Light Hadron Spectroscopy at BESIII

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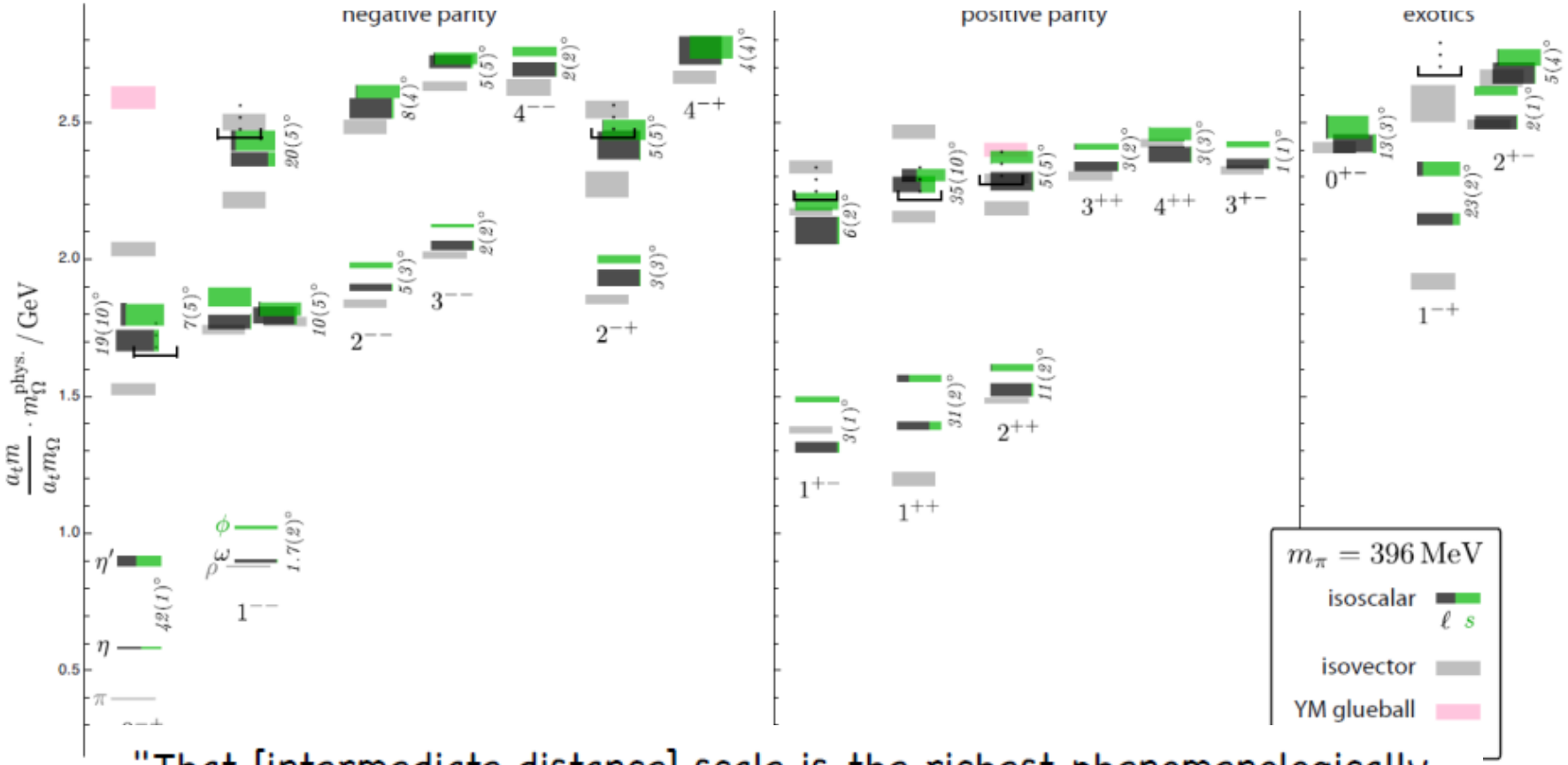
10th International Workshop e^+ e^- Collisions from Phi to Psi

USTC, Hefei, China

OUTLINE

- Introduction
- Current status
  - Meson spectroscopy
  - Baryon spectroscopy
  - Light meson decays
- Summary

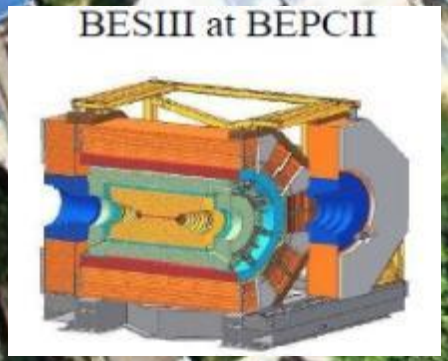
Meson spectroscopy in LQCD



"That [intermediate distance] scale is the richest phenomenologically, and is certainly the crux region to understand...what QCD is really about. And at the heart of the subject is the hadron spectrum, in particular the spectrum built from light quarks. (...) Without question, there is a great need... for a new round of experiments,..."

James D. Bjorken (2000)

Bird view of BEPCII



BESIII physics

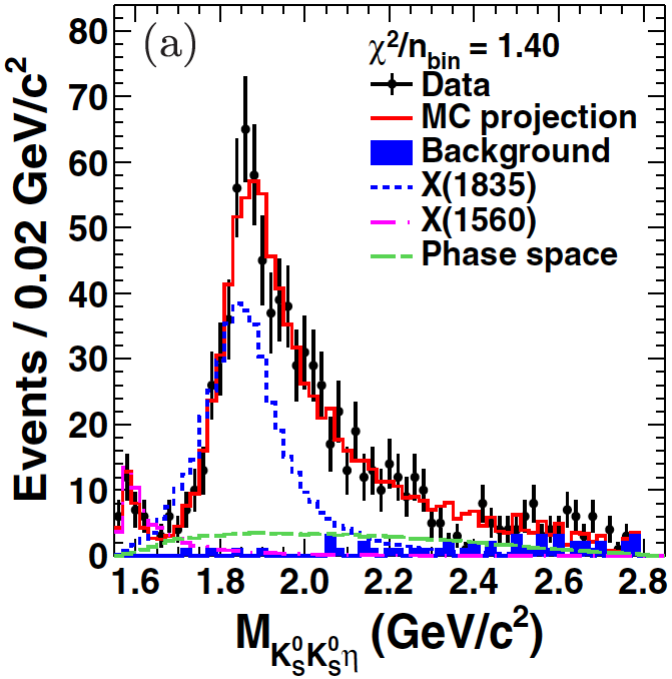
- Charmonium(-like) physics
- Light hadron spectroscopy
- Charm physics
- τ physics

Light meson spectroscopy

- 2009+2012 : 0.5 billion $\psi(2S)$ events
  1.3 biliion J/ψ events

Observation of X(1835) in J/ψ→γKsKsη

Phys.Rev.Lett. 115 091803(2015)



PWA for $M(K_SK_S)$<1.1 GeV/c²

- **X(1560) → $f_0(980)\eta$: $J^{PC}=0^{-+}$, (> 8.9 σ)**

M=1565 $\pm 8^{+0}_{-63}$ MeV/c², Γ=45 $^{+14}_{-13}$ $^{+21}_{-28}$ MeV

$\eta(1405)$ / $\eta(1475)$ within 2.0 σ

- **X(1835)→$K_SK_S\eta$**

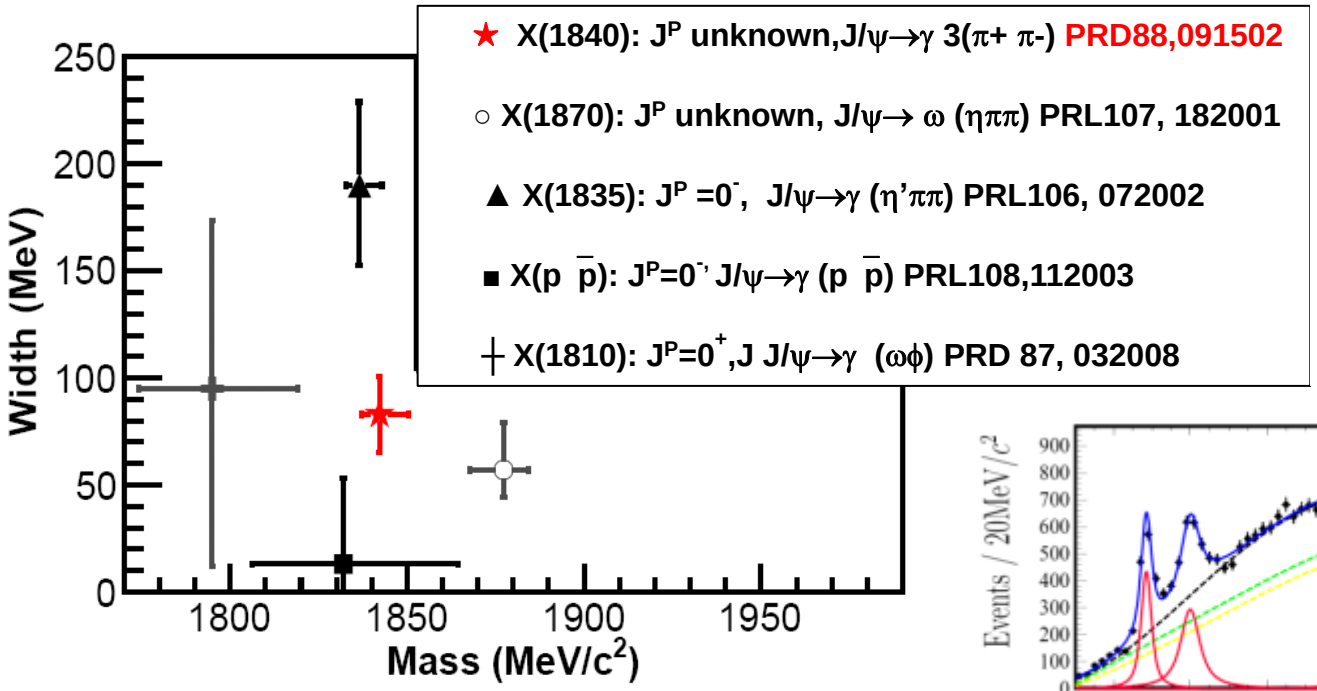
$J^{PC}=0^{-+}$, (> 12.9 σ)

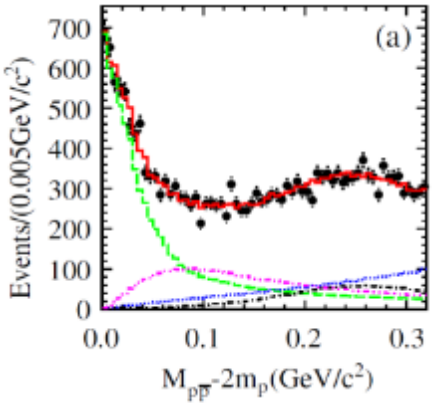
M=1844 $\pm$ 9(stat) $^{+16}_{-25}$(syst) MeV/c²

Γ=192 $^{+20}_{-17}$ $^{+62}_{-43}$ MeV

Consistent with X(1835) observed in J/ψ → γπ⁺π⁻η'!

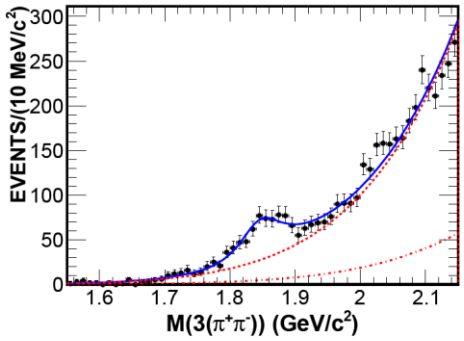
Comparisons of the observations at BES





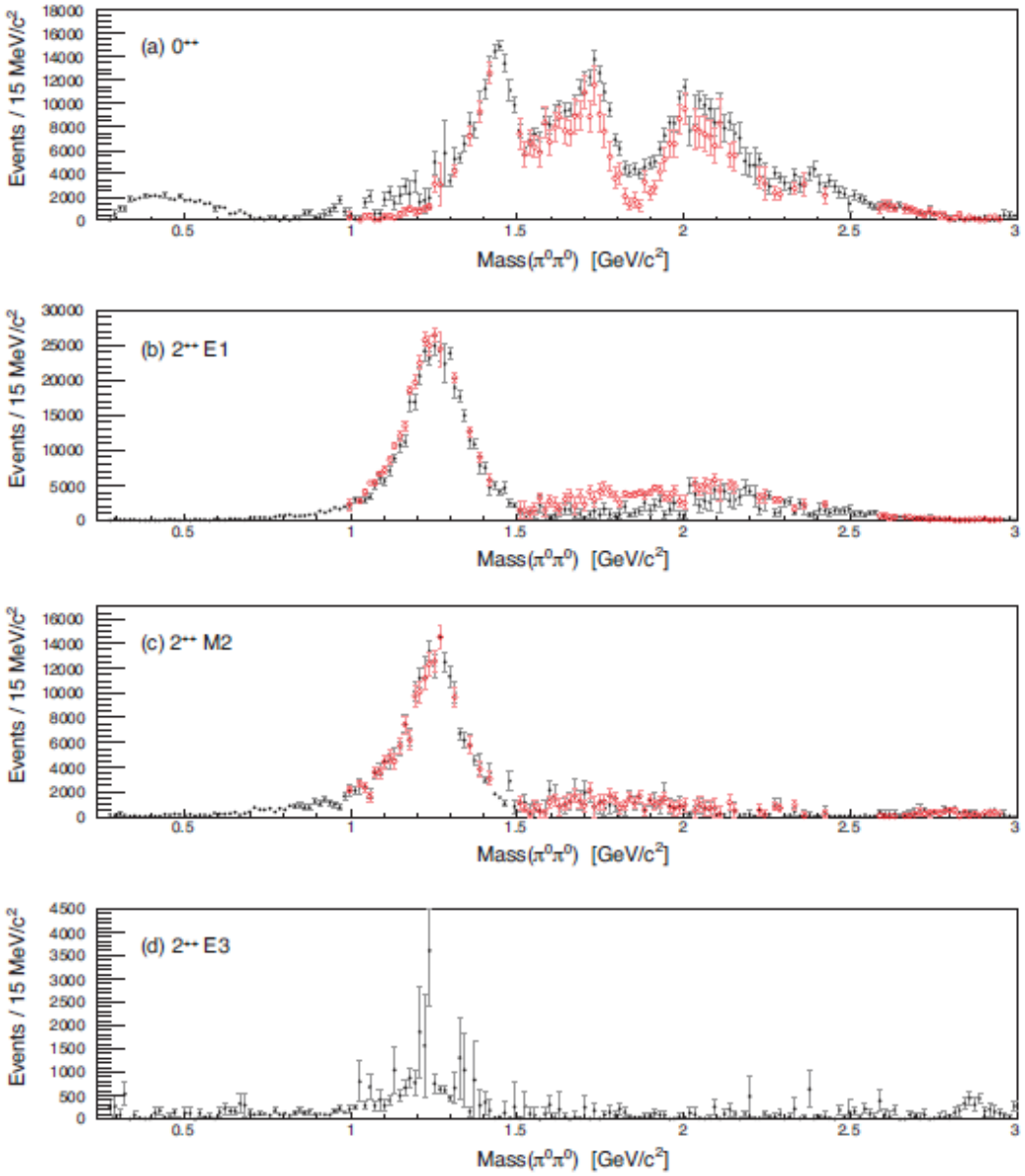
X(18??) near the threshold position of p $\bar{p}$

Are they the same particle?



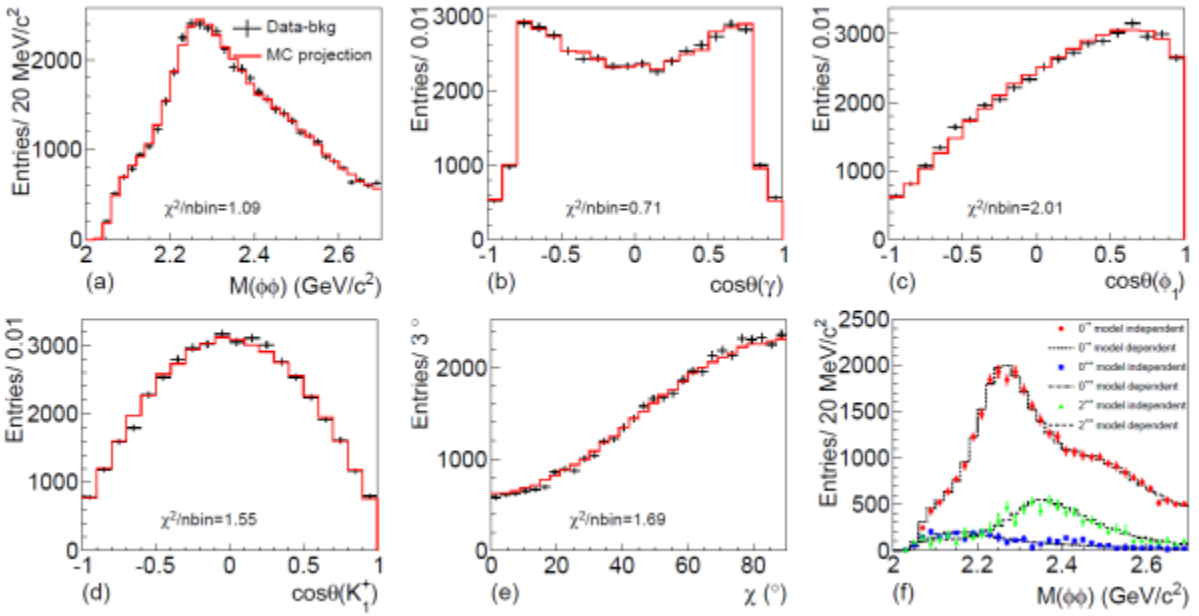
PWA of $J/\psi \to \gamma\pi^0\pi^0$

Phys. Rev. D 92, 052003



- **Model independent**
- **0^{++}: σ, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$ and $f_0(2020)$**
- **2++: dominant by $f_2(1270)$**

Partial Wave Analysis of J/ψ→γϕϕ (preliminary)



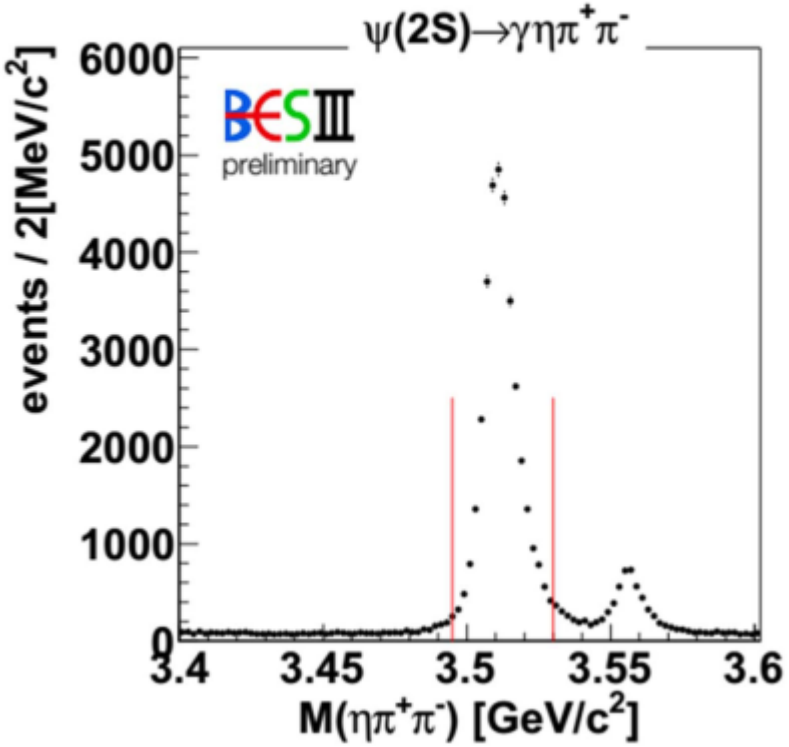
Resonance	M(MeV/c^2)	Γ(MeV/c^2)	B.F.($\times 10^{-4}$)	Sig.
$\eta(2225)$	2216^{+4+18}_{-5-11}	185^{+12+44}_{-14-17}	$(2.40 \pm 0.10^{+2.47}_{-0.18})$	28.1σ
$\eta(2100)$	2050^{+30+77}_{-24-26}	$250^{+36+187}_{-30-164}$	$(3.30 \pm 0.09^{+0.18}_{-3.04})$	21.5σ
X(2500)	2470^{+15+63}_{-19-23}	230^{+64+53}_{-35-33}	$(0.17 \pm 0.02^{+0.02}_{-0.08})$	8.8σ
$f_0(2100)$	2102	211	$(0.43 \pm 0.04^{+0.24}_{-0.03})$	24.2σ
$f_2(2010)$	2011	202	$(0.35 \pm 0.05^{+0.28}_{-0.15})$	9.5σ
$f_2(2300)$	2297	149	$(0.44 \pm 0.07^{+0.09}_{-0.15})$	6.4σ
$f_2(2340)$	2339	319	$(1.91 \pm 0.07^{+0.72}_{-0.69})$	10.7σ
0^{-+} PHSP			$(2.74 \pm 0.15^{+0.16}_{-1.48})$	6.8σ

- Dominant contribution from pseudoscalars
  - η(2225) is confirmed;
  - η(2100) and X(2500) are observed with large significance.
- The three tensors $f_2(2010)$, $f_2(2300)$ and $f_2(2340)$ stated in p^-p reactions are also observed with a strong production of $f_2(2340)$.

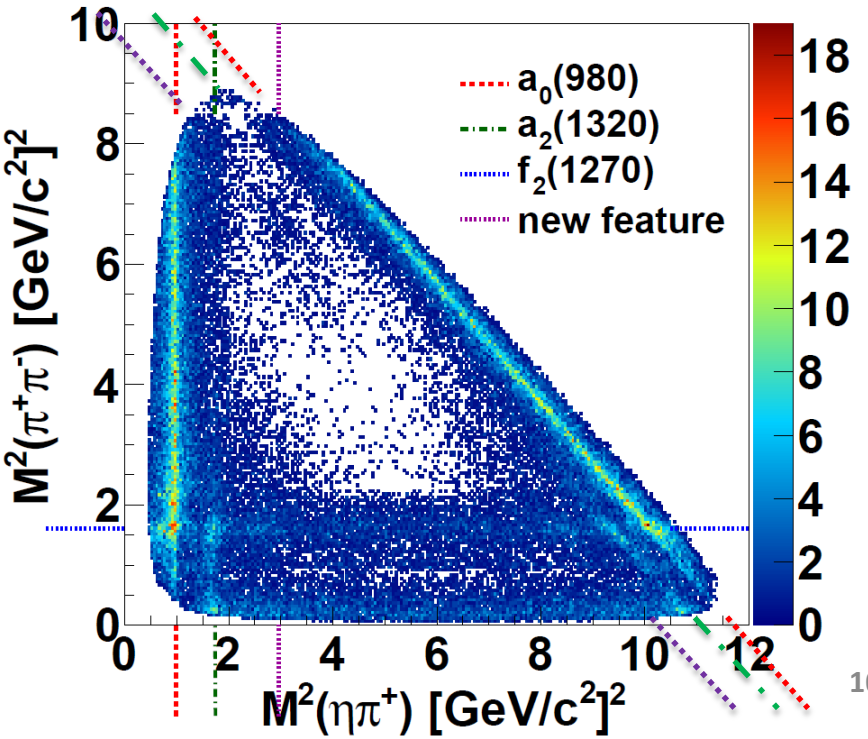
Amplitude analysis of $\chi_{c1} \to \eta\pi^+\pi^-$

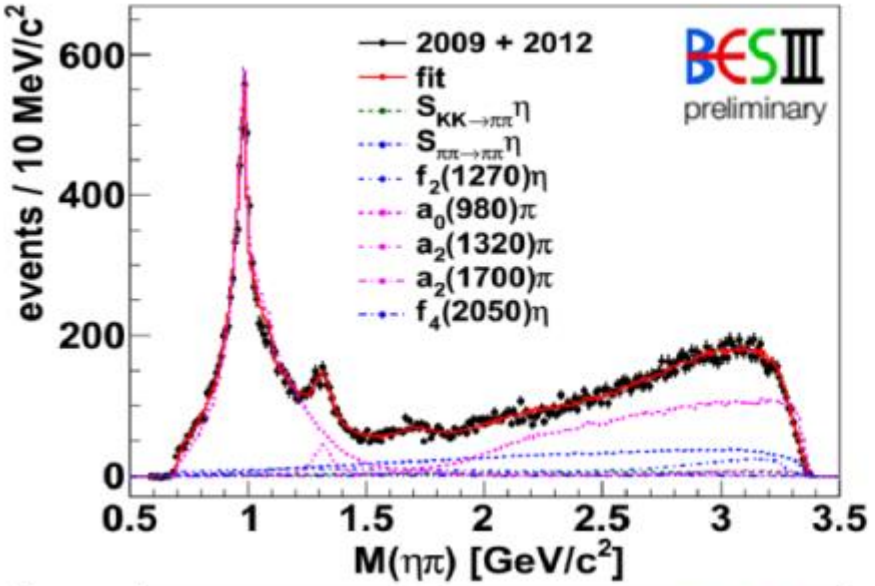
- χ_{c1} provides another suitable environment to look for 1^{-+}
  - $\pi_1(1600)$ studied in χ_{c1} decays by CLEO-c
  - only $\pi_1(1400)$ has been reported decays to $\eta\pi$
- Properties of a_0 and a_2 still need further studies

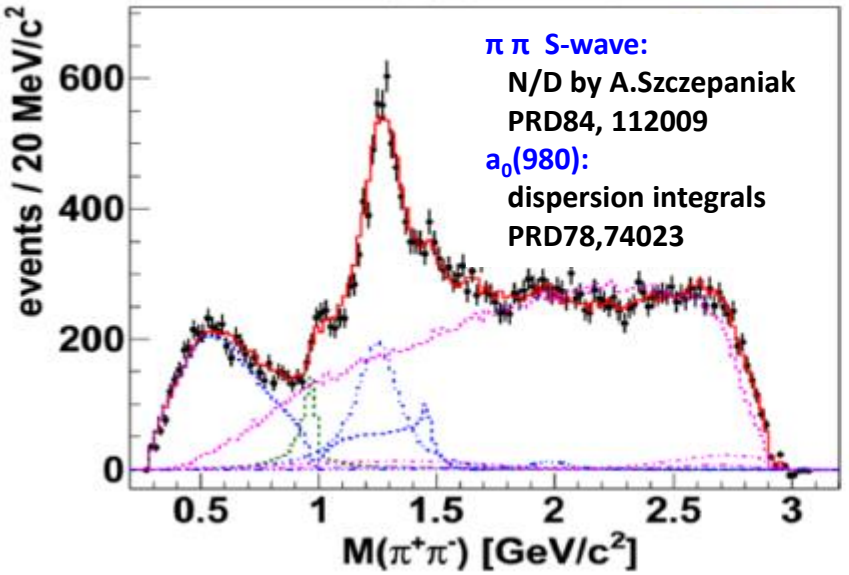
$N(\chi_{c1}) \sim 35000$



compatible with $a_2(1700)$ hypothesis







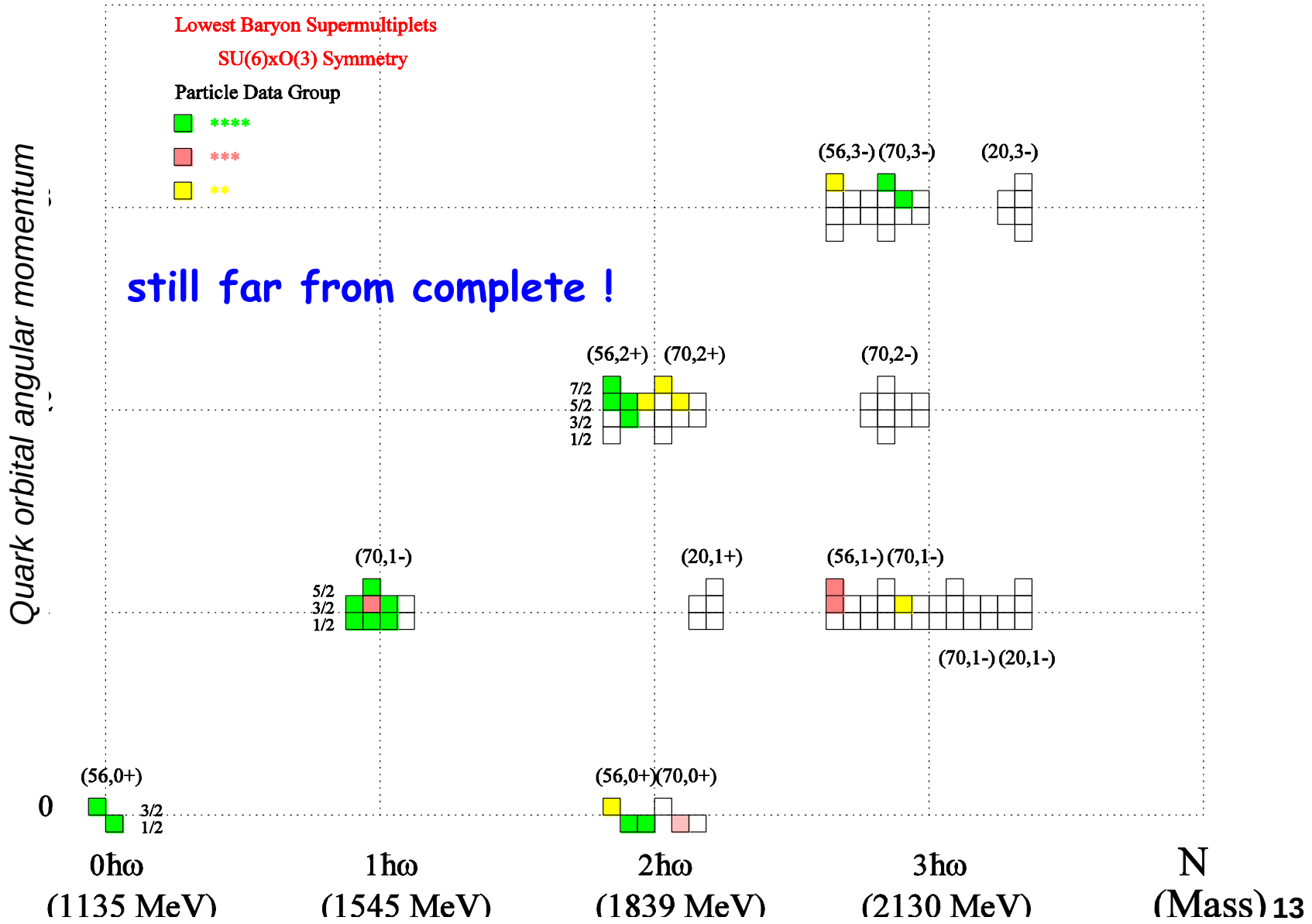
Decay mode	$\mathcal{B}(\chi_{c1} \to \eta\pi^+\pi^-) \times 10^{-3}$
$\eta\pi^+\pi^-$	$4.819 \pm 0.031 \pm 0.088 \pm 0.210$
$a_0(980)^\pm\pi^\mp$	$3.506 \pm 0.034 \pm 0.182 \pm 0.153$
$a_2(1320)^\pm\pi^\mp$	$0.185 \pm 0.009 \pm 0.038 \pm 0.008$
$a_2(1700)^\pm\pi^\mp$	$0.048 \pm 0.005 \pm 0.014 \pm 0.002$
$S_{kk}\eta$	$0.123 \pm 0.007 \pm 0.018 \pm 0.005$
$S_{pp}\eta$	$0.791 \pm 0.019 \pm 0.037 \pm 0.035$
$\pi\pi_S\eta$	$0.859 \pm 0.021 \pm 0.031 \pm 0.037$
$f_2(1270)\eta$	$0.371 \pm 0.012 \pm 0.054 \pm 0.016$
$f_4(2050)\eta$	$0.027 \pm 0.004 \pm 0.009 \pm 0.001$
BESIII Preliminary	U.L. [90% c.l.]
$\pi_1(1400)^\pm\pi^\mp$	0.028 ± 0.010 < 0.048
$\pi_1(1600)^\pm\pi^\mp$	0.005 ± 0.005 < 0.016
$\pi_1(2015)^\pm\pi^\mp$	0.003 ± 0.002 < 0.008

Errors: stat. ± syst. ± extern.

- Clear evidence for $a_2(1700)$ in χ_{c1} decays.
- First measurement of $g'_{\eta'\pi} \neq 0$ using $a_0(980) \to \eta\pi$ line shape.
- Measured upper limits for $\pi_1(1^{-+})$ in 1.4 - 2.0 GeV/c² region.

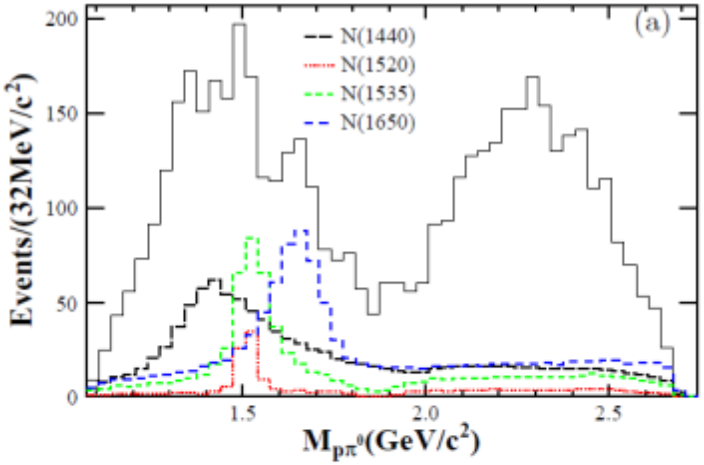
Light baryon spectroscopy

SU(6)xO(3) Classification of Baryons



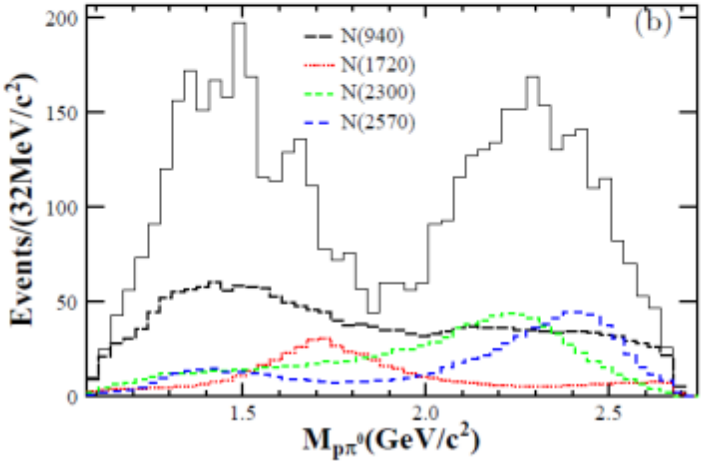
PWA results on N* baryons in $\psi' \to \pi^0 p \bar{p}$

Phys.Rev.Lett. 110 (2013) 022001



- 2-body decay:
  $\psi(2S) \to X\pi^0, X \to p\bar{p}$
  $\psi(2S) \to p\bar{N}^*, \bar{N}^* \to \bar{p}\pi^0$ + c.c.
- isospin conservation:
  Δ suppressed

Two new baryonic excited states are observed !

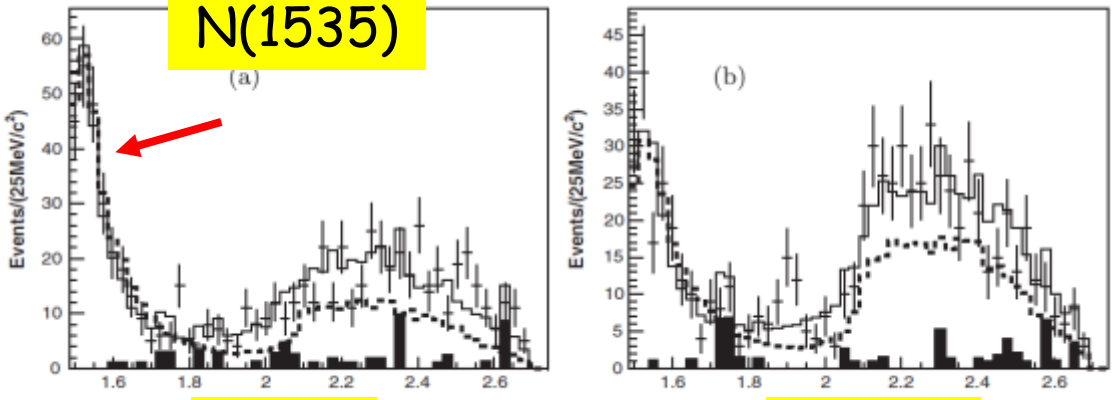


Resonance	M(MeV/c^2)	Γ(MeV/c^2)	ΔS	ΔN_{dof}	C.L.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	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

N(1535) in $\psi' \to \eta p \bar{p}$

PRD 88, 032010(2013)

N(1535)



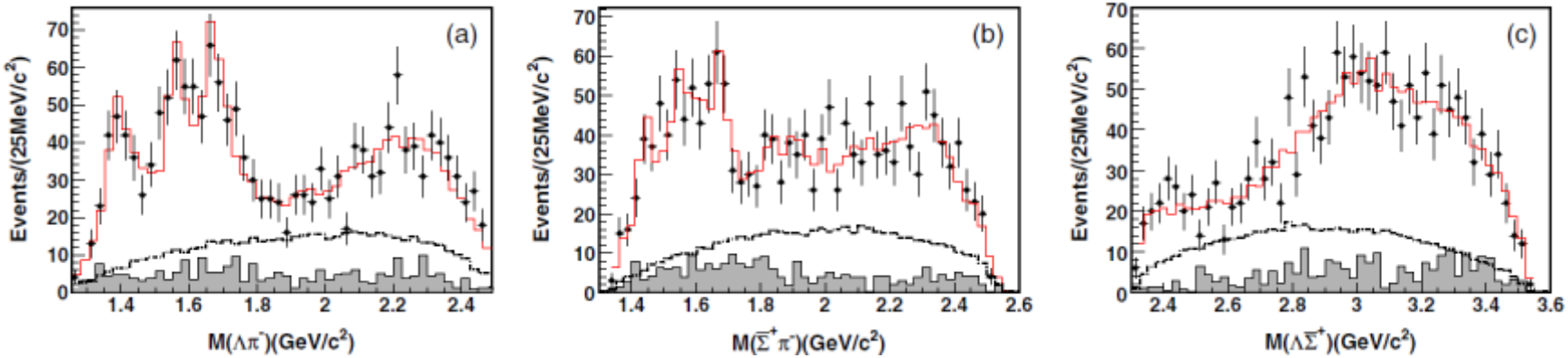
M(pη) M($\bar{p}$η)

Mass: $1524 \pm 5^{+10}_{-4}$ MeV/c^2

Width: 130^{+27+57}_{-24-10} MeV/c^2

$$\psi(3686) \to \Lambda \bar{\Sigma}^+ \pi^-$$

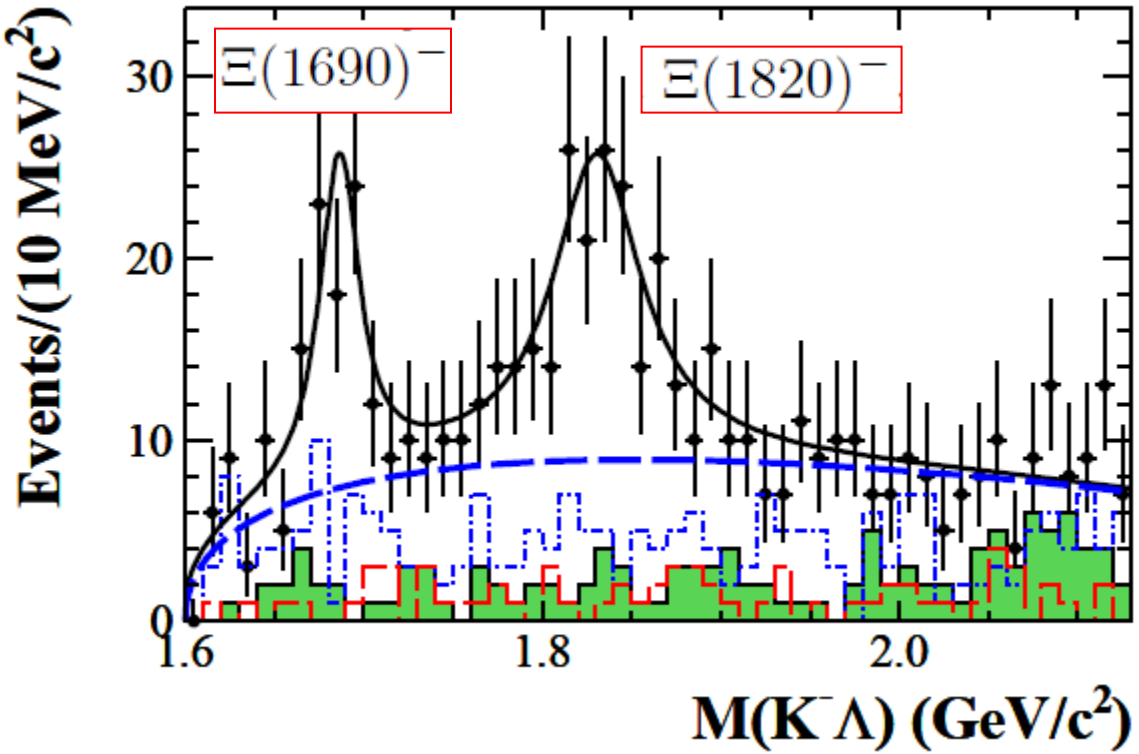
PRD 88, 112007 (2013)



- **Clear structures were observed**

$\psi(3686) \to K^- \Lambda \bar{\Xi}^+$

Phys.Rev. D91 (2015) 092006



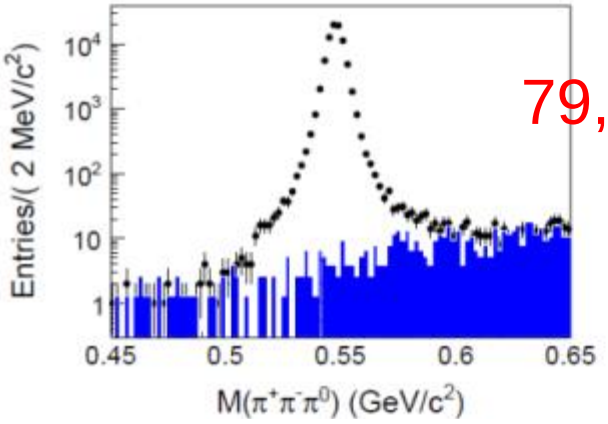
Light meson decays

Matrix Element for the Decays $\eta \to \pi^+\pi^-\pi^0$, $\eta/\eta' \to \pi^0\pi^0\pi^0$

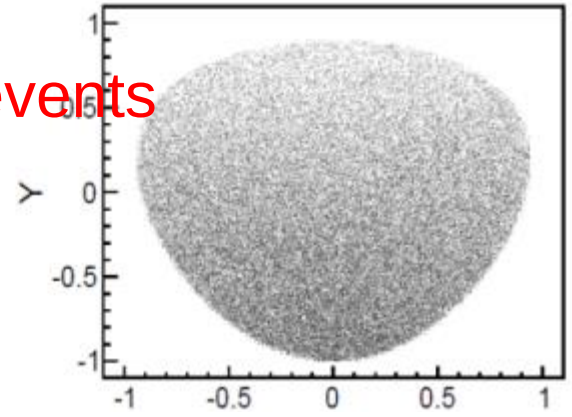
PRD92,012014,2015

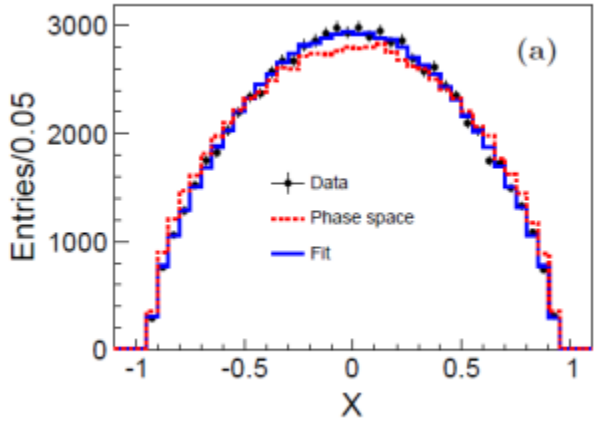
$\eta \to \pi^+\pi^-\pi^0$

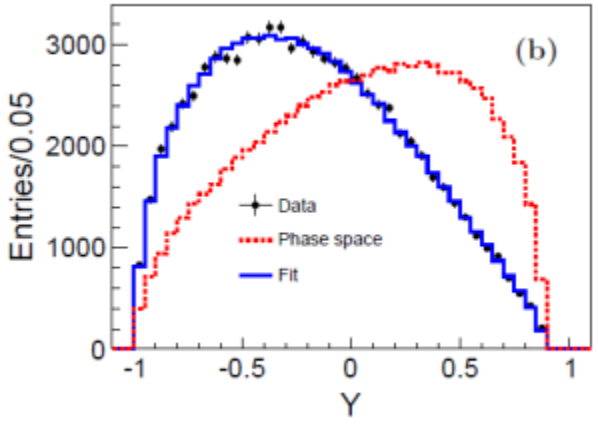
$$X = \frac{\sqrt{3}}{Q}(T_{\pi^+} - T_{\pi^-}) \qquad Y = \frac{3T_{\pi^0}}{Q} - 1,$$



79,625 events

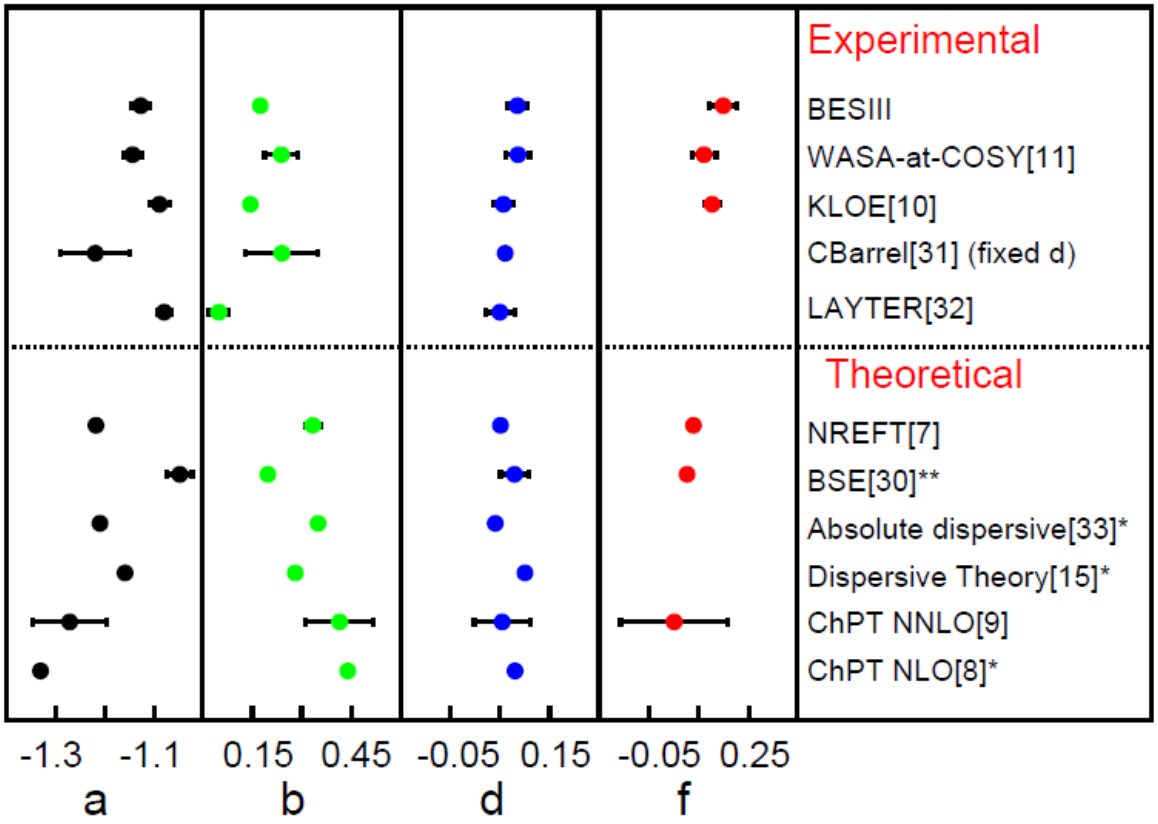






Comparison to experimental and theoretical results

$$
\begin{aligned}
a &= -1.128 \pm 0.015 \pm 0.008 \\
b &= 0.153 \pm 0.017 \pm 0.004 \\
d &= 0.085 \pm 0.016 \pm 0.009 \\
f &= 0.173 \pm 0.028 \pm 0.021
\end{aligned}
$$

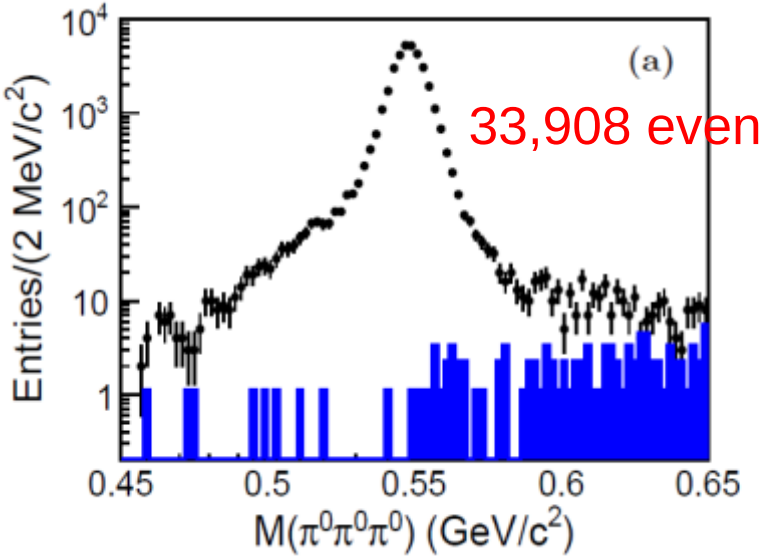


$$
\begin{aligned}
a &= -1.128 \pm 0.015, \\
b &= 0.153 \pm 0.017, \\
c &= (0.047 \pm 0.851) \times 10^{-2} \\
d &= 0.085 \pm 0.016, \\
e &= 0.017 \pm 0.019, \\
f &= 0.173 \pm 0.028.
\end{aligned}
$$

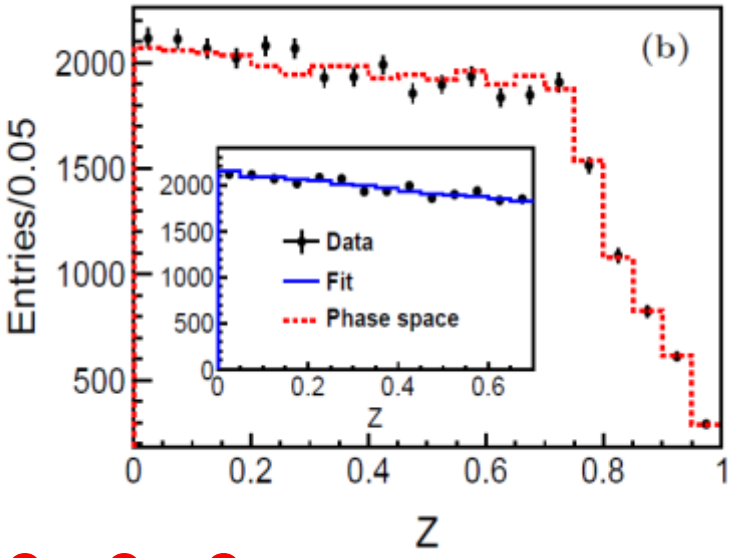
No charge-parity violation is seen

$\eta \to \pi^0\pi^0\pi^0$

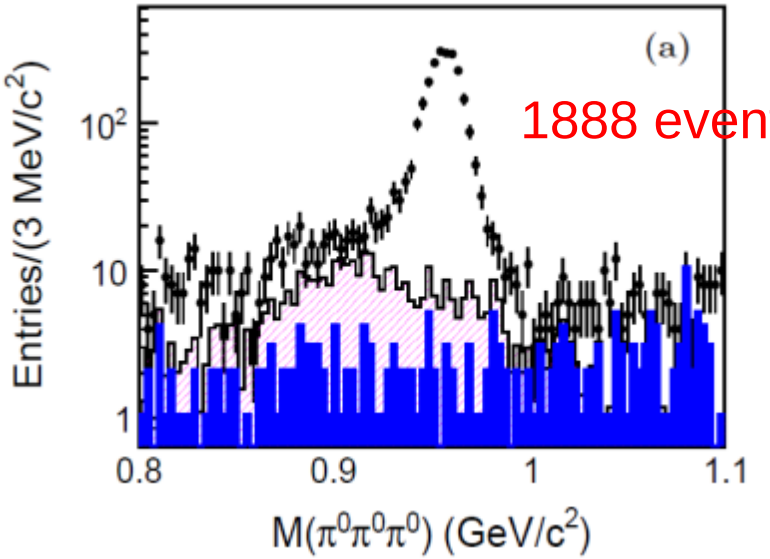
$$|A(Z)|^2 = N(1 + 2\alpha Z + \ldots)$$



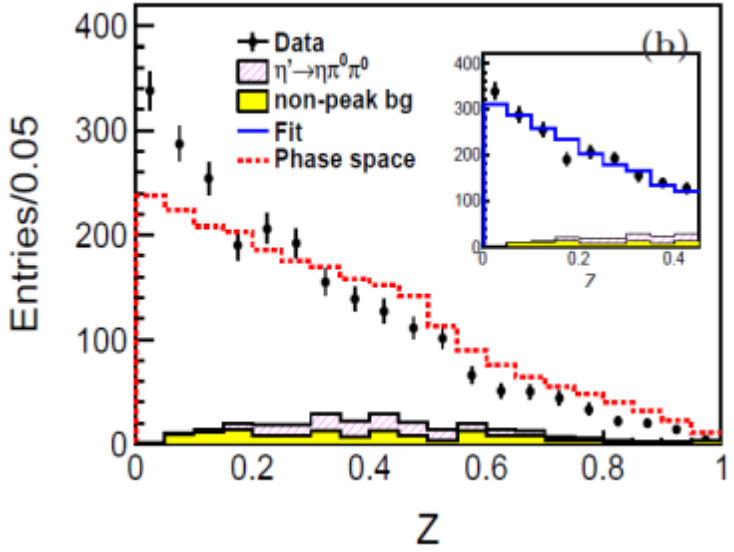
33,908 events



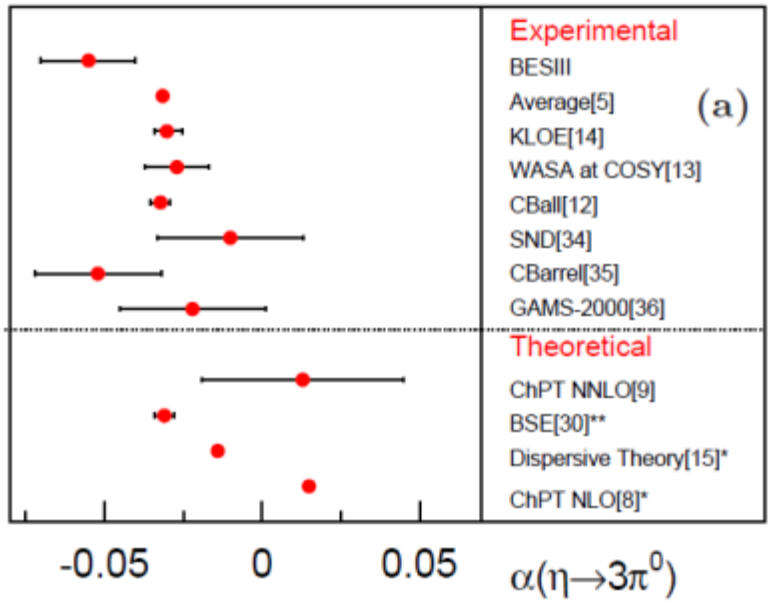
$\eta' \to \pi^0\pi^0\pi^0$

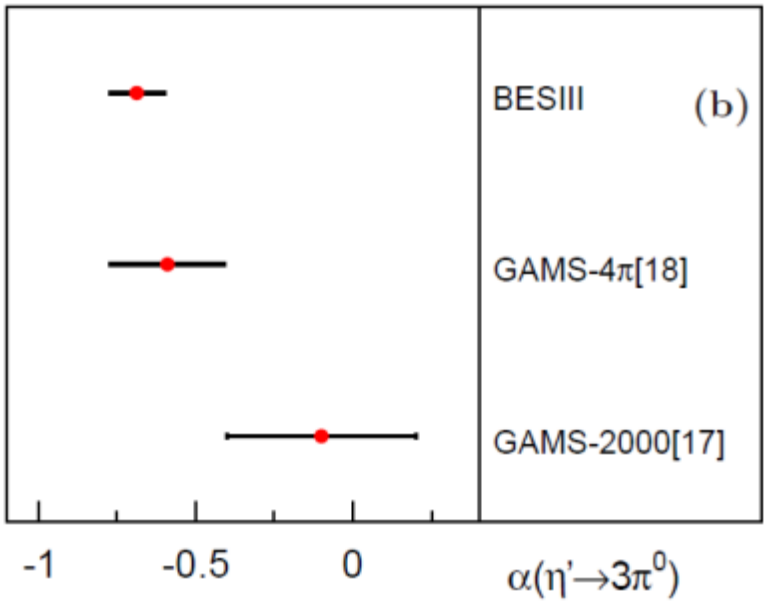


1888 events



Comparison to experimental and theoretical results

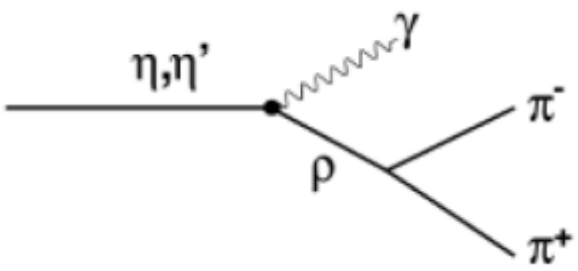


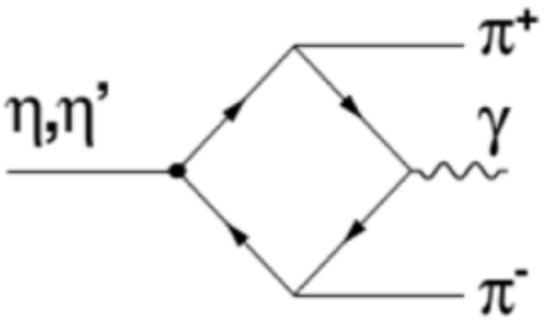


- In agreement with previous measurements
- α for $\eta' \to \pi^0\pi^0\pi^0$ significantly deviates from zero

$\eta' \to \gamma\pi^+\pi^-$ decay dynamics

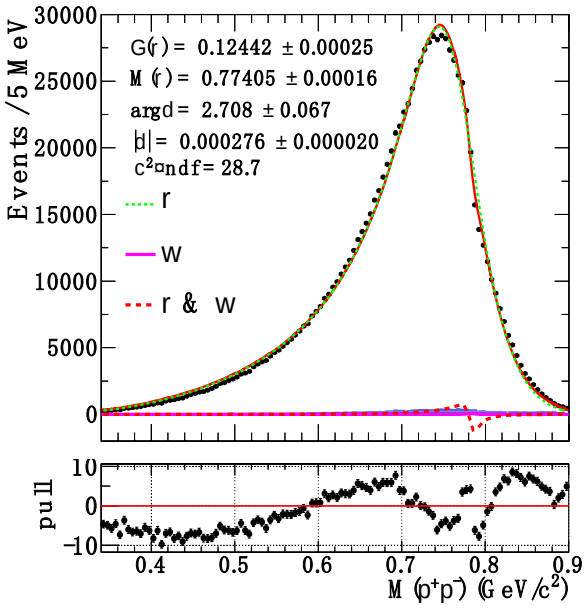
- high term of WZW ChPT$\to$ box anomaly
- studied by many experiments (CB, L3 …)
- no consistent picture due to limited statistics
  - ρ mass shift or not ?
  - box anomaly or not ?



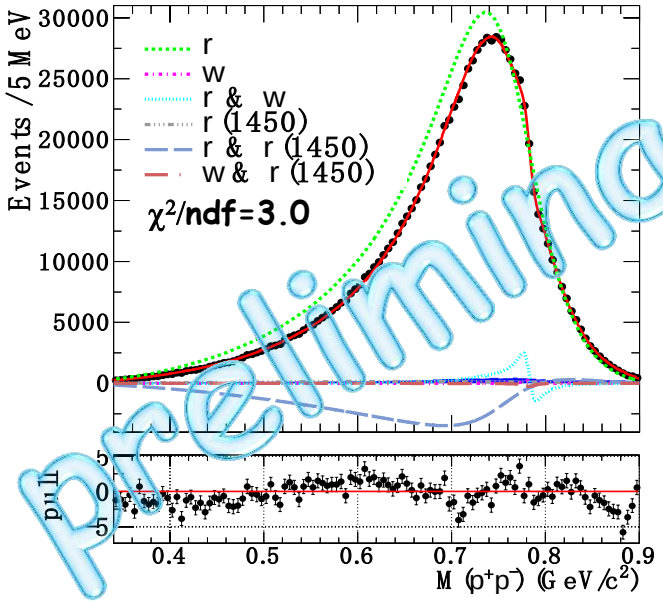


η´→γπ+π- decay dynamics

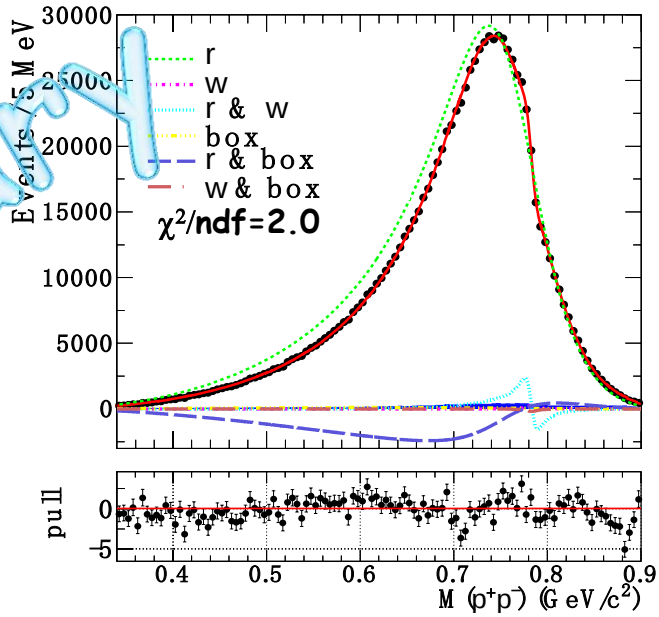
1). fit with ρ(770)-ω



2). fit with ρ(770)-ω-ρ(1450)



3). fit with ρ(770)-ω-box anomaly

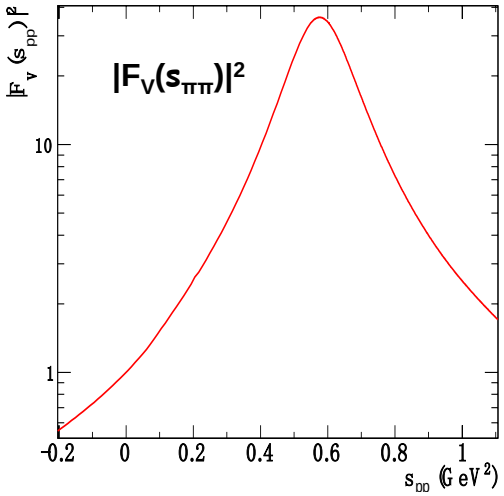


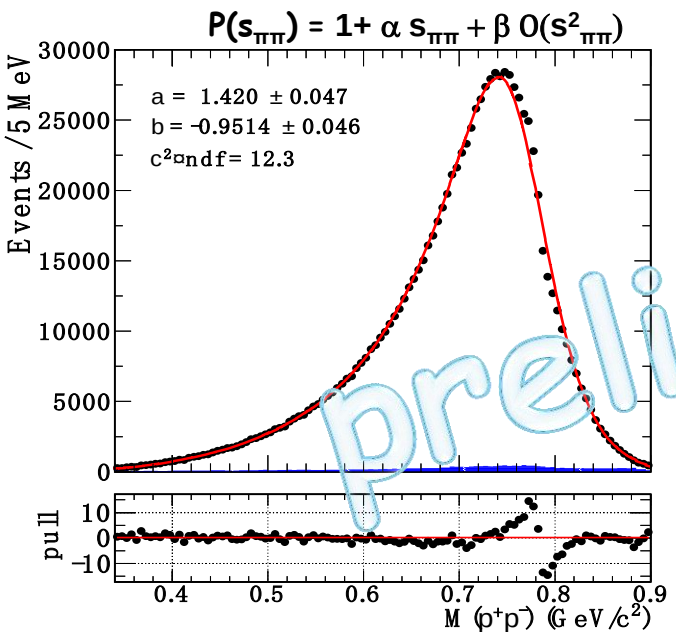
Model-dependent fit

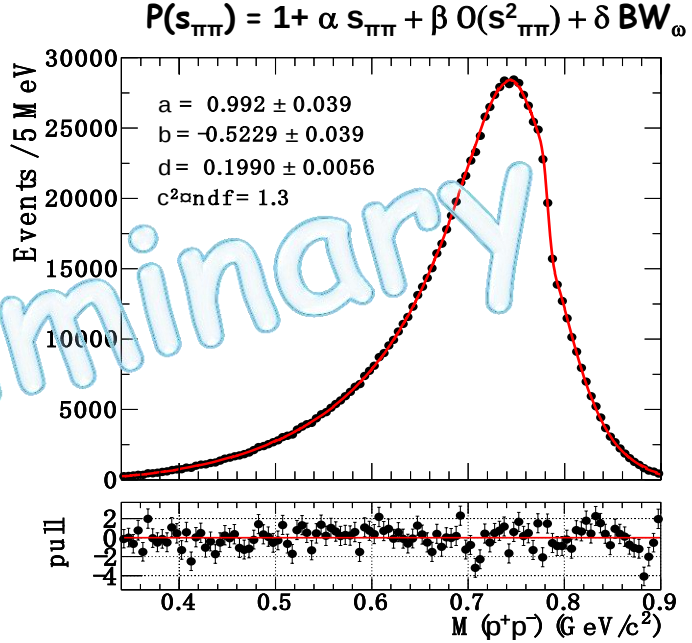
- ✓ Besides ρ(770), the ω is needed
- ✓ ρ(770)-ω cannot describe data well;
- ✓ Extra contribution (maybe ρ(1450) or box-anomaly, maybe both of them) is also necessary to provide a good description of data

Model-independent fit

$$\frac{d\Gamma}{ds_{\pi\pi}} = \left|AP(s_{\pi\pi})F_V(s_{\pi\pi})\right|^2 \Gamma_0(s_{\pi\pi})$$







Crystal barrel: $\alpha = (1.80 \pm 0.49 \pm 0.04)\text{GeV}^{-2}$
$\beta = (0.04 \pm 0.36 \pm 0.03)\text{GeV}^{-4}$

GAMS-2000: $\alpha = (2.7 \pm 1.0)\text{GeV}^{-2}$

- ω is necessary
- Linear polynomial is insufficient

* Physics Letters B 707 (2012) 184-190

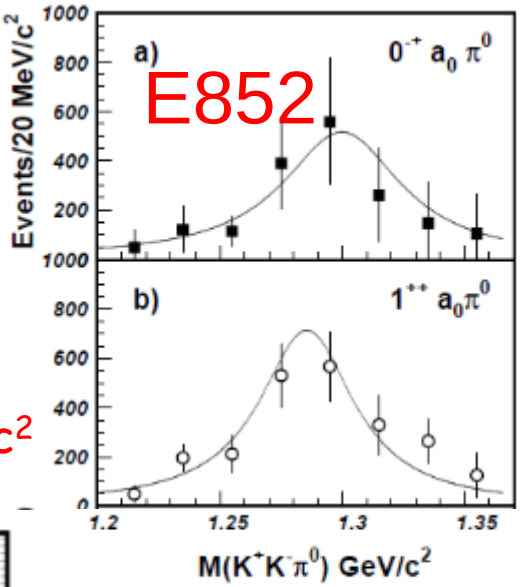
η(1295) & $f_1(1285)$

E852, PLB516,264(2001)

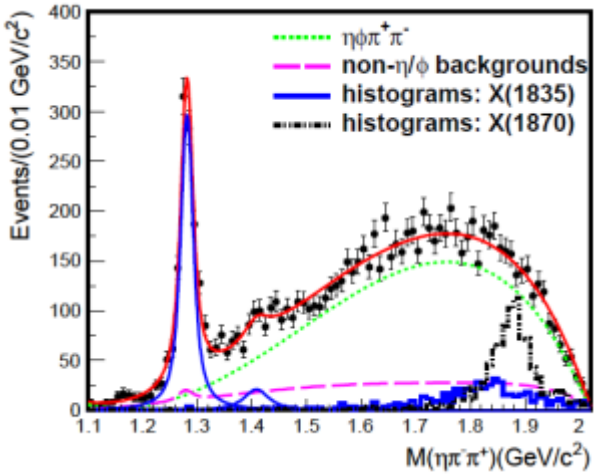
Resonance	M (MeV/c^2)	Γ (MeV/c^2)
$f_1(1285)$	$1288 \pm 4 \pm 5$	$45 \pm 9 \pm 7$
$\eta(1295)$	$1302 \pm 9 \pm 8$	$57 \pm 23 \pm 21$

- **η(1295)**
  - only observed in πp interactions
  - Due to interference between $f_1(1285)$ and $\eta(\pi\pi)_{S\text{-wave}}$ E. Klempt Phys. Reports 454,1(2007)
- More decays, e.g.,

J/ψ→{ρ, γ}X, may shed light on η(1295)

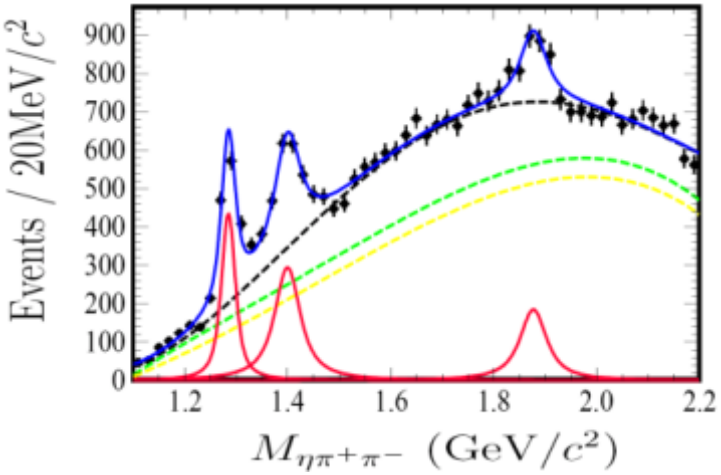


Γ =21.0±1.7 MeV
M=1281.7±0.6 MeV/c²



BESIII, PRD91,052017(2015)

Γ =22.0±3.1$^{+2.0}_{-1.5}$ MeV
M=1285.1±1.0$^{+1.6}_{-0.3}$ MeV/c²



BESIII, PRL107,182001(2011)

Summary

- Rich physics in light hadrons
  - meson spectroscopy→ QCD
  - search for missing baryons→ QCD, Quark model
  - light meson decays → test of ChPT

  ……
- Mapping out the light hadron spectroscopy is crucial
- 1.3 billion J/Ψ and 0.5 billion Ψ' @ BESIII
- BESIII plays an important role in light hadron physics

Thank you !