Highlights from BESIII

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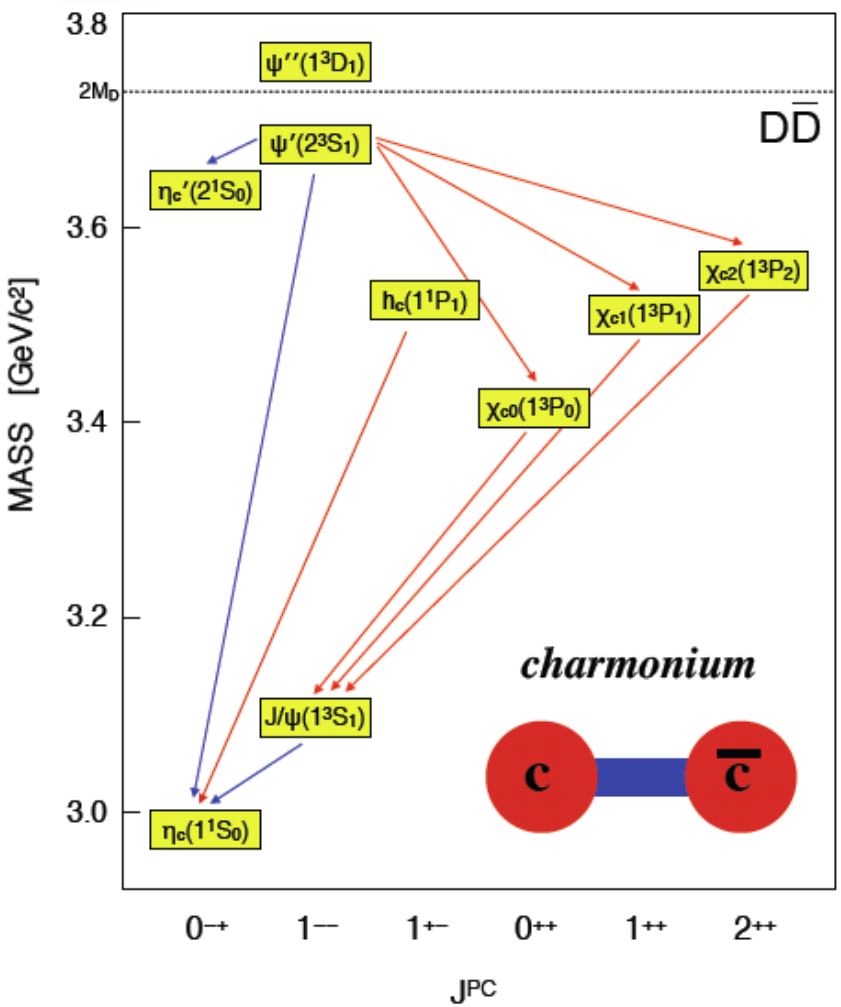
***Künstlerhaus, in München*, Germany**

Outline

- Status of BEPCII/BESIII
- Results from Charmonium data samples
- 2010-11: First open charm runs
- Charm Physics: advantage near threshold
- Conclusion

BESIII - physics using "charm"



Charmonium physics:
- Spectroscopy
- transitions and decays

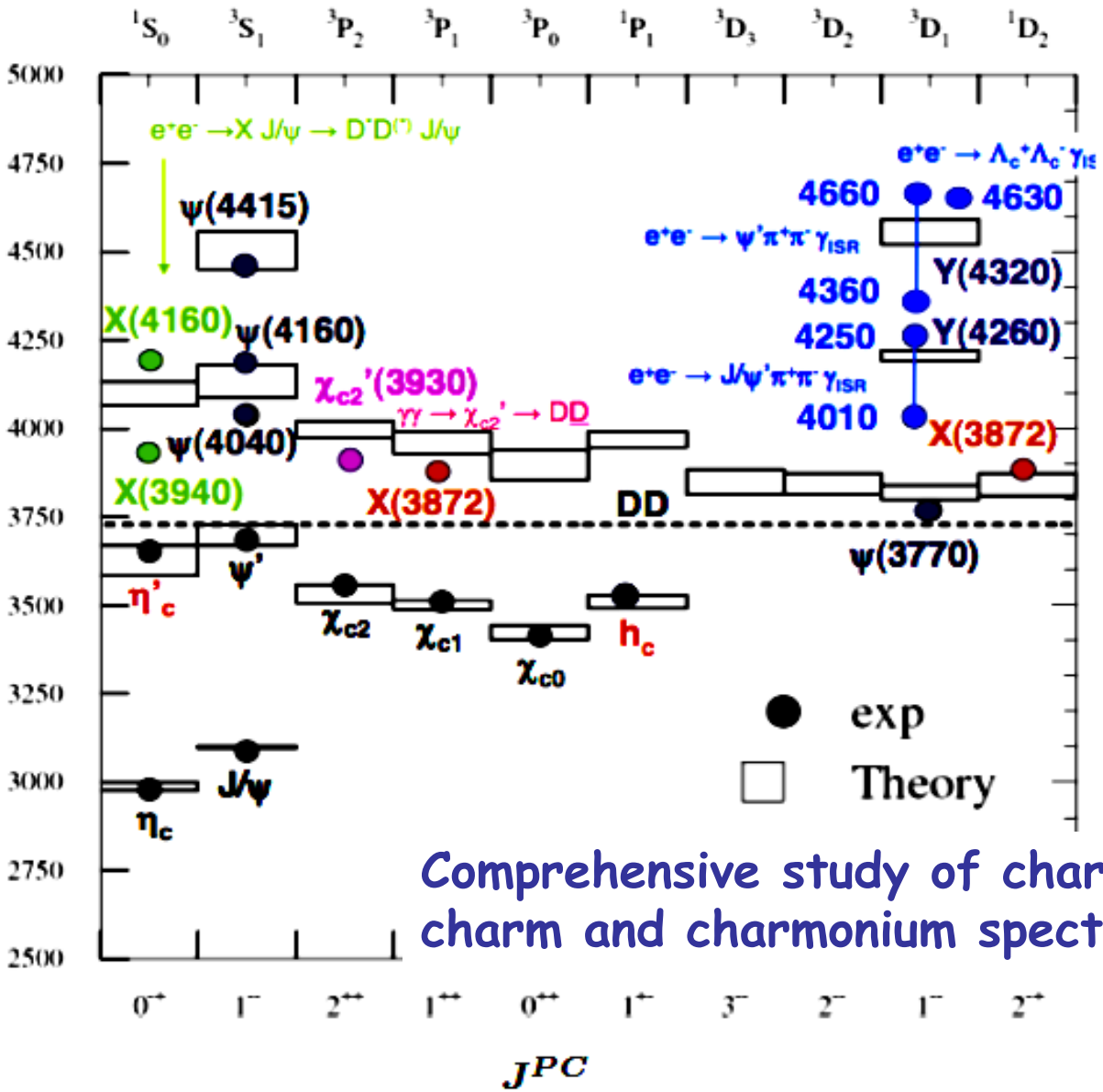
Light hadron physics:
- meson & baryon spectroscopy
- glueball & hybrid
- two-photon physics
- e.m. form factors of nucleon

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.

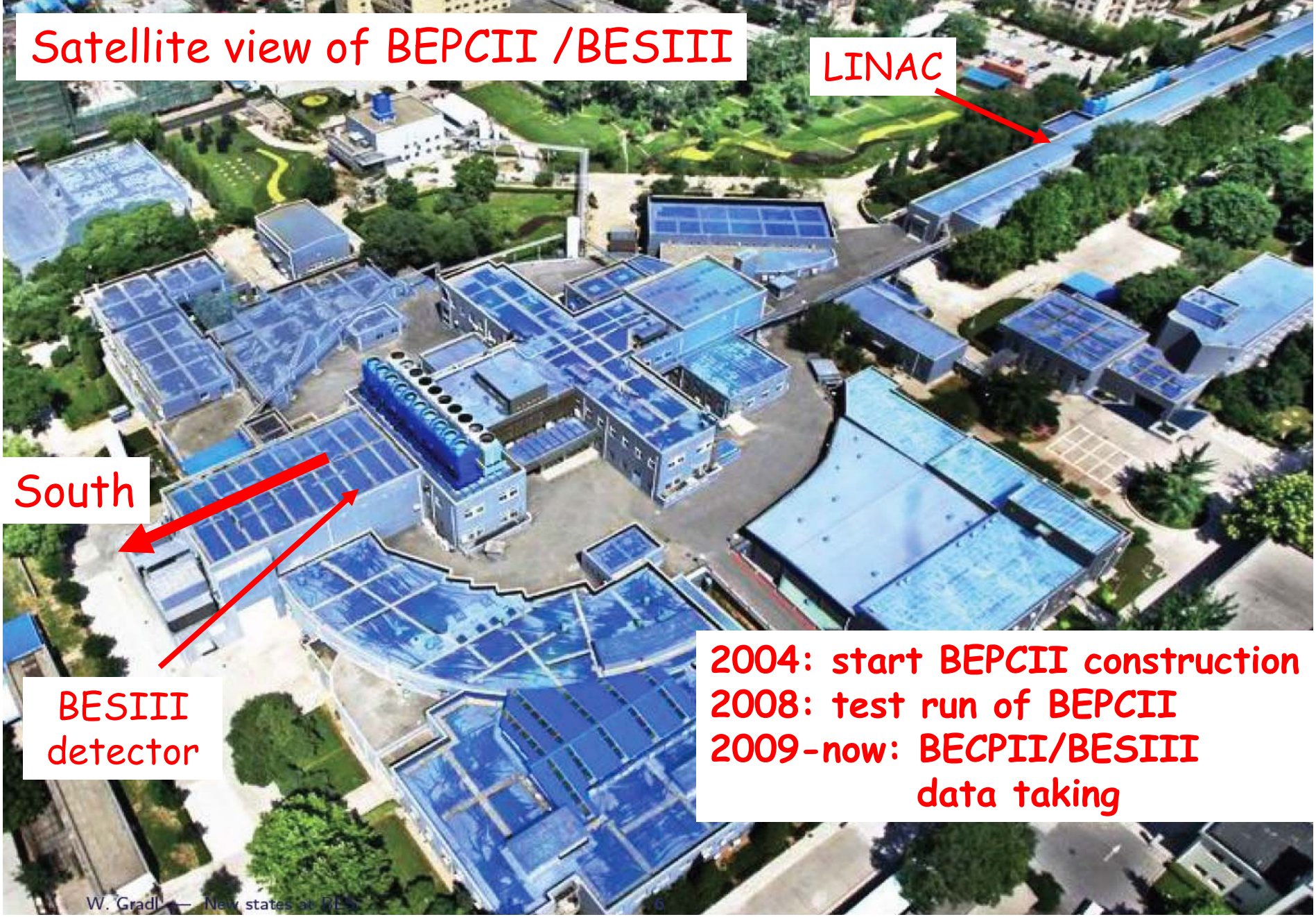
Charmonium spectroscopy after the B-factories



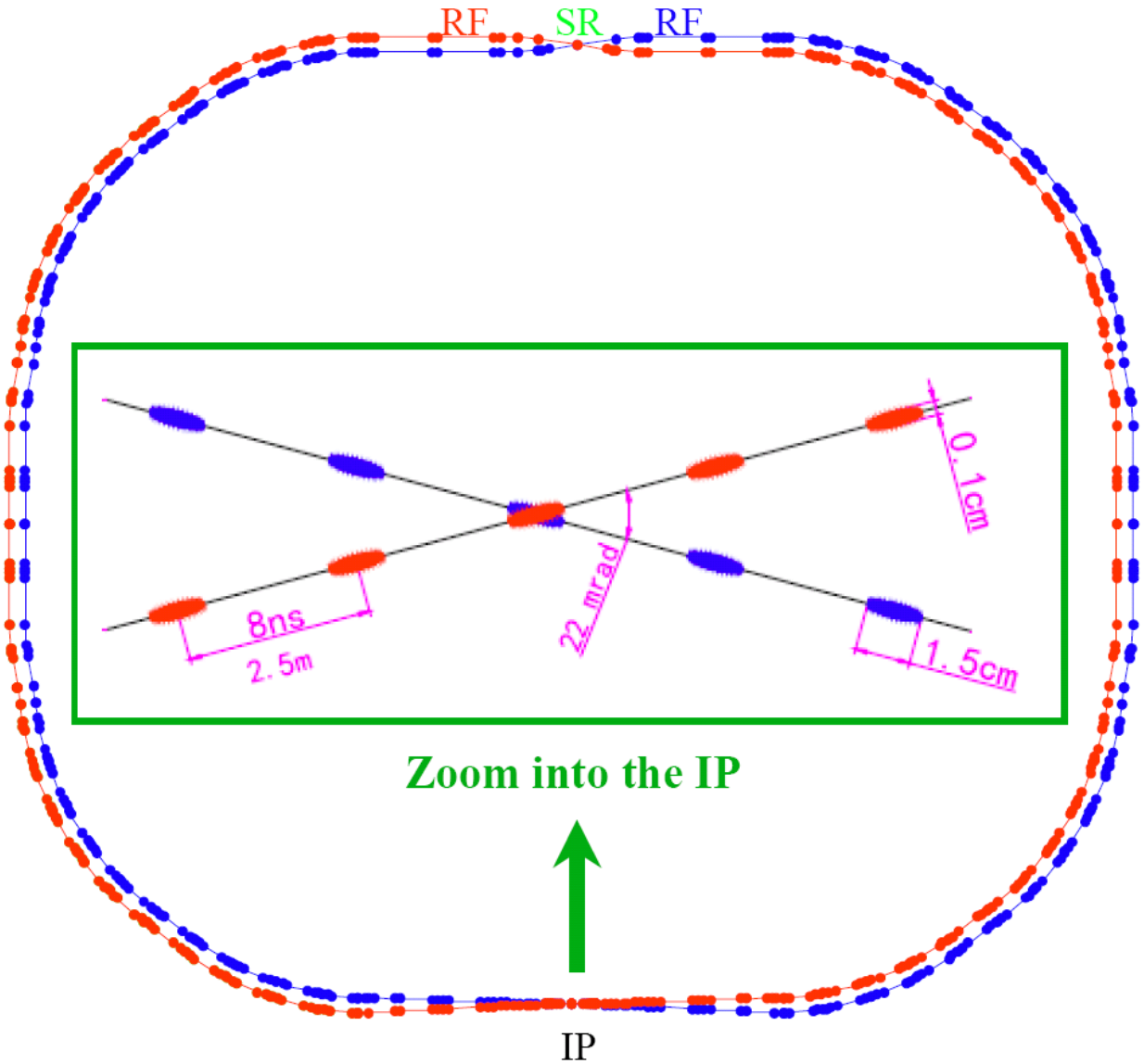
BESIII final goal
J/ψ – 10^{10}
$\psi(2S)$ – 3×10^9
$\psi(3770)$ – 6×10^8
Higher ψ's – 10^7

In decays:
$\eta_c(1S)$-10^8
χ_{cJ} – 10^8
h_c – 10^7
($\psi(2S)\to h_c\pi^0$)
10^8 η/η' samples
Rare η/η' decays

Comprehensive study of charmonium decays
charm and charmonium spectroscopy


Satellite view of BEPCII /BESIII
LINAC
South
BESIII detector
2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking
W. Gradl — New states at BES

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

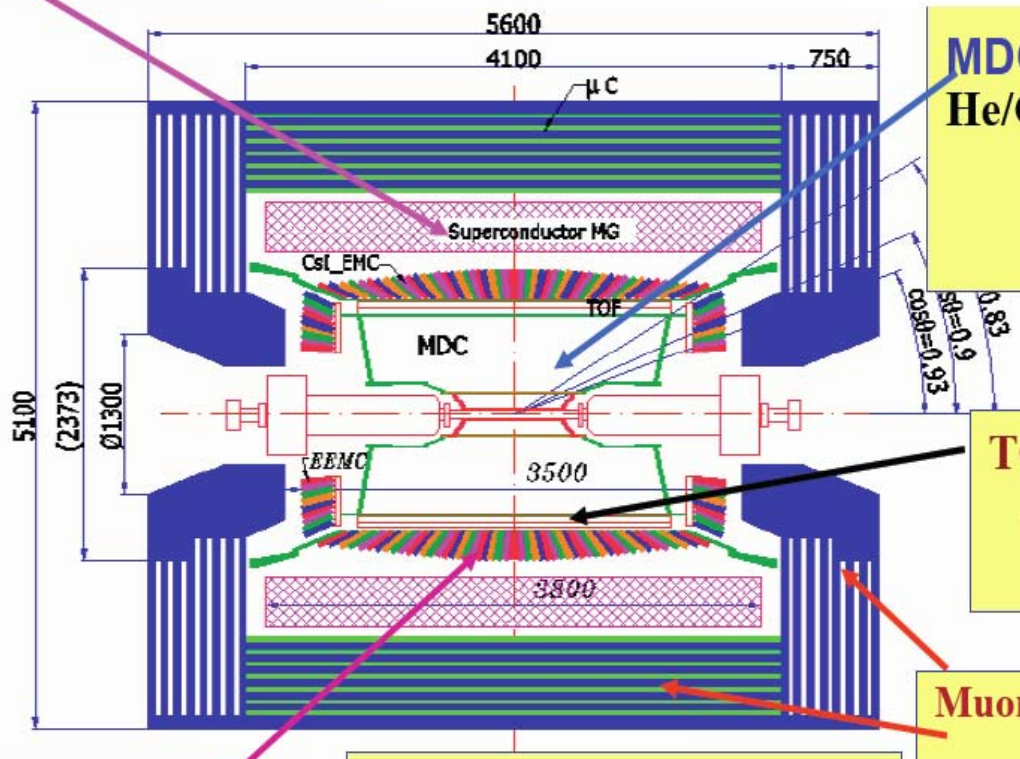
Circumference：
237m

BESIII Detector

BESIII detector: all new !

CsI calorimeter
Precision tracking
Time-of-flight + dE/dx PID

Magnet: 1 T Super conducting



MDC: small cell & Gas:
He/C_3H_8 (60/40), 43 layers
σ_{xy}=130 μm
σ_p/p = 0.5% @1GeV
dE/dx=6%

TOF:
σ_T = 100 ps Barrel
110 ps Endcap

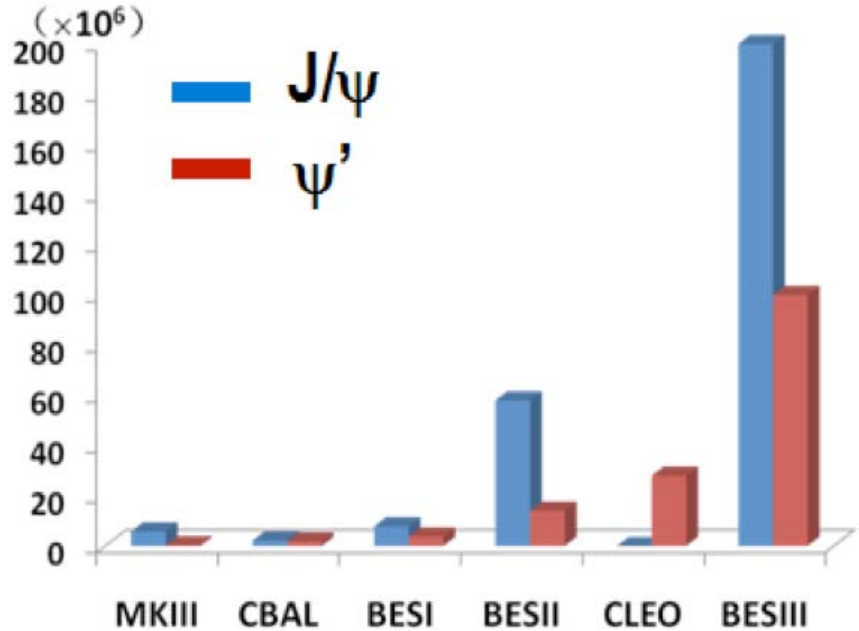
Muon ID: 9 layers RPC
8 layers for endcap

EMC: CsI crystal, 28 cm
$\Delta E/E$ = 2.5% @1 GeV
$\sigma z = 0.6\ cm/\sqrt{E}$

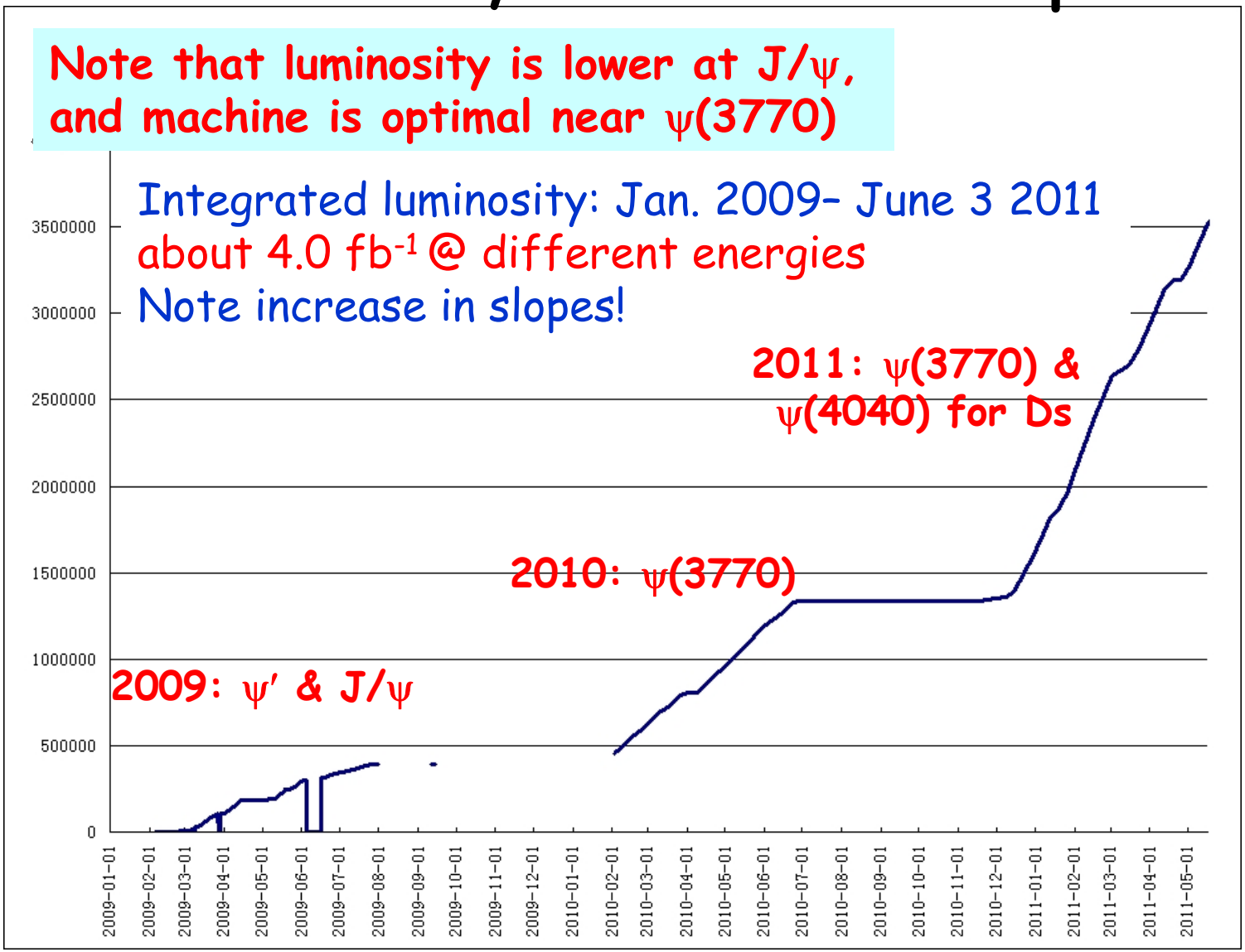
Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s

Data samples

- So far BESIII has collected :
  - 2009: 225 Million J/ψ
  - 2009: 106 Million ψ'
  - **2010-11: 2.9 fb^{-1} ψ(3770) (3.5 × CLEO-c 0.818fb^{-1})**
  - **May 2011: 0.5fb^{-1} @4010 MeV (one month) for Ds and XYZ spectroscopy**
- BESIII will also collect:
  - more J/ψ, ψ', ψ(3770)
  - data at higher energies （for XYZ searches, R scan and Ds physics）

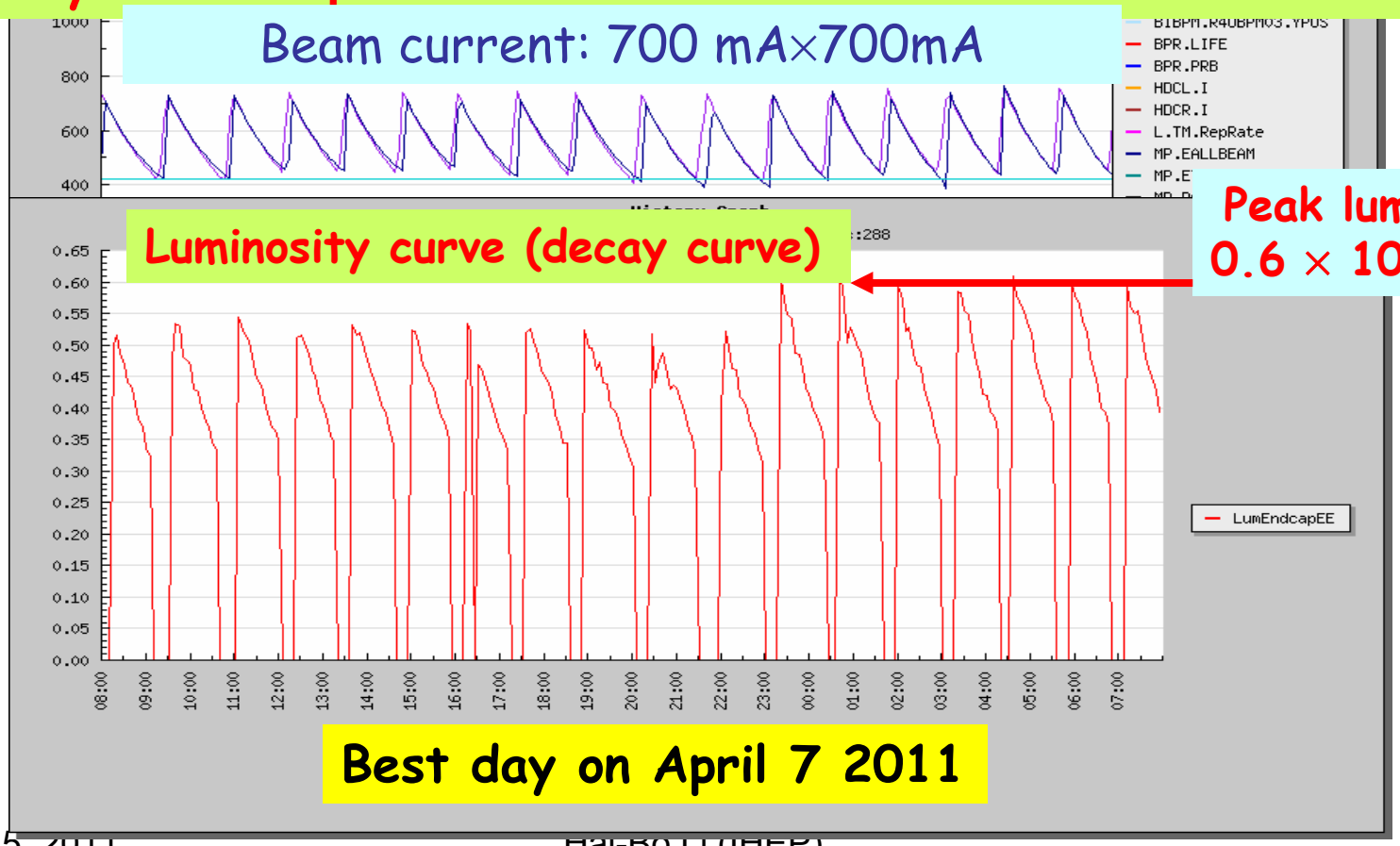


luminosity since startup



Recent ψ(3770) running

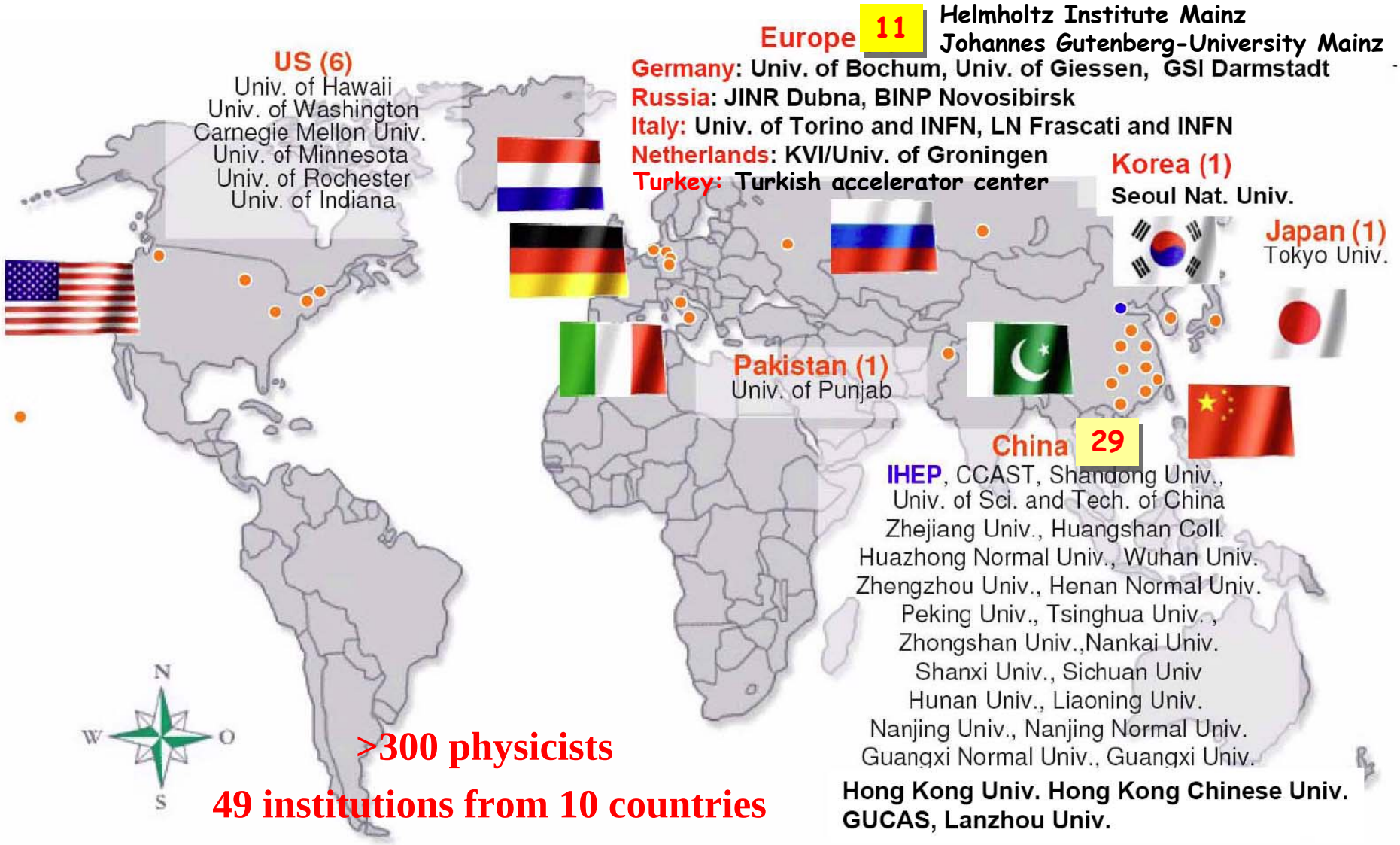
Reference point: $\mathcal{L}$ = 0.5 × 10^{33} /cm^2/s (maximum 0.65 × 10^{33})
theoretically lumi: 43 pb^{-1} /day
But, filling beam, HV ramp, lumi. decay and down time loss 40%
Best week : 160.8 pb^{-1}
Best day : 29 pb^{-1}



Peak luminosity 0.6 × 10^{33}/cm^2/s

6 groups from Germany

BESIII Collaboration



>300 physicists

49 institutions from 10 countries

Released results of BESIII

- Charmonium Spectroscopy and Transitions
  - Properties of the h_c *(PRL 104, 132002 (2010))*
  - $\psi' \to \gamma\gamma J/\psi$ *(submitted soon)*
- Charmonium Decays
  - $\chi_{cJ} \to \pi^0\pi^0, \eta\eta$ *(PRD 81, 052005 (2010))*
  - $\chi_{cJ} \to \gamma\rho, \gamma\omega, \gamma\phi$ *(PRD83,112005(2011))*
  - $\chi_{cJ} \to \omega\omega, \phi\phi, \omega\phi$ *(submitted to PRL)*
  - $\psi' \to \gamma\pi^0, \gamma\eta, \gamma\eta'$ *(PRL 105, 261801 (2010))*
  - $\chi_{cJ} \to 4\pi^0$ *(PRD 83, 012006 (2011))*
  - **Observation of $\chi_{cJ} \to p\bar{p}K^+K^-$ (accepted by PRD)**
- Light Quark States
  - $a_0(980) - f_0(980)$ mixing *(PRD 83, 032003 (2011))*
  - $\eta' \to \eta\pi^+\pi^-$ matrix element *(PRD 83, 012003 (2011))*
  - X(1860) in $J/\psi \to \gamma(p\bar{p})$ *(Chinese Physics C 34, 4 (2010))*
  - X(1835) in $J/\psi \to \gamma(\eta'\pi^+\pi^-)$ *(PRL 106, 072002 (2011))*
  - X(1870) in $J/\psi \to \omega(\eta\pi^+\pi^-)$ *(submitted soon)*

10 papers published

More than 20 analyses are under internal review!

Property of h_c (1p1)

PRL104, 132002 (2010)

Study isospin forbidden transition

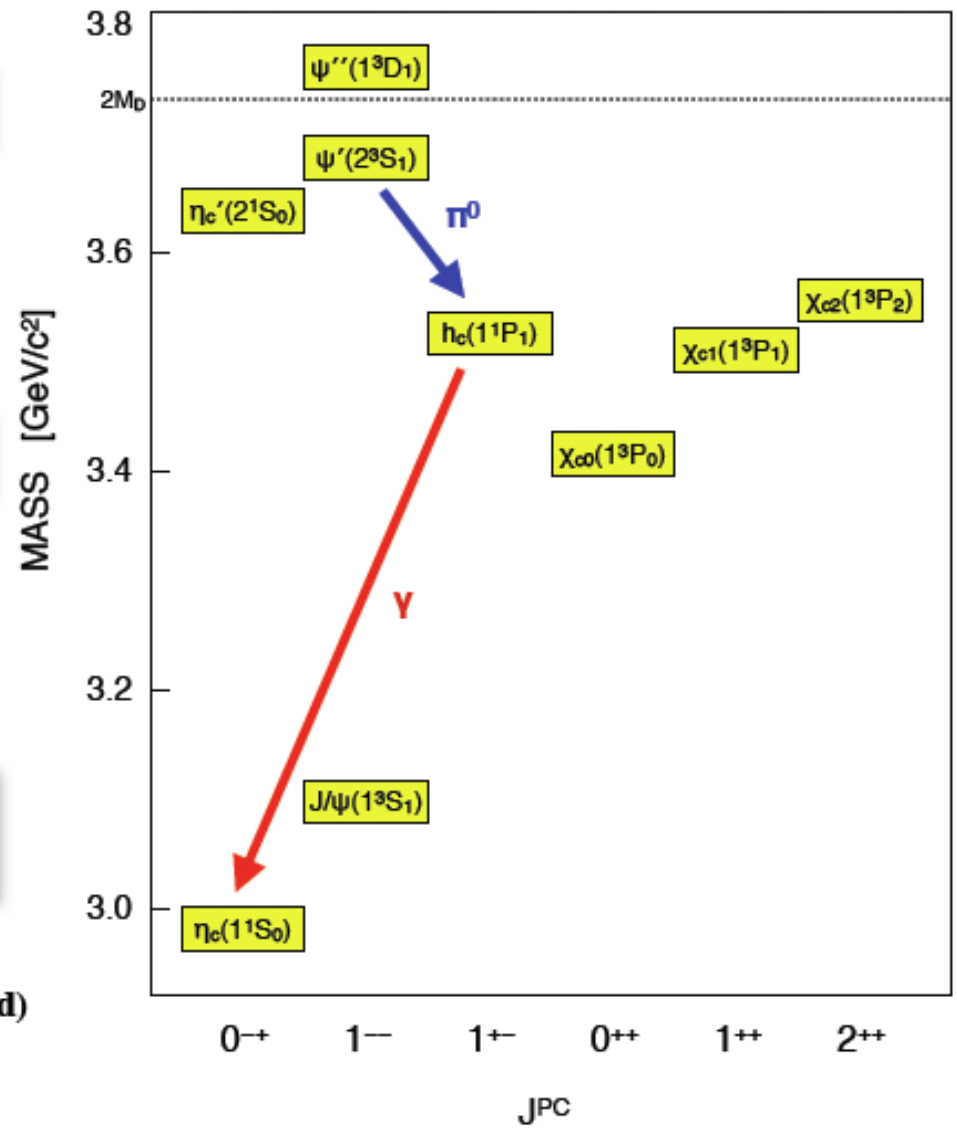
$$B(\Psi' \to \pi^\circ h_c)$$

Measure as well the E1 transition

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

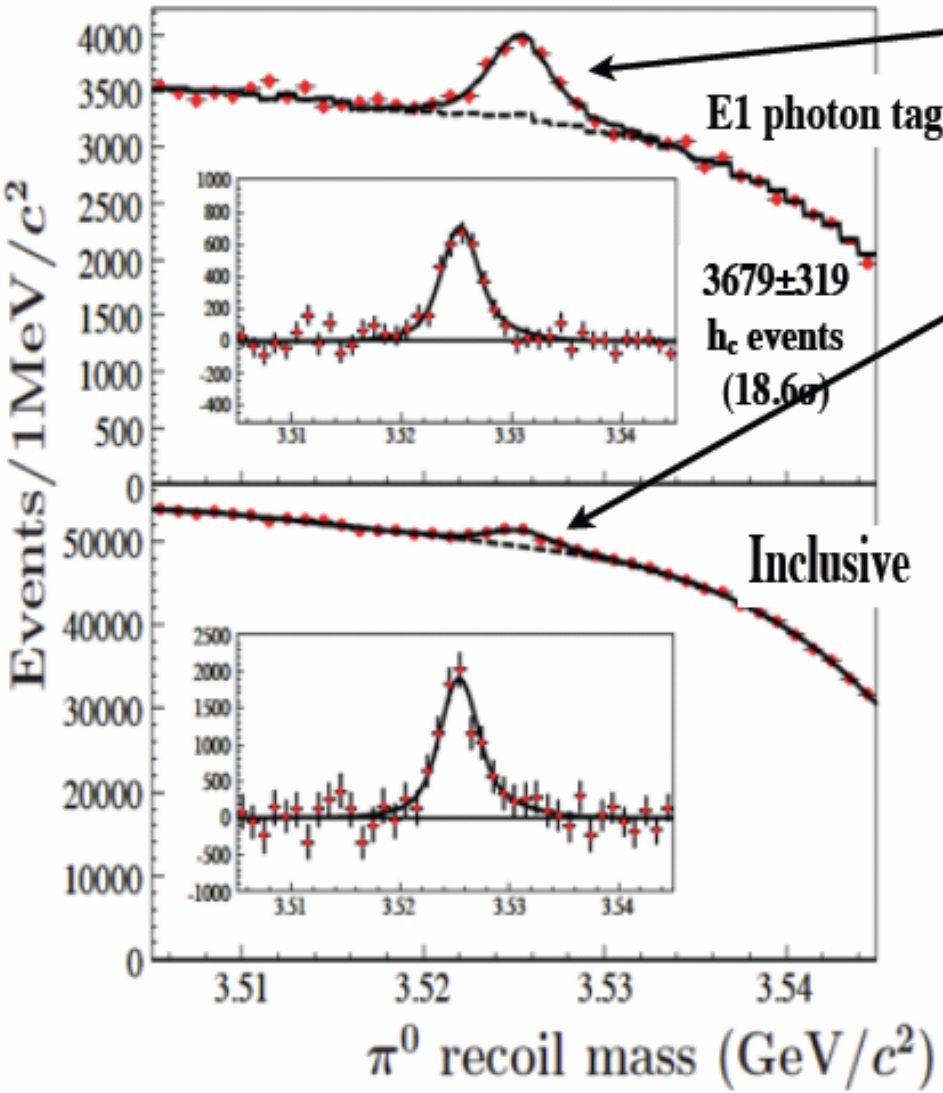
Hyperfine splitting of the 1P states (spin-spin interaction term):

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



Observation of h_c in inclusive reaction

PRL104, 132002 (2010)



Tag the E1 photon, yields:

$\psi(2S) \to \pi^0 h_c) \times B(h_c \to \gamma\eta_c)$
$= (4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$

(consistent with CLEO-c)

Inclusive analysis provides:

$B(\psi(2S) \to \pi^0 h_c)$ (first measurement)
$= (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$

Combining the two results:

$B(h_c \to \gamma\eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$

(first measurement)

Natural width of h_c:

$\Gamma(h_c) = 0.73 \pm 0.45 \pm 0.28\,\mathrm{MeV}/c^2$

(first measurement)

Hyperfine splitting:

$\Delta M_{hf} = -0.10 \pm 0.13 \pm 0.18\,\mathrm{MeV}/c^2$

(consistent with zero)

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

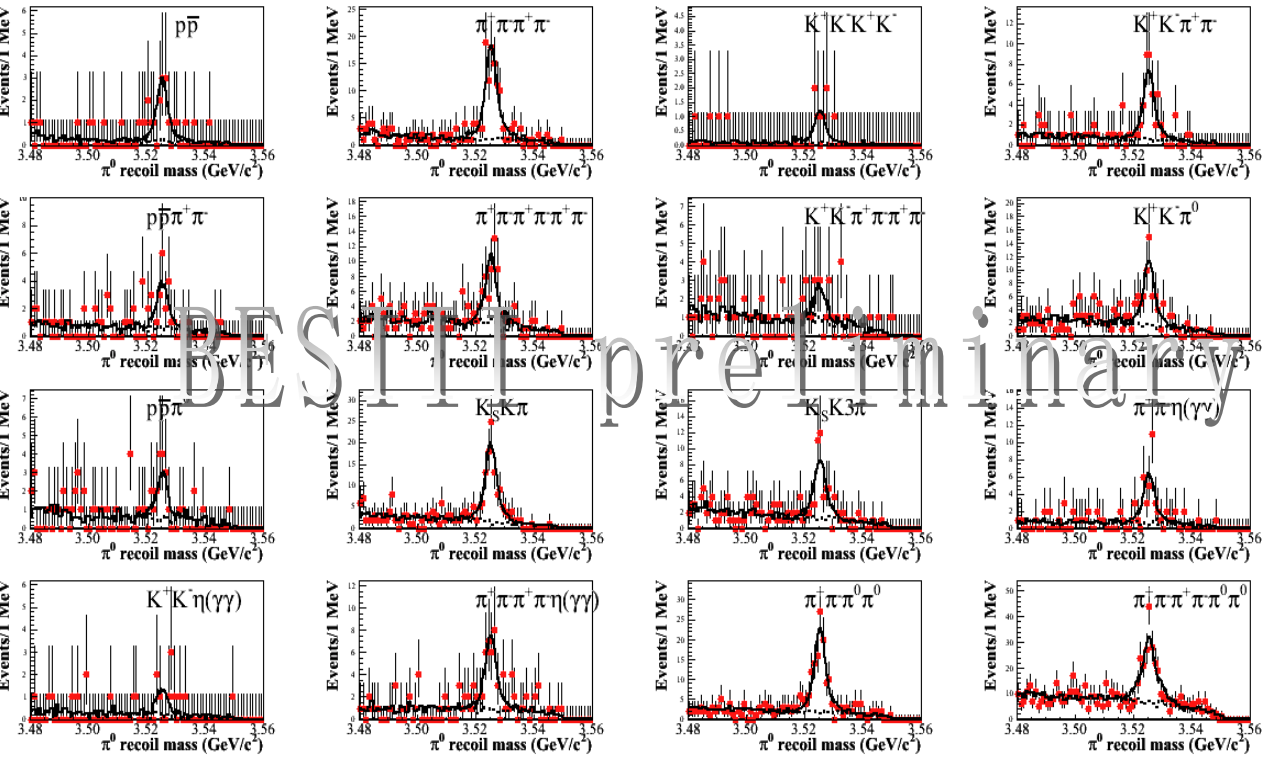
$\psi' \to \pi^0 h_C$, $h_C \to \gamma \eta_C$, η_C is reconstructed exclusively with 16 decay modes

16 Decay modes	$BR(\eta_c \to X)$
$\eta_c \to pp^-$	~0.13%
$\eta_c \to \pi^+\pi^- pp^-$	~0.45%
$\eta_c \to 2(\pi^+\pi^-)$	~1.20%
$\eta_c \to 2K^+2K^-$	~0.16%
$\eta_c \to \pi^+\pi^- k^+k^-$	~1.50%
$\eta_c \to 3(\pi^+\pi^-)$	~1.50%
$\eta_c \to K^+K^- 2(\pi^+\pi^-)$	~0.71%
$\eta_c \to k^+k^-\pi^0$	~1.17%
$\eta_c \to pp^{bar}\pi^0$	~0.18%
$\eta_c \to k_s kp;$	~2.33%
$\eta_c \to k_s k3\pi$	~2.40%
$\eta_c \to \pi^+\pi^-\eta;\ \eta \to \gamma\gamma$	~3.27%
$\eta_c \to k^+k^-\eta$	~0.57%
$\eta_c \to 2(\pi^+\pi^-)\eta$	~2.70%
$\eta_c \to \pi^+\pi^-\pi^0\pi^0$	~2.40%
$\eta_c \to 2(\pi^+\pi^-)\pi^0\pi^0$	~11.0%

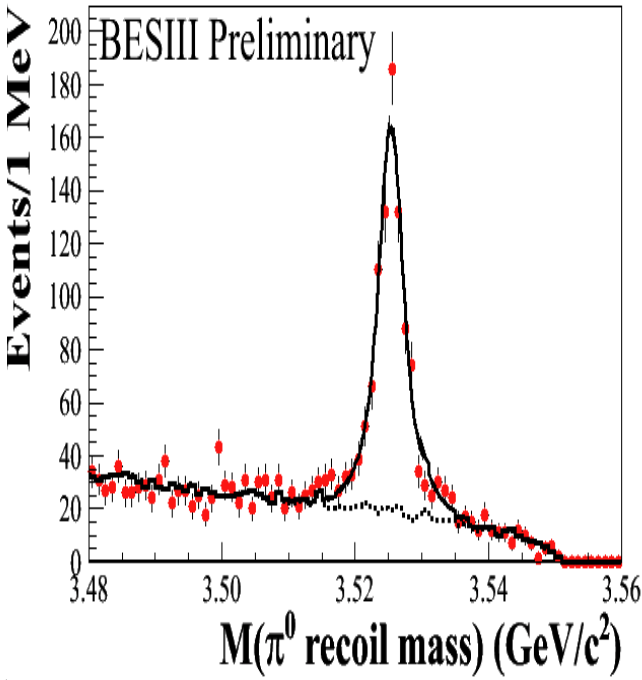
Black from PDG2010,
blue from estimation of $\psi' \to \gamma \eta_c$

For detail see Quarkonia session:
Liangliang Wang's talk on June 13

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



Sum of π^0 recoil mass

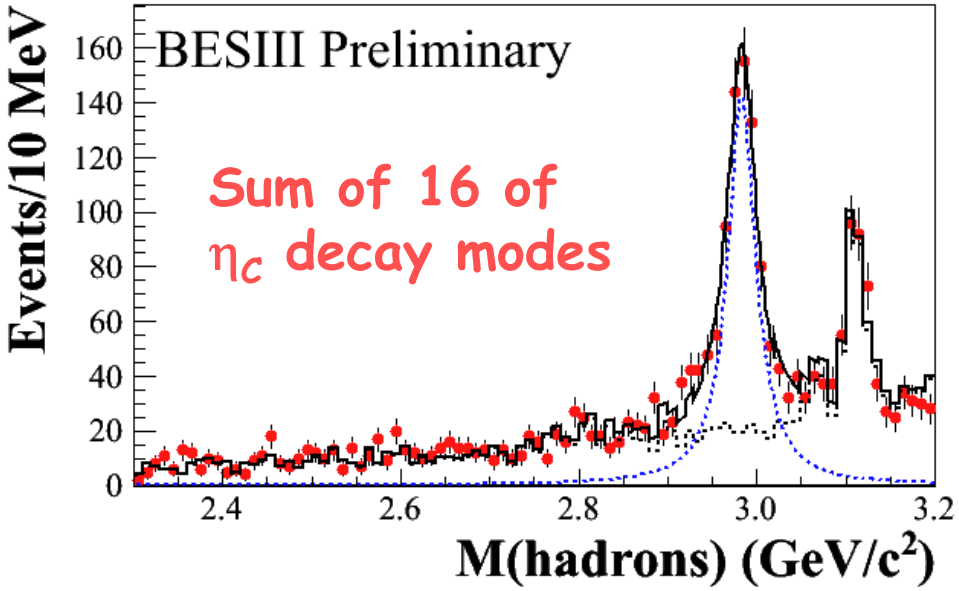


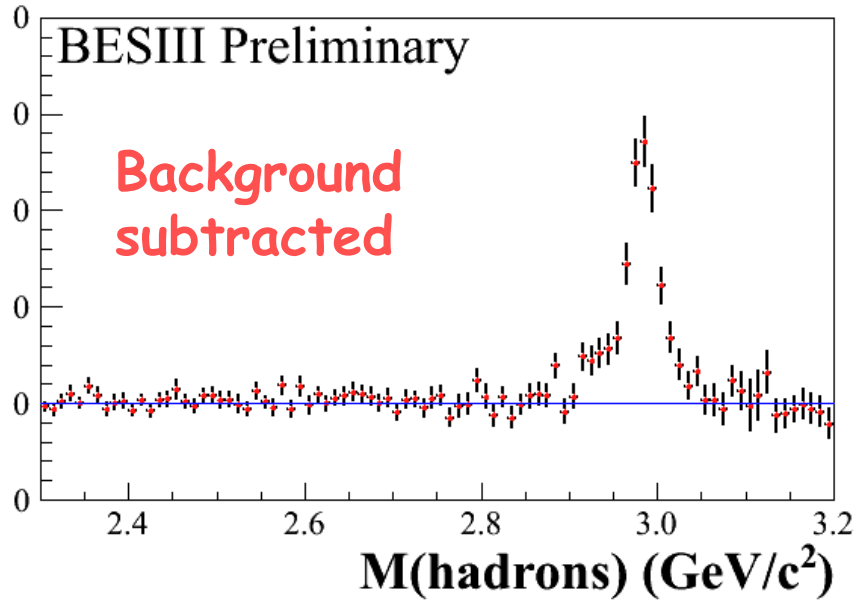
Simultaneous fit to π^0 recoiling mass in 106M ψ' sample (preliminary results):

$M(h_c) = 3525.31 \pm 0.11_{(stat)} \pm 0.15_{(sys)}$ MeV/c²
$\Gamma(h_c) = 0.70 \pm 0.28_{(stat)} \pm 0.25_{(sys)}$ MeV
N = 832±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/c²
N = 136±14
PRL101, 182003(2008)

η_c lineshape from $\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$

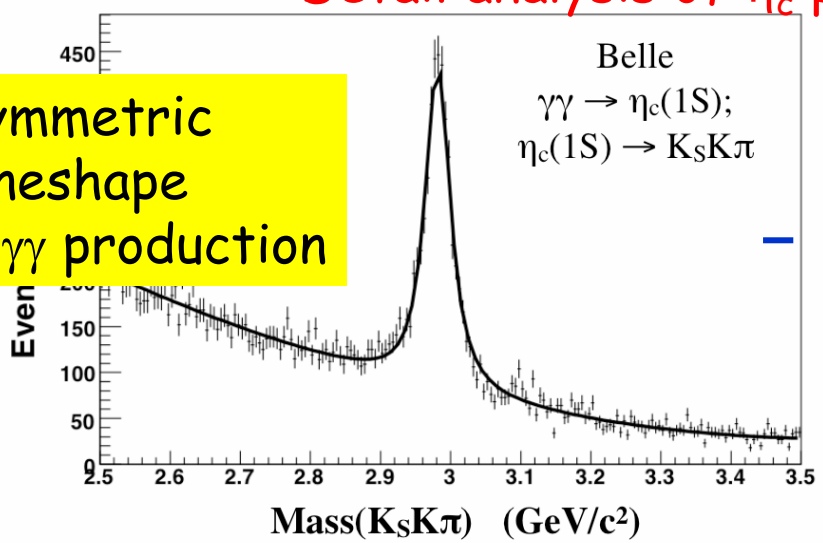


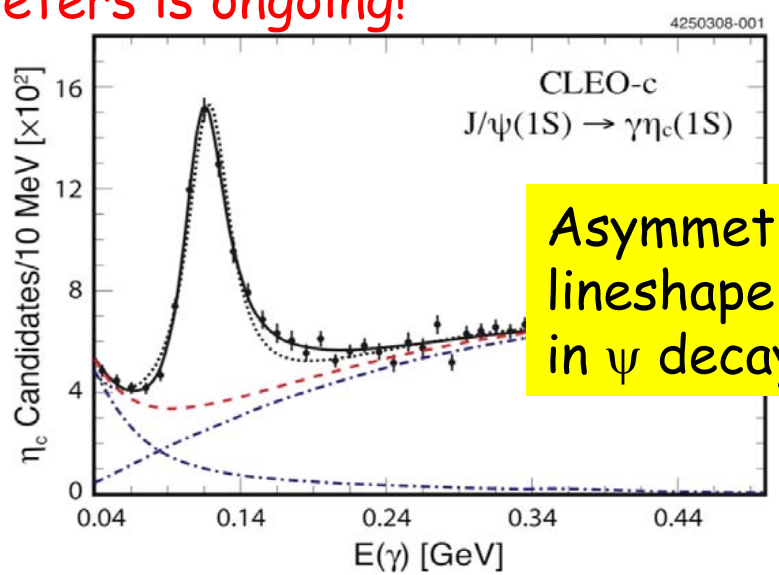


The η_c lineshape is not distorted in the $h_c \to \gamma\eta_c$

Detail analysis of η_c parameters is ongoing!

Symmetric lineshape in $\gamma\gamma$ production

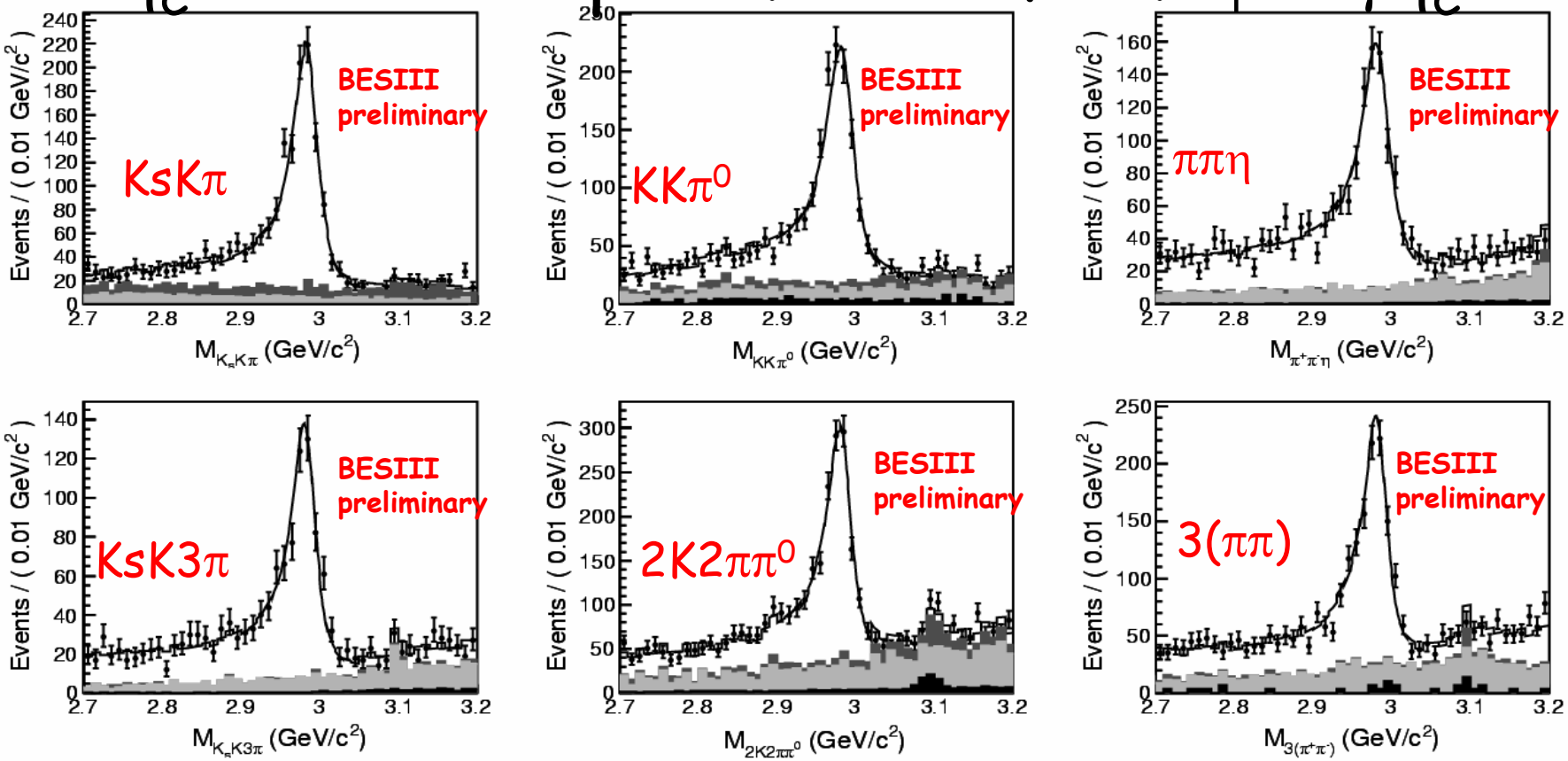




Asymmetric lineshape in ψ decay

ɔ Li (IH

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



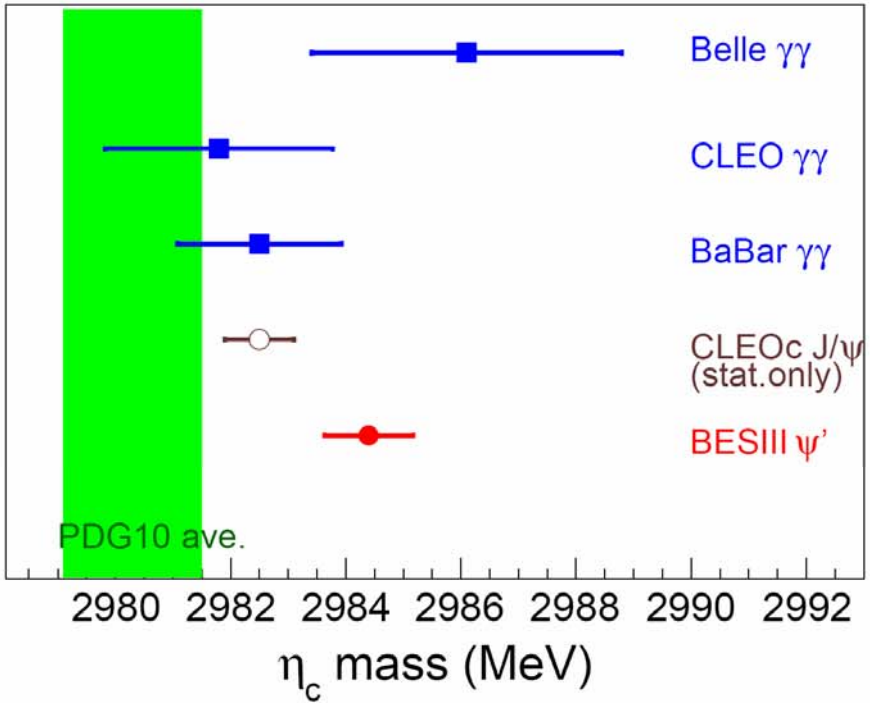
Simultaneous fit with r-BW by considering **the interference between η_c and non-η_c decays**, as well as the energy dependence of phase space:

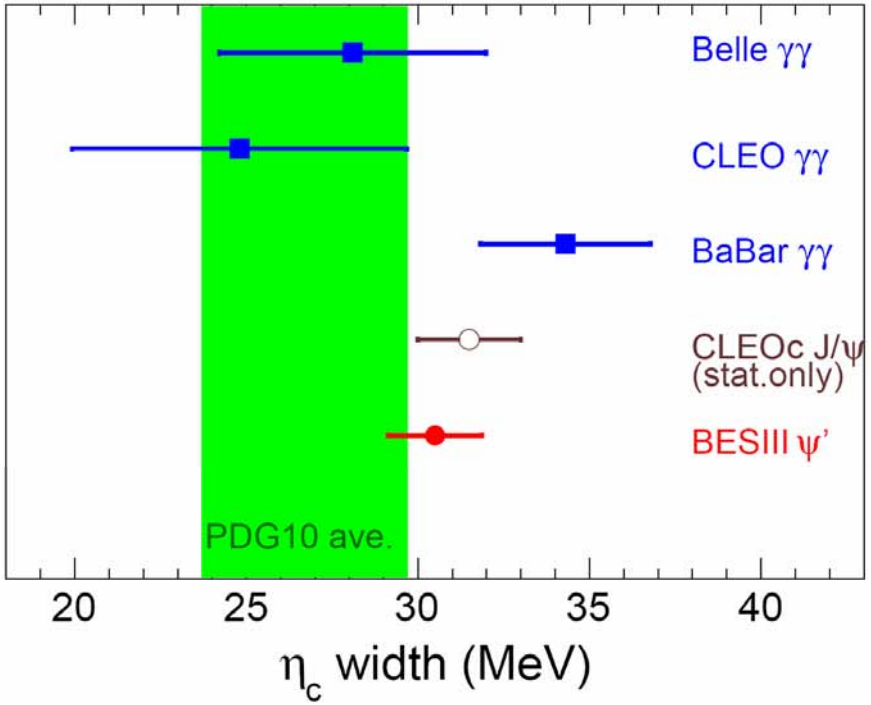
mass: $2984.4 \pm 0.5_{stat} \pm 0.6_{sys}$ MeV/c^2
width: $30.5 \pm 1.0_{stat} \pm 0.9_{sys}$ MeV
ϕ: $2.35 \pm 0.05_{stat} \pm 0.04_{sys}$ rad

ϕ: relative phase between η_c decay and non-resonant component under the signal region by assuming all non-η_c is 0^{-+}, and an universal phase for different modes is used.

Comparison of the mass and width for η_c

The world average in PDG2010 was using earlier results

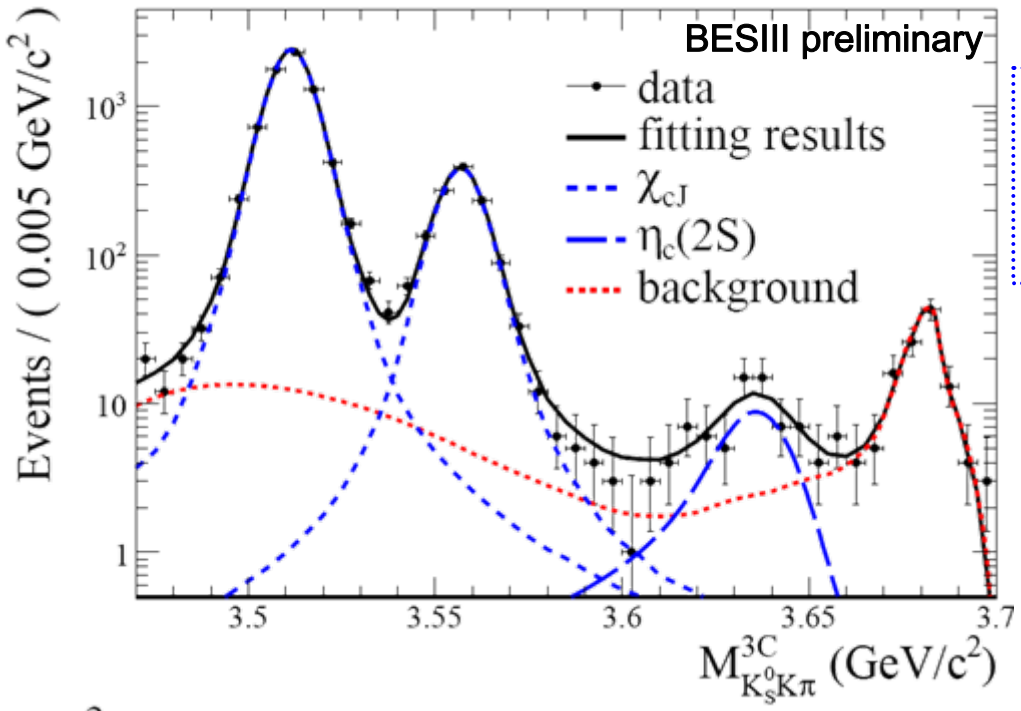




BESIII results include both stat. and syst. errors, which is the most precision measurement, the interference between η_c decay and non-resonance is important.

For detail see Quarkonia session on June 13:
Liangliang Wang

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



$$(E_\gamma^3 \times BW(m) \times damping(E_\gamma)) \otimes Gauss(0, \sigma)$$

M1 transition

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

$\Gamma(\eta_c(2S))$ fixed to 12MeV (world average)

With 106M ψ' events:

$M(\eta_c(2S)) = (3638.5 \pm 2.3 \pm 1.0)$ MeV/c^2
$N(\eta_c(2S)) = 50.6 \pm 9.7$
Statistical significance larger than 6.0σ!

$Br(\psi' \to \gamma\eta_c(2S) \to \gamma K_s K\pi)$
$= (2.98 \pm 0.57_{stat} \pm 0.48_{sys}) \times 10^{-6}$

+

$Br(\eta_c(2S) \to KK\pi) = (1.9 \pm 0.4 \pm 1.1)\%$
From BABAR(PRD78,012006)

$Br(\psi' \to \gamma\eta_c(2S))$
$= (4.7 \pm 0.9_{stat} \pm 3.0_{sys}) \times 10^{-4}$

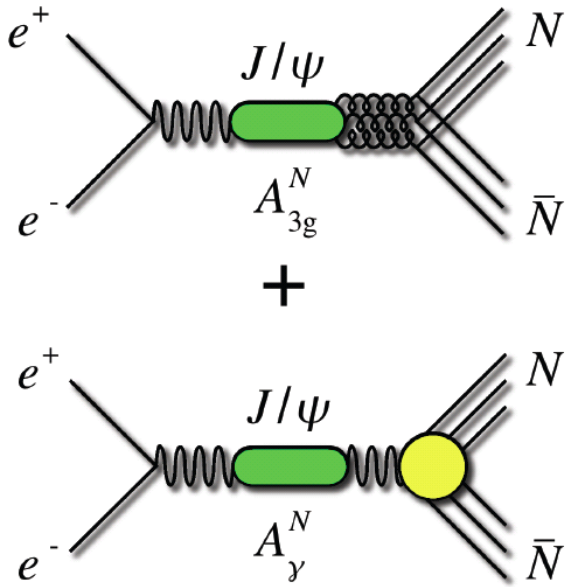
CLEO-c: $<7.6\times10^{-4}$ PRD81,052002(2010)

Potential model: $(0.1–6.2)\times10^{-4}$
PRL89,162002(2002)

For detail see Quarkonia session on June 13: Liangliang Wang

Measurement of $J/\psi \to p\bar{p}$, $n\bar{n}$

- $p\,\bar{p}$ amplitude A_γ^p from BABAR data
- $n\,\bar{n}$ amplitude A_γ^n from FENICE data
- $A_\gamma^p - A_\gamma^n$ relative phase from pQCD



$$B(J/\psi \to n\,\bar{n}) = \left| \frac{A_{3g} + A_\gamma^n}{A_{3g} + A_\gamma^p} \right|^2 B(J/\psi \to p\,\bar{p}) = (1.4 \pm 0.2) \times 10^{-3}$$

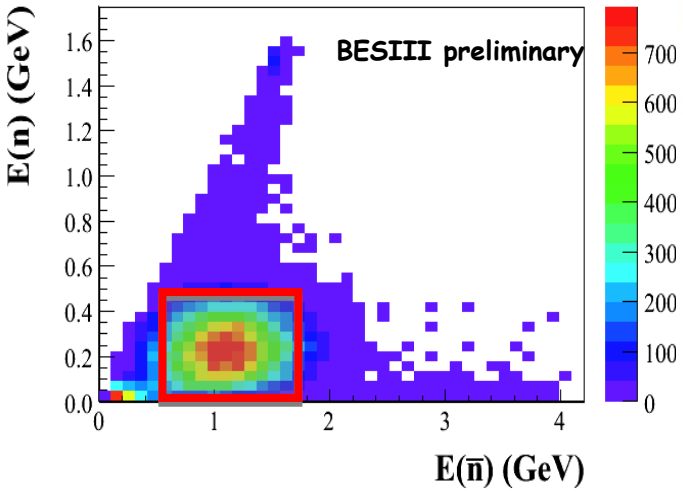
- **BESII at BEPC** [PLB591,42]: $BR(J/\psi \to p\,\bar{p}) = (2.26 \pm 0.01 \pm 0.14) \times 10^{-3}$
- **FENICE at ADONE** [PLB444,111]: $BR(J/\psi \to n\,\bar{n}) = (2.2 \pm 0.4) \times 10^{-3}$

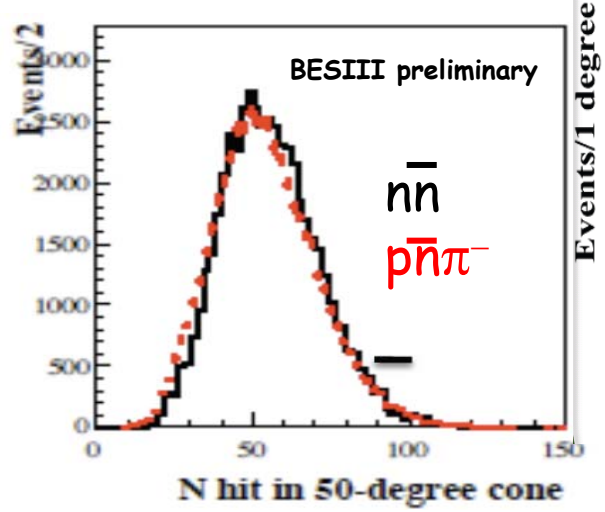
$B(J/\psi \to p\,\bar{p}) \sim B(J/\psi \to n\,\bar{n}) \Rightarrow$ large $A_{3g}^N - A_\gamma^N$ relative phase?

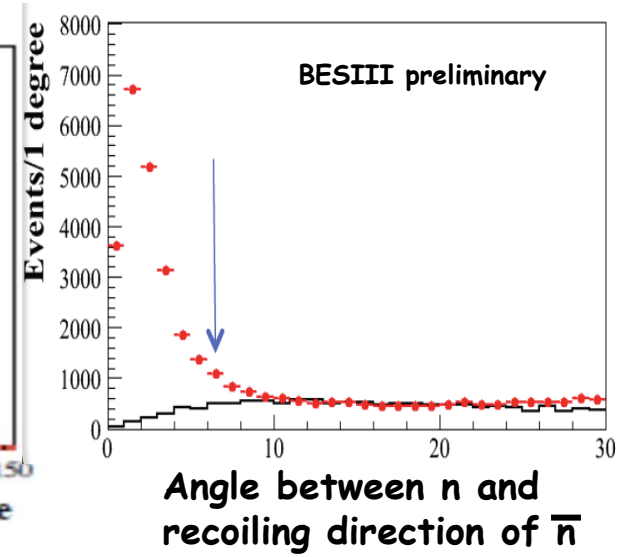
With 2.2 million J/ψ at BESIII, with help of EMC, we can access neutron-anti-neutron final states

Preliminary results: $J/\psi \to p\bar{p}$, $n\bar{n}$

Anti-neutron identifications:







EMC energy deposit: 0.6<E(anti-neutron)<2.0 GeV
Comparison for anti-neutron in $J/\psi \to n\bar{n}$ and $p\bar{n}\pi^-$
Angle between n and recoiling direction of $\bar{n}$

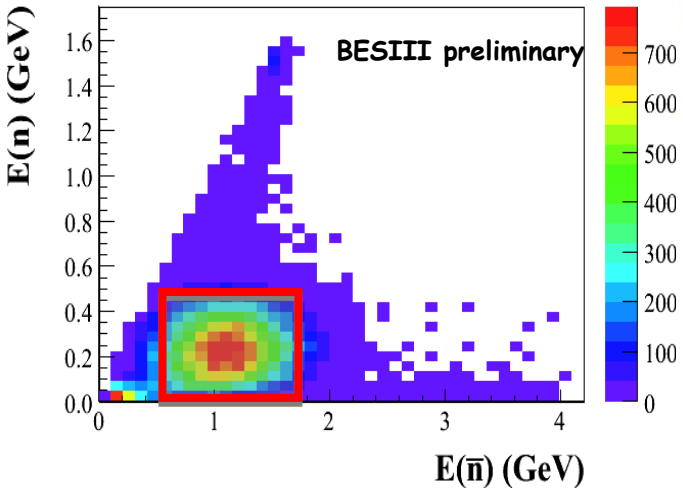
$Br(J/\psi \to p\bar{p}) = (2.112 \pm 0.004 \pm 0.027) \times 10^{-3}$
PDG: $Br(J/\psi \to p\bar{p}) = (2.17 \pm 0.07) \times 10^{-3}$

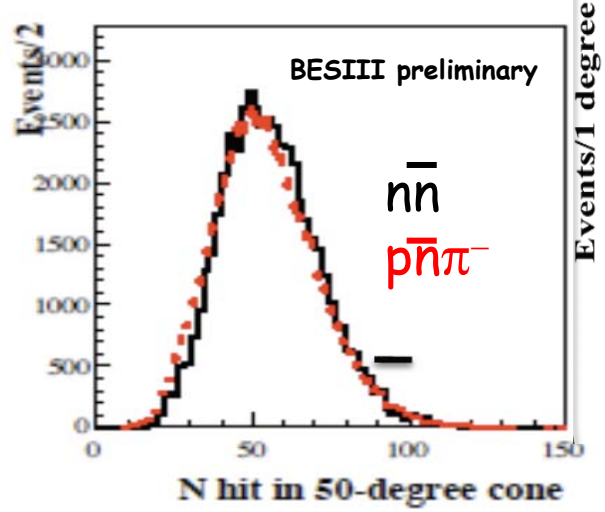
$Br(J/\psi \to n\bar{n}) = (2.07 \pm 0.01 \pm 0.14) \times 10^{-3}$
PDG: $Br(J/\psi \to n\bar{n}) = (2.2 \pm 0.4) \times 10^{-3}$

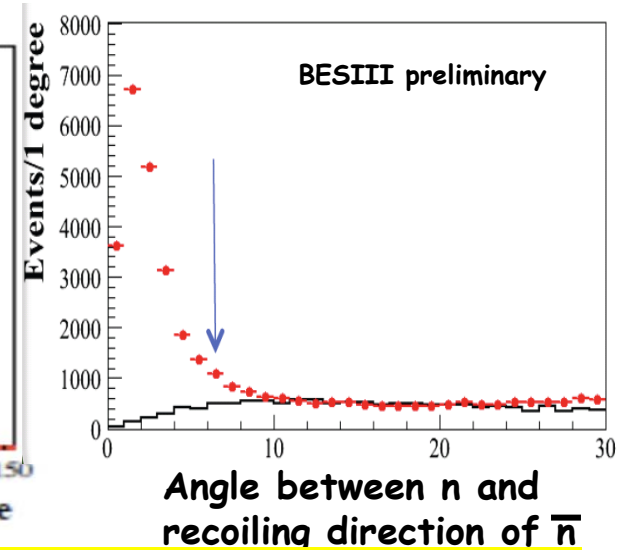
$Br(J/\psi \to p\bar{p}) \sim Br(J/\psi \to n\bar{n})$ suggests a large angle (~90^0) between strong and EM amplitudes!

Preliminary results: $J/\psi \to p\bar{p}$, $n\bar{n}$

Anti-neutron identifications:







EMC energy deposit: 0.6
Comparison for anti-neu
Angle between n and re

This technique tells us that we can measure neutron-antineutron cross section between 2.0-4.0 GeV by using scan data, which is important.
See MAGGIORA, Marco in Quarkonia session on June 13

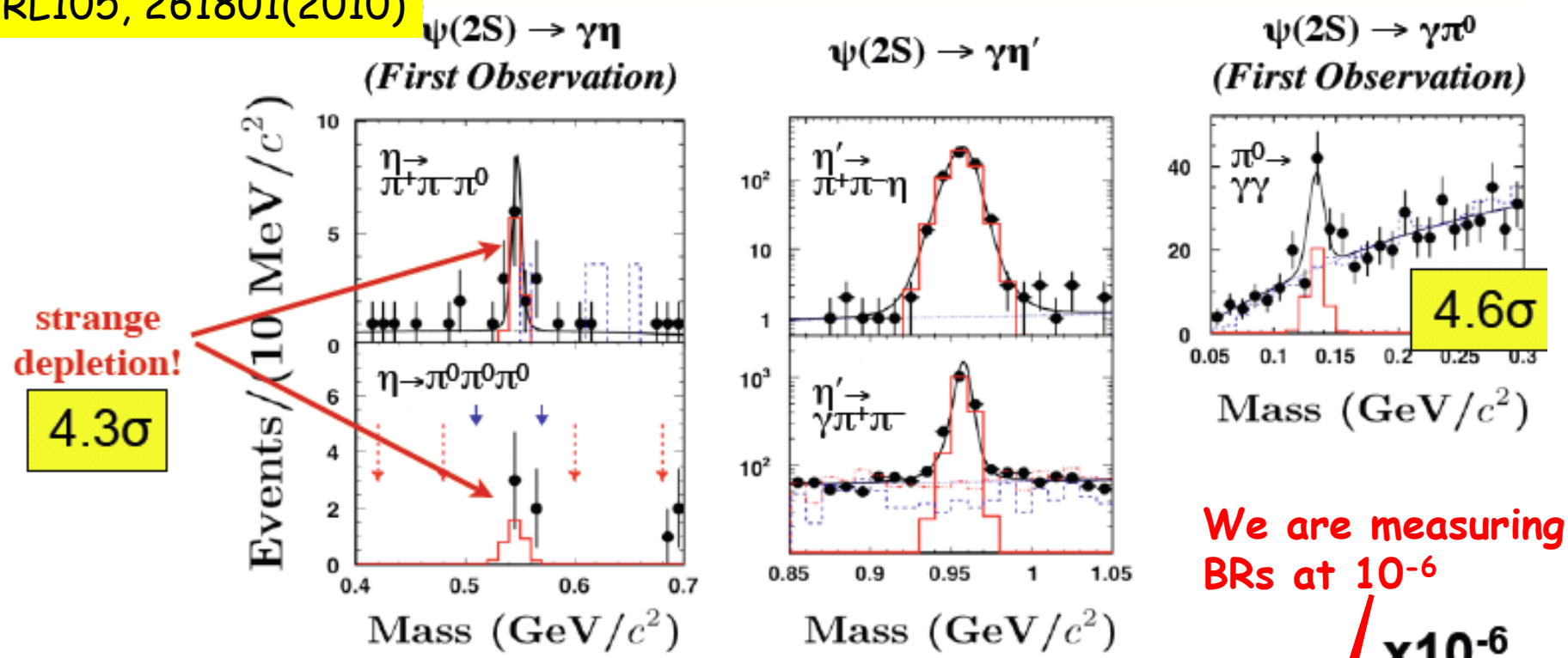
$Br(J/\psi \to p\bar{p})$ = (2.112±0
PDG: $Br(J/\psi \to p\bar{p})$ = (2.

$Br(J/\psi \to n\bar{n})$ = $(2.07 \pm 0.01 \pm 0.14) \times 10^{-3}$
PDG: $Br(J/\psi \to n\bar{n})$ = $(2.2 \pm 0.4) \times 10^{-3}$

suggests a large angle (~90°) between strong and EM amplitudes!

Evidence for ψ' decays into $\gamma\pi$ and $\gamma\eta$

PRL105, 261801(2010)



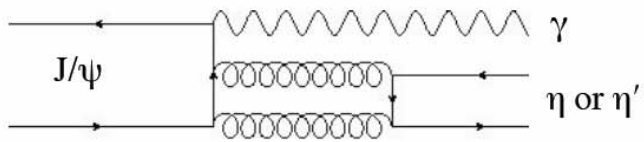
We are measuring BRs at 10^{-6}

x10^{-6}

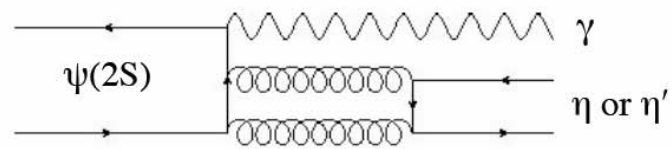
BR $[10^{-6}]$	BESIII	Combined BESIII	PDG10
$\psi' \to \gamma\pi^0$	$1.58 \pm 0.40 \pm 0.13$	$1.58 \pm 0.40 \pm 0.13$	≤ 5
$\psi' \to \gamma\eta(\pi^+\pi^+\pi^0)$	$1.78 \pm 0.72 \pm 0.17$		
$\psi' \to \gamma\eta(\pi^0\pi^0\pi^0)$	$1.07 \pm 0.65 \pm 0.08$	$1.38 \pm 0.48 \pm 0.09$	≤ 2
$\psi' \to \gamma\eta'_{(958)}(\pi^+\pi^+\eta)$	$120 \pm 5 \pm 8$		
$\psi' \to \gamma\eta'_{(958)}(\pi^+\pi^+\gamma)$	$129 \pm 3 \pm 8$	$126 \pm 3 \pm 8$	121 ± 8

Some surprises

PRL105, 261801(2010)



VS



Theory

$$R_{(c\bar{c})} = \frac{Br((c\bar{c})\to\gamma\eta)}{Br((c\bar{c})\to\gamma\eta')}$$

LO-pQCD

$\Downarrow$

$$R_{\psi'} \simeq R_{J/\psi}$$

PRP 112,173 (1984)

Experiment

CLEO-c

PRD79, 111101 (2009)

$$R_{J/\Psi} = \frac{B(J/\psi\to\gamma\eta)}{B(J/\psi\to\gamma\eta')} = (21.1 \pm 0.9)\ \%$$

(consistent with other measurements of η-η′ mixing angle and LO-pQCD)

BESIII

$$R_{\Psi'} = \frac{B(\psi(2S)\to\gamma\eta)}{B(\psi(2S)\to\gamma\eta')} = (1.10 \pm 0.38 \pm 0.07)\ \%$$

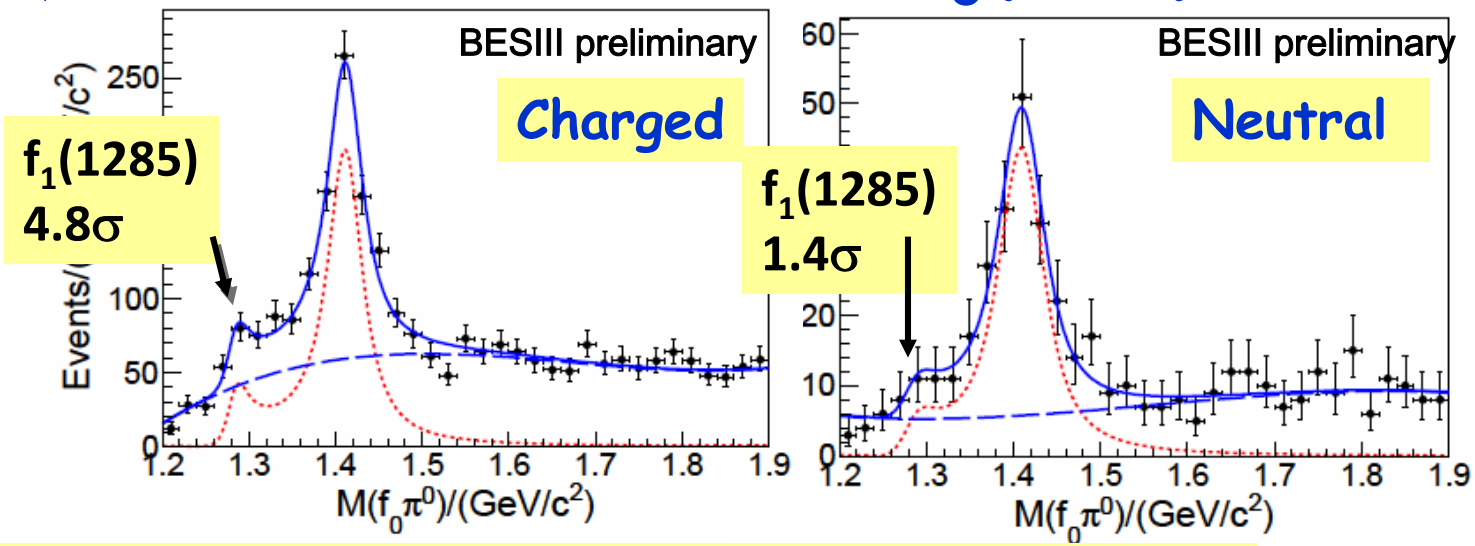
(consistent with upper limit from CLEO-c)

$\Rightarrow$ $R_{\psi'} << R_{J/\psi}$

Difference?: Other processes contributing? Related to ρπ puzzle, ... ??

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

Changed:
$f0(980) \to \pi^+\pi^-$
Neutral
$f0(980) \to \pi^0\pi^0$



Helicity analysis indicates that peak at 1400MeV is from $\eta(1405) \to f_0(980)\pi^0$ not from $f_1(1420)$:

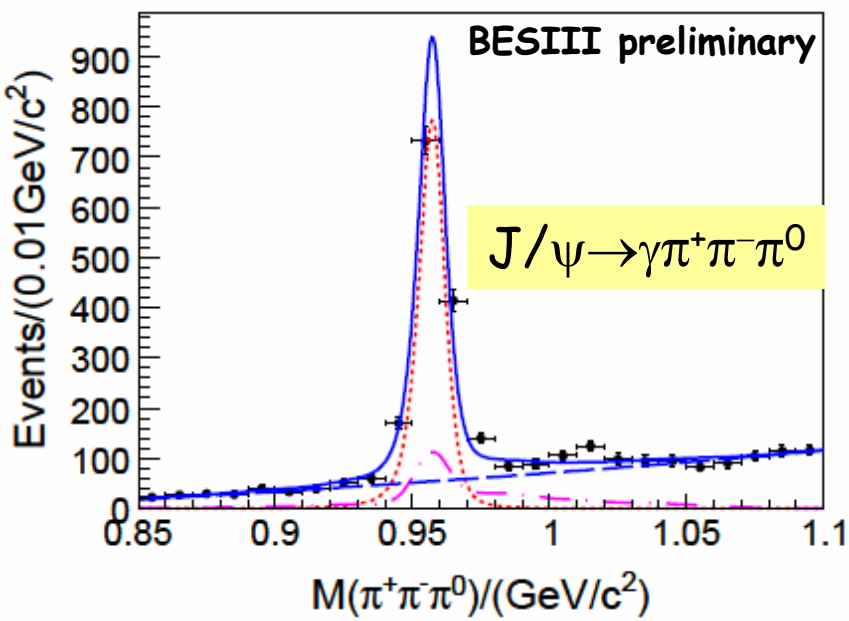
First observation of $\eta(1405) \to f_0(980)\pi^0$ (isospin violated decays) and $J/\psi \to \gamma f_0(980)\pi^0$

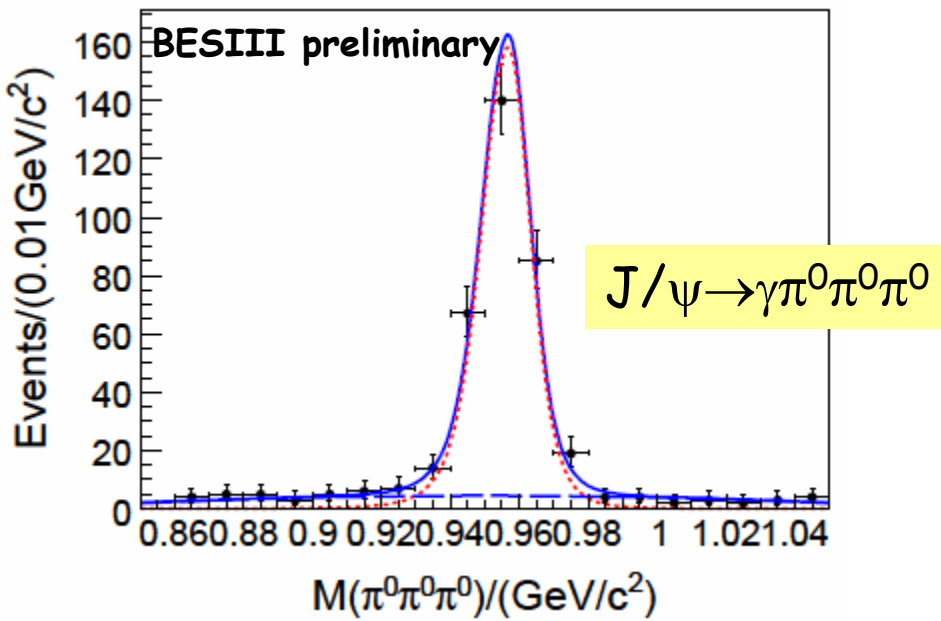
Preliminary results:

$$Br(J/\psi \to \gamma\eta(1405) \to \gamma f_0\pi^0 \to \gamma\pi^0\pi^+\pi^-) = (1.48 \pm 0.13(stat.) \pm 0.17(sys.)) \times 10^{-5}$$

$$Br(J/\psi \to \gamma\eta(1405) \to \gamma f_0\pi^0 \to \gamma\pi^0\pi^0\pi^0) = (6.99 \pm 0.93(stat.) \pm 0.95(sys.)) \times 10^{-6}$$

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





Preliminary results:

$$Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15(stat.) \pm 0.39(sys.)) \times 10^{-3}$$

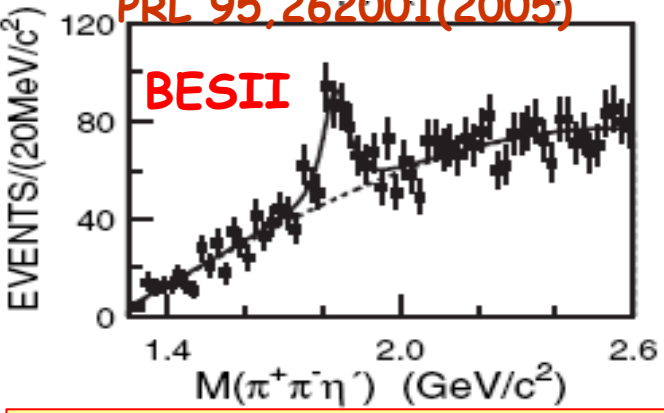
PDG2010: $(3.6^{+1.1}_{-0.9})\times 10^{-3}$ **(2009 CLEO-c)**

$$Br(\eta' \to 3\pi^0) = (3.56 \pm 0.22(stat.) \pm 0.34(sys.)) \times 10^{-3}$$

PDG2010: $(1.68\pm 0.22)\times 10^{-3}$ (1984: GAM2)

Confirmation of X(1835) and two new structures

PRL 95,262001(2005)

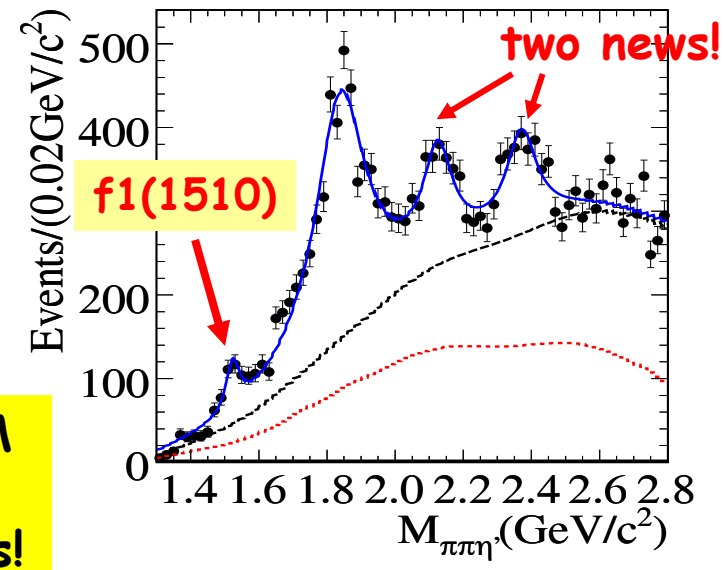


$J/\psi \to \gamma\eta'\pi^+\pi^-$

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

$\eta' \to \gamma\rho$

PRL 106, 072002(2011)



BESII result (Stat. sig. ~ 7.7σ):

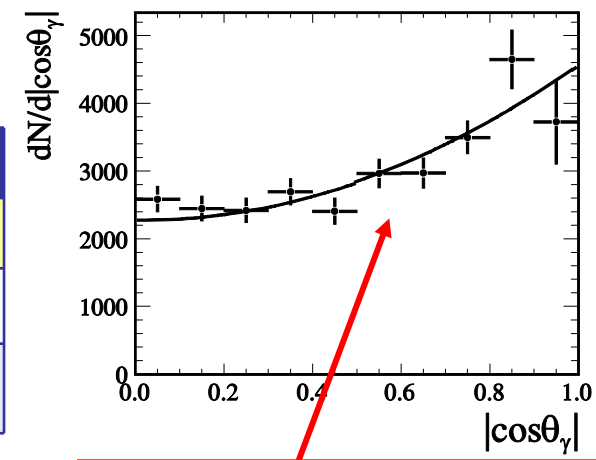
$M = 1833.7 \pm 6.1(stat) \pm 2.7(syst) MeV$

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

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

BESIII fit results:

Resonance	M(MeV/c²)	Γ(MeV/c²)	Stat.Sig.
X(1835)	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190.1 \pm 9.0^{+38}_{-36}$	>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

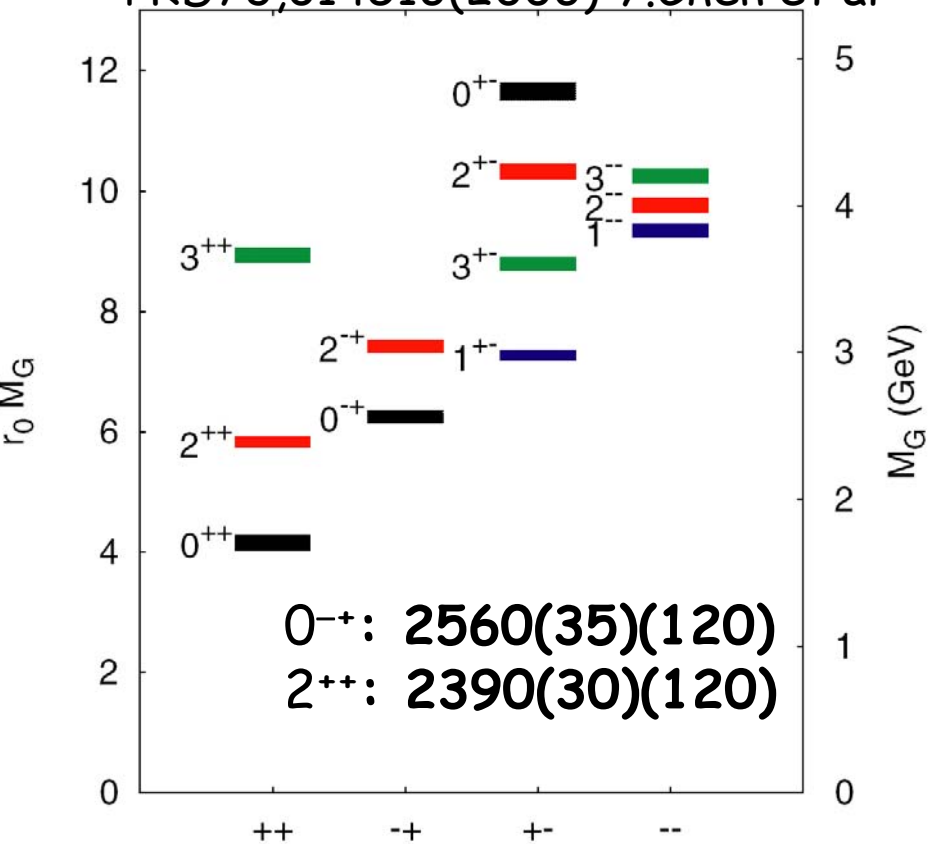


X(1835) consistent with 0^{-+}, but the others are not excluded

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

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/c^2 region, it is interesting since:

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

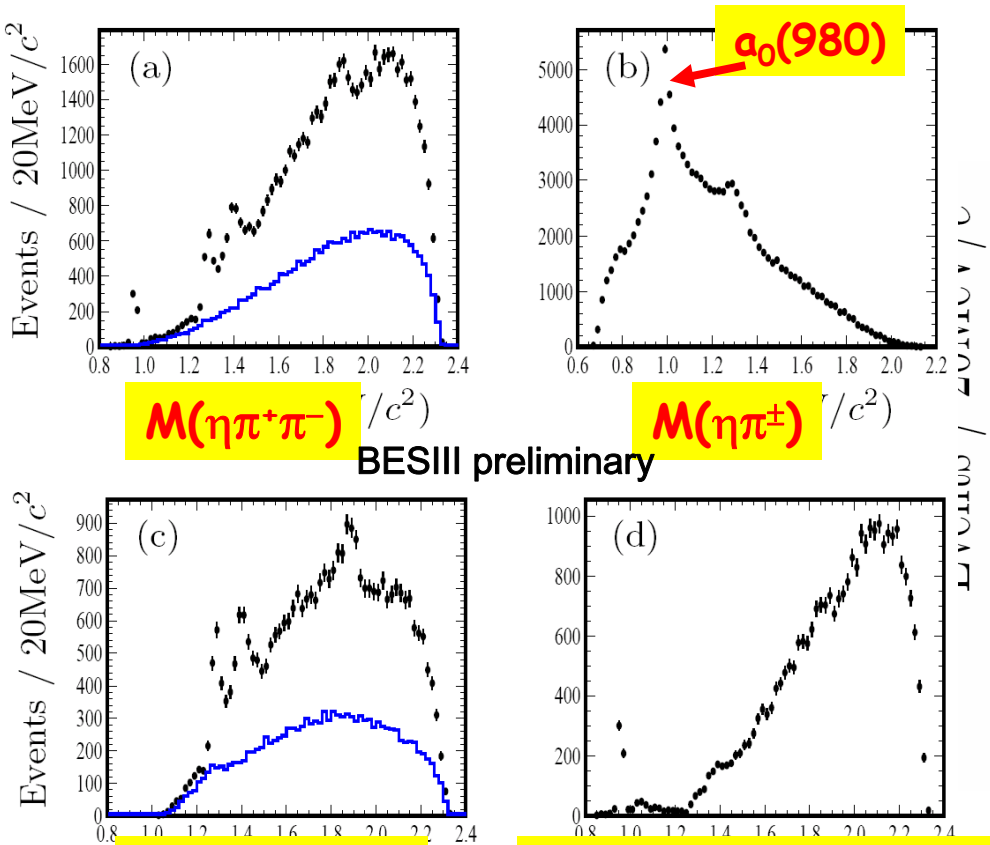
$J/\psi \to \gamma\pi\pi\eta'$ decay is a good channel for finding 0^{-+} glueballs.

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

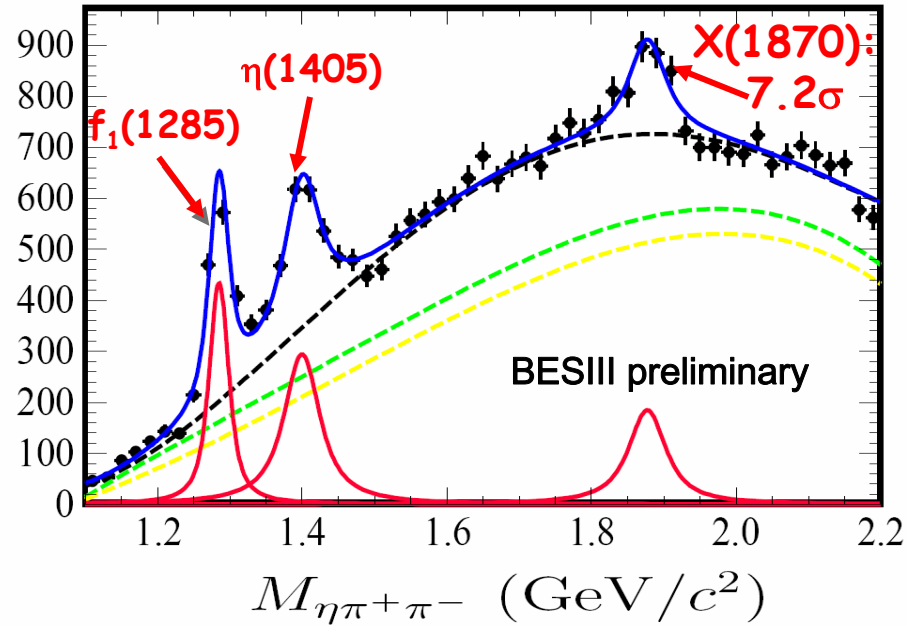
PRD82,074026,2010
J.F. Liu, G.J. Ding and M.L.Yan
PRD**83:114007,2011**
(J.S. Yu, Z.-F. Sun, X. Liu, Q. zhao),
and more…

For detail see Light meson session:
Hongwei Liu's talk on June 17

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 $\eta\pi^\pm$

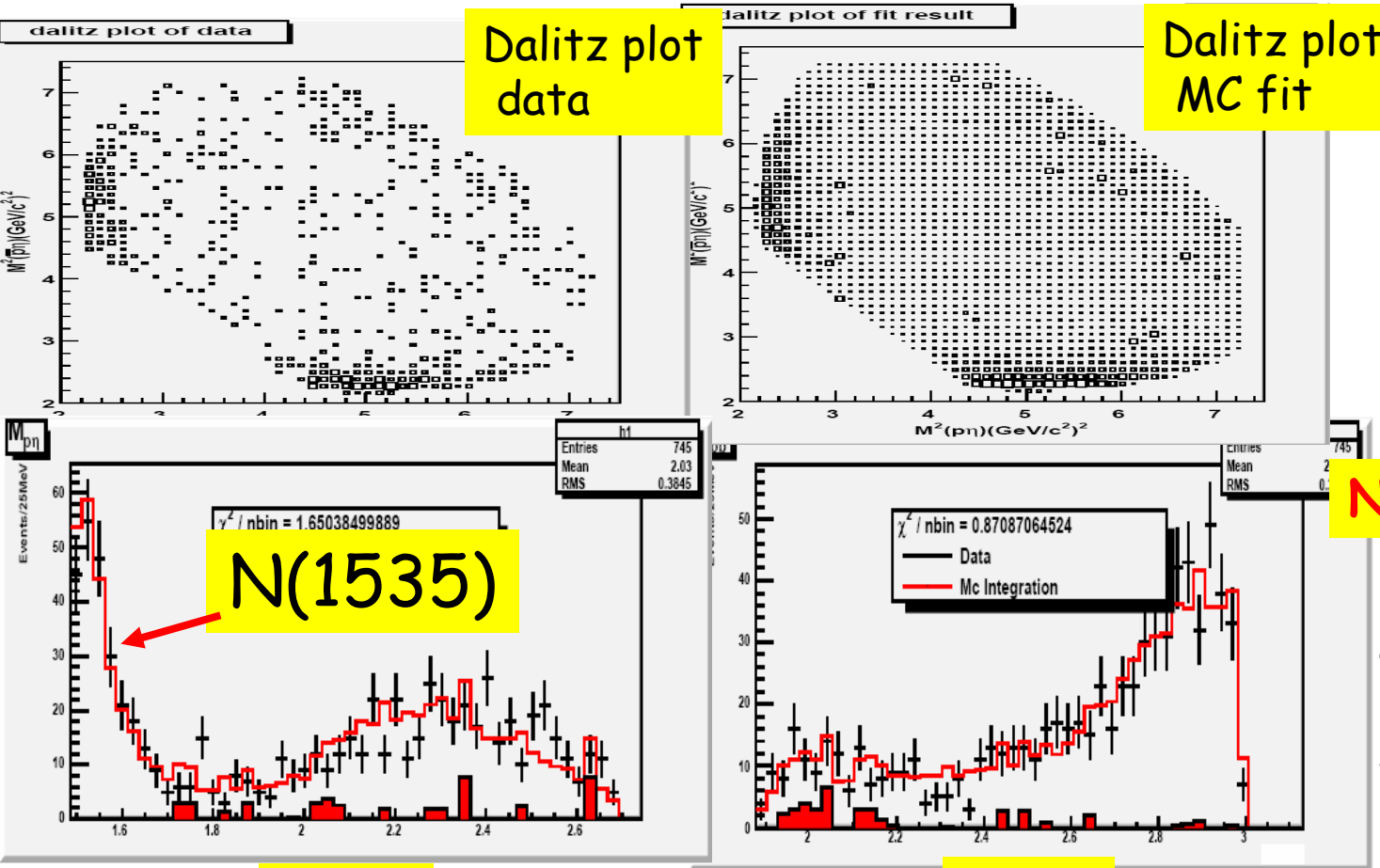


Identification of X(1870): 0^{-+}(?)
It is X(1835)? Need PWA!

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

Preliminary results on N* baryon in $\psi' \to \eta p\bar{p}$ decay



A full PWA analysis performed selected in 106 M ψ' events Background clean!

N(1535) is $1/2^-$

Mass:

$1.524^{+0.005+0.010}_{-0.005-0.004}$ GeV/C²

Width:

$0.130^{+0.027+0.061}_{-0.027-0.014}$ GeV

$Br(\psi' \to pp\eta) = (6.6 \pm 0.2 \pm 0.6) \times 10^{-5}$

PDG2010: $(6 \pm 1.2) \times 10^{-5}$

$Br(\psi' \to N(1535)p) \times Br(N(1535) \to p\eta + c.c.)$

$= 5.5^{+0.3+7.4}_{-0.3-1.1} \times 10^{-5}$

Running plan

- **The luminosity of BEPCII is better than expected.**
- **Data taking for open charm:**
  - **$\psi(3770)$: 2.9 fb^{-1} (2010 and 2011)**
  - **4010 MeV : 0.5 fb^{-1} in May 2011 for Ds physics and XYZ**

Year	Running
2012	J/ ψ: 1 billion / $\psi(2S)$: 0.5 billion (approved)
2013	4170 MeV: Ds decay + R scan (E > 4 GeV)
2014	$\psi(2S)/\tau$ / R scan (E > 4 GeV)
2015	$\psi(3770)$: 5-10 fb^{-1} (our final goal)

Red: be approved by BESIII Collaboration

Prospect of charm physics at BESIII

Advantage of open charm at threshold

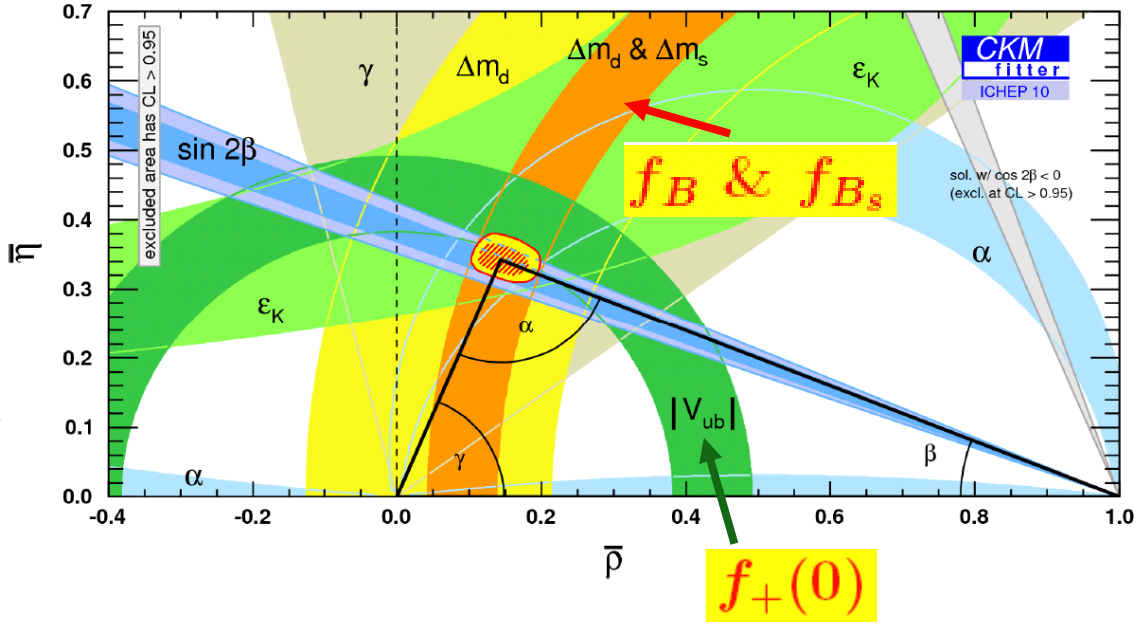
e^+e^- Colliders@threshold: CLEO-c, BESIII, Super-tau-charm

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

Charm role in flavor physics



Theoretical errors dominate width of bands

$|V_{ub}|$ from $B \to \pi \ell \nu$:

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{ub}|^2 p_\pi^3 |f_+(q^2)|^2$$

Form factor $f(q^2)$:

- Hard to calculate
- Limits $|V_{ub}|$ precision
- Lattice QCD can do from first principles

precision QCD calculations tested with *precision* charm data at threshold

➔theory errors of a few % on B system decay constants & semileptonic form factors

Charm decay measurements

decay constants

form factors

V_{CKM} clean extraction

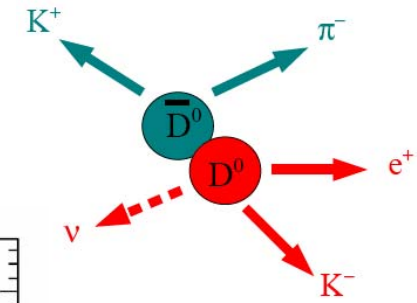
validate QCD.

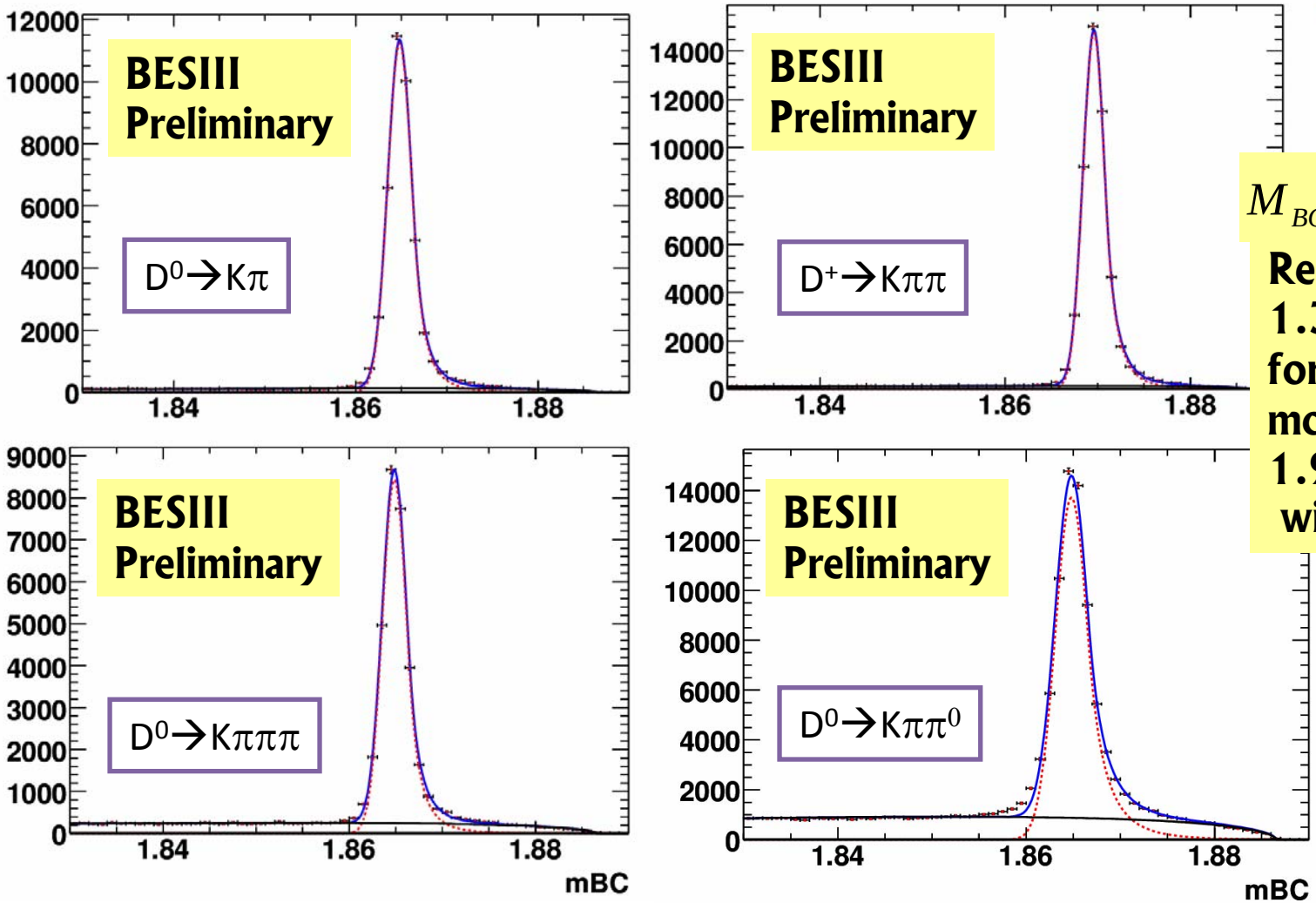
over-constrain V_{CKM}

Inconsistency → New Physics

Clean single tag at BESIII

@ψ(3770) with 420pb^{-1} first clean single tagging sample:





$$M_{BC} = \sqrt{E_{beam}^2 - |p_D|^2}$$

Resolution:
1.3 MeV for pure charged modes;
1.9 MeV for modes with one π^0.

Prospects for Charm at BESIII

Look for the size of the statistics/systematic/FSR errors for precision measurements at BESIII after CLEO-c.

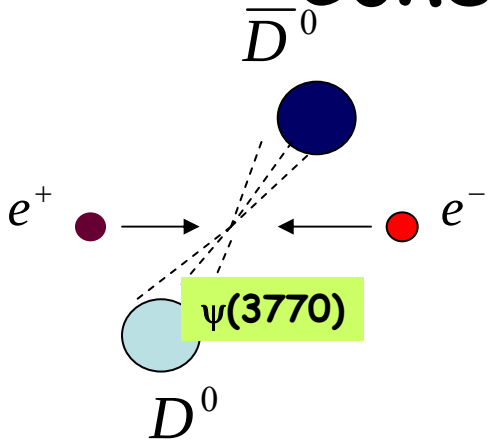
CLEO-c errors for D^0 /D^+ physics with 818 pb^{-1}@3770		BESIII ($5fb^{-1}$)
f_{D+} ($D^+ \to \mu^+ \nu$):	±4.1% (stat.) ± 1.2% (sys.)	±2.0% (stat.)
$f_\pi(0)$ ($D^0 \to \pi l \nu$):	±5.3% (stat.) ± 0.7%(sys.)	±2.3% (stat.)
BR($D^0 \to K \pi$):	±0.9% (stat.) ± 1.8%(sys.)	limited by sys.
BR($D^+ \to K \pi \pi$):	±1.1% (stat.) ± 2.0%(sys.)	limited by sys.

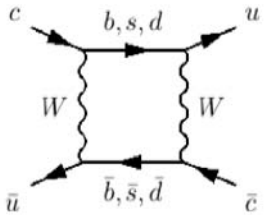
CLEO-c errors for Ds physics with 600pb^{-1}@4170 MeV		
f_{Ds} ($Ds^+ \to \mu^+ \nu, \tau \nu$):	±2.5% (stat.) ± 1.2% (sys.)	±0.8% (stat.)
BR($Ds^+ \to KK \pi$):	±4.2% (stat.) ± 2.9%(sys.)	±2.0% (stat.)

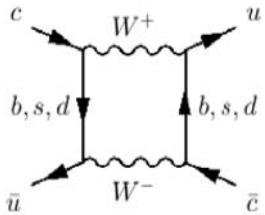
For Ds physics, BESIII are taking data at both 4010 and 4170 MeV:
4010 MeV (clean single tag, lower cross section 0.3 nb) → BESIII 0.5 fb^{-1}
4170MeV (dirty single tag, maximum cross section 0.9 nb) → CLEO-c 0.6 fb^{-1}

Significant gains will be made with increased luminosity at BESIII.

Coherence physics @threshold







$$x \equiv \frac{\Delta m}{\Gamma} = \frac{m_2 - m_1}{\Gamma}$$

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

$$\Gamma = \frac{\Gamma_1 + \Gamma_2}{2}$$

For coherent process:

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

The initial state C=-1

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

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

The coherent amplitude

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

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

~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 $D^0 \to K_S h^+h^-$ will be reduced to less than 1^0.
- ✓ CP violation in D sector : 10^{-3}

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$< 4.3\times10^{-7}$
  - $D \to X_u l^+ l^-$ 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} @ψ(3770)
BESIII will provide 10^{-7} -10^{-8} sensitivity.

Conclusion

- Huge data samples collected for Charmonium decays at BESIII
- The first observation of $\eta_c(2S)$ in $\psi' \to \gamma\eta_c(2S)$ decay
- Precision measurements of $\eta_c(1S)$ parameters in $\psi' \to \gamma\eta_c(1S)$
- Confirmation of X(1835) in $J/\psi \to \gamma\eta'\pi^+\pi^-$,
- Observation of two new structures X(2120) and X(2370) in $J/\psi \to \gamma\pi\pi\eta'$ decays
- Observation of new structure X(1870) in $J/\psi \to \omega\pi\pi\eta$
- Charm near threshold undertake complementary studies of D mixing and CPV, and unique test of QCD techniques
- We expect rich physics results in the coming years from BESIII.

After 36 years of discovery,
Charm is still charming!

Thanks !

Back up slides

Preliminary: relative phase between η_c decays and non-η_c background

mode	yield	ϕ_i (stat.)	χ^2/ dof
$K_S K\pi$	880.4	2.9±0.3	1.1
$KK\pi^0$	948.4	2.4±0.4	0.9
$\pi\pi\eta$	573.4	2.2±0.2	1.2
$K_S K3\pi$	432.3	2.3±0.2	0.7
$2K2\pi\pi^0$	1033.6	2.6±0.2	1.2
6π	664.4	2.5±0.1	1.1
combined	4532.5	2.35±0.05	-

ϕ_i values from each mode are consistent within 3σ:
➔ use a common phase in the simultaneous fit.

Vcs / Vcd from semileptonic D decays

From Bo Xin

The data determine $|V_{cs(d)}|f_+(0)$.
To extract $|V_{cs(d)}|$, we combine the measured $|V_{cs(d)}|f_+(0)$ values using the Becher-Hill parameterization with (FNAL-MILC-HPQCD) for $f_+(0)$

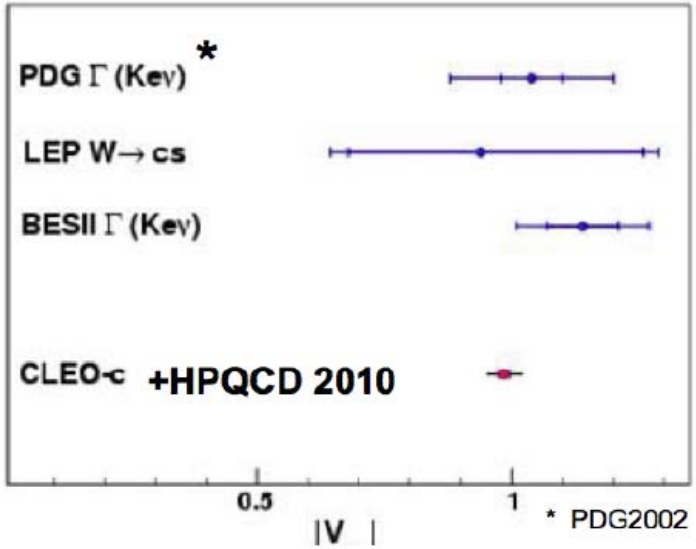
CLEO-c: the most precise *direct* determination of $|V_{cs}|$ $\sigma(|V_{cs}|)/|V_{cs}| \sim 1.1\%(\text{expt}) \oplus 2.5\%(\text{theory})$

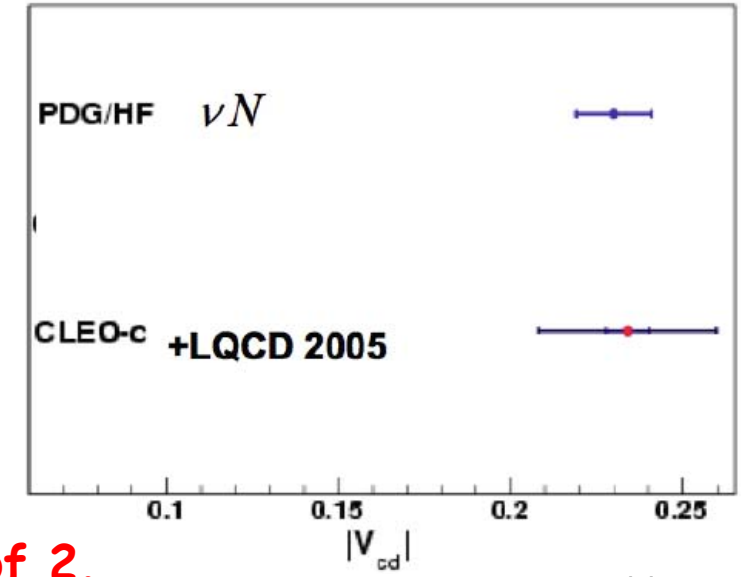
$CLEO-c$	$\lvert V_{cs}\rvert$
$(818\ \text{pb}^{-1})$	$0.963 \pm 0.009 \pm 0.006 \pm 0.024$
	stat syst theory

CLEO-c: $\sigma(|V_{cd}|)/|V_{cd}| \sim 3.1\%(\text{expt}) \oplus 10\%(\text{theory})$

νN remains most precise determination

$CLEO-c$	$\lvert V_{cd}\rvert$
$(818\ \text{pb}^{-1})$	$0.234 \pm 0.007 \pm 0.002 \pm 0.025$
	stat syst theory

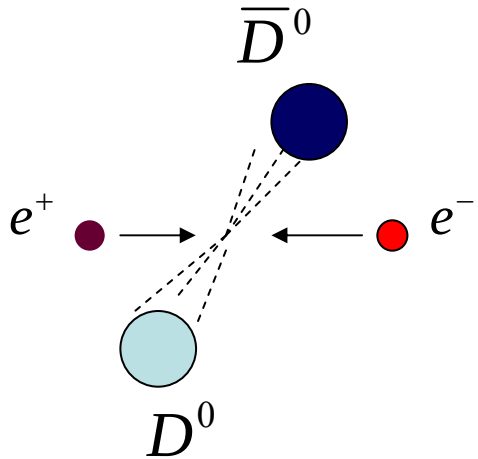




Vcd will be improved at BESIII by a factor of 2.

$D^0\bar{D}^0$ quantum correlation @ψ(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:

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

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

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

The correlated amplitude:

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

$$\frac{\left\langle K^-\pi^+ \,|\, \overline{D^0}\right\rangle_{DCS}}{\left\langle K^-\pi^+ \,|\, D^0\right\rangle_{CF}} = -\underbrace{r_{K\pi}}_{\sim 0.06} e^{-i\delta_{K\pi}}$$

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

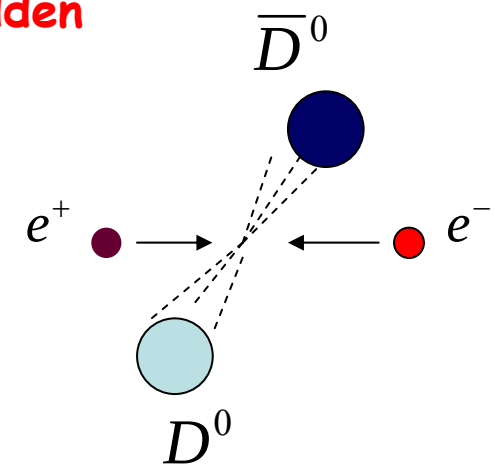
D^0 strong phase is necessary input for D^0 mixing and CKM measurements at B factories and LHCb

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:

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

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)

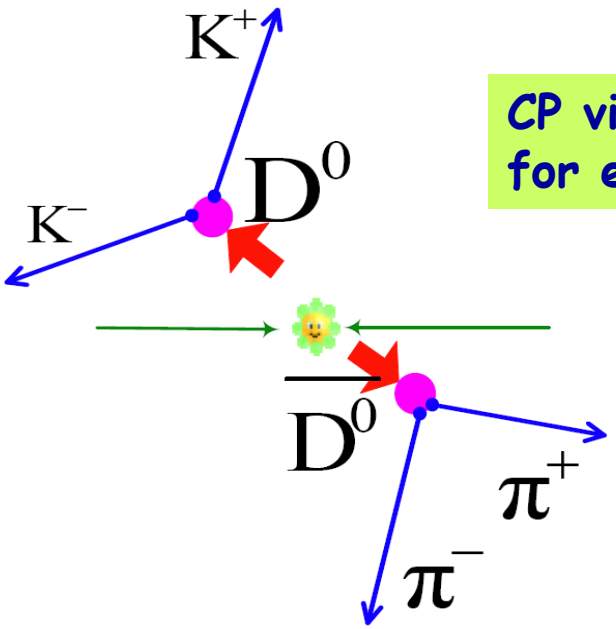
Best limits:

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 : Ks $\pi^+\pi^0$
$A_{CP}(K_S\pi^+\pi^0)=(0.3\pm0.9\pm0.3)\%$

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 .

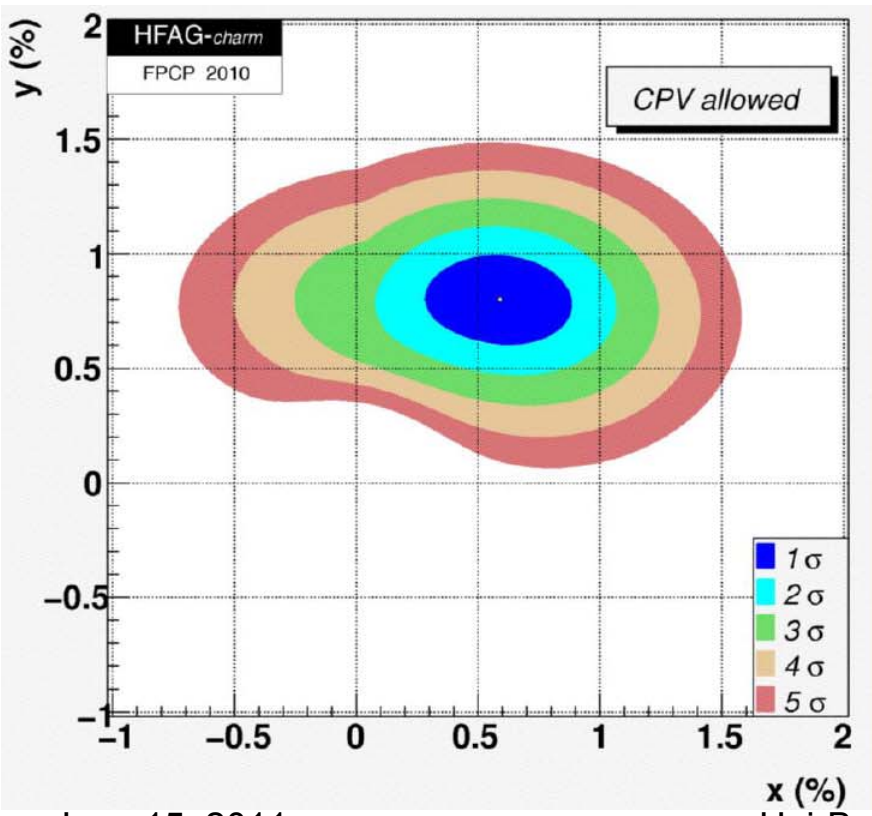
HFAG: new charm mixing with CLEO-c

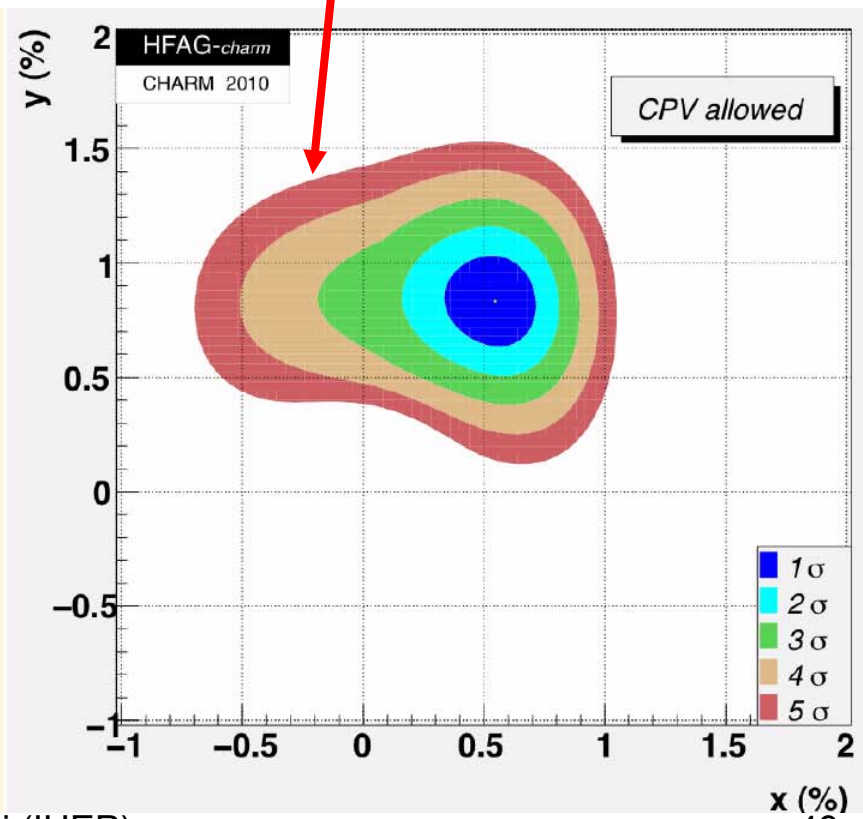
D. Asner
Charm 2010

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

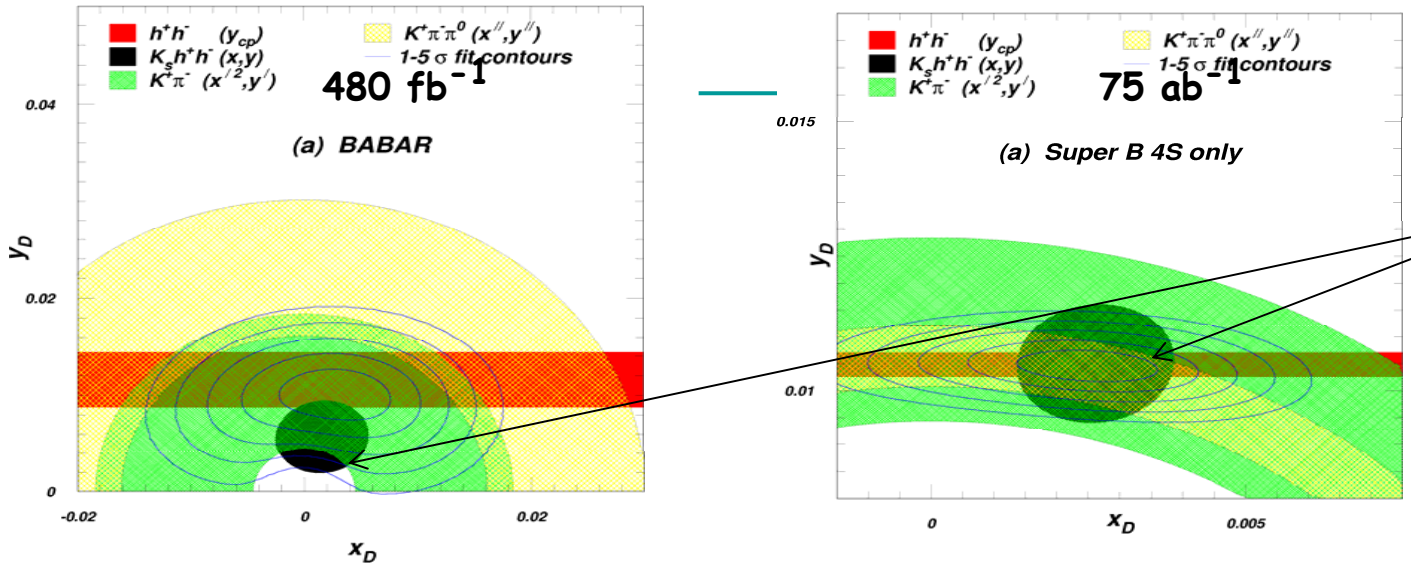
Surprising? Large impact on x uncertainty





Brian Meadows ICHEP2010

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}^*

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

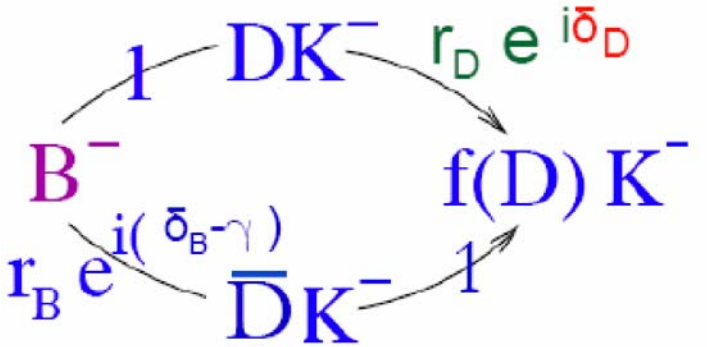
$$\frac{A\left(B^- \to \bar{D}^0 K^-\right)}{A\left(B^- \to D^0 K^-\right)} = r_B e^{i\delta} e^{-i\phi_3}$$

Parameters: ϕ_3, (r_B, δ) per mode

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

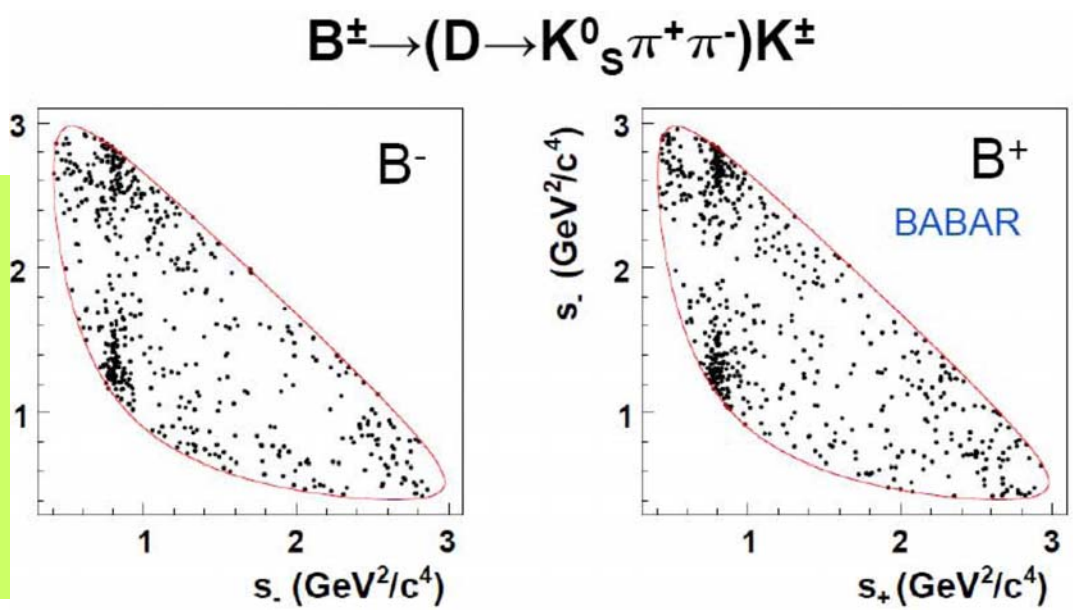
- Gronau, London, Wyler (GLW): Use CP eigenstates of $D^{(*)0}$ decay, e.g. $D^0 \to K_s \pi^0$, $D^0 \to \pi^+ \pi^-$
- Atwood, Dunietz, Soni (ADS): Use doubly Cabibbo-suppressed decays, e.g. $D^0 \to K^+ \pi^-$
- Giri, Grossman, Soffer, Zupan (GGSZ) / Belle: Use Dalitz plot analysis of 3-body D^0 decays,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

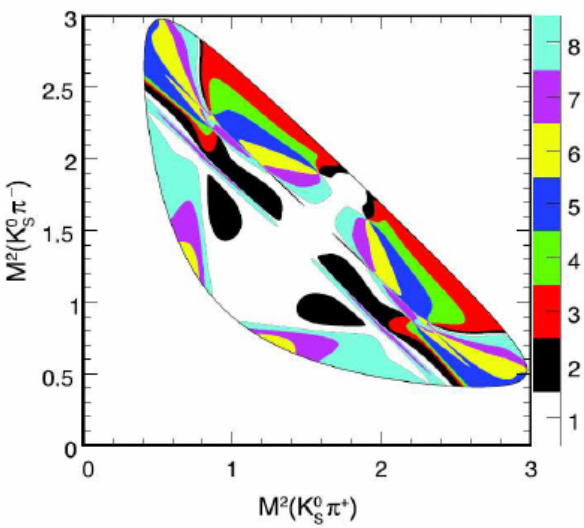
$x_{\pm} = r_B \cos(\delta_B \pm \gamma)$

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

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

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

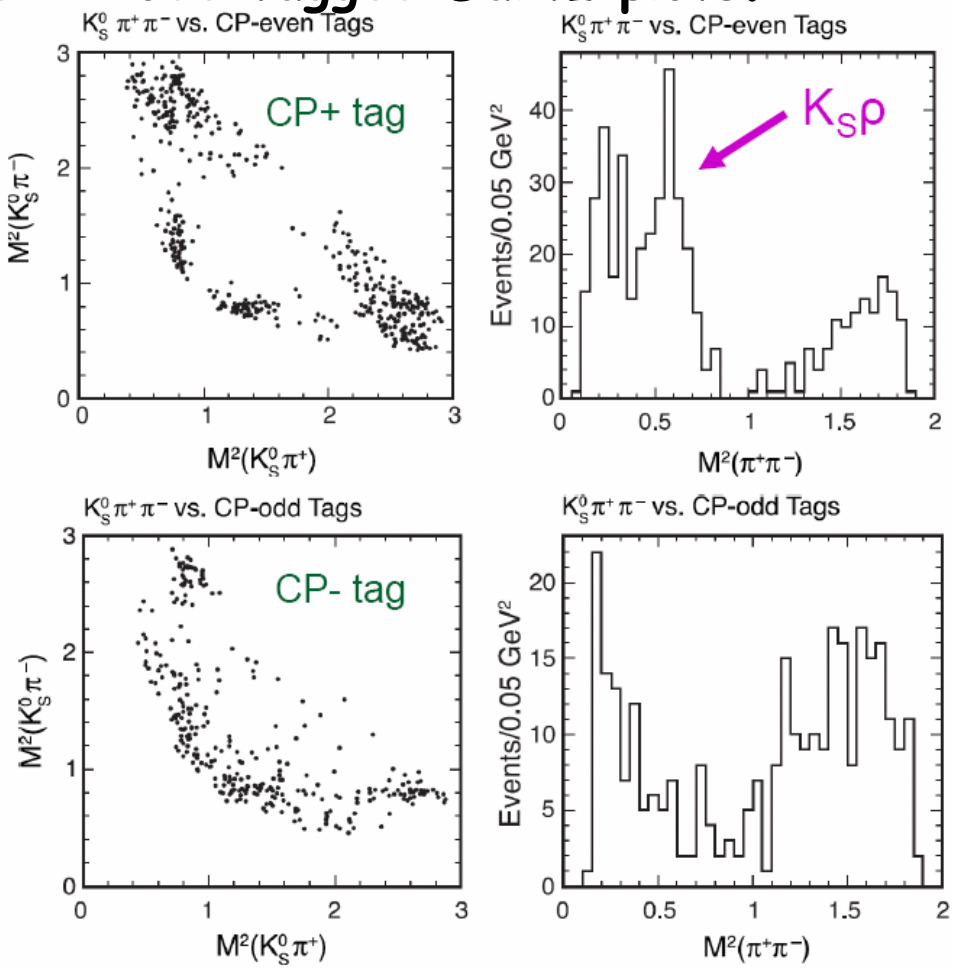
CP-tagged Dalitz plots

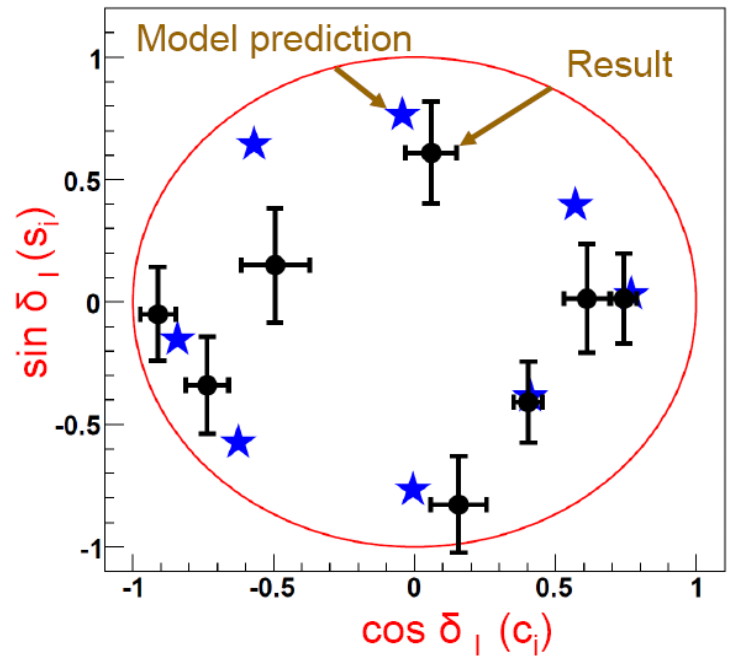
Clear difference between CP-even and CP-odd tagged Dalitz plots.

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°