Study of Excited Nucleons in $\psi' \to p\bar{p}\pi^0, p\bar{p}\eta$

Yuan Wenlong

On behalf of the BESIII Collaboration

Nanjing University, China

NSTAR 2013, *Peñiscola*, May 27-30, 2013

Outlines

- Introduction to BESIII/BEPCII

- Advantages of N^* studies at e^+e^- colliders

- Partial wave analysis of $\psi' \to p\bar{p}\eta$

- Partial wave analysis of $\psi' \to p\bar{p}\pi^0$
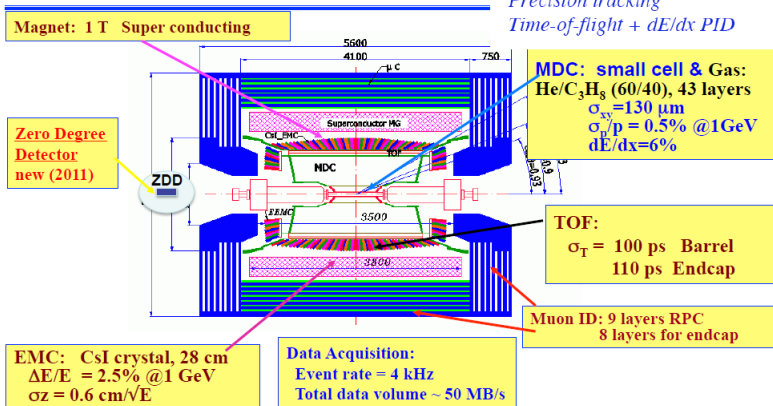
- Summary

The BEPCII/BESIII Project

BESIII Detector
[NIM A614 (2010)345]

BESIII detector: all new !
CsI calorimeter
Precision tracking
Time-of-flight + dE/dx PID

Magnet: 1 T Super conducting

Zero Degree Detector new (2011)

MDC: small cell & Gas:
He/C_3H_8 (60/40), 43 layers
$\sigma_{xy}=130 \ \mu m$
$\sigma_p/p = 0.5\%$ @1GeV
dE/dx=6%

TOF:
$\sigma_T = 100$ ps Barrel
110 ps Endcap

Muon ID: 9 layers RPC
8 layers for endcap

EMC: CsI crystal, 28 cm
$\Delta E/E = 2.5\%$ @1 GeV
$\sigma z = 0.6$ cm/$\sqrt{E}$

Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s

The detector is hermetic for neutral and charged particle with excellent resolution, PID, and large coverage.

Physics of τ-charm region

- Light hadron physics
  - meson and baryon spectroscopy
  - glueball and hybid
  - two-photon physics
  - e.m. form factors of nucleon
- Charmonium phyiscs
  - Spectroscopy
  - transitions and decays
- Open Charm physics
  - (semi)leptonic and hadronic decays
  - decay constant, form factors
  - CKM matrix: Vcd,Vcs
  - D^0-$\overline{D^0}$ misxing and CP violation
  - rare/forbidden decays
- τ physics
  - τ decay near threshold
 - τ mass scan
- ... ...

N^* Problem

- "Missing" baryon resonance problem: Quark models predict many more baryon resonances than have been observed"

- Possible explanations:
  - ▶ Theoretically: Reduce the number of degree of freedom. (Quark-diquark)
  - ▶ Experimentally: If the missing N^*s have small couplings to πN & γN, they would not have been discovered by experiments using photons or pions
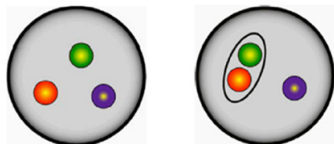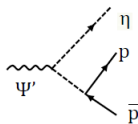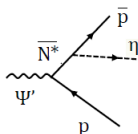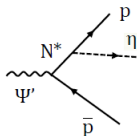
Advantages of "Missing" baryons studing at BESIII

- Pure isospin $1/2$
- Study by many decay channels, such as $\psi \to N\overline{N}\pi/\eta/\eta'/\omega/\phi$
- Not only N^*, but also $\Lambda^*, \Sigma^*, \Xi^*$
- High statistics of charmonium at BESIII
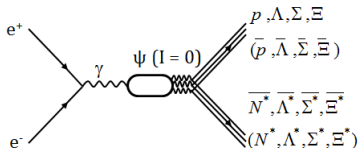
Analysis related to N^* Physics at BESIII

- Partial wave analysis of $\psi' \to p\bar{p}\eta$

Introduction to Partial Wave Analysis(PWA)

- Construct amplitude A_i for each possible partial wave

$$A_i = A_{prod} A(Breit - Wigner) A_{decay}$$

- Construct differential corss section

$$\frac{d\sigma}{d\Omega} = | \sum_i A_i + A_{background} |^2$$
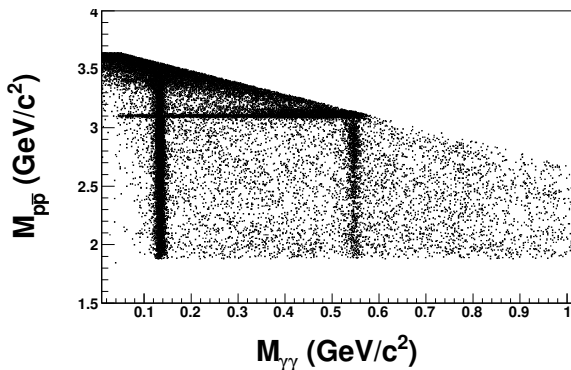
- Construct log likelihood function

$$lnL = \sum_{i=1}^{n} ln(\frac{d\sigma}{d\Omega}/\sigma)$$

- Maximize log likelihood function

Partial wave analysis of $\psi' \to p\bar{p}\eta$
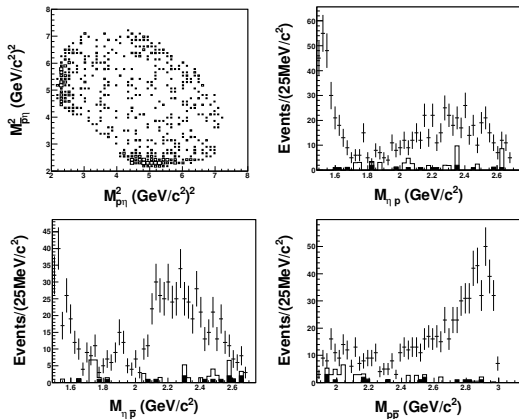
Scatter plots of $p\bar{p}$ invariant mass verus $\gamma\gamma$ invariant mass

Two heretical bands: $\psi' \to p\bar{p}\pi^0$, $\psi' \to p\bar{p}\eta$
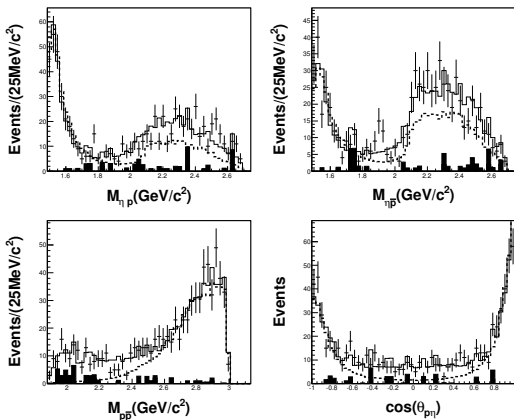Horizontal band: $\psi' \to X + J/\psi (J/\psi \to p\bar{p})$

Partial wave analysis of $\psi' \to p\bar{p}\eta$

Dalitz plot of $\psi' \to p\bar{p}\eta$ and distribution for $M_{\eta p}, M_{\eta \bar{p}}, M_{p\bar{p}}$

- Crosses: data
- Blank histograms: background events from continuum data
- Shaded histograms: background events from η sidebands

Partial wave analysis of $\psi' \rightarrow p\bar{p}\eta$

- Crosses: data
- Blank histograms: PWA projections
- Shaded histograms: background events from η sidebands and continuum data
- dashed lines: contribution of N(1535)

Best solution: N(1535) combined with an interfering phase space

Partial wave analysis of $\psi' \to p\bar{p}\eta$

- Mass and width of N(1535)
  - M $= 1524 \pm 5^{+10}_{-4}$ MeV/c^2
  - $\Gamma = 130^{+27+57}_{-24-10}$ MeV/c^2
- PDG value:
  - M $= 1525$ to 1545 MeV/c^2
  - $\Gamma = 125$ to 175 MeV/c^2
- Branching fraction:
  - $B(\psi' \to N(1535)\bar{p}) \times B(N(1535) \to p\eta) + c.c. = (5.2 \pm 0.3^{+3.2}_{-1.2} \times 10^{-5})$

Paper is available at: http://arxiv.org/abs/1304.1973

# Partial wave analysis of $\psi' \to p\bar{p}\pi^0$

Dalitz plot of $\psi' \to p\bar{p}\pi^0$ and distribution for $M_{p\bar{p}}$, $M_{p\pi^0}$, $M_{\bar{p}\pi^0}$
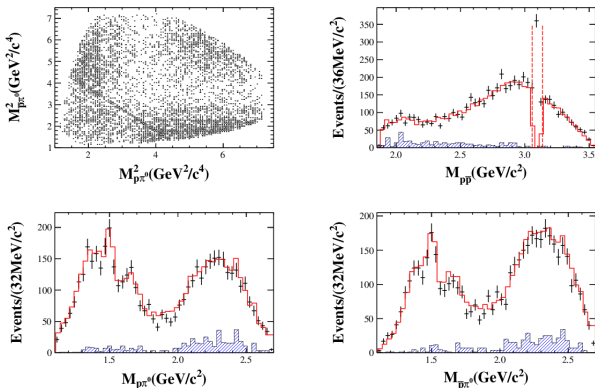
- Crosses: data
- Shaded histograms: background events from continuum process and π^0 sidebands
- Histograms in solid line: the sum of MC prediction and the background
- dashed line in $M_{p\bar{p}}$ distribution: J/ψ mass region

Partial wave analysis of $\psi' \to p\bar{p}\pi^0$

The contribution of each intermediate resonance in the $p\pi^0$ mass spectra
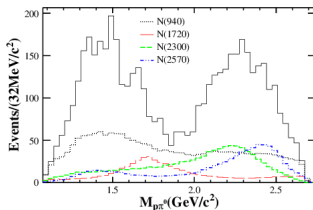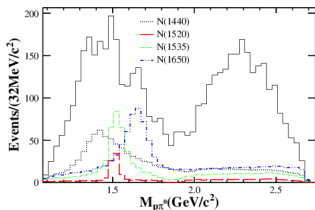
| Resonance	M(MeV/c^2)	Γ(MeV/c^2)	ΔS	ΔN_{dof}	Sig.
$N(1440)$	$1390^{+11\,+21}_{-21\,-30}$	$340^{+46\,+70}_{-40\,-156}$	72.5	4	11.5σ
$N(1520)$	$1510^{+3\,+11}_{-7\,-9}$	$115^{+20\,+0}_{-15\,-40}$	19.8	6	5.0σ
$N(1535)$	$1535^{+9\,+15}_{-8\,-22}$	$120^{+20\,+0}_{-20\,-42}$	49.4	4	9.3σ
$N(1650)$	$1650^{+5\,+11}_{-5\,-30}$	$150^{+21\,+14}_{-22\,-50}$	82.1	4	12.2σ
$N(1720)$	$1700^{+30\,+32}_{-28\,-35}$	$450^{+109\,+149}_{-94\,-44}$	55.6	6	9.6σ
$N(2300)$	$2300^{+40\,+109}_{-30\,-0}$	$340^{+30\,+110}_{-30\,-58}$	120.7	4	15.0σ
$N(2570)$	$2570^{+19\,+34}_{-10\,-10}$	$250^{+14\,+69}_{-24\,-21}$	78.9	6	11.7σ

Partial wave analysis of $\psi' \to p\bar{p}\pi^0$

Summary of number of events, MC efficiency (ϵ), and branching fraction (B.F.)

Resonance	N	$\epsilon(\%)$	B.F.($\times 10^{-5}$)
$N(940)$	$1870^{+90\ +487}_{-90\ -327}$	27.5 ± 0.4	$6.42^{+0.20\ +1.78}_{-0.20\ -1.28}$
$N(1440)$	$1060^{+90\ +459}_{-90\ -227}$	27.9 ± 0.4	$3.58^{+0.25\ +1.59}_{-0.25\ -0.84}$
$N(1520)$	$190^{+14\ +64}_{-14\ -48}$	28.0 ± 0.4	$0.64^{+0.05\ +0.22}_{-0.05\ -0.17}$
$N(1535)$	$673^{+45\ +263}_{-45\ -256}$	25.8 ± 0.4	$2.47^{+0.28\ +0.99}_{-0.28\ -0.97}$
$N(1650)$	$1080^{+77\ +382}_{-77\ -467}$	27.2 ± 0.4	$3.76^{+0.28\ +1.37}_{-0.28\ -1.66}$
$N(1720)$	$510^{+27\ +50}_{-27\ -197}$	26.9 ± 0.4	$1.79^{+0.10\ +0.24}_{-0.10\ -0.71}$
$N(2300)$	$948^{+68\ +394}_{-68\ -213}$	34.2 ± 0.4	$2.62^{+0.28\ +1.12}_{-0.28\ -0.64}$
$N(2570)$	$795^{+45\ +127}_{-45\ -83}$	35.3 ± 0.4	$2.13^{+0.08\ +0.40}_{-0.08\ -0.30}$
Total	4515 ± 93	25.8 ± 0.4	$16.5 \pm 0.3 \pm 1.5$

Phys. Rev. Lett. 110, 022001 (2013)

Compare with CLEOc

Phys. Rev. D **82**, 092002 (2010)
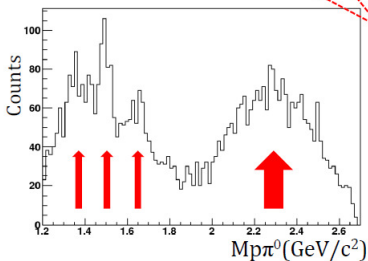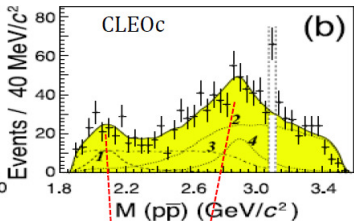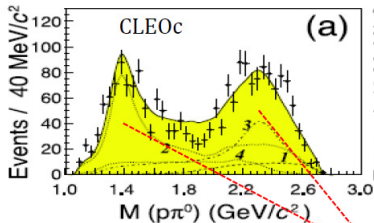
Resonance	M (MeV/c^2)
$N_1^*(1440)$	1400 ± 25
$N_2^*(2300)$	2300 ± 25
$R_1(2100)$	2103 ± 8
$R_2(2900)$	2900 ± 20

Summary

- Two new N^* resonances are found from $\psi' \to p\overline{p}\pi^0$: N(2300) and N(2570)
- The mass and width of N(1535) are measured from $\psi' \to p\overline{p}\eta$
- BESIII is a great tool to study baryon resonances