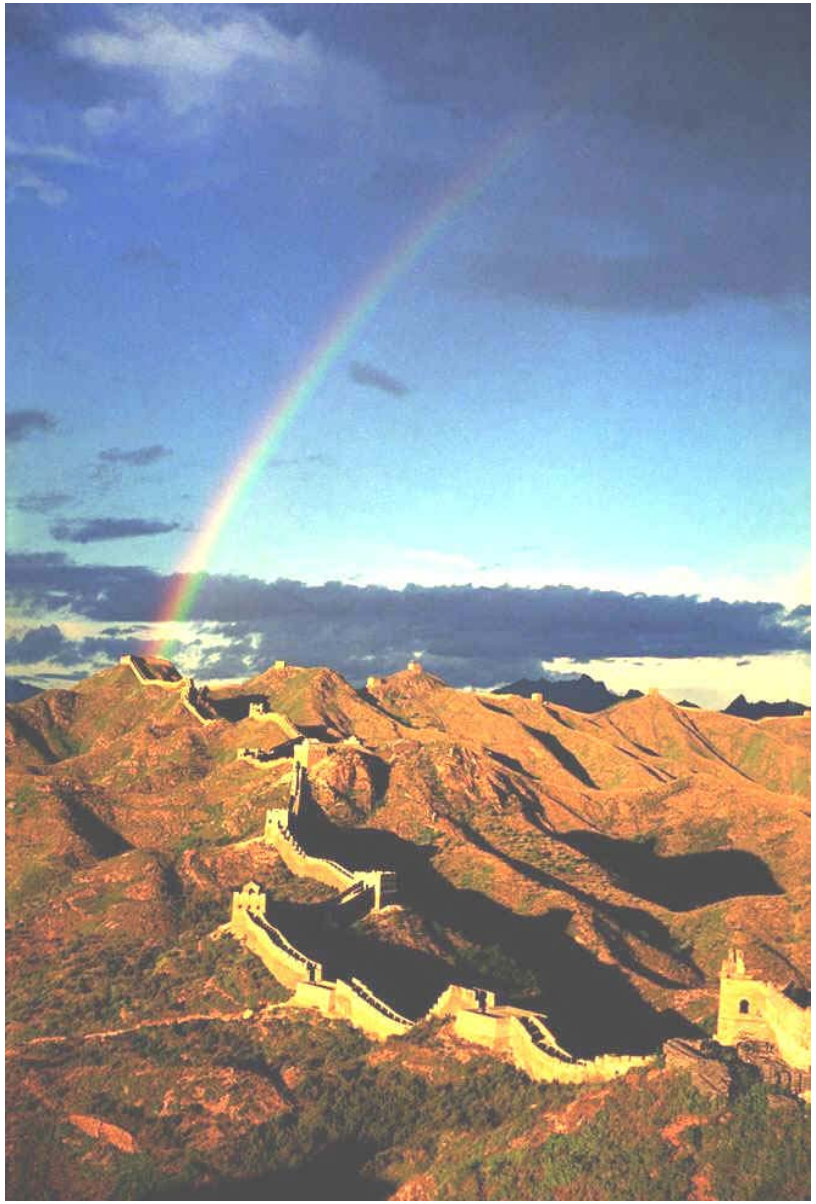
New Physics Opportunities in the Charm/Tau Region:

The BESIII - Experiment at IHEP/Beijing



Introduction

BES3/BEPC2

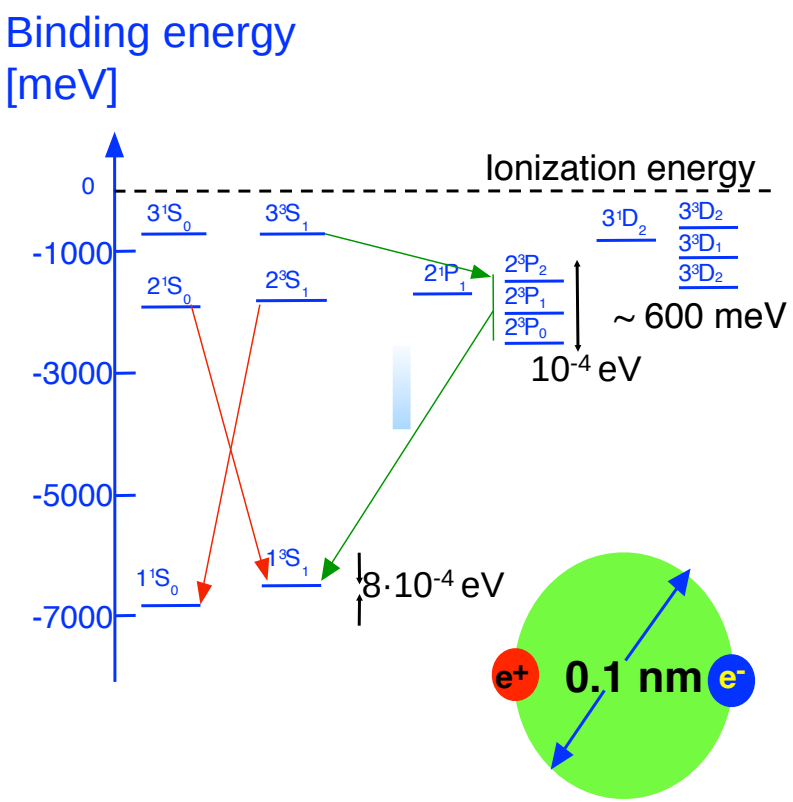
Physics Programme

First Results

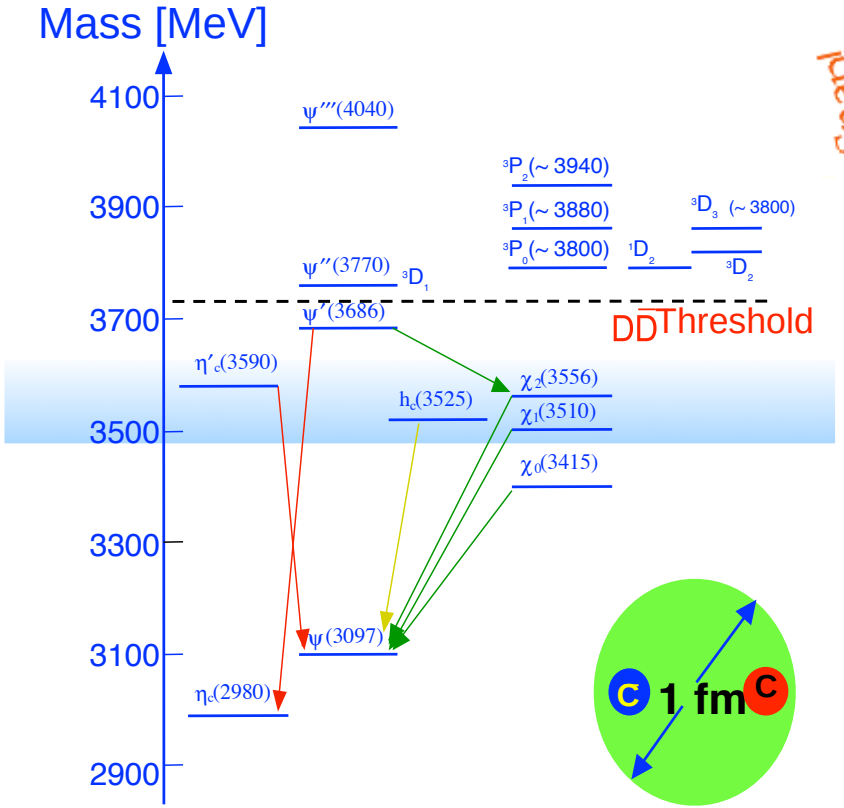
Summary

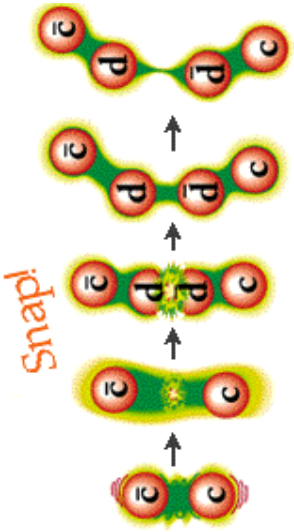
Charmonium: Positronium of QCD

Positronium



Charmoniun

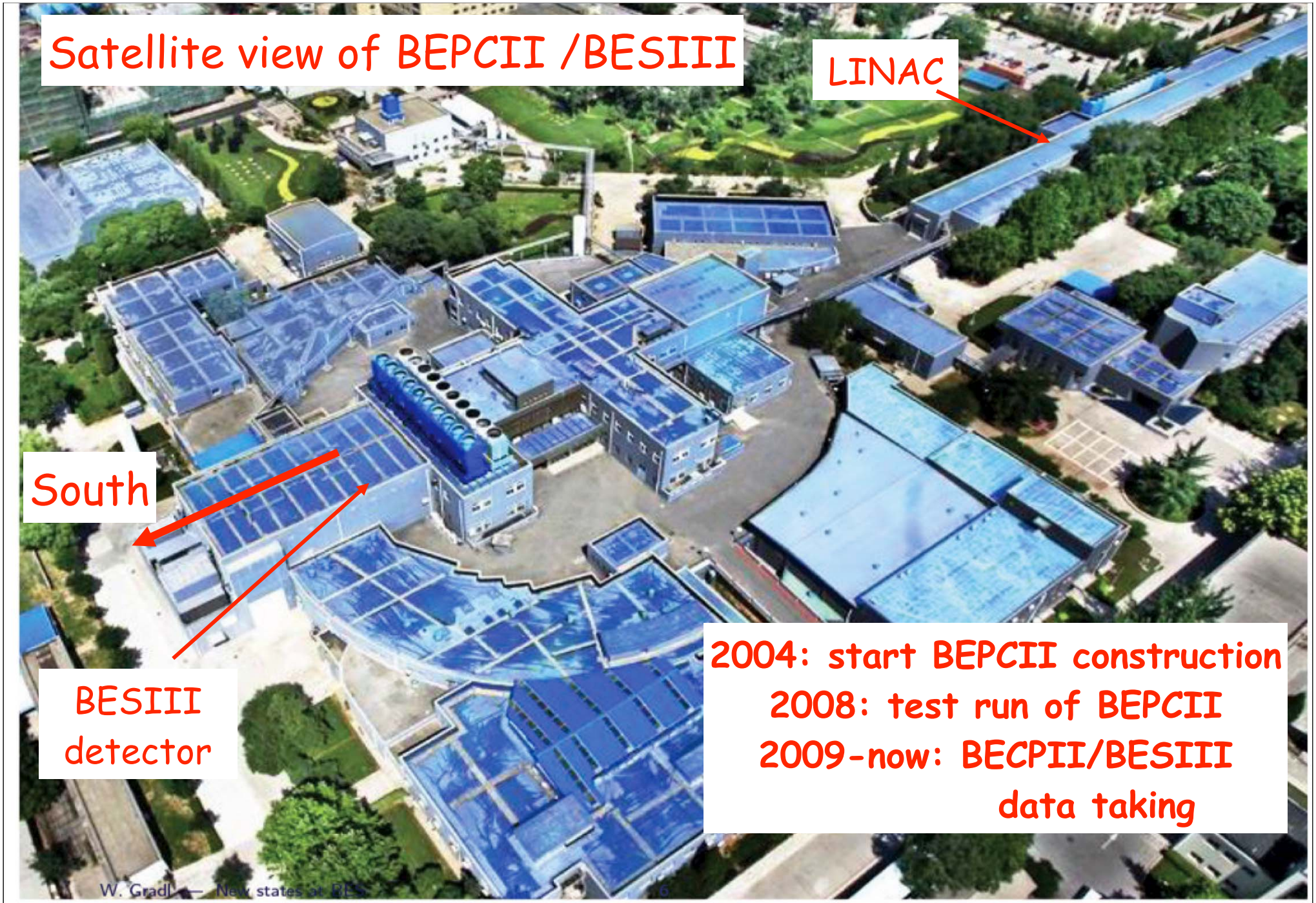




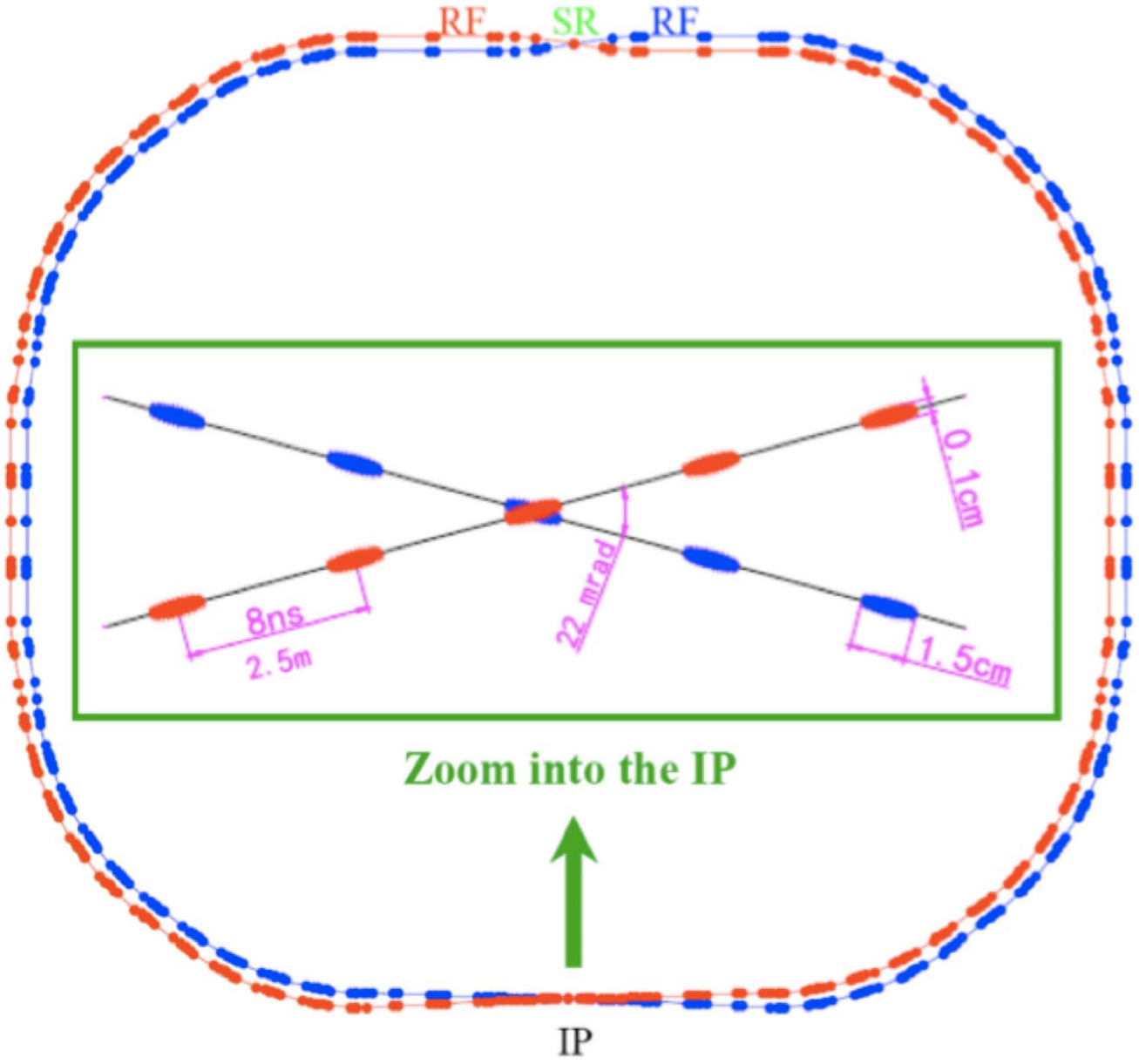
Charmonium states are narrow and well separated !

Institute of High Energy Physics, Beijing

- The Institute of High Energy Physics (IHEP) is the biggest and most comprehensive fundamental research center in China.
- The major research fields of IHEP are particle physics, accelerator physics and technologies, radiation technologies and applications
  - 1000 employees, ~ 650 physicists and engineers,
  - 400 PhD Students and Postdocs
- Established in 1950, and became an independent institute for HEP in 1973


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} $cm^{-2}s^{-1}$
Achieved Luminosity:
0.65×10^{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

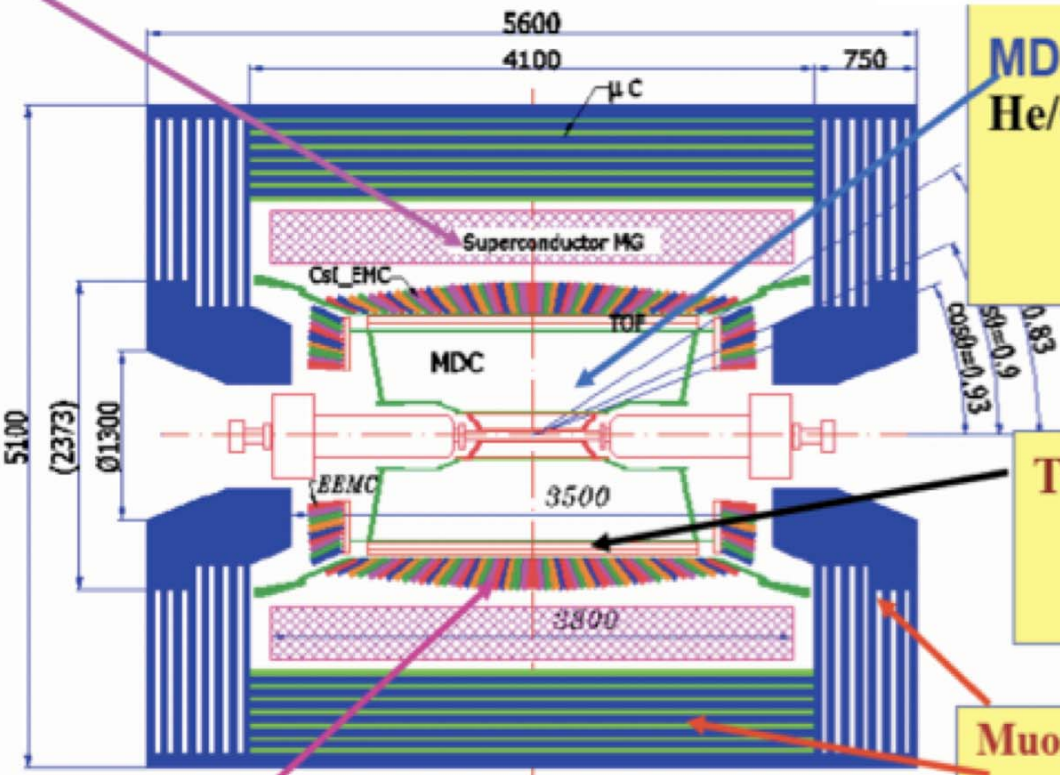
BESIII detector: all new !

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

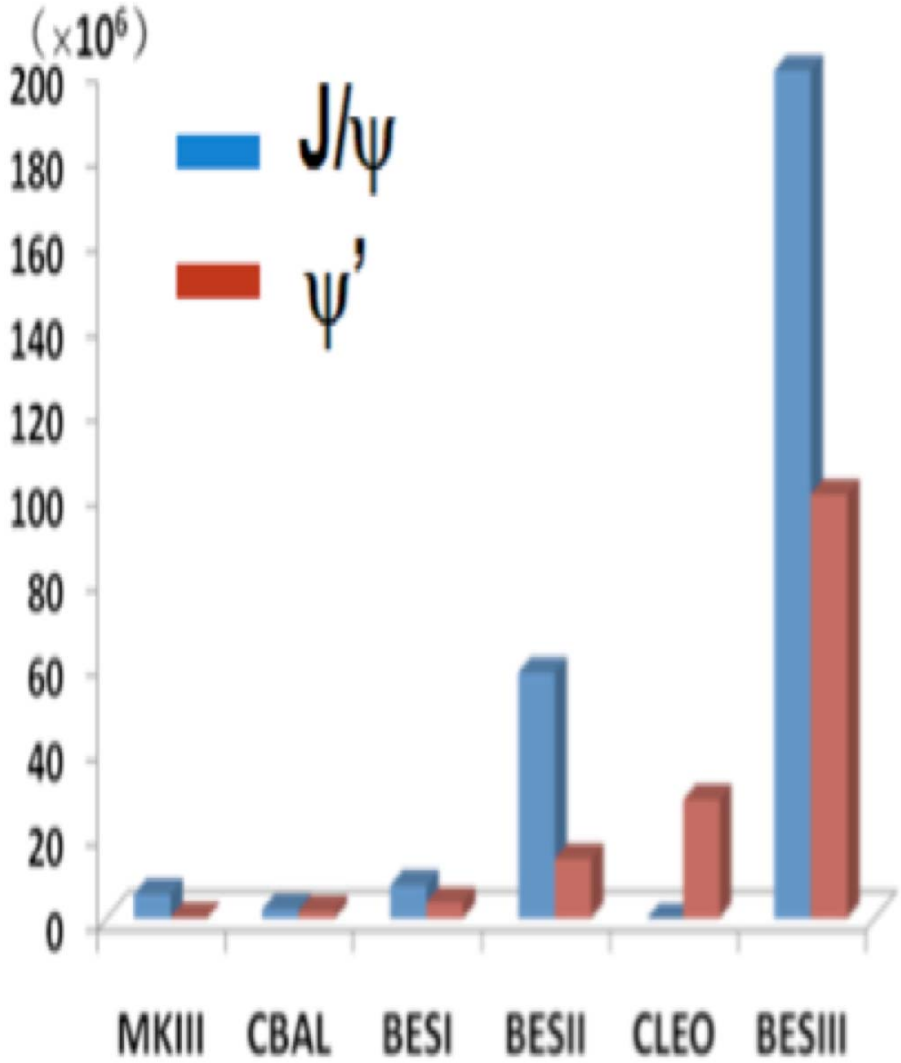
Muon ID: 9 layers RPC
8 layers for endcap

EMC: CsI crystal, 28 cm
ΔE/E = 2.5% @1 GeV
σz = 0.6 cm/√E

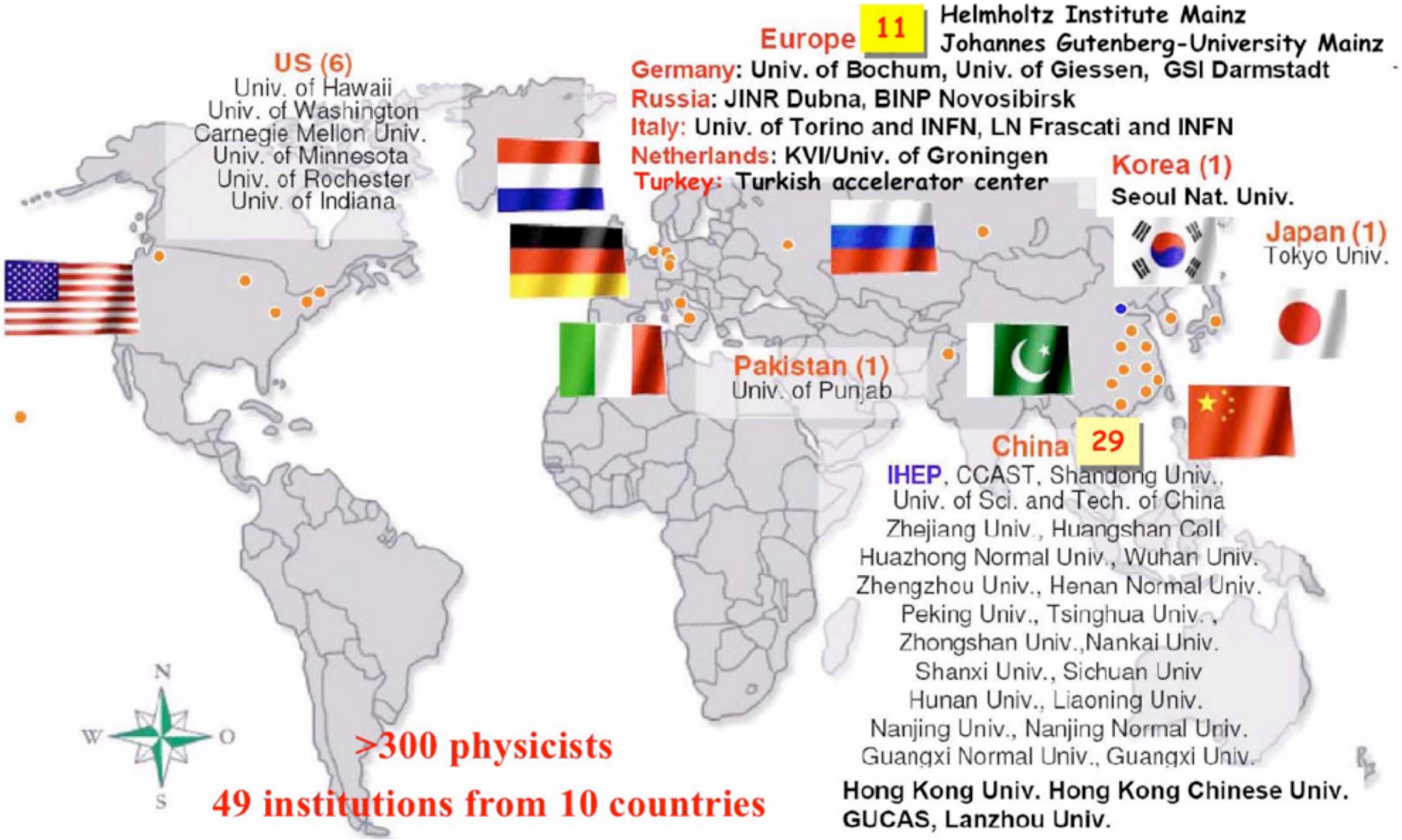
Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s

Data samples

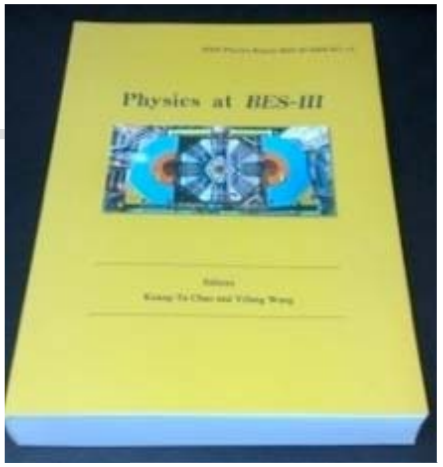
- **So far BESIII has collected :**
  - **2009: 225 Million J/ψ**
  - **2009: 106 Million ψ'**
  - **2010-11: 2.9 fb^{-1} ψ(3770)**
    (3.5 x CLEO-c)
    - May 2011: 0.48fb^{-1} @4010 MeV: Ds, XYZ spectroscopy
- **Plans for 2012:**
  - **1 Billion J/ψ, 700 Million ψ'**
  - **Tau mass scan**



BESIII Collaboration



Physics Topics at BESIII



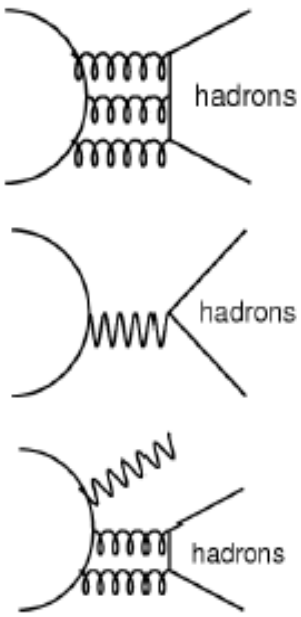
arXiv:
0809.1869

- Light hadron spectroscopy
  - search for non-$q\bar{q}$ or non-qqq states
  - meson spectroscopy
  - baryon spectroscopy
- Production and decay mechanisms of charmonium states: J/ψ, $\psi(2S)$, $\eta_c(1S)$, $\chi_{c\{0,1,2\}}$, $\eta_c(2S)$, $h_c(^1P_1)$, $\psi(3770)$, etc.

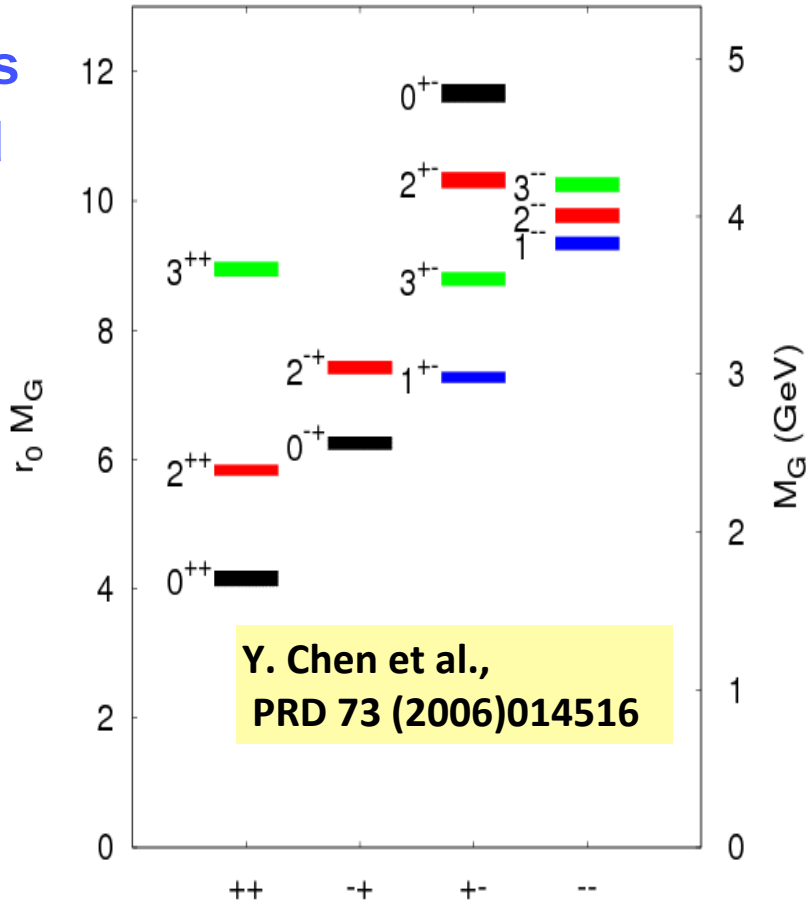
  New Charmonium states above open charm threshold (X,Y,Z)
- Precise measurement of R values
- Precise measurement of CKM matrix elements
- Search for DDbar mixing, CP violation, etc.
- Search for rare and forbidden decays
- Precision Tau mass measurement via threshold scan

Study of the spectroscopy – towards deeper understanding of hadron structure

- **Motivation:**
  - Establish spectrum of light hadrons
  - Search for non-conventional hadrons
  - Understand how hadrons are formed
- **Why at a τ-charm collider ?**
  - Gluon rich
  - Clean environment
  - J^{PC} filter



Glueball spectrum from LQCD



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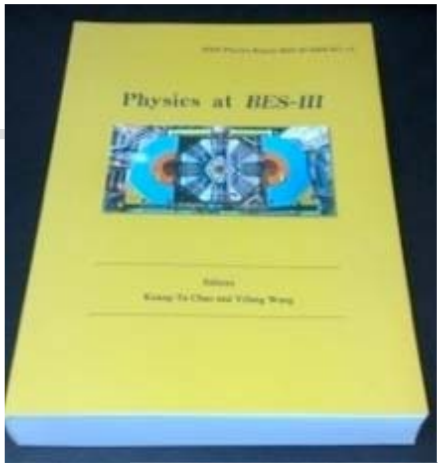

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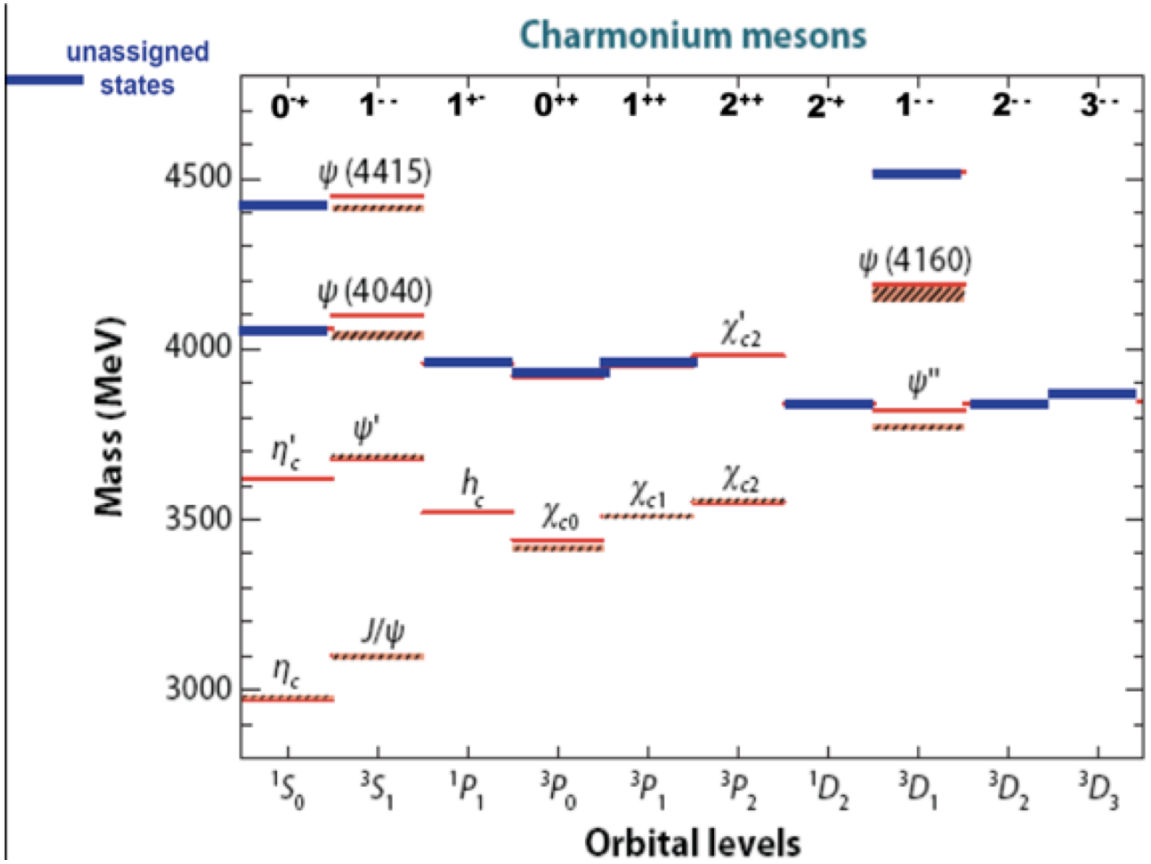
Charmonium physics

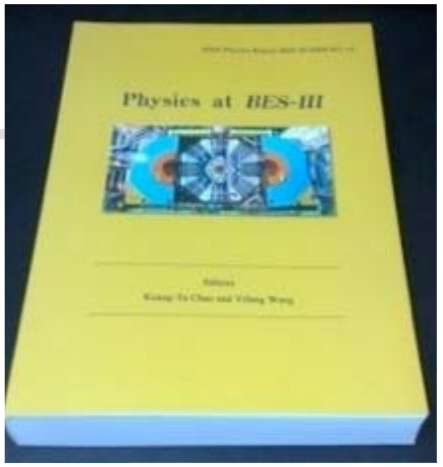
- What to study ?
  - Production, decays, transitions, spectrum
- For what ?
  - A lab at the interface of pQCD and non-pQCD
  - Calibrate LQCD
  - How do quarks form a hadron ?
- Why at a tau-charm collider ?
  - A clean environment
  - Tagging possible
  - Abundantly produced



Examples of interesting/long standing issues:

- $\rho\pi$ puzzle
- Missing states ?
- Mixing of states ?
- New states above open charm threshold(X,Y,Z)

Physics Topics at BESIII



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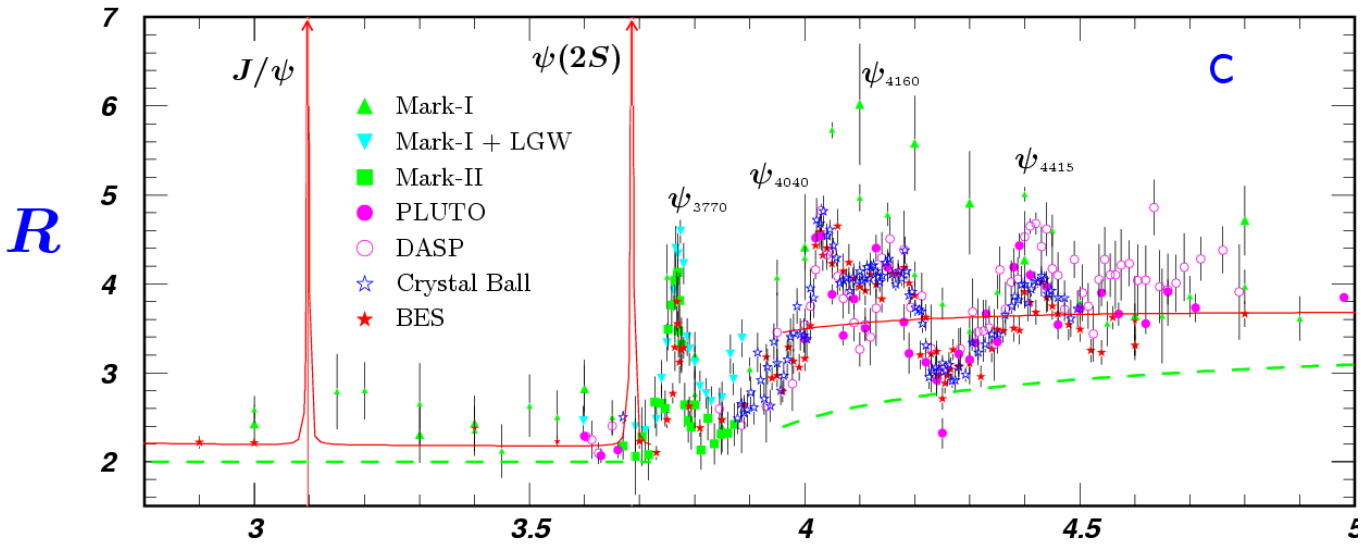
R values and precision tests of the Standard Model

- Measurements of the total cross section for e^+e^-–annihilation into hadrons are
  - Indispensable input for the determination of the non–perturbative hadronic contribution to the running of the QED fine structure constant,
  - An essential input parameter in precision electroweak measurements

$$R_{\mathrm{had}}(s) = \frac{\sigma_{tot}(e^+e^- \to \gamma^* \to hadrons)}{\sigma(e^+e^- \to \gamma^* \to \mu^+\mu^-)}$$



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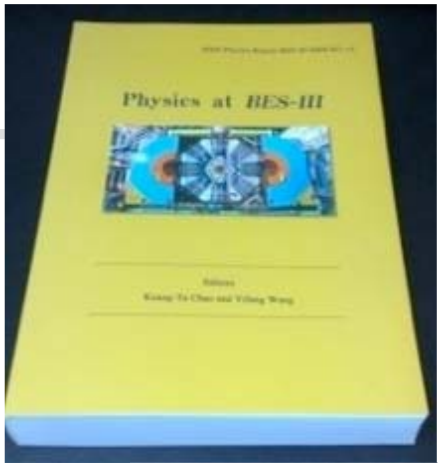

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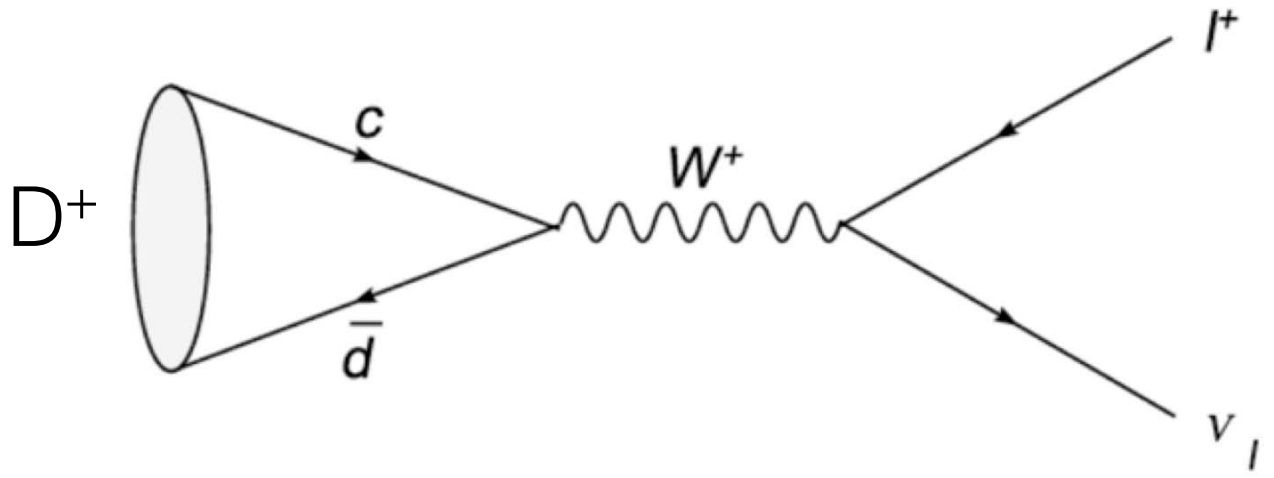
Leptonic decays of D mesons:

Non-perturbative QCD meets CKM physics

D^+ decay constant **CKM Matrix Element**

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



Decay constants and Lattice QCD

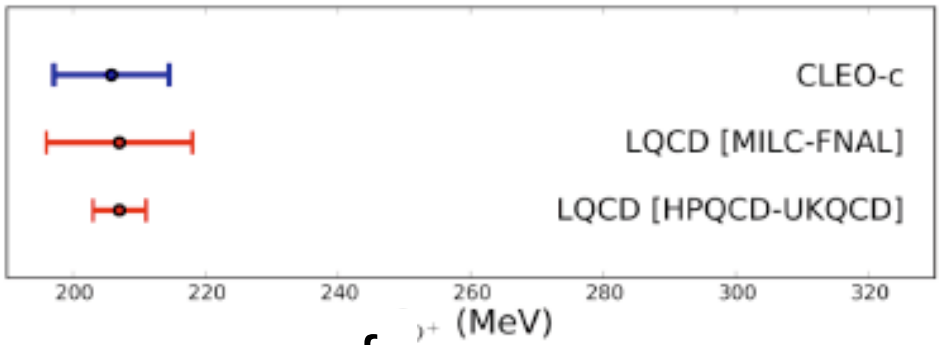
CLEO-c f_{Ds} = 259.5 ± 6.6 ± 3.1 MeV
Lattice: 241 ± 3 MeV [HPQCD-UKQCD]
249 ± 11 MeV [Fermilab-MILC]

CLEO-c f_D = 205.8 ± 8.5 ± 2.5 MeV
Lattice: 208 ± 4 MeV [HPQCD-UKQCD]
207 ± 11 MeV [Fermilab-MILC]

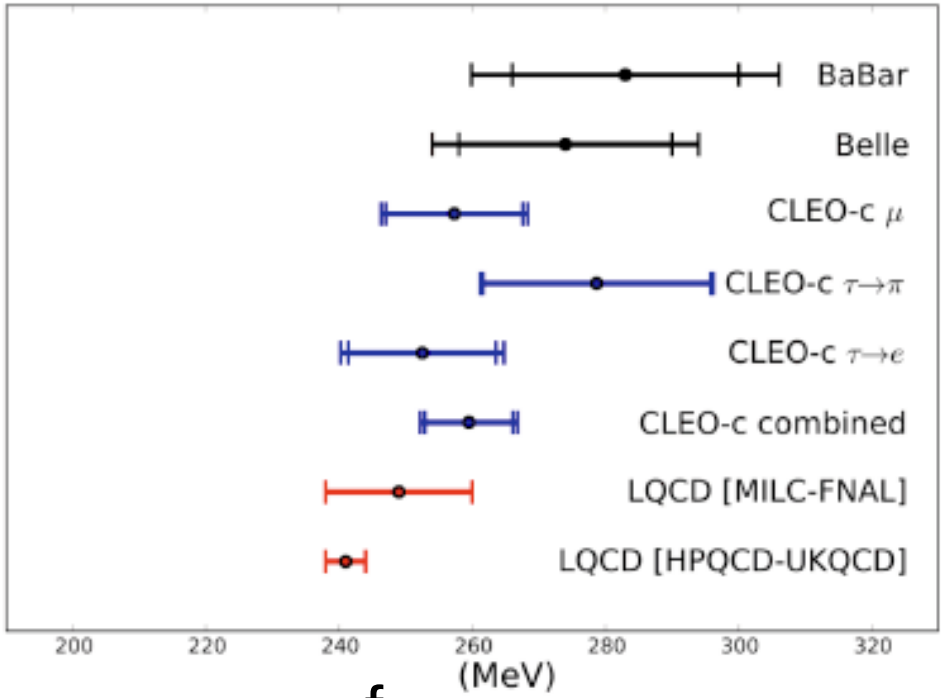
CLEO-c f_{Ds}/f_D = 1.26 ± 0.06 ± 0.02
Lattice: 1.162 ± 0.009 [HPQCD-UKQCD]
1.200 ± 0.027 [Fermilab-MILC]

2.3 σ difference for f_{Ds}. real ?

BESIII may resolve this issue, reaching the precision of LQCD.



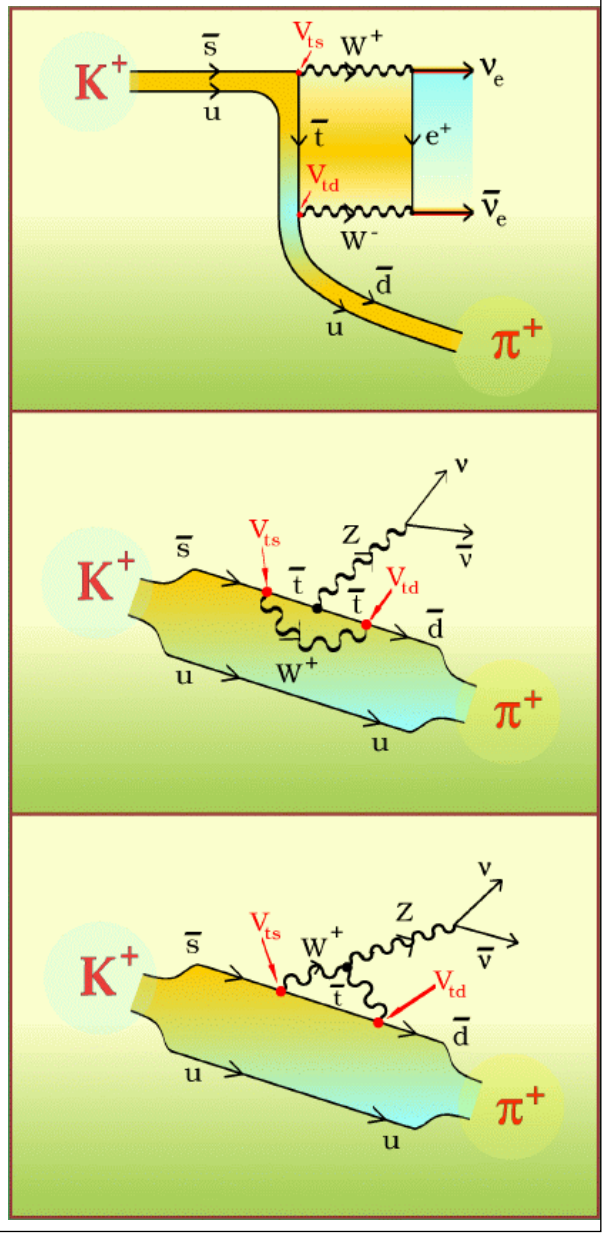
f_D



f_{Ds}

Search for new physics

- Energy frontier (LHC)
  - Direct production of new particles
    - Higgs, SUSY etc.
- Precision frontier (SuperB, Tau/Charm factories, other precision experiments)
  - New physics appears in loops
    - Modified SM decay rates
      - Look at rare or forbidden decay modes
  - Non-SM-CP violation
  - Invisible decays

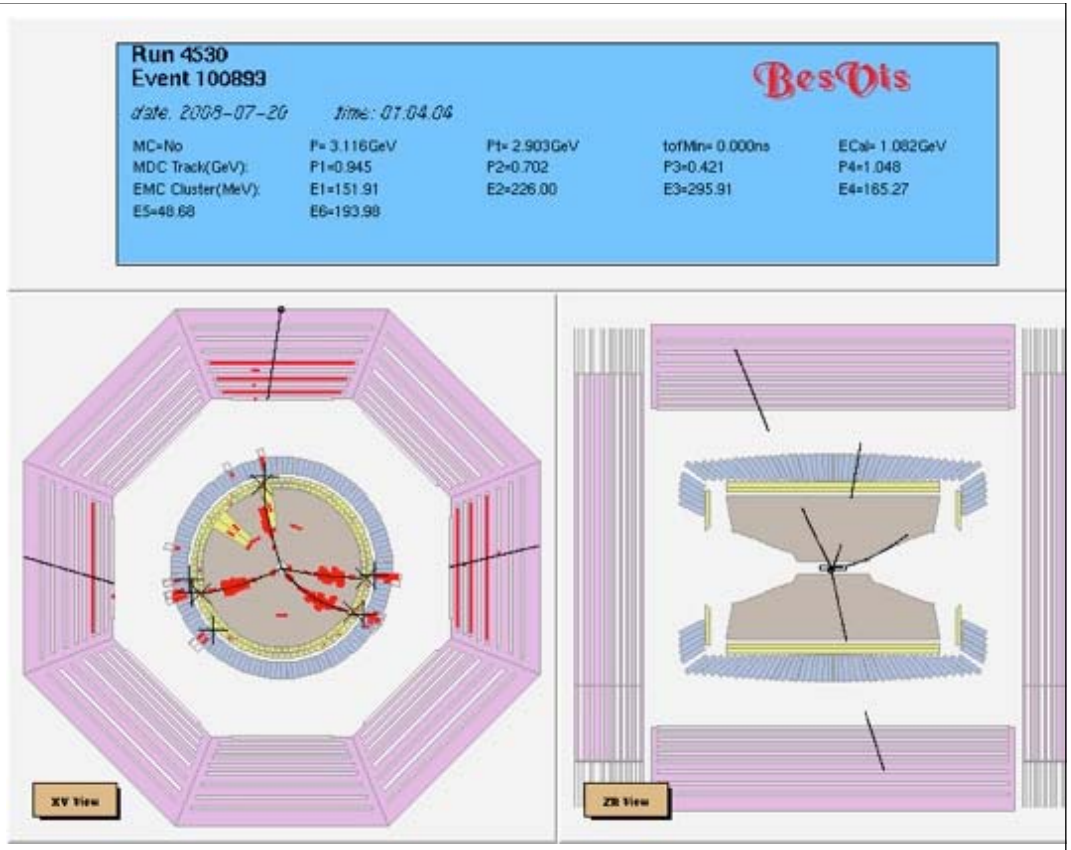


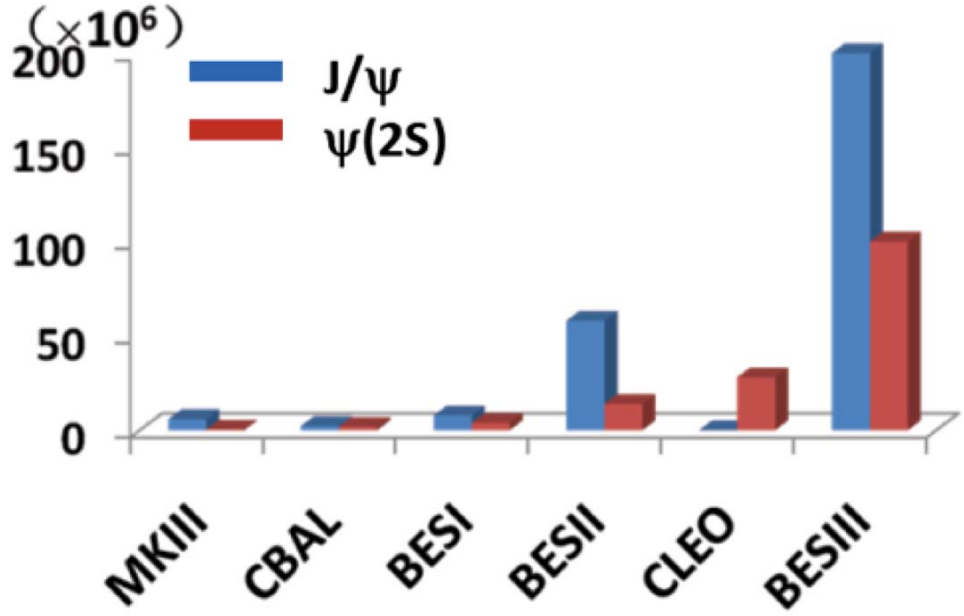
Selected results

Light hadron spectroscopy

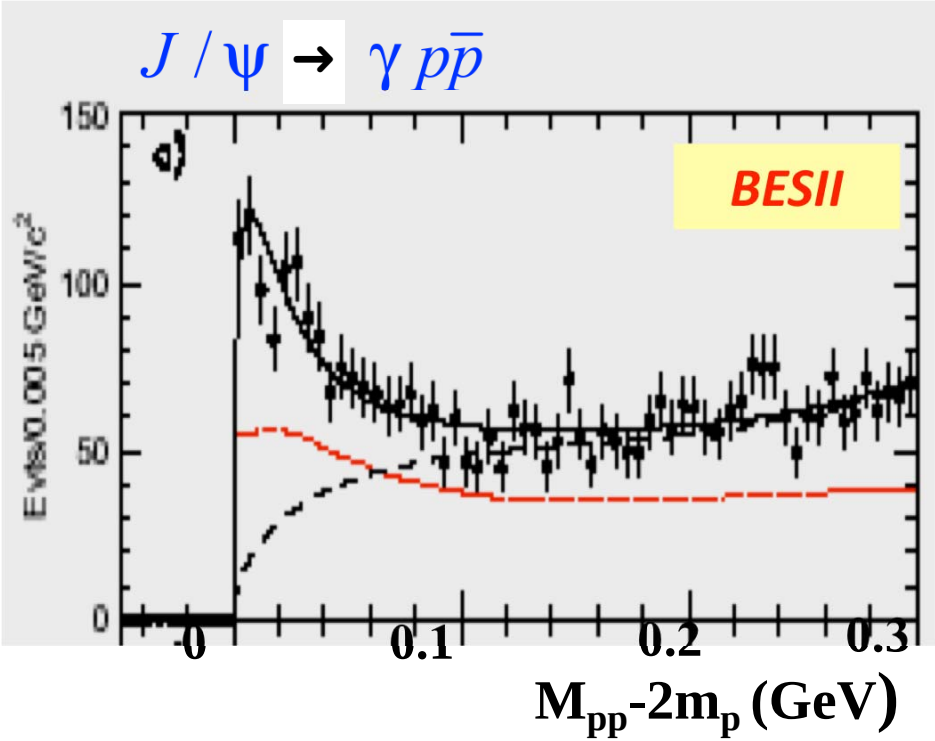
Charmonium spectroscopy

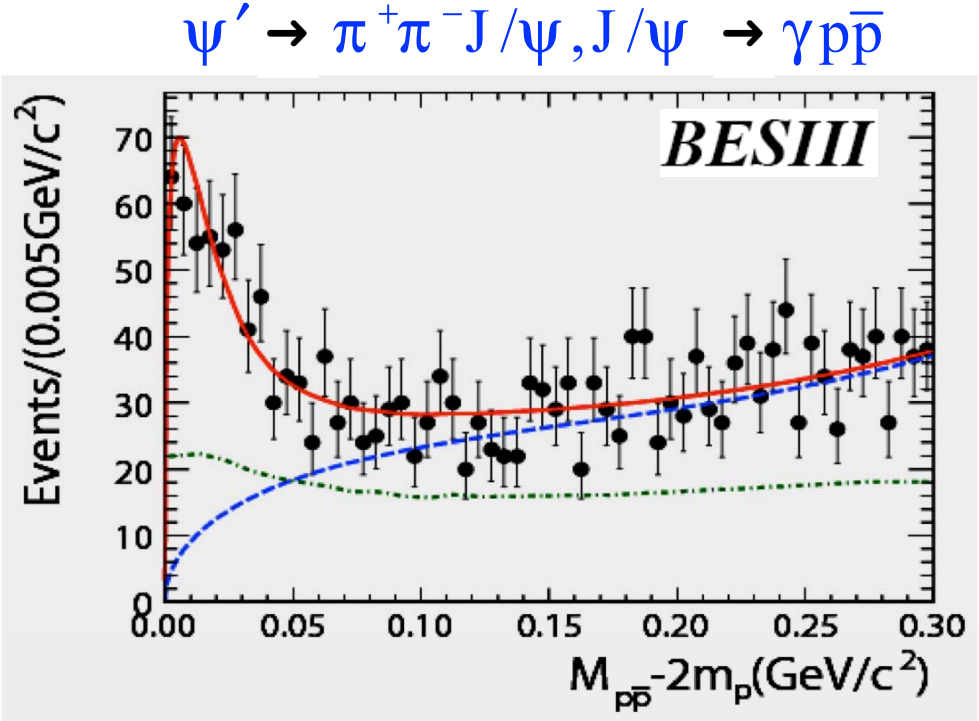
Open charm production





Observation of proton-antiproton mass threshold enhancement





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

$\Gamma < 30$ MeV/c² (90% CL)

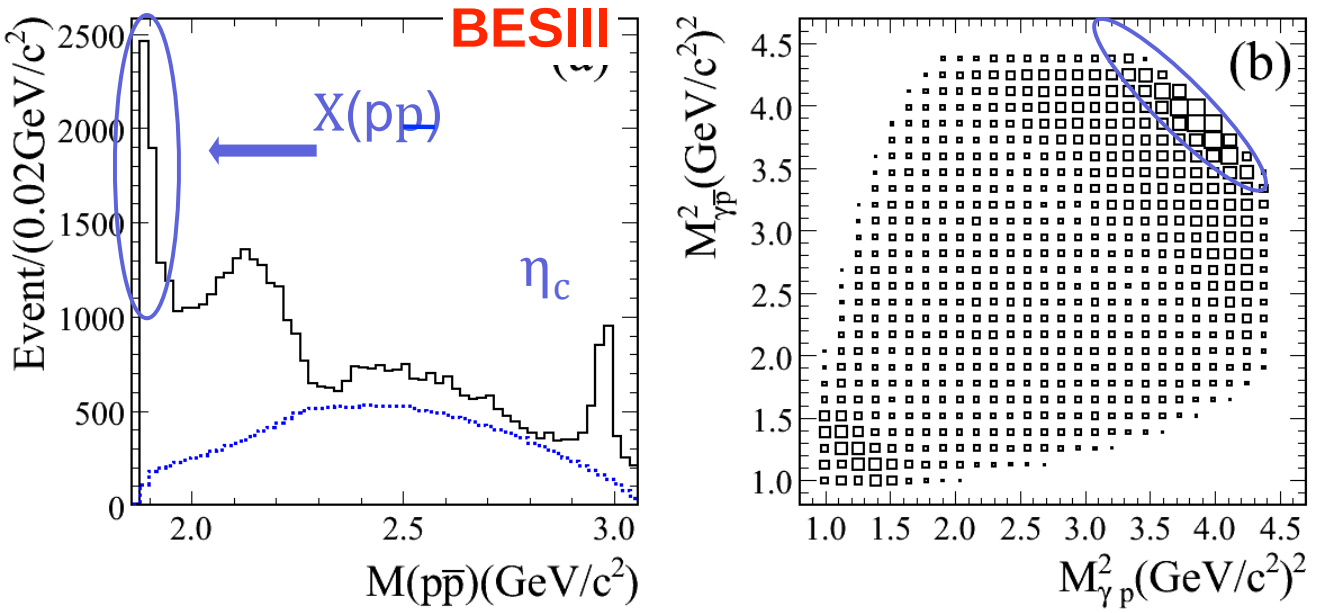
PRL 91 (2003) 022001

$M=1861\ ^{+6}_{-13}\ ^{+7}_{-26}$ MeV/c²

$\Gamma < 38$ MeV/c² (90% CL)

Chinese Physics C 34, 421 (2010)

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

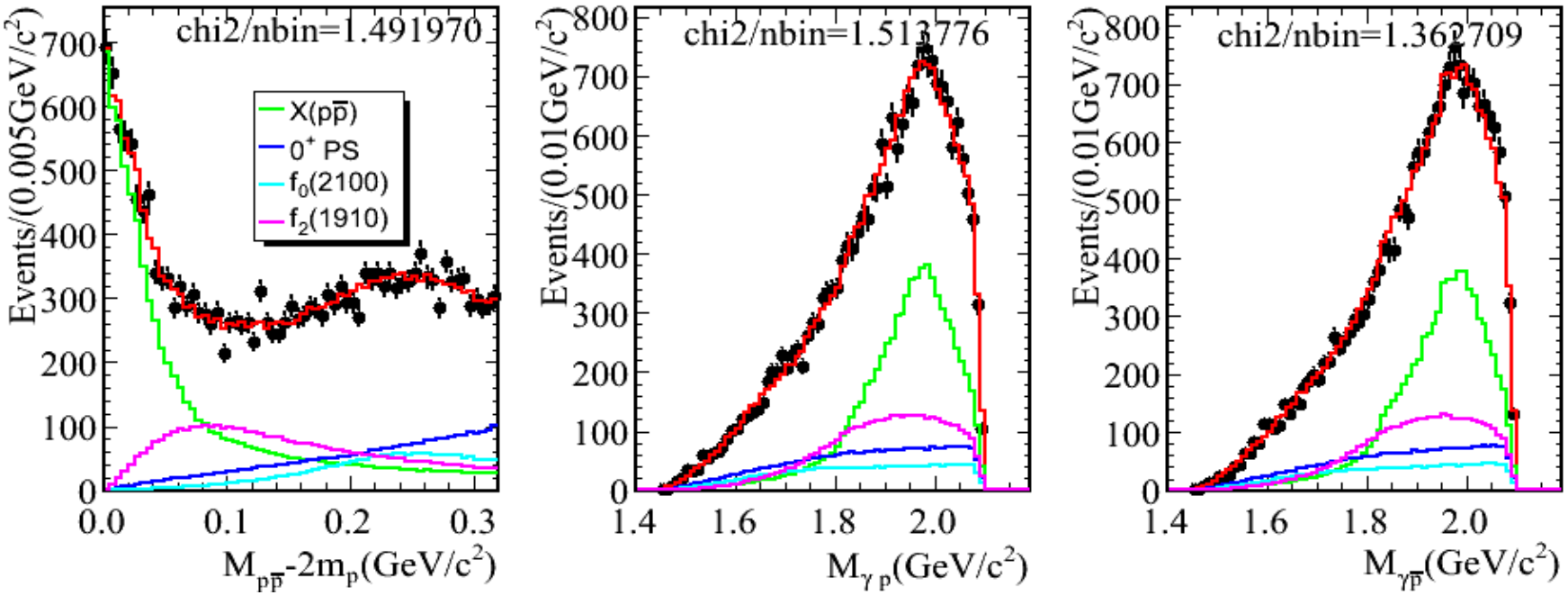


- **Evident narrow ppbar mass threshold enhancement in J/ψ decays.**

- **Partial Wave Analysis (PWA)**
  - Convariant tensor amplitudes (S. Dulat and B. S. Zou, Eur.Phys.J A 26:125, 2005).
  - Include the Julich-FSI effect (A. Sirbirtsev et al. Phys.Rev.D 71:054010, 2005).

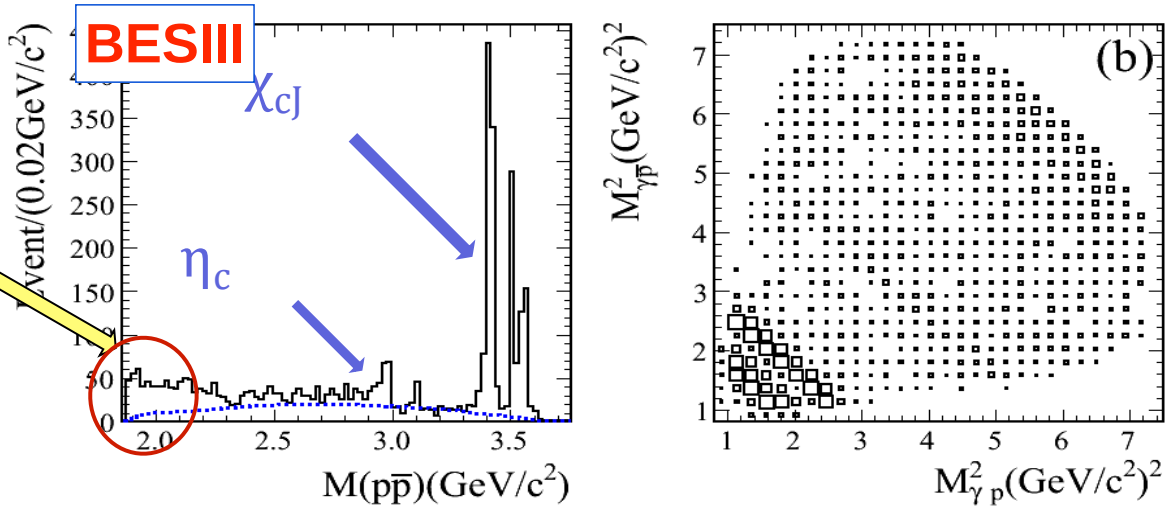
Preliminary:
PWA results and projections in $J/\psi \rightarrow \gamma p\bar{p}$

Component	J^{PC}	M (GeV)	Γ (GeV)	Stat.sig.
$X(p\bar{p})$	0^{-+}	1.832 ± 0.005	0.013 ± 0.020	$\gg 30\sigma$
$f_0(2100)$	0^{++}	2.103	0.209	11.2σ
$f_2(1910)$	2^{++}	1.903	0.196	7.7σ
phase space	0^{++}	–	–	6.3σ



PWA on the ppbar mass threshold structure in $\psi' \to \gamma p\bar{p}$

Obviously different line shape of ppbar mass spectrum near threshold from that in J/ψ decays



PWA results:

- Significance of X(ppbar) is larger than 6.9σ.
- The production ratio R:

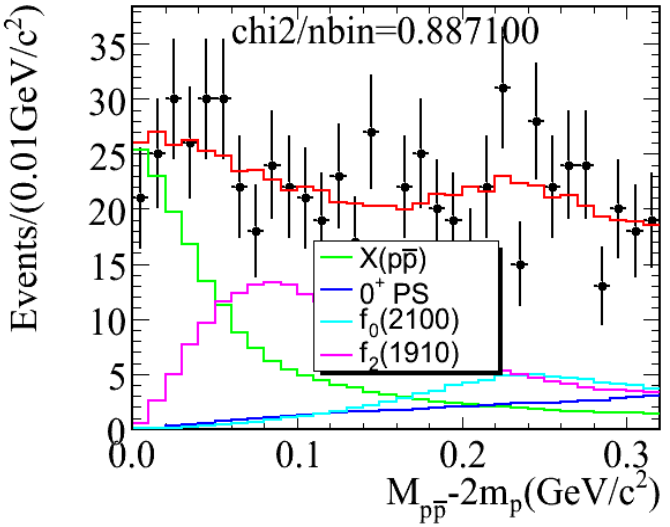
first measurement

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

$$= (5.08 \pm 0.56(\text{stat})^{+0.72}_{-3.83}(\text{syst}) \pm 0.12(\text{mod}))\%$$

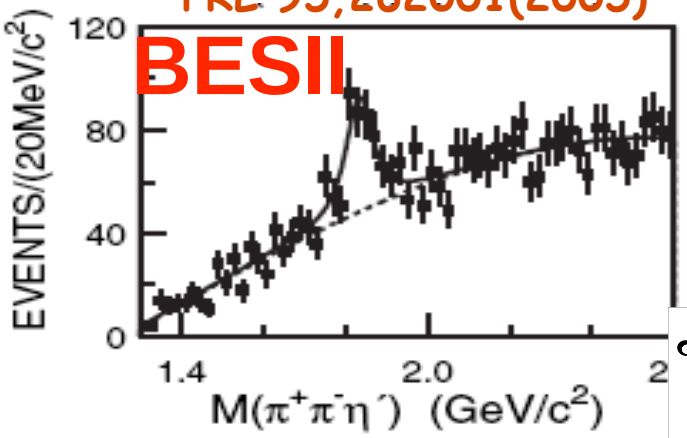
- Suppressed, consistent with "12% rule".

PWA Projection:



Confirmation of X(1835) and Observation of two new structures

PRL 95,262001(2005)

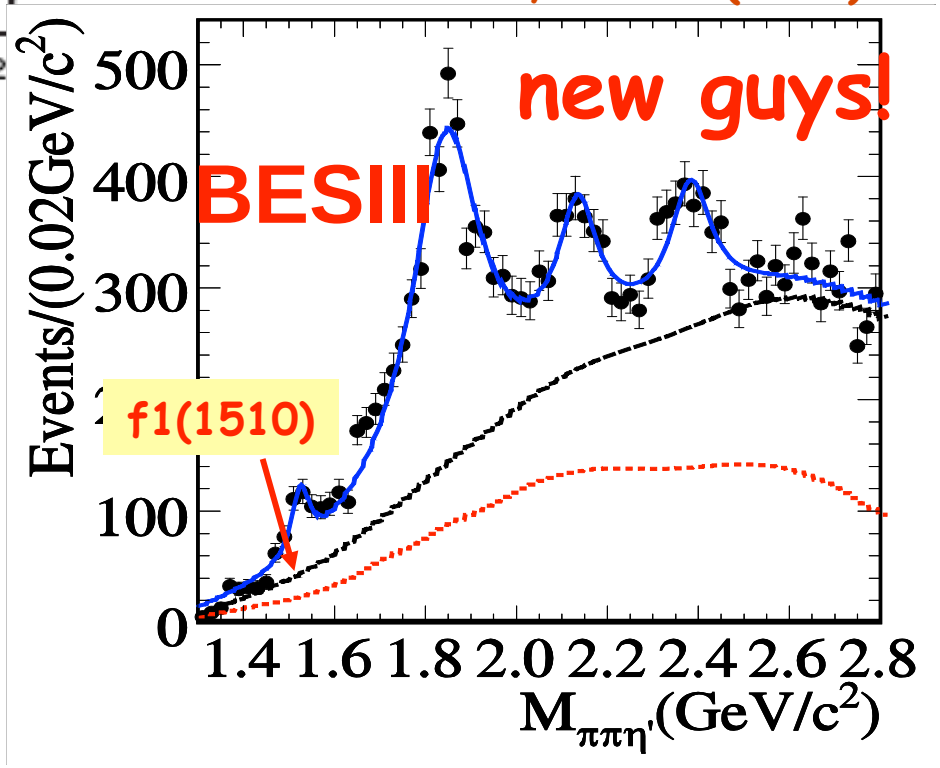


$J/\psi \to \gamma\eta' pi^+ pi^-$

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

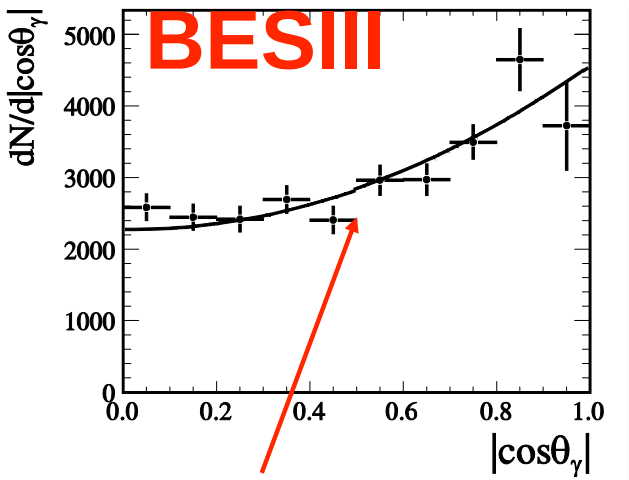
$\eta' \to \gamma rho$

PRL 106, 072002(2011)



Confirmation of X(1835) and Observation of two new structures

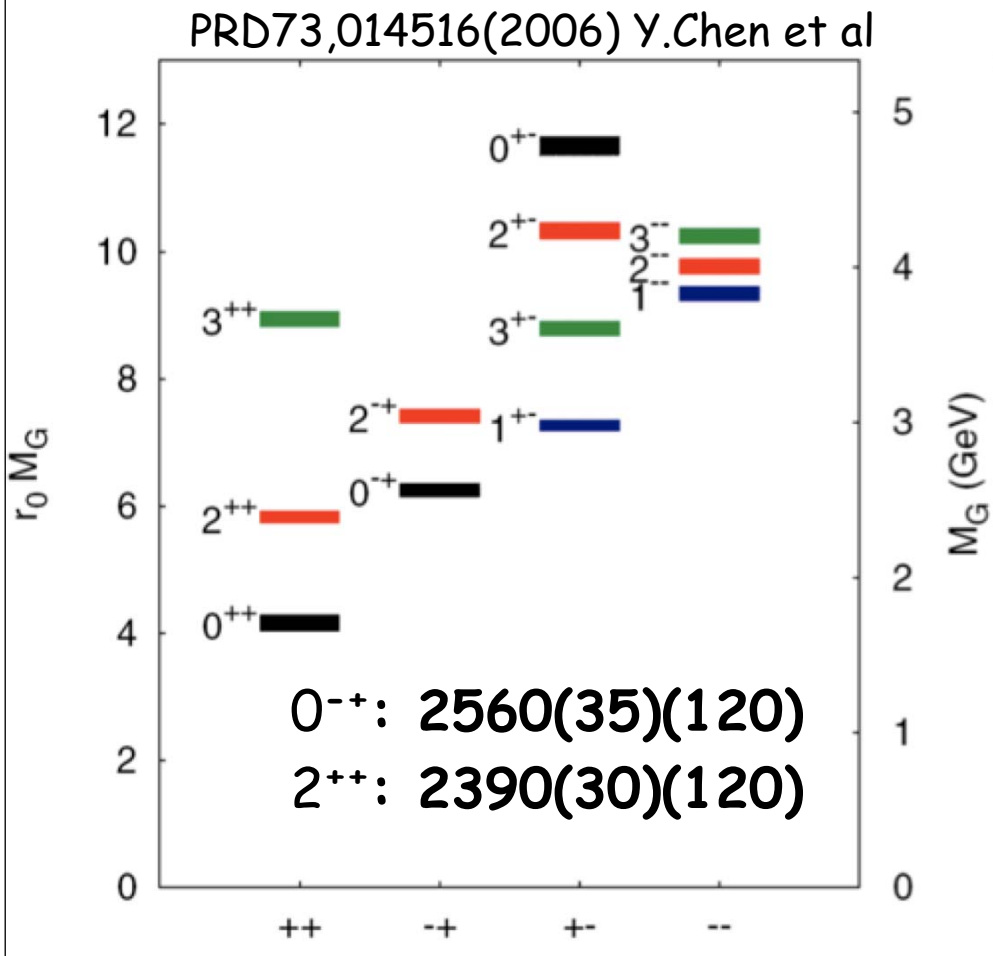
Resonance	M(MeV/c^2)	Γ(MeV/c^2)	Stat.Sig.
X(1835)	$1836.5\pm3.0^{+5.6}_{-2.1}$	$190.1\pm9.0^{+38}_{-36}$	>20σ
X(2120)	$2122.4\pm6.7^{+4.7}_{-2.7}$	$83\pm16^{+31}_{-11}$	7.2σ
X(2370)	$2376.3\pm8.7^{+3.2}_{-4.3}$	$83\pm17^{+44}_{-6}$	6.4σ



X(1835) consistent with 0^{-+}

PWA is needed to understand these structures.

What's the nature of these structures?



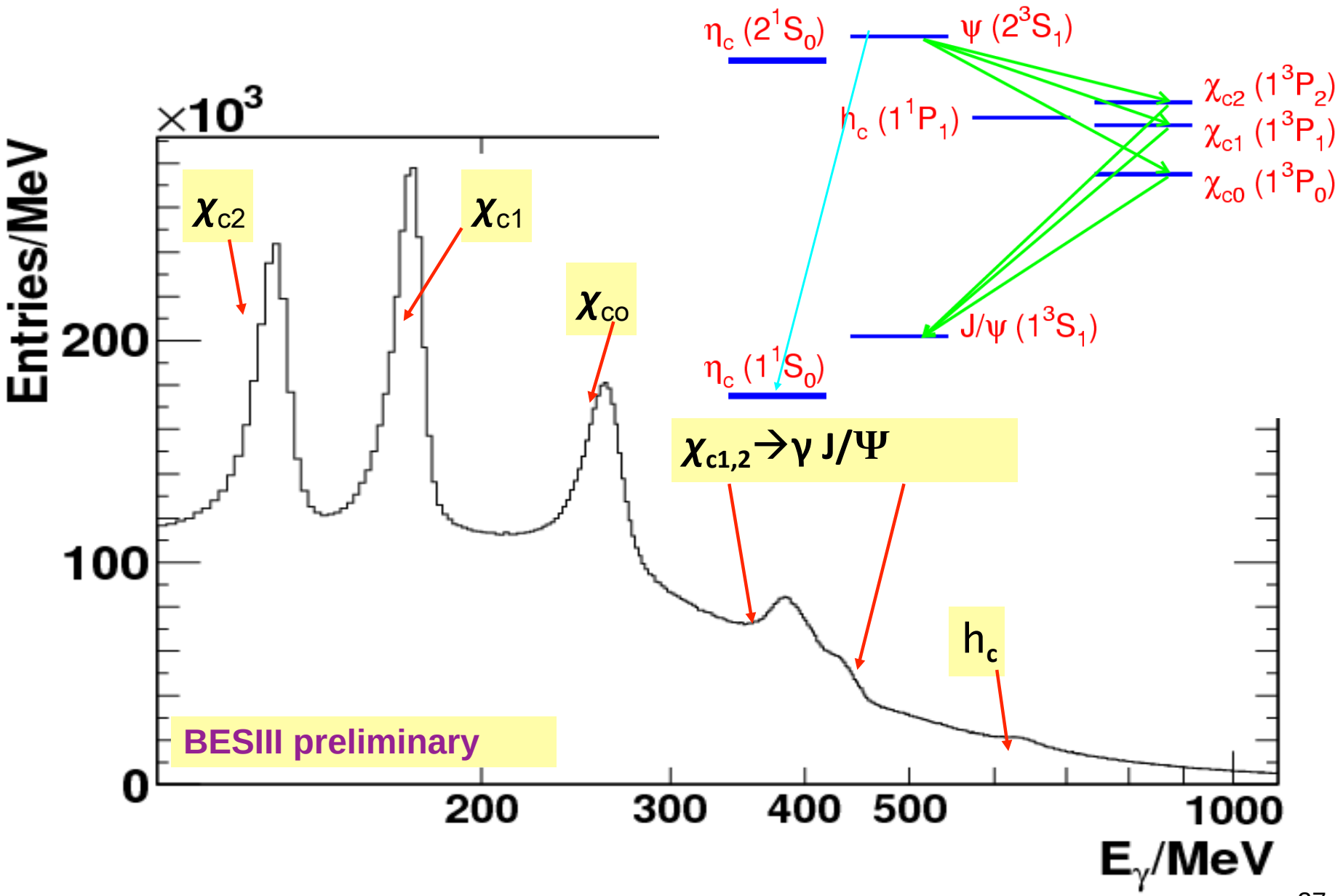
✓First time observation of resonant structures in the 2.4 GeV/c^2 region

LQCD prediction: lowest pseudoscalar glueball: around 2.4 GeV

J/ψ-->γppη' decay suitable for observing 0^{-+} glueballs.

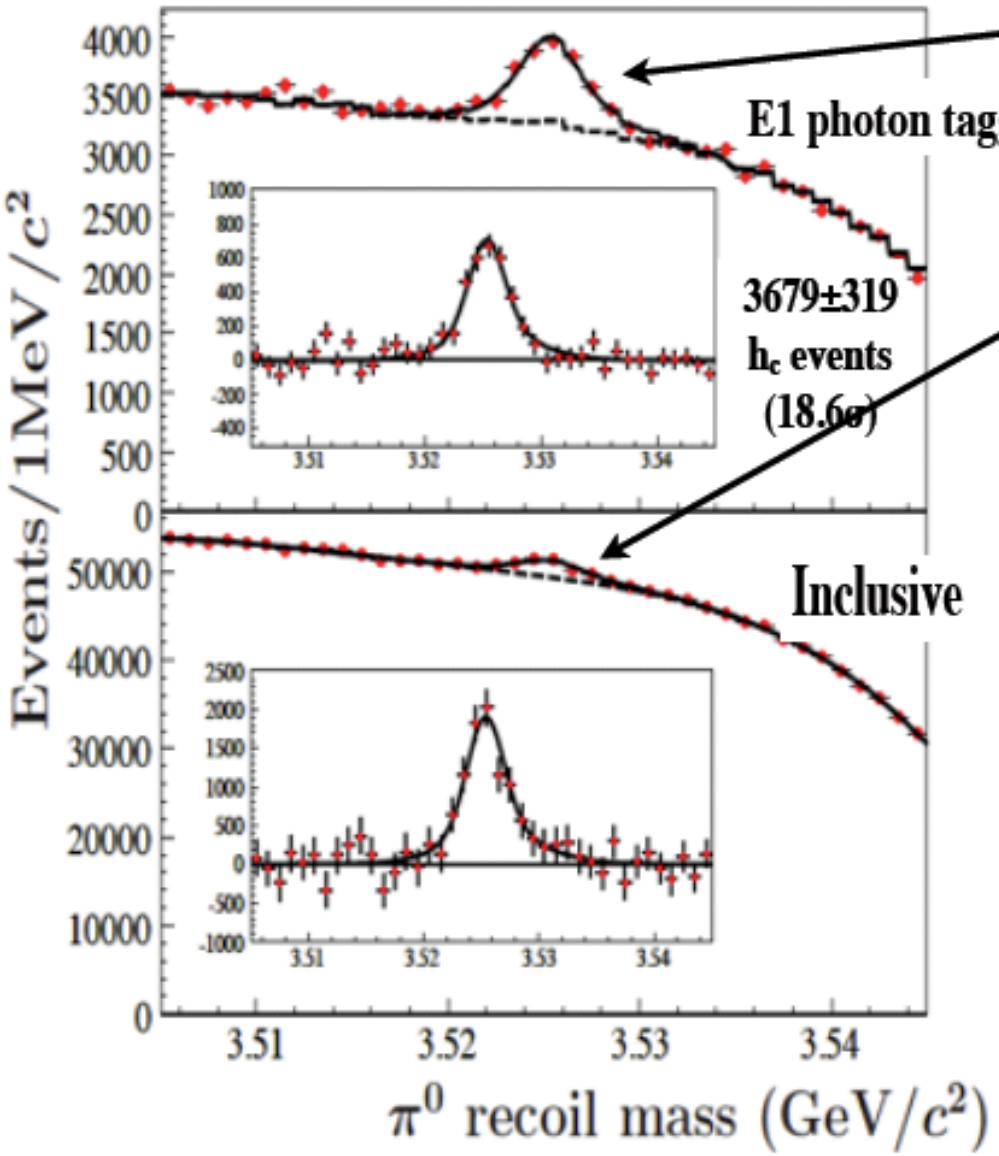
✓Nature of X(2120)/X(2370) pseudoscalar glueball ? η/η′ excited states?

EM transition inclusive photon spectrum



Observation of h_c (taged and inclusive)

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:

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

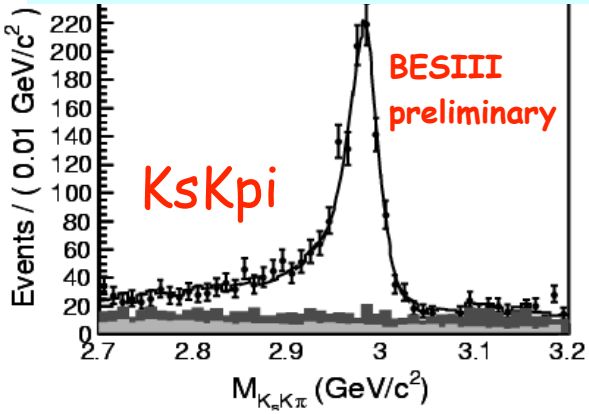
(first measurement)

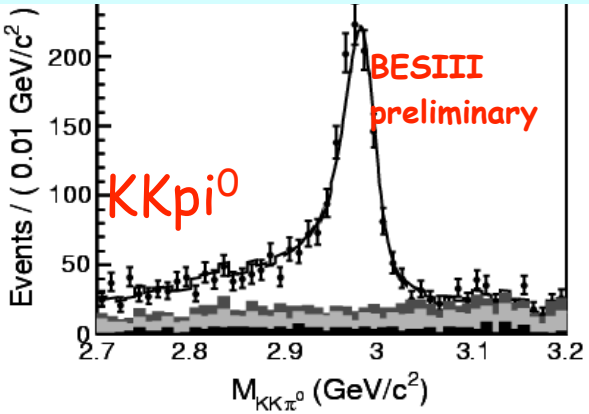
Hyperfine splitting:

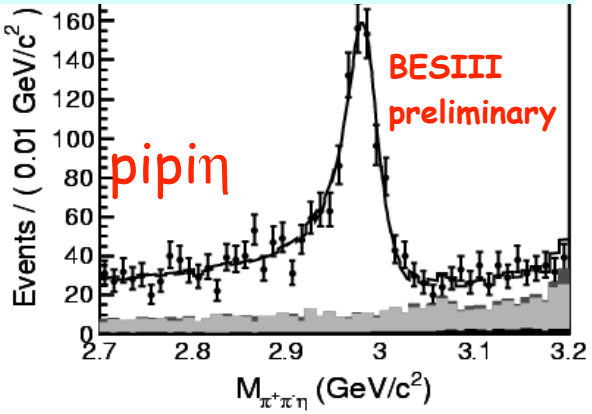
$\Delta M_{hf} = -0.10 \pm 0.13 \pm 0.18\,\mathrm{MeV}/c^2$

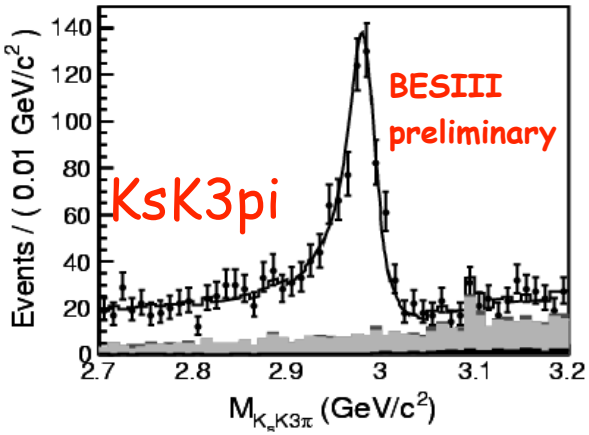
(consistent with zero)

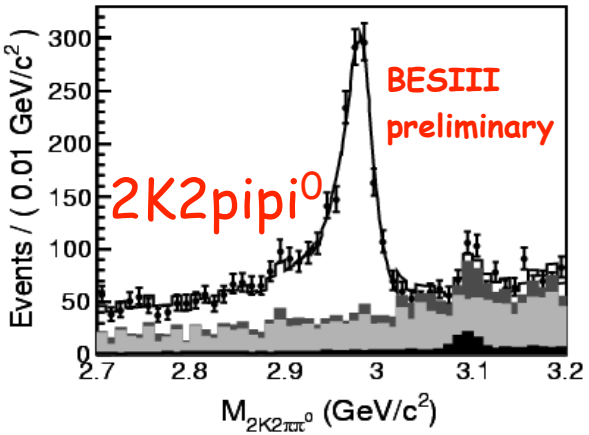
η_c resonance parameters from $\psi' \to \gamma\eta_c$

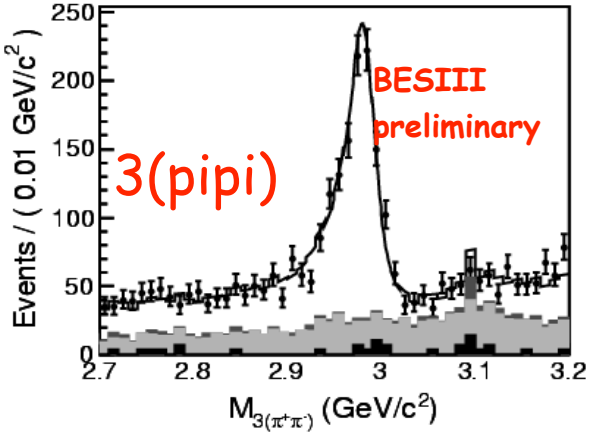












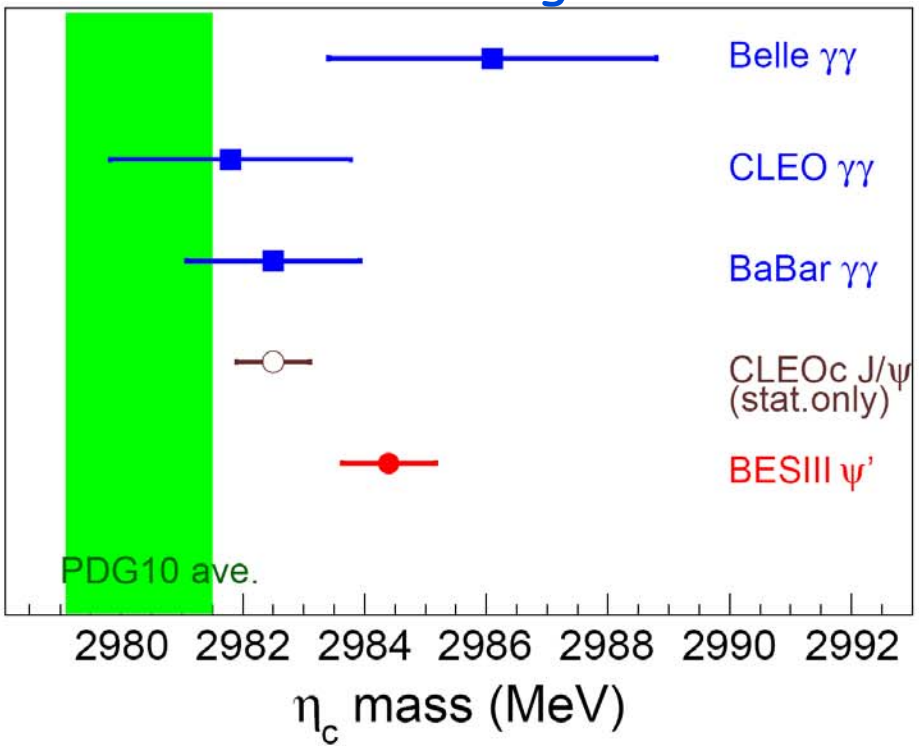
Simultaneous fit with BW by considering **the interference between η_c and non-η_c decays**, as well as the energy dependence of phase space:

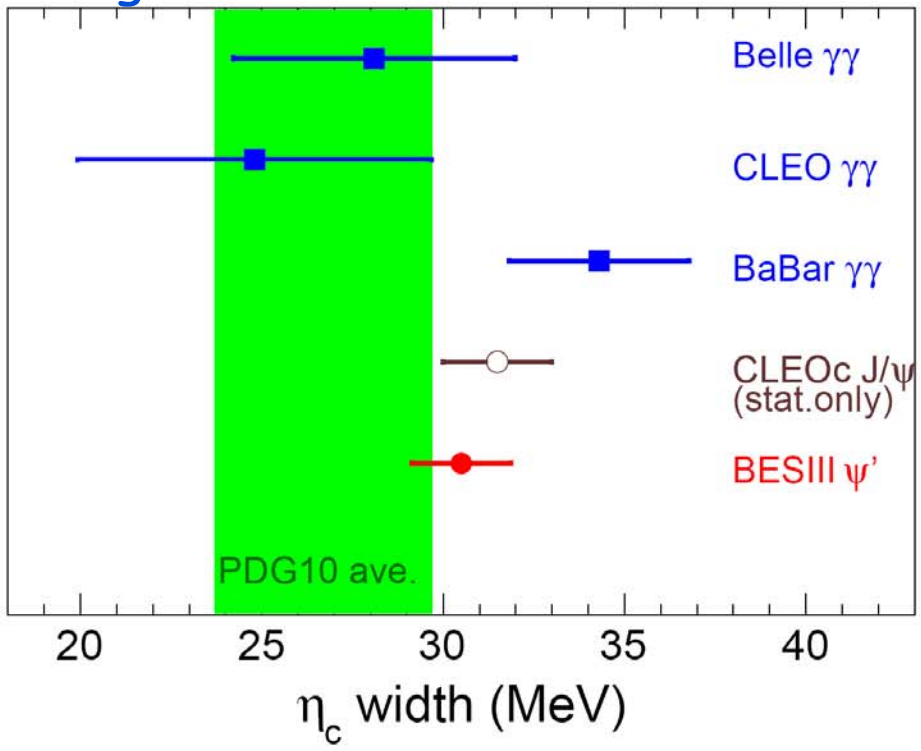
mass: $2984.4 \pm 0.5_{stat} \pm 0.6_{sys}$ MeV/c^2
width: $30.5 \pm 1.0_{stat} \pm 0.9_{sys}$ MeV
f: $2.35 \pm 0.05_{stat} \pm 0.04_{sys}$ rad

f: relative phase between η_c decay and non-resonant component at the signal region, assuming non-η_c is 0^{-+}

Comparison of the mass and width for η_c

The world average in PDG2010 was using earlier results

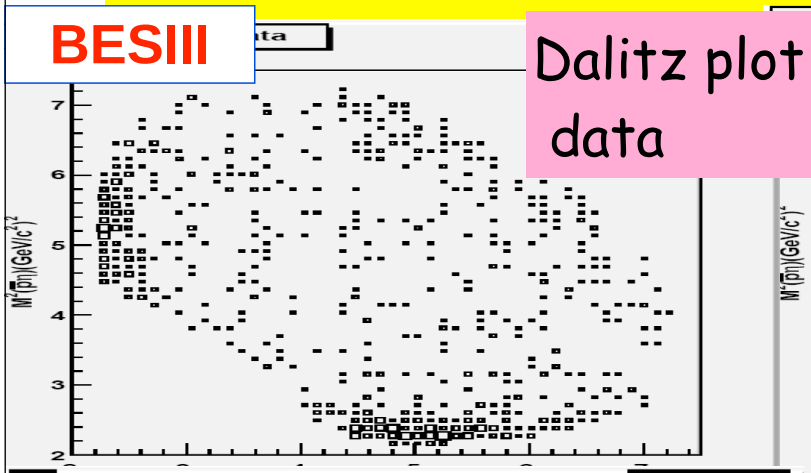


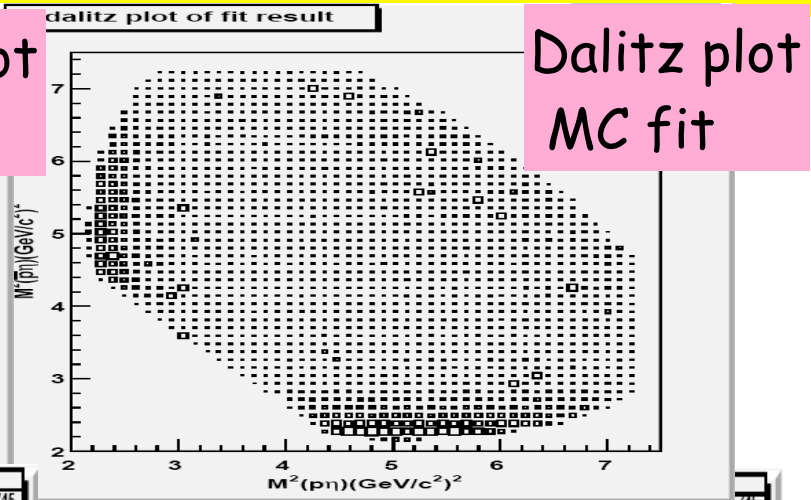


BESIII results include both stat. and syst. errors, which is the most precision measurement: the interference between η_c decay and non-resonant contributions is important.

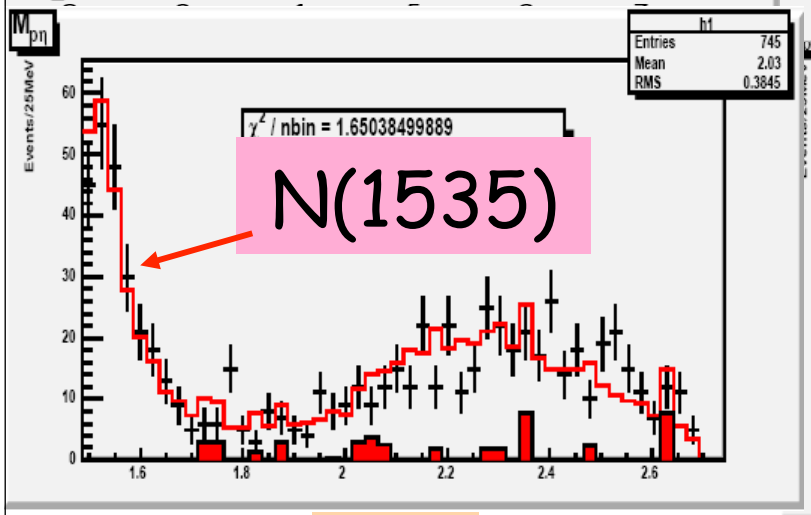
Preliminary results on N* baryon in $\psi' \to \eta p\bar{p}$ decay

BESIII

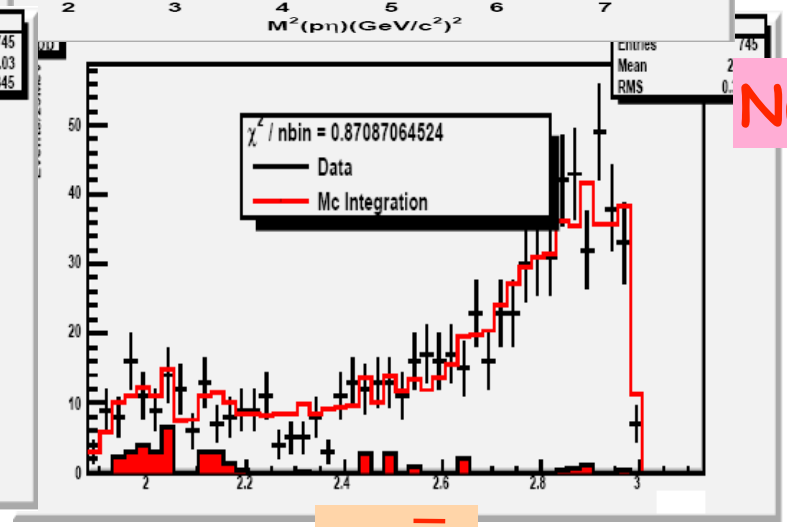




A full PWA is performed.



M(pη)



M(p$\bar{p}$)

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

Mass:

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

Width:

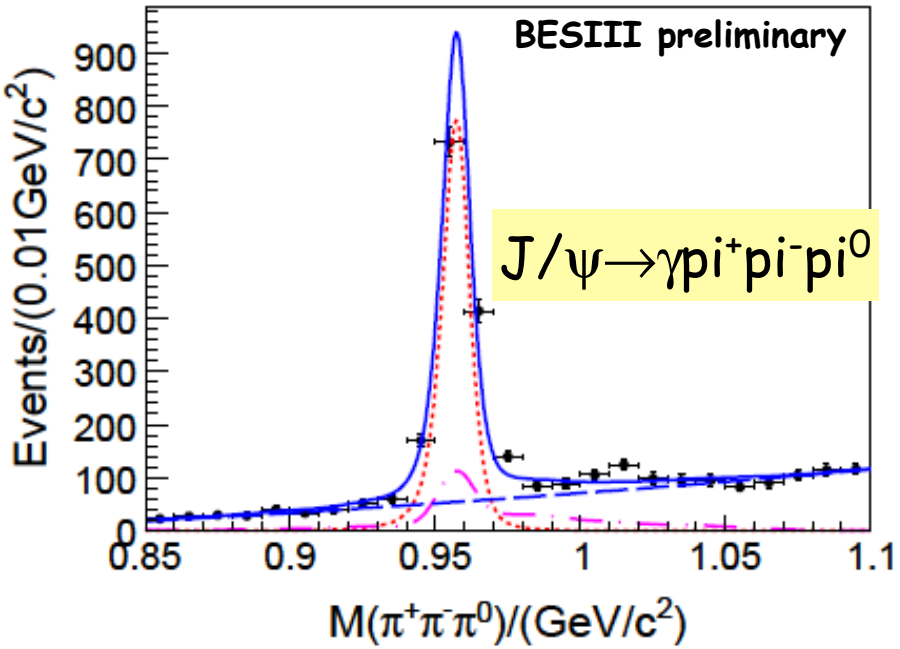
$0.130^{+0.027+0.061}_{-0.027-0.014}$ GeV

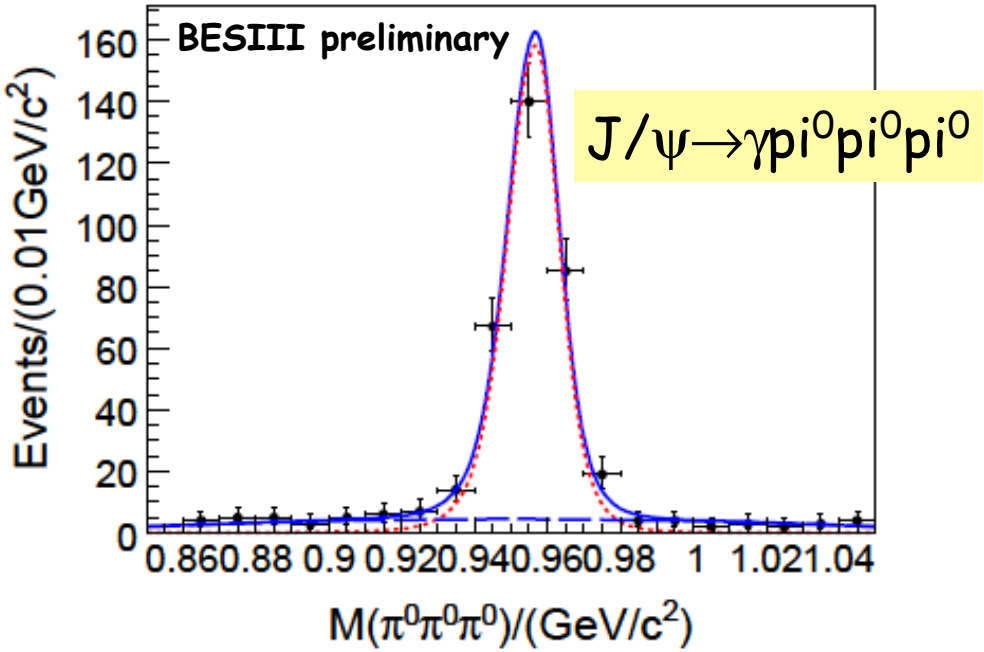
$Br(\psi' \to p p \eta) = (6.6 \pm 0.2 \pm 0.6) \times 10^{-5}$

PDG2010: $(6.0 \pm 1.2) \times 10^{-5}$

$Br(\psi' \to N(1535)p) \times Br(N(1535) \to p\eta + c.c.) = 5.5^{+0.3+7.4}_{-0.3-1.1} \times 10^{-5}$

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





Preliminary results:

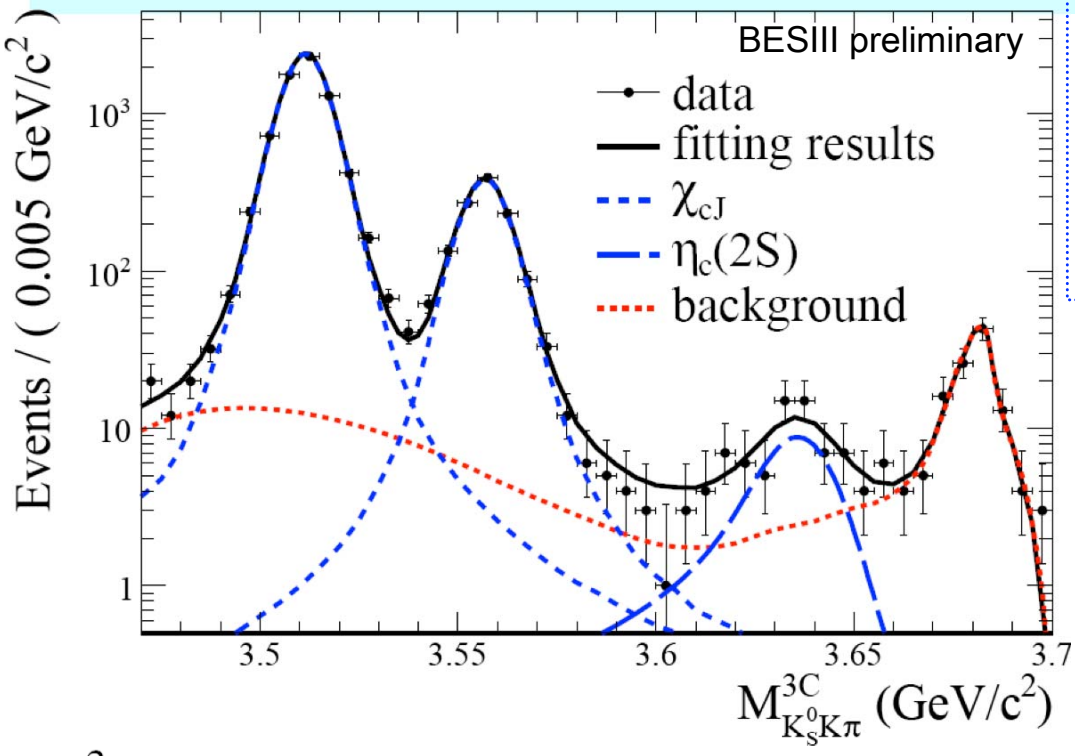
$$Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15(stat.) \pm 0.39(sys.)) \times 10^{-3}$$

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)

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



$M(\eta_c(2S)) = (3638.5 \pm 2.3 \pm 1.0)$ MeV/c^2

$N(\eta_c(2S)) = 50.6 \pm 9.7$

Statistical significance larger than 6.0s!

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

+

$Br(\eta_c(2S) \to KK\pi) = (1.9 \pm 0.4 \pm 1.1)\%$

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´10^{-4}

PRD81,052002(2010)

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

M1 transition

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

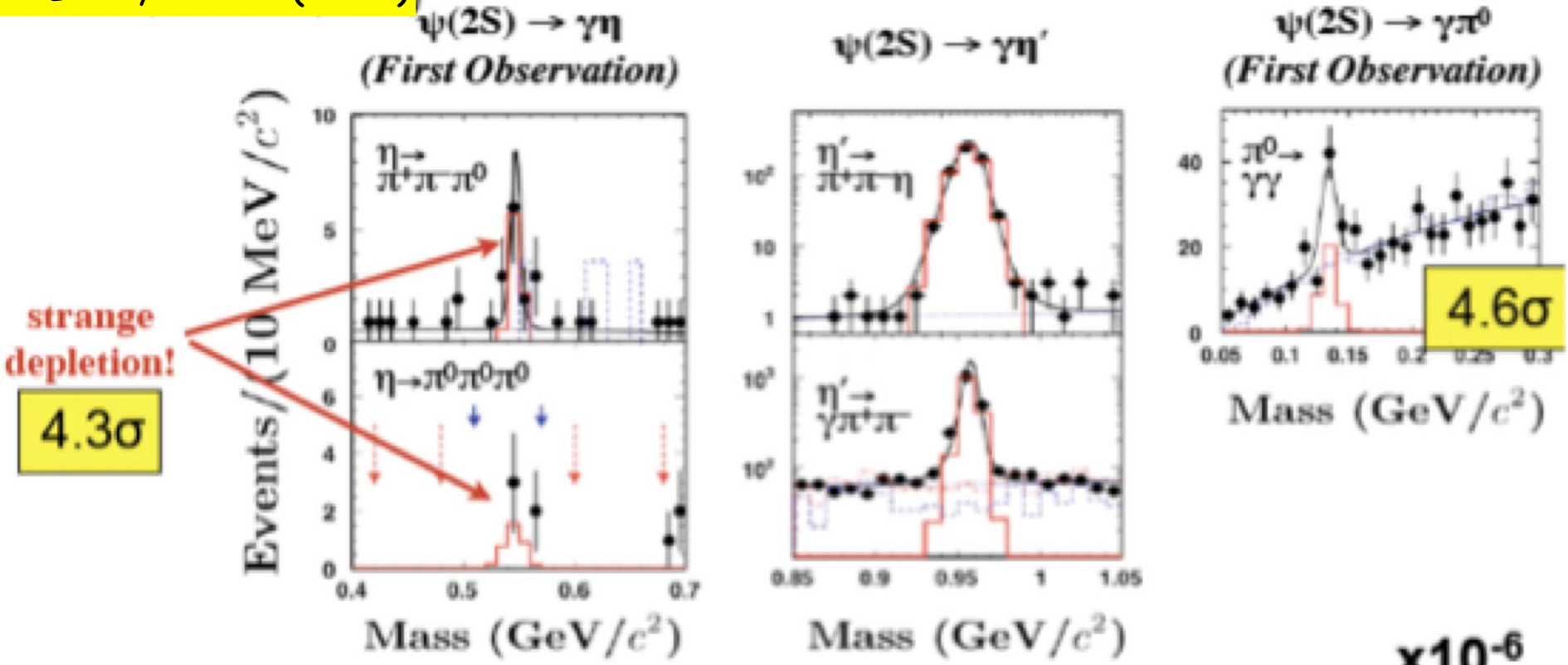
$\Gamma(\eta_c(2S))$ fixed to 12MeV (world average)

Potential model: (0.1-6.2)x10^{-4}

PRL89,162002(2002)

Evidence for ψ′ decays into γpi and γη

PRL105, 261801(2010)



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)

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)

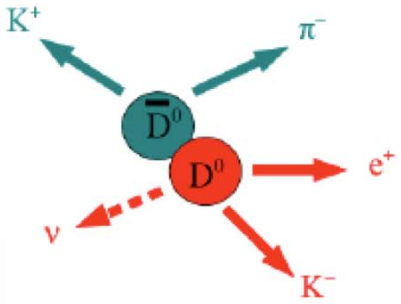
$$R_{\psi'} << R_{J/\psi}$$

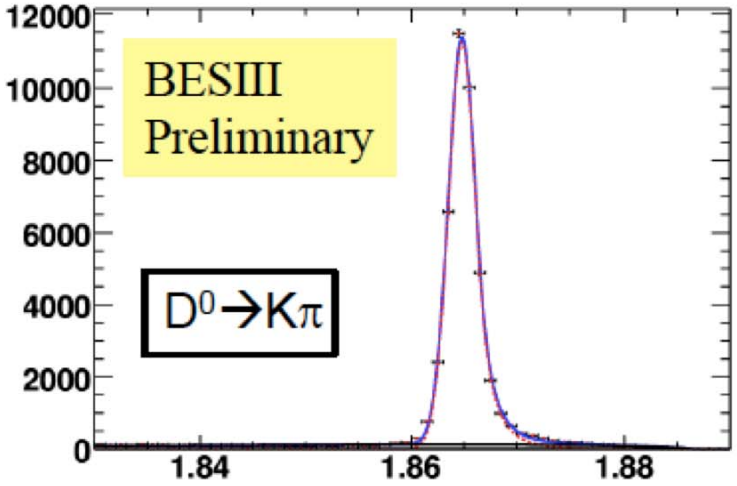
Difference?: Other processes contributing? Related to ρπ puzzle, ... ??

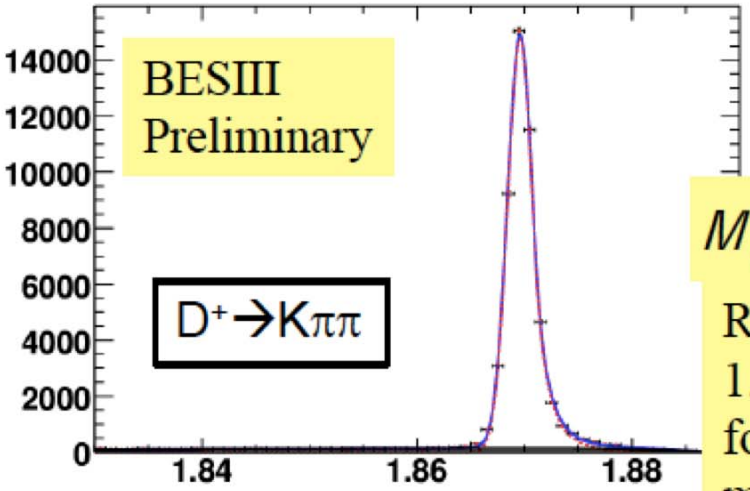
Q. Zhao, PLB697(2011)52

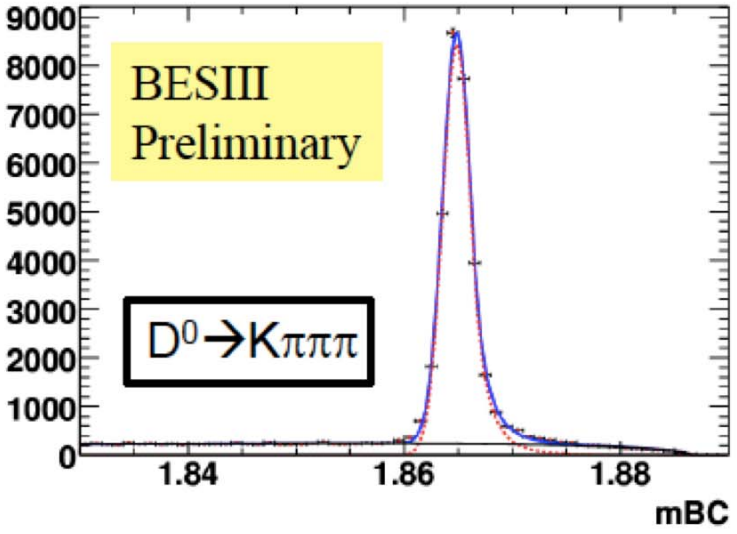
Clean single tag at BESIII

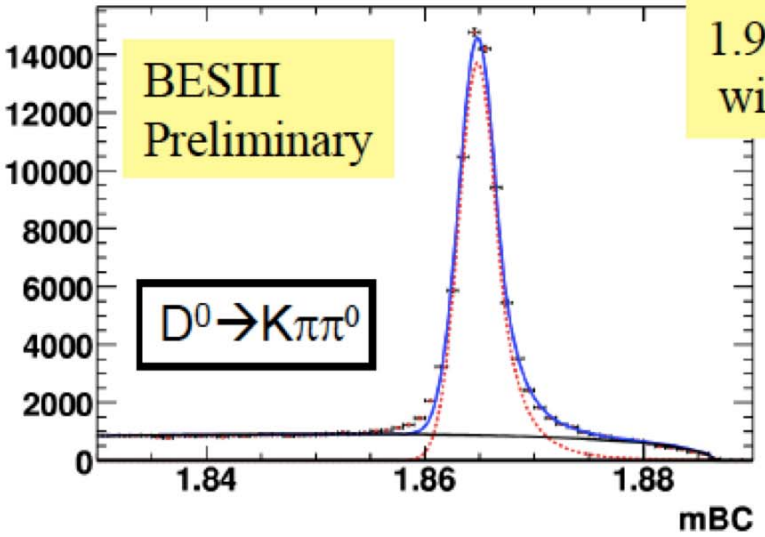
@ψ(3770) with 420pb^{-1} first clean single tagging signals:











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

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

Summary

- A new facility for Charm/Tau physics went successfully into operation
- Huge amounts of J/ψ, ψ (2s) and D mesons can be produced and studied with a state-of-the art detector
- Precision physics with the potential for standard model tests
- Light hadron spectroscopy, search for exotica in charmonium decays (glue-rich environment)
- Charmonium spectroscopy, open charm physics
- First two years of running
  - Many updates to PDG
  - New states of unknown structure
  - Some puzzles and surprises

Publications (2010/11)

- **Charmonium Spectroscopy and Transitions**
  - Properties of the h_c *(PRL 104, 132002 (2010))*
  - $\psi' \to \gamma\gamma J/\psi$ *(submitted soon)*
- **Charmonium Decays**
  - $cJ \to \pi^0\pi^0, \eta\eta$ *(PRD 81, 052005 (2010))*
  - $cJ \to \gamma\rho, \gamma\omega, \gamma\varphi$ *(PRD83,112005(2011))*
  - $cJ \to \omega\omega, \varphi\varphi, \omega\varphi$ *(PRL 107, 092001 (2011))*
  - $\psi' \to \gamma\pi^0, \gamma\eta, \gamma\eta'$ *(PRL 105, 261801 (2010))*
  - $\chi_{cJ} \to 4\pi^0$ *(PRD 83, 012006 (2011))*
  - η, η' and $\eta_c \to \pi\pi$ *(Phys. Rev. D 84, 032006 (2011))*
  - Observation of $\chi_{cJ} \to ppK^+K^-$ *(PRD83,112009(2011))*
- **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 $J/\psi \to \gamma(pp)$ *(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 to PRL)*