REVIEW

CHARMONIUM DECAYS

BY 9 PAPERS

Celebration Ceremony of the 500 Publications of BESIII Collaboration

2023-5-31, IHEP & on-line Joint

Kai Zhu

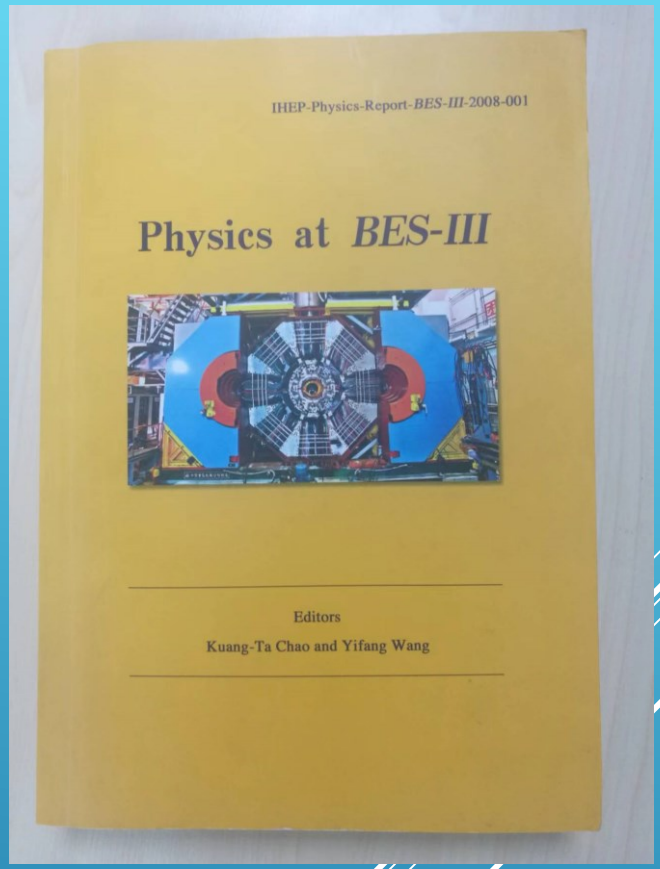
- arXiv: 0809.1869
- **2008-10-10**

0# PAPER OF BESIII

Chapter 13

Theoretical Frameworks of Charmonium Physics

dynamics both within and beyond the Standard Model [1]. These are multi-scale systems that probe all of the energy regimes of QCD: from the hard region, where expansions in the coupling constant are legitimate, to the low-energy region, where nonperturbative effects dominate. Heavy quark-antiquark states are thus an ideal, and to some extent unique, laboratory where our understanding of nonperturbative QCD and its interplay with perturbative QCD can be tested in a controlled framework. In correspondence with the hierarchy of energy scales in quarkonia, a hierarchy of nonrelativistic effective field theories (NR EFT) may be constructed, each one with fewer degrees of freedom that are left dynamical and thus simpler. Some of these physical scales are large and may be



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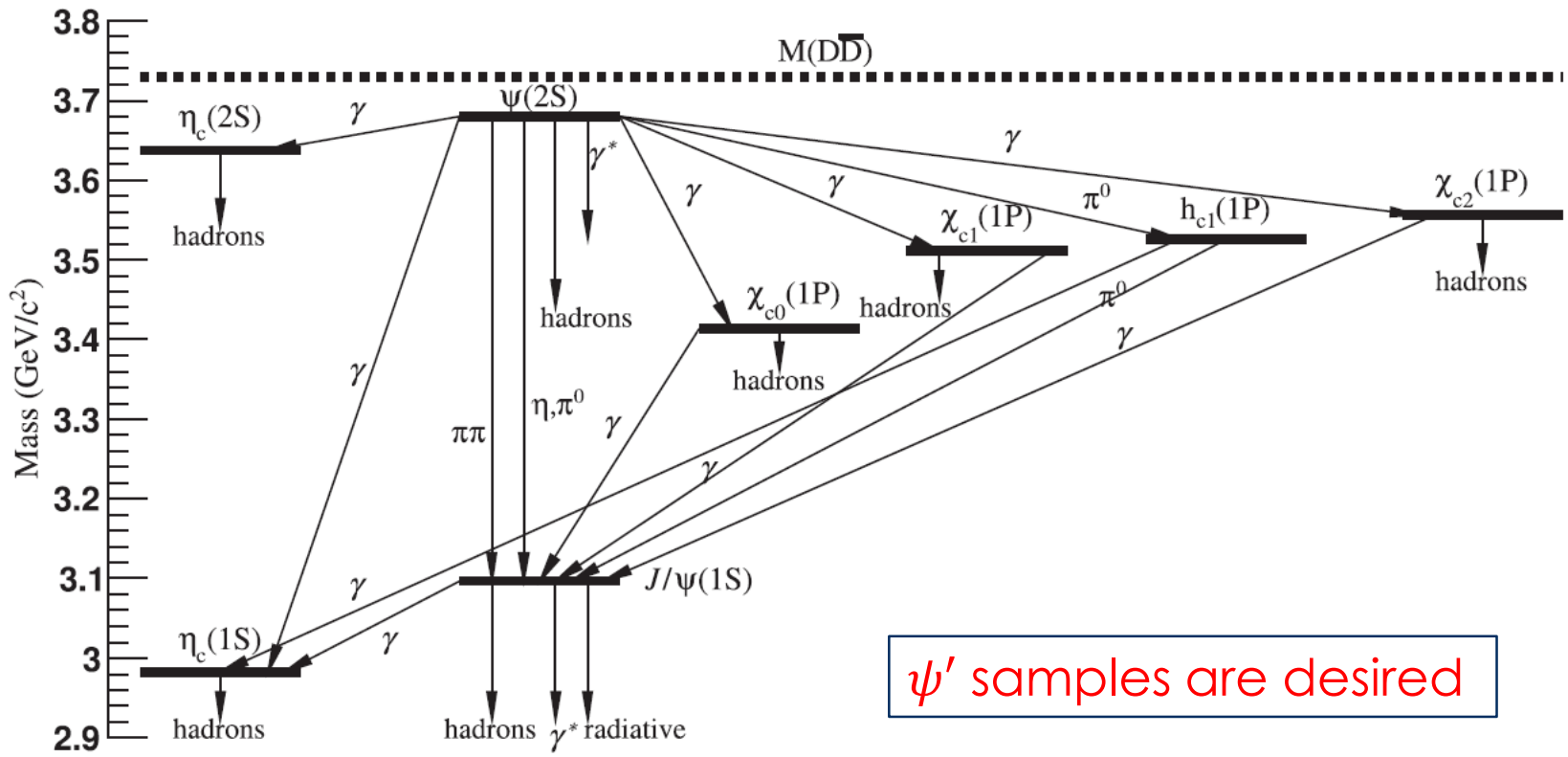

ψ' samples are desired

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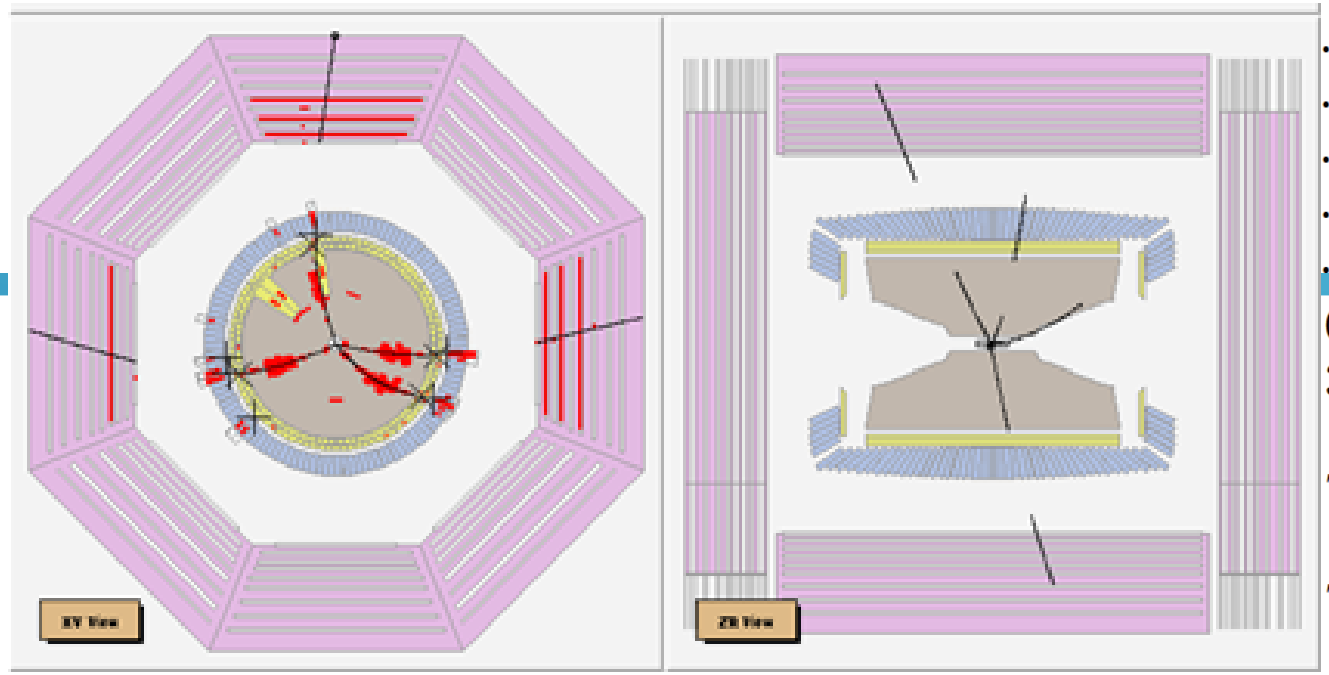
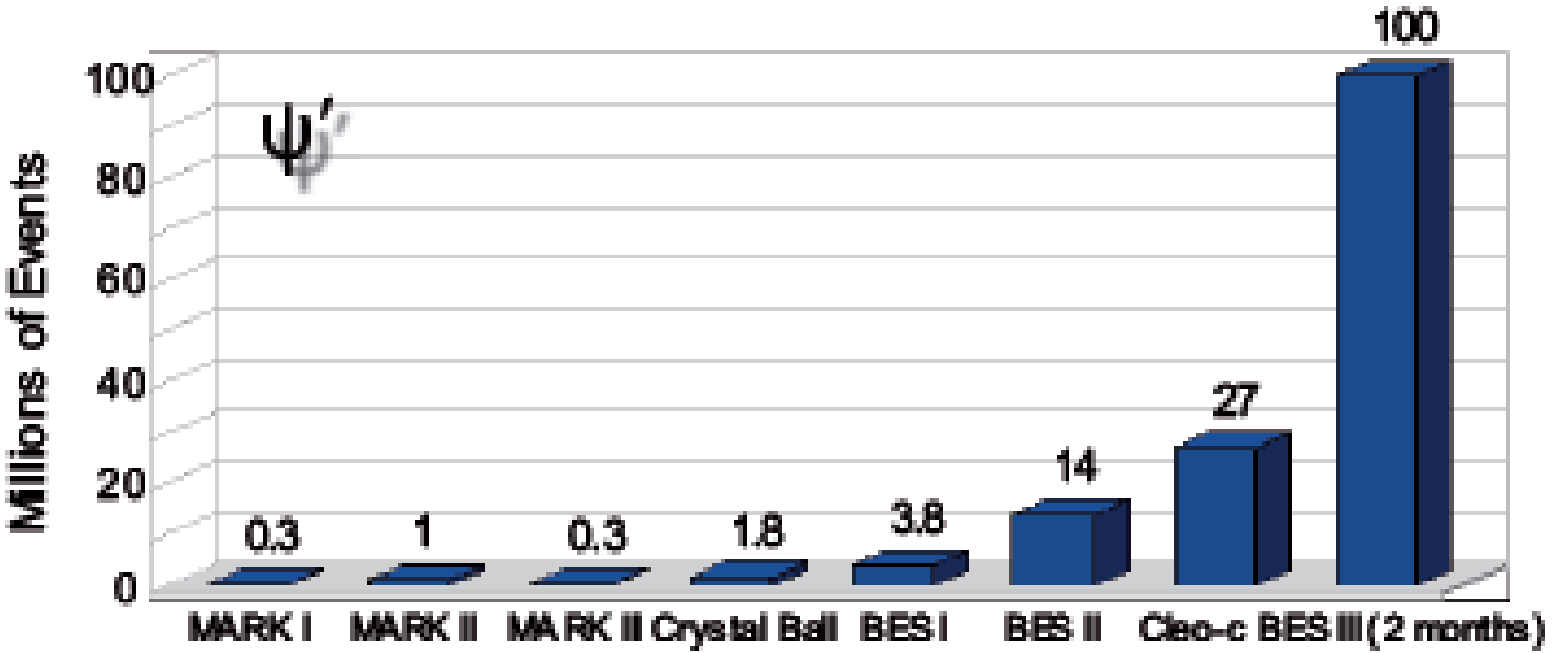
* runno	status	start-time	end-time	no-of-evts	no-of-had	lumi
0007958	0	2009-03-03 19:14:23	2009-03-03 20:39:01	6107517	-1	-1.000
0007959	0	2009-03-03 20:47:00	2009-03-03 20:56:22	344811	-1	-1.000
0007960	0	0000-00-00 00:00:00	0000-00-00 00:00:00	-1	-1	-1.000
0007961	0	0000-00-00 00:00:00	0000-00-00 0		1	-1.000
0008092	2	2009-03-06 03:24:00	2009-03-06 0		42	894.400
MDC HV warned once at 4:15 AM						
0008093	3	2009-03-06 06:14:00				.600
0008094	-2	0000-00-00 00:00:00				.000
0008095	-2	0000-00-00 00:00:00				.000
0008096	-2	0000-00-00 00:00:00				.000
0008097	-2	0000-00-00 00:00:00				.000
0009022	-3	2009-04-14 01:28:49				000
0009023	2	2009-04-14 02:11:05				336
MUC BD4 no HV						
0009024	2	2009-04-14 04:42:21				745
MUC BD4 no HV, TOF T east high noise level						
0009025	2	2009-04-14 06:21:35				753
MUC BD4 no HV, beam lost, MDC trip-- stop						

ψ' data taking



8093: First Physics Run @ BESIII

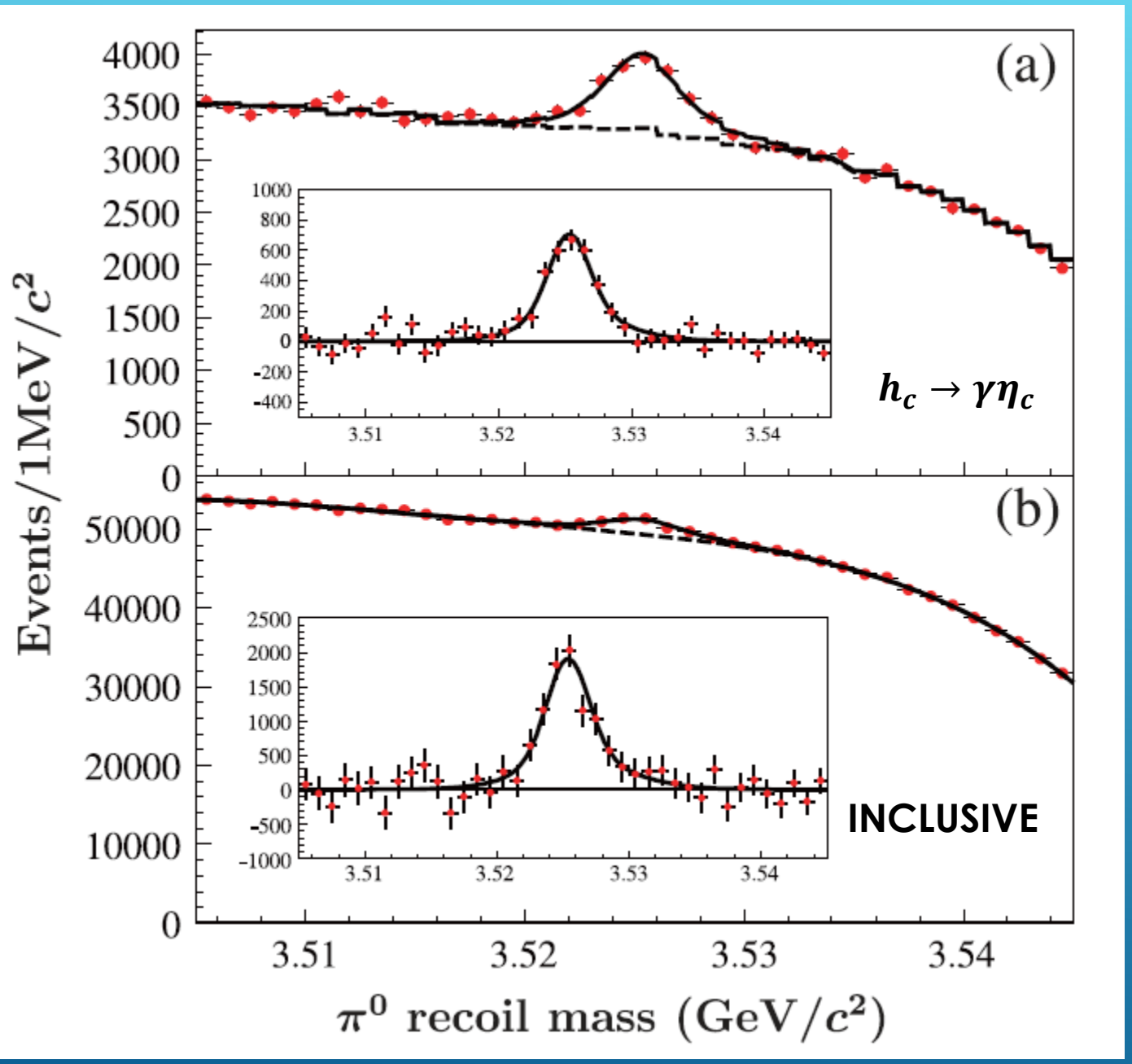


107M

Copy from MESON 2010

- arXiv: 1002.0501
- **2010-02-02**
- Phys. Rev. Lett. 104, 132002 (2010)

1# PAPER OF BESIII



First measurement:

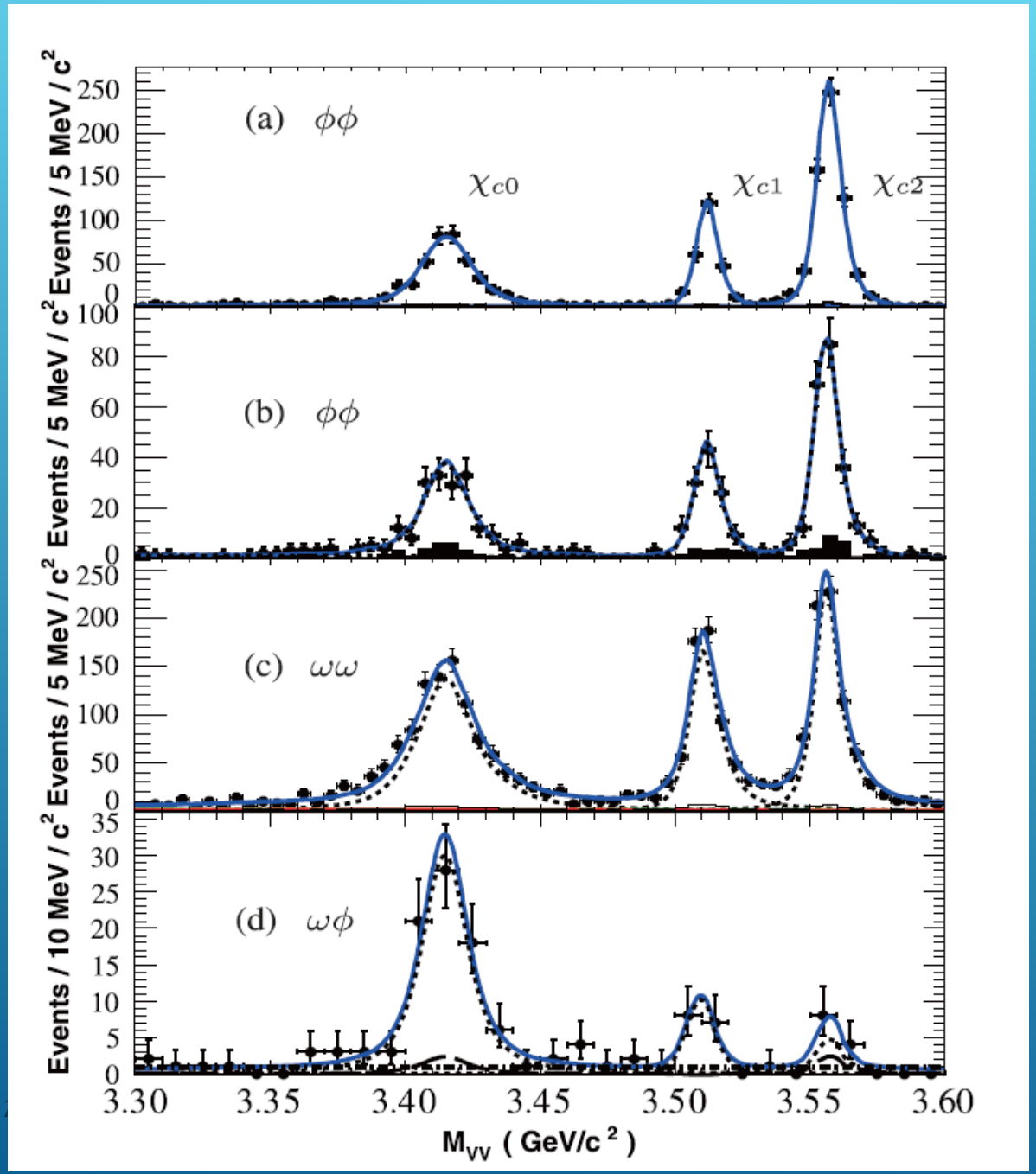
$B(\psi(3686) \to \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$

$B(h_c \to \gamma\eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$

Measurement of h_c in $\psi(3686)$ decay

- arXiv: 1104.5068
- **2011-04-28**
- Phys. Rev. Lett.107, 092001 (2011)

9# PAPER



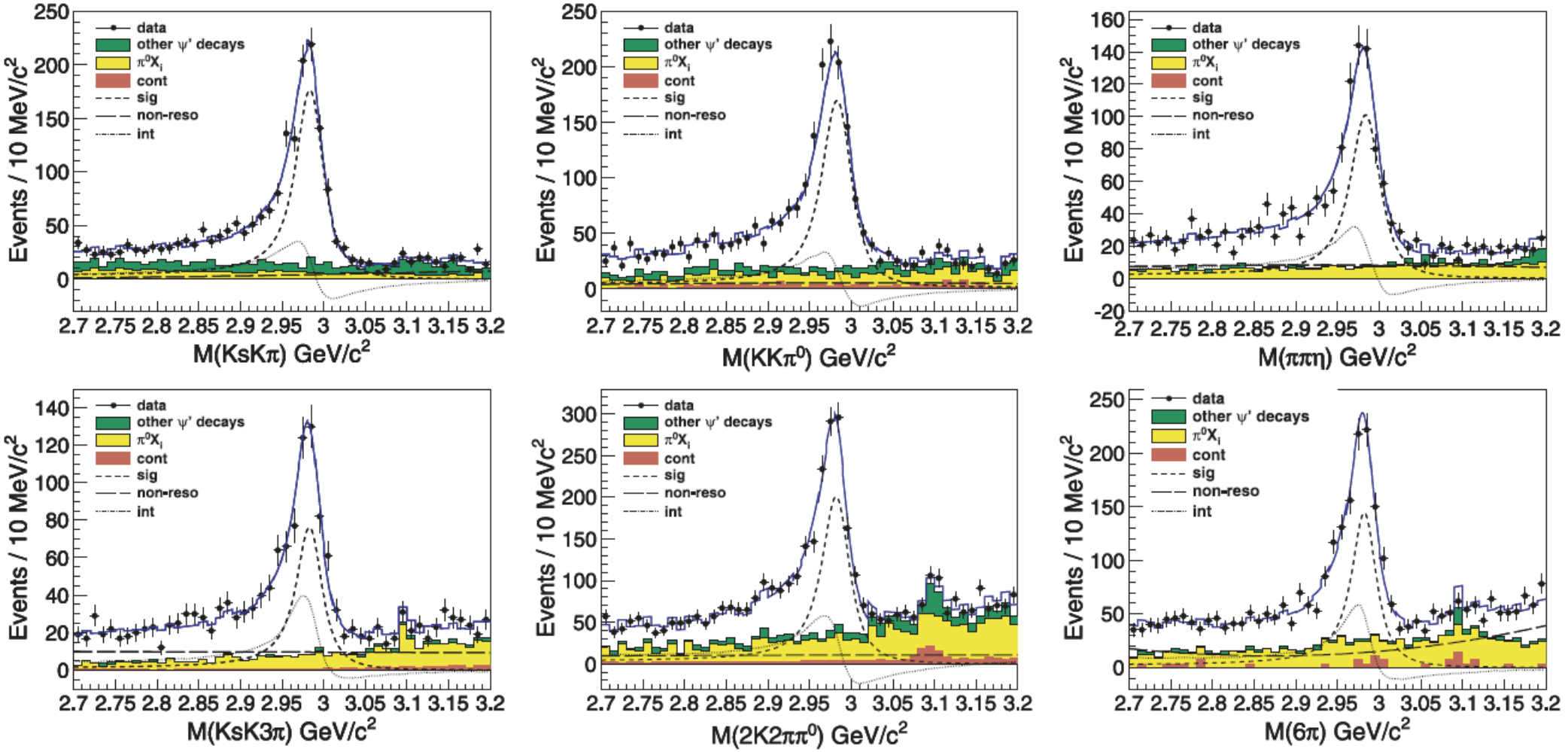
$$B(\chi_{c1} \to \phi\phi) = (4.4 \pm 0.3 \pm 0.5) \times 10^{-4}$$
$$B(\chi_{c1} \to \omega\omega) = (6.0 \pm 0.3 \pm 0.7) \times 10^{-4}$$
$$B(\chi_{c1} \to \omega\phi) = (2.2 \pm 0.6 \pm 0.2) \times 10^{-5}$$

Observations of $\chi_{c1} \to VV$

violate helicity selection rule

- arXiv:1111.0398
- **2011-11-02**
- Phys. Rev. Lett. 108, 222002 (2012)

14# PAPER



M: $2984.3 \pm 0.6 \pm 0.6$ MeV; Γ: $32.0 \pm 1.2 \pm 1.0$ MeV

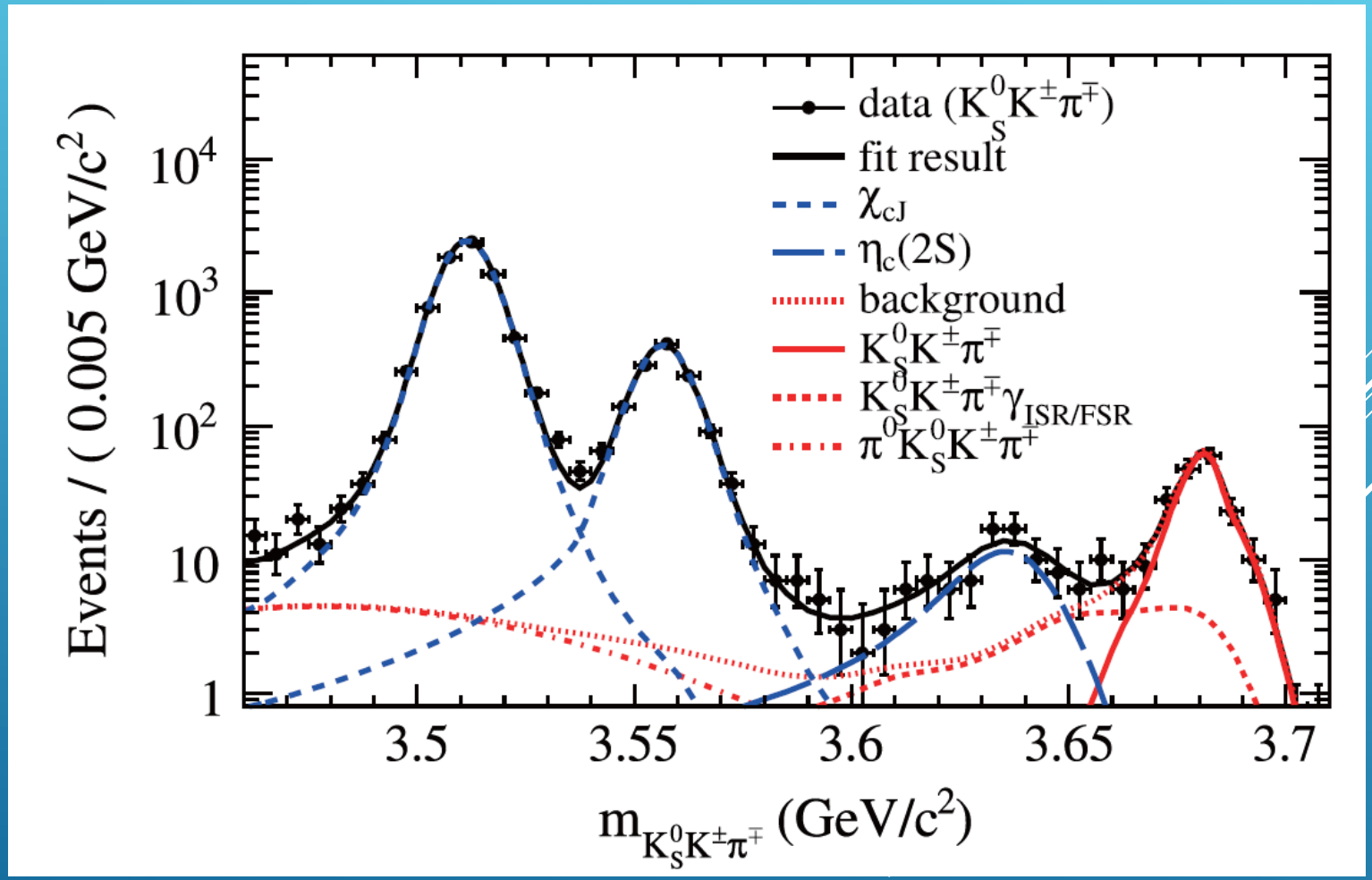
η_c parameters: consider interference

- arXiv: 1205.5103
- **2012-05-23**
- Phys. Rev. Lett. 109, 042003 (2012)

22# PAPER

$$B\left(\psi(3686) \to \gamma\eta_c(2S)\right) \times B(\eta_c(2S) \to K\bar{K}\pi) = (1.30 \pm 0.20 \pm 0.30) \times 10^{-5}$$

First observation of the M1 transition $\psi(3686) \to \gamma\eta_c(2S)$



- Run: 25338-27090
- **Time: 2011-12-31 to 2012-03-30**
- Lum: 600/pb
- Nevt: 341 M

More ψ' data set: total 448M (2009+2012)

- arXiv: 1603.04936
- **2016-03-17**
- Phys.Rev.Lett. 116, 251802 (2016)

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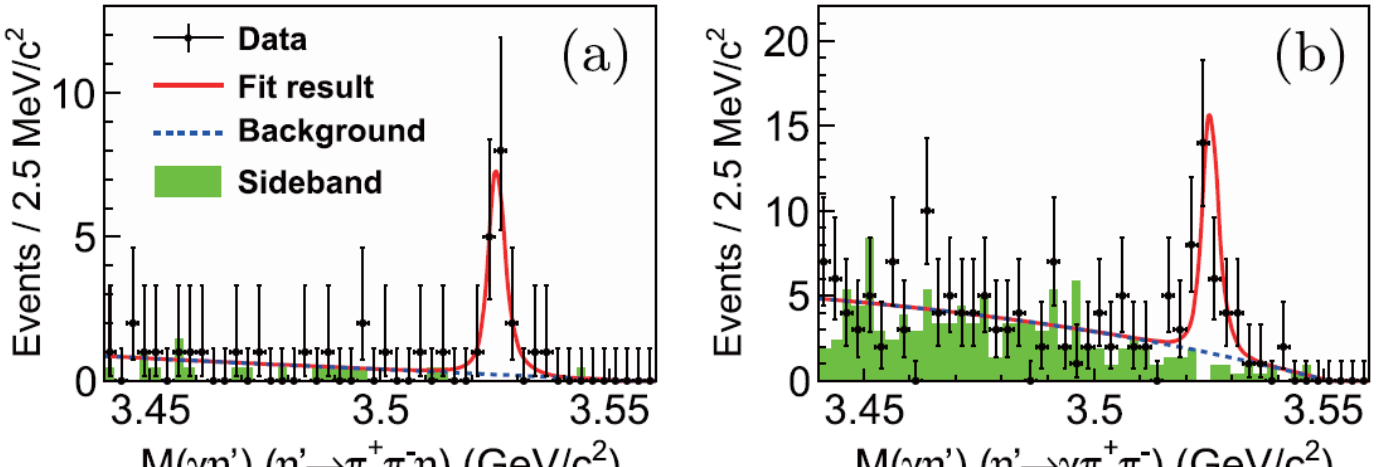


$$B(h_c \to \gamma\eta') = (1.52 \pm 0.27 \pm 0.29) \times 10^{-3}$$
$$B(h_c \to \gamma\eta) = (4.7 \pm 1.5 \pm 1.4) \times 10^{-4}$$

$h_c \to \gamma\eta' : 8.4\sigma$

$h_c \to \gamma\eta : 4.0\sigma$

Observation of h_c radiative decay

based on 448M ψ'

- arXiv: 1912.05983
- **2019-12-12**
- Chin. Phys. C 44, 040001 (2020)

288# PAPER

FUTURE PHYSICS PROGRAMME OF BESIII (WHITE PAPER)

The charmonium observables can be taken from spectroscopy (e.g. masses and widths), transitions (e.g. transition rates), leptonic and electromagnetic decays, radiative decays, hadronic decays, rare and forbidden decays, and some miscellaneous topics such as the Bell inequalities in high energy physics and special topics in $B\bar{B}$ final states, where B refers to baryon. BESIII is well suited to address the remaining experimental questions that are related to the low-mass charmonium spectrum, i.e. below the open-charm threshold, such as a precise determination of the mass and width of η_c, h_c, and $\eta_c(2S)$. The QCD multipole expansion (QCDME) [15, 16] is a feasible approach for the charmonium hadronic transitions. Its results can be examined via observations at BESIII such as the $\pi\pi$ transitions of S-wave (P-wave or D-wave) charmonium states, the η transition $\psi(3686) \to \eta J/\psi$, and the iso-spin violating π^0 transition $\psi(3686) \to \pi^0 h_c$. Many ra-

measurement	expected sensitivity on branching fraction
$h_c \to hadrons$	observation of 5×10^{-4}
$\eta_c(2S) \to X$	observation of 1×10^{-6}
$\chi_{c1} \to \pi^+\pi^-\eta_c$	evidence of 3×10^{-3}
$h_c \to \pi^+\pi^- J/\psi$	evidence of 2×10^{-3}
$\chi_{cJ} \to \gamma V$	observation of 1×10^{-6}
$h_c \to p\bar{p}$	evidence of 2×10^{-4}

plan	data sets
XYZ plan (1)	500 pb^{-1} at a large number of points between 4.0 and 4.6 GeV
XYZ plan (2)	5 fb^{-1} at 4.23, 4.42 GeV for large Z_c samples
XYZ plan (3)	5 fb^{-1} above 4.6 GeV
charmonium plan	3×10^9 $\psi(3686)$ decays

2021 psi(2S), 3.4/fb (on-line), 2.26 B (preliminary)_	66257-69292

2022 3.65, 3.682 (ON-LINE) [edit]

Sample	Runno	Ecms(MeV)	luminosity(1/pb)	location
3650	69612-70132	3650	410	/bes3fs/offline/data/709-1/3650/round15/
3682	70133-70505	3682	404	/bes3fs/offline/data/709-1/3682/round15/

large continuum

Total ~2.7B ψ'(2009+2012+2021)

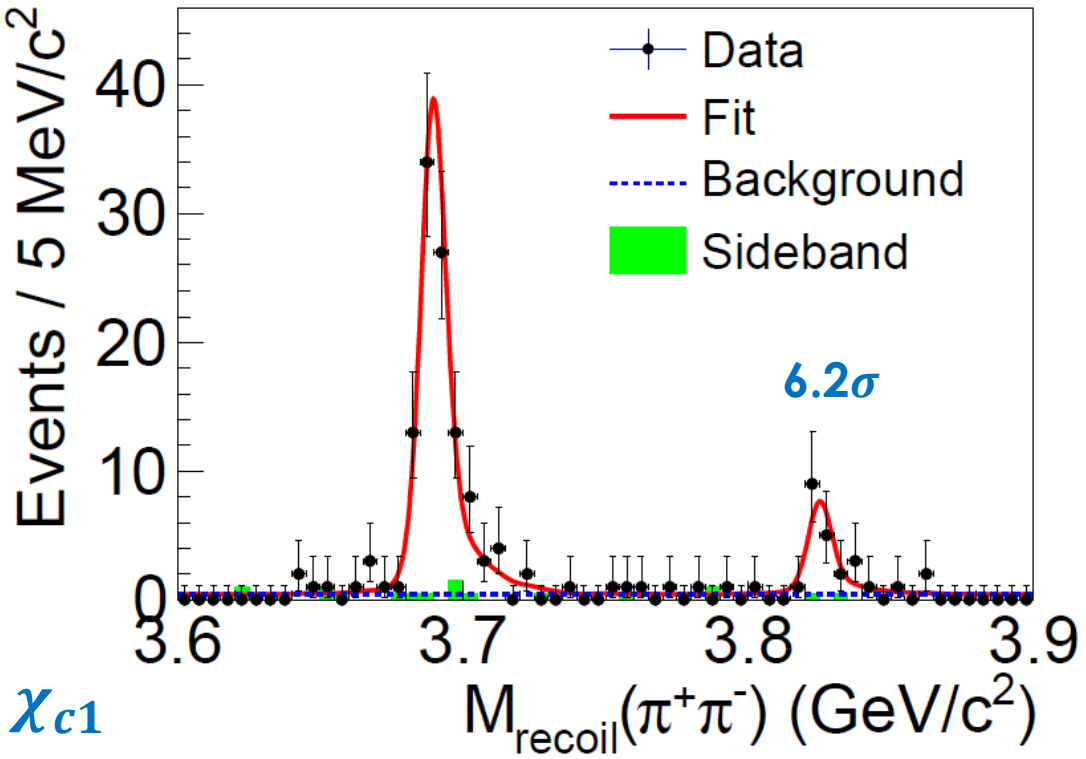
measurements based on whole data are on-going

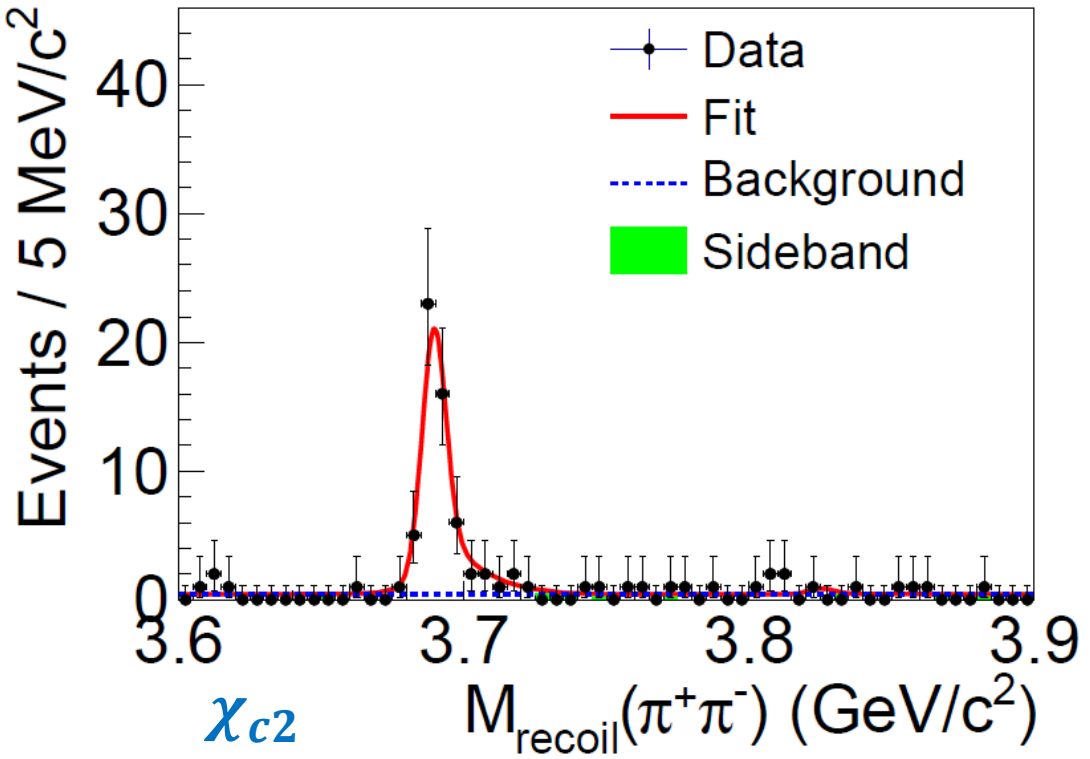
- arXiv: 1503.08203
- **2015-03-26**
- Phys. Rev. Lett. 115, 011803 (2015)

85# PAPER

$\sqrt{s} = 4.23, 4.26, 4.36, 4.42, 4.60$ GeV

M: $(3821.7 \pm 1.3 \pm 0.7)$ MeV, Γ: < 16 MeV





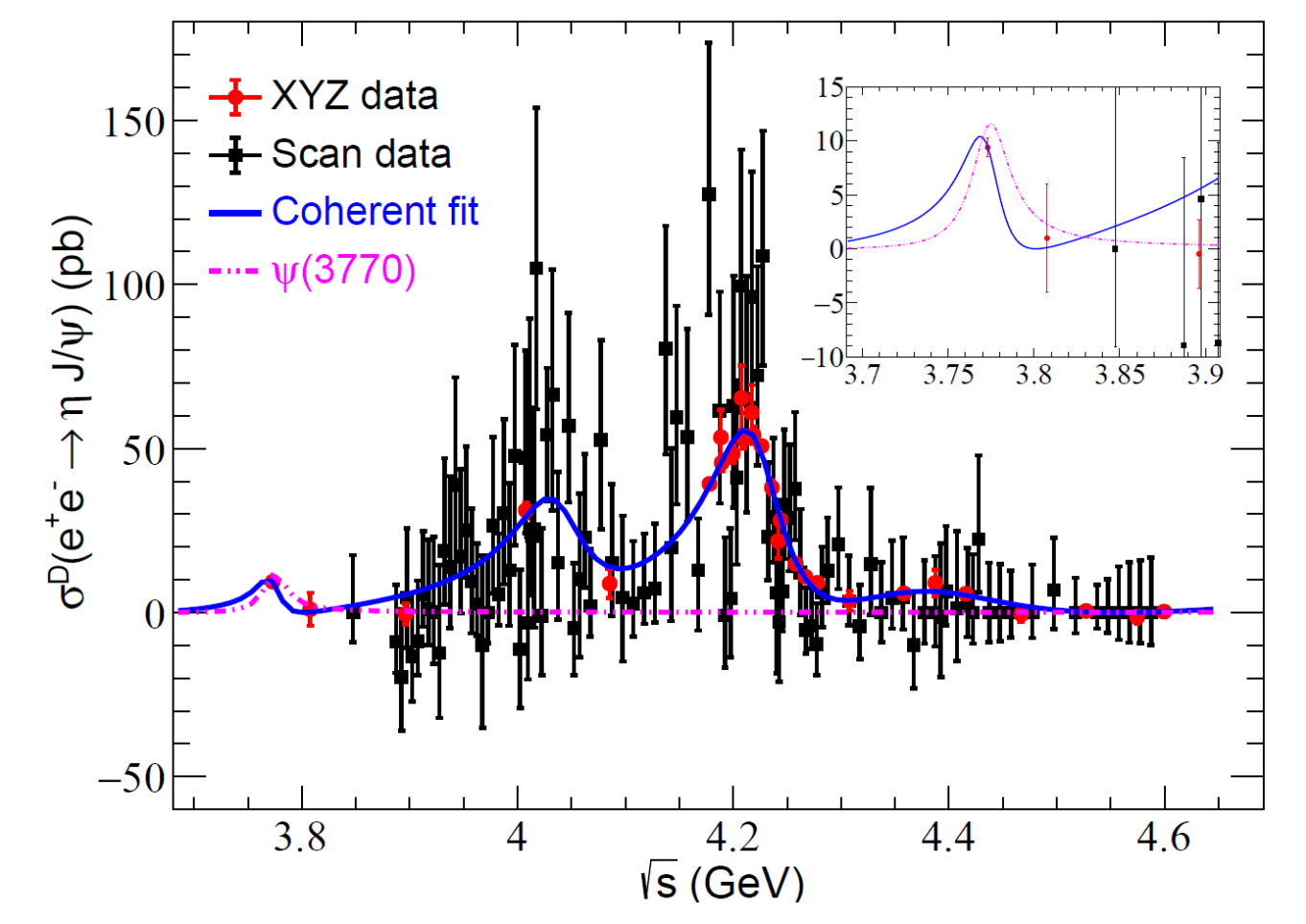
$$e^+e^- \to \pi^+\pi^- X(3823), X(3823) \to \gamma\chi_{c1}$$

$$\psi_2(1^3\mathrm{D}_2)$$

- arXiv: 2212.12165
- **2022-12-23**
- Phys. Rev.D 107, L091101 (2023)

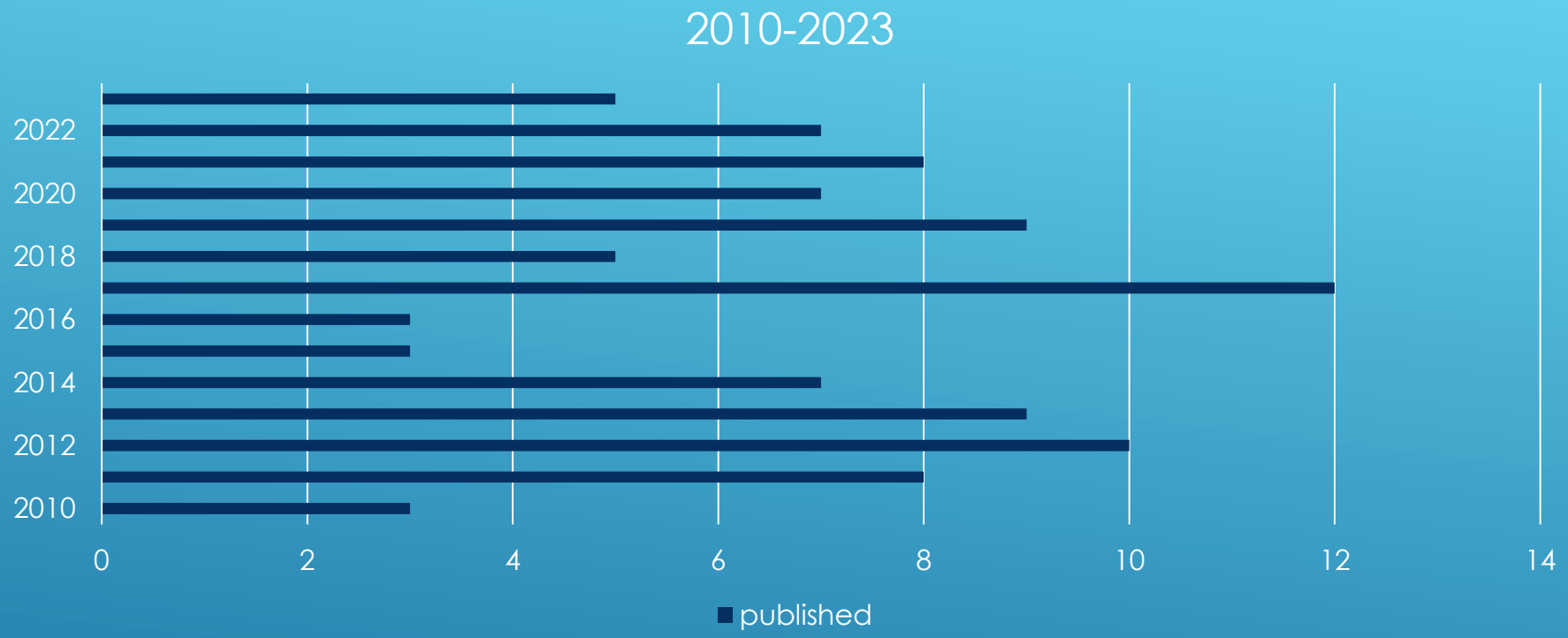
470# PAPER

$$\sigma^B(e^+e^- \to \eta J/\psi) = (8.88 \pm 0.87 \pm 0.42)pb, \sqrt{s} = 3.773\ GeV$$
$$B(\psi(3770) \to \eta J/\psi) = (11.3 \pm 5.9 \pm 1.1) \times 10^{-4}$$



$\psi(3770) \to \eta J/\psi$

interference with continuum and higher vector states



Total 96
Same to XYZ in numbers

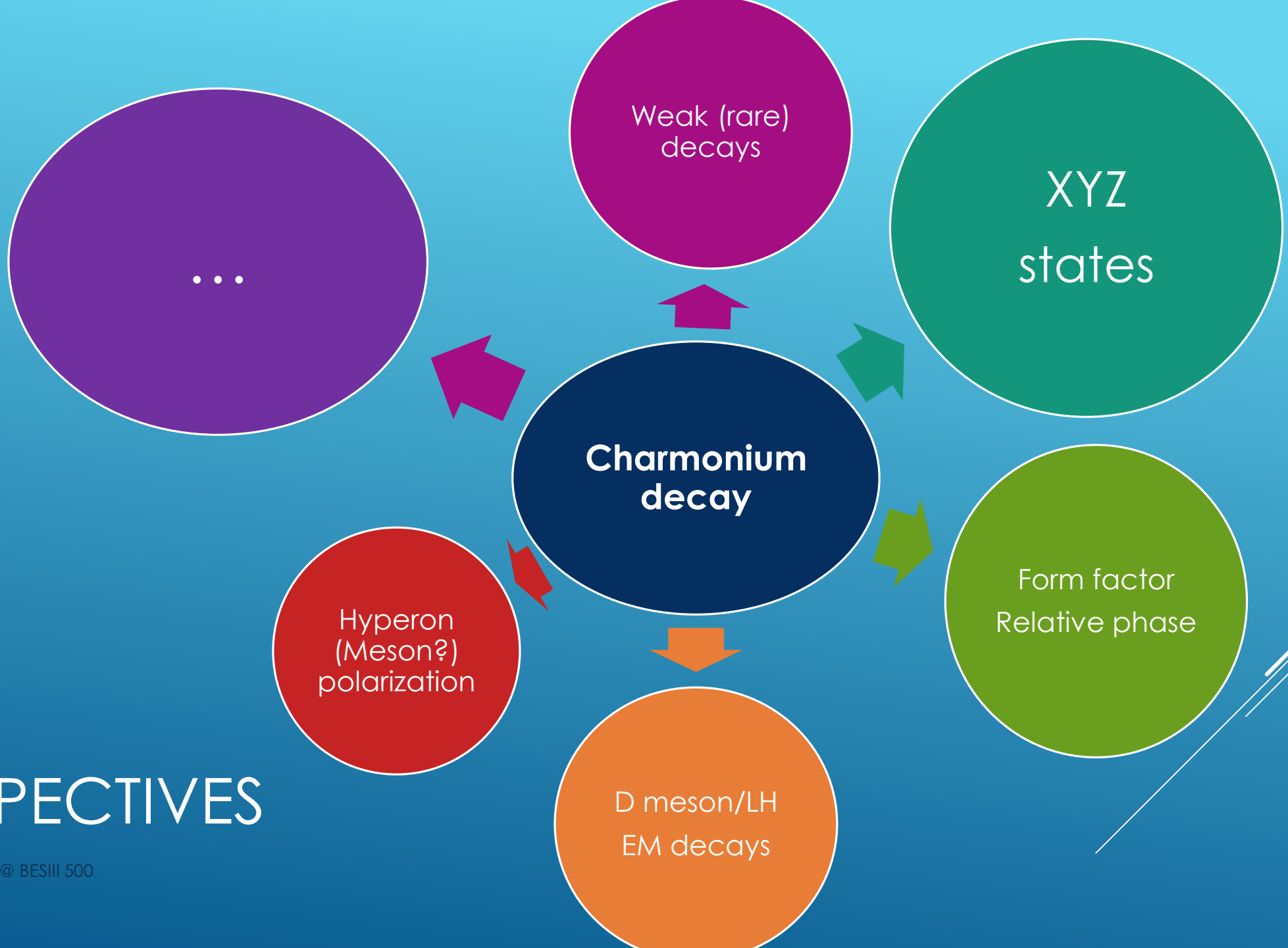
VARIOUS MEASUREMENTS

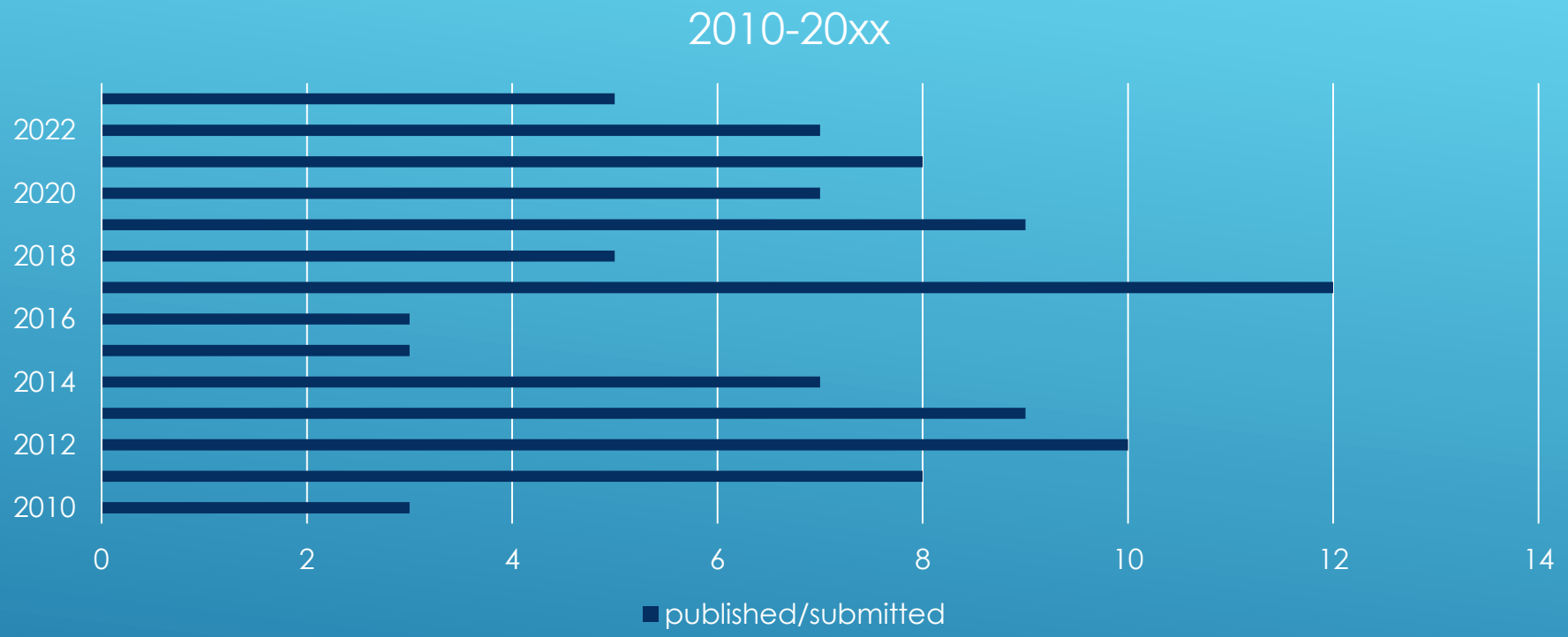
Understanding Fundamental Interactions

We are excited, we are proud, but we are still far away from the target.

Matching LQCD for non-perturbative part
Test predictions based perturbative calculations
Inputs for phenomenological (potential) models
Check features from EFT (NRQCD, pNRQCD), etc.
…

PERSPECTIVES





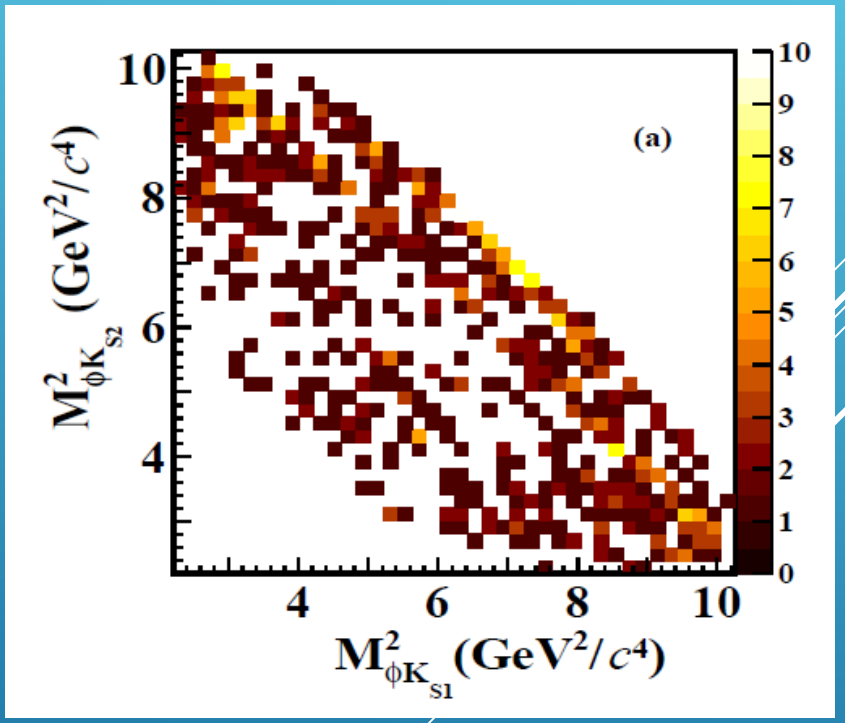
OPEN MIND, WORK HARD, PUBLISH MORE, UNDERSTAND BETTER

THANK YOU!

BACKUP

Measurement of the Branching Fraction for the Decay $\psi(3686) \to \phi K_S^0 K_S^0$

- arXiv: 2303.08317
- **2023-03-15**
- Submitted to Phys. Rev. D
- Most recent charmonium decay paper till 2023-5-31



488# PAPER