Status of $Z_c(3900)$ simulation in $\bar{p}$-d collisions at PANDA

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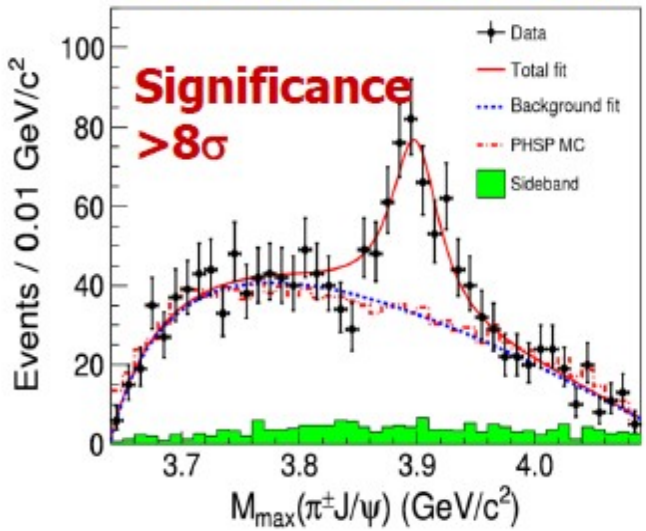
1. Status of Z_c-states,
2. Z_c-coupling with nucleon-antinucleon channel,
3. Z_c-production in $\bar{p}$-d collisions,
4. Simulation of $\bar{p}\, d \rightarrow p_{spec}\, Z_c(3900) \rightarrow \pi^- J/\psi \rightarrow l^+l^-$,
5. Simulation of $\bar{p}\, d \rightarrow p_{spec}\, 2\pi^- \pi^+$ background,
6. Conclusions .

Observation of Zc(3900) at BESIII

PRL110, 252001 (2013)

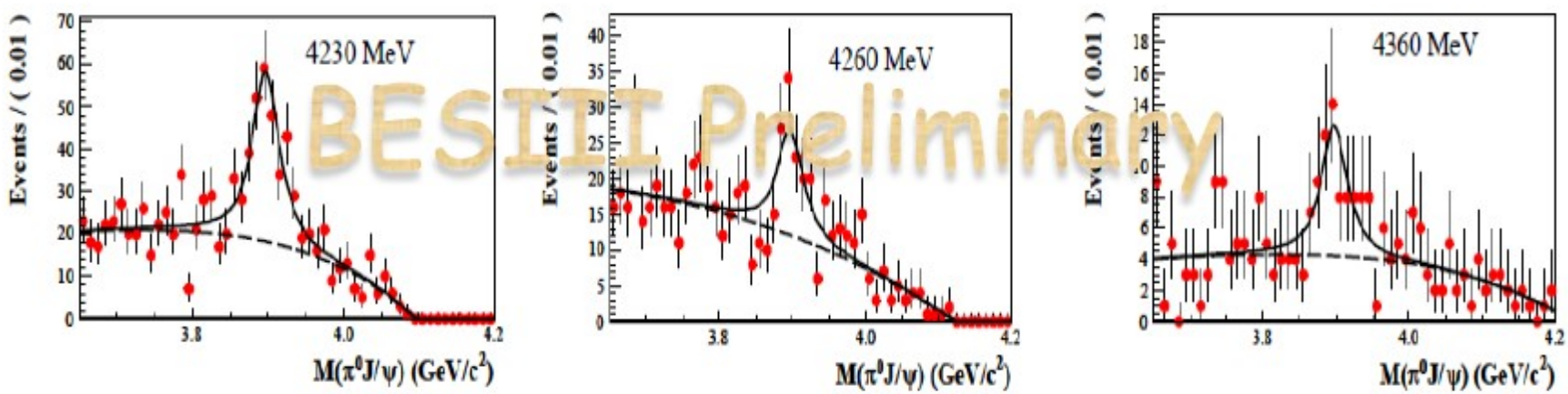


$e^+e^- \to \pi Z_c(4020) \to \pi^+\pi^- J/\psi$

- $M = 3899.0 \pm 3.6 \pm 4.9$ MeV/c^2
- $\Gamma = 46 \pm 10 \pm 20$ MeV

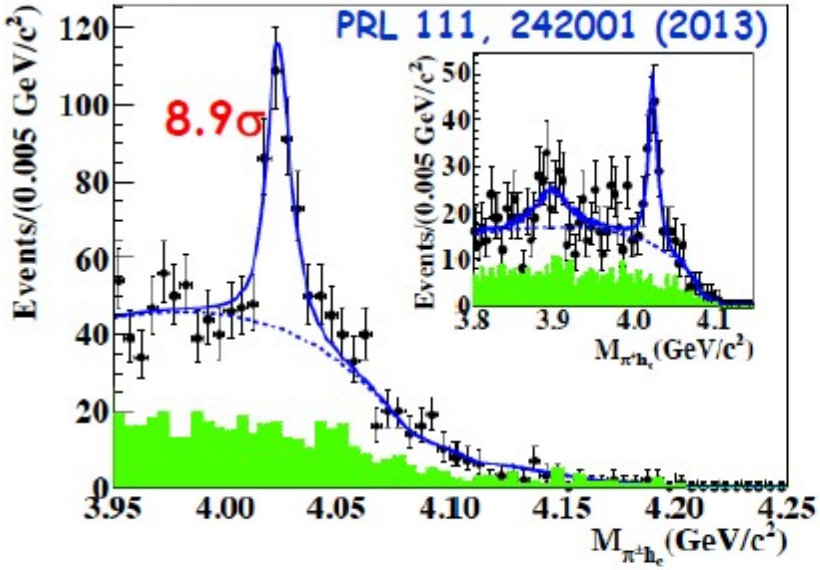
$e^+e^- \to \pi Z_c(4020) \to \pi^0\pi^0 J/\psi$

- $M = 3894.8 \pm 2.3$ MeV/c^2
- $\Gamma = 29.6 \pm 8.2$ MeV

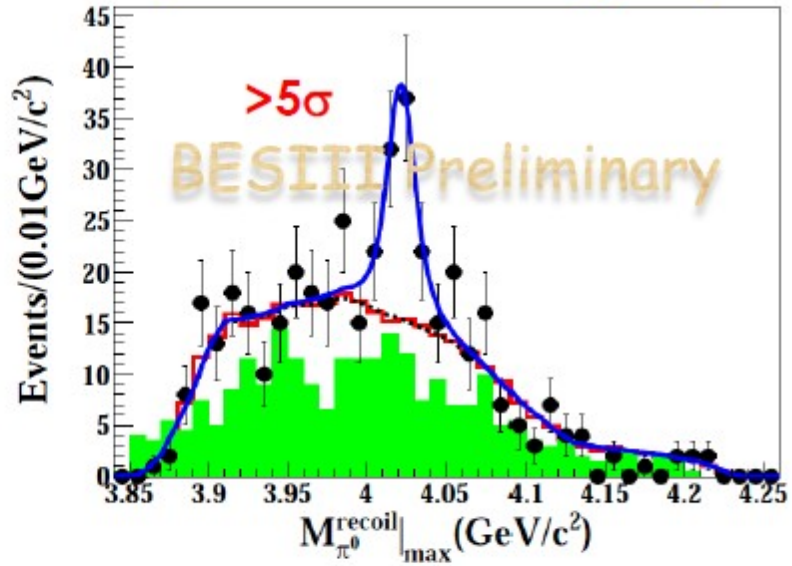


Observation of Zc(4020) in $e^+e^- \to \pi\pi h_c$

$e^+e^- \to \pi^+\pi^- h_c$



$e^+e^- \to \pi^0\pi^0 h_c$



No significant: $Z_c(3900)$ (2.1σ)

$M = 4022.9 \pm 0.8 \pm 2.7$ MeV/c^2

$\Gamma = 7.9 \pm 2.7 \pm 2.6$ MeV

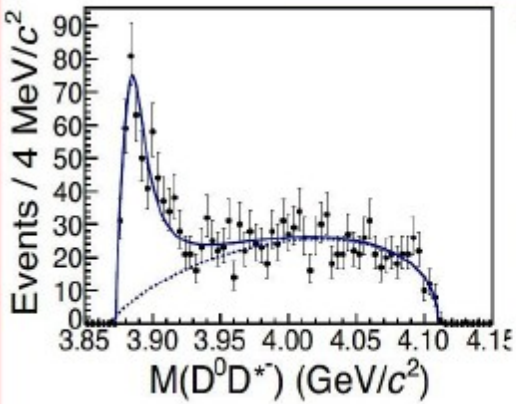
$$\frac{\sigma(e^+e^- \to \pi^0 Z_c(4020)^0 \to \pi^0\pi^0 h_c)}{\sigma(e^+e^- \to \pi^\pm Z_c(4020)^\mp \to \pi^\pm\pi^\mp h_c)}$$

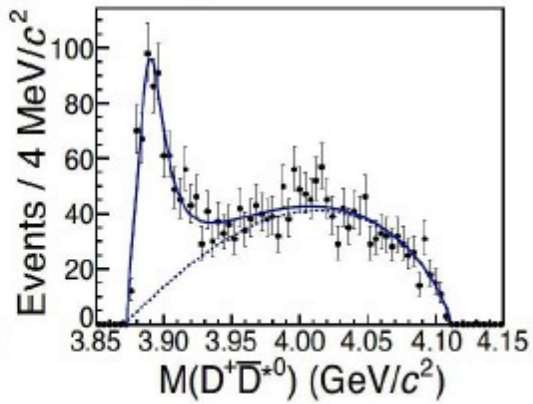
$M = 4023.6 \pm 2.3 \pm 3.9$ MeV/c^2

$\sqrt{s}$ (GeV)	$R_{\pi Z_c(4020)}$
4.230	$0.79 \pm 0.30 \pm 0.26$
4.260	$1.18 \pm 0.46 \pm 0.37$
4.360	$0.99 \pm 0.47 \pm 0.32$

Observation of Zc(3885) and $Z_c(4025)$

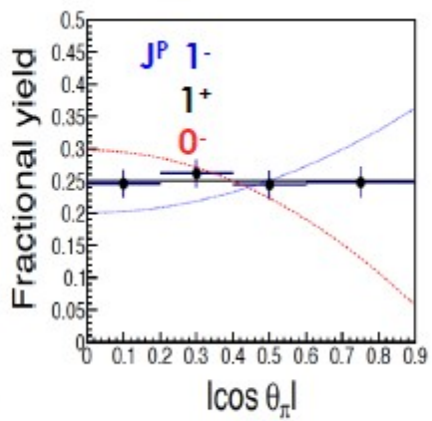
$e^+e^- \to \pi^- (D^* \bar{D})^+$





$M = 3883.9 \pm 1.5 \pm 4.2$ MeV/c^2

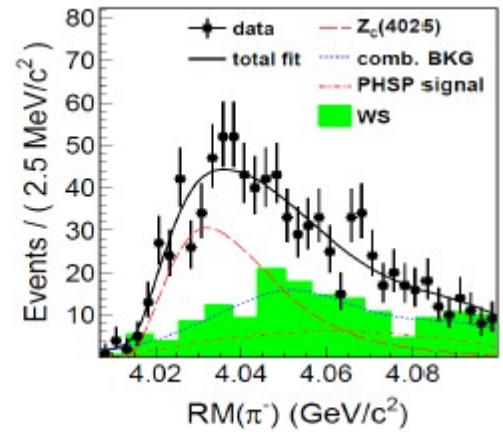
$\Gamma = 24.8 \pm 3.3 \pm 11.0$ MeV



- fits favor 1^+ distribution assumption

PRL 112, 022001 (2014)

$e^+e^- \to \pi^- (D^* \bar{D}^*)^+$



$M = 4026.3 \pm 2.6 \pm 3.7$ MeV/c^2

$\Gamma = 24.8 \pm 5.6 \pm 7.7$ MeV

PRL 112, 132001 (2014)

the Zc states at BESIII

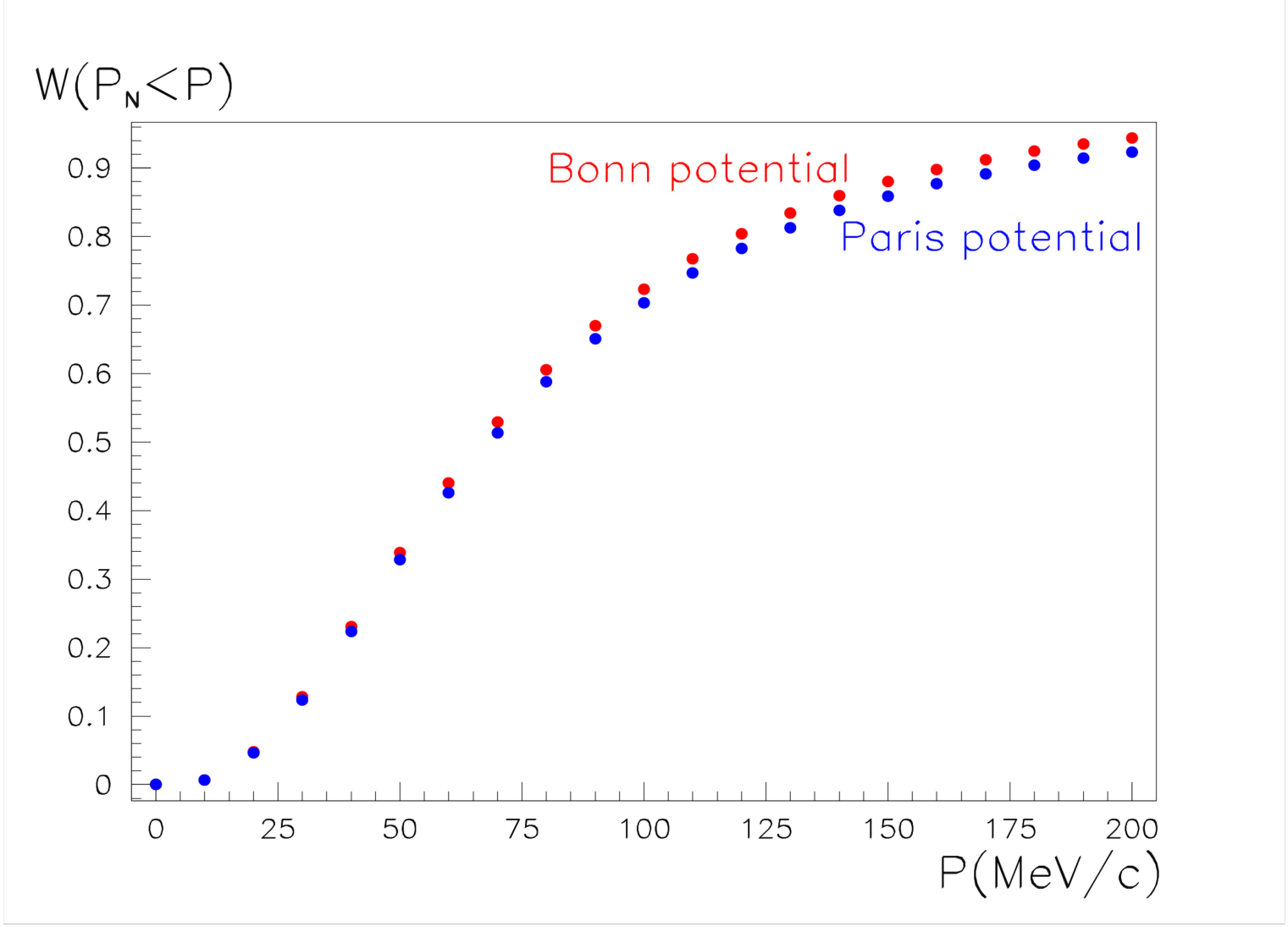
Channel	Mass (MeV/c^2)	Width (MeV)
$\pi J/\psi$	$3899.0 \pm 3.6 \pm 4.9$ 3894.8 ± 2.3(Prel.)	$46 \pm 10 \pm 20$ 29.6 ± 8.2 (Prel.)
$(D\bar{D}^*)^\pm$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 11.0$
	2σ difference	1σ difference
πh_c	$4022.9 \pm 0.8 \pm 2.7$ $4022.9 \pm 0.8 \pm 2.7$(Prel.)	$7.9 \pm 2.7 \pm 2.6$
$(D^*\bar{D}^*)^\pm$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$
	1σ difference	2σ difference

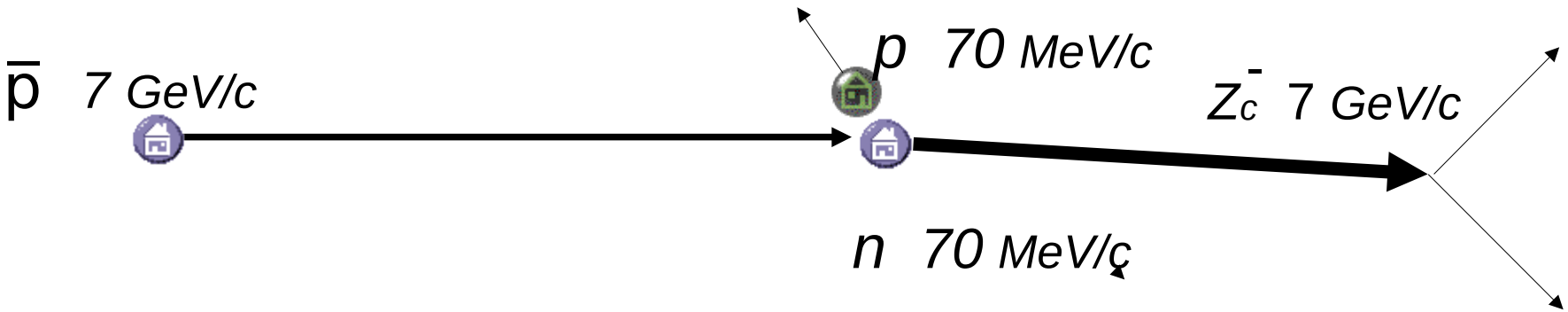
Close to $D\bar{D}^*$ threshold (3875 MeV)

Close to $D^*\bar{D}^*$ threshold (4017 MeV)

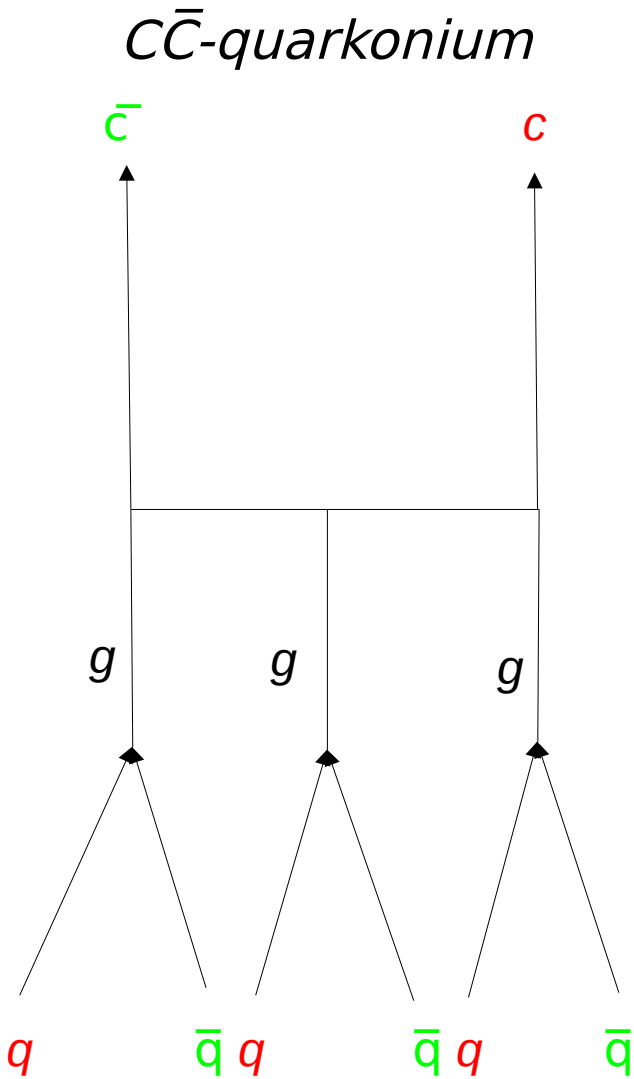
- At least 4-quarks; Near threshold;
- Isospin: I=1, hint of a new spectroscopy ?
- Whether they are two states need further understanding (couple channel analysis? quantum number determination? interference?)

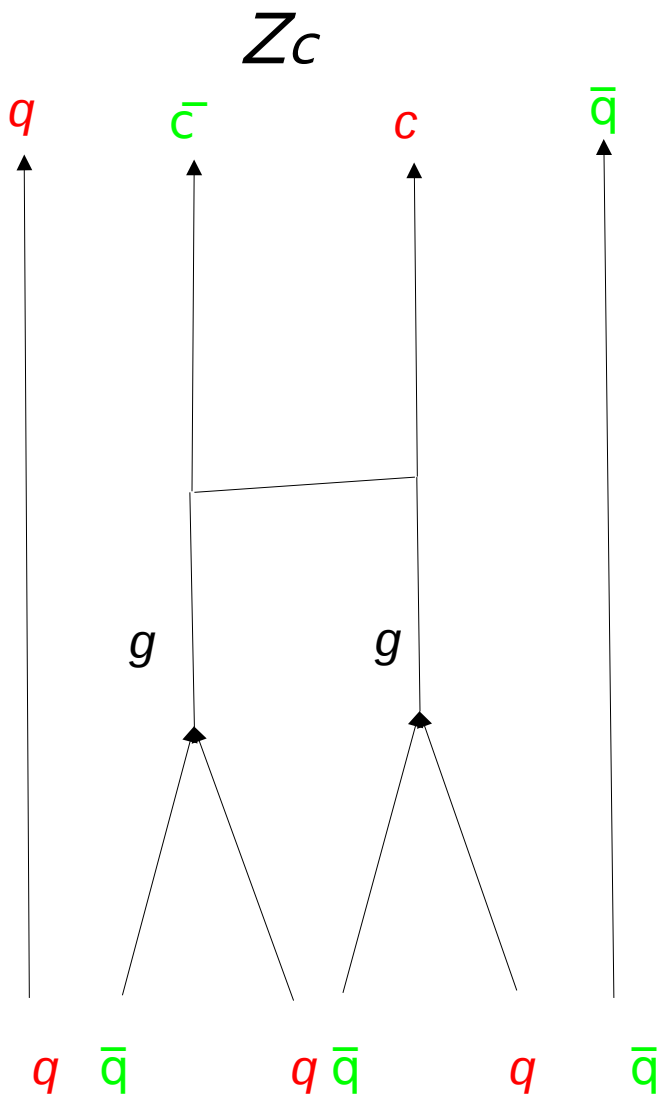
Cumulative probability distribution of P_N in deuteron




p̄ 7 GeV/c
p 70 MeV/c
Zc- 7 GeV/c
n 70 MeV/c

$c\bar{c}$ v.s. Z_c couplings with nucleon-antinucleon channel





pp_{bar} couplings of cc_{bar} states

Γ[KeV]	J/ψ	Ψ'	$\psi(3770)$
$\Gamma(R \to e^+e^-)$	5.55	2.35	0.26
$\Gamma(R \to pp_{bar})$	0.20	0.08	$0.20^{+0.23}_{-0.08}$

M. Ablikim *et al.* (BESIII), Phys.Lett.B735(2014)101 :

$$\sigma(p_{bar}\, p \to \psi(3770)) = 9.8^{+11.8}_{-3.9}\ nb$$

IF Coupling $(Z_c(3900)\text{-}p_{bar}\, n)$ = Coupling $(\psi(3770)\text{-}p_{bar}\, p)$ =>

$$\sigma(p_{bar}\, n \to Z_c) = \sigma(p_{bar}\, p \to \psi(3770)) \times \Gamma(\psi(3770))/\Gamma(Z_c) = 8.8\ nb$$

Simulation of p d → Z_c(3900) → π- J/ψ → l+l-

Inputs & assumptions:

$M(Z_c)$ = 3890 MeV ($P_{p_{bar}}$ = 7.05 GeV/c)

$\Gamma(Z_c)$ = 30 MeV

Br(J/ψ → l+l-) = 5.9 %

σ(p_{bar} n → Z_c) = 8.8 nb;

σ(p_{bar} d → Z_c) = 0.2 σ(p_{bar} n → Z_c) = 1.7 nb (Fermi smearing) =>

σ(p_{bar} n → Z_c → π- l+l-) = 0.5 nb x Br(Z_c → π- J/ψ);

σ(p_{bar} d → Z_c → π- l+l-) = 0.1 nb x Br(Z_c → π- J/ψ) =>

Lt = 10 pb-1 (12 days of data taking) (x 2?) yields

1000 x Br(Z_c → π- J/ψ) Z_c(3900) → π- l+l- events

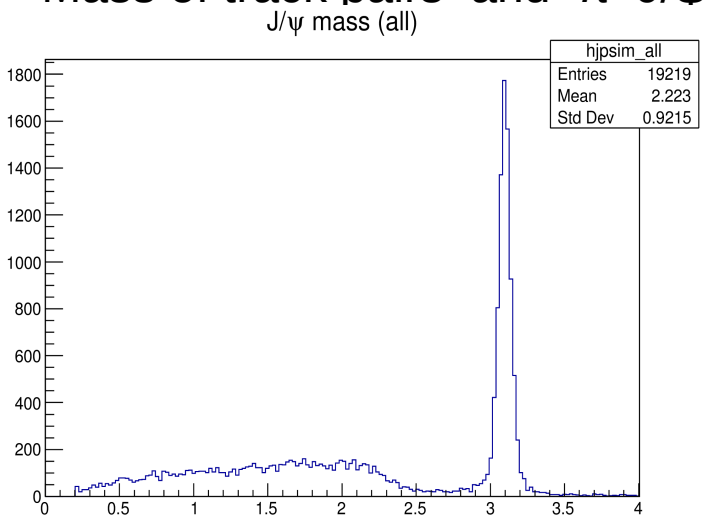
AND (200-400)M p_{bar} n → π-π+π- events => B/S=O(1.000.000)

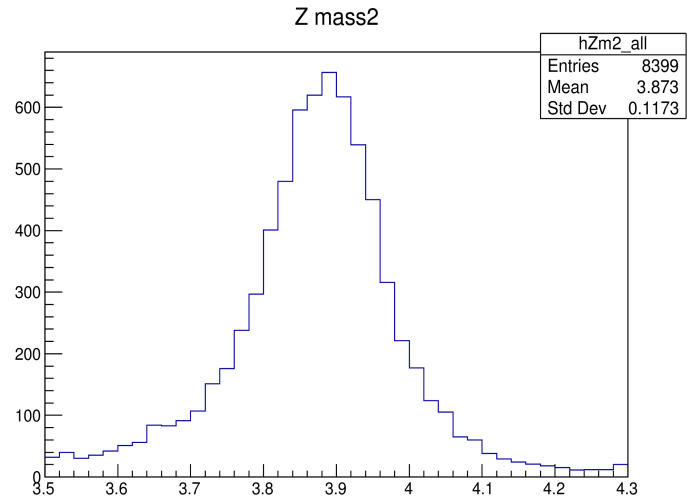
Simulation of p-$\bar{d}$ → π- J/ψ → μ+μ- in PANDAroot

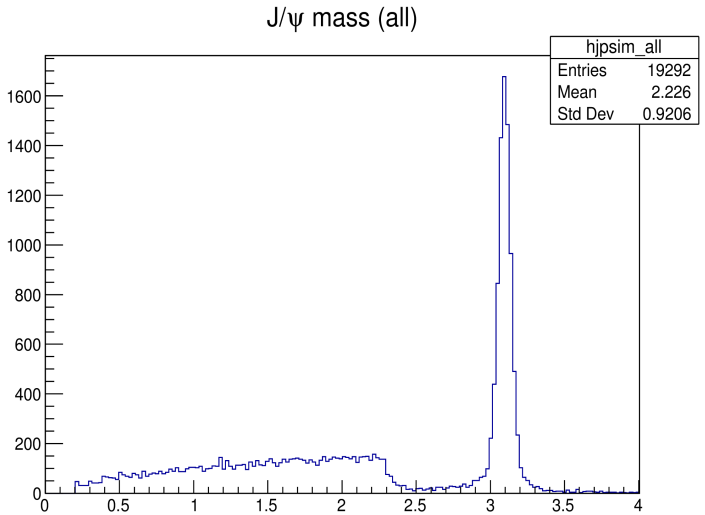
```
Decay pbardSystem
  1.0   p+  pbarnSystem        DeuteronSpectator 1.0  3.25;  <- constant pbar n x-section
Enddecay
#
Decay pbarnSystem
  1.0   J/psi pi-       PHSP;
Enddecay
#
Decay J/psi
  1.0   mu+ mu-         VLL;
Enddecay
#
End
==================================================
Decay pbardSystem
  1.0   p+  pbarnSystem        DeuteronResonance 1.0 3.25 3.890 0.030;  <- resonant pbar n x-section
Enddecay
#
Decay pbarnSystem
  1.0   J/psi pi-       PHSP;
Enddecay
#
Decay J/psi
  1.0   mu+ mu-         VLL;
Enddecay
#
End
```

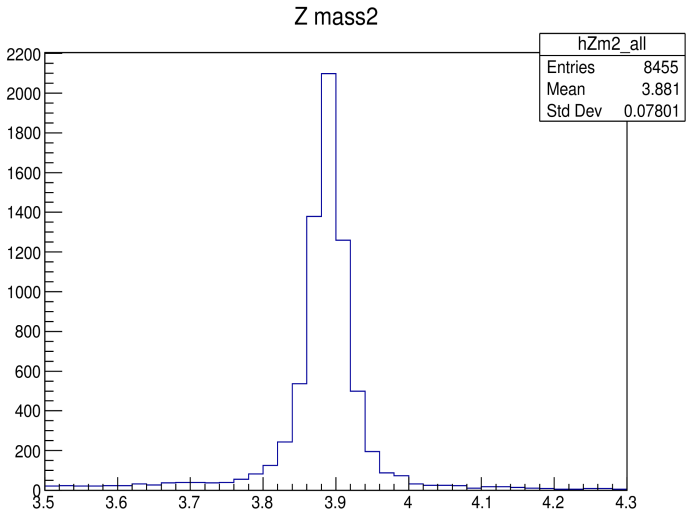
Non-resonant v.s. resonant p d → π- J/ψ → μ+μ- (10 K events)

Mass of track pairs and π- J/ψ candidates ('PionAll', 'MuonAll')



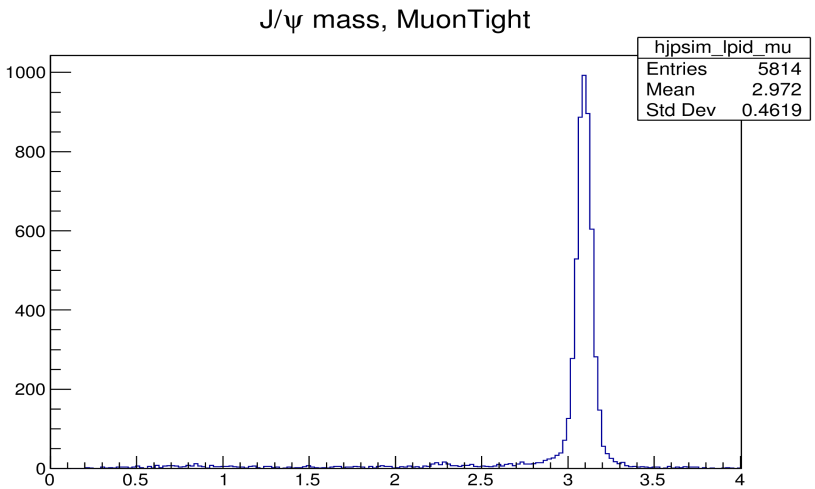


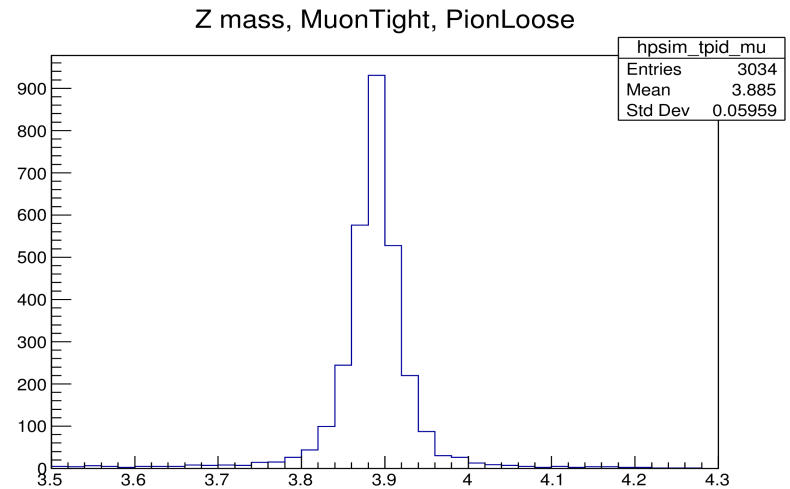




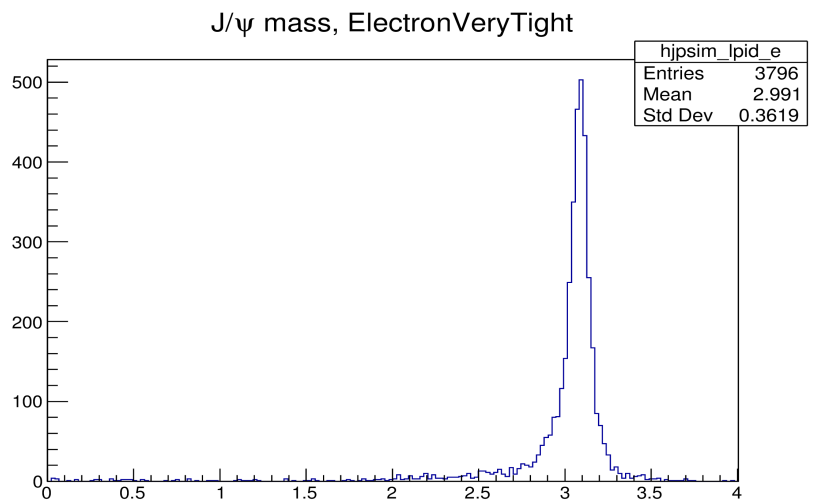
J/ψ mass cut: 2.9< M(π-π+)<3.2 GeV

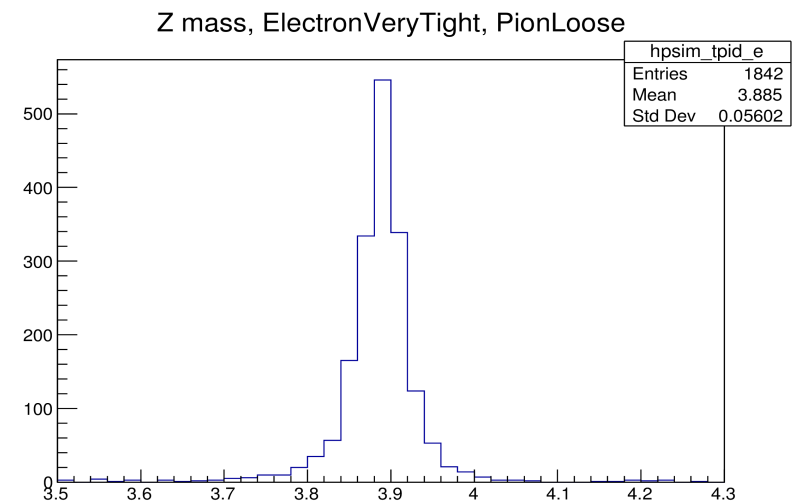
$p_{bar}\ d \rightarrow Z_c(3900) \rightarrow \pi^-\ J/\psi \rightarrow \mu^+\mu^-\ (e^+e^-)$ (10 K events)





Masses of $J/\psi \rightarrow \mu^+\mu^-$ and $Z_c \rightarrow \pi^-\ J/\psi$ candidates ('MuonTight', 'PionLoose')



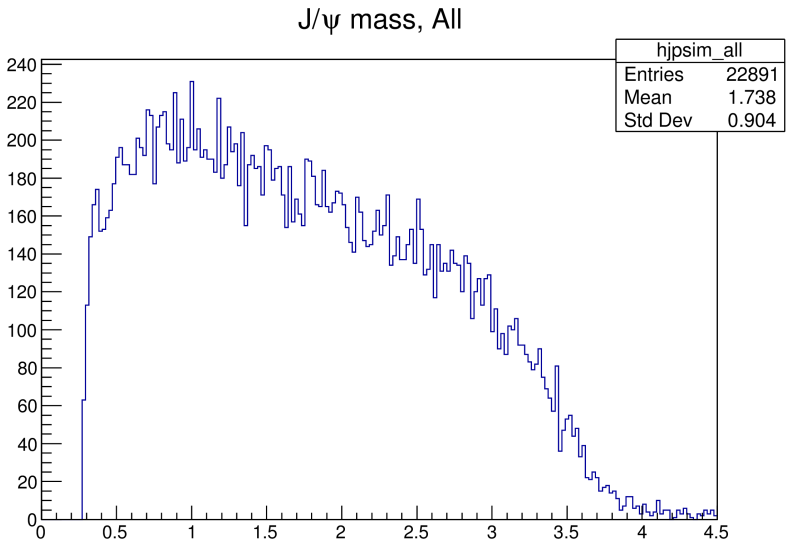


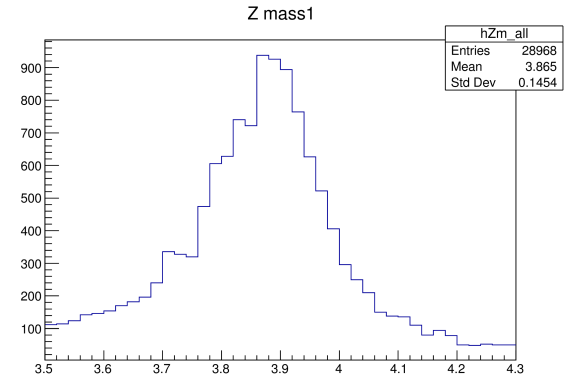
Masses of $J/\psi \rightarrow e^+e^-$ and $Z_c \rightarrow \pi^-\ J/\psi$ candidates ('ElectronVeryTight', 'PionLoose')

Simulation of $\bar{p}$-d → π-π+π- in PANDAroot

```
Decay pbardSystem
  1.0   p+  pbarnSystem        DeuteronSpectator 1.0  3.25;  <-constant pbarn x-section
Enddecay
#
Decay pbarnSystem
  1.0   pi+ pi- pi-     PHSP;
Enddecay
#
End
```

Suppression of $p_{bar}\, n \rightarrow 2\pi\text{-}\pi+$ (PHSP) by J/ψ mass cut

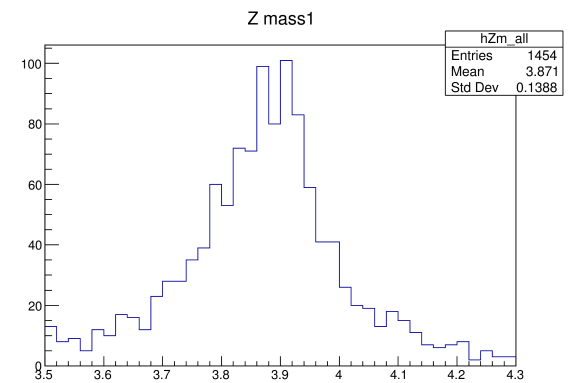




all 2π-π+ combinations

2.9< M(π-π+)<3.2 GeV cut suppress PHSP 2π-π+ states by a factor of 10

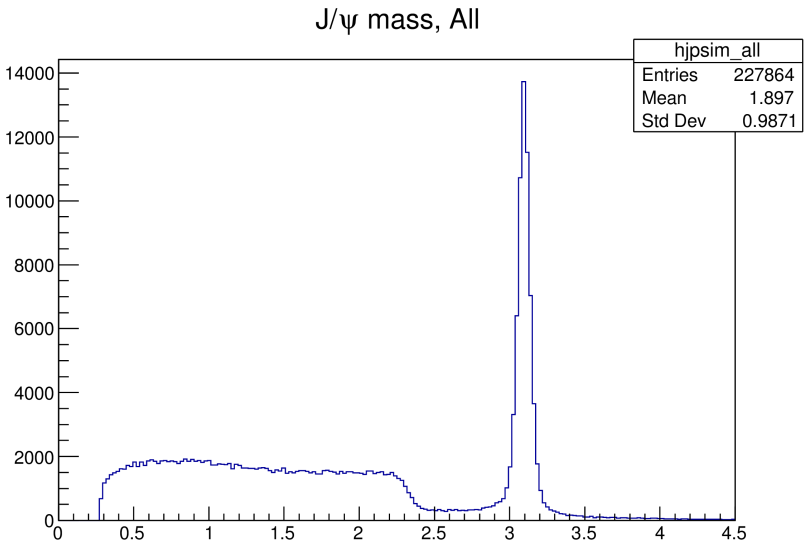
=>



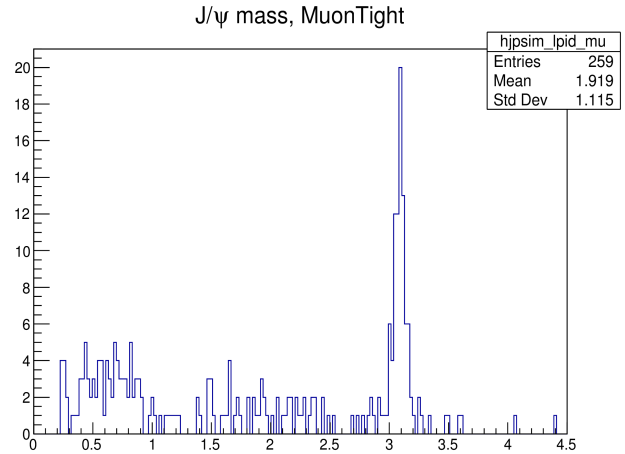
2π-π+ combinations with J/ψ mass cut

Suppression of $p_{bar}\ n \rightarrow 2\pi^- \pi^+$ by lepton PID in J/ψ mass region

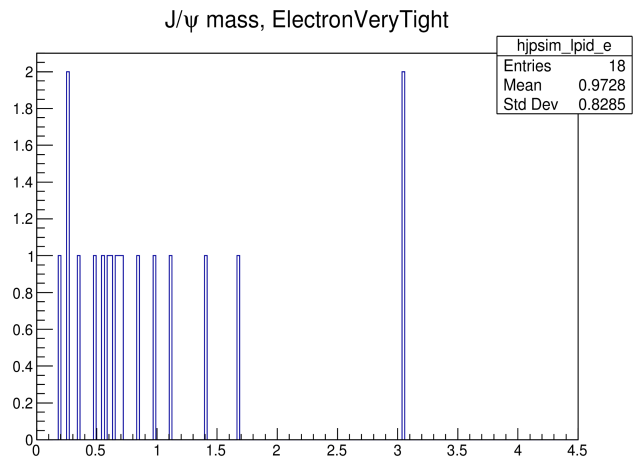
100K π- J/ψ events
→ π+π-



μpid →



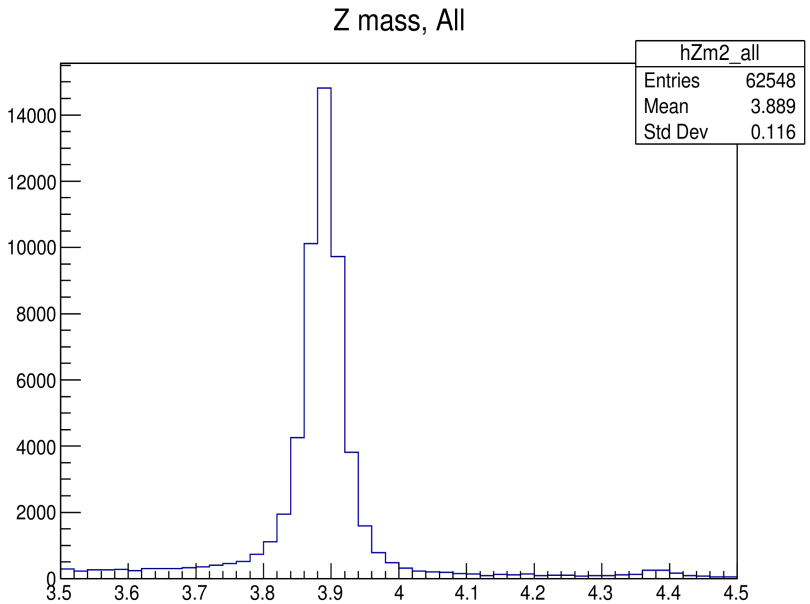
epid →



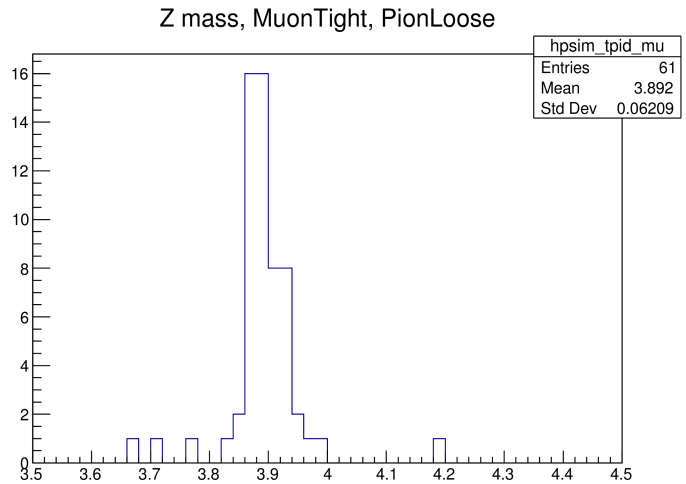
From 200K π- J/ψ → π+π- events only 2 J/ψ → e+e- candidates survived "ElectronVeryTight":"PidAlgoEmcBayes"

Suppression of $p_{bar}\, n \rightarrow 2\pi^- \pi^+$ by lepton PID in J/ψ mass region

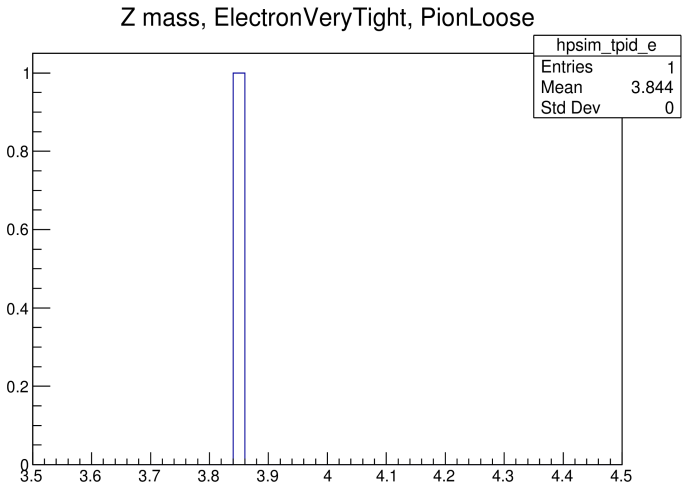
100K π- J/ψ events
→ π+π-



μpid →



epid →



From 200K π- J/ψ → π+π- events only one survived "ElectronVeryTight"&"PionLoose"

Putting things together:

If $Br(Z_c \rightarrow D_{bar}D^*)/Br(Z_c \rightarrow \pi^- J/\psi)=6$ *and*

$Br(Z_c \rightarrow D_{bar}D^*)+Br(Z_c \rightarrow \pi^- J/\psi)=1$

$Br(Z_c \rightarrow \pi^- J/\psi)=0.14$

Thus:

$1000 \times Br(Z_c \rightarrow \pi^- J/\psi)$ produced $Z_c(3900) \rightarrow \pi^- l^+l^-$ events yield

$303 \times Br(Z_c \rightarrow \pi^- J/\psi) = 42$ selected $\pi^- \mu^+\mu^-$ and

$184 \times Br(Z_c \rightarrow \pi^- J/\psi) = 26$ selected $\pi^- e^+e^-$

and 200M produced $p_{bar}\, n \rightarrow 2\pi^-\pi^+$ events

x 0.1 (2.9< M(π-π+)<3.2 GeV cut)

x 0.000005 ("ElectronVeryTight","PidAlgoEmcBayes"&"PionLoose")

yield O(100) selected $\pi^- e^+e^-$ candidates (with 3+ times broader mass distribution) and 10-100 times more $\pi^- \mu^+\mu^-$ candidates.

Conclusions

1. For p_{bar} d → Z_c(3900) → π- J/ψ → e+e- signal v.s. p_{bar} n → 2π-π+ background S/N=O(1) seems feasible,

2. For J/ψ → μ+μ- S/N is 10-100 times lower,

3. The p_{bar} d data at P=7.05 GeV/c can be used also for search of charged partner of X(3872) in J/ψ π- π0 channel since the X(3872)-Z_c(3900) mass difference is well within Fermi smearing.