Overview on BES Experiment

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BESIII

Institute of High Energy Physics, Beijing

10th Workshop on Hadron physics in China and Opportunities Worldwide
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Outline

- History of BEPC/BES
- Physics accomplishments
- Future upgrades
- Summary

Beijing Electron Positron Collider(BEPC)

- April 1983, the State Council officially approved the proposal to construct the Beijing Electron Positron Collider (BEPC)
- October 1984, the groundbreaking ceremony for the BEPC project

First e+e- collision at BEPC

- On October 16, 1988, the first electron-positron collision took place at BEPC

30 years anniversary of BEPC/BES !


我国高科技领域又取得重大突破

北京正负电子对撞机对撞成功

为粒子物理和同步辐射应用研究开辟广阔前景

据新华社北京10月19日电 （记者**施宝华、陈金武**）10月16日凌晨5点56分，位于北京西郊的中国科学院高能物理研究所传出令人振奋的喜讯：我国第一座高能加速器——北京正负电子对撞机首次对撞成功。

这是我国继原子弹、氢弹爆炸成功、人造卫星上天之后，在高科技领域又一重大突破性成就。

北京正负电子对撞机是党中央、国务院决策建设的高科技工程。它包括电子注入器、贮存环、探测器及数据处理中心、同步辐射区等4个主要组成部分，是由数百种、上万台件高精尖专用设备组成的复杂的系统工程。它的建成和对撞成功，为我国粒子物理和同步辐射应用研究开辟了广阔的前景，揭开了我国高能物理研究的新篇章。

这项被认为是中国科学技术史上最大的科研工程，是邓小平同志在1984年10月7日奠基破土动工的。4年来，在党中央、国务院委托的北京正负电子对撞机工程领导小组卓有成效的组织指挥下，中国科学院高能物理研究所同中央10多个部委及所属的几百个工厂、研究所、高等院校近万名科技人员、工人、干部、解放军官兵，发扬自信、自立、自强的精神，充分吸取了世界先进技术，自力更生，艰苦奋斗，顽强拼搏，克服了重重困难，出色地完成了自行设计、研制、生产、安装、调试任务，创造了建设速度快、投资省、质量好、水平高的奇迹。昨日来京参加中美高能合作会议的李政道教授说，北京正负电子对撞机对撞成功，是国际高能物理界的一件大事。仅用4年时间就完成了如此复杂的高技术工程，这样快的速度在国际上是不多的。它能一次对撞成功，表明对撞机的各种设备、部件的质量、安装调试的水平在世界上也属一流。

据中国科学院有关人士说，北京正负电子对撞机今后将建设成为对外开放的国家实验室，根据它同时具有粒子物理和同步辐射应用研究的特点，它将成为跨部门、跨学科共同享用的实验研究基地。

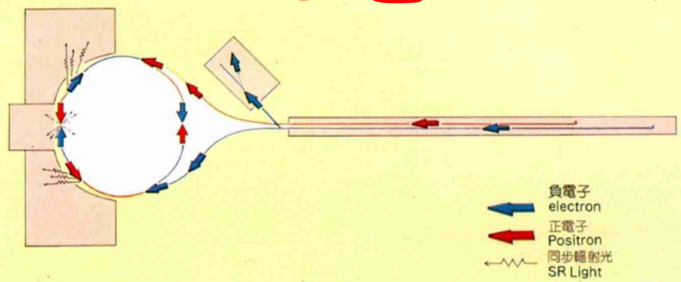
目前，高能物理研究所的专家们正在继续进行调试和进行物理实验的准备工作，以求不断提高各种设备的稳定性，使亮度等各项指标尽快达到设计要求，并作出有意义的物理实验。

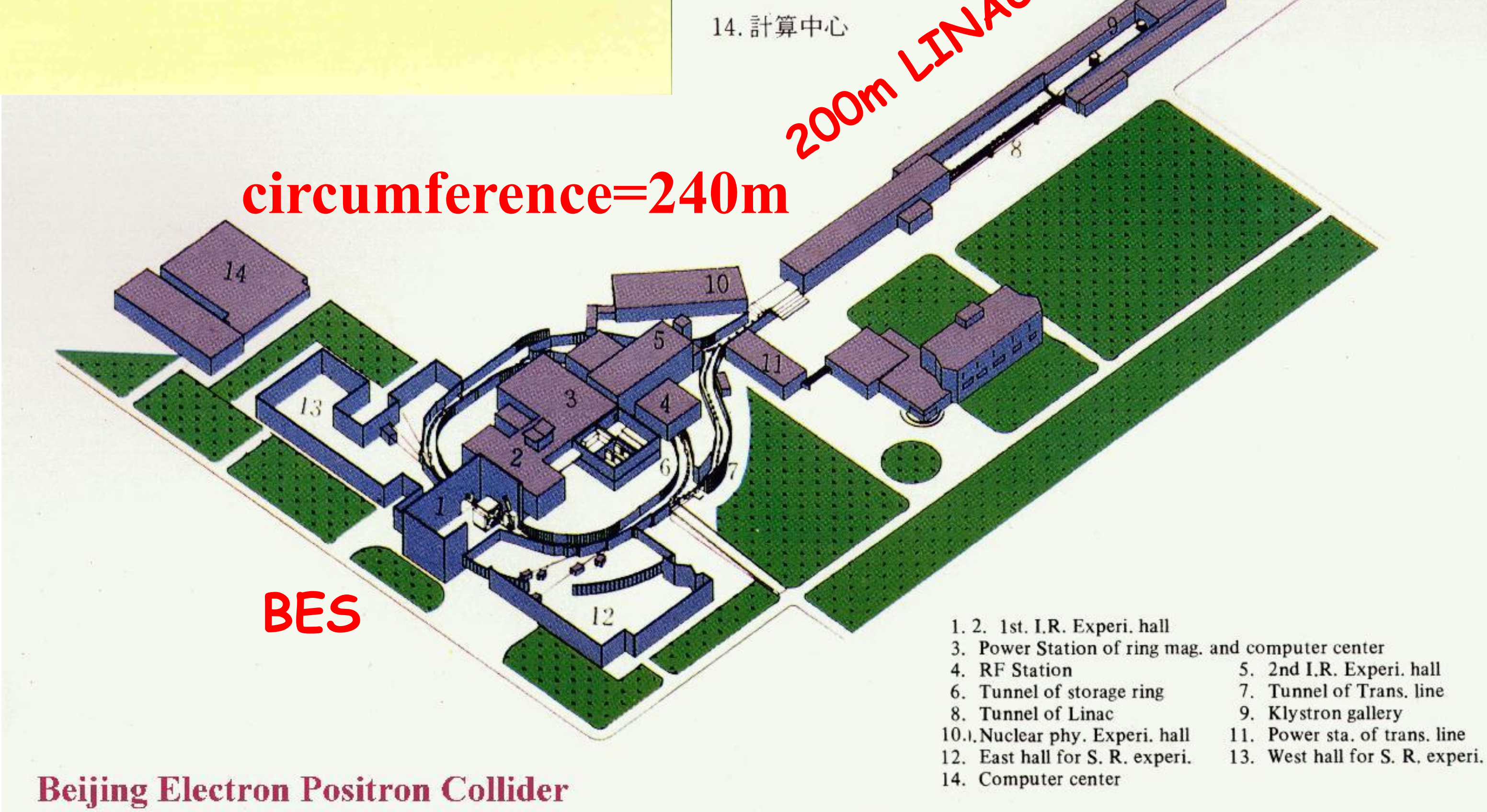
Report by *People's Daily*

Bird view of BEPC

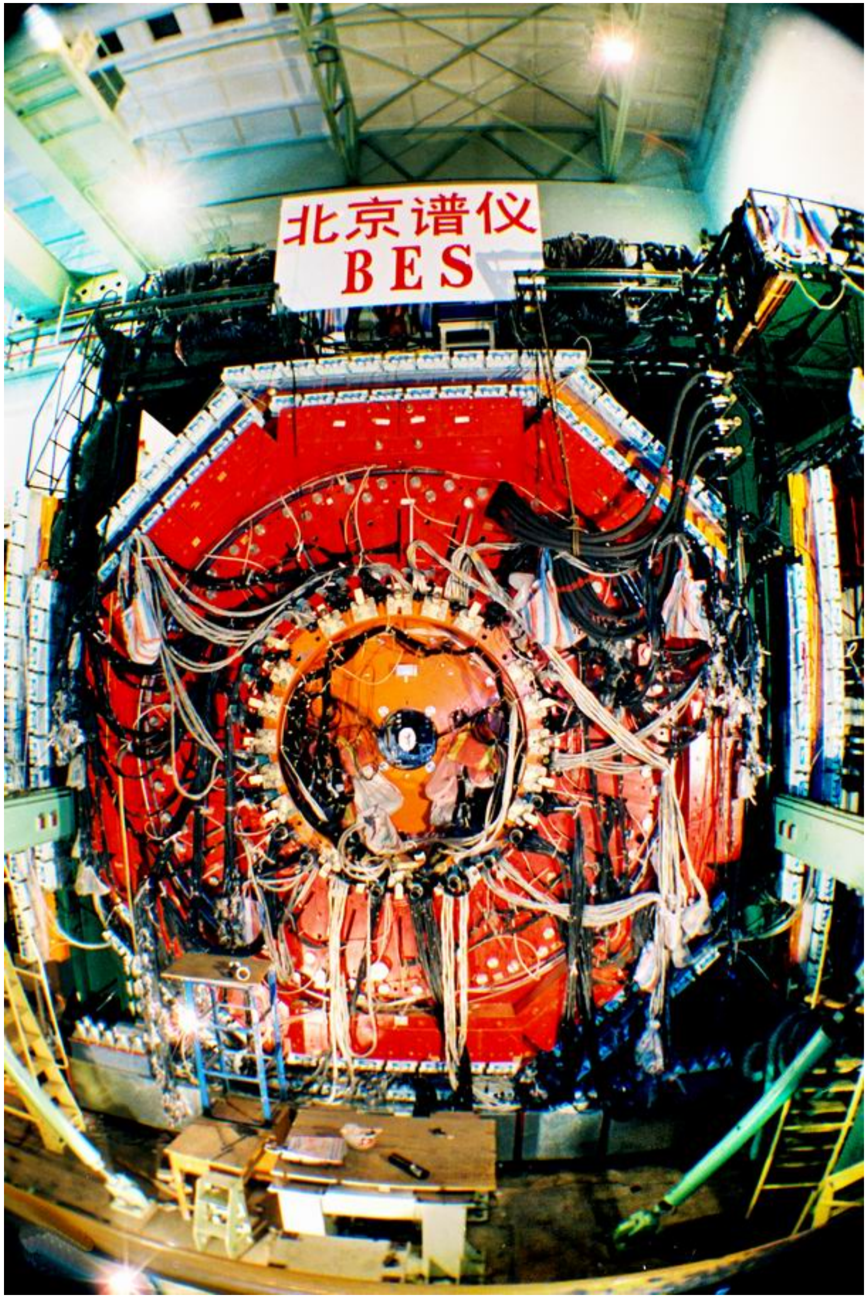
BEPC

BEPC constructed in 1984 –1988 with beam energy: 1 – 2.8 Gev Physics Run: Luminosity $10^{31}cm^{-2}s^{-1}$ @ 1.89GeV





Upgrade in 1996-1998 （BES→BESII）

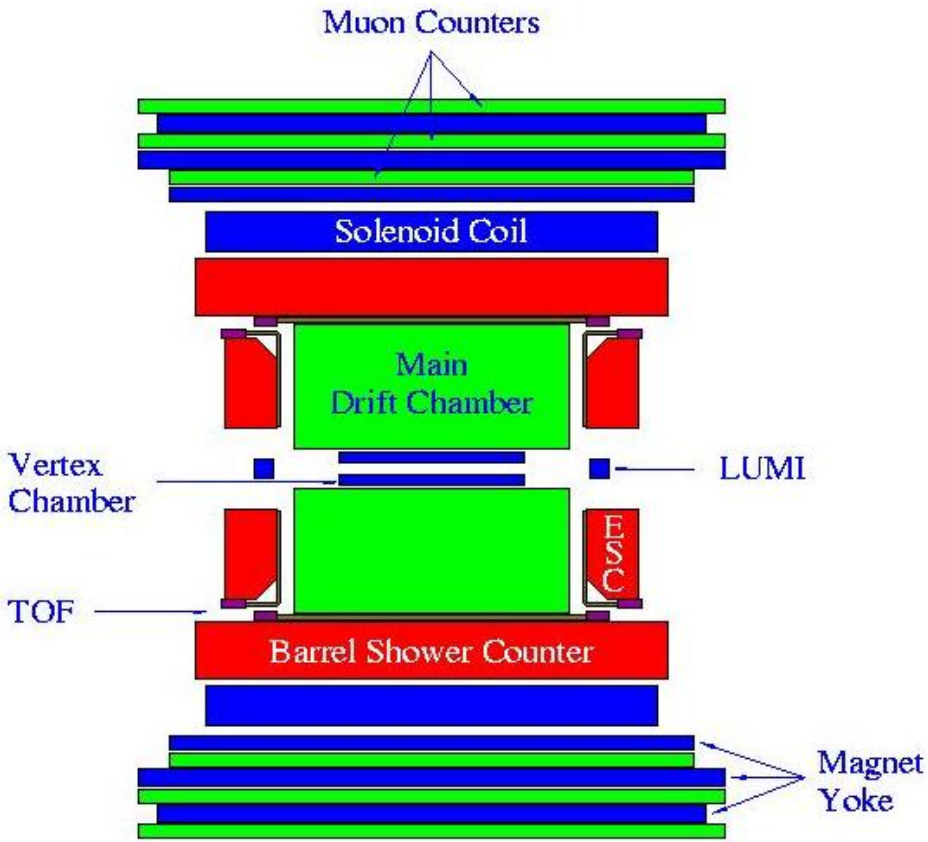


	MDCI	MDCII
Cells	702	804
Total wires	19 380	22 936
Sense wires	2808	3216
Symmetry	2-fold	4-fold
Feedthrough	2 parts	1 part
Layer 10 design voltage	4.25 kV	3.8 kV

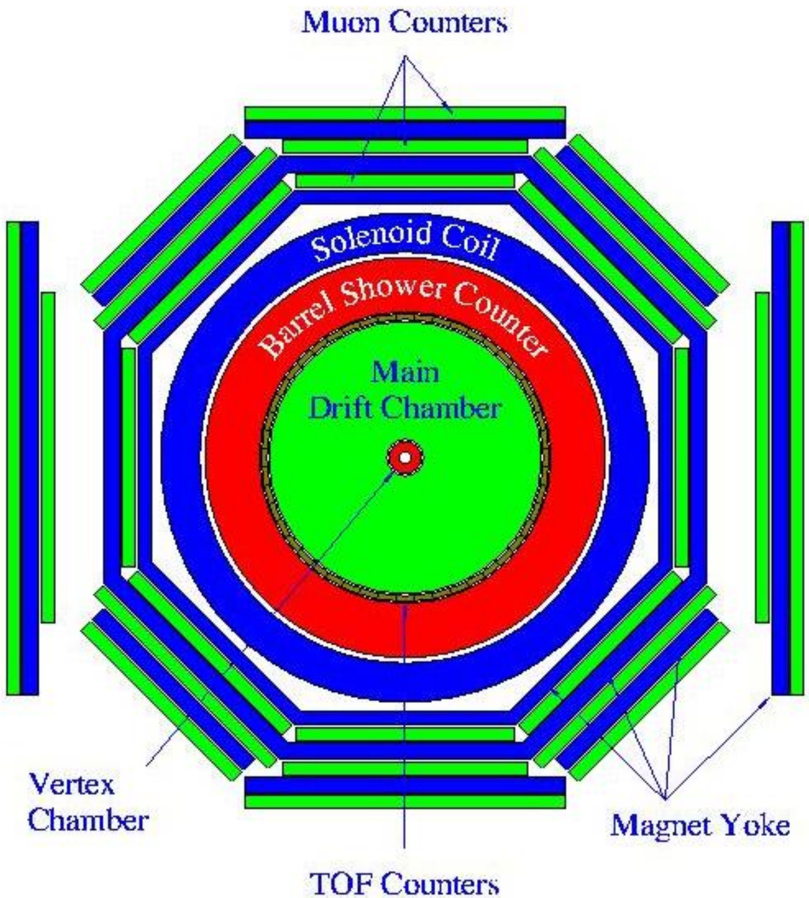
	TOFI	TOFII
Scintillator	NE110	BC-408
Phototubes	XP2020	R2409-05
Light guide length	112 cm	16 cm
Attenuation length	2.5 m	4.4 m

	CDC	VC
Chamber	Drift chamber	Straw tubes
Layers	4	12
Gas	$Ar/CO_2/CH_4$	Ar/ethane
Pressure	1 atm	3 atm
Beam pipe	2 mm Al	1.2 mm Be

Schematic plots for BES

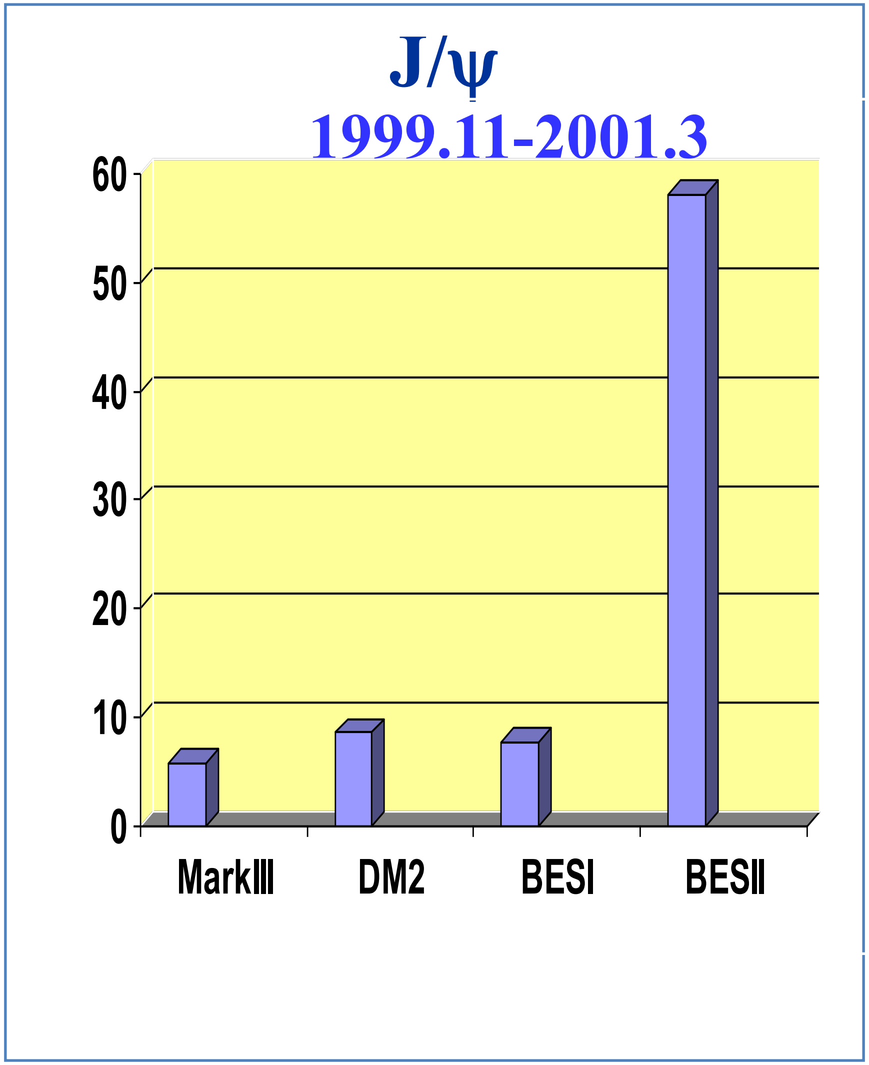


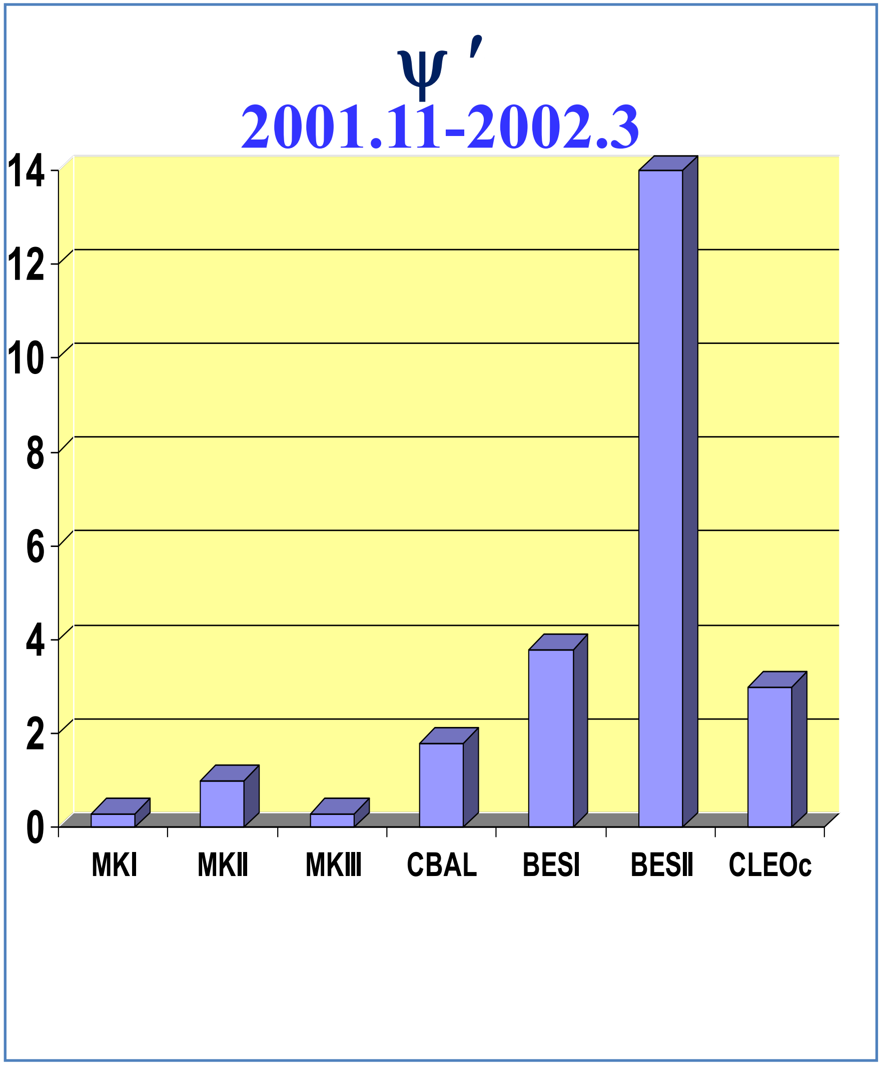
Side view of the BES detector



End view of the BES detector

J/ψ and ψ' data sample (10^6) at BESII





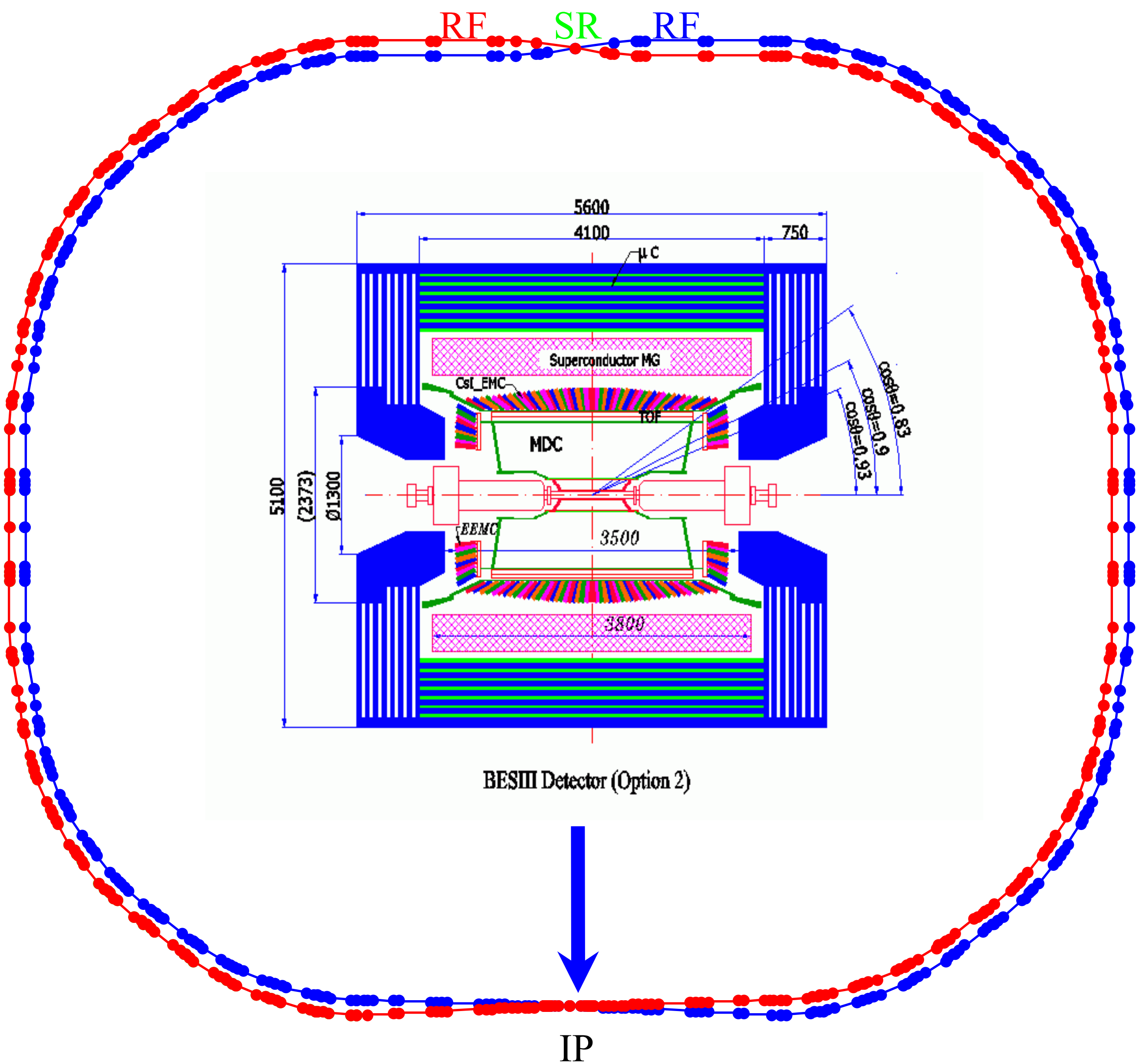
BEPCII and BESIII

- BEPC (Beijing Electron-Positron Collider)
  - BESI/BESII detector worked on it from 1988 to 2004
  - Beam energy: 1.5 - 2.8GeV

- BEPC → BEPCII
  - Luminosity:
    - $1.0 \times 10^{31} cm^{-2} s^{-1} \rightarrow 1.0 \times 10^{33} cm^{-2} s^{-1}$
  - Number of beam bunches:
    - 1→ 93

- BESIII: a new spectrometer to be working on BEPCII
  - Very good energy and angle resolution for photon measurement
  - Accurate 4-momenta measurement of charged particles with low momentum
  - Good hadron identification capabilities

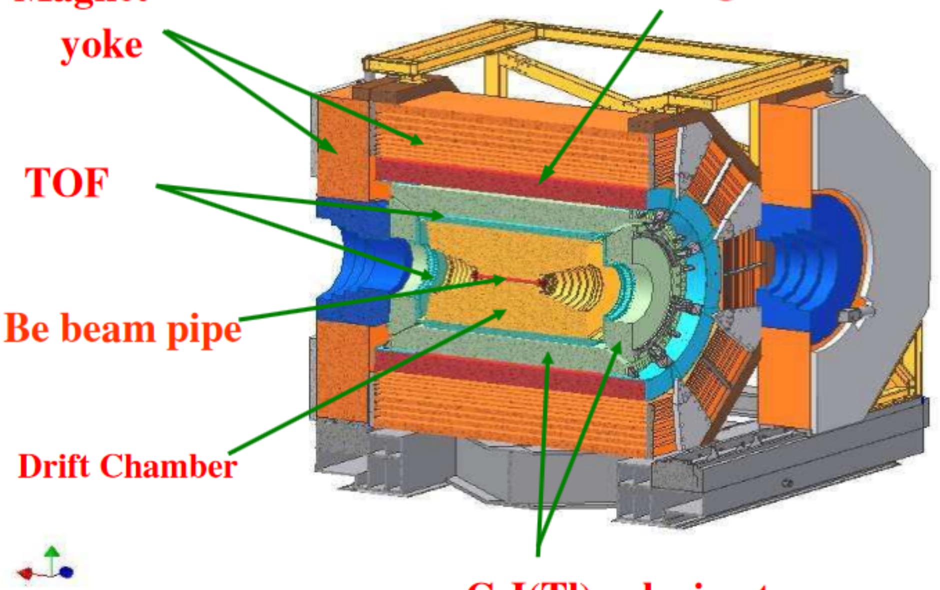
BEPC II Storage ring: Large angle, double-ring



Beam energy:
1-2 GeV
Luminosity:
1×10^{33} $cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A
SR mode:
0.25A @ 2.5 GeV

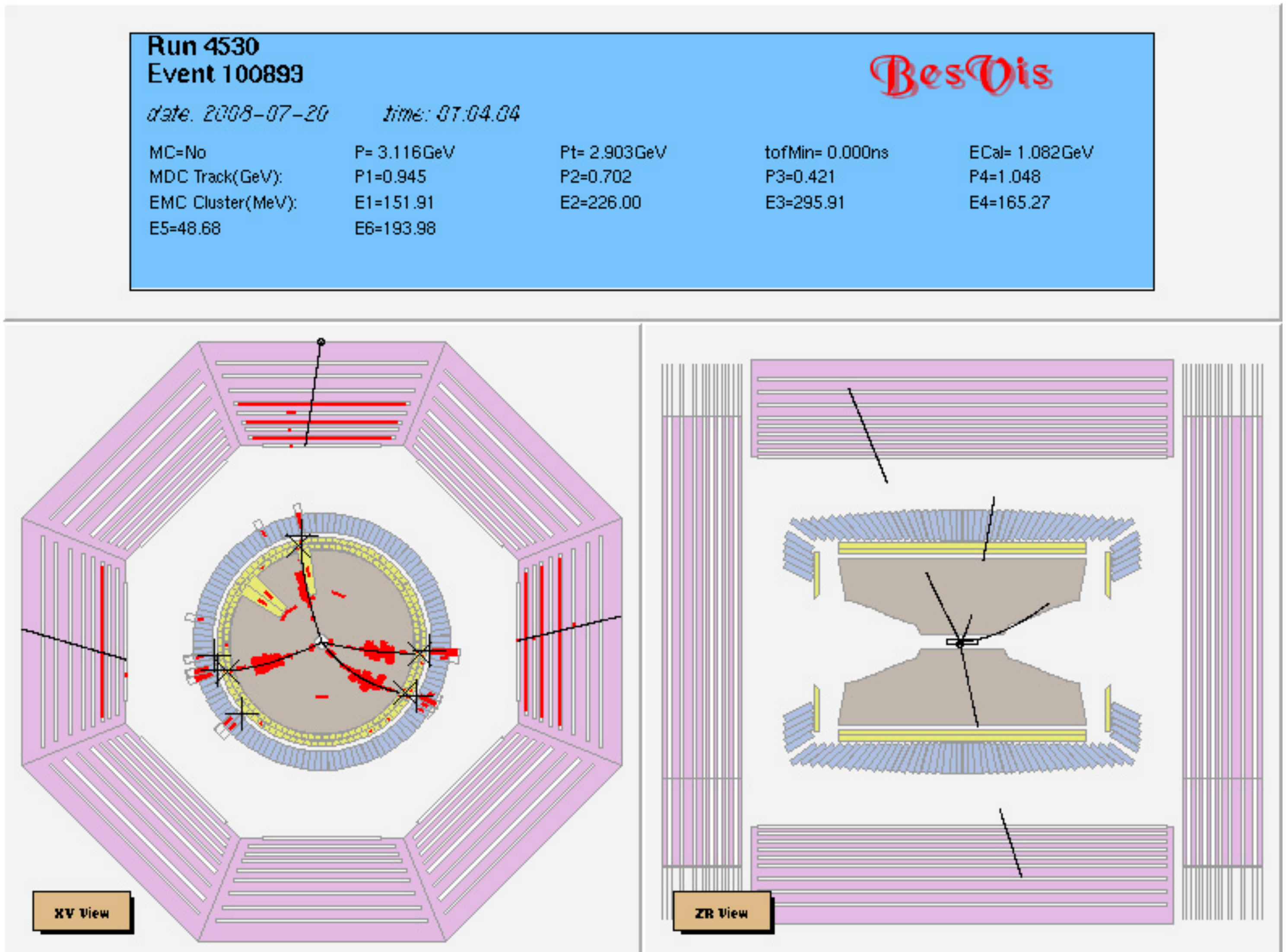
Luminosity reached 1×10^{33} $cm^{-2}s^{-1}$ on 5 April, 2016 !

BESIII detector



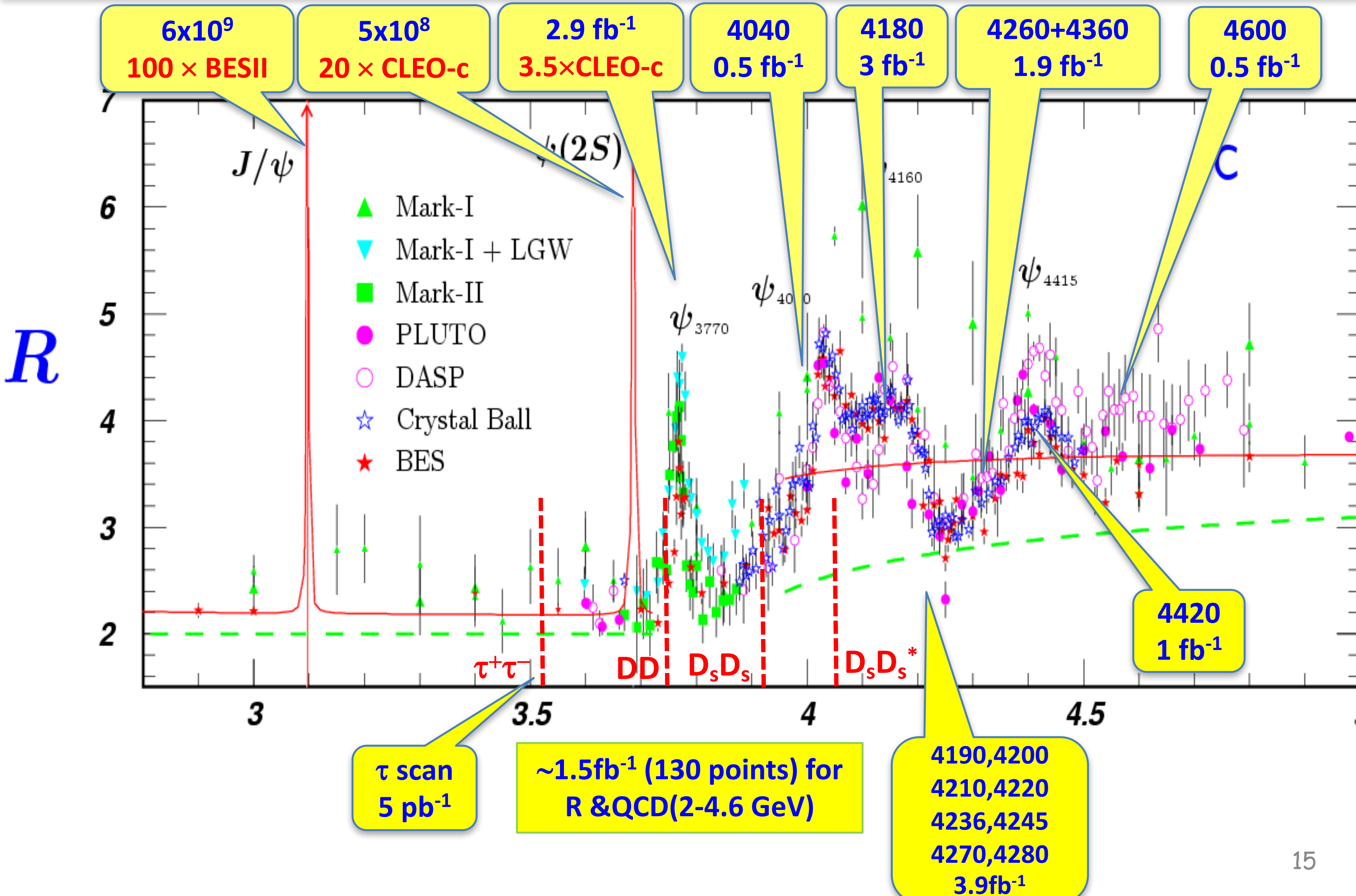
Sub-system	BESIII		BESII
MDC	$\sigma_{xy} = 130\ \mu$m		250 μm
	$\Delta P/P = 0.5\%$ @ 1 GeV	SC magnet	2.4% @ 1 GeV
	$\sigma_{dE/dx} = (6-7)\%$		8.5%
EM Calorimeter	$\Delta E/E = 2.5\%$ @ 1 GeV $\sigma_z = 0.6$ cm @ 1 GeV		20% @ 1 GeV 3 cm @ 1 GeV
TOF Detector	$\sigma_T =$ 100 ps barrel 110 ps endcap		180 ps barrel 350 ps endcap
μ Counters	9 layers		3 layers
Magnet	1.0 Tesla		0.4 Tesla

First collision event on July 19, 2008



10 years anniversary of BEPCII/BESIII !

World largest data sample directly collected in the tau-charm region

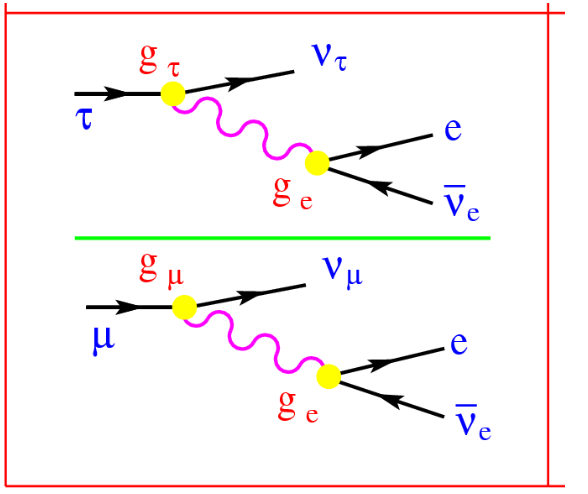


Physics accomplishments

- τ mass measurement (BES+BESIII)
- R value measurement (BESII)
- Charm physics (BESII+BESIII)
- Exotic hadrons (BESII+BESIII)

τ mass measurement

τ mass measurement



- Lepton Universality relation

$$\frac{g_\tau^2}{g_\mu^2} = \frac{m_\mu^5}{m_\tau^5}\frac{B(\tau\to e\bar{\nu}_e\nu_\tau)}{B(\mu\to e\bar{\nu}_e\nu_\mu)}\frac{\tau_\mu}{\tau_\tau}$$

- It should be ~1 if universality holds
- PDG1992:

$$\frac{g_\tau}{g_\mu} = 0.941 \pm 0.025$$

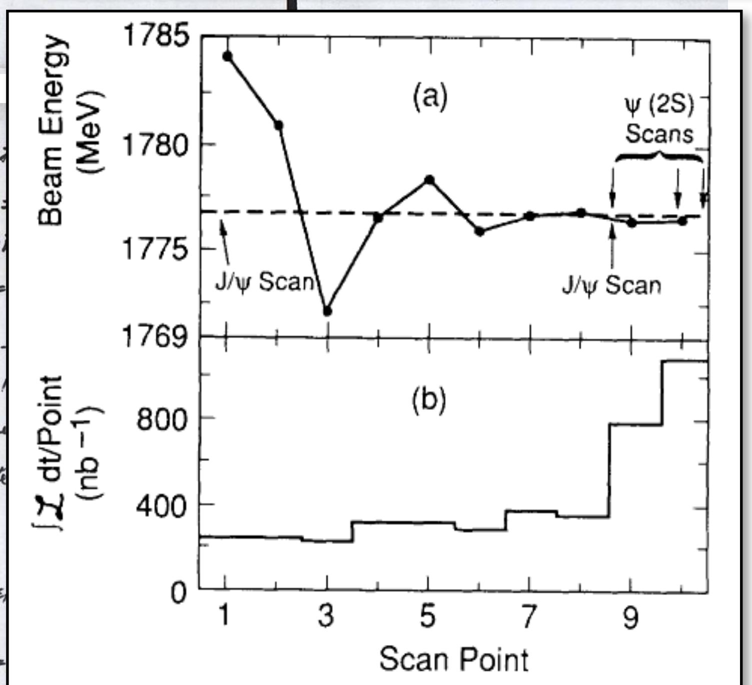
- τ mass: DASP, SPEC,DELCO,MARK-II

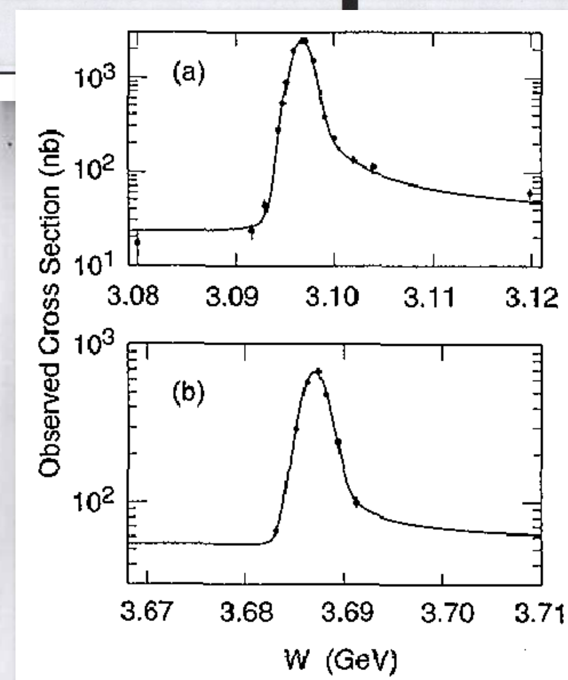
$$m_\tau = 1784.1^{+2.7}_{-3.6}\,MeV$$

- More likely τ mass come down in case of lepton universality

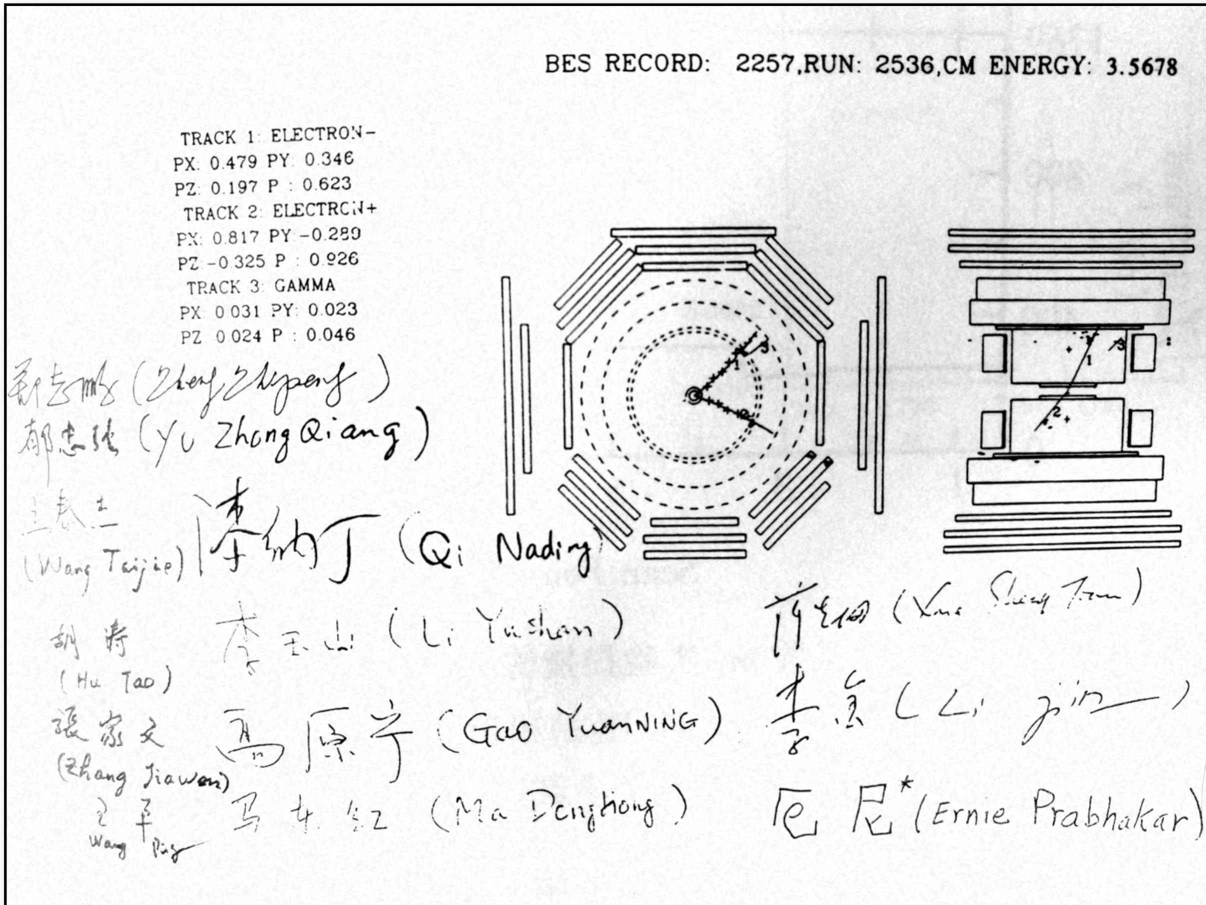
Proposal for τ mass measurement

- Measure the **τ pair** production threshold by energy scan $E_{threshold} = 2m_\tau$
- J/ψ and ψ(2S) allow to calibrate and monitor detector performance

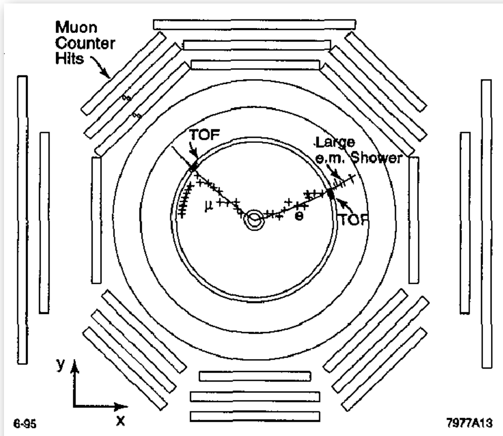




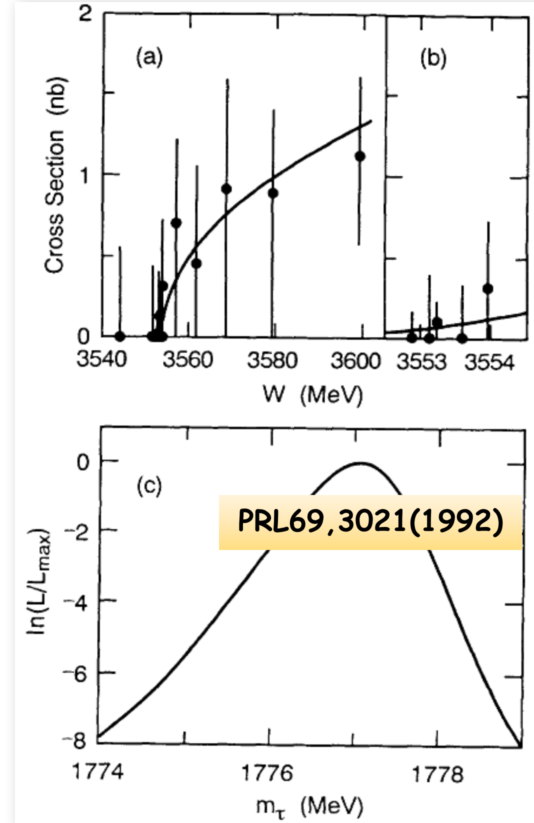
First τ events

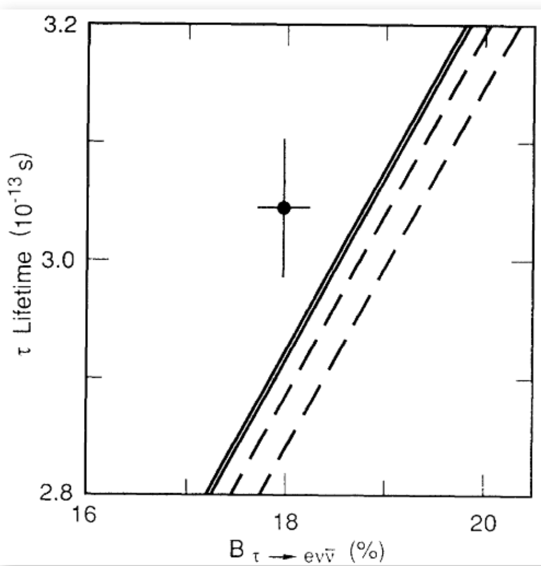


τ mass: $e\mu$ events only



Scan point	$W/2$ (MeV)	Δ (MeV)	$\mathcal{L}$ (nb^{-1})	N ($e\mu$ event
1	1784.19	1.34	245.8	2
2	1780.99	1.33	248.9	1
3	1772.09	1.36	232.8	0
4	1776.57	1.37	323.0	0
5	1778.49	1.44	322.5	2
6	1775.95	1.43	296.9	0
7	1776.75	1.47	384.0	0
8	1776.98	1.47	360.8	1
9	1776.45	1.44	794.1	0
10	1776.62	1.40	1109.1	1
11	1799.51	1.44	499.7	5
12	1789.55	1.43	250.0	2





$$m_\tau = 1776.9^{+0.4}_{-0.5} \pm 0.2 MeV$$

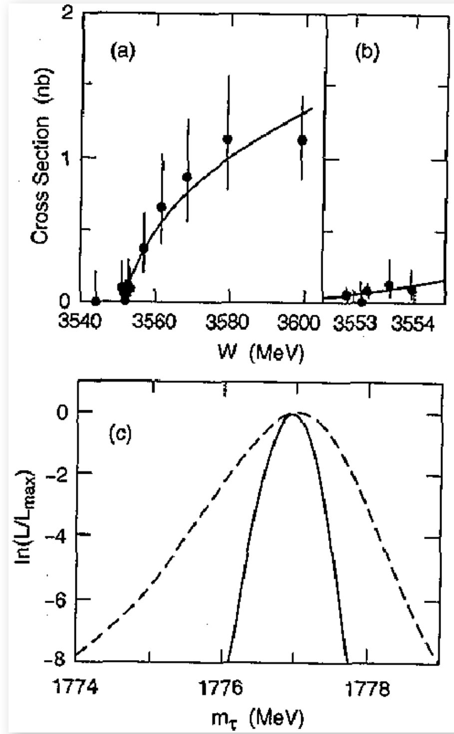
$$\frac{g_\tau}{g_\mu} = 0.960 \pm 0.024$$

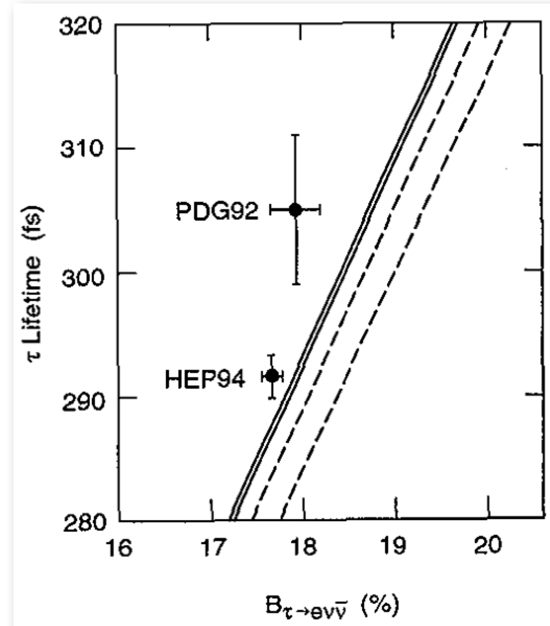
PDG1992: $m_\tau = 1784.1^{+2.7}_{-3.6} MeV$ $\frac{g_\tau}{g_\mu} = 0.941 \pm 0.025$

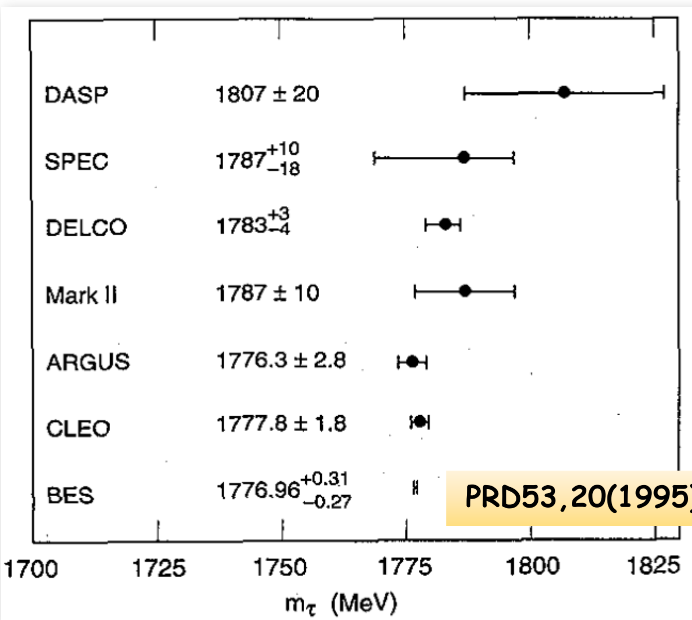
- 7.2 MeV below the PDG average
- Deviation from the lepton universality is reduced from 2.4 to 1.7 standard deviations

τ mass: eμ +other events

Scan point	All final states	ee	eμ	eh	μμ	μh	hh
1	9		2	3		2	2
2	7		2	3	1	1	
3	0						
4	0						
5	5		2	2		1	
6	1	1					
7	2	1				1	
8	1		1				
9	1			1			
10	3		1	1			1
11	24	2	5	8	1	2	6
12	12	2	1	3		4	2
Total	65	6	14	21	2	11	11





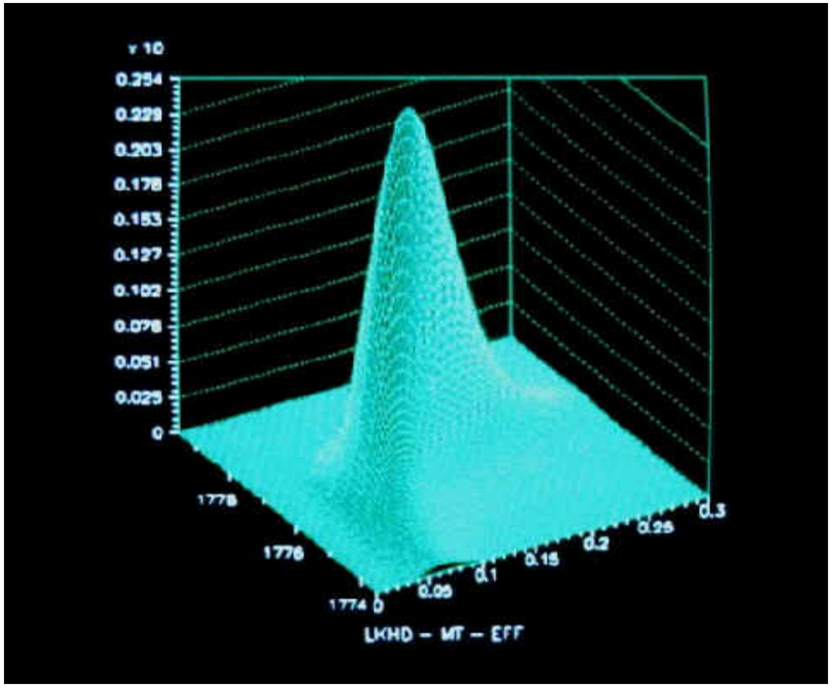


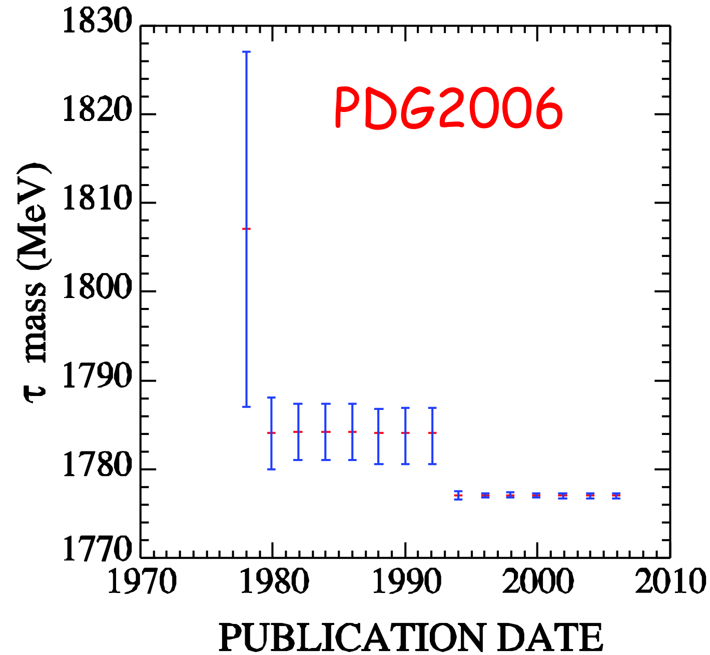
PRD53,20(1995)

$$m_\tau = 1776.96^{+0.18+0.25}_{-0.21-0.17}\, MeV$$

$$\frac{g_\tau}{g_\mu} = 0.9886 \pm 0.0085$$

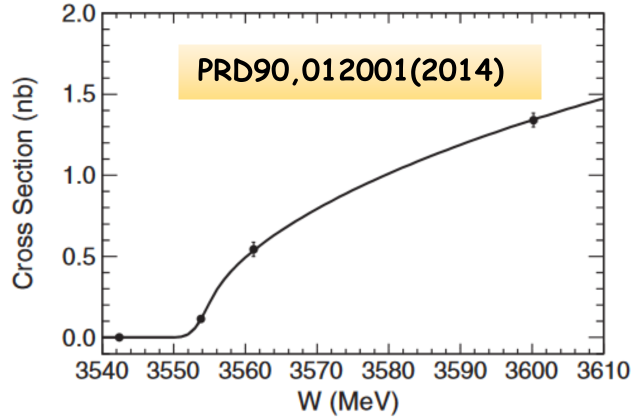
- Lepton universality !

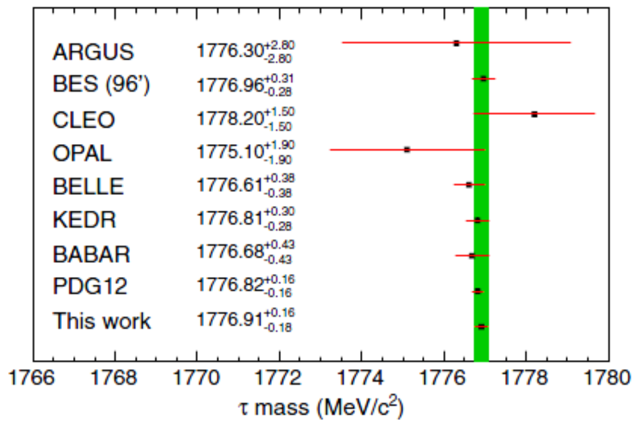


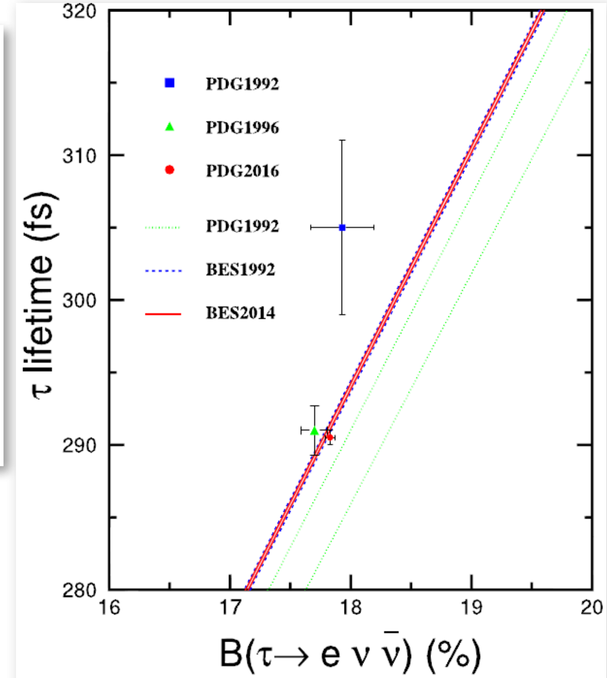


- **Reported at APS1992, LP1993**
- **1995: State Natural Science Award**

τ mass measurement at BESIII







Scan	$E_{c.m.}$ (MeV)	$\mathcal{L}$ (nb^{-1})
J/ψ	3088.7	78.5 ± 1.9
	3095.3	219.3 ± 3.1
	3096.7	243.1 ± 3.3
	3097.6	206.5 ± 3.1
	3098.3	223.5 ± 3.2
	3098.8	216.9 ± 3.1
	3103.9	317.3 ± 3.8
τ	3542.4	4252.1 ± 18.9
	3553.8	5566.7 ± 22.8
	3561.1	3889.2 ± 17.9
	3600.2	9553.0 ± 33.8
ψ'	3675.9	787.0 ± 7.2
	3683.7	823.1 ± 7.4
	3685.1	832.4 ± 7.5
	3686.3	1184.3 ± 9.1
	3687.6	1660.7 ± 11.0
	3688.8	767.7 ± 7.2
	3693.5	1470.8 ± 10.3

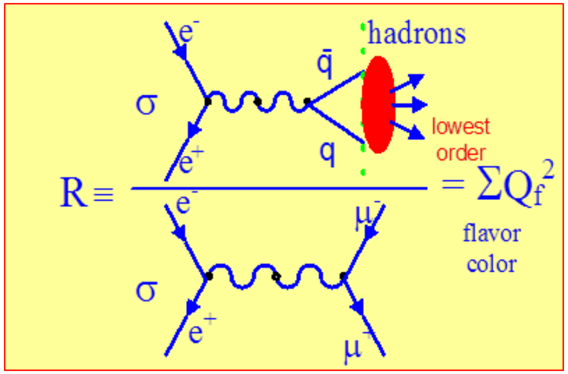
$$m_\tau = 1776.91 \pm 0.12^{+0.10}_{-0.13}\, MeV$$

$$\frac{g_\tau}{g_\mu} = 1.0016 \pm 0.0042$$

R value measurement

R value measurement at BESII

$$R(s) = \frac{\sigma_{tot}(e^+e^- \to hadrons)}{\sigma_{tot}(e^+e^- \to \mu^+\mu^-)} = 3\sum_q Q_q^2$$



R provides strong evidence for the quark model and 3 colors

For u, d, s

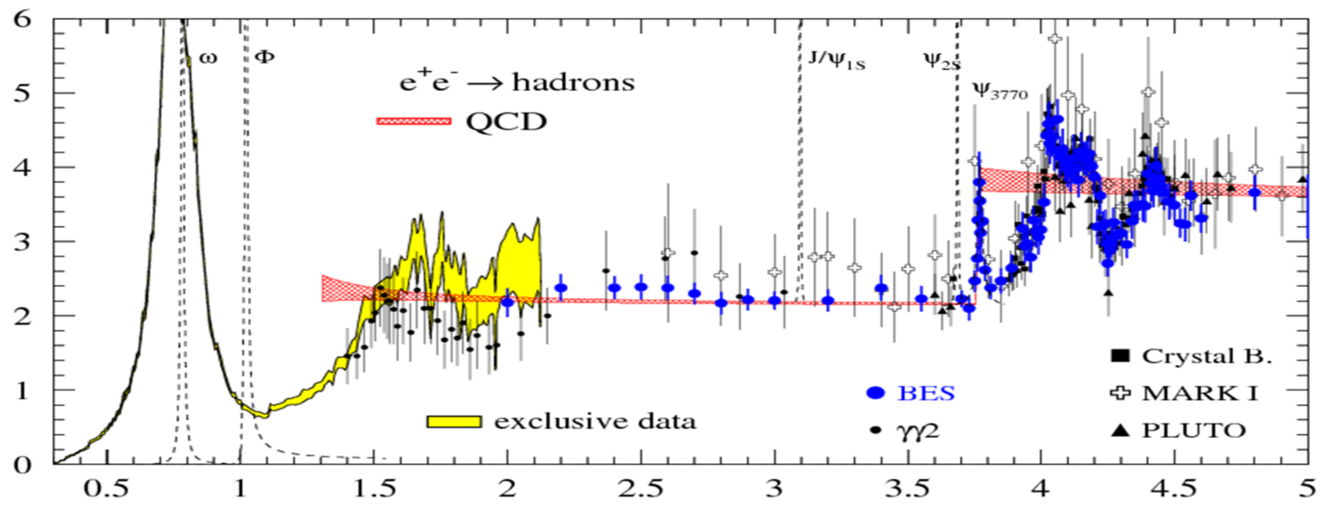
R ≈ 2

For u, d, s, c

R ≈ 3 1/3

For u, d, s, c, b

R ≈ 3 2/3



R value measurement at BESII

- Needed to improve precision of $\alpha(M^2_Z)$:
  - Uncertainties in α introduced when it is extrapolated to the Z-pole:

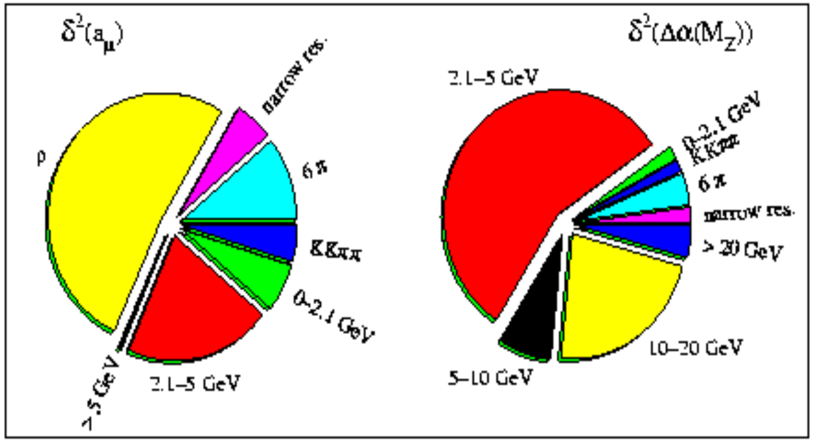
$$\alpha(q^2) = \frac{\alpha_0}{1-\Delta\alpha(q^2)}$$

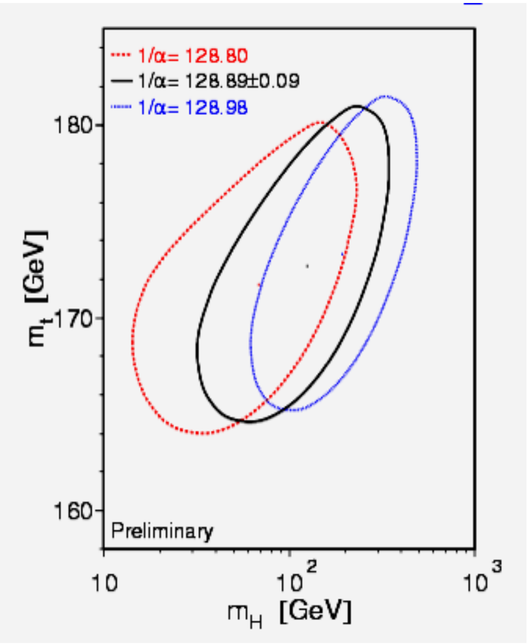
$$\Delta\alpha(q^2) = \Delta\alpha_l(q^2) + \Delta^{(5)}_{\rm had}\alpha(q^2) + \Delta_{\rm top}\alpha(q^2)$$

  - Dominant uncertainty due to hadronic vacuum polarization.
  - This is determined from R values using a dispersion relation

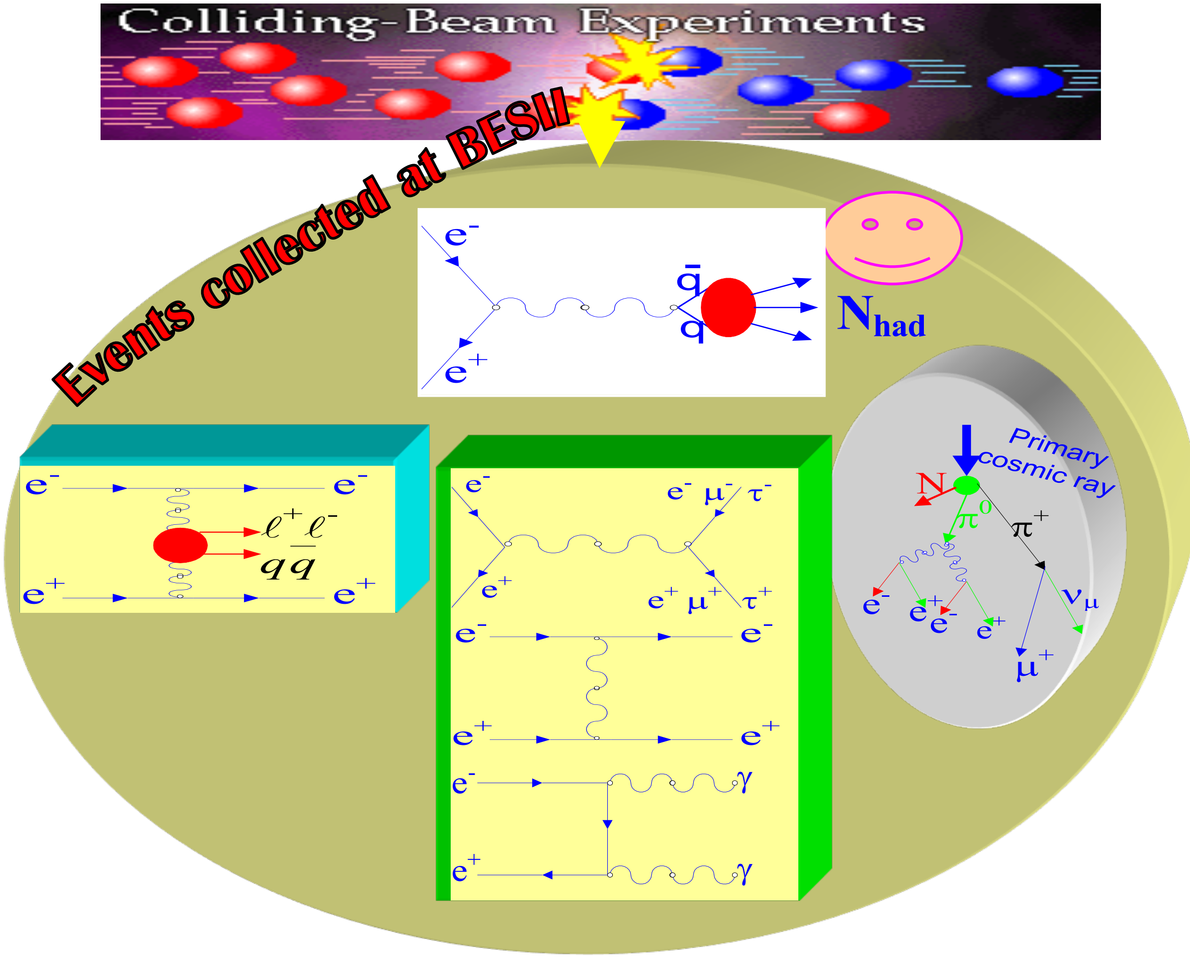
$$\Delta\alpha_{\rm had}(s) = -\frac{\alpha\, s}{3\pi}\, P\int_{4m_\pi^2}^{\infty} \frac{R_{\rm had}(s')}{s'(s'-s)}ds'$$

  - m_H is sensitive to $\alpha(M^2_Z)$





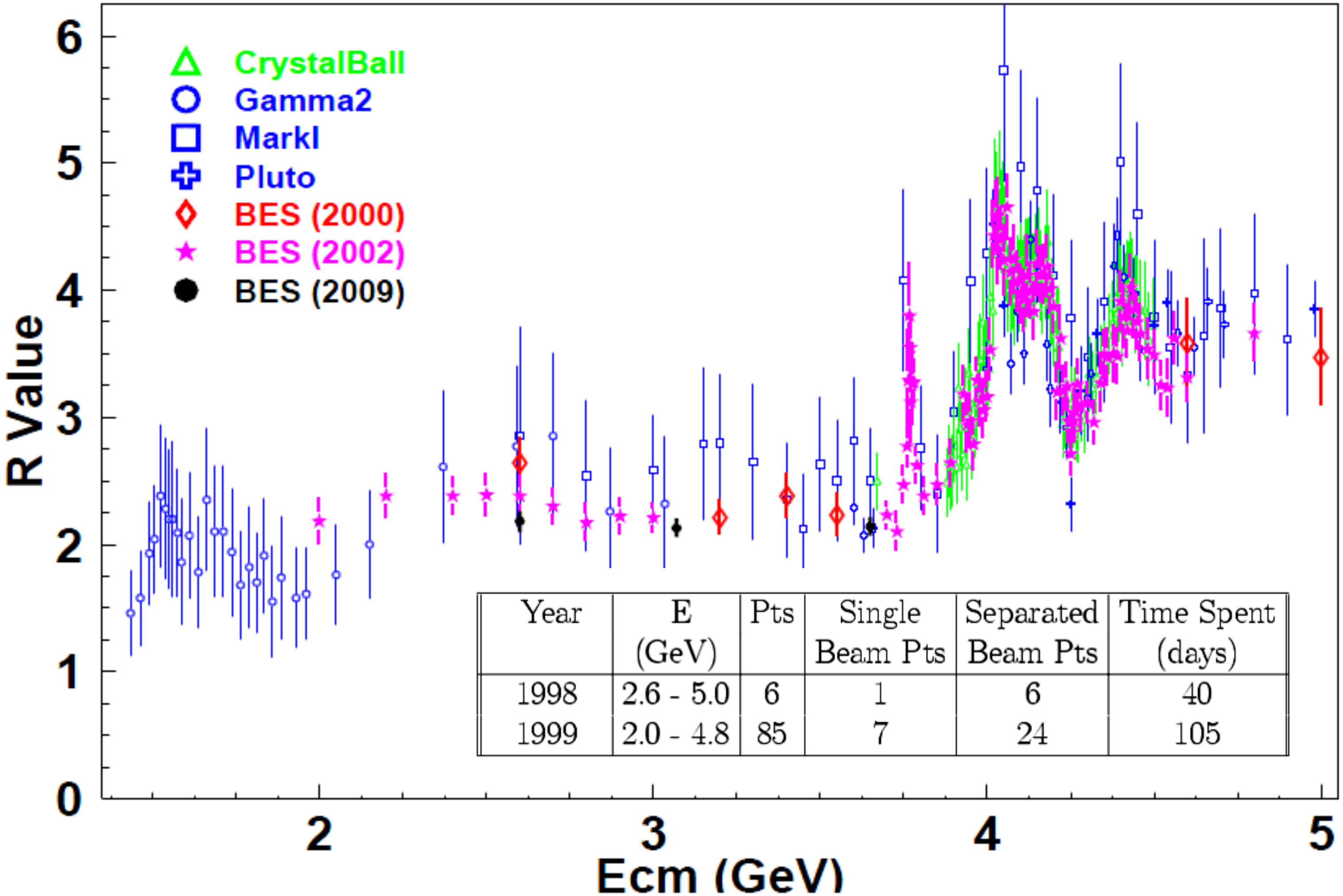
Events Recorded by BESII



$$R = \frac{1}{\sigma_{\mu^+\mu^-}} \cdot \frac{N_{had} - N_{bg}}{L \cdot \varepsilon_{had} \cdot (1+\delta)}$$

R value measurement at BESII

PRL**84**, 594 (2000), PRL**88**, 101802 (2002), PLB**677**, 239 (2009)

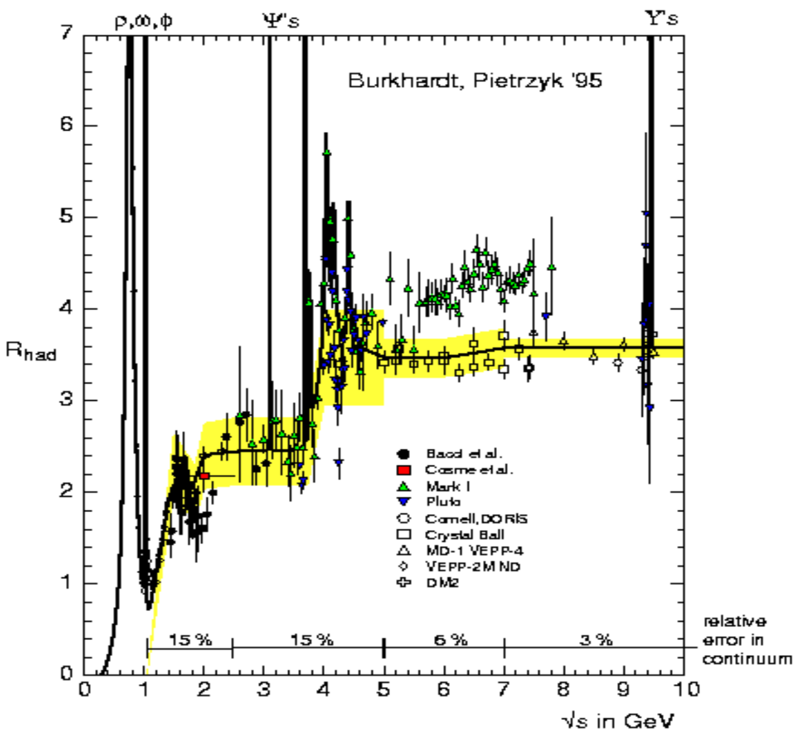


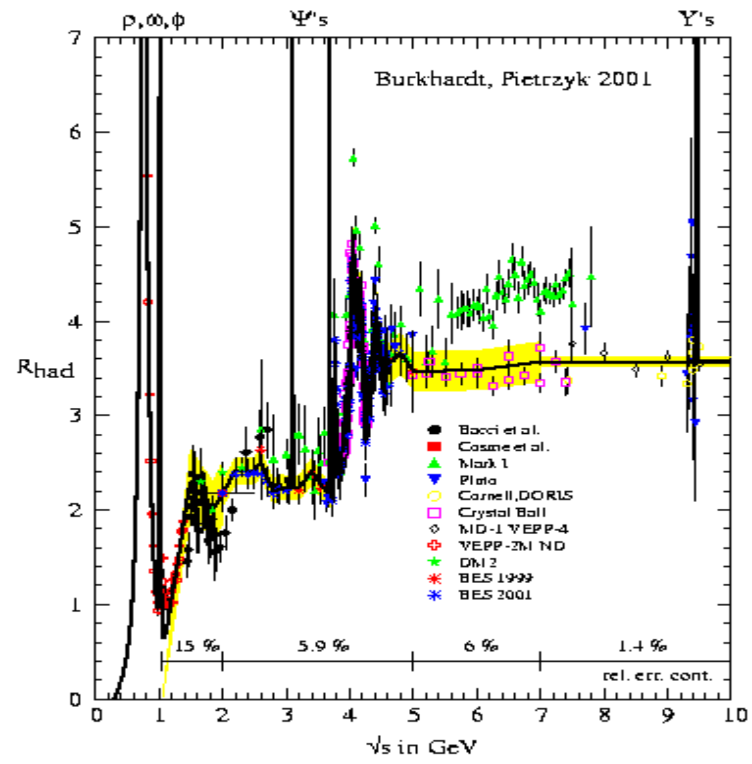
Year	E (GeV)	Pts	Single Beam Pts	Separated Beam Pts	Time Spent (days)
1998	2.6 - 5.0	6	1	6	40
1999	2.0 - 4.8	85	7	24	105

- **2004: State Natural Science Award**

R below 10 GeV

BES reduces R errors from 15 - 20 % to an average of 6% in the 2 - 5 GeV region. Important region!





Before BES R Scan **After BES R Scan**

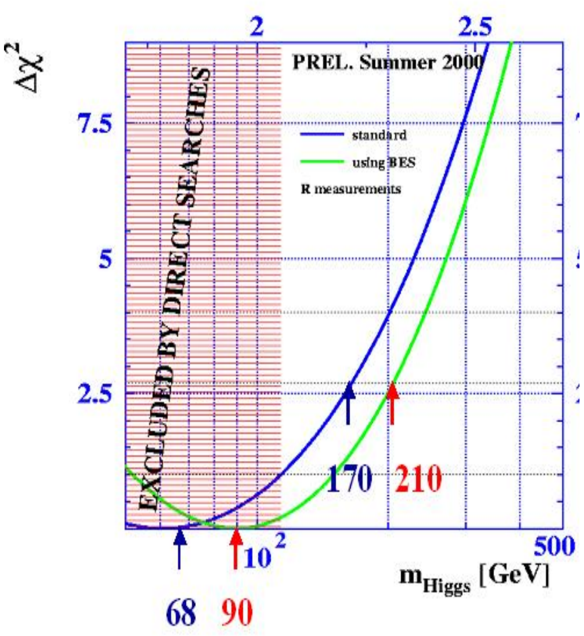
Impact on α (M_z^2) and Higgs mass

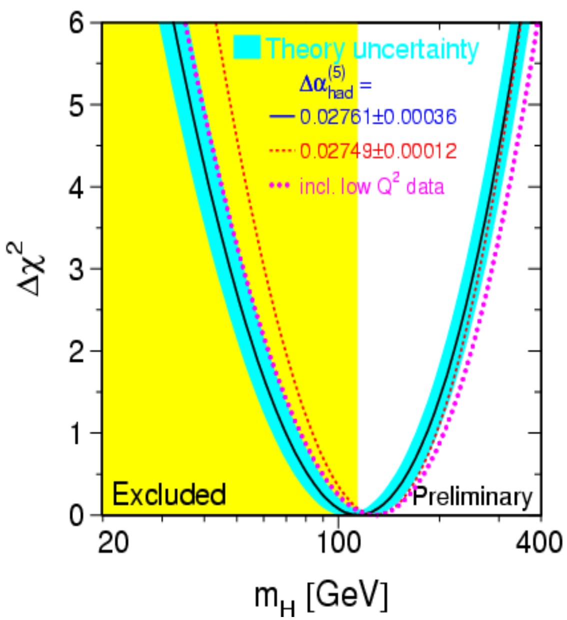
1995 before BES R data

$\alpha(M_Z^2)^{-1} = 128.890 \pm 0.090$ $m_H = 62^{+53}_{-30}\,GeV,\ m_H < 170\ GeV$

2001 with BES R data

$\alpha(M_Z^2)^{-1} = 128.936 \pm 0.046$ $m_H = 98^{+58}_{-38}\,GeV,\ m_H < 212\ GeV$





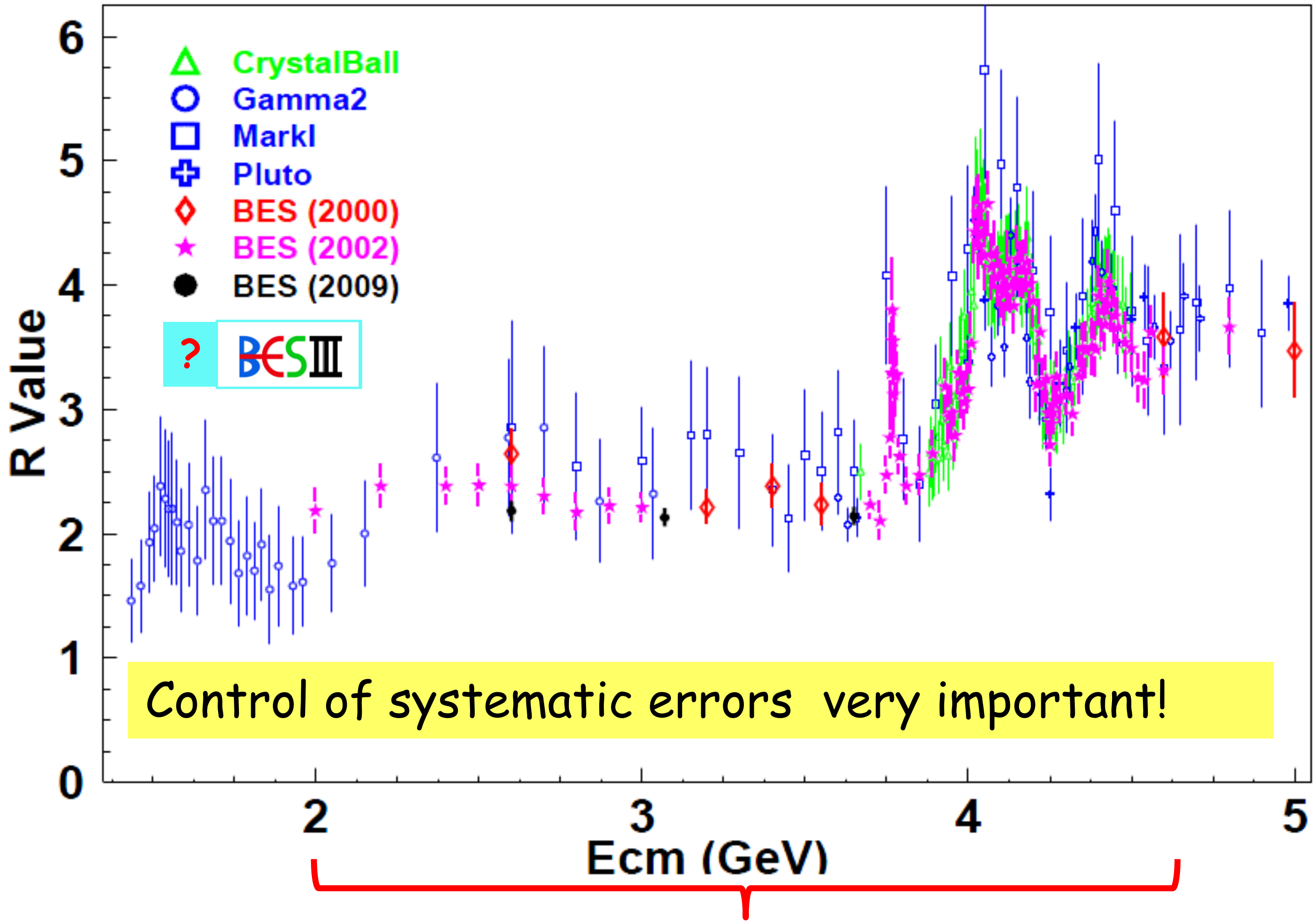
In 2004 with new top mass

$m_H = 114^{+69}_{-45}\,GeV$

$m_H < 260\,GeV$

Nucl.Phys.Proc.Suppl. 131 (2004) 97

R value measurement at BESIII

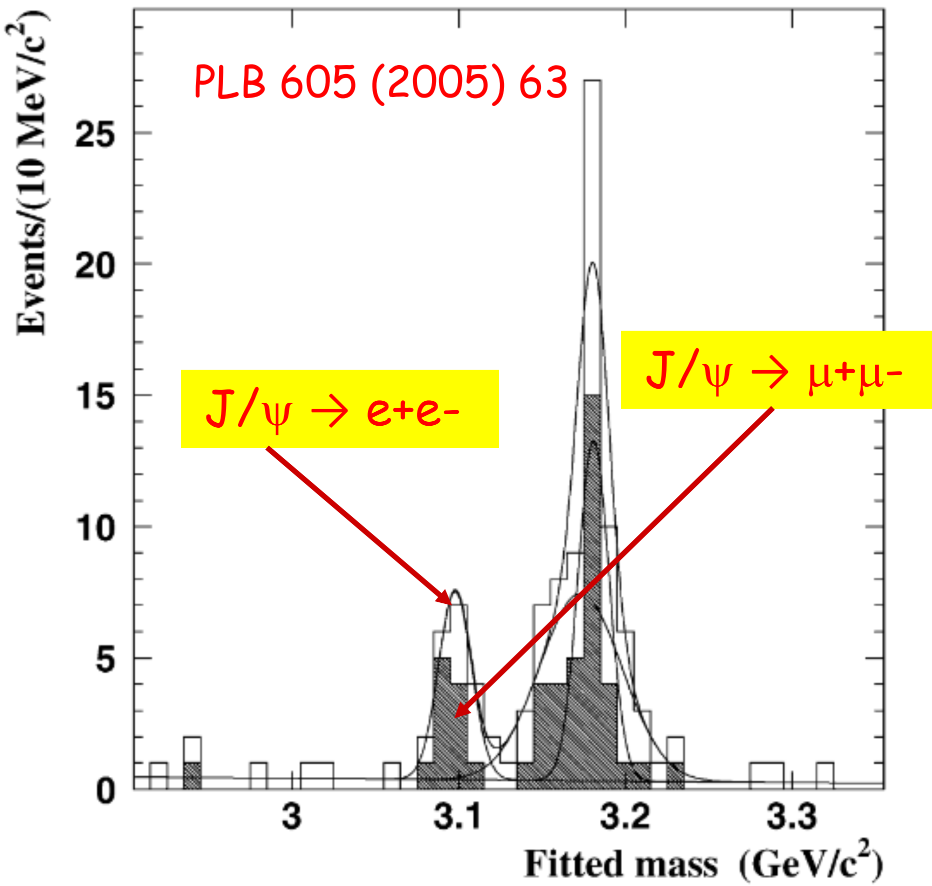


2014-2015: ~1.5fb^{-1} (130 points) for R &QCD

Charm physics

Observation of non-D $\bar{D}$ decays of ψ(3770)

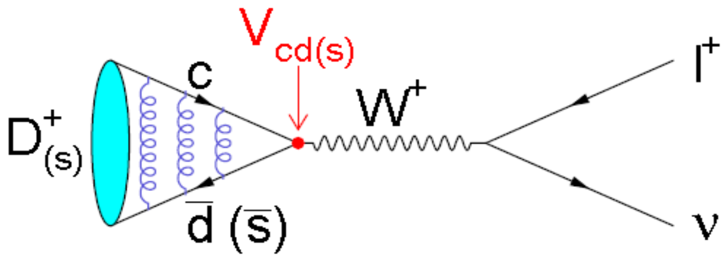
$\psi(3770) \to \pi^+\pi^- J/\psi$



B(ψ(3770) → π+π-J/ψ) = (0.34±0.14±0.09)%

- **2010: State Natural Science Award**

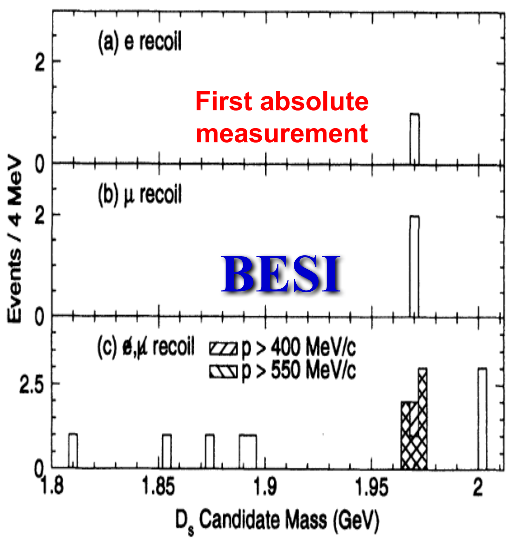
$D_{(s)}^+ \to l^+ \nu$ at BESI/II



$$\Gamma(D_{(s)}^+ \to \ell^+ \nu_\ell) = \frac{G_F^2 f_{D_{(s)}^+}^2}{8\pi} |V_{cd(s)}|^2 m_\ell^2 m_{D_{(s)}^+} \left(1 - \frac{m_\ell^2}{m_{D_{(s)}^+}^2}\right)^2$$

22.3 pb^{-1} at 4.03 GeV

3 $D_s^+ \to \mu^+ \nu$

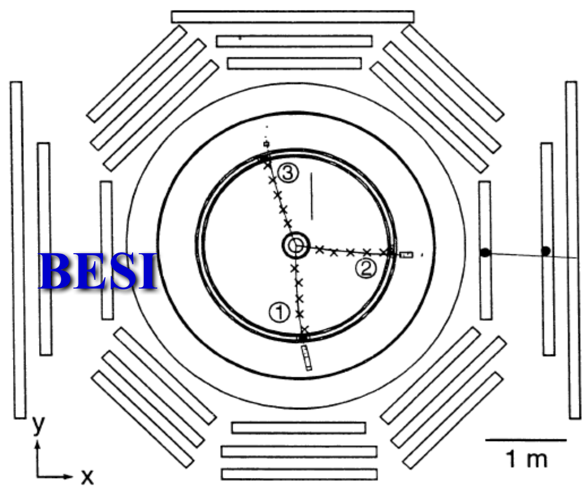


PRL74(1995)4599

$f_{D_s^+} = (430^{+150+40}_{-130-40})$ MeV

22.3 pb^{-1} at 4.03 GeV

1 $D^+ \to \mu^+ \nu$

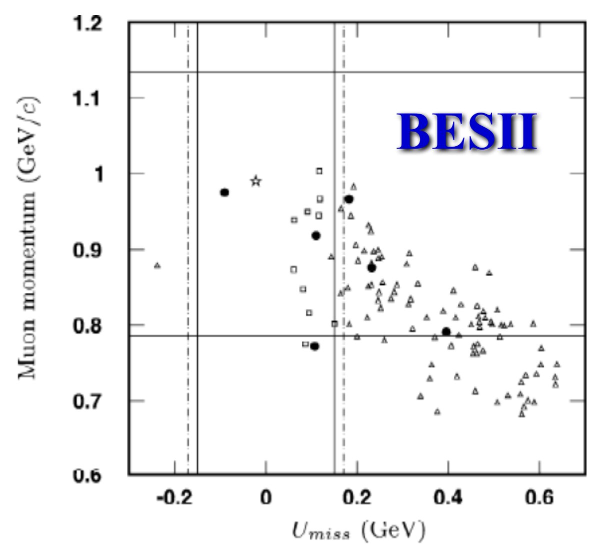


PLB429(1998)188

$f_{D^+} = (300^{+180+80}_{-150-40})$ MeV

33 pb^{-1} around ψ(3770)

3 $D^+ \to \mu^+ \nu$

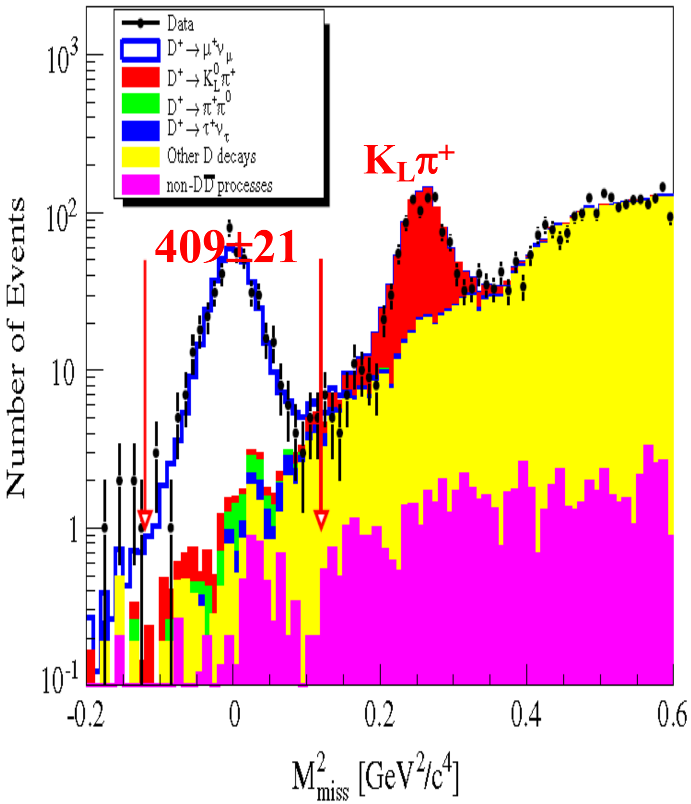


PLB610(2005)183

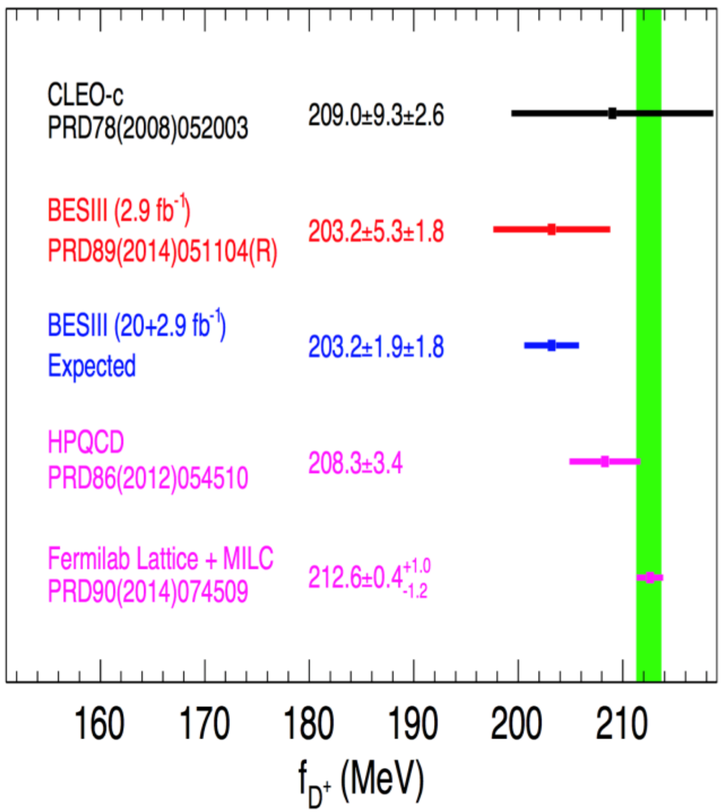
$f_{D^+} = (371^{+129}_{-119} \pm 25)$ MeV

$D^+ \to l^+ \nu$ at BESIII

2.93 fb^{-1} data@ 3.773 GeV



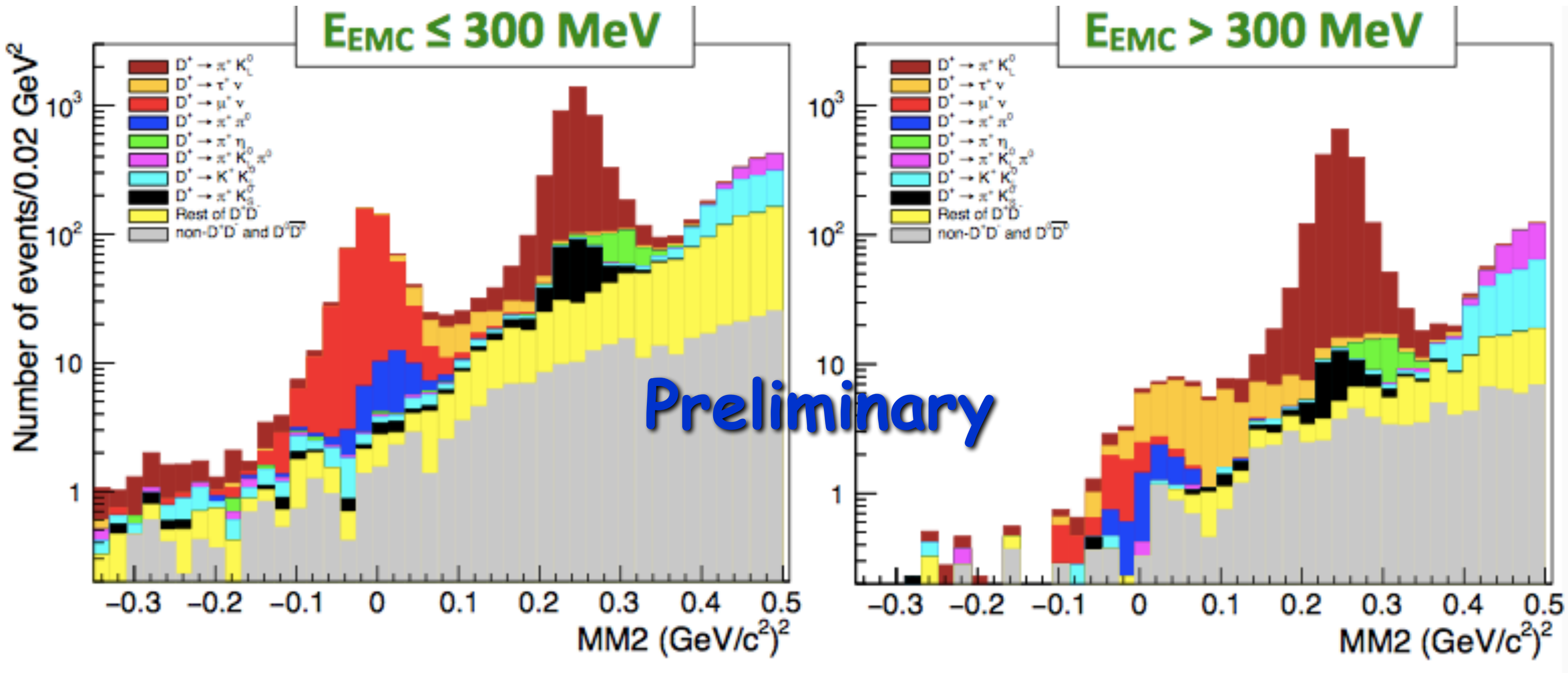
PRD89(2014)051104R



f_{D+}=(203.2±5.3±1.8) MeV

$|V_{cd}|$=0.2210±0.0058±0.0047

$D^+ \to l^+ \nu$ at BESIII



- The signal component (orange) includes $D^+ \to \tau^+(\to \pi^+ \bar{\nu}_\tau)\nu_\tau$ and $D^+ \to \tau^+(\to \text{the rest})\nu_\tau$

4σ

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

$$R \equiv \frac{\Gamma(D^+ \to \tau^+\nu)}{\Gamma(D^+ \to \mu^+\nu)} = \frac{m^2_{\tau^+}\left(1 - \frac{m^2_{\tau^+}}{M^2_{D^+}}\right)^2}{m^2_{\mu^+}\left(1 - \frac{m^2_{\mu^+}}{M^2_{D^+}}\right)^2}$$

SM prediction: 2.66

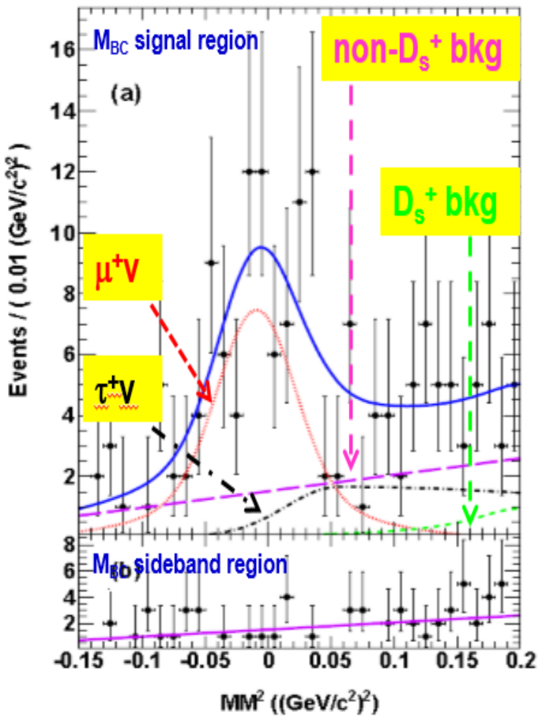
BESIII: 3.21±0.64

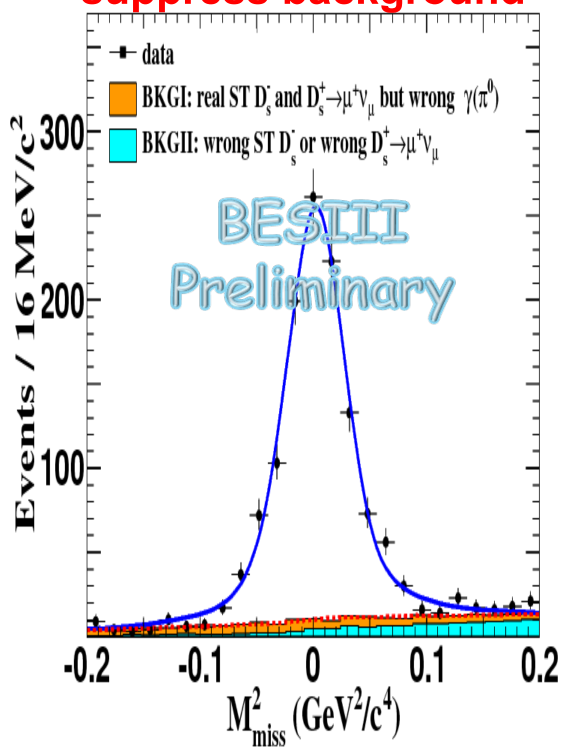
Ds⁺→l⁺v at BESIII

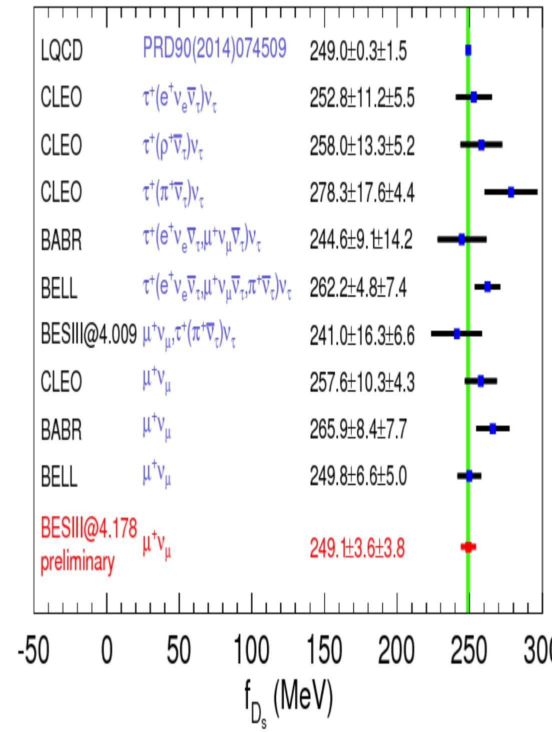
0.48 fb⁻¹ data@4.01 GeV **3.19 fb⁻¹ data@4.178 GeV**

PRD94(2016)072004

Use μ counter to suppress background





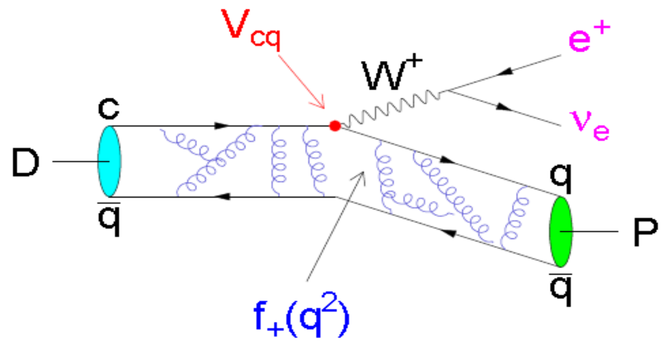


f_{Ds+}=(241.0±16.3±6.6) MeV

$f_{Ds}|V_{cs}|$=242.5±3.5±3.7 MeV

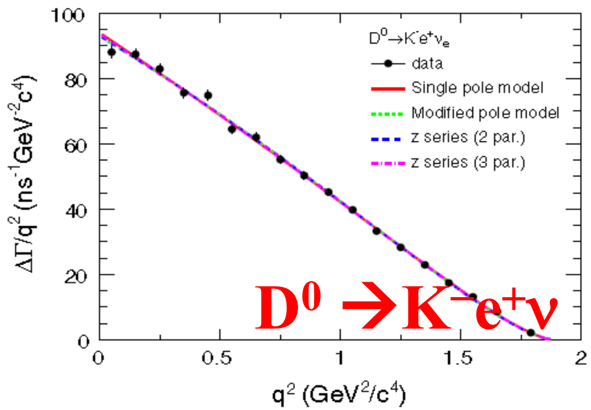
BESIII f_{Ds+}:~2%， reaches 1.5% after combining τ⁺v

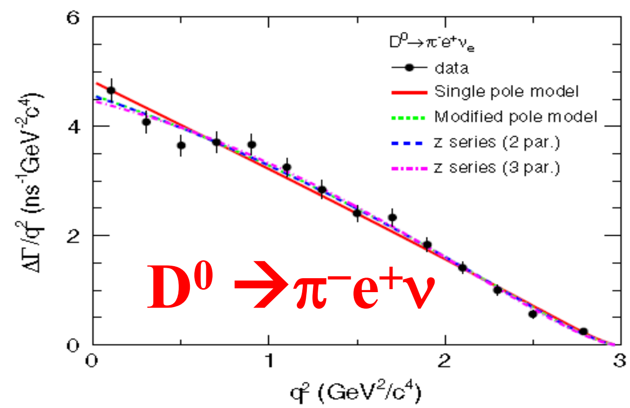
Test $f^{D\to K(p)}_+(q^2)$

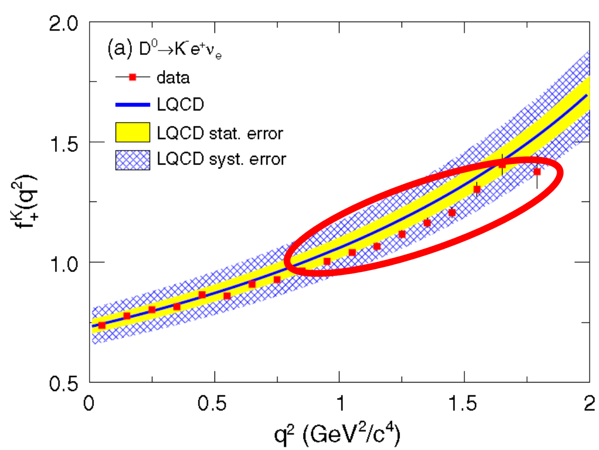


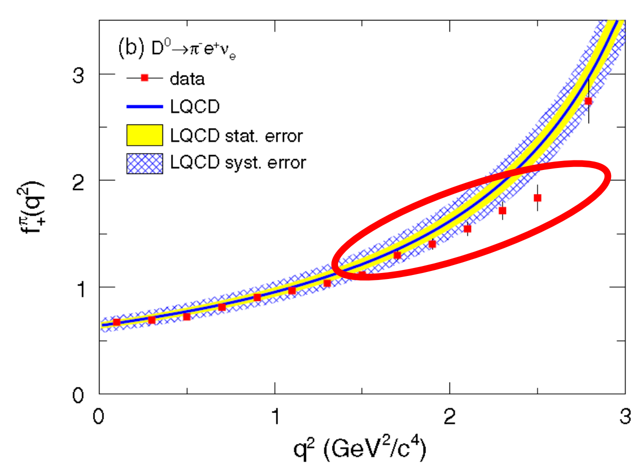
$$\frac{d\Gamma}{dq^2} = X \frac{G_F^2 |V_{cd(s)}|^2}{24\pi^3} p^3 |f_+(q^2)|^2$$

PRD92(2015)072012

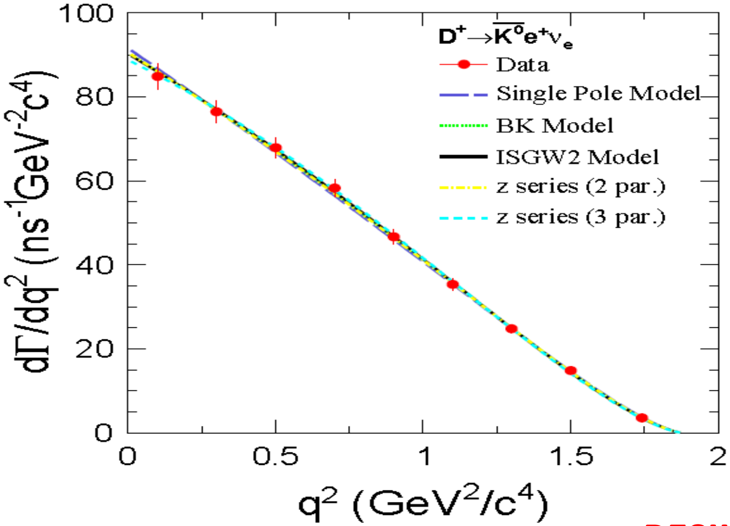


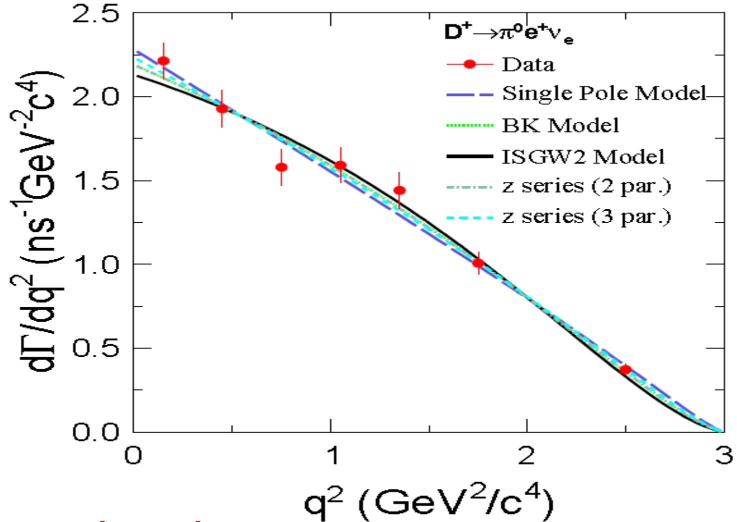




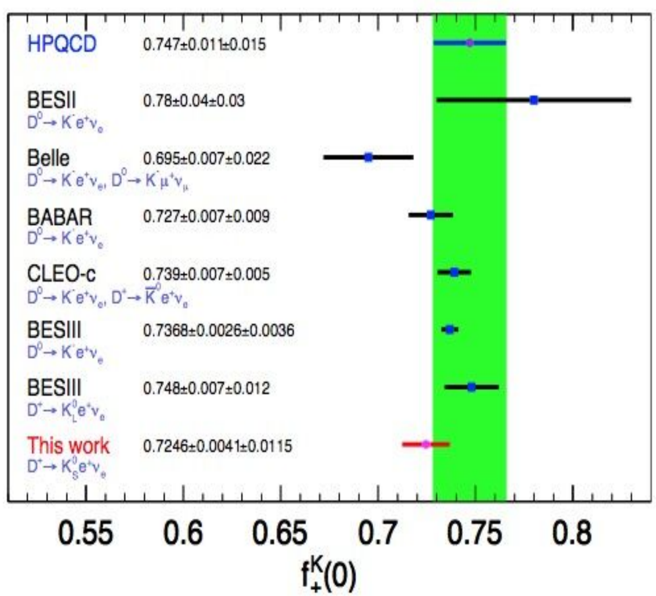


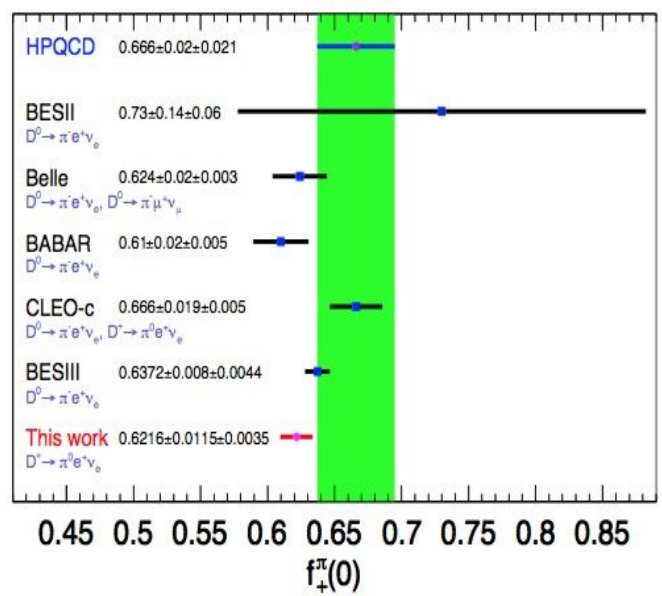
Comparisons of $f^{D\to K(\pi)}_+(0)$





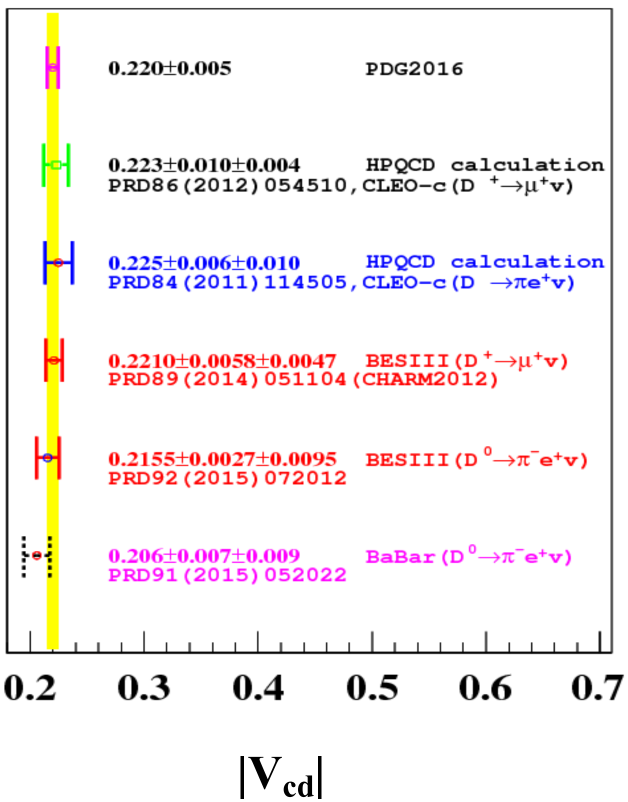
BESIII, PRD96(2017)012002

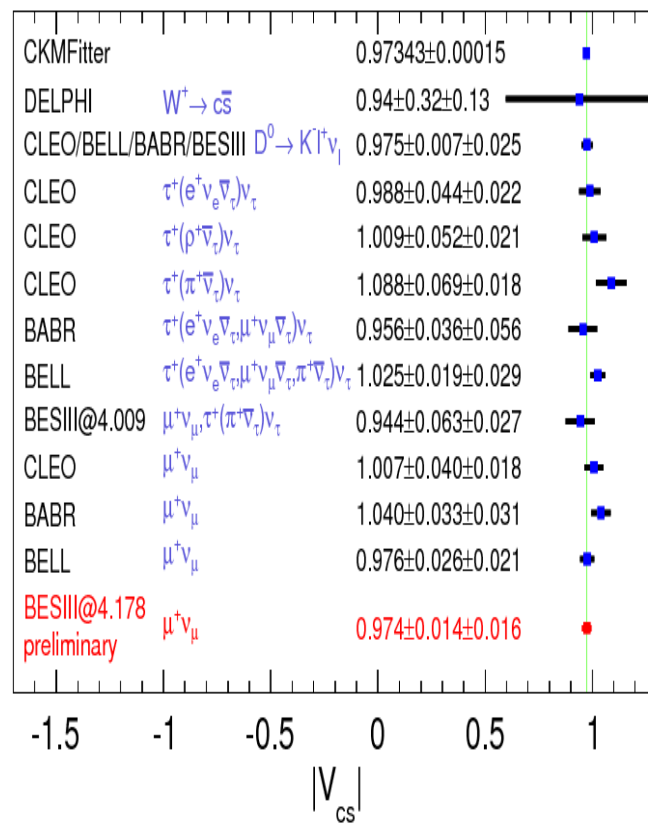




Comparisons of $|V_{cs(d)}|$

- **Leptonic decays** $f_{D(s)+}|V_{cd(s)}|$ → $|V_{cd(s)}|$
- **Semilepton decays** $f^{D\to K(\pi)}_{+}(0)|V_{cs(d)}|$ → $|V_{cs(d)}|$

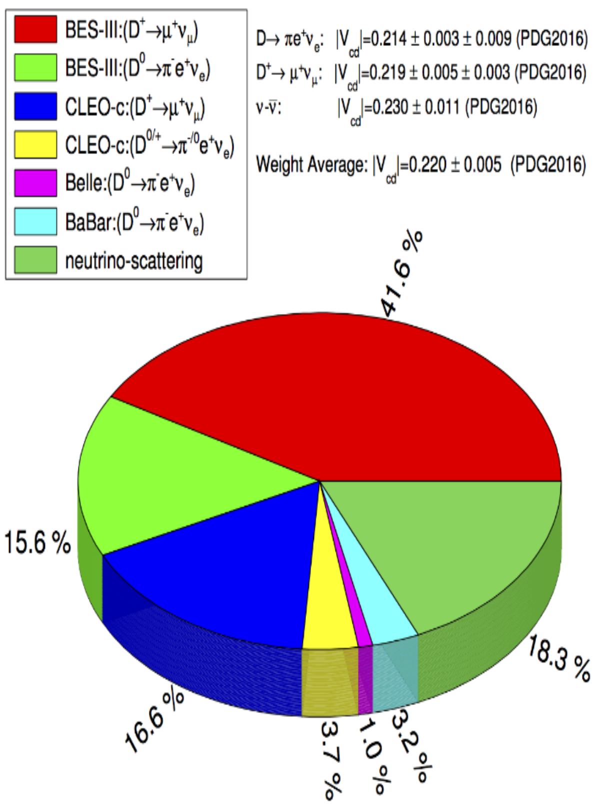


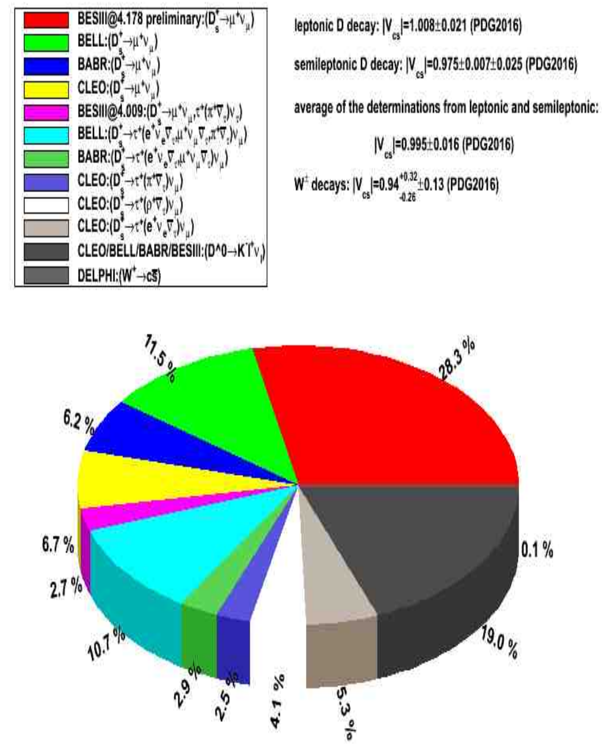


Taken from PDG, and the SL method suffers about 2.4% error from LQCD

$f_+^{D\to K(\pi)}(0)$: precision depends on LQCD [2.4(4.4)%]

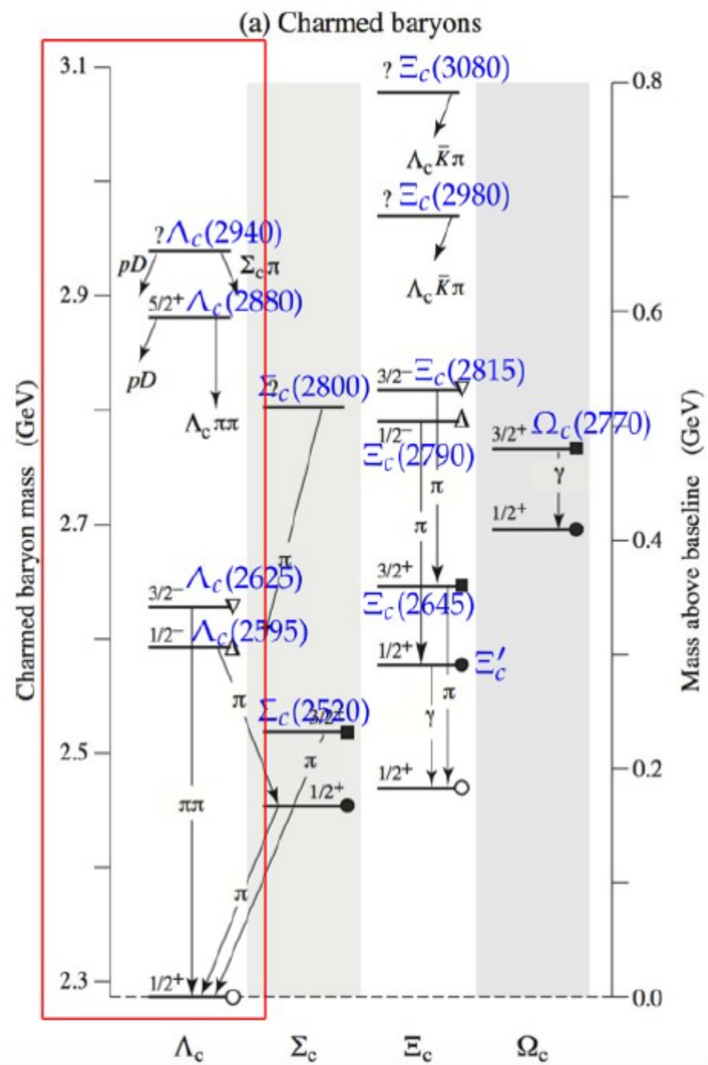
BESIII's contribution to $|V_{cs(d)}|$





After combining $D_s^+\to\tau^+\nu$ $|V_{cs}|$, the weight of BESIII will be greater than 50%

Charm baryons before 2014



- Λ_c^+ was observed in 1979

- All decays of Λ_c^+ were measured with high energy data and relative to pK^-p^+, which suffers an error of 25%. No absolute measurement using threshold Λ_c^+ data

- Only about 60% decays are known

Λ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes with a p: $S = -1$ final states				
$p\overline{K}^0$		(2.3 ± 0.6) %		873
$pK^-\pi^+$	[a]	(5.0 ± 1.3) %		823
$p\overline{K}^*(892)^0$	[b]	(1.6 ± 0.5) %		685
$\Delta(1232)^{++}K^-$		(8.6 ± 3.0) $\times 10^{-3}$		710
$\Lambda(1520)\pi^+$	[b]	(1.8 ± 0.6) %		627
$pK^-\pi^+$ nonresonant		(2.8 ± 0.8) %		823
$p\overline{K}^0\pi^0$		(3.3 ± 1.0) %		823
$p\overline{K}^0\eta$		(1.2 ± 0.4) %		568

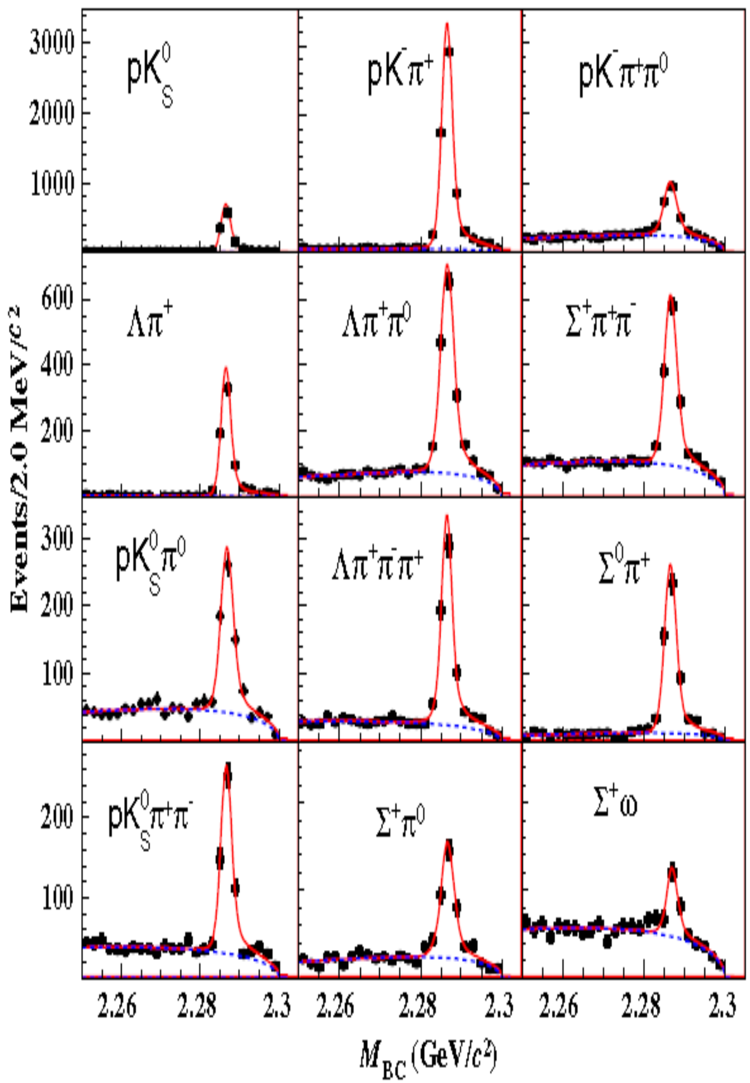
Systematic studies of Λ_c^+, search for new decays, absolute BF measurements are important to explore Λ_c^+ decay mechanisms

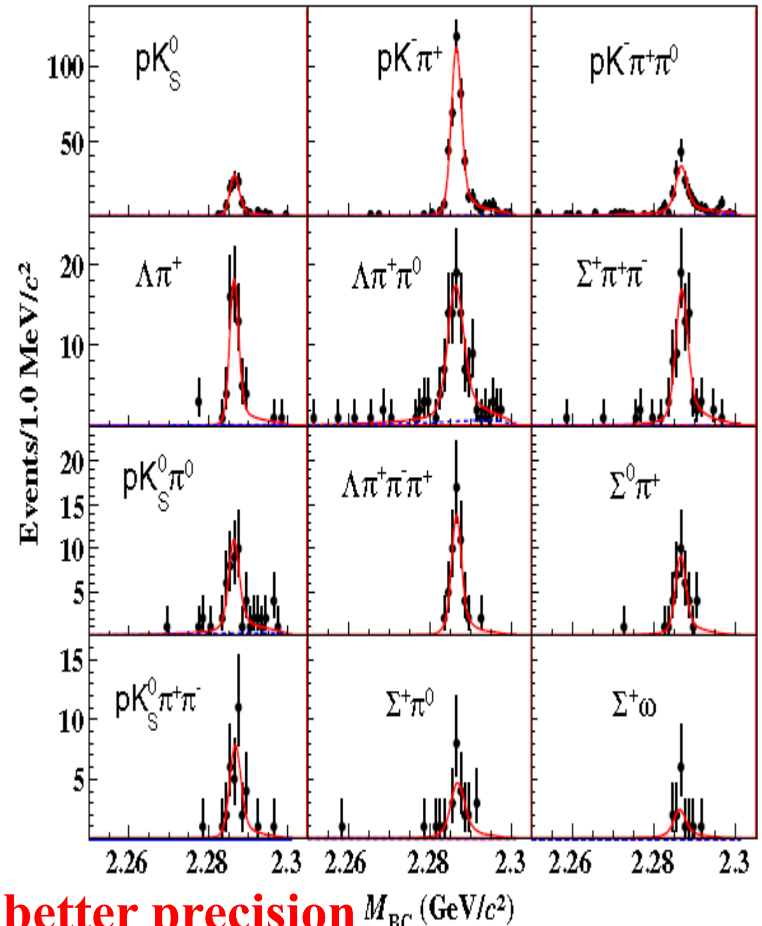
Λ_c^+ hadronic decays

BESIII, PRL116(2016)052001

ST: ~15000

DT: ~1000

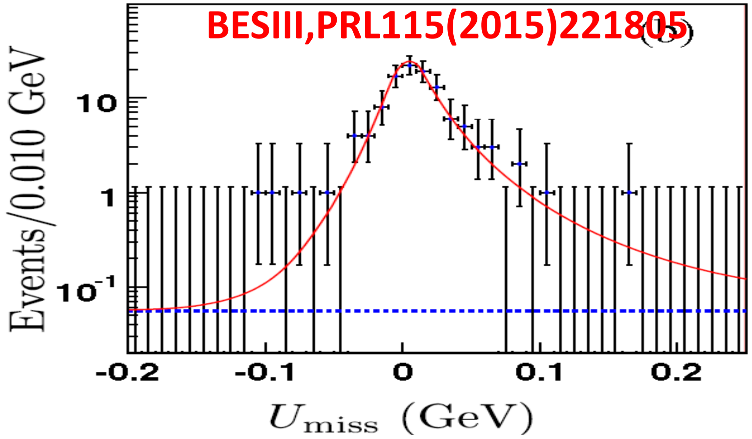




Much better precision

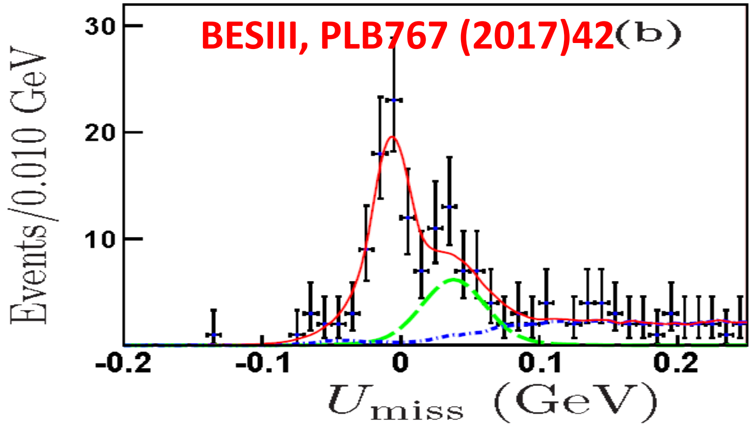
Mode	This work (%)	PDG (%)
pK_S^0	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50
$pK_S^0\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0
$\Lambda\pi^+$	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28
$\Lambda\pi^+\pi^0$	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3
$\Lambda\pi^+\pi^-\pi^+$	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7
$\Sigma^0\pi^+$	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28
$\Sigma^+\pi^0$	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34
$\Sigma^+\pi^+\pi^-$	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0
$\Sigma^+\omega$	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0

First measurement of $\Lambda_c^+ \to \Lambda l^+ \nu$



$B[\Lambda_c^+ \to \Lambda e^+ \nu] = (3.63 \pm 0.38 \pm 0.20)\%$

3 fb^{-1} data help to explore FF studies

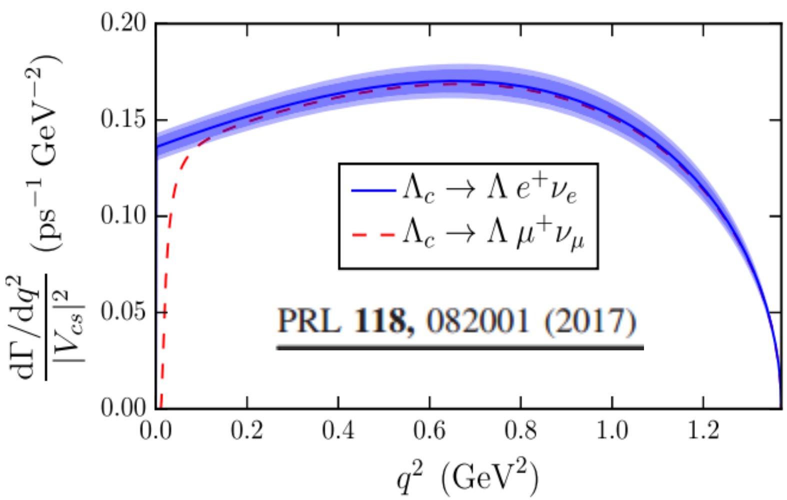


$B[\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu] = (3.49 \pm 0.46 \pm 0.26)\%$

$\Gamma[\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu]/\Gamma[\Lambda_c^+ \to \Lambda e^+ \nu_e] = 0.96 \pm 0.16 \pm 0.04$

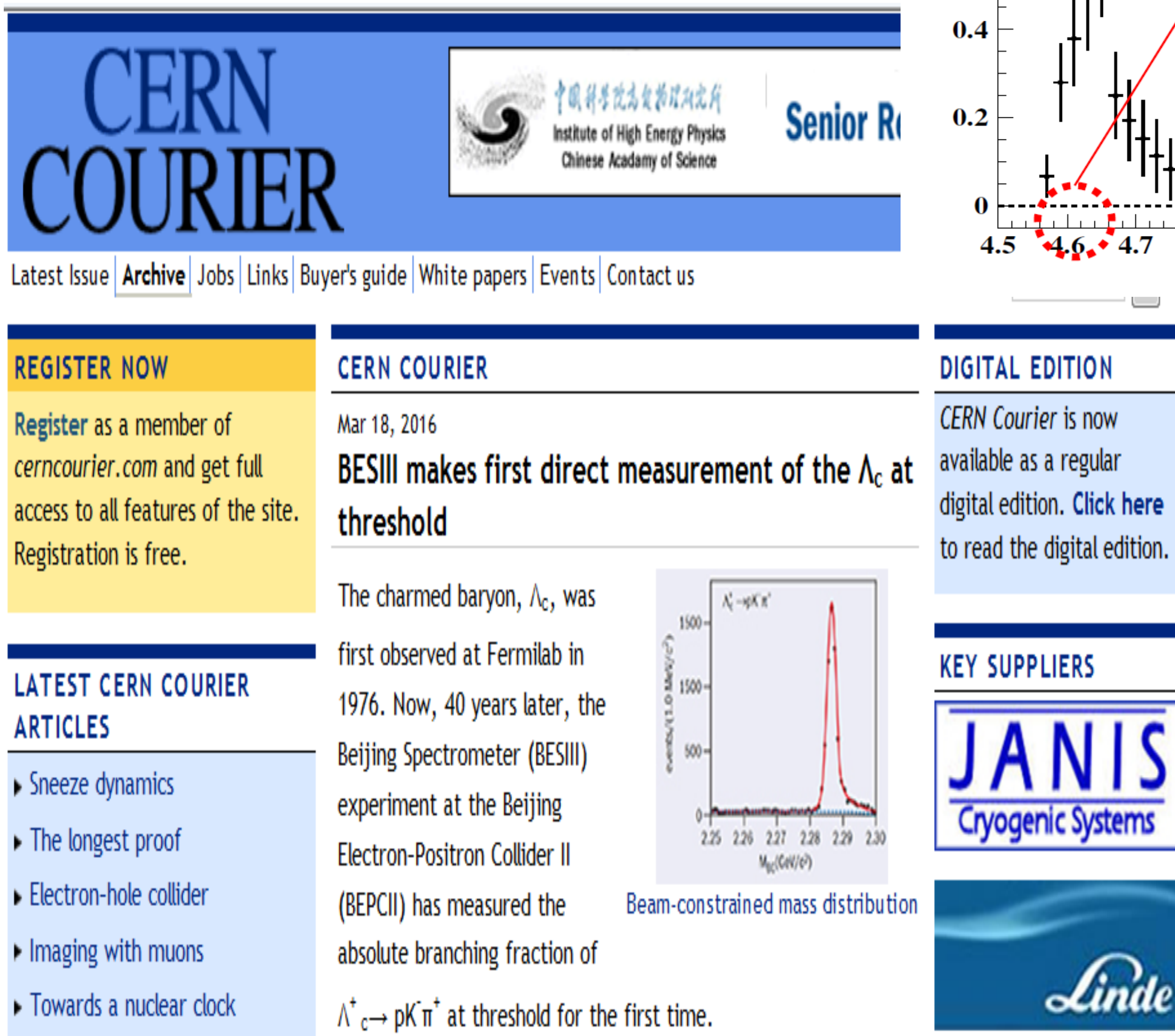
Calibrate theoretical calculations: (1.4-9.2)%

Theoretical Models	predicated branching fraction for $\Lambda_c^+ \to \Lambda e^+ \nu_e$
MBM [1]	1.9%
NRQM [1]	2.6%
SU(4)-symmetry limit [2]	9.2%
RSQM [3]	4.4%
QCM [4]	5.62%
SQM [5]	1.96%
NRQM2 [6]	2.15%
NRQM3 [7]	1.42%
QCD SR1 [8]	$(3.0 \pm 0.9)\%$
QCD SR2 [9]	$(2.6 \pm 0.4)\%$
QCD SR3 [9]	$(5.8 \pm 1.5)\%$
STSR [10]	2.22% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
STNR [10]	1.58% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
HOSR [10]	4.72% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
HONR [10]	4.2% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
LCSRs [11]	$(3.0 \pm 0.3)\%$ for $\Lambda_c^+ \to \Lambda l^+ \nu_l$ (CZ-type)
PDG 2014 [14]	$(2.1 \pm 0.6)\%$
BESIII	$(3.63 \pm 0.38 \pm 0.20)\%$



Larger threshold Λ_c^+ data at BESIII

BESIII open a new window to study Λ_c^+ decays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Mar 18, 2016

BESIII makes first direct measurement of the Λ_c at threshold

The charmed baryon, Λ_c, was first observed at Fermilab in 1976. Now, 40 years later, the Beijing Spectrometer (BESIII) experiment at the Beijing Electron-Positron Collider II (BEPCII) has measured the absolute branching fraction of $\Lambda^+_c \to pK^-\pi^+$ at threshold for the first time.

Beam-constrained mass distribution

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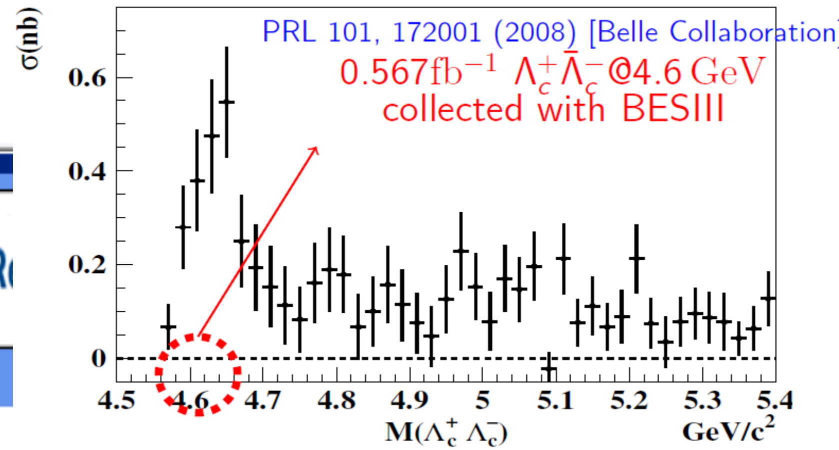
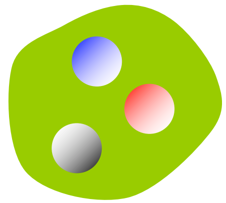


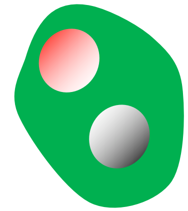
Exotic hadrons

Conventional & Exotic hadrons

- Quark Model

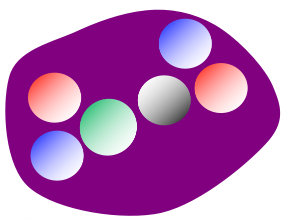


baryon

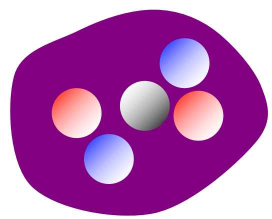


meson

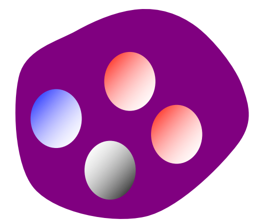
- QCD allows for hadrons beyond Quark Model



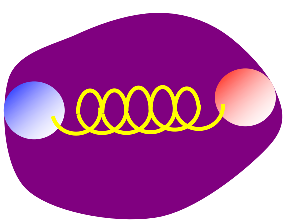
dibaryon



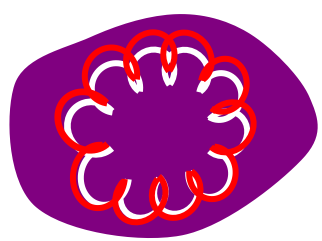
Pentaquark



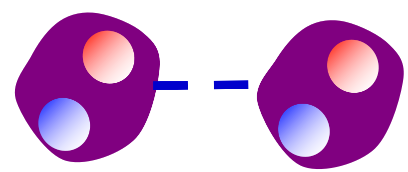
tetraquark



hybrid

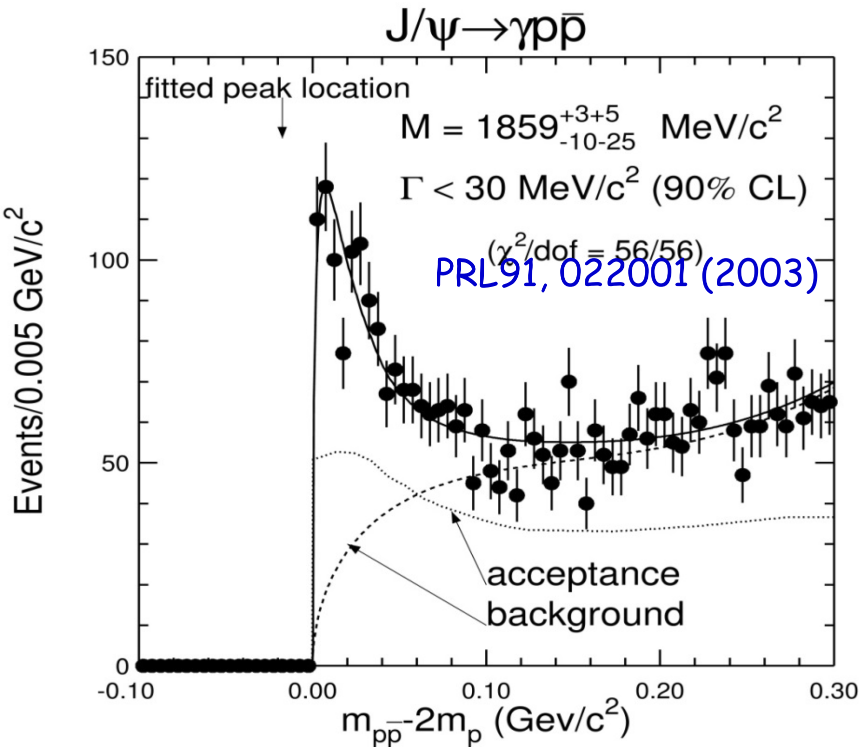


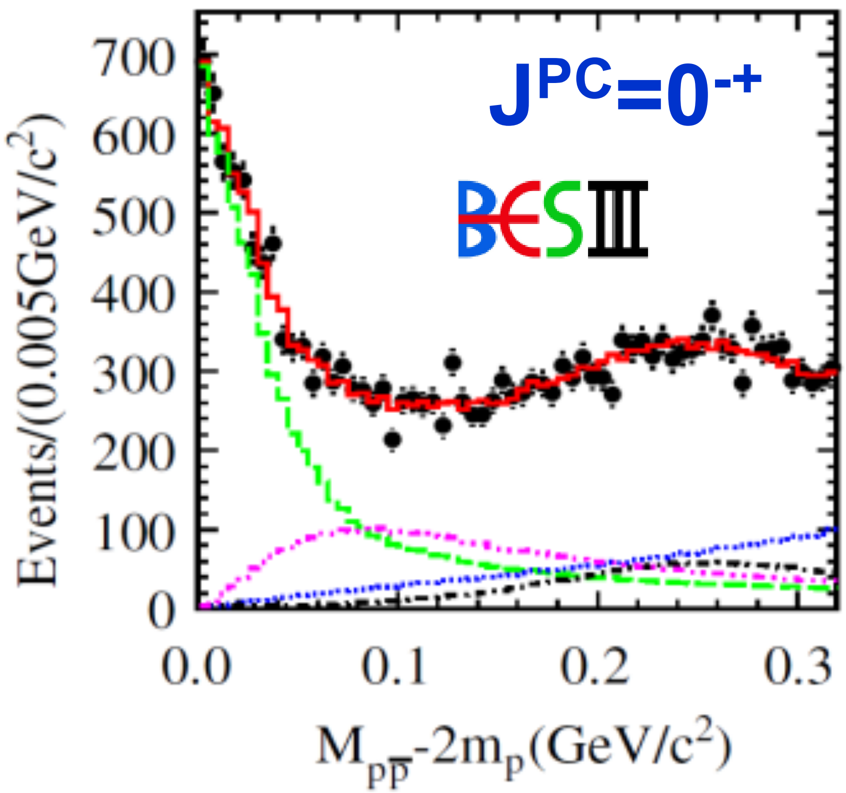
glueball



molecule

Threshold enhancement in $J/\psi \to \gamma p \bar{p}$



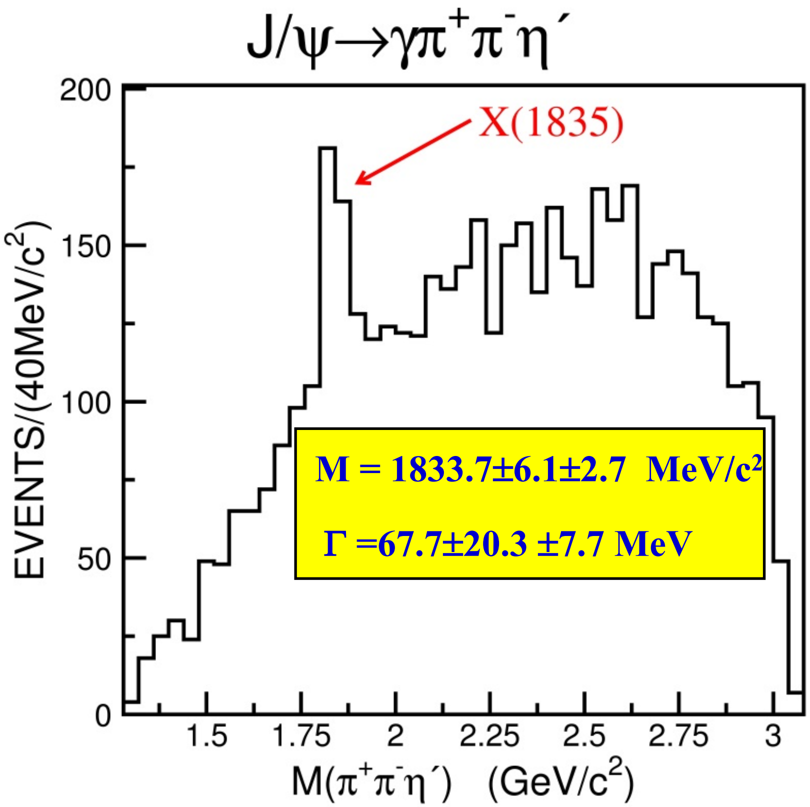


$$M = 1859^{+3}_{-10}{}^{+5}_{-25}\ \mathrm{MeV}/c^2$$

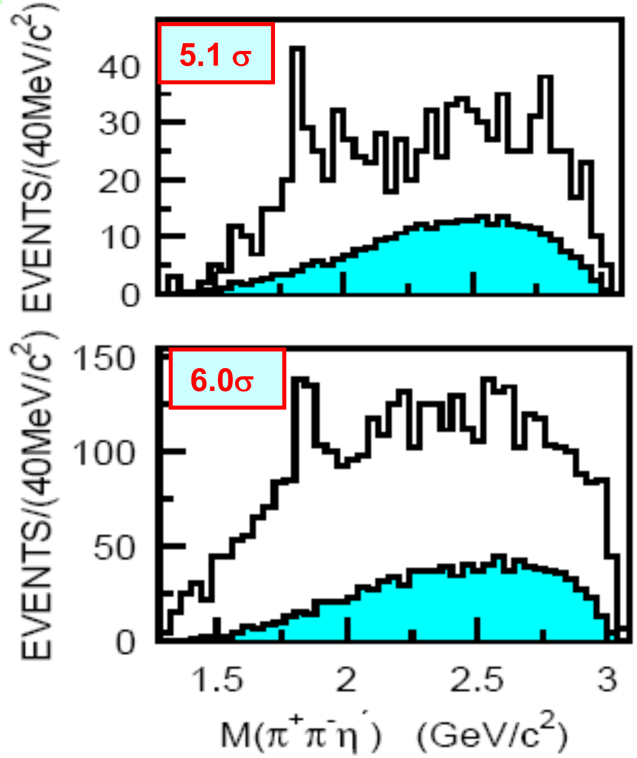
$$\Gamma < 30\ \mathrm{MeV}/c^2\ (90\%\ \mathrm{CL})$$

Baryonium ?? New decay modes ?

Observation of X(1835) at BESII



The $\pi^+\pi^-\eta'$ mass spectrum for η' decaying into $\eta'\to\pi^+\pi^-\eta$ and $\eta'\to\gamma\rho$



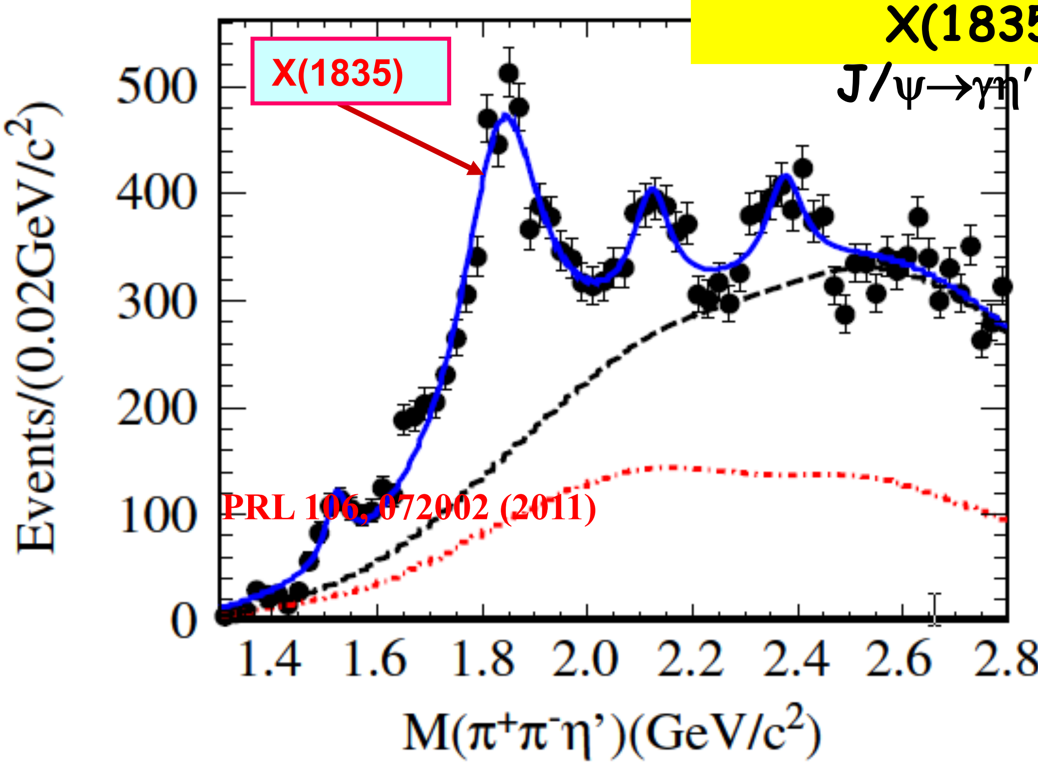
X(1835) same as $p\,\bar{p}$ mass threshold enhancement?

- **2004: State Natural Science Award**

PRL95, 262001 (2005)

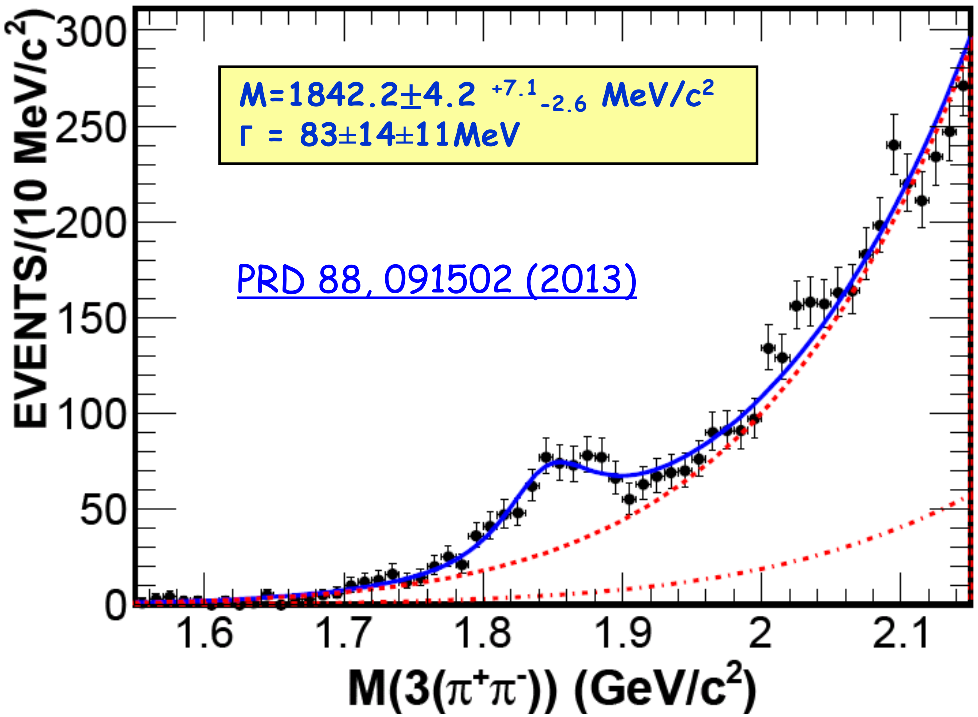
Confirmation of X(1835) at BESIII

X(1835) in $J/\psi \rightarrow \gamma\eta'$



Resonance	M(MeV/c²)	Γ(MeV/c²)	Stat.Sig.
X(1835)	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190.1 \pm 9.0^{+38}_{-36}$	>20σ
X(2120)	$2122.4 \pm 6.7^{+4.7}_{-2.7}$	$83 \pm 16^{+31}_{-11}$	7.2σ
X(2370)	$2376.3 \pm 8.7^{+3.2}_{-4.3}$	$83 \pm 17^{+44}_{-6}$	6.4σ

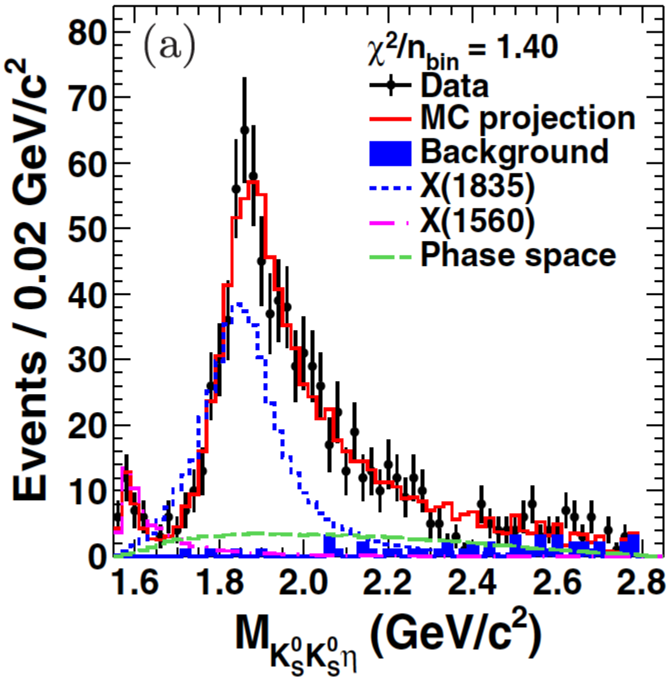
Observation of X(1840) in $J/\psi \to \gamma 3(\pi^+\pi^-)$



- Mass is consistent with that of X(1835), but the width is much smaller than $\Gamma_{X(1835)} = 190.1 \pm 9.0^{+38}_{-36}$ MeV
- A new decay modes of X(1835)?

Observation of X(1835) in $J/\psi \to \gamma K_S K_S \eta$

Phys.Rev.Lett. 115 091803(2015)



PWA for $M(K_S K_S)$<1.1 GeV/c²

- **X(1835)→$K_S K_S \eta$**

$M=1844 \pm 9^{+16}_{-25}$ MeV/c²

$\Gamma=192^{+20}_{-17}{}^{+62}_{-43}$ MeV

$J^{PC}=0^{-+}$

- **X(1560) → $f_0(980)\eta$: $J^{PC}=0^{-+}$**

$M=1565 \pm 8^{+0}_{-63}$ MeV/c²

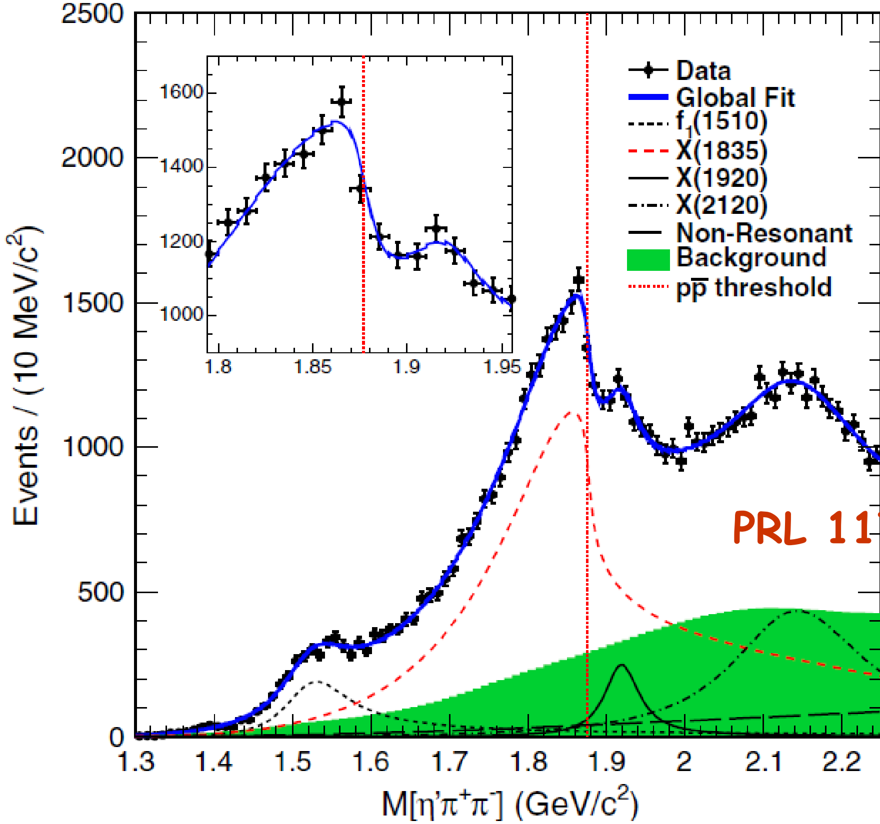
$\Gamma=45^{+14}_{-13}{}^{+21}_{-28}$ MeV

$\eta(1405)$ / $\eta(1475)$ within 2.0 σ

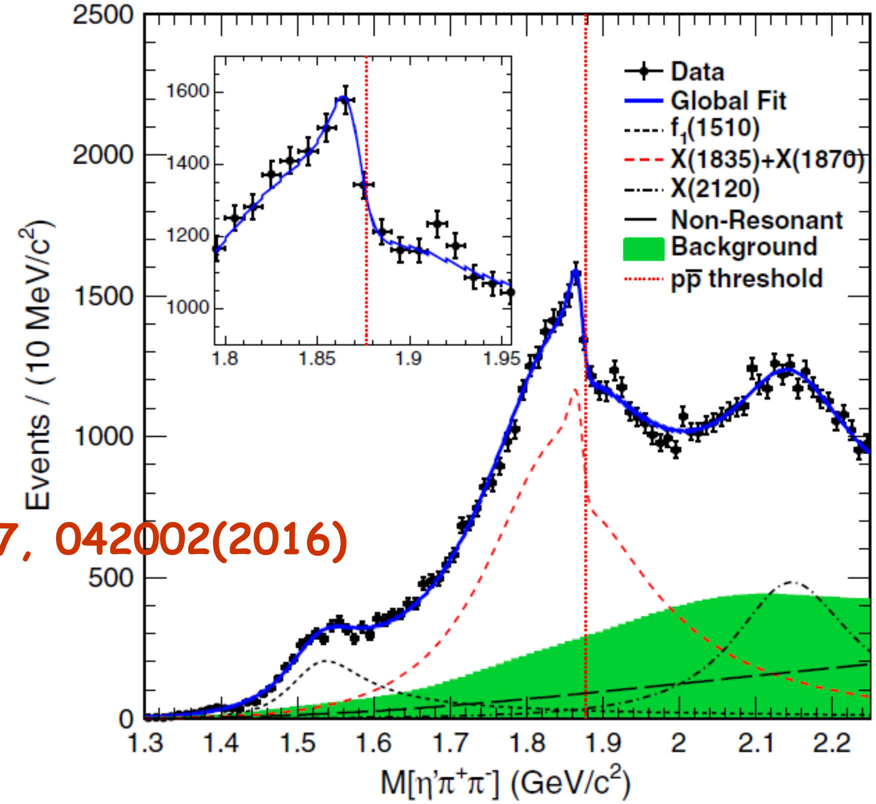
Consistent with X(1835) observed in $J/\psi \to \gamma\pi^+\pi^-\eta'$!

Latest result on X(1835) from $J/\psi \to \gamma\eta'\pi^+\pi^-$

Faltte formula



Two BWs



PRL 117, 042002(2016)

$M=1638.2\pm121.9\ ^{+127.8}_{-254.3}$ MeV/c^2
$g^2_0 = 93.7\pm35.4\ ^{+47.6}_{-43.9}$ GeV/c^2
$g^2_{p\bar{p}}/g^2_0 = 2.31\pm0.37\ ^{+0.83}_{-0.60}$

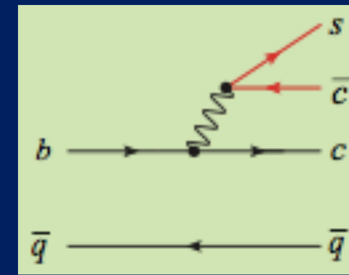
$M_1=1825.3\pm2.4\ ^{+17.2}_{-2.4}$ MeV/c^2
$\Gamma_1 = 245.2\pm13.1\ ^{+4.6}_{-9.6}$ MeV

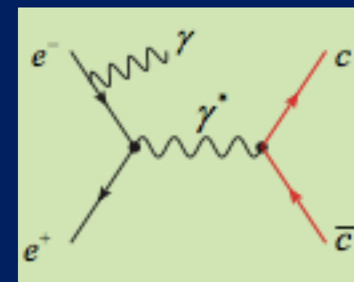
$M_2=1870.2\pm2.2\ ^{+2.3}_{-0.7}$ MeV/c^2
$\Gamma_2 = 13.0\pm6.1\ ^{+2.1}_{-3.8}$ MeV

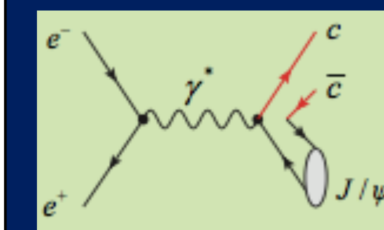
existence of a structure strongly coupling to $p\bar{p}$!

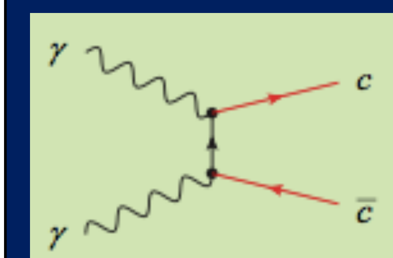
2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017

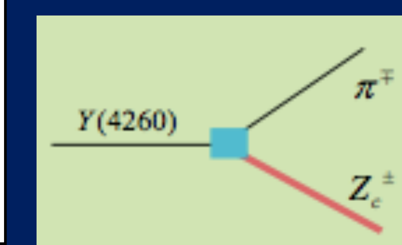
	Observed	Confirmed
X(3872)	Belle	
X(3872)		CDF, D0
X(3915) [as Y(3940)]		Belle
Y(4260)		BaBar
$\chi_{c2}(2P)$ [as Z(3930)]	Belle	
Y(4260)		CLEO-c
X(3940), Y(4008), Y(4660)	Belle	
Y(4360)	BaBar	
Y(4360)		Belle
X(3915) [as Y(3940)]		BaBar
X(3940)		Belle
$Z^+(4050)$, X(4160), $Z^+(4250)$, $Z^+(4430)$, X(4630)	Belle	
Y(4140)		CDF
X(3915), X(4350), $Y_b(10888)$	Belle	
$\chi_{c2}(2P)$ [as Z(3930)]		BaBar
Y(4274)	CDF	
X(3915)		BaBar
$Z_b^+(10610)$		Belle
$Z_b^+(10650)$		Belle
X(3823), $Z_b^0(10610)$	Belle	
$Z_c^+(3900)$, $Z_c^+(4020)$	BESIII	
$Z_c^+(3900)$		Belle
$Z_c^0(3900)$	CLEO-c	
$Z_c^0(4020)$	BESIII	
Y(4140)		D0, CMS
Y(4274)		CMS
Y(4660)		BaBar
$Z_c^+(4020)$	BESIII	
$Z^+(4200)$		Belle
$Z^+(4240)$		LHCb
$Z^+(4430)$		LHCb
X(3823), $Z_c^0(3900)$, $Z_c^0(4020)$		BESIII
$Z_c^+(4055)$	Belle	
Y(4230)	BESIII	
$P_c^+(4380)$, $P_c^+(4450)$	LHCb	
$Y_b(10880)$		NOT Belle
$X^+(5568)$	D0	
$X^+(5568)$		NOT LHCb
Y(4140), Y(4274)		LHCb
X(4500), X(4700)	LHCb	







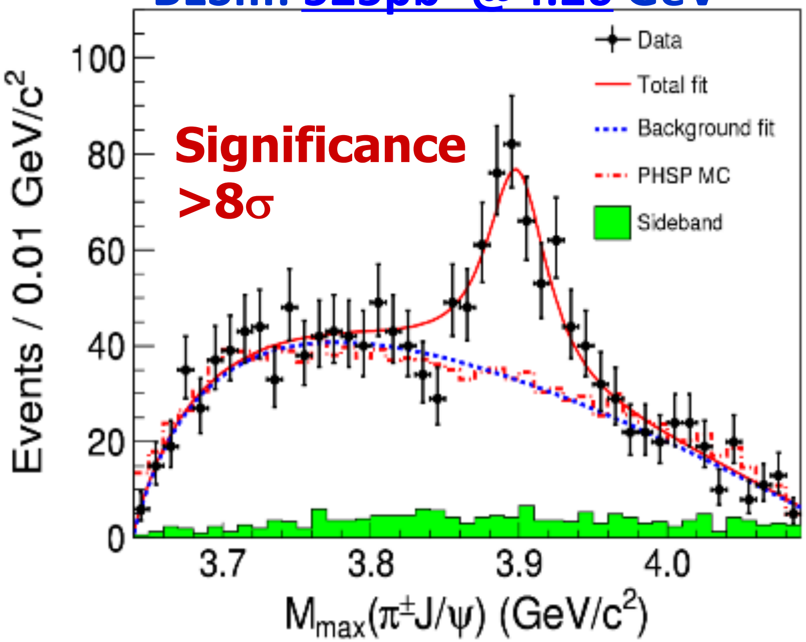




PPNP,143(2017), Phys.Rept.1(2016)

Observation of Zc(3900) in $e^+e^- \to \pi^+\pi^- J/\psi$

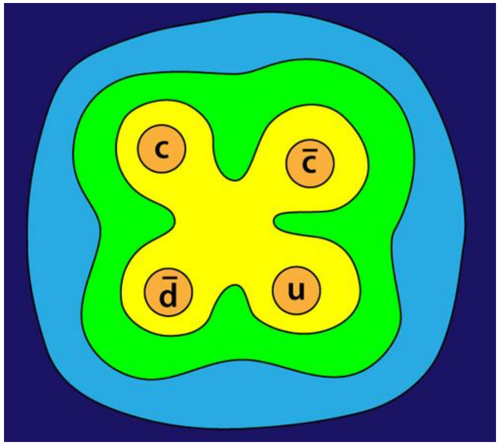
BESIII: 525pb^{-1}@4.26 GeV



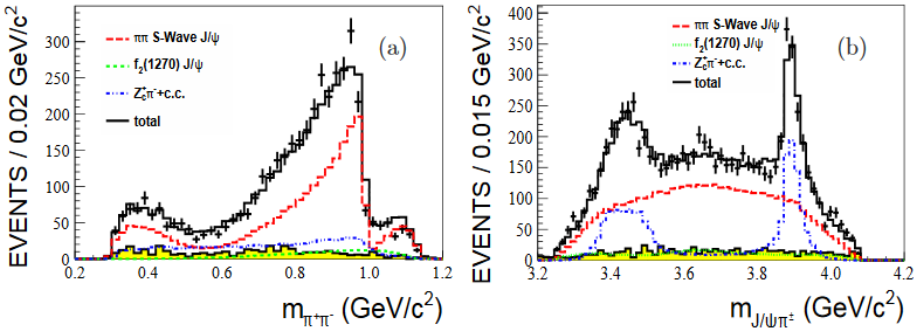
PRL110, 252001 (2013)

- $M = 3899.0 \pm 3.6 \pm 4.9$ MeV
- $\Gamma = 46 \pm 10 \pm 20$ MeV

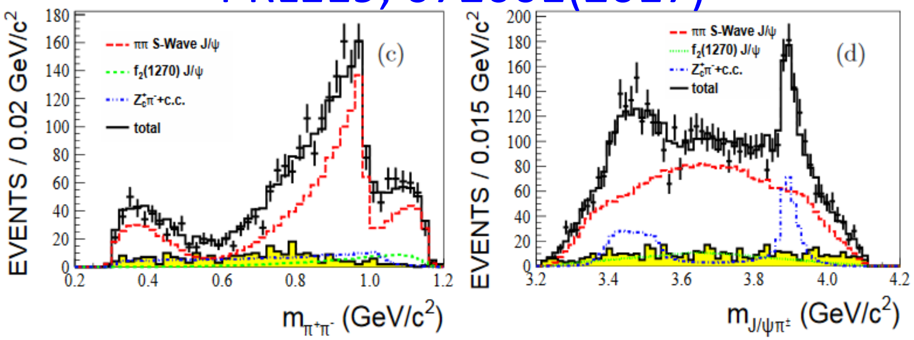
Confirmed by Belle and CLEOc: established!



PWA indicates $J^P=1^+$



PRL119, 072001(2017)



Physics
spotlighting exceptional research

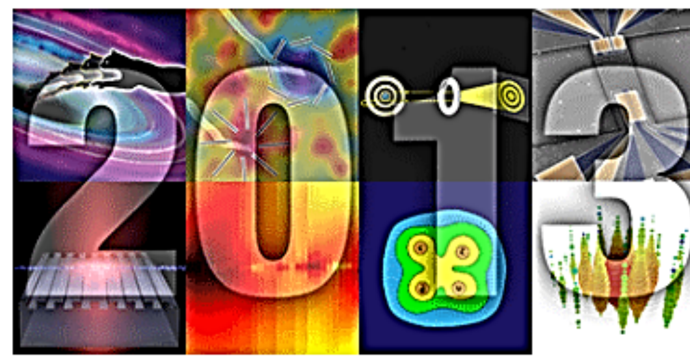
Notes from the Editors: Highlights of the Year

Published December 30, 2013 | Physics **6**, 139 (2013) | DOI: 10.1103/Physics.6.139

***Physics* looks back at the standout stories of 2013.**

As 2013 draws to a close, we look back on the research covered in *Physics* that really made waves in and beyond the physics community. In thinking about which stories to highlight, we considered a combination of factors: popularity on the website, a clear element of surprise or discovery, or signs that the work could lead to better technology. On behalf of the *Physics* staff, we wish everyone an excellent New Year.

– Matteo Rini and Jessica Thomas

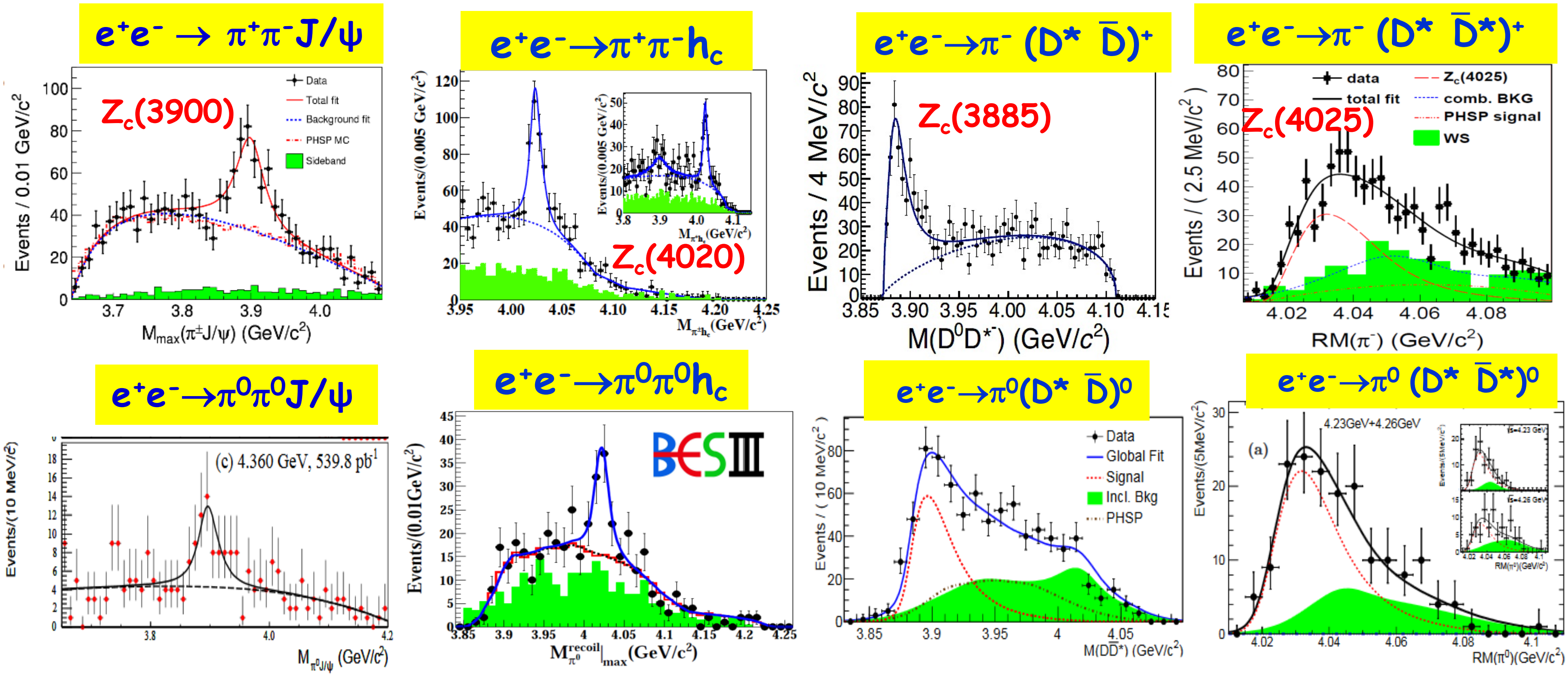


Images from popular *Physics* stories in 2013.

Four-Quark Matter

Quarks come in twos and threes—or so nearly every experiment has told us. This summer, the BESIII Collaboration in China and the Belle Collaboration in Japan reported they had sorted through the debris of high-energy electron-positron collisions and seen a mysterious particle that appeared to contain four quarks. Though other explanations for the nature of the particle, dubbed $Z_c(3900)$, are possible, the "tetraquark" interpretation may be gaining traction: BESIII has since seen a series of other particles that appear to contain four quarks.

Zc(3900), Zc(4020)

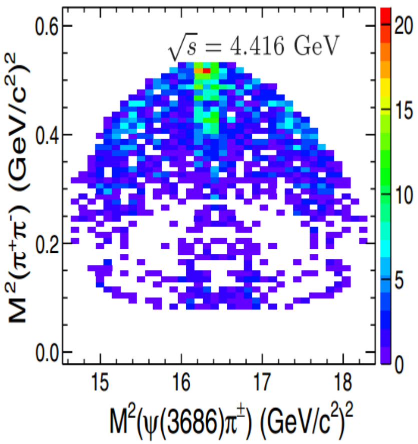


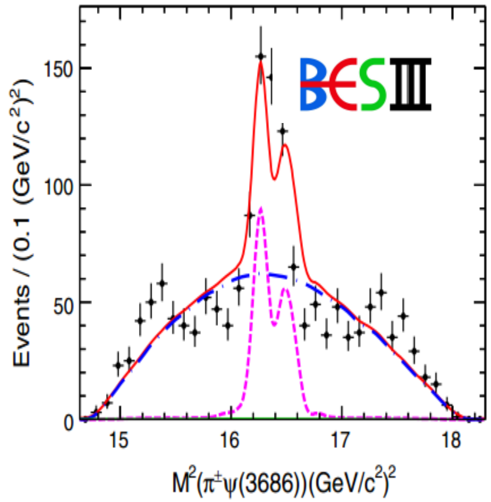
- Observed in different processes
- $Z_c(3900)$: J^P favors 1^+
- Strongly coupling $D\bar{D}^*$, $D^*\bar{D}^*$
- Molecule states ?
- **Two isospin triplets established !**

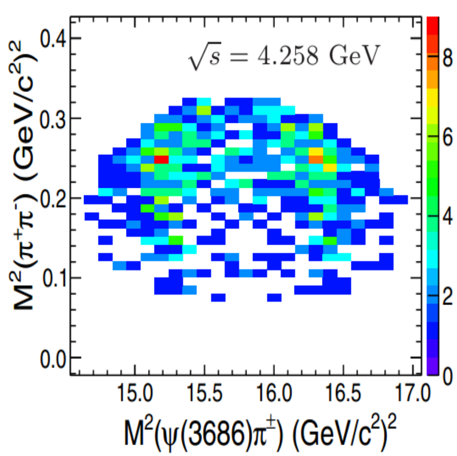
PRL110, 252001 (2013)
PRL115, 112003 (2015)
PRL111, 242001 (2013)
PRL113, 212002 (2014)
PRL112, 022001 (2014)
PRL115, 222002 (2015)
PRL112, 132001 (2014)
PRL115, 182002 (2015)
PRL119, 072001 (2017)

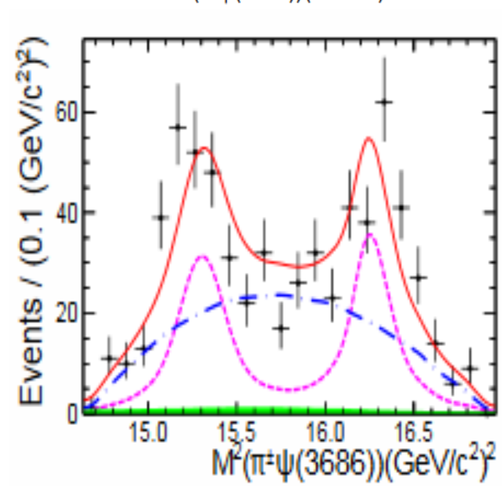
Zc(4030) in $e^+e^- \to \pi^+\pi^-\psi(3686)$

PRD96,032004(2017)



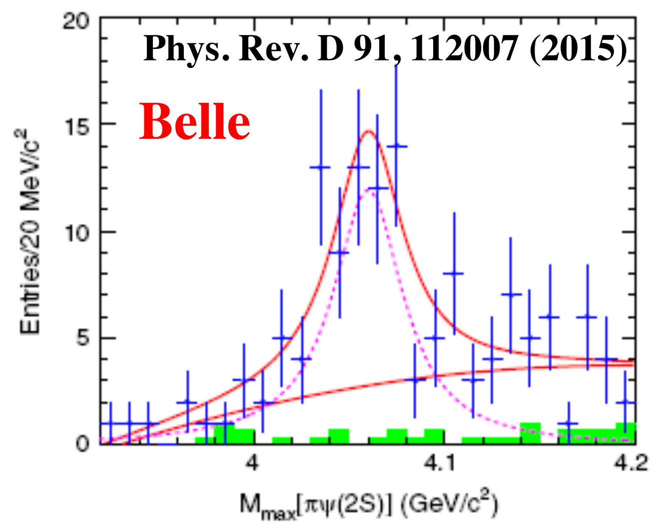






Charge structure in $M(\pi^\pm\psi(3686))$

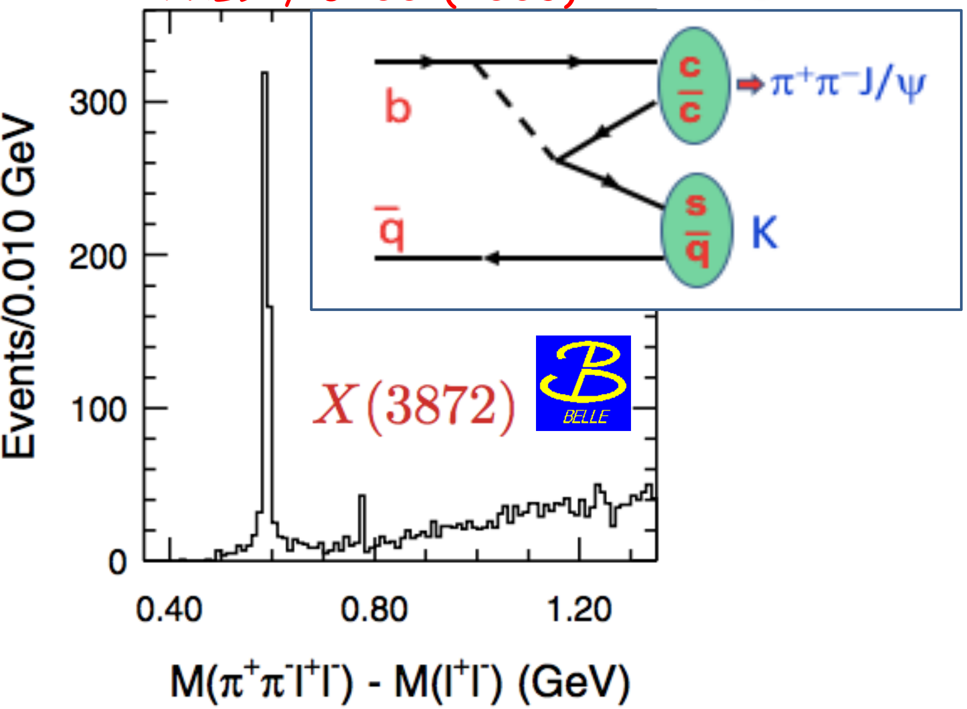
Mass = (4032.1 ± 2.4) MeV/c²
Width = (26.1±5.3) MeV



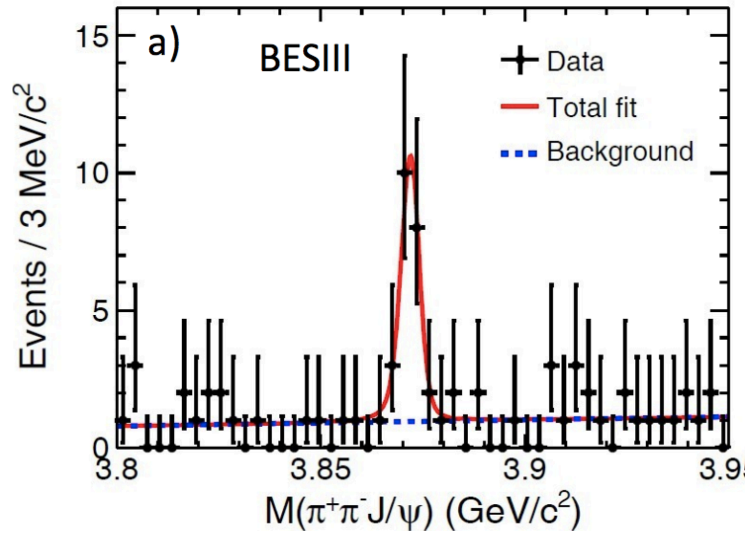
Mass = $(4054 \pm 3 \pm 1)$ MeV/c²
Width = (45±11±6) MeV

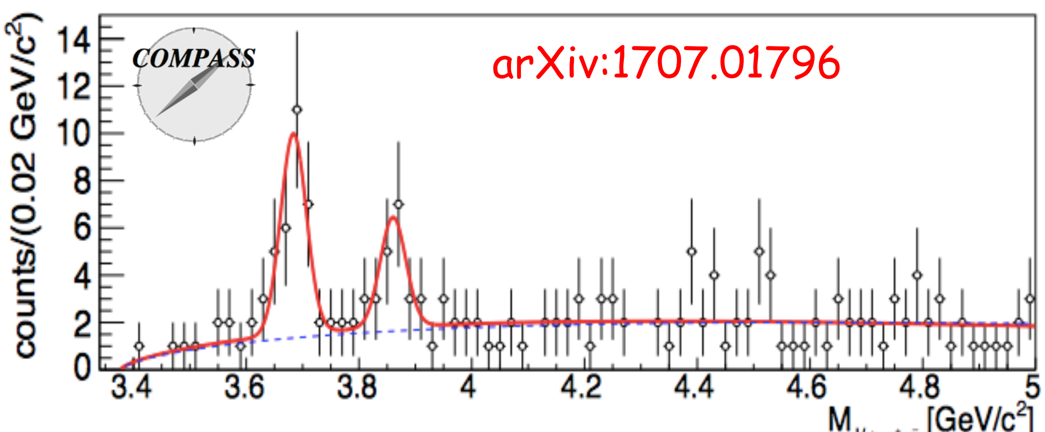
X(3872)

PRL91,262001(2003)

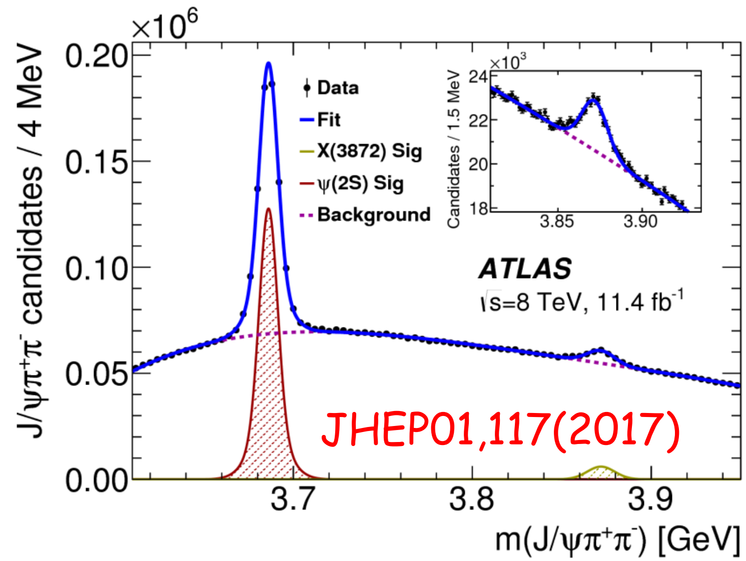


PRL112,092001(2014)

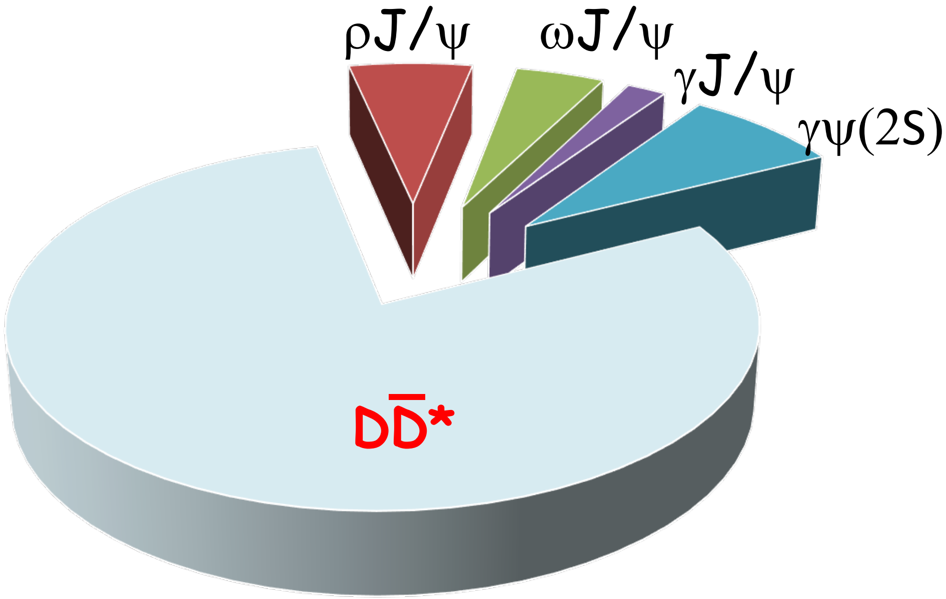




$$\mu^+ N \rightarrow \mu^+ X^0 \pi^\pm N' \rightarrow \mu^+ (J/\psi \pi^+ \pi^-) \pi^\pm N'$$



X(3872) decays



- Properties

  M-M($D^0 \bar{D}^{*0}$)=0.01±0.18 MeV

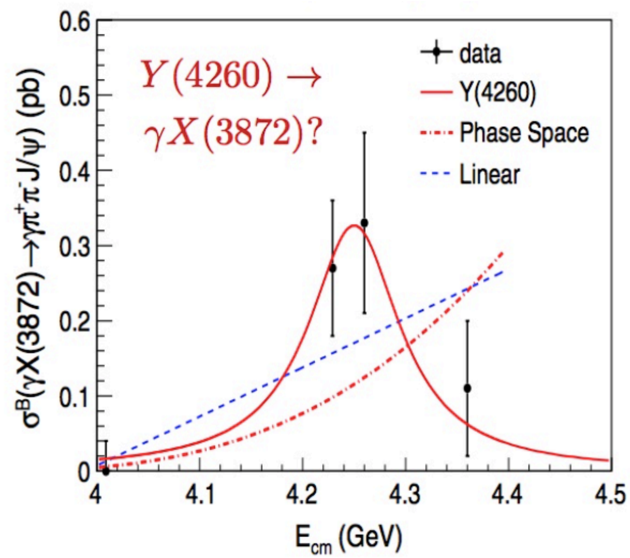
  Γ<1.2 MeV I=0, $J^{PC}=1^{++}$
- I=0, $J^{PC}=1^{++}$
- Production

  B decays, hadron collisions,

  Y(4260) decays?, muonproduction?

- Named $\chi_{c1}(3872)$ in PDG2018
- Strongly coupling to $D\bar{D}^*$
- $$\frac{\mathcal{B}(X(3872)\to\psi(2S)\gamma)}{\mathcal{B}(X(3872)\to J/\psi\gamma)} = 2.46 \pm 0.64 \pm 0.29$$

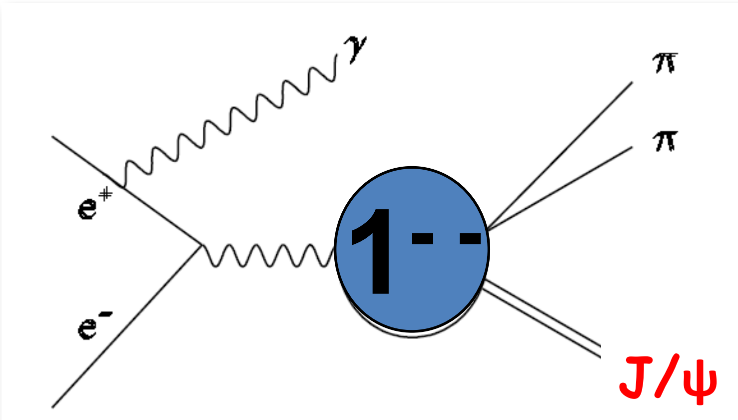
  LHCb, NPB886,665(2014)
- X(3872) is not a pure molecule
- Mixing of $\chi_{c1}(2P)$ and molecule ?

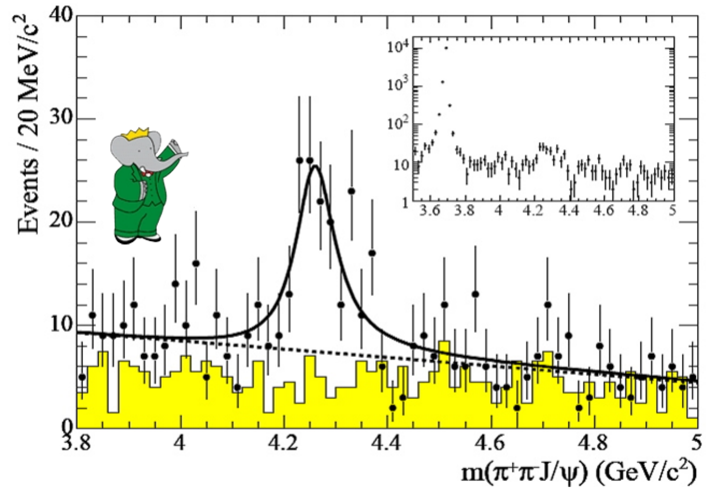


Suggestive of $Y(4260)\to\gamma X(3872)$

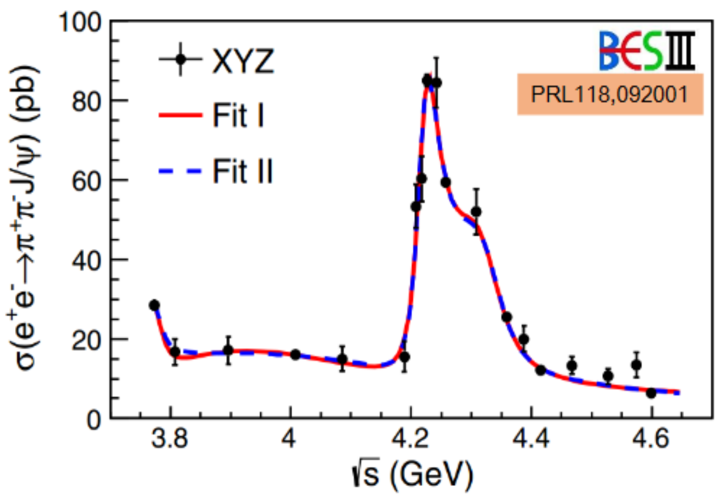
Y(4260)

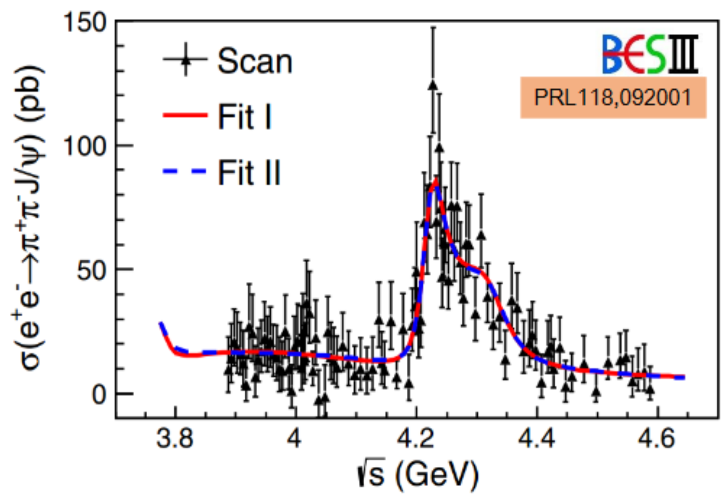
PRL95, 142001 (2005)





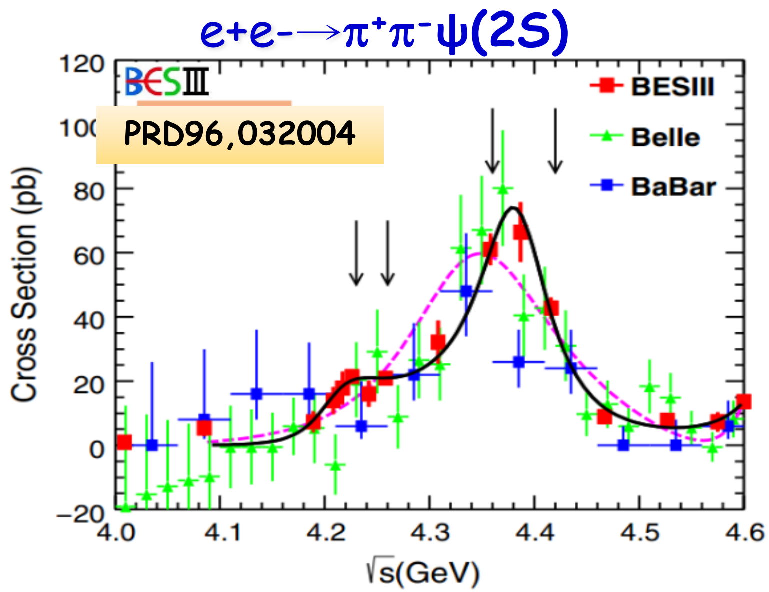
-9

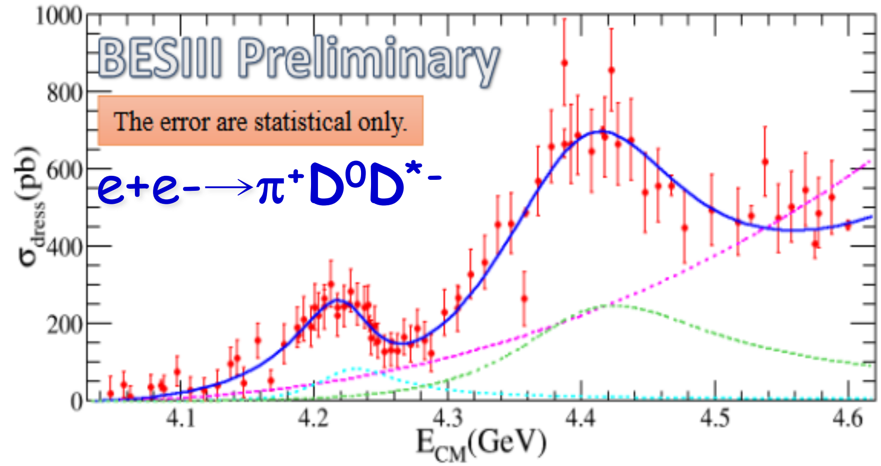


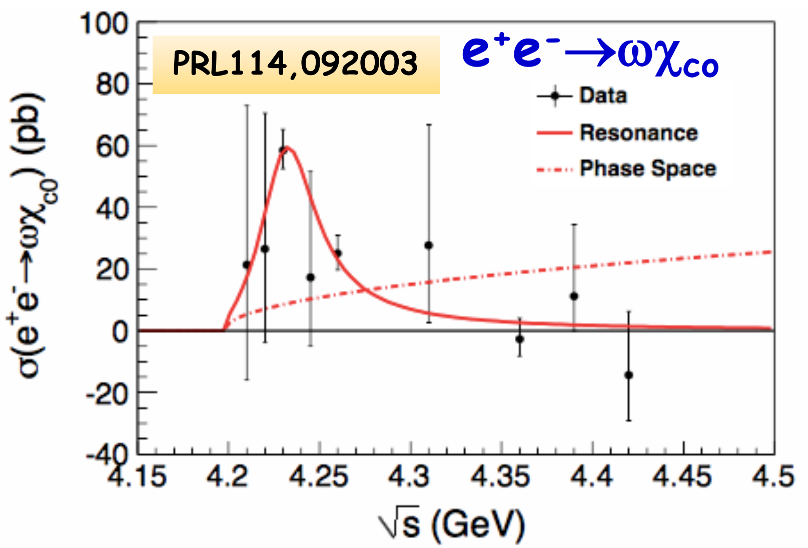


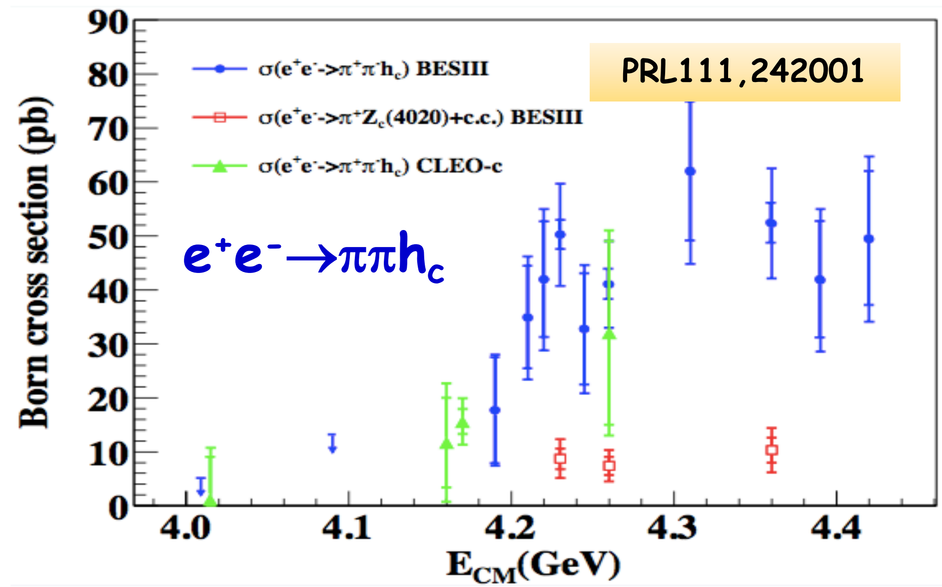
A shoulder around 4.3 GeV is observed (7.9σ). A new state?

Fit results: Y(4220) and Y(4360)









- ✓ Line-shapes are different from that of $\pi^+\pi^- J/\psi$
- ✓ Both Y(4220) and Y(4360) seem significant

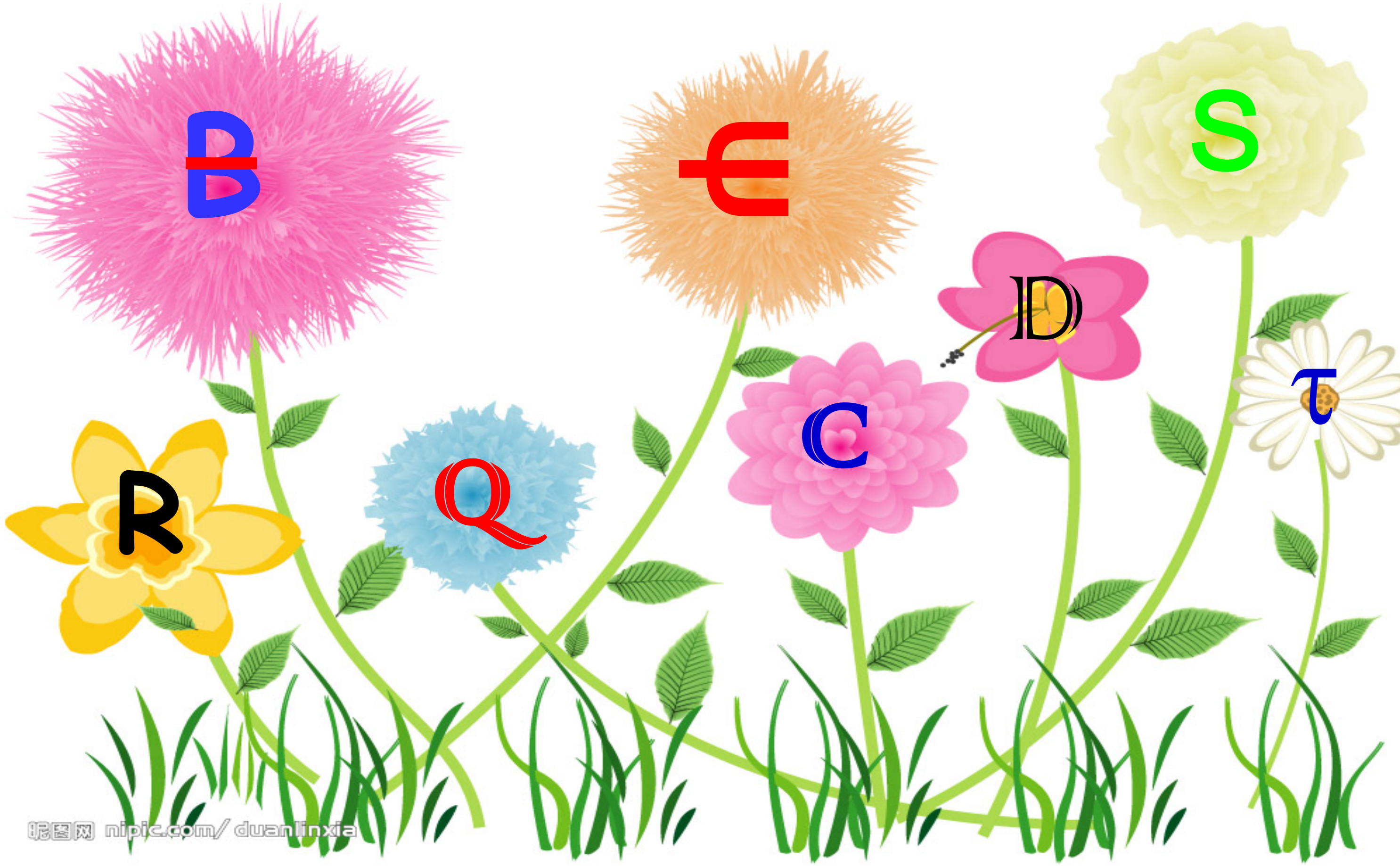
Upgrades on BEPCII/BESIII

- Beam energy
  - Ebeam = 2.3→2.35 GeV in 2019
  - Ebeam = 2.35→2.45 GeV in 2020-21, change ISPB(Interaction region SePtum Bending) magnet
- Top-up injection
  - Data taking efficiency increases by 20-30%
- Inner tracker →CGEM inner tracker
  - Construction by Italian group
  - Will be shipped to IHEP this summer, installation in summer 2019
- Super conducting magnet
  - New valve box of SC magnet

Summary

- 30 (10) years anniversary of BEPC(II)/BES(III)
  - 1988: First collision at BEPC/BES
  - 2008: First collision at BEPCII/BESIII
- Lots of important results were achieved
  - Mass measurement
  - R-value measurement
  - Charm physics
  - Exotic hadrons
  - ....
- Competitions from LHCb, BelleII
- Will continue to play an vital role in tau-charm physics

Summary



More important results are expected from BESIII !

Thank you !