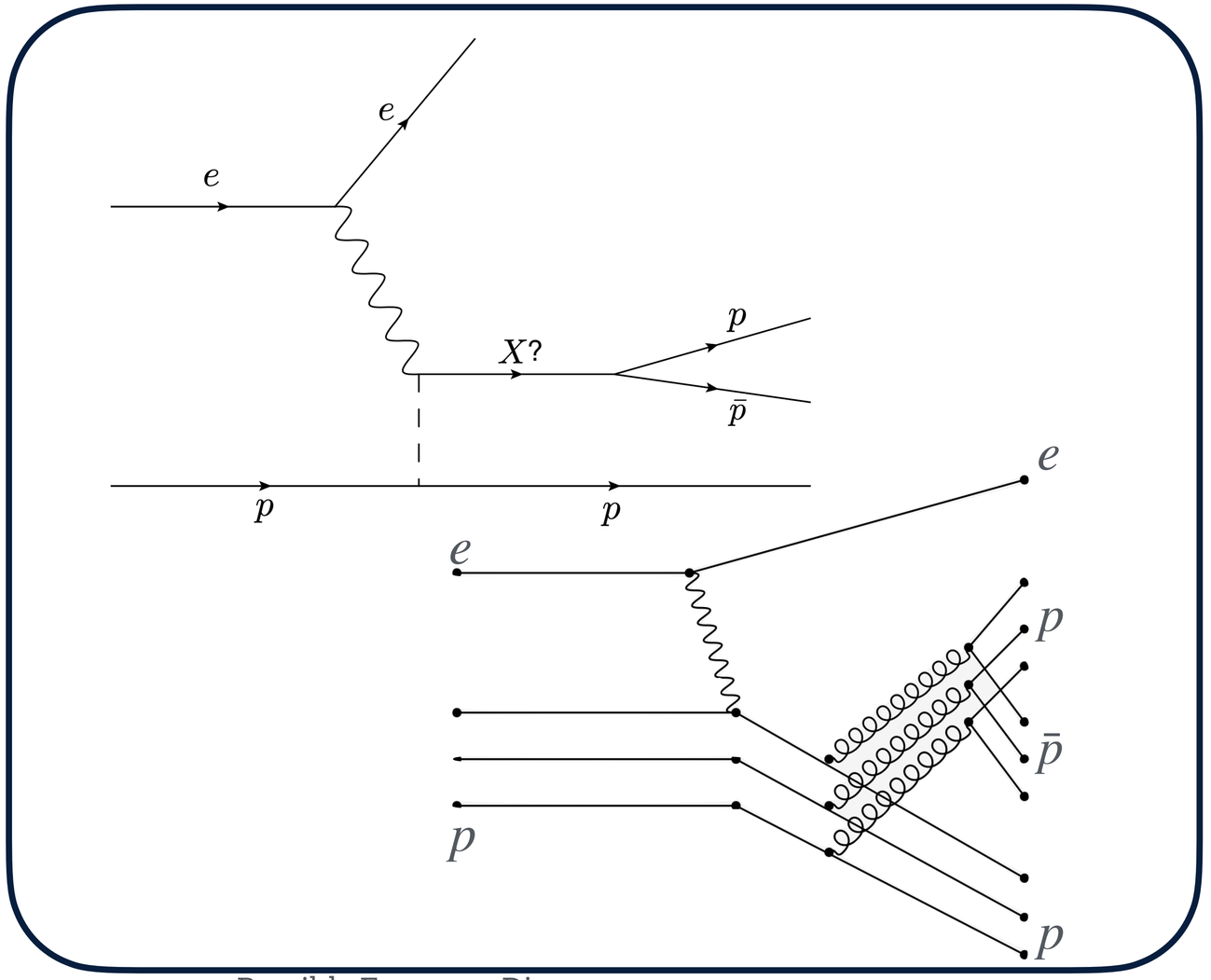


[4] J. Bodenkamp et al. "Measurement of the reaction γp →pp¯p at photon energies 4.7 ≤Eγ ≤6.6GeV".
[5] B G Gibbard et al. "Cross sections and possible resonances in pp-bar electroproduction".
[6] P. Benkheiri et al. "Evidence for two narrow p¯p resonances at 2020 MeV and 2200 MeV".
[7] Phelps, Will. "Antibaryon Photoproduction Using CLAS at Jefferson Lab." Florida International University, 2017.
[8] Li, Hao. "Baryon–Antibaryon Photoproduction Off the Proton." Carnegie Mellon University, 2023.

Reaction and Data

A quick recap

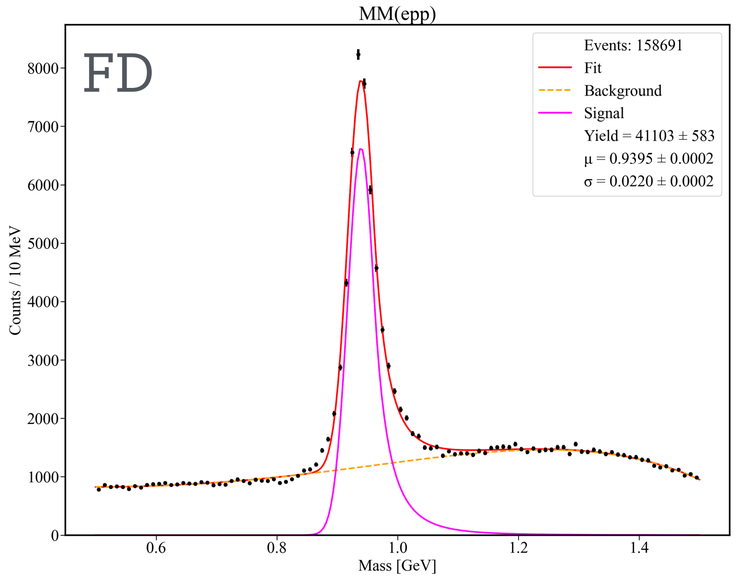
- Looking into the reaction
  - $ep \rightarrow epp\bar{p}$
  - $10.2GeV$ Electron beam
  - Electron beam incident on LH_2
- Requiring a recoil electron in either
  - $\theta_{e'} \in [2.5°, 5°]$
  - $\theta_{e'} \in [5°, 35°]$

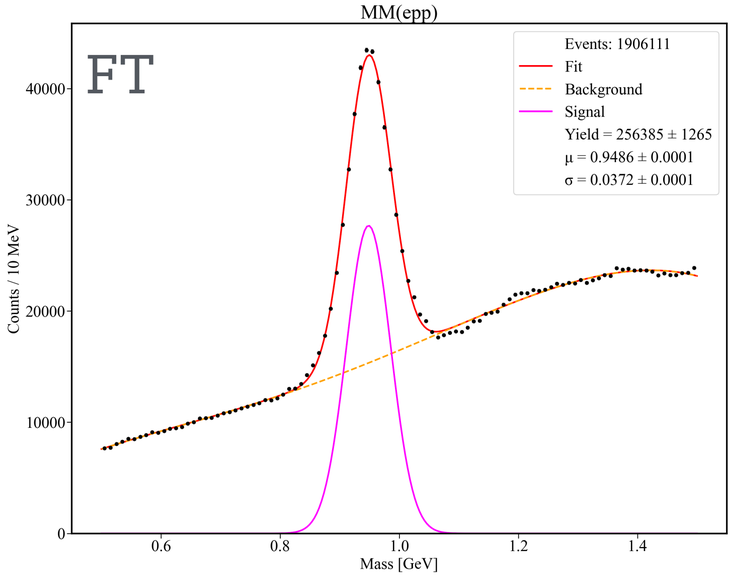


Possible Feynman Diagrams

Available Statistics

- $\bar{p}$ reconstructed through missing mass technique
  - 1 Electron and 2 protons required
- Determine total statistics post selection criteria
  - Crystal ball + 4th order polynomial fit
- 4th order polynomial not physically motivated
- Background not fully understood
  - Non $pp\bar{p}$ background
  - Combinatorial background in the $p\bar{p}$ system



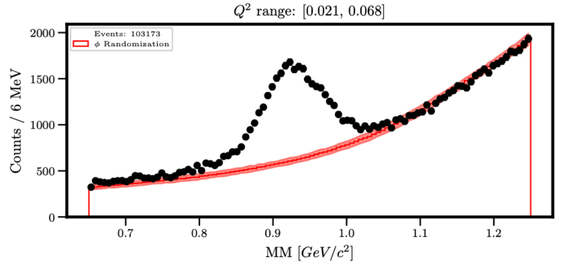


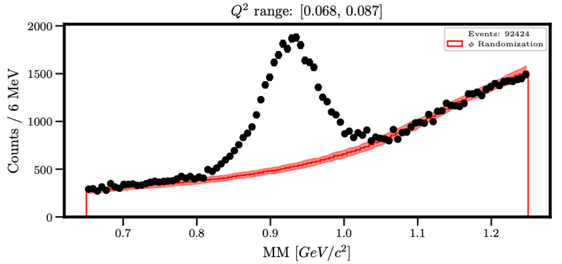
Non $pp\bar{p}$ Background

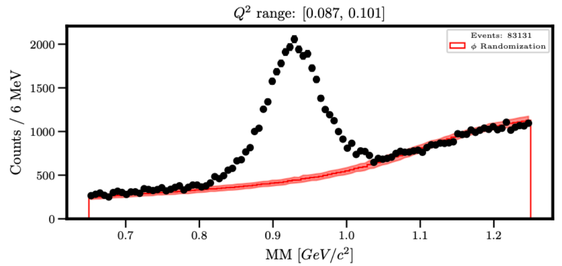
- Possible to determine the non $pp\bar{p}$ background in the system?
- Data driven technique to estimate background
  - ϕ Randomization: break correlation in final state by randomly rotating the final state protons
- Multi step process
  - Average over many exclusion ranges
- How about other distributions of the $p\bar{p}$ system?
  - Combinatorial Background

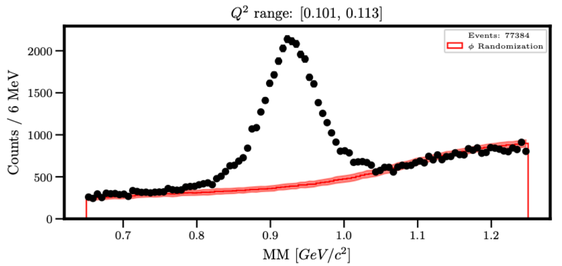
Non $pp\bar{p}$ Background

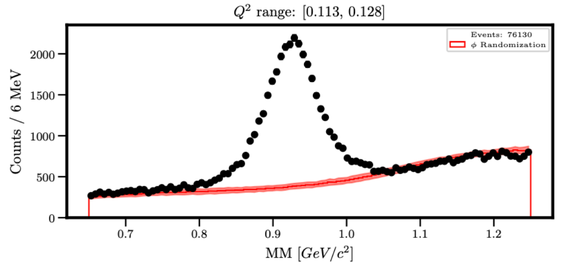
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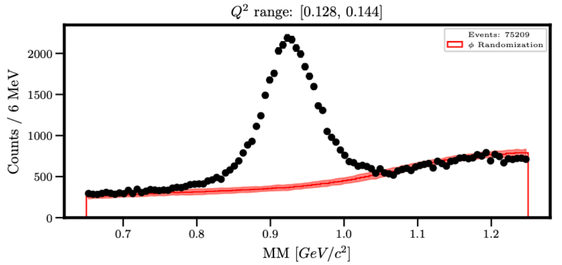






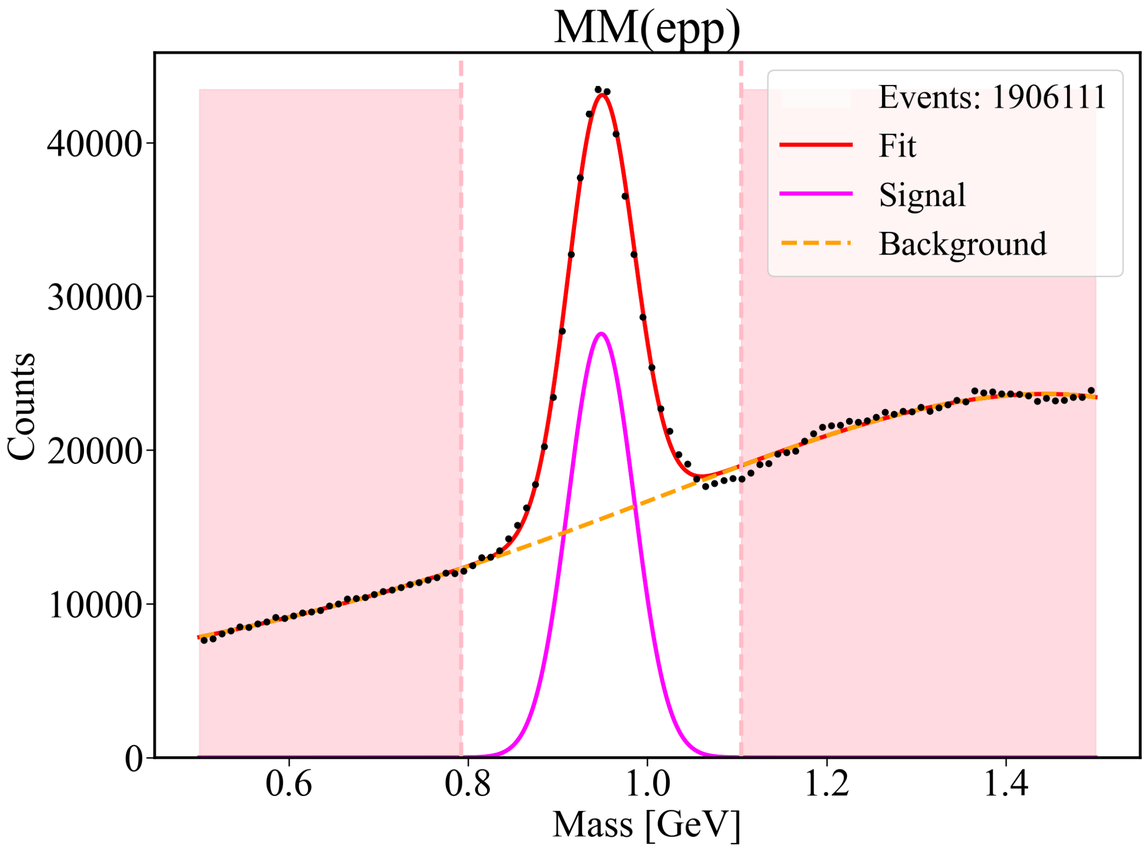






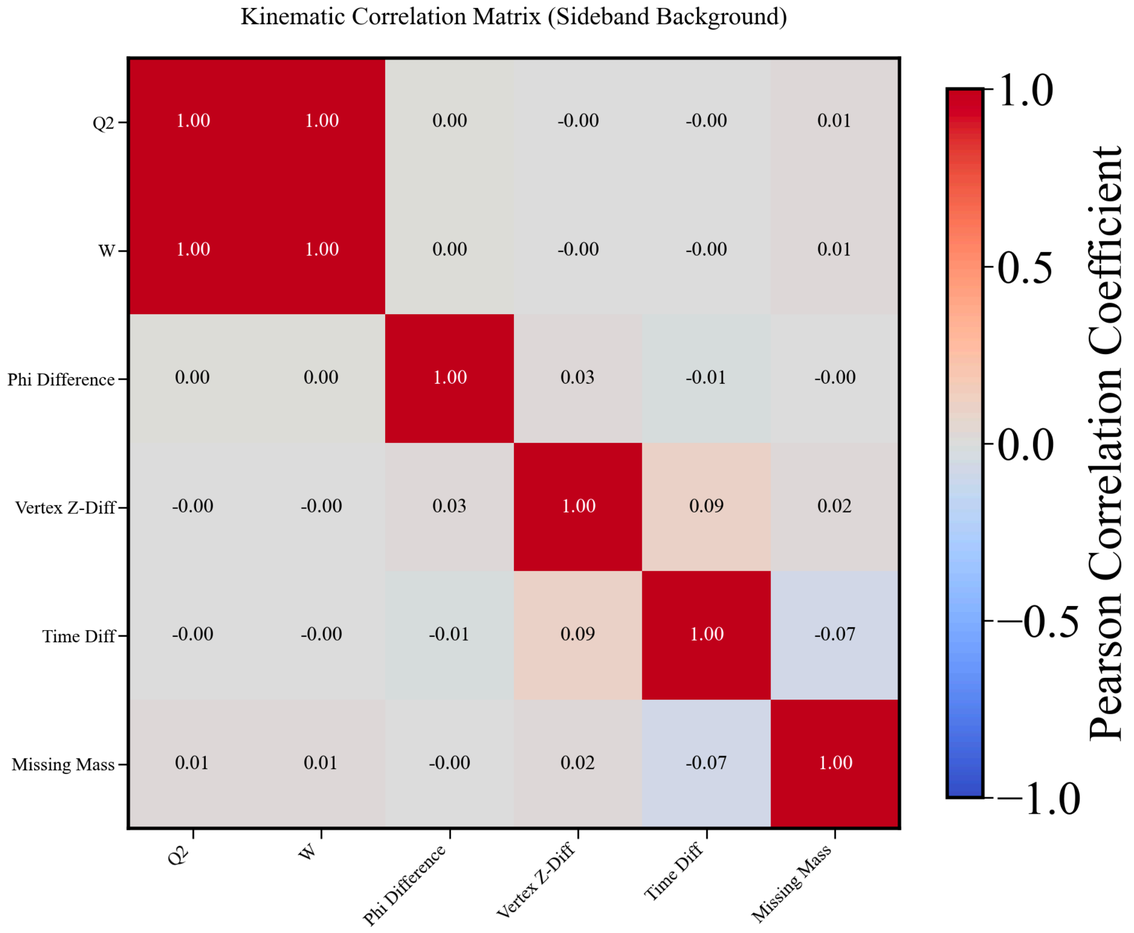
Extracting Signal of the $pp\bar{p}$ system

- Classification without Labels (CWoLa)
  - Multi-dimensional phase space using kinematic variables
  - Global kinematic variables are used to differentiate between sideband and signal region
- The model separates signal and background events through a global phase space
- A “raw” output on how signal-like a given event is —> NOT A PROBABILITY



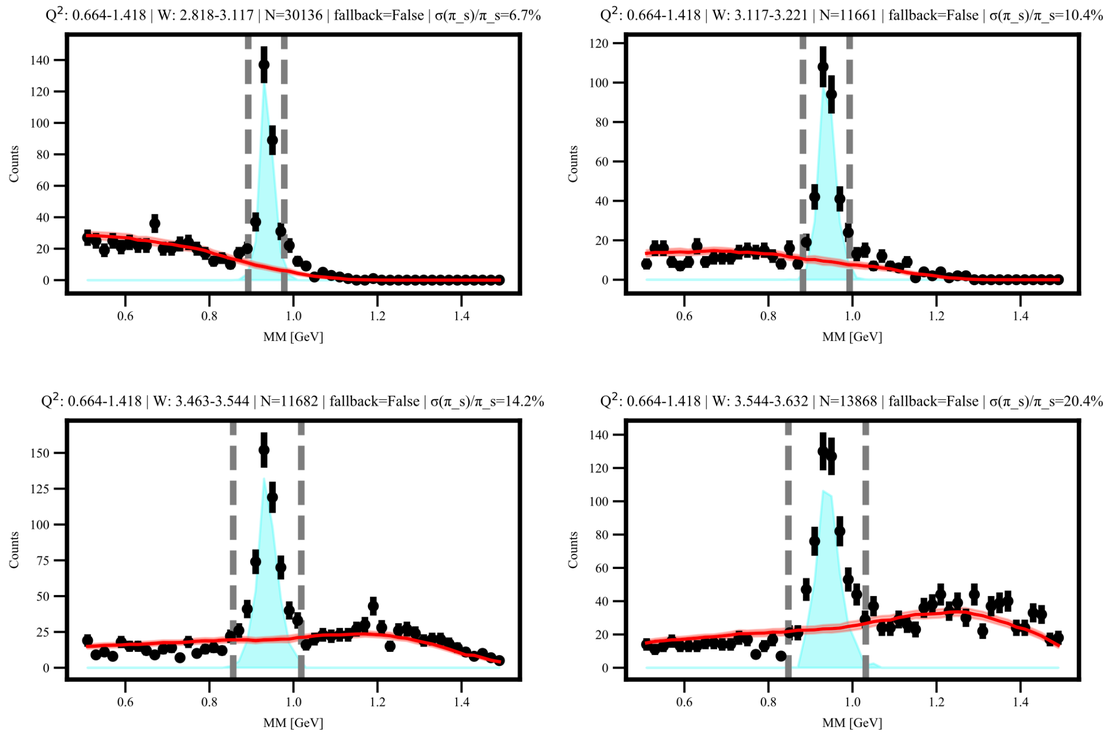
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Extracting Probabilistic Weights

- The model must be anchored to the physical yield of the signal
- Coarse kinematic bins are used to determine yields across the phase space
- The global ML score is then calibrated using “localized” phase space
- The global kinematics provide high-resolution, multi-dimensional shape of the signal
- Local kinematics enforce normalization

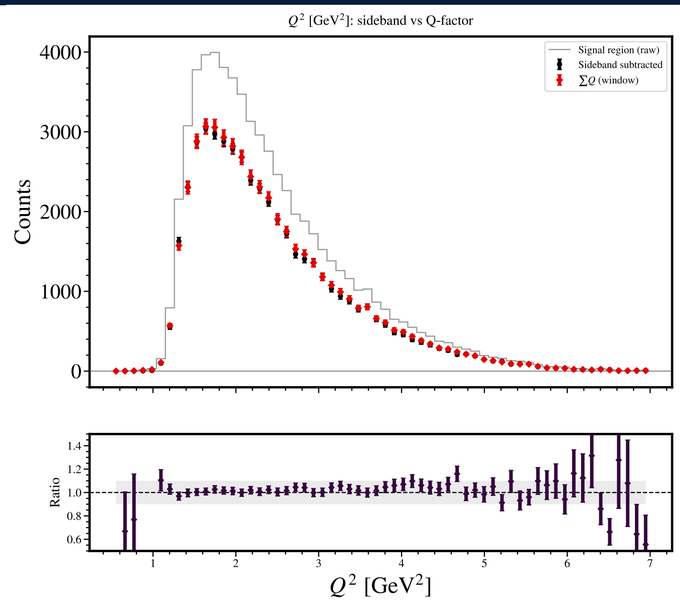


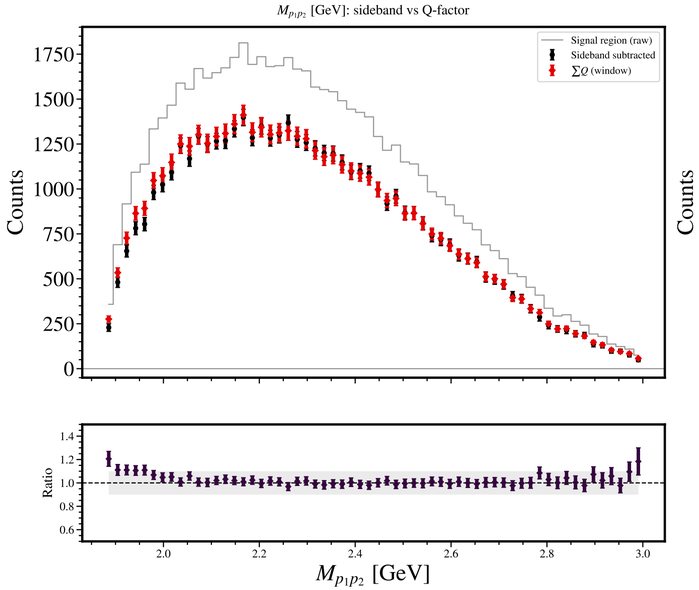
Extracting Signal

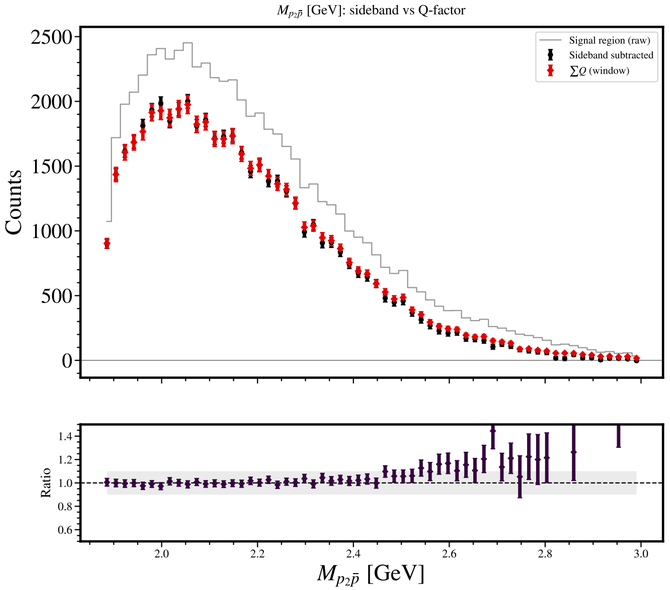
- Applying the weights to each event extracts the signal distribution
- Binned distributions and yields are extracted through

$$Y_i = \sum_i Q_i$$

- Per event signal weight, no need for distribution based subtraction
- Agrees with traditional signal extraction methods
  - Integrated and binned distributions

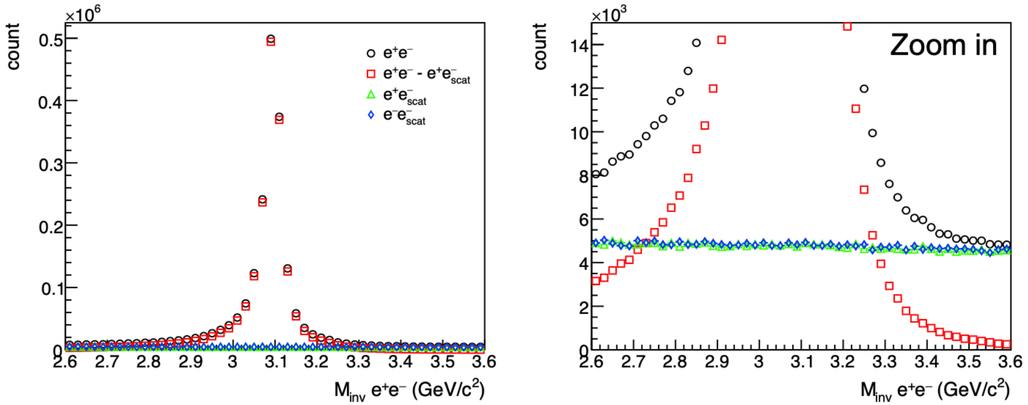




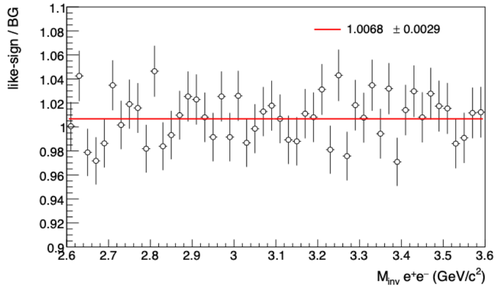


Isolating the $p\bar{p}$ System

- Impossible to determine the correct $p\bar{p}$ system on an event-by-event level
- What if there is a way to extract the system on a distribution level?
  - $J/\psi \rightarrow e^+e^-$: Like-sign subtraction uses e^+e^+ distribution to mimic background
  - $ep \rightarrow epp\bar{p}$: Use pp distributions to mimic uncorrelated background in $p\bar{p}$ distributions
  - The pp system is uncorrelated much like e^+e^+ and e^-e^-
- Can extract any relevant $p\bar{p}$ distribution



Good description of the combinatorial scattered electron background using like-sign pairs



Brookhaven National Laboratory

Cheuk-Ping Wong

Like Sign Subtraction

The recipe

1. Pooled:

   Fill both $p\bar{p}$ pairings per event into one distribution

2. Like-Sign:

   Fill the pp pair distribution separately

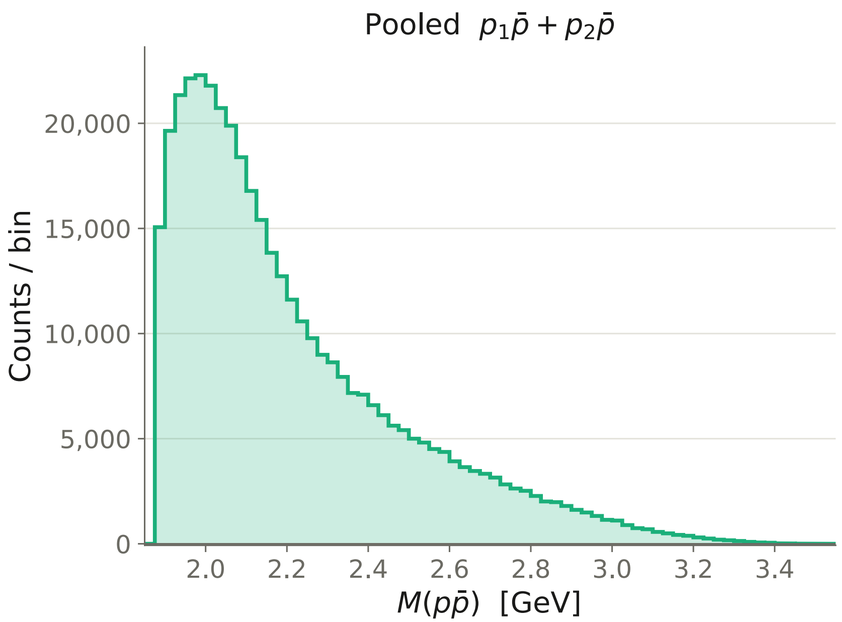
3. Subtraction

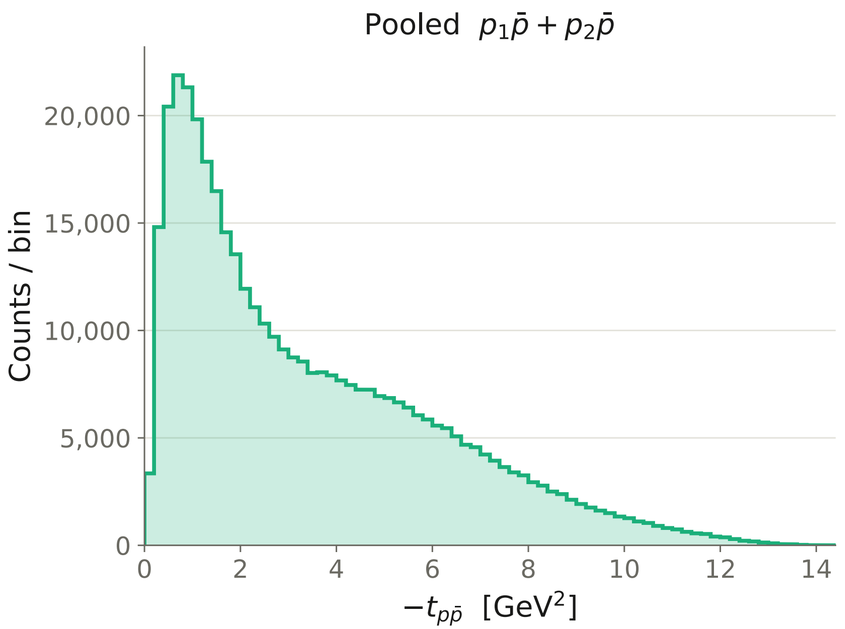
   Subtract the acceptance-corrected distributions

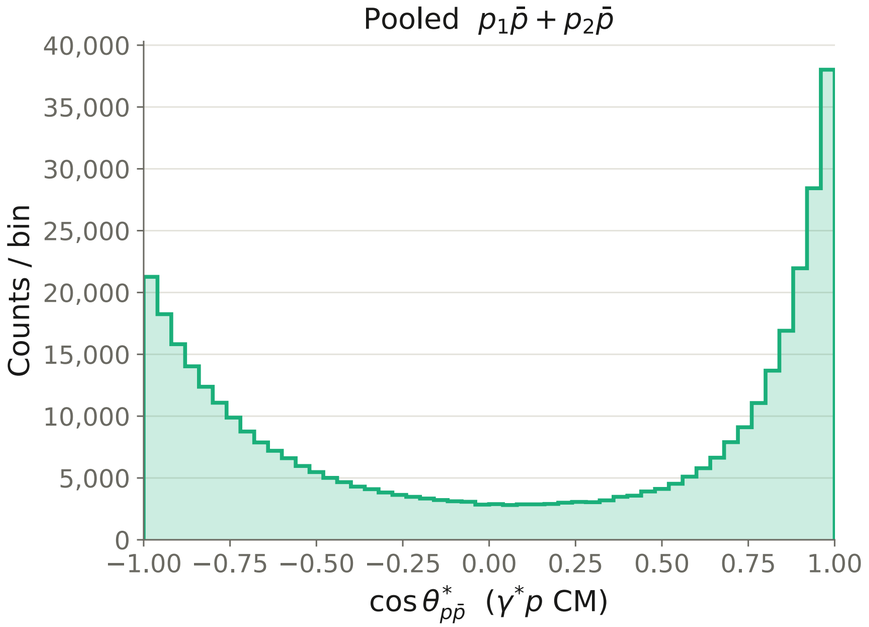
- Simple assumptions:
  - $X \to p\bar{p}$: p and $\bar{p}$ must be symmetric in X rest frame
  - Classical model: no incoherent background between the different particles

$$\frac{d\sigma_{X\to p\bar{p}}}{dx} = \frac{d\sigma_{p\bar{p}}}{dx} - \kappa\frac{d\sigma_{pp}}{dx}$$

Proof of Concept: Toy MC



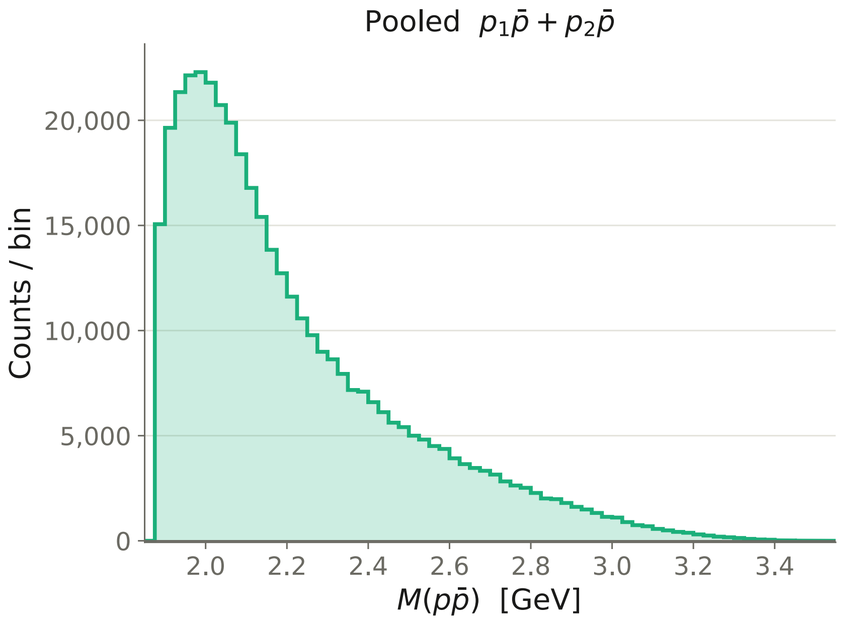


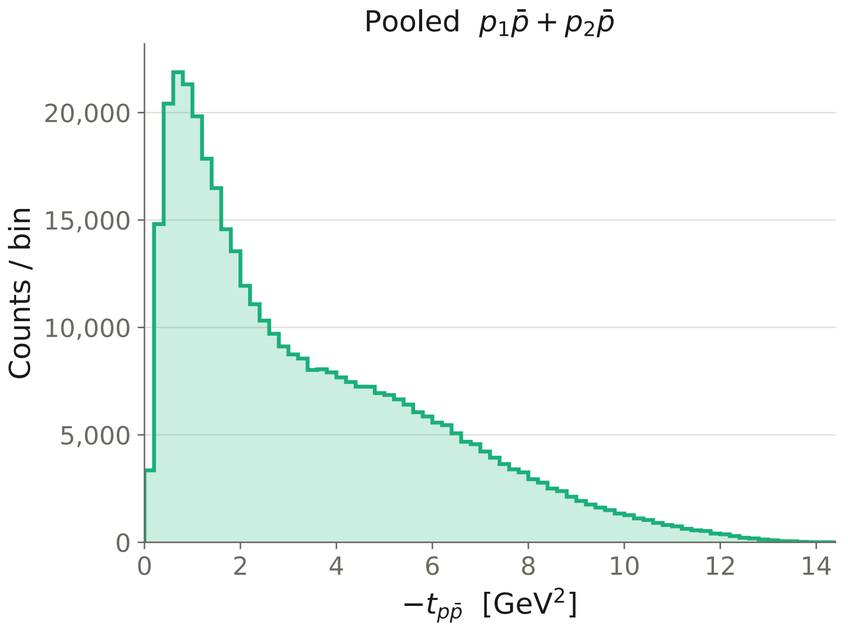


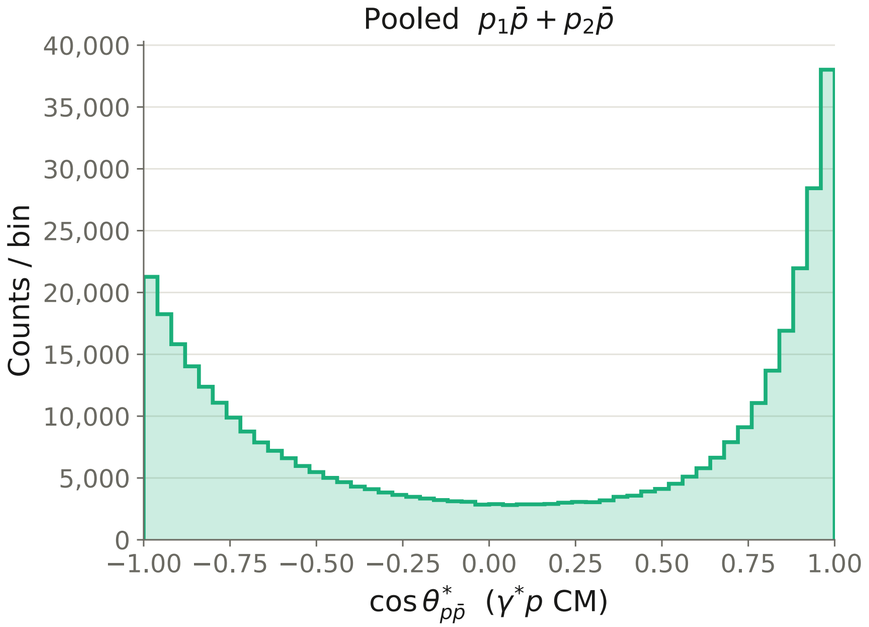
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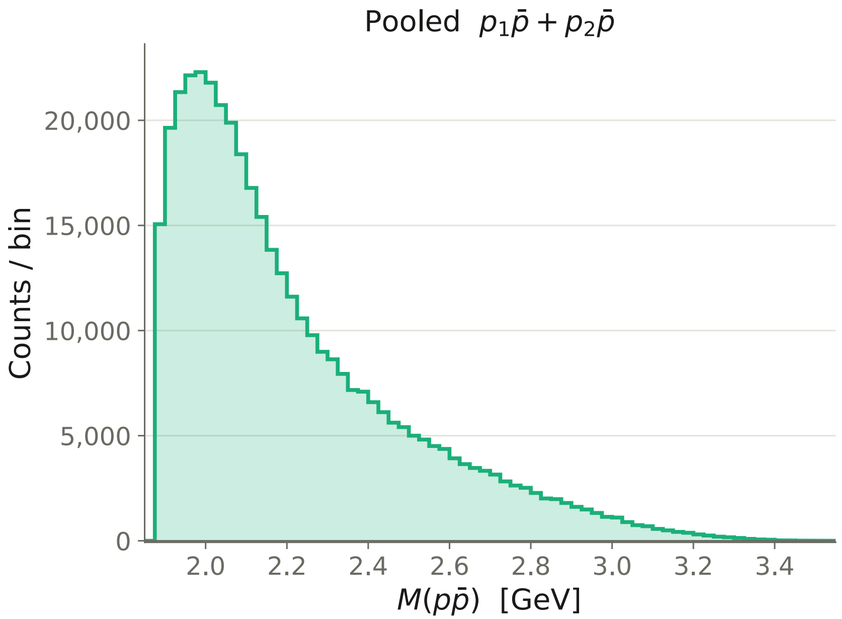


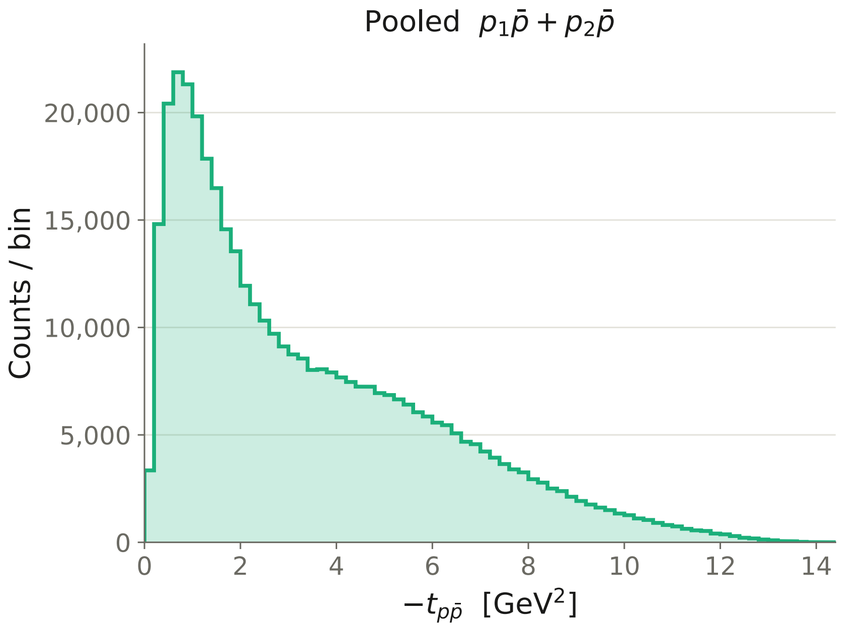


2. Like-Sign:

Fill the pp pair distribution separately

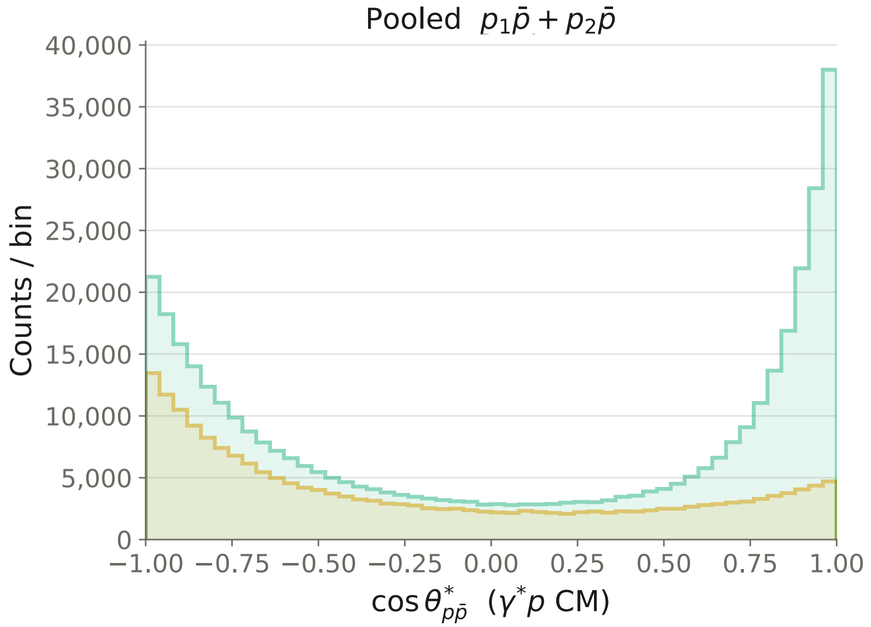
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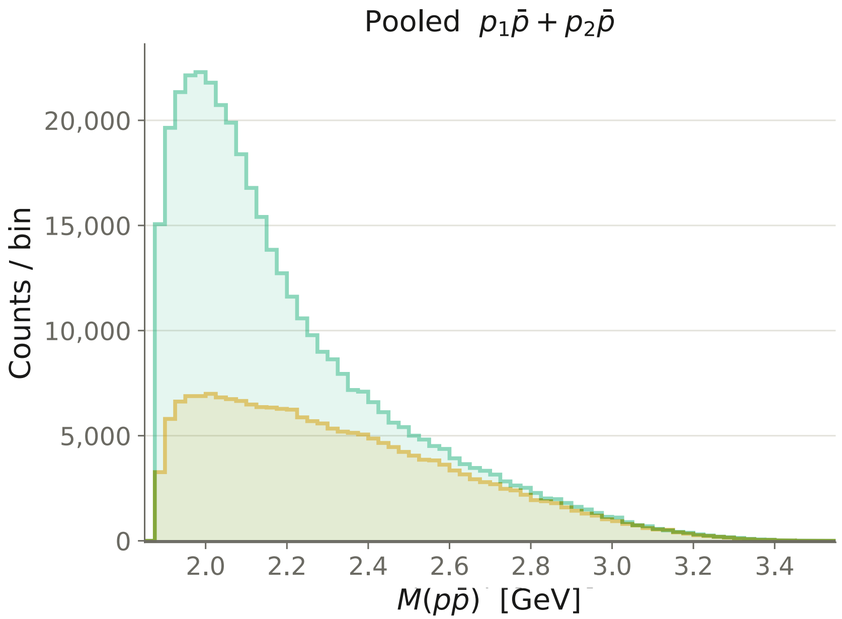


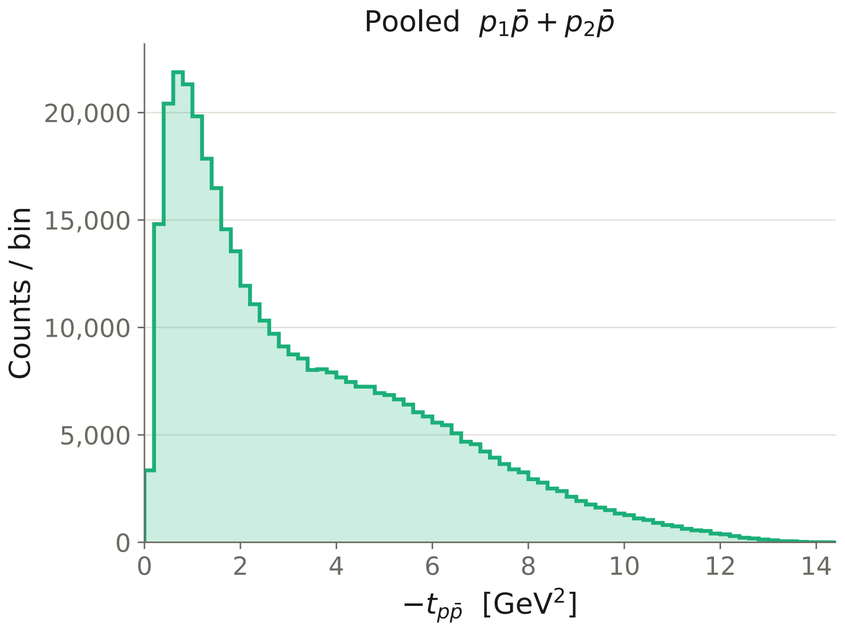
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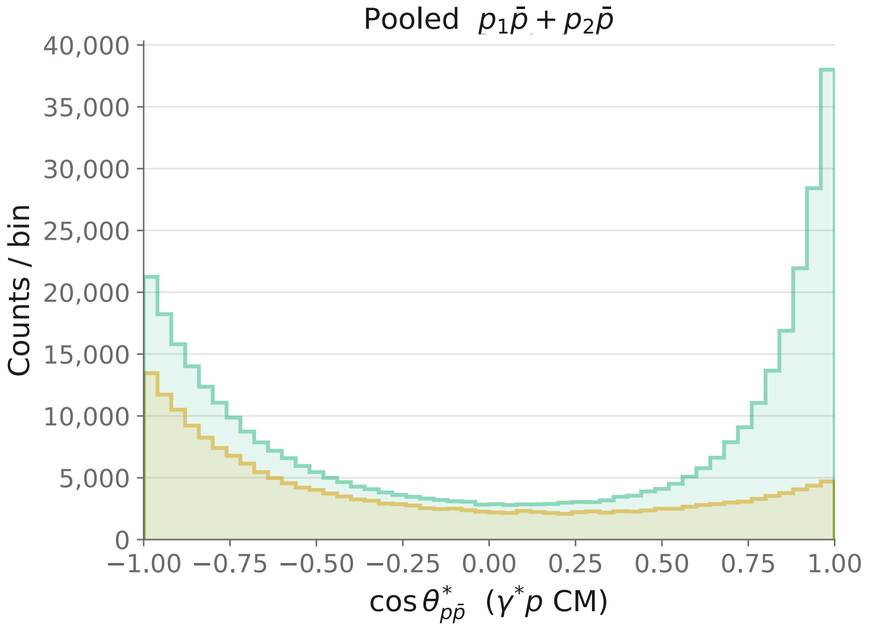
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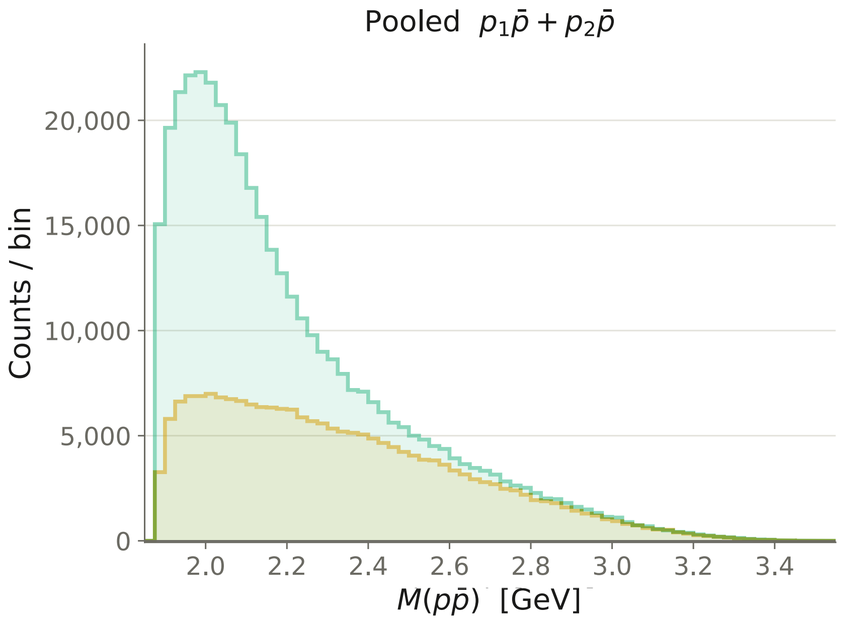


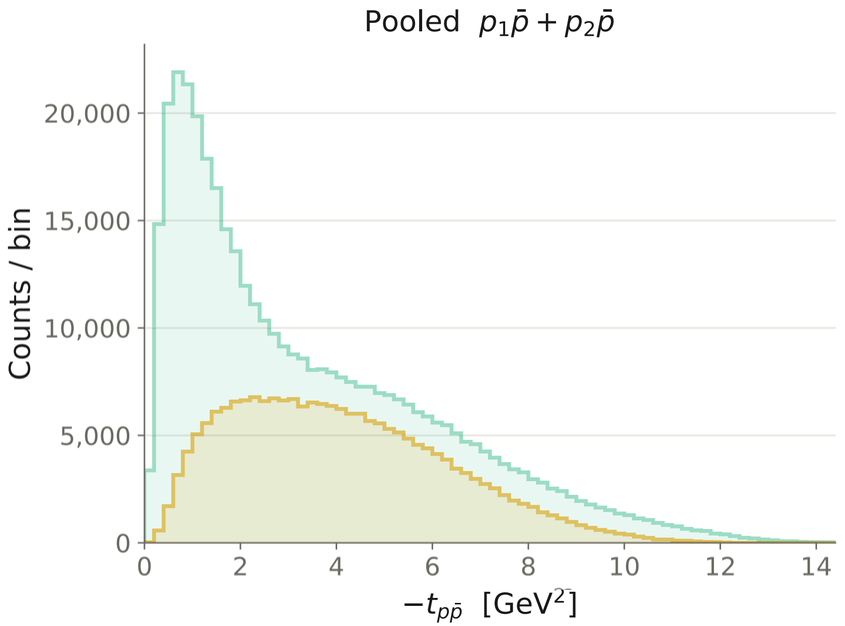


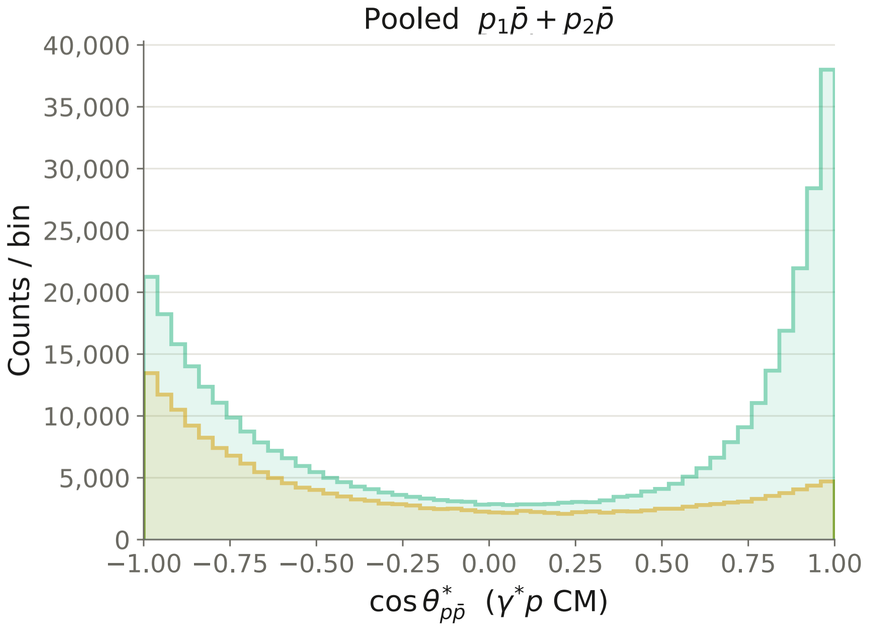
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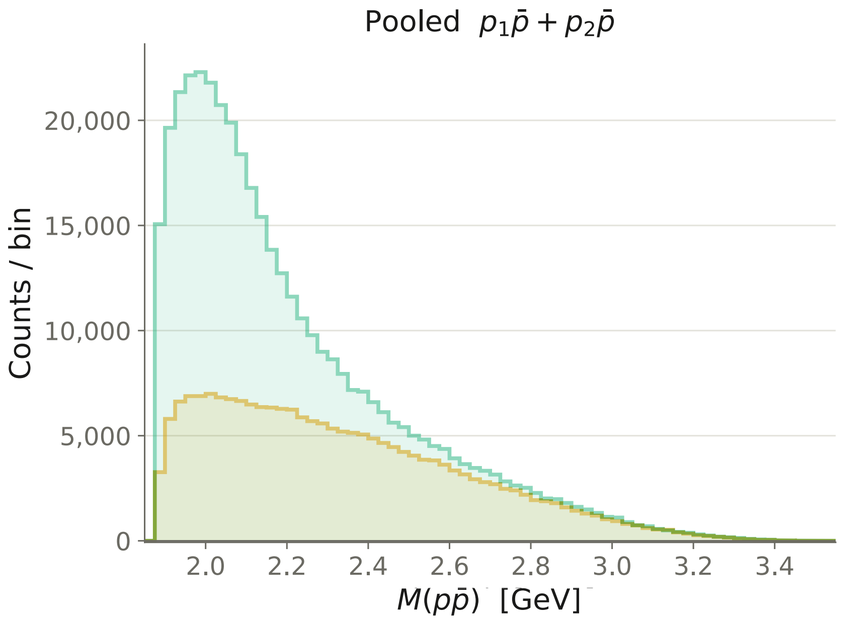


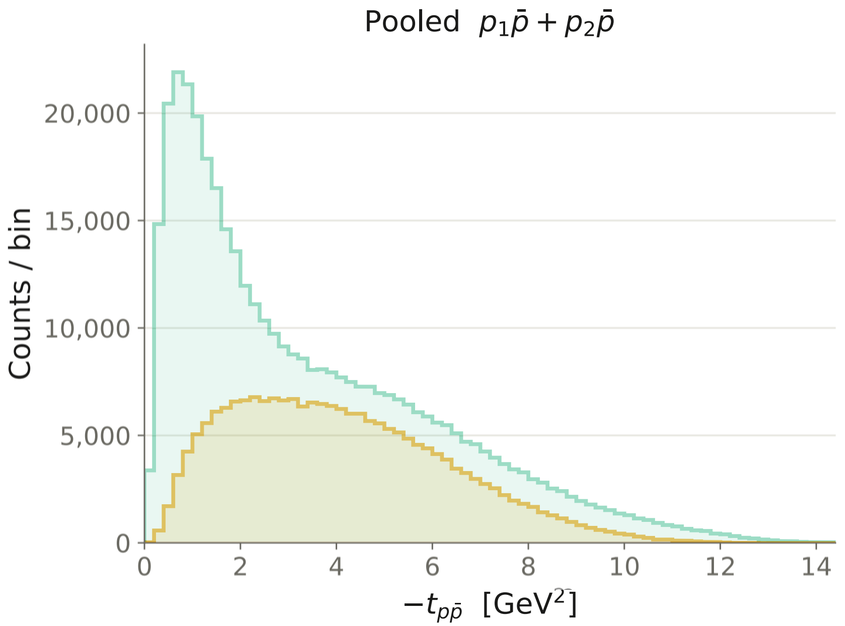


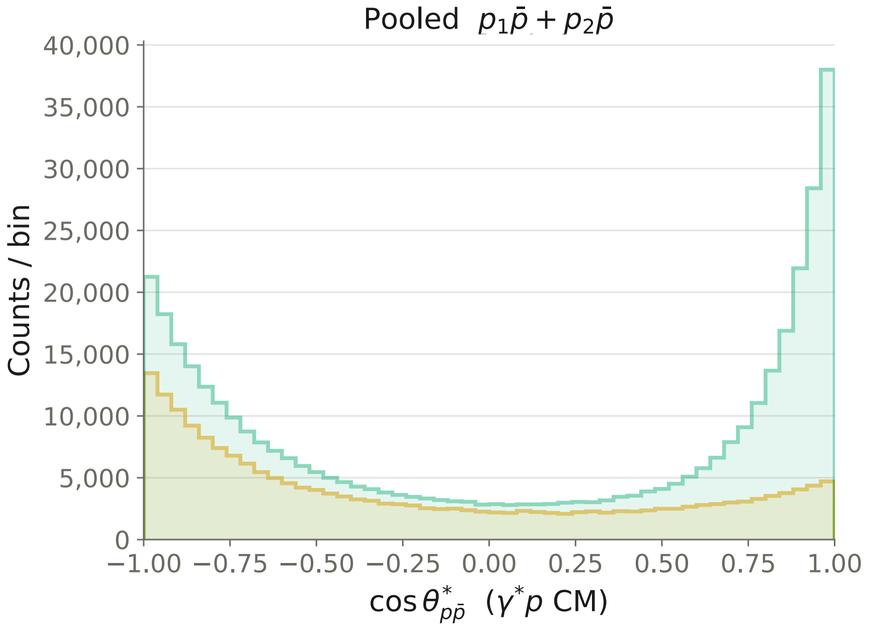
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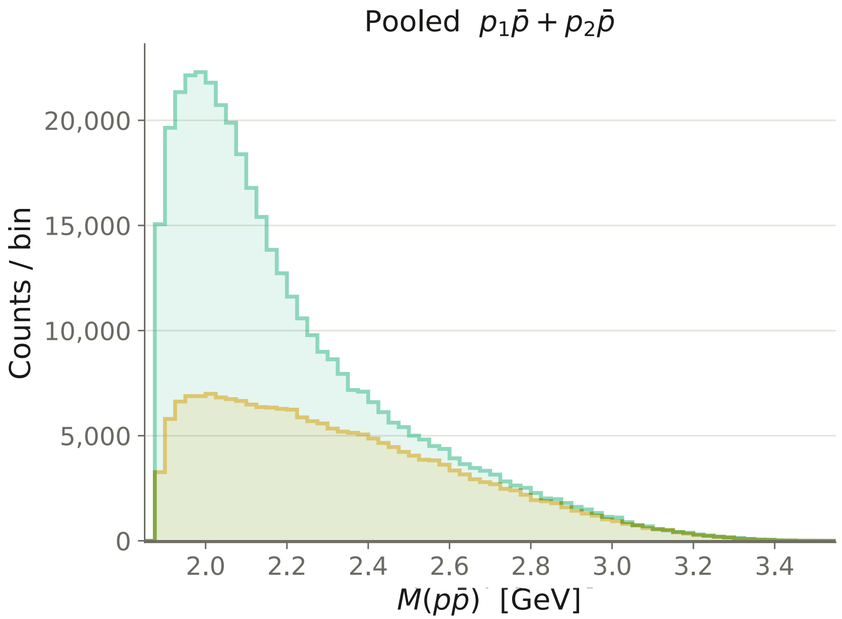


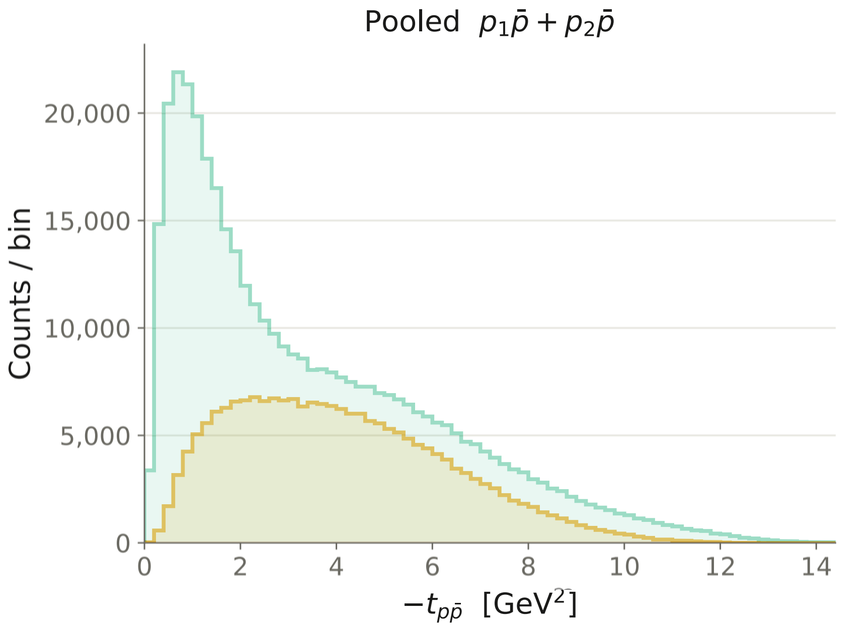


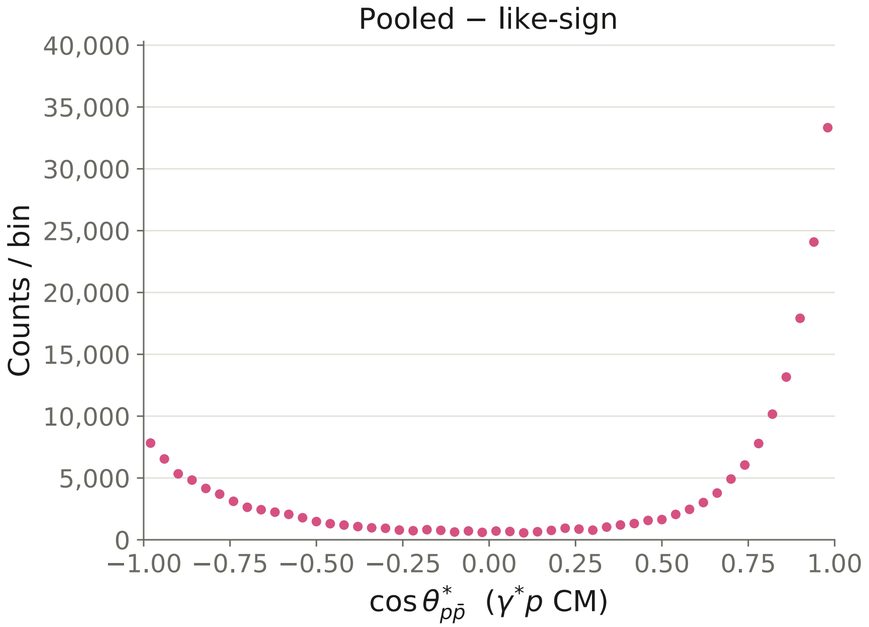
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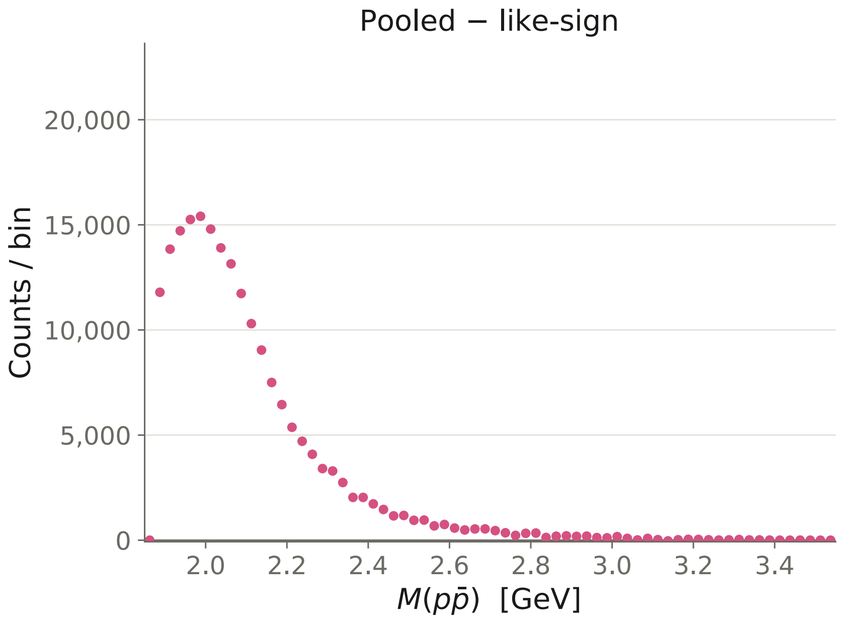


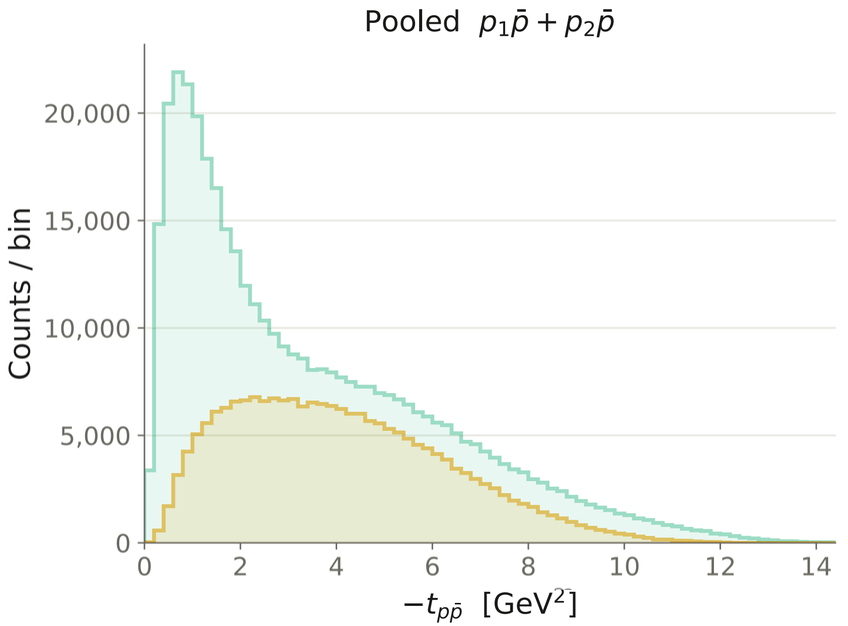


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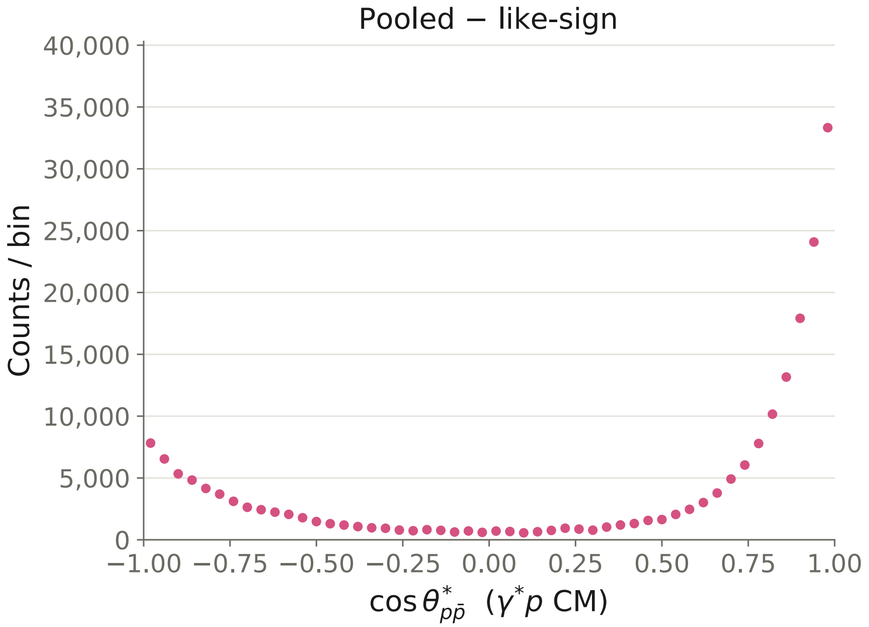
Proof of Concept: Toy MC



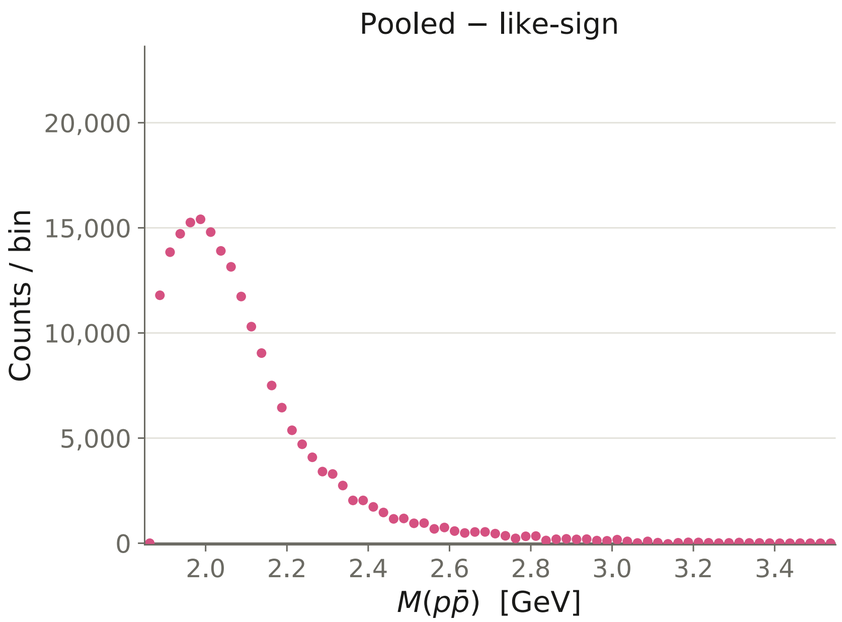


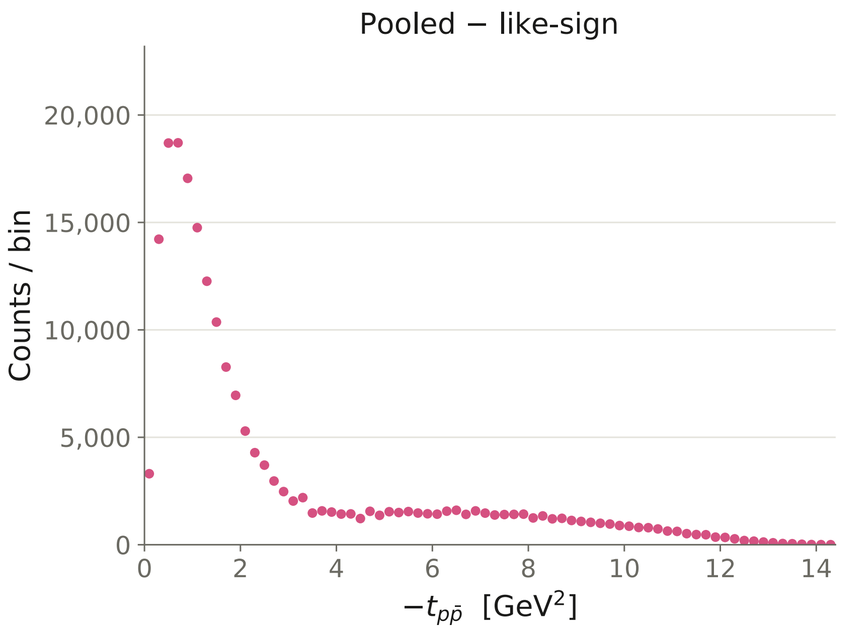
3. Subtraction

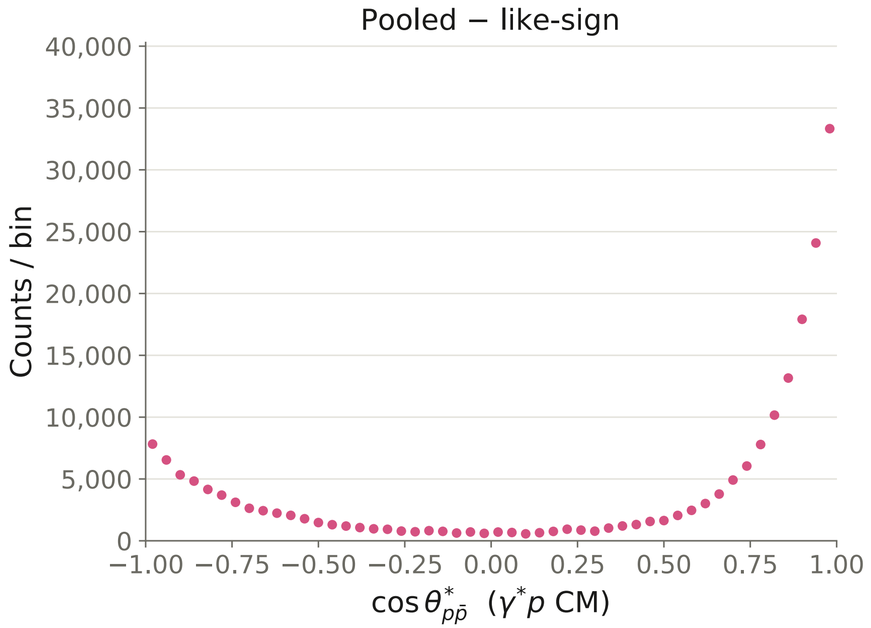
Subtract the acceptance-corrected distributions



Proof of Concept: Toy MC



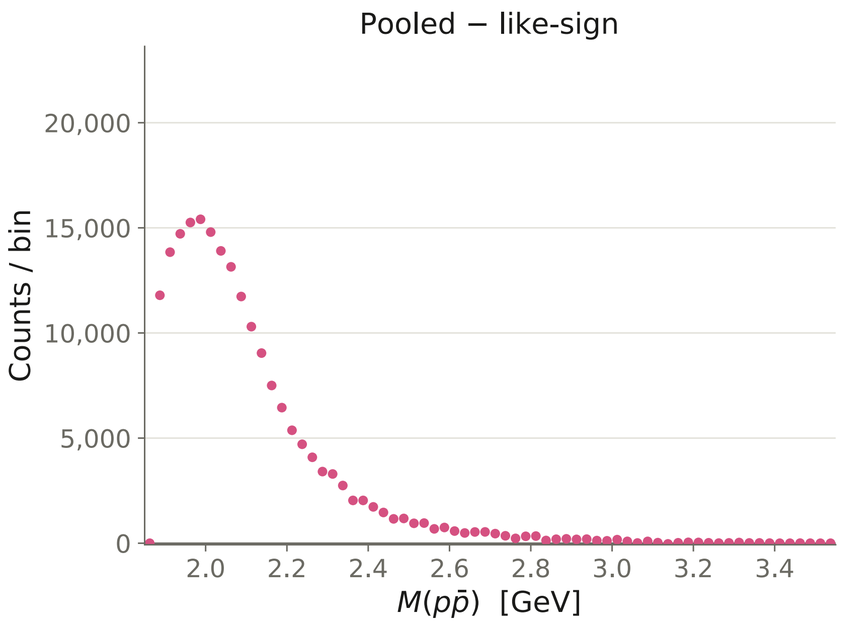


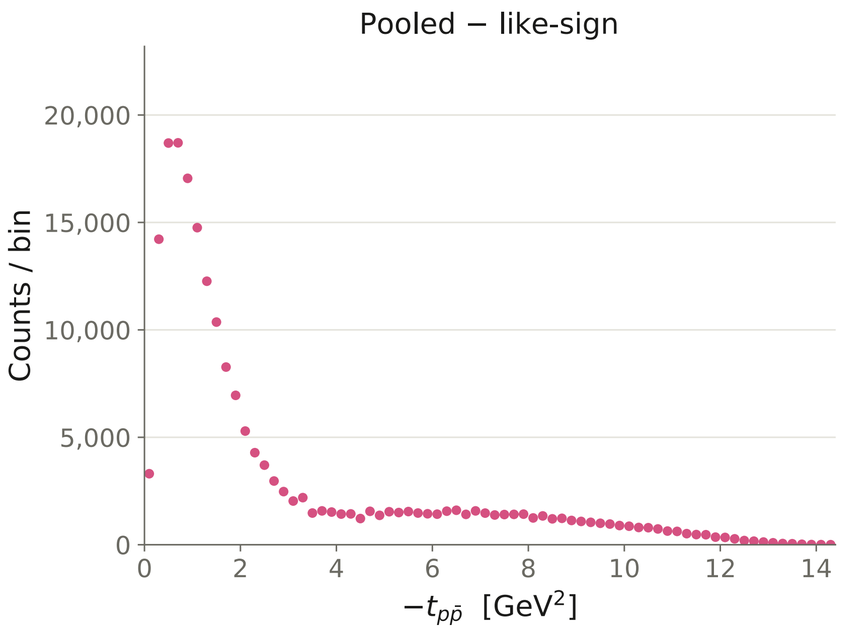


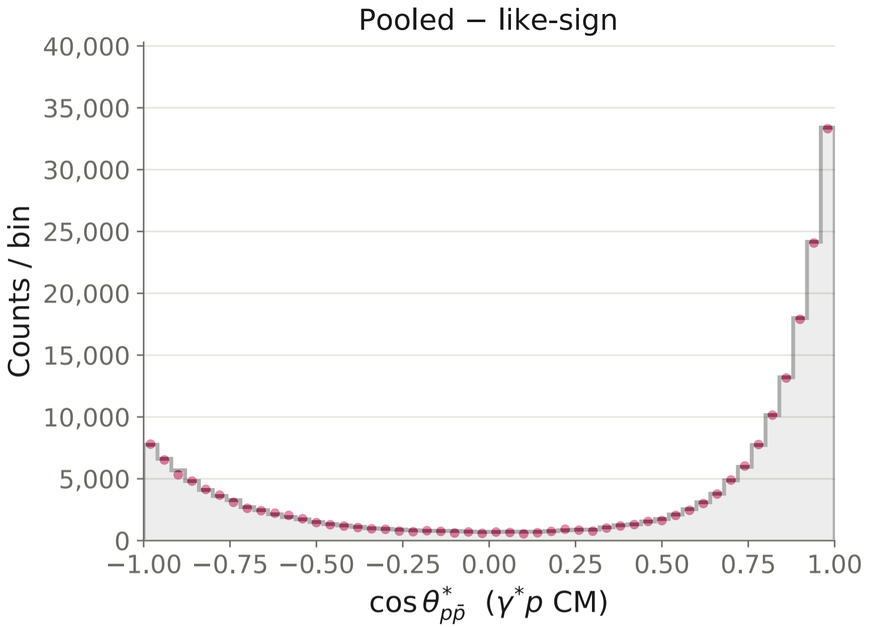
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Proof of Concept: Toy MC



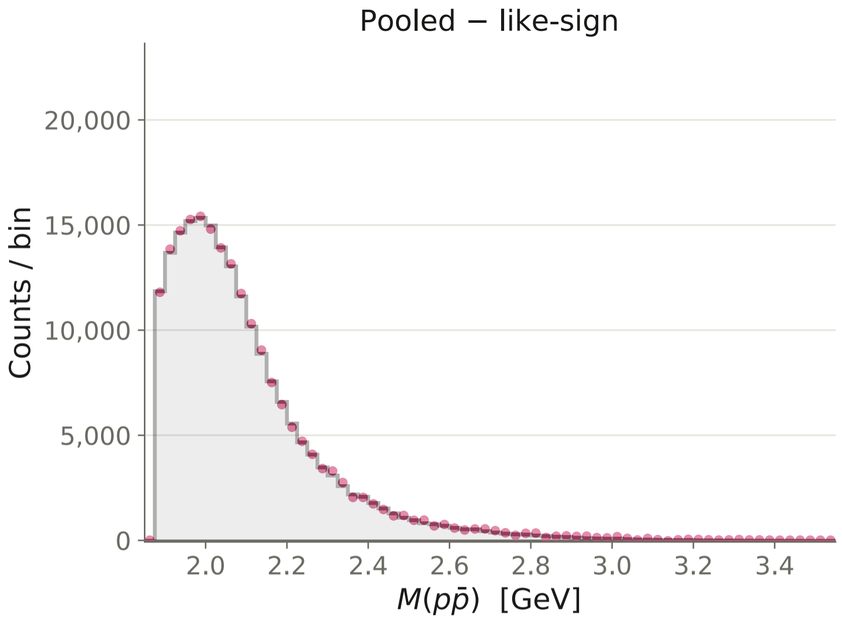


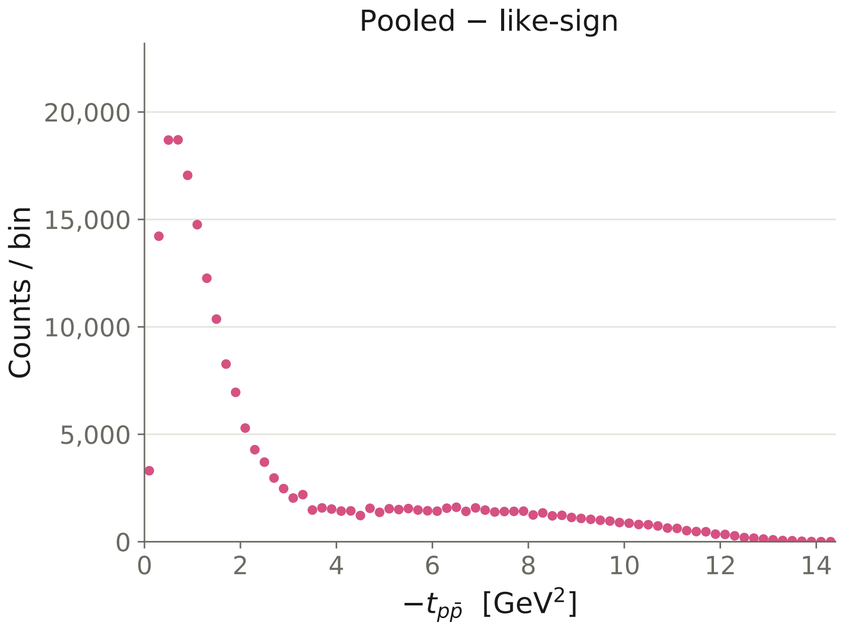


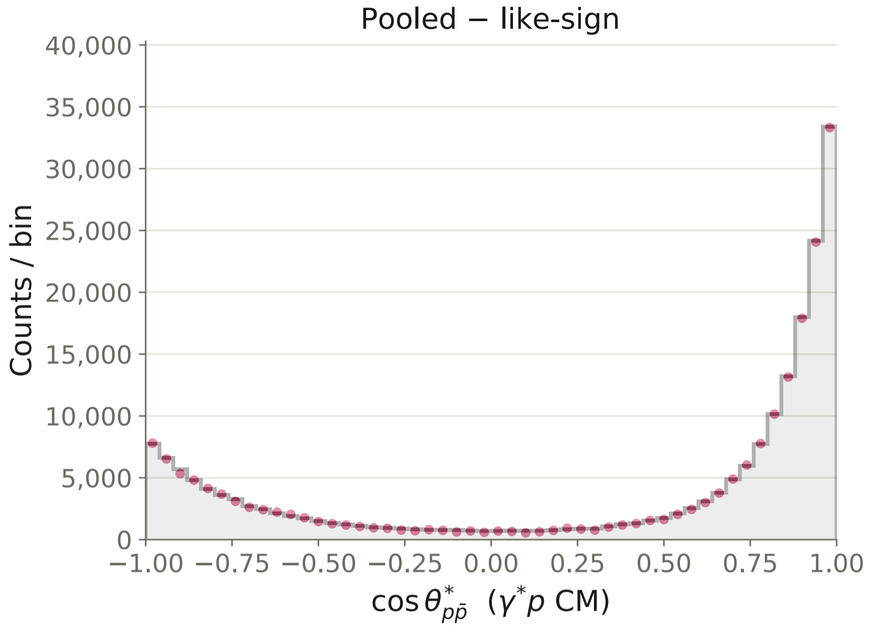
3. Subtraction

Subtract the acceptance-corrected distributions

Proof of Concept: Toy MC



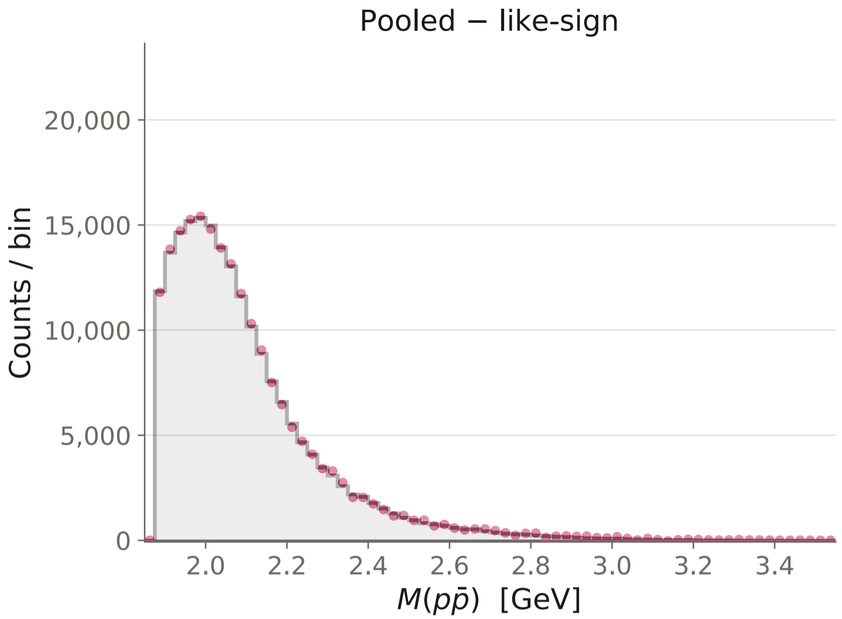


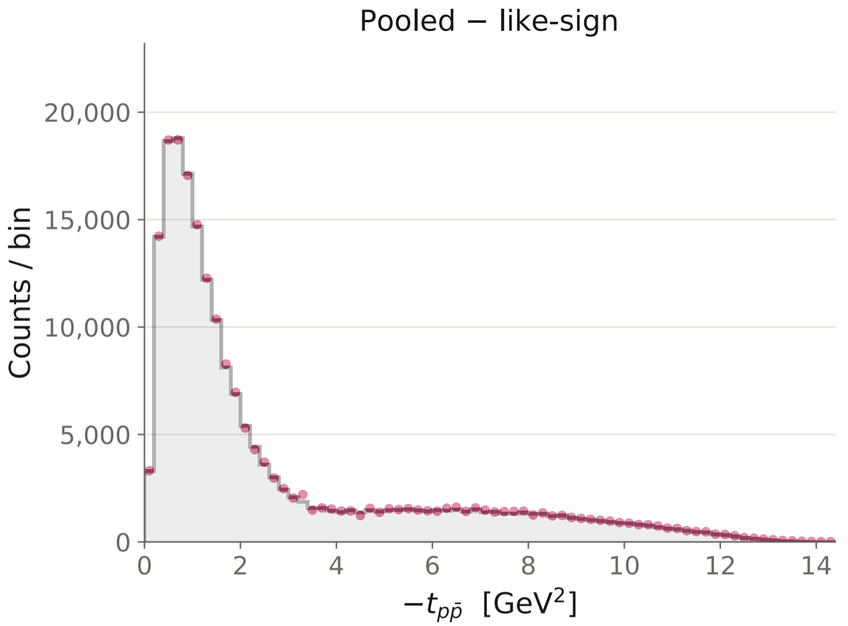


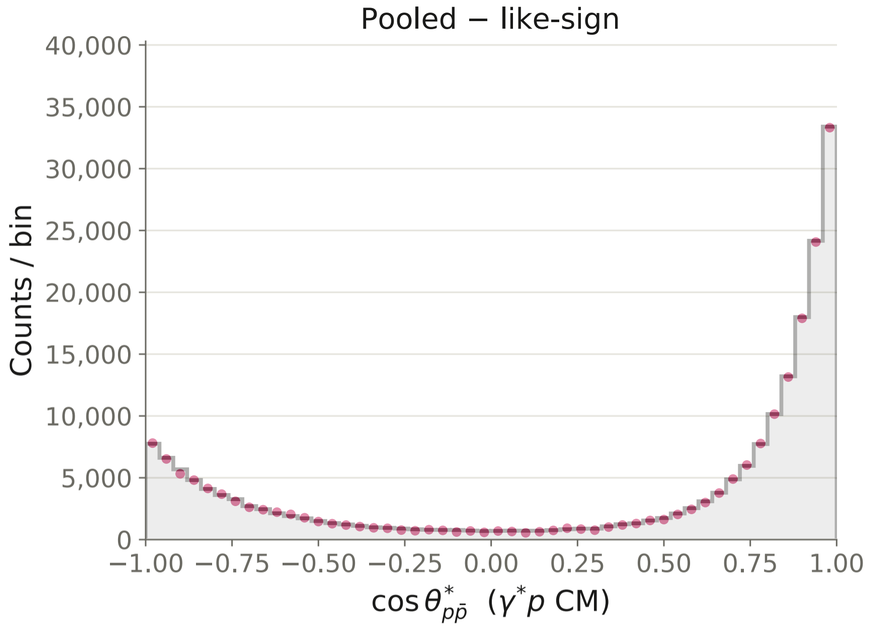
3. Subtraction

Subtract the acceptance-corrected distributions

Proof of Concept: Toy MC







3. Subtraction

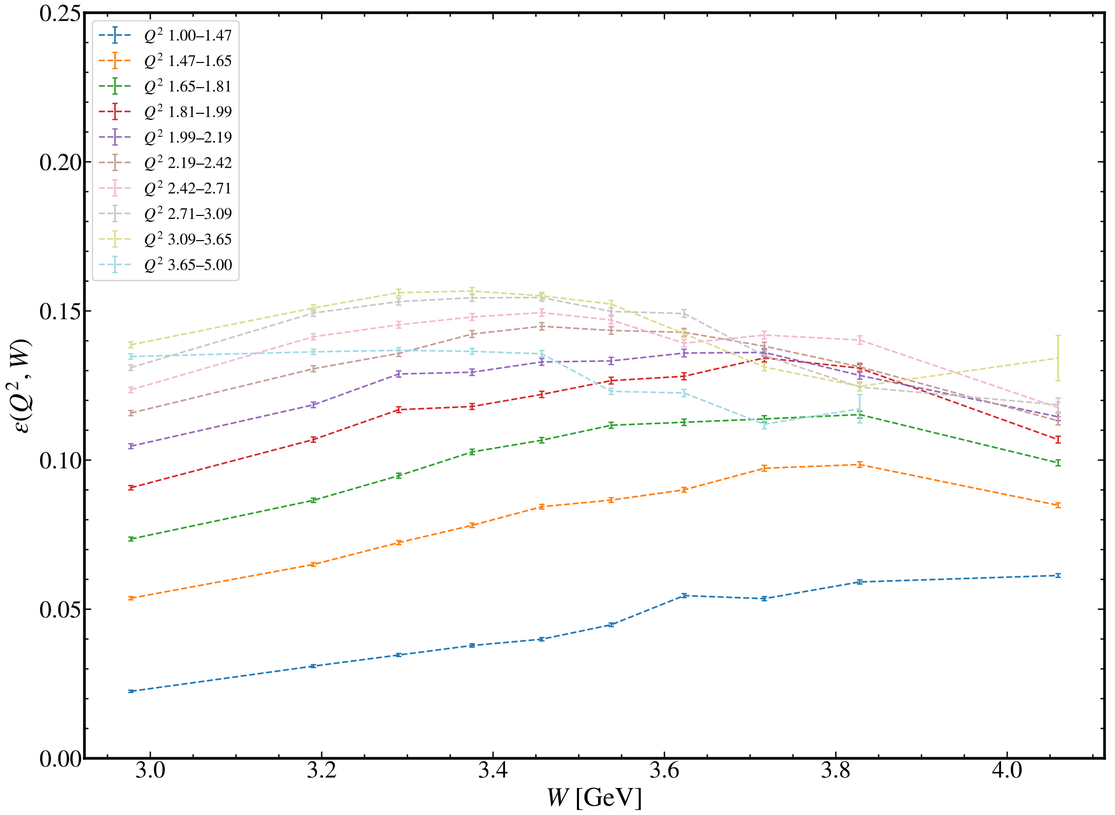
Subtract the acceptance-corrected distributions

Acceptance $\varepsilon(Q^2,\ W)$

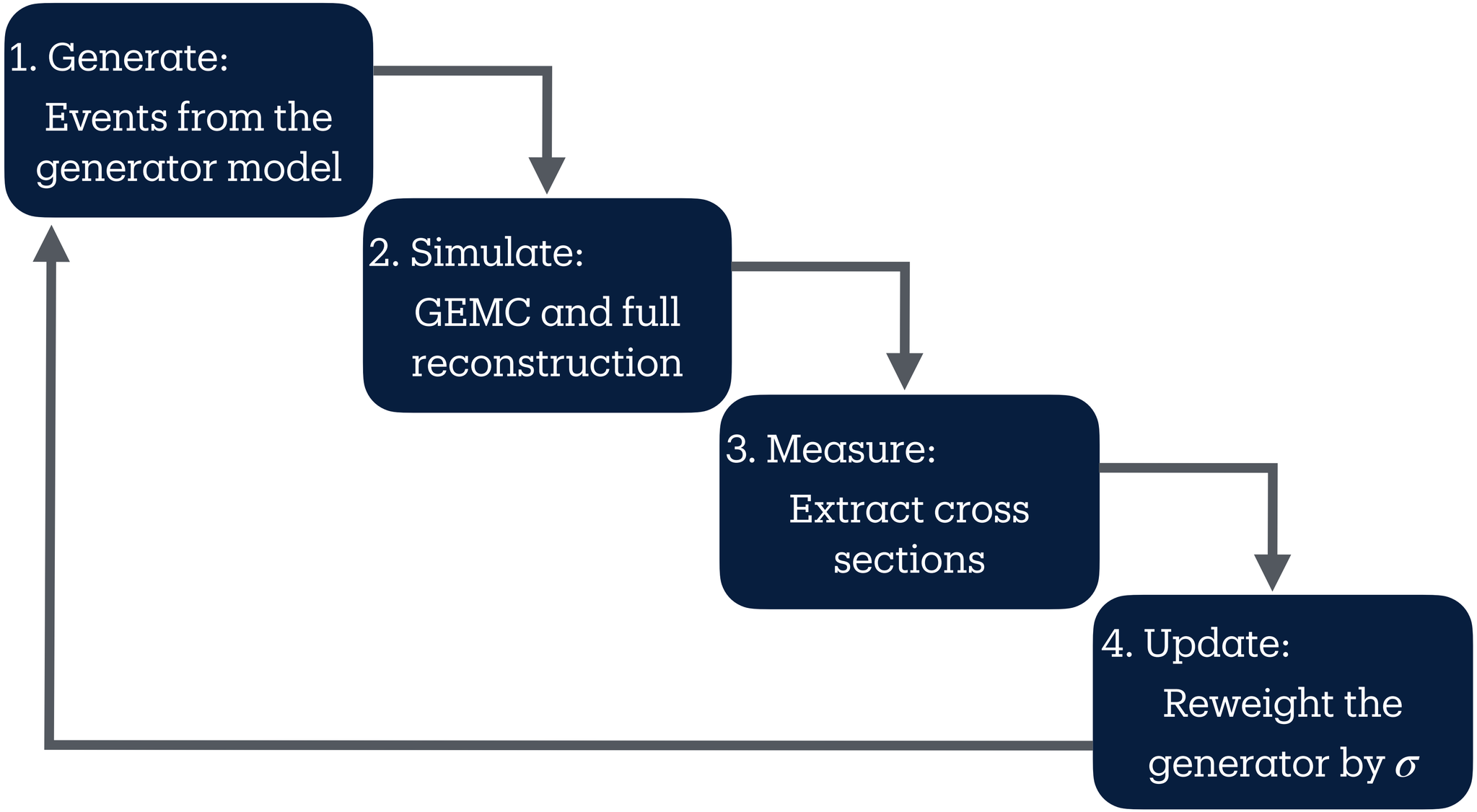
- Extracted in Q^2 and W bins
- Yield extracted using ratio:

$$\varepsilon(Q^2,\ W) = \frac{Y_R}{Y_G}$$

- Acceptance determined on a bin-by-bin basis for Q^2 and W
- 10 $Q^2 \times 10$ W bins
  - $Q^2 \in [1,5]\ GeV^2$
  - $W \in [3m_p, 4.5]$
- 10 Million Generated Events

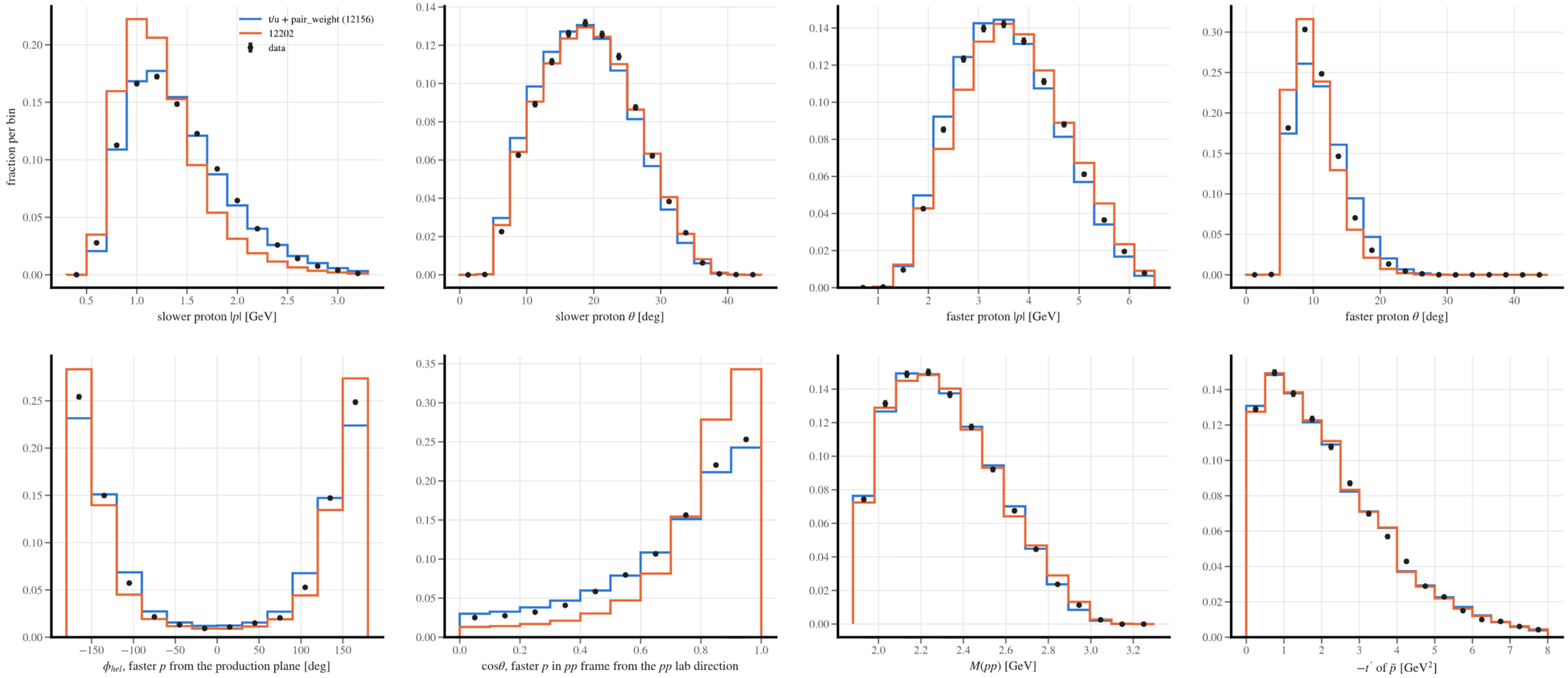


Iterative MC Weighting

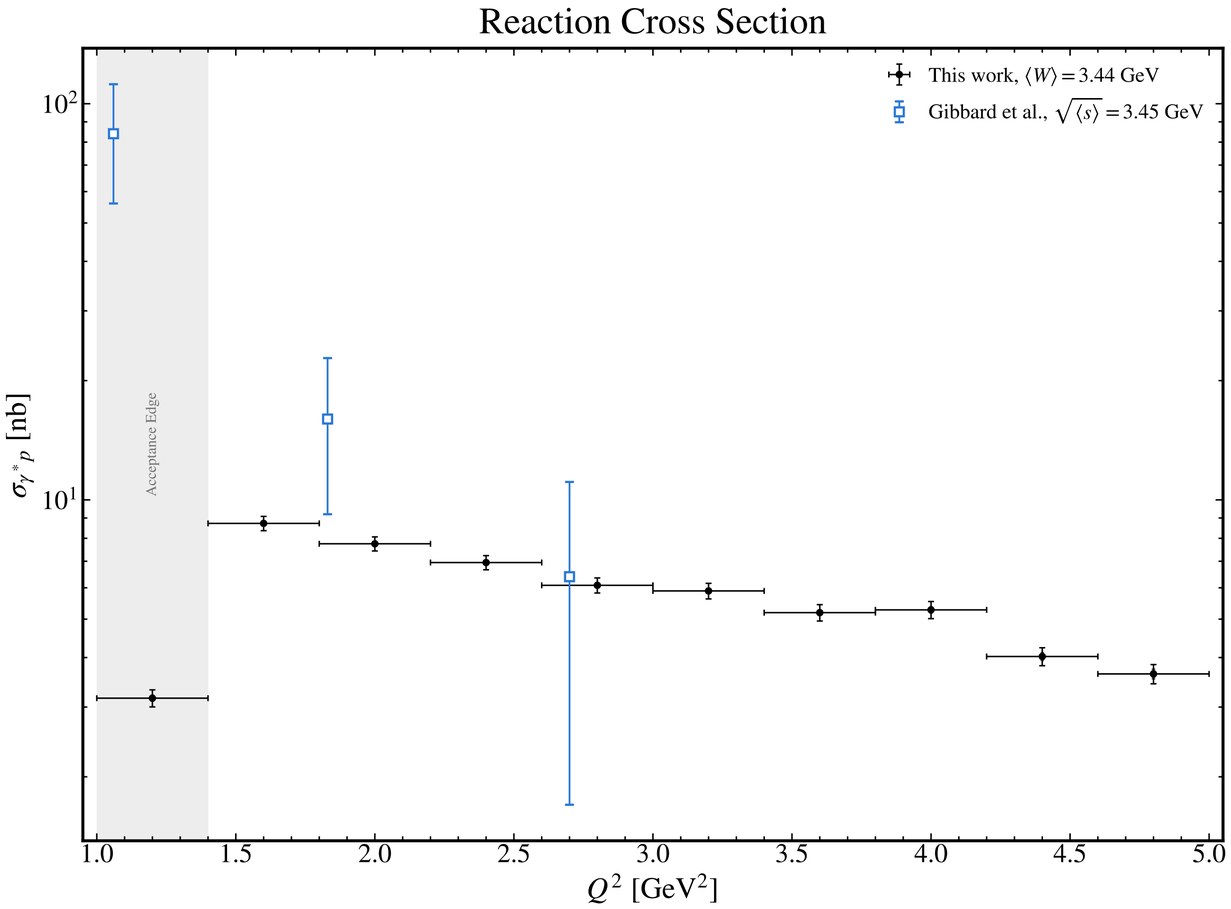


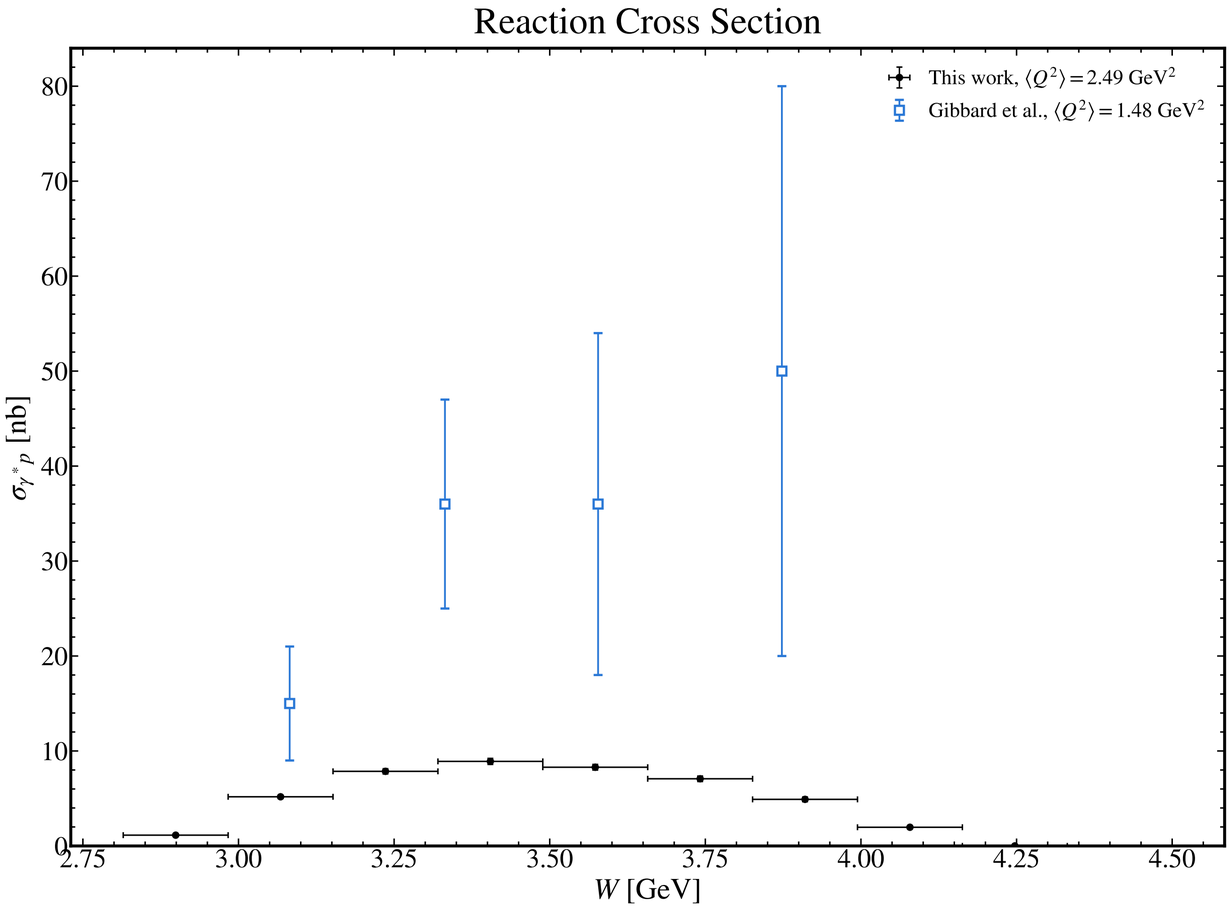
Acceptance Matching

Data vs Reconstructed MC



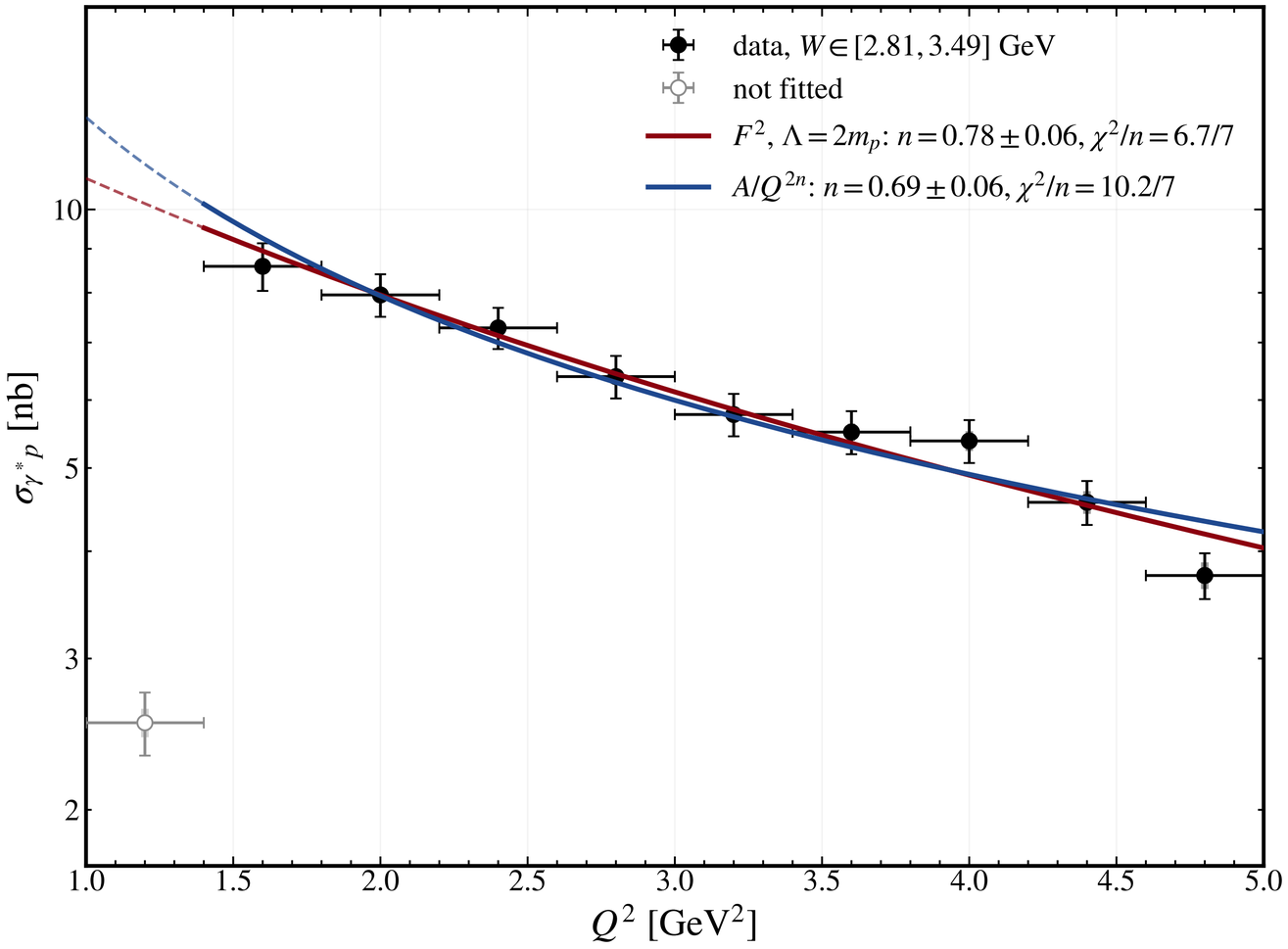
Integrated Cross Sections



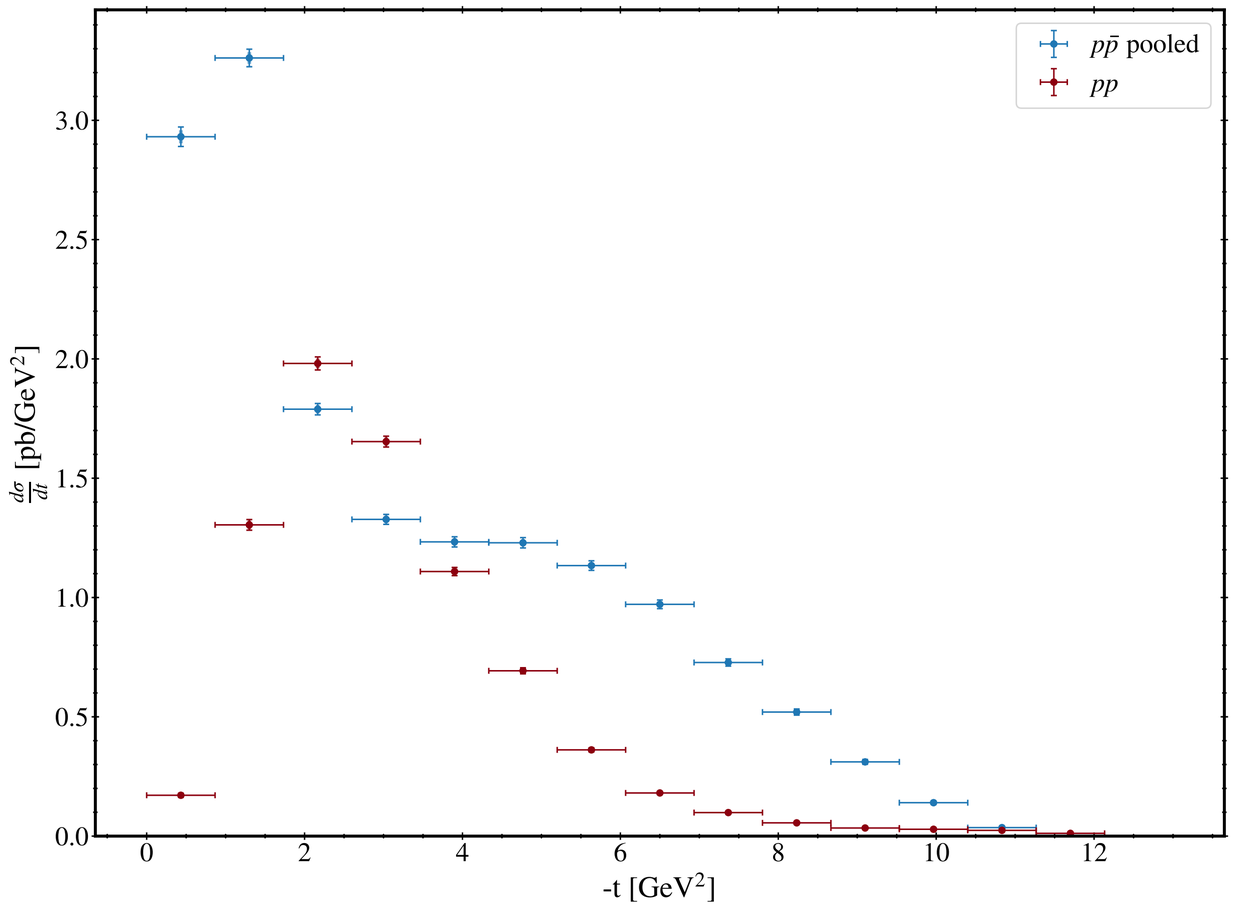


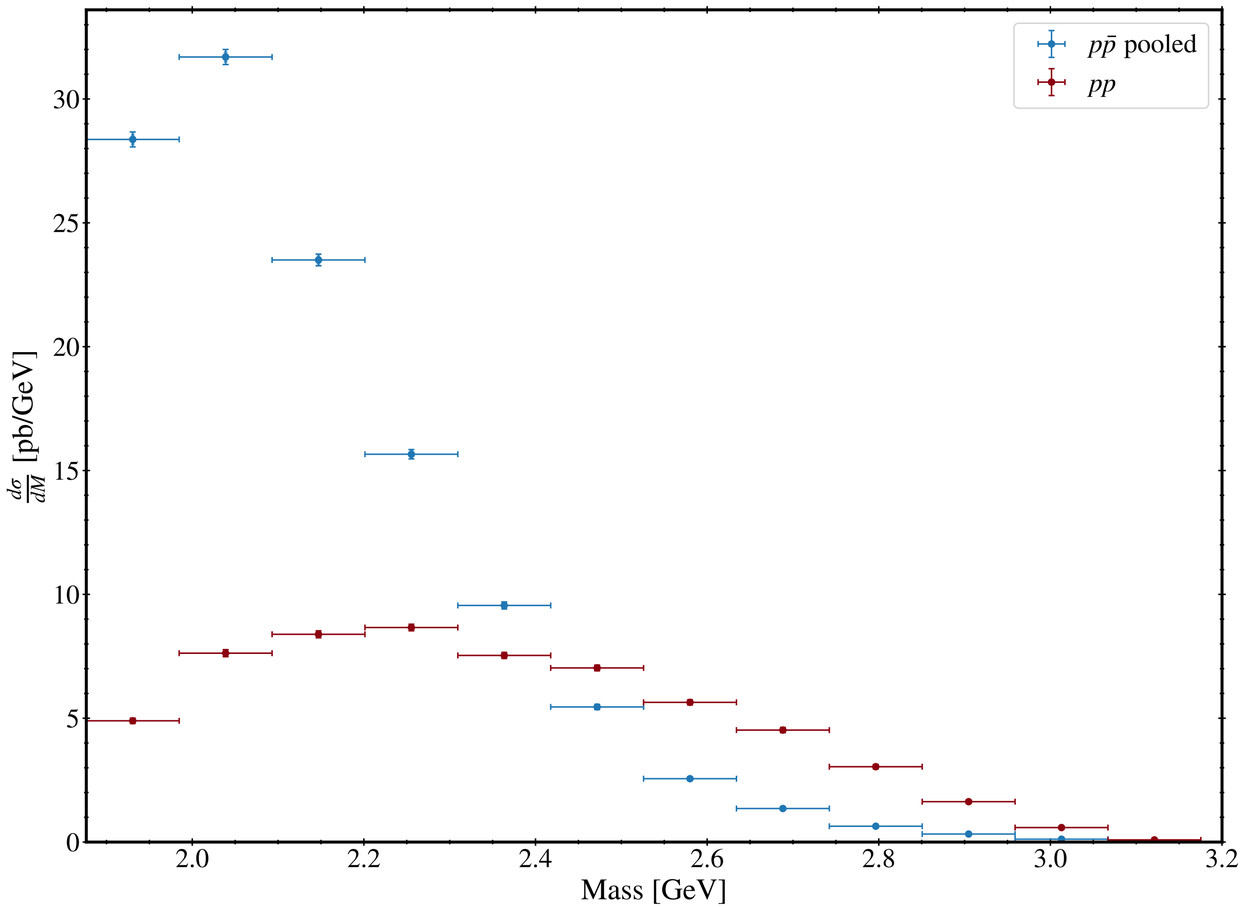
Q^2 Dependence

- Fit $\sigma_{\gamma^* p}$ over all W using
  - $\sigma(Q^2) = \dfrac{A}{(1 + Q^2/\Lambda^2)^{2n}}$, with $\Lambda = 2m_p$
  - $\sigma(Q^2) = \dfrac{A}{Q^{2n}}$
- Cross section has a slow drop off
- Excluded high W region due to scattered electron outside of FD

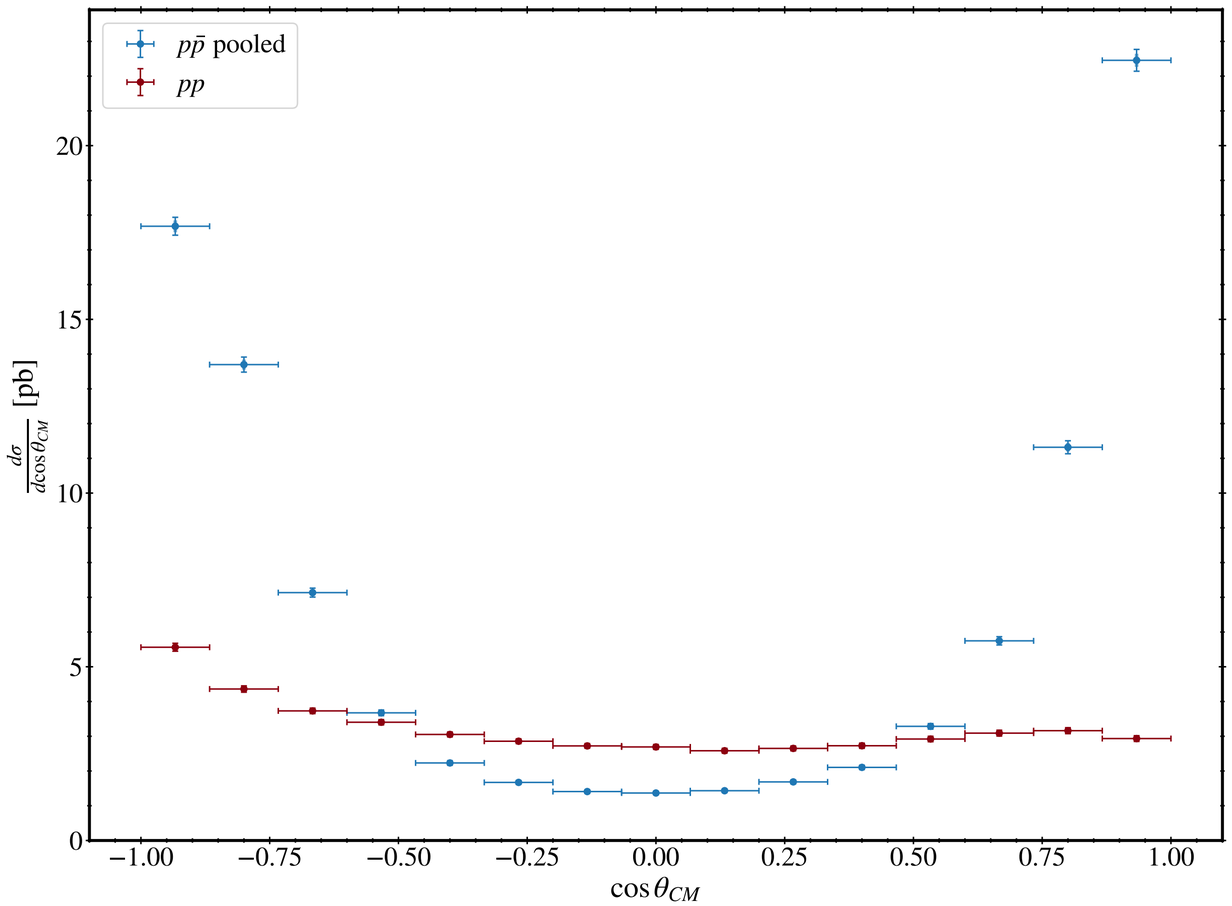


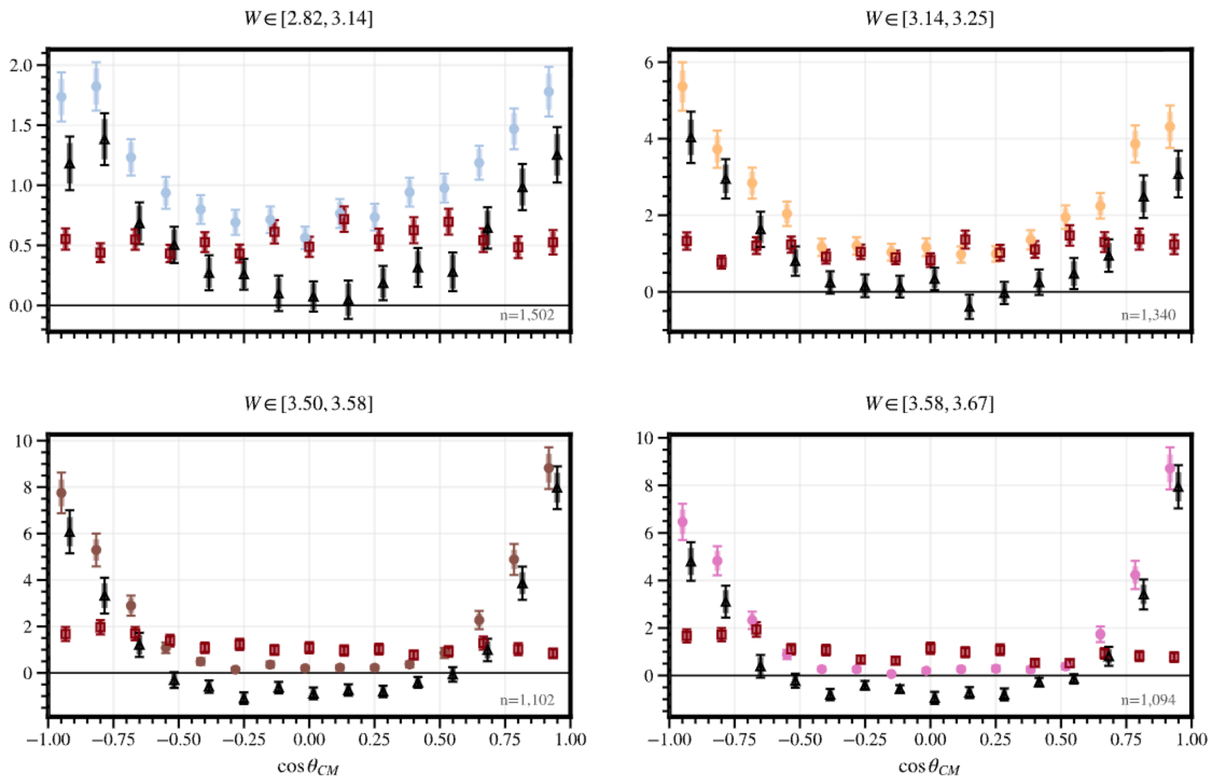
Differential Cross Sections





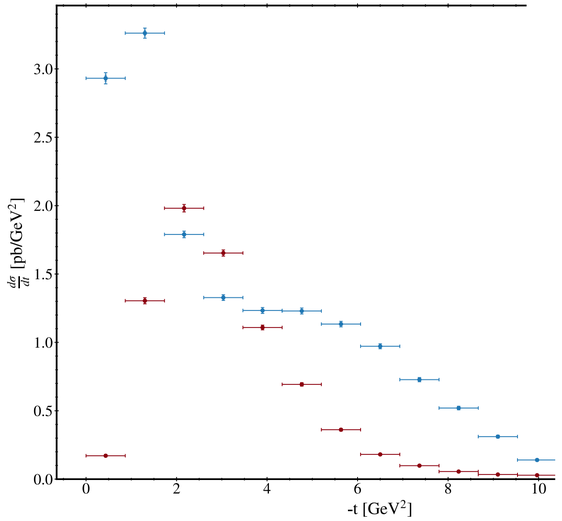
Differential Cross Sections (cont.)

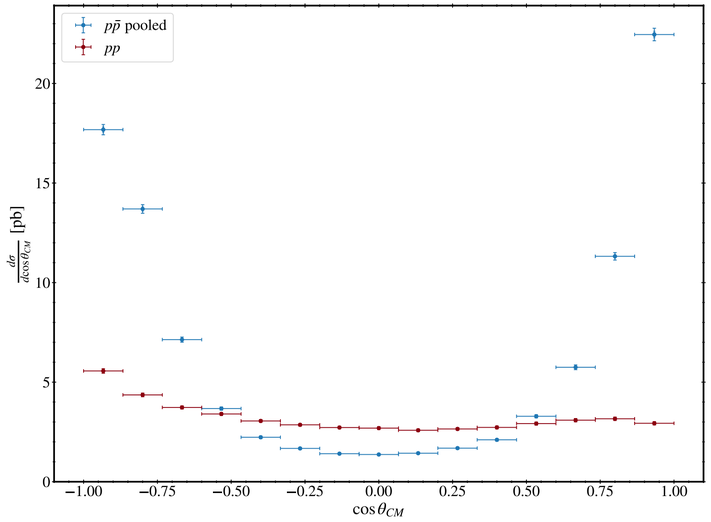


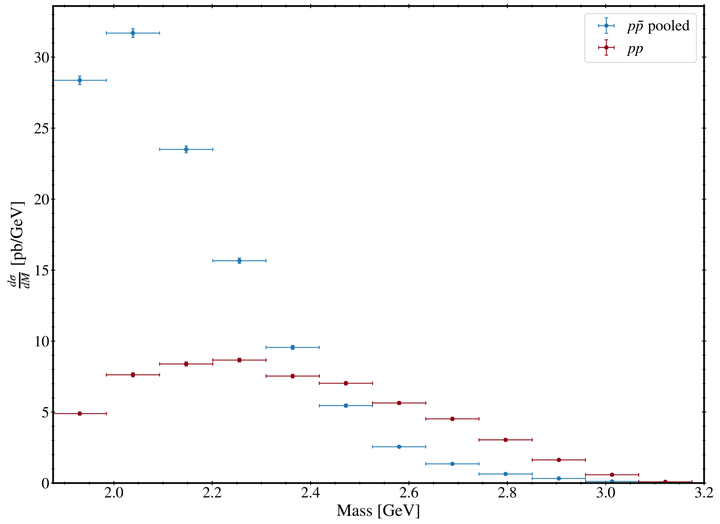


Interpretation of Results

- Clear difference between the $p\bar{p}$ and pp distributions in all 3 variables
- 3 body phase space of 3 identical mass particles
  - All 3 individual pairs have the same M, t, an $\cos\theta_{CM}$ distributions
- No clear understanding of what these distributions should look like
- Little variation across Q^2 and W bins for $\cos\theta_{CM}$
- Non trivial dynamics in the $p\bar{p}$ system







Summary

- First high statistics differential cross section extraction of $ep \rightarrow e'pp\bar{p}$
- Like-Sign subtraction isolates $p\bar{p}$ at the distribution level
- Forward and backward peaks in the $\cos\theta^{CM}_{p\bar{p}}$ distribution
- Near threshold pileup in the $M_{p\bar{p}}$ distribution