Exotic Hadrons at BESIII

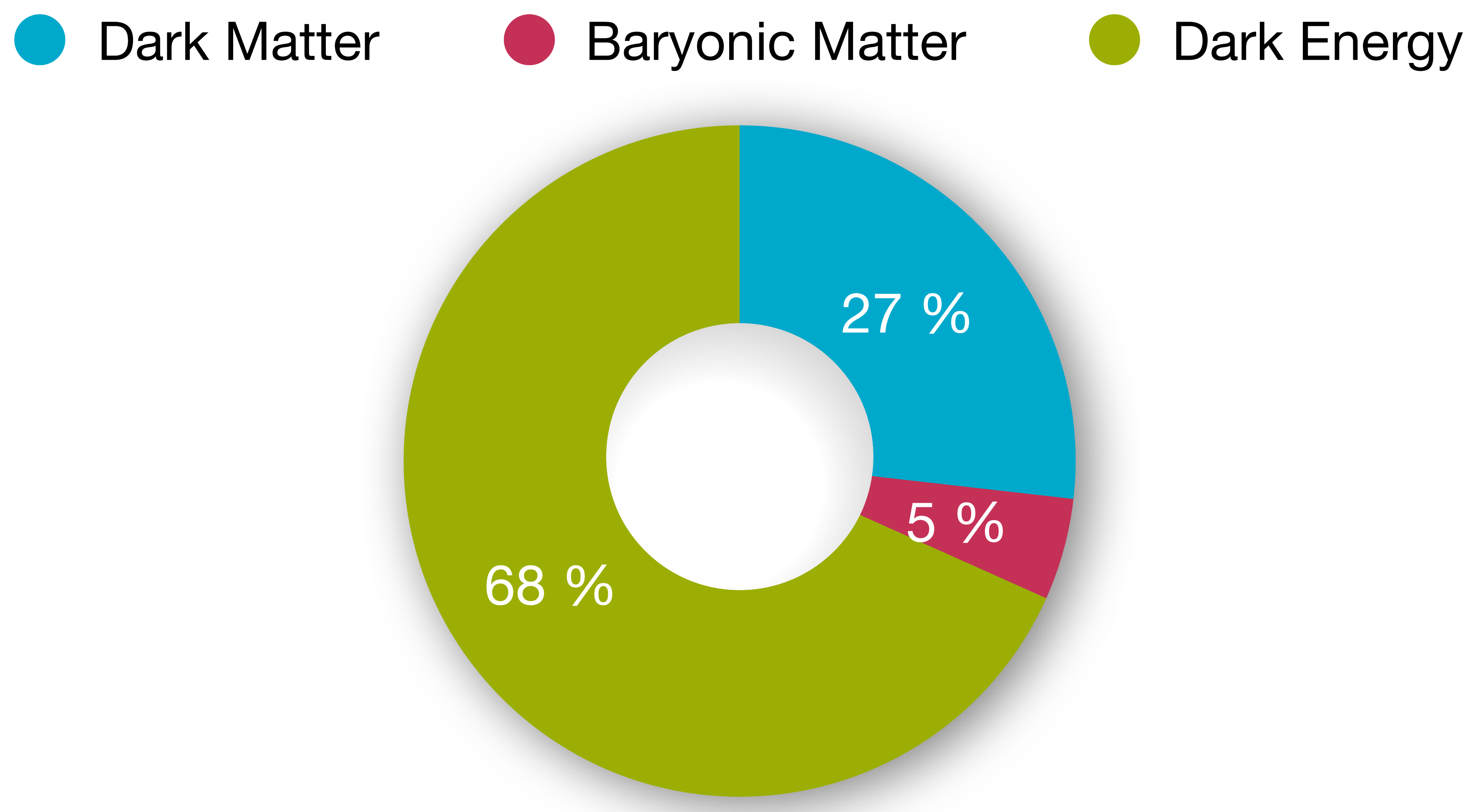
Meike Küßner - on behalf of the BESIII Collaboration

Exotic Hadron Spectroscopy 2024 - Swansea

2nd of July 2024

Fundamental Questions

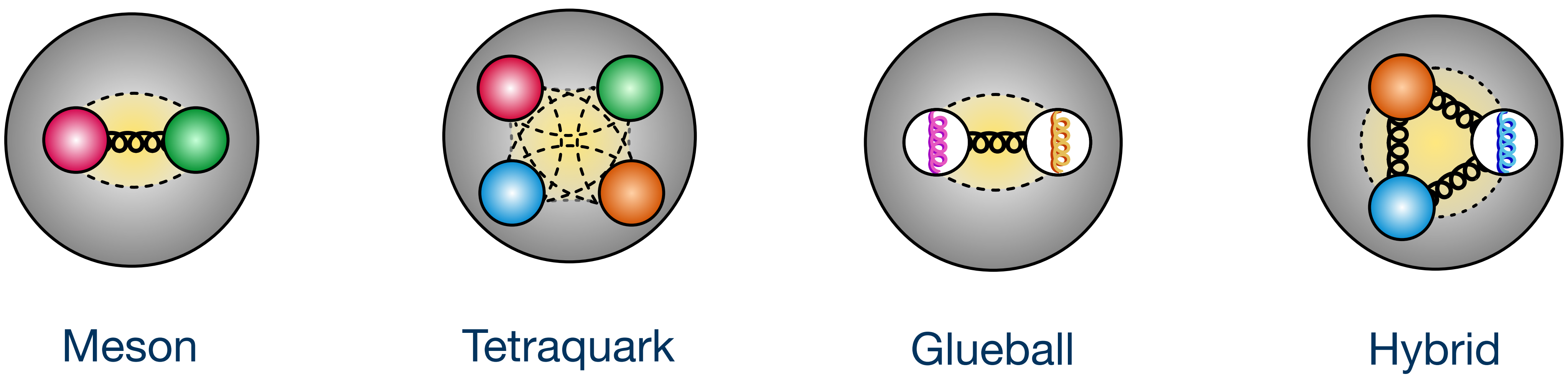
The Higgs mechanism creates the mass of the fundamental particles, but this is not the end of the story!



We even do not understand „conventional“ matter like the proton!

From the Perspective of Meson Spectroscopy

- The mass of hadrons is predominantly generated by strong interaction (>90% in case of the proton)
- To understand how mass is generated we investigate other systems, e.g. with explicit gluonic degrees of freedom



- For a fermion-antifermion system not all quantum numbers can be formed

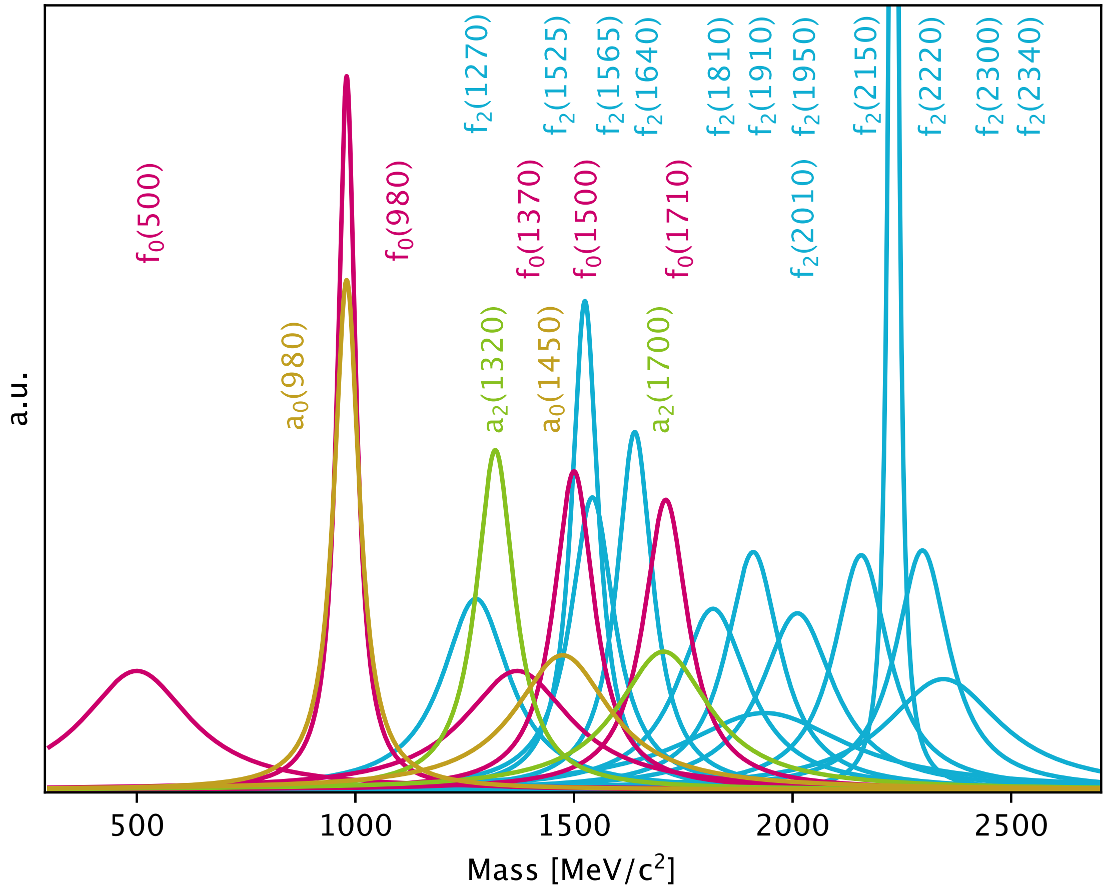
$$P = (-1)^{L+1}\,,\; C = (-1)^{L+S}$$

- Exotic quantum numbers: $J^{PC} = 0^{+-}, 0^{--}, 1^{-+}, 2^{+-}, \ldots$
- But: Further states have been found which show odd properties or even exotic quantum numbers!

Light Meson Regime

- Light meson regime is extremely populated!
- Several (broad) interfering resonances of the same q.n.
- Various inelastic channels and thresholds opening
- Identifying and measuring resonance properties is not straight forward
- Resonances not always look like peaks
  ⬌ Peaks not necessarily caused by a resonance
- Analysing a single channel is not enough to disentangle states unambiguously
- More sophisticated tools and descriptions needed!

spectrum of well established states



We should start thinking beyond experimental collaborations!

Experimental Possibilities

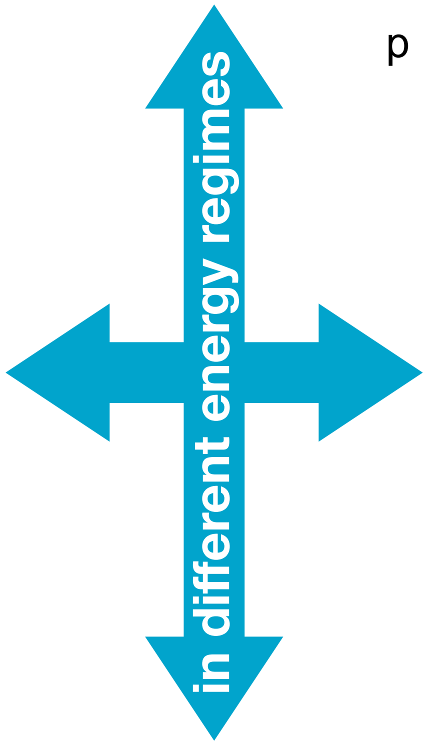
- Each experiment, detector and process has its own advantages
- To tackle these challenges, we need to combine forces

Gluon rich processes

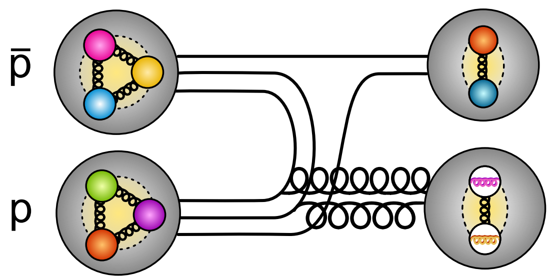
- Radiative charmonium decays
- p̄p annihilation
- pp central production
- …

QED mediated process

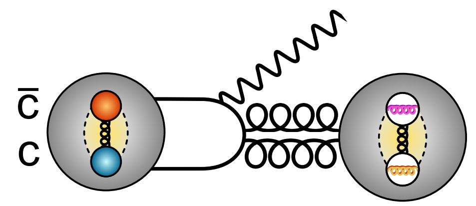
- Two-photon production



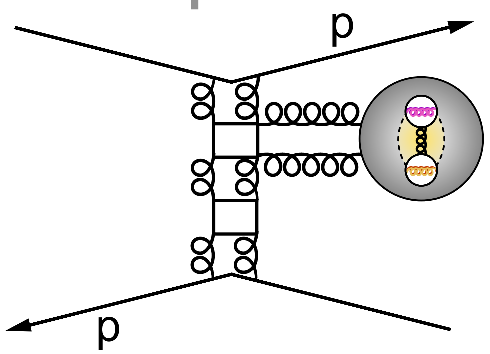
p̄p annihilation



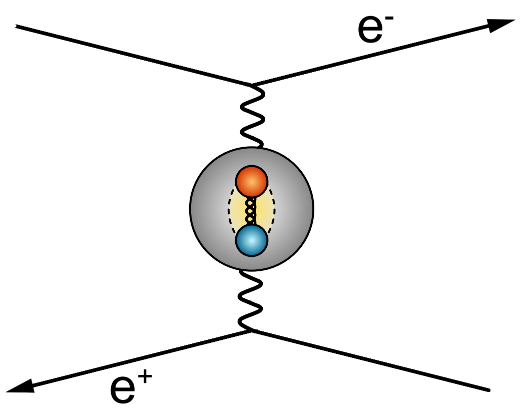
radiative J/ψ decays



central production

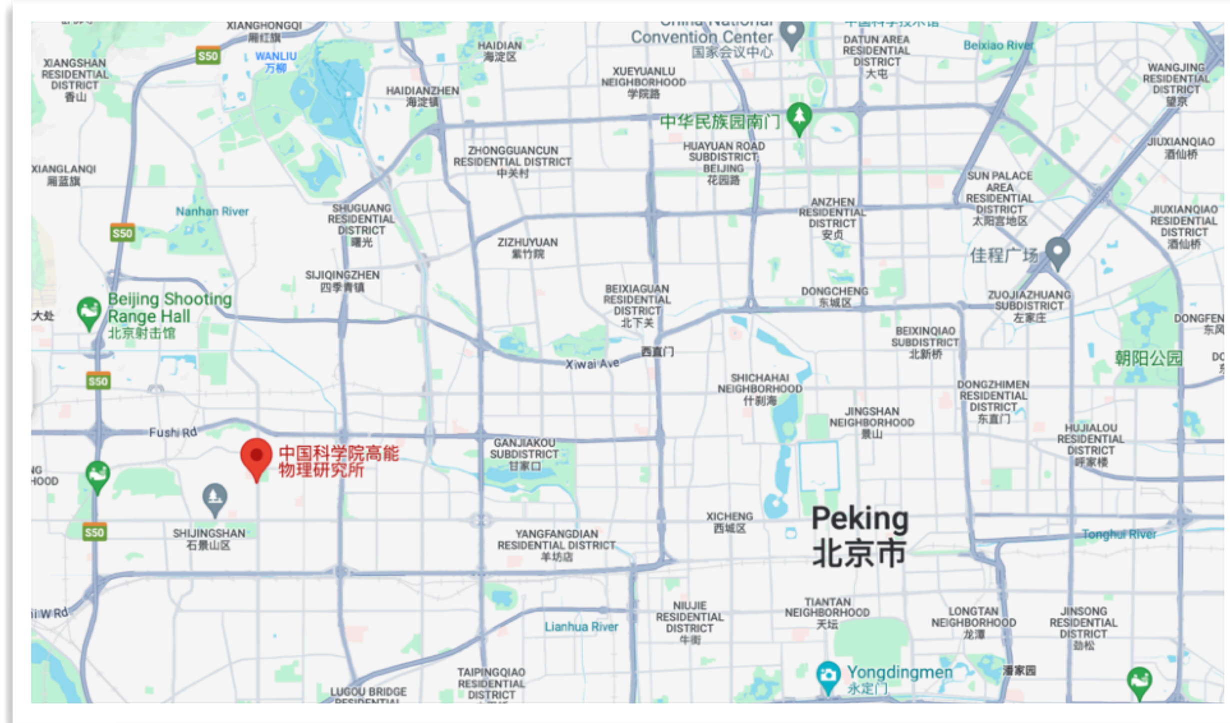


two-photon production

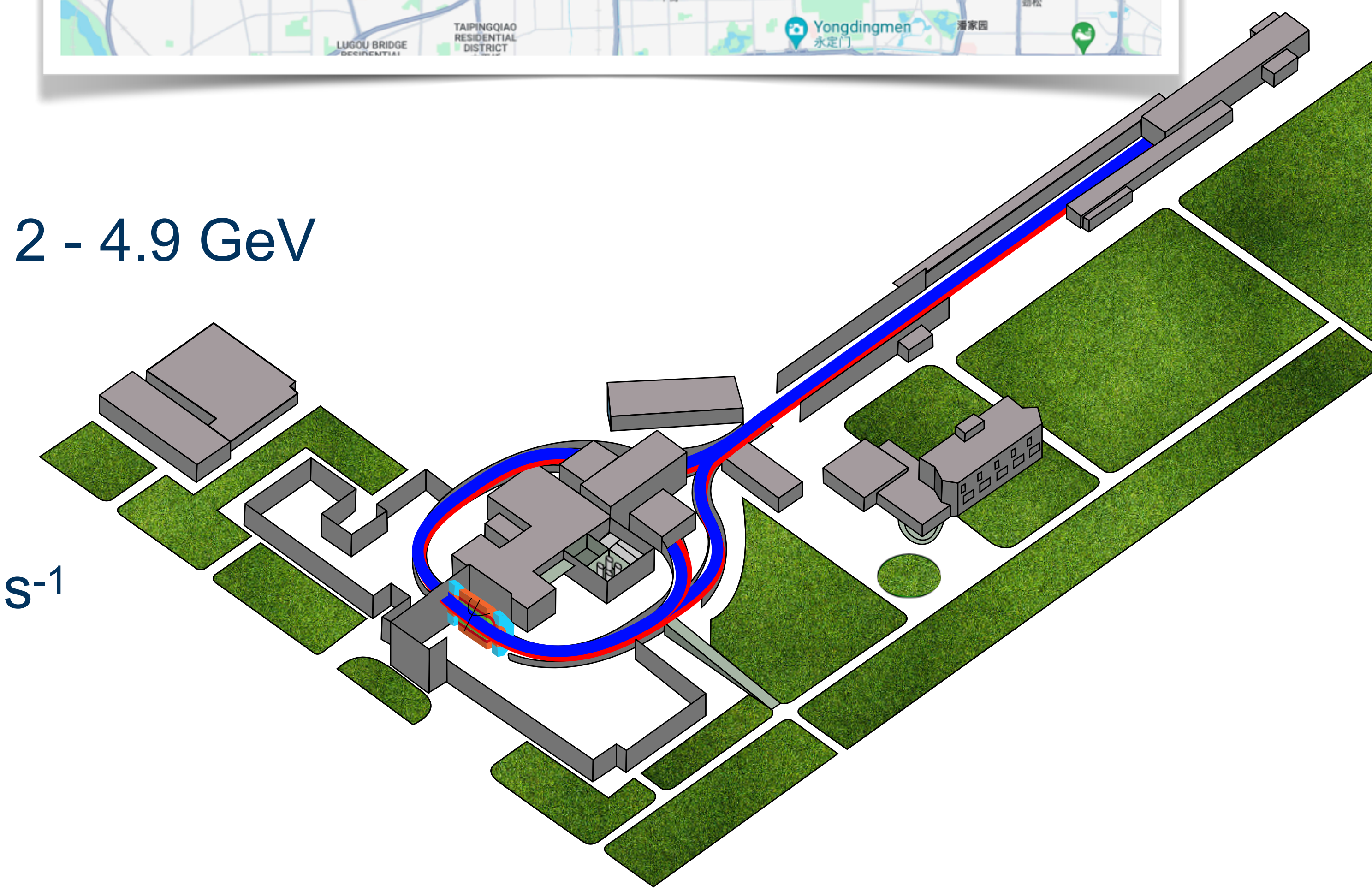


Combine different production mechanisms and decay channels to reveal a particle's nature

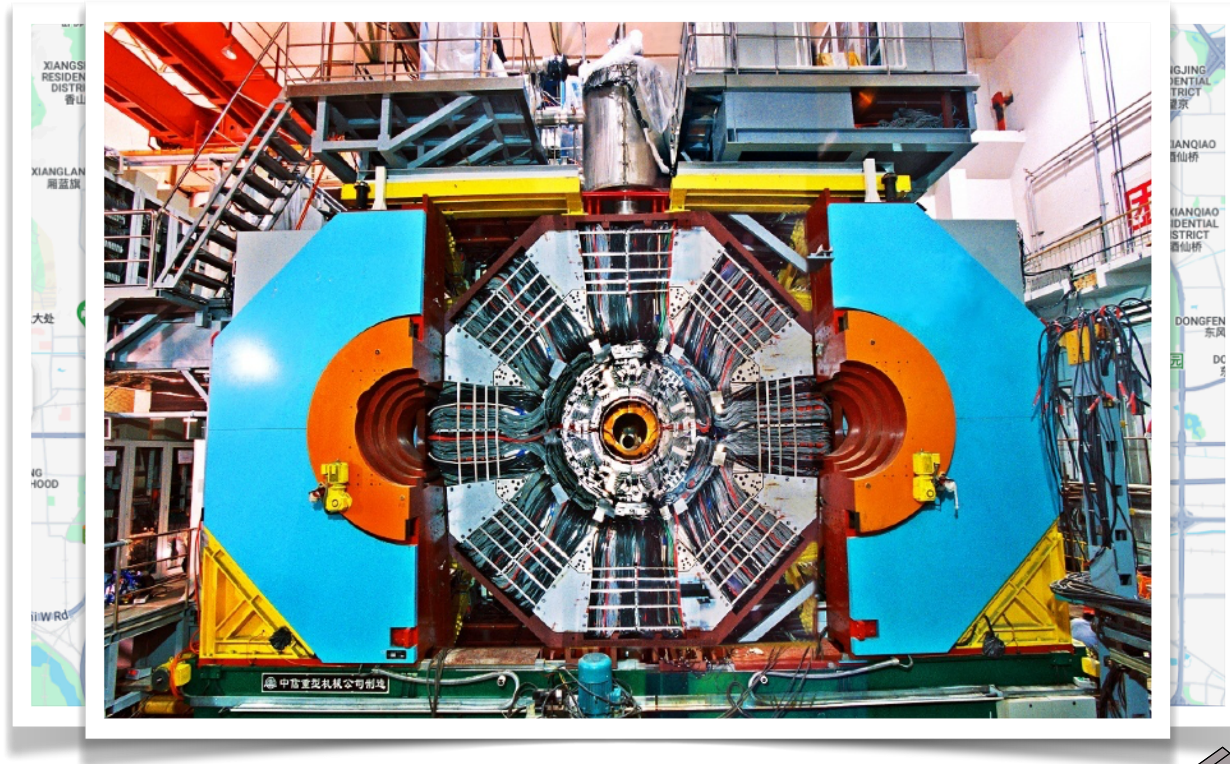
BESIII at BEPCII



- Symmetric e^+e^- collider in Beijing
- Update of BEPC accelerator
  - 2004: construction started
  - 2008: first collisions
  - 2009-today: BESIII physic runs
- Center of mass energy range: $\sqrt{s}$ = 2 - 4.9 GeV
- Single beam current: 0.91 A
- Design luminosity: $1 \cdot 10^{33}$ cm^{-2} s^{-1}
- Achieved luminosity: $1.01 \cdot 10^{33}$ cm^{-2} s^{-1}



BESIII at BEPCII



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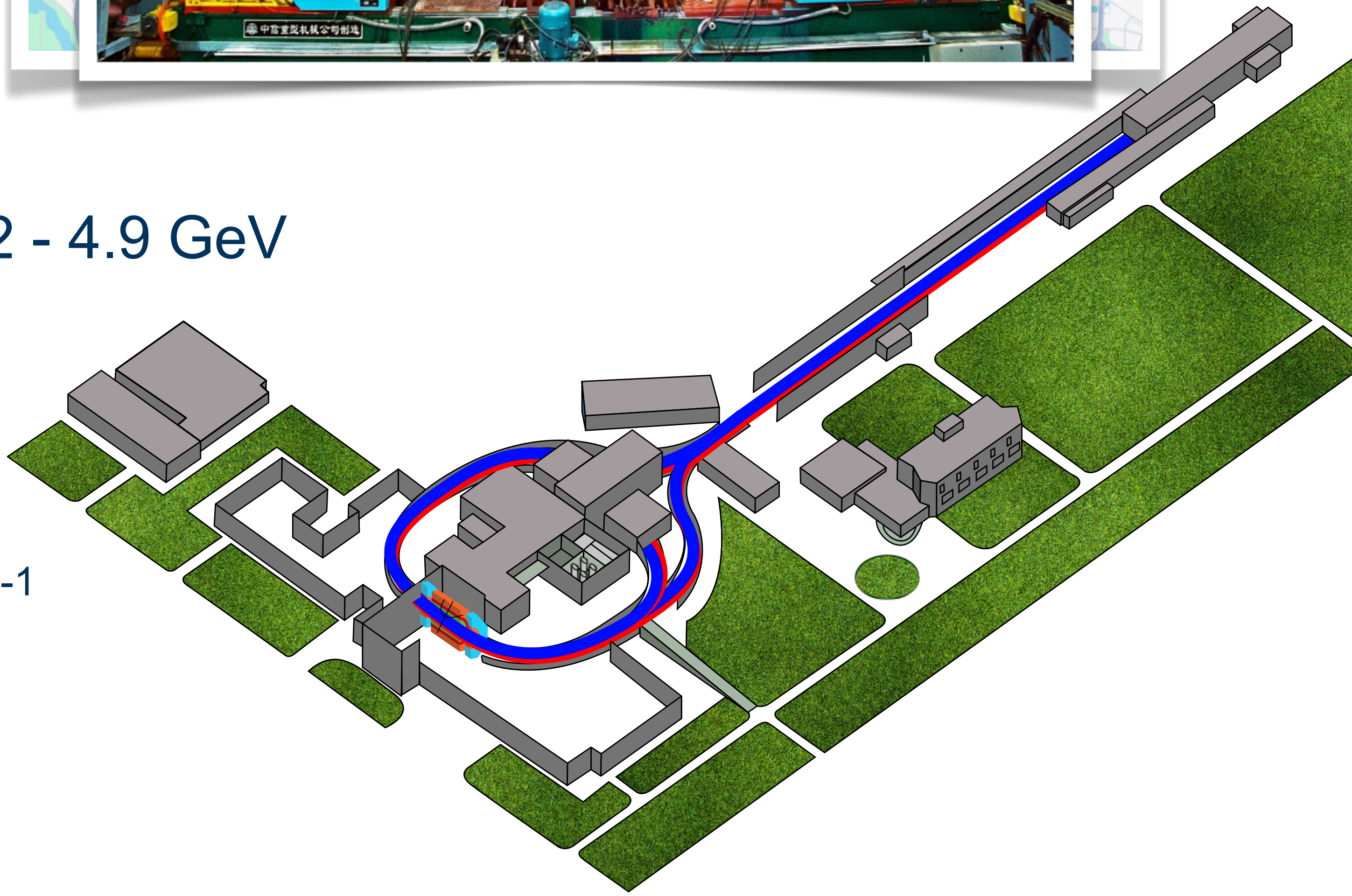
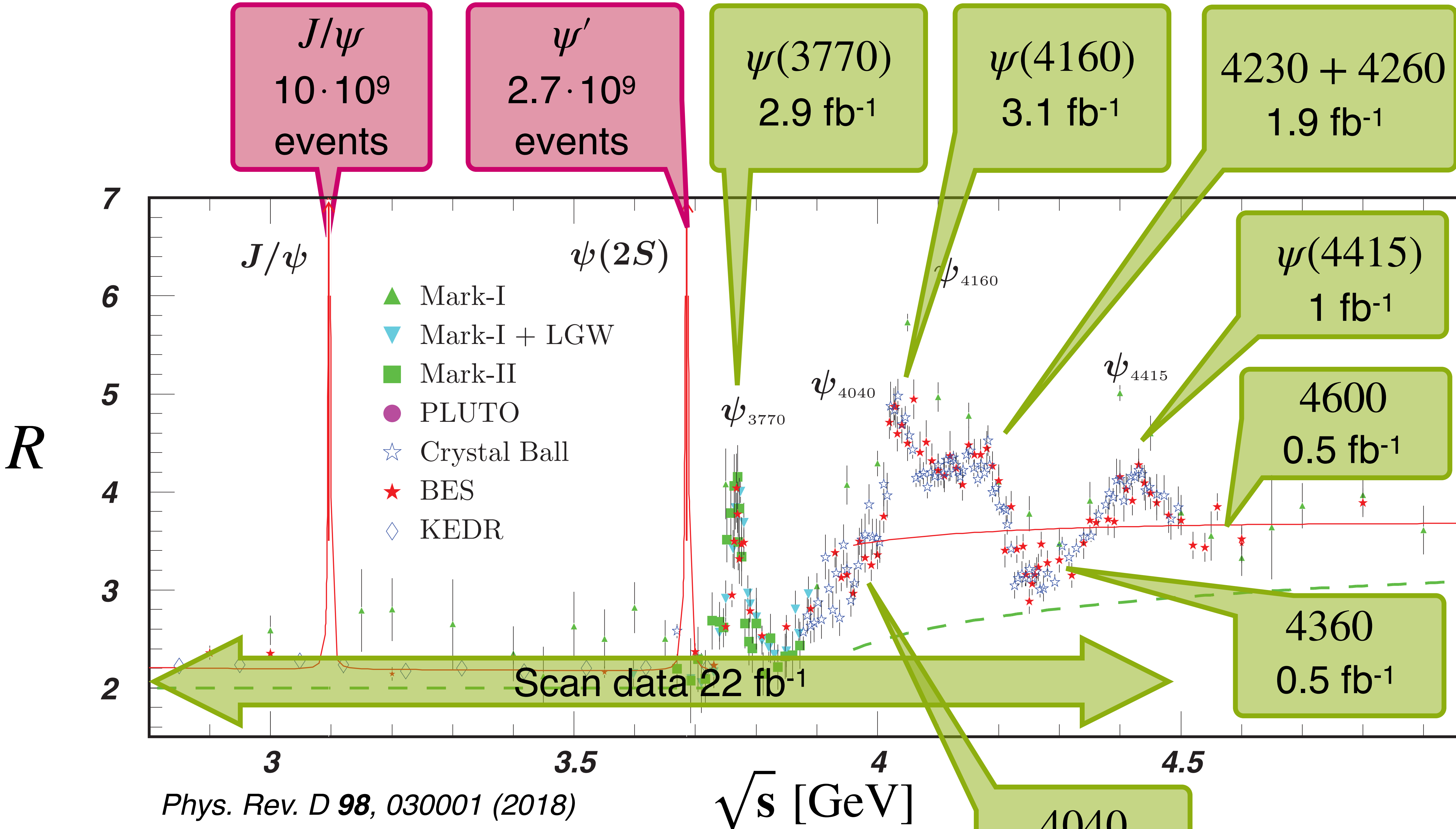


Data Samples



Phys. Rev. D ***98***, *030001 (2018)*

World largest J/ψ, ψ(3686), ψ(3770), ...
data samples on resonance

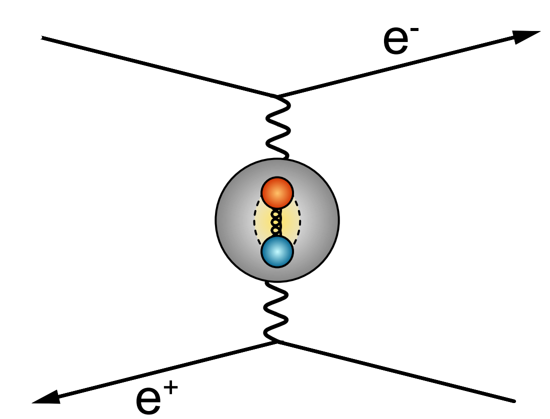
Learning More About the Inner Structure

Two photon physics

- Clean e.m. process, only sensitive to charge
- Complementary information on glueball candidates!
- States with even C-parity $0^{\pm +}, 2^{\pm +}, \ldots$ can be directly produced

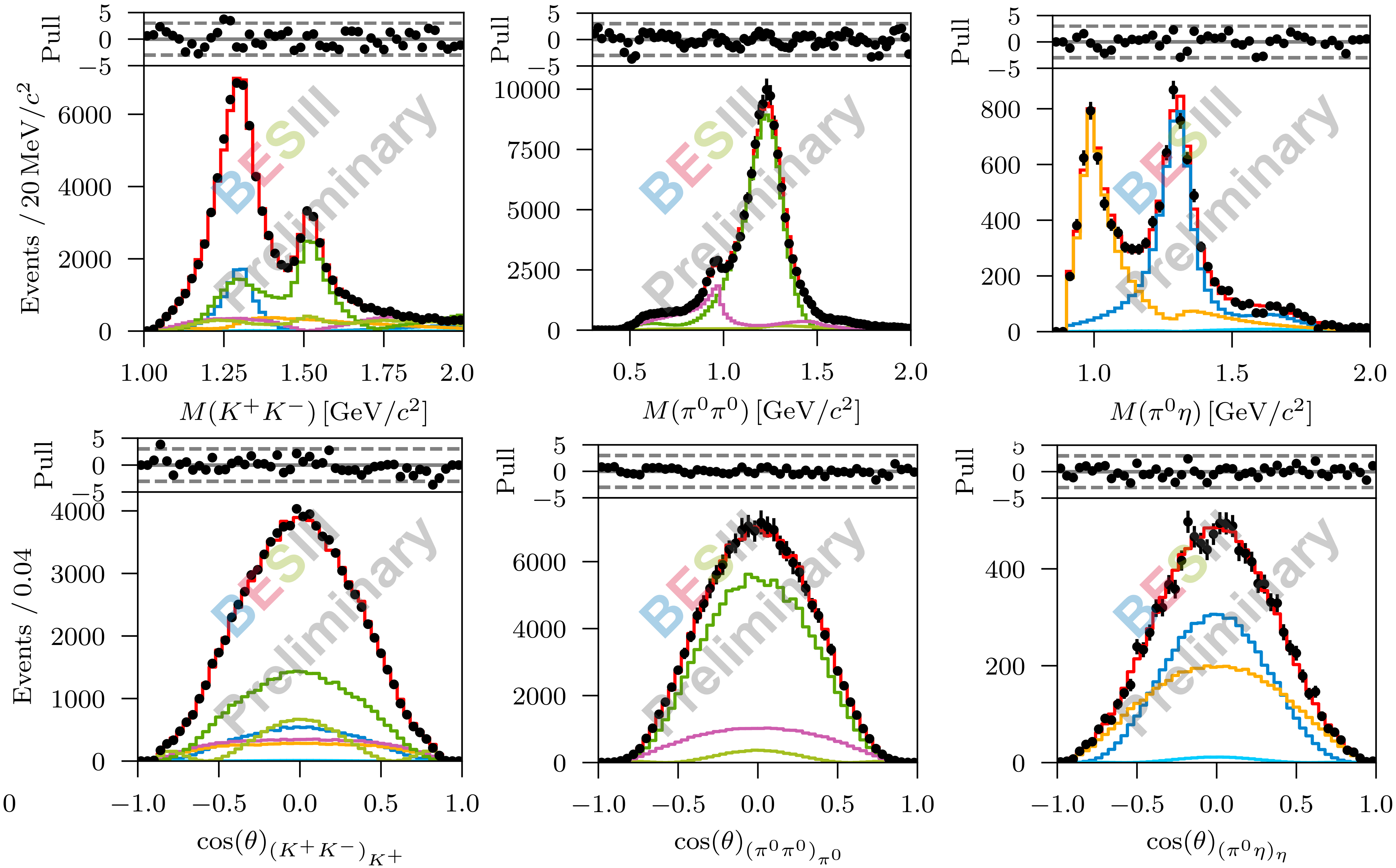
Untagged reactions:

- Scattering angles of electron and positron are small and are not detectable
- Quasi real photons carrying small virtuality ➡ spin 1 strongly suppressed



Coupled Channel Analysis of Two-Photon Data

- K-matrix parameterisation (*EPJ C* (2021) 81, 1056) fixing all pole parameters on decay side
- Determination of two-photon width based on pole residue (even for f_0 wave)



Data
Total Fit
a_2, $\lambda = 2$
a_2, $\lambda = 0$
f_2, $\lambda = 2$
f_2, $\lambda = 0$
a_0
f_0

Coupled Channel Analysis of p̄p and COMPASS Data

name	relevant data	Breit-Wigner mass [MeV/c^2]	Breit-Wigner width Γ [MeV]
$K^*(892)^{\pm}$	$\bar{p}p$	$893.8 \pm 1.0 \pm 0.8$	$56.3 \pm 2.0 \pm 1.0$
$\phi(1020)$	$\bar{p}p$	$1018.4 \pm 0.5 \pm 0.2$	4.2 (fixed)

name	relevant data	pole mass [MeV/c^2]	pole width Γ [MeV]
$f_0(980)^{---++}$	scat	$977.8 \pm 0.6 \pm 1.4$	$98.8 \pm 6.6 \pm 11.2$
$f_0(980)^{--+++}$	scat	$992.6 \pm 0.3 \pm 0.5$	$61.2 \pm 1.2 \pm 1.7$
$f_0(1370)$	scat	$1281 \pm 11 \pm 26$	$410 \pm 12 \pm 50$
$f_0(1500)$	$\bar{p}p$ + scat	$1511.0 \pm 8.5\ ^{+3.5}_{-14.0}$	$81.1 \pm 4.5\ ^{+26.9}_{-0.5}$
$f_0(1710)$	$\bar{p}p$ + scat	$1794.3 \pm 6.1\ ^{+47.0}_{-61.2}$	$281 \pm 32\ ^{+12}_{-80}$
$f_2(1810)$	scat	$1769 \pm 26\ ^{+3}_{-26}$	$201 \pm 57\ ^{+13}_{-87}$
$f_2(X)$	scat	$2119.9 \pm 6.4\ ^{+25.7}_{-1.1}$	$343 \pm 11\ ^{+32}_{-11}$

name	relevant data	pole mass [MeV/c^2]	pole width Γ [MeV]	$\Gamma_{\pi\eta'}/\Gamma_{\pi\eta}$ [%]
π_1	$\bar{p}p + \pi p$	$1623 \pm 47\ ^{+24}_{-75}$	$455 \pm 88\ ^{+144}_{-175}$	$554 \pm 110\ ^{+180}_{-27}$

name	relevant data	pole mass [MeV/c^2]	pole width Γ [MeV]	$\Gamma_{KK}/\Gamma_{\pi\eta}$ [%]
$a_0(980)^{--}$	$\bar{p}p$	$1002.7 \pm 8.8 \pm 4.2$	$132 \pm 11 \pm 8$	$14.8 \pm 7.1 \pm 3.6$
$a_0(980)^{-+}$	$\bar{p}p$	$1003.3 \pm 8.0 \pm 3.7$	$101.1 \pm 7.2 \pm 3.0$	$13.5 \pm 6.2 \pm 3.1$
$a_0(1450)$	$\bar{p}p$	$1303.0 \pm 3.8 \pm 1.9$	$109.0 \pm 5.0 \pm 2.9$	$396 \pm 72 \pm 72$

name	relevant data	pole mass [MeV/c^2]	pole width Γ [MeV]	$\Gamma_{KK}/\Gamma_{\pi\eta}$ [%]	$\Gamma_{\pi\eta'}/\Gamma_{\pi\eta}$ [%]
$a_2(1320)$	$\bar{p}p + \pi p$	$1318.7 \pm 1.9\ ^{+1.3}_{-1.3}$	$107.5 \pm 4.6\ ^{+3.3}_{-1.8}$	$31 \pm 22\ ^{+9}_{-11}$	$4.6 \pm 1.5\ ^{+7.0}_{-0.6}$
$a_2(1700)$	$\bar{p}p + \pi p$	$1686 \pm 22\ ^{+19}_{-7}$	$412 \pm 75\ ^{+64}_{-57}$	$2.9 \pm 4.0\ ^{+1.1}_{-1.2}$	$3.5 \pm 4.4\ ^{+6.9}_{-1.2}$

name	relevant data	pole mass [MeV/c^2]	pole width Γ [MeV]	$\Gamma_{\pi\pi}/\Gamma$ [%]	Γ_{KK}/Γ [%]	$\Gamma_{\eta\eta}/\Gamma$ [%]
$f_2(1270)$	$\bar{p}p$ + scat	$1262.4 \pm 0.2\ ^{+0.2}_{-0.3}$	$168.0 \pm 0.7\ ^{+1.7}_{-0.1}$	$87.7 \pm 0.3\ ^{+4.8}_{-4.4}$	$2.6 \pm 0.1\ ^{+0.1}_{-0.2}$	$0.3 \pm 0.1\ ^{+0.0}_{-0.1}$
$f_2'(1525)$	$\bar{p}p$ + scat	$1514.7 \pm 5.2\ ^{+0.3}_{-7.4}$	$82.3 \pm 5.2\ ^{+11.6}_{-4.5}$	$2.1 \pm 0.3\ ^{+0.8}_{-0.0}$	$67.2 \pm 4.2\ ^{+5.0}_{-3.8}$	$9.8 \pm 3.8\ ^{+1.7}_{-3.3}$
$\rho(1700)$	$\bar{p}p$ + scat	$1700 \pm 27\ ^{+13}_{-16}$	$181 \pm 25\ ^{+0.0}_{-16}$	$13.6 \pm 1.2\ ^{+0.9}_{-0.5}$	$0.8 \pm 0.1\ ^{+0.0}_{-0.0}$	-

Several resonance properties measured simultaneously within one fit!

This parameterisation is universal - Can be used in other analyses!

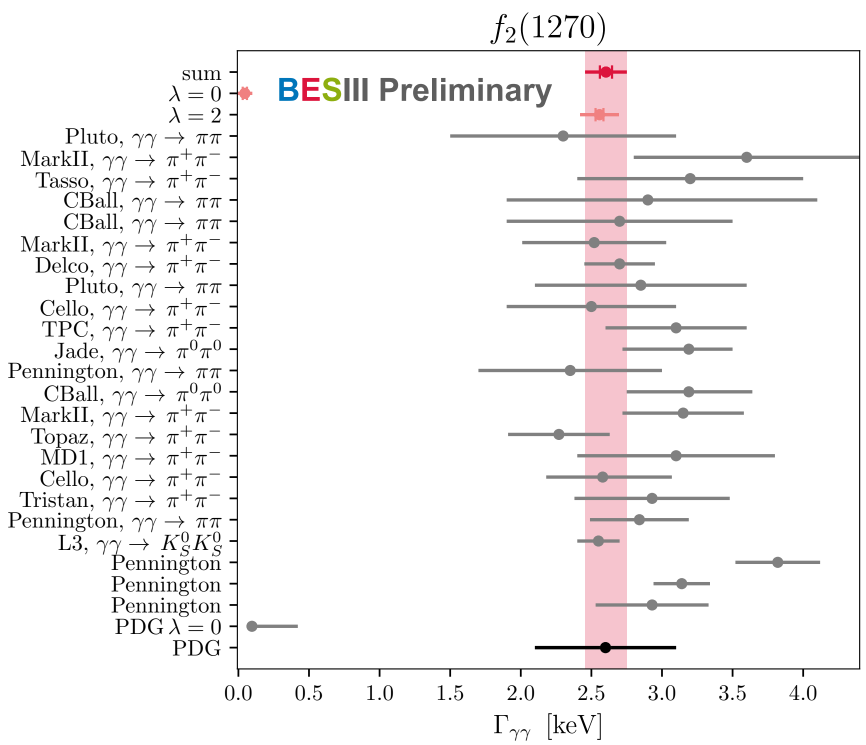
PArtial Wave Interactive ANalysis

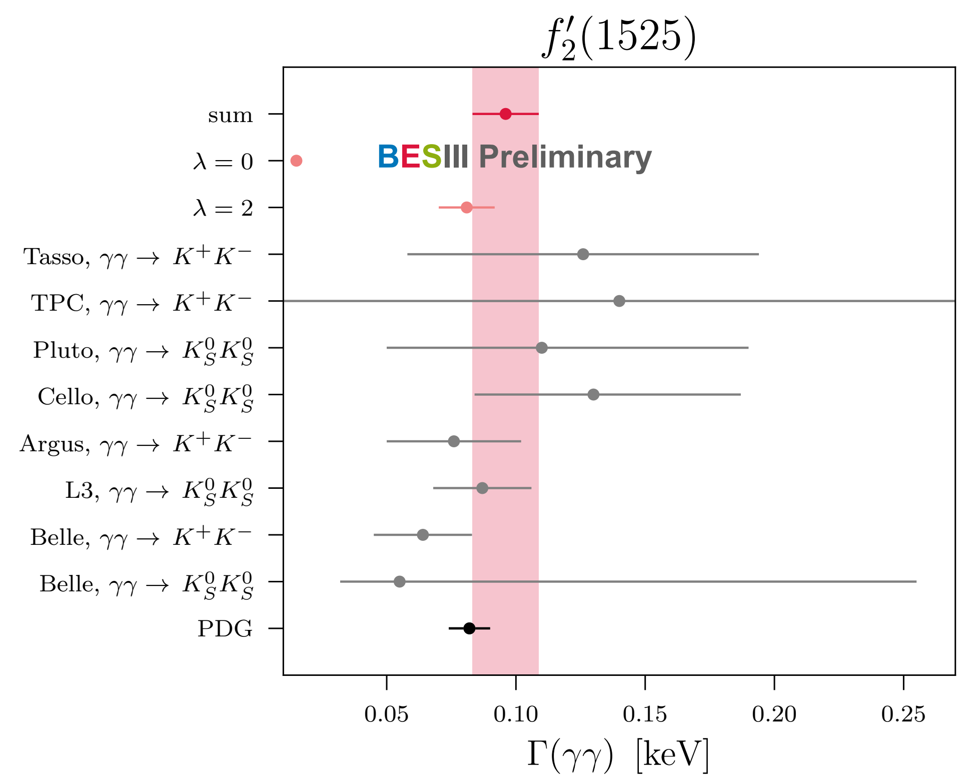
Determination of the Coupling Strength

- Determination of the two-photon width using the F-vector pole residue itself

$$\Gamma(X \to \gamma\gamma) = \frac{\alpha^2}{4\,(2J+1)\,M_R} \cdot \frac{Res_X(\gamma\gamma \to FS)}{\Gamma_{dec}}$$

Phys. Rev. D **90**, 036004

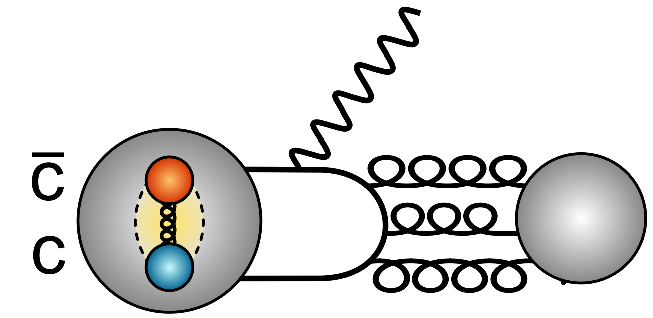




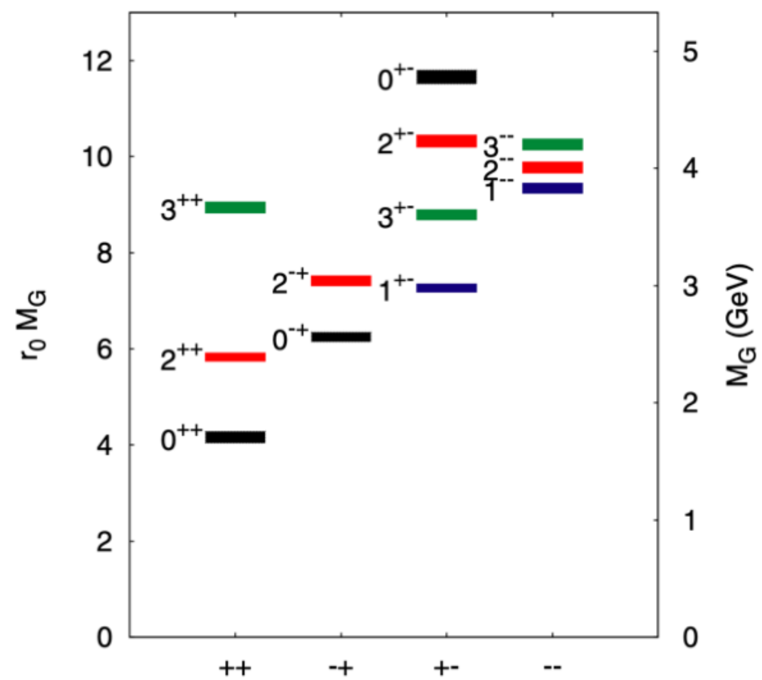
- First determination of the helicity contributions for the $f_2'(1525)$
- Most accurate measurement for $f_2(1270)$ and $a_2(1320)$
- Scalar mesons $f_0(1370)$, $f_0(1500)$ und $f_0(1710)$ measured for the first time

Unique Features of Radiative J/ψ decays

- Gluon-rich process ➡ production of glueballs expected
- Lightest glueball 0^{++} is predicted below $2\,\mathrm{GeV}/c^2$
- Observed states $f_0(1370), f_0(1500), f_0(1710)$ likely to be mixtures of pure glueball and quark component
- BESIII has accumulated very high statistics at J/ψ
  - ➡ 50 times more than 10 years ago!



Physics-, statistics- and phase space-wise great opportunities to search for glueball candidates!

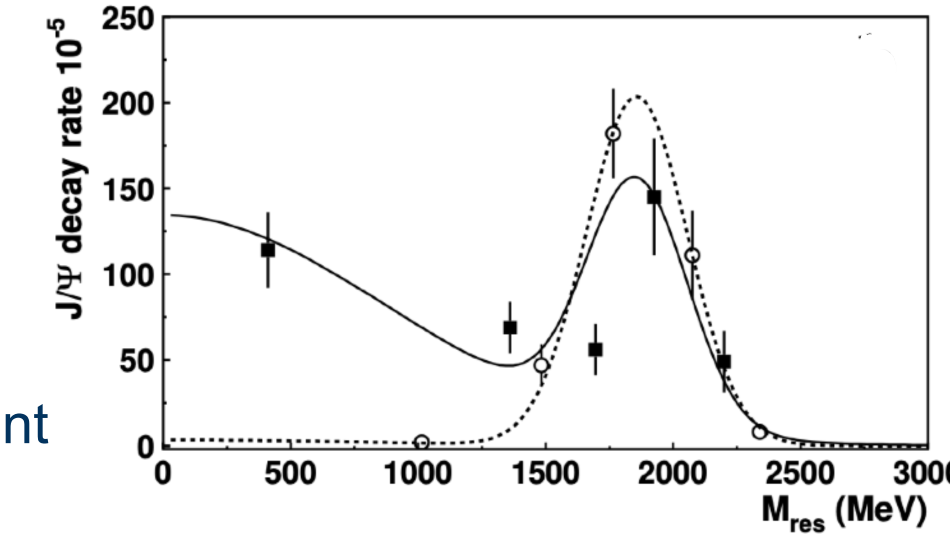


Phys. Rev. D 73, 014516 (2006)

Recent Analyses

Coupled channel fit by Sarantsev et. al.: *Phys. Lett. B 816* (2021), 136227

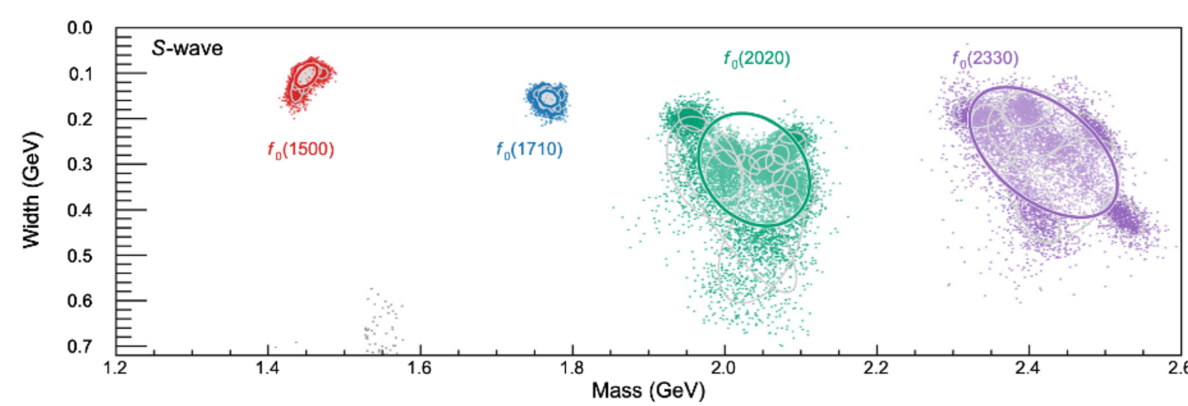
- $J/\psi \rightarrow \gamma + (\pi^0\pi^0, K_S^0K_S^0, \eta\eta, \omega\phi)$ (BESIII)
- $\pi^+\pi^-$- scattering data (CERN-Munich, GAMS, BNL)
- $\bar{p}N \rightarrow$ 3 mesons (CB-LEAR)



- Indirect hint for the light scalar glueball candidate by measuring production strengths of scalar states
- 0^{++} glueball mixing interpretation via coupling of the 10 different scalar singlet and octet states

Coupled channel fit by JPAC group: *EPJ C* ***82****, 80 (2022)*

- Used $J/\psi \rightarrow \gamma\,\pi^0\pi^0, \gamma\,K_S^0K_S^0$ (BESIII) data
- Only 4 scalar poles needed - not as 10
- No statement towards glueball contributions
- But: Theory has only access to binned data based on older data samples



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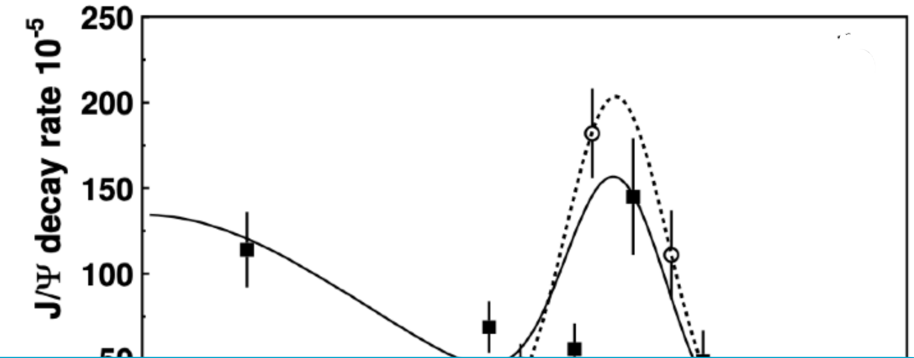
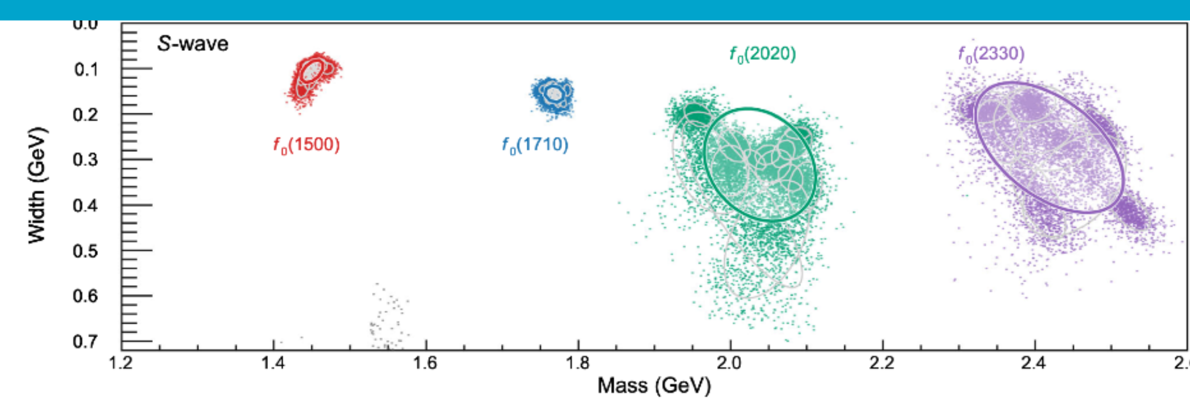


- Indirect hint for the light scalar glueball candidate by measuring production strengths of scalar states

Much higher statistics available now - *50 times more!*

Event based mass-independent and coupled channel amplitude analyses in preparation for $J/\psi \to \gamma\pi^0\pi^0, \gamma K_S^0K_S^0$ and $\gamma\eta\eta$!



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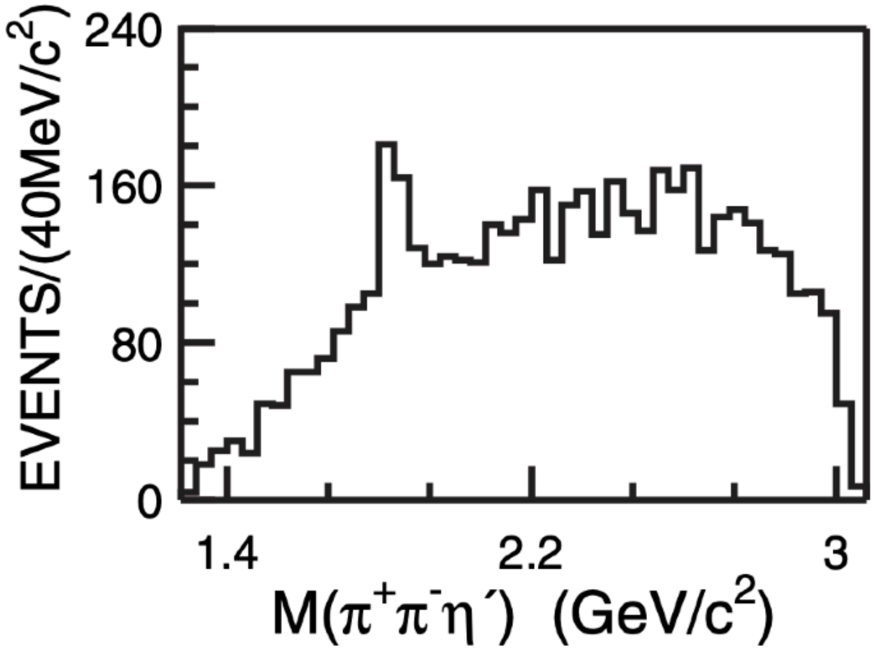
$J/\psi \to \gamma\eta'\pi^+\pi^-$

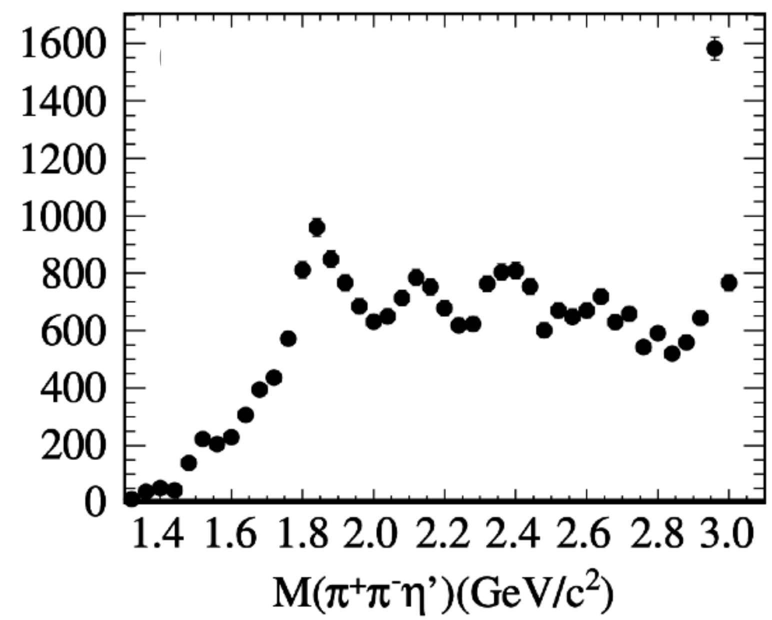
PRL 129, 042001 (2022)

58M J/ψ events



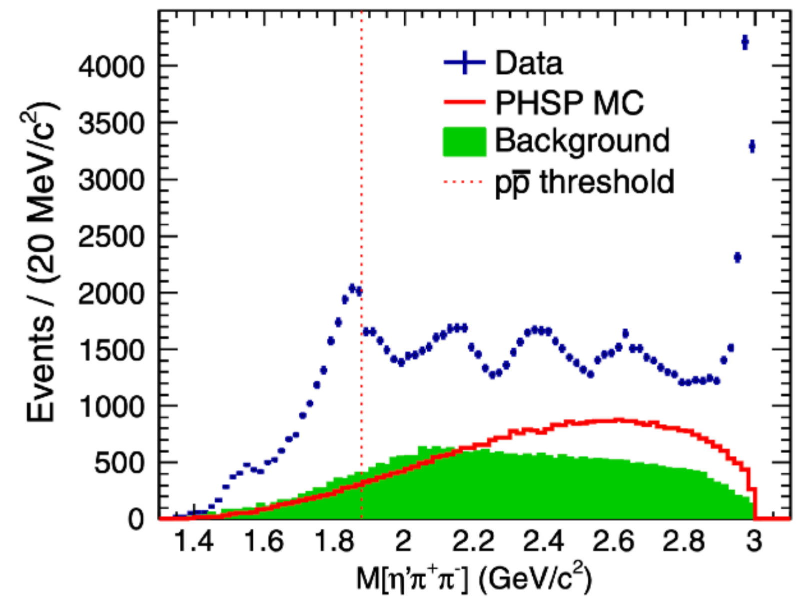
BES, PRL 95, 262001 (2005)

225M J/ψ events



BESIII, PRL 106, 072002 (2011)

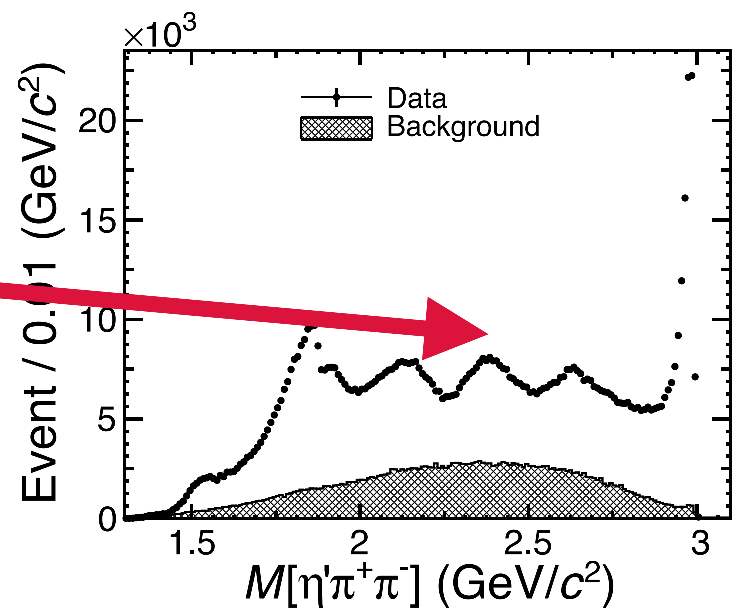
1090M J/ψ events



BESIII, PRL 117, 042002 (2016)

- Spin-parity of $X(2370)$ recently determined to be 0^{-+}!

PRL 132 181901 (2024)



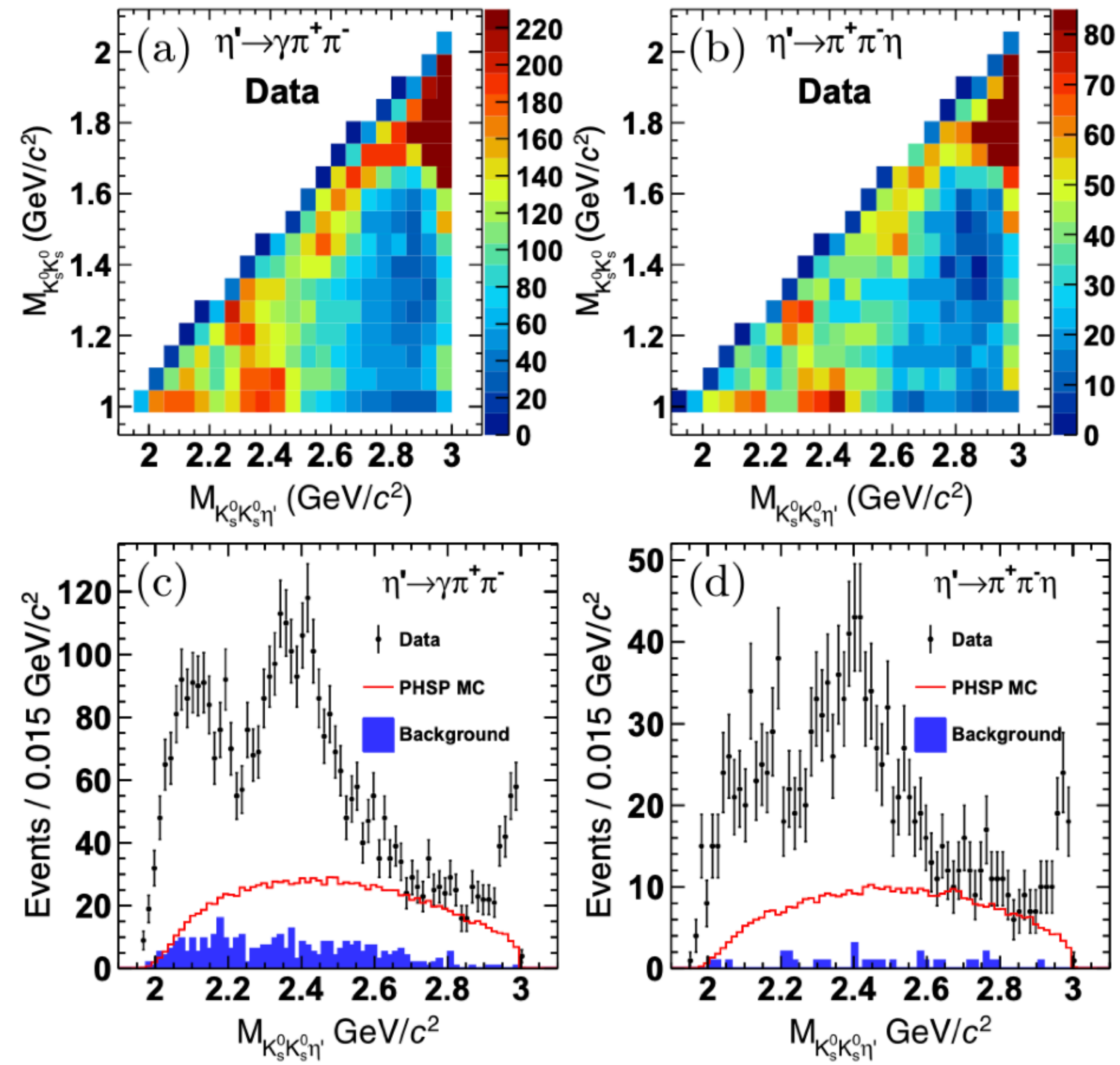
BESIII, PRL 129, 042001 (2022)

10B J/ψ events

$J/\psi \to \gamma\eta' K_S^0 K_S^0$

PRL 132 181901 (2024)

- Amplitude analysis using covariant tensor formalism including mostly Breit-Wigner line shapes + Flatté for $f_0(980)$
- Spin-parity of $X(2370)$ determined to be 0^{-+}!
- Could be a glueball candidate PRD 100 054511 (2019) but predictions vary strongly…
- Further analyses of other channels will help to learn about sub processes and interplay with $K\bar{K}$ and $\pi^+\pi^-$ system



state	J^{PC}	Decay mode	Mass (MeV/c^2)	Width (MeV/c^2)	Significance
X(2370)	0^{-+}	$f_0(980)\eta'$	2395^{+11}_{-11}	188^{+18}_{-17}	14.9σ
X(1835)	0^{-+}	$f_0(980)\eta'$	1844	192	22.0σ
X(2800)	0^{-+}	$f_0(980)\eta'$	2799^{+52}_{-48}	660^{+180}_{-116}	16.4σ
η_c	0^{-+}	$f_0(980)\eta'$	2983.9	32.0	$> 20.0\sigma$
PHSP	0^{-+}	$\eta'(K_S^0K_S^0)_{S-wave}$	− − −	− − −	9.0σ
		$\eta'(K_S^0K_S^0)_{D-wave}$	− − −	− − −	16.3σ

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

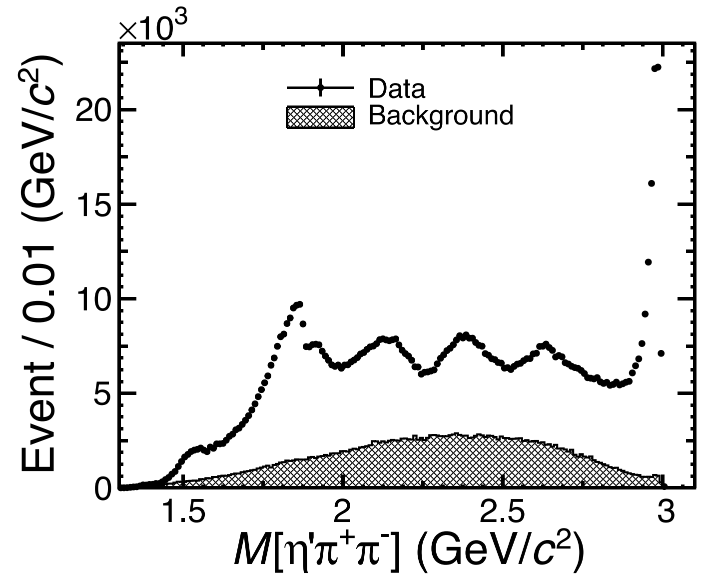
PRL 129, 042001 (2022)

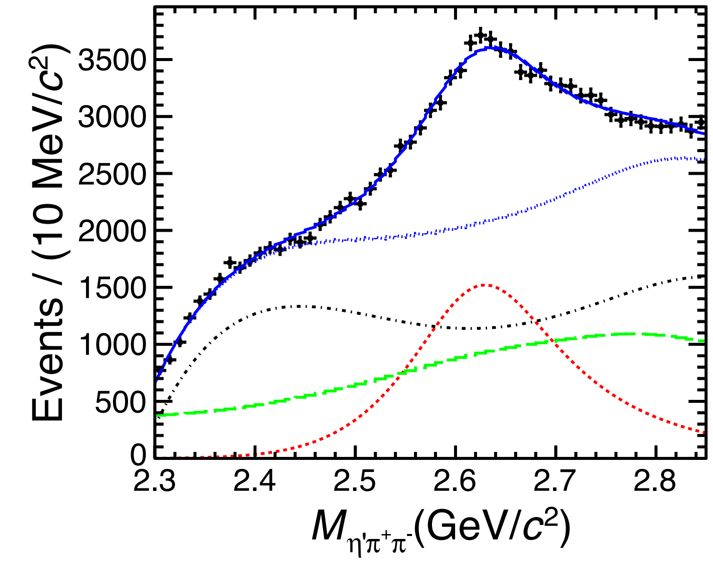
- Likely connected to a non trivial structure at $1500\,\mathrm{MeV}/c^2$ in $\pi^+\pi^-$ system
- Simultaneous fit to $\pi^+\pi^-$ system and $\eta'\pi^+\pi^-$ systems performed
- $\pi^+\pi^-$ system described by $f_0(1500)$ and additional state $X(1540)$

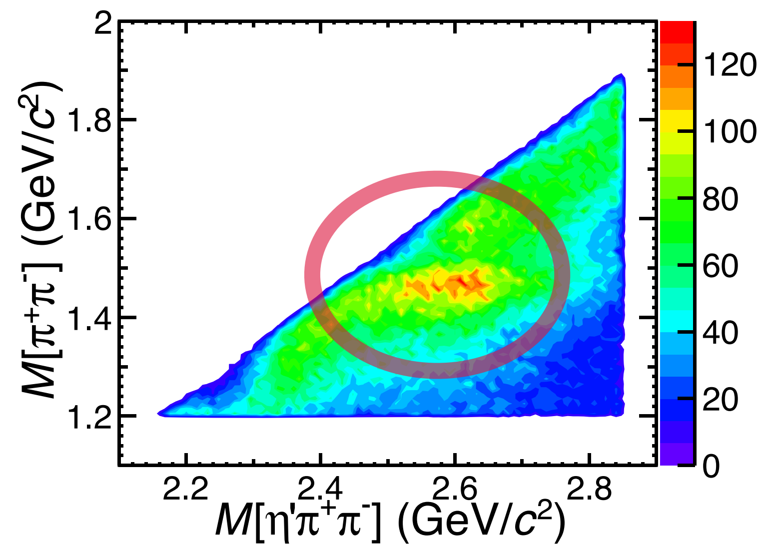
Resonance	Mass (MeV$/c^2$)	Width (MeV)
$f_0(1500)$	$1492.5 \pm 3.6^{+2.4}_{-20.5}$	$107 \pm 9^{+21}_{-7}$
$X(1540)$	$1540.2 \pm 7.0^{+36.3}_{-6.1}$	$157 \pm 19^{+11}_{-77}$
$X(2600)$	$2618.3 \pm 2.0^{+16.3}_{-1.4}$	$195 \pm 5^{+26}_{-17}$

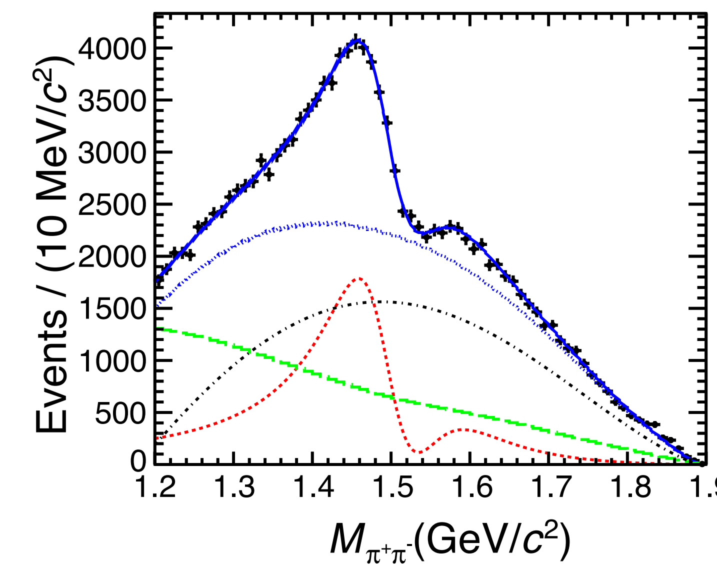
- Further studies ongoing, full PWA needed…

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



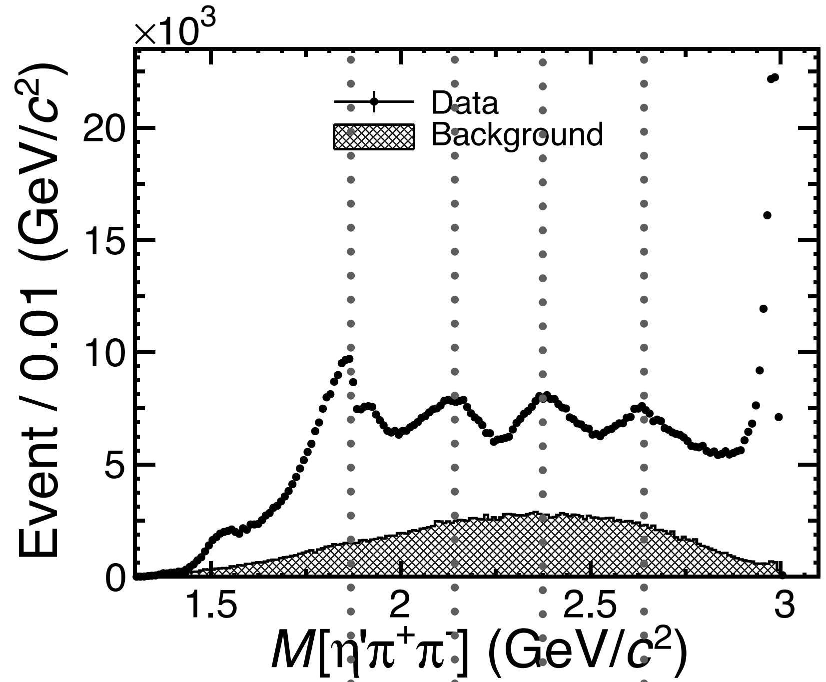






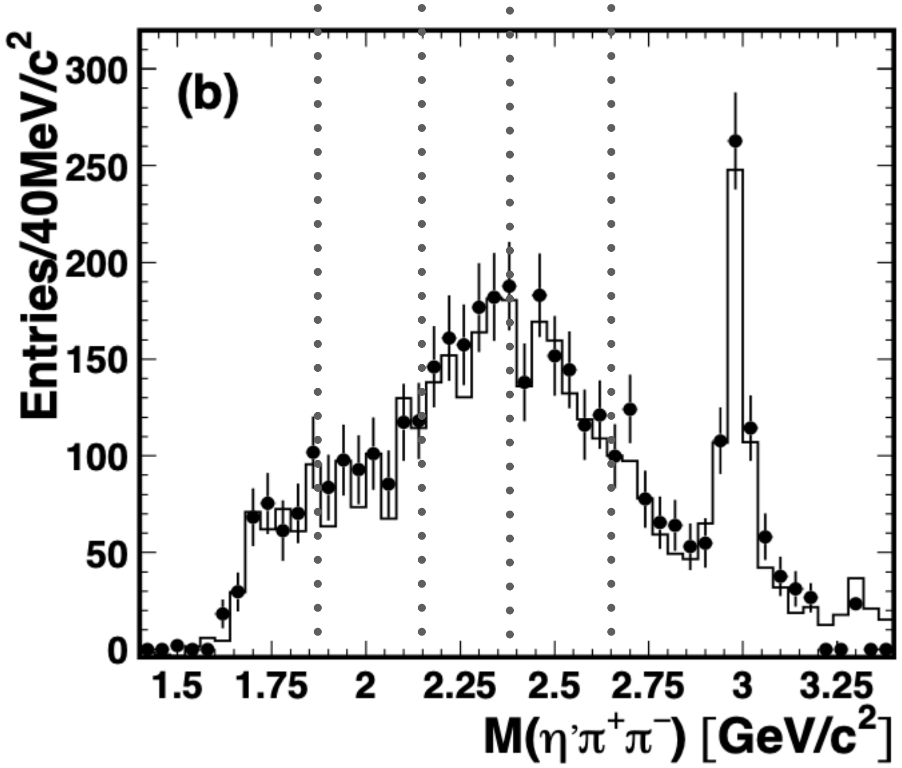
- Would be interesting to search for X states in two-photon data…

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



PRL 129, 042001 (2022)

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



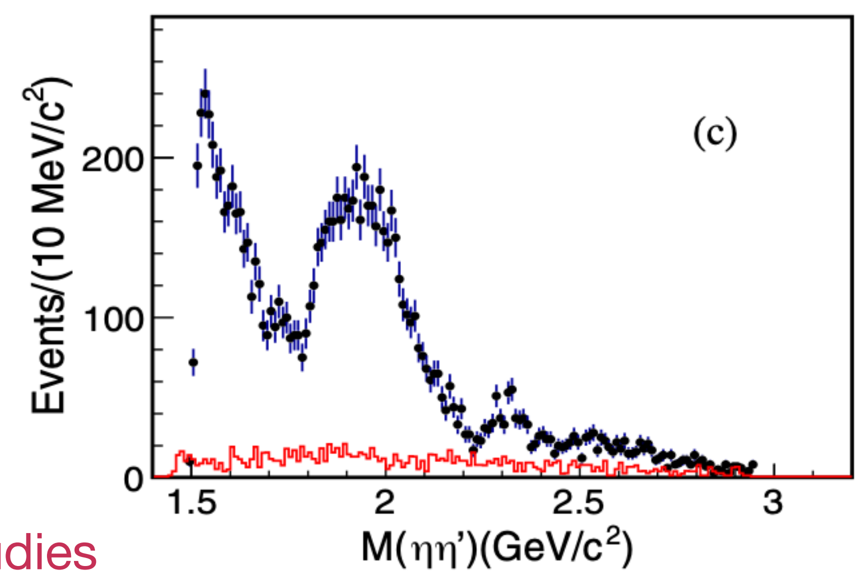
PRD 86 (2012) 052002

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

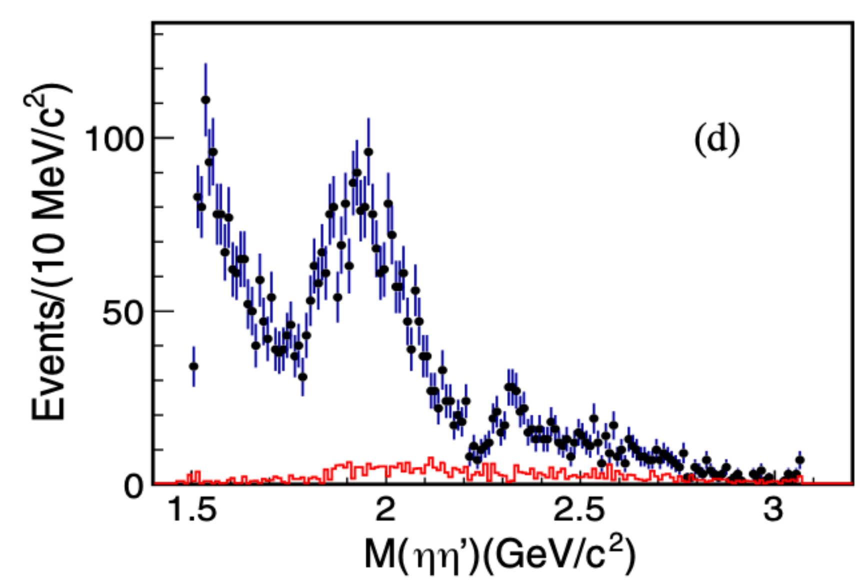
PRL 129, 19, 192002 (2022)
PRD 106, 7, 072012 (2022)

- PWA of $J/\psi \to \gamma\eta\eta'$ using 10 Billion J/ψ events
- Veto ϕ in $\gamma\eta$ system
- 15000 signal events and ∼ 8-13% background events remaining
- All kinematically allowed resonances as listed in the PDG considered
  - $J^{PC} = 0^{++}$, 2^{++} and 4^{++} ($\eta'\eta$ system)
  - $J^{PC} = 1^{+-}$ and 1^{--} ($\gamma\eta^{(\prime)}$ system)

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



$\eta' \to \eta\pi^+\pi^-$

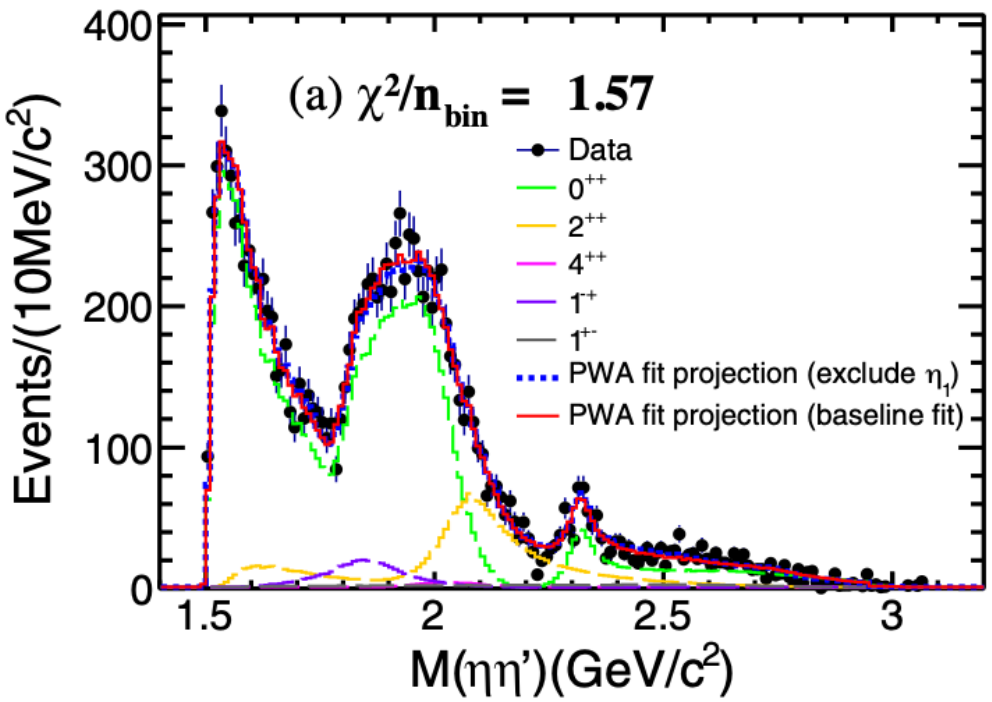


fixed… floated for syst. studies

Decay mode	Resonance	M (MeV/c^2)	Γ (MeV)	M_{PDG} (MeV/c^2)	Γ_{PDG} (MeV)	B.F. ($\times 10^{-5}$)	Sig.
$J/\psi \to \gamma X \to \gamma\eta\eta'$	$f_0(1500)$	1506	112	1506	112	3.05 ± 0.07	$\gg 30\sigma$
	$f_0(1810)$	1795	95	1795	95	0.07 ± 0.01	7.6σ
	$f_0(2020)$	1935 ± 5	266 ± 9	1992	442	1.67 ± 0.07	11.0σ
	$f_0(2100)$	2109 ± 11	253 ± 21	2086	284	0.33 ± 0.03	5.2σ
	$f_0(2330)$	2327 ± 4	44 ± 5	2314	144	0.07 ± 0.01	8.5σ
	$f_2(1565)$	1542	122	1542	122	0.20 ± 0.03	6.2σ
	$f_2(1810)$	1815	197	1815	197	0.37 ± 0.03	7.0σ
	$f_2(2010)$	2022 ± 6	212 ± 8	2011	202	1.36 ± 0.10	8.8σ
	$f_2(2340)$	2345	322	2345	322	0.25 ± 0.04	6.5σ
	$f_4(2050)$	2018	234	2018	234	0.11 ± 0.02	5.6σ
$J/\psi \to \eta' X \to \gamma\eta\eta'$	$h_1(1415)$	1416	90	1416	90	0.14 ± 0.01	10.3σ
	$h_1(1595)$	1584	384	1584	384	0.41 ± 0.04	9.7σ
	$\phi(2170)$	2160	125	2160	125	0.24 ± 0.03	5.6σ
$J/\psi \to \eta X \to \gamma\eta\eta'$	$h_1(1595)$	1584	384	1584	384	0.50 ± 0.03	11.0σ
	$\rho(1700)$	1720	250	1720	250	0.22 ± 0.03	8.8σ

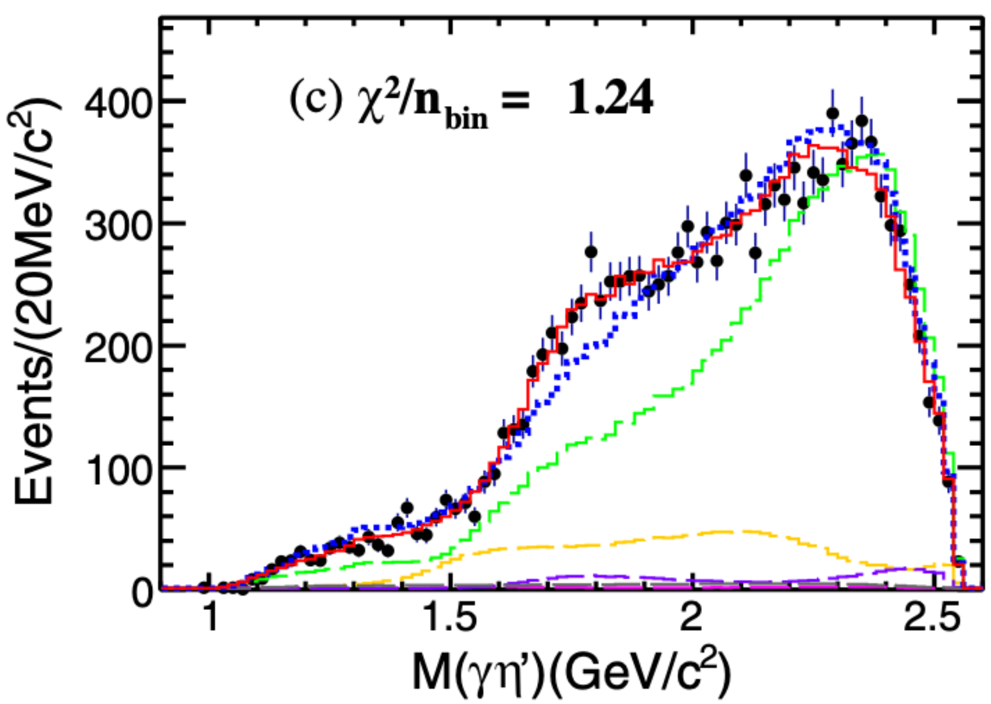
$J/\psi \rightarrow \gamma\eta'\eta$

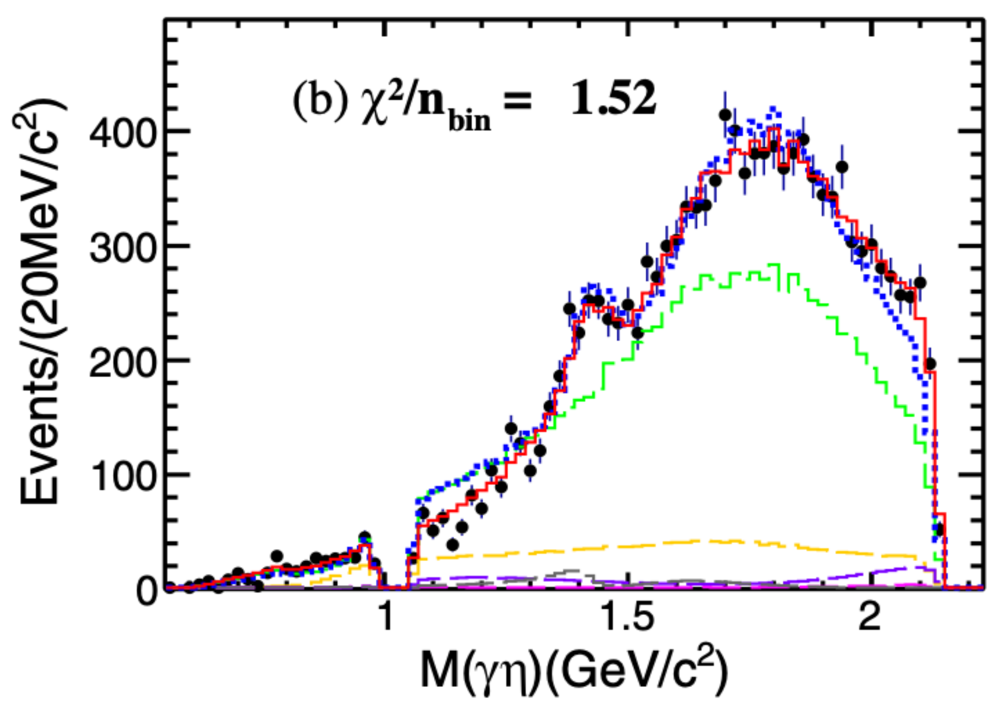
PRL 129, 19, 192002 (2022)
PRD 106, 7, 072012 (2022)



Additionally need of a spin exotic contribution found! ➡ $\eta_1(1855)$

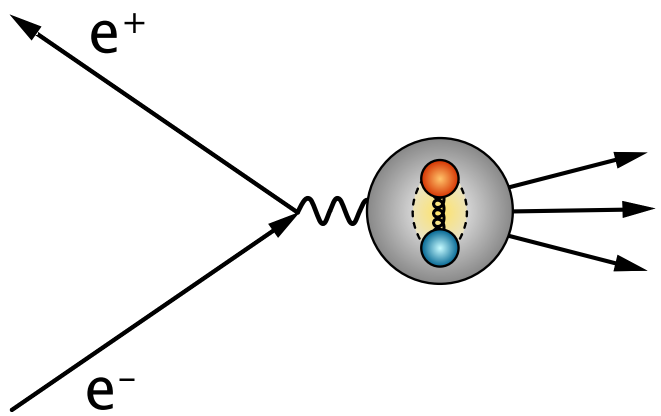
- $M = (1855 \pm 9^{+6}_{-1})\,\mathrm{MeV}/c^2, \Gamma = (199 \pm 18^{+3}_{-8})\,\mathrm{MeV}$
- May be the isoscalar partner of the $\pi_1(1600)$
- Further studies needed!
- Additional decay channels need to be investigated to improve the PWA model



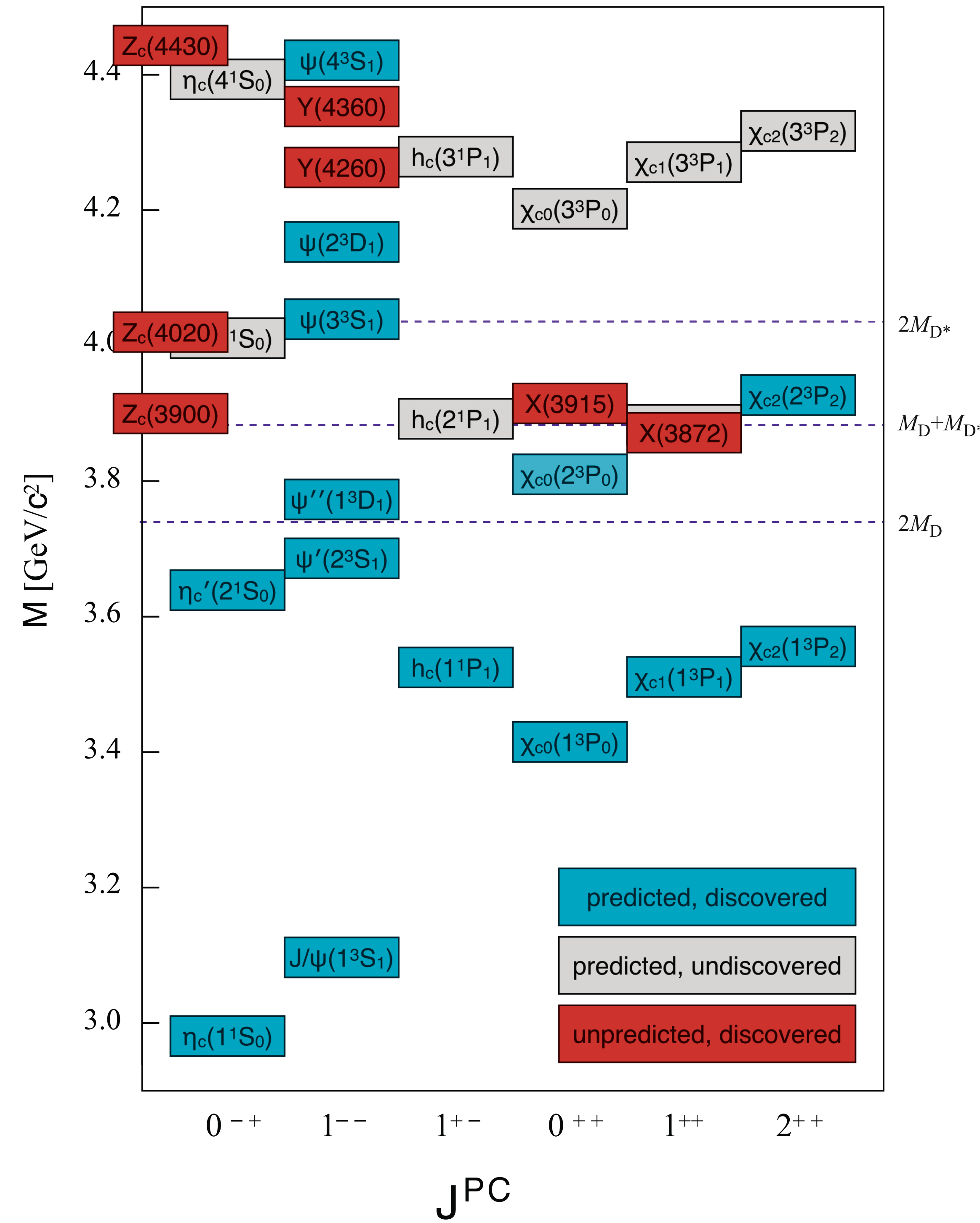


Charmonium Sector

- Charmonia with vector q.n. can be directly created at e^+e^-colliders

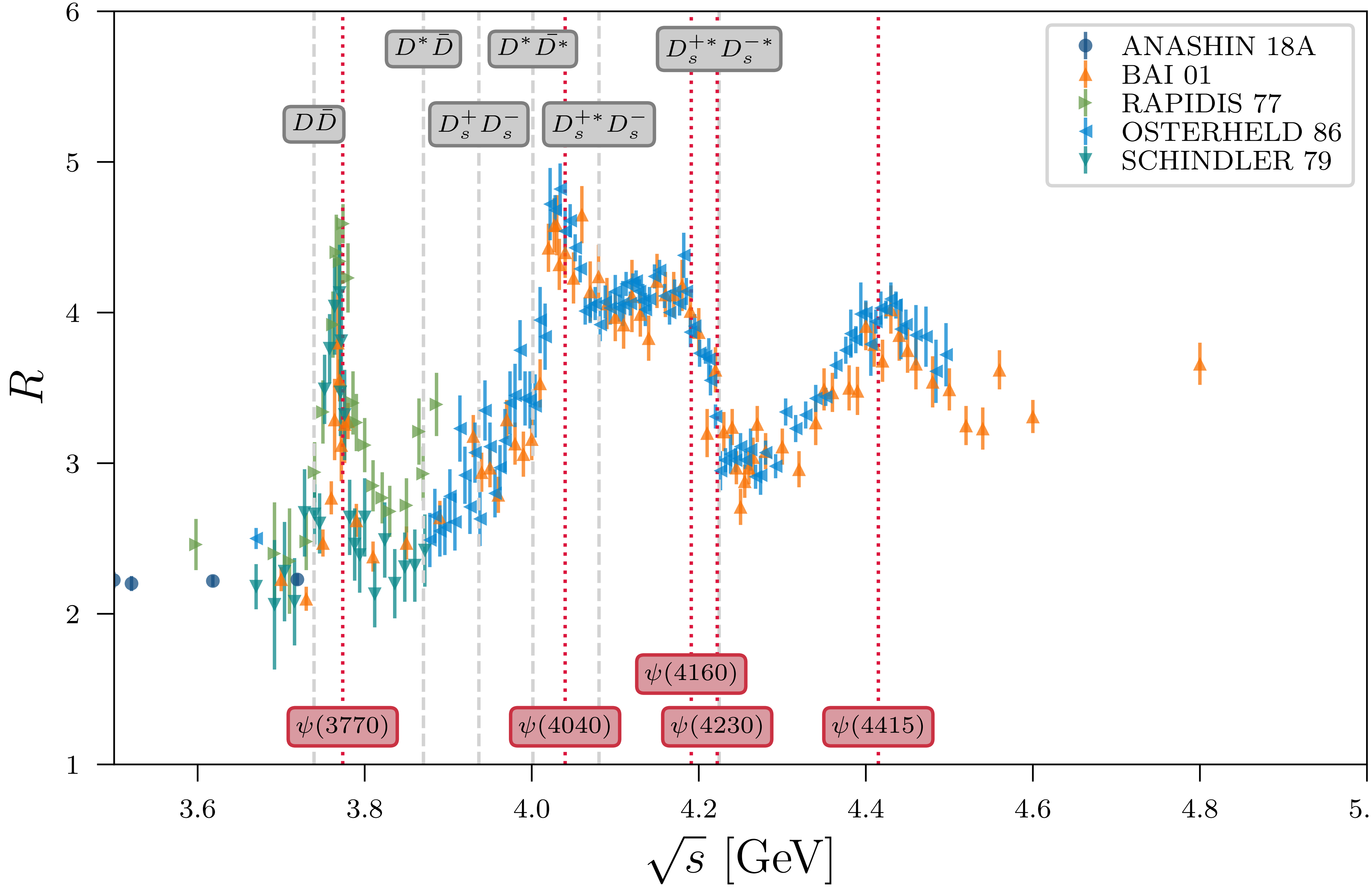


- Other q.n. can only be accessed by sequential decays which limits the statistics

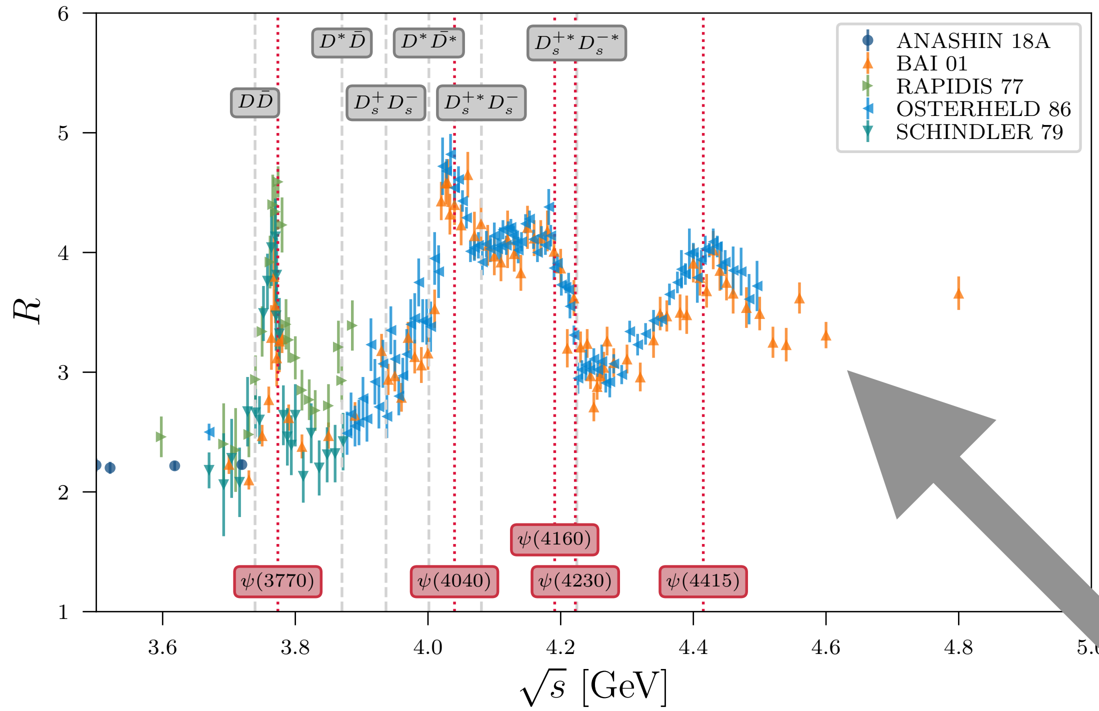


- Besides expected states, additional „unconventional“ states where observed!

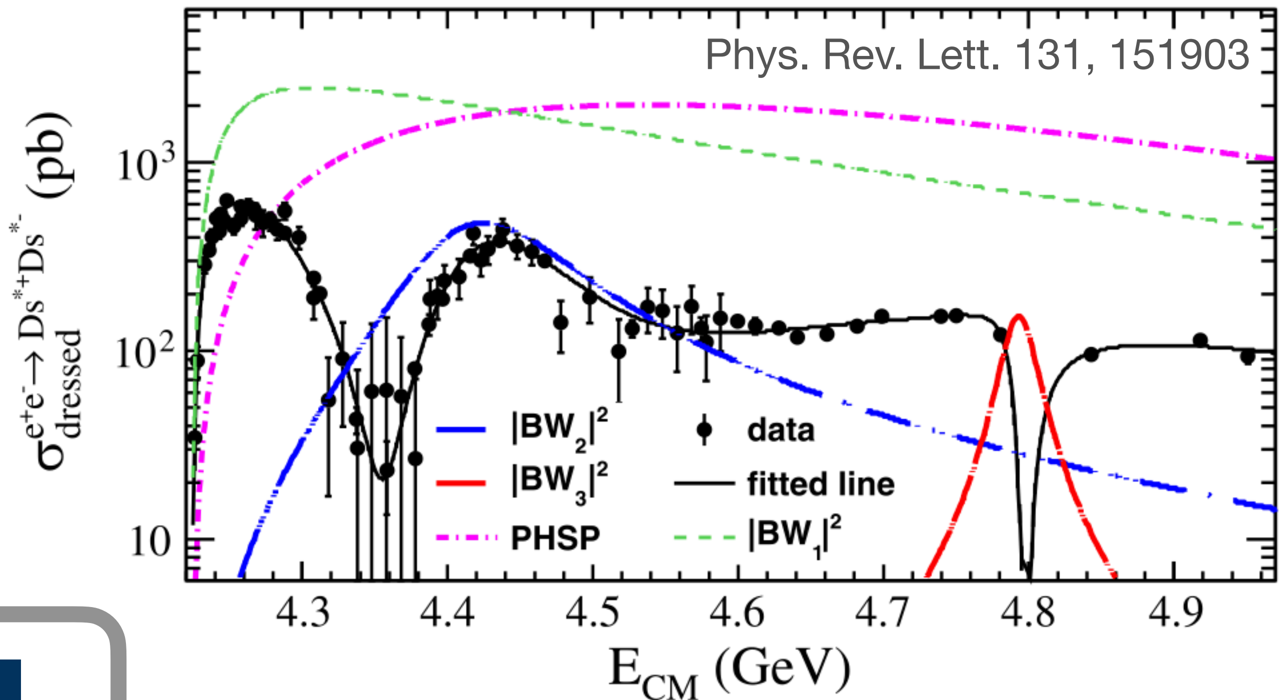
Vector Charmonia



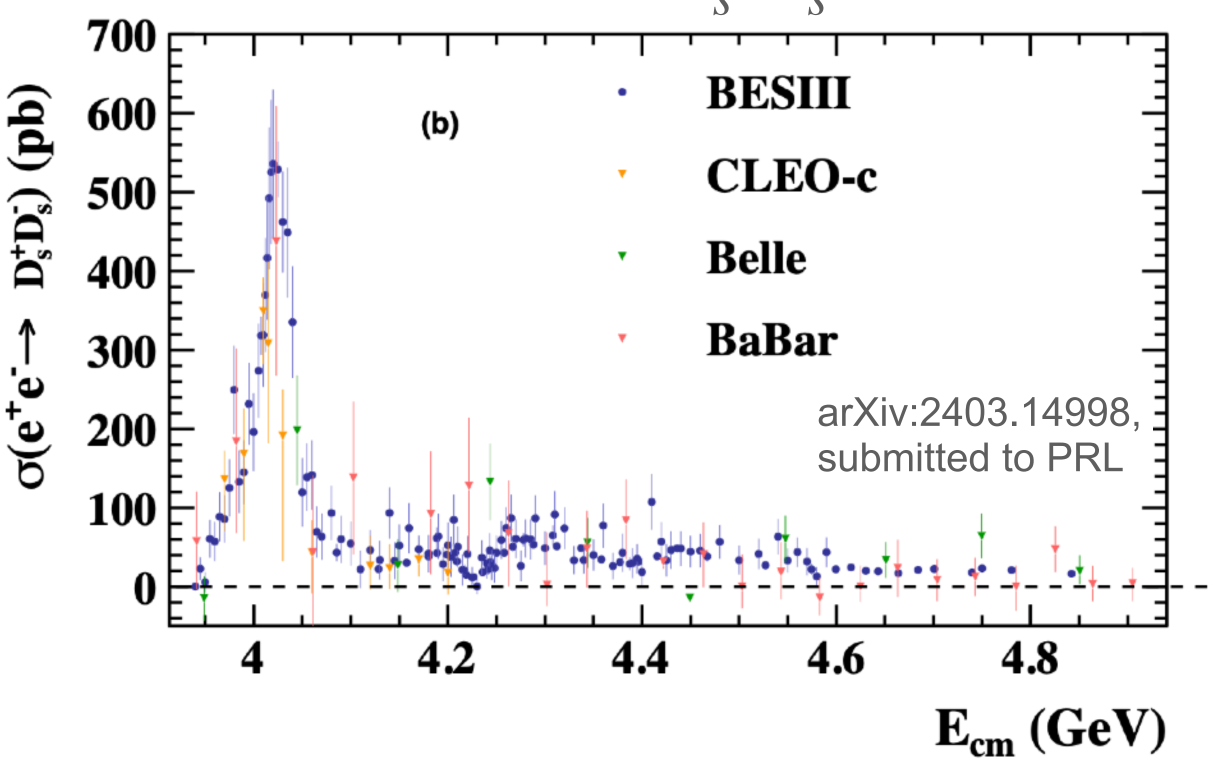
Vector Charmonia



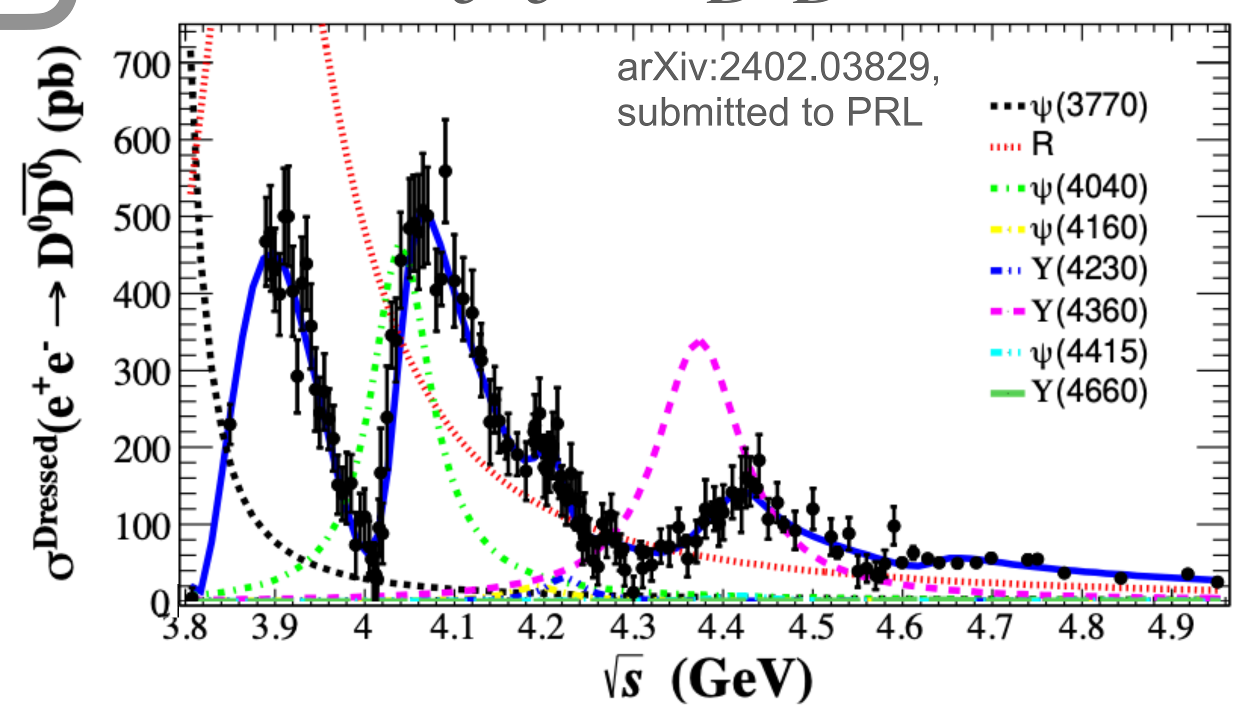
$e^+e^- \to D_s^{+*}D_s^{-*}$



$e^+e^- \to D_s^+D_s^-$



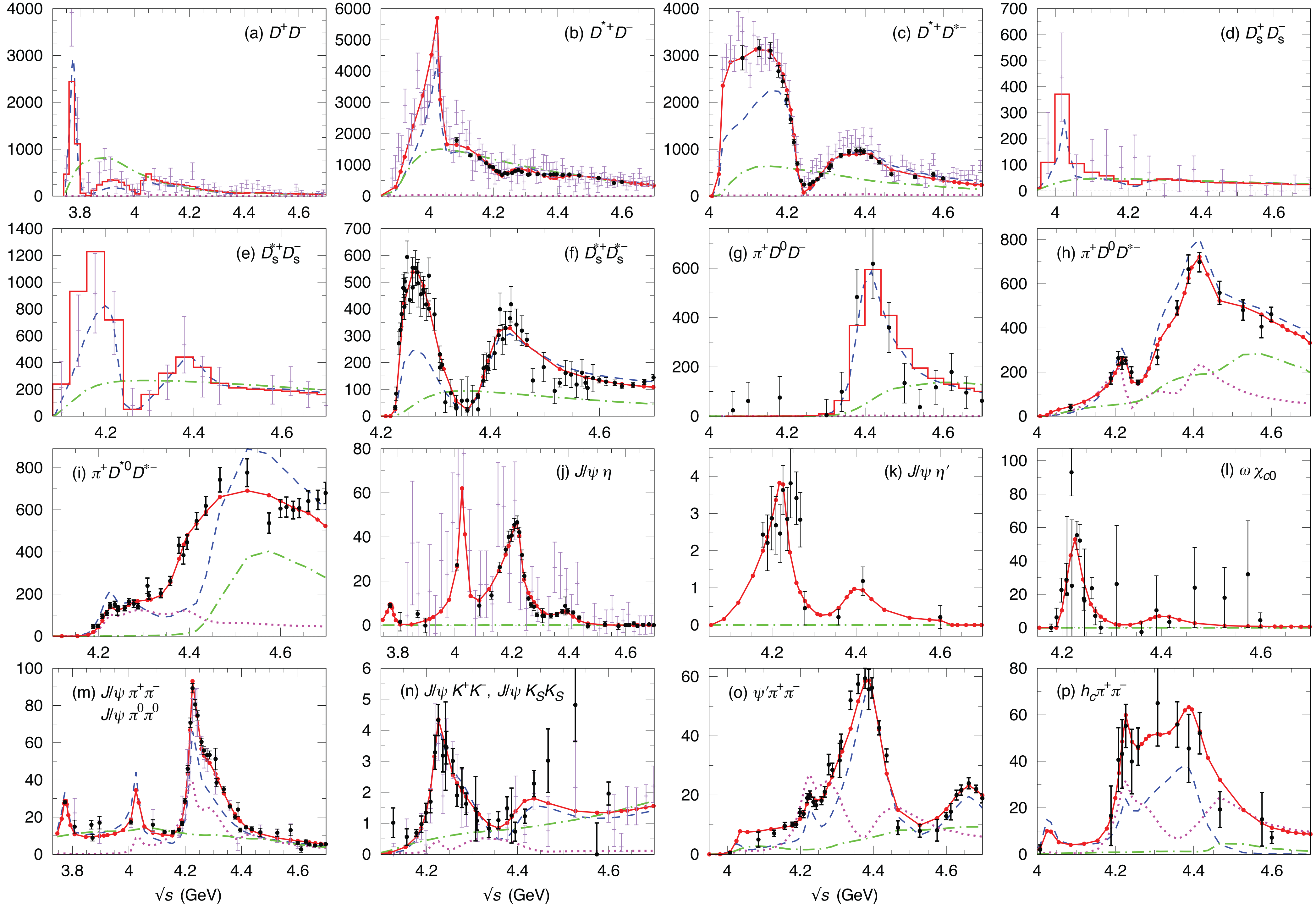
$e^+e^- \to D^0\overline{D^0}$



A first Step Towards a Global Description

- Combined fit to 19 BESIII and Belle cross section results

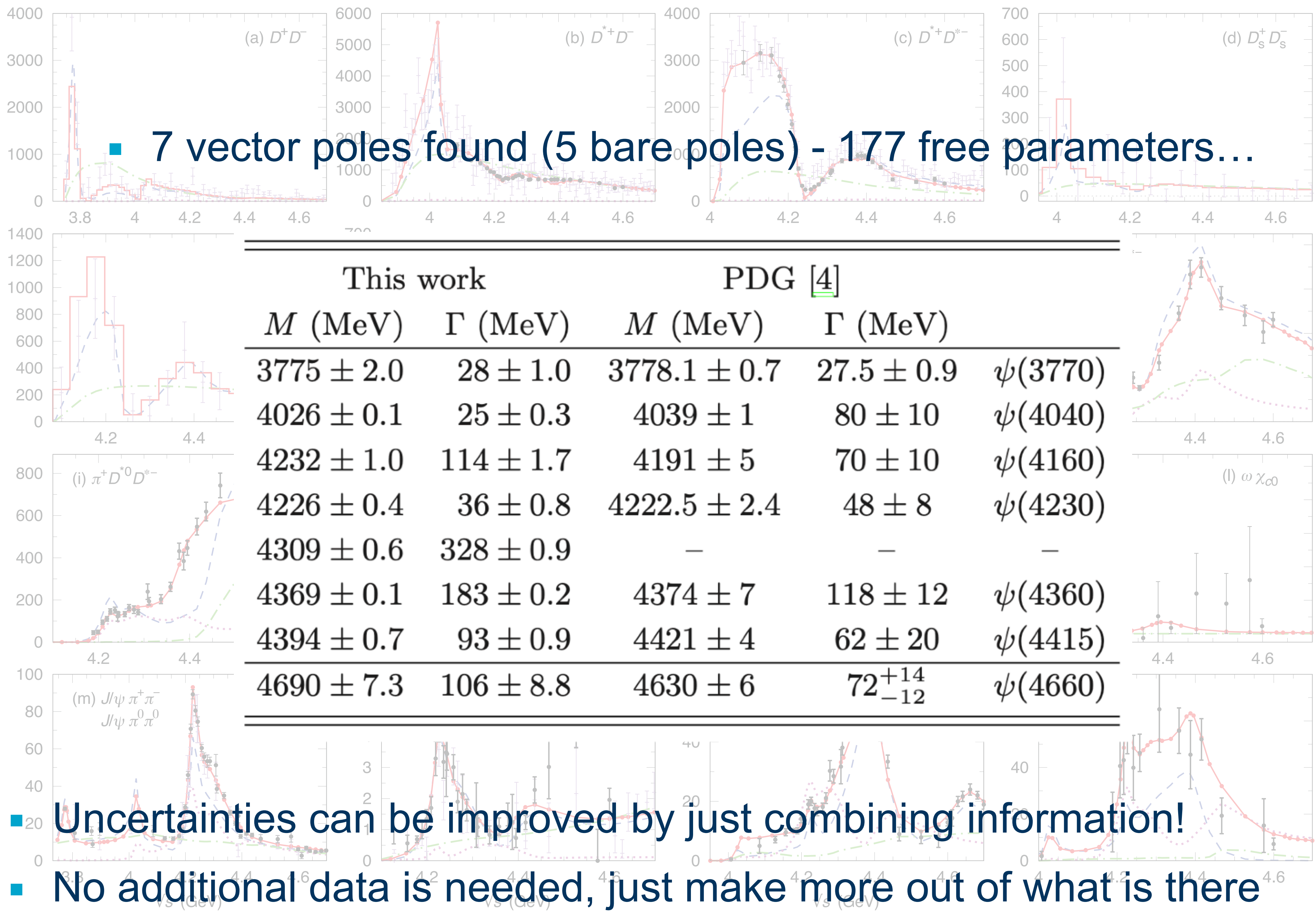
arXiv:2312.17658



A first Step Towards a Global Description

arXiv:2312.17658

- Combined fit to 19 BESIII and Belle cross section results



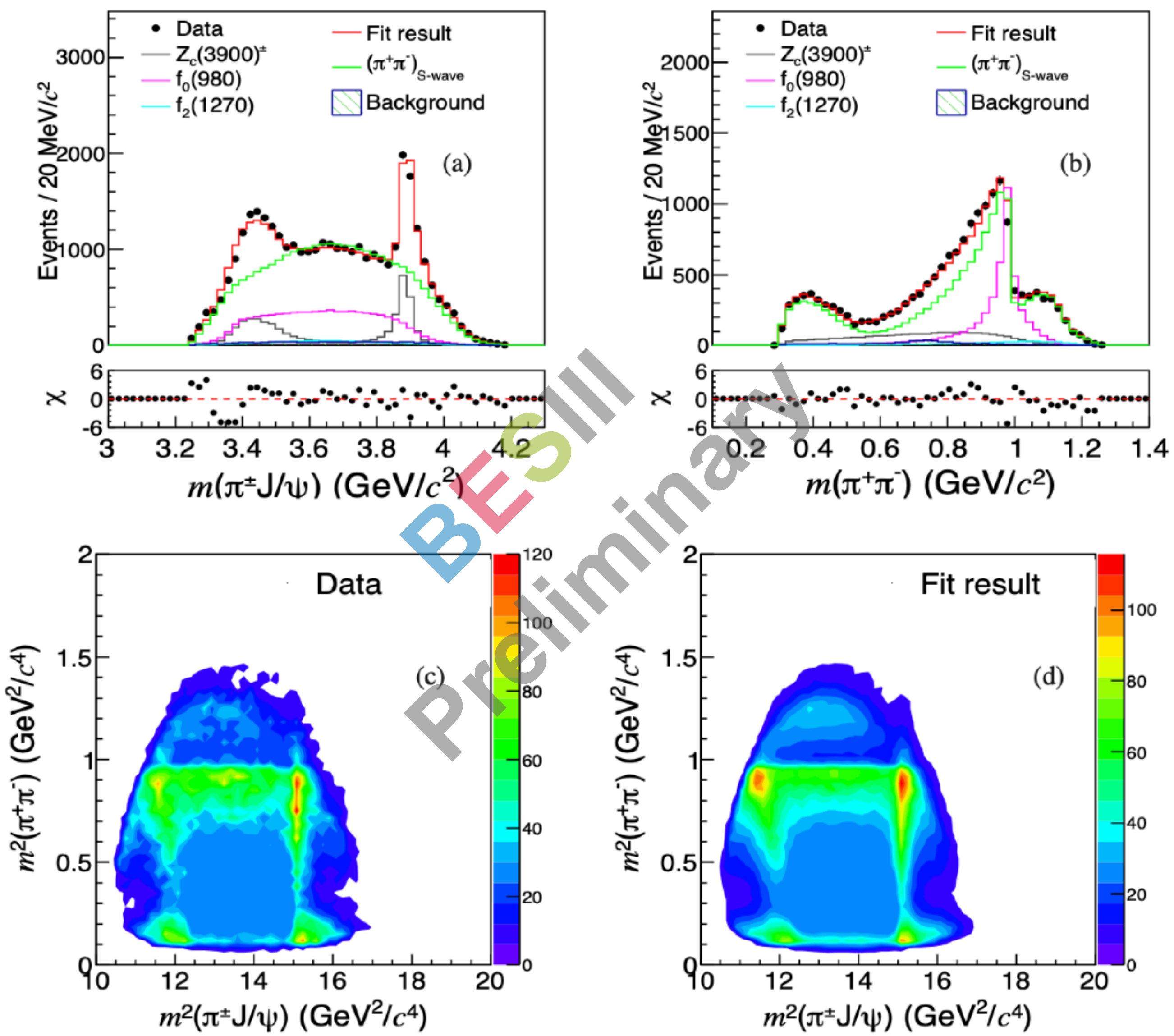
- 7 vector poles found (5 bare poles) - 177 free parameters…

This work		PDG [4]		
M (MeV)	Γ (MeV)	M (MeV)	Γ (MeV)	
3775 ± 2.0	28 ± 1.0	3778.1 ± 0.7	27.5 ± 0.9	$\psi(3770)$
4026 ± 0.1	25 ± 0.3	4039 ± 1	80 ± 10	$\psi(4040)$
4232 ± 1.0	114 ± 1.7	4191 ± 5	70 ± 10	$\psi(4160)$
4226 ± 0.4	36 ± 0.8	4222.5 ± 2.4	48 ± 8	$\psi(4230)$
4309 ± 0.6	328 ± 0.9	–	–	–
4369 ± 0.1	183 ± 0.2	4374 ± 7	118 ± 12	$\psi(4360)$
4394 ± 0.7	93 ± 0.9	4421 ± 4	62 ± 20	$\psi(4415)$
4690 ± 7.3	106 ± 8.8	4630 ± 6	72^{+14}_{-12}	$\psi(4660)$

- Uncertainties can be improved by just combining information!
- No additional data is needed, just make more out of what is there

News on the $Z_c(3900)$

- New results based using 12 fb-1 at 17 energies between 4.13 and 4.36 GeV
- PWA performed in helicity formalism, 2 models used:
- (I) $f_0(980)$ with Flatté, $\sigma(500)$, $f_0(1370)$, $f_2(1270)$ and $Z_c(3900)$ as Breit-Wigner PLB 607, 243 (2005)
- (II) $f_0(980)$, $\sigma(500)$, $f_0(1370)$ using K-matrix, $f_2(1270)$ and $Z_c(3900)$ as Breit-Wigner EPJA 16, 229 (2003)



sum of all energy points

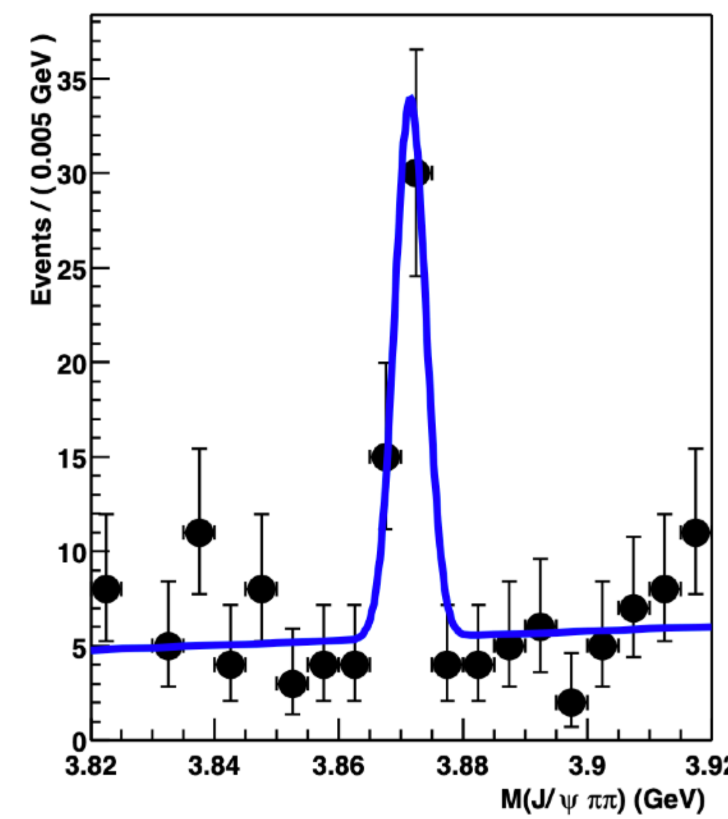
- Mass and width of $Z_c(3900)$ determined via simultaneous fit

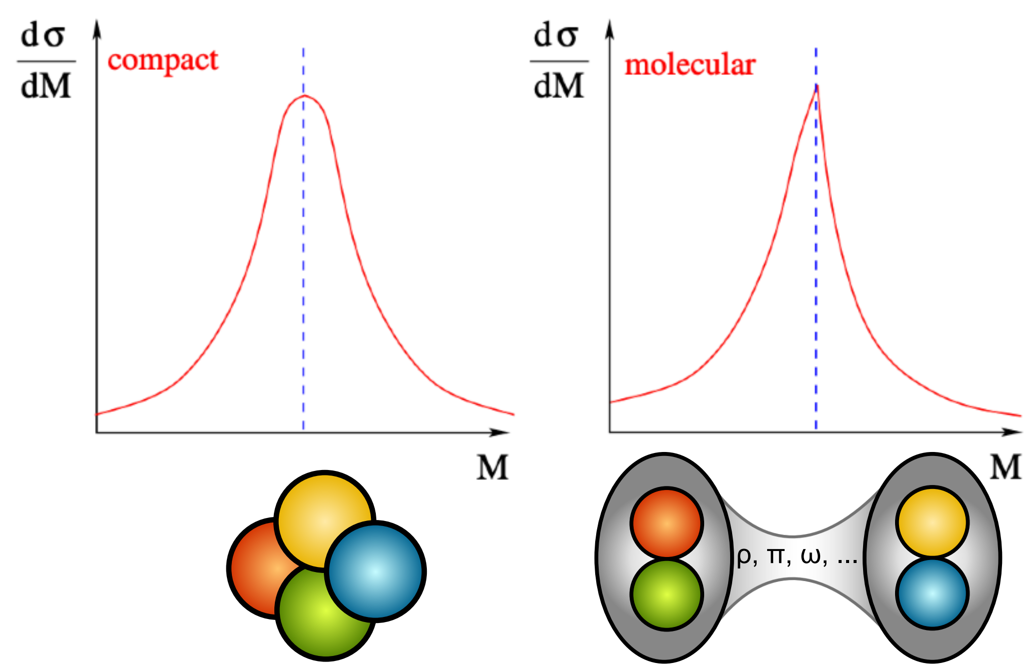
Sample	M (MeV/c^2)	Γ (MeV)
$4.1567 - 4.1989$	3883.5 ± 1.6	38.6 ± 3.6
$4.2091 - 4.2357$	3884.0 ± 1.0	37.8 ± 1.6
$4.2438 - 4.2776$	3884.9 ± 1.8	34.2 ± 3.3
$4.2866 - 4.3583$	3890.0 ± 2.3	36.1 ± 4.2
Average	$3884.6 \pm 0.7 \pm 3.3$	$37.2 \pm 1.3 \pm 6.6$

The Story of χ_{c1}(3872)/X(3872)

- Very narrow 1^{++} state, sitting just at the $D^0\bar{D}^{*0}$ threshold
- Well established production channel: $\psi(4230) \rightarrow \gamma\chi_{c1}(3872)$
  - ➡ Precision studies possible!
- Seen in various production channels by now: B/Λ_b decays, pp, $\mathrm{Pb\,Pb}$, e^+e^-
- ... and in various decay modes: $J/\psi(\pi^+\pi^-)\rho$, $D^0\bar{D}^{*0}$, $J/\psi\gamma$ $\psi(2S)\gamma$, $\chi_{c1}\pi^0$, …
- Ispospin violating decay is enhanced by a factor of 5 compared to „ordinary“ charmonia
- Sensitivity to underlying lineshape is washed out by detector resolution

PRL 91, 262001 (2003)





The Story of $\chi_{c1}(3872)/X(3872)$

- Very narrow 1^{++} state, sitting just at the $D^0\bar{D}^{*0}$ threshold
- Well established production channel: $\psi(4230) \to \gamma\chi_{c1}(3872)$
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- Seen in various production channels by now: B/Λ_b decays, pp, $\mathrm{Pb\,Pb}$, e^+e^-
- ... and in various decay modes: $J/\psi(\pi^+\pi^-)\rho$, $D^0\bar{D}^{*0}$, $J/\psi\gamma$ $\psi(2S)\gamma$, $\chi_{c1}\pi^0$, …
- Isospin violating decay is enhanced by a factor of 5 compared to „ordinary“ charmonia
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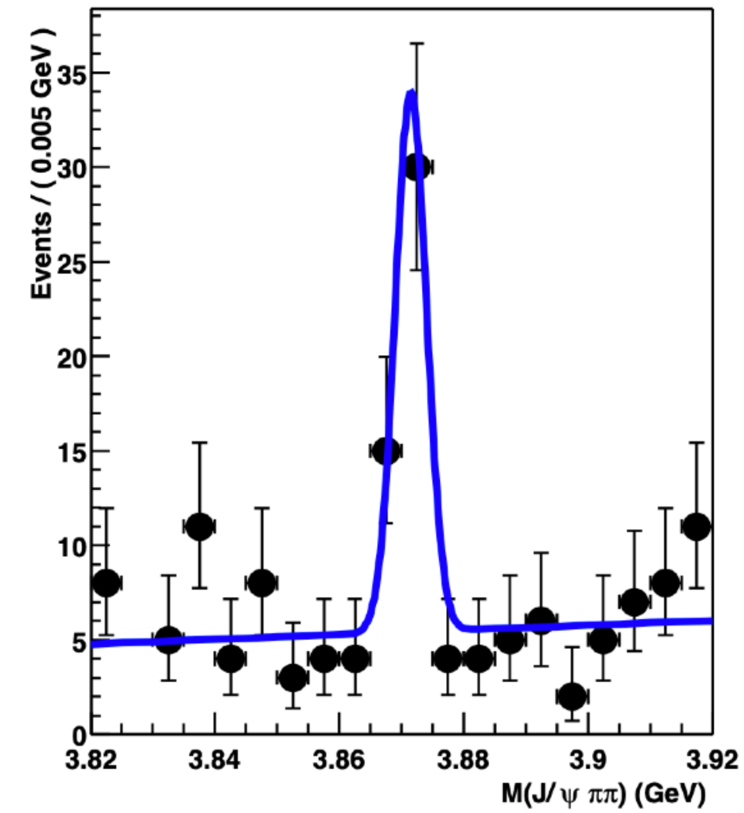
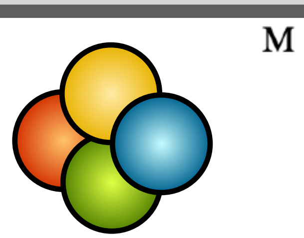
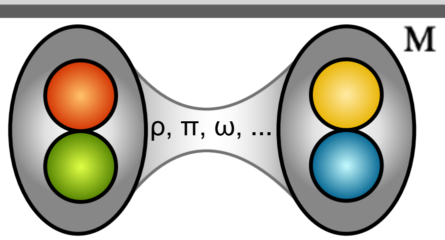
PRL 91, 262001 (2003)



- If we want to clarify this we need << MeV resolution! No detector can do this.
- Similar structures seen in $D^0D^0\pi^+$: $T_{cc}(3875)$
- How are they related? Is it the same underlying physics?

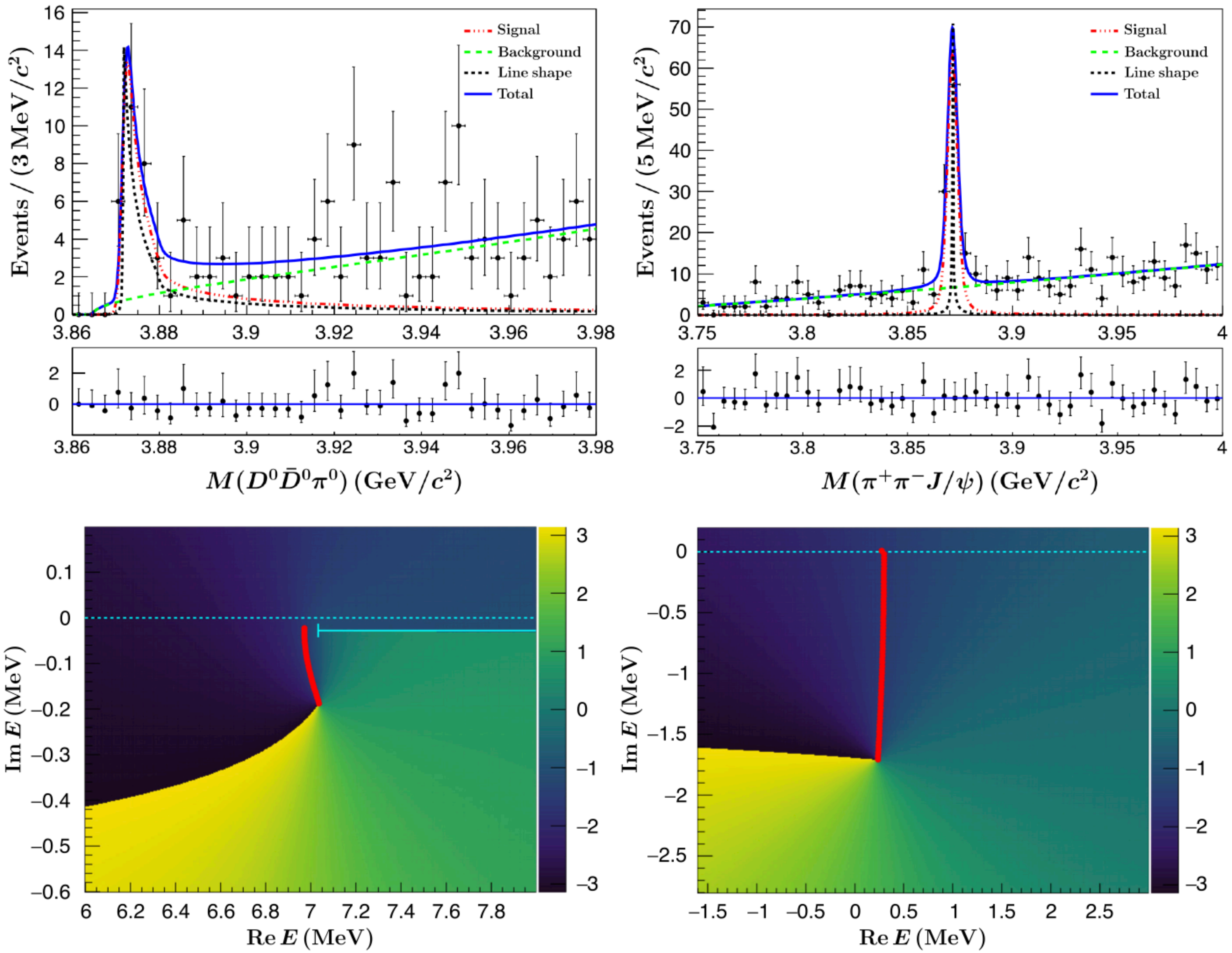




Coupled Channel Fit to $\chi_{c1}(3872)$

PRL 132 (2024) 15, 151903

- Simultaneous fit to $D^0\bar{D}^0\pi^0$ and $\pi^+\pi^- J/\psi$



(a) Sheet I: $E_{\mathrm{I}} = 7.04 - 0.19i$ MeV

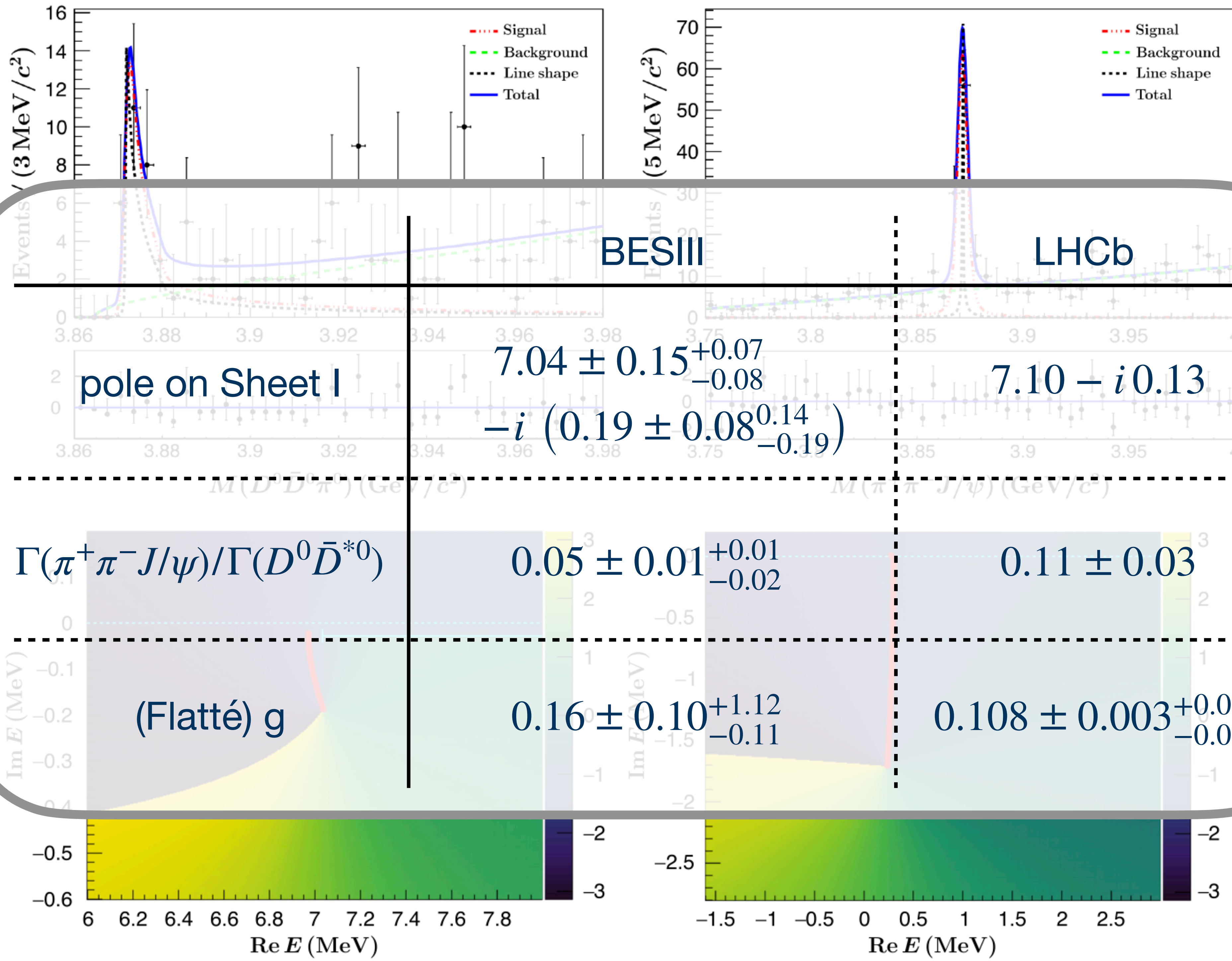
(b) Sheet II: $E_{\mathrm{II}} = 0.26 - 1.71i$ MeV

Coupled Channel Fit to $\chi_{c1}(3872)$

PRL 132 (2024) 15, 151903

- Simultaneous fit to $D^0\bar{D}^0\pi^0$ and $\pi^+\pi^-J/\psi$

	BESIII	LHCb
pole on Sheet I	$7.04 \pm 0.15^{+0.07}_{-0.08}$ $-i\left(0.19 \pm 0.08^{0.14}_{-0.19}\right)$	$7.10 - i\,0.13$
$\Gamma(\pi^+\pi^-J/\psi)/\Gamma(D^0\bar{D}^{*0})$	$0.05 \pm 0.01^{+0.01}_{-0.02}$	0.11 ± 0.03
(Flatté) g	$0.16 \pm 0.10^{+1.12}_{-0.11}$	$0.108 \pm 0.003^{+0.005}_{-0.006}$



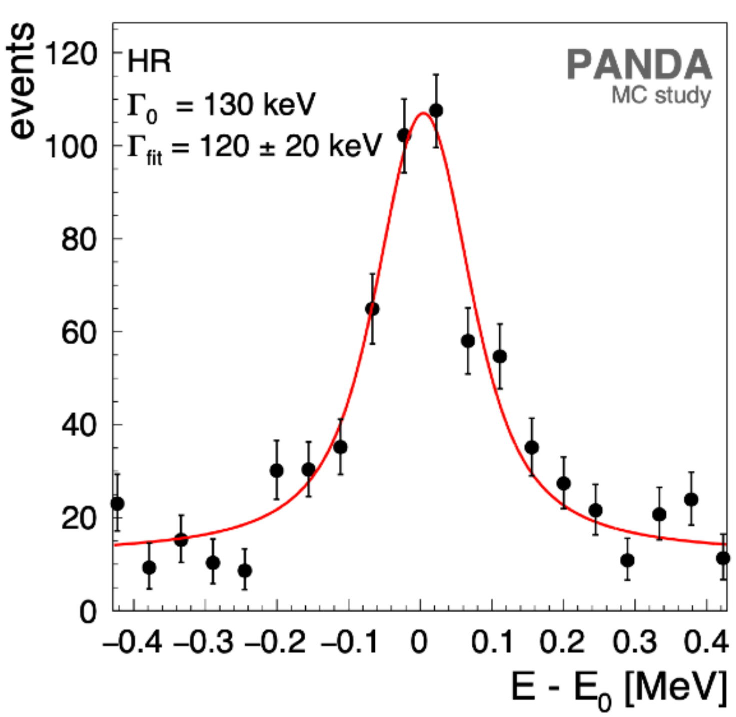
(a) Sheet I: $E_{\rm I} = 7.04 - 0.19i$ MeV (b) Sheet II: $E_{\rm II} = 0.26 - 1.71i$ MeV

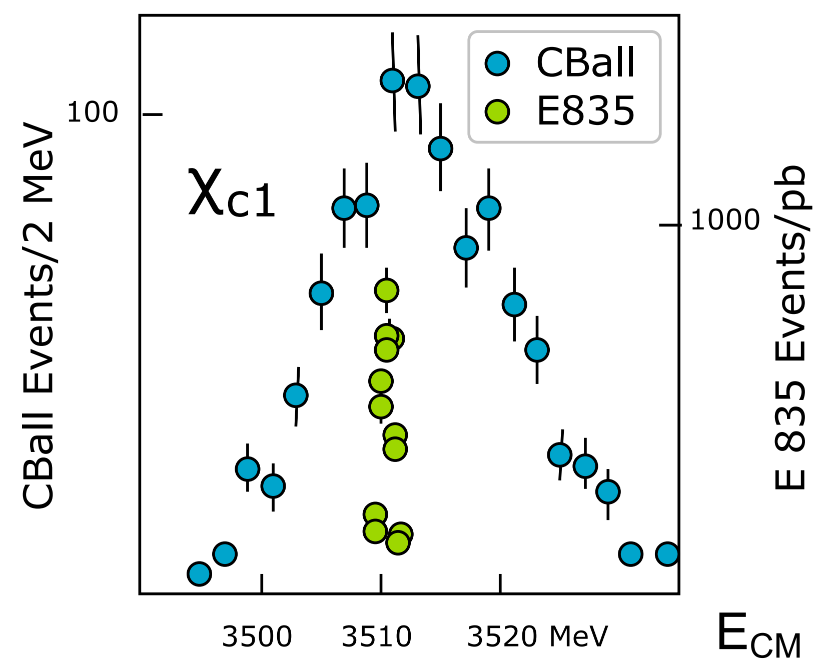
Line Shape Scans at $\bar{\text{P}}$ANDA

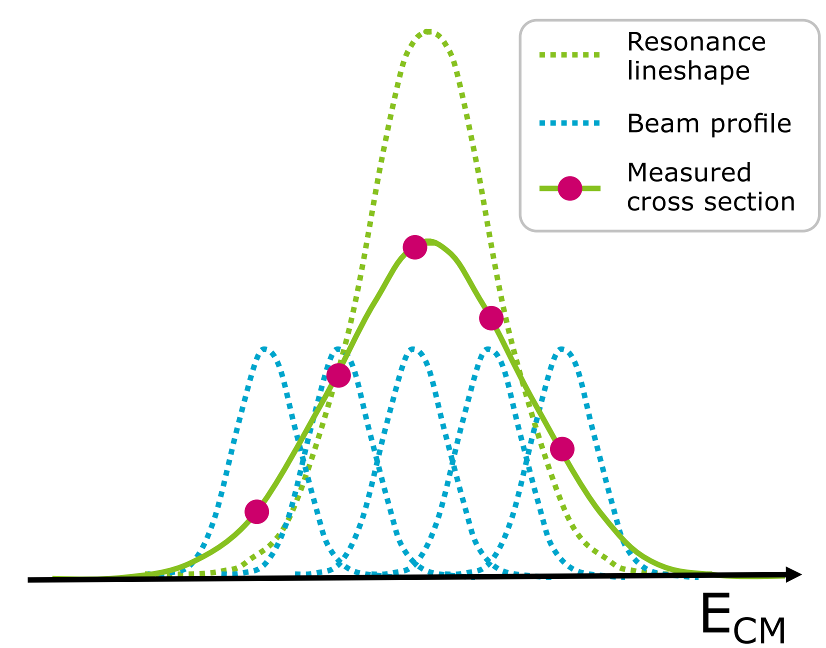
- Measure the lineshape with high precision by scanning the resonance in production
- **Line shape resolution is only limited by the beam resolution, not the detector resolution here!**
- Analysis performed for 20 energy points around nominal mass
- In sensitivity studies able to distinguish the two scenarios

➡ With the $\bar{\text{P}}$ANDA setup this corresponds to only about a month of data taking!

➡ In $\bar{p}p$ annihilation almost all Q.N. can be produced directly!





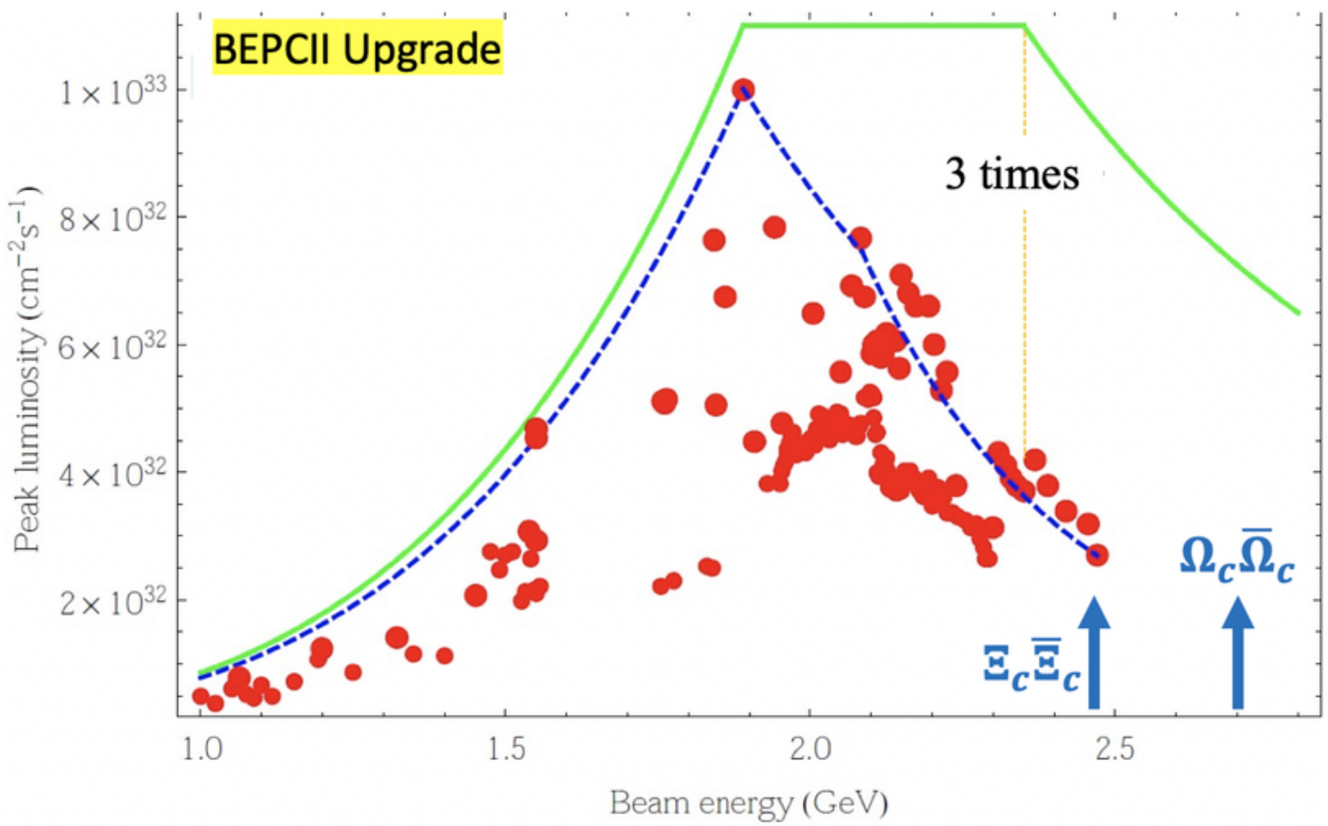


Summary

- Although light mesons are studied for decades, there are still many open questions
- The non-perturbative regime of QCD challenges theory and experiment!
- This affects also other sectors as CP violation!
- Sophisticated line shape models should be used whenever possible
- Different experiments and theory need to collaborate to solve this
- Coupled channel analyses seem to be a good tool to disentangle crowded spectra
- Work closer together in the community - common effort is needed to answer fundamental questions!
- BESIII is very much open to experiment-theory collaboration!

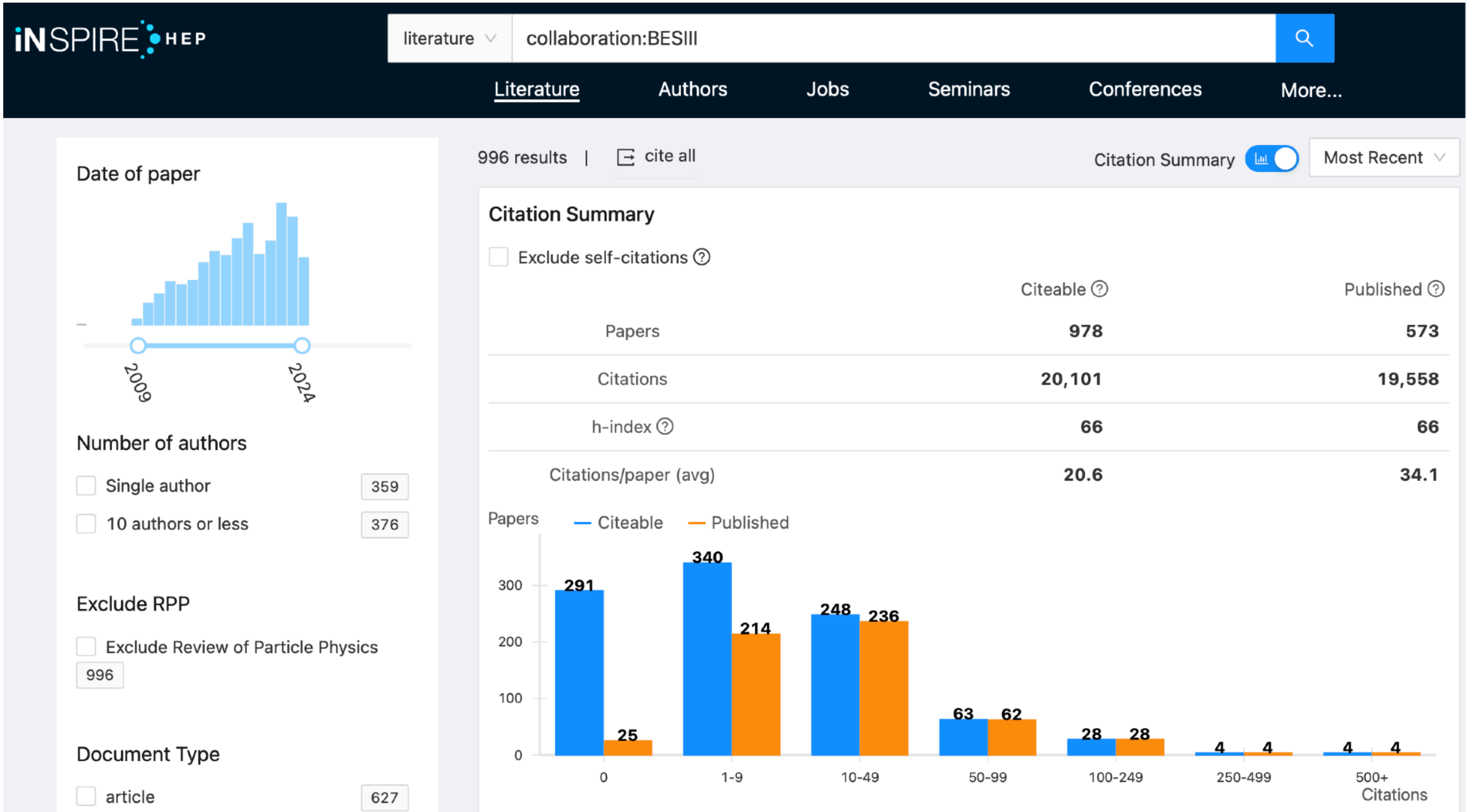
Outlook

- Upgrade of the accelerator BEPCII:



  - Center-of-mass energies up to 5.6 GeV
  - Charmed baryon thresholds in reach: $e^+e^- \rightarrow \Sigma_c\bar{\Sigma}_c, \Xi_c\bar{\Xi}_c, \Omega_c\bar{\Omega}_c$
  - Pentaquarks above above $J/\psi\bar{p}p$ threshold?
  - Historically there where not many facilities studying this energy regime
  - Up to 3x higher luminosities in XYZ region
  - Precision XYZ physics at BESIII including fine energy and lineshape scans tlineshapes

Outlook



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Thank you!

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