Highlights of BESIII results and IHEP-LAL collaboration

Liangliang Wang

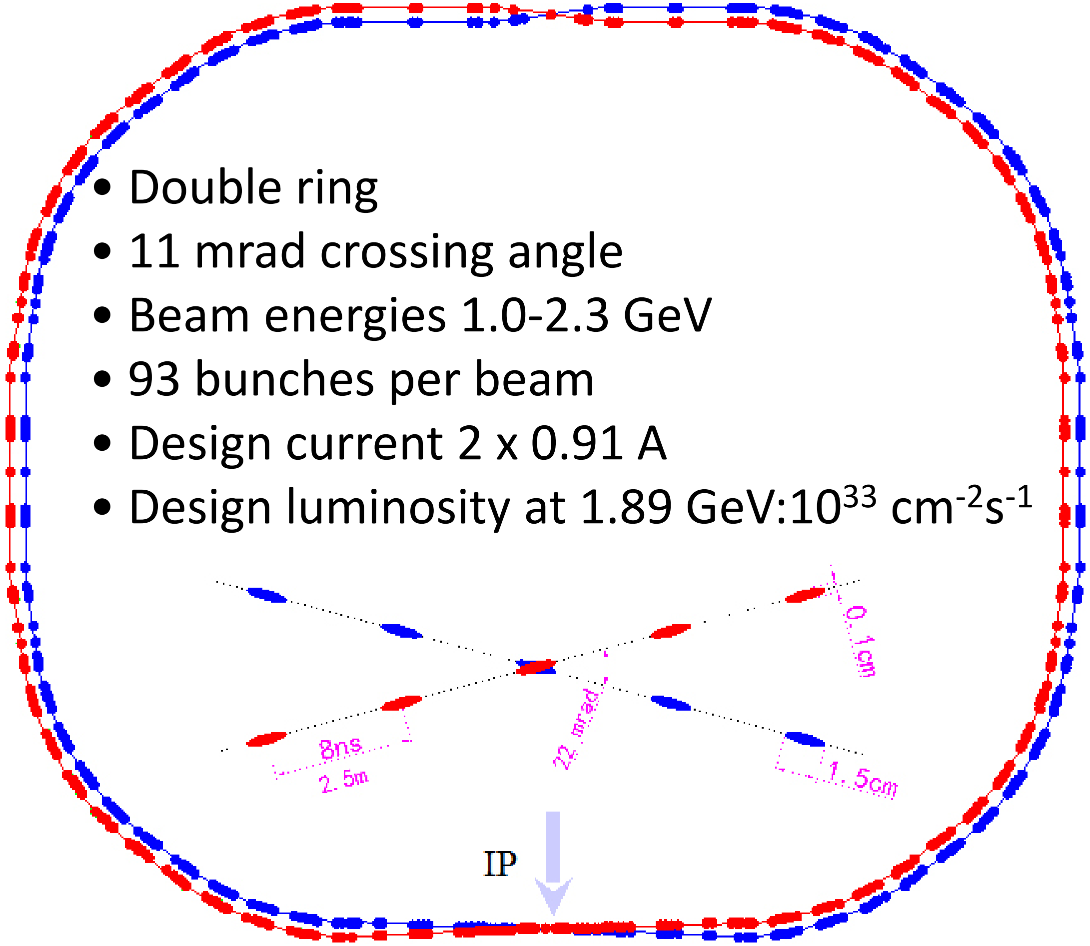
中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

Outline

- Introduction to BEPCII and BESIII
- Highlights of BESIII results
  - Charmonium spectroscopy
  - Charmonium decay
  - Light hadrons
  - τ mass measurement
- IHEP-LAL collaboration
  - Hadron cross-section measurement via ISR at BaBar
  - Muon anomalous magnetic moment (g-2)
- Summary

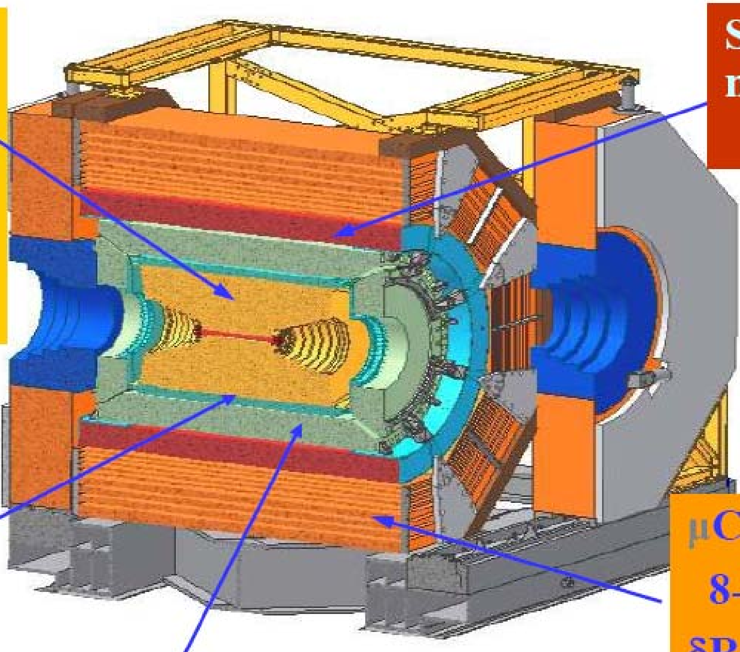
The Beijing Electron-Positron Collider II

- Double ring
- 11 mrad crossing angle
- Beam energies 1.0-2.3 GeV
- 93 bunches per beam
- Design current 2 x 0.91 A
- Design luminosity at 1.89 GeV: $10^{33}\ cm^{-2}s^{-1}$



The Beijing Spectrometer III (BESIII)

Main Drift Chamber (MDC)
$\sigma(p_T)/p_T$=0.32%⊕0.37% (1 GeV)
$\sigma_{dE/dx}$ = 5.3%



Super-conducting magnet
1.0 tesla

Time Of Flight (TOF)
σ_T = 80ps Barrel
100ps endcap

μCounter
8- 9 layers
δRΦ=1.4 cm~1.7 cm

EMC: $\Delta E/\sqrt{E}$ = 2.5 % @ 1 GeV
$\sigma_{z,\phi}$= 0.6 cm /$\sqrt{E}$

Data accumulated by BESIII

Time	Energy points	Luminosity
2009	J/ψ	$65pb^{-1}$ (226 million)
	ψ'	$150pb^{-1}$ (106 million)
	3.65 GeV	$45pb^{-1}$
2010-2011	$\psi(3770)$	$2900pb^{-1}$
	Scan around $\psi(3770)$ (3.646~3.892 GeV)	$76pb^{-1}$
2011	4.01 GeV ($\psi(4040)$)	$470pb^{-1}$
2012	τ mass scan, J/ψ , ψ'	…

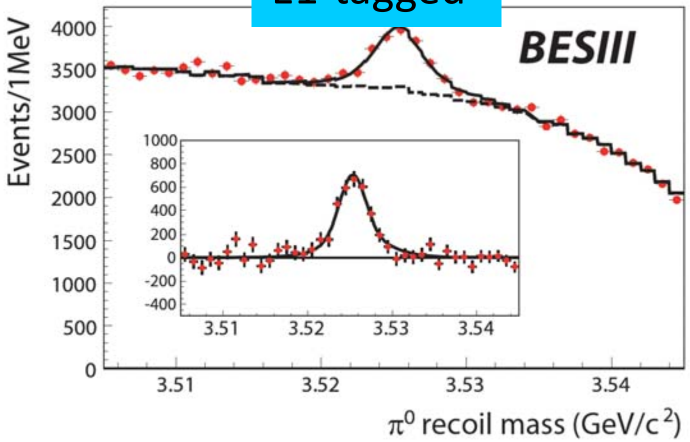
CHARMONIUM SPECTROSCOPY

Measurements of the h_c properties at BESIII

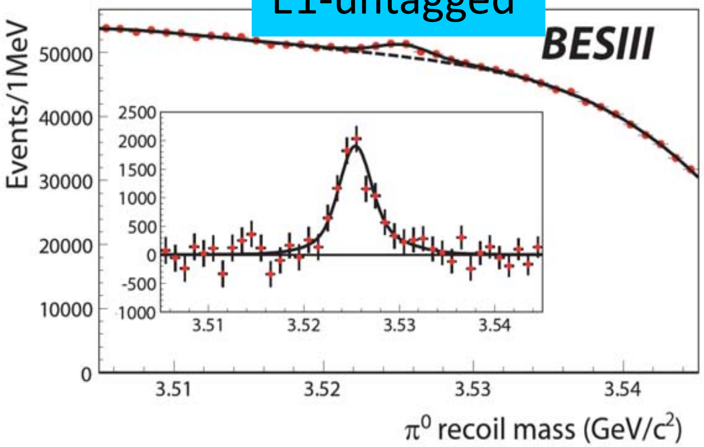
$\psi' \to \pi^0 h_c$ (inclusive)

BESIII Collaboration: PRL104, 132002, (2010)

E1-tagged



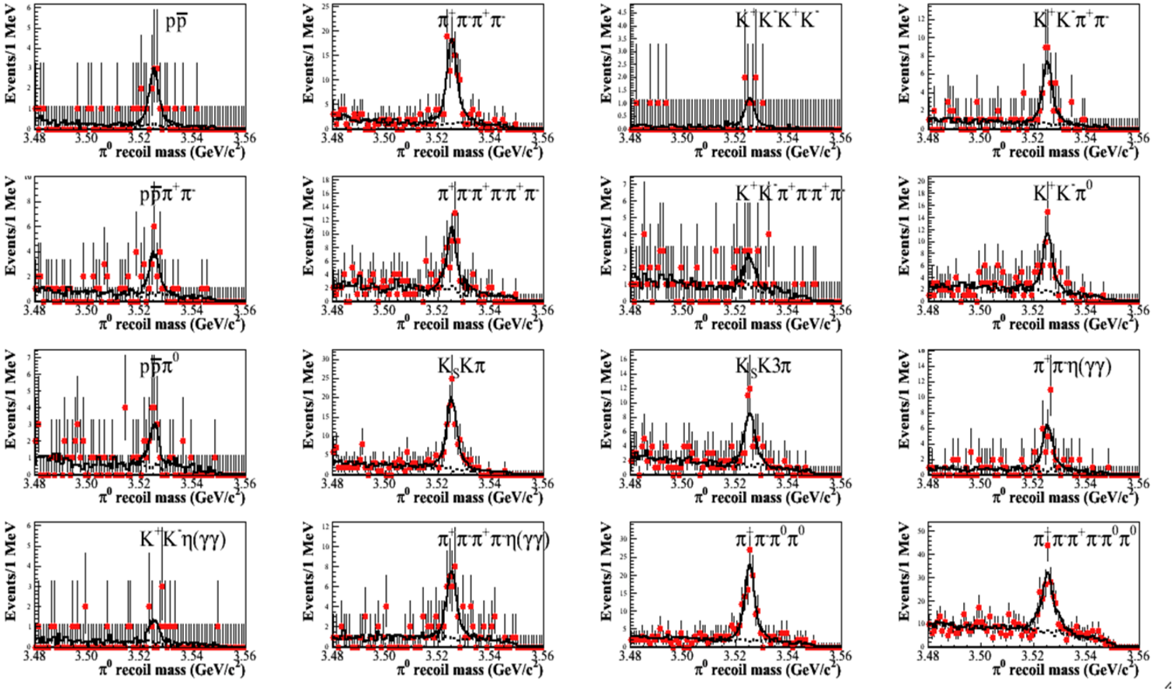
E1-untagged



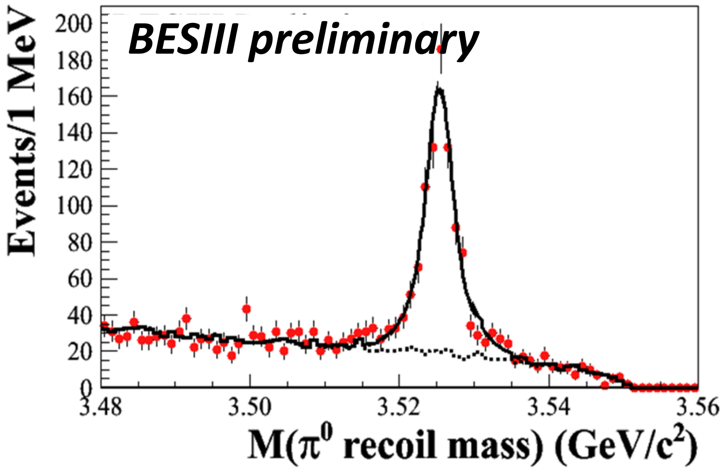
- Select inclusive π^0 ($\psi' \to \pi^0 h_c$)
- Select E1-photon in $h_c \to \gamma\eta_c$ (E1 tagged) or not (E1 untagged)
- E1-tagged selection gives
  $M(h_c)=3525.40 \pm 0.13 \pm 0.18$MeV
  ($\Delta M_{hf}(1P)=0.10 \pm 0.13 \pm 0.18$MeV/$c^2$)
  $\Gamma(h_c)=0.73 \pm 0.45 \pm 0.28$MeV
  (<1.44MeV at 90% CL)
  $Br(\psi' \to \pi^0 h_c) \times Br(h_c \to \gamma\eta_c)=$
  $(4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$
- E1-untagged together with tagged selection gives the first measurement
  $Br(\psi' \to \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$
  $Br(h_c \to \gamma\eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$

Measurements of the h_c properties at BESIII

$\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$ (exclusive)



Summed π^0 recoil mass



Simultaneous fit to π^0 recoiling mass
$M(h_c)$ = 3525.31±0.11±0.15 MeV
$\Gamma(h_c)$ = 0.70±0.28±0.25 MeV
N = 832±35
χ^2/d.o.f. = 32/46

BESIII preliminary

Consistent with BESIII inclusive results PRL104,132002(2010)

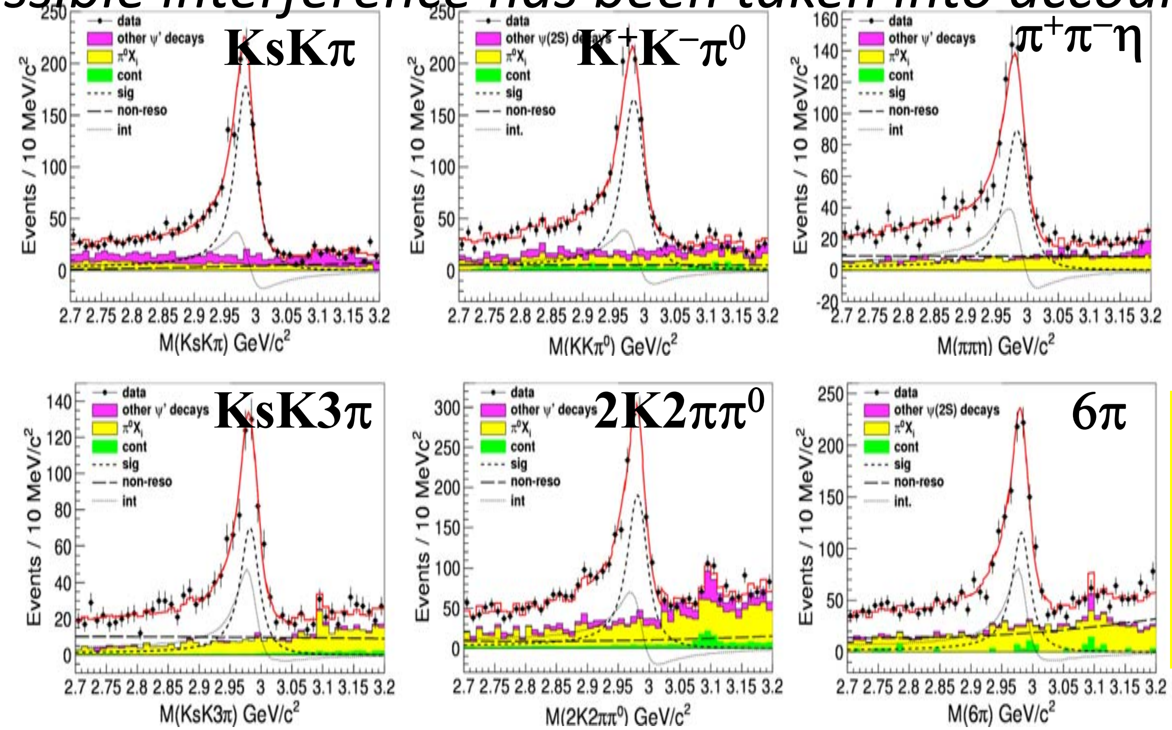
CLEOc exlusive results
$M(h_c)$=3525.21±0.27±0.14 MeV/c^2
N = 136±14
PRL101, 182003(2008)

Precision measurement of the η_c properties ($\psi' \rightarrow \gamma\eta_c$)

- The lowest lying S-wave spin singlet charmonium, discovered in 1980 by MarkII
- Parameters:
  J/ψ radiative transition: M ~ 2978.0MeV/c^2, Γ ~ 10MeV
  γγ process: M = 2983.1 ± 1.0 MeV/c^2, Γ = 31.3 ± 1.9 MeV
- CLEOc found the distortion of the η_c line shape in ψ' decays.

Possible interference has been taken into account

arXiv:1111.0398

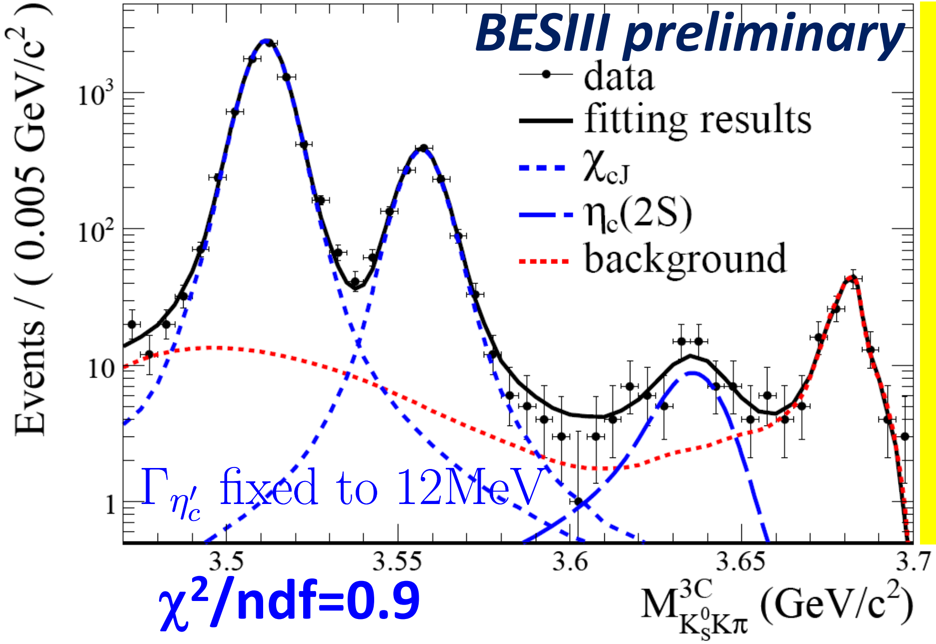


Relative phase ϕ values from each mode are consistent within 3σ => a common phase value in the simultaneous fit.

M: **2984.4±0.6±0.6** MeV/c^2
width: **32.0±1.2±1.0** MeV
ϕ: **2.40±0.07±0.08 rad**
4.19 ±0.03±0.09rad

The first observation of the M1 transition $\psi' \to \gamma\eta_c'$

- First "observation" by Crystal Ball in 1982 (M=3.592, B=0.2%-1.3% from ψ' radiative decay, but never confirmed by other experiments.)
- Observed at B factories through B decay, two-photon process and double charmonium production.



$\chi^2/ndf=0.9$

- **$N(\eta_c')$ = 50.6 ± 9.7**
- **Significance with systematic variations not less than 5σ**
- **$M(\eta_c')=3638.5 \pm 2.3_{stat} \pm 1.0_{sys}$ (MeV/c^2)**
- **$Br(\psi' \to \gamma\eta_c' \to \gamma K_s K\pi)= (2.98 \pm 0.57_{stat} \pm 0.48_{sys}) \times 10^{-6}$**
- **$Br(\psi' \to \gamma\eta_c')=(4.7 \pm 0.9_{stat} \pm 3.0_{sys}) \times 10^{-4}$** if $Br(\eta_c' \to KK\pi)=(1.9 \pm 0.4 \pm 1.1)\%$ from BaBar is used

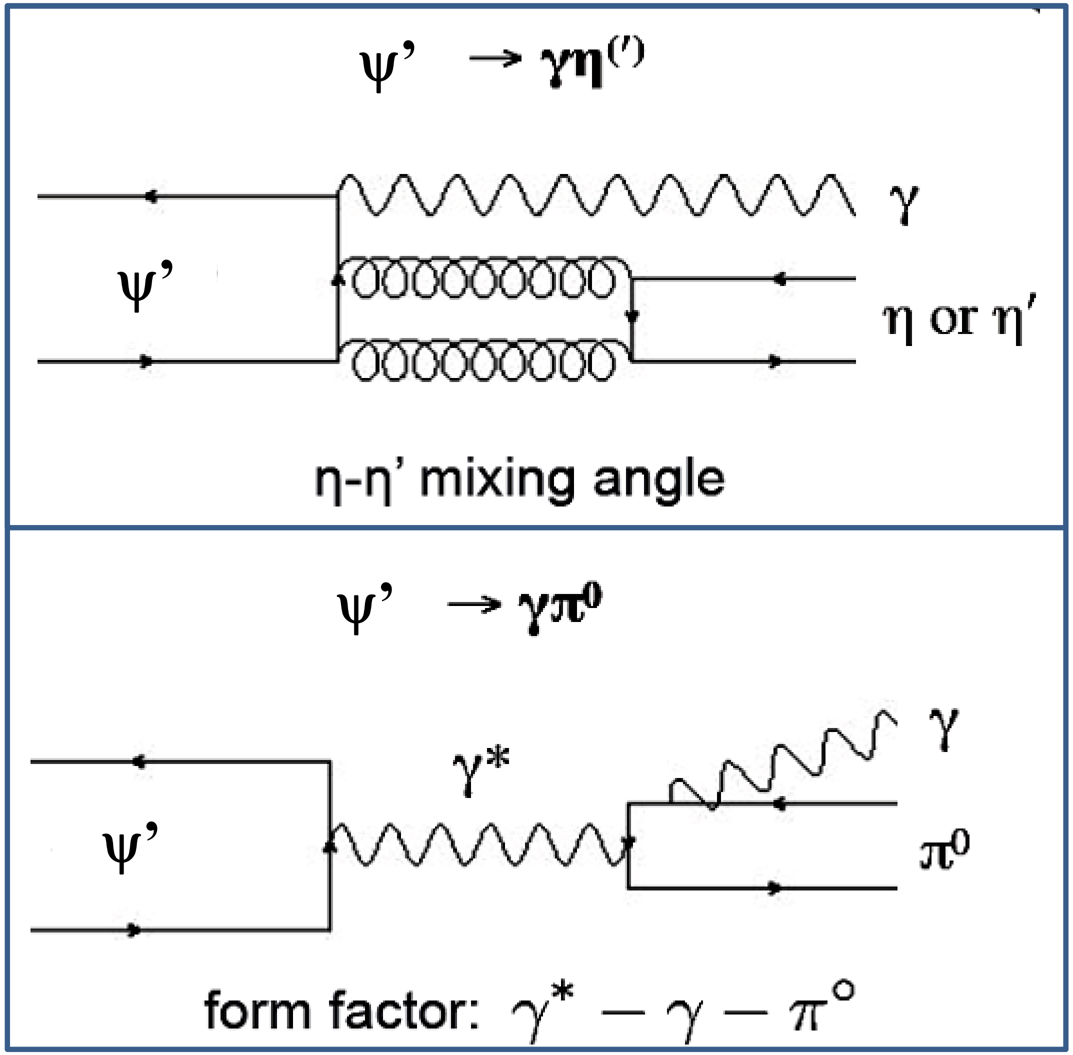
CLEO-c: $<7.6\times10^{-4}$ (PRD81,052002(2010))
Potential model: $(0.1–6.2)\times10^{-4}$ (PRL89,162002(2002))

CHARMONIUM DECAY

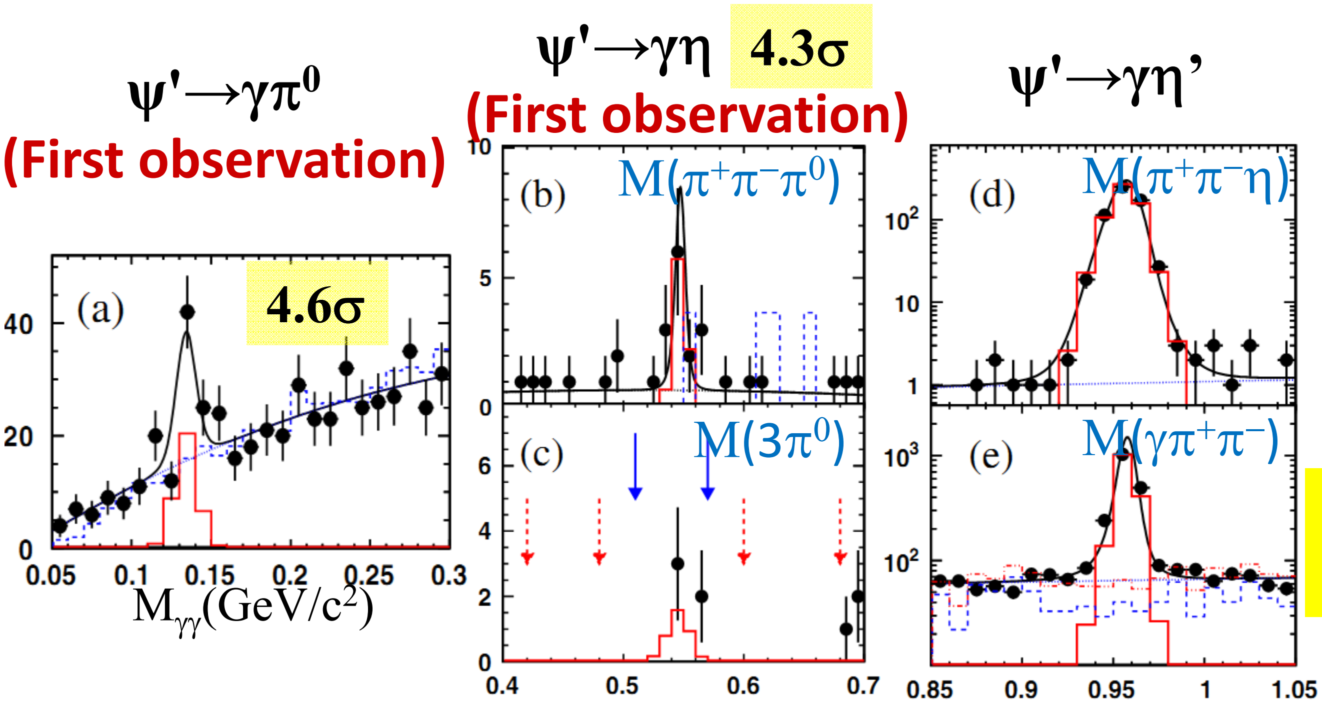
Study of $\psi' \to \gamma P$ (π^0, η, η')

$V \to \gamma P$ can provide important tests for various mechanisms:

- Vector meson Dominance Model (VDM);
- Couplings & form factor;
- Mixing of η-η'(-η_c);
- FSR by light quarks;
- 12% rule and "$\rho\ \pi$ puzzle".



Study of ψ’→γP (π⁰,η,η’) (conti.)



$$R_V = \frac{Br(V \to \gamma\eta)}{Br(V \to \gamma\eta')}$$

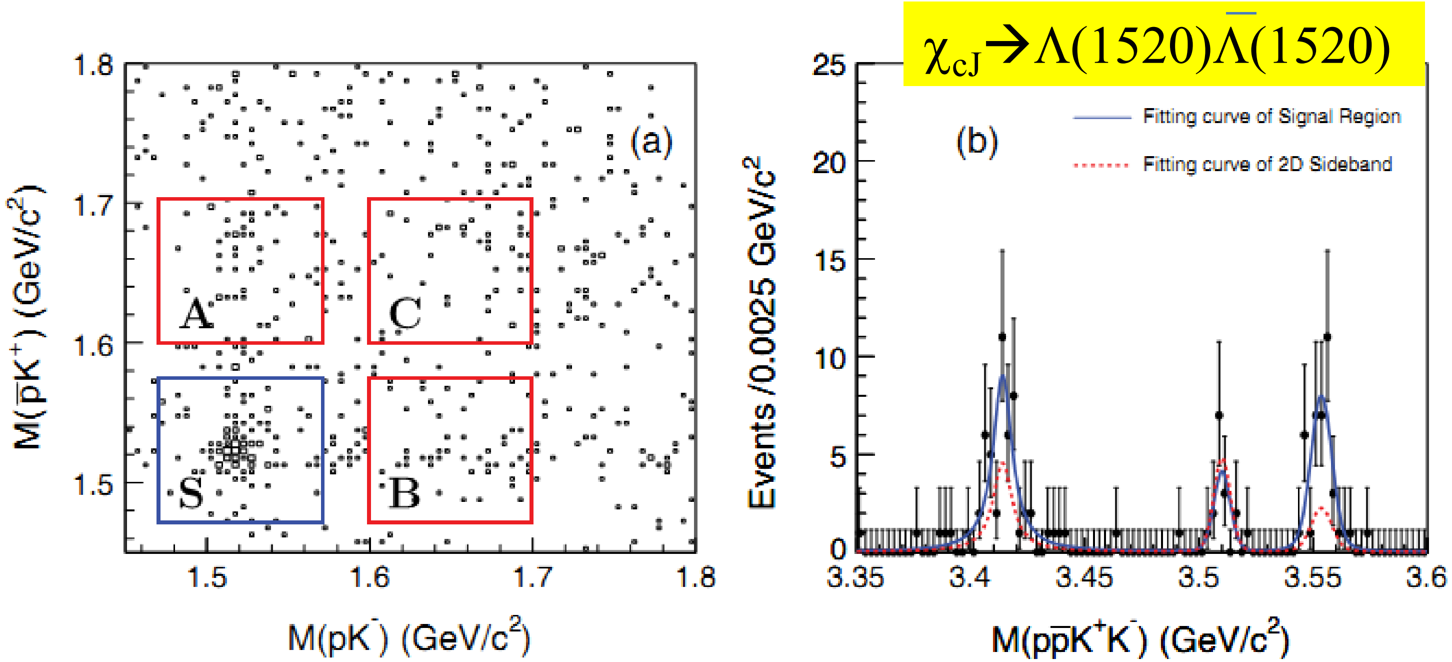
$R_{\psi'}$= (1.10±0.38±0.07)%

<< $R_{J/\psi}$= （20.9±0.9）%

Mode	B(ψ’) [x10⁻⁶]	B(J/ψ) [x10⁻⁴]	Q (%)
γπ⁰	1.58±0.42	0.35±0.03	4.5 ± 1.3
γη	1.38±0.49	11.04±0.34	0.13 ± 0.04
γη’	126±9	52.8±1.5	2.4 ± 0.2

Possible interpretation: Q. Zhao, Phys. Lett. B697, 52 (2011)

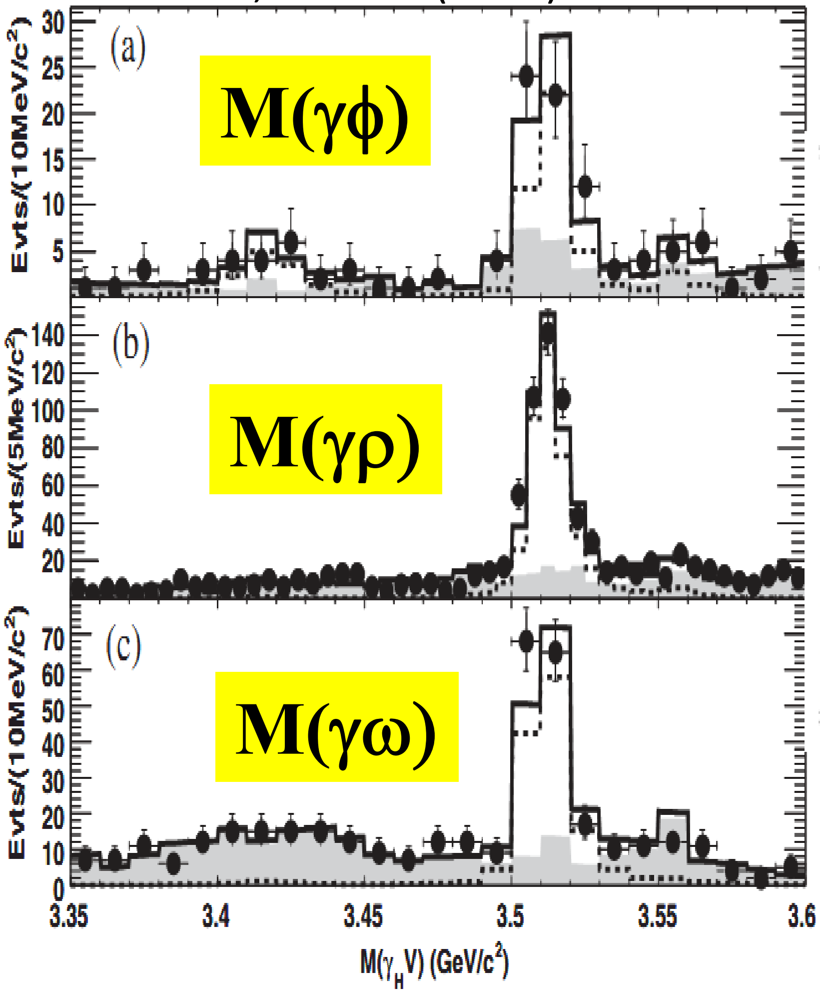
First measurement of $\chi_{cJ} \to p\bar{p}K^+K^-$



	χ_{c0}	χ_{c1}	χ_{c2}
$\mathcal{B}(\chi_{cJ} \to p\bar{p}K^+K^-)$ (10^{-4})	$1.24 \pm 0.20 \pm 0.18$	$1.35 \pm 0.15 \pm 0.19$	$2.08 \pm 0.19 \pm 0.30$
$\mathcal{B}(\chi_{cJ} \to \bar{p}K^+\Lambda(1520) + \text{c.c.})$ (10^{-4})	$3.00 \pm 0.58 \pm 0.50$	$1.81 \pm 0.38 \pm 0.28$	$3.06 \pm 0.50 \pm 0.54$
$\mathcal{B}(\chi_{cJ} \to \Lambda(1520)\bar{\Lambda}(1520))$ (10^{-4})	$3.18 \pm 1.11 \pm 0.53$	<1.00	$5.05 \pm 1.29 \pm 0.93$
$\mathcal{B}(\chi_{cJ} \to p\bar{p}\phi)$ (10^{-5})	$6.12 \pm 1.18 \pm 0.86$	<1.82	$3.04 \pm 0.85 \pm 0.43$

Study of $\chi_{cJ}\rightarrow\gamma V$ (V=ρ,ω,ϕ)

PRD 83, 112005 (2011)



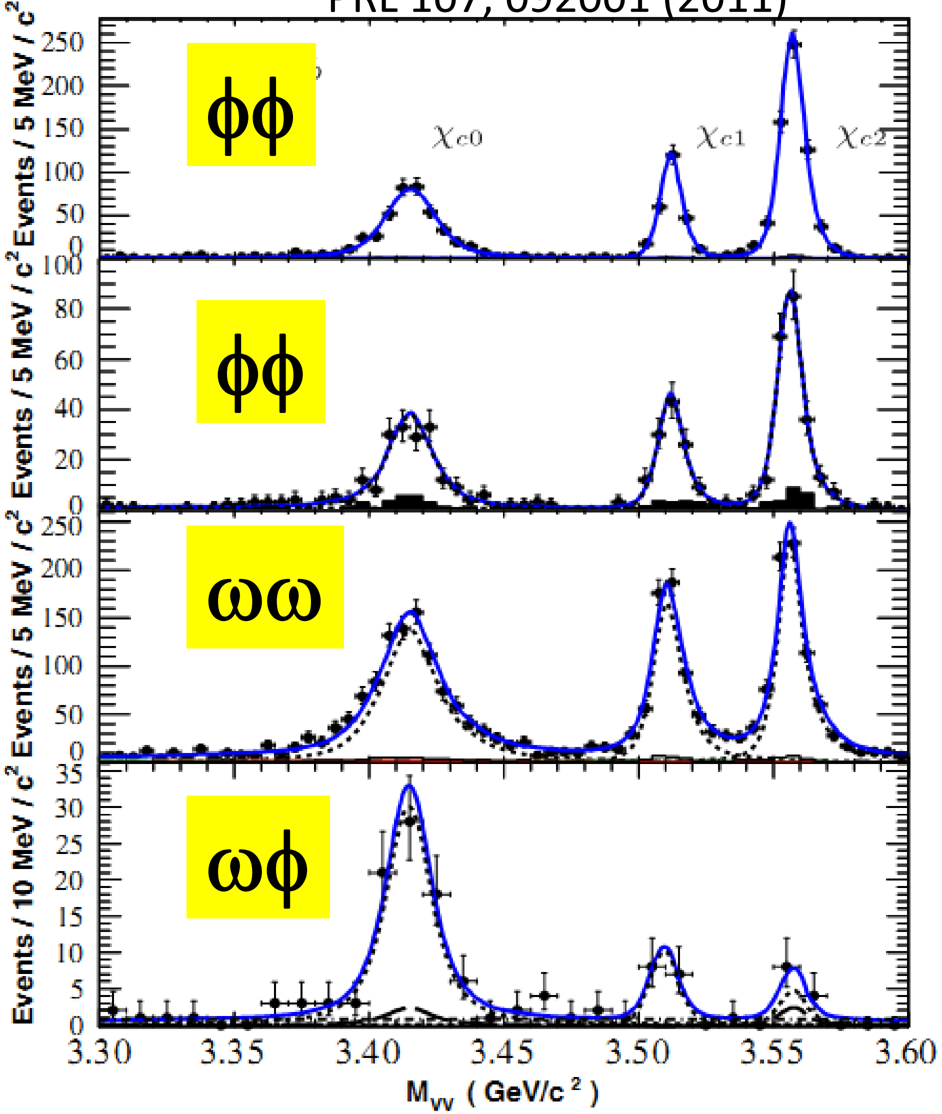
First observation

Decay mode	No. of evts.	Eff. (%)	Syst. err.(%)	Br. (10^{-6})	Stat. sign.
$\chi_{c0}\rightarrow\gamma\phi$	15.0 ± 6.6	32.4	8.8	<16.2	
$\chi_{c1}\rightarrow\gamma\phi$	42.6 ± 8.6	34.6	8.8	$25.8\pm5.2\pm2.3$	6σ
$\chi_{c2}\rightarrow\gamma\phi$	4.6 ± 4.9	32.6	9.3	<8.1	
$\chi_{c0}\rightarrow\gamma\rho^0$	6 ± 12	22.6	8.1	<10.5	
$\chi_{c1}\rightarrow\gamma\rho^0$	432 ± 25	19.4	8.3	$228\pm13\pm22$	$>10\sigma$
$\chi_{c2}\rightarrow\gamma\rho^0$	13 ± 11	15.7	8.7	<20.8	
$\chi_{c0}\rightarrow\gamma\omega$	5 ± 11	18.6	9.3	<12.9	
$\chi_{c1}\rightarrow\gamma\omega$	136 ± 14	22.7	9.4	$69.7\pm7.2\pm6.6$	$>10\sigma$
$\chi_{c2}\rightarrow\gamma\omega$	1 ± 6	19.2	9.8	<6.1	

Upper limits set @ 90% C.L.

Observation of $\chi_{cJ}\rightarrow VV$

PRL 107, 092001 (2011)



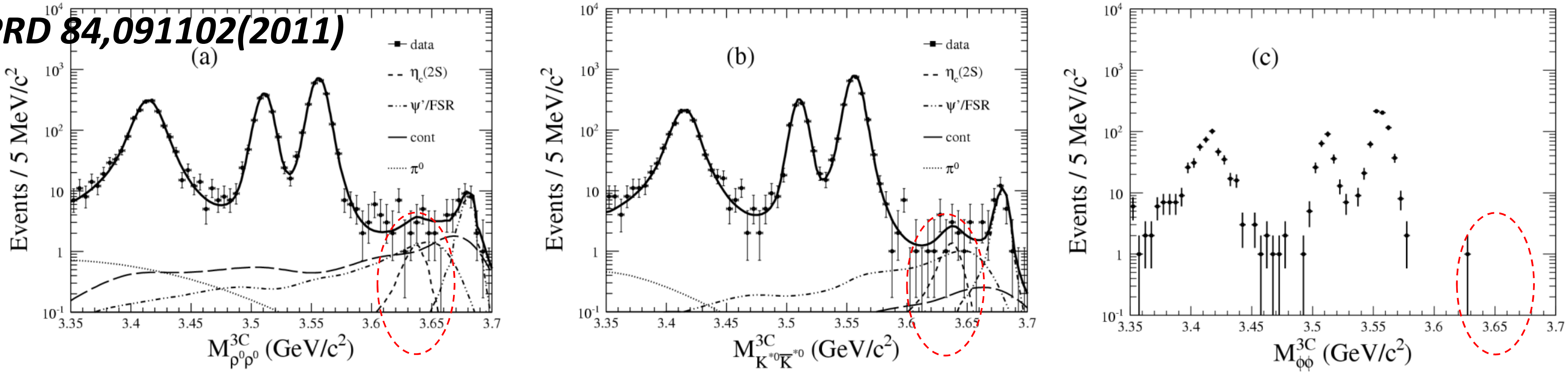
Mode	$N_{\rm net}$	ϵ (%)	$\mathcal{B}(\times 10^{-4})$
$\chi_{c0}\to\phi\phi$	433 ± 23	22.4	7.8 ± 0.4 ± 0.8
$\chi_{c1}\to\phi\phi$	254 ± 17	26.4	4.1 ± 0.3 ± 0.4
$\chi_{c2}\to\phi\phi$	630 ± 26	26.1	10.7 ± 0.4 ± 1.1
$\to 2(K^+K^-)$			
$\chi_{c0}\to\phi\phi$	179 ± 16	12.8	9.2 ± 0.7 ± 1.0
$\chi_{c1}\to\phi\phi$	112 ± 12	15.3	5.0 ± 0.5 ± 0.6
$\chi_{c2}\to\phi\phi$	219 ± 16	14.9	10.7 ± 0.7 ± 1.2
$\to K^+K^-\pi^+\pi^-\pi^0$			
Combined:			
$\chi_{c0}\to\phi\phi$	···	···	8.0 ± 0.3 ± 0.8
$\chi_{c1}\to\phi\phi$	···	···	**4.4 ± 0.3 ± 0.5**
$\chi_{c2}\to\phi\phi$	···	···	10.7 ± 0.3 ± 1.2
$\chi_{c0}\to\omega\omega$	991 ± 38	13.1	9.5 ± 0.3 ± 1.1
$\chi_{c1}\to\omega\omega$	597 ± 29	13.2	**6.0 ± 0.3 ± 0.7**
$\chi_{c2}\to\omega\omega$	762 ± 31	11.9	8.9 ± 0.3 ± 1.1
$\to 2(\pi^+\pi^-\pi^0)$			
$\chi_{c0}\to\omega\phi$	76 ± 11	14.7	**1.2 ± 0.1 ± 0.2**
$\chi_{c1}\to\omega\phi$	15 ± 4	16.2	0.22 ± 0.06 ± 0.02
$\chi_{c2}\to\omega\phi$	<13	15.7	<0.2
$\to K^+K^-\pi^+\pi^-\pi^0$			

First observation

Search for $\eta_c' \rightarrow$ vector meson pair

- The process $\eta_c' \rightarrow VV$ is supposed to be highly suppressed by helicity selection rule.
- The intermediate charmed meson loops could contribute and predict higher production rate of $\eta_c' \rightarrow VV$. **arXiv:1010.1343**

PRD 84,091102(2011)



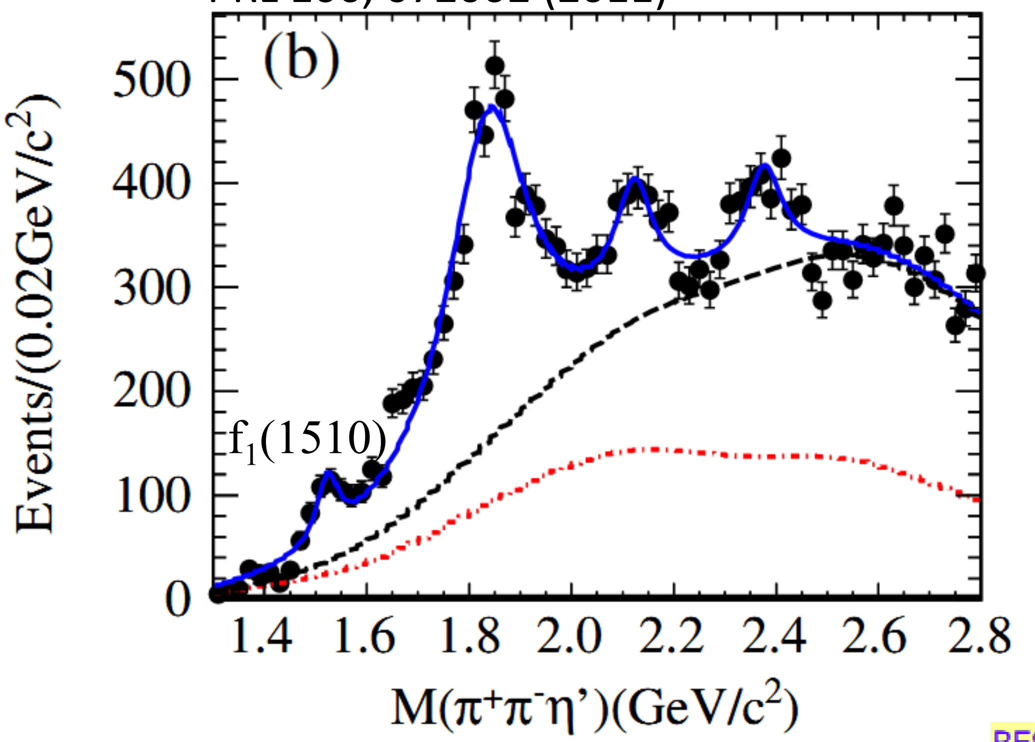
	$Br(\psi' \rightarrow \gamma\eta_c' \rightarrow \gamma VV)$ (10^{-7})	$Br(\eta_c' \rightarrow VV)$ (10^{-3})	Theory $Br(\eta_c' \rightarrow VV)$ (10^{-3})
$\rho^0\rho^0$	<11.4	<3.1	6.4 ~ 28.9
$K^{*0}K^{*0}$	<19.4	<5.3	7.9 ~ 35.8
$\phi\phi$	<7.8	<2.0	2.1 ~ 9.8

LIGHT HADRONS

More states decays into $\eta'\pi^+\pi^-$

$(J/\psi \rightarrow \gamma\, \eta'\pi^+\pi^-)$

PRL 106, 072002 (2011)



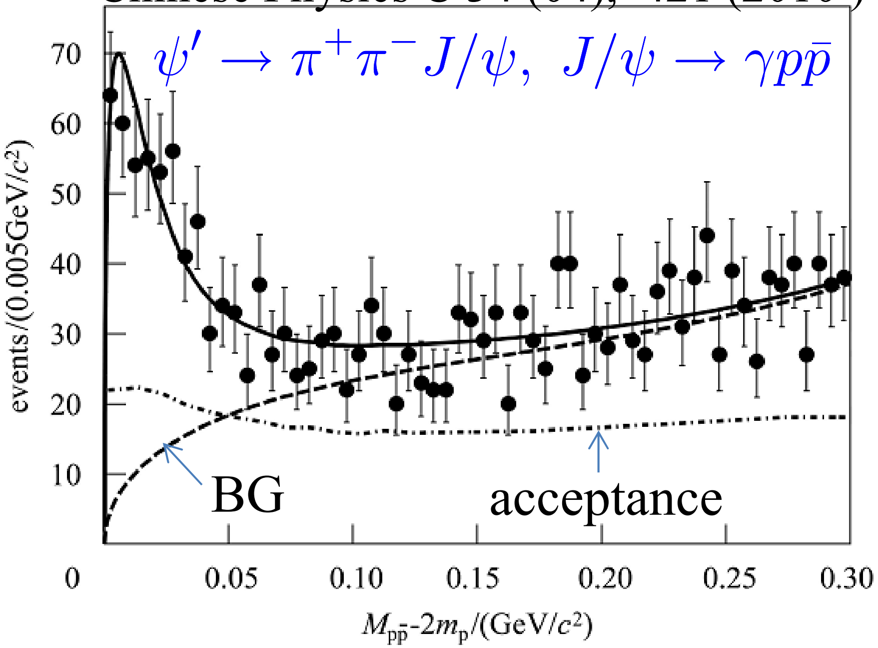
- X(1835) at BESII
- Confirmed at BESIII, width much larger
- Two more peaks!!
- JP unknown, need PWA
- Nature?
  - X1835=X1859=ppbar bound state?
  - Pseudoscalar glueballs?
  - Excited η or η' states?
  - …

BESII X(1835): $M = 1833.7 \pm 6.1 \pm 2.7$ MeV/c^2
$\Gamma = 67.7 \pm 20.3 \pm 7.7$ MeV/c^2

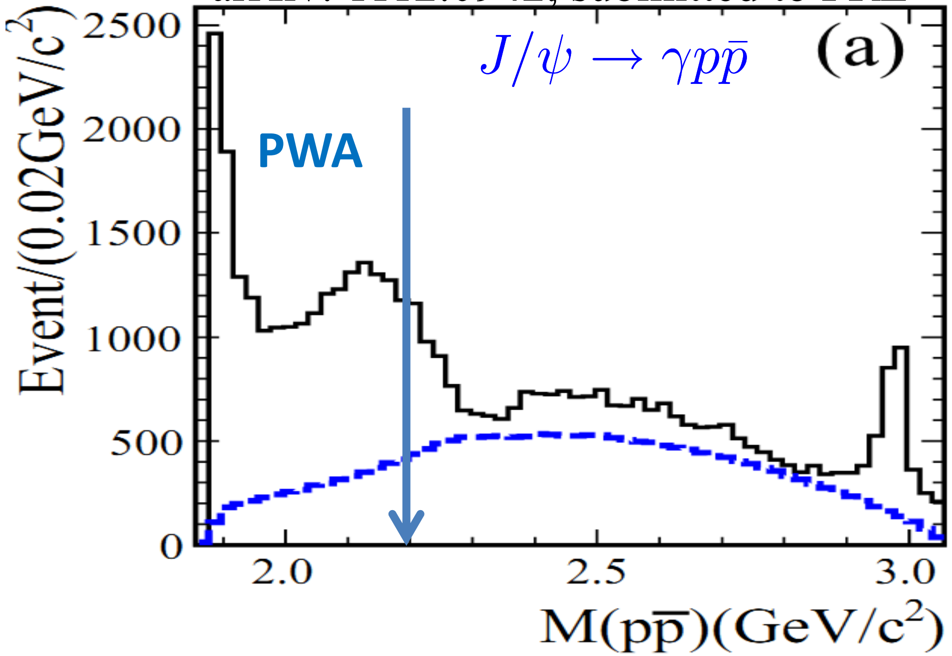
State	X(1835)	X(2120)	X(2370)
Mass (MeV)	$1836.5\pm3.0^{+5.6}_{-2.1}$	$2122.4 \pm6.7^{+4.7}_{-2.7}$	$2376.3 \pm8.7^{+3.2}_{-4.3}$
Width (MeV)	$190\pm9^{+38}_{-36}$	$83 \pm16^{+31}_{-11}$	$83 \pm17^{+44}_{-6}$

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

Chinese Physics C 34 (04), 421 (2010)



arXiv: 1112.0942, submitted to PRL



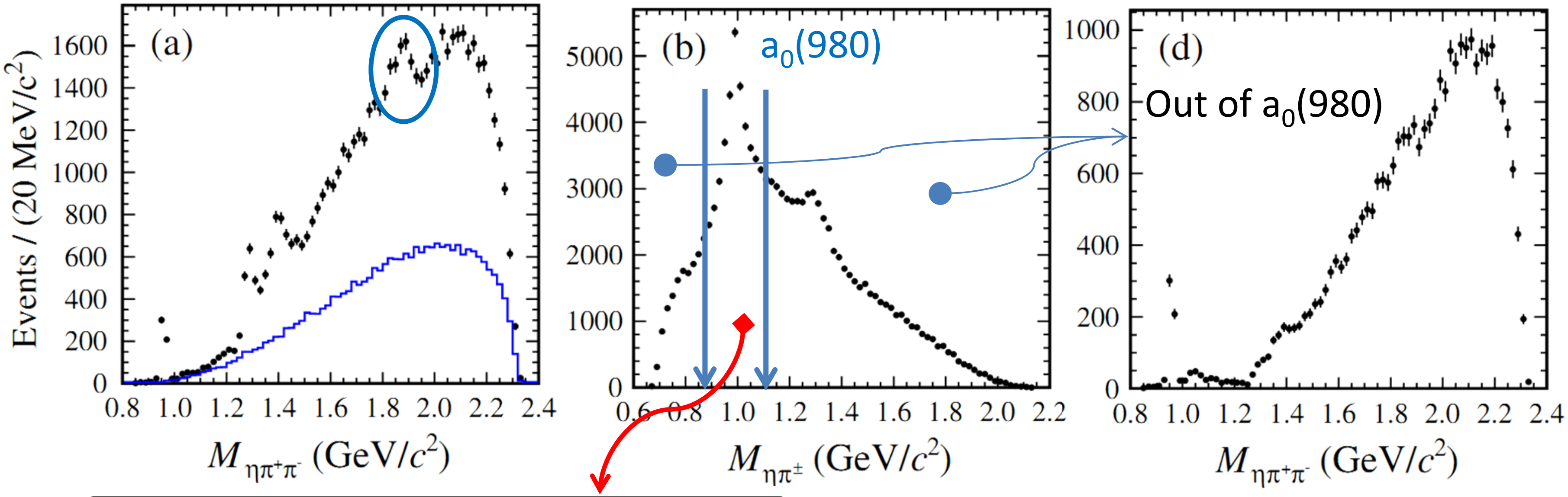
- PWA:
  - Signal described by covariant tensor amplitudes (S. Dulat and B. S. Zou, Eur.Phys.J A 26:125, 2005)
  - Juish-FSI effect included (A. Sirbirtsen et al. Phys.Rev.D 71:054010, 2005)
  - four components: $X(p\bar{p})$, $f_2(1910)$, $f_0(2100)$, 0^{++} phase space
- $M = 1832^{+19}_{-5}(\text{stat.})^{+18}_{-17}(\text{syst.}) \pm 19(\text{model})$ MeV/c^2

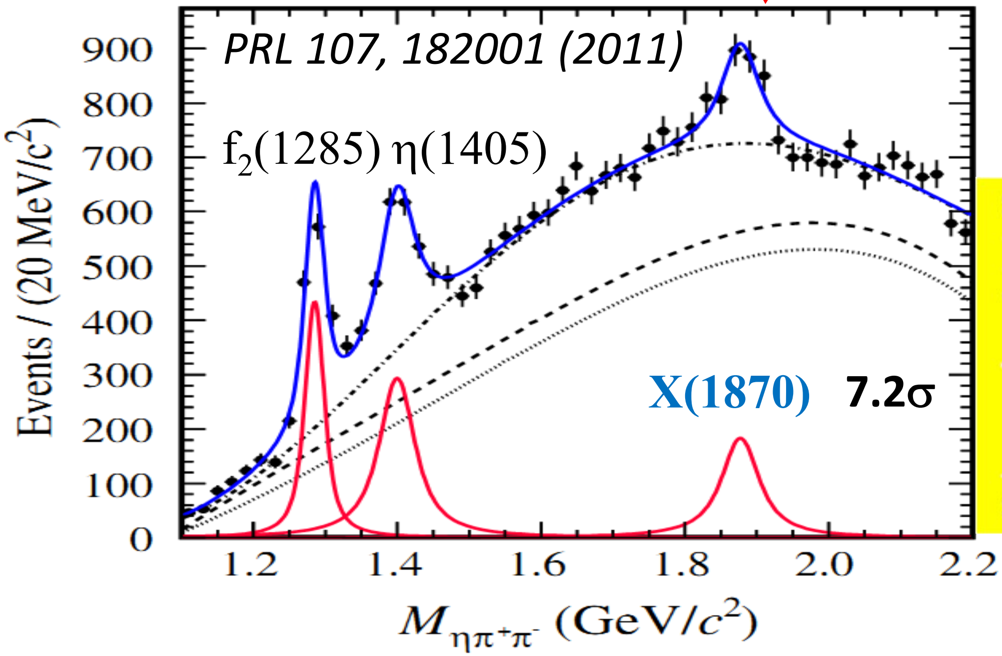
  $\Gamma = 13 \pm 39(\text{stat.})^{+10}_{-13}(\text{syst.}) \pm 4(\text{model})$ MeV ($\Gamma < 76$ MeV @ 90% C.L.)

  $Br(J/\psi \to \gamma X) \cdot Br(X \to p\bar{p}) = (9.0^{+0.4}_{-1.1}(\text{stat.})^{+1.5}_{-5.0}(\text{syst.}) \pm 2.3(\text{model})) \times 10^{-5}$

0^{-+}

Observation of X(1870) in J/ψ→ωηπ⁺π⁻

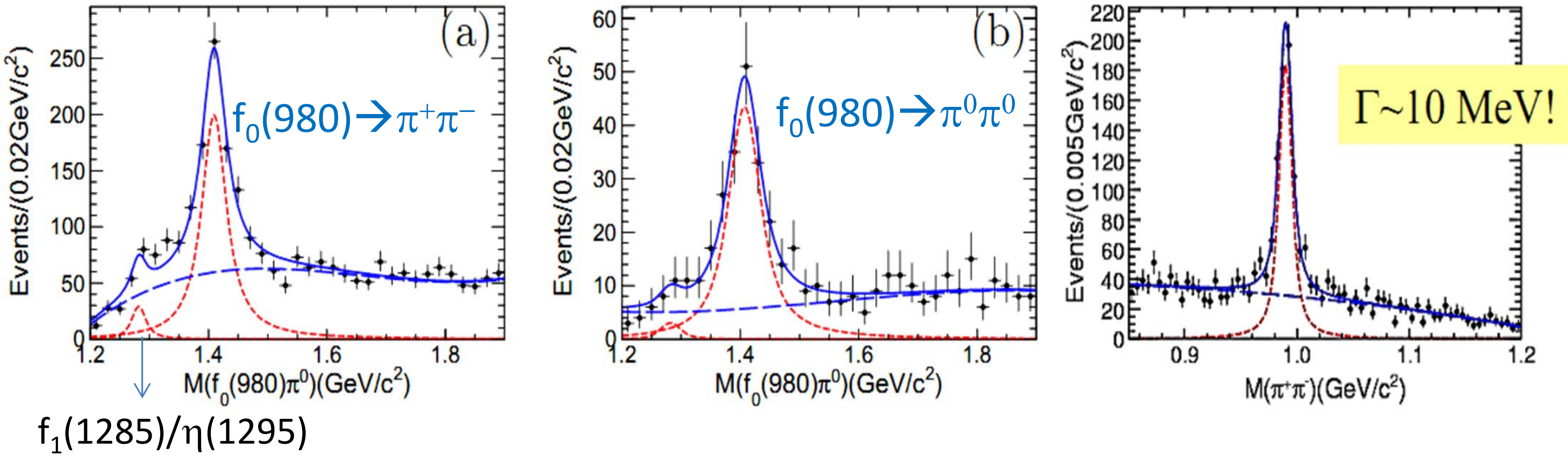




$$\mathcal{B}(J/\psi \to \omega X) \times \mathcal{B}(X \to a_0^{\pm}(980)\pi^{\pm}) \times \mathcal{B}(a_0^{\pm}(980) \to \eta\pi^{\pm})$$

Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	$\mathcal{B}(10^{-4})$
$f_1(1285)$	$1285.1 \pm 1.0^{+1.6}_{-0.3}$	$22.0 \pm 3.1^{+2.0}_{-1.5}$	$1.25 \pm 0.10^{+0.19}_{-0.20}$
$\eta(1405)$	$1399.8 \pm 2.2^{+2.8}_{-0.1}$	$52.8 \pm 7.6^{+0.1}_{-7.6}$	$1.89 \pm 0.21^{+0.21}_{-0.23}$
$X(1870)$	$1877.3 \pm 6.3^{+3.4}_{-7.4}$	$57 \pm 12^{+19}_{-4}$	$1.50 \pm 0.26^{+0.72}_{-0.36}$

First observation of $\eta(1405)$ in $J/\psi \rightarrow \gamma f_0(980)\pi^0$



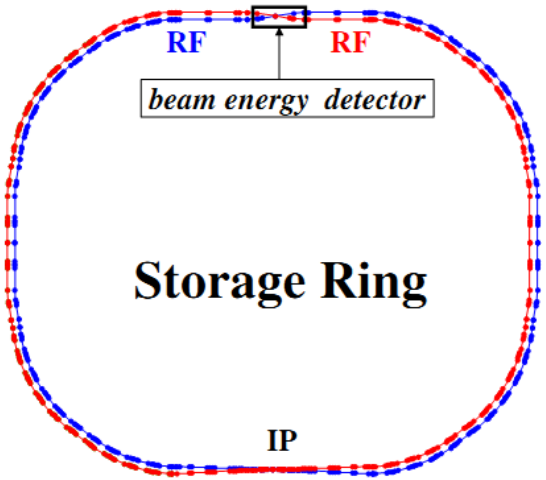
$$Br(J/\psi \rightarrow \gamma\eta(1405) \rightarrow \gamma\pi^0 f_0(980) \rightarrow \gamma\pi^0\pi^+\pi^-) = (1.50 \pm 0.11(stat) \pm 0.11(sys)) \times 10^{-5}$$
$$Br(J/\psi \rightarrow \gamma\eta(1405) \rightarrow \gamma\pi^0 f_0(980) \rightarrow \gamma\pi^0\pi^0\pi^0) = (7.10 \pm 0.82(stat) \pm 0.72(sys)) \times 10^{-6}$$

- Large isospin violating:
  $B(f_0\pi^0)/B(a_0\pi^0)$~18%, one order of magnitude larger than $a_0(980)$-$f_0(980)$ mixing intensity (PRD 83, 032003 (2011))
- Possibly explained by KK*(K) loop, triangle singularity (arXiv: 1108.3772)

τ MASS MEASUREMENT AT BESIII

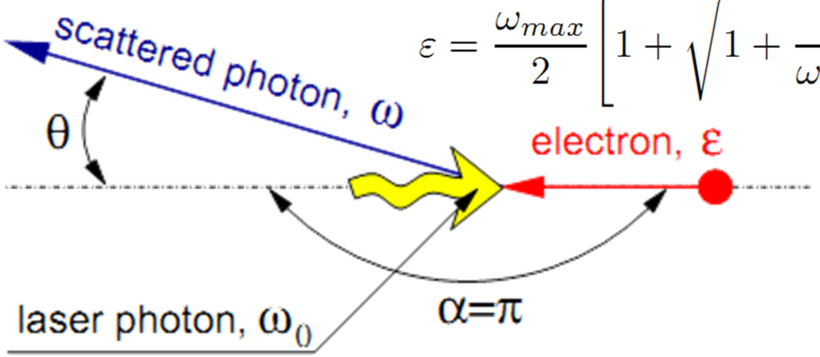
Beam energy measurement for BEPCII

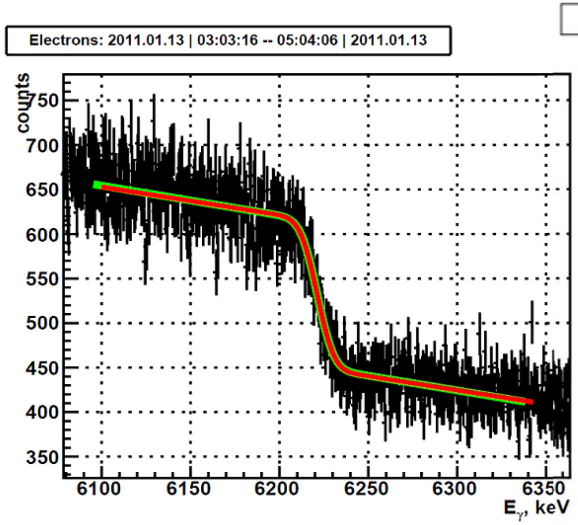
NIMA 659,21 (2011)

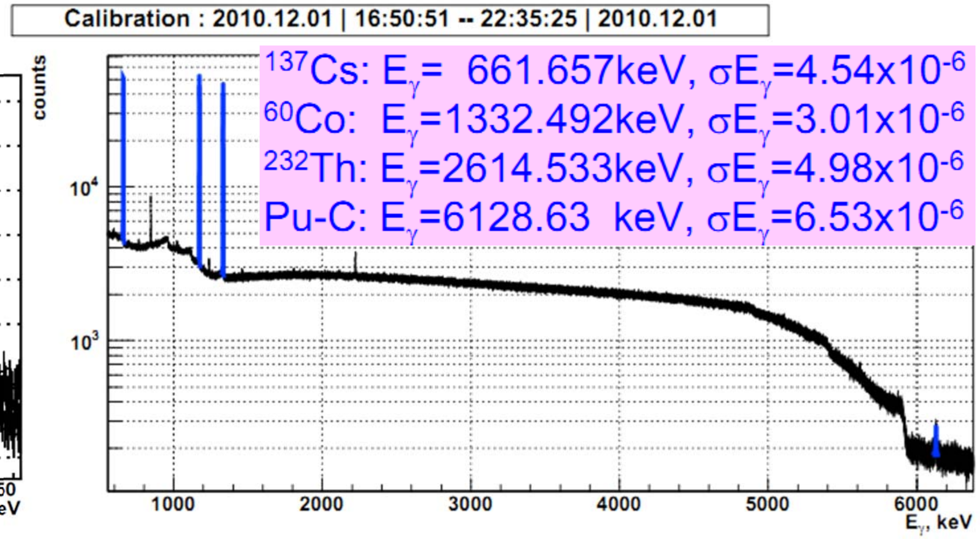


Compton back-scattering technique

$$\varepsilon = \frac{\omega_{max}}{2}\left[1+\sqrt{1+\frac{m_e^2}{\omega_0\omega_{max}}}\right]$$



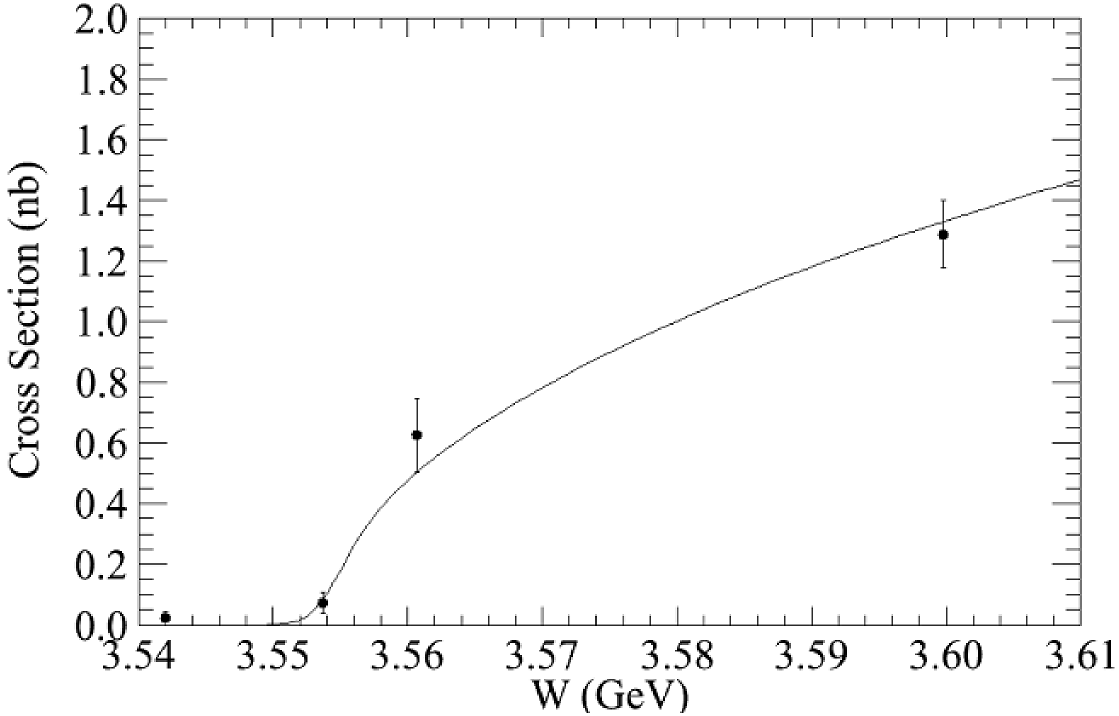




Sys. Error $2*10^{-5}$

τ mass measurement

- Data at 4 energy points were taken (~4-10 pb^{-1} each point) around τ mass threshold.
- The expected statistical uncertainty is ~ 0.3 MeV, systematic error < 0.1MeV.
- More data expected in 2012 to reduce the statistical error to ~0.1MeV.



IHEP-LAL collaboration

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

IHEP
中国科学院高能物理研究所

Michel DAVIER
Bogdan MALAESCU
ZHANG Zhiqing

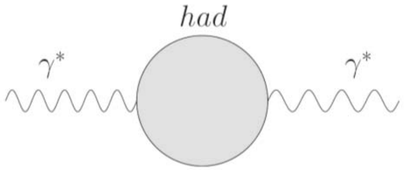
YUAN Changzheng
MO Xiaohu
WANG Ping

WANG Liangliang (co-PhD thesis defended 2009)

Precision measurement of $e^+e^- \rightarrow \pi^+\pi^-$ cross section using ISR method at BaBar

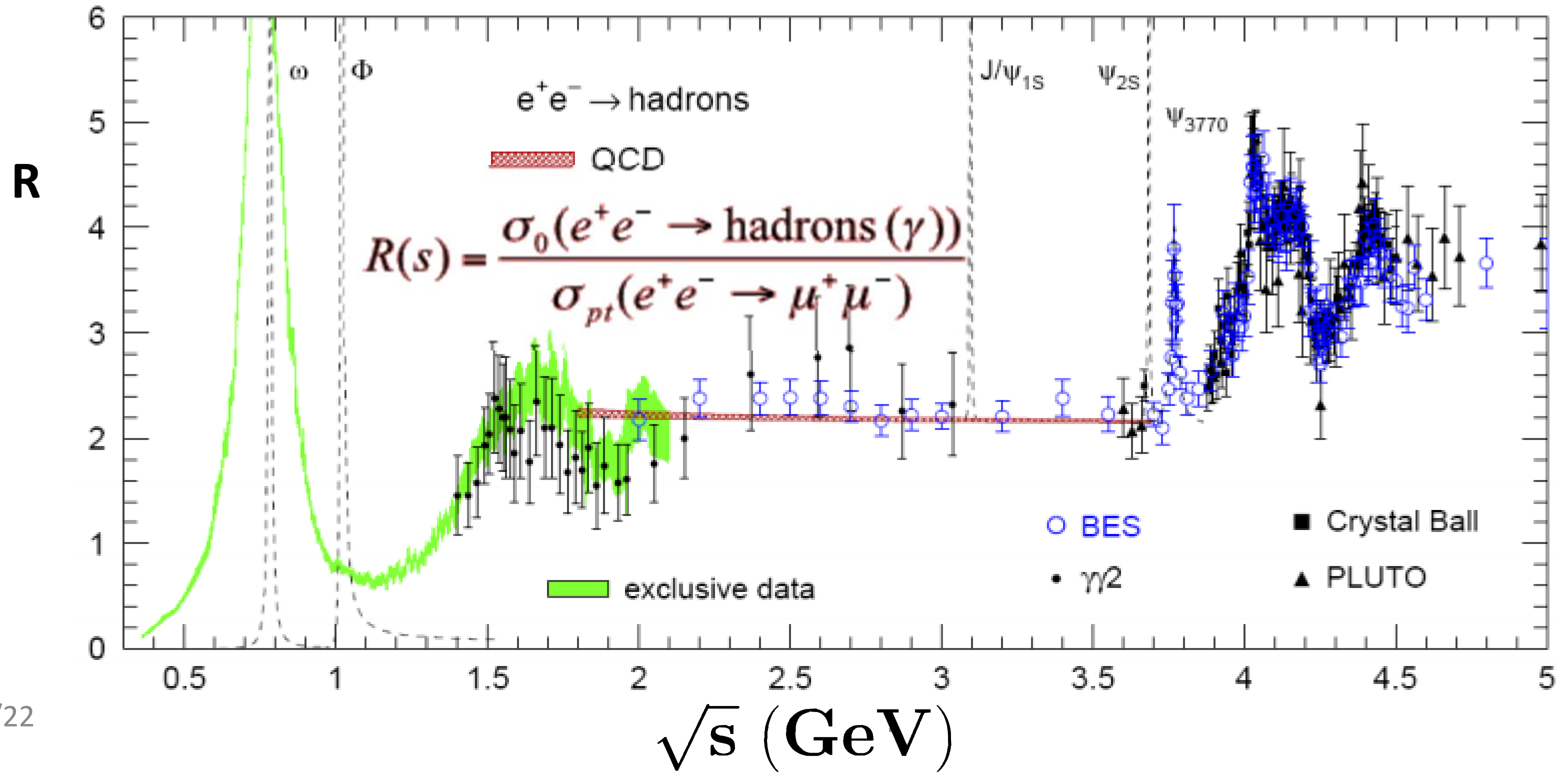
[+A. Höcker (CERN), G. Lopez Castro, G. Toledo (Mexico)]

Hadronic vacuum polarization and R

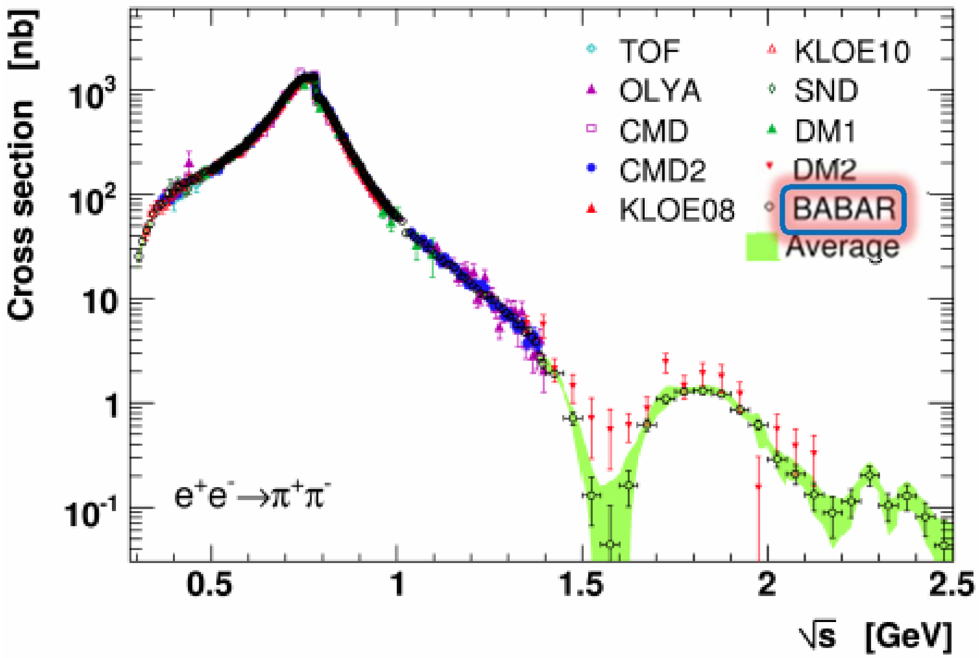


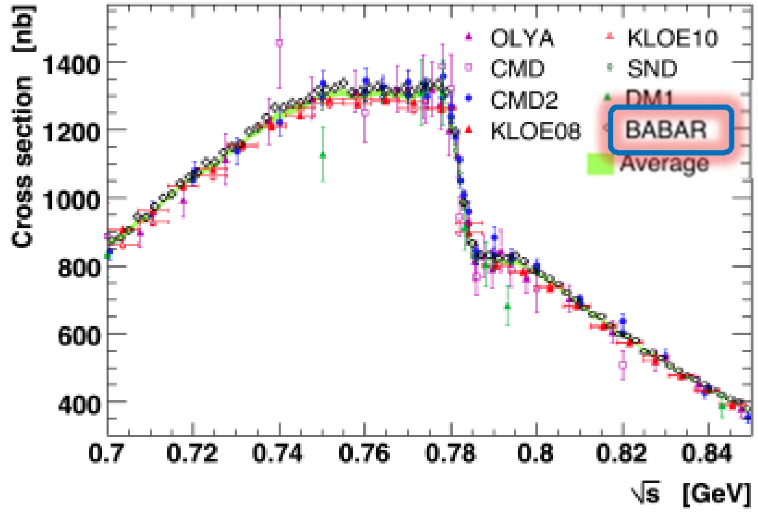
Cannot be calculated from QCD ("first principles")

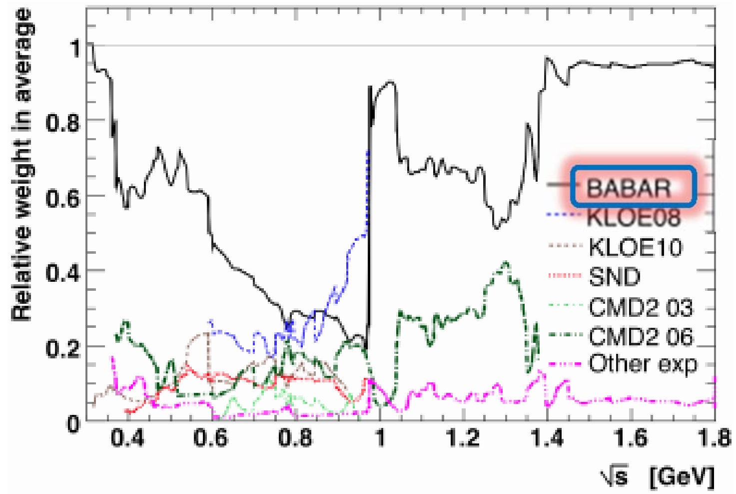
but: we can use experiment!



$\sigma_0(e^+e^- \rightarrow \pi^+\pi^-)$

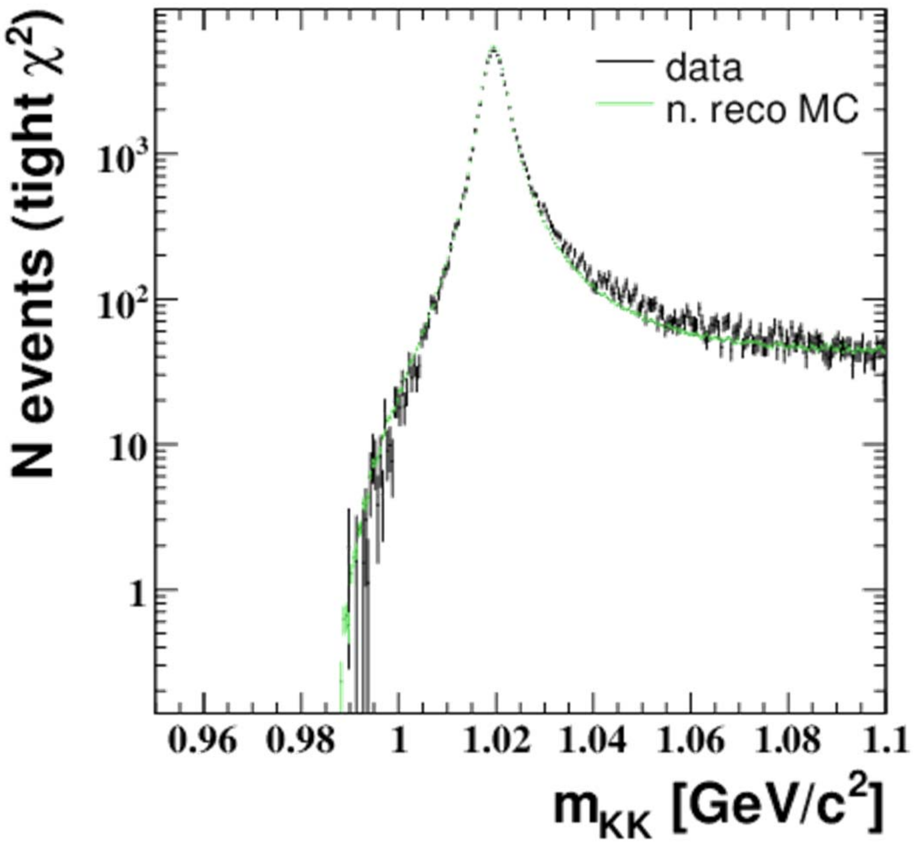


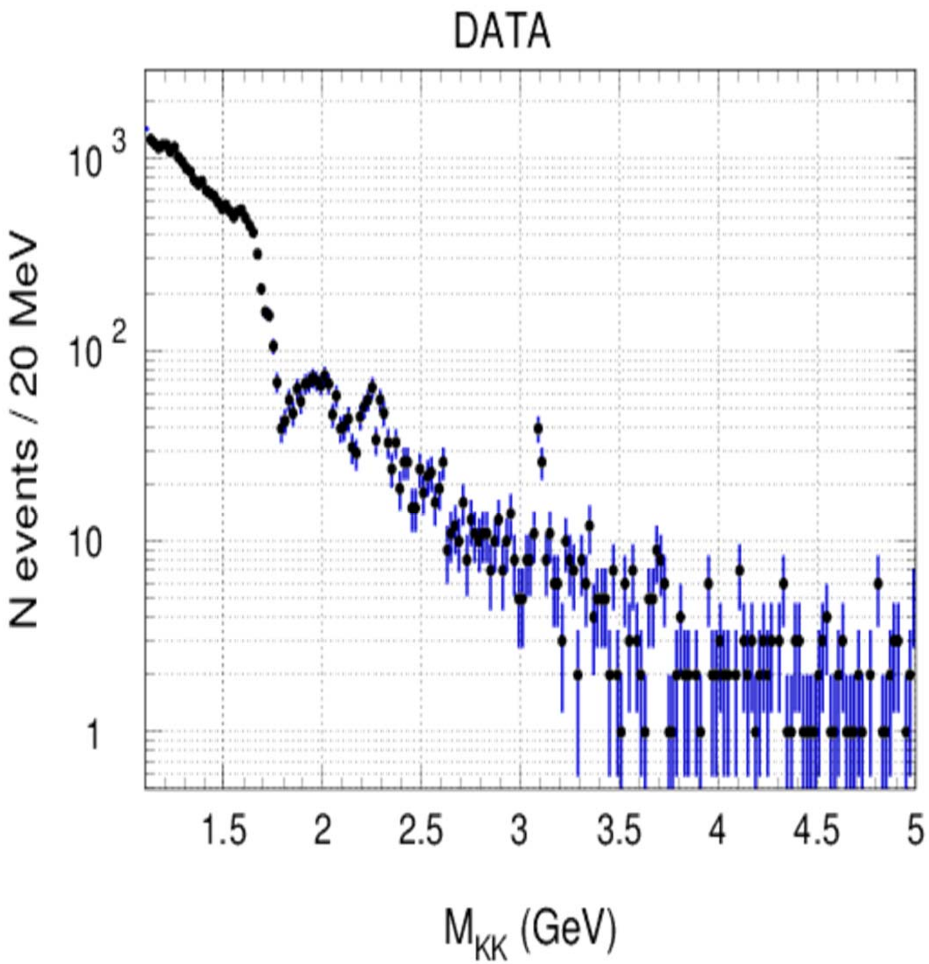




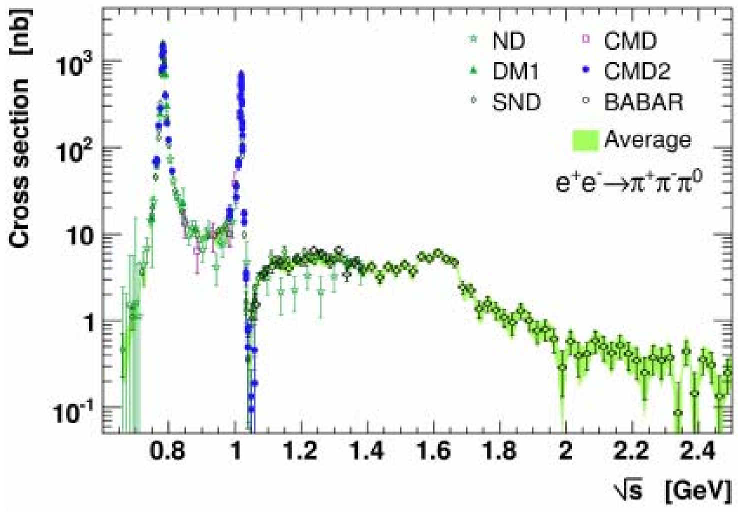
- Measured by many experiments
- BABAR dominates over almost all energy region
- Discrepancy between BABAR and KLOE

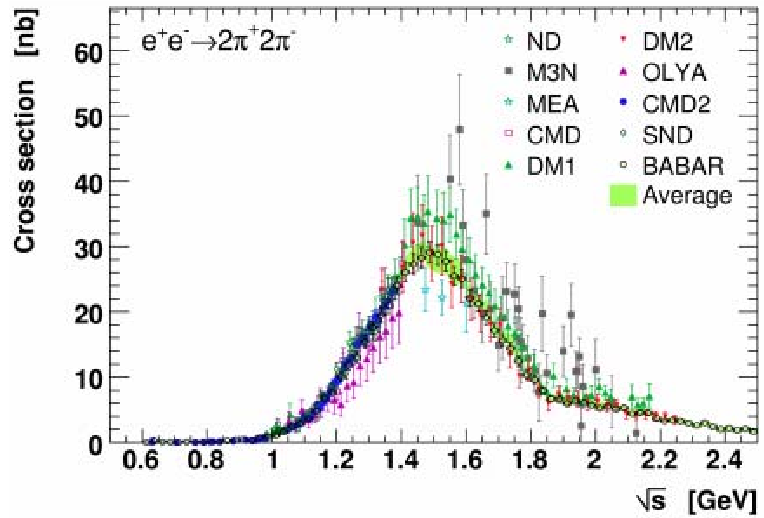
$\sigma_0(e^+e^- \rightarrow K^+K^-)$ measurement via ISR at BaBar (to be published)

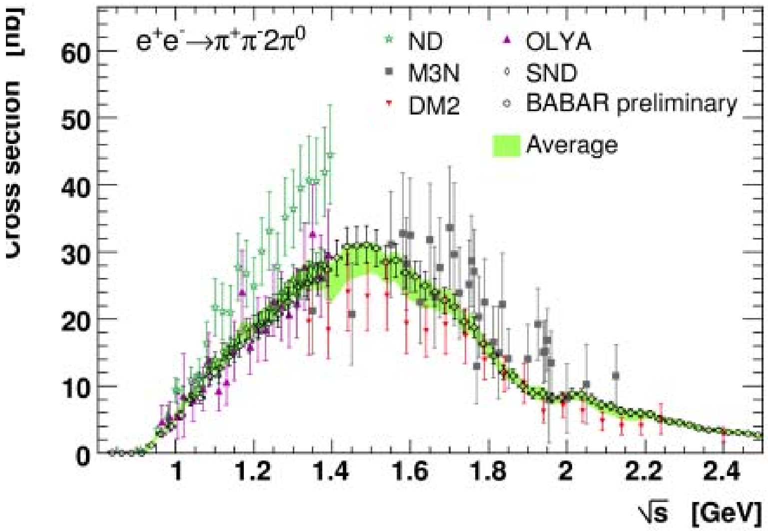




$\pi^+\pi^-\pi^0$, $2(\pi^+\pi^-)$, $\pi^+\pi^-2\pi^0$ channels

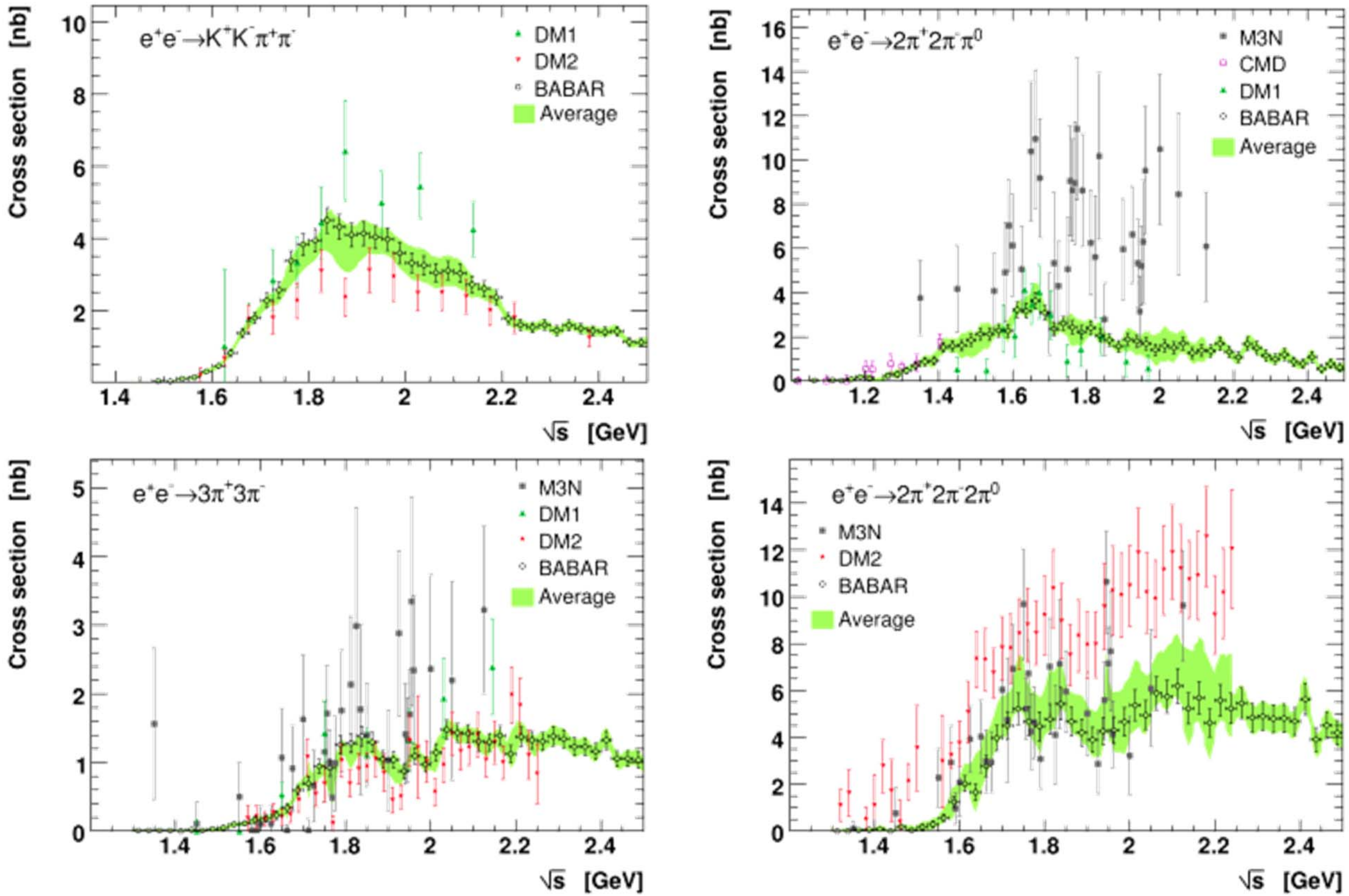




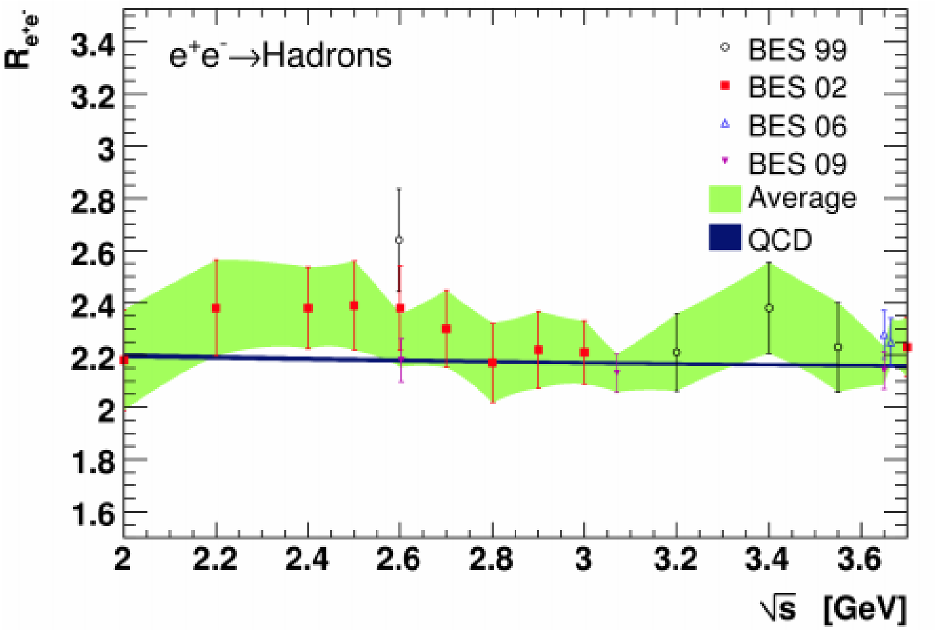


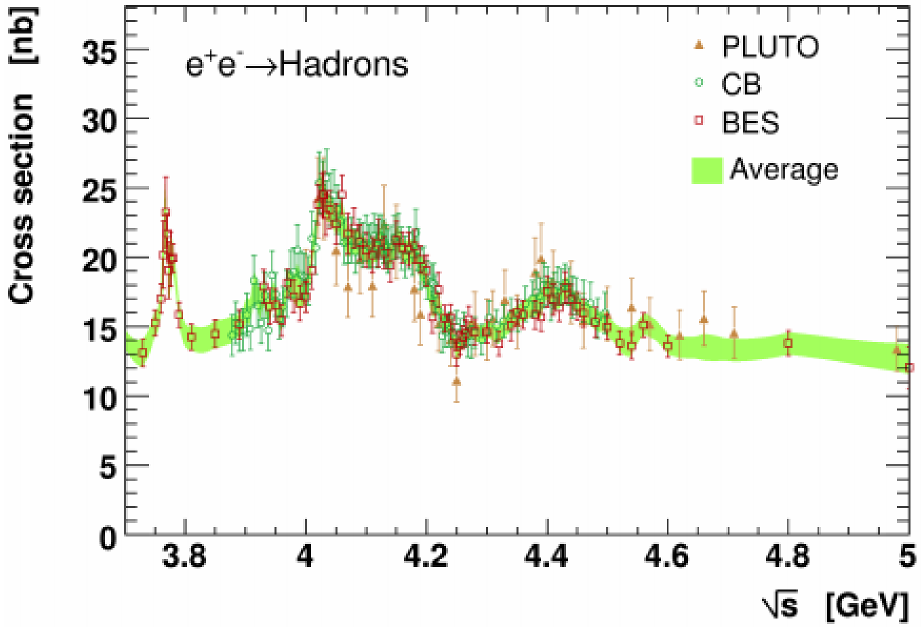
Again BABAR dominates over other experiments though data for $\pi^+\pi^-2\pi^0$ channel still preliminary

Other multi-hadron channels



R below and above the open charm threshold





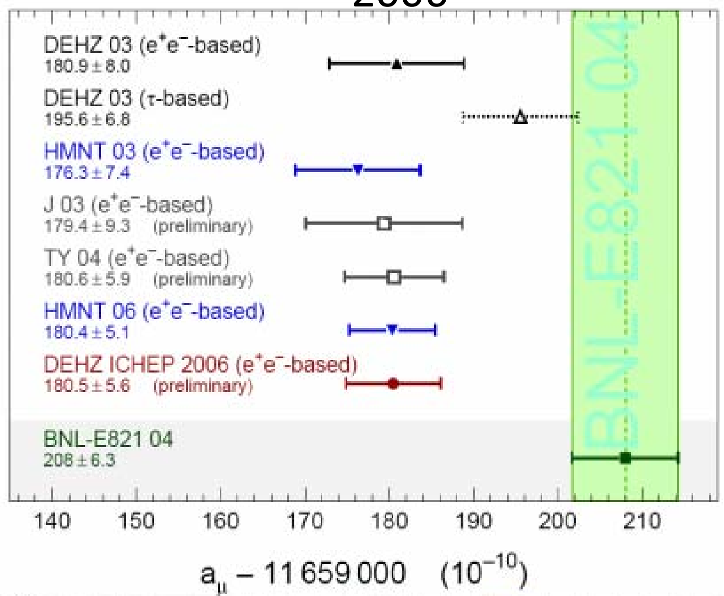
pQCD calculation in good agreement with the direct measurements in non-resonance regions and are applied down to 1.8GeV

BES data precision steadily improving

$R_{\rm QCD}$	$[1.8 - 3.7 \text{ GeV}]_{uds}$
$R_{\rm QCD}$	$[5.0 - 9.3 \text{ GeV}]_{udsc}$
$R_{\rm QCD}$	$[9.3 - 12.0 \text{ GeV}]_{udscb}$
$R_{\rm QCD}$	$[12.0 - 40.0 \text{ GeV}]_{udscb}$
$R_{\rm QCD}$	$[> 40.0 \text{ GeV}]_{udscb}$
$R_{\rm QCD}$	$[> 40.0 \text{ GeV}]_{t}$

Precision predictions on a_μ and $\alpha(M_Z)$

- Muon magnetic anomaly a_μ:
  - one of the most precisely measured and prediction quantities in particle physics
  - sensitive to QED, strong and weak sectors of SM
  - data/prediction discrepancy → hint for new physics
  - discrepancy ee & τ-based predictions

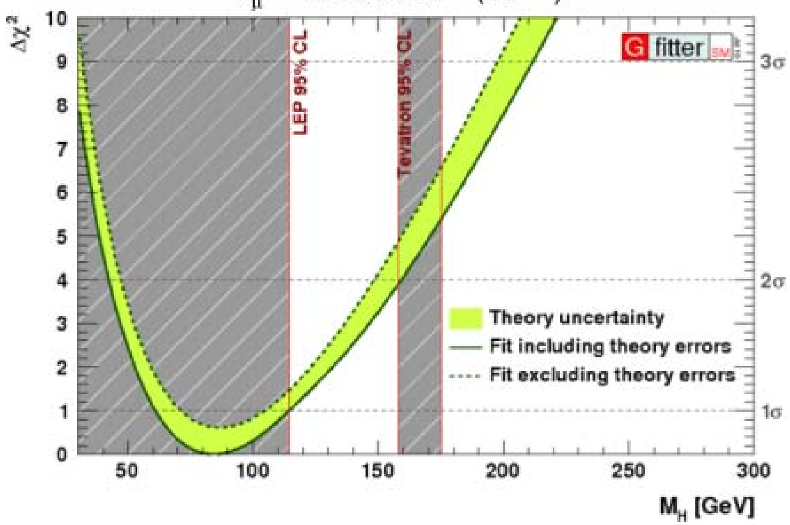


- Running fine-structure constant $\alpha(M_Z)$:

$$\alpha(M_Z) = \frac{\alpha}{1 - \Delta\alpha(M_Z)}$$

$$\Delta\alpha(M_Z) = \Delta\alpha_{\text{leptonic}}(M_Z) + \Delta\alpha_{\text{had}}(M_Z)$$

  - one of limiting factors for global fit to EW precision data
  - an example constraint is on Higgs mass



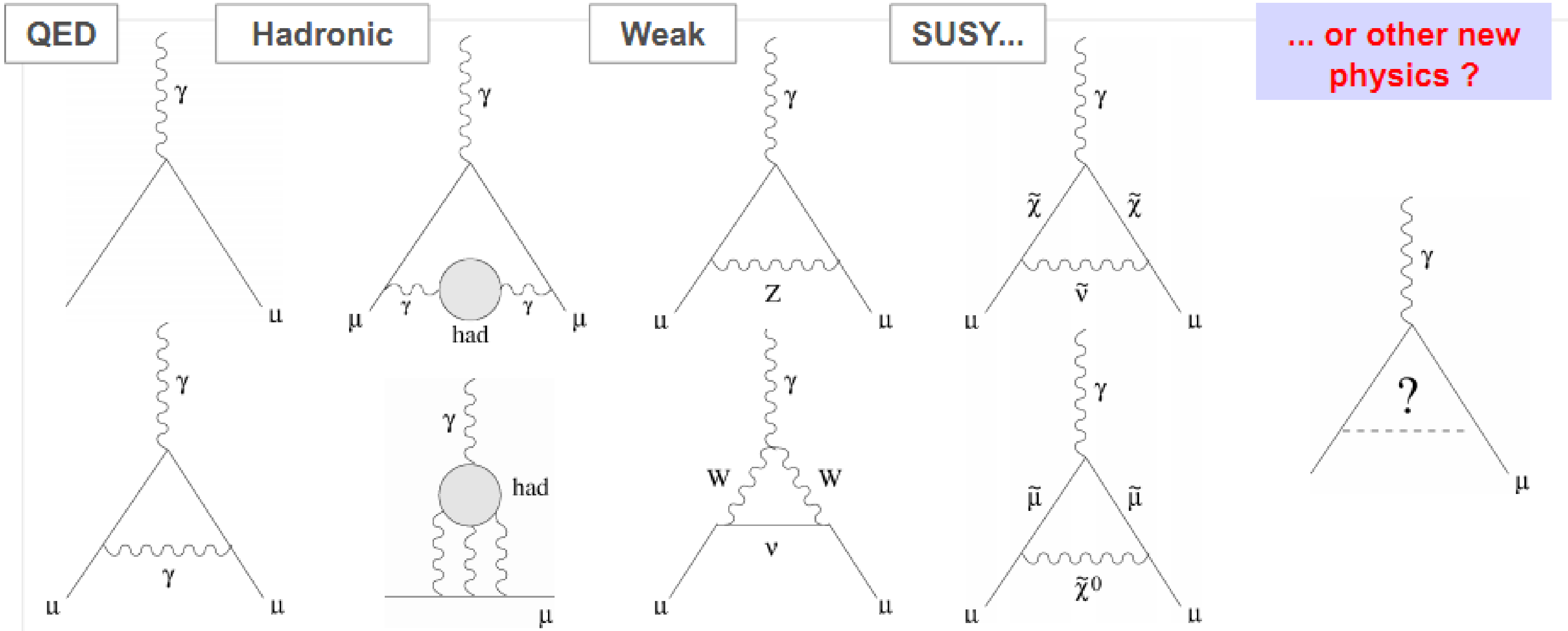
Muon magnetic moment anomaly

$\vec{\mu} = g \frac{\pm e}{2m} \vec{s}$ $\quad g = 2 + \cdots$ $\quad$ → Magnetic Moment anomaly: $a_l = \frac{g-2}{2}$

a_e is better measured but a_μ is more sensitive to new physics effects by $(m_\mu/m_e)^2 \sim 43000$

(>99%) (10^{-6}) → Dominant error

$$a_\mu^{th} = a_\mu^{SM} + a_\mu^{non\text{-}SM}, \qquad a_\mu^{SM} = a_\mu^{QED} + a_\mu^{had} + a_\mu^{Weak}$$



a_μ^{had}

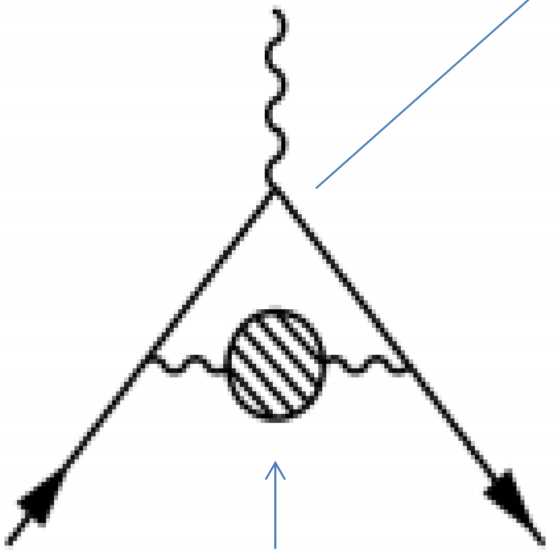
$$a_\mu^{had} = a_\mu^{had,LO} + a_\mu^{had,HO} + a_\mu^{had,LBL}$$

Dominant error

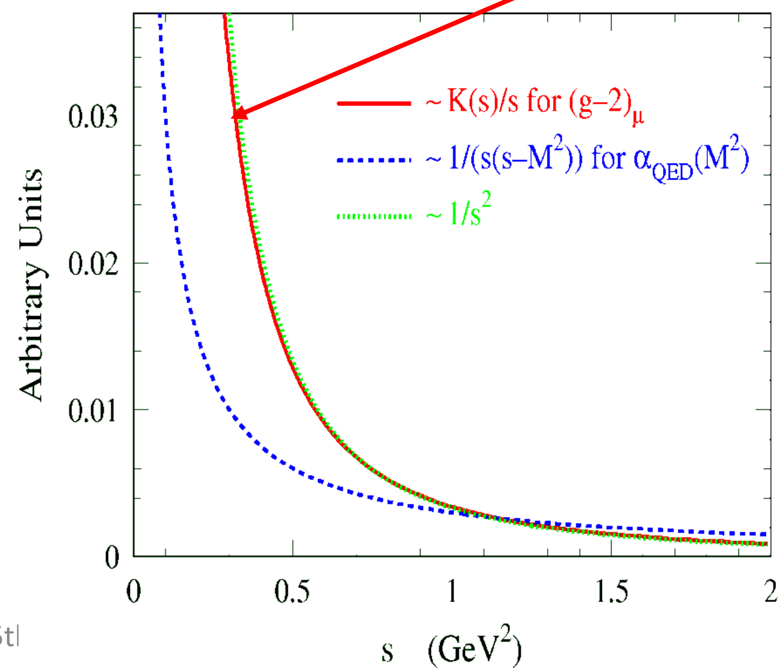
Isospin symmetry connect I=1 e+e- cross section to vector τ spectral functions

Can be rigorously calculated using ee annihilation data via dispersion relation:

$$a_\mu^{had,LO} = \frac{\alpha^2}{3\pi^2} \int_{4m_\pi^2}^{+\infty} ds \frac{K(s)}{s} R(s)$$



Vacuum Polarization

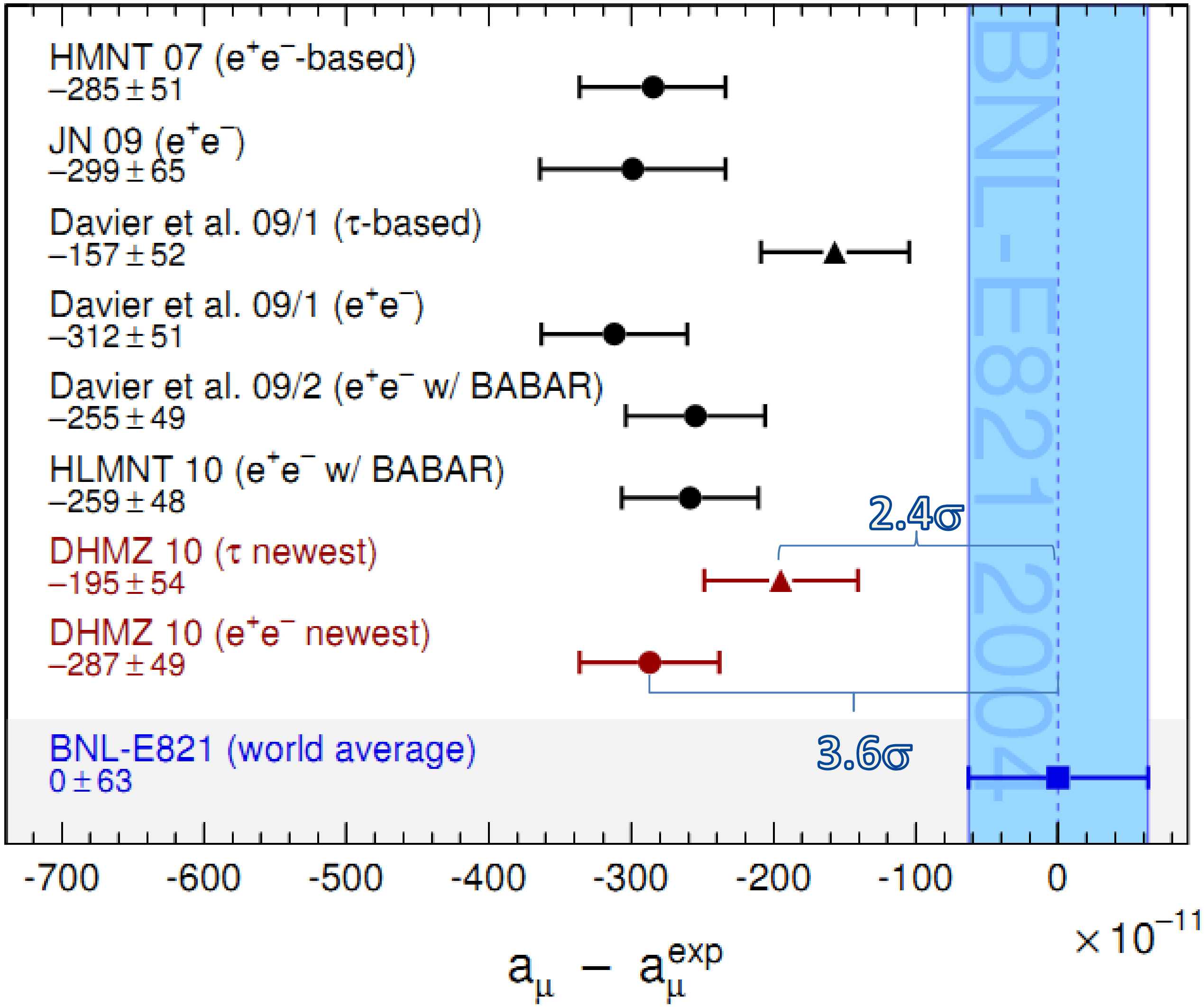


New items in the reevaluation of a_μ and $\alpha(M_Z)$

Eur. Phys. J. C71 (2011) 1, arXiv:1010.4180v2 [hep-ph].

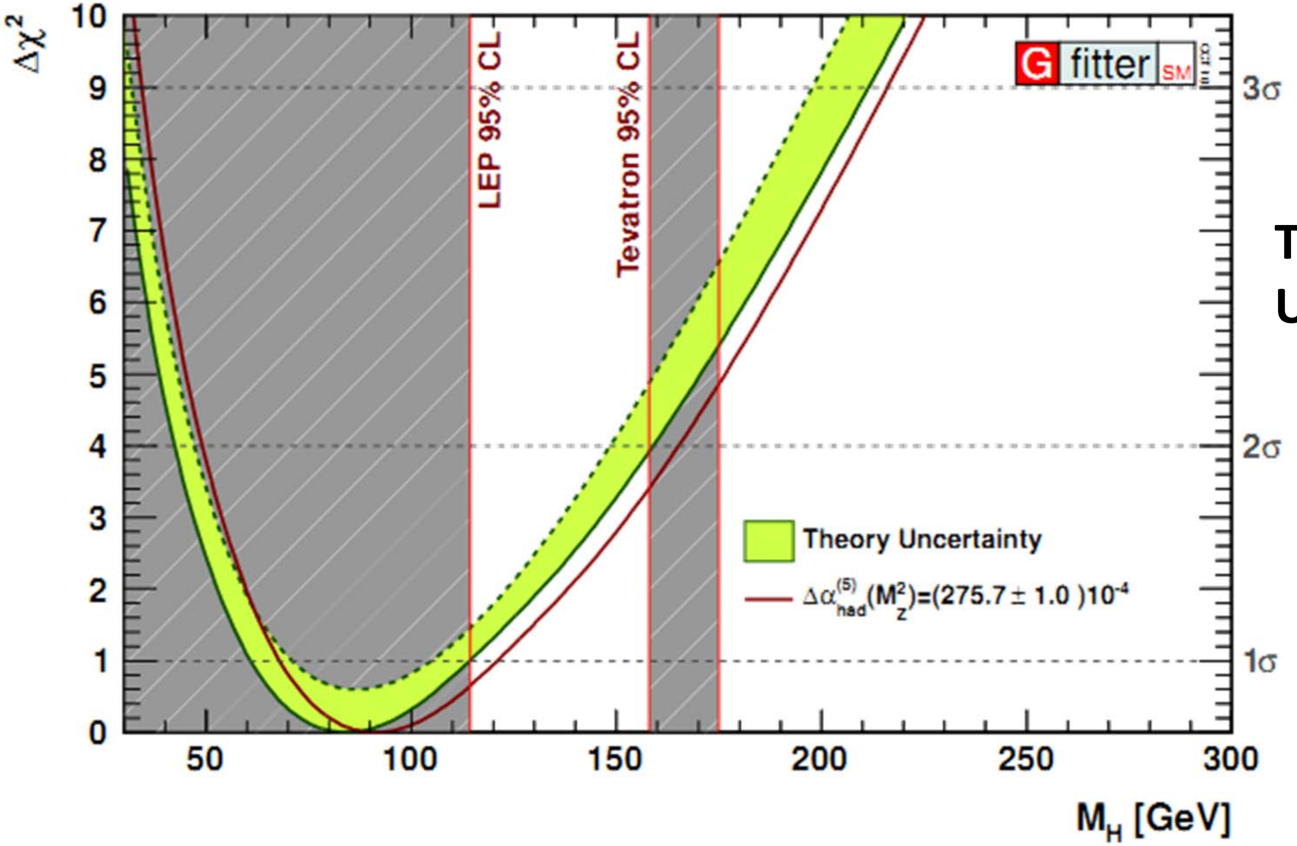
- τ based prediction
  - Revisited iso-spin corrections (Eur. Phys. J. C66 (2010) 127, arXiv:0906.5443v2 [hep-ph])
  - New data from Belle
- New ee annihilation data
- Include the unmeasured channels through iso-spin relations
- New HVPTools package
  - data combination
  - data interpolation
  - handling inter-exp, inter-channel correlations

a_μ prediction and measurement comparison



New result on $\alpha(M_Z)$ and constraint on m_{Higgs}

$$\Delta\alpha_{\rm had}(M_Z^2) = (275.0 \pm 1.0) \cdot 10^{-4} \Rightarrow \alpha^{-1}(M_Z^2) = 128.952 \pm 0.014$$



The fitted m_H=91^{+30}_{-23}GeV
Up limits: 163GeV@95%CL
193GeV@99%CL

Summary

- BESIII is running well and accumulated the world largest samples at J/ψ, ψ', ψ'' peaks and 4.01GeV.
- Lots of results have been published and more are coming soon (esp. on open charm).
- The collaboration between IHEP-LAL is quite active and fruitful.
- Precise measurement of hadron cross section, and prediction of a_μ and $\alpha(M_Z)$.
- We shall continue the project (e.g. new e+e- data, R, τ at BESIII).