Recent results from BESIII

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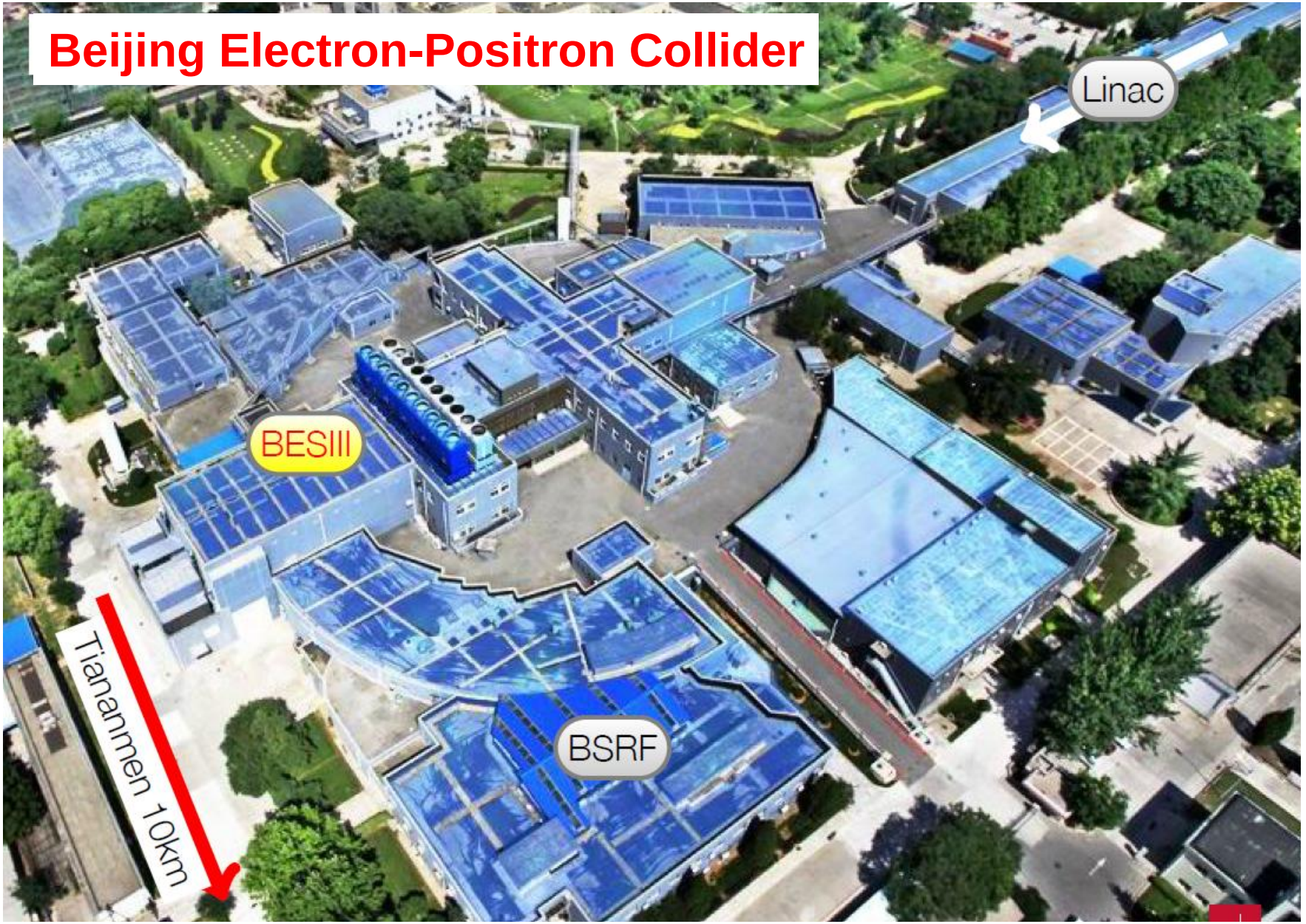
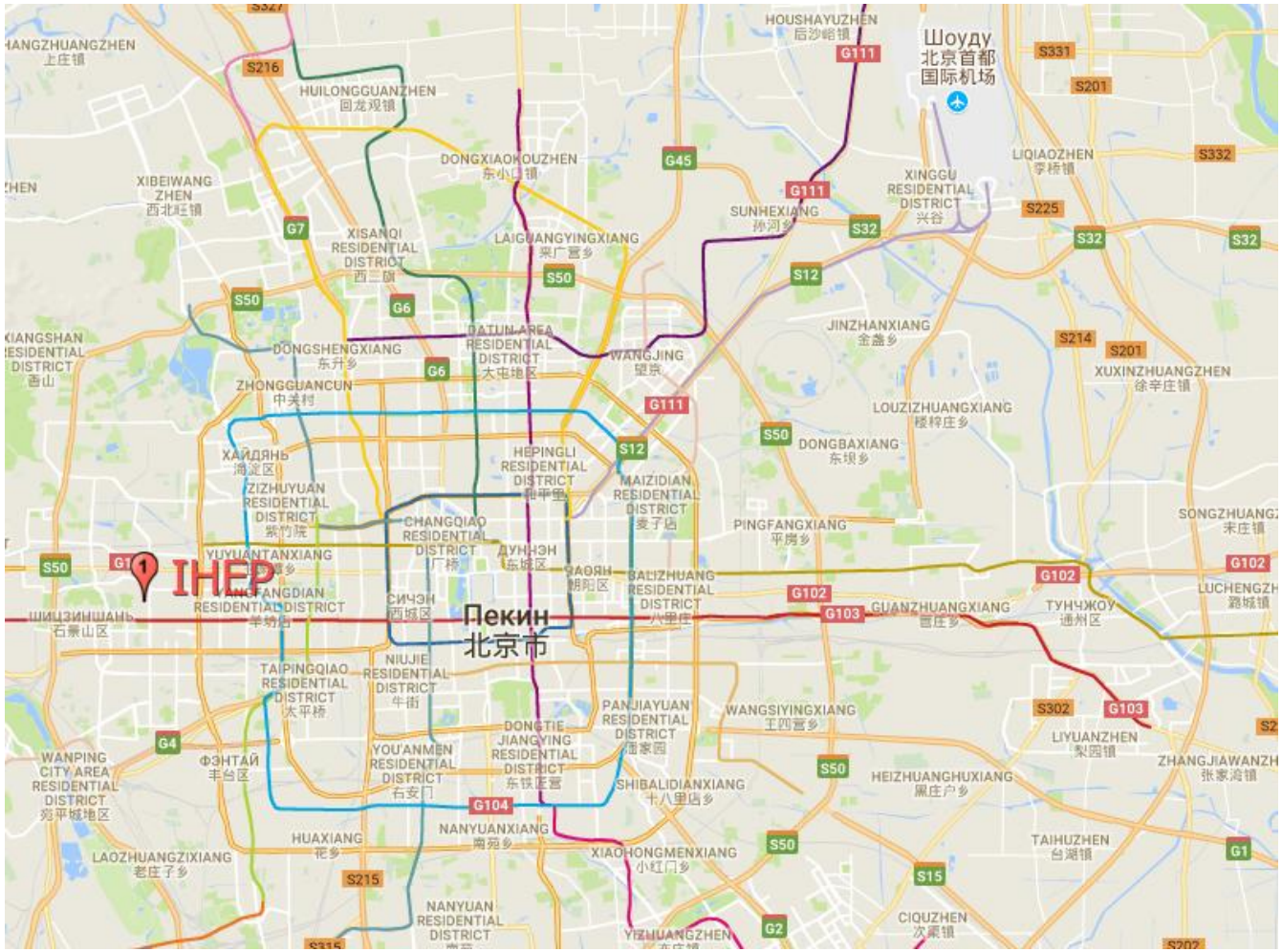
XXIV International Baldin Seminar
Dubna, 18 Sept 2018

Beijing Electron-Positron Collider



Location of IHEP in Beijing



History

- BES: 1989-1993 (BEPC)
- BESII: 1998-2004 (BEPC)
- BESIII: 2008-… (BEPCII)

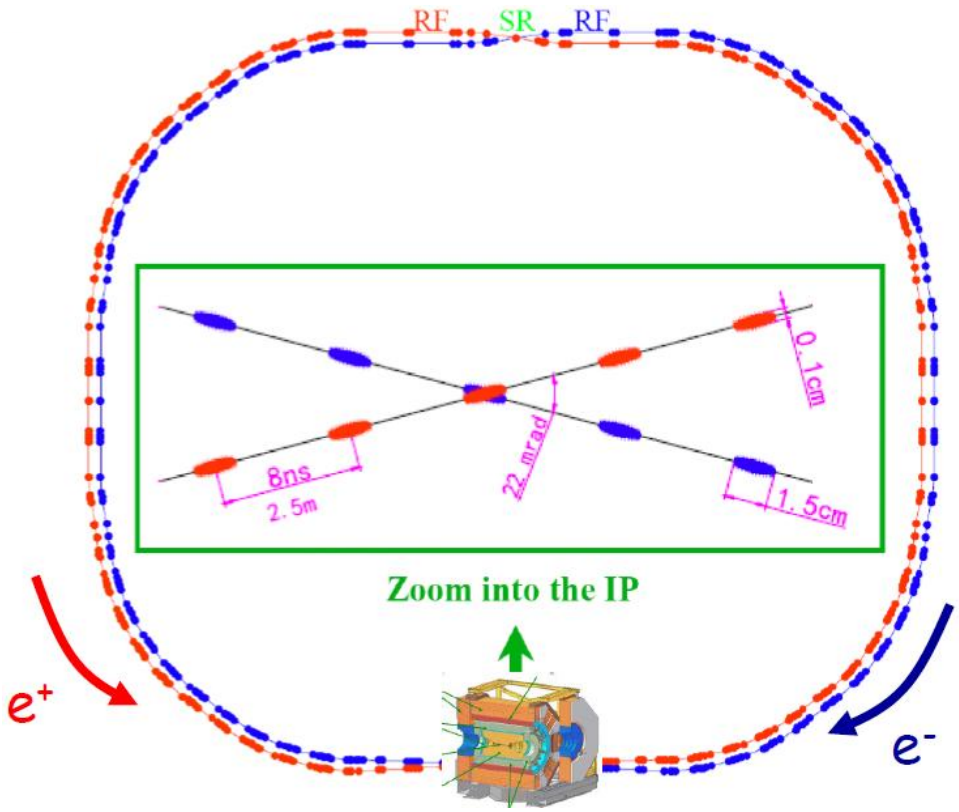
BES = BEijing Spectrometer

BEPC = Beijing Electron-Positron Collider

BESIII collaboration

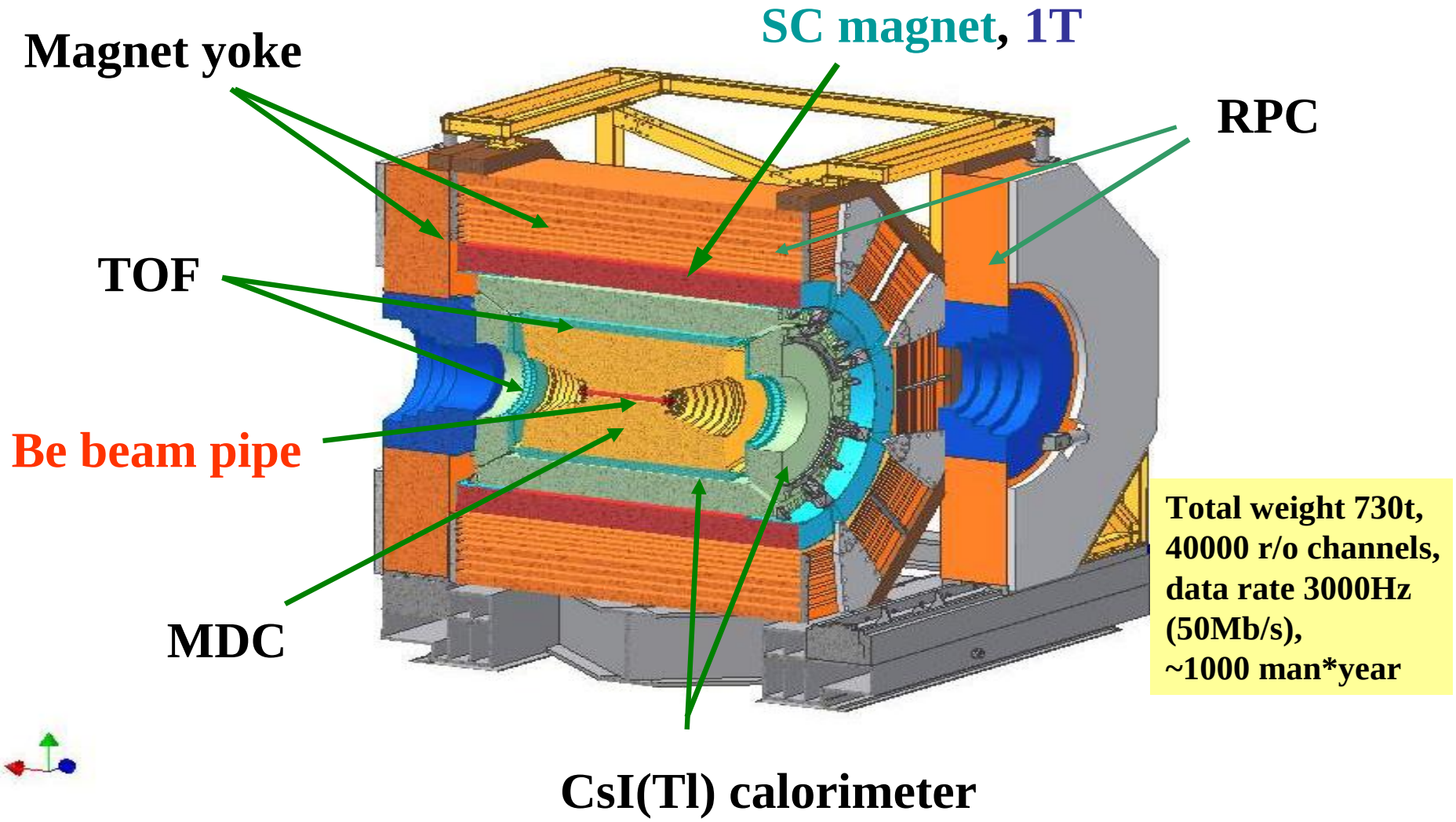
- Almost 500 members, 66 institutions, 14 countries
- 38 institutions from China, 7 rest of Asia,
  16 Europe (incl. Dubna and Novosibirsk), 5 USA

BEPCII storage rings

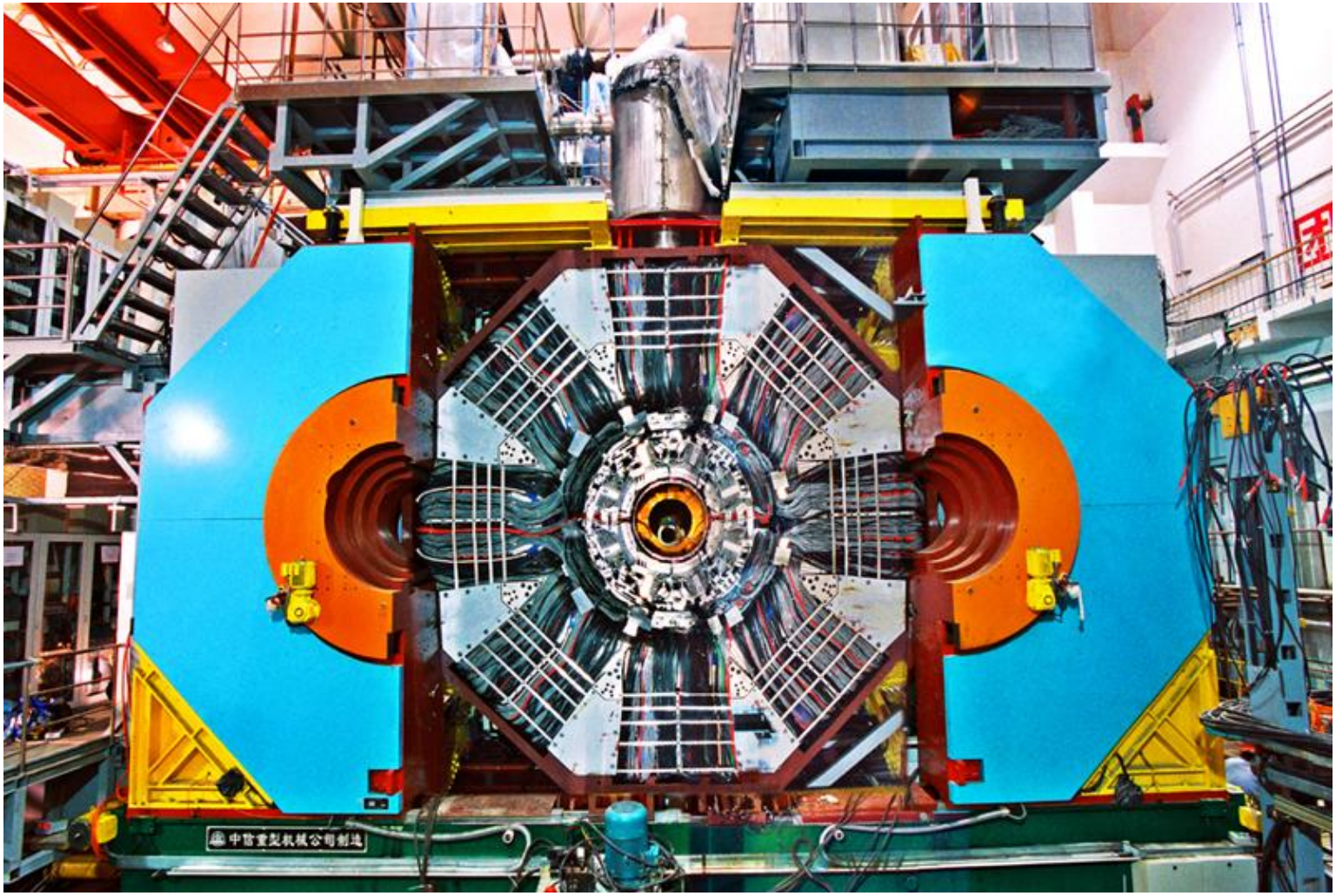


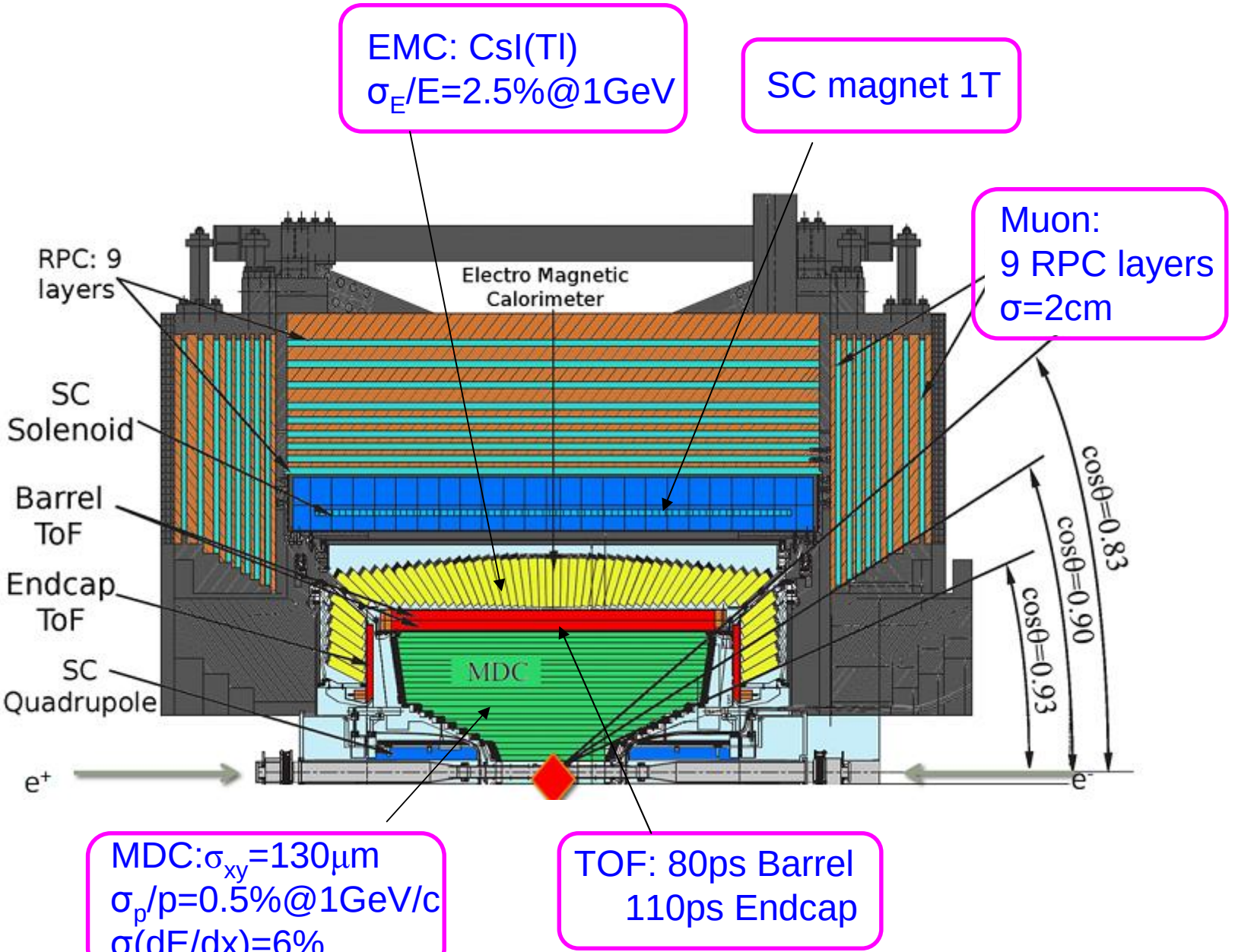
- Collision energy
  2.0 – 4.6 GeV
  → 4.9 GeV
- Design luminosity
  1.0×10^{33} cm^{-2} s^{-1}
- Achieved luminosity
  1.0×10^{33} cm^{-2} s^{-1}
- Energy spread
  5×10^{-4}
- No. of bunches
  93
- Total current
  0.91A
- Circumference
  237m

BESIII detector



BESIII general view

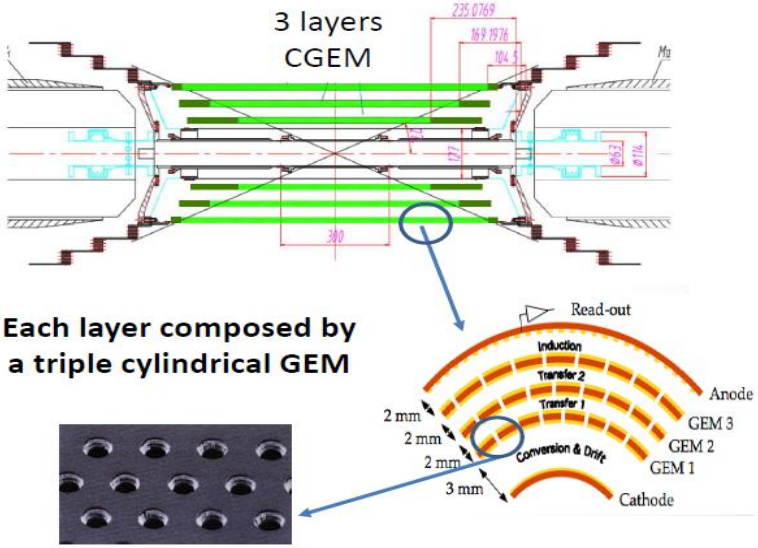


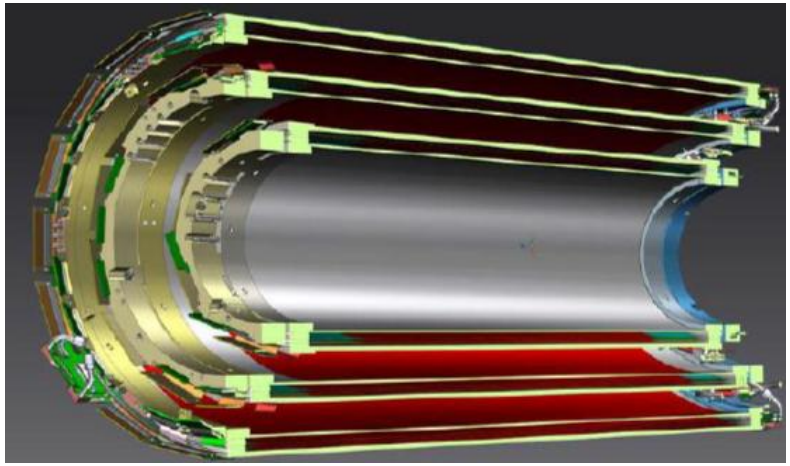

EMC: CsI(Tl)
σ_E/E=2.5%@1GeV
SC magnet 1T
Muon:
9 RPC layers
σ=2cm
RPC: 9 layers
Electro Magnetic Calorimeter
SC Solenoid
Barrel ToF
Endcap ToF
SC Quadrupole
MDC
cosθ=0.83
cosθ=0.90
cosθ=0.93
e+
e-
MDC:σ_{xy}=130μm
σ_p/p=0.5%@1GeV/c
σ(dE/dx)=6%
TOF: 80ps Barrel
110ps Endcap

Inner tracker upgrade

- Inner part of the Main Drift Chamber suffers from aging
- In summer 2019 it will be replaced by a Cylindrical GEM
- Similar to KLOE-2 CGEM

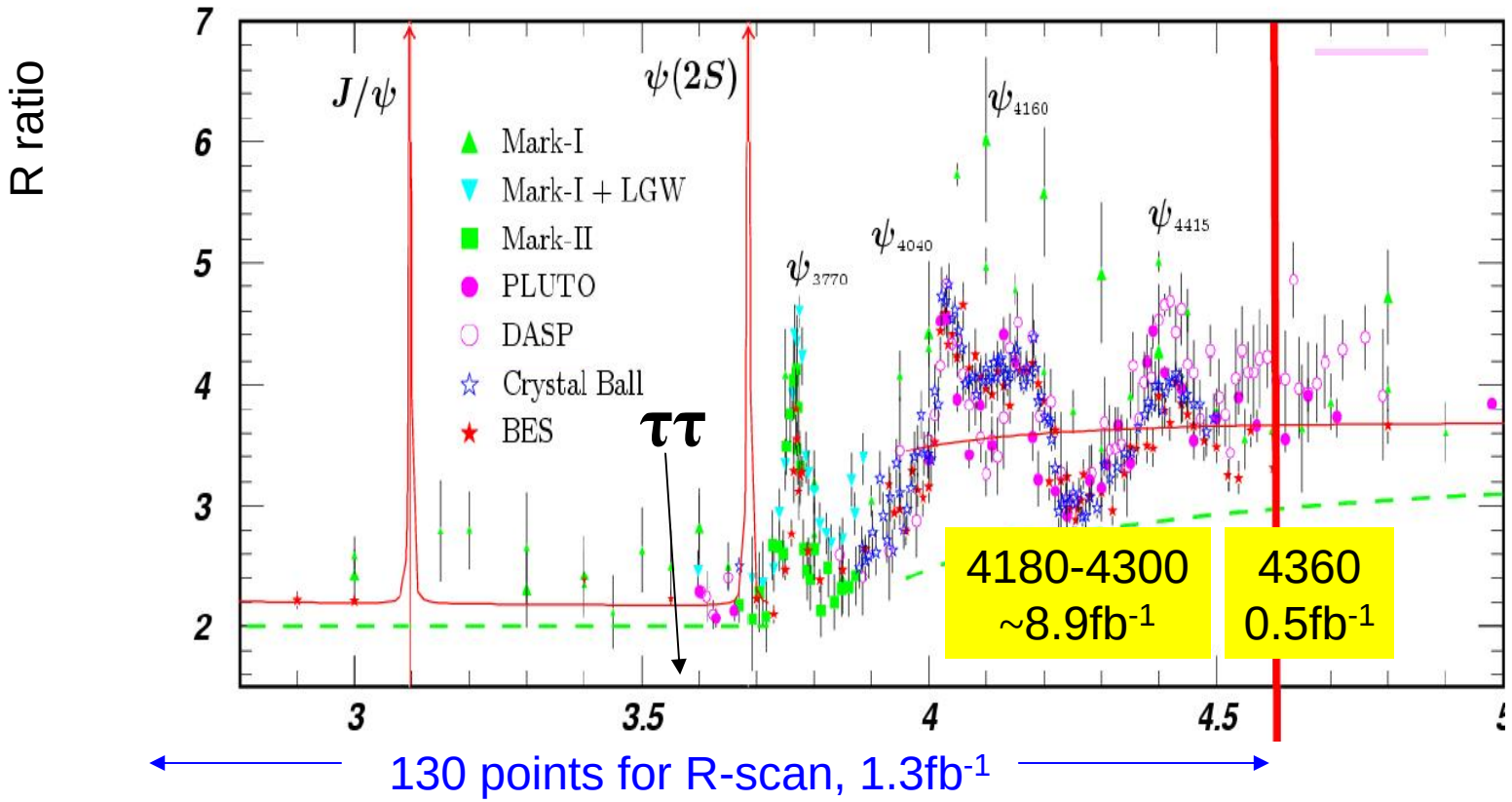
- Material <1.5%X_0
- Rate 10^4 Hz/cm^2
- $\sigma_{r\varphi}$ ~130 μm
- σ_p/p=0.5%@1GeV/c





BESIII data

J/ψ	ψ′	ψ′′	4040	4420	4600
1.3x10^9	0.5x10^9	2.9fb^{-1}	0.5fb^{-1}	1.0fb^{-1}	0.6fb^{-1}



World largest samples of J/ψ, ψ(2S), ψ(3770), ψ(4040), ψ(4180), Y(4260), …

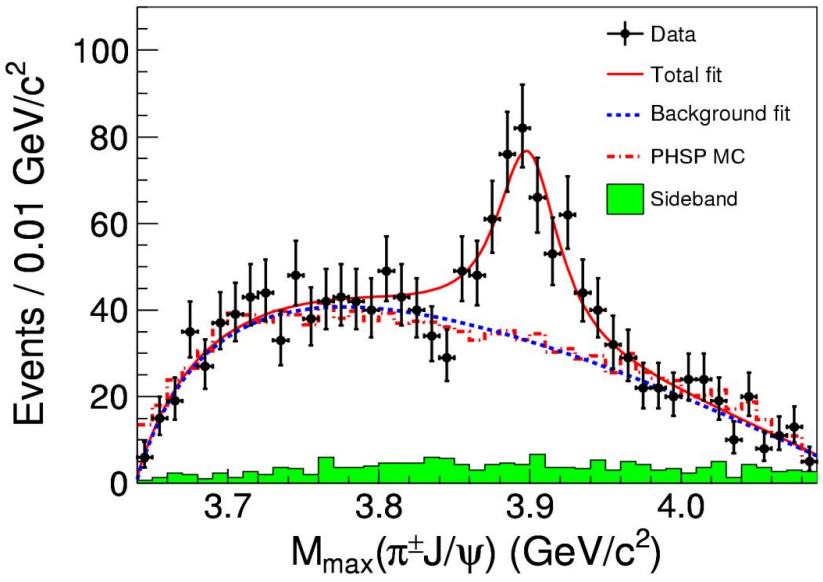
BESIII physics program

- Charmonium physics
- Charmed hadrons
- Exotic states
- Light hadron spectroscopy
- Tau lepton physics
- R-scan (inclusive hadron yield)
- Baryon form-factors
- Searches for new physics

Zc states

First observation of a charged charmonium-like state

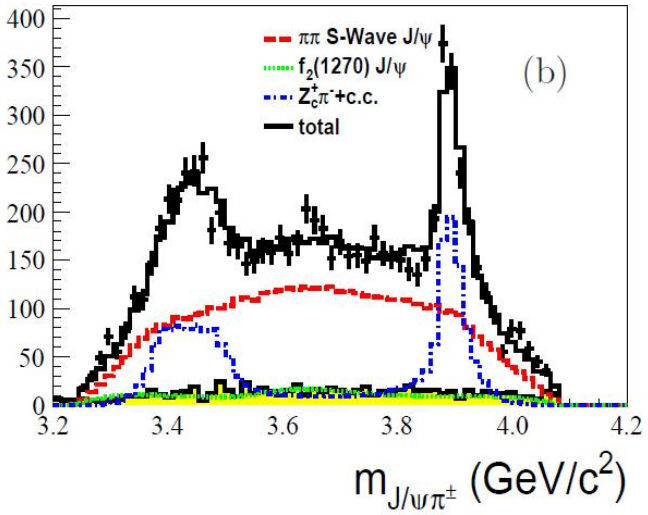
$Z_c(3900)^+$



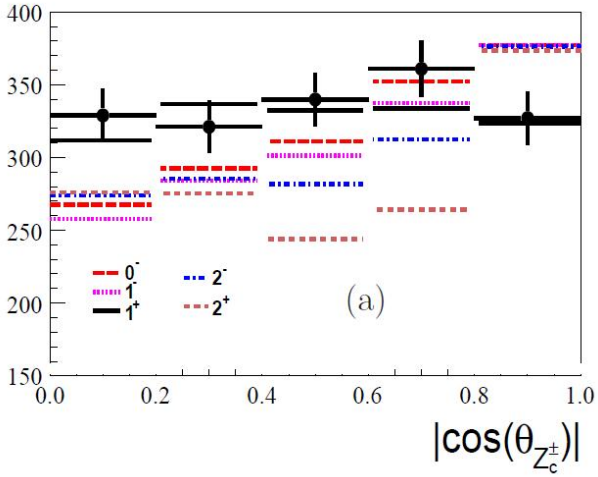
PRL 110, 252001

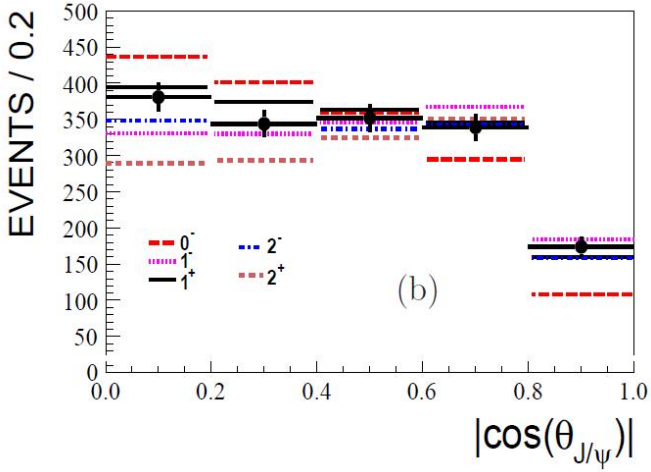
- An unambiguous peak of $(\pi^{\pm}J/\psi)$ mass observed in $ee \to \pi^+\pi^- J/\psi$ data
- $M = 3899.0 \pm 3.6 \pm 4.9$ MeV
- $\Gamma = 46 \pm 10 \pm 20$ MeV
- Most natural interpretation is a 4-quark state ccqq (tetraquark); other interpretations also possible

PWA of Zc(3900)



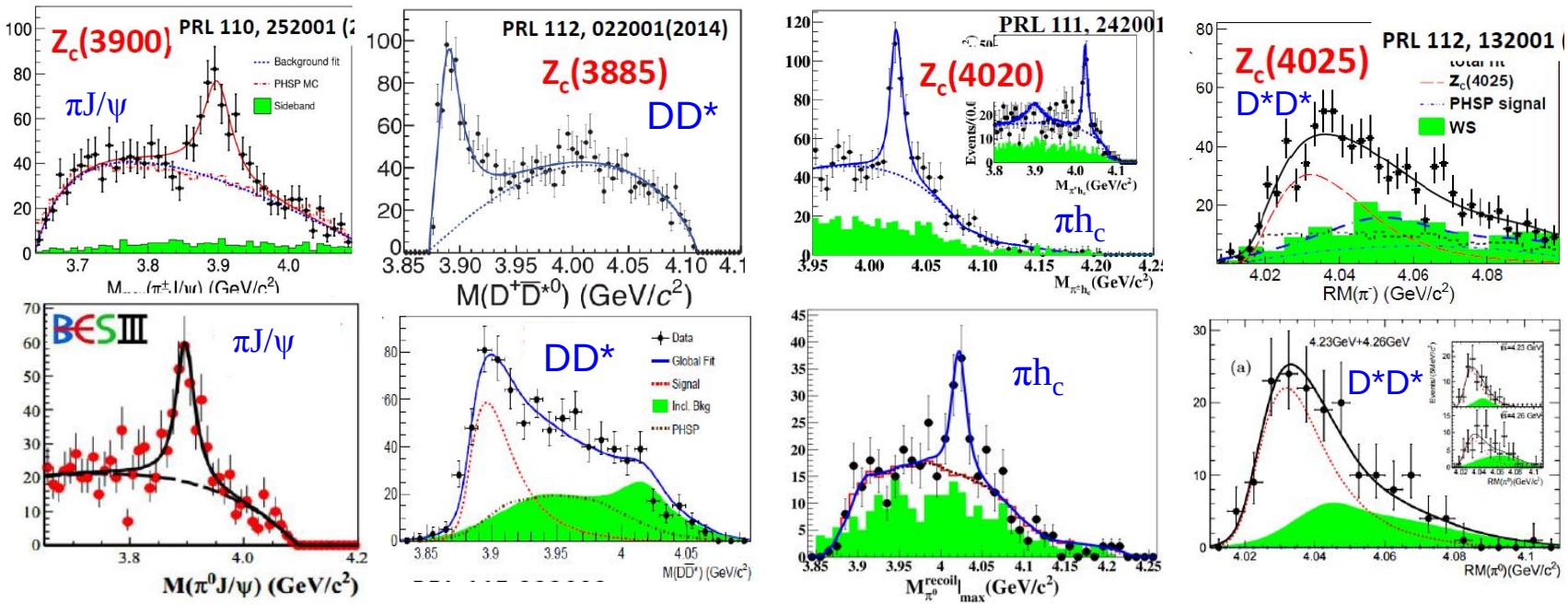
- Contributions from σ, $f_0(980)$, $f_2(1270)$ and $f_0(1370)$ have been considered
- Spin-parity established to be 1^+ at more than 7σ level





PRL 119, 072001

Other Zc states



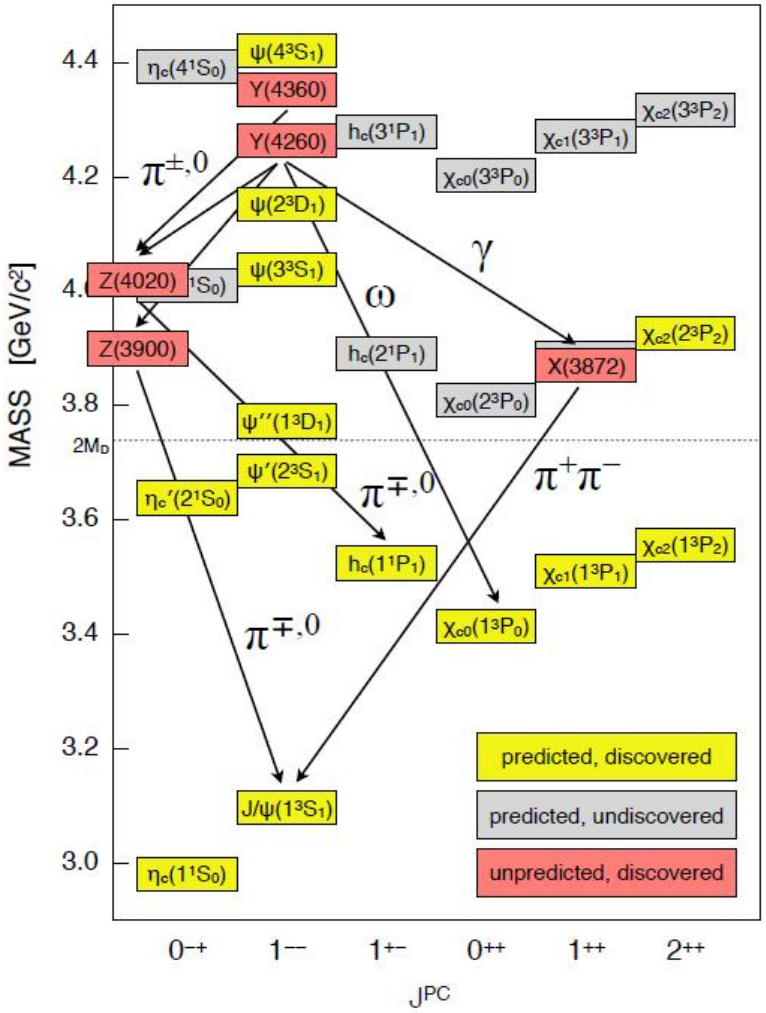
- In total, 4 charged and 4 neutral states have been observed at ~3900 and ~ 4020 MeV in decay modes $\pi\pi J/\psi$, πh_c, D*D and D*D*
- A natural hypothesis: we observe 2 doublets of charged and neutral partners

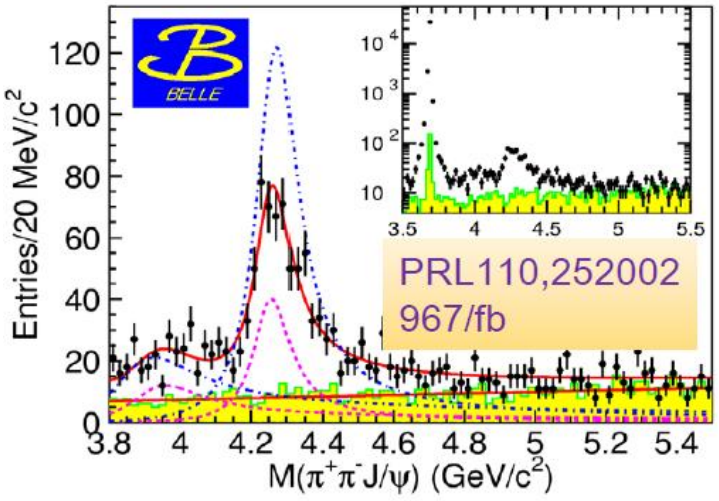
Summary on Zc decay modes

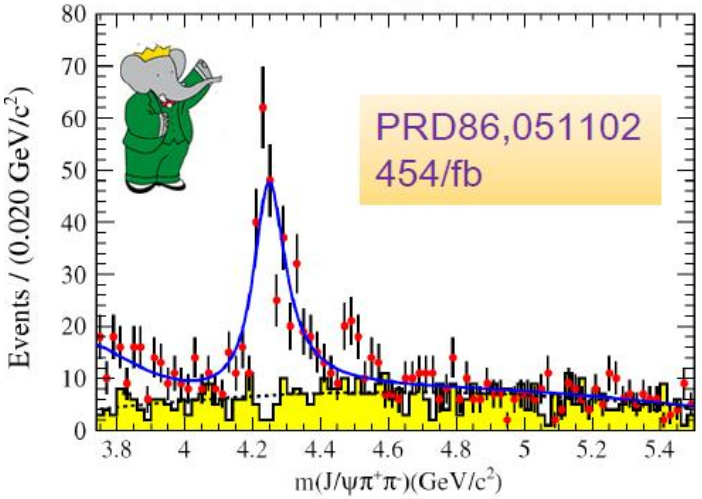
3900 MeV		4020 MeV	
charged	neutral	charged	neutral
$\pi^{\pm}J/\psi$ M = 3899.0 ± 6.1 Γ = 46 ± 22	$\pi^{0}J/\psi$ M = 3894.8 ± 2.3 Γ = 29.6 ± 8.2	$\pi^{\pm}h_c$ M = 4022.9 ± 2.8 Γ = 7.9 ± 3.7	$\pi^{0}h_c$ M = 4023.9 ± 4.4 Γ = 7.9 (fixed)
$(D^*D)^{\pm}$ M = 3882.0 ± 1.9 Γ = 26.5 ± 2.7	$(D^*D)^{0}$ M=3885.7 ± 10.2 Γ = 35 ± 19	$(D^*D^*)^{\pm}$ M = 4026.3 ± 4.5 Γ = 24.8 ± 9.5	$(D^*D^*)^{0}$ M = 4025.5 ± 5.6 Γ = 23.0 ± 6.1

XYZ states

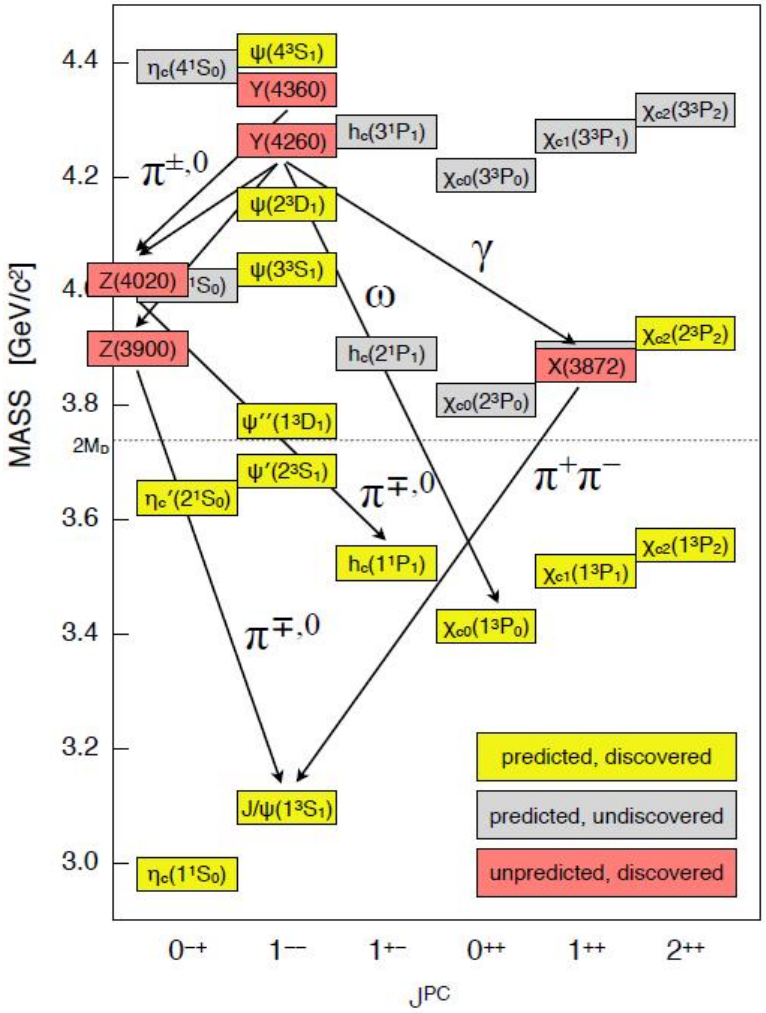
XYZ states


MASS [GeV/c²]
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2M_D
ηc(4¹S0)
ψ(4³S1)
Y(4360)
Y(4260)
hc(3¹P1)
χc2(3³P2)
χc1(3³P1)
χc0(3³P0)
ψ(2³D1)
ψ(3³S1)
Z(4020)
Z(3900)
ω
γ
hc(2¹P1)
χc2(2³P2)
X(3872)
χc0(2³P0)
ψ''(1³D1)
ψ'(2³S1)
ηc'(2¹S0)
π∓,0
π⁺π⁻
hc(1¹P1)
χc2(1³P2)
χc1(1³P1)
χc0(1³P0)
J/ψ(1³S1)
ηc(1¹S0)
predicted, discovered
predicted, undiscovered
unpredicted, discovered
0⁻⁺
1⁻⁻
1⁺⁻
0⁺⁺
1⁺⁺
2⁺⁺
JPC


BELLE
Entries/20 MeV/c²
M(π⁺π⁻J/ψ) (GeV/c²)
PRL110,252002
967/fb

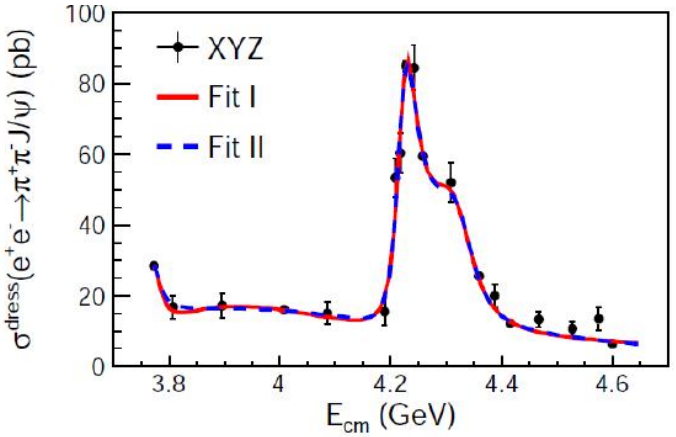

Events / (0.020 GeV/c²)
m(J/ψπ⁺π⁻)(GeV/c²)
PRD86,051102
454/fb

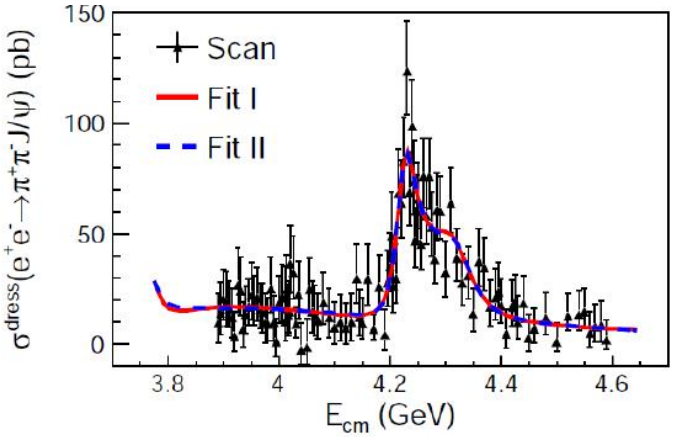
XYZ states

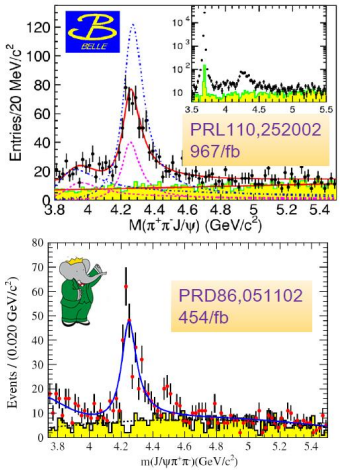


- An energy scan was performed in the energy domain of XYZ states
- Total 9.0 fb^{-1} data have been collected
  - Of them, 8.2 fb^{-1} from a dedicated XYZ-scan
  - Additional 0.8 fb^{-1} from earlier scans
- Collision energy between 3.77 and 4.60 GeV

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

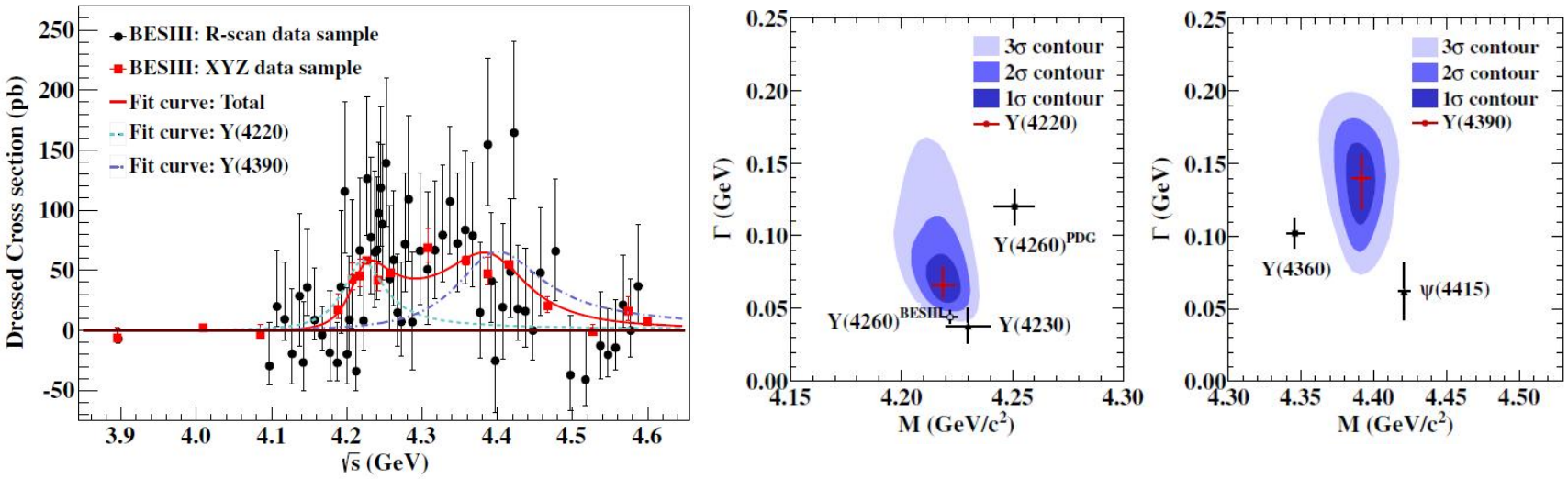






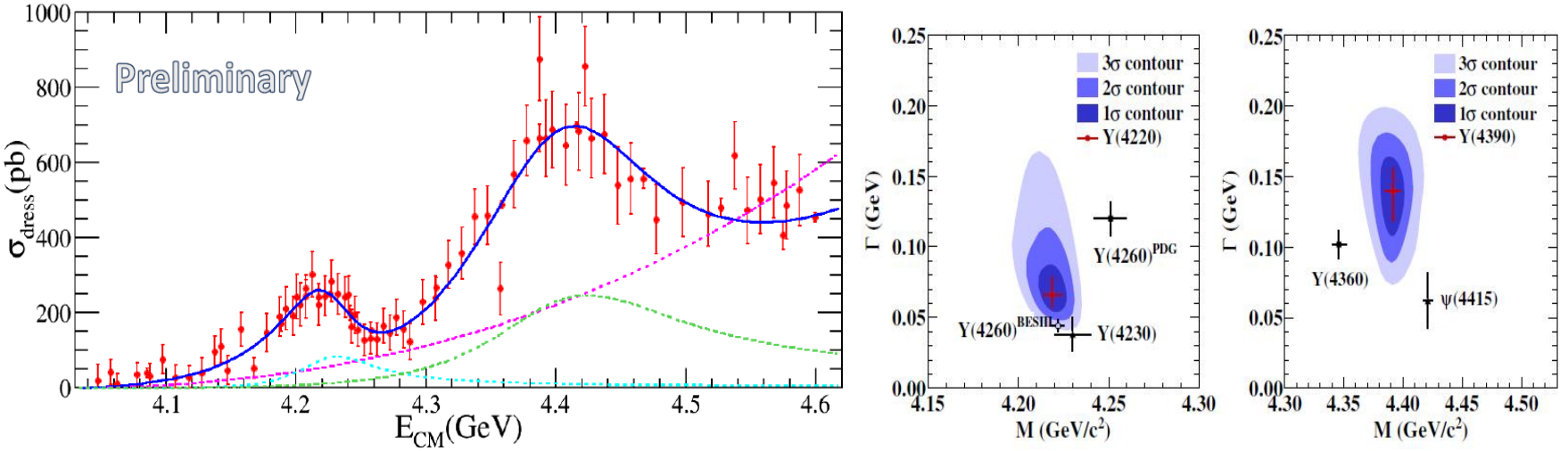
- Two resonant structures are observed:
  - Y(4260)? M = 4222.0 ± 3.1 ± 1.4, Γ = 44.1 ± 4.3 ± 2.0 MeV
  - Y(4360)? M = 4320.0 ± 10.4 ± 7, Γ = 101.4 ± 25 ± 10 MeV
- Precision on Y(4260) improved
- Y(4360): first observation in $ee \to \pi^+\pi^- J/\psi$
  - Seen in $ee \to \pi^+\pi^- \psi'$ by Belle and BaBar

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



- Two resonances observed:
  - Y(4220): M = 4218.0 ± 5 ± 0.9, Γ = 66 ± 12 ± 0.4 MeV
  - Y(4390): M = 4391.5 ± 6.8 ± 1.0, Γ = 139.5 ± 20 ± 0.6 MeV
- Inconsistent with $Y(4260)^{PDG}$, Y(4360), ψ(4415)
- Y(4220) consistent with the structure observed in $ee \to \omega\chi_{c0}$

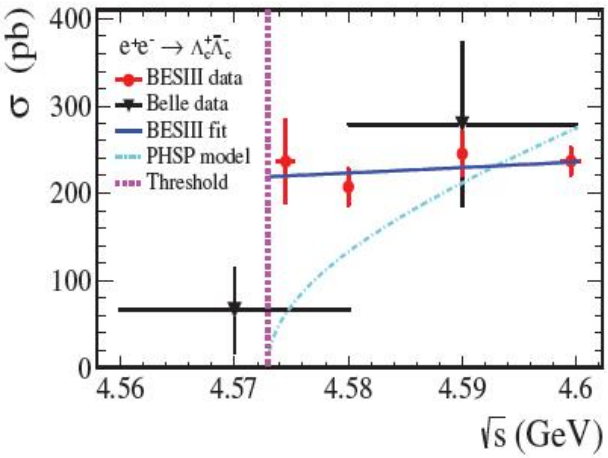
$ee \to \pi^- D^0 D^{*+}$

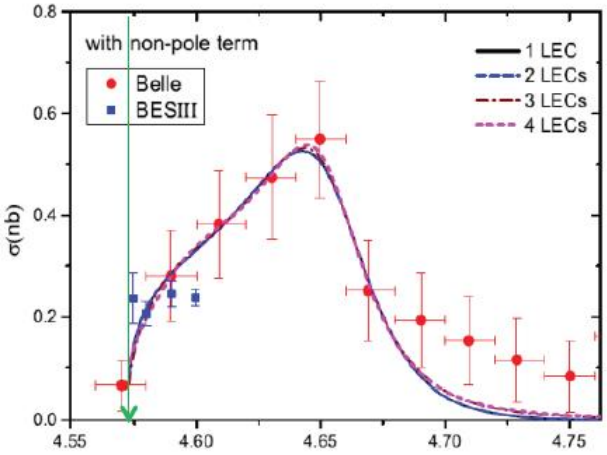


- Again, 2 resonances observed:
  - Y(4220): M = 4224.8 ± 5.6 ± 4, Γ = 72.3 ± 9.1 ± 0.9 MeV
  - Y(4390): M = 4400.1 ± 9.3 ± 2.1, Γ = 181.7 ± 16.9 ± 7.4 MeV
- Y(4220) consistent with $\pi^+\pi^- h_c$, $\pi^+\pi^- J/\psi$, $ee \to \omega\chi_{c0}$
- Y(4390) consistent with $\pi^+\pi^- h_c$

Baryonic form-factors

Λ_C: the lightest charmed baryon

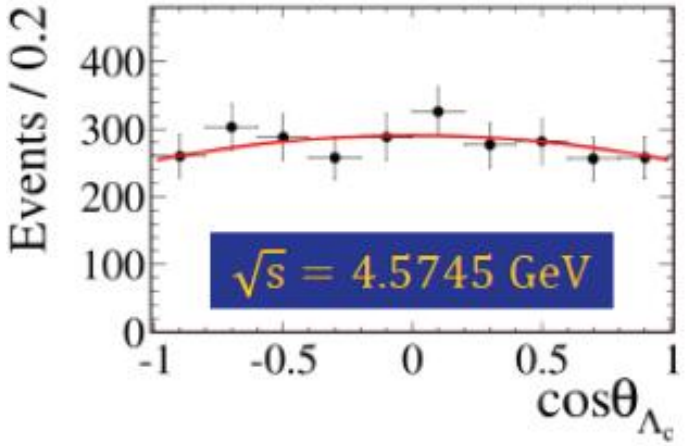


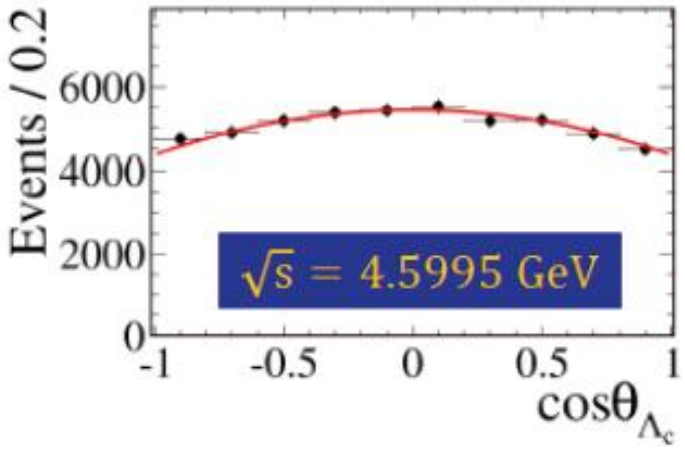


- Belle data can be described by a Y(4660) resonance
  - ➢ M = 4652.5 ± 3.4 MeV
- BESIII data show flat cross-section down to the threshold
- There is some tension between BESIII and Belle data

Λ_C polar angle distribution

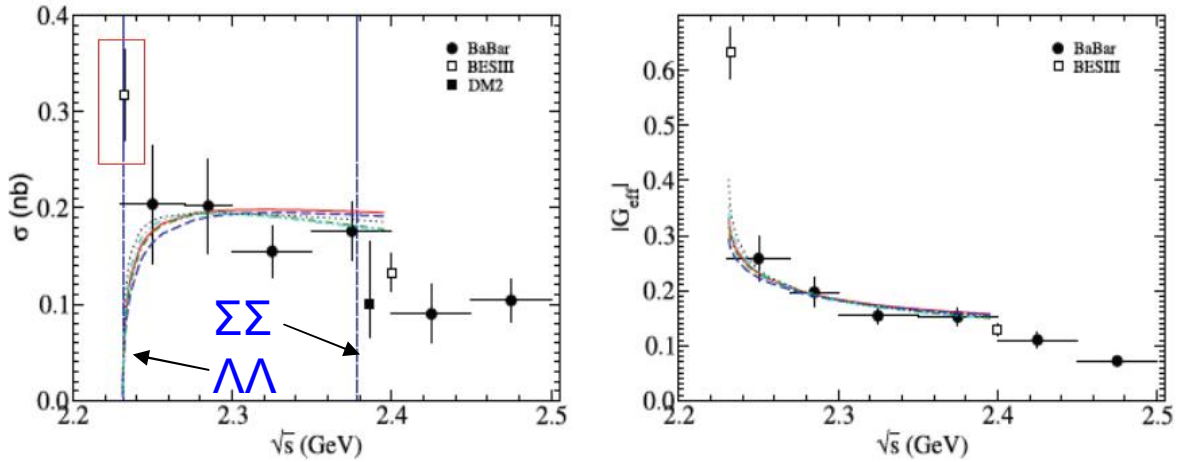
- Can be parameterized by $1+\alpha_{\Lambda c}\cos^2\theta$
- Form-factor ratio given by: $|G_E/G_M|^2(1-\beta^2) = (1 - \alpha_{\Lambda c})/(1 + \alpha_{\Lambda c})$





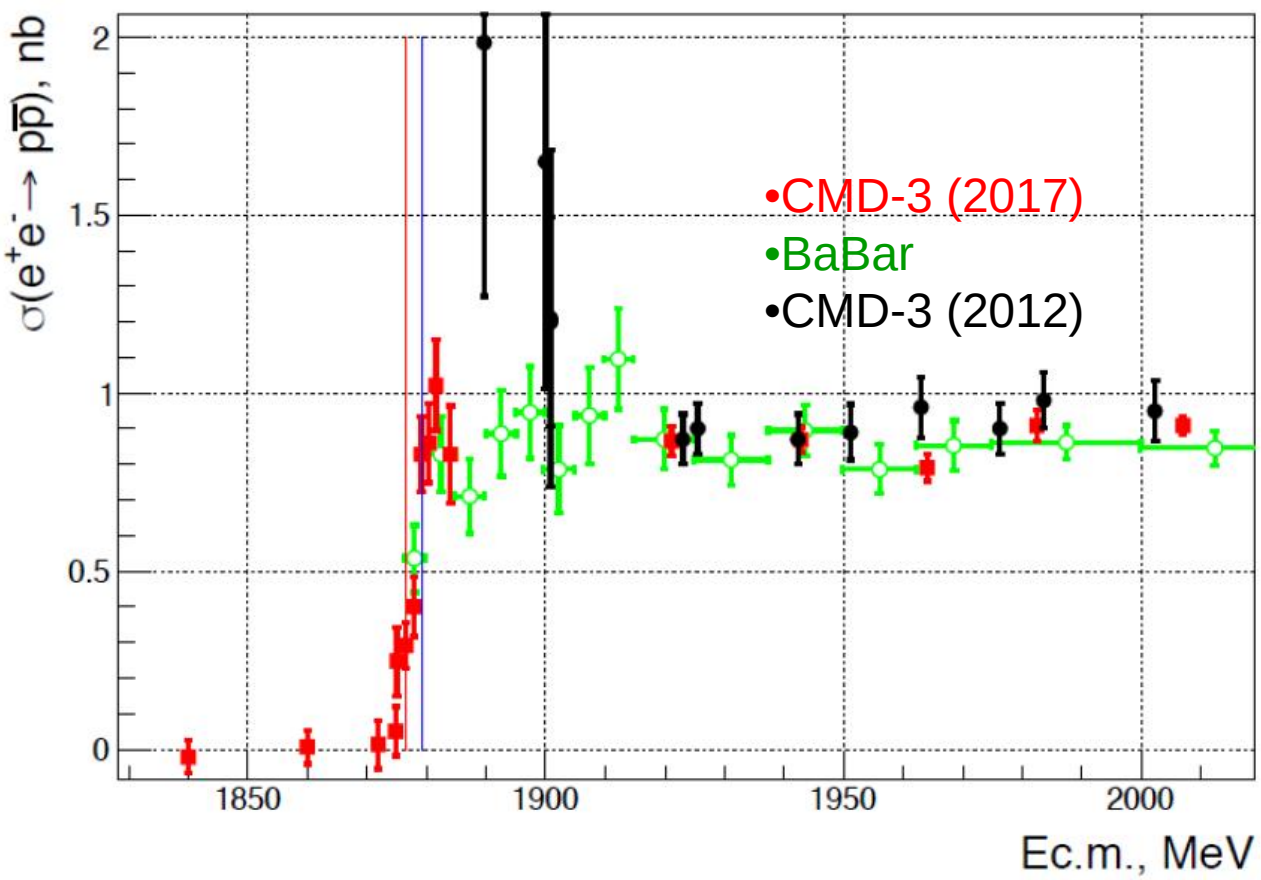
|GE/GM| **1.14 ± 0.14 ± 0.07** **1.23 ± 0.05 ± 0.03**

Lambda form-factor



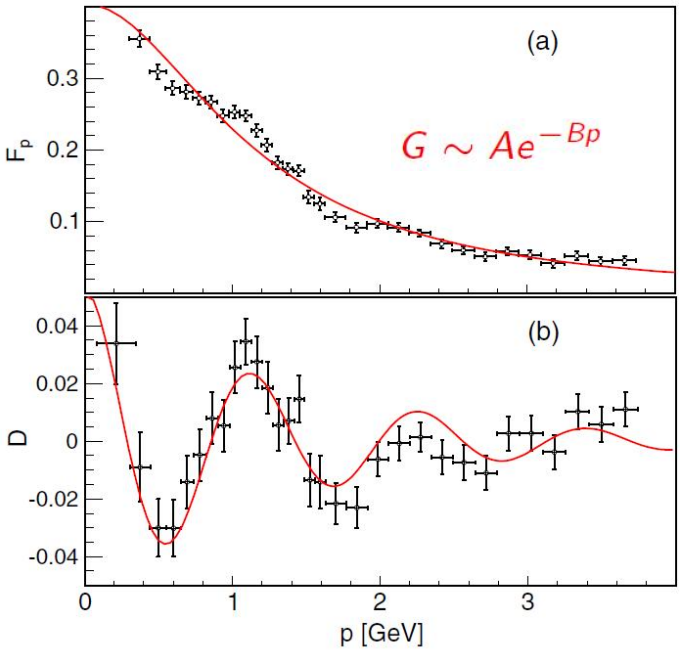
- At BESIII it is possible to measure cross-section down to the threshold energy (just 1 MeV above!)
- Like for Λ_C, BESIII observes a threshold enhancement
- BESIII results marginally consistent with BaBar, but not with the theoretical description

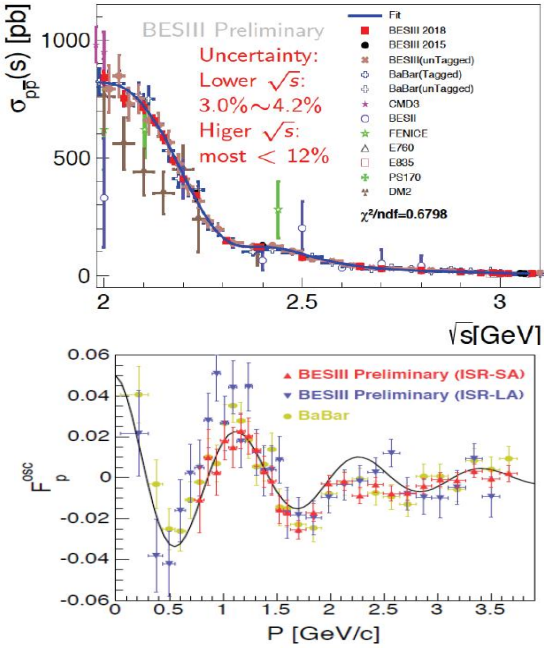
The ppbar threshold



- Steep rise of ppbar cross-section is observed by CMD and BaBar
- BESIII scan down to 2000 MeV confirms the observations (see next slide)

Oscillations of ppbar form-factor





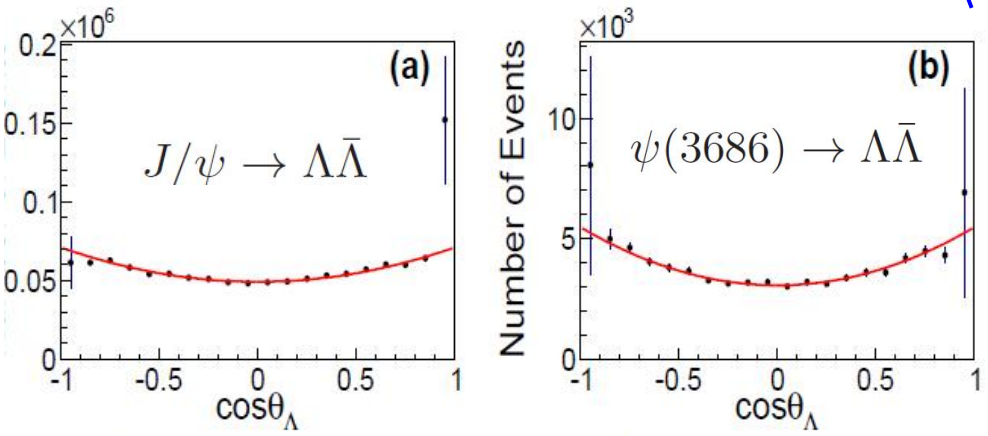
- BESIII confirms the periodic oscillations of the effective form-factor as a function of p-pbar relative momentum (first seen in BaBar data)
- An explanation is proton-antiproton rescattering at ~1 fm distances

Charmonia baryonic decays (1)

$$\frac{dN}{d\cos\theta} \propto 1 + \alpha\cos^2\theta$$

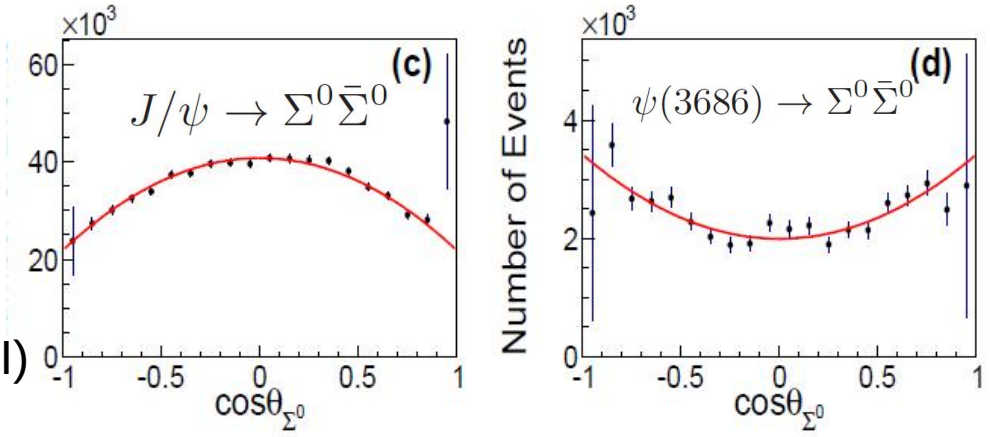
PRD 95 (2017) 052003

BESIII:
0.469 ± 0.027
Theory:
0.32-0.51



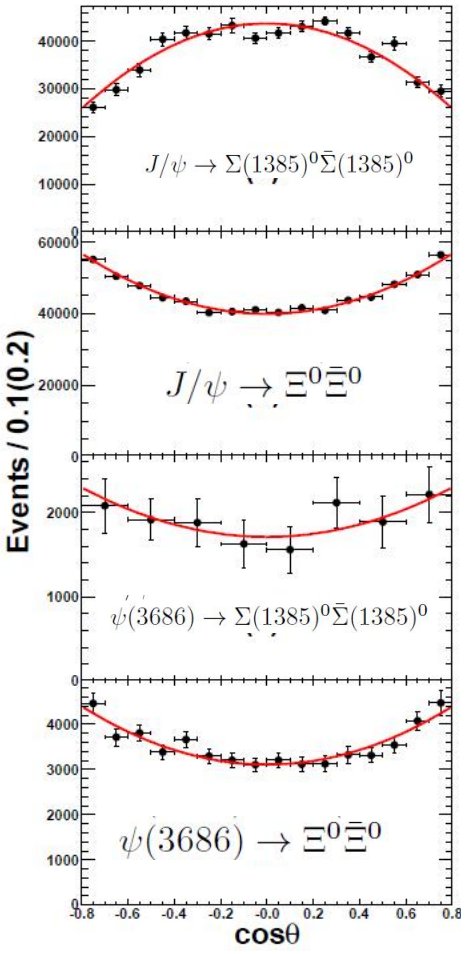
BESIII:
0.82 ± 0.08
(first measurement)

BESIII:
-0.449 ± 0.022
Theory:
0.31-0.43
Opposite sign!
(Confirm BESII)



BESIII:
0.71 ± 0.12
(first measurement)

Charmonia baryonic decays (2)



α = -0.64 ± 0.10

α = 0.66 ± 0.06

α = 0.59 ± 0.35

α = 0.65 ± 0.16

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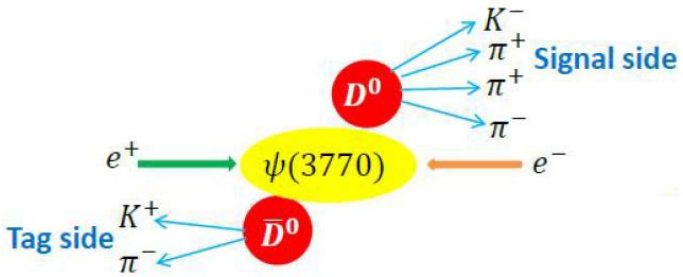
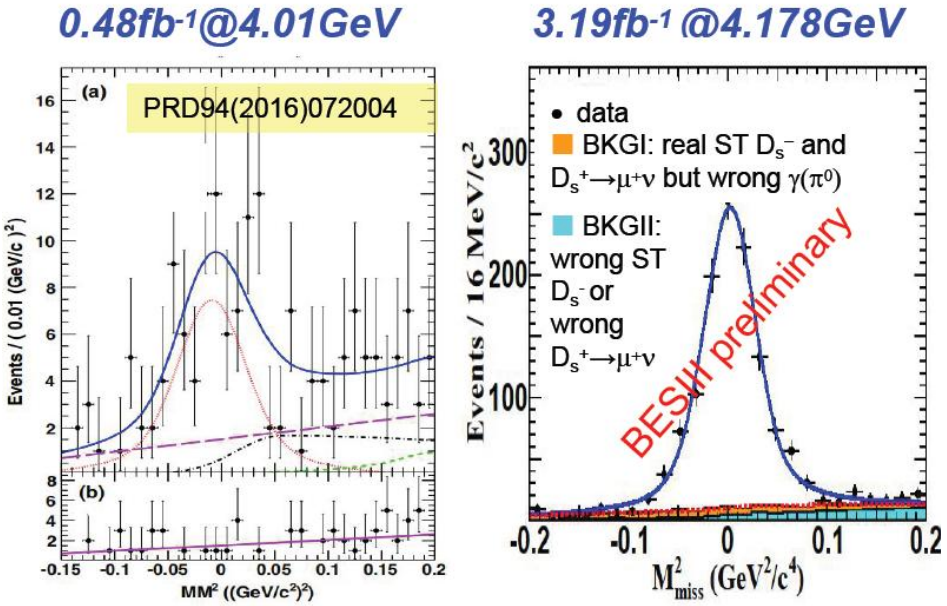
- Again, negative angular parameter is observed in $J/\psi \to \Sigma\Sigma$
- Not the case for ψ' decays and for non-Σ final states
- LO QCD predicts positive α in all cases
- More sophisticated theoretical model are necessary to explain the observations

Charm decays

$D_s^+ \to \mu^+ \nu$





- $B[D_s^+ \to \mu^+\nu] = 0.528 \pm 0.015 \pm 0.014\%$
- $f_{Ds}|Vcs| = 242.5 \pm 3.5 \pm 3.7$ MeV

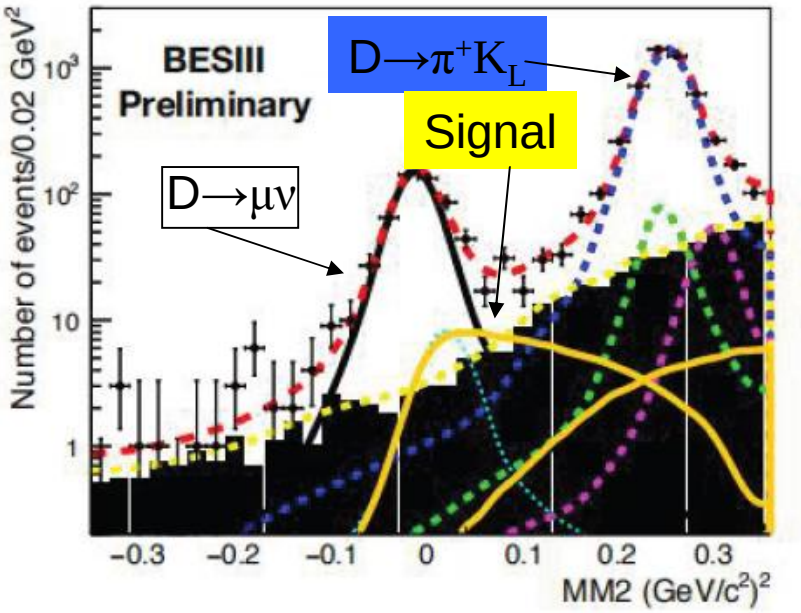
$$R \equiv \frac{\Gamma(D_s^+ \to \tau^+ \nu)}{\Gamma(D_s^+ \to \mu^+ \nu)}$$

SM: R = 9.74 ± 0.1

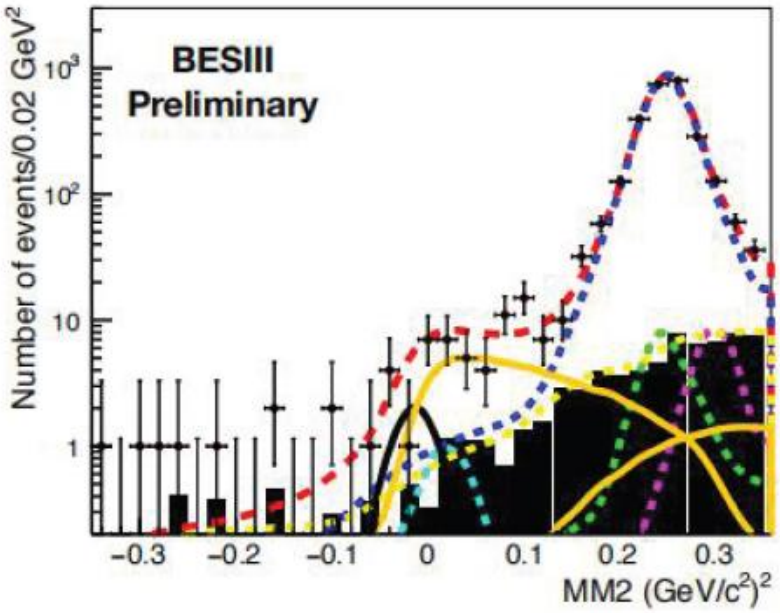
BESIII: R = 10.2 ± 0.5

$D^+ \to \tau^+ \nu$

E_{EMC} < 300 MeV



E_{EMC} > 300 MeV



- Nsig = 137 ± 27
- $B[D^+ \to \tau^+ \nu] = (1.20 \pm 0.24_{stat}) \times 10^{-3}$

$$R \equiv \frac{\Gamma(D^+ \to \tau^+ \nu)}{\Gamma(D^+ \to \mu^+ \nu)}$$

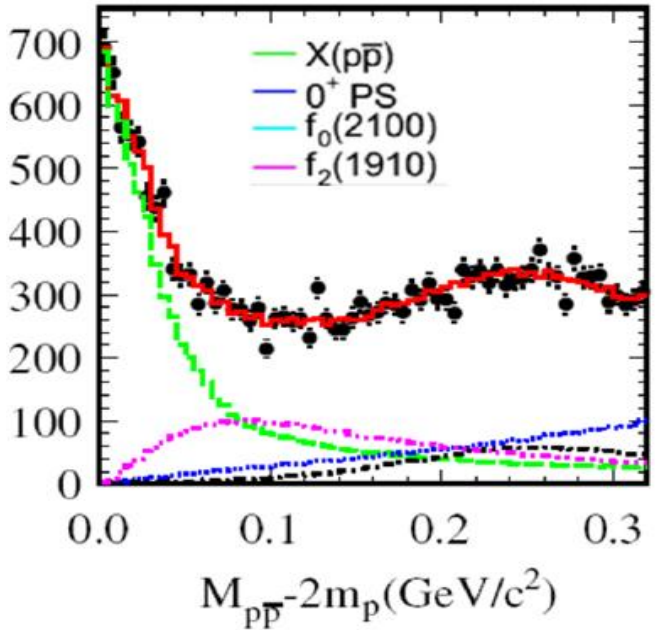
SM: R = 2.66 ± 0.01

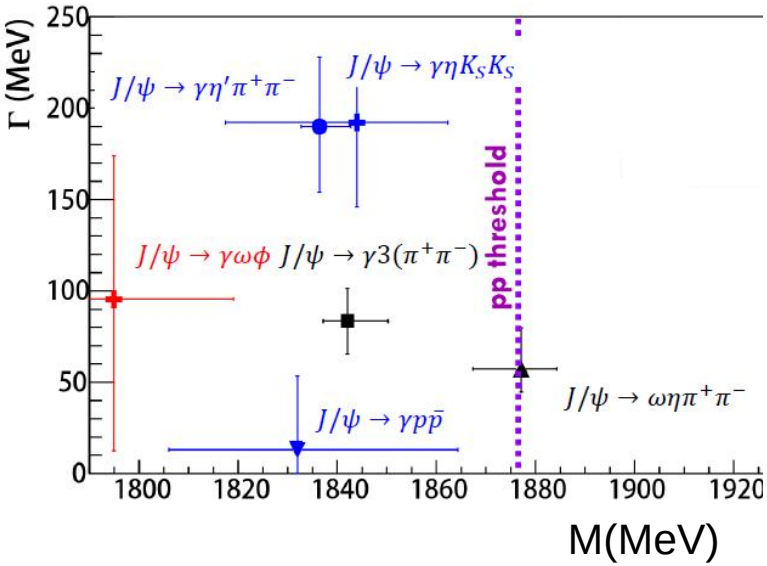
BESIII: R = 3.21 ± 0.64

Light hadron spectroscopy

Structures at the pp threshold

$J/\psi \rightarrow \gamma pp$



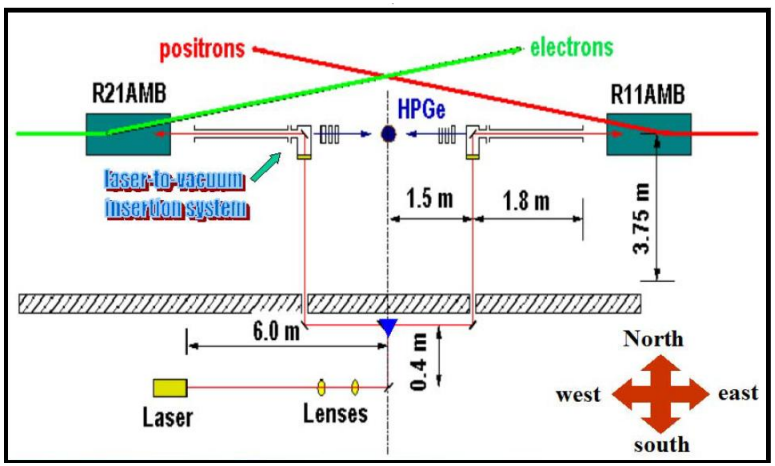


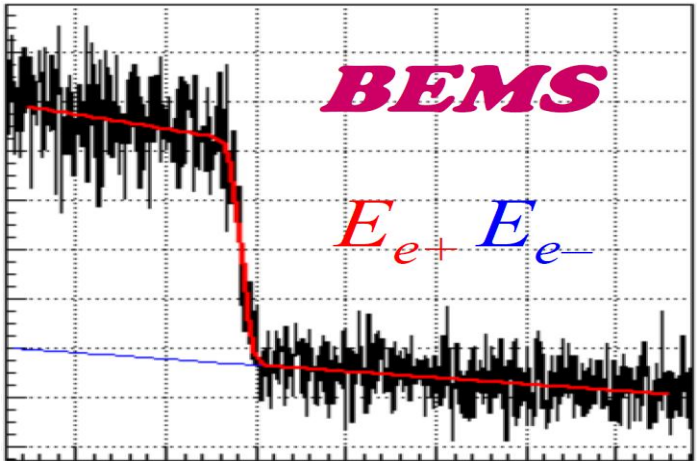
- M(X) = 1832 ± 32 MeV
- Γ(X) = 13 ± 40 MeV
- $J^{PC} = 0^{-+}$
- $B(J/\psi \rightarrow \gamma X) = (9.0 \pm 1.5) \times 10^{-5}$

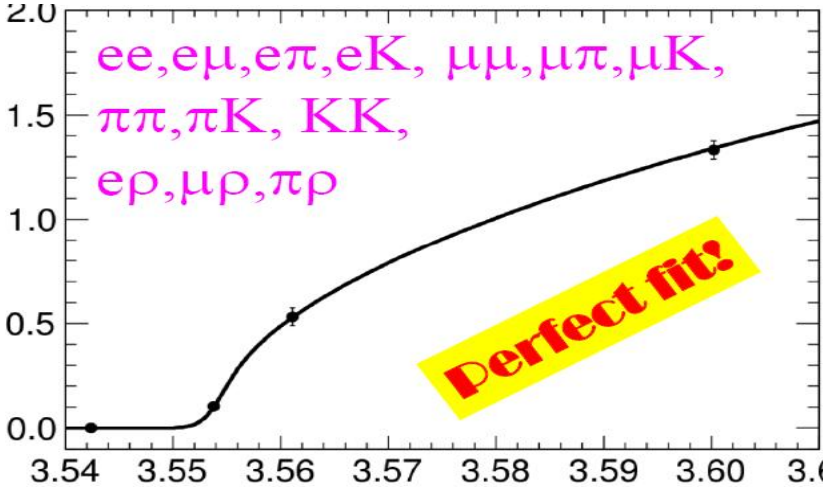
- BESIII observed quite a number of structures right below the pp threshold
- Recent increase of J/ψ statistics by factor of 4 (1.3B → 6B) will be extremely useful to clarify the situation

Physics of τ-leptons

Precision measurement of Mτ







- Mτ = **1776.91±0.12±0.12**
  - As good as the rest of the world
- PDG: 1776.86±0.12
- BESIII systematics: mostly the statistics of energy calibration runs

Summary

- With its excellent detector and huge statistics, BESIII is now the world leader in the energy domain of charm and charmonium
- An exotic state of matter (Zc resonances) has been discovered
- Many intriguing and puzzling results obtained in spectroscopy of XYZ mesons
- High precision measurements allow a detailed scrutiny of the Standard Model predictions
- After 10 years of successful running, an upgrade of both machine and detector is planned – expect even more results !