Recent Results from BESIII

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On behalf of BESIII Collaboration

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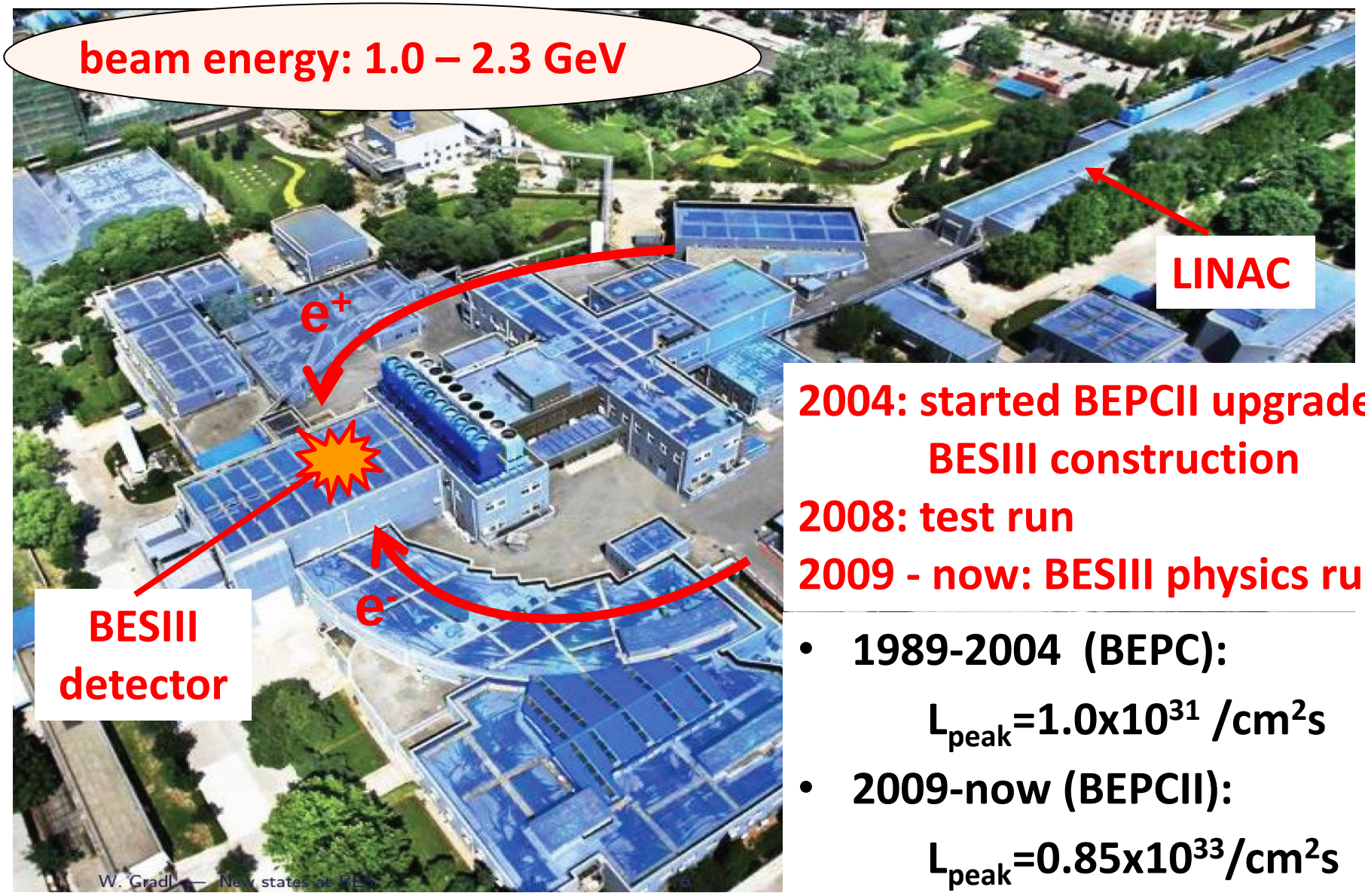
Outline

- Introduction
- Status of BESIII
- Selected results from BESIII
- Summary

Beijing Electron Positron Collider (BEPC)



2004: started BEPCII upgrade, BESIII construction

2008: test run

2009 - now: BESIII physics run

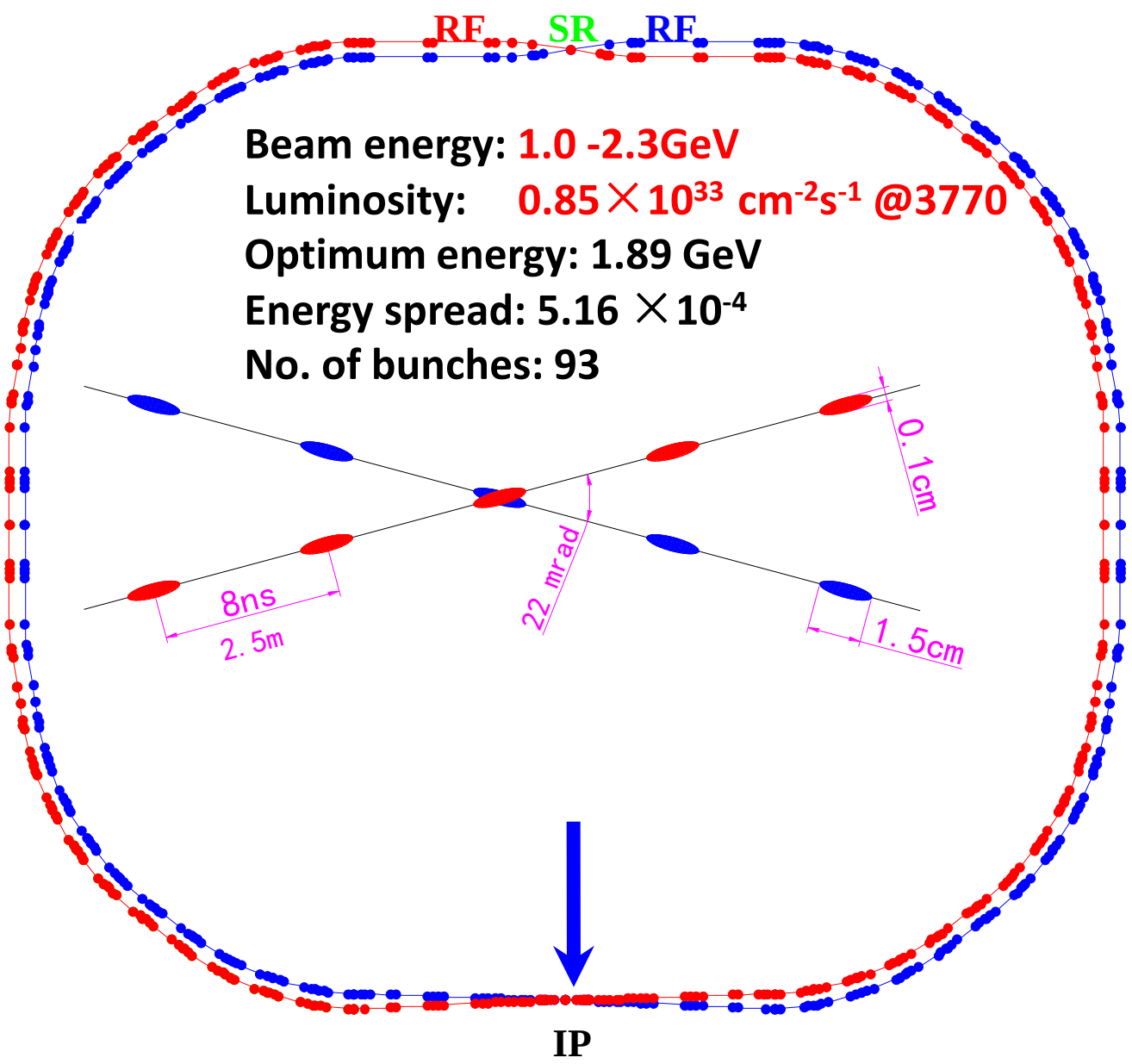
- **1989-2004 (BEPC):**

  $L_{peak}=1.0\times10^{31}$ /cm^{2}s

- **2009-now (BEPCII):**

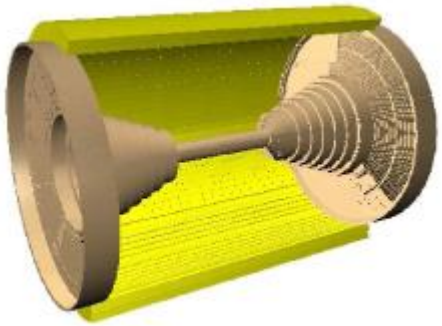
  $L_{peak}=0.85\times10^{33}$/cm^{2}s

Upgraded BEPC-BEPCII



BESIII Detector

MDC

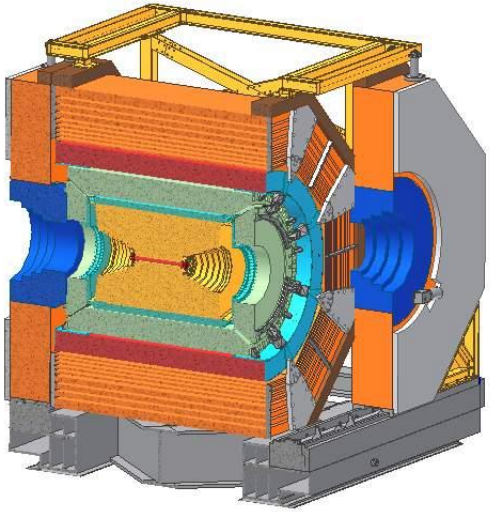


R inner: 63mm ;

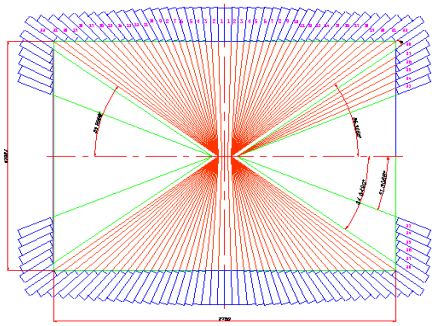
R outer: 810mm

Length: 2582 mm

Layers: 43



CsI(Tl) EMC



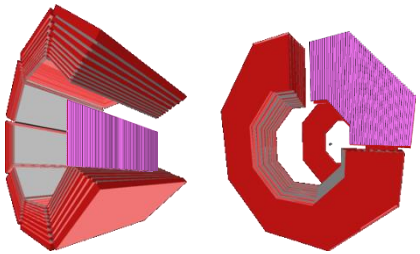
Crystals: 28 cm(15 X_0)

Barrel: $|\cos\theta|<0.83$

Endcap:

$0.85 < |\cos\theta| < 0.93$

RPC MUC



BMUC: 9 layers – 72 modules

EMUC: 8 layers – 64 modules

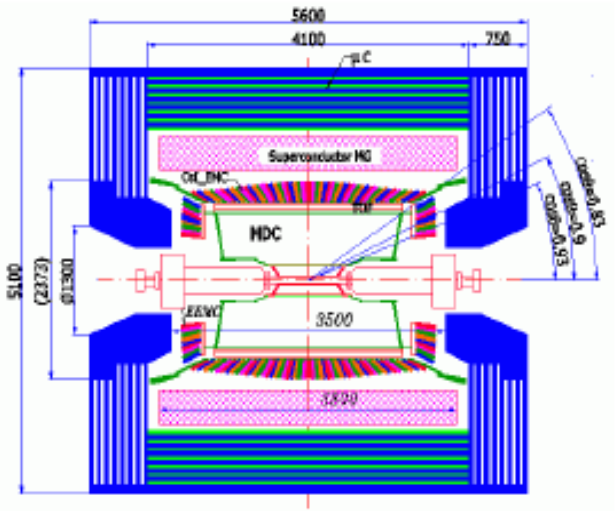
TOF

BTOF: two layers

ETOF: 48 for each

BESIII Detector

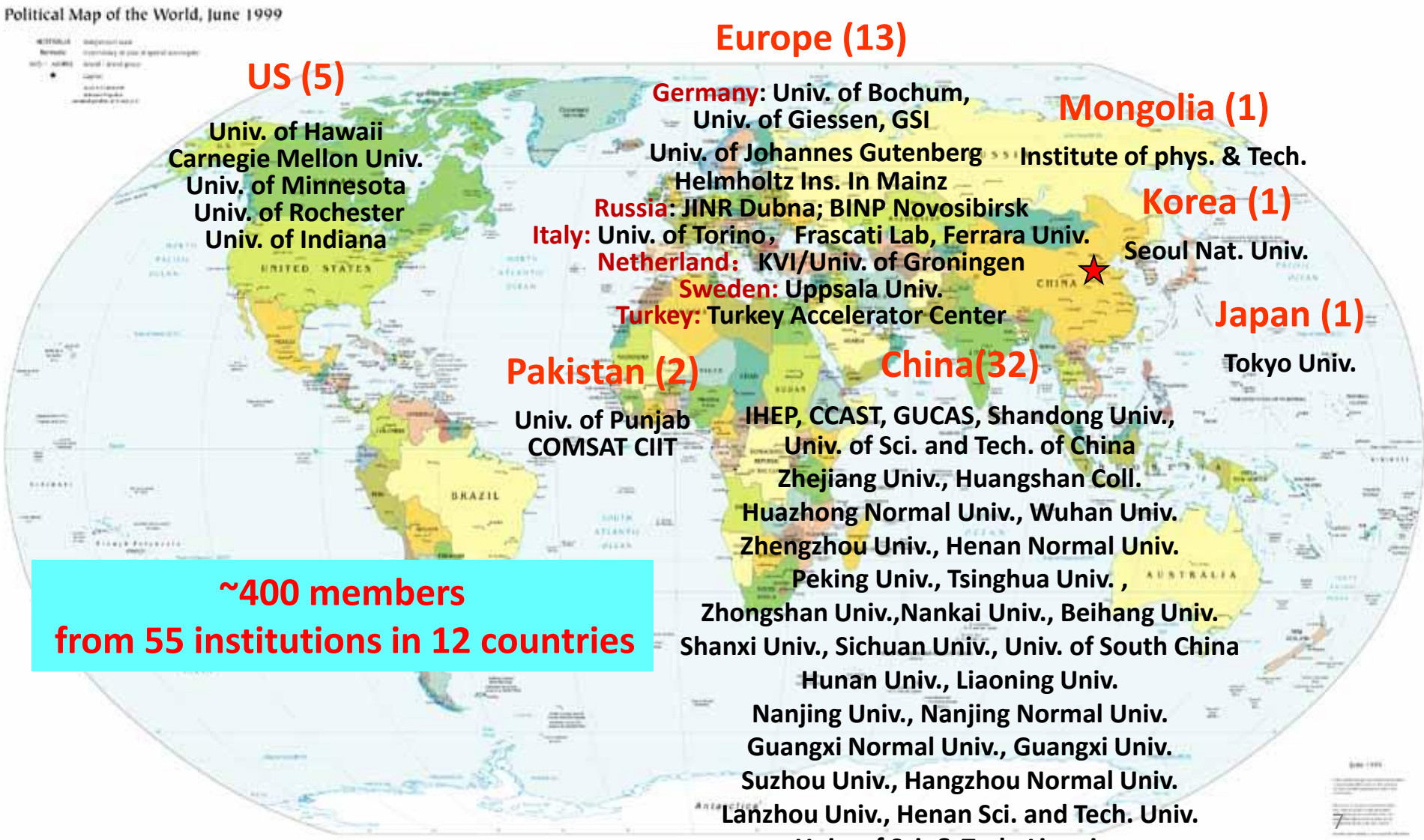
Exps.	MDC Wire resolution	MDC dE/dx resolution	EMC Energy resolution
CLEO	110 μm	5%	2.2-2.4 %
Babar	125 μm	7%	2.67 %
Belle	130 μm	5.6%	2.2 %
BESIII （XYZ data）	115 μm	<5% (Bhabha)	2.3%



Exps.	TOF time resolution
CDFII	100 ps
Belle	90 ps
BESIII (XYZ data)	68 ps (BTOF) 100 ps (ETOF)

- New ETOF (MRPC), will be installed
- New Inner MDC, being built

BESIII Collaboration



US (5)

Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Europe (13)

Germany: Univ. of Bochum, Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino， Frascati Lab, Ferrara Univ.
Netherland： KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

Mongolia (1)

Institute of phys. & Tech.

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

China(32)

IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
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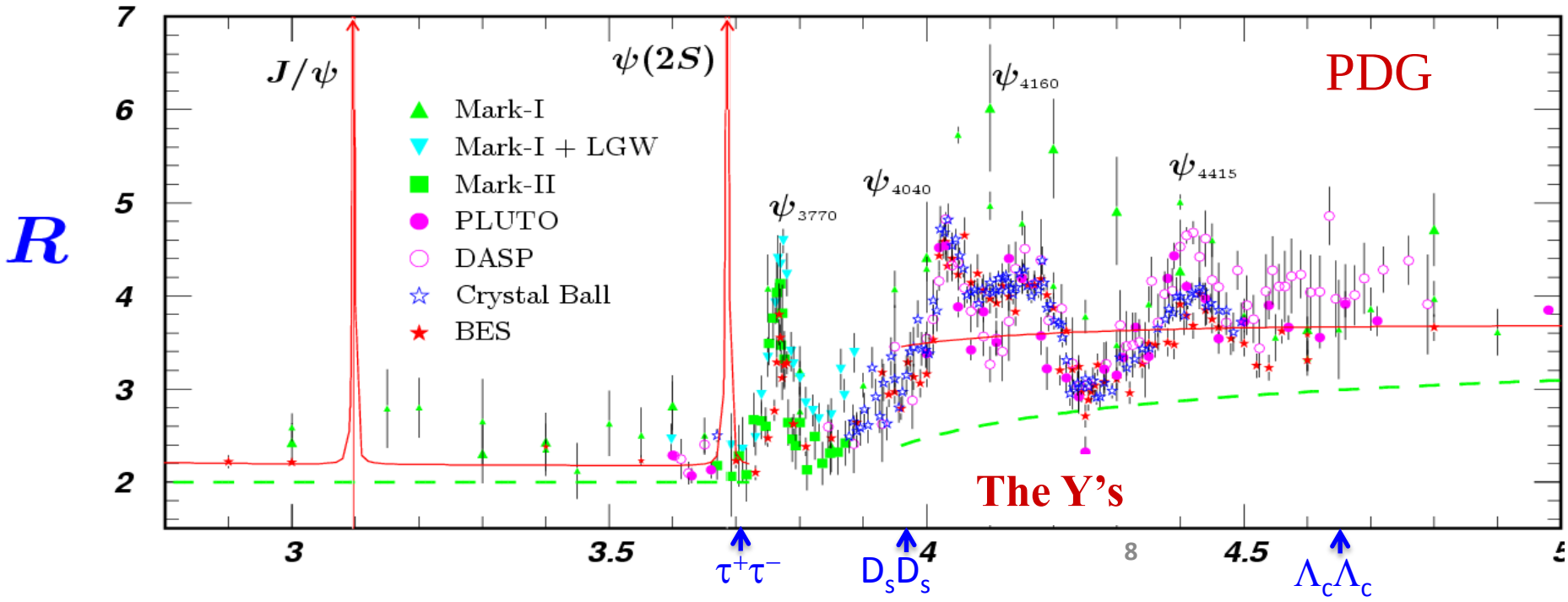
Zhongshan Univ.,Nankai Univ., Beihang Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Univ. of Sci. & Tech. Liaoning

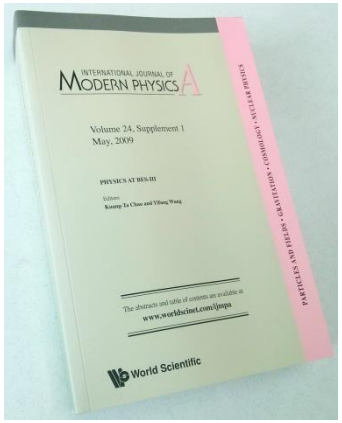
~400 members
from 55 institutions in 12 countries

Features of the BEPC Energy Region

- Rich of **resonances:** charmonia and charm mesons
- **Threshold** characteristics (pairs of τ, D, D_s, …)
- **Transition between** smooth and resonances, perturbative and non-perturbative QCD
- Energy location of the **new hadrons: glueballs, hybrids, multi-quark states**



Physics Topics at BESIII



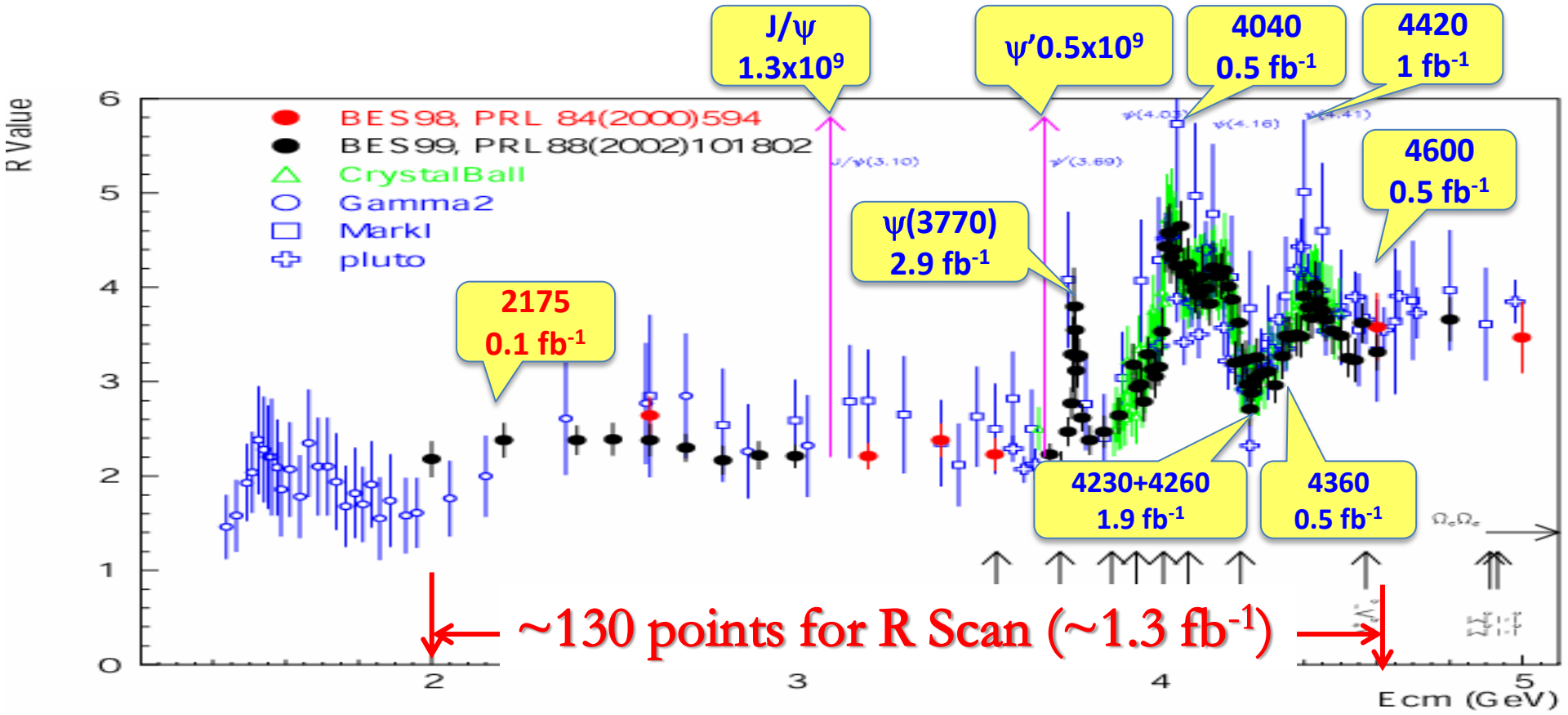
Int. J. Mod. Phys. A, Vol. 24 (2009)

- Hadron spectroscopy
  - search for the new forms of hadrons
  - meson spectroscopy
  - baryon spectroscopy
- Study of the production and decay mechanisms of charmonium states: J/ψ, $\psi(2S)$, $\eta_C(1S)$, $\chi_{C\{0,1,2\}}$, $\eta_C(2S)$, $h_C(^1P_1)$, $\psi(3770)$, etc.

  Calibrate QCD

  XYZ states
- Precision measurement of R values, hadron FF, ...
- Charm physics, charmed baryon
- Rare decays, new physics

BESIII data samples



World largest J/ψ, ψ(2S), ψ(3770), Y(4260), …
produced directly from e^+e^- collision

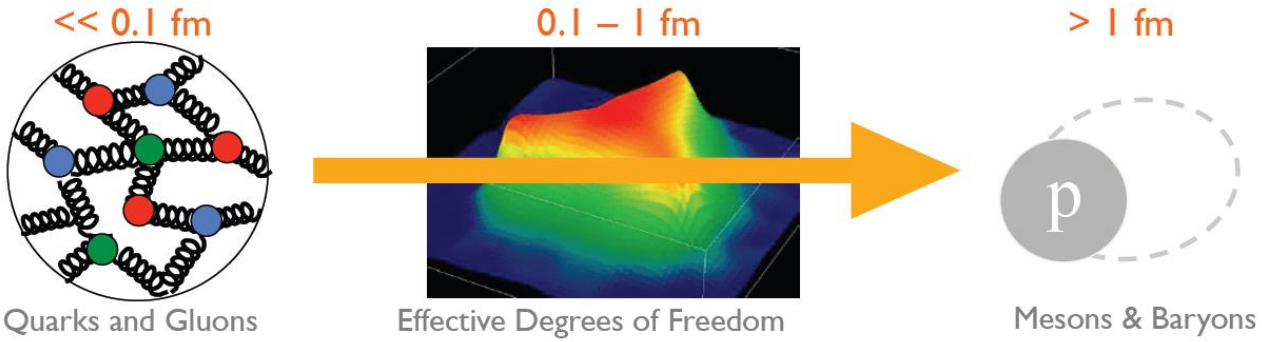
Selected results

- XYZ studies
- Scalars
- Baryons
- Charm physics
- Nucleon form factor
- Λ_c absolute branching fractions

Hadron spectrum

- **Hadron spectroscopy is a key tool to investigate QCD**

- **test QCD in the confinement regime**
- **provide insights into the fundamental degrees of freedom**



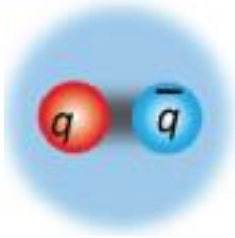
Continuous efforts in experiment and theory.

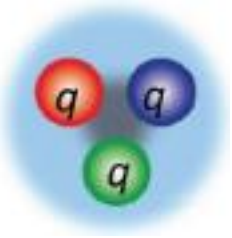
New forms of hadrons

- **Conventional hadrons consist of 2 or 3 quarks:**

Naive Quark Model:

meson

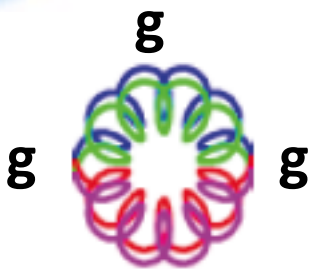


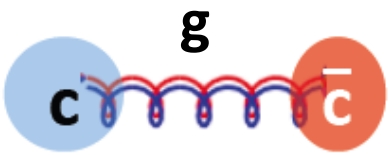


baryon

- **QCD predicts the new forms of hadrons:**
  - **Multi-quark states： Number of quarks >＝ 4**

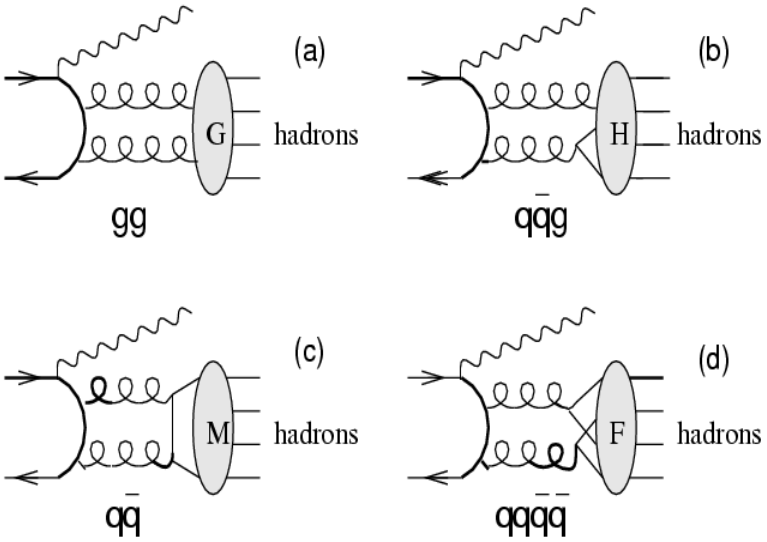
  - **Hybrids： $q\bar{q}g$， qqqg …**
  - **Glueballs： gg， ggg …**





None of the new forms of hadrons is settled !

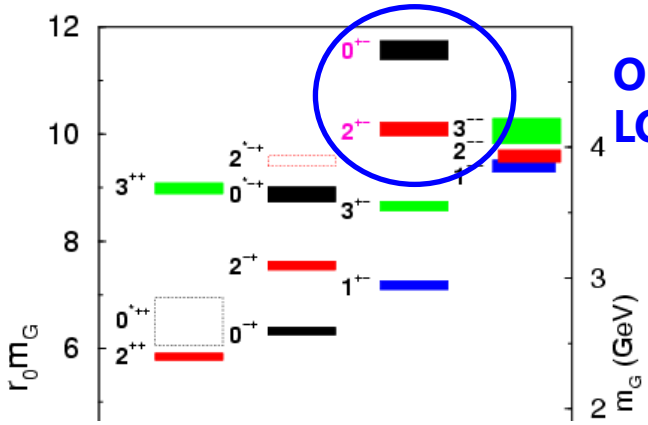
Charmonium decays provide ideal hunting ground for light glueballs and hybrids



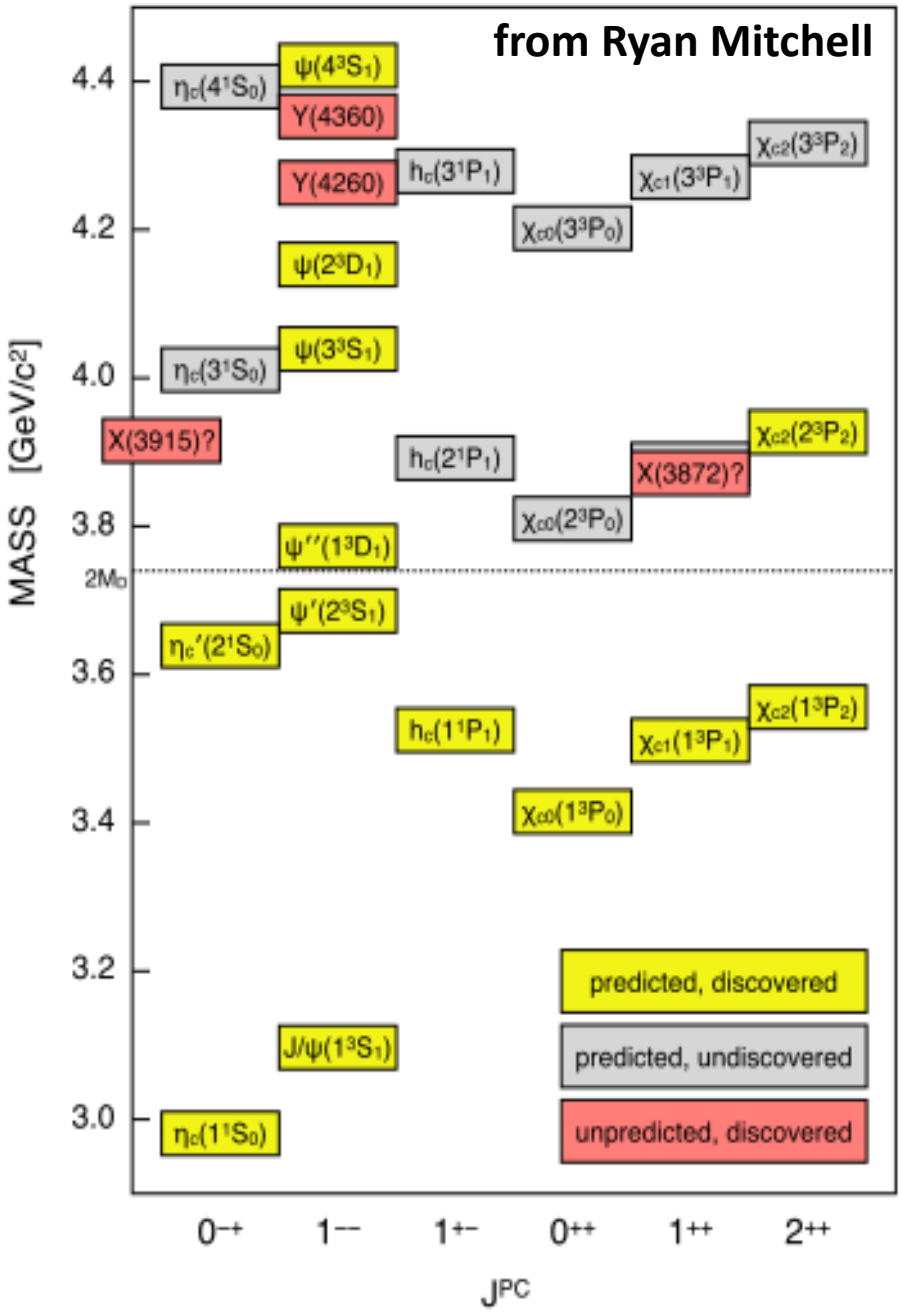
$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2), \Gamma(J/\psi \to \gamma H) \sim O(\alpha\alpha_s^3),$

$\Gamma(J/\psi \to \gamma M) \sim O(\alpha\alpha_s^4), \Gamma(J/\psi \to \gamma F) \sim O(\alpha\alpha_s^4)$

- "Gluon-rich" process
- Clean high statistics data samples from e+e- annihilation
- $I(J^{PC})$ filter in strong decays of charmonium



Odd-balls in LQCD



Charmonium spectroscopy

- **Charmonium states below open charm threshold are all observed**

Above open charm threshold:

- **many expected states not observed**
- **many unexpected observed**

Z(4430)
Z(4250)
Z(4050)
Z(3900)

X(3872)

XYZ(3940)

X(3915)
X(4160)
Y(4008)
Y(4140)
Y(4260)
Y(4360)
X(4350)
Y(4660)

Observation of $Z_c(3900)^{\pm}$

BESIII: PRL 110, 252001 (2013)

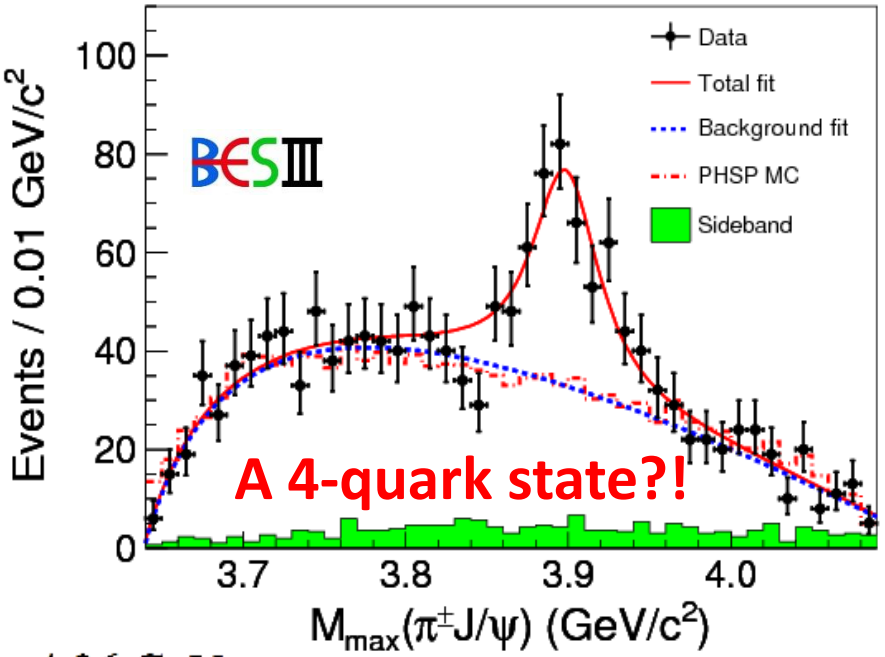
$Z_c(3900)^+$:

$m = (3899.0 \pm 3.6 \pm 4.9)\ \mathrm{MeV}/c^2$

$\Gamma = (46 \pm 10 \pm 20)\ \mathrm{MeV}$

Mass close to $D\bar{D}^*$ threshold

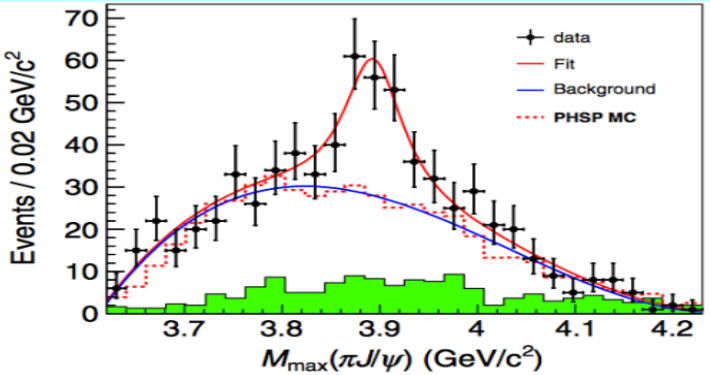
Decays to J/ψ → contains $c\bar{c}$
Electric charge → contains $u\bar{d}$



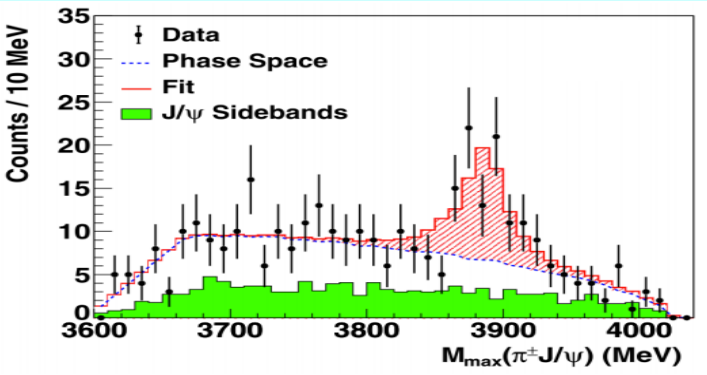
$$\sigma[e^+e^- \to \pi^+\pi^- J/\psi] = 62.9 \pm 1.9 \pm 3.7\ \mathrm{pb}\ \text{at}\ 4.26\ \mathrm{GeV}$$

$$\frac{\sigma[e^+e^- \to \pi^\pm Z_c(3900)^\mp \to \pi^+\pi^- J/\psi]}{\sigma[e^+e^- \to \pi^+\pi^- J/\psi]} = (21.5 \pm 3.3 \pm 7.5)\%\ \text{at}\ 4.26\ \mathrm{GeV}$$

Belle with ISR data (PRL 110, 252002)

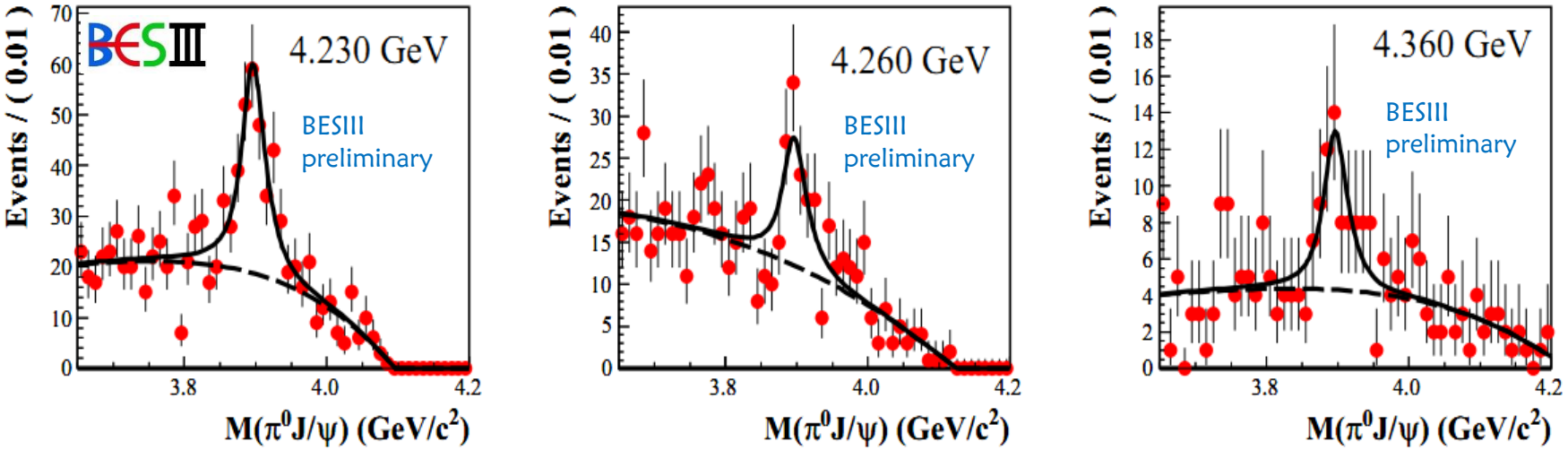


CLE0c data at 4.17 GeV (PLB 727, 366)



The neutral isospin partner: $Z_c(3900)^0$

Studying the $e^+e^- \to \pi^0\pi^0 J/\psi$ process

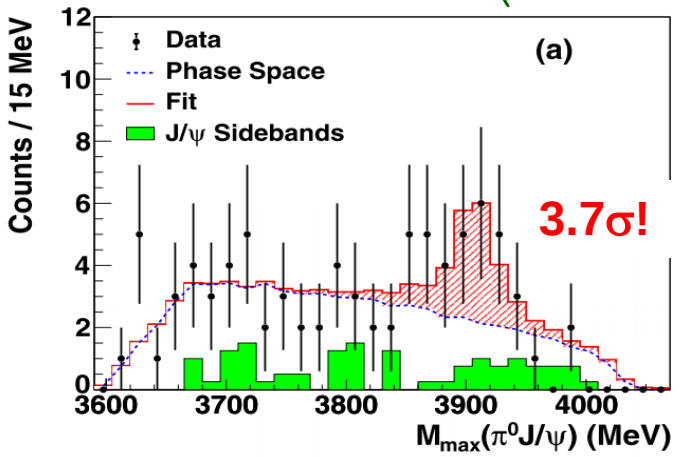


A structure on $\pi^0 J/\psi$ invariant mass spectrum can be observed:

Mass = $3894.8 \pm 2.3 \pm 2.7$ MeV
Width = $29.6 \pm 8.2 \pm 8.2$ MeV
Significance = 10.4 σ

Isospin triplet is established!

CLEOc data at 4.17 GeV (PLB 727, 366)

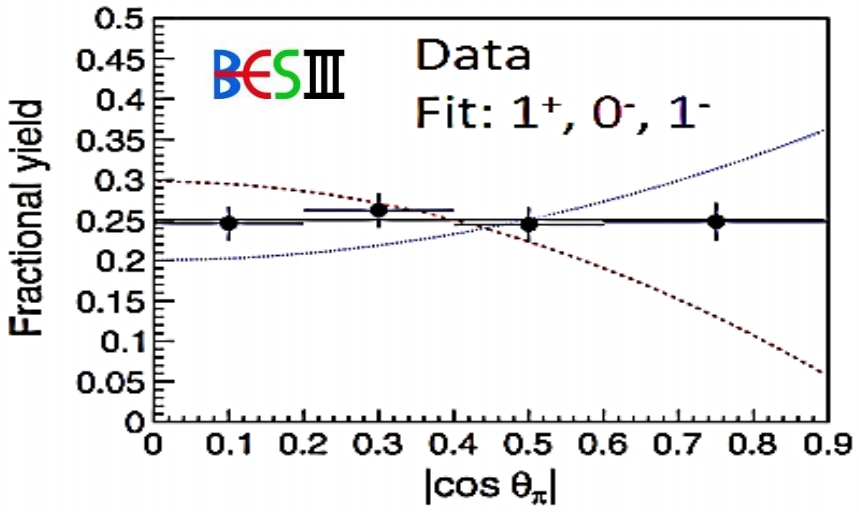


Observation of $Z_c(3885)^{\pm}$ in $e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}$ at $\sqrt{s} = 4.26\text{GeV}$ using single D tag method

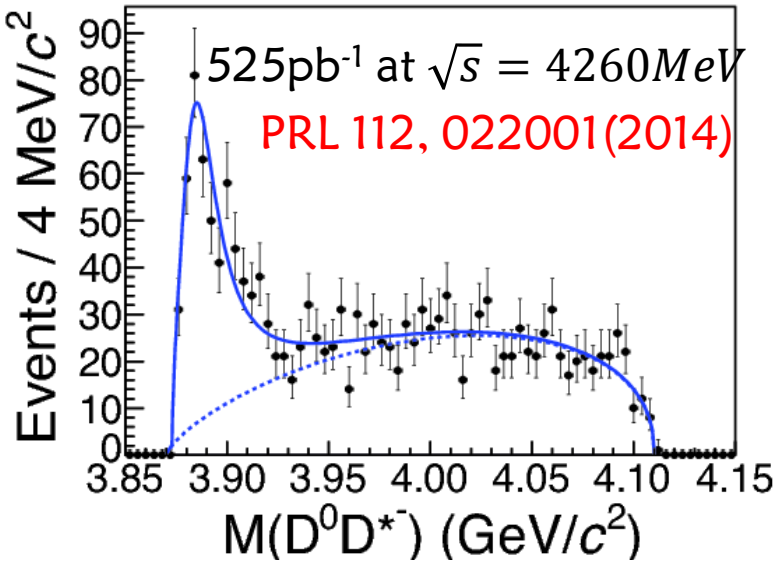
Reconstruct the π^+ and $D^0 \to K^-\pi^+$ and infer the D^{*-}.
(Also analyze $\pi^+D^-D^{*0}$ with the same method.)

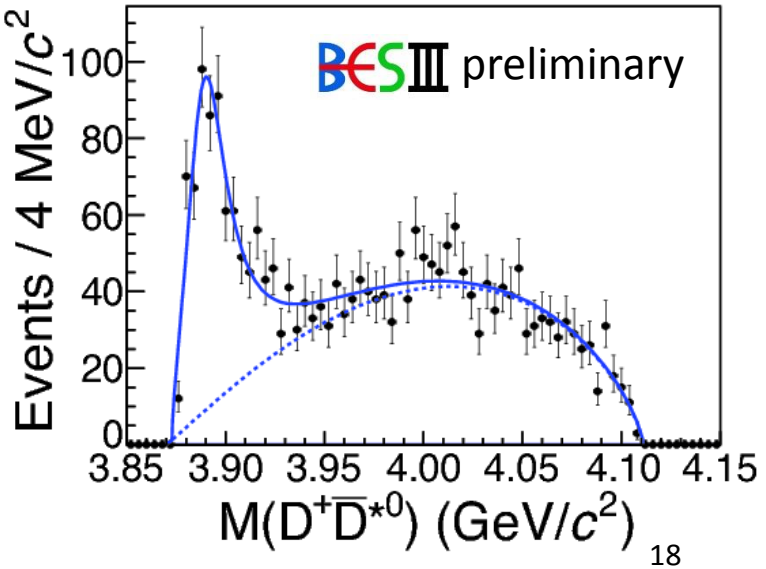
Enhancement at $D\bar{D}^*$ threshold in both channels ($Z_c(3885)^+$):

Mass = $3883.9 \pm 1.5 \pm 4.2$ MeV, (fit with BW function)
Width = $24.8 \pm 3.3 \pm 11.0$ MeV



Fit to angular distribution favors $J^P = 1^+$ over 0^- and 1^-





Observation of $Z_c(4020)^{\pm}$ in $e^+e^- \to \pi^+\pi^- h_c$

PRL 111, 242001(2013)

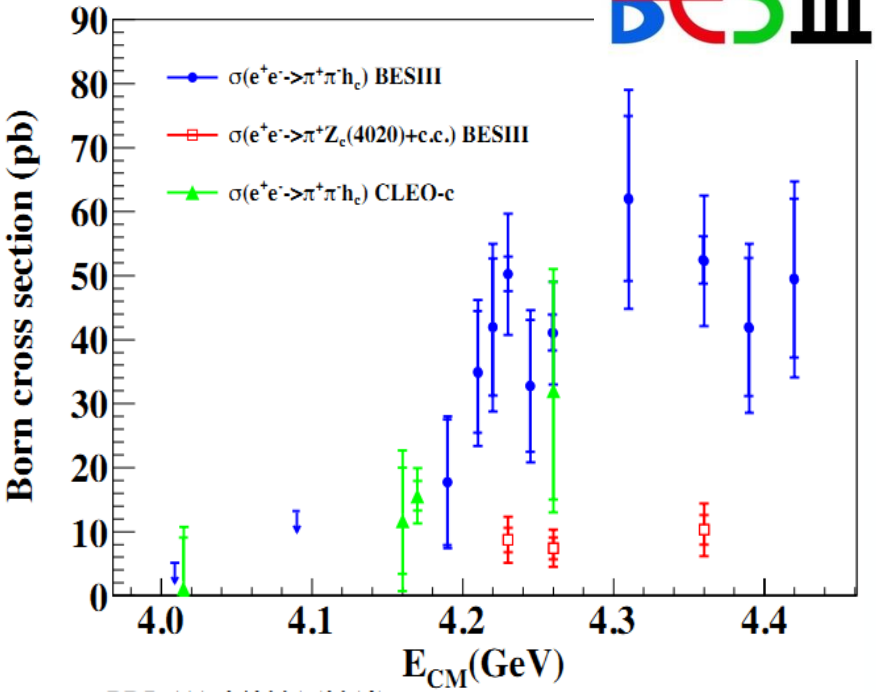
$h_c \to \gamma\eta_c$,
$\eta_c \to$ 16 hadronic decay modes

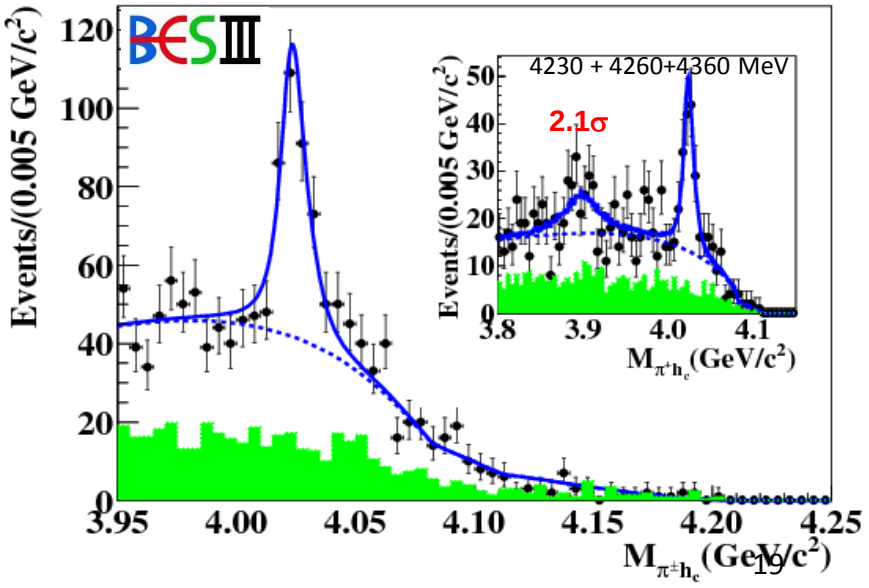
The cross section of $e^+e^- \to \pi^+\pi^- h_c$ is measured, and the shape is not trivial.

A structure, $Z_c(4020)^{\pm}$, is observed.

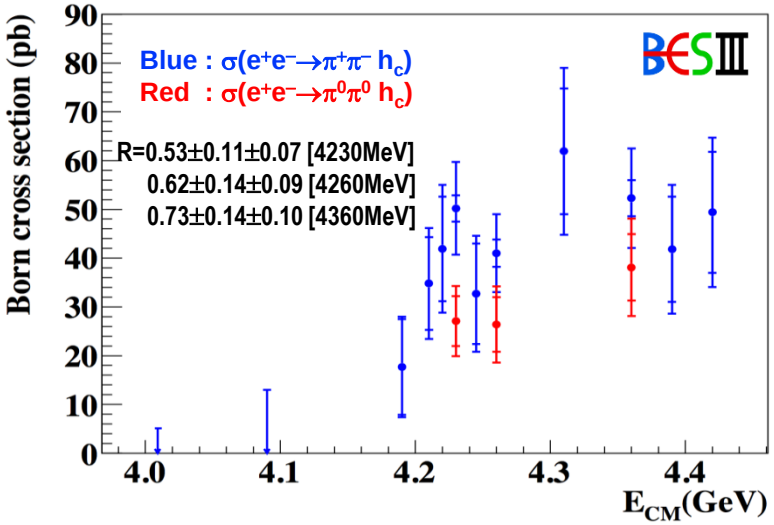
Mass = 4022.9 ± 0.8 ± 2.7 MeV,
Width = 7.9 ± 2.7 ± 2.6 MeV

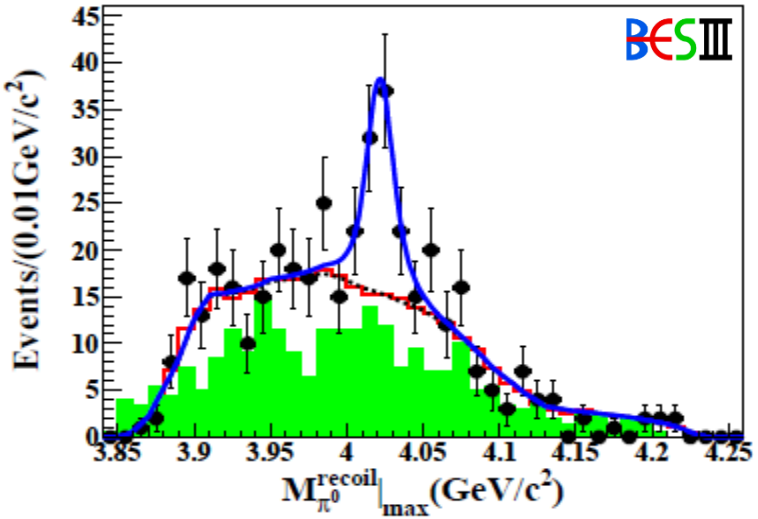
A weak evidence for $Z_c(3900)^{\pm} \to \pi^{\pm} h_c$





Observed neutral $Z_c(4020)^0$ in $e^+e^- \to \pi^0\pi^0 h_c$





$M[Z_c(4020)^0] = 4023.6 \pm 2.2 \pm 3.9$ MeV

$[M[Z_c(4020)^\pm] = 4022.9 \pm 0.8 \pm 2.7$ MeV$]$

– Width fixed to charged $Z_c(4020)$

– Significance : $>5\sigma$

Observation of neutral $Z_c(4020)$ → Isovector nature of Z_c states established

BESIII：PRL113，212002 (2014)

Observation of $Z_c(4025)^{\pm}$

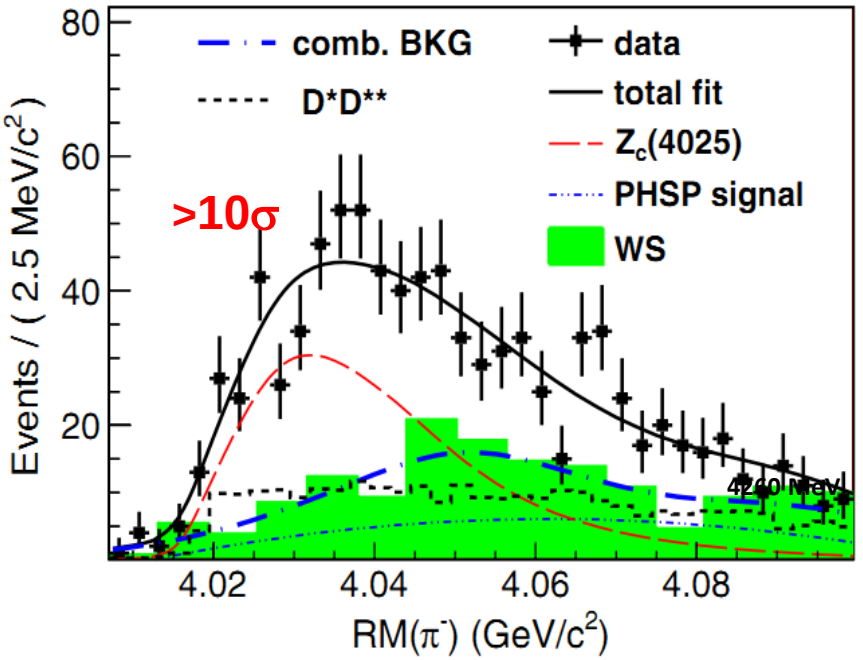
$e^+e^- \to \pi^{\pm}(D^*\bar{D}^*)^{\mp}$ at $\sqrt{s} = 4.26$GeV

PRL 112, 132001 (2014)

Tag a D^+ and a bachelor π^-, reconstruct one π^0 to suppress the background.

A structure, named as Zc(4025), can be observed in the recoil mass of the bachelor π^- .

$M(Z_c(4025)) = 4026.3 \pm 2.6 \pm 3.7$ MeV;
$\Gamma(Z_c(4025)) = 24.8 \pm 5.6 \pm 7.7$ MeV



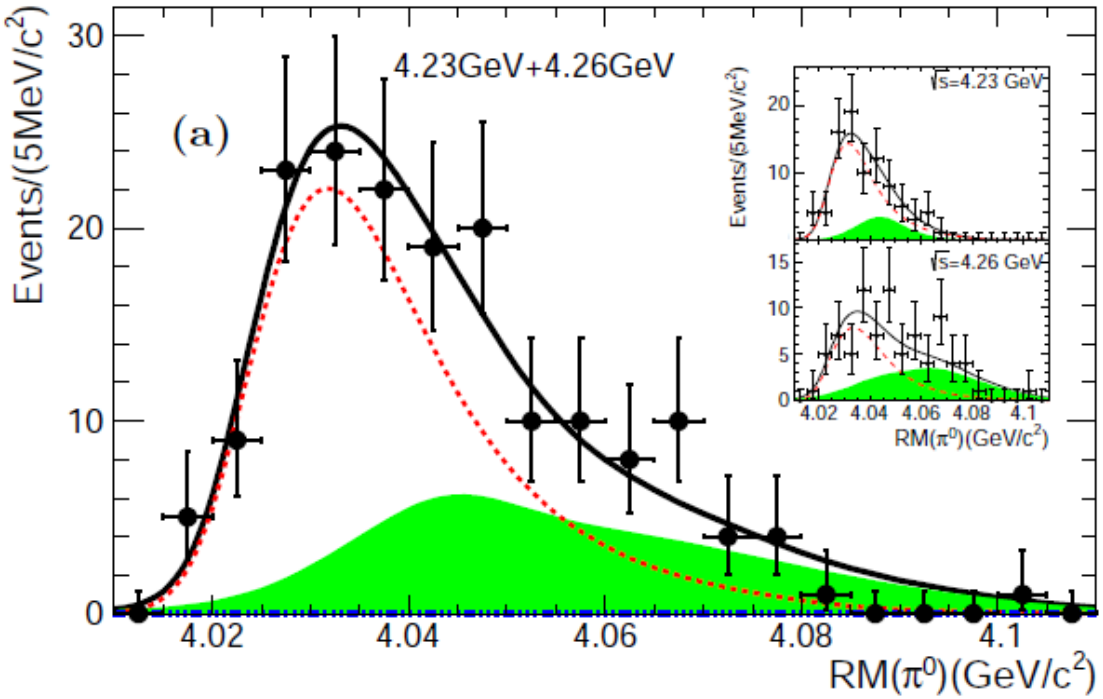
$$\sigma[e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}] = 137 \pm 9 \pm 15 \text{ pb at } 4.26 \text{ GeV}$$

$$\frac{\sigma[e^+e^- \to \pi^{\pm}Z_c(4025)^{\mp} \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}]}{\sigma[e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}]} = 0.65 \pm 0.09 \pm 0.06 \text{ at } 4.26 \text{ GeV}$$

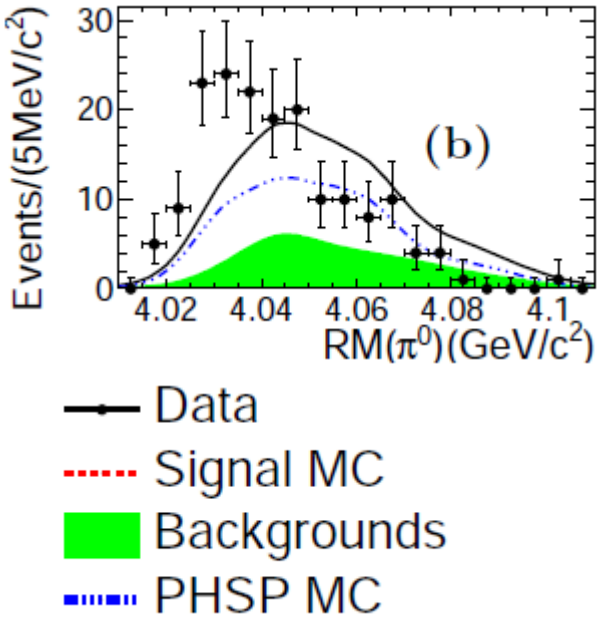
Coupling to $\bar{D}^*D^*$ is much larger than to πh_c if $Z_c(4025)$ and $Z_c(4020)$ are the same state.

Observation of $Z_c(4025)^0$ in $e^+e^- \to \pi^0(D^* \bar{D}^*)^{\mp}$

arXiv:1507.02404



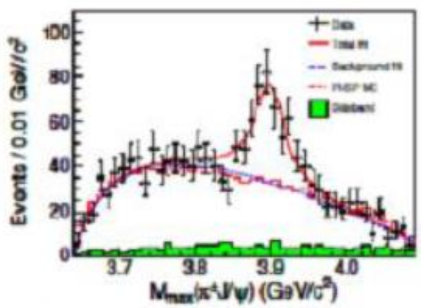
Phase space + BG



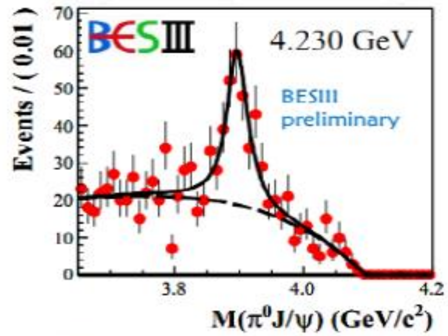
Data sample	Mass(MeV/c^2)	Width(MeV/c^2)	$\sigma(e^+e^- \to Z_c(4025)^0\pi^0 \to D^*\bar{D}^*\pi^0)$(pb)
@4.23GeV	$4025.5^{+2.0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$	$61.6 \pm 8.2 \pm 9.0$
@4.26GeV			$43.4 \pm 8.0 \pm 5.4$

Summary on Z_c states

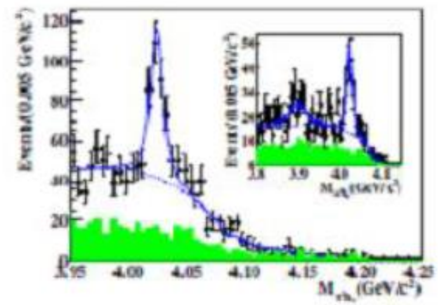
From Kornicer CHARM 2015



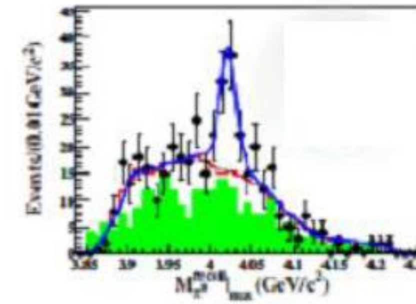
$e^+e^- \to \pi^-\pi^+ J/\psi$



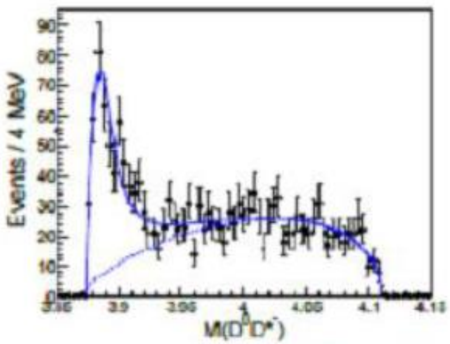
$e^+e^- \to \pi^0\pi^0 J/\psi$



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



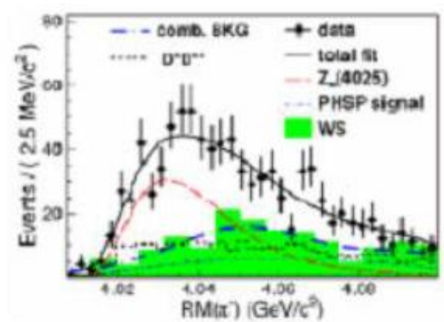
$e^+e^- \to \pi^0\pi^0 h_c$



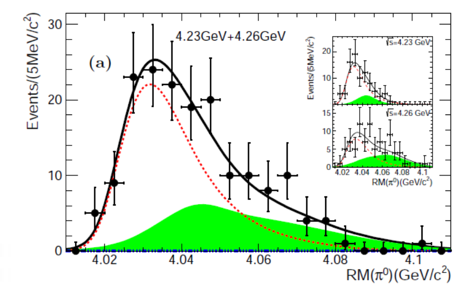
$e^+e^- \to \pi^-(D\bar{D}^*)^+$

preliminary

soon …



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



$e^+e^- \to \pi^0(D^*\overline{D^*})^0$

$Z_c(3900)^+$? **$Z_c(3900)^0$?** **$Z_c(4020)^+$?** **$Z_c(4020)^0$?**

Summary on Z_c states

From Kornicer CHARM 2015

State	Mass(MeV)	Width(MeV)	Decay mode	Process
$Z_c(3900)^{\pm}$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	$\pi^{\pm} J/\psi$	$e^+e^- \to \pi^+\pi^- J/\psi$
$Z_c(3900)^0$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$	$\pi^0 J/\psi$	$e^+e^- \to \pi^0\pi^0 J/\psi$
$Z_c(3885)^{\pm}$	$3883.9 \pm 1.5 \pm 4.2$ [single D tag] $3884.3 \pm 1.2 \pm 1.5$ [double D tag]	$24.8 \pm 3.3 \pm 11.0$ [single D tag] $23.8 \pm 2.1 \pm 2.6$ [double D tag]	D^0D^{*-} D^-D^{*0}	$e^+e^- \to \pi^+ D^0 D^{*-}$ $e^+e^- \to \pi^+ D^- D^{*0}$
$Z_c(4020)^{\pm}$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	$\pi^{\pm} h_c$	$e^+e^- \to \pi^+\pi^- h_c$
$Z_c(4020)^0$	$4023.9 \pm 2.2 \pm 3.8$	fixed	$\pi^0 h_c$	$e^+e^- \to \pi^0\pi^0 h_c$
$Z_c(4025)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	$D^{*0}D^{*-}$	$e^+e^- \to \pi^+ (D^* \bar{D}^*)^-$
$Z_c(4025)^0$	$4025.5^{+2.0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$	$(D^*D^*)^0$	$e^+e^- \to \pi^0 (D^*D^*)^0$

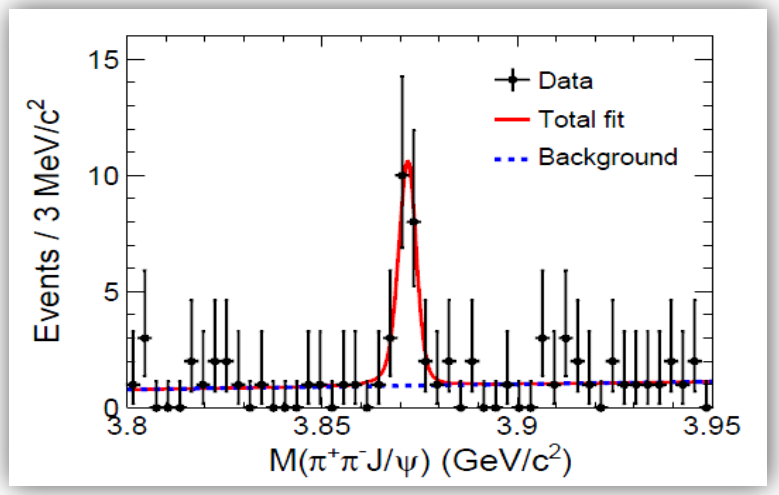
$e^+e^- \rightarrow \gamma X(3872)$

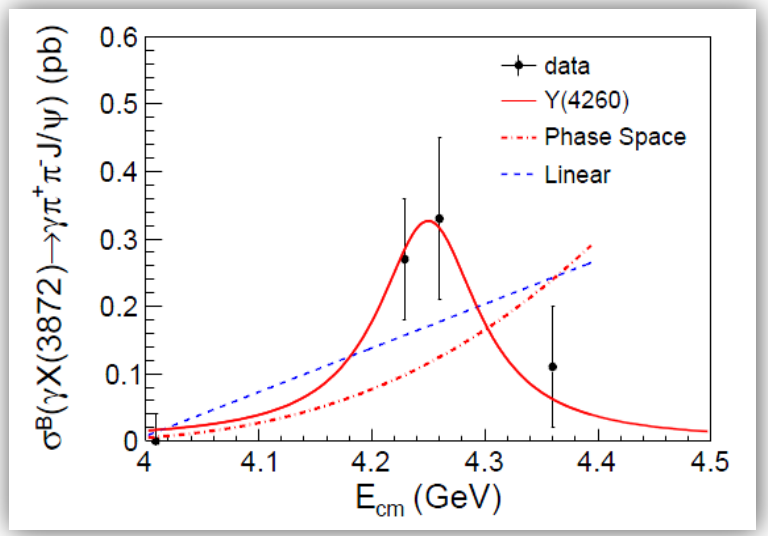
[BESIII RPL112,092001]

- Search for $\gamma X(3872)$ with $X(3872) \rightarrow \pi\pi J/\psi$ at E_{cm}=4.23, 4.26 and 4.36 GeV
- summed over all data

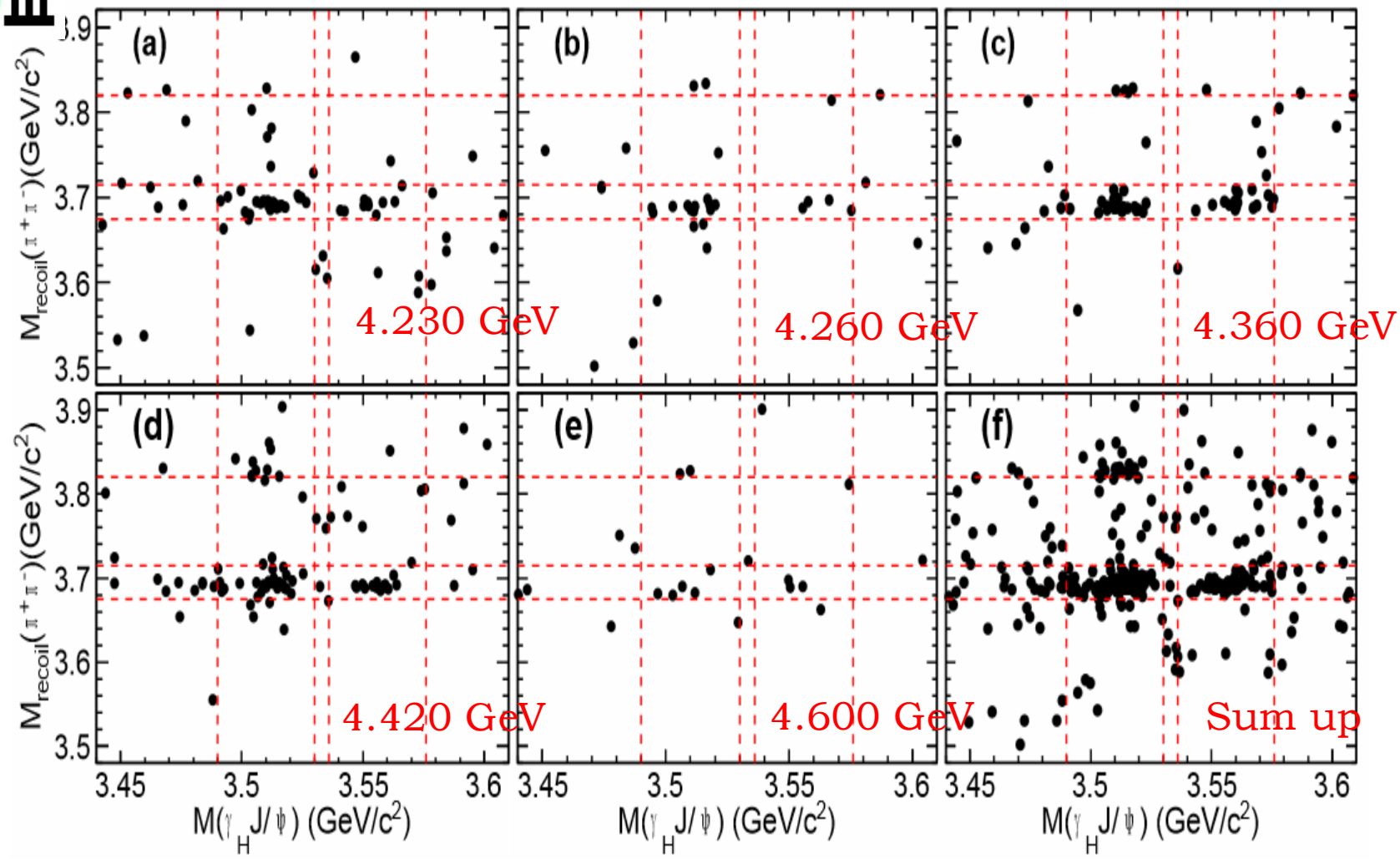
  X(3872) significance = 6.3 σ
- Production in Y(4260) decay suggestive, but not conclusive
- If from Y(4260)

$$\frac{B(Y(4260) \rightarrow \gamma X(3872))}{B(Y(4260) \rightarrow \pi^+\pi^- J/\psi)} \sim 0.1$$





$e^+e^- \to \pi^+\pi^- X(3823), X \to \gamma\chi_{cJ}, \chi_{cJ} \to \gamma J/\psi$



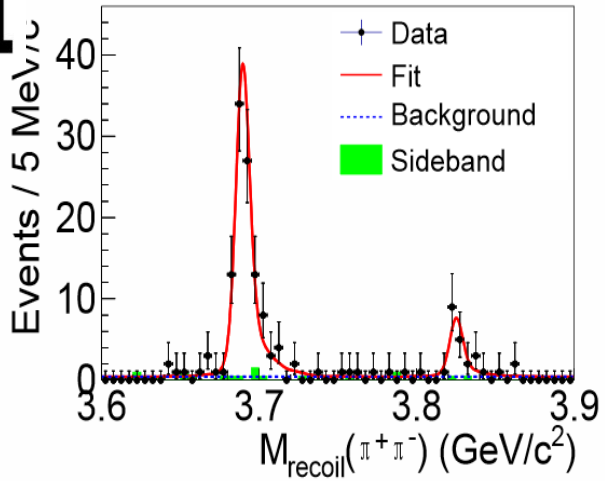
arXiv:1503.08203

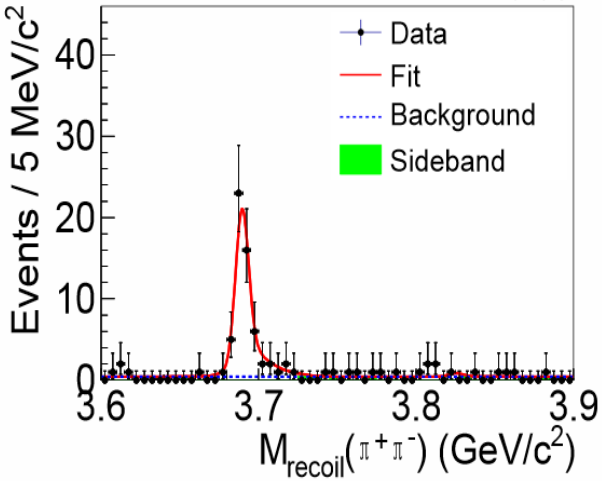
arXiv:1503.08203

$\psi(1\ ^3D_2)$

$e^+e^- \to \pi^+\pi^- X(3823), X \to \gamma\chi_{cJ}, \chi_{cJ} \to \gamma J/\psi$

PRL 115, 011803 (2015)



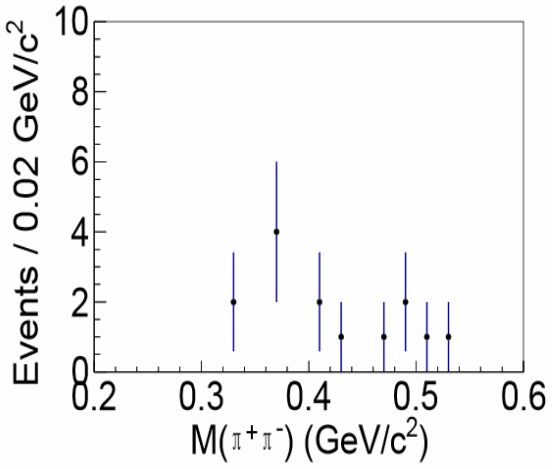


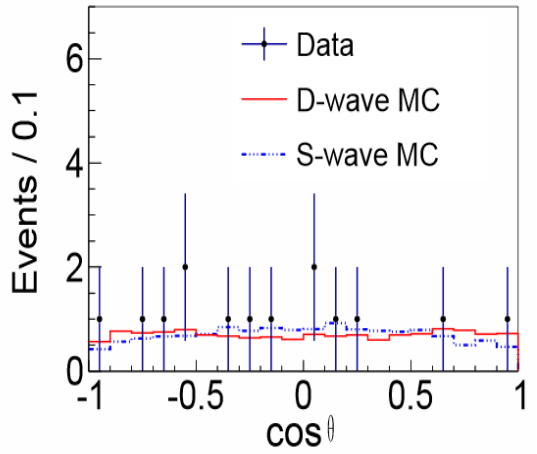
$\psi(1\ ^3D_2)$

Simultaneous fit of $\gamma\chi_{c1}$ (left) and $\gamma\chi_{c2}$ (right) events

$M(X(3823)) = (3821.7 \pm 1.3(stat) \pm 0.7(syst))\ \mathrm{MeV}/c^2$

$\Gamma(X(3823)) < 16\ \mathrm{MeV}$ at 90% C. L. consist with Belle





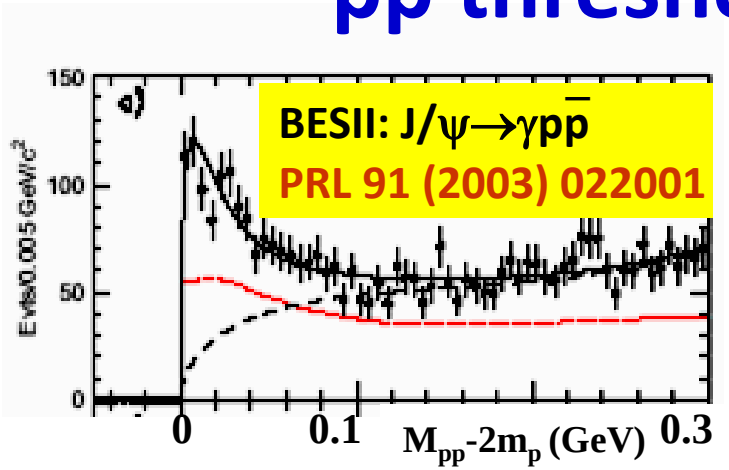
D-wave is expected.
Limited statistics
limited information

Light meson spectroscopy

- ✓ X(18xx) states:
  - X(1835) in J/ψ→γπ+π-η' , PRL 106, 072002
  - X($p\bar{p}$) in J/ψ→ $\gamma p\bar{p}$, PRL 108, 112003
  - X(1870) in J/ψ→ωηππ, PRL 107, 182001
  - X(1840) in J/ψ→γ3(π+π-), PRD 88, 091502
  - X(1810) in J/ψ→γωϕ, PRD 87, 032008
- ✓ PWA of J/ψ→γηη, PRD 87, 092009
- Model independent PWA of $J/\psi \to \gamma\pi^0\pi^0$ [arXiv: 1506.00546]

- Based on 0.22*10^9 J/ψ data (now 1.3*10^9 J/ψ)

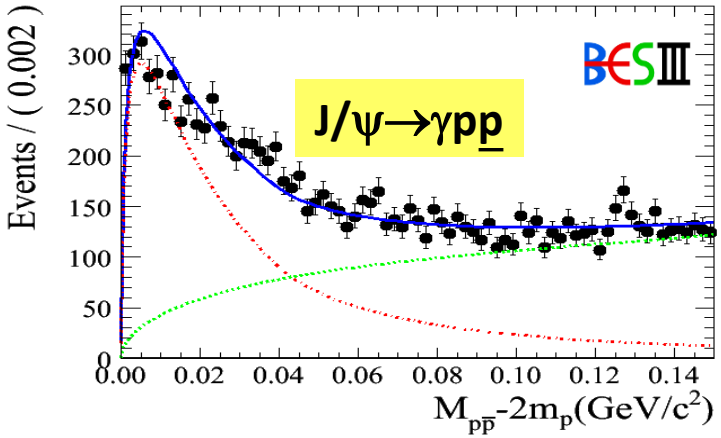
$p\bar{p}$ threshold Enhancement

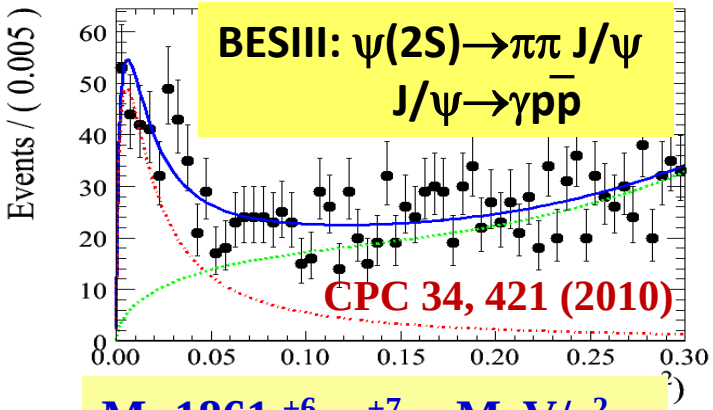


$M=1859\ ^{+3}_{-10}\ ^{+5}_{-25}\ MeV/c^2$

$\Gamma < 30\ MeV/c^2$ (90% CL)

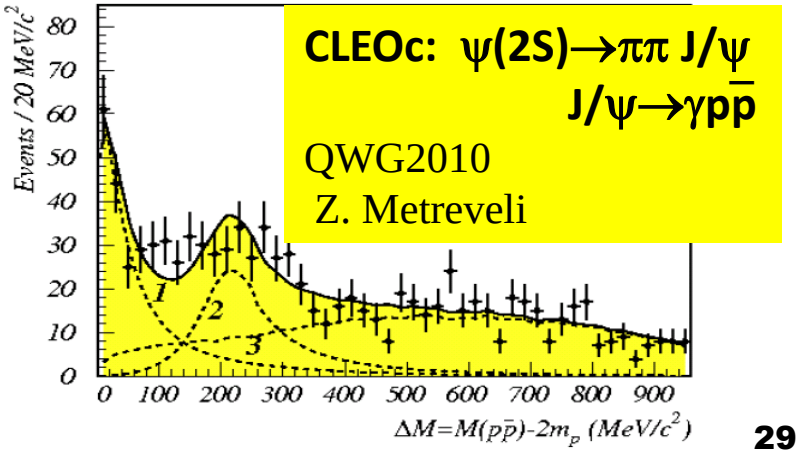
- Observed at BESII in 2003
- Confirmed by CLEOc and BESIII
- Agree with BESII results





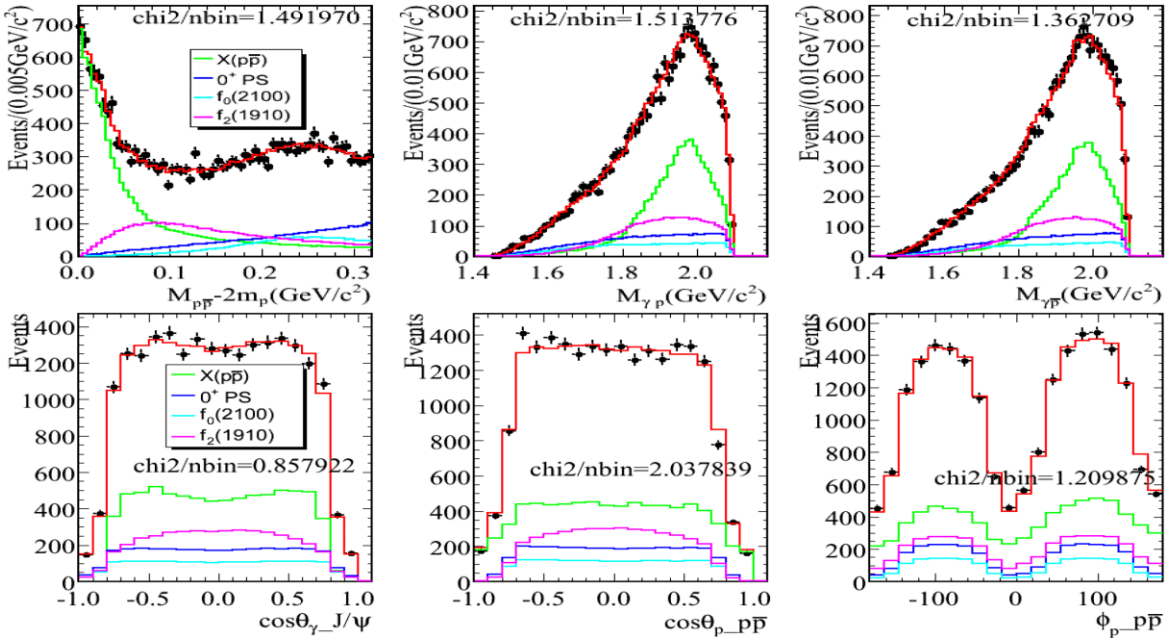
$M=1861\ ^{+6}_{-13}\ ^{+7}_{-26}\ MeV/c^2$

$\Gamma < 38\ MeV/c^2$ (90% CL)



PWA of J/ψ →γpp̄

$f_0(2100)$ and $f_2(1910)$ fixed to PDG.
Significance of X(pp̄) >>30σ



- The fit with a BW and S-wave FSI(I=0) factor can well describe ppb mass threshold structure.
- It is much better than that without FSI effect, and Δ2lnL=51 ⇒ 7.1σ.

Nature of X(pp̄)?

$J^{pc} = 0^{-+}$

$M = 1832 \pm 5(\text{stat})^{+19}_{-17}(\text{syst}) \pm 19(\text{mod})\ \text{MeV/c}^2$

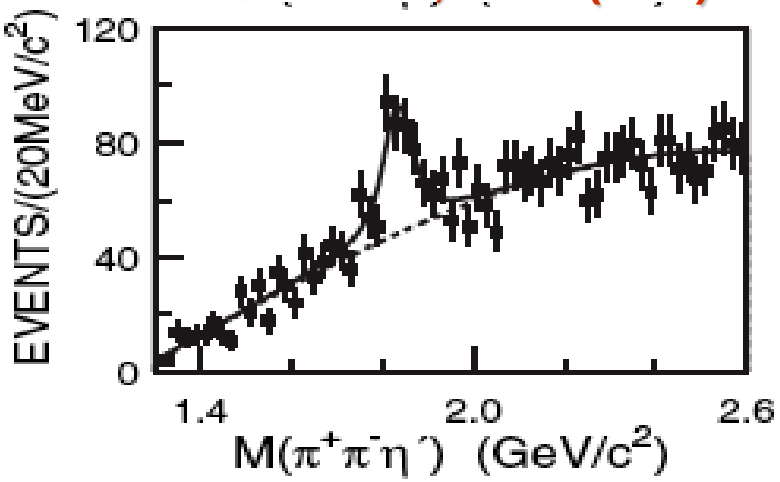
$\Gamma = 13 \pm 20(\text{stat})^{+11}_{-33}(\text{syst}) \pm 4(\text{mod})\text{MeV/c}^2 \ \text{ or } \ \Gamma < 48\text{MeV/c}^2 @ 90\%\ C.L.$

$B(J/\psi \to \gamma X(p\bar{p}))B(X(p\bar{p}) \to p\bar{p}) = (9.0 \pm 0.7(\text{stat})^{+1.5}_{-5.1}(\text{syst}) \pm 2.3(\text{mod})) \times 10^{-5}$

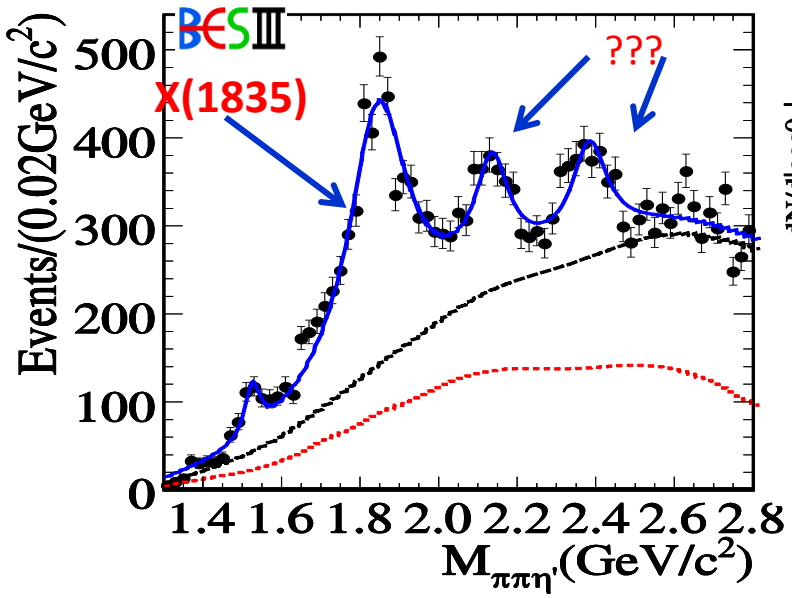
X(1835) in J/ψ → γπ⁺π⁻η' (η'→γρ/ηππ) at BESIII

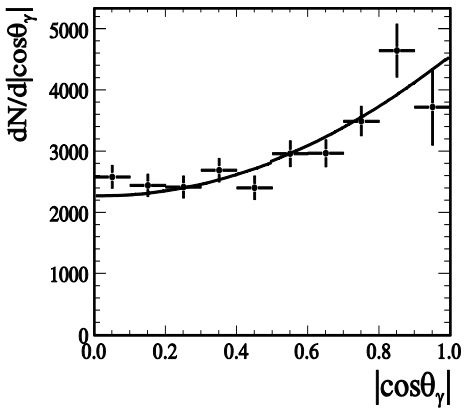
PRL., 106 (2011) 072002

BESII PRL 95,262001(2005)



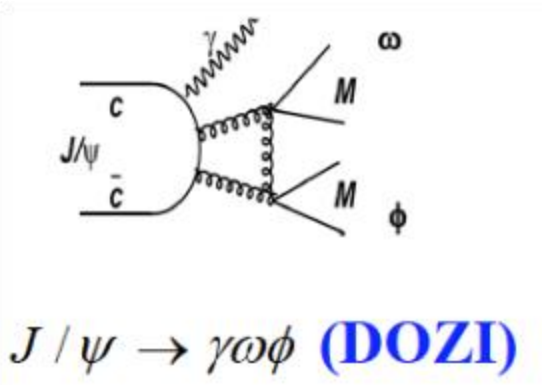
- BESII observed X(1835)
- BESIII confirmed X(1835)
- Observed two new resonances.



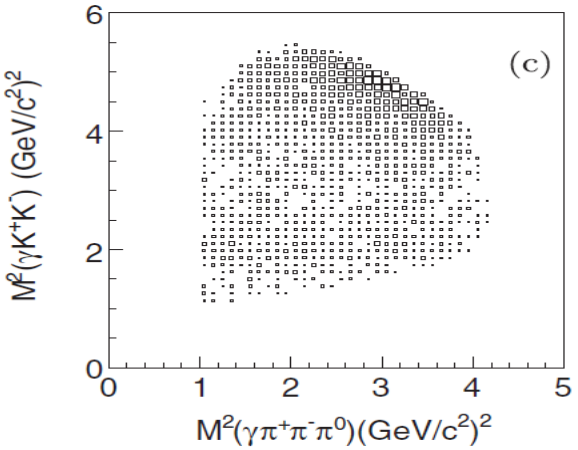


- X(1835) consistent with 0^{-+}. Others not excluded.
- η' excited state? Glueball state? Same as ppbar enhancement?
- LQCD predicts 0-+ glueball at 2.4 GeV

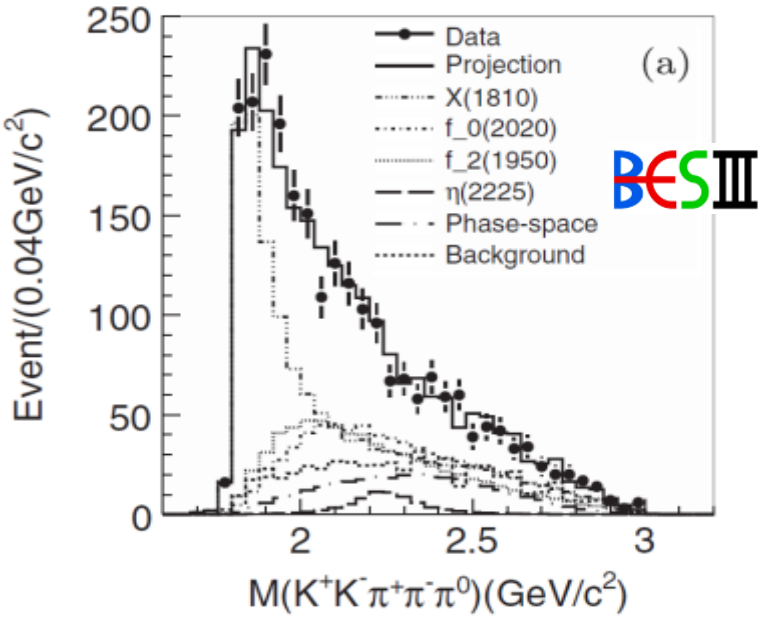
PWA of J/ψ→γ ωϕ



$J/\psi \to \gamma\omega\phi$ **(DOZI)**



PRD 87, 032008(2013)

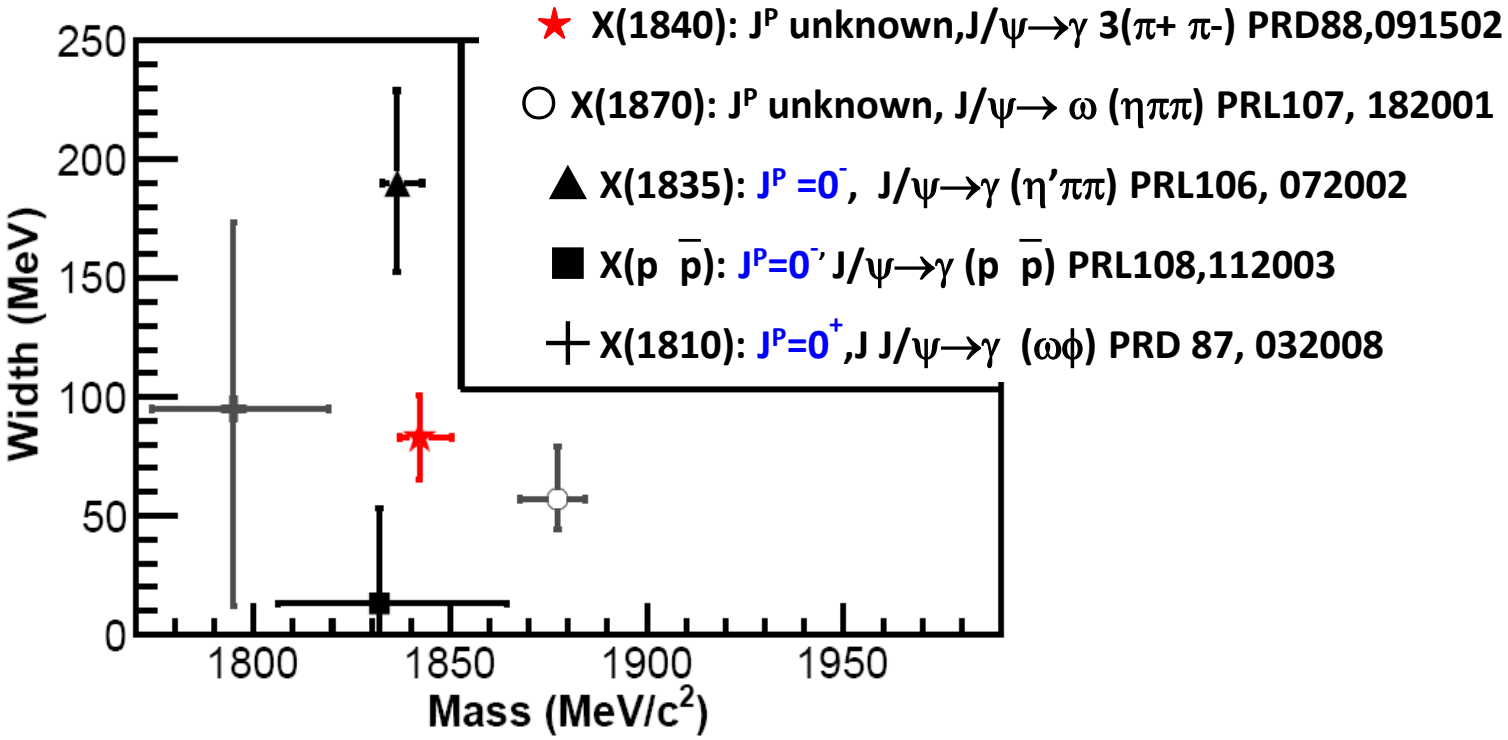


- **Confirmed the enhancement observed at BESII**

M= $1795 \pm 7^{+13}_{-5} \pm 19$(model) MeV/$c^2$,
Γ =$95 \pm 10^{+21}_{-34} \pm 75$(model) MeV
Spin-parity is determined to be 0^+

- **the same as $f_0(1710)/f_0(1790)$, or a new state ?**

X(18xx) at BES

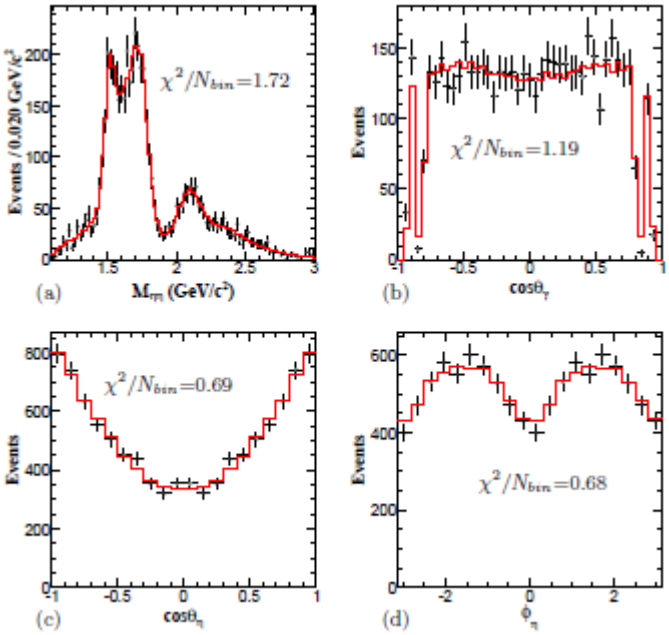


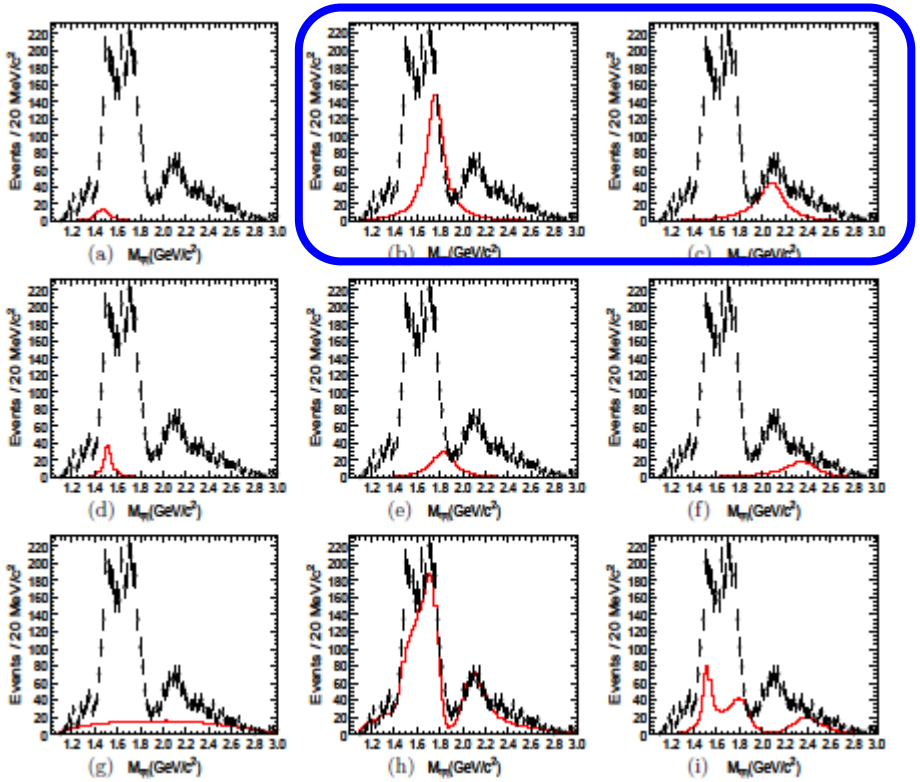
- Any relations?
- What is the role of the proton-antiproton threshold?

PWA of $J/\psi \to \gamma\eta\eta$

(Phys. Rev. D87 092009 (2013)

Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2 σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0 σ
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9 σ
$f_2'(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0 σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4 σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6 σ





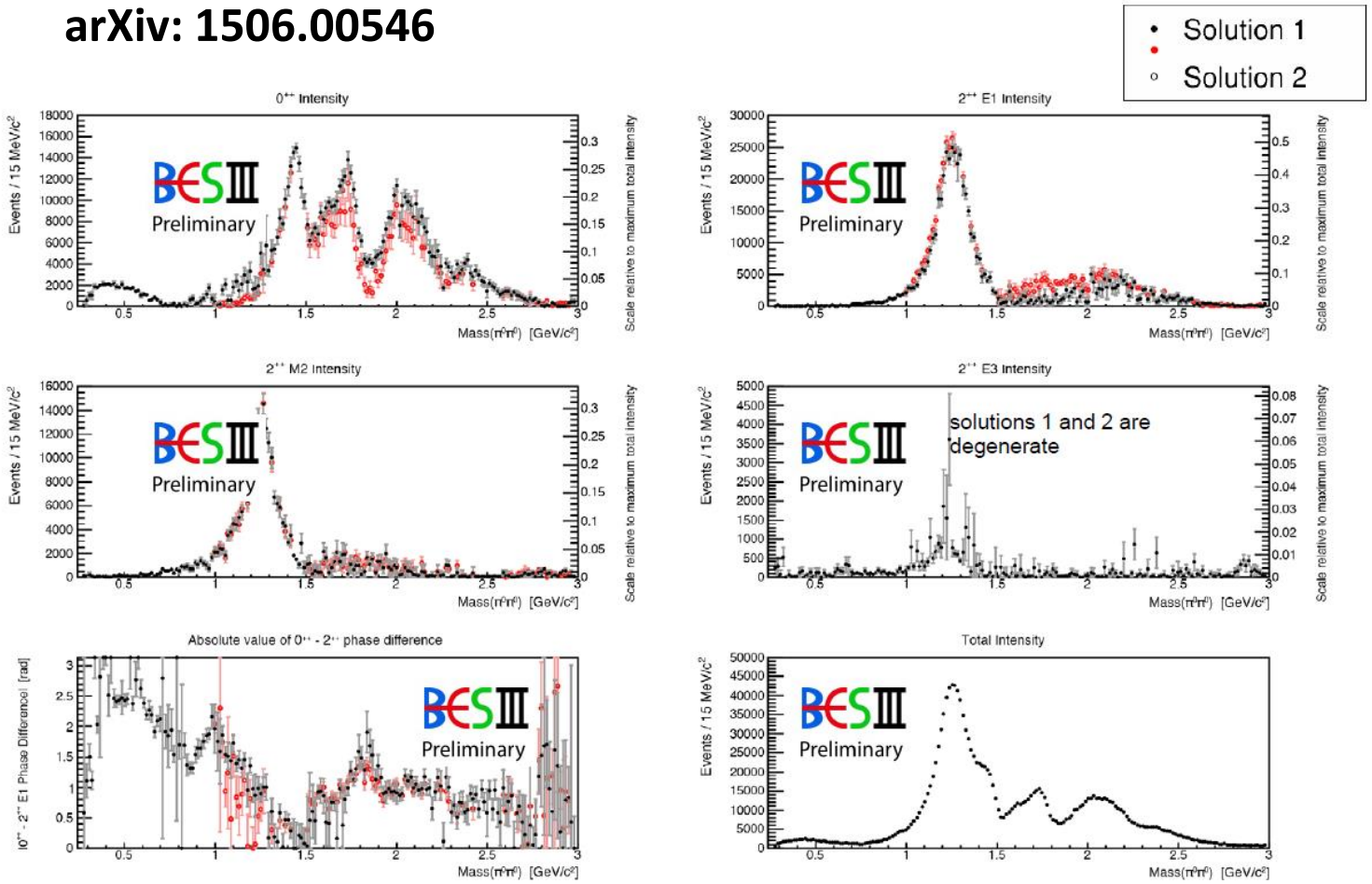
- Br of $f_0(1710)$ and $f_0(2100)$ are ~10x larger than that of $f_0(1500)$
- Possible large overlap with LQCD predictions of 0^+ Glueball:

  PRL 110 021601 (2013)

- Further studies of $J/\psi \to \gamma\eta\eta'$ and $J/\psi \to \gamma\eta'\eta'$ are crucial for glueball ID and solving the mixing scheme.

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

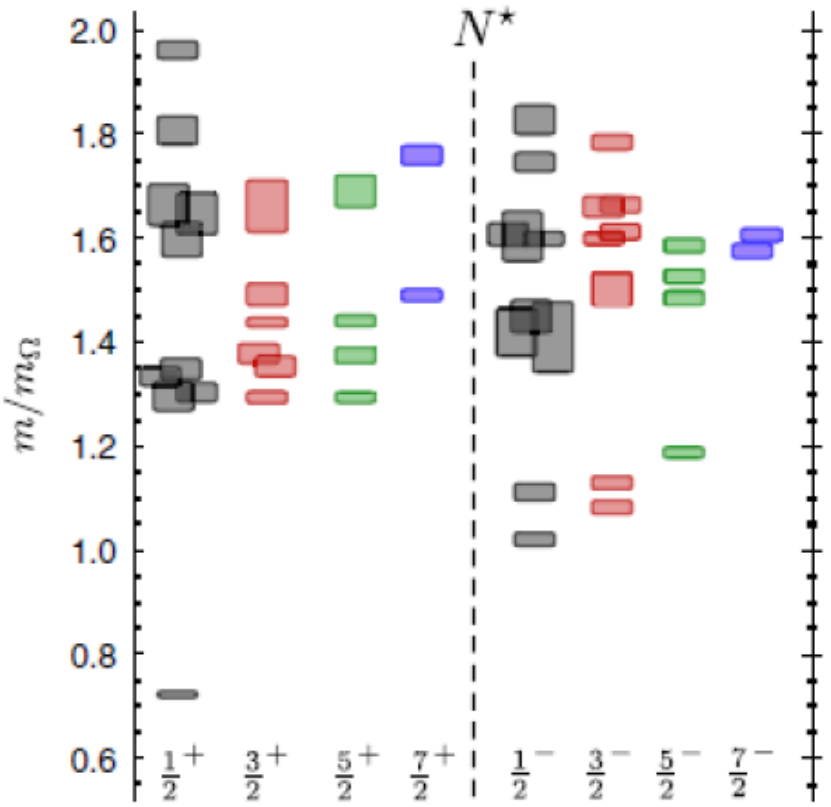
arXiv: 1506.00546



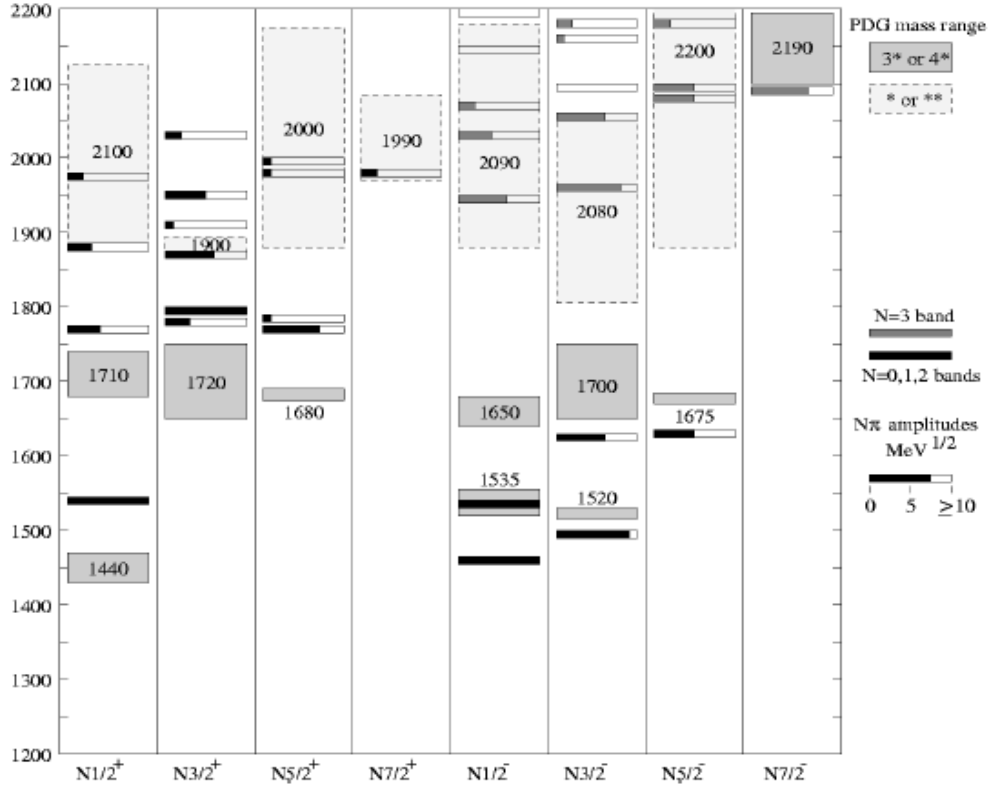
Significant features of the scalar spectrum include structures near 1.5, 1.7, and 2.0 GeV/c^2

Two problems in qqq model

1) "Missing resonances" ; 2) mass ordering for the lowest ones



Lattice, R.Edwards et al, PRD84(2011)074508



q^3 model, Capstck&Roberts, PPNP45(2000)S241

Missing N* Resonances (uud, udd)

			Status as seen in —						
Particle	$L_{2I\cdot 2J}$	Overall status	$N\pi$	$N\eta$	ΛK	ΣK	$\Delta\pi$	$N\rho$	$N\gamma$
$N(939)$	P_{11}	****							
$N(1440)$	P_{11}	****	****	*			***	*	***
$N(1520)$	D_{13}	****	****	***			****	****	****
$N(1535)$	S_{11}	****	****	****			*	**	***
$N(1650)$	S_{11}	****	****	*	***	**	***	**	***
$N(1675)$	D_{15}	****	****	*	*		****	*	****

PDG

Theory predicts much more baryons than what observed → missing baryons

$N(1990)$	F_{17}	**	**	*	*	*			*
$N(2000)$	F_{15}	**	**	*	*	*	*	**	
$N(2080)$	D_{13}	**	**	*	*				*
$N(2090)$	S_{11}	*	*						
$N(2100)$	P_{11}	*	*	*					
$N(2190)$	G_{17}	****	****	*	*	*		*	*
$N(2200)$	D_{15}	**	**	*	*				
$N(2220)$	H_{19}	****	****	*					
$N(2250)$	G_{19}	****	****	*					
$N(2600)$	$I_{1,11}$	***	***						
$N(2700)$	$K_{1,13}$	**	**						

(**)
not well-established

	* * **	* * *	**	*
N Spectrum	11	3	6	2
Δ Spectrum	7	3	6	6

Order of masses for lowest states

- **the lowest spatial excited baryon is expected to be a N*(uud) state with one quark in orbital angular momentum L=1, and hence should have negative P**

PDG: N*(1535) (1/2-) (?)

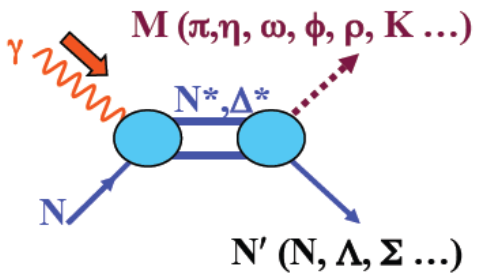
N*(1440) (1/2+) (uud) (should be heavier than N*(1535))

Λ*(1405) (1/2-) (uds) (should be 130MeV heavier than N*(1535))

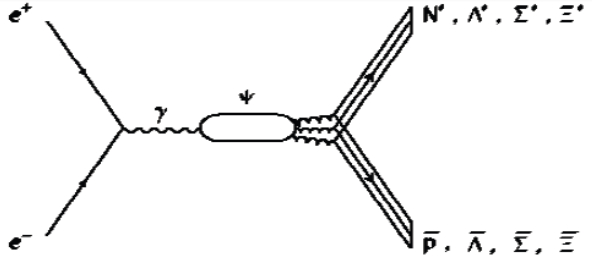
(N*(1535) partner)

Charmonium decays provide novel insights into baryons --- complementary to other experiments

JLAB, MAMI, ELSA, …..



$J/\psi(\psi') \to \bar{B}BM \Rightarrow N^*, \Lambda^*, \Sigma^*, \Xi^*$

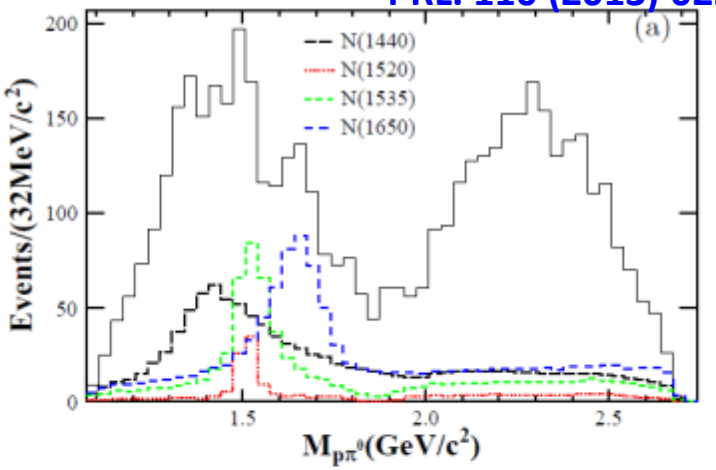


- ✓ Isospin 1/2 filter: $\psi \to N\bar{N}\pi$, $\psi \to N\bar{N}\pi\pi$
- ✓ Missing N* with small couplings to πN & γN , but large coupling to gggN : $\psi \to N\bar{N}\pi/\eta/\eta'/\omega/\phi, \bar{p}\Sigma\pi, \bar{p}\Lambda K$ …
- ✓ Not only N*, but also Λ^*, Σ^*, Ξ^*
- ✓ Gluon-rich environment: a favorable place for producing hybrid (qqqg) baryons
- ✓ Interference between N* and $\bar{N}$ * bands in $\psi \to N\bar{N}\pi$ Dalitz plots may help to distinguish some ambiguities in PWA of πN
- ✓ High statistics of charmonium @ BES III

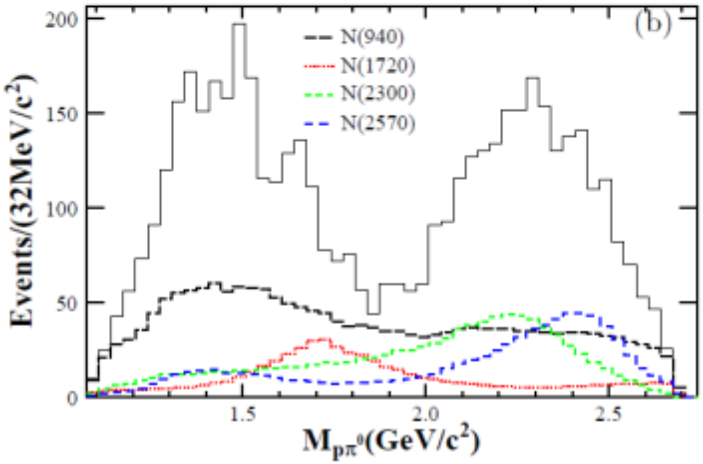
Study of N* and Ξ*

N* in $\psi' \to \pi^0 p \bar{p}$

PRL. 110 (2013) 022001

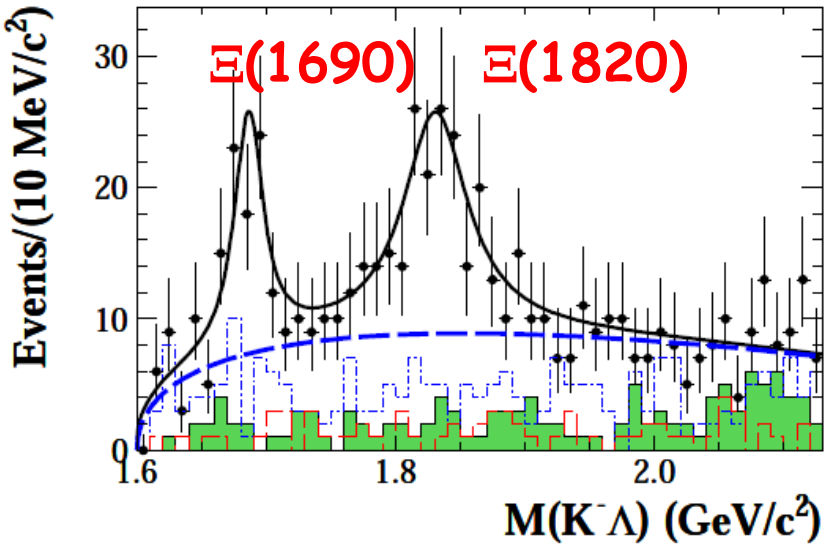


New N*s: N(2300) and N(257



Ξ* in $\psi' \to K\Lambda\Xi$

arXiv:1504.02025

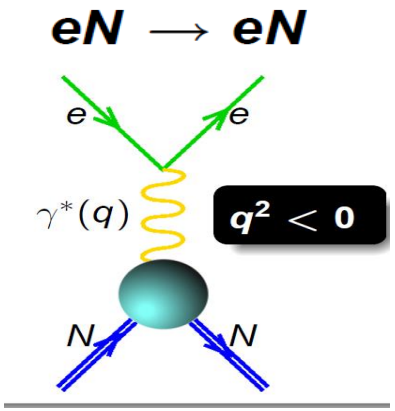


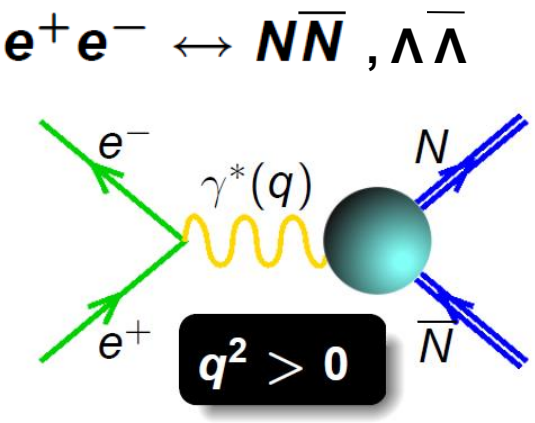
- PWA of
  - $J/\psi(\psi') \to \pi^0 p \bar{p}$
  - $J/\psi(\psi') \to \eta p \bar{p}$
  - $J/\psi(\psi') \to pK \bar{\Lambda}$
  - …

Nucleon Form Factor

- **Fundamental properties of the nucleon**
  - **Connected to charge, magnetization distribution**
  - **Crucial testing ground for models of the nucleon internal structure**
  - **Necessary input for experiments probing nuclear structure, or trying to understand modification of nucleon structure in nuclear medium**
- **Can be measured from space-like processes (eN) (precision 1%) or time-like process (e^+e^- annihilation) (precision 10%-30%)**

Space-like: FF real





Time-like: FF complex

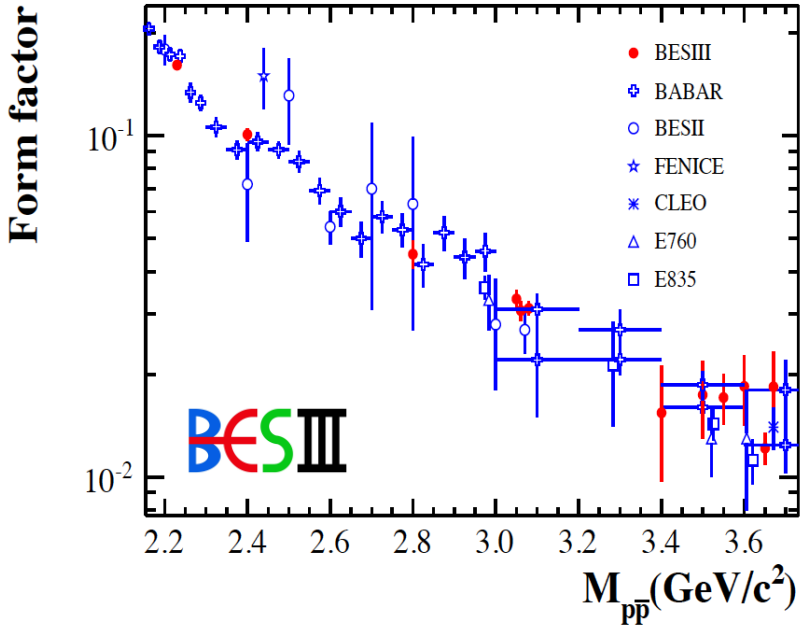
Proton FF measurement at BESIII

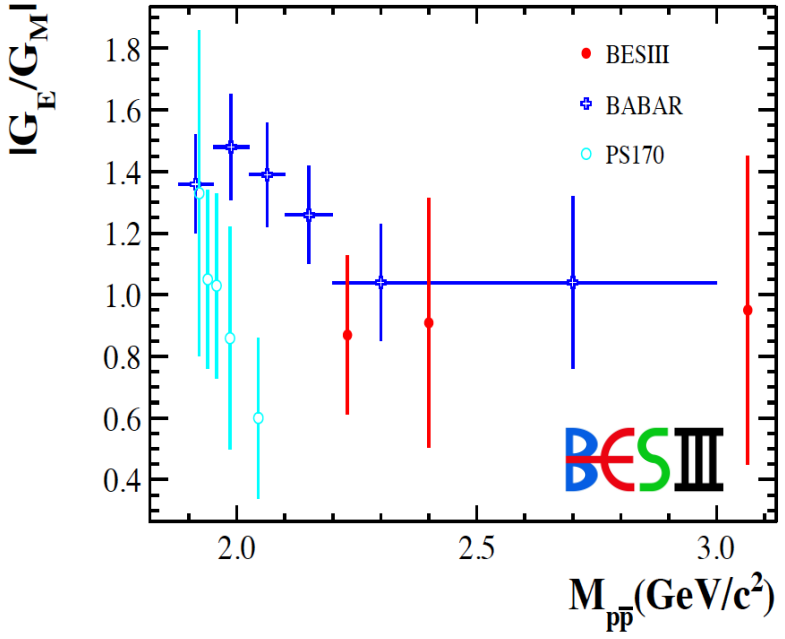
Phys.Rev. D91 (2015) 11, 112004 .

Analysis Features:

- **Radiative corrections from Phokhara8.0 (scan)**
- **Normalization to $e^+e^- \to e^+e^-$, $e^+e^- \to \gamma\gamma$ (BABAYAGA 3.5)**
- **Efficiencies 60% (2.23 GeV) .... 3% (~4 GeV)**
- **$|G_E/G_M|$ ratio obtained for 3 c.m. energies**

E_{cm}/GeV	L_{int} / pb^{-1}
2.23	2.6
2.40	3.4
2.80	3.8
3.05, 3.06, 3.08	60.7
3.40, 3.50, 3.54, 3.56	23.3
3.60, 3.65, 3.67	63.0

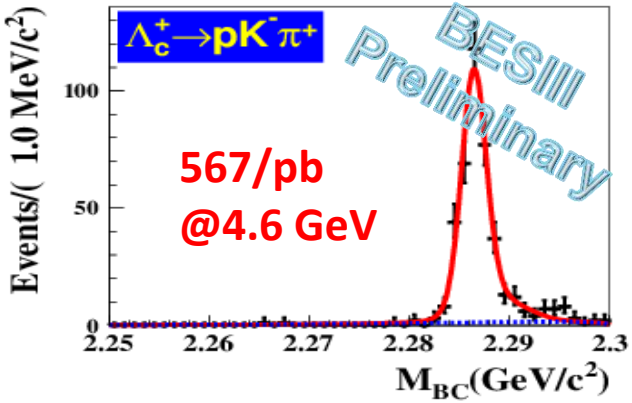




- **Precise study of Λ_c decays**

  stringent test on Heavy Quark Effective Theory

  - absolute branching fractions (BF) of Λ_c^+ decays suffers from large uncertainties since its discovery 30 years ago
  - hadronic decays:
    to explore as-yet-unmeasured channels and understand full picture of intermediate structures
  - semi-leptonic decays:
    test on form factor predictions



BESIII prel.

Decay modes	global fit $\mathcal{B}$	PDG $\mathcal{B}$	Belle $\mathcal{B}$
pK_S	1.48 ± 0.08	1.15 ± 0.3	
$pK^-\pi^+$	5.77 ± 0.27	5.0 ± 1.3	$4.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S\pi^0$	1.77 ± 0.12	1.65 ± 0.40	
$pK_S\pi^+\pi^-$	1.43 ± 0.10	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	4.25 ± 0.22	3.4 ± 1.0	
$\Lambda\pi^+$	1.20 ± 0.07	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	6.70 ± 0.35	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	3.67 ± 0.23	2.6 ± 0.7	
$\Sigma^0\pi^+$	1.28 ± 0.08	1.05 ± 0.28	
$\Sigma^+\pi^0$	1.18 ± 0.11	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	3.58 ± 0.22	3.6 ± 1.0	
$\Sigma^+\omega$	1.47 ± 0.18	2.7 ± 1.0	

BESIII Preliminary

only stat. errors

- ✓ **$B(pK^-\pi^+)$: BESIII precision comparable with Belle's result**
- ✓ **BESIII rate $B(pK^-\pi^+)$ is smaller**
- ✓ **Improved precisions of the other 11 modes significantly**