Recent results from BESIII experiment: observation of the $Z_{cs}(3985)$ strange four-quark meson

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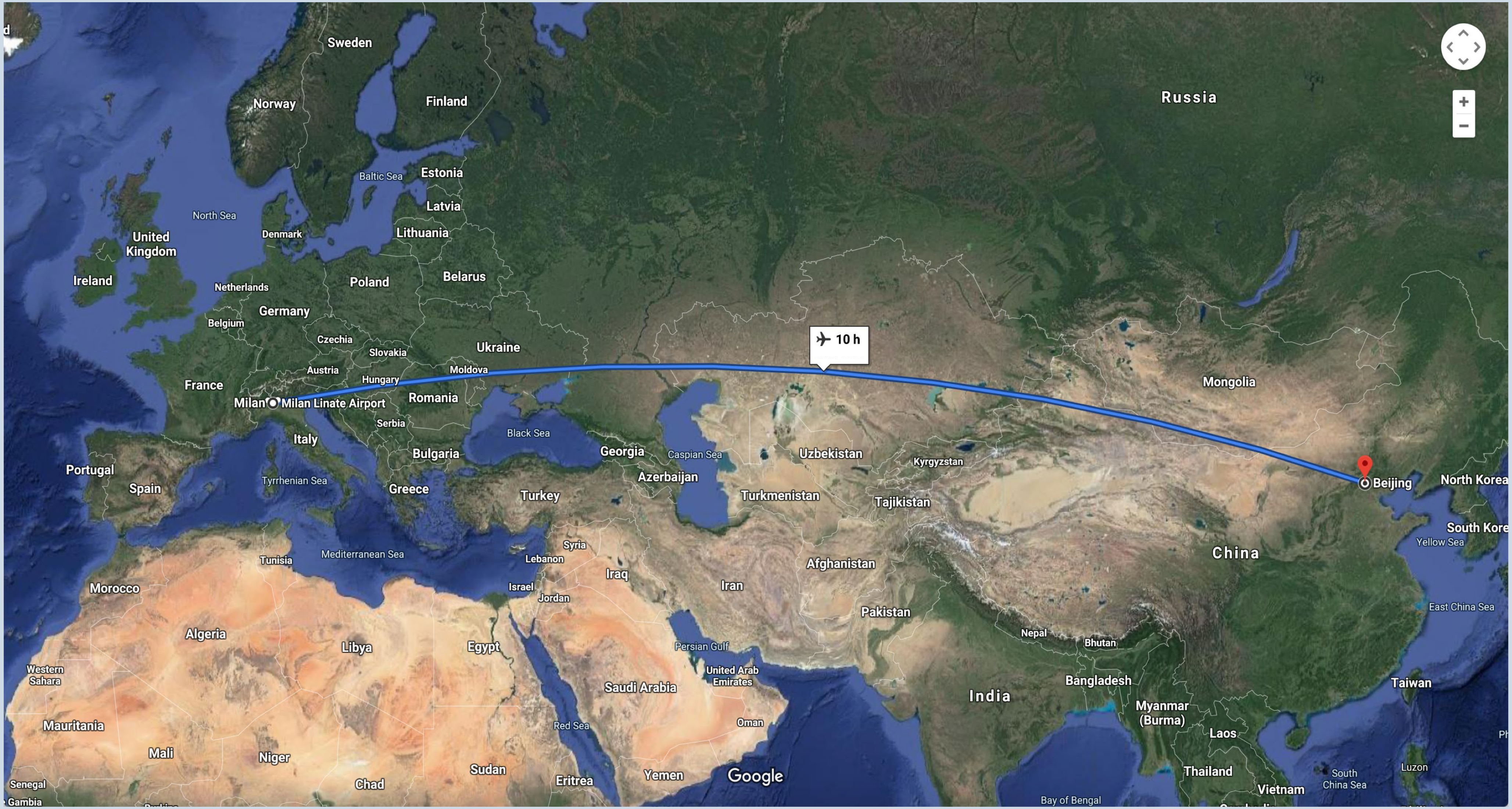
SEZIONE DI TORINO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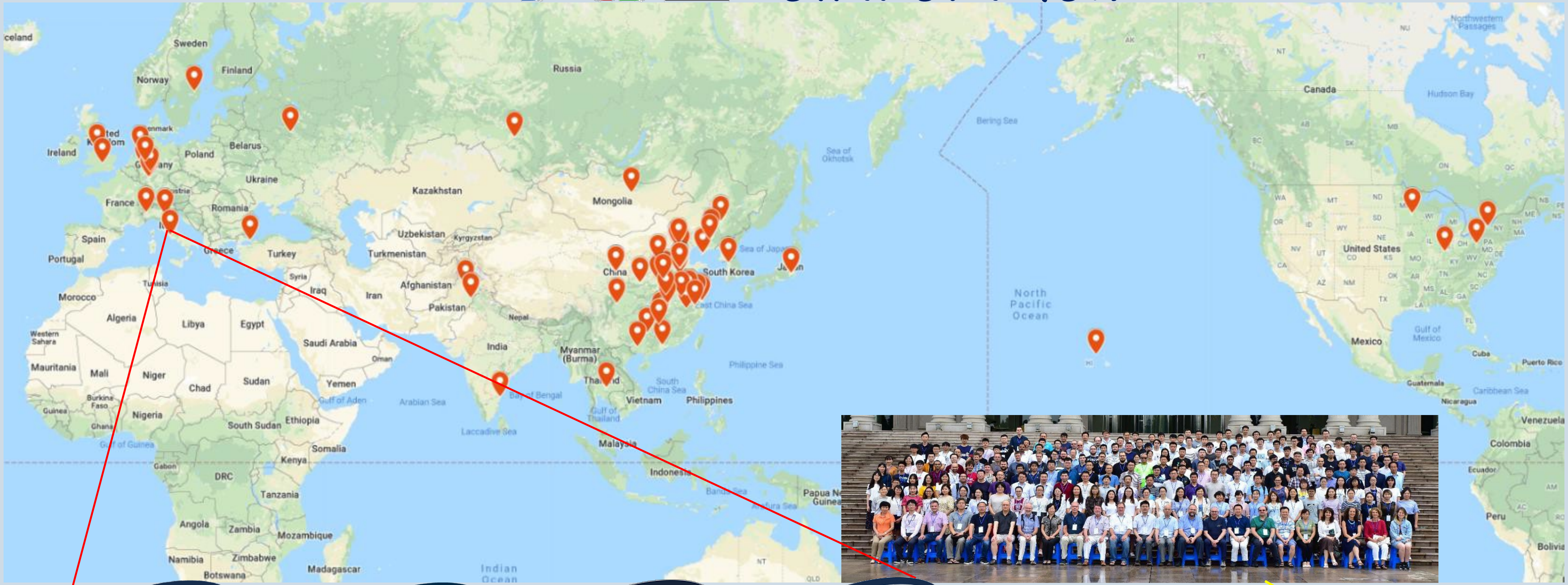
BESIII

BESIII Collaboration



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Sezione di Ferrara

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Sezione di Torino

15 countries, 72 institutions
~500 members

Beijing Electron Positron Collider II

Construction started: 1984

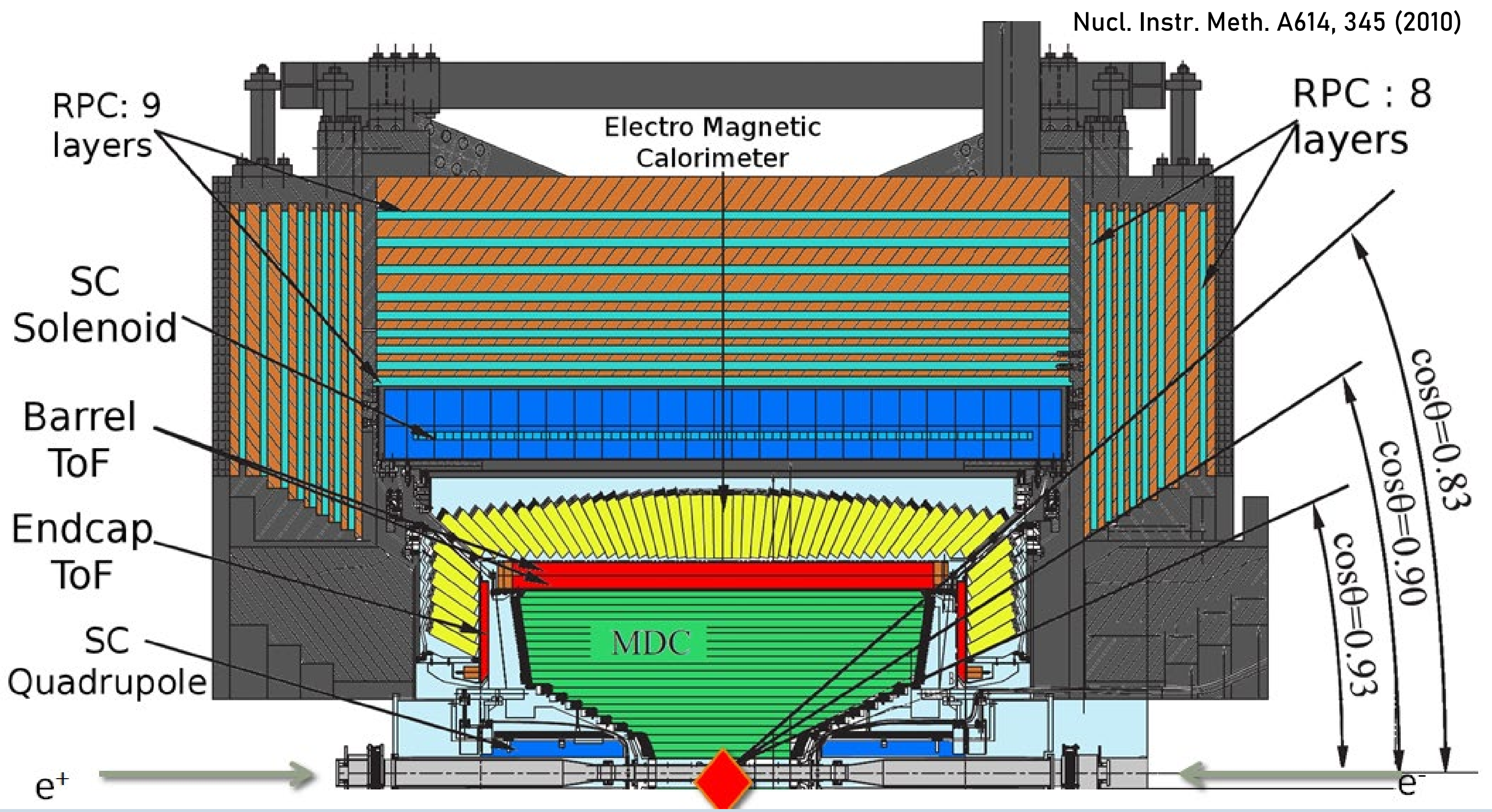
BEPC 1989-2005

L_{peak}=1.0x10^{31} /cm^2s

BEPCII 2008-now

L_{peak}=1.0x10^{33}/cm^2s (April 2016)

E_{cm}: 2 — 5 GeV



Total weight 750 tonnes, ~40,000 readout channels, Data rate: 5 kHz, 50 Mb/s

BESIII is designed to study physics in the tau-charm energy region.
BESIII has collected the J/ψ world largest data sample (10B).

Data taking will continue till 2030 (at least)

MDC, 0.5% at 1 GeV/c
CsI(Tl) calorimeter, 2.5% @ 1 GeV
BTOF, 70 ps / ETOF, 60 ps
dE/dx 6% e^- Bhabha scattering

Physics program

Light hadron
Charmonium
Charm
τ/R/QCD
New physics

1989-2019

- -tests of electroweak interactions with high precision in both the quark and lepton sectors
- -high statistics study of light hadron spectroscopy and decay properties
- -study of the production and decay properties of J/ψ, ψ(2S), ψ(3770) states with large data samples and search for exotic states (glueballs, quark-hybrids, multi-quark states etc.) via charmonium hadronic and radiative decays
- -studies of XYZ states
- -studies of τ-physics
- -precision measurements of QCD and CKM parameters
- -barion form factors measurements via ISR process and via energy scan
- -search for new physics by studying rare and forbidden decays, oscillations, and CP violations in c-hadron and τ -lepton sectors

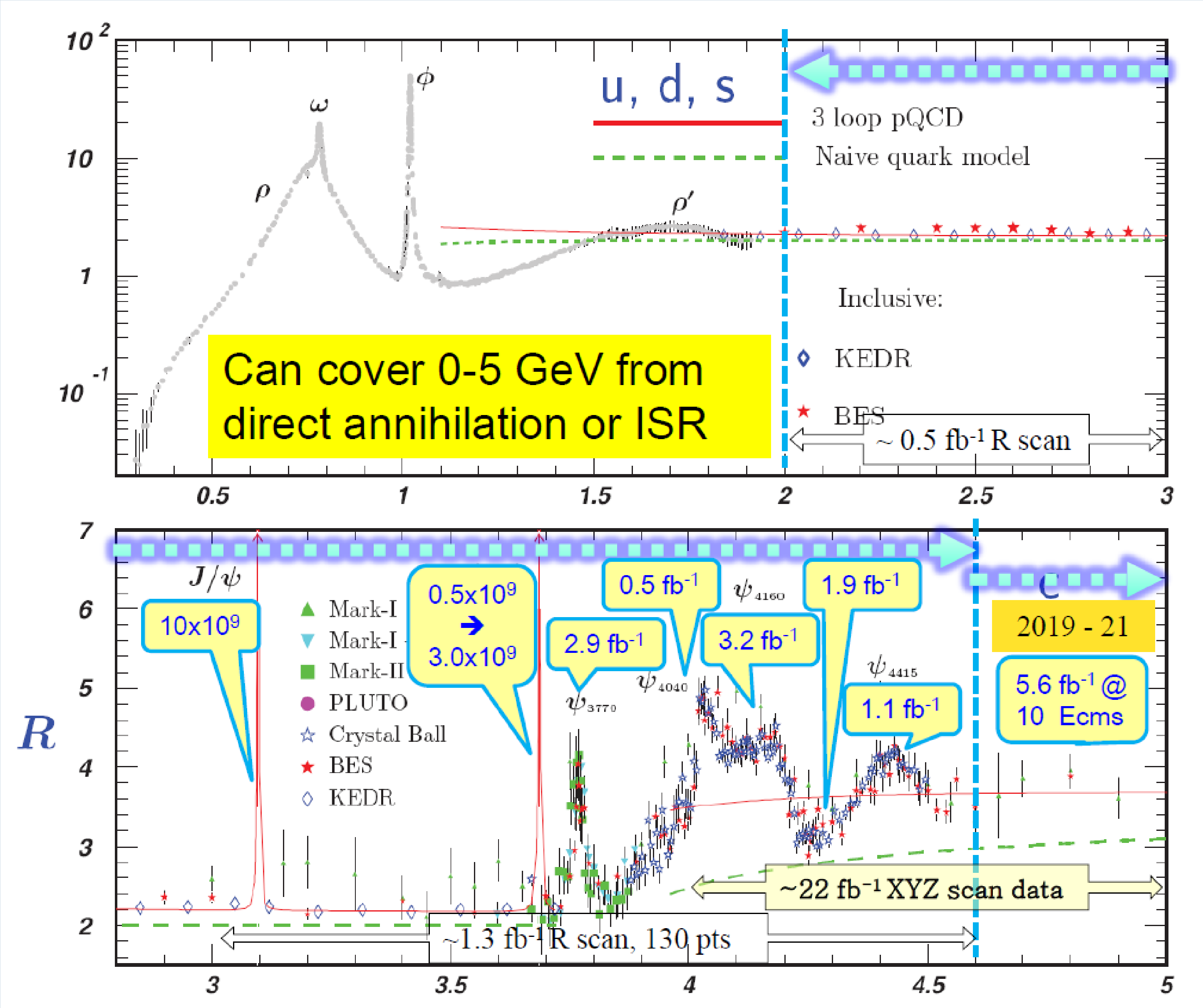
Future physics program

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

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

white paper on future physics program
Chinese Physics C, vol. 44, no. 4, 2020

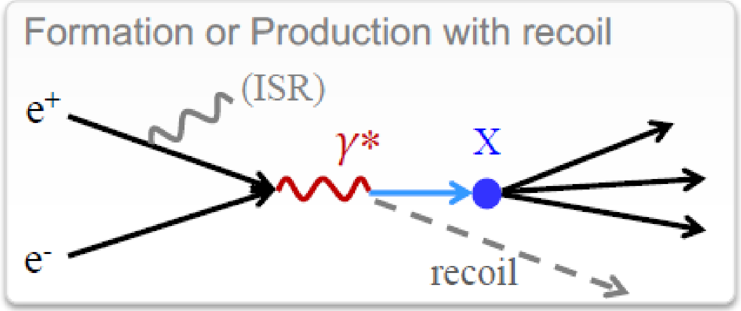
BESIII Data taking



12 years of successful data taking
10B J/ψ events
448M ψ(2S) events

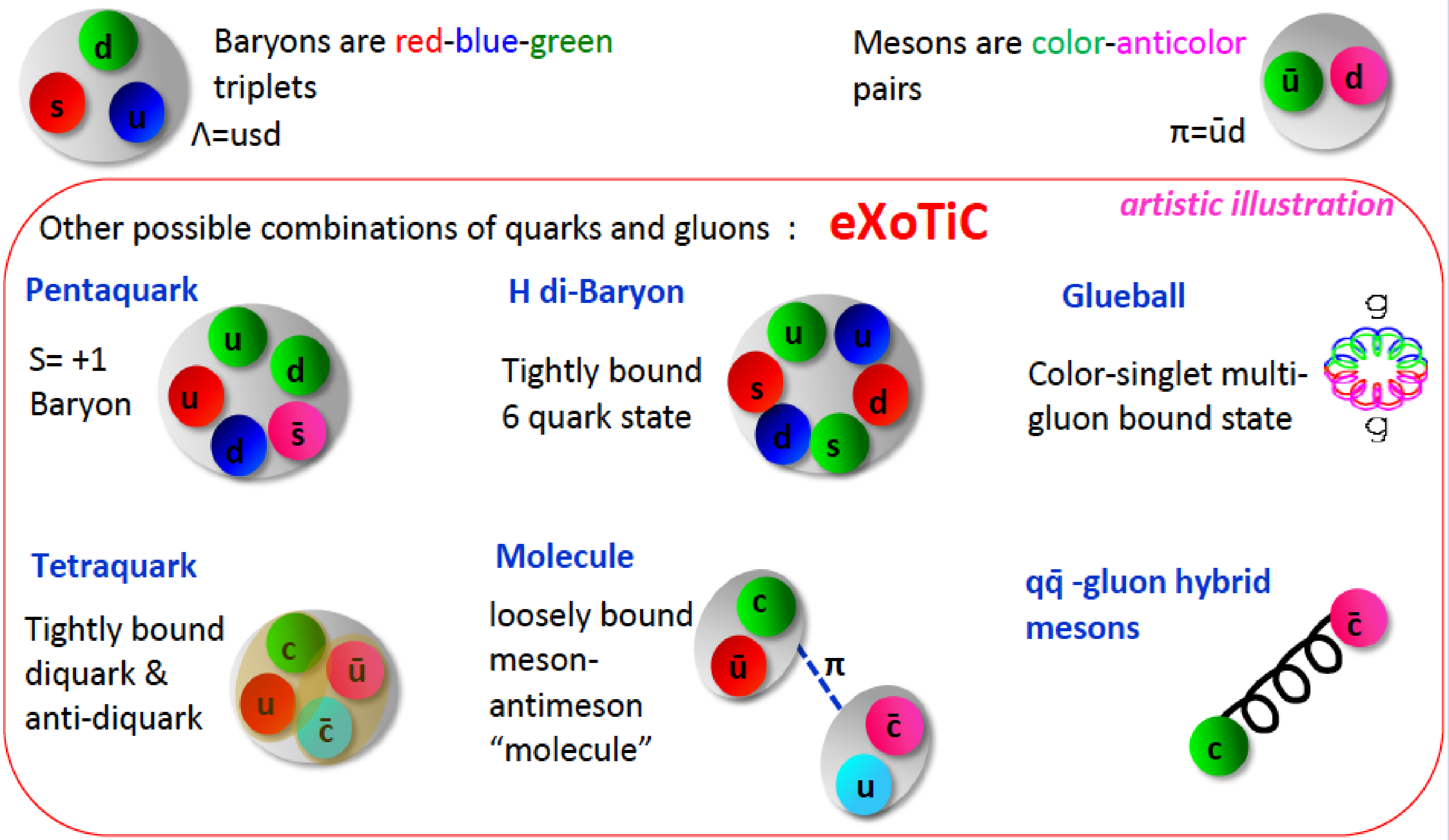
R-Scan data
between 2.0 and 3.08 GeV,
and above 3.735 GeV

Large dataset for XYZ studies



low hadronic background
high discovery potential
direct formation of exotic vector states

The exotic alphabet



Non conventional hadrons

Y – 1^{--} charmonium-like vector states,

Z –non-zero isospin, charmonium-like states with heavy $c\bar{c}$ quark pair inside

X – all the remaining cases

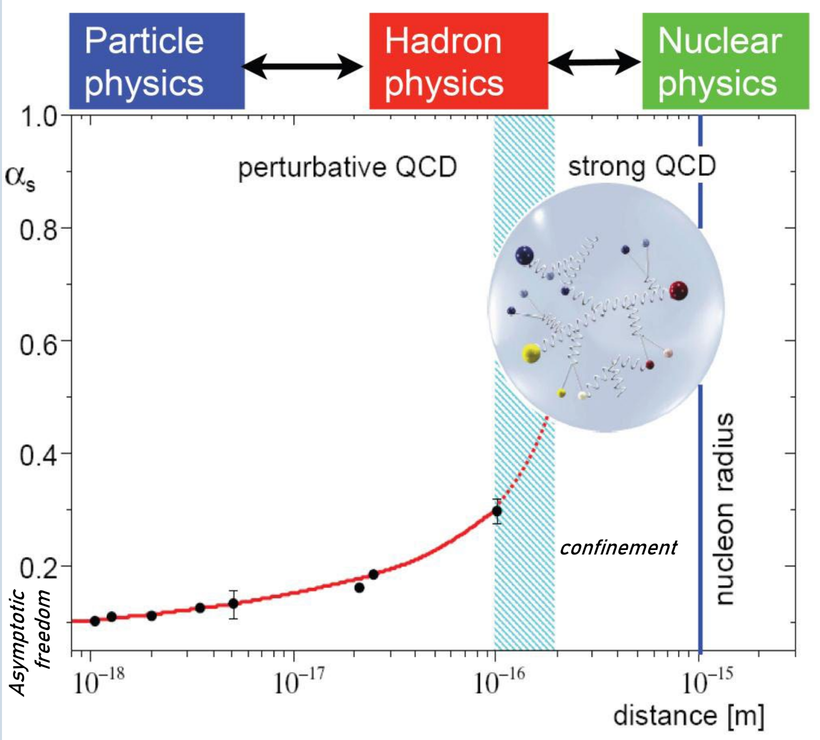
P – pentaquark candidates

PDG'2018: reflects quantum numbers J^{PC} in name, regardless of quark configuration

Isospin	heavy quark content / PC	$-+$	$+-$	$--$	$++$
$I=0$	with $c\bar{c}$	η_c	h_c	ψ	χ_c
$I=0$	with $b\bar{b}$	η_b	h_b	Υ	χ_b
$I=1$	with $c\bar{c}$	(Π_c)	Z_c	(R_c)	(W_c)
$I=1$	with $b\bar{b}$	(Π_b)	Z_b	(R_b)	(W_b)

J^{PC}	Name	Example
1^{--}	$\psi(\ldots)$	$\psi(4260)$ (was $Y(4260)$)
1^{++}	$\chi(\ldots)$	$\chi_{c1}(3872)$ (was $X(3872)$)

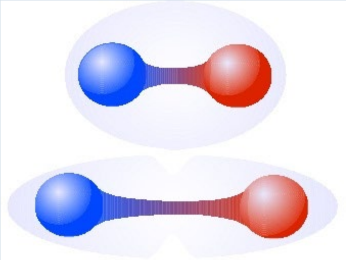
Heavy quarks: potential model

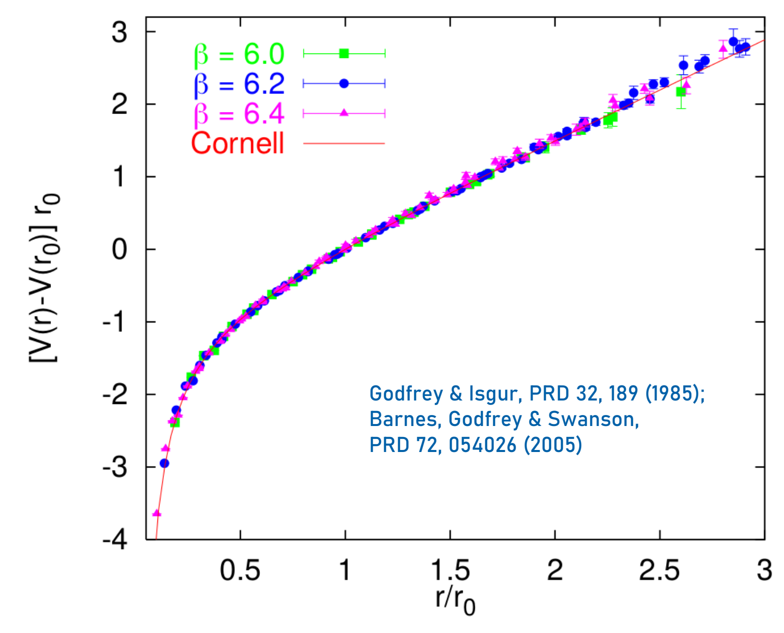


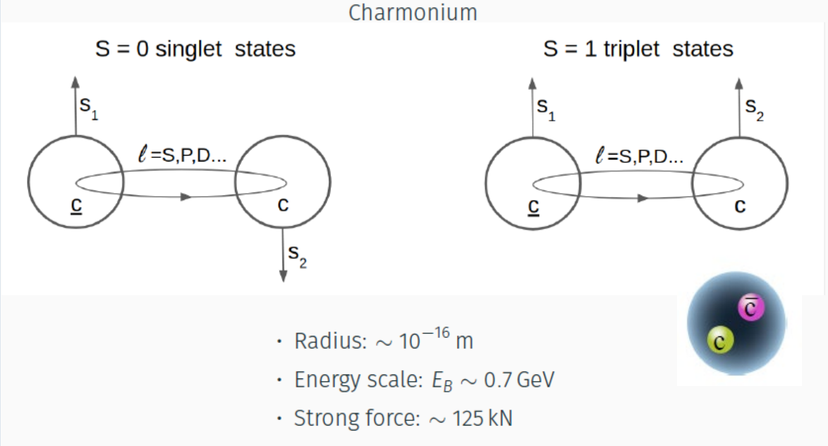
Devise a potential for the quark-quark interaction and solve a Schrödinger type equation.
For heavy quarks→$q\bar{q}$ static potential

Cornell potential

$$V^{q\bar{q}}(r) = -\frac{4\alpha_s}{3r} + kr + C$$







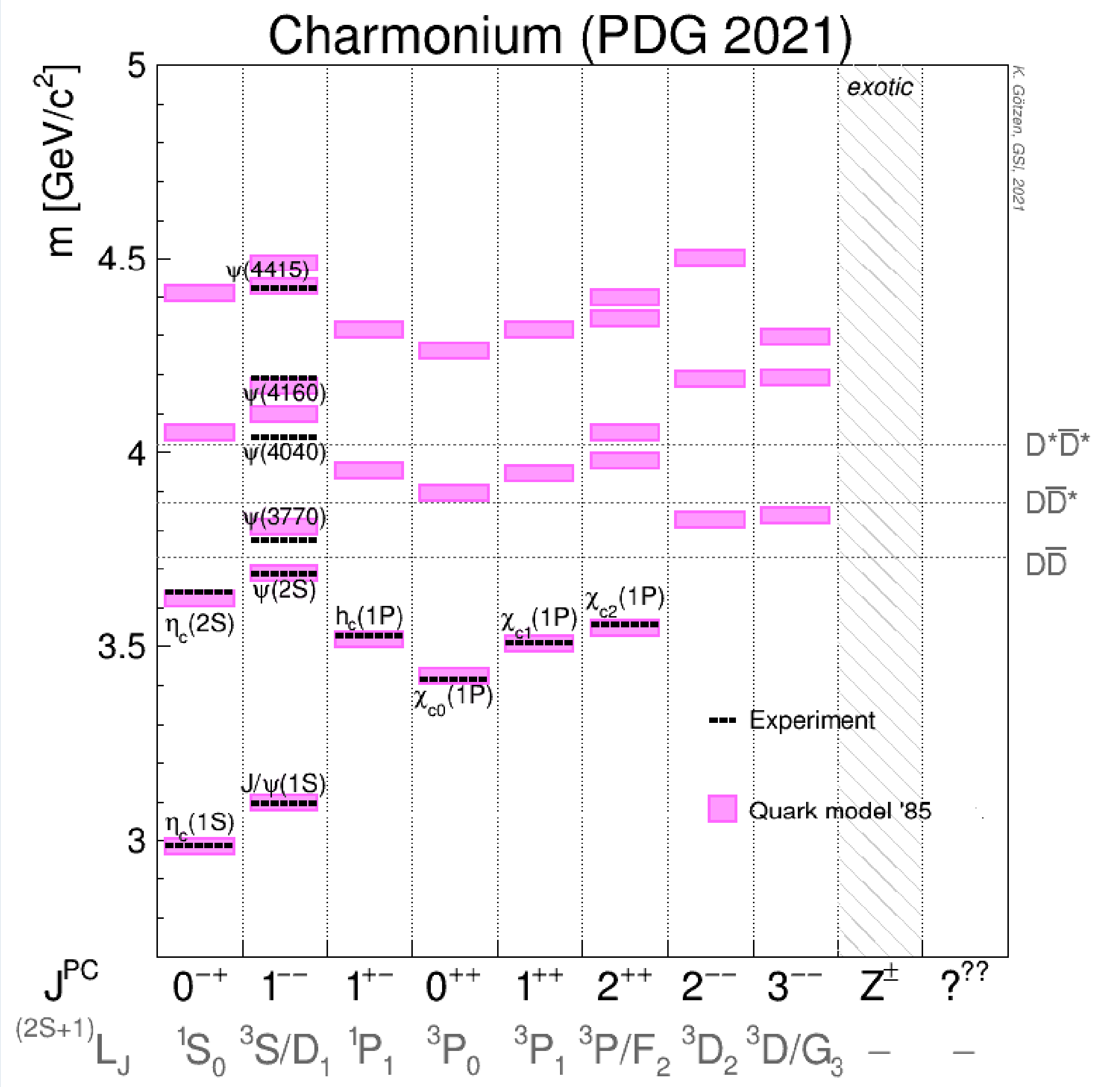
$$V^{c\bar{c}}(r) = -\frac{4\alpha_s}{3r} + kr + \frac{1}{m_c m_{\bar{c}}}\left[\frac{32\pi\alpha_s}{9}\delta_\sigma(r)\overrightarrow{s_c}\overrightarrow{s_{\bar{c}}} + \left(\frac{2\alpha_s}{r^3} - \frac{k}{2r}\right)\vec{l}\cdot\vec{s} + \frac{4\alpha_s}{r^3}T\right] +$$

+relativistic corrections

$$T = (\overrightarrow{s_c}\cdot\hat{r})(\overrightarrow{s_{\bar{c}}}\cdot\hat{r}) - \frac{1}{3}\overrightarrow{s_c}\,\overrightarrow{s_{\bar{c}}}$$

Simple quark model

Before 2003:
Good agreement between theory and experiment, particularly beneath open charm thresholds



Simple quark model

Before 2003:
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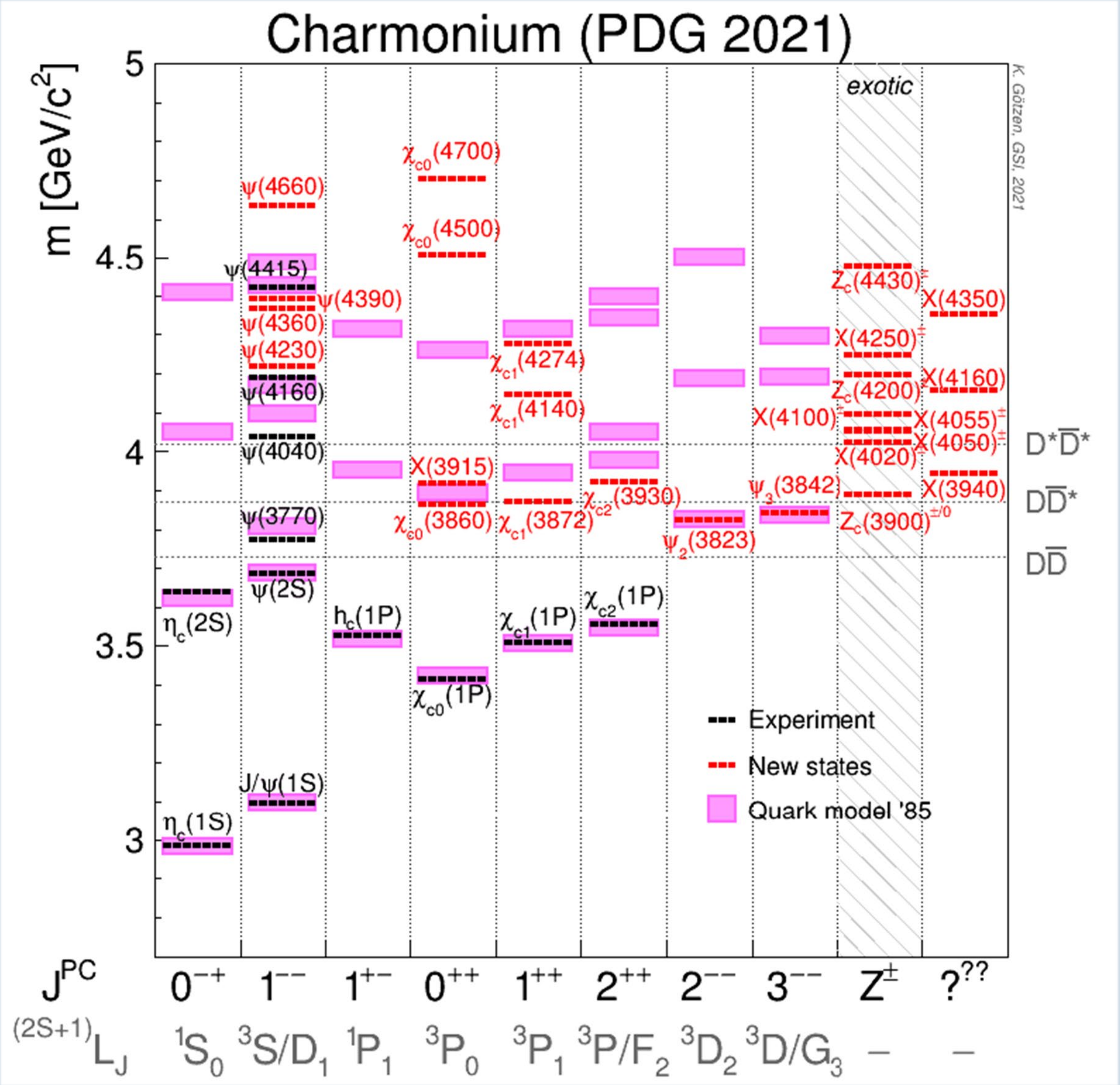
After 2003:
Severe mismatch between predicted and observed spectrum



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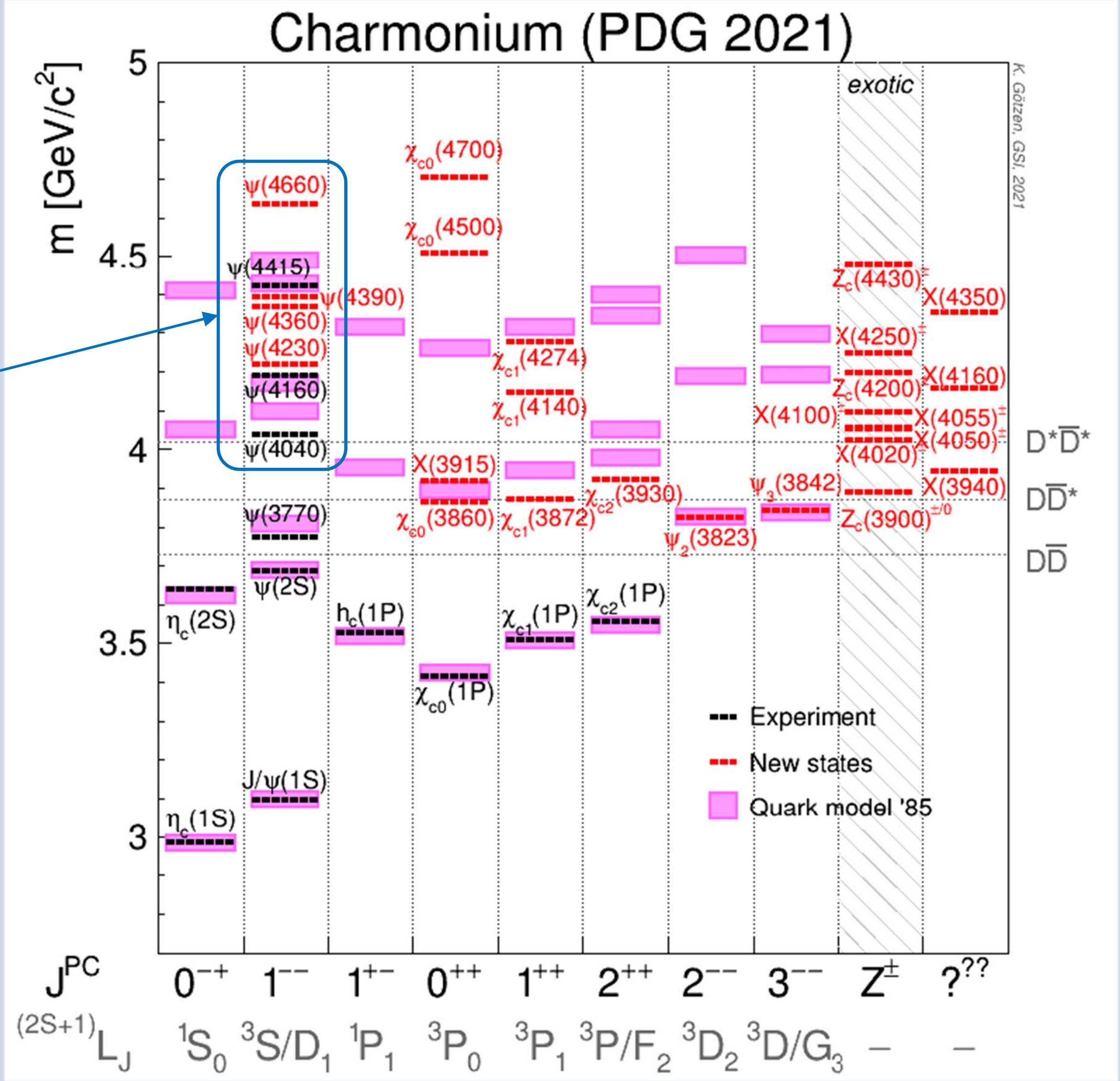
After 2003:
Severe mismatch between predicted and observed spectrum

Several supernumerary vector states: $Y(4260)$, …, $Y(4660)$



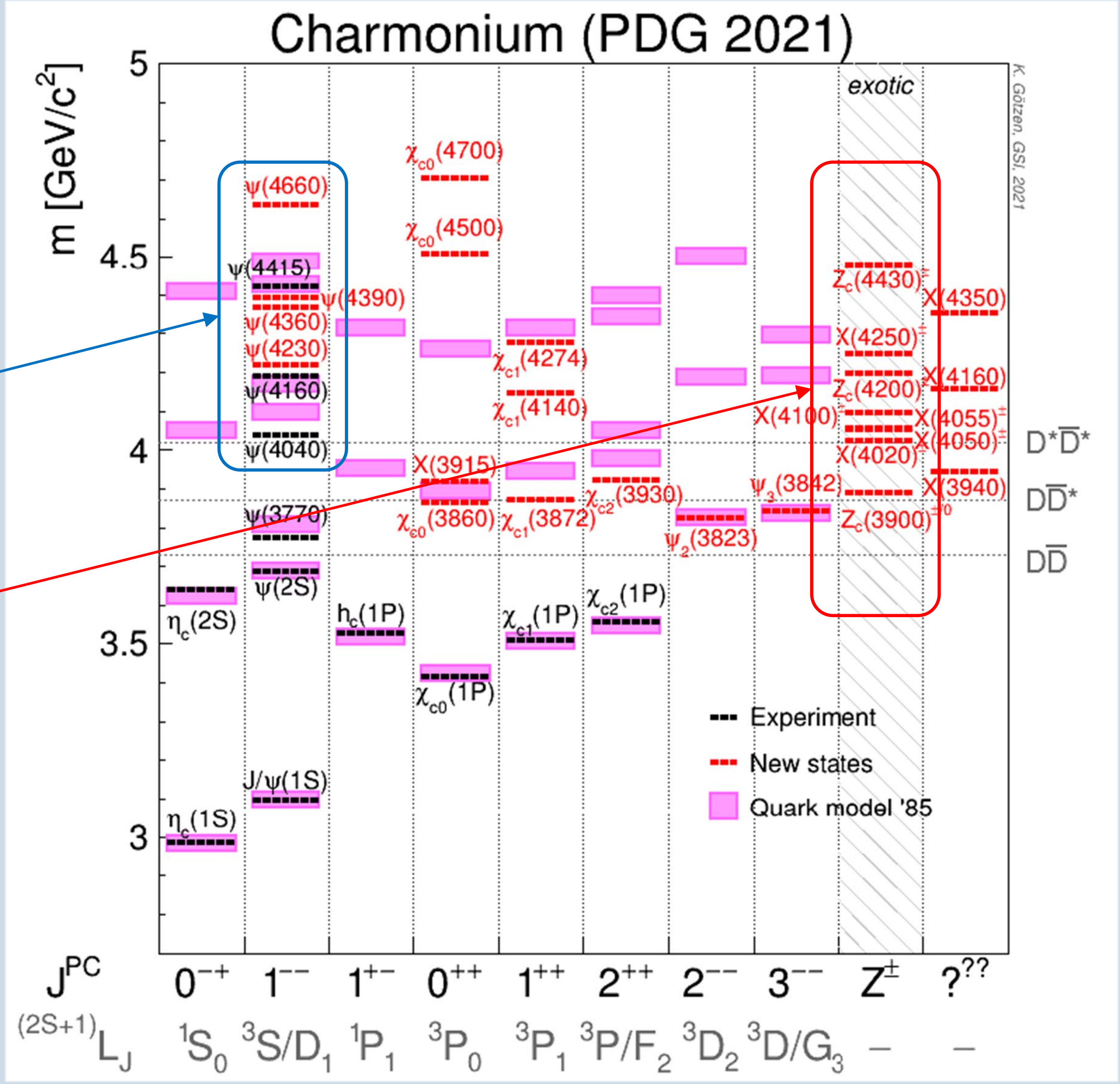
Simple quark model

Before 2003:
Good agreement between theory and experiment, particularly beneath open charm thresholds

After 2003:
Severe mismatch between predicted and observed spectrum

Several supernumerary vector states: $Y(4260)$, …, $Y(4660)$

Several charged states, manifestly exotics: $Z_c(4430)$… $Z_c(3900)$



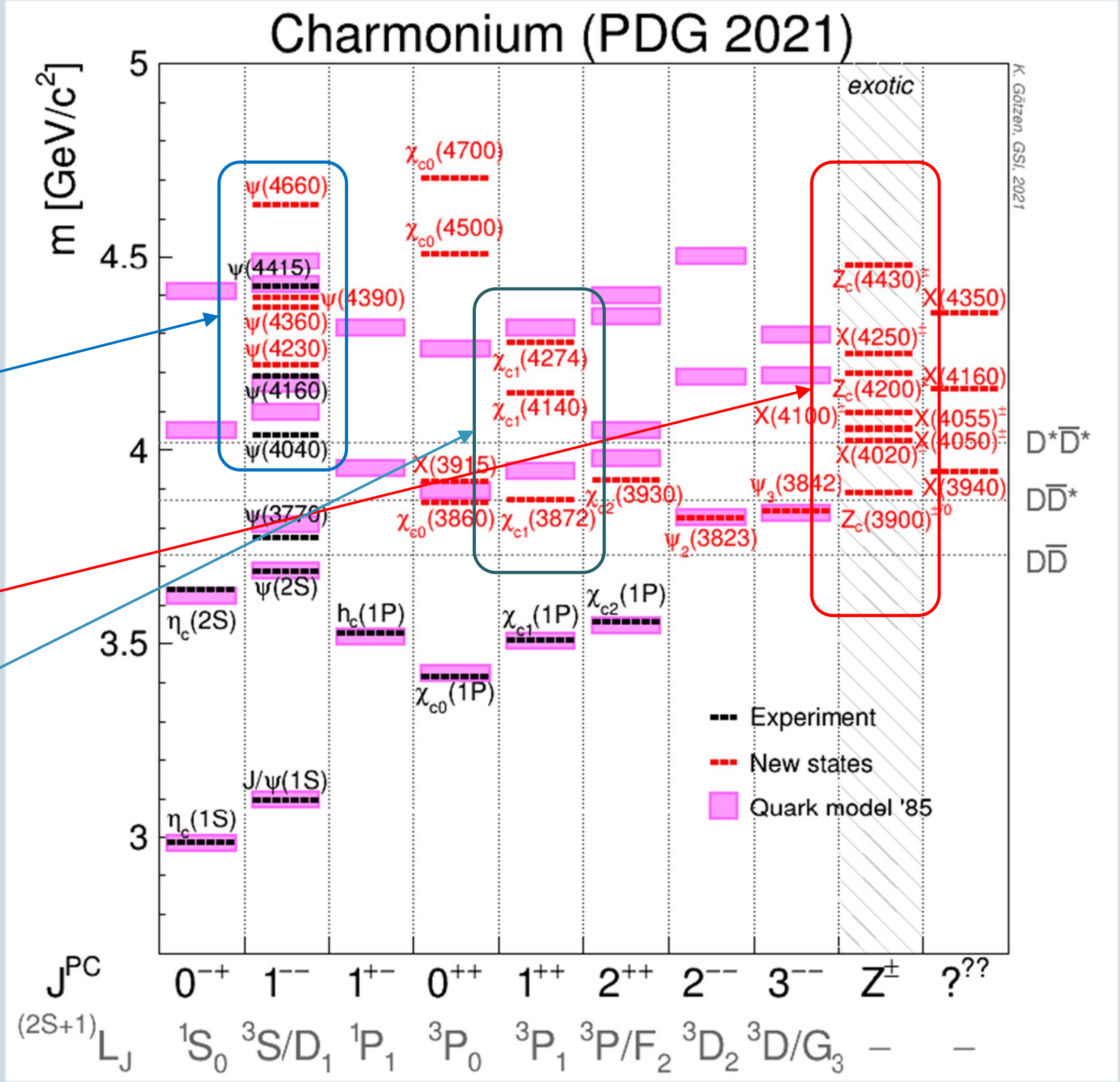
Before 2003:
Good agreement between theory and experiment, particularly beneath open charm thresholds

After 2003:
Severe mismatch between predicted and observed spectrum

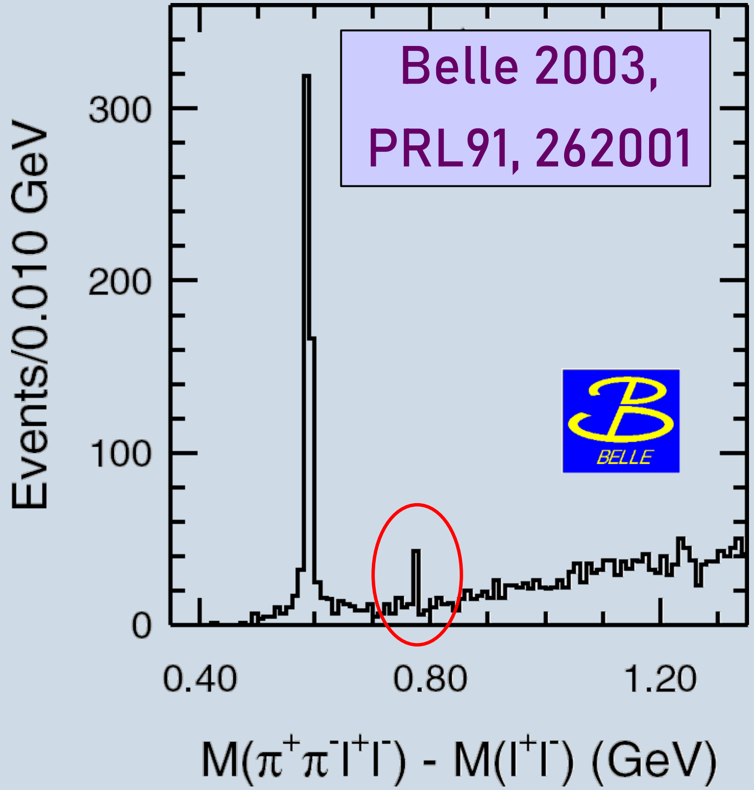
Several supernumerary vector states: $Y(4260)$, …, $Y(4660)$

Several charged states, manifestly exotics: $Z_c(4430)$… $Z_c(3900)$

The X states – $X(3872)$ was the first observed in 2003



$X(3872)$, $Y(4260)$, $Z_c(3900)$

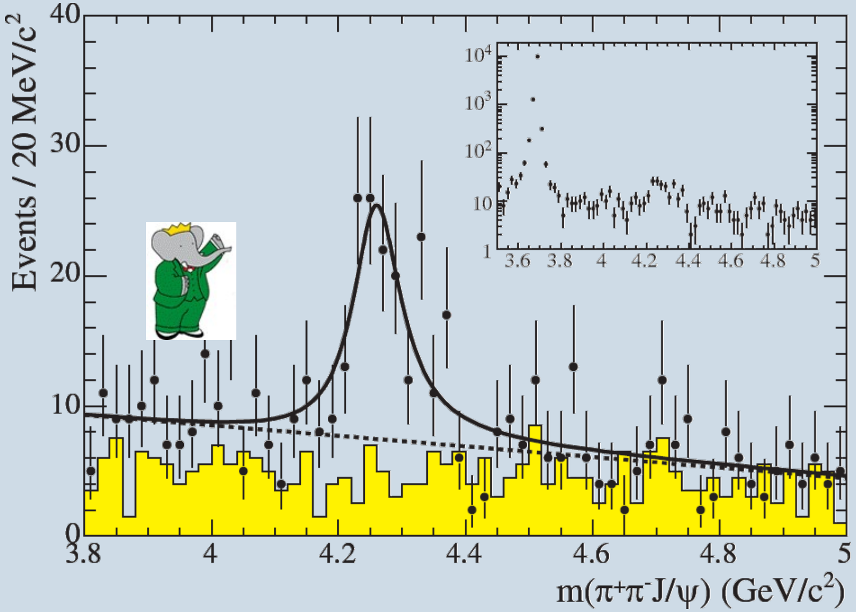


Belle 2003, PRL91, 262001

Extremely narrow, sits at or just below the $D^0\overline{D}^{*0}$threshold

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

$\Gamma < 1.2 \text{ MeV}$

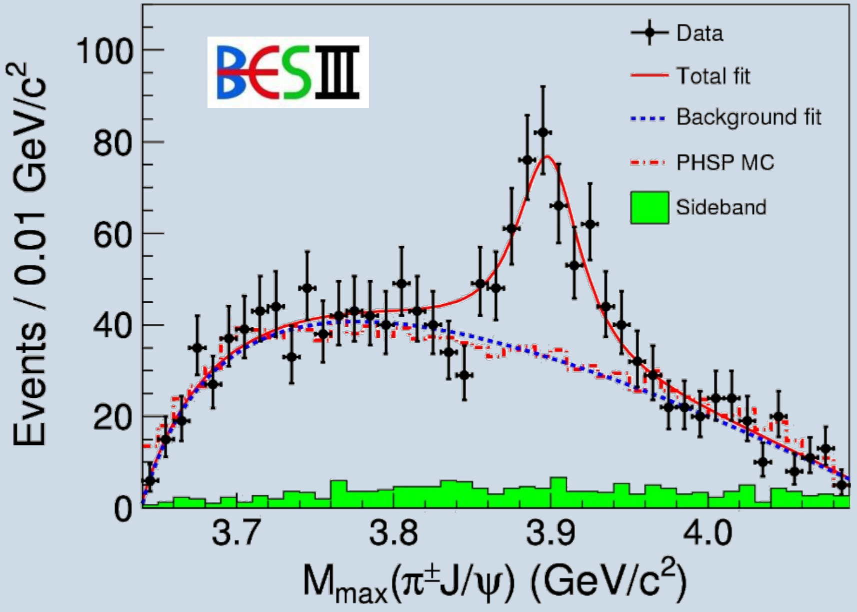


BaBar 2005, PRL95, 142001

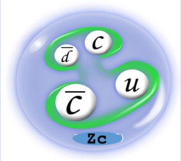
$e^+e^- \rightarrow \pi^+\pi^- J/\psi$

BESIII: Cross-section inconsistent with the single resonance Y(4260)! Two favoured over one by >7σ

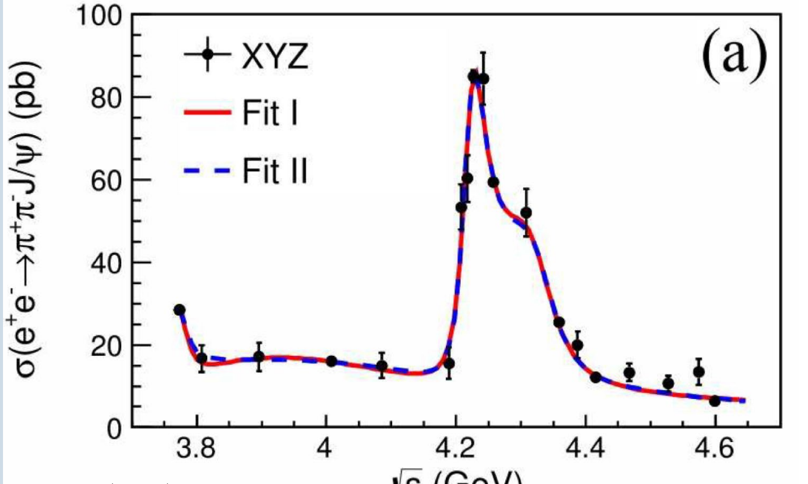
PRL 118 (2017) 092001



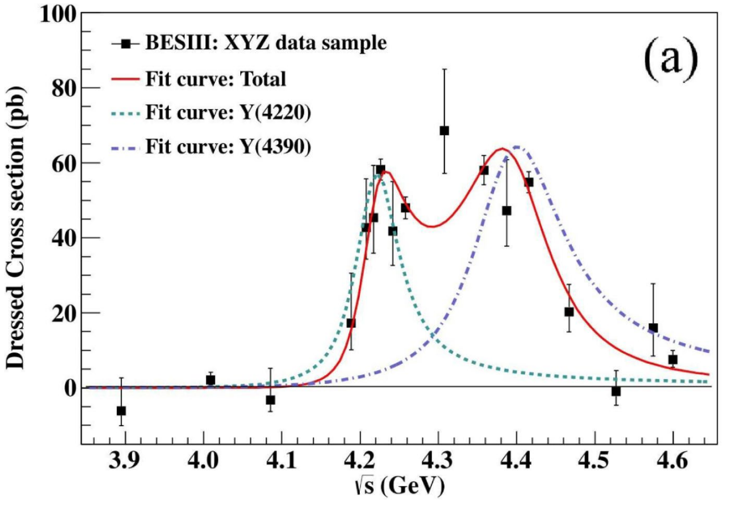
BESIII 2013, PRL110, 252001



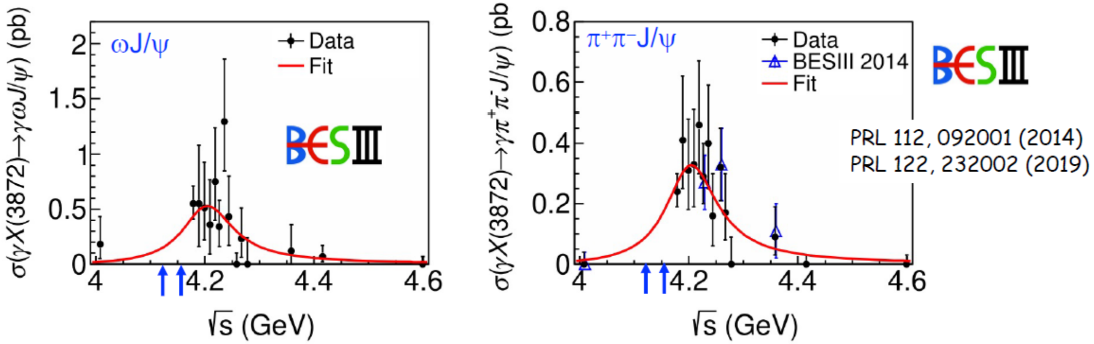
Y(4230)



PRL 118 (2017) 092001



Y(4230)→γX(3872)



PRL 112, 092001 (2014)
PRL 122, 232002 (2019)

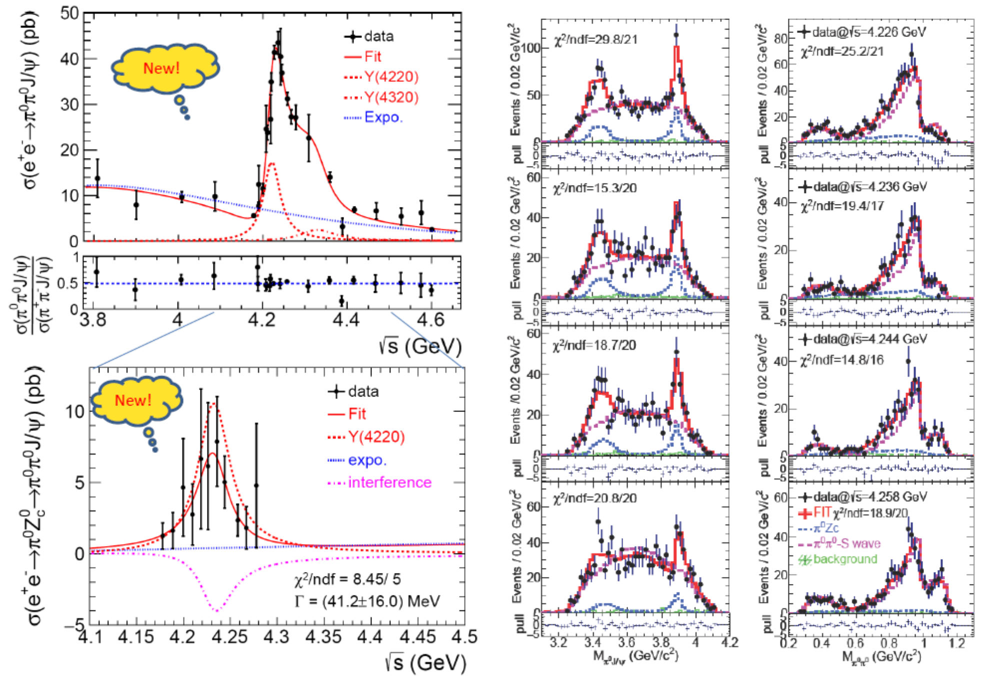
- $e^+e^-\to\gamma X(3872)$ cross section line shape by BESIII
- $M=4200.6^{+7.9}_{-13.3}\pm3.0$ MeV, $\Gamma=115^{+38}_{-26}\pm12$ MeV
- Unique at BESIII, $Br[Y(4260)\to\gamma X(3872)]/Br[Y\to\pi^+\pi^- J/\psi]\sim9\%$

Strongly suggest the Y(4260)→γX(3872) transition → *Commonality between Y(4260) & X(3872)…*

PLB 725, 127 (2013) / RMP 90, 015003 (2018)

Phys. Rev. D 102, 012009 (2020)

Y(4230)→π Z_c(3900)→ππJ/ψ

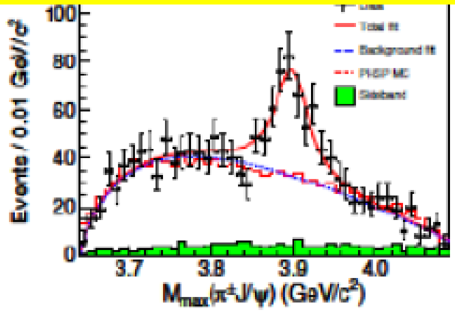


Z_c family

BESIII

Zc(3900)$^+$

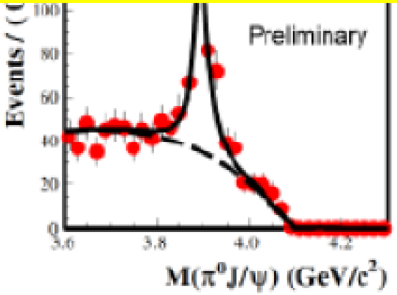
PRL 110, 252001 (2013)



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

Zc(3900)^0

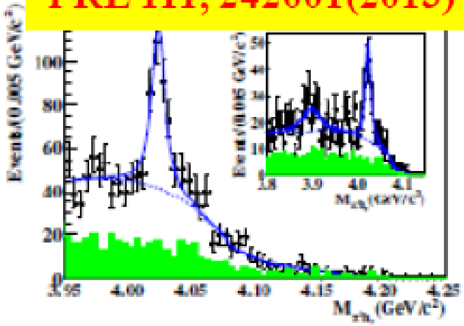
PRL 115, 112003 (2015)



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

Zc(4020)$^+$

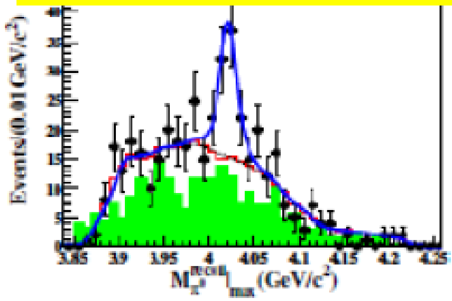
PRL 111, 242001(2013)



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

Zc(4020)^0

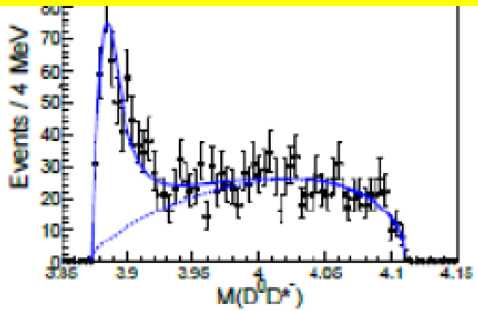
PRL113,212002 (2014)



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

Zc(3885)$^+$

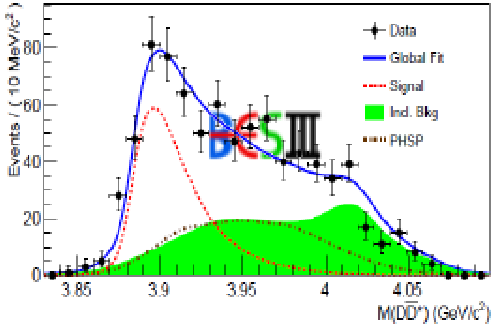
ST: PRL 112, 022001(2014)
DT: PRD92, 092006 (2015)



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

Zc(3885)^0

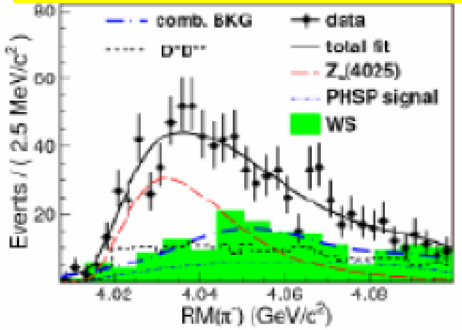
PRL115, 222002 (2015)



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

Zc(4025)$^+$

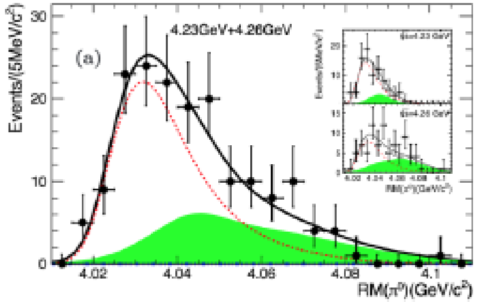
PRL 112, 132001 (2014)



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

Zc(4025)^0

PRL115, 182002 (2015)

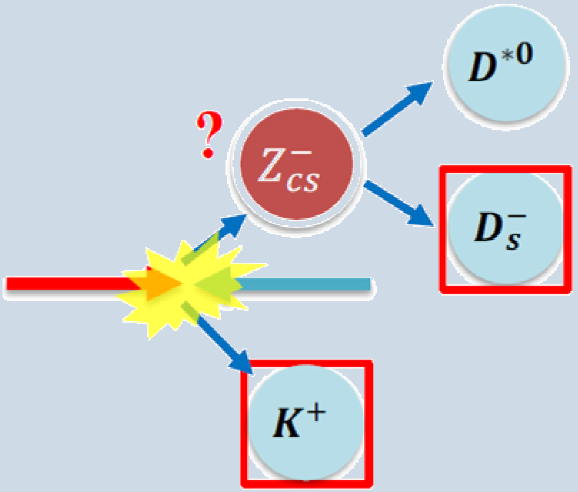


$e^+e^- \to \pi^0(D^*\bar{D}^*)^0$

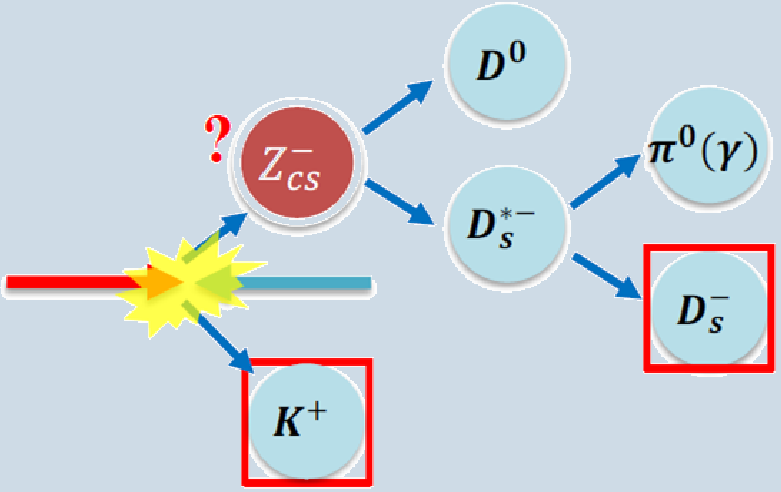
...

Search for Z_{cs}

Searches for Z_{cs} partners were proposed few years ago. e.g., $Z_{cs}/Z'_{cs} \to KJ/\psi,\ D_sD^*, D_s^*D, D_s^*D^*$
→ decay rate of Z_{cs} to open-charm final states is supposed to be larger than hidden-charm



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



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

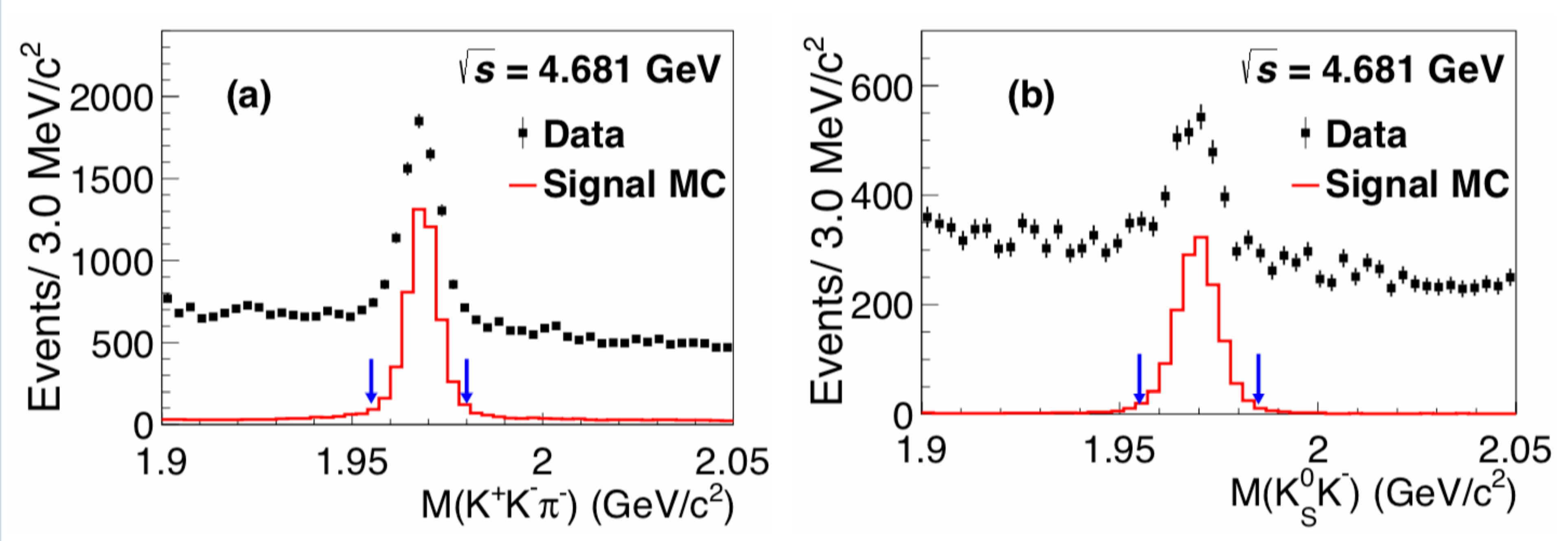
$$e^+e^- \to K^+(D_s^-D^{*0} + D_s^{*-}D^0)$$

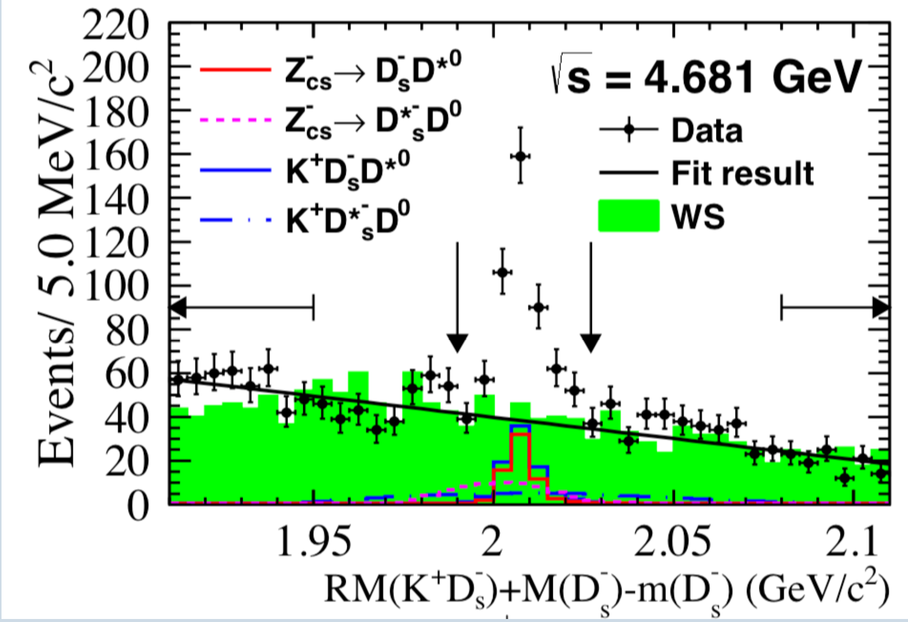
Partial reconstruction of the process

Reconstruct a D_s^- with two tag modes $D_s^- \to K_S^0K^-$ $D_s^- \to K^+K^-\pi^-$
Tag a bachelor charged K^+
Use signature in the recoil mass spectrum of $K^+D_s^-$
Study the spectrum of recoil mass of K^+

the charge conjugated modes are always implied unless specified

Tag a D_s^-





For $D_s^- \to K^+K^-\pi^-$

1) $D_s^- \to \pi^-\phi$: $M(K^+K^-)$<1.05 GeV/c²

2) $D_s^- \to K^-K^*(892)^0$: $M(K^+\pi^-)\epsilon$ (0.85,0.93)GeV/c²

For $D_s^- \to K_s^0K^-$

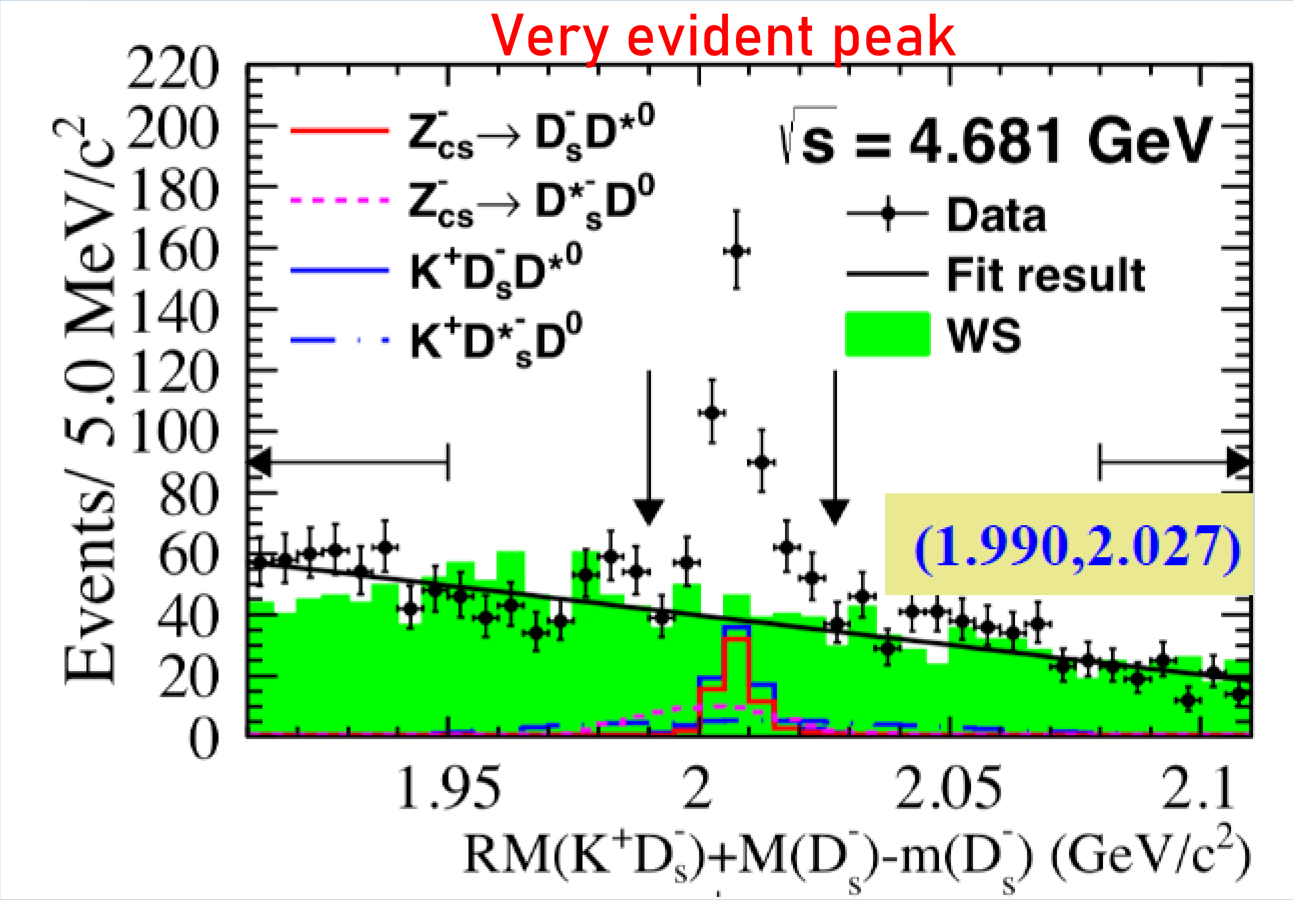
$M(\pi^+\pi^-)\epsilon$ (0.485,0.511)GeV/c²

RM→recoil mass

M→reconstructed mass

m→ mass taken from PDG

Select candidates

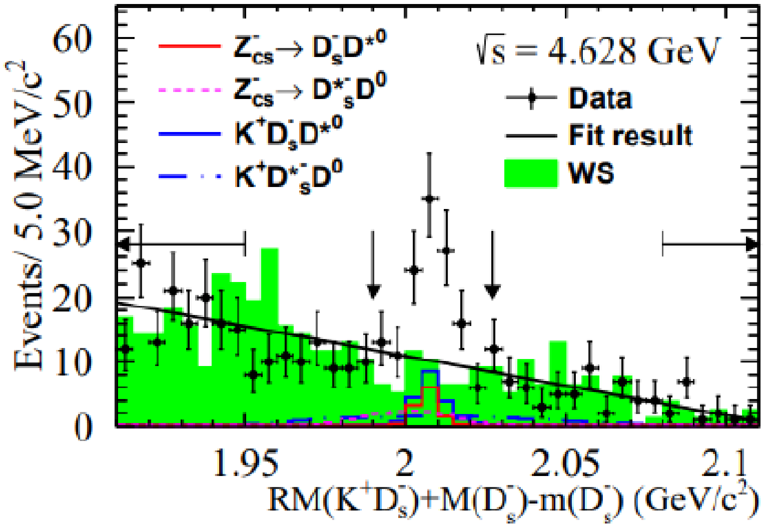


Data driven technique to describe combinatorial bkg
Right sign (RS) combination of D_s^- and K^+
Wrong sign (WS) combination of D_s^- and K^-
to mimic combinatorial bkg

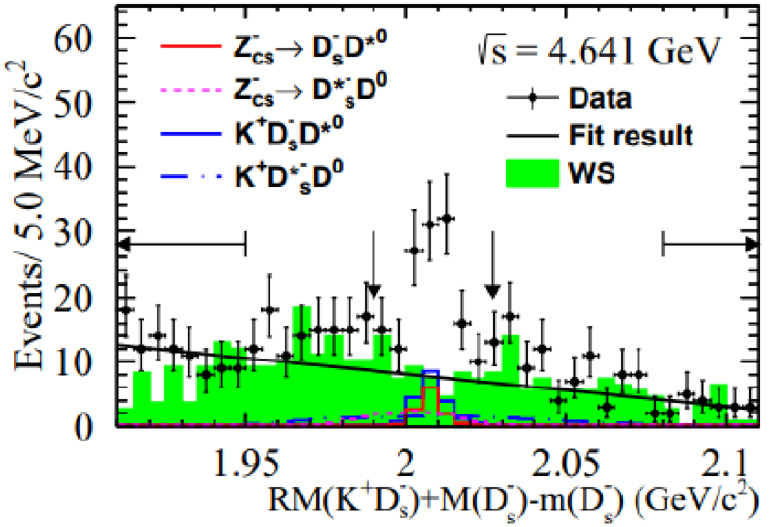
No peaking bkg in WS events → WS is well validated by MC simulations and data sideband events
Both $e^+e^- \to K^+ D_s^- D^{*0}$ and $e^+e^- \to K^+ D_s^{*-} D^0$ can survive with this criterion
Fitting to $RM(K^+ D_s^-)$ sideband events gives the number of WS in the signal region: 282.6+/-12

This WS number will be fixed in fitting $RM(K^+)$

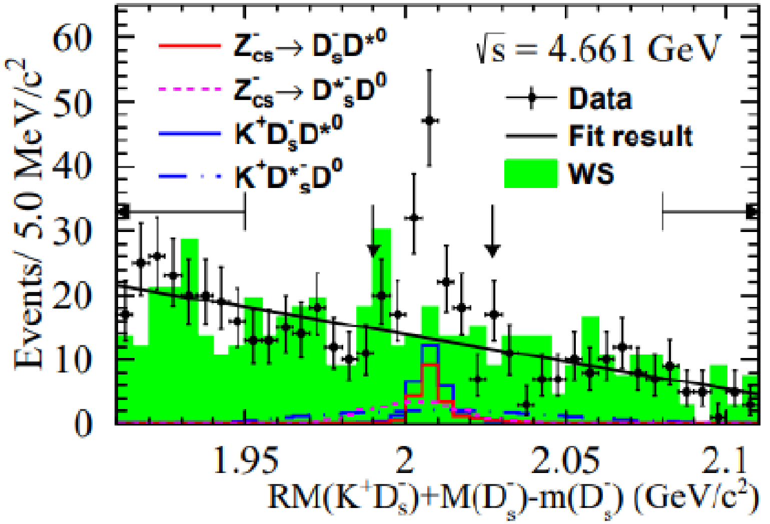
Recoil Mass



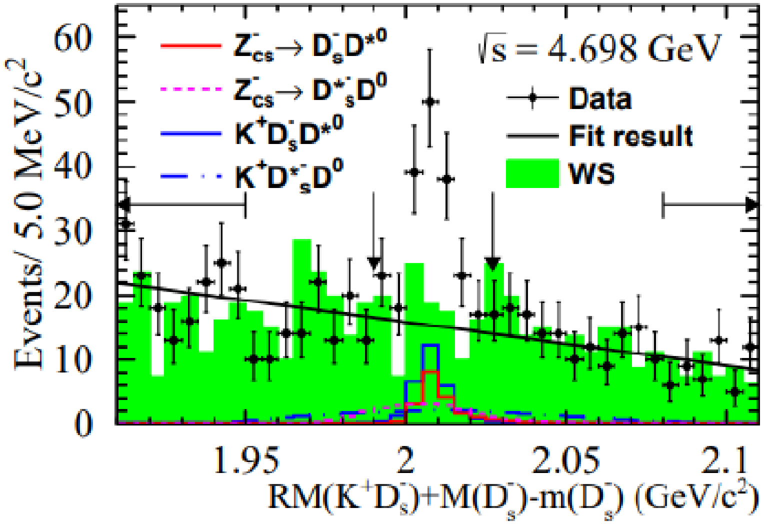
(a)Recoil mass of $K^+ D_s^-$ at $\sqrt{s} = 4.628$ GeV.



(b)Recoil mass of $K^+ D_s^-$ at $\sqrt{s} = 4.641$ GeV.

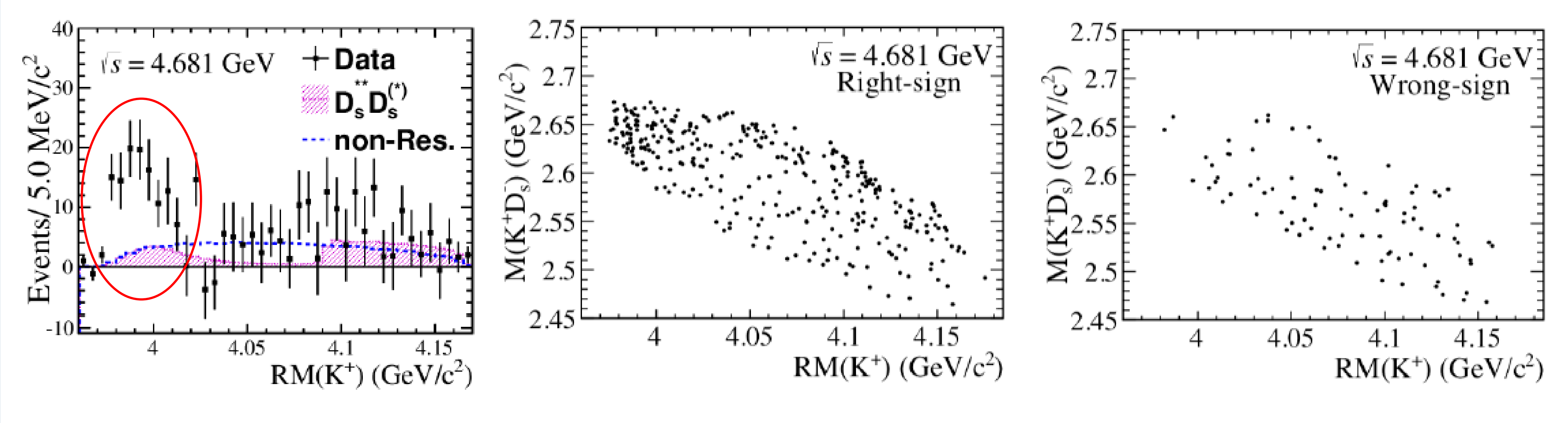


(c)Recoil mass of $K^+ D_s^-$ at $\sqrt{s} = 4.661$ GeV.



(d)Recoil mass of $K^+ D_s^-$ at $\sqrt{s} = 4.698$ GeV.

Recoil mass $RM(K^+)$

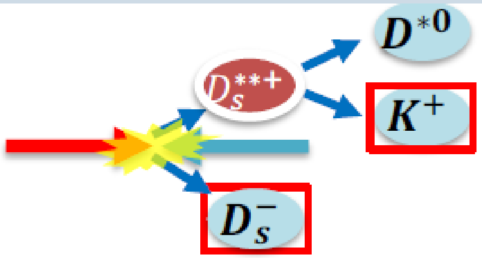


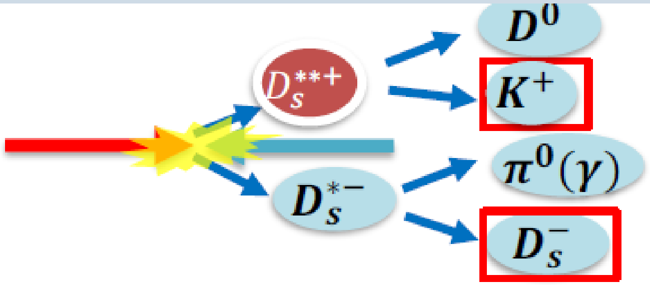
A structure next to threshold ranging from 3.96 to 4.02 GeV/c^2

Enhancement cannot be attributed to the non-resonant signal processes

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

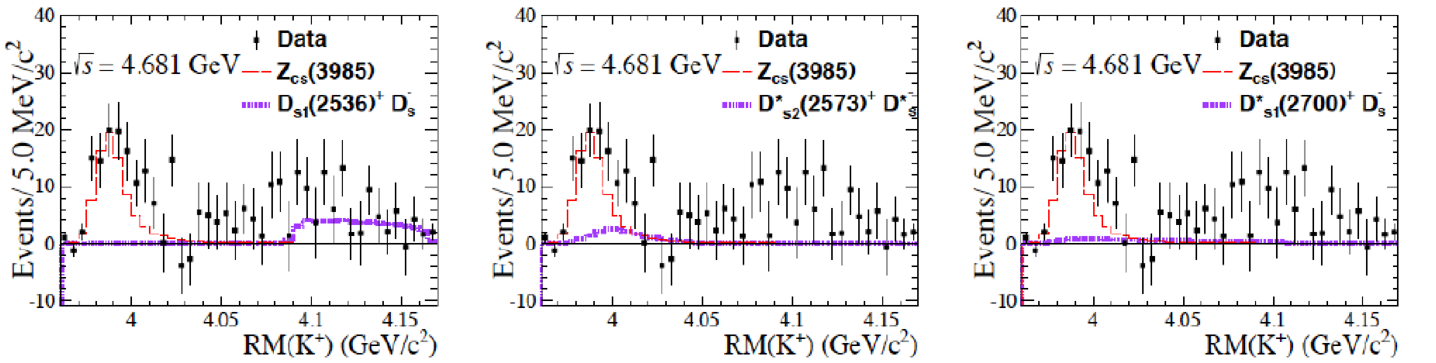
High excited D_s^{**} states





D_s^{**+}	mass(MeV/c²)	width(MeV)	J^P	$D_s^{**+}(K^+D^{*0})D_s^-$	$D_s^{**+}(K^+D^0)D_s^{*-}$
$D_{s1}(2536)^+$	2535.11±0.06	0.92±0.05	1^+	(*) Fixed in nominal fitting	Parity Violation in decay
$D_{s2}^*(2573)^+$	2569.1±0.8	16.9±0.7	2^+	Not decay to KD*	(*) Fixed in nominal fitting
$D_{s1}^*(2700)^+$	$2708.3^{+4.0}_{-3.4}$	120±11	1^-	(*) Fixed in nominal fitting	Q=-139.3MeV P-wave suppression in production.
$D_{s1}^*(2860)^+$	2859±27	159±80	1^-	(*)less contribution than $D_{s1}^*(2700)^+$; Q=-146MeV.	Q=-290MeV; P-wave suppression in production.
$D_{s3}^*(2860)^+$	2860±7	53±10	3^-	(*)F-wave suppression; Q=-147MeV	Q=-291MeV

• $D_s^\pm$	$0(0^-)$
• $D_s^{*\pm}$	$0(?^?)$
• $D_{s0}^*(2317)^\pm$	$0(0^+)$
• $D_{s1}(2460)^\pm$	$0(1^+)$
• $D_{s1}(2536)^\pm$	$0(1^+)$
• $D_{s2}^*(2573)$	$0(2^+)$
• $D_{s1}^*(2700)^\pm$	$0(1^-)$
$D_{s1}^*(2860)^\pm$	$0(1^-)$
$D_{s3}^*(2860)^\pm$	$0(3^-)$
$D_{sJ}(3040)^\pm$	$0(?^?)$

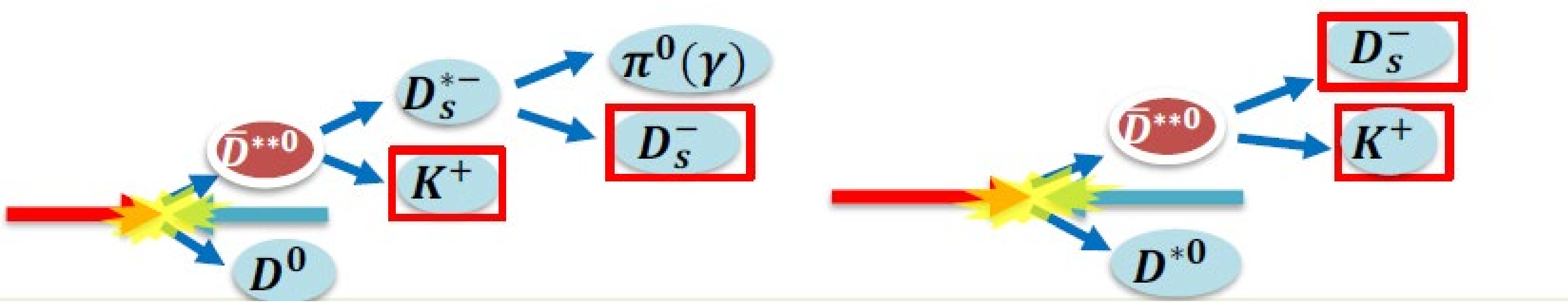


(a) $D_{s1}(2536)^+(\to D^{*0}K^+)D_s^-$ (b) $D_{s2}^*(2573)^+(\to D^0K^+)D_s^{*-}$ (c) $D_{s1}^*(2700)^+(\to D^{*0}K^+)D_s^-$

Most high excited states have negative Q value or are forbidden due to parity violation

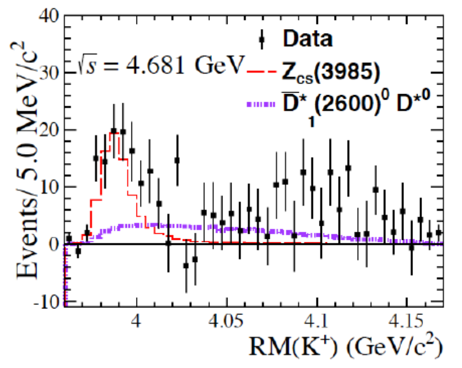
Contribution around 4 GeV/c²

High excited $\bar{D}^{**0}$ states



$\bar{D}^{**0}$	mass(MeV/c²)	width(MeV)	JP	$\bar{D}^{**0}(K^+D_s^{*-})D^0$	$\bar{D}^{**0}(K^+D_s^-)D^{*0}$
$\bar{D}_1(2430)^0$	2427±40	384^{+130}_{-110}	1⁺	below KDs* threshold; Q=-72.22MeV soft Kaon	Parity Violation decay
$\bar{D}_2^*(2460)^0$	2460.7±0.4	47.5±1.1	2⁺	below KDs* threshold; Q=-39.52MeV soft Kaon	(*)Test fit
$\bar{D}(2550)^0$	2564±20	135±17	0-	(*)Test fit	Parity Violation in decay
$\bar{D}_J^*(2600)^0$	2623±12	139±31	1-	(*)Test fit	(*)Control sample & nominal fit
$\bar{D}^*(2640)^0$	2637±6	<15	?	(*)Test fit	(*)Test fit
$\bar{D}(2740)^0$	2737±12	73±28	2-	(*)Test fit	Parity Violation in decay
$\bar{D}_3^*(2750)^0$	2763±3.4	66±5	3-	(*)Control sample	P-wave suppressed. Q=-89.8MeV

$D_1(2420)^{\pm}$	$1/2(?^?)$
$D_1(2430)^0$	$1/2(1^+)$
• $D_2^*(2460)^0$	$1/2(2^+)$
• $D_2^*(2460)^{\pm}$	$1/2(2^+)$
$D(2550)^0$	$1/2(?^?)$
$D_J^*(2600)$ was $D(2600)$	$1/2(?^?)$
$D^*(2640)^{\pm}$	$1/2(?^?)$
$D(2740)^0$	$1/2(?^?)$
$D_3^*(2750)$	$1/2(3^-)$
$D(3000)^0$	$1/2(?^?)$

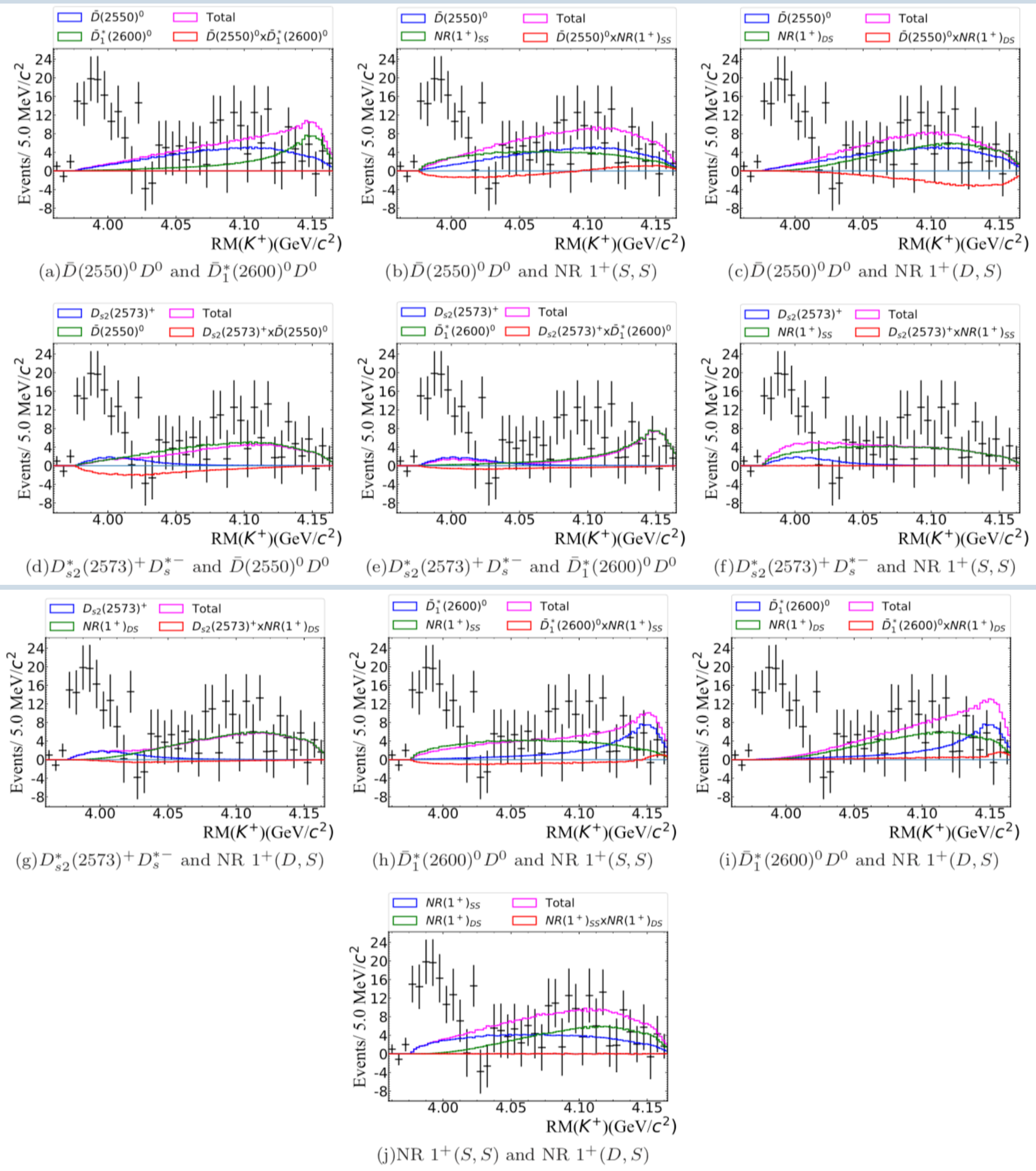


(c) $\bar{D}_1^*(2600)^0(\to D_s^- K^+)D^{*0}$

Most are not favoured from the check of test fit →systematic uncertainties

Enhancement cannot be attributed to resonant $D_{[s]}^{**}$ processes

Interference effects of $K^+ D_s^{*-} D^0$ final states



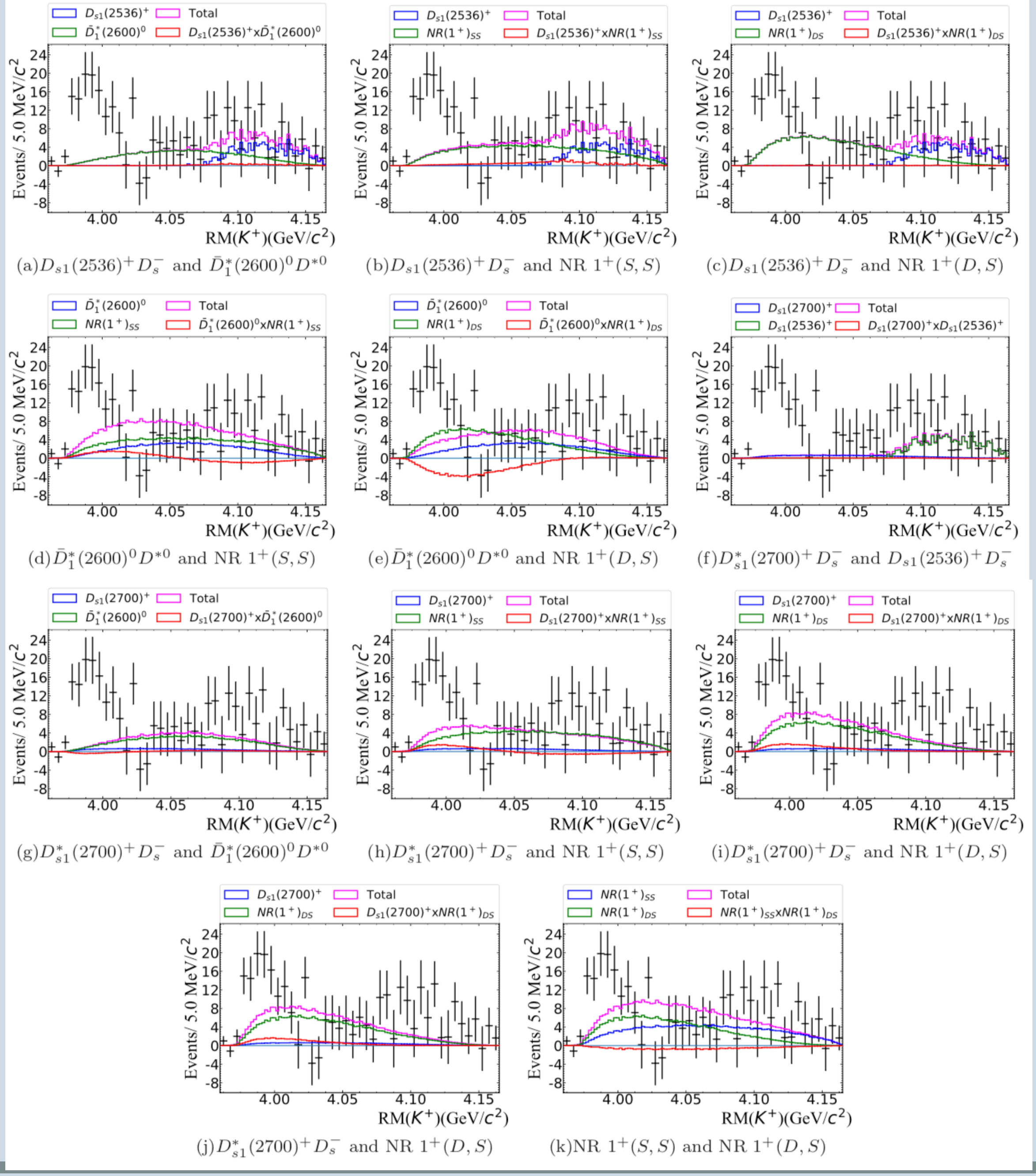
(a) $\bar{D}(2550)^0 D^0$ and $\bar{D}_1^*(2600)^0 D^0$
(b) $\bar{D}(2550)^0 D^0$ and NR $1^+(S,S)$
(c) $\bar{D}(2550)^0 D^0$ and NR $1^+(D,S)$
(d) $D_{s2}^*(2573)^+ D_s^{*-}$ and $\bar{D}(2550)^0 D^0$
(e) $D_{s2}^*(2573)^+ D_s^{*-}$ and $\bar{D}_1^*(2600)^0 D^0$
(f) $D_{s2}^*(2573)^+ D_s^{*-}$ and NR $1^+(S,S)$
(g) $D_{s2}^*(2573)^+ D_s^{*-}$ and NR $1^+(D,S)$
(h) $\bar{D}_1^*(2600)^0 D^0$ and NR $1^+(S,S)$
(i) $\bar{D}_1^*(2600)^0 D^0$ and NR $1^+(D,S)$
(j) NR $1^+(S,S)$ and NR $1^+(D,S)$

Data subtracted with WS background
Any two MC simulated backgrounds with interferences are taken into account

The interference angle is tuned to give the largest interference effect around 4 GeV/c^2

The component of non-resonant process is also considered under different angular momenta.

Normalizations are scaled according to the observed yields in control samples

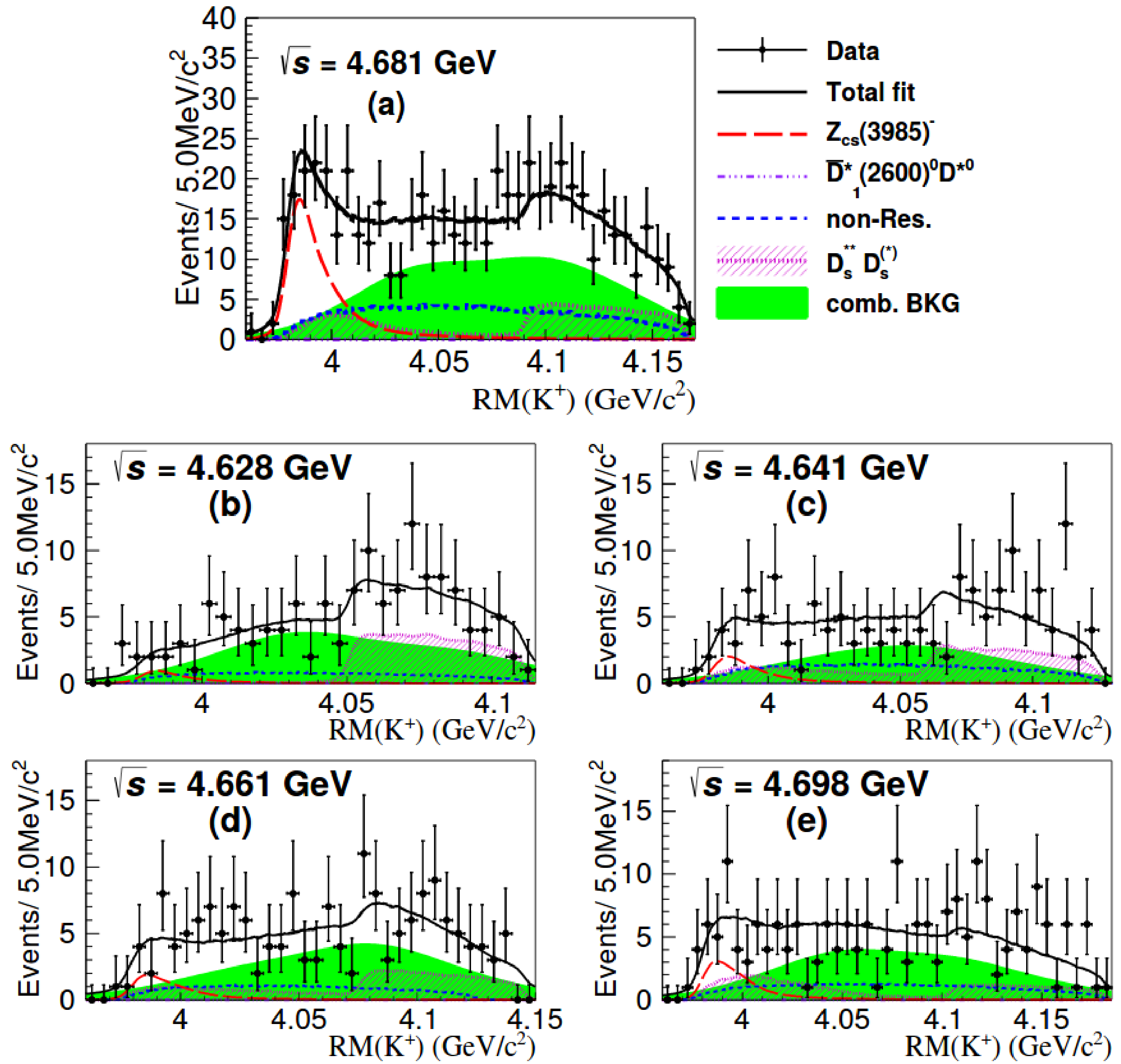


Interference effects of $K^+D_s^-D^{*0}$ final states

Interference effects will not produce such a narrow peak observed in data.

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

$Z_{cs}(3985)$



Product of an S-wave Breit-Wigner with a mass-dependent width:

$$\mathcal{F}_j(M) \propto \left| \frac{\sqrt{q \cdot p_j}}{M^2 - m_0^2 + i m_0 (f\Gamma_1(M) + (1-f)\Gamma_2(M))} \right|^2$$

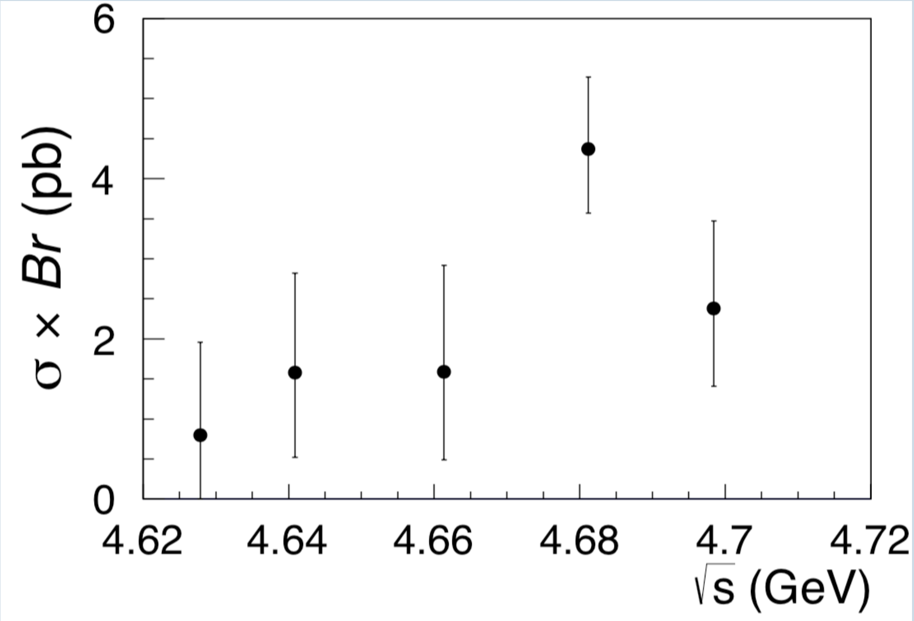
Simultaneous unbinned maximum likelihood fit to all energy values

$$m_0(Z_{cs}(3985)^-) = 3985.2^{+2.1}_{-2.0}\,\mathrm{MeV}/c^2,$$
$$\Gamma_0(Z_{cs}(3985)^-) = 13.8^{+8.1}_{-5.2}\,\mathrm{MeV}.$$

5.3σ significance

Born cross section

$$\sigma^{Born}(e^+e^- \to K^+Z_{cs}^- + cc) \cdot \mathcal{B}\big(Z_{cs}^- \to (D_s^- D^{*0} + D_s^{*-} D^0)\big) = \frac{n_{sig}}{\mathcal{L}_{int} \cdot f_{corr}\,(\tilde{\varepsilon}_1 + \tilde{\varepsilon}_2)/2}$$



$\sqrt{s}$(GeV)	$\mathcal{L}_{int}$(pb^{-1})	n_{sig}	$f_{corr}\bar{\varepsilon}$(%)	$\sigma^B \cdot \mathcal{B}$ (pb)
4.628	511.1	$4.2^{+6.1}_{-4.2}$	1.03	$0.8^{+1.2}_{-0.8} \pm 0.6\,(< 3.0)$
4.641	541.4	$9.3^{+7.3}_{-6.2}$	1.09	$1.6^{+1.2}_{-1.1} \pm 1.3\,(< 4.4)$
4.661	523.6	$10.6^{+8.9}_{-7.4}$	1.28	$1.6^{+1.3}_{-1.1} \pm 0.8\,(< 4.0)$
4.681	1643.4	$85.2^{+17.6}_{-15.6}$	1.18	$4.4^{+0.9}_{-0.8} \pm 1.4$
4.698	526.2	$17.8^{+8.1}_{-7.2}$	1.42	$2.4^{+1.1}_{-1.0} \pm 1.2\,(< 4.7)$

Main sources of systematic uncertainties include: mass scaling, detector resolution, the signal model, background models, and the input cross section lineshape for

$$\sigma^{Born}(e^+e^- \to K^+Z_{cs}^- + cc)$$

$$m_0(Z_{cs}(3985)^-) = 3985.2^{+2.1}_{-2.0}(stat.) \pm 1.7(sys.)\mathrm{MeV/c^2},$$

$$\Gamma_0(Z_{cs}(3985)^-) = 13.8^{+8.1}_{-5.2}(stat.) \pm 4.9(sys.)\mathrm{MeV}.$$

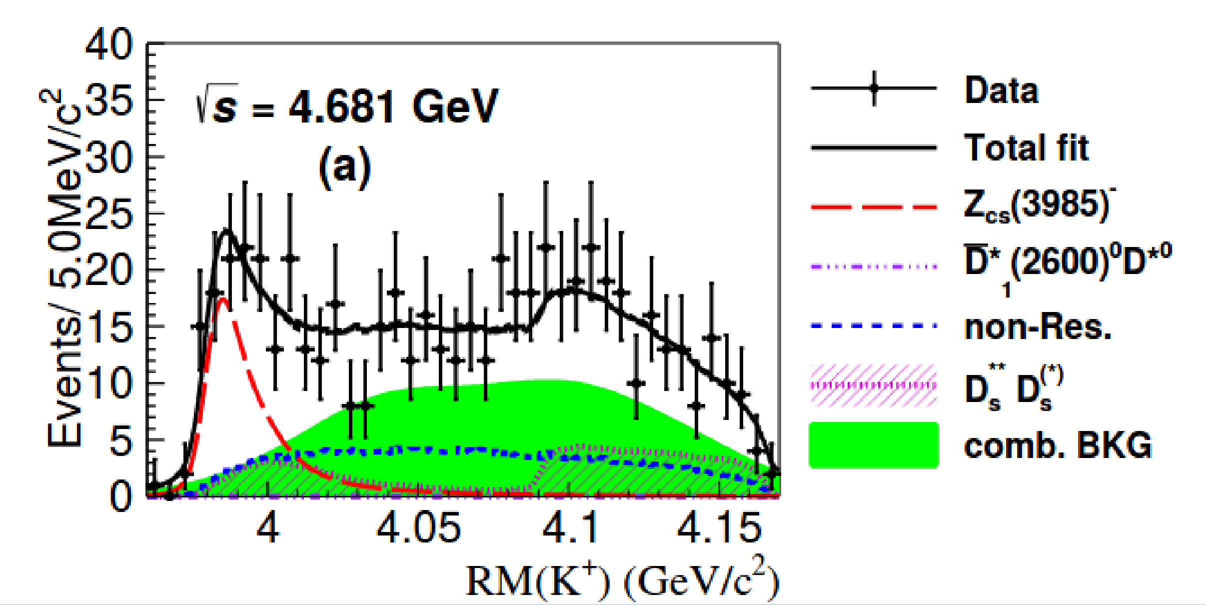
$$m_{pole}(Z_{cs}(3985)^-) = 3982.5^{+1.8}_{-2.6}(stat.) \pm 2.1(sys.)\mathrm{MeV/c^2},$$

$$\Gamma_{pole}(Z_{cs}(3985)^-) = 12.8^{+5.3}_{-4.4}(stat.) \pm 3.0(sys.)\mathrm{MeV}.$$

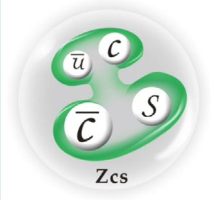
Higher order interference effects not included due to limited statistics
Need further investigation with PWA

Discussion

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

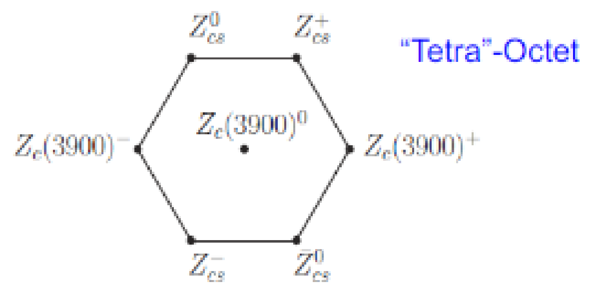


Only a few MeV higher than the threshold of $D_s^- D^{*0}/D_s^{*-} D^0$ (3975.2/3977) MeV/c^2



At least four quark state ($c\bar{c}s\bar{u}$), hidden charm with strangeness

The production is dominated at $\sqrt{s} = 4.681$ GeV
Any Y contribution?

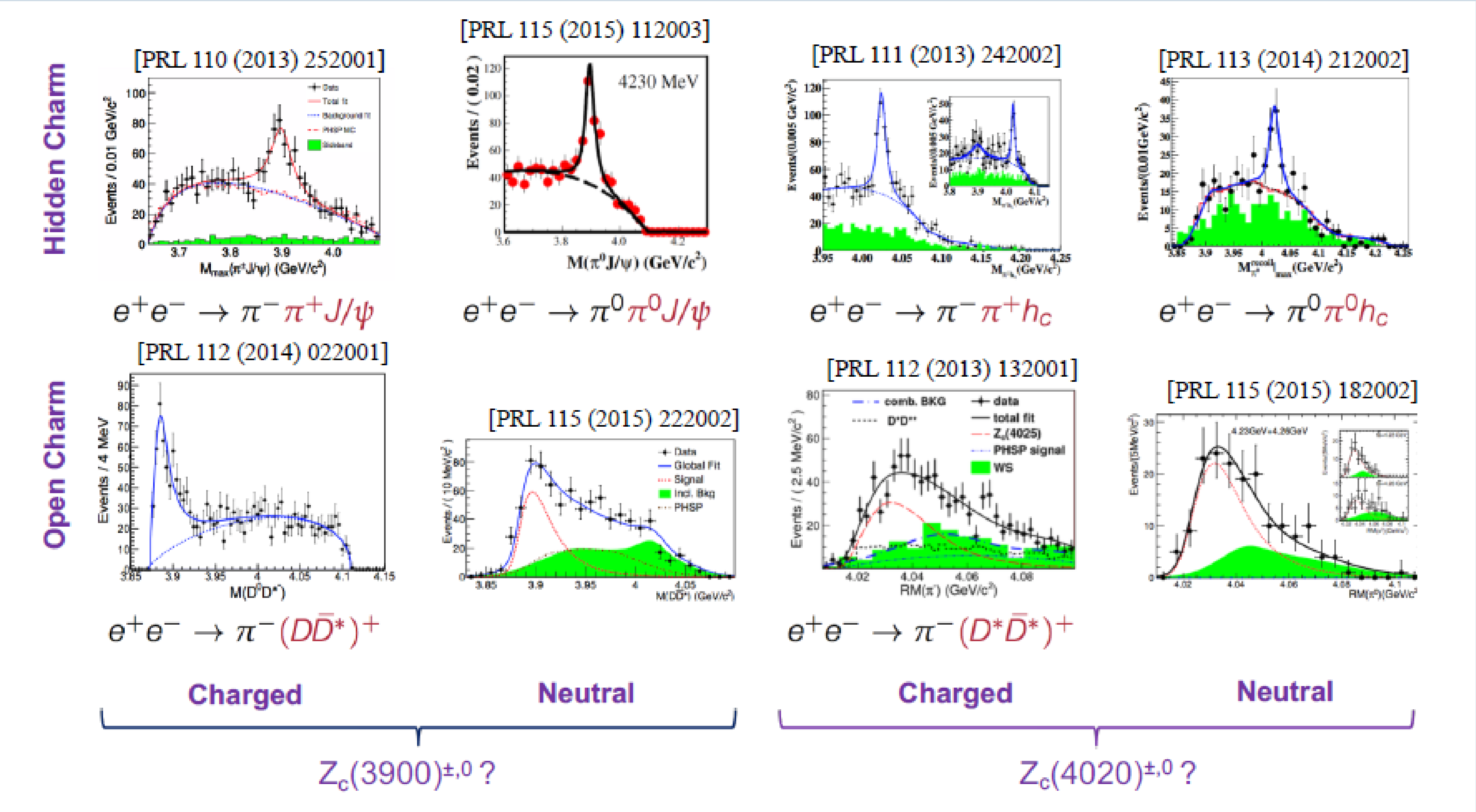


Can $Z_{cs}(3985)^-$form with partner $Z_c(3900)$ a “tetra octet”?

Is it a tetraquark state or a molecule-like?
Or threshold kinematic effects? Or other?

Search for other decay modes Z_{cs}^0/Z_{cs}^{*-}can help

Discussion



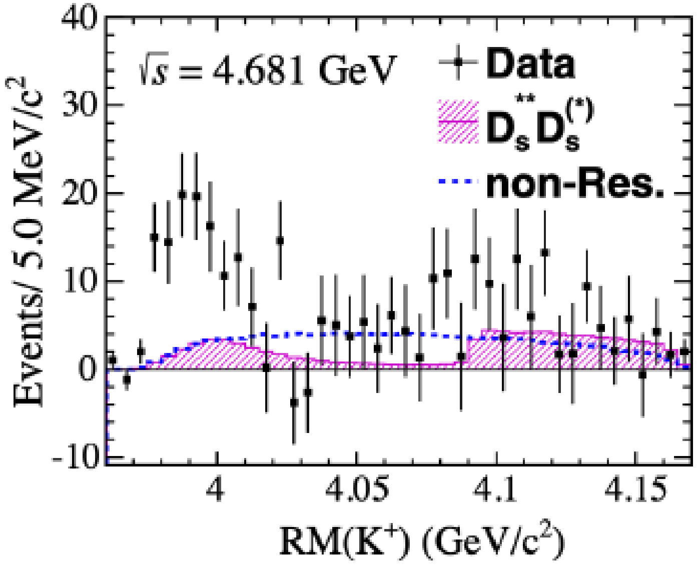
$Z_c(3900)$, $Z_c(4020)$
two isospin triplets of charmonium-like exotic states established

$Z_c(3885)$, $Z_c(4025)$:
what is the nature of these states?
Different decay modes (hidden vs. open charm) of same state observed? (most likely)

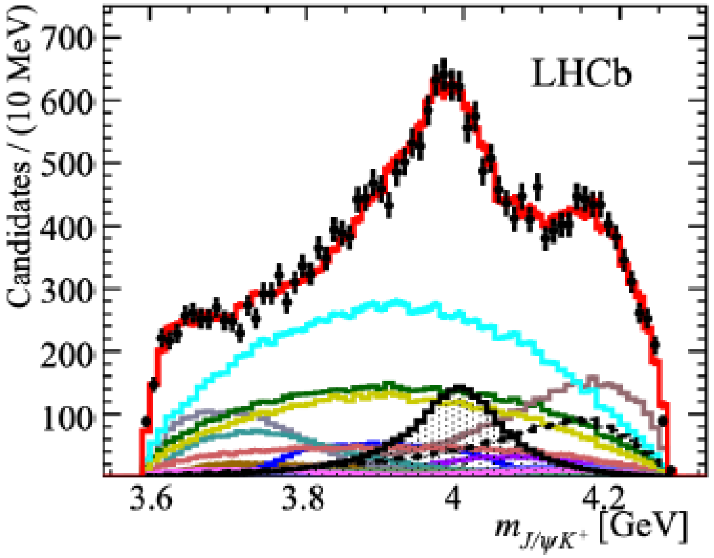
No consensus yet on their four-quark nature

Discussion

BESIII PRL 126, 102001 (2021)



arXiv:2103.01803



BESIII $e^+e^- \to K^+(D_sD^*/D_s^*D)^-$

- Mass: $(3982.5^{+1.8}_{-2.6} \pm 2.1)$ MeV/c^2
- Width: $(12.8^{+5.3}_{-4.4} \pm 3.0)$ MeV
- Open charm final state

LHCb $Z_{cs}(4000)$ in $B^+ \to \phi(J/\psi K^+)$

- Mass: $(4003 \pm 6^{+4}_{-14})$ MeV/c^2
- Width: $(131 \pm 15 \pm 26)$ MeV
- $J^P = 1^+$
- Hidden charm final state

Different decay modes (hidden vs. open charm) of same state observed?

New era of charmonium-like states started two decades ago, and more than 20 unexpected XYZ states have been discovered

Charged Z_c states are manifestly exotic states
First complete isospin triplets established
First strange partner(s) reported
More candidates reported, further to be studied

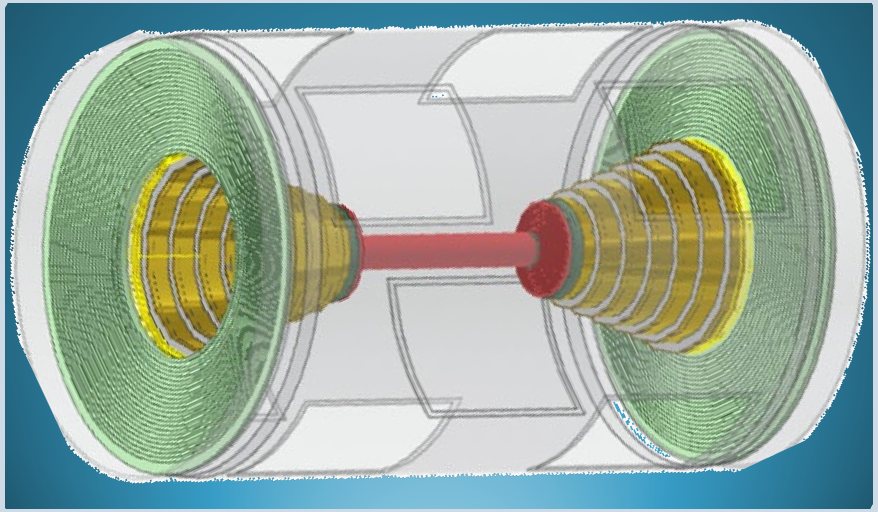
Completion of the exotic multiplets
High statistics and precision, in combination with different probes

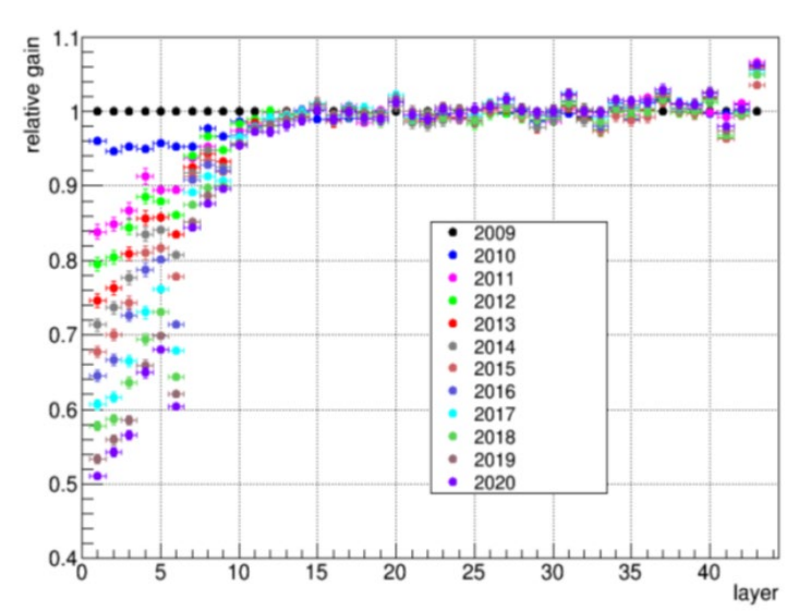
BESIII successfully operating since 2008
World largest data sets in tau-charm mass region, unique XYZ data
Machine upgrade allows to extend studies up to E_{cm} = 5 GeV

Further machine upgrade →2024
Spectrometer upgrade→CGEM detector

INFN
中國科學院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences
JOHANNES GUTENBERG UNIVERSITÄT MAINZ
UPPSALA UNIVERSITET

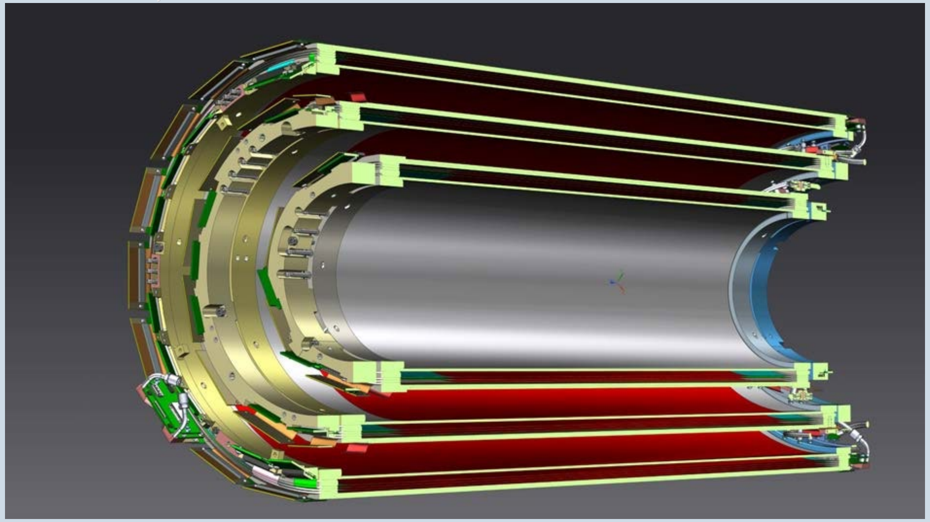
MDC>inner chamber

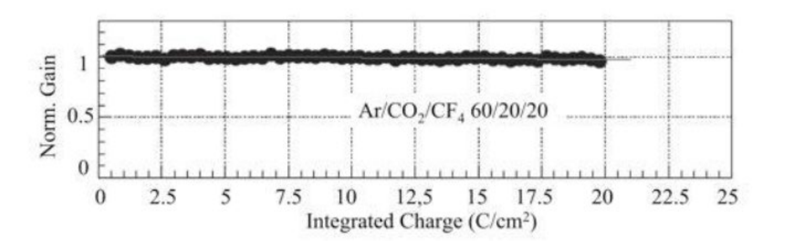




Aging
Gain loss/year
~ 4% on inner layers

CGEM> GEM technology



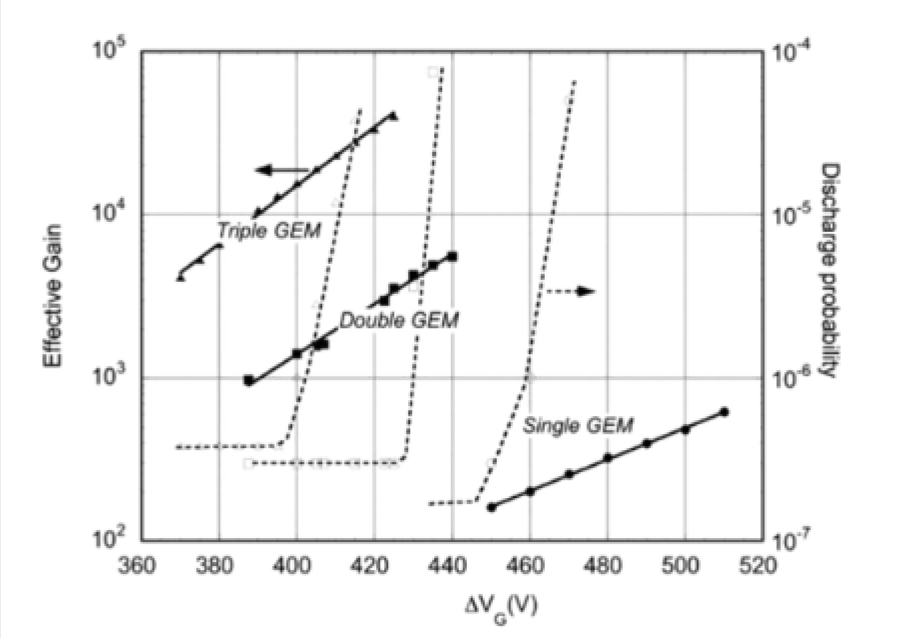


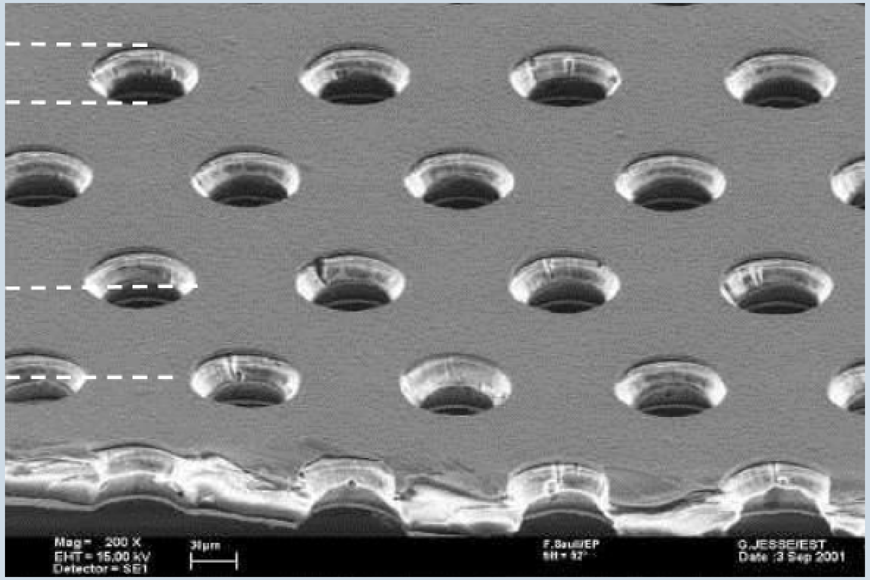
Low spatial charge
High rate capability
Fast response
Light support frame
Very low aging

GEM detectors

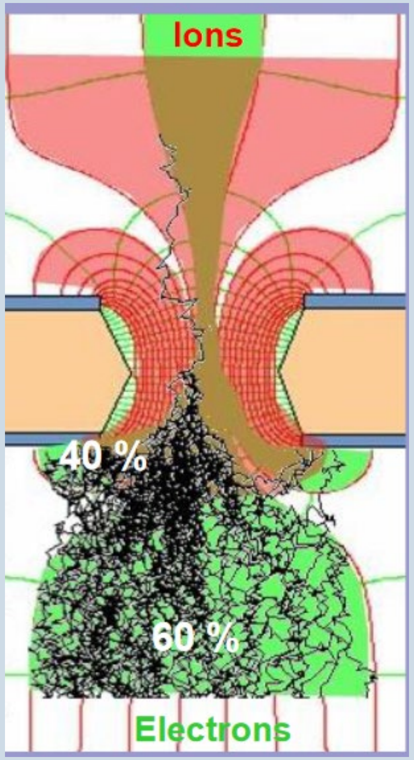
GEM (Gaseous Electron Multiplier) is a Micro Pattern Gas Detector, invented by Sauli in 1997

- High rate capability
- High radiation hardness
- Scalable and flexible geometry





NIMA 386, 1997

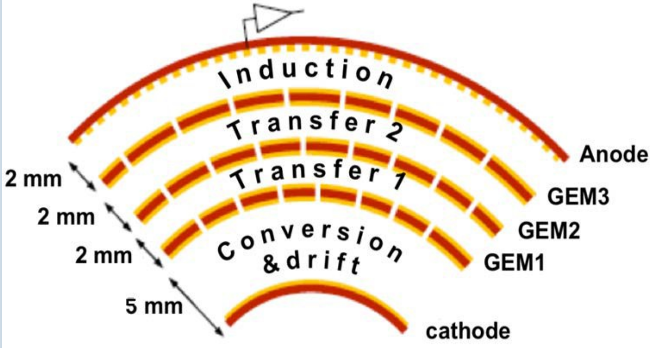


More layers of GEM grant high gain with lower applied voltages → lower spark rate

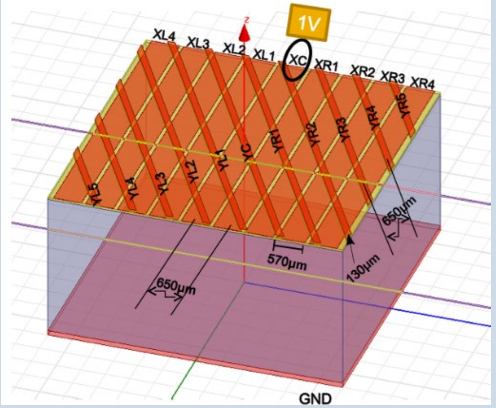
NIMA 805, 2016

CGEM> Cylindrical Gaseous Electron Multiplier

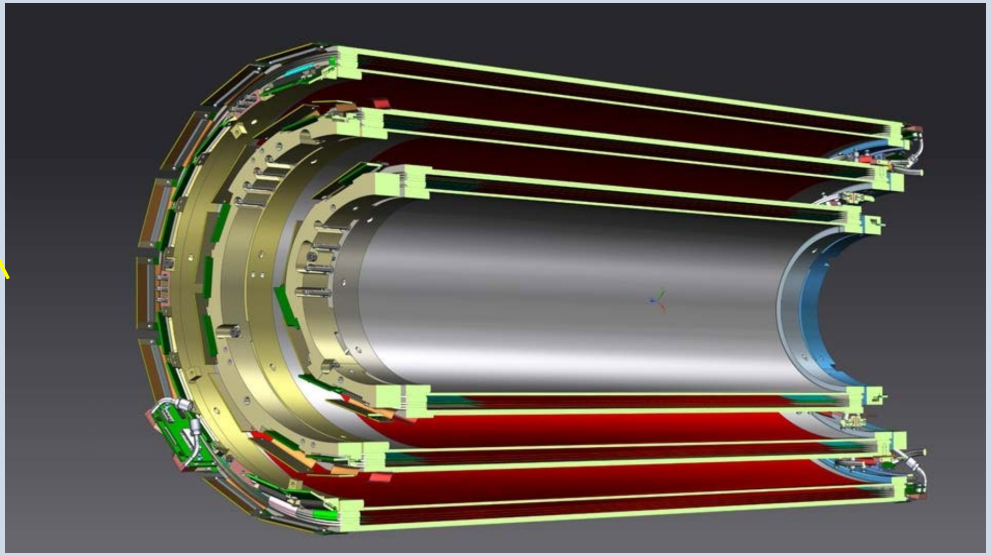
- σ_{xy} ~ 130 µm
- σ_z < 1 mm (~ 350 µm)
- σ_{pt}/p_t ~ 0.5% @ 1 GeV/c
- Operation in 1T magnetic field
- Material budget $\leq$ 1.5% X_0
- High rate capability: 10^4 Hz/cm^2

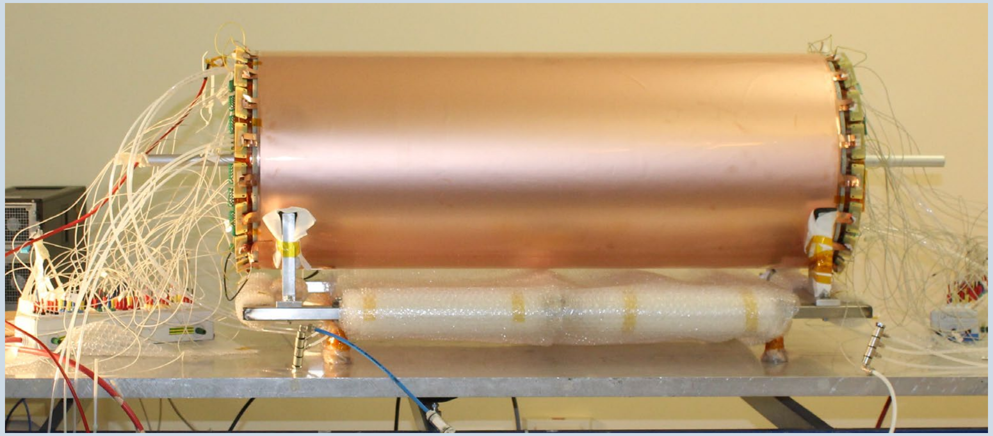


Three layers of cylindrical triple-GEM
Each layer has two "views" to reconstruct the 3D position of the hits



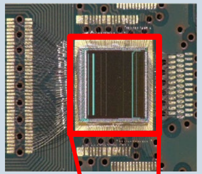
Ar-iC4H10 (90%-10%)
1.5/3/3/5 kV/cm

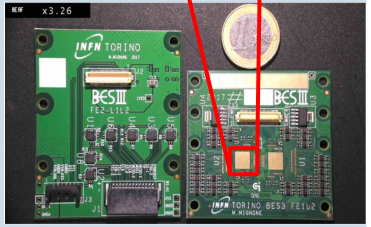




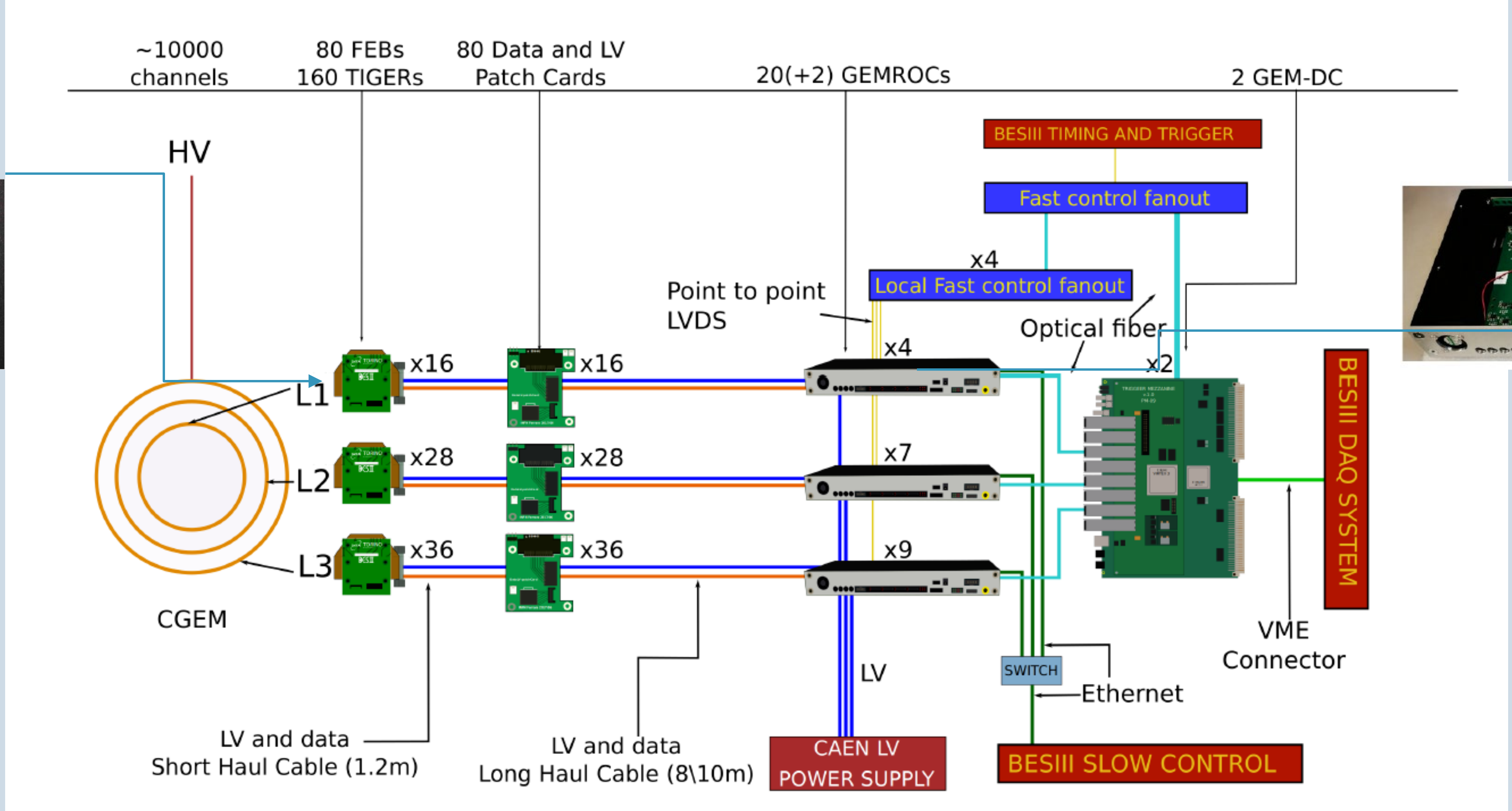
CGEM> Readout electronics

TIGER

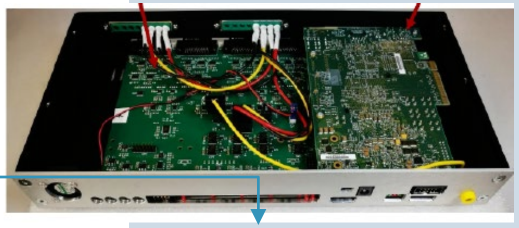




JINST 12 C07017

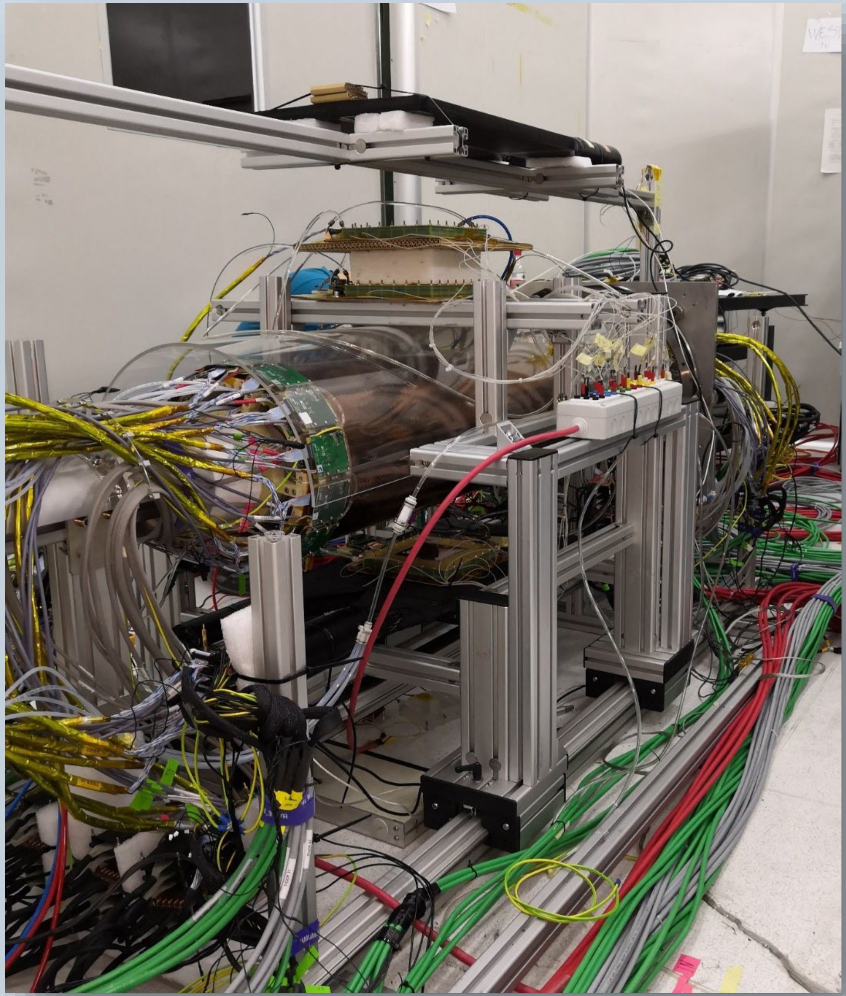


GEMROC



arXiv:2105.08979

CGEM> Cosmic setup in Beijing



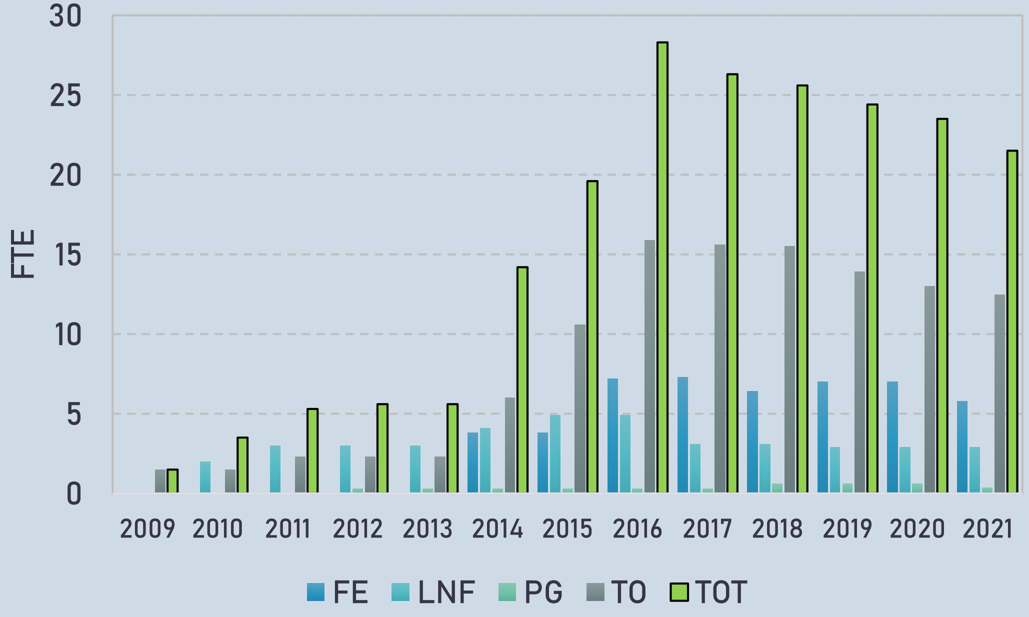
On site operations carried out thanks to the BESIII MDC group

~5.6k channels connected
Final LV/HV systems

More than one year of data taking

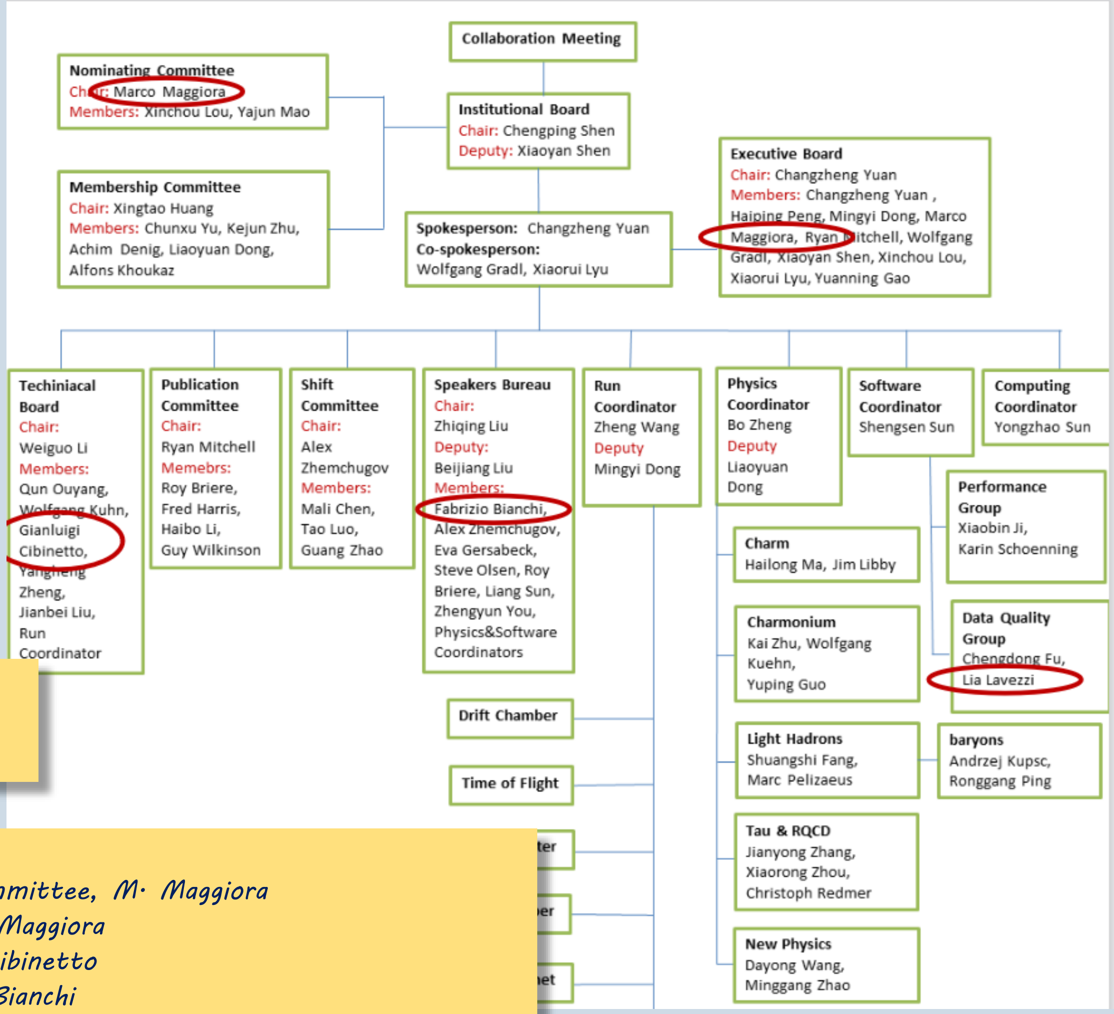
Remote data taking carried out by the Italian groups

Italian Collaboration



~22 FTE
~30 authors (~6% of the total)
~ 50 people

~ 350 publications +
~ 20 technical papers



Activities
- data analysis
- analysis internal referral
- support computing production
- data taking shifts
- CGEM-IT

BESIII Responsibility roles
- Chair Nominating committee, M. Maggiora
- Executive Board, M. Maggiora
- Technical Board, G. Cibinetto
- Speakers Bureau, F. Bianchi
- CGEM-IT System Manager, G. Cibinetto
- Data Quality Group Coordinator, L. Lavezzi
- Institution Board (M. Bertani, M. Maggiora, G. Cibinetto)

Credits
Disclaimer

Credits

BESIII collaboration;
Bettoni D;
Brambilla N et al;
CGEM working group;
Cibinetto G;
Goetzen K;
Gradl W;
Hüsken N;
Li P-R;
Liao L;
Liu Z;
Maiani L et al;
Mussa R;
Nerling F;
Neubert S;
Olsen S L;
Mezzadri G;
Pelizäus M;
Spataro S;
Xu Y-C;
Yuan C-Z
...

A lot of really interesting stuff was not presented,

*X-Y states in details
*Atlas, BaBar, Belle, CDF, Cleo-c, CMS, DO, LHCb... results (apart from some citations)

- Exotic states from bottomonium

Many reviews from theoretical and experimental point of view
Brambilla N et al (arXiv: 1907.0783v2)
Mezzadri G and Spataro S, under preparation

Stay tuned for other BESIII exotic news!

謝謝

Thank You