Roma 8-10 aprile 2015
IFAE
INCONTRI DI FISICA DELLE ALTE ENERGIE
2015

BESIII

Risultati recenti dell'esperimento BESIII

F.De Mori

per la collaborazione BESIII

Università degli studi di Torino

INFN sez. Di Torino

UNIVERSITÀ DEGLI STUDI DI TORINO

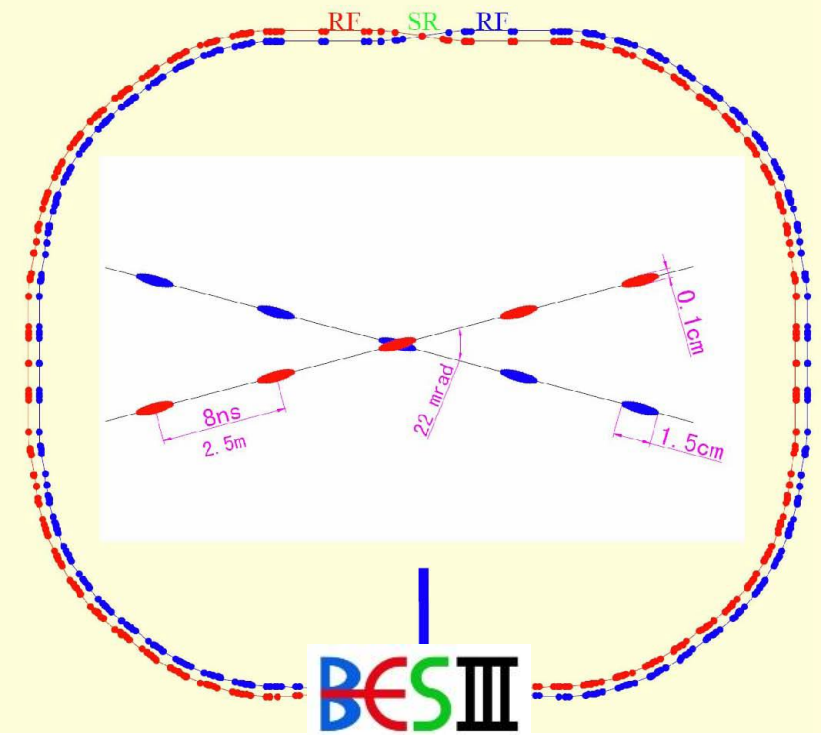
INFN Istituto Nazionale di Fisica Nucleare

Outline

- L'esperimento BESIII
- L'upgrade del tracciatore interno di BESIII:
  il progetto CGEM-IT
- Una personale scelta tra i moltissimi risultati di BESIII:
  - Misura delle asimmetrie di Collins
  - Una selezione di stati XYZ

- Conclusioni

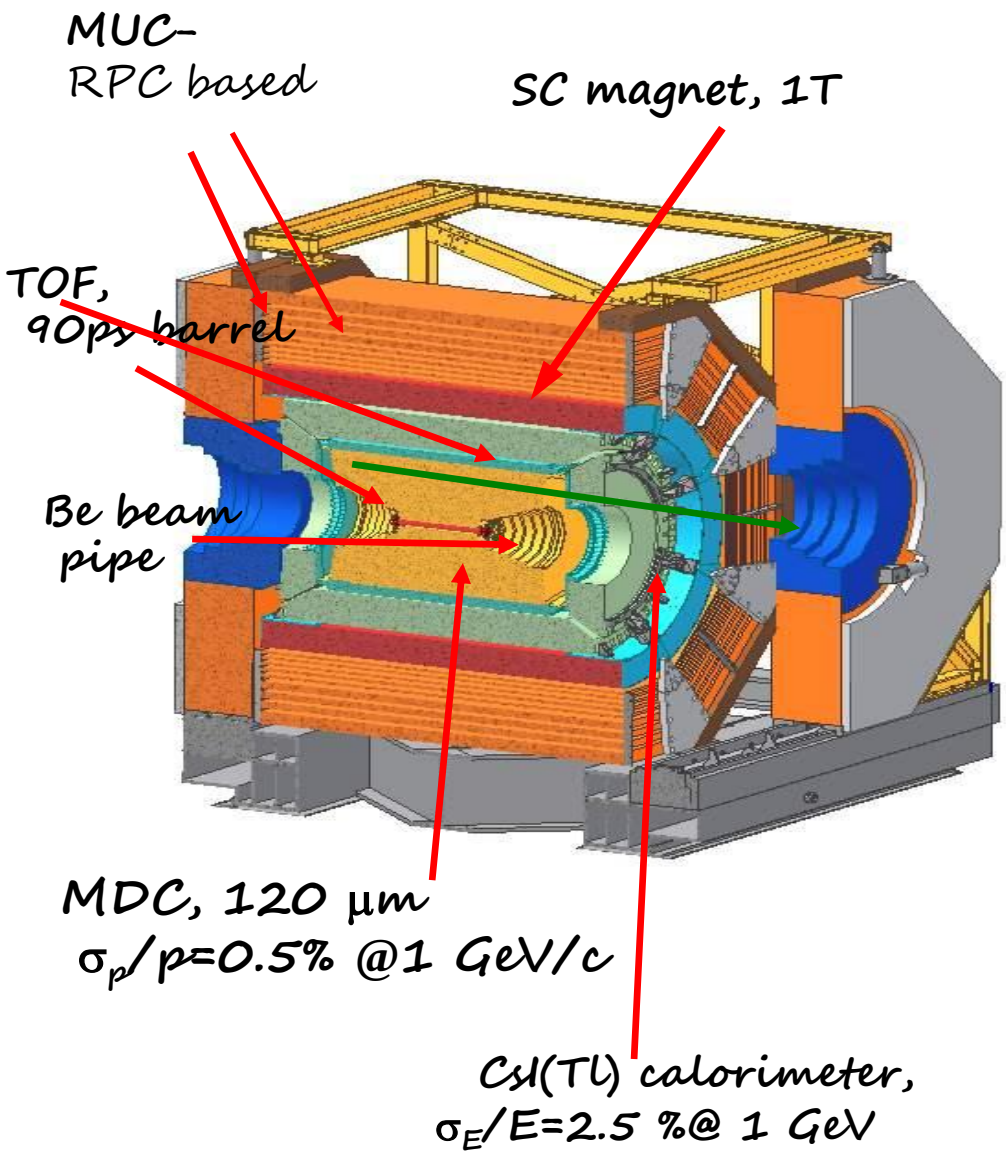
BEPCII: una τ-charm factory



Upgrade of BEPC (started 2004, first collisions July 2008)
Beam energy 1 . . . 2.3 GeV
Optimum energy 1.89 GeV
Single beam current 0.91 A
Crossing angle: ±11 mrad
Energy spread: 5.16 ×10-4

Design luminosity: 10^{33} cm^{-2} s^{-1}
Achieved: $8*10^{32}$ $cm^{-2}s^{-1}$
Beam energy measurement by Laser compton backscattering
$\Delta E/E \approx 5*10^{-5}$ (50 keV at τ threshold)

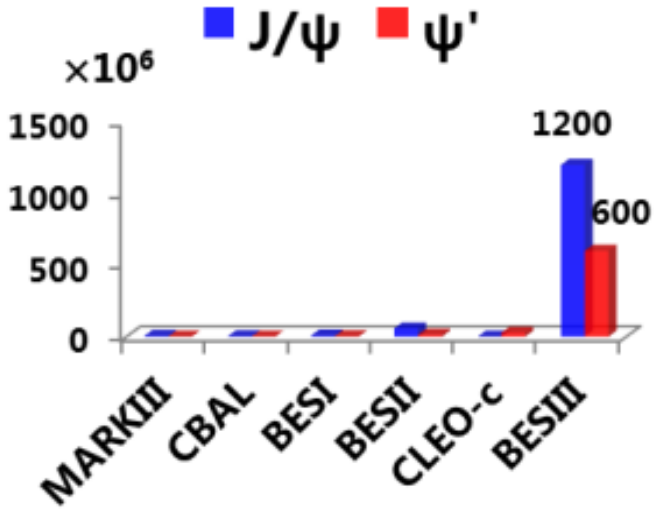
BESIII: il rivelatore e la fisica

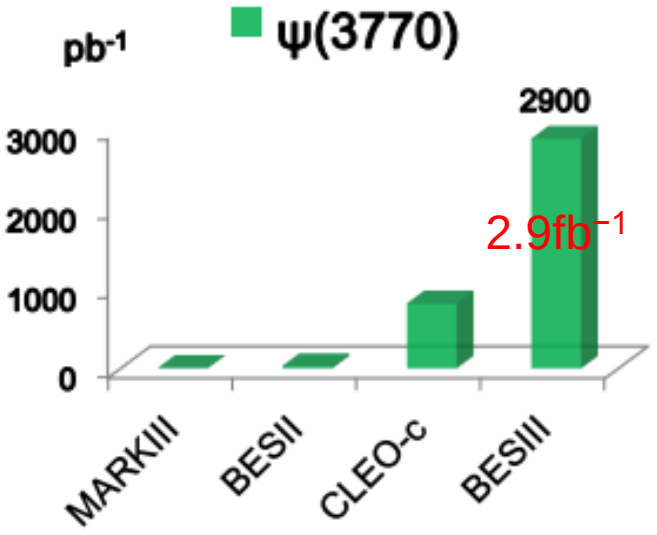


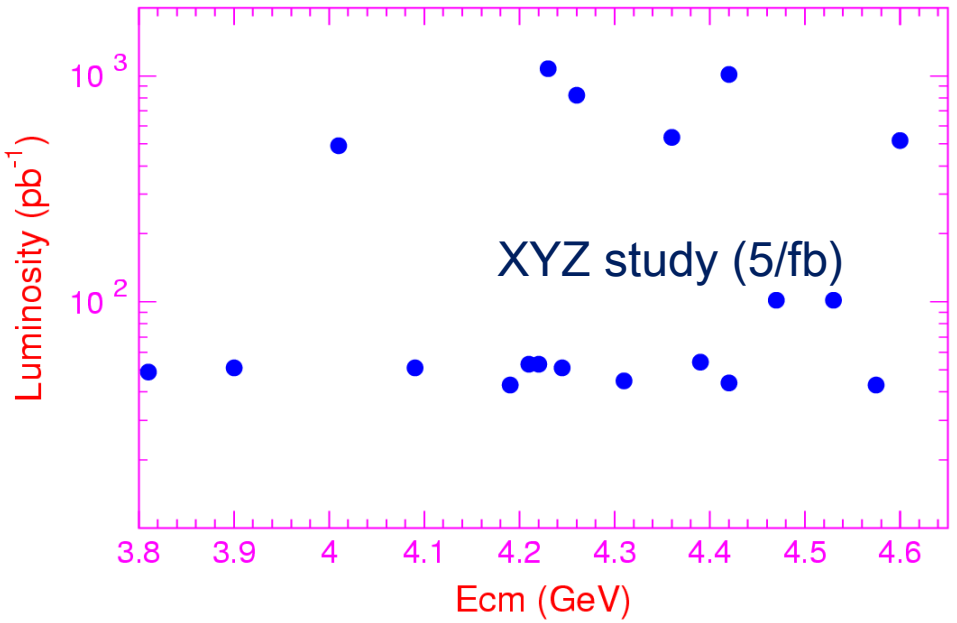
Large acceptance: 93% 4π

- Charmonium physics
- Charm Physics
- Light Hadron Spectroscopy
- QCD & τ-Physics
- Spin Physics
- …

BESIII data-set







- + 104 energy points between 3.85 and 4.59 GeV
- + 20 energy points between 2.0 and 3.1 GeV (ongoing)
- Direct production of 1^{--} states studied with world's largest scan dataset

High luminosity,clean environment
Access to precise measurements of rare processes: Key to understanding of **exotic matter**

BESIII: la collaborazione

US (5)

Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Europe (13)

Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna: BINP Novosibirsk
Italy: INFN e Univ. di Torino , : INFN e Univ. di Ferrara, LNF Frascati
Netherland : KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

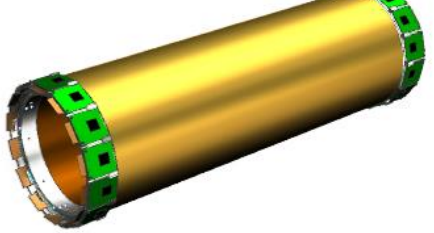
Univ. of Punjab
COMSAT CIIT

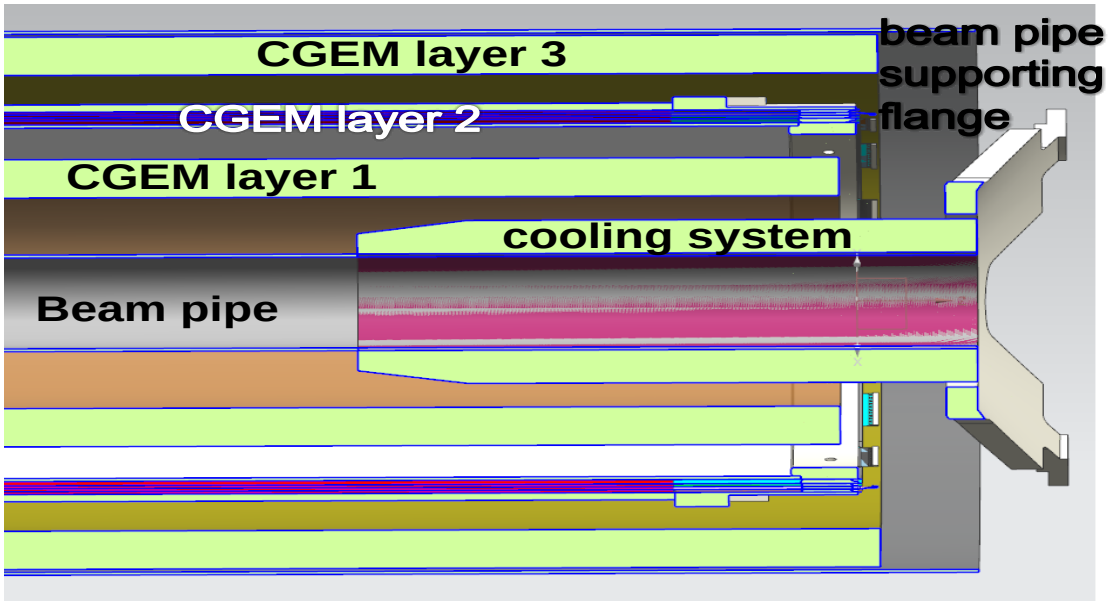
China(31)

IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Beihang Univ., Beijing Petrol Chemical Univ.

400 membri
55 istituzioni
11 nazioni

BESIII Inner Tracker upgrade: The BESIII CGEM-IT





Length of the three layers will be slightly incremental with the radius (Inner radius 78 mm and outer radius 179 mm).

.

Each of the three detector layer is composed by five cylindrical elements:
- one cathode (conversione/drift)
- three GEM (amplification)
- one anode (signal collection)

- Rate capability: ~10^4 Hz/cm^2
- Spatial resolution: σ_{xy} =~100μm : σ_z=~1mm
- Momentum resolution:: σ_{pt}/P_t =~0.5% @1GeV
- Efficiency = ~98%
- Material budget ≤ 1.5%X_0 all layers
- Coverage: 93% 4π
- Operation duration ~ 5 years

Key Innovations from KLOE2 CGEM base
- *Analogue readout* to reach the required *spatial resolution*
- *Rohacell* in the cathode instead honeycomb→ *thickness reduction*
- Anode design

Per i dettagli→ Presentazione di Mezzadri G. alle 18:50

In June 2014 the CDR of CGEM-IT was released to BESIII collaboration

CGEM-IT milestones:

- to deliver to IHEP and deploy the assembled CGEM-IT at the beginning of 2017;
- to conclude the commissioning of the detector within the end of 2017.

CGEM-IT follow-up:

- 2018 first effective year of BESIII data taking including CGEM-IT information

CGEM-IT

The design

The BESIII CGEM-IT

DAQ & TRIGGER

HV System –Slow control

FEE : On-detector

Off Detector

Software development

Funding from H2020-MSCA-RISE 2014 PROGRAM for the 2015-2018 period.

The consortium (italian leadership): INFN, IHEP, JGU-Mainz, Uppsala

Collins Asymmetries Measurement in $e^+e^- \to \pi^\pm \pi^{\mp(\pm)} X$

J. C. Collins, Nucl.Phys. B396, 161 (1993)

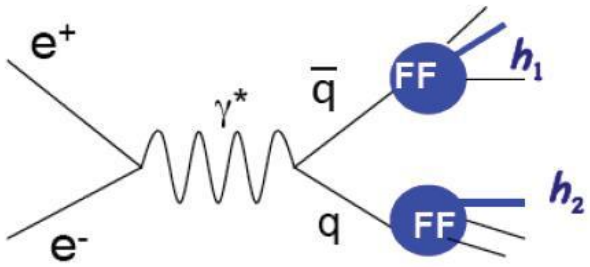
Number density for finding a spinless hadron h produced from a transversely polarized quark:

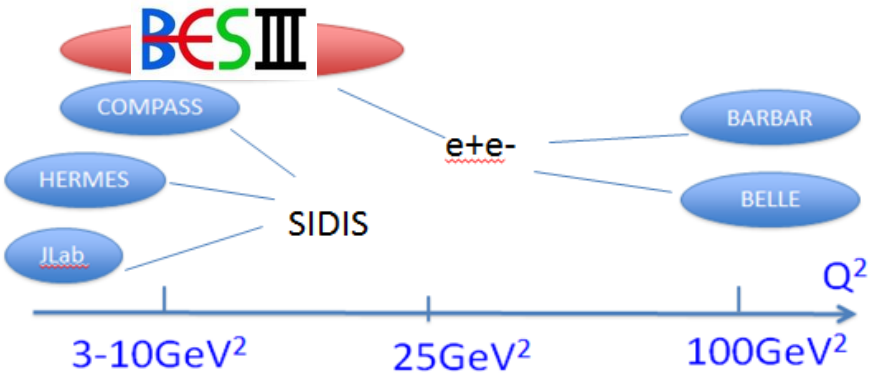
$$D_{hq^\uparrow}(z, P_{h\perp}) = D_1^q(z, P_{h\perp}^2) + H_1^{\perp q}(z, P_{h\perp}^2) \frac{(\hat{\mathbf{k}} \times \mathbf{P}_{h\perp}) \cdot \mathbf{S}_q}{z M_h},$$

unpolarized FF

Collins(Polarized) FF depends on $z = 2E_h/\sqrt{s}$, $\mathbf{P}_{h\perp}$

Collins FF ⊗ Collins FF





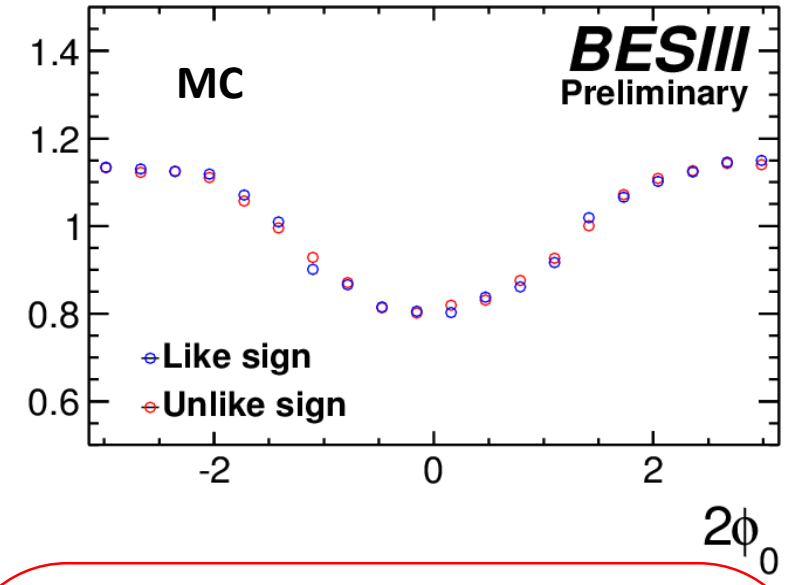
leads to an azimuthal modulation of hadrons around the quark momentum ($\hat{k}$)

measurement of Collins function in $e^+e^- \to \pi^{\pm)} X$
is not possible being quark spin direction unknown
BUT
In $e^+e^- \to \pi^\pm \pi^{\mp(\pm)} X$
correlation between two hadrons in opposite jets results in
azimuthal angle modulation of the observed dihedron yield

Collins Asymmetries Measurement in $e^+e^- \to \pi\pi X$

Authors: Garzia I., Guan Y., Li H., Lu X.

$$\sigma \sim 1 + \frac{\sin^2\theta_2}{1+\cos^2\theta_2}\cos(2\phi_0)\mathcal{F}\left[\frac{H_1^{\perp}(z_1)\bar{H}_1^{\perp}(z_2)}{D_1(z_1)\bar{D}_1(z_2)}\right]$$



Accessing the Collins Asymmetries: measurement of cos(2Φ_0) modulation of hadron pair (N(2Φ_0)) on the top of flat distribution due to unpolarized part of fragmentation function (<N>).

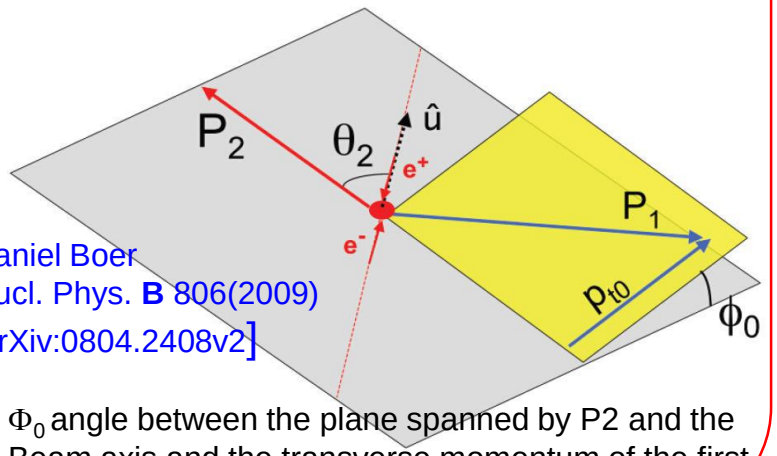
$$R := \frac{N(2\phi_0)}{\langle N_0 \rangle}$$

The **Favored** fragmentation function is of quark of flavor q into hadron with a valence quark of the same flavor: i.e.: $u \to \pi^+, d \to \pi^-$
The **Disfavored ->**for $u \to \pi^-, d \to \pi^+$

In the two hemispheres, we can detect:
–Unlike-sign (UL)pairs ($\boldsymbol{\pi}+\boldsymbol{\pi}-$) (fav x fav)+(dis x dis)
–Like-sign (L)pairs ($\boldsymbol{\pi}+\boldsymbol{\pi}+$ ***and*** $\boldsymbol{\pi}-\boldsymbol{\pi}-$) (fav x dis)+(dis x fav)
–All Charged pairs ($\boldsymbol{\pi}\ \boldsymbol{\pi}$)

<u>Small deviations in Like and Unlike in data indicate asymmetries</u>

Second hadron momentum frame



Daniel Boer
Nucl. Phys. **B** 806(2009)
[arXiv:0804.2408v2]

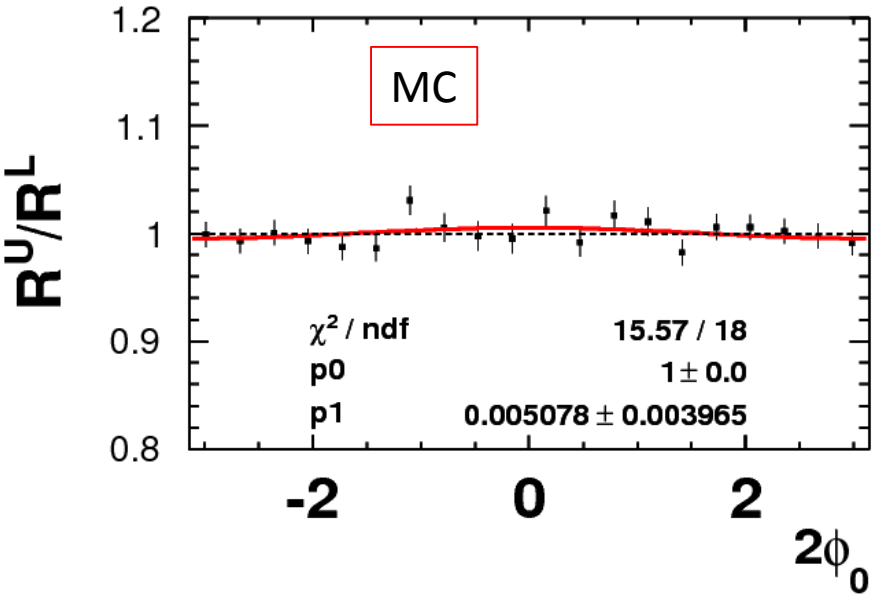
Φ_0 angle between the plane spanned by P2 and the Beam axis and the transverse momentum of the first one respect to the second hadron momentum

Collins Asymmetries Measurement in $e^+e^- \to \pi\pi X$

Authors: Garzia I., Guan Y., Li H., Lu X.

data @3.65GeV

To eliminate the acceptance effects and the first order radiative effects, a double ratio is built:



$$\frac{R^U}{R^{L(C)}} = a\cos(2\phi_0) + b,$$

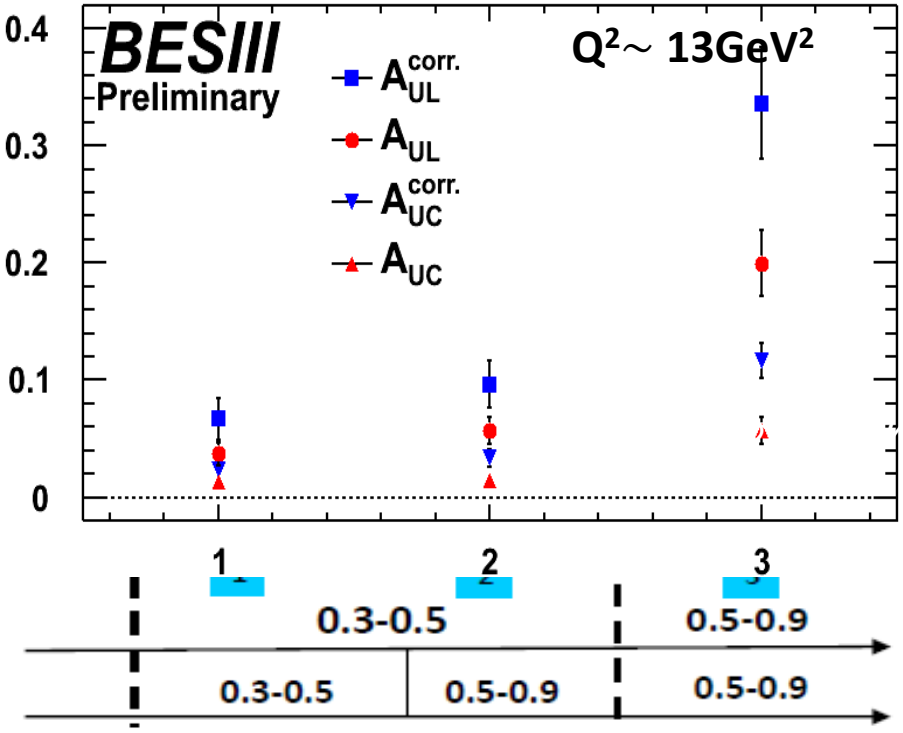
It contains only the Collins asymmetry and higher order radiative effects

Should be consistent with 1 within the statistical error

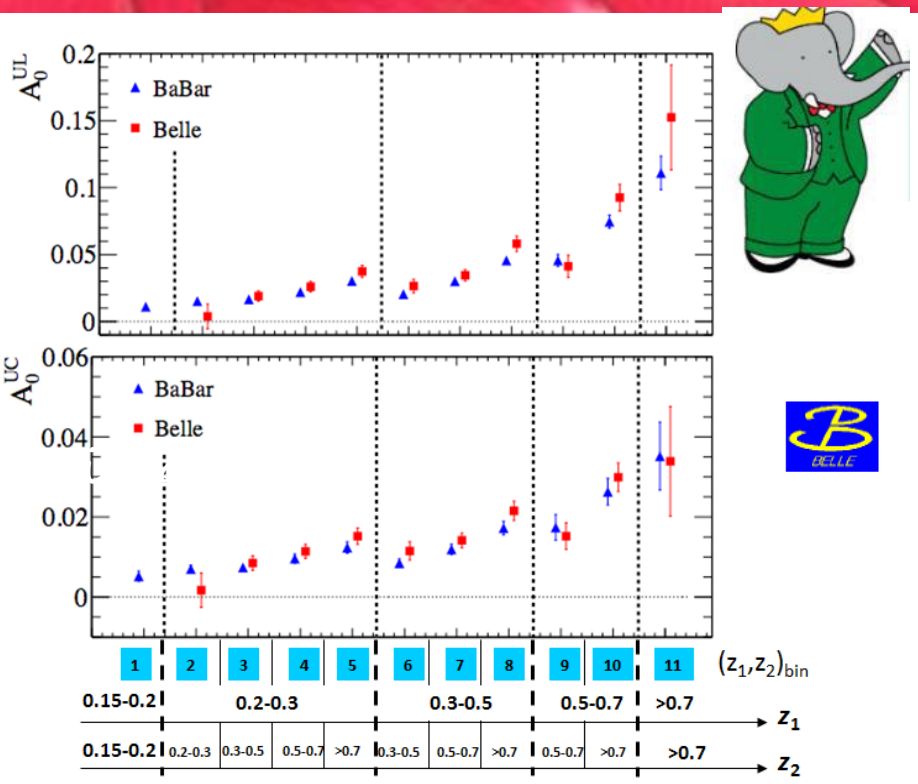
$$A_{UL(C)} = \frac{a}{b}$$

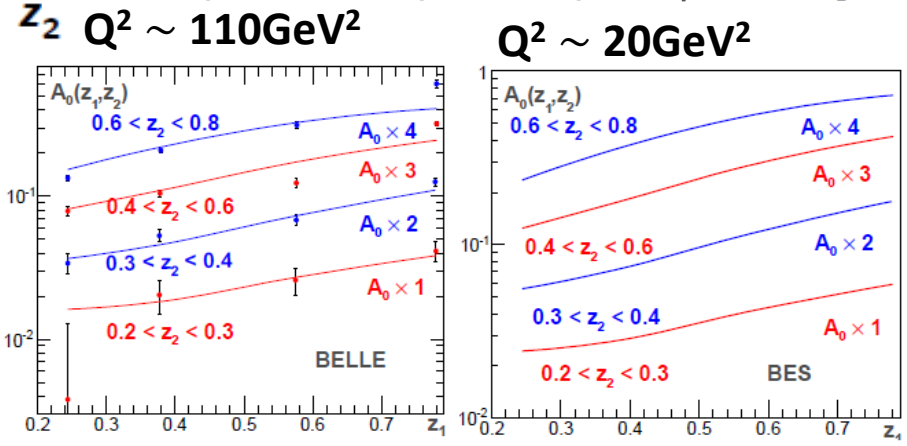
asymmetries of interest (in 3 symmetrized z-bins)

Collins Asymmetries Measurement in $e^+e^- \to \pi\pi X$



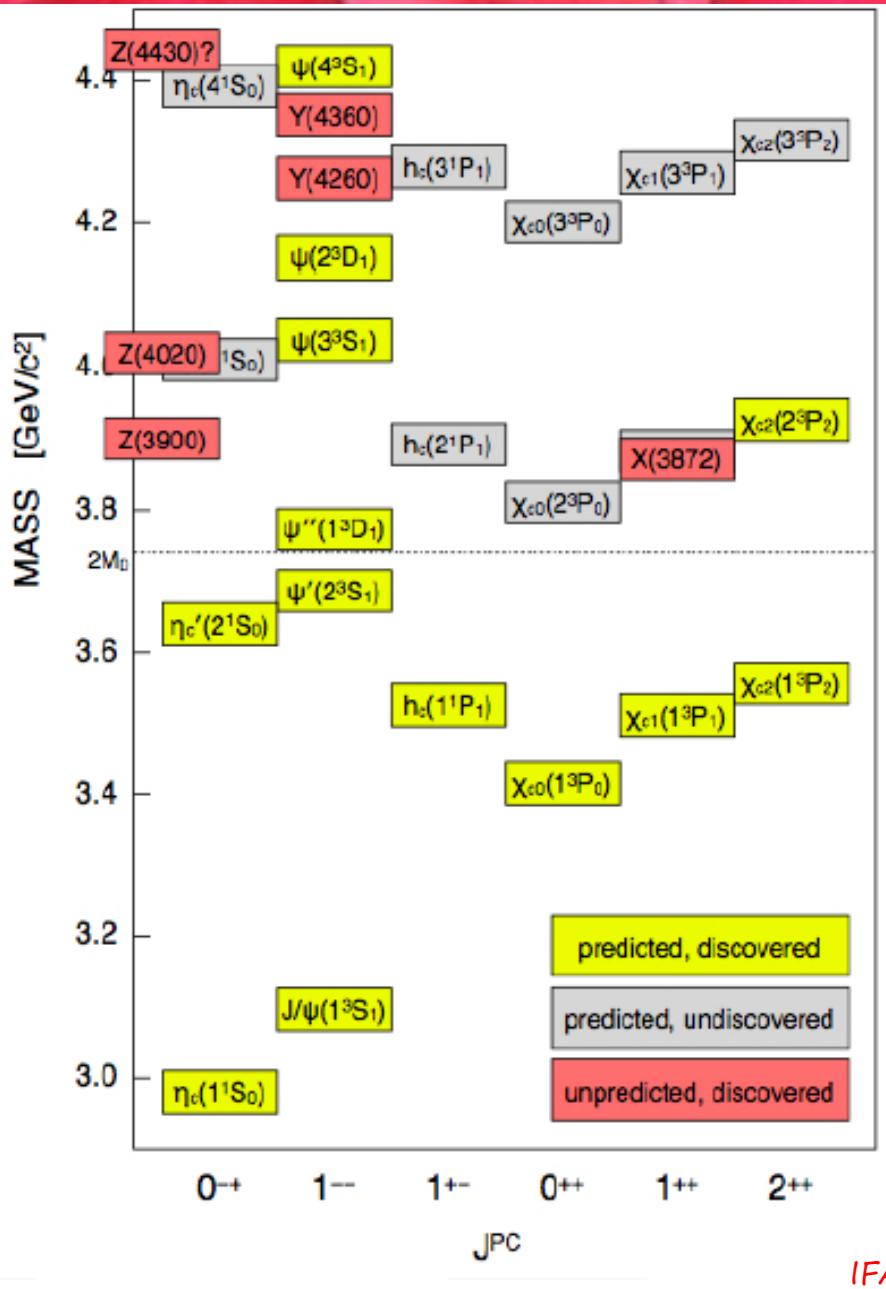
- Statistical uncertainties only.





The measured Collins asymmetris at BESIII are larger than those at higher Q^2 at B factories.
This trend agrees with prediction in PRD 88. 034016 (2013).

XYZ states



Many unexpected states have been reported above the $D\bar{D}$ threshold (XYZ). Several exotic hypotheses for their nature: tetraquarks, hadronic molecules, hybrids, glueballs, ~~hadro-quarkonia~~

Talk di Pilloni A.

X states:
- charmonium-like states with $J^{PC} \neq 1^{--}$
- Observed in B decays, pp and $p\bar{p}$ collisions

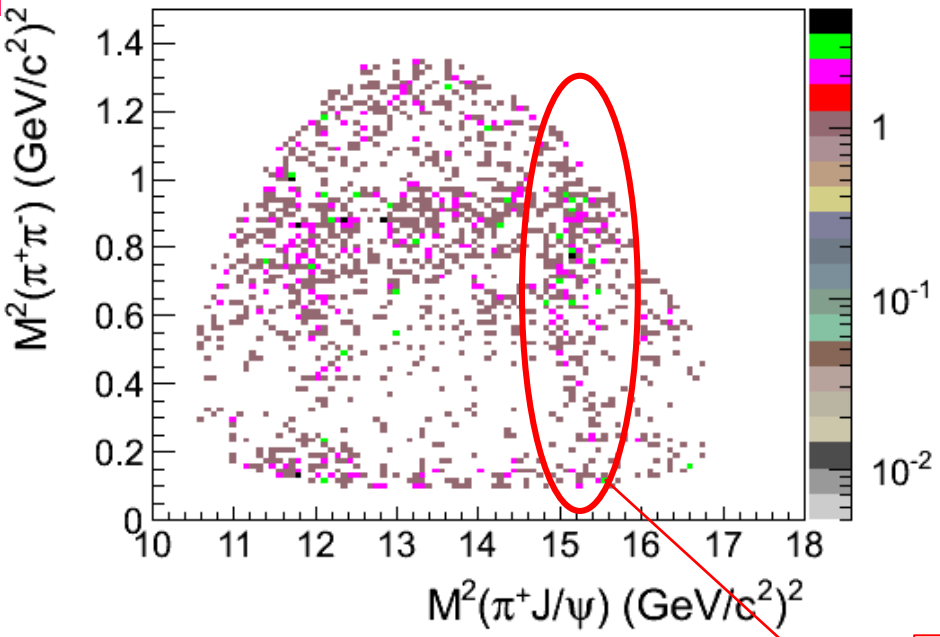
Y states:
- charmonium-like states with $J^{PC} = 1^{--}$
- Observed in direct e+e- annihilation or in ISR

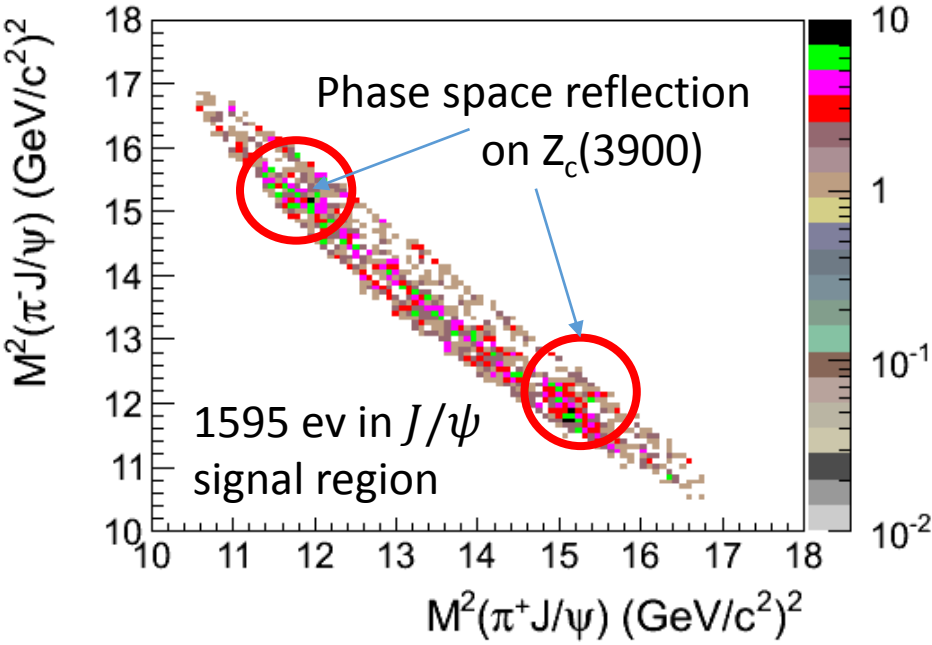
Z states:
- charmonium-like states carrying electric charge
- Must contain at least a $c\bar{c}$ and a light $q\bar{q}$ pair

The BESIII dedicated program from December 2012 to May 2014

$e^- e^+ \to J/\psi\pi^+\pi^-$ @ 4.26 GeV

BESIII: PRL110,252001(2013)

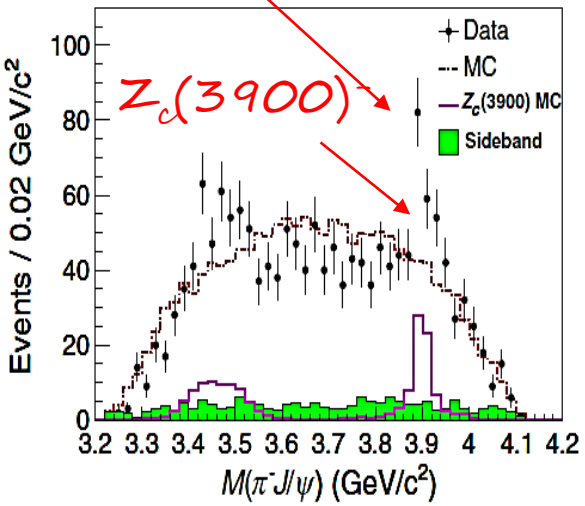


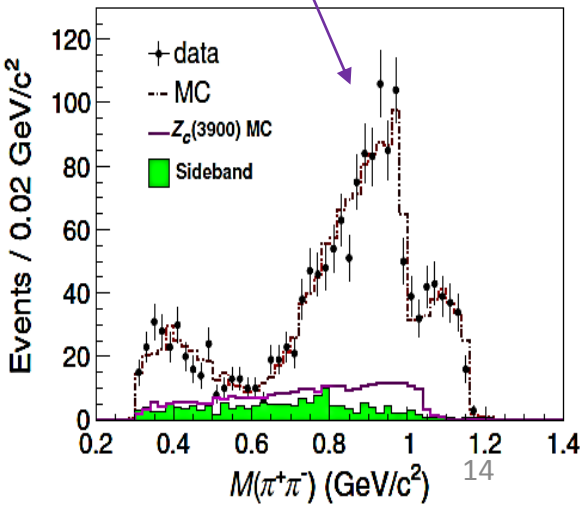


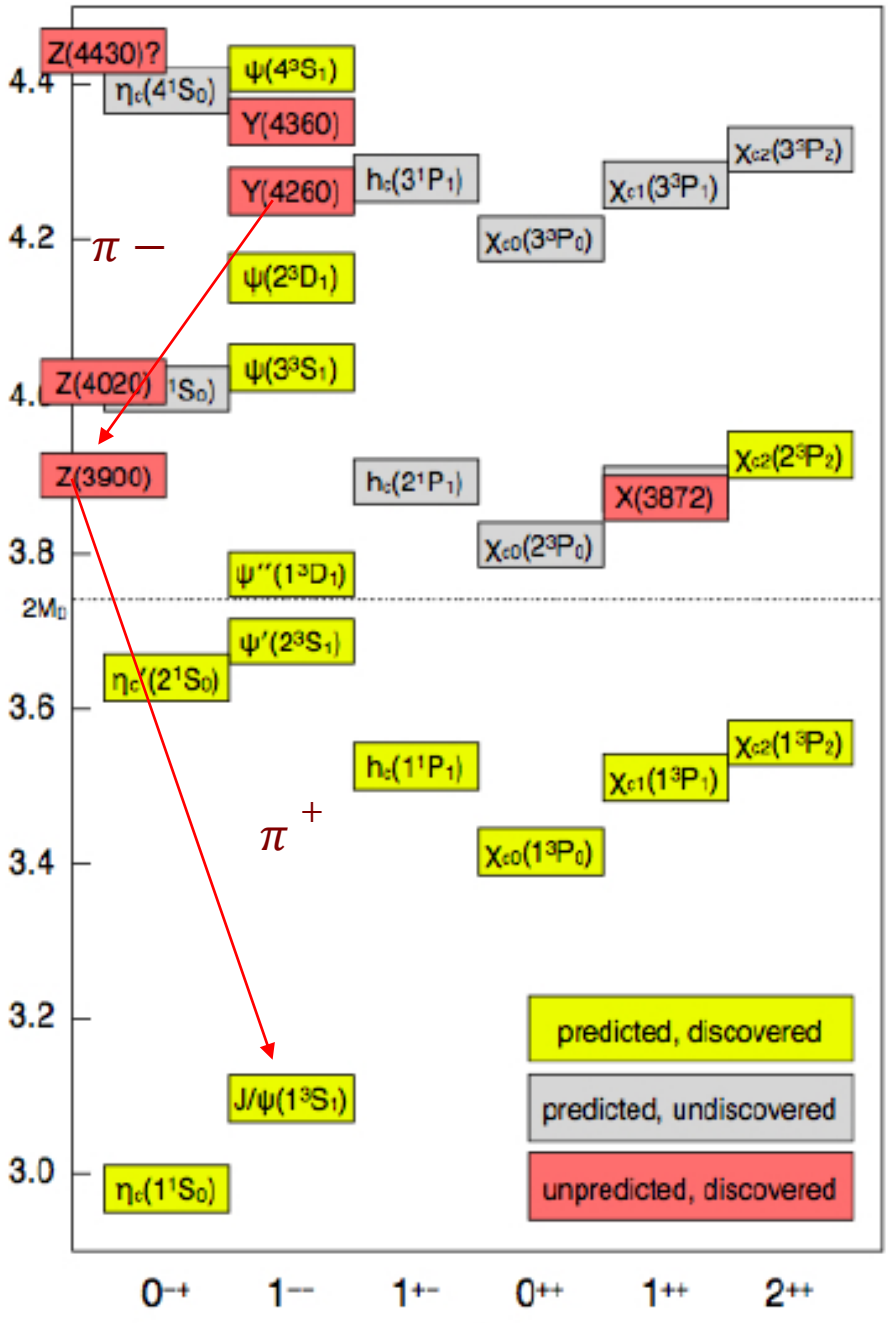
Non-trivial substructure in Dalitz Plot: Resonant substructure in decay

$\pi^+\pi^-$ model: $f_0(500)$, $f_0(980)$, non-resonant→good fit of $\pi^+\pi^-$ mass projection

$J/\psi(\to \ell\ell)\pi^+\pi^-$
very clean sample, high efficiency(about 45%)
Main background : continuum in 4 charged pions



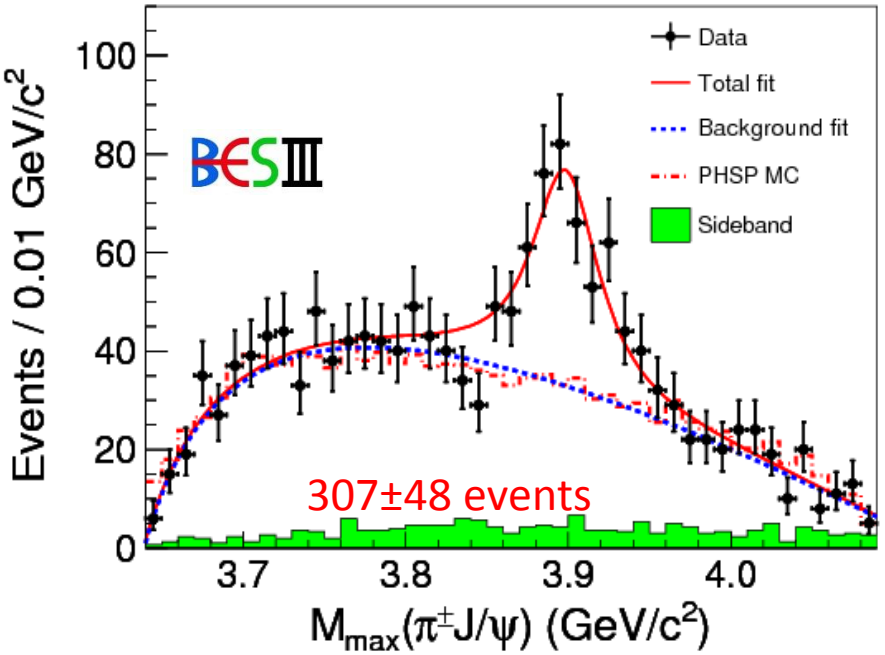




BESIII: PRL 110, 252001 (2013)

Choosing the heavier J/ψπ combination removes reflection

- Fit with S-wave Breit-Wigner



Discovery of charged charmonium-like structure $Z_c(3900)^{\pm}$

$M = (3899.0 \pm 3.6 \pm 4.9)$ MeV/c^2

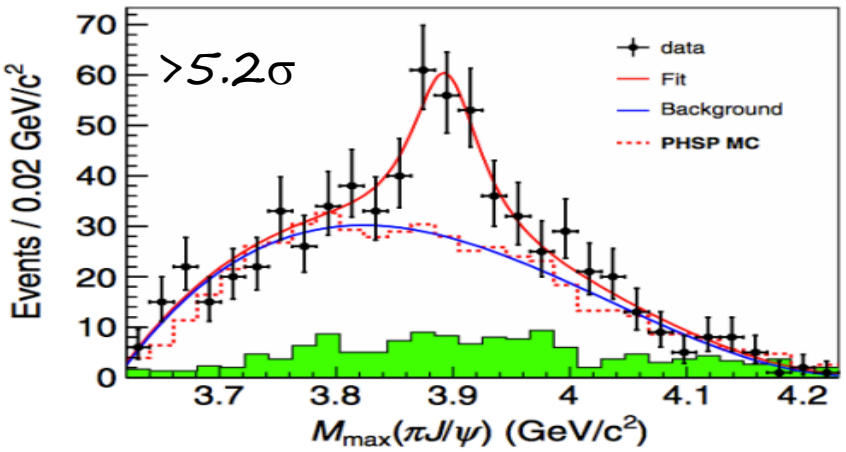
$\Gamma = (46 \pm 10 \pm 20)$ MeV

Significance>8σ

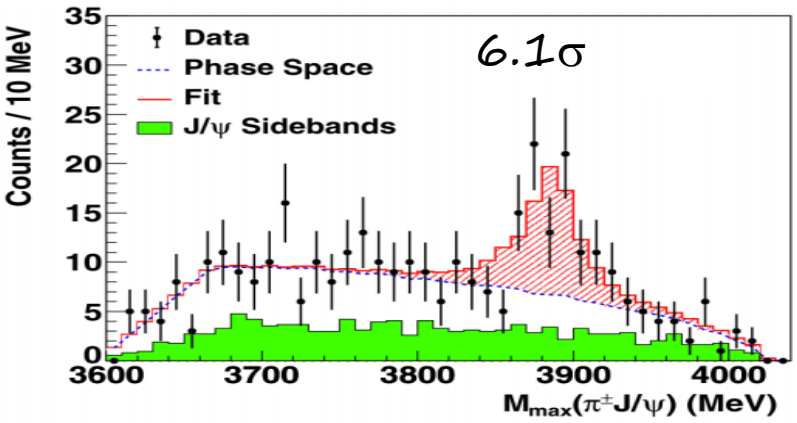
Close to $D\bar{D}^*$ Threshold

$Z_c(3900)^{\pm}$

Belle with ISR data
(PRL 110, 252002(2013))



CLE0-c data@4.17 GeV
(PLB 727, 366(2013))



$Z_c(3900)^{\pm} \to J/\psi\pi^{\pm}$ seen @BESIII, confirmed by Belle and CLEO-c with compatible mass and width

Has electric charge, couples strongly with ccbar, mass close to DD* thr (24 MeV/c^2).

What is it?

	m / MeV	Γ / MeV
BESIII	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$
Belle	$3894.5 \pm 6.6 \pm 4.5$	$63 \pm 24 \pm 26$
CLEOc	$3885 \pm 5 \pm 1$	$34 \pm 12 \pm 4$

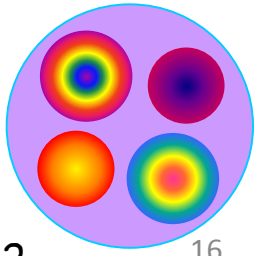
Necessarily exotic (at least $c\bar{c}u\bar{d}$).

Tetraquark state?

DD*molecule?

Hadro-Charmonium?

.....



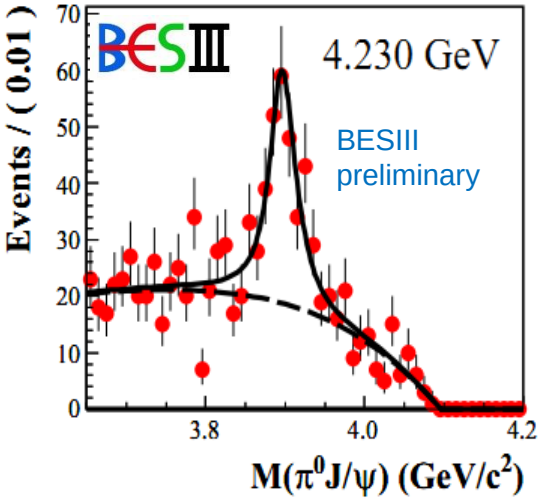
Which are sensitive probes?

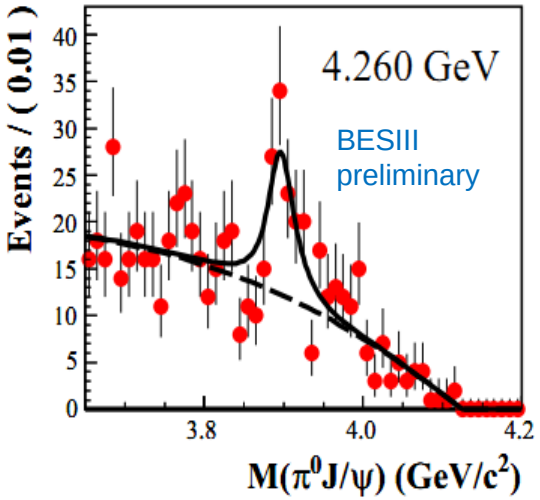
Patner of $Z_c(3900)^+$?Decay modes?

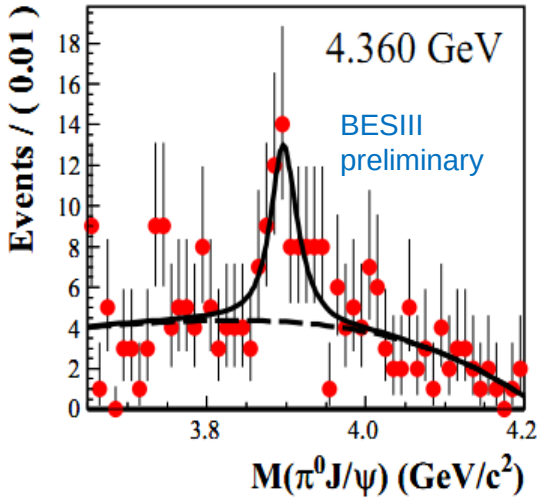
The neutral isospin partner: $Z_c(3900)^0$

New: observation of the Zc(3900)^0 decaying into $\pi^0 J/\psi$ in $e^+e^- \to \pi^0\pi^0 J/\psi$ (2.8 fb^{-1} in [4.19-4.420] GeV)

BESIII preliminary







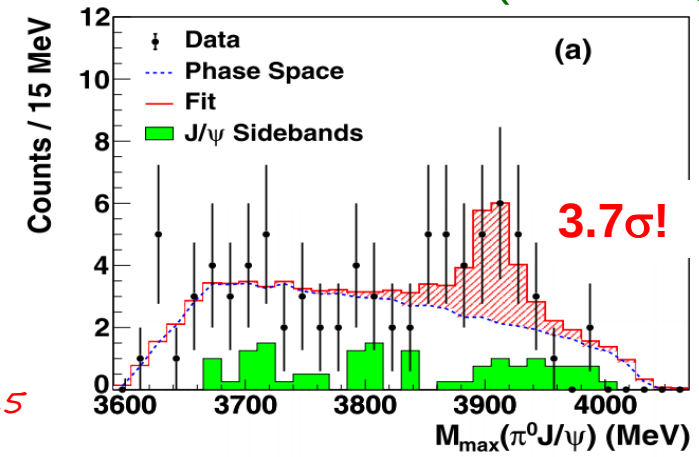
A structure in π^0 J/ψ invariant mass spectrum observed:

M = 3894.8±2.3±2.7 MeV

Γ = 29.6±8.2±8.2 MeV

Significance >10 σ

CLE0c data at 4.17 GeV (PLB 727, 366)



Isospin triplet is established!

Observation of $Z_c(3885)^{\pm}$ in $e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}$ @ $\sqrt{s} = 4.26\text{GeV}$

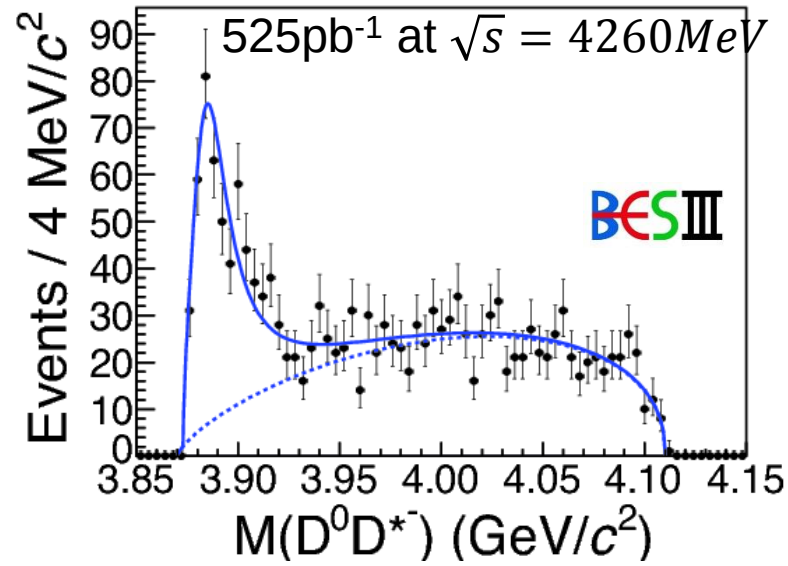
PRL 112, 022001(2014)

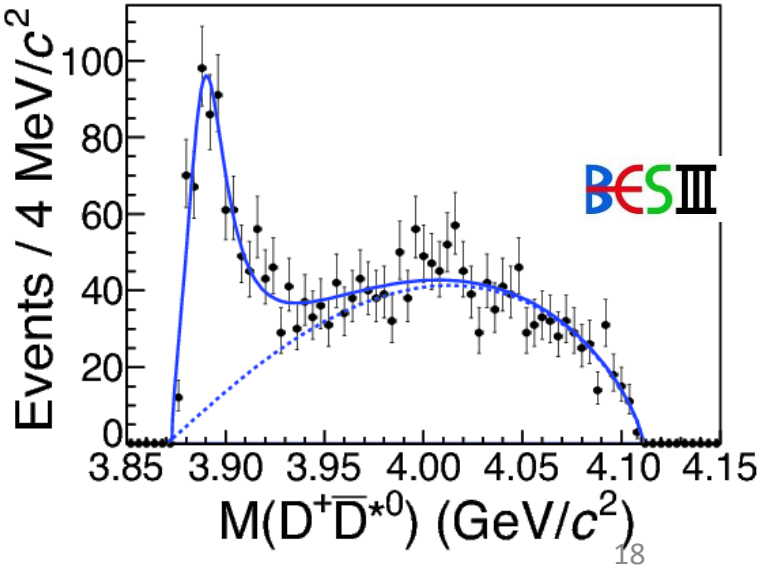
Single tag analysis:

- reconstruct π^+/π^- and $D^0 \to K^-\pi^+$ or $D^+ \to K^+\pi^-\pi^-$
- require $\overline{D^*}$ in missing mass
- Veto $e^+e^- \to (D^*\bar{D}^*)^0$
- apply kinematic fit; look in mass recoiling against π^+ / π^-

Enhancement at $D\bar{D}^*$ threshold in both channels:

M = 3883.9±1.5±4.2 MeV,
Γ = 24.8±3.3 ±11.0 MeV
(fit with BW function)





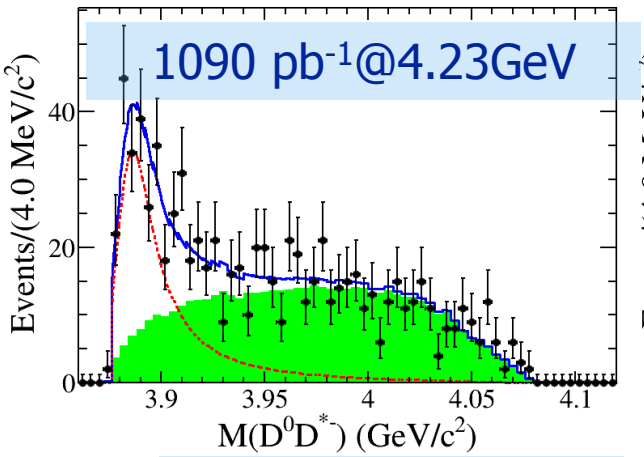
data clearly favour $J^P = 1^+$ for this $D\bar{D}^*$ structure

The mass and width compatible with $Z_c(3900)^{\pm}$ within **2σ** and **1σ** respectively!
Quantum number determination of $Z_c(3900)^{\pm}$ needed

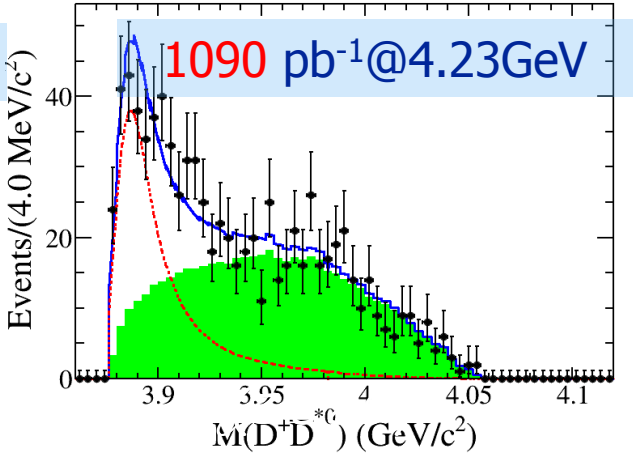
$Z_c(3885)^{\mp}$ in $e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}$ with double D-tag method

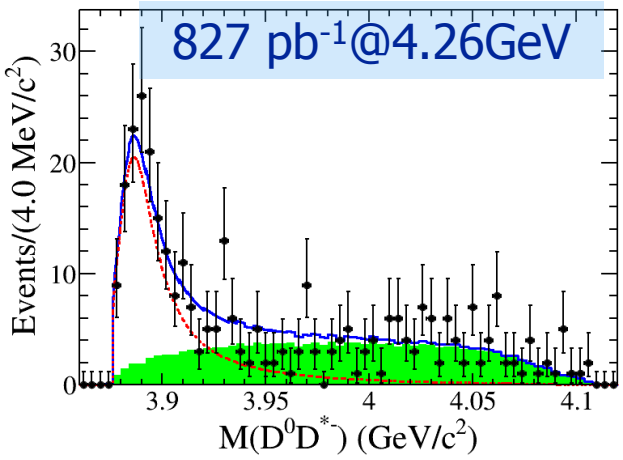
BESIII preliminary

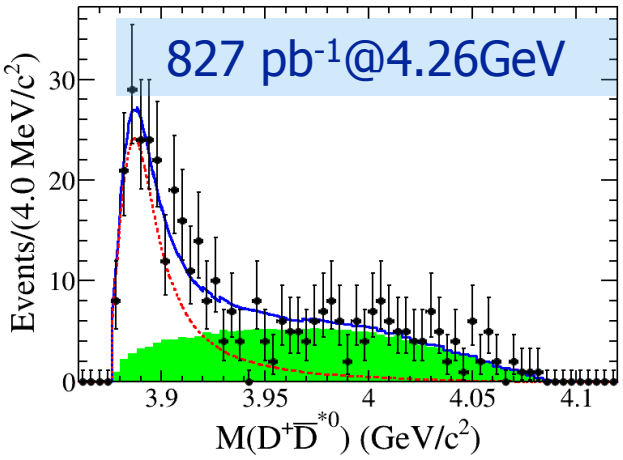
$e^+e^- \to \pi^+ D^0 D^{*-}$

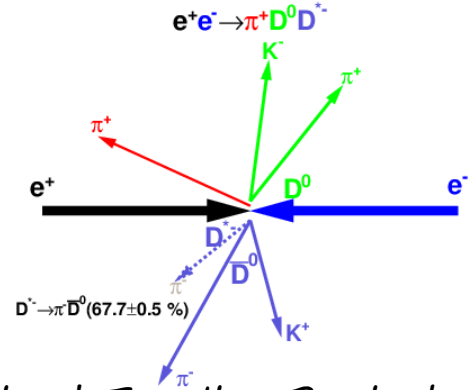


$e^+e^- \to \pi^+ D^- D^{*0}$









Method: Tag the Bachelor π^+ and D^0, D^- in 4 or 6 decay-modes

require π from D^* in Missing mass

apply kinematic fit; look in mass recoiling against π^+

improved statistics, much better control over background shape improved systematics

$M = 3884.3 \pm 1.2 \pm 1.5$ MeV,
$\Gamma = 23.8 \pm 2.1 \pm 2.6$ MeV

Compatible with single D tag results but significantly more precise. . $J^P = 1^+$ confirmed

Discovery of $Z_c(4020)^{\pm}$ in $e^+e^- \to \pi^+\pi^- h_c(1P)$

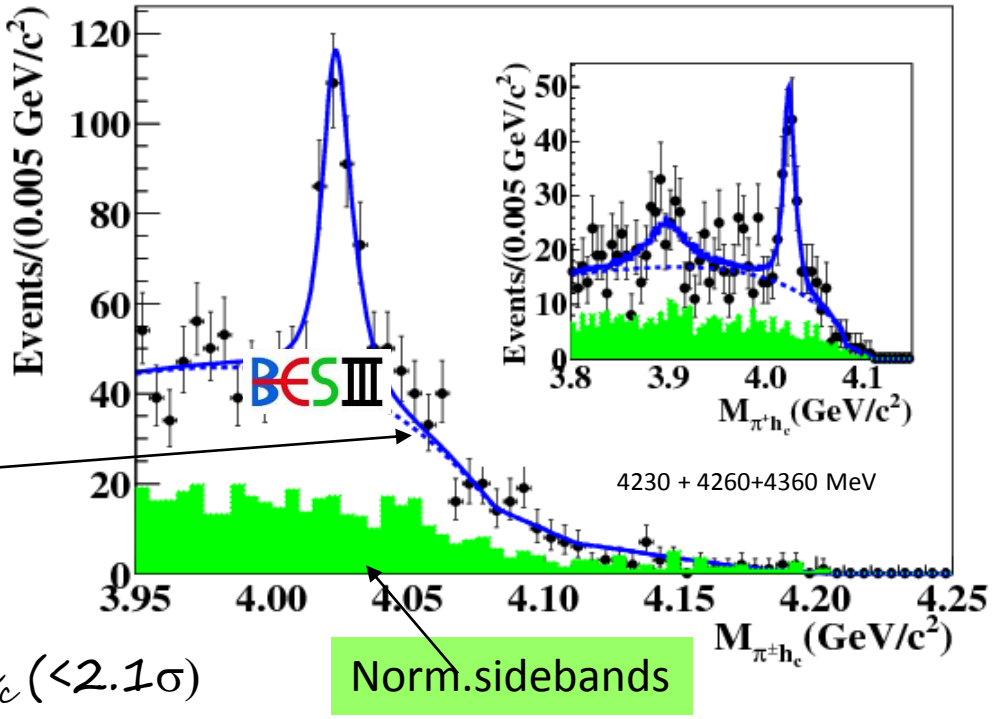
Exclusive reconstruction:

$h_c(1P) \to \gamma\eta_c(1S)$ E1 transition and η_c →16 hadronic decay channels

Simultaneous fit to 4.23/4.26/4.36 GeV data and 16 η_c decay modes.

A charged charmonium-like structure, $Z_c(4020)^{\pm}$, is observed.

$M = 4022.9 \pm 0.8 \pm 2.7$ MeV,
$\Gamma = 7.9 \pm 2.7 \pm 2.6$ MeV
Significance>8.9σ
Close to (D*D*)threshold



BW+Argus func for background

Not significant $Z_c(3900)^{\pm} \to \pi^{\pm} h_c$ (<2.1σ)

PRL 111, 242001(2013)

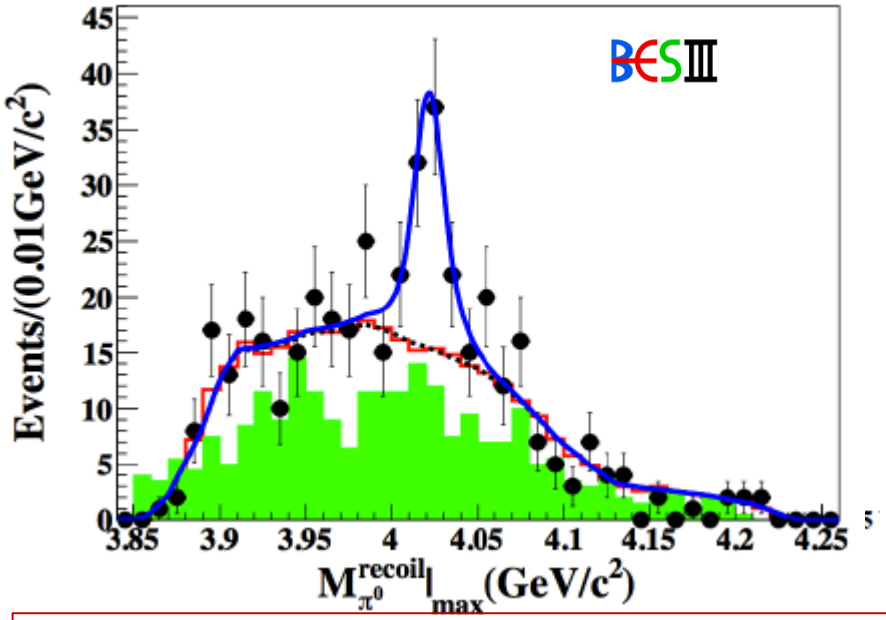
Upper limit on Zc(3900)+ production cross section at $\sqrt{s}$=4.26 GeV:

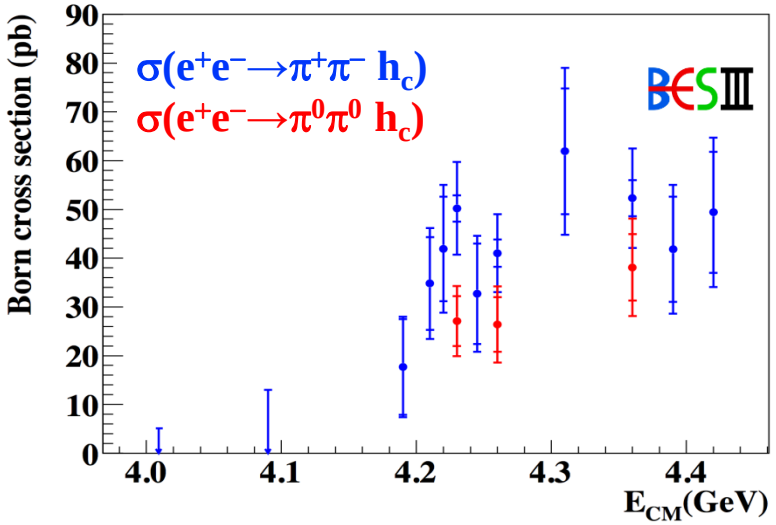
$$\sigma(e^+e^- \to Z_c(3900)^+\pi^- \to h_c\pi^+\pi^-) < 11\,\text{pb} \quad \text{(at 90\% CL)}$$

$e^+e^- \to \pi^0 Z_c(4020)^0 \to \pi^0\pi^0 h_c(1P)$

- 2.8 fb^{-1} data at 10 energy points from 4230~4420 MeV
- $Z_c(4020)^0$ is observed clearly at: E_{cm}=4230, 4260, 4360MeV

PRL 113, 212002 (2014)





$M_{Z_c(4020)^0}$ = (4023.6±2.2±3.8) MeV/c^2

$M_{Z_c(4020)^\pm}$ = (4022.9±0.8±2.7) MeV/c^2

$\Gamma_{Z_c(4020)^0}$ fixed @ $\Gamma_{Z_c(4020)^\pm}$

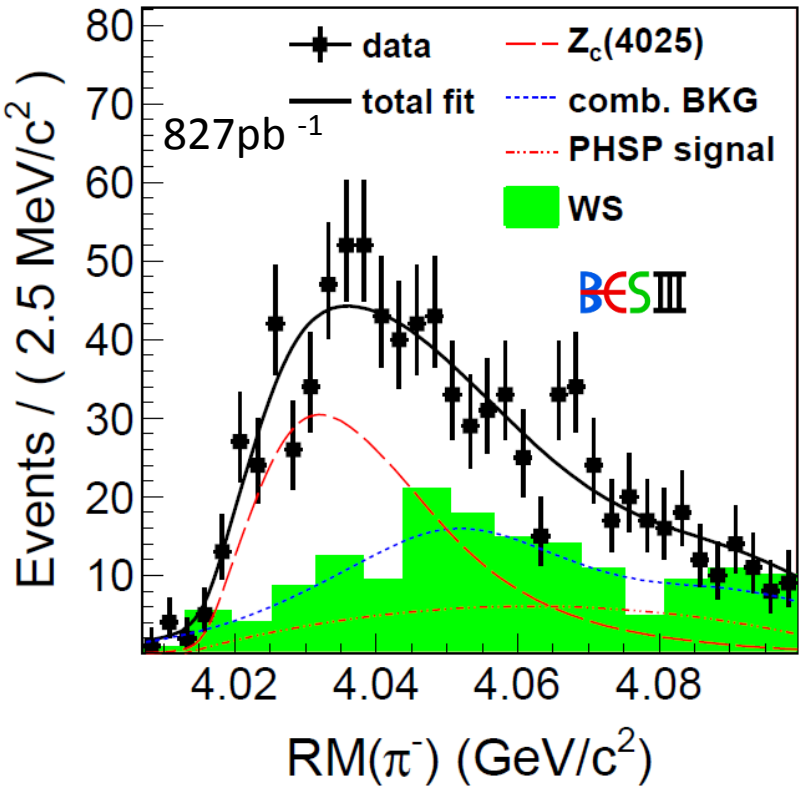
significance>5σ

$\sigma(e^+e^- \to \pi^+\pi^- h_c) \sim 2\,\sigma(e^+e^- \to \pi^0\pi^0 h_c)$

In agreement with isospin conservation within 2σ

An isospin triplet for $Z_c(4020)$ has also been observed!

$e^+e^- \to \pi Z_c(4025) \to \pi^- (D^*\bar{D}^*)^+ + c.c.$ @ 4.260 GeV



Partial reconstruction technique

Only the bachelor π^-, the D^+ decaying from $D^{*+} \to D^+ \pi^0$ and at least one soft π^0 from $D^{*+} \to D^+ \pi^0$ Or $\bar{D}^{*0} \to \bar{D}^0 \pi^0$ decay are reconstructed.

A structure near $(D^*\bar{D}^*)^\pm$ threshold is observed in π-recoil.mass distribution

M = (4026.3±2.6±3.7) MeV/c²
Γ = (24.8±5.7±7.7) MeV/c²
>10σ

$\sigma(e^+e^- \to \pi^- (D^*\bar{D}^*)^+ + c.c.) =$ (137±9±15) pb

The mass and width compatible with $Z_c(4020)^\pm$ within **1.5σ**, but further investigations needed

$$R = \frac{\sigma(e^+e^- \to \pi^- Z_c^+ \to \pi^- (D^*\bar{D}^*)^+ + c.c.)}{\sigma(e^+e^- \to \pi^- (D^*\bar{D}^*)^+ + c.c.)} = (65 \pm 9 \pm 6)\%$$

Spin analysis with higher statistics needed.

PRL 112, 132001

BESIII: Z_c states

State	Mass(MeV)	Width(MeV)	Decay mode	Process
$Z_c(3900)^{\pm}$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	$\pi^{\pm} J/\psi$	$e^+e^- \to \pi^+\pi^- J/\psi$
$Z_c(3900)^0$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$	$\pi^0 J/\psi$	$e^+e^- \to \pi^0\pi^0 J/\psi$
$Z_c(3885)^{\pm}$	$3883.9 \pm 1.5 \pm 4.2$ [single D tag] $3884.3 \pm 1.2 \pm 1.5$ [double D tag]	$24.8 \pm 3.3 \pm 11.0$ [single D tag] $23.8 \pm 2.1 \pm 2.6$ [double D tag]	D^0D^{*-} D^-D^{*0}	$e^+e^- \to \pi^+ D^0 D^{*-}$ $e^+e^- \to \pi^+ D^- D^{*0}$
$Z_c(4020)^{\pm}$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	$\pi^{\pm} h_c$	$e^+e^- \to \pi^+\pi^- h_c$
$Z_c(4020)^0$	$4023.9 \pm 2.2 \pm 3.8$	fixed	$\pi^0 h_c$	$e^+e^- \to \pi^0\pi^0 h_c$
$Z_c(4025)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	$D^{*0}D^{*-}$	$e^+e^- \to \pi^+ (D^* \bar{D}^*)^-$

States must contain at least 4 quarks

- Many theoretical interpretations:
  - Tetraquarks (L. Maiani et al., PRD71,014028)
  - Hadronic molecules (Dubynskiy et al.,PLB666,344)
  - Hadro-charmonia (Voloshin, arXiv:1304.0380)

Are the Z(3900)/Z(4020) and Z(3885)/Z(4025) the same states?

- Determine the J^{PC} (Angular analysis).
- Search for more partner states.
- More decay pattern on both open/hidden charm channel.

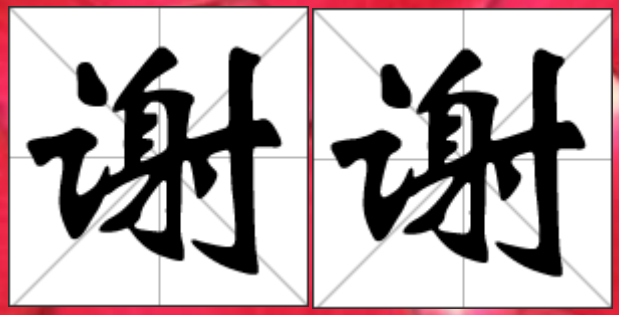
Sommario

- **BESIII ha raccolta un'elevata statistica di:**
  - J/ψ, ψ(2S), ψ(1D)
  - XYZ
  - R-scan
- Molte analisi sono ancora in corso ..
  Presto vi saranno nuovi risultati!

- **BESIII** sta ancora raccogliendo dati a basse energie per finire R-scan
- Ci si attende da BEPCII una maggiore luminosità
- Probabilmente il prossimo anno :
  - Scan alla ψ(2S) per determinare la fase relativa tra l'ampiezza di decadimento forte ed e.m. come fatto per la J/ψ
  - Ulteriore statistica per $e^+e^- \to \bar{\Lambda}_c\Lambda_c$ a soglia

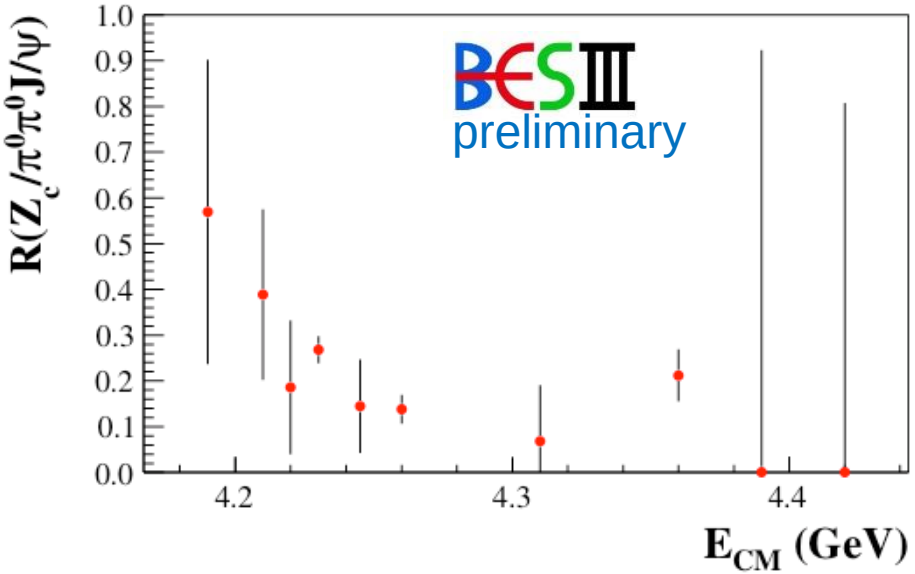
- **Upgrade and R&D:**
  - BESIII CGEM-IT
  - ASIC R&D per il CGEM-IT Analogue Readout

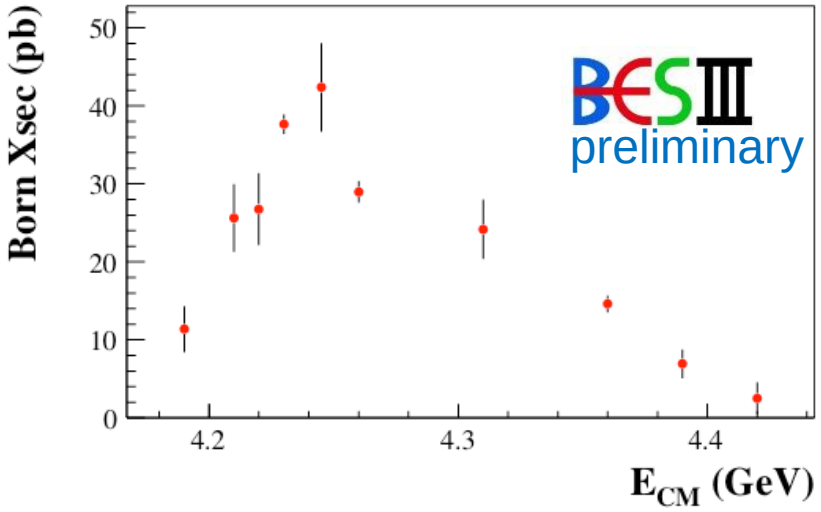
Grazie per l'attenzione!



$R(Z_c^0/\pi^0\pi^0 J/\psi)$ and $\pi^0\pi^0 J/\psi$ cross section

$R(Z_c^0/\pi^0\pi^0 J/\psi)=N(Z_c^0(3900))/N(\pi^0\pi^0 J/\psi)$





R and cross sections

$N(Z_c^0(3900))/N(\pi^0\pi^0 J/\psi)$ and $\pi^0\pi^0 J/\psi$ cross section at each energy point.

BESIII preliminary

E_{cm} GeV	$R(Z_c/\pi^0\pi^0 J/\psi)$	Obs. Xsec (pb)	Born Xsec (pb)
4.260	$0.14 \pm 0.03 \pm 0.01$	$23.68 \pm 1.04 \pm 1.75$	$28.95 \pm 1.27 \pm 2.14$
4.360	$0.21 \pm 0.06 \pm 0.01$	$15.00 \pm 1.10 \pm 1.11$	$14.57 \pm 1.07 \pm 1.08$
4.230	$0.27 \pm 0.03 \pm 0.01$	$30.28 \pm 1.02 \pm 2.24$	$37.61 \pm 1.27 \pm 2.78$
4.190	< 1.00	$9.45 \pm 3.00 \pm 0.70$	$11.37 \pm 3.61 \pm 0.84$
4.210	< 0.65	$20.79 \pm 3.85 \pm 1.54$	$25.54 \pm 4.73 \pm 1.89$
4.220	< 0.41	$21.60 \pm 3.82 \pm 1.60$	$26.74 \pm 4.73 \pm 1.98$
4.245	< 0.30	$34.24 \pm 4.69 \pm 2.53$	$42.38 \pm 5.80 \pm 3.14$
4.310	< 0.30	$22.04 \pm 4.16 \pm 1.63$	$24.17 \pm 4.56 \pm 1.79$
4.390	< 0.55	$7.56 \pm 2.53 \pm 0.56$	$6.93 \pm 2.32 \pm 0.51$
4.420	< 1.00	$2.87 \pm 2.13 \pm 0.21$	$2.52 \pm 1.87 \pm 0.19$