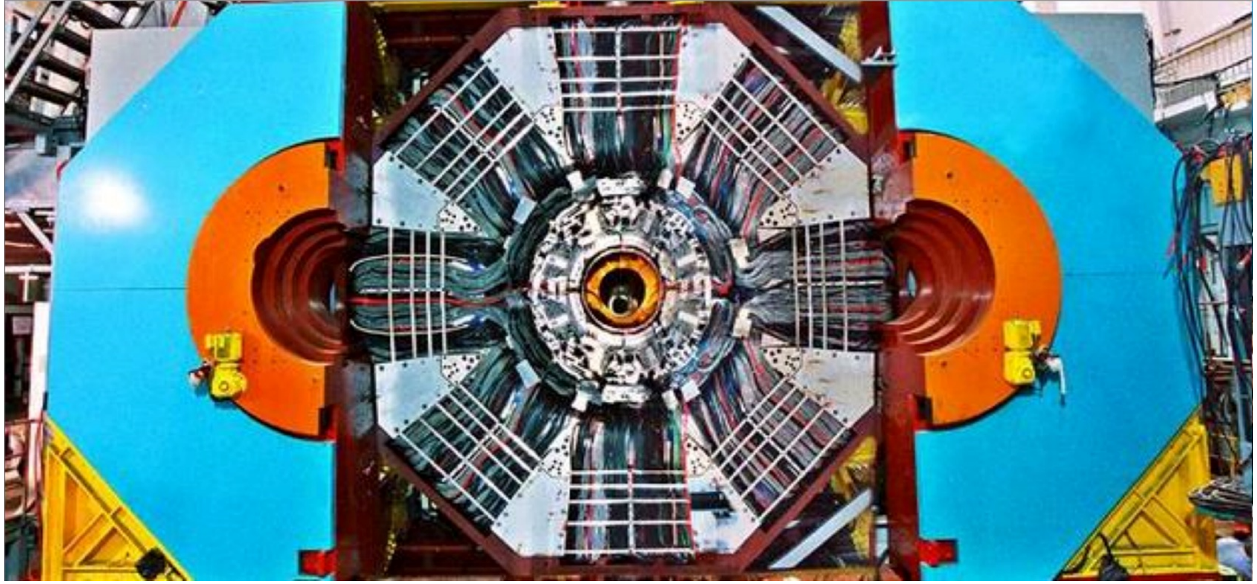


Physics overview on the BESIII experiment

Xiao-Rui Lyu

University of Chinese Academy of Sciences (UCAS)

(On behalf of the BESIII collaboration)

Outline

- **Introduction to BEPCII/BESIII**
- **Selected highlights of BESIII results**
  - *charmed hadron decays*
  - *charmonium- and strangenium-like states*
  - *light hadrons*
  - *form factors of baryons*
- **Prospects for the future**
- **Summary**

Disclaimer: selective overview, not comprehensive;
More results will be covered in the following BESIII talks.

SESSION 22.08. A (Colliders: New Physics)

16.30 D.Wang (PKU) *Recent results of new physics searching at BESIII* (15 min)

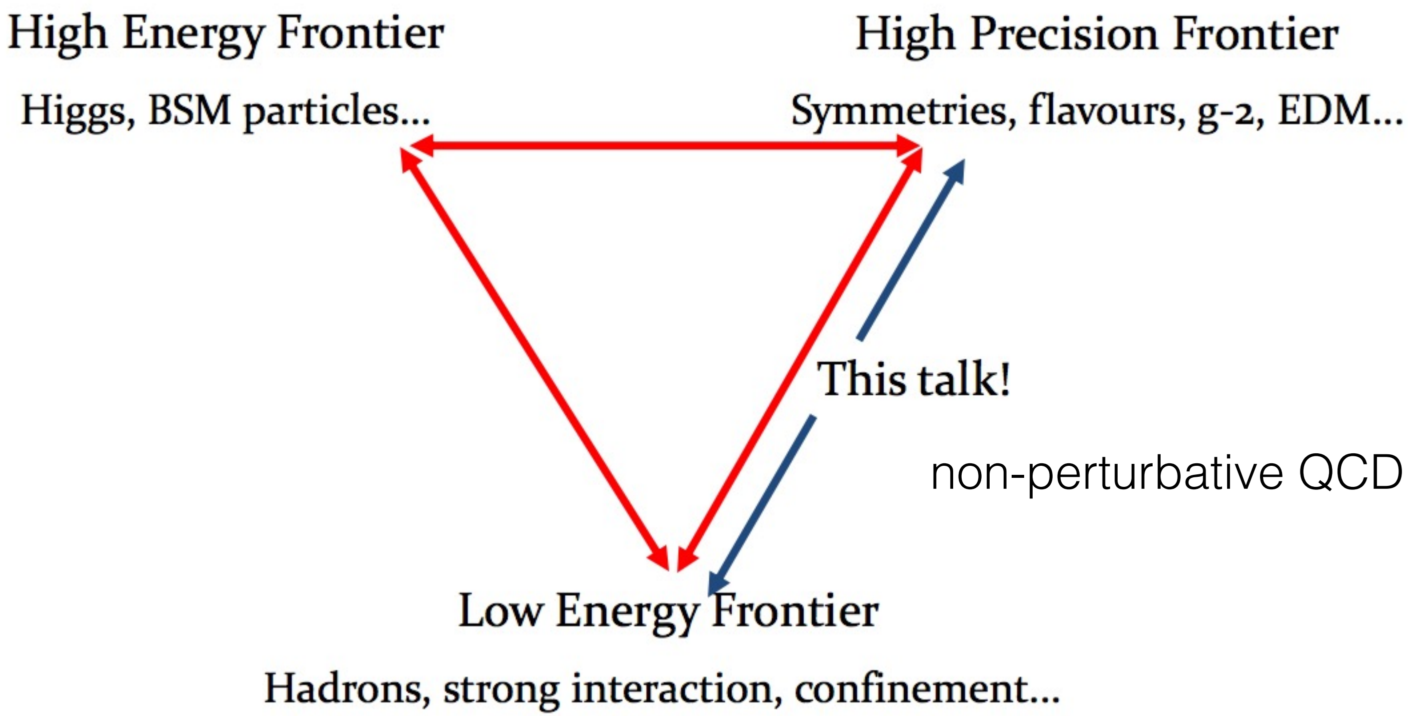
SESSION 23.08. C (Physics at Colliders)

15.15 Y.Huang (IHEP, Beijing) *Progresses on light hadron physics* (15 min)

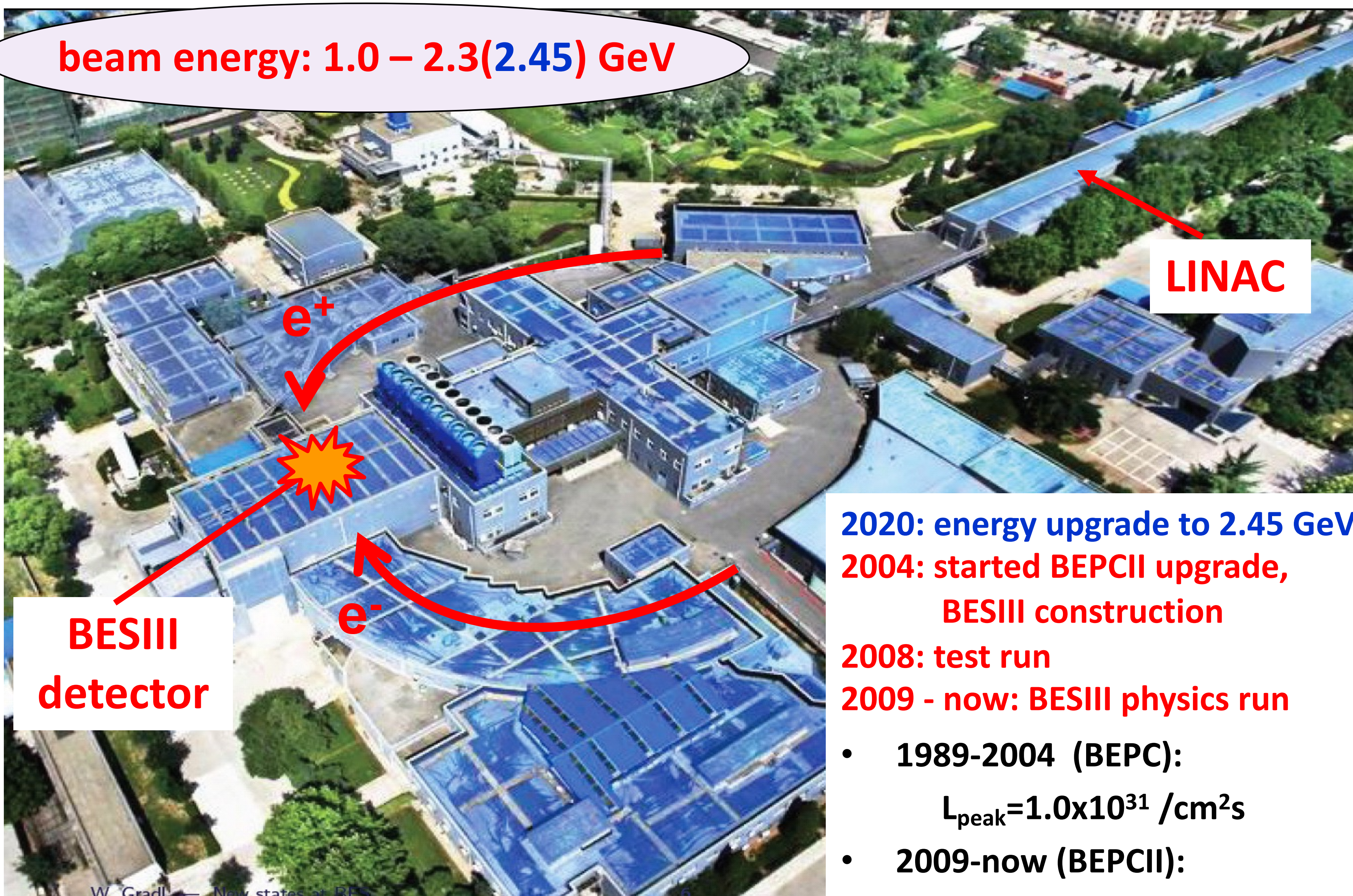
SESSION 25.08. A (Charm Physics)

8.30 H.Li (Henan Normal Univ.) *Recent results of charm physics at BESIII* (20 min)
8.50 X.Qin (Fudan Univ.) *Recent searches for exotic charmonium-like states at BESIII* (20 min)

Frontiers of the Standard Model



Beijing Electron Positron Collider (BEPCII)

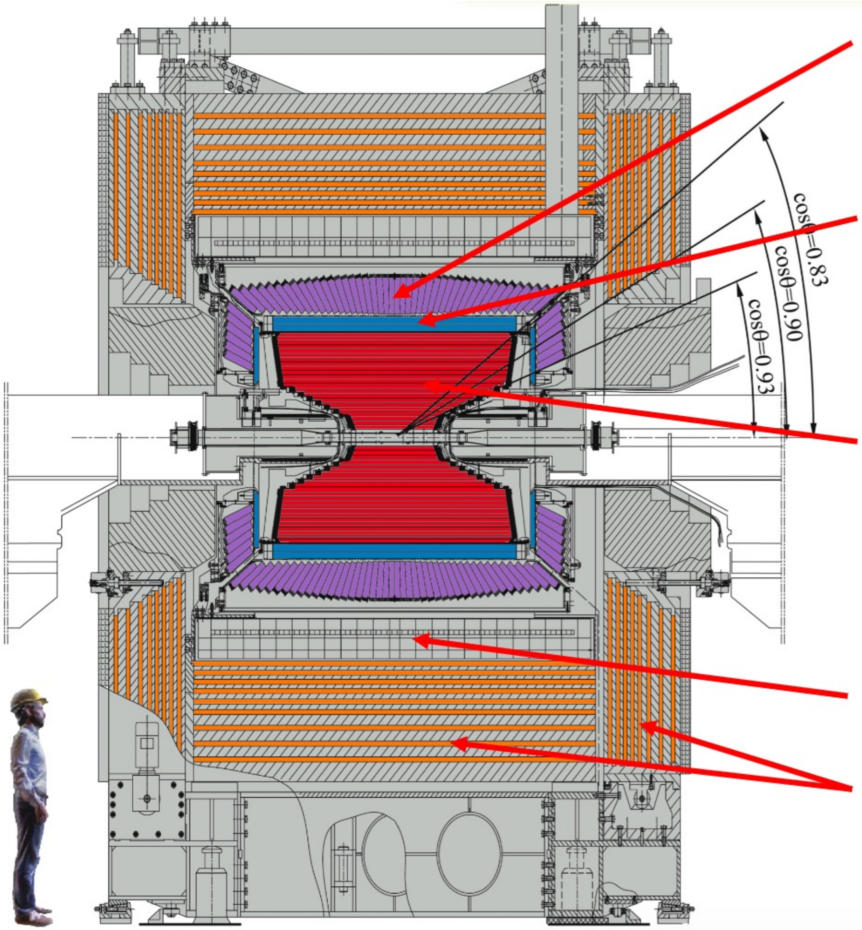


2020: energy upgrade to 2.45 GeV
2004: started BEPCII upgrade, BESIII construction
2008: test run
2009 - now: BESIII physics run

- 1989-2004 (BEPC): L_{peak}=1.0x10^{31} /cm^{2}s
- 2009-now (BEPCII): L_{peak}= 1.0 x10^{33}/cm^2(4/5/2016)

The BESIII detector

NIM A614, 345 (2010)



EMC: CsI crystals
$\Delta E/E$ = 2.5% @ 1 GeV - Barrel
$\Delta E/E$ = 5.0% @ 1 GeV - Endcaps

TOF:
σ_T = 80 ps Barrel
σ_T = 110 (60) ps Endcap

MDC: small cell & He gas
σ_{xy}= 130 μm
σ_p/p = 0.5% @1GeV
dE/dx = 6%

Magnet: 1T Super conducting

Muon ID: 9 layer RPC

Trigger: Tracks & Showers

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

BESIII Collaboration

Europe (17/115)

Germany (6): Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen,University of Münster

Italy (3): Ferrara University, INFN, University of Torino

Netherlands (1): KVI/University of Groningen

Russia (2): Budker Institute of Nuclear Physics, Dubna JINR

Sweden (1): Uppsala University

Turkey (1): Turkish Accelerator Center Particle Factory Group

UK (2): University of Manchester, University of Oxford

Poland (1) National Centre for Nuclear Research

USA(4/8)

Carnegie Mellon University
Indiana University
University of Hawaii
University of Minnesota

South America (1/1)

Chile: University of Tarapaca

China (48/367)

Institute of High Energy Physics (146), other units(221): Beijing Institute of Petro-chemical Technology, Beihang University, China Center of Advanced Science and Technology, Fudan University, Guangxi Normal University, Guangxi University, Hangzhou Normal University, Henan Normal University, Henan University of Science and Technology, Huazhong Normal University, Huangshan College, Hunan University, Hunan Normal University, Henan University of Technology Institute of modern physics, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University, Peking University, Qufu normal university, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Normal University, Shandong University, Shanghai Jiaotong Univeristy, Soochow University, South China Normal University, Southeast University, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, Unive Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xinyang Normal University, Zhejiang University, Zhengzhou University,YunNan University , China University of Geosciences

Asia (6/10)

Pakistan (2): COMSATS Institute of Information Technology
University of the Punjab, University of Lahore

Mongolia (1): Institute of Physics and Technology

Korea (1): Chung-Ang University

India (1): Indian Institute of Technology madras

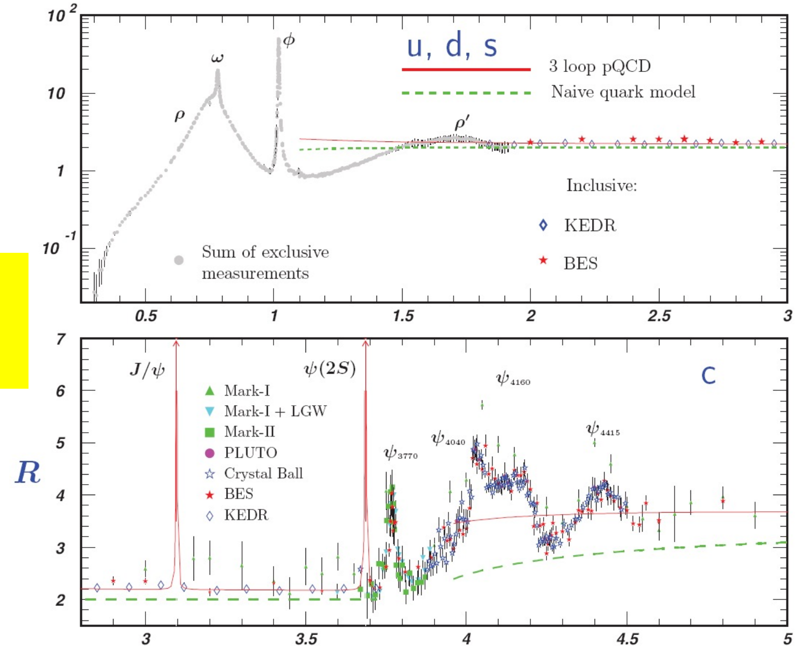
Thailand (1): Suranaree University of Technology

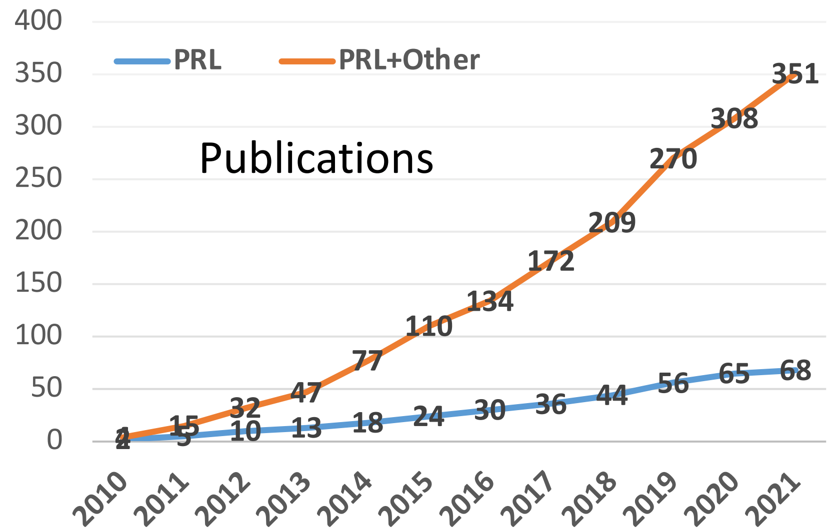
~500 members
from 76 institutions in 16 countries

BESIII Data Samples

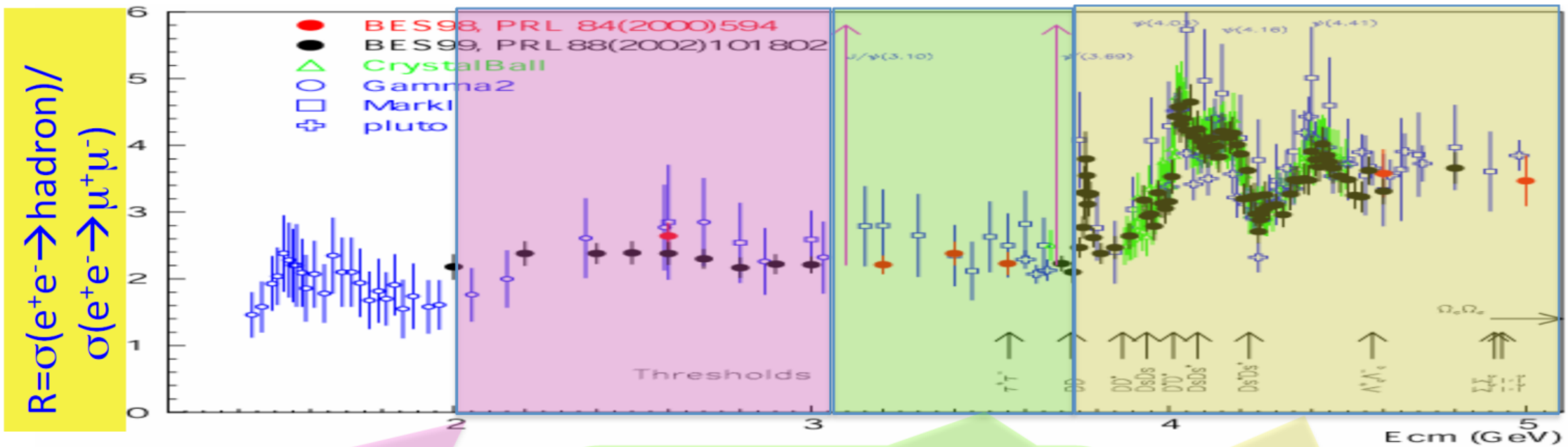
2009: 106M $\psi(2S)$
225M J/ψ
2010: 975 pb^{-1} at $\psi(3770)$
2011: 2.9 fb^{-1} *(total)* at $\psi(3770)$
482 pb^{-1} at 4.01 GeV
2012: 0.45B *(total)* $\psi(2S)$
1.3B *(total)* J/ψ
2013: 1092 pb^{-1} at 4.23 GeV
826 pb^{-1} at 4.26 GeV
540 pb^{-1} at 4.36 GeV
10×50 pb^{-1} scan 3.81 — 4.42 GeV
2014: 1029 pb^{-1} at 4.42 GeV
110 pb^{-1} at 4.47 GeV
110 pb^{-1} at 4.53 GeV
48 pb^{-1} at 4.575 GeV
567 pb^{-1} at 4.6 GeV
0.8 fb^{-1} R-scan 3.85 — 4.59 GeV
2015: R-scan 2 — 3 GeV + 2.175 GeV
2016: ~3fb^{-1} at 4.18 GeV (for D_s)
2017: 7×500 pb^{-1} scan 4.19 — 4.27 GeV
2018: more J/ψ *(and tuning new RF cavity)*
2019: 10B *(total)* J/ψ
8×500 pb^{-1} scan 4.13, 4.16, 4.29 — 4.44 GeV
2020: 3.8 fb^{-1} scan 4.61-4.7 GeV
2021: 2 fb^{-1} scan 4.74-4.946 GeV
2021: 3.35 fb^{-1} @$\psi(2S)$ 3.0 B

Totally about 32 fb^{-1} in 12 year running





Physics at tau-charm Energy Region



- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

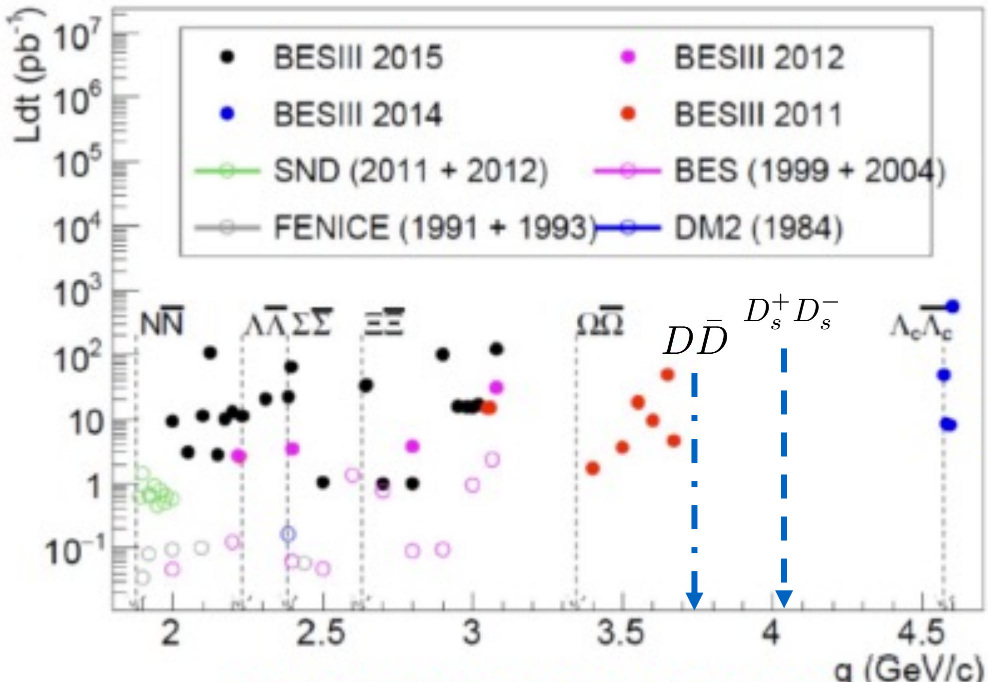
- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

- XYZ particles
- D mesons
- f_D and f_{Ds}
- D_0-D_0 mixing
- Charm baryons

Unique data sets near thresholds

e^+e^- symmetric collision:
energy scan data sets at open charm thresholds

3.773 GeV, 2.93 fb^{-1}, $D\bar{D}$
4.008 GeV, 0.48 fb^{-1}, $D_s\bar{D}_s$
4.18-4.23 GeV, 6.32 fb^{-1}, $D_s\bar{D}_s^*$
4.6-4.7 GeV, 4.4 fb^{-1}, $\Lambda_c\bar{\Lambda}_c$



Energy scan in 2014-2015 at BESIII

- **Meson and Baryon pair-productions near thresholds:**
  form-factors in the time-like production, precision branching fractions, relative phase;
- **Quantum-entangled pair productions of charmed mesons**
- **Hyperon and charmed baryon spin polarization in quantum entangled productions;**

BESIII advantage: unique data near to the thresholds

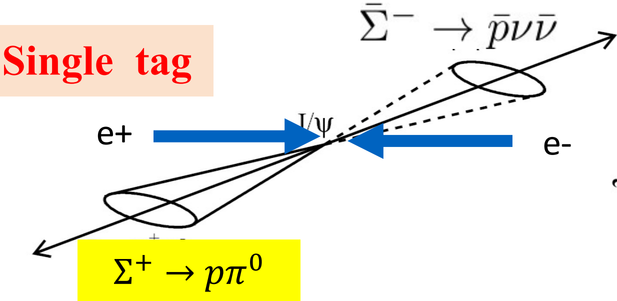
Known initial 4-momentum

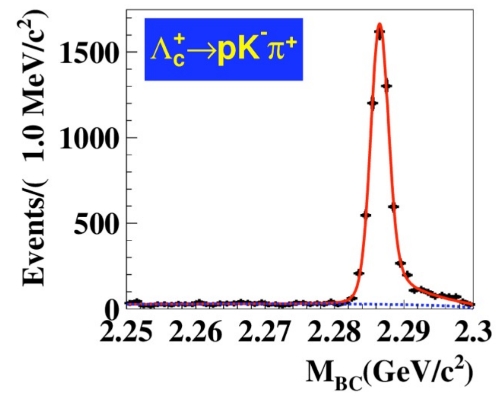
Known beam energy: pair productions

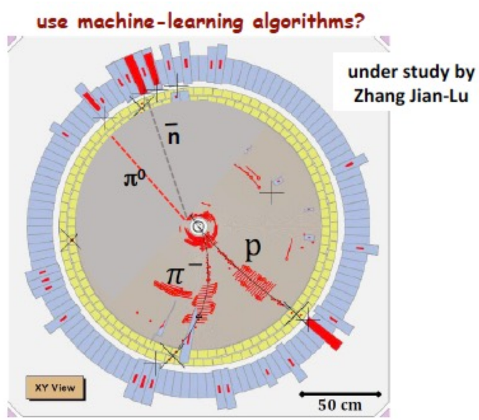
Decay with neutron & π^0

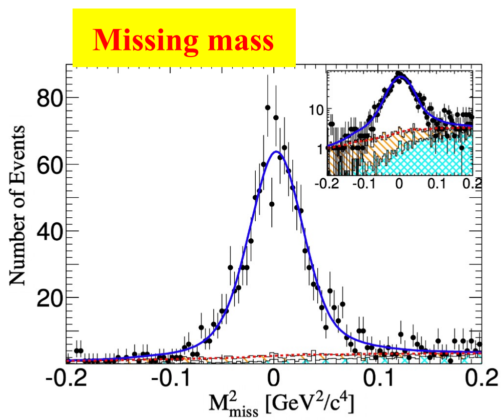
Decay with invisibles: neutrinos

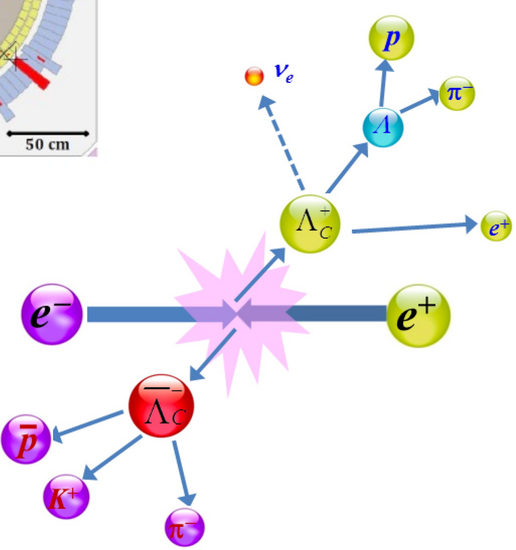
Missing mass or missing energy

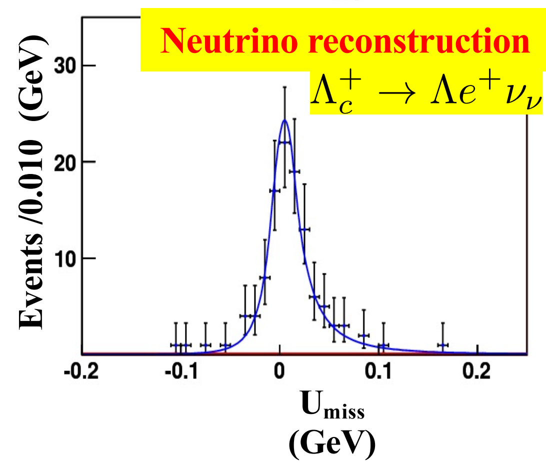




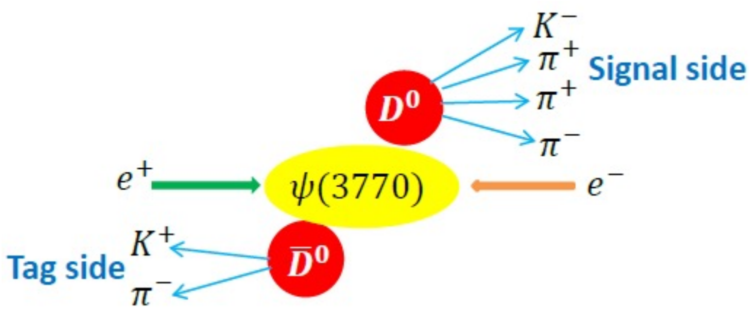




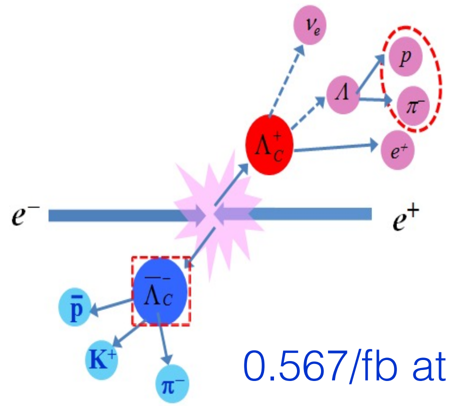




Charm hadron decays

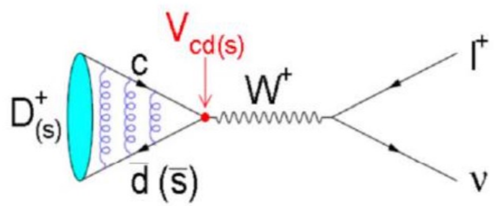


2.93/fb at $\psi(3770)$

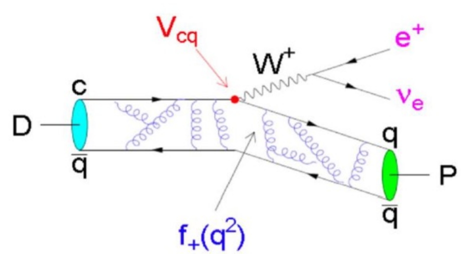


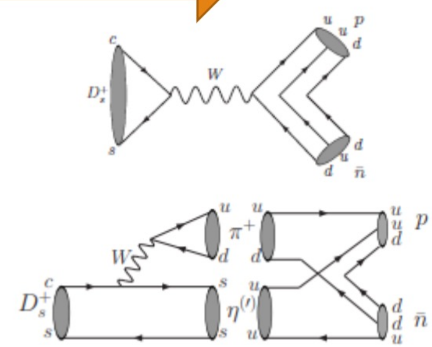
0.567/fb at 4.6 GeV

COMPLEXITY



$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f_{D^+_{(s)}}^2}{8\pi}|V_{cd(s)}|^2 m_\ell^2 m_{D^+_{(s)}}\left(1-\frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2$$





Purely Leptonic	Semi Leptonic	Hadronic
Take V_{cx} from fits to CKM assuming unitarity and measure f Precise test of lattice QCD in charm and extrapolate to beauty	Similar to leptonic decay but now q (= four-momentum of W) dependent Test QCD models of the form factor	Models of hadronic decay • Isospin • SU(3) flavour • Different amplitudes T, P, A, E • Long and short distance effects

Precision measurement of CKM elements -- Test EW theory

CKM matrix elements are fundamental SM parameters that describe the mixing of quark fields due to weak interaction.

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

CKM matrix

BESIII + B factories + LQCD

Three generations of quark?

Unitary matrix?

Expected precision < 2% at BESIII

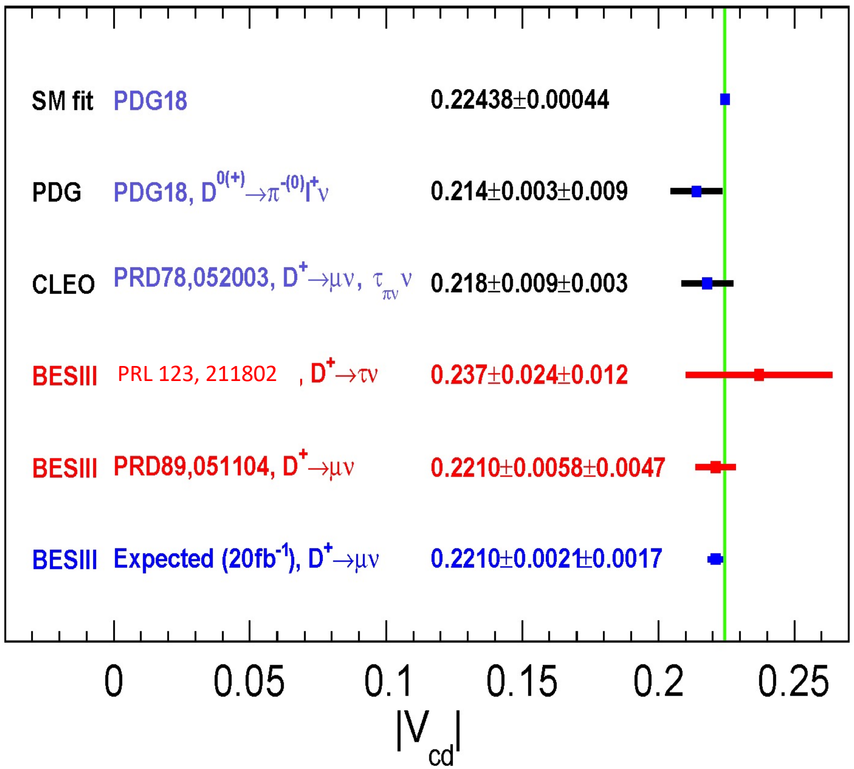
BESIII + B factories + LHCb + LQCD

- **Precision measurement of CKM matrix elements**
- **A precise test of SM model**
- **New physics beyond SM?**

Extraction of $|V_{cd}|$ and f_{D^+}

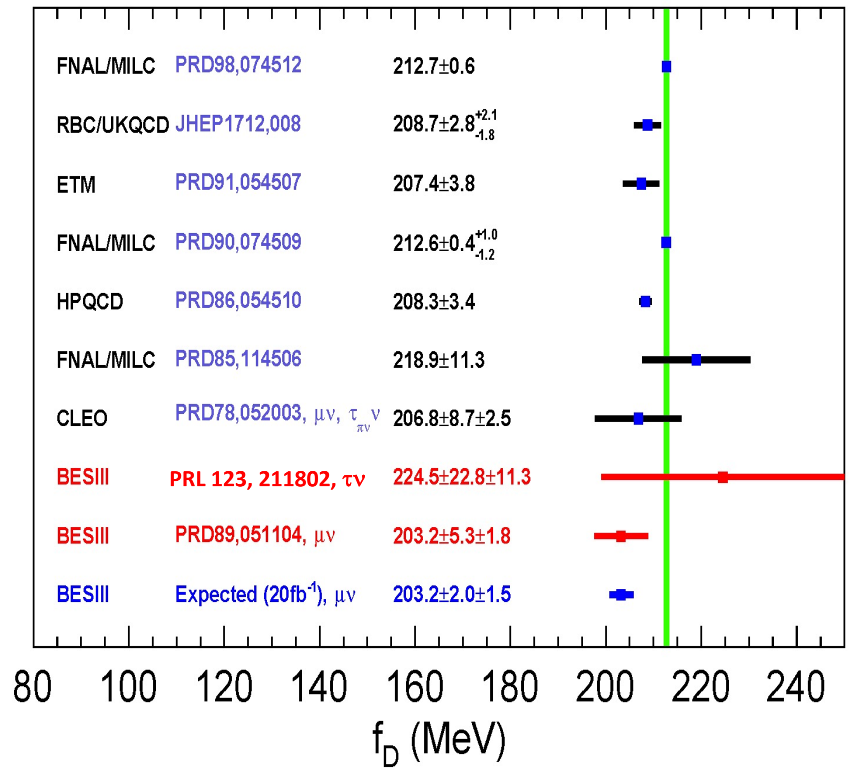
Take f_D^{LQCD} as input：

$|V_{cd}|$=(0.2210±0.0058±0.0047) ($\mu^+\nu$ mode)



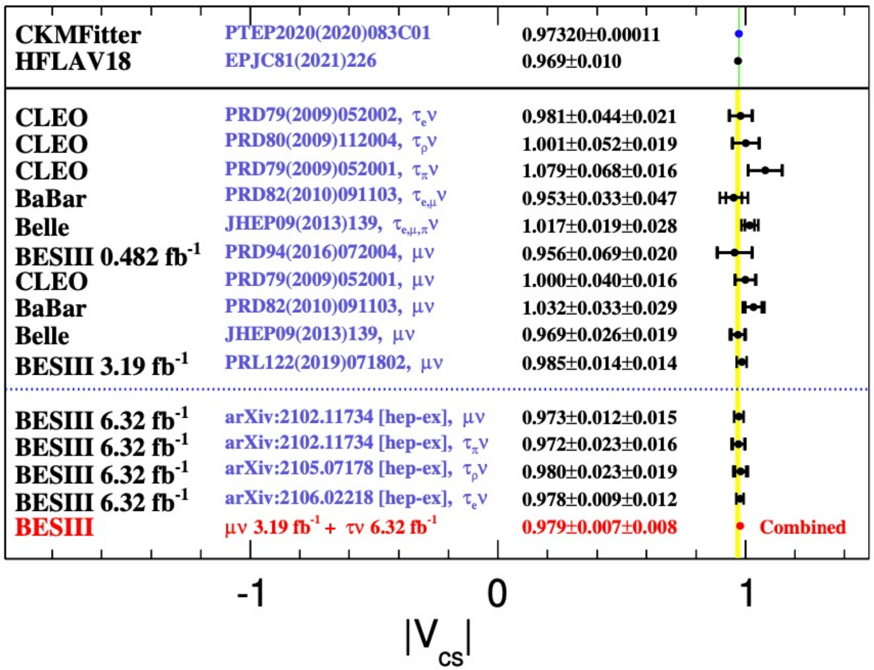
Take $|V_{cd}|^{CKMfitter}$ as input：

f_{D^+}=(203.2±5.3±1.8) MeV ($\mu^+\nu$ mode)

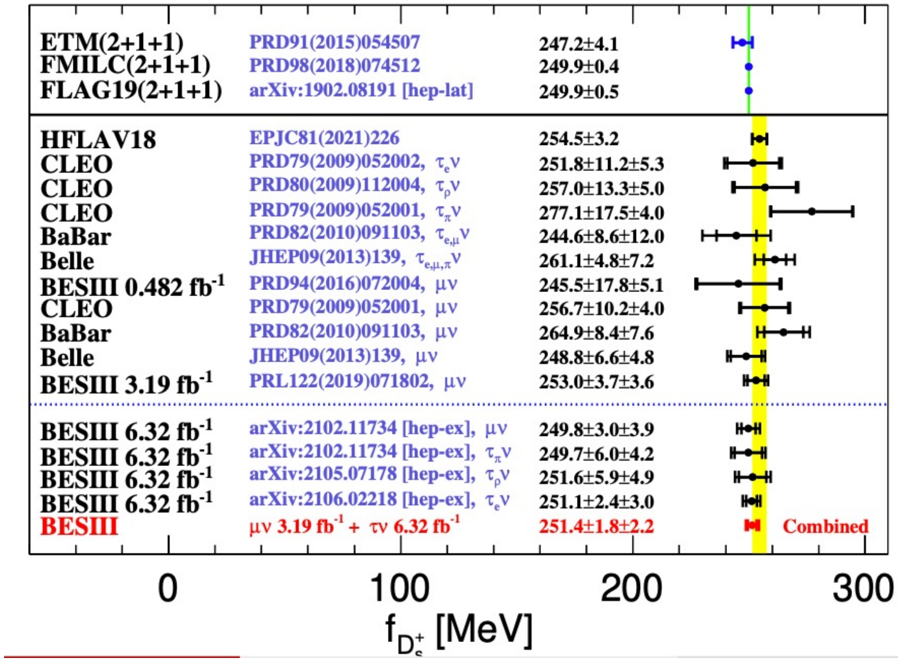


Most precise measurement

Extraction of $|V_{cs}|$ and $f_{D_s^+}$



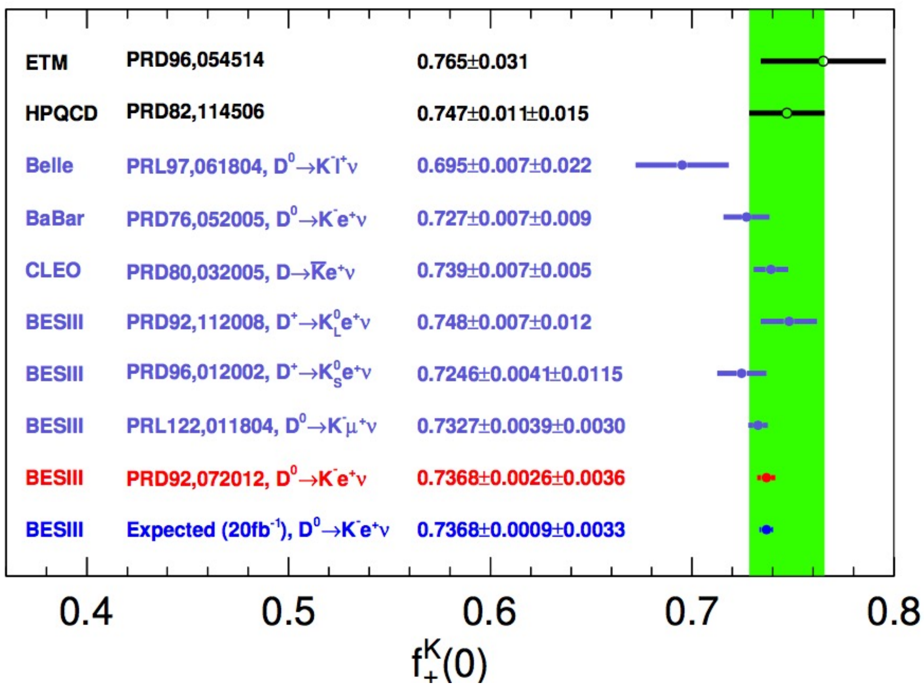
- **Input $f_{D_s^+} = 249.9 \pm 0.5$ MeV from LQCD calculations**

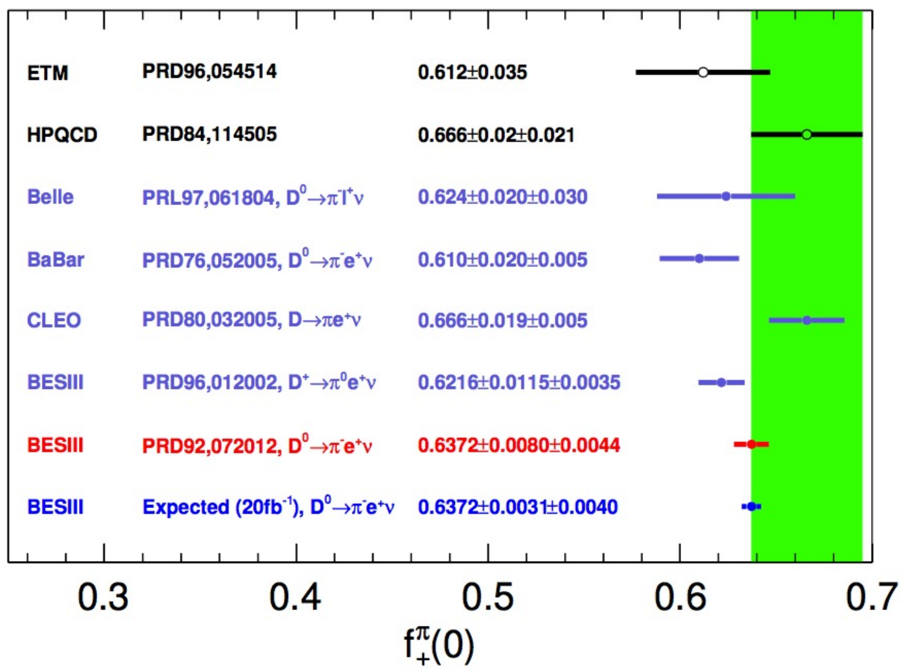


- **Input $|V_{cs}| = 0.97320 \pm 0.00011$ from CKM global fit**

Most precise measurement

Form factors $f_+^{D\to h}$





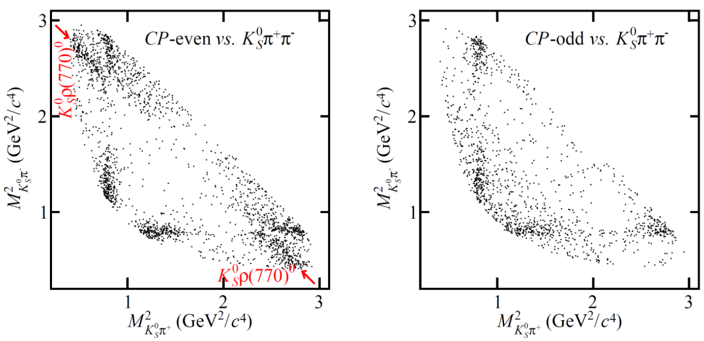
Precisions better than those of LQCD results

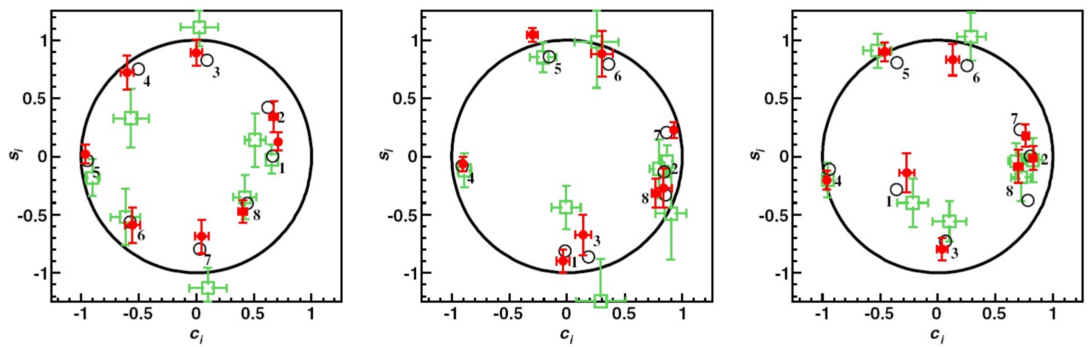
Quantum entangled $D^0 D^0$ Strong phase measurements

$2.93\ \mathrm{fb}^{-1} @ E_{cm} = 3.773\ \mathrm{GeV}$
$e^+e^- \to \psi(3770) \to D\bar{D}$

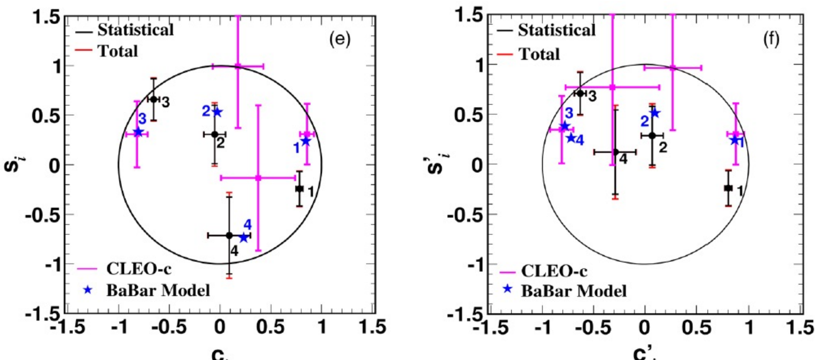
- **$D \to K^0_{S/L}\pi^+\pi^-$** PRL 124 (2020)241802

Constraint on γ measurement ~ 0.9^0





- **$D \to K^0_{S/L}K^+K^-$** PRD102(2020)052008



Constraint on γ measurement ~ 1.3^0

- **$D \to K^-\pi^+\pi^+\pi^-$ and $K^-\pi^+\pi^0$**

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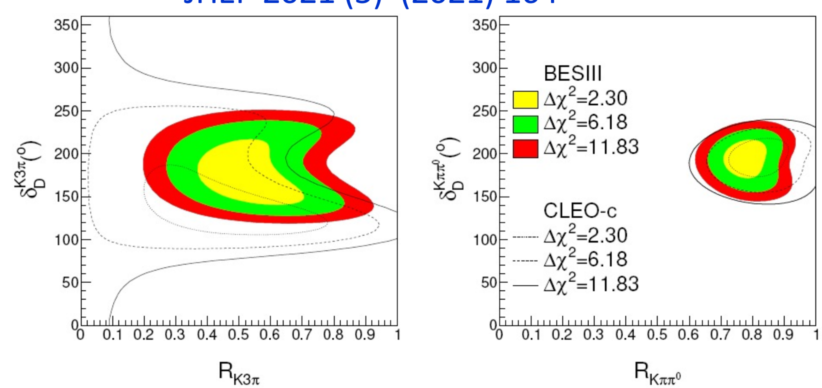
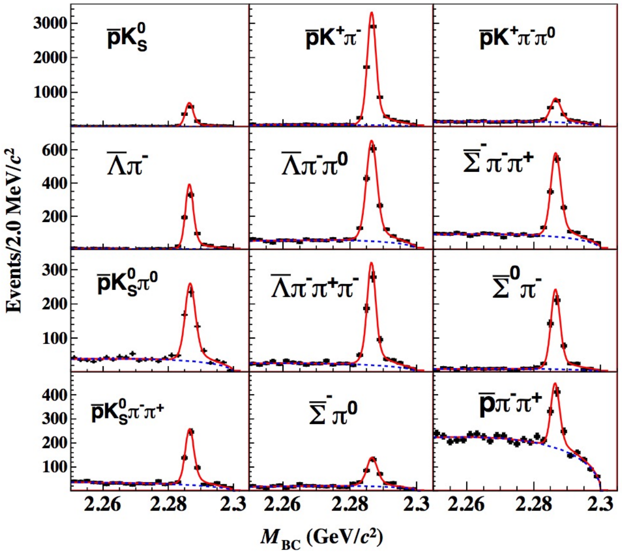


Constraint on γ measurement ~ 6^0

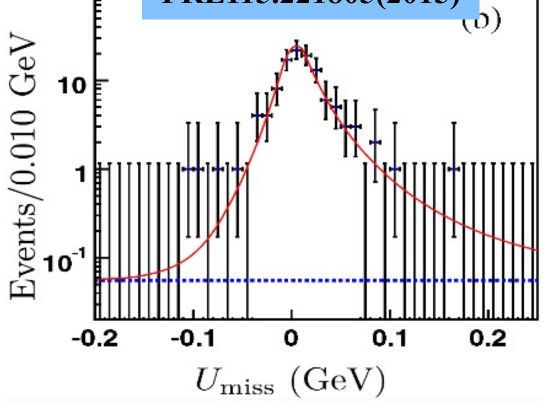
BESIII

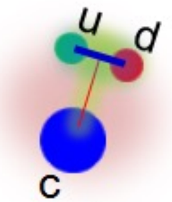
The Λ_c^+ decays

PRL116.052001(2016)



PRL115.221805(2015)





Hadronic decay

$\Lambda_c^+ \to pK^-\pi^+$ + 11 CF modes	PRL 116, 052001 (2016)
$\Lambda_c^+ \to pK^+K^-$, $p\pi^+\pi^-$	PRL 117, 232002 (2016)
$\Lambda_c^+ \to nK_S\pi^+$	PRL 118, 12001 (2017)
$\Lambda_c^+ \to p\eta$, $p\pi^0$	PRD 95, 111102(R) (2017)
$\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$	PLB 772, 388 (2017)
$\Lambda_c^+ \to \Xi^{0(*)}K^+$	PLB783, 200 (2018)
$\Lambda_c^+ \to \Lambda\eta\pi^+$	PRD99, 032010 (2019)
$\Lambda_c^+ \to \Sigma^+\eta, \Sigma^+\eta'$	CPC43, 083002 (2019)
$\Lambda_c^+ \to$ BP decay asymmetries	PRD100, 072004 (2019)
$\Lambda_c^+ \to pK_s\eta$	arXiv: 2012.11106

Semi-leptonic decay

$\Lambda_c^+ \to \Lambda e^+\nu_e$	PRL 115, 221805(2015)
$\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$	PLB 767, 42 (2017)

Inclusive decay

$\Lambda_c^+ \to \Lambda X$	PRL121, 062003 (2018)
$\Lambda_c^+ \to e^+X$	PRL 121 251801(2018)
$\Lambda_c^+ \to K_s^0X$	EPJC 80, 935 (2020)

Production

$\Lambda_c^+\Lambda_c^-$ cross section	PRL 120,132001(2018)

Impacts on Λ_c decay data

D_s^+ BRANCHING RATIOS

A number of older, now obsolete results have been omitted. They may be found in earlier editions.

Inclusive modes

$\Gamma(e^+ \text{semileptonic})/\Gamma_{total}$ — Γ_1/Γ

This is the purely e^+ semileptonic branching fraction: the e^+ fraction from τ^+ decays has been subtracted off. The sum of our (non-τ) exclusive e^+ fractions — an $e^+ \nu_e$ with an η, η', ϕ, K^0, or K^{*0} — is 5.99 ± 0.31 %.

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
6.52±0.39±0.15	536 ± 29	[1] ASNER	10	CLEO	e^+e^- at 3774 MeV

[1] Using the D_s^+ and D^0 lifetimes, ASNER 10 finds that the ratio of the D_s^+ and D^0 semileptonic widths is 0.828 ± 0.051 ± 0.025.

$\Gamma(\pi^+ \text{anything})/\Gamma_{total}$ — Γ_2/Γ

Events with two π^+'s count twice, etc. But π^+'s from $K_S^0 \to \pi^+\pi^-$ are not included.

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
119.3±1.2±0.7	DOBBS	09	CLEO	e^+e^- at 4170 MeV

$\Gamma(\pi^- \text{anything})/\Gamma_{total}$ — Γ_3/Γ

Events with two π^-'s count twice, etc. But π^-'s from $K_S^0 \to \pi^+\pi^-$ are not included.

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
43.2±0.9±0.3	DOBBS	09	CLEO	e^+e^- at 4170 MeV

$\Gamma(\pi^0 \text{anything})/\Gamma_{total}$ — Γ_4/Γ

Events with two π^0's count twice, etc. But π^0's from $K_S^0 \to \pi^0\pi^0$ are not included.

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
123.4±3.8±5.3	DOBBS	09	CLEO	e^+e^- at 4170 MeV

$\Gamma(K^- \text{anything})/\Gamma_{total}$ — Γ_5/Γ

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
18.7±0.5±0.2	DOBBS	09	CLEO	e^+e^- 4170 MeV

$\Gamma(K^+ \text{anything})/\Gamma_{total}$ — Γ_6/Γ

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
28.9±0.6±0.3	DOBBS	09	CLEO	e^+e^- at 4170 MeV

$\Gamma(K_S^0 \text{anything})/\Gamma_{total}$ — Γ_7/Γ

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
19.0±1.0±0.4	DOBBS	09	CLEO	e^+e^- at 4170 MeV

$\Gamma(\eta \text{anything})/\Gamma_{total}$ — Γ_8/Γ

This ratio includes η particles from η' decays.

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
29.9±2.2±1.7		DOBBS	09	CLEO	e^+e^- at 4170 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
23.5±3.1±2.0	674 ± 91	HUANG	06B	CLEO	See DOBBS 09

$\Gamma(\omega \text{anything})/\Gamma_{total}$ — Γ_9/Γ

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
6.1±1.4±0.3	DOBBS	09	CLEO	e^+e^- at 4170 MeV

$\Gamma(\eta' \text{anything})/\Gamma_{total}$ — Γ_{10}/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
10.3±1.4 OUR AVERAGE	Error includes scale factor of 1.1.				
8.8±1.8±0.5	68	ABLIKIM	15Z	BES3	482 pb^{-1}, 4009 MeV
11.7±1.7±0.7		DOBBS	09	CLEO	e^+e^- at 4170 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
8.7±1.9±0.8	68	HUANG	06B	CLEO	See DOBBS 09

$\Gamma(f_0(980) \text{anything}, f_0 \to \pi^+\pi^-)/\Gamma_{total}$ — Γ_{11}/Γ

VALUE (units 10^{-2})	CL%	DOCUMENT ID		TECN	COMMENT
<1.3	90	DOBBS	09	CLEO	e^+e^- at 4170 MeV

$\Gamma(\phi \text{anything})/\Gamma_{total}$ — Γ_{12}/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
15.7±0.8±0.6		DOBBS	09	CLEO	e^+e^- at 4170 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
16.1±1.2±1.1	398 ± 27	HUANG	06B	CLEO	See DOBBS 09

$\Gamma(K^+K^- \text{anything})/\Gamma_{total}$ — Γ_{13}/Γ

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
15.8±0.6±0.3	DOBBS	09	CLEO	e^+e^- at 4170 MeV

CLEOc dominants the D_s Branching Fraction measurements. (Sys. Err. Dominates CF modes. Many SCS&DCS modes observed.)

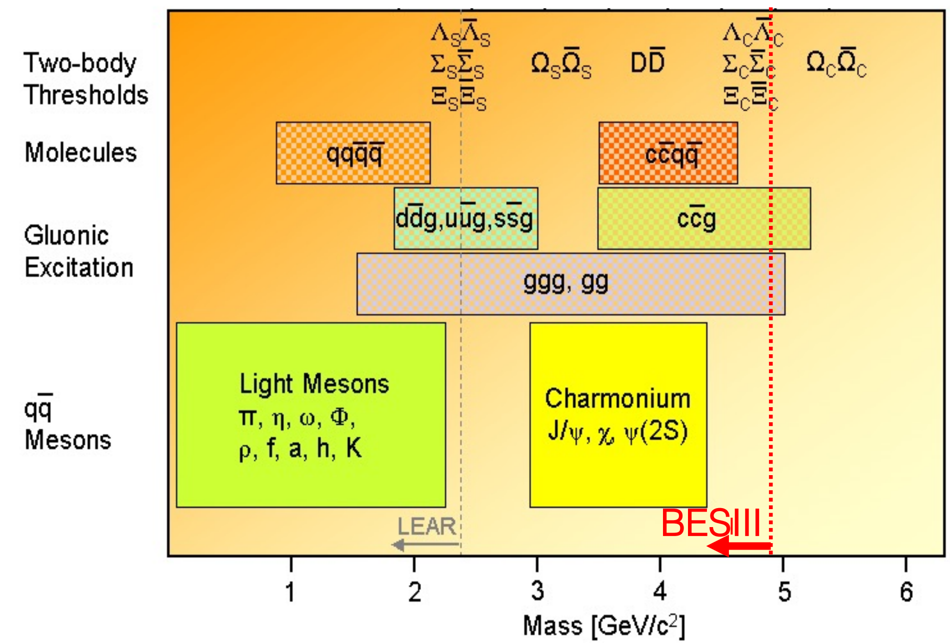
Citation: P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020)

Λ_c^+ REFERENCES

We have omitted some papers that have been superseded by later experiments. The omitted papers may be found in our 1992 edition (Physical Review **D45**, 1 June, Part II) or in earlier editions.

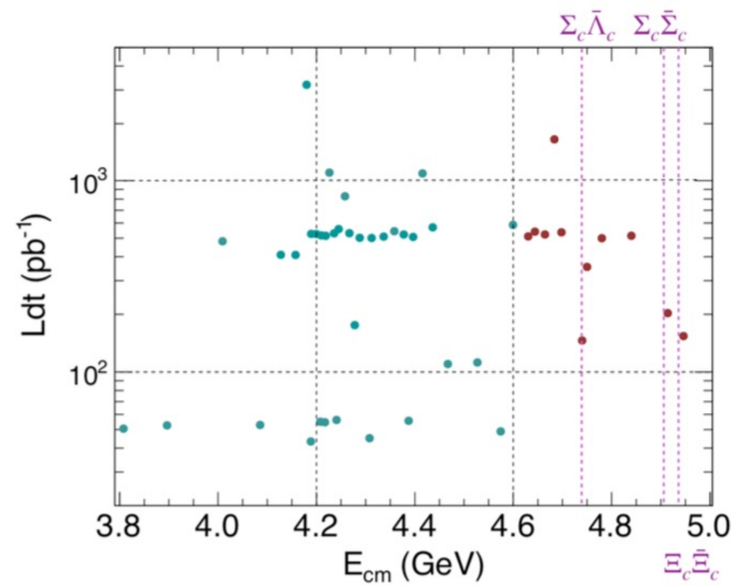
AAIJ	19AG	PR D100 032001	R. Aaij *et al.*	(LHCb Collab.)
ABLIKIM	19AX	PR D100 072004	M. Ablikim *et al.*	(BESIII Collab.) ★
ABLIKIM	19X	CP C43 083002	M. Ablikim *et al.*	(BESIII Collab.) ★
ABLIKIM	19Y	PR D99 032010	M. Ablikim *et al.*	(BESIII Collab.) ★
AAIJ	18N	PR D97 091101	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	18R	JHEP 1803 182	R. Aaij *et al.*	(LHCb Collab.)
AAIJ	18V	JHEP 1803 043	R. Aaij *et al.*	(LHCb Collab.)
ABLIKIM	18AF	PRL 121 251801	M. Ablikim *et al.*	(BESIII Collab.) ★
ABLIKIM	18E	PRL 121 062003	M. Ablikim *et al.*	(BESIII Collab.) ★
ABLIKIM	18Y	PL B783 200	M. Ablikim *et al.*	(BESIII Collab.) ★
BERGER	18	PR D98 112006	M. Berger *et al.*	(BELLE Collab.)
ABLIKIM	17D	PL B767 42	M. Ablikim *et al.*	(BESIII Collab.) ★
ABLIKIM	17H	PRL 118 112001	M. Ablikim *et al.*	(BESIII Collab.) ★
ABLIKIM	17Q	PR D95 111102	M. Ablikim *et al.*	(BESIII Collab.) ★
ABLIKIM	17Y	PL B772 388	M. Ablikim *et al.*	(BESIII Collab.) ★
PAL	17	PR D96 051102	B. Pal *et al.*	(BELLE Collab.)
ABLIKIM	16	PRL 116 052001	M. Ablikim *et al.*	(BESIII Collab.) ★
ABLIKIM	16U	PRL 117 232002	M. Ablikim *et al.*	(BESIII Collab.) ★
YANG	16	PRL 117 011801	S.B. Yang *et al.*	(BELLE Collab.)
ABLIKIM	15Y	PRL 115 221805	M. Ablikim *et al.*	(BESIII Collab.) ★
ZUPANC	14	PRL 113 042002	A. Zupanc *et al.*	(BELLE Collab.)
LEES	11G	PR D84 072006	J.P. Lees *et al.*	(BABAR Collab.)

Hadron Landscape



Hadron-physics challenges:

- Understanding of established states: precision spectroscopy
- Nature of exotic states: search and spectroscopy of unexpected states



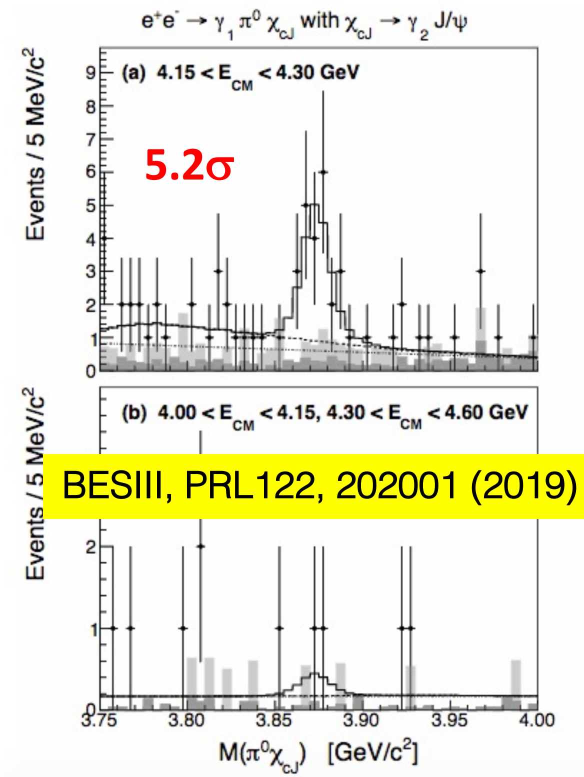
XYZ studies: about 23 /fb data above 3.8 GeV

At BESIII, two golden measures to study hadron spectroscopy, *esp*., to search for exotics

- Light hadrons: charmonium radiative decays (act as spin filter) (10 B J/ψ and 0.4 B $\psi(2S)$)
- Heavy hadrons: direct production, radiative and hadronic transitions (data above 3.8 GeV)

More X(3872) decay information

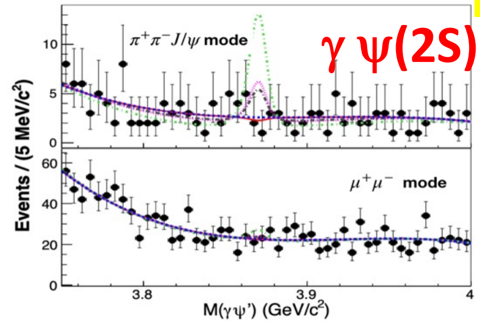
- Observation of X(3872) $\rightarrow \pi^0 \chi_{c1}$

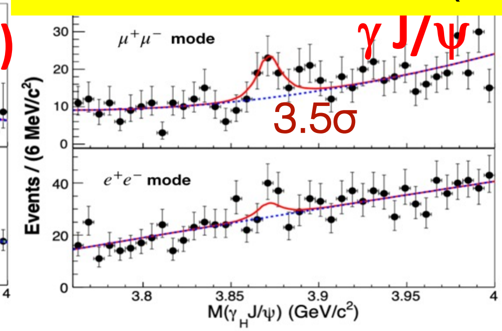


BESIII, PRL122, 202001 (2019)

- Transition of $X(3872) \rightarrow \gamma J/\psi$, $\gamma\psi(2S)$

BESIII, PRL 124, 242001 (2020)





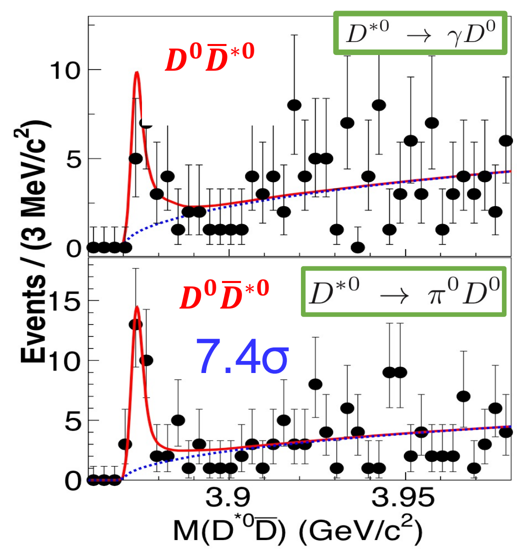
$R = \frac{BF(X(3872) \rightarrow \gamma\psi(2S))}{BF(X(3872) \rightarrow \gamma J/\psi)} < 0.59$ at 90% C.L. , agrees with Belle(<2.1), while challenges Babar(3.4±1.1) and LHCb results (2.46± 0.70)

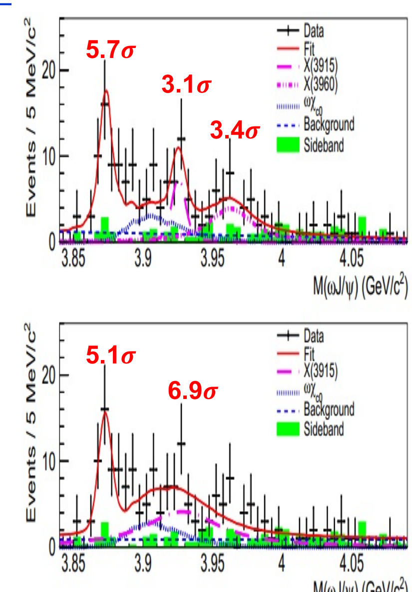
- Observation of X(3872) → ωJ/ψ

BESIII, PRL 122, 232002 (2019)

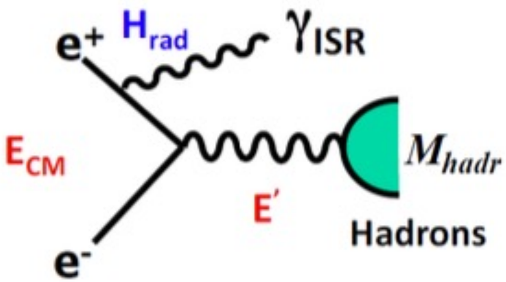
- Observation of X(3872) $\rightarrow D^0\bar{D}^{*0}$

BESIII, PRL 124, 242001 (2020)

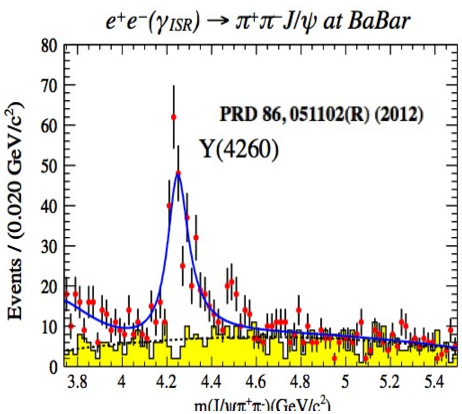


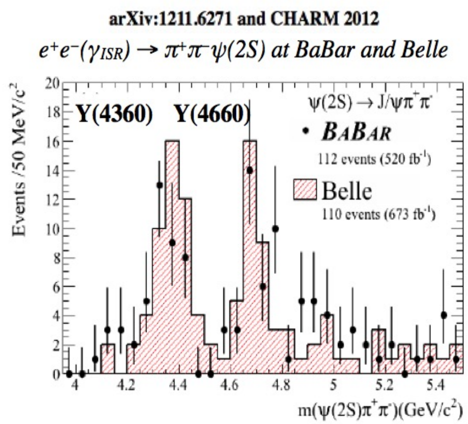


The Y states



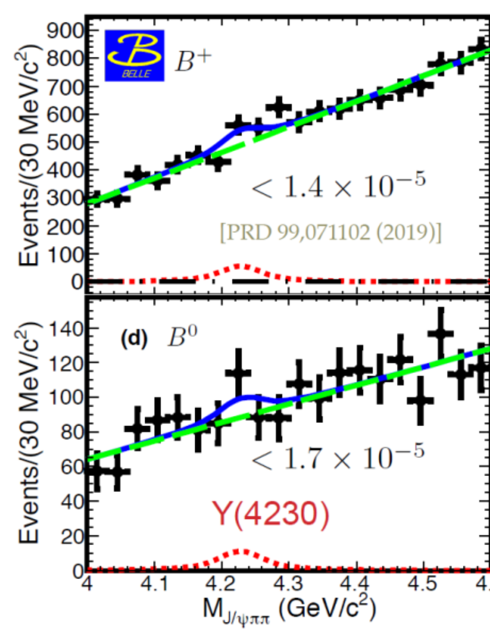
Y states: charmonium-like states with $J^{PC}=1^{--}$; Observed in direct e+e- annihilation or initial state radiation (ISR).



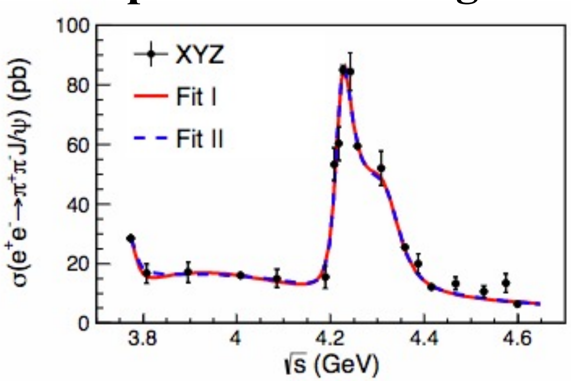


- **While not seen yet in B decays**

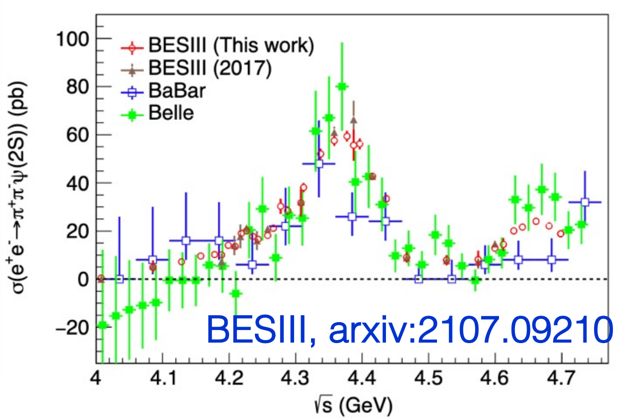
$B^{\pm,0} \to K^{\pm,0}\pi^+\pi^- J/\psi$



- **Improved knowledges from BESIII**

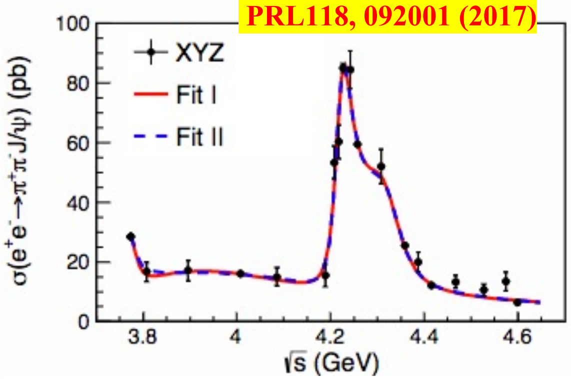


BESIII, PRL118, 092001 (2017)

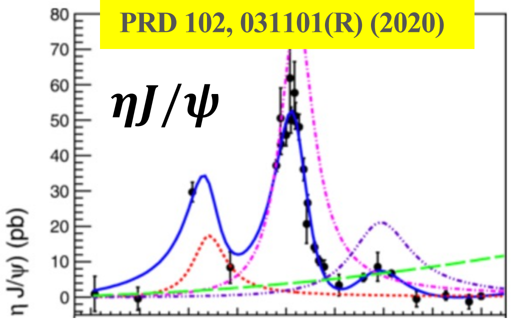


Y(4260) ➔ Y(4220) and new Y's

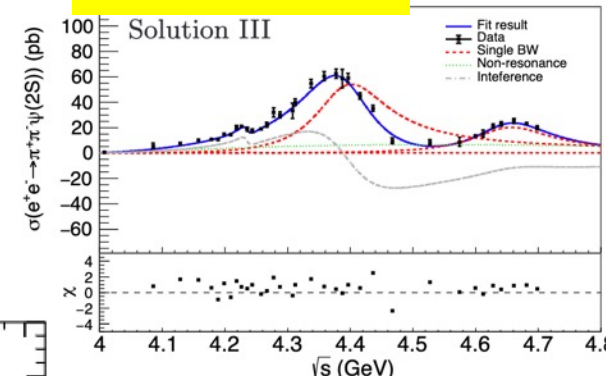
PRL118, 092001 (2017)



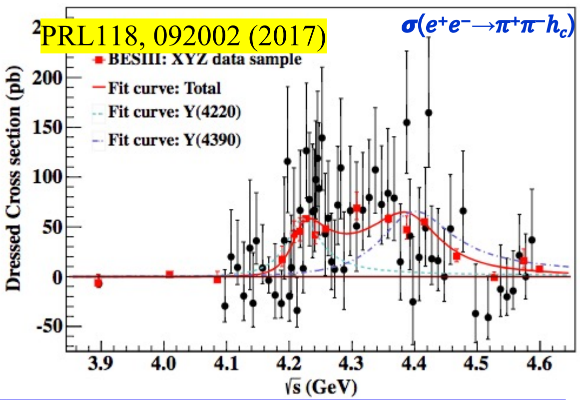
PRD 102, 031101(R) (2020)



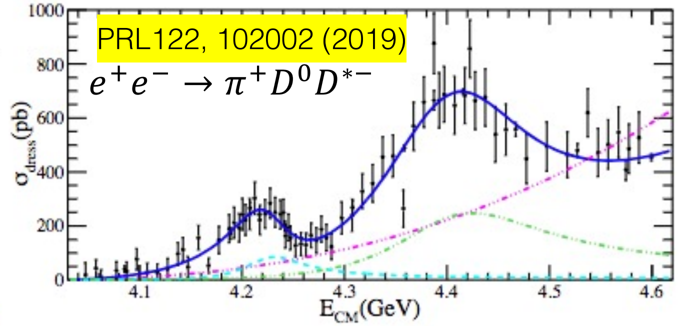
arxiv:2107.09210



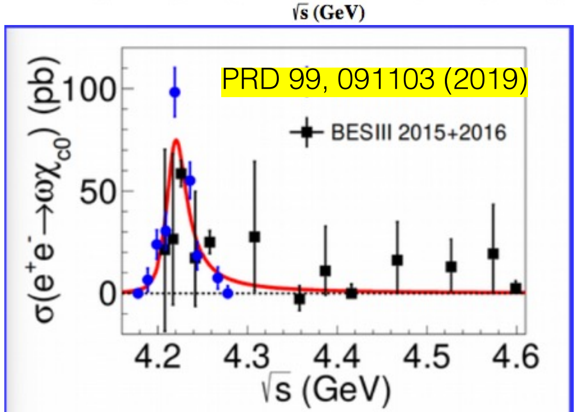
PRL118, 092002 (2017)

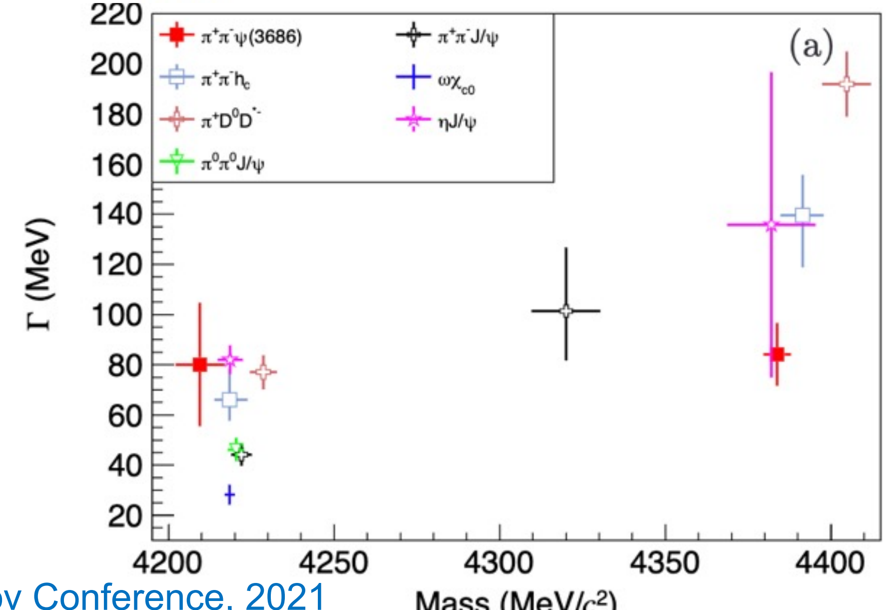


PRL122, 102002 (2019)



PRD 99, 091103 (2019)

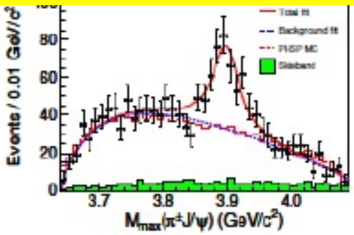




The Zc Family at BESIII

Zc(3900)$^+$

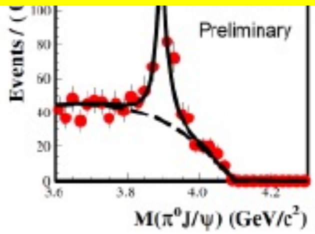
PRL 110, 252001 (2013)



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

Zc(3900)^0

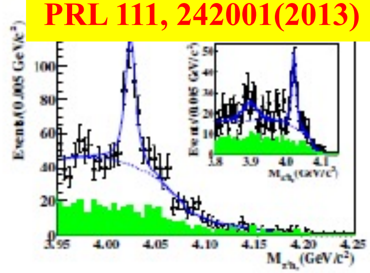
PRL 115, 112003 (2015)



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

Zc(4020)$^+$

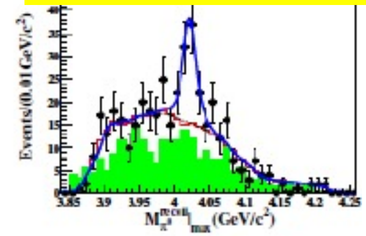
PRL 111, 242001(2013)



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

Zc(4020)^0

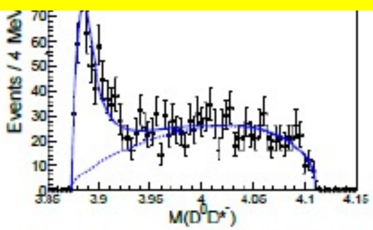
PRL113,212002 (2014)



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

Zc(3885)$^+$

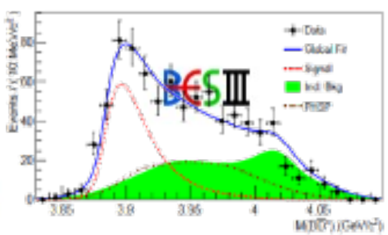
ST: PRL 112, 022001(2014)
DT: PRD92, 092006 (2015)



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

Zc(3885)^0

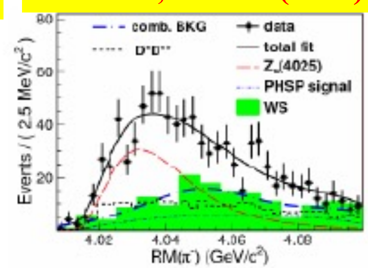
PRL 115, 222002 (2015)



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

Zc(4025)$^+$

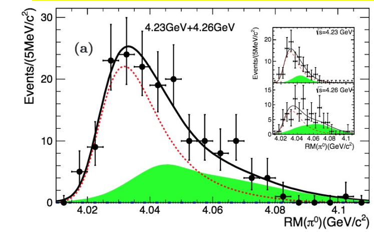
PRL 112, 132001 (2014)



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

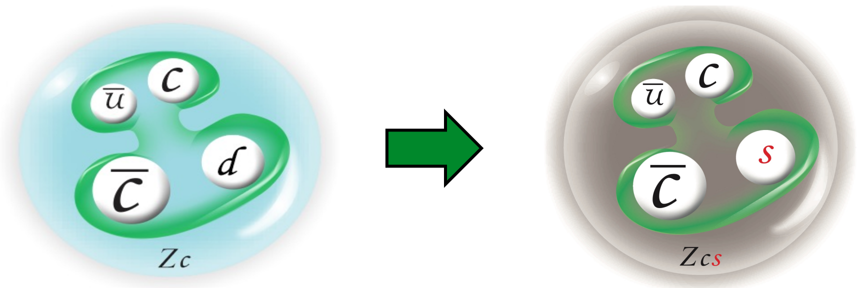
Zc(4025)^0

PRL115, 182002 (2015)



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

Which is the nature of these states?
If exists, there should be SU(3) counter-part Zcs state with strangeness

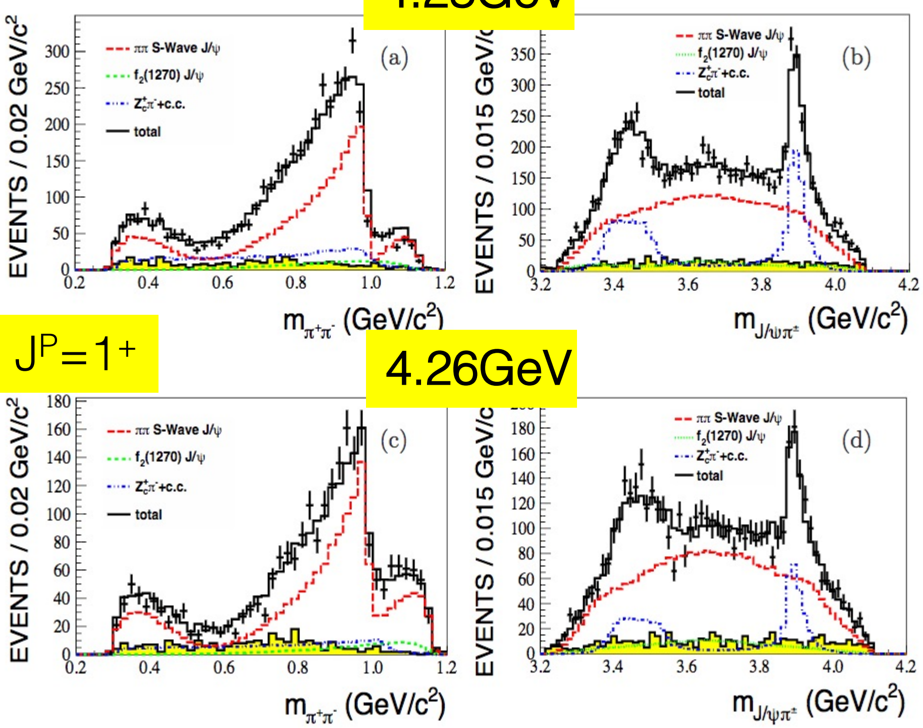


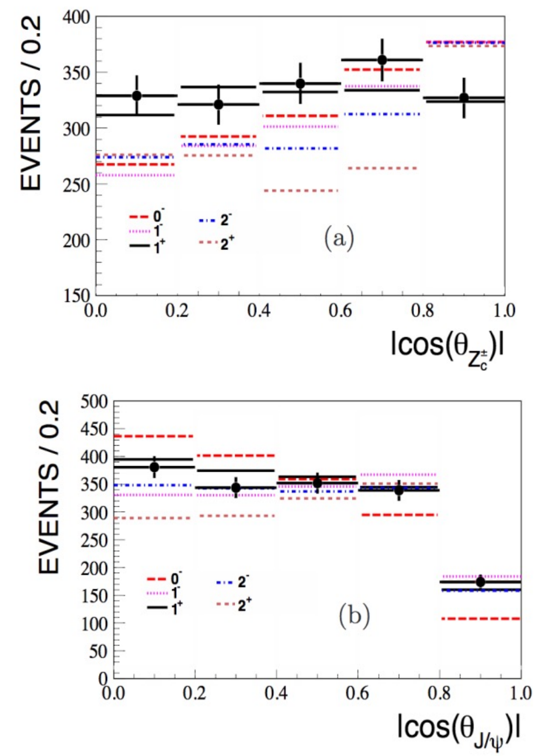
Spin-parity determination of the $Z_c^+(3900)$

- Zc line shape parameterized with Flatte-like formula

PRL 119.072001 (2017)

$$BW(s) = \frac{1}{s - M^2 + i(g_1' \rho_{\pi J/\psi}(s) + g_2' \rho_{D^* D}(s))},$$



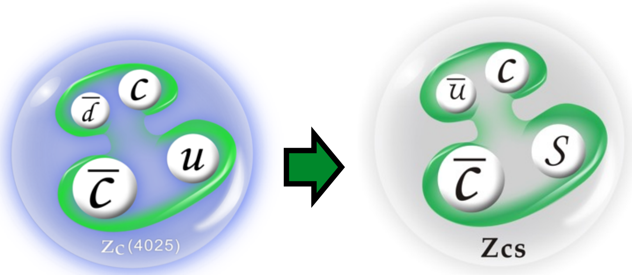


Hypothesis	$\Delta(-2\ln L)$	Δ(ndf)	Significance
1^+ over 0^-	94.0	13	7.6σ
1^+ over 1^-	158.3	13	10.8σ
1^+ over 2^-	151.9	13	10.5σ
1^+ over 2^+	96.0	13	7.7σ

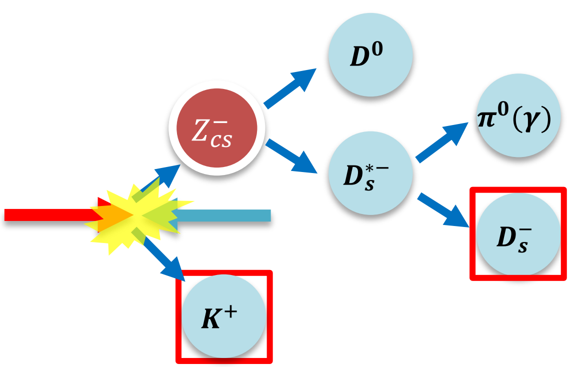
J^P is measured to be 1^+ with significance larger than $7.6\boldsymbol{\sigma}$

Zcs: SU(3) partner of Zc state

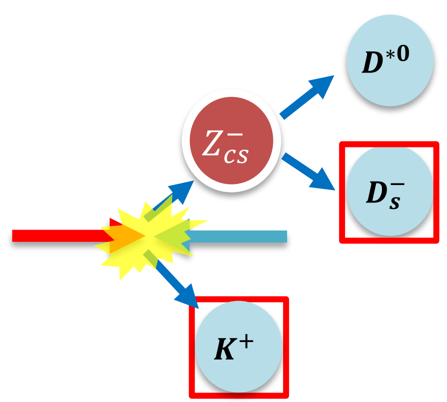
- **Important to look for Z_{cs}, the SU(3) partners of $X(3872)/Z_c(3900)$**
- **It's useful to distinguish different models**
  - Less exchange particles expected the Z_{cs} molecule picture



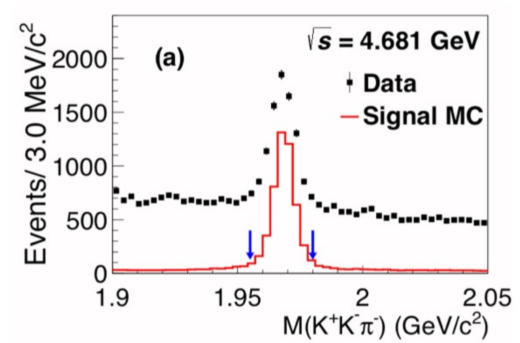
- BESIII analyzes 3.7fb^{-1} data at energies between 4.628 and 4.698GeV
- **Partial reconstruction of K^+ and D_s^-** PRL 126, 102001 (2021)
- Signature in the **recoil mass spectrum of $K^+D_s^-$** to identify the process of $e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$

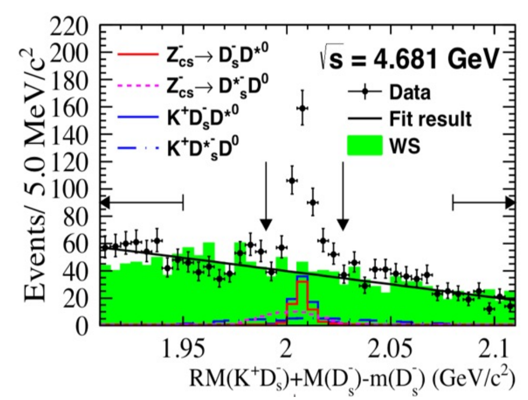


$e^+e^- \to K^+ D_s^{*-} D^0$



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

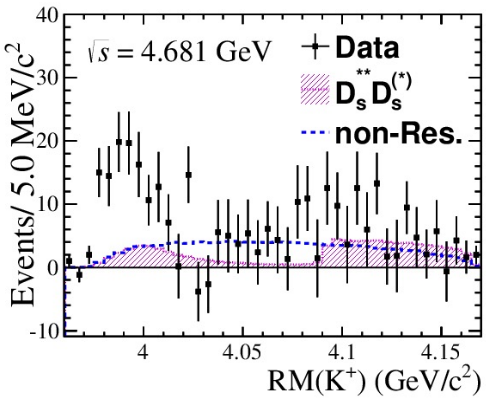


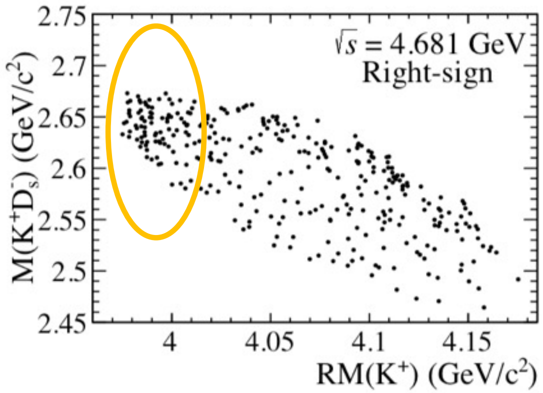


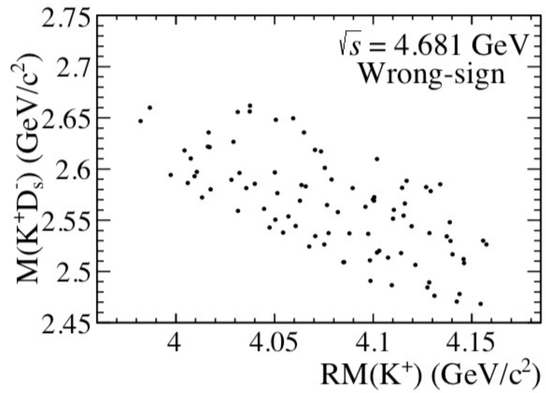
Observation of the $Z_{cs}(3985)^{\pm}$

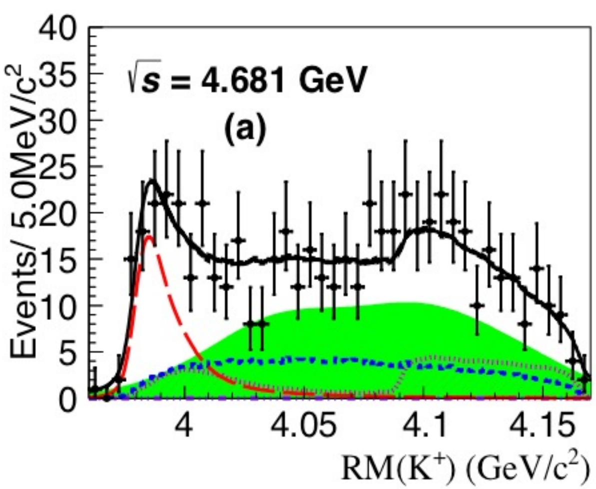
PRL 126, 102001 (2021)

- Data driven background description: wrong Sign (WS) combination of D_s^- and K^-
- Conventional charmed mesons can not describe the enhancement below 4.0 GeV/c^2 at 4.681 GeV









- Assume the structure as a $D_s^- D^{*0}/D_s^{*-} D^0$ resonance, denoting it as the $Z_{cs}(3985)^-$.
- A fit of $J^P=1^+$ S-wave Breit-Wigner with mass dependent width returns:

$$\boldsymbol{m} = 3985.2^{+2.1}_{-2.0} \pm 1.7 \text{ MeV/c}^2$$
$$\boldsymbol{\Gamma} = 13.8^{+8.1}_{-5.2} \pm 4.9 \text{ MeV}$$

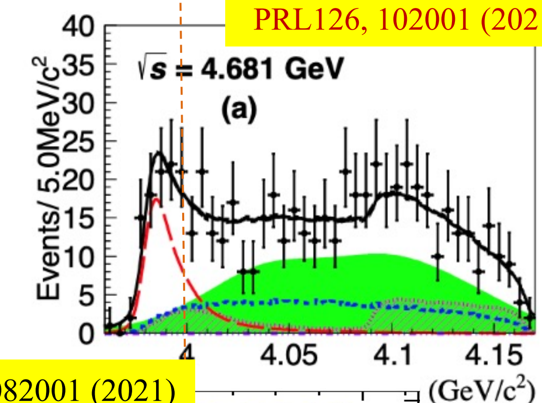
- Global significance: >5.3 $\boldsymbol{\sigma}$

First candidate of the hidden-charm tetraquark with strangeness

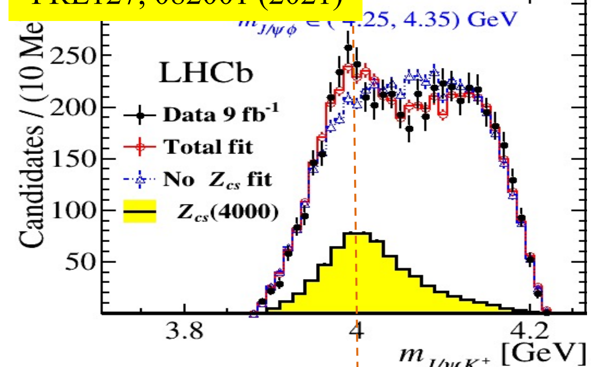
Discussions on the nature of $Z_{cs}(3985)^{\pm}$

- Various interpretations are possible for the structure
  - Tetraquark state
  - Molecule
  - $D_{s2}^{*}(2573)^{+}D_{s}^{*-}$ threshold kinematic effects (Re-scattering , Reflection, Triangle singularity)
  - Mixture of molecular and tetraquark
  - …

PRL126, 102001 (2021)

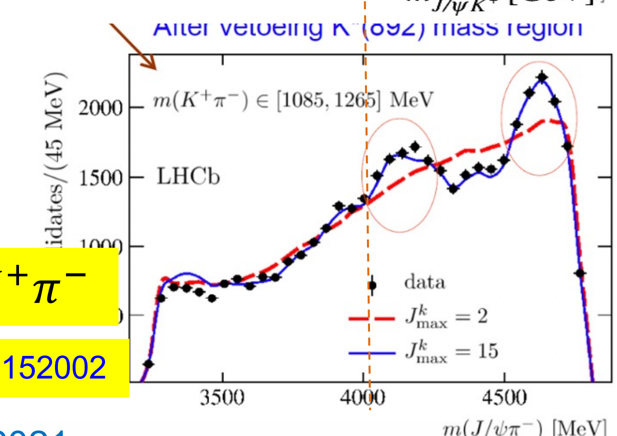


PRL127, 082001 (2021)



$Z_{cs}(3985)$ from e^+e^- annihilations and $Z_{cs}(4000)$ from B decays

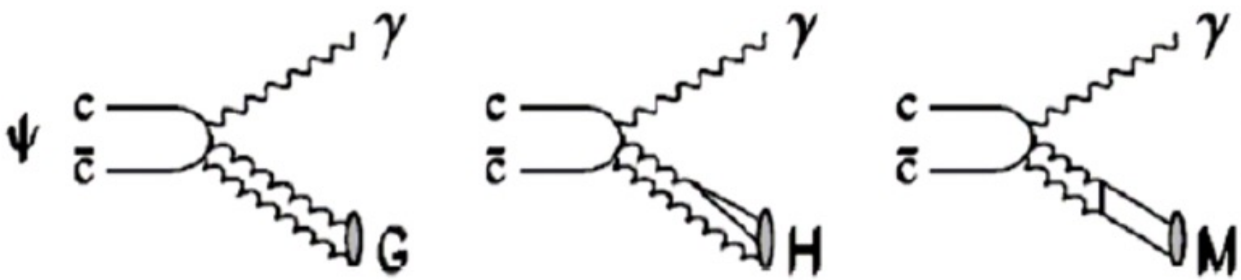
- their masses are close, but widths are different
- If they are same, why width so different?
- If they are not same, is there the corresponding wide Zc(3900)?
- Looking for more channels will be useful



$B^0 \to J/\psi K^+\pi^-$

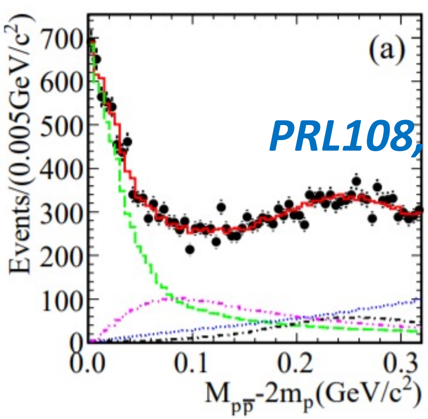
PRL 122 (2019) 152002

Light hadrons
(containing *u/d/s* quarks)



$X(p\bar{p})$/X(1835) from J/ψ radiative decays

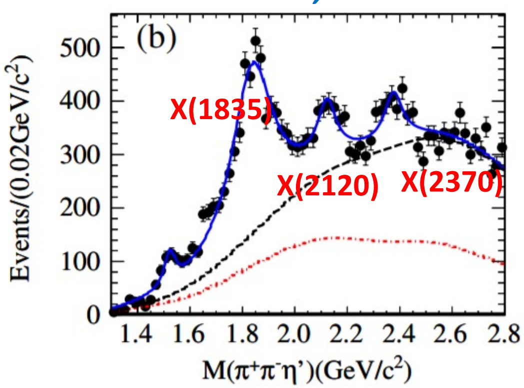
- $X(p\bar{p})$
  - An anomalous strong $p\bar{p}$ threshold enhancement structure which was first observed by BESII in $J/\psi\rightarrow\gamma p\bar{p}$
  - BESIII confirmed its existence with much higher significance and PWA (with FSI considered) is performed
    - 0^{-+}
    - Mass = $1836.5^{+19+18}_{-5\ -17} \pm 19$ MeV/c^2
    - Width < 76 MeV/c^2 @ 90% C.L.



PRL108, 112003

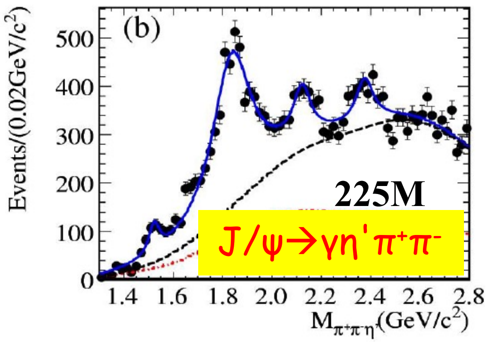
- X(1835)
  - First observed by BESII in $J/\psi\rightarrow\gamma\eta'\pi^+\pi^-$
  - BESIII confirmed its existence with much higher significance
    - **Spin-parity is not known**
    - Mass = $1836.5 \pm 3.0^{+5.6}_{-2.1}$ MeV/c^2
    - Width = $190 \pm 9^{+38}_{-36}$ MeV/c^2

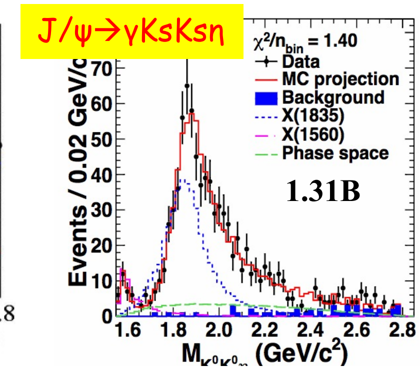
PRL106, 072002

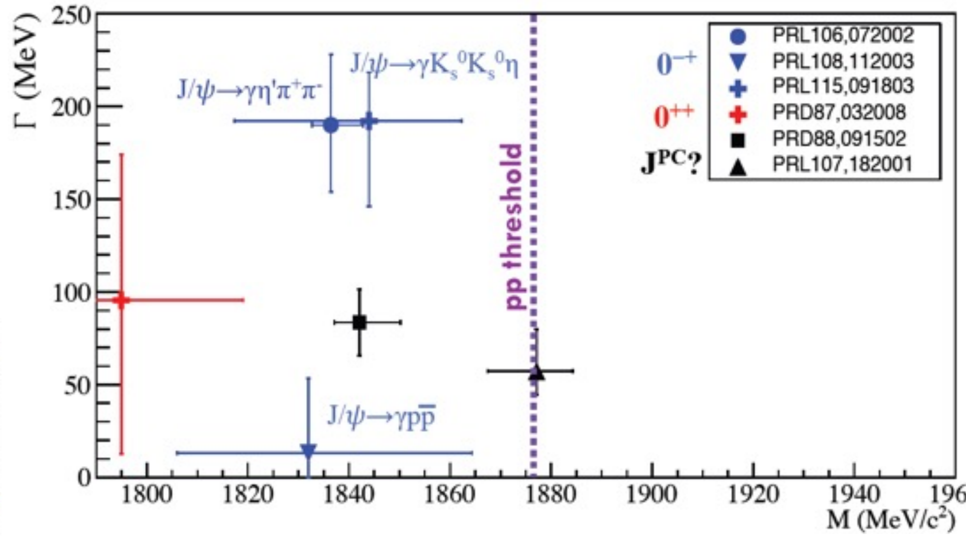


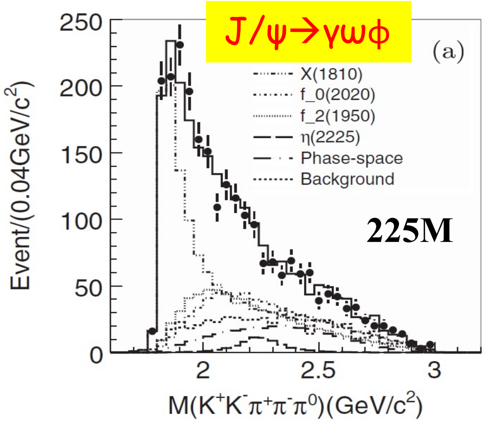
Are they the same state? A $p\bar{p}$ bound state?
What's the spin-parity of X(1835)?
Why their widths are so different?

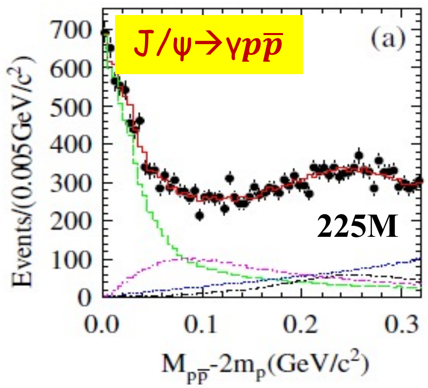
X($p\bar{p}$)/X(18??) from J/ψ radiative decays









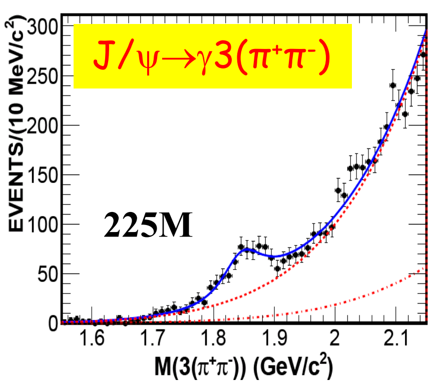


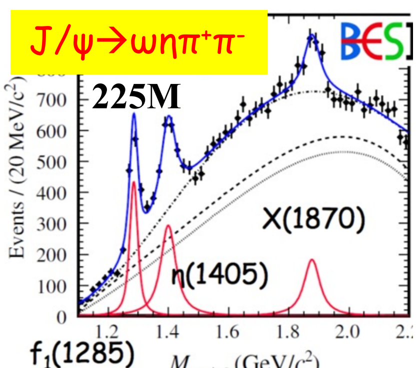
PRL117, 042002 (2016)

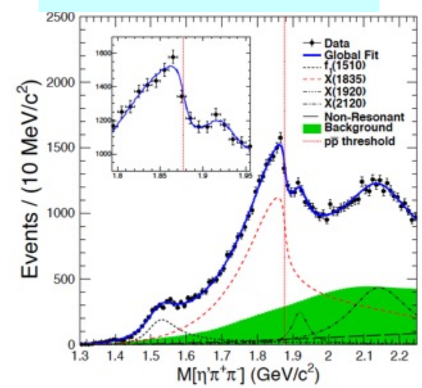
PRD97, 051101(R)(2018)

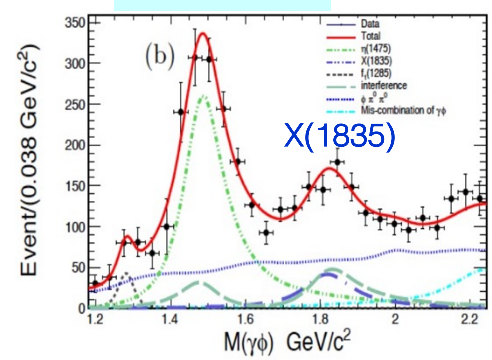
$J/\psi \to \gamma\eta'\pi^+\pi^-$

$J/\psi \to \gamma\gamma\phi$





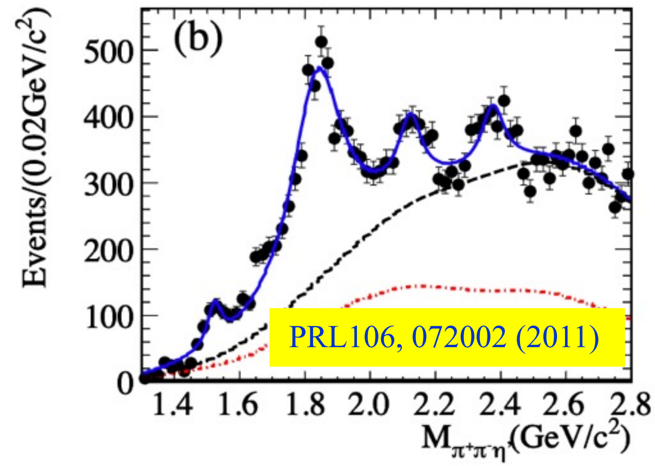




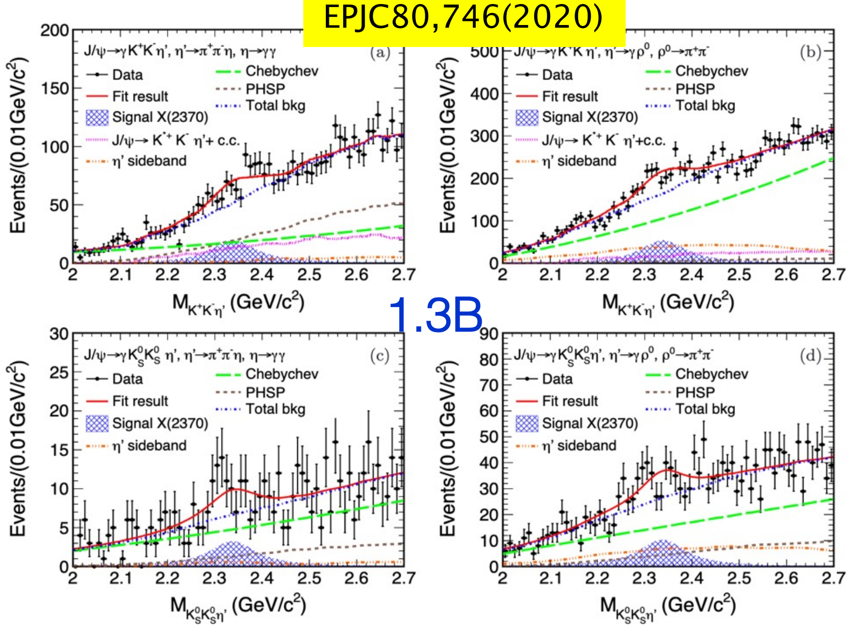
Are they the same state? It is crucial to understand their connections.

The X(2120) and X(2370)

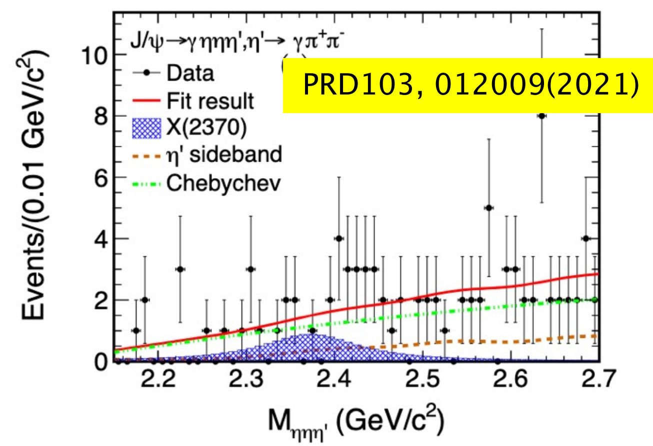
- Observed in $J/\psi \to \gamma\eta'\pi^+\pi^-$ at BESIII [PRL106, 072002 (2011)][PRL117, 042002(2016)]
- Candidates of glueball states
- Combined analysis of $J/\psi \to \gamma K^+K^-\eta'$ and $\gamma K_S K_S \eta'$
- Search for X(2370) in $J/\psi \to \gamma\eta\eta\eta'$



EPJC80,746(2020)



$$M_{X(2370)} = 2341.6 \pm 6.5(\text{stat.}) \pm 5.7(\text{syst.})\ \text{MeV}/c^2,$$
$$\Gamma_{X(2370)} = 117 \pm 10(\text{stat.}) \pm 8(\text{syst.})\ \text{MeV},$$

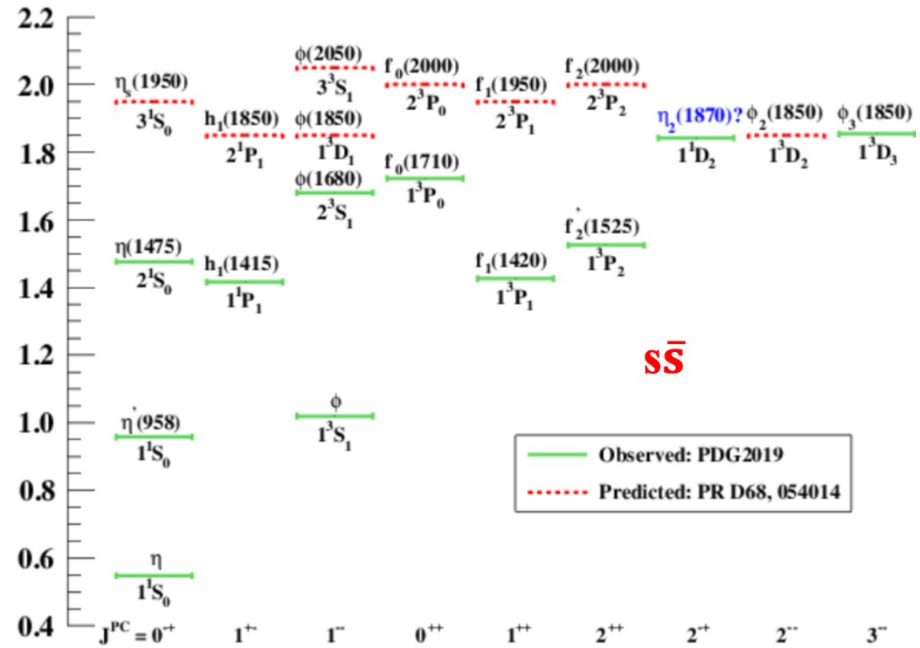


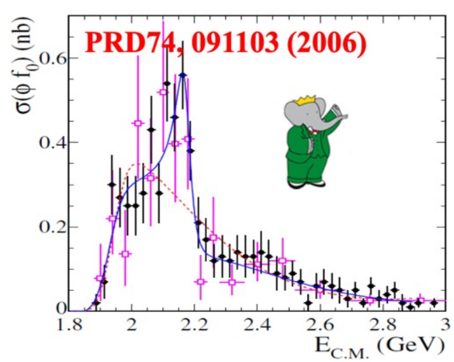
- Observation of $X(2370) \to K\bar{K}\eta'$ with stat. significance of 8.3σ
- No evidence of $X(2120) \to K\bar{K}\eta'$
- No evidence of $X(2370) \to K\bar{K}\eta'$

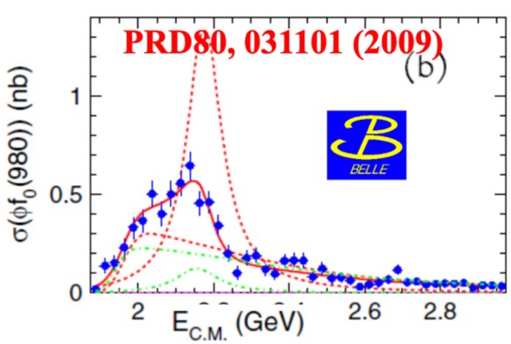
Studies on the $\phi(2170)/Y(2175)$

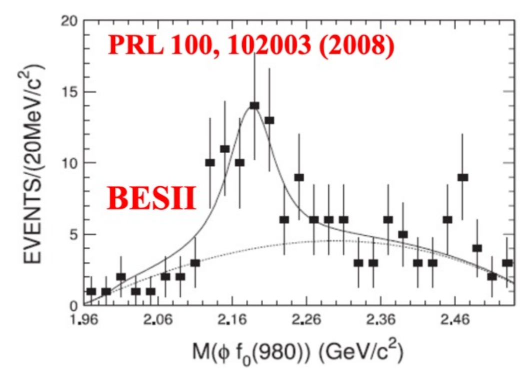
- A strangenium(-like) state: Y-particle with strange quark

> **Theorists explain $\phi(2170)$ as**
> - ✓ $s\bar{s}g$ hybrid
> - ✓ 2^3D_1 or 3^3S_1 $s\bar{s}$
> - ✓ tetraquark
> - ✓ Molecular state $\Lambda\bar{\Lambda}$
> - ✓ $\phi f_0(980)$ resonance with FSI
> - ✓ Three body system ϕKK



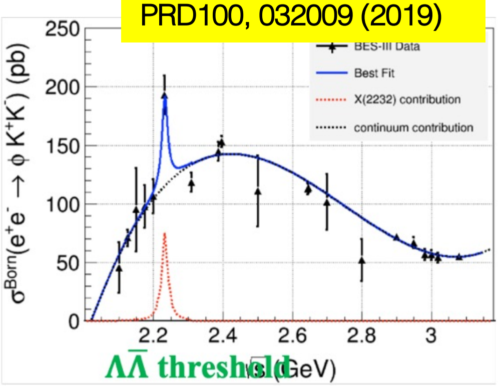




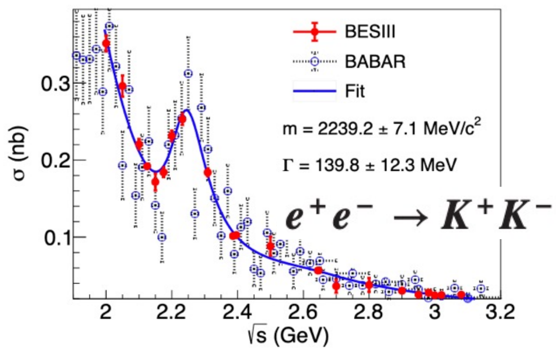


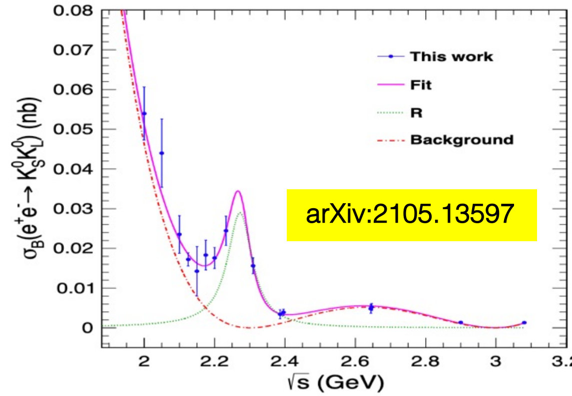
More results on the $\phi(2170)$/Y(2175)

PRD100, 032009 (2019)

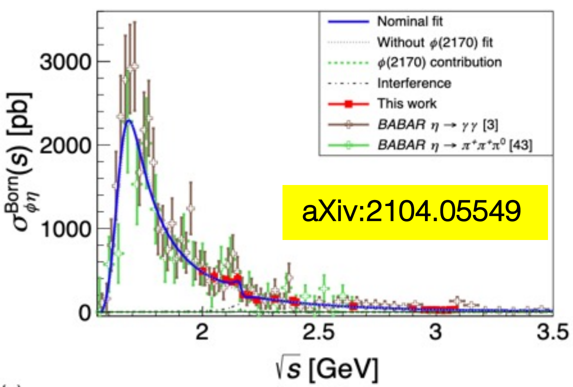


PRD99, 032001(2019)

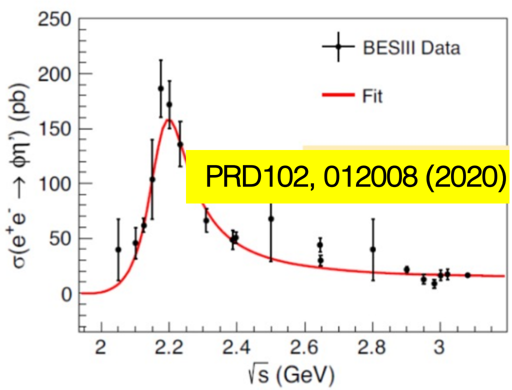




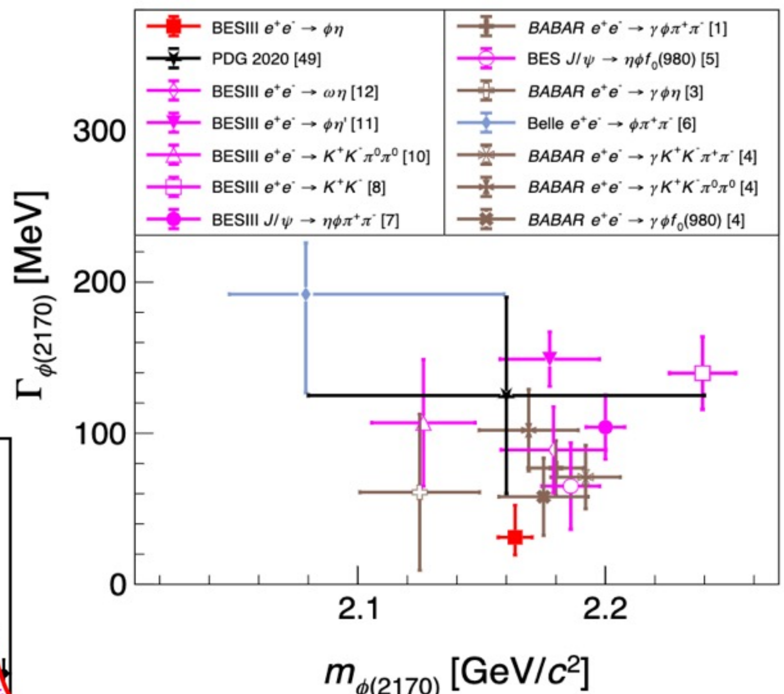
arXiv:2105.13597



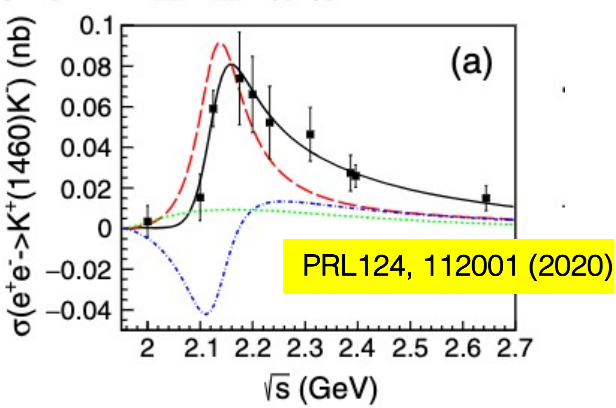
aXiv:2104.05549



PRD102, 012008 (2020)

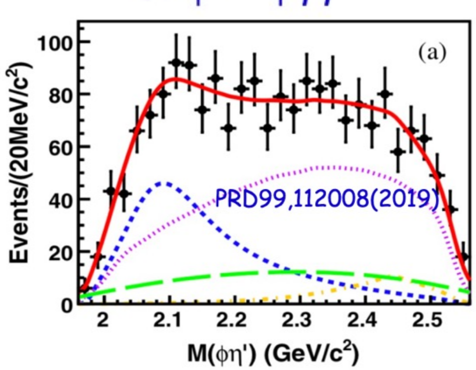


$e^+e^- \to K^+K^-\pi^0\pi^0$



PRL124, 112001 (2020)

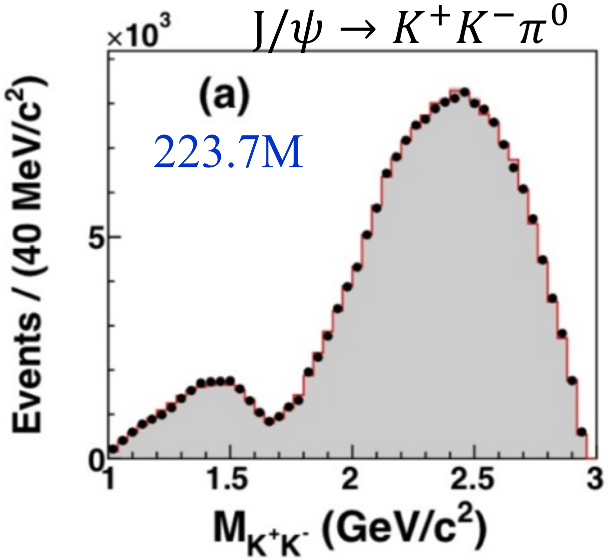
$J/\psi \to \phi\eta\eta'$



$\phi(2170)$/Y(2175) is still a mystery

Strangenium and strange-mesons in $J/\psi \to K^+K^-\pi^0$ and $\psi(3686) \to K^+K^-\eta$

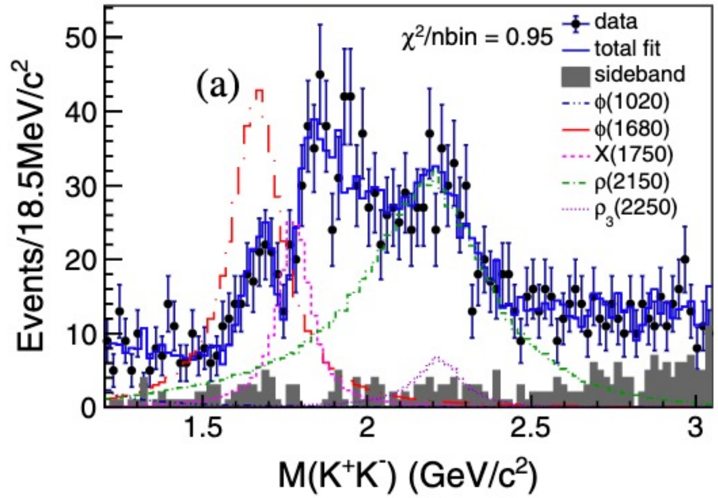
PRD100, 032004 (2019)



- First observations of $K_2^*(1980)$ and $K_4^*(2045)$ in J/ψ decays
- Two broad K^+K^- 1^{--} structures are observed: possible from $\omega(1650)$ and $\rho(2150)$

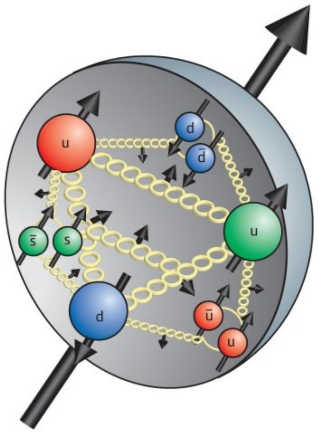
PRD101, 032008 (2020)

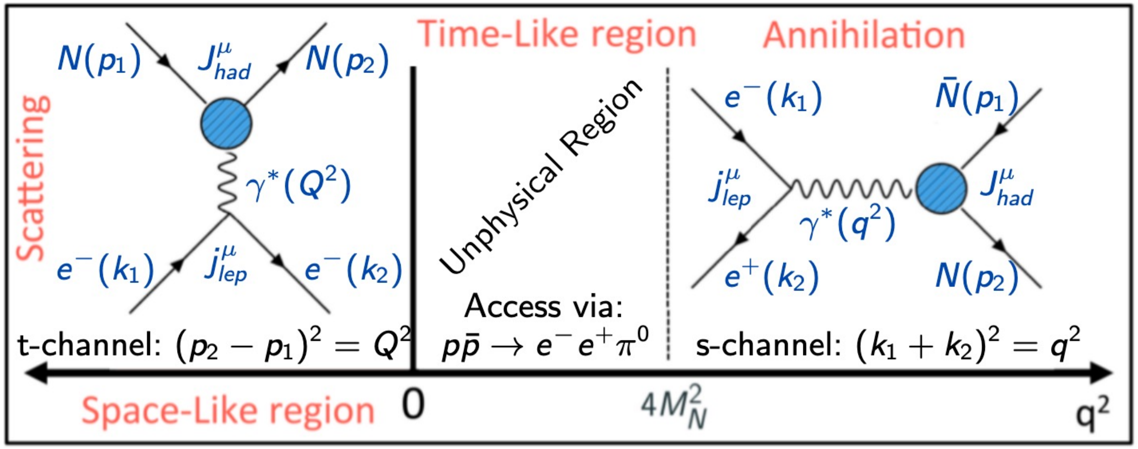
448M $\psi(3686)$ decays



- Dip around 1.75 GeV requires another 1^{--} resonance X(1750) to introduce interference with $\phi(1680)$: could be $\rho(1700)$ or X(1750) (photoproduction at FOCUS)
- Broad K^+K^- structure around 2.2 GeV: contributions from $\rho(2150)$ and/or $\rho_3(2250)$ resonances

Form factors of baryons



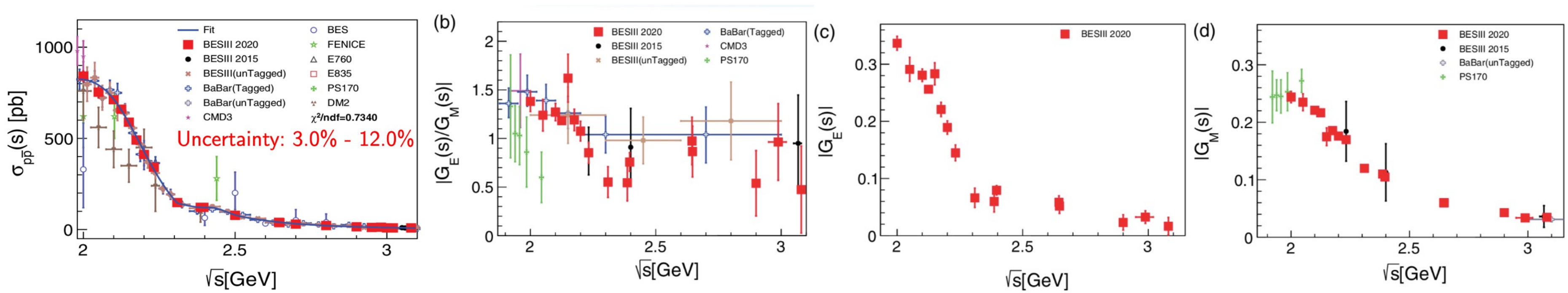


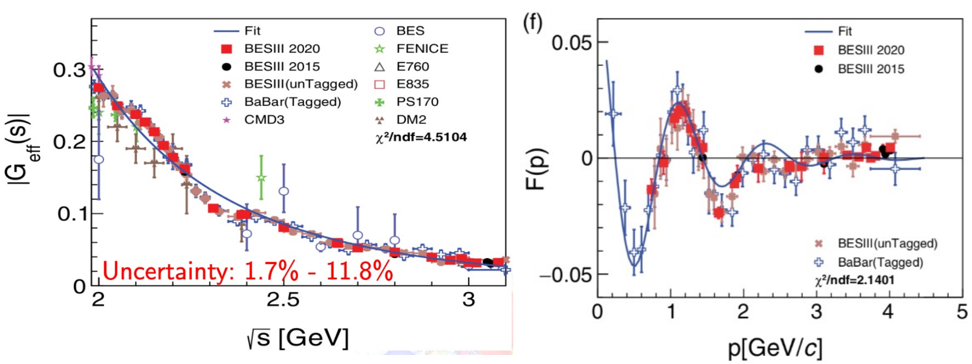
In the time-like region, access to the Electromagnetic Form Factors (EFF) of the baryons, which characterize the internal structure of the baryon

Threshold production of the nucleon

$$\frac{d\sigma_{p\bar{p}}(s)}{d\Omega} = \frac{\alpha^2\beta C}{4s}\left[|G_M(s)|^2(1+\cos^2\theta) + \frac{4m_p^2}{s}|G_E(s)|^2\sin^2\theta\right]$$

BESIII 2020 energy scan: PRL124, 042001 (2020)
BESIII untagged ISR: PRD99, 092002 (2019)
BESIII 2015 energy scan: PRD91, 112004(2015)





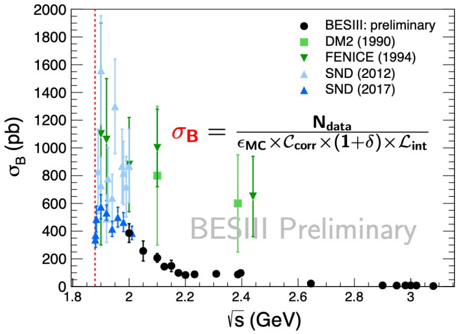
$$|G_{\rm eff}| = \sqrt{\frac{2\tau|G_{\rm M}|^2 + |G_{\rm E}|^2}{2\tau+1}}$$

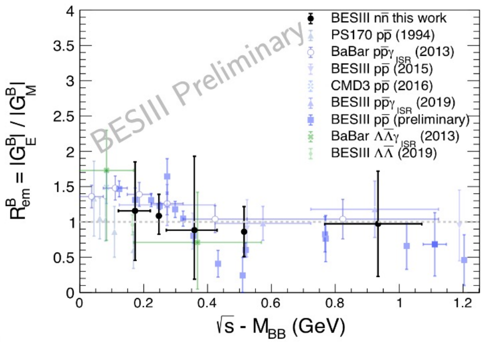
- BESIII provides best precisions: cross section threshold enhancement established
- Oscillating structures observed in the EFF after subtracted the modified dipole parameterization [PRL**114**, 232301 (2015)]
  - confirming the observation at BaBar

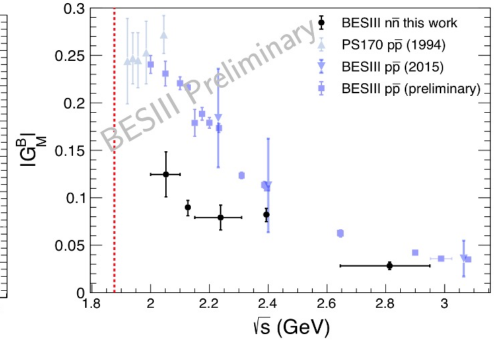
Threshold production of $e^+e^- \to n\bar{n}$

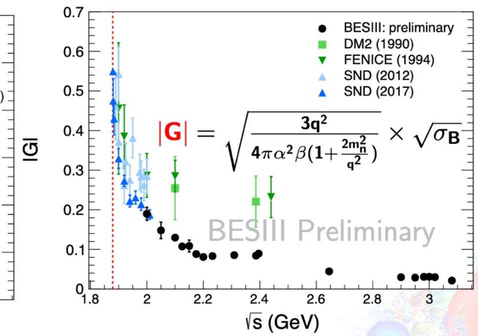
arXiv: 2103.12486
Accepted by Nature Physics

- Very challenging measurement due to pure neutron final states
- BESIII takes three approaches and provide validations among each other

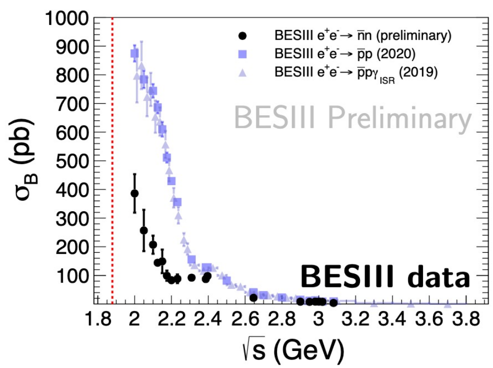


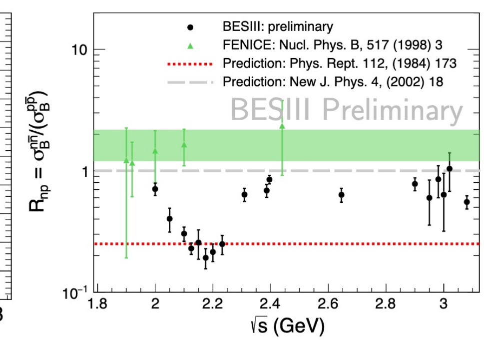


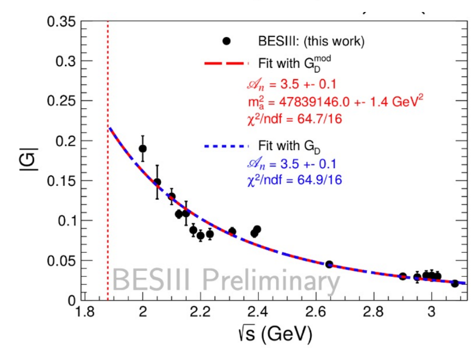


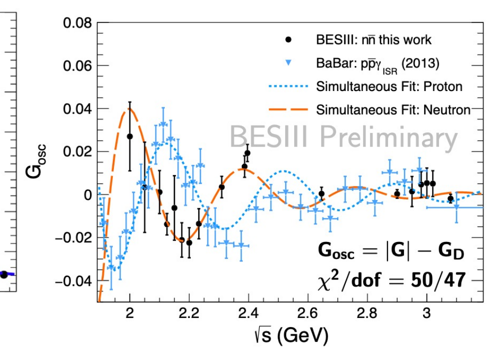


- XS measured in a wide range with unprecedented precision (~10%): confirming threshold enhancement
- EFF ratio R_{em} and G_M determined for the first time
- XS ratio between proton and neutron: do not support the FENICE conjecture, but are within the theoretical predictions
- Oscillation of EFF observed in neutron data: simultaneous fit of proton and neutron data gives shared frequency (5.55±0.28) GeV^{-1} with almost orthogonal phase difference of (125±12)^{O}





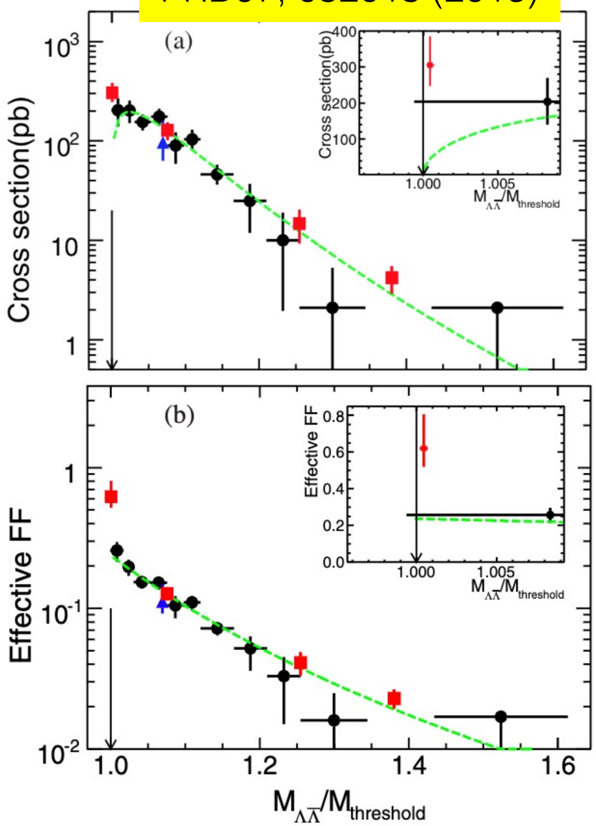




Form factors of hyperons

- Through the weak decay of hyperons, we could probe its polarization. Hence more information of the EFF can be studied
- $\Delta\phi$ is the phase angle difference of G_E and G_M: can be explored via angular analysis of the spin-coherent hyperon-pair weak decays

PRD97, 032013 (2018)



Threshold enhancement observed

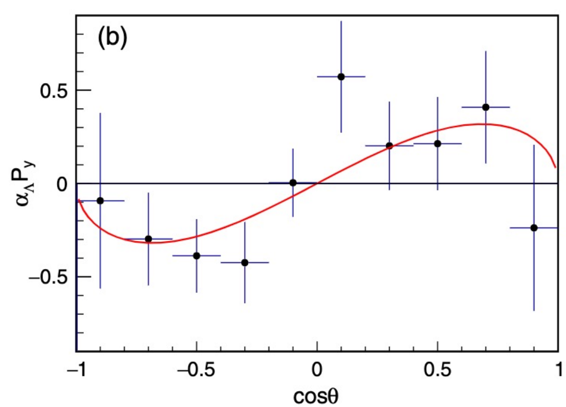
Unpolarized part Polarized part Spin correlated part

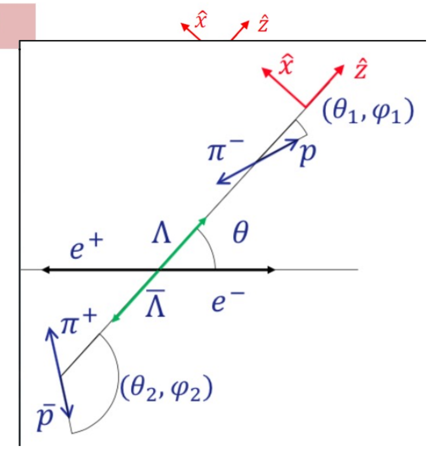
$$W(\xi) = F_0(\xi) + \eta F_5(\xi) + \alpha\bar{\alpha}\left(F_1(\xi) + \sqrt{1-\eta^2}\cos(\Delta\Phi) F_2(\xi) + \eta F_6(\xi)\right)$$
$$+\sqrt{1-\eta^2}\sin(\Delta\Phi)\left(\alpha F_3(\xi) + \bar{\alpha} F_4(\xi)\right)$$

$$R = |G_E/G_M|,\ \Delta\Phi = \Phi_E - \Phi_M,\ \eta = \frac{\tau - R^2}{\tau + R^2}$$

- First complete EFF measurement of the Λ at 2.396 GeV

PRL123,122003 (2019)



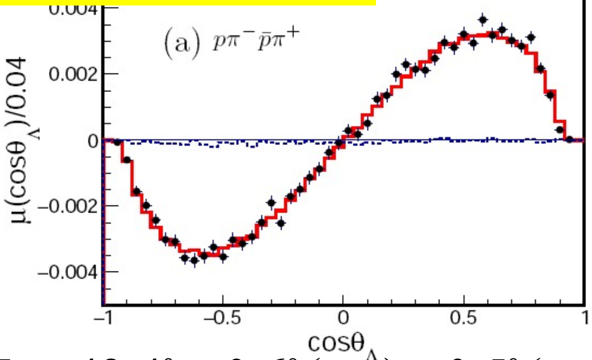


R	0.96±0.14±0.02
Δϕ	37°±12°±6°

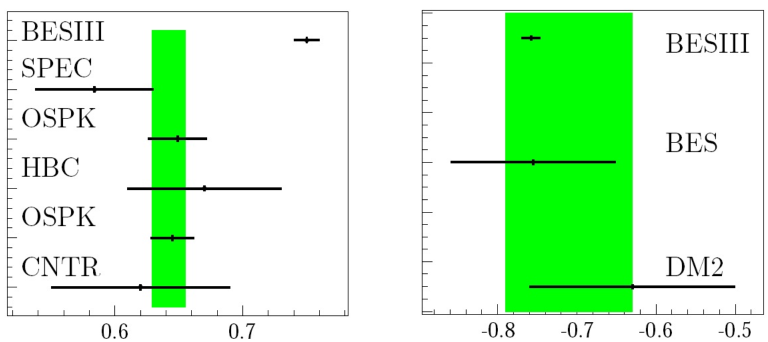
Hyperons produced at ψ peaks

$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda} \to p\bar{p}\pi^+\pi^-$

Nature Physics 15, 631 (2019)



$$\Delta\Phi = 42.4^\circ \pm 0.6^\circ (sta) \pm 0.5^\circ (sys.)$$

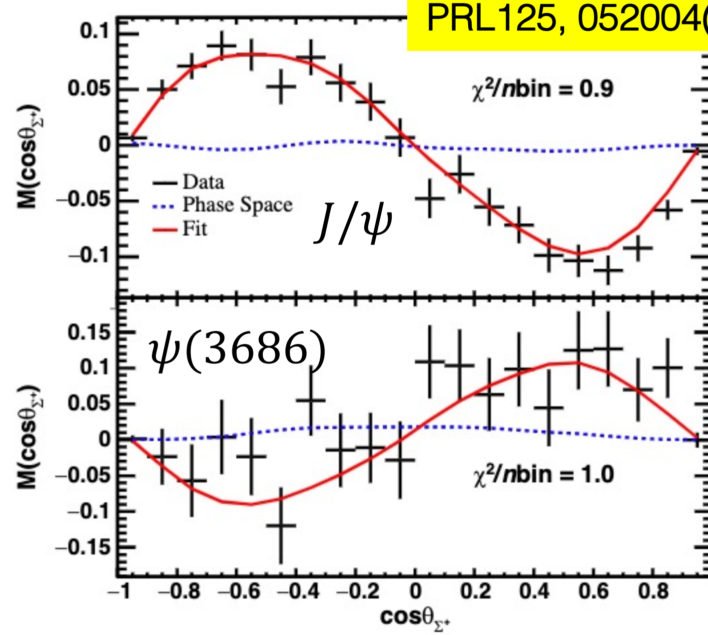


(a) α_- for $\Lambda \to p\pi^-$ (b) α_+ for $\bar{\Lambda} \to \bar{p}\pi^+$

- Very precise determination of hyperon decay asymmetry: ➔ CPV search
- Correct a long-history underestimation of Λ decay asymmetry

$e^+e^- \to \psi \to \Sigma^+\bar{\Sigma}^- \to p\bar{p}\pi^0\pi^0$

PRL125, 052004(2020)



Parameter	Measured value
$\alpha_{J/\psi}$	$-0.508 \pm 0.006 \pm 0.004$
$\Delta\Phi_{J/\psi}$	$-0.270 \pm 0.012 \pm 0.009$
$\alpha_{\psi'}$	$0.682 \pm 0.03 \pm 0.011$
$\Delta\Phi_{\psi'}$	$0.379 \pm 0.07 \pm 0.014$
α_0	$-0.998 \pm 0.037 \pm 0.009$
$\bar{\alpha}_0$	$0.990 \pm 0.037 \pm 0.011$

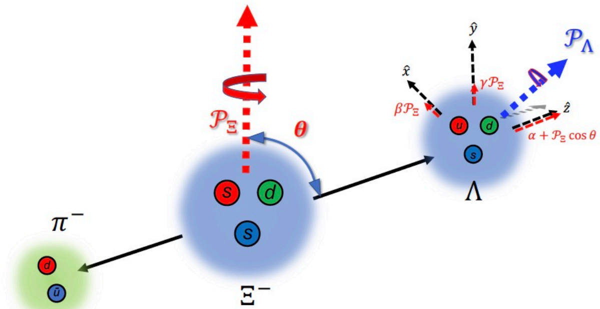
CPV in $\Xi^- \rightarrow \Lambda\pi^-$ decay

BESIII: arXiv:2105.11155

$$e^+e^- \rightarrow J/\psi \rightarrow \Xi^-\bar{\Xi}^+$$

Parameter	This work	Previous result	Ref.
α_ψ	$0.586 \pm 0.012 \pm 0.010$	$0.58 \pm 0.04 \pm 0.08$	38
$\Delta\Phi$	$1.213 \pm 0.046 \pm 0.016$ rad.	–	
α_Ξ	$-0.376 \pm 0.007 \pm 0.003$	-0.401 ± 0.010	22
ϕ_Ξ	$0.011 \pm 0.019 \pm 0.009$ rad.	-0.037 ± 0.014 rad.	22
$\alpha_{\bar{\Xi}}$	$0.371 \pm 0.007 \pm 0.002$	–	
$\phi_{\bar{\Xi}}$	$-0.021 \pm 0.019 \pm 0.007$ rad.	–	
α_Λ	$0.757 \pm 0.011 \pm 0.008$	$0.750 \pm 0.009 \pm 0.004$	3
$\alpha_{\bar{\Lambda}}$	$-0.763 \pm 0.011 \pm 0.007$	$-0.758 \pm 0.010 \pm 0.007$	3
$\xi_p - \xi_s$	$(1.2 \pm 3.4 \pm 0.8) \times 10^{-2}$ rad.	–	
$\delta_p - \delta_s$	$(-4.4 \pm 3.6 \pm 1.8) \times 10^{-2}$ rad.	$(8.7 \pm 3.3) \times 10^{-2}$ rad.	2
A_{CP}^{Ξ}	$(6.0 \pm 13.4 \pm 5.6) \times 10^{-3}$	–	
$\Delta\phi_{CP}^{\Xi}$	$(-4.8 \pm 13.7 \pm 2.9) \times 10^{-3}$ rad.	–	
A_{CP}^{Λ}	$(-3.7 \pm 11.7 \pm 9.0) \times 10^{-3}$	$(-6 \pm 12 \pm 7) \times 10^{-3}$	3
$< \phi_\Xi >$	$0.016 \pm 0.014 \pm 0.007$ rad.		

Based on 1.3 B J/ψ events (13% of total J/ψ events) 9-dimentional fit:



~73200 event candidates
Negligible background

First measurement of baryon weak phase difference

We obtain the same precision for ϕ as HyperCP with ***three orders of magnitude*** smaller data sample!

HyperCP: $\phi_{\Xi,HyperCP} = -0.042 \pm 0.011 \pm 0.011$
BESIII: $<\phi_\Xi> = 0.016 \pm 0.014 \pm 0.007$

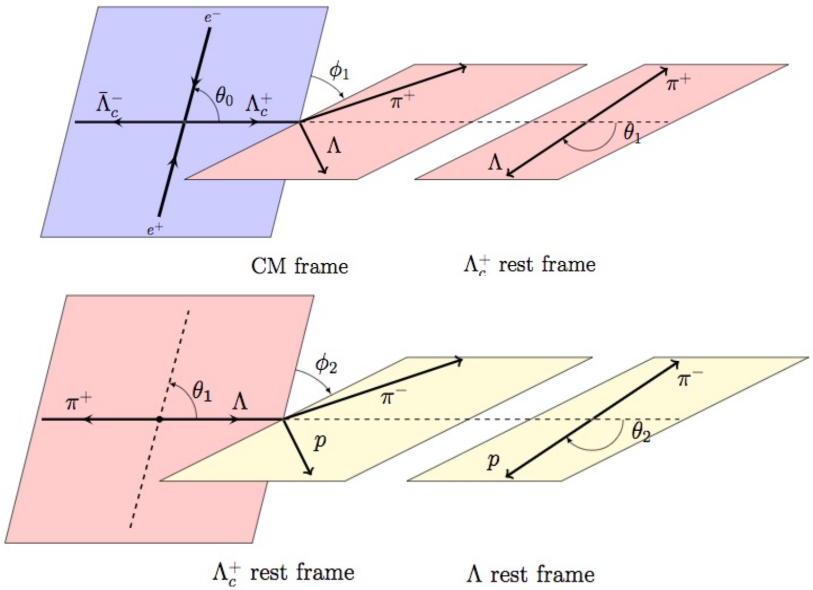
HyperCP: PRL 93(2004) 011802

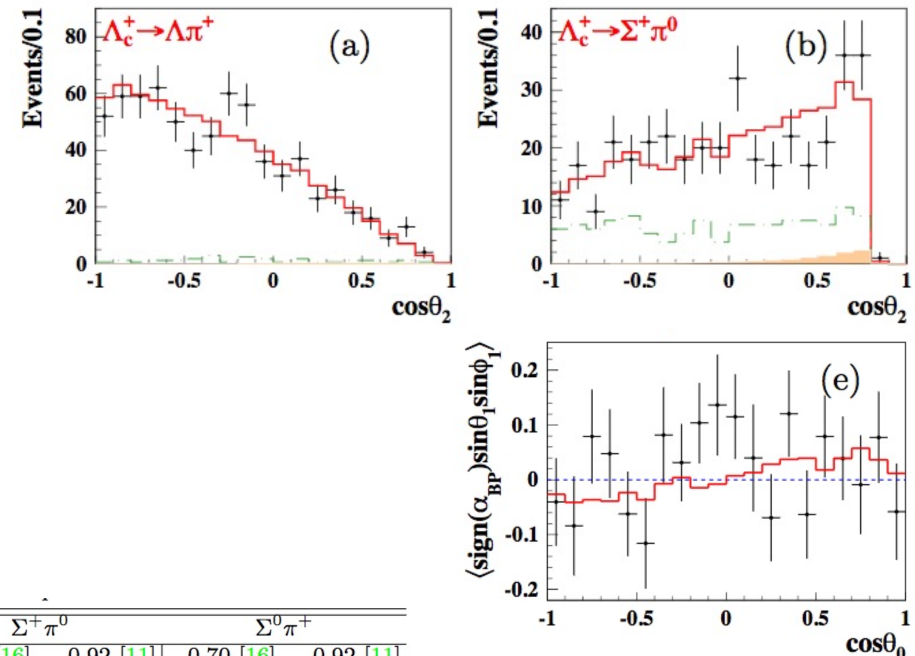
Λ_c decay asymmetries

single tag method

PRD100, 072004 (2019)

- 4(6)-fold angular analysis of the cascade decays of $\Lambda_c \to pK_s, \Lambda\pi^+, \Sigma^+\pi^0$ and $\Sigma^0\pi^+$ based on 567/pb data

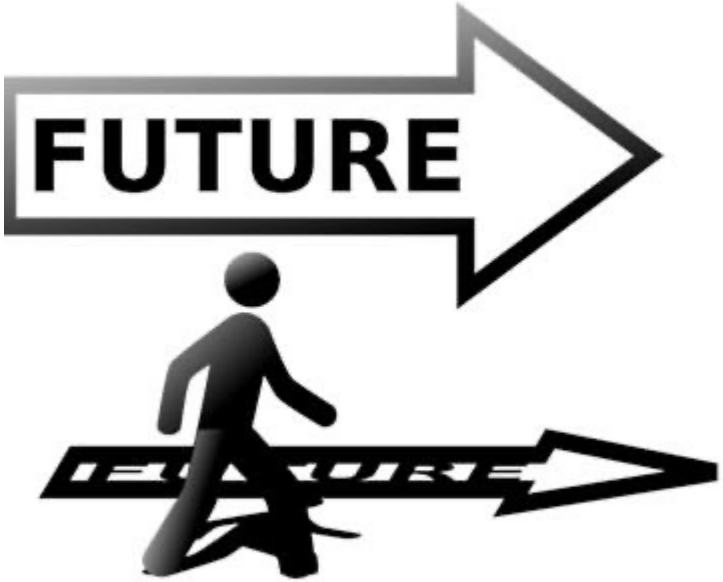




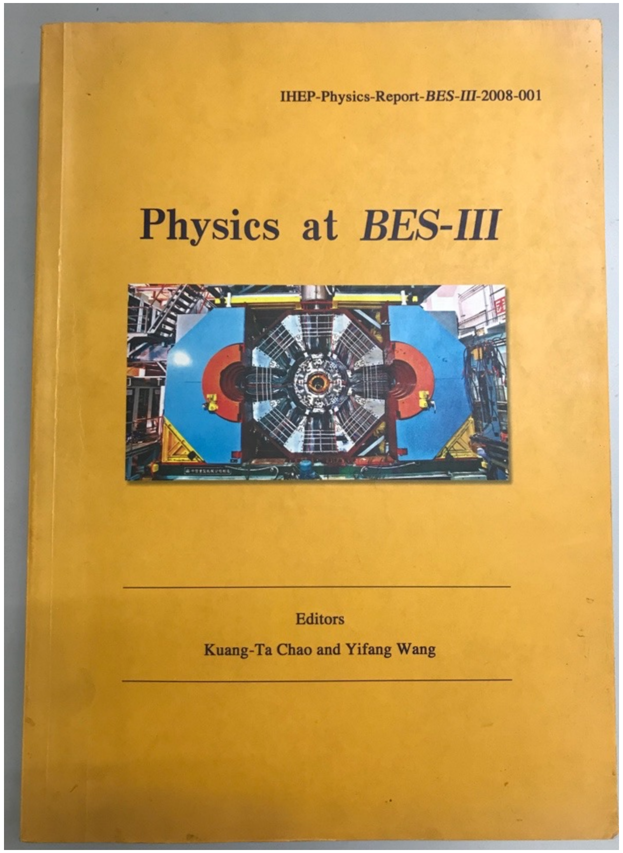
$\Lambda_c^+ \to$		pK_S^0	$\Lambda\pi^+$	$\Sigma^+\pi^0$	$\Sigma^0\pi^+$
$\alpha_{BP}^{\Lambda_c^+}$	Predicted	−1.0 [16], 0.51 [11]	−0.70 [16], −0.67 [11]	0.71 [16], 0.92 [11]	0.70 [16], 0.92 [11]
		−0.49 [10], −0.90 [10]	−0.95 [10], −0.99 [10]	0.79 [10] −0.49 [10]	0.78 [10], −0.49 [10]
		−0.49 [17], −0.97 [18]	−0.96 [17], −0.95 [18]	0.83 [17], 0.43 [18]	0.83 [17], 0.43 [18]
		−0.66 [19], −0.90 [30]	−0.99 [19], −0.86 [30]	0.39 [19], −0.76 [30]	0.39 [19], −0.76 [30]
		−0.99 [20], −0.91 [31]	−0.99 [20], −0.94 [31]	−0.31 [20], −0.47 [31]	−0.31 [20], −0.47 [31]
	PDG [2]		-0.91 ± 0.15	-0.45 ± 0.32	
	This work	$0.18 \pm 0.43 \pm 0.14$	$-0.80 \pm 0.11 \pm 0.02$	$-0.57 \pm 0.10 \pm 0.07$	$-0.73 \pm 0.17 \pm 0.07$

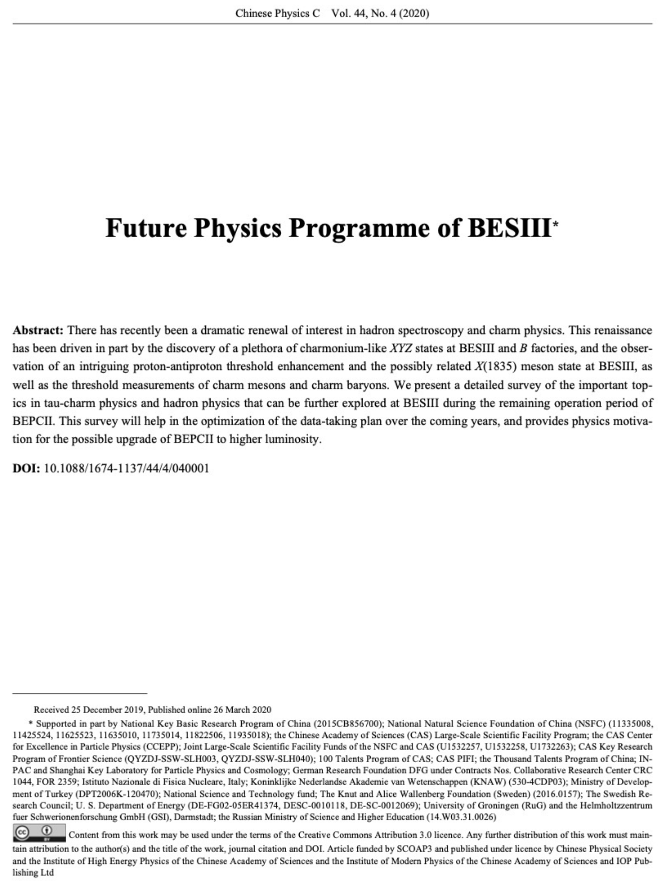
$\sin\Delta\phi = -0.28 \pm 0.13 \pm 0.03$

- Best precisions on the hadronic weak decay asymmetries
- The transverse polarization is firstly studied and found to be non-zero with 2.1σ


FUTURE

BESIII Physics





Chinese Physics C Vol. 44, No. 4 (2020)

Future Physics Programme of BESIII*

Abstract: There has recently been a dramatic renewal of interest in hadron spectroscopy and charm physics. This renaissance has been driven in part by the discovery of a plethora of charmonium-like *XYZ* states at BESIII and *B* factories, and the observation of an intriguing proton-antiproton threshold enhancement and the possibly related *X*(1835) meson state at BESIII, as well as the threshold measurements of charm mesons and charm baryons. We present a detailed survey of the important topics in tau-charm physics and hadron physics that can be further explored at BESIII during the remaining operation period of BEPCII. This survey will help in the optimization of the data-taking plan over the coming years, and provides physics motivation for the possible upgrade of BEPCII to higher luminosity.

DOI: 10.1088/1674-1137/44/4/040001

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Int. J. Mod. Phys. A 24, S1-794 (2009) [arXiv:0809.1869 [hep-ex]].

Chin. Phys. C 44, 040001 (2020) doi:10.1088/1674-1137/44/4/040001 [arXiv:1912.05983 [hep-ex]].

Planned future data set

Table 7.1: List of data samples collected by BESIII/BEPCII up to 2019, and the proposed samples for the remainder of the physics program. The most right column shows the number of required data taking days in current (T_C) or upgraded (T_U) machine. The machine upgrades include top-up implementation and beam current increase.

Energy	Physics motivations	Current data	Expected final data	T_C / T_U
1.8 - 2.0 GeV	R values Nucleon cross-sections	N/A	0.1 fb^{-1} (fine scan)	60/50 days
2.0 - 3.1 GeV	R values Cross-sections	Fine scan (20 energy points)	Complete scan (additional points)	250/180 days
J/ψ peak	Light hadron & Glueball J/ψ decays	3.2 fb^{-1} (10 billion)	3.2 fb^{-1} (10 billion)	N/A
$\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	0.67 fb^{-1} (0.45 billion)	4.5 fb^{-1} (3.0 billion)	150/90 days
$\psi(3770)$ peak	$D^0/D^\pm$ decays	2.9 fb^{-1}	20.0 fb^{-1}	610/360 days
3.8 - 4.6 GeV	R values XYZ/Open charm	Fine scan (105 energy points)	No requirement	N/A
4.180 GeV	D_s decay XYZ/Open charm	3.2 fb^{-1}	6 fb^{-1}	140/50 days
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	16.0 fb^{-1} at different $\sqrt{s}$	30 fb^{-1} at different $\sqrt{s}$	770/310 days
4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	15 fb^{-1} at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	1.0 fb^{-1}	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}	130/50 days

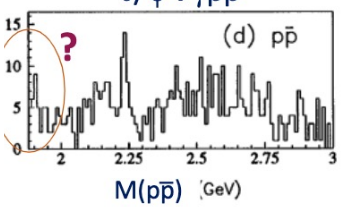
10 billon J/ψ events on tape！

from Stephen Olsen

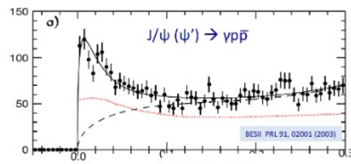
you never have enough J/ψ events

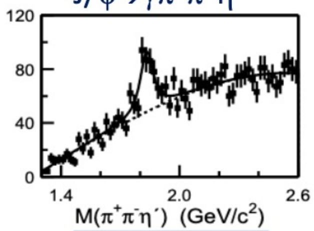
1996: 8 M J/ψ's | **2002: 58 M J/ψ's** | **2011: 225 M J/ψ's** | **2016: 1.3 B J/ψ's** | **2019: 10 B J/ψ's**

J/ψ→γpp̄

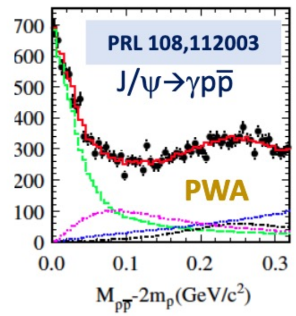


PRL 76, 3502

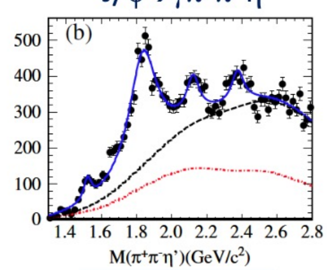




PRL 95,262001

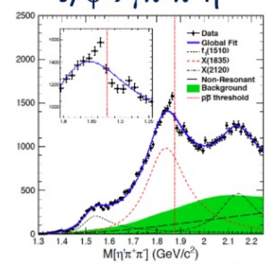


J/ψ→γπ⁺π⁻η'



PRL 106,072002

J/ψ→γπ⁺π⁻η'

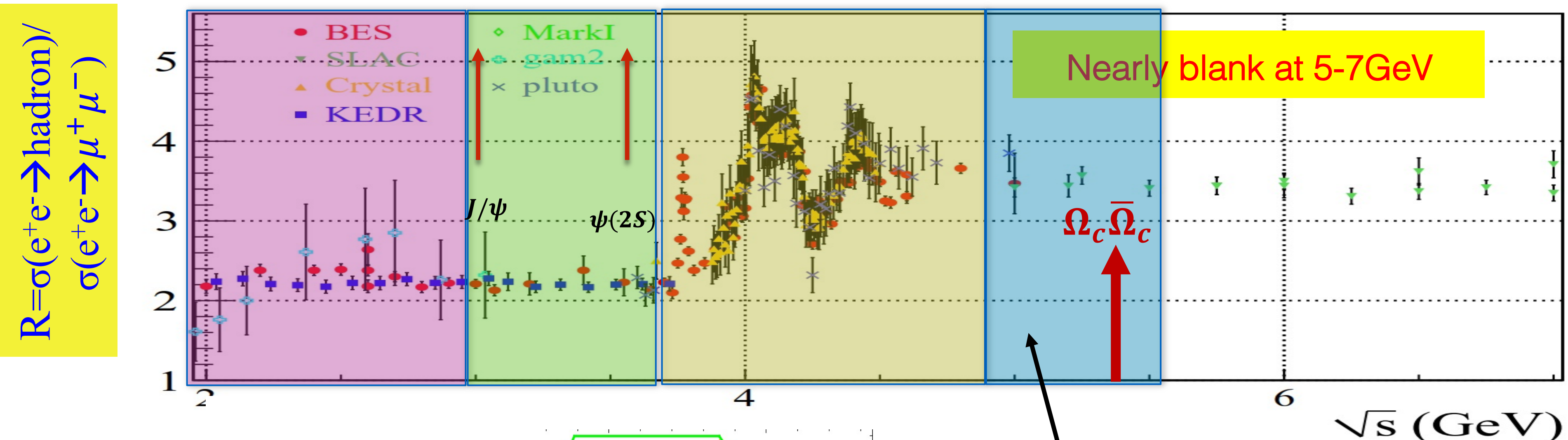


PRL 117,042002

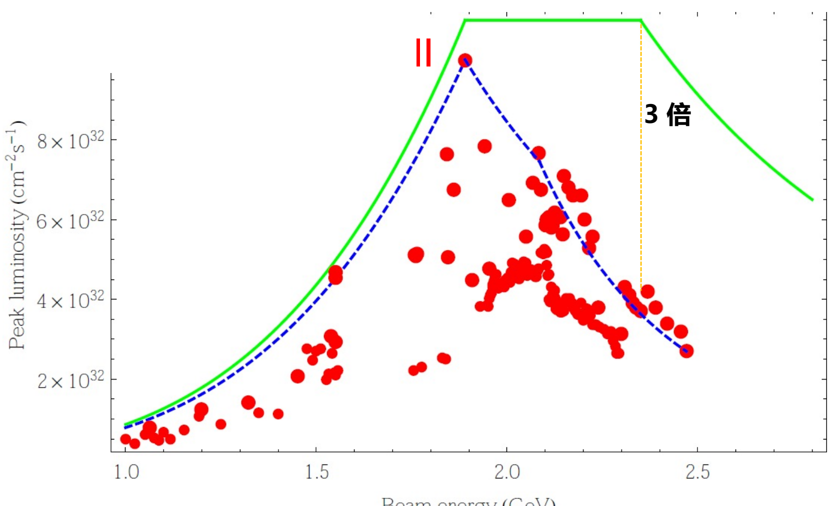
???

Plan of the BEPCII upgrade

- optimized energy at 2.35 GeV with luminosity 3 times higher than the current BEPCII.
- extend the maximum energy up to 5.6 GeV



4.95 ~ 5.6 GeV: new energy coverage of BEPCII



Summary

- **BESIII is successfully operating since 2008, and will continue to run for 5–10 years**
  – collected large data samples in the τ-charm mass region
- **Many exciting results have been published covering many aspects:**
  - ✓ Charmed mesons and baryons
  - ✓ XYZ states and light hadron spectroscopy
  - ✓ Form factors of the nucleon and hyperons
  - ✓ Low-Q^2 QCD studies: R value, multi-meson production, fragmentation function, …
  - ✓ Rare decays and new physics search
  - ✓ …
- **Future goals:**
  50M D^0, 50M D^+, 15M Ds, 2M Λ_c , high-lumi. fine scan up to 5.6 GeV

Thank you!

谢谢!

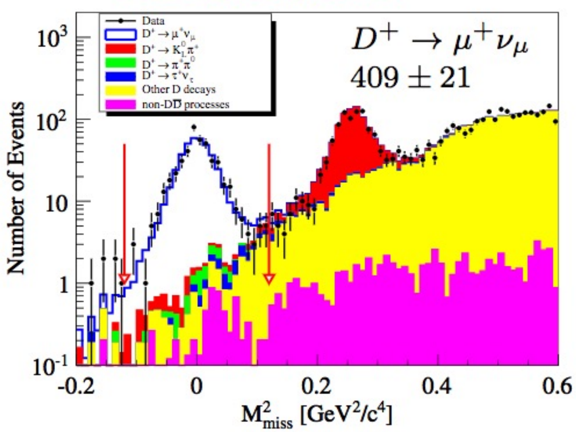
$D_{(S)}$ Leptonic decays

Purely Leptonic:

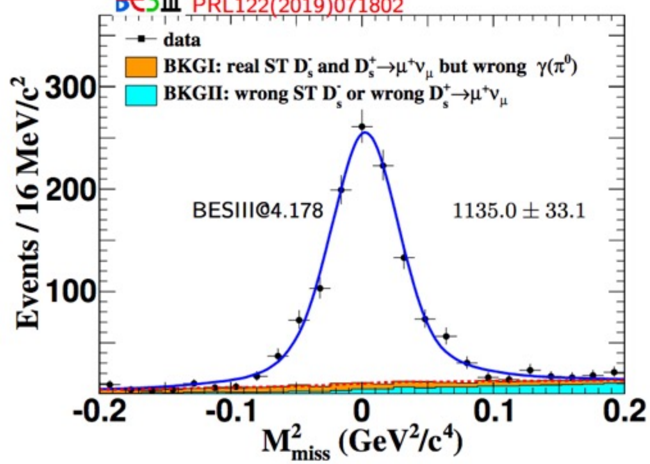
- Extract decay constant $f_{D(s)}$ incorporates the strong interaction effects (wave function at the origin)
- To validate Lattice QCD calculation of $f_{D(s)}$ and provide constrain of CKM-unitarity

$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f^2_{D^+_{(s)}}}{8\pi} \mid V_{cd(s)} \mid^2 m_\ell^2 m_{D^+_{(s)}} \left(1 - \frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2$$

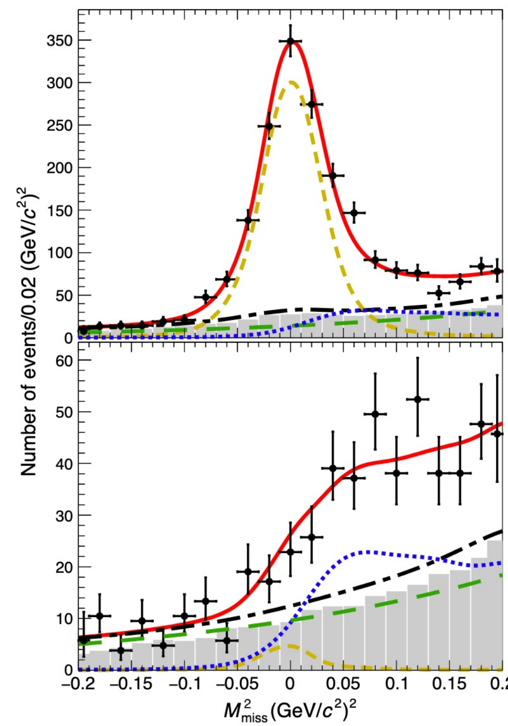
PRD89(2014)051104



PRL122(2019)071802



arXiv:2102.11734



$D_s^+ \to \mu^+\nu$: 2198 ± 55

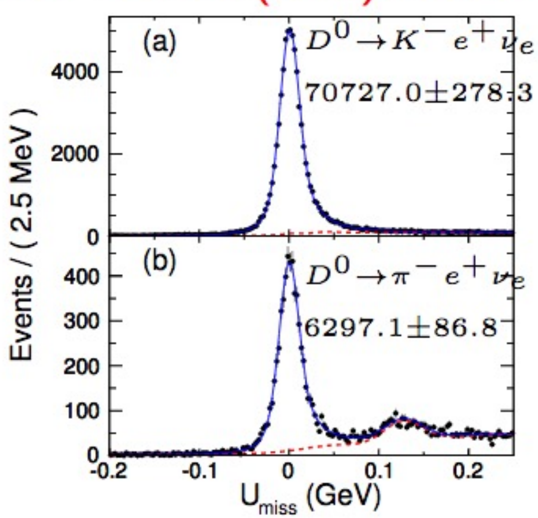
$D_s^+ \to \tau^+(\to \pi^+\nu)\nu$: 946^{+46}_{-45}

$D_{(S)}$ Semi-Leptonic decays: *e*-mode

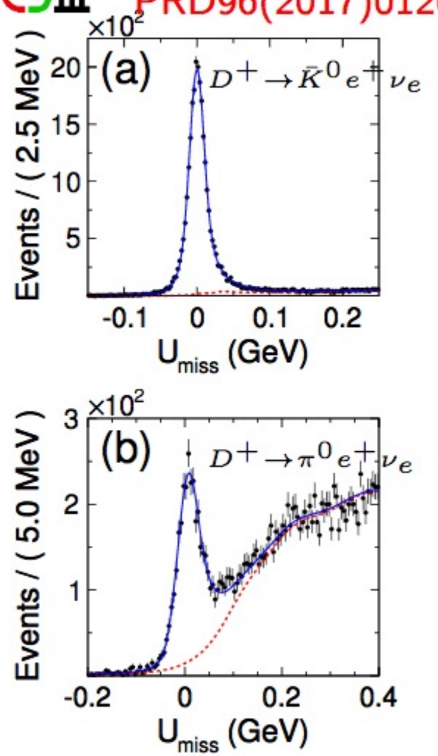
Semi-leptonic: form factor (FF)

- Measure $|V_{cx}|$ x FF
- Charm physics:
  - CKM-unitarity ⇒ $|V_{cx}|$, extract FF, test LQCD
  - Input LQCD FF to test CKM-unitarity

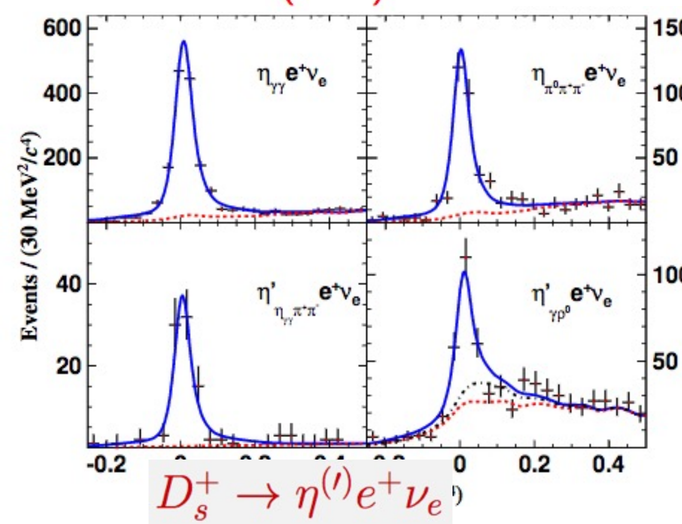
BESIII PRD92(2015)072012



BESIII PRD96(2017)012002

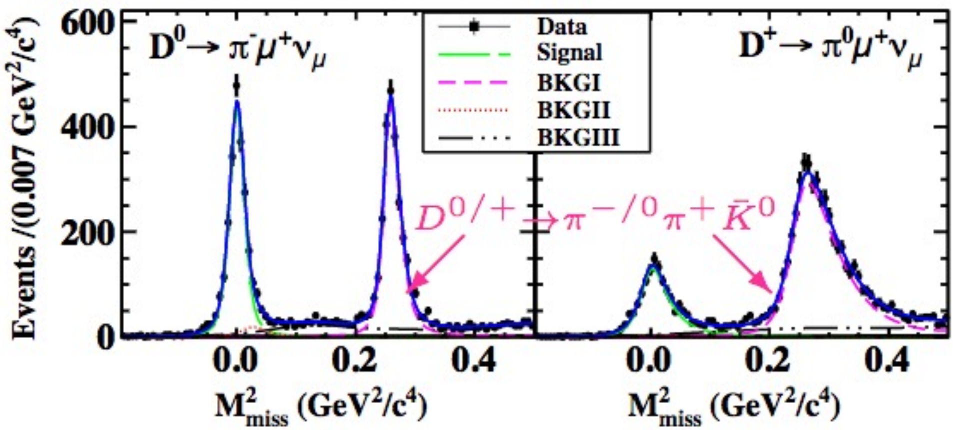


BESIII PRL122(2019)121801

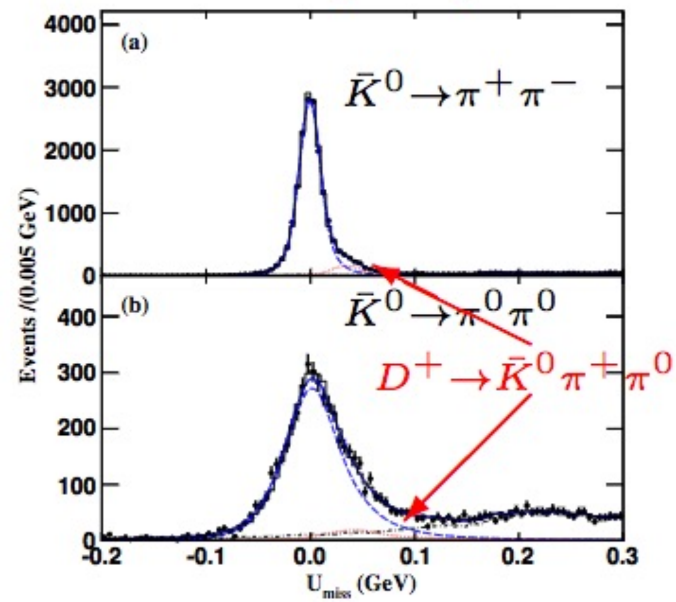


$D_{(S)}$ Semi-Leptonic decays: μ-mode

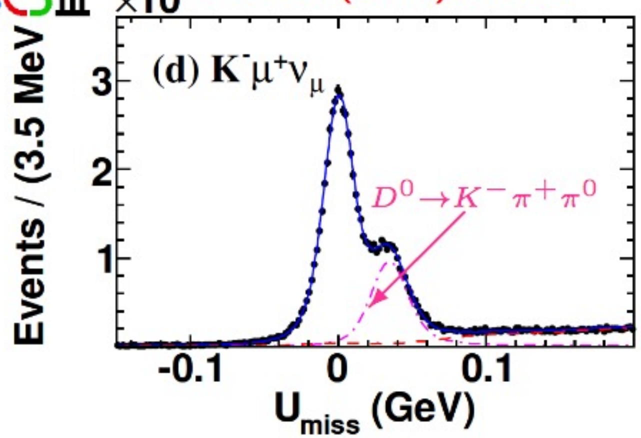
BESIII PRL121(2018)171803



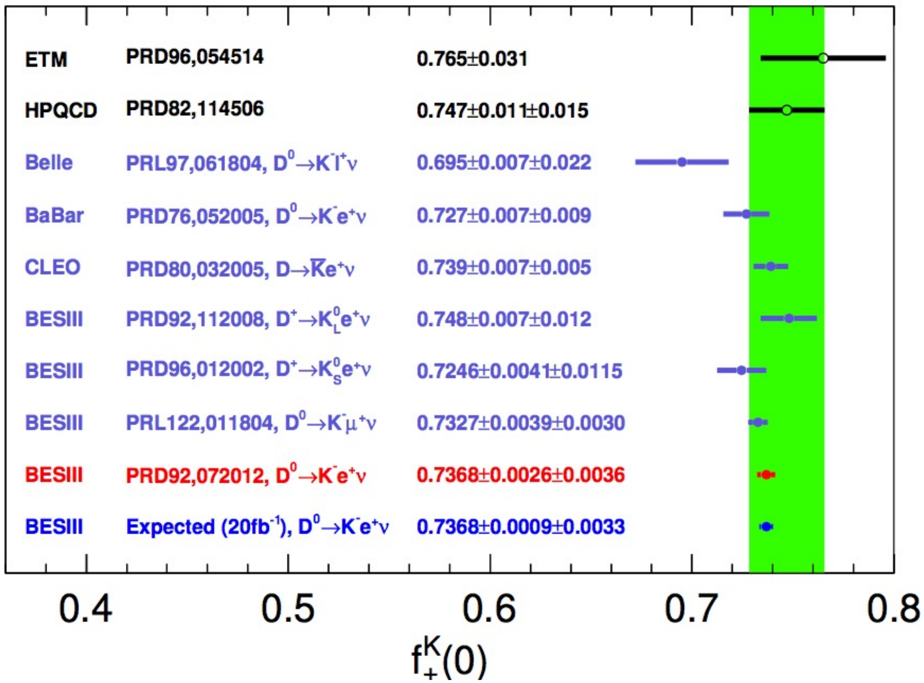
BESIII EPJC76(2016)369

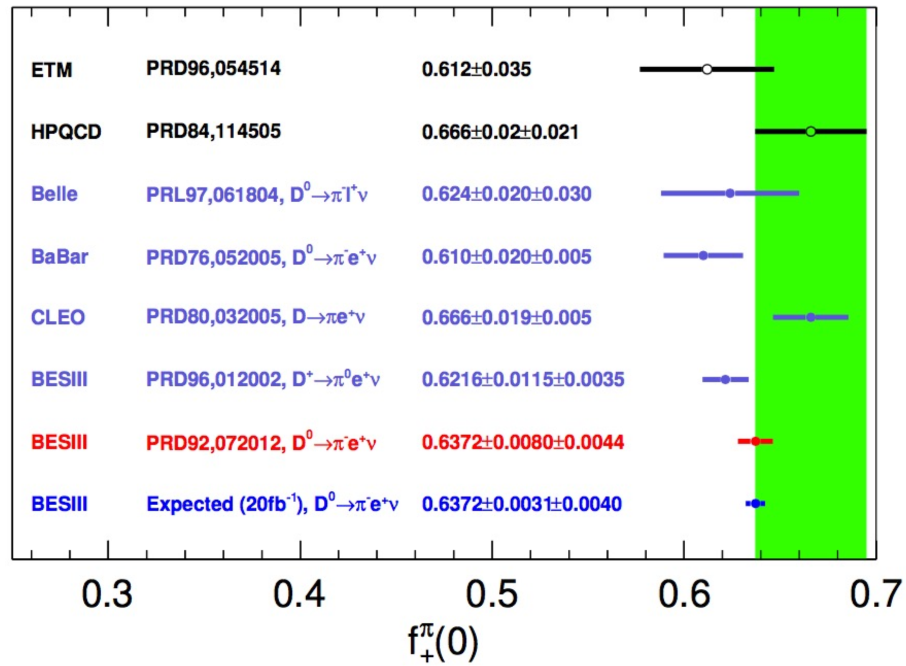


BESIII $\times 10^3$ PRL122(2019)011804



Form factors $f_{+}^{D\to h}$





Precisions better than those of LQCD results

BESIII Determiend properties of the $Z_c^+(3900)$

PRL 119.072001 (2017)

- If Z_c is parameterized with a Flatte-like formula

  $M_{\text{pole}} = 3881.2 \pm 4.2 \pm 52.7$ MeV, $\Gamma_{\text{pole}} = 51.8 \pm 4.6 \pm 36.0$ MeV

  $g_1' = 0.075 \pm 0.006 \pm 0.025 \text{GeV}^2$

  $g_2'/g_1' = 27.1 \pm 2.0 \pm 1.9$

  (consistent with the previous published results)

- Born cross section for $e^+e^- \to Z_c^+\pi^- + c.c. \to \pi^+\pi^- J/\psi$

  $21.8 \pm 1.0 \pm 4.4$ pb at 4.23 GeV

  $11.0 \pm 1.2 \pm 5.4$ pb at 4.26 GeV

- Search for $e^+e^- \to Z_c^+(4020)\pi^- + c.c. \to \pi^+\pi^- J/\psi$ gives

  upper limits at 90% C.L.:

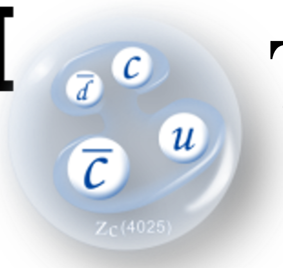
  <0.9 pb at 4.23 GeV; <1.4 pb at 4.26 GeV

  then $\frac{\sigma(e^+e^- \to Z_c^+(4020)\ \pi^- + c.c \to \pi^+\pi^- J/\psi)}{\sigma(e^+e^- \to Z_c^+(3900)\ \pi^- + c.c \to \pi^+\pi^- J/\psi)} < 4\%$ at 4.23 GeV

  <13% at 4.26 GeV

Further couple channel amplitude analysis is on-going on more energy points.

BESIII



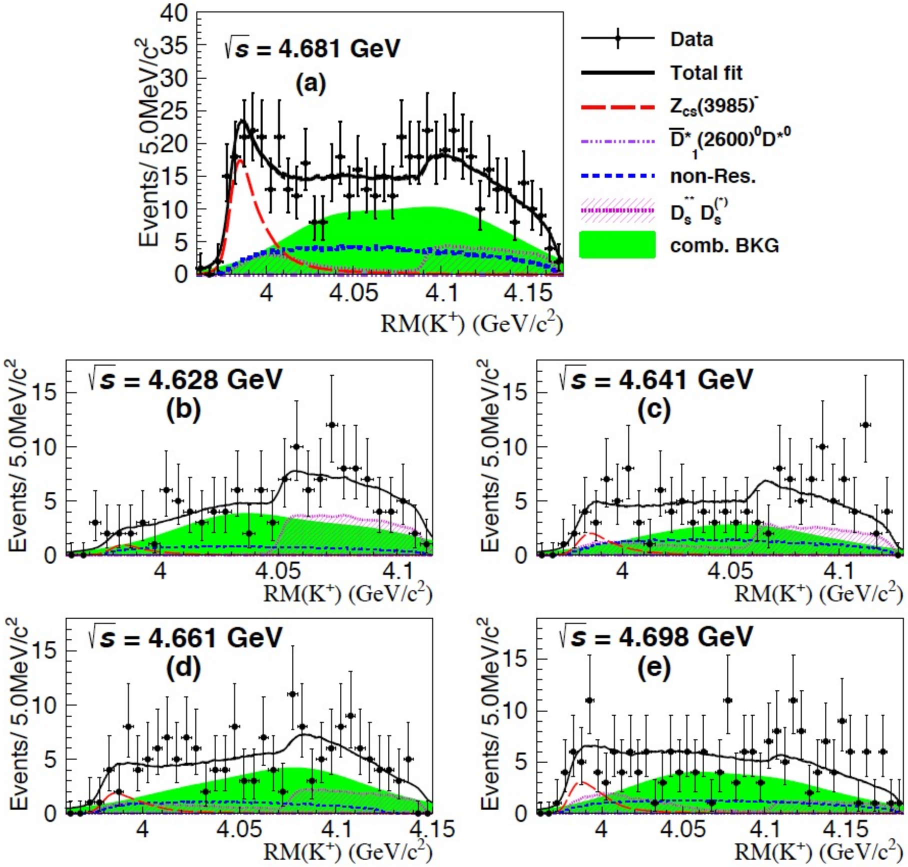
The Zc Family at BESIII

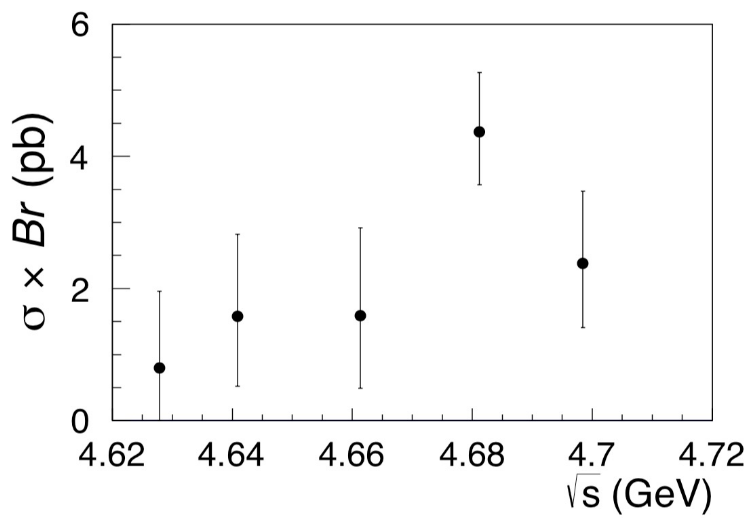
State	Mass (MeV/c²)	Width (MeV)	Decay	Process
$Z_c(3900)^{\pm}$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	$\pi^{\pm} J/\psi$	$e^+e^- \to \pi^+\pi^- J/\psi$
$Z_c(3900)^0$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$	$\pi^0 J/\psi$	$e^+e^- \to \pi^0\pi^0 J/\psi$
$Z_c(3885)^{\pm}$	$3883.9 \pm 1.5 \pm 4.2$ Single D tag	$24.8 \pm 3.3 \pm 11.0$ Single D tag	$(D\bar{D}^*)^{\pm}$	$e^+e^- \to (D\bar{D}^*)^{\pm}\pi^{\mp}$
	$3881.7 \pm 1.6 \pm 2.1$ Double D tag	$26.6 \pm 2.0 \pm 2.3$ Double D tag	$(D\bar{D}^*)^{\pm}$	$e^+e^- \to (D\bar{D}^*)^{\pm}\pi^{\mp}$
$Z_c(3885)^0$	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35^{+11}_{-12} \pm 15$	$(D\bar{D}^*)^0$	$e^+e^- \to (D\bar{D}^*)^0\pi^0$
$Z_c(4020)^{\pm}$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	$\pi^{\pm} h_c$	$e^+e^- \to \pi^+\pi^- h_c$
$Z_c(4020)^0$	$4023.9 \pm 2.2 \pm 3.8$	fixed	$\pi^0 h_c$	$e^+e^- \to \pi^0\pi^0 h_c$
$Z_c(4025)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	$D^*\bar{D}^*$	$e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}$
$Z_c(4025)^0$	$4025.5^{+2,0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$	$D^*\bar{D}^*$	$e^+e^- \to (D^*\bar{D}^*)^0\pi^0$

Cross sections of the $Z_{cs}(3985)^{\pm}$ production

PRL126, 102001 (2021)

- Simultaneous fit to the five energy points



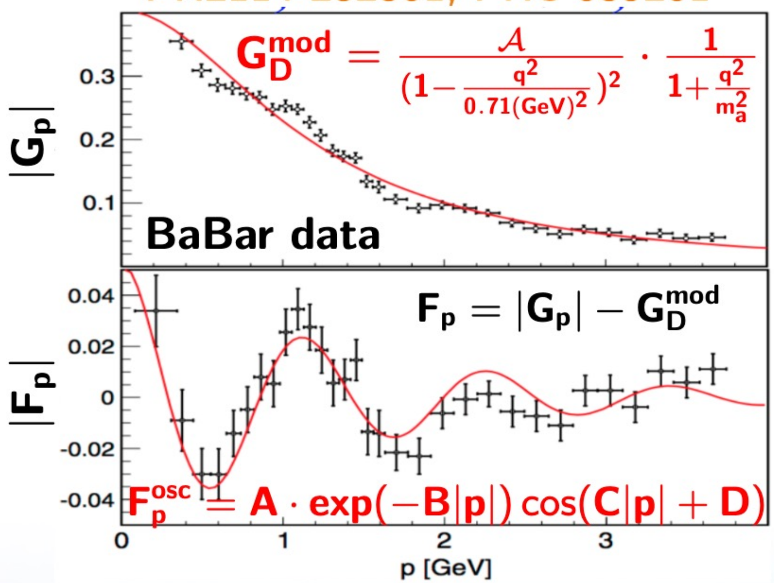


- Largest cross sections around 4.681 GeV

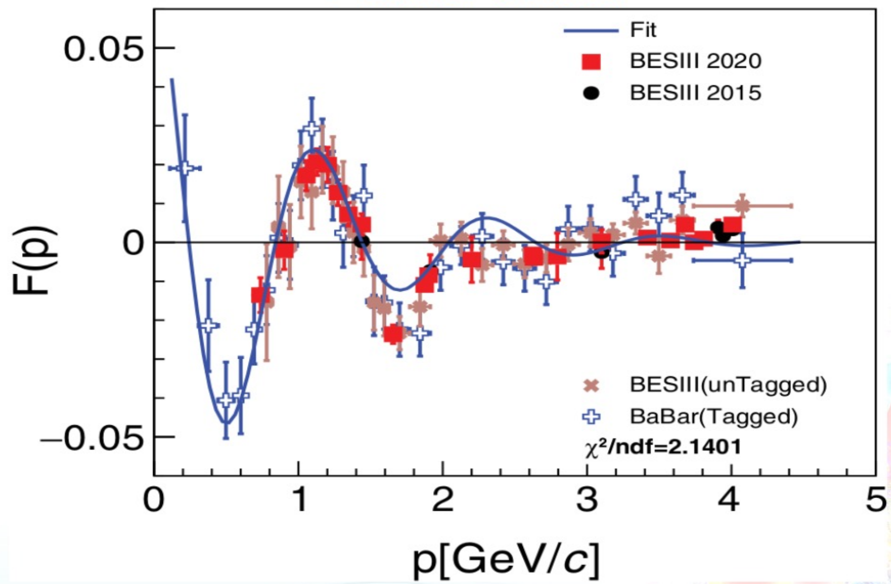
Proton: Oscillating Structure in the Effective Form Factor

Periodic behavior in $|G_p|$ observed by BaBar experiment, confirmed by BESIII experiment

PRL114 232301, PRC 035201

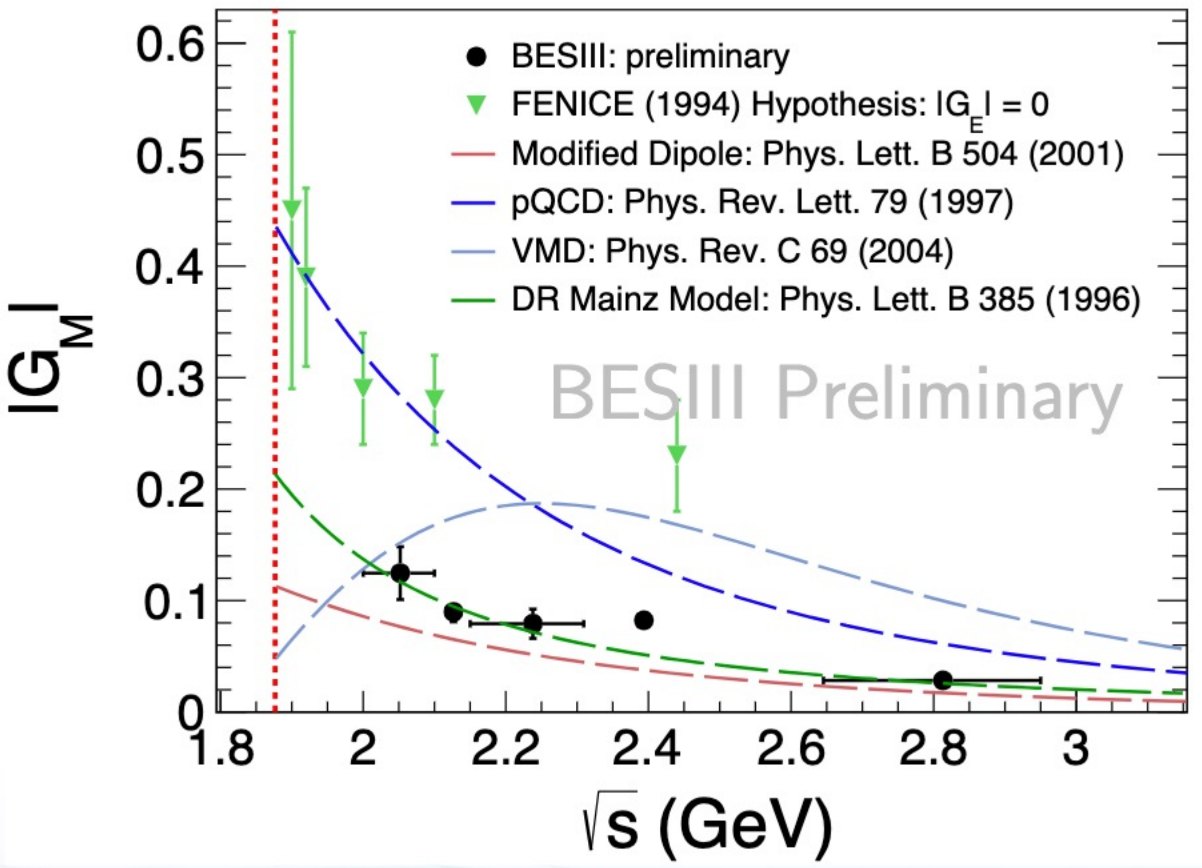


PRL124 042001



- Oscillation observed by BaBar experiment and three different BESIII analyses
- Possible explanations (discussion ongoing):
  - Interference effects in final state re-scattering at moderate kinetic energies?
  - Resonant structures in data (i.e. $\phi(1020)$, $\Delta(1232)$, ...)?

Magnetic form factor of the neutron

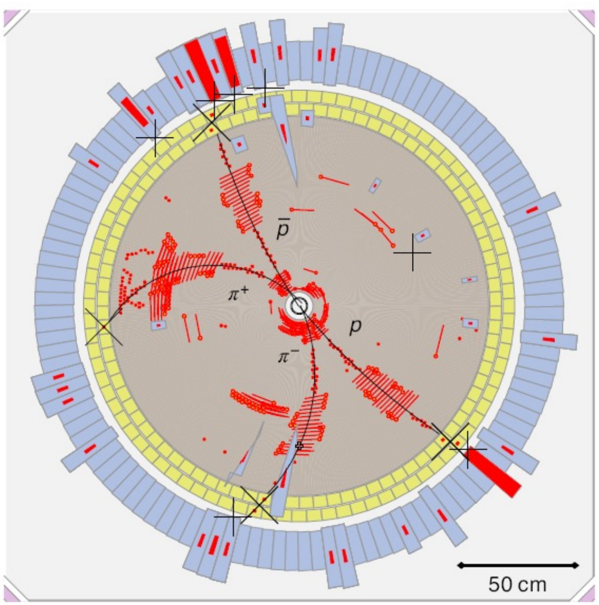


Hyperon decay parameters @ BESIII

$$e^+e^- \rightarrow J/\psi \rightarrow \Lambda\bar{\Lambda} \rightarrow p\bar{p}\pi^+\pi^-$$

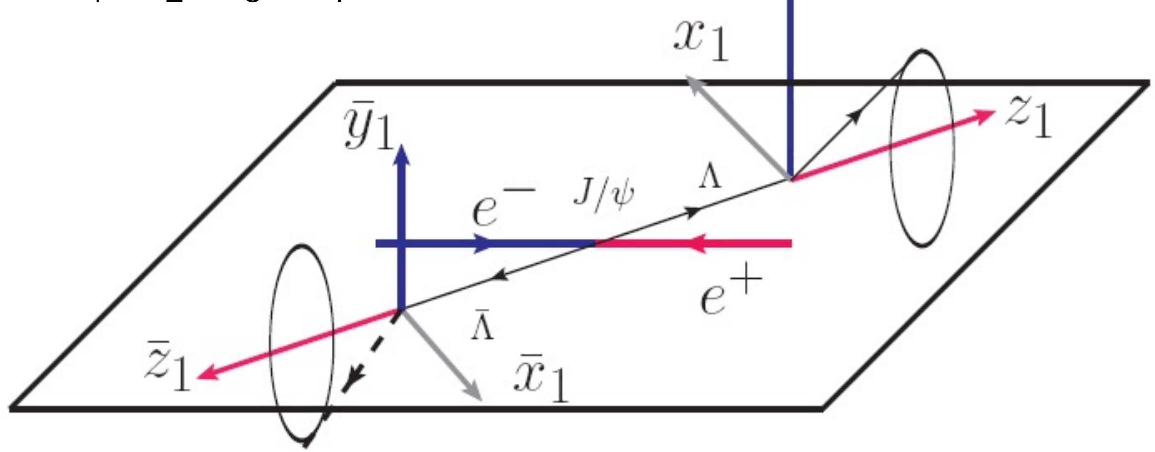
G. Faldt and A. Kupsc
PLB,772, 16 (2017)
EPJA, 52, 141 (2016)
EPJA, 51, 74 (2015).

$$\frac{d\sigma}{d\Omega} \propto T_0 + \sqrt{1-\alpha_{J/\psi}^2}\sin(\Delta)(\alpha_\Lambda T_3 + \alpha_{\bar{\Lambda}} T_4) + \alpha_\Lambda \alpha_{\bar{\Lambda}}[T_1 + \sqrt{1-\alpha_{J/\psi}^2}\cos(\Delta) T_2 + \alpha_{J/\psi} T_5],$$



T_0: angular distribution of Λ and $\bar{\Lambda}$
T_3, T_4, transverse polarization

T_1, T_2, T_5: spin correlation



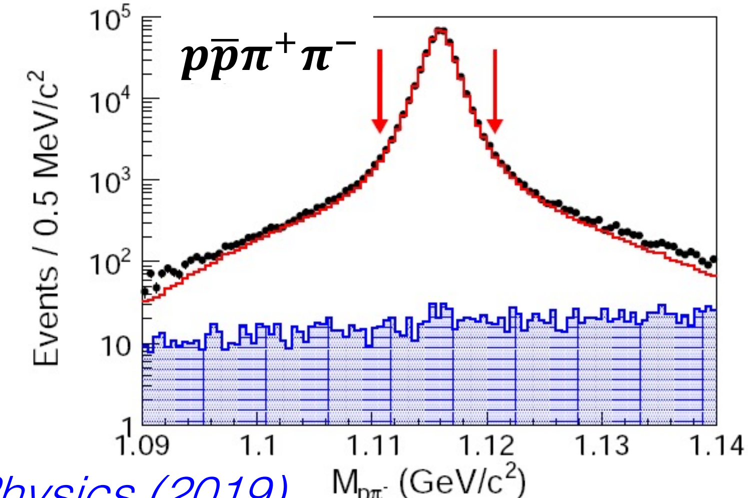
$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda} \to p\bar{p}\pi^+\pi^-,\ p\bar{n}\pi^-\pi^0$

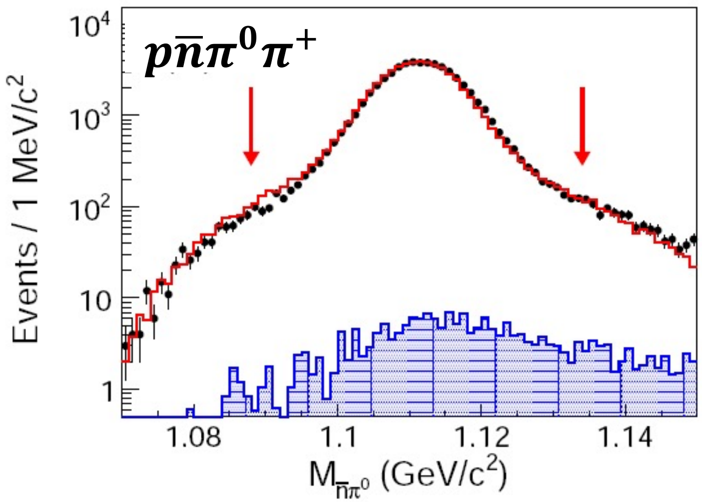
1.3 billion J/ψ events

simultaneous fit to the two data samples

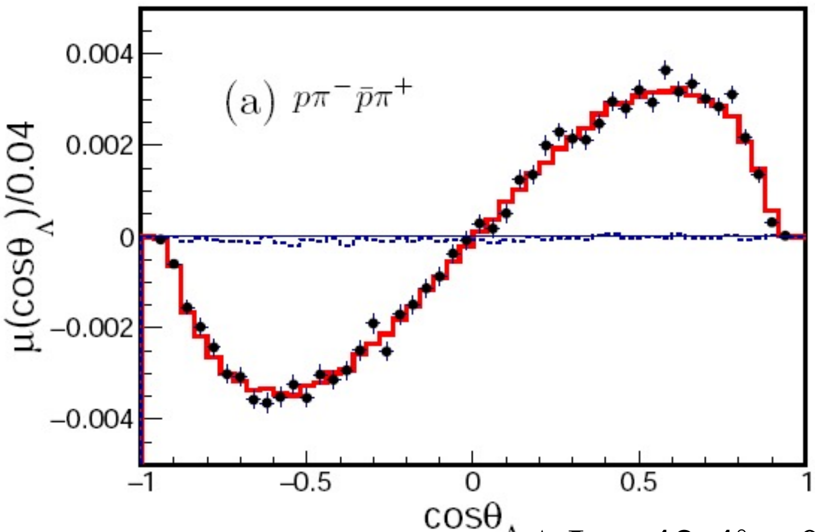
420,593 events selected

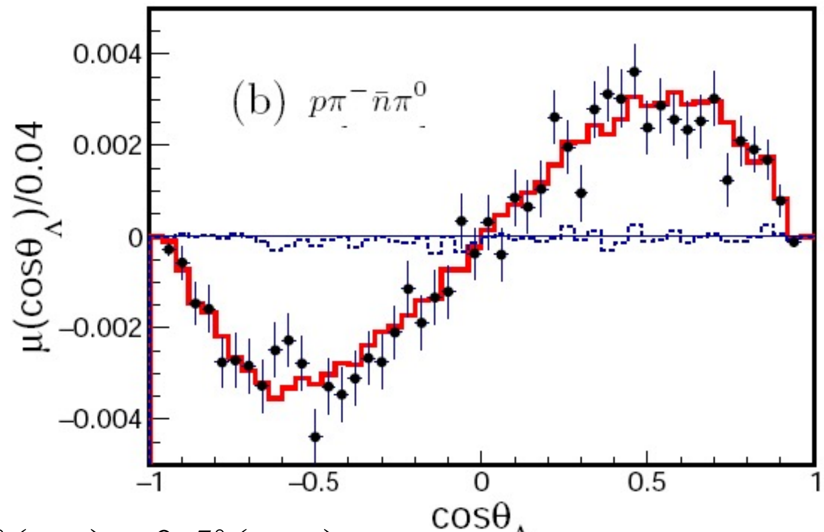
47,009 events selected





Nature Physics (2019)



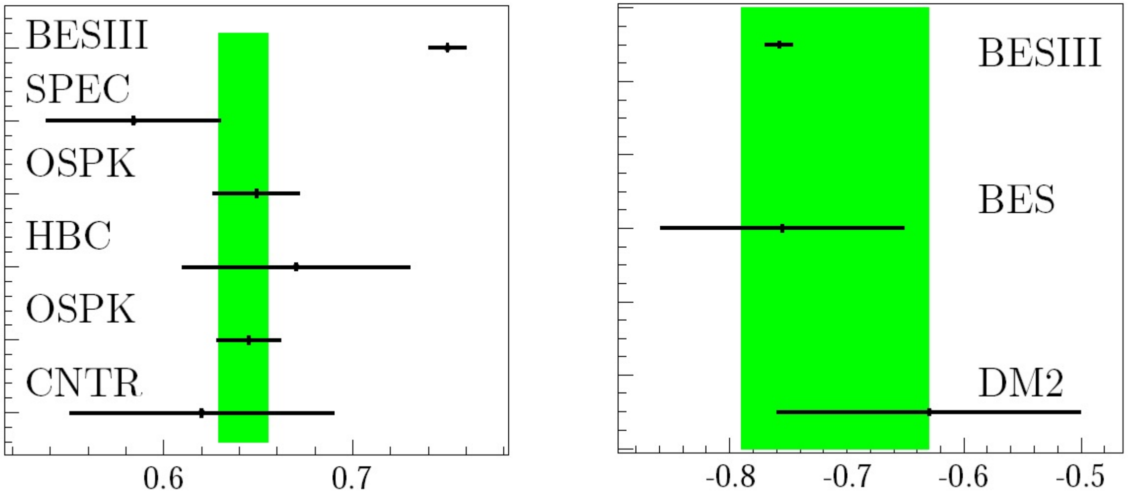


$$\Delta\Phi = 42.4^\circ \pm 0.6^\circ (sta) \pm 0.5^\circ (sys.)$$

Fitting results and Λ decay asymmetries

Nature Physics (2019)

Parameters	This measurement	Previous results
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 [19]
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013 [8]
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08 [8]
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	——
$\Delta\Phi$ (rad)	$0.740 \pm 0.010 \pm 0.008$	——
A_Λ	$-0.006 \pm 0.012 \pm 0.007$	0.006 ± 0.021 [8]
$\bar{\alpha}_0/\alpha_+$	$0.913 \pm 0.028 \pm 0.012$	——



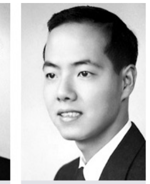
(a) α_- for $\Lambda \to p\pi^-$ (b) α_+ for $\bar{\Lambda} \to \bar{p}\pi^+$

BESIII

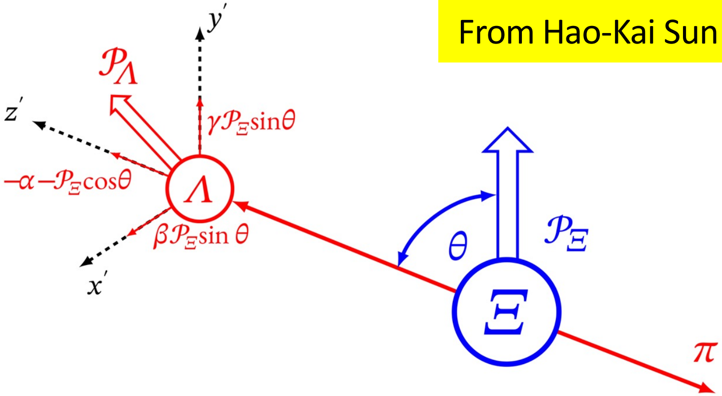
1957

Phys. Rev. 108 1645 (1957)


Chen Ning Yang


Tsung-Dao Lee

From Hao-Kai Sun



$$\alpha = \frac{2\mathrm{Re}(S^*\cdot P)}{|S|^2+|P|^2} \qquad \beta = \frac{2\mathrm{Im}(S^*\cdot P)}{|S|^2+|P|^2} \qquad \gamma = \frac{|S|^2-|P|^2}{|S|^2+|P|^2}$$

$$\beta = \sqrt{1-\alpha^2}\sin\phi_\Xi \qquad \gamma = \sqrt{1-\alpha^2}cos\phi_\Xi$$

$$\alpha^2+\beta^2+\gamma^2 = 1 \qquad tan\phi_\Xi = \frac{\beta}{\gamma}$$

Both α and ϕ_Ξ of $\Xi(\bar{\Xi})$ can be measured via $J/\psi \to \Xi\bar{\Xi}$ at BESIII!

$$\alpha_\mp = \pm\frac{2\mathrm{Re}(S^*\cdot P)}{|S|^2+|P|^2} = \pm\frac{|S||P|\cos(\Delta_s\pm\Delta_w)}{|S|^2+|P|^2} \qquad \beta_\mp = \pm\frac{2\mathrm{Im}(S^*\cdot P)}{|S|^2+|P|^2} = \pm\frac{|S||P|\sin(\Delta_s\pm\Delta_w)}{|S|^2+|P|^2}$$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$$\frac{\beta_- - \beta_+}{\alpha_- - \alpha_+} = \frac{\sin\Delta_s\cos\Delta_w}{\cos\Delta_s\cos\Delta_w} = \tan\Delta_s \qquad \frac{\beta_- + \beta_+}{\alpha_- - \alpha_+} = \frac{\cos\Delta_s\sin\Delta_w}{\cos\Delta_s\cos\Delta_w} = \tan\Delta_w$$