The $\tilde{\eta_{c1}}$ analysis using genetic algorithm

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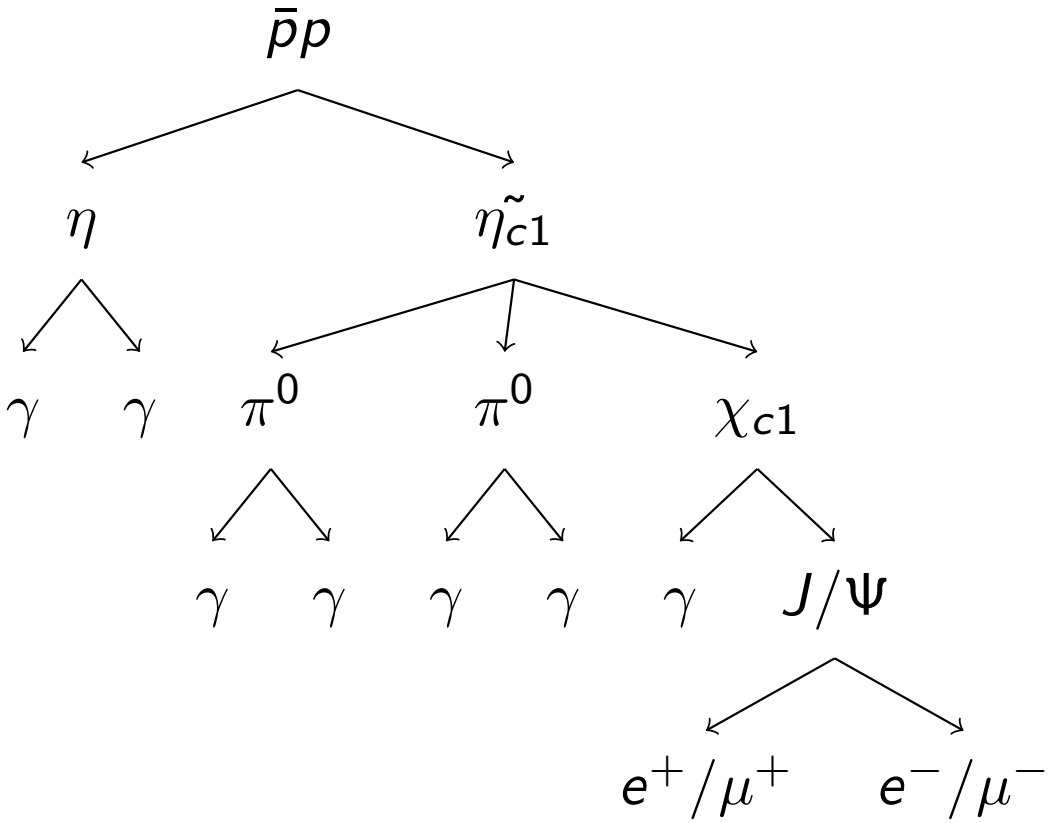
Exotic Charmonium - Motivation

- For hybrid charmonium states the ground state is expected to be 1^{-+} spin-exotic
- Lattice QCD calculations predict its mass to be around 4290 MeV with a width of 20 MeV
- Flux-tube model calculations predict for a hybrid state of this mass suppressed decays to open charm with respect to hidden charm decays
- An OZI-allowed decay to hidden charm would be the transition to χ_{c1} with emission of light hadrons, preferable scalar particles
- The lightest scalar system is composed out of two neutral pions in a relative s-wave
- One of its possible decay channel is used as a benchmark channel in the EMC TDR

Decay Tree


$\bar{p}p$
η
$\tilde{\eta_{c1}}$
γ γ
π^0
π^0
χ_{c1}
γ γ γ γ γ
J/Ψ
e^+/μ^+
e^-/μ^-

Dedicated Background Channels

- $\bar{p}p \to \chi_{c0}\pi^0\pi^0\eta$
- $\bar{p}p \to \chi_{c1}\pi^0\pi^0\pi^0\eta$
- $\bar{p}p \to \chi_{c1}\pi^0\eta\eta$
- $\bar{p}p \to J/\Psi\pi^0\pi^0\pi^0\eta$

Simulation and Reconstruction

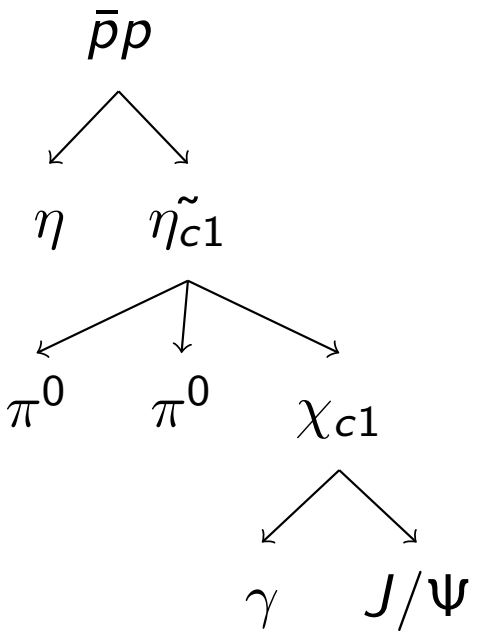
- Antiproton momentum: 15 GeV
- 100000 signal with electron and with muon pairs
- 1000000 x 4 dedicated background channel with electron and with muon pairs
- 250000000 filtered DPM events (1 muon pair and their mass is 2.5-4 GeV)
- During the event generation the PHSP model was used - all spins of particles in the initial and final state are averaged
- In case of electrons the Bremstrahlung-correction is used

Genetic Algorithm

- Machine learning technique inspired by natural selection
- Useful when the parameters to be optimized have different ranges
- The results can be easily understood (not a black box)
- Individual: represents a parameter set
- Mutation: randomly modify a parameter with a few percent
- Cross-over: generate new individuals by taking parameters from 2 or more individuals
- Selection: Delete the worst individuals

Different Analysis Methods

- 2 analysis methods for comparison:
  - Analysis method suggested in the EMC TDR
  - TDR method with cuts optimized by the genetic algorithm

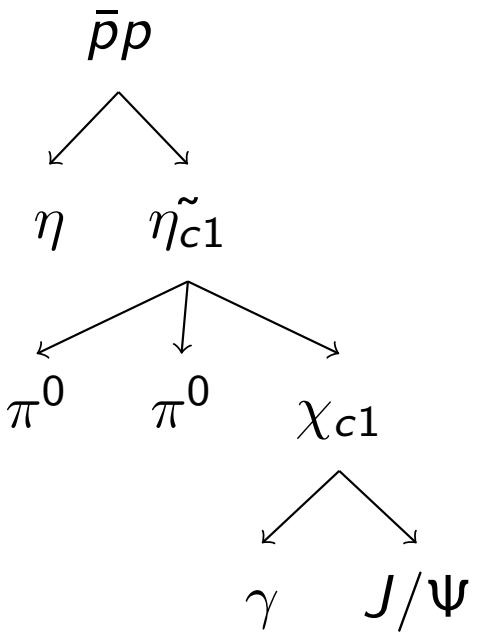


TDR Analysis

- Two photon candidates are combined and accepted as π and η candidates if their invariant mass is within 3 σ
- Combine all e/μ candidates and accept them as J/Ψ if their mass is within 3 σ and apply a vertex fit with a mass constraint
- Combine these with a photon and accept them as a χ_{c1} if their mass is within 3 σ
- Then reconstruct the initial system and perform a 4-constraint fit and accept only those ones which have a probability $> 0.1\%$
- Apply a stricter mass cut on the remaining χ_{c1} and η candidates (1 σ)
- Perform mass constraint fits on all intermediate states except the charmonium and a new 4-constraint fit on the system created from the fitted states - a probability $> 0.1\%$ is required at every step

Genetic Algorithm Based on the TDR

- The same procedure as previously until the first 4-constraint fit
- But the stricter χ_{c1} and η mass cuts and all the probability cuts are determined by the genetic algorithm



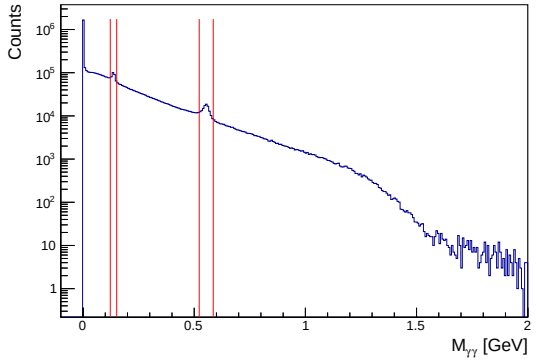
Cuts

	Genetic TDR	**TDR analysis**	**G. TDR e^+e^-**
4C fit	0.0100477	0.001	0.022675
χ_{c1} mass fit	0.427254	0.001	0.585162
η mass fit	0.06143	0.001	0.355322
π mass fit	0.0394484	0.001	0.0835868
Other π mass fit	0.0223424	0.001	0.0751305
Second 4C fit	0.187512	0.001	0.0515629
η mass cut	3.4 σ	1 σ	1.35 σ
χ_{c1} mass cut	1.58 σ	1 σ	1.007 σ

Results of the Cuts

	Gen. $\mu^+\mu^-$	**TDR** $\mu^+\mu^-$	**Gen.** e^+e^-	**TDR** e^+e^-	**Generated**
Bck. 1	1199	3060	109	1673	1000000
Bck. 2	57	867	6	282	1000000
Bck. 3	349	804	46	396	1000000
Bck. 4	1477	3057	343	3140	1000000
All bck.	4616	9132	722	5998	4000000+comb.
Signal	452	315	48	47	100000
Significance	6.65	3.29	1.79	0.61	FTM/$\sqrt{\mathrm{Reconst.}}$
Filt. DPM	158	43	-	-	250000000

$\gamma\gamma$ invariant mass



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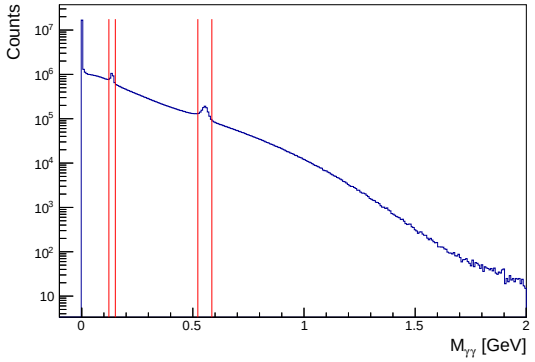

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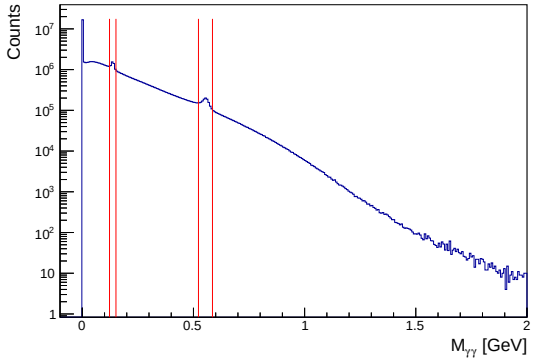

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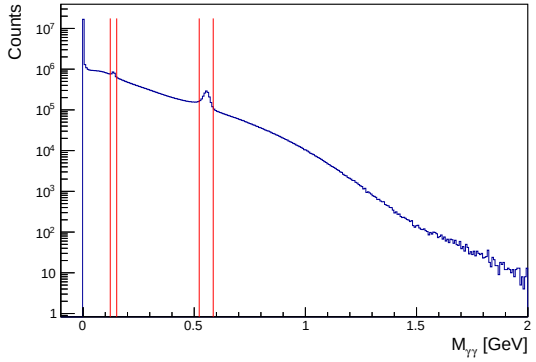

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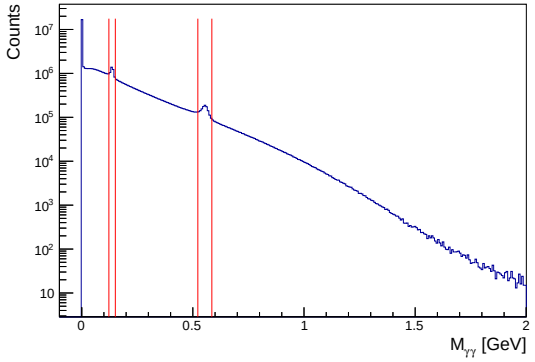

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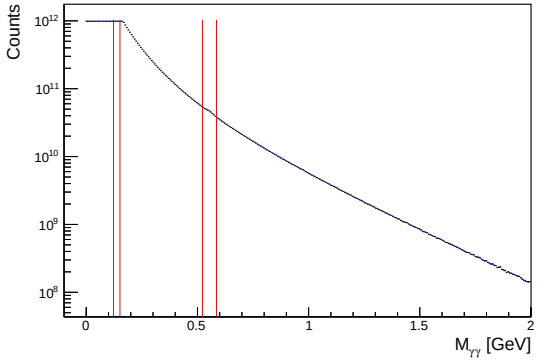
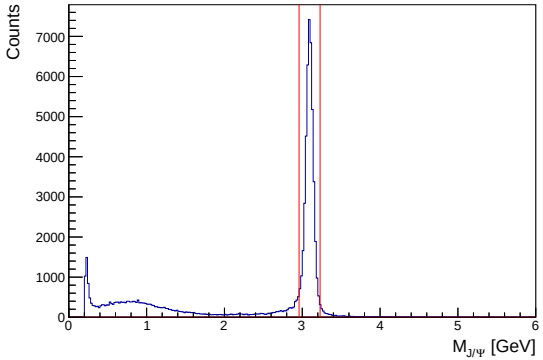


DPM

J/Ψ invariant mass



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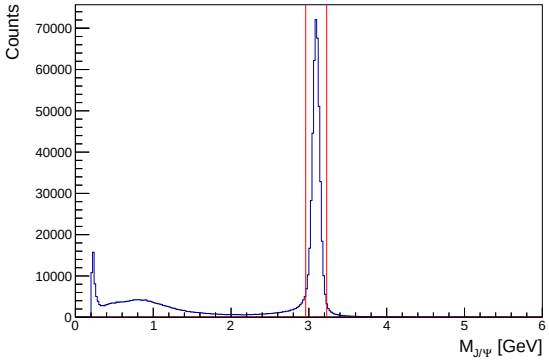

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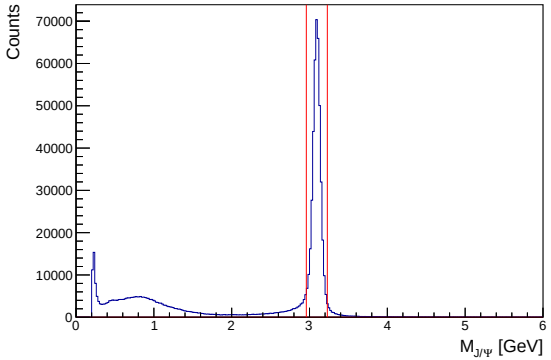

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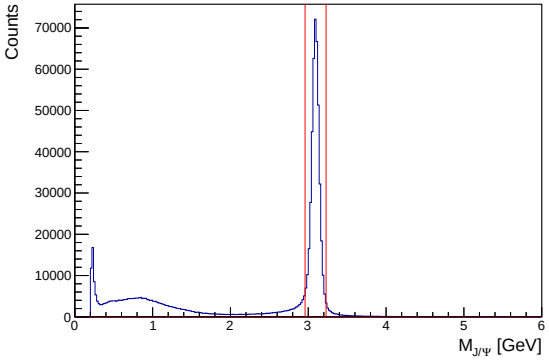

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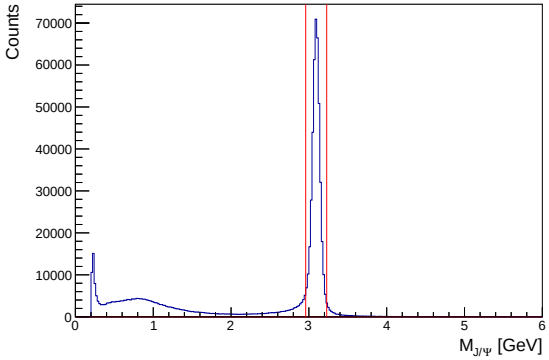

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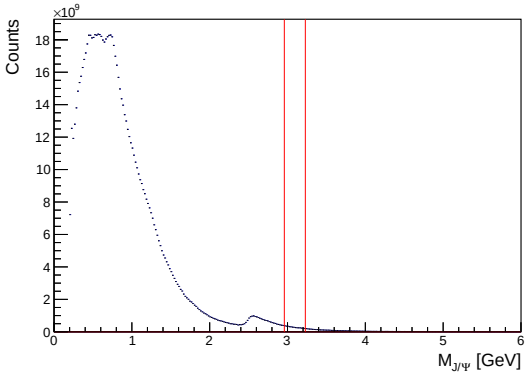
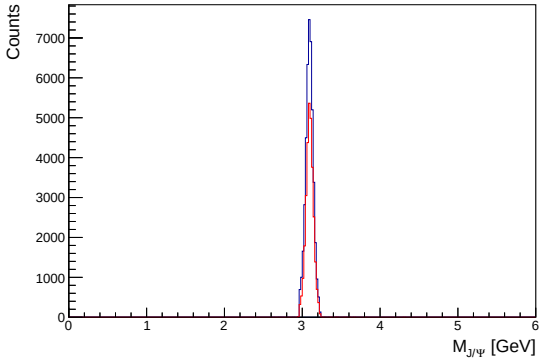


DPM

J/Ψ invariant mass after the fit and cut



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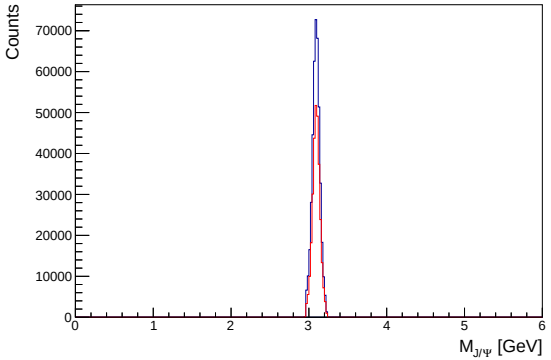

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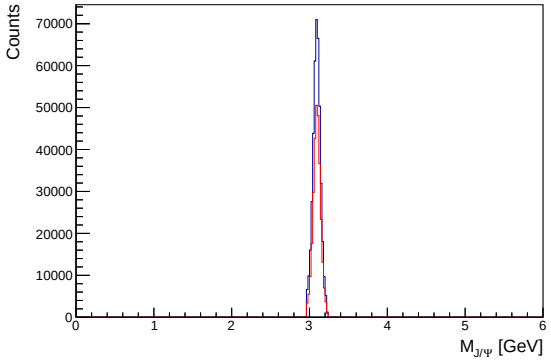

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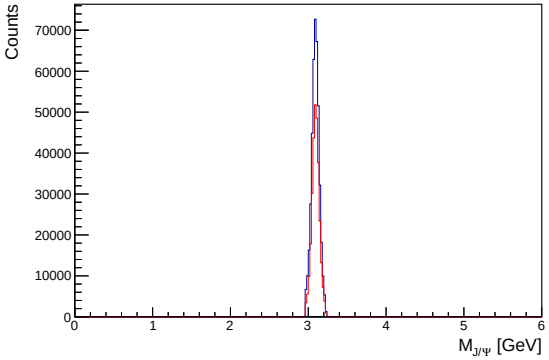

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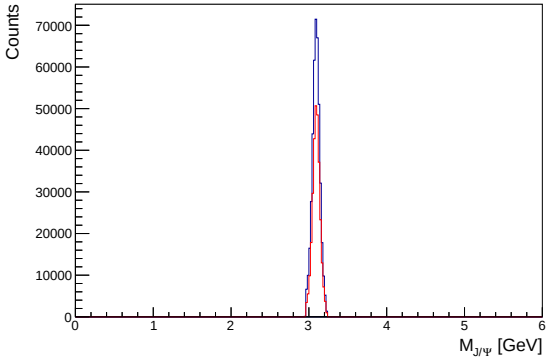

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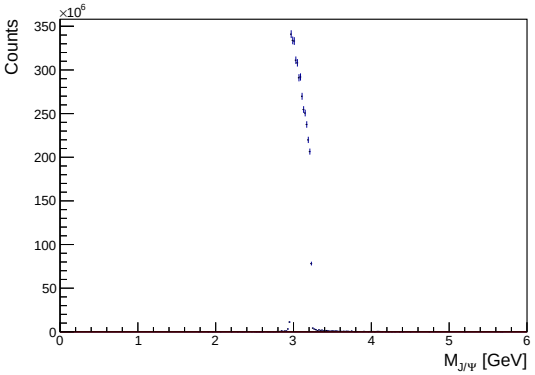
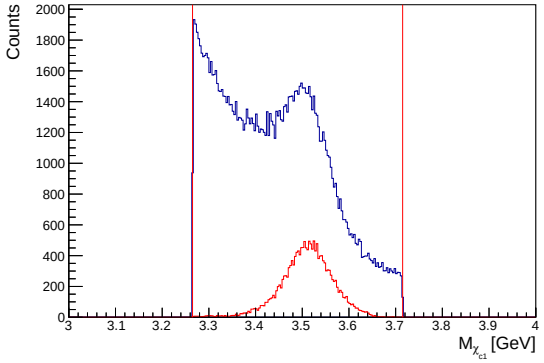


DPM

χ_{c1} invariant mass



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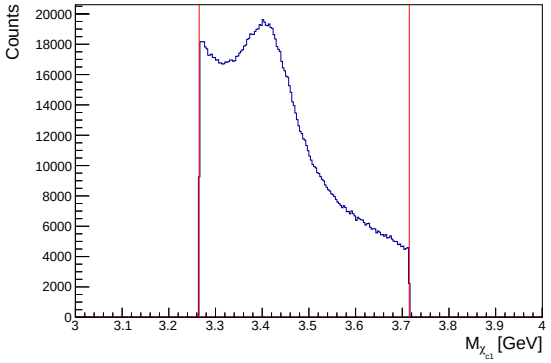

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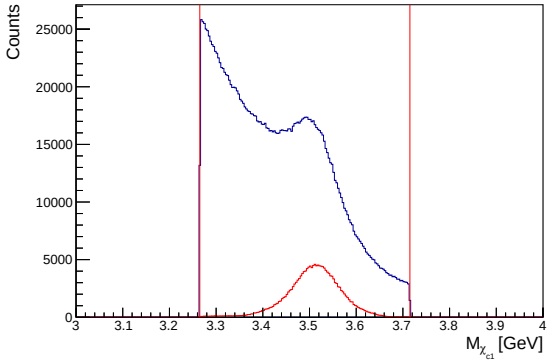

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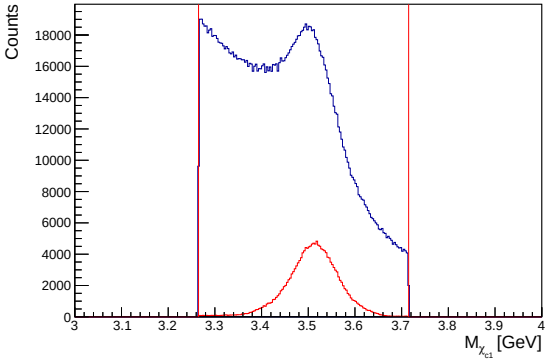

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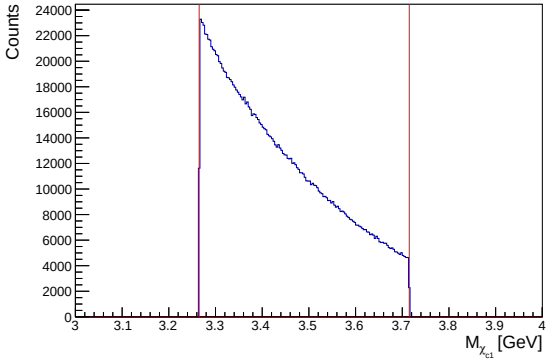

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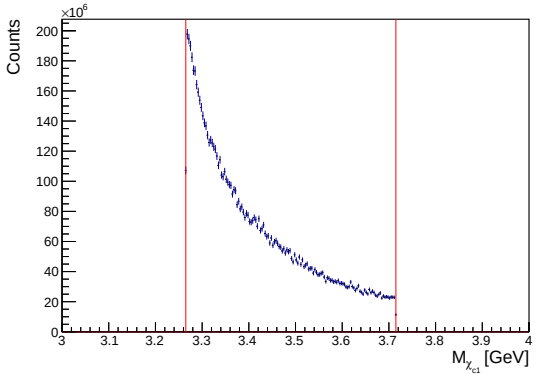
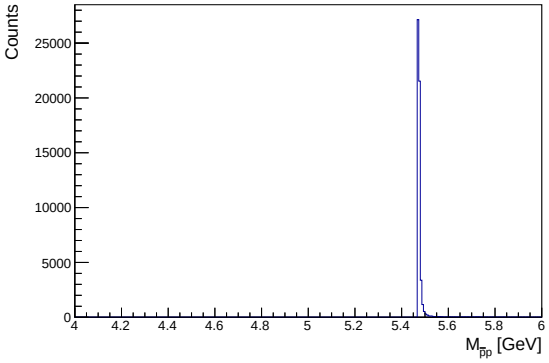


DPM

$\bar{p}p$ invariant mass



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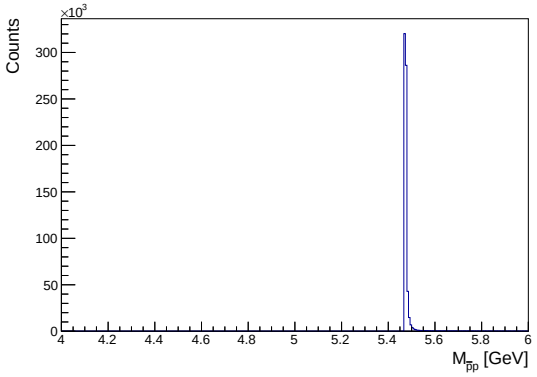

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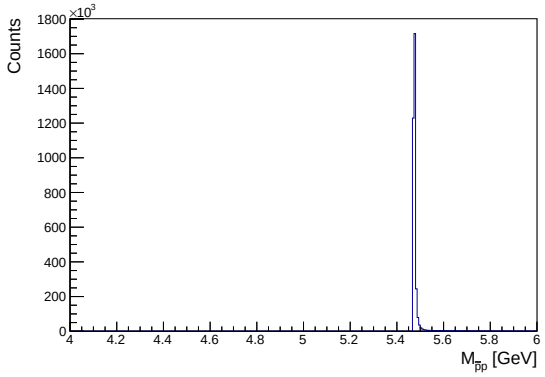

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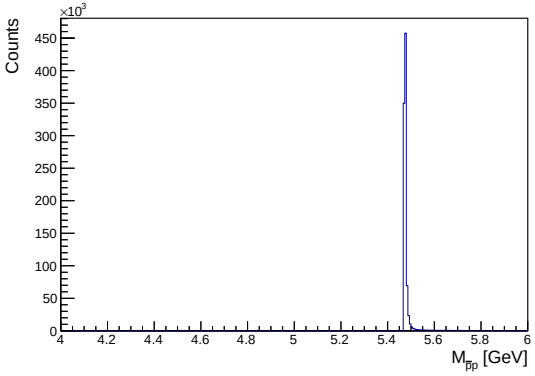

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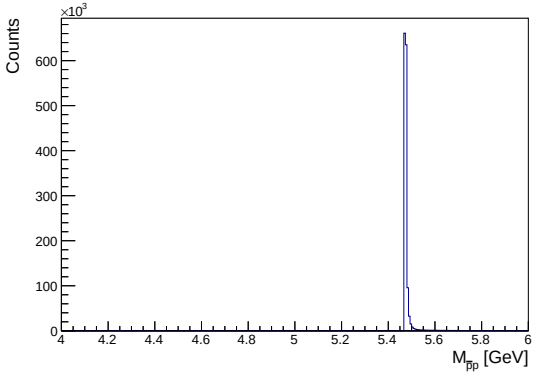

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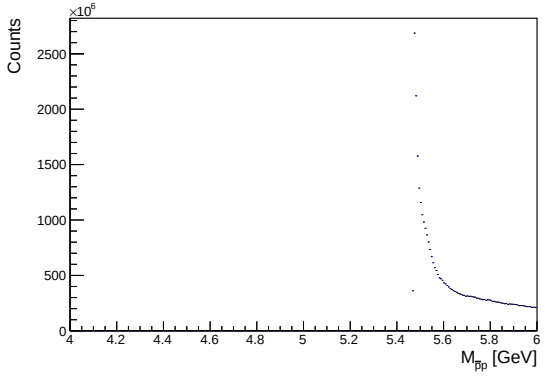
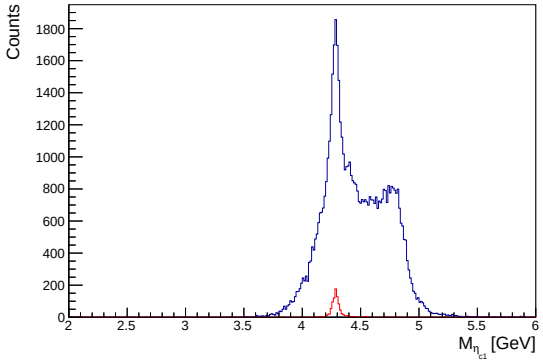


DPM

$\tilde{\eta_{c1}}$ invariant mass



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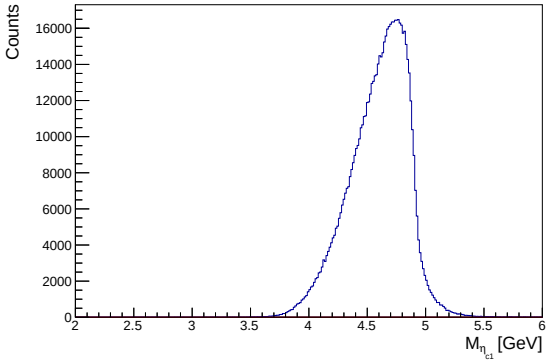

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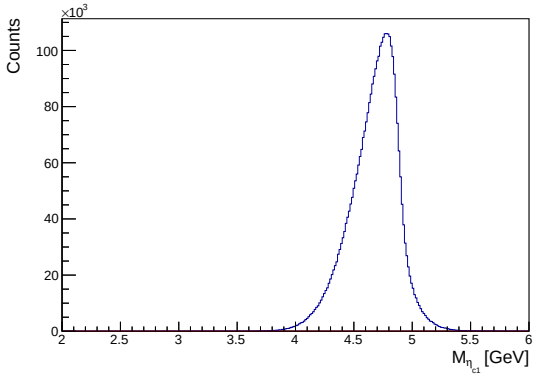

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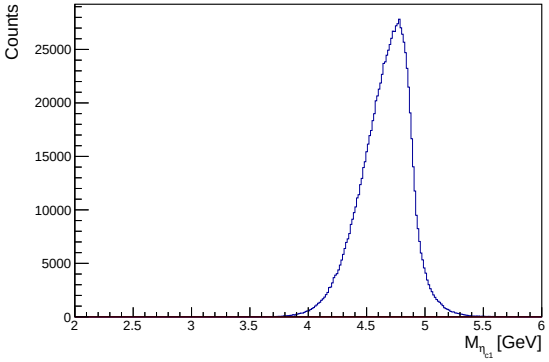

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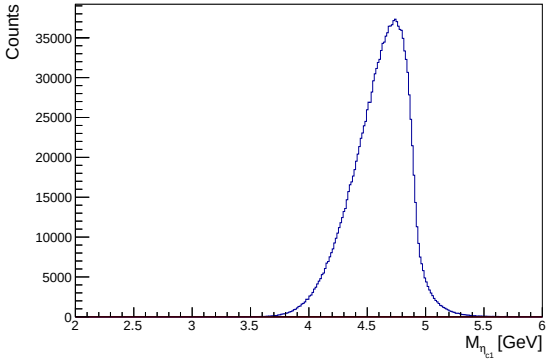

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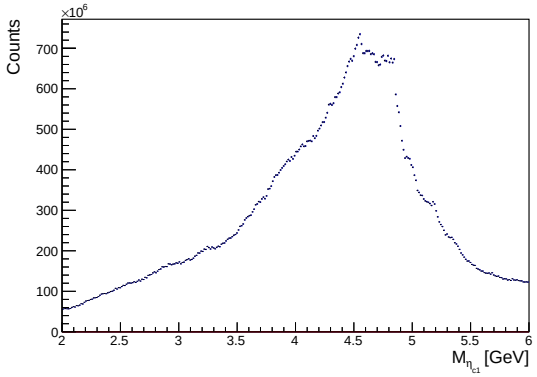
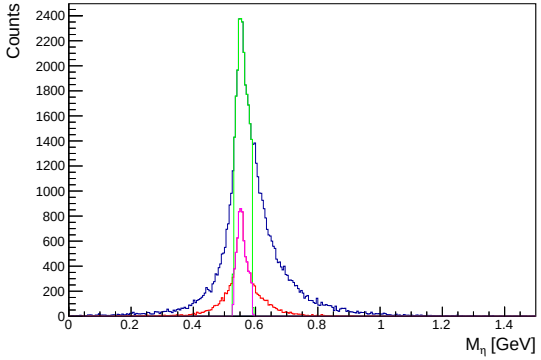


DPM

η invariant mass cut



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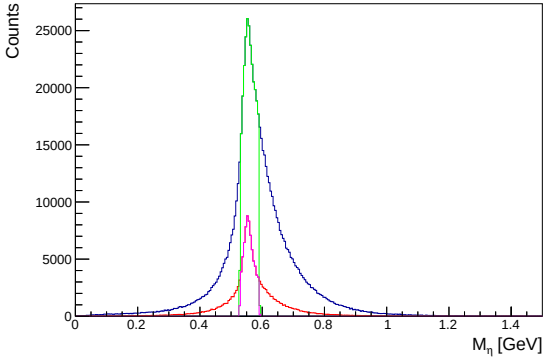

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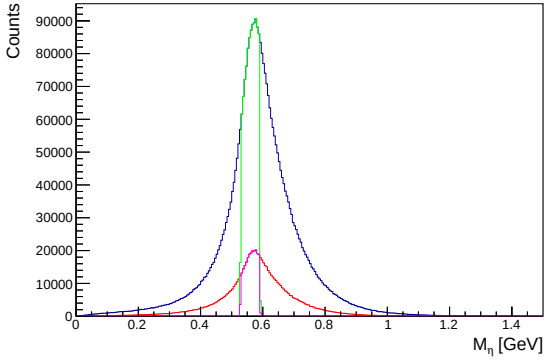

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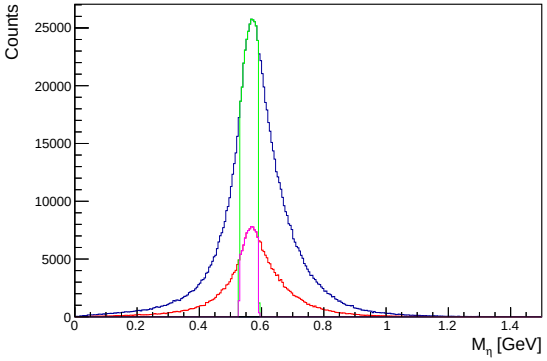

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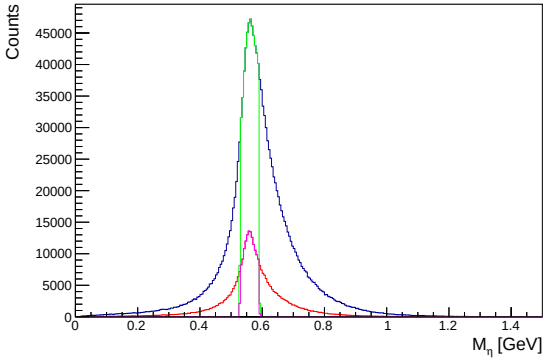

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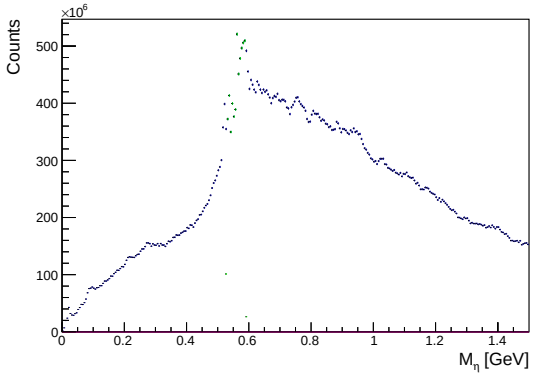
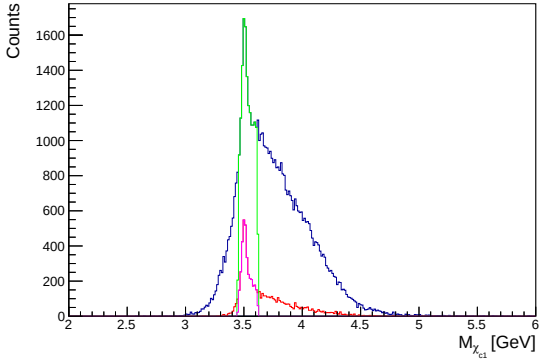
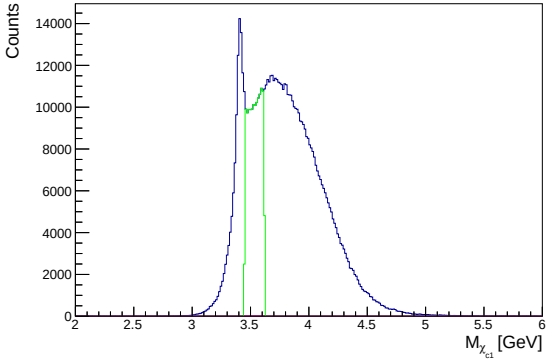


DPM

χ_{c1} invariant mass cut



Signal



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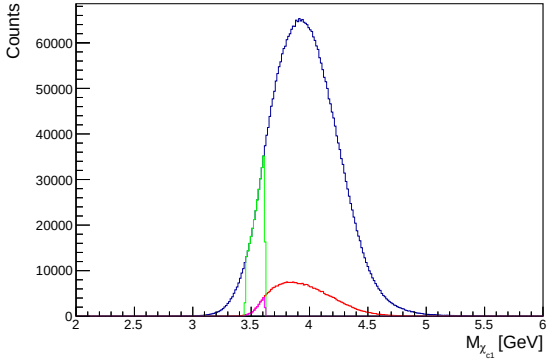

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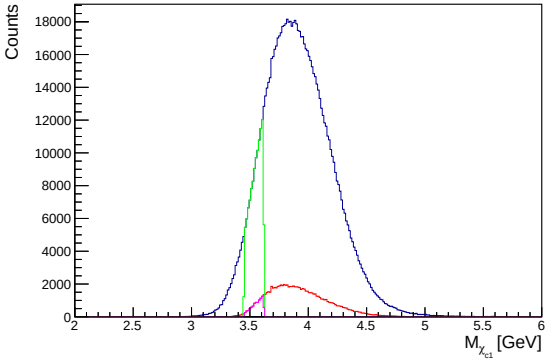

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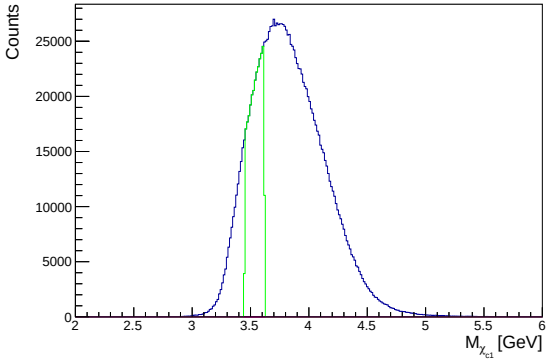

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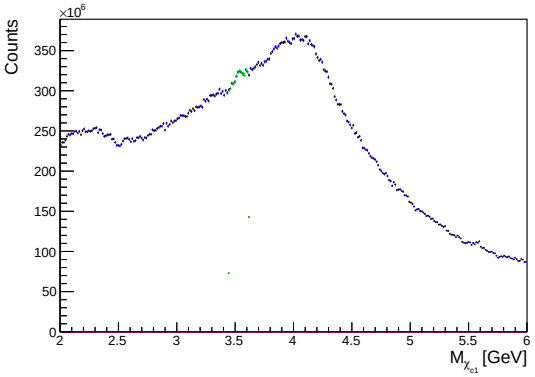
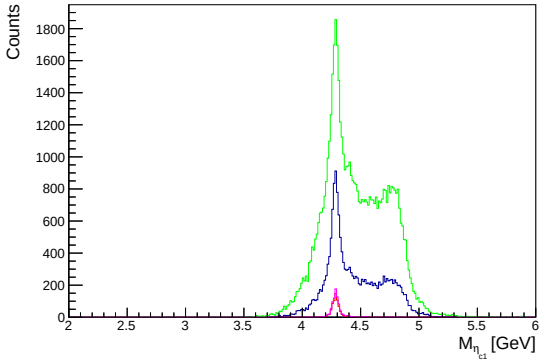
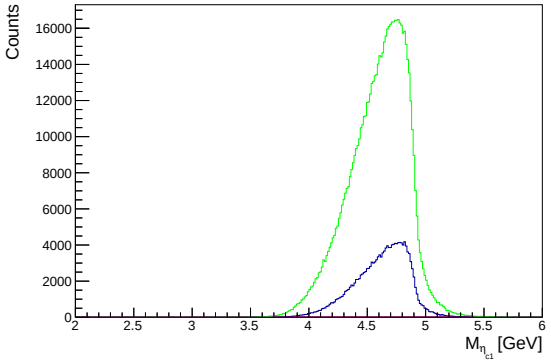


DPM

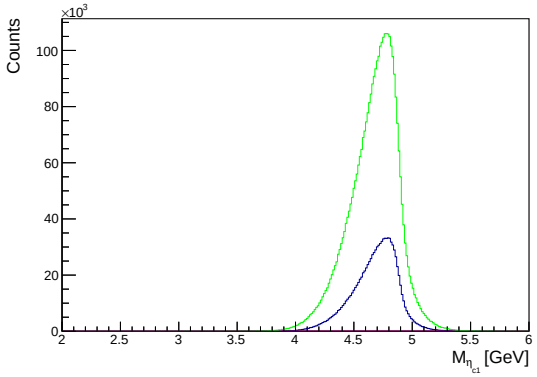
$\tilde{\eta_{c1}}$ invariant mass after the mass cuts



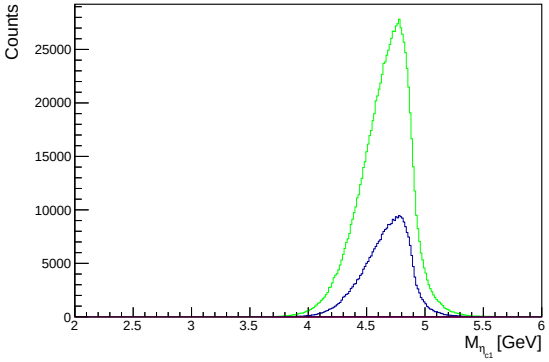
Signal



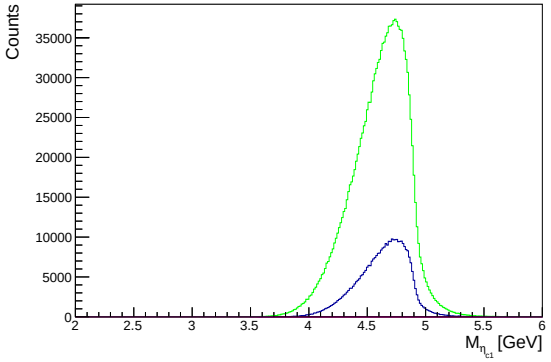
Background 1



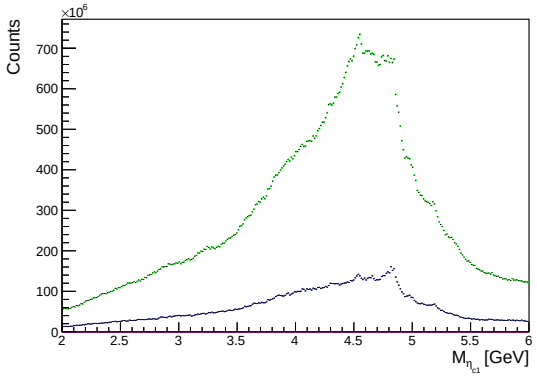
Background 2



Background 3

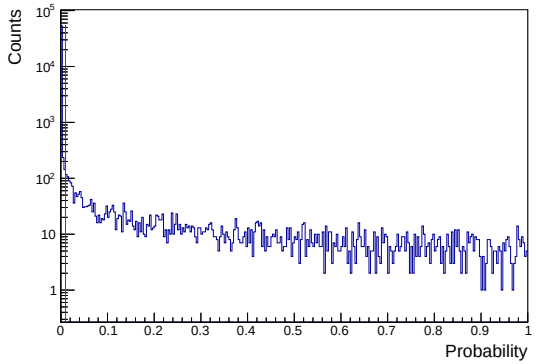


Background 4

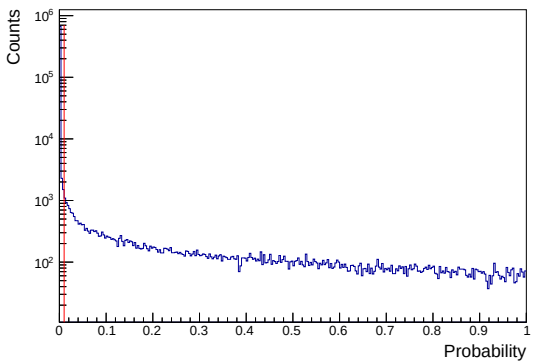


DPM

4C fit probability



Signal



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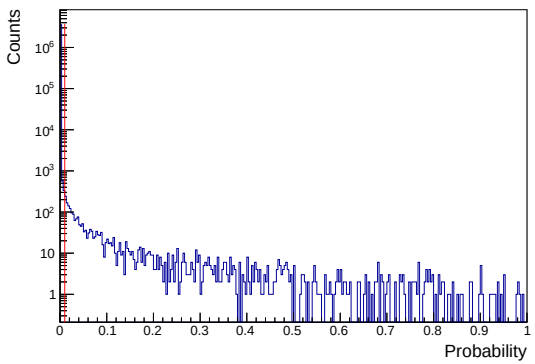

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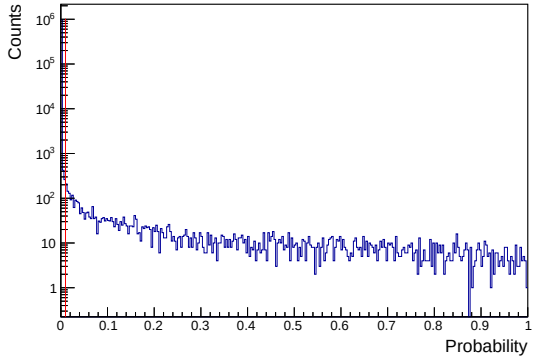

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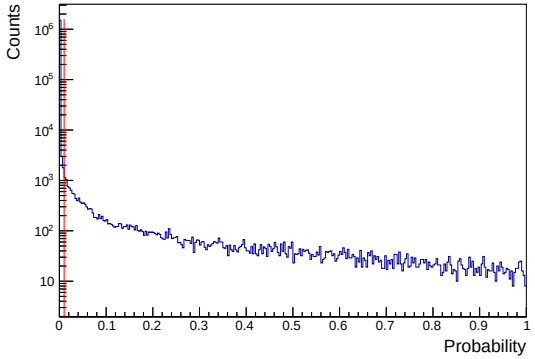

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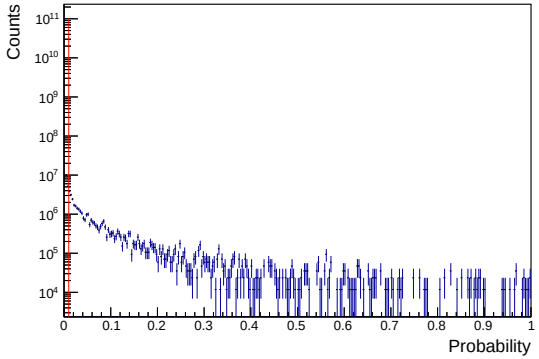
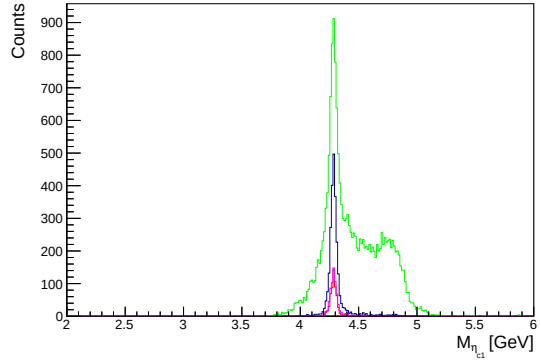
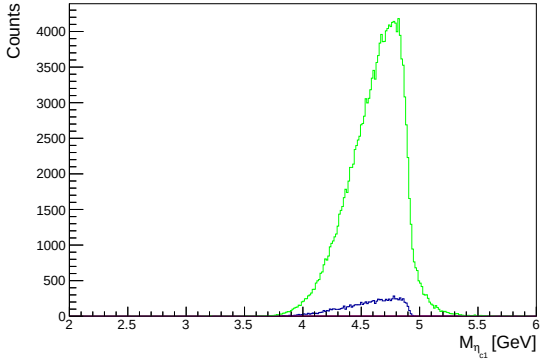


DPM

$\tilde{\eta_{c1}}$ invariant mass after the mass and prob. cuts



Signal



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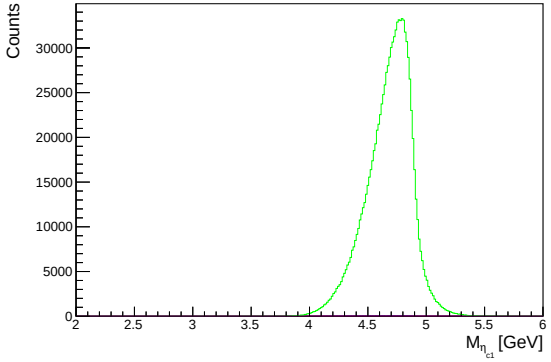

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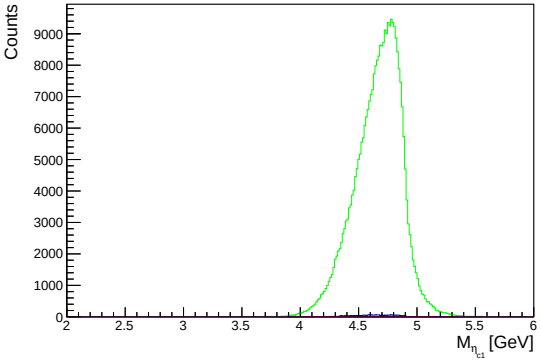

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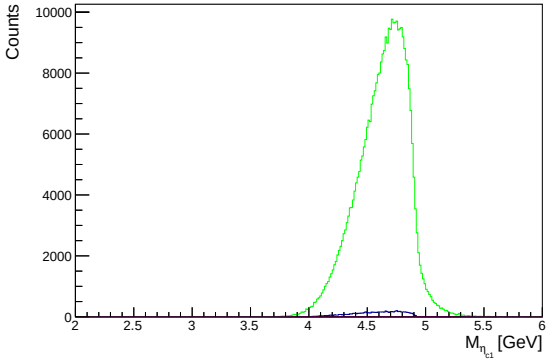

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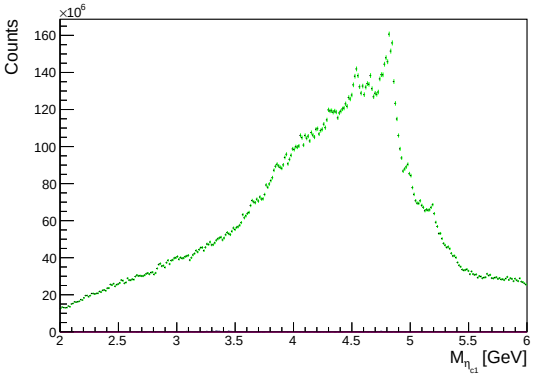
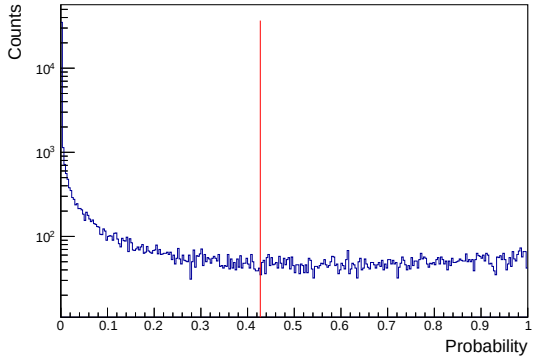
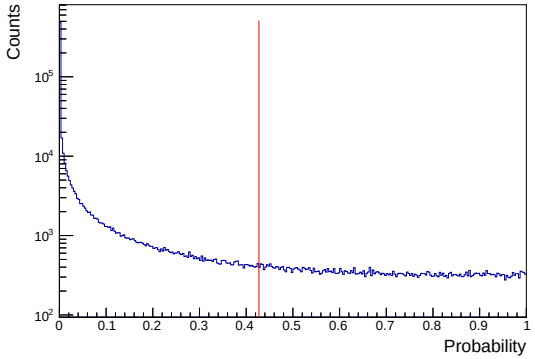


DPM

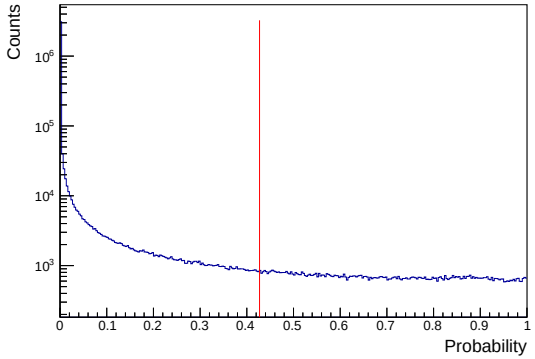
χ_{c1} mass fit probability



Signal



Background 1



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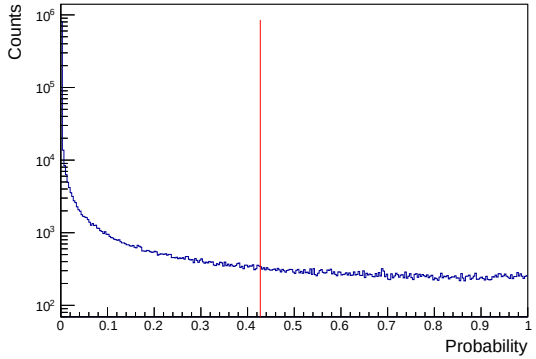

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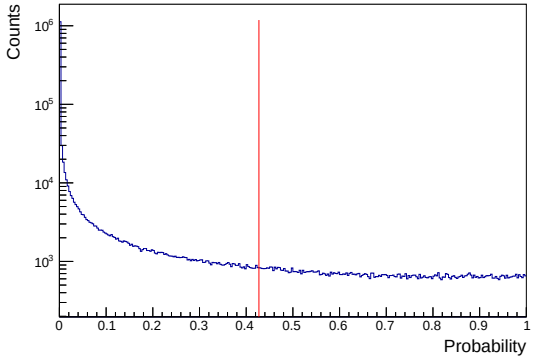

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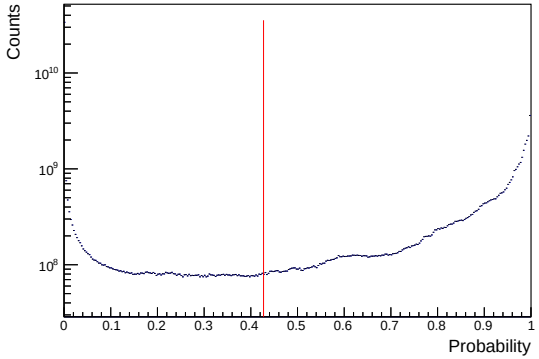
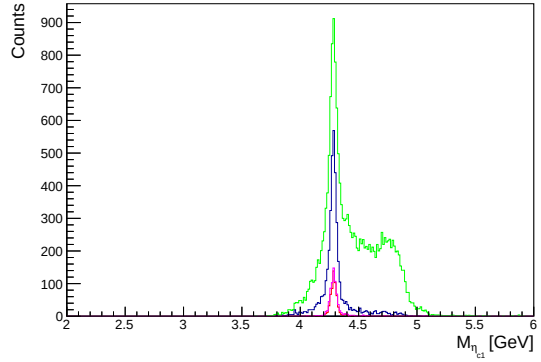
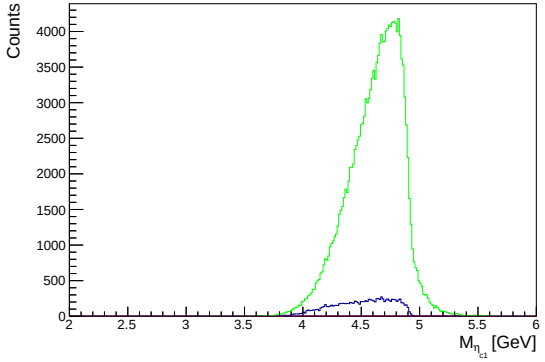


DPM

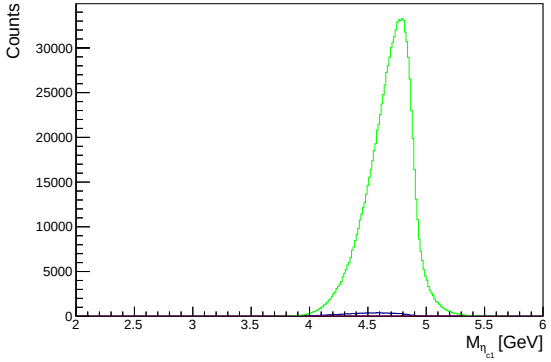
$\tilde{\eta_{c1}}$ invariant mass after the mass and prob. cuts



Signal



Background 1



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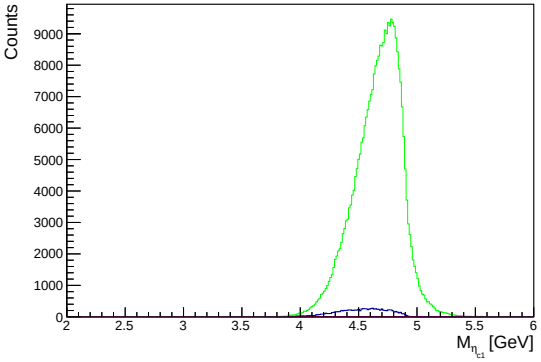

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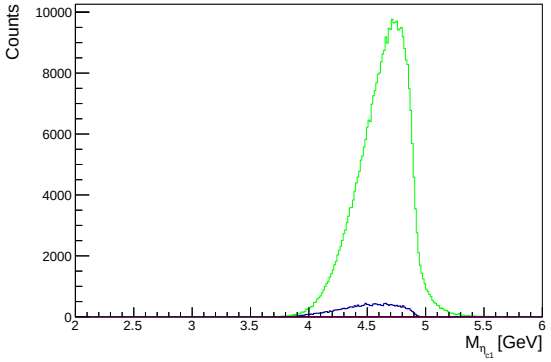

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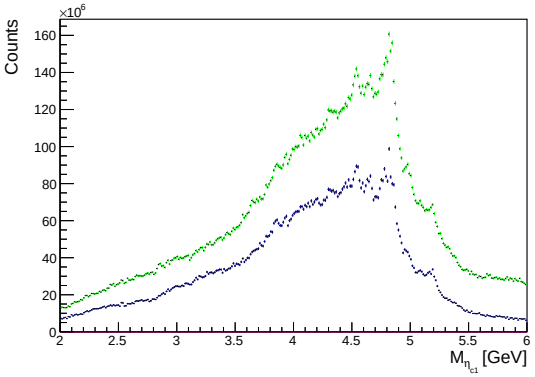
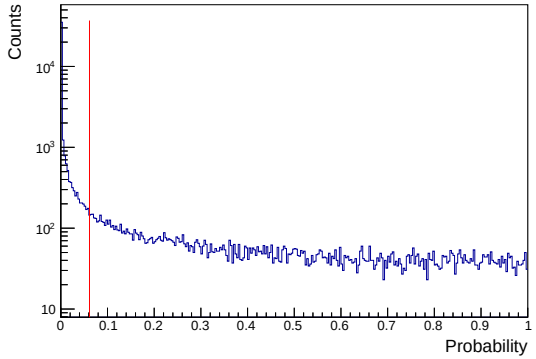
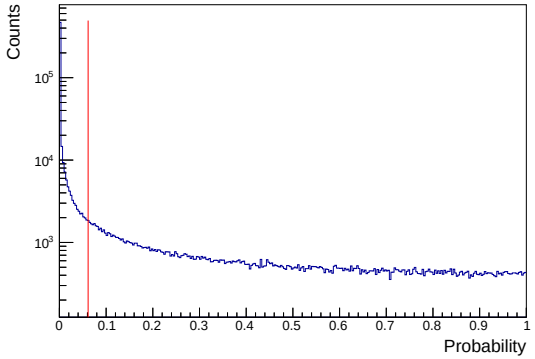


DPM

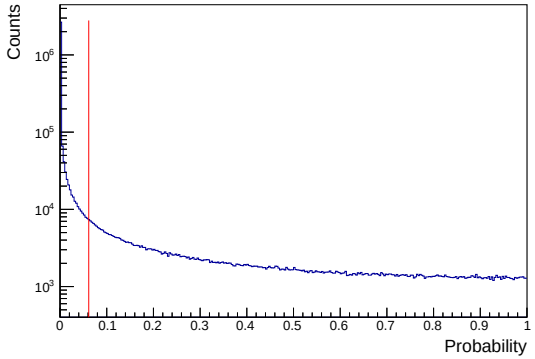
η mass fit probability



Signal



Background 1



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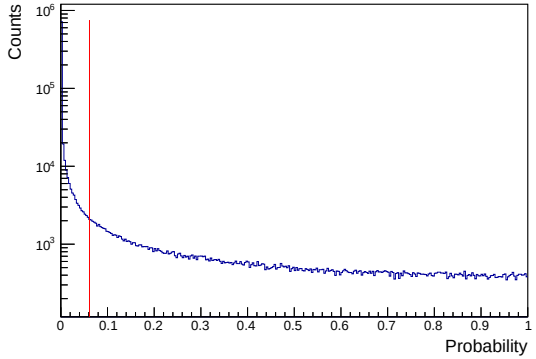

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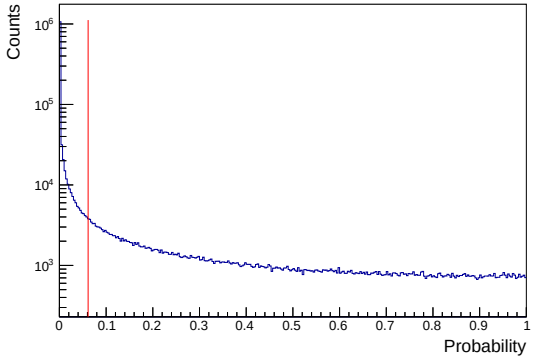

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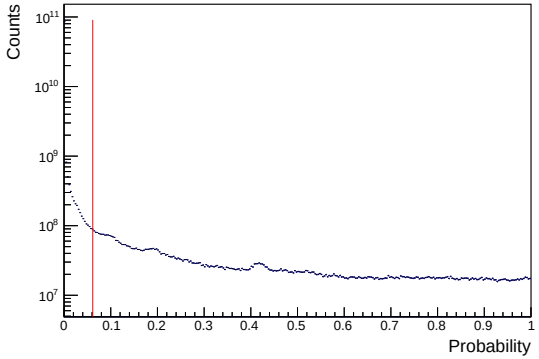
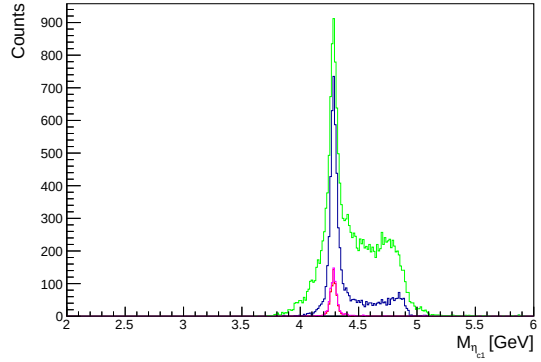
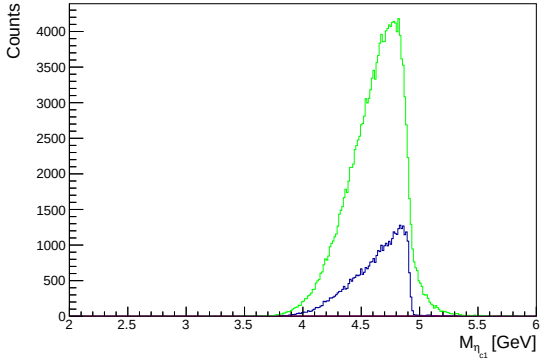


DPM

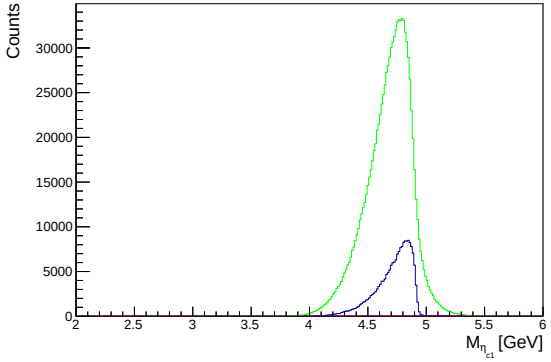
$\tilde{\eta_{c1}}$ invariant mass after the mass and prob. cuts



Signal



Background 1



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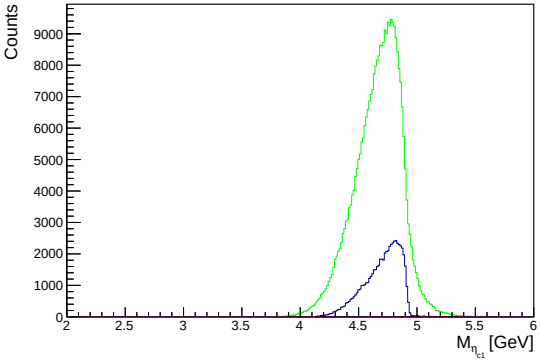

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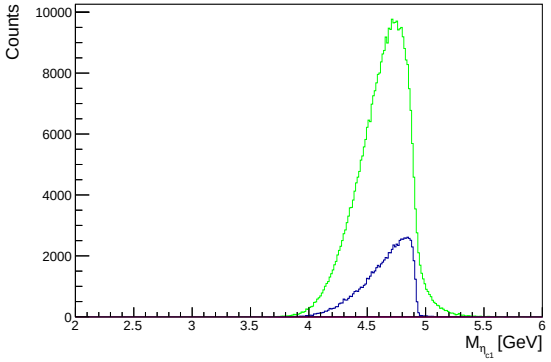

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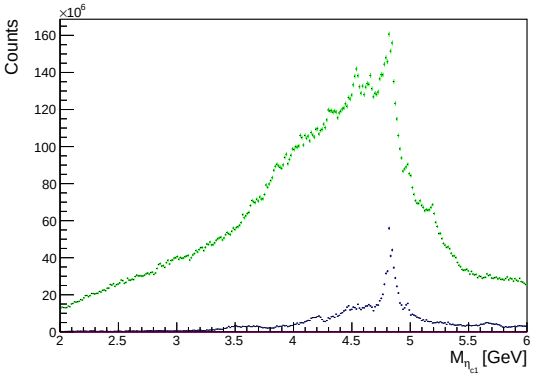
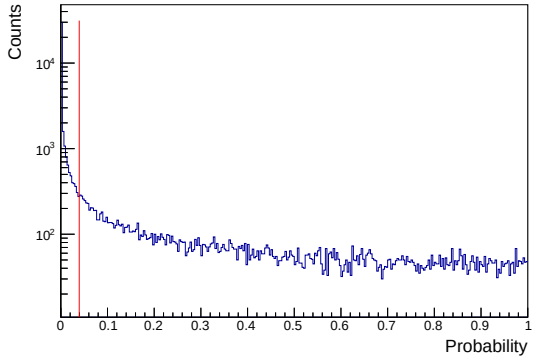
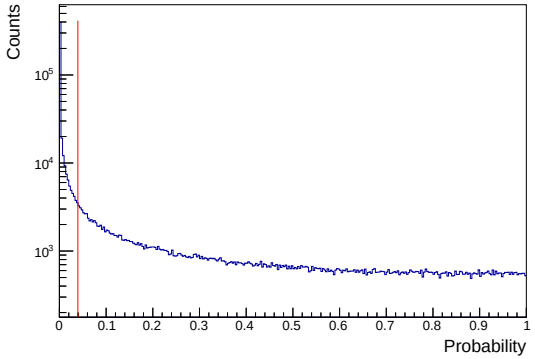


DPM

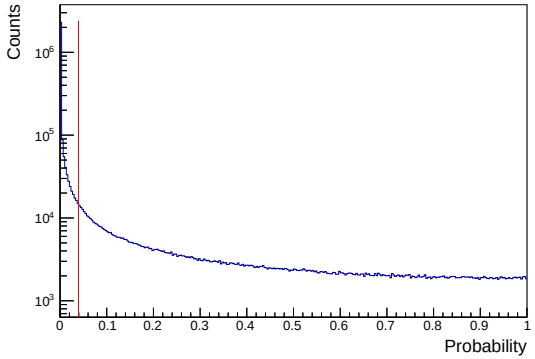
π mass fit probability



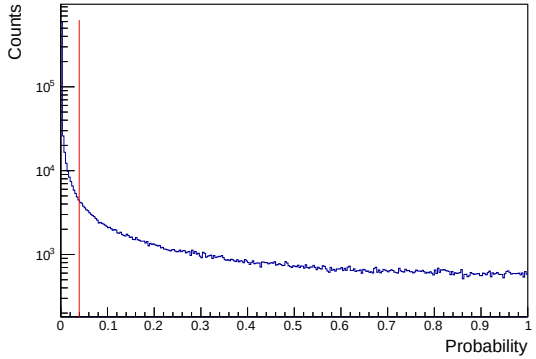
Signal



Background 1



Background 2



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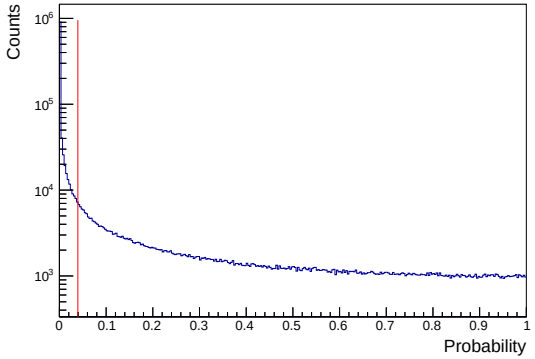

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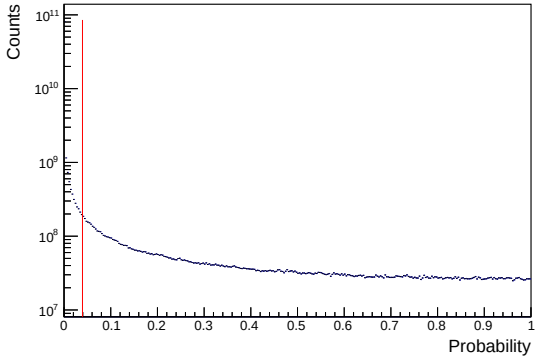
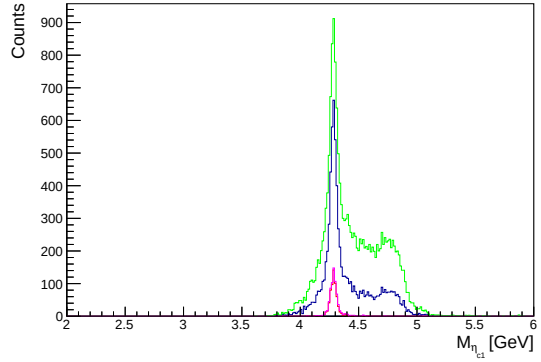
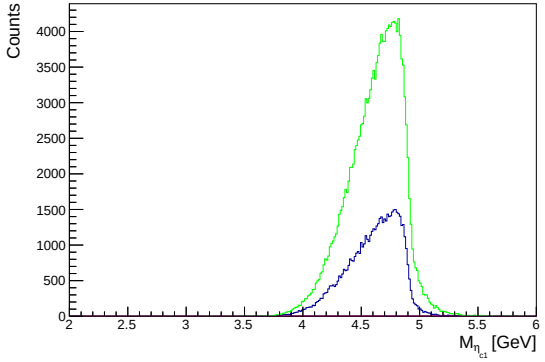


DPM

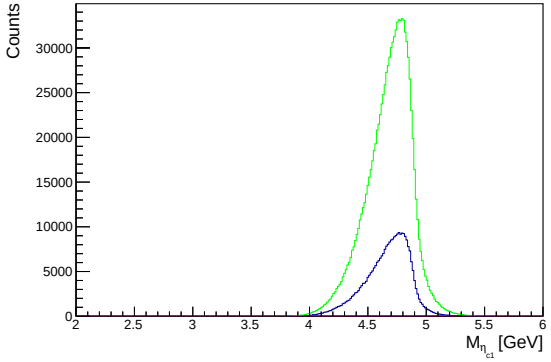
$\tilde{\eta_{c1}}$ invariant mass after the mass and prob. cuts



Signal



Background 1



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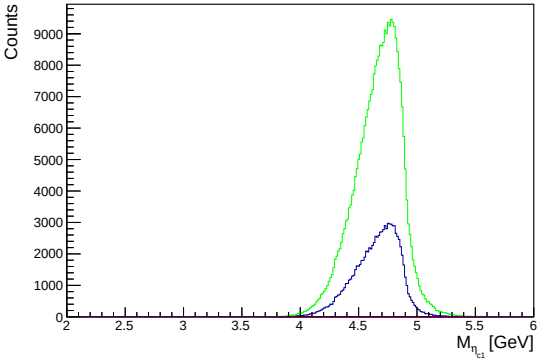
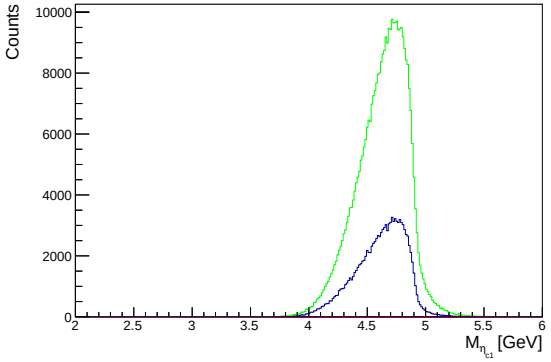


Background 3



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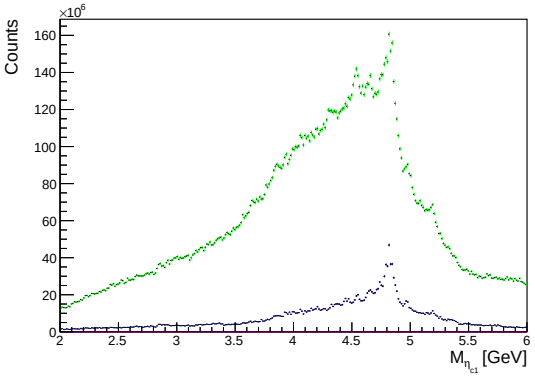
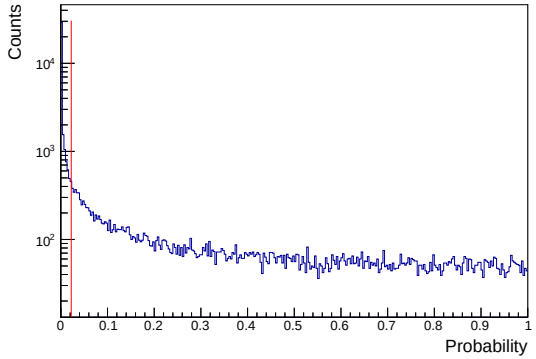
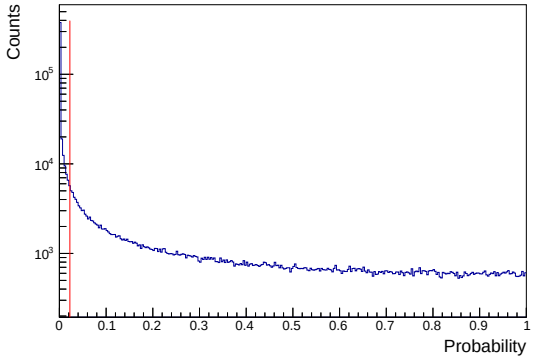


DPM

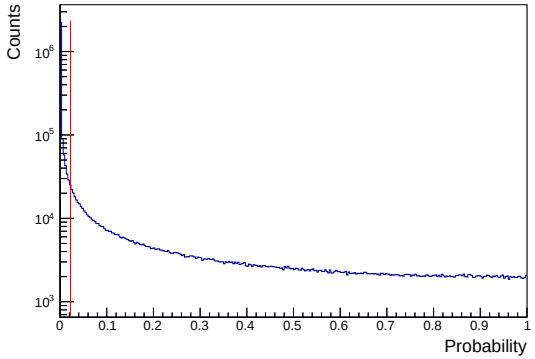
Other π mass fit probability



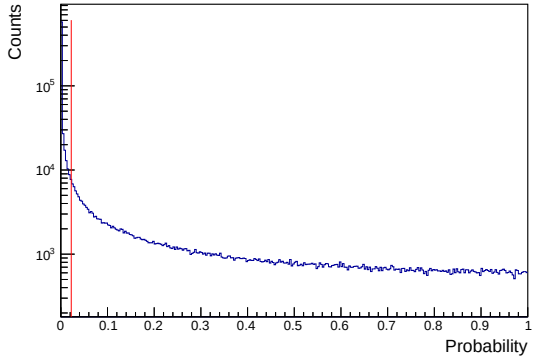
Signal



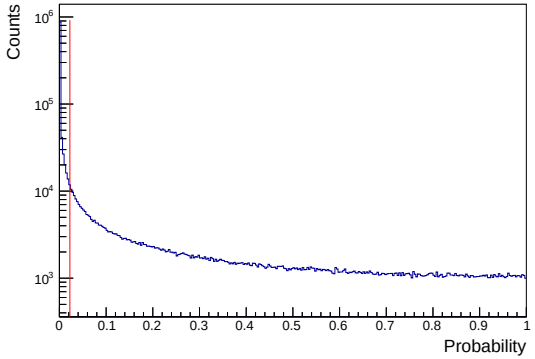
Background 1



Background 2



Background 3



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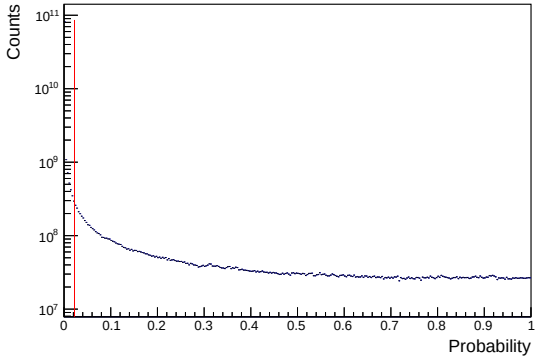
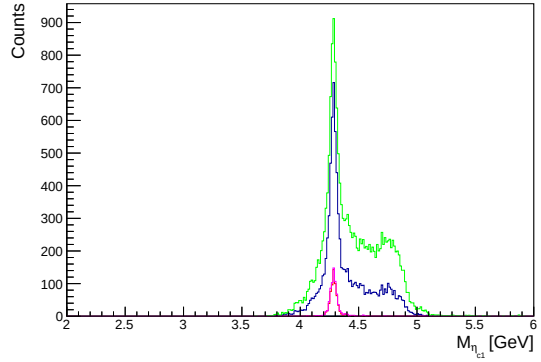
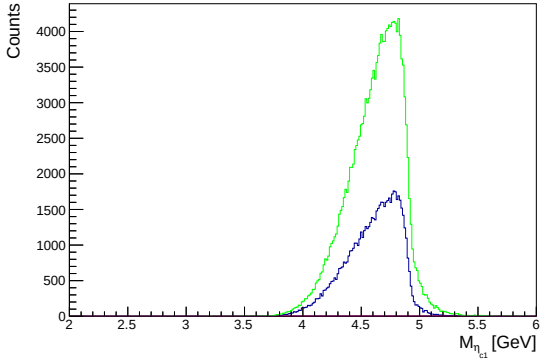


DPM

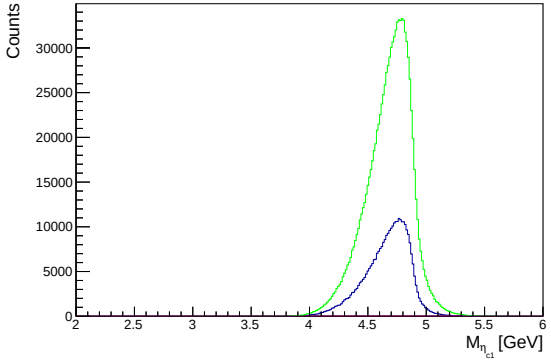
$\tilde{\eta_{c1}}$ invariant mass after the mass and prob. cuts



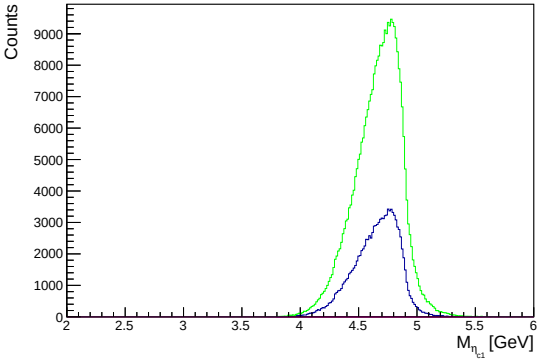
Signal



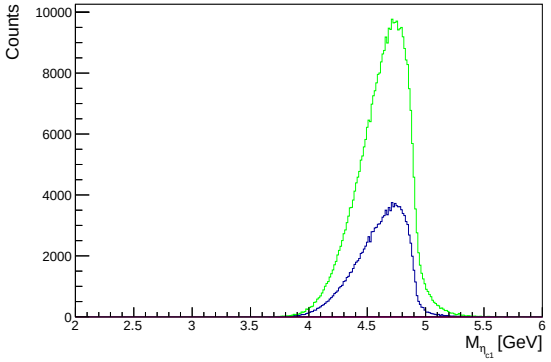
Background 1



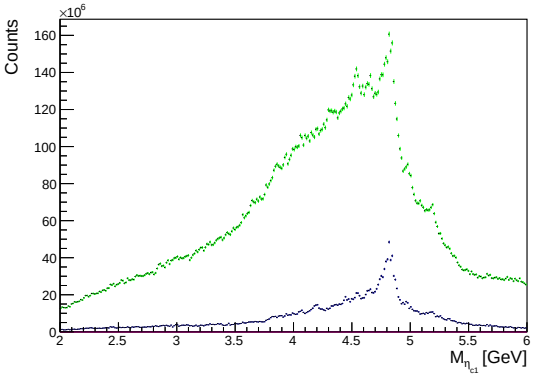
Background 2



Background 3

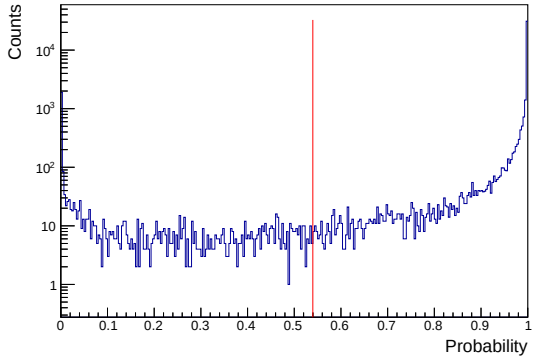


Background 4

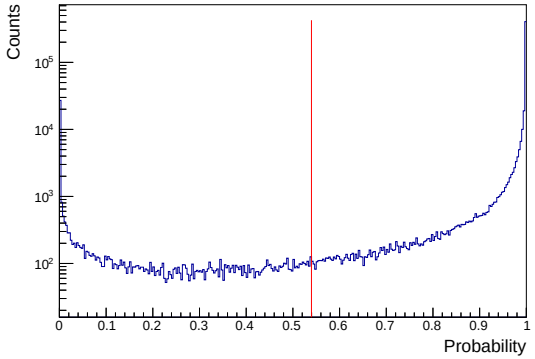


DPM

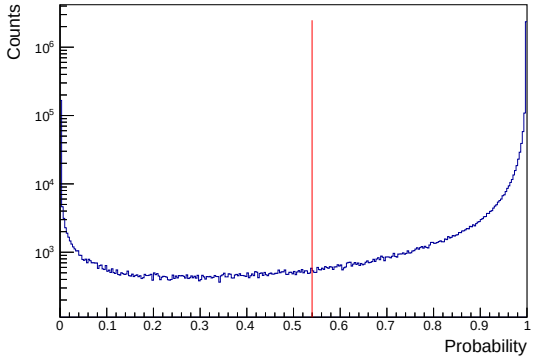
Second 4C fit probability



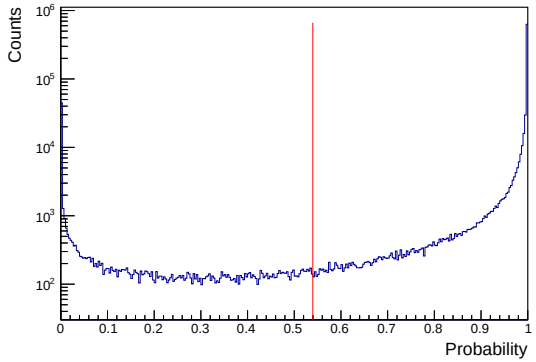
Signal



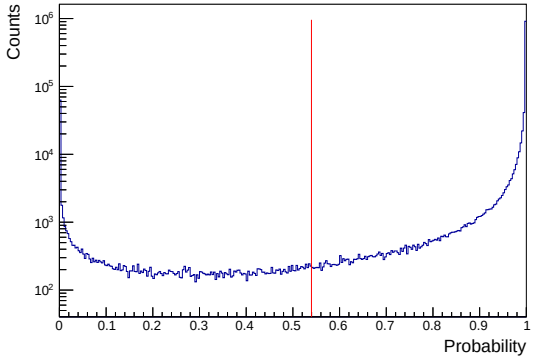
Background 1



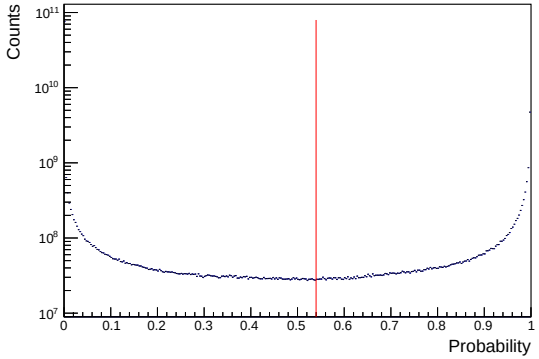
Background 2



Background 3

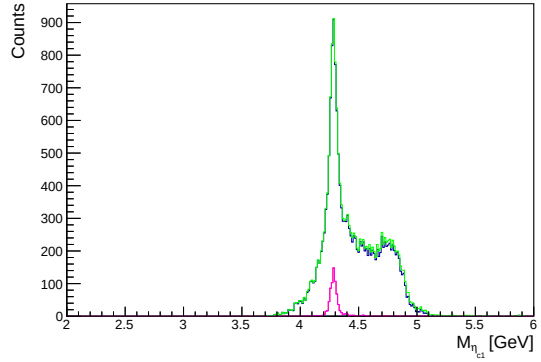


Background 4

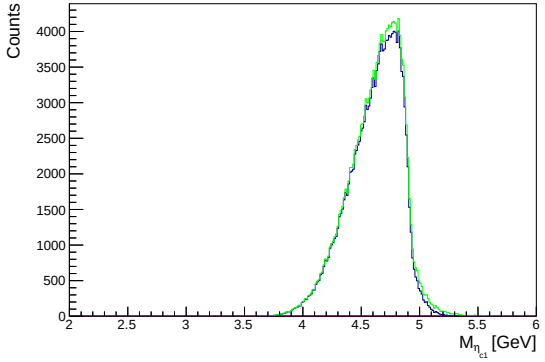


DPM

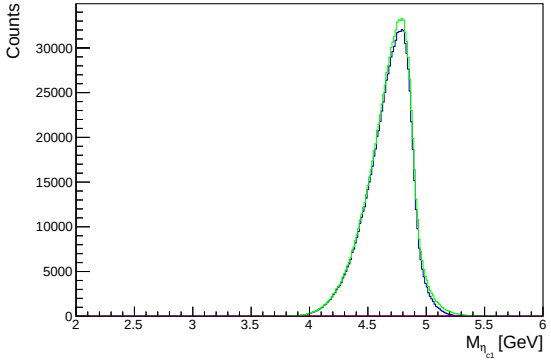
$\tilde{\eta_{c1}}$ invariant mass after the mass and prob. cuts



Signal



Background 1



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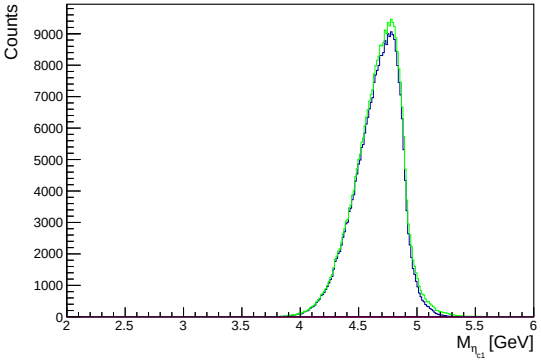

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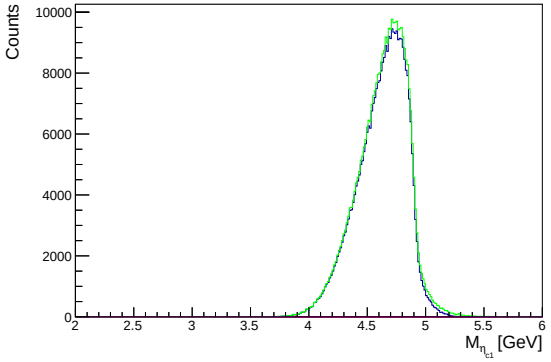
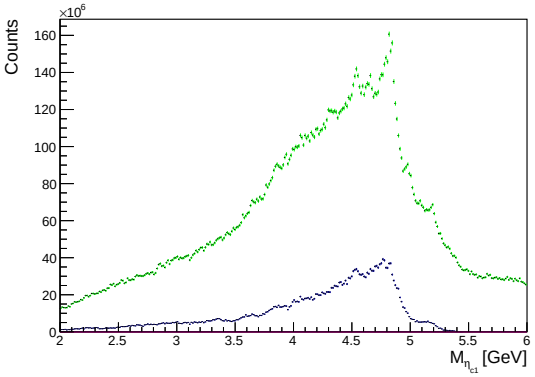
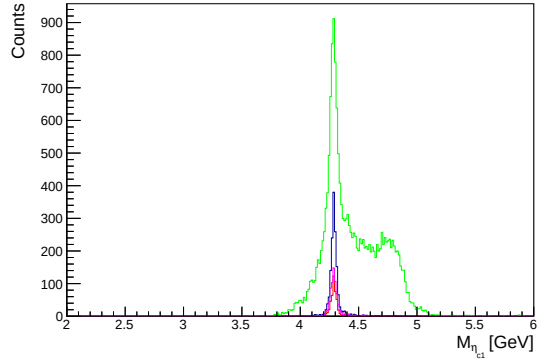


Background 4

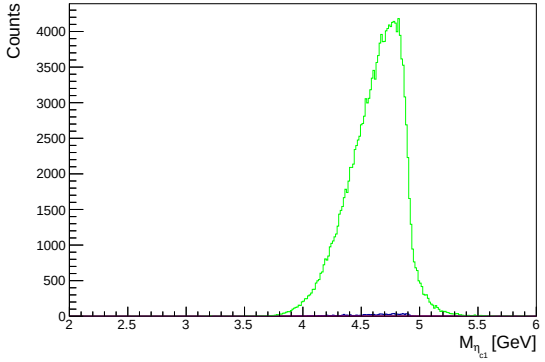


DPM

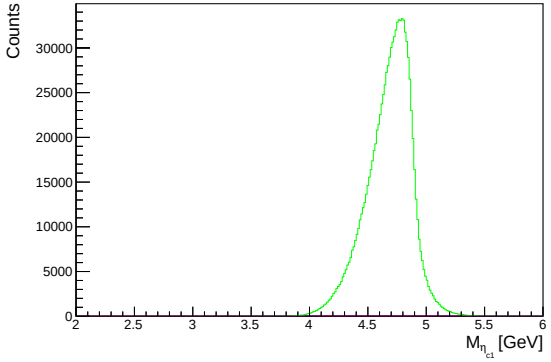
$\tilde{\eta_{c1}}$ invariant mass after the mass and all prob. cuts



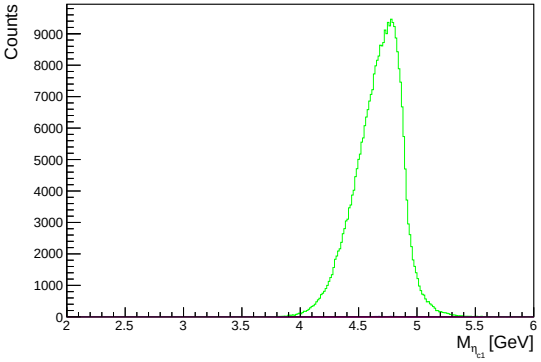
Signal



Background 1



Background 2



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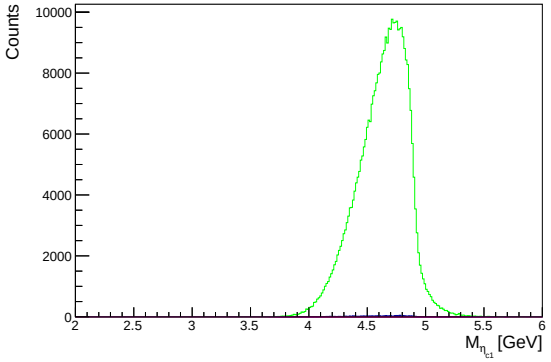
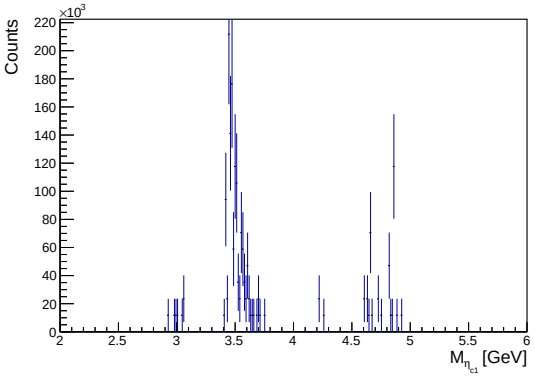
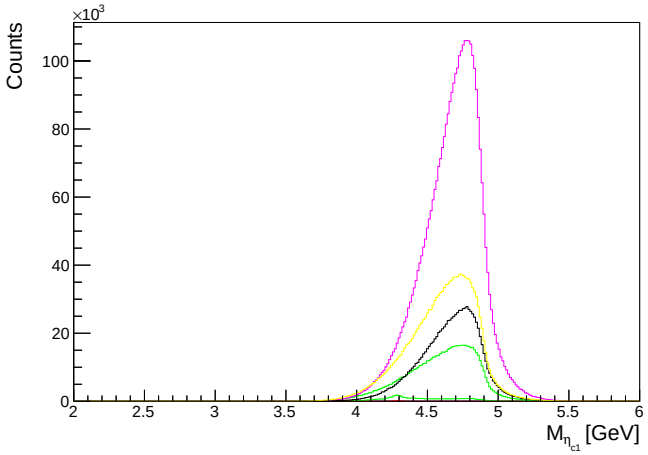


Background 4

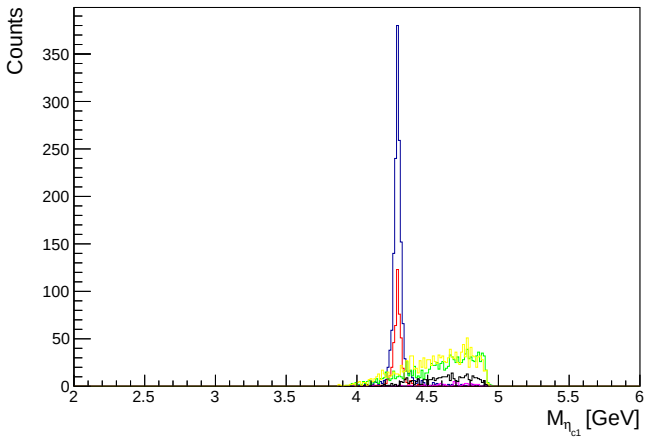


DPM

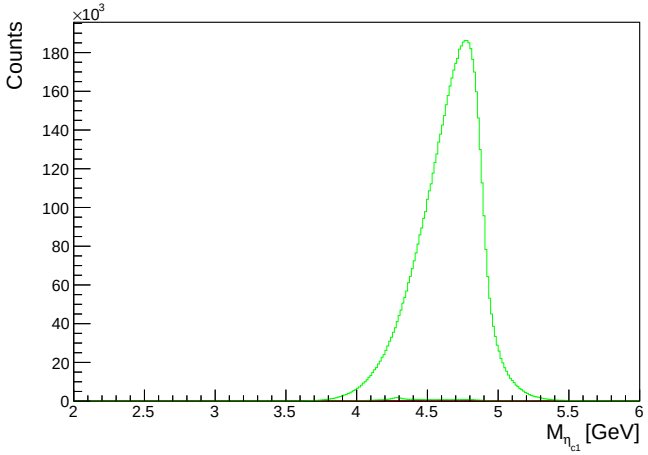
$\tilde{\eta_{c1}}$ invariant mass comparison



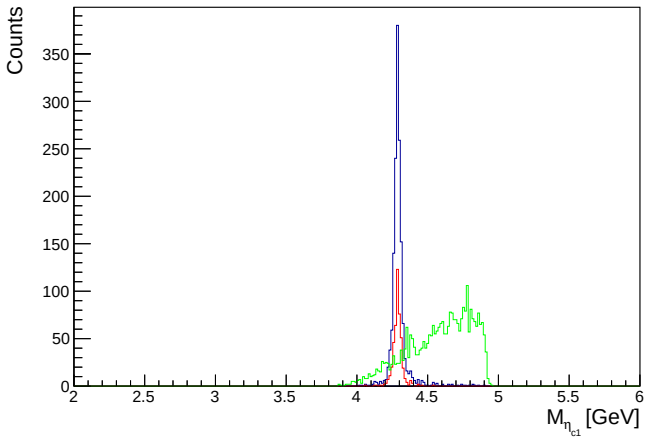
Without cuts



With cuts

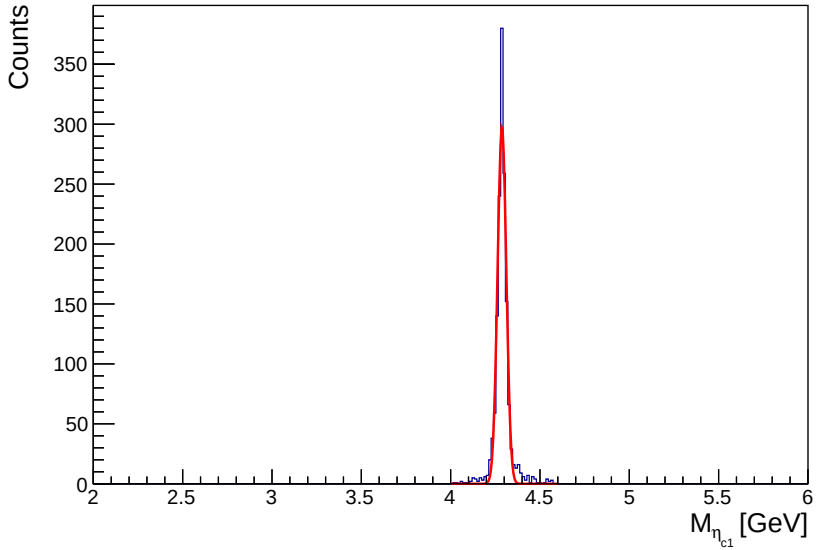


Without cuts



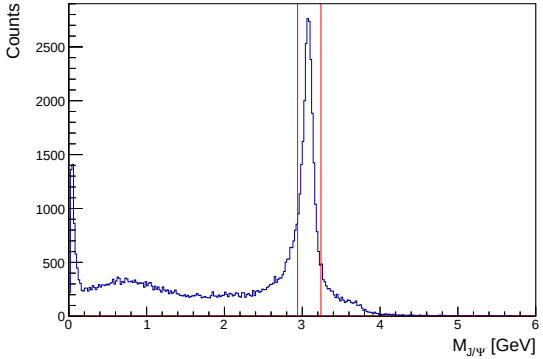
With cuts

Extracted $\tilde{\eta_{c1}}$ Parameters

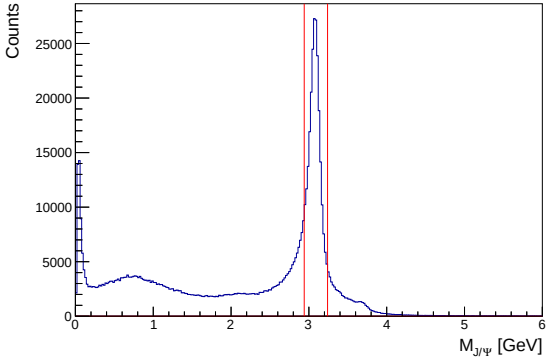


- Mass: $(4.29 \pm 6{\cdot}10^{-4})$ GeV
- Width: $(2.42{\cdot}10^{-2} \pm 7{\cdot}10^{-4})$ GeV

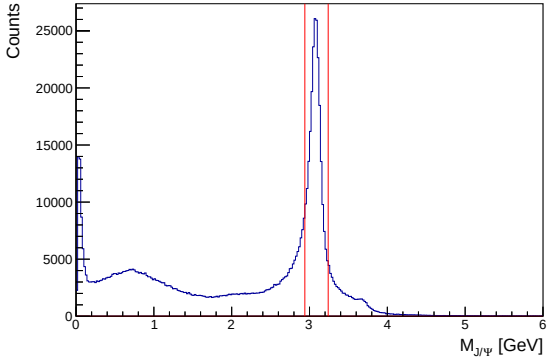
J/Ψ invariant mass e^+e^-



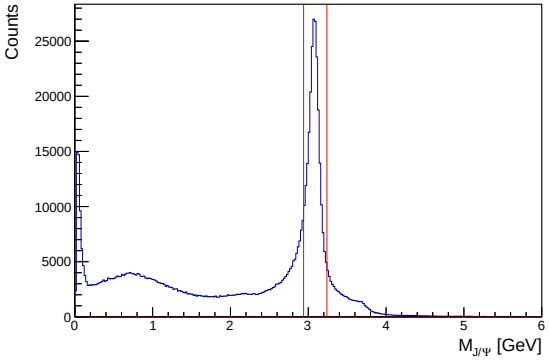
Signal



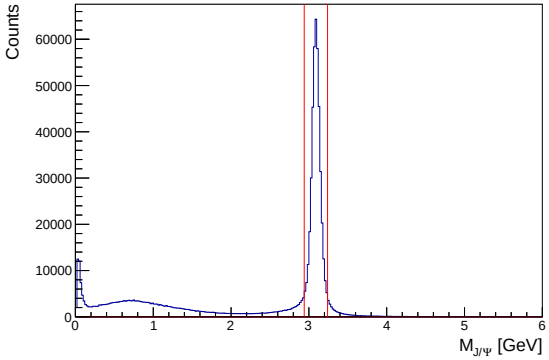
Background 1



Background 2

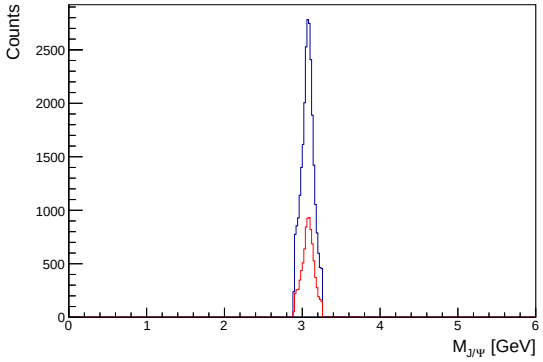


Background 3

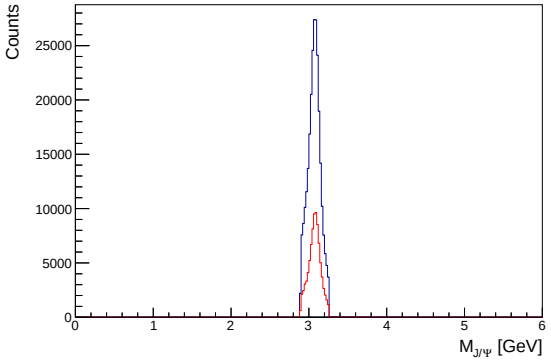


Background 4

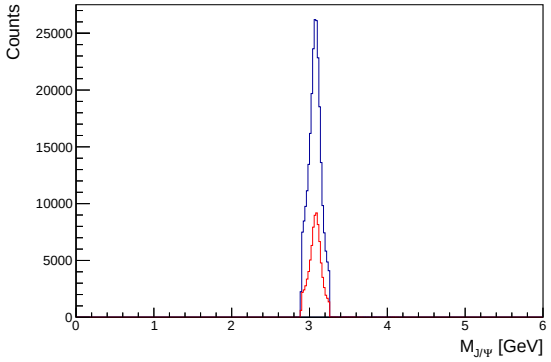
J/Ψ invariant mass after the fit and cut e^+e^-



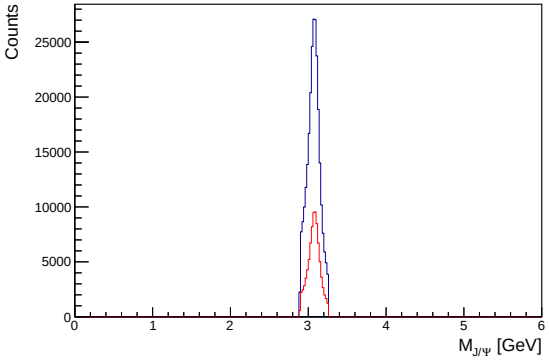
Signal



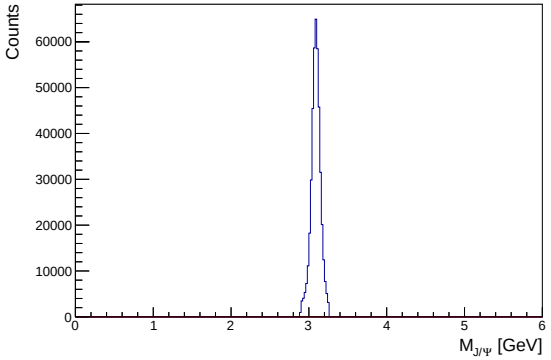
Background 1



Background 2

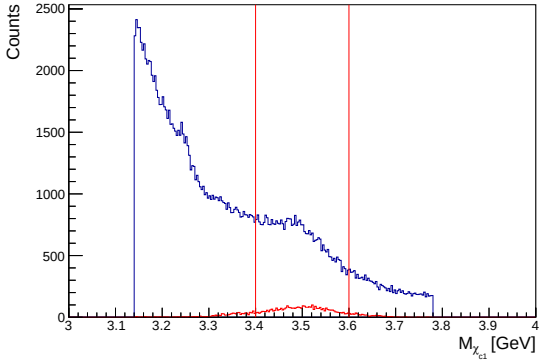


Background 3

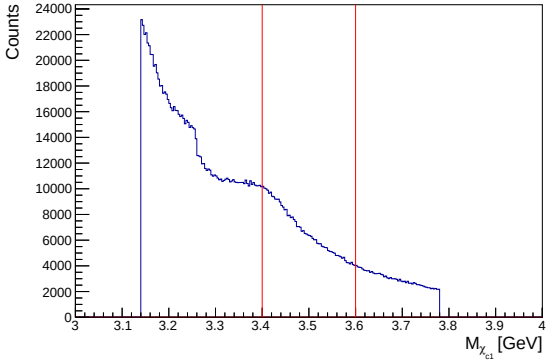


Background 4

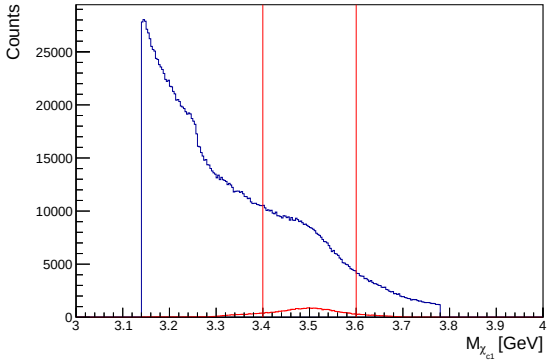
χ_{c1} invariant mass e^+e^-



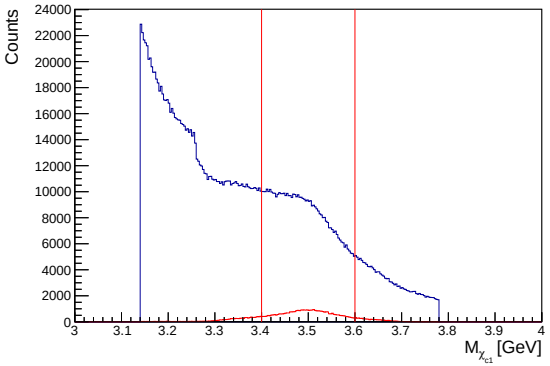
Signal



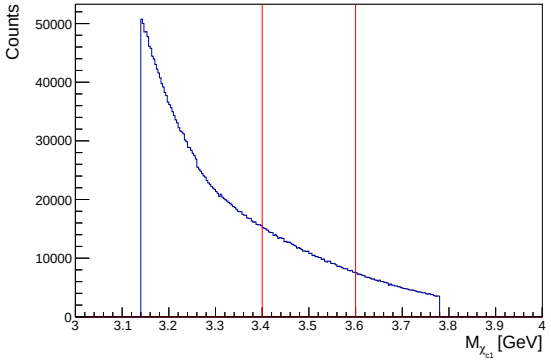
Background 1



Background 2

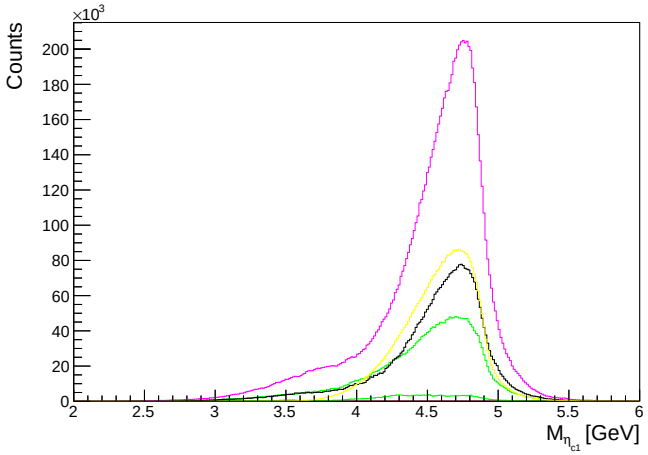


Background 3

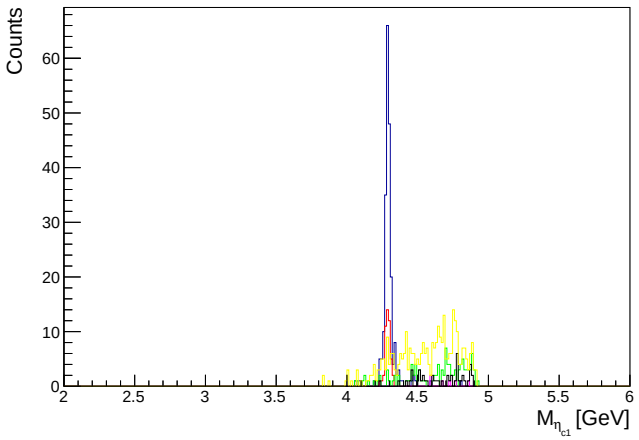


Background 4

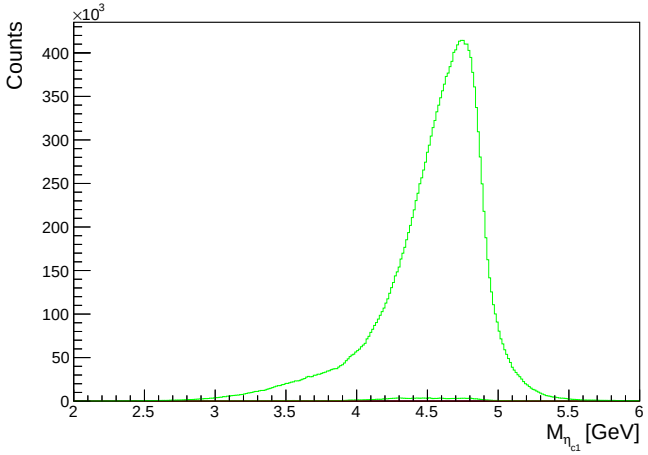
$\tilde{\eta_{c1}}$ invariant mass comparison e^+e^-



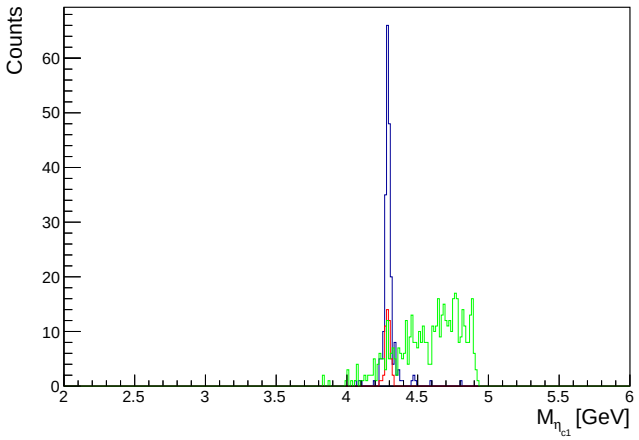
Without cuts



With cuts

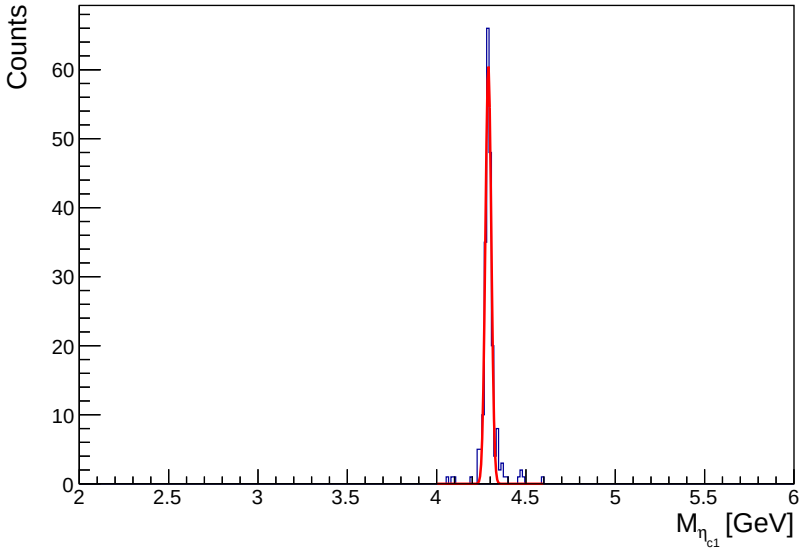


Without cuts



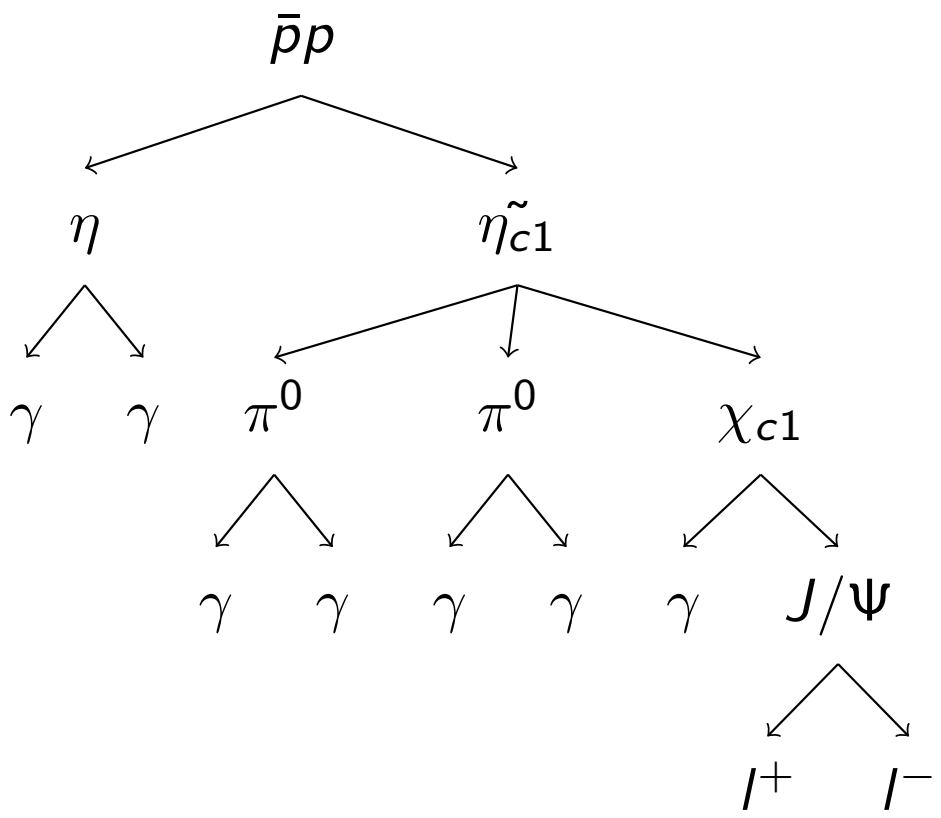
With cuts

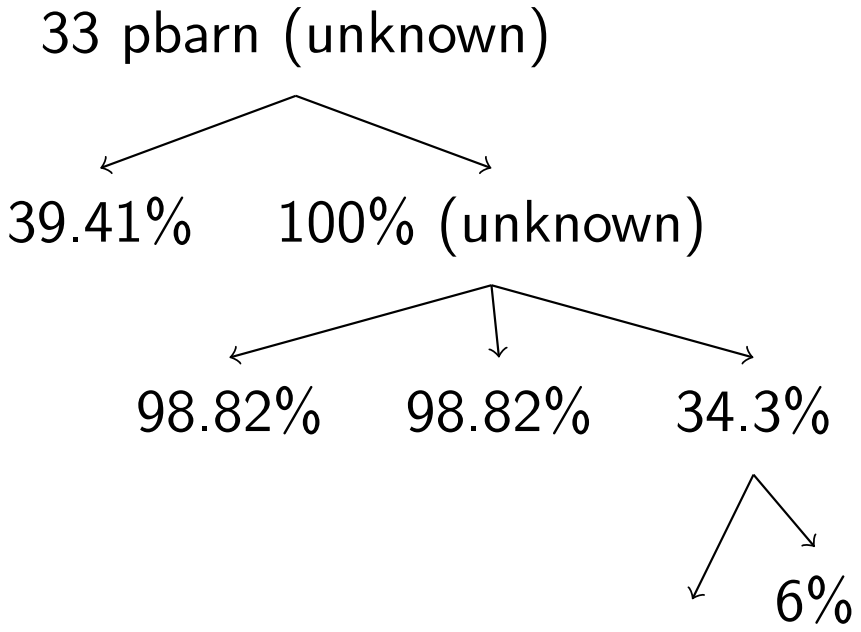
Extracted $\tilde{\eta_{c1}}$ Parameters e^+e^-



- Mass: $(4.29 \pm 1.2{\cdot}10^{-3})$ GeV
- Width: $(1.63{\cdot}10^{-2} \pm 1.1{\cdot}10^{-3})$ GeV

Branching Ratios and Cross-sections

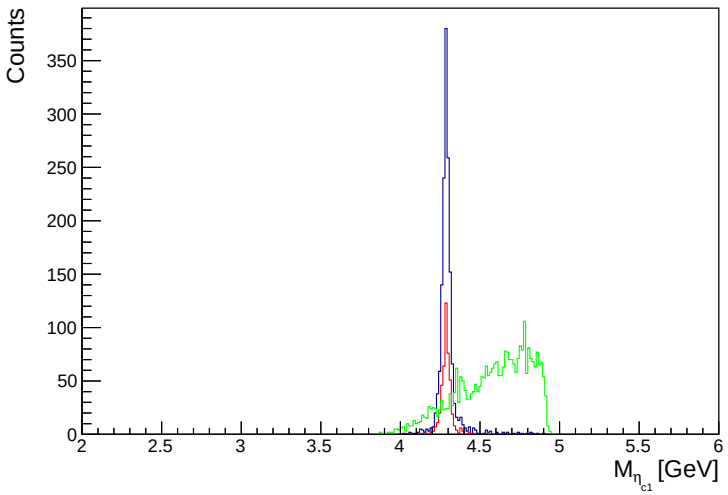




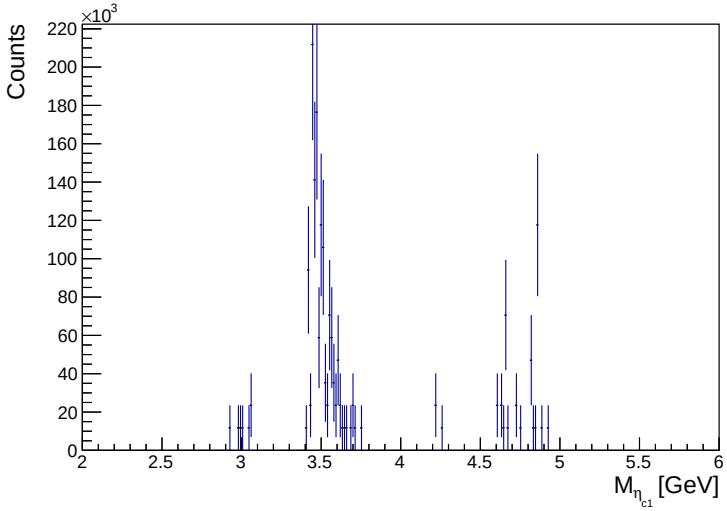
Beam time assumtions

- In high luminosity mode: $L = 2 \cdot 10^{32} \frac{1}{cm^2 s}$
- Assuming 33 pbarn cross-section and 0.81% branching ration, it would take 2165 days to collect the same ammount of signals as were simulated
- The $\bar{p}p$ cross-section at 15 GeV is around 50 mbarn
- The number of generated events / number of events which survived the event filter = 5.1 / 1
- To save cumputing time only $2.5 \cdot 10^8$ filtered DPM events were simulated $\rightarrow$ the resulting histograms were multiplied by 11765

Background scaling



Signal and dedicated background



DPM