The $\eta_{c1}^{\sim}$ analysis using genetic algorithm

Áron Kripkó

Justus-Liebig University, Gießen

AG Brinkmann

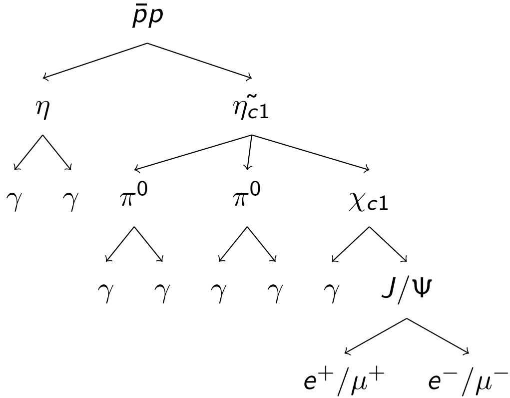
October 28, 2020

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

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

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

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

Simulation and Reconstruction

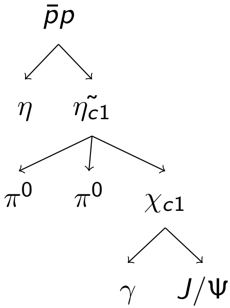
- Antiproton momentum: 15 GeV
- 100000 signal with electron and with muon pairs
- 1000000 x 4 dedicated background channel with electron and with muon pairs
- 250000000 filtered DPM events (1 muon pair and their mass is 2.5-4 GeV)
- During the event generation the PHSP model was used - all spins of particles 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

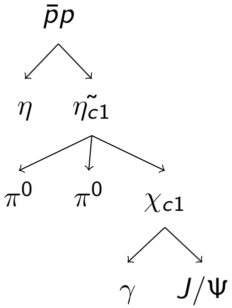


TDR Analysis

- 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



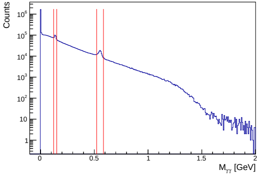
Cuts

	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

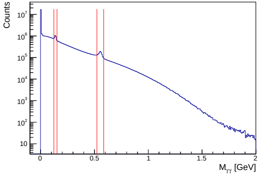
Results of the Cuts

	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

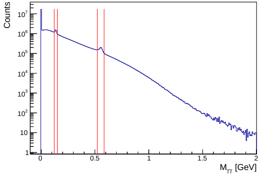
$\gamma\gamma$ invariant mass



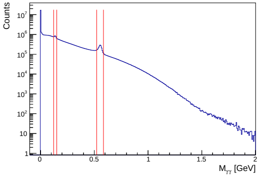
Signal



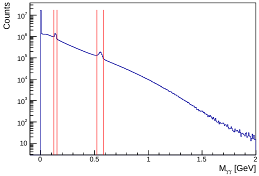
Background 1



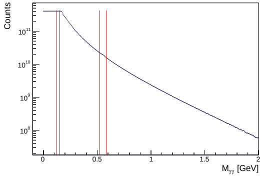
Background 2



Background 3

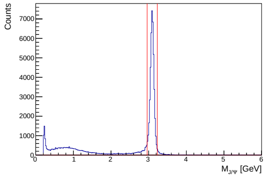


Background 4

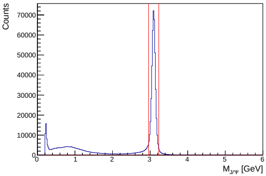


DPM

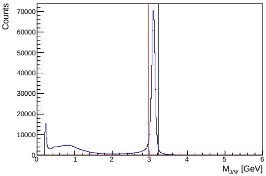
J/Ψ invariant mass



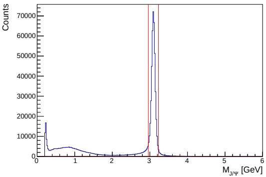
Signal



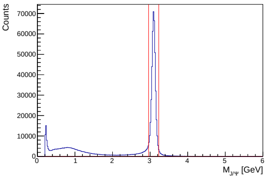
Background 1



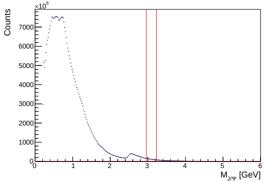
Background 2



Background 3

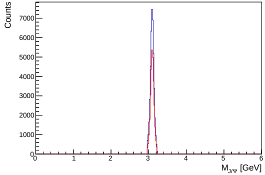


Background 4

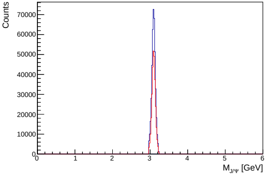


DPM

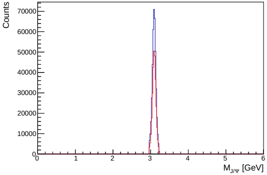
J/Ψ invariant mass after the fit and cut



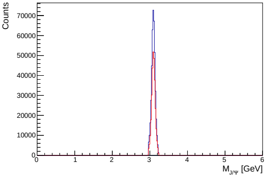
Signal



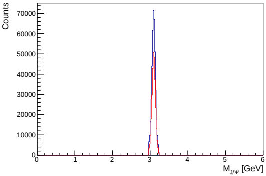
Background 1



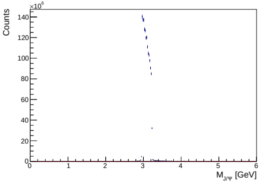
Background 2



Background 3

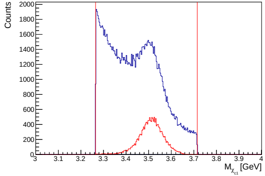


Background 4

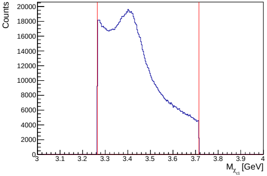


DPM

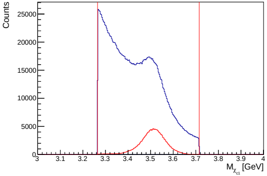
χ_{c1} invariant mass



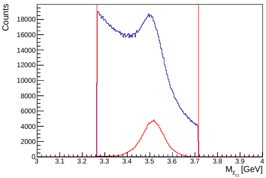
Signal



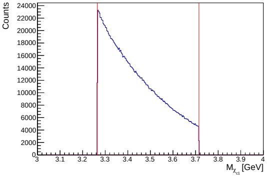
Background 1



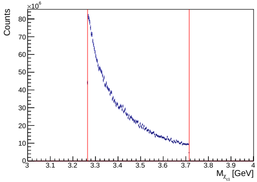
Background 2



Background 3

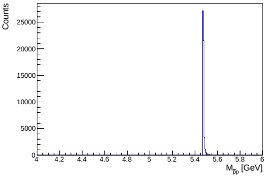


Background 4

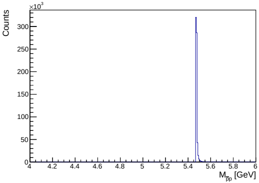


DPM

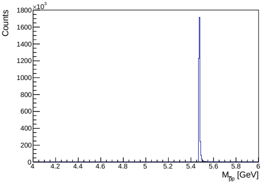
$\bar{p}p$ invariant mass



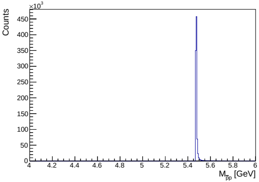
Signal



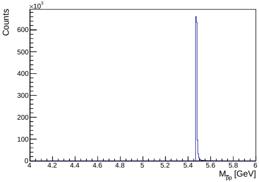
Background 1



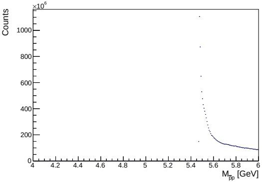
Background 2



Background 3

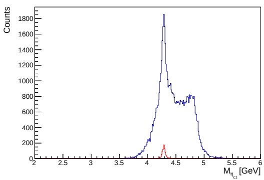


Background 4

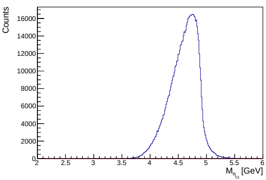


DPM

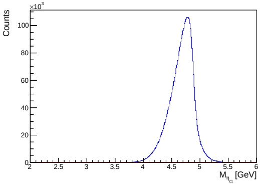
$\eta_{\tilde{c}1}$ invariant mass



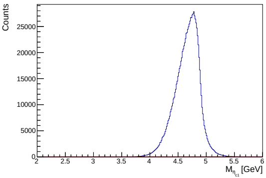
Signal



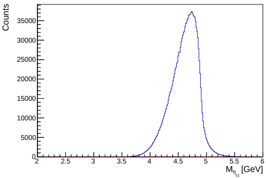
Background 1



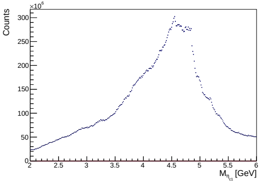
Background 2



Background 3

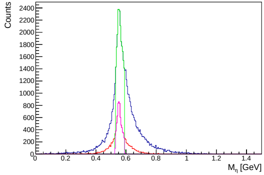


Background 4

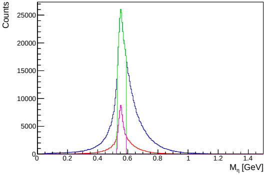


DPM

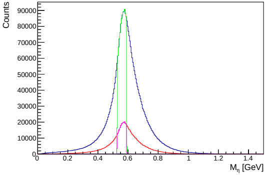
η invariant mass cut



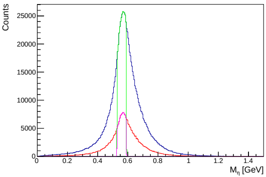
Signal



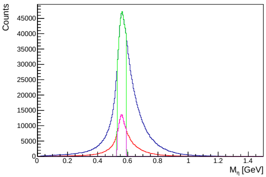
Background 1



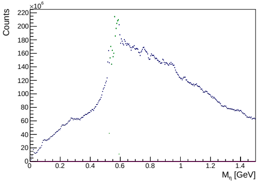
Background 2



Background 3

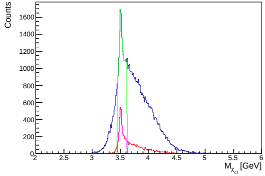


Background 4

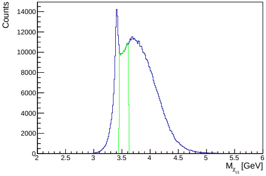


DPM

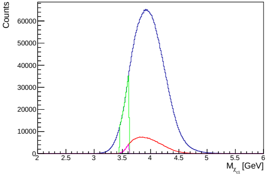
χ_{c1} invariant mass cut



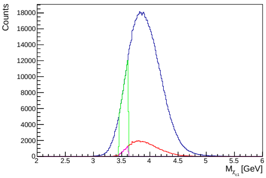
Signal



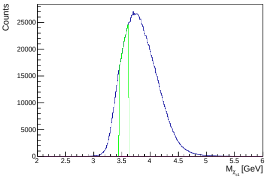
Background 1



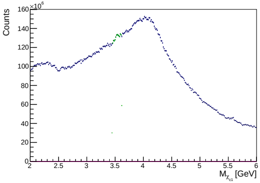
Background 2



Background 3

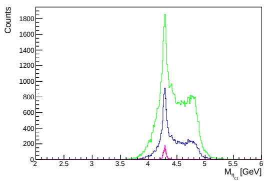


Background 4

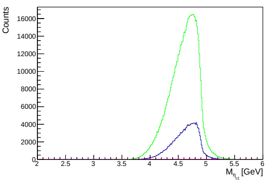


DPM

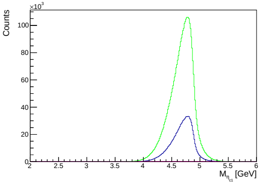
$\eta_{\tilde{c}1}$ invariant mass after the mass cuts



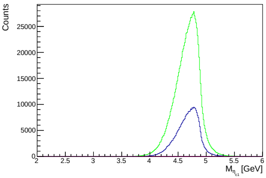
Signal



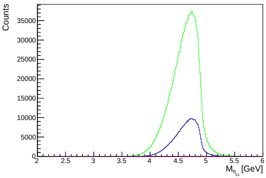
Background 1



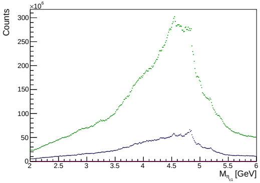
Background 2



Background 3

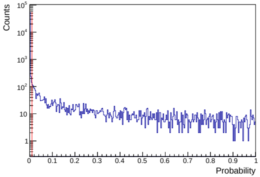


Background 4

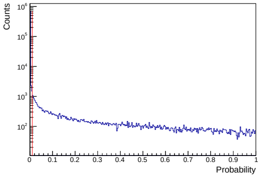


DPM

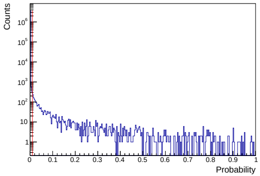
4C fit probability



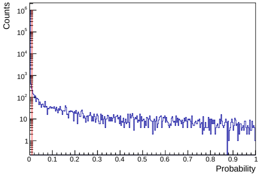
Signal



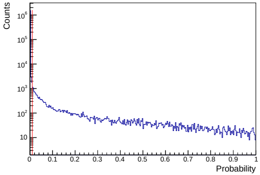
Background 1



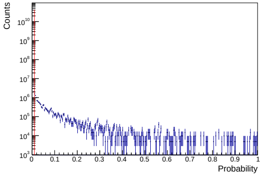
Background 2



Background 3

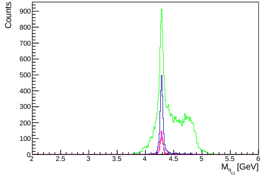


Background 4

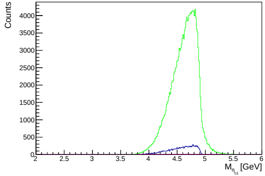


DPM

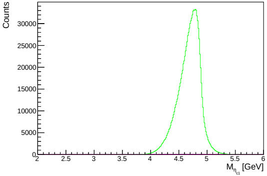
$\eta_{c1}^{\sim}$ invariant mass after the mass and prob. cuts



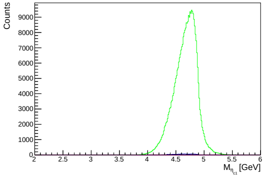
Signal



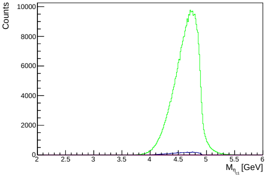
Background 1



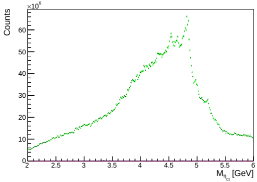
Background 2



Background 3

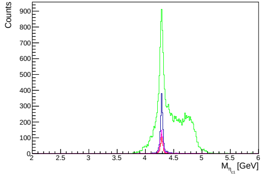


Background 4

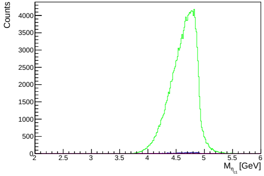


DPM

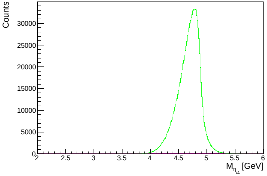
$\tilde{\eta_{c1}}$ invariant mass after the mass and all 6 prob. cuts



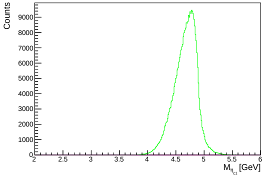
Signal



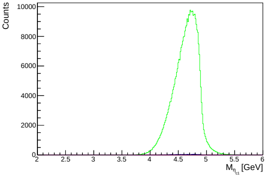
Background 1



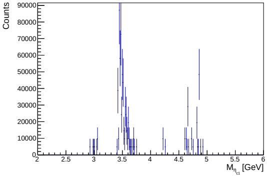
Background 2



Background 3

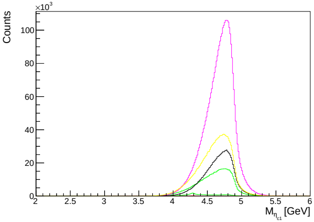


Background 4

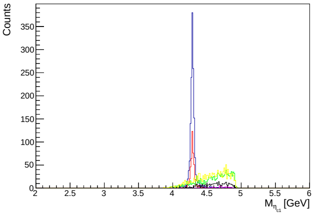


DPM

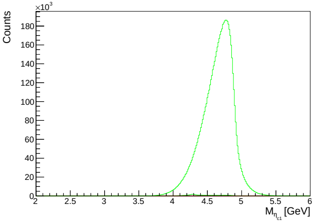
$\tilde{\eta}_{c1}$ invariant mass comparison



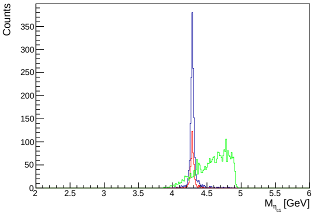
Without cuts



With cuts

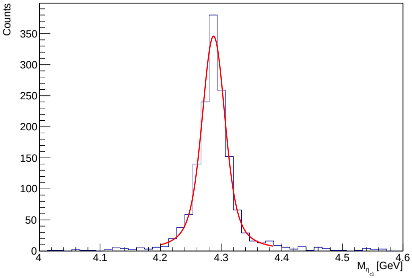


Without cuts



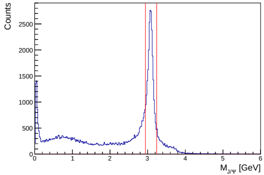
With cuts

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

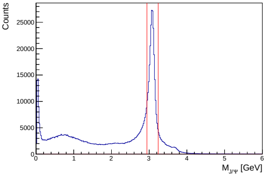


- Mass: $(4.287 \pm 6.6{\cdot}10^{-4})$ GeV
- Width: $(2.21{\cdot}10^{-2} \pm 0.34{\cdot}10^{-2})$ GeV
- Resoultion: $(1.38{\cdot}10^{-2} \pm 0.19{\cdot}10^{-2})$ GeV

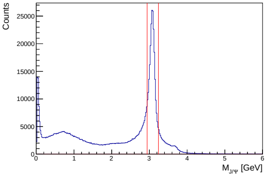
J/Ψ invariant mass e^+e^-



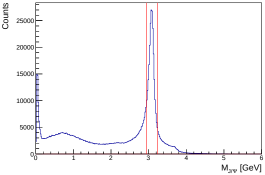
Signal



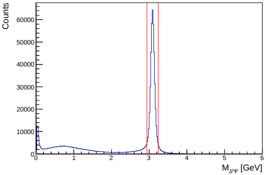
Background 1



Background 2

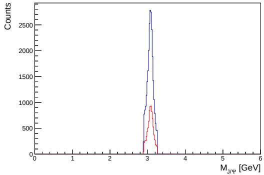


Background 3

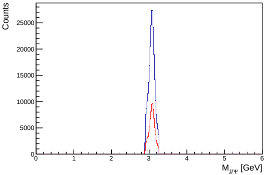


Background 4

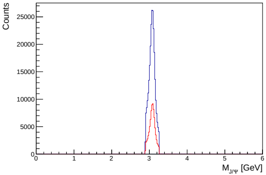
J/Ψ invariant mass after the fit and cut e^+e^-



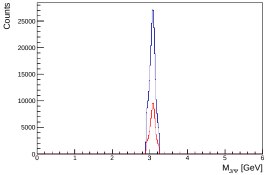
Signal



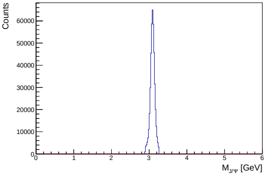
Background 1



Background 2

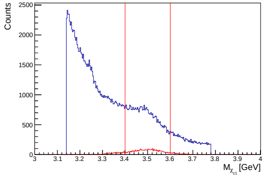


Background 3

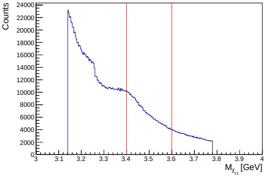


Background 4

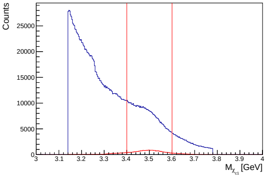
χ_{c1} invariant mass e^+e^-



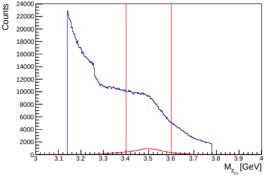
Signal



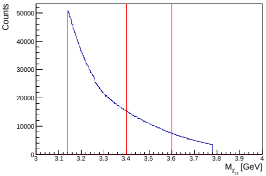
Background 1



Background 2

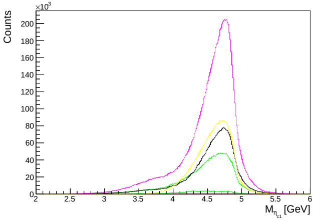


Background 3

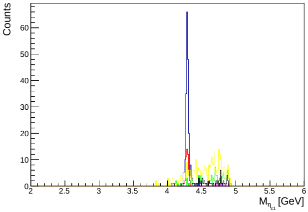


Background 4

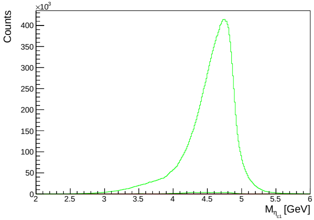
$\tilde{\eta}_{c1}$ invariant mass comparison e^+e^-



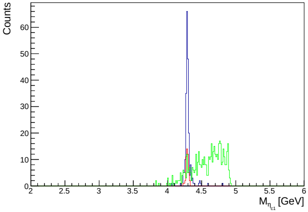
Without cuts



With cuts

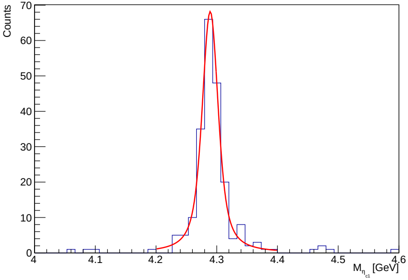


Without cuts



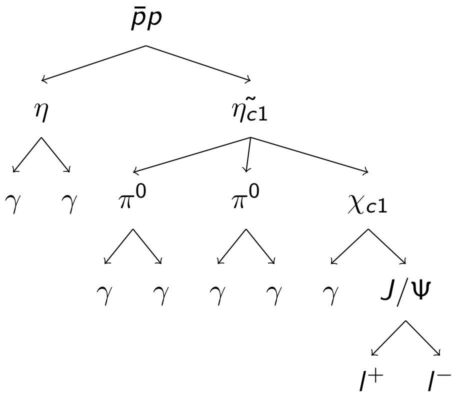
With cuts

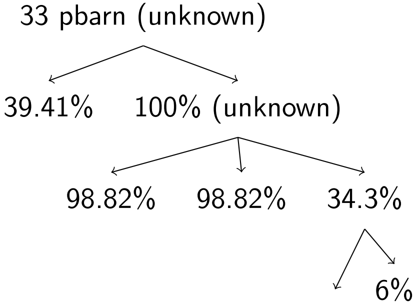
Extracted $\tilde{\eta_{c1}}$ Parameters e^+e^- - Voigt



- Mass: (4.289 ± 0.0013) GeV
- Width: $(1.88{\cdot}10^{-2} \pm 0.46{\cdot}10^{-2})$ GeV
- Resoultion: $(0.83{\cdot}10^{-2} \pm 0.28{\cdot}10^{-2})$ GeV

Branching Ratios and Cross-sections

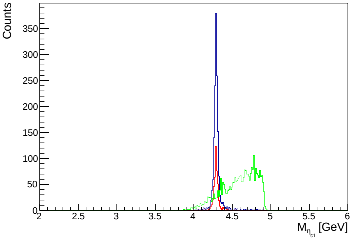




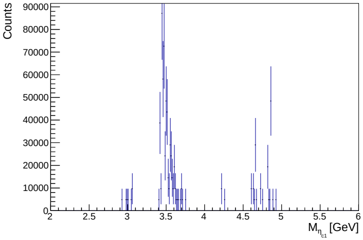
Beam time assumtions

- 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 21649 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 should be multiplied by 14671200
- The histograms were multiplied by 4841 - this assumes 100 nbarn cross-section

Background scaling



Signal and dedicated background



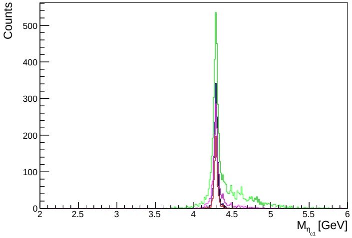
DPM

Beam time assumtions

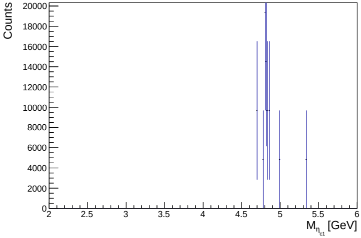
Cross-section [pbarn]	Significance	Beam time [days]	Significance after 1 year
33	0.07 ± 0.03	21650	0.009 ± 0.004
50	0.08 ± 0.04	14289	0.012 ± 0.006
500	0.27 ± 0.13	1429	0.14 ± 0.07
2000	0.5 ± 0.3	357	0.51 ± 0.3
100000	3.7 ± 2	7	26.7 ± 14.4

Outlook - Charged pions

- Results with not optimized cuts
- Signal: 758
- Unscaled DPM: 16



Signal



DPM

Summary

- A benchmark channel from the EMC TDR was studied with the most recent PANDARoot version
- DPM background studies were performed
- The application of genetic algorythm increased the significance by a factor of 2
- The cross-section and the branching ratios are unknown
- Due to the low efficiency, using the assumptions from the TDR, this channel is not suitable to measure this state
- Alternative channels should be investigated