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

Áron Kripkó

Justus-Liebig University, Gießen

AG Brinkmann

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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
- One of its possible decay channel with 7 photons in the final state is used as a benchmark channel in the EMC TDR
- Due to the low efficiency of this channel, alternative channels should be investigated

[1] Nora Brambilla et al., Spin structure of heavy-quark hybrids, PRD 99, 014017 (2019)

Beam time assumtions - previously presented

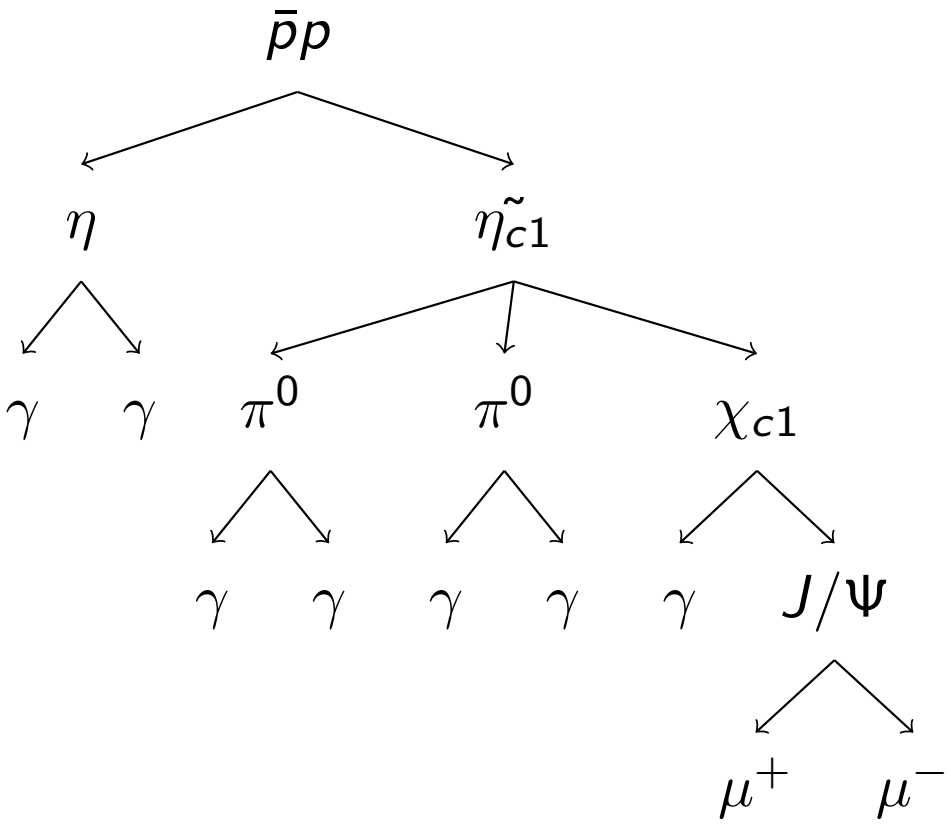
Cross-section [pbarn]	Significance	Beam time [days]	Significance after 1 year
33	0.07 ± 0.03	21650	0.009 ± 0.004
50	0.08 ± 0.04	14289	0.012 ± 0.006
500	0.27 ± 0.13	1429	0.14 ± 0.07
2000	0.5 ± 0.3	357	0.51 ± 0.3
100000	3.7 ± 2	7	26.7 ± 14.4

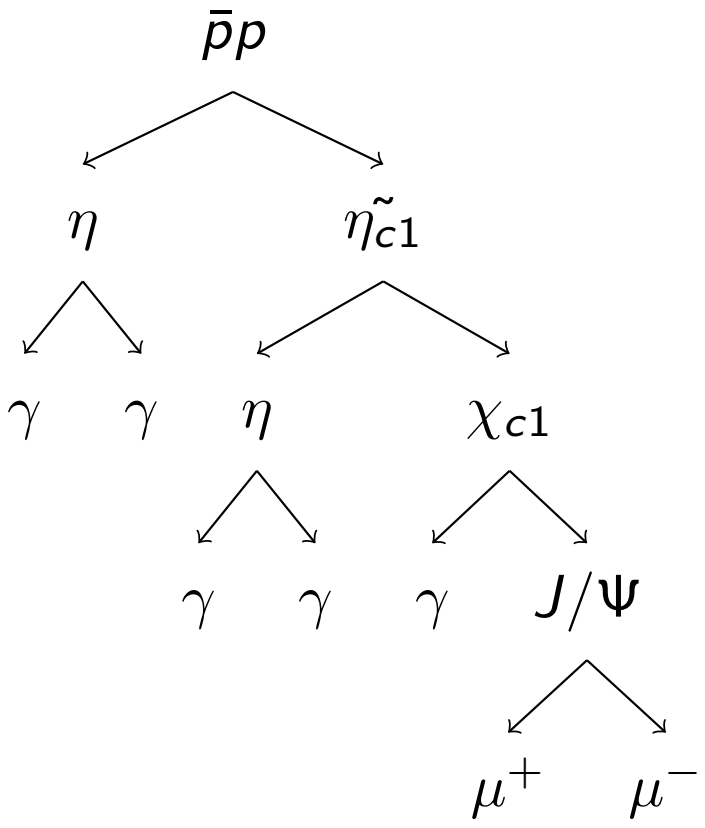
Possible decay channels - Frank E. Close et al. Gluonic Hadrons and Charmless β Decays (1997)

Table 1: Some possible experimentally accessible final states of J^{PC} exotic charmed hybrids and glueballs below $D^{**}D$ threshold. Note that open charm modes of ψ_g may be suppressed by a selection rule [4]. For hidden charm modes, the charmonia tend to have the same C as that of the parent ψ_g. The light hadron modes are expected to be enhanced for ψ_g with $C = +$. See the main text for details. Decays to $p\bar{p}\{\pi, \eta^{(\prime)}, \omega, \rho, \phi\}$ are allowed for all states listed.

J^{PC}	Open charm	Hidden charm	Light hadrons
0^{+-}	Quantum numbers forbid $D^{(*)}D^{(*)}$	$J/\psi\{f_{\{0,1,2\}}, (\pi\pi)_S\}$ $h_c\eta;\ \eta_c h_1$ $\chi_{c0}\omega$ $\chi_{c\{1,2\}}\{\omega, h_1, \gamma\}$	$a_{\{0,1,2\}}\rho;\ a_{\{1,2\}}\{b_1, \gamma\}$ $b_1\pi;\ h_1\eta^{(\prime)}$ $\{(\pi\pi)_S, f_0\}\{\omega, \phi\}$ $f_{\{1,2\}}\{\omega, h_1, \phi, \gamma\}$
0^{--}	D^*D	$h_c(\pi\pi)_S$ $J/\psi\{f_{\{1,2\}}, \eta^{(\prime)}\}$ $\chi_{c0}h_1;\ \eta_c\{\omega, \phi\}$ $\chi_{c\{1,2\}}\{\omega, h_1, \gamma\}$	$a_{\{0,1,2\}}b_1;\ a_{\{1,2\}}\{\rho, \gamma\}$ $\rho\pi$ $f_0h_1;\ \eta^{(\prime)}\{\omega, \phi\}$ $f_{\{1,2\}}\{\omega, h_1, \phi, \gamma\}$
1^{-+}	$D^*D,\ D^*D^*$	$\chi_{c\{0,1,2\}}(\pi\pi)_S$ $\eta_c\{f_{\{1,2\}}, \eta^{(\prime)}\}$ $\chi_{c\{1,2\}}\eta$ $\{h_c, J/\psi\}\{\omega, h_1, \phi, \gamma\}$	$a_{\{0,1,2\}}a_{\{0,1,2\}};\ a_{\{1,2\}}\pi$ $f_{\{0,1,2\}}f_{\{0,1,2\}};\ f_{\{1,2\}}\eta^{(\prime)}$ $\{\rho, \gamma\}\{\rho, b_1\};\ b_1b_1$ $\{\omega, h_1, \phi, \gamma\}\{\omega, h_1, \phi, \gamma\}$
2^{+-}	$D^*D,\ D^*D^*$	$\{h_c, J/\psi\}\{f_{\{0,1,2\}}, (\pi\pi)_S\}$ $\{h_c, J/\psi\}\eta^{(\prime)}$ $\{\eta_c, \chi_{c\{0,1,2\}}\}\{\omega, h_1, \phi, \gamma\}$	$a_{\{0,1,2\}}\{\rho, b_1, \gamma\}$ $\{\rho, \gamma, b_1\}\pi$ $\{\eta^{(\prime)}, f_{\{0,1,2\}}\}\{\omega, h_1, \phi, \gamma\}$

New decay channel

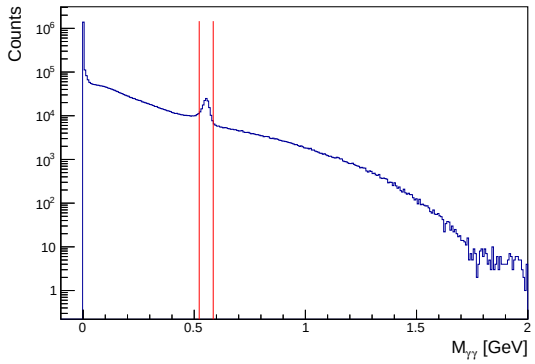




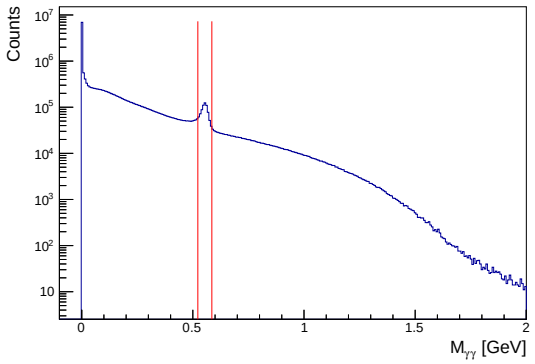
Simulations

- 100000 signal events
- 500000 dedicated background events
  - $\bar{p}p \to \chi_{c1}\eta\eta$
  - $\bar{p}p \to J/\psi\eta\eta\pi^0$

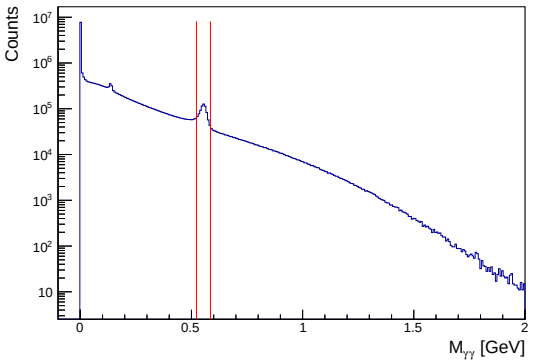
$\gamma\gamma$ invariant mass



Signal

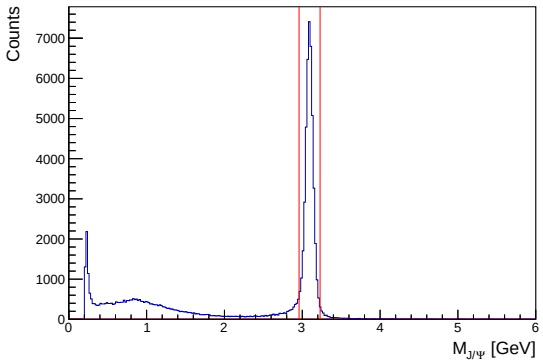


Background 1



Background 2

J/Ψ invariant mass



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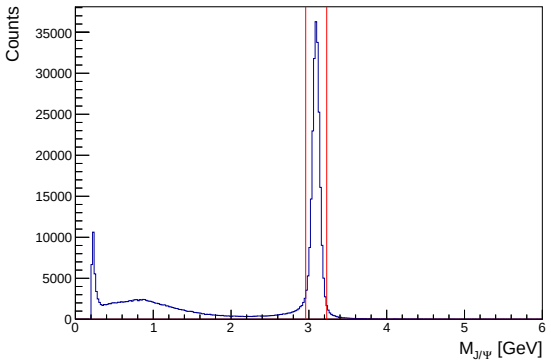

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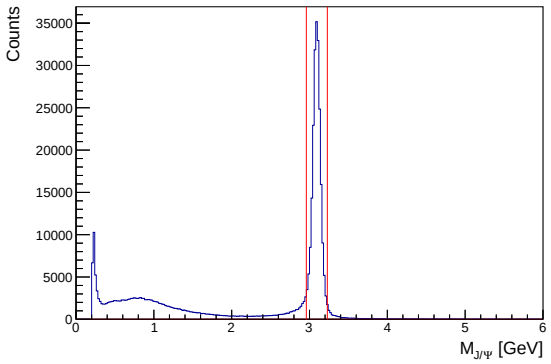
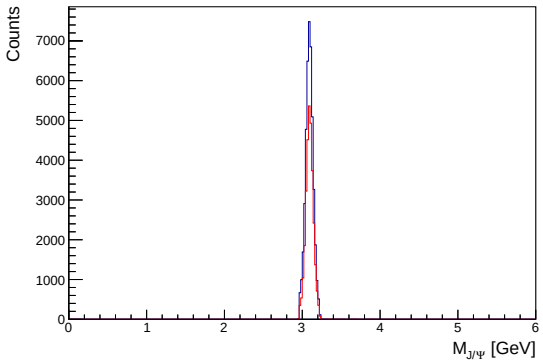


Background 2

J/Ψ invariant mass after the fit and cut



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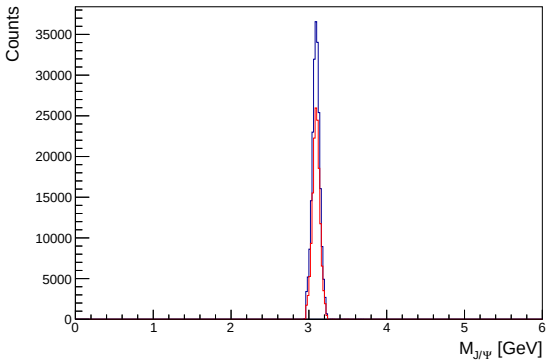

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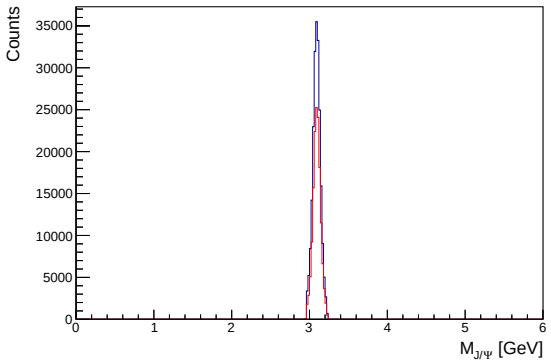
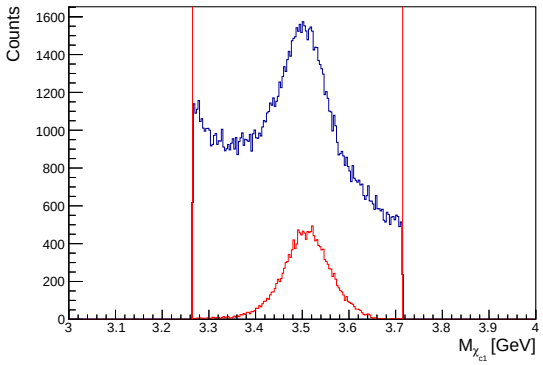


Background 2

χ_{c1} invariant mass



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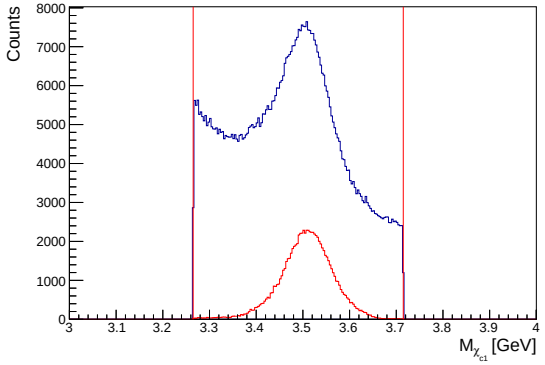

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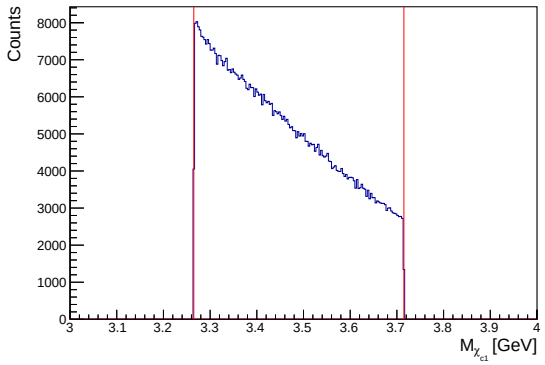
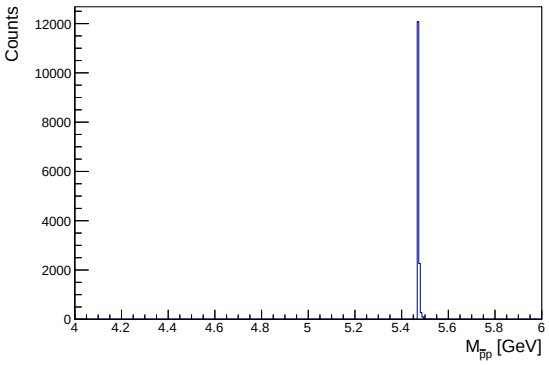


Background 2

$\bar{p}p$ invariant mass



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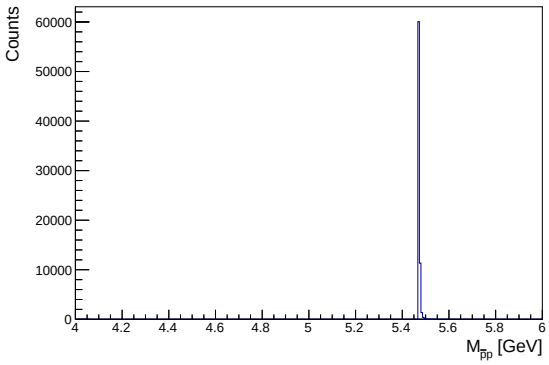

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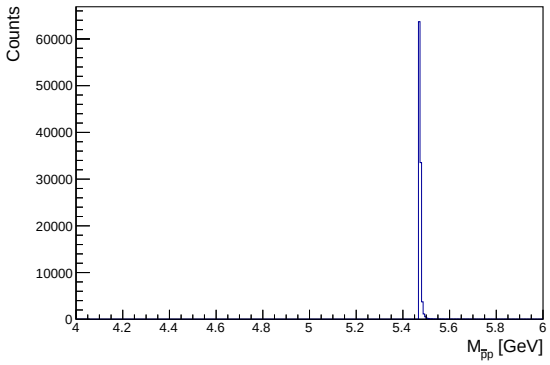
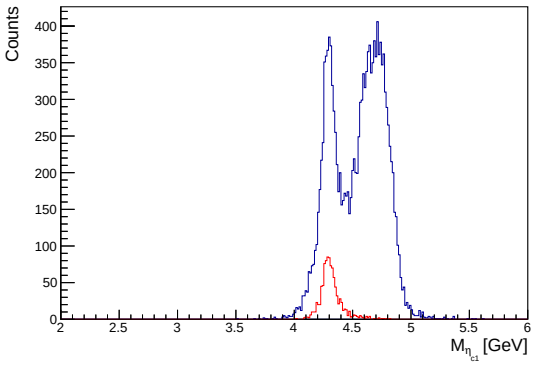
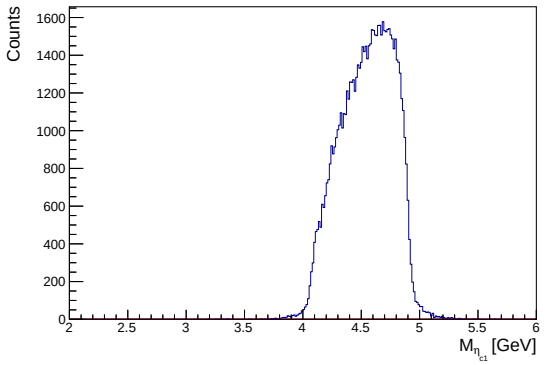


Background 2

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



Signal



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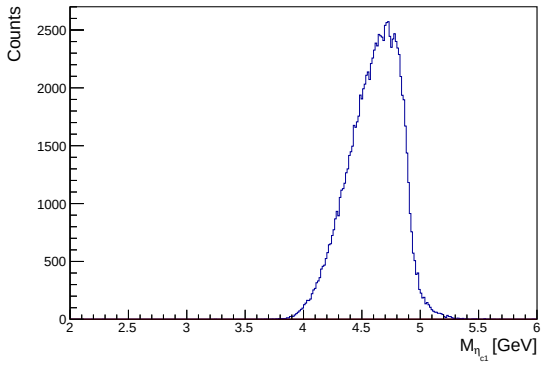
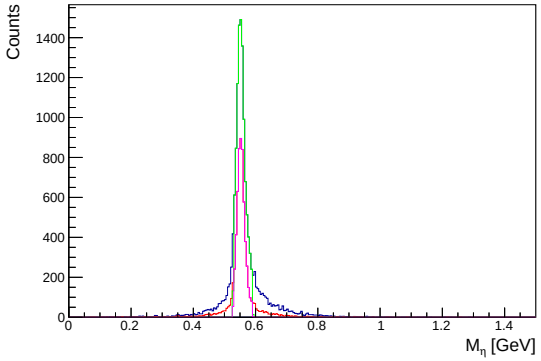
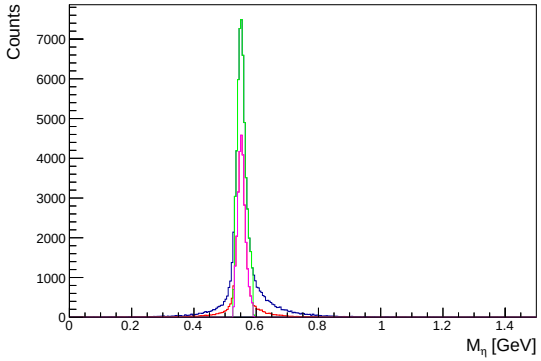


Background 2

η invariant mass cut



Signal



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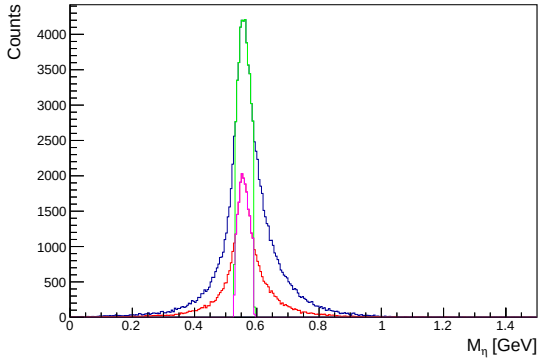

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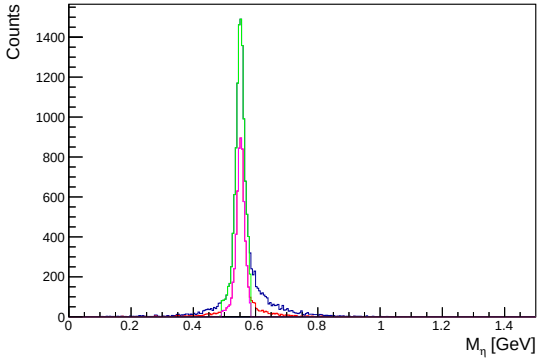
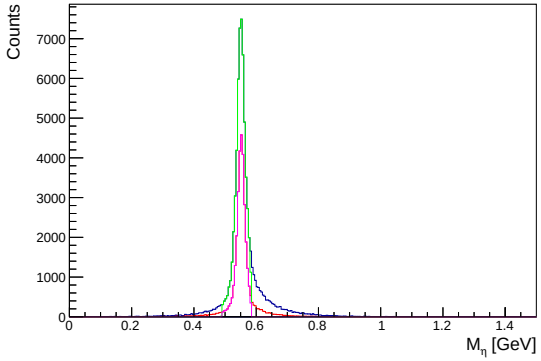
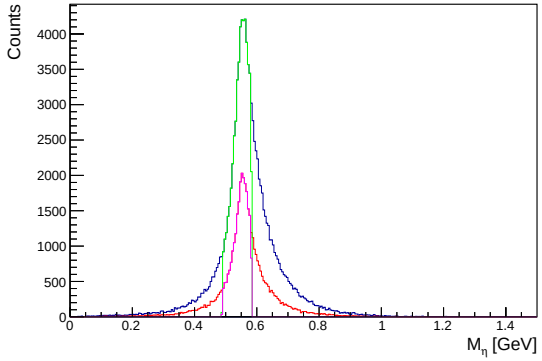


Signal - Gen. cuts

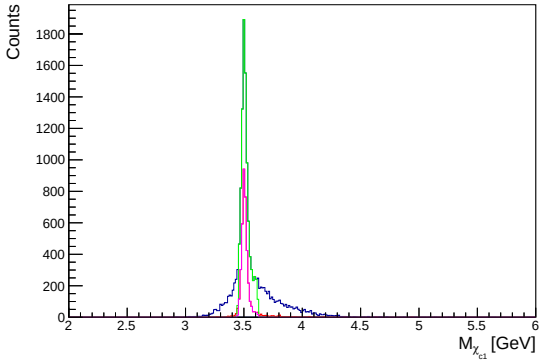


Background 1 - Gen. cuts

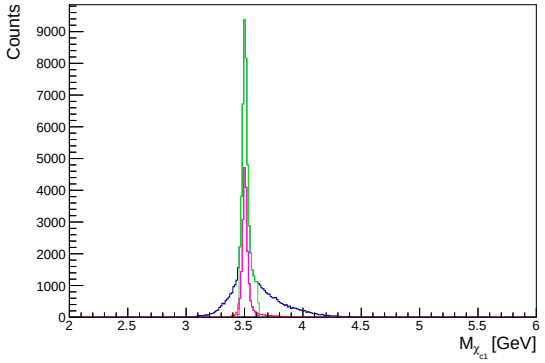


Background 2 - Gen. cuts

χ_{c1} invariant mass cut



Signal



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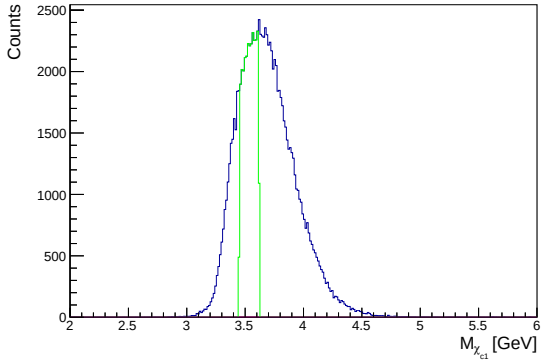

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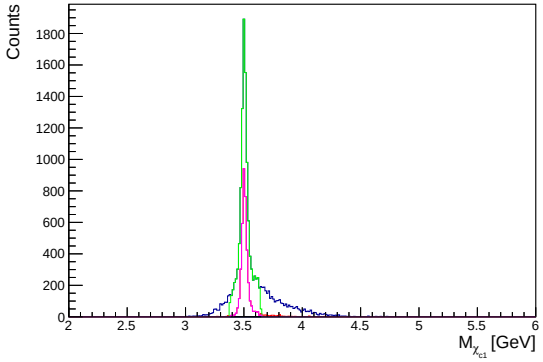
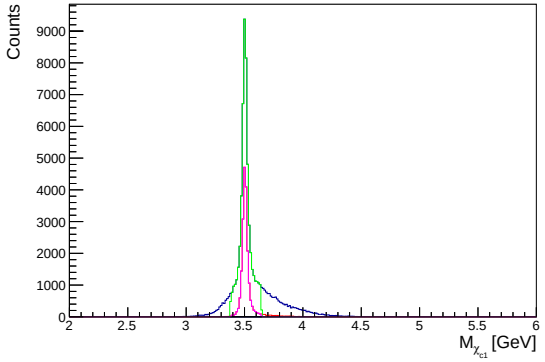
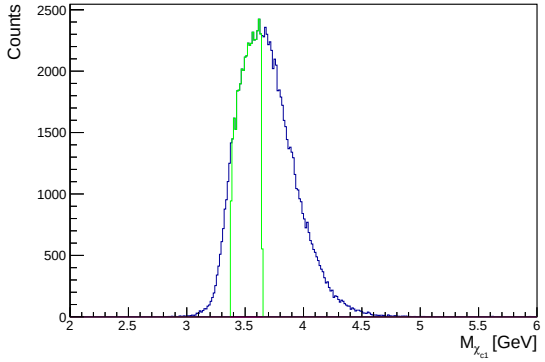


Signal - Gen. cuts

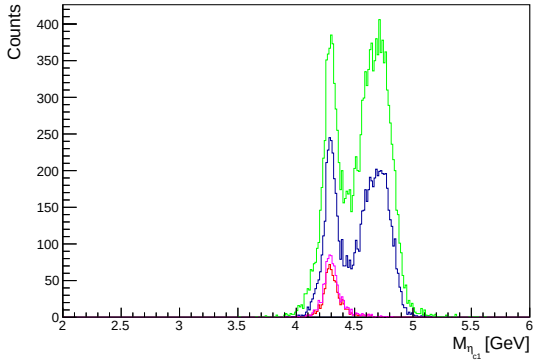


Background 1 - Gen. cuts

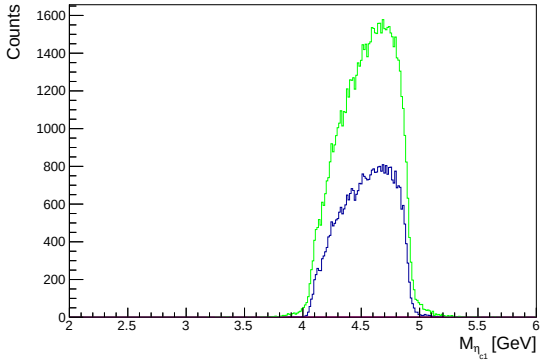


Background 2 - Gen. cuts

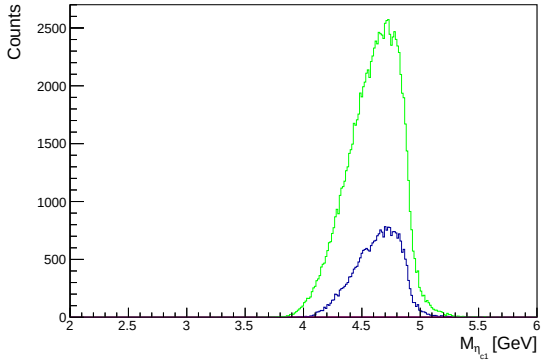
$\tilde{\eta_{c1}}$ invariant mass after the mass cuts



Signal



Background 1



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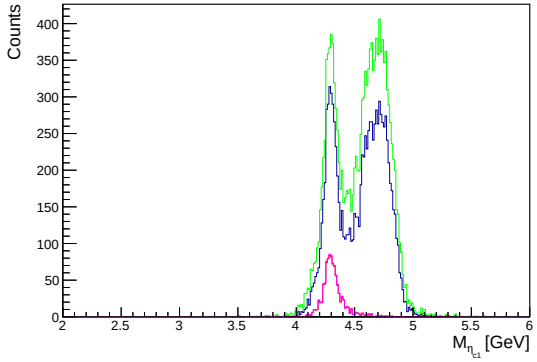
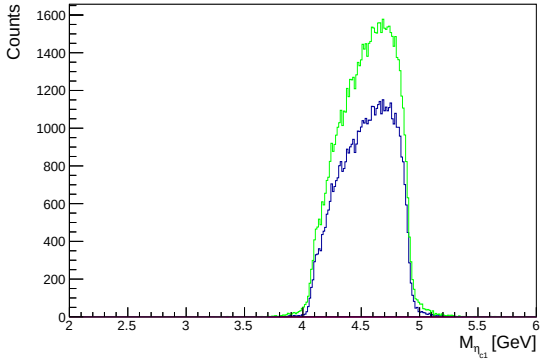
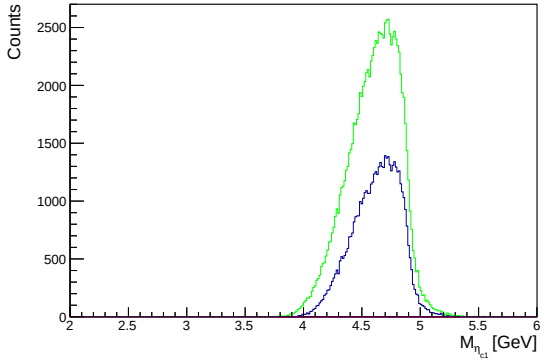


Signal - Gen. cuts

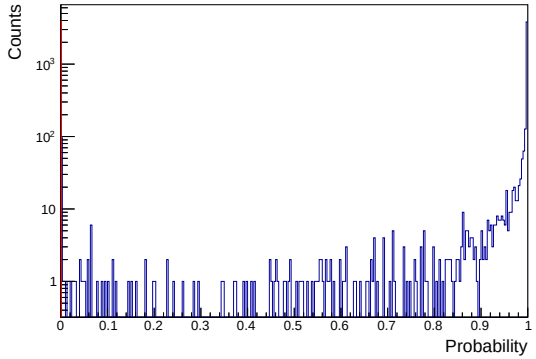


Background 1 - Gen. cuts



Background 2 - Gen. cuts

Charmonium mass constraint fit probability with other cuts



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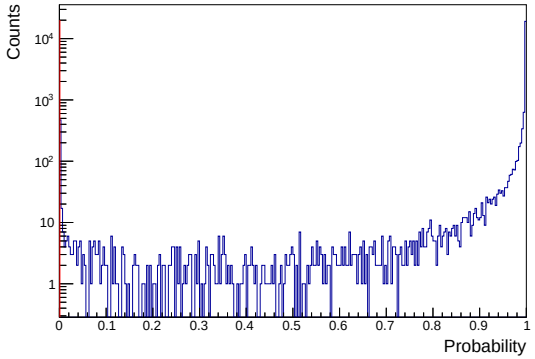

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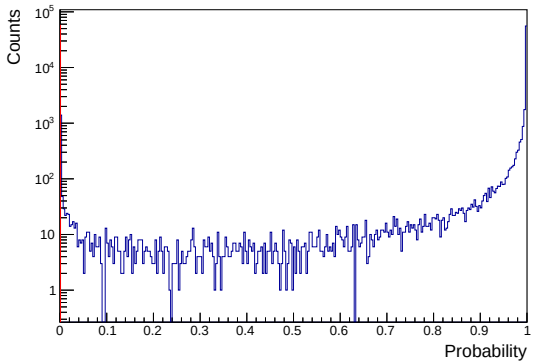

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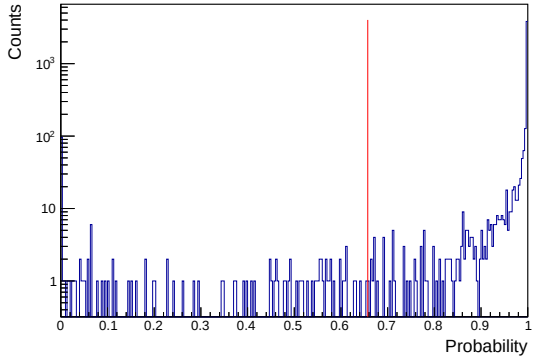
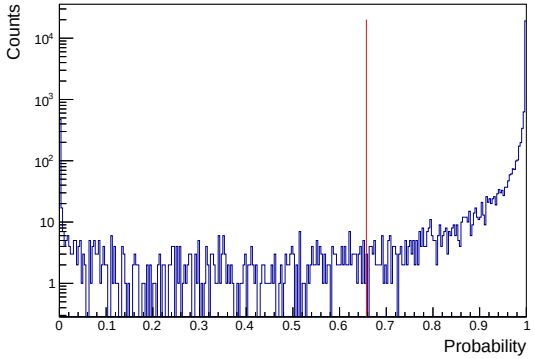
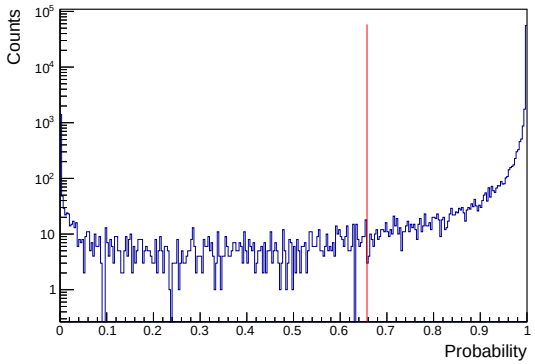


Signal - Gen. cuts

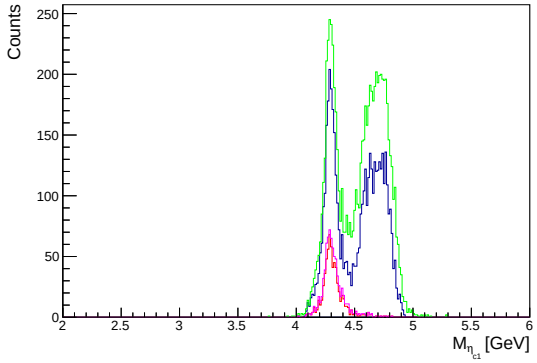


Background 1 - Gen. cuts

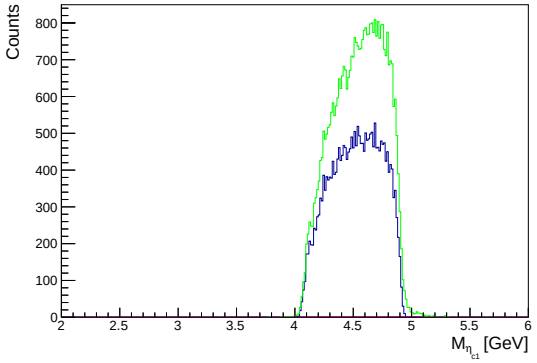


Background 2 - Gen. cuts

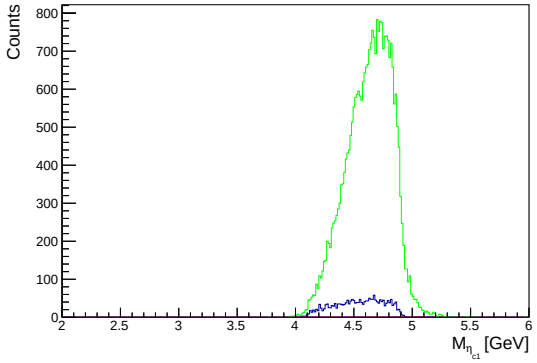
$\tilde{\eta_{c1}}$ invariant mass after the mass and all 6 prob. cuts



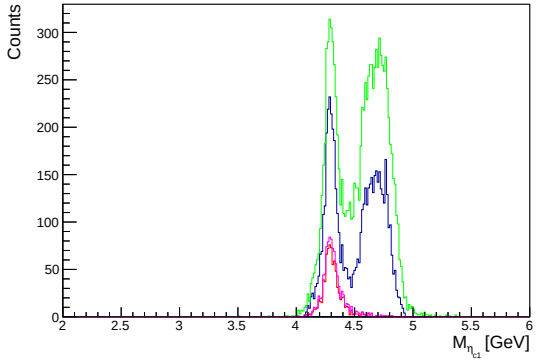
Signal



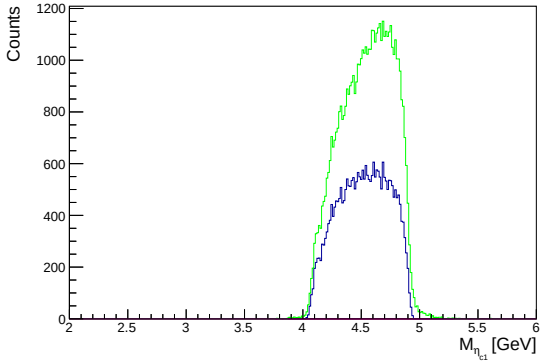
Background 1



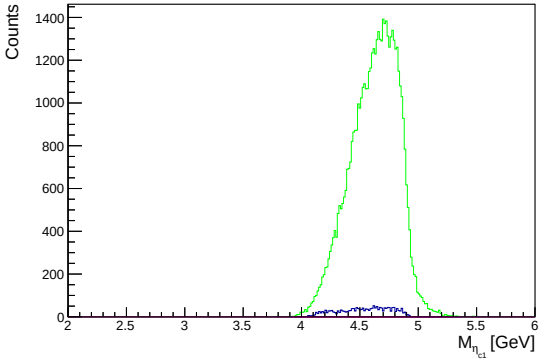
Background 2



Signal - Gen. cuts

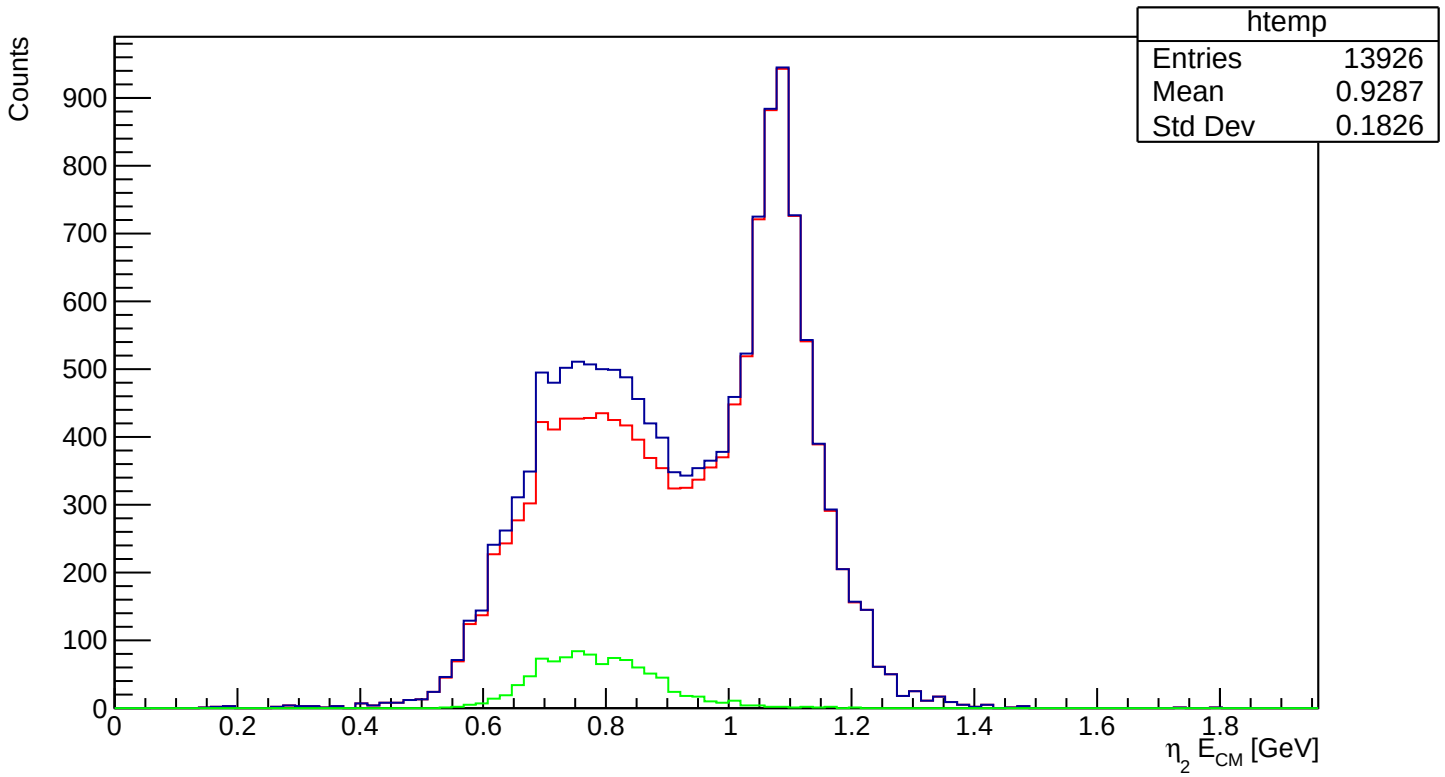


Background 1 - Gen. cuts

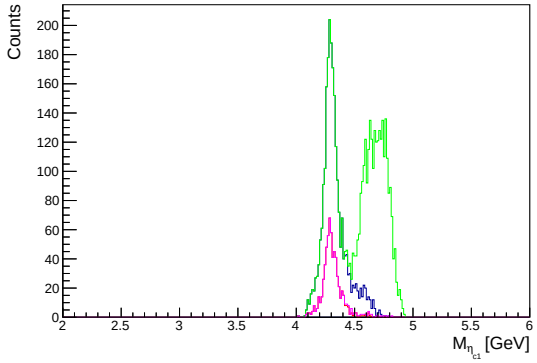


Background 2 - Gen. cuts

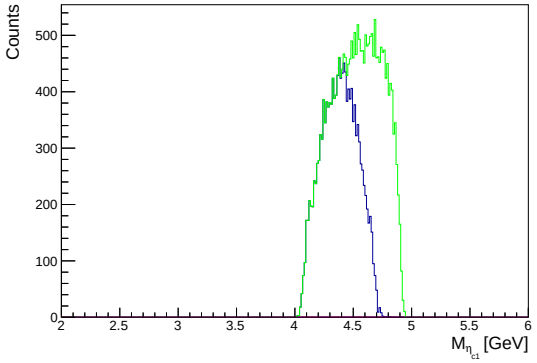
The η E_{CM} cut - 1 GeV



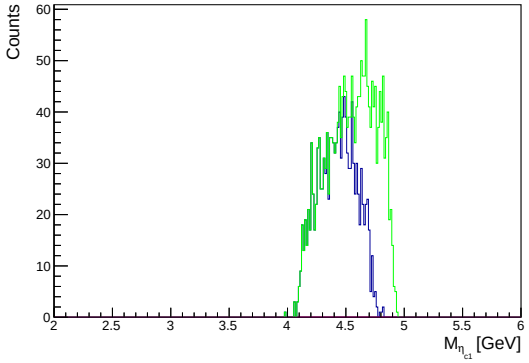
$\tilde{\eta_{c1}}$ invariant mass after adding the η E_{CM} cut



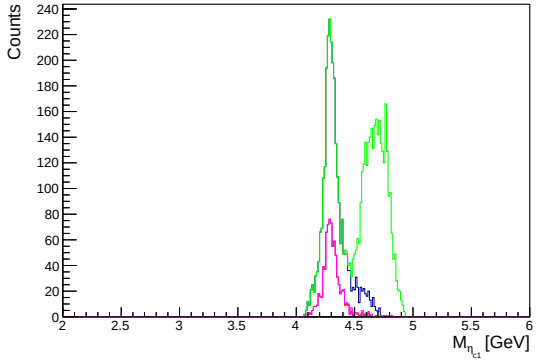
Signal



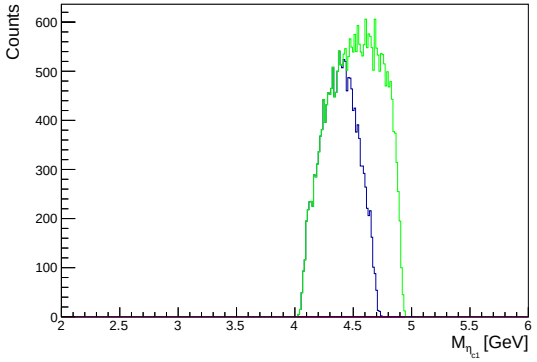
Background 1



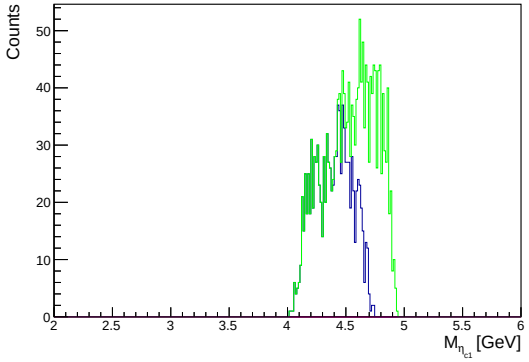
Background 2



Signal - Gen. cuts



Background 1 - Gen. cuts



Background 2 - Gen. cuts

Cuts

	Genetic	**Manual**
4C fit	0.000024	0.001
χ_{c1} mass fit	0.273	0.001
η mass fit	0.014	0.001
Other η mass fit	0.583325	0.001
Second 4C fit	0.6574	0.001
η mass cut	490-583 MeV	528-590 MeV
χ_{c1} mass cut	3.38-3.64 GeV	3.45-3.62 GeV

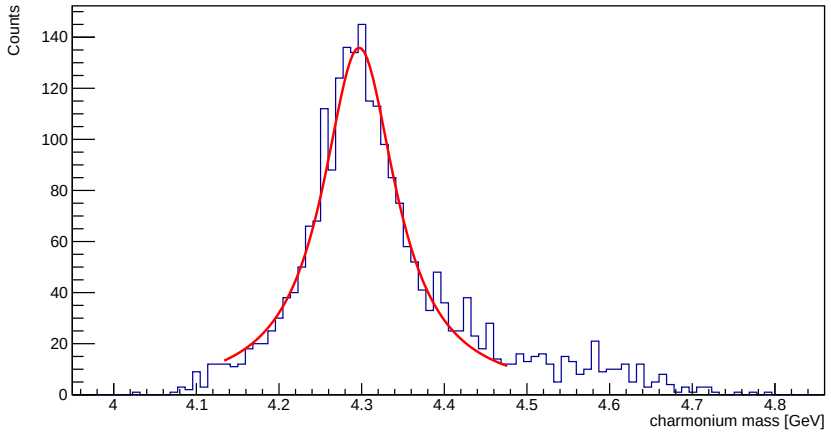
Results of the cuts

	Genetic	Manual	Generated
Bck. 1	16633	14141	500000
Bck. 2	1055	1277	500000
All bck.	19406	17167	1000000+comb.
Signal	782	629	100000
Significance	5.6	4.8	FTM/$\sqrt{\mathrm{Reconst.}}$

Results with the previous decay channel

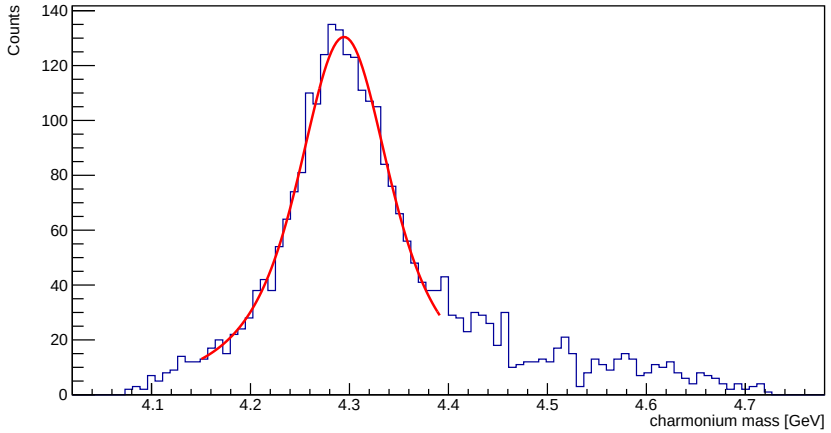
	Gen. $\mu^+\mu^-$	**TDR** $\mu^+\mu^-$	**Gen.** e^+e^-	**TDR** e^+e^-	**Generated**
Bck. 1	1199	3060	109	1673	1000000
Bck. 2	57	867	6	282	1000000
Bck. 3	349	804	46	396	1000000
Bck. 4	1477	3057	343	3140	1000000
All bck.	4616	9132	722	5998	4000000+comb.
Signal	452	315	48	47	100000
Significance	6.65	3.29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

Extracted $\tilde{\eta_{c1}}$ Parameters - Voigt - Manual cuts



- Mass: (4.297 ± 0.002) GeV
- Width: (0.003 ± 2) GeV
- Resoultion: (0.108 ± 0.004) GeV

Extracted $\tilde{\eta_{c1}}$ Parameters - Voigt - Genetic cuts



- Mass: (4.295 ± 0.002) GeV
- Width: (0.021 ± 0.017) GeV
- Resoultion: (0.091 ± 0.042) GeV

Summary and outlook

- The efficiency is better
- The genetic algorithm improves the significance in case of this decay channel as well
- Further background reduction (Bck. 1)
- Perform DPM studies and beam time assumptions for this channel - Access to Virgo/Kronos
- Investigate other decay channels