Proton Antiproton Electroproduction off Protons at CLAS12

CLAS Collaboration

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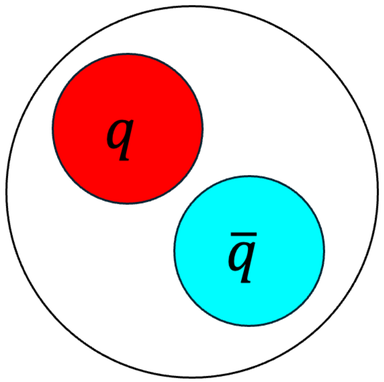
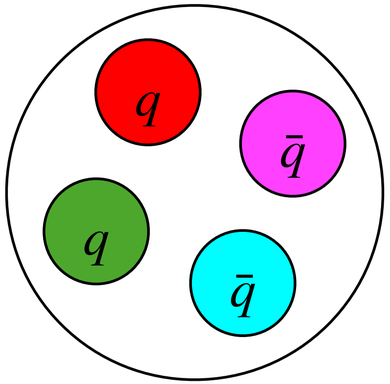
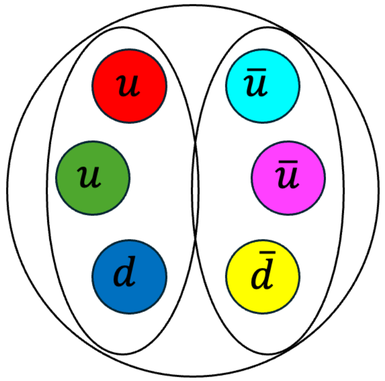
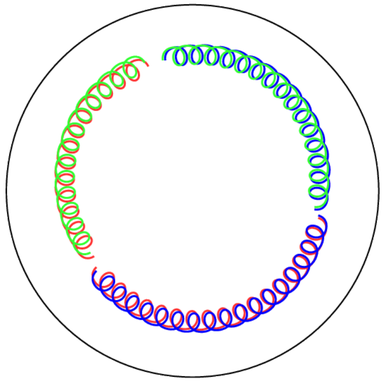
Why?

- Production mechanism of the $p\bar{p}$ system is unclear
  - Is there an intermediate state?
- Recent theories suggest non-conventional intermediate state
  - Baryonium[1, 2]: bound nucleon-anti nucleon
  - Glueball[3]: bound gluons
  - Tetraquark: 4 quark state ($qq\bar{q}\bar{q}$)









[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,"

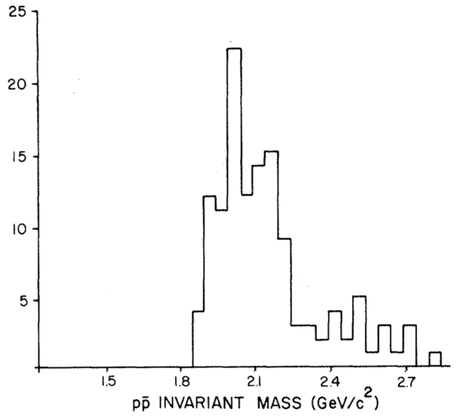
Previous Experiments

$p\bar{p}$ Production Experiments

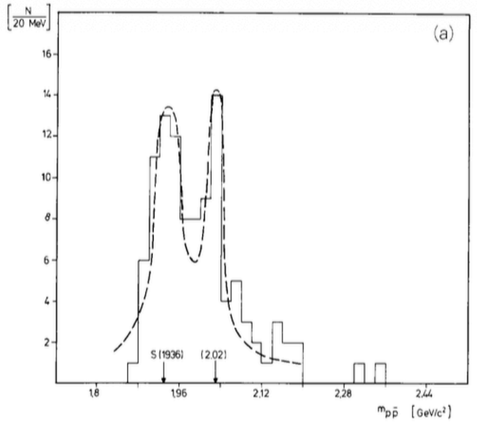
- Particle beam incident on stationary proton target

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

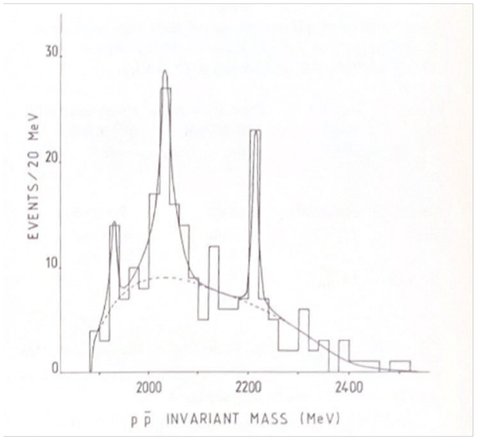
- Observed narrow resonances in $M(p\bar{p})$ system
- Limited statistics prevented firm conclusions on underlying production mechanism
- Little evidence to justify potential narrow states
- Sensitive to the production mechanism



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



$M(p\bar{p})$ from the reaction $\gamma p \rightarrow pp\bar{p}$



$M(p\bar{p})$ 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".

Previous Experiments

Radiative Decays

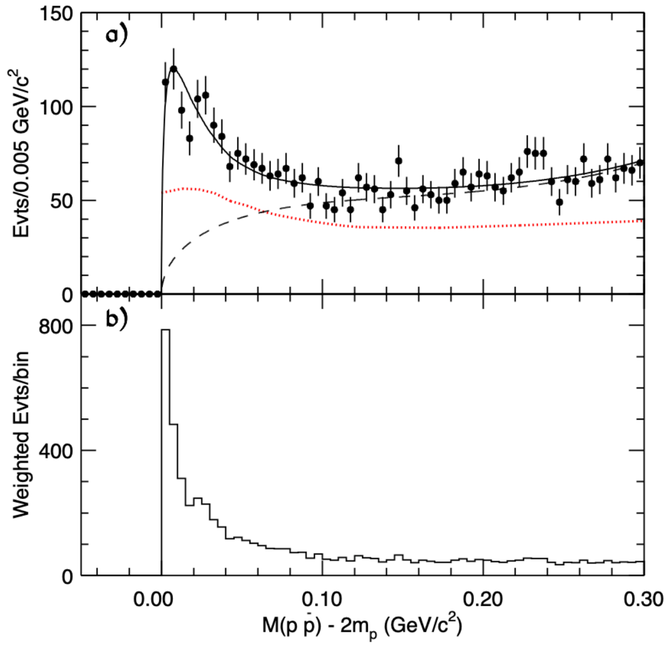
- Using J/ψ radiative decays[7, 8]

$$J/\psi \rightarrow \gamma p\bar{p}$$

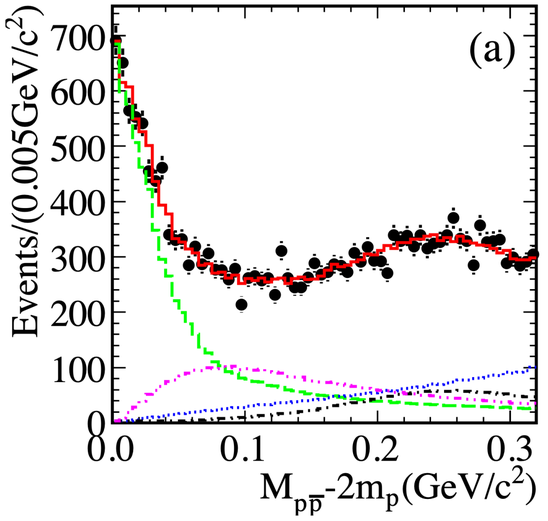
- Found near mass threshold resonance in $M(p\bar{p})$
  - $M(p\bar{p}) = 1.832GeV$
  - $\Gamma < 76MeV/c^2$
- Extracted J^{PC} numbers using PWA
  - $J^{PC} = 0^{-+}$
- Using $\psi(2S)$ radiative decays [9]

$$\psi(2S) \rightarrow \gamma p\bar{p}$$

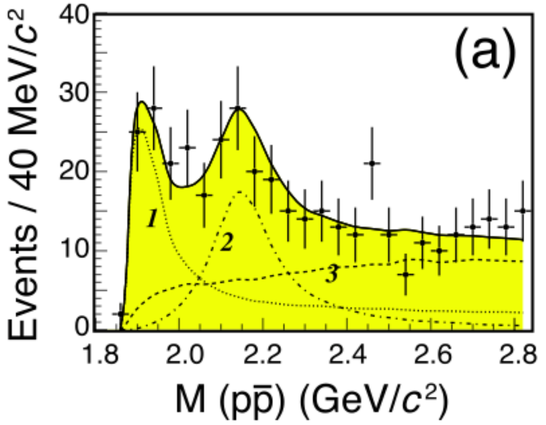
- Found $f_2(1950)$ and $f_2(2150)$ resonant structures



BES-II: a) $M(p\bar{p}) - 2m_p$, dashed curve is background from $J/\psi \rightarrow \pi^0 p\bar{p}$. b) Events weighted by $|\vec{p}_p^{RF}|/2$



BES-III: Black with error bars is data. Red histogram is the PWA total projection. With the green, pink and two blue lines showing the $X(p\bar{p})$, 0^{++}, $f_0(2100)$, and $f_2(2100)$ contributions



The labelled lines correspond to 1.) $f_2(1950) \rightarrow p\bar{p}$, 2.) $f_2(2150) \rightarrow p\bar{p}$ and 3.) is phase space.

[7]Bai, J. Z., et al. "Observation of a Near-Threshold Enhancement in Th P Pbar Mass Spectrum from Radiative J/Psi-->gamma P Pbar Decays." *arXiv.Org*, 7 Mar. 2003, arxiv.org/abs/hep-ex/0303006v1.

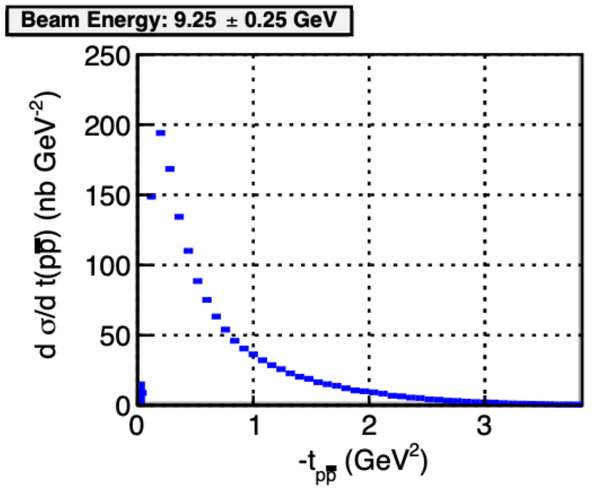
[8] Ablikim, M, et al. "Spin-Parity Analysis of Ppbar Mass Threshold Structure in J/PSI and Psi' Radiative Decays." *arXiv.Org*, 5 Dec. 2011, arxiv.org/abs/1112.0942.

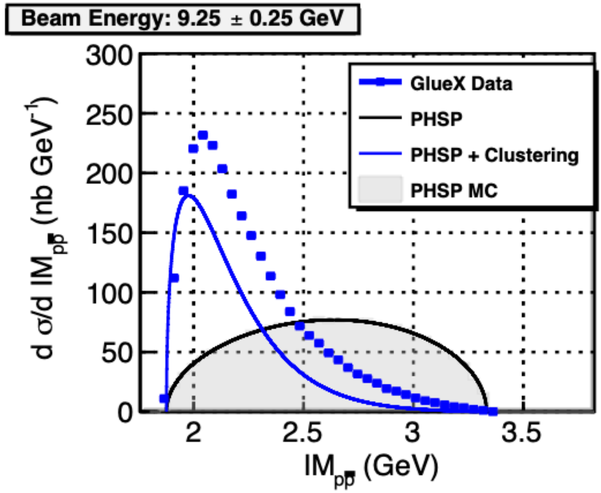
[9]J. P. Alexander et al. (CLEO Collaboration), "Study of ψ(2S) Decays to γ p p̄, π^0 p p̄ and η p p̄ and Search for p p̄ Threshold Enhancements," Phys. Rev. D 82, 092002 (2010).

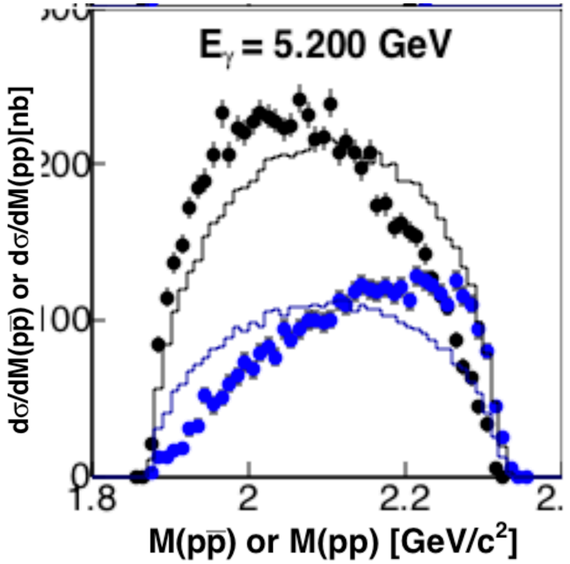
Previous Experiments

More recent γp experiments

- $\gamma p \rightarrow p p \bar{p}$
- Recent high statistics photoproduction experiments have found no evidence of narrow resonances
  - CLAS g12 (Will Phelps)[10]
  - Glue-X (Hao Li)[11]
- Focused on cross section extraction
- High statistics needed for resonance extraction
- Combinatorial background affects final results
  - Two identical fermions in the final state







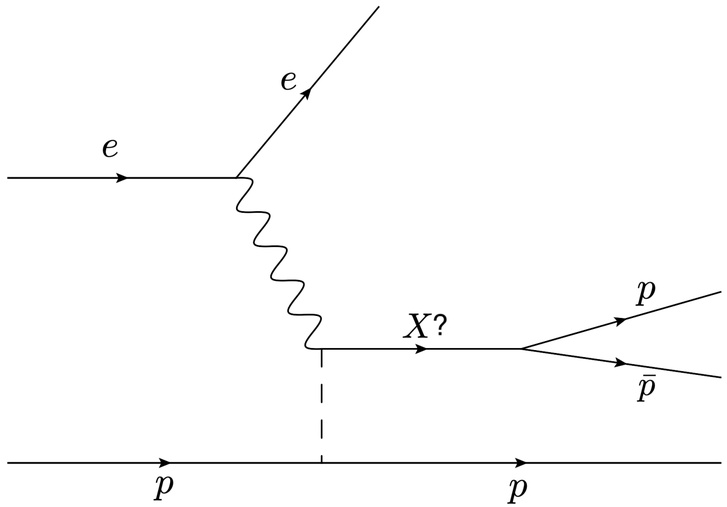
[10] Phelps, Will. "Antibaryon Photoproduction Using CLAS at Jefferson Lab." *Florida International University*, 2017.

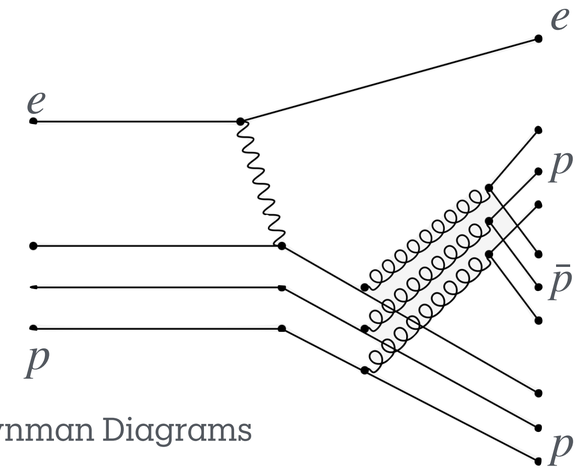
[11] Li, Hao. "Baryon–Antibaryon Photoproduction Off the Proton." *Carnegie Mellon University*, 2023.

Reaction and Data

A quick recap

- Looking into the reaction
  - $ep \rightarrow epp\bar{p}$
- Run Group A Spring 2019 Data
  - $10.2GeV$ Electron beam
  - Electron beam incident on LH_2
- Requiring an electron in either the FD or the FT
  - Different Q^2 range

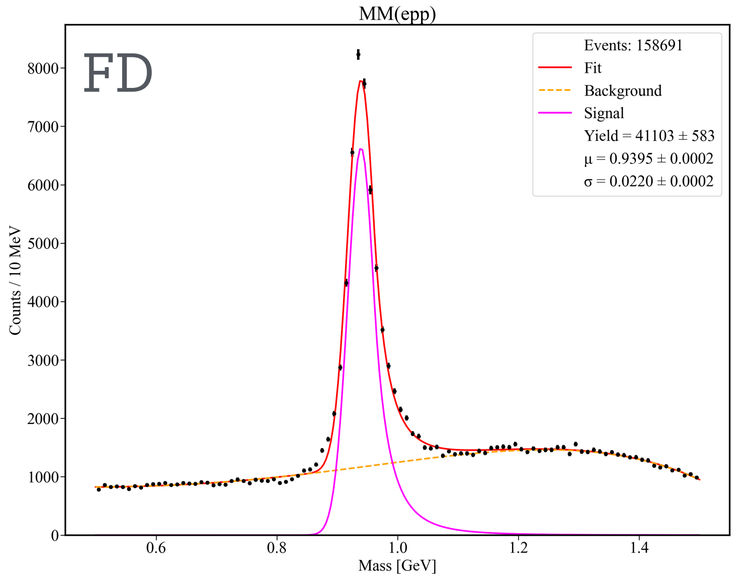


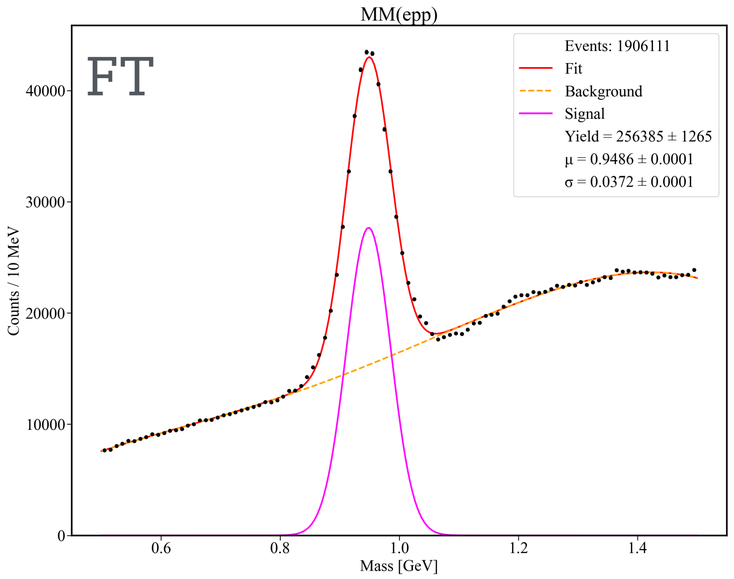


Possible Feynman Diagrams

Available Statistics

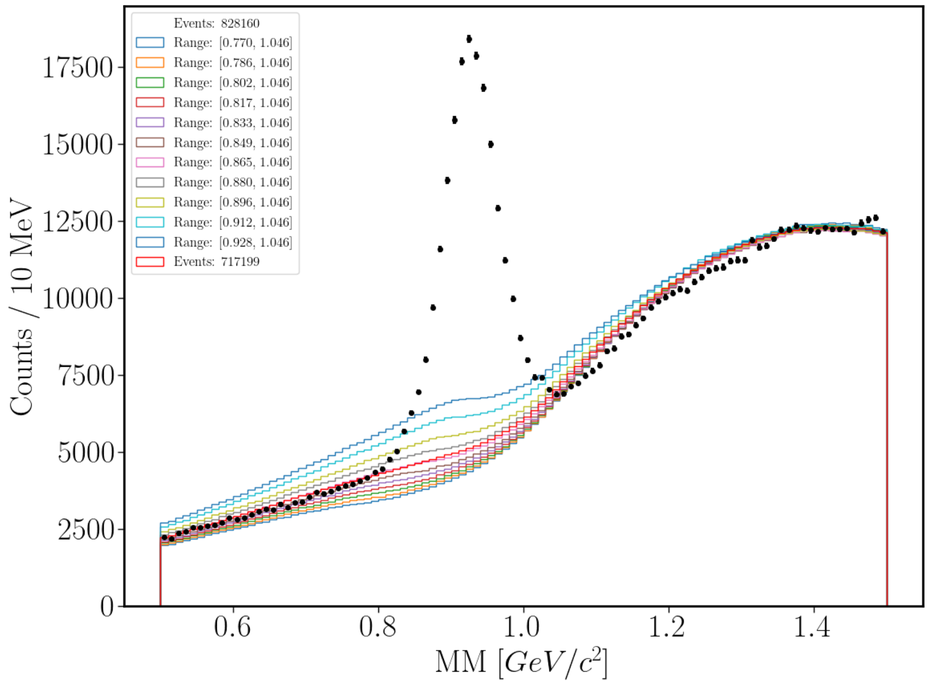
- $\bar{p}$ reconstructed through missing mass technique
  - 1 Electron and 2 protons required
- Determine total statistics post selection criteria
  - Crystal ball + 4th order polynomial fit
- 4th order polynomial not physically motivated
- Background not fully understood
  - Non $pp\bar{p}$ background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



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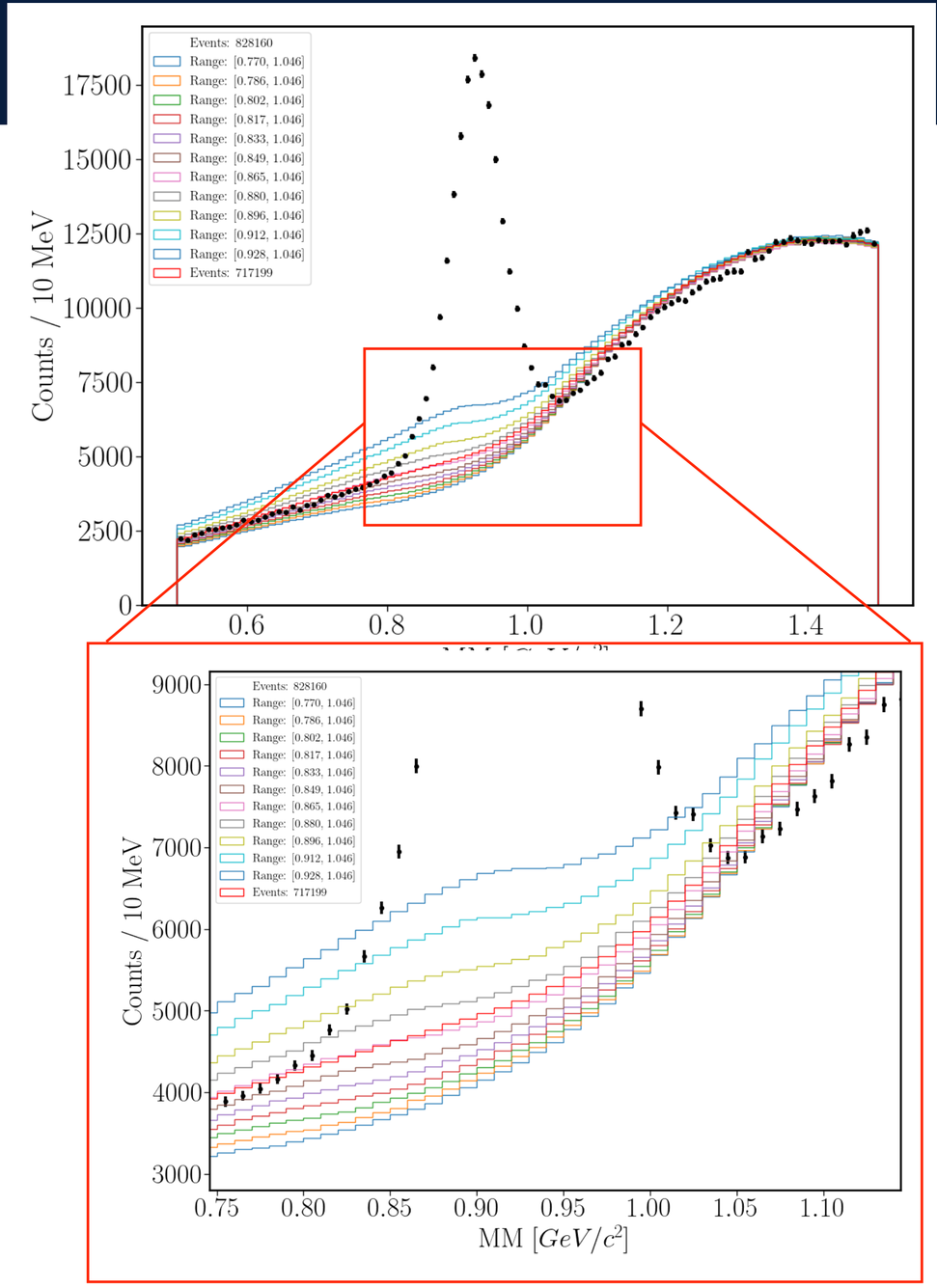

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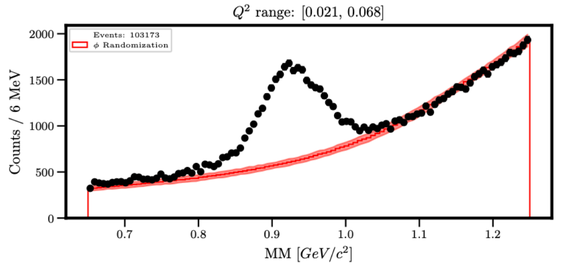
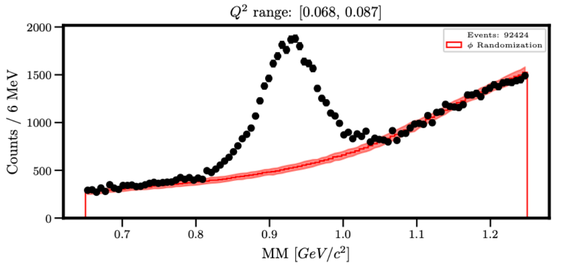
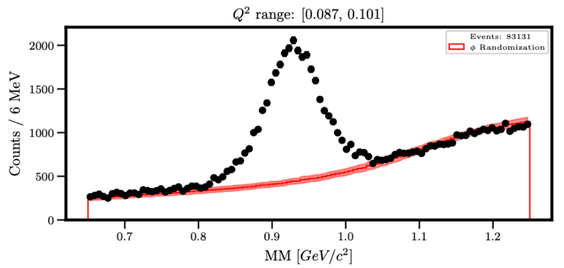
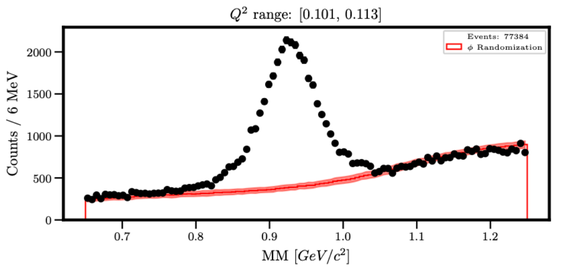
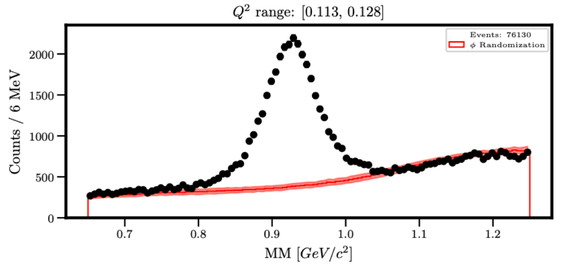
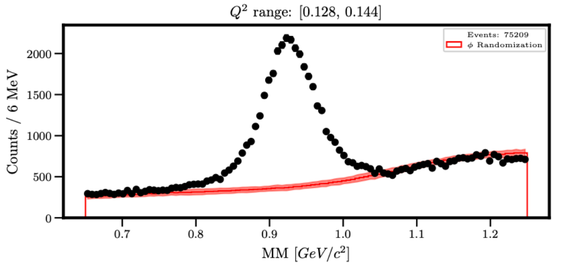








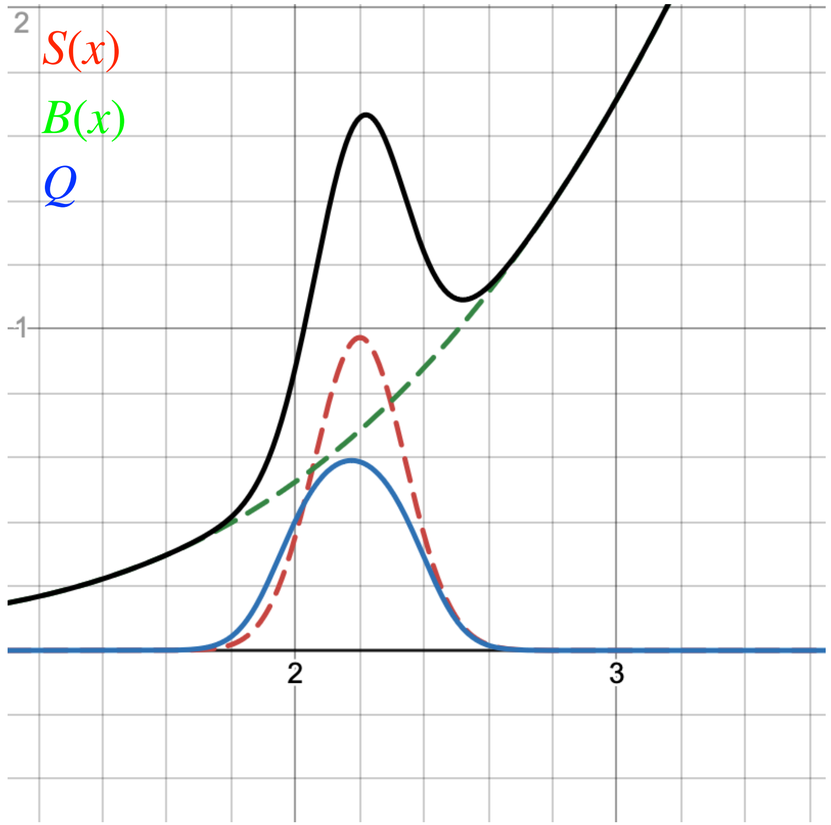




Event by Event Signal Extraction

Quality Factors

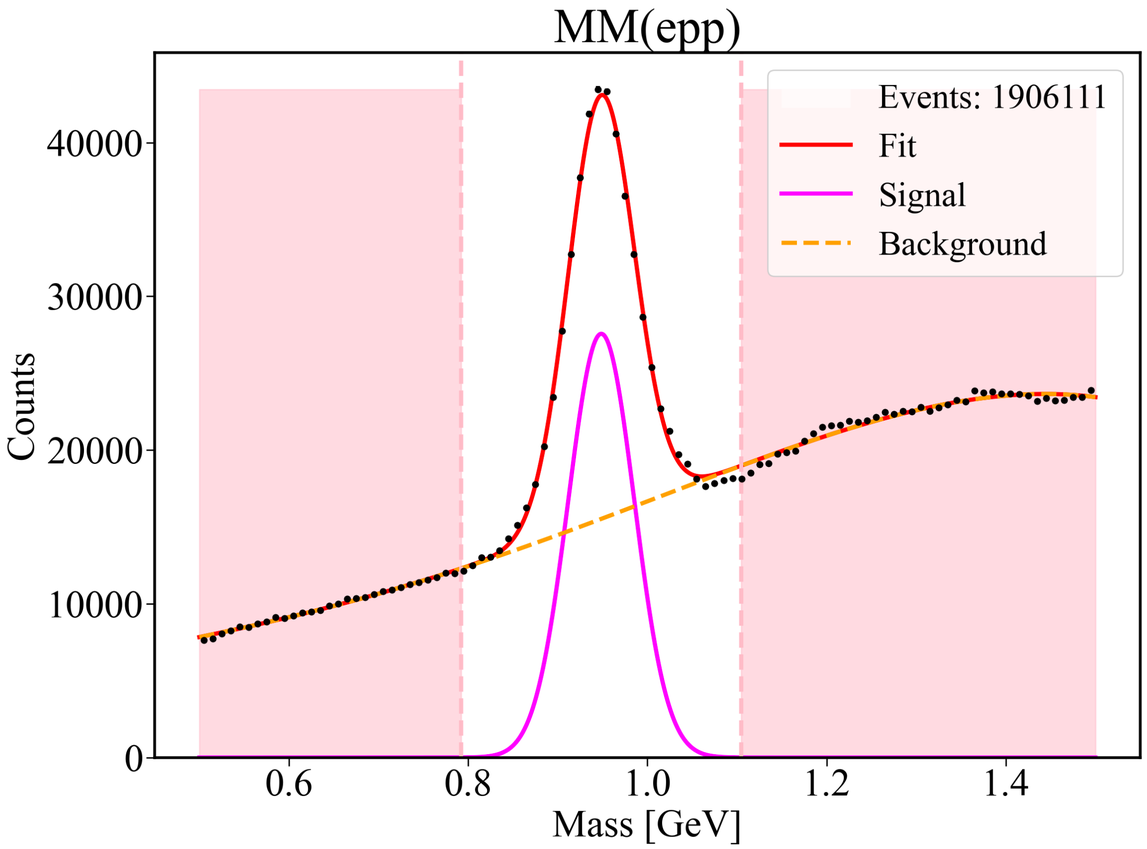
- Isolating signal from background is a complex process
- High-dimensional data can be distorted due to kinematic correlations
- Solution:
  - Assign an event by event weight (Q)
  - Q acts as a weight on how likely a given event is to be signal
- Drawback:
  - Classical Q factor extraction is incredibly slow



How can we speed this up?

Machine Learning

- 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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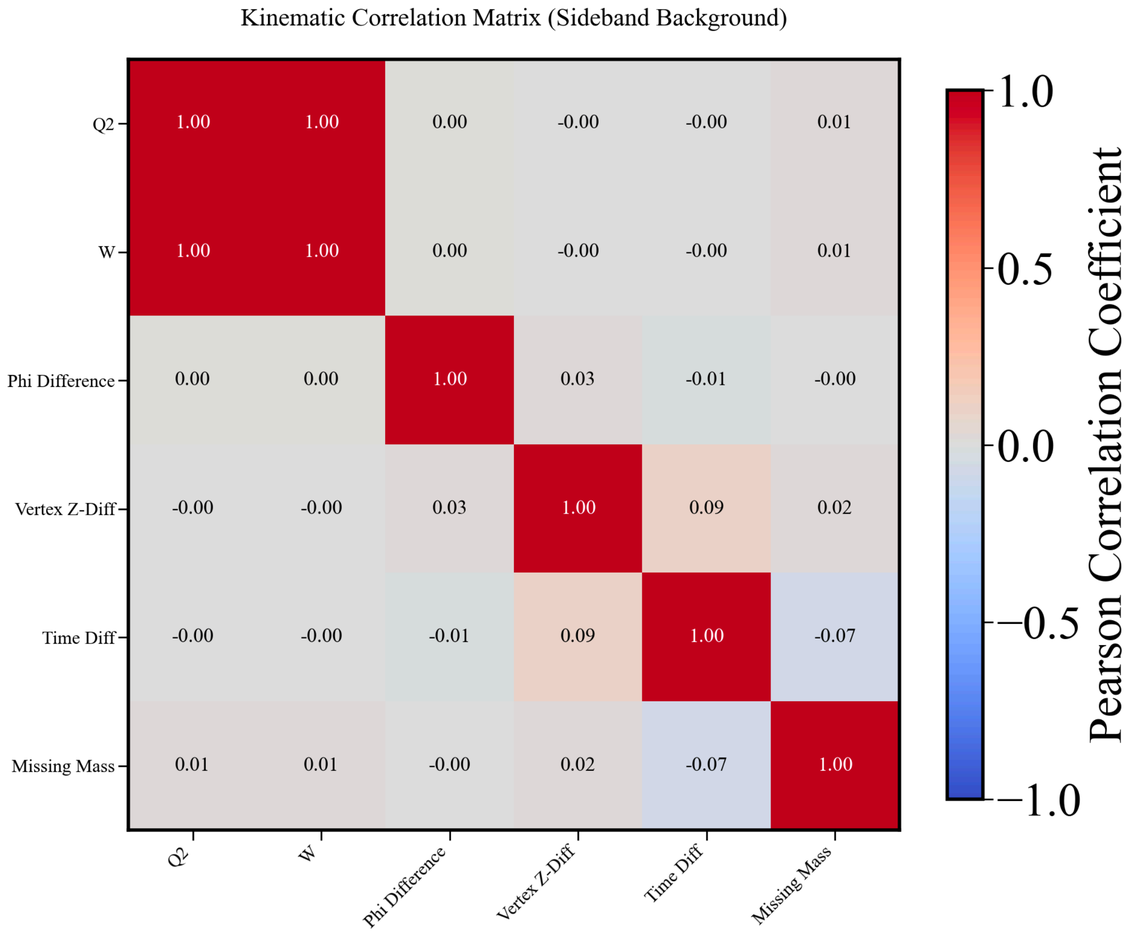
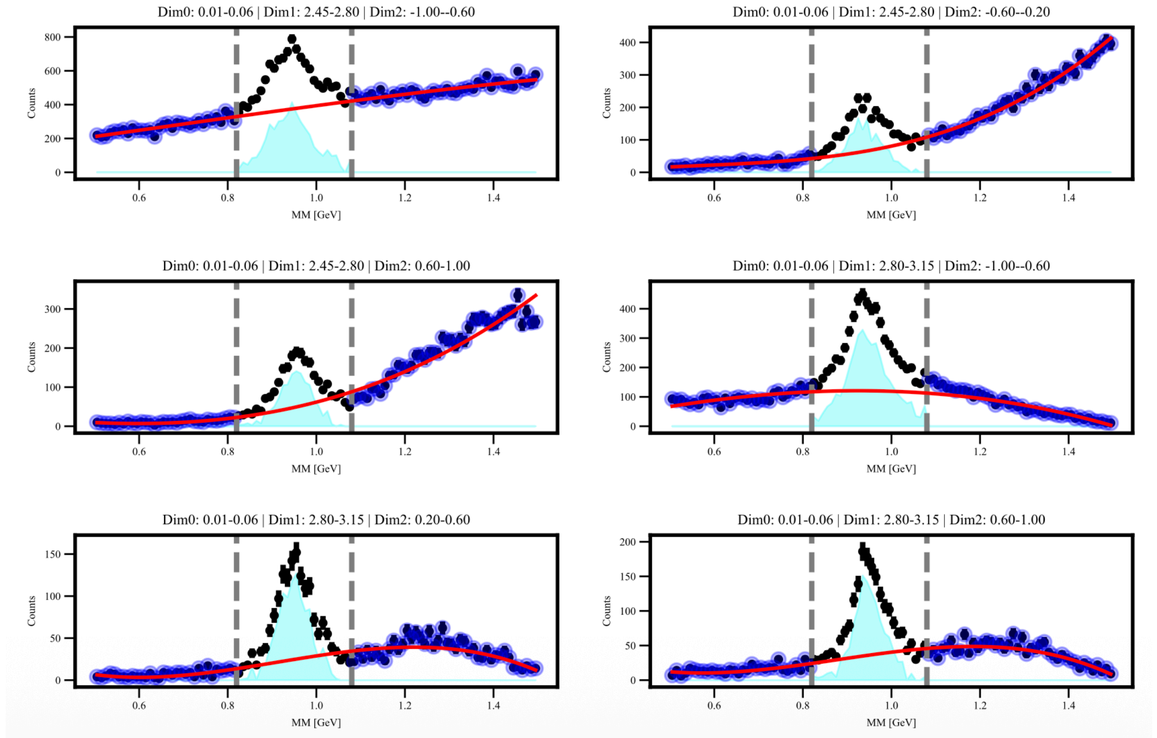


Extracting Probabilistic Weights

- 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



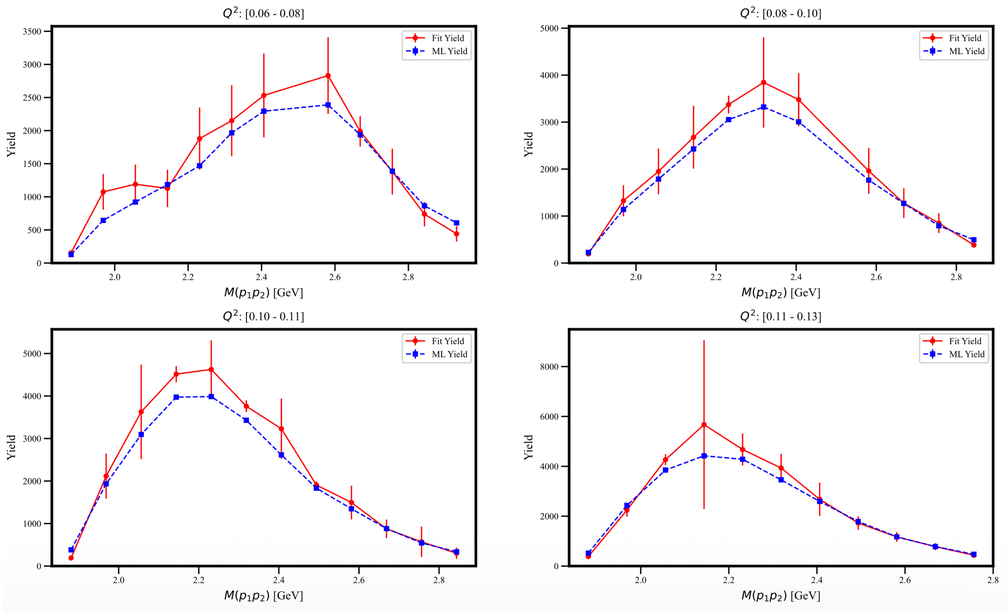
The Results

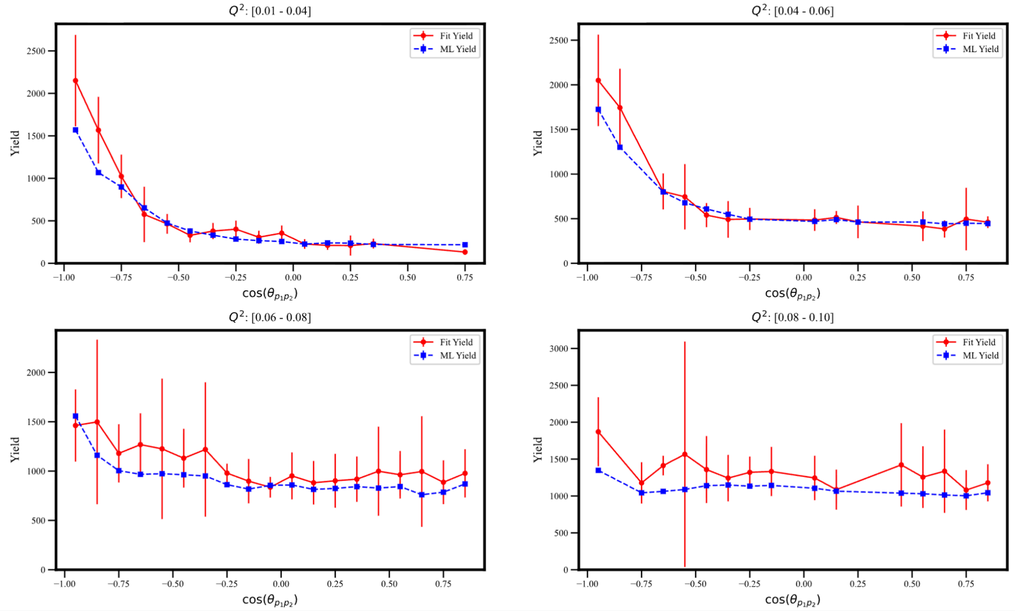
Comparing to binned fits

- Multidimensional binned fits to extract yield
  - Crystal ball + 4th order polynomial
- Sum of all Q in a multidimensional bin

$$Y = \sum_i Q_i,\ \sigma_{Q_i} = \sqrt{\sum_i Q_i^2}$$

- Binned fits and ML Q follow the same shape
- Binned fits are affected by low statistics





Future Work

- <u>Needed for Dissertation</u>
  - Simulations needed for differential cross sections
    - $\frac{d\sigma}{dM(p\bar{p})}$: Probe resonances, continuum states
    - $\frac{d\sigma}{d\cos\theta_{\bar{p}}}$: Production mechanism, beam / target fragmentation
    - $\frac{d\sigma}{dt}$: Exchange processes, constituent counting
  - Beam Spin Asymmetry
    - Interference between amplitudes
    - Sensitive to reaction mechanisms
- <u>Not necessary for completion</u>
  - Partial Wave Analysis (AI PWA)
  - Moment Analysis

Outlook

A quick summary

- Extract event by event weights to determine signal shape in other distributions of $p\bar{p}$ system
- Data driven ML model uses coarse bin yields to determine signal fraction
- Interpolate into finer bins
- Simulations have been started (cross sections soon?)

Thank you!

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