Review of charm physics at BESIII

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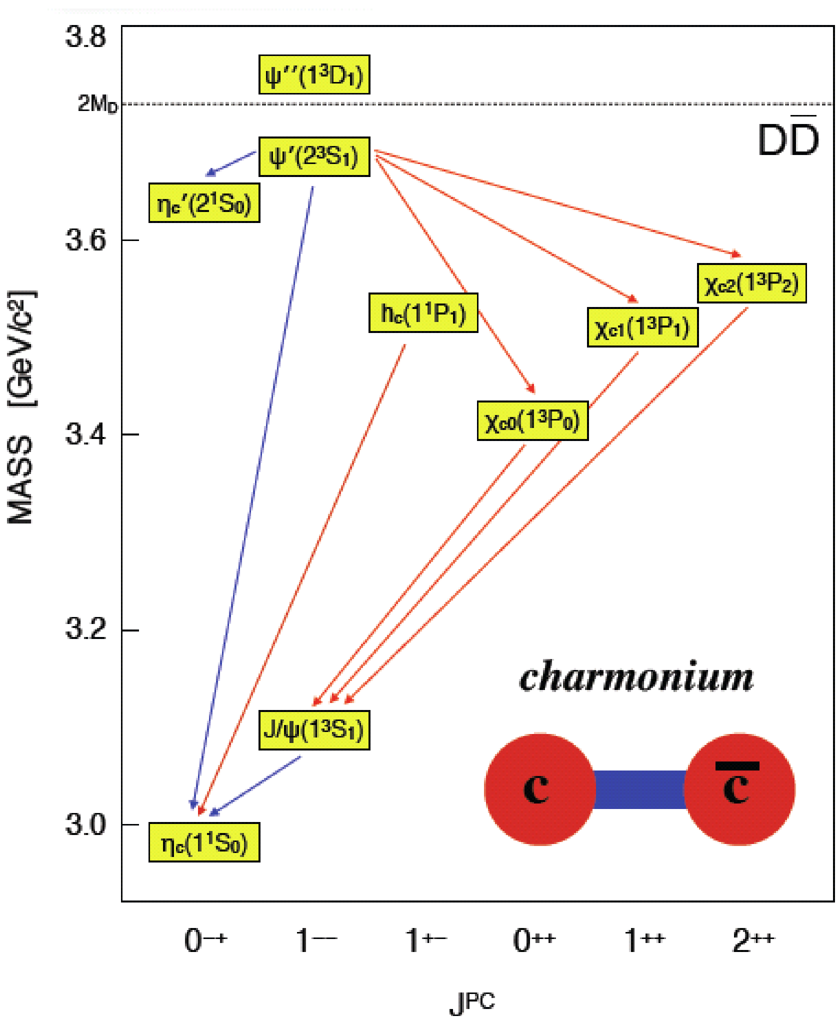
BEACH 2012
July 23rd-28th, 2012
Wichita, USA

Outline

- Status of BEPCII/BESIII
- Charmonium transitions
- Charmonium decays
- Light hadrons from Charmonium decays
- Charm meson: advantage near DDbar threshold
- Conclusion

BESIII - physics using "charm"



Charmonium physics:
- Spectroscopy
- transitions and decays

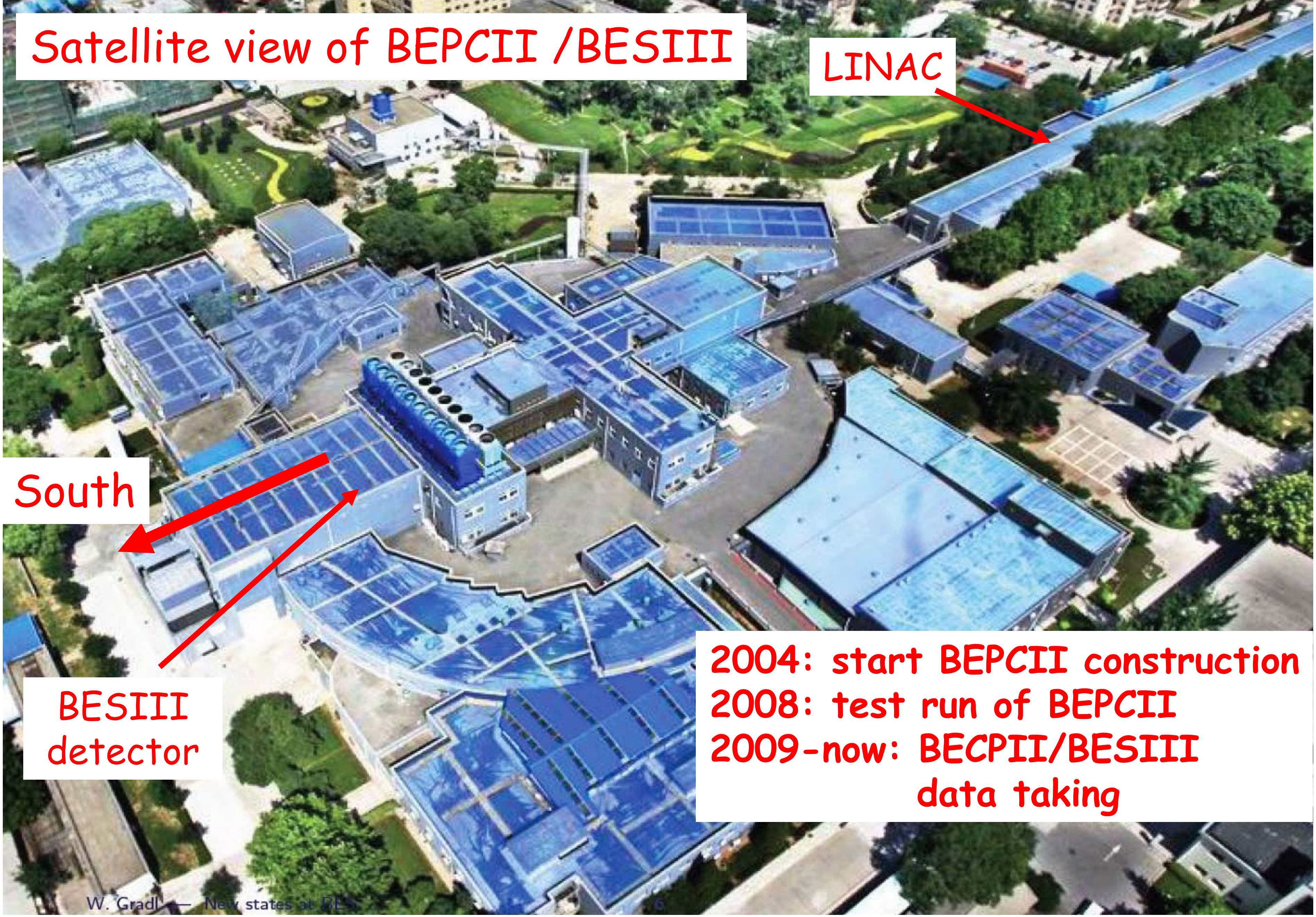
Light hadron physics:
- meson & baryon spectroscopy
- glueball & hybrid
- two-photon physics
- e.m. form factors of nucleon

Charm physics:
- (semi)leptonic + hadronic decays
- decay constant, form factors
- CKM matrix: Vcd, Vcs
- D^0-D^0bar mixing and CP violation
- rare/forbidden decays

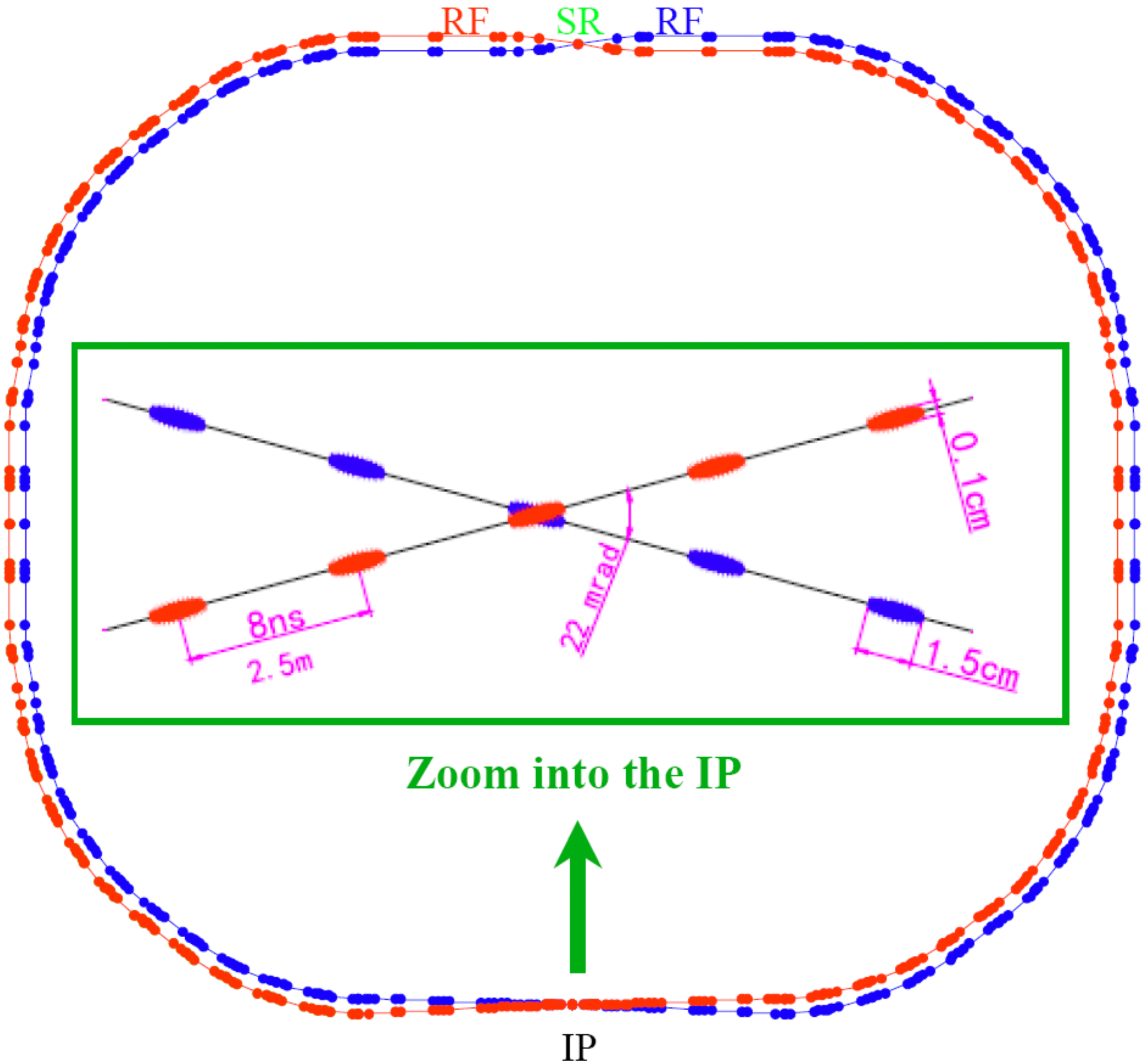
Tau physics:
- Tau decays near threshold
- tau mass scan

…and many more.

Satellite view of BEPCII /BESIII

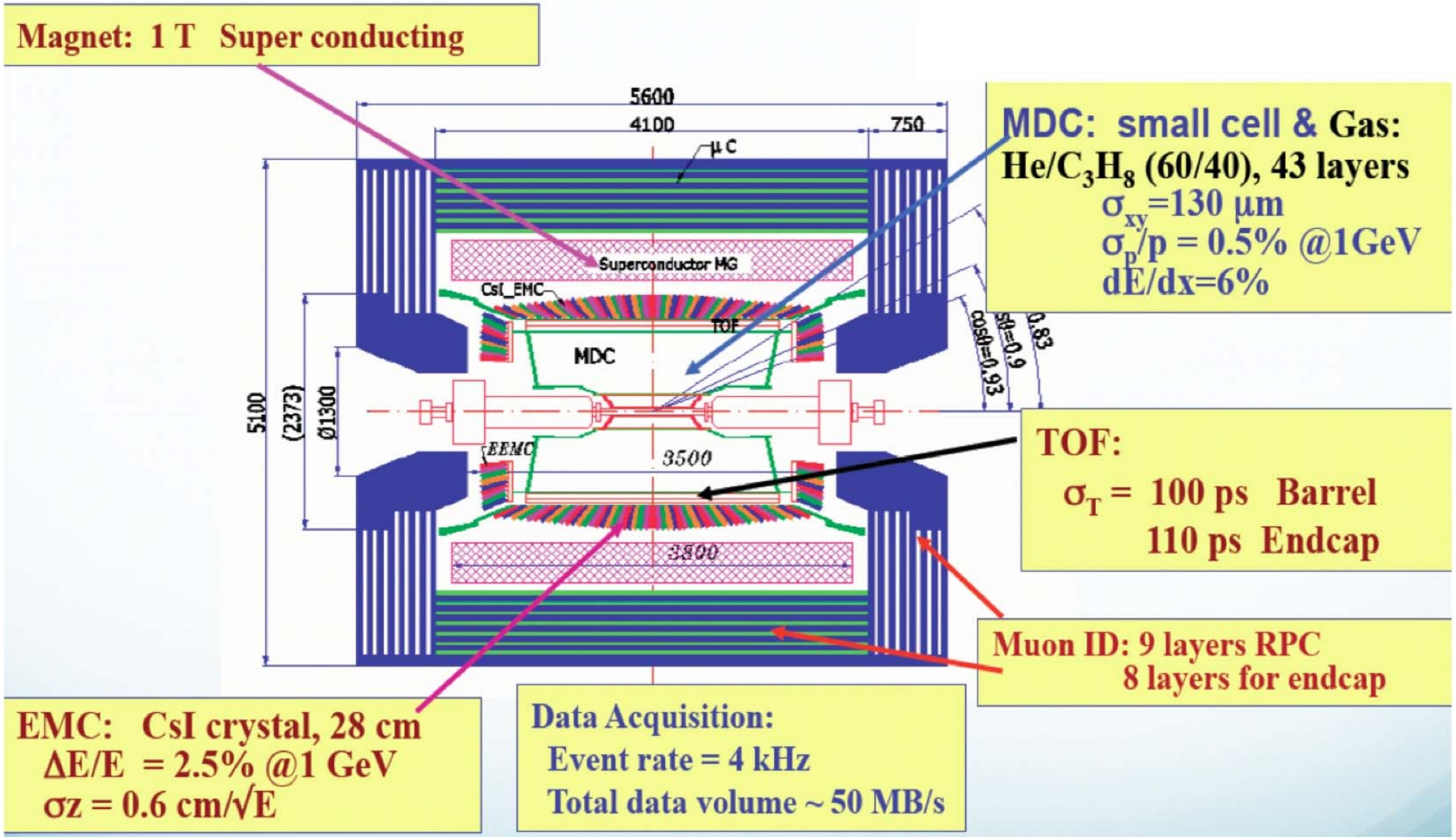


BEPCII storage rings



Beam energy:
1.0-2.3 GeV
Design 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
Circumference：
237m

BESIII detector



- Comparable capabilities to CLEO-c, plus muon ID
- The big advantage: BEPCII is a two-ring machine designed for charm
  - Design (achieved) luminosity at $\psi(3770)$: 1 (0.65) x 10^{33}

BESIII data set and future plans

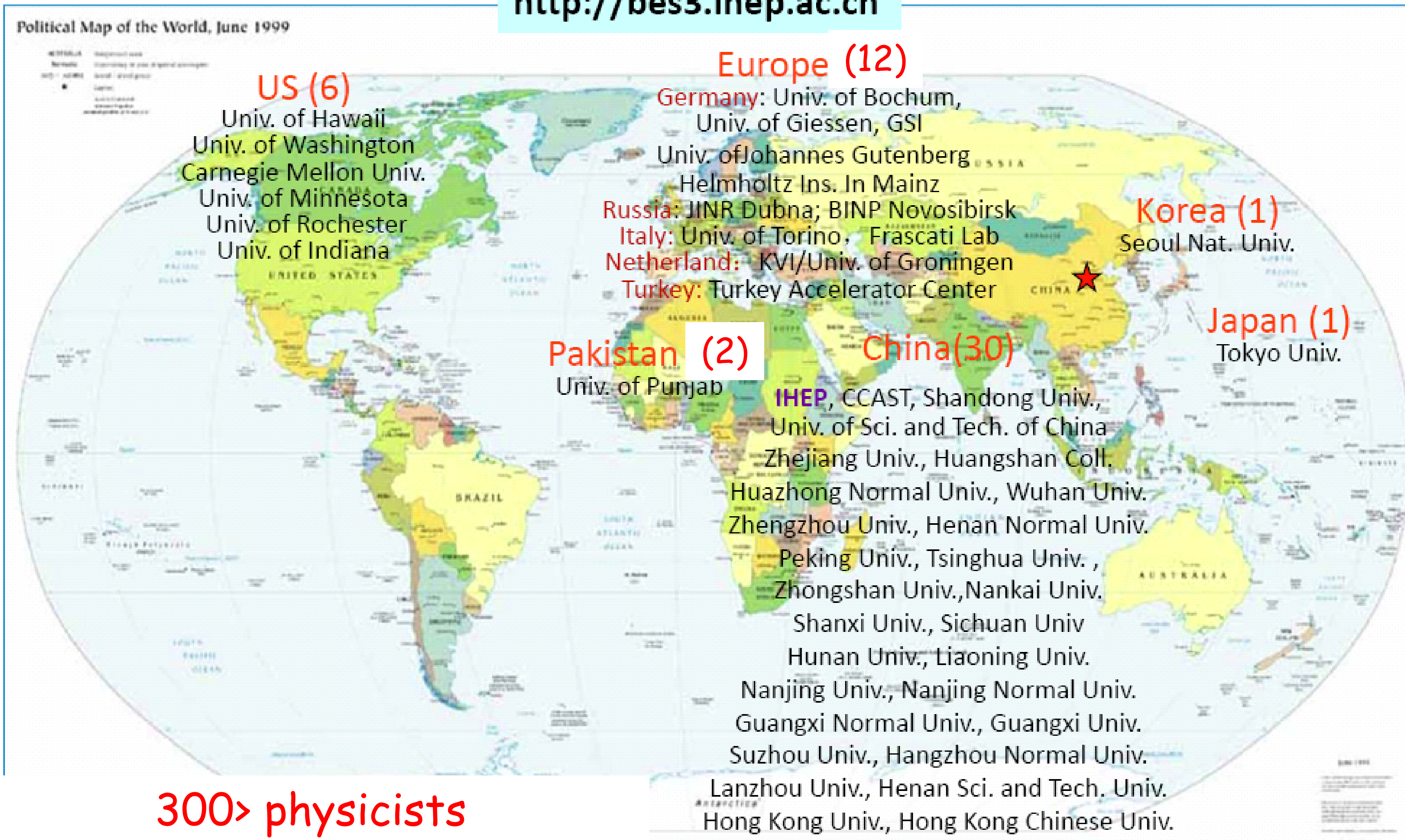
- 2009: 106M $\psi(2S)$
  225M J/ψ
- 2010-2011: 2.9fb^{-1} @ $\psi(3770)$ 3.5 ×CLEO-c
- 2011: 470pb^{-1} @ 4010MeV
- 2012: τ mass scan, R scan [2.0 3.65] GeV
  0.4 billion $\psi(2S)$ and 1 billion J/ψ

Tentative future running plans:

2013: E_{CM}=4260 and 4360 MeV:
For "XYZ" studies (0.5 fb^{-1} each point)
2014: E_{CM}=4170 MeV for Ds (~2.4 fb^{-1})
2015: TBD → additional $\psi(3770)$ data

BESIII Collaboration

http://bes3.ihep.ac.cn



US (6)
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Univ. of Washington
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

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

Korea (1)
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Japan (1)
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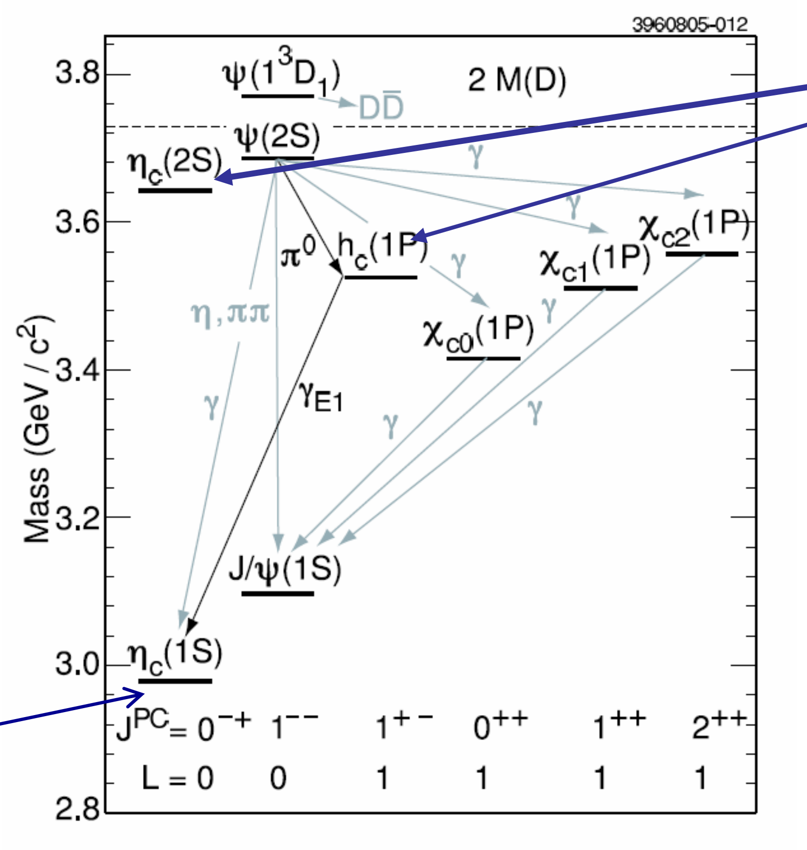
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Hong Kong Univ., Hong Kong Chinese Univ.
Univ. of South China, GUCAS.

300> physicists
52 institutes from 11 countries

Below Threshold Charmonium



Properties not well known

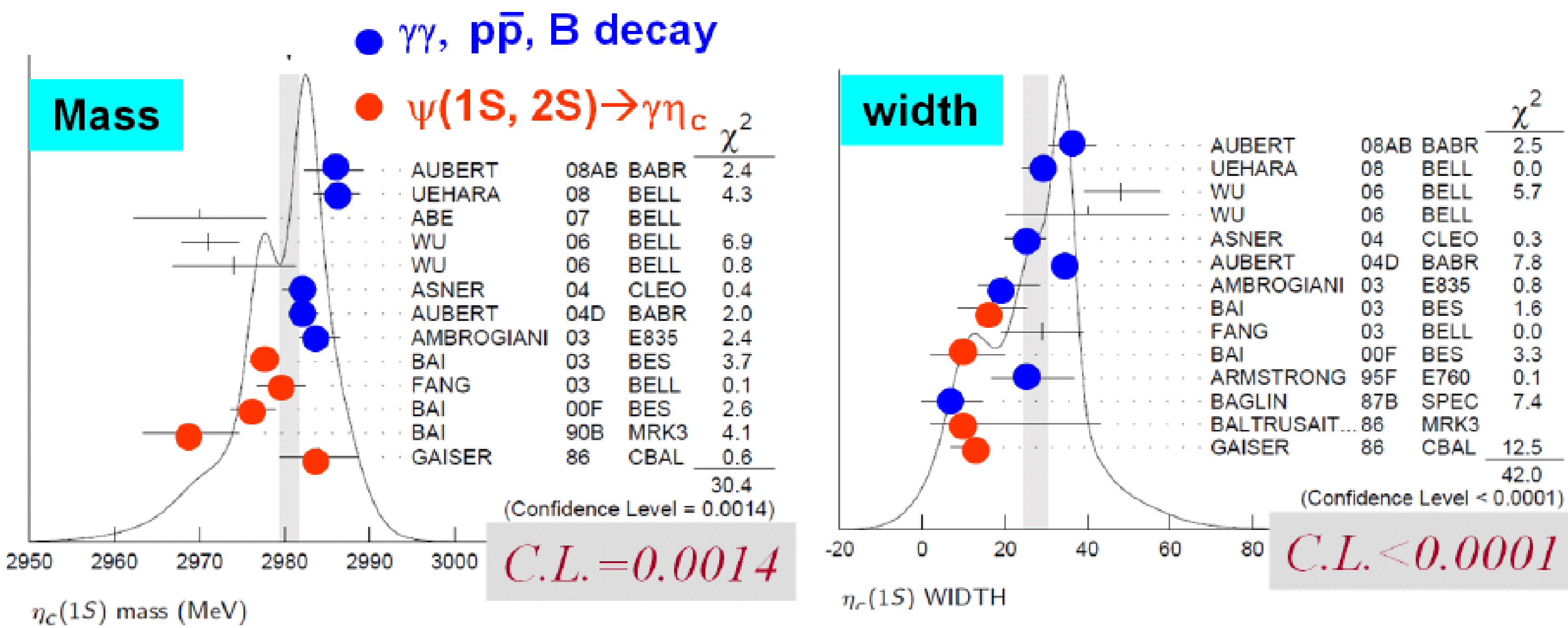
Problems with mass and width measurements

Mass and width of $\eta_c(1S)$

- Ground state of $c\bar{c}$ system, but its properties are not well known:

J/ψ radiative transition: $M \sim 2978.0 \mathrm{MeV}/c^2$, $\Gamma \sim 10 \mathrm{MeV}$

γγ process: $M = 2983.1 \pm 1.0 \ \mathrm{MeV}/c^2$, $\Gamma = 31.3 \pm 1.9 \ \mathrm{MeV}$

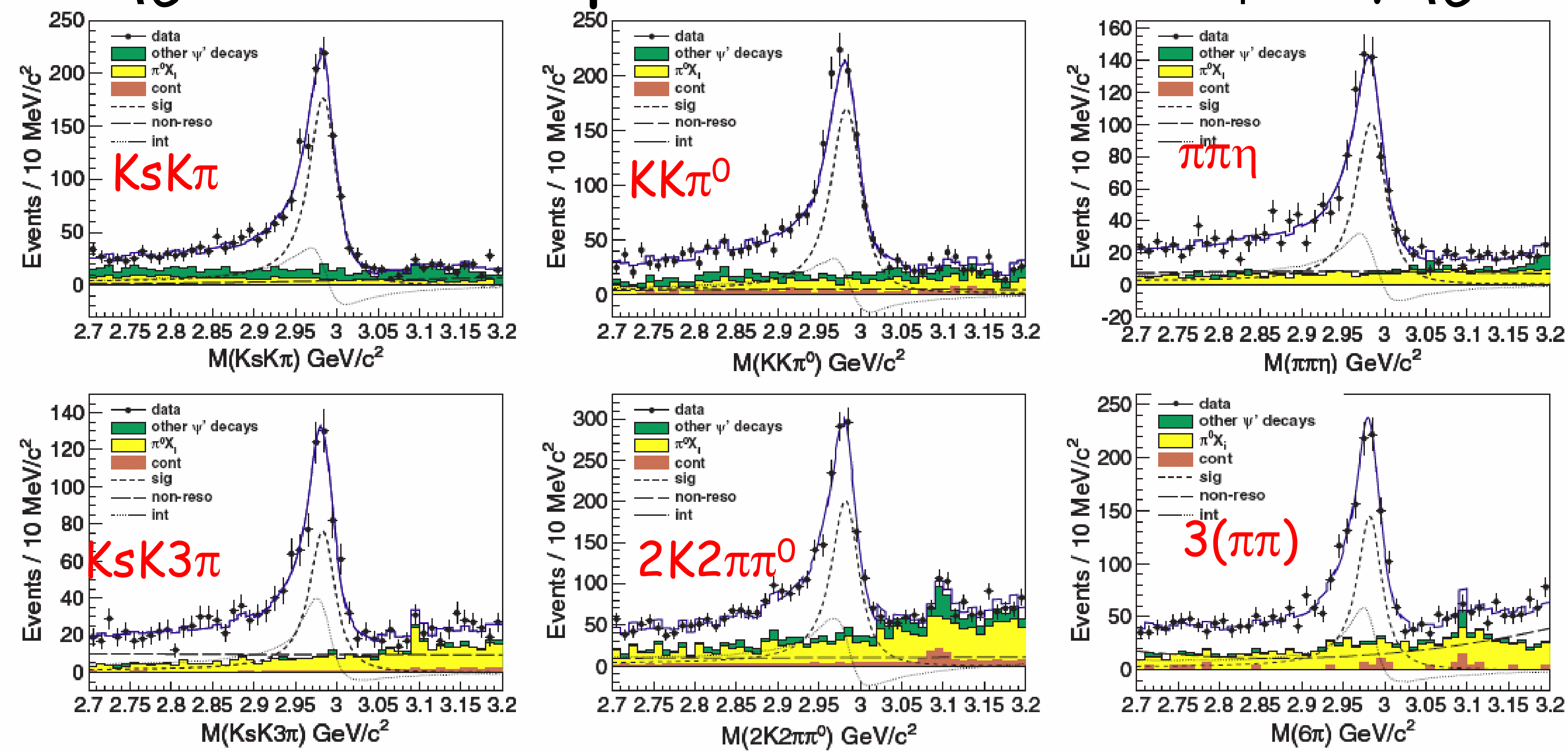


- CLEOc found the distortion of the η_c lineshape in ψ′ decays

- $c\bar{c}$ hyperfine splitting: $M(J/\psi)$- $M(\eta_c)$ is important experimental input to test the lattice QCD, but is dominated by error on $M(\eta_c)$

9

η_c resonance parameters from $\psi' \to \gamma\eta_c$



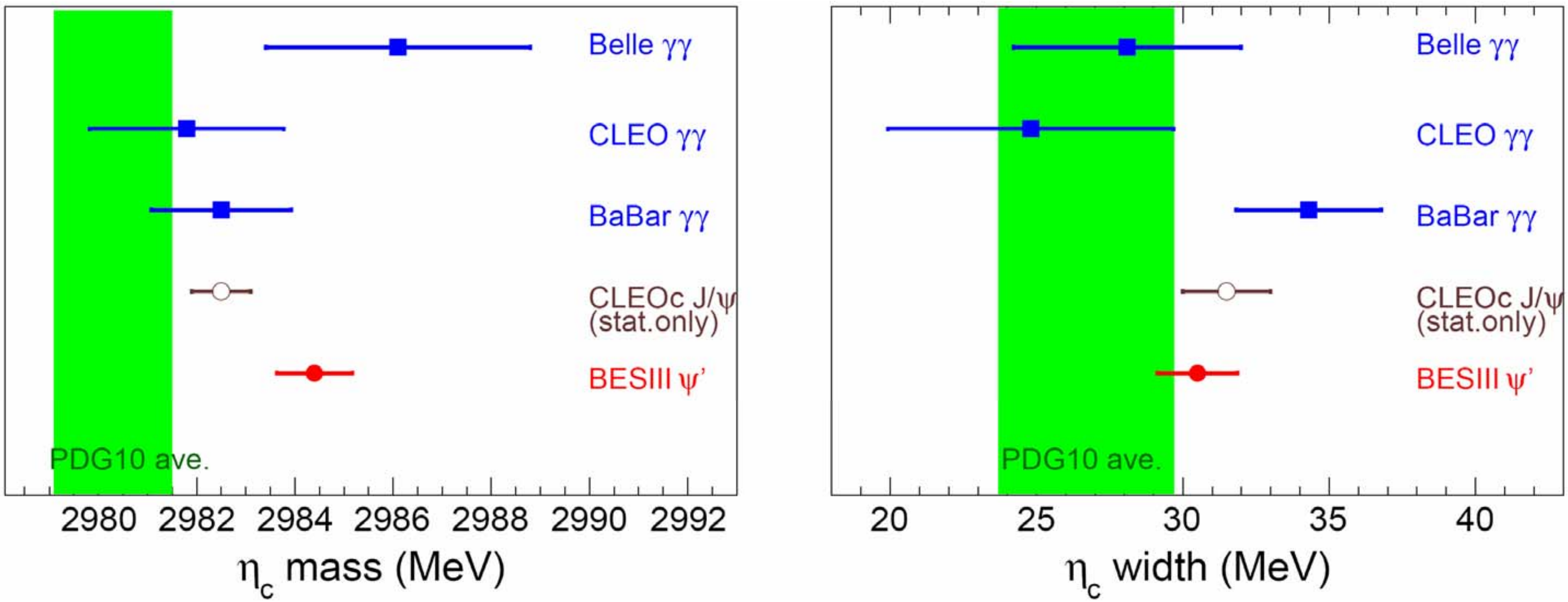
The interference between η_c and non-η_c decays:

mass: $2984.3 \pm 0.6_{stat} \pm 0.6_{sys}$ MeV/c^2
width: $32.0 \pm 1.2_{stat} \pm 1.0_{sys}$ MeV
ϕ: $2.40 \pm 0.07_{stat} \pm 0.08_{sys}$ rad (constructive)
or $4.19 \pm 0.03_{stat} \pm 0.09_{sys}$ rad (desconstruct)

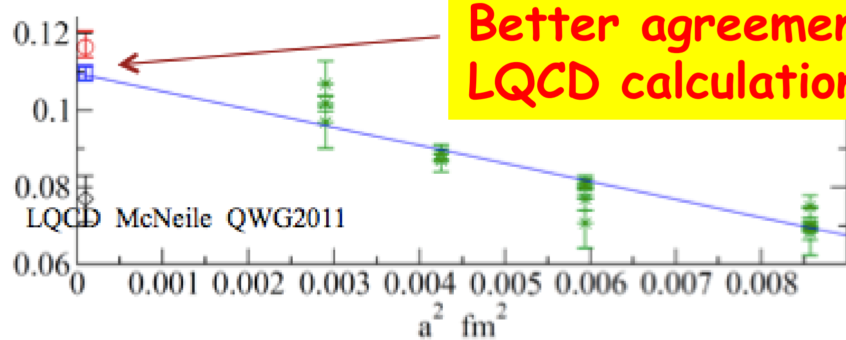
Relative phase ϕ values from each mode are consistent within 3σ,
➔ use a common phase value in the simultaneous fit.

Phys.Rev.Lett. 108 (2012) 222002

Comparison of the mass and width for η_c



Hyperfine splitting: $\Delta M(1S) = 112.5 \pm 0.8$ MeV (earlyer results: ~117MeV)



Better agreement with LQCD calculations

Property of h_c (1p1)

PRL104, 132002 (2010)

Study isospin forbidden transition

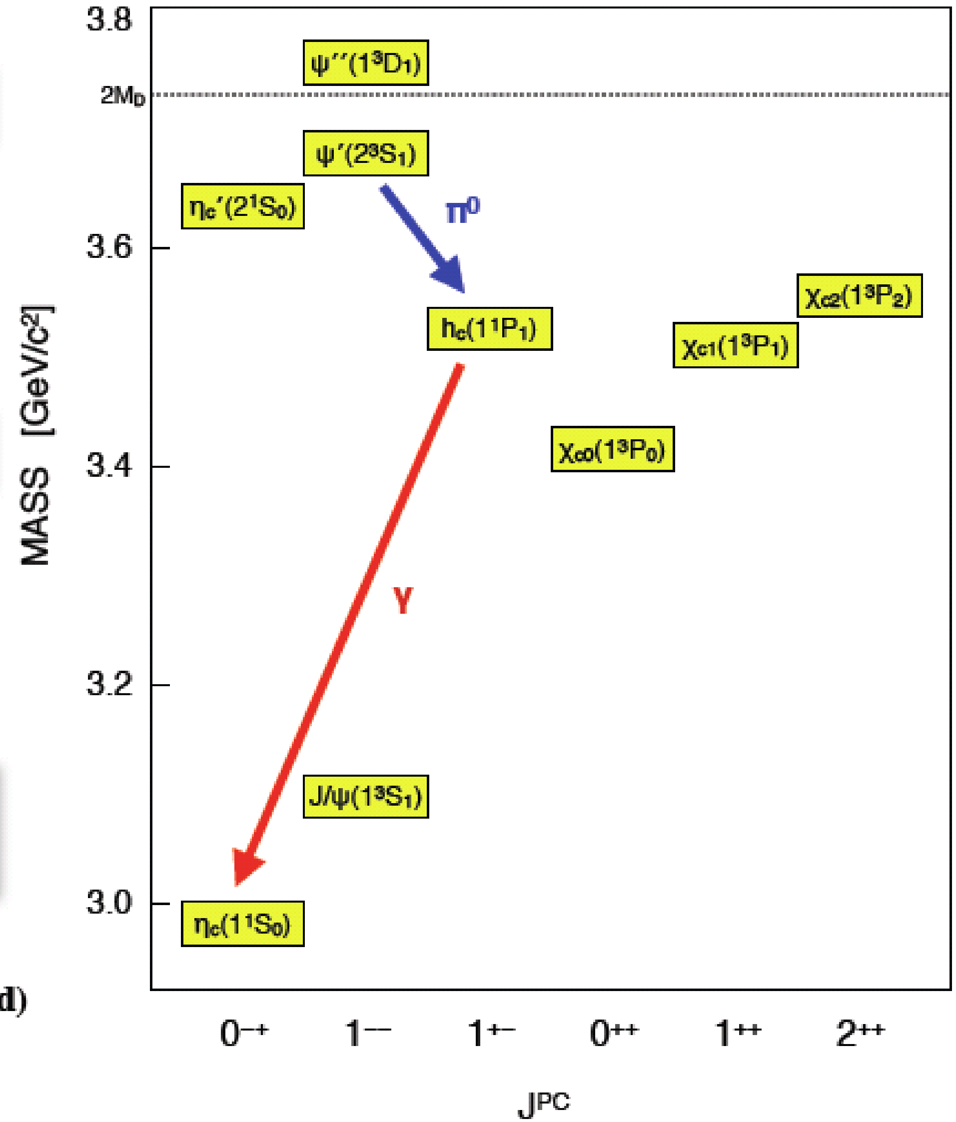
$$B(\Psi' \to \pi^\circ h_c)$$

Measure as well the E1 transition

$$B(h_c \to \gamma \eta_c)$$

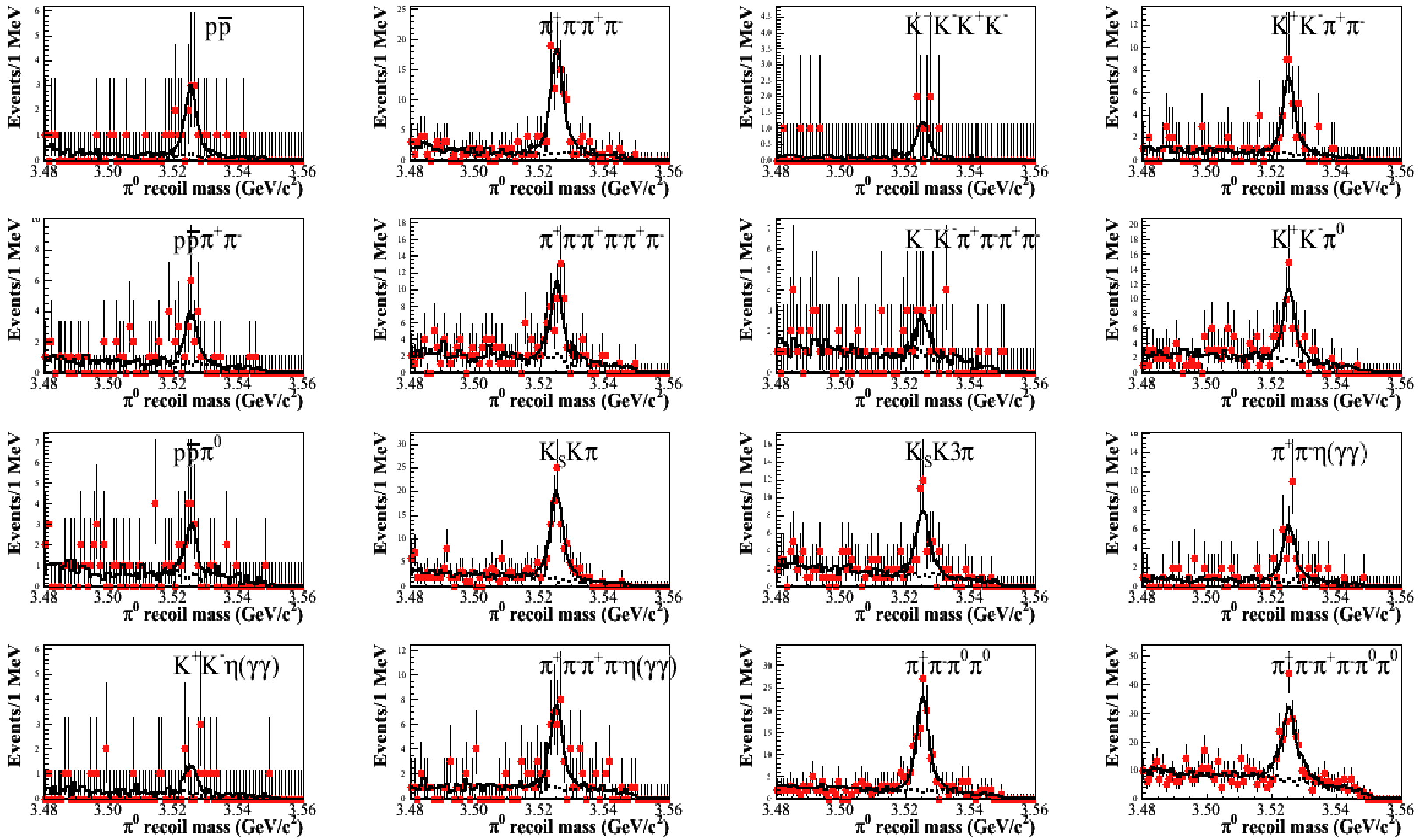
Hyperfine splitting of the 1P states (spin-spin interaction term):

$$M(h_c(1P)) - \langle M(\chi_{cJ}(1P)) \rangle_{(spin\text{-}weighted)}$$

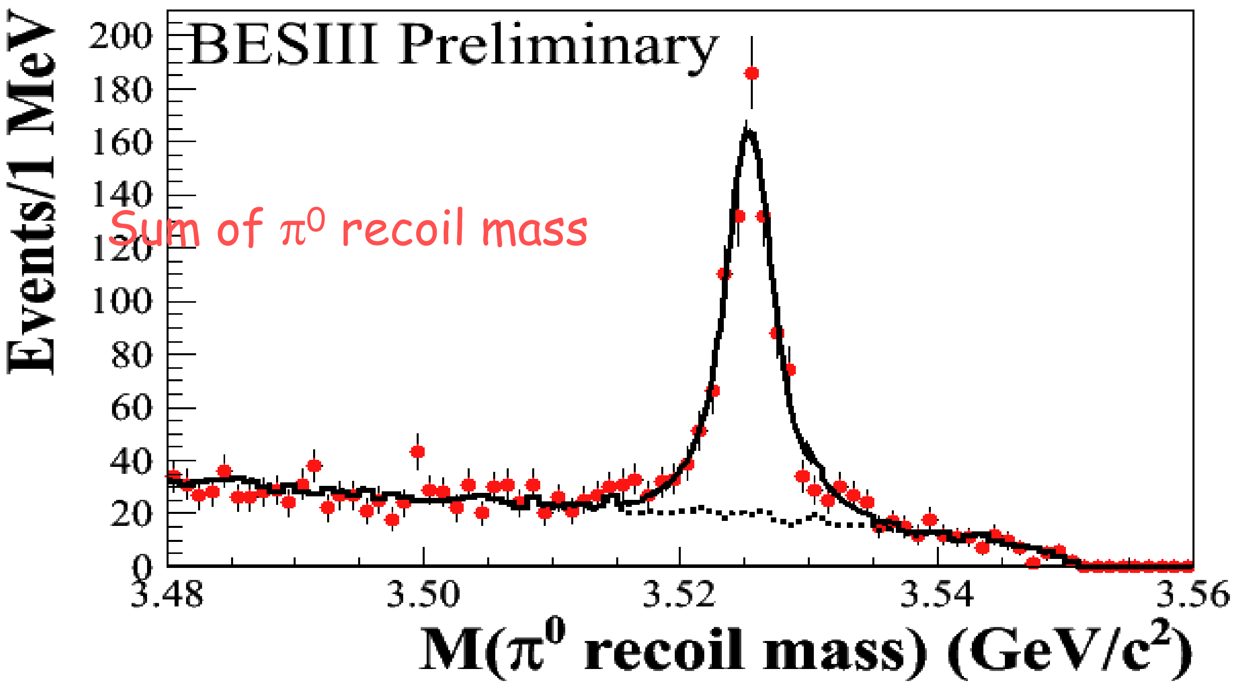


$h_c(1P1)$ in $\psi'\to\pi^0 h_c$, $h_c \to \gamma\eta_c$, $\eta_c \to X_i$ (exclusive)

$\psi'\to\pi^0 h_C$, $h_C\to\gamma\eta_C$, η_C is reconstructed exclusively with 16 decay modes: BESIII preliminary



π^0 recoil mass in $h_c \rightarrow \gamma\eta_c$, $\eta_c \rightarrow X_i$



Simultaneous fit to π^0 recoiling mass in 106M ψ' sample (preliminary results):

$M(h_c) = 3525.31 \pm 0.11_{(stat)} \pm 0.15_{(sys)}$ MeV/c^2
$\Gamma(h_c) = 0.70 \pm 0.28_{(stat)} \pm 0.25_{(sys)}$ MeV
$N = 832 \pm 35$
χ^2/d.o.f. = 32/46

Consistent with BESIII inclusive Results: PRL104,132002(2010)

CLEOc exlusive results:
$M(h_c) = 3525.21 \pm 0.27 \pm 0.14$ MeV/c^2
PRL101, 182003(2008)

$\eta_c(2S)$

- First "observation" by Crystal Ball in 1982 (M=3.592, B=0.2%-1.3% from $\psi' \to \gamma X$, never confirmed by other experiments.)
- Published results about $\eta_c(2S)$ observation:

Experiment	M [MeV]	Γ [MeV]	Process
Belle [1]	$3654 \pm 6 \pm 8$	—	$B^{\pm} \to K^{\pm}\,\eta_c(2S), \eta_c(2S) \to K_S K^{\pm}\pi^{\mp}$
CLEO [2]	$3642.9 \pm 3.1 \pm 1.5$	$6.3 \pm 12.4 \pm 4.0$	$\gamma\gamma \to \eta_c(2S) \to K_S K^{\pm}\pi^{\mp}$
BaBar [3]	$3630.8 \pm 3.4 \pm 1.0$	$17.0 \pm 8.3 \pm 2.5$	$\gamma\gamma \to \eta_c(2S) \to K_S K^{\pm}\pi^{\mp}$
BaBar [4]	$3645.0 + 5.5^{+4.9}_{-7.8}$	—	$e^+e^- \to J/\psi c\bar{c}$
PDG [5]	3638 ± 4	14 ± 7	—

Combined with the results based on two-photon processes from BaBar and Belle reported at ICHEP 2010, the world average $\Gamma(\eta_c(2S))=12 \pm 3$ MeV

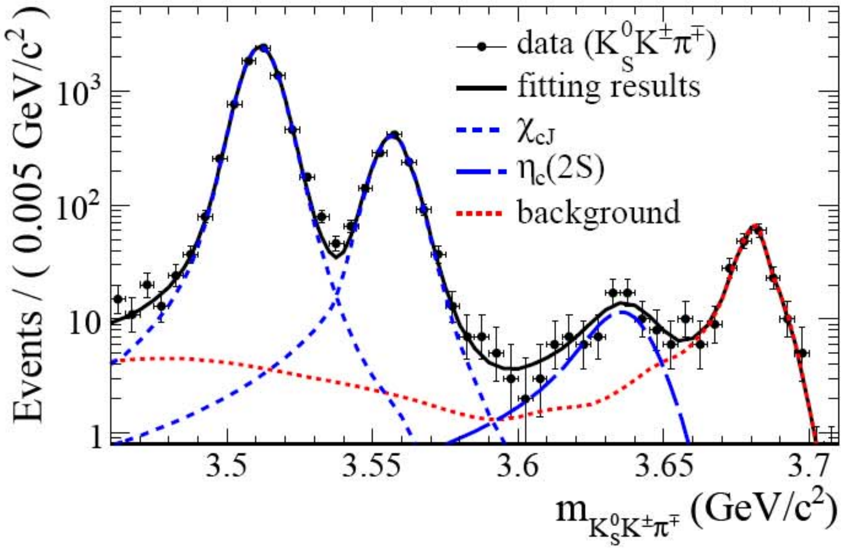
- The M1 transition $\psi' \to \gamma\eta_c(2S)$ has not been observed.

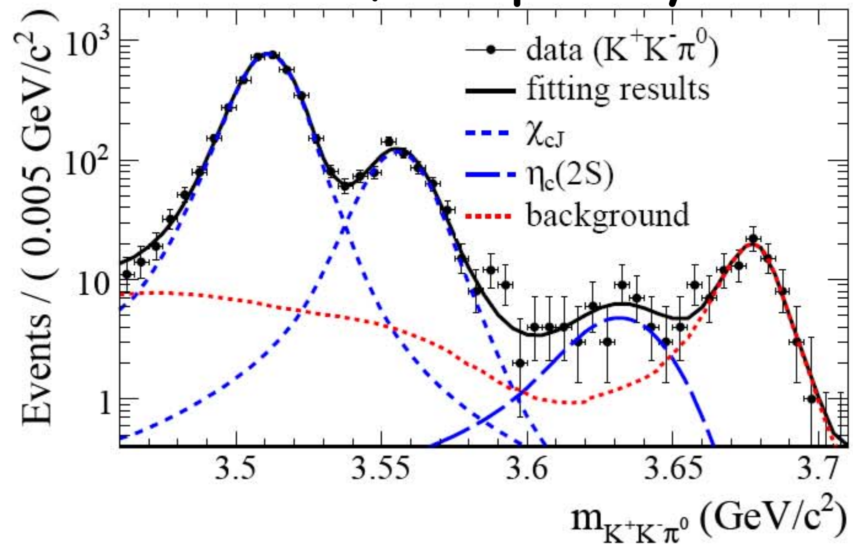
  (experimental challenge : search for real photons ~50MeV,)

- Better chance to observe $\eta_c(2S)$ in ψ' radiative transition with ~106M ψ' data at BESIII.
- Decay mode studied: $\psi' \to \gamma\eta_c(2S) \to \gamma KK\pi$

Observation of $\eta_c(2S)$ in $\psi' \to \gamma\eta_c(2S), \eta_c(2S) \to KK\pi$

arXiv:1205.5103, accepted by PRL





Signal lineshape:

$$(E_\gamma^3 \times BW(m) \times f_d(E_\gamma) \times \epsilon(m)) \otimes G(\delta m, \sigma)$$

Phase space factor

$$\frac{E_0^2}{E_\gamma E_0 + (E_\gamma - E_0)^2}$$

Dumping factor

Combined fit of two channels:

- significance >10σ
- $M = 3637.6 \pm 2.9(stat.) \pm 1.6(syst.)\,MeV$
  $\Gamma = 16.9 \pm 6.4(stat.) \pm 4.8(syst.)\,MeV$
- combined branching ratios

$$Br(\psi' \to \gamma\eta_c(2S)) \times Br(\eta_c(2S) \to KK\pi) = (1.30 \pm 0.20 \pm 0.30) \times 10^{-5}$$

PRD 78 012006(2008) →

$$Br(\psi' \to \gamma\eta_c(2S)) = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$$

$\psi' \to \gamma\gamma J/\psi$

- Two photon transitions are well known in excitations of molecules, atomic hydrogen, and positronium.

*[F. Bassani etal, PRL **39**, 1070 (1977);A. Quattropani etal, PRL **50**, 1258 (1983)]*

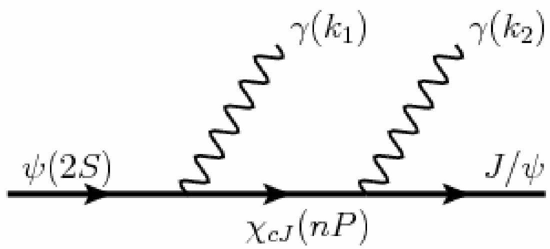
- Never been observed in the quarkonium system.

CLEOc: upper limit of $Br(\psi' \to \gamma\gamma J/\psi)$ is 1×10^{-3} (PRD 78,011102(2008))

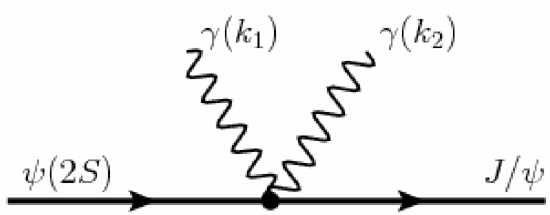
- Observation helpful to understand heavy quarkonium spectrum & strong interaction

Theoretically:

- Potential models give discrete spectra ($\psi(2S) \to \gamma\chi_{cJ}, \chi_{cJ} \to \gamma J/\psi$)



- Possibility of testing the hadron-loop effect

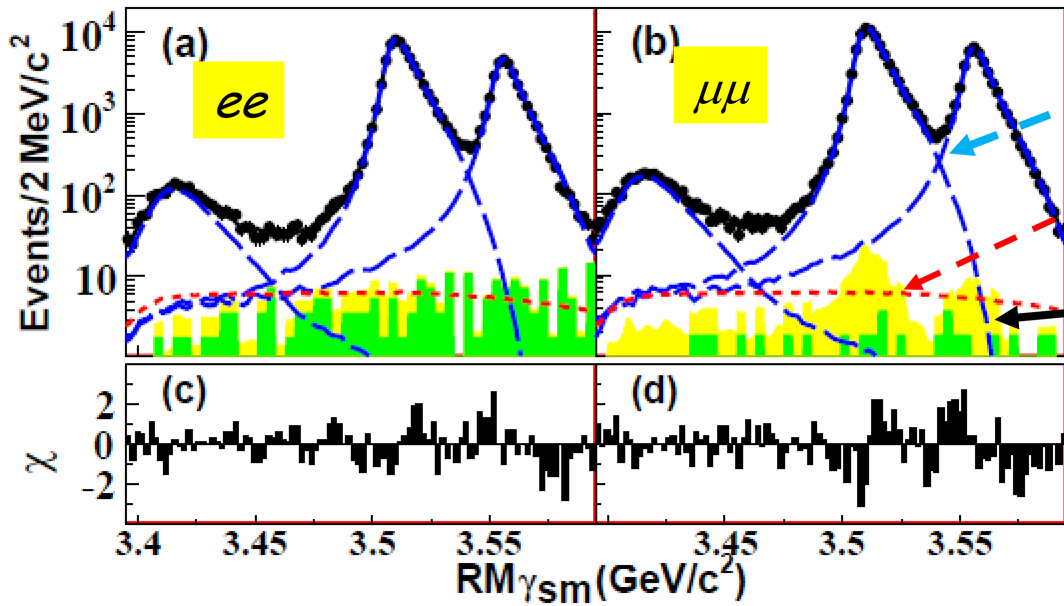


- Coupled channel: **the hadron-loop effect also may play a important role in the continuous spectra** arXiv: 1112.0942 Submit to PRL

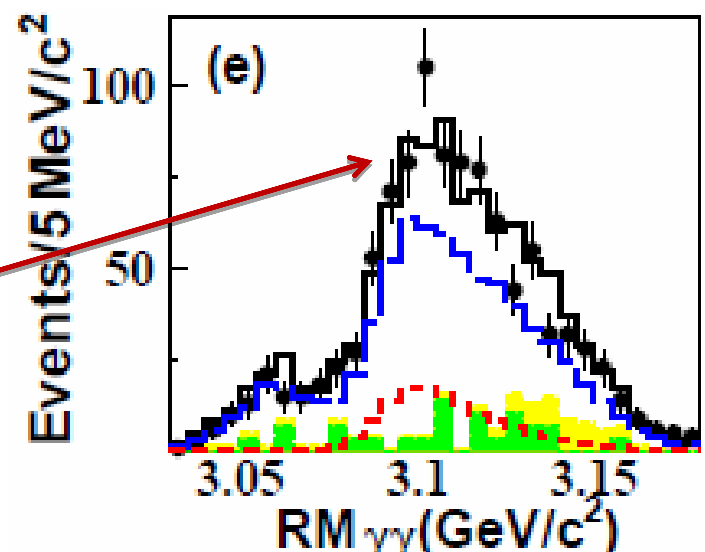
First evidence of $\psi' \rightarrow \gamma\gamma J/\psi$

- Select $\psi(2S) \rightarrow \gamma\gamma J/\psi$, $J/\psi \rightarrow e^+e^-$ and $\mu^+\mu^-$ events

γ_{sm} - low energy gamma



- The χ_{cJ} components
- Yields of the two-photon transition
- Continuum(green)+ ψ'-decay BG(yellow)



3.44<RM(γ_{sm})<3.48GeV

- Global fit of including χ_{cJ} states
- See **clear excess** over BG + continuum

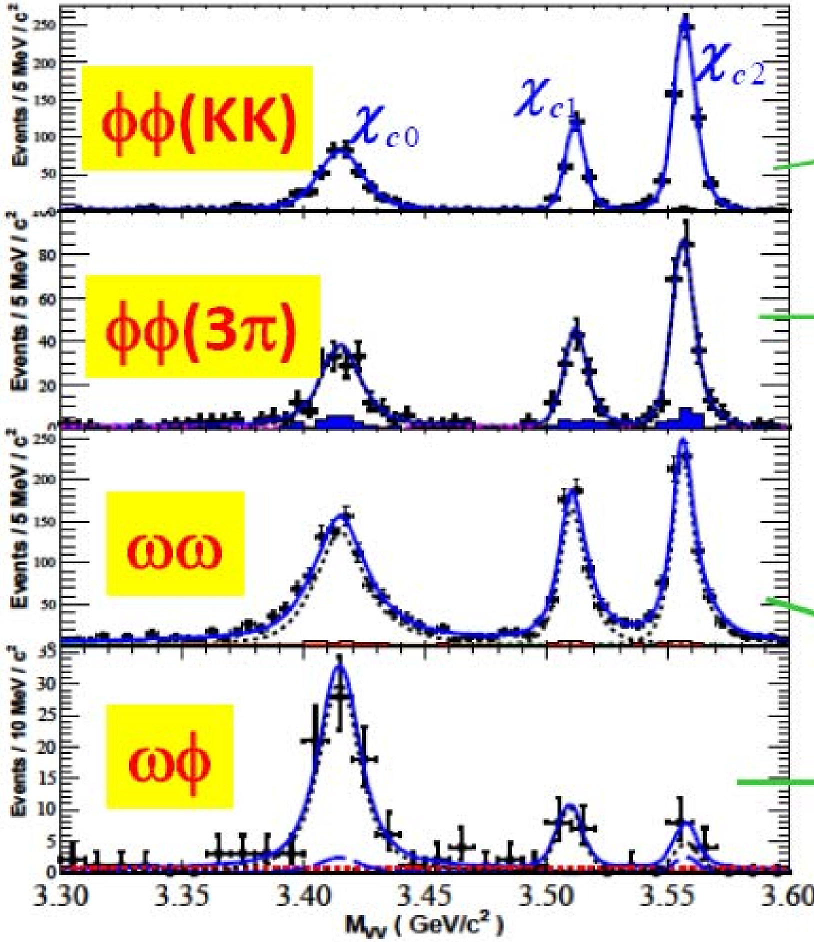
- $Br(\psi' \rightarrow \gamma\gamma J/\psi) = (3.3 \pm 0.6^{+0.8}_{-1.1}) \times 10^{-4}$ (both *ee* and $\mu\mu$)

- **Significance : 3.8σ including systematics**

- $Br(\psi' \rightarrow \gamma\chi_{cJ}, \chi_{cJ} \rightarrow \gamma J/\psi)$ are also measured

$\chi_{cJ} \rightarrow VV$

PRL107, 091803 (2011)



Mode	N_{net}	ϵ (%)	$\mathcal{B}(\times 10^{-4})$
$\chi_{c0} \to \phi\phi$	433 ± 23	22.4	$7.8 \pm 0.4 \pm 0.8$
$\chi_{c1} \to \phi\phi$	254 ± 17	26.4	$4.1 \pm 0.3 \pm 0.4$
$\chi_{c2} \to \phi\phi$	630 ± 26	26.1	$10.7 \pm 0.4 \pm 1.1$
$\to 2(K^+K^-)$			
$\chi_{c0} \to \phi\phi$	179 ± 16	1.9	$9.2 \pm 0.7 \pm 1.0$
$\chi_{c1} \to \phi\phi$	112 ± 12	2.3	$5.0 \pm 0.5 \pm 0.6$
$\chi_{c2} \to \phi\phi$	219 ± 16	2.2	$10.7 \pm 0.7 \pm 1.2$
$\to K^+K^-\pi^+\pi^-\pi^0$			
Combined:			
$\chi_{c0} \to \phi\phi$	—	—	$8.0 \pm 0.3 \pm 0.8$
$\chi_{c1} \to \phi\phi$	—	—	$4.4 \pm 0.3 \pm 0.5$
$\chi_{c2} \to \phi\phi$	—	—	$10.7 \pm 0.3 \pm 1.2$
$\chi_{c0} \to \omega\omega$	991 ± 38	13.1	$9.5 \pm 0.3 \pm 1.1$
$\chi_{c1} \to \omega\omega$	597 ± 29	13.2	$6.0 \pm 0.3 \pm 0.7$
$\chi_{c2} \to \omega\omega$	762 ± 31	11.9	$8.9 \pm 0.3 \pm 1.1$
$\to 2(\pi^+\pi^-\pi^0)$			
$\chi_{c0} \to \omega\phi$	76 ± 11	14.7	$1.2 \pm 0.1 \pm 0.2$
$\chi_{c1} \to \omega\phi$	15 ± 4	16.2	$0.22 \pm 0.06 \pm 0.02$
$\chi_{c2} \to \omega\phi$	< 13	15.7	< 0.2
$\to K^+K^-\pi^+\pi^-\pi^0$			

Evidence

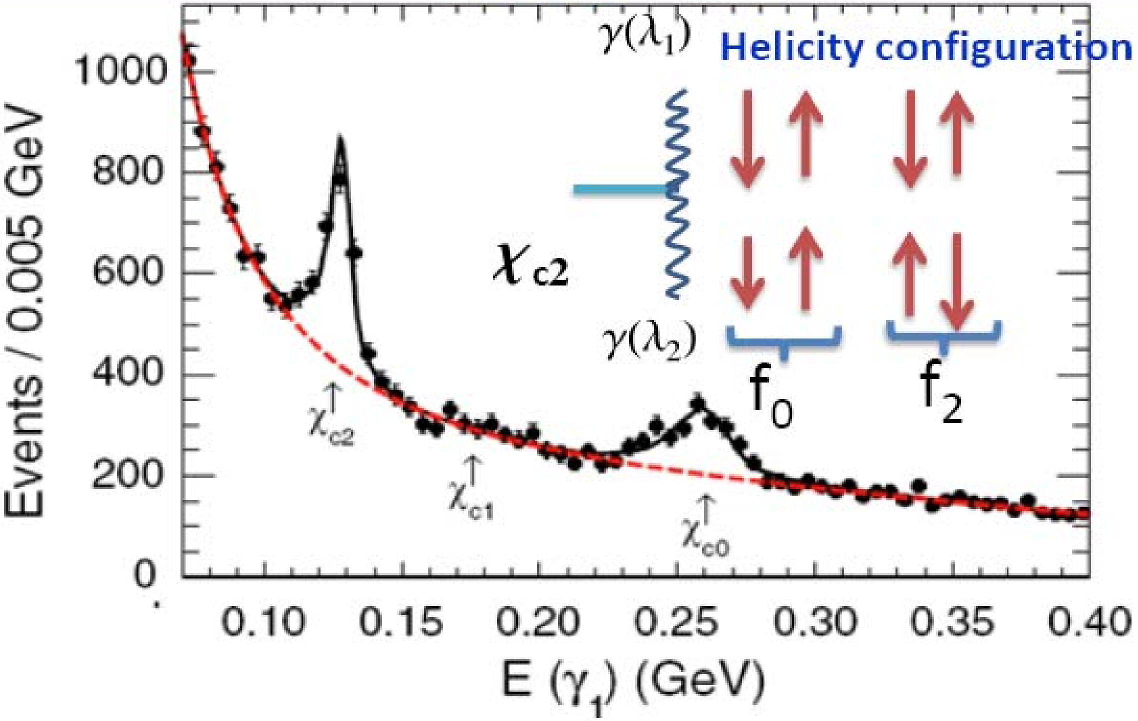
First observation

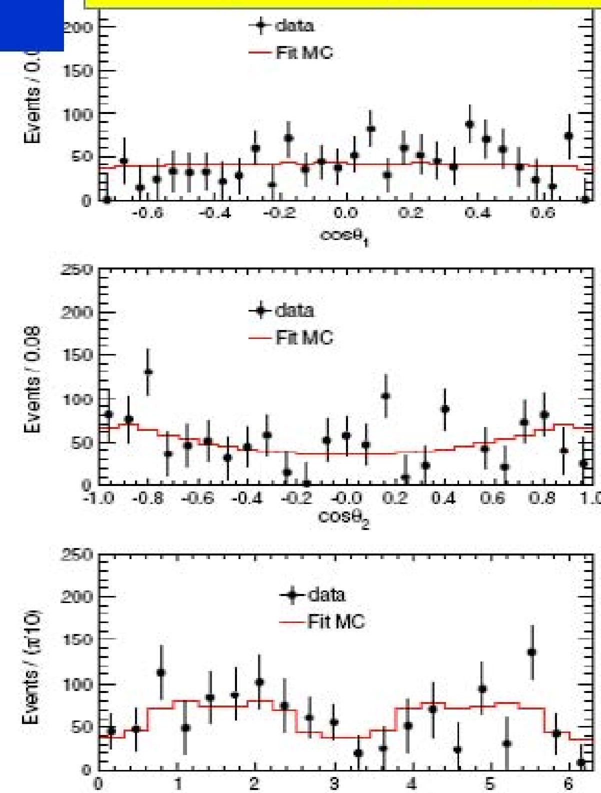
Long distance transitions could contribute via the intermediate meson loops.

PRD81 014017 (2010) , PRD81 074006 (2010)

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

PRD85, 112008, (2012)





$\mathcal{B}_1 = \mathcal{B}(\psi(2s) \to \gamma\chi_{c0,c2})$, $\mathcal{B}_2 = \mathcal{B}(\chi_{c0,c2\to\gamma\gamma})$, and $\Gamma_{\gamma\gamma}(\chi_{c0,c2}) = \Gamma_{\gamma\gamma}(\chi_{c0,c2\to\gamma\gamma})$.

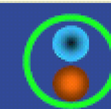
Quantity	PDG global fit results[a]	CLEO-c[b]	This measurement[b]
$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^5(\chi_{c0})$[c]	2.16 ± 0.18	$2.17 \pm 0.32 \pm 0.10$	$2.17 \pm 0.17 \pm 0.12$
$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^5(\chi_{c2})$[c]	2.24 ± 0.17	$2.68 \pm 0.28 \pm 0.15$	$2.81 \pm 0.17 \pm 0.15$
$\mathcal{B}_2 \times 10^4(\chi_{c0})$[c]	2.23 ± 0.17	$2.31 \pm 0.34 \pm 0.15$	$2.24 \pm 0.19 \pm 0.15$
$\mathcal{B}_2 \times 10^4(\chi_{c2})$[c]	2.56 ± 0.16	$3.23 \pm 0.34 \pm 0.24$	$3.21 \pm 0.18 \pm 0.22$
$\Gamma_{\gamma\gamma}(\chi_{c0})$ (keV)	2.32 ± 0.22	$2.36 \pm 0.35 \pm 0.22$	$2.33 \pm 0.20 \pm 0.22$
$\Gamma_{\gamma\gamma}(\chi_{c2})$ (keV)	0.50 ± 0.05	$0.66 \pm 0.07 \pm 0.06$	$0.63 \pm 0.04 \pm 0.06$
$\mathcal{R}$	0.22 ± 0.03	$0.28 \pm 0.05 \pm 0.04$	$0.27 \pm 0.03 \pm 0.03$
$f_{0/2} = \Gamma^{\lambda=0}_{\gamma\gamma}(\chi_{c2})/\Gamma^{\lambda=2}_{\gamma\gamma}(\chi_{c2})$	...	...	$0.00 \pm 0.02 \pm 0.02$

Charm as a tool to study light hadron spectroscopy

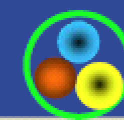
- Hadrons consist of 2 or 3 quarks：

Naive Quark Model：

Meson（q $\bar{q}$）

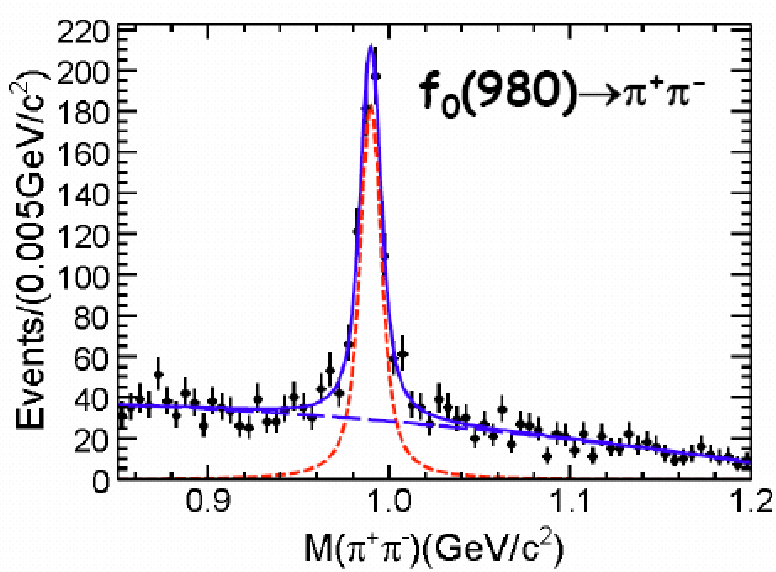


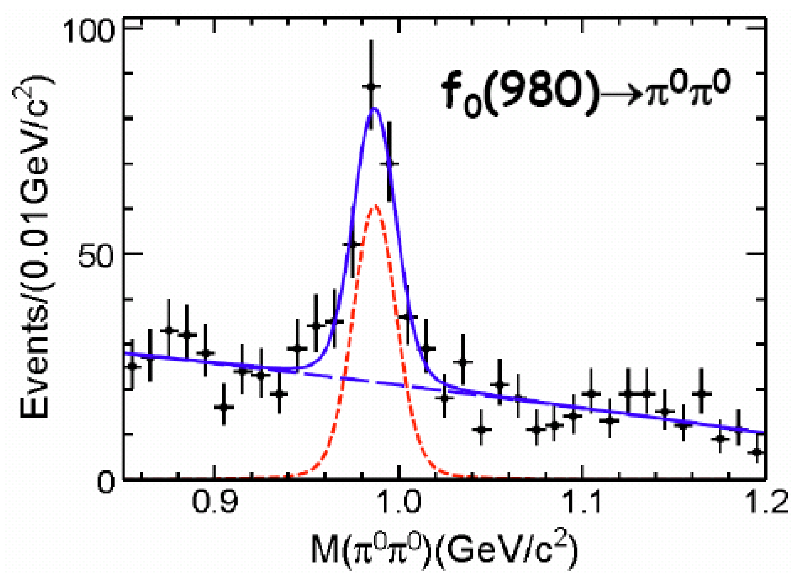
Baryon（q q q）



- QCD predicts the new forms of hadrons:
  - Multi-quark states： Number of quarks >= 4
  - Hybrids： $q\bar{q}g$， qqqg …
  - Glueballs： gg， ggg …

Anomalous lineshape of $f_0(980)$ in $J/\psi \to \gamma f_0(980)\pi^0$ decays at BESIII





$M = 989.9 \pm 0.4 \mathrm{MeV}/c^2$
$\Gamma = 9.5 \pm 1.1 \ \mathrm{MeV}/c^2$

$M = 987.0 \pm 1.4 \mathrm{MeV}/c^2$
$\Gamma = 4.6 \pm 5.1 \ \mathrm{MeV}/c^2$

Surprising result:

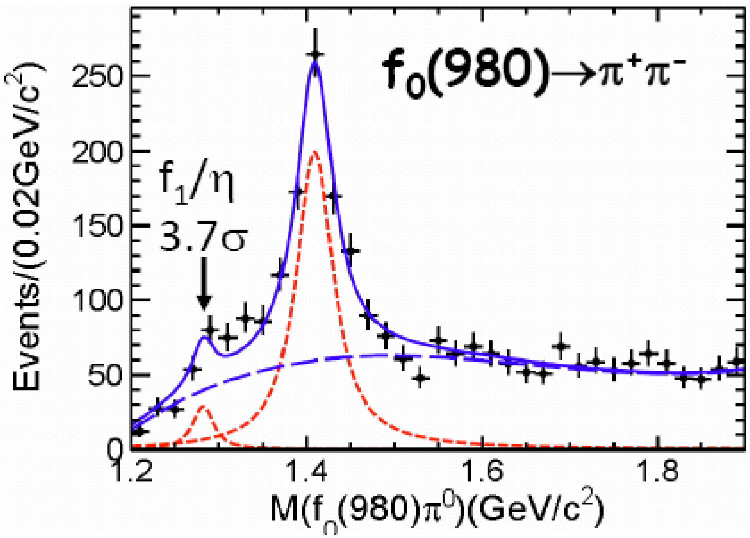
PRL 108, 182001 (2012)

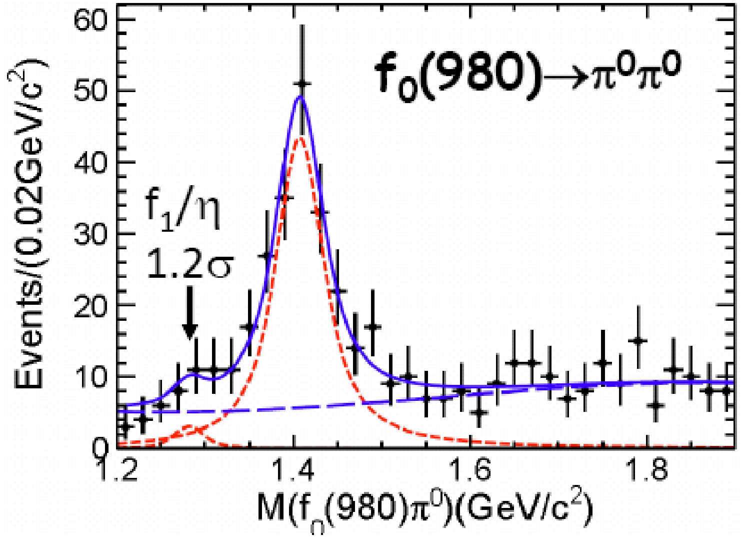
very narrow $f_0(980)$ width: <11.8 MeV/c^2 @90% C.L.

much narrower than the world average (PDG 2010: 40-100 MeV/c^2)

A possible explanation is KK^* loop, Triangle Singularity (TS) (J.J. Wu et al, PRL 108, 081803(2012))

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





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

$$Br(J/\psi \to \gamma\eta(1405) \to \gamma\pi^0 f_0 \to \gamma\pi^0\pi^+\pi^-) = (1.50 \pm 0.11(stat.) \pm 0.11(syst.)) \times 10^{-5}$$

$$Br(J/\psi \to \gamma\eta(1405) \to \gamma\pi^0 f_0 \to \gamma\pi^0\pi^0\pi^0) = (7.10 \pm 0.82(stat.) \pm 0.72(syst.)) \times 10^{-6}$$

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

PRL 108, 182001 (2012)

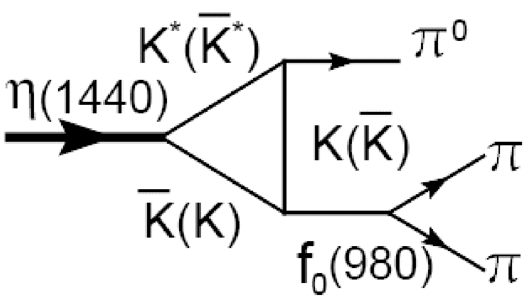
Large isospin violation in η(1405) decay

In general, magnitude of isospin violation in strong decay should be less than 1% or at 0.1% level. For example:

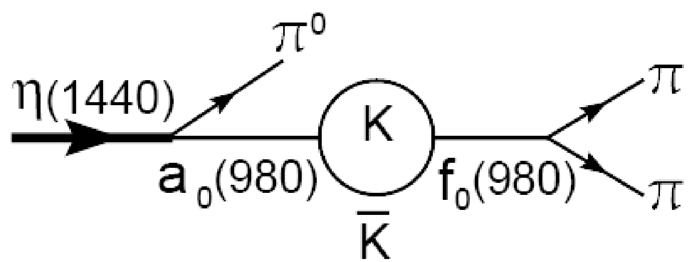
$$\frac{BR(\psi' \to \pi^0 J/\psi)}{BR(\psi' \to \eta J/\psi)} = 0.2\times 10^{-2} \times \frac{|P_\pi|^3}{|P_\eta|^3}, \quad \frac{BR(\eta' \to \pi^+\pi^-\pi^0)}{BR(\eta' \to \pi^+\pi^-\eta)} = 0.8\times 10^{-2}$$

However:

$$\frac{BR(\eta(1405) \to f_0(980)\pi^0)}{BR(\eta(1405) \to a_0(980)\pi)} \approx 25\%$$



Triangle Singularity (TS)

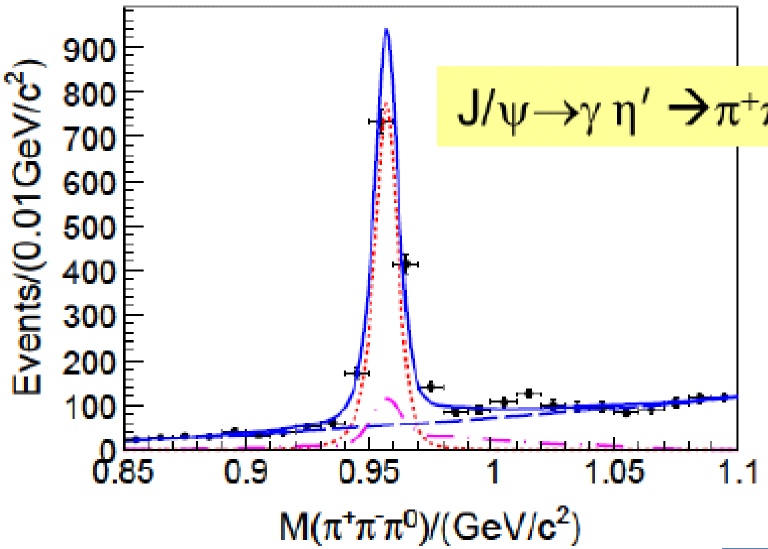


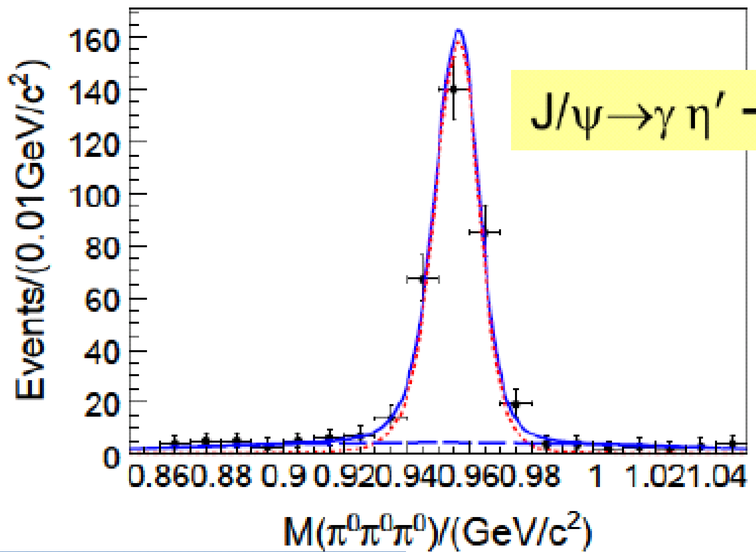
a_0—f_0 mixing

K*K pair in TS is almost on-shell, together with mixing explain the narrow $f_0(980)$, and large isospin violation.

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

New results on $\eta' \to 3\pi$ in $J/\psi \to \gamma\pi\pi\pi$





PRL 108, 182001 (2012)

New results:

$Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15 \pm 0.39) \times 10^{-3}$ (PDG2010: $(3.6^{+1.1}_{-0.93}) \times 10^{-3}$)

$Br(\eta' \to \pi^0\pi^0\pi^0) = (3.56 \pm 0.22 \pm 0.34) \times 10^{-3}$ (PDG2010: $(1.68 \pm 0.22) \times 10^{-3}$)

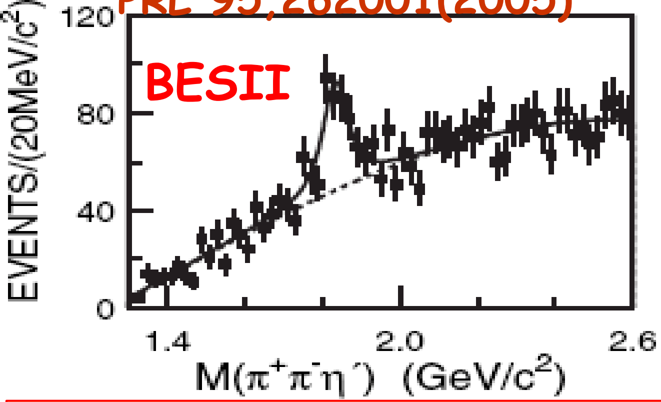
For the decay $\eta' \to \pi^0\pi^0\pi^0$, it is two times larger than the world average value.

Comparison: Isospin violations in $\eta' \to \pi\pi\pi$:

$$\frac{BR(\eta' \to \pi^+\pi^-\pi^0)}{BR(\eta' \to \pi^+\pi^-\eta)} \approx 0.9\%, \quad \frac{BR(\eta' \to \pi^0\pi^0\pi^0)}{BR(\eta' \to \pi^0\pi^0\eta)} \approx 1.6\%$$

Confirmation of X(1835) and two new structures

PRL 95,262001(2005)

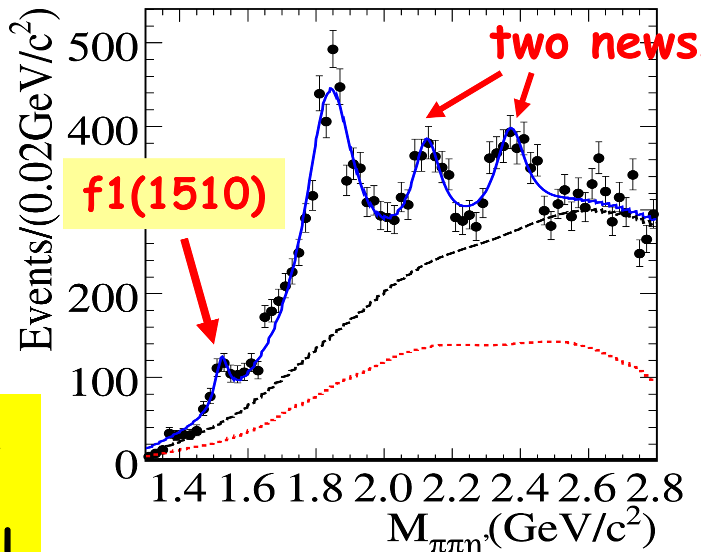


$J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$

$\eta' \rightarrow \eta\pi^+\pi^-$

$\eta' \rightarrow \gamma\rho$

PRL 106, 072002(2011)



BESII result(Stat. sig. ~ 7.7σ) :

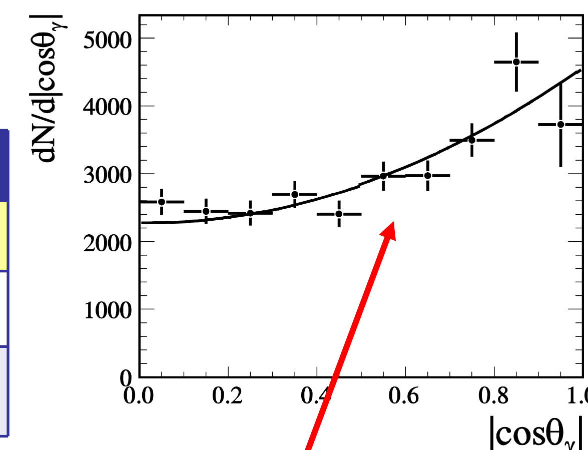
$M = 1833.7 \pm 6.1(stat) \pm 2.7(syst) MeV$

$\Gamma = 67.7 \pm 20.3(\mathrm{stat}) \pm 7.7(\mathrm{syst})\mathrm{MeV}$

BESIII: 225M J/ψ events, new structures!

BESIII fit results:

Resonance	M(MeV/c^2)	Γ(MeV/c^2)	Stat.Sig.
X(1835)	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190.1 \pm 9.0^{+38}_{-36}$	>20 σ
X(2120)	$2122.4 \pm 6.7^{+4.7}_{-2.7}$	$83 \pm 16^{+31}_{-11}$	7.2 σ
X(2370)	$2376.3 \pm 8.7^{+3.2}_{-4.3}$	$83 \pm 17^{+44}_{-6}$	6.4 σ

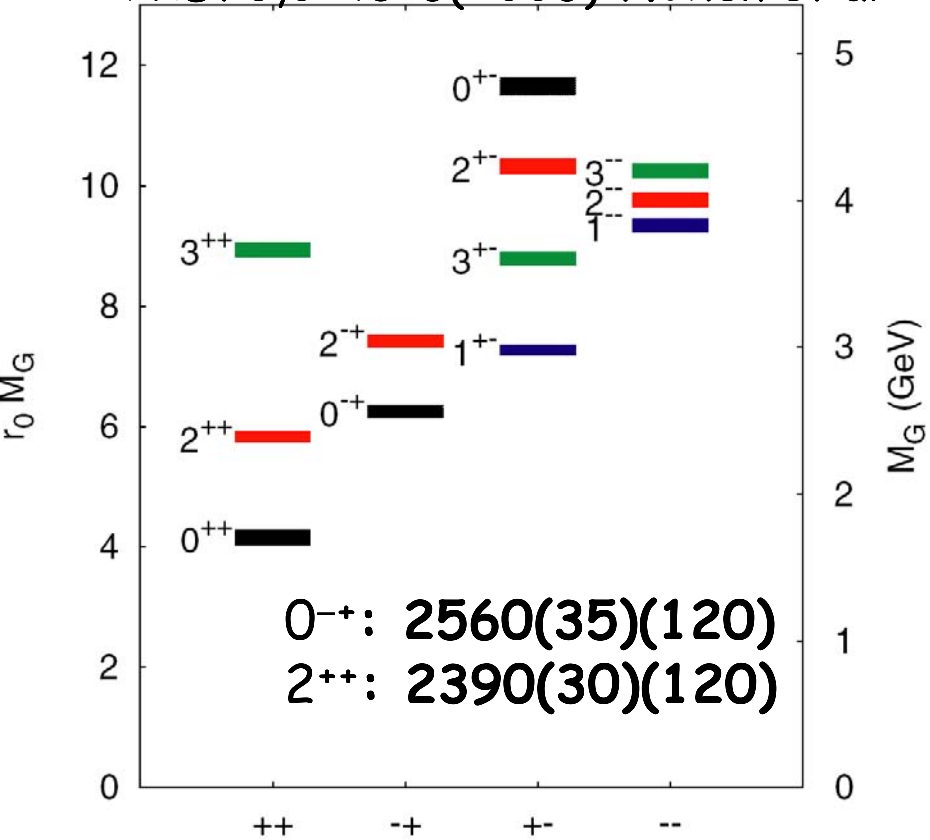


An amplitude analysis could help with interpretation for the additional new structures!

X(1835) consistent with 0^{-+}, but the others are not excluded

What's the nature of new structures?

PRD73,014516(2006) Y.Chen et al



✓It is the first time resonant structures are observed in the 2.3 GeV/c2 region, it is interesting since:

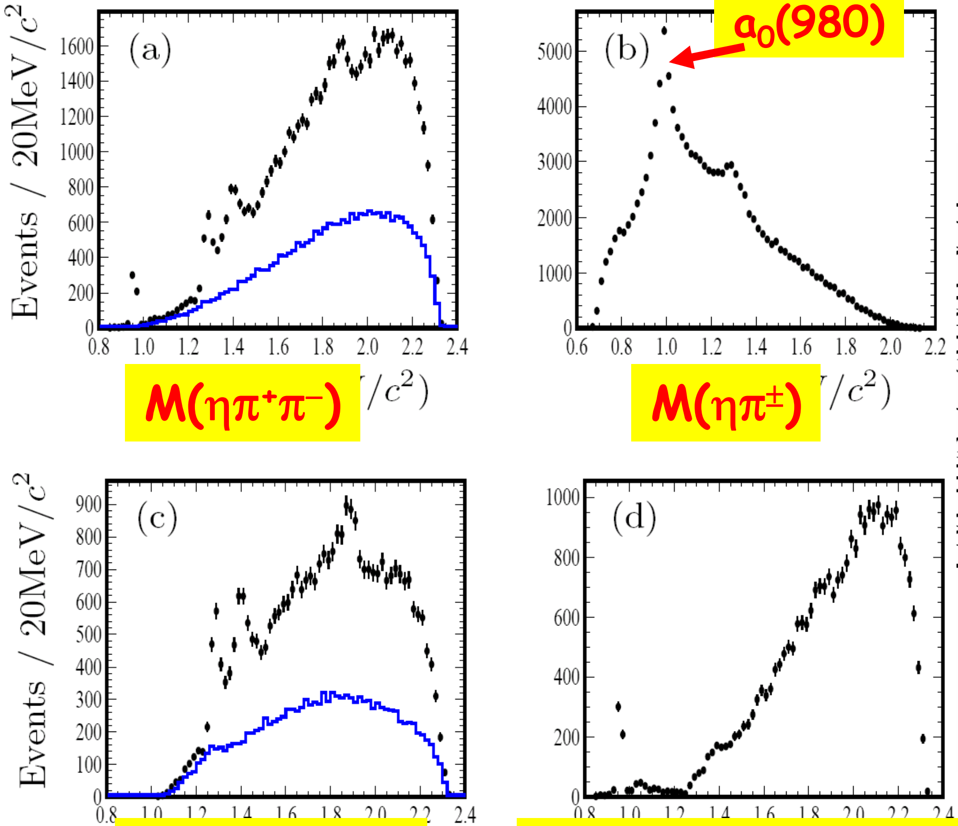
LQCD predicts that the lowest lying pseudoscalar glueball: around 2.3 GeV/c^2.

$J/\psi \to \gamma\pi\pi\eta'$ decay is a good channel for finding 0^{-+} glueballs.

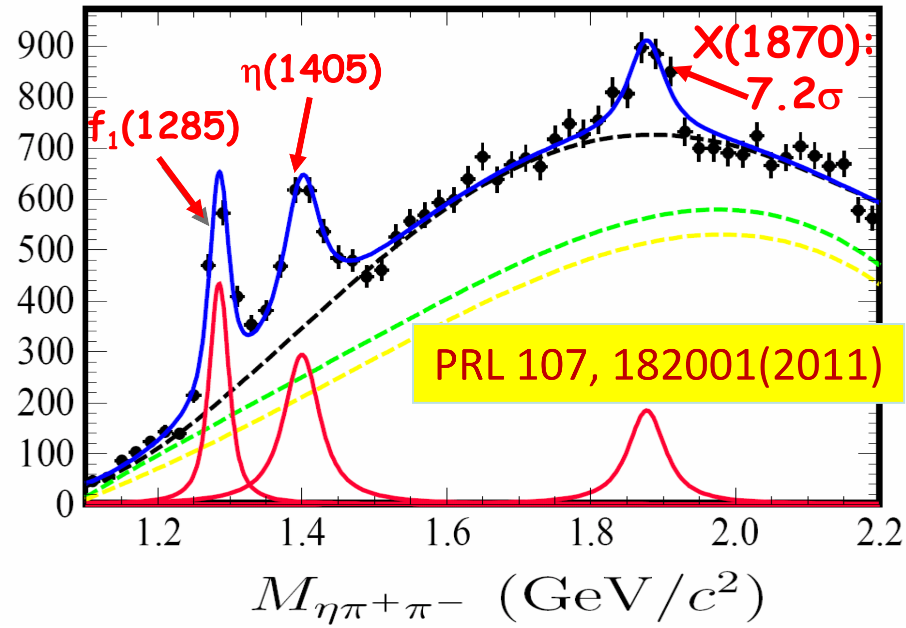
✓Nature of X(2120)/X(2370)
pseudoscalar glueball ?
η/η' excited states?

PRD82,074026,2010
J.F. Liu, G.J. Ding and M.L.Yan
PRD**83:114007,2011**
(J.S. Yu, Z.-F. Sun, X. Liu, Q. zhao),
and more...

X(1870) in $J/\psi \to \omega X$, $X \to a_0^{\pm}(980)\pi^{\mp}$



$J/\psi \to \omega\eta\pi^+\pi^-$,
$a_0(980)$ reconstructed in $\eta\pi^{\pm}$

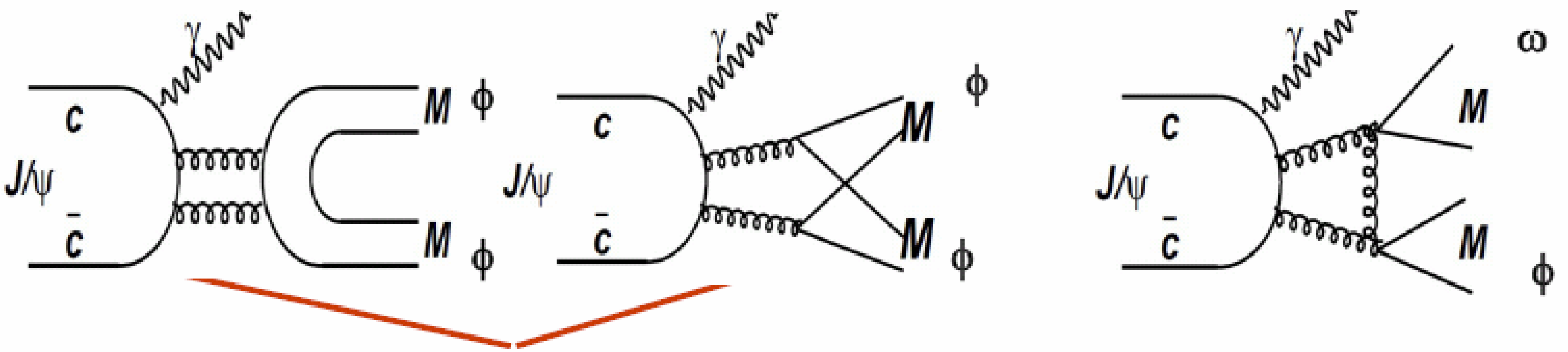


Identification of X(1870): 0^{-+}(?)
It is X(1835)?
Need PWA!

BR($J/\psi \to \omega X$, $X \to a_0^{\pm}(980)\pi^{\mp}$)

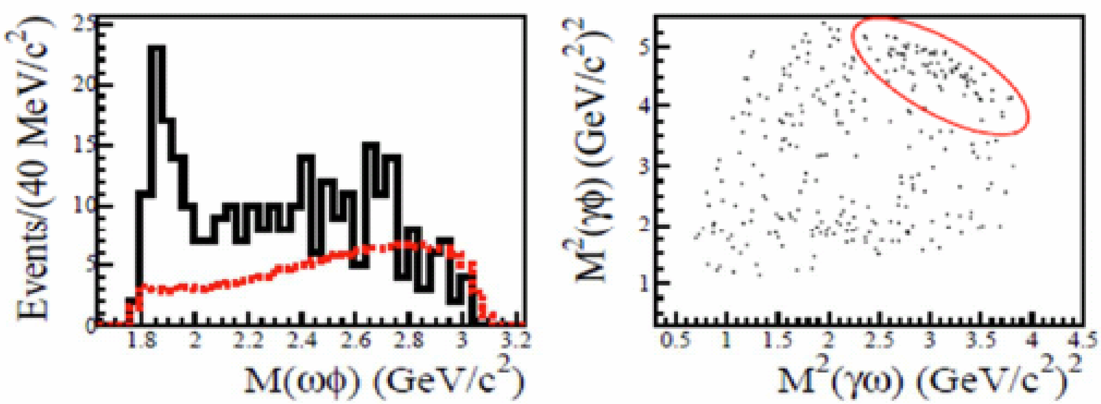
Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	Branch ratio (10^{-4})
$f_1(1285)$	$1285.1 \pm 1.0^{+1.6}_{-0.3}$	$22.0 \pm 3.1^{+2.0}_{-1.5}$	$1.25 \pm 0.10^{+0.19}_{-0.20}$
$\eta(1405)$	$1399.8 \pm 2.2^{+2.8}_{-0.1}$	$52.8 \pm 7.6^{+0.1}_{-7.6}$	$1.89 \pm 0.21^{+0.21}_{-0.23}$
$X(1870)$	$1877.3 \pm 6.3^{+3.4}_{-7.4}$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

ωϕ threshold enhancement in $J/\psi \to \gamma\omega\phi$



$J/\psi \to \gamma\phi\phi,\ \phi \to K^+K^-$ **(OZI)** $J/\psi \to \gamma\omega\phi$ **(DOZI)**

BESII



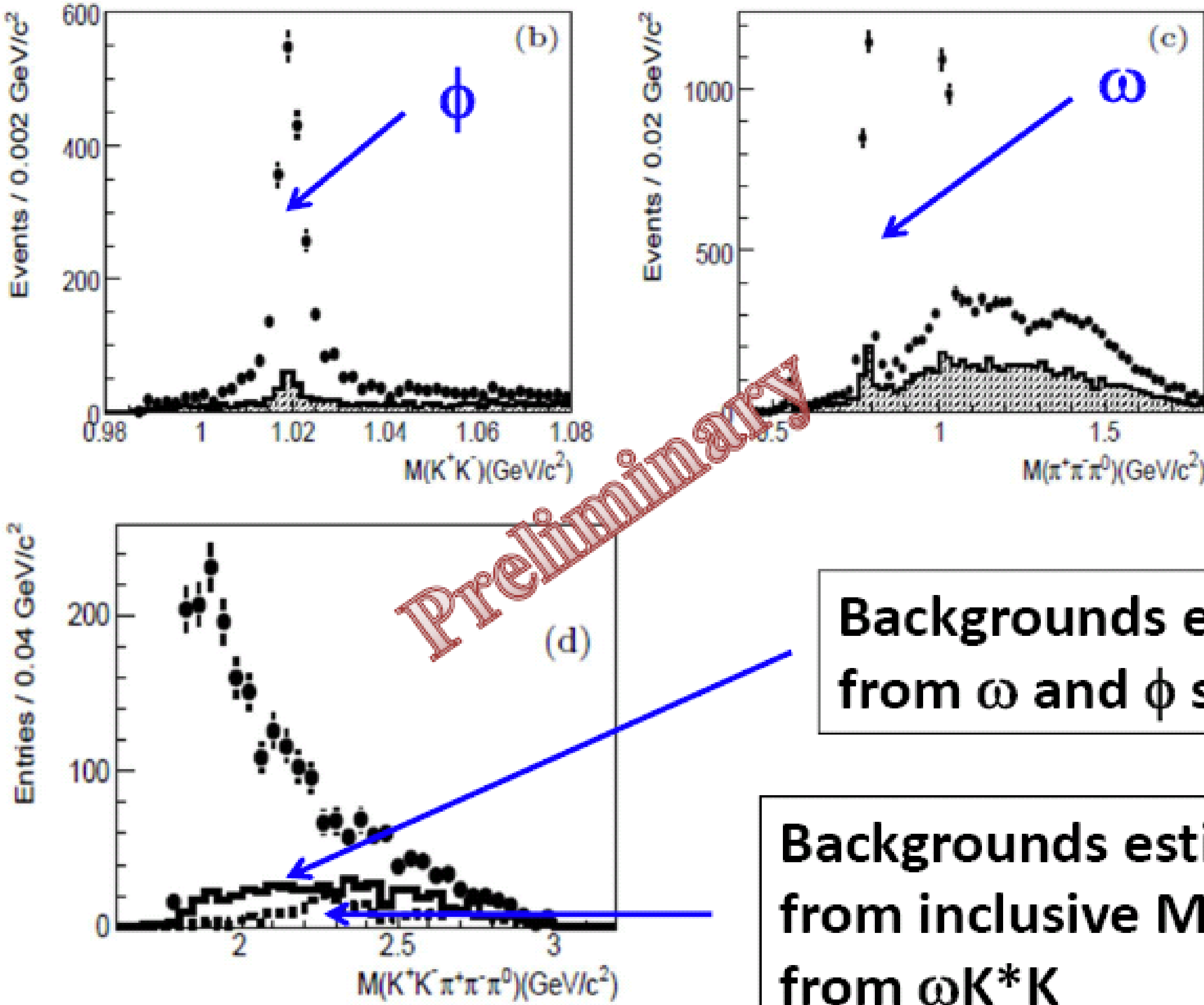
$M = 1812^{+19}_{-26} \pm 18\ \mathrm{MeV/c^2}$

$\Gamma = 105 \pm 20 \pm 28\ \mathrm{MeV/c^2}$

J^{PC} favors 0^{++} over 0^{-+} and 2^{++}

Phys. Rev. Lett. 96(2006)162002

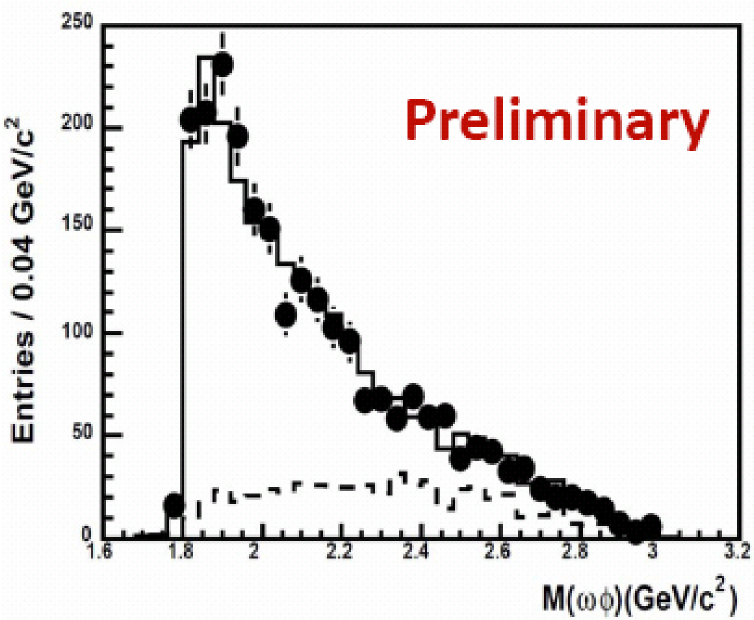
$J/\psi \to \gamma\omega\phi$ @ BESIII

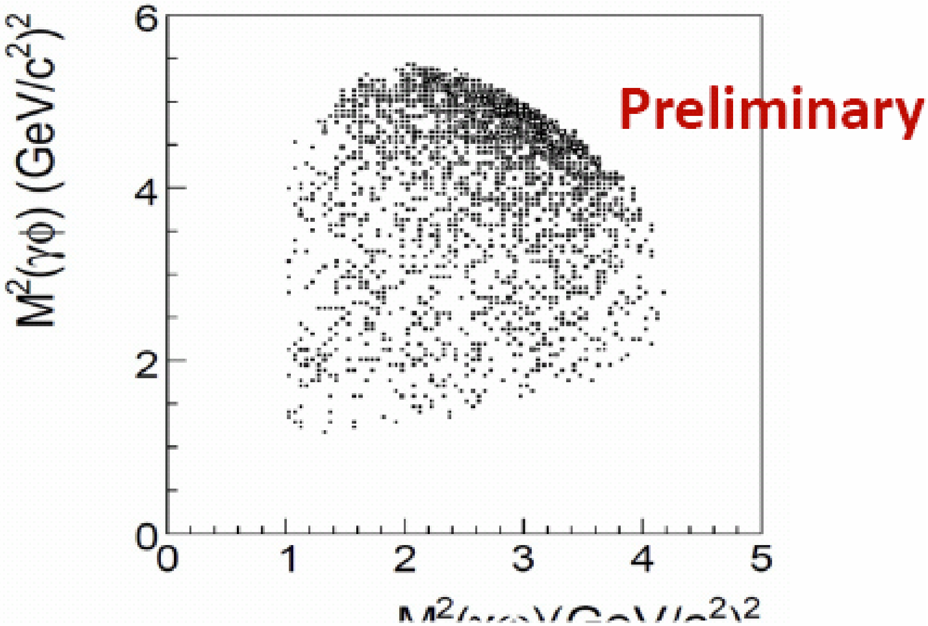


Backgrounds estimated from ω and ϕ sidebands

Backgrounds estimated from inclusive MC -- mainly from ωK^*K

Preliminary PWA results at BESIII:



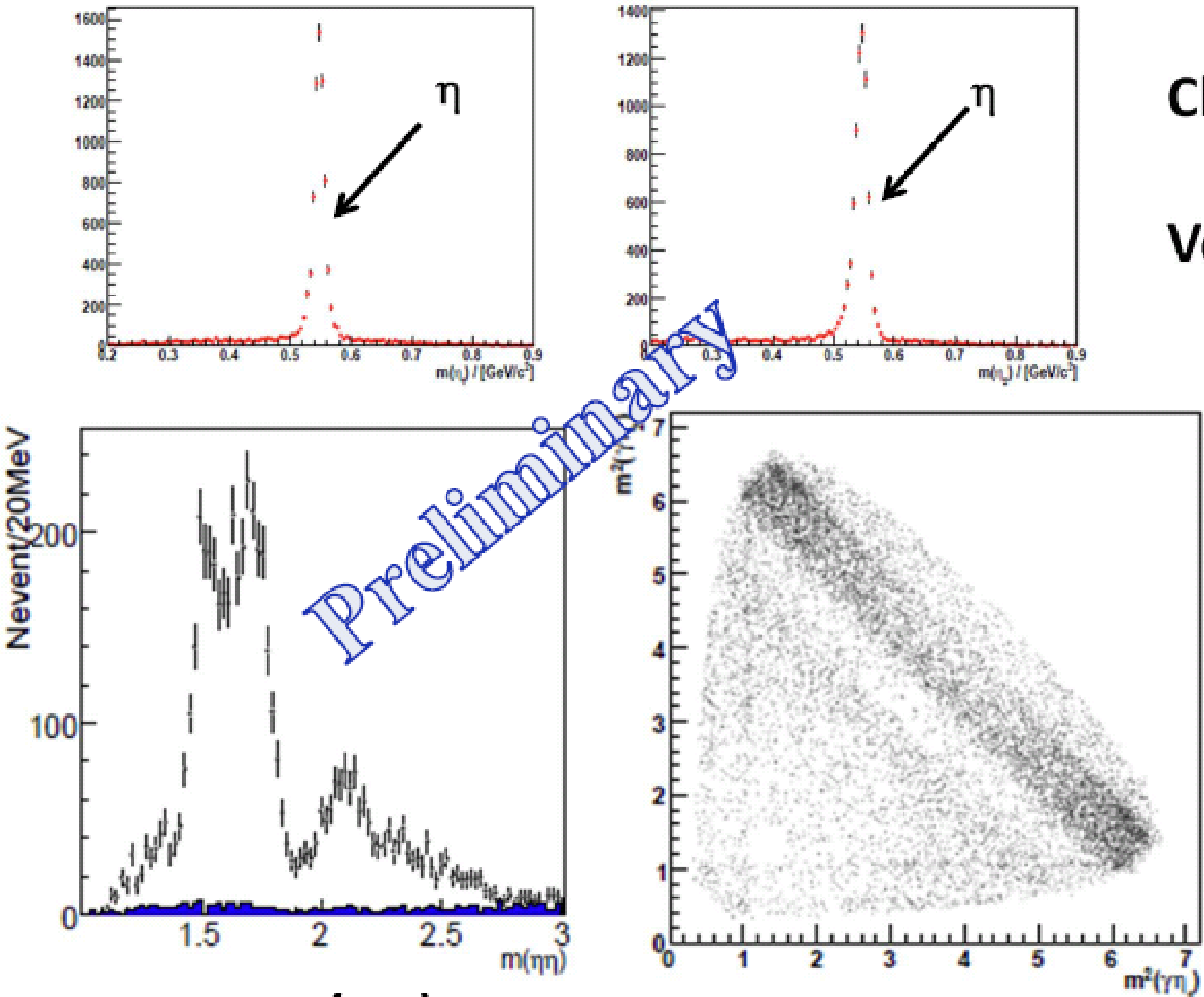


Resonance	J^{PC}	$M(MeV/c^2)$	$\Gamma(MeV/c^2)$	Significance
$X(1810)$	0^{++}	1795 ± 7	95 ± 10	$> 30\sigma$
$f_2(1950)$	2^{++}	1944	472	$> 10\sigma$
$f_0(2020)$	0^{++}	1992	442	$> 10\sigma$
$\eta(2225)$	0^{-+}	2240	1903	6.4σ

Preliminary

Is X(1810) the $f_0(1710)/f_0(1790)$ or new state?

J/ψ→γηη @ BESIII

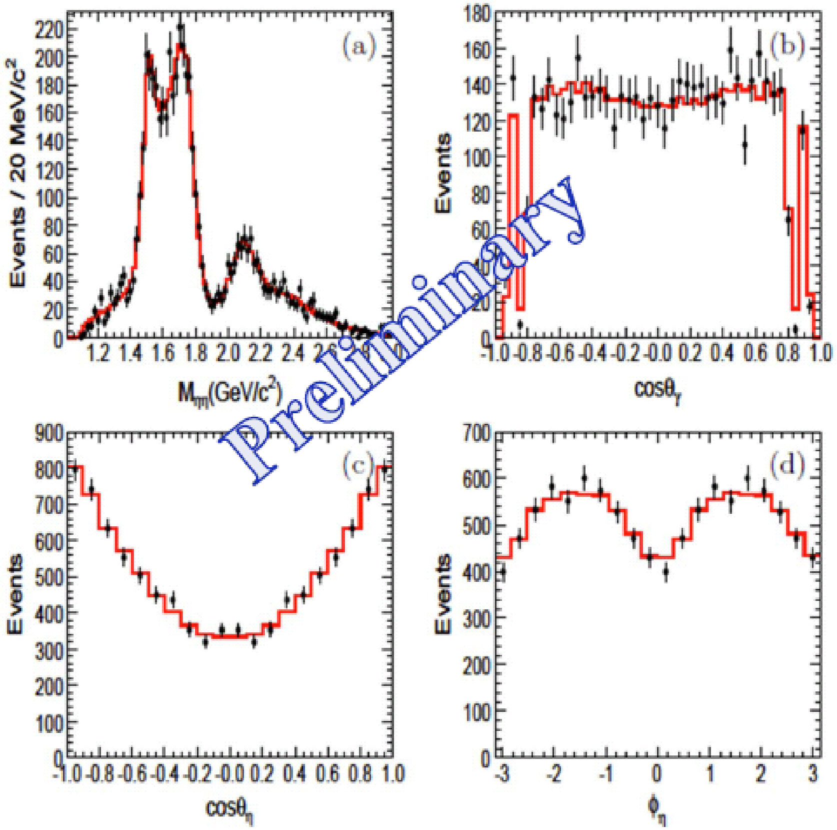


M(ηη)

Clear resonances

Very low BG level

Preliminary PWA results of $J/\psi \rightarrow \gamma\eta\eta$

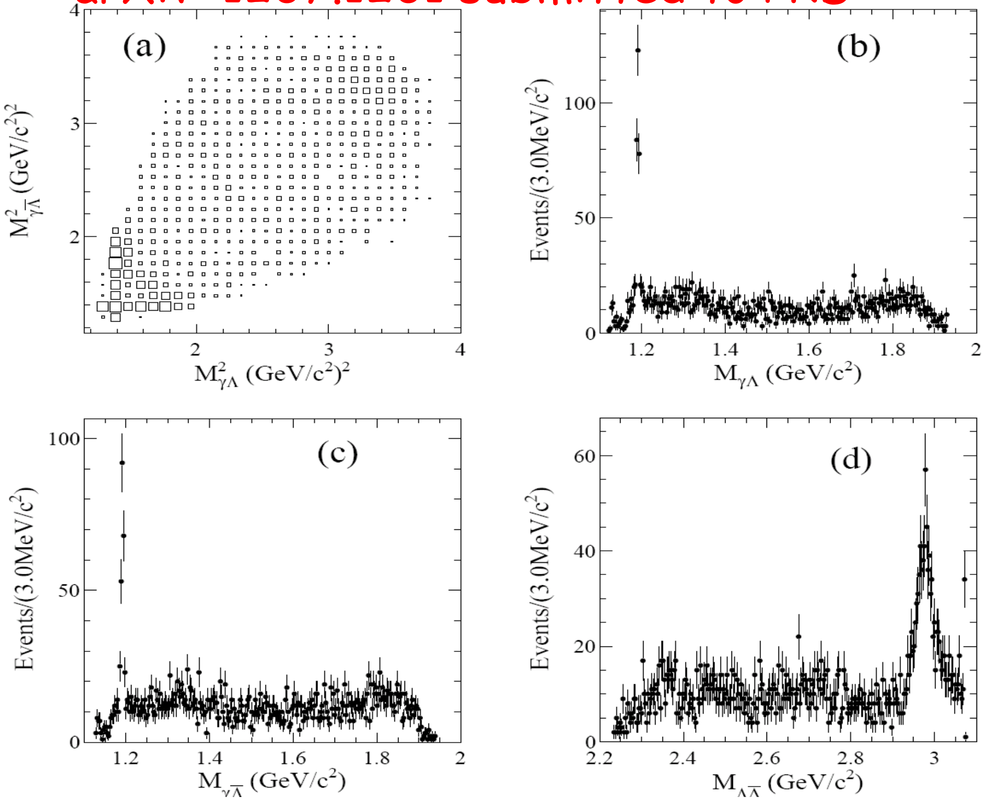


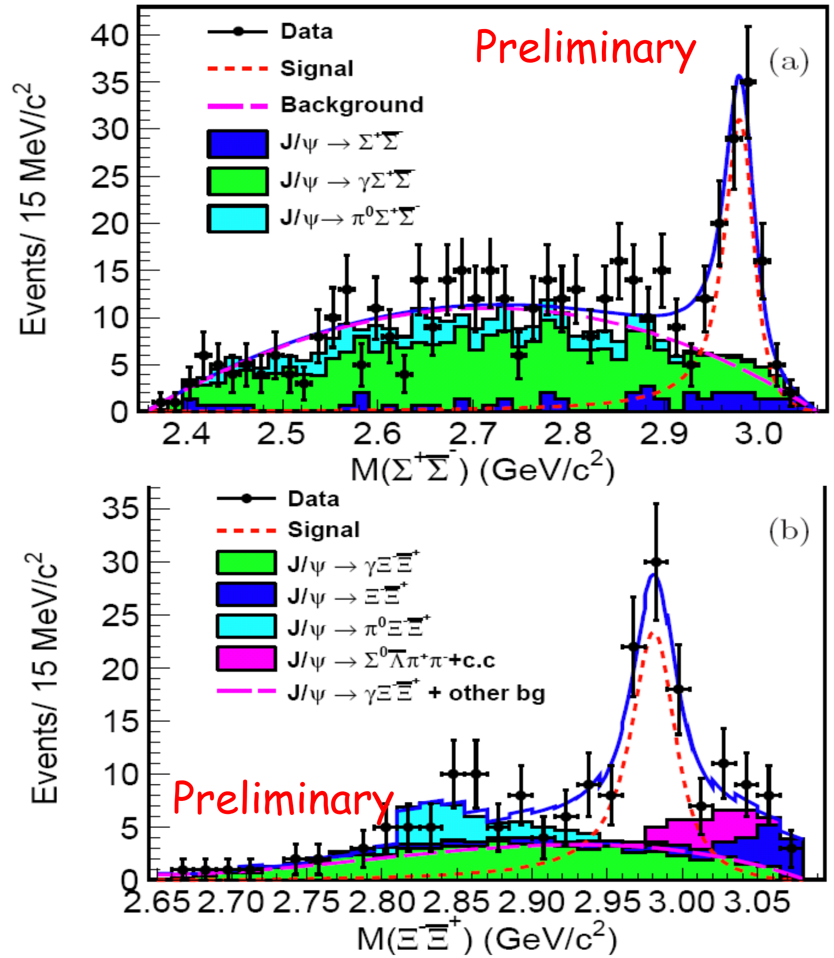
- **f_0(1710) and f_0(2100) are dominant scalars**
- **f_0(1500) exists (8.2 σ)**
- **f2'(1525) is the dominant tensor**

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+20}_{-15-74}	$136^{+41+8}_{-26-100}$	$(1.61^{+0.29+0.41}_{-0.32-1.28}) \times 10^{-5}$	8.2 σ
$f_0(1710)$	1759^{+6+14}_{-6-25}	172^{+10+31}_{-10-15}	$(2.35^{+0.07+1.23}_{-0.07-0.72}) \times 10^{-4}$	25.0 σ
$f_0(2100)$	2081^{+13+23}_{-13-34}	273^{+27+65}_{-24-18}	$(9.\text{[illegible]}^{+0.57+5.52}_{-0.52-2.21}) \times 10^{-5}$	13.9 σ
$f_2'(1525)$	1513^{+5+3}_{-5-10}	75^{+12+15}_{-10-7}	$(\text{[illegible]}.41^{+0.43+1.22}_{-0.50-1.23}) \times 10^{-5}$	11.0 σ
$f_2(1810)$	1822^{+29+61}_{-24-54}	$229^{+52+64}_{-42-\text{[illegible]}}$	$(5.38^{+0.60+3.31}_{-0.67-2.24}) \times 10^{-5}$	6.4 σ
$f_2(2340)$	$2362^{+31+139}_{-30-59}$	$334^{+\text{[illegible]}+64}_{-\text{[illegible]}-99}$	$(5.58^{+0.61+1.93}_{-0.65-1.81}) \times 10^{-5}$	7.6 σ

Study of decays of $J/\psi \to \gamma\Lambda\bar{\Lambda}$

arXiv: 1207.1201 submitted to PRD





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

$$\mathcal{B}(\eta_c \to \Sigma^+\bar{\Sigma}^-) = (2.10 \pm 0.28 \pm 0.53) \times 10^{-3}$$

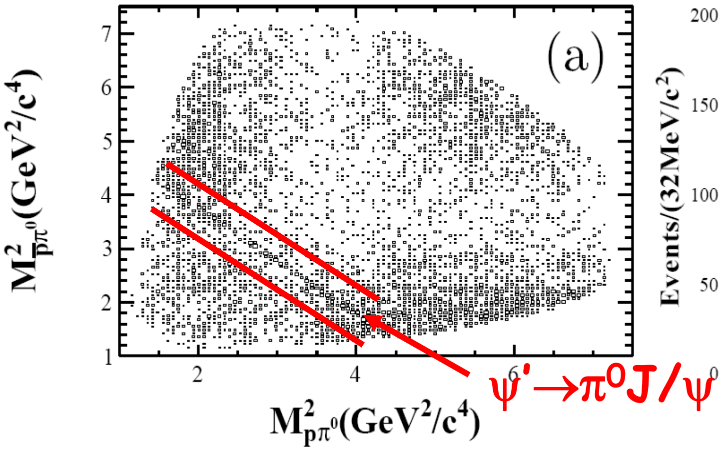
$$\mathcal{B}(\eta_c \to \Xi^-\bar{\Xi}^+) = (0.88 \pm 0.16 \pm 0.22) \times 10^{-3}$$

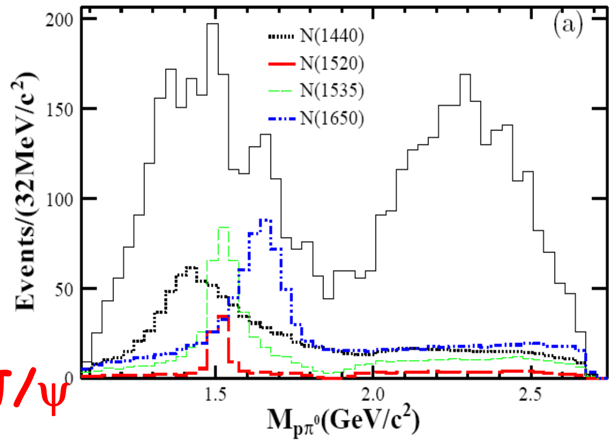
$$\mathcal{B}(\eta_c \to \Lambda\bar{\Lambda}) = (0.87^{+0.24+0.09}_{-0.21-0.14} \pm 0.27\ (\text{PDG})) \times 10^{-3}$$

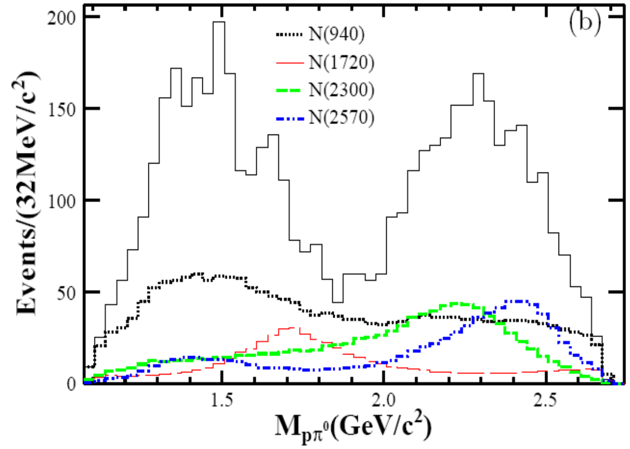
N* resonances in $\psi(3686)\to p\bar{p}\pi^0$

arXiv: 1207.0223 submitted to PRL

106M $\psi(2S)$







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

Agree with data in PDG

$J^P = 1/2^+$

$J^P = 5/2^-$

Two new N* resonances are observed for the first time.

Charm physics at BESIII

Advantage of open charm at threshold

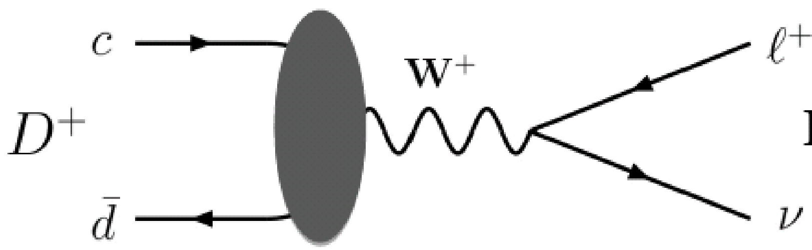
e^+e^- Colliders@threshold:

$e^+e^- \to \psi(3770) \to D^0\overline{D}^0$ $[C = -1]$ OR $e^+e^- \to \gamma^* \to D^0\overline{D}^0\gamma$ $[C = +1]$

Good for charm flavor physics:

- Threshold production: clean
- Known initial energy and quantum numbers
- Both D and Dbar fully reconstructed (double tag)
- Absolute measurements

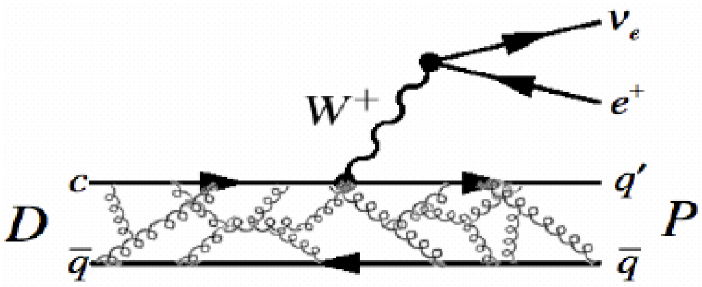
Leptonic Decay



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

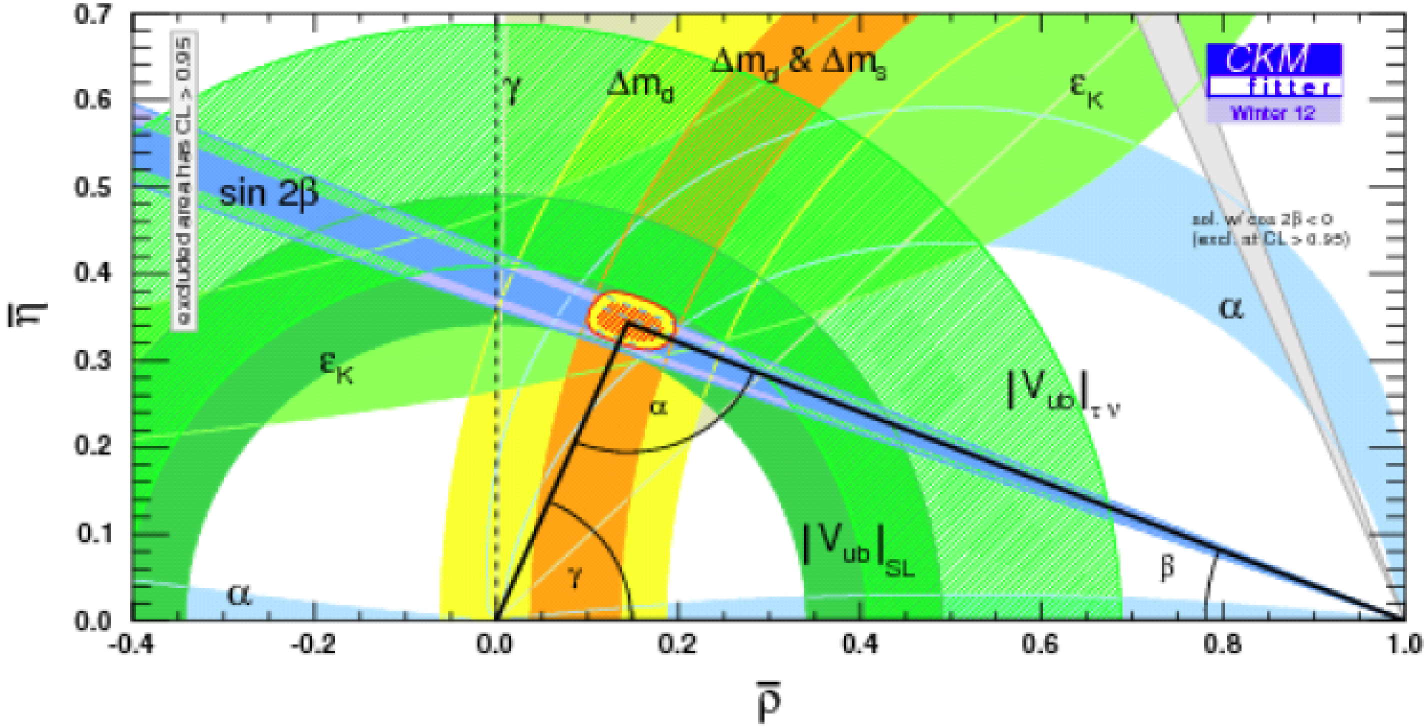
- Decay constant f_D incorporates the strong interaction effects (wave function at the origin)
- Use charm leptonic decays to validate theory (LQCD) and apply to *B* mixing, which requires f_B
- Multiple tests with charm: f_D, f_{Ds} (esp. ratios)
- Sensitivity to New Physics

Semileptonic Decay



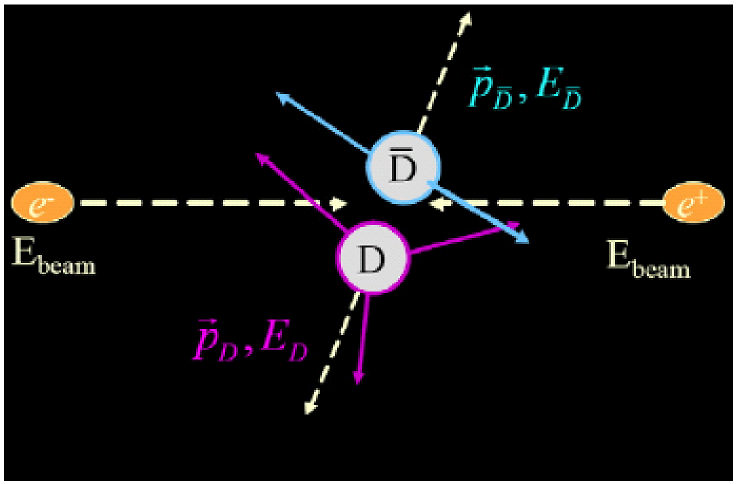
$$\frac{d\Gamma\left(D \to K(\pi)e\nu\right)}{dq^2} = \frac{G_F^2 \left|V_{cs(d)}\right|^2 P_{K(\pi)}^3}{24\pi^3} \left|f_+\left(q^2\right)\right|^2$$

- Use Strong Interaction theory (LQCD) for form factor, extract CKM
- Use other measurements and unitarity for CKM and test theory
- Theoretical uncertainties can be reduced in determinations of $|V_{ub}|$ if FF calculations can be validated with charm
- Multiple tests available, semileptonic *D* decays to pseudoscalar mesons are cleanest



- Widths of mixing and $|V_{ub}|$ bands will be reduced as charm validates LQCD
- Long-term goal: Over-constrain CKM and search for New Physics

- At $\psi(3770)$ charm production is $D^0\bar{D}^0$ and D^+D^-
- Fully reconstruct about 15% of *D* decays



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

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

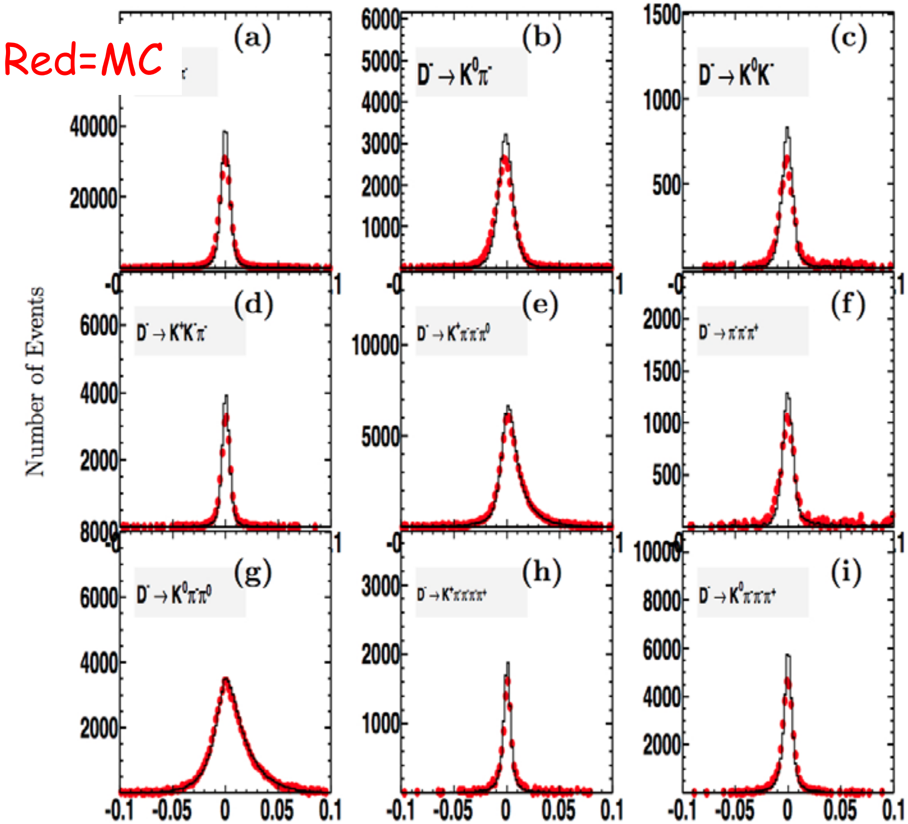
- Hadronic tag on one side gives "beam" of D^0 or D^+ on the other side for leptonic/semileptonic studies. Neutrino is reconstructed from missing energy and momentum

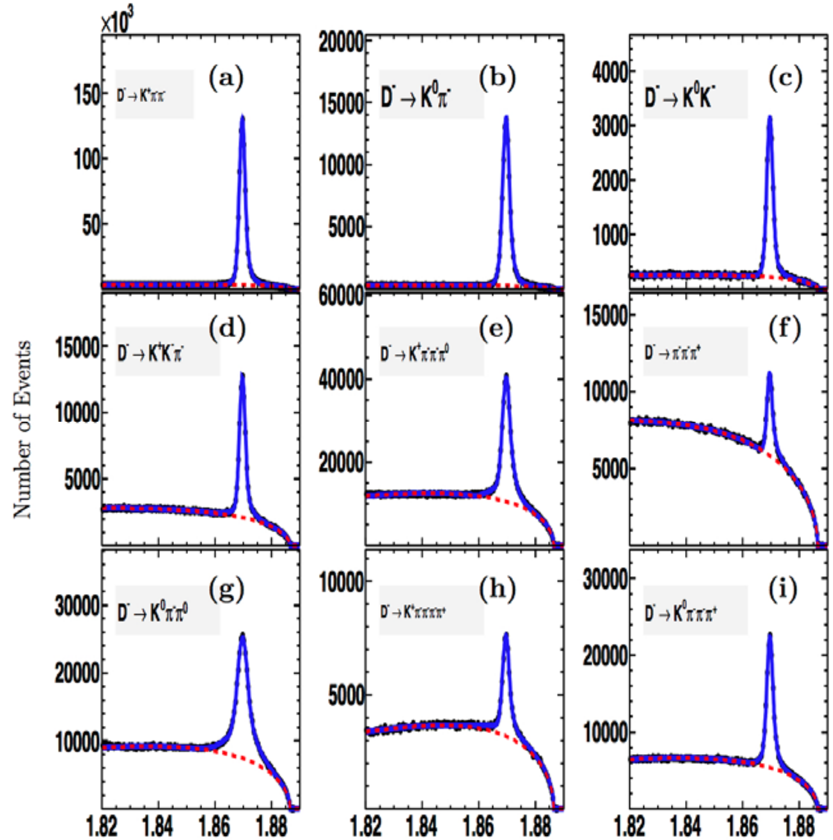
D^+ Leptonic Decays – Tag Selection

- Nine D^- tag modes

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

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





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

BESIII Preliminary

D^+ Leptonic Decays – Signal Selection

- Exactly one track in addition to tag, with the right charge
- Positively muon identification
- No extra photon
- Select on consistency with leptonic decay:

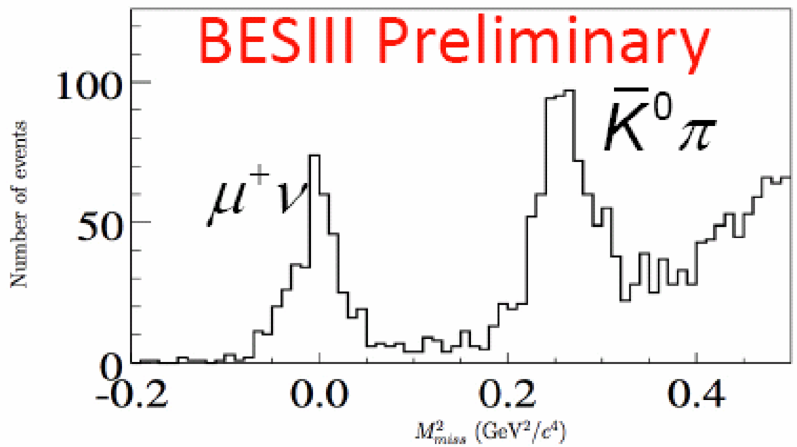
$$M^2_{\text{miss}} = \left(E_{\text{Beam}} - E_{\mu}\right)^2 - \left(-\vec{p}_{\text{tag}} - \vec{p}_{\mu}\right)^2 \approx 0$$

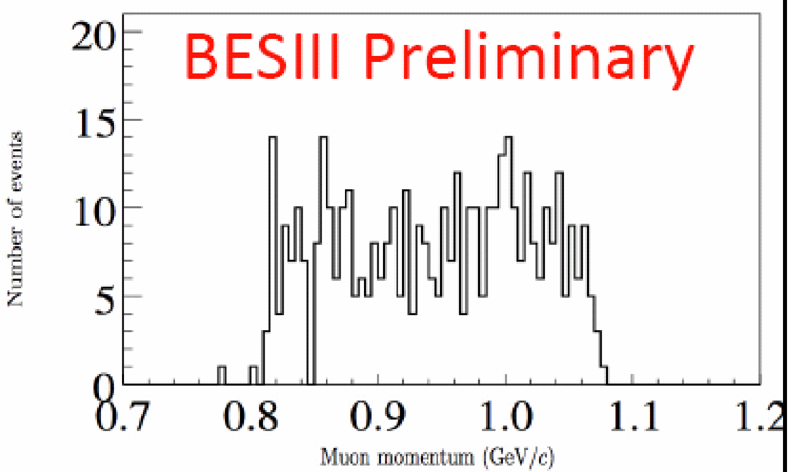
425 signal candidates:

small BG, mom. dist.

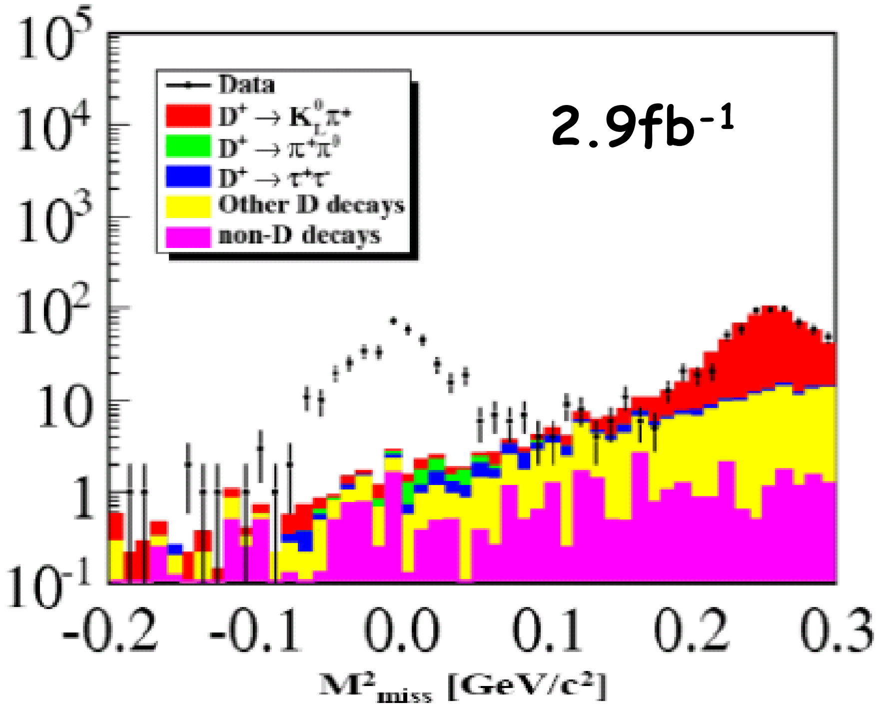
consistent with $D^+ \to \mu^+ \nu$

2.9fb^{-1}





D^+ Leptonic Decays



BESIII Preliminary

$$N\left(D^+ \to \mu^+\nu\right) = 377.3 \pm 20.6$$

$$\mathcal{B}\left(D^+ \to \mu^+\nu\right) = \left(3.74 \pm 0.21 \pm 0.06\right) \times 10^{-4}$$

$$f_{D^+} = \left(203.9 \pm 5.7 \pm 2.0\right)\ \text{MeV}$$

Consistent with CLEO-c

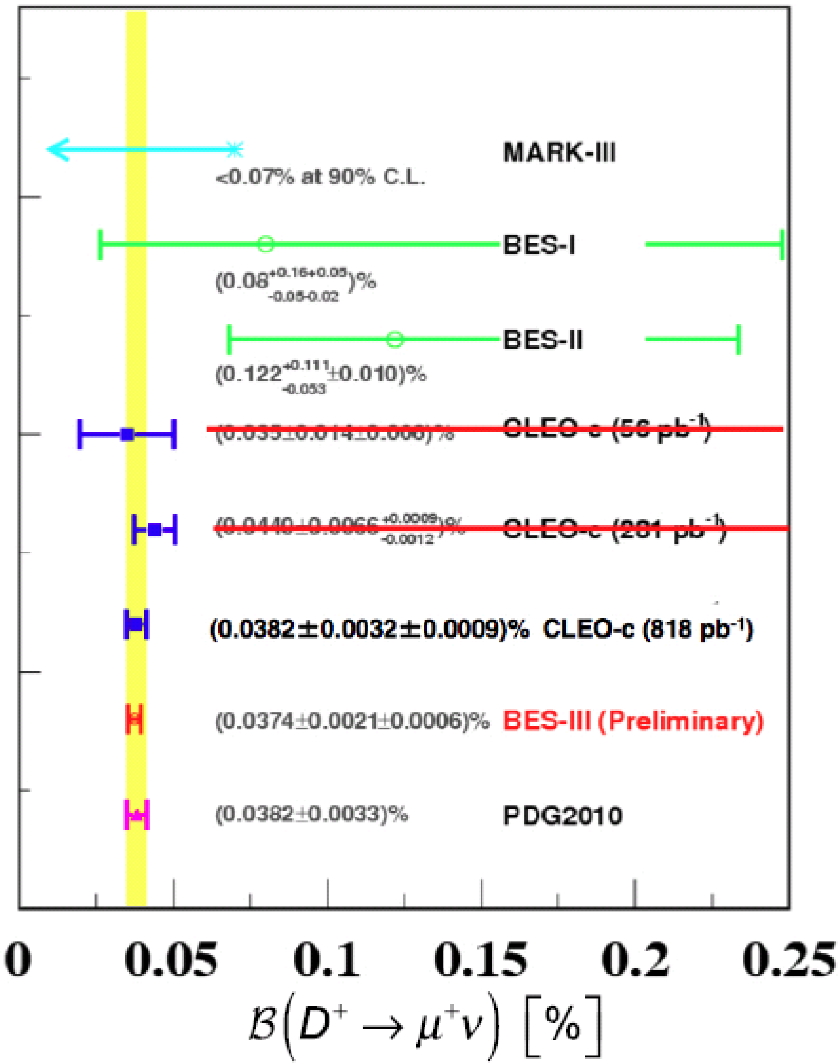
Still statistics limited – need more data!

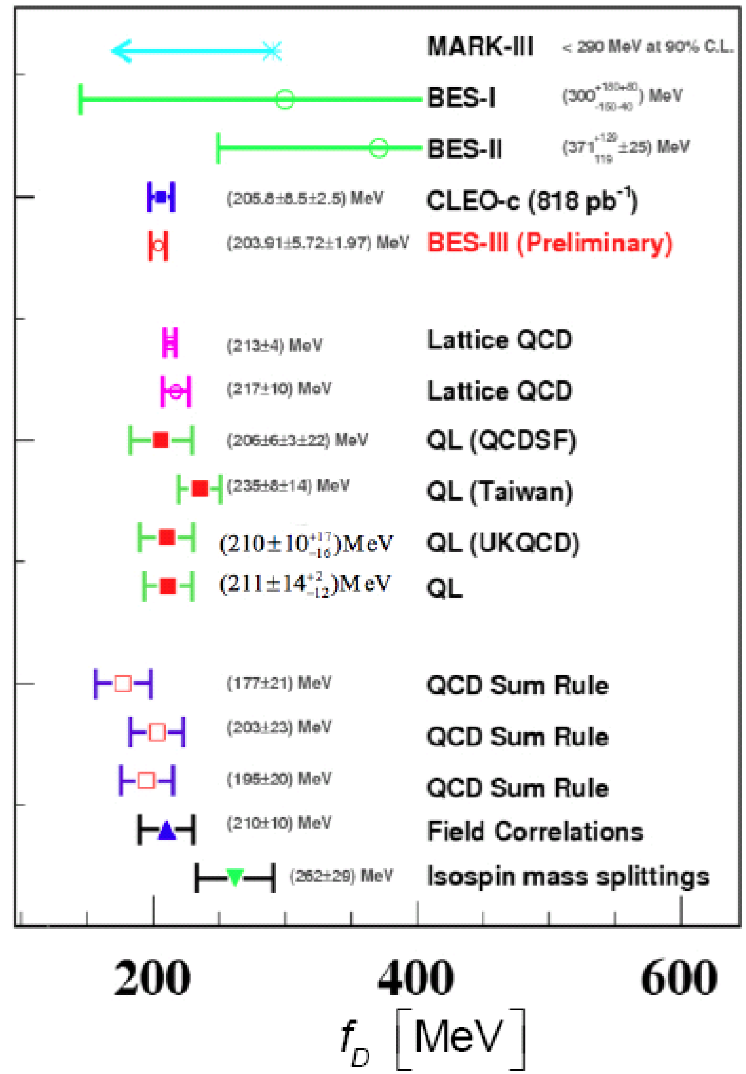
CLEO-c results **[PRD 78, 052003 (2008)]**

$$\mathcal{B}(D^+ \to \mu^+\nu) = (3.82 \pm 0.32 \pm 0.09) \times 10^{-4}$$

$$f_{D^+} = (205.8 \pm 8.5 \pm 2.5)\ \text{MeV}$$

D^+ Leptonic Decays – Comparisons (from G. Rong)



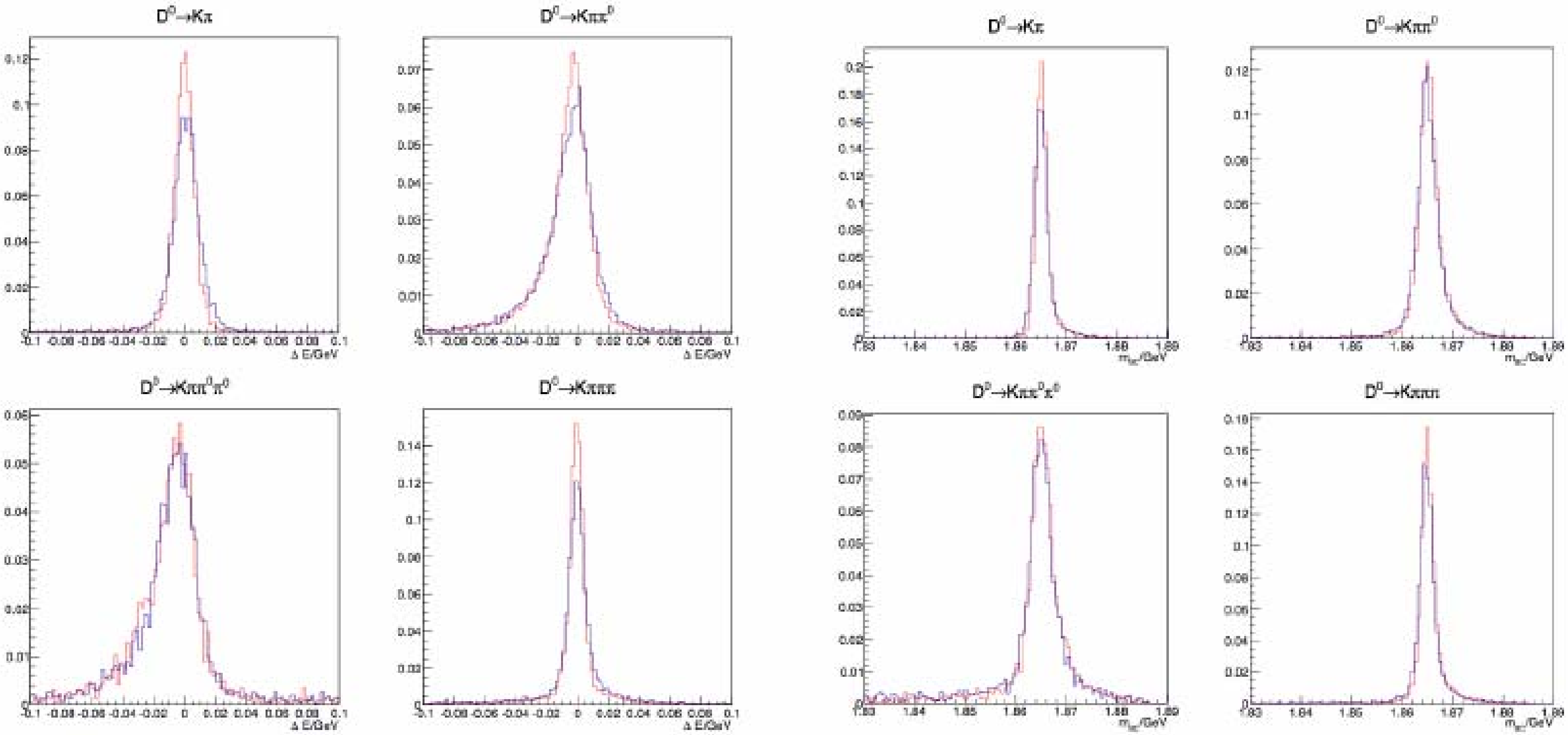


D^0 Semileptonic Decays – Tag Selection

- Four D^0 tag modes

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

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



$\Delta E \ [\text{GeV}]$ $\qquad M_{BC} \ [\text{GeV}]$

$$N^{\text{taged-D0}} = (0.774 \pm 0.001) \times 10^6 \text{ in } 0.92 \text{ fb}^{-1}$$

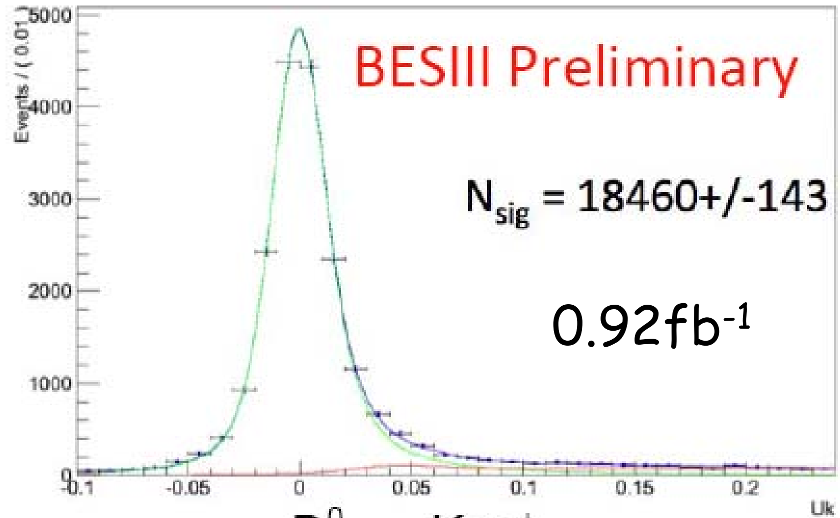
BESIII Preliminary

D^0 Semileptonic Decays – Signal Selection

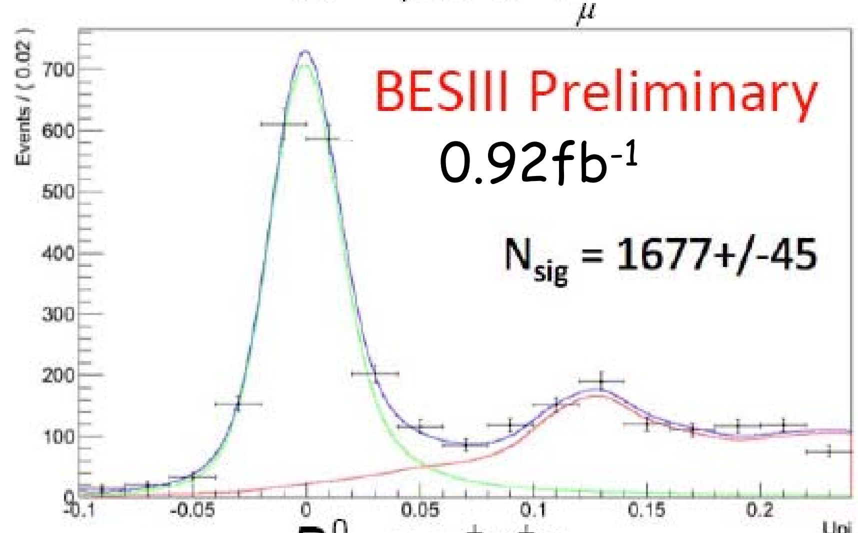
- Tag plus exactly two oppositely-charged tracks
- Kaon/pion/electron ID
- Electron has right charge
- No extra neutral energy
- Select on consistency with semileptonic decay

$$U = E_{\text{miss}} - \left|\vec{P}_{\text{miss}}\right| \approx 0$$

- Fit U distribution to extract yield



$D^0 \to K^- e^+ \nu_\mu$



$D^0 \to \pi^+ e^+ \nu_\mu$

D^0 Semileptonic Decays – Branching Fraction

BESIII Preliminary

$0.92 fb^{-1}$

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

- Systematic uncertainties are preliminary
- Good consistency with CLEO-c, statistical precision comparable with only 1/3 data analyzed

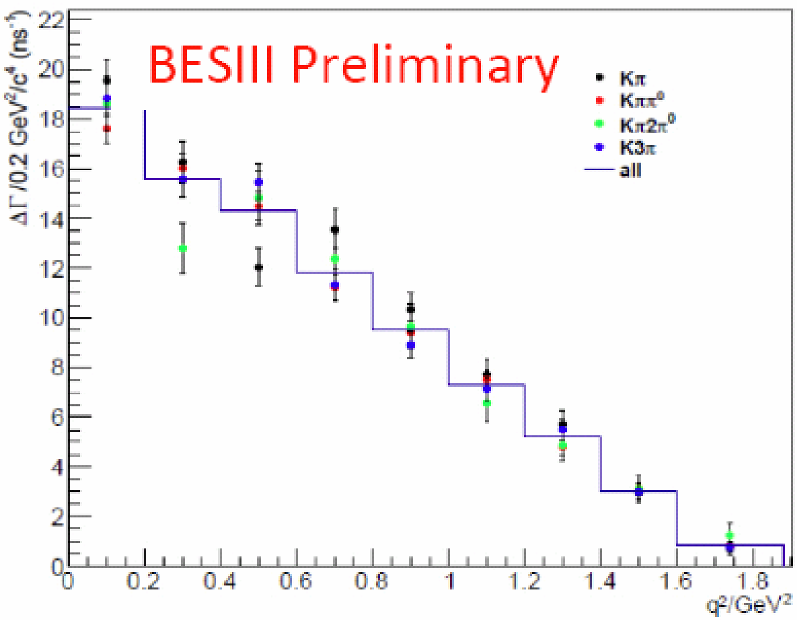
D^0 Semileptonic Decays – q^2 Distribution

- Partition D^0 semileptonic candidates in bins of

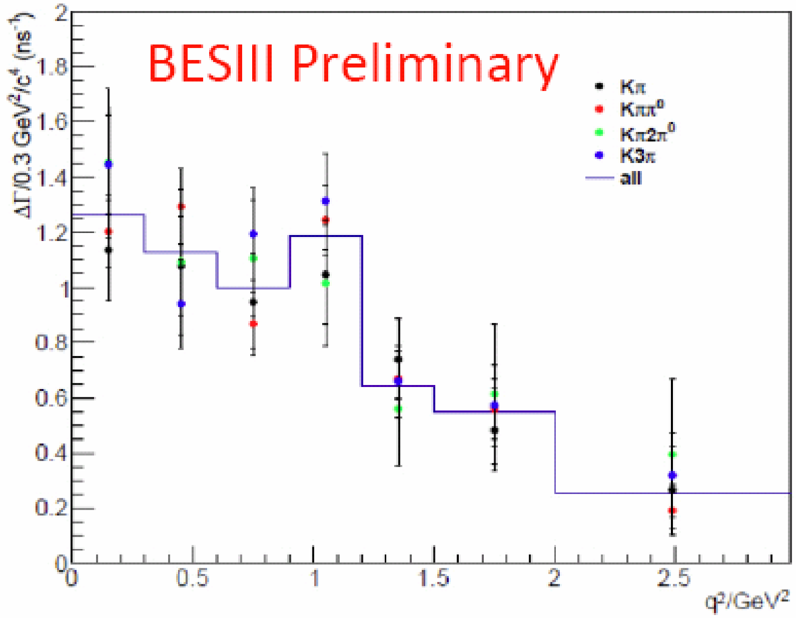
$$q^2 = \left(E_\nu + E_e\right)^2 - \left|\vec{p}_\nu + \vec{p}_e\right|^2 \qquad E_\nu = E_{miss} \qquad \left|\vec{p}_\nu\right| = E_{miss}$$

- Fit U distribution in each q^2 bin

0.92fb^{-1}



$D^0 \to K^- e^+ \nu_\mu$

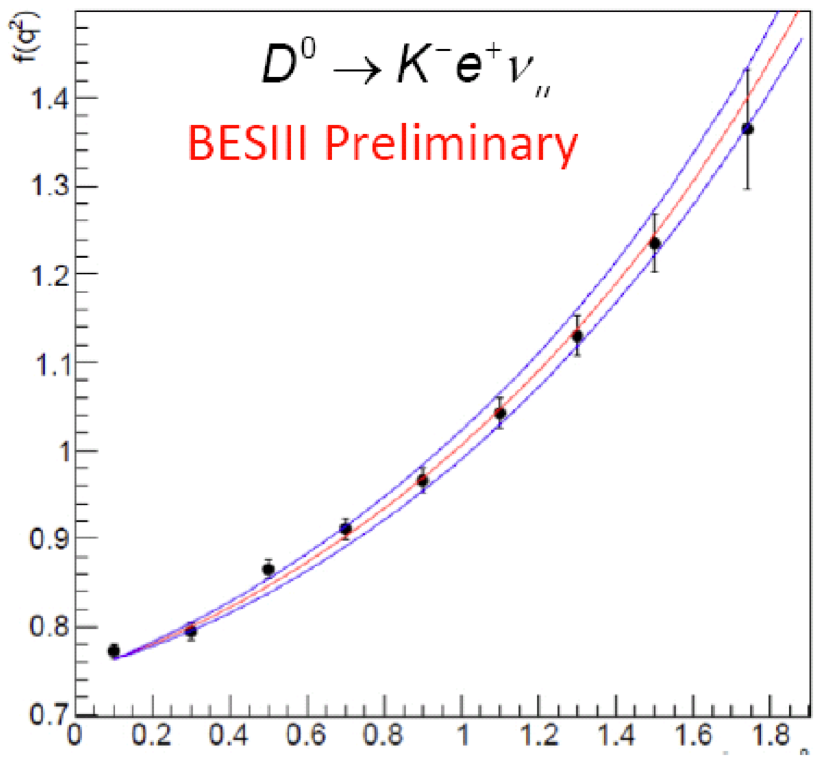


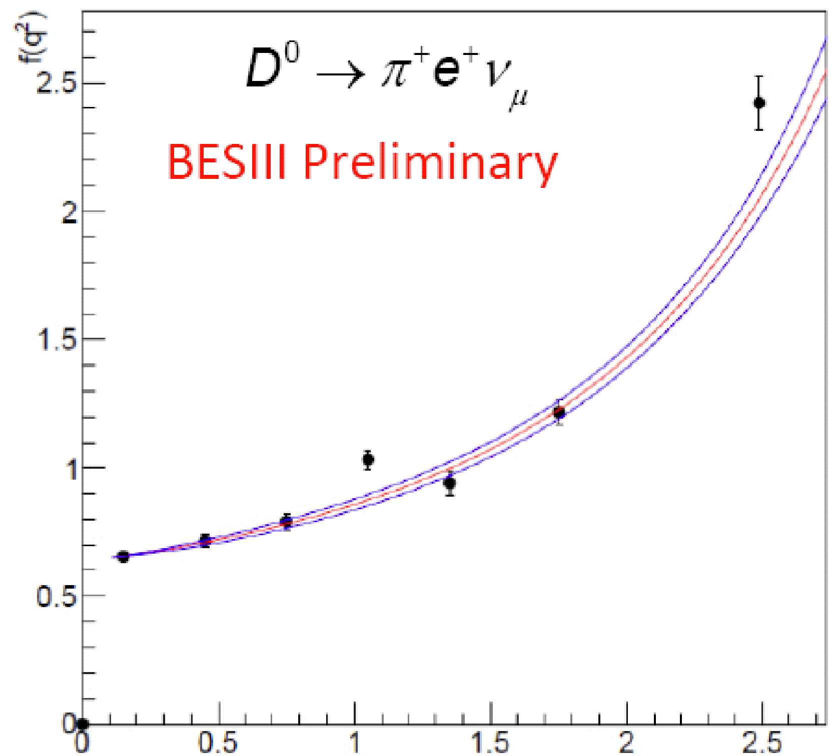
$D^0 \to \pi^+ e^+ \nu_\mu$

D^0 Semileptonic Decays – extract $f(q^2)$

- Points are data with statistical errors only
- Curves are Fermilab-MILC (arXiv:1111.5471) with $\pm 1\,\sigma$ (statististical) bands

0.92fb^{-1}





D^0 Semileptonic Decays – Form Factor Parameterizations

Simple Pole Model

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

Modified Pole Model

Becirevic and Kaidalov
PLB 478, 417 (‘00)

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

Series Expansion

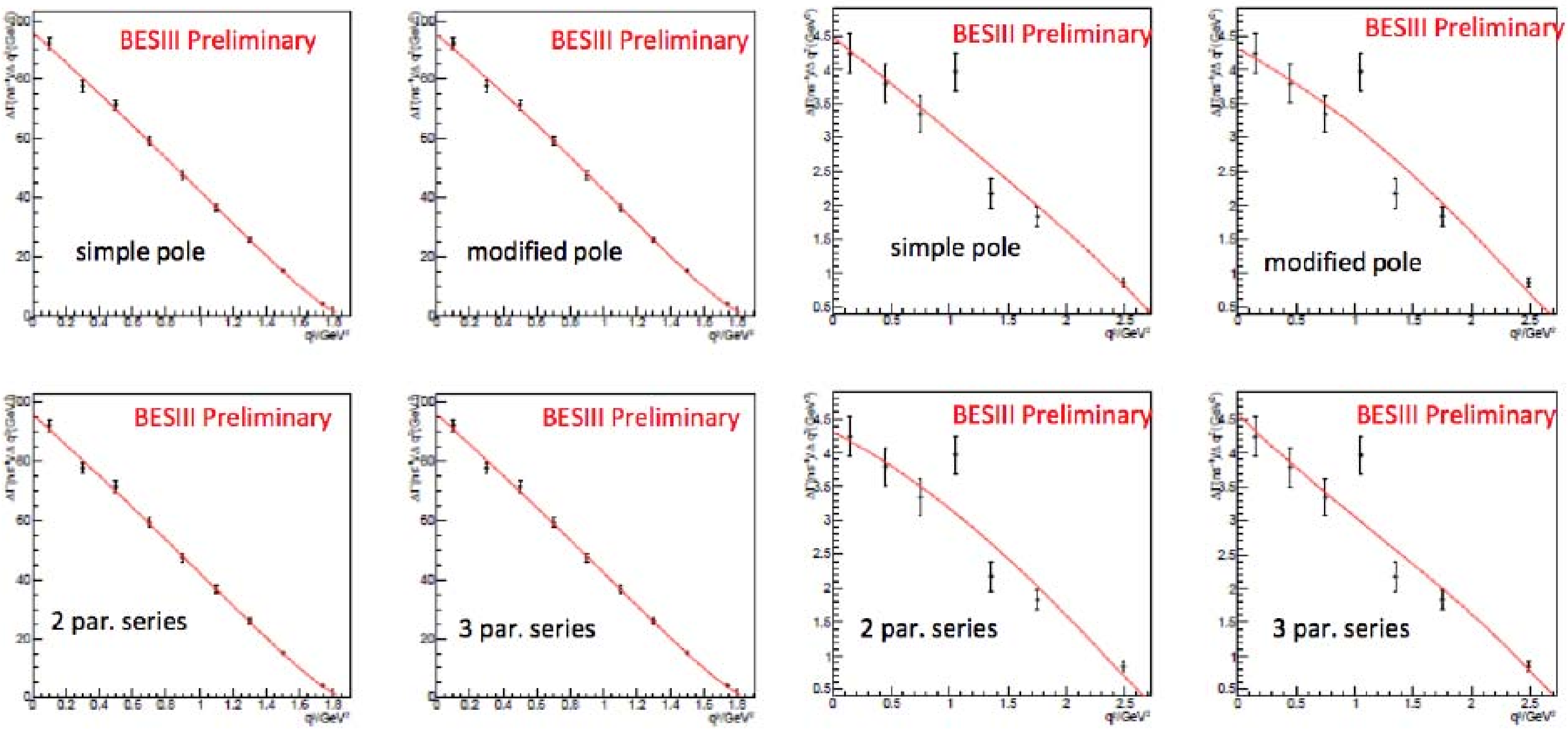
Becher and Hill
PLB 633, 61 (‘06)

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

$$z(q^2, t_0) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - q^2} + \sqrt{t_+ - t_0}} \qquad t_\pm = (m_D \pm m_X)^2$$

D^0 Semileptonic Decays – $f(q^2)$

$0.92 fb^{-1}$



$D^0 \to K^- e^+ \nu_\mu$ $D^0 \to \pi^+ e^+ \nu_\mu$

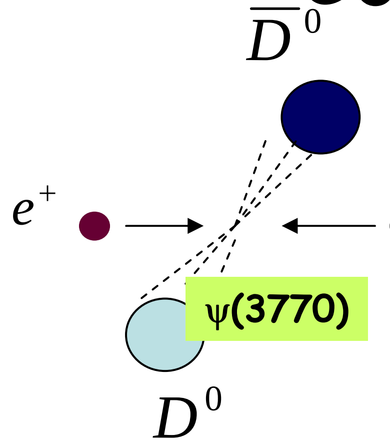
D^0 Semileptonic Decays – Form Factor Results

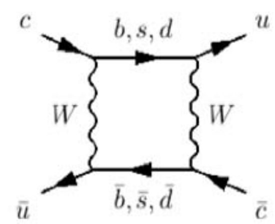
$0.92 fb^{-1}$

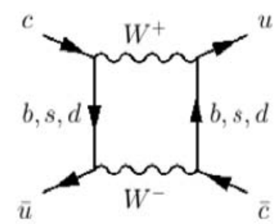
Simple Pole	$f_+(0)\|V_{cd(s)}\|$	m_{pole}	
$D^0 \to K e \nu$	$0.729 \pm 0.005 \pm 0.007$	$1.943 \pm 0.025 \pm 0.003$	
$D^0 \to \pi e \nu$	$0.142 \pm 0.003 \pm 0.001$	$1.876 \pm 0.023 \pm 0.004$	
Modified Pole	$f_+(0)\|V_{cd(s)}\|$	α	
$D^0 \to K e \nu$	$0.725 \pm 0.006 \pm 0.007$	$0.265 \pm 0.045 \pm 0.006$	
$D^0 \to \pi e \nu$	$0.140 \pm 0.003 \pm 0.002$	$0.315 \pm 0.071 \pm 0.012$	
2 par. series	$f_+(0)\|V_{cd(s)}\|$	r_1	
$D^0 \to K e \nu$	$0.726 \pm 0.006 \pm 0.007$	$-2.034 \pm 0.196 \pm 0.022$	
$D^0 \to \pi e \nu$	$0.140 \pm 0.004 \pm 0.002$	$-2.117 \pm 0.163 \pm 0.027$	
3 par. series	$f_+(0)\|V_{cd(s)}\|$	r_1	r_2
$D^0 \to K e \nu$	$0.729 \pm 0.008 \pm 0.007$	$-2.179 \pm 0.355 \pm 0.053$	$4.539 \pm 8.927 \pm 1.103$
$D^0 \to \pi e \nu$	$0.144 \pm 0.005 \pm 0.002$	$-2.728 \pm 0.482 \pm 0.076$	$4.194 \pm 3.122 \pm 0.448$

Reasonable consistency with CLEO-c,
comparable precision with 2/3 of data still to analyze

Coherence physics @threshold







$$x \equiv \frac{\Delta m}{\Gamma} = \frac{m_2 - m_1}{\Gamma} \qquad \Gamma = \frac{\Gamma_1 + \Gamma_2}{2}$$

$$y \equiv \frac{\Delta \Gamma}{2\Gamma} = \frac{\Gamma_2 - \Gamma_1}{2\Gamma}$$

For coherent process:

$$e^+e^- \rightarrow \psi'' \rightarrow D^0\overline{D}^0$$

The initial state C=-1

$$\psi_- = \frac{1}{\sqrt{2}}(|D^0\rangle|\overline{D}^0\rangle - |\overline{D}^0\rangle|D^0\rangle)$$

$$\hat{C}|D^0\rangle = |\overline{D}^0\rangle \qquad \hat{C}|\overline{D}^0\rangle = |D^0\rangle$$

The coherent amplitude

$$\Gamma_{ij}^2 = \left|\langle i|D^0\rangle\langle j|\overline{D^0}\rangle \mp \langle j|D^0\rangle\langle i|\overline{D^0}\rangle\right|^2$$

$$\frac{\langle K^-\pi^+|\overline{D}^0\rangle_{DCS}}{\langle K^-\pi^+|D^0\rangle_{CF}} = -r_{K\pi}e^{-i\delta_{K\pi}}$$

~0.06

$\delta_{K\pi}$ connects measurements of y and y'

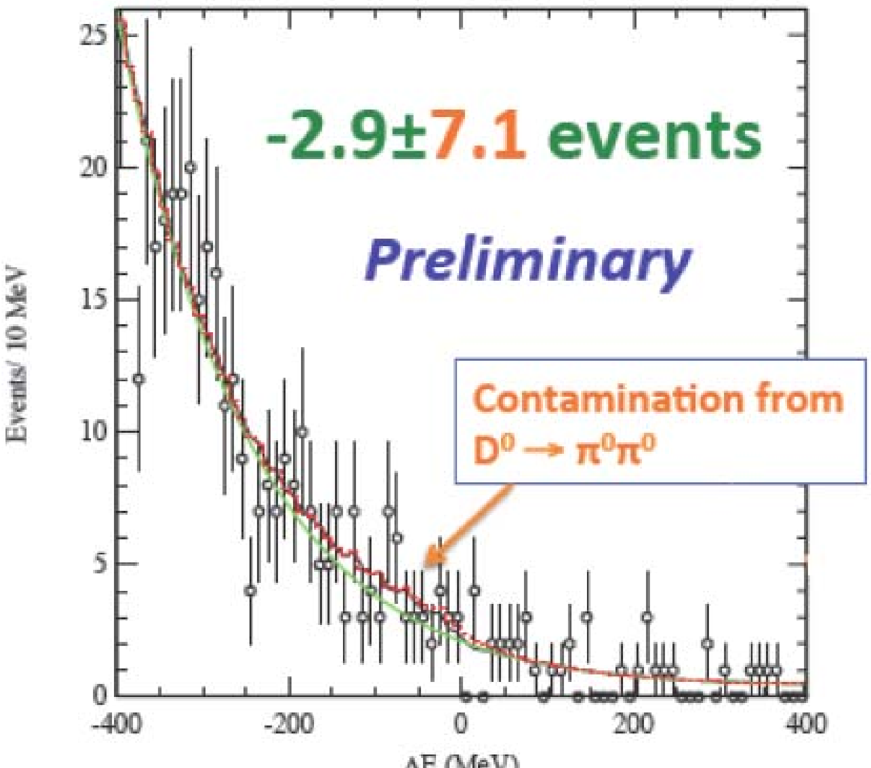
- ✓ D^0 mixing: $R_M = (x^2+y^2)/2 \sim 10^{-4}$
- ✓ Strong phase can be accessed, will be helpful for mixing measurements at super-B factories:

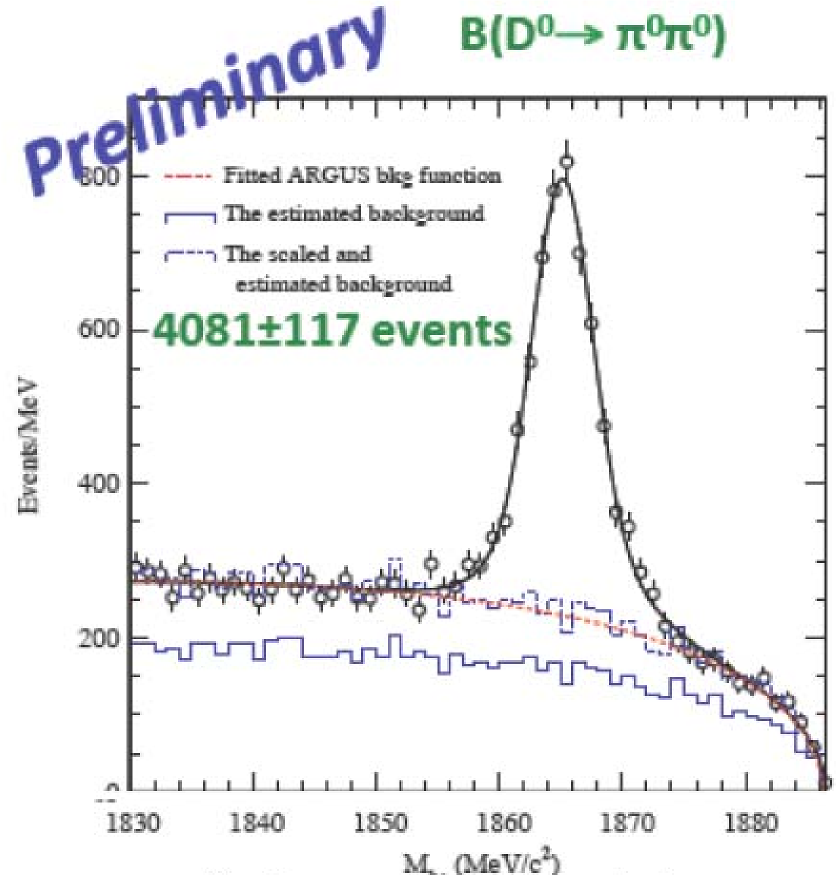
  Sensitivity on x will be improved by a factor of 3

  Uncertainty of γ due to unknown relative phase on Dalitz decays $D^0 \rightarrow K_s h^+h^-$ will be reduced to less than 1^0.

- ✓ CP violation in D sector : 10^{-3}

FCNC: $D^0 \to \gamma\gamma$





$B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0) < 5.8\times10^{-3}$ @90% CL, with

PDG value: $B(D^0 \to \pi^0\pi^0) = 8\times10^{-4}$,

BESIII: $B(D^0 \to \gamma\gamma) < 4.6\times10^{-6}$ @90% CL.

BaBar: $B(D^0 \to \gamma\gamma) < 2.2\times10^{-6}$ @90% CL.

27

Sensitivity of rare D decays at BESIII

- Flavor Changing Neutral Current ($c \to u\, l^+ l^-$)
  - $D^0 \to \mu^+\mu^-$ SM $<10^{-12}$ NP $\sim 10^{-6}$
    - CDF BR$< 4.3\times10^{-7}$
  - $D^0 \to \pi^0 \nu\nu$bar, $D^0 \to \nu\nu$bar , $D^0 \to \gamma\nu\nu$bar
  - $D^0 \to \gamma\gamma$
  - $D \to X_u l^+ l^-$ SM $<10^{-8}$ NP $\sim 10^{-6}$
    - D0 BR($D^+ \to \pi^+\mu^+\mu^-$)$< 3.9\times10^{-6}$
    - CLEO-c BR($D^+ \to \pi^+ e^+ e^-$)$< 7.4\times10^{-6}$
- Lepton Flavor Violation NP $\sim 10^{-6}$
    - BABAR BR($D^0 \to \mu^+ e^-$) $<0.81\times10^{-6}$
    - BABAR BR($D^+ \to \pi^+ e^+ \mu^-$) $<1.1\times10^{-5}$

With 5-10fb^{-1} @$\psi(3770)$
BESIII will provide 10^{-6} -10^{-7} sensitivity.

Summary

- **BESIII is successfully operating since 2008**

  World largest data sample at J/ψ. $\psi(3686)$, $\psi(3770)$, $\psi(4040)$ already collected, more data in the future @ 4170 MeV, 4260MeV and 4360MeV coming soon

- **Charmonium transitions**
  - Precision measurements of h_C and $\eta_C(1S)$ properties.
  - first observation of $\eta_c(2S)$ in $\psi' \to \gamma\eta_c(2S)$ decay.
  - First evidence of $\psi' \to \gamma\gamma J/\psi$.
- **Charmonium decays**
- **Light hadron spectroscopy**
  - confirmation X(1835) with two new structures in $J/\psi \to \gamma\pi\pi\eta'$.
  - observation a new structure X(1870) in $J/\psi \to \omega\pi\pi\eta$.
  - First observation: $\eta(1405) \to f_0(980)\pi^0$ (isospin breaking).
- **Charm decays**

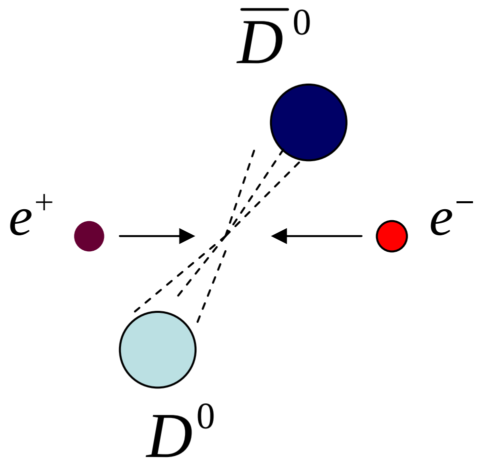
  Precision D physics to come soon.

Thank you!

Back up slides

$D^0\bar{D}^0$bar quantum correlation @$\psi(3770)$

For a physical process producing $D^0\ \bar{D}^0$ such as



$$e^+e^- \to \psi'' \to D^0\overline{D}^0$$

The quantum number of ψ'' is $J^{PC} = 1^{--}$

∴ For a correlated state C=-1:

$$\psi_- = \frac{1}{\sqrt{2}}(|D^0\rangle|\overline{D}^0\rangle - |\overline{D}^0\rangle|D^0\rangle)$$

$$\hat{C}|D^0\rangle = |\overline{D}^0\rangle$$
$$\hat{C}|\overline{D}^0\rangle = |D^0\rangle$$

Z.Z . Xing, PRD55, 196(1997)

The correlated amplitude:

$$\Gamma_{ij}^2 = \left| \langle i|D^0\rangle\langle j|\overline{D^0}\rangle - \langle j|D^0\rangle\langle i|\overline{D^0}\rangle \right|^2$$

$$\frac{\langle K^-\pi^+|\overline{D^0}\rangle^{DCS}}{\langle K^-\pi^+|D^0\rangle_{CF}} = -r_{K\pi}e^{-i\delta_{K\pi}}$$

~0.06

$\delta_{K\pi}$ connects measurements of y and y'

D⁰ strong phase is necessary input for D⁰ mixing and CKM measurements at B factories and LHCb

Measure D^0 mixing at threshold

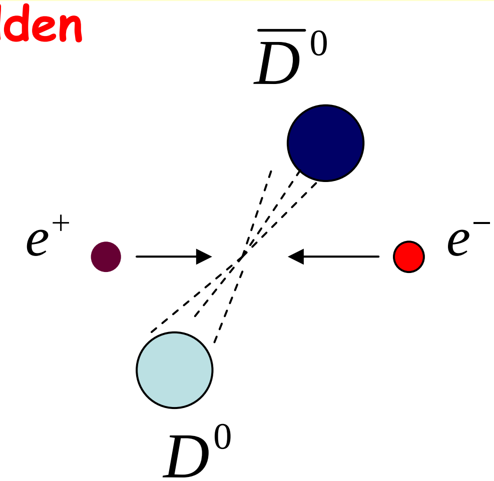
Z.Z . Xing, PRD55, 196(1997)

Without mixing in D^0, the following process is forbidden due to Boson-Einstein statistics :

$$e^+e^- \to \psi(3770) \to D^0\overline{D}^0 \to (K^\pm\pi^\mp)(K^\pm\pi^\mp)$$

With mixing happened, it is allowed:

$$e^+e^- \to \psi(3770) \to D^0_H D^0_L \to (K^\pm\pi^\mp)_H (K^\pm\pi^\mp)_L$$



At $\psi(3770)$ $R_M=(x^2+y^2)/2$ can be measured using the ratios

$$R_M = \frac{N[D^0\overline{D}^0 \to (K^-\pi^+)(K^-\pi^+)]}{N[D^0\overline{D}^0 \to (K^-\pi^+)(K^+\pi^-)]}, \quad \frac{N[D^0\overline{D}^0 \to (K^-e^+\nu)(K^-e^+\nu)]}{N[D^0\overline{D}^0 \to (K^-e^+\nu)(K^+e^-\nu)]}$$

For 10^8 D-pairs about 10 events will be detected.
Sensitivity to R_M is about 1×10^{-4}

Expected sensitivity to mixing parameters:
1 ab^{-1} at tau-charm factory = 10 ab^{-1} at Super B-factory

CPV in D decay at BESIII

Direct CP violation in D decays is expected to be small in SM.

For CF and DCS decays direct CP violation requires New Physics.
Exception: $D^{\pm}\to K_{S,L}\pi^{\pm}$ with $A_{CP}=-3.3\times10^{-3}$.

For Singly Cabibbo Suppressed (SCS) decays SM CPV could reach 10^{-3}.

$$A_{CP} = \frac{\Gamma(D\to f) - \Gamma(\bar{D}\to \bar{f})}{\Gamma(D\to f) + \Gamma(\bar{D}\to \bar{f})}$$

D.S.Du , EPJC5,579(2007)
Y. Grossman et al
PRD75, 036008(2007)

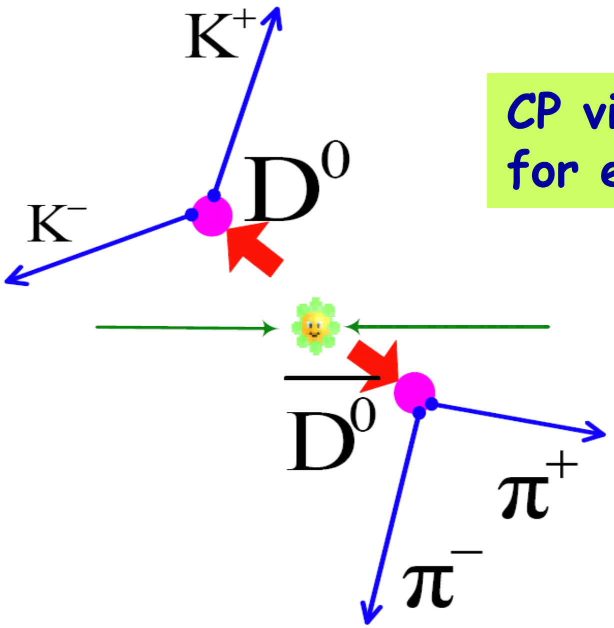
Best limits:

Belle: $D^0\to K^+K^-,\pi^+\pi^-$
$A_{CP}(K^+K^-)=(0.43\pm0.30\pm0.11)\%$
$A_{CP}(\pi^+\pi^-)=(0.43\pm0.52\pm0.12)\%$

BABAR: $D^+\to K_S\pi^+$
$A_{CP}(K_S\pi^+)=(-0.44\pm0.13\pm0.10)\%$
CLEO-c : $K_S\,\pi^+\pi^0$
$A_{CP}(K_S\pi^+\pi^0)=(0.3\pm0.9\pm0.3)\%$

At BESII, CP asymmetry can be tested with 10^{-3} sensitivity for many final states.

CP violation near threshold



CP violating asymmetries can be measured by searching for events with two CP odd or two CP even final states:

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

for the decay of $\psi'' \to D^0\overline{D}^0 \to f_1 f_2$

$CP(f_1 f_2) = CP(f_1)\cdot CP(f_2)\cdot(-1)^L = -$

$CP(\psi'') = +$

A_{CP} sensitivity : $\Delta A \sim 10^{-3}$

CP violation in mixing can be measured with:

$$A_{SL} = \frac{\Gamma_{l^+l^+} - \Gamma_{l^-l^-}}{\Gamma_{l^+l^+} + \Gamma_{l^-l^-}} = \frac{1 - |q/p|^4}{1 + |q/p|^4}$$

With 10^8 D pairs in $(K^+e^-\nu)(K^+e^-\nu)$ mode, |q/p| can be measured with (15-20)% accuracy. Current world averaged value is 0.86±0.16 .

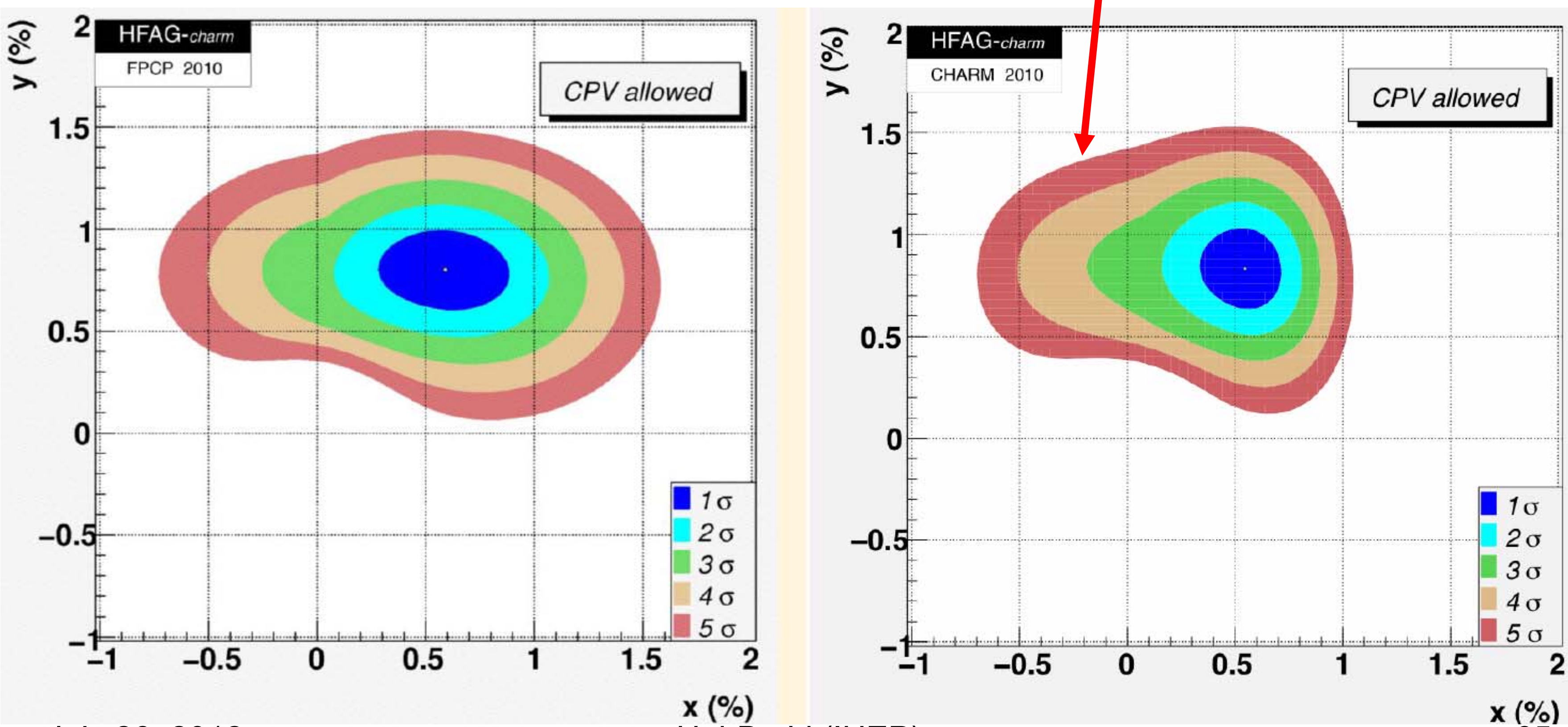
HFAG: new charm mixing with CLEO-c

D. Asner
Charm 2010

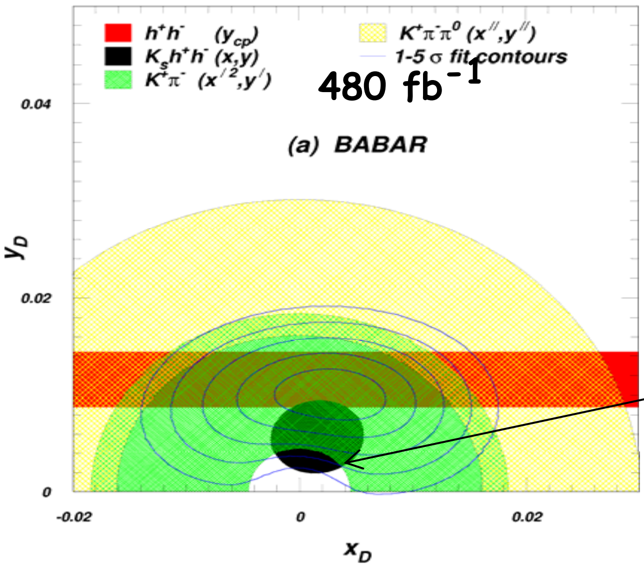
Parameter	HFAG:FPCP2010	HFAG:CHARM2010
y (10^{-2})	0.79 ± 0.13	0.83 ± 0.13
x (10^{-2})	0.59 ± 0.20	$0.55^{+0.12}_{-0.13}$
$r_{K\pi}^2$ (10^{-3})	3.32 ± 0.08	3.32 ± 0.08
$\delta_{K\pi}$ ($^\circ$)	$27.6^{+11.2}_{-12.2}$	$31.0^{+10.7}_{-12.2}$

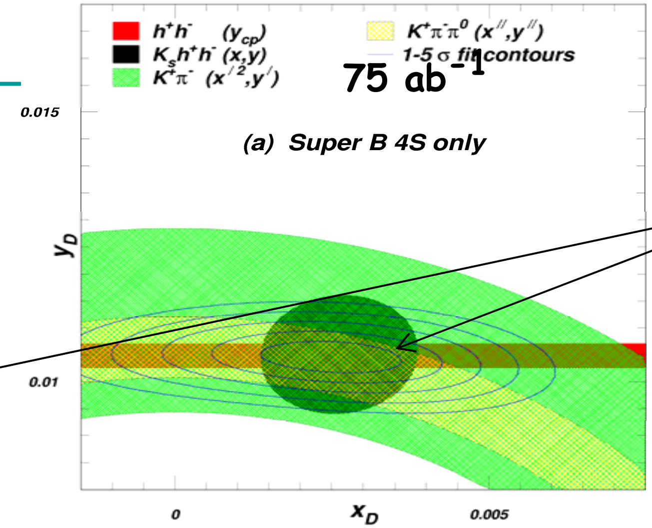
Consider CLEO-c results

Surprising? Large impact on x uncertainty



Project to 75ab^{-1}@Υ(4S):





Golden channels

Min. χ^2 fits (blue contours)

$$x_D = (5.5 \pm^{1.3}_{1.2}) \times 10^{-3}$$
$$y_D = (8.3 \pm 1.3) \times 10^{-3}$$

→

$$x_D = (xxx^{+0.72}_{-0.75}) \times 10^{-3}$$
$$y_D = (xxx \pm 0.19) \times 10^{-3}$$

Uncertainties shrink: but are limited by the irreducible model uncertainty (biggest effect on x_D)

Strong phase measurement from ψ(3770) can greatly reduce this.

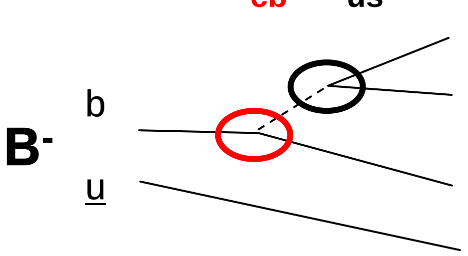
$$x_D = (xxx \pm 0.20) \times 10^{-3}, \quad y_D = (xxx \pm 0.12) \times 10^{-3}$$

The weak phase γ (ϕ_3)

From A. Bondar CHARM2010

Interference between tree-level decays; theoretically clean

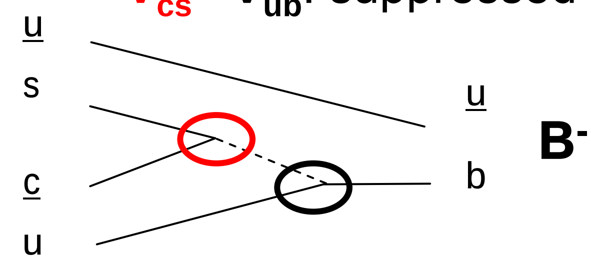
Favored: V_{cb} V_{us}^*



$K^{(*)-}$ Common final state $K^{(*)-}$

$D^{(*)0} \longrightarrow f \longleftarrow \bar{D}^{(*)0}$

V_{cs}^* V_{ub}: suppressed



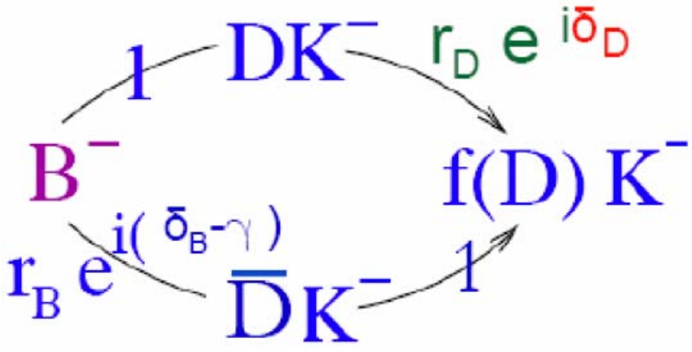
$$\frac{A(B^- \to \bar{D}^0 K^-)}{A(B^- \to D^0 K^-)} = r_B e^{i\delta} e^{-i\phi_3}$$

Parameters: ϕ_3, (r_B, δ) per mode

Three methods for exploiting interference (choice of D^0 decay modes):

- Gronau, London, Wyler (GLW): Use CP eigenstates of $D^{(*)0}$ decay, e.g. $D^0 \to K_s \pi^0$, $D^0 \to \pi^+ \pi^-$
- Atwood, Dunietz, Soni (ADS): Use doubly Cabibbo-suppressed decays, e.g. $D^0 \to K^+ \pi^-$
- Giri, Grossman, Soffer, Zupan (GGSZ) / Belle: Use Dalitz plot analysis of 3-body D^0 decays, e.g. $K_s \pi^+ \pi^-$

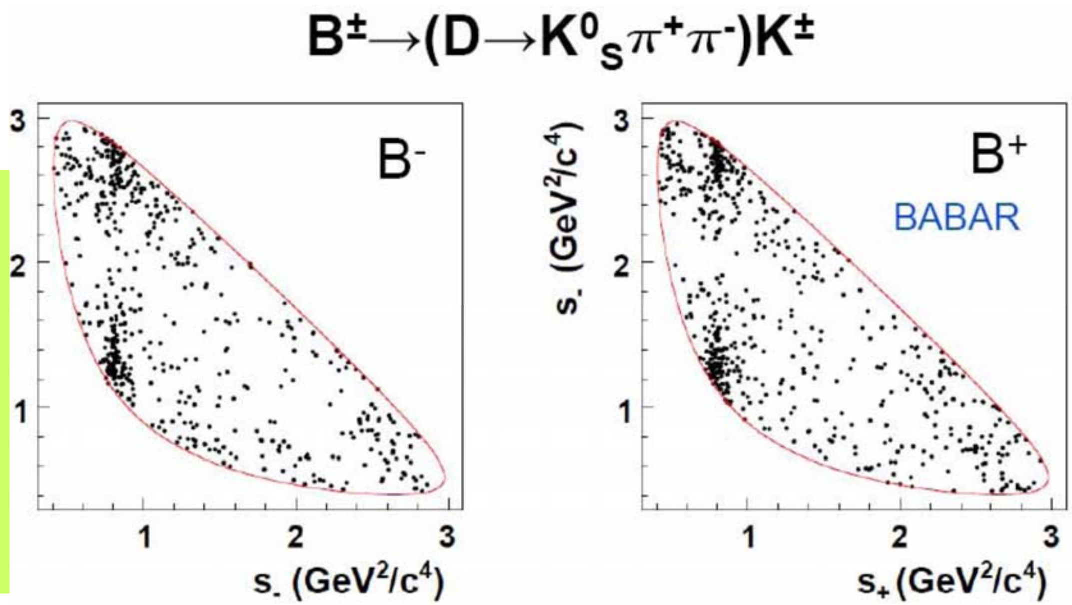
$B^- \to D(K_s h^+ h^-) K^-$ Dalitz plot for γ at B factory



A powerful choice of common state f(D) in $K_s h^+ h^-$

BABAR: PRL 105, 121801 (2010)

Belle : PRD 81, 112002 (2010)



Differents between B^- and B^+ Dalitz plots allow γ extracted in unbinned fit. However, need to understand different amplitudes from D^0 and D^0bar decay modes across Dalitz space, esp. variation in strong phase.

Approach of B factories: construct Dalitz plot model of D with flavor-tagged decays, estimated model uncertainty of 30-90, which is << statistical error.

But super-B and LHC-b will start to be limited by this model uncertainty –

Highly desirable to have precision model independent approach!

Binned Model-Independent Fit

Binned fit proposed by Giri *et al.* [PRD 68 (2003) 054018] and developed by Bondar & Poluektov [EPJ C 55 (2008) 51; EPJ C47 (2006) 347] removes model dependence by relating events in bin i of Dalitz plot to *experimental observables.*

$B^{\pm}$ events in bin i of Dalitz plot

Number of events for flavour-tagged D sample

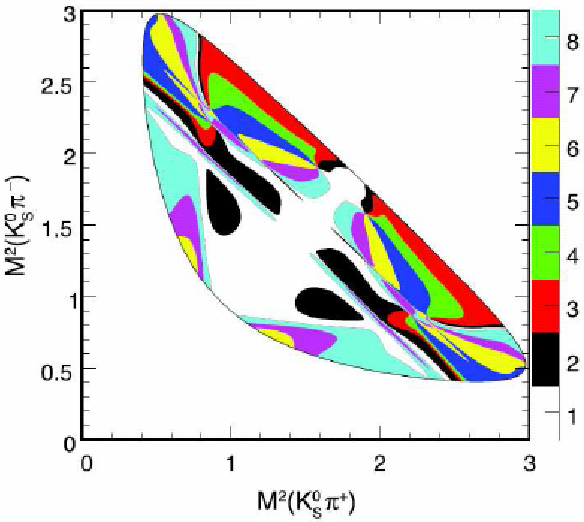
$x_{\pm} = r_B \cos(\delta_B \pm \gamma)$

$y_{\pm} = r_B \sin(\delta_B \pm \gamma)$

$$N_i^{\pm} = h(K_{\pm i} + r_B^2 K_{\mp i} + 2\sqrt{K_i K_{-i}}(x_{\pm} c_i \pm y_{\pm} s_i))$$

c_i, s_i : average in bin of cosine, sine of strong phase δ_D

Can be measured in quantum correlated decays at ψ(3770)!



Choosing bins of *expected* similar strong phase difference maximises statistical precision

Here take 8 bins of equal spacing in $\Delta\delta_D$ (using as reference model: BaBar, PRL 95 (2005) 121802)

Loss in statistical sensitivity w.r.t. unbinned result…(here ~20%) but no model error!

From Jim Libby CHARM2010

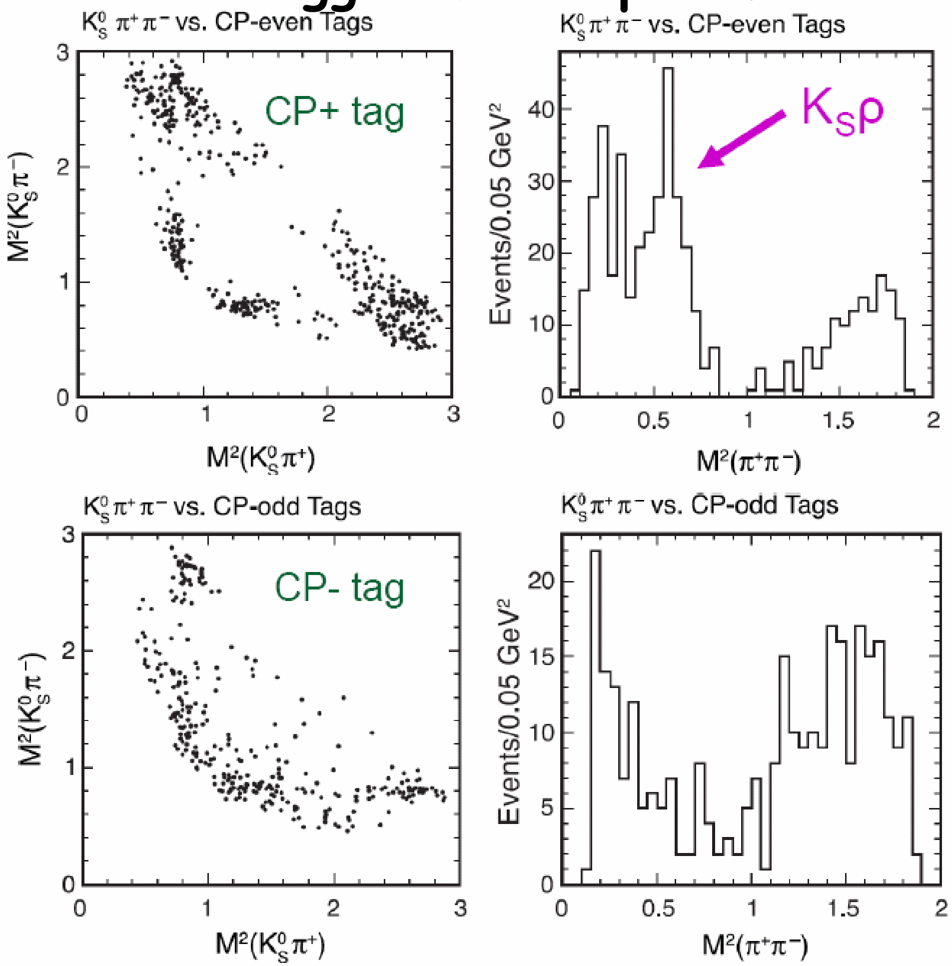
CP-tagged Dalitz plots

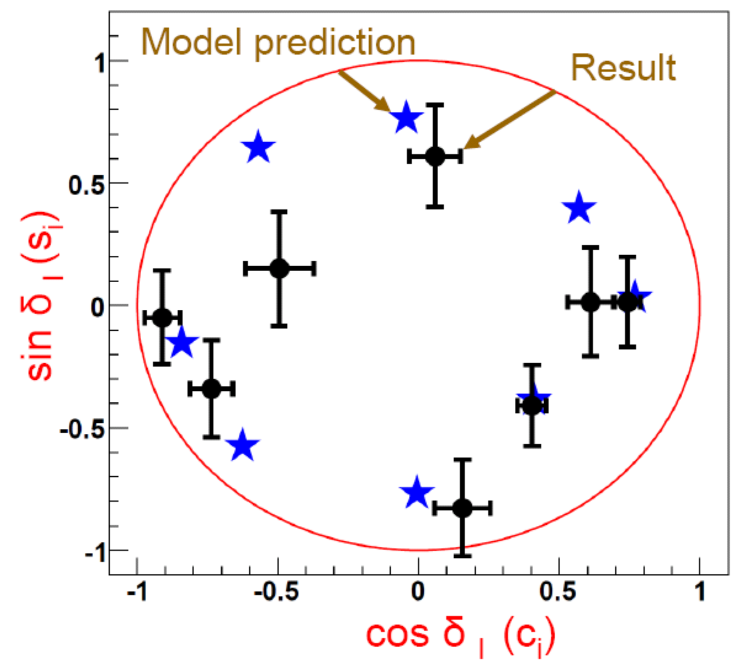
Clear difference between CP-even and CP-odd tagged Dalitz plots.

R. Briere *et al.*, PRD 80 (2009) 032002

(model = BABAR PRL 95 (2005) 121802)

CLEO-c, PRD 80 (2009) 032002





Projected uncertainty on γ arising from uncertainty on c_i & s_i is 1.7°:

- Smaller than model error

BESIII will reduce this error to less than 1°