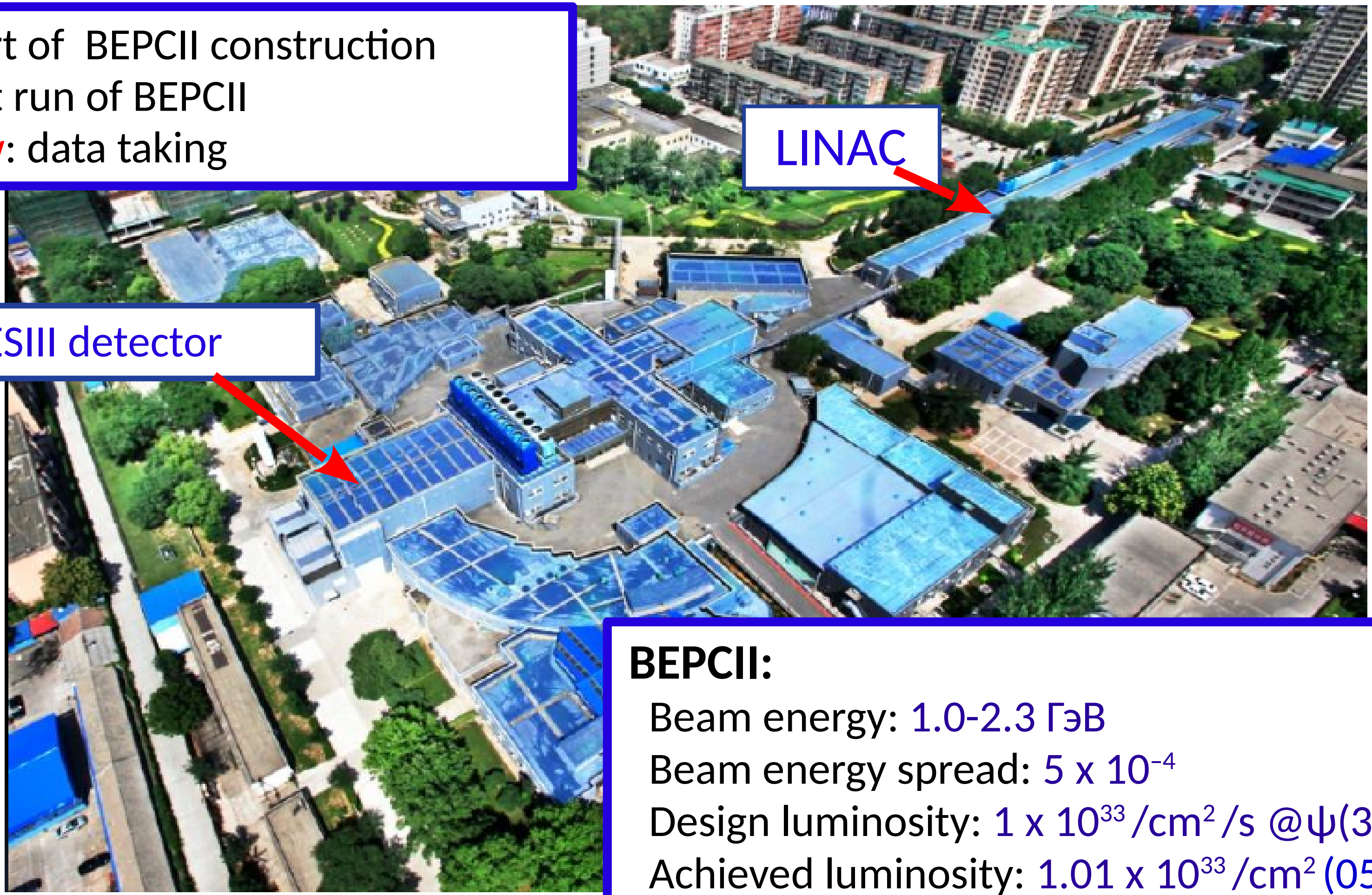
BESIII Project

Igor Denisenko

JINR PAC
21.06.2023

BESIII and BEPCII (IHEP, Beijing, China)

2004: start of BEPCII construction
2008: test run of BEPCII
2009-now: data taking



BEPCII:

Beam energy: 1.0-2.3 ГэВ
Beam energy spread: 5×10^{-4}
Design luminosity: 1×10^{33} /cm^2/s @ψ(3770)
Achieved luminosity: 1.01×10^{33} /cm^2 (05.04.2016)

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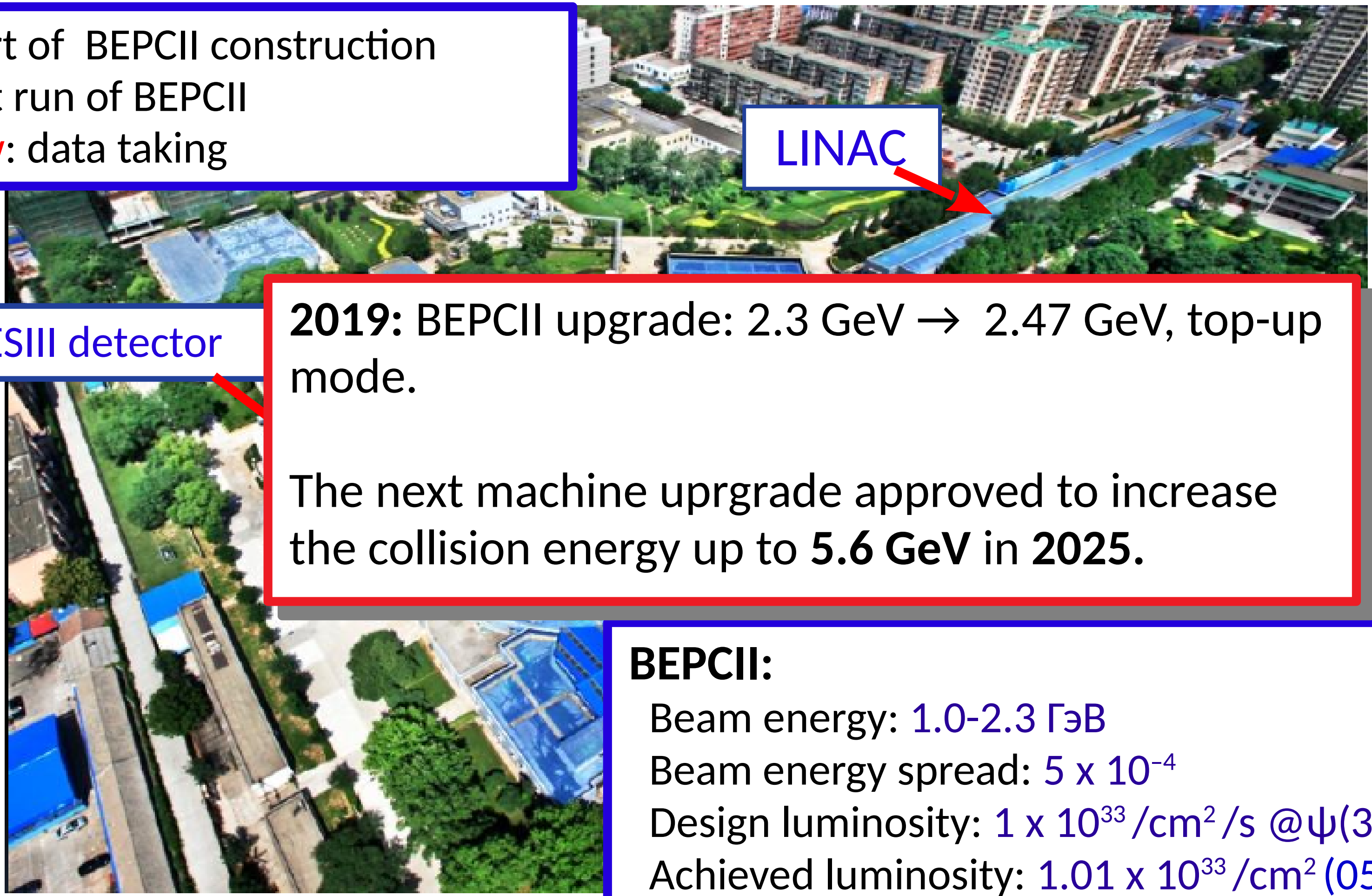

2019: BEPCII upgrade: 2.3 GeV → 2.47 GeV, top-up mode.

The next machine uprgrade approved to increase the collision energy up to **5.6 GeV** in **2025.**

BEPCII:
- Beam energy: 1.0-2.3 ГэВ
- Beam energy spread: 5×10^{-4}
- Design luminosity: 1×10^{33} /cm^2 /s @ψ(3770)
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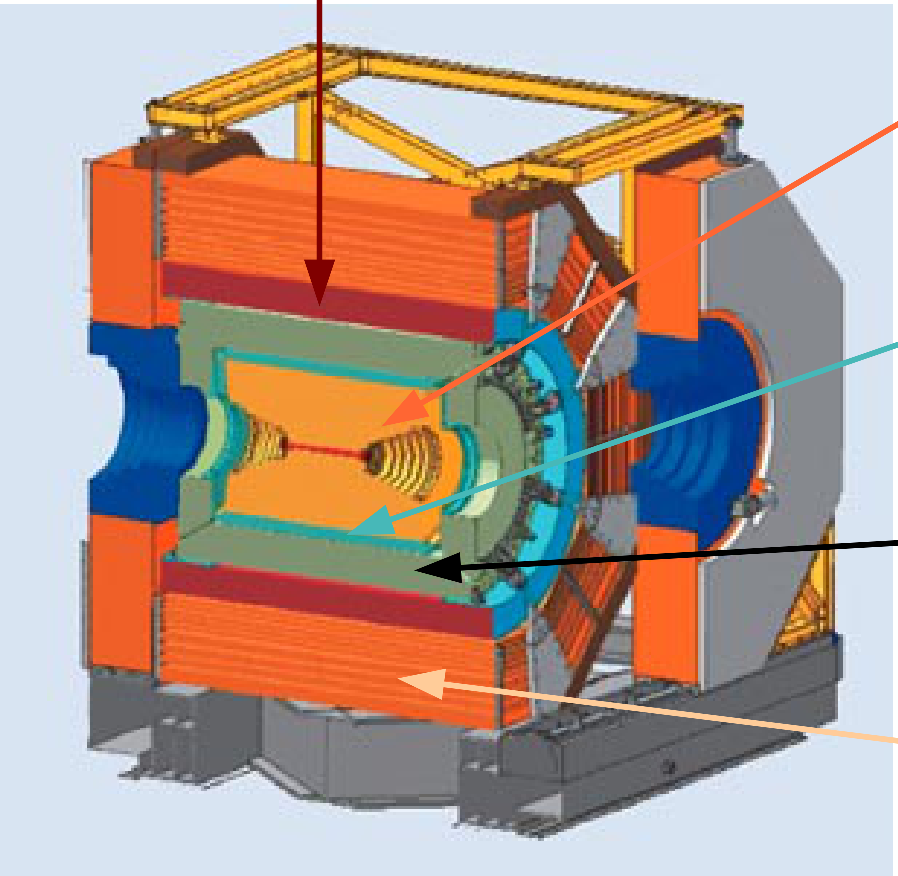
BESIII detector

Superconducting magnet: **1 T**

NIM A614, 345(2010)



MDC:

- Spatial resolution: σ_{xy} **= 120µm**
- Momentum resolution:**0.5% @ 1GeV**
- **dE/dx** resolution: 6%

TOF (double layer scintillator/MRPC):

Time resolution: **80ps** (barrel)

60ps (endcaps)

EMC: CsI cristal

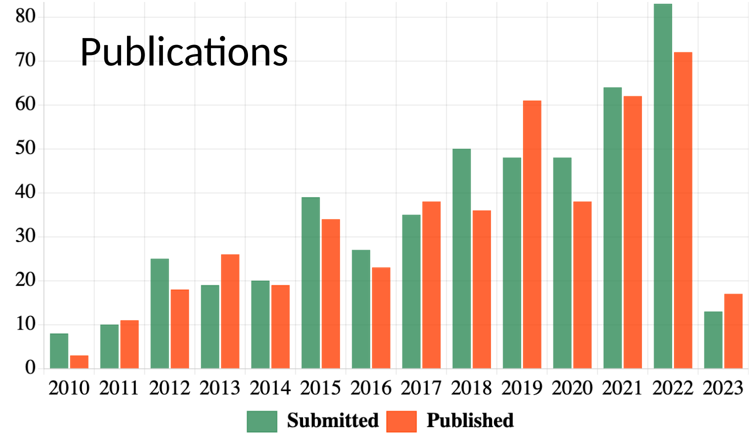
- Energy resolution: **2.5% @1GeV**
- Spatial resolution: **6mm**

Muon ID:

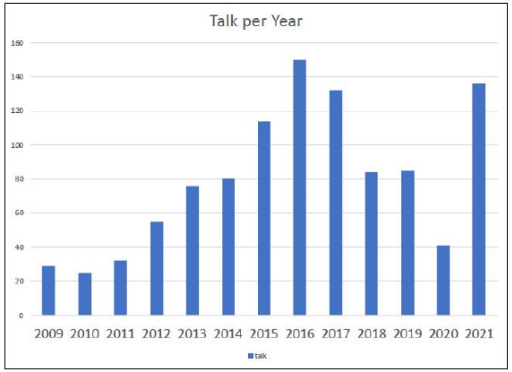
9 layers RPC (8 for endcaps) in the flux-return yoke

The BESIII Collaboration

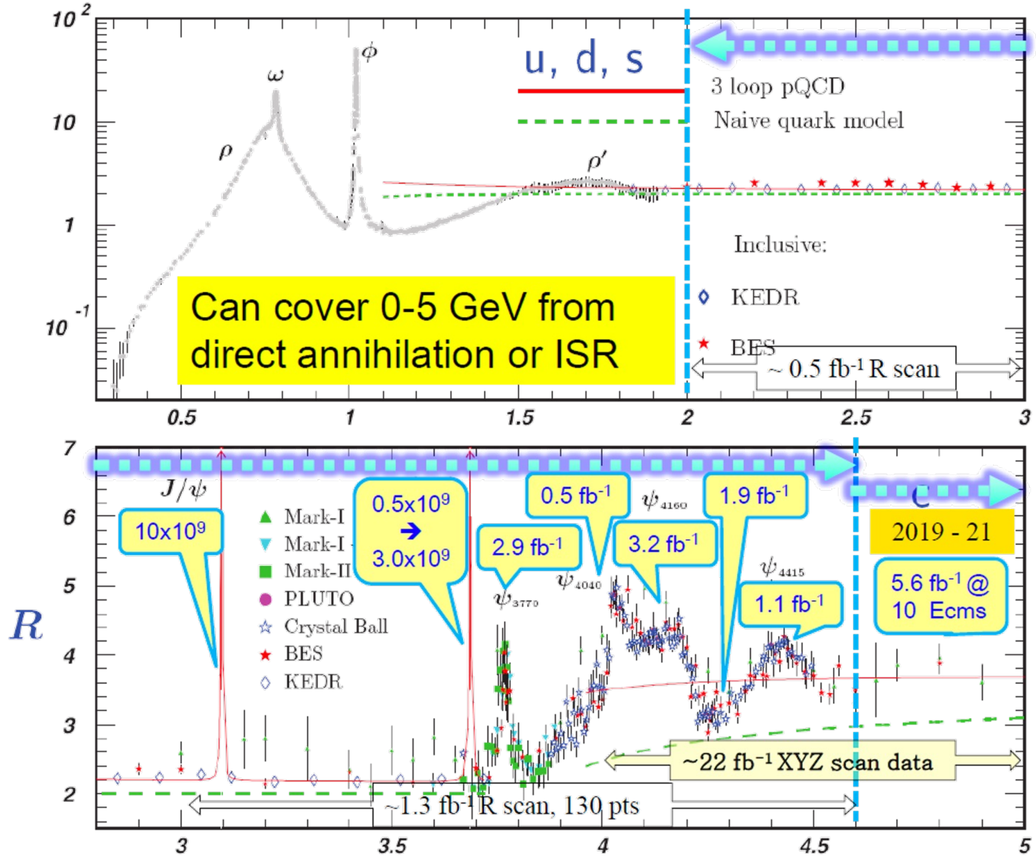
The collaboration consists of more than 500 members from 17 countries.

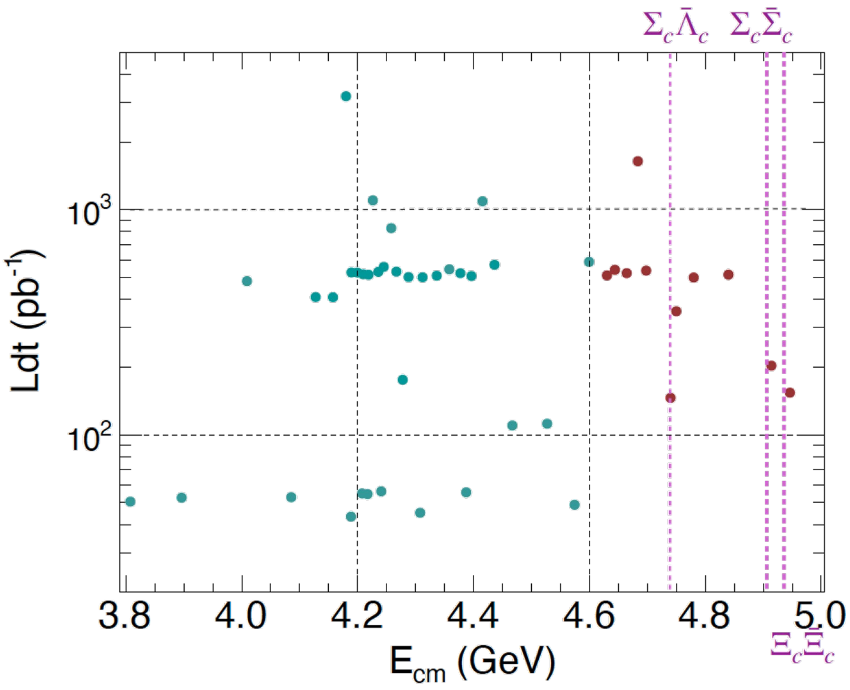


Talks



Physics at BESIII



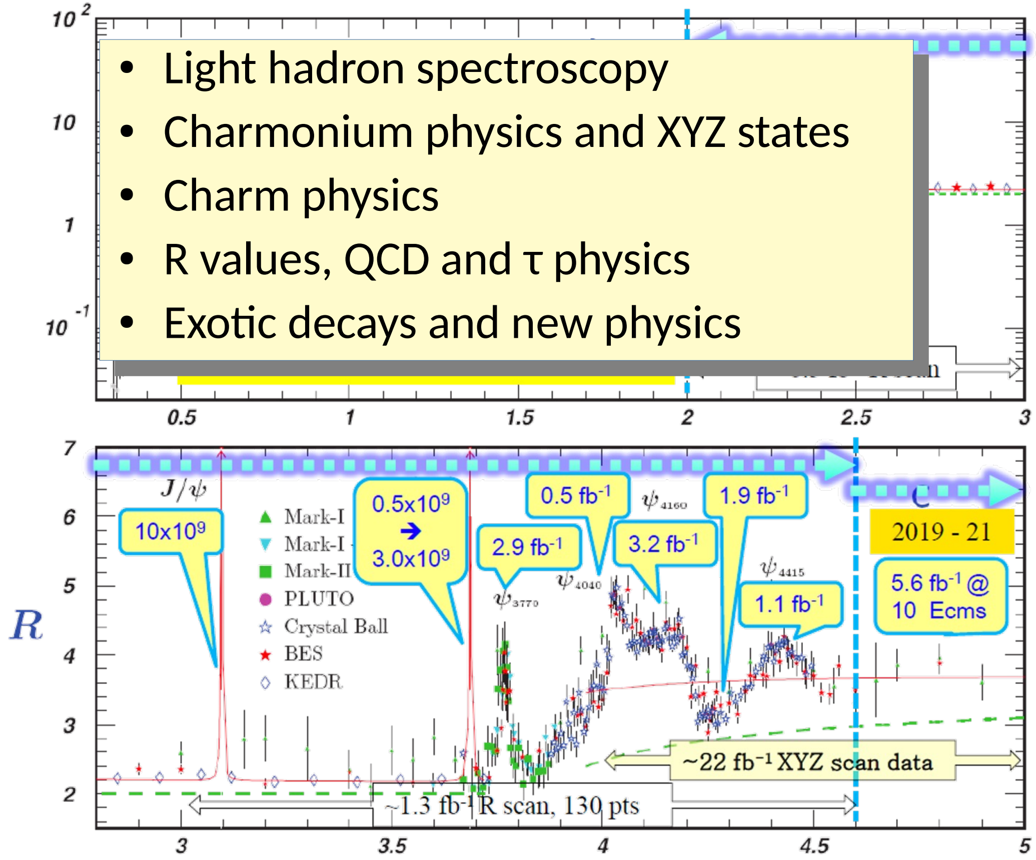


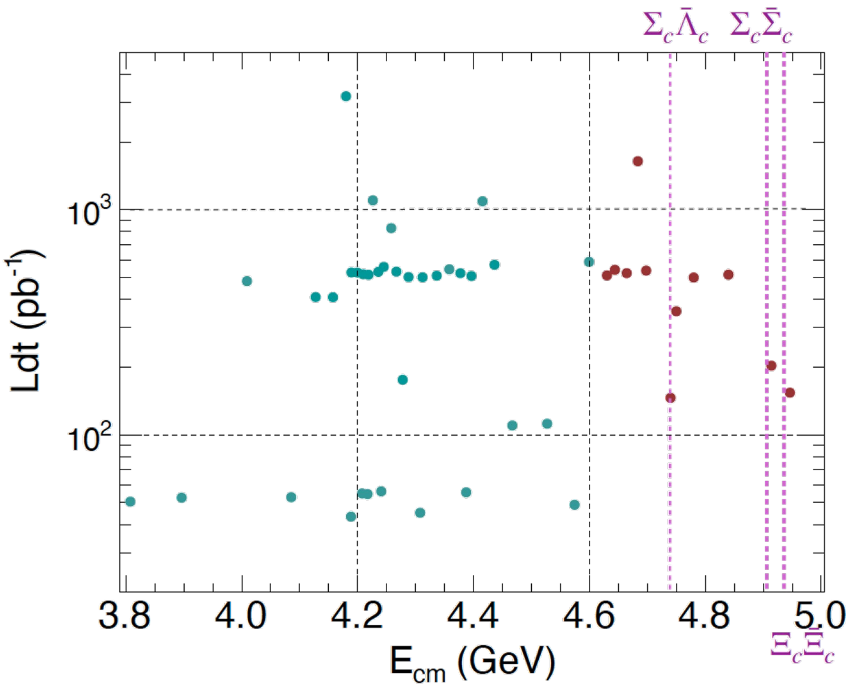
46 data samples L ~21.9 fb^{-1}

29 with L_i > 0.4 fb^{-1}

Physics at BESIII

- Light hadron spectroscopy
- Charmonium physics and XYZ states
- Charm physics
- R values, QCD and τ physics
- Exotic decays and new physics





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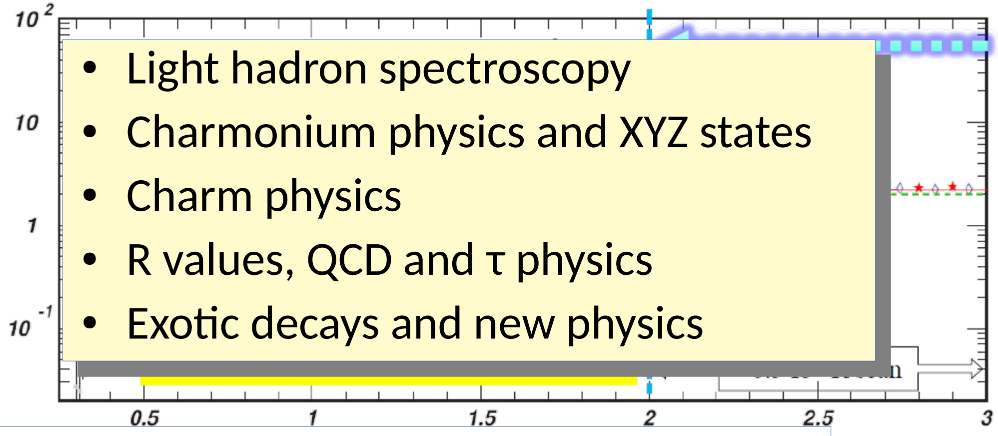
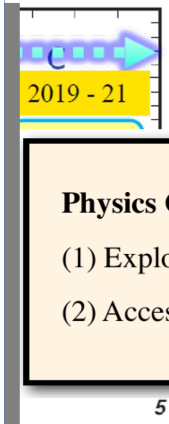
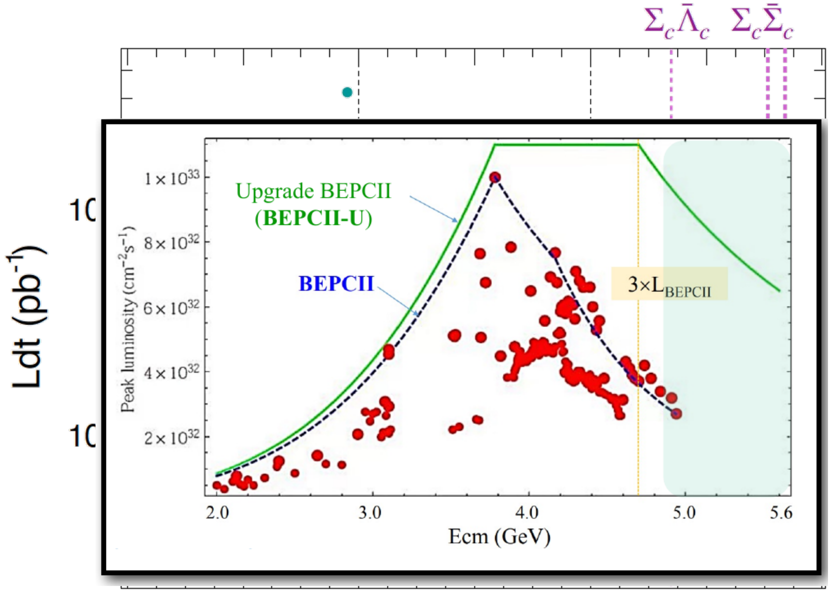


Future Physics Programme of BESIII

IHEP-Physics-Report-BESIII-2020-4-7

Published in Chinese Physics C **44**, 040001 (2020)





Physics Goals:

(1) Explore an unknown energy region.

(2) Access charm baryons at threshold.

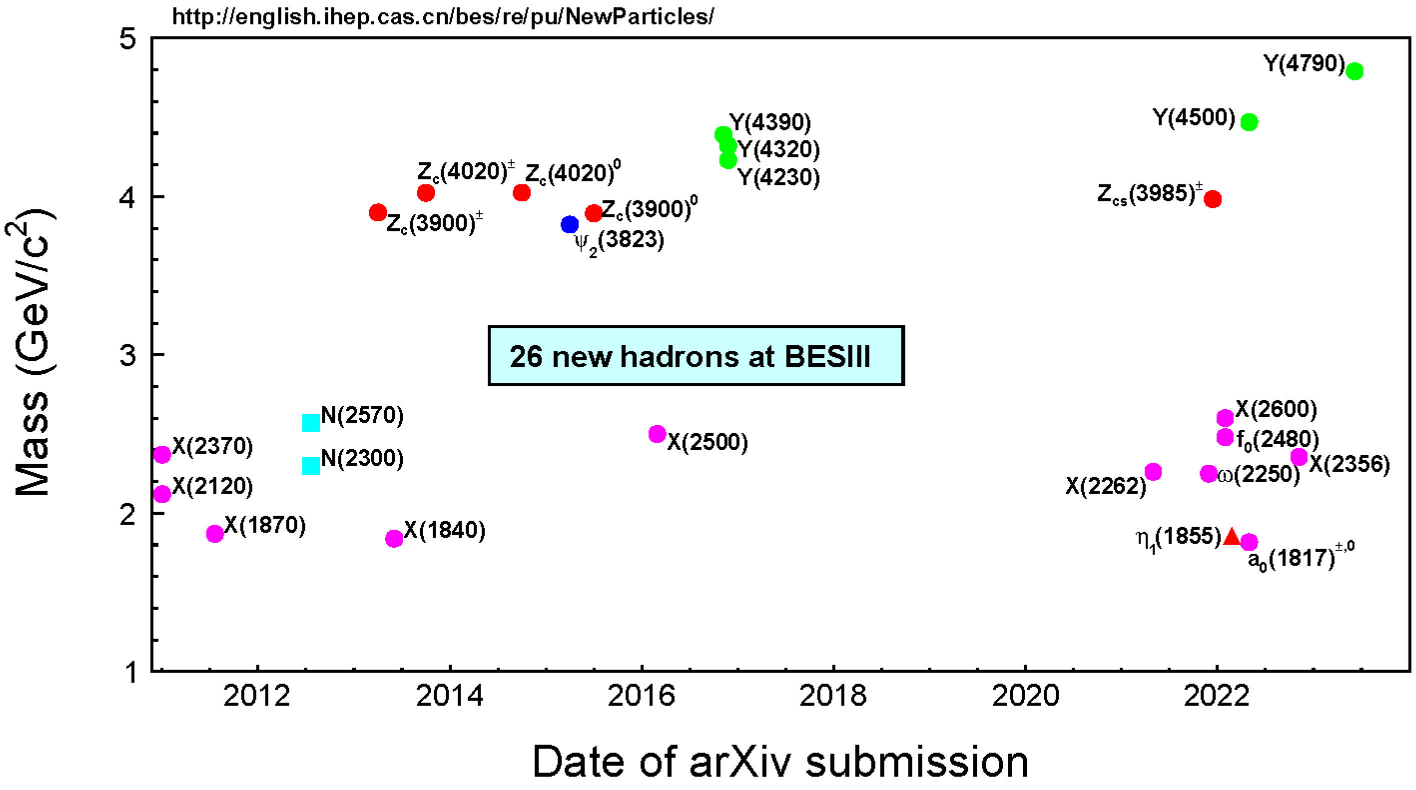
$2\times M(\Lambda_c^+) = 4572.9$ MeV

$2\times M(\Sigma_c^{++,+,0}) = 4905.8 - 4907.9$ MeV

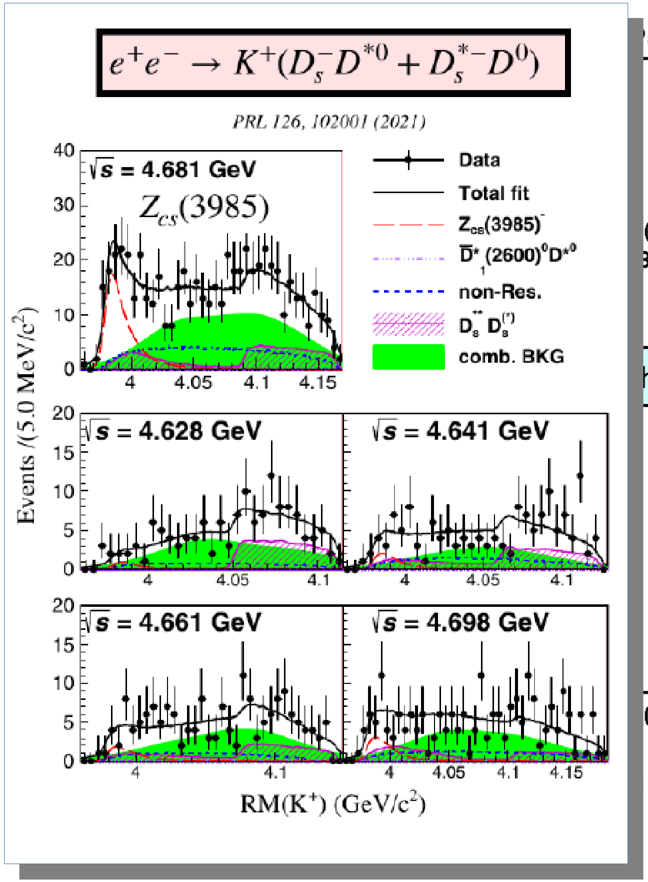
$2\times M(\Xi_c^{+,0}) = 4935.4 - 4940.9$ MeV

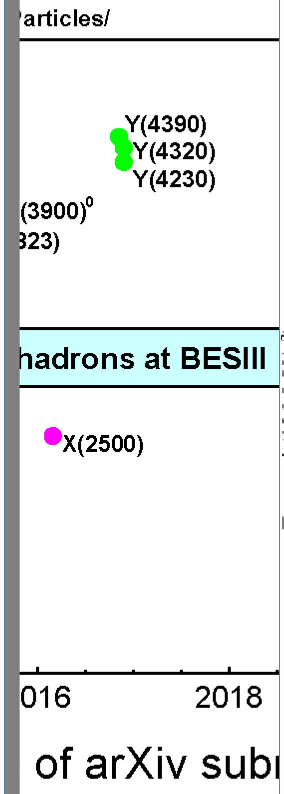
$2\times M(\Omega_c^0) = 5390.4$ MeV

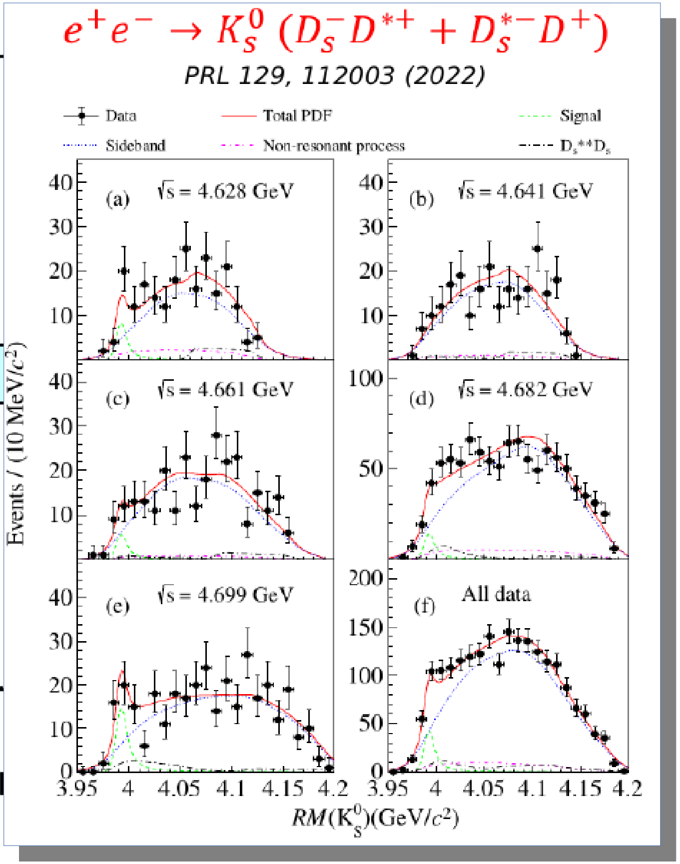
BESIII highlights



BESIII highlights







JINR group at BESIII

- Light hadron spectroscopy
  - spectra of f_0 and f_2 mesons and search for scalar and tensor glueballs
- Charmonium states
  - study of the production properties
- Phase difference between strong and EM phases in J/ψ decays
- FF of c-quark
- Internal refereeing, RG
- Software and analysis tools development and maintenance
- Distributed computing
- Machine learning algorithms for track finding and vertex reconstruction

LNP: O. Bakina, I. Boyko, G. Chelkov, D. Dedovich, I. Denisenko, P. Egorov, A. Guskov, Yu. Nefedov, A. Zhemchugov

BLTP: V. Bytyev

LIT: V. Korenkov, G.A.Ososkov, I.Pelevanyuk

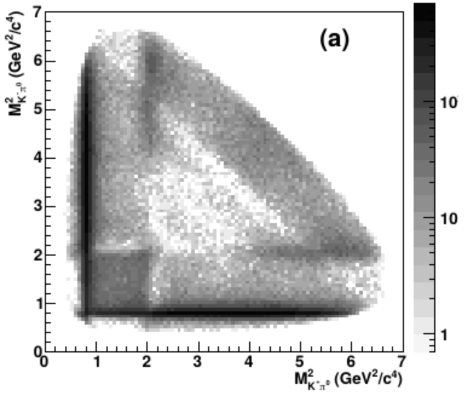
JINR group at BESIII

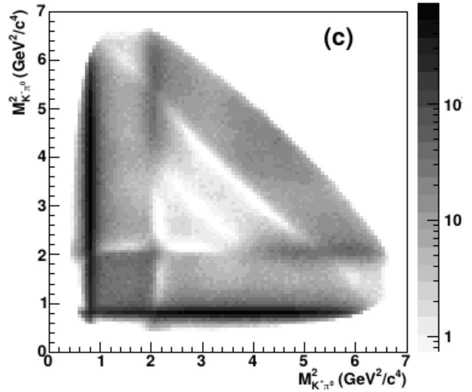
№ № п/а	Category of employees	NAME	Division	Position	Amount of FTE
1.	scientific staff	Bakina O. Boyko I. Shelkov G. Dedovich D. Denisenko I. Guskov A. Nefedov Y. Egorov P. Pogodin S. Zhemchugov A. Bytyev V. Korenkov V. Ososkov G. Pelevanyuk I.	DLNP DLNP DLNP DLNP DLNP DLNP DLNP DLNP DLNP DLNP BLTP LIT LIT LIT	researcher researcher researcher researcher researcher researcher researcher trainee trainee researcher researcher researcher researcher researcher	1 0.3 0.1 0.3 0.5 0.1 1 1 1 0.5 0.5 0.1 0.2 0.2
2.	engineers				
3.	professionals				
4.	workers				
	Total:				**7.8**

Partial wave analysis of $J/\psi \to K^+K^-\pi^0$ (PRD 100, 032004 (2019))

			$K^\pm\pi^0$ **channels**			
J^{PC}	PDG	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	$b(\%)$	$b^{+(-)}(\%)$	ΔNLL
1^-	$K^*(892)^\pm$	$893.6\pm0.1^{+0.2}_{-0.3}$	$46.7\pm0.2^{+0.1}_{-0.2}$	$93.4\pm0.4^{+1.8}_{-5.8}$	$42.5\pm0.1^{+0.5}_{-1.7}$	–
1^-	$K^*(1410)^\pm$	$1380^\star$	$176^\star$	0.26 ± 0.04	0.11 ± 0.02	80
1^-	$K^*(1680)^\pm$	$1677^\star$	$205^\star$	0.20 ± 0.03	0.08 ± 0.01	56
2^+	$K_2^*(1430)^\pm$	$1432.7\pm0.7^{+2.2}_{-2.3}$	$102.5\pm1.6^{+3.1}_{-2.8}$	$9.4\pm0.1^{+0.8}_{-0.5}$	$4.2\pm0.1^{+0.3}_{-0.2}$	–
2^+	$K_2^*(1980)^\pm$	$1868\pm8^{+40}_{-57}$	$272\pm24^{+50}_{-15}$	$0.38\pm0.04^{+0.22}_{-0.05}$	$0.15\pm0.02^{+0.08}_{-0.02}$	192
3^-	$K_3^*(1780)^\pm$	$1781^\star$	$203^\star$	0.16 ± 0.02	0.07 ± 0.01	105
4^+	$K_4^*(2045)^\pm$	$2090\pm9^{+11}_{-29}$	$201\pm19^{+57}_{-17}$	$0.21\pm0.02^{+0.10}_{-0.05}$	$0.09\pm0.01^{+0.04}_{-0.02}$	212
3^-	non-resonant	– –	– –	$\sim 1.5\%$	$\sim 0.6\%$	629
			K^+K^- **channel**			
J^{PC}	PDG	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	b(%)		$\Delta\ln L$
1^{--}		$1651\pm3^{+16}_{-6}$	$194\pm8^{+15}_{-7}$	$1.83\pm0.11^{+0.19}_{-0.17}$		796
1^{--}		$2039\pm8^{+36}_{-18}$	$193\pm23^{+25}_{-27}$	$0.23\pm0.04^{+0.07}_{-0.06}$		102

Nucl. Phys. B 296, 493 (1988)



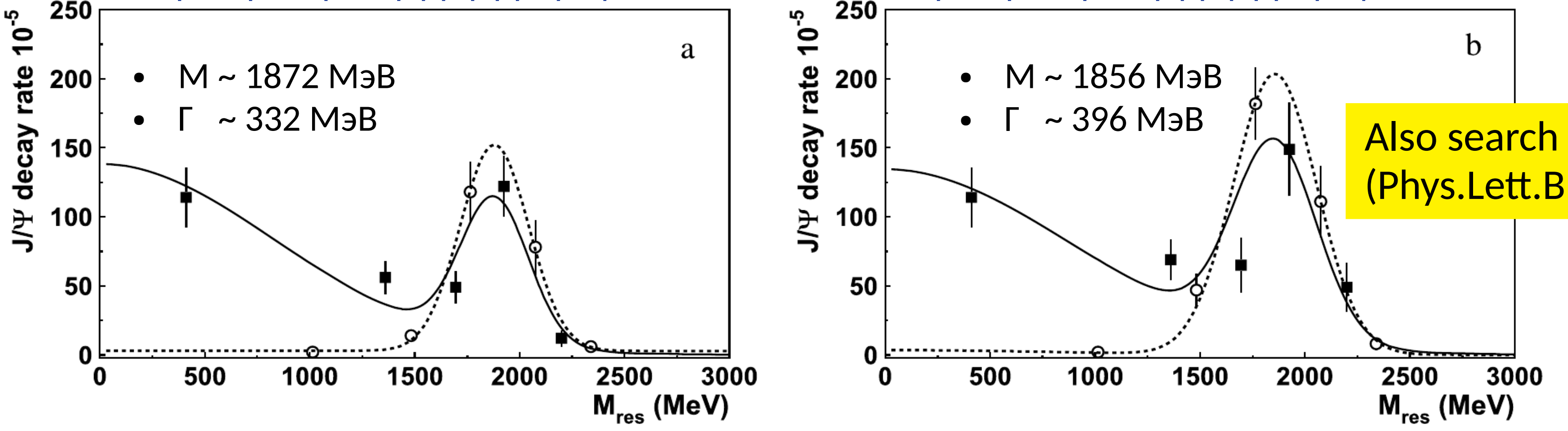


- Four states are observed in the decay for the first time.
- The most precise measurements of $K^*(892)^\pm$ and $K_2(1430)^\pm$.
- **No evidence for exotic X(1575)!**

J/ψ → γPP: spectroscopy of f_0 mesons and scalar glueball (PLB 816, 136227 (2021))

J/ψ → γππ, γKK, γηη, γηη`, γωφ

J/ψ → γππ, γKK, γηη, γηη`, γωφ + «ЧЯ»



Also search for tensor glueball (Phys.Lett.B 830 (2022))

Best estimate $M_G = (1865 \pm 25^{+10}_{-30})\,\mathrm{MeV} \quad \Gamma_G = (370 \pm 50^{+30}_{-20})\,\mathrm{MeV}$

Nonperturbative approach	Ref.	Predicted mass (MeV)
Unquenched LQCD	JHE1210, 170(2012)	1795±60
Instanton calculations	PLB577,61(2003)	~1980
Dyson-Schwinger and Bethe-Salpeter equations	EPJC80,1077(2020)	1850±130
Dual models	PRD104,034016(2021)	~1920

Production partial width

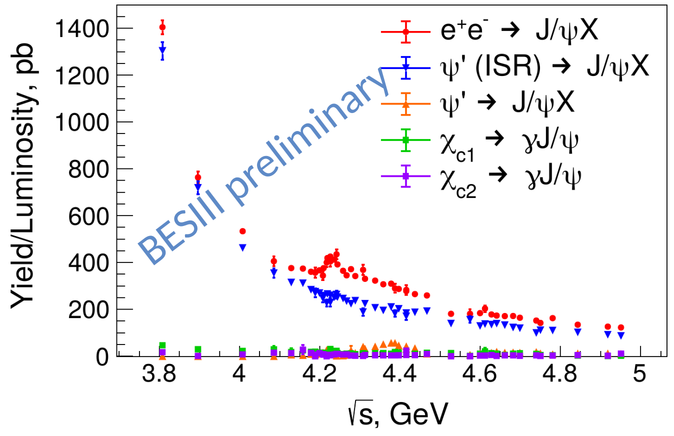
$$B_{J/\psi\to\gamma G} = (5{,}8 \pm 1{,}0) \times 10^{-3}$$

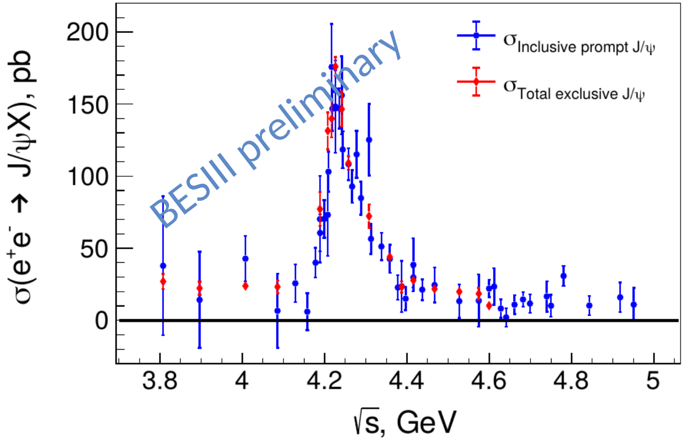
Lattice calculations (PRL110, 021601 (2013))

$$B_{J/\psi\to\gamma G} = (3{,}8 \pm 0.9) \times 10^{-3}$$

Ongoing work

- Cross-section measurement of the prompt inclusive J/ψ and ψ(2S) production at center-of-mass energies from 3.81 to 4.95 GeV
  - the paper draft approved by internal referring, ongoing CWR
- Phase between strong and electromagnetic amplitudes in J/ψ decays
  - analysis under internal review
- Model-independent partial wave analysis of $\psi(2S) \to \gamma\pi^0\pi^0$
  - the first stage presented to the collaboration
- FF of c-quark





Conference talks

- I. Denisenko, “Light hadron spectroscopy at BESIII”, 19-th Lomonosov Conference on Elementary Particle Physics, Moscow, 22 - 28, August 2019.
- Ю. Нефедов, “Обзор эксперимента BESIII”, сессия-конференция СЯФ ОФН РАН, Новосибирск, март 2020.
- I. Denisenko, “Partial wave analysis of $J/\psi \to K^+K^-\pi^0$”, 9th International Conference on New Frontiers in Physics (ICNFP 2020), Crete, 4-12 October 2020.
- I. Denisenko, “Partial wave analysis of $J/\psi \to K^+K^-\pi^0$”, 5-th International Conference on Particle Physics and Astrophysics (ICPPA 2020), Moscow, 5-9 October 2020.
- I. Denisenko, “Partial wave analysis of $J/\psi \to K^+K^-\pi^0$”, XXIV International Scientific Conference of Young Scientists and Specialists (AYSS-2020), 9-13 November 2020.
- O. Bakina, poster “Proposal for the prompt inclusive J/ψ production measurement at future Super c-tau factories”, Workshop on future Super c-tau factories, 15-17 November 2021.
- O. Bakina, poster "Studies of charmonium decay from BESIII", 30th International Symposium on Lepton Photon Interactions at High Energies, 10-14 January 2022.

Qualification works

- S. Pogodin, “Search for proton-antiproton bound state in the reaction $e^+e^- \to 2p2\bar{p}$ in the BESIII experiment”, BSc thesis, Dubna, 2020.
- S. Pogodin, “Branching fraction of J/psi → φη (η → γγ, η → π+π-π0) at the BESIII experiment”, MSc thesis, Dubna, 2022.
- P. Egorov, “Measurement of the cross-section of $e^+e^- \to \eta\pi^+\pi^-$ in energy range 2.00 − 3.08 GeV”, MSc thesis, Dubna, 2022.
- I. Denisenko, “Light hadron spectroscopy and search for exotic states in the $J/\psi \to K^+K^-\pi^0$ decay and radiative J/ψ decays to two pseudoscalars”, PhD thesis, 2021.

Software development

- Maintenance of the BESIII offline software and analysis tools.
- Distributed computing
- New R&D of algorithms for reconstruction of events using deep learning methods
  - Two new approaches to tracking using ML were developed in scope of the joint RFBR-NSFC project No. 19-57-53002
  - Existing well-established event reconstruction of the BESIII experiment based on classical algorithms allows to study the performance of ML algorithms, to investigate stability of these methods against noise and other data imperfections, and to elaborate methods for effective estimation of the systematic uncertainty connected with the use of the ML tools.
  - Will be useful not only for BESIII, but also for any other collider experiment including the ones of the NICA project.

Publications:

- CRM, 2020, vol. 12, no. 6, 1361
- JINST 17 (2022) 12, P12023

Requirements for computing resources

Computing resources	Distribution by year				
	1st year	2nd year	3rd year	4th year	5th year
Data storage (TB)					
- EOS	-	-	-	-	-
- Ribbons	-	-	-	-	-
Tier 1 (core-hour)	-	-	-	-	-
Tier 2 (core-hour)	120000	120000	120000	120000	120000
SC Talker (core-hour)					
- CPU	-	-	-	-	-
- GPU	-	-	-	-	-
Clouds (CPU cores)	60000	60000	60000	60000	60000

Funding request 2024-2028

Names of costs, resources, sources of funding		Cost (thousands of dollars) resource requirements	Cost, distribution by year				
			1st year	2nd year	3rd year	4th year	5th year
	International cooperation (IC)	125	25	25	25	25	25
	Materials						
	Equipment and third-party services (commissioning)	50	10	10	10	10	10

The main costs are travel expenses for

1) data taking shifts and technical work
2) data analysis, presentation of results, and preparation of publication within the Collaboration
3) conference talks
4) hardware for machine learning

Thank you!

Backup

Prompt inclusive J/ψ production (I)

Goal:

- **Test the NRQCD factorization hypothesis:** the independence of Long Distance Matrix Elements (LDME) that describe the hadronization of the $c\bar{c}$ pair from the process (hadron-hadron collisions, electroproduction, or e^+e^- annihilation);
- **Clarify the contribution of the color octet channel** in the range of $\sqrt{s}$ below the $J/\psi c\bar{c}$ threshold (~6 GeV): the color-octet LDMEs are non-zero if $\sigma > 10$ pb at $\sqrt{s} = 4.6 \sim 5.6$ GeV (Eur. Phys. J. C (2017) 77: 597);
- **Test if unknown channels/states exist.**

Data only available at $\sqrt{s} = 10.6$ GeV:

- **2.5 ± 0.3 pb** (BaBar)
- **1.5 ± 0.2 pb** (Belle)
- **1.9 ± 0.2 pb** (CLEO)

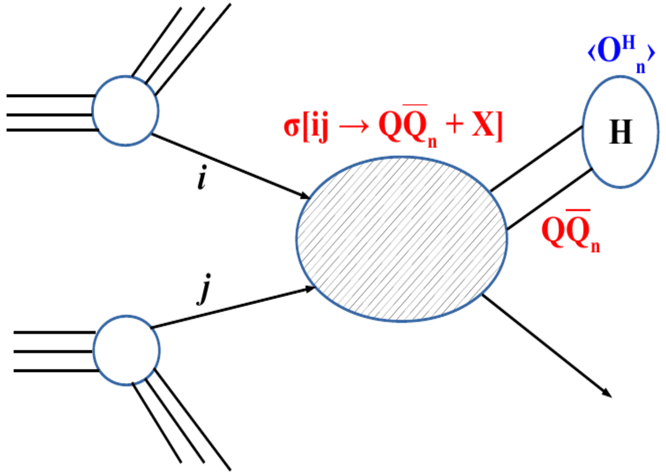


Figure: NRQCD factorization. The LDMEs $\langle O^H_n \rangle$ are determined from experimental data.

Prompt inclusive J/ψ production (II)

Data: $\mathcal{L} = 22\ fb^{-1}$, $\sqrt{s} = 3.8 - 4.95$ GeV

Channel: $J/\psi \to \mu^+\mu^-$, $\psi(3686) \to J/\psi\ \pi^+\pi^-$, $\chi_{cJ} \to \gamma J/\psi$, $(J = 1, 2)$

- Prompt J/ψ originates from sources other than known decays or initial-state radiation (ISR).
- Major background sources:
  - inclusive J/ψ decays of ψ(3686) and χ_{cJ}, (J = 1, 2);
  - ISR return to the J/ψ and ψ(3686) resonances.
- The preliminary result for the prompt inclusive J/ψ production in the range 4.5 ~ 4.7 GeV is

$$\sigma = 13.2 \pm 2.1_{stat} \pm 3.4_{syst}\ \text{pb}$$

Analysis status: **approved by internal referees, ongoing CWR.**

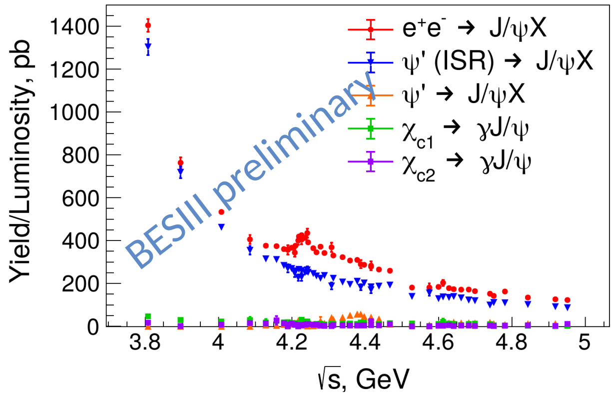


Figure: Yield of J/ψ from different sources normalized to corresponding luminosity.

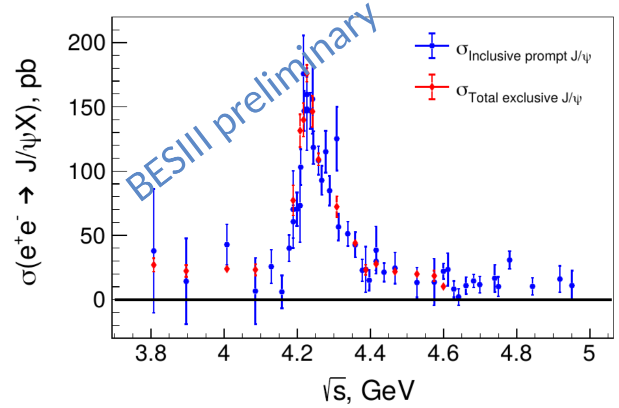
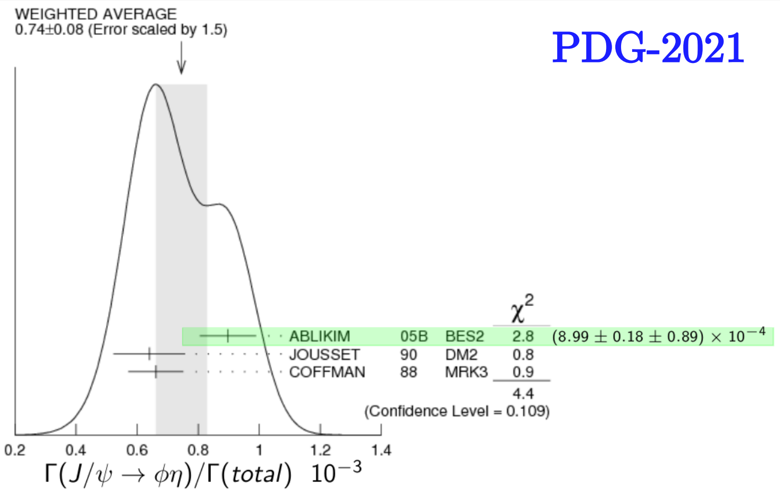


Figure: Prompt and total exclusive J/ψ cross-sections.

Mixing angle between strong and EM amplitudes in $J/\psi \to \phi\eta$ (I)

- **The existing measurements** of $B(J/\psi \to \phi\eta)$ are **ambiguous** (PDG-2021);
- We plan to **use the precise measurements** of the $B(J/\psi \to \phi\eta)$ to **improve the estimation of the mixing angle between the strong and electromagnetic amplitudes** in the analysis of the energy dependence of $e^+e^- \to \phi\eta$ cross-section in the scan data around the J/ψ peak.

PDG-2021



Formulas of cross section for lineshape fit of $e^+e^- \to \phi\eta$

$$\sigma_{\rm born}(s) = |\mathcal{A}_{cont.} + \mathcal{A}_\gamma + \mathcal{A}_{3g}|^2 = \frac{\sigma_0}{s^2}\left|1 + \frac{3/\alpha\sqrt{s\,\Gamma_e\Gamma_\mu}}{(s-M^2)+i\sqrt{s}\,\Gamma}\cdot(1+Ae^{i\varphi})\right|^2 \times \left[\frac{|P|}{\sqrt{s}}\right]^3$$

$$\text{where}\quad \sigma_0 = \frac{4\pi\alpha^2 s}{3}\cdot\frac{Br(J/\psi\to\phi\eta)}{Br(J/\psi\to\mu\mu)}\cdot\frac{1}{|1+Ae^{i\varphi}|^2}\left[\frac{\sqrt{s}}{|P|}\right]^3$$

Mixing angle between strong and EM amplitudes in $J/\psi \to \phi\eta$ (II)

Data: **448M** $\psi(3686)$ in 2009 and 2012, **2.2B** $\psi(3686)$ in 2021
Channel: $\psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to \phi\eta$, $\phi \to K^+K^-$, $\eta \to \gamma\gamma$

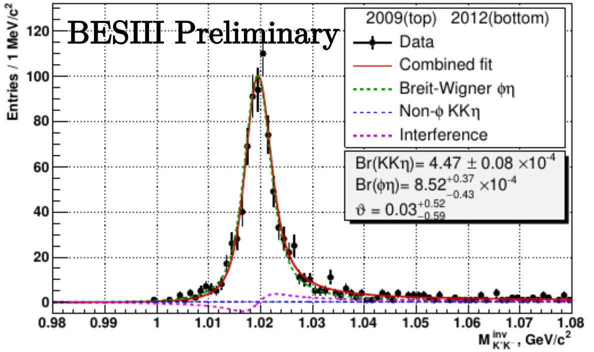
- We need to use data in which there is no mixing of $J/\psi \to \phi\eta$ and $e^+e^- \to \phi\eta$.
- A good description of the invariant mass of K^+K^- is obtained only under the assumption of interference $J/\psi \to \phi\eta$ with other processes decaying to the same final state.
- The preliminary result for $M(K^+K^-) < 1.08$ GeV/c^2 is

$$B(J/\psi \to \phi\eta) = (8.52 + 0.37/-0.43_{stat} \pm 0.14_{syst}) \times 10^{-4}$$

Analysis status: internal review of the BESIII collaboration.

Comparison with previous measurements

BES2	$(8.99 \pm 0.18 \pm 0.89) \times 10^{-4}$
DM2	$(6.4 \pm 0.4 \pm 1.1) \times 10^{-4}$
MARK-III	$(6.61 \pm 0.45 \pm 0.78) \times 10^{-4}$
PDG2020	$(7.4 \pm 0.8) \times 10^{-4}$



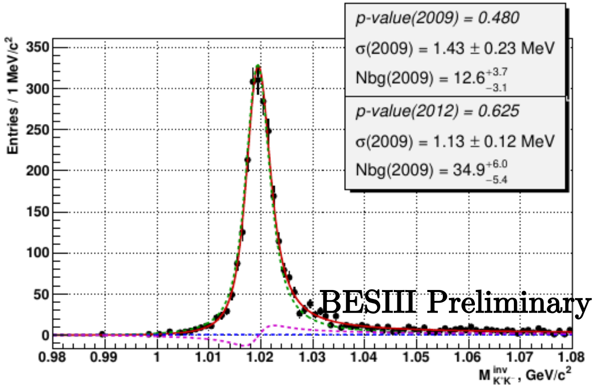


Figure: Combined fit to the $M(K^+K^-)$ to determine the number of ϕ mesons.