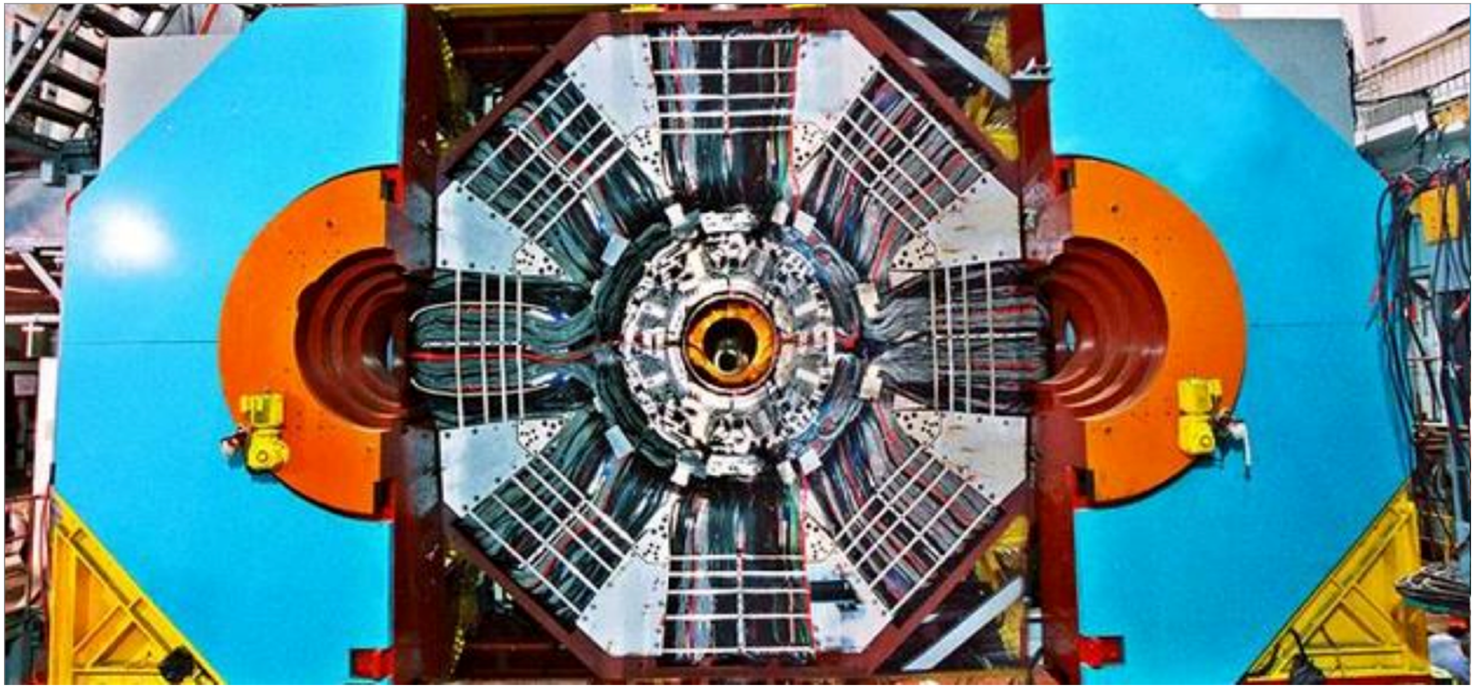


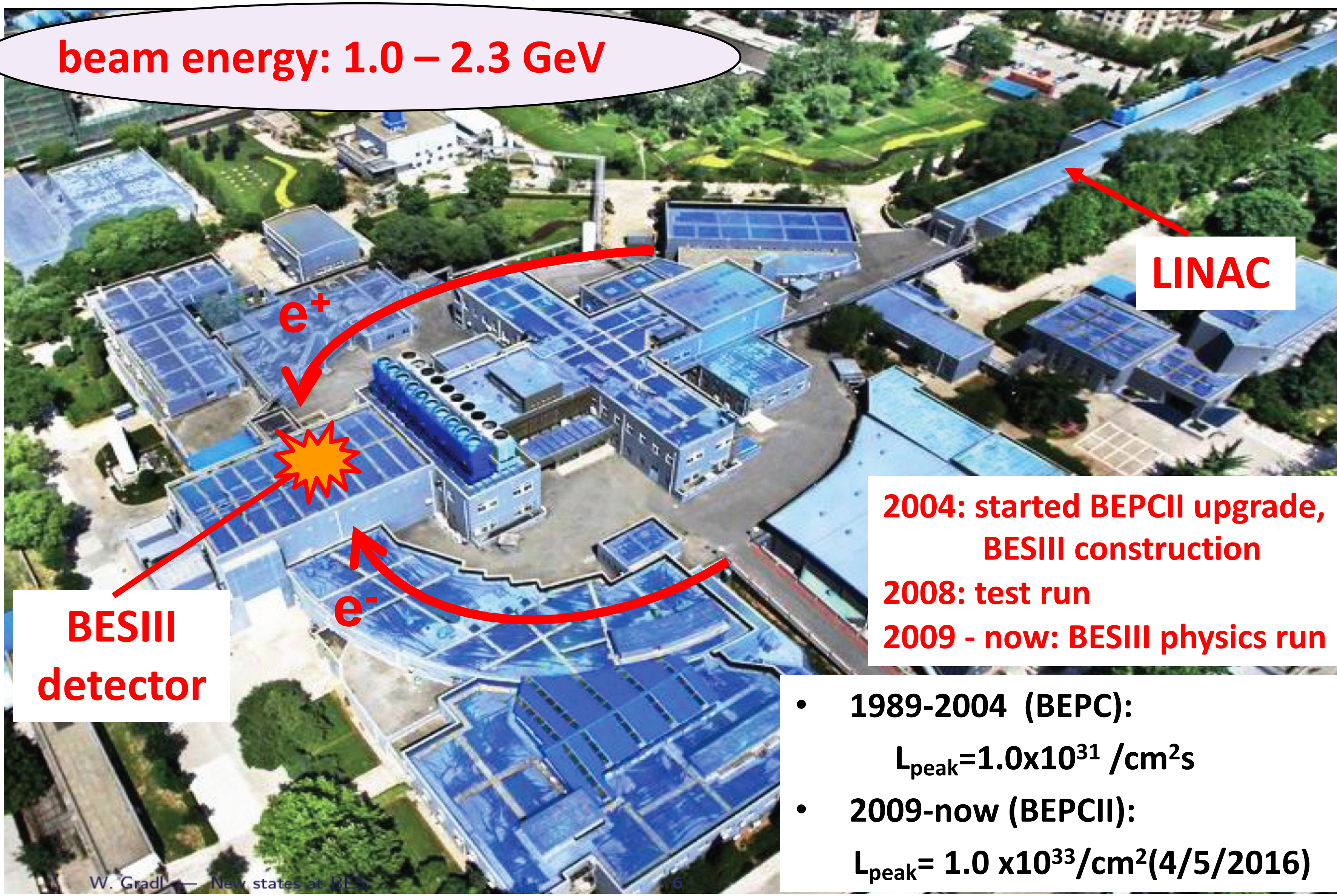
Charm Prospects at BESIII

Xiao-Rui Lyu (吕晓睿)
中国科学院大学
(On behalf of the BESIII collaboration)

Outline

- Introduction
- Status of BESIII
- Upgrade plan
- Physics prospects
- Summary

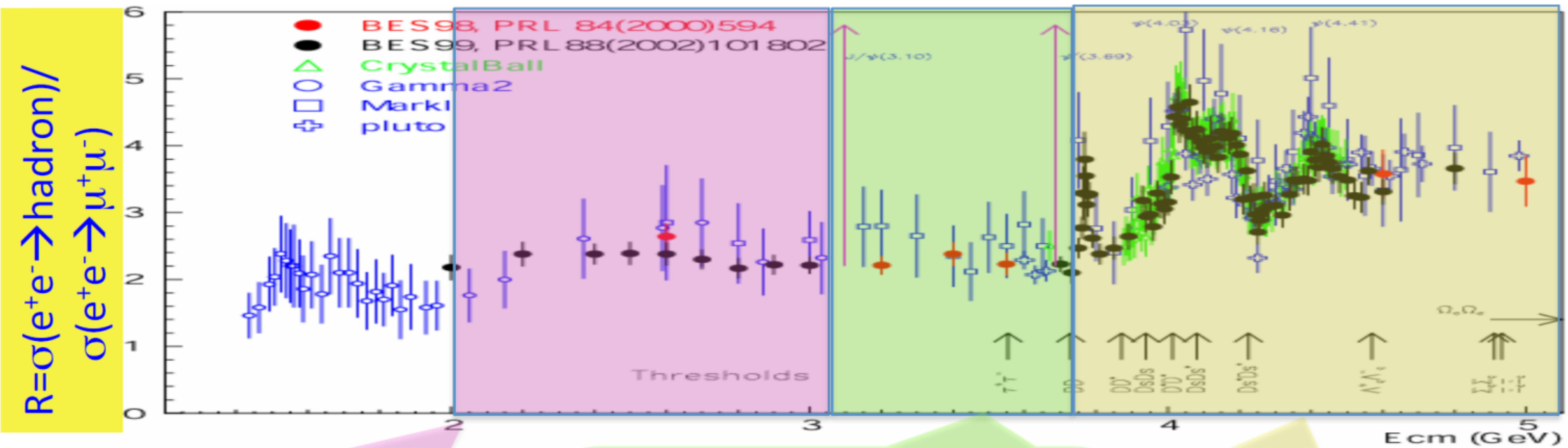
Beijing Electron Positron Collider (BEPC)



2004: started BEPCII upgrade, BESIII construction
2008: test run
2009 - now: BESIII physics run

- 1989-2004 (BEPC):
  L_{peak}=1.0x10^{31} /cm^{2}s
- 2009-now (BEPCII):
  L_{peak}= 1.0 x10^{33}/cm^2(4/5/2016)

Physics at tau-charm Energy Region



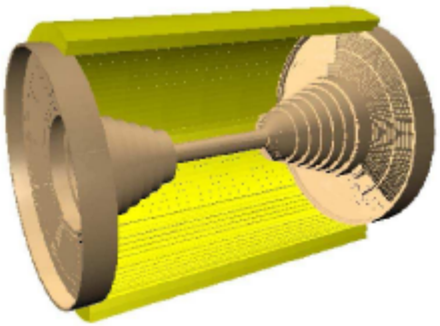
- Hadron form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with τ lepton

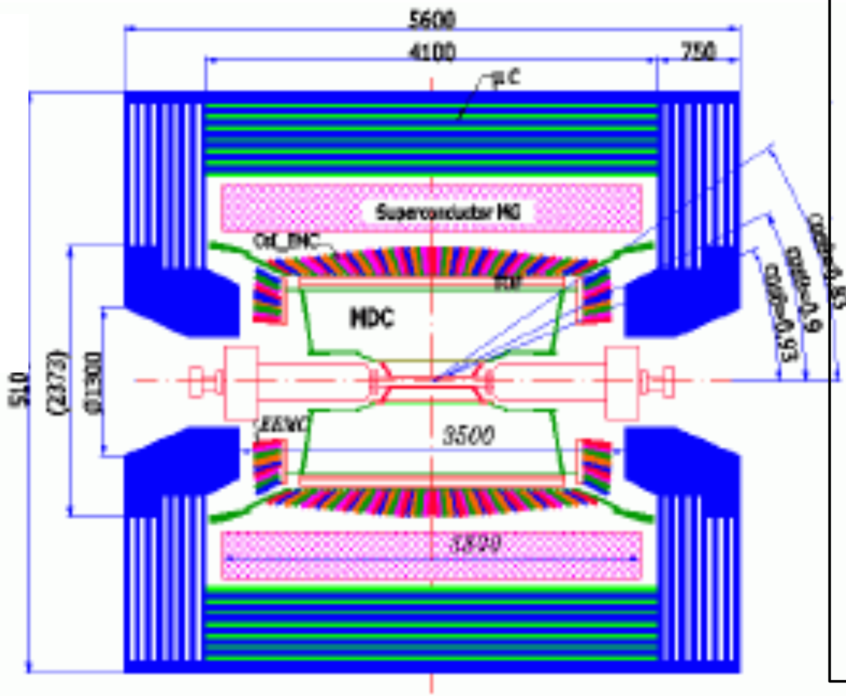
- XYZ particles
- D mesons
- f_D and f_{Ds}
- D_0-$\bar{D}_0$ mixing
- Charm baryons

BESIII Detector

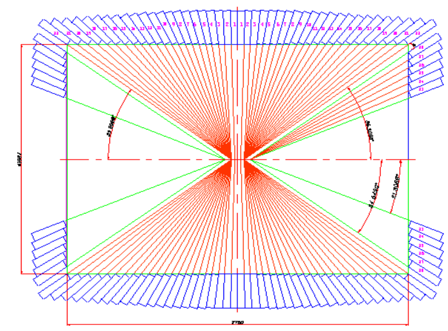
MDC



R inner: 63mm ;
R outer: 810mm
Length: 2582 mm
Layers: 43

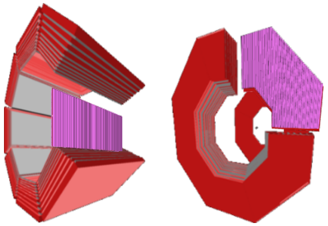


CsI(Tl) EMC



Crystals: 28 cm(15 X_0)
Barrel: $|\cos\theta|<0.83$
Endcap:
$0.85 < |\cos\theta| < 0.93$

RPC MUC



BMUC: 9 layers – 72 modules
EMUC: 8 layers – 64 modules

TOF

BTOF: two layers
ETOF: 48 crys. for each

BESIII Detector Performance

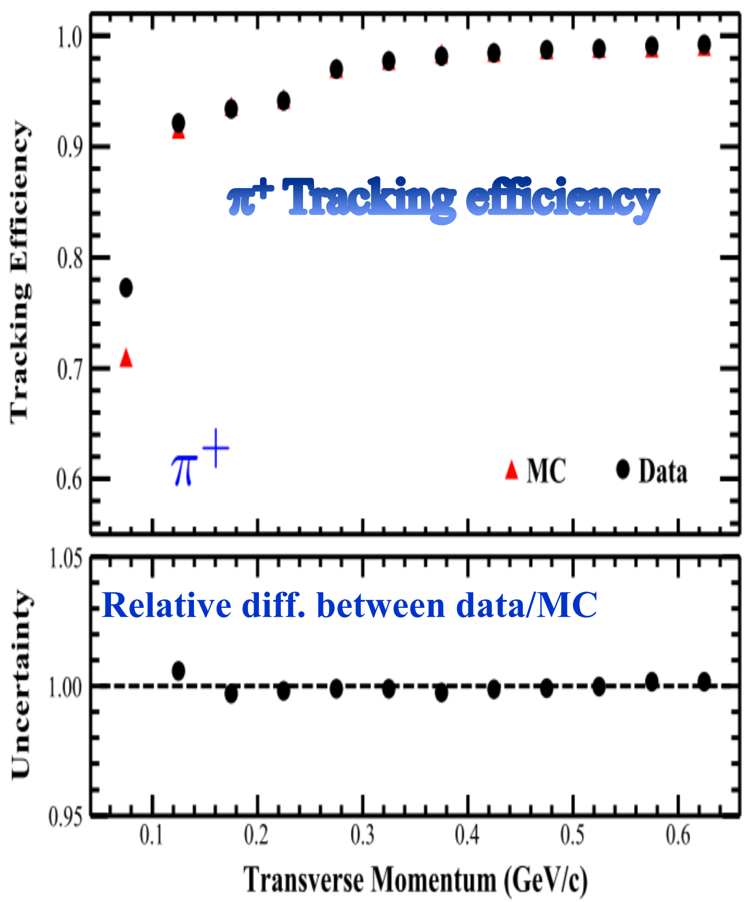
Exps.	MDC Spatial resolution	MDC dE/dx resolution	EMC Energy resolution
CLEO-c	110 μm	5%	2.2-2.4 %
BaBar	125 μm	7%	2.67 %
Belle	130 μm	5.6%	2.2 %
BESIII	115 μm	<5% (Bhabha)	2.4%

Exps.	TOF Time resolution
CDFII	100 ps
Belle	90 ps
BESIII	68 ps (BTOF) 60 ps (ETOF)

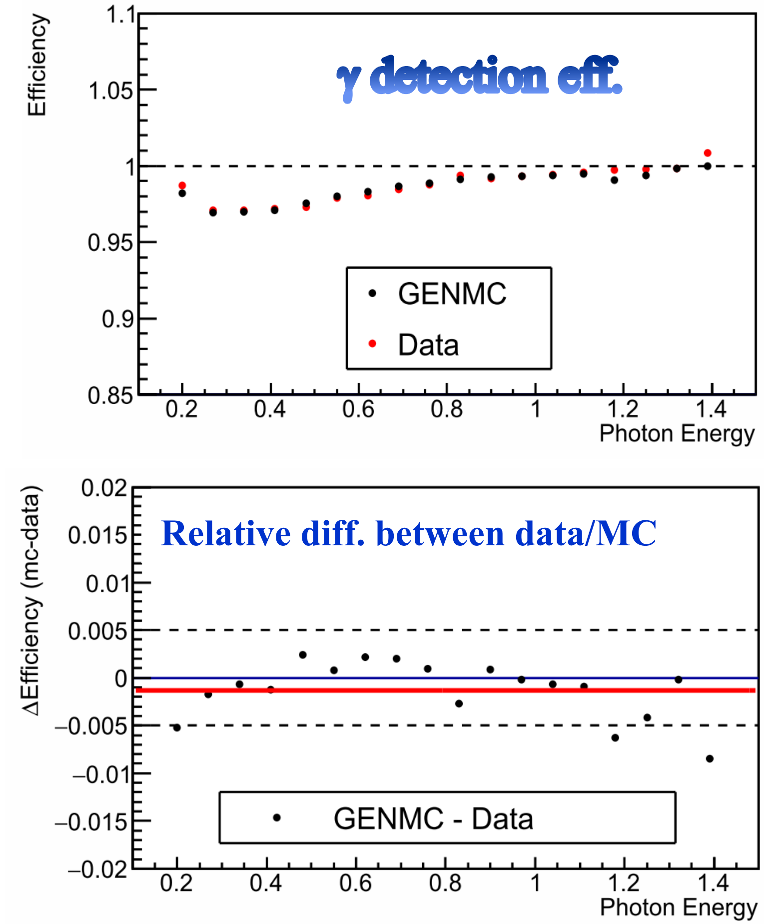
MUC: Efficiency ~ 96%
backgroun level: < 0.04 Hz/cm^2(B-MUC), < 0.1 Hz/cm^2(E-MUC)

Data/MC consistency

- **For tracking efficiency data/MC difference < 1%**



- **For photon detection efficiency data/MC difference < 1%**

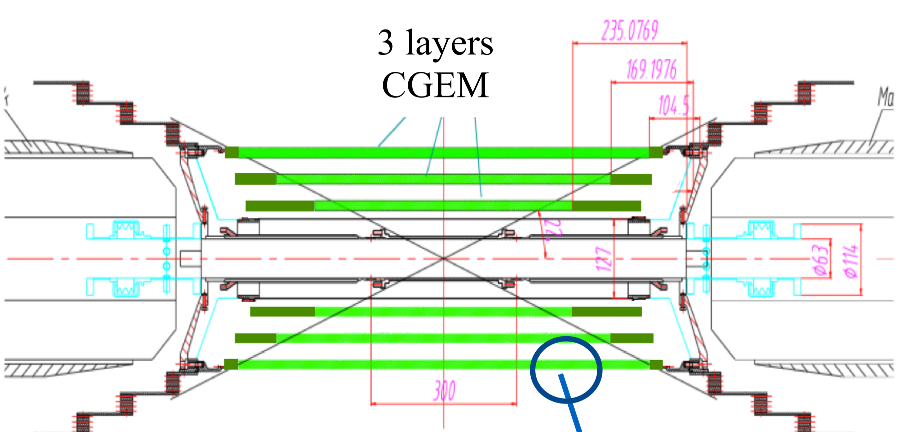


BESIII upgrade

- ☐ MDC: Malter effect found in inner chamber in 2012, add water vapor to the chamber to cure the aging problem
  - – New inner chamber, built by IHEP, is ready now
  - – Cylindrical GEM Inner Tracker (CGEM) as the inner chamber ongoing : Italy group in collaboration with other groups
- ☐ Other possible upgrade plan is under discussion

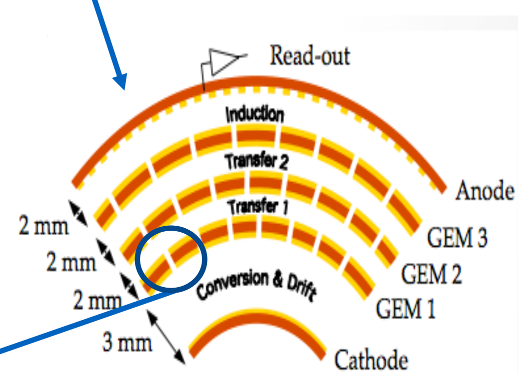
Cylindrical GEM Inner Tracker in a nutshell

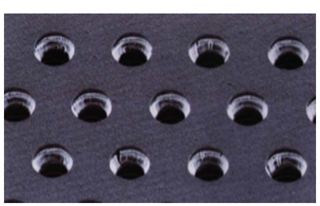
BESIII is building a cylindrical GEM detector (CGEM-IT) to replace the BESIII Inner MDC to recover some efficiency loss due to aging and to improve the secondary vertex resolution.



- **Low Material budget ≤ 1.5% of X_0 for all layers**
- **High Rate capability: ~10^4 Hz/cm^2**
- **Coverage: 93%**
- **Spatial resolution s_{rf} ~130 mm in 1 T magnetic filed**
- **Operation duration at least 5 years**

Each layer composed by a triple cylindrical GEM



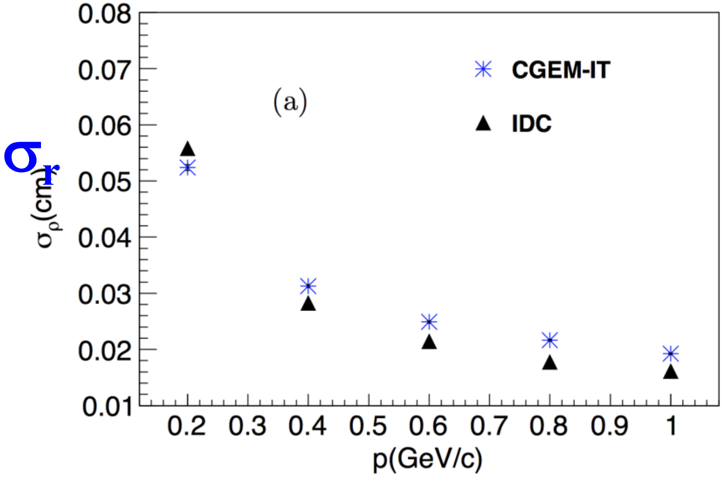


The CGEM is co-funded by the European Commission Research and Innovation Staff Exchange (RISE) project 2015-2018.

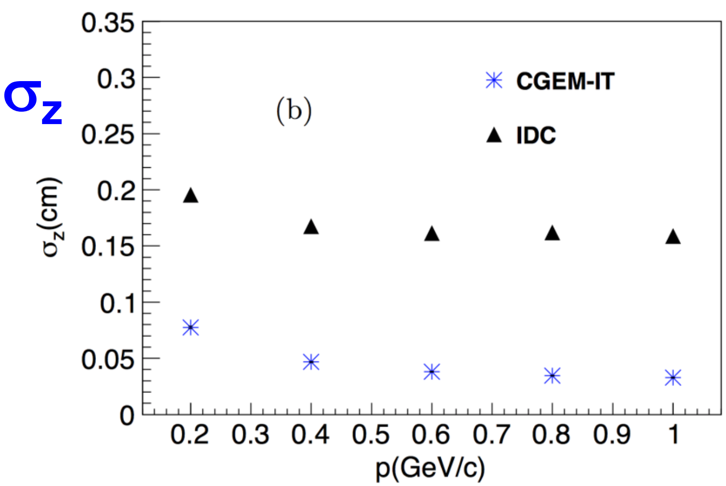
Expected performance of CGEM

Track fitting with Kalman Filter

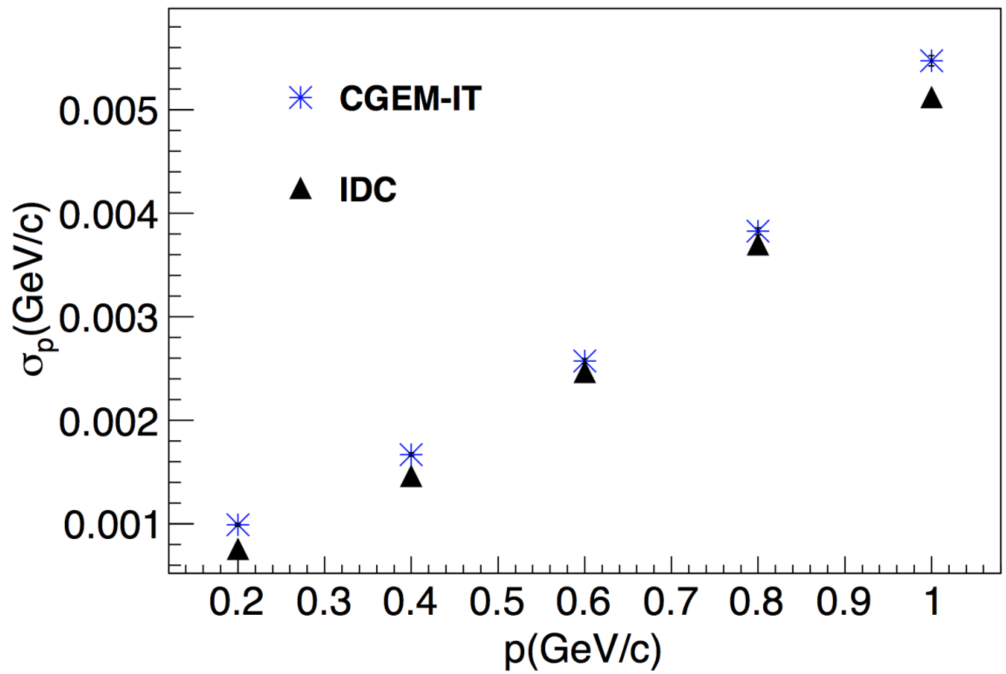
Approaching point resolution



Approaching point resolution



Momentum resolution

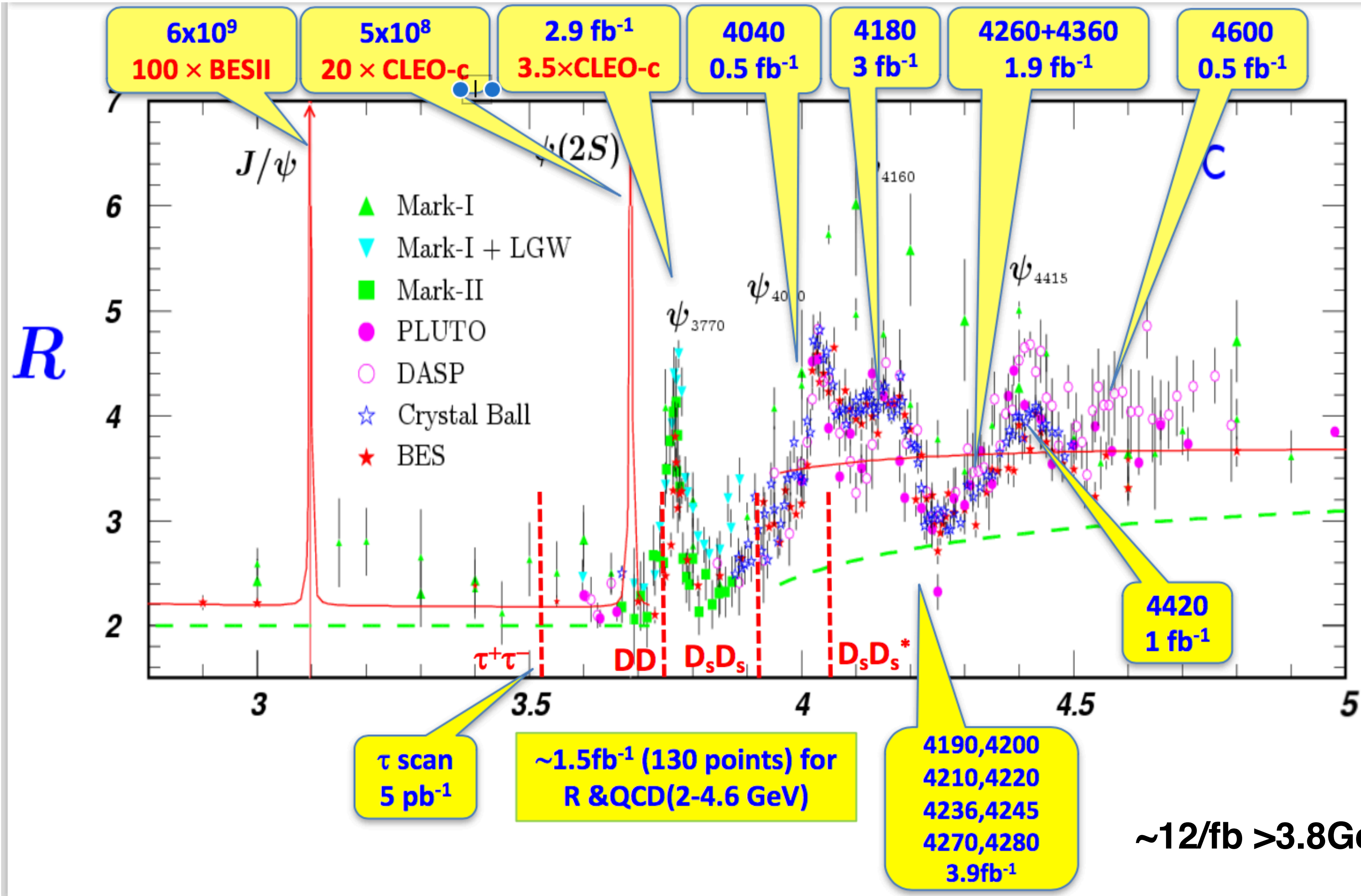


Data/MC discrepancy

$\varepsilon_{data}/\varepsilon_{MC}-1$	2010	2016	2019?
Tracking eff./track	~2%	~1%	~0.5%
PID/track	~2%	~1%	~0.5%
Photon eff./photon	~1%	0.5-1%	~0.5%

Control of systematic errors.

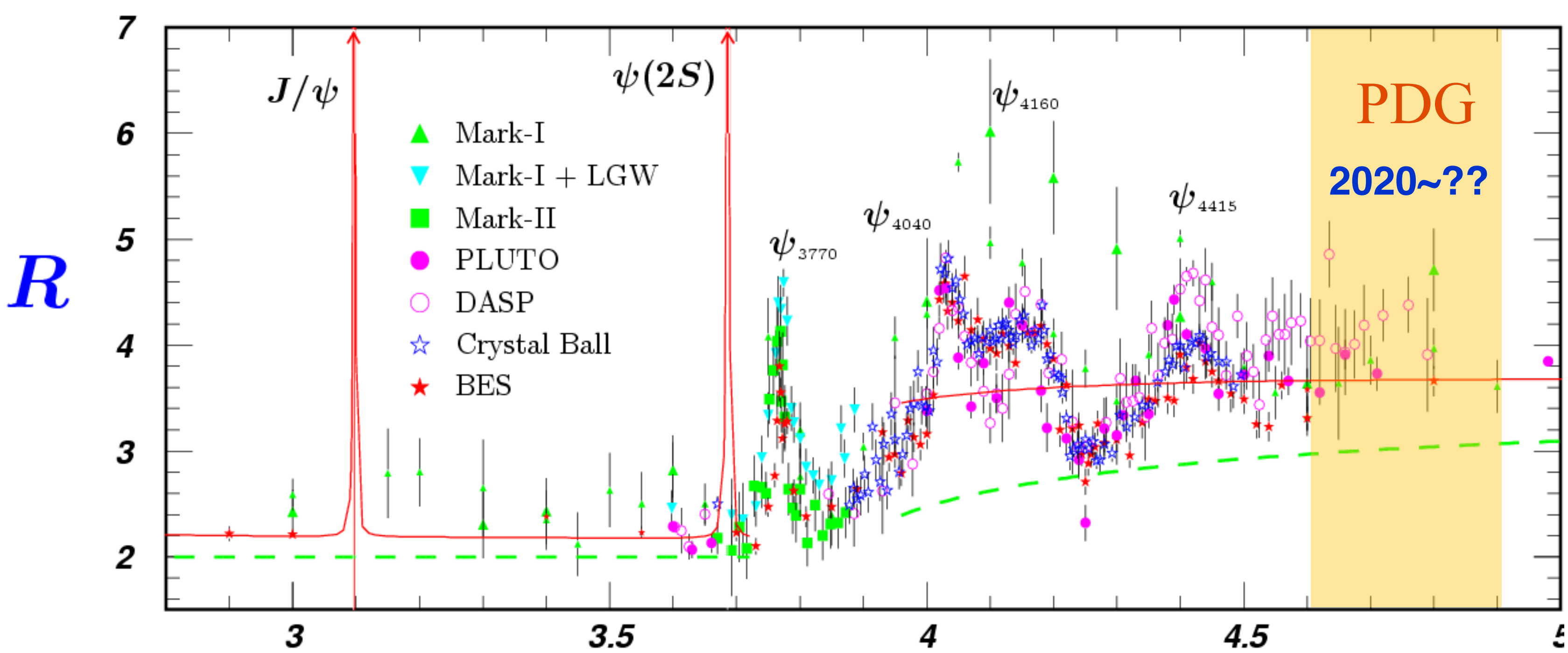
BESIII existing data samples



~12/fb >3.8GeV

BEPCII upgrade

- Increase of beam energy 2.30→2.35→2.45 GeV
  - → 2.35 GeV in 2018 summer (done)
  - → 2.45 GeV in 2020-21, change ISPB (Interaction region SePtum Bending) magnet
- Top-up injection
  - Data taking efficiency increases by 20~30%



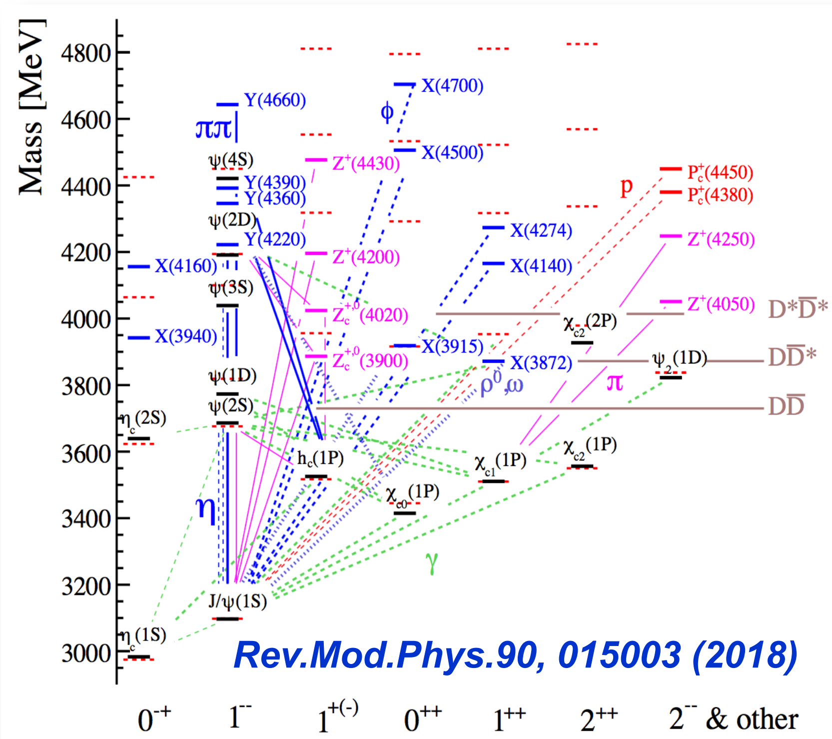
Future BESIII data Set

Year budget is not considered

Best Wishes

Energy	physics highlight	Current data # of events or integrated luminosity	Expected final data # of events or integrated luminosity
1.8 - 2.0 GeV	R values cross-sections	N/A	Scan: 3 energy points
2.0 - 3.1 GeV	R values cross-sections	Scan: 20 energy points	No requirement
J/ψ peak	Light Hadron & Glueball Charmonium decay	5.0 billion	10.0 billion **by 2019**
$\psi(3686)$ peak	Light hadron& Glueball Charmonium decay	0.5 billion	3.0 billion
$\psi(3770)$ peak	$D^0/D^\pm$ decays Form-factor/CKM decay constant	2.9 fb^{-1}	20.0 fb^{-1}
3.8 - 4.6 GeV	R value XYZ/Open charm	Scan: 105 energy points	No requirement
4.180 GeV	D_s decay XYZ/Open charm	3.1 fb^{-1}	6.0 fb^{-1}
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	Scan: 12.0 fb^{-1}	Scan: 30.0 fb^{-1} 10 MeV step/0.5 fb^{-1}/point 30 energy points
4.60 GeV	Λ_c/XYZ	0.56 fb^{-1}	1.0 fb^{-1}
4.64 GeV	Λ_c/XYZ	N/A	5.0 fb^{-1}
4.65 GeV	Λ_c/XYZ	N/A	0.2 fb^{-1}
4.70 GeV	Λ_c/XYZ	N/A	0.65 fb^{-1}
4.80 GeV	Λ_c/XYZ	N/A	1.0 fb^{-1}
4.90 GeV	Λ_c/XYZ	N/A	1.3 fb^{-1}
$\Sigma_c^+\bar{\Lambda}_c^-$ 4.74 GeV	Charm Baryons	N/A	1.0 fb^{-1}
$\Sigma_c\bar{\Sigma}_c$ 4.91 GeV	Charm Baryons	N/A	1.0 fb^{-1}
$\Xi_c\bar{\Xi}_c$ 4.95 GeV	Charm Baryons	N/A	1.0 fb^{-1}

Charmonium-like states

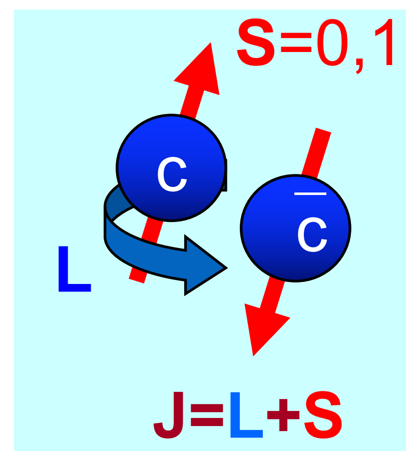


State	Decay modes	Seen by
$Z_c(3900)^{\pm,0}$	$\pi^{\pm}J/\psi$, $(D^*\bar{D})^{\pm}$	BESIII, Belle CLEO
$Z_c(4020)^{\pm,0}$	$\pi^{\pm}h_c$, $(D^*\bar{D}^*)^{\pm}$	BESIII
$Z_c(4430)^{\pm}$	$\pi^{\pm}\psi(2S)$ $\pi^{\pm}J/\psi$	Belle, ~~BaBar,~~ LHCb

in $e^+e^- \to \pi^- Zc$

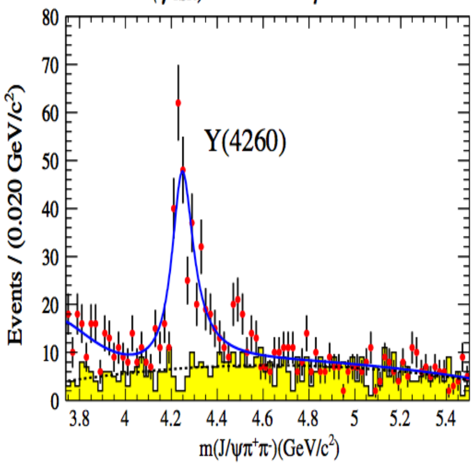
in $e^+e^- \to \pi^- Zc$

in $B \to KZc$



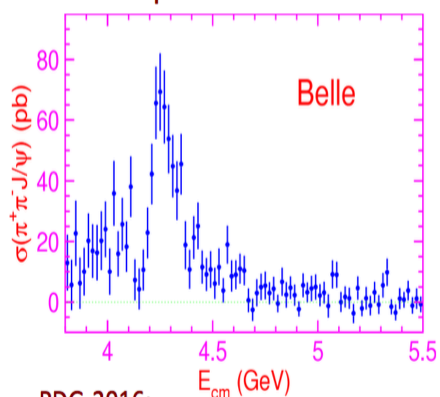
Overpopulated observed new charmonium-like states, i.e. "XYZ".

Y(4260): $e^+e^- \rightarrow \pi^+\pi^- J/\psi$

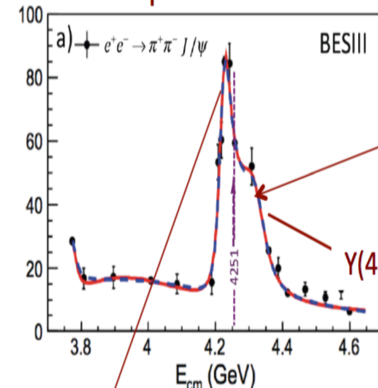


PRD 86, 051102(R) (2012)

pre-2017

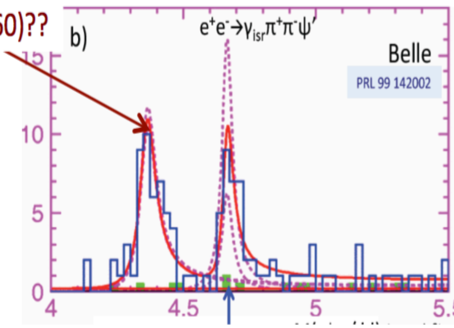


post-2017



what is the 2nd peak?

Y(4360)??



PDG-2016:

$M(Y(4260)) = 4251 \pm 9$ MeV/c^2 —(-31 MeV)→ $M_1 = 4220 \pm 4$ MeV/c^2

$\Gamma(Y(4260)) = 120 \pm 12$ MeV. —(×⅓)→ $\Gamma_1 = 44 \pm 5$ MeV

Y(4220) decay modes:

- $\pi^+\pi^- J/\psi$
  - $\pi Z_c(3900)$
  - $f_0(980)\, J/\psi$
- $\pi^+\pi^- h_c$
- $\omega\chi_{c0}$
- $\eta J/\psi$
- $\gamma X(3872)$
- $\pi D\bar{D}^*$

$M_2 = 4320 \pm 13$ MeV/c^2 —(δM≈-1.8σ)→ $M(Y(4360)) = 4346 \pm 6$ MeV/c^2

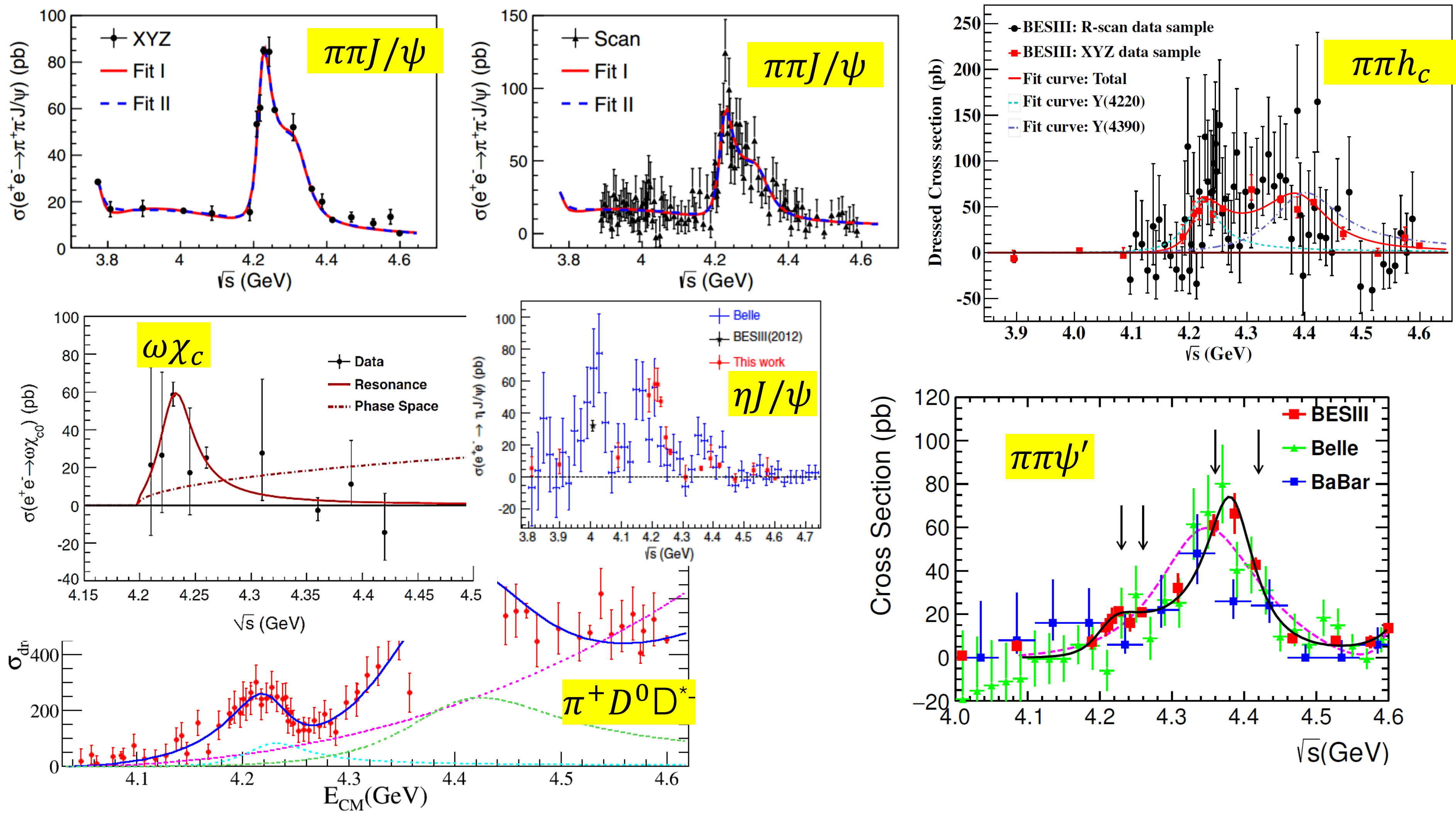
$\Gamma_2 = 101^{+27}_{-22}$ MeV —(spot on)→ $\Gamma(Y(4360)) = 102 \pm 12$ MeV.

Y(4320) decay modes:

- $\pi^+\pi^- J/\psi$
- $\pi^+\pi^-\psi'$

See Dayong's talk

BESIII Y(4260)➔Y(4220): what's nature?



$$\omega\chi_{c0},\ \pi\pi J/\psi,\ \pi^+\pi^-\psi(3686),\ \pi\pi h_c,\ \pi^+D^0D^{*-}+c.c.$$

Mass ~ 4220 MeV, width~60 MeV

Some ratios at 4.23 GeV@BESIII

$$\sigma^{\sqrt{s}=4.23GeV}(e^+e^- \to \pi^+\pi^- J/\psi) = (85.1 \pm 1.5 \pm 4.9)pb^{-1}$$

$$\frac{\sigma^{e^+e^- \to \pi^+\pi^- h_c}_{\sqrt{s}=4.23GeV}}{\sigma^{e^+e^- \to \pi^+\pi^- J/\psi}_{\sqrt{s}=4.23GeV}} = (65 \pm 12)\%$$

$$\frac{\sigma^{e^+e^- \to \pi^+\pi^-\pi^0 \eta_c}_{\sqrt{s}=4.23GeV}}{\sigma^{e^+e^- \to \pi^+\pi^- J/\psi}_{\sqrt{s}=4.23GeV}} = (54 \pm 18)\%$$

$$\frac{\sigma^{e^+e^- \to \eta J/\psi}_{\sqrt{s}=4.23GeV}}{\sigma^{e^+e^- \to \pi^+\pi^- J/\psi}_{\sqrt{s}=4.23GeV}} = (55 \pm 5)\%$$

$$\frac{\sigma^{e^+e^- \to \omega \chi_{c0}}_{\sqrt{s}=4.23GeV}}{\sigma^{e^+e^- \to \pi^+\pi^- J/\psi}_{\sqrt{s}=4.23GeV}} = (65 \pm 11)\%$$

$$\frac{\sigma^{e^+e^- \to \pi^+\pi^- \psi'}_{\sqrt{s}=4.23GeV}}{\sigma^{e^+e^- \to \pi^+\pi^- J/\psi}_{\sqrt{s}=4.23GeV}} = (25 \pm 3)\%$$

$$\frac{\sigma^{e^+e^- \to \pi^+ D^0 D^{*-}}_{\sqrt{s}=4.23GeV}}{\sigma^{e^+e^- \to \pi^+\pi^- J/\psi}_{\sqrt{s}=4.23GeV}} = (264 \pm 24)\%$$

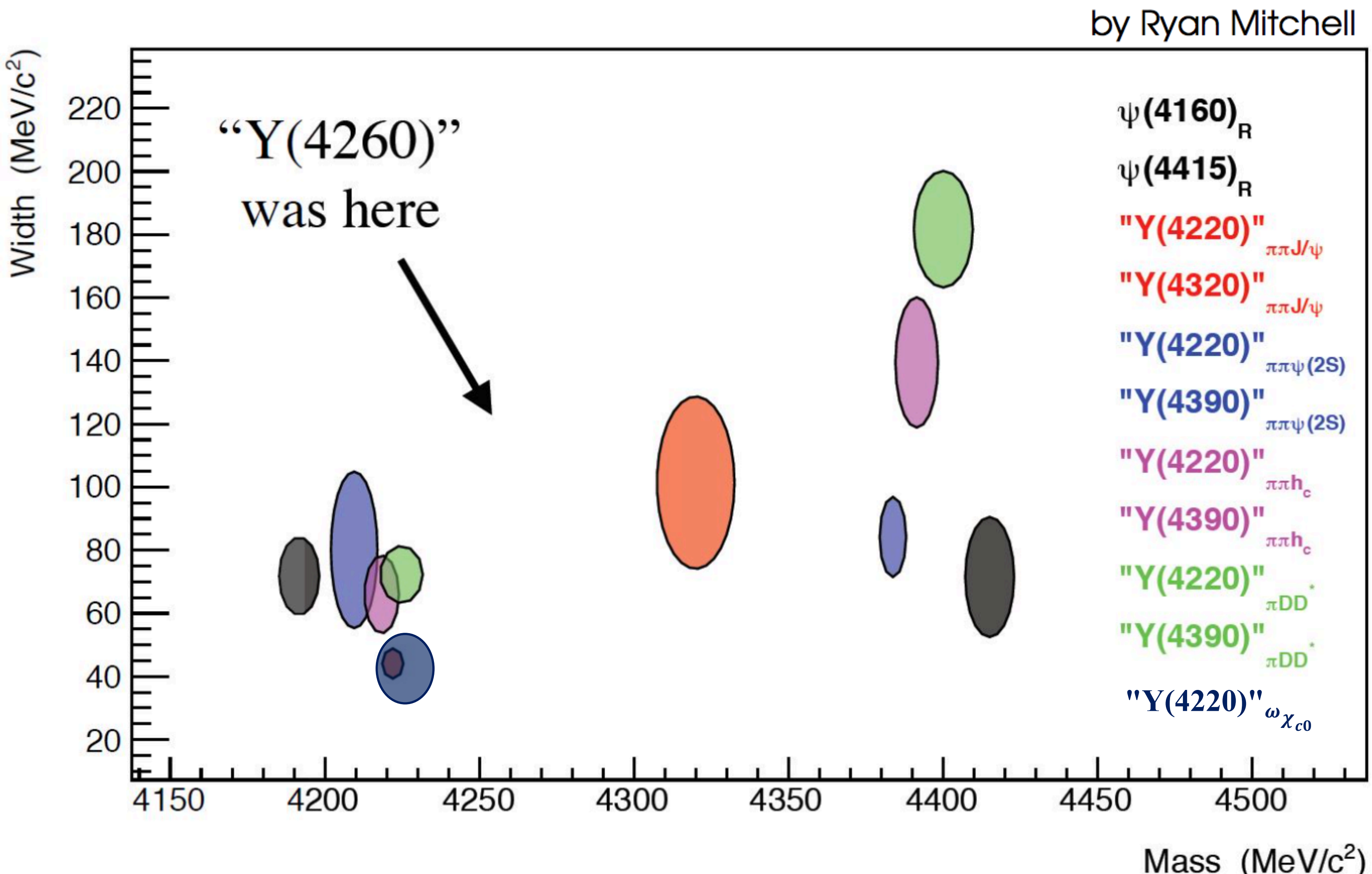
$$\frac{\sigma^{e^+e^- \to K^+K^- J/\psi}_{\sqrt{s}=4.23GeV}}{\sigma^{e^+e^- \to \pi^+\pi^- J/\psi}_{\sqrt{s}=4.23GeV}} = (6.4 \pm 1.1)\%$$

$$\frac{\sigma^{e^+e^- \to \eta h_c}_{\sqrt{s}=4.23GeV}}{\sigma^{e^+e^- \to \pi^+\pi^- J/\psi}_{\sqrt{s}=4.23GeV}} = (11 \pm 4)\%$$

$$\frac{\sigma^{e^+e^- \to \gamma X(3872)}_{\sqrt{s}=4.23GeV}}{\sigma^{e^+e^- \to \pi^+\pi^- J/\psi}_{\sqrt{s}=4.23GeV}} = (9 \pm 3)\%$$

Y(4220) has strong coupling to spin-singlet states
More decay modes to be searched for

And the new Y's

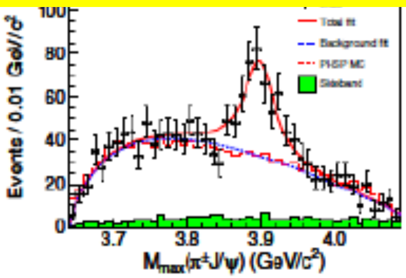


More precise data are needed

The Zc Family at BESIII

Zc(3900)$^+$?

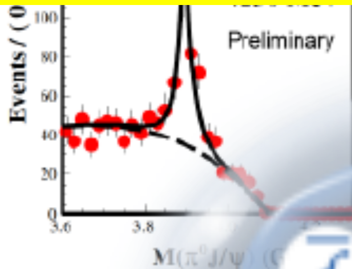
PRL 110, 252001 (2013)



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

Zc(3900)^0?

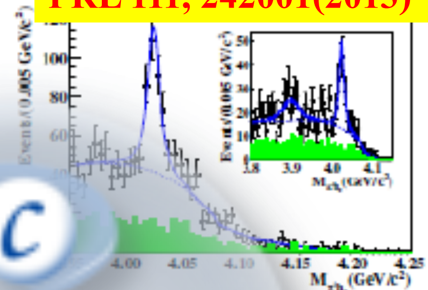
PRL 115, 112003 (2015)



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

Zc(4020)$^+$?

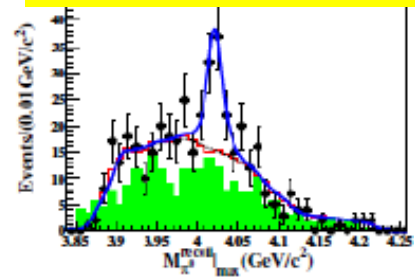
PRL 111, 242001(2013)



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

Zc(4020)^0?

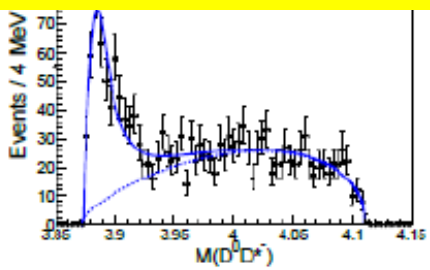
PRL113,212002 (2014)



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

Zc(3885)$^+$?

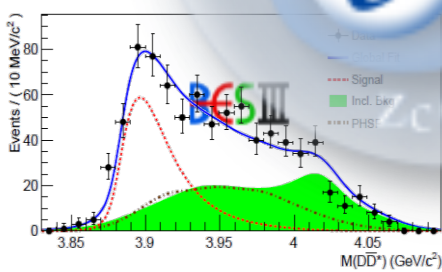
ST: PRL 112, 022001(2014)
DT: PRD92, 092006 (2015)



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

Zc(3885)^0?

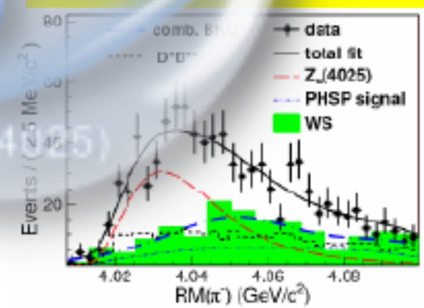
PRL 115, 222002 (2015)



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

Zc(4025)$^+$?

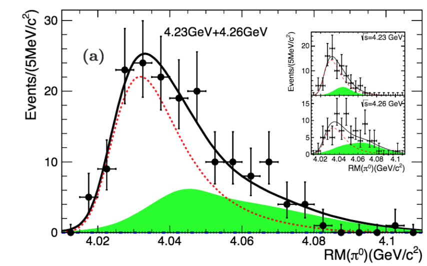
PRL 112, 132001 (2014)



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

Zc(4025)^0?

PRL115, 182002 (2015)

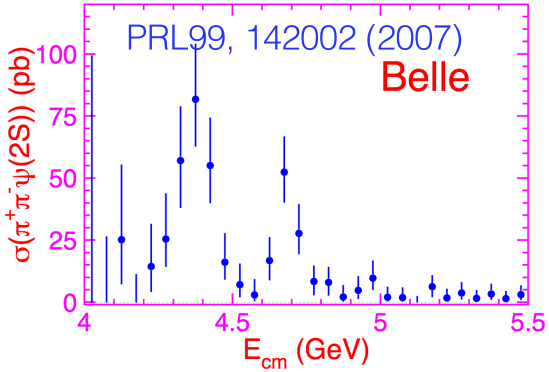


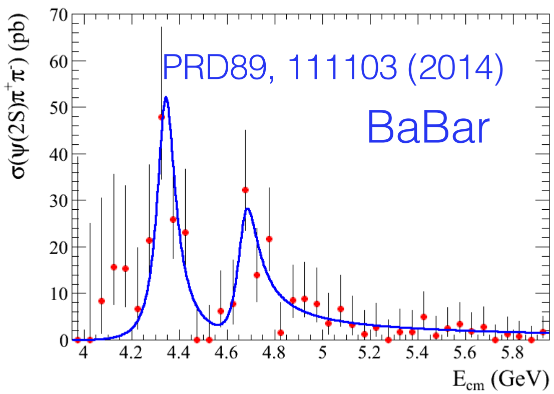
$e^+e^- \to \pi^0(D^*\bar{D}^*)^0$

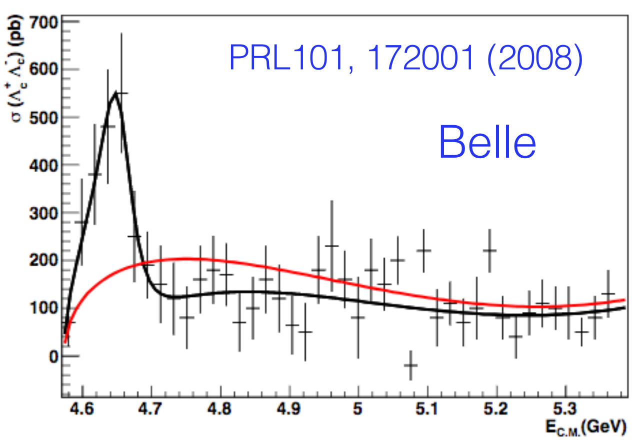
Which is the nature of these states? Quantum numbers?
Different decay channels of the same observed states? Other decay modes?

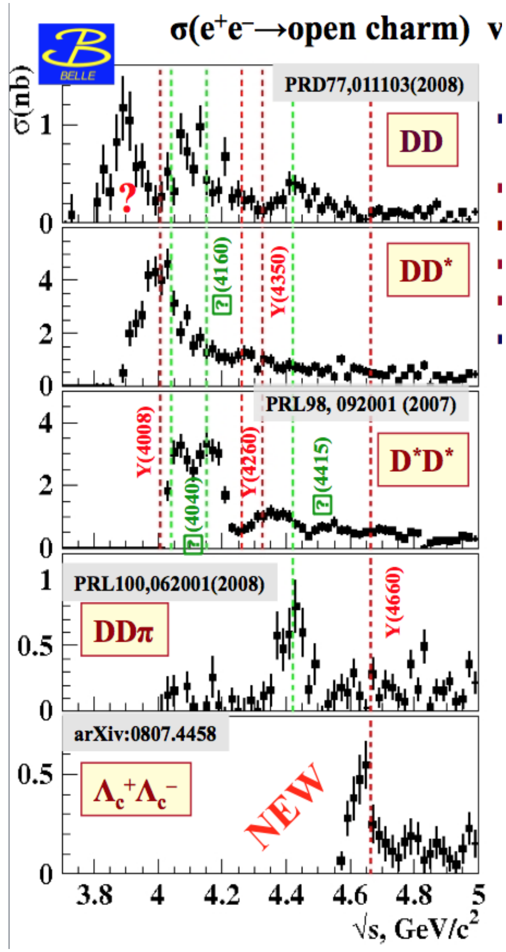
sophisticated couple channel analysis on these channels are ongoing

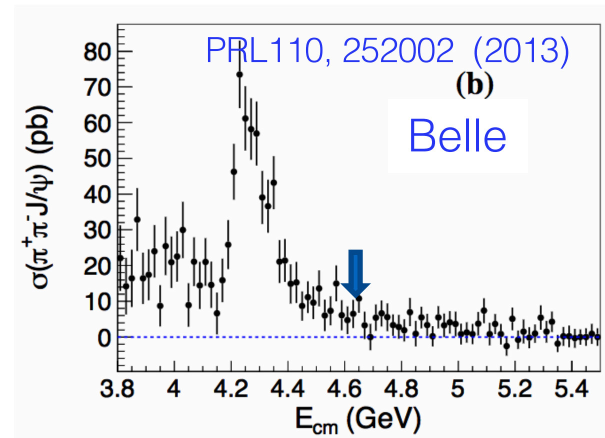
The Y(4630)/Y(4660) after BEPCII energy upgrade











$$\frac{\mathcal{B}(Y_B \to \Lambda_c \bar{\Lambda}_c)}{\mathcal{B}(Y_B \to \psi(2S)\pi^+\pi^-)} = 25 \pm 7,$$

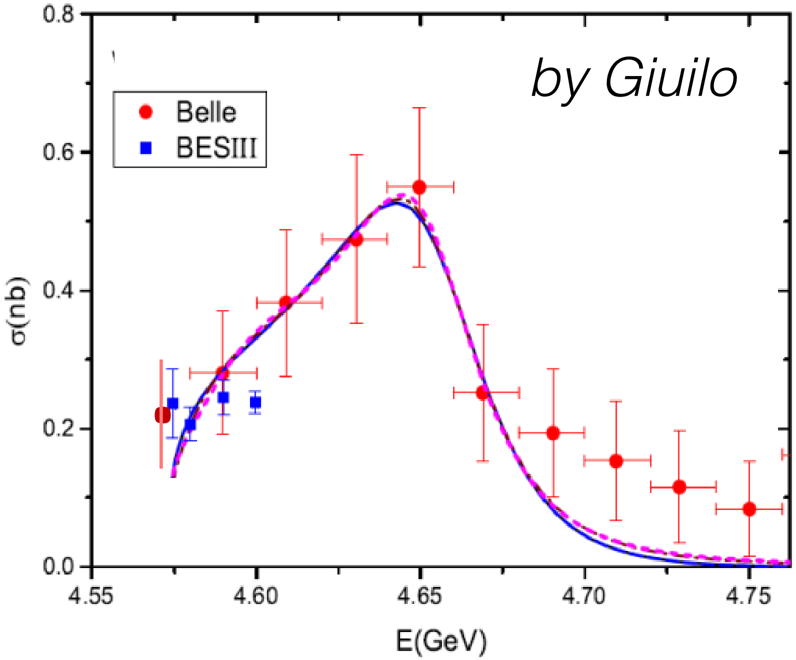
Phys.Rev.Lett. 104 (2010) 132005

$$\frac{B(Y_B \to D^0 D^{*-}\pi^+)}{B(Y_B \to \psi(2S)\pi^+\pi^-)} < 10$$

PDG

- Y(4660) baryonic coupling $\geq$ 10 mesonic coupling (unexpected!)
- Another missing large mesonic decay? Or Y(4660) is a charmed baryonium?

Lineshape of $e^+e^- \to \Lambda_c^+\overline{\Lambda}_c^-$

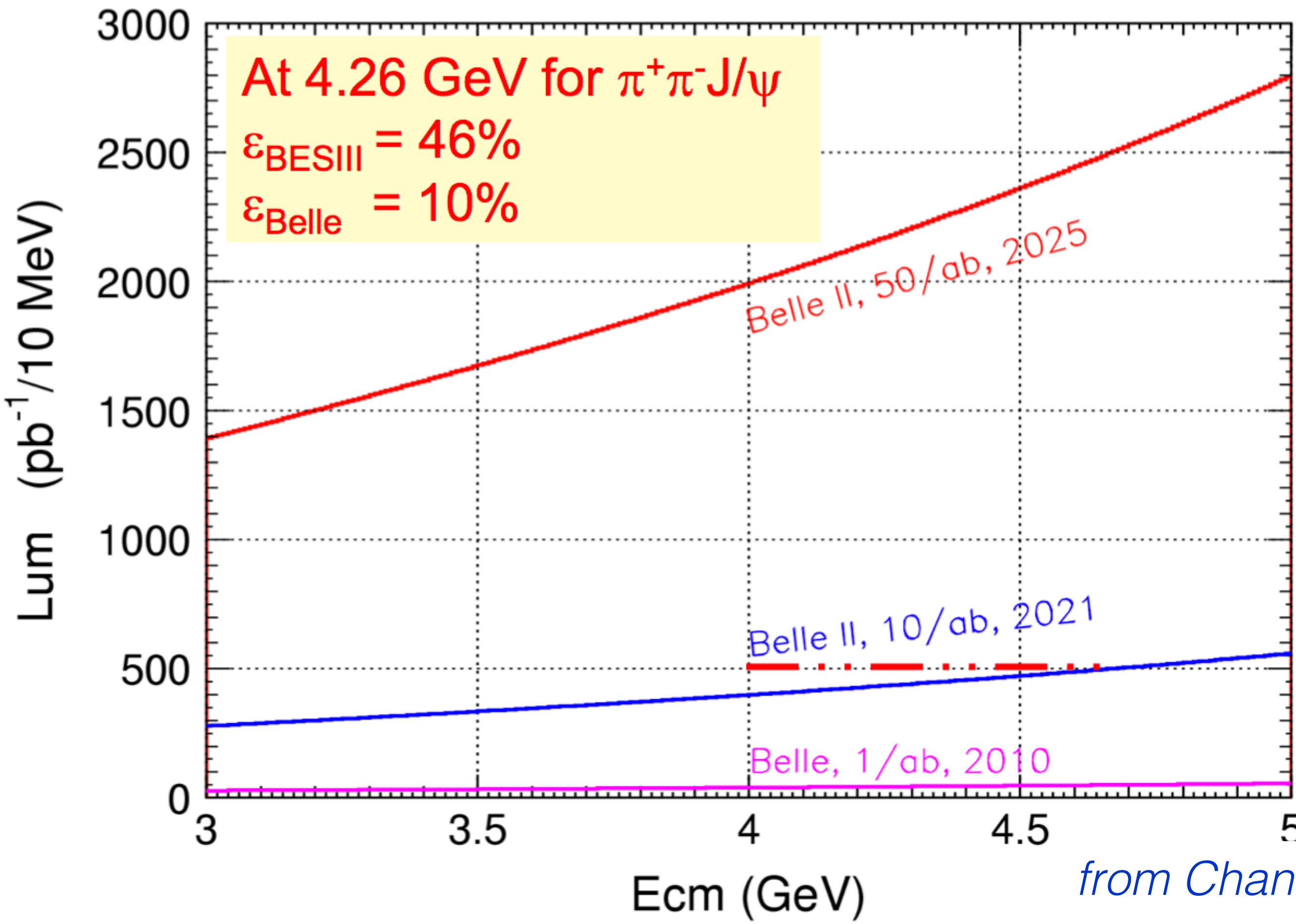


Belle: PRL101, 172001 (2008)
BESIII: PRL120,132001(2018)

- Some tension between BELLE and BESIII data on $e^+e^- \to \Lambda_c^+\overline{\Lambda}_c^-$
- BESIII future data above 4.6 GeV will follow a sharp rise of the Y(4660) or a flat cross section near threshold?

BELLE-II versus BESIII

ISR produces events at all CM energies BESIII can reach



from Changzheng

History

Steve Olsen, CHARM2018

70 years ago

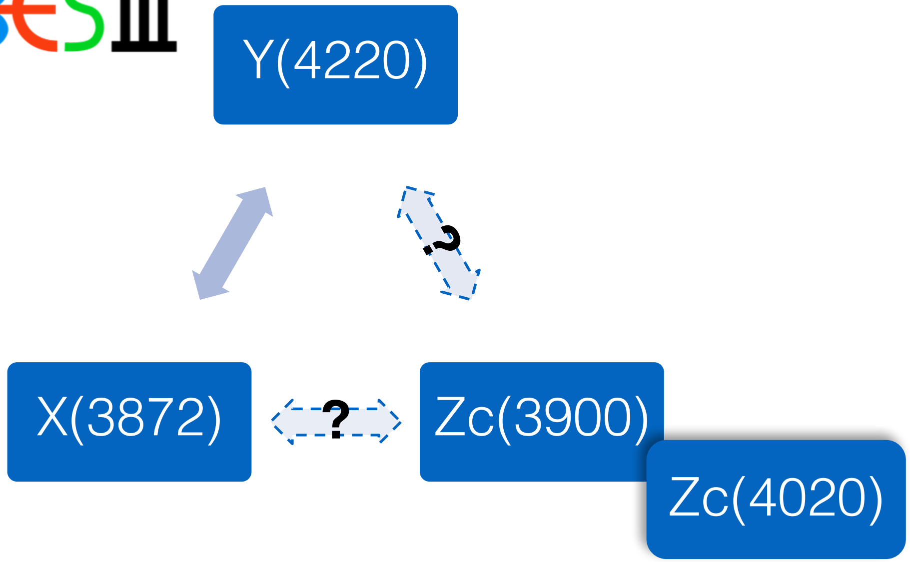
K-mesons discovered -- *associated production – strangeness – SU(3)* -- quark model

Dec. 1947 ← 16 years → Jan 1964

16 years ago

X(3872) discovered -- *molecule? – diquark? – molecule? – diquark?* -- – *diquark? – molecule? – diquark?* -- *molecule?* -- ????

Aug. 2003 ← 16 years → today



Multiquark
Hybrid
Hadrocharmonium

Molecule
Threshold effects
Cusps
… **States or/and interactions**

What is the role of threshold

--Many new observations near thresholds: D*D,D*D*, D_1D, …

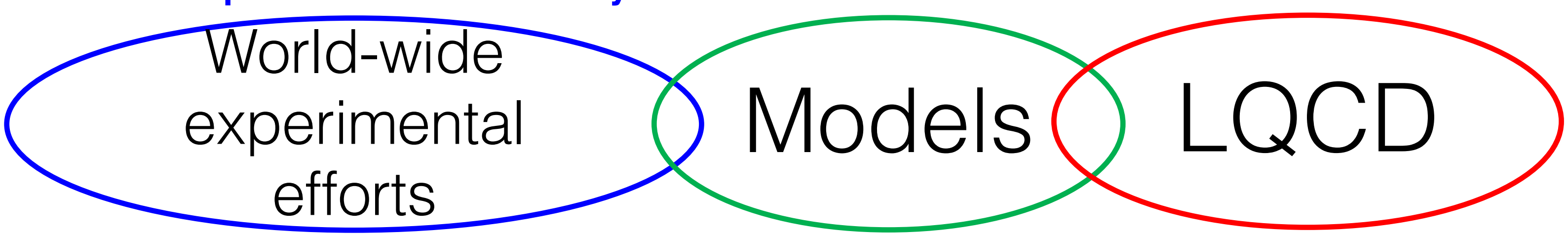
* Phase variations appear in many process: not unique for resonance

To have a complete picture, more investigations are desired, e.g., the consistency among direction productions and *B* hadron decays $B \to KY, Y \to X$

- **Energy-dependence**
- **Patterns in productions and decays**

Pole properties

For XYZ, the picture is still unclear

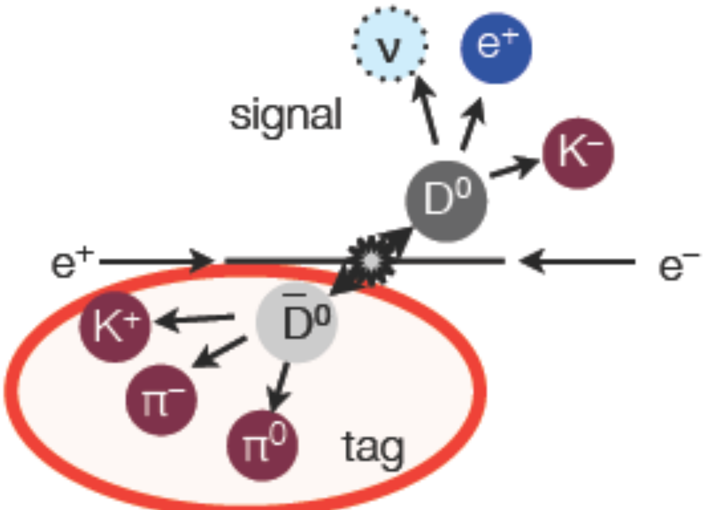


Charm facilities

- ***p* − *p* collider:** LHCb (**RUN1-4 50 fb^{-1}: 10^{10} reconstructed *D***)
- e^+e^- colliders (more kinematic constrains, clean environment, ~100% trigger efficiency)
  - Belle-II(**50 ab^{-1}: 1nb charm cross-section**)
  - Threshold production (BESIII)
    - Can not compete in statistics with Hadron colliders & B-factories！！！
    - Quantum Correlations (QC) and CP-tagging are unique
    - Only hadron pairs, no extra CM Energy for pions
    - Systematic uncertainties cancellations while applying double tag technique
- **$p - \bar{p}$ collider: PANDA …**
- ***e*-*p*/*γ*-*p* production (Glue-X…)**

Double Tag (DT) techniques

- 100% of beam energy converted to D pair (Clean environment, kinematic constrains ν Recon.)
- D generated in pair ⇒ absolute Branching fractions
- At ψ(3770) charm production is $\boldsymbol{D^0\bar{D}^0}$ and $\boldsymbol{D^+D^-}$
- Fully reconstruct about 15% of $D_{(S)}$ decays



$$\Delta E = E_D - E_{\text{Beam}}$$

$$M_{\text{BC}} = \sqrt{E_{\text{Beam}}^2 - p_D^2}$$

◆ **Double tag techniques: Hadronic tag on one side, on the other side for leptonic/semileptonic studies. Neutrino is reconstructed from missing energy and momentum (Double tag efficiency is high.)**

Precision measurement of CKM elements -- Test EW theory

see Minggang's talk

CKM matrix elements are fundamental SM parameters that describe the mixing of quark fields due to weak interaction.

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

CKM matrix

BESIII + B factories + LQCD

Three generations of quark?

Unitary matrix?

BESIII + B factories + LHCb + LQCD

Expected precision < 2% at BESIII

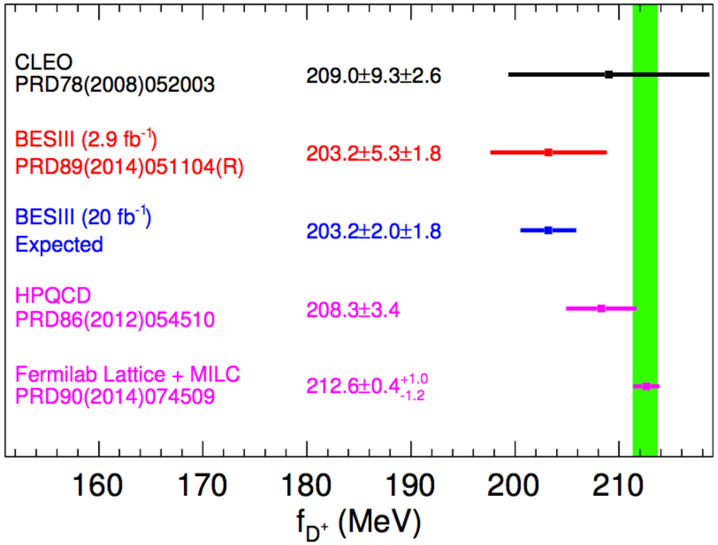
- **Precision measurement of CKM matrix elements**
- **A precise test of SM model**
- **New physics beyond SM?**

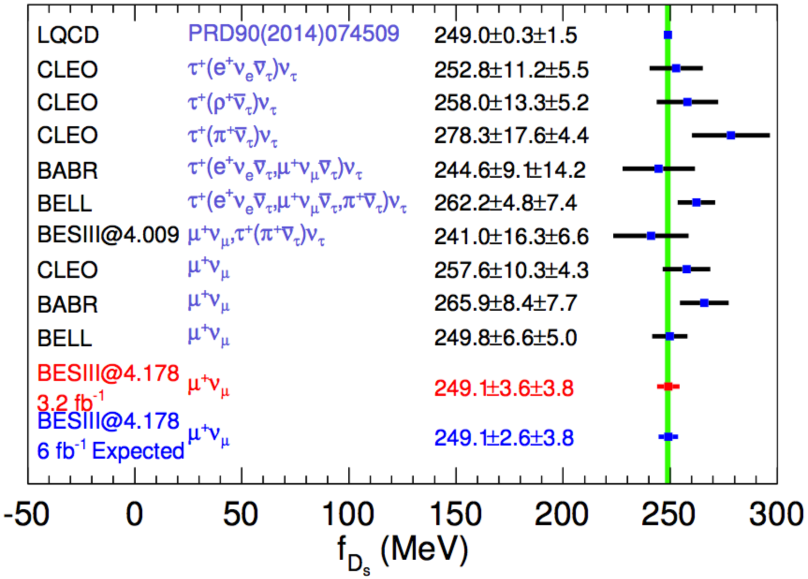
$D_{(S)}$ Leptonic decays

Purely Leptonic:

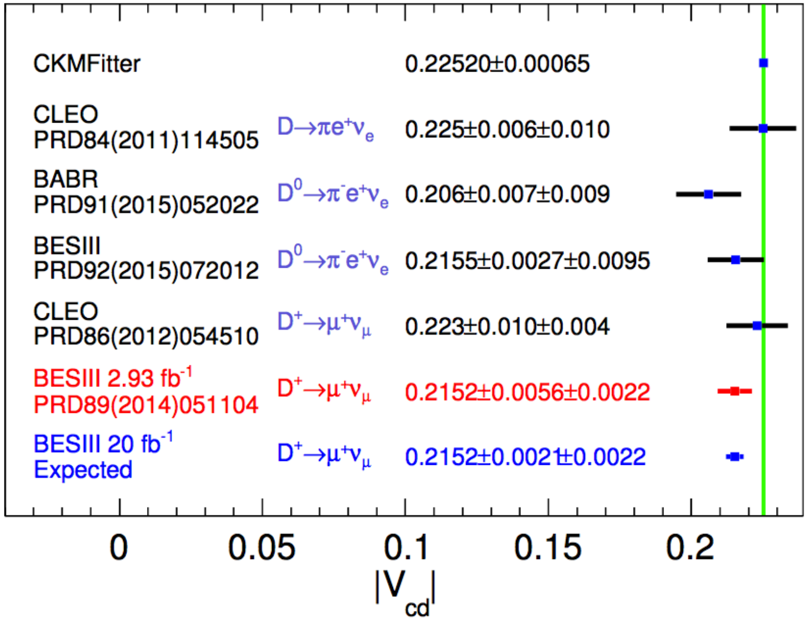
- Extract decay constant $f_{D(s)}$ incorporates the strong interaction effects (wave function at the origin)
- To validate Lattice QCD calculation of $f_{B(s)}$ and provide constrain of CKM-unitarity

$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f^2_{D^+_{(s)}}}{8\pi} \mid V_{cd(s)} \mid^2 m_\ell^2 m_{D^+_{(s)}} \left(1 - \frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2$$

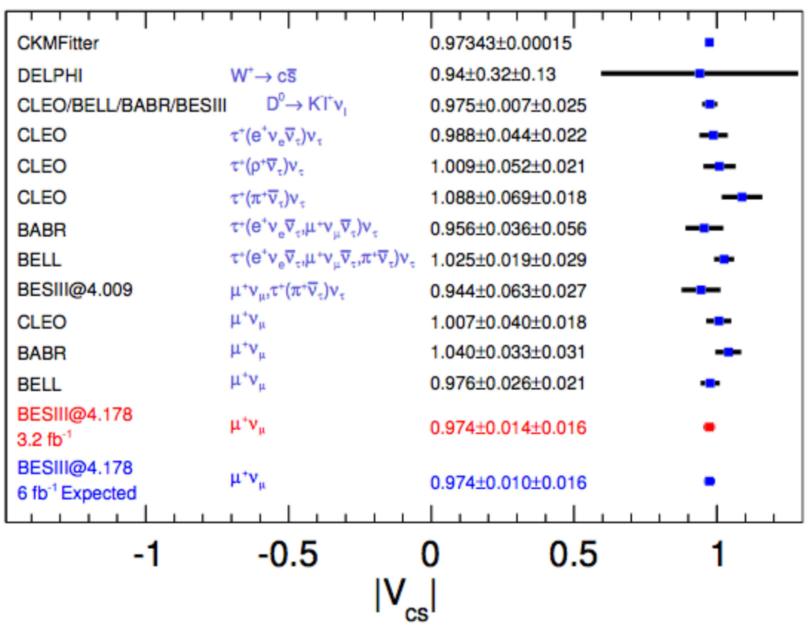


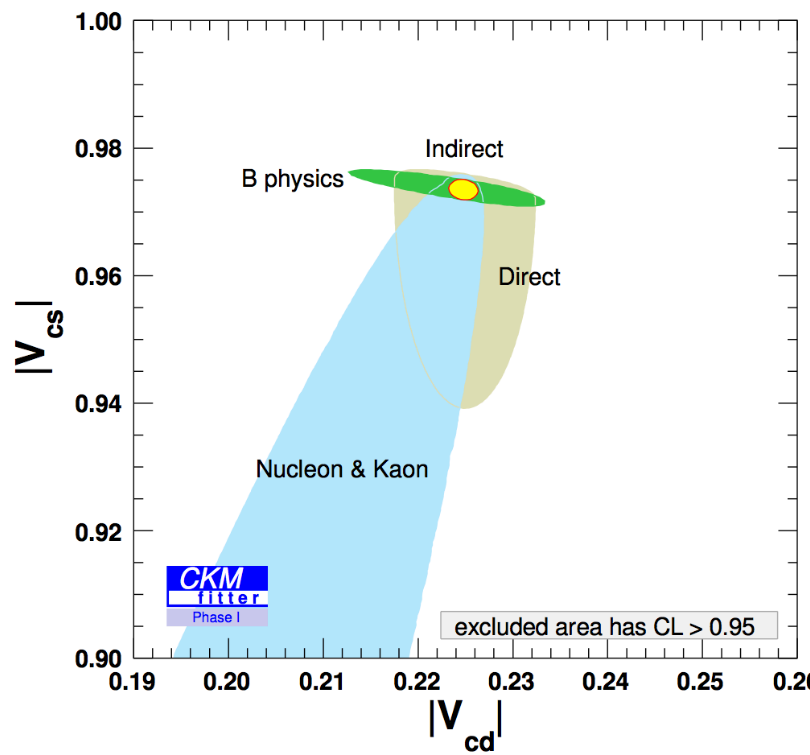


Vcs and Vcd



BESIII: best precision and systematic dominant

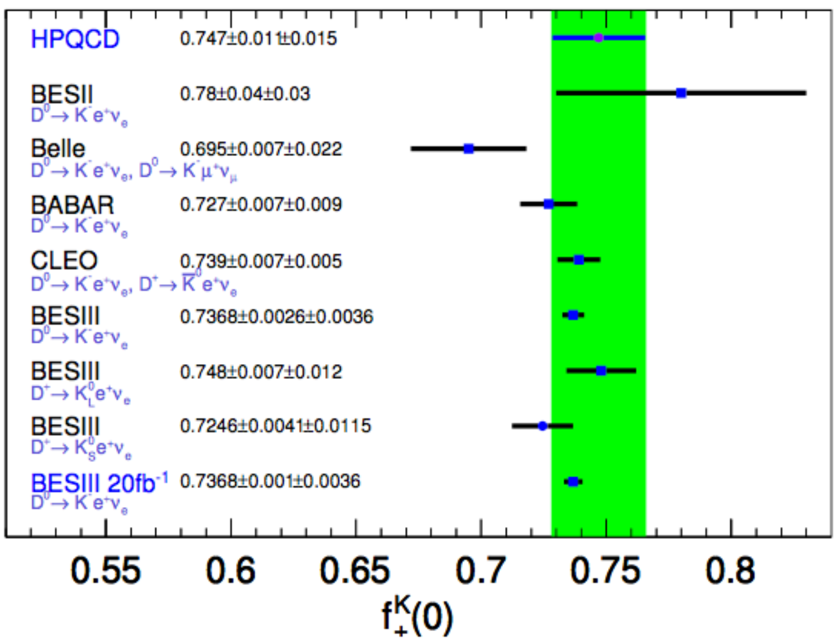


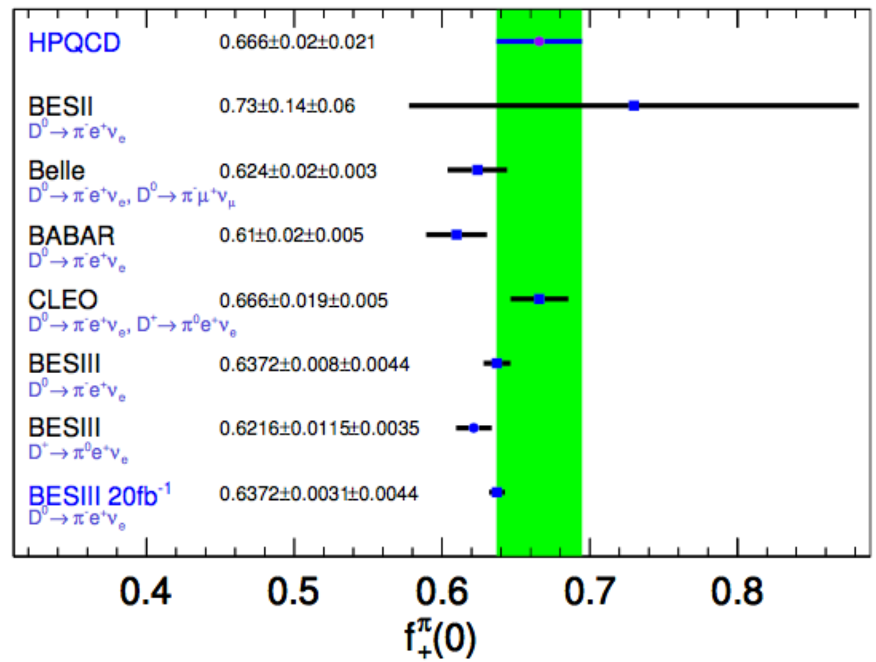


$D_{(S)}$ Semi-Leptonic decays

Semi-leptonic: form facotr (FF)

- Measure $|V_{cx}|$ x FF
- Charm physics:
  - CKM-unitarity ⇒ $|V_{cx}|$, extract FF, test LQCD
  - Input LQCD FF to test CKM-unitarity





BESIII: best precision and systematic dominant

Tests of lepton flavor universality

$$R_{D^+_{(s)}} = \frac{\Gamma(D^+_{(s)} \to \tau^+\nu_\tau)}{\Gamma(D^+_{(s)} \to \mu^+\nu_\mu)} = \frac{m^2_{\tau^+}\left(1-\frac{m^2_{\tau^+}}{m^2_{D^+_{(s)}}}\right)^2}{m^2_{\mu^+}\left(1-\frac{m^2_{\mu^+}}{m^2_{D^+_{(s)}}}\right)^2}.$$

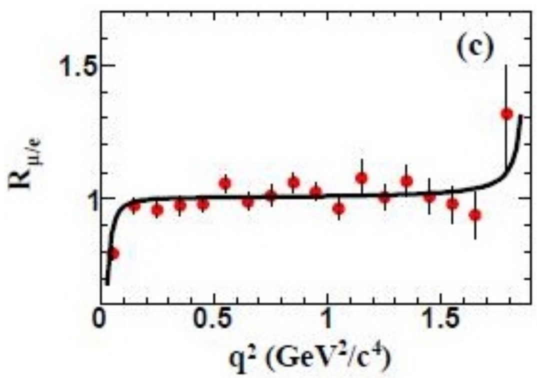
SM prediction: R_D =2.66±0.01

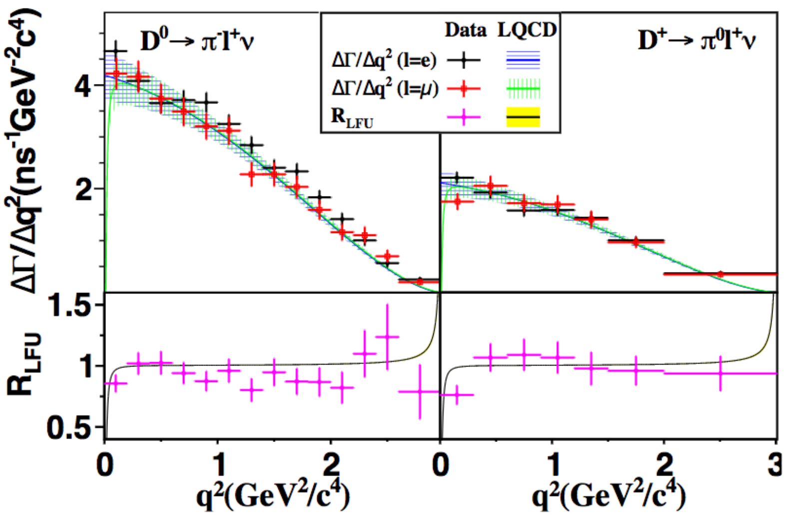
BESIII: R_D =3.21±0.64 (preliminary)

1σ difference?

Semi-leptonic modes

$$R_{\mu/e} = \Gamma_{D^0\to K^-\mu^+\nu_\mu}/\Gamma_{D^0\to K^-e^+\nu_e}$$





2.93/fb@3773MeV;
3.19/fb @ 4178MeV

	$R(D_s^+)$	$R(D^+)$	$R(K^-)$	$R(\bar{K}^0)$	$R(\pi^-)$	$R(\pi^0)$
SM	9.74(1)	2.66(1)	0.975(1)	0.975(1)	0.985(2)	0.985(2)
BESIII	10.19(52)	3.21(64)	0.974(14)	1.013(29)	0.922(37)	0.964(45)

2σ difference?

Future 20/fb @3773MeV data will improve these test.

Status of $D^0-\bar{D}^0$ mixing and CPV

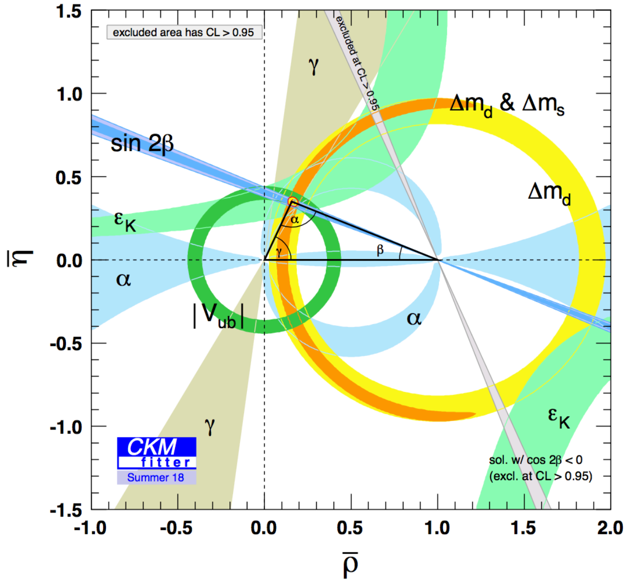
L.K. Li *Beauty 2018*

Decay Type	Final State	BELLE	BaBar	LHCb	CDF	CLEO	BESIII
DCS 2-body(WS)	$K^+\pi^-$	★	☆	★[a]	★	✓	✓ $\delta_{K\pi}$
DCS 3-body(WS)	$K^+\pi^-\pi^0$	o[c]	☆			✓ A_{CP}	o δ
CP-eigenstate	(even) h^+h^-	☆	☆	☆[b] A_{CP}	✓ A_{CP}	✓	
	(odd) $K^0_S\phi$	✓					
Self-conj. 3-body decay	$K^0_S\pi^+\pi^-$	✓	✓	✓	✓ A_{CP}	✓	o δ
	$K^0_SK^+K^-$	o	✓	o			o δ
	$K^0_S\pi^0\pi^0$					✓ Dalitz	o y_{CP}
Self-conj. SCS 3-body decay	$\pi^+\pi^-\pi^0$	✓ A_{CP}	✓ mixing A_{CP}	✓ A_{CP}			o δ
	$K^+K^-\pi^0$		✓ A_{CP}				o δ
SCS 3-body	$K^0_SK^\pm\pi^\mp$			✓ A_{CP}		✓ δ	o δ
Semileptonic decay	$K^+\ell^-\nu_\ell$	✓	✓			✓	
Multi-body(n≥4)	$K^+\pi^-\pi^+\pi^-$	✓ R_{WS}	✓	★			o δ_{RS}
	$\pi^+\pi^-\pi^+\pi^-$	o A_{CP}		✓[d] A_{CP}			
	$K^+K^-\pi^+\pi^-$	o A_T	✓ A_T	✓[e] A_{CP}		✓ A_{CP}	o
	$K^0_S\pi^+\pi^-\pi^0$	✓ A_T					
$\psi(3770)\to D^0\bar{D}^0$ via correlations						✓ $\delta_{K\pi}$	✓ y_{CP}

In $D^0-\bar{D}^0$ mixing measurements: ★for observation (>5σ); ☆for evidence (>3σ); √for measurement published; o for analysis on going. A_T stands for measuring *CP* asymmetry using T-odd correlations.

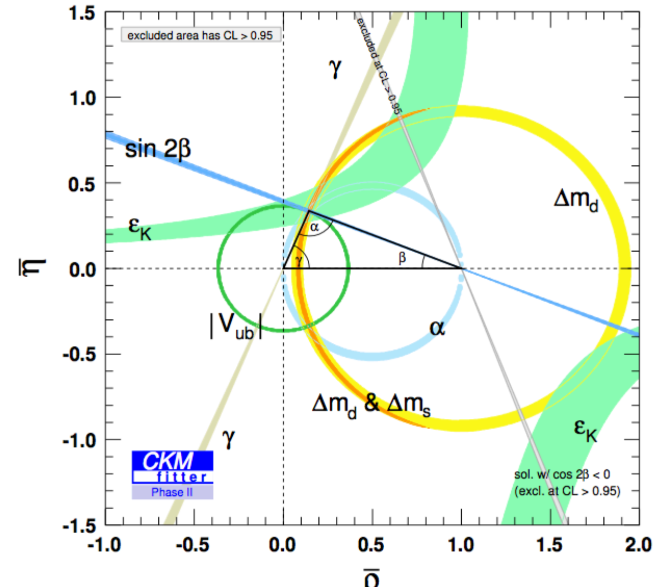
Determination of γ/ϕ_3 angle in CKM

- The cleanest way to extract γ is from B→DK decays:
  - current uncertainty $\sigma(\gamma) \sim 5^0$
  - however, theoretical relative error $\sim 10^{-7}$ (very small!) *[JHEP 1401 (2014) 051]*
  - use for "direct" vs "indirect" ("tree" vs "loop" disagreement)
  - over-constrain the Unitarity Triangle
- Information of *D decay strong phase* is needed
  - Best way is to employ quantum coherence of DD production at threshold



$\sigma(\gamma) \sim 5^0$

20 fb^{-1} BESIII $\psi(3770)$ data



$\sigma(\gamma) \sim 0.4^0$

Λ_c^+ decays

See Yue's talk

EPJC 77, 895 (2017) *PRL 116, 052001 (2016)* *PRL113, 042002 (2014)*

Mode	HFLAV2016	BESIII (%)	PDG 2014 (%)	BELLE (%)
pK_S^0	1.59 ± 0.07	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	6.46 ± 0.24	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0\pi^0$	2.03 ± 0.12	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK_S^0\pi^+\pi^-$	1.69 ± 0.11	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	5.05 ± 0.29	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0	
$\Lambda\pi^+$	1.28 ± 0.06	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	7.09 ± 0.36	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	3.73 ± 0.21	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7	
$\Sigma^0\pi^+$	1.31 ± 0.07	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28	
$\Sigma^+\pi^0$	1.25 ± 0.09	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	4.64 ± 0.24	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0	
$\Sigma^+\omega$	1.77 ± 0.21	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0	
$\Lambda e^+\nu_e$	3.18 ± 0.32	$3.63 \pm 0.38 \pm 0.20$	2.1 ± 0.6	

Improved precisions significantly with factors of 4~10

Features in studying Λ_c decays

	BESIII	Belle(-II)	LHCb
Production yields	★★	★★★★	★★★★★
Background level	★★★★★	★★	★★
Systematic error	★★★★★	★★★	★★
Completeness	★★★★★	★★★	★
(Semi)-Leptonic mode	★★★★★	★★★	★
Neutron/K_L mode	★★★★★	★★	☆
Photon-involved	★★★★★	★★★★★	☆
Absolute measurement	★★★★★	★★★	☆

BESIII has overall advantage in studying the charmed baryon decays

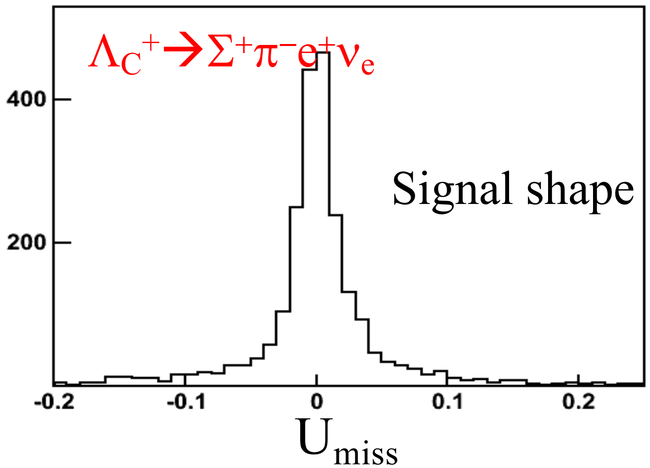
Prospects for Λ_c semi-leptonic decays

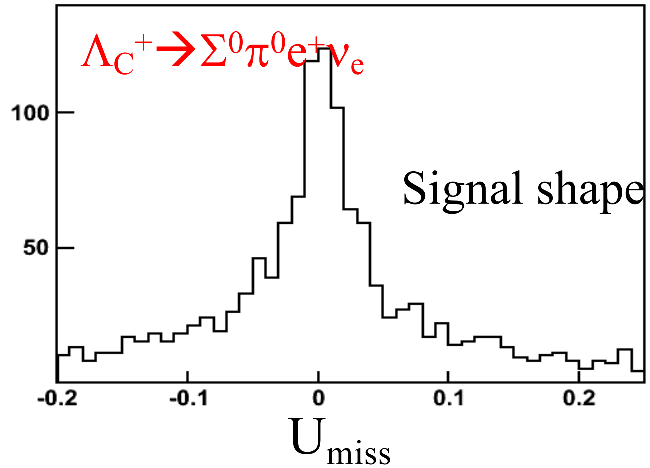
2 M Λ_c^+ pairs

- So far, only mode $\Lambda e^+ \nu_e$ is measured
- Many more semi-leptonic modes can be established at BESIII!

modes	Expected B[%]	δB/B
$\Lambda l^+ \nu_l$	3.6	3%
$\Lambda^* l^+ \nu_l$	0.7	17%
$(pK^-, \Sigma\pi)\ l^+ \nu_l$	0.7	17%
$n l^+ \nu_l$	0.2	30%

	SL	δB/B
D0	B(Kev)=(3.55±0.05)%	1.4%
D+	B(K0ev)=(8.83±0.22)%	2.5%
Ds	B(phiev)=(2.49±0.14)%	5.6%
Λc	B(Λev)=(2.1±0.6)% (PDG2014) =(3.63±0.43)% (BESIII) **=(3.63±0.11)% (new BESIII)**	29% 12% **3%**

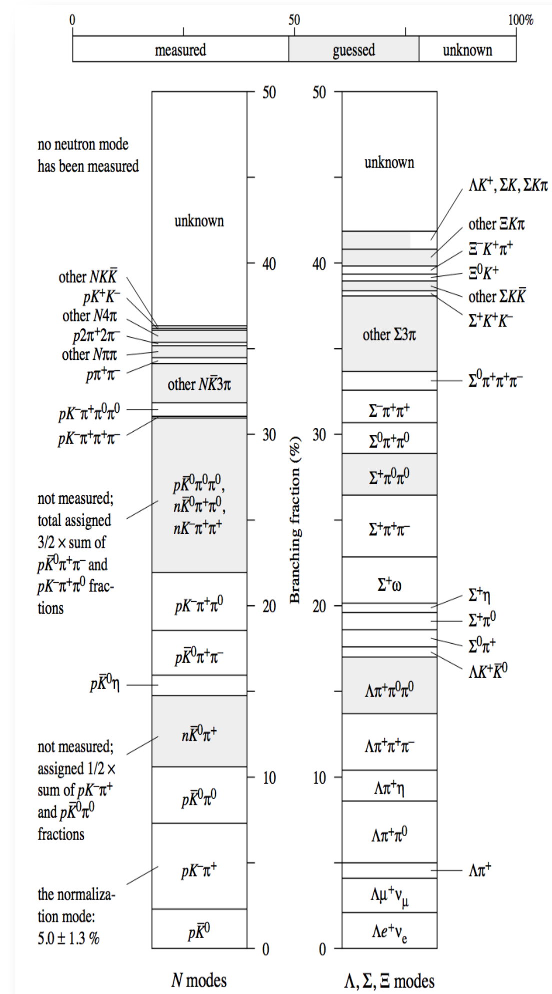




Other relevant Λ_c^+ potentials

2 M Λ_c^+ pairs

- **Studies on new Cabibbo-suppressed modes**
- **Many neutron modes will be firstly measured:** ***to test isospin symmetry*** PRD93, 056008 (2016)
- **Λ_c^+ hadronic weak decays**
  - ✓ Decay asymmetry parameters in two-body hadronic weak decays, such as $\Lambda_c^+ \to BP$ and $\Lambda_c^+ \to BV$ ➔ to measure the relative phase between the S- and P-wave decays
  - ✓ We can provide precise measurements on this observables
- **Search for Λ_c^+ low rate decays and rare decays**
  - ✓ Weak radiative decay $\Lambda_c^+ \to \gamma\Sigma^+$; predictions of BF are $10^{-4} \sim 10^{-5}$: expected sensitivity $\sim 10^{-4}$
  - ✓ FCNC, lepton number/family violation, baryon family violation ...: expected sensitivity$\sim 10^{-5}$



We will find more the Λc-decay Mosaic!

$e^+e^- \to \Sigma_c^{(*)+}\bar{\Lambda}_c^-, \Lambda_c^{*+}\bar{\Lambda}_c^-$

4.74~4.90 GeV

(MeV)

Decay	Expt. [3]	HHChPT [10]	Tawfiq et al. [25]	Ivanov et al. [26]	Huang et al. [27]	Albertus et al. [28]
$\Sigma_c^{++} \to \Lambda_c^+\pi^+$	$1.89^{+0.09}_{-0.18}$	input	1.51 ± 0.17	2.85 ± 0.19	2.5	2.41 ± 0.07
$\Sigma_c^{+} \to \Lambda_c^+\pi^0$	< 4.6	$2.3^{+0.1}_{-0.2}$	1.56 ± 0.17	3.63 ± 0.27	3.2	2.79 ± 0.08
$\Sigma_c^{0} \to \Lambda_c^+\pi^-$	$1.83^{+0.11}_{-0.19}$	$1.9^{+0.1}_{-0.2}$	1.44 ± 0.16	2.65 ± 0.19	2.4	2.37 ± 0.07
$\Sigma_c(2520)^{++} \to \Lambda_c^+\pi^+$	$14.8^{+0.3}_{-0.4}$	$14.5^{+0.5}_{-0.8}$	11.77 ± 1.27	21.99 ± 0.87	8.2	17.52 ± 0.75
$\Sigma_c(2520)^{+} \to \Lambda_c^+\pi^0$	< 17	$15.2^{+0.6}_{-1.3}$			8.6	17.31 ± 0.74
$\Sigma_c(2520)^{0} \to \Lambda_c^+\pi^-$	$15.3^{+0.4}_{-0.5}$	$14.7^{+0.6}_{-1.2}$	11.37 ± 1.22	21.21 ± 0.81	8.2	16.90 ± 0.72

- Precise determination of $\Gamma(\Sigma_c^+ \to \Lambda_c^+\pi^0)$ can be used for for testing heavy quark symmetry and chiral symmetry *Wise; Yan et al.; Burdman, Donoghue ('92)*
- measurements of Σ_c^+ & $\Sigma_c(2520)$ widths by Belle [PRD89, 091102 (2014)]: BESIII has potential to improve the partial widths

BESIII will search for the more decay modes

Decay	HHChPT +QM	Ivanov et al.	Bañuls et al.	Tawfiq et al.	Dey et al.	Majethiya et al.	Fayyazuddin et al.	Aliev et al.
$\Sigma_c^+ \to \Lambda_c^+\gamma$	88	60.7 ± 1.5		87	98.7	$60.1 - 85.6$	89.0	

(keV)

Summary

- **BESIII is successfully operating since 2008**
  – Collected large data samples in the τ-charm mass region
- **Many exciting results have been published:**
  - ✓ Study of X, Y and Z states *see Dayong's and other BESIII talks*
  - ✓ Charmed mesons and baryons
    - – best measurements: $f_{D(s)}$ & FF
    - – hadronic decays of the charmed mesons
    - – strong phases based on neutral *D* quantum correlation
    - – Λ_c physics
- **BESIII will continue to run 6 – 8 years.**
- **BEPCII/BESIII upgrade**
  trackers, ETOF, beam energy, Top-up injection, luminosity ...
- **Future goals**
  roughly 50M D^0, 50M D^+ , 15M Ds, 2M Λ_c , 10B J/ψ
- **We are working on BESIII physics survey for future BESIII potentials**
  you are welcome to join the effort.

Thank you!

谢谢!

Reaches for rare charm decays?

SM predictions and experimental reaches

10^{-0}

10^{-1}

10^{-2} Cabibbo favor

10^{-3} Single Cabibbo suppressed

10^{-4} Doubly Cabibbo suppressed

10^{-5}

10^{-6} Radiative decays

$$D^0 \to \overline{K}^{*0}\gamma / \phi\gamma / \rho\gamma / \omega\gamma$$

$$D^+ \to K^{*+}\gamma / \rho^+\gamma \quad D_S^+ \to K^{*+}\gamma / \rho^+\gamma$$

CLEO-c

BESIII

BESIII final/B factory

10^{-7} Long distance:

10^{-8} Vector meson Dominance

$$D^0 \to \gamma\gamma / VV'(\to ll) / hV(\to ll) / hh'V(\to ll)$$

LHCb

Super-B

Super-τ-charm

10^{-9}

10^{-10}

10^{-11} Short distance FCNC

$$D^0 / D^+ \to \gamma\gamma / Vl^+l^- / hl^+l^- / hh'l^+l^-$$

10^{-12}

$$D^0 \to \mu^+\mu^-$$

10^{-13}

$$D^0 \to e^+e^-$$

10^{-14}

10^{-15}

$$D \to (h)\mu^+e^-$$

Forbidden decays: LNV, LFV, BNV

$$D \to (hh)e^+e^+ / (hh)\mu^+\mu^+$$

δ and γ/ϕ_3 input

- *D* hadronic parameters for a final state

$$f: \frac{A(\bar{D}^0 \to f)}{A(D^0 \to f)} \equiv -r_D e^{-i\delta_D}$$

- Charm mixing parameters: $x = \frac{\Delta M}{\Gamma}$, $y = \frac{\Delta\Gamma}{2\Gamma}$
  – Time-dependent WS $D^0 \to K^+\pi^-$ rate $\Rightarrow$

$$y' = y\cos\delta_{K\pi} - x\sin\delta_{K\pi} \text{ (LHCb)}$$

  – $\delta_{K\pi}$: QC measurements from Charm factory
- γ/ϕ_3 measurements from $B \to D^0 K$
  – $b \to u$: $\gamma/\phi_3 = \arg V^*_{ub}$
  – most sensitive method to constrain γ/ϕ_3 at present
  – GLW, ADS method
    - r_D, δ_D : QC measurements from Charm factory
  – GGSZ method
    - c_i, s_i : QC measurements from Charm factory

Time-integrated decay rates

- **No time dependent information at Charm threshold**
- **Anti-symmetric wavefuction:**
  $\Gamma^2_{ij} = |\langle i|D^0\rangle\langle j|\bar{D}^0\rangle - \langle j|D^0\rangle\langle i|\bar{D}^0\rangle|^2$
- **Double tag rates:**
  $A_i^2 A_j^2[1 + r_i^2 r_j^2 - 2r_i r_j \cos(\delta_i + \delta_j)]$
  - **CP tag: r=1, δ=0 or π; $l^\pm$ tag: r=0**
- **Single and Double tag rates**
  - $z_f \equiv 2\cos\delta_f, r_f \equiv \frac{A_{DCS}}{A_{CF}}, R_M \approx \frac{x^2+y^2}{2}$

$$\psi(3770) \to [D^0\bar{D}^0 - \bar{D}^0 D^0]/\sqrt{2}$$
$$= -[D_{CP+}D_{CP-} - D_{CP-}D_{CP+}]/\sqrt{2}$$
$$D_{CP\pm} = [D^0 \pm \bar{D}^0]/\sqrt{2}$$

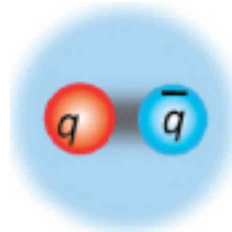
C-odd	f	$\bar{f}$	l^+	l^-	*CP+*	*CP-*
f	$R_M[1 + r_f^2(2 - z_f^2) + r_f^4]$					
$\bar{f}$	$1 + r_f^2(2 - z_f^2) + r_f^4$	$R_M[1 + r_f^2(2 - z_f^2) + r_f^4]$				
l^+	r_f^2	*1*	R_M			
l^-	*1*	r_f^2	*1*	R_M		
CP+	$1 + r_f(r_f + z_f)$	$1 + r_f(r_f + z_f)$	*1*	*1*	*0*	
CP-	$1 + r_f(r_f - z_f)$	$1 + r_f(r_f - z_f)$	*1*	*1*	*4*	*0*
Single Tag	$1 + r_f^2 - r_f z_f(A - y)$		*1*		$2[1 \pm (A - y)]$	

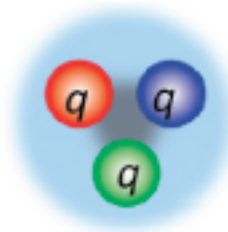
New forms of hadrons

- Conventional hadrons consist of 2 or 3 quarks：

Naive Quark Model：

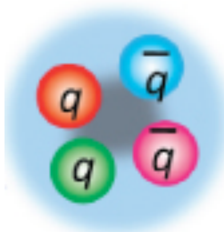
meson

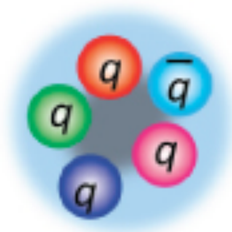




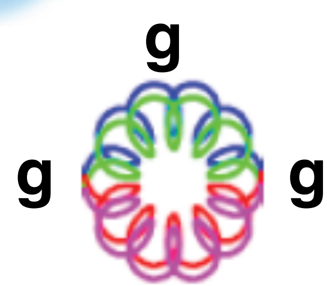
baryon

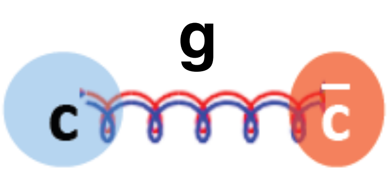
- QCD predicts the new forms of hadrons:
  - **Multi-quark states： Number of quarks >= 4**





  - **Hybrids：** $q\bar{q}g$， $qqqg$ …
  - **Glueballs：** gg， ggg …



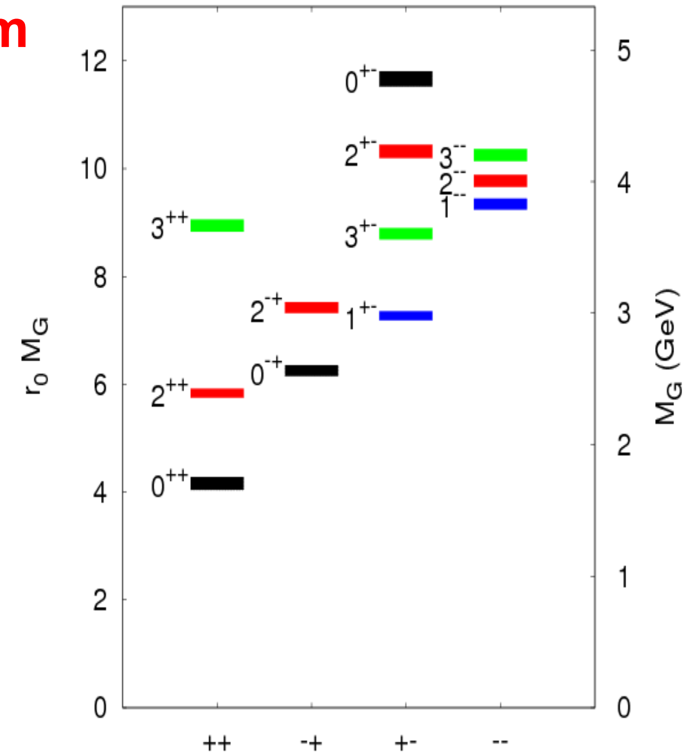


None of the new forms of hadrons is settled！

Glueballs

- **Low lying glueballs have ordinary quantum number**
  0^{++}(1.5~1.7 GeV), 2^{++}(2.3~2.4 GeV), 0^{-+}(2.3~2.6 GeV)
  mixing with qqbar mesons
- The mix of glueball with ordinary qq meson makes the situation more difficult.
- The spectrum is from unquenched LQCD calculations

  Glueball candidates: $f_0(1500)$, $f_0(1700)$, $f_J(2220)$, …

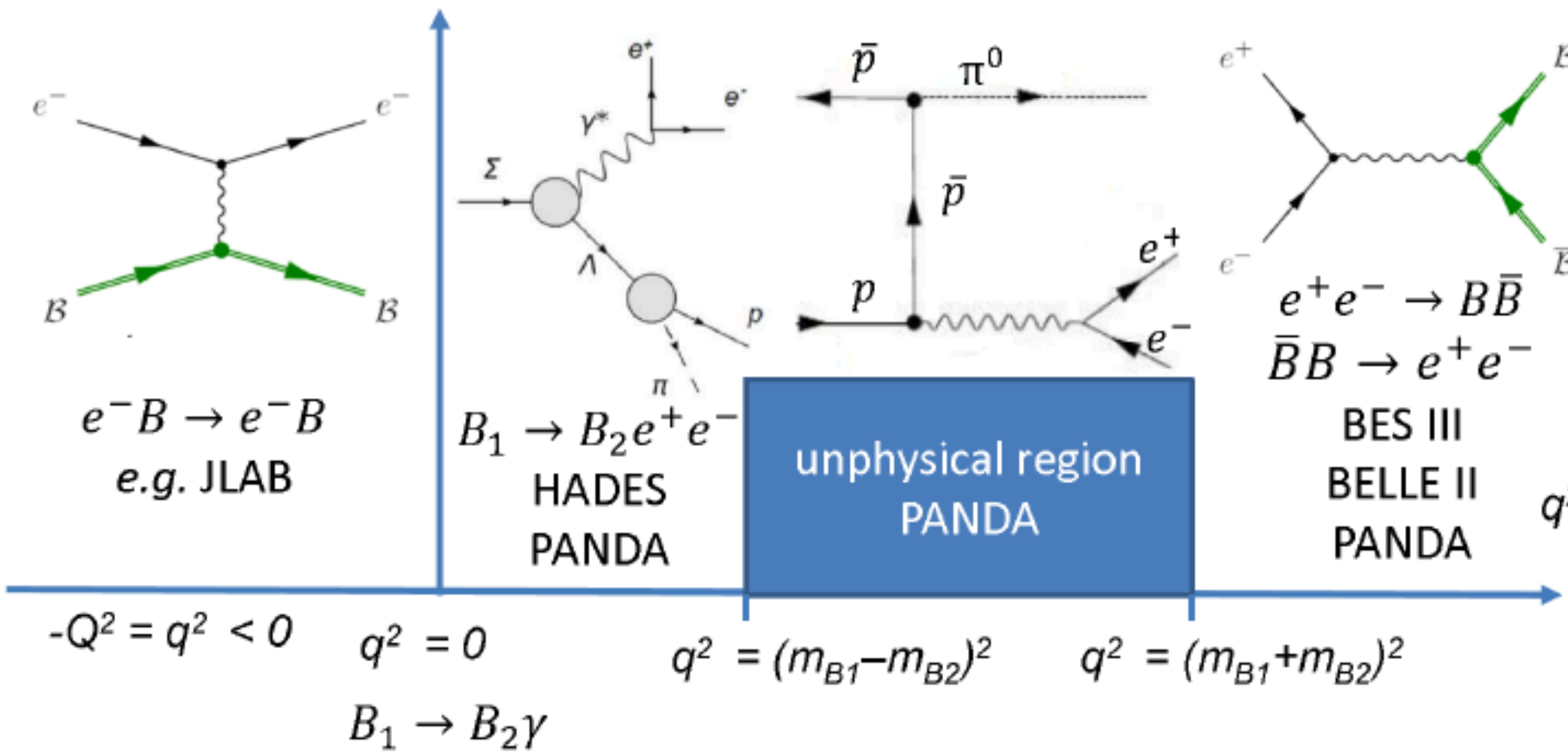


- **J/ψ radiative decays are believed to be an ideal place to search for glueballs.**
  - J/ψ→γωφ Phys.Rev. D 87,032008(2013)
  - J/ψ→γφφ Phys. Rev. D 93, 112011 (2016)
  - J/ψ→γηη Phys. Rev. D 87, 092009 (2013)
  - J/ψ→γ$\pi^0\pi^0$ Phys. Rev. D 92, 052003 (2015)

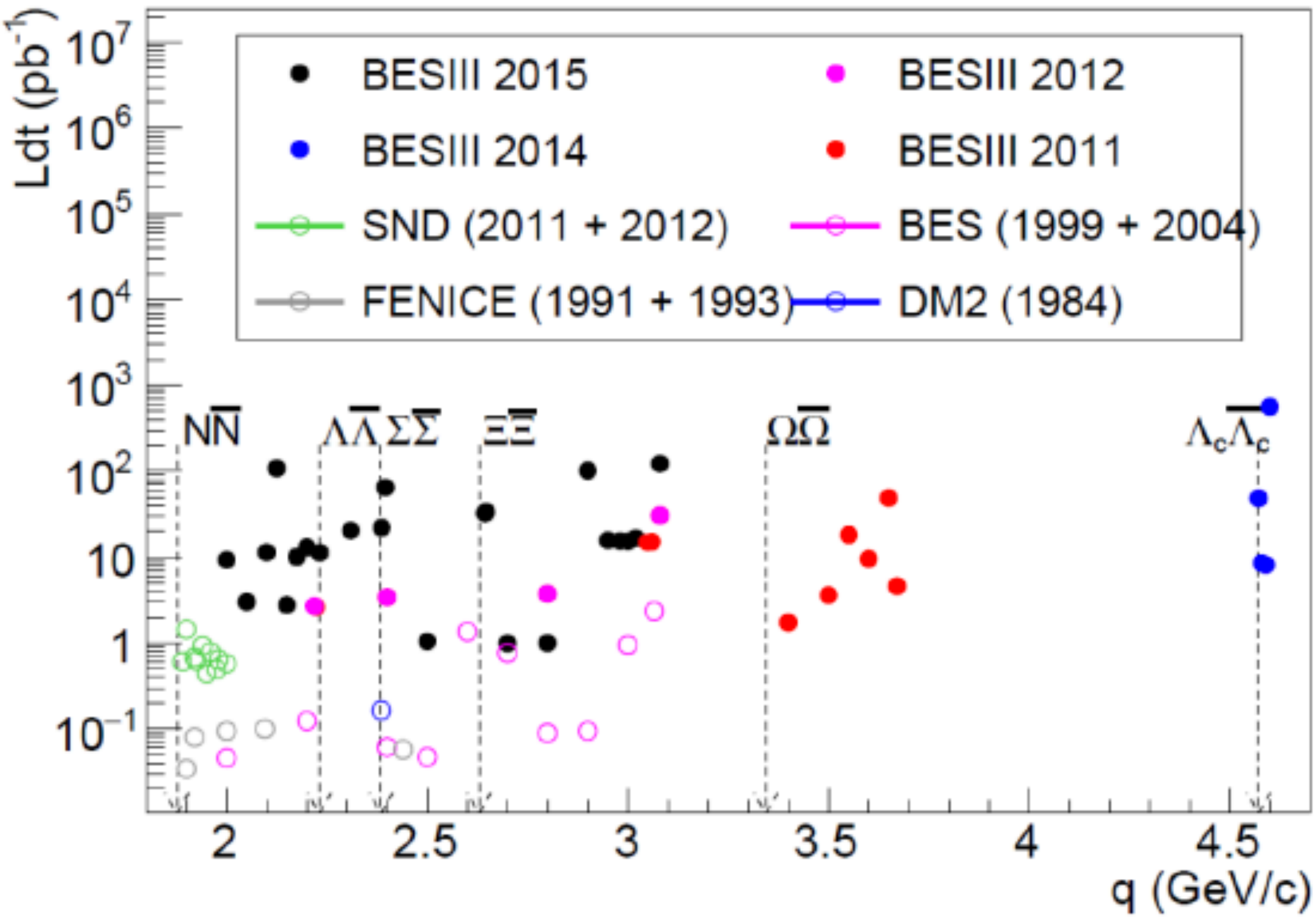
	0+	2+	0-
J/ψ→γPP			
J/ψ→γVV			
J/ψ→γPPP			

Time-like Form-factors at BESIII

Space-like *versus* Time-like Electromagnetic Form Factors



Energy scan data



- World leading scan from 2.0 GeV – 3.08 GeV energy region
- Nucleon and Hyperon form-factor available