Charmonium decays from BESIII

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Outline

- **Introduction of charmonium decay**

- **Selected results from BESIII**
  - **2&3 photons decay**
  - **Light hadrons decay**
  - **Baryonic decay**

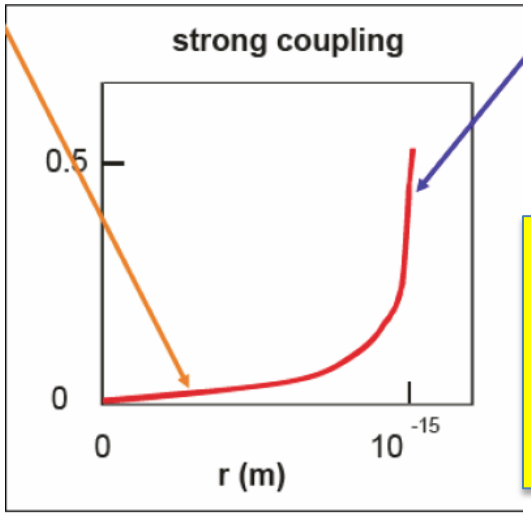
- **Summary**

Charmonium physics

Charmonium is a bound state of $c\bar{c}$ quark.

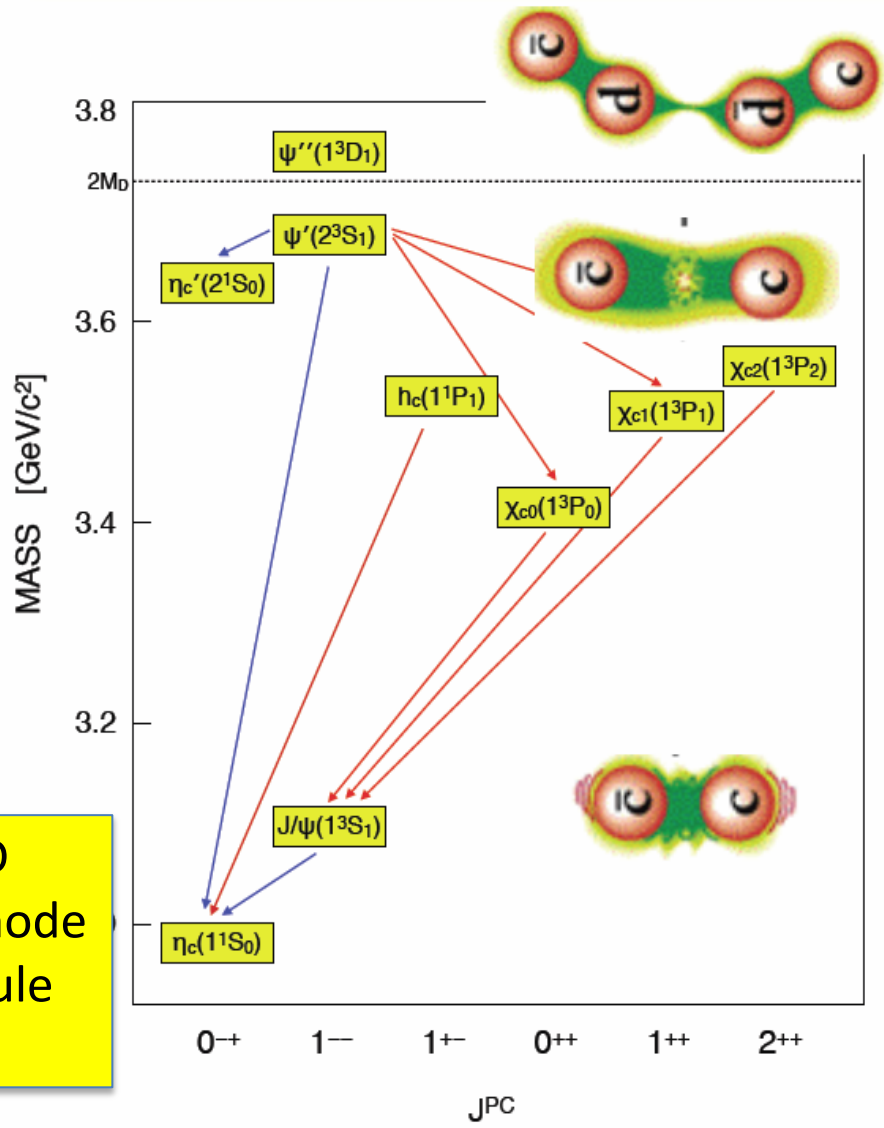
- Many narrow states below $D\bar{D}$ production threshold.
- v^2~0.3, non-relativistic bound state.
- Probes regime between perturbative QCD and strong QCD.

pQCD



strong QCD

Lattice QCD
Potential mode
QCD sum rule
...



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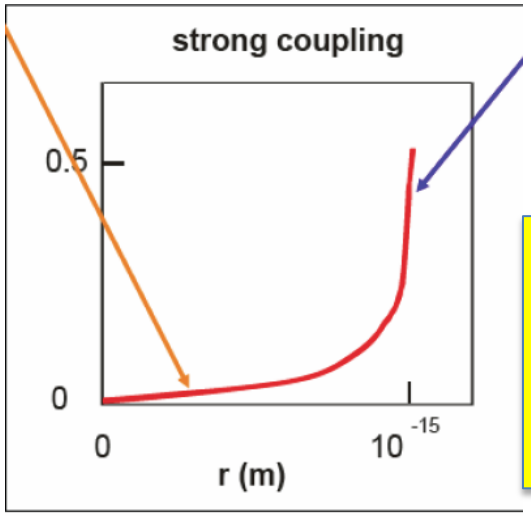

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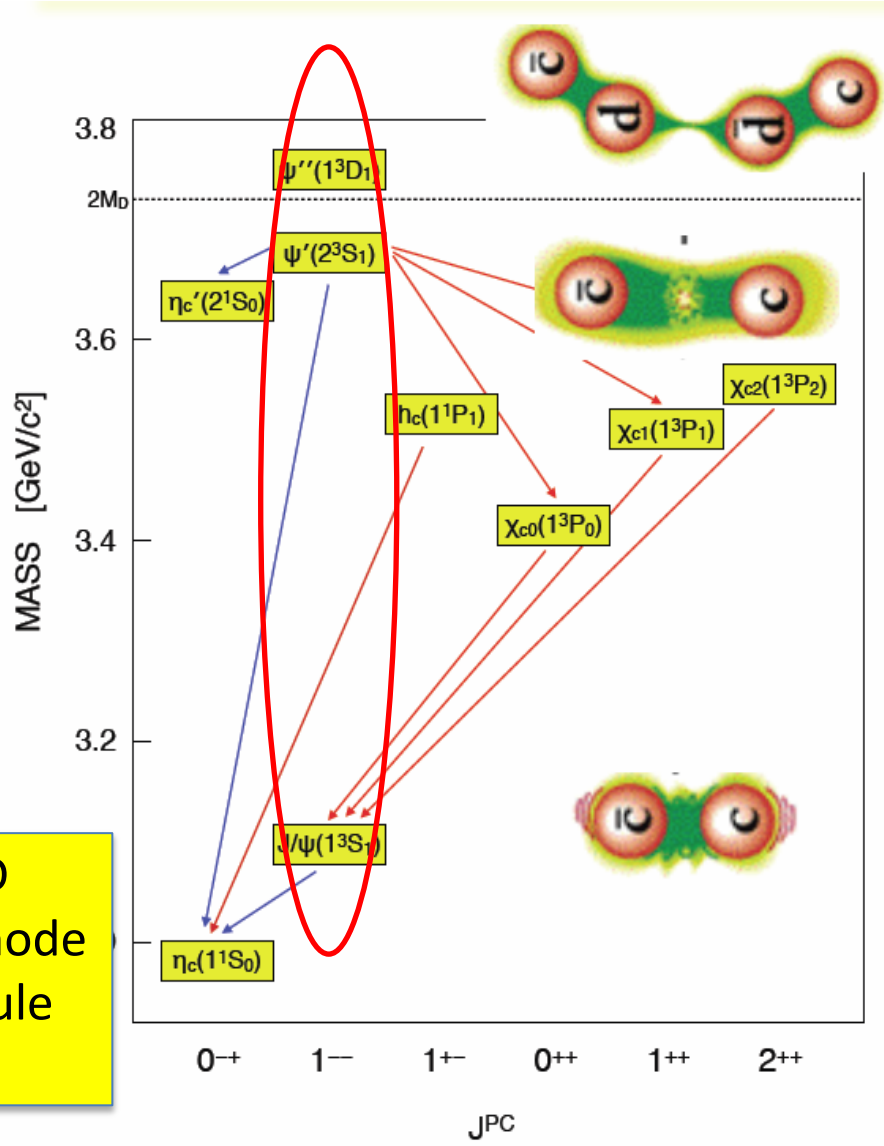
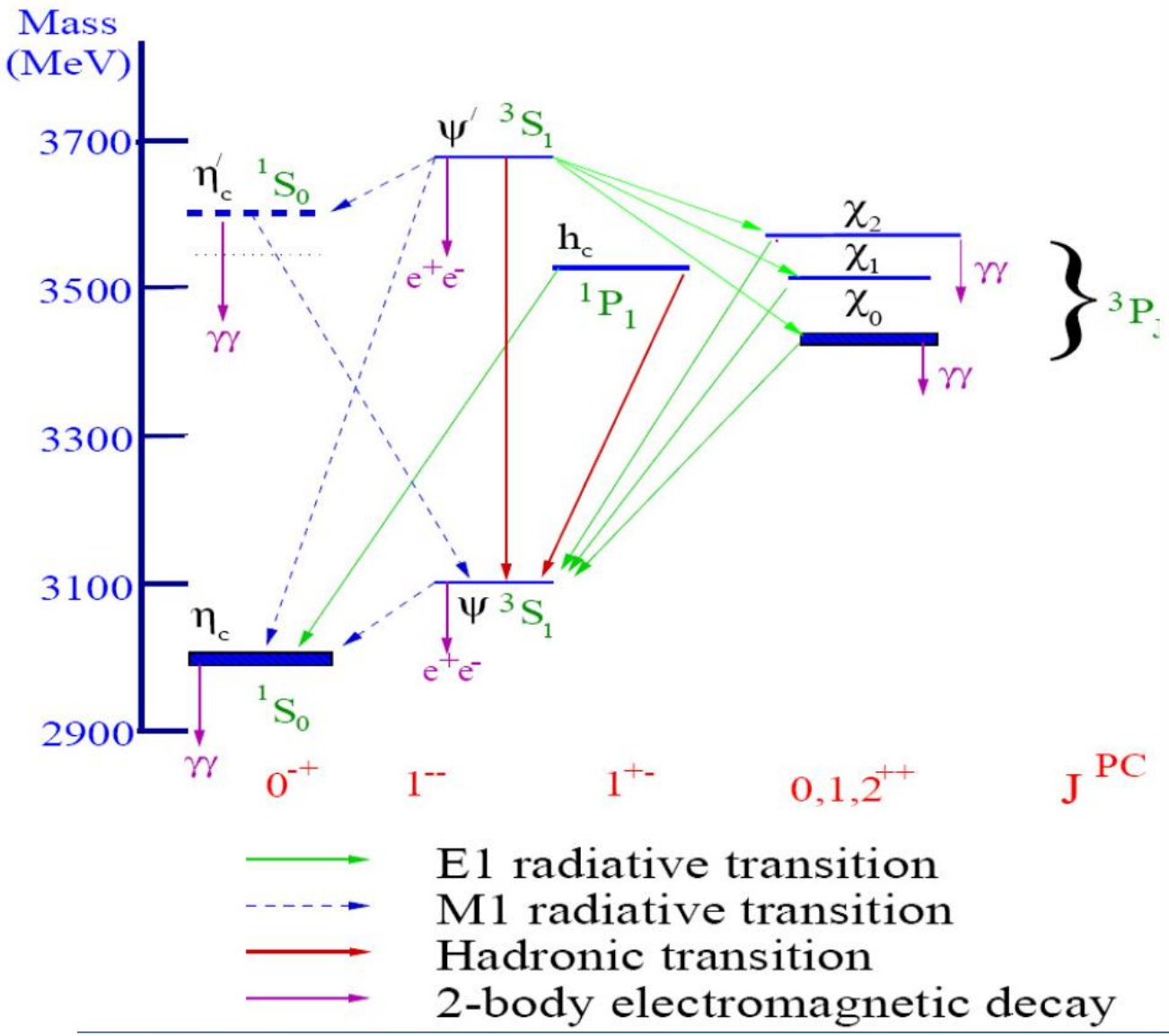


Charmonium Decay



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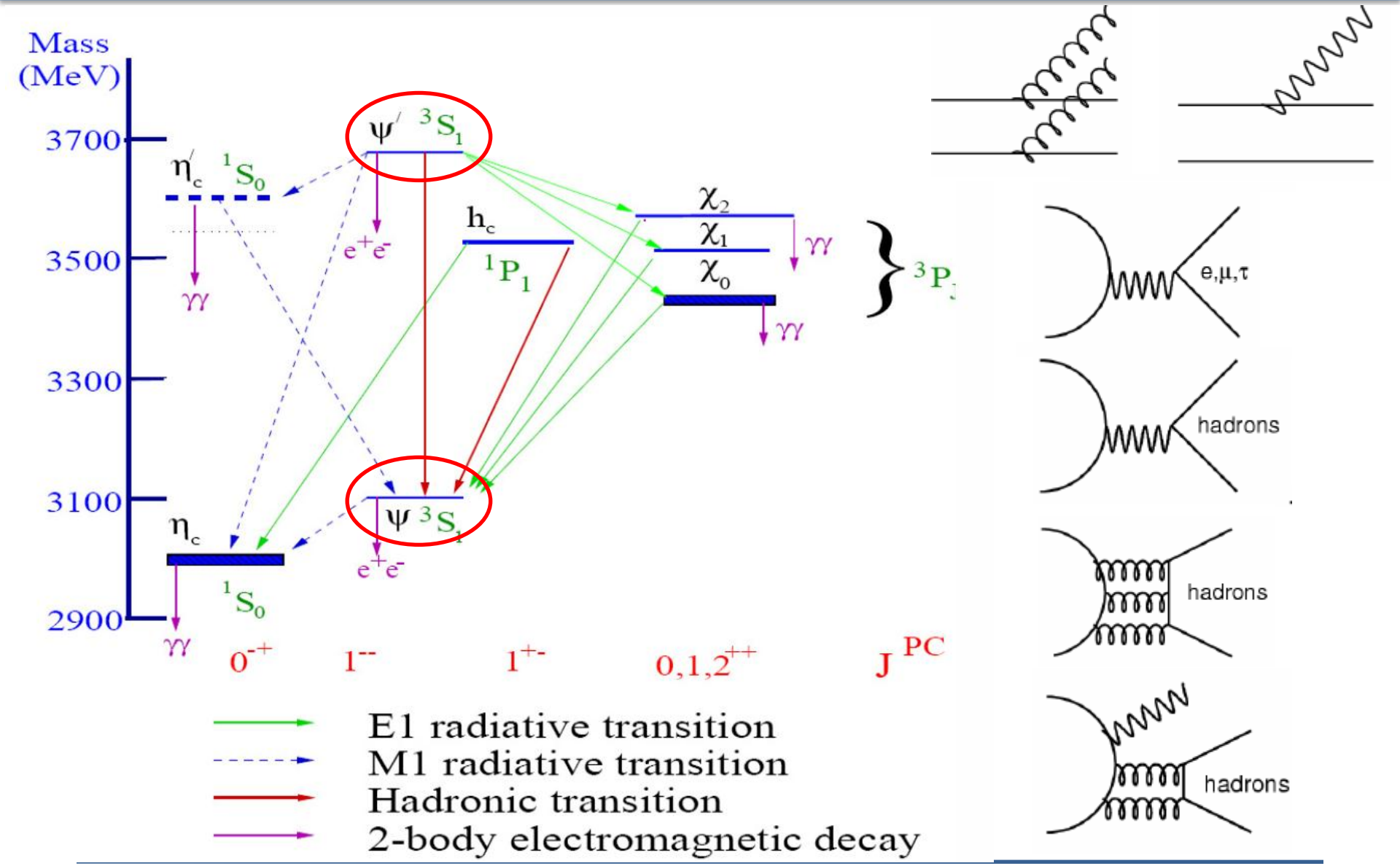


Selected analyses from BESIII

1. **2&3 Photons decay**
   - $\chi_{c0/2} \to \gamma\gamma$
   - $J/\Psi \to \gamma\gamma\gamma$ & $\eta_c \to \gamma\gamma$
2. **Light hadrons decay**
   - $\Psi(2S) \to K^+K^-\pi^0$, $K^+K^-\eta$
   - $\Psi(2S) \to \omega\bar{K}K\pi$
3. **Baryonic decay**
   - $\eta_c \to \Sigma^+\bar{\Sigma}^-$, $\Xi^-\bar{\Xi}^+$
   - $J/\Psi \to \bar{\Lambda}\Sigma^0$ +c.c.
   - $\chi_{cJ} \to B\bar{B}$
   - J/Ψ, $\Psi(2S) \to \Lambda\bar{\Lambda}\pi^0/\eta$
   - $\Psi(2S) \to \bar{p}K^+\Sigma^0$, $\chi_{cJ} \to \bar{p}K^+\Lambda$
   - $\Psi(2S) \to p\bar{p}\pi^0$

Analog to positronium
Test on non-PQCD theory

$\rho\pi$ puzzle
Test on HSR
Search for excited states

$\rho\pi$ puzzle
Test on color octet model(COM)
Study iso-spin breaking mechanism
Search for new resonance
……

All analyses based on 106M $\Psi(2S)$ and 225M J/Ψ data!

2&3 photons decay

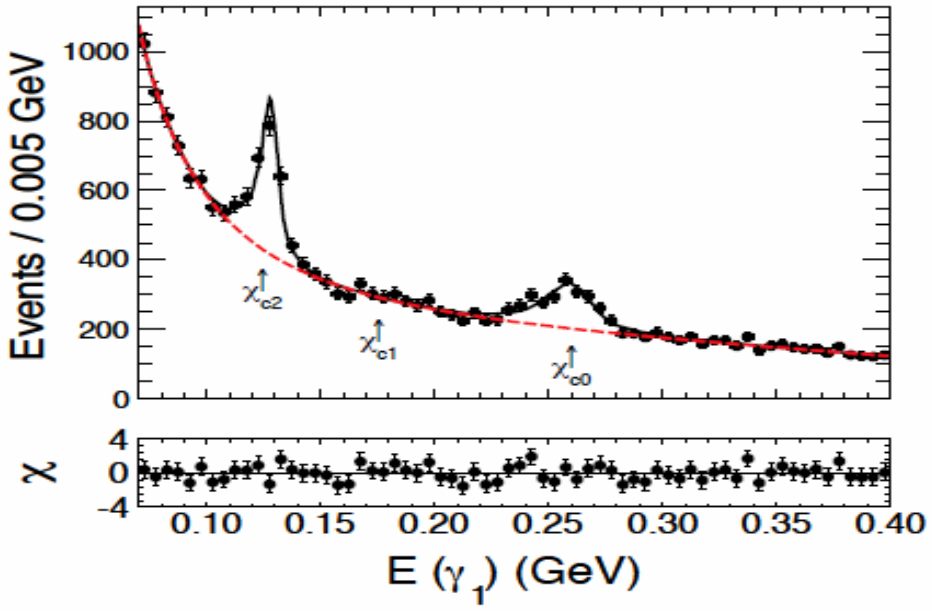
$\chi_{c0/2} \rightarrow \gamma\gamma$

- Analog to P-wave triplet states in positronium, Lowest order predicts:
  - **$R=\Gamma(\chi_{c2}\rightarrow\gamma\gamma)/\Gamma(\chi_{c0}\rightarrow\gamma\gamma)$ = 0.27**

Phys. Lett. B60,183(1976)

- **R vary from 0.09-0.36 with high order corrections**

Phys.Rev. D54, 2075 (1996)



Quantity	χ_{c0}	χ_{c2}
$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^5$	$2.17\pm0.17\pm0.12$	$2.81\pm0.17\pm0.15$
$\mathcal{B}_2 \times 10^4$	$2.24\pm0.19\pm0.12\pm0.08$	$3.21\pm0.18\pm0.17\pm0.13$
$\Gamma_{\gamma\gamma}$ (keV)	$2.33\pm0.20\pm0.13\pm0.17$	$3.63\pm0.24\pm0.04\pm0.04$
$\mathcal{R}$	$0.271\pm0.029\pm0.013\pm0.027$	

$B_1=Br(\psi\rightarrow\chi_{c0/2})$
$B_2=Br(\chi_{c0/2}\rightarrow\gamma\gamma)$
$R=\Gamma_{\gamma\gamma}(\chi_{c2})/\Gamma_{\gamma\gamma}(\chi_{c0})$

BESIII PRD85, 112008, (2012)

Measured R is consistent with the lowest order prediction!

$J/\Psi \to \gamma\gamma\gamma$ & $\eta_c \to \gamma\gamma$

Motivation:

- Test of non-perturbative QCD corrections to a QED process (at first order):

$$\mathcal{R} \equiv \frac{\mathcal{B}(J/\psi \to 3\gamma)}{\mathcal{B}(J/\psi \to e^+e^-)} = \frac{64(\pi^2-9)}{243\pi}\alpha(1-7.3\frac{\alpha_s(r)}{\pi})$$

- Using α_s=0.19: R=3.0×10^{-4}

Results:

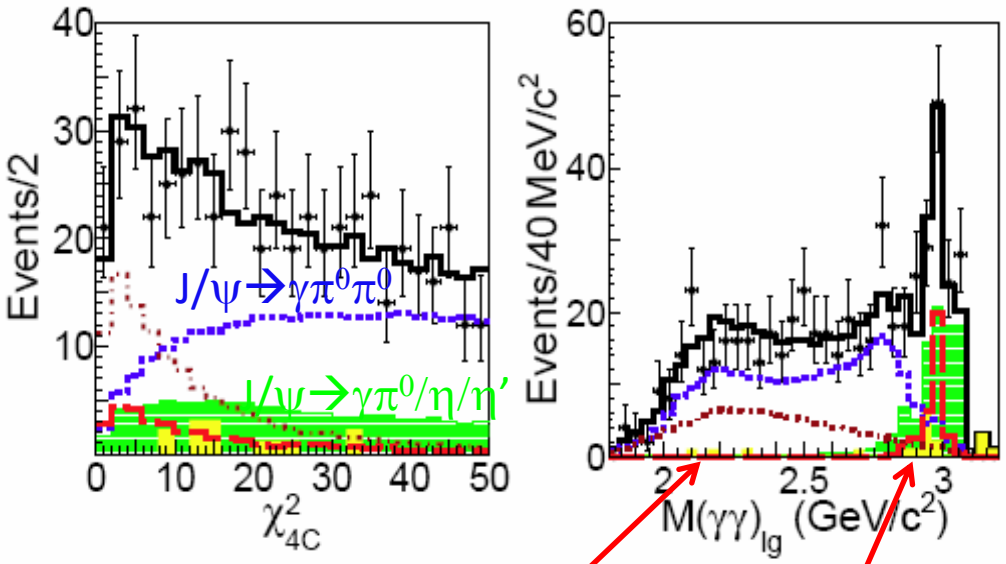
- Combine w/CLEO-c [PRL 101 101809(2008)] give:

  R=1.95±0.37 ×10^{-4} Incompatible!

  QCD radiative and relativistic correction are needed.

- Evidence of $\eta_c \to \gamma\gamma$ is observed.

BESIII, PRD 87, 032003 (2013)



modes	$J/\psi \to 3\gamma$	$J/\psi \to \gamma\eta_c \to 3\gamma$
ϵ (%)	27.9 ± 0.1	20.7 ± 0.2
yields	113.4 ± 18.1	33.2 ± 9.5
significance	$8.3(7.3)\sigma$	$4.1(3.7)\sigma$
$\mathcal{B}(\times 10^{-6})$	$11.3 \pm 1.8 \pm 2.0$	$4.5 \pm 1.2 \pm 0.6$

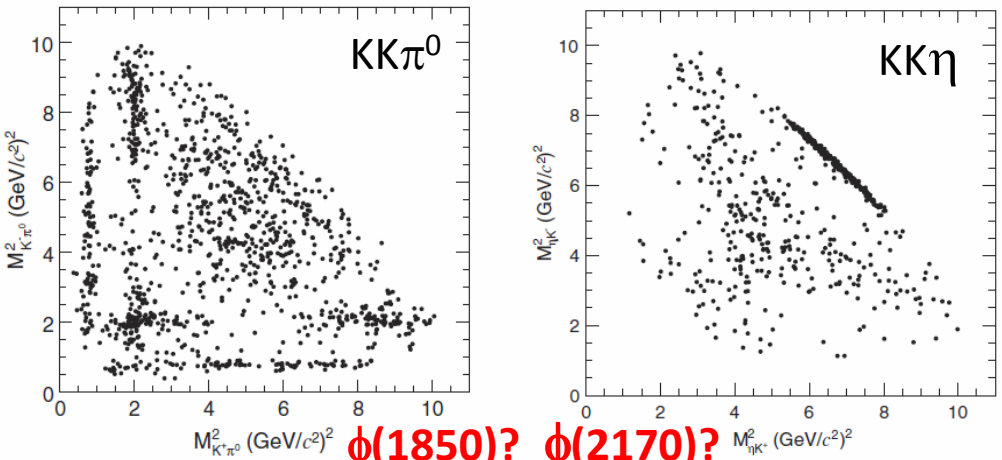
Light hadron decay

$\Psi(2S) \to K^+K^-\pi^0$, $K^+K^-\eta$

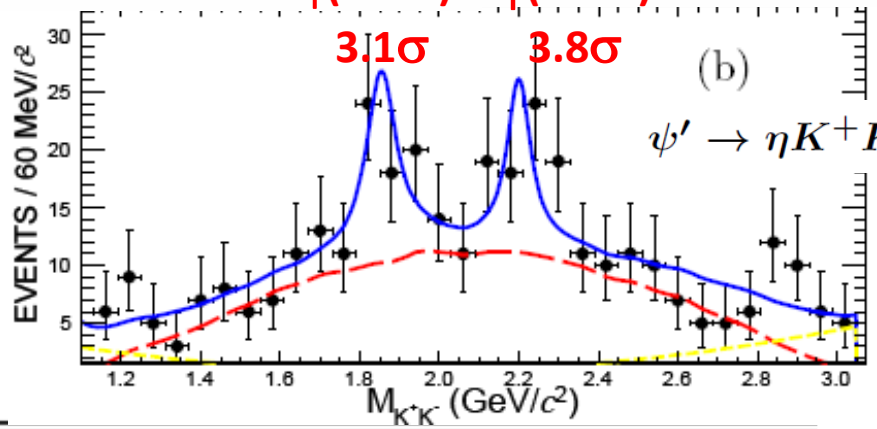
- Motivation
  - Test on 12% rule (Q_h)
  - Test on HSR
  - Search for excited ϕ, K^* states
- PWA applied
  - Measured $\psi(2S) \to KK^*$, $\phi\eta$, $\phi\pi^0$ (isospin violated)
  - Q_h in VP decays significantly deviate from 12%
- First observation: $\psi(2S) \to K^+K^*_2(1430)^-$ (HSR suppressed decay)

BESIII, PRD 86, 072011 (2012)

Dalitz Plot



$\phi(1850)$? $\phi(2170)$?

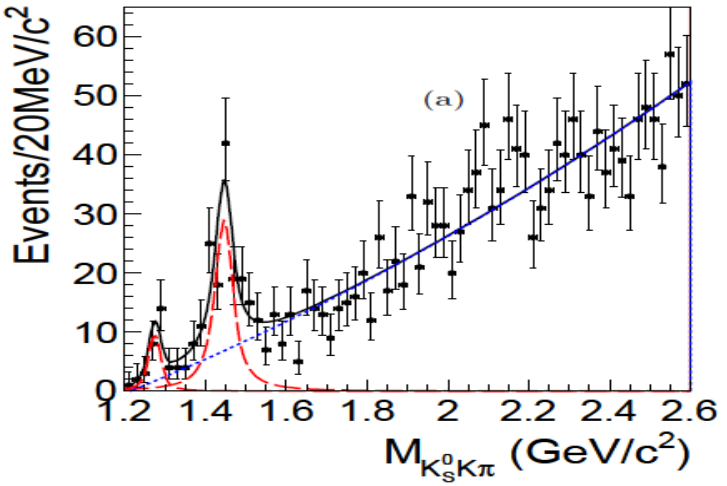


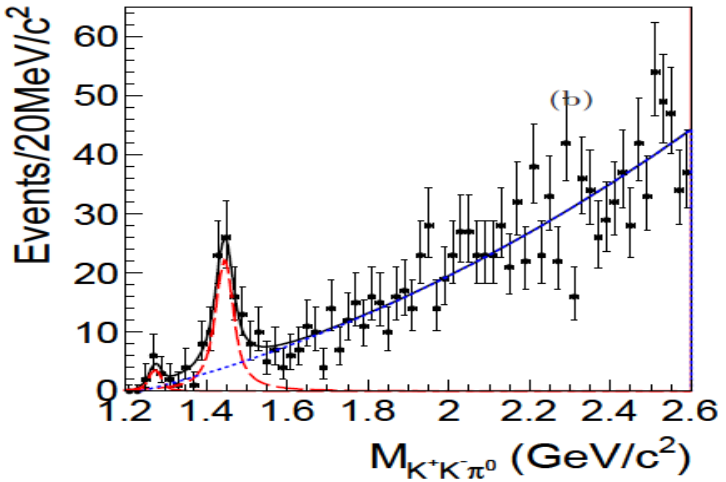
BR($\psi' \to VP$)	EM	Short distance	Long distance	Strong	Total	BESIII ($\times 10^{-5}$)
$K^{*+}K^- + c.c.$	7.03×10^{-6}	9.81×10^{-4}	1.33×10^{-3}	3.64×10^{-5}	1.70×10^{-5}	$3.18 \pm 0.30^{+0.26}_{-0.31}$
$\phi\eta$	2.26×10^{-6}	1.55×10^{-4}	1.73×10^{-4}	1.92×10^{-6}	2.25×10^{-6}	$3.14 \pm 0.23 \pm 0.23$
$\phi\pi^0$	9.78×10^{-8}	0	0	0	9.78×10^{-8}	<0.04

$\Psi(2S) \rightarrow \omega K\bar{K}\pi$

- Motivation:
  - Test on 12% rule (Q_h)
  - Search for gluonium candidate X(1440), which was observed in $p\bar{p}$ annihilation in 1967.
- Results:
  - X(1440) is observed from $K\bar{K}\pi$ mass spectrum(9.3σ), but the statistics is not sufficient to determine its quantum number.
  - Evidence of $f_1(1285)$ is observed. (3.2σ)
  - Measured Q_h(s) are suppressed by a factor of 2-4 (Comparing with 12% rule).

BESIII, arXiv:1303.6360



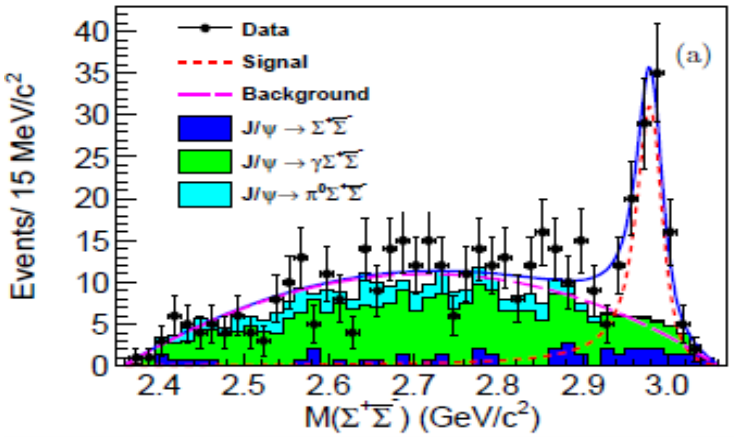


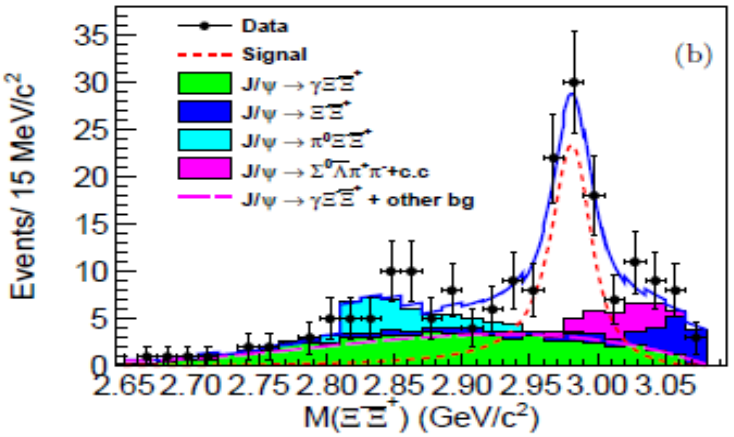
Baryonic decay

$\eta_c \to \Sigma^+\bar{\Sigma}^-, \Xi^-\bar{\Xi}^+$

- Test on intermediate meson loop(IML) calculation, which agree with the measured $Br(\eta_c \to p\bar{p})$ and $Br(\eta_c \to \Lambda\bar{\Lambda})$

PRD 87, 012003 (2013)





	$\eta_c \to \Sigma^+\bar{\Sigma}^-$	$\eta_c \to \Xi^-\bar{\Xi}^+$
Statistical significance	9.3σ	6.4σ
N_{obs}	112 ± 15	78 ± 14
$N_{peaking}$	0.7	2.0
ε	5.3%	5.5%
Branching fraction (10^{-3})	$2.11 \pm 0.28 \pm 0.18 \pm 0.50$	$0.89 \pm 0.16 \pm 0.08 \pm 0.21$
Branching fraction based on IML [13] (10^{-3})	0.51–1.00	0.48–0.96

Larger than prediction

$J/\psi \to \Lambda \bar{\Sigma}^0$+c.c.

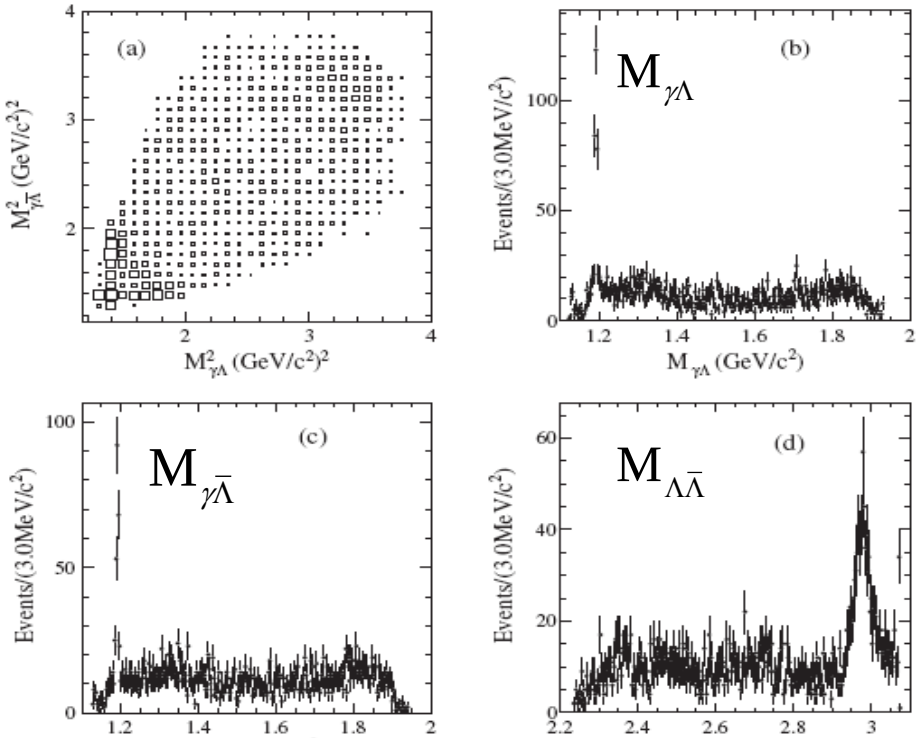


TABLE Branching fractions (10^{-5})

J/ψ decay mode	BESIII	PDG
$\bar{\Lambda}\Sigma^0$	$1.46 \pm 0.11 \pm 0.12$	<7.5
$\Lambda\bar{\Sigma}^0$	$1.37 \pm 0.12 \pm 0.11$	<7.5
$\gamma\eta_c(\eta_c \to \Lambda\bar{\Lambda})$	$1.98 \pm 0.21 \pm 0.32$	···
$\Lambda\bar{\Lambda}(1520)$ + c.c.$(\bar{\Lambda}(1520) \to \gamma\bar{\Lambda})$	<0.41	···

Motivation:

- Study isospin breaking mechanism in $J/\psi \to \Lambda\Sigma^0$ + c.c.
- Search for $\Lambda(1520) \to \gamma\Lambda$
- Measured $\eta_c \to \Lambda\Lambda$ (Only observed by Belle in $B \to \Lambda\Lambda K$ before)

Results:

- First observation
- No evidence of $\Lambda(1520) \to \gamma\Lambda$
- Measured $\eta_c \to \Lambda\Lambda$ consists with results of Belle.

PRD 86, 032008(2012)

$J/\psi, \psi(2S) \to \Lambda \bar{\Lambda} \pi^0/\eta$

- Large error in previous measurement
- Systematic measurement $\Lambda \bar{\Lambda} \pi^0$: isospin violating decay
  $\Lambda \bar{\Lambda} \eta$: isospin conserving decay
- Test on 12% rule

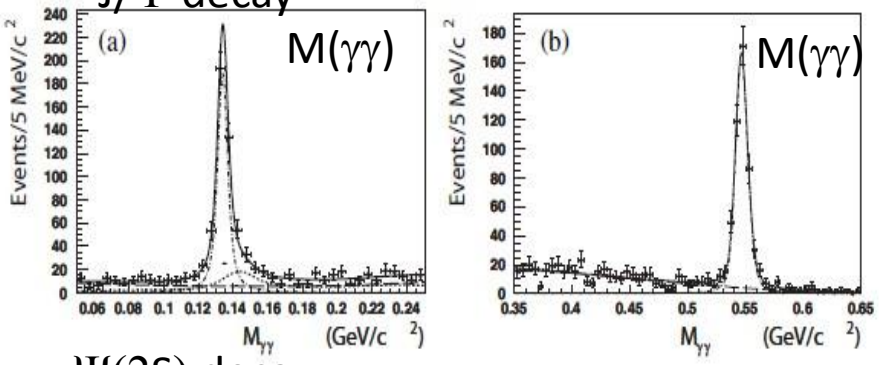
BESIII, Phys. Rev. D 87, 052007 (2013)

$\times 10^{-5}$

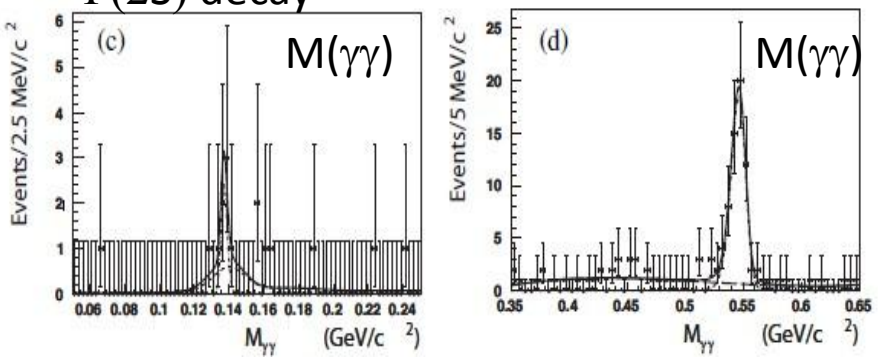
$B(J/\Psi \to \Lambda\Lambda\pi^0)$	$3.78 \pm 0.27 \pm 0.29$
$B(\Psi(2S) \to \Lambda\Lambda\eta)$	$15.7 \pm 0.79 \pm 1.52$
$B(J/\Psi \to \Lambda\Lambda\pi^0)$	<0.29 @90%C.L
$B(\Psi(2S) \to \Lambda\Lambda\eta)$	$2.47 \pm 0.34 \pm 0.19$

First observation

J/Ψ decay



$\Psi(2S)$ decay



$$Q_h = \frac{\mathcal{B}(\psi' \to \Lambda\bar{\Lambda}\pi^0)}{\mathcal{B}(J/\psi \to \Lambda\bar{\Lambda}\pi^0)} < 10.0\%$$

$$Q_h = \frac{\mathcal{B}(\psi' \to \Lambda\bar{\Lambda}\eta)}{\mathcal{B}(J/\psi \to \Lambda\bar{\Lambda}\eta)} = (15.7 \pm 2.9)\%.$$

Measurement of $\chi_{cJ} \to B\bar{B}$

Color-Octet contribution: Large effect in P-wave state. Test on Color Octet Model(COM) by

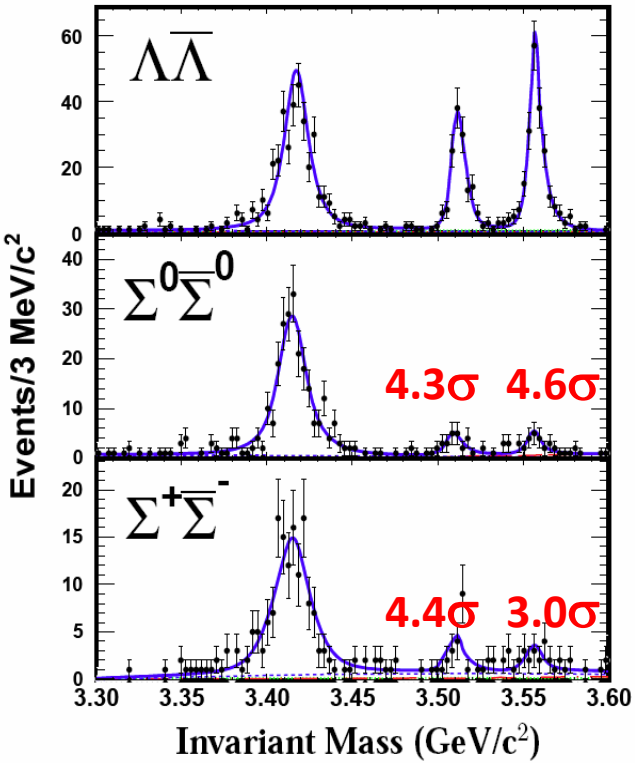
- $\chi_{cJ} \to \Lambda\bar{\Lambda}$
- $\chi_{cJ} \to \Sigma^0\bar{\Sigma}^0$
- $\chi_{cJ} \to \Sigma^+\bar{\Sigma}^-$
- $\chi_{cJ} \to \Sigma(1385)\bar{\Sigma}(1385)$

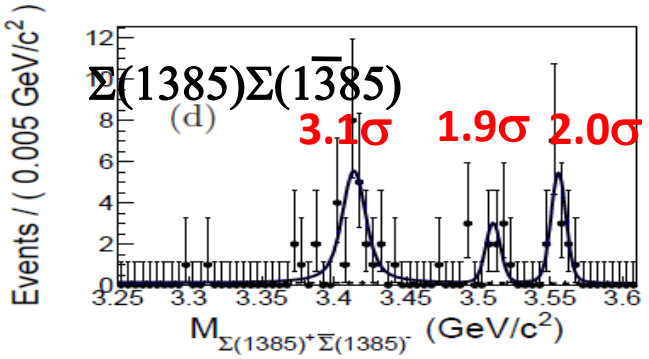
BESIII, Phys. Rev. D 87, 032007 (2013)

BESIII, Phys. Rev. D 86, 052004 (2012)

Results:

- $B(\chi_{cJ} \to \Lambda\bar{\Lambda})$ are larger than the COM prediction
- $B^{up}(\chi_{cJ} \to \Sigma\bar{\Sigma})$ are consistent with the COM prediction
- $B^{up}[\chi_{cJ} \to \Sigma(1385)\bar{\Sigma}(1385)]$ are consistent with the COM prediction

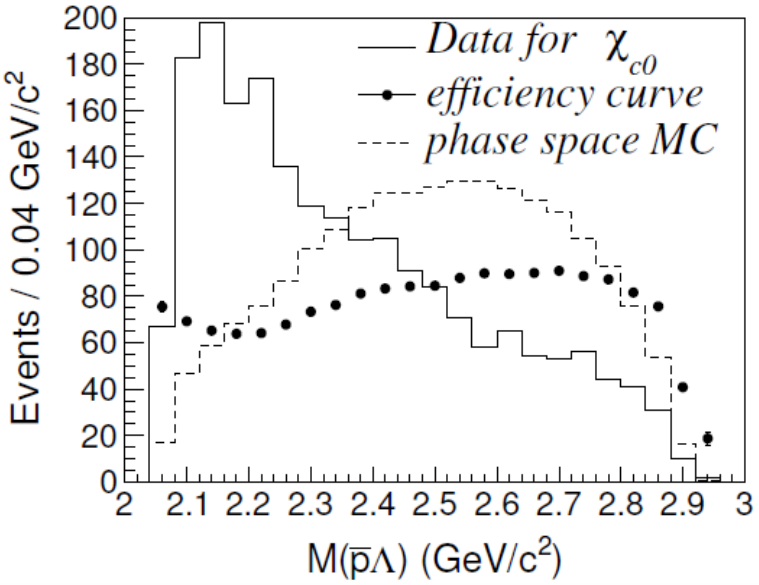


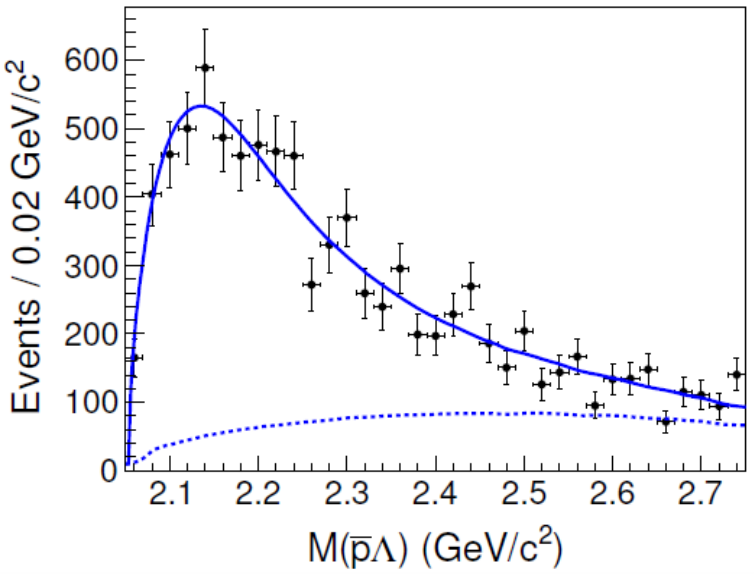


$\psi(2S)\to\bar{p}K^+\Sigma^0$ and $\chi_{cJ}\to\bar{p}K^+\Lambda$

- Test on Color Octet Model(COM)
- $\psi(2S)\to\bar{p}\,K^+\Sigma^0$ (first observation)
- There is an enhancement in the mass of $\bar{p}\,\Lambda$ in the decay $\chi_{cJ}\to\bar{p}\,K^+\Lambda$

BESIII, PRD87, 012007(2013)





Channel	$\psi' \to \bar{p}K^+\Sigma^0 + \text{c.c.}$	$\chi_{c0} \to \bar{p}K^+\Lambda + \text{c.c.}$	$\chi_{c1} \to \bar{p}K^+\Lambda + \text{c.c.}$	$\chi_{c2} \to \bar{p}K^+\Lambda + \text{c.c.}$
$\mathcal{B}$(BESIII)	$(1.67 \pm 0.13 \pm 0.12) \times 10^{-5}$	$(13.2 \pm 0.3 \pm 1.0) \times 10^{-4}$	$(4.5 \pm 0.2 \pm 0.4) \times 10^{-4}$	$(8.4 \pm 0.3 \pm 0.6) \times 10^{-4}$
PDG		$(10.2 \pm 1.9) \times 10^{-4}$	$(3.2 \pm 1.0) \times 10^{-4}$	$(9.1 \pm 1.8) \times 10^{-4}$

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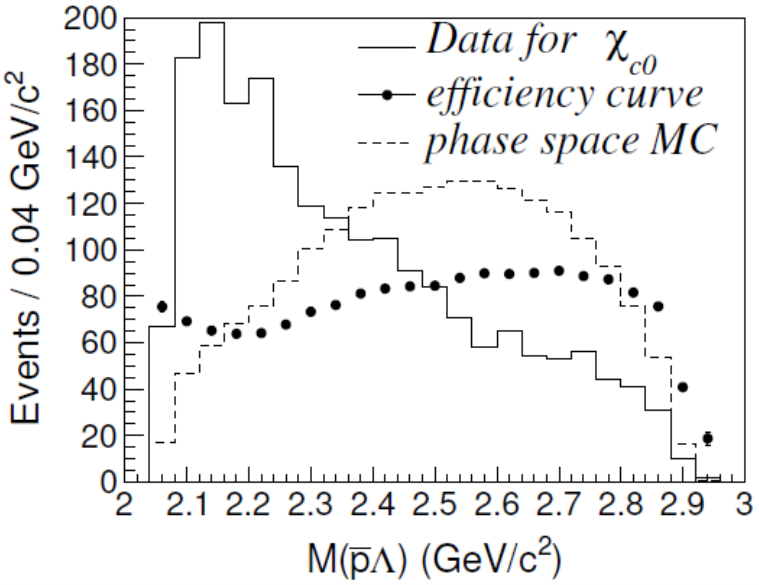
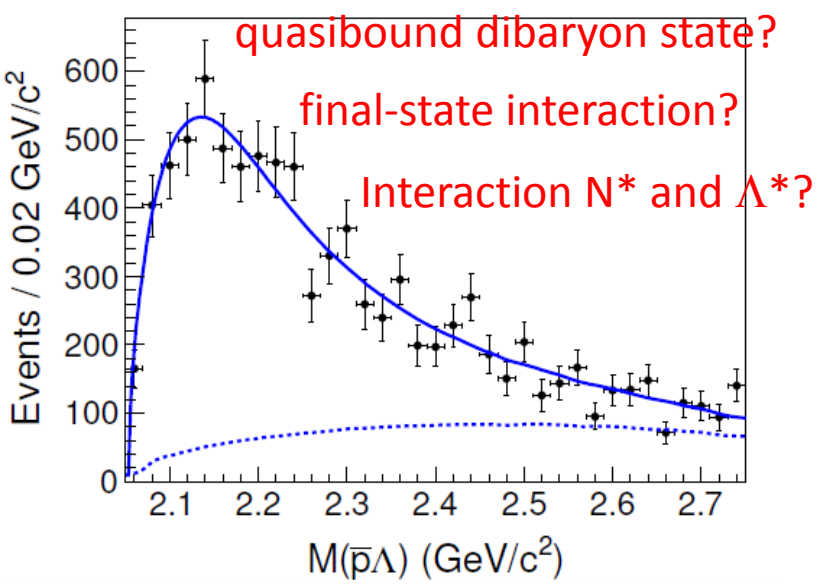
BESIII, PRD87, 012007(2013)





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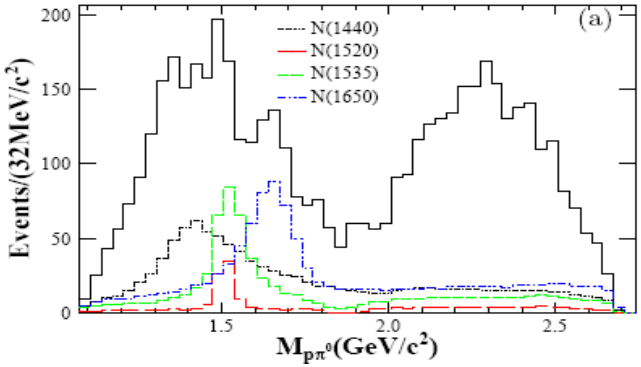
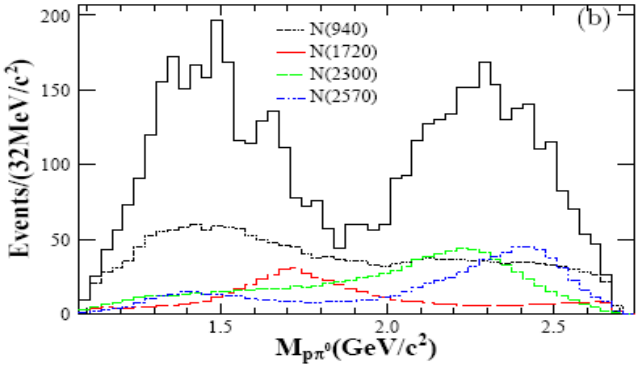
PWA of $\psi(2S) \to \bar{p}p\pi^0$

- Non-relativistic 3 quark model predicted far more excited baryons states than experimental observation.
- Δ supressed due to isospin conservation in charmonium decay.
- N(2065) was observed in $J/\Psi \to p\bar{p}\pi^0$, close to the edge of the phase space.





Resonance	M(MeV/c^2)	Γ(MeV/c^2)	ΔS	ΔN_{dof}	C.L.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	4	12.2σ
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94-44}$	55.6	6	9.6σ
$N(2300)$	$2300^{+40+109}_{-30-0}$	$340^{+30+110}_{-30-58}$	120.7	4	15.0σ
$N(2570)$	2570^{+19+34}_{-10-10}	250^{+14+69}_{-24-21}	78.9	6	11.7σ

Resonance	N	ϵ(%)	B.F.($\times 10^{-5}$)
$N(940)$	$1870^{+90+487}_{-90-327}$	27.2 ± 0.4	$6.42^{+0.20+1.78}_{-0.20-1.28}$
$N(1440)$	$1060^{+90+459}_{-90-227}$	27.6 ± 0.4	$3.58^{+0.25+1.59}_{-0.25-0.84}$
$N(1520)$	190^{+14+64}_{-14-48}	27.7 ± 0.4	$0.64^{+0.05+0.22}_{-0.05-0.17}$
$N(1535)$	$673^{+45+263}_{-45-256}$	25.5 ± 0.4	$2.47^{+0.28+0.99}_{-0.28-0.97}$
$N(1650)$	$1080^{+77+382}_{-77-467}$	26.9 ± 0.4	$3.76^{+0.28+1.37}_{-0.28-1.66}$
$N(1720)$	$510^{+27+50}_{-27-197}$	26.6 ± 0.4	$1.79^{+0.10+0.24}_{-0.10-0.71}$
$N(2300)$	$948^{+68+394}_{-68-213}$	33.8 ± 0.4	$2.62^{+0.28+1.12}_{-0.28-0.64}$
$N(2570)$	$795^{+45+127}_{-45-83}$	34.9 ± 0.4	$2.13^{+0.08+0.40}_{-0.08-0.30}$
Total	4515 ± 93	25.5 ± 0.4	$16.5 \pm 0.3 \pm 1.5$

BESIII, PRL 110,022001 (2013)

2 new N* states are observed, but no clear evidence for N(1885) and N(2065).

Summary

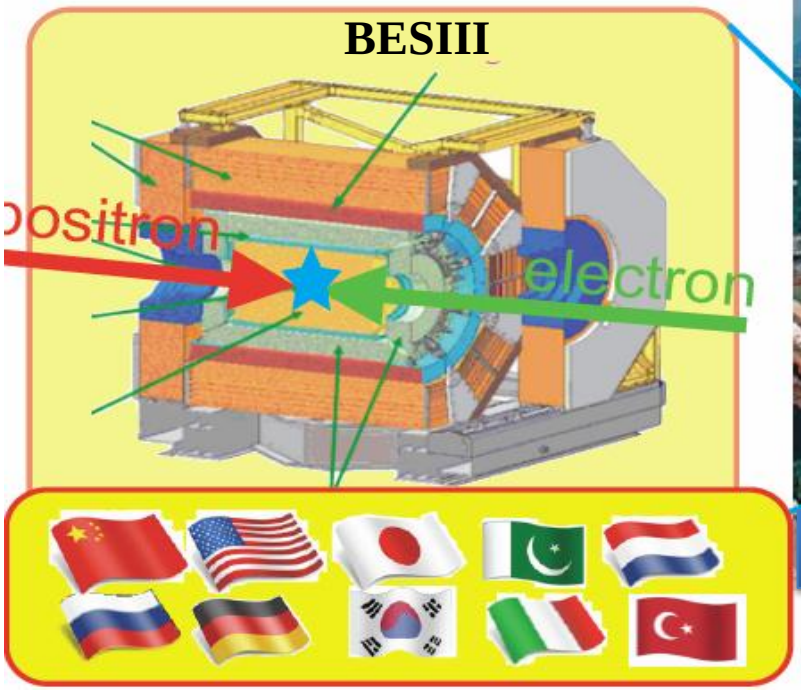
Based on the large J/ ψ and ψ' data samples at BESIII, many interesting results came out:

- Testing on non-pQCD calculation by $\chi_{cJ} \to \gamma\gamma$ and $J/\psi \to \gamma\gamma\gamma$.
- Evidence of $\phi(1850)$ and $\phi(2170)$ in $\psi(2S) \to K^+K^-\eta$.
- Observation of X(1440) in $\psi(2S) \to \omega K\bar{K}\pi$.
- Testing on 12% rule by $J/\psi/\psi(2S) \to$hadrons.
- Testing on COM by $\chi_{cJ} \to$ baryons.
- Study of IML and isospin breaking mechanism by J/ψ /$\psi(2S)/\eta_c \to$ baryons.
- Observation of new N* states in PWA of $p\bar{p}\,\pi^0$.


Thank you!

BEPCII & BESIII

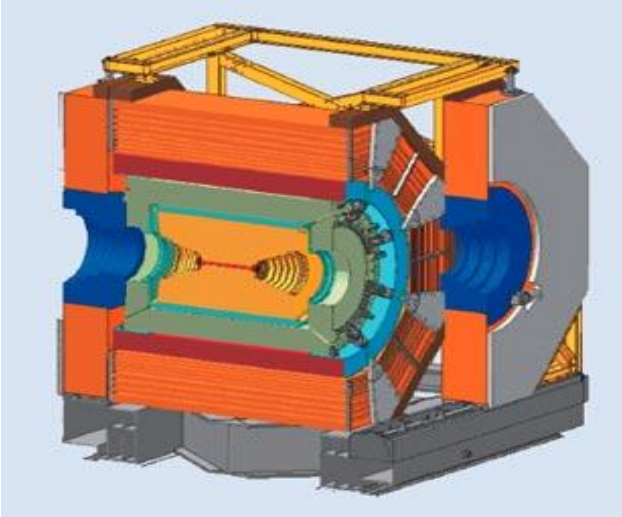
Work beam energy: 1.0-2.3 GeV
Design luminosity: 1.00×1033 $cm^{-2}s^{-1}$
100 times as BEPC !
Much better detector !!

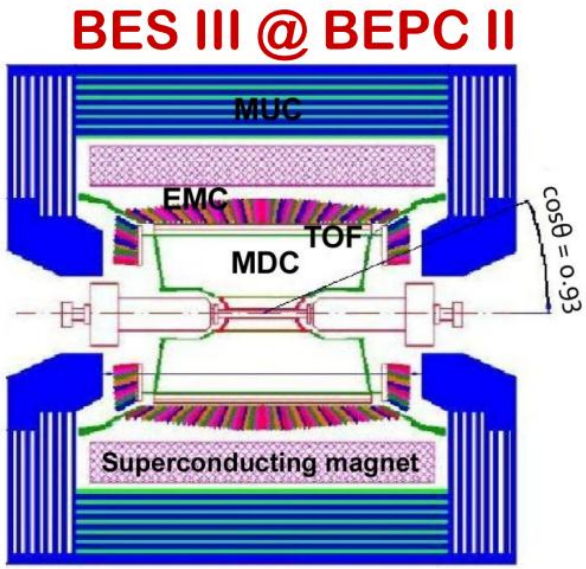


>300 physicists

BEijing Spectrometer - III

BESIII





Components	Parameters
MDC	$\sigma(p_t)/p_t = 0.32\% \bullet p_t$; $dE/dx_{reso} < 6\%$
TOF	90 ps (for bhabha)
EMC	$\sigma(E)/E = 2.3\% \bullet \sqrt{E}$
MUC	9 layers for barrel, 8 for endcap

BESIII data set

- July 19, 2008: first e^+e^- collision event
- Nov. 2008: ~14M p(2S) events for calibration
- 2009: 106M $\psi(2S)$
  225M J/ψ
- 2010: 900 pb^{-1} $\psi(3770)$
- 2011: 2000 pb^{-1} $\psi(3770)$
  478 pb^{-1}@4.009 GeV
- 2012: τ mass measurement
  $\psi(2S)$:0.4 billion; J/ψ: 1 billion
- 2013: 0.5 fb^{-1}@ each of 4.26 and 4.36 GeV(XYZ)

World's largest J/ψ, $\psi(2S)$ and $\psi(3770)$ samples! (still growing)

Measurement of $\chi_{cJ}\to\Lambda\bar{\Lambda}\pi\pi$

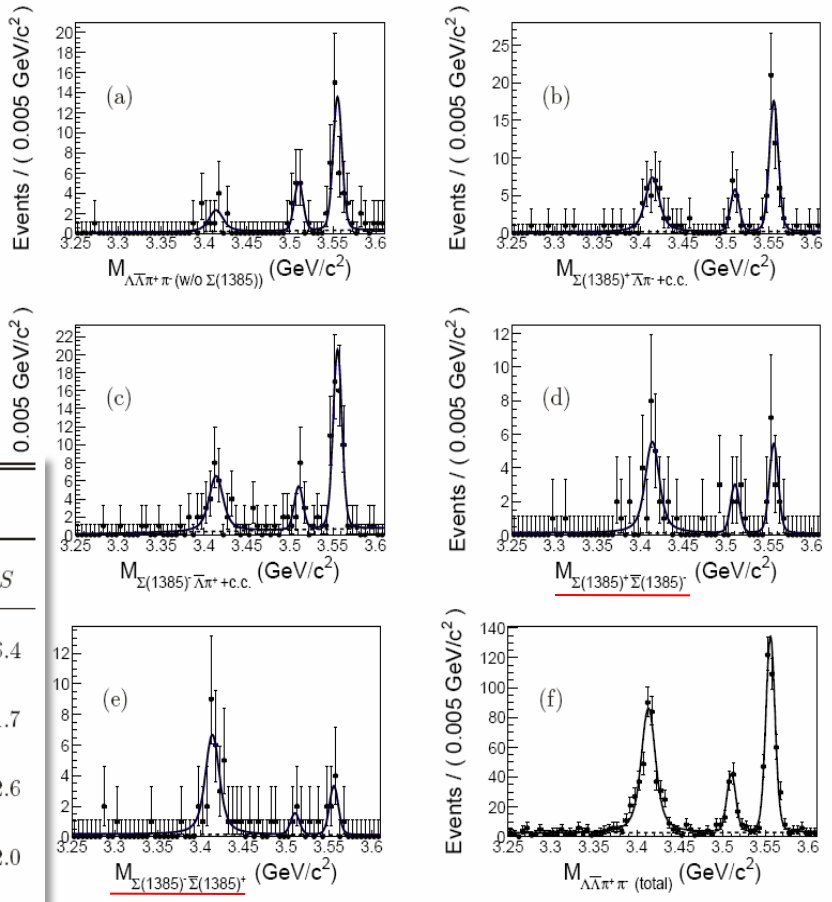
- COM predicted:
  $B[\chi_{c1}\to\Sigma(1385)\bar{\Sigma}(1385)]=(2.15\pm0.12)\times10^{-5}$
  $B[\chi_{c2}\to\Sigma(1385)\bar{\Sigma}(1385)]=(3.61\pm0.20)\times10^{-5}$

  Nucl. Phys. A 674,185 (2000)

- $B^{up}[\chi_{c1,2}\to\Sigma(1385)\bar{\Sigma}(1385)]$ are consistent with the COM prediction

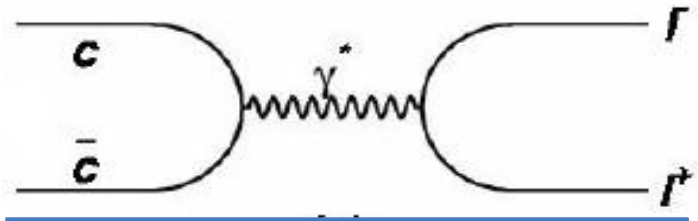
BF[$\times10^{-5}$]

χ_{cJ} decay mode	χ_{c0}			χ_{c1}			χ_{c2}		
	$\mathcal{B}$	UL	S	$\mathcal{B}$	UL	S	$\mathcal{B}$	UL	S
$\Lambda\bar{\Lambda}\pi^+\pi^-$ (w/o $\Sigma(1385)$)	28.6±12.6±2.7	<54	2.2	26.2±5.5±3.3		4.8	71.8±14.5±8.2		6.4
$\Sigma(1385)^+\bar{\Lambda}\pi^- + c.c.$	34.8±13.2±3.4	<55	2.2		<14	0.3	23.6±11.8±2.7	<42	1.7
$\Sigma(1385)^-\bar{\Lambda}\pi^+ + c.c.$	24.6±12.7±2.4	<50	1.6		<14	0.0	37.8±11.8±4.4	<61	2.6
$\Sigma(1385)^+\bar{\Sigma}(1385)^-$	16.4±5.7±1.6		3.1	4.4±2.5±0.6	<10	1.9	7.9±4.0±0.9	<17	2.0
$\Sigma(1385)^-\bar{\Sigma}(1385)^+$	23.5±6.2±2.3		4.3		<5.7	0.9		<8.5	0.0
$\Lambda\bar{\Lambda}\pi^+\pi^-$(total)	119.0±6.4±11.4		> 10	31.1±3.4±3.9		> 10	137.0±7.6±15.7		> 10

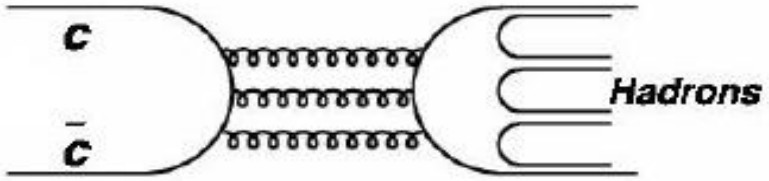


BESIII, Phys. Rev. D 86, 052004 (2012)

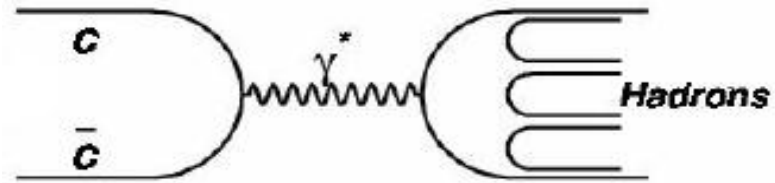
Charmonium Decay (J/Ψ & $\Psi(2S)$)



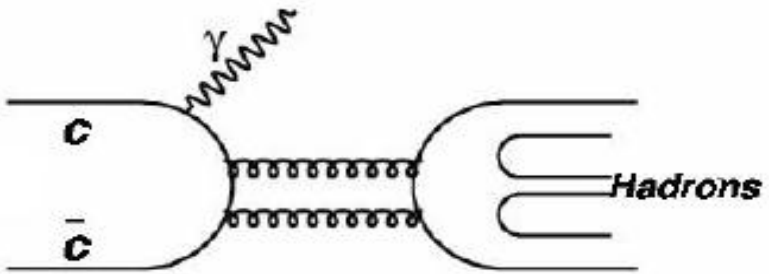
EM decay to leptons



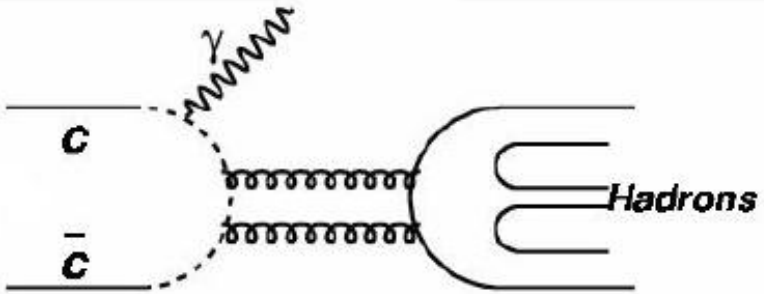
Strong decay to hadrons



EM decay to hadrons



Radiative decay to hadrons



E1/M1 transit and decay