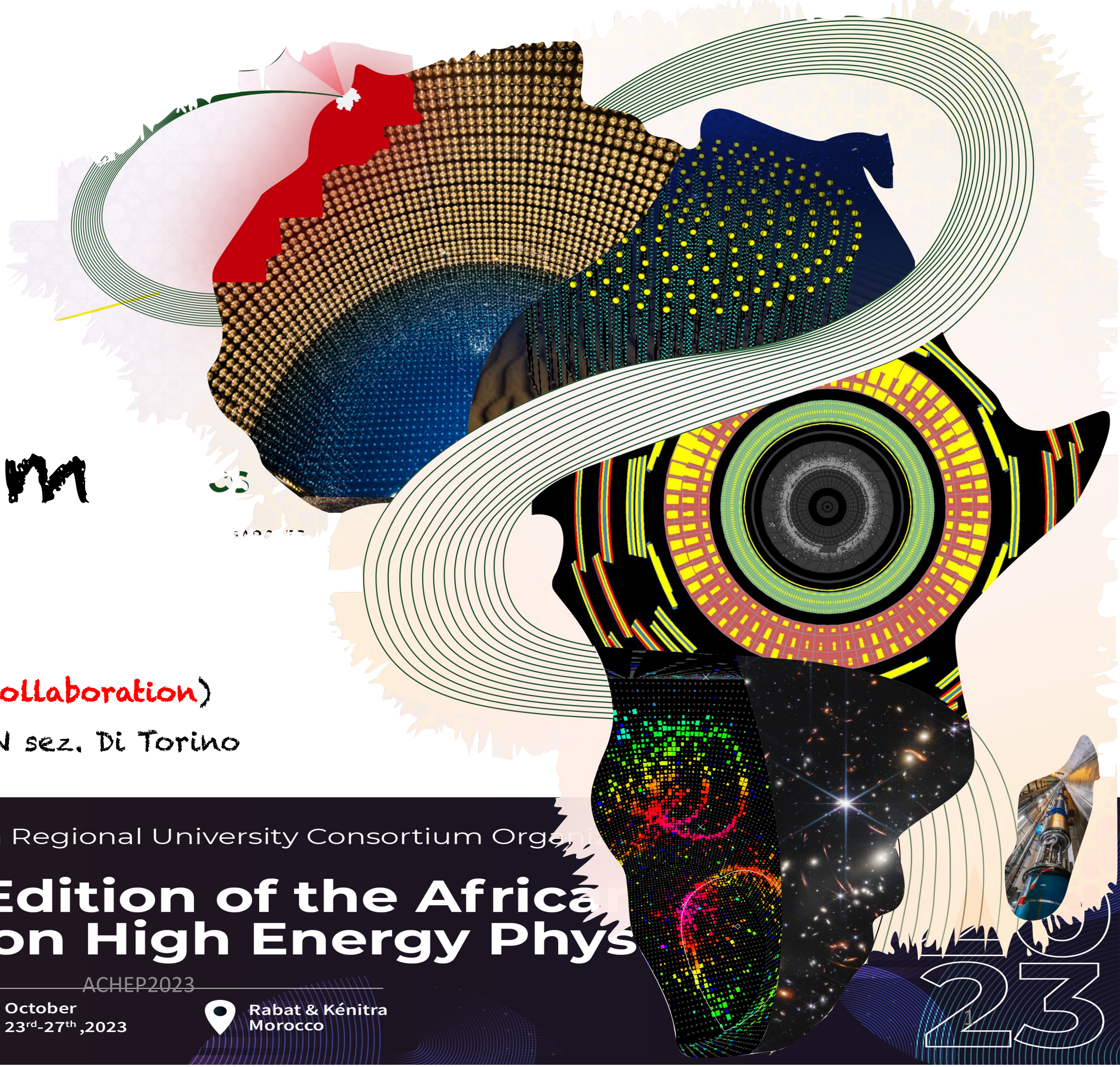
INFN Istituto Nazionale di Fisica
SEZIONE DI TORINO

Highlights from BESIII

Francesca De Mori (on behalf of BESIII collaboration)
Università degli Sudi di Torino and INFN sez. Di Torino



ACHEP 2023 Rabat Kénitra

Rabat - Salé - Kénitra Regional University Consortium Organi

The First Edition of the African Conference on High Energy Phys

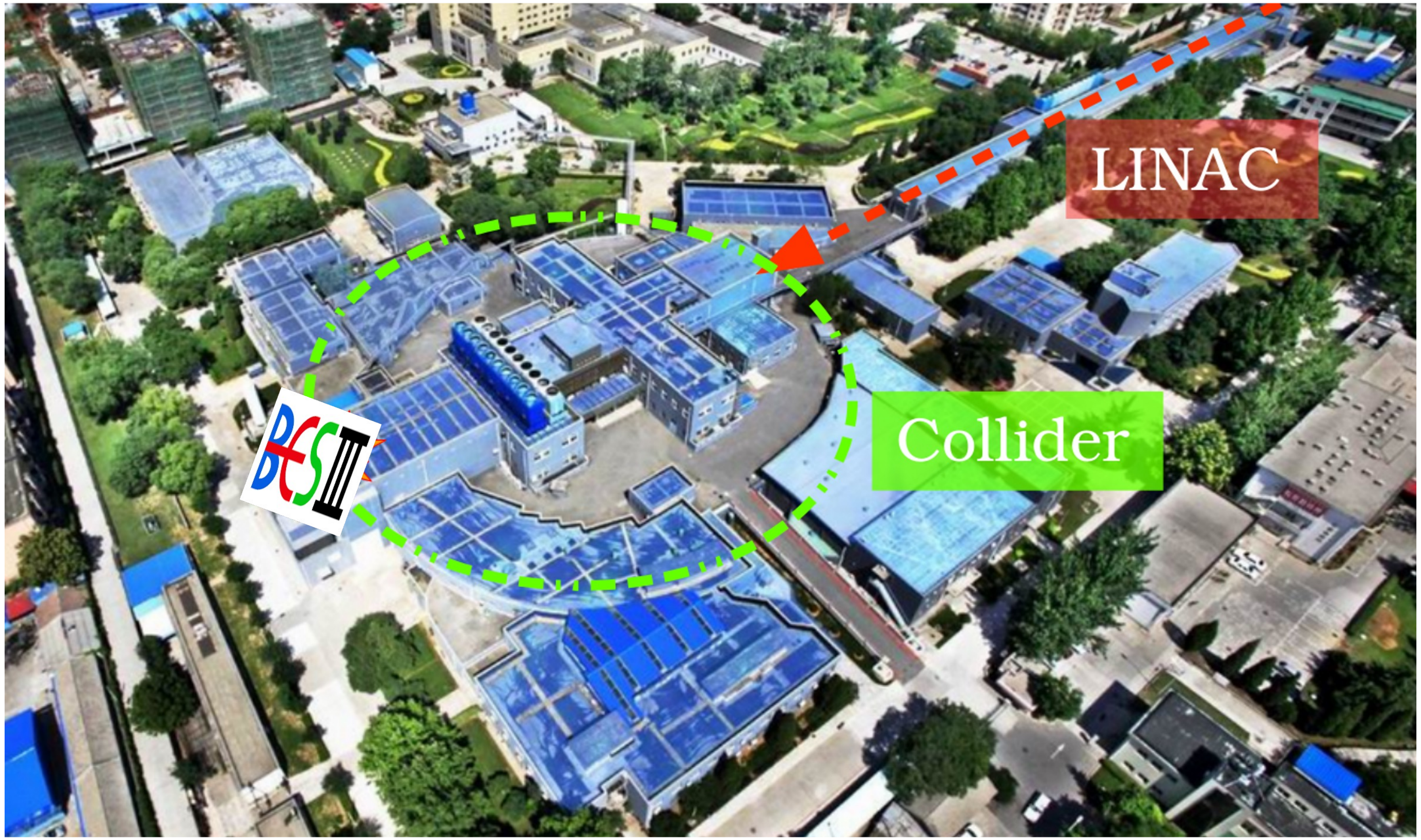
ACHEP2023

October 23rd-27th ,2023

Rabat & Kénitra Morocco

BEPCII @ IHEP

中國科學院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences



Electron-positron collider

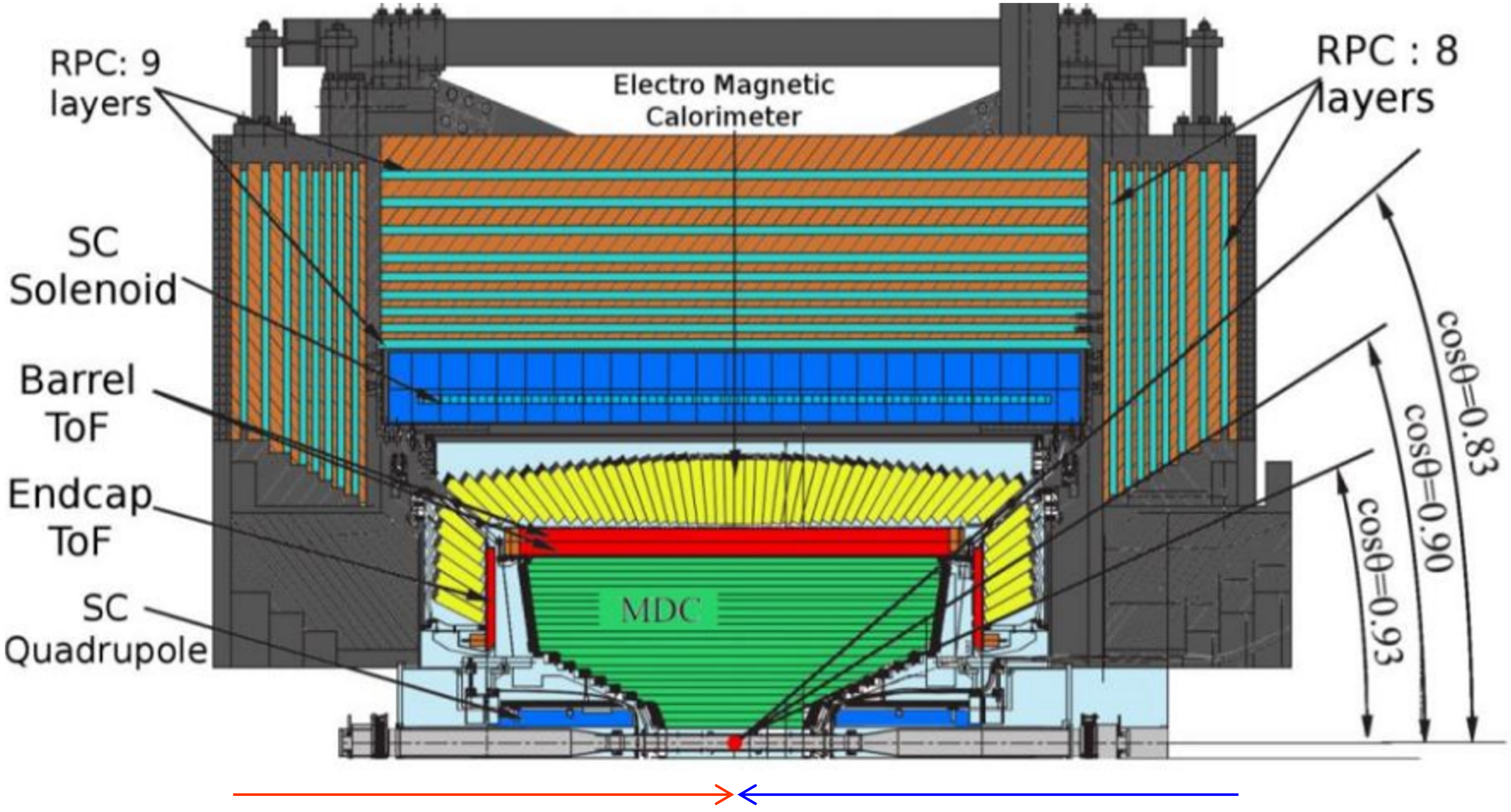
E_{cm} = 2 - 4.95 GeV

Luminosity = 10^{33} $cm^{-2}s^{-1}$

To be upgraded in 2024 to increase luminosity at high energy and extend the cme energy range

BESIII @ BEPCII

1 Tesla Magnetic field



Muon counters:
$\delta_{r\varphi}$ = 1.4 cm – 1.7 cm

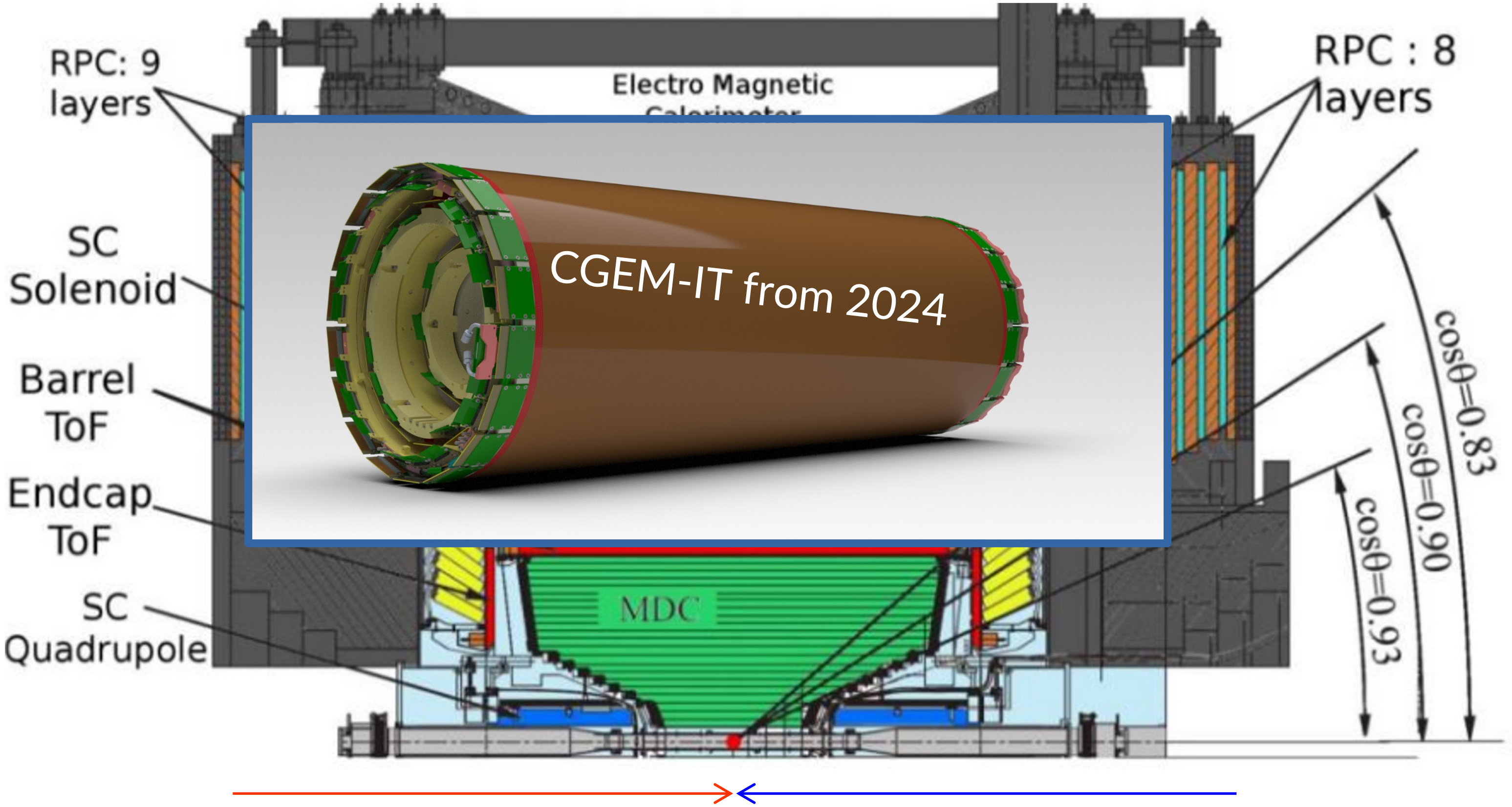
Electromagnetic Calorimeter:
dE/√E (1 GeV) = 2.5 %

Time Of Flight:
σ_t (barrel) = 70 ps
σ_t (endcap) = 60 ps

Main Drift Chamber:
σ_x (1 GeV/c) ~ 130 μm
dp/p (1 GeV/c) = 0.5 %

BESIII @ BEPCII

1 Tesla Magnetic field



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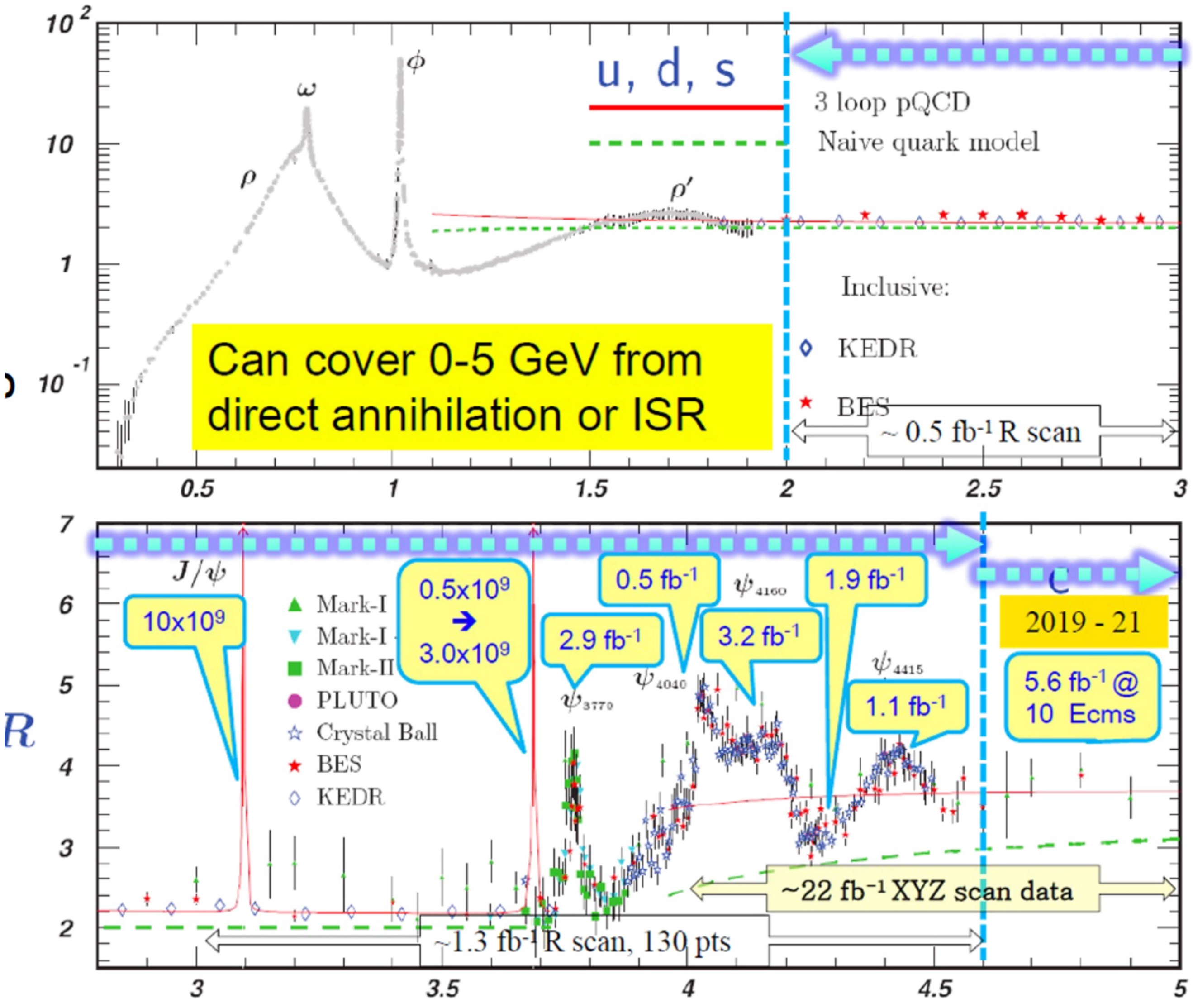
BESIII datasets guarantee rich physics program



Optimised for flavour physics in the τ-charm region

- world's largest 10B J/ψ dataset for light hadron searches

- 2.7B ψ(2S) for conventional charmonia below threshold

~30/fb for XYZ measurements and above threshold searches

- fine scan at low mass for R and light hadron searches (about 139 points)

Outline

A personal selection!

Physics with baryons
- ❑ Hyperon polarization
- ❑ Hyperon scattering
- ❑ Charmed baryon EMFF
- ❑ Dark photon from charmed baryons

XYZ states
- ❑ X(3872) production at BESIII
- ❑ X(3872) coupled channel analysis
- ❑ Status of Y states
- ❑ $Z_{cs}(3985)$ isospin triplet

Light Hadron spectroscopy
- ❑ 10B era: X(2600) in $J/\psi \to \gamma\eta'\pi\pi$
- ❑ $\eta_1(1855)$
- ❑ Observation of the narrow structure near the pΛbar Threshold

Physics with Baryons

………….Understanding the structure of the baryons and more

Ξ^0 hyperon polarization

BEPCII as an hyperon factory with 10B J/ψ

Phys. Rev. D 108, L031106

Hyperons have the most precise CP measurements in the baryon sector

Doubly strange hyperons can be used as a probe for weak and strong phase differences by measuring the sequential decay chain

$$\bar{\Xi}^0 \to \bar{\Lambda}\pi^0$$

$$J/\psi \to \Xi^0\bar{\Xi}^0$$

$$\Xi^0 \to \Lambda\pi^0$$

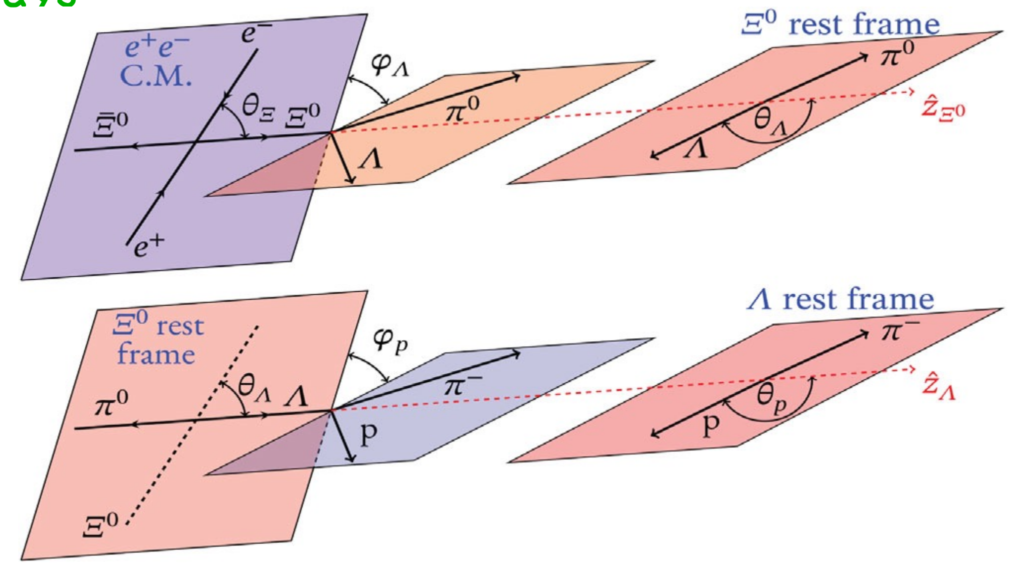
$$\tan(\xi_P - \xi_S) = \frac{\sqrt{1-\alpha_\Xi^2}\sin\phi_\Xi + \sqrt{1-\bar{\alpha}_\Xi^2}\sin\bar{\phi}_\Xi}{\alpha_\Xi - \bar{\alpha}_\Xi},$$

$$\tan(\delta_P - \delta_S) = \frac{\sqrt{1-\alpha_\Xi^2}\sin\phi_\Xi - \sqrt{1-\bar{\alpha}_\Xi^2}\sin\bar{\phi}_\Xi}{\alpha_\Xi - \bar{\alpha}_\Xi}.$$

Formalism exploits polarization, entanglement and sequential decays

PRD 99(1019) 056008
PRD 100(2019) 114005

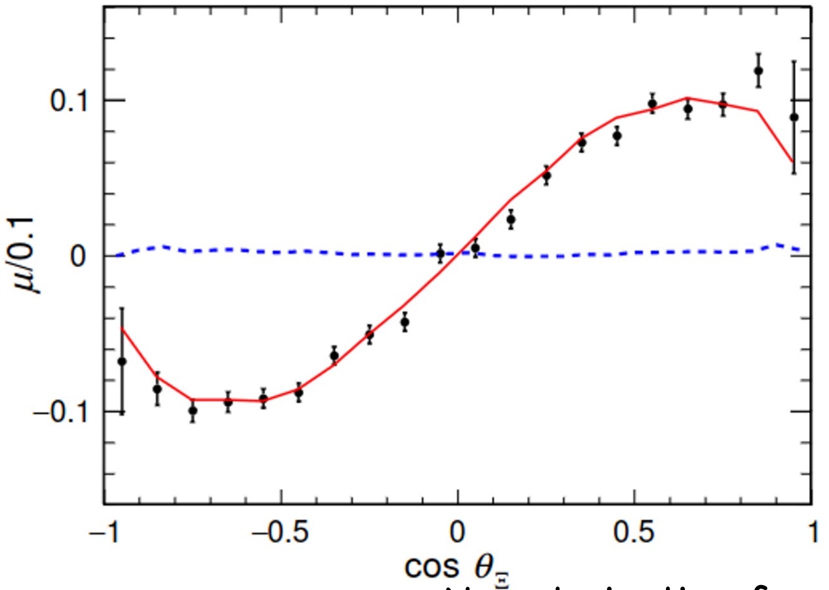
$$\mathcal{W}(\boldsymbol{\xi},\boldsymbol{\omega}) = \sum_{\mu,\bar{\nu}=0}^{3} C_{\mu\bar{\nu}} \sum_{\mu',\bar{\nu}'=0}^{3} a_{\mu\mu'}^{B_1} a_{\bar{\nu}\bar{\nu}'}^{\bar{B}_1} a_{\mu'0}^{B_2} a_{\bar{\nu}'0}^{\bar{B}_2}$$



9-dim phase space given by 9 helicity angles,
8 free parameters determined by unbinned MLL method

Ξ^0 hyperon polarization

Phys. Rev. D 108, L031106



No polarization found in ψ(3686) decay

$$\mu(\cos\theta_\Xi) = \frac{\alpha_\Xi - \bar{\alpha}_\Xi}{2}\frac{1+\alpha_{J/\psi}\cos^2\theta_\Xi}{3+\alpha_{J/\psi}}P_y(\theta_\Xi)$$

Significant Polarization of Ξ^0 hyperons From J/ψ decay!

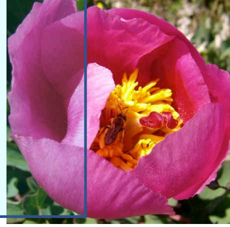
Parameter	This work	Previous result
$\alpha_{J/\psi}$	$0.514 \pm 0.006 \pm 0.015$	0.66 ± 0.06 [34]
$\Delta\Phi$(rad)	$1.168 \pm 0.019 \pm 0.018$	-
α_Ξ	$-0.3750 \pm 0.0034 \pm 0.0016$	-0.358 ± 0.044 [18]
$\bar{\alpha}_\Xi$	$0.3790 \pm 0.0034 \pm 0.0021$	0.363 ± 0.043 [18]
ϕ_Ξ(rad)	$0.0051 \pm 0.0096 \pm 0.0018$	0.03 ± 0.12 [18]
$\bar{\phi}_\Xi$(rad)	$-0.0053 \pm 0.0097 \pm 0.0019$	-0.19 ± 0.13 [18]
α_Λ	$0.7551 \pm 0.0052 \pm 0.0023$	0.7519 ± 0.0043 [13]
$\bar{\alpha}_\Lambda$	$-0.7448 \pm 0.0052 \pm 0.0017$	-0.7559 ± 0.0047 [13]
$\xi_P - \xi_S$(rad)	$(0.0 \pm 1.7 \pm 0.2) \times 10^{-2}$	-
$\delta_P - \delta_S$(rad)	$(-1.3 \pm 1.7 \pm 0.4) \times 10^{-2}$	-
A_{CP}^{Ξ}	$(-5.4 \pm 6.5 \pm 3.1) \times 10^{-3}$	$(-0.7 \pm 8.5) \times 10^{-2}$ [18]
$\Delta\phi_{CP}^{\Xi}$(rad)	$(-0.1 \pm 6.9 \pm 0.9) \times 10^{-3}$	$(-7.9 \pm 8.3) \times 10^{-2}$ [18]
A_{CP}^{Λ}	$(6.9 \pm 5.8 \pm 1.8) \times 10^{-3}$	$(-2.5 \pm 4.8) \times 10^{-3}$ [13]
$\langle\alpha_\Xi\rangle$	$-0.3770 \pm 0.0024 \pm 0.0014$	-
$\langle\phi_\Xi\rangle$(rad)	$0.0052 \pm 0.0069 \pm 0.0016$	-
$\langle\alpha_\Lambda\rangle$	$0.7499 \pm 0.0029 \pm 0.0013$	0.7542 ± 0.0026 [13]

Results:

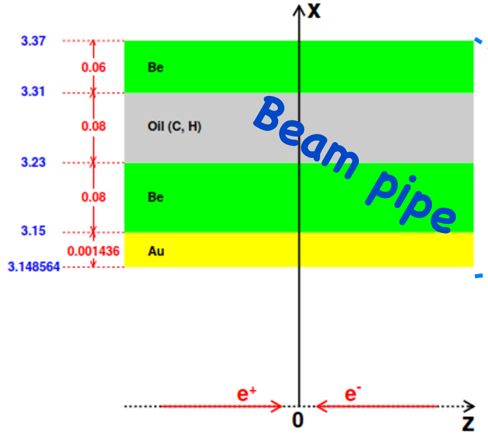
- **First** measurement of Ξ^0 transverse polarization
- $\Xi^0\bar{\Xi}^0$ decay parameters with unprecedented accuracies
- First direct measurement of weak phase difference (improved compared to Ξ^- decay – Nature 606 (2022) 64)
- Independent CP tests: the most precise values for CP asymmetry observables !!!

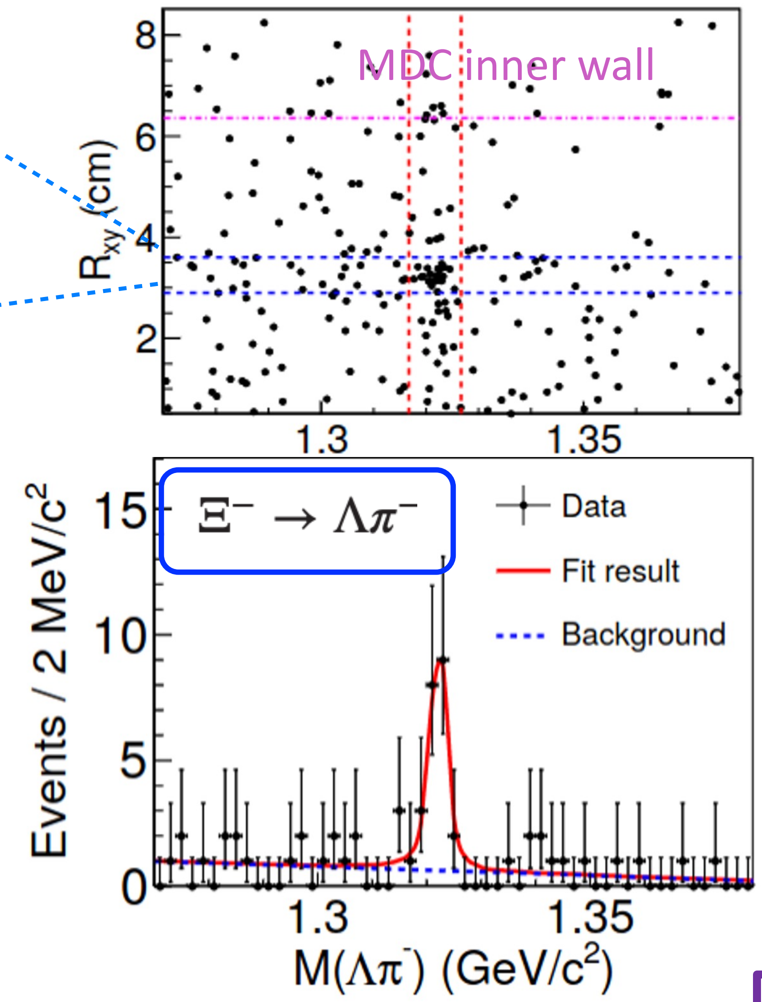
$\Xi^0 n \to \Xi^- p$ scattering

PRL130 (2023) 251902



First study of hyperon-nucleon interaction at an electron-positron collider





Hyperon-nucleon scattering with a Ξ^0 beam with 818 MeV/c momentum (direct reaction, pure surface process)

$$\sigma(\Xi^0 + {}^9\mathrm{Be} \to \Xi^- + p + {}^8\mathrm{Be}) = \frac{N^{\mathrm{sig}}}{\epsilon \mathcal{B} \mathcal{L}_{\mathrm{eff}}}$$

Product of the BR of all intermediate resonances

$$\mathcal{L}_{\mathrm{eff}} = \frac{N_{J/\psi}\mathcal{B}_{J/\psi}}{2+\frac{2}{3}\alpha} \int_a^b \int_0^\pi (1+\alpha\cos^2\theta) e^{-\frac{x}{\sin\theta\beta\gamma L}} N(x) C(x) \mathrm{d}\theta \mathrm{d}x.$$

Clear signal found with **7.1σ** significance

Cross section estimated to be

$$\sigma(\Xi^0 + {}^9\mathrm{Be} \to \Xi^- + p + {}^8\mathrm{Be}) = (22.1 \pm 5.3_{\mathrm{stat}} \pm 4.5_{\mathrm{sys}})\ \mathrm{mb}$$

For the single neutron (effective number=3)

$$\sigma(\Xi^0 n \to \Xi^- p) = (7.4 \pm 1.8_{\mathrm{stat}} \pm 1.5_{\mathrm{sys}})\ \mathrm{mb}$$

Ξ^0 from the decay

$$J/\psi \to \Xi^0 \overline{\Xi}^0$$

$$\overline{\Xi}^0 \to \overline{\Lambda}\pi^0$$

the neutron is a component of nuclei in the beam pipe.

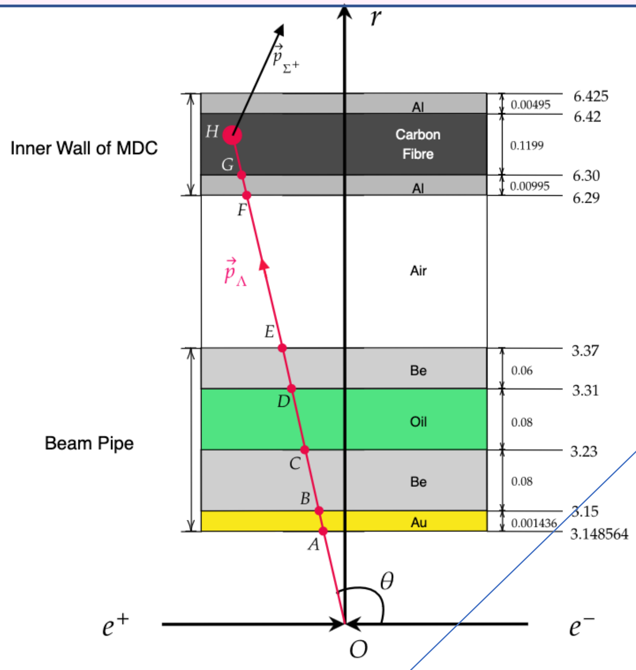
DT technique

$\Lambda N \to \Sigma^+ X$ inelastic scattering

https://arxiv.org/abs/2310.00720v1 submitted to PRL

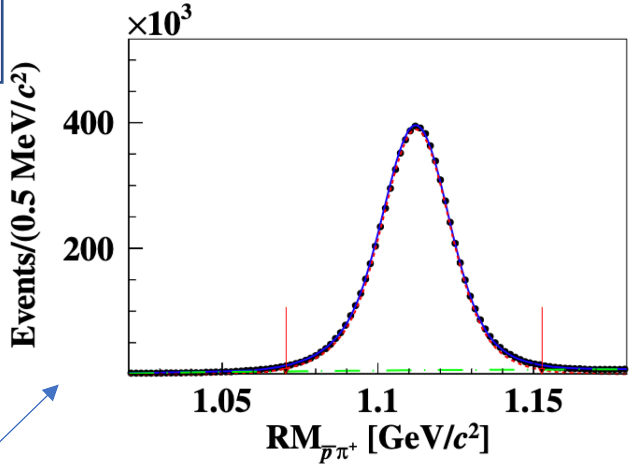
$$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$$

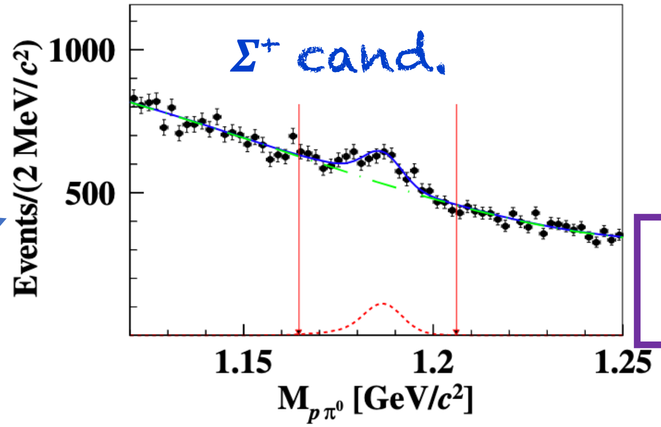
momentum within [1.057, 1.091] GeV/c.



DT:
TAG Σ^+
TAG $\bar{\Lambda}$

first attempt to investigate Λ-nucleus interactions at an e⁺e⁻ collider





$$\sigma(\text{Be}) = \frac{N_{\text{DT}}}{\epsilon_{\text{sig}} \cdot \mathcal{L}_\Lambda} \cdot \frac{1}{\mathcal{B}(\Sigma^+ \to p\pi^0)}.$$

$$\mathcal{L}_\Lambda = N_{\text{ST}} \cdot \frac{N_A}{N_{\text{ST}}^{\text{MC}}} \cdot \sum_j^7 \sum_i^{N_{\text{ST}}^{\text{MC}}} \frac{\rho_T^j \cdot l^{ij}}{M^j} \cdot \mathcal{R}_\sigma^j,$$

$$\sigma(\Lambda +^9 Be \to \Sigma^+ + X) = (37.3 \pm 4.7_{stat} \pm 3.5_{syst})mb$$

Assuming surface reaction(factor 1.93)

$$\sigma(\Lambda + p \to \Sigma^+ + X) = (19.3 \pm 2.4_{\text{stat.}} \pm 1.8_{\text{syst.}})\ \text{mb}.$$

Measurement of the Energy-Dependent EMFF of a Charmed Baryon

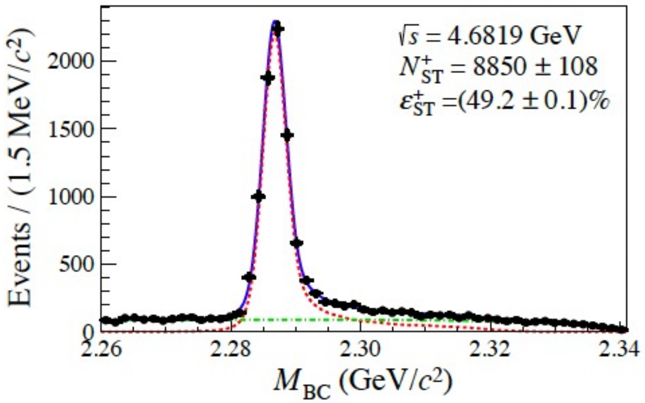
arXiv:2307.07316v1 Submitted to PRL

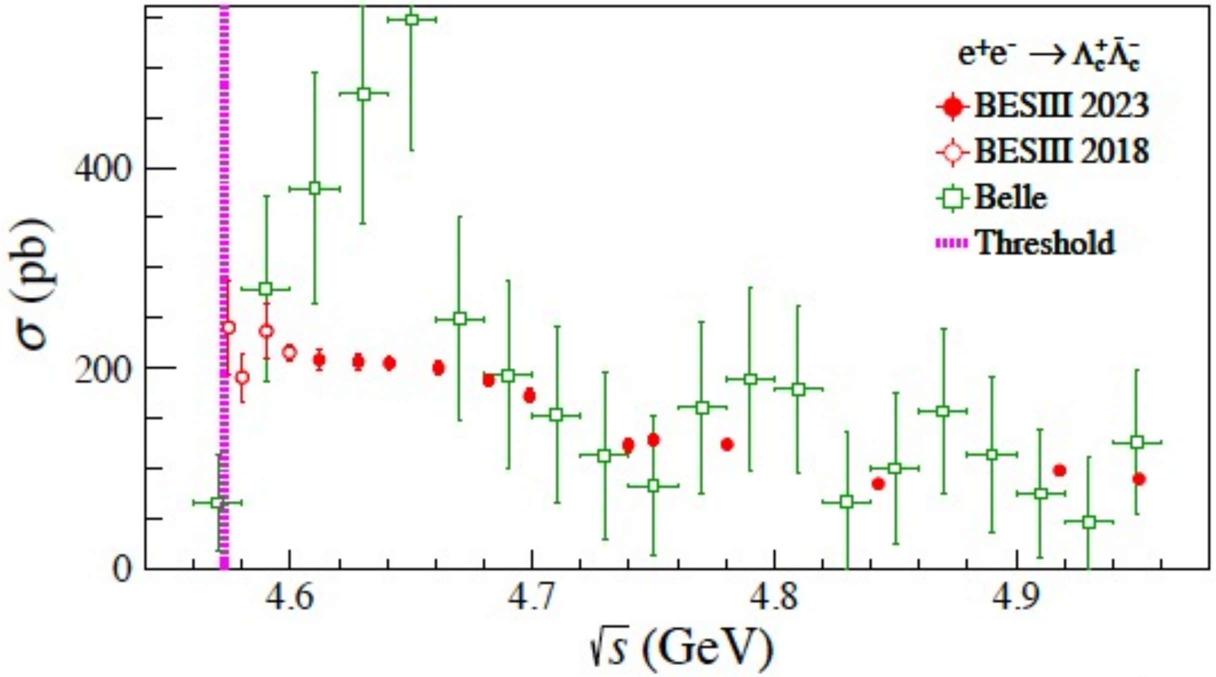
$$e^+e^- \rightarrow \Lambda_c\bar{\Lambda}_c$$

$$\Lambda_c^+ \rightarrow pK^-\pi^+$$

@ 12 c.m.e. from 4.6119 to 4.9509 GeV

Unique key to access internal structure. They encode all the information concerning their dynamics.





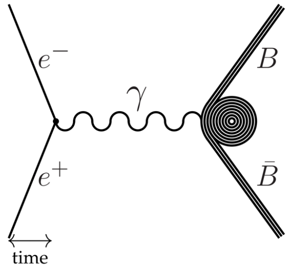
$$\sigma_\pm = \frac{N_{\rm ST}^{\pm}}{\varepsilon_{\rm ST}^{\pm} f_{\rm ISR} f_{\rm VP} \mathcal{L}_{\rm int} \mathcal{B}_\pm}$$

$$N_{\rm DT} = \mathcal{B}_\pm \sum_{n=1}^{9} \left(\frac{N_{\rm ST}^{\mp,n}\varepsilon_{\rm DT}^{n}}{\varepsilon_{\rm ST}^{\mp,n}} \right)$$

$$\sigma_\pm = \frac{N_{\rm ST}^{\pm}}{\varepsilon_{\rm ST}^{\pm} f_{\rm ISR} f_{\rm VP} \mathcal{L}_{\rm int} N_{\rm DT}} \sum_{n=1}^{9} \left(\frac{N_{\rm ST}^{\mp,n}\varepsilon_{\rm DT}^{n}}{\varepsilon_{\rm ST}^{\mp,n}} \right)$$

Approach combines ST and DT to reduce systematics

Measurement of the Energy-Dependent EMFF of a Charmed Baryon



Sachs parameterization:

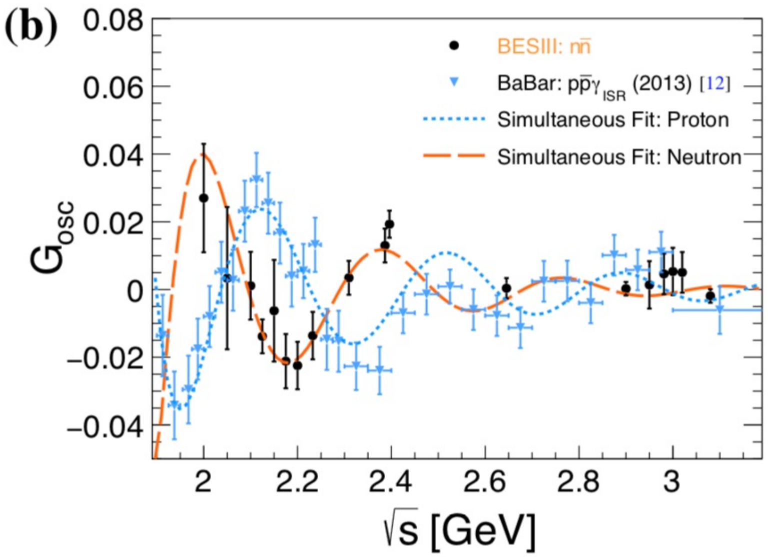
arXiv:2307.07316v1 Submitted to PRL

$$G_E(q^2) = F_1(q^2) + \frac{q^2}{4M_B} F_2(q^2)$$

$$G_M(q^2) = F_1(q^2) + F_2(q^2)$$

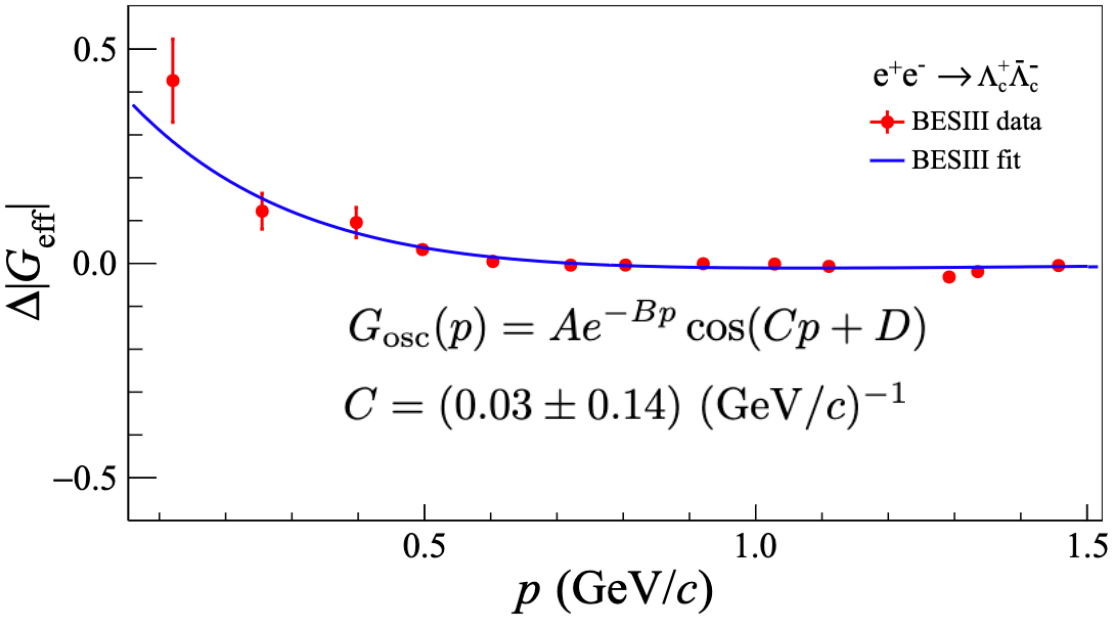
$$|G_{\text{eff}}| = \sqrt{\frac{\sigma}{\frac{\sigma_0}{3}\left(1+\frac{\kappa}{2}\right)}},$$

⇒ equivalent to $|G_M|$ under the assumption $|G_E|=|G_M|$



Nature Physics 17,1200–1204

The three-pole model used to fit the |Geff|



oscillatory behavior expected in the residuals..
No discernable oscillatory behaviour unlike n and p.

Measurement of the Energy-Dependent EMFF of a Charmed Baryon

arXiv:2307.07316v1 Submitted to PRL

$$e^+e^- \to \Lambda_c\overline{\Lambda}_c$$

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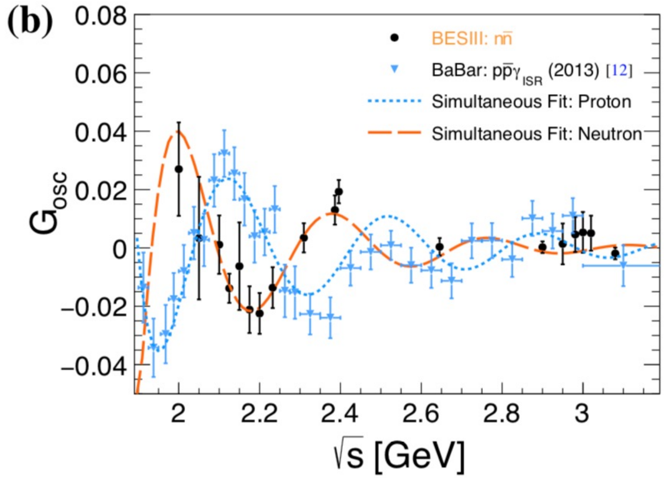

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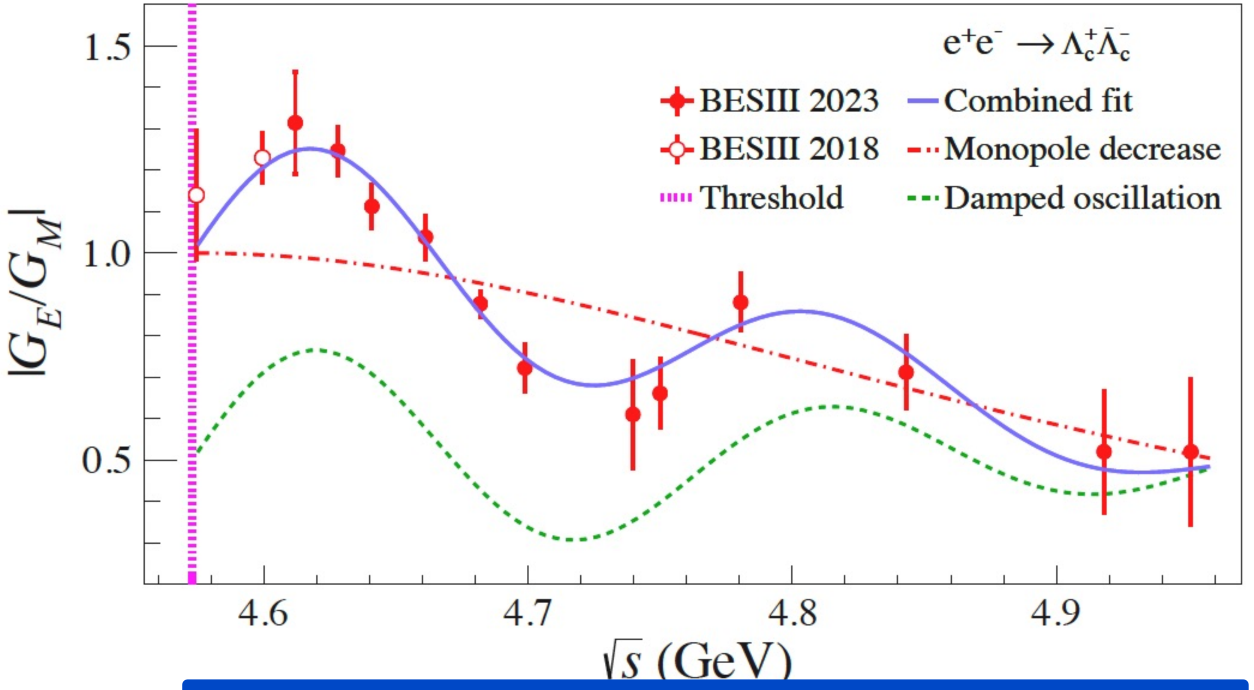
The three-pole model used to fit the |Geff|

$$|G_{\rm eff}| = \sqrt{\frac{\sigma}{\frac{\sigma_0}{3}\left(1+\frac{\kappa}{2}\right)}},$$

oscillatory behavior expected in the residuals..
No discernable oscillatory behaviour unlike n and p Eff. FF

FIRST MEASUREMENT

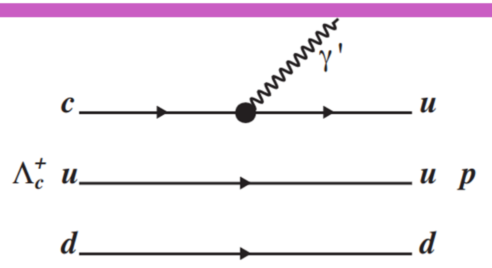
From polar angular analysis, $|G_E/G_M|$ is obtained



$$|G_E/G_M|(s) = \frac{1}{1+\omega^2/r_0}\left[1 + r_1 e^{-r_2\omega}\sin(r_3\omega)\right]$$

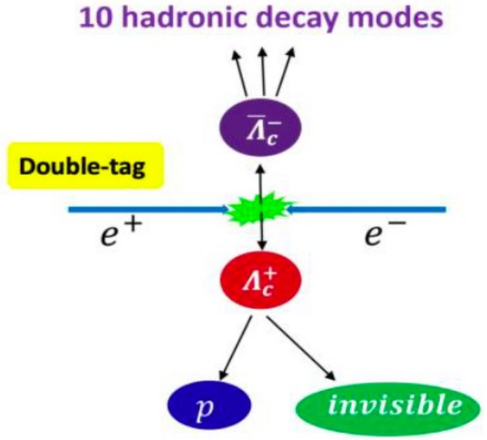
Damped oscillations found with frequency about 3.5 times greater than that for proton

Dark photon in Charmed baryon decays



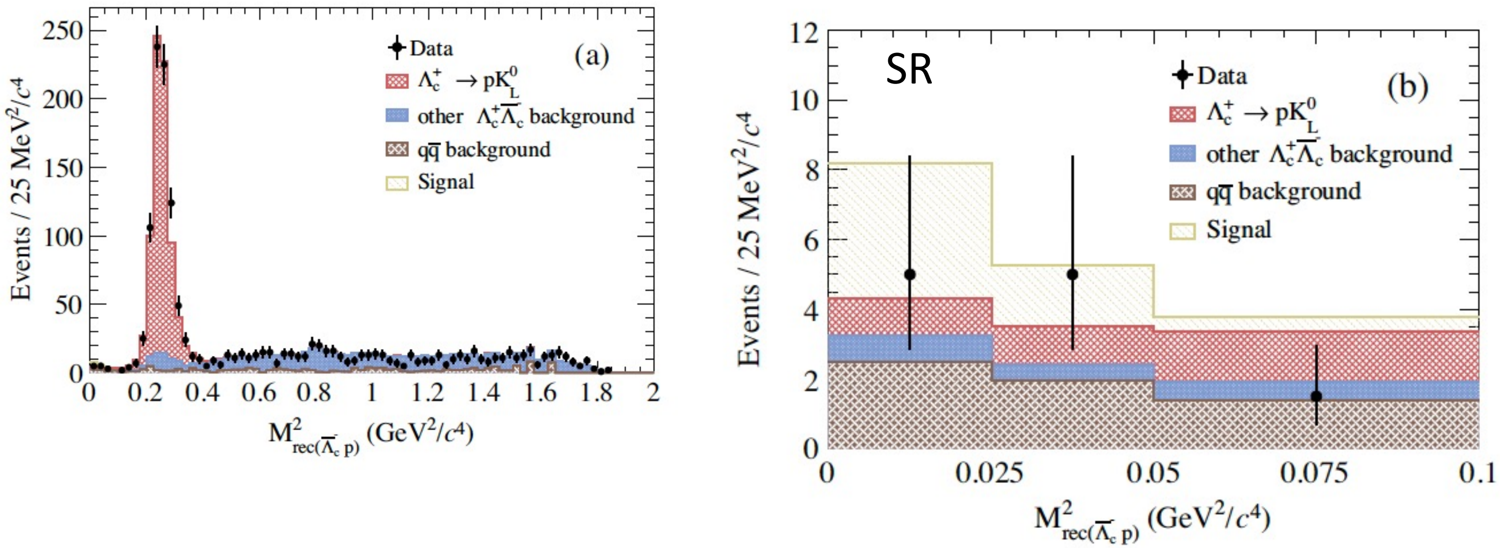
FCNC transitions can provide indications for BSM physics.

BR predicted ~ 10^{-5}
(PRD 102 (2020) 115029)



PRD 106, 072008 (2022)

Double tag approach used to remove larger backgrounds and search for **massless dark photon (γ').**

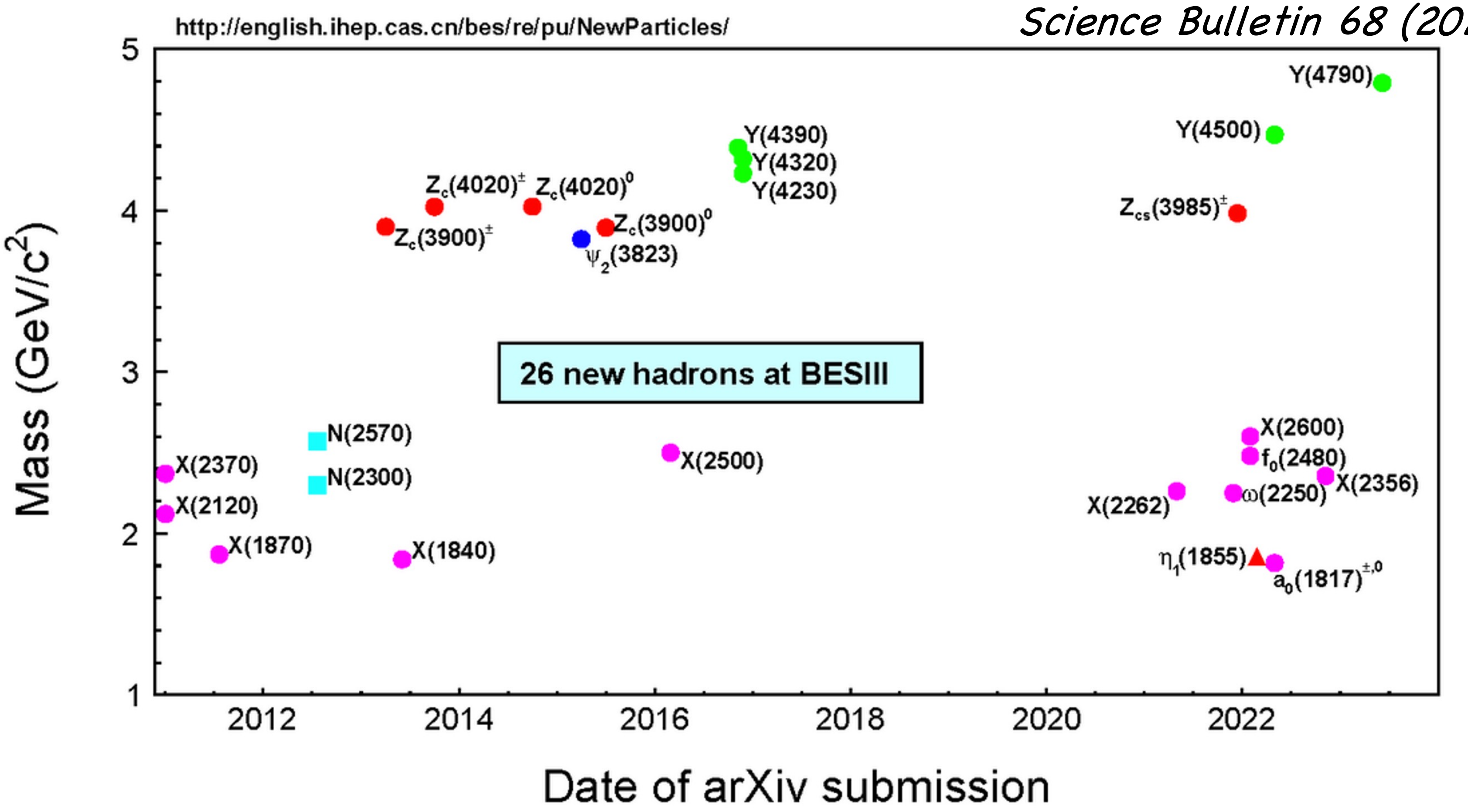


no significant signal is observed,

$B(\Lambda_c \to p\gamma') < 8\times10^{-5}$ @ 90% C.L.

New hadrons @ BESIII

Science Bulletin 68 (2023) 2148-2150

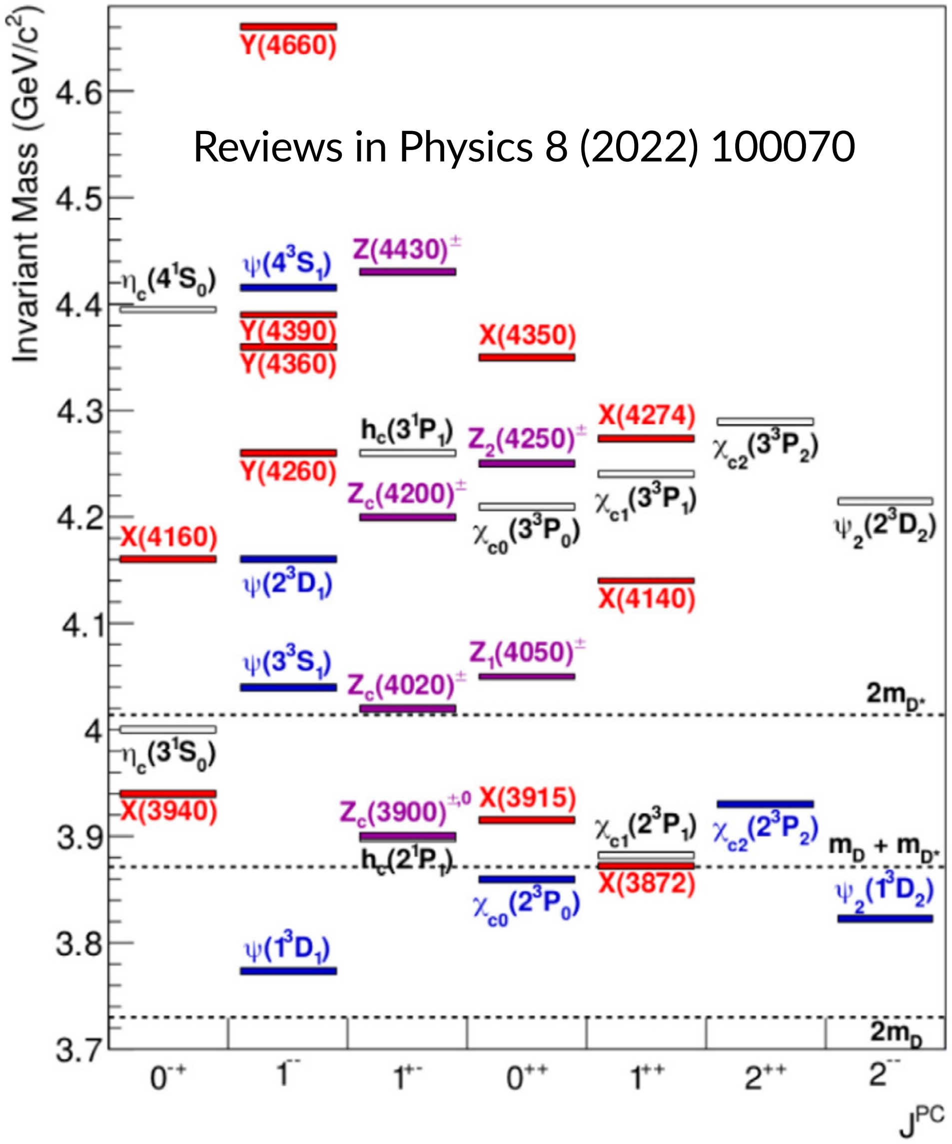


Manifestly exotic
- *Quark contents more than qq or qqq*
- *Quantum number J^{PC} not reachable for ordinary mesons or baryons*

'Cryptoexotic' exotic
- *overpopulation of states*
- *mass/width not fitting in spectra*
- *production and/or decay patterns incompatible with standard mesons/baryons*

XYZ states

Beyond the conventional baryon and meson picture…

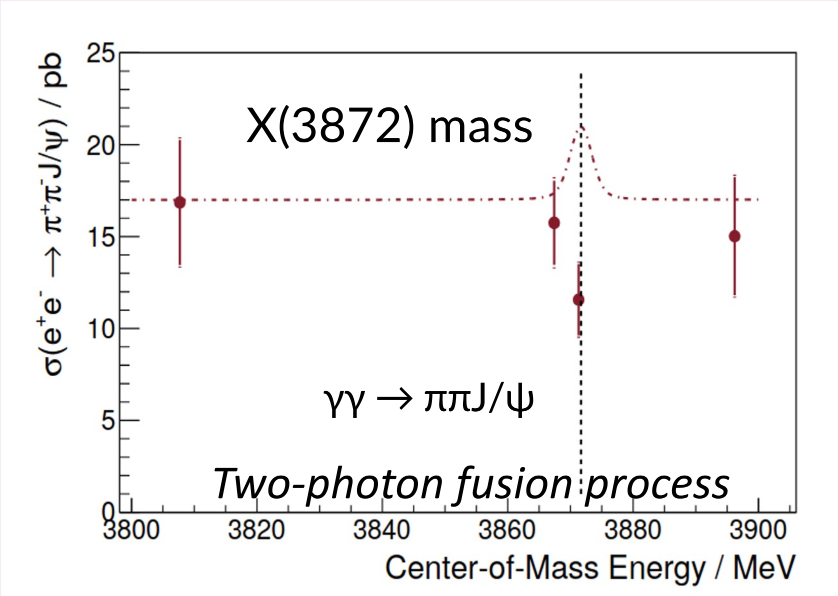


Reviews in Physics 8 (2022) 100070

X(3872) ($\chi_{c1}(3872)$) production

20th anniversary of X(3872) discovery. Still, only clues on its nature.

PRD 107 (2023), 032007

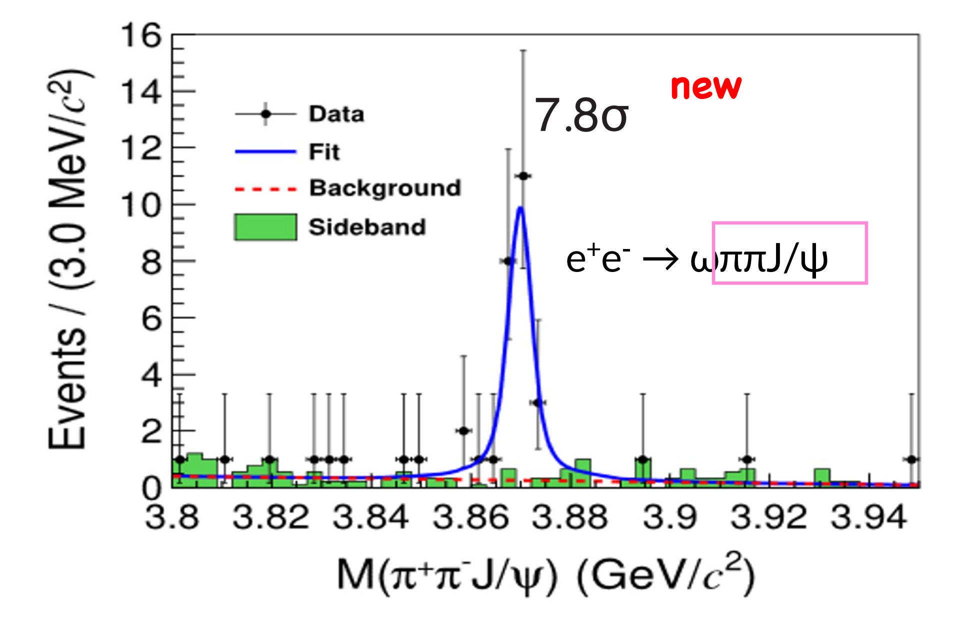


$$\sigma(\sqrt{s}) = \sigma_{\rm cont} + 12\pi \frac{\Gamma_{\rm tot}\Gamma_{ee} \times \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)}{(s - m_0^2)^2 + m_0^2\Gamma_{\rm tot}^2}$$

UL: $(\Gamma ee \times B) < 7.5 \times 10^{-3}$ eV @ the 90% C.L.,

PRL 130, 151904 (2023)

FIRST OBSERVATION
FOR THIS PRODUCTION MODE



4.66 < Ecm < 4.95 GeV

arXiv:**2309.01502v1** Submitted to PRL

A coupled-channel analysis of the X(3872) line-shape

11 c.m.e. @Y(4230) [4.178, 4.278] GeV $e^+e^- \to \gamma X(3872)$

Simultaneous fit to IM in the two decay channels of X(3782)

Differential decay rates

$$\frac{d\mathrm{Br}(D^0\bar{D}^0\pi^0)}{dE} = \mathcal{B}\frac{\mathrm{Br}(D^{*0}\to D^0\pi^0)\times g\times k_{\mathrm{eff}}(E)}{|D(E)|^2}$$

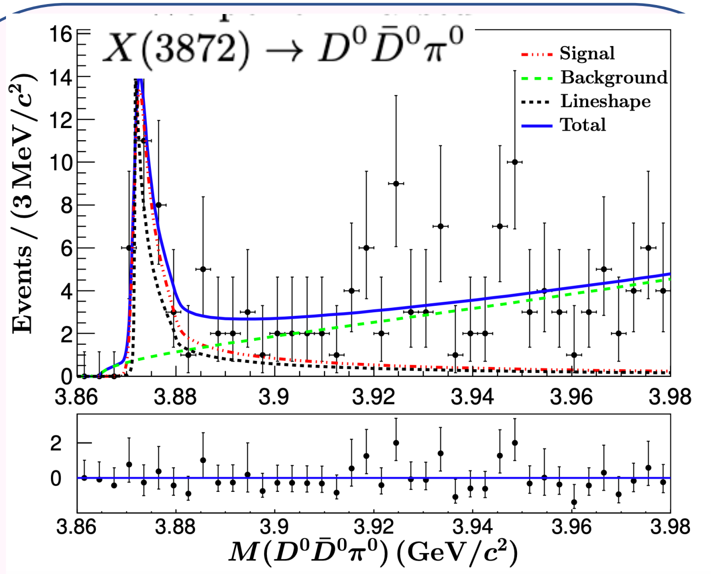
$$\frac{d\mathrm{Br}(\pi^+\pi^-J/\psi)}{dE} = \mathcal{B}\frac{\Gamma_{\pi^+\pi^-J/\psi}}{|D(E)|^2},$$

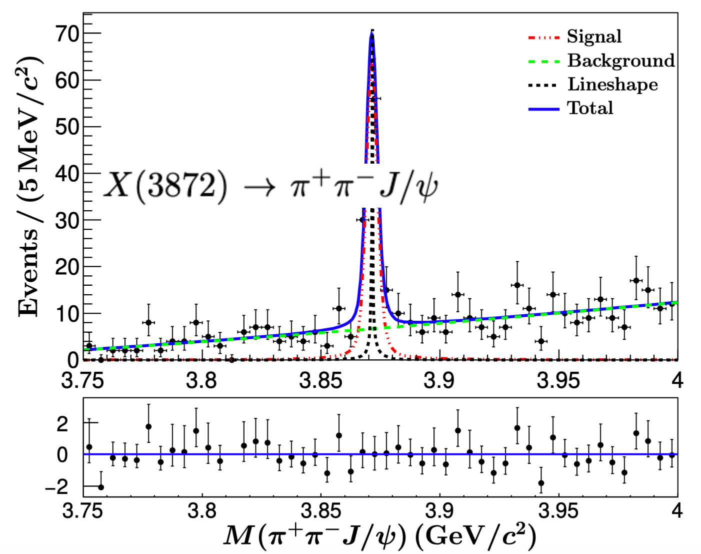
All production details

Eff. Coupling const of the X(3872) to D*D Intermediate state

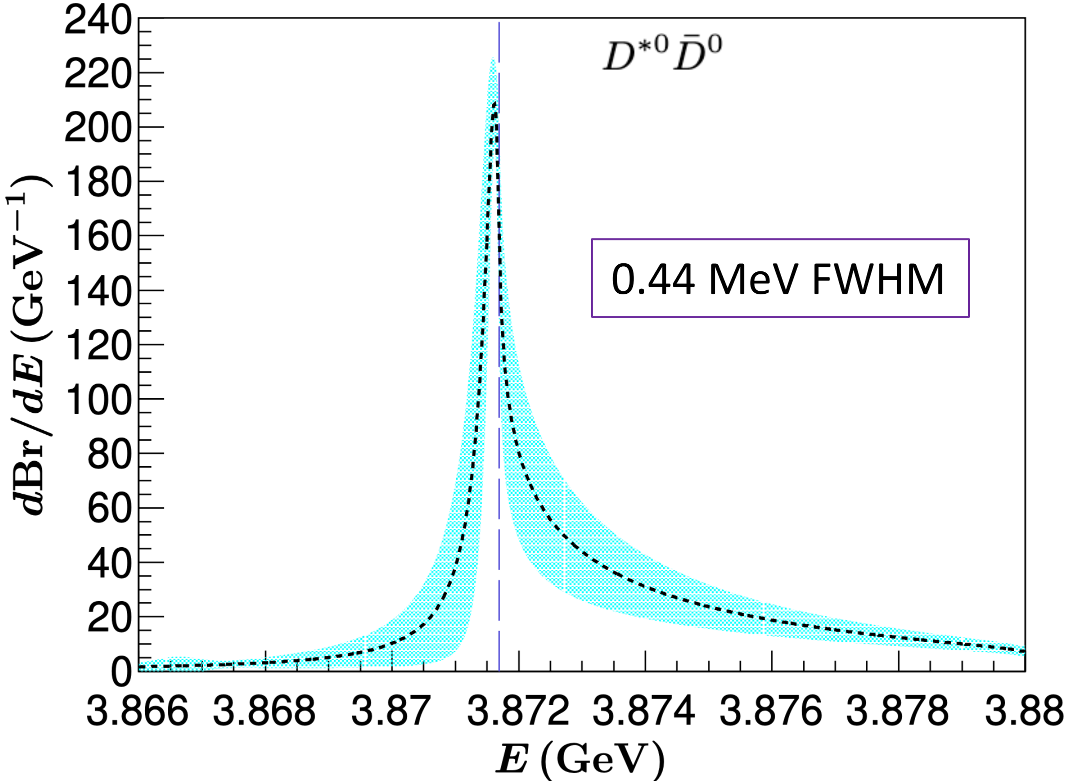
$$D(E) = E - E_X + \frac{1}{2}g\left[(\kappa_{\mathrm{eff}}(E) + ik_{\mathrm{eff}}(E)) + (\kappa^c_{\mathrm{eff}}(E) + ik^c_{\mathrm{eff}}(E))\right] + \frac{i}{2}\Gamma_0.$$

effects of the coupled-channels and the off-shell D^{*0} width included in the parameterization of the lineshape





A coupled-channel analysis of the X(3872) line-shape



arXiv:**2309.01502v1** Submitted to PRL

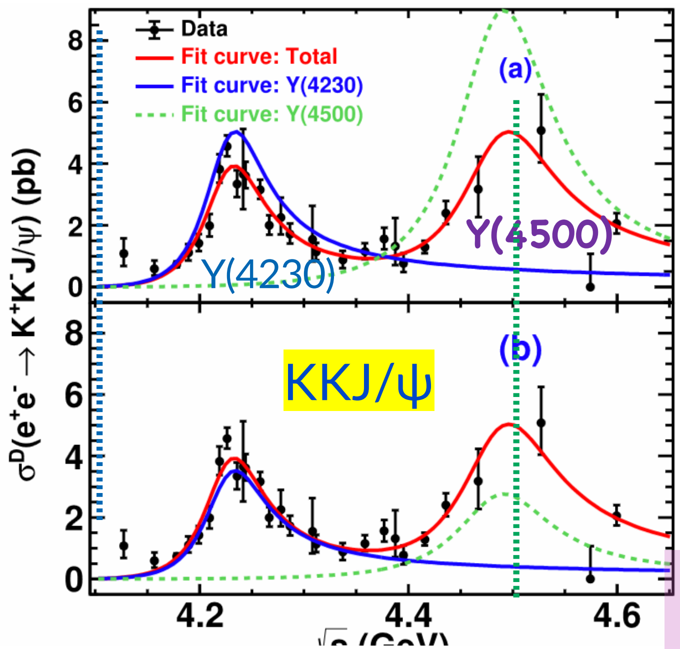
Lineshape best estimation adding all channels together

Parameters determination

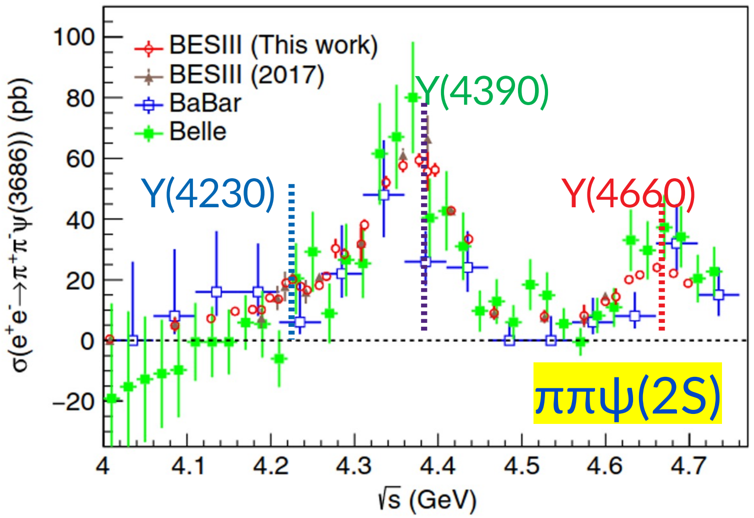
Parameters	g	Γ_0 (MeV)	M_X (MeV)
Fit results	0.16 ± 0.10	2.67 ± 1.77	3871.63 ± 0.13
Syst. Uncert.	$+1.12 \;\; -0.11$	$+8.01 \;\; -0.82$	$+0.06 \;\; -0.05$

Vector charmonium-like states

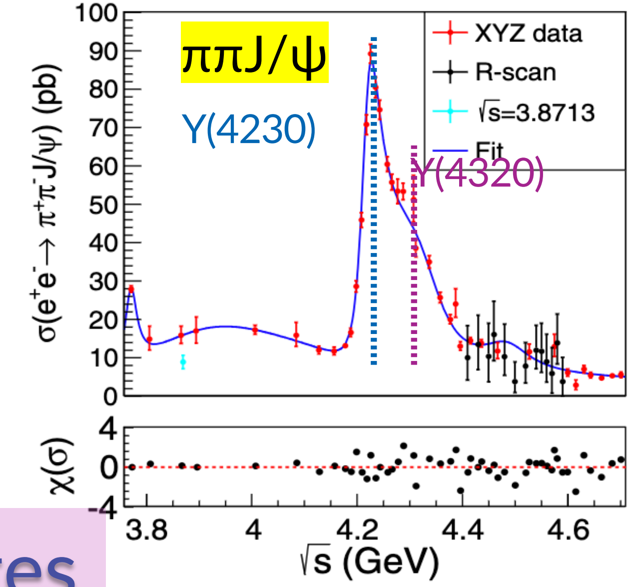
CPC 64 (2022) 111002

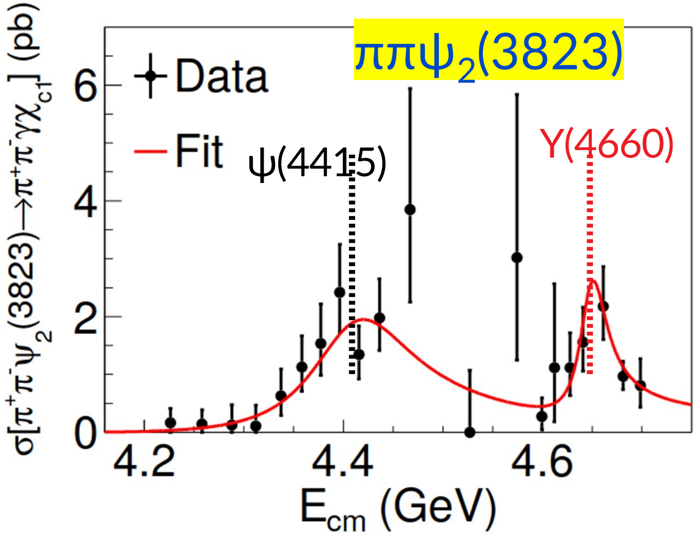


PRD 104 (2021) 052012

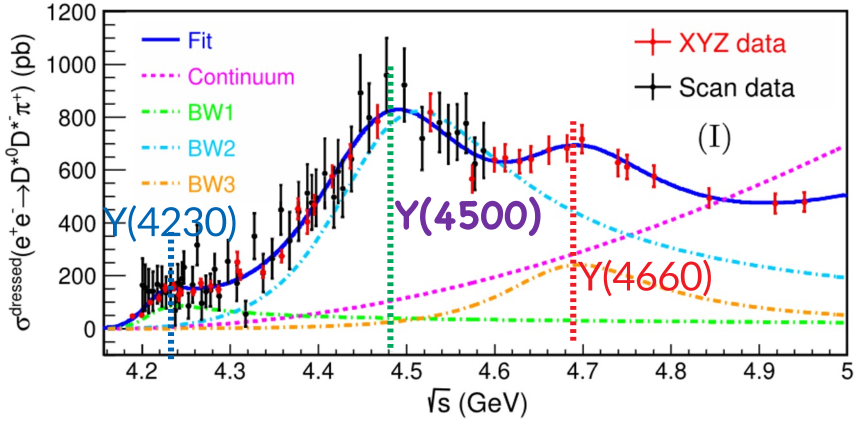


PRD 106, 072001 (2022)



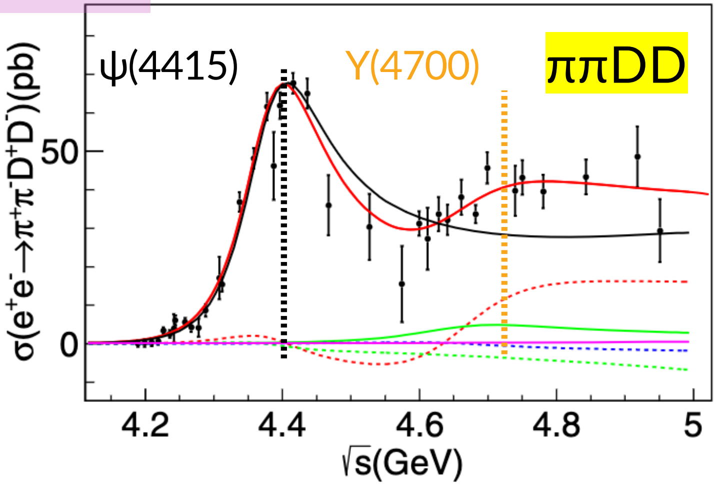


PRL 129 (2022) 102003



$D^{*0}D^{*-}\pi^+$

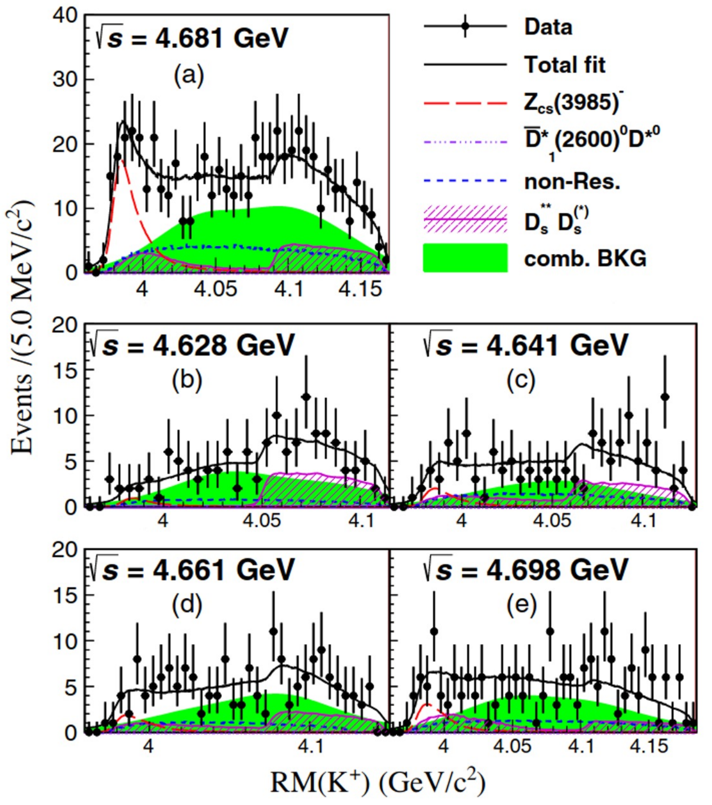
PRL 130, 121901 (2023)



PRD 106 (2022) 052012

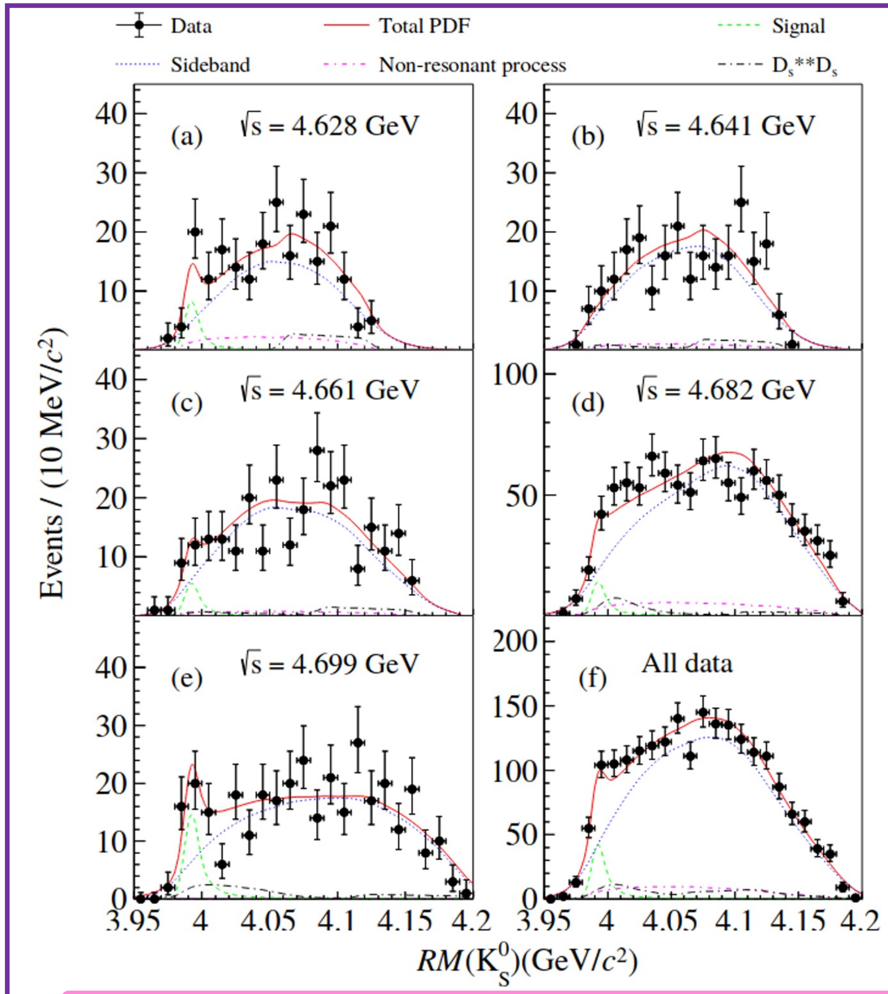
$Z_{cs}(3985)^{\pm,0}$

PRL 126 (2021) 102001



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

Observation in
($D_s^-D^{*0}$ + $D_s^{*-}D^0$)



$$e^+ + e^- \to K_S^0 D_S^+ D^{*-}, K_S^0 D_S^{*+} D^-$$

Evidence (4.6σ) in
($D_s^+D^{*-}$ +$D_s^{*+}D^-$)

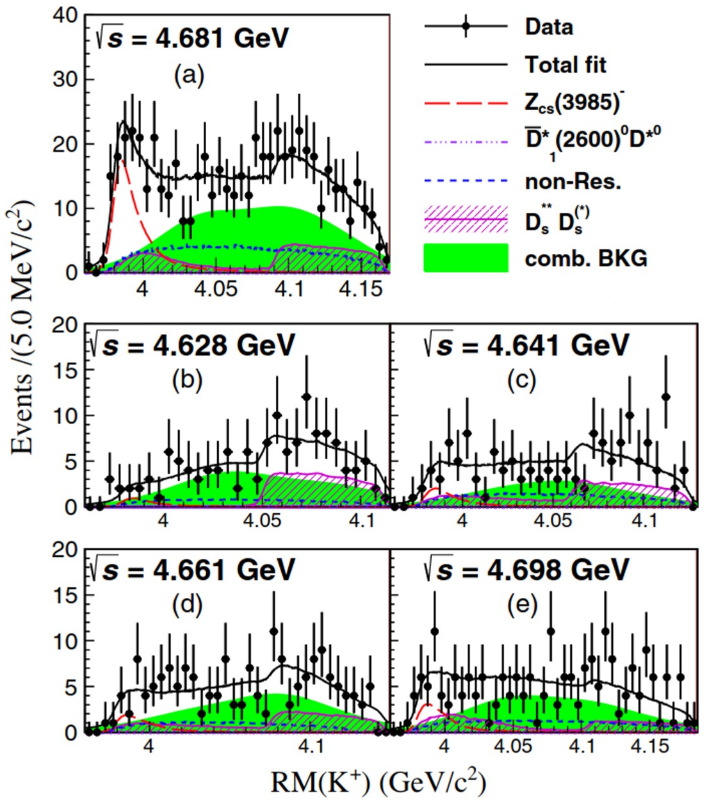
Minimal quark content $\bar{c}cs\bar{d}$

PRL 129 (2022) 112003

State	Mass (MeV/c^2)	Width (MeV)	Significance
$Z_{cs}(3985)^+$	$3985.2^{+2.1}_{-2.0} \pm 1.7$	$13.8^{+8.1}_{-5.2} \pm 4.9$	5.3σ
$Z_{cs}(3985)^0$	$3992.2 \pm 1.7 \pm 1.6$	$7.7^{+4.1}_{-3.8} \pm 4.3$	4.6σ

$Z_{cs}(3985)^{\pm,0}$

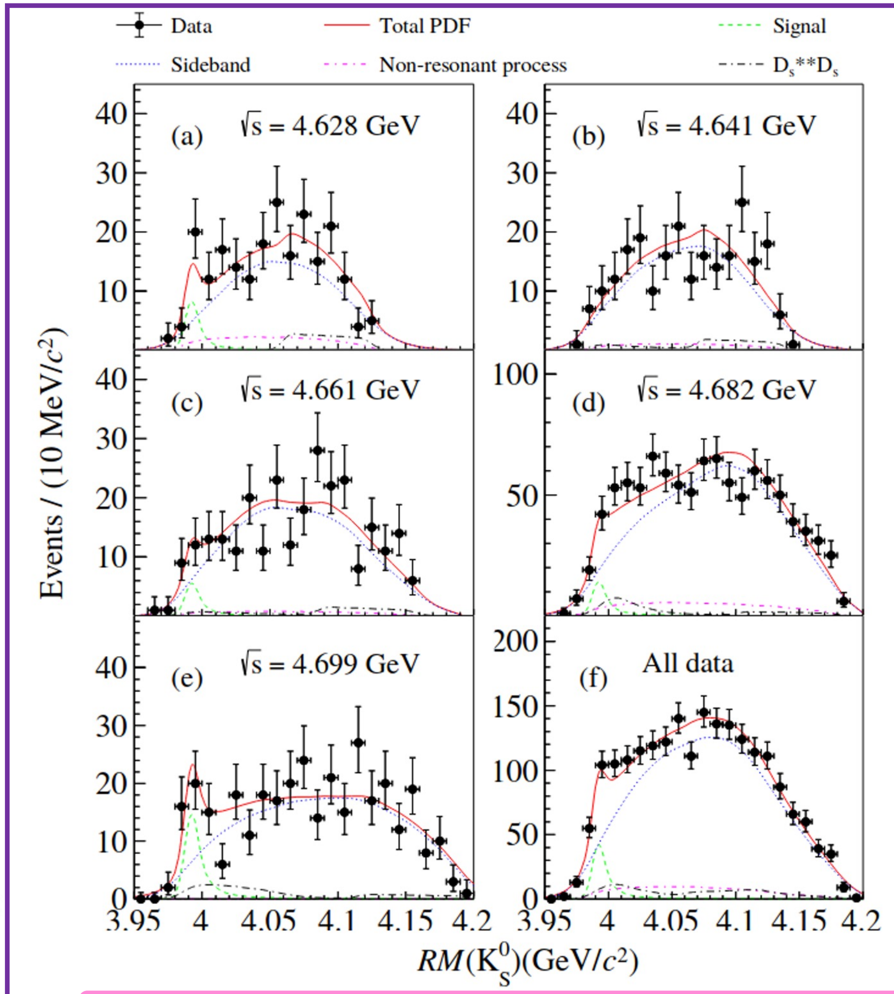
PRL 126 (2021) 102001



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

Observation in

($D_s^- D^{*0}$ + $D_s^{*-} D^0$)



$$e^+ + e^- \to K_S^0 D_S^+ D^{*-}, K_S^0 D_S^{*+} D^-$$

Evidence (4.6σ) in

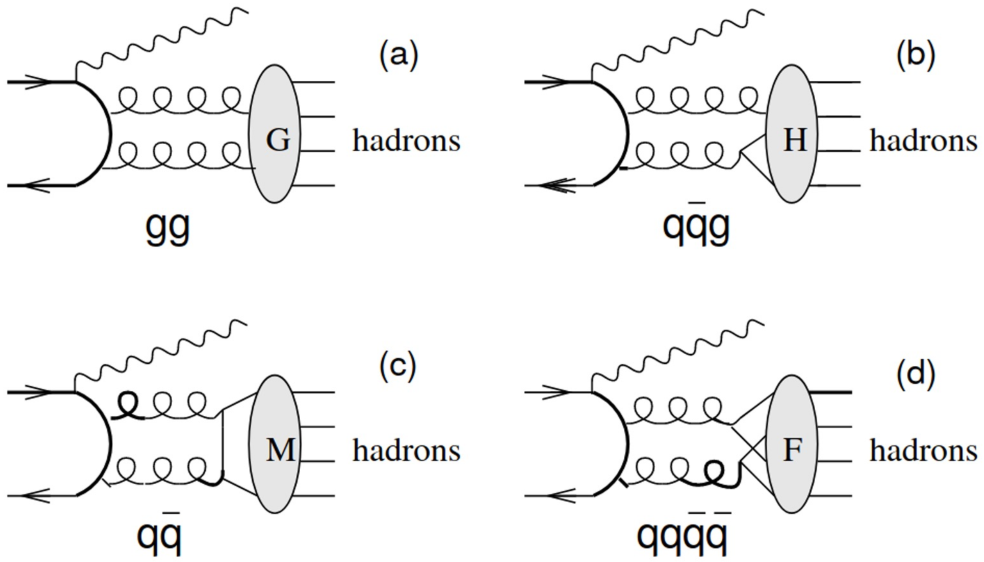
($D_s^+ D^{*-}$ + $D_s^{*+} D^-$)

Minimal quark content $\bar{c}cs\bar{d}$

PRL 129 (2022) 112003

Iso-Vector open strangeness triplet

State	Mass (MeV/c^2)	Width (MeV)	Significance
$Z_{cs}(3985)^+$	$3985.2^{+2.1}_{-2.0} \pm 1.7$	$13.8^{+8.1}_{-5.2} \pm 4.9$	5.3σ
$Z_{cs}(3985)^0$	$3992.2 \pm 1.7 \pm 1.6$	$7.7^{+4.1}_{-3.8} \pm 4.3$	4.6σ



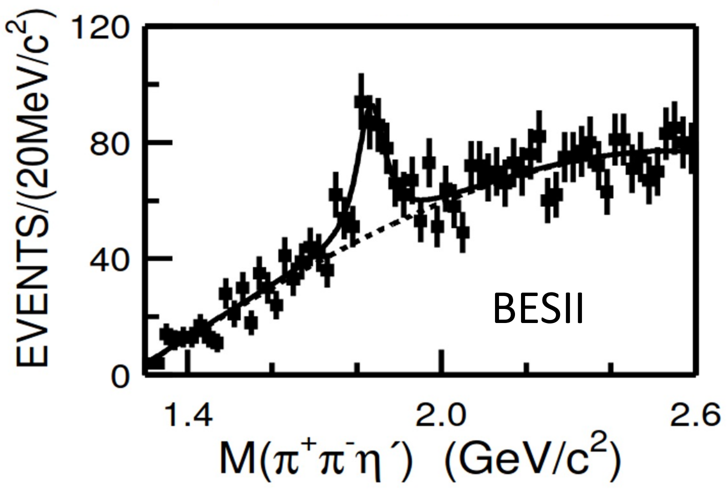
Light hadrons spectroscopy

……..Hunting exotics in gluon-rich charmonia decays

A «generous» decay

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

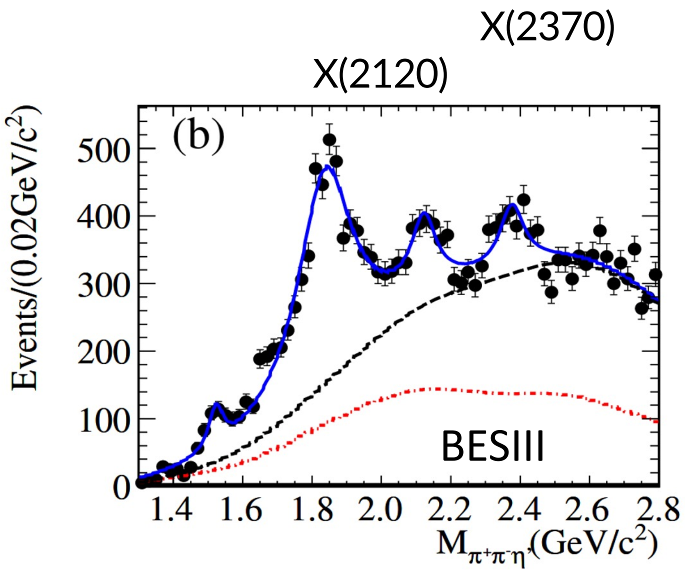
PRL 95 (2005) 262001



58 Million J/ψ

Clear signal of exotic X(1835)

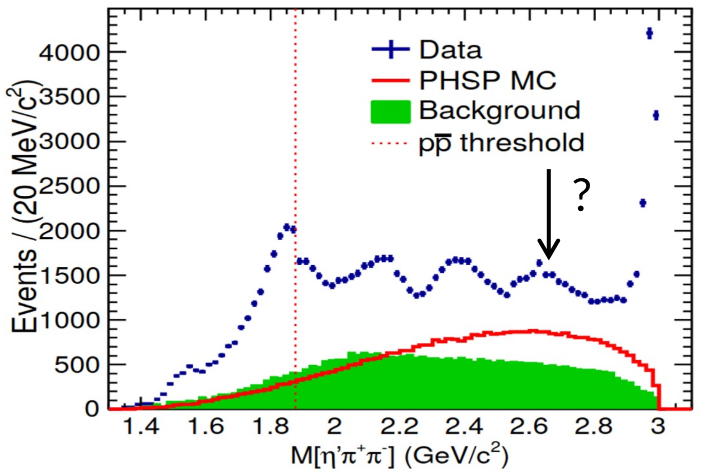
PRL 106 (2011) 072002



225 Million J/ψ

X(1835) confirmed
other two structures emerge

PRL 117 (2016) 042002



1.3 Billion J/ψ

@ 1835 MeV:
2 states or threshold effect?

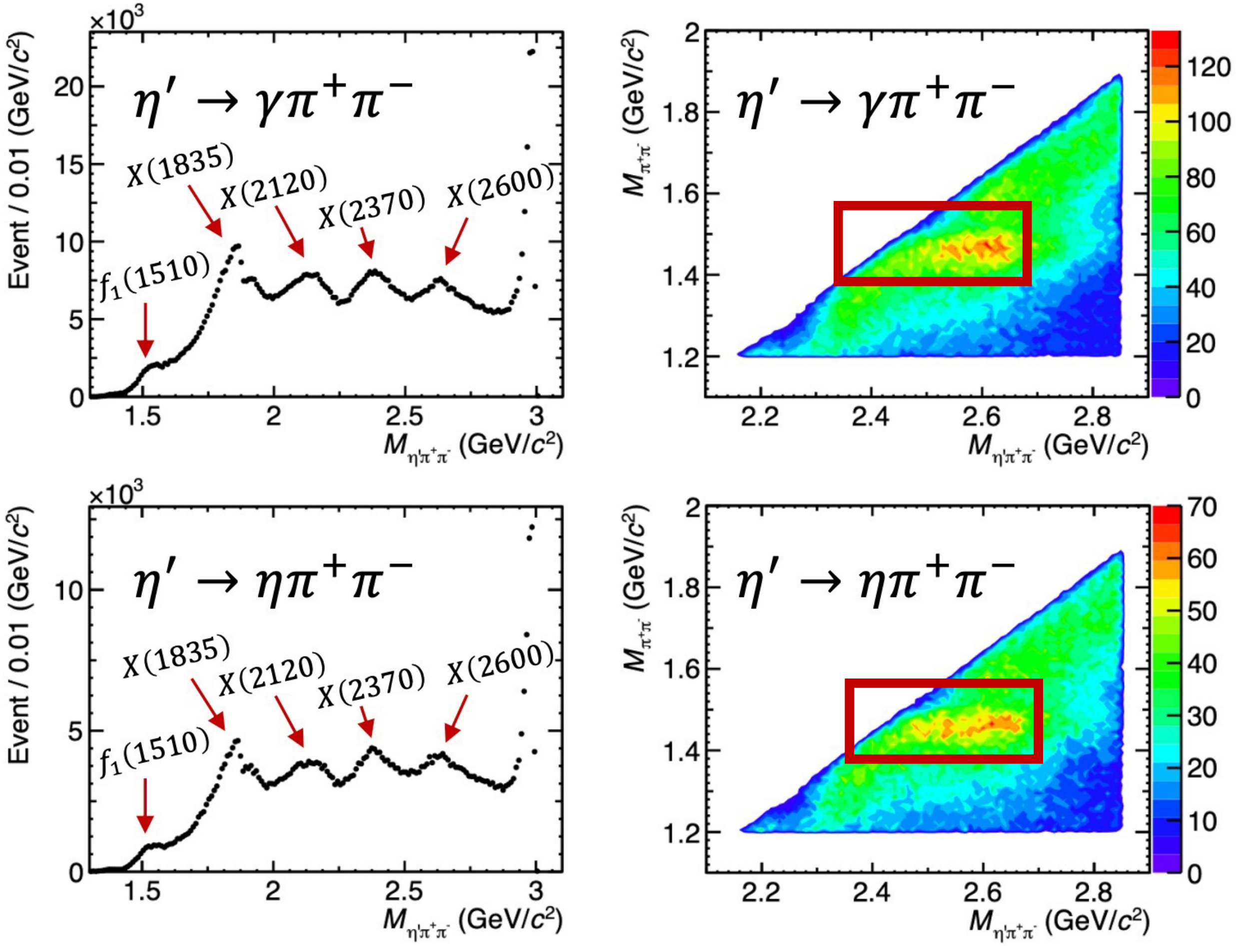
10B J/ψ era

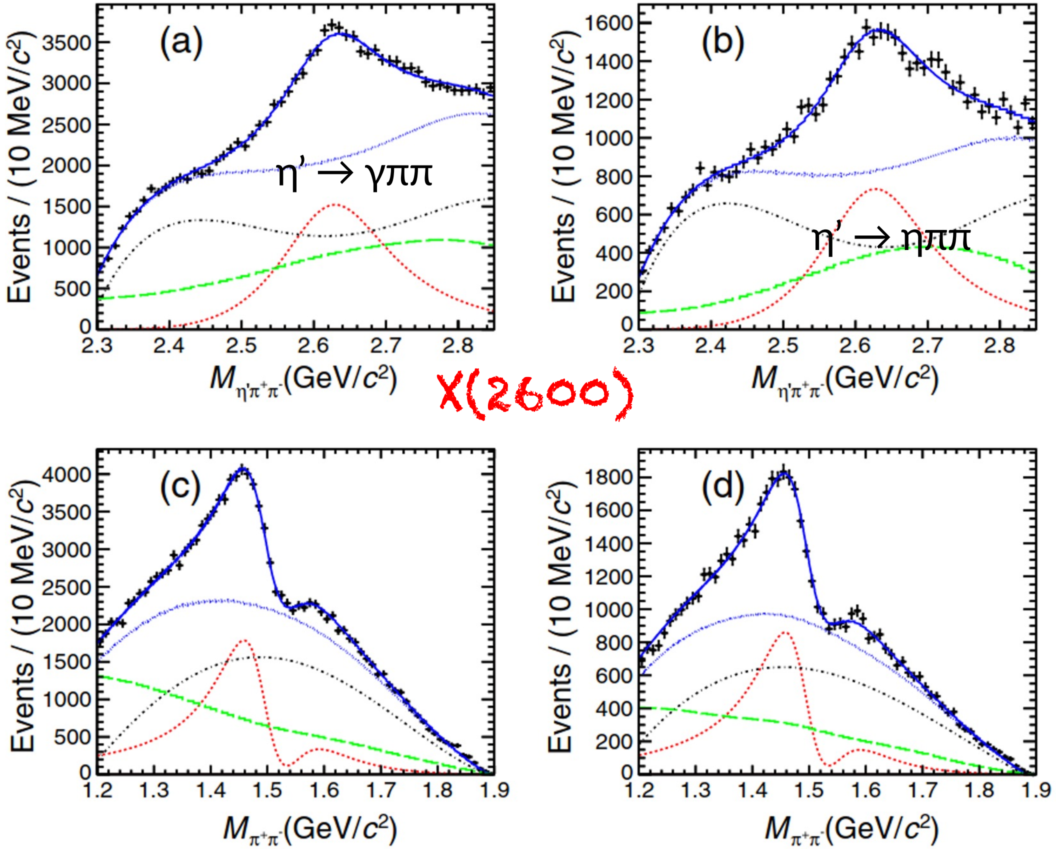
Phys. Rev. Lett. 129 (2022) 042001

Most accurate measurement of this final state. Confirmed known states

- Observed a new state!

  Strongly correlated with structure $M_{\pi\pi}$ ~1.5 GeV



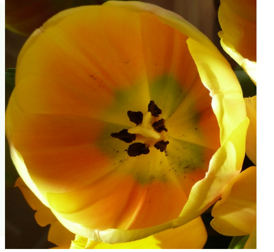


P2023

Simultaneous fit with the two η′ decay modes (> 20σ)

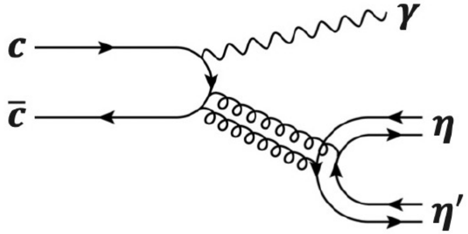
Resonance	Mass (MeV/c^2)	Width (MeV)
$f_0(1500)$	$1492.5 \pm 3.6^{+2.4}_{-20.5}$	$107 \pm 9^{+21}_{-7}$
$X(1540)$	$1540.2 \pm 7.0^{+36.3}_{-6.1}$	$157 \pm 19^{+11}_{-77}$
$X(2600)$	$2618.3 \pm 2.0^{+16.3}_{-1.4}$	$195 \pm 5^{+26}_{-17}$

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



PWA of $J/\psi\to\gamma\eta\eta'$ using 10 Billion of J/ψ data @ BESIII

$\eta\to\gamma\gamma$ and $\eta'\to\gamma\pi^+\pi^-$/ $\eta\pi^+\pi^-$

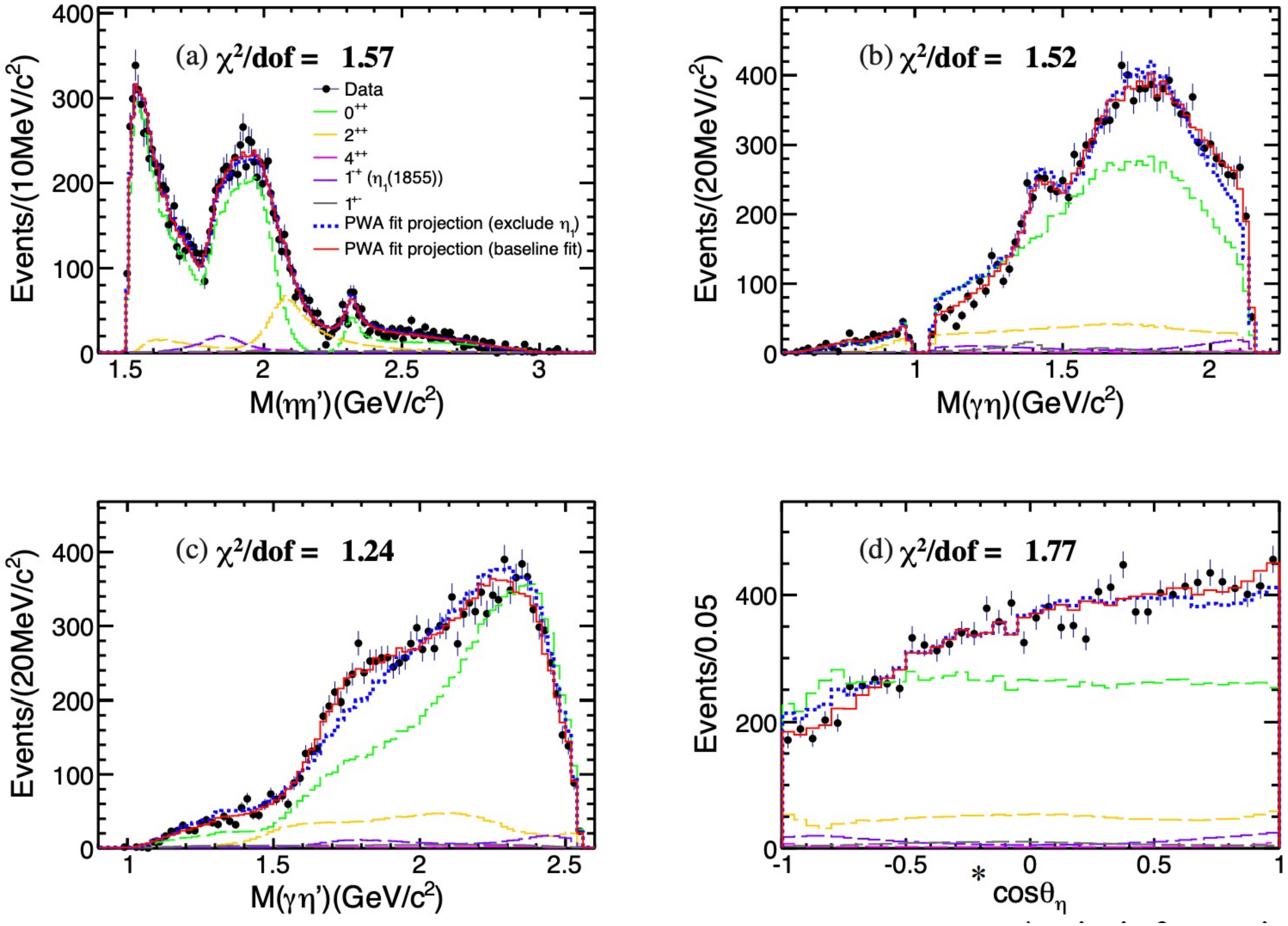


An isoscalar 1^{-+} state, $\eta_1(1855)$, has been observed with statistical significance >19σ

Mass is consistent with LQCD calculation for the 1^{-+} hybrid (1.7 – 2.1 GeV/c²)

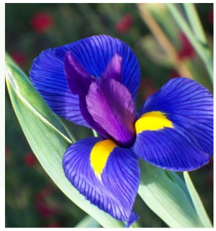
$$M = (1855 \pm 9^{+6}_{-1})\,\mathrm{MeV}/c^2; \quad \Gamma = (188 \pm 18^{+3}_{-8})\,\mathrm{MeV}$$

$$\mathcal{B}(J/\psi \to \gamma\eta_1(1855) \to \gamma\eta\eta') = (2.70 \pm 0.41^{+0.16}_{-0.35}) \times 10^{-6}$$



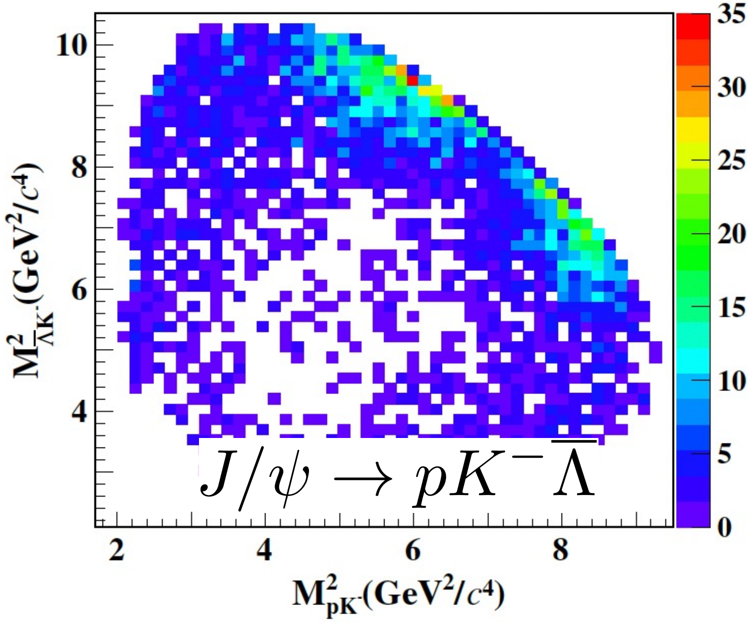
PRL 129, 192002 (2022)
PRD 106,072012 (2022)
PRD 107,079901 (2023)

Observation of the Narrow Structure near the $p\bar{\Lambda}$ Tthreshold

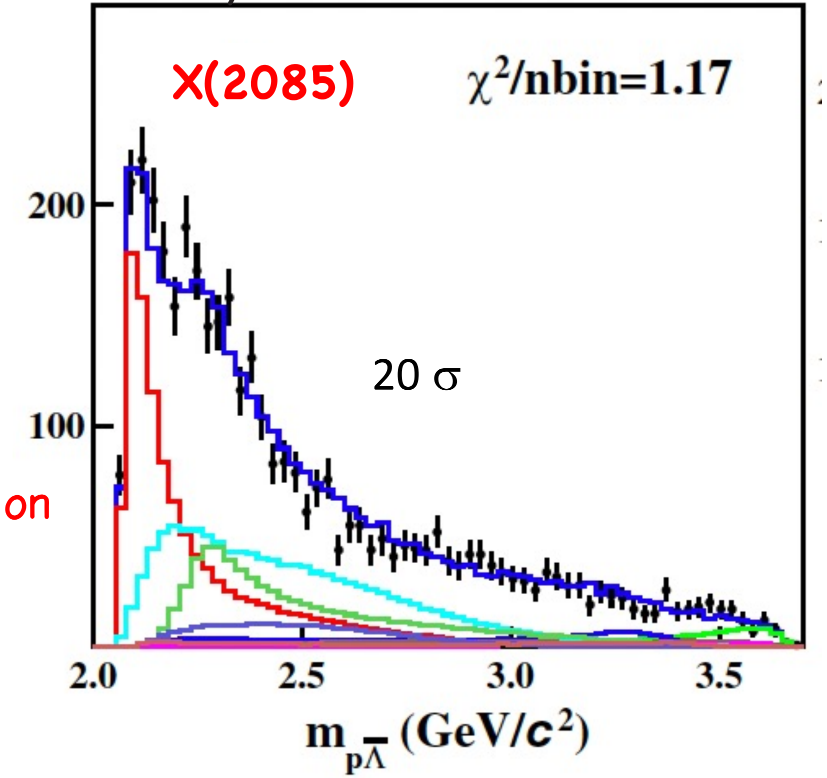


PRL 131, 151901 (2023)

Anomalous enhancement near the $p\bar{\Lambda}$ mass threshold **first** observed by BESIII



amplitude analysis
for spin parity determination



8.35 fb^{-1} @ $\sqrt{s} = 4.008, 4.178, 4.226, 4.258, 4.416$, and 4.682 GeV,

The spin and parity of X(2085) determined to be 1^+ with a statistical significance greater than 5σ

$$M_{\text{pole}} = (2086^{+4}_{-2} \pm 9)\,\text{MeV} \quad \Gamma_{\text{pole}} = (58^{+4}_{-3})\,\text{MeV}.$$

Near threshold

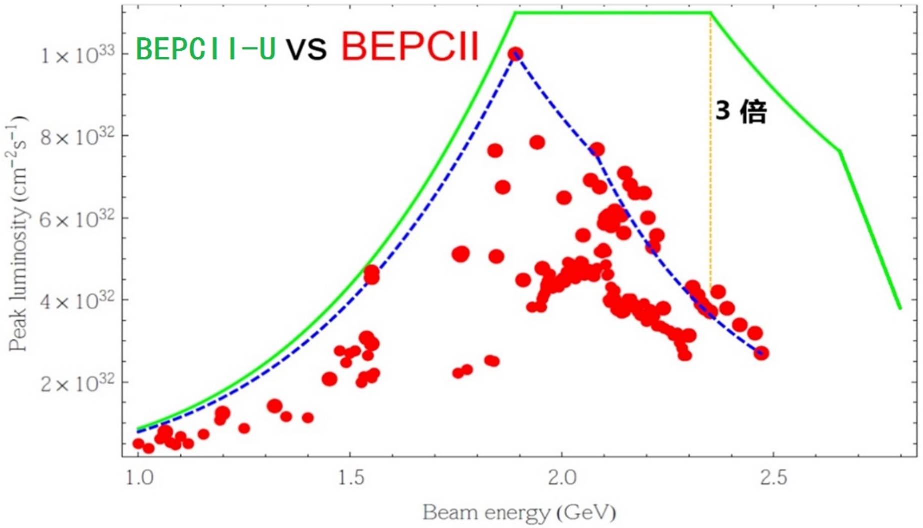
narrow

may suggest exotic properties!!!!!

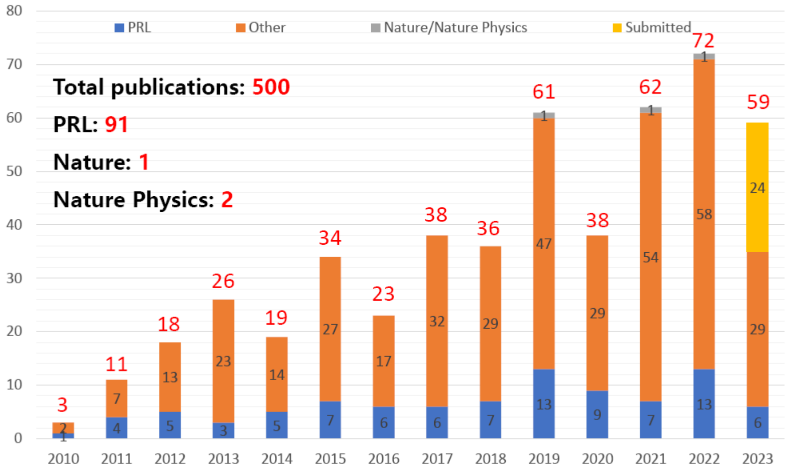
Summary and outlook

- BESIII is taking data since 2008. It will continue to run till ~2030.
- This year the landmark of 500 publications was reached!
- It is an excellent laboratory to study a wide physics program.
- A personal selection of latest BESIII physics results is presented
- Latest large data-sets under study→ STAY TUNED!
- BEPCII-U will extend the lifetime of BESIII (3x lum above 4 GeV &max energy to 5.6 GeV)! Exciting times are coming!

Chin.Phys.C 44 (2020) 4, 040001



BESIII publications (May 9, 2023)



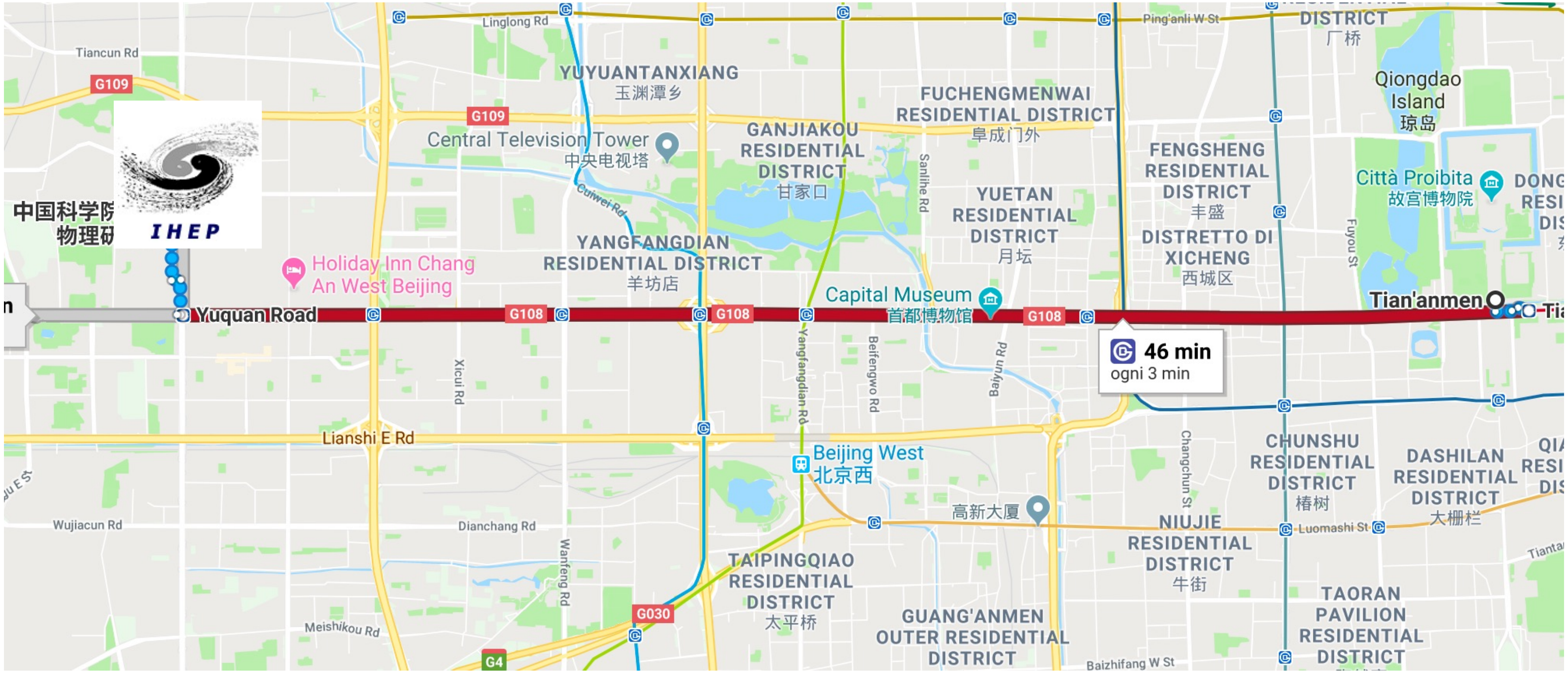
Thank you
For your attention

謝謝

BACKUP

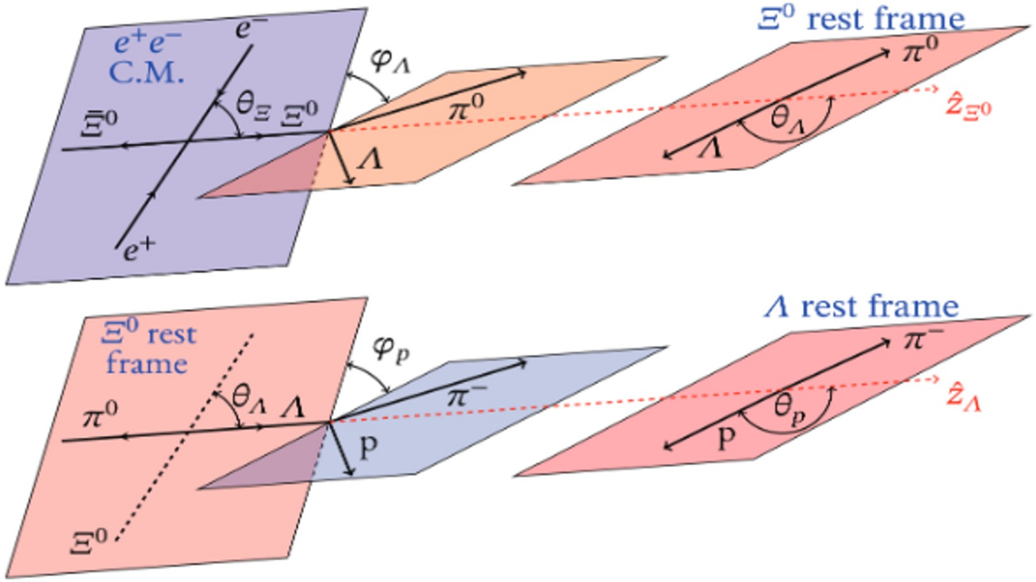

Where is IHEP?
9.940 km
14 ore 35 min
Rabat
Pechino
Danimarca
Irlanda
Bielorussia
Polonia
Germania
Ucraina
Kazakistan
Austria
Francia
Romania
Mongolia
Italia
Spagna
Portogallo
Grecia
Turchia
Kirghizistan
Turkmenistan
Cina
Marocco
Tunisia
Siria
Iraq
Iran
Afghanistan
Pakistan
Nepal
Algeria
Libia
Egitto
Arabia Saudita
Oman
India
Myanmar (Birmania)
Mauritania
Mali
Niger
Ciad
Sudan
Yemen
Thailandia
Mar Cinese Meridionale
Vietnam
Golfo di Aden
Mar Arabico
Golfo del Bengala
Golfo del Siam
Guinea
Burkina Faso
Nigeria
Ghana
Golfo di Guinea
Sudan del Sud
Etiopia
Somalia
Mare delle Laccadive
Malesia
Kenya
Gabon
Repubblica Democratica del Congo
Tanzania
Indonesia
Angola
Zambia
Mozambico
Namibia
Zimbabwe
Botswana
Madagascar
Oceano Indiano
Oceano Atlantico Meridionale
Sudafrica

Where is IHEP?



Ξ^0 polarization

Helicity angles definition



CP variables

$$A^{\Xi}_{CP} = (\alpha_\Xi + \bar{\alpha}_\Xi)/(\alpha_\Xi - \bar{\alpha}_\Xi),$$
$$\Delta\phi^{\Xi}_{CP} = (\phi_\Xi + \bar{\phi}_\Xi)/2,$$
$$A^{\Lambda}_{CP} = (\alpha_\Lambda + \bar{\alpha}_\Lambda)/(\alpha_\Lambda - \bar{\alpha}_\Lambda),$$

A^{Ξ}_{CP} is sensitive to weak phase difference and it can be washed out if small phase

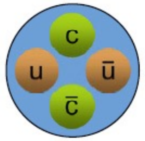
$\Delta\phi^{\Xi}_{CP}$ has no dependence so it more sensitive to CPV

Polarization term in moment distribution

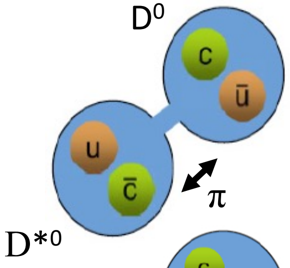
$$P_y(\theta_\Xi) = \sqrt{1-\alpha^2_{J/\psi}}\sin(\Delta\Phi)\cos\theta_\Xi\sin\theta_\Xi/(1+\alpha_{J/\psi}\cos^2\theta_\Xi)$$

Nature of XYZ states

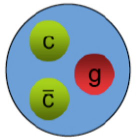
- **Tetraquarks**
  - Bound states of **(coloured diquark anti-diquark), Large number** of states (charged



  and neutral) foreseen (a nonet for each spin-parity) ,
  Small widths above threshold

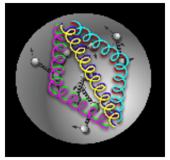


- **Hadronic Molecules**
  - Loosely bound states of **pair of mesons**, **Small number** of states,
  Small widths above threshold



- **Hybrids**
  - Bound States with a pair of quarks and **excited gluonic** degrees of freedom
  - Lattice and model predictions for the **lowest-mass** hybrid ~ **4.2 GeV/c^2**
- **Glueball**

  Bound states of gluons



Unprecedented possibility to test our knowledge of the QCD

- **HadroCharmonium**

Compact charmonium enbadded in light quark mesonic excitation interacting by analog of Van der Waals force

- **Others:** **Threshold**, **cusp**, or **coupled-channel** effect produce a **cross section enhancement**

EXPERIMENTAL CONTRIBUTION

1)Establish the spectrum: search for more XYZ states, determine their properties and investigate new decays for known ones
2) Build connections: look for transitions between different states

The X(3872) was discovered by Belle in 2003 in $B^+ \rightarrow K^+ J/\psi \pi^+ \pi^-$

$$M = 3871.69 \pm 0.17 \text{ MeV}/c^2$$

Very close to the $D^0\bar{D}^{*0}$ threshold, Very narrow(< 1.2 MeV/c^2)

Confirmed by BABAR, CDF, D0, LHCb.

-$J^{PC} = 1^{++}$,

-no isospin partners currently known –

-decays into $J/\psi\ \pi^+\pi^-$, $D^{*0}\bar{D}^0$, $J/\psi\ \pi^+\pi^-\pi^0$, $D^0D^0\pi^0$, $\gamma J/\psi$, $\gamma\psi(2S)$. Also isospin-violating → $\rho J/\psi$ and $\omega J/\psi$.

Unconventional meson candidate :

molecular states, tetraquark states, mixture of excited χ_{c1} and D^0D^{*0} bound state. …

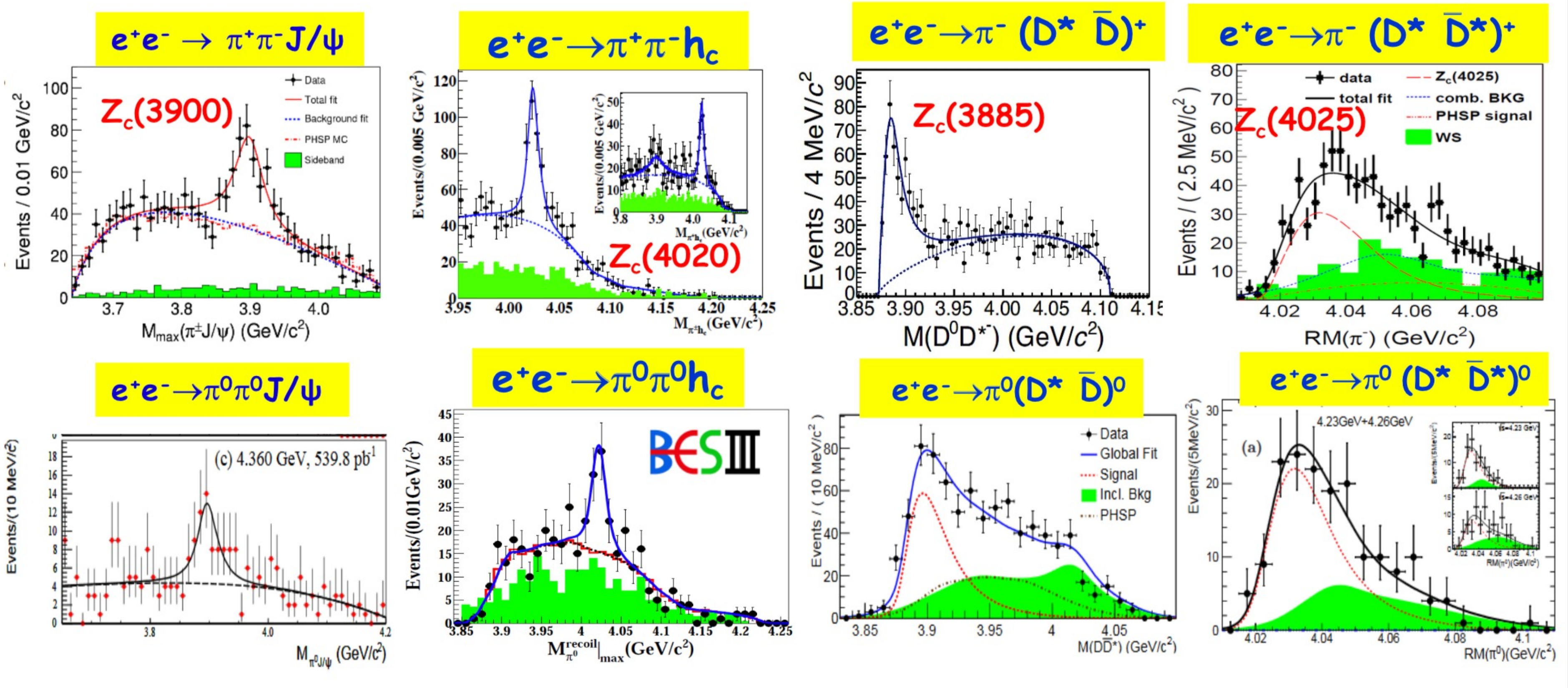
Much is now known about the X(3872), except exactly what it is

$Z_c(3900)/Z_c(4020)$

Must contain at least a $c\bar{c}$ and a light $q\bar{q}$ pair:exotic!

PRL110, 252001 (2013)

PRD 92, 092006



PRL115 , 182002(2015)

PRL112, 022001 (2014) PRL115, 222002 (2015) PRL112, 132001 (2014)

PRL111, 242001 (2013)

PRL113, 212002 (2014)

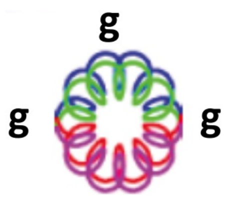
- Observed in various channels
- strong coupling with $D\bar{D}^*$. $D^*\bar{D}^*$
- 2 Isospin triplets estabilished by BESIII

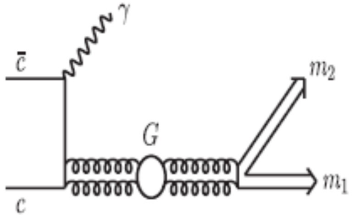
Light Hadron Spectroscopy

Conventional hadrons:

But QCD allows other forms of hadrons:

- ✓ Multi-quark state: > 3 quarks
- ✓ Glueball: gg, ggg, …
- ✓ Hybrid: : $q\bar{q}g$, $qqqg$ …
- ✓ molecule: bound state of more then 2 hadrons



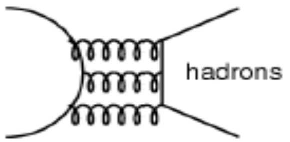


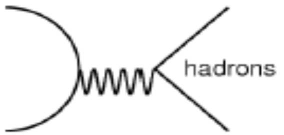
Lots of candidates
but not established yet

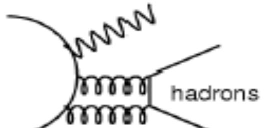
- BESIII advantages?

  Charmonium decays can be used (high statistics)

  - Gluon rich processes
  - Kinematics favorable
  - Clean environment, no combinatorial bkg
  - J^{PC} and Isospin filters in strong decays compared to hadron colliders







Hunting Glueballs

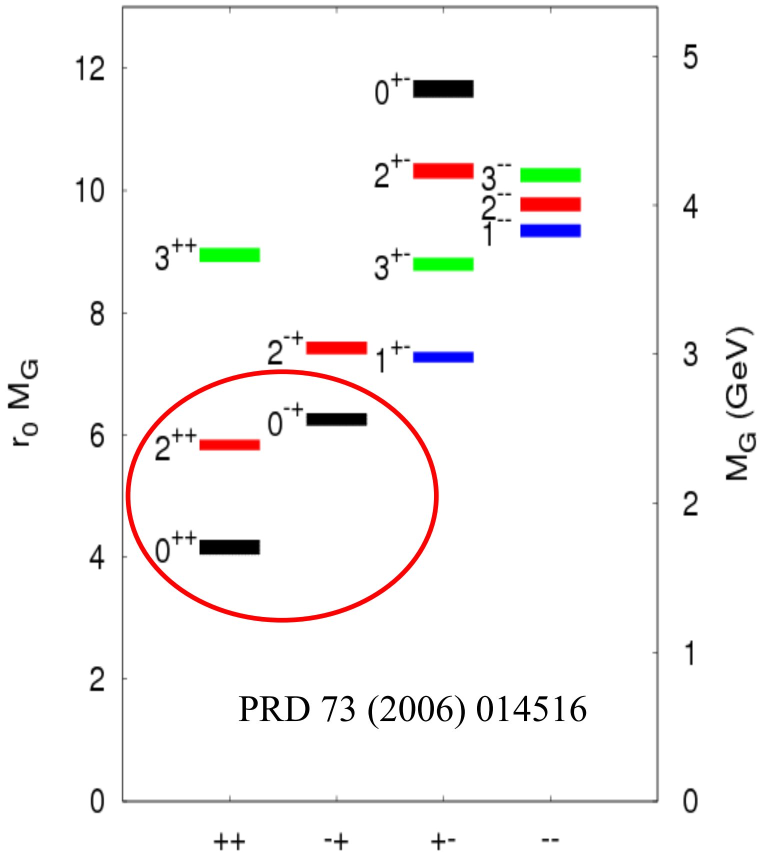
J/ψ radiative decays are gluon-rich environment (large BR forseen): an ideal place to search for glueballs.

- Lattice QCD prediction
  - 0^{++} ground state: 1~1.7 GeV/c²
  - 2^{++} ground state: 2.3~2.4 GeV/c²
  - 0^{-+} ground state: 2.3~2.6 GeV/c²

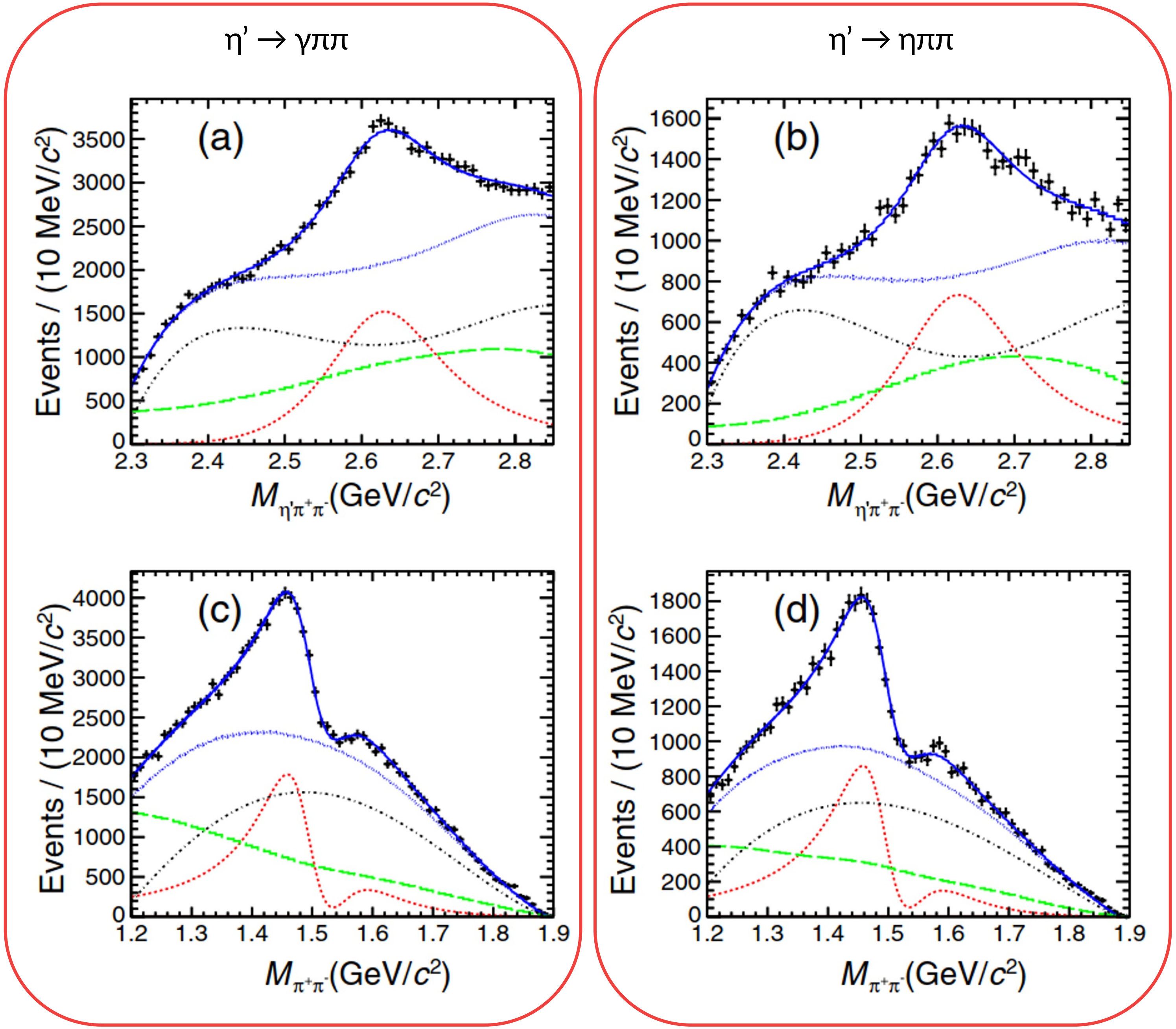
They can mix with ordinary $q\bar{q}$ states

Systematic experimental studies needed:
- Map of the resonances
- Study of the production patterns ($J/\psi \to \gamma/\omega/\phi + X$)
- Study of the decay patterns

Glueballs from quenched LQCD



Glueball is important :
fundamental test of QCD, critical information to gluon field and confinement



X(2600)

Phys. Rev. Lett. 129 (2022) 042001

TABLE I. Masses and widths of the $f_0(1500)$, $X(1540)$, and $X(2600)$. The first uncertainties are statistical, and the second are systematic.

Resonance	Mass (MeV/c^2)	Width (MeV)
$f_0(1500)$	$1492.5 \pm 3.6^{+2.4}_{-20.5}$	$107 \pm 9^{+21}_{-7}$
$X(1540)$	$1540.2 \pm 7.0^{+36.3}_{-6.1}$	$157 \pm 19^{+11}_{-77}$
$X(2600)$	$2618.3 \pm 2.0^{+16.3}_{-1.4}$	$195 \pm 5^{+26}_{-17}$

Simultaneous fit results with the two η′ decay modes
More than 20σ significance for the 3 resonances

Structure @ 1.5 GeV well described by interference between $f_0(1500)$ and X(1540)

X(2600)
$J^{PC} = 0^{-+}$ or 2^{-+}

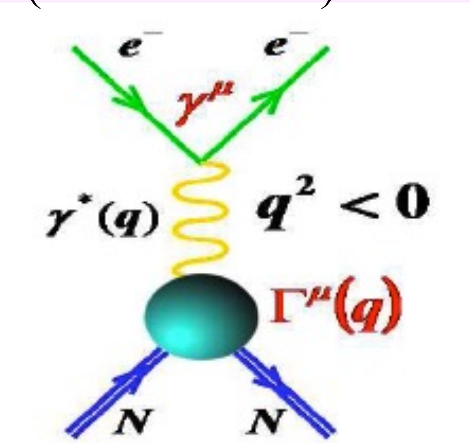
ElectroMagnetic Form Factors

Hadrons are not point-like particles
- Internal structure
- Internal dynamics → $M_{hadron} \neq \sum m_{q\text{-valence}}$

Form Factors (FFs) used to parametrize the structure and internal dynamics:
2 FFs involved for nucleons
EMFF simplest structure observables

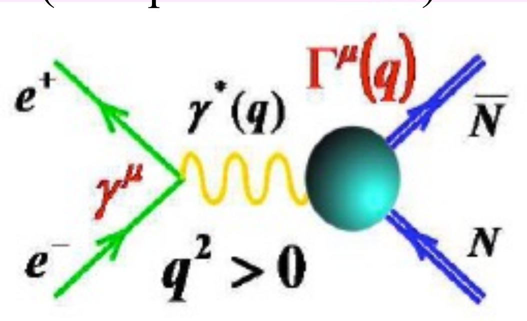
test ground for our understanding of the strong interactions

SPACE-LIKE FF
(Real functions)



Electron scattering
$q^2 < 0$

TIME-LIKE FF
(Complex functions)



Annihilation processes
$q^2 > 0$

Unphysical region

Γ_μ **Vertex** contains the unknown structure, parametrized by F1 and F2:

Dirac FF: related to the charge

$$\Gamma^\mu = \gamma^\mu F_1^N(q^2) + \frac{i\sigma^\mu_\nu q^\nu}{2M} F_2^N(q^2)$$

Pauli FF: related to the Magnetization