Recent Results from the BESIII Experiment

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Indiana University
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Introduction to the BESIII Experiment

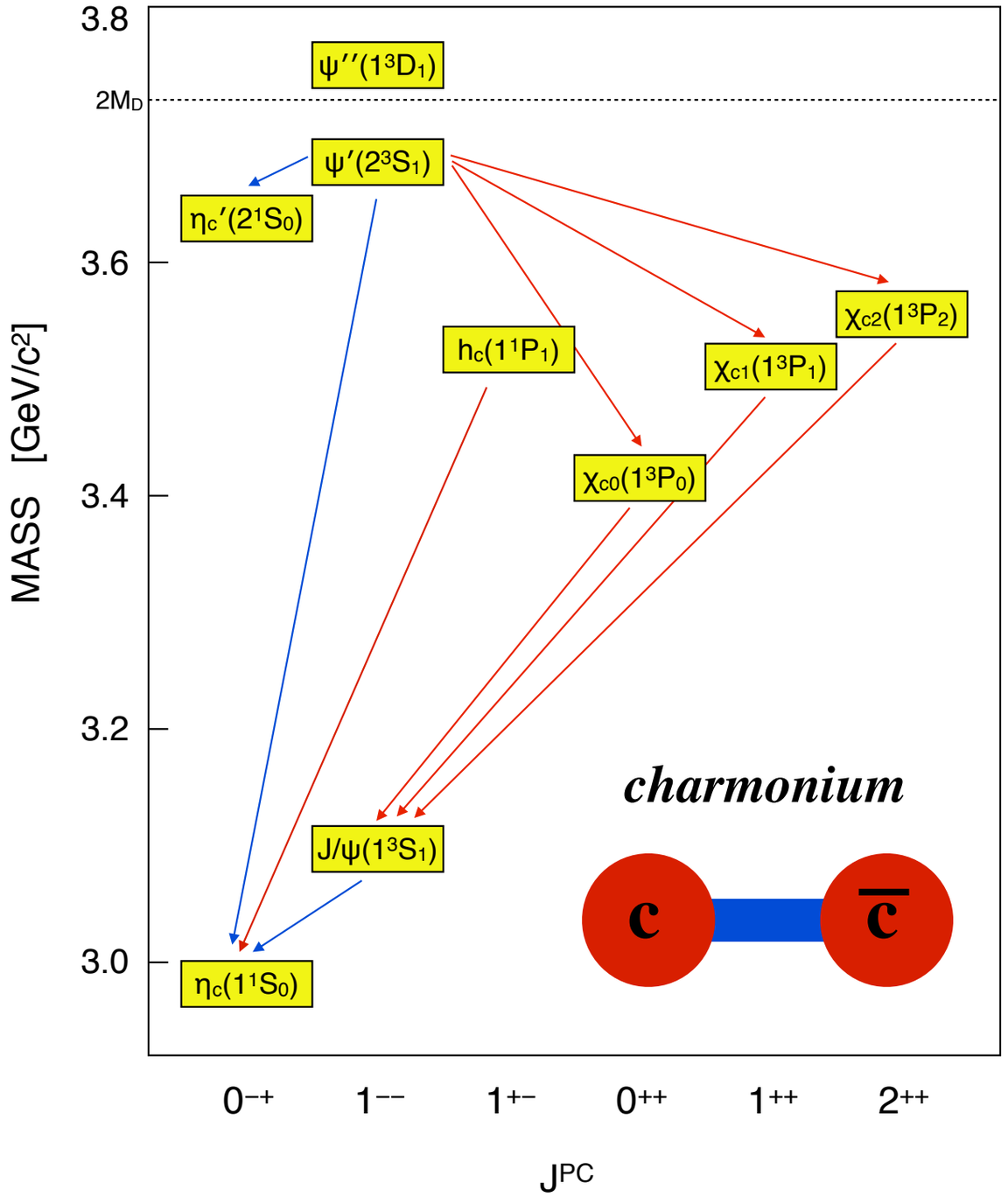
The primary goal of BESIII: Use e^+e^- collisions to produce charmonium states, then use their properties and their decays to learn about the strong force.

(and the properties and the decays of their decay products, etc.)

accelerator

QCD

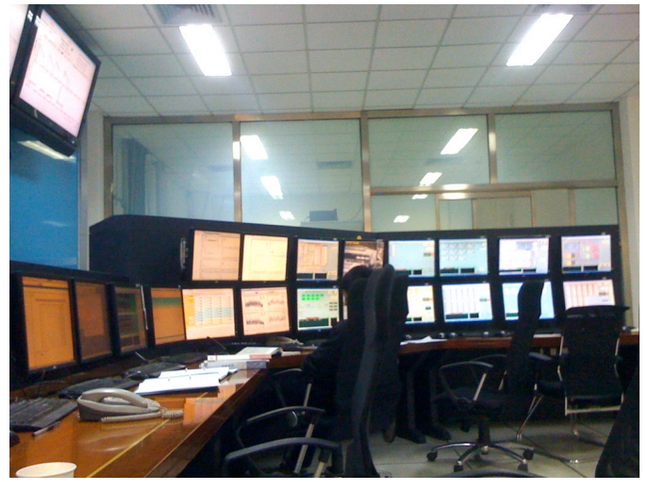
phenomenology and theory



Introduction to the BESIII Experiment

accelerator

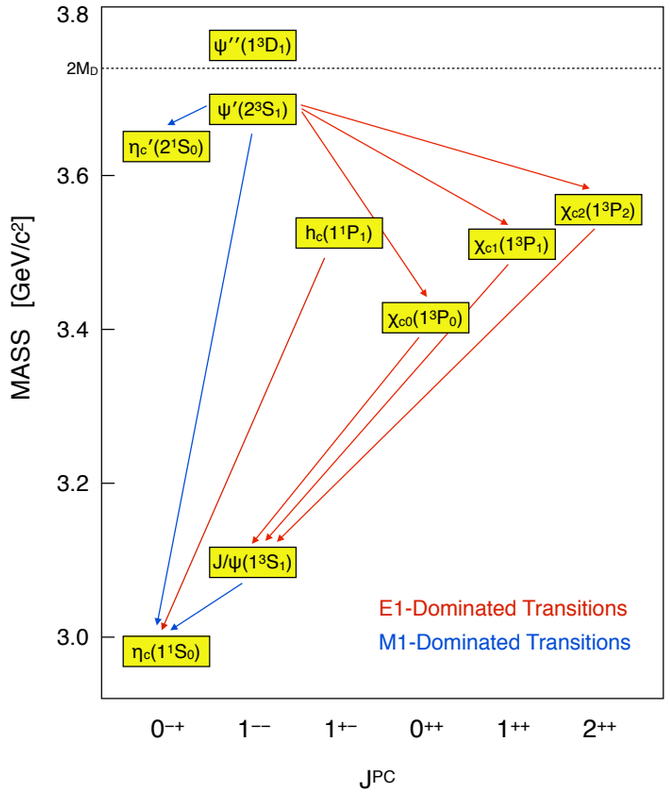
detector



data

QCD

phenomenology and theory



a bigger picture

analysis

Introduction to the BESIII Experiment

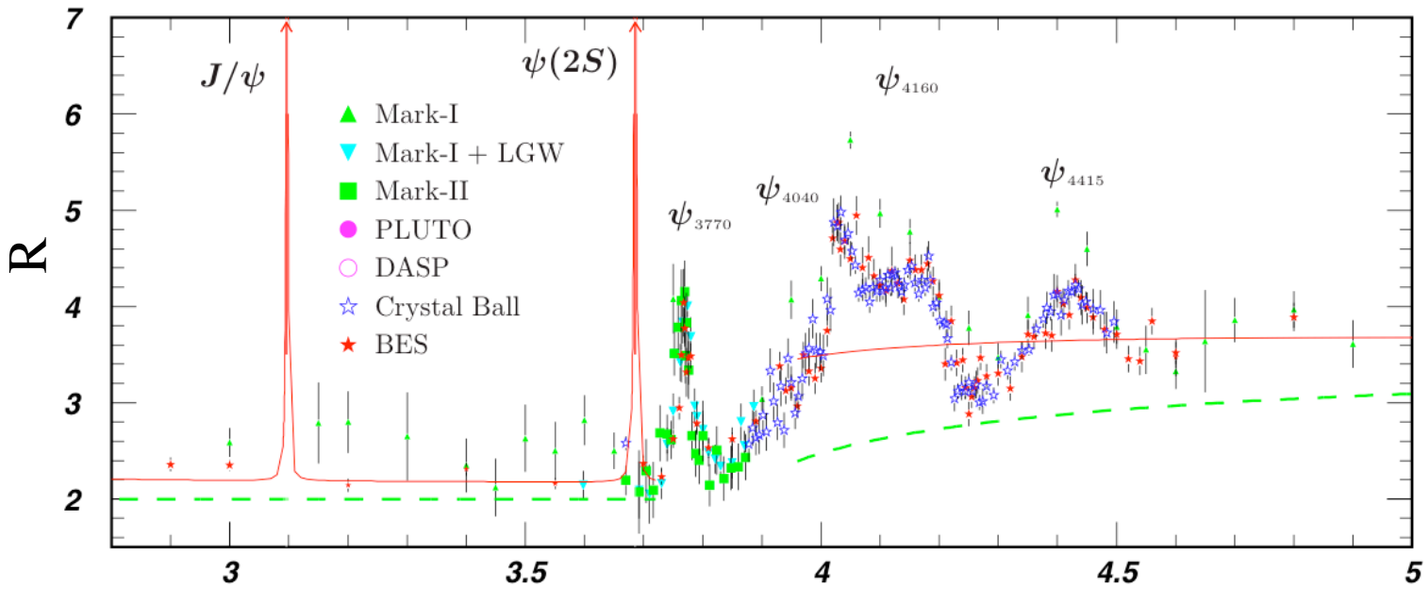
accelerator

Introduction to the BESIII Experiment

accelerator

BEPCII:
Institute for High Energy Physics
Beijing, China

Collide e^+e^- in the τ-charm region:



e^+e^- Center of Mass Energy

First collisions: March 2008

Record luminosity: ~$5 \times 10^{32}\,cm^{-2}s^{-1}$
(~8× CESRc and ~45× BEPC)

Introduction to the BESIII Experiment

accelerator

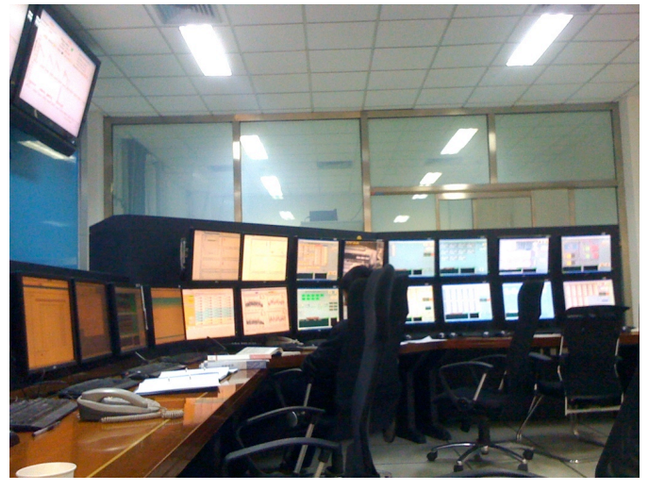
aerial view of BEPCII at IHEP

to Beijing

Introduction to the BESIII Experiment

accelerator

detector



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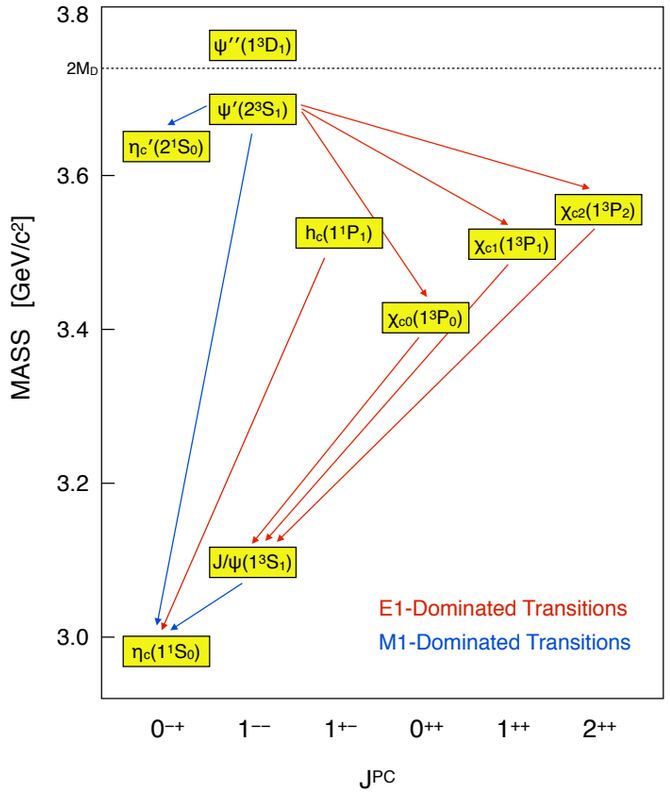

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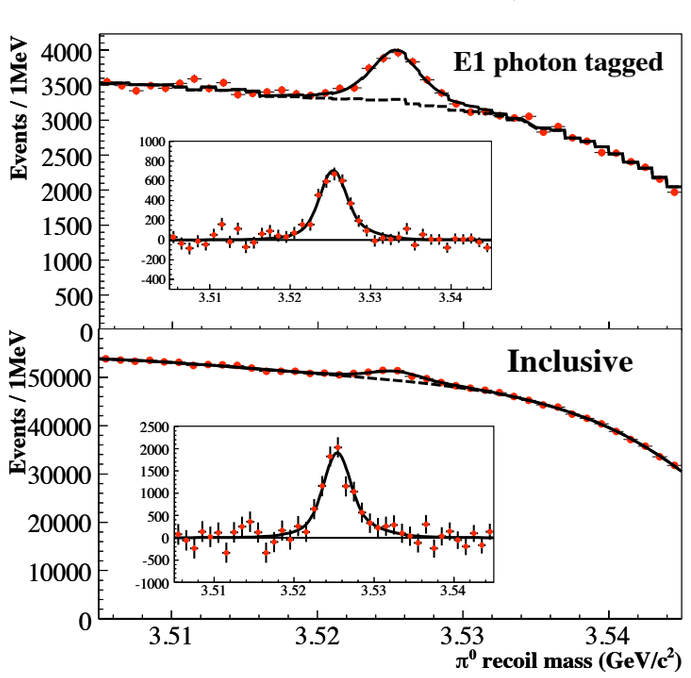


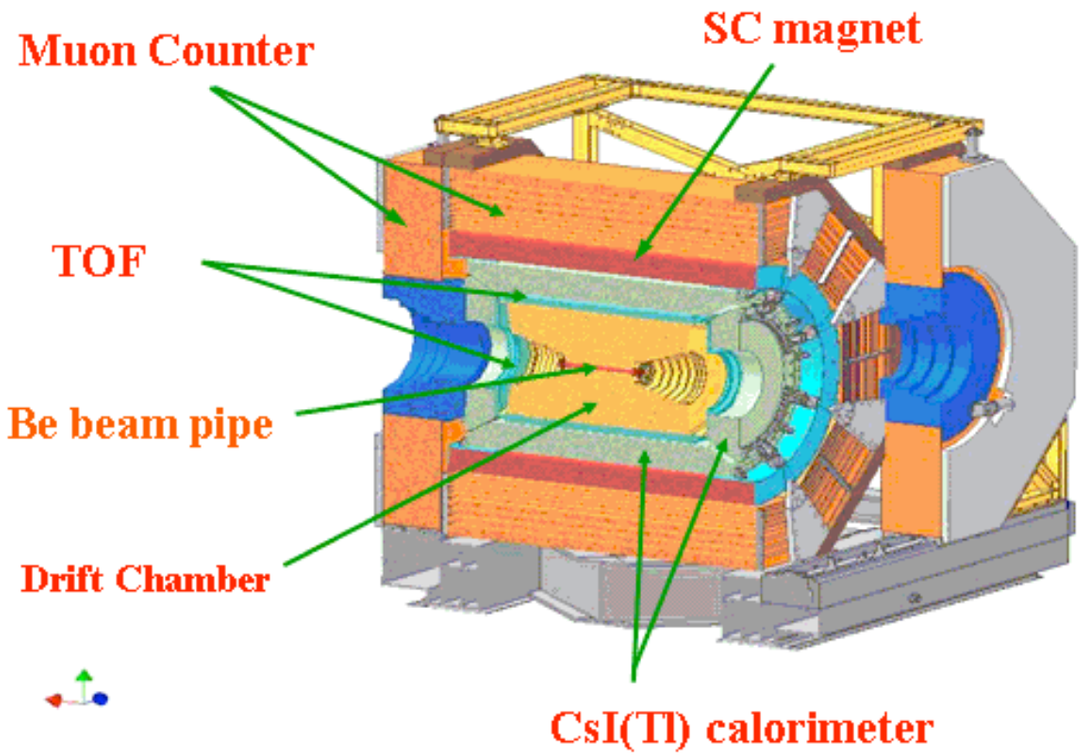
analysis

Introduction to the BESIII Experiment

detector

Introduction to the BESIII Experiment

The BESIII Detector



Excellent tracking and calorimetry with a uniform acceptance:

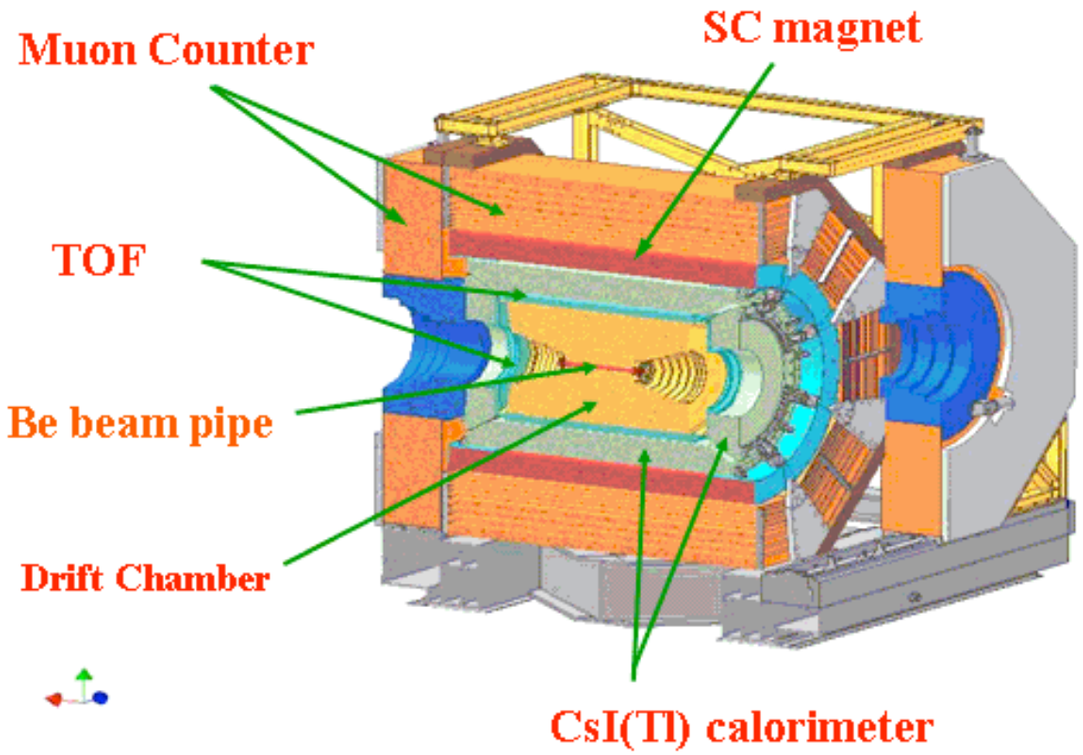
tracks: $\sigma_p/p = 0.58\%$ at 1 GeV/c

photons: $\sigma_E/E = 2.5\%$ at 1 GeV

detector

Introduction to the BESIII Experiment

The BESIII Detector



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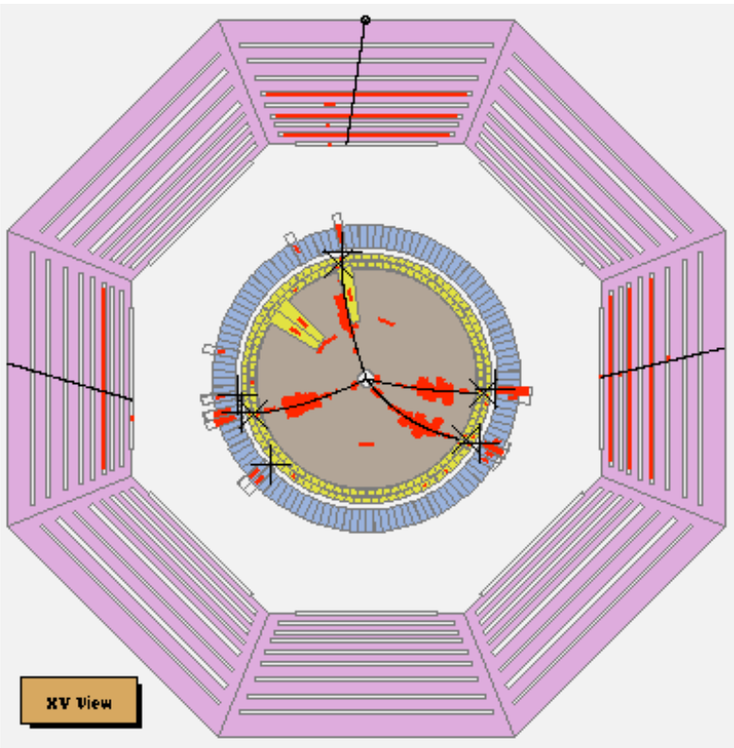
detector

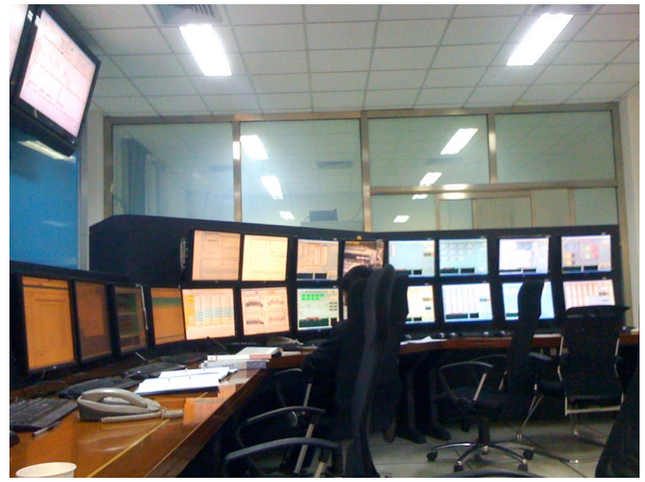
First Hadronic Event:
July 2008



Introduction to the BESIII Experiment

accelerator

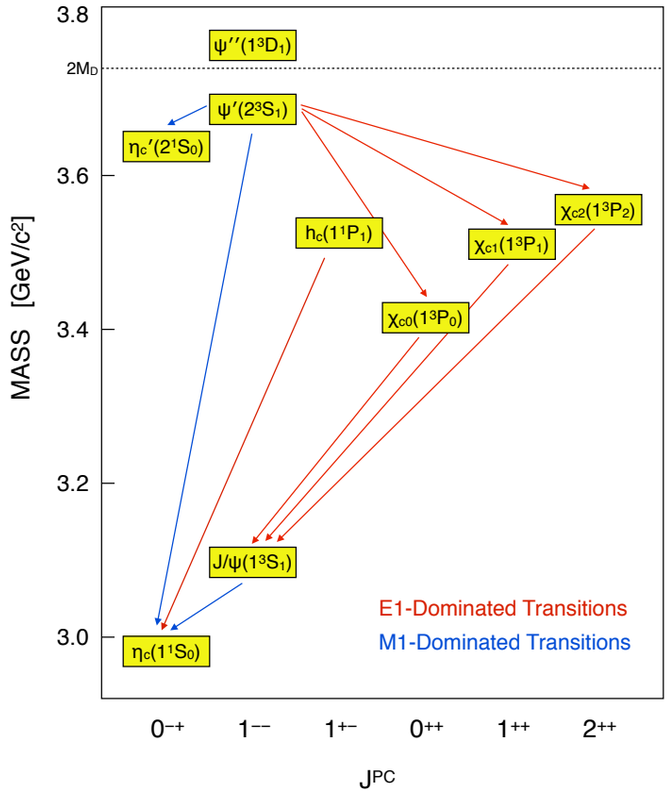
detector



data

QCD

phenomenology and theory



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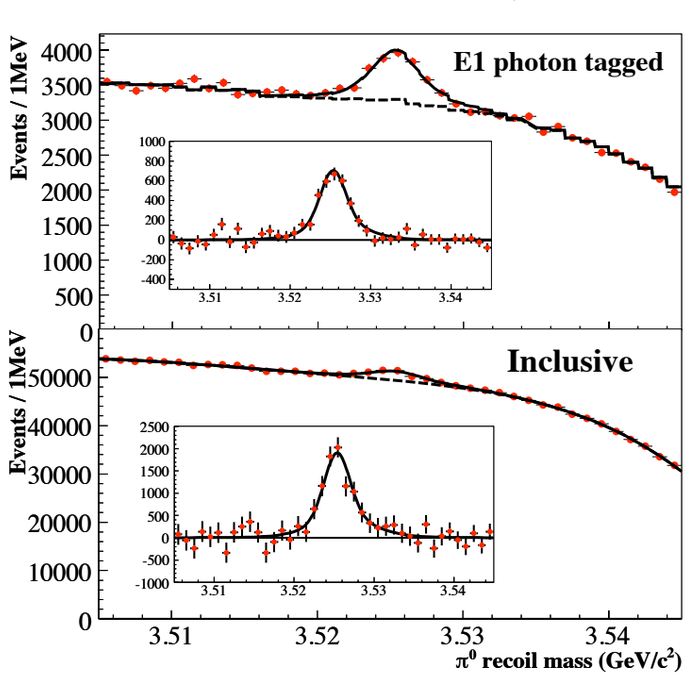

analysis

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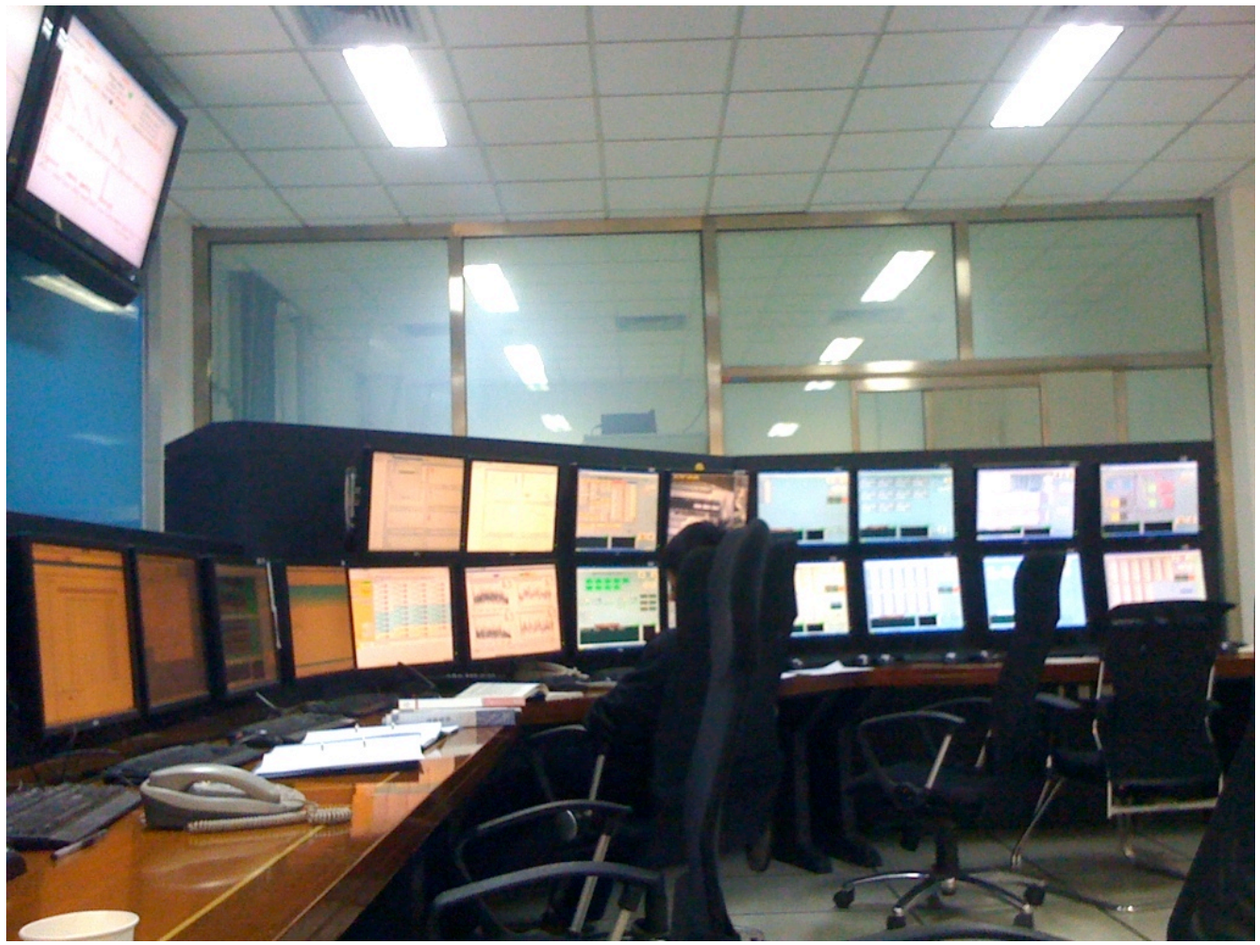

data

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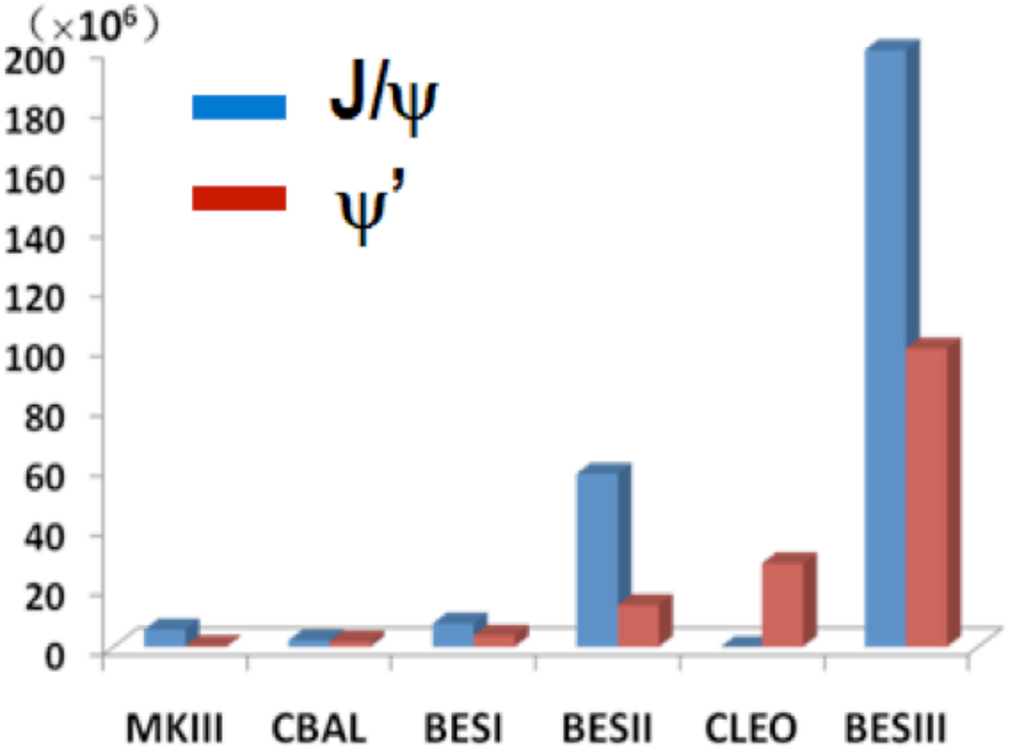
BESIII Data

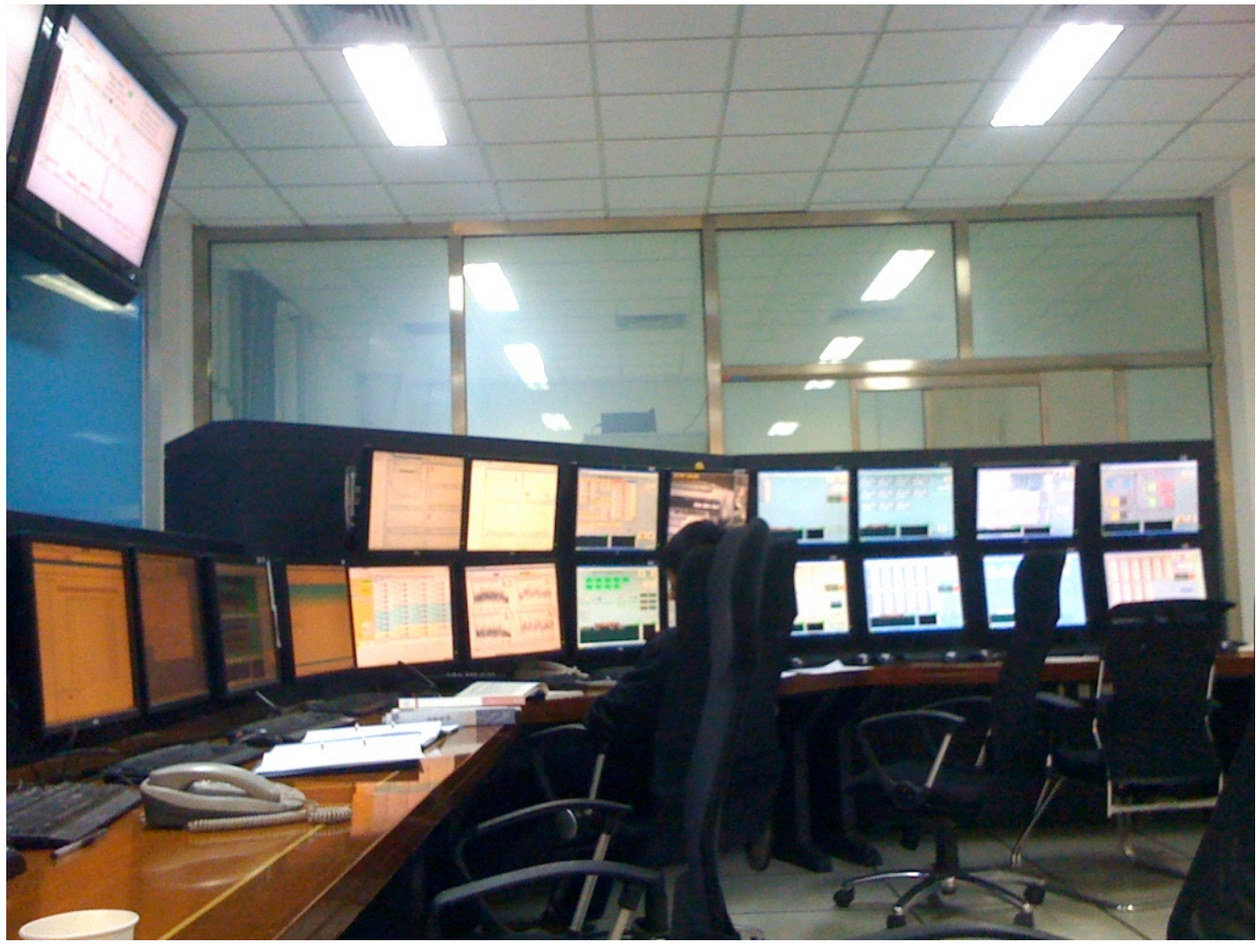


So far BESIII has collected:

~ 225 Million J/ψ

~ 106 Million ψ(2S)

~ 1fb^{-1} at the ψ(3770)



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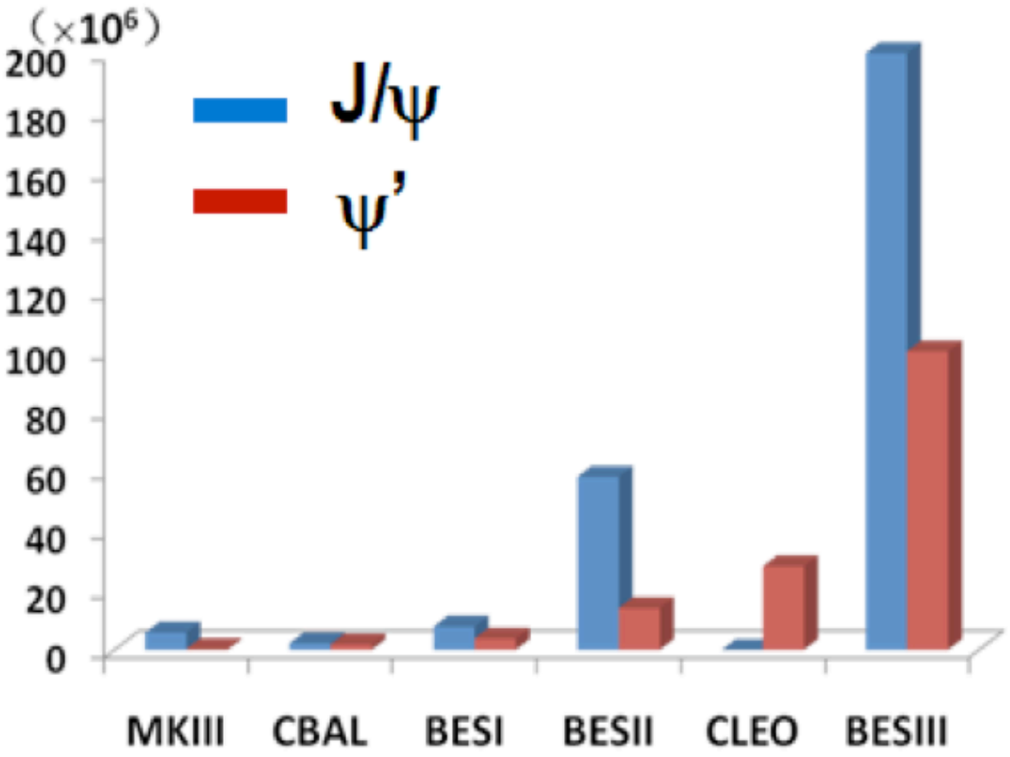
BESIII Data



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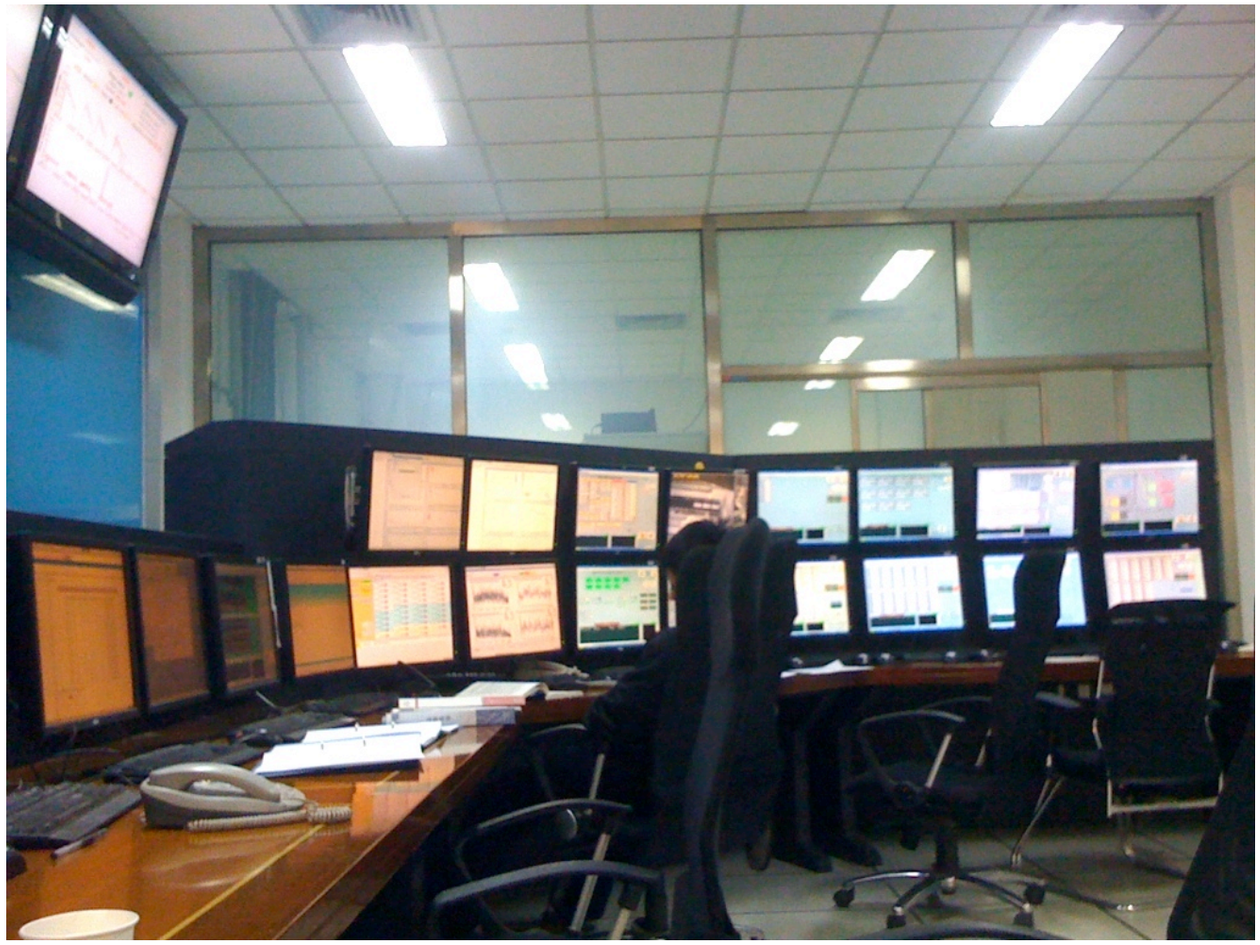


data

BESIII will also collect:

more J/ψ, ψ(2S), ψ(3770)

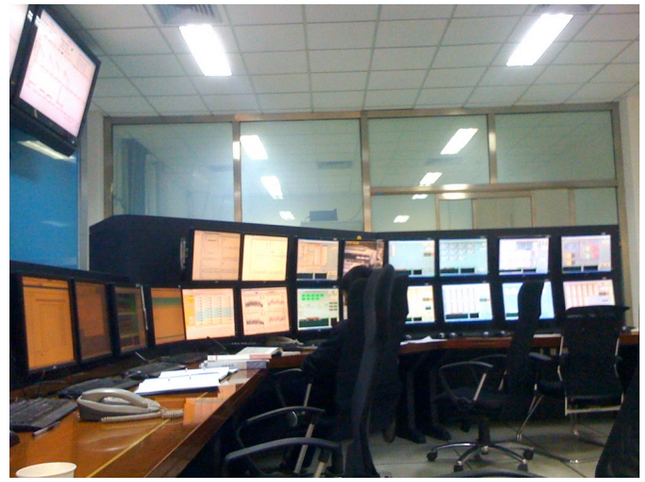
+ data at higher energies

(for XYZ searches and D_s physics...)

Introduction to the BESIII Experiment

accelerator

detector



data

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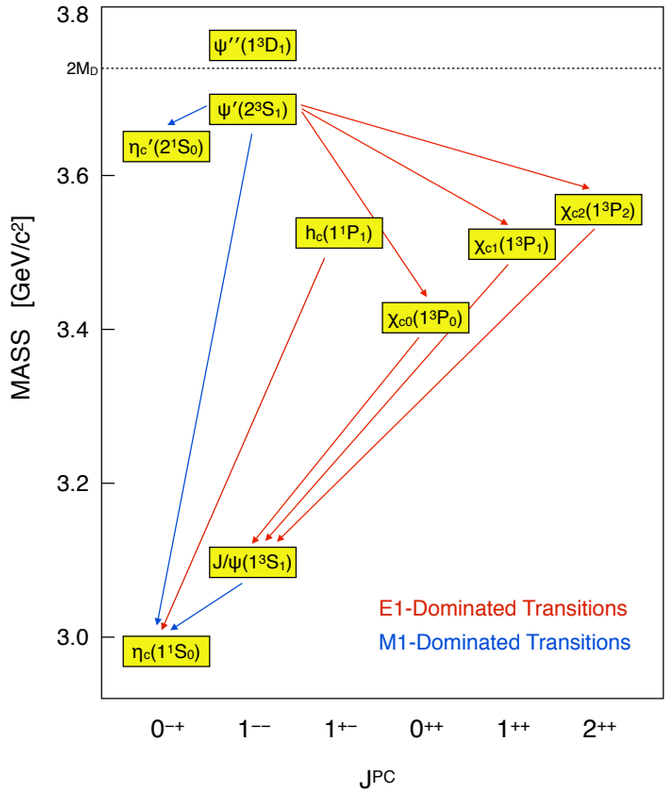
phenomenology and theory



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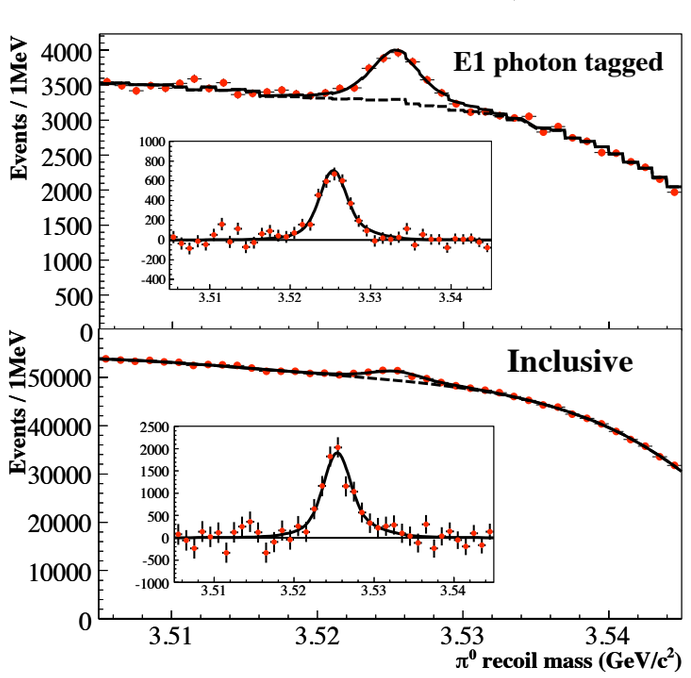

analysis

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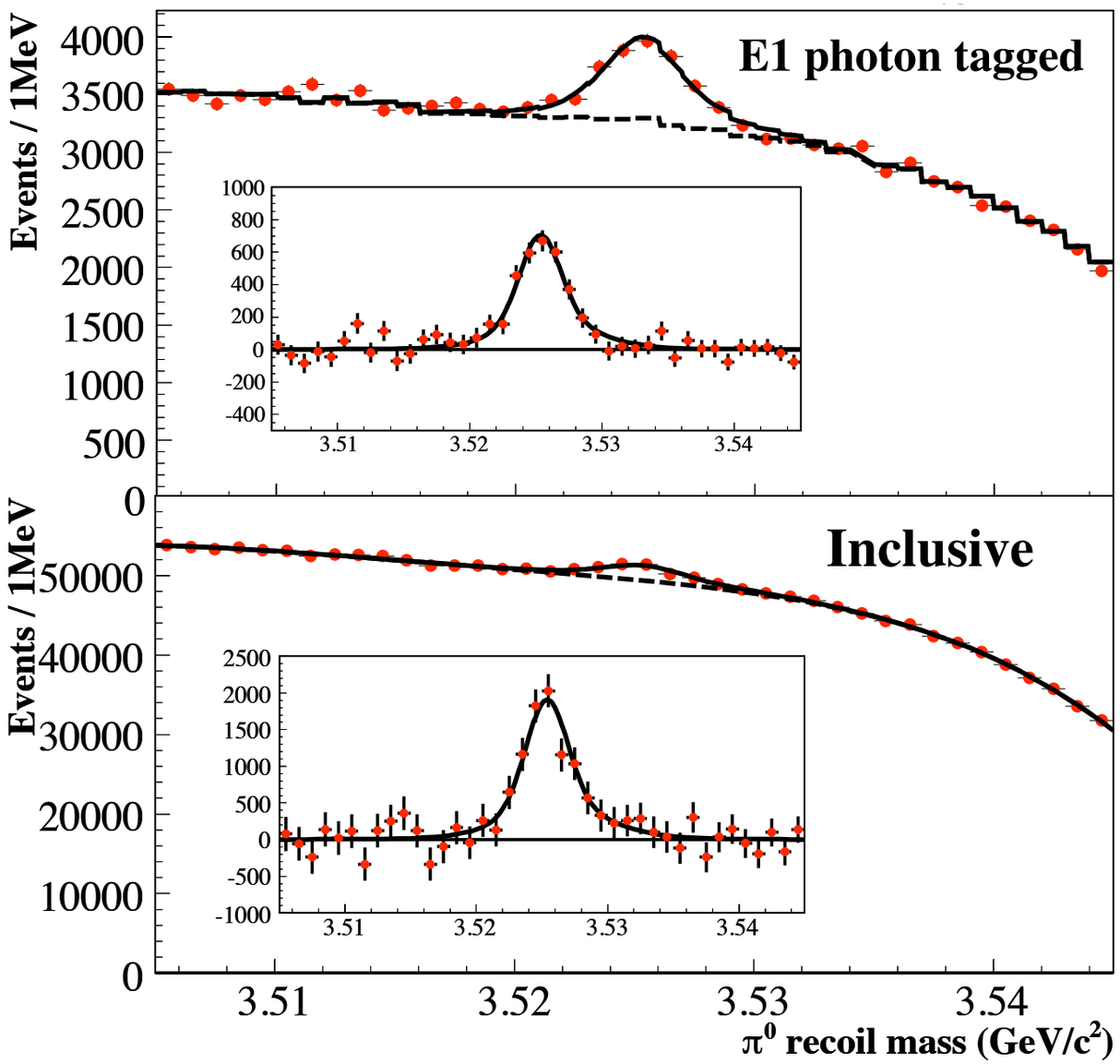

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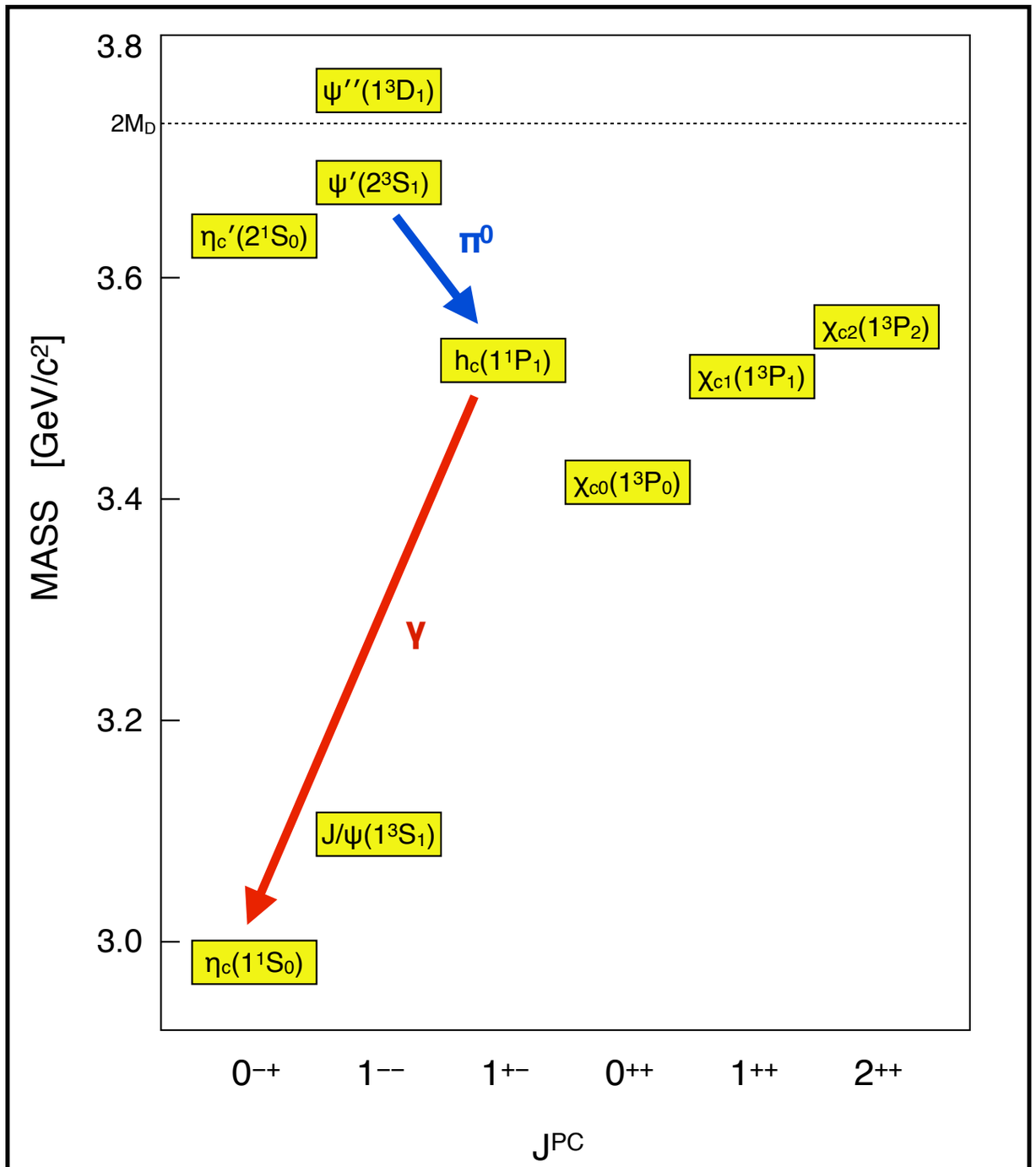
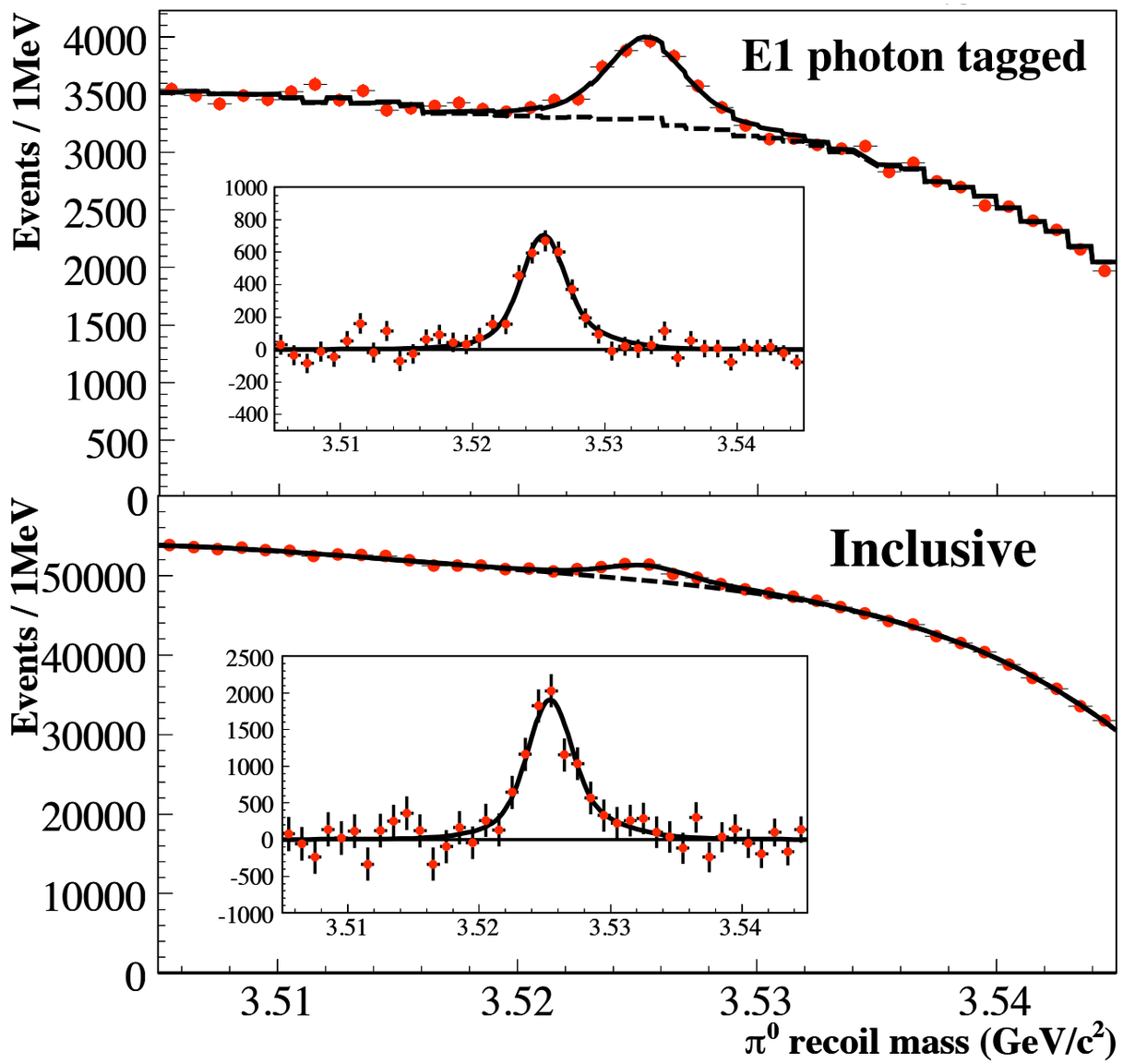


For example:

Properties of the h_c *(PRL 104, 132002 (2010))*



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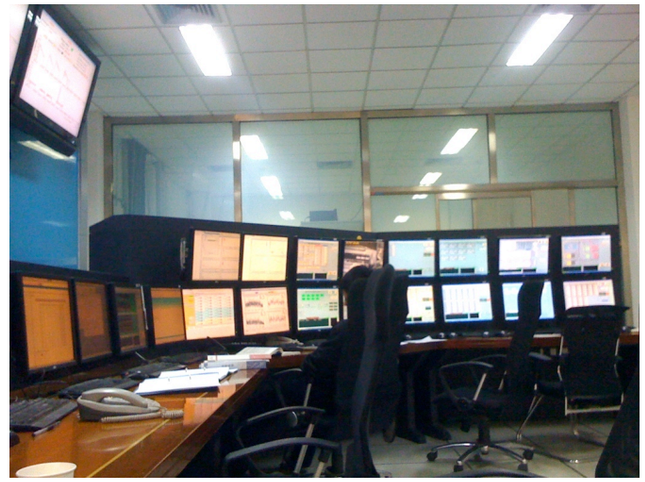

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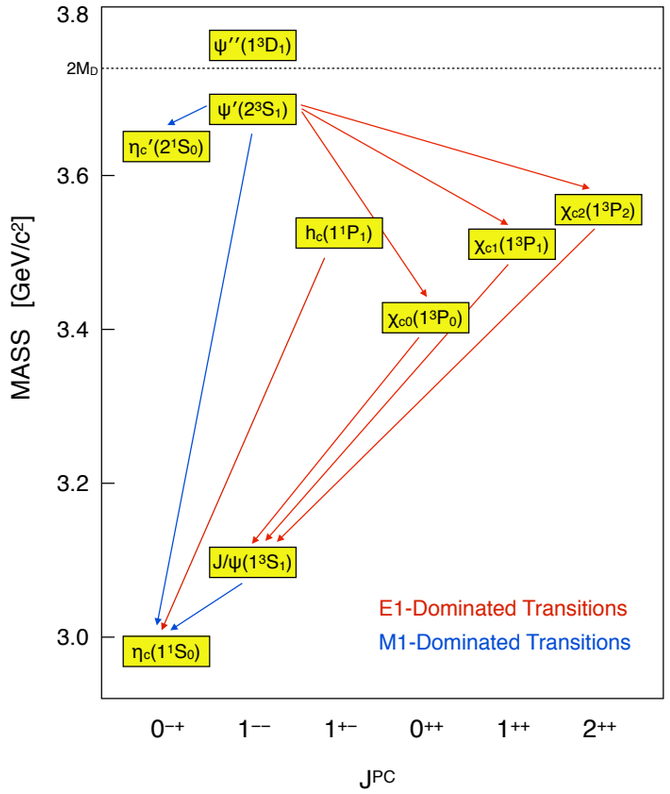

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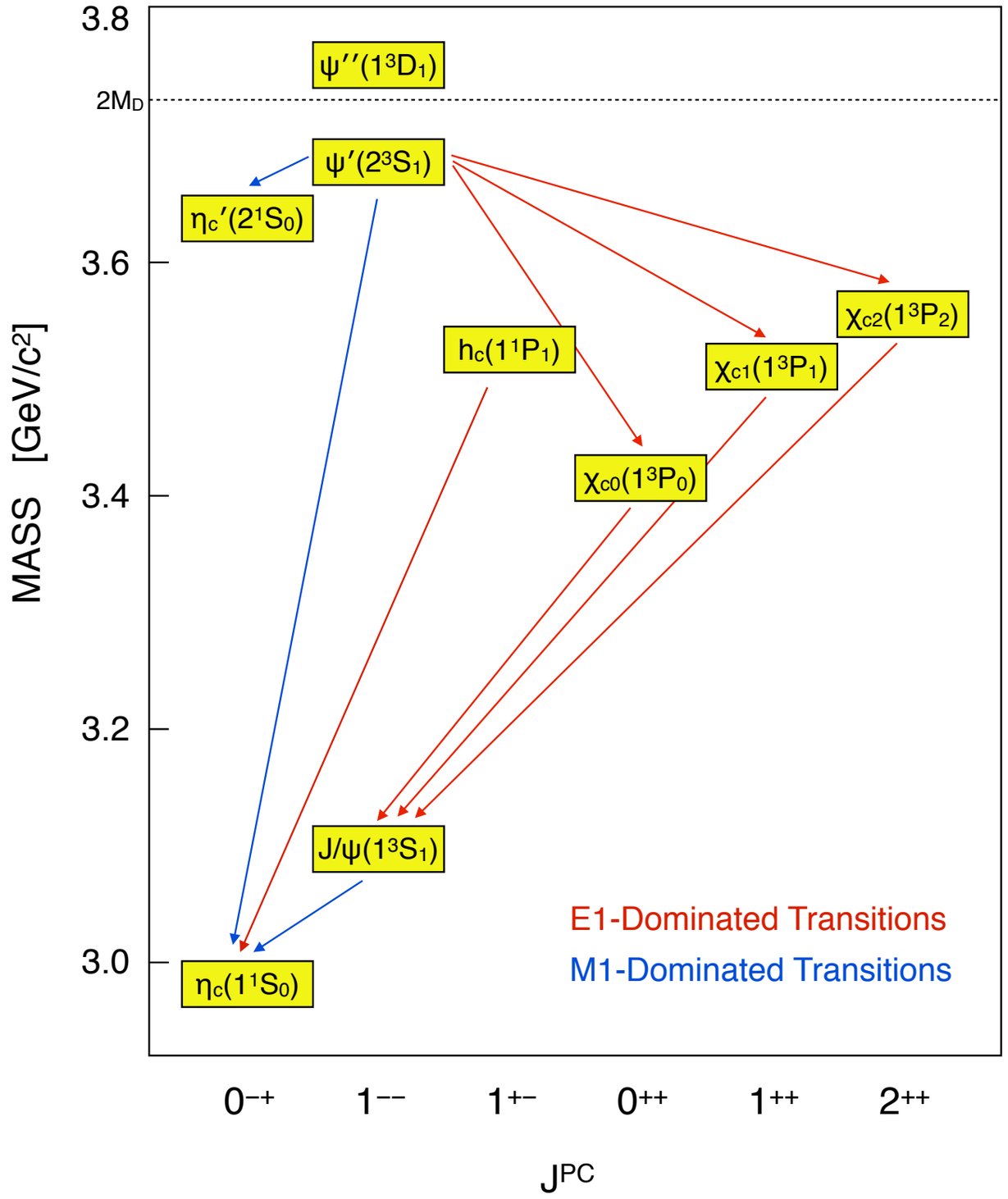

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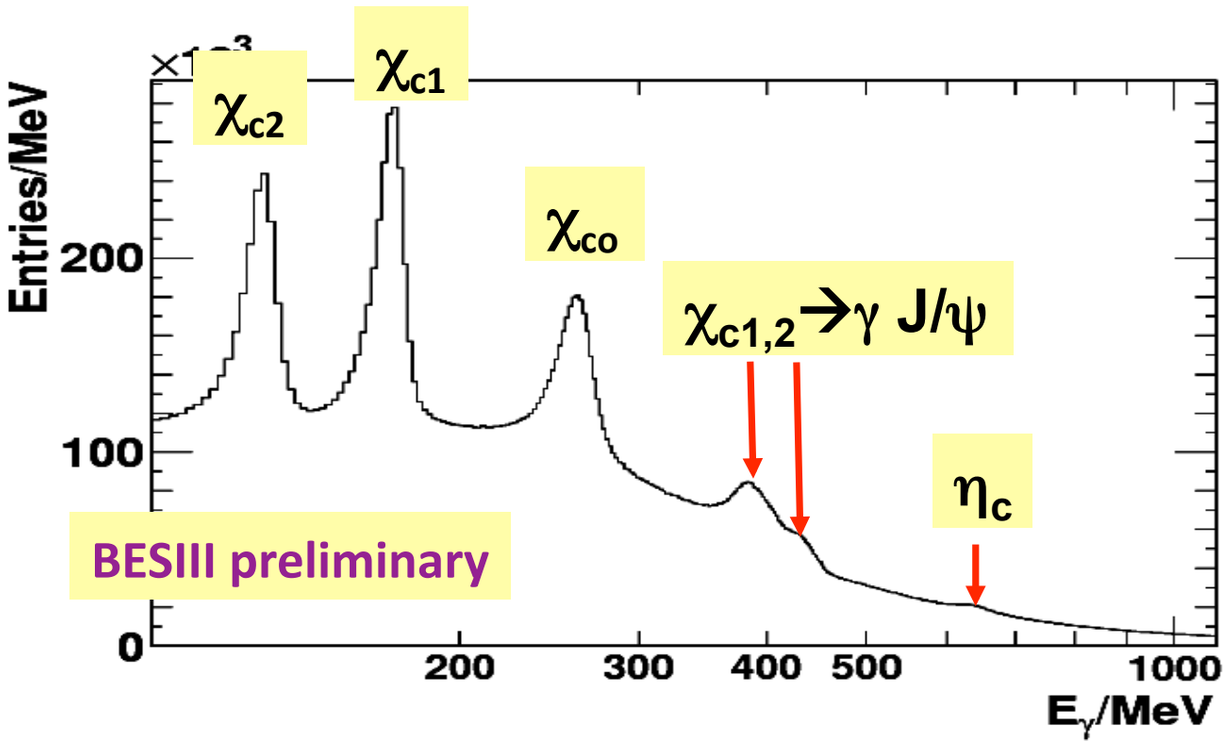
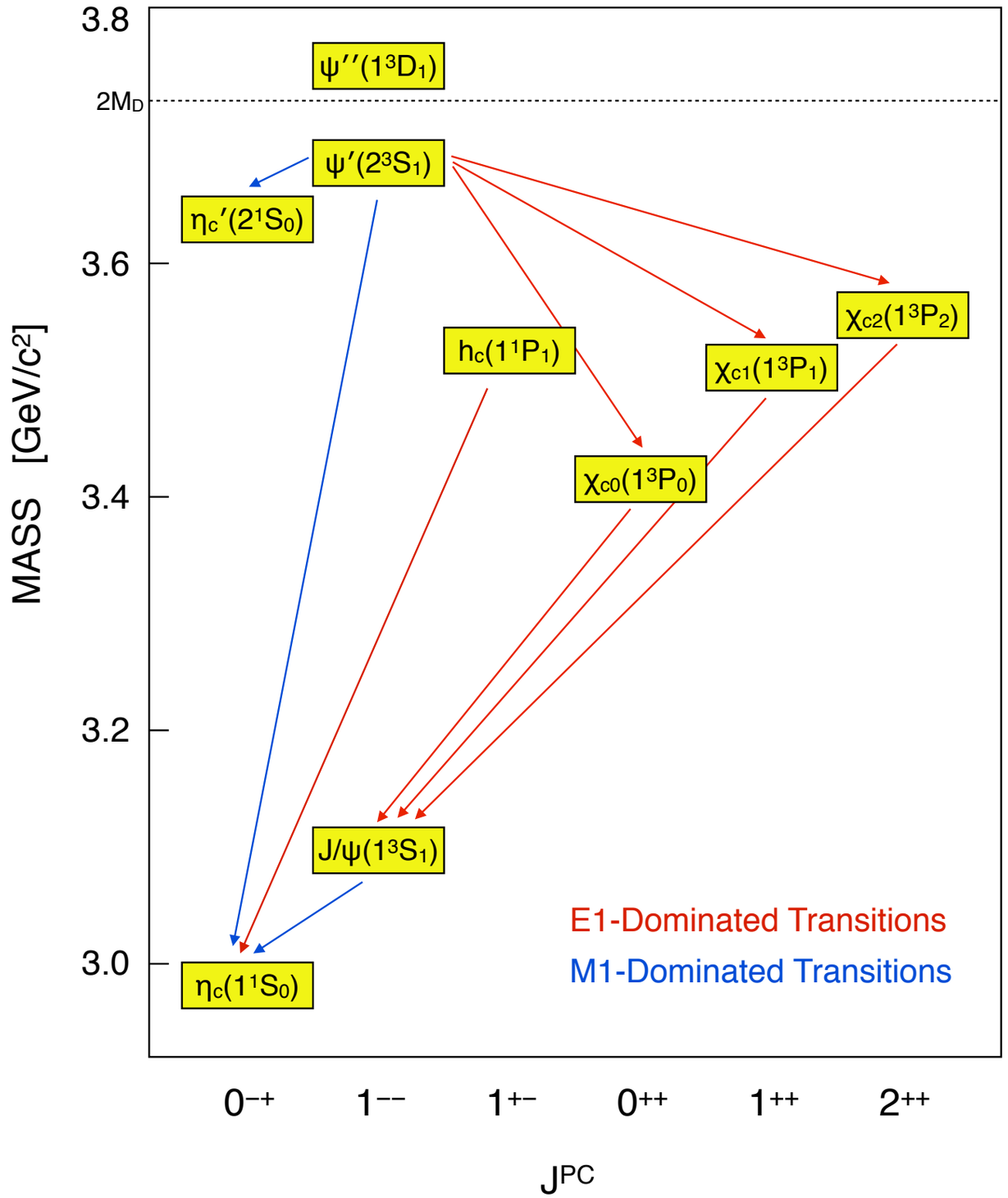


photons from ψ(2S) decays



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Introduction to the BESIII Experiment

Physics at BESIII

- **Charmonium Spectroscopy and Transitions**
  - Properties of the h_c *(PRL 104, 132002 (2010))*
  - $\psi(2S) \rightarrow \gamma\gamma J/\psi$ *(preliminary)*
- **Charmonium Decays**
  - $\chi_{cJ} \rightarrow \pi^0\pi^0, \eta\eta$ *(PRD 81, 052005 (2010))*
  - $\chi_{cJ} \rightarrow \gamma\varrho, \gamma\omega, \gamma\phi$ *(preliminary)*
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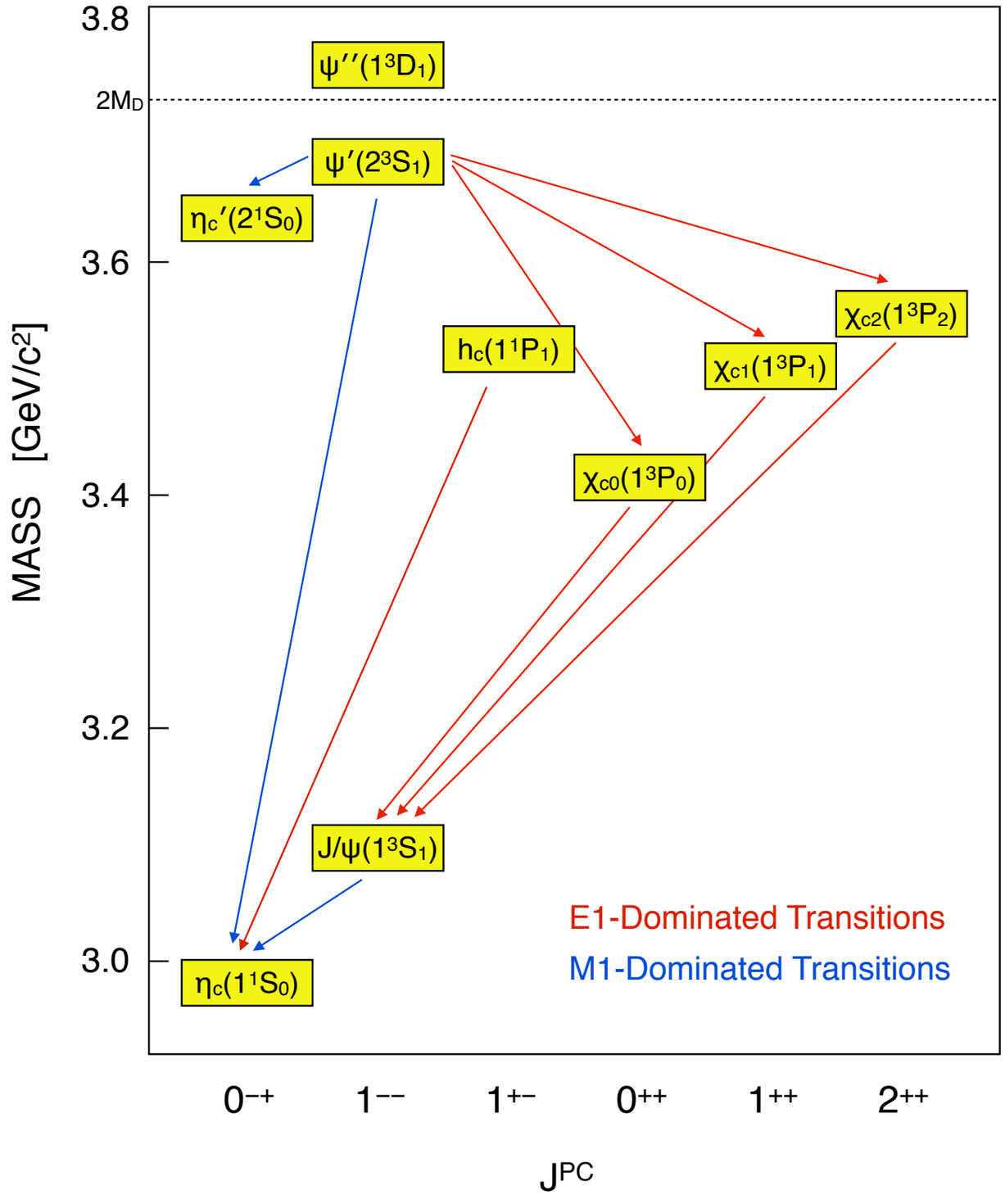
  - $\psi(2S) \rightarrow \gamma\pi^0, \gamma\eta, \gamma\eta'$ *(PRL 105, 261801 (2010))*
  - $\chi_{cJ} \rightarrow 4\pi^0$ *(arXiv:1011.6556)*
- **Light Quark States**
  - $a_0(980)$ – $f_0(980)$ mixing *(arXiv:1012.5131)*
  - $\eta' \rightarrow \eta\pi^+\pi^-$ matrix element *(arXiv:1012.1117)*
  - X(1860) in $J/\psi \rightarrow \gamma(p\bar{p})$ *(Chinese Physics C 34, 4 (2010))*
  - X(1835) in $J/\psi \rightarrow \gamma(\eta'\pi^+\pi^-)$ *(arXiv:1012:3510)*
  - X(1870) in $J/\psi \rightarrow \omega(\eta\pi^+\pi^-)$ *(preliminary)*
- **Open Charm, etc., etc.!**



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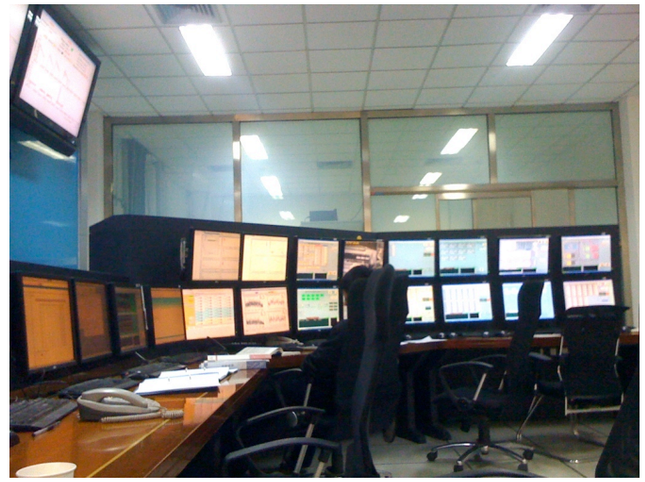
Introduction to the BESIII Experiment

accelerator

detector



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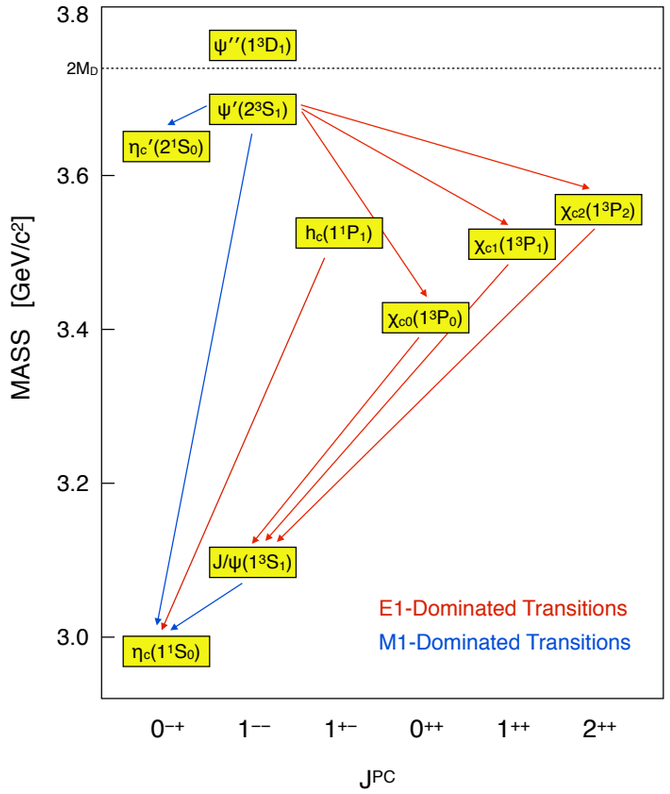
QCD

phenomenology and theory



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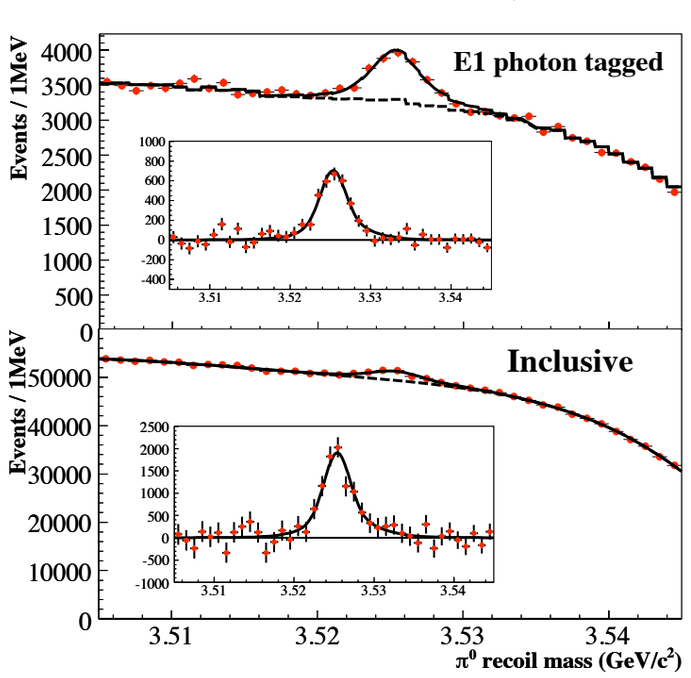


analysis

Introduction to the BESIII Experiment

QCD

phenomenology and theory

Introduction to the BESIII Experiment

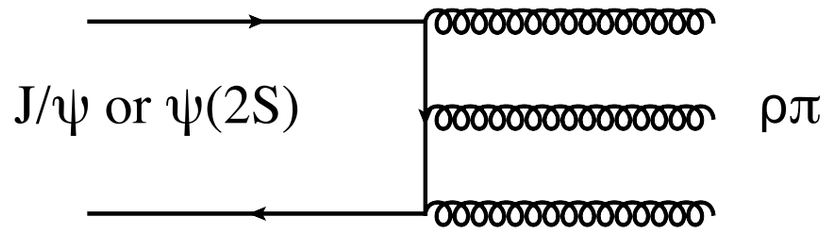
QCD

phenomenology and theory

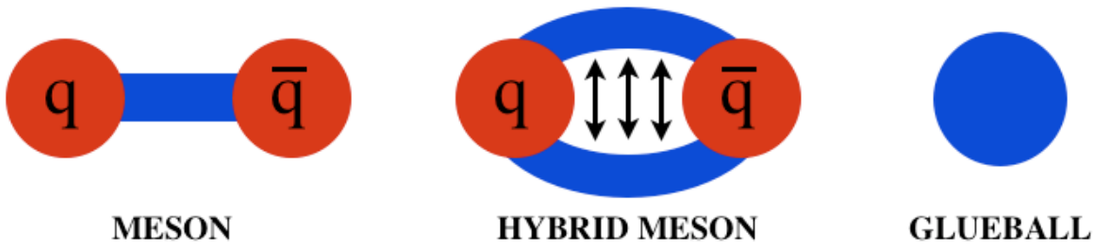
- **Quantitative Comparisons with Lattice QCD**
  - *e.g.:*
    - charmonium masses
    - radiative transitions
    - open charm decay constants

- **Decay Dynamics**
  - *e.g.:*
    - the "ϱπ puzzle"

$$\frac{B(\psi(2S) \to \rho\pi)}{B(J/\psi \to \rho\pi)} << 12\%$$



- **The Structure of Mesons**
  - *e.g.:*
    - gluonic excitations?



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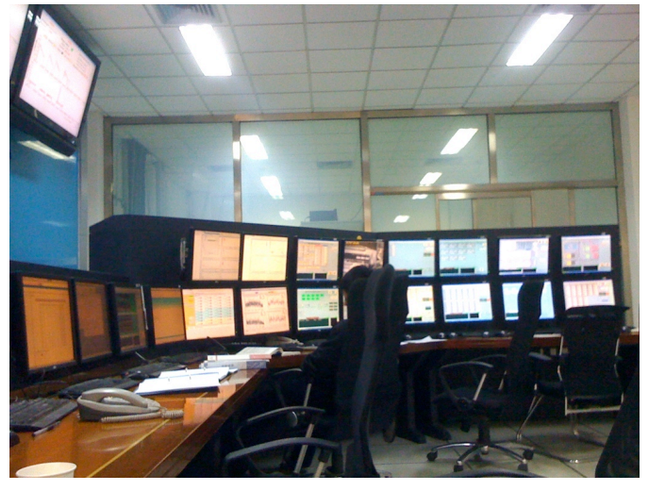

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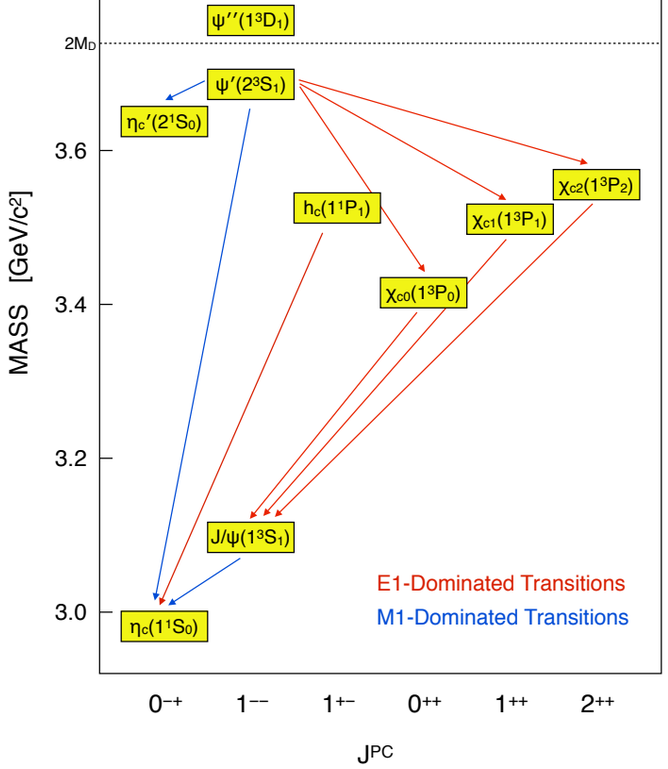

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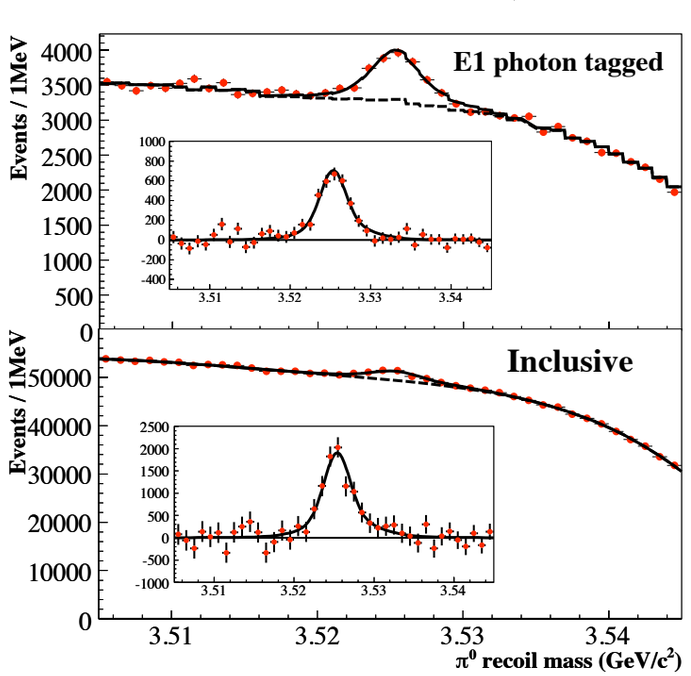

analysis

First Analyses from the BESIII Experiment

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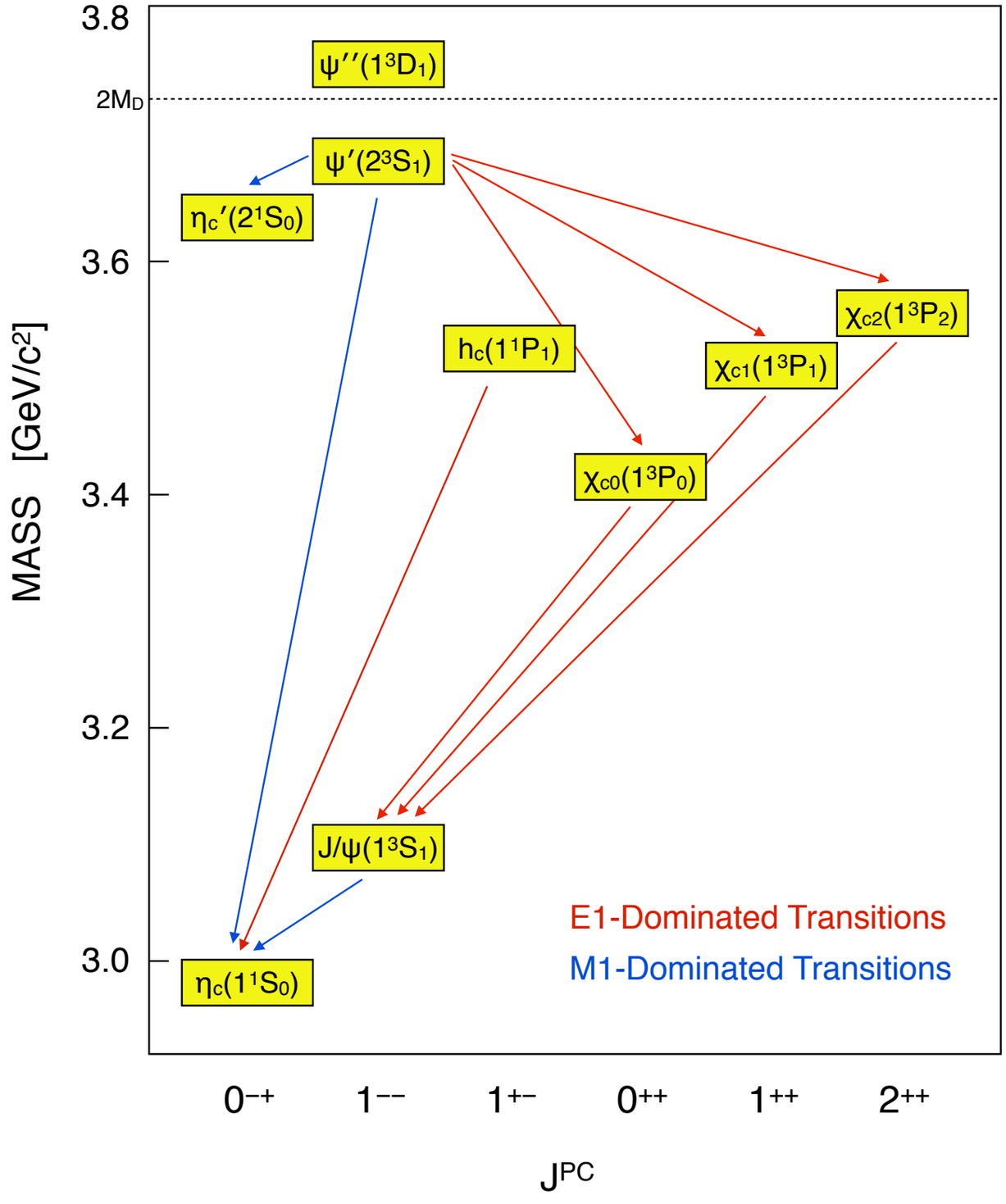

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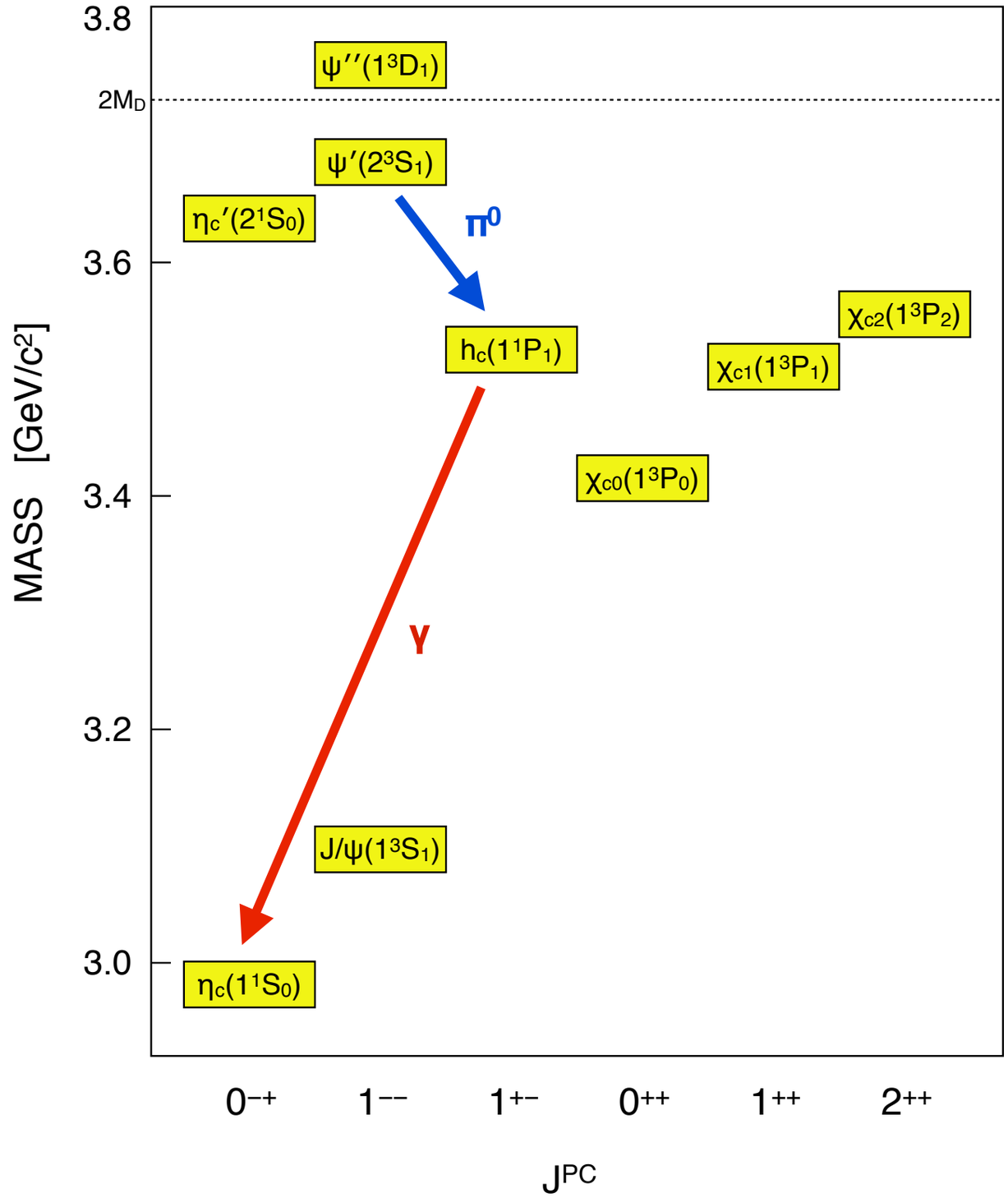


Introduction to the $h_c(1P)$

- Produced in the isospin-violating process:

  $$\psi(2S) \rightarrow \pi^0 h_c$$

- $\mathbf{B(\psi(2S) \rightarrow \pi^0 h_c)}$ is a measure of isospin violation.

- $\mathbf{B(h_c \rightarrow \gamma \eta_c)}$ is a large E1 transition.

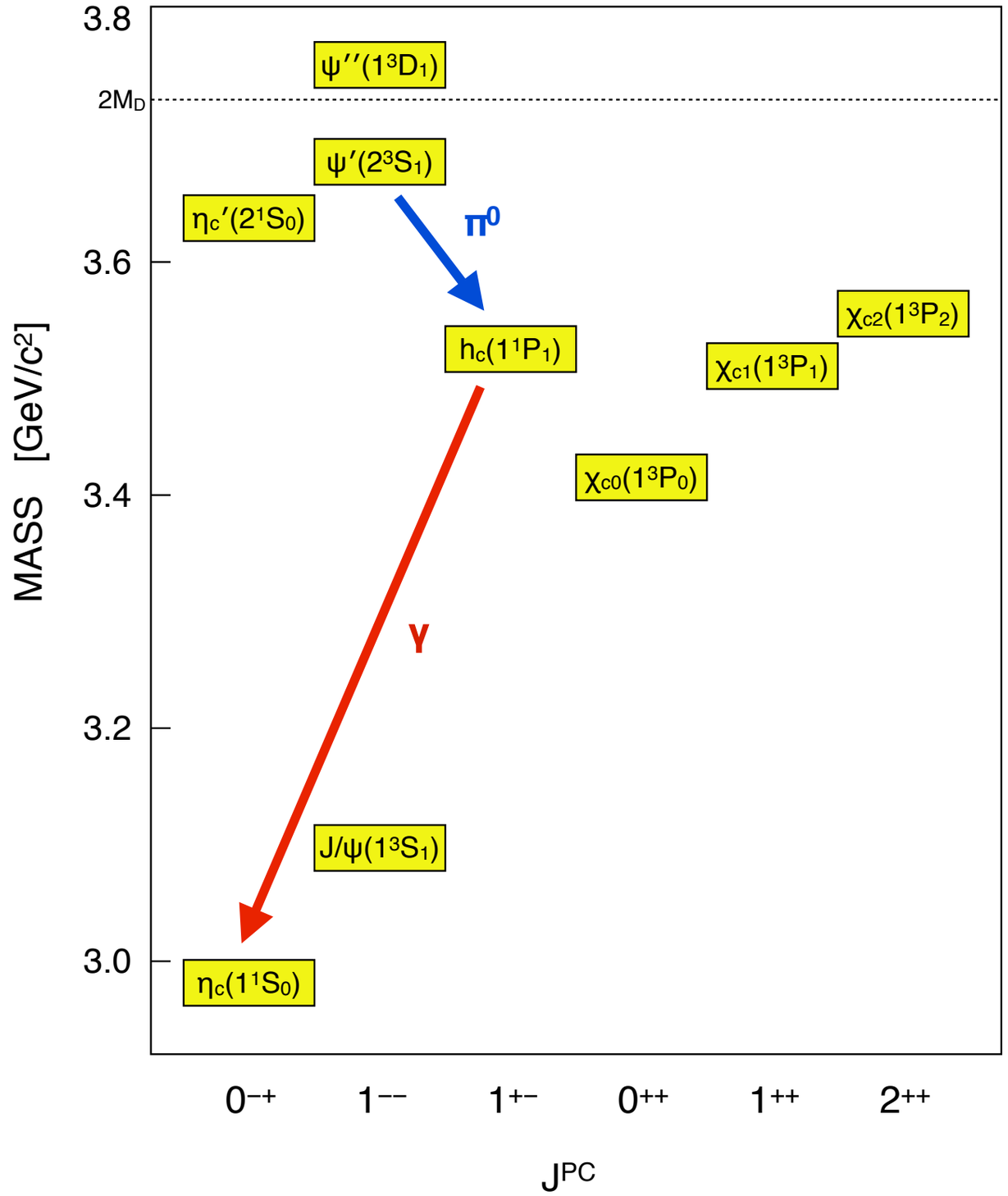
- CLEO could only measure the product:

  $$\mathbf{B(\psi(2S) \rightarrow \pi^0 h_c) \times B(h_c \rightarrow \gamma \eta_c)}$$

  but BESIII has measured the individual branching fractions.

- $\mathbf{M(h_c)}$ gives a measure of the hyperfine splitting of the 1P states:

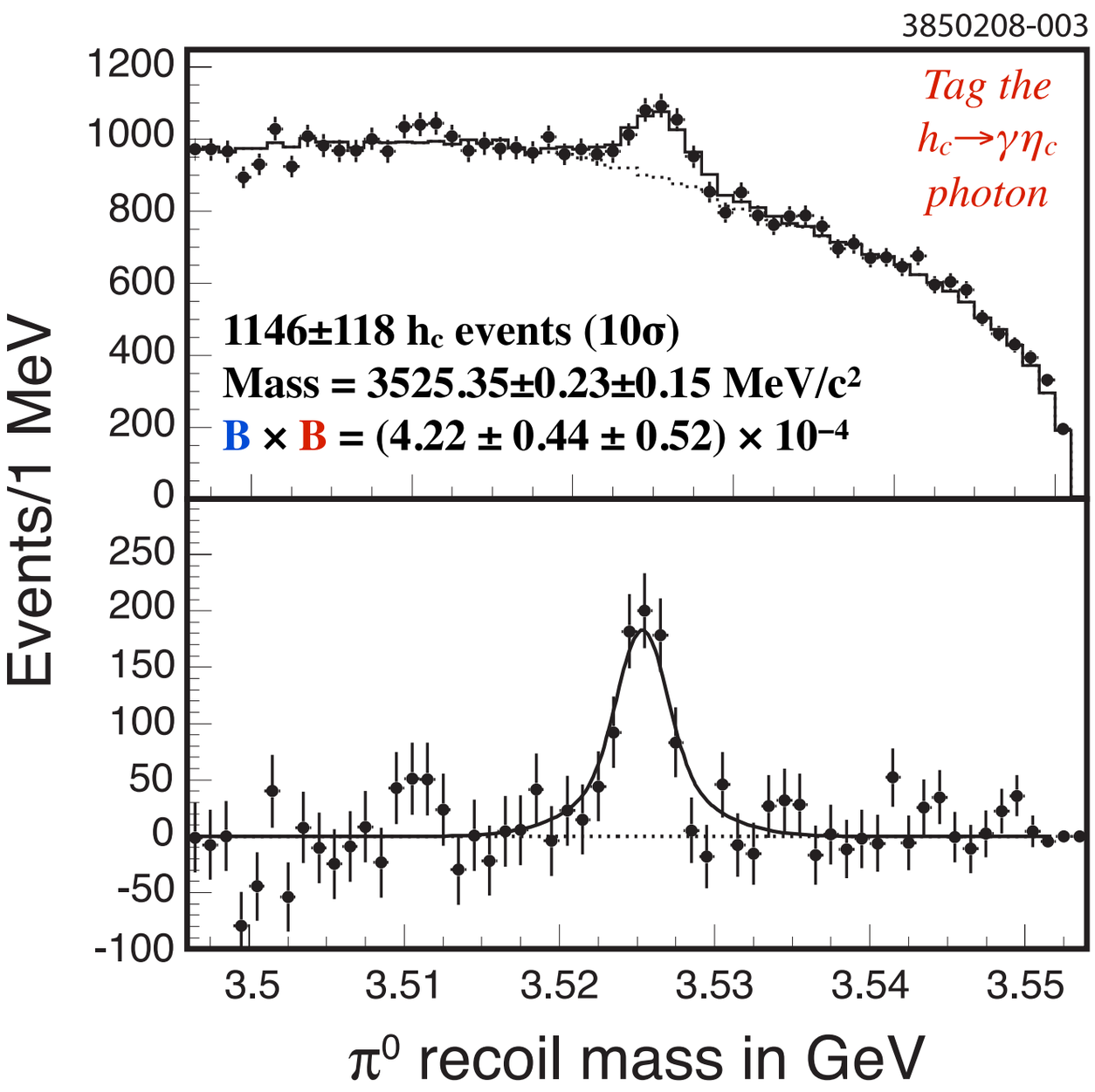
  $$\mathbf{M(h_c(1P)) - \langle M(\chi_{cJ}(1P)) \rangle_{(spin\text{-}weighted)}}$$

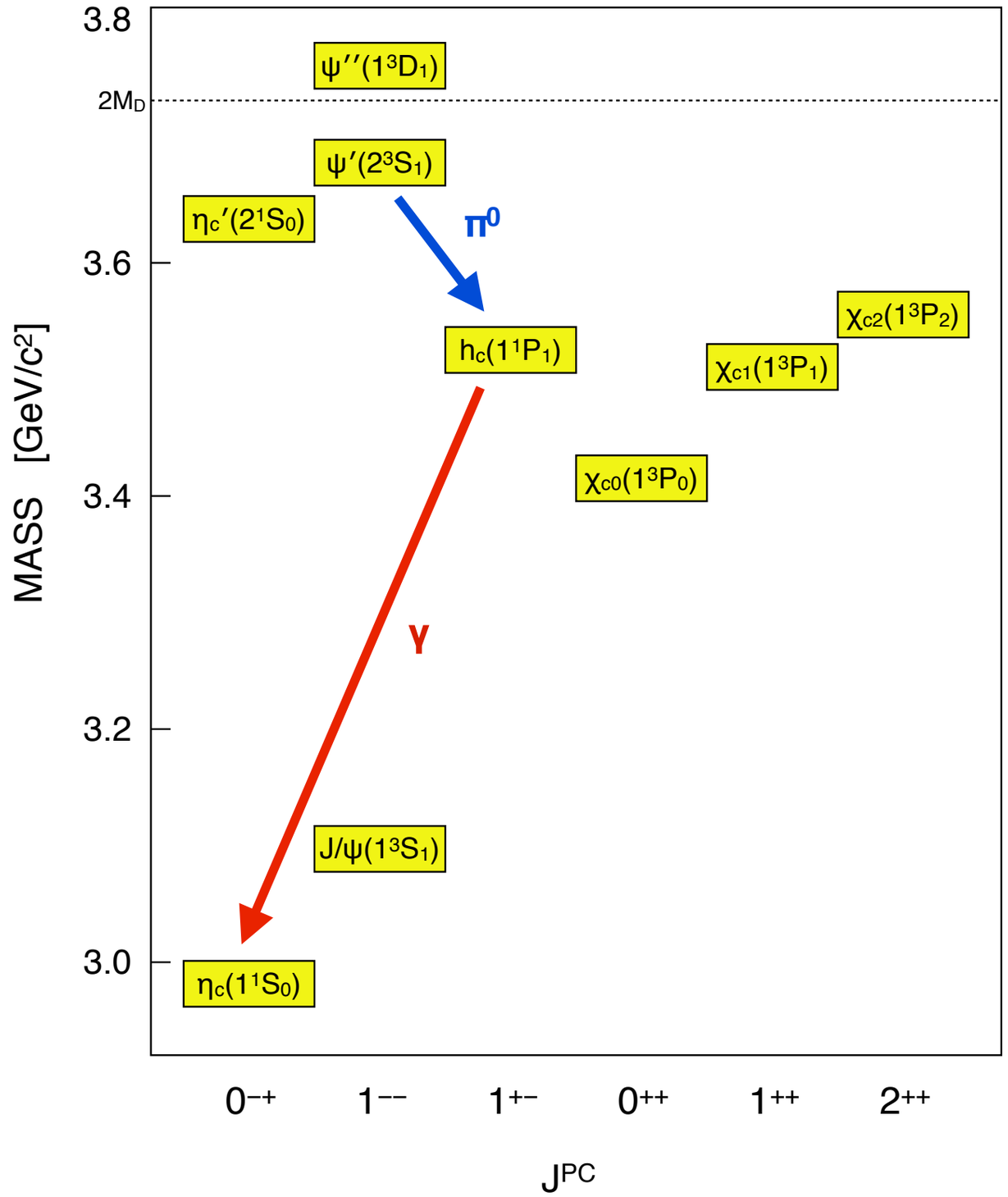


The $h_c(1P)$ at CLEO-c

PRL 101, 182003 (2008)

(using 27M $\psi(2S)$ decays)

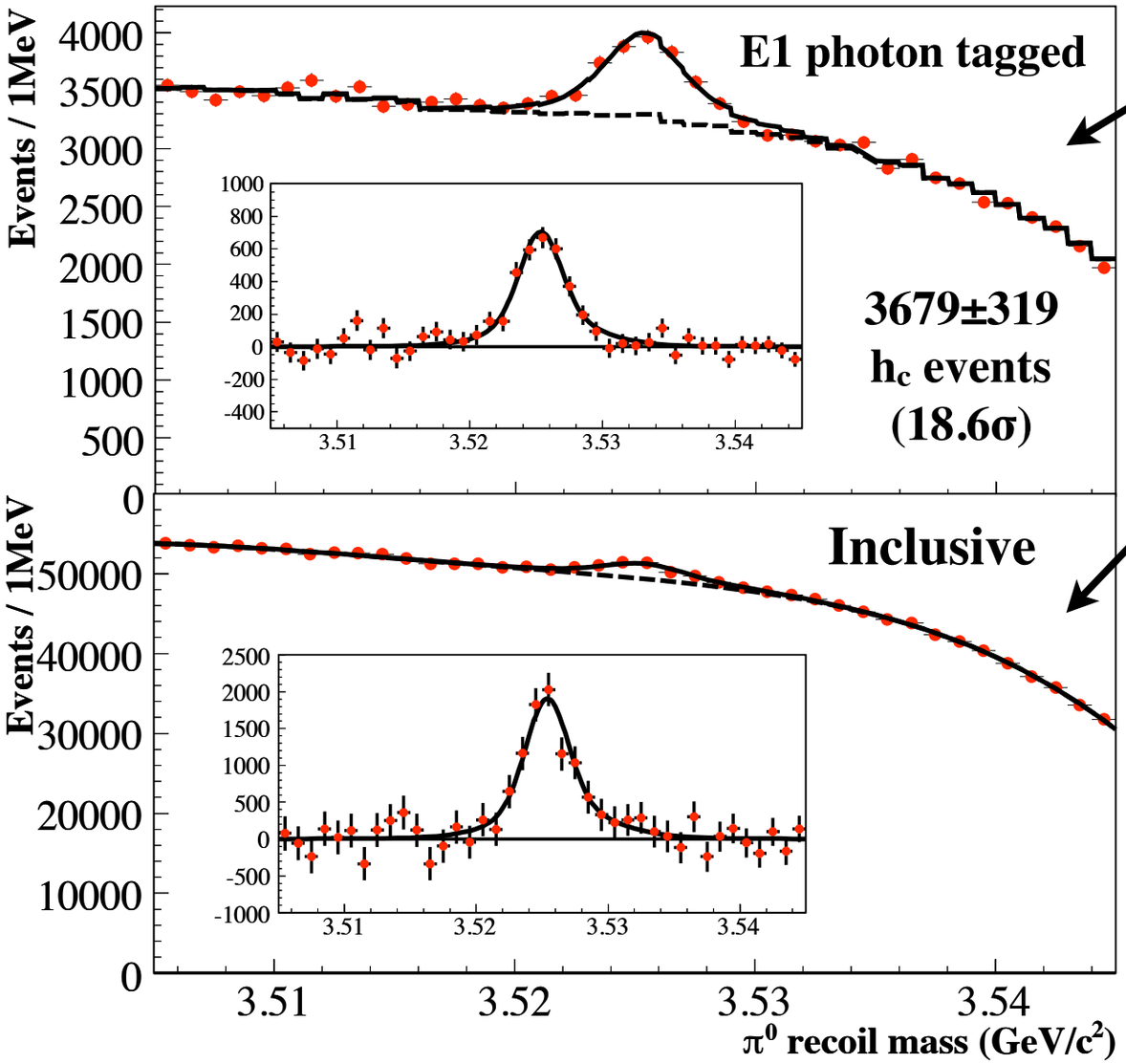




(Note: CLEO also measured Mass and B×B using exclusive decays of the η_c, not included in these numbers.)

The $h_c(1P)$ at BESIII

PRL 104, 132002 (2010)
(using 106M ψ(2S) decays)



- Tag the photon to measure
  $B(\psi(2S) \to \pi^0 h_c) \times B(h_c \to \gamma\eta_c)$
  $= (4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$
  (consistent with CLEO)

- Don't tag the photon to measure
  $B(\psi(2S) \to \pi^0 h_c)$
  $= (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$
  (first measurement)

- Combining branching fractions gives
  $B(h_c \to \gamma\eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$
  (first measurement)

- Also measure the mass
  $M(h_c) = 3525.40 \pm 0.13 \pm 0.18$ MeV
  (consistent with CLEO)

- Compare to:
  $\langle M(\chi_{cJ}(1P)) \rangle_{\text{(spin-weighted)}} =$
  3525.30 ± 0.11 MeV/c^2 (PDG)

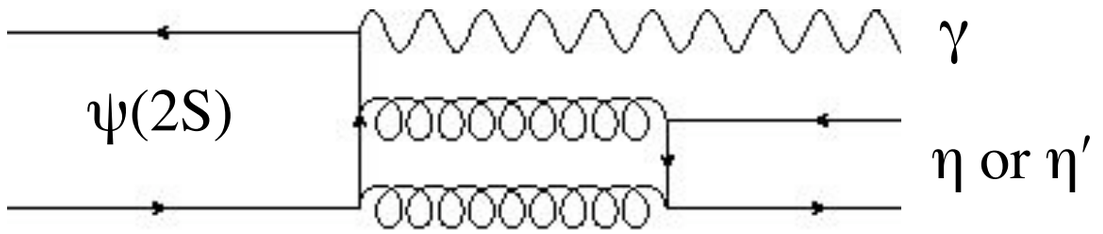
⇐ ***Hyperfine splitting of 1P states is small (or 0).***

First Analyses from the BESIII Experiment

Physics at BESIII

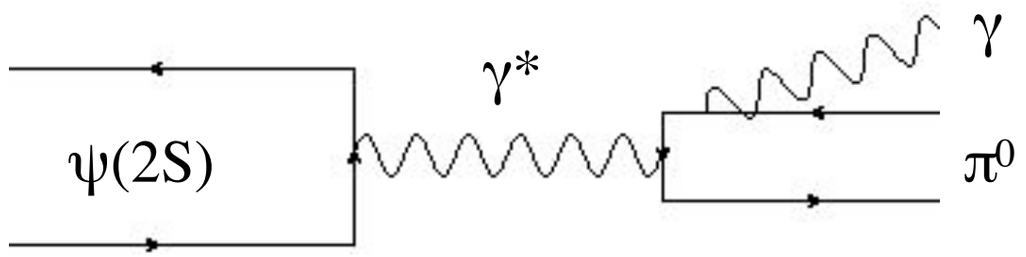
- **Charmonium Spectroscopy and Transitions**
  - Properties of the h_c *(PRL 104, 132002 (2010))*
  - $\psi(2S) \to \gamma\gamma J/\psi$ *(preliminary)*
- **Charmonium Decays**
  - $\chi_{cJ} \to \pi^0\pi^0, \eta\eta$ *(PRD 81, 052005 (2010))*
  - $\chi_{cJ} \to \gamma\varrho, \gamma\omega, \gamma\phi$ *(preliminary)*
  - $\chi_{cJ} \to \omega\omega, \phi\phi, \omega\phi$ *(preliminary)*
  - **$\psi(2S) \to \gamma\pi^0, \gamma\eta, \gamma\eta'$**
    (PRL 105, 261801 (2010))
  - $\chi_{cJ} \to 4\pi^0$ *(arXiv:1011.6556)*
- **Light Quark States**
  - $a_0(980) - f_0(980)$ mixing *(arXiv:1012.5131)*
  - $\eta' \to \eta\pi^+\pi^-$ matrix element *(arXiv:1012.1117)*
  - X(1860) in $J/\psi \to \gamma(p\bar{p})$
    (Chinese Physics C 34, 4 (2010))
  - X(1835) in $J/\psi \to \gamma(\eta'\pi^+\pi^-)$ *(arXiv:1012:3510)*
  - X(1870) in $J/\psi \to \omega(\eta\pi^+\pi^-)$ *(preliminary)*
- **Open Charm, etc., etc.!**

$\psi(2S) \to \gamma\eta^{(\prime)}$



$\Rightarrow$ ideally, study the η–η' mixing angle, but $\psi(2S) \to \gamma\eta$ is anomalously suppressed...

$\psi(2S) \to \gamma\pi^0$

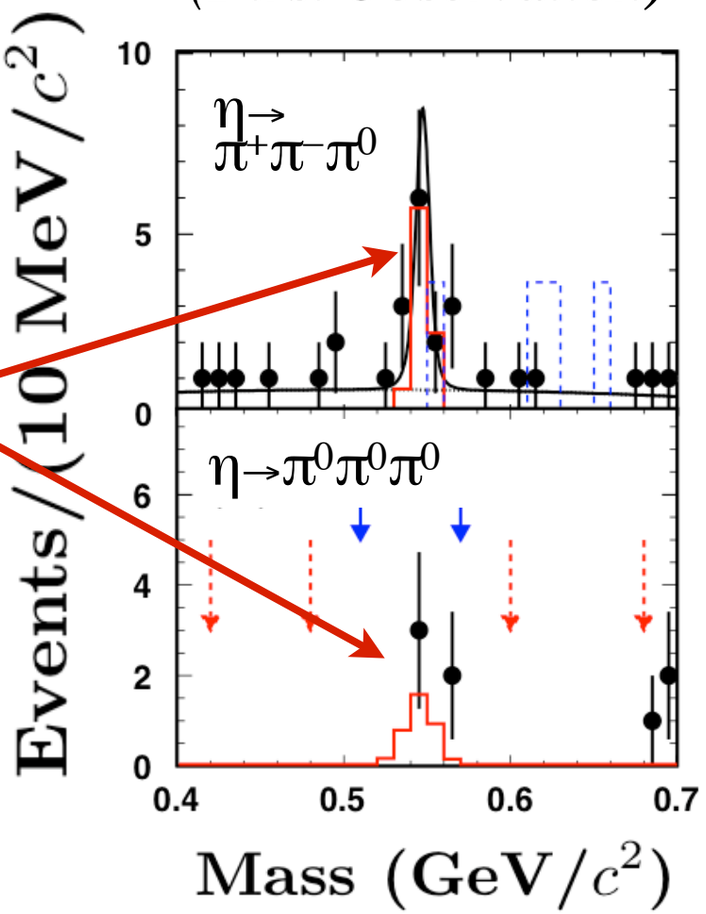


$\Rightarrow$ possibly study the $\gamma^* - \gamma - \pi^0$ form factor for timelike γ^*

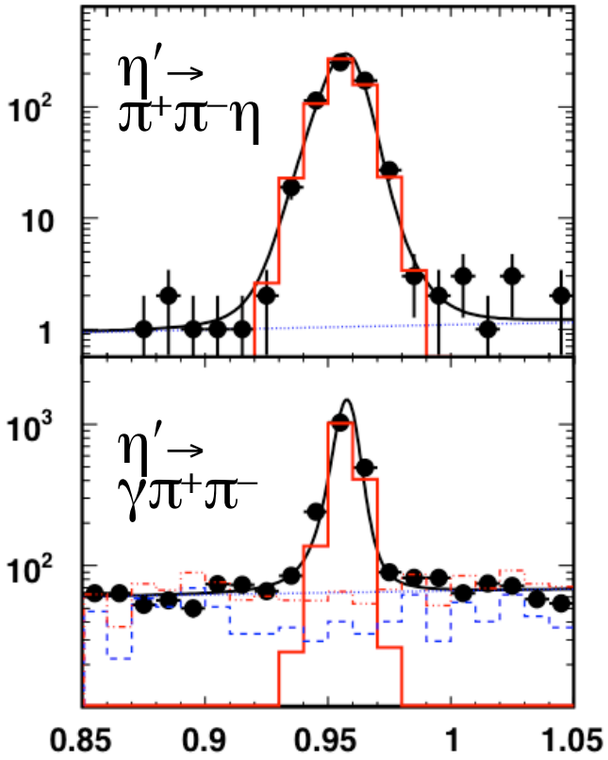
Analysis of $\psi(2S) \to \gamma(\pi^0,\eta,\eta')$ at BESIII

strange depletion!

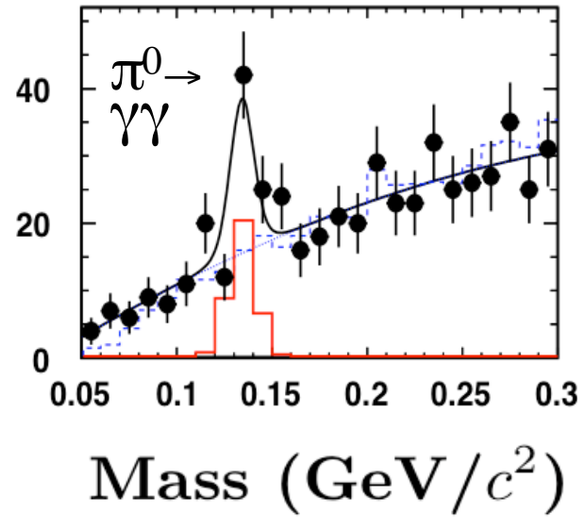
$\psi(2S) \to \gamma\eta$
(First Observation)



$\psi(2S) \to \gamma\eta'$



$\psi(2S) \to \gamma\pi^0$
(First Observation)



Mode	BESIII	Combined BESIII	PDG
$\psi' \to \gamma\pi^0$	$1.58 \pm 0.40 \pm 0.13$	$1.58 \pm 0.40 \pm 0.13$	≤ 5
$\psi' \to \gamma\eta(\pi^+\pi^-\pi^0)$	$1.78 \pm 0.72 \pm 0.17$	$1.38 \pm 0.48 \pm 0.09$	≤ 2
$\to \gamma\eta(\pi^0\pi^0\pi^0)$	$1.07 \pm 0.65 \pm 0.08$		
$\psi' \to \gamma\eta'(\pi^+\pi^-\eta)$	$120 \pm 5 \pm 8$	$126 \pm 3 \pm 8$	121 ± 8
$\to \gamma\eta'(\pi^+\pi^-\gamma)$	$129 \pm 3 \pm 8$		

(Branching fractions in units of 10^{-6})

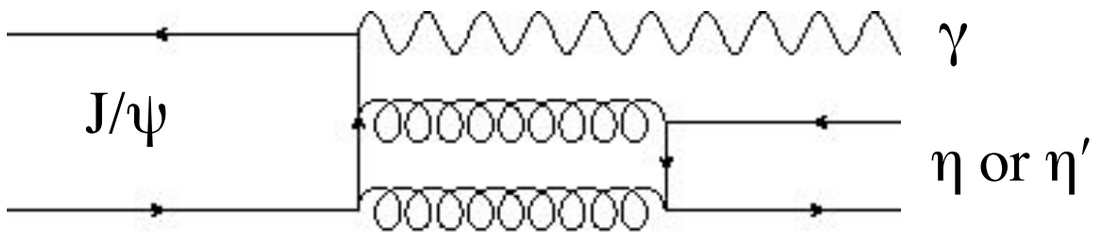
The Suppression of $\psi(2S) \to \gamma\eta$?

- **For J/ψ,**

$$\frac{B(J/\psi \to \gamma\eta)}{B(J/\psi \to \gamma\eta')} = \textbf{(21.1 ± 0.9) \%}$$

consistent with other measurements of the η–η′ mixing angle.

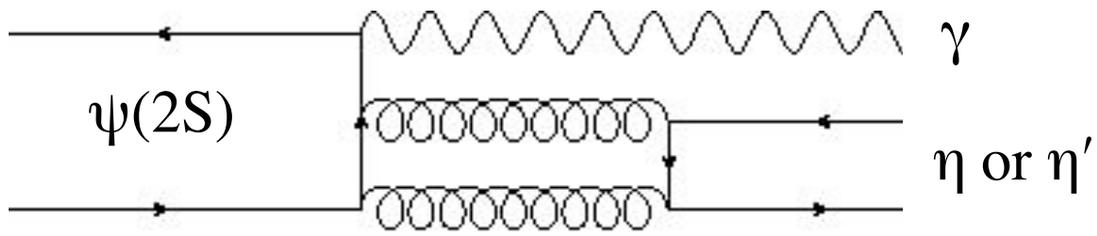
$J/\psi \to \gamma\eta^{(\prime)}$



- **But for ψ(2S),**

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

$\psi(2S) \to \gamma\eta^{(\prime)}$



- **Why the difference?**
  - **interference with the continuum?**
  - **contributions of other processes?**
  - **something related to the "ϱπ puzzle?"**

First Analyses from the BESIII Experiment

Physics at BESIII

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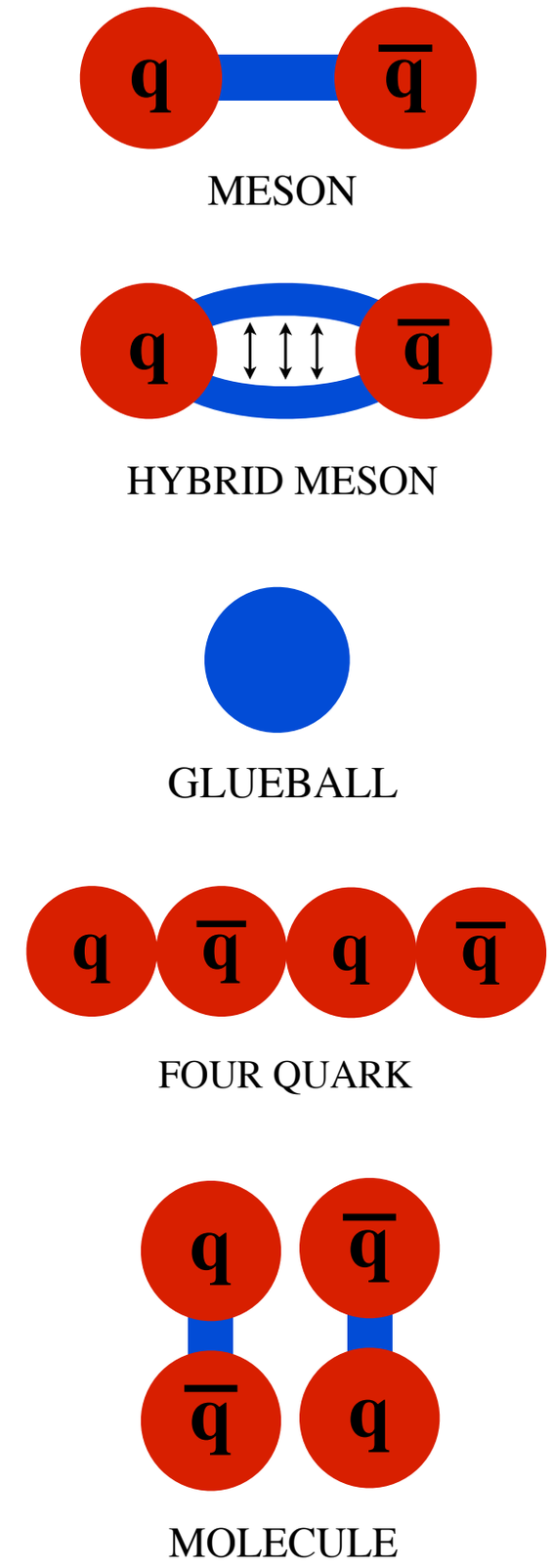
  - Properties of the h_c *(PRL 104, 132002 (2010))*
  - $\psi(2S) \rightarrow \gamma\gamma J/\psi$ *(preliminary)*
- **Charmonium Decays**
  - $\chi_{cJ} \rightarrow \pi^0\pi^0, \eta\eta$ *(PRD 81, 052005 (2010))*
  - $\chi_{cJ} \rightarrow \gamma\varrho, \gamma\omega, \gamma\phi$ *(preliminary)*
  - $\chi_{cJ} \rightarrow \omega\omega, \phi\phi, \omega\phi$ *(preliminary)*
  - $\psi(2S) \rightarrow \gamma\pi^0, \gamma\eta, \gamma\eta'$ *(PRL 105, 261801 (2010))*
  - $\chi_{cJ} \rightarrow 4\pi^0$ *(arXiv:1011.6556)*
- **Light Quark States**
  - **$a_0(980)$ – $f_0(980)$ mixing *(arXiv:1012.5131)***
  - $\eta' \rightarrow \eta\pi^+\pi^-$ matrix element *(arXiv:1012.1117)*
  - X(1860) in $J/\psi \rightarrow \gamma(p\bar{p})$ *(Chinese Physics C 34, 4 (2010))*
  - X(1835) in $J/\psi \rightarrow \gamma(\eta'\pi^+\pi^-)$ *(arXiv:1012:3510)*
  - X(1870) in $J/\psi \rightarrow \omega(\eta\pi^+\pi^-)$ *(preliminary)*
- **Open Charm, etc., etc.!**

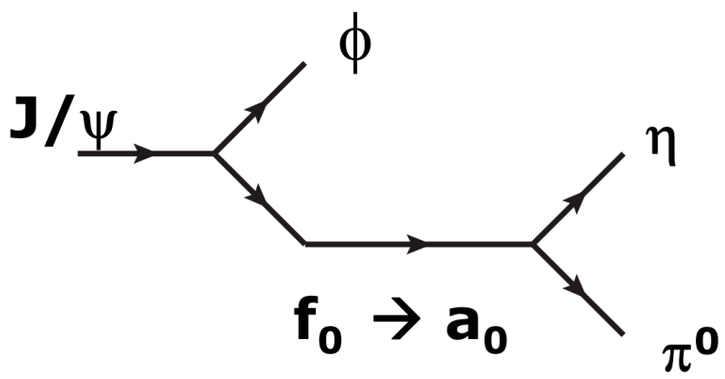
What are the $a_0(980)$ and $f_0(980)$?

Types of Meson States Allowed by QCD

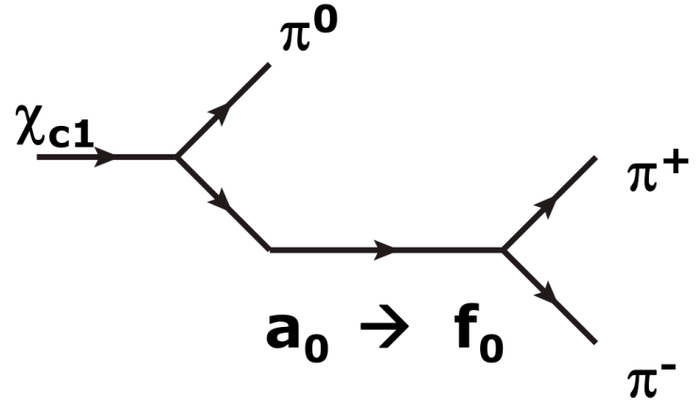


$a_0(980)$ – $f_0(980)$ Mixing at BESIII

- Search for **$a_0(980)$ – $f_0(980)$ mixing** in these channels:

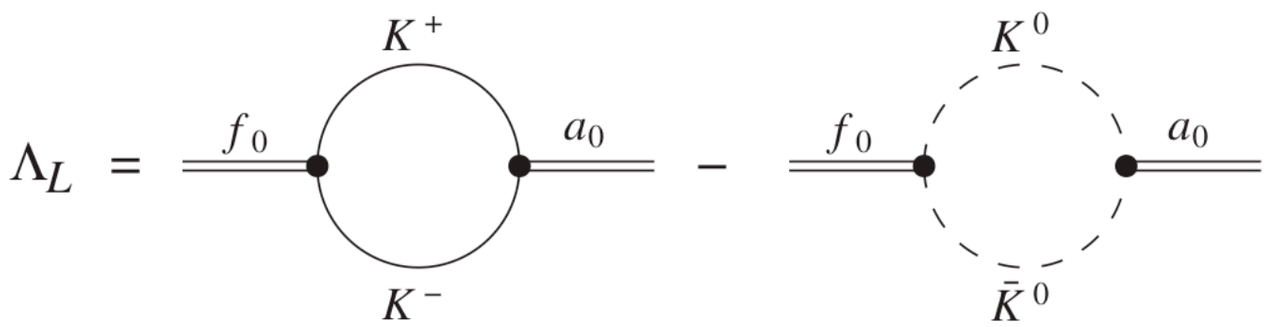


(normalize to $J/\psi \rightarrow \phi f_0$)



(normalize to $\chi_{c1} \rightarrow \pi^0 a_0$)

- The leading contribution to the mixing is through:

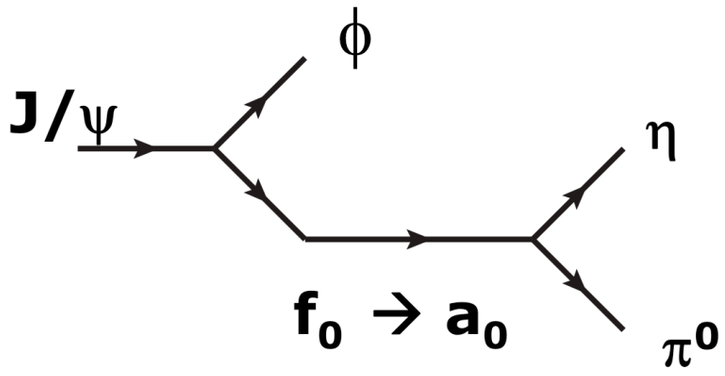


⇒ mixing appears as a narrow peak between the K^+K^- and $K^0\bar{K}^0$ thresholds

(Hanhart, et al., PRD76, 074028(2007) and references within)

$a_0(980)$ – $f_0(980)$ Mixing at BESIII

- Search for $J/\psi \to \phi(\eta\pi^0)$:

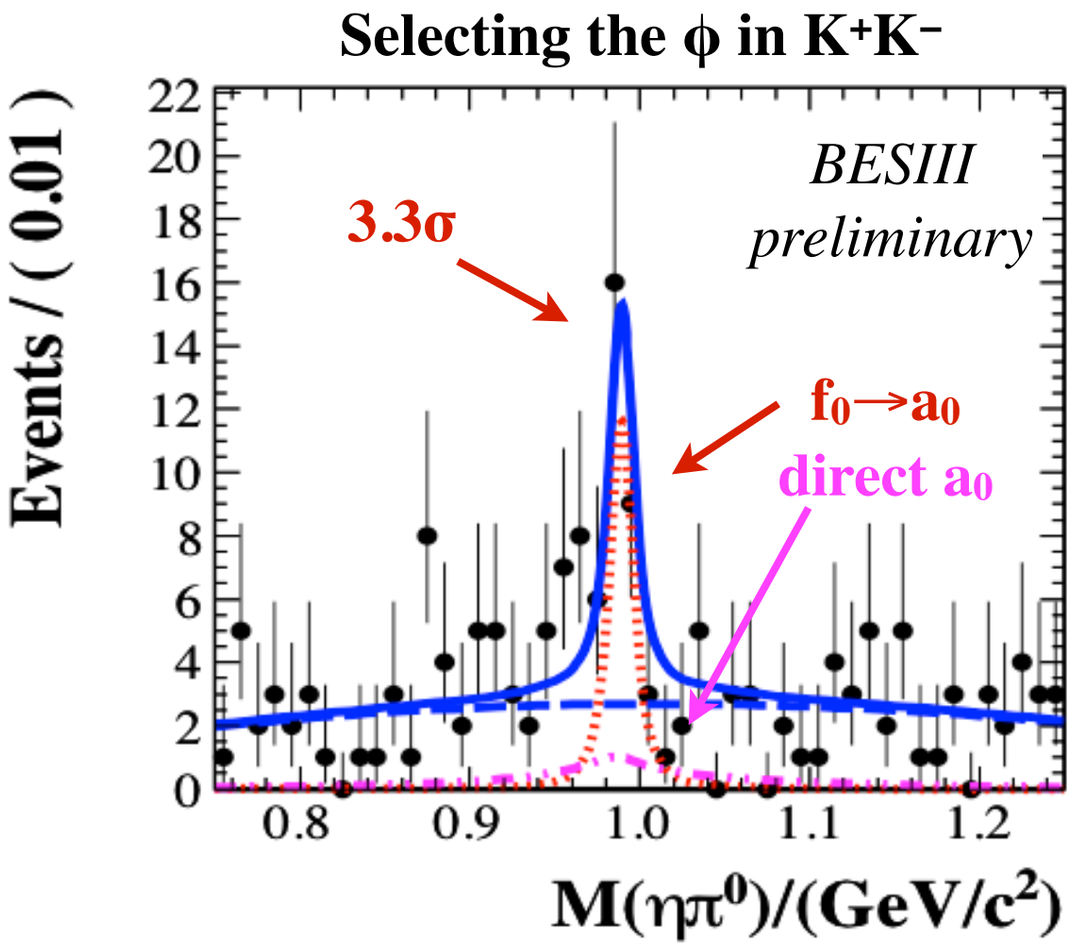


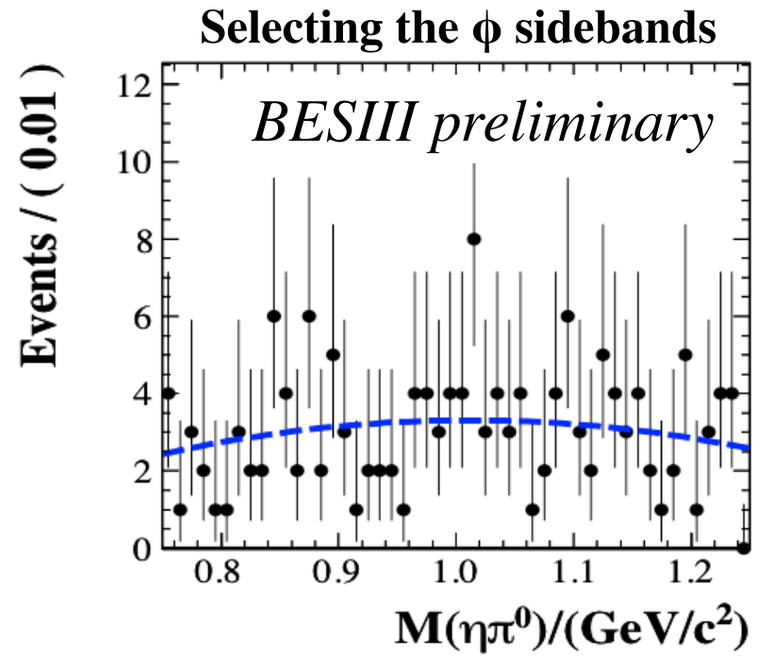
- Use 225 million J/ψ decays.

- Measure:

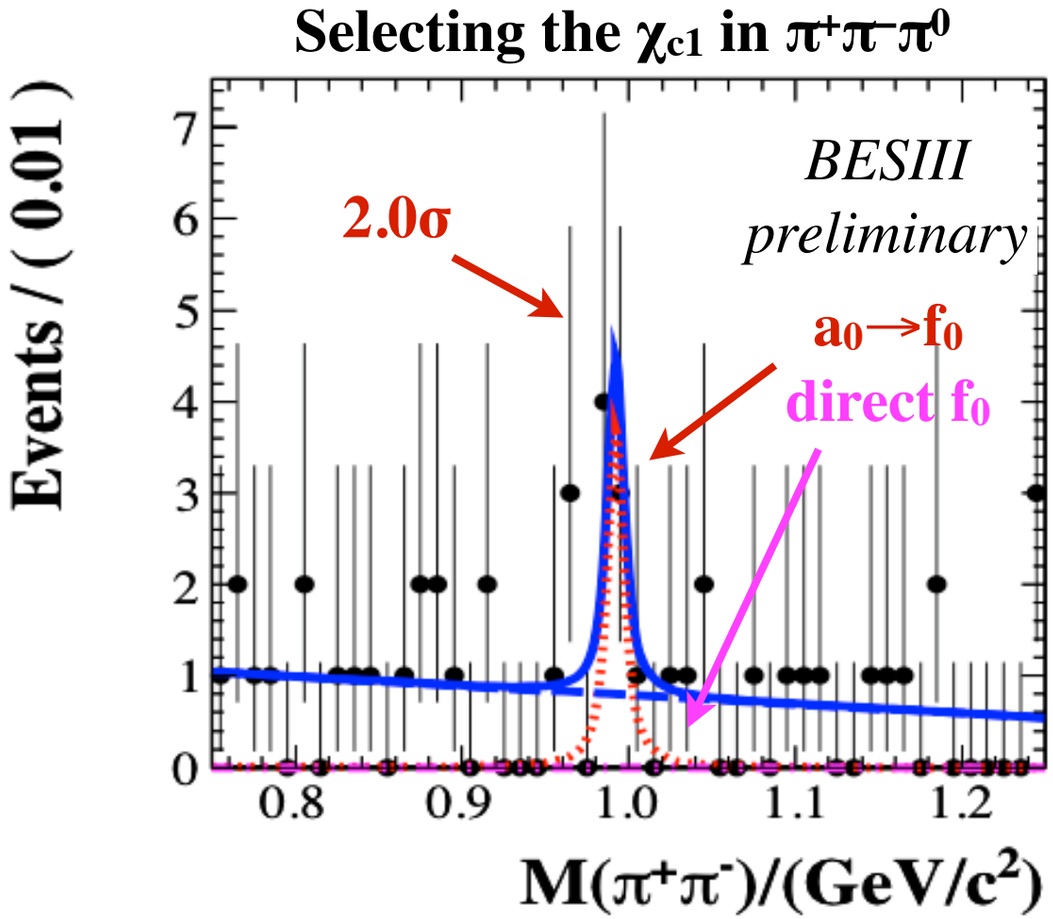
$$\xi_{fa} \equiv \frac{\mathcal{B}([J/\psi \to \phi f_0(980)][f_0(980) \to a_0(980)][a_0(980) \to \eta\pi^0])}{\mathcal{B}([J/\psi \to \phi f_0(980)][f_0(980) \to \pi^+\pi^-])}$$

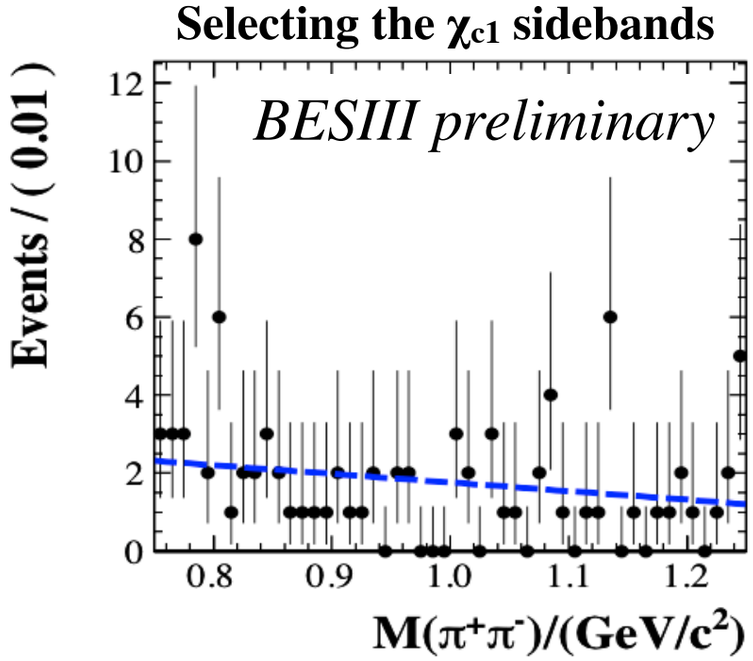
$$= 0.6 \pm 0.2(stat.) \pm 0.2(syst.)\%$$



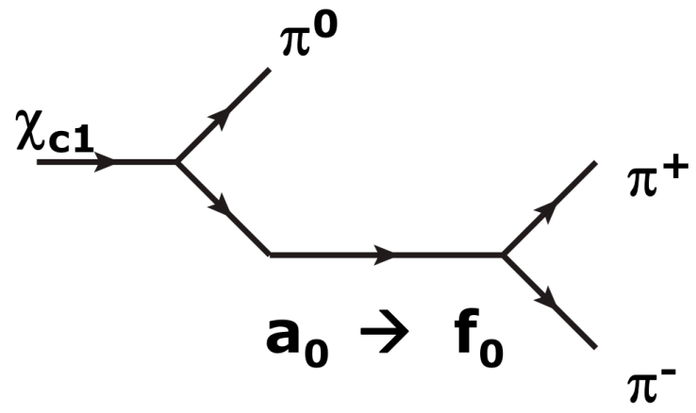


$a_0(980)$ – $f_0(980)$ Mixing at BESIII





- Search for $\chi_{c1} \to \pi^0(\pi^+\pi^-)$:



- Use 106 million $\psi(2S)$ decays and $\psi(2S) \to \gamma\chi_{c1}$

- Measure:

$$\xi_{af} \equiv \frac{\mathcal{B}([\chi_{c1} \to \pi^0 a_0(980)][a_0(980) \to f_0(980)][f_0(980) \to \pi^+\pi^-])}{\mathcal{B}([\chi_{c1} \to \pi^0 a_0(980)][a_0(980) \to \eta\pi^0])}$$

$$= 0.3 \pm 0.2(stat.) \pm 0.1(syst.)\%$$

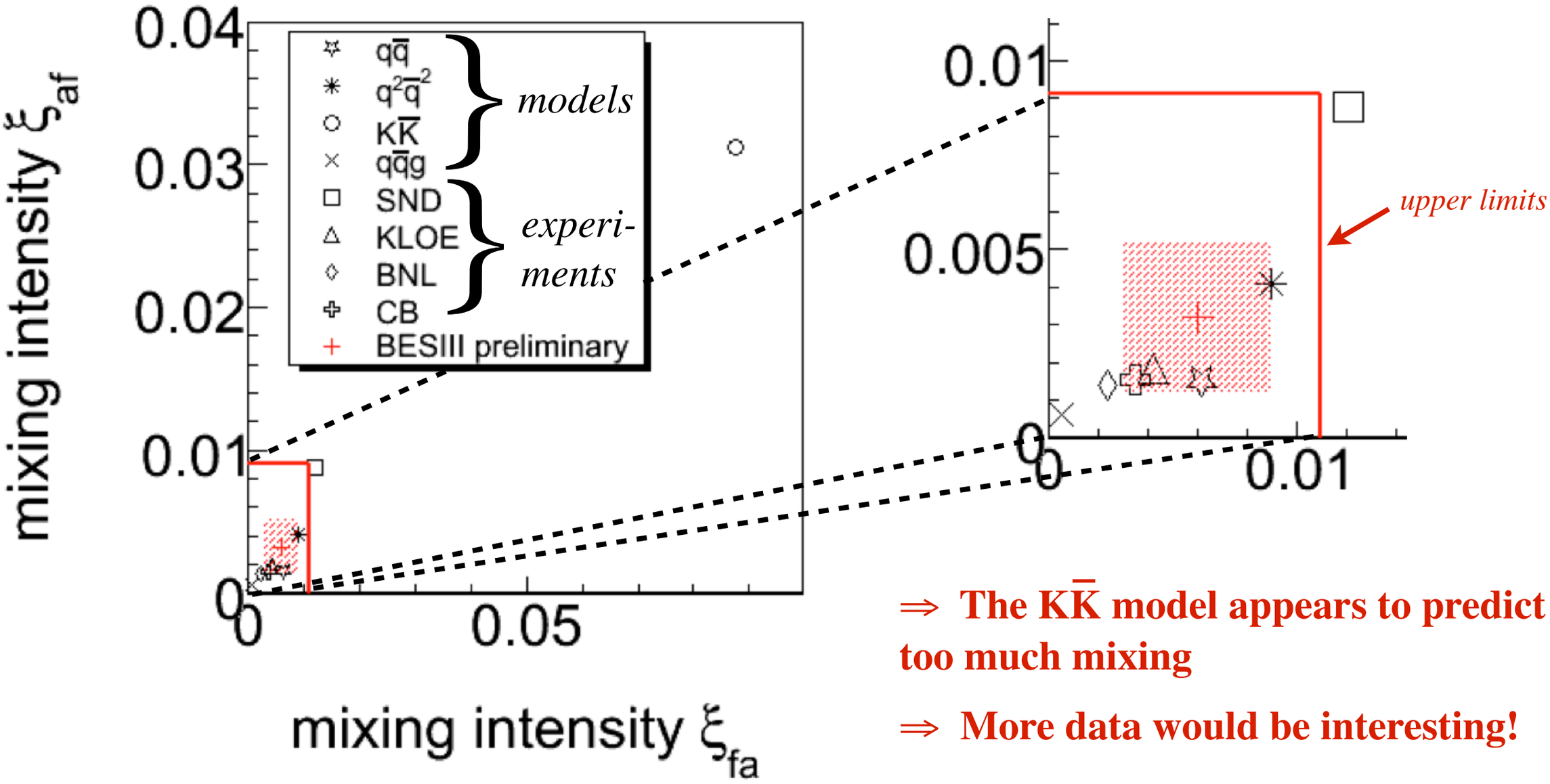
$a_0(980)$ – $f_0(980)$ Mixing at BESIII

- Mixing intensities can be derived from coupling constants and masses.

(Wu et al., PRD75, 114012 (2007) and references within)

- Coupling constants and masses can be predicted by models or measured by experiments.

⇒ **Compare the BESIII measurement to models and experiments...**



⇒ **The $K\bar{K}$ model appears to predict too much mixing**

⇒ **More data would be interesting!**

First Analyses from the BESIII Experiment

Physics at BESIII

- **Charmonium Spectroscopy and Transitions**
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  - $\chi_{cJ} \rightarrow \omega\omega, \phi\phi, \omega\phi$ *(preliminary)*
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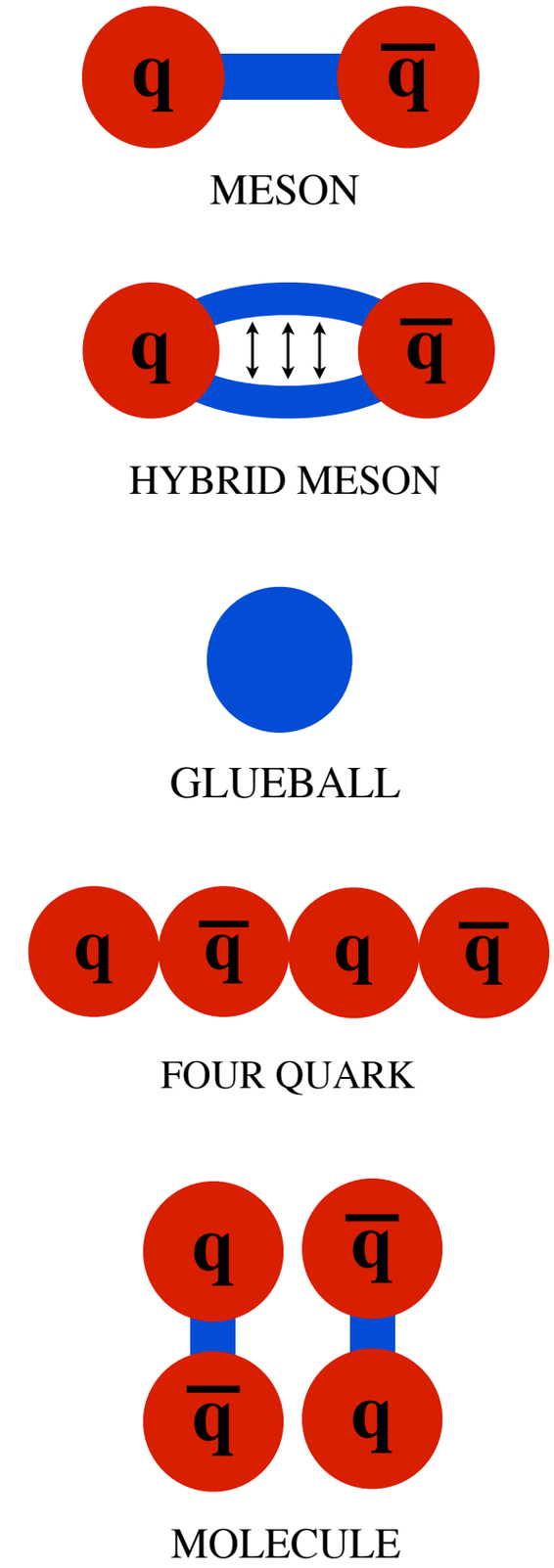
  - $\eta' \rightarrow \eta\pi^+\pi^-$ matrix element *(arXiv:1012.1117)*
  - **X(1860) in $J/\psi \rightarrow \gamma(p\bar{p})$** ***(Chinese Physics C 34, 4 (2010))***
  - **X(1835) in $J/\psi \rightarrow \gamma(\eta'\pi^+\pi^-)$** ***(arXiv:1012:3510)***
  - **X(1870) in $J/\psi \rightarrow \omega(\eta\pi^+\pi^-)$** ***(preliminary)***
- **Open Charm, etc., etc.!**

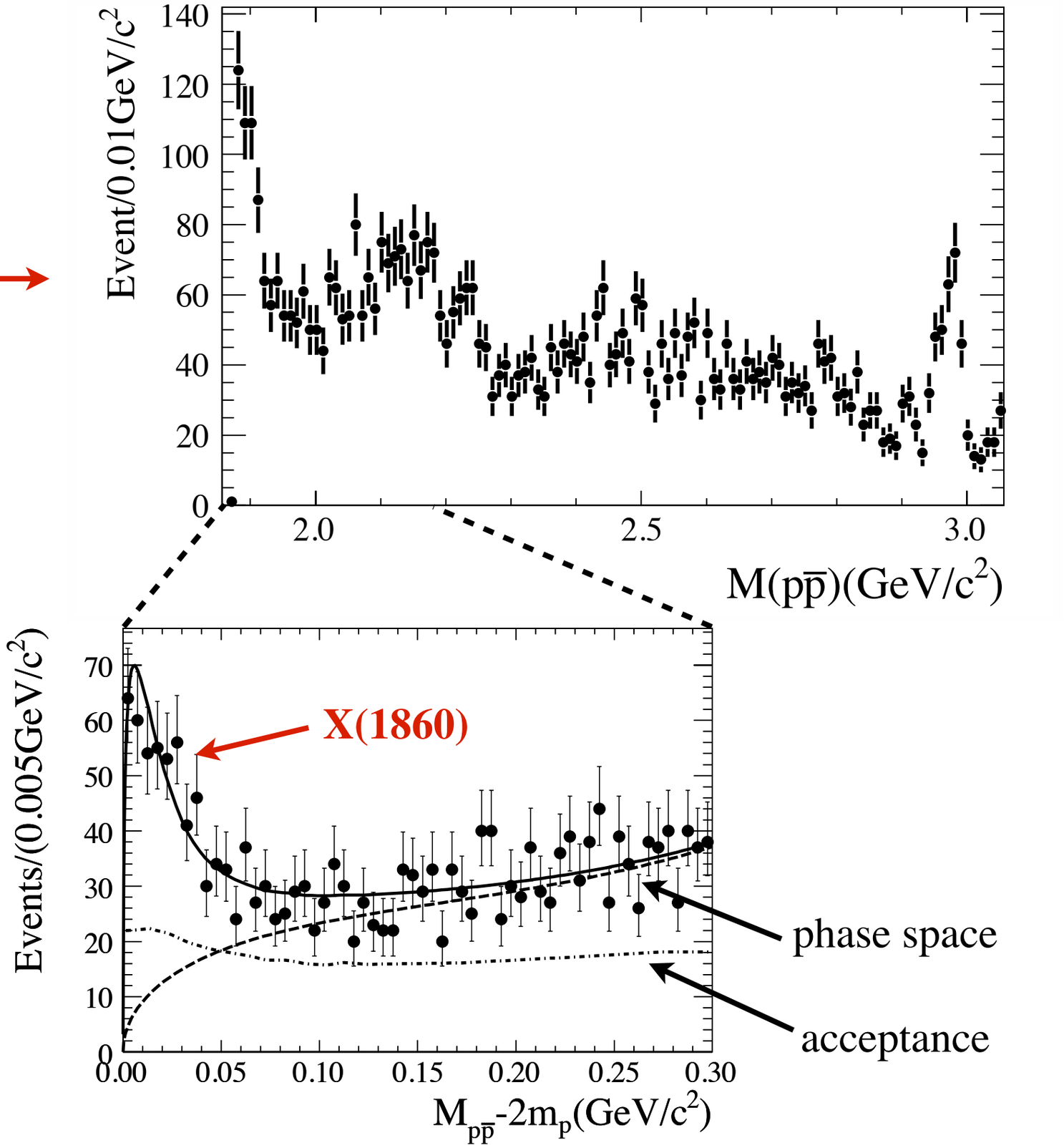
What other states can we find in the light quark meson sector?

Types of Meson States Allowed by QCD



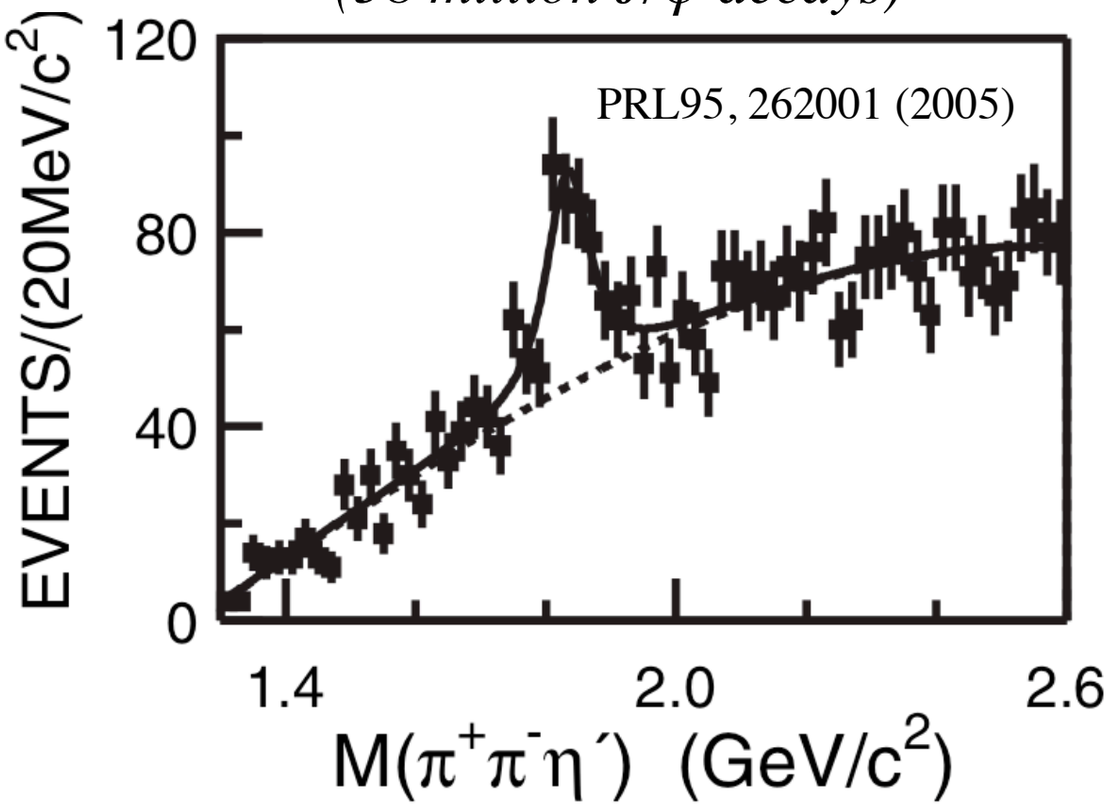
The "X(1860)" in J/ψ → γ(pp̄) at BESIII

- First observed by BESII
- **Now confirmed by BESIII in**
  ψ(2S) → π+π−J/ψ
  J/ψ → γpp̄
  using 106 million ψ(2S) decays
- Also recently confirmed by CLEO-c (with lower statistics) in the same reaction
- No clear evidence in:
  - ψ(2S) → γpp̄ (BESII)
  - J/ψ → ωpp̄ (BESII)
  - J/ψ → π^0pp̄ (BESIII)
  - ϒ(1S) → γpp̄ (CLEO III)
  - etc.
- **Possibly baryonium?**

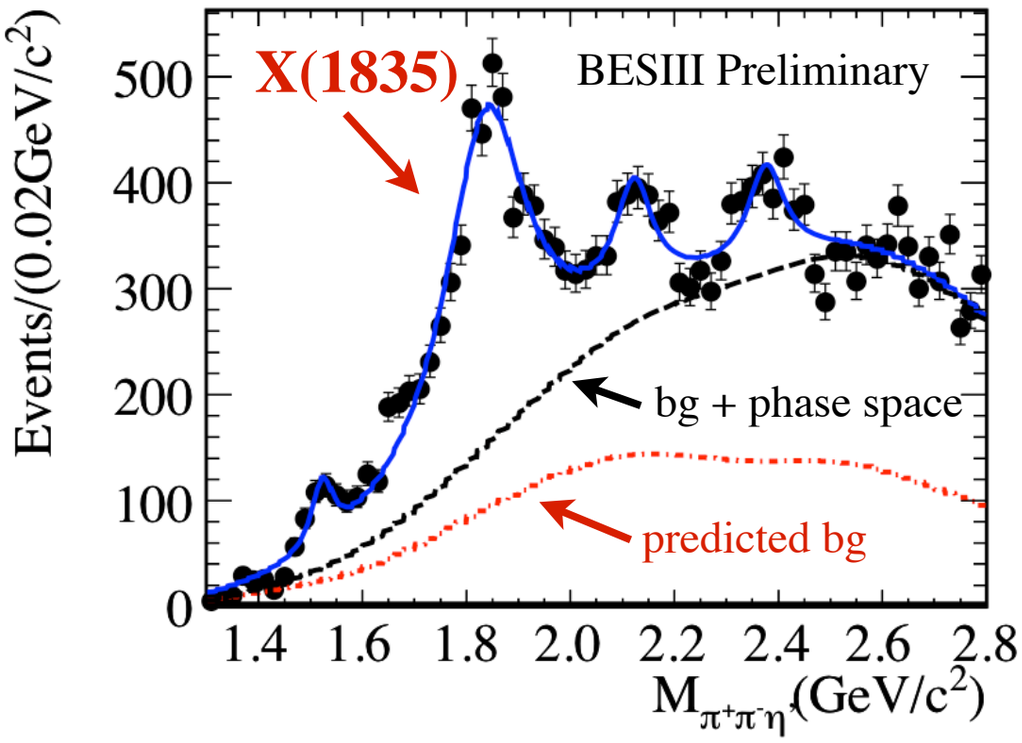


The "X(1835)" in $J/\psi \to \gamma(\eta'\pi^+\pi^-)$ at BESIII

First observed by BESII:
(58 million J/ψ decays)



Confirmed by BESIII:
(225 million J/ψ decays)



Rich Substructure!

(an amplitude analysis could help with interpretation)

But with surprises:

resonance	$M(\ \mathrm{MeV}/c^2)$	$\Gamma(\ \mathrm{MeV}/c^2)$	N_{event}
$f_1(1510)$	1522.7 ± 5.0	48 ± 11	230 ± 37
$X(1835)$	1836.5 ± 3.0	190.1 ± 9.0	4265 ± 131
$X(2120)$	2122.4 ± 6.7	84 ± 16	647 ± 103
$X(2370)$	2376.3 ± 8.7	83 ± 17	565 ± 105

The "X(1870)" in J/ψ → ω(ηπ⁺π⁻) at BESIII

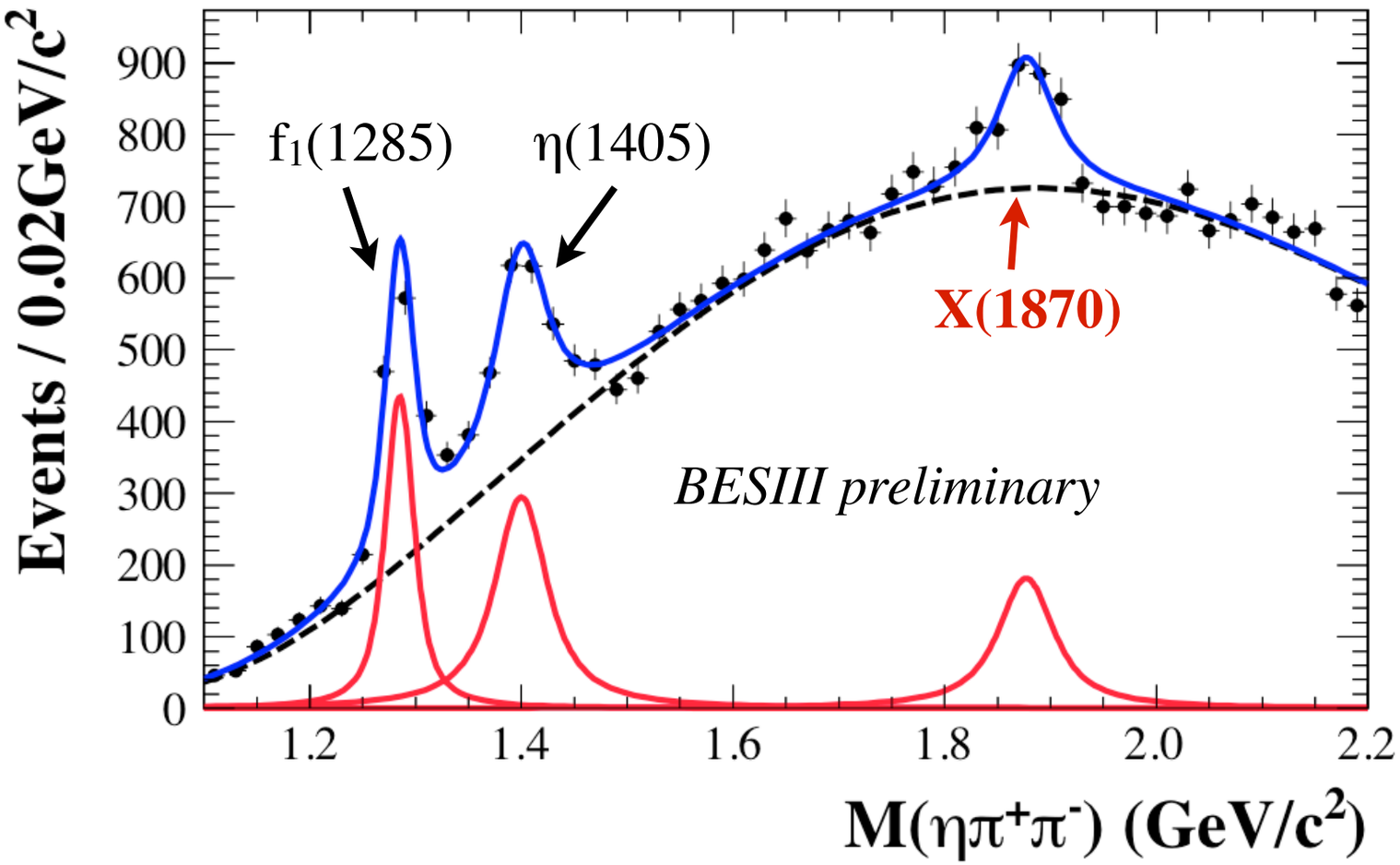
- One more surprise...

- Look at M(ηπ⁺π⁻) from

  J/ψ → ω(ηπ⁺π⁻)

  after selecting $a_0^{\pm} \to \eta\pi^{\pm}$

- A new signal appears at a mass of **1870 MeV/c²** with a width of **~80 MeV/c²**!



⇒ ***In general, amplitude analyses will be needed to learn more about these new states...***

First Analyses from the BESIII Experiment

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  - $\chi_{cJ} \rightarrow \omega\omega, \phi\phi, \omega\phi$ *(preliminary)*
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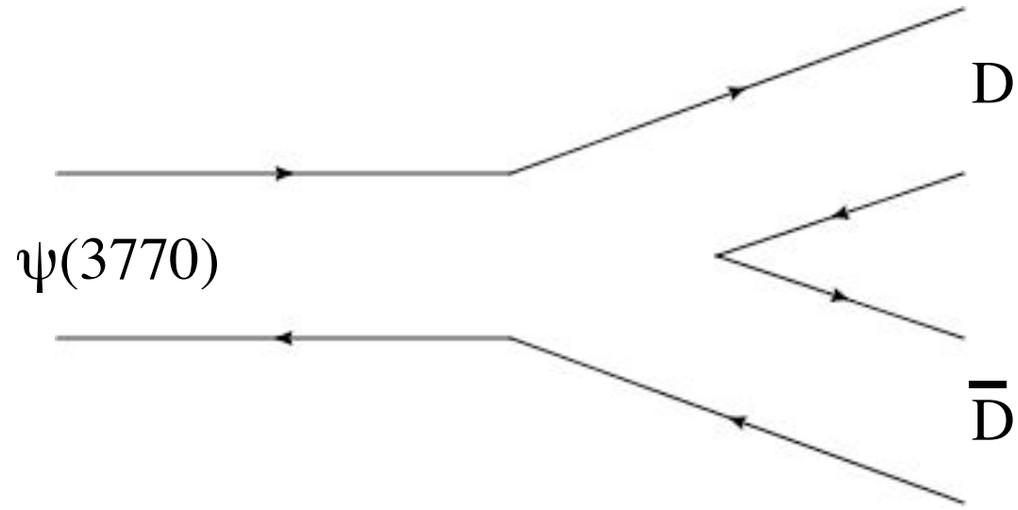
- **Open Charm, etc., etc.!**



- Use $\psi(3770) \rightarrow D\bar{D}$ to produce two quantum correlated D mesons (almost) at rest.

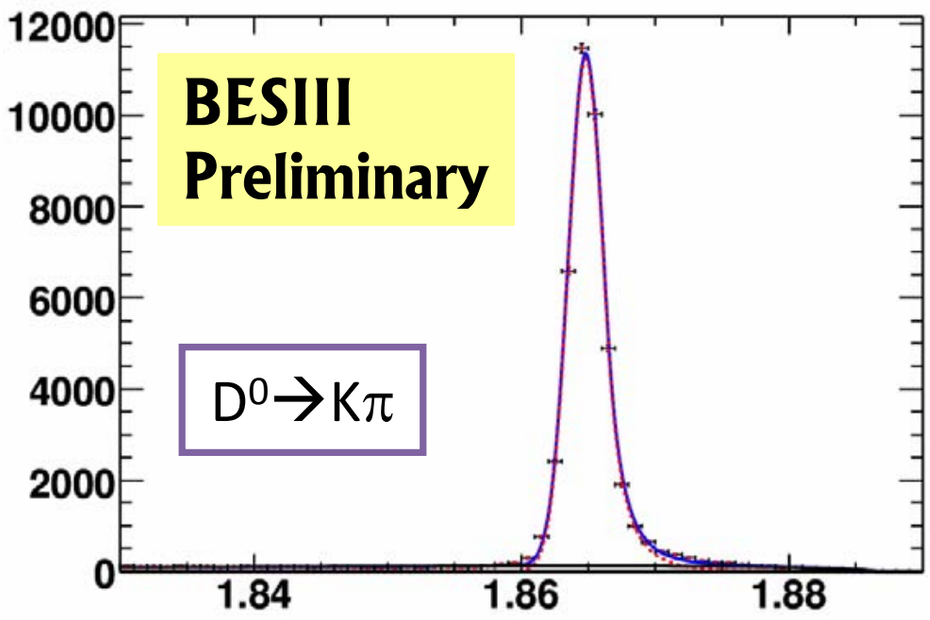
- "Tag" one D meson to learn about the other.

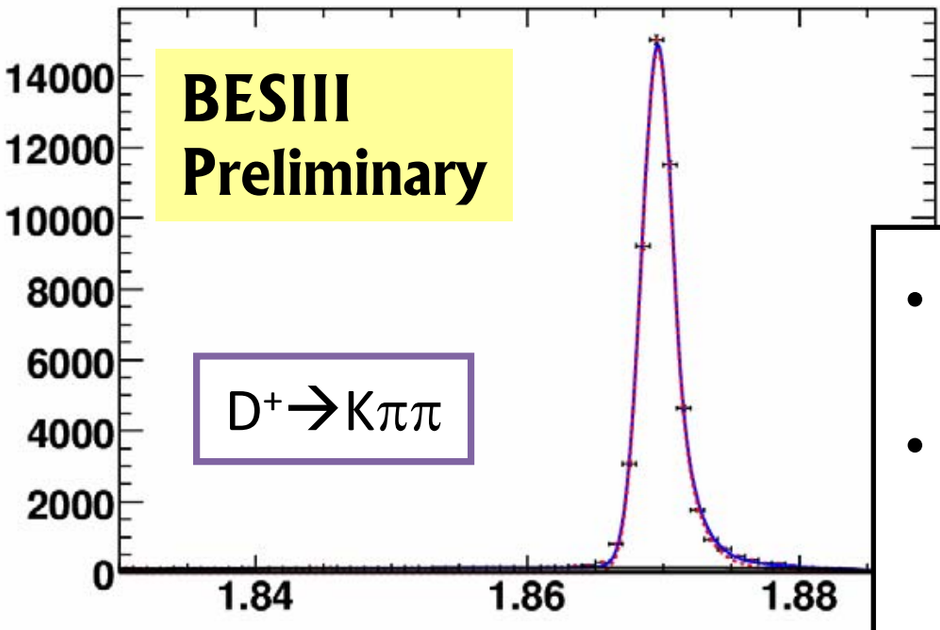
- Powerful tool for studying:
  - mixing and CP violation
  - hadronic decays (e.g. Dalitz analyses)
  - semileptonic decays (form factors)
  - leptonic decays (decay constants)
  - etc.

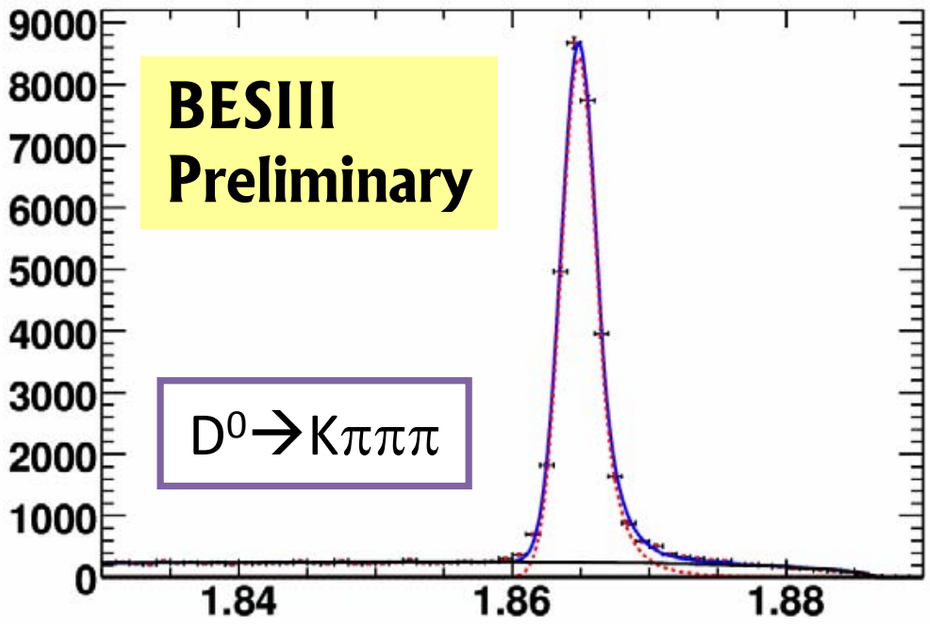
- ***BESIII has ~1fb^{-1} (~same as CLEO), but is collecting more...***

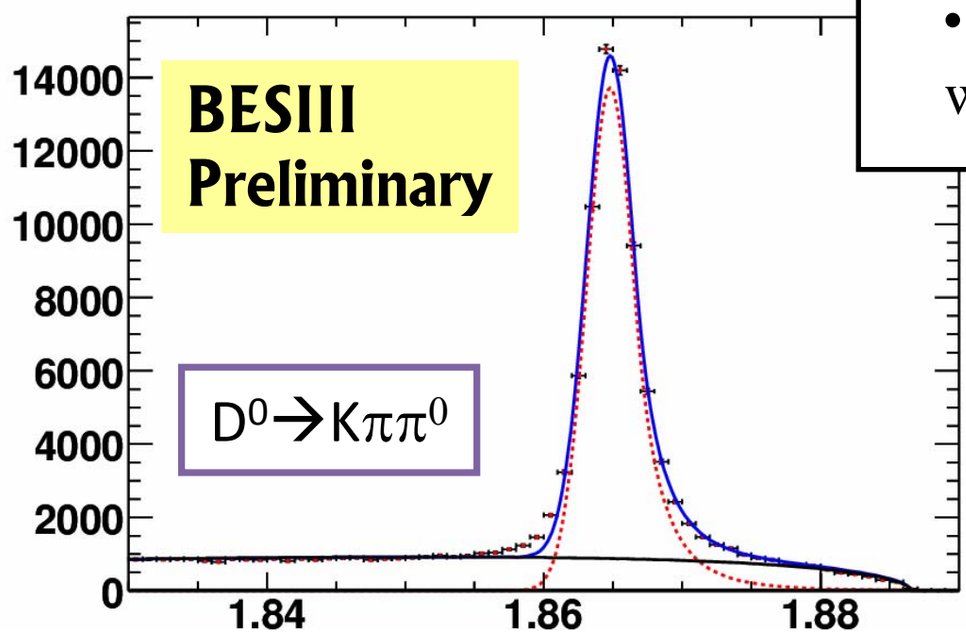
Open Charm at BESIII

Examples of a few D-tag modes...









- very clean
- excellent resolution
  - ~1.3 MeV for pure charged
  - ~1.9 MeV with a π^0

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

(using only 420 pb^{-1}...)

Summary

Physics at BESIII

- **Charmonium Spectroscopy and Transitions**
  - Properties of the h_c *(PRL 104, 132002 (2010))*
  - $\psi(2S) \rightarrow \gamma\gamma J/\psi$ *(preliminary)*
- **Charmonium Decays**
  - $\chi_{cJ} \rightarrow \pi^0\pi^0, \eta\eta$ *(PRD 81, 052005 (2010))*
  - $\chi_{cJ} \rightarrow \gamma\varrho, \gamma\omega, \gamma\phi$ *(preliminary)*
  - $\chi_{cJ} \rightarrow \omega\omega, \phi\phi, \omega\phi$ *(preliminary)*
  - $\psi(2S) \rightarrow \gamma\pi^0, \gamma\eta, \gamma\eta'$ *(PRL 105, 261801 (2010))*
  - $\chi_{cJ} \rightarrow 4\pi^0$ *(arXiv:1011.6556)*
- **Light Quark States**
  - $a_0(980)$ – $f_0(980)$ mixing *(arXiv:1012.5131)*
  - $\eta' \rightarrow \eta\pi^+\pi^-$ matrix element *(arXiv:1012.1117)*
  - X(1860) in $J/\psi \rightarrow \gamma(p\bar{p})$ *(Chinese Physics C 34, 4 (2010))*
  - X(1835) in $J/\psi \rightarrow \gamma(\eta'\pi^+\pi^-)$ *(arXiv:1012:3510)*
  - X(1870) in $J/\psi \rightarrow \omega(\eta\pi^+\pi^-)$ *(preliminary)*
- **Open Charm, etc., etc.!**

- BESIII is now fully operational and many analyses are underway *(as well as many systematic studies)*

- BESIII has already made many contributions beyond the reach of CLEO-c

- Many more results are on their way! *(including analyses of open charm)*