Overview on BESIII Experiment

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超级陶粲装置研讨会

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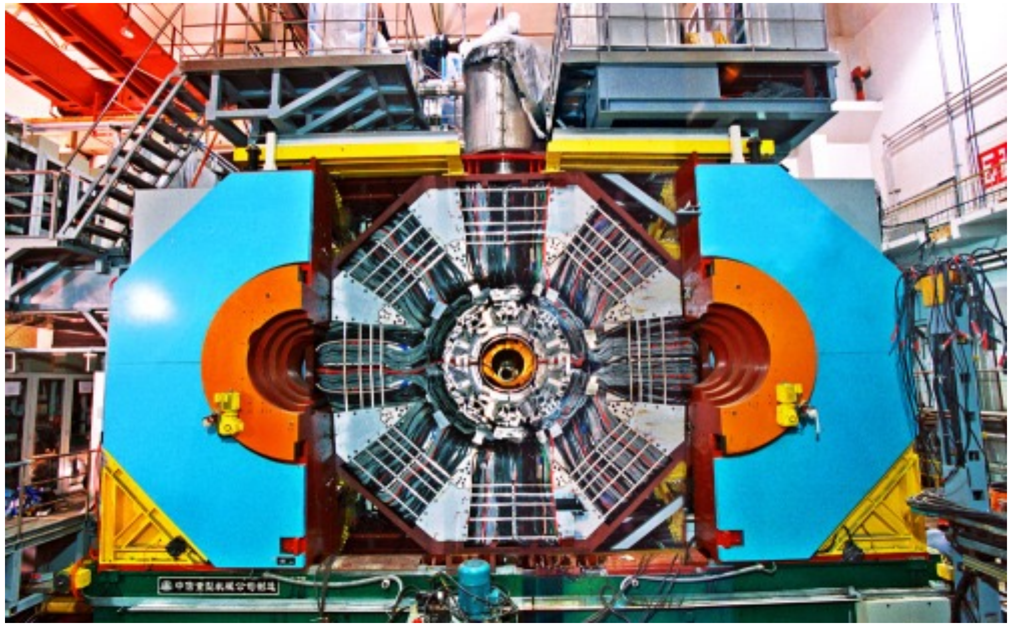
Outline

- BEPCII/BESIII
- Physics accomplishments
- Future prospects

BEPCII and BESIII

- BEPC → BEPCII
  - Luminosity:1.0×10^{31}→ $1.0\times10^{33}cm^{-2}s^{-1}$



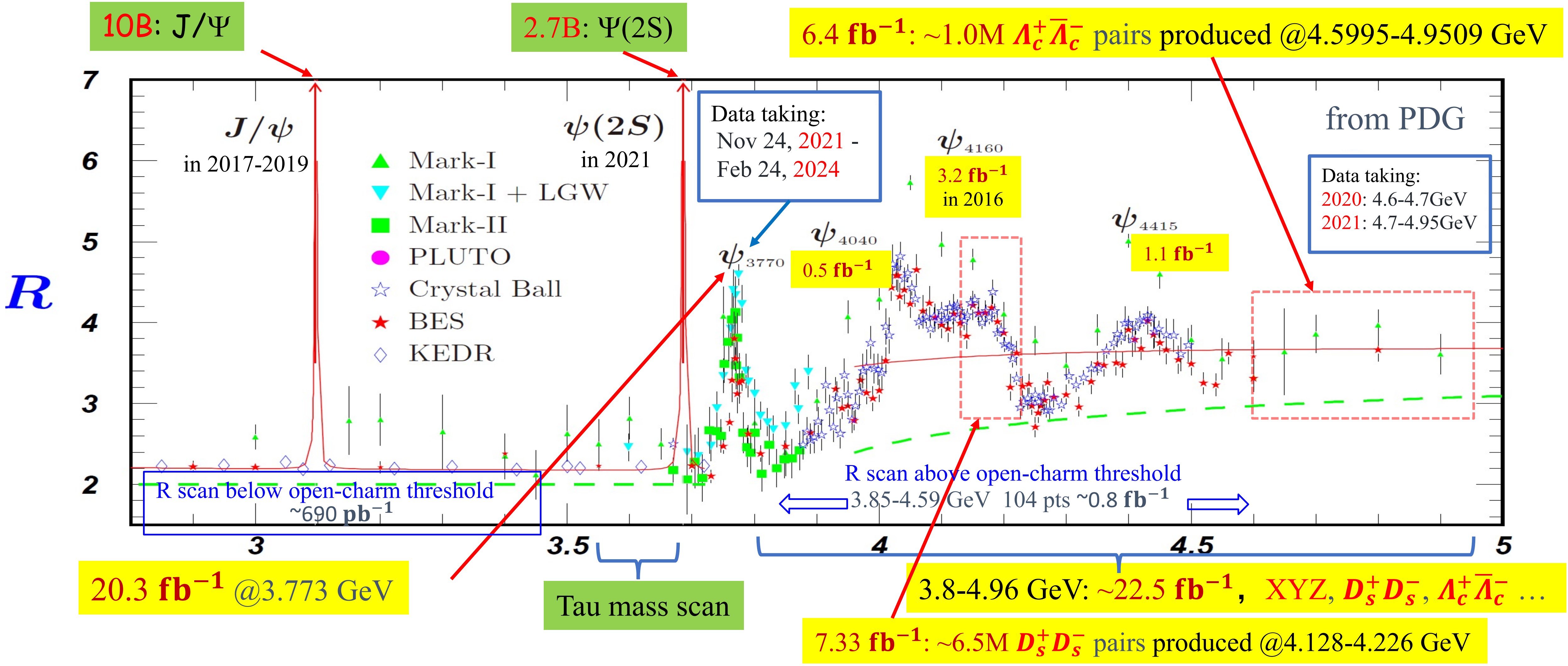
Upgrade in 1996-1998
(BES→BESII)

Upgrade in 2004-2008
(BESII→BESIII)

BESIII: a new spectrometer

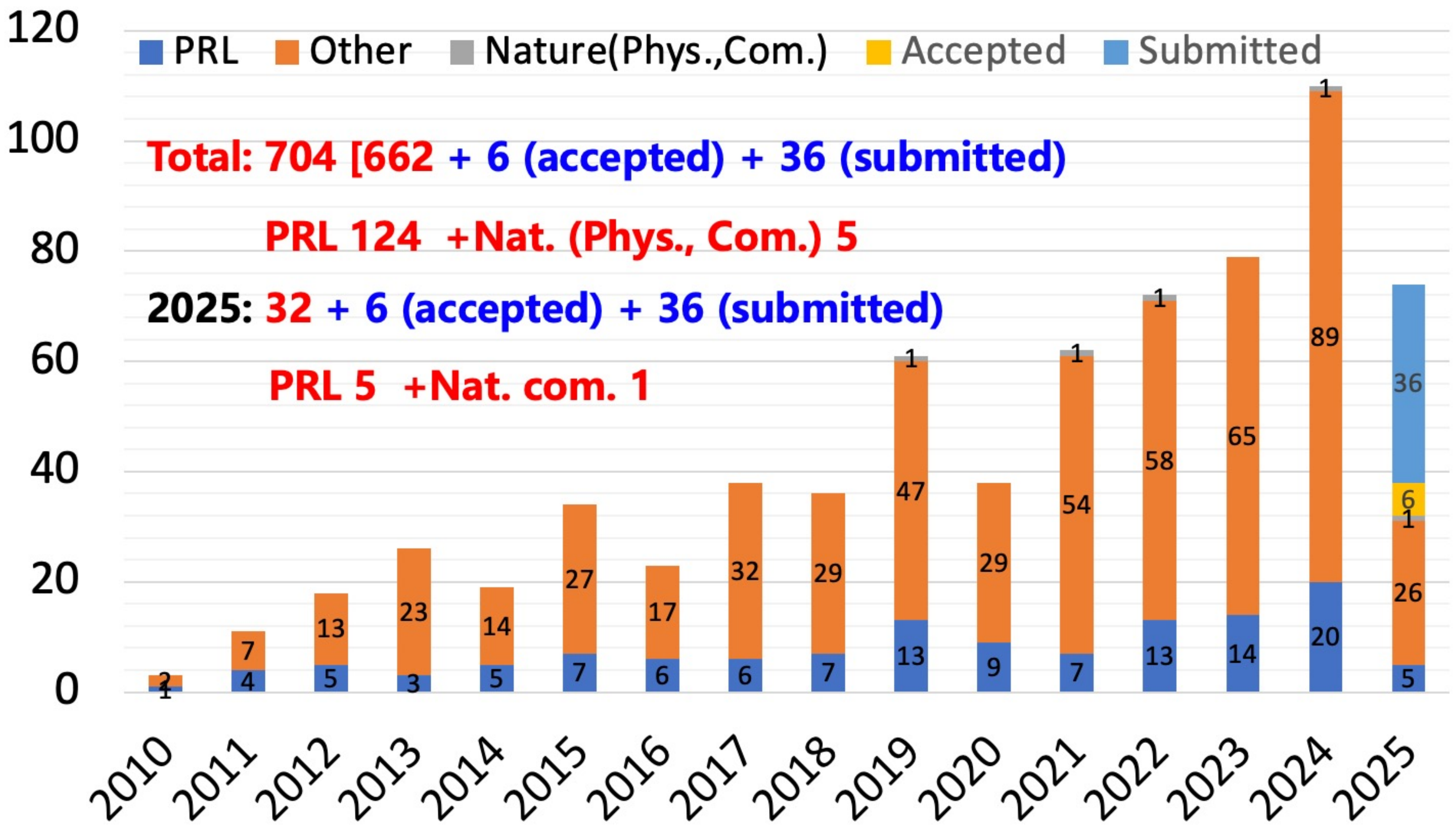
- Very good energy resolution for photon
- Excellent momentum resolution for charged particles
- Good hadron identification capabilities

World largest data sample directly collected in the τ-charm region



BESIII: ~50 fb^{-1} from 1.84 – 4.95 GeV

Publications (till May 2025)



Physics accomplishments

- τ mass measurement
- R value measurement
- Light exotics
- Charmonium-like states
- Charm physics
- New physics searches

τ mass measurement

τ mass measurement

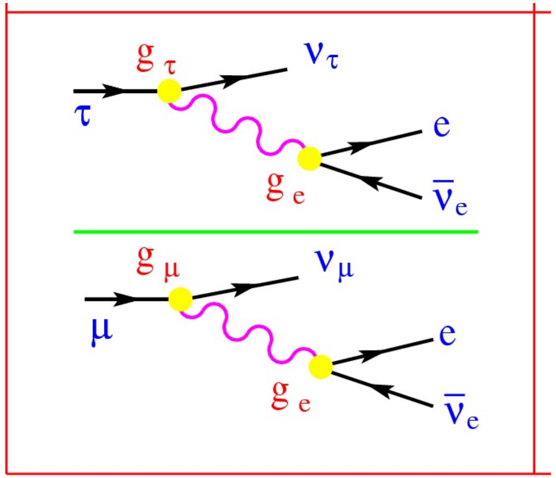
- Lepton Universality relation

$$\frac{g_\tau^2}{g_\mu^2} = \frac{m_\mu^5}{m_\tau^5} \frac{B(\tau \to e\bar{\nu}_e\nu_\tau)}{B(\mu \to e\bar{\nu}_e\nu_\mu)} \frac{\tau_\mu}{\tau_\tau}$$

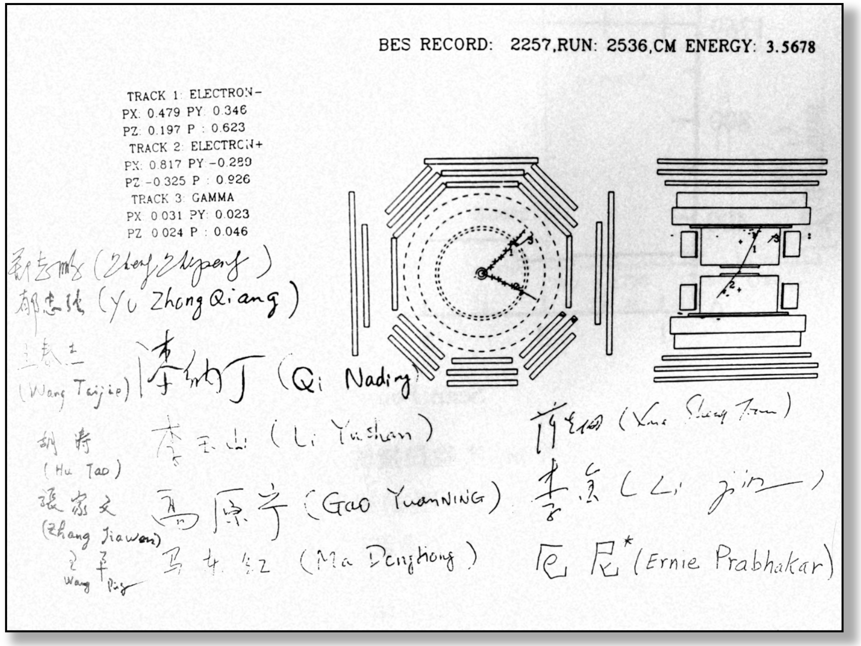
- PDG1992:

$$\frac{g_\tau}{g_\mu} = 0.941 \pm 0.025$$

- More likely **τ mass** come down in case of lepton universality ?

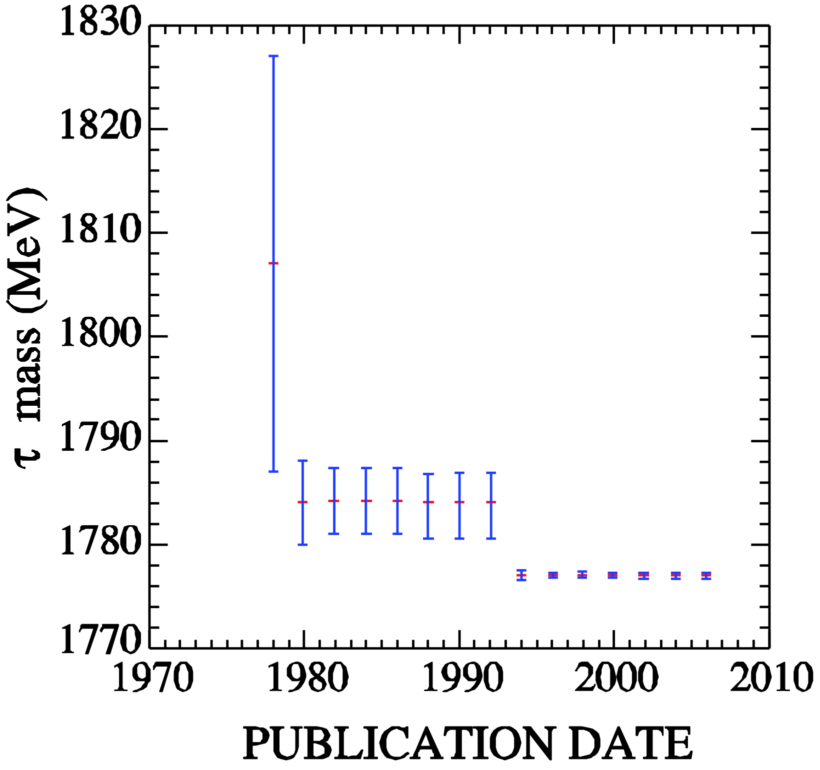


First τ events



- Measure the τ **pair** production threshold by energy scan
- J/ψ and ψ(2S) allow to calibrate and monitor detector performance

τ mass: BES

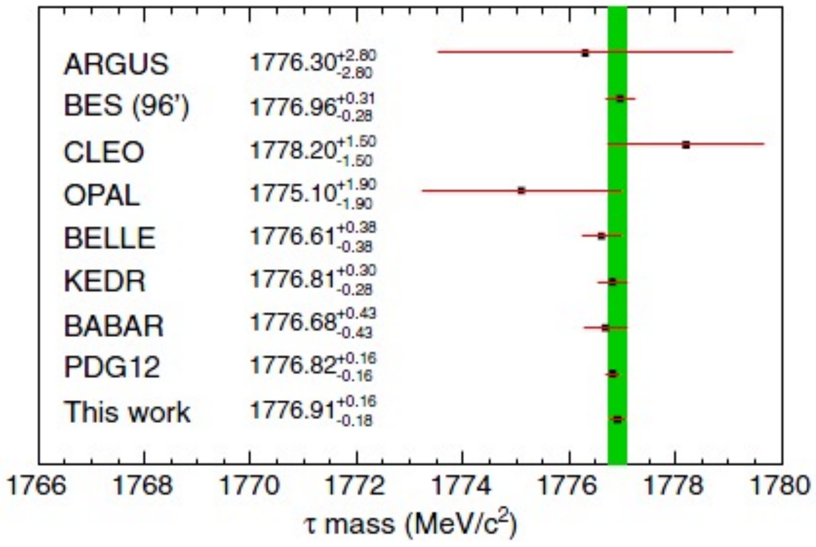


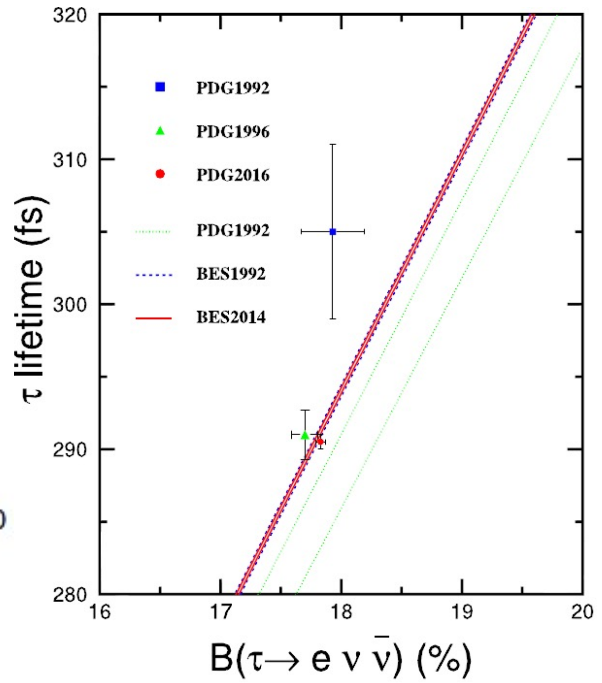
$$m_\tau = 1776.96^{+0.18+0.25}_{-0.21-0.17}\ MeV$$

$$\frac{g_\tau}{g_\mu} = 0.9886 \pm 0.0085$$

PRL69,3021(1992)

τ mass: BESIII





PRD90,012001(2014)

$$m_\tau = 1776.91 \pm 0.12^{+0.10}_{-0.13}\ MeV$$

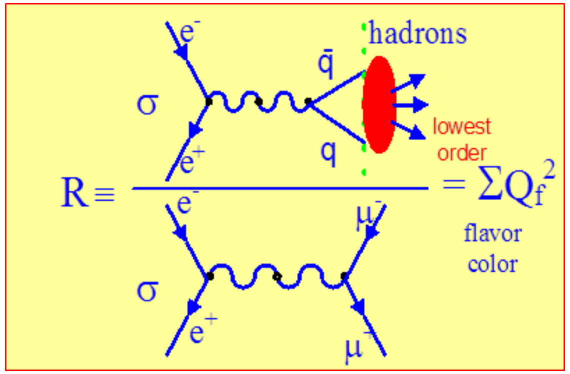
$$\frac{g_\tau}{g_\mu} = 1.0016 \pm 0.0042$$

Lepton universality !

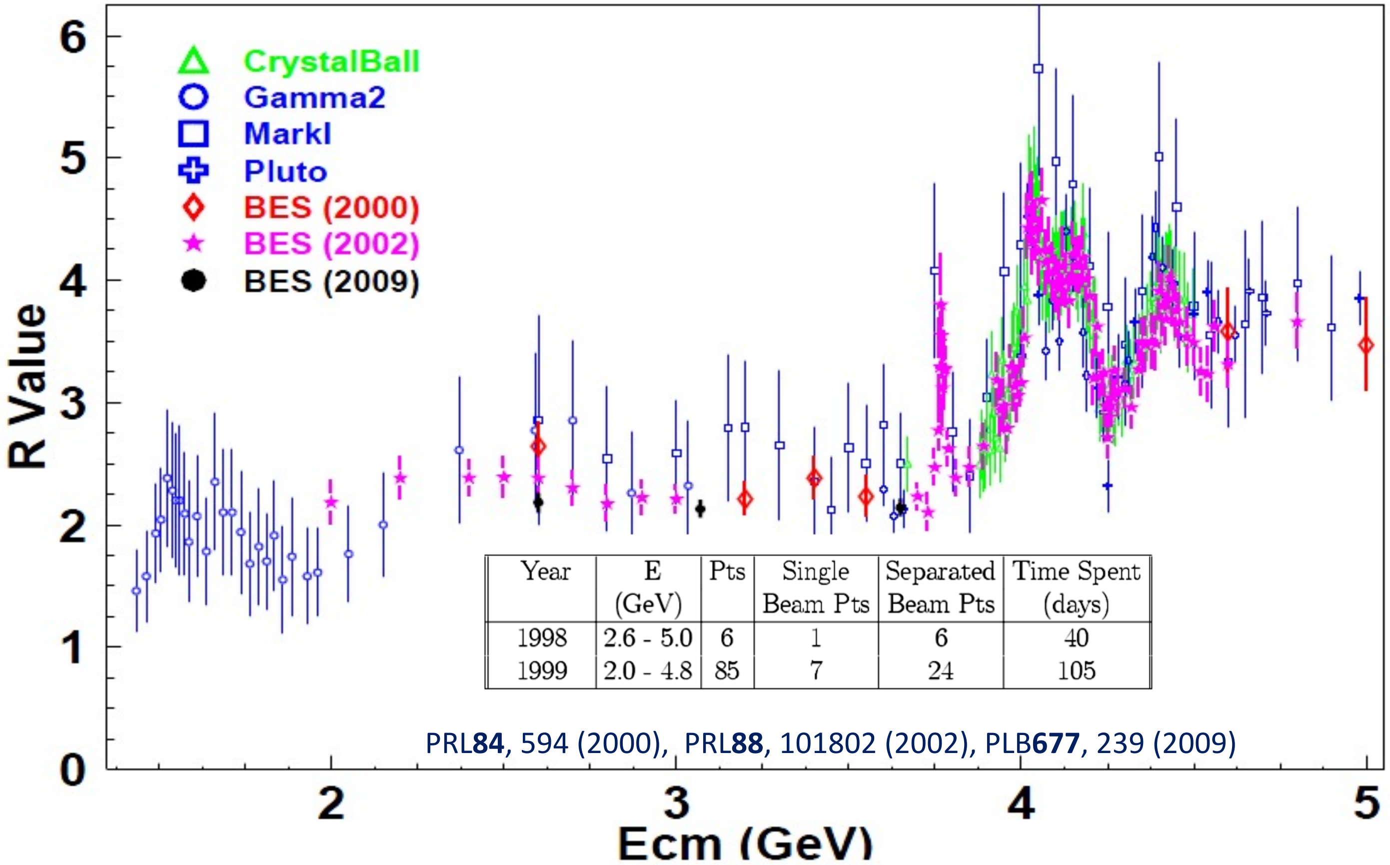
R value measurement

R value measurement at BESII

$$R(s) = \frac{\sigma_{tot}(e^+e^- \to hadrons)}{\sigma_{tot}(e^+e^- \to \mu^+\mu^-)} = 3\sum_q Q_q^2$$



- R provides strong evidence for the quark model and 3 colors
- Mass of Higgs particle ?



Year	E (GeV)	Pts	Single Beam Pts	Separated Beam Pts	Time Spent (days)
1998	2.6 - 5.0	6	1	6	40
1999	2.0 - 4.8	85	7	24	105

PRL**84**, 594 (2000), PRL**88**, 101802 (2002), PLB**677**, 239 (2009)

1995 before BES R data

$$\alpha(M_Z^2)^{-1} = 128.890 \pm 0.090$$

$$m_H = 62^{+53}_{-30}\,GeV,\; m_H < 170\;GeV$$

2001 with BES R data

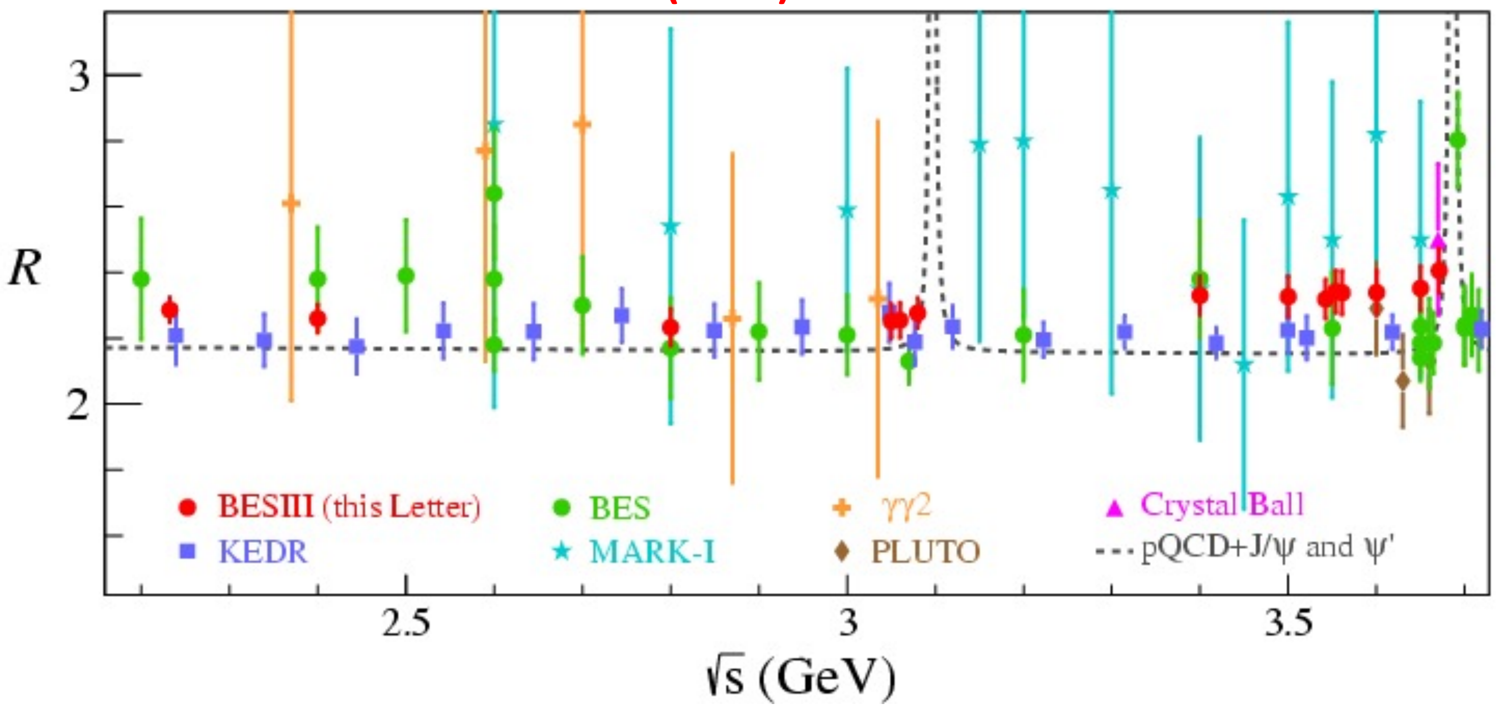
$$\alpha(M_Z^2)^{-1} = 128.936 \pm 0.046$$

$$m_H = 98^{+58}_{-38}\,GeV,\; m_H < 212\;GeV$$

R value measurement at BESIII

PRL128(2022)062004

- R values :2.23-3.67 GeV
- Precision is better than 3%
- Constraints on (g-2)μ



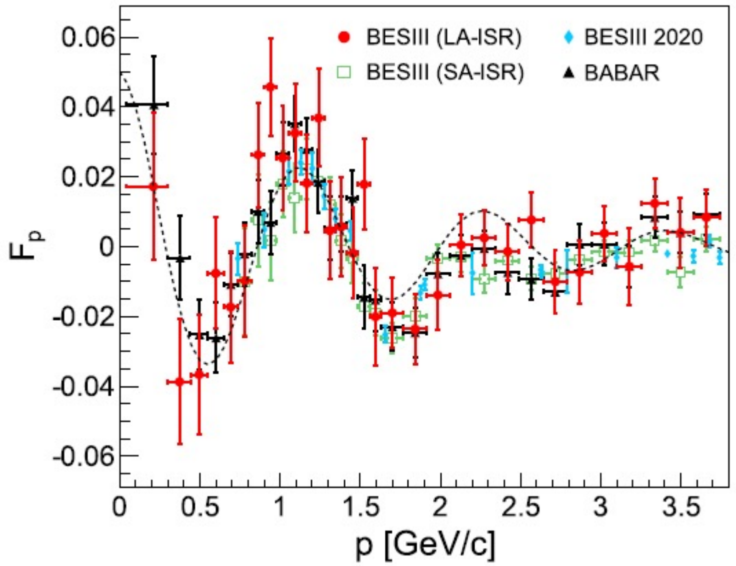
R scan above open-charm threshold
3.85-4.59 GeV 104 pts ~0.8 $\mathbf{fb}^{-1}$

- Full energy region in progress
- Exclusive hadron cross section
- Form factors of baryons and light mesons

Electromagnetic form factors of baryons

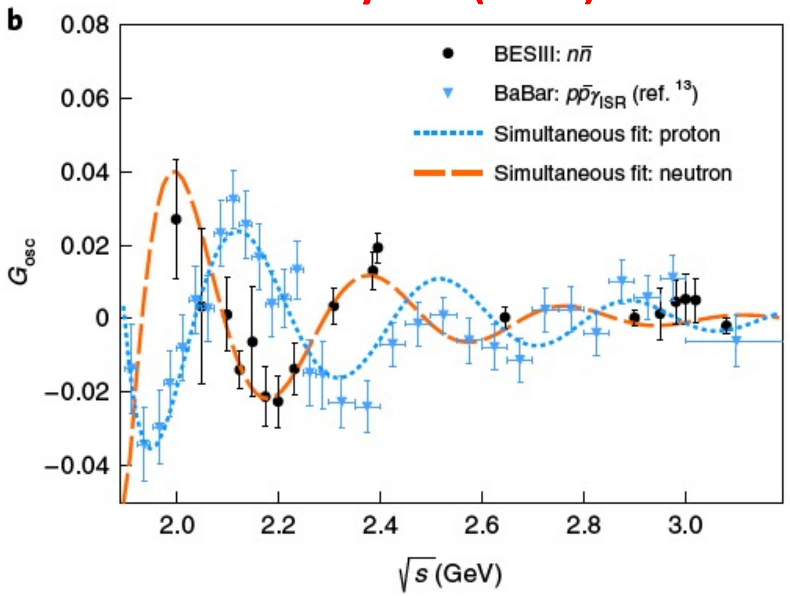
$e^+e^- \to p\bar{p}$

PLB817(2021)136328



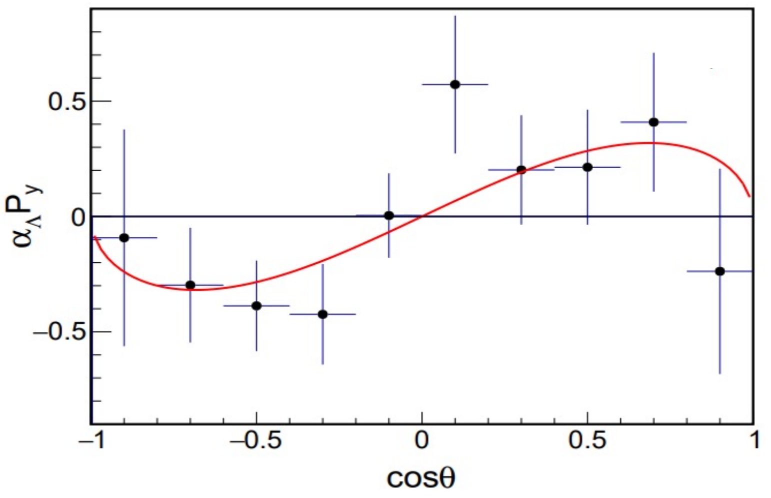
$e^+e^- \to n\bar{n}$

Nat. Phys. 17(2021)1200



$e^+e^- \to \Lambda\bar{\Lambda}$ with data@2.396 GeV

PRL123(2019)122003



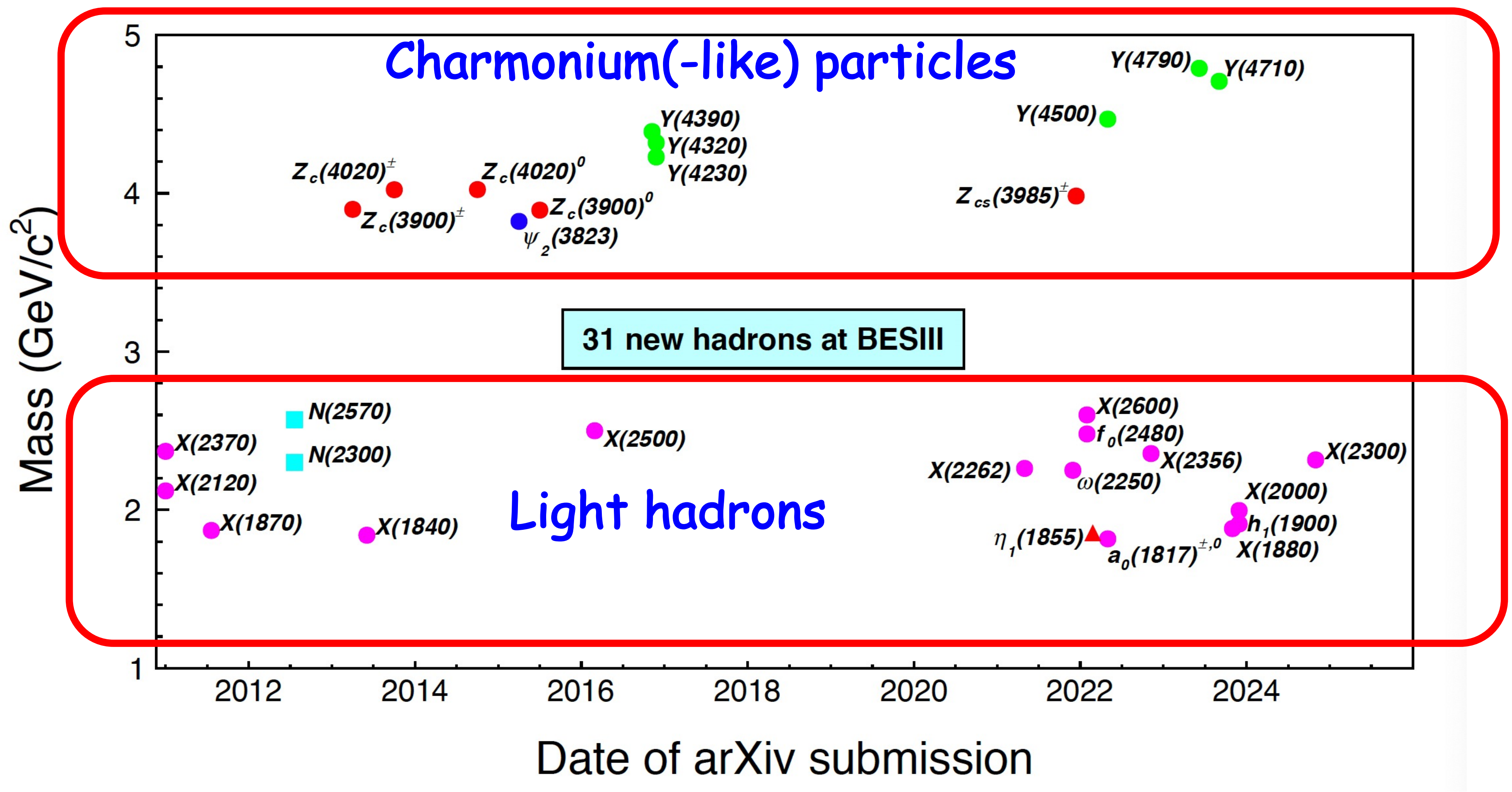
$$\left|\frac{G_E}{G_M}\right| = 0.96 \pm 0.14(\text{stat.}) \pm 0.02(\text{sys.})$$

$$\Delta\Phi = 37^\circ \pm 12^\circ(\text{stat.}) \pm 6^\circ(\text{sys.})$$

- In the time-like region, the electromagnetic form factors of baryons characterize the internal structure of baryons
- Periodic behavior of $|G_p|$ was first observed at BaBar and **was later confirmed at BESIII**
- **Oscillation of $|G_n|$ is observed at BESIII for the first time**

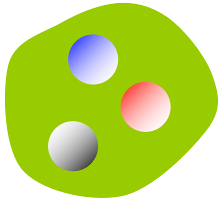
Confirm the complex form of electromagnetic form factors

New resonant structures at BESIII

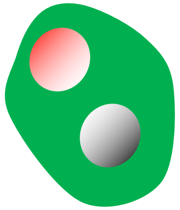


Conventional & Exotic hadrons

- Quark Model

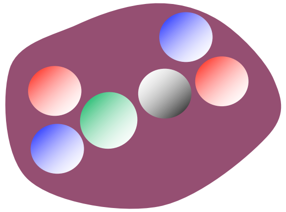


baryon

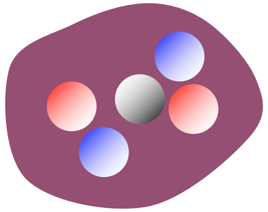


meson

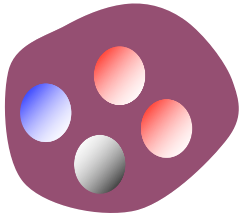
- QCD allows for hadrons beyond Quark Model



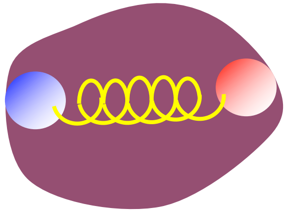
dibaryon



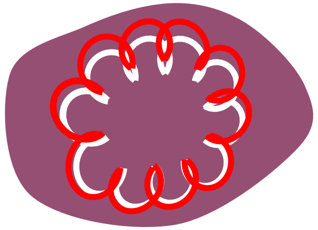
Pentaquark



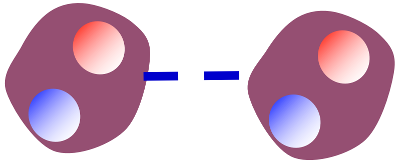
tetraquark



hybrid



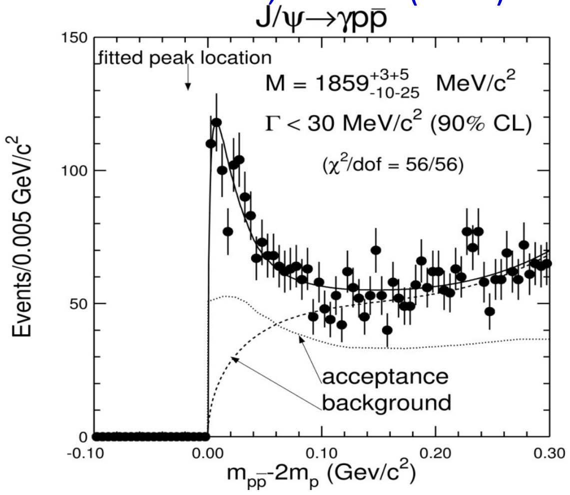
glueball

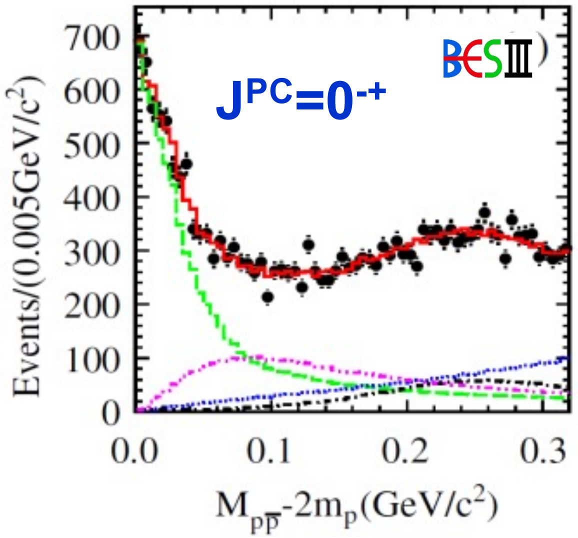


molecule

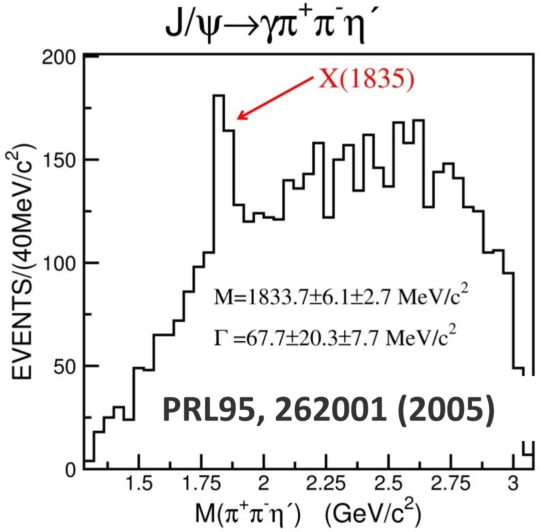
Observation of X(18??) at BESII-BESIII

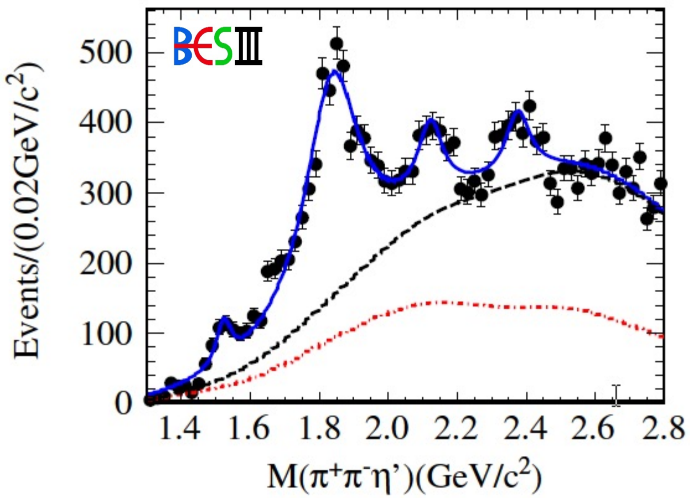
PRL91, 022001 (2003)

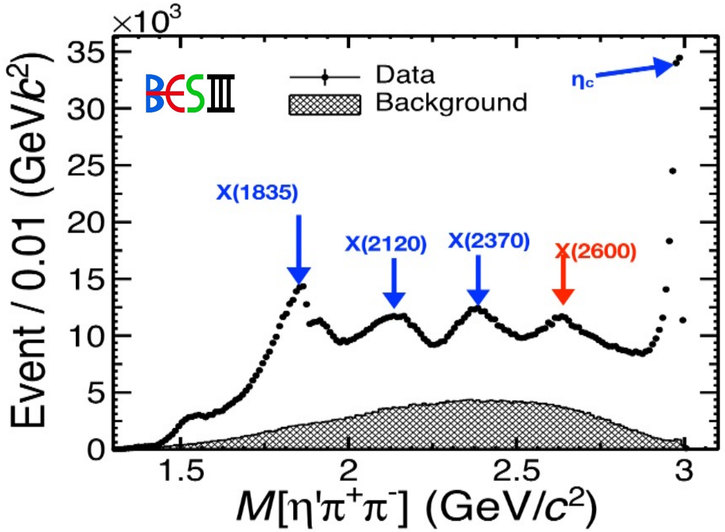




Are they the same state? Nature is still mysterious. It is crucial to understand their connections

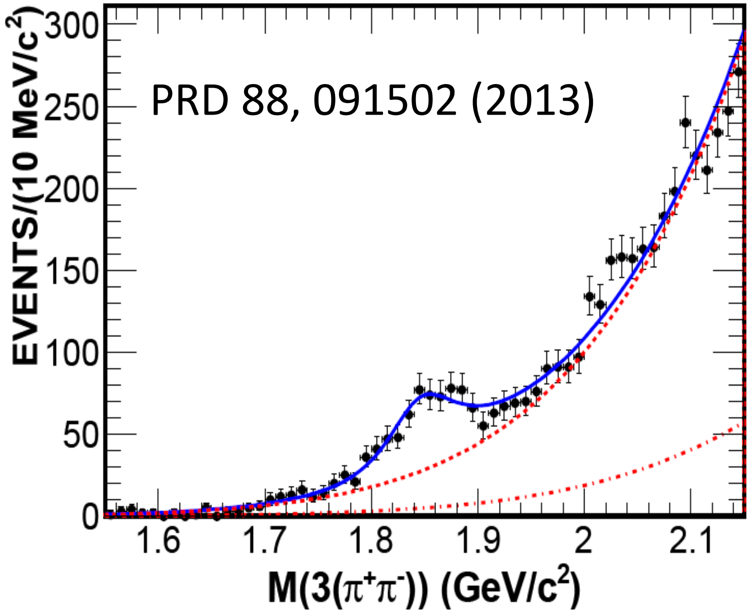




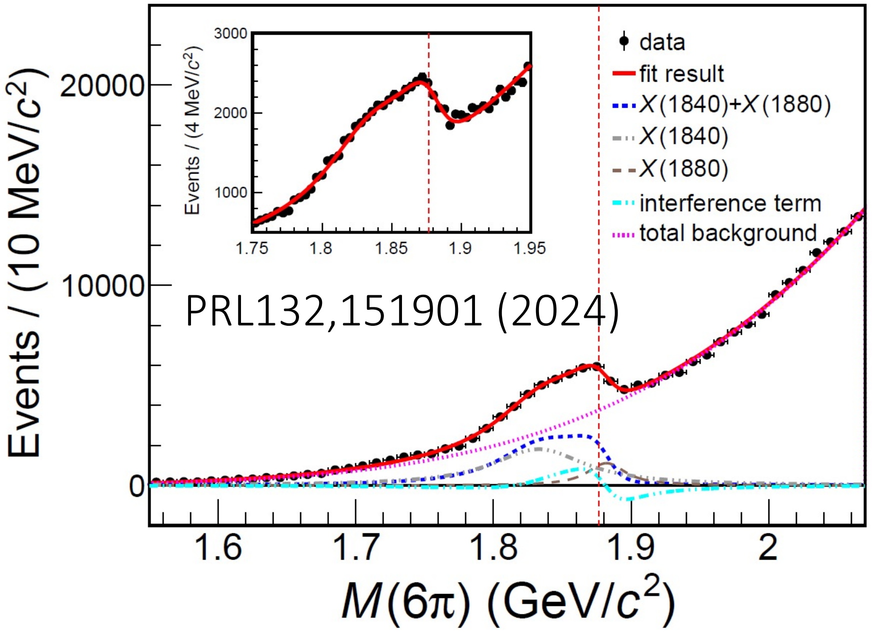


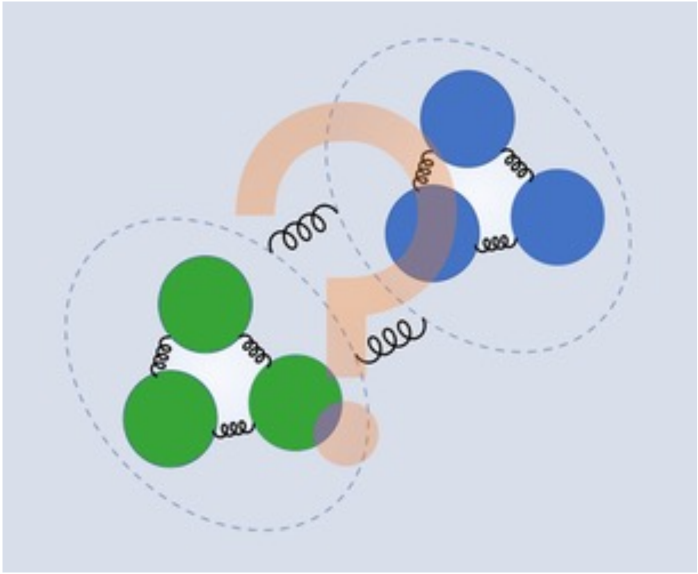
Observation of the anomalous structure around 1.84 GeV

J/ψ→γ 3(π⁺π⁻)



J/ψ→γ 3(π⁺π⁻)





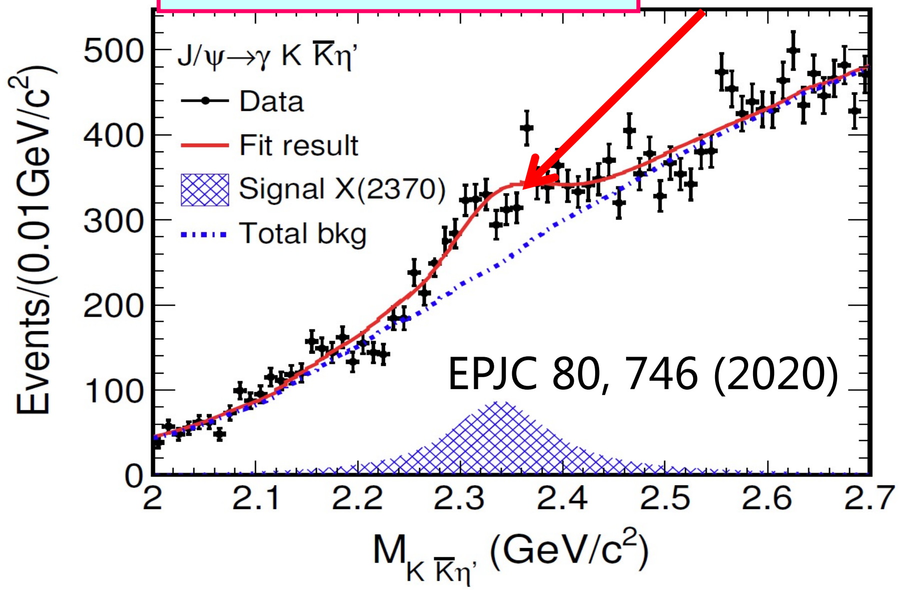
Resonance	M(MeV/c²)	Γ(MeV/c²)
X(1880)	1882.1±1.7±0.7	30.7±5.5±2.4
X(1830)	1832.5±3.1±2.5	80.7±5.2±7.7

Featured in Physics:
"Evidence of a new subatomic particle"

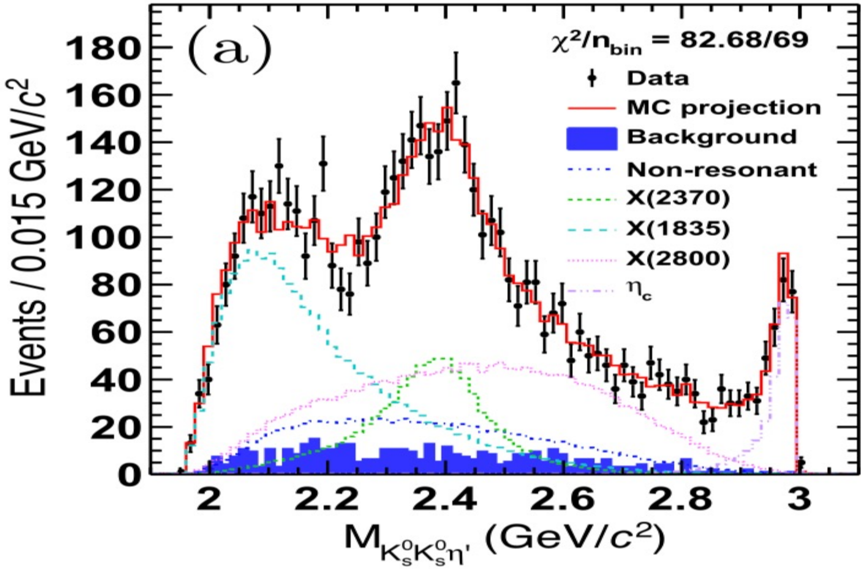
Narrow state around NN-bar threshold !

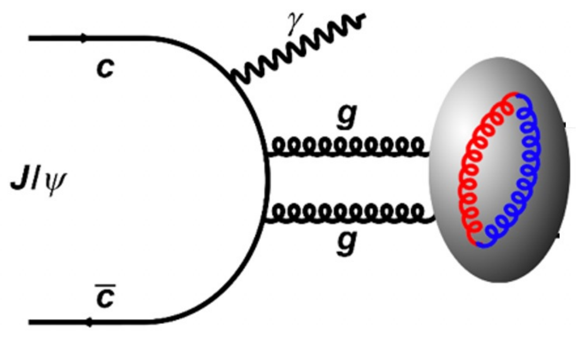
Pseudoscalars above 2 GeV: X(2370)

new glueball candidates ?



Rept.Prog.Phys. 86 (2023) 2, 026201





BESIII实验发现胶球存在的迹象

Physics \ General Physics   Editors' notes

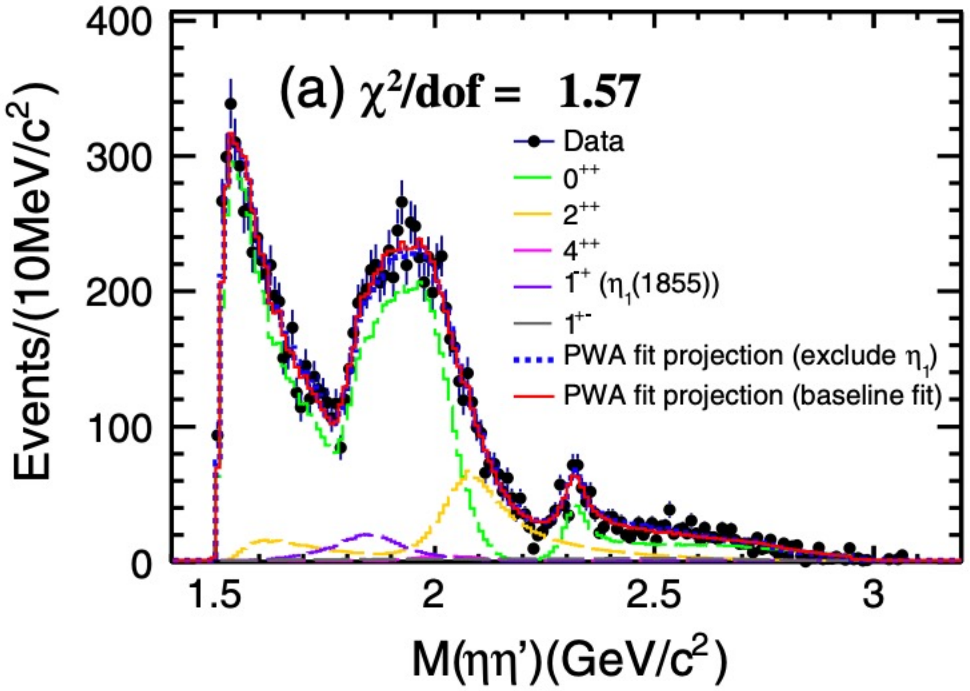
Physics \ Quantum Physics

Possible evidence of glueballs found during Beijing Spectrometer III experiments

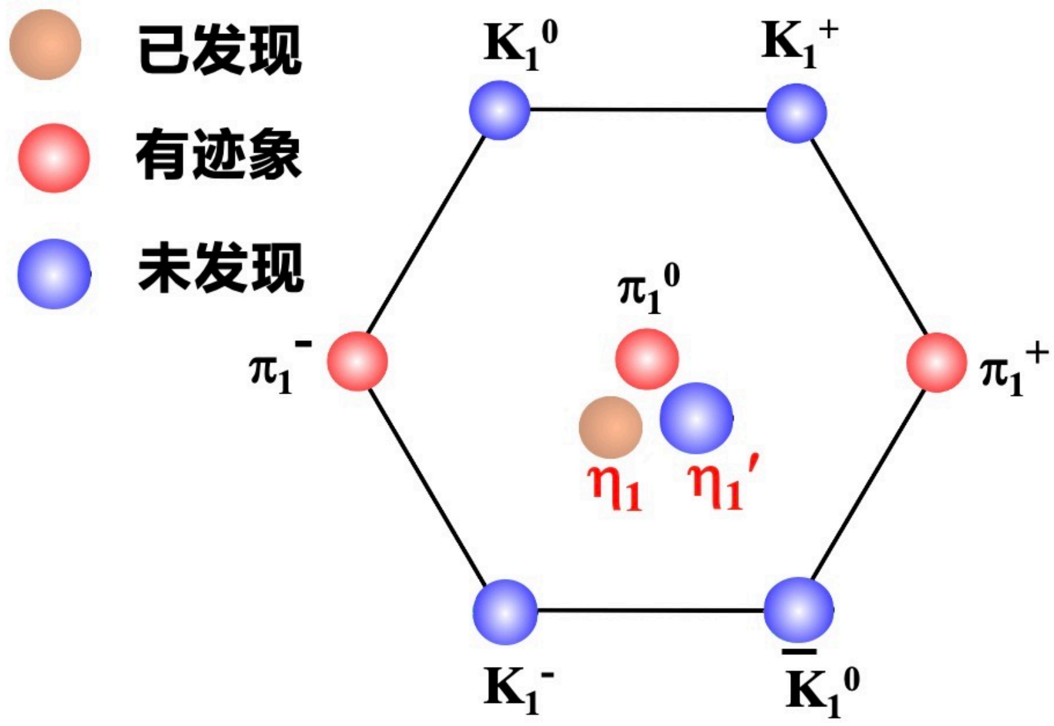
by Bob Yirka , Phys.org

REPORT

Observation of $\eta_1(1855)$ in $J/\psi \to \gamma\eta\eta'$



PRL129, 192002(2022)



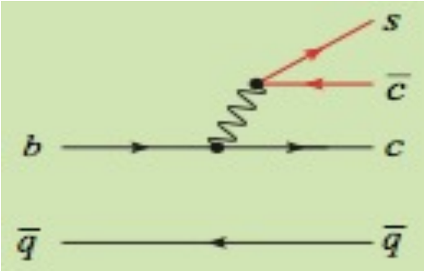
Isoscalar state with J^{PC}=1^{-+}

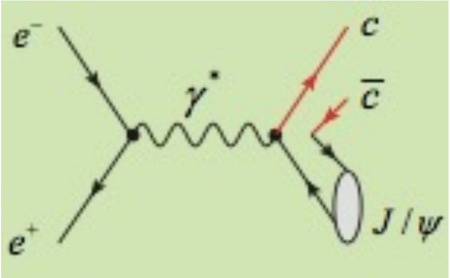
$$M = 1855 \pm 9^{+6}_{-1} \text{ MeV/c}^2$$
$$\Gamma = 188 \pm 18^{+3}_{-8} \text{ MeV}$$

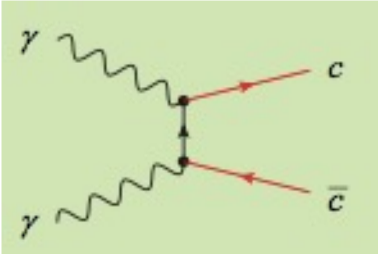
Critical to establish the 1^{-+} hybrid nonet !

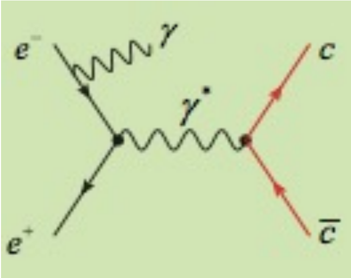
Multi-quark states

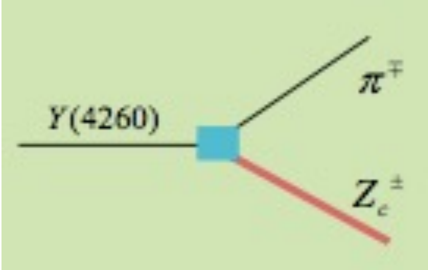
Hints of a new heavy flavor spectrum

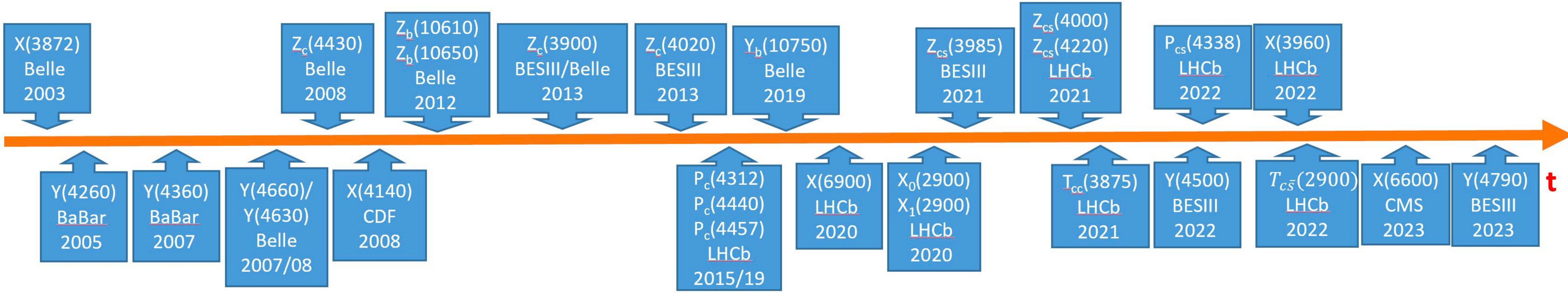








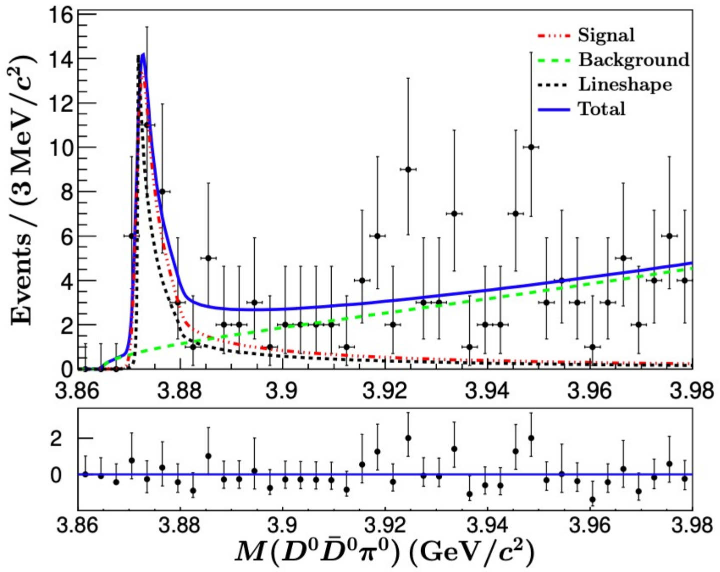


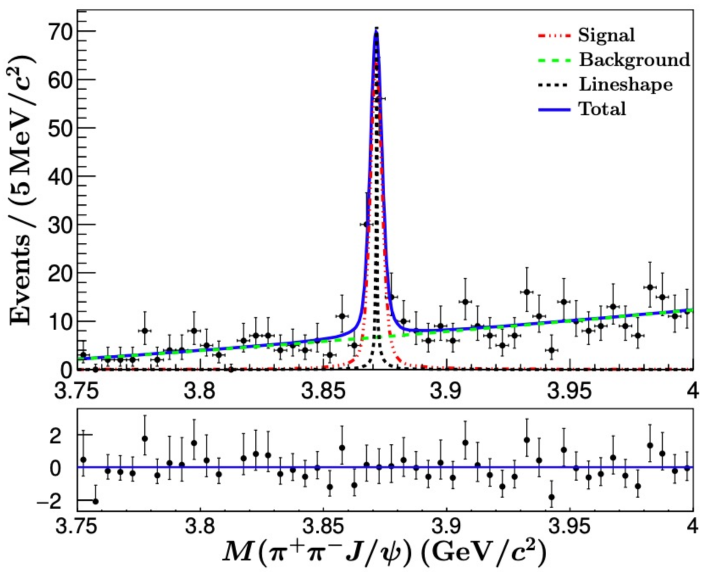


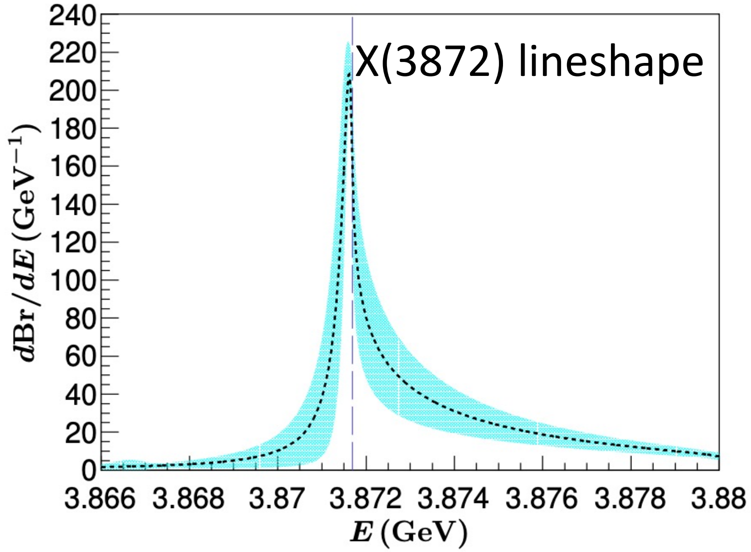
Candidates of hadronic molecules, hybrids, and multiquark states !

From C.Z. Yuan

Couple channel analysis of X(3872) line shape







PRL132, 151903(2024)

Parameters	g	Γ_0 (MeV)	M_X (MeV)
Fit results	0.16 ± 0.10	2.67 ± 1.77	3871.63 ± 0.13

$$\frac{\Gamma(X(3872)\to\pi^+\pi^- J/\psi)}{\Gamma(X(3872)\to D^0\bar{D}^{*0})} = 0.05 \pm 0.01^{+0.01}_{-0.02}$$

LHCb: 0.11$\pm$0.03

Hanhart, Kalashnikova, Nefediev, PRD 81, 094028 (2010)

A. Esposito et al., Phys. Rev. D 105, L031503 (2022).

Field renormalization constant : Z=1: pure elementary state;

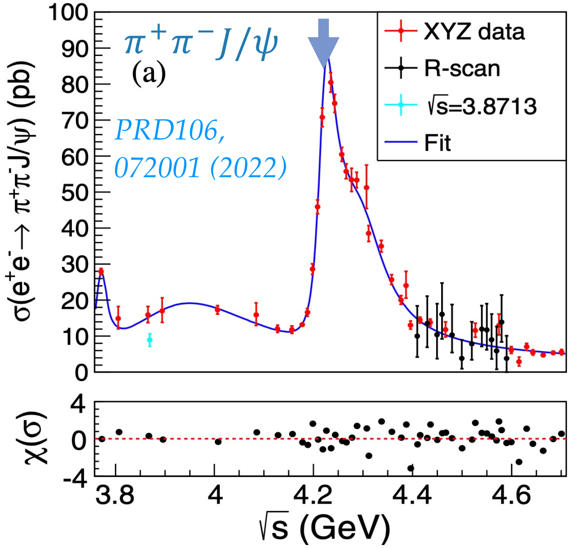
Z=0: pure bound (composite) state.

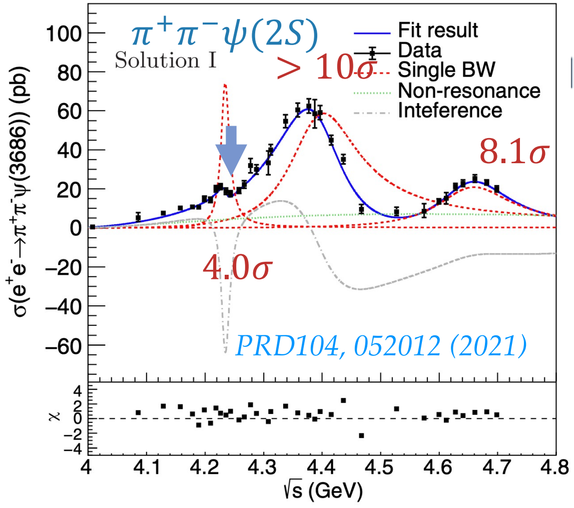
$$Z = 0.18$$

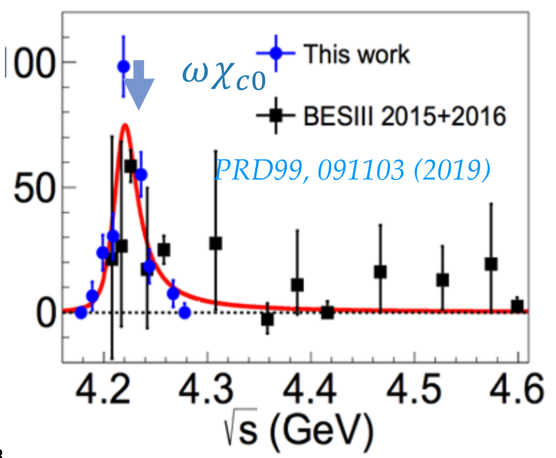
LHCb: Z=0.15

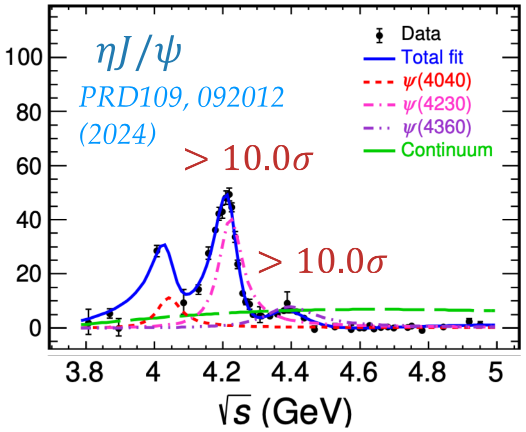
Y(4260)⇒Y(4230)

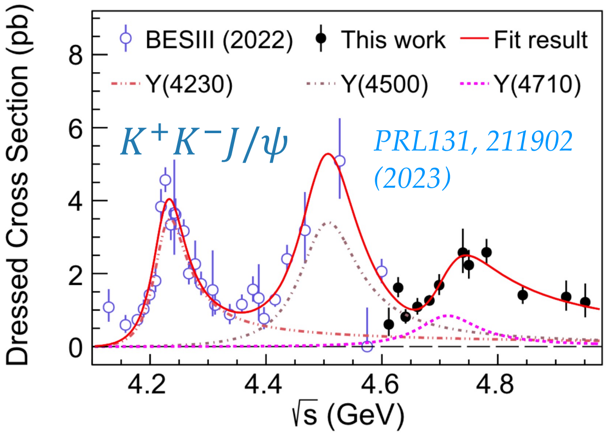
- Seen in more than 10 decay modes, including open charm final states

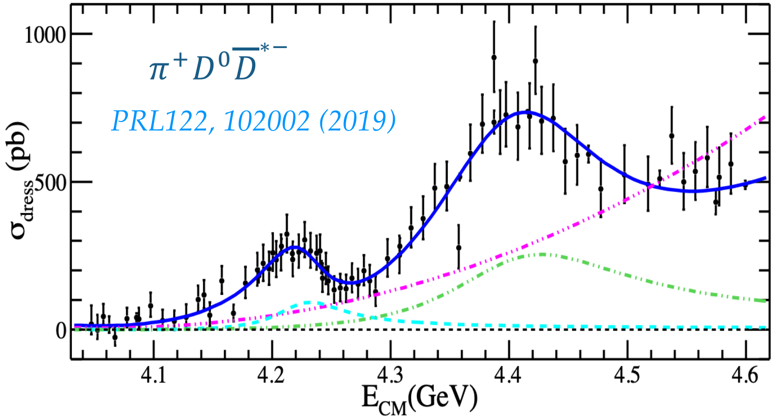


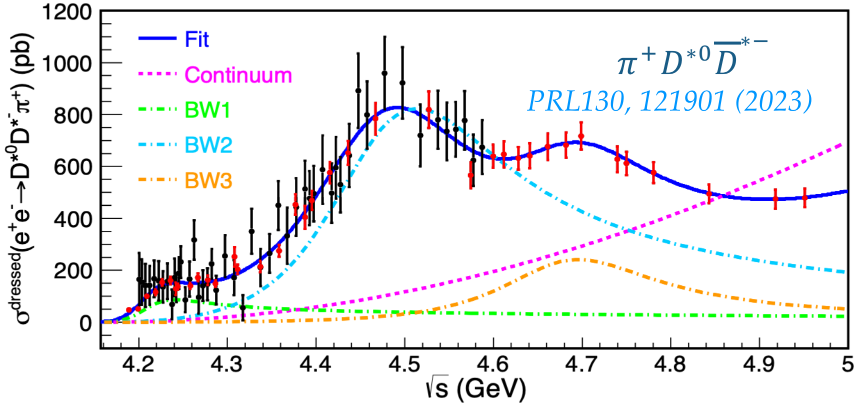






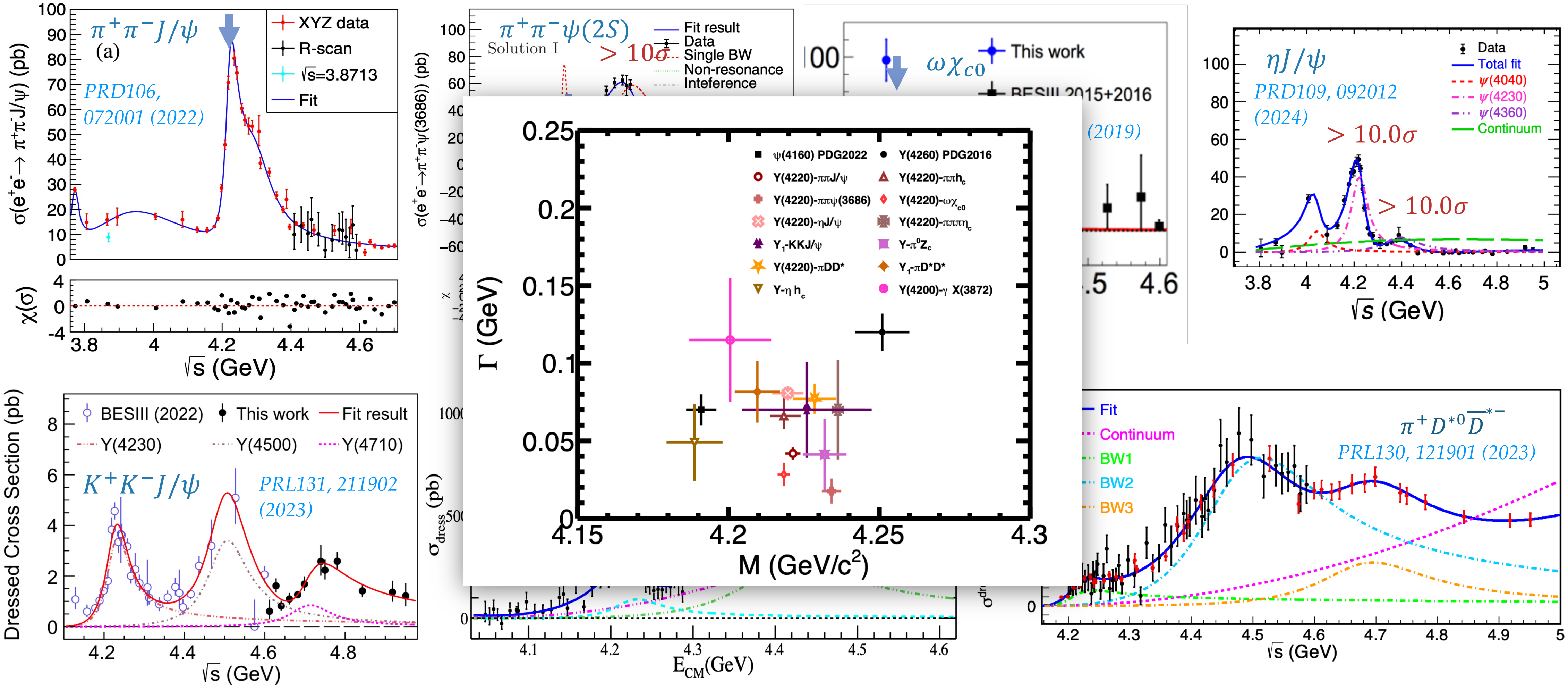






Y(4260)⇒Y(4230)

- Seen in more than 10 decay modes, including open charm final states

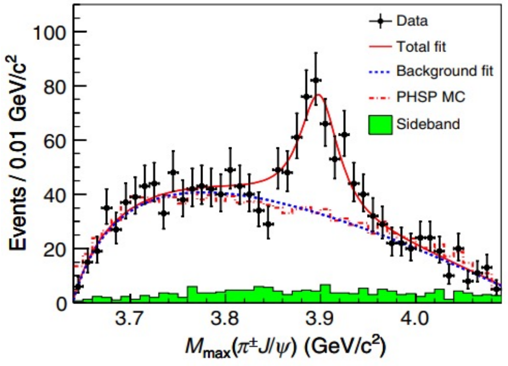


Z_c states $e^+e^- \to \pi^+\pi^- + c\bar{c}$

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

$Z_c(3900)^+$

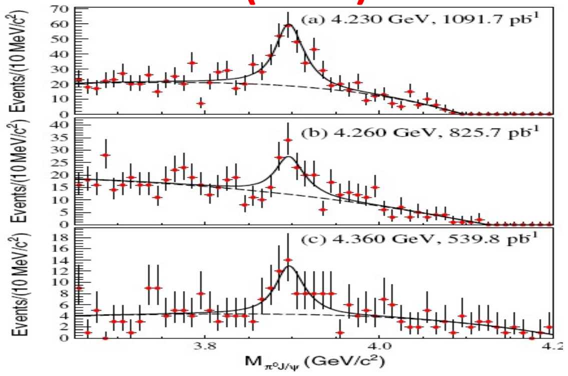
PRL110(2013)252001



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

$Z_c(3900)^0$

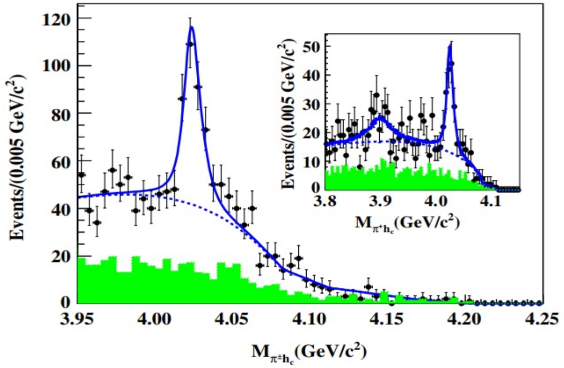
PRL115(2015)112003



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

$Z_c(4020)^+$

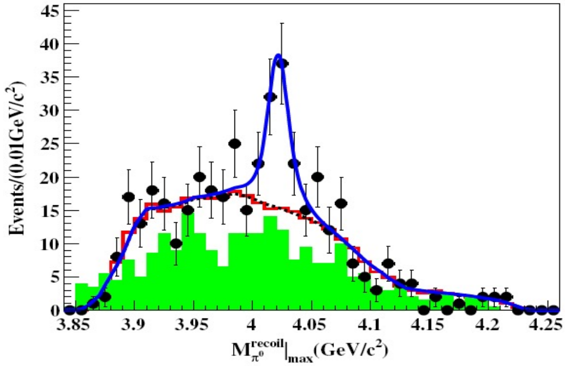
PRL111(2013)242001



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

$Z_c(4020)^0$

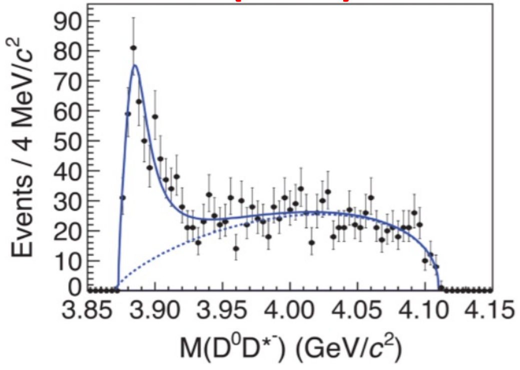
PRL113(2014)212002



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

$Z_c(3885)^+$

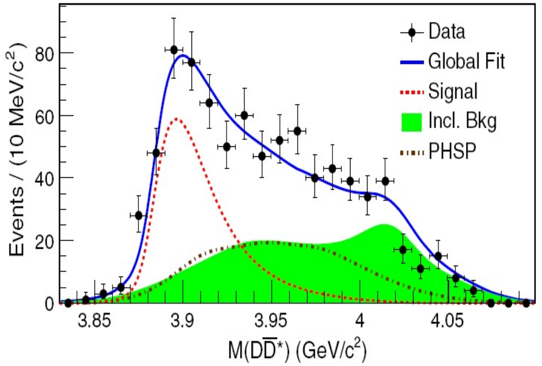
PRL112(2014)022001



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

$Z_c(3885)^0$

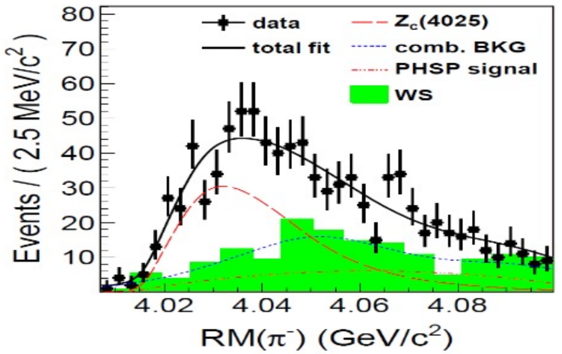
PRL115(2015)222002



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

$Z_c(4025)^+$

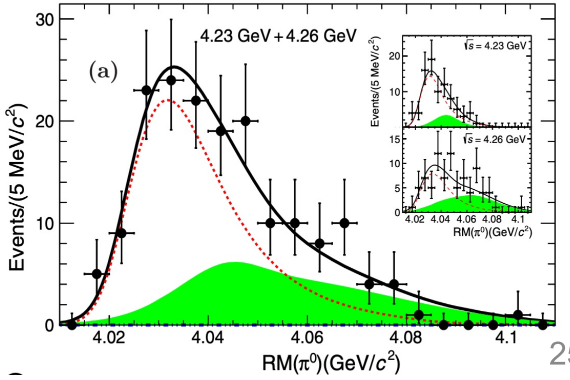
PRL112(2014)132001



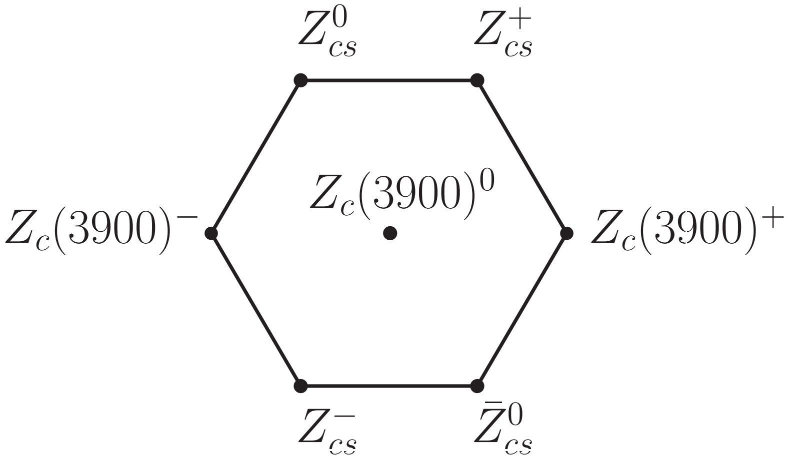
$e^+e^- \to \pi^0(D^*\bar{D}^*)^0$

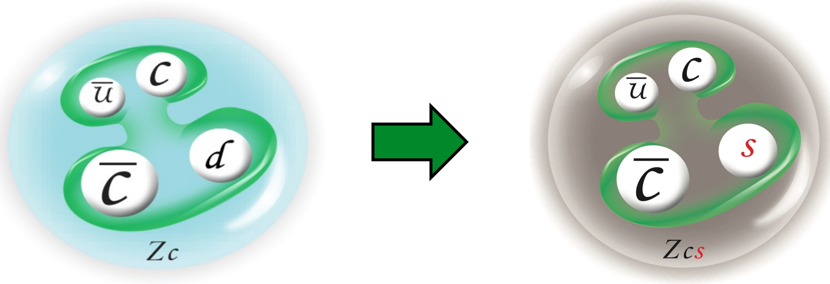
$Z_c(4025)^0$

PRL115(2015)182002

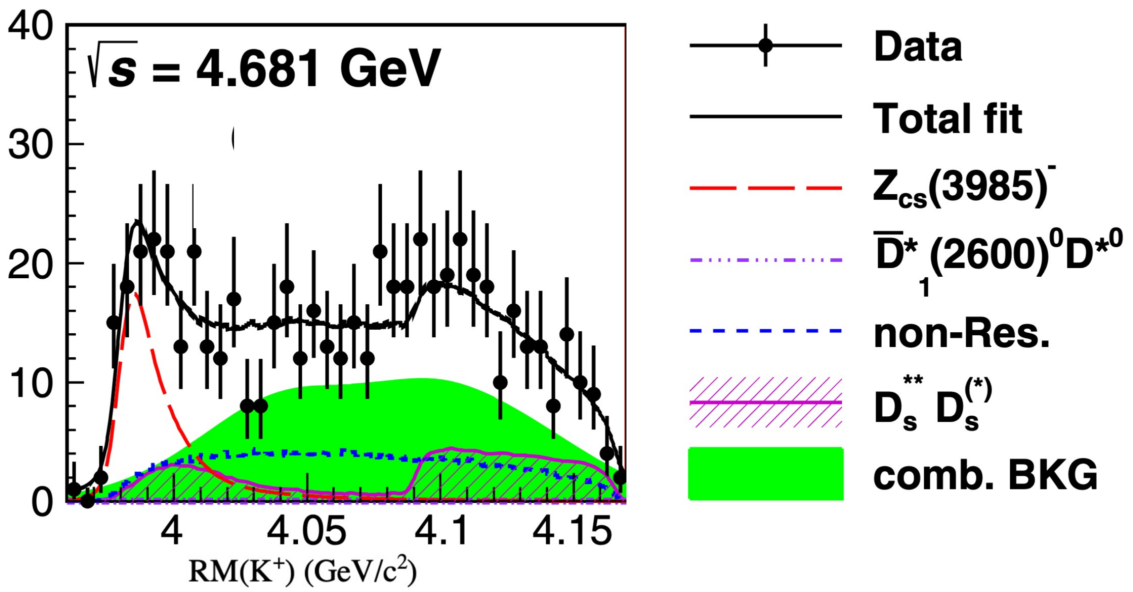


Observation of $Z_{cs}(3985)$: SU(3) partner of Z_c



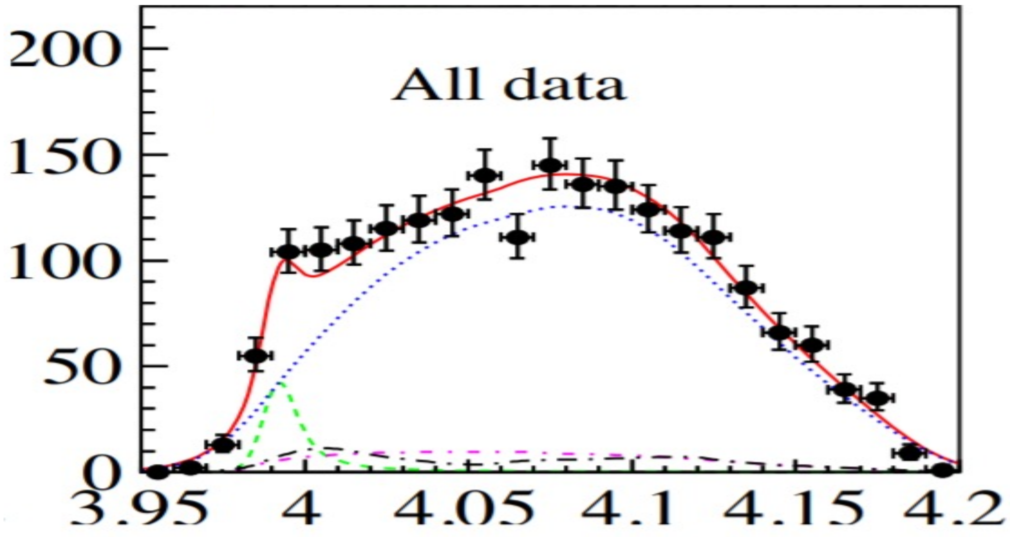


$e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$



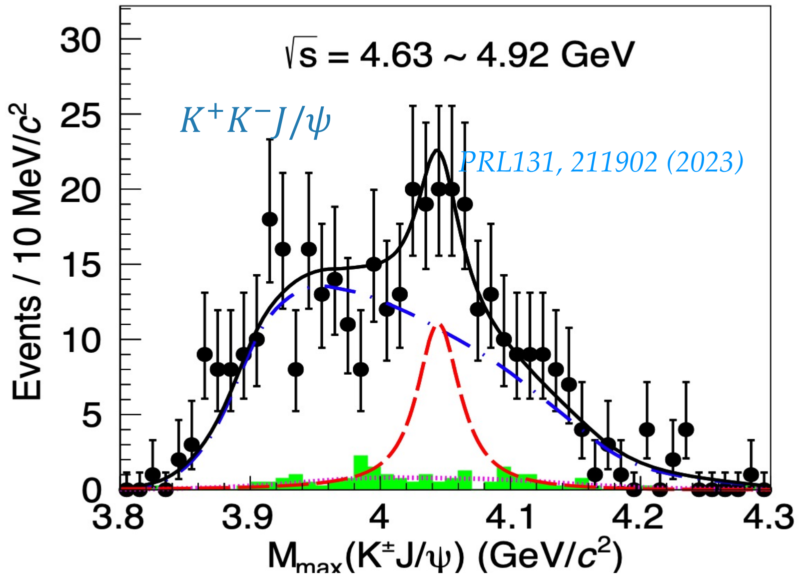
PRL126(2021)102001

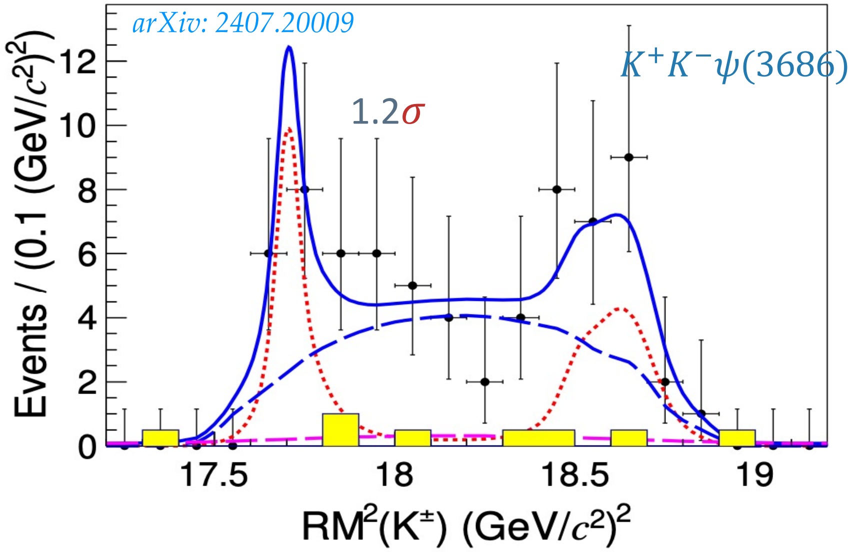
$e^+e^- \to K_S^0(D_s^+ D^{*-} + D_s^{*+} D^-)$



PRL129(2022)112003

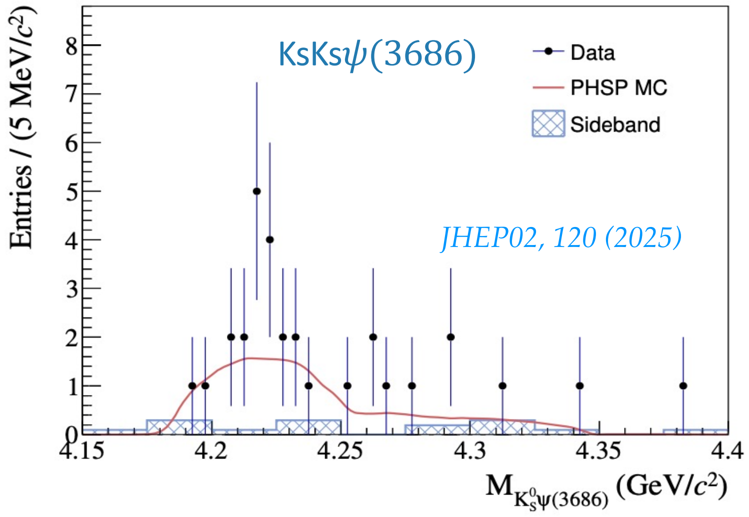
Z_{cs} in $e^+e^- \rightarrow K\overline{K} + c\overline{c}$

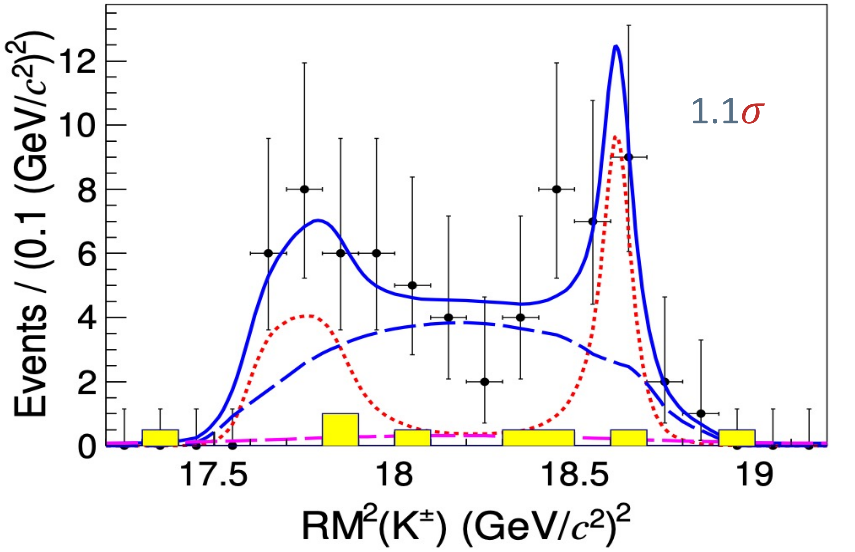




M= 4208.4 ± 3.1 MeV/c^2

$\Gamma = 6.1 \pm 5.7$ MeV





M= 4316.0 ± 2.7 MeV/c^2

$\Gamma = 9.0 \pm 8.6$ MeV

High statistics needed !

Charm physics

CKM Matrix

- CKM matrix elements are fundamental parameters of the Standard Model (SM):

$$V_{\mathrm{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

Charm decays + LQCD
Expected precision < 1% at BESIII

B decays + LQCD

- Any deviation of V_{CKM} from unitarity indicates new physics

→ Measurements of CKM matrix elements [from PDG2024]

$|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2=0.9984 \pm 0.0009$ =1(SM)

$|V_{cd}|^2+|V_{cs}|^2+|V_{cb}|^2 = 1.001 \pm 0.007$ =1(SM)

Precision: 0.7%

Precision: (0.6-1.8)%

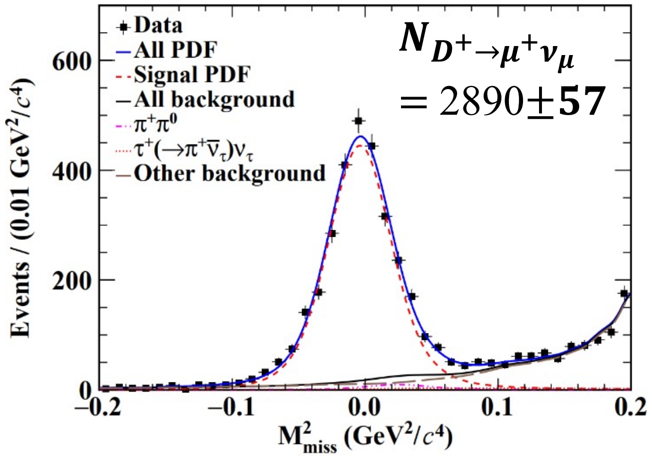
$|V_{cd}| = 0.221 \pm 0.004$

$|V_{cs}| = 0.975 \pm 0.006$

$|V_{cb}| = 0.0410 \pm 0.0012$

- $\boldsymbol{D/D_s}$ (Semi-)leptonic decays provide direct measurements of $|V_{cs}|$ and $|V_{cd}|$

$|V_{cd}|$ from $D^+ \to \mu^+\nu_\mu$ and $D^+ \to \tau^+\nu_\tau$ via $\tau^+ \to \pi^+\bar{\nu}_\tau$



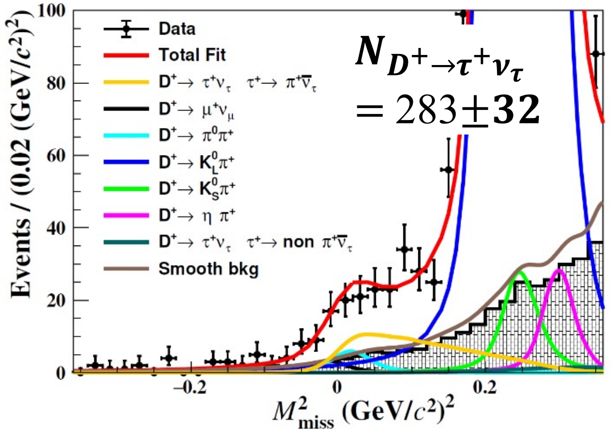
20.3 fb^{-1}@ 3.773 GeV
arXiv:2410:07626

$$\mathcal{B}_{D^+\to\mu^+\nu_\mu} = (3.98 \pm 0.08_{\rm stat.} \pm 0.04_{\rm syst.}) \times 10^{-4}$$

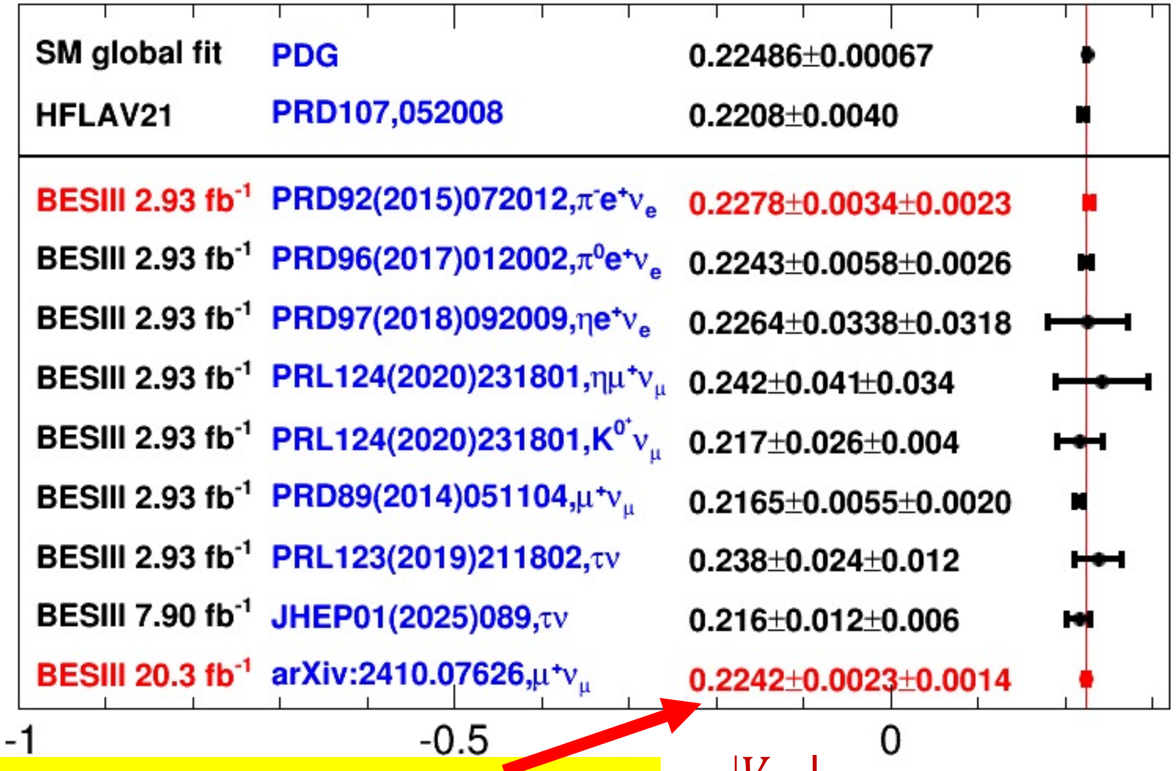
$$f_{D^+}|V_{cd}| = (47.53 \pm 0.48_{\rm stat} \pm 0.24_{\rm syst} \pm 0.12_{\rm input})\ \mathrm{MeV}$$

$$f_{D^+} = (211.5 \pm 2.1_{\rm stat} \pm 1.1_{\rm syst} \pm 0.8_{\rm input})\ \mathrm{MeV}$$

$$|V_{cd}| = 0.2242 \pm 0.0023_{\rm stat} \pm 0.0011_{\rm syst} \pm 0.0009_{\rm input}$$



7.9 fb^{-1}@ 3.773 GeV
JHEP01(2025)089



$|V_{cd}|$

$$\mathcal{B}_{D^+\to\tau^+\nu_\tau} = (9.9 \pm 1.1_{\rm stat.} \pm 0.5_{\rm syst.}) \times 10^{-4}$$

$$f_{D^+}|V_{cd}| = (45.9 \pm 2.5_{\rm stat} \pm 1.2_{\rm syst} \pm 0.1_{\rm input})\ \mathrm{MeV}$$

$$|V_{cd}| = (0.216 \pm 0.012_{\rm stat} \pm 0.006_{\rm syst} \pm 0.001_{\rm input})$$

LFU test: $\mathcal{R}_{\tau/\mu} = \dfrac{\mathcal{B}_{D^+\to\tau^+\nu_\tau}}{\mathcal{B}_{D^+\to\mu^+\nu_\mu}} = 2.49 \pm 0.31$

SM=2.67

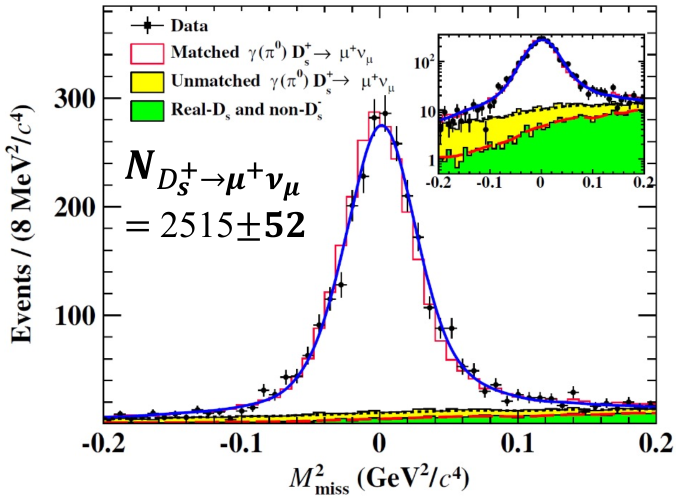
Highest precision of $|V_{cd}|$ to date: ~1.2%

$|V_{cs}|$ from $D_s^+ \to \mu^+\nu_\mu$ and $D_s^+ \to \tau^+\nu_\tau$

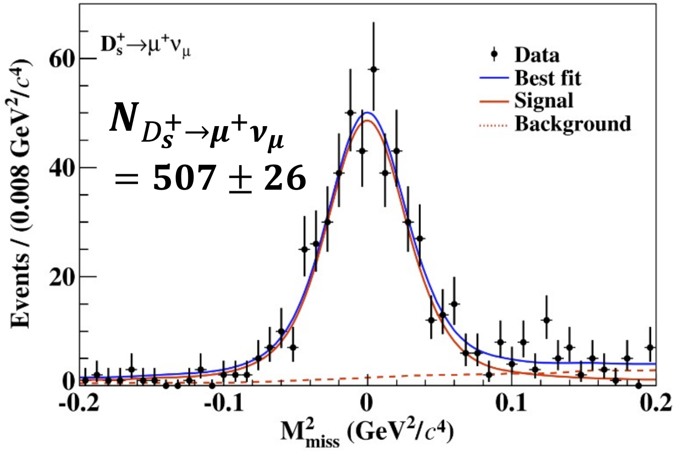
7.33 fb^{-1}@ 4.128-4.226 GeV
PRD 108, 112001 (2023)

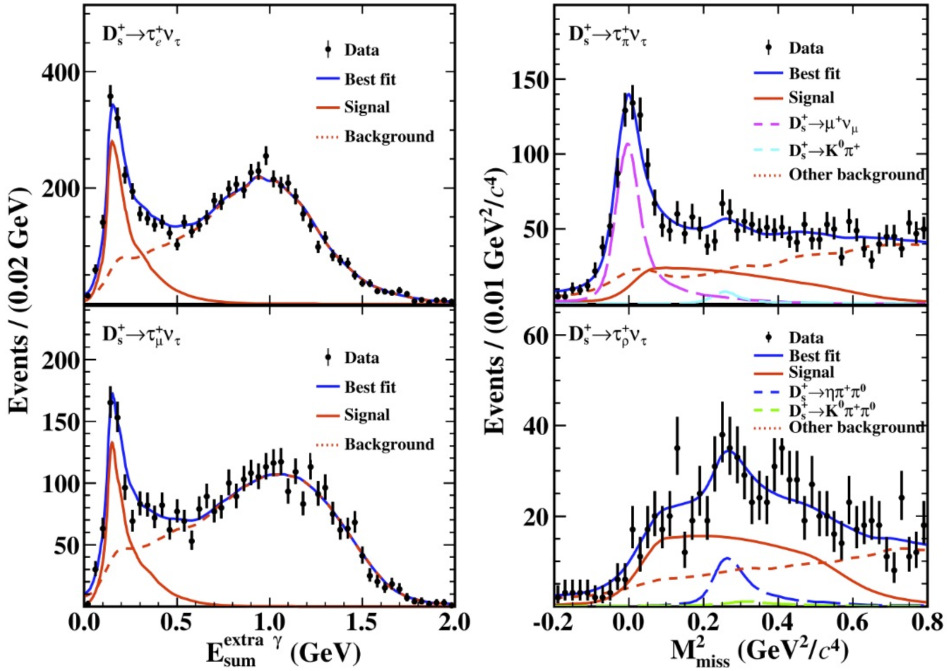
10.64 fb^{-1}@ 4.237-4.699 GeV， PRD 110, 052002 (2024)

$e^+e^- \to D_s^{*\pm}D_s^{\mp}$



$e^+e^- \to D_s^{*+}D_s^{*-}$





$N_{D^+\to\tau^+\nu_\tau} = 2845 \pm 83$

$$\mathcal{B}_{D_s^+\to\mu^+\nu_\mu} = (0.5294 \pm 0.0108_{\rm stat} \pm 0.0085_{\rm syst})\%$$

$$f_{D_s^+}|V_{cs}| = 241.8 \pm 2.5_{\rm stat} \pm 2.2_{\rm syst}\ \text{MeV}$$

$$f_{D_s^+} = 248.4 \pm 2.5_{\rm stat} \pm 2.2_{\rm syst}\ \text{MeV}$$

$$|V_{cs}| = 0.968 \pm 0.010_{\rm stat} \pm 0.009_{\rm syst}$$

Precision : ~1.4%

$$\mathcal{B}_{D_s^+\to\mu^+\nu_\mu} = (0.547 \pm 0.026_{\rm stat} \pm 0.016_{\rm syst})\%$$

$$f_{D_s^+} = (253.2 \pm 6.0_{\rm stat} \pm 3.7_{\rm syst} \pm 0.6_{\rm input})$$

$$|V_{cs}| = (0.986 \pm 0.023_{\rm stat} \pm 0.014_{\rm syst} \pm 0.003_{\rm input})$$

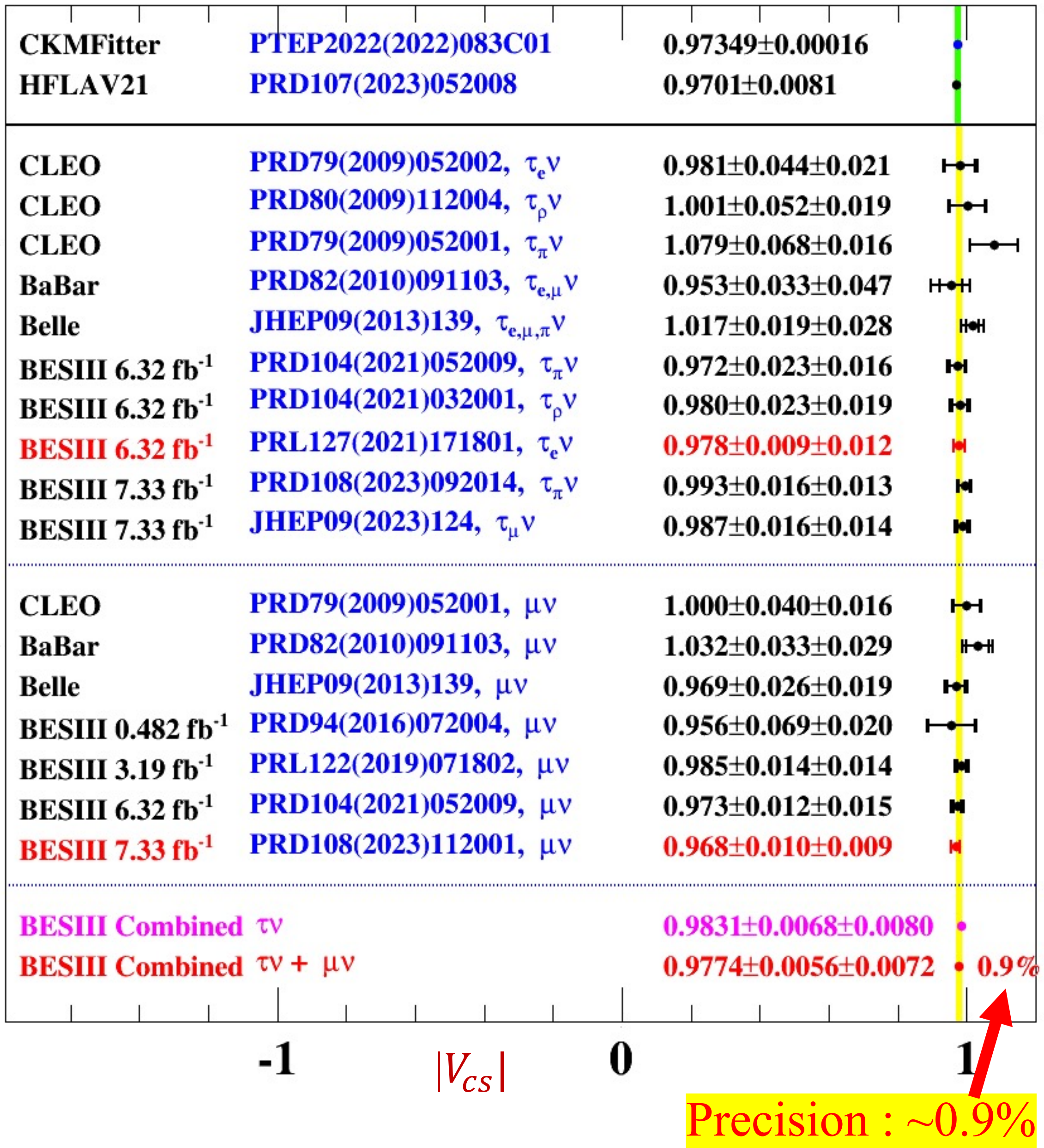
$$\mathcal{B}_{D_s^+\to\tau^+\nu_\tau} = (5.60 \pm 0.16_{\rm stat} \pm 0.20_{\rm syst})\%$$

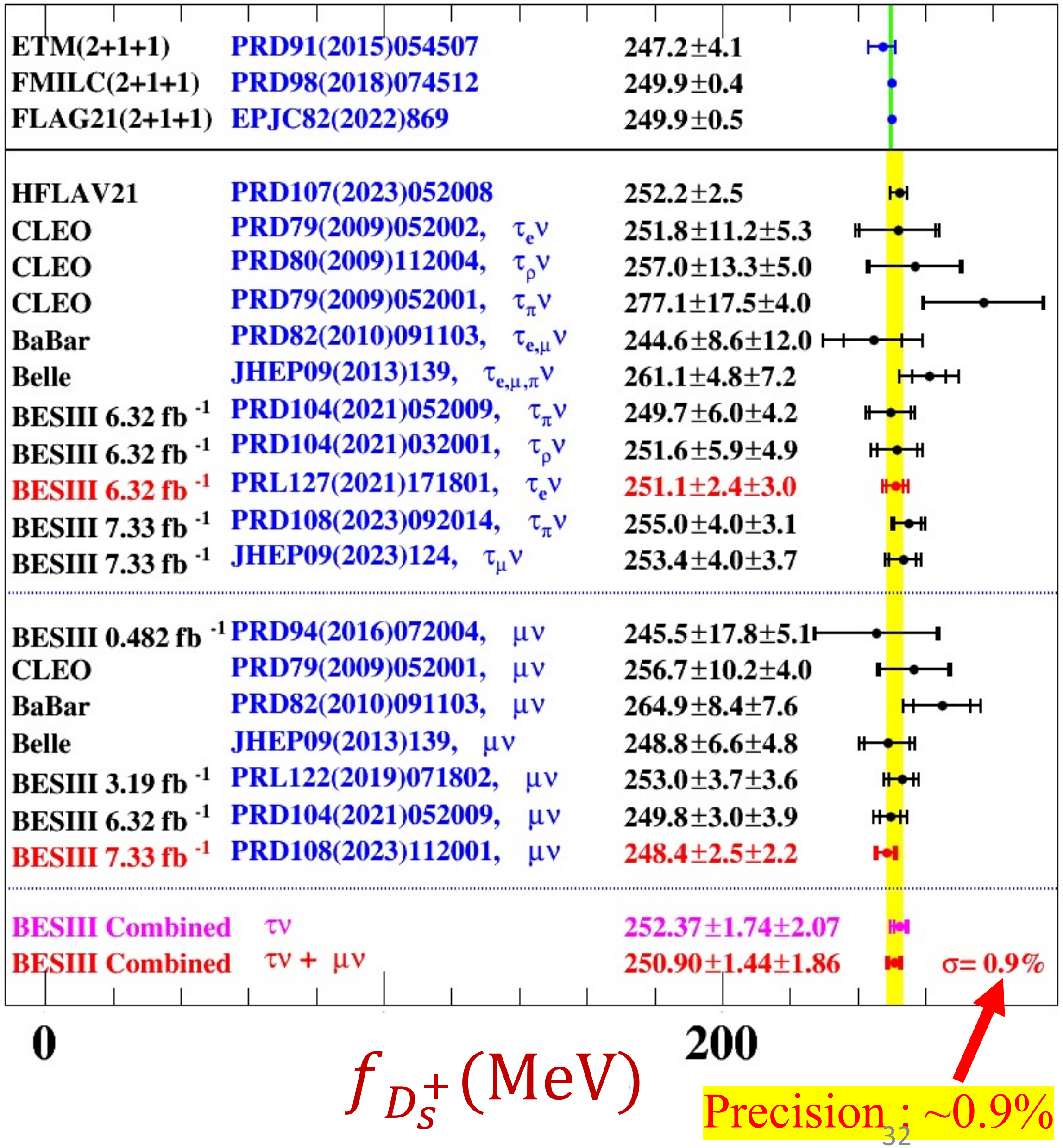
$$f_{D_s^+} = (259.6 \pm 3.7_{\rm stat} \pm 4.6_{\rm syst} \pm 0.6_{\rm input})$$

$$|V_{cs}| = (1.011 \pm 0.014_{\rm stat} \pm 0.018_{\rm syst} \pm 0.003_{\rm input})$$

LFU test: $\frac{\Gamma_{D_s^+\to\tau^+\nu_\tau}}{\Gamma_{D_s^+\to\mu^+\nu_\mu}} = 10.24 \pm 0.57$ SM=9.75

$|V_{cs}|$ and $f_{D_s^+}$ from $D_s^+ \to \mu^+\nu_\mu$ and $D_s^+ \to \tau^+\nu_\tau$

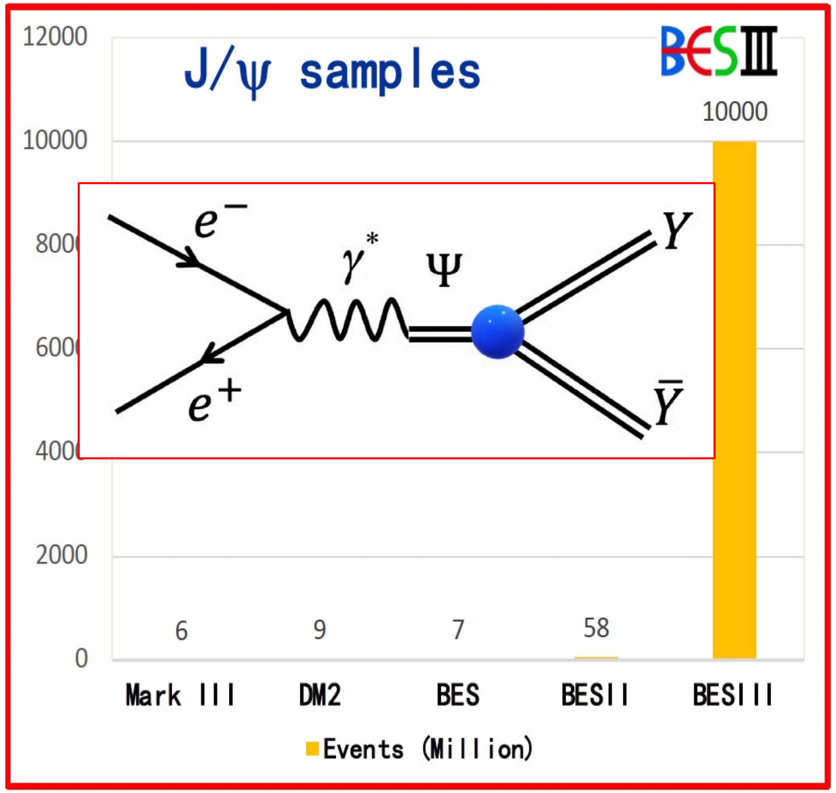


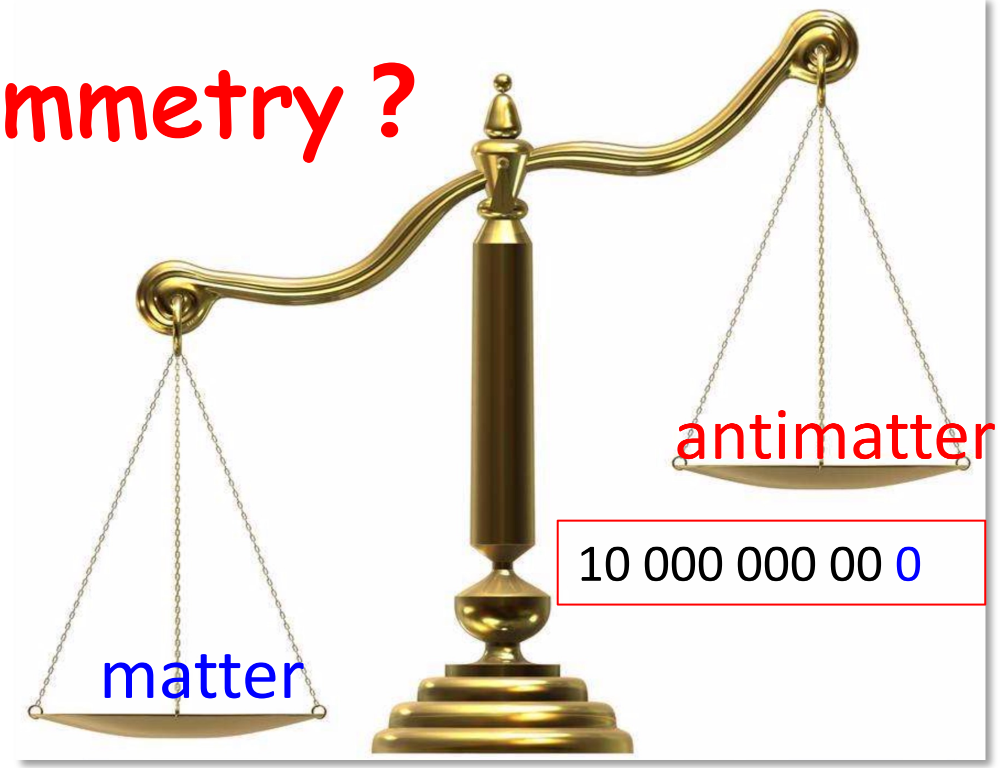


New physics searches

New source for CP asymmetry ?

CPV in SM is small：		# events	Experiments
B meson (2001) :	**O(1)**	**10^3**	***B factory***
K meson (1964) :	**O(10^{-3})**	**10^6**	***Fix targets***
D meson (2019) :	**O(10^{-4})**	**10^8**	***LHCb***
Hyperon :	**O(10^{-4})**	**O(10^8)**	***Fix targets, BESIII***





10 000 000 00 0

10 000 000 00 1

➢**Not enough !**

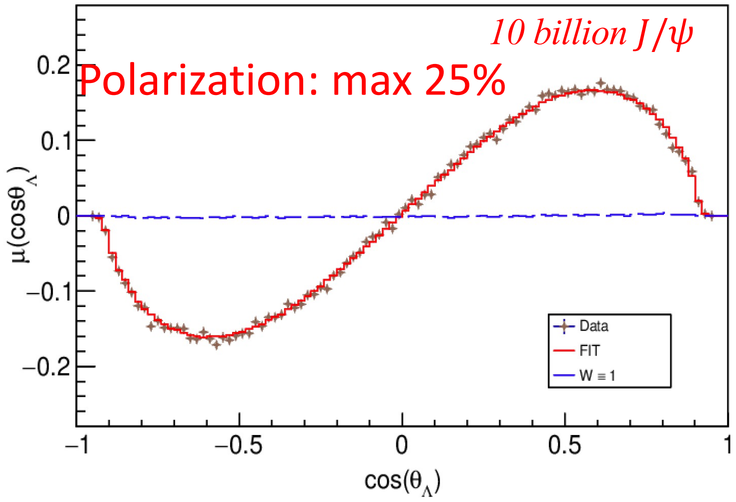
CP asymmetry : 10^{-10} → present universe

CP asymmetry in SM : 10^{-20} ~ 10^{-16}

The most precise CP test in Λ and $\bar{\Lambda}$ decay

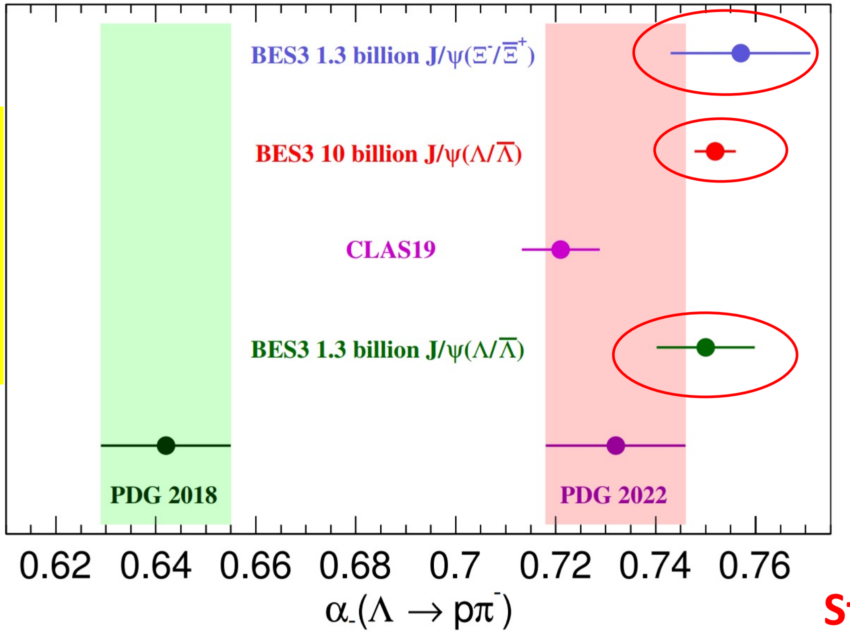
10 billion **J/ψ** (PRL. 129, 131801 (2022))

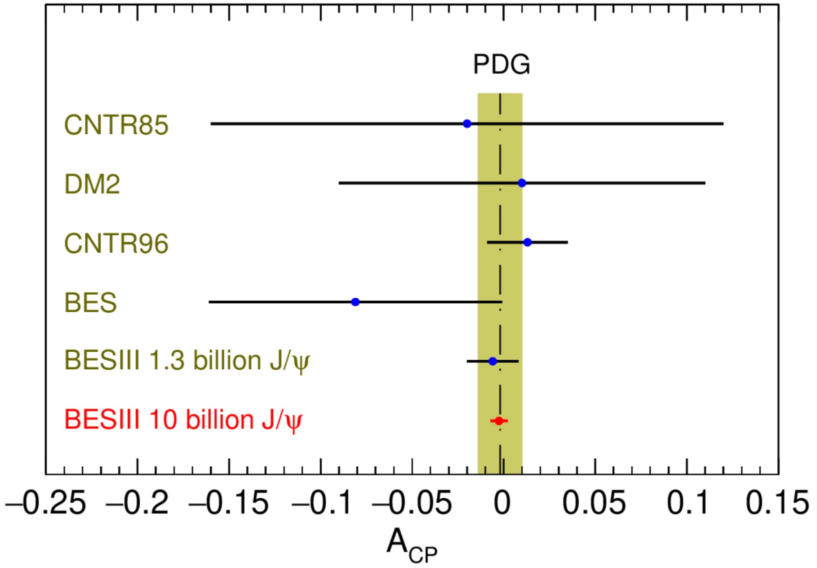
Nat. Phys. 15, 631 (2019)



Paras.	This Work (10 billion J/ψ)	Previous Results (1.3 billion J/ψ)
$\alpha_{J/\psi}$	$0.4748 \pm 0.0022 \pm 0.0024$	$0.461 \pm 0.006 \pm 0.007$
$\Delta\Phi$	$0.7521 \pm 0.0042 \pm 0.0080$	$0.740 \pm 0.010 \pm 0.009$
α_-	$0.7519 \pm 0.0036 \pm 0.0019$	$0.750 \pm 0.009 \pm 0.004$
α_+	$-0.7559 \pm 0.0036 \pm 0.0029$	$-0.758 \pm 0.010 \pm 0.007$
A_{CP}	$-0.0025 \pm 0.0046 \pm 0.0011$	$-0.006 \pm 0.012 \pm 0.007$
α_{avg}	$0.7542 \pm 0.0010 \pm 0.0020$	—

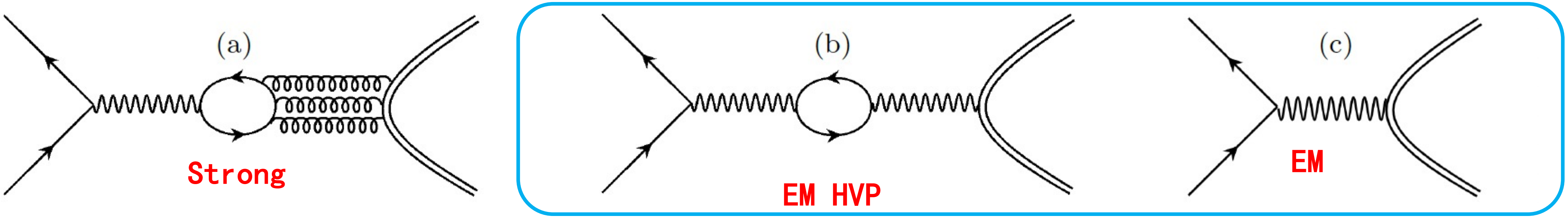
More than 10 standard deviation shift from all previous measurements

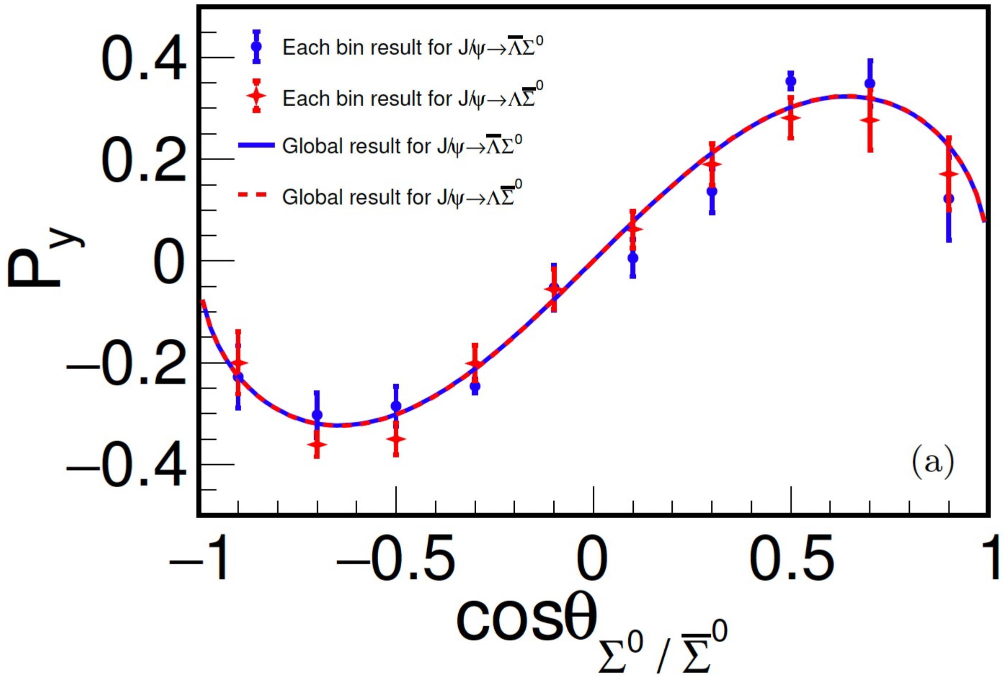




Standard mode prediction : A_{CP}~ 10^{-4} (PRD 34, 833 (1986))

CP test in $J/\psi \to \Lambda \bar{\Sigma}$





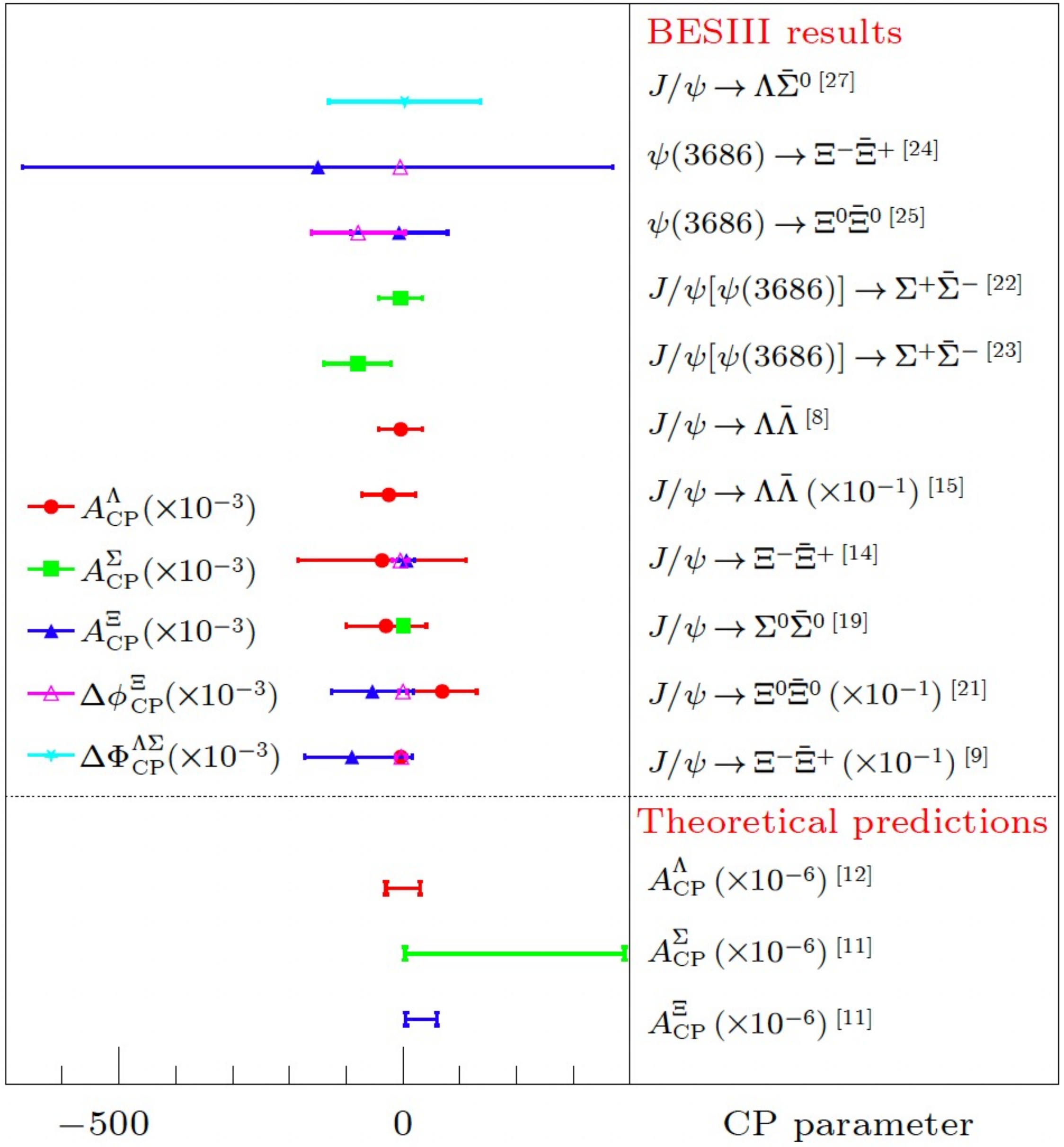
First measurements:

$\Delta\phi_1 = 1.011 \pm 0.094 \pm 0.010$
$\Delta\phi_2 = 2.128 \pm 0.094 \pm 0.010$
$|G_E/G_M| = 0.086 \text{+-} 0.029 \text{+-} 0.010$

$\Delta\phi_1 + \Delta\phi_2 = (3.139 \pm 0.133 \pm 0.014)$

Nature Communications, 15,8812,(2024)

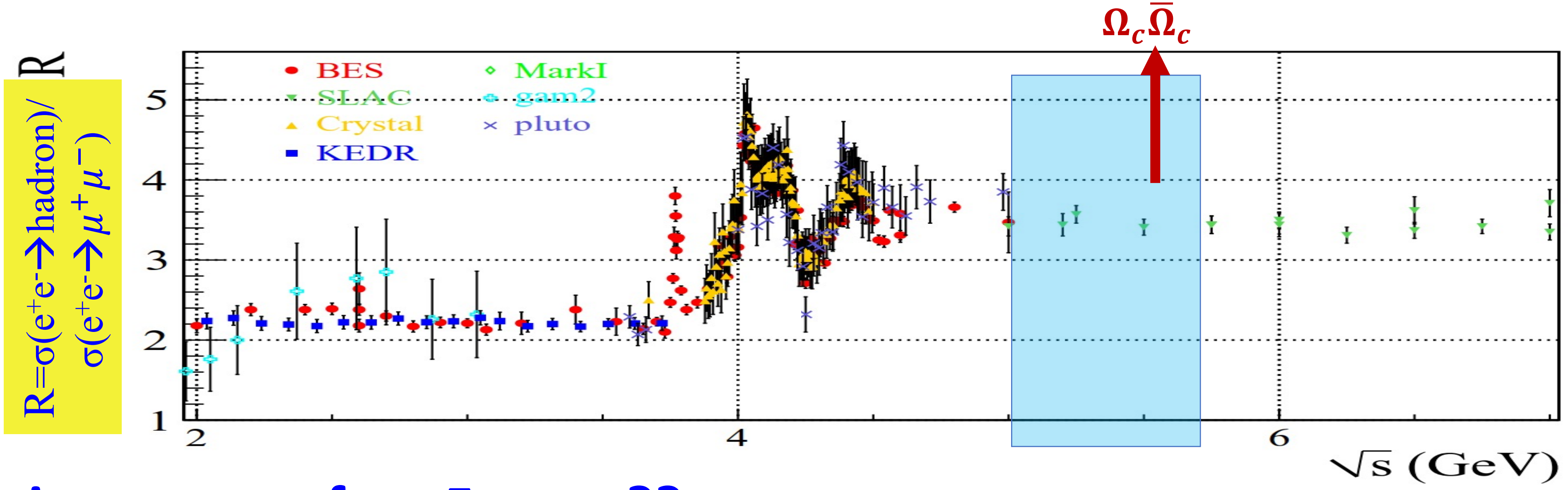
CP tests at BESIII



- SM predicts very small violations of CP symmetry.
- Sizeable CP violations prerequisite for *Baryogenesis*
- BESIII: 10 billion J/ψ events
- CPV at BESIII: ~ 10^{-3}
- More data strongly needed!
- $10^{13} J/\psi$ per year @STCF ??

Future prospects

- BEPCII/BESIII upgraded in 2024
- Optimization E_{cm} at 4.7 GeV with luminosity 3 times higher than the current BEPCII → more effective data taking
- Extend the maximum E_{cm} up to 5.6 GeV → more physics opportunity



Continue to run for >5 years??

More exciting results are expected in the near future!

非常感谢！