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Proton Antiproton Electroproduction off Protons at CLAS12

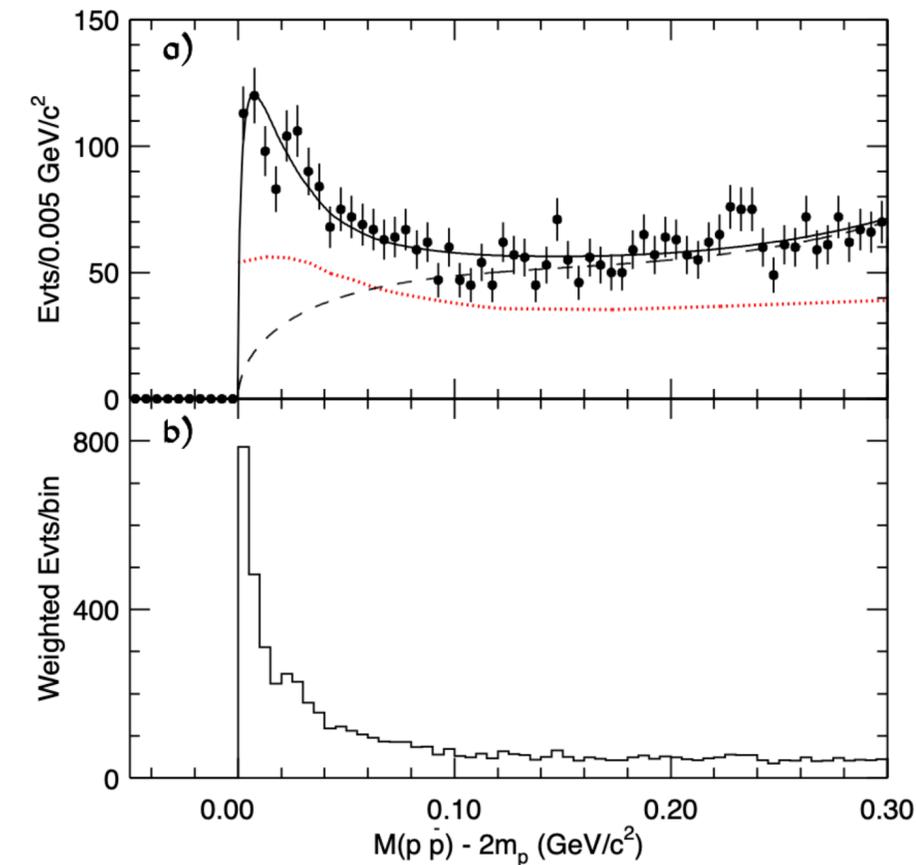
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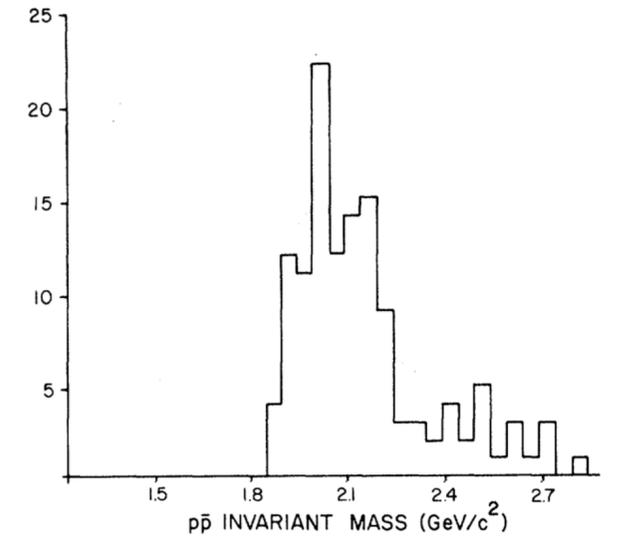
History

A brief overview

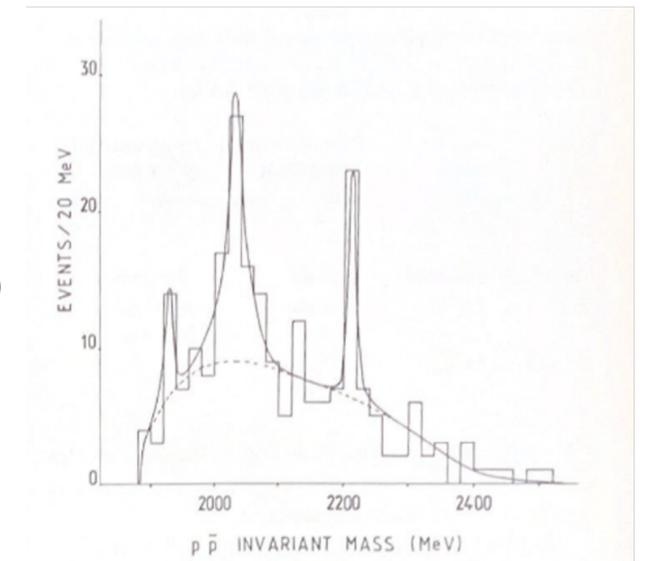
- $p\bar{p}$ system has long been used to search for intermediate resonances
- Evidence for narrow resonances has been inconclusive
- Low statistic experiments (pre 1990's)
- BES-II[1] found near mass threshold resonance
 - $M(p\bar{p}) = 1.832\text{GeV}$
 - $\Gamma < 76\text{MeV}/c^2$
- BES-III[2] extracted quantum numbers
 - 0^{-+}



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 $|\vec{p}_p^{RF}|/2$



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



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

[1] Bai, J. Z., et al. "Observation of a Near-Threshold Enhancement in the $P\bar{P}$ Mass Spectrum from Radiative $J/\psi \rightarrow \gamma P\bar{P}$ Decays." *arXiv.Org*, 7 Mar. 2003, arxiv.org/abs/hep-ex/0303006v1.

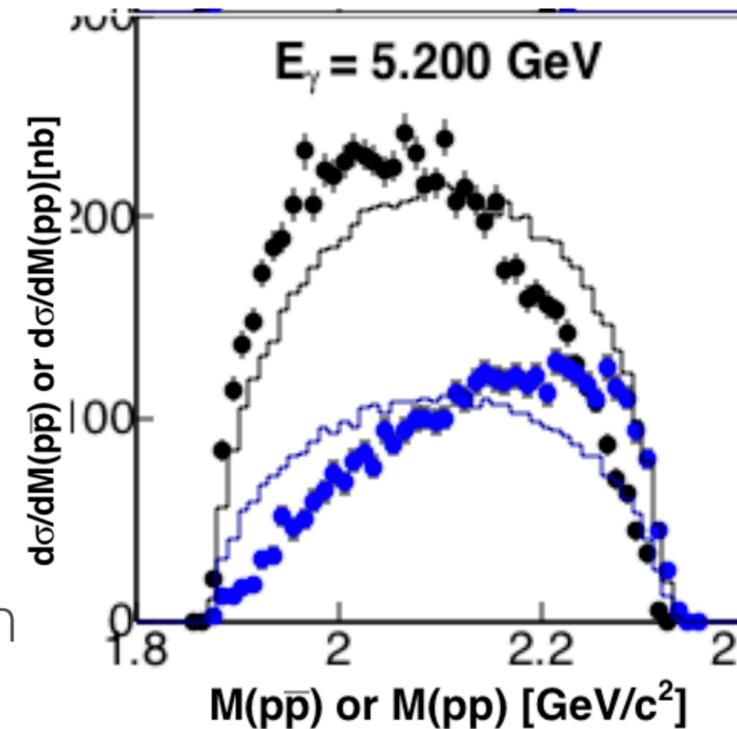
[2] Ablikim, M., et al. "Spin-Parity Analysis of $P\bar{P}$ Mass Threshold Structure in J/ψ and ψ' Radiative Decays." *arXiv.Org*, 5 Dec. 2011, arxiv.org/abs/1112.0942.

Previous γp Analyses

- $\gamma p \rightarrow pp\bar{p}$
- Recent high statistics photoproduction experiments have found no evidence of narrow resonances
 - CLAS g12 (Will Phelps)[3]
 - Glue-X (Hao Li)[4]
- Focused on cross section extraction
- High cross section needed for resonance extraction

Experiment (year)	# of $p\bar{p}$	Mass (MeV)	Width (MeV)	Comment
CERN (1977) [5] (details in Fig. 109)	6000	2020±3 2204±5	24±12 16 $^{+20}_{-16}$	$\pi^- p \rightarrow p_{fwd} p\bar{p} \pi^-$
Cornell (1979) [6]	65	2020 2200	<40 60	Virtual photoproduction via $ep \rightarrow epp\bar{p}$ Signal cross section 6.6±2.2 nb Signal cross section 5±2.5 nb
LAMP2 (1979) [99]	137	-	-	No evidence
DESY(1984) [9] (details in Fig. 110)	200	1939±6 2024±5	52±16 29±12	Signal cross section 14±5 nb Signal cross section 21±4 nb
CLAS g6b (2003) (internal notes [10])	2500	1950 2020	7.8 3.3	
CLAS g6c (2006) (unpublished thesis [11])	25000	-	-	No evidence, upper limit set at $\sigma(\gamma p \rightarrow pX(2020)) < 0.35nb$
CLAS g12 (2017) (unpublished thesis [12])	250000	-	-	No evidence
GlueX (this work)	14.1 million	-	-	No evidence

Various experiments and their results on whether an intermediate resonance was detected.



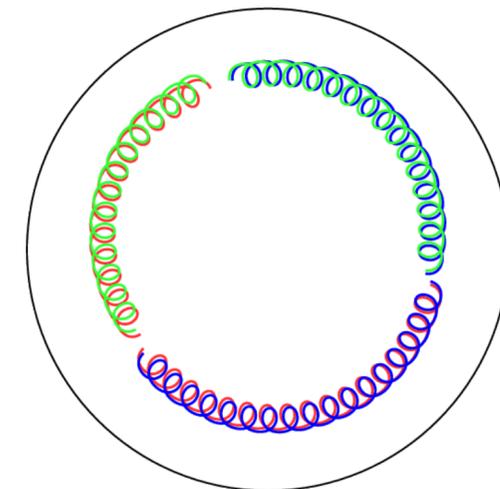
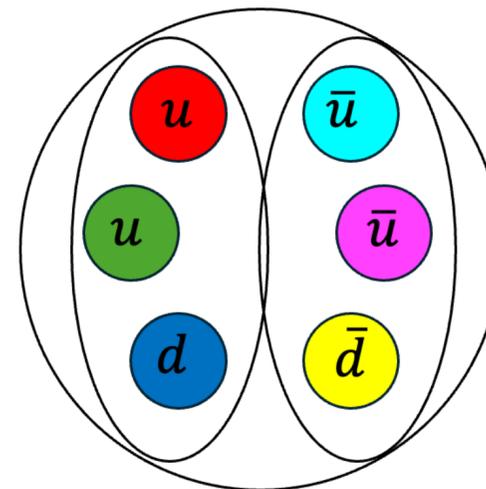
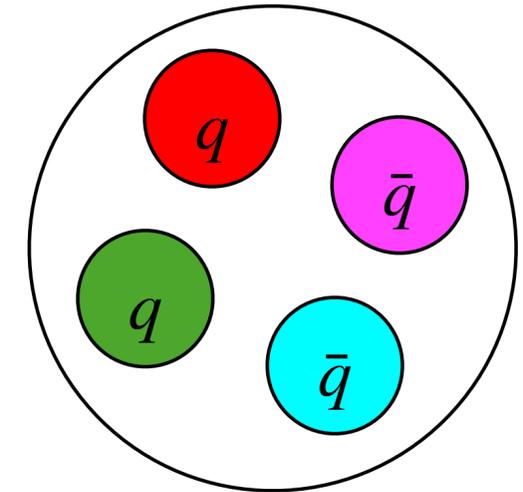
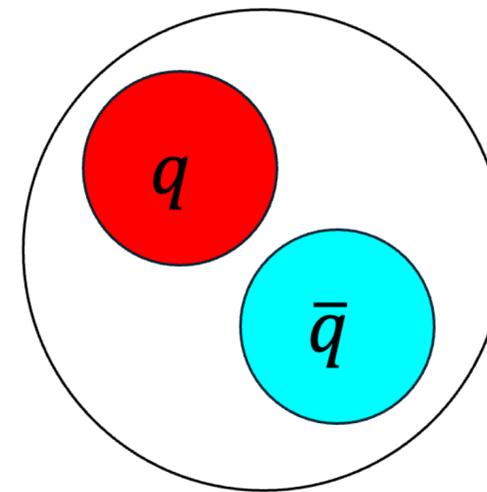
Differential cross section as a function of the invariant mass of either $M(p\bar{p})$ or $M(pp)$.

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

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

Motivation

- Narrow resonances have conflicting evidence
- Potential wide resonances
- Production mechanism of $p\bar{p}$ remains unclear
- $p\bar{p}$ is a prime candidate to look for potential intermediate exotic states
 - Glueballs[5]
 - Tetraquarks[6]: $qq\bar{q}\bar{q}$
 - Baryonium[6]: Bound $N\bar{N}$
 - Intermediate Mesons: $q\bar{q}$



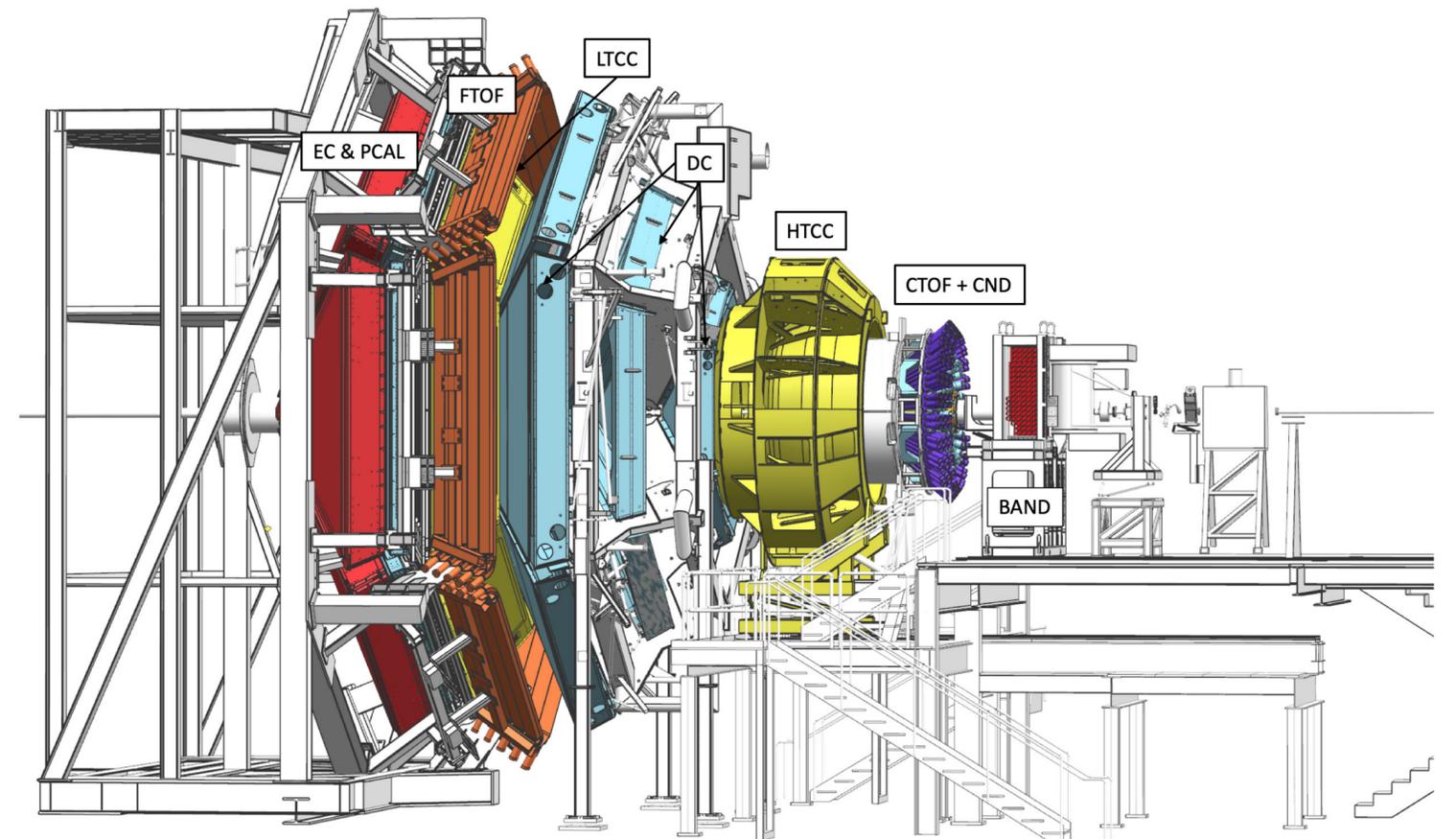
[5] Gutsche, Thomas, et al. "Search for the Glueball Content of Hadrons in Gamma P Interactions at Gluex." *arXiv.Org*, 17 Aug. 2016, arxiv.org/abs/1605.01035.

[6] Olsen, Stephen Lars. "A New Hadron Spectroscopy." *arXiv.Org*, 28 Nov. 2014, arxiv.org/abs/1411.7738.

CLAS12

Jefferson Lab Hall B

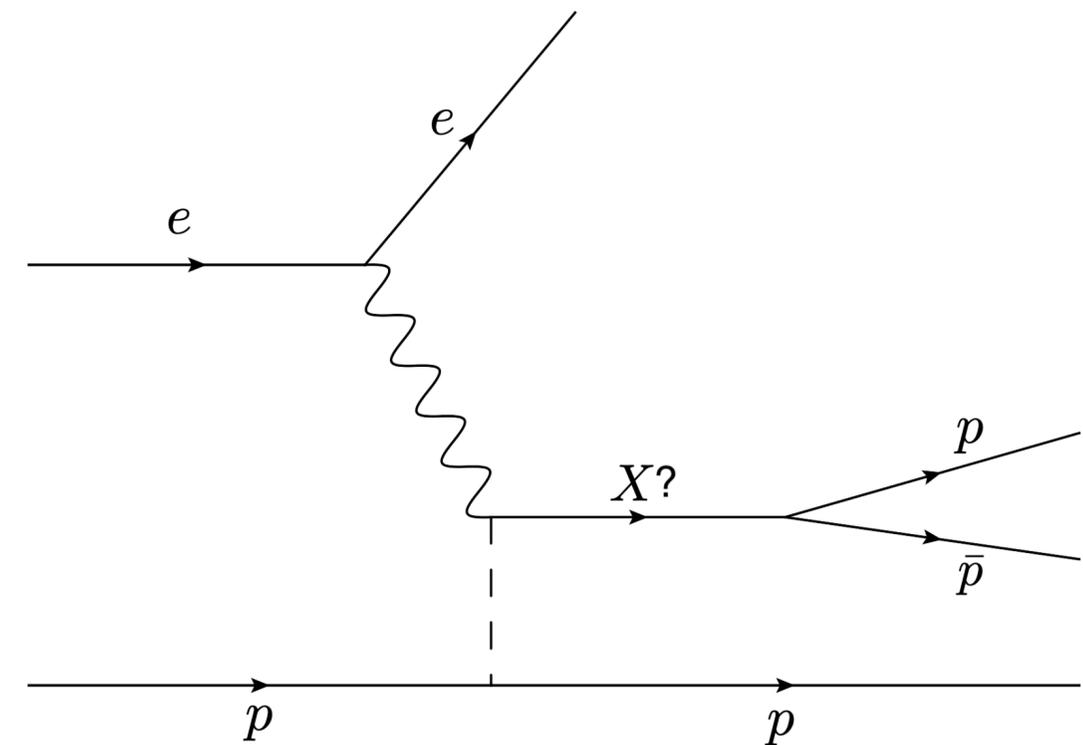
- CEBAF Large Acceptance Spectrometer
- Main detector subsystems (of interest)
 - Forward Detector (FD) $\theta \in [5^\circ, 35^\circ]$
 - High momentum forward going particles
 - Forward Tagger (FT) $\theta \in [2.5^\circ, 5^\circ]$
 - Low angle scattered electrons



Reaction and Data

- 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

A possible Feynman Diagram

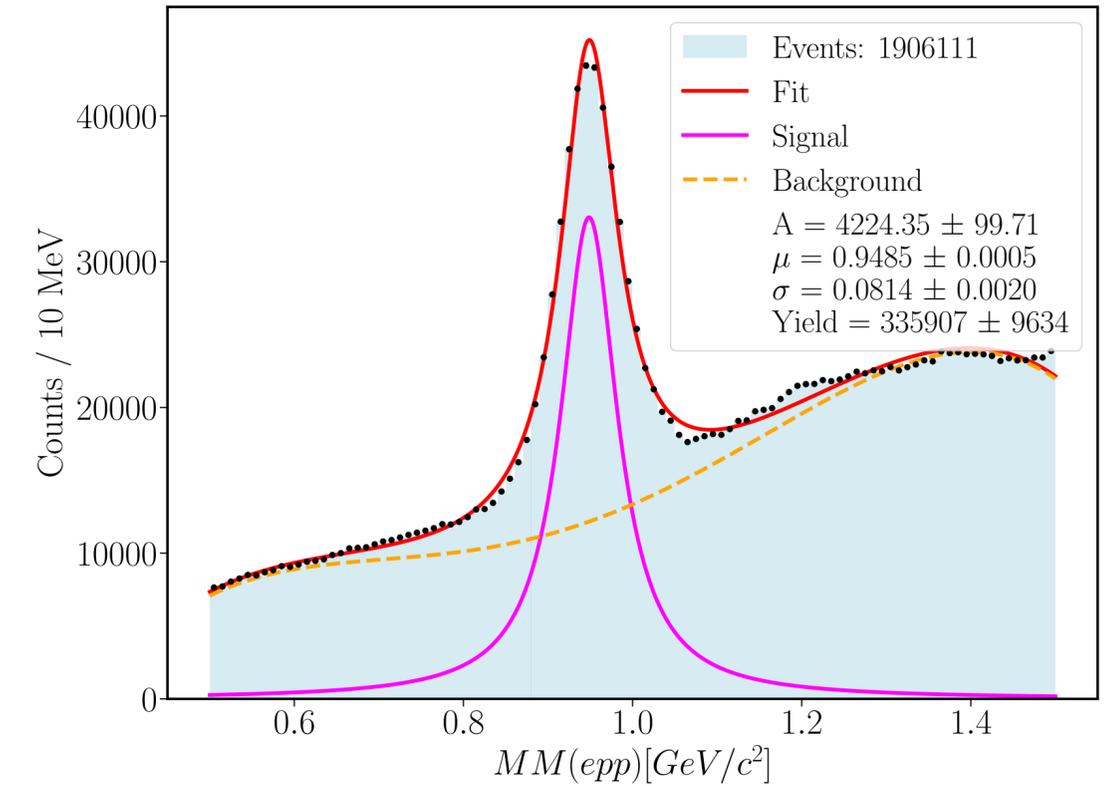


Reaction Statistics

- Missing mass technique
 - $ep \rightarrow epp(\bar{p})$
- Different kinematic regions
 - $Q^2 \in [0, 0.6]$
 - $Q^2 \in [1, 6]$
 - $Q^2 \propto \sin^2 \frac{\theta_e}{2}$

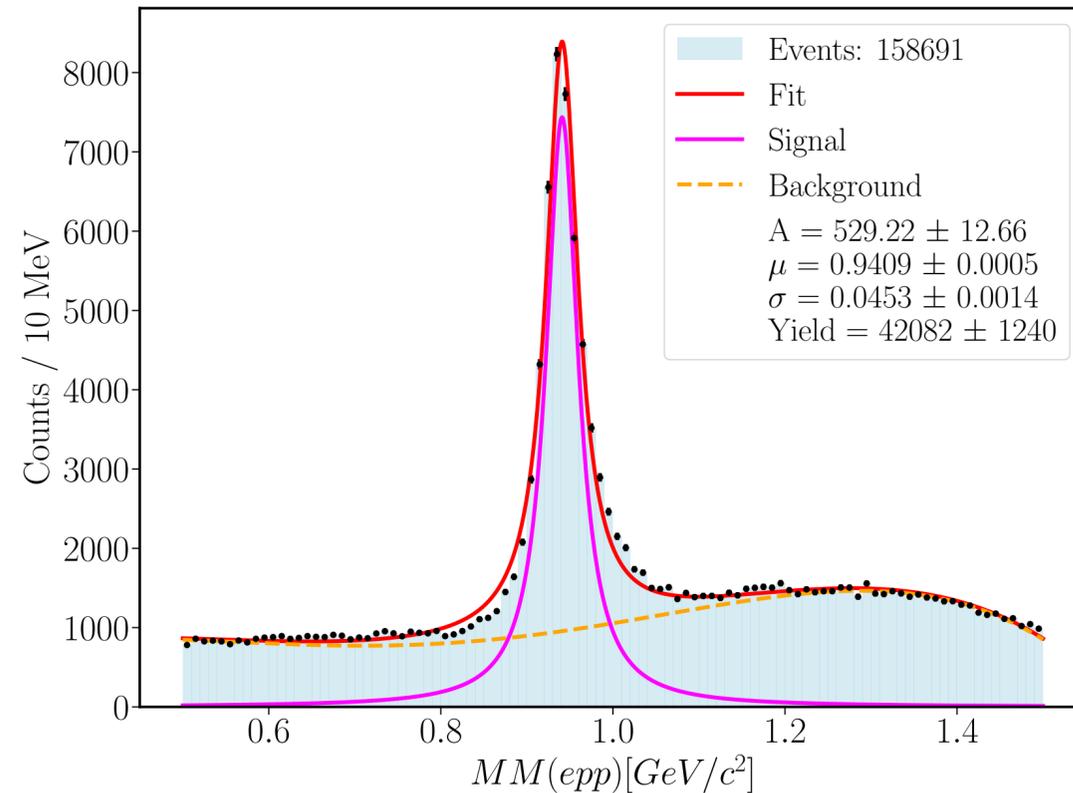
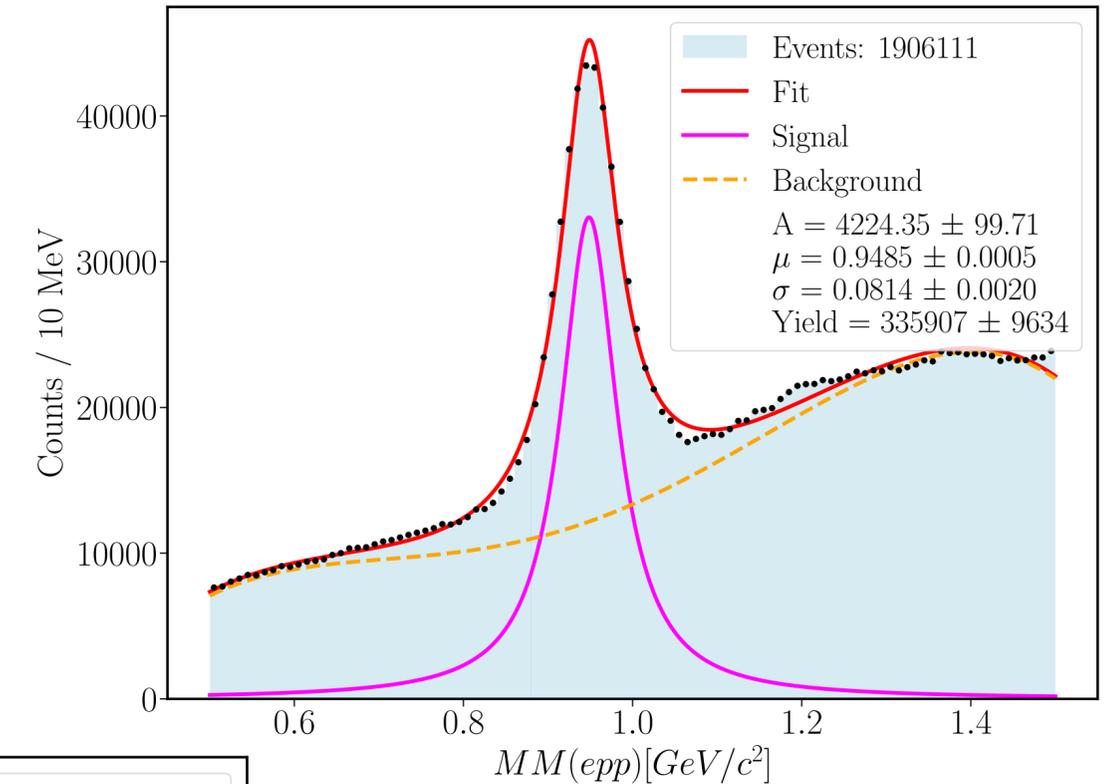
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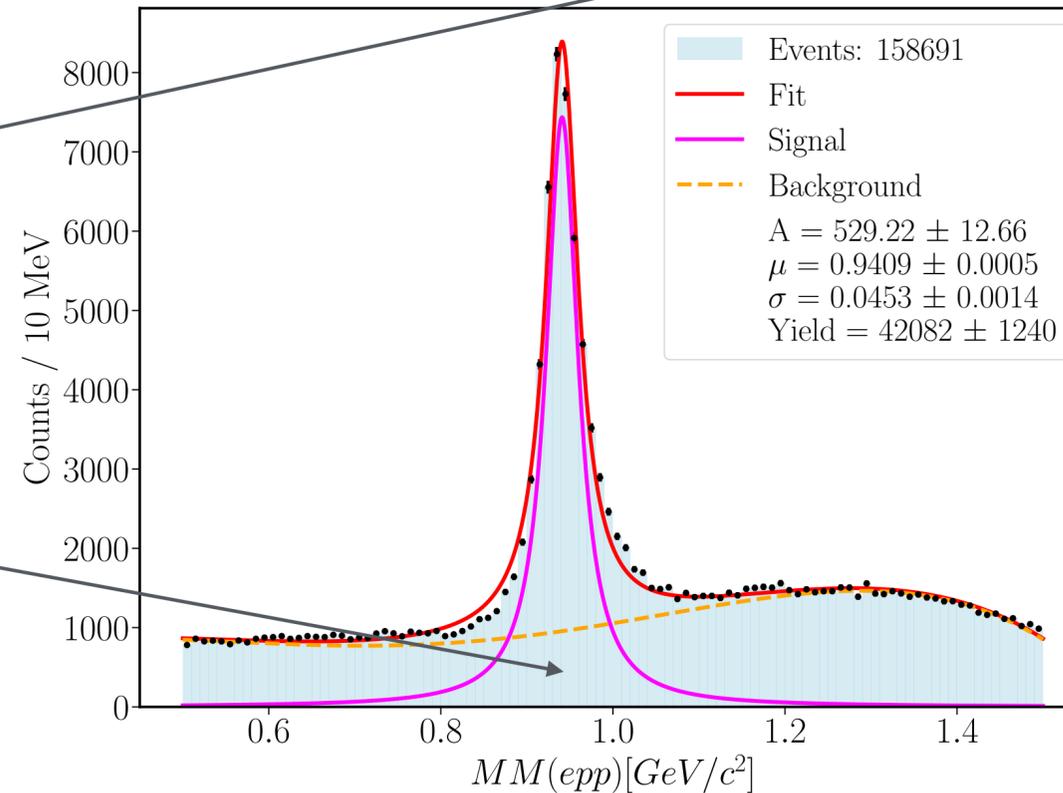
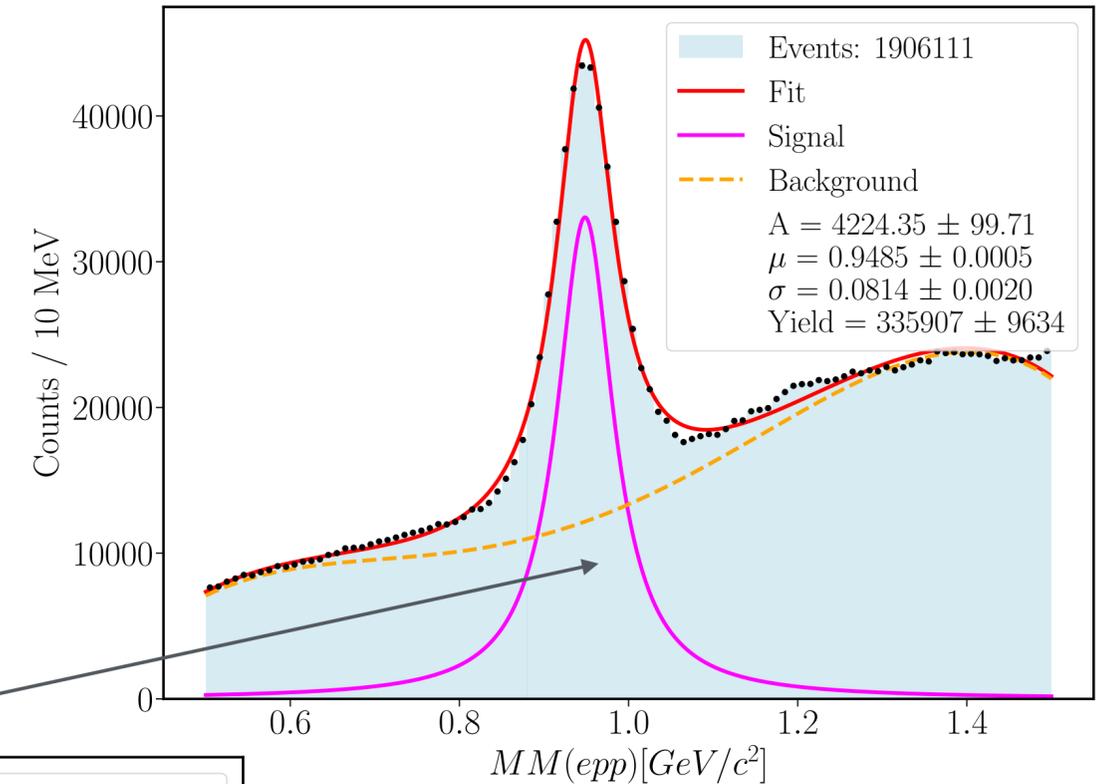
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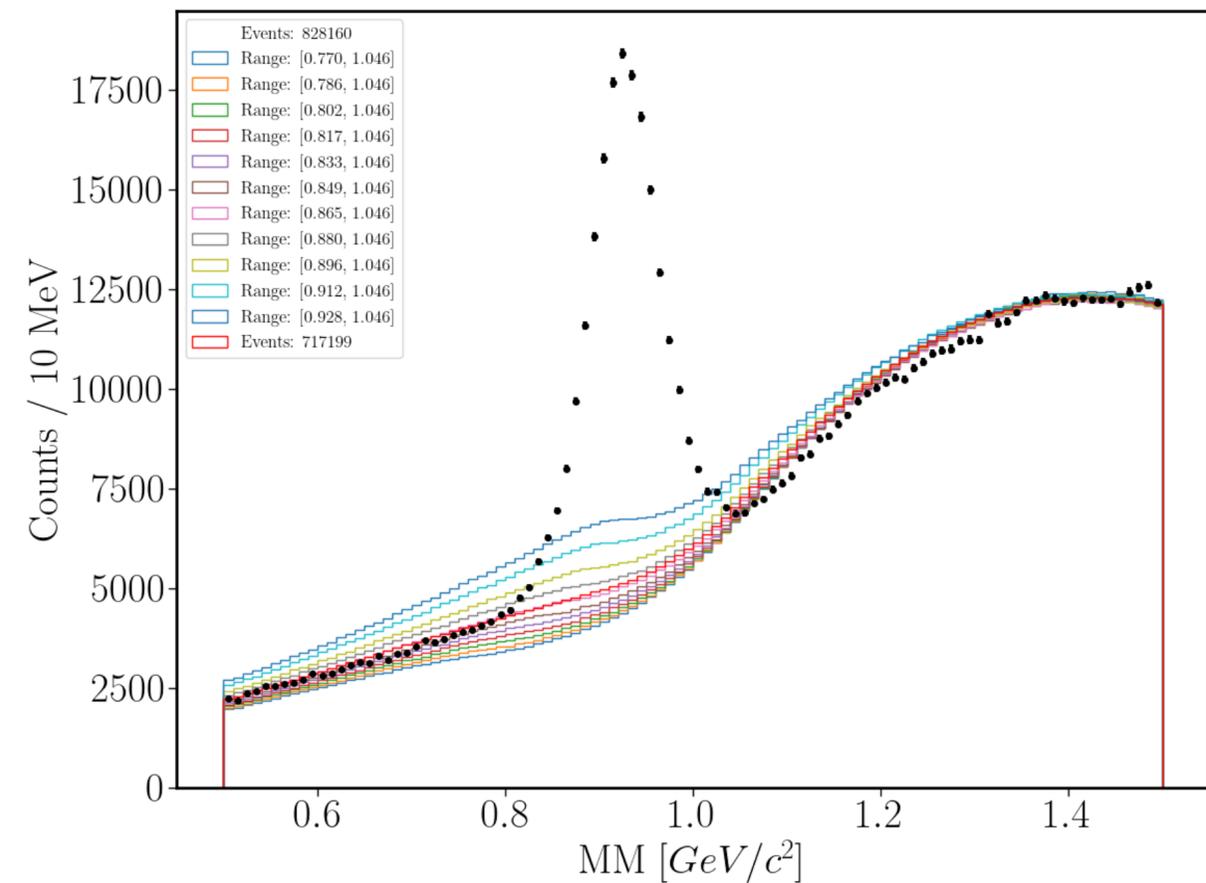
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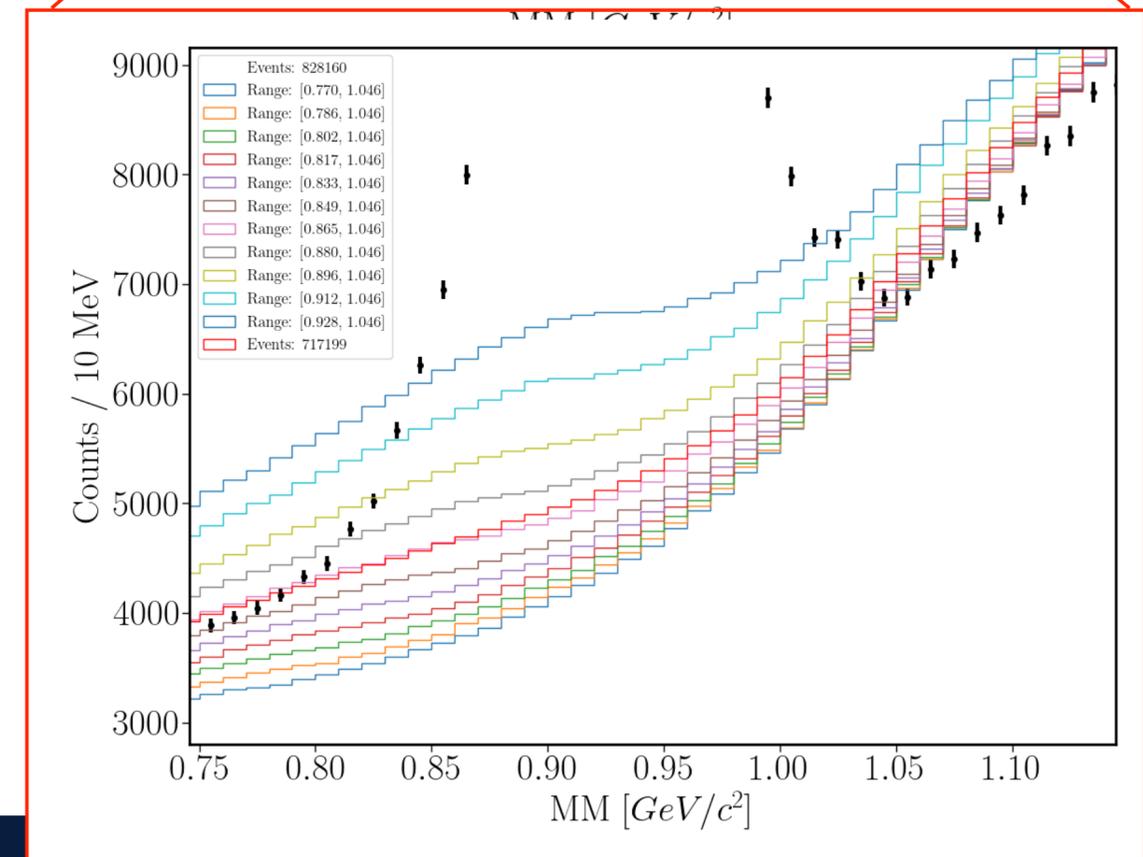
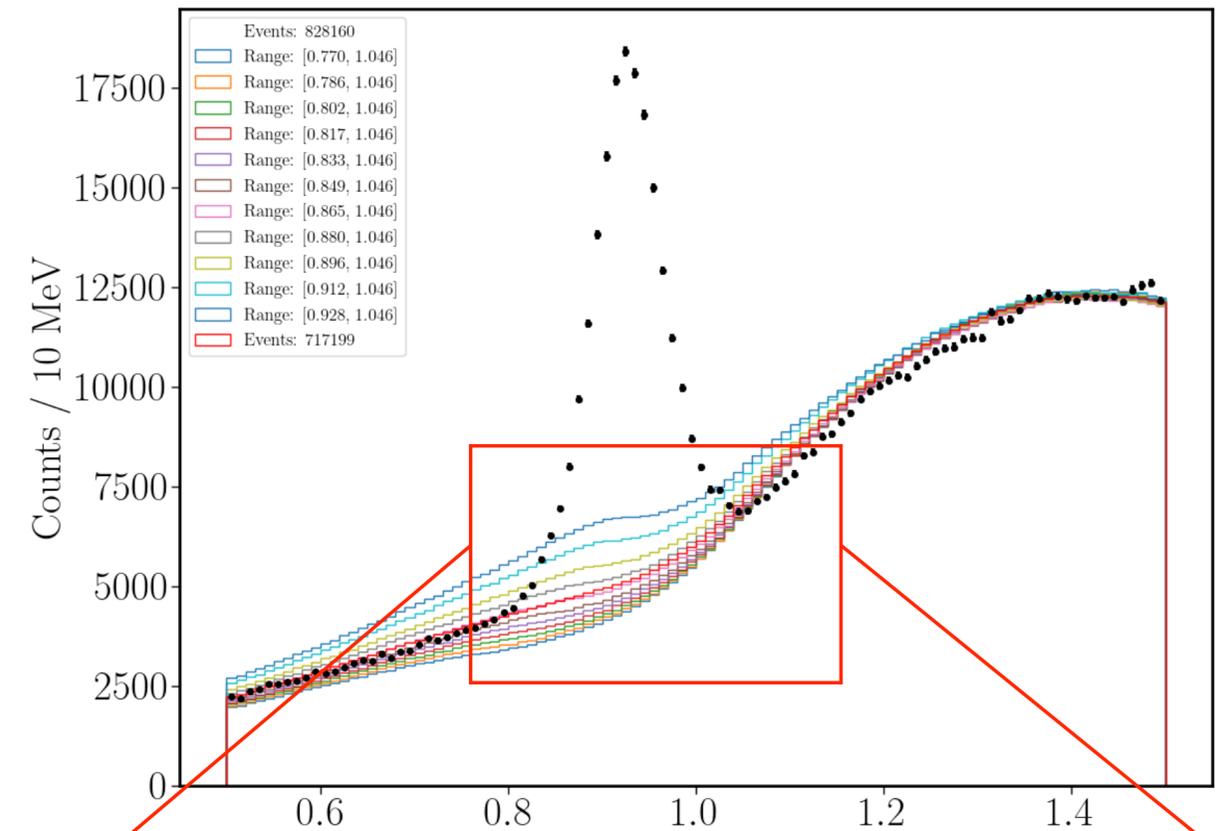
Background Studies

- Data driven background estimation technique
- ϕ Randomization
 - Break correlation of final state protons
 - Estimate uncorrelated background
- Multi step process
 - **Average** over many exclusion ranges



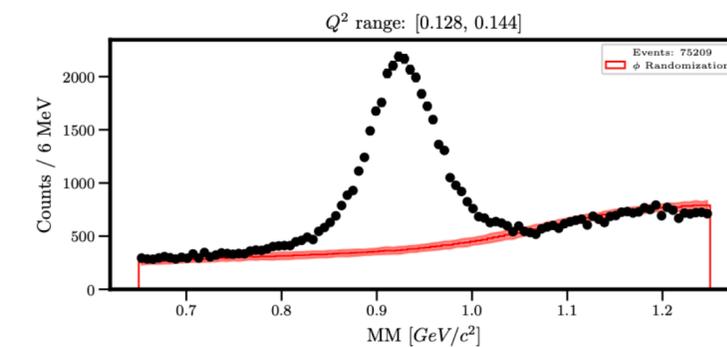
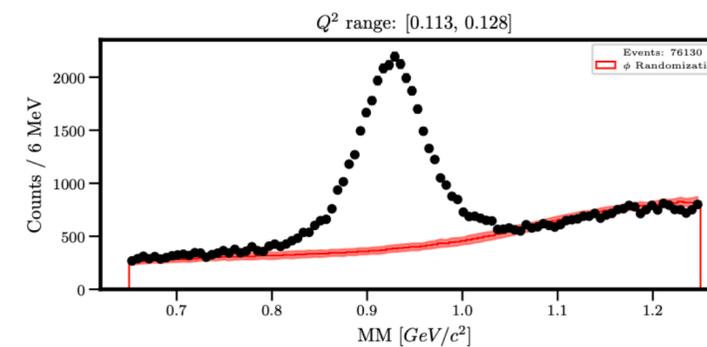
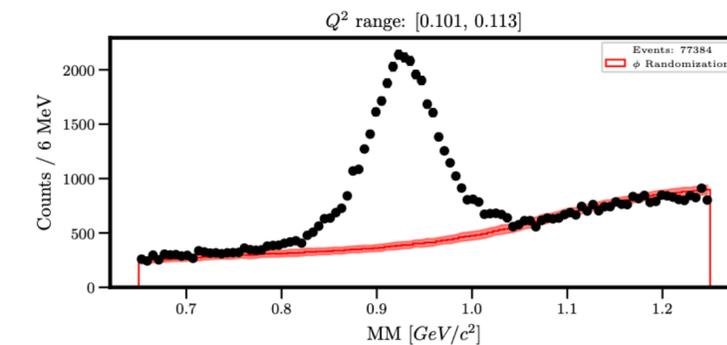
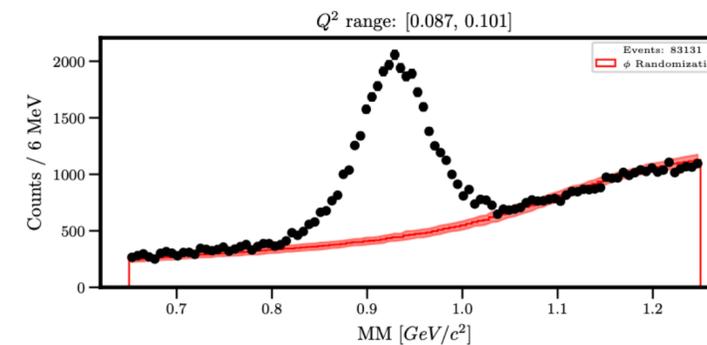
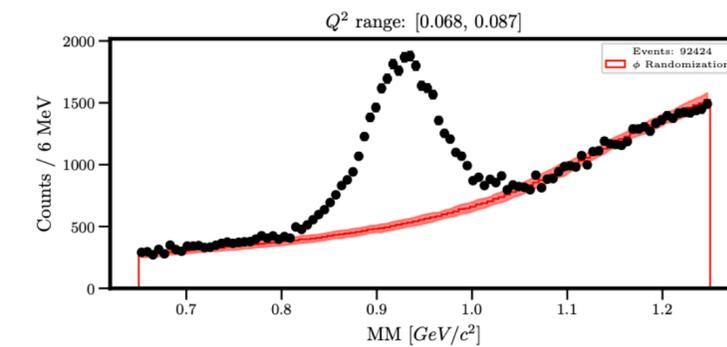
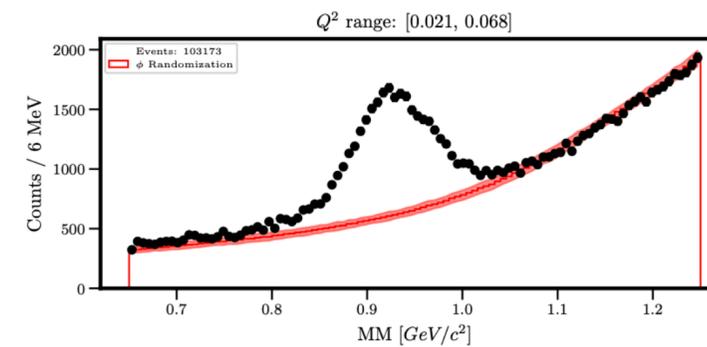
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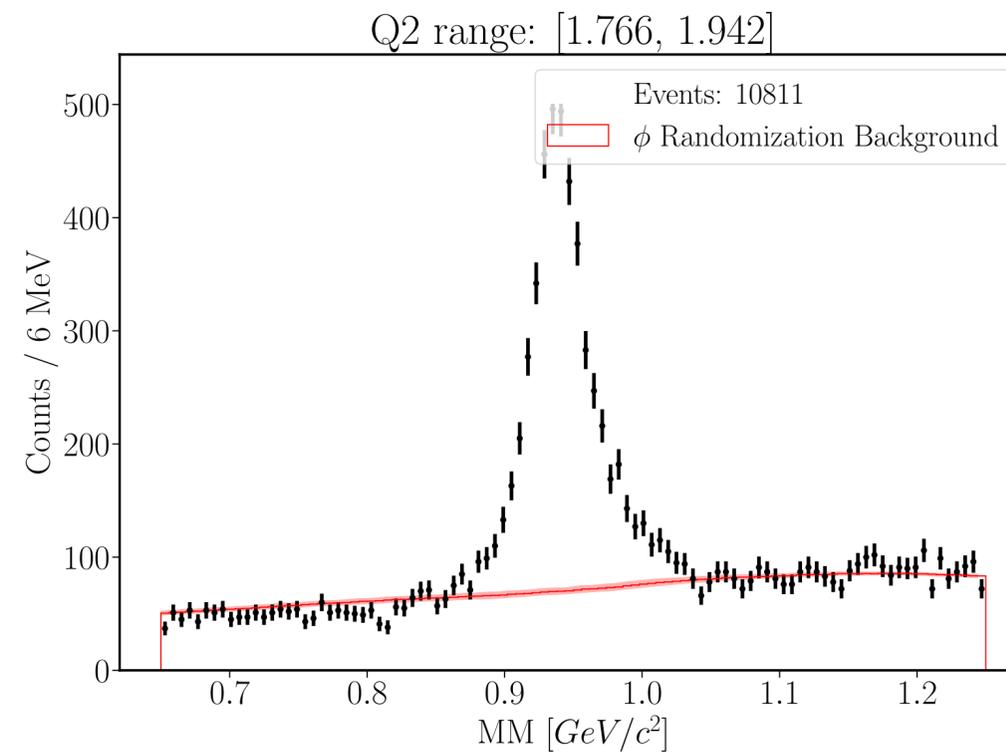
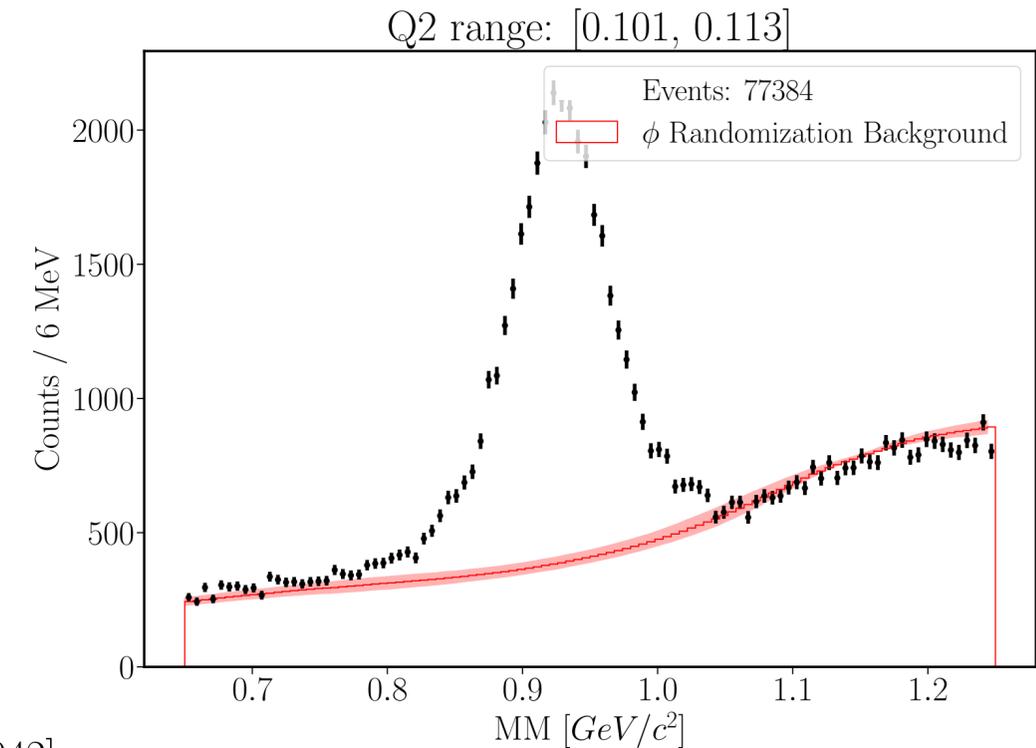
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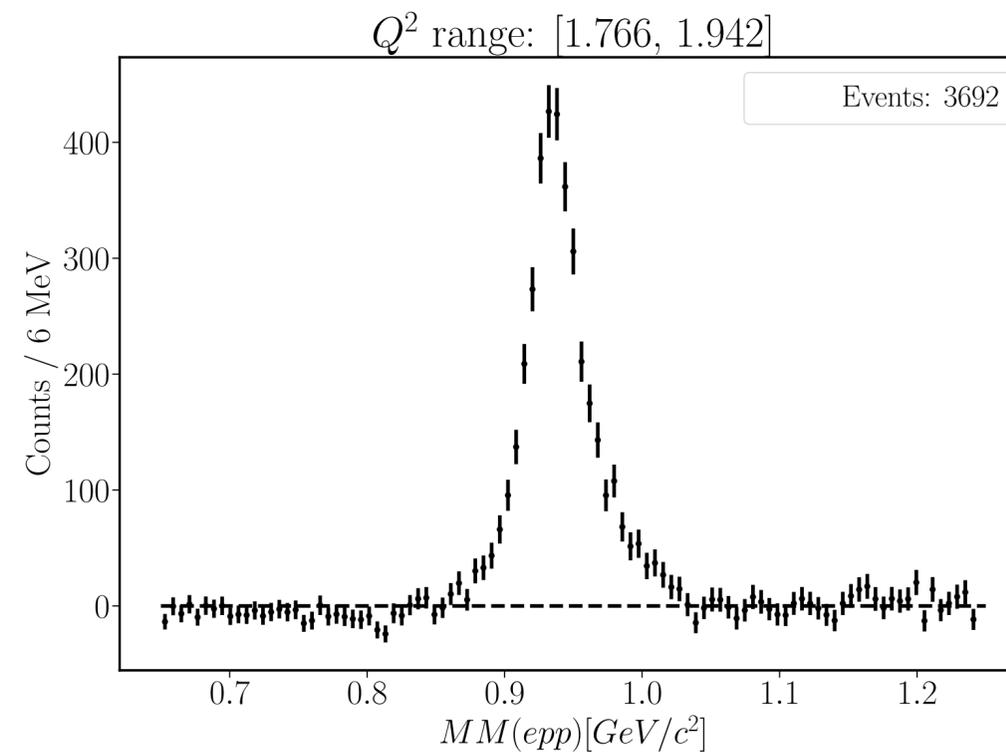
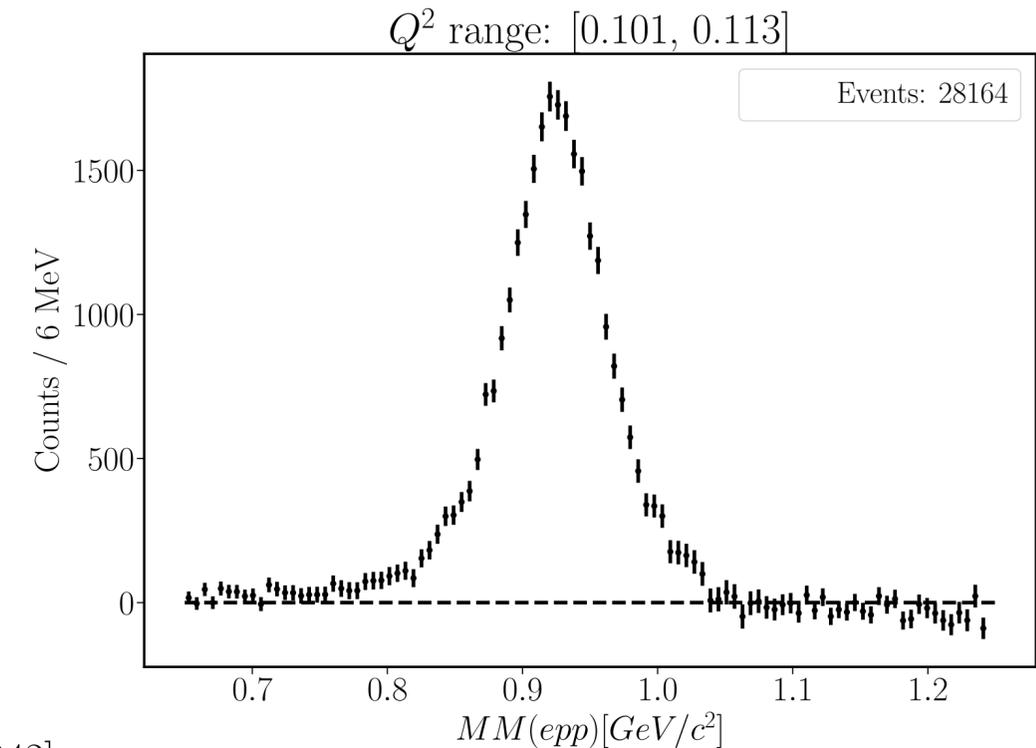
Background Subtraction

- How well does data driven background estimation work?
 - Subtract estimated background
- Isolate physics of interest
- Background under the peak is removed
- Shape of background useful for other distributions of $p\bar{p}$ system
 - Invariant Mass, Angular Distributions, ...



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Outlook

A brief summary

- $ep \rightarrow epp\bar{p}$
- First time high statistics electroproduction cross section extraction
- Amplitude Analysis
- Further background studies
 - Uncorrelated and combinatorial background

Backup Slides

Uncorrelated Background

- ϕ Angle Randomization to break the correlation in the final state
- $p_T^x = |p_T| \cos(\phi_1 + \delta_1)$
- $p_T^y = |p_T| \sin(\phi_1 + \delta_1)$
- Correlation between final state particles
 - Not $ep \rightarrow epp\bar{p}$ events

