Recent Results from BESIII

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(For BESIII Collaboration)

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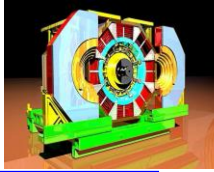
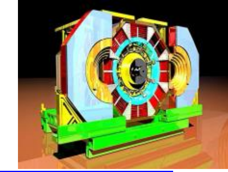
Workshop on τ-charm at High Luminosity, Isola d'Elba, Italy

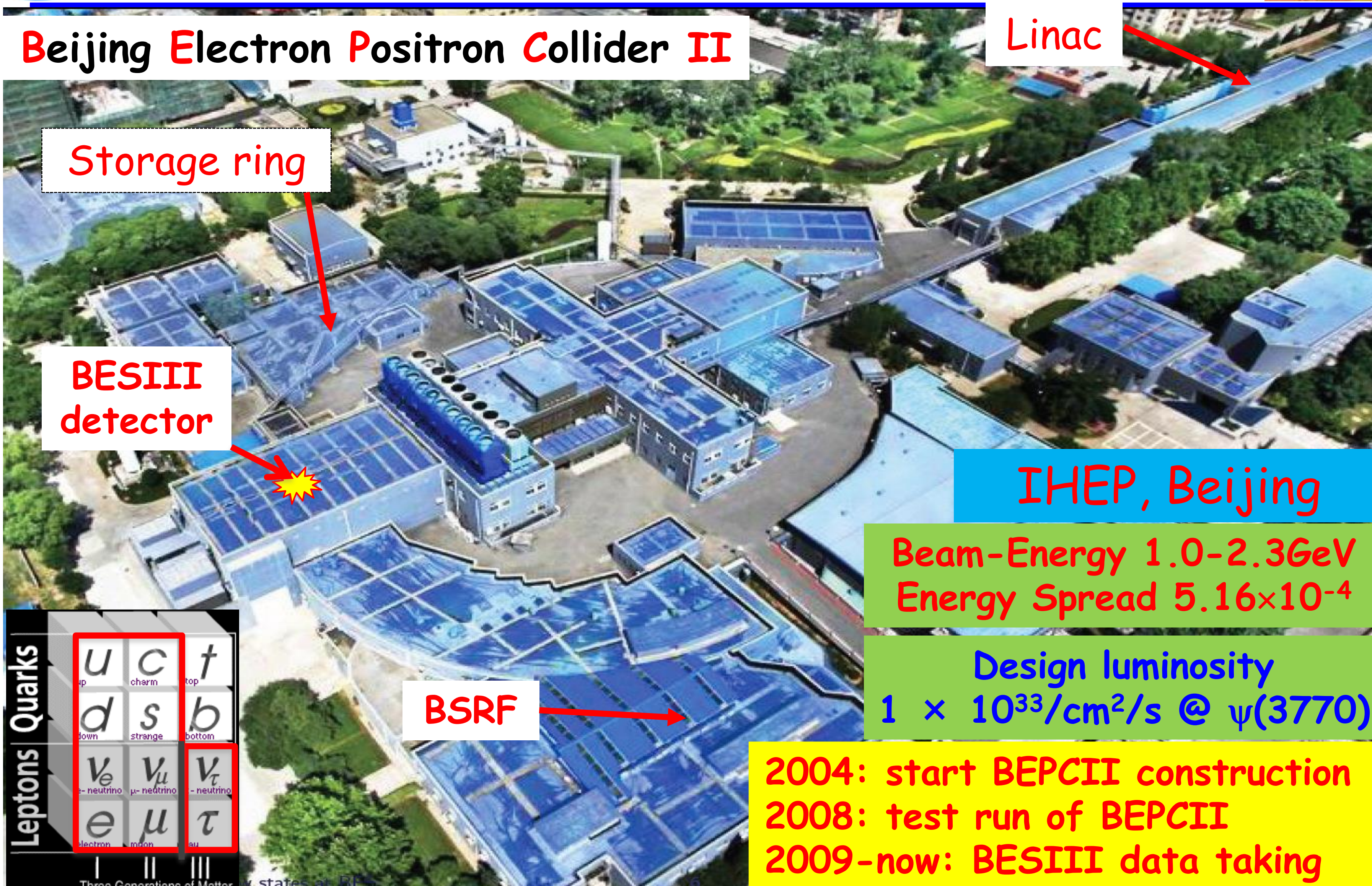


Outline

- **Status of BEPCII/BESIII**
- **Selected Results from BESIII**
  - Light Hadrons Spectroscopy
  - Charm Decays
  - New Physics Search and SM Test
- **Summary**



Bird view of BEPCII /BESIII

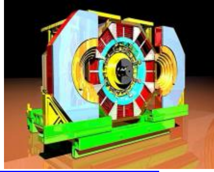


Beam-Energy 1.0-2.3GeV
Energy Spread 5.16×10^{-4}

Design luminosity
$1 \times 10^{33}/cm^2/s$ @ ψ(3770)

2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BESIII data taking

BESIII Detector



NIM A614, 345 (2010)

Drift Chamber (MDC)

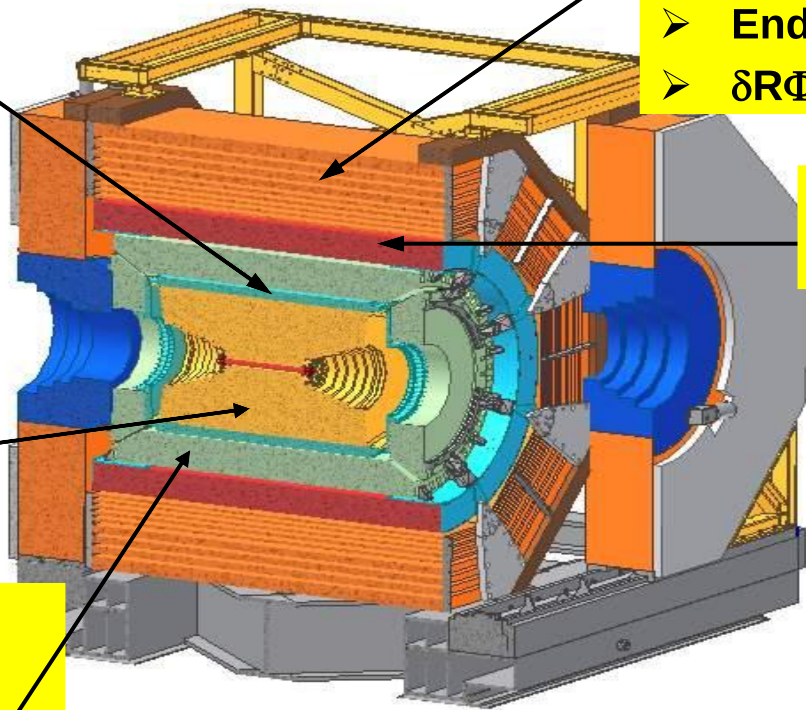
- Small cell, 43 layer
- Gas He/C_3H_8=40/60
- $\sigma P/P$ ($^0/_0$) = 0.5%(1GeV)
- $\sigma_{dE/dx}$ ($^0/_0$) = 6%

Time Of Flight (TOF)

- Plastic Scintillator
- σ_T (Barrel) : 90 ps
- σ_T (Endcap) : 110 ps
- Endcap upgrading ......

EM Calorimeter

- CSI(Tl) : L=28cm (15 X_0)
- Energy Range : 0.02-2GeV
- $\sigma E/\sqrt{E}$($^0/_0$) = 2.5 % (1 GeV)
- $\sigma_{z,\phi}$(cm) = 0.5 - 0.7 cm/$\sqrt{E}$



Muon Counter

- Resistive Plate Chamber
- Barrel: 9 layers
- Endcaps: 8 layers
- $\delta R\Phi$=1.4 cm~1.7 cm

Super-conducting

magnet (1.0 Tesla)

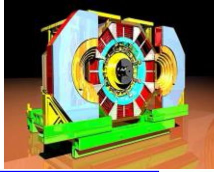
RO channels: 10^4
Cost: 200 M RMB

Data acquisition

- Event rate: 4 kHz
- Data size: 50 MB/s

"Grid" computing

- CPU: 3200 core
- Storage: 2.2 pB



BESIII Collaboration

Europe (12)

Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. ofJohannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino, Frascati Lab
Netherland : KVI/Univ. of Groningen
Turkey: Turkey Accelerator Center

US (6)

Univ. of Hawaii
Univ. of Washington
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Korea (1)

Seoul Nat. Univ.

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

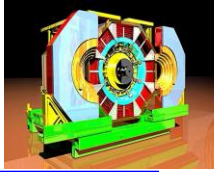
China(30)

IHEP, CCAST, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Hong Kong Univ., Hong Kong Chinese Univ.
Univ. of South China, GUCAS.

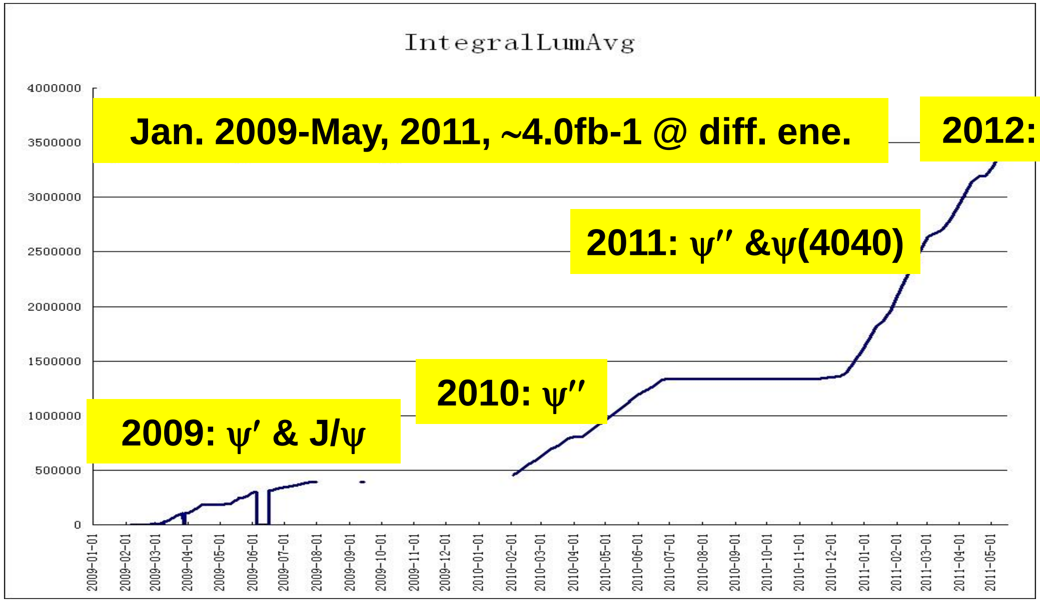
Japan (1)

Tokyo Univ.

351 Authors, 11 Countries, 52 Institutions,



BESIII Commissioning



Jan. 2009-May, 2011, ~4.0fb-1 @ diff. ene.

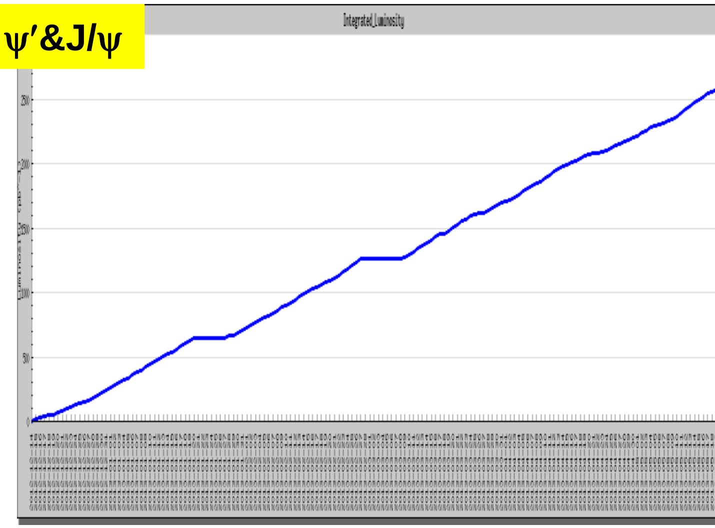
2009: ψ′ & J/ψ

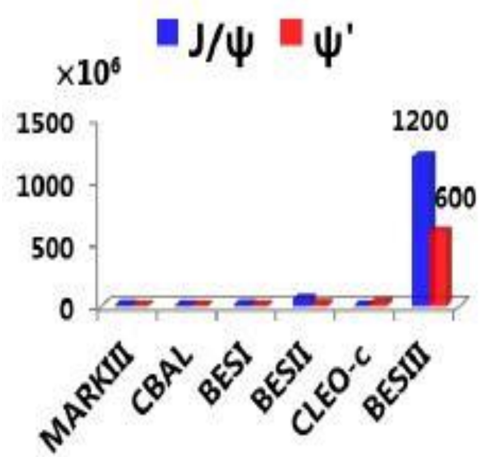
2010: ψ″

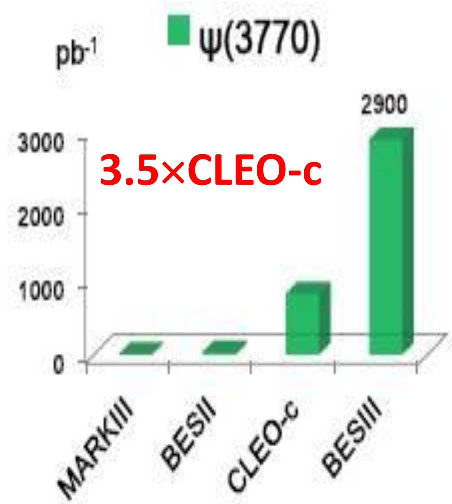
2011: ψ″ &ψ(4040)

2012: ψ′&J/ψ

2.6fb^{-1} XYZ data (25pb^{-1}/day)



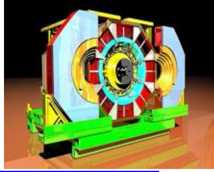




- 12pb^{-1} @ 2.23, 2.4, 2.8, 3.4
- 25pb^{-1} @ τ mass Scan

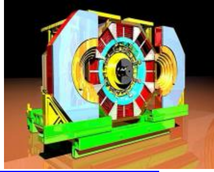
BES have collected World's largest threshold produced sample of J/ψ, ψ′, ψ″ and XYZ data!!!

Physics Programs @ BESIII



- ***Light hardron physics***
  - meson & baryon spectroscopy
  - threshold effects
  - multiquark states
  - glueballs & hybrids
  - two-photon physics
  - form-factors
- ***Charmonium physics:***
  - precision spectroscopy
  - transitions and decays
- ***QCD & τ-physics:***
  - precision R-measurement
  - τ mass / τ decays
- ***Charm physics:***
  - (semi-)leptonic form factors
  - f_D & f_{Ds} decay constants.
  - CKM matrix: V_{cd} , V_{cs}
  - D^0-D^0 mixing and CPV
  - strong phases
- ***SM Test & New Physics Searches :***
  - η&η'decay physics
  - Light dark matter, LFV ……
  - Rare decay
- ***XYZ meson physics:***
  - Y(4260) $\pi\pi h_c$ decays
  - Searches for new states

Physics Programs @ BESIII



➢ *Light hardron physics*
- meson & baryon spectroscopy
- threshold effects
- multiquark states
- glueballs & hybrids
- two-photon physics
- form-factors

➢ *Charmonium physics:*
- precision spectroscopy
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➢ *QCD & τ-physics:*
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➢ *SM Test & New Physics Searches*
- η&η'decay physics
- Light dark matter, LFV ……
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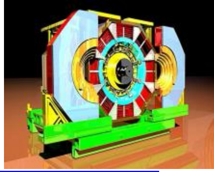
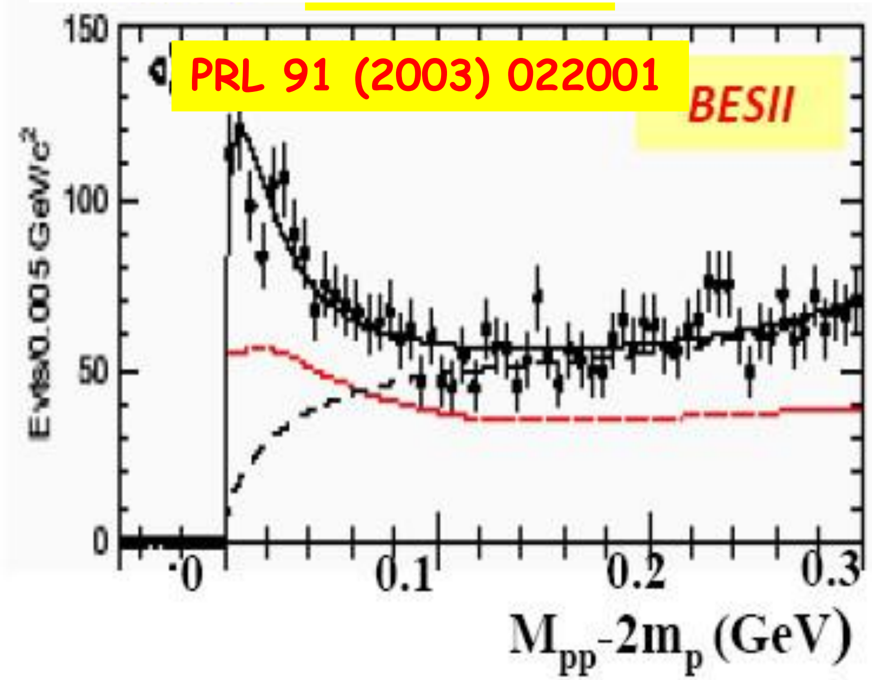
➢ *XYZ meson physics:*
- Y(4260) $\pi\pi h_c$ decays
- Searches for new states

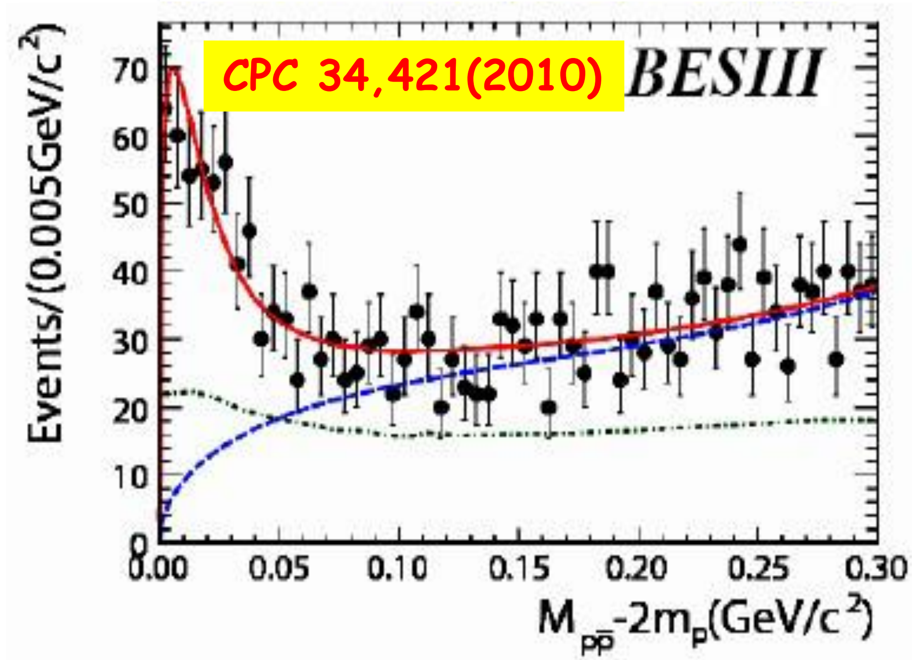
$p\bar{p}$ Threshold Enhancement



BESII 58M J/ψ: $J/\psi \to \gamma p\bar{p}$

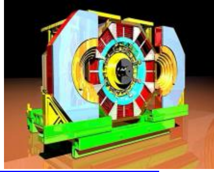


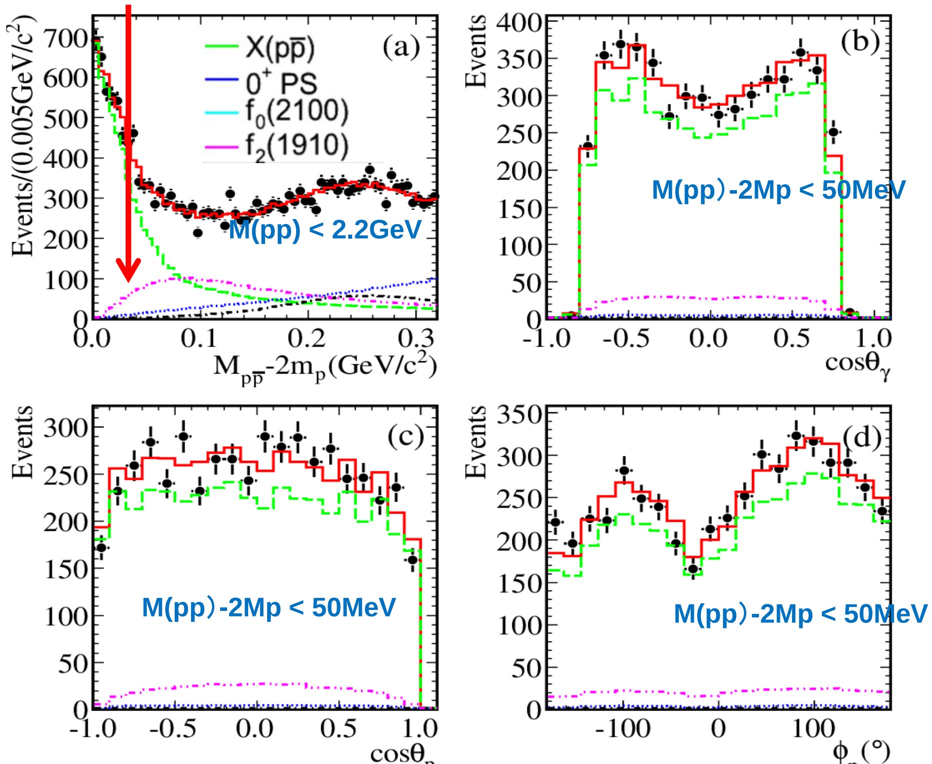
$\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to \gamma p\bar{p}$



- **Observed at BESII:**
  - Agree with spin zero expectation
  - $M = 1860_{-10-25}^{+3+5}$ MeV/c^2
  - $\Gamma < 38$ MeV/c^2 (90% C.L.)
- **Confirmed at BESIII in 2010:**
  - $M = 1859_{-13-26}^{+6+6}$ MeV/c^2
  - $\Gamma < 30$ MeV/c^2 (90% C.L.)

PWA of $J/\psi \to \gamma p\bar{p}$ (m_{pp}<2.2GeV)





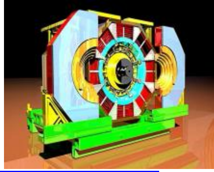
- ✓ **BESIII 5 Times more data**
- ✓ **Include the FSI effect**
- ✓ **Fit features:**
  - — The fit with BW and S-wave FSI (I=0) factor can well describe $p\bar{p}$ mass threshold structure.
  - — It is much better than that w/o FSI effect (7.1σ)
  - — Different FSI model → Model dependent uncertainty

✓ BESIII Results:

- — $J^{PC} = 0^{-+}$, >6.8σ better than other J^{PC} assignments.
- — $M = 1832^{+19}_{-5}(stat)^{+18}_{-17}(syst) \pm 19(model)\ MeV/c^2$
- — $\Gamma = 13 \pm 39(stat)^{+10}_{-13}(syst) \pm 4(model)\ MeV/c^2$ or $\Gamma < 76 MeV/c^2$ @ 90 C.L.
- — $Br(J/\psi \to \gamma X(p\bar{p})) \times Br(X(p\bar{p}) \to p\bar{p}) = (9.0^{+0.4}_{-1.1}(stat)\ ^{+1.5}_{-5.0}(syst) \pm 2.3(model)) \times 10^{-5}$

PRL 108,112003(2012)

Suggest Br(X→ $p\bar{p}$) is large !!!

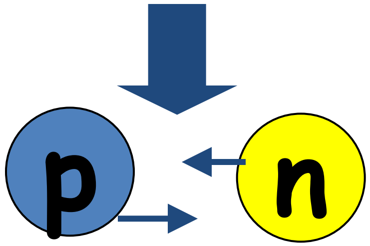


A $p\bar{p}$ bound state (baryonium)?

- **Many theoretical Interpretation:**
  - Normal meson, multi-quark, glueball….
  - Final state interaction (FSI)
  - $p\bar{p}$ bound state?

deuteron

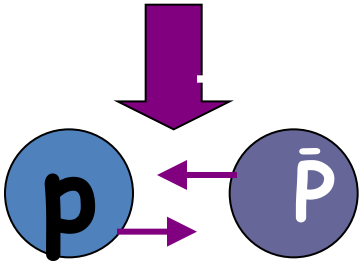
attractive nuclear force



loosely bound 3-q & 3-q color singlets with $M_d=2m_p-\varepsilon$

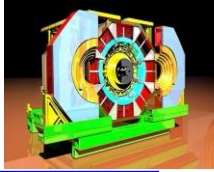
Baryonium

attractive nuclear force?



loosely bound 3-q & 3-$\bar{q}$ color singlets with $M_b=2m_p-\delta$?

A $p\bar{p}$ bound state (baryonium)?



Fermi & Yang in 1949
(7 years before p discovery):

If NN potential is attractive, they could bind to form π-like states.

THE

PHYSICAL REVIEW

A journal of experimental and theoretical physics established by E. L. Nichols in 1893

SECOND SERIES, VOL. 76, NO. 12 DECEMBER 15, 1949

Are Mesons Elementary Particles?

E. FERMI AND C. N. YANG*
Institute for Nuclear Studies, University of Chicago, Chicago, Illinois

(Received August 24, 1949)

The hypothesis that π-mesons may be composite particles formed by the association of a nucleon with an anti-nucleon is discussed. From an extremely crude discussion of the model it appears that such a meson would have in most respects properties similar to those of the meson of the Yukawa theory.

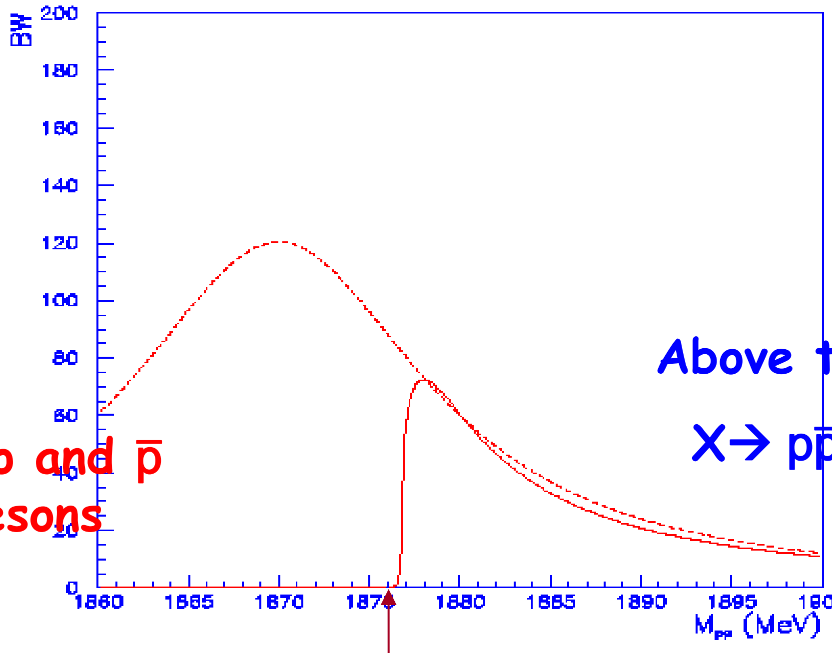
A $p\bar{p}$ bound state (baryonium)?

If baryonium :

—Above-threshold : $X \to p\bar{p}$ ~100%

—Below-threshold : annihilate to mesons

—I=0, $J^{PC}=0^{-+}$, decay to $\pi^+\pi^-\eta'$ is common



below-threshold: p and $\bar{p}$ annihilate to mesons

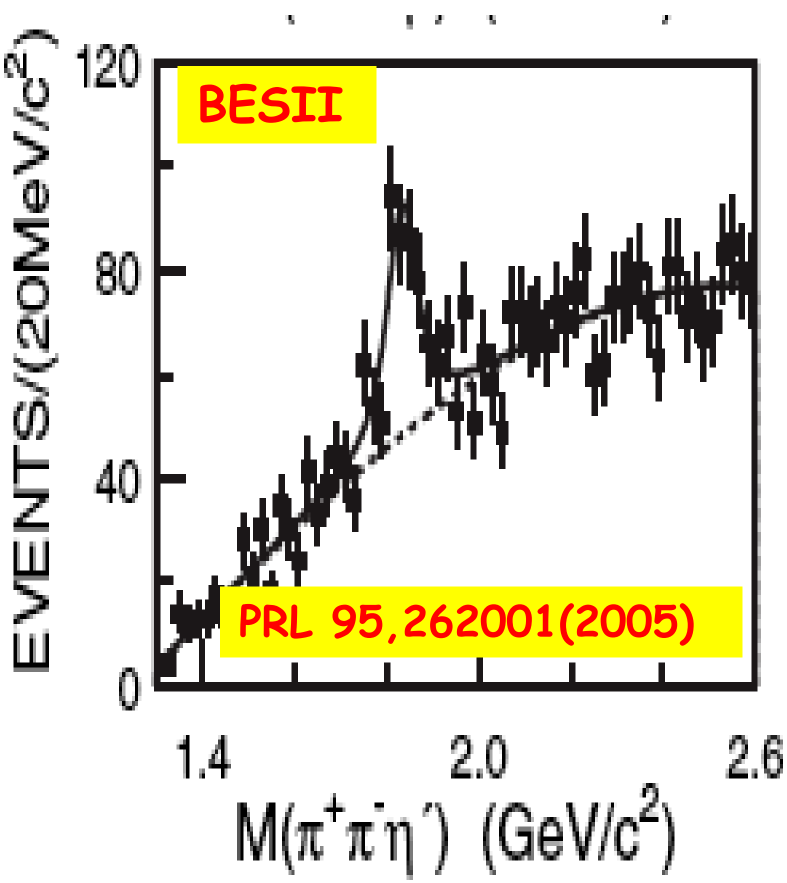
Above threshold: $X \to p\bar{p}$ ~100%

$m_p + m_p$

Phys. Rev. C 72, 015208 (2005) G.J. Ding and M.L.Yan

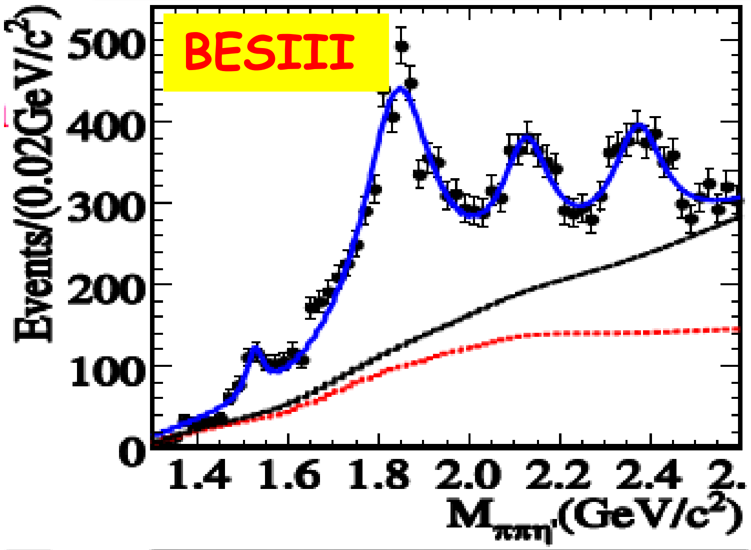
Comm. Theor. Phys. 42, 844 (2004) C.S. Gao and S.L. Zhu

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



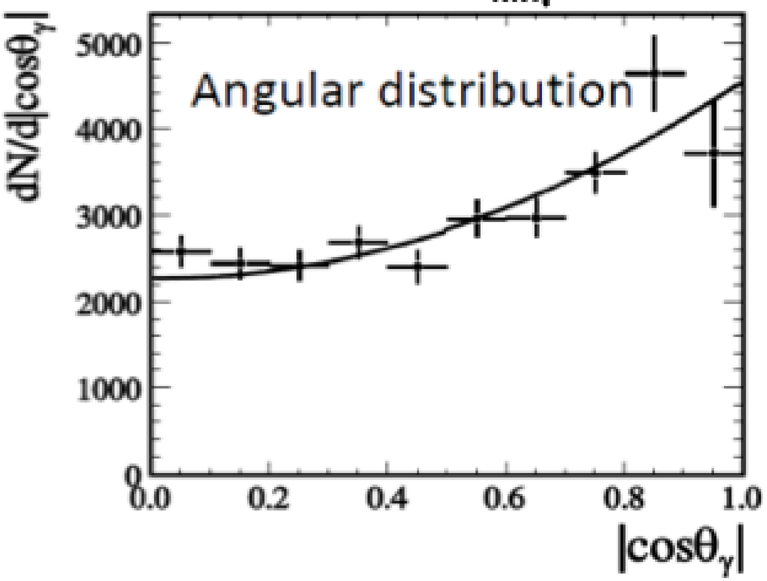
- **BESII Results:**
  - M=1833.7±6.1(stat)±2.7(syst) MeV/c^2
  - Γ=67.7 ±20.3(stat) ±7.7(syst) MeV/c^2
  - $B(J/\psi \to \gamma X(1835))B(X(1835) \to \pi^+\pi^-\eta')$ =(2.2±0.4(stat)±0.4(syst))×10^{-4}
  - Statistical Significance 7.7σ
- **Many Theoretical interpretations:**
  - $p\bar{p}$ bound state
  - η excitation
  - ….
  - Are $X(p\bar{p})$ and X(1835) from the same source?

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



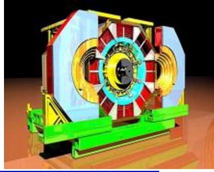
PRL 106, 072002 (2011)

resonance	$M(\mathrm{MeV}/c^2)$	$\Gamma(\mathrm{MeV}/c^2)$	significance
X(1835)	1836.5 ± 3.0	190.1 ± 9.0	$>> 20\sigma$
X(2120)	2122.4 ± 6.7	84 ± 16	$> 7.2\sigma$
X(2370)	2376.3 ± 8.7	83 ± 17	$> 6.4\sigma$



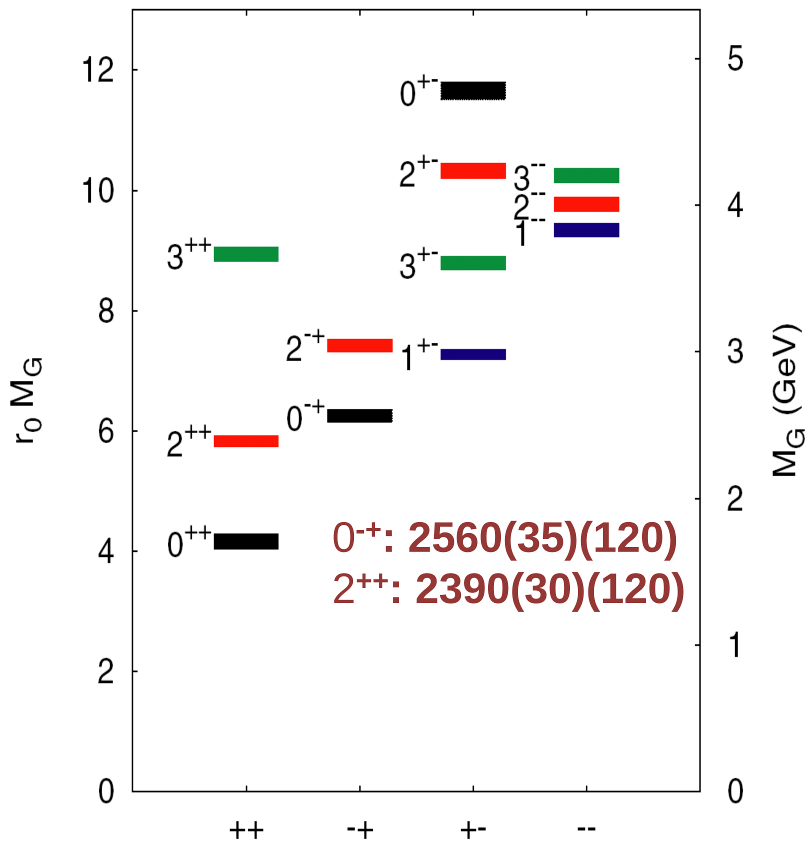
✓ **BESIII Results:**

- **$B(J/\psi \to \gamma X(1835)) B(X(1835) \to \pi^+\pi^-\eta')$ =**
  $$(2.87 \pm 0.09(stat)^{+0.49}_{-0.52}(syst)) \times 10^{-4}$$
- **The polar angle of the photon is consistent with expectation for a pseudoscalar.**
- **Two more structures are observed.**



What are the two new structures?

PRD73,014516(2006) Y.Chen et al

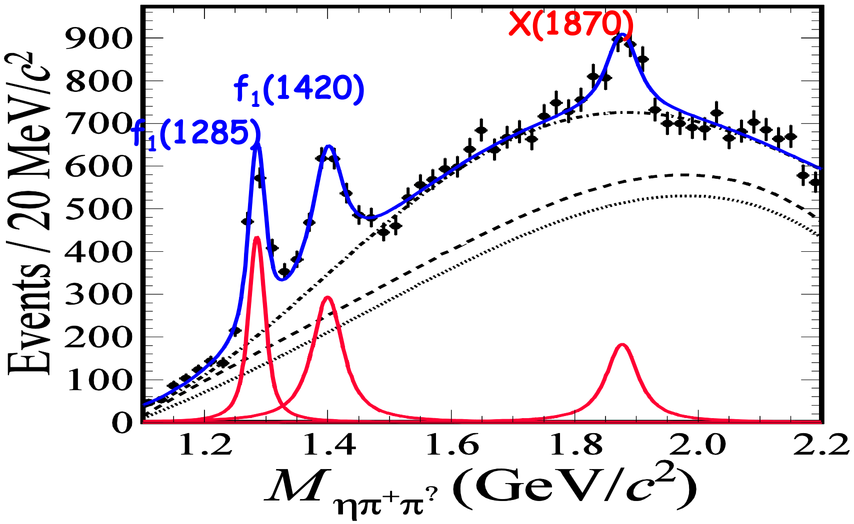


- **First distinct structures observed above 2 GeV, but narrow (Γ<100MeV)**
  - — LQCD predicts that the lowest–lying pseudoscalar glueball: around 2.3GeV
  - — $J/\psi \to \gamma\eta' \pi^+\pi^-$ is a good decay channel for searching 0^{-+} glueballs.
- **X(2120)/X(2370) possibilities:**
  - — pseudoscalar & tensor glueballs?
  - — η/η' excited states?
  - — ……
- **PWA is needed, interference among the resonances needs to be considered**
- **More processes to search these status are necessary.**

PRD82, 074026, 2010 (J.F. Liu, G.J. Ding and M.L.Yan)
PRD83: 114007, 2011 (J.S. Yu, Z.-F. Sun, X. Liu, Q. zhao),
and more…

Others Observations

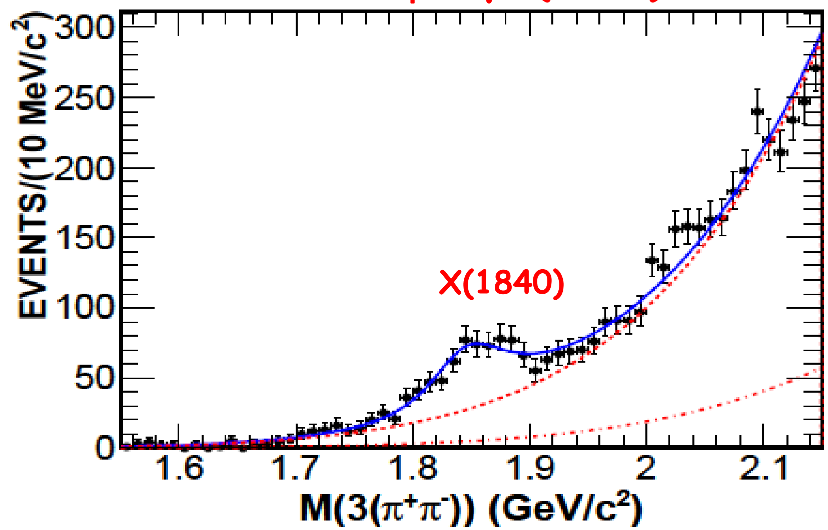
$J/\psi \to \omega a_0(980)\pi \to \omega\pi^+\pi^-\eta$



PRL 107, 182001(2011)

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

$J/\psi \to \gamma 3(\pi^+\pi^-)$



Preliminary Results

$M = 1842.2 \pm 4.2^{+7.1}_{-2.6}$ MeV/c^2,

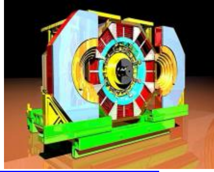
$\Gamma = 83 \pm 14 \pm 11$ MeV/c^2

B r($J\psi \to \gamma X(1840) \to \gamma 3(\pi+\pi-)$)

$= (2.44 \pm 0.36^{+0.60}_{-0.74}) \times 10^{-5}$

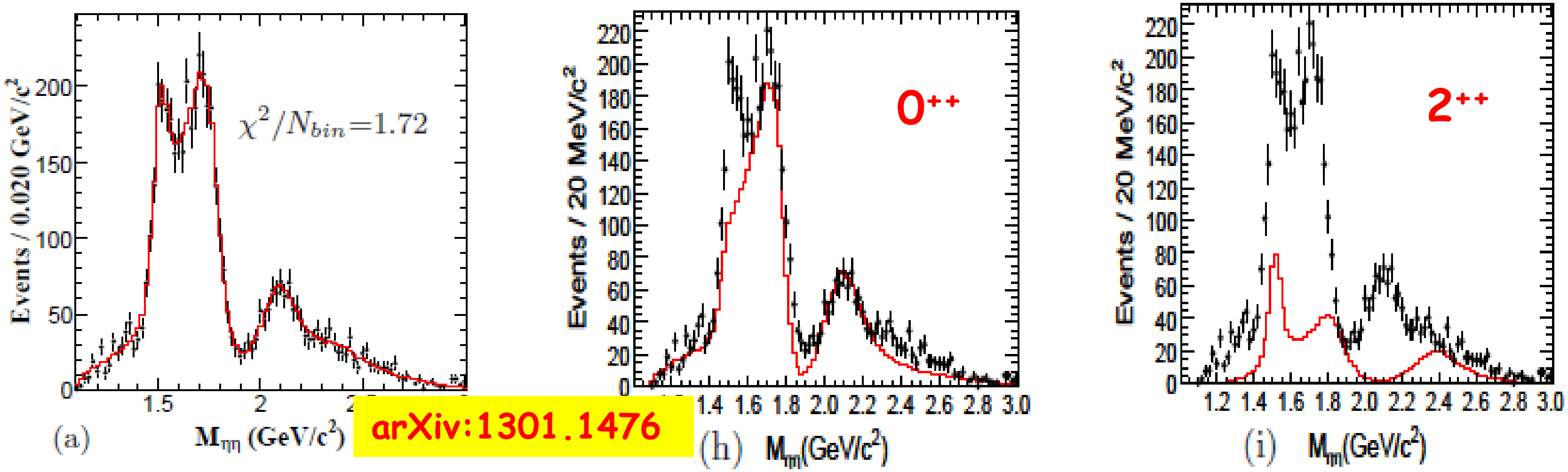
- ✧ Are new structures or existing states? J^{pc}?
- ✧ Relationship between different observations ?
- ✧ Need more investigation in both theory and experiments !!!

PWA of $J/\psi \to \gamma\eta\eta$



- Glueball searches is the directly test of QCD.
- Radiative J/ψ decay is a gluon-rich process and is regarded as one of most promising hunting grounds for glueballs.
- Glueball is flavor blindness, and predicted :

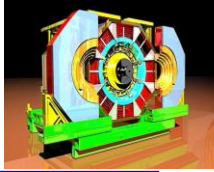
— $\Gamma(G \to \pi\pi : KK : \eta\eta : \eta\eta' : \eta'\eta') = 3:4:1:0:1$



arXiv:1301.1476

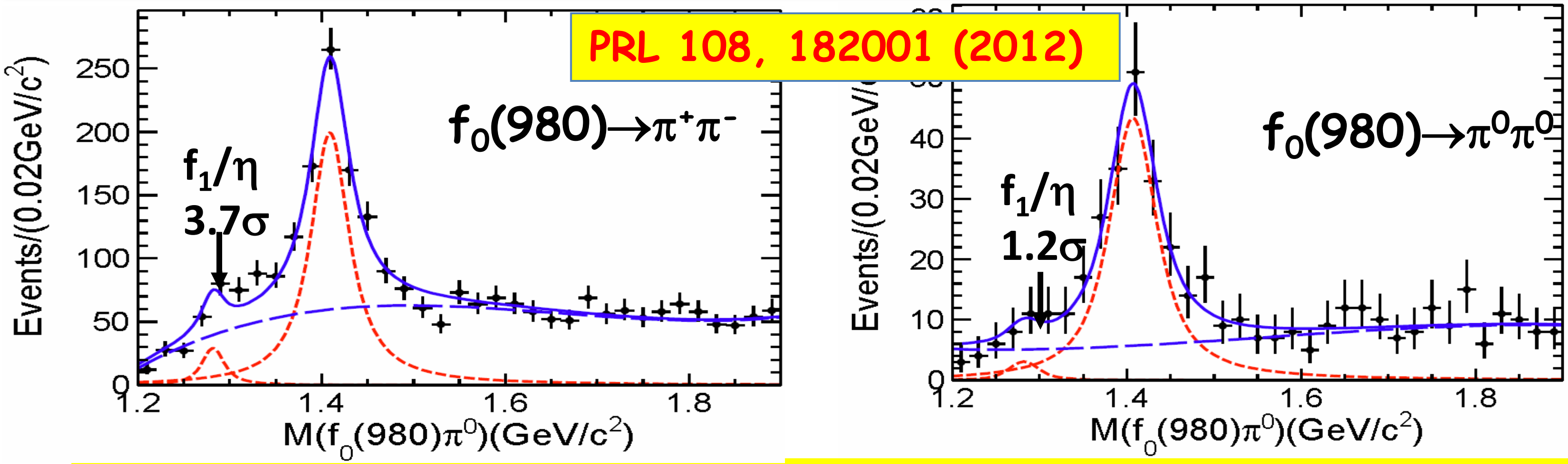
Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2 σ
$f_0(1710)$	$1759\pm6^{+14}_{-25}$	$172\pm10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0 σ
$f_0(2100)$	$2081\pm13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9 σ
$f_2'(1525)$	$1513\pm5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0 σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4 σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6 σ

- The scalar contribution are mainly from $f_0(1500)$, $f_0(1710)$ and $f_0(2100)$.
- No evident contribution from $f_0(1370)$ and $f_0(1790)$.
- The tensor components are dominantly from $f_2(1525)$, $f_2(1810)$ and $f_2(2340)$.



$\eta(1405)$ in $J/\psi \to \gamma f_0(980)\pi^0$

PRL 108, 182001 (2012)



First observed: $\eta(1405) \to f_0(980)\pi^0$ (Large isospin breaking)

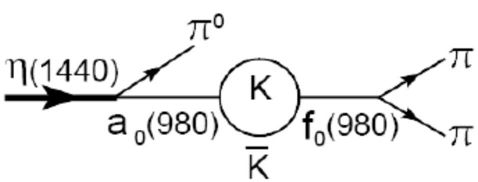
- Helicity analysis indicates the peak at 1.4GeV is from $\eta(1405)$, not from $f_1(1420)$
- Large Isospin-violating decay rate:

$$\frac{BR(\eta(1405) \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)}{BR(\eta(1405) \to a_0(980)\pi^0 \to \pi^0\pi^0\eta)} \approx (17.9 \pm 4.2)\%$$

- In general, magnitude of isospin violation in strong decay should be <1%.

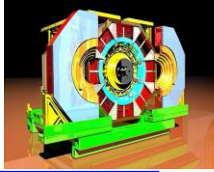
$$\xi_{af} = \frac{Br(\chi_{c1} \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)}{Br(\chi_{c1} \to a_0(980)\pi^0 \to \eta\pi^0\pi^0)} < 1\% (90\% \, C.L.)$$

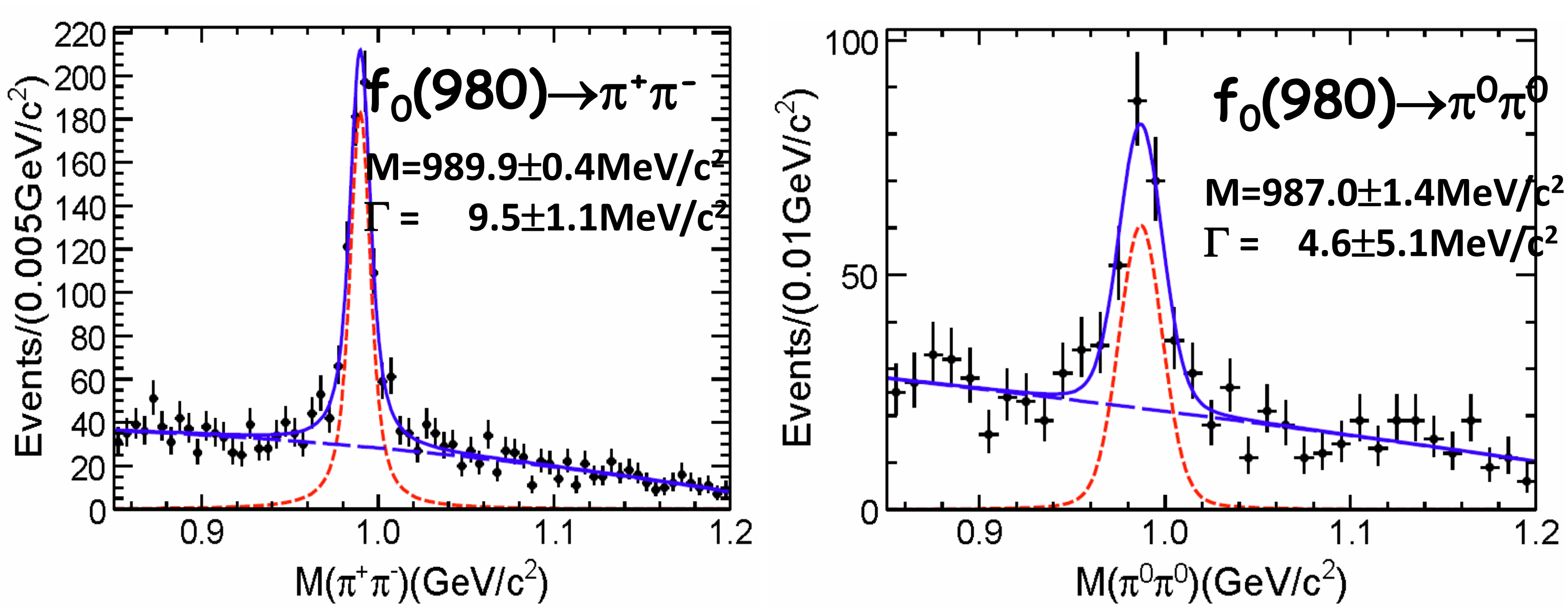
PRD, 83(2100)032003



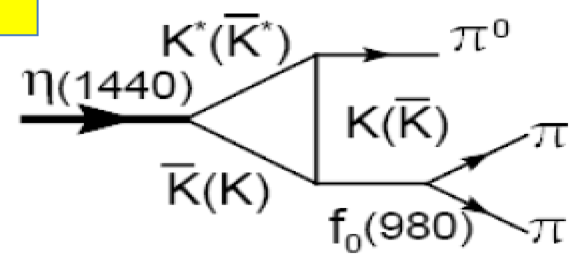
a_0-f_0 mixing alone can not explain the branching ratio of $\eta(1405) \to f_0(980)\pi^0$

Anomalous line shape of $f_0(980)$





PRL 108, 182001 (2012)

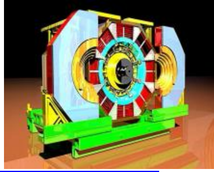


- **Surprising result:**
  - Very narrow $f_0(980)$ width: <11.8MeV/c²@90 % C.L.
  - The world average (PDG 2010: 40-100 MeV/c²)

A possible explanation is KK^* loop, Triangle Singularity (TS)

(J.J. Wu et al, PRL 108, 081803(2012))

Physics Programs @ BESIII



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  - threshold effects
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  - strong phases
- ***New Physics Searches and SM Test:***
  - η&η'decay physics
  - Light dark matter, LFV ……
  - Rare decay……
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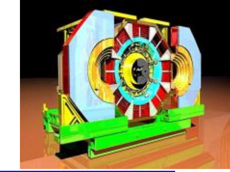
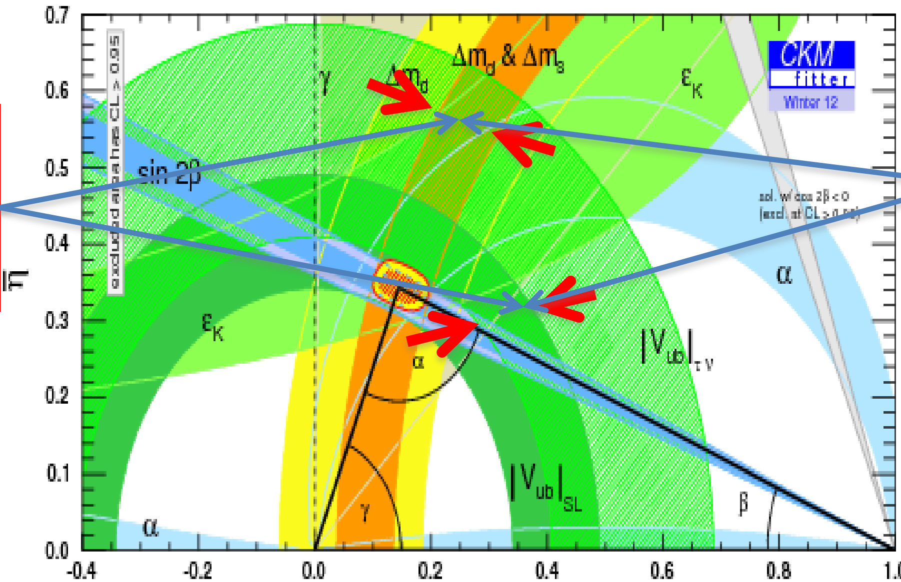
  - Y(4260) $\pi\pi h_c$ decays
  - Searches for new states



Charm Physics

- D leptonic decays is the window on weak and strong physics, and play an important role in understanding of the SM of the particles.
- Weak decay is theoretically clean, and the strong interaction can test Lattice QCD and over-constrain CKM.
- Unitary triangle

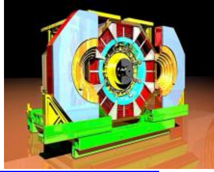
The widths of bands are dominated by the error of f_B and f_{Bs} from LQCD.



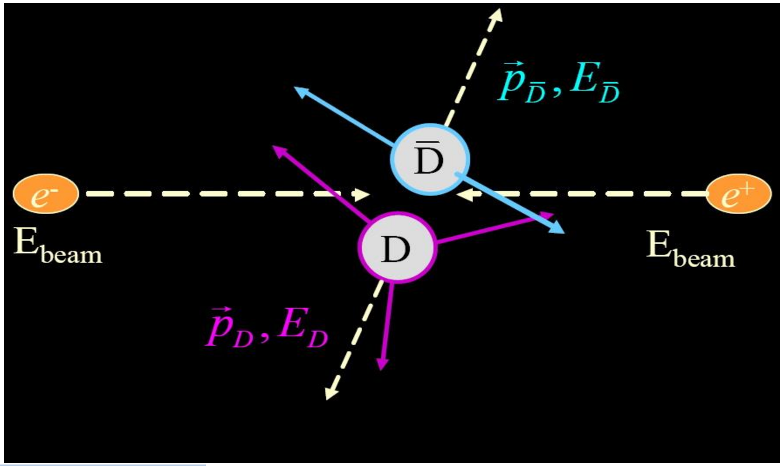
The widths of bands will be reduced if LQCD pass the test with measured f_D and f_{Ds}.

- Reduce width of band in triangle would lead to precisely test SM and search for new physics beyond the SM.

Charm Physics @BESIII



- **Charm pair is produced at mass threshold ψ(3770)**



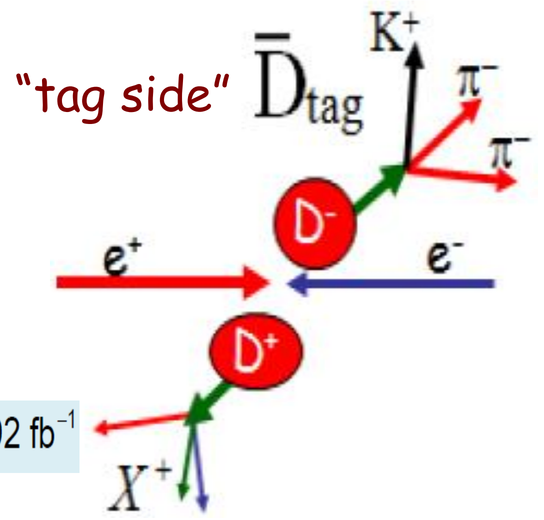
- **Advantage :**

— Clean environment.
— Known initial energy and quantum numbers (quantum correlated for $D^0 \bar{D}^0$ pair)
— Both D and $\bar{D}$ fully reconstructed.
— Absolute measurements.

- **Double-tag technique**

— Reconstruct D first, search for signal $\bar{D}$ on the others side
— Two variables ΔE & M_{BC}
— Fully reconstruct about 15% of D decays.

$$\Delta E = E_D - E_{Beam}$$
$$M_{BC} = \sqrt{E_{Beam}^2 - p_D^2}$$



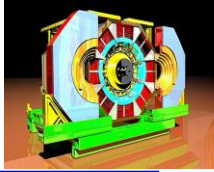
- **Nine D^+ tag and four D^0 modes :**

$K^+\pi^-\pi^-$	$K^0\pi^-$	K^0K^-	$K^+K^-\pi^-$	$K^+\pi^-\pi^-\pi^0$
$\pi^+\pi^-\pi^-$	$K^0\pi^-\pi^0$	$K^+\pi^-\pi^-\pi^-\pi^+$	$K^0\pi^-\pi^-\pi^+$	

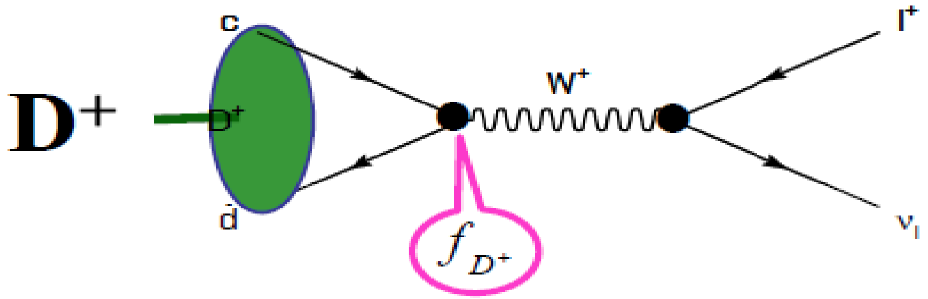
$K^-\pi^+$	$K^-\pi^+\pi^0$
$K^-\pi^+\pi^0\pi^0$	$K^-\pi^+\pi^+\pi^-$

$N_{D^-}^{tag} = (1.566 \pm 0.002) \times 10^6$ in 2.9 fb^{-1}

$N_{D^-}^{tag} = (0.774 \pm 0.001) \times 10^6$ in 0.92 fb^{-1}



Leptonic Decay

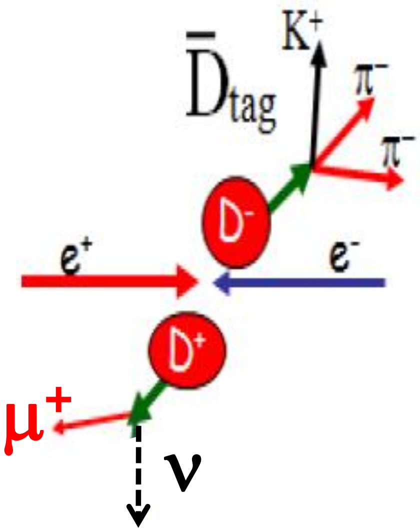


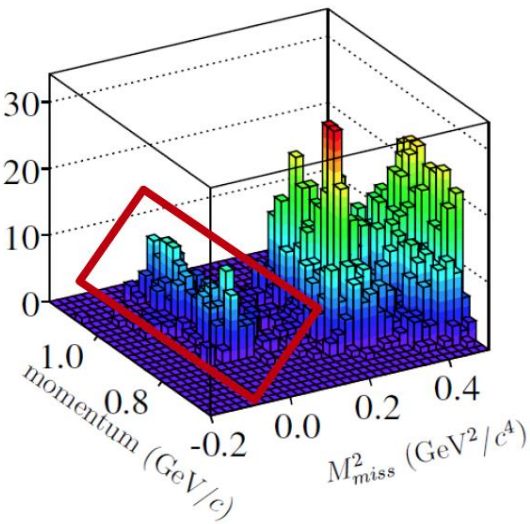
from CKM fitter

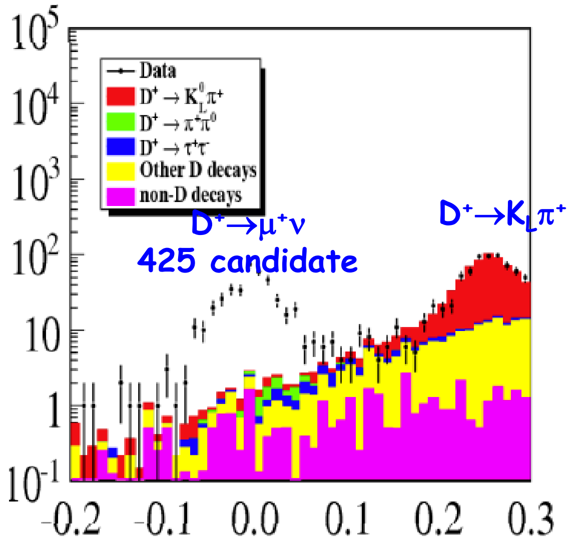
$$\Gamma_{SM}(D^+_{(s)} \to l^+\nu) = \frac{G_F^2}{8\pi} m_l^2 m_{D_{(s)}} \left(1 - \frac{m_l^2}{m_{D_{(s)}}^2}\right)^2 |V_{cd(s)}|^2 f_{D^+_{(s)}}$$

- Decay constant f_D incorporates the strong interaction effects (Wave function at the origin).
- Use charm leptonic decay to validate theory (LQCD) and apply to B mixing, which requires f_B.
- Multiple test with charm : f_D, f_{Ds} and f_D/f_{Ds}.
- Sensitivity to new physics (charged Higgs contribution …..)

Leptonic decay $D^+ \to \mu^+ \nu$







$M^2_{miss} = E^2_{miss} - p^2_{miss}$

Results: $N(D^+ \to \mu\nu) = 377.3 \pm 20.6 \pm 2.6$
$BF(D^+ \to \mu\nu) = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$

CLEOc: $(3.82 \pm 0.32 \pm 0.09) \times 10^{-4}$

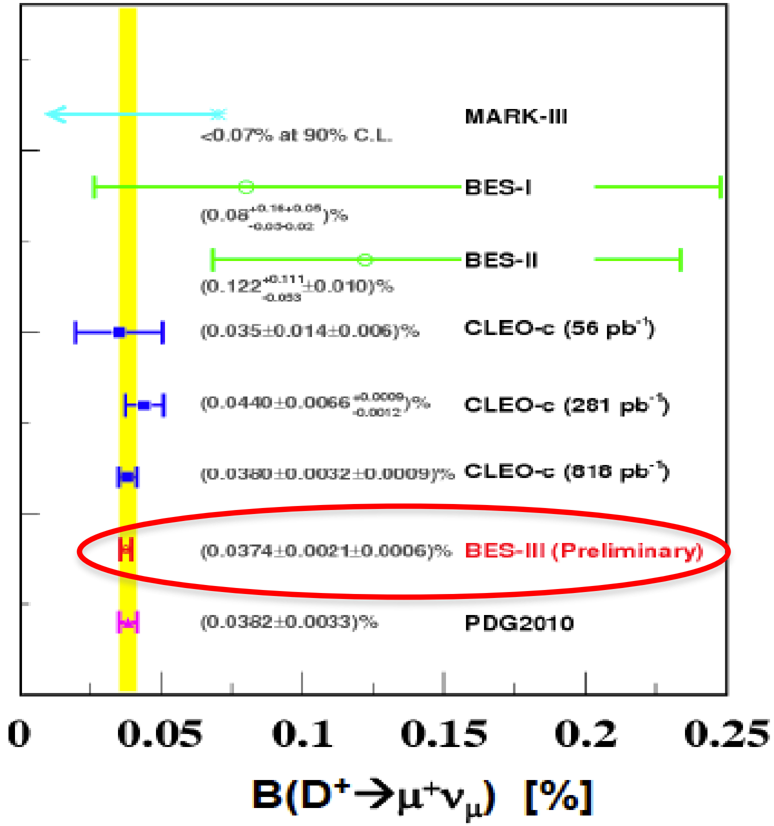
$$\Gamma(D^+ \to l^+ \upsilon_l) = \frac{G_F^2 f_{D^+}^2}{8\pi} |V_{cd}|^2 m_l^2 m_{D^+} \left(1 - \frac{m_l^2}{m_{D^+}^2}\right)^2$$

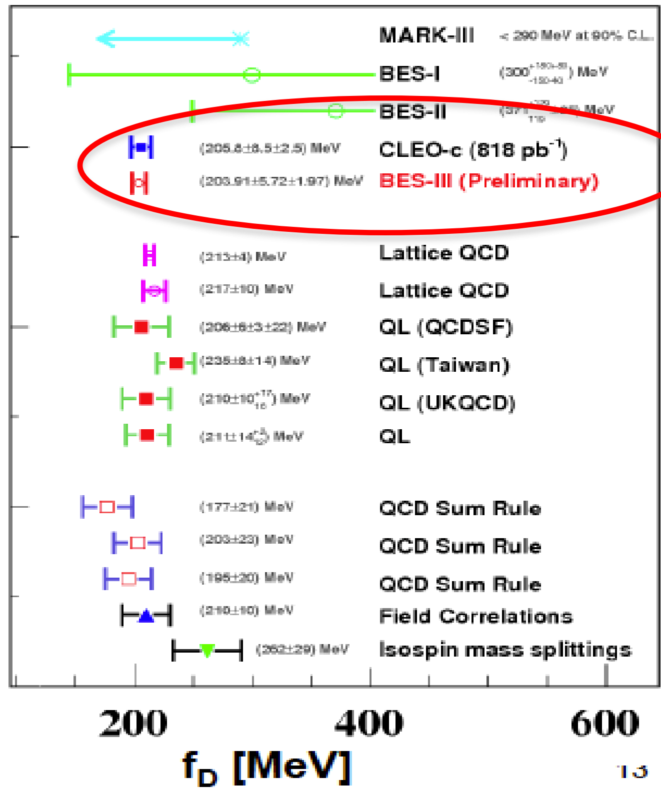
$f_{D+} = (203.91 \pm 5.72 \pm 1.97)$ MeV/c^2
$|V_{cd}| = (0.222 \pm 0.006 \pm 0.005)$

$f_{D+} = (207 \pm 4)$ MeV/c^2 LQCD
$|V_{cd}| = (0.2252 \pm 0.007)$ CKM Fitter

Preliminary results

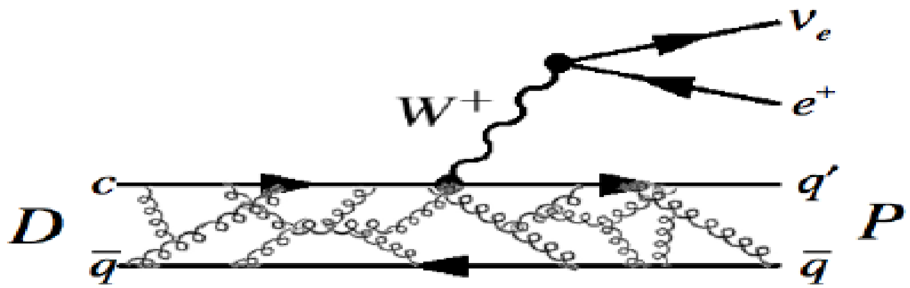
Preliminary results of $D^+ \to \mu^+ \nu$





- The most precise measurement is provided by BESIII
- The error is still dominated by statistics, needing more data to reduce it.

Semi-leptonic Decays

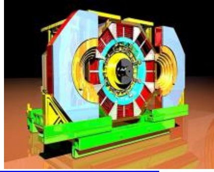


$$\frac{d\Gamma\left(D \to K(\pi) e\nu\right)}{dq^2} = \frac{G_F^2 \left|V_{cs(d)}\right|^2 P_{K(\pi)}^3}{24\pi^3} \left|f_+\left(q^2\right)\right|^2$$

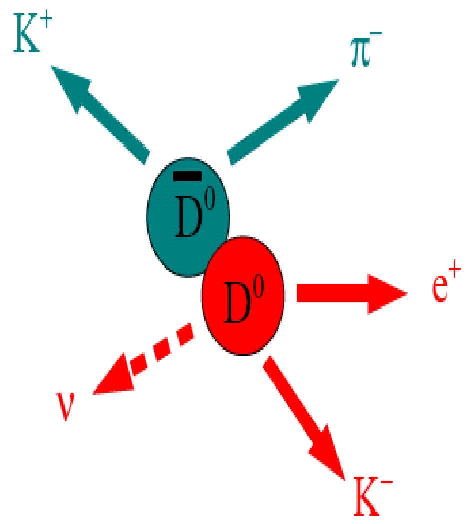
q2 – the invariant mass square of the lepton-neutrino system

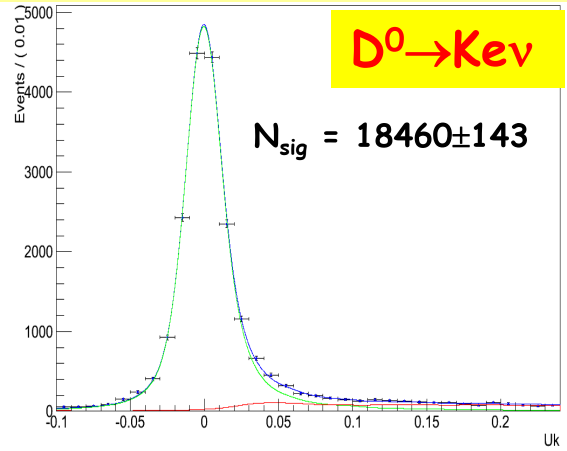
- Use strong interaction theory (LQCD) for form factor, extract CKM.
- Use other measurements and unitarity for CKM and test theory.
- Theoretical uncertainties can be reduce in determination of $|V_{ub}|$ if FF calculation can be validated with Charm.
- Multiple tests are available, semi-leptonic D decays to pseudoscalar mesons are cleanest.

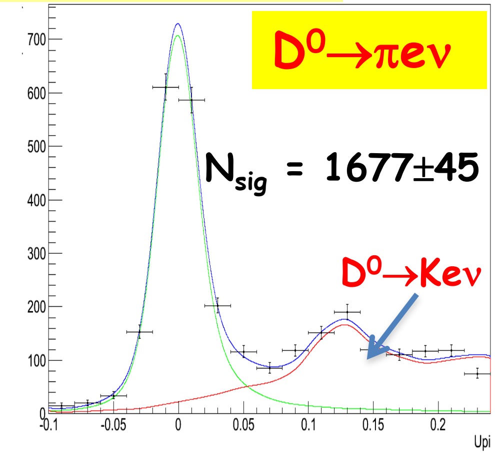
Semi-leptonic Decays $D^0 \to K/\pi\, e\nu$



4 tag modes, 0.92 fb^{-1} data @3.773 (BESIII preliminary)





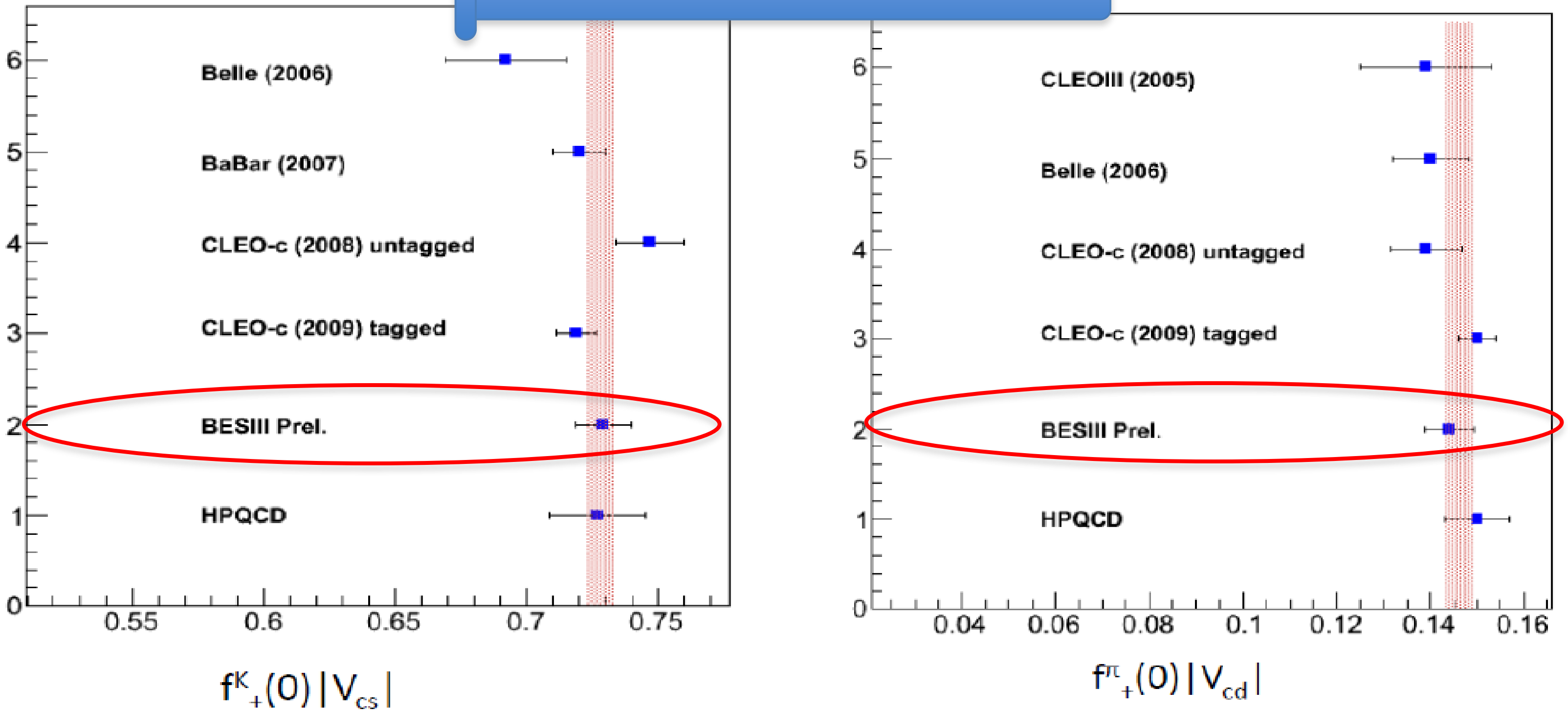


Mode	measured branching fraction(%)	PDG	CLEOc
$\bar{D}^0 \to K^+ e^- \bar{\nu}$	3.542 ±0.030±0.067	3.55 ±0.04	3.50 ±0.03 ±0.04
$\bar{D}^0 \to \pi^+ e^- \bar{\nu}$	0.288 ±0.008±0.005	0.289 ±0.008	0.288 ±0.008±0.003

- *Systematics are preliminary*
- Will improve with full data set 2.9/fb in the near future.
- *Good consistency with CLEO-c, statistical precision is compareble with only 1/3 data analyzed.*

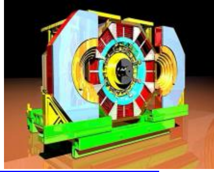
Semi-leptonic Decays $D^0 \to K/\pi e\nu$

Preliminary results



- Number are from HFAG2012 report (arXiv:1207.1158).
- Error bar of BESIII preliminary results Will shrink with full data.
- BESIII results from D^0 only, CLEO-c use both D^0 and D^+

Physics Programs @ BESIII



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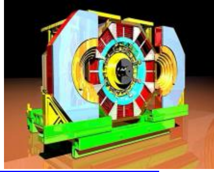


Search for $D^0 \to \gamma\gamma$

- Flavor Changing Neutral Current (FCNC) ($c \to u + \gamma$) is forbidden at tree level.

- Charm meson FCNC including two effects :

— Long distance effect : $c \to uV(V=\rho,\omega,\phi)$, non-perturbative calculated, large errors, Dominated.

— Short distance effect : perturbative calculated, interested, test SM.

- Within SM :

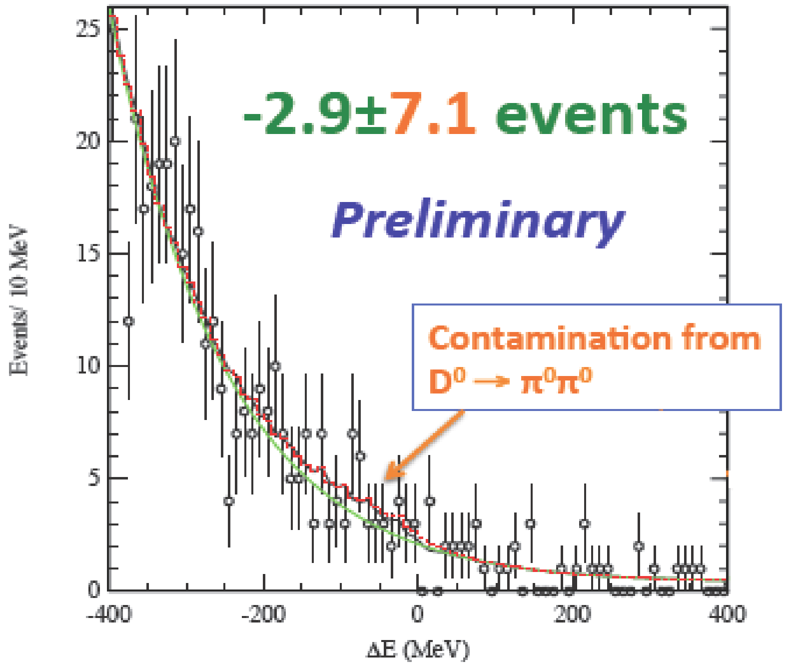
— Long distance : $Br(D^0 \to \gamma\gamma) \sim 10^{-8}$ (PRD 64, 074008)

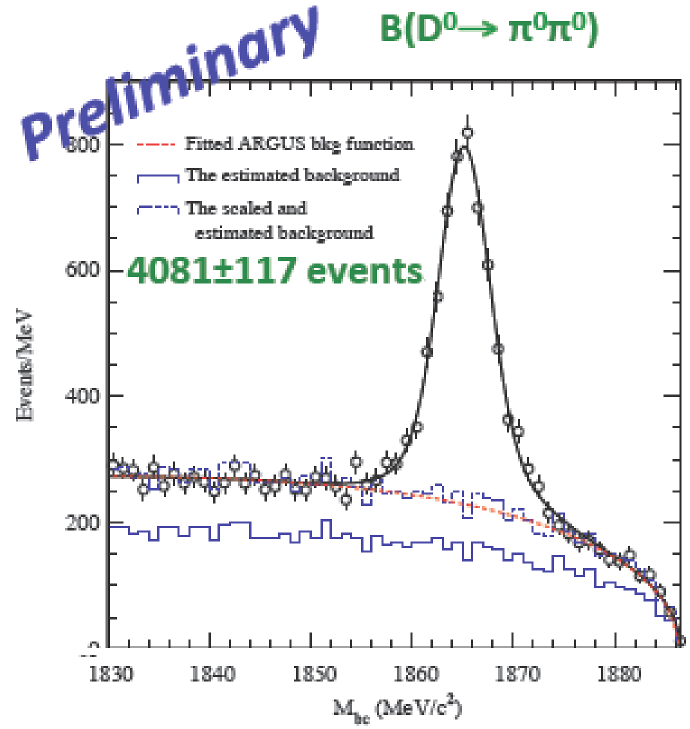
— Short distance : $Br(D^0 \to \gamma\gamma) \sim 10^{-11}$

- Beyond SM – minimal super-symmetric (MSSM) predicts the rate could be enhanced by a factor of 100 by exchanging gluino :

— $Br(D^0 \to \gamma\gamma) \sim 10^{-8}$ (PLB 500, 304)

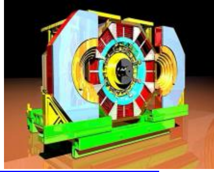
Search for $D^0 \to \gamma\gamma$





$B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0) < 5.8 \times 10^{-3}$ @90%C.L.

Experiments	BESIII	BABAR	CLEOc	PDG11
$B^{up}(D^0 \to \gamma\gamma)$ [$\times 10^{-6}$]	<4.6	<2.2	<8.63	<27



Search for LFV in $J/\psi \to e\mu$

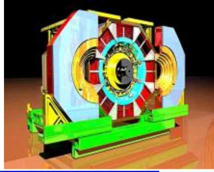
- With finite neutrino masses included, Lepton Flavor Violation (LFV) is allowed, but the smallness of the mass leads to the predicted branching fraction well beyond current experimental sensitivity.
- However, there are various theoretical models such as SUSY may enhance LFV effects up to a detectable level.
- Any detection of a LFV decay indicates the existence of new physics.
- The LFV decay have been searched in lepton (μ/τ) decay, pseudoscalar meson (k/π) decay and vector meson ($\phi, J/\psi, \Upsilon$) decay.

$Br(J/\psi \to e\mu) < 1.5\times10^{-7}$ (90% C.L.) (BESIII 225M J/ψ)

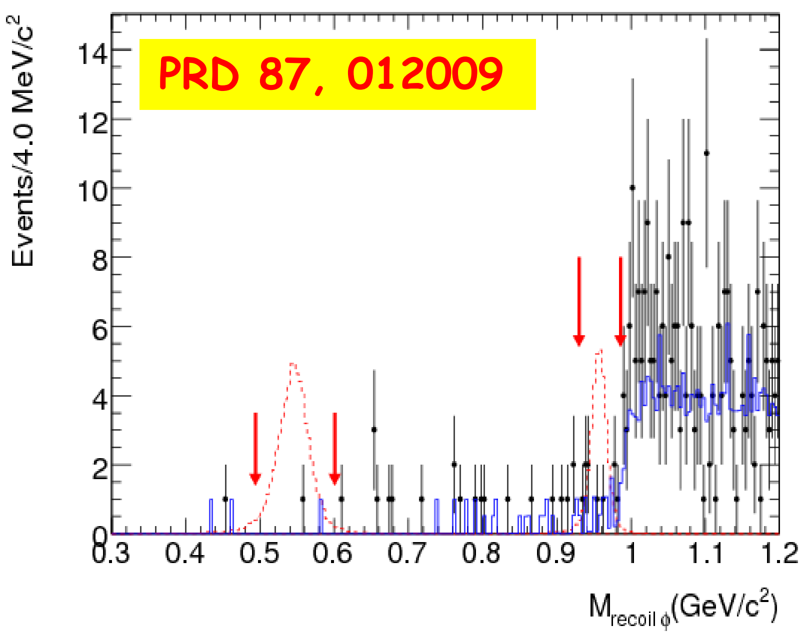
Literature:

		$Br(\phi \to \mu^+e^-) < 2.0\times10^{-6}$
		$Br(J/\psi \to \mu e) < 1.1\times10^{-6}$
$Br(\mu^+ \to \gamma e^+) < 2.4\times10^{-12}$	$Br(K_L^0 \to \mu^+e^-) < 4.7\times10^{-12}$	$Br(J/\psi \to e\tau) < 8.3\times10^{-6}$
$Br(\tau^+ \to \gamma e^+) < 3.3\times10^{-8}$	$Br(\pi^0 \to \mu^+e^-) < 3.8\times10^{-10}$	$Br(J/\psi \to \mu\tau) < 2.0\times10^{-6}$

Search for η/η' invisible in $J/\psi \to \phi\eta/\eta'$



- η/η' decay play special role in low energy scale QCD theory.
- Invisible and radiative decays offer a window for new physics beyond the SM.
- The observation of the invisible final states provide information for light dark matter states χ, spin-0 axions, and light spin-1 U bosons.
- Huge J/ψ sample, large branching fraction of $J/\psi \to (\gamma/\phi)\eta/\eta'$ and narrow intermediate meson widths provide clean, large η/η' sample.



$Br(\eta' \to invisible)/Br(\eta' \to \gamma\gamma) < 2.39\times10^{-2}$
$Br(\eta \to invisible)/Br(\eta \to \gamma\gamma) < 2.58\times10^{-4}$

$Br(\eta' \to invisible) < 5.21\times10^{-4}$ @90%C.L.
$Br(\eta \to invisible) < 1.01\times10^{-4}$ @90%C.L.
Improved PDG Values

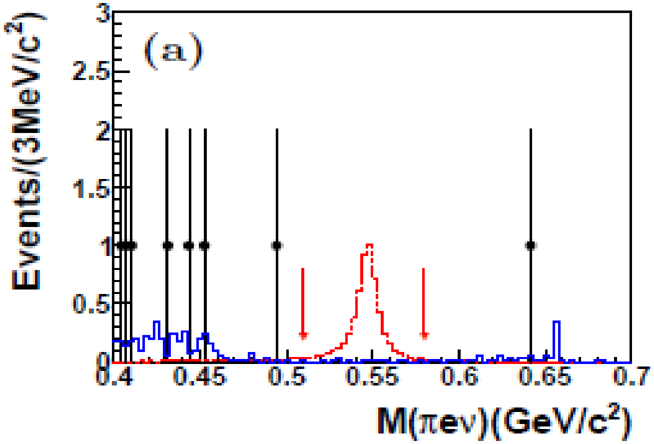
PDG : $Br(\eta' \to invisible) < 9\times10^{-4}$ @90%C.L
$Br(\eta \to invisible) < 6\times10^{-4}$ @90%C.L.

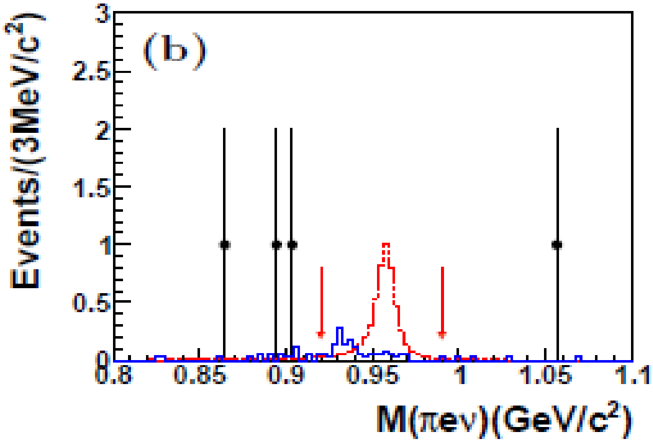
Theory : $Br(\eta' \to \chi\chi) \sim 8.1\times10^{-7}$
$Br(\eta \to \chi\chi) \sim 7.4\times10^{-5}$
B. McElrath, PRD 72, 103508 (2005)

η/η' weak decay in $J/\psi \to \phi\eta/\eta'$

- The rates of quarkonium weak decays are expected to be tiny in SM ($Br(\eta\to\pi l\nu)\sim 2.6\times10^{-13}$)
- The $Br(\eta/\eta'\to\pi l\nu)$ is expected at level of $10^{-8}\sim10^{-9}$ by considering scalar or vector type interaction.
- Search for η/η' weak decay will provide information on the new physics beyond the SM.

225M J/ψ , $\eta/\eta'\to\pi^+e^-\nu_e$ PRD 87, 032006, (2013)

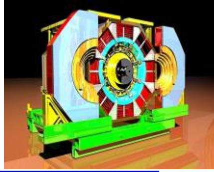




$Br(\eta\to\pi^+e^-\nu_e)/Br(\eta\to\pi^+\pi^-\pi^0) < 7.3\times10^{-4}$
$Br(\eta'\to\pi^+e^-\nu_e)/Br(\eta'\to\pi^+\pi^-\eta) < 5.0\times10^{-4}$

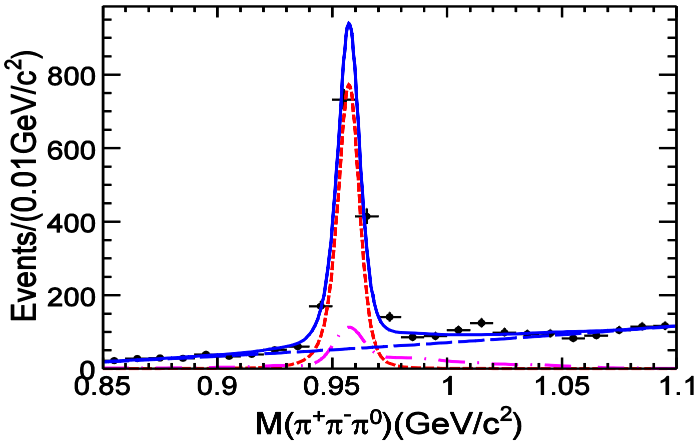
$\Rightarrow$

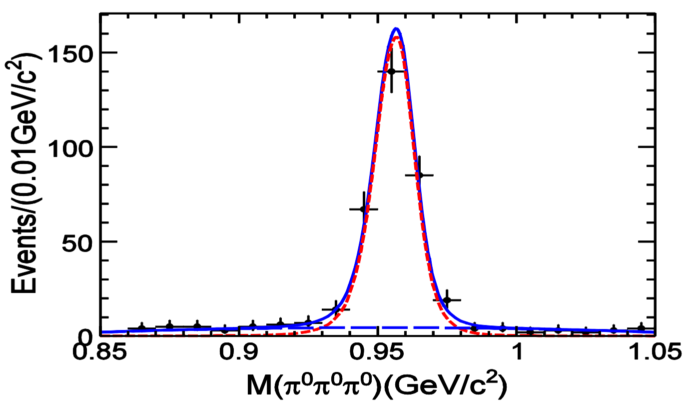
$Br(\eta\to\pi^+e^-\nu_e) < 1,7\times10^{-4}$ @90% C. L.
$Br(\eta'\to\pi^+e^-\nu_e) < 2.2\times10^{-4}$ @90% C. L.



η' three-pion decay in $J/\psi \to \gamma\eta'$

- The three-pion decays of the η' can probe isospin breaking.
- The decay branching ratio are related to the strange quark mass and SU(3) breaking.





$Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15 \pm 0.39) \times 10^{-3}$
$Br(\eta' \to \pi^0\pi^0\pi^0) = (3.56 \pm 0.22 \pm 0.34) \times 10^{-3}$

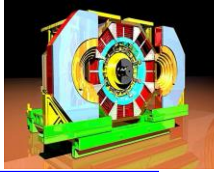
PDG: $Br(\eta' \to \pi^+\pi^-\pi^0) = (3.6^{+1.1}_{-0.9}) \times 10^{-3}$
$Br(\eta' \to \pi^0\pi^0\pi^0) = (1.68 \pm 0.22) \times 10^{-3}$

$Br(\eta' \to \pi^+\pi^-\pi^0)/Br(\eta' \to \pi^+\pi^-\eta) = (8.87 \pm 0.98) \times 10^{-3}$
$Br(\eta' \to \pi^0\pi^0\pi^0)/Br(\eta' \to \pi^0\pi^0\eta) = (16.41 \pm 1.94) \times 10^{-3}$

Theory : $Br(\eta' \to \pi^+\pi^-\pi^0)/Br(\eta' \to \pi^+\pi^-\eta) = 3.90\%$
$Br(\eta' \to \pi^0\pi^0\pi^0)/Br(\eta' \to \pi^0\pi^0\eta) = 0.73\%$
B. Borasoy et. al PLB 643, 41, 2006

More than 4 standard deviations away from both π^0-η mixing prediction and the chiral unitary framework prediction.

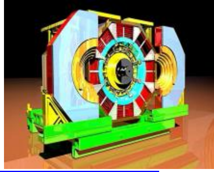
Summary



- ✓ **BEPCII is operating near design luminosity &BESIII is performing successfully**
  - ➢ **World largest threshold produced samples J/ψ, ψ', $\psi(3770)$, $\psi(4040)$**
  - ➢ **Large samples of Y(4260), Y(4360) etc. are produced directly, are growing ……**

- ✓ **Some of results have been shown in this talk :**
  - ➢ **Light hadron spectroscopy** :
    - – Are $X(p\bar{p})$ in $J/\psi \to \gamma p\bar{p}$, X(1835) in $J/\psi \to \gamma\, \eta'\pi^+\pi^-$, X(1870) in $J/\psi \to \omega\eta\pi^+\pi^-$ and X(1840) in $J/\psi \to \gamma 3(\pi^+\pi^-)$ same states？
    - – Are X(2120), X(2370) in $J/\psi \to \gamma\, \eta'\pi^+\pi^-$ glueballs?
    - – First observation: $\eta(1405) \to f_0(980)\pi^0$ (isospin breaking, Triangle Singularity?).
  - ➢ **Charm decays**:
    - – Leptonic decay $D^+ \to \mu^+\nu$
    - – Semi-Leptonic decay $D^0 \to K/\pi\, e\nu$
  - ➢ **New Physics Search and SM Test :**
    - – FCNC process : $D^0 \to \gamma\gamma$
    - – LFV
    - – η/η' invisible decay, weak decay ……(more data will help)

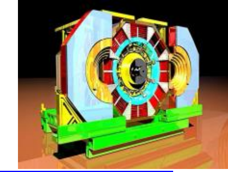
- ✓ **Expect many more results from BESIII in the future !!!!**

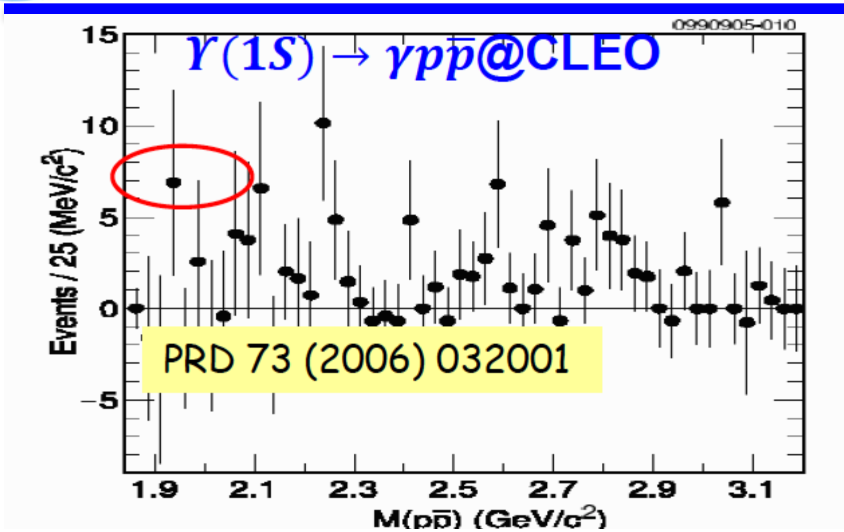


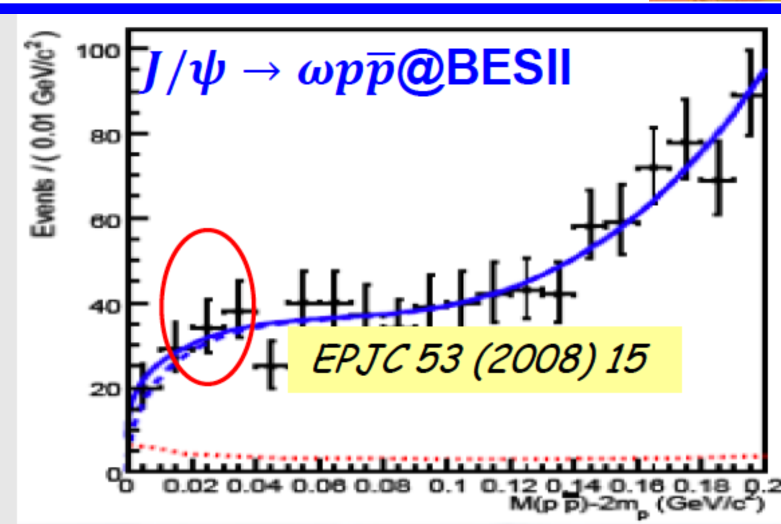
Thanks !

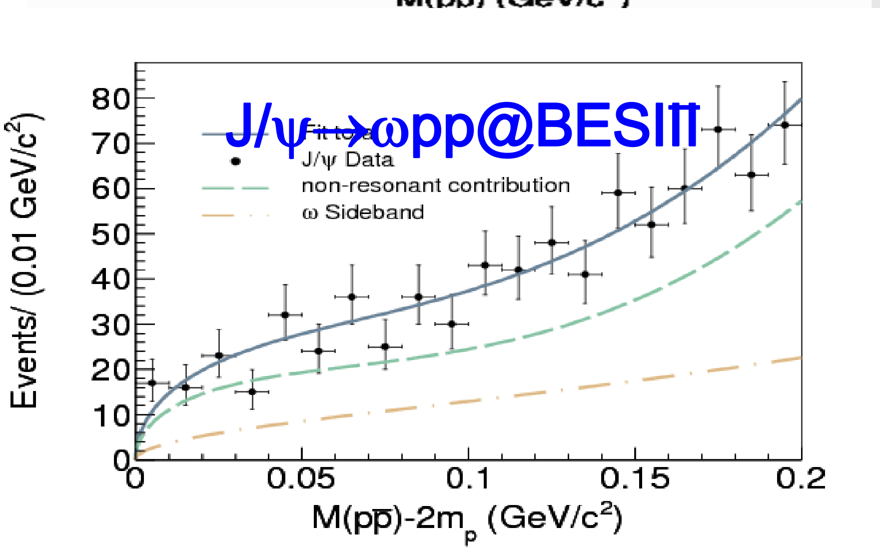
Backup

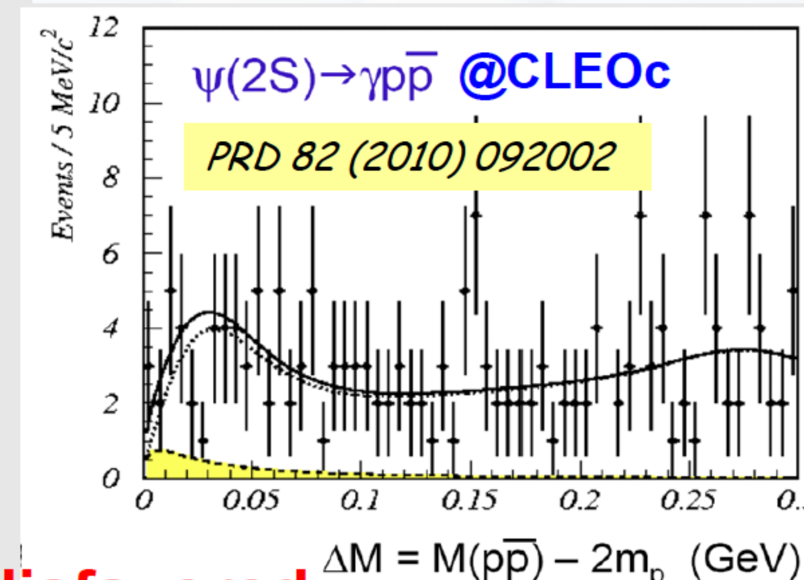
Some non-Observation





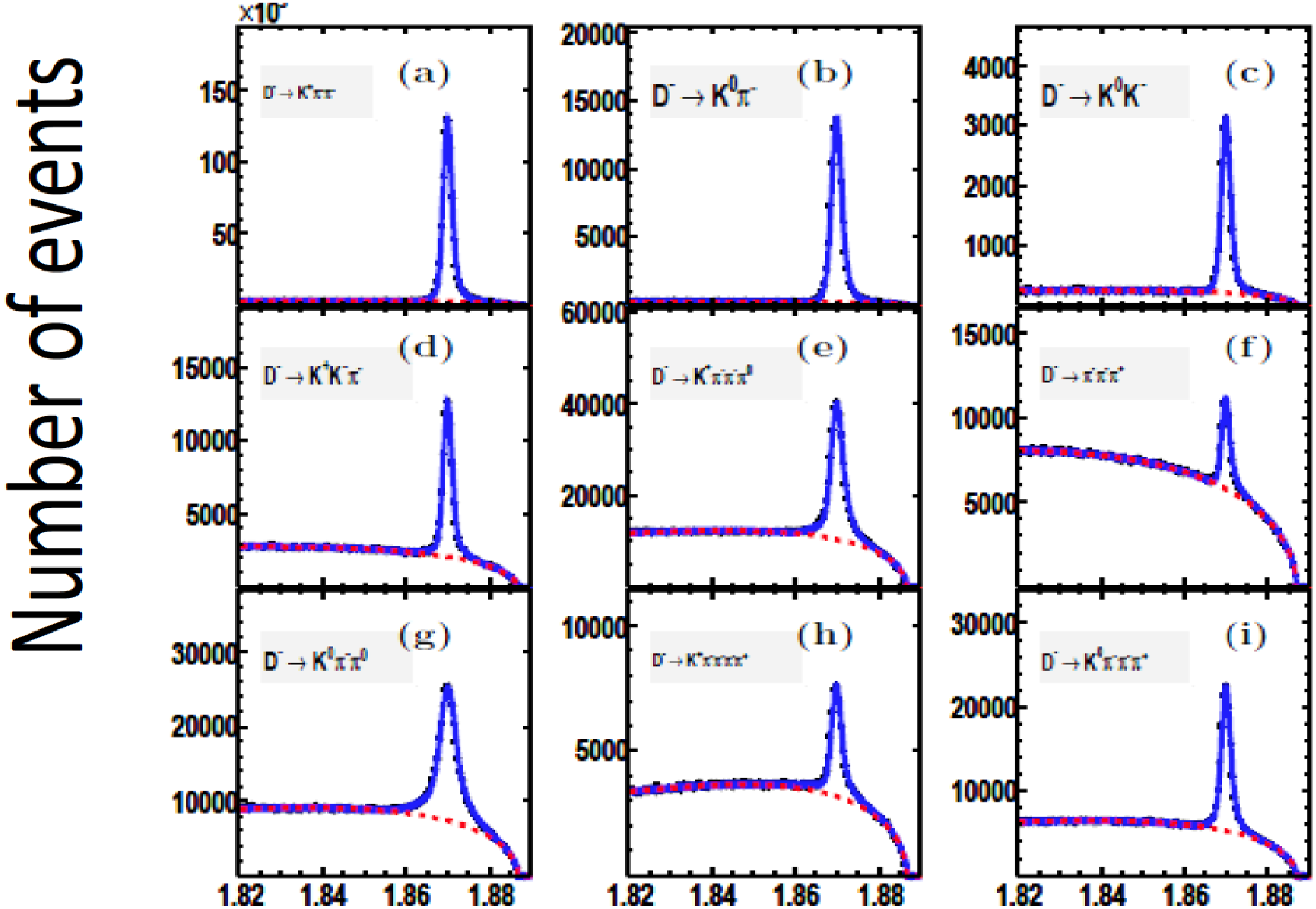


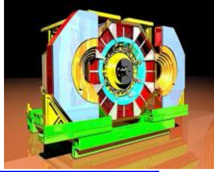




Pure FSI interpretation is disfavored

D tag modes


Number of events
$\times 10^3$
(a) $D^- \to K^+\pi^-\pi^-$
(b) $D^- \to K^0\pi^-$
(c) $D^- \to K^0K^-$
(d) $D^- \to K^+K^-\pi^-$
(e) $D^- \to K^+\pi^-\pi^-\pi^0$
(f) $D^- \to \pi^-\pi^-\pi^+$
(g) $D^- \to K^0\pi^-\pi^0$
(h) $D^- \to K^+\pi^-\pi^-\pi^-\pi^+$
(i) $D^- \to K^0\pi^-\pi^-\pi^+$
1.82
1.84
1.86
1.88



Is the X(1835) from the same source of $X(p\bar{p})$?

- The mass of $X(p\bar{p})$ is consistent with X(1835)

- The width of $X(p\bar{p})$ is much narrower.

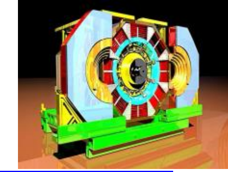
  Possible reasons:

  – $X(p\bar{p})$ and X(1835) come from different sources

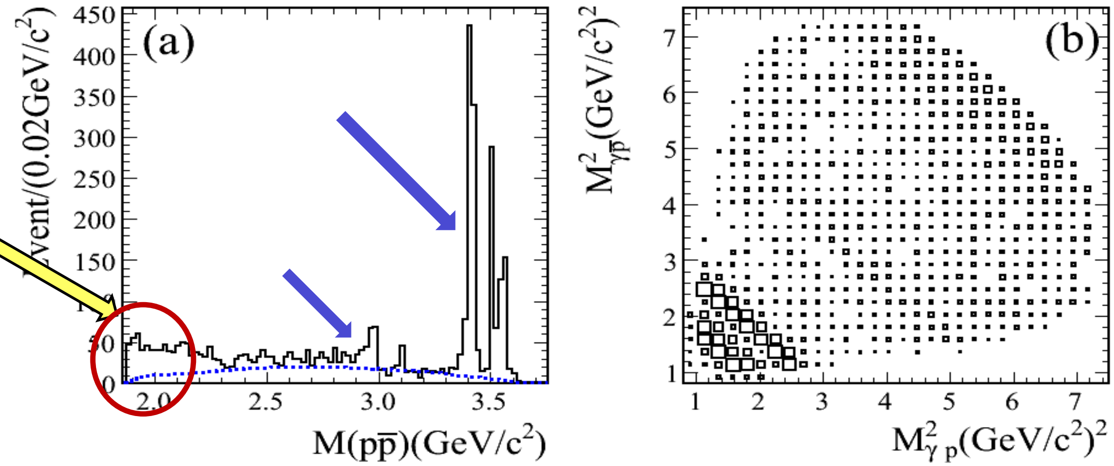
  – Interference effect in $J/\psi \to \gamma\pi\pi\eta'$ process should not be ignored in the determination of the X(1835) mass and width

  – There may be more than one resonance in the mass peak around 1.83GeV in $J/\psi \to \gamma\pi\pi\eta'$ decays.

M$p\bar{p}$ threshold structure of @ BESIII



Obviously different line shape of $p\bar{p}$ mass spectrum near threshold from that in J/ψ decays



PWA results:

- Significance of X($p\bar{p}$) is > 6.9σ.
- The production ratio R:

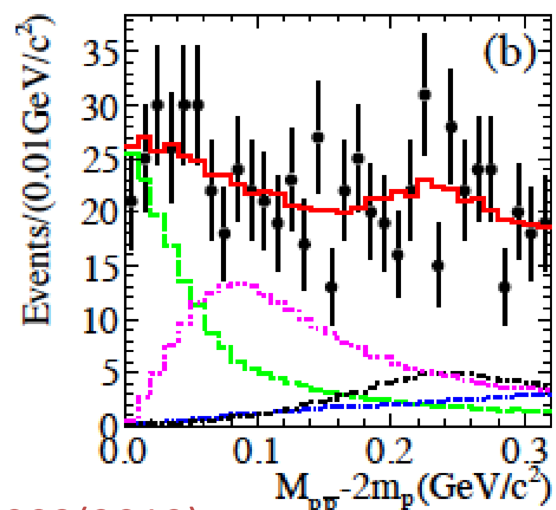
first measurement

$$R = \frac{B(\psi' \to \gamma X(p\bar{p}))}{B(J/\psi \to \gamma X(p\bar{p}))}$$

$$= (5.08^{+0.71}_{-0.45}(\text{stat})^{+0.67}_{-3.58}(\text{syst}) \pm 0.12(\text{mod}))\%$$

- It is suppressed compared with "12% rule".

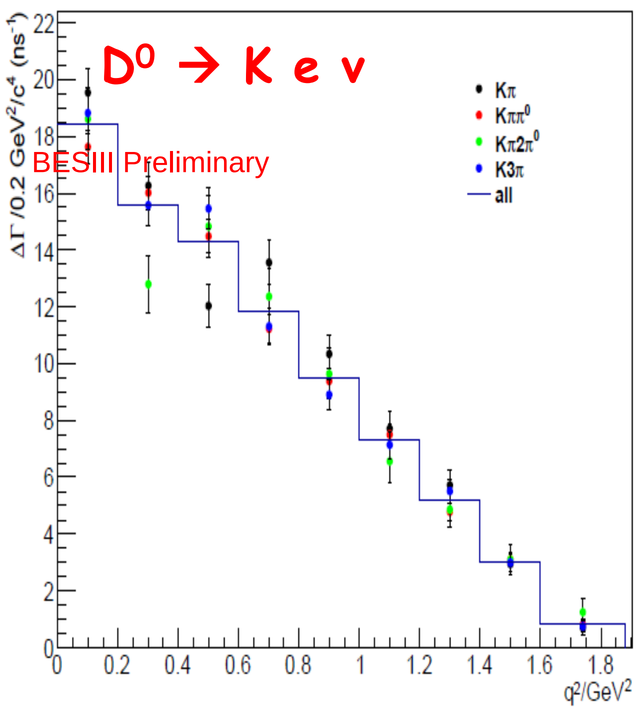
PWA Projection:

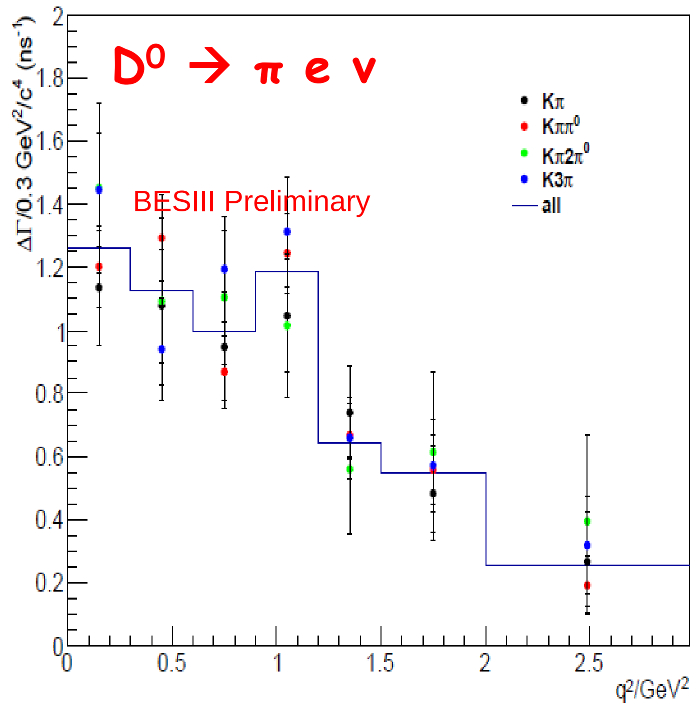


PRL 108,112003(2012)

Semi lepton decays : Partial Decay Rates Results

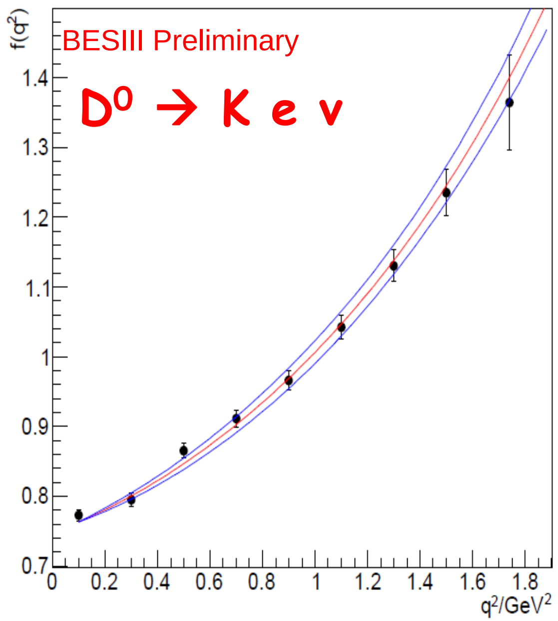
- Measured in each q^2 bin, by fitting U distribution
- Compare results from each tag mode

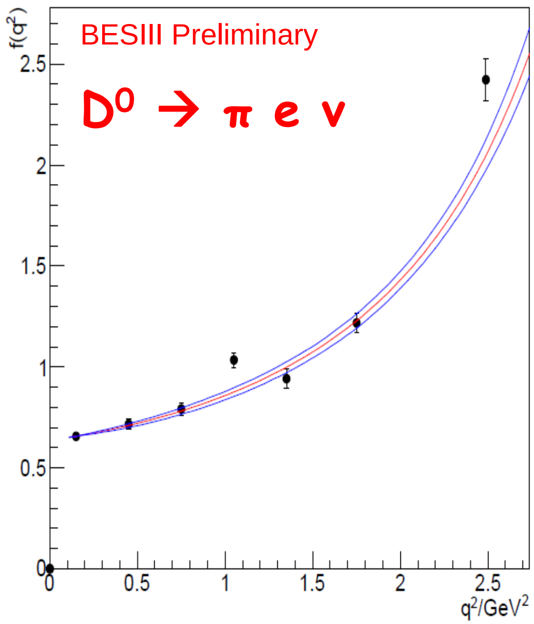


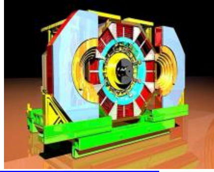


$f(q^2)$ Results

- Points: data with stat. error only
- Curves: from Fermilab-MILC within one stat. error, preliminary, **arXiv:1111.5471** (XXIX International Symposium on Lattice Field Theory);
- Other theoretical work: HPQCD, arXiv:1111.0225
- Comparing shape only here ($f_+(0)$ not known)







Form Factor Fits

BESIII Preliminary

Simple pole model:

$$f_+(q^2) = \frac{f_+(0)}{1 - q^2/m_{pole}^2}$$

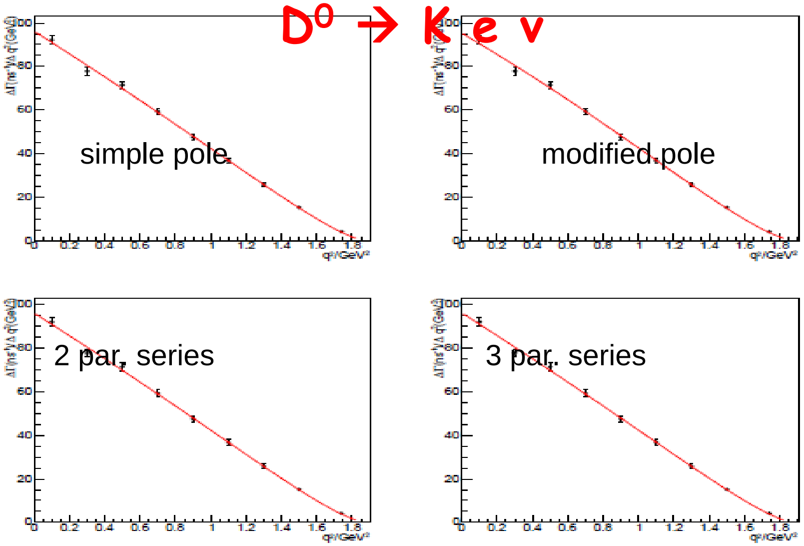
Modified pole model:
Beciirevic and Kaidalov PLB 478, 417 (2000)

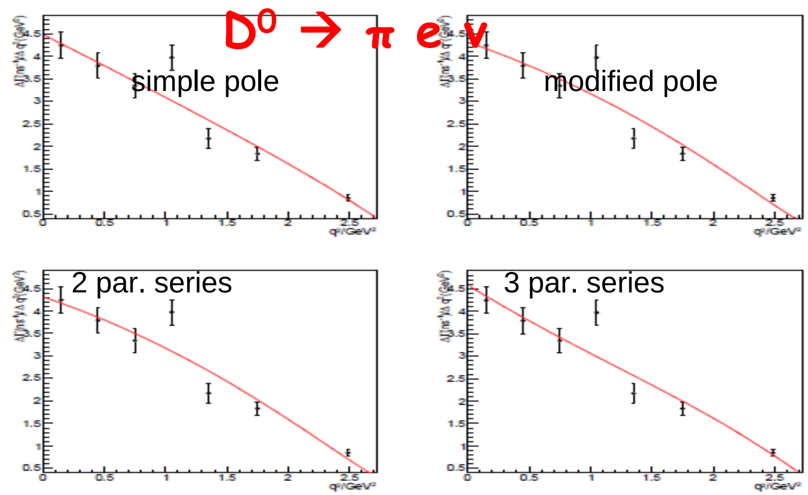
$$f_+(q^2) = \frac{f_+(0)}{\left(1 - \frac{q^2}{m_{pole}^2}\right)\left(1 - \alpha\frac{q^2}{m_{pole}^2}\right)}$$

Series expansion:
Becher and Hill PLB 633, 61 (2006)

$$f_+(q^2) = \frac{1}{P(q^2)\,\phi(q^2,t_0)} \sum_{k=0}^{\infty} a_k(t_0)\,\left[z(q^2,t_0)\right]^k$$

Could fit: $f_+(0)$, $r_1 = a_2/a_1$, $r_2 = a_3/a_1$





Form Factor Results

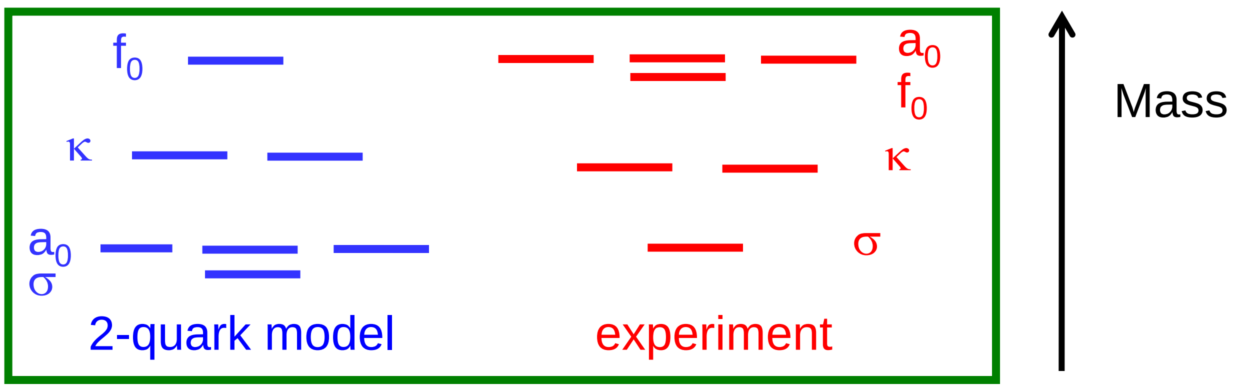
BESIII Preliminary

Simple Pole	$f_+(0)\|V_{cd(s)}\|$	m_{pole}	
$D^0 \to Ke\nu$	$0.729\pm0.005\pm0.007$	$1.943\pm0.025\pm0.003$	
$D^0 \to \pi e\nu$	$0.142\pm0.003\pm0.001$	$1.876\pm0.023\pm0.004$	
Modified Pole	$f_+(0)\|V_{cd(s)}\|$	α	
$D^0 \to Ke\nu$	$0.725\pm0.006\pm0.007$	$0.265\pm0.045\pm0.006$	
$D^0 \to \pi e\nu$	$0.140\pm0.003\pm0.002$	$0.315\pm0.071\pm0.012$	
2 par. series	$f_+(0)\|V_{cd(s)}\|$	r_1	
$D^0 \to Ke\nu$	$0.726\pm0.006\pm0.007$	$-2.034\pm0.196\pm0.022$	
$D^0 \to \pi e\nu$	$0.140\pm0.004\pm0.002$	$-2.117\pm0.163\pm0.027$	
3 par. series	$f_+(0)\|V_{cd(s)}\|$	r_1	r_2
$D^0 \to Ke\nu$	$0.729\pm0.008\pm0.007$	$-2.179\pm0.355\pm0.053$	$4.539\pm8.927\pm1.103$
$D^0 \to \pi e\nu$	$0.144\pm0.005\pm0.002$	$-2.728\pm0.482\pm0.076$	$4.194\pm3.122\pm0.448$

Light Scalar Meson

Problems :

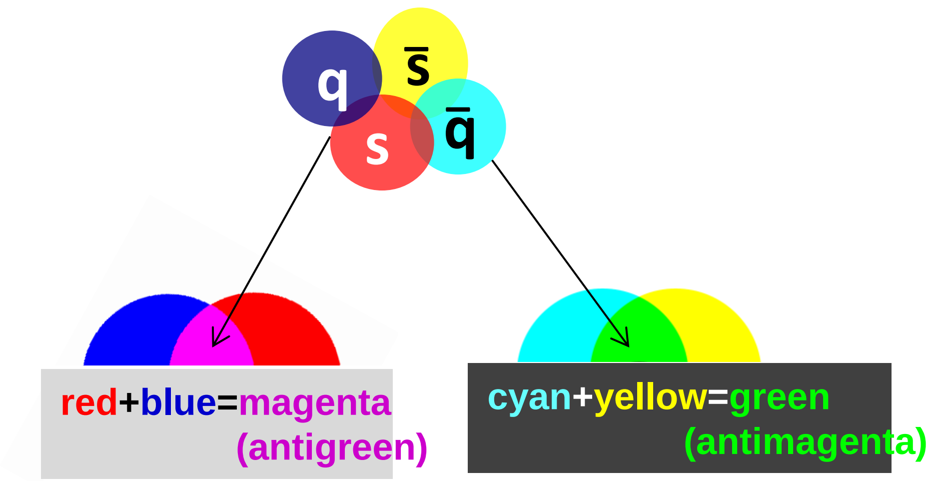
- Inverted mass spectrum.



- In qqbar meson monets, the 1=1 state (here the $a_0(980)$) has not s-quarks
- $M(f_0(980))\sim M(a_0(980)$ → "ideal" mixing & small s-quark content in $f_0(980)$.
- But strong $a_0(980)$ & $f_0(980)$ coupling to Kkbar indicate strong OZI rule violations.
- No "light" $J^P=1^+$ and 2^{++} partner nonet in the same mass region.

If not qqbr, then what

tightly bound diquark-diantiquark

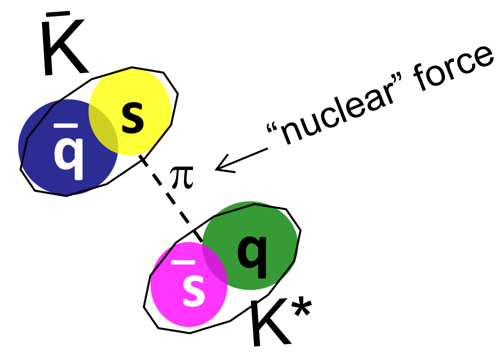


A colored diquark
is like a antiquark

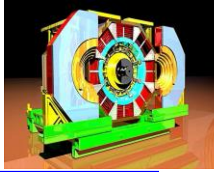
A colored diantiquark
is like a quark

R.L.Jaffe PRD 15, 267 (1977)

loosely bound meson-antimeson "molecule"



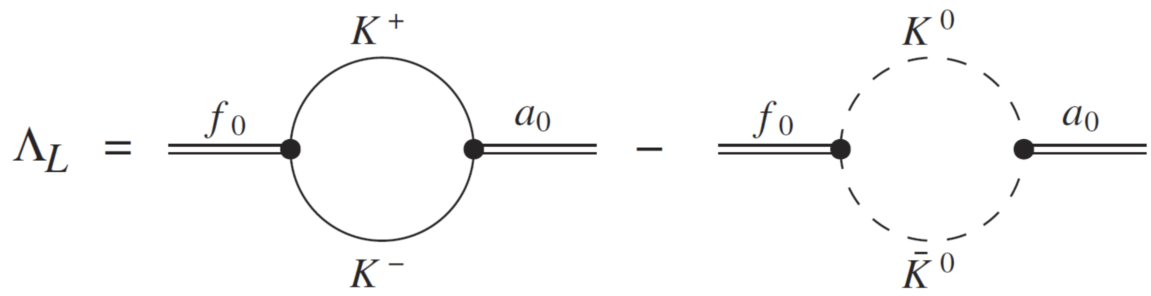
J.D.Weinstein & N.Isgur PRD 27, 588 (1983)



$a_0(980)$-$f_0(980)$ mixing

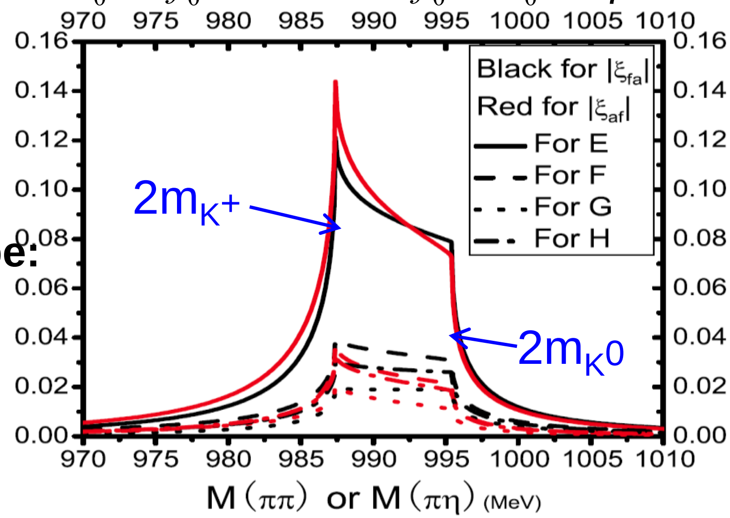
isospin violation enhanced by $K^0 - K^+$ mass difference

C. Hanhart, B. Kubis, and J.R. Pelaez, Phys. Rev. D **76**, 074028 (2007)



$2m_{K^+} = 987.4$ MeV $\quad 2m_{K^0} = 995.2$ MeV

$a_0^0 \to f_0 \to \pi^+\pi^-$ or $f_0 \to a_0^0 \to \eta\pi^0$



expect a narrow line shape:

$G \approx 2(m_{K^0} - m_{K^+}) = 7.8$ MeV

PDG2010:

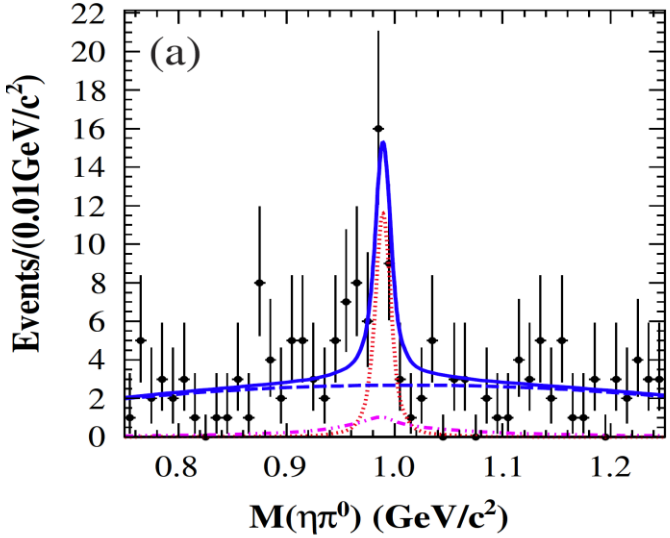
$M_{f_0} = 980 \pm 10$ MeV
$\Gamma_{f_0} = 40 \sim 100$ MeV

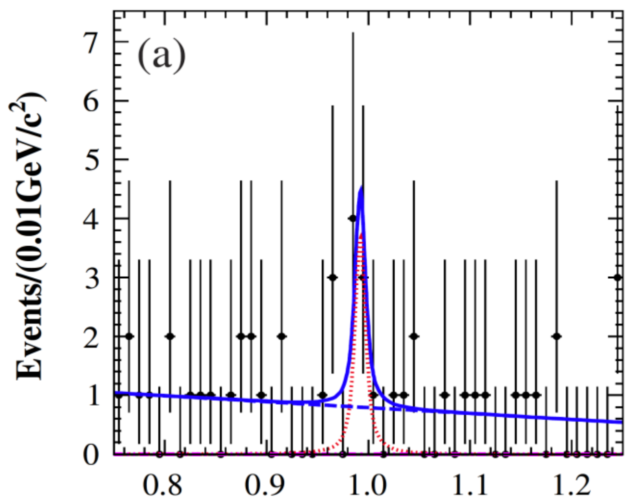
$M_{a_0} = 980 \pm 20$ MeV
$\Gamma_{a_0} = 50 \sim 100$ MeV

BESIII $a_0(980)$-$f_0(980)$ mixing

$J/\psi \to \phi f_0 \to \varphi a_0^0 \to K^+K^-\eta\pi^0$

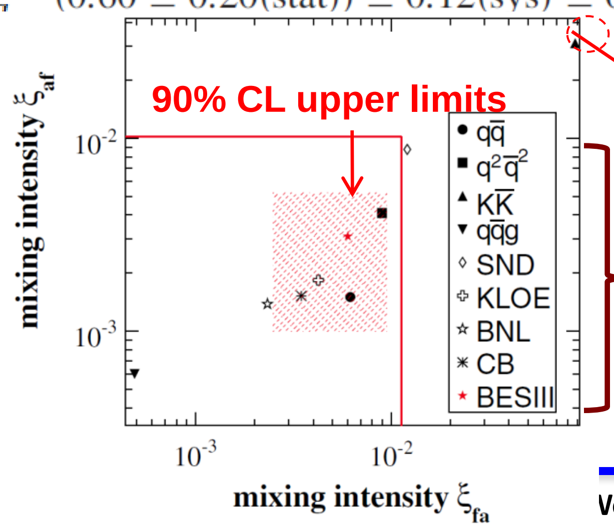
$\psi' \to \gamma\chi_{c1} \to \gamma\pi^0 a_0^0 \to \gamma\pi^0 f_0 \to \gamma\pi^0\pi^+\pi^-$





$\xi_{fa} = (0.60 \pm 0.20(\text{stat})) \pm 0.12(\text{sys}) \pm 0.26(\text{para})\%$

$\xi_{af} = (0.31 \pm 0.16(\text{stat}) \pm 0.14(\text{sys}) \pm 0.03(\text{para}))\%$



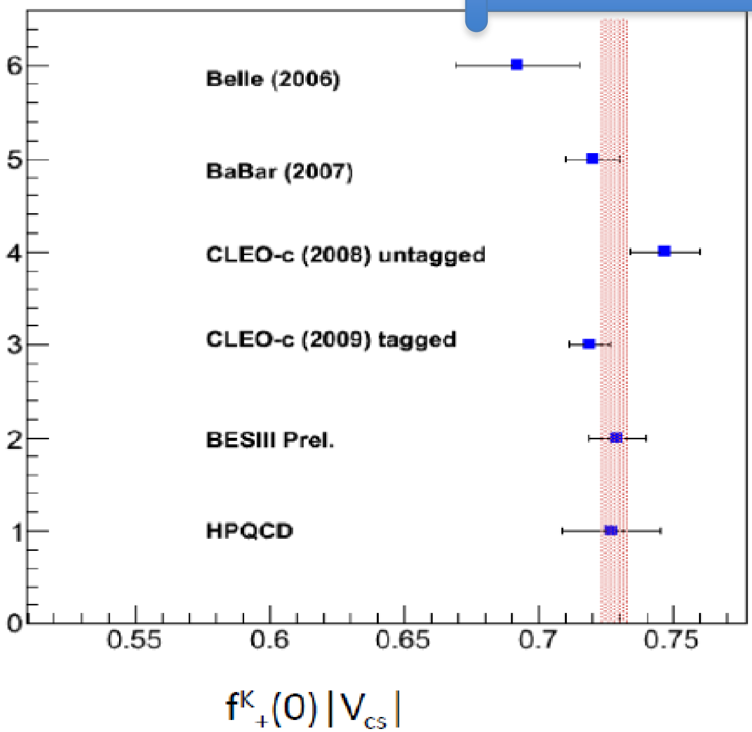
KK molecule model

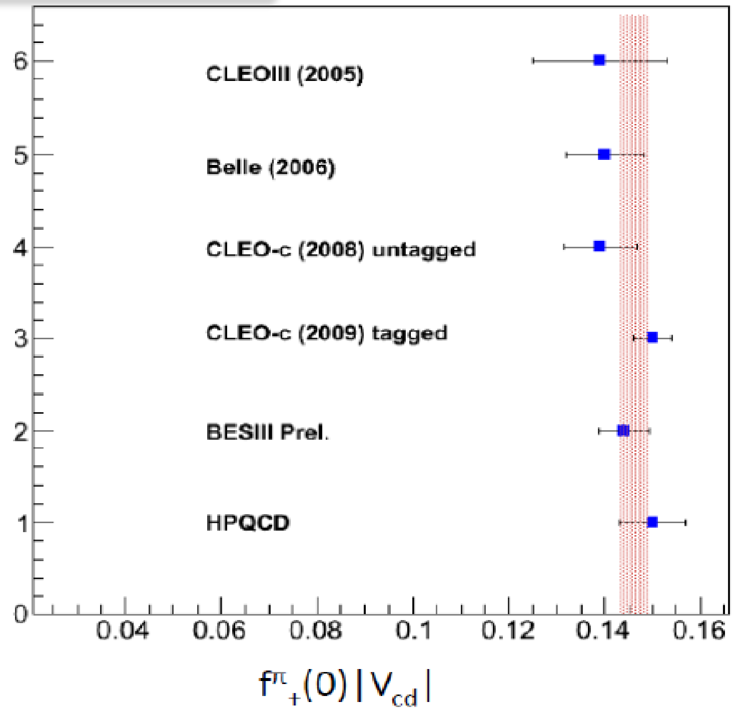
different models & parameterizations

BESIII PRD 83, 032003 (2011)

Semi-leptonic Decays $D^0 \to K/\pi e\nu$

Preliminary results

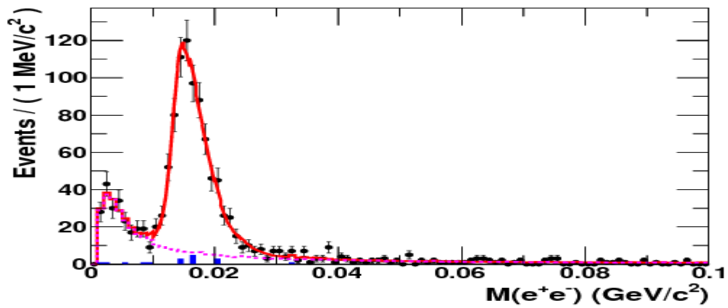


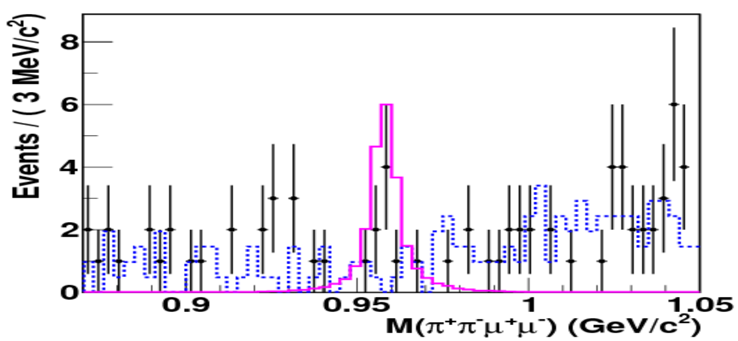


- Number are from HFAG2012 report (arXiv:1207.1158).
- Error bar of BESIII preliminary results Will shrink with full data.
- BESIII results from D^0 only, CLEO-c use both D^0 and D^+

$\eta' \to \pi^+\pi^-\ell^+\ell^-$ in $J/\psi \to \gamma\eta'$

- $\eta' \to \pi^+\pi^- e^+e^-$ have been discussed based on the Vector Meson Dominance model and Chiral Perturbation Theory.
- $\eta' \to \pi^+\pi^- e^+e^-$ is expected to proceed via virtual photon intermediate state, $\eta' \to \pi^+\pi^-\gamma^* \to \pi^+\pi^- e^+e^-$, and provides a more stringent test of theories.
- The e^+e^- mass spectrum is expected to be a peak with a long tail just above $2m_e$. While a dominant ρ^0 contribution in $M_{\pi^+\pi^-}$.





BESIII Results

$Br(\eta' \to \pi^+\pi^- e^+e^-) = (2.11 \pm 0.12 \pm 0.15) \times 10^{-3}$

$Br(\eta' \to \pi^+\pi^- \mu^+\mu^-) < 2.9 \times 10^{-5}$ @ 90% C. L.

Effective Meson theory

(PRC 61, 0305206, 2000)

$Br(\eta' \to \pi^+\pi^- e^+e^-) = 1.8 \times 10^{-3}$

$Br(\eta' \to \pi^+\pi^- \mu^+\mu^-) = 2.9 \times 10^{-5}$

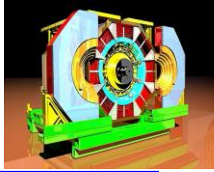
Chiral Unitary

(EPJA 33, 95 (2007))

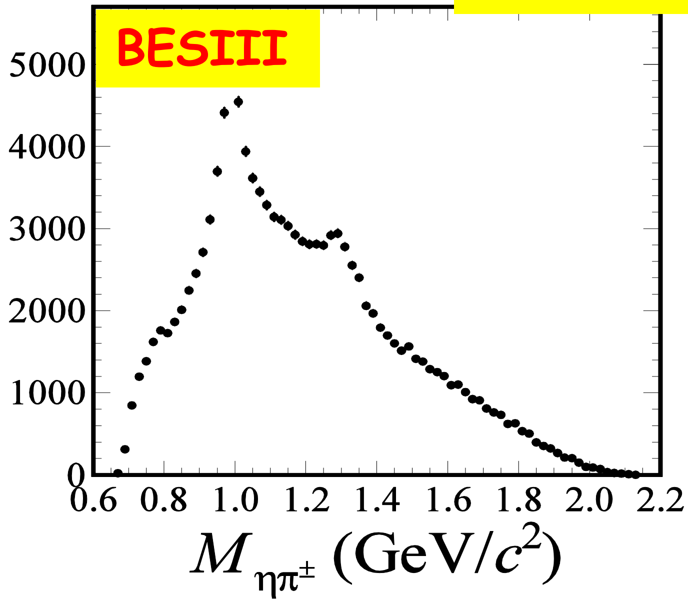
$Br(\eta' \to \pi^+\pi^- e^+e^-) = 2.13^{+0.19}_{-0.32} \times 10^{-3}$

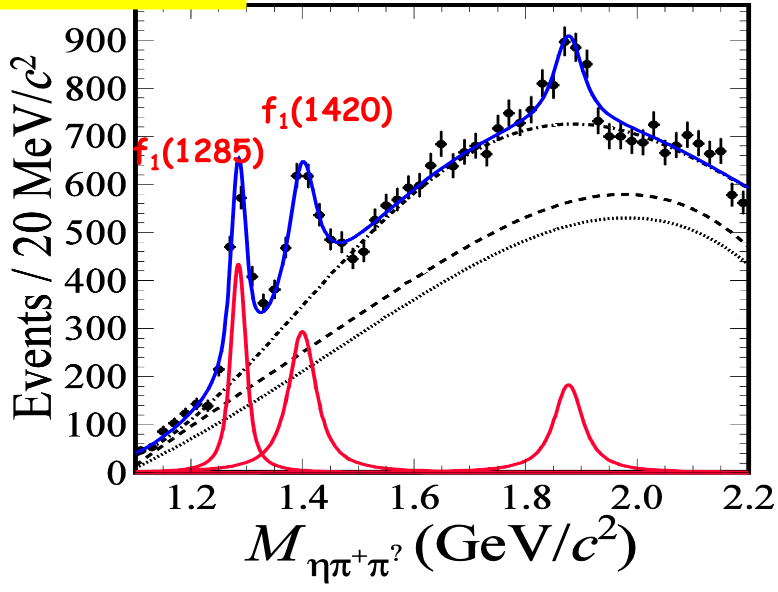
$Br(\eta' \to \pi^+\pi^- \mu^+\mu^-) = 1.57^{+0.96}_{-0.75} \times 10^{-5}$

X(1870) in $J/\psi \to \omega\pi^+\pi^-\eta$



PRL 107, 182001(2011)

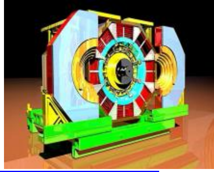




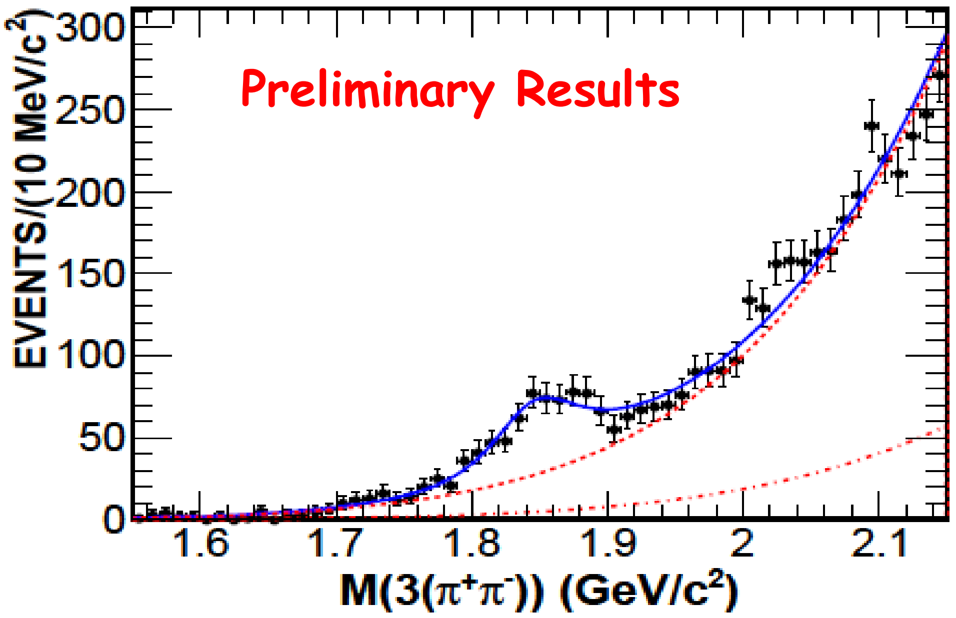
Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	$\mathcal{B}(10^{-4})$
$f_1(1285)$	$1285.1 \pm 1.0^{+1.6}_{-0.3}$	$22.0 \pm 3.1^{+2.0}_{-1.5}$	$1.25 \pm 0.10^{+0.19}_{-0.20}$
$\eta(1405)$	$1399.8 \pm 2.2^{+2.8}_{-0.1}$	$52.8 \pm 7.6^{+0.1}_{-7.6}$	$1.89 \pm 0.21^{+0.21}_{-0.23}$
$X(1870)$	$1877.3 \pm 6.3^{+3.4}_{-7.4}$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

Is it a new structure, X(1835) or $\eta_2(1870)$?

J^{PC}? PWA and more data will help !!!



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

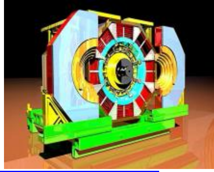


- A structure at 1.84GeV/c2 is observed.
- No obviously structure observed above 2.0 GeV/c2

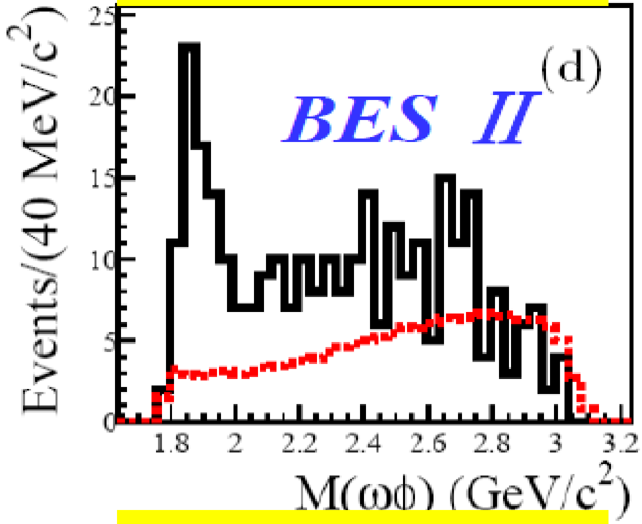
- The Mass is in agreement with those of X(1835) and X($p\bar{p}$), but width do not :
  - **$M=1842.2\pm4.2{+7.1}{-2.6}$MeV/C2, $\Gamma=83\pm14\pm11$MeV/C2**
- The production ratio :
  - **$Br(J/\psi\to\gamma X(1840))\times Br(X(1840)\to3(\pi+\pi-))=(2.44\pm0.36^{+0.60}_{-0.74})\times10^{-5}$**

A new structure or an existing state? Need more study!
(J^{PC}, relationship between different observations)

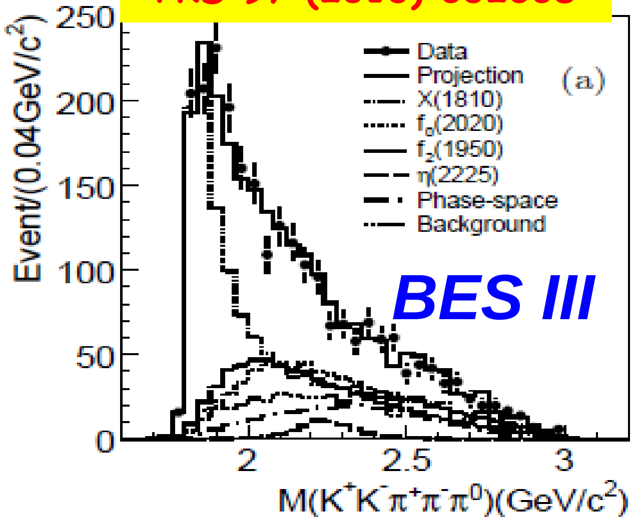
Threshold Enhancement in $J/\psi \to \gamma\omega\phi$

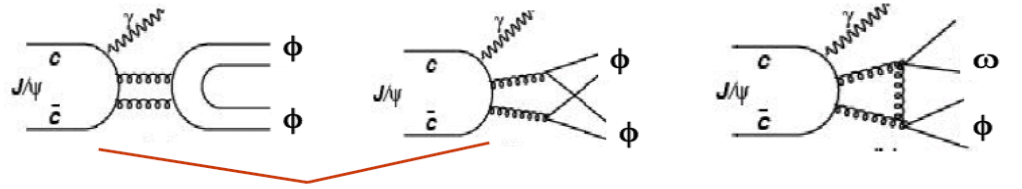


PRL 96 (2006) 162002



PRD 97 (2013) 032008





OZI

$J/\psi \to \gamma\phi\phi, \phi \to K^+K^-$

DOZI

$J/\psi \to \gamma\omega\phi$

- First observed in the 58M J/ψ in BESII
- Confirmed and improved measurement in 225M J/ψ in BESIII.
  - $J^{PC}=0^{++}$,
  - $M=1795\pm7^{+23}_{-5}MeV/c^2$, $\Gamma=95\pm10^{+78}_{-34}MeV/c^2$
- DOZI suppressed, but large branching ratio.
  - $Br(J/\psi\to\gamma X)\times Br(X\to\omega\phi)=(2.00\pm0.08^{+1.38}_{-1.00})\times10^{-4}$
  - $\sim 1/2\ Br(J/\psi\to\gamma\phi\phi)$
- Exotic states, $f_0(1710)$, FSI …..?
- More channels search