Tau-Charm Physics at BESIII

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(on behalf of BESIII Collaboration)

Outline

- Introduction to Tau-Charm Physics
- Status of BEPCII/BESIII experiment
  - Accelerator and detector performance
  - Data taking plan
  - Selected results
  - Future upgrade
- Charm experiments in the future
- Summary

Why Charmonium Interesting: onia states

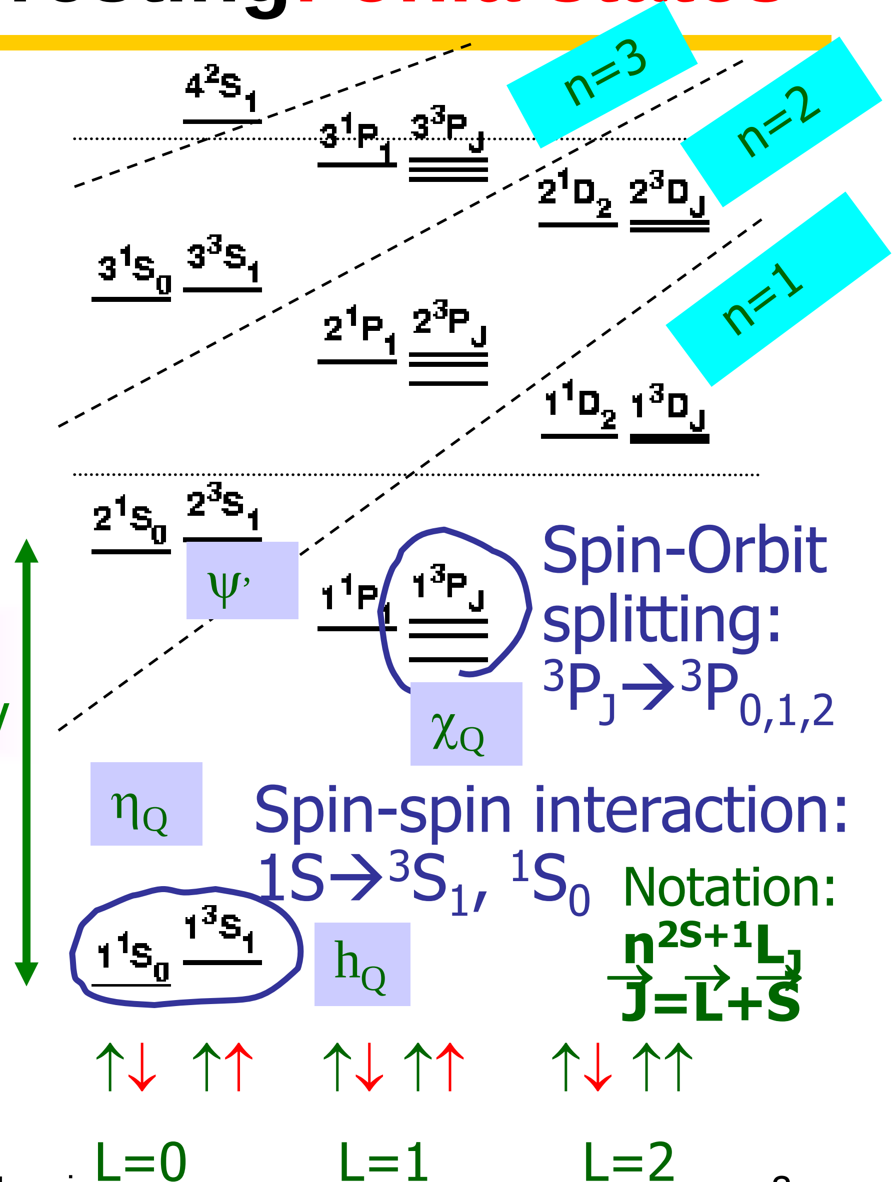
- Strongly bound $q\bar{q}$ states
- Non-relativistic QM applicable
  (Appelquist, Politzer)
  - QCD analog to positronium
  - Provide insight into QCD
- Low Q^2, non-perturbative

? **Masses** $c\bar{c}$: 589MeV

? **Widths** e^+e^-:5×10^{-6}MeV

? **Production and decay dynamics**

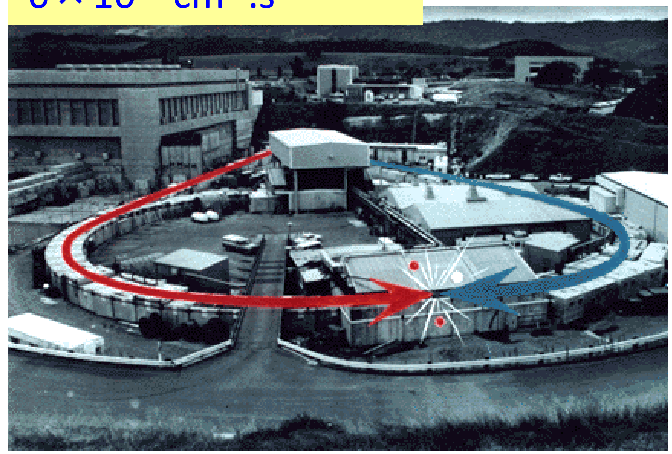
Partly discovery, partly precision measurements



Charm from Dedicated Colliders

ADONE, FRASCATI ’69-’93

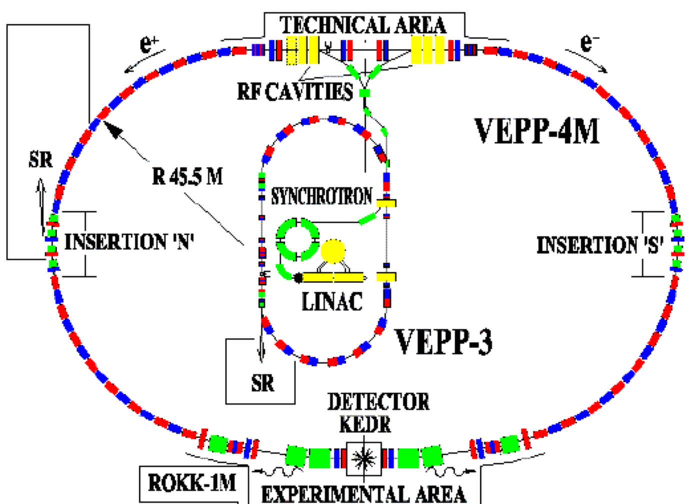
SPEAR, SLAC, ’72-’90
6×10^{29} cm^{-2}.s^{-1}



BEPC, IHEP, ’90-’04
5×10^{30} cm^{-2}.s^{-1}

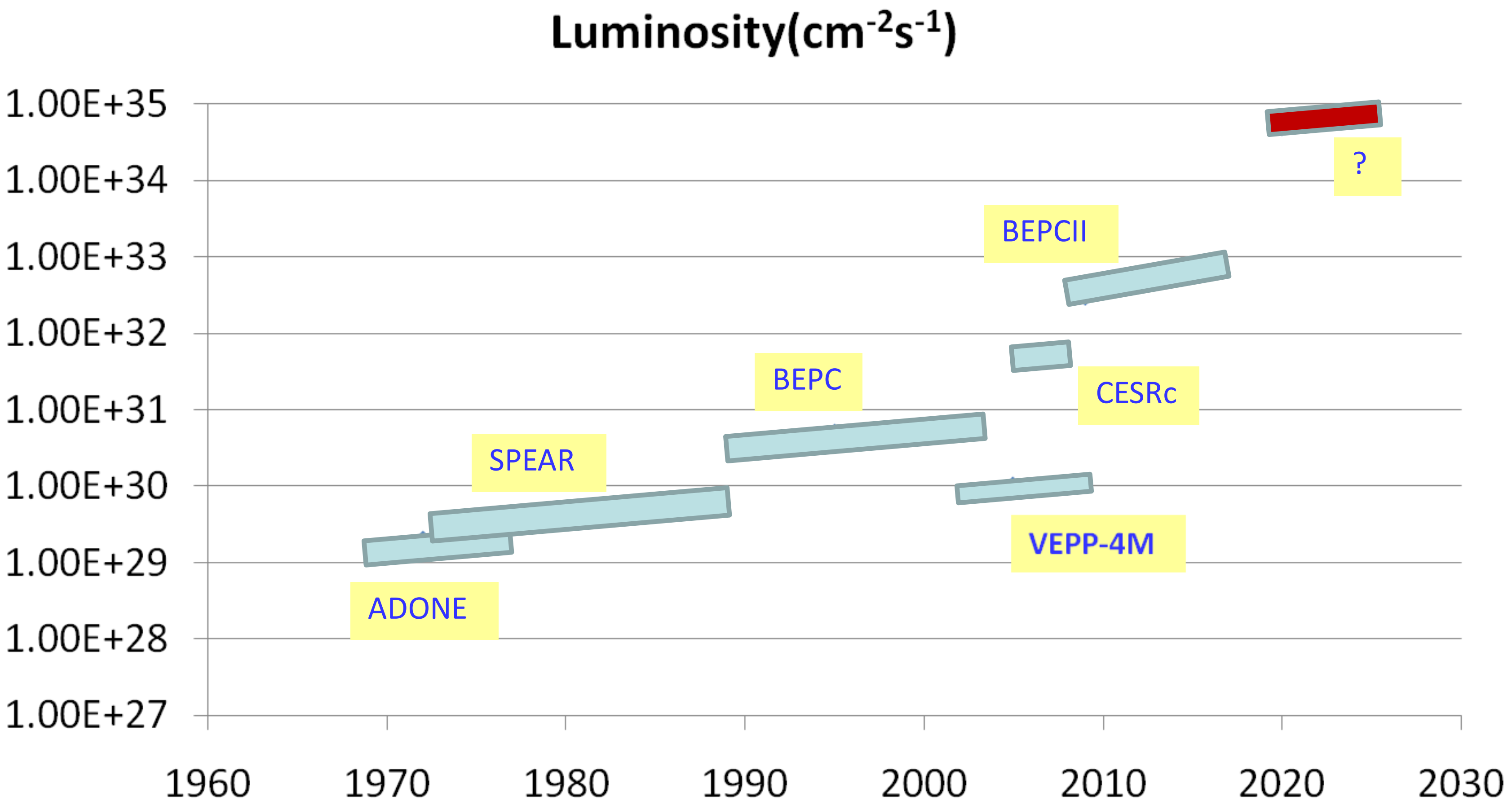
CESRc, Cornell, ’04-’08
7×10^{31} cm^{-2}.s^{-1}

VEPP-4M, Novosibisk, ’02-’12(?)
1×10^{30} cm^{-2}.s^{-1}



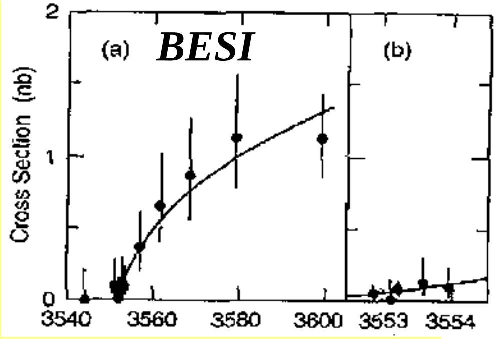
BEPCII, IHEP, ’08-’18(?)
1×10^{33} cm^{-2}.s^{-1}

A very long history

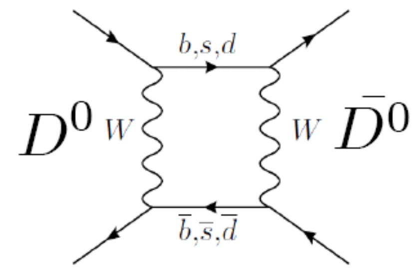


Physics at τ-Charm Factory

- Precision τ-physics and QCD
  - •τ mass and τ decays (lepton universality; CPV; LFV)
  - •R values



- High statistic spectroscopy and search for exotics
  - •charm and charmonium spectroscopy
  - •light hadron spectroscopy in charmonium decays ($N_{J/\psi} \sim 10^{10}$)
- Precision charm physics:
  - • precise measurement (~1.6%) of CKM (Vcd, Vcs)
  - • f_{D+}, f_{Ds}, form factors in leptonic D decays
  - • D^0 - $\underline{D^0}$ mixing
  - • CP violation, strong phase.
  - • Absolute BR measurements of D and Ds decays
  - • Rare D decay
  - •light meson spectroscopy in D^0 and D^+ Dalitz plot analyses.



test on standard model and search for new physics

D Meson Productions

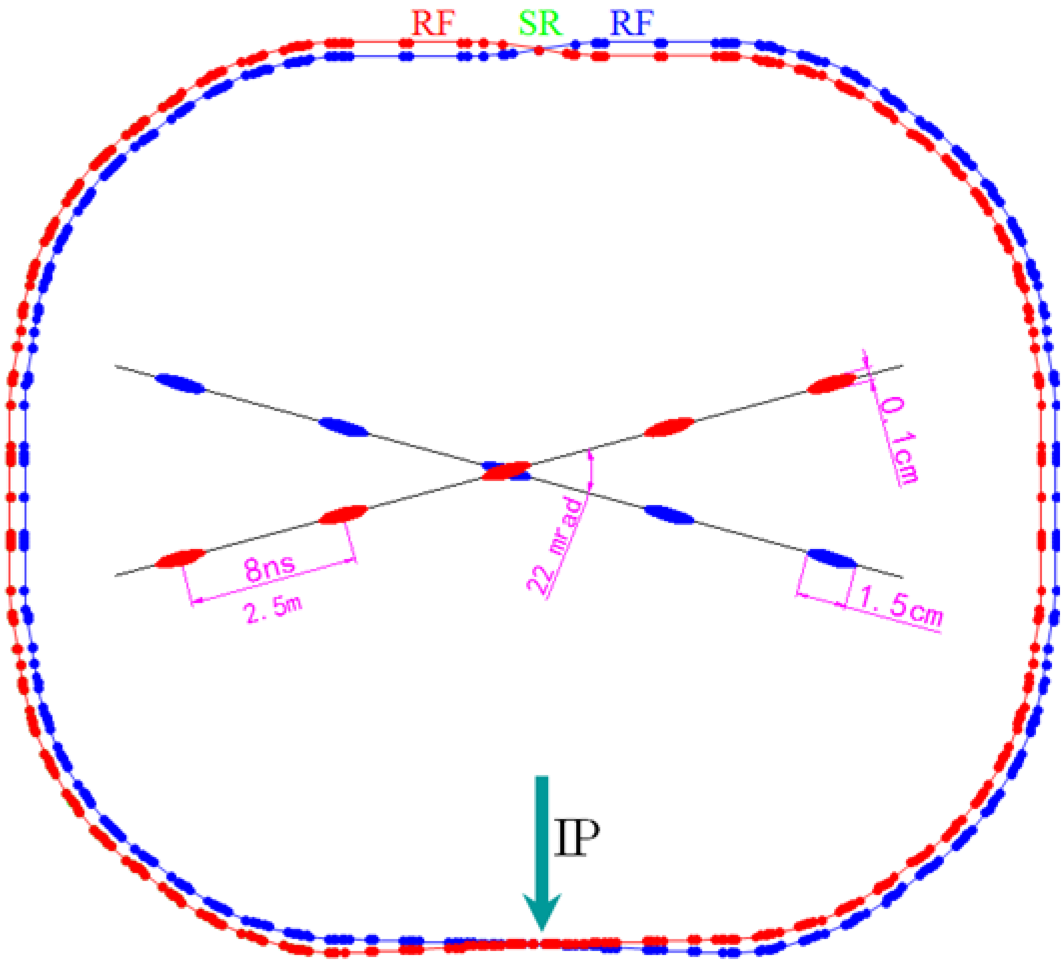
- Hadron colliders (huge cross-section, energy boost)
  - Tevatron
  - LHC (LHCb, CMS, ATLAS)
- e^+e^- Colliders (clean environment, ~100% trigger efficiency)
  - B-factories (Belle, BaBar)
  - Threshold production (CLEOc, BESIII)
    - Quantum correlations and CP-tagging are unique
    - Double Tag techniques: (partial-) reconstruct both D mesons
    - Ratio of signal to background is optimum
    - Lots of systematic uncertainties cancellation while applying double tag method

BEPCII/BESIII Experiment

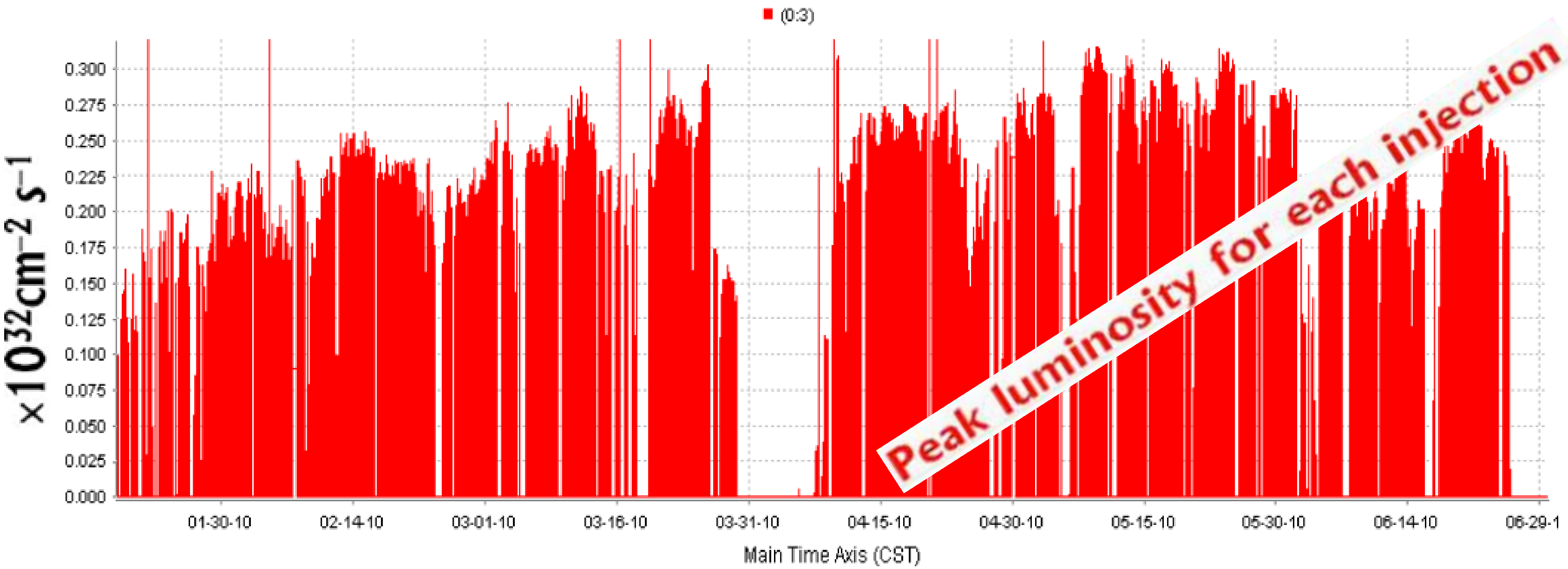
- A mainstream High Energy Physics project in China
  - A major upgrading from BEPC/BES(II)
  - BEPCII : e^+e^- collider
    - ~60% Physics run
    - ~30% Synchrotron radiation run
  - BESIII: particle detector
  - Start testing run on July, 2008
  - Start official data taking on March, 2009
  - In 2010, 3 published papers and 5 – 7 more expected

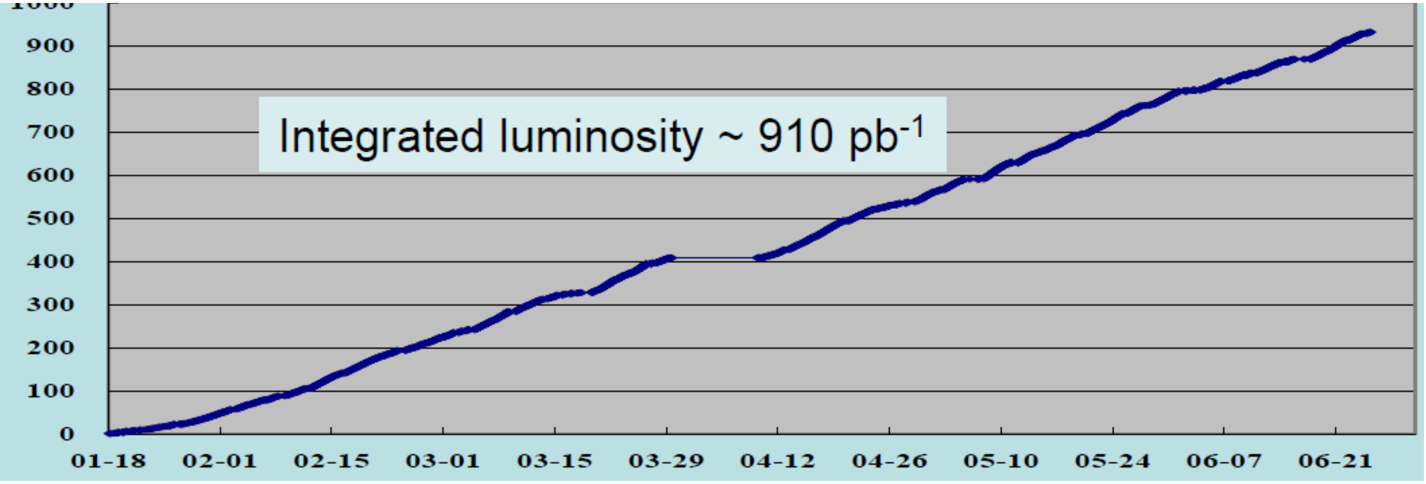
BEPCII Storage Ring: Double Ring

Beam energy:
 1.0-2.3 GeV
Design Luminosity:
 $1 \times 10^{33}\ cm^{-2}s^{-1}$
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



BEPCII Luminosity (in 2010)



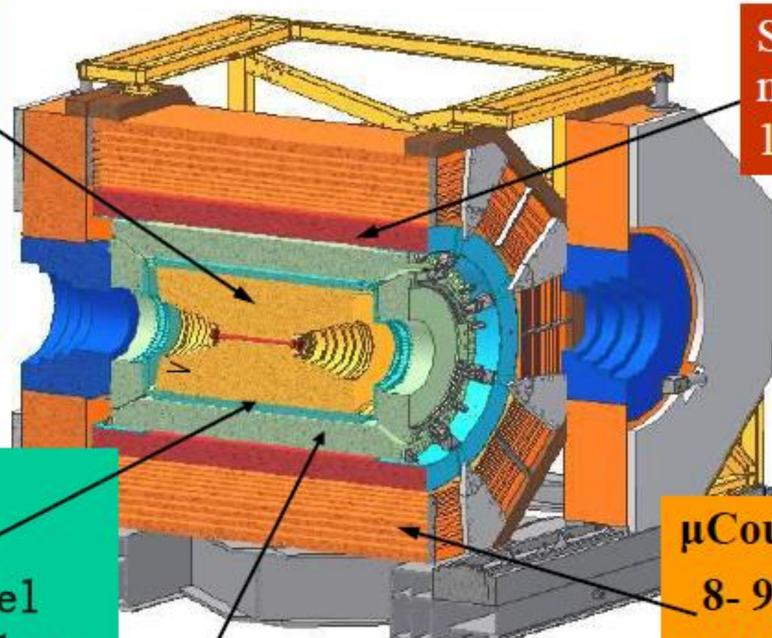


The BESIII Detector

NIM A614 (2010)

Main Drift Chamber (MDC)
$\Delta P/P$ (%) = 0.5-0.7 %
(1 GeV)
$\sigma_{dE/dx}$ (%) = 6-8%

Super-conducting magnet
1.0 tesla



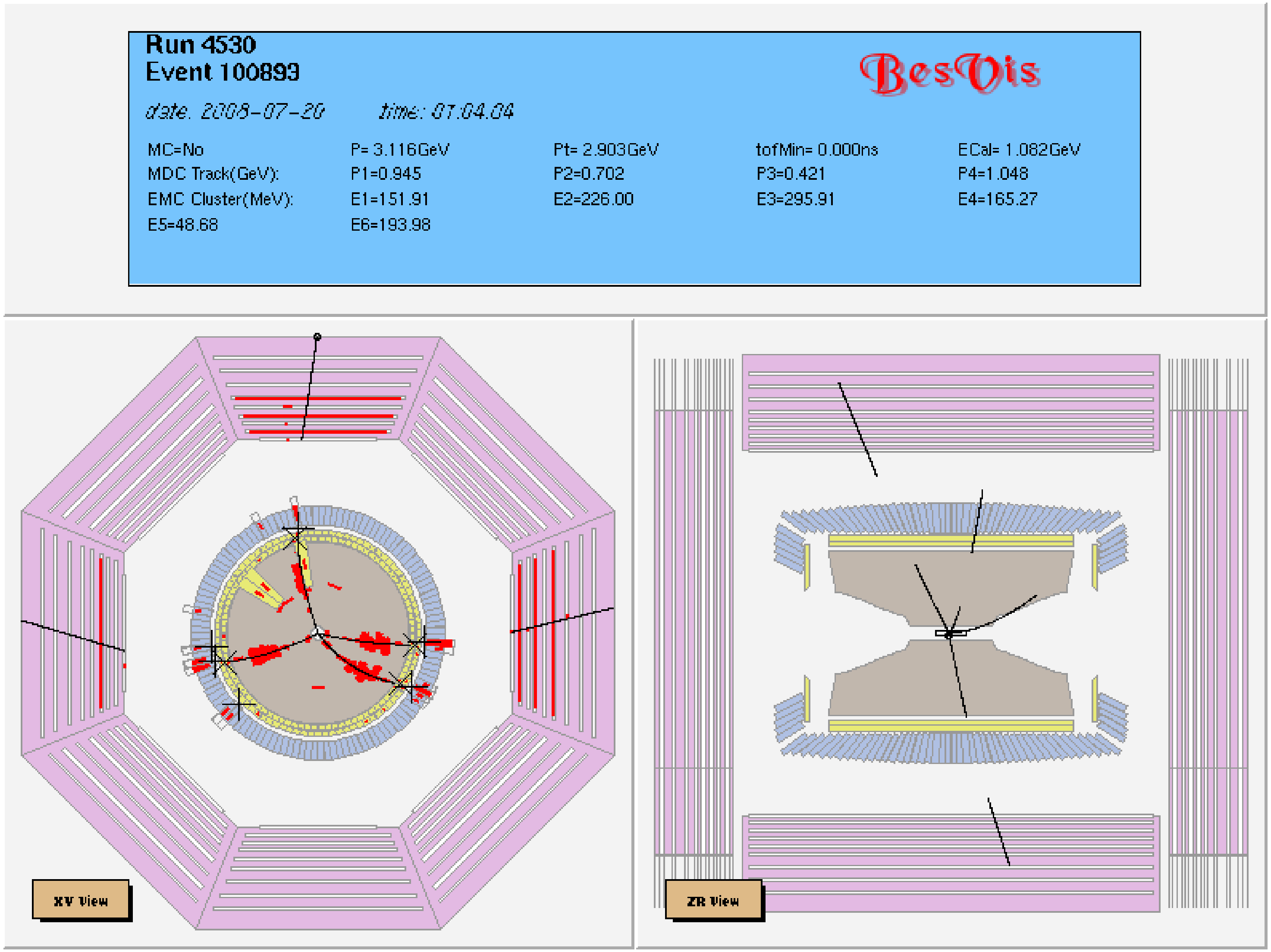
Time Of Flight (TOF)
σ_T (ps) =80-90 ps Barrel
100-110 ps endcap

μCounter
8- 9 layers RPC
$\delta R\Phi$=1.4 cm~1.7 cm

EMC: $\Delta E/\sqrt{E}$ (%) = 2.5 -3 % (1 GeV)
(CsI) $\sigma_{z,\phi}$(cm) = 0.5 - 0.7 cm/$\sqrt{E}$

A total weight of 730t, ~40000 readout channels, data rate 6000Hz ~50Mb/s, ~1000 man*year, 30 M$

First Hadronic Event on June 20, 2008



Data Samples at BESIII

Until June 2010:

Type	BES-III ($\times 10^6$)	BESII ($\times 10^6$)	CLEO-c ($\times 10^6$)
J/ψ	230	58	-
$\psi(2S)$	108	14	27
DDbar	6.58(0.98fb^{-1})	0.2(0.03fb^{-1})	5.4(0.8fb^{-1})
DsDs	-	-	Scan
DsDs*	-	-	0.55(0.6fb^{-1})

Long Term Plan (>5 years):

- 10 B J/ψ events
- 3 B $\psi(2S)$
- 20 fb^{-1} $\psi(3770) + \psi(4040) + \psi(4160)$
- R scan/resonance scan: 2 ~ 4.6 GeV
- Tau physics

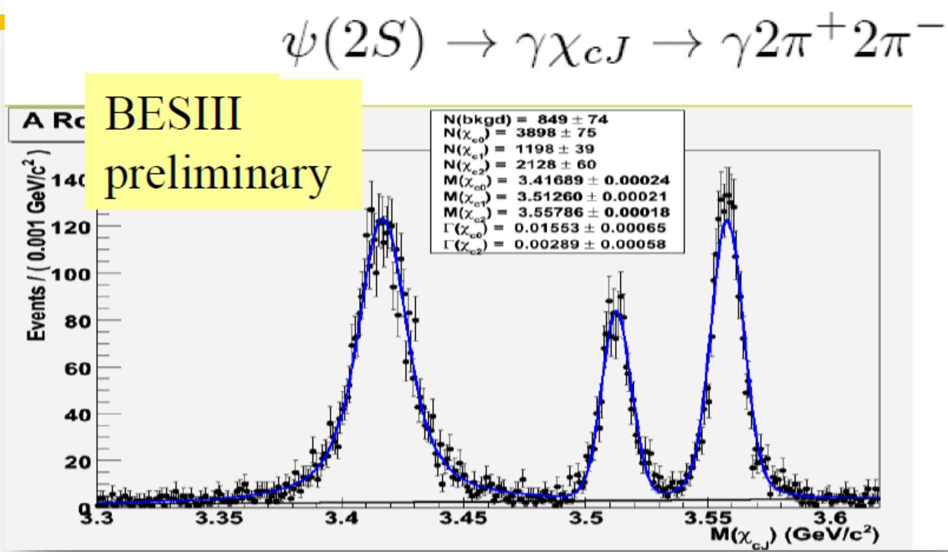
Good Data Quality

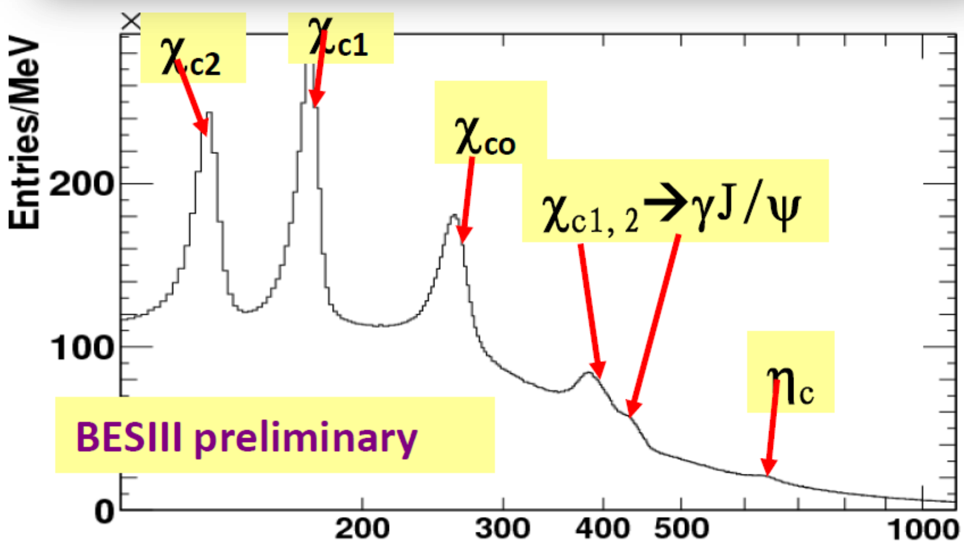
Clean exclusive signals

High statistics

Clear inclusive photon spectrum

Excellent photon resolution





BESIII Physics Results

- BESIII results published
  - Branching fraction measurements of χ_{c0} and χ_{c2} to $\pi^0\pi^0$ and $\eta\eta$
    PRD 81, 052005 (2010)
  - Measurements of $h_c(^1P_1)$ in ψ' decays
    PRL 104, 132002 (2010)
  - Observation of a ppbar mass threshold enhancement in $\psi' \to \pi^+\pi^- J/\psi(J/\psi \to \gamma ppbar)$ decay
    CPC 34 (2010)

More charmonium results

- First evidence of $\psi' \to \gamma\gamma J/\psi$
- First evidence of $\psi' \to \gamma P$ ($P=\pi^0, \eta$)
- First measurement of $\chi_{cJ} \to 4\pi^0$
- Study of $\chi_{cJ} \to \gamma V$ ($V=\rho,\omega,\phi$)
- Study of $\chi_{cJ} \to VV$ ($V=\omega,\phi$)

Preliminary

More light haron results

- Observation of $X(1870) \to a_0(980)\pi$ in $J/\psi \to \omega\pi^+\pi^-\eta$
- Study of $a_0(980) - f_0(980)$ mixing from
  $J/\psi \to \phi f_0 \to \phi a_0 \to \phi\eta\pi$
  $\chi_{c1} \to a_0\pi^0 \to f_0\pi^0 \to \pi^+\pi^-\pi^0$
- Measurement of the matrix element from $\eta' \to \pi^+\pi^-\eta$

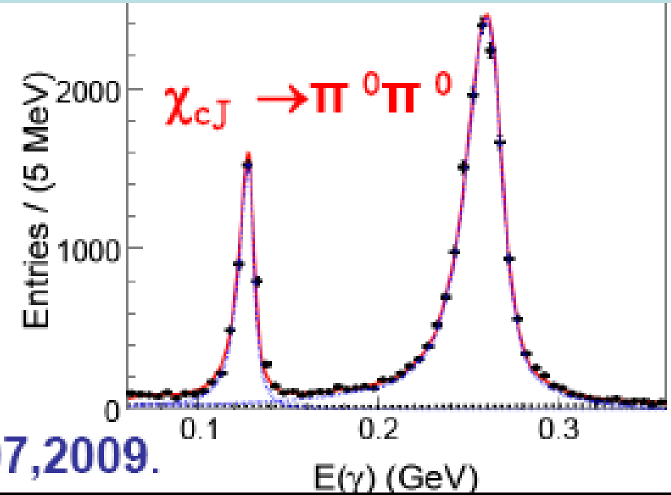
Charm physics at BESIII

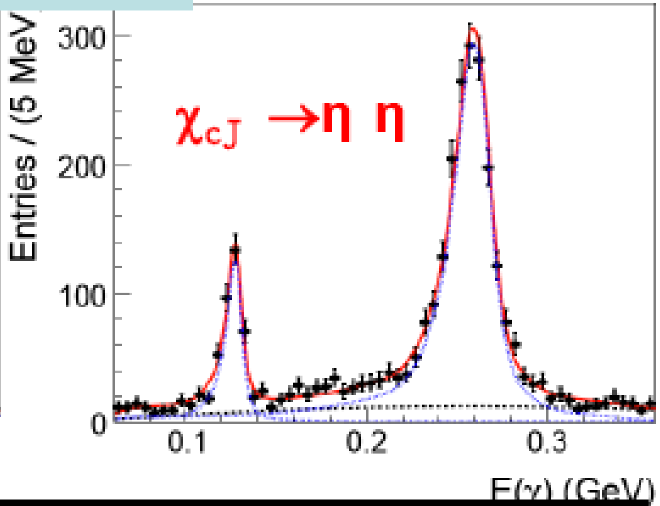
- **$\psi(3770)$ experimental data**
  being reprocessed with new software
- **Physics analysis in progress**

$\chi_{cJ} \to \pi^0\pi^0$, $\eta\eta$ from $\psi' \to \gamma\chi_{cJ}$ decays

BESIII: PRD 81, 052005 (2010)

Radiative photon spectrum





CLEO, PRD79:072007,2009.

Decay mode		χ_{c0} (10^{-3})	χ_{c2} (10^{-3})
$\pi^0\pi^0$	BESIII	3.23±0.03±0.23±0.14	0.88±0.02±0.06±0.04
	PDG08	2.43±0.20	0.71±0.08
	CLEOc	2.94±0.07±0.32±0.15	0.68±0.03±0.07±0.04
$\eta\eta$	BESIII	3.44±0.10±0.24±0.20	0.65±0.04±0.05±0.03
	PDG08	2.4±0.4	<0.5
	CLEOc	3.18±0.13±0.31±0.16	0.51±0.05±0.05±0.03

CLEO-c used their own measured BRs for $\psi \to \gamma\chi_{cJ}$ decays.

h_c: Spin-Spin Interaction

- **Spin singlet P wave (L=1, S=0)**
- **Hyperfine Splitting of 1P states**
- **Test of QCD and potential model**

spin-spin-interaction tells us:

$$\Delta M_{hf}(1P) = m(h_c) - \frac{1}{9}(m(\chi_{c0}) + 3m(\chi_{c1}) + 5m(\chi_{c2}))$$

$\Delta M_{hf}(1P) \neq 0$: **if spin-spin interaction.**

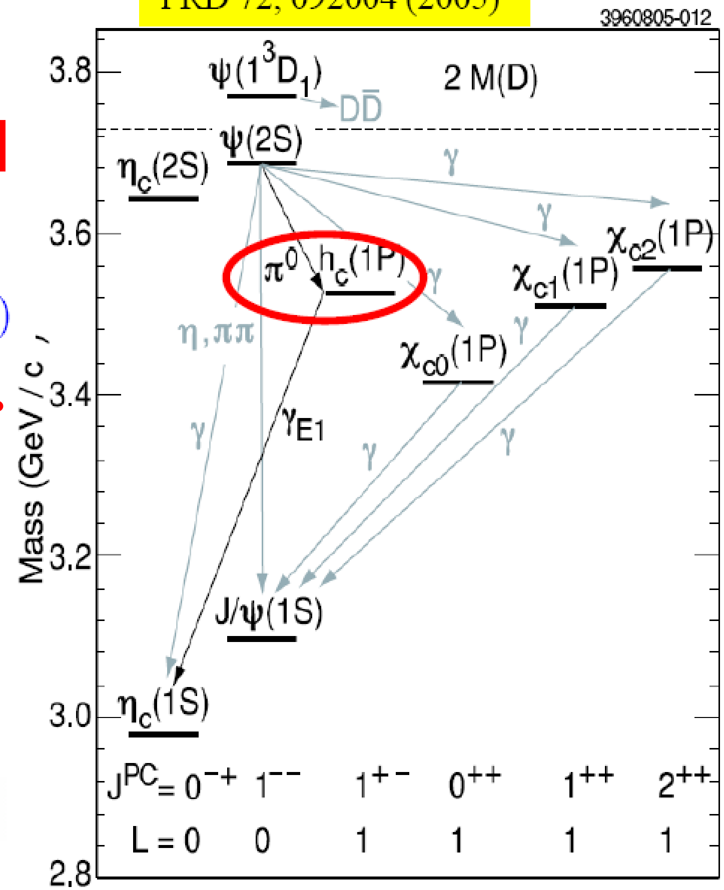
- E835: Evidence in $\bar{p}p \to h_c \to \eta_c\gamma$
- CLEO: Observation in ***PRL 101, 182003(2008)***

$$e^+e^- \to \psi(2S) \to h_c\pi^0$$
$$h_c \to \eta_c\gamma$$

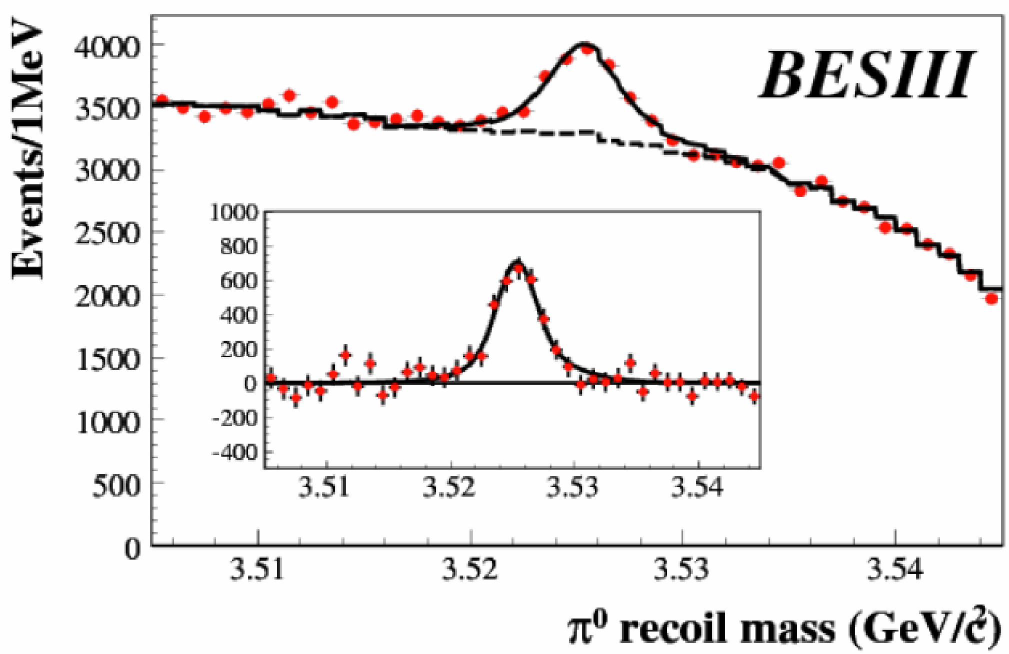
$$\Delta M_{hf}(1P) = 0.08 \pm 0.18 \pm 0.12 \,\mathrm{MeV}/c^2$$

zero 1P hyperfine splitting???

PRD 72, 092004 (2005)



E1-tagged $\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$



$N(h_c) = 3679 \pm 319$

$M(h_c) = 3525.40 \pm 0.13 \pm 0.18$ MeV

$\Gamma(h_c) = 0.73 \pm 0.45 \pm 0.28$ MeV

< 1.44 MeV@90%CL

First measurement

Consistent with CLEO:

$3525.35 \pm 0.19 \pm 0.11$ MeV

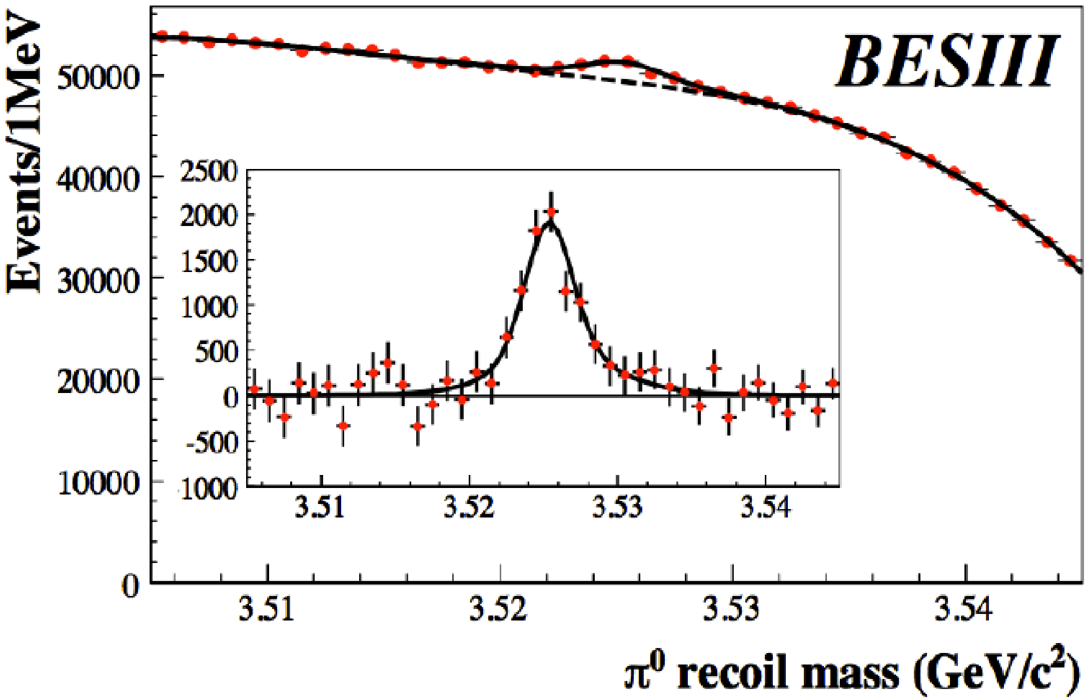
and theoretical prediction.

BW (signal) convolved with Di-Gaussian (reso) + background.

Mass, width and strength of h_c floated.

BG modeled by the π^0 recoil mass spectrum in the sideband of the E1 photon.

Inclusive $\psi' \rightarrow \pi^0 h_c$



First measurement

$N(h_c) = 10353 \pm 1097$

$Br(\psi' \rightarrow \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$

$Br(h_c \rightarrow \gamma\, \eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$

$Br(\psi' \rightarrow \pi^0 h_c) \times Br(h_c \rightarrow \gamma \eta_c)$
$=(4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$
consistent with CLEO:
$(4.22 \pm 0.44 \pm 0.52) \times 10^{-4}$

The shape of h_c fixed to that from the fit of E1-tagged

The background parameterized by a 4th-order polynomial.

BESIII Collaboration, PRL 104, 132002 (2010)

Short Summary of h_c

BESIII Collaboration, PRL 104, 132002 (2010)

	BESIII	CLEO
$m[\mathrm{MeV}/c^2]$	$3525.4 \pm 0.13 \pm 0.18$	$3525.8 \pm 0.19 \pm 0.11$
$\Delta_{hf}(1P)[\mathrm{MeV}/c^2]$	$0.10 \pm 0.13 \pm 0.18$	$0.08 \pm 0.18 \pm 0.12$
$\Gamma[\mathrm{MeV}/c^2]$	$(0.73 \pm 0.45 \pm 0.28)$ $< 1.44(90\%\mathrm{CL})$	
$Br(\psi' \to h_c\pi^0) \times Br(h_c \to \gamma\eta_c)[10^{-4}]$	$4.58 \pm 0.40 \pm 0.50$	$4.22 \pm 0.44 \pm 0.52$

→Consistent with CLEO

	BESIII	Theory
$Br(\psi' \to h_c\pi^0)[10^{-4}]$	$8.4 \pm 1.3 \pm 1.0$	$4...13^{(1)}$
$Br(h_c \to \gamma\eta_c)[\%]$	$54.3 \pm 6.7 \pm 5.2$	$48(\mathrm{NRQCD})^{(1)}$ $88(\mathrm{PQCD})^{(1)}$ $38^{(2)}$

First Measurement!

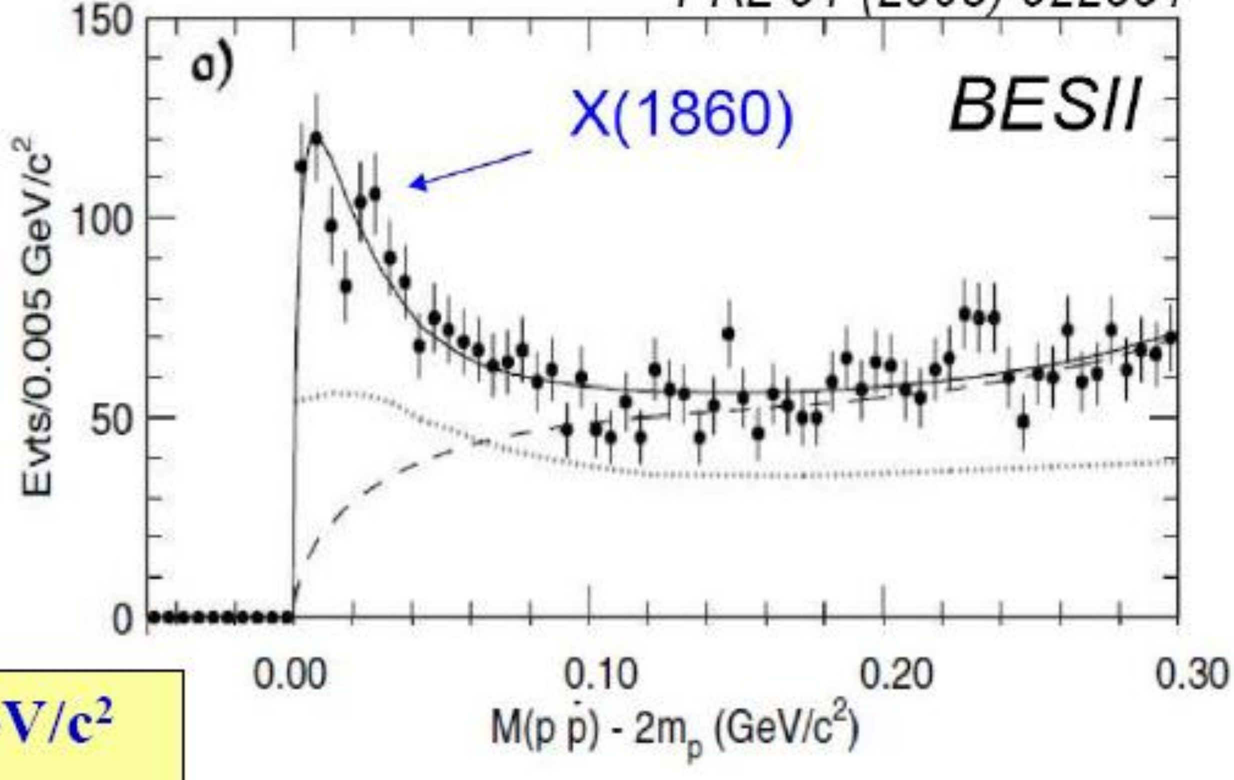
(1) Kuang, PRD65, 094042 (2002)
(2) Godfrey, Rosner, PRD66, 014012 (2002)

$p\bar{p}$ threshold enhancement @ BESII

- What could it be?
  - $p\bar{p}$ bound state? (baryonium)
  - FSI effect?
  - or some of both?

$J/\psi \to \gamma p\bar{p}$

PRL 91 (2003) 022001

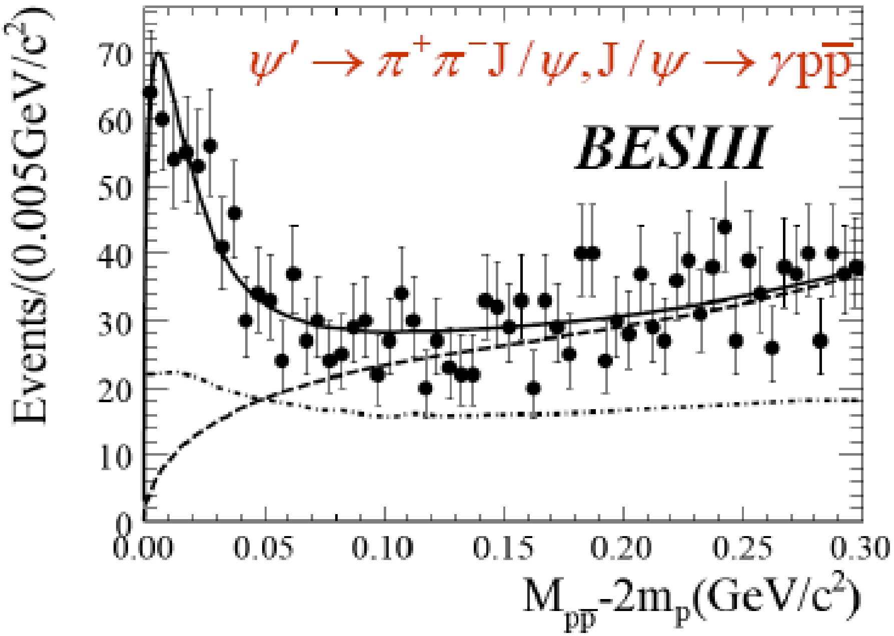


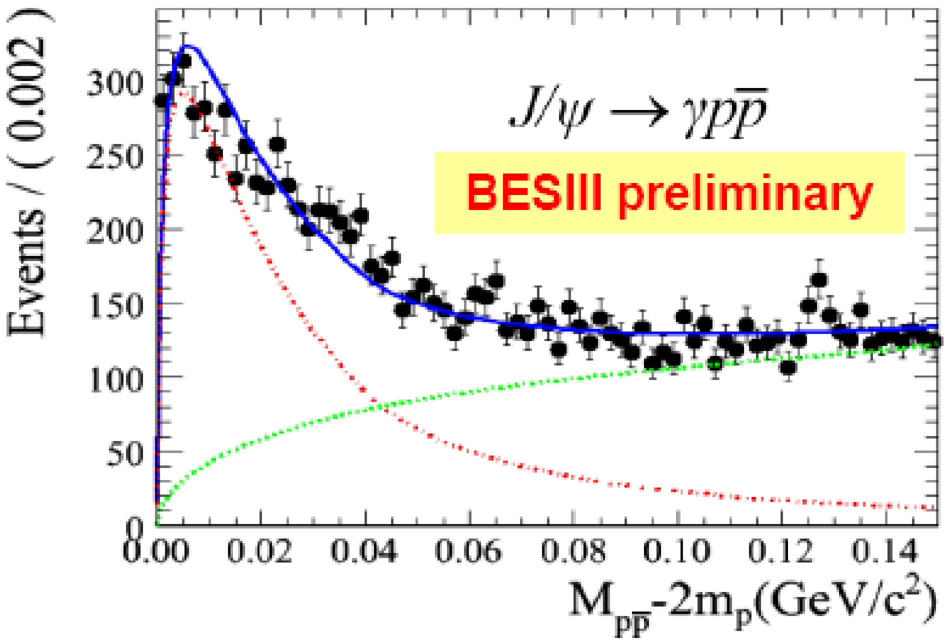
$M=1859^{+3}_{-10}\,^{+5}_{-25}$ MeV/c²

$\Gamma < 30$ MeV/c² (90% CL)

$p\bar{p}$ threshold enhancement @ BESIII

BESIII: Chinese Physics C 34(2010)421





$M=1861^{+6}_{-13}{}^{+7}_{-26}$ MeV/c^2

$\Gamma < 38$ MeV/c^2 (90% CL)

$M=1861.6 \pm 0.8$ MeV/c^2

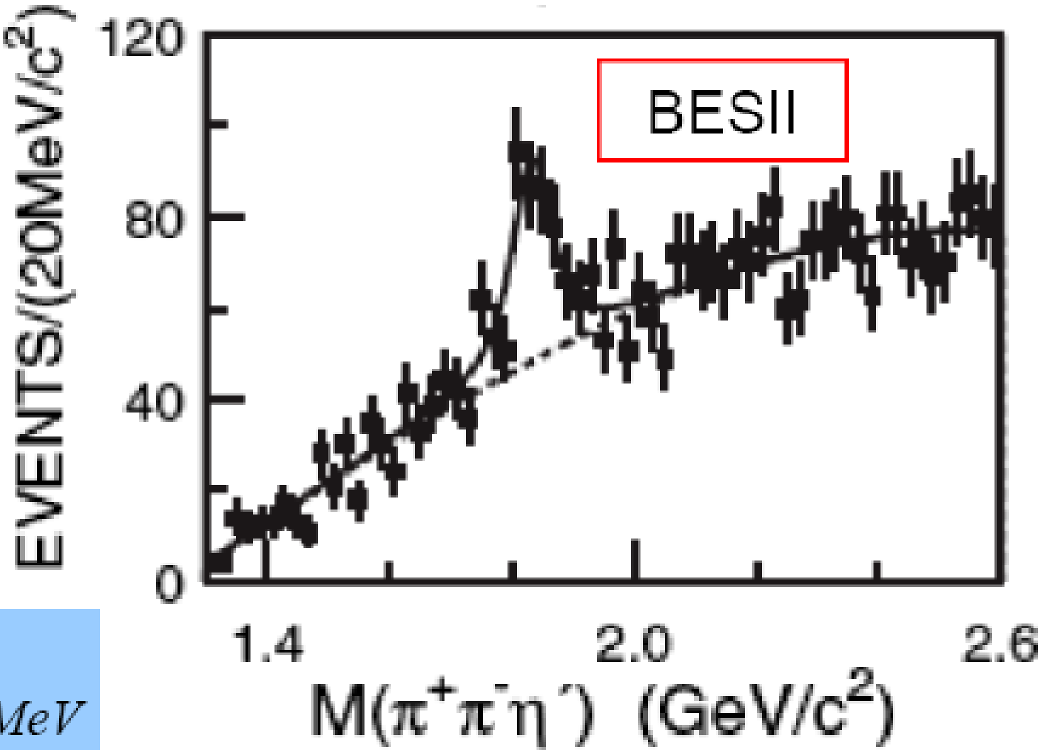
$\Gamma < 8$ MeV/c^2 (90% CL)

Consistent observation by BESIII !

X(1835) at BESII

BESII: PRL 95,262001(2005)

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

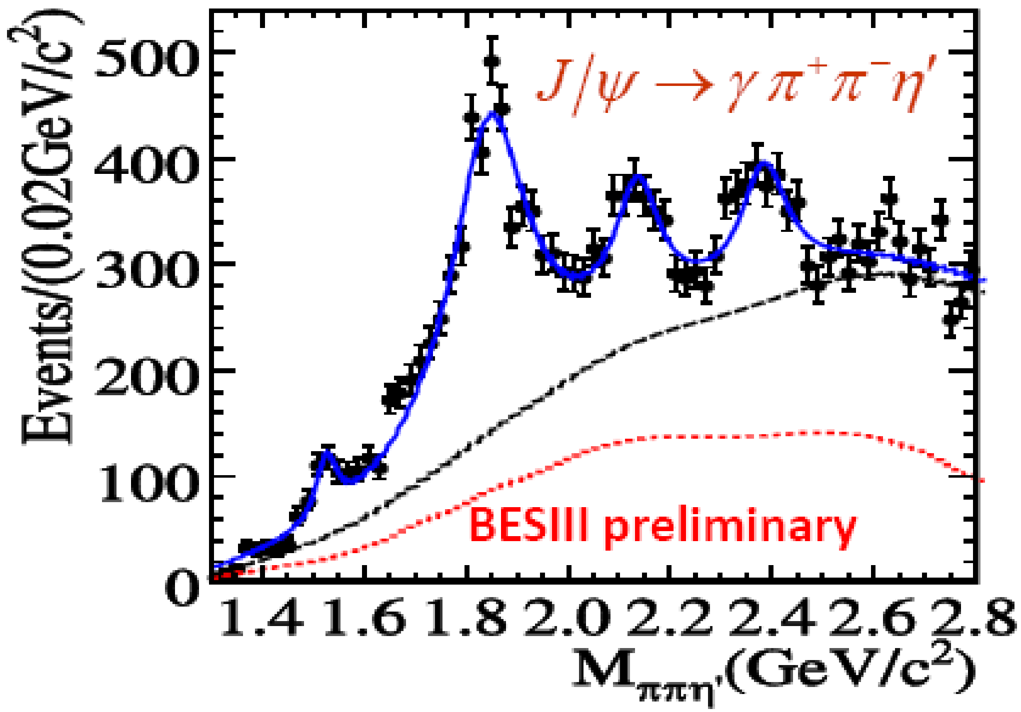


BESII result (Stat. sig. ~ 7.7σ):

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

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

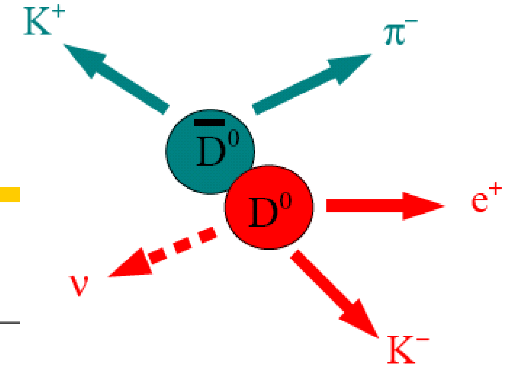
Confirmation of X(1835) and observation of two new resonances at BESIII



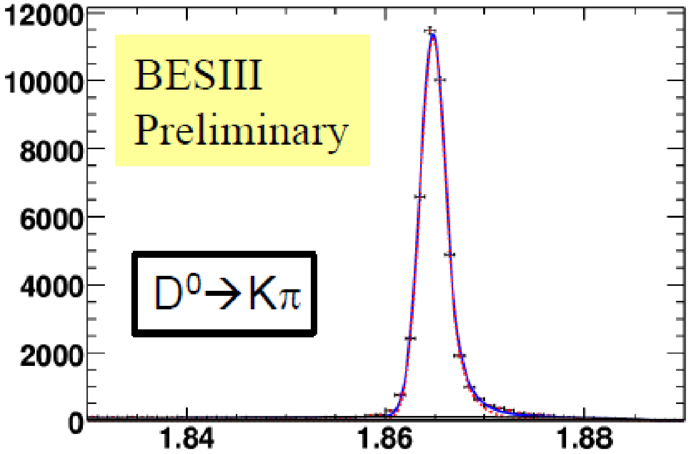
resonance	$M(\text{MeV}/c^2)$	$\Gamma(\text{MeV}/c^2)$	Stat. sig.
X(1835)	1838.1 ± 2.8	179.5 ± 9.1	$> 25\sigma$
X(2120)	2124.8 ± 5.6	101 ± 14	$> 7.2\sigma$
X(2370)	2371.0 ± 6.4	108 ± 15	$> 6.7\sigma$

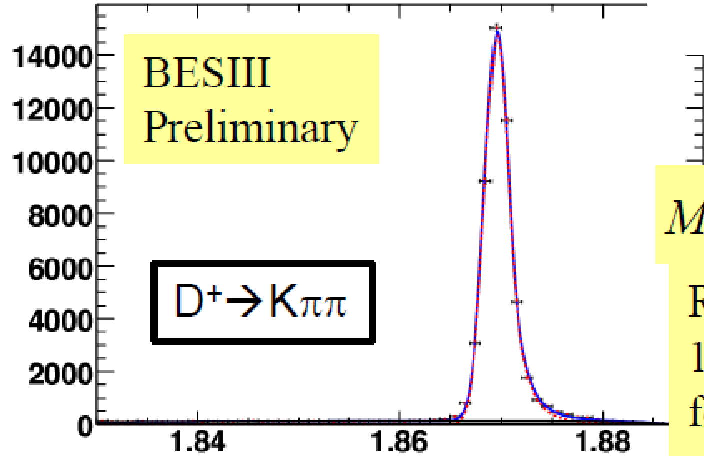
new

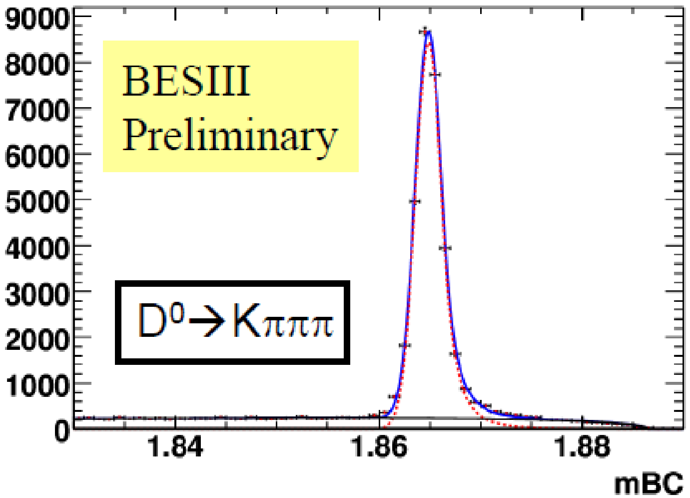
Clean Single *D* Tag at BESIII

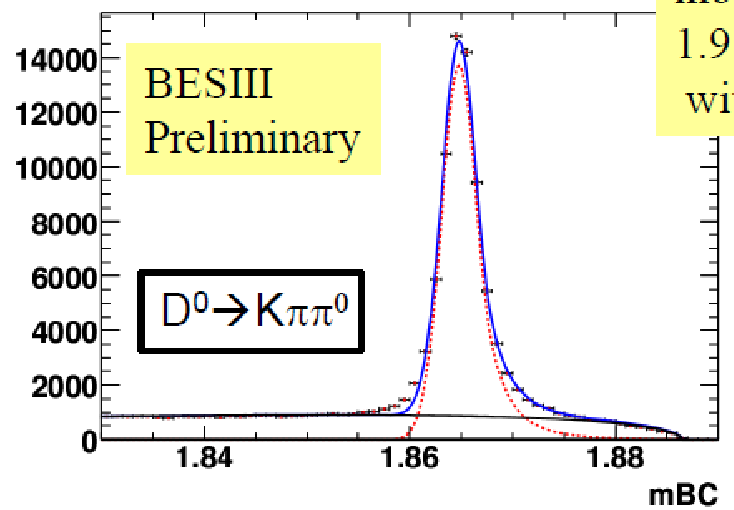


@ψ(3770) with $420 pb^{-1}$ first clean single tagging signals:









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

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

Prospects for Charm Physics

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

f_{D+} ($D^+ \to \mu^+ \nu$): ±4.1% (stat.) ± 1.2% (sys.)

$f_{\pi(0)}$ ($D^0 \to \pi l \nu$): ±5.3% (stat.) ± 0.7%(sys.)

BR($D^0 \to K\pi$): ±0.9% (stat.) ± 1.8%(sys.)

BR($D^+ \to K\pi\pi$): ±1.1% (stat.) ± 2.0%(sys.)

CLEO-c errors for Ds physics with 600pb^{-1}@4170

f_{Ds} ($Ds^+ \to \mu^+ \nu, \tau\nu$): ±2.5% (stat.) ± 1.2% (sys.)

BR($Ds^+ \to KK\pi$): ±4.2% (stat.) ± 2.9%(sys.)

Significant gains will be made with increased luminosity at BESIII even if systematic errors remain the same.

CP and D^0 mixing using quantum correlation are all statistics-starved at CLEO-c, improvement will be made at BESIII.

Status of BEPCII/BESIII

- BEPCII
  - Commissioning and stable running of Linac necessary
  - 1/3 of the luminosity design value was reached, further studies are needed.
  - The dark current of detector limits the beam current right now, and needs to be improved.
- BESIII
  - 22 analysis memos are under the referees review, and 5 - 7 will be submitted in a few months
  - Systematic studies for neutral tracks (γ, π^0, $\eta^{(')}$) are in good shape (MC agrees with data)
  - It will take time to fully understand the systematics for the charged tracks (expecting <1% per track)

Long Term Upgrade

- BEPCII
  - Crab-waist for higher luminosity
    - Some changes in the IR (crossing angle of collision beams, magnets' positions near the IP, etc.)
    - Limit from the constraints of BESIII solenoid
  - Beam Energy: E_{max} = 4.6 GeV $\Rightarrow$ 5 GeV
  - polarized e^- beam
- BESIII
  - Beam energy measurement system: $\Delta\varepsilon$= 40keV
  - PID system : *Endcap TOF counter (MRPC, ~80ps)*
  - Inner Drift Chamber: to tolerate high beam noise

Future Charm Experiment(s)

- Hadron Colliders
  - FAIR/PANDA Experiment (Under construction, operating on 2015?)
  - Fermilab proposals
- e^+e^- Colliders (Running at threshold?)
  - Super tau-Charm factory
  - Super B factory (Approved, complete on 2014?)
  - Super Flavor factory (Linear collider?)
- Other ideas…

Summary

- BEPCII reached a luminosity of 3.3×10^{32} $cm^{-2}s^{-1}$
- BESIII detector performance excellent, physics results published
  - High quality data samples in hand (110 M ψ' and 230 M J/ψ, 910pb^{-1} ψ(3770) data obtained)
  - Analysis in progress, more publications in a few months
  - "Open Charm" analyses have already be launched, expect more exciting results
- Few billions of J/ψ and ψ' , ~10 fb^{-1} open charm data will be accumulated in the future
  - Test on Standard Model and New Physics Search
- Rich physics topics in Charm sector. More experiments are coming.

BESIII Collaboration

http://bes3.ihep.ac.cn

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

Europe(10)
Germany: Univ. of Bochum, Univ. of Giessen, GSI, Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino, Frascati Lab
Netherland: KVI/Univ. of Groningen

Korea (1)
Seoul Nat. Univ.

Japan (1)
Tokyo Univ.

Pakistan (1)
Univ. of Punjab

China(29)
IHEP, CCAST, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Hong Kong Univ., Hong Kong Chinese Univ.

~300 physicists from 48 institutions

Thank You!

谢谢！

Backups

Absolute Charm Branching Fractions at Threshold

N_j = number of single tags $D \rightarrow f_j$

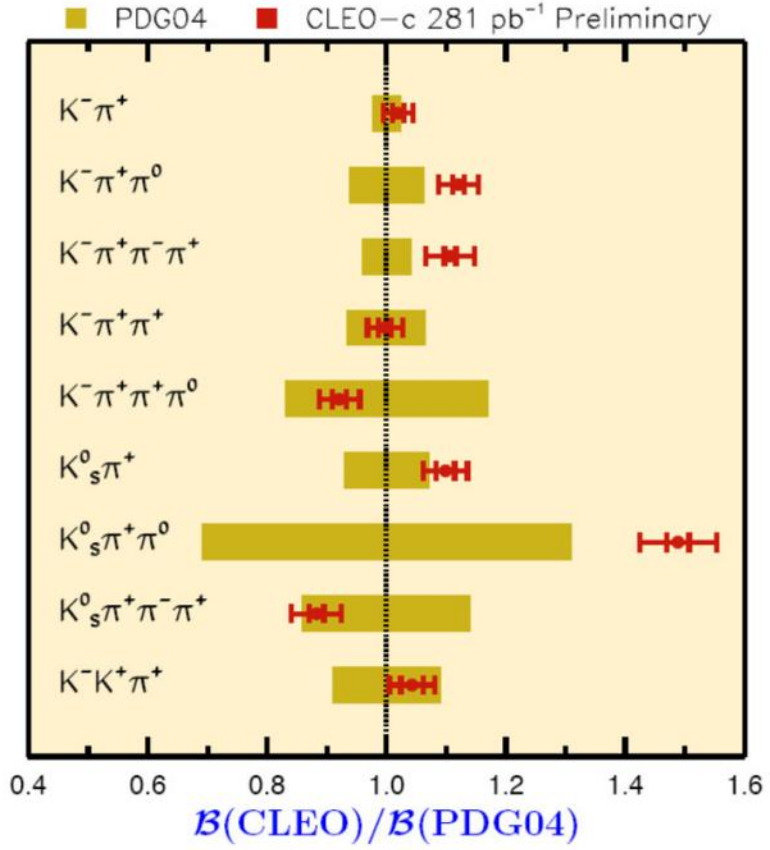
$$= N_{D\bar{D}} Br(D \rightarrow f_j) eff_{f_j}$$

N_{jk} = number of double tags $D \rightarrow f_j$ and $\bar{D} \rightarrow \bar{f}_k$

$$= N_{D\bar{D}} Br(D \rightarrow f_j) eff_{f_j} Br(\bar{D} \rightarrow \bar{f}_k) eff_{\bar{f}_k}$$

$$Br(\bar{D} \rightarrow \bar{f}_k) = \frac{N_{jk}}{N_j} \frac{1}{eff_{\bar{f}_k}}$$

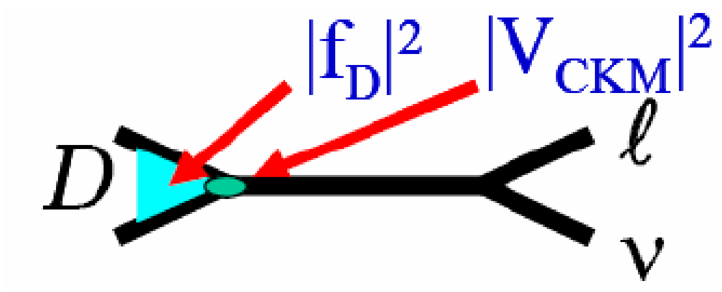
No dependence on N_{DD} or eff_{fj}



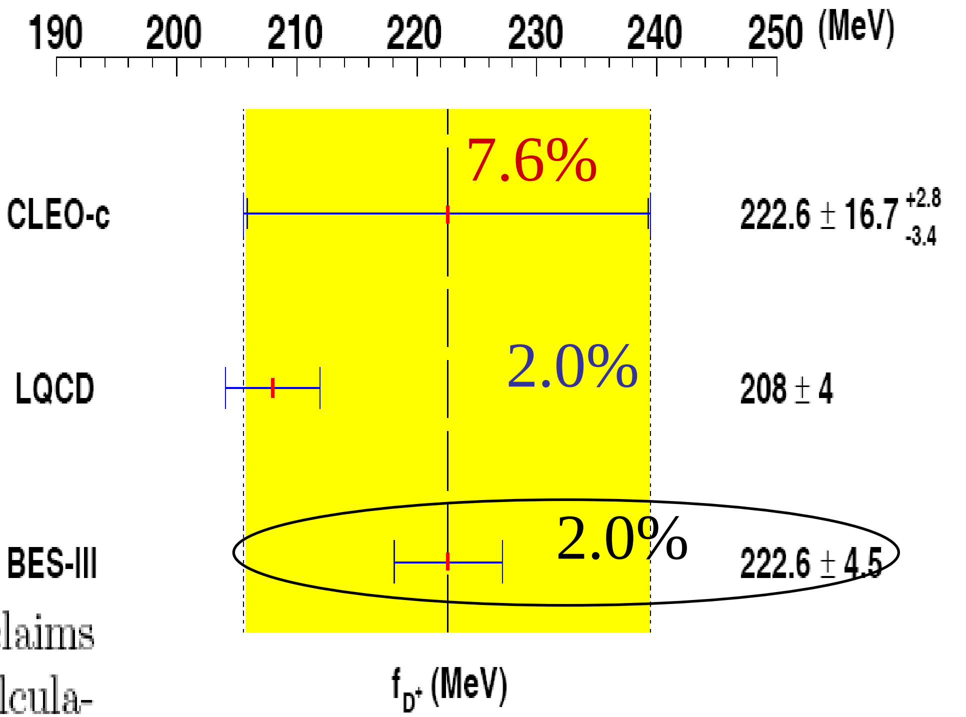
- **$s(M_{BC}) \sim$ 1.2-1.3 MeV, x2 with π^0**
- **$s(\Delta E) \sim$ 7—10 MeV, x2 with π^0**

***BESIII* should do even better**

f_{D+} and Challenge of QCD



PRL 100, 062002(2008)



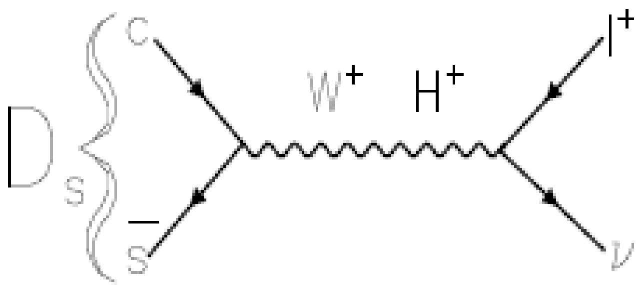
Recently, the HPQCD+UKQCD collaboration claims better than 2% precision for their unquenched calculations [11]

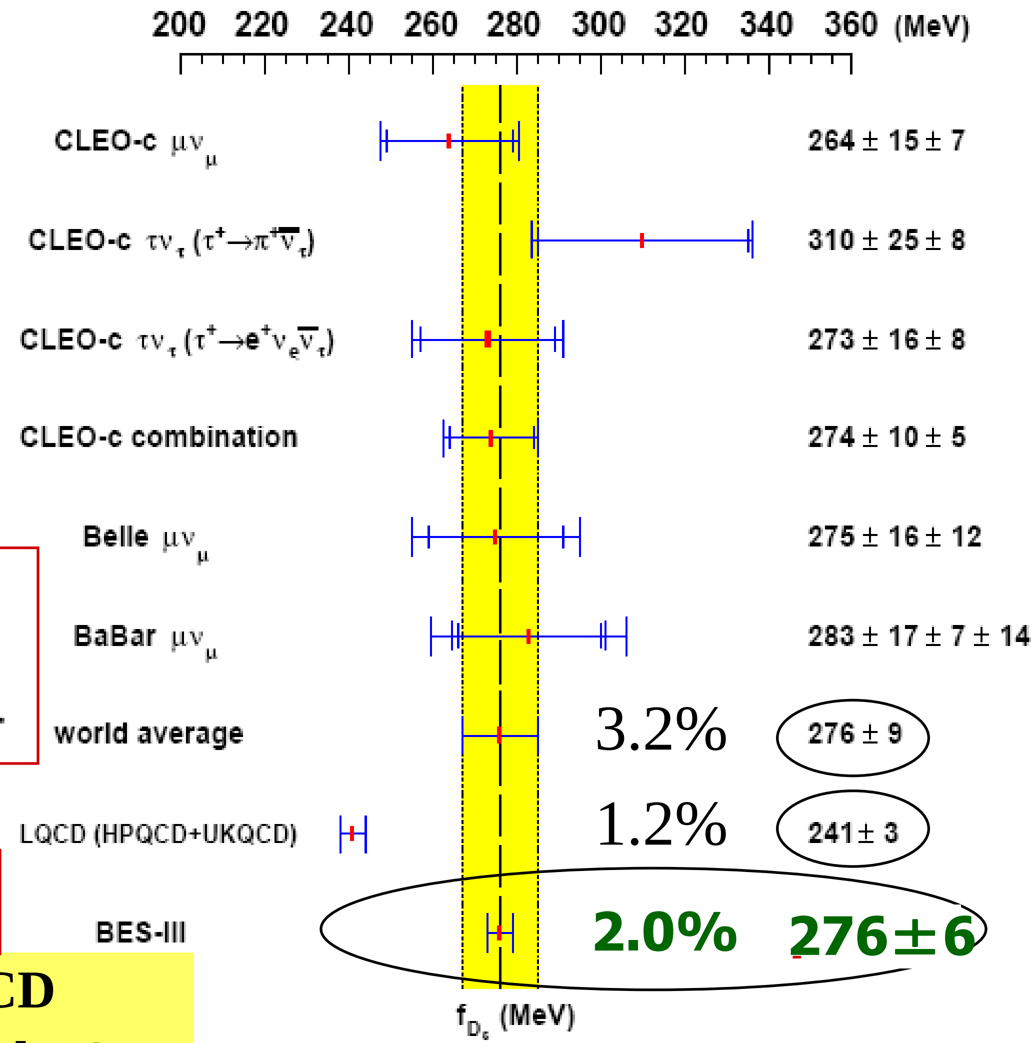
$$
\begin{aligned}
(f_{D+})_{QCD} &= (208 \pm 4)\mathrm{MeV}, \\
(f_{D_s^+})_{QCD} &= (241 \pm 3)\mathrm{MeV}, \qquad (7)
\end{aligned}
$$

BES-III reaches 2% with 20 fb^{-1} data @ psi(3770).

f_{D_s} – Challenge LQCD

See Hewett [hep-ph/9505246] & Hou, PRD 48, 2342 (1993).





CLEO-c, Belle and BaBar:

The average of $\tau\nu_\tau$ and $\mu\nu_\mu$ values is

$$(f_{D_s^+})_{exp} = (276 \pm 9)\,\mathrm{MeV}.$$

PRL 100, 062002(2008)

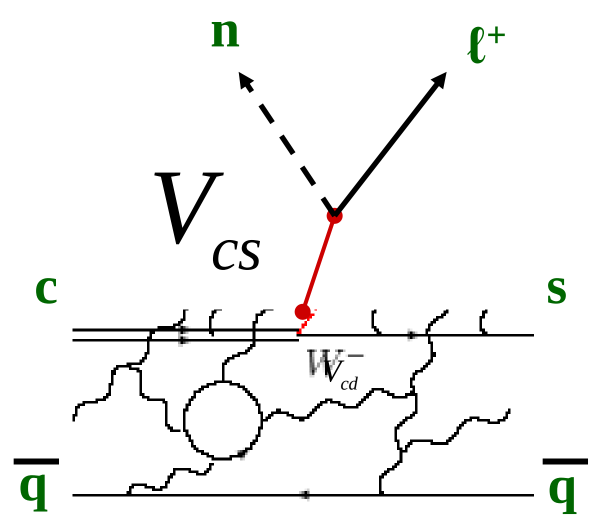
$$(f_{D_s^+})_{QCD} \;=\; (241 \pm 3)\mathrm{MeV},$$

4.0 sigma discrepancy between LQCD and experimental determination in the SM.

H.B.Li ,J.H.Zou arXiv:0804.1822

Semileptonic decay and CKM Matrix

$$\frac{d\Gamma(D\to P\ell\nu)}{dq^2}=\frac{|V_{cq}|^2 P_P^3}{24\pi^3}\left|f_+(q^2)\right|^2$$



$\frac{\Delta\tau_D}{\tau_D}\approx 0.6\%$ $\frac{\Delta\tau_{D_s}}{\tau_{D_s}}\approx 1.0\%$ Well measured

To find V_{cs} & V_{cd} need form factor from theory at one fixed q^2 point.

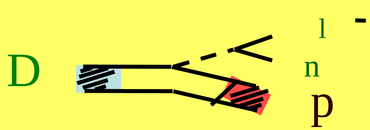
$$f_+(q^2)=\frac{f_+(0)}{1-q^2/m_{pole}^2}$$

Form Factor (FF) term comes from Lattice QCD.
Supposing ΔFF/FF ~3%.

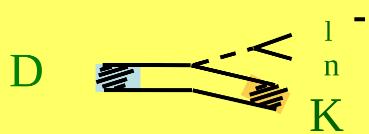
$$\frac{\Delta|V_{cq}|}{|V_{cq}|}=\sqrt{\left(\frac{\Delta B}{2B}\right)^2+\left(\frac{\Delta\tau_D}{2\tau_D}\right)^2+\left(\frac{\Delta FF}{2FF}\right)^2}$$

BESIII: Integrate Lumi. 20fb^{-1} DDbar
MC simulation@BESIII:

δVcd/Vcd 1.7%



δVcs/Vcs 1.6%



BESIII

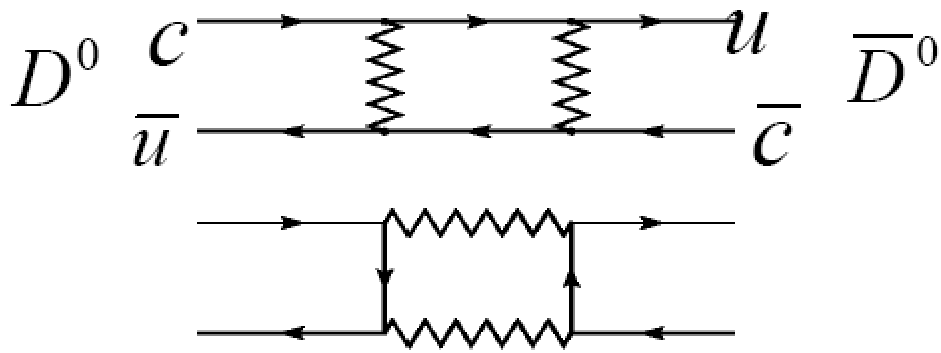
Great contribution to CKM Unitarity

Neutral D Meson Mixing

- D_0 and $\overline{D}_0$ can transform into each other (like Kaons an Bs)
- The mass eigenstates are

$$|D_1\rangle = p|D^0\rangle + q|\overline{D}^0\rangle$$

$$|D_2\rangle = p|D^0\rangle - q|\overline{D}^0\rangle$$



+ long distance physics (Kaon loop)

- With eigenvalues

$$\mu_1 = m_1 - \frac{i}{2}\Gamma_1$$

$$\mu_2 = m_2 - \frac{i}{2}\Gamma_2$$

$$m \equiv \frac{m_1 + m_2}{2}, \qquad \Delta m \equiv m_2 - m_1$$

$$\Gamma \equiv \frac{\Gamma_1 + \Gamma_2}{2}, \qquad \Delta\Gamma \equiv \Gamma_2 - \Gamma_1$$

x mixing: Channel for New Physics.

y (long-distance) mixing: SM background.

$$x \equiv \frac{\Delta m}{\Gamma}, \qquad y \equiv \frac{\Delta\Gamma}{2\Gamma}$$

Quantum Coherence at Threshold

$D\overline{D}$ pair with L =1 must be in anti-asymmetric state

$$|D^0\overline{D}^0\rangle^{C=-1} = \frac{1}{\sqrt{2}}\left[|D^0\rangle|\overline{D}^0\rangle - |\overline{D}^0\rangle|D^0\rangle\right]$$

Suppose Both D^0 decay to CP eigenstate f_1 and f_2 .

for the decay of $\psi'' \rightarrow f_1 f_2$

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

$$CP(\psi'') = +$$

(C=−1) $e^+e^- \rightarrow \psi(3770) \rightarrow$	D	$\overline{D}$
Forbidden if no mixing	$K^-\pi^+$	$K^-\pi^+$
Forbidden if no mixing	$K^-l^+\nu$	$K^-l^+\nu$
Forbidden by CP conservation	CP+	CP+
Forbidden by CP Conservation	CP−	CP−

Mixing Rate

no mixing: $D^0 \to K^-\pi^+$ $\bar{D}^0 \to K^+\pi^-$

mixing: $D^0 \to K^-\pi^+$ $\bar{D}^0 \to D^0 \to K^-\pi^+$

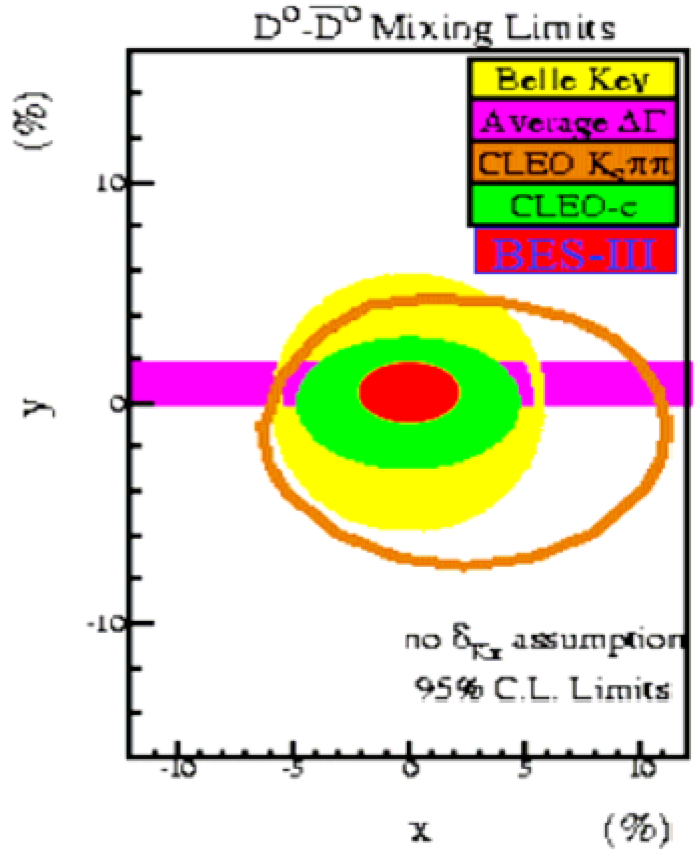
- **Golden channel**
  - **$D^0 \to K\pi$**
- **Semileptonic channel**
  - **$Ke\nu$, $K\mu\nu$, etc**

Sensitivity: current limit: 10^{-3}

$\psi(3770) \to D^0\bar{D}^0 \to (K^-\pi^+)(K^-\pi^+)$

$$R_M = \frac{x^2 + y^2}{2} = \frac{N[(K^\pm\pi^\mp)(K^\pm\pi^\mp)]}{N[(K^\pm\pi^\mp)(K^\mp\pi^\pm)]}$$

Sensitivity in 20 fb^{-1} data at BES-III:



Double tag measurements.

At BESIII sensitivities of R_M will @ 10^{-4}—10^{-5}

CP Violation

1. Direct CP Violation (in decay)

$$A = \frac{\Gamma(D_q^+ \to f^+) - \Gamma(D_q^- \to f^-)}{\Gamma(D_q^+ \to f^+) + \Gamma(D_q^- \to f^-)}$$

2. Indirect CP Violation (in mixing)

$$A = \frac{\Gamma(D^0_{phys}(t) \to X l^+ \nu) - \Gamma(\overline{D^0_{phys}}(t) \to X l^- \nu)}{\Gamma(D^0_{phys}(t) \to X l^+ \nu) + \Gamma(\overline{D^0_{phys}}(t) \to X l^- \nu)}$$

3. CP violation in the interference between decays w/o mixing

$$A = \frac{\Gamma(D^0_{phys}(t) \to f_{CP}) - \Gamma(\overline{D^0_{phys}}(t) \to f_{CP})}{\Gamma(D^0_{phys}(t) \to f_{CP}) + \Gamma(\overline{D^0_{phys}}(t) \to f_{CP})}$$

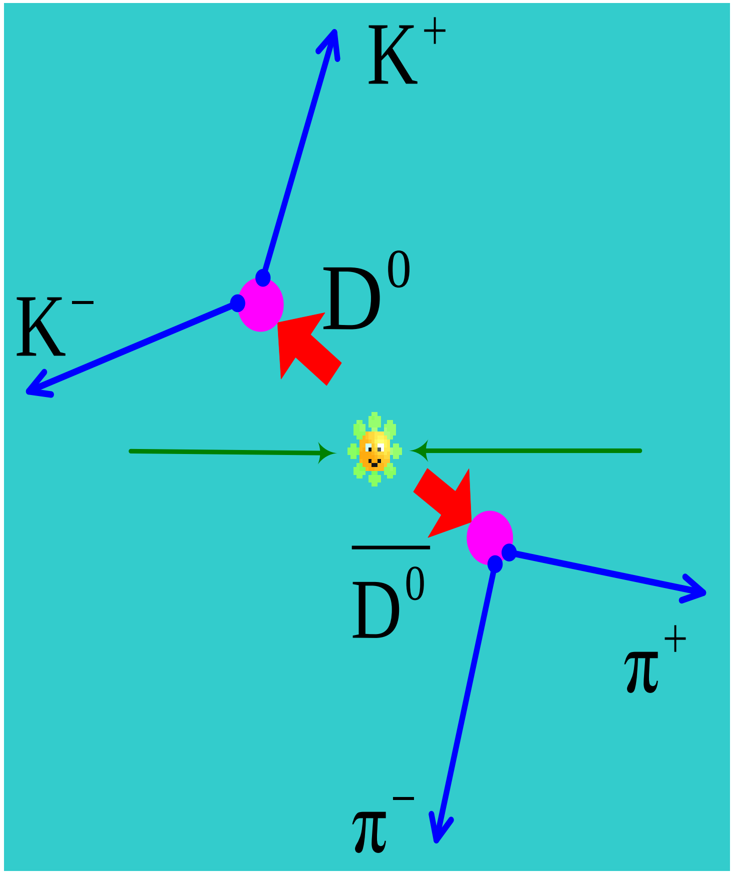
Above all, SM predicts an unobservable asymmetry of $\sim 10^{-4}$

- 1% level CPV likely indicates new physics.

Needs extremely good control of systematic effects at the 10^{-3} level -- very challenging!

Direct CP Violation

Thus if a final state such as (*KK*)($\pi\pi$) observed, we immediately have evidence of CP violation



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

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

In 20 fb^{-1} y(3770) data, > 1000 double CP+ and CP- tags can be obtained. if 100%CPV, it lead to A_{CP}~10^{-3} level

Rare and forbidden decays

Search for New Physics in Charm Sector:

- **Lepton flavour and lepton number violating decays of charmonium and open charm**
- **Rare charm decays heavily GIM suppressed: BF($c \rightarrow ull$)~10^{-8}**
- **Weak charmonium decays: $J/\psi \rightarrow DX$**
  - **BES almost reaches down to rates predicted in SM**

- **Charm Mixing (Large CPV in mixing indicates New Physics)**
- **CP Violation - Direct (New Physics could be ~%)**