e^+e^- annihilation cross section measurements at BESIII

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FCPPL 2017

March 29, 2017 at Tsinghua University

Outline

- Why measure e^+e^- cross sections
- The BESIII experiment
- The data
- The results
- Summary & outlook

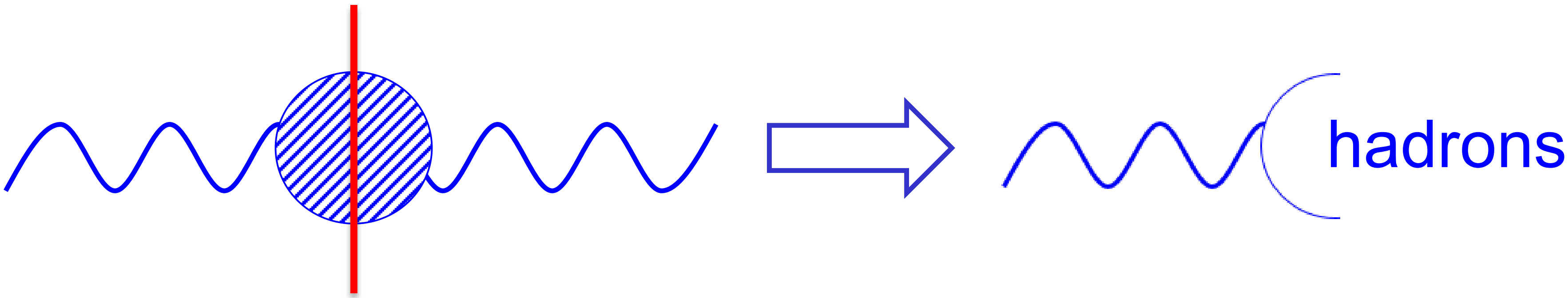
God created light, we try to understand it!

- "Let there be light"; and there was light. And God saw that the light was good. [good=understandable!]

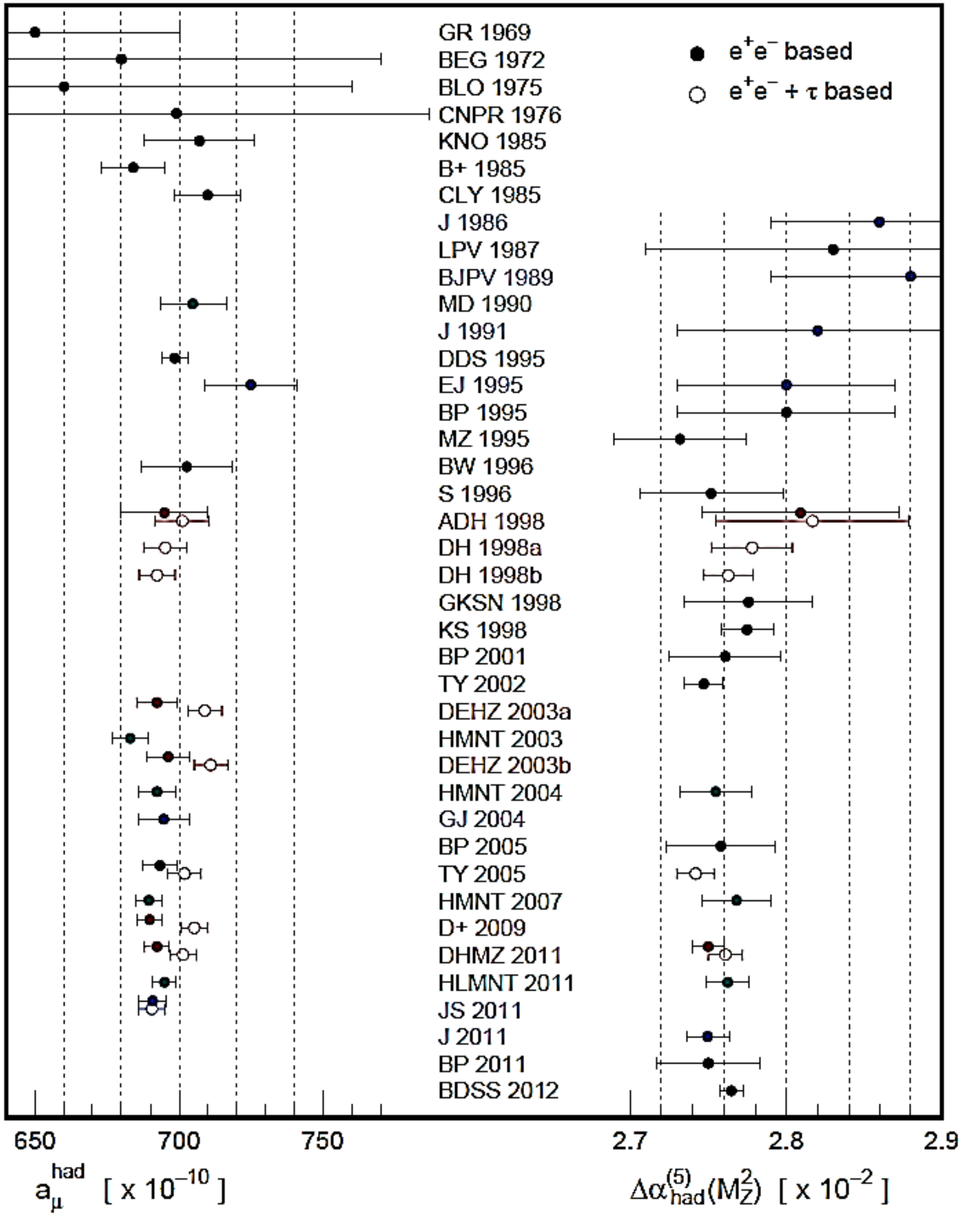
If ? = l^+l^-, we can calculate it!

If ? = $\bar{q}q$, we can not calculate it,

but we CAN measure it!



Photon propagator appears everywhere



LO Hadronic Vacuum Polarization (HVP) being the most uncertain part for a_μ & $\Delta\alpha$ has been in focus over the last 5 decades.

The precision is steadily improving thanks to

- more precise/complete e+e- annihilation (& tau) data
- state of the art techniques for data interpolation, combination and error correlation treatment

Davier-Hoecker-Malaescu-Zhang, in "*Standard Theory Essays in the 60th Anniversary of CERN*"

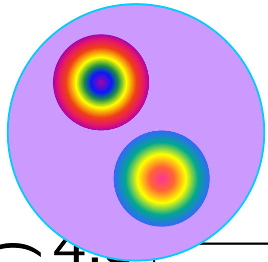
R(s) is the key to improve $\Delta\alpha$ and a_μ

$$\Delta\alpha_{\rm had}(s) = -\frac{\alpha(0)s}{3\pi}\,{\rm Re}\int_0^\infty ds'\,\frac{R(s')}{s'(s'-s)-i\varepsilon}$$

$$a_\mu^{\rm had,LO} = \frac{1}{3}\left(\frac{\alpha}{\pi}\right)^2\int_{m_\pi^2}^\infty ds\,\frac{K(s)}{s}R^{(0)}(s)$$

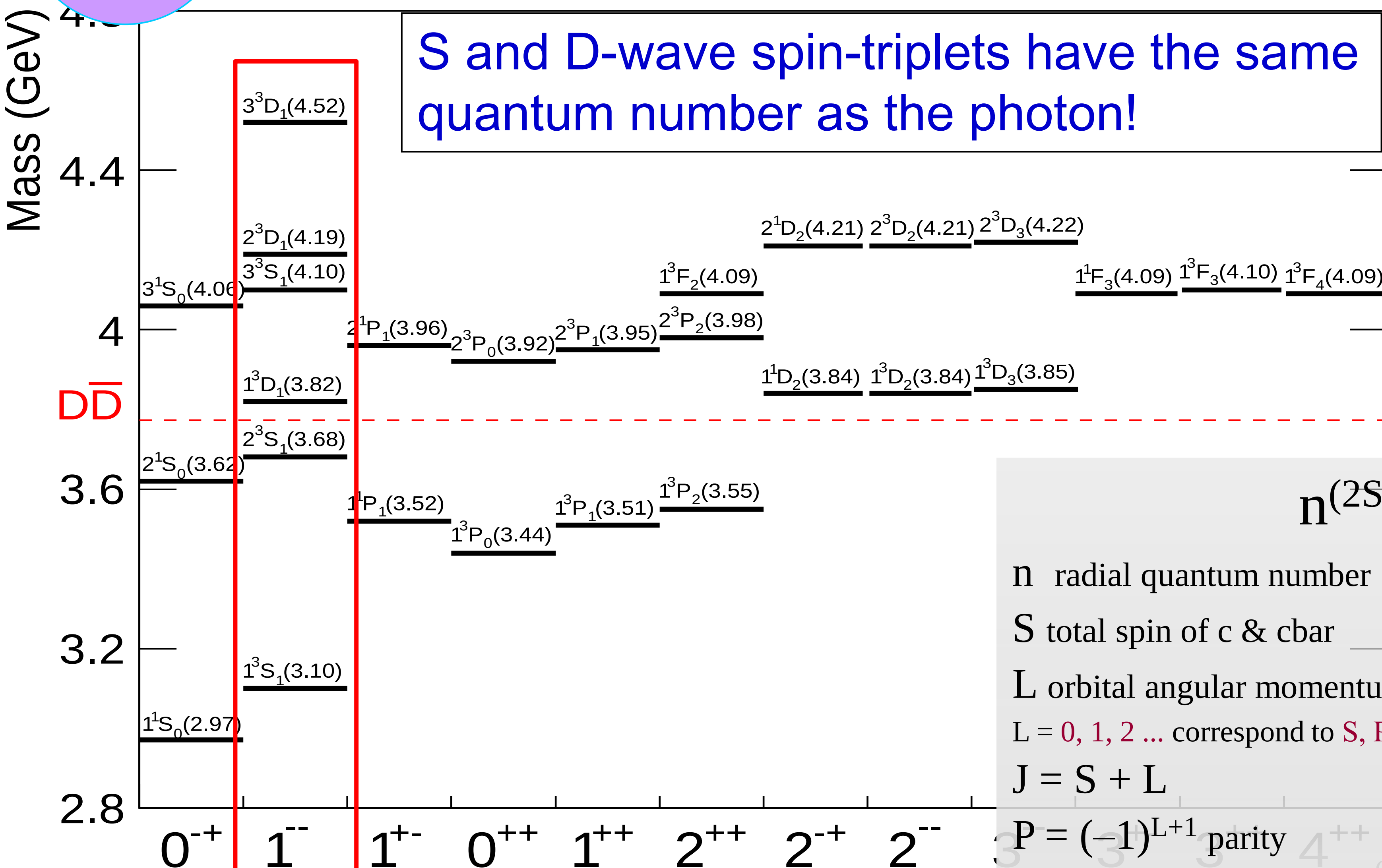
$$R = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

- Improve the precision of e^+e^- annihilation cross sections to improve the sensitivity of new physics hunting!
- Low energy contribution is enhanced!



Charmonium spectroscopy

S and D-wave spin-triplets have the same quantum number as the photon!



$n^{(2S+1)}L_J$

n radial quantum number

S total spin of c & cbar

L orbital angular momentum

L = 0, 1, 2 ... correspond to S, P, D, …

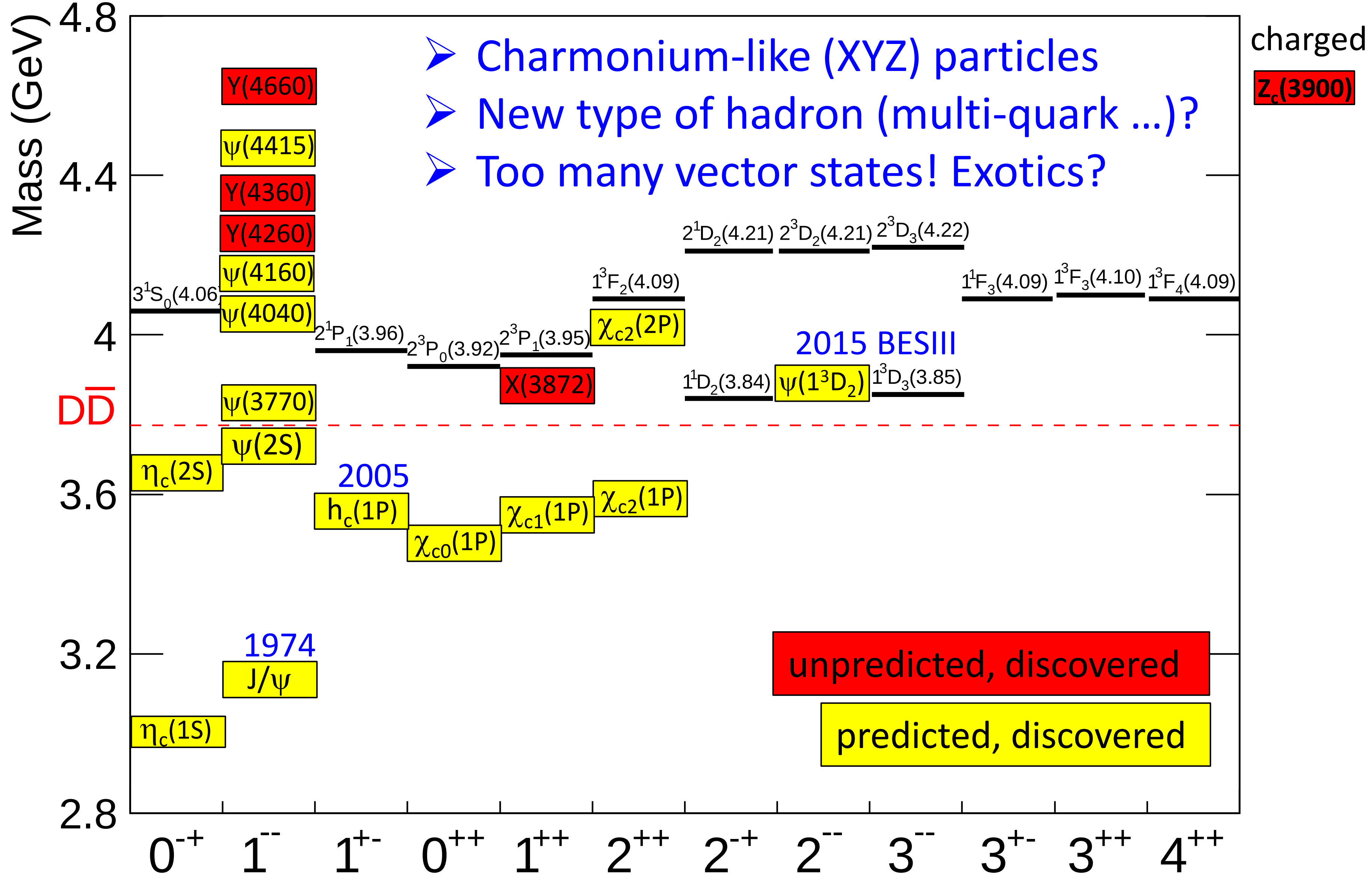
J = S + L

$P = (-1)^{L+1}$ parity

$C = (-1)^{L+S}$ charge conj.

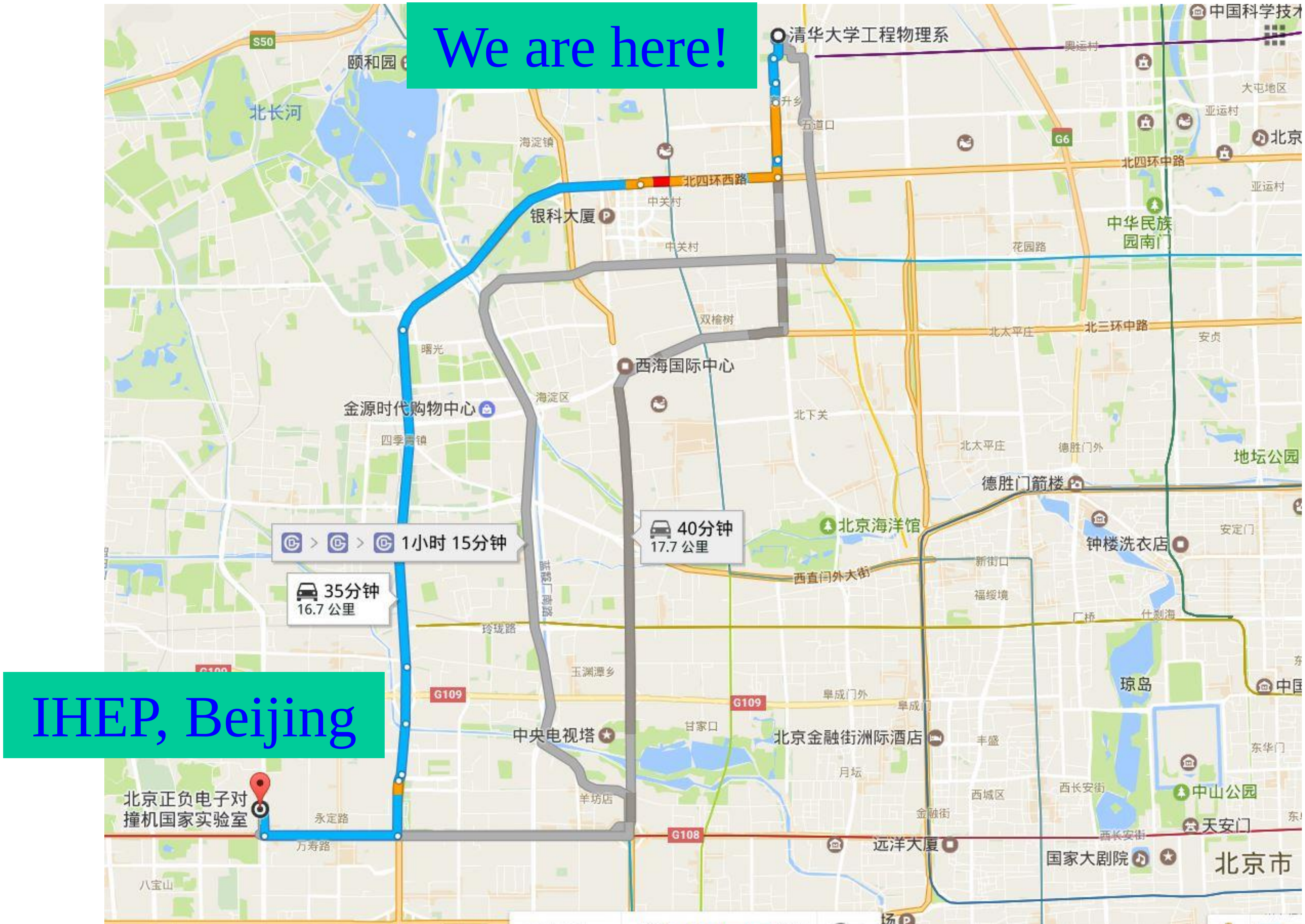
Godfrey & Isgur, PRD32, 189 (1985)

Charmonium(like) spectroscopy

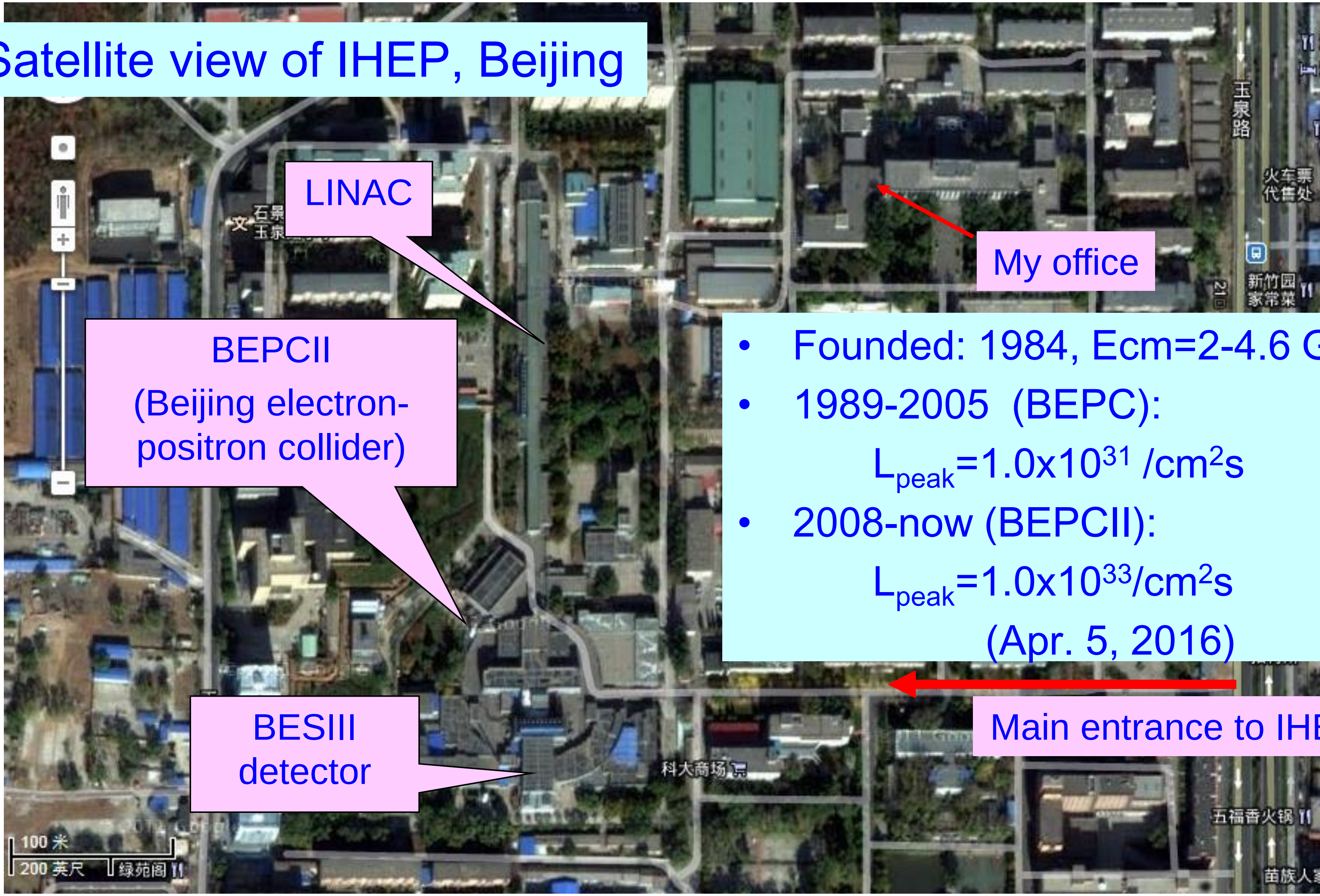


Godfrey & Isgur, PRD32, 189 (1985)

Where is the experiment

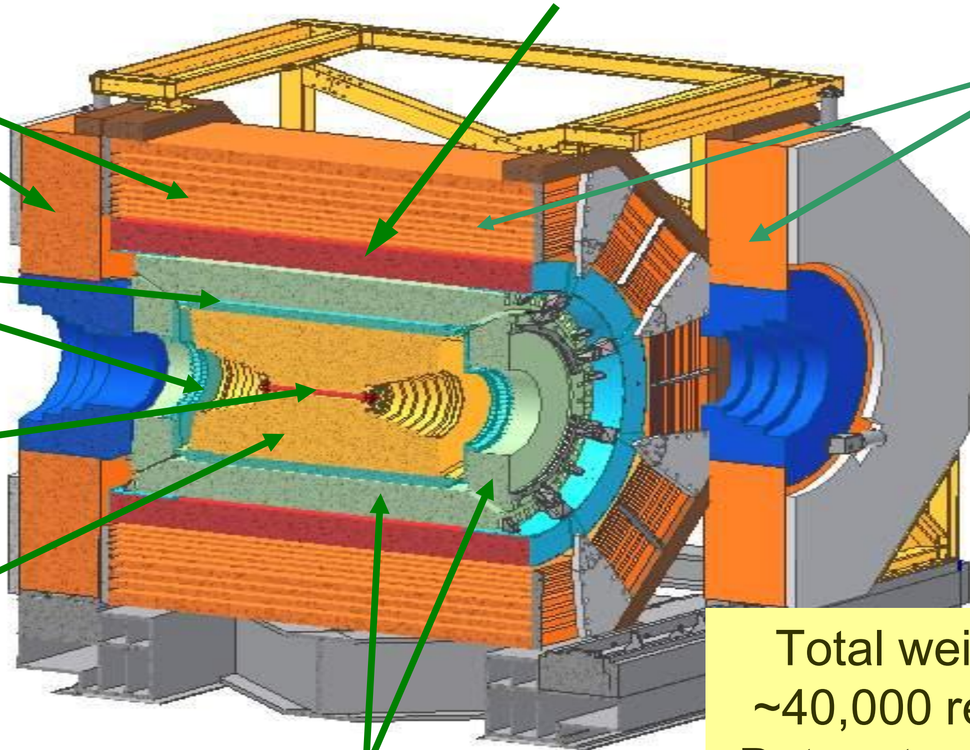


Beijing Electron Positron Collider (BEPC)



- Founded: 1984, Ecm=2-4.6 GeV
- 1989-2005 (BEPC):
  L_{peak}=1.0x10^{31} /cm^{2}s
- 2008-now (BEPCII):
  L_{peak}=1.0x10^{33}/cm^{2}s
  (Apr. 5, 2016)

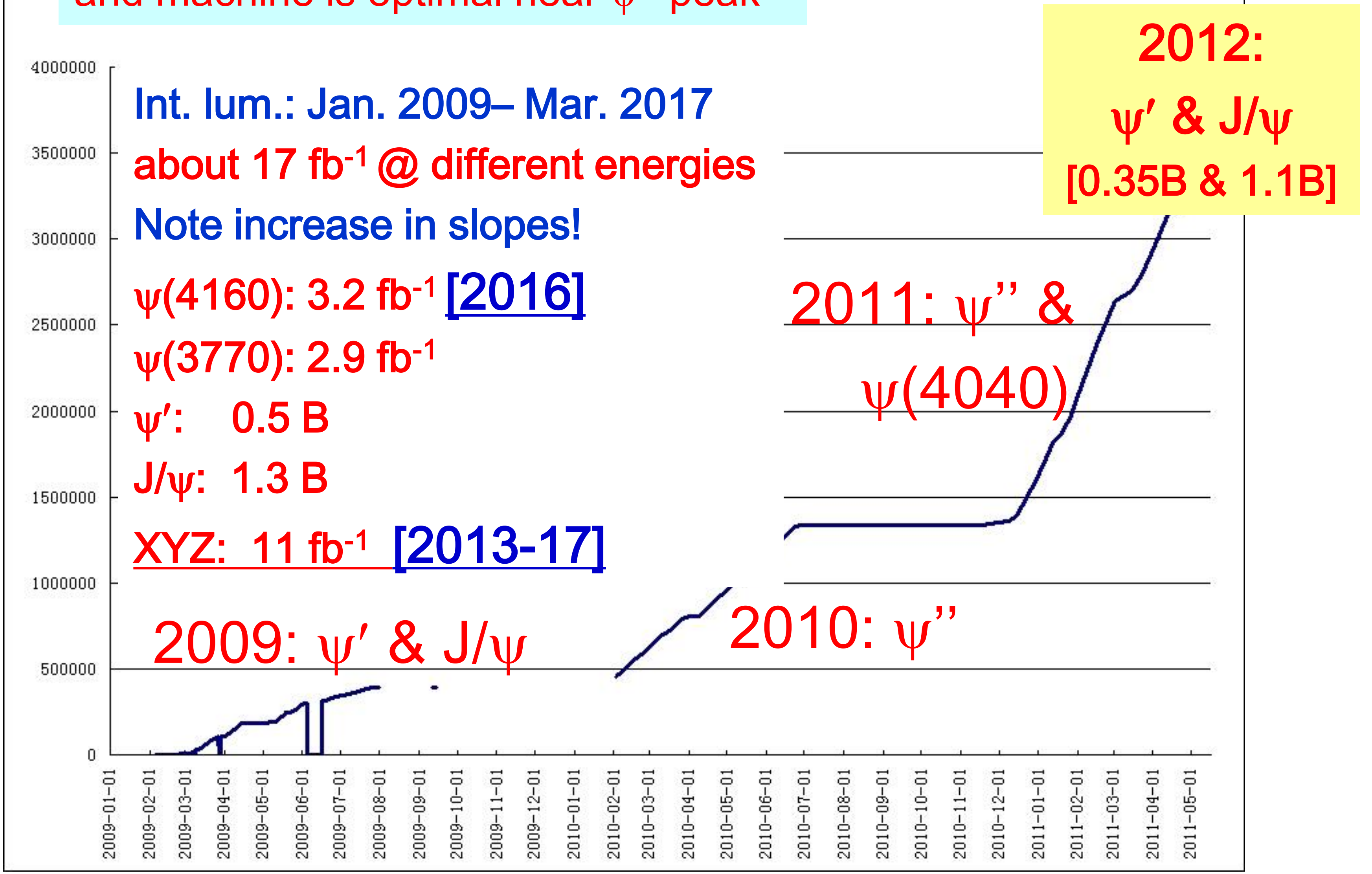
BESIII Detector

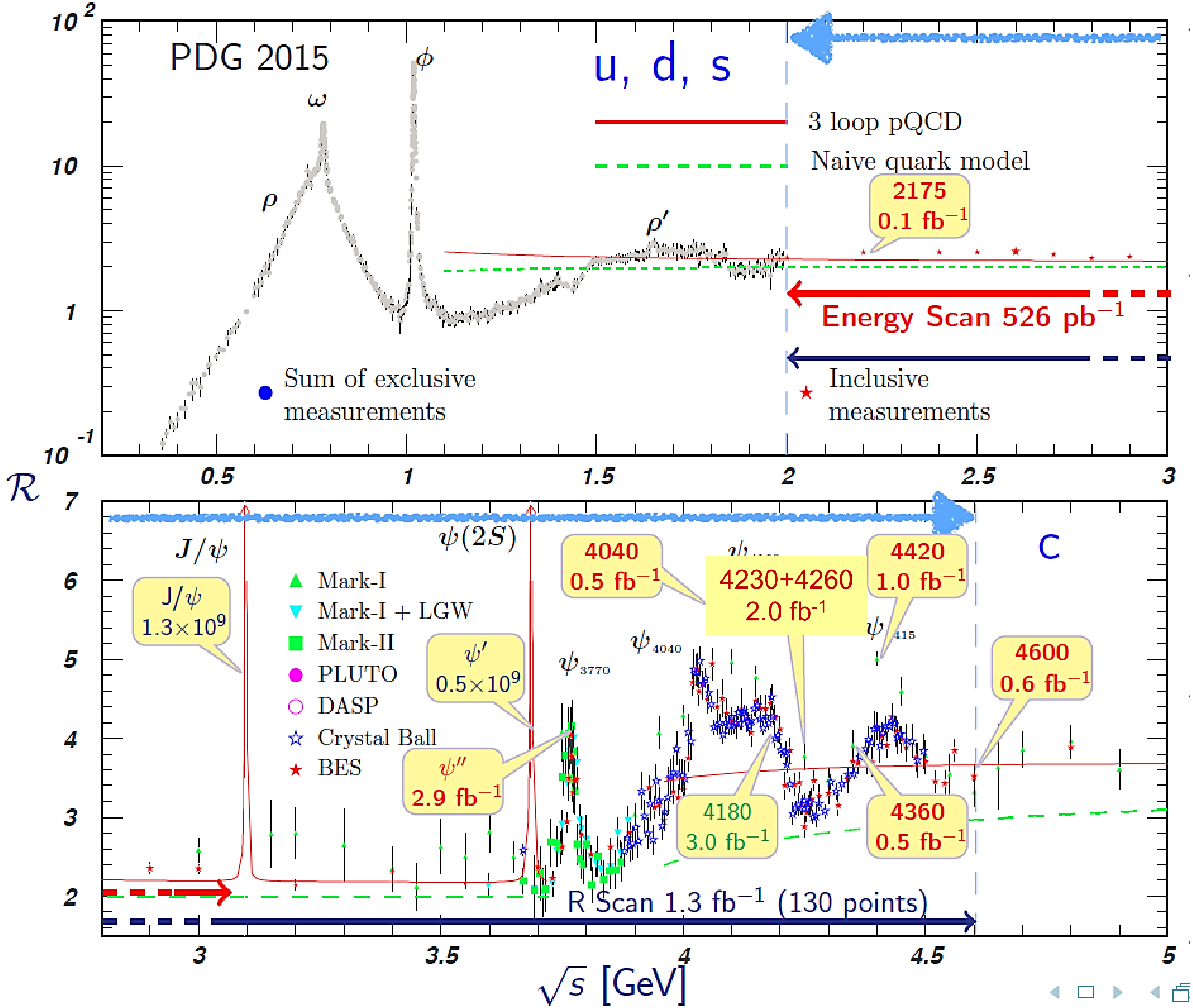


We know every particle recorded in the detector!

BESIII data samples

Note that luminosity is lower at J/ψ, and machine is optimal near ψ'' peak

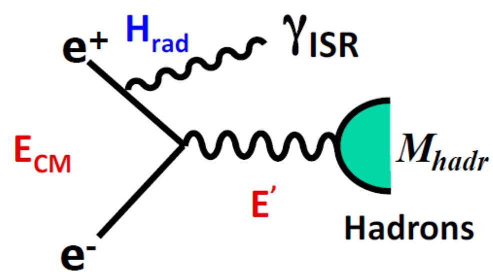




PDG 2015
u, d, s
3 loop pQCD
Naive quark model
2175
0.1 fb^{-1}
Energy Scan 526 pb^{-1}
Sum of exclusive measurements
Inclusive measurements
ω
ϕ
ρ
ρ'
$\mathcal{R}$
10^2
10
1
10^{-1}
0.5
1
1.5
2
2.5
3
7
6
5
4
3
2
C
J/ψ
$\psi(2S)$
J/ψ 1.3×10^9
ψ' 0.5×10^9
ψ'' 2.9 fb^{-1}
Mark-I
Mark-I + LGW
Mark-II
PLUTO
DASP
Crystal Ball
BES
4040
0.5 fb^{-1}
4230+4260
2.0 fb^{-1}
4420
1.0 fb^{-1}
4600
0.6 fb^{-1}
4180
3.0 fb^{-1}
4360
0.5 fb^{-1}
ψ_{3770}
ψ_{4040}
ψ_{4415}
R Scan 1.3 fb^{-1} (130 points)
3
3.5
4
4.5
5
$\sqrt{s}$ [GeV]

The method and the modes

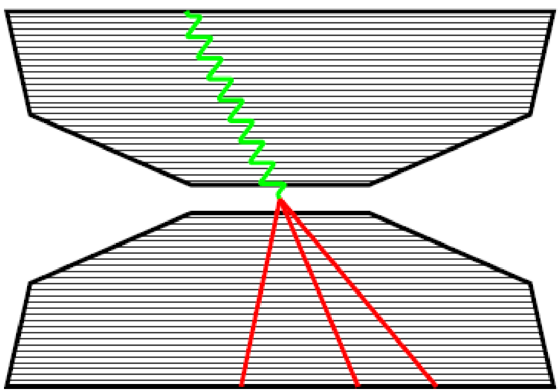
- ISR to reach low mass region (below 2 GeV)
  - $e^+e^- \rightarrow \pi^+\pi^-$
  - $e^+e^- \rightarrow \pi^+\pi^-\pi^0$
  - $e^+e^- \rightarrow \bar{p}p$

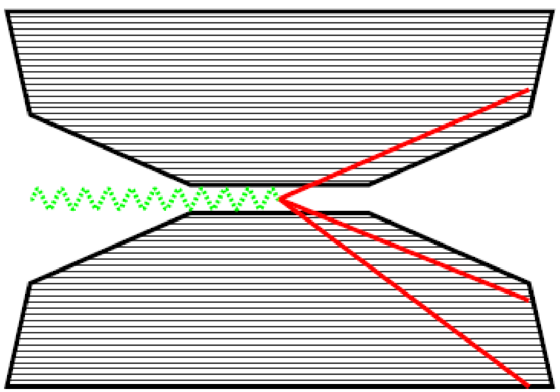


- Fine scan around narrow resonances (J/ψ, ψ')
- Direct measurement of e^+e^- annihilation
  - Exclusive
    - Final states with charmed mesons or baryons, $DD^*\pi$， $\Lambda_c^+\Lambda_c^-$
    - Final states with charmonium and light hadrons $\pi\pi J/\psi$, $\pi\pi hc$
  - Inclusive [leave for future FCPPL workshops]
    - $Rc=R(D^+)+ R(D^0) + R(D_s) + R(\Lambda_c)$
    - R(hadrons) for Ecm=2.0—4.6 GeV

ISR analyses at Ecm=3.773 GeV

- Hadronic system should be detected
- Angular distribution of the γ_{ISR}
  - tagged: Wide range, huge BG in high $\sqrt{s'}$ — $\sqrt{s'} < 1$ GeV
  - untagged: higher statistics, less BG — $\sqrt{s'} > 1$ GeV



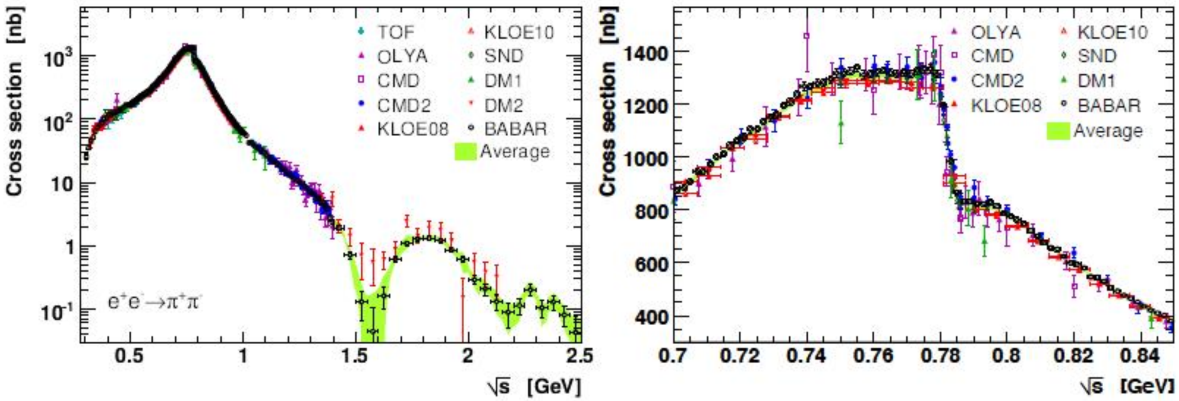


Tagged for ISR ππ analysis

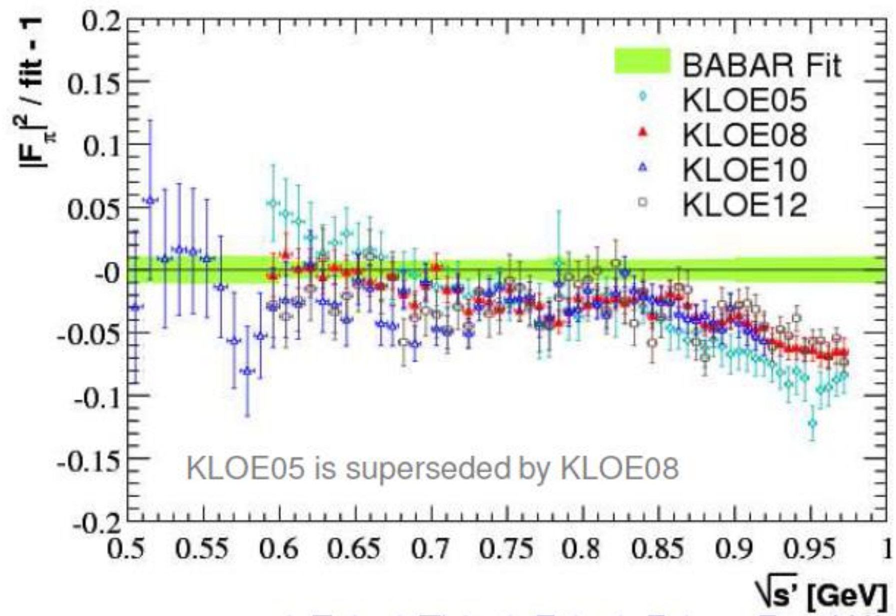
Both tagged and untagged for ISR πππ analysis

$e^+e^- \to \pi^+\pi^-$

M. Davier et al., Eur. Phys. J. C **71** 1515 (2011)



Precision measurements

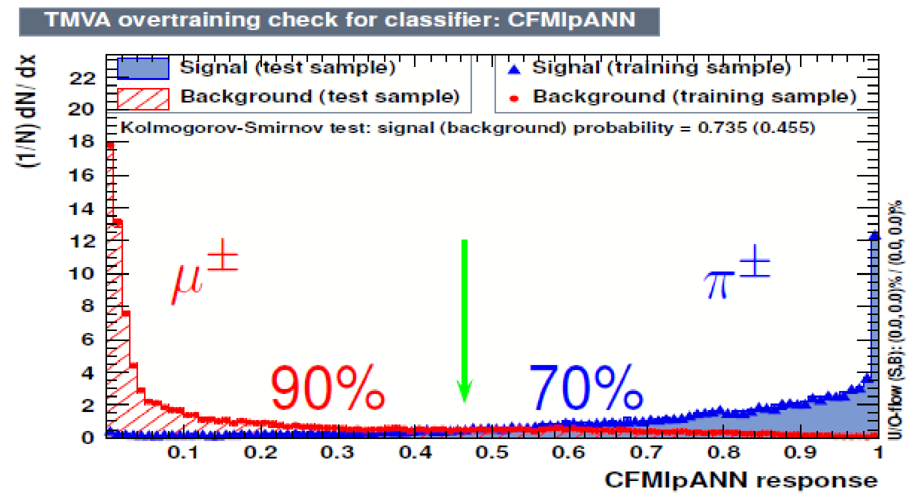


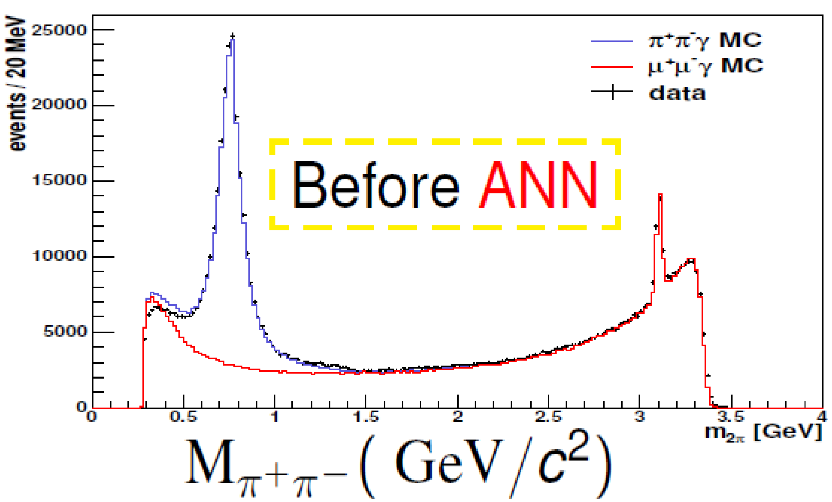
BaBar and KLOE

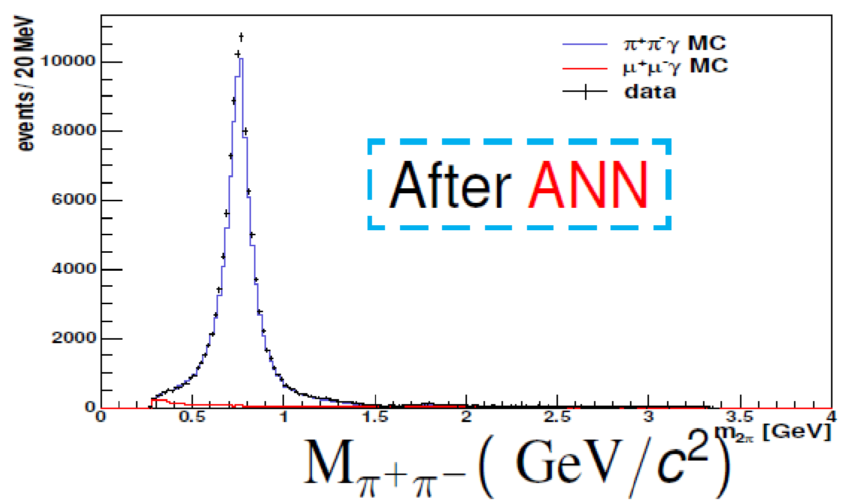
- 3% diff. on ρ peak
- New measurement

Tagged Selections

- Kinematic Fit for $\pi^+\pi^-\gamma_{ISR}$
- MDC, TOF, and EMC for electron rejection
- Artificial Neuronal Network (ANN) for $\mu - \pi$ separation



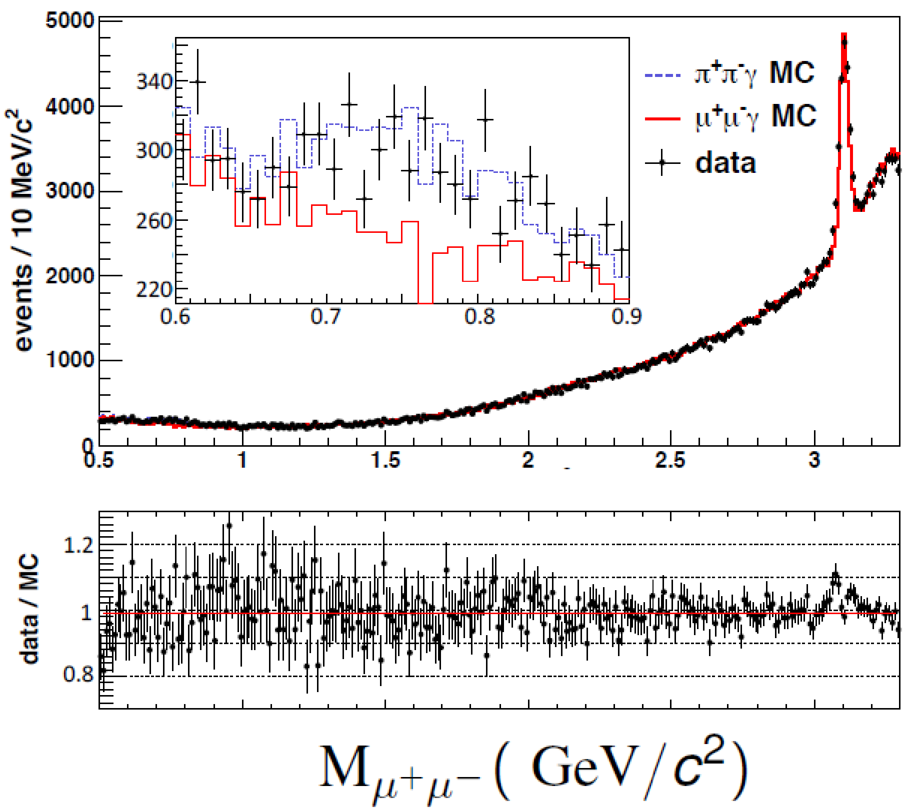




- Data-MC corrections vs. momentum and polar angle

QED test $e^+e^- \to \mu^+\mu^-\gamma$

- Select μ using ANN
- Small π background
- Efficiency corrections
- Compare to PHOKHARA
  - 0.5% accuracy

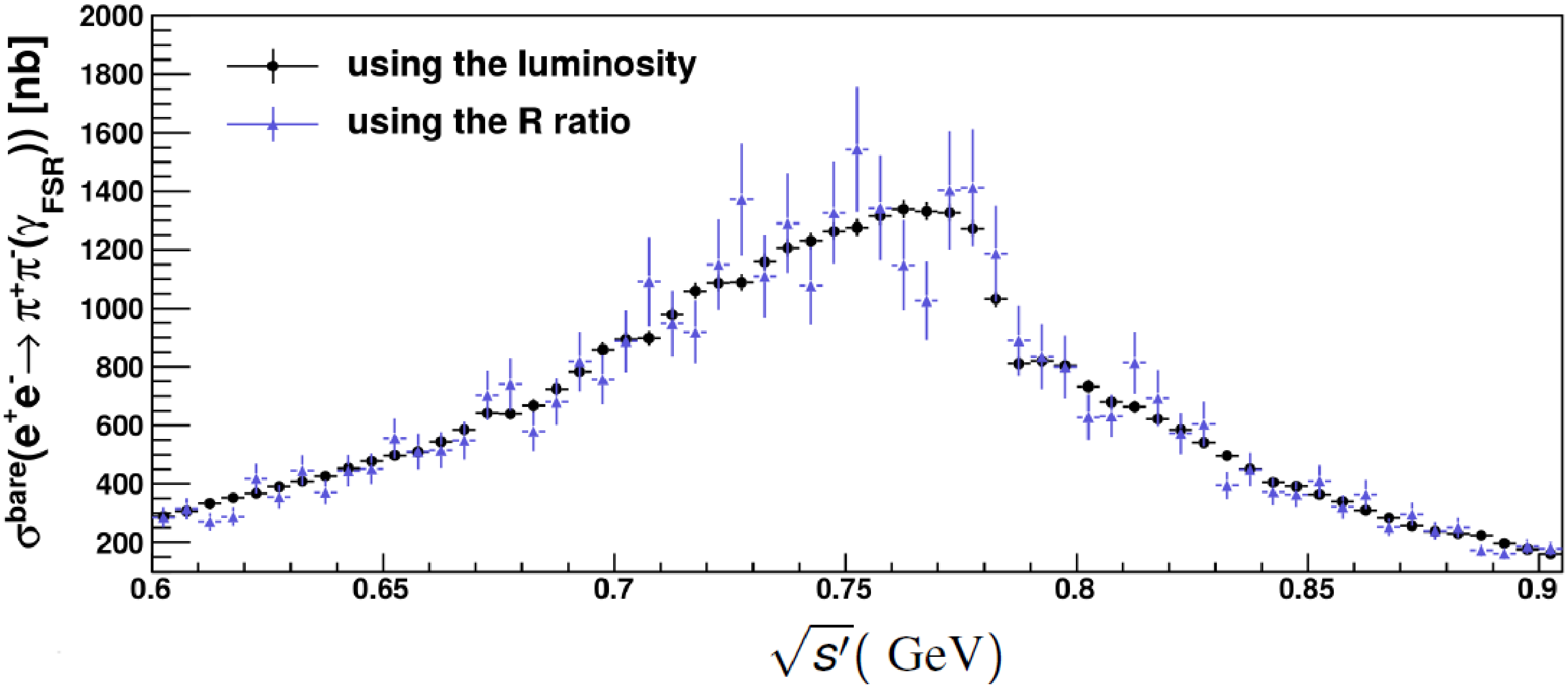


- Good agreement:
  - $1.0 \pm 0.3 \pm 0.9\%$ $(\chi^2/\mathrm{ndf} = 134/139)$
  - $2.0 \pm 1.7 \pm 0.9\%$ $(0.6 < M_{\mu^+\mu^-} < 0.9)$

Cross section

$$\sigma^{\text{bare}}_{\pi\pi(\gamma_{\text{FSR}})} = \frac{N_{\pi\pi\gamma}\cdot(1+\delta^{\pi\pi}_{\text{FSR}})}{\mathcal{L}\cdot\epsilon^{\pi\pi\gamma}_{\text{global}}\cdot H(s)\cdot\delta_{\text{vac}}}$$

$$\sigma^{\text{bare}}_{\pi\pi(\gamma_{\text{FSR}})} = \frac{N_{\pi\pi\gamma}}{N_{\mu\mu\gamma}}\cdot\frac{\epsilon^{\mu\mu\gamma}_{\text{global}}}{\epsilon^{\pi\pi\gamma}_{\text{global}}}\cdot\frac{1+\delta^{\mu\mu}_{\text{FSR}}}{1+\delta^{\pi\pi}_{\text{FSR}}}\cdot\sigma^{\text{bare}}_{\mu\mu}$$

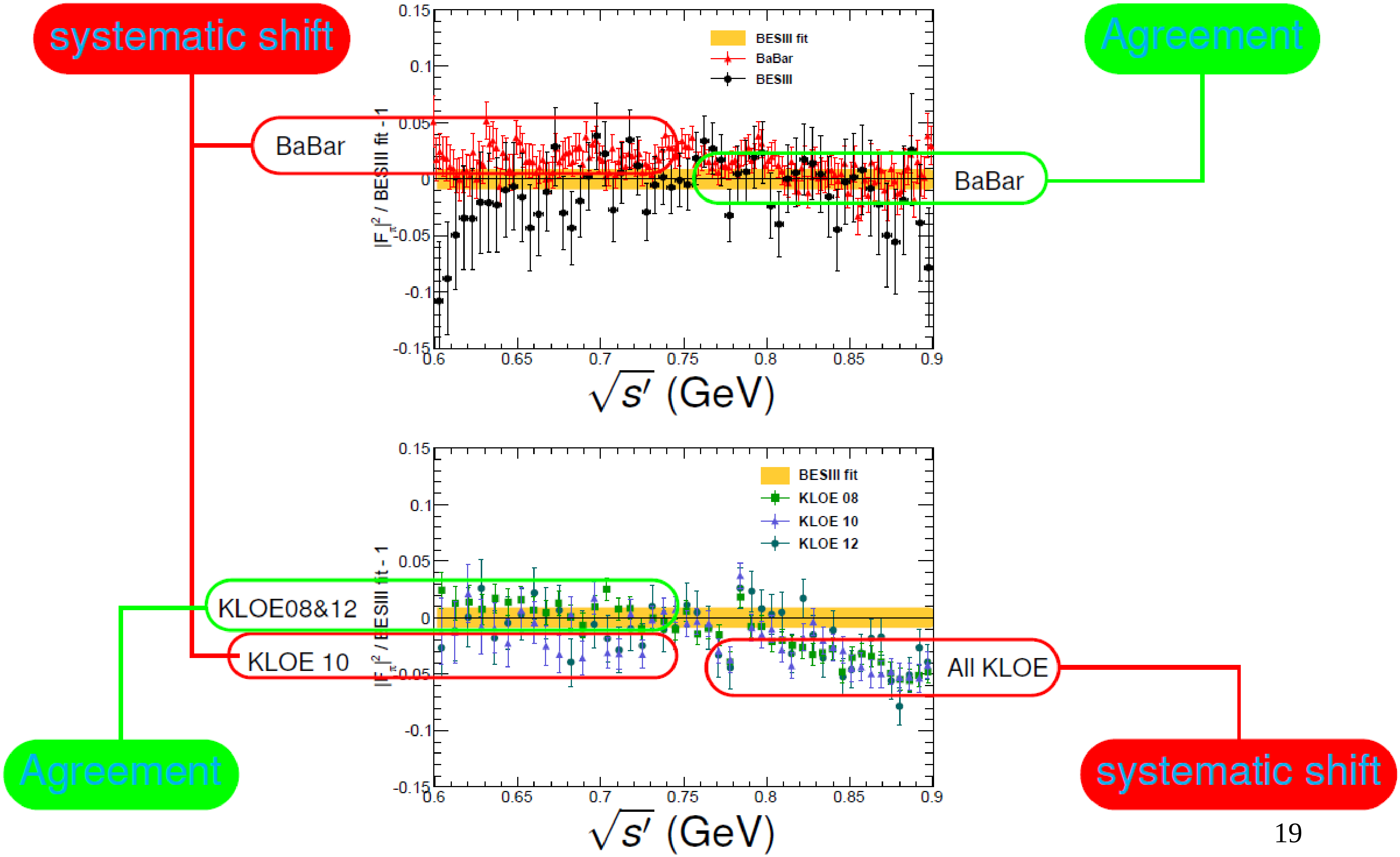


Relative difference: $(0.85 \pm 1.68)\%$

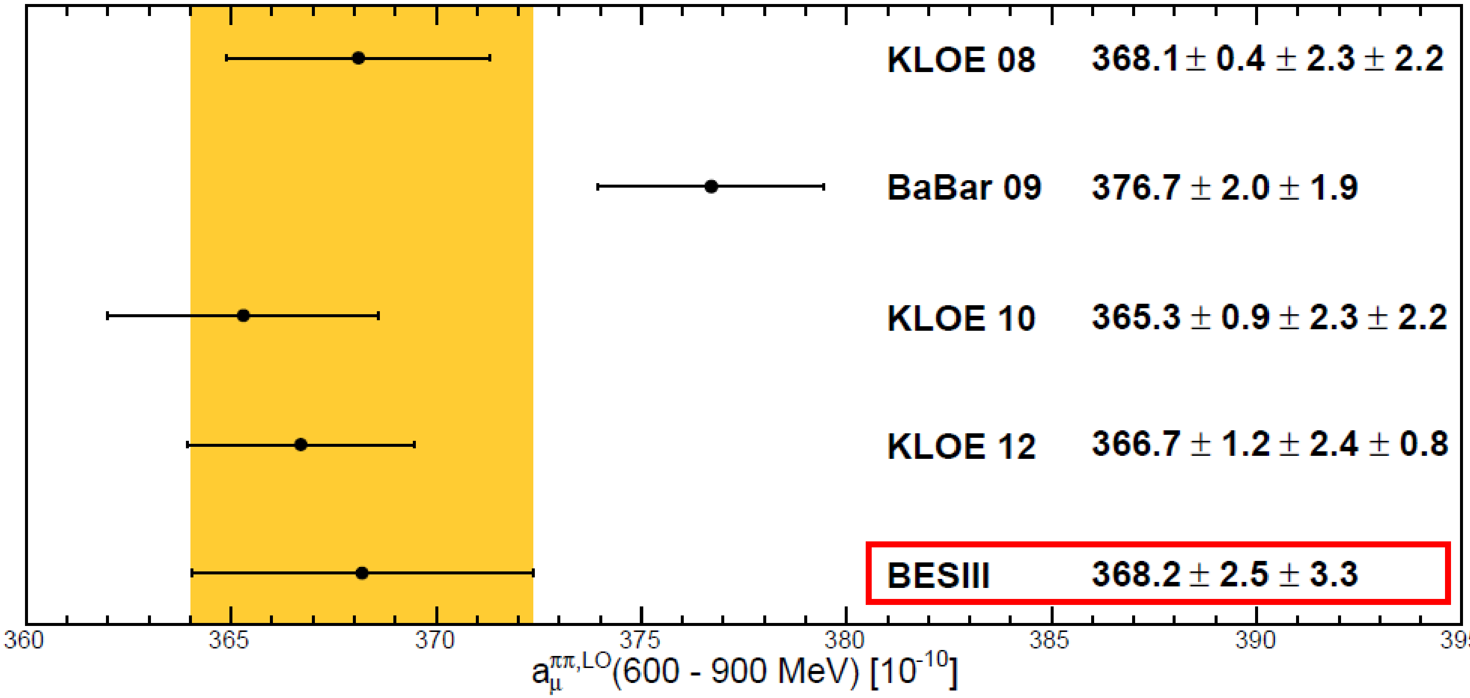
Good agreement!

Physics Letters B 753 (2016) 629–638

Comparison with BaBar and KLOE



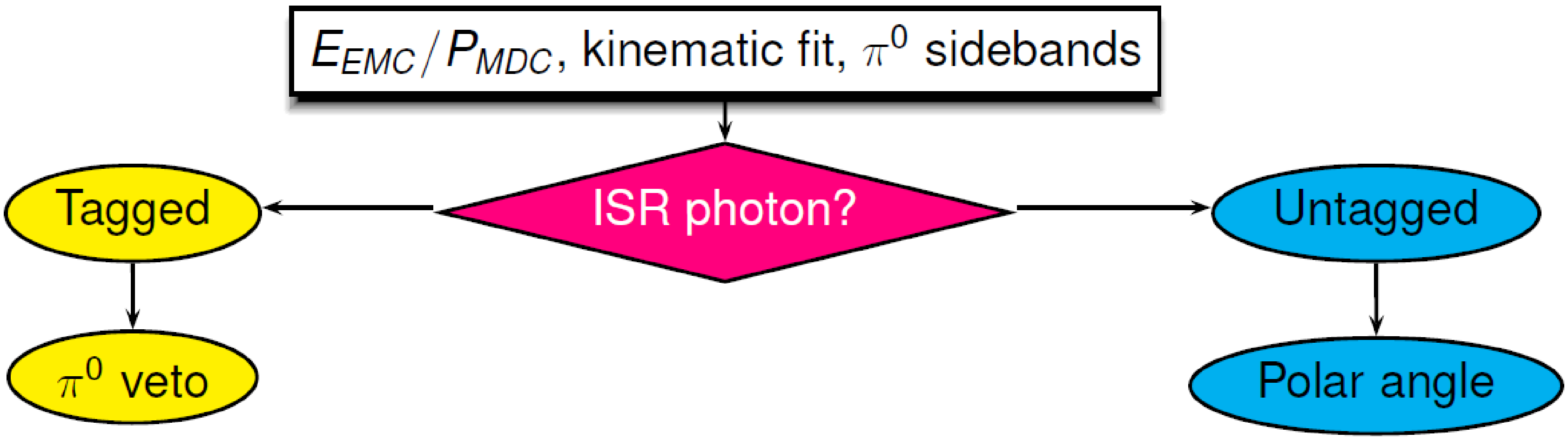
Contribution to $a_\mu^{VP,LO}$



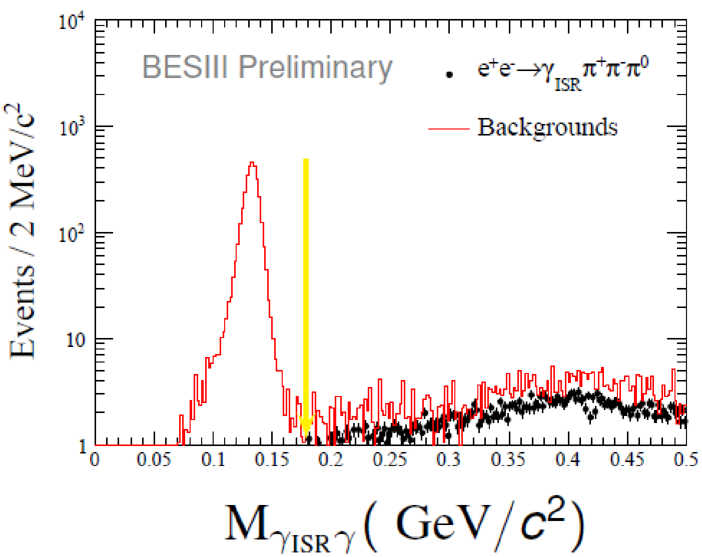
- Precision competitive with previous measurements
- BESIII measurement well agrees with KLOE
- Confirmed deviation between experiment and theory

ISR $e^+e^- \to \pi^+\pi^-\pi^0$

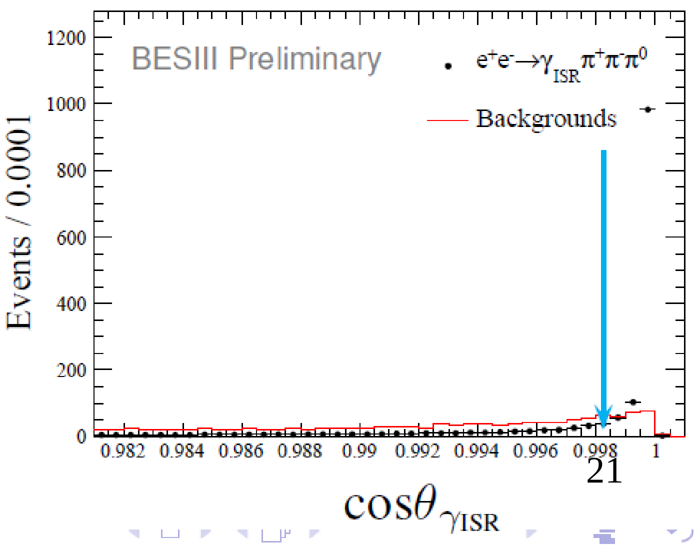
Event selections



Combination of the ISR photon and any other photon

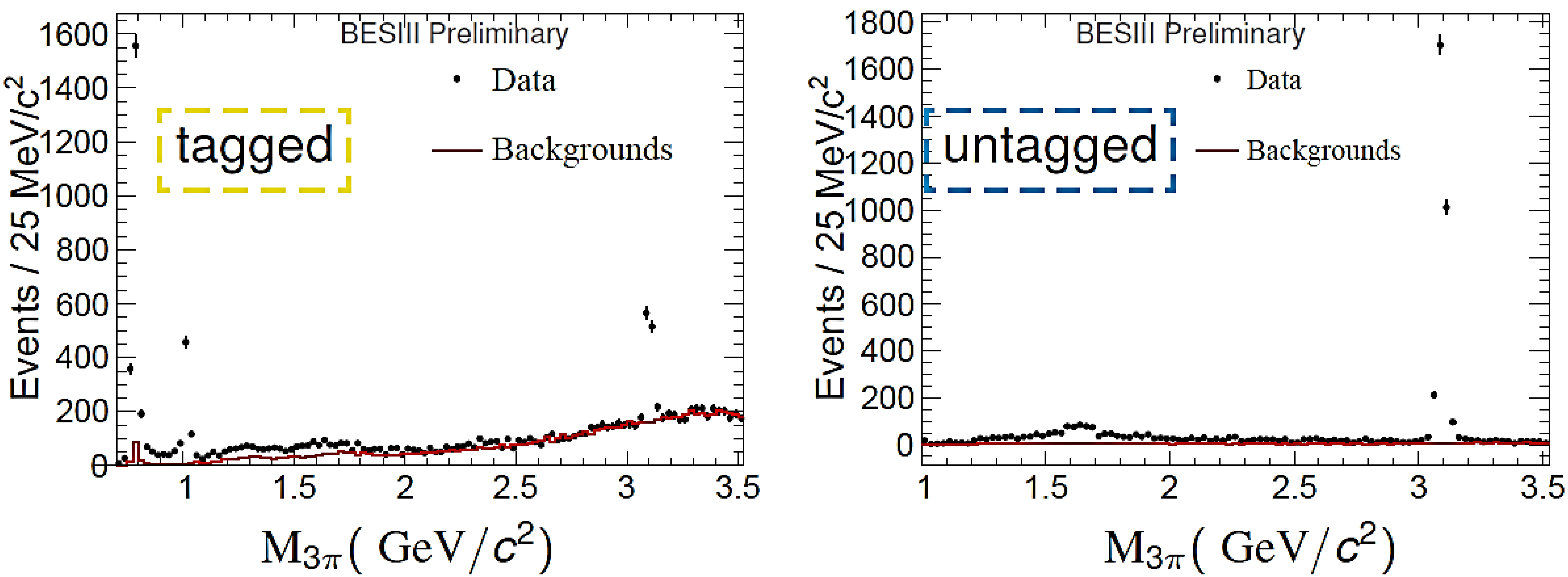


Polar angle of the ISR photon



Background estimation

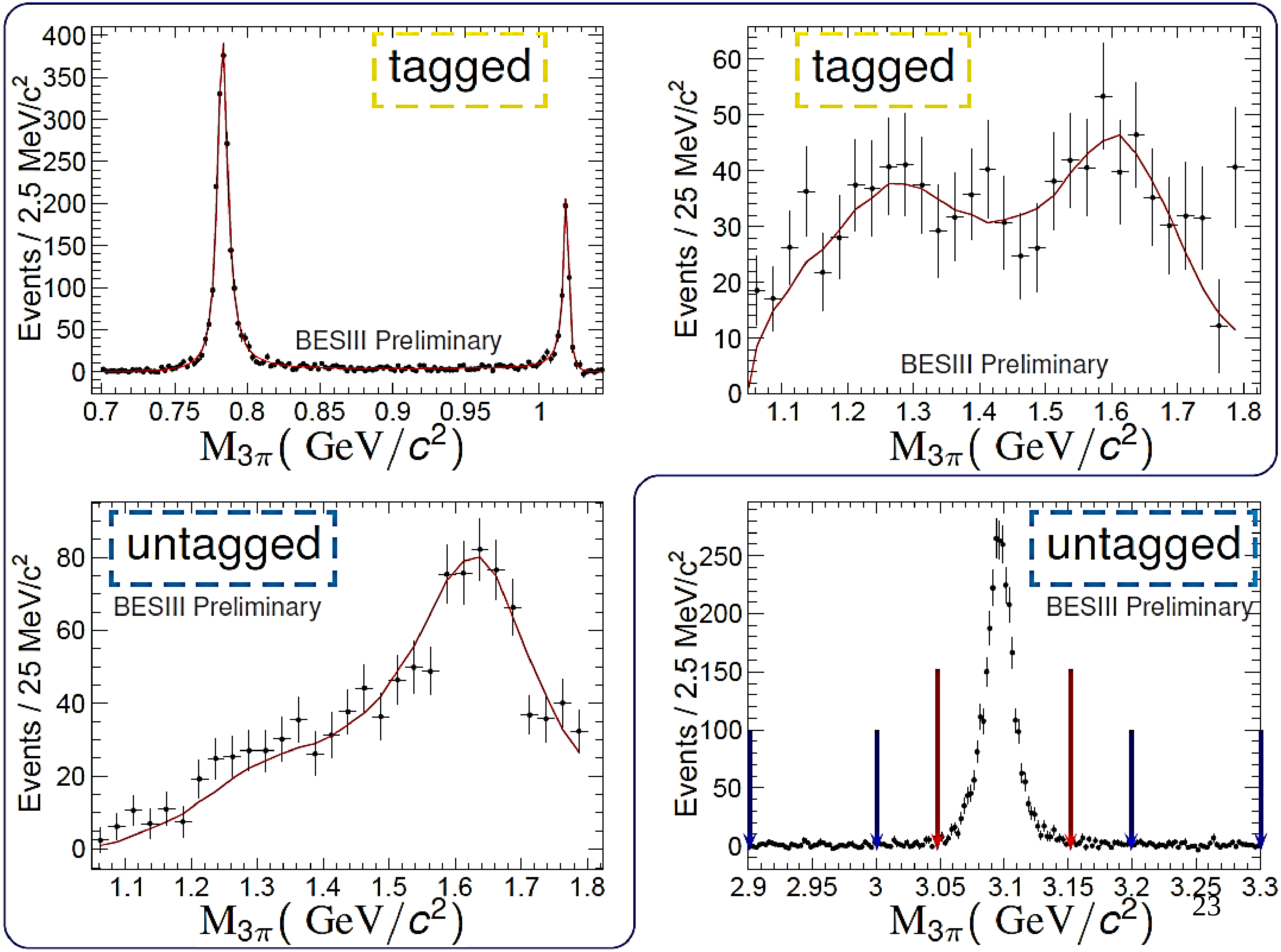
- Data-driven background estimation: $e^+e^- \rightarrow (\gamma_{ISR})\pi^+\pi^-\pi^0\pi^0$



- Clear ω and ϕ signals
- Huge BG in high mass region

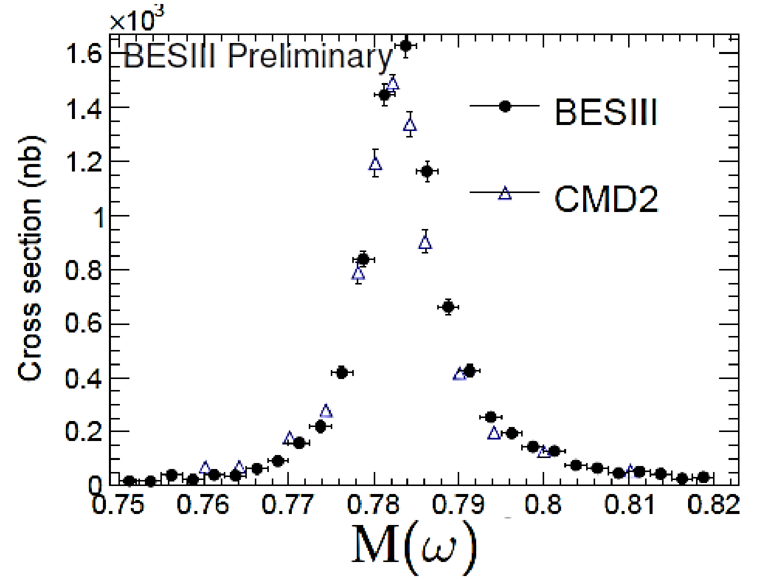
- Limited by acceptance
- Negligible BackGround

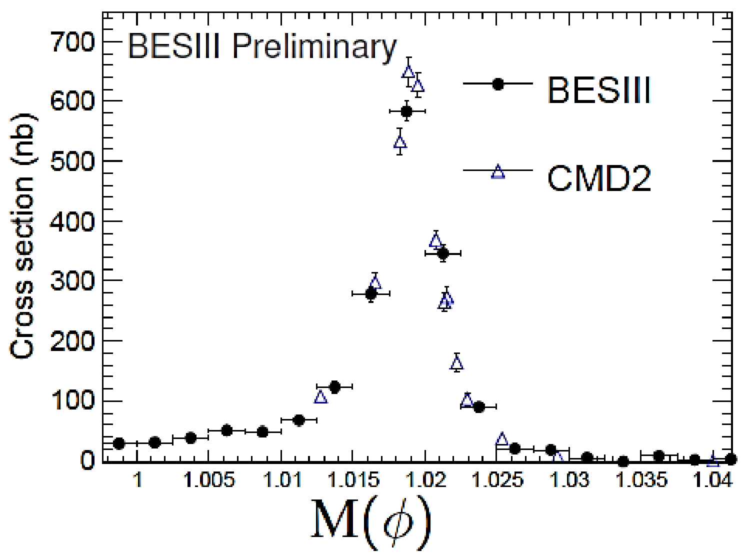
Fit the signals

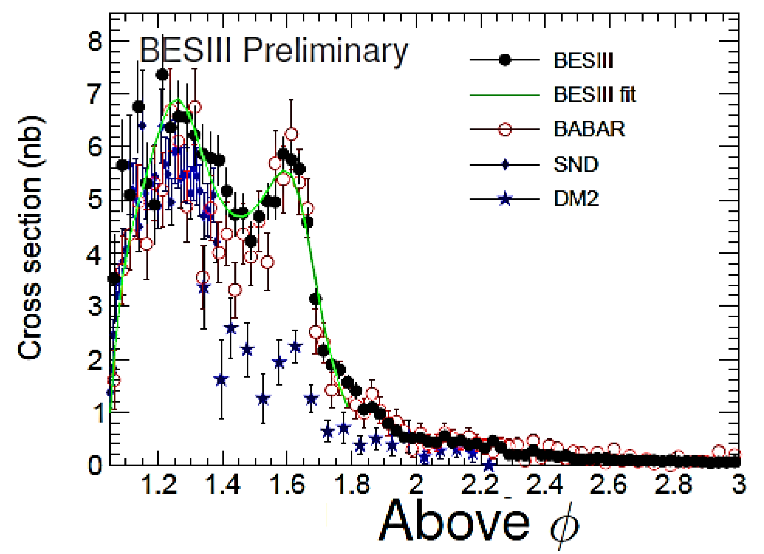


Cross section

- $\sigma_i = \frac{N_i}{\varepsilon \cdot L_i} \cdot \frac{1}{|1+\Pi|^2}$
  - : N_i: No. of signal events
  - L_i: effective luminosity
  - ε: corrected efficiency
  - $\frac{1}{|1+\Pi|^2}$: vacuum polarization

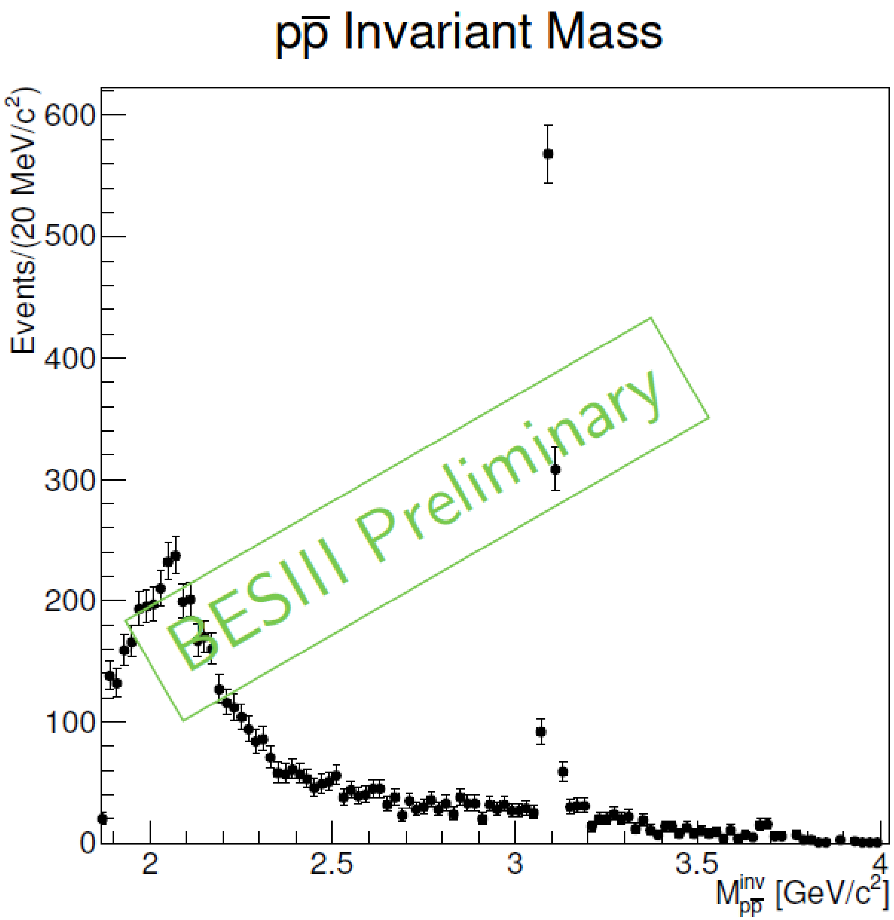






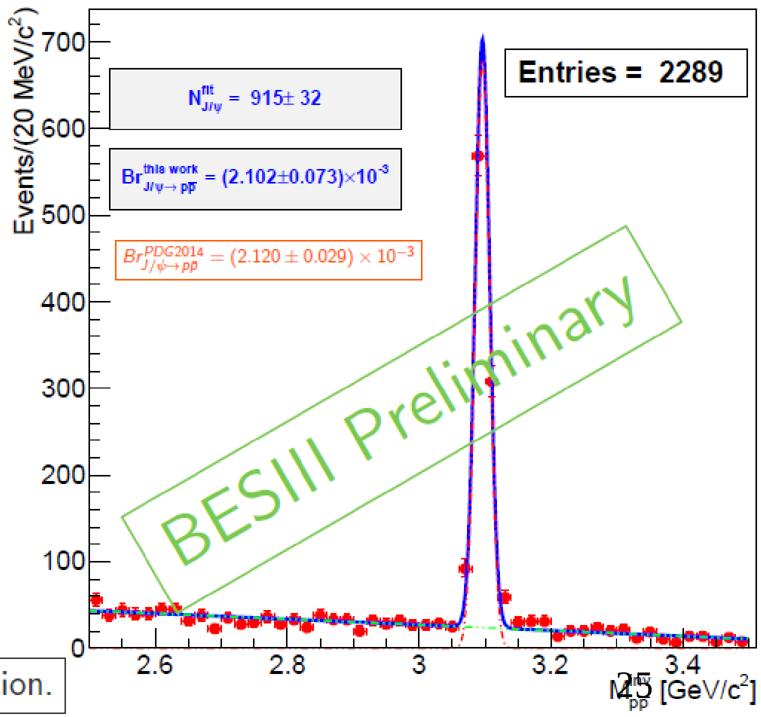
$$\mathcal{B}(J/\psi \to \pi^+\pi^-\pi^0) = (2.18 \pm 0.03(\text{stat.}) \pm 0.06(\text{sys.}))\%$$

ISR-Tagged Analysis for $p\bar{p}$ Channel



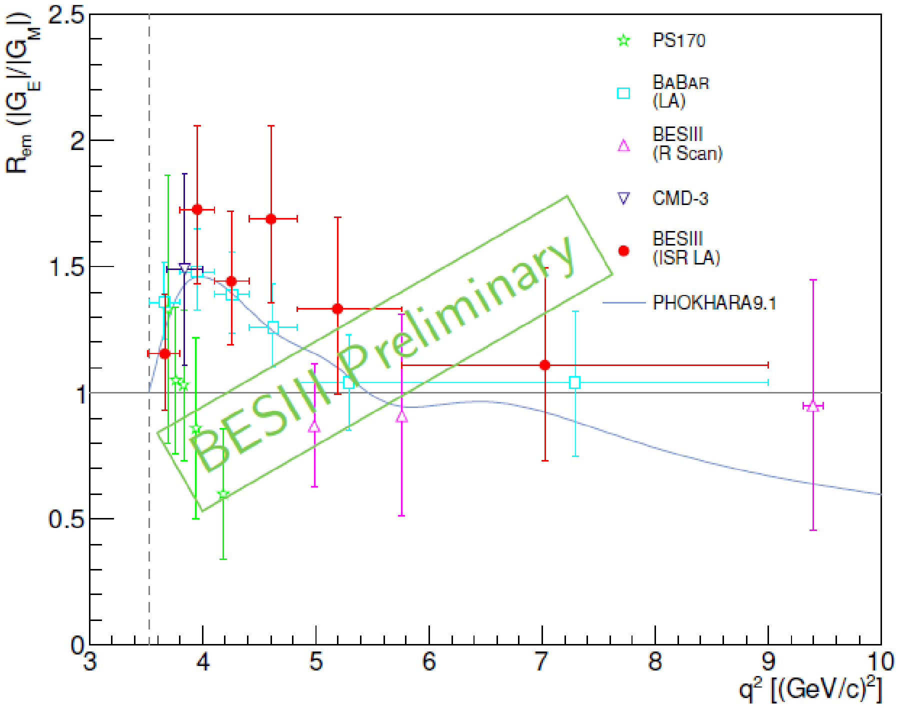
$p\bar{p}$ invariant mass spectrum from threshold
combined from 7 data samples
($p\bar{p}\pi^0$ background not completely removed)

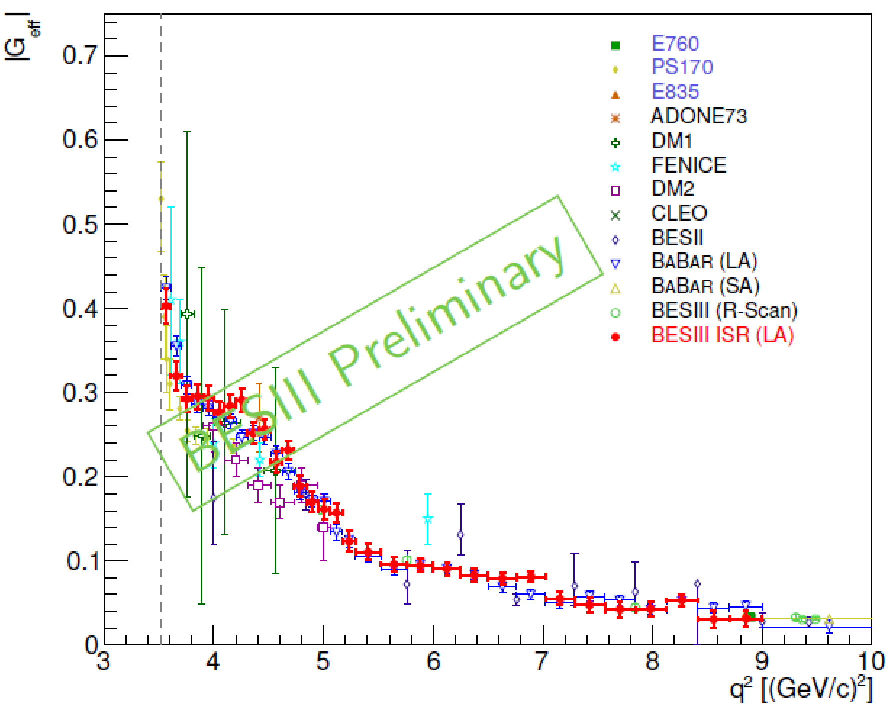
- 7 data samples ($\geq$ 3.773 GeV)
- Total luminosity 7.4 fb^{-1}
- Event selction:
  - Two charged tracks from vertex
  - One high energy shower in EMC
  - Kinematic constraints applied
- Background evaluation and subtraction



BESIII Preliminary: Analysis internal reviewing and preparing for publication.

Preliminary Results from ISR-Tagged Analysis





- ➢ Background subtraction and efficiency correcting
- ➢ Combine the seven data samples
- ➢ The proton FFs extracted between th. – 3.0 GeV
- ➢ Systematic uncertainty included

	$\delta R_{em}/R_{em}$	$\delta\|G_{eff}\|/\|G_{eff}\|$
stat.	16% - 34%	5% - 32%
syst.	4% - 8%	2% - 12%

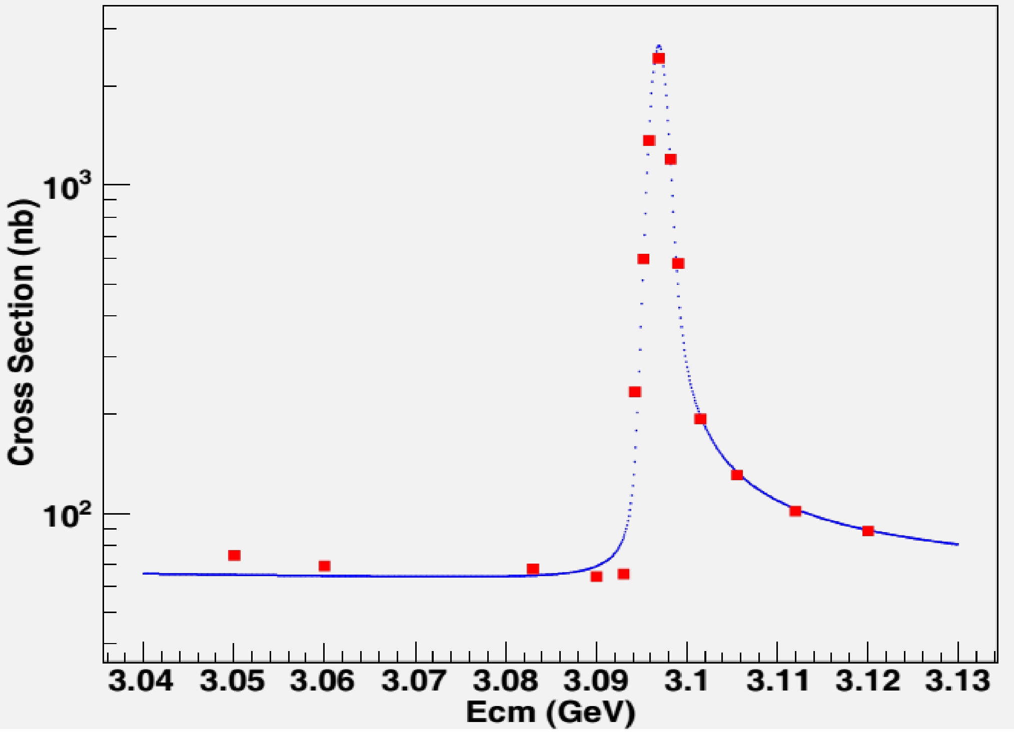
LA: **L**arge polar **A**ngle of ISR photon
SA: **S**mall polar **A**ngle of ISR photon

J/ψ line shape scan

Data have been taken around the J/ψ peak at 15 energy points

Req Ecm (GeV)	Int Lum (nb^{-1})
3.0500	14918 ± 169
3.0600	15059 ± 170
3.0830	4768 ± 58
3.0900	15558 ± 173
3.0930	14909 ± 160
3.0943	2143 ± 25
3.0952	1816 ± 22
3.0958	2134 ± 25
3.0969	2069 ± 26
3.0982	2203 ± 27
3.0990	756 ± 11
3.1015	1612 ± 21
3.1055	2106 ± 25
3.1120	1720 ± 21
3.1200	1264 ± 17

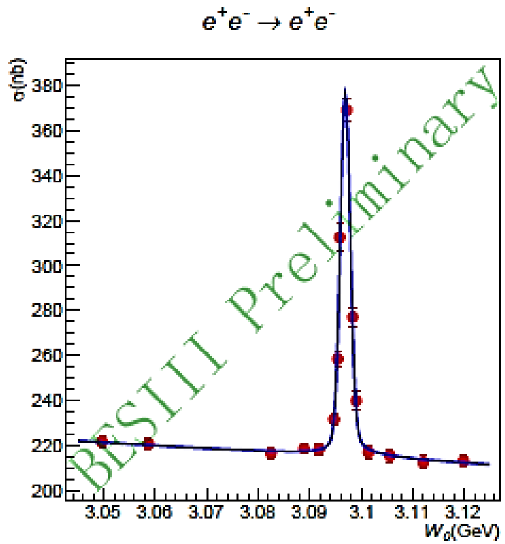
On-line cross section and J/psi line shape fit

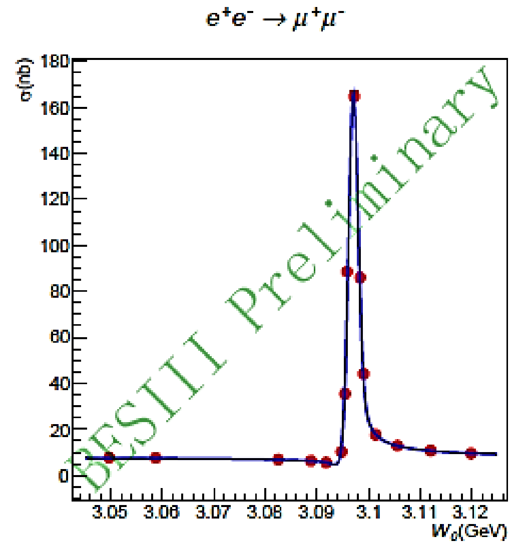


Measure the resonant parameters of J/ψ with:

1. $e^+e^- \to e^+e^-$
2. $e^+e^- \to \mu^+\mu^-$
3. $e^+e^- \to$ hadrons

Simultaneous fitting results of $e^+e^- \to e^+e^-$ and $e^+e^- \to \mu^+\mu^-$





Parameters and their covariance matrix from fitting

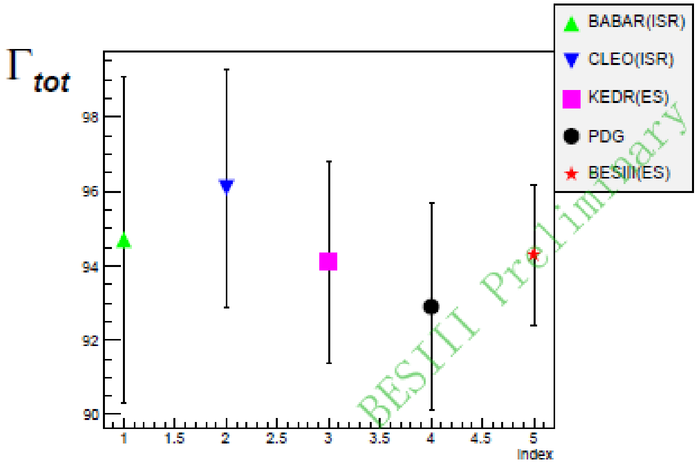
Symbol	Value (keV)	V_{i1} (keV^2)	V_{i2} (keV^2)
$\Gamma_{ee}\Gamma_{ee}/\Gamma_{tot}$	0.348	0.0000684	0.0000373
$\Gamma_{ee}\Gamma_{\mu\mu}/\Gamma_{tot}$	0.339	0.0000373	0.0000300

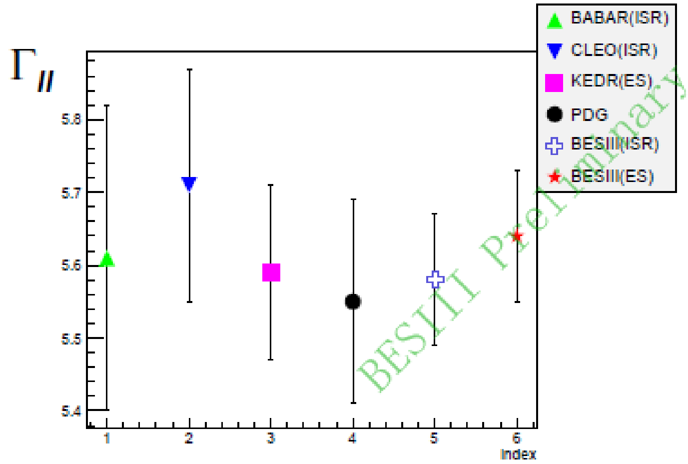
$\Downarrow$

Combined with $B(J/\psi \to l^+l^-) = \Gamma_{ll}/\Gamma_{tot} = (5.978 \pm 0.040)\%$ [1]

$\Downarrow$

Symbol	Result
$\Gamma_{ee}/\Gamma_{\mu\mu}$	1.025 ± 0.014
Γ_{tot}	(94.3 ± 1.9) keV
Γ_{ll}	(5.64 ± 0.09) keV





Index	Collaboration	Method	Year	Γ_{tot} (keV)	Γ_{ll} (keV)
1	BABAR	ISR	2004	94.7±4.4	5.61±0.21
2	CLEO	ISR	2006	96.1±3.2	5.71±0.16
3	KEDR	ES	2010	94.1±2.7	5.59±0.12
4	PDG	—	2016	92.9±2.8	5.55±0.14
5	BESIII	ISR	2016	—	5.58±0.09
6	BESIII	ES	2017	94.3±1.9	5.64±0.09

BESIII Preliminary

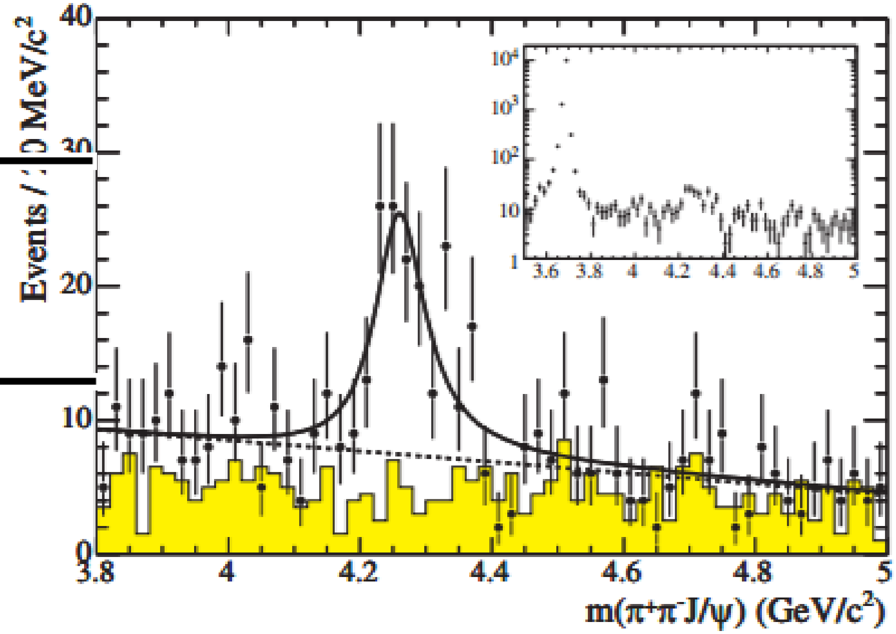
- Our result is consistent with those from others.
- Together with the other BESIII result using ISR, our result achieves the best accuracy in the world by far.

$e^+e^- \rightarrow \pi^+\pi^- J/\psi$ cross section

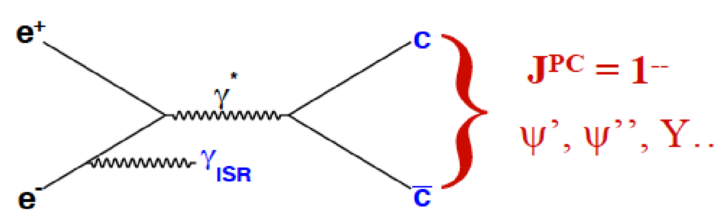
BABAR PRL95,142001(2005)

$X(4260)$ $\quad I^G(J^{PC}) = ?^?(1^{--})$

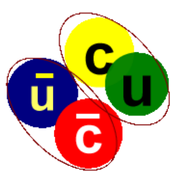
X(4260) MASS	**4251 ± 9**	**PDG AVERAGE**
X(4260) WIDTH	**120 ±12**	**PDG AVERAGE**



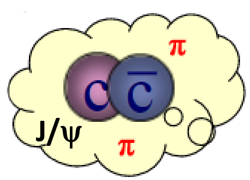
Y(4260)/X(4260)



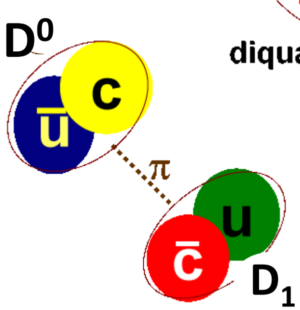
Confirmed by Belle, CLEO, BESIII



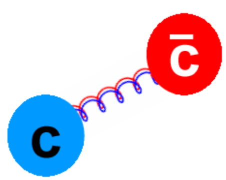
diquark-diantiquark



Hadro-charmonium

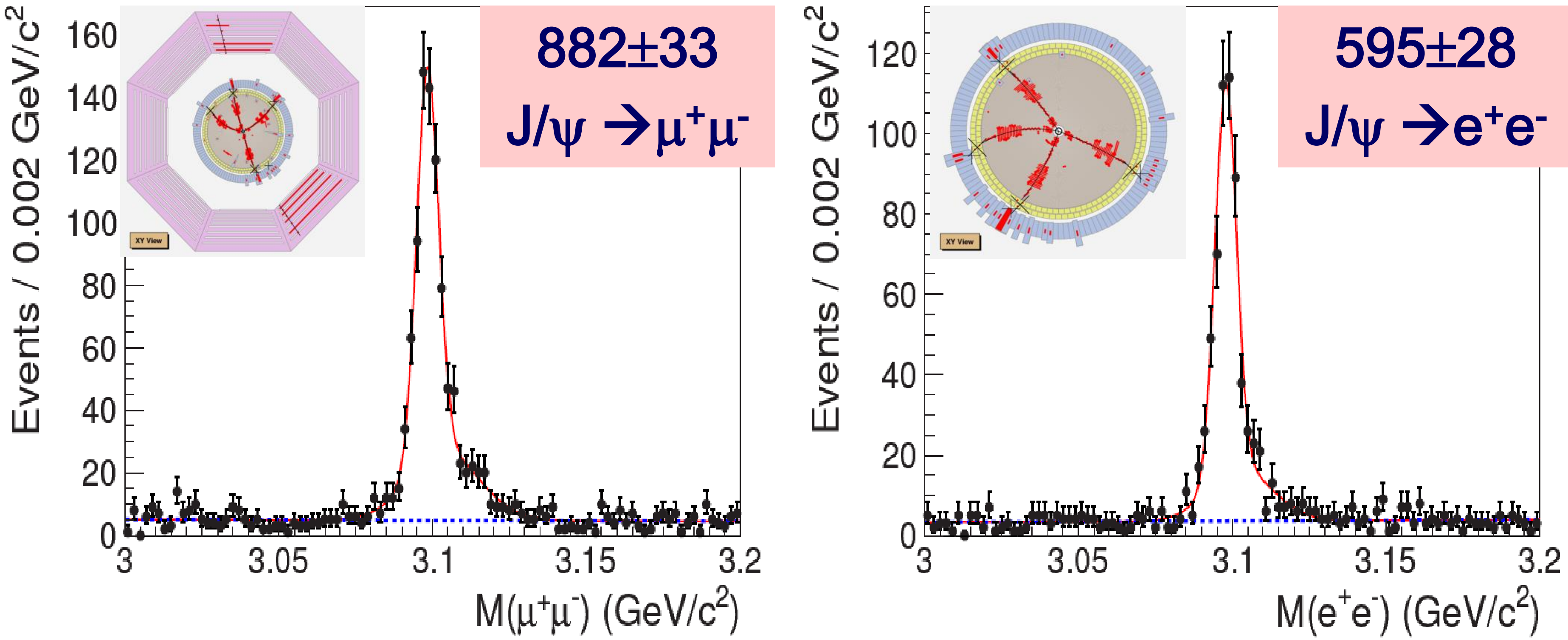


$D^0 - D_1$ "molecule"



$q\bar{q}$-gluon"hybrid"

$e^+e^- \to \pi^+\pi^- J/\psi$ at 4.26 GeV

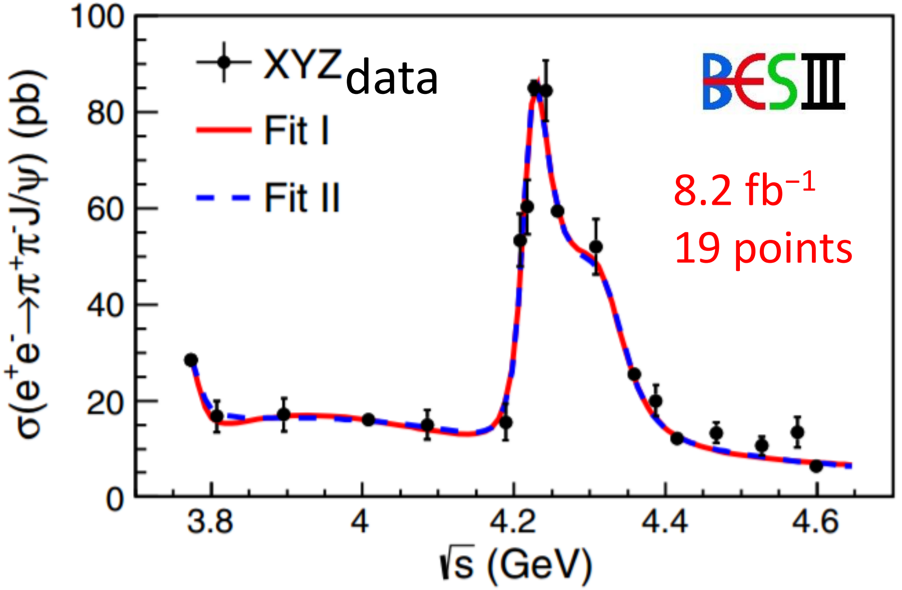


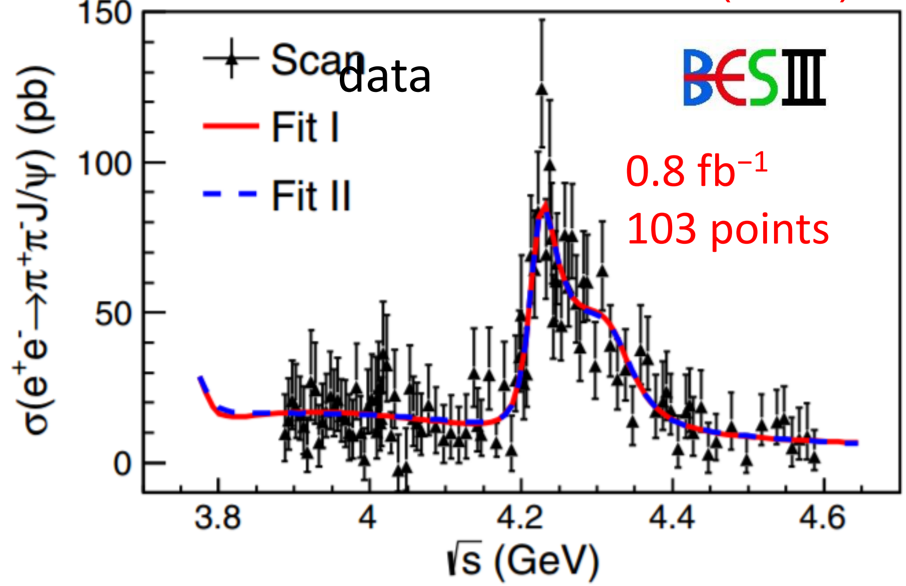
- Select 4 charged tracks and reconstruct J/ψ with lepton pair.
- Very clean sample, very high efficiency (~45%).
- $\sigma(e^+e^- \to \pi^+\pi^- J/\psi) = (62.9 \pm 1.9 \pm 3.7)$ pb

BESIII: PRL110, 252001

$e^+e^- \rightarrow \pi^+\pi^- J/\psi$ cross section at BESIII

PRL118, 092001 (2017)





- Most precise cross section measurment to date from BESIII
- Fit I = $|BW_1+BW_2*e^{i\phi2}+BW_3*e^{i\phi3}|^2$ or Fit II = $|exp+BW_2*e^{i\phi2}+BW_3*e^{i\phi3}|^2$ (other fits ruled out)

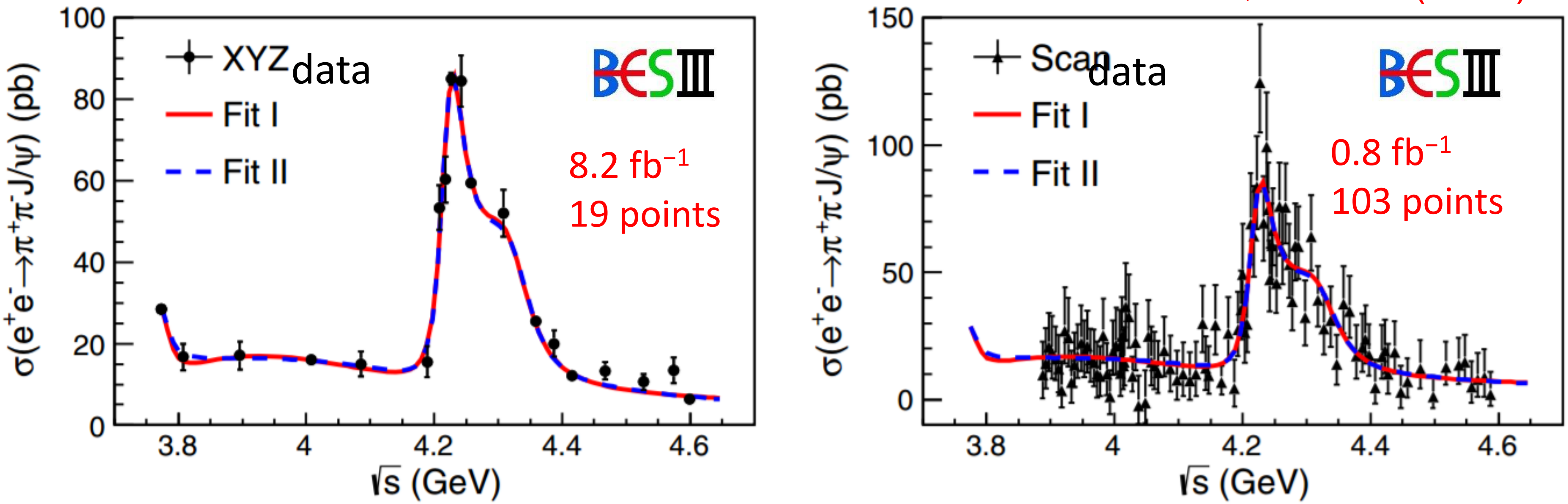
M = 4222.0 ± 3.1 ± 1.4 MeV (lower)

Γ = 44.1 ± 4.3 ± 2.0 MeV (narrower)

X(4260) MASS	4251 ± 9	AVERAGE	PDG
X(4260) WIDTH	120 ±12	AVERAGE	

$e^+e^- \rightarrow \pi^+\pi^- J/\psi$ cross section at BESIII

PRL118, 092001 (2017)

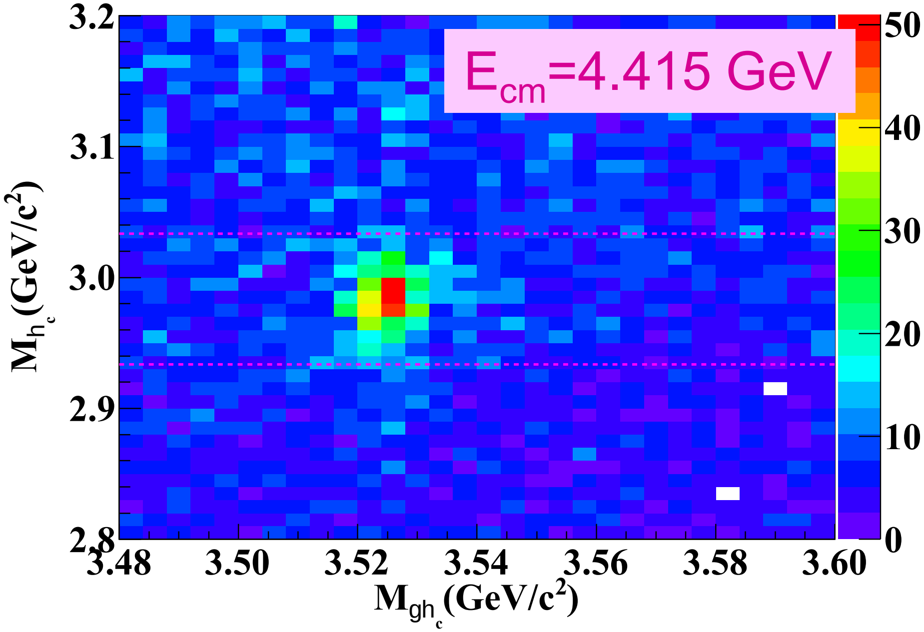


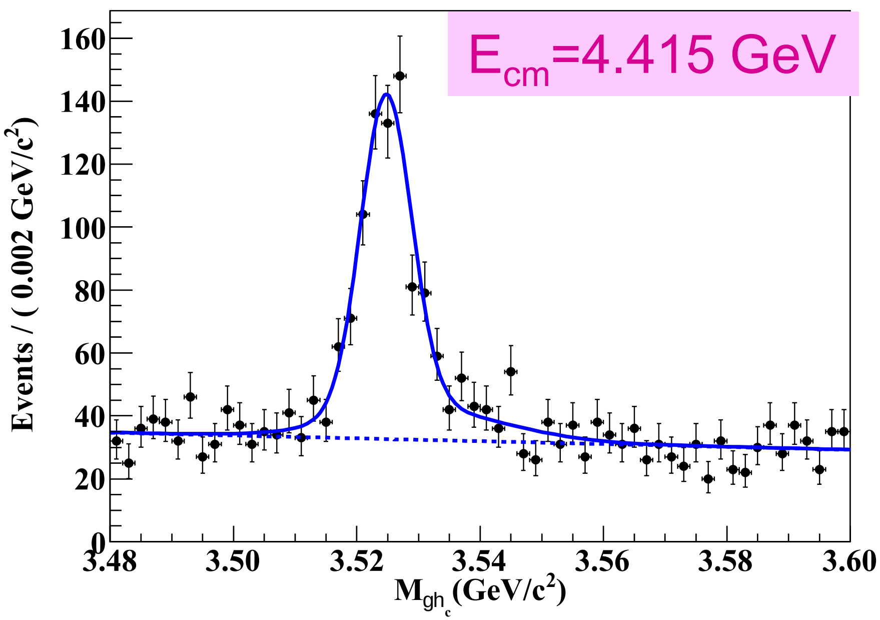
- Most precise cross section measurment to date from BESIII
- Fit I $= |BW_1 + BW_2 * e^{i\phi 2} + BW_3 * e^{i\phi 3}|^2$ or Fit II $= |\exp + BW_2 * e^{i\phi 2} + BW_3 * e^{i\phi 3}|^2$ (other fits ruled out)
- M = $4222.0 \pm 3.1 \pm 1.4$ MeV (lower)
- Γ = $44.1 \pm 4.3 \pm 2.0$ MeV (narrower)

- A 2nd resonance Y_2 with M=$4320.0 \pm 10.4 \pm 7.0$ MeV/c^2
  $\Gamma = 101.4^{+25.3}_{-19.7} \pm 10.2$ MeV
- Observed for the first time, significance > 7.6σ

$e^+e^- \to \pi^+\pi^- h_c(1P)$ at BESIII

- $h_c \to \gamma\eta_c$, $\eta_c \to$ hadrons [16 exclusive decay modes]
  - pp, $\pi^+\pi^-K^+K^-$, $\pi^+\pi^-pp$, $2(K^+K^-)$, $2(\pi^+\pi^-)$, $3(\pi^+\pi^-)$
  - $2(\pi^+\pi^-)K^+K^-$, $K_S^0K^+\pi^-$+c.c., $K_S^0K^+\pi^-\pi^+\pi^-$+c.c., $K^+K^-\pi^0$
  - $pp\pi^0$, $K^+K^-\eta$, $\pi^+\pi^-\eta$, $\pi^+\pi^-\pi^0\pi^0$, $2(\pi^+\pi^-)\eta$, $2(\pi^+\pi^-\pi^0)$

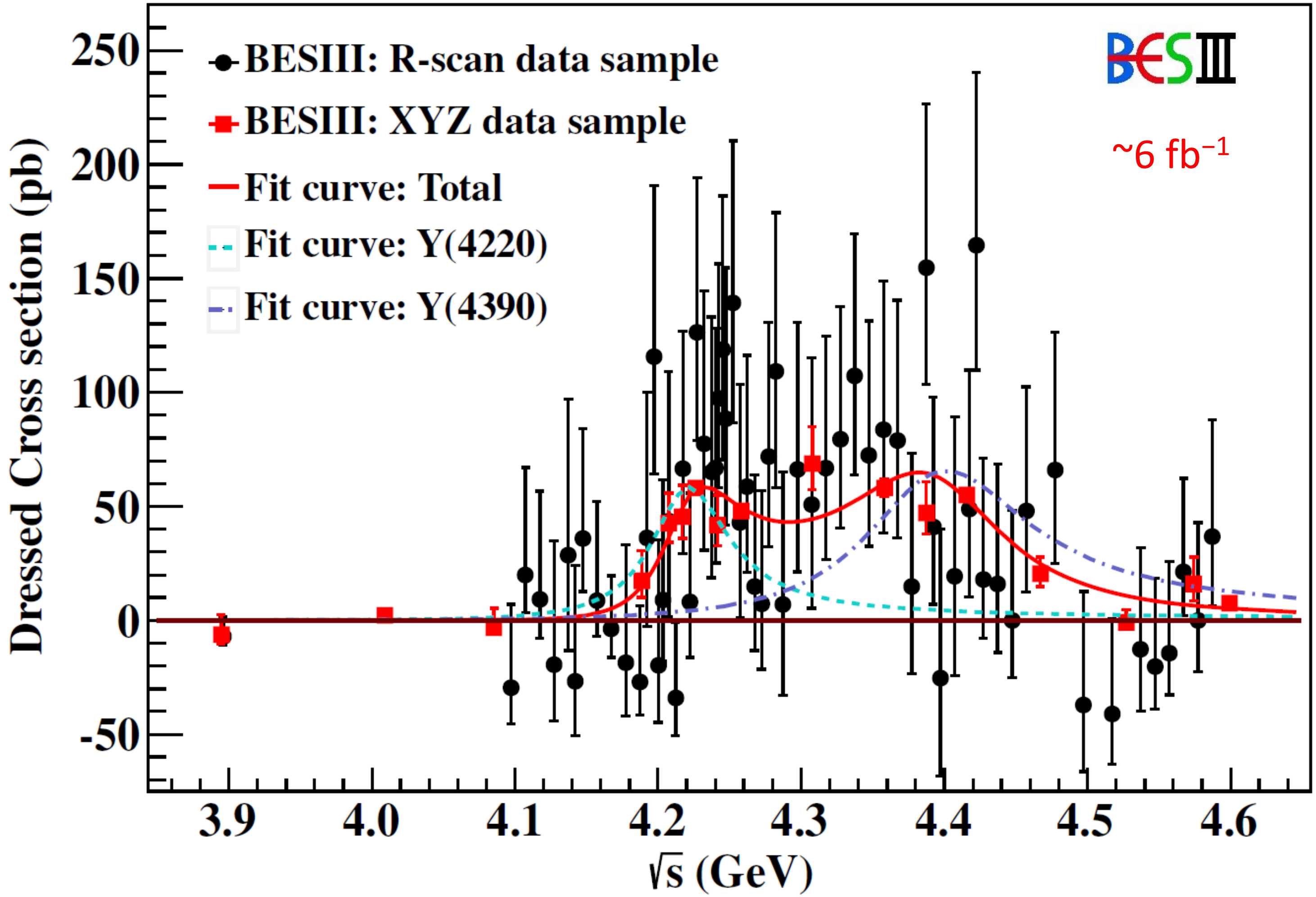




Method same as in arXiv:1309.1896, PRL111, 242001

$e^+e^- \rightarrow \pi^+\pi^- h_c$ cross section at BESIII

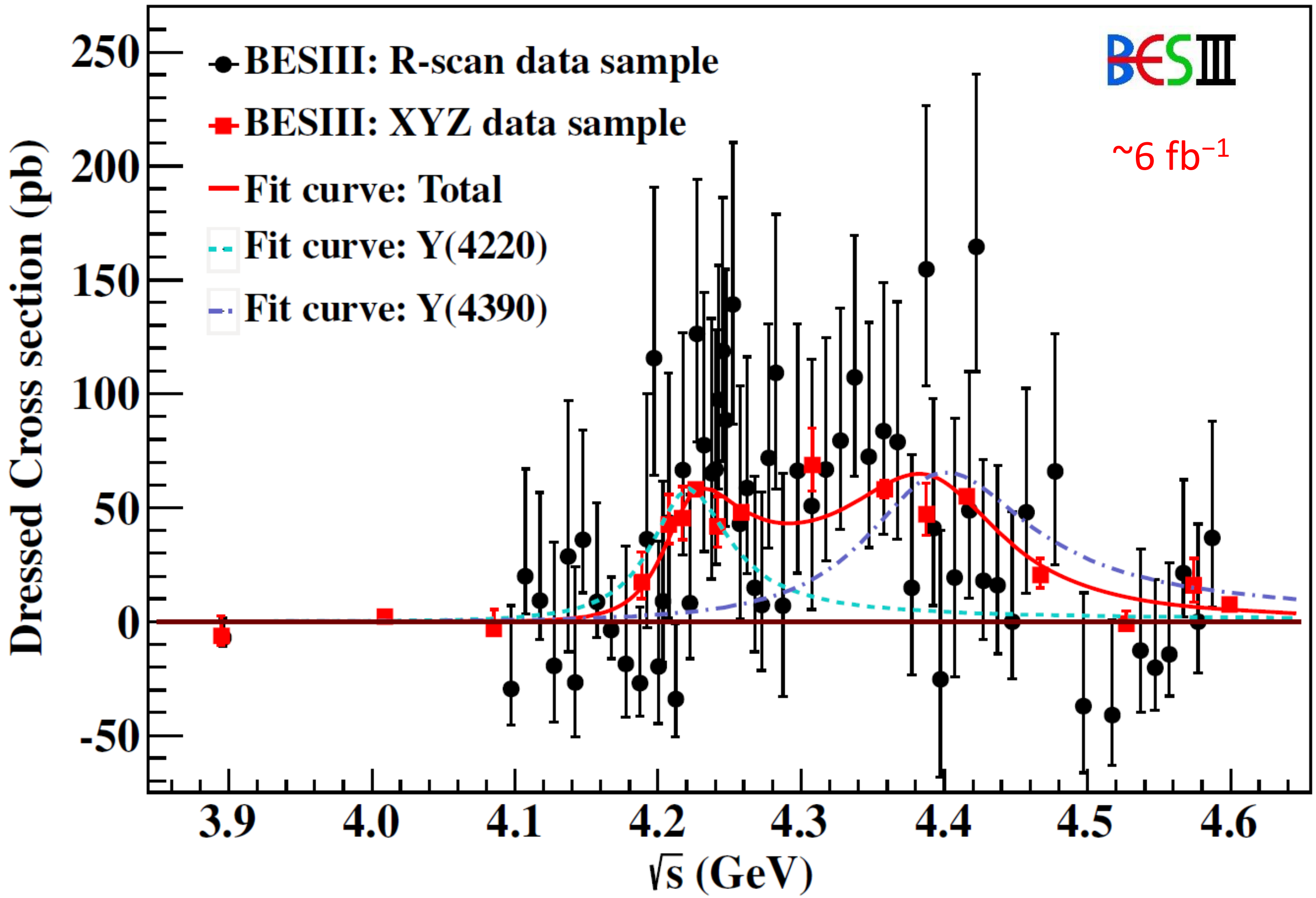
PRL118, 092002 (2017)



- First precise cross section measurement from threshold to 4.6 GeV
- Fit with $|BW_1+BW_2*e^{i\phi2}|^2$, two resonant structures are evident

$e^+e^- \rightarrow \pi^+\pi^- h_c$ cross section at BESIII

PRL118, 092002 (2017)

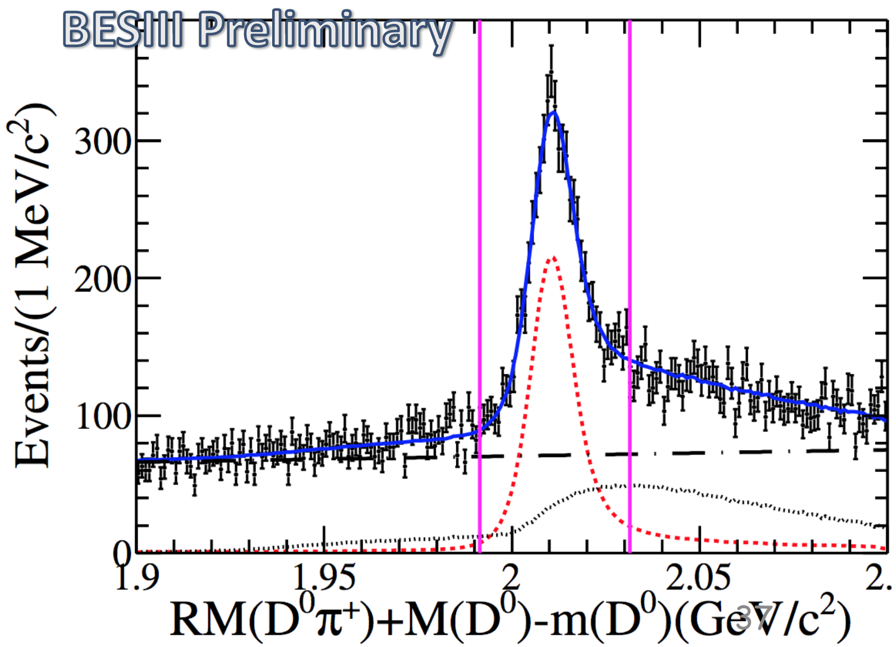


- $M_1=4218.4^{+5.5}_{-4.5}\pm0.9$ MeV/c^2, $\Gamma_1= 66.0^{+12.3}_{-8.3}\pm0.4$ MeV $\rightarrow$ Y(4220)
- $M_2=4391.5^{+6.3}_{-6.8}\pm1.0$ MeV/c^2, $\Gamma_2=139.5^{+16.2}_{-20.6}\pm0.6$ MeV $\rightarrow$ Y(4390)

$e^+e^- \to \pi^+ D^0 D^{*-}$+c.c.

- Reconstruct $D^0 \to K^-\pi^+$
- Select the combination closest to D^0 mass ($m(D^0)$)
- Find an additional π^+;
- 1.9 < $M(D^{*-})$ ($RM(D^0\pi^+) + M(D^0) - m(D^0)$) < 2.1 GeV/$c^2$
- select the candidate closest to D^{*-} mass

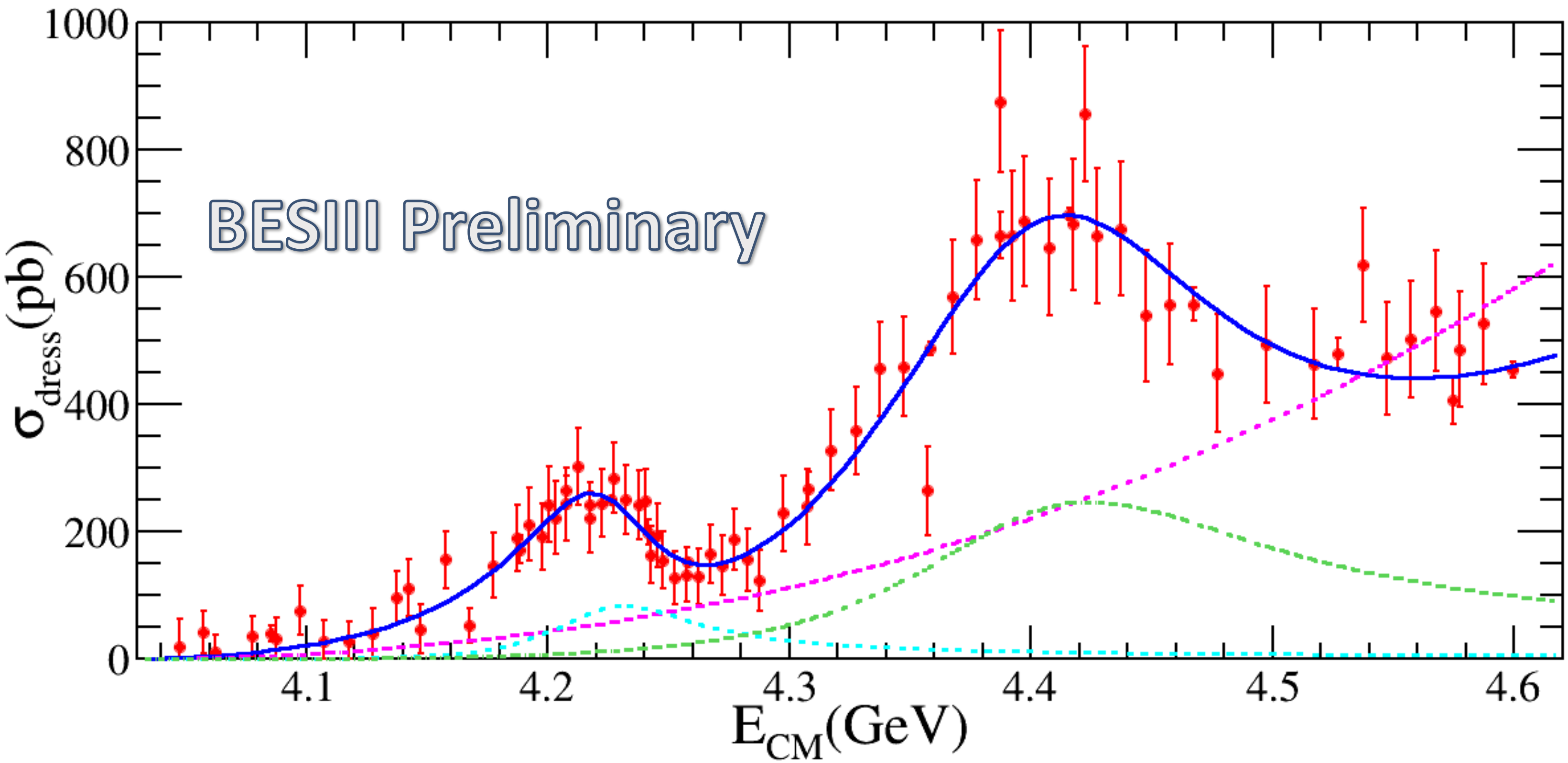
- An un-binned maximum likelihood fit
- Signal shape: MC convoluted with a Gaussian;
- The isospin partner background (dotted line) is parameterized with MC;
- A linear function for other bkg



Fit to the dressed cross section of $e^+e^- \to \pi^+D^0D^{*-}$+c.c.

$$\sigma_{dress} = \frac{N^{obs}}{\mathcal{L}(1+\delta^r)B(D^0 \to K^-\pi^+)\varepsilon}$$

$$\sigma_{\rm dress}(m) = |c \cdot \sqrt{P(m)} + e^{i\phi_1}B_1(m)\sqrt{\frac{P(m)}{P(M_1)}} + e^{i\phi_2}B_2(m)\sqrt{\frac{P(m)}{P(M_2)}}|^2$$



Fit with a constant (pink dashed triple-dot line) and two constant width relativistic BW functions (green dashed double-dot line and aqua dashed line).

Resonant parameters

Parameters	SolutionI	SolutionII	SolutionIII	SolutionIV
c (10^{-4})		5.5 ± 0.6		
M_1 (MeV/c^2)		4224.8 ± 5.6		
Γ_1 (MeV)		72.3 ± 9.1		
M_2 (MeV/c^2)		4400.1 ± 9.3		
Γ_2 (MeV)		181.7 ± 16.9		
Γ_1^{el} (eV)	62.9 ± 11.5	7.2 ± 1.8	81.6 ± 15.9	9.3 ± 2.7
Γ_2^{el} (eV)	88.5 ± 15.8	55.3 ± 8.7	551.9 ± 85.3	344.9 ± 70.6
ϕ_1	-2.1 ± 0.1	2.8 ± 0.3	-0.9 ± 0.1	-2.3 ± 0.2
ϕ_2	1.9 ± 0.3	2.3 ± 0.2	2.3 ± 0.1	-1.9 ± 0.1

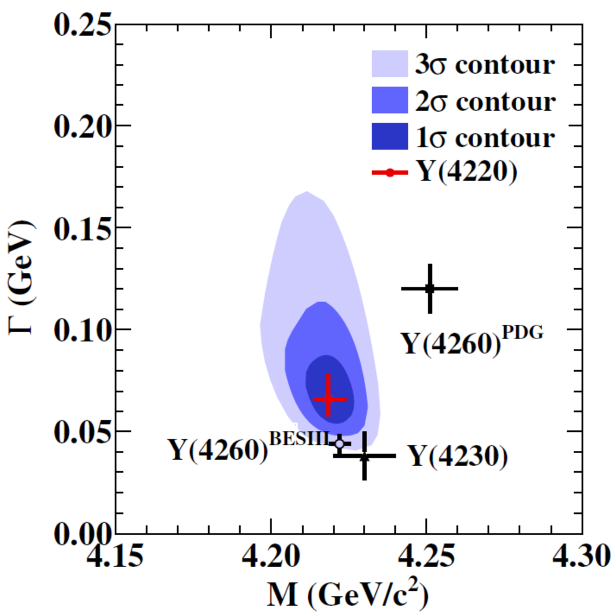
The error are statistical only.

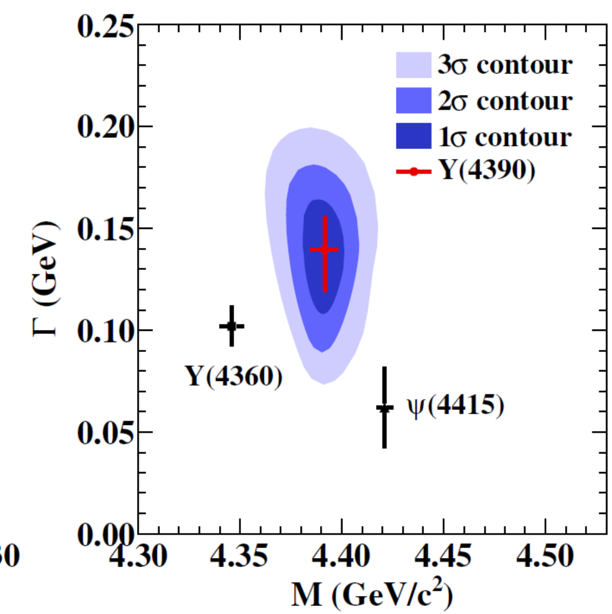
BESIII Preliminary

- Statistical significance is greater than 10σ.
- Consistent with those of Y(4220) and Y(4390) in $e^+e^- \to \pi^+\pi^-h_c$.

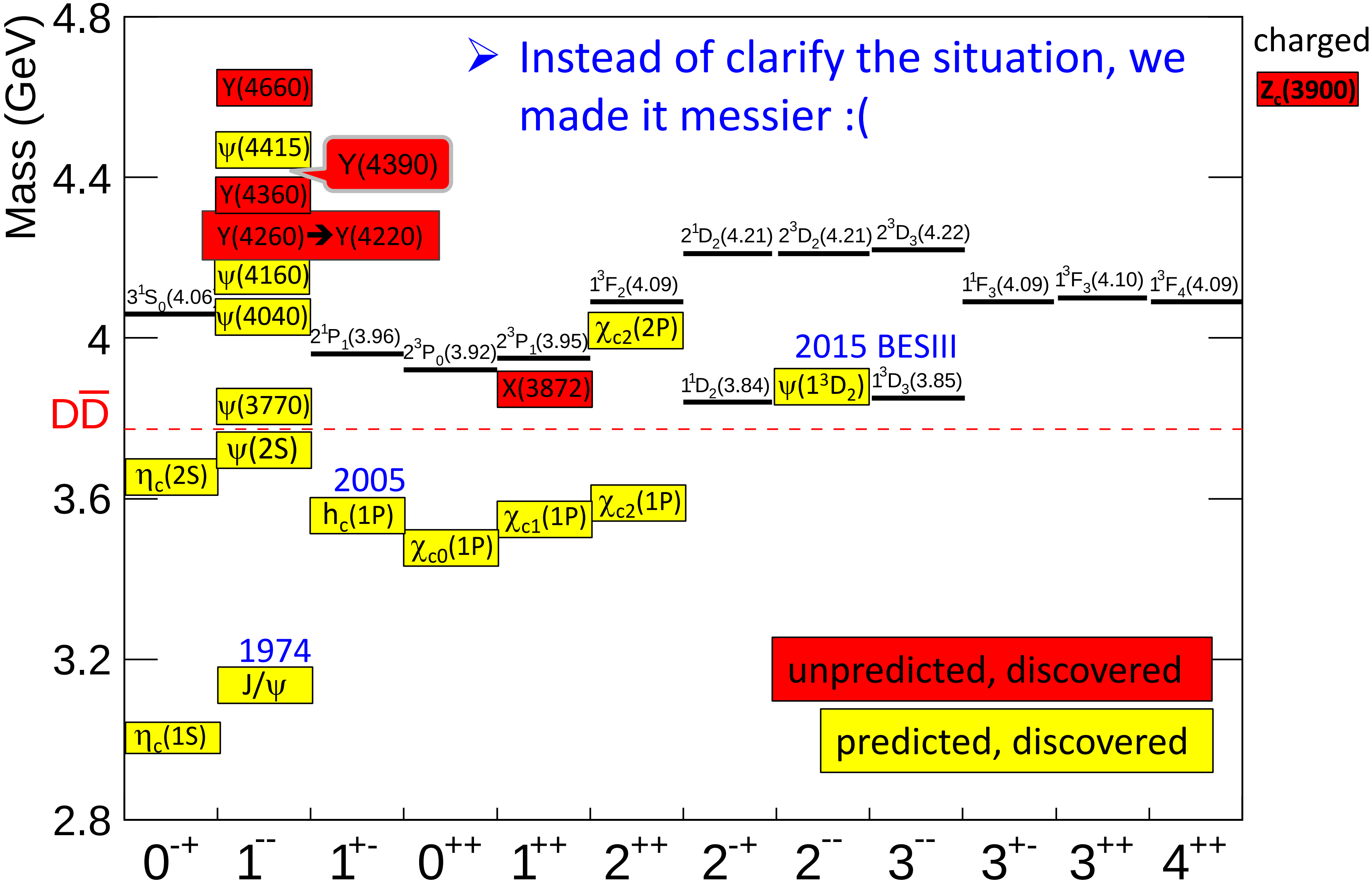
Y or ψ structures

Parameters	$Y(4220)$ in $\pi^+\pi^- h_c$	$Y(4260)$	$\psi(4160)$	Structure in $\omega\chi_{c0}$
M (MeV)	$4218.4 \pm 4.0 \pm 0.9$	4251 ± 9	4191 ± 5	$4226 \pm 8 \pm 6$
Γ_{tot} (MeV)	$66.0 \pm 9.0 \pm 0.4$	120 ± 12	70 ± 10	$39 \pm 12 \pm 2$
Parameters	**$Y(4390)$ in $\pi^+\pi^- h_c$**	**$Y(4360)$**	**$\psi(4415)$**	
M (MeV)	$4391.6 \pm 6.3 \pm 1.0$	4362 ± 13	4421 ± 4	
Γ_{tot} (MeV)	$139.5 \pm 16.1 \pm 0.6$	74 ± 18	62 ± 20	





Charmonium(like) spectroscopy



Godfrey & Isgur, PRD32, 189 (1985)

Summary & outlooks

- We can measure e^+e^- annihilation cross sections from threshold up to 4.6 GeV at BESIII
- We have made progress in improving vacuum polarization calculation precision & in understanding vector states betters
- A lot more to come with current data samples
  - More exclusive modes, improved precisions
  - High precision inclusive measurement
- BESIII may continue data taking for x years, and we are discussing a "Big Plan" ——

The plan

— a fine scan with large statistics —

- Ecm=4.0 up to 4.6+ GeV
- 10 MeV step (slight adjust ~ thresholds, skip those points we have already collected large samples)
- 500 pb^{-1}/point

➔ total luminosity ~ 25 fb^{-1}

- With peak luminosity of $10^{33}/cm^2/s$
- Top-up injection at BEPCII !
- This plan can be finished in about 5 years!

2016-17 running year: Ecm=4.19, 4.20, 4.21, …, 4.30 GeV

2017-18 running year: Ecm=4.31, 4.32, 4.33, …, 4.40 GeV?

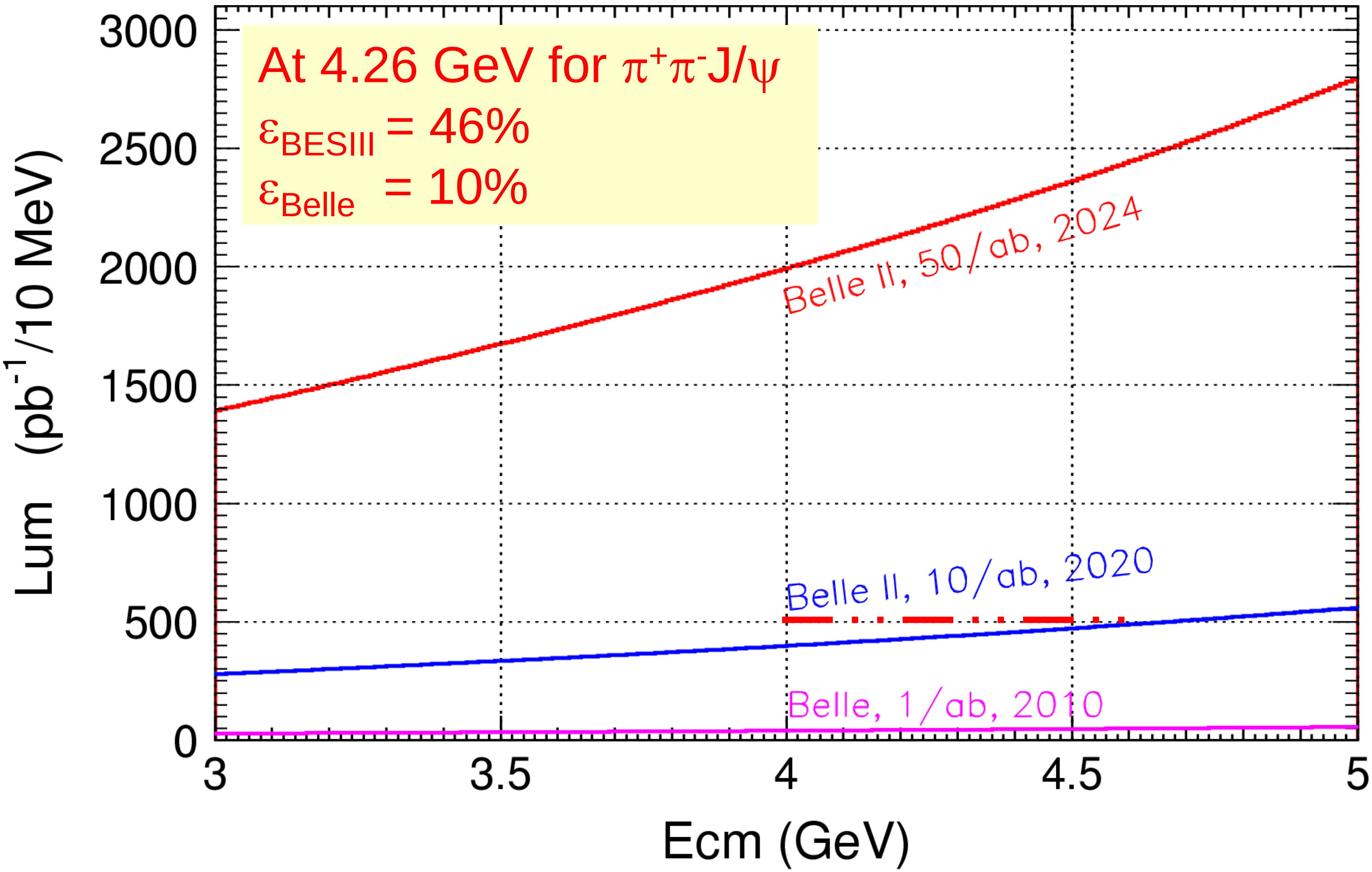
Thanks a lot!

Merci!

谢谢！

ISR at Belle II vs. BESIII

ISR produces events at all CM energies BESIII can reach



Discovery of $Z_c(3900)^{\pm}$

PRL 110, 252001 (2013)

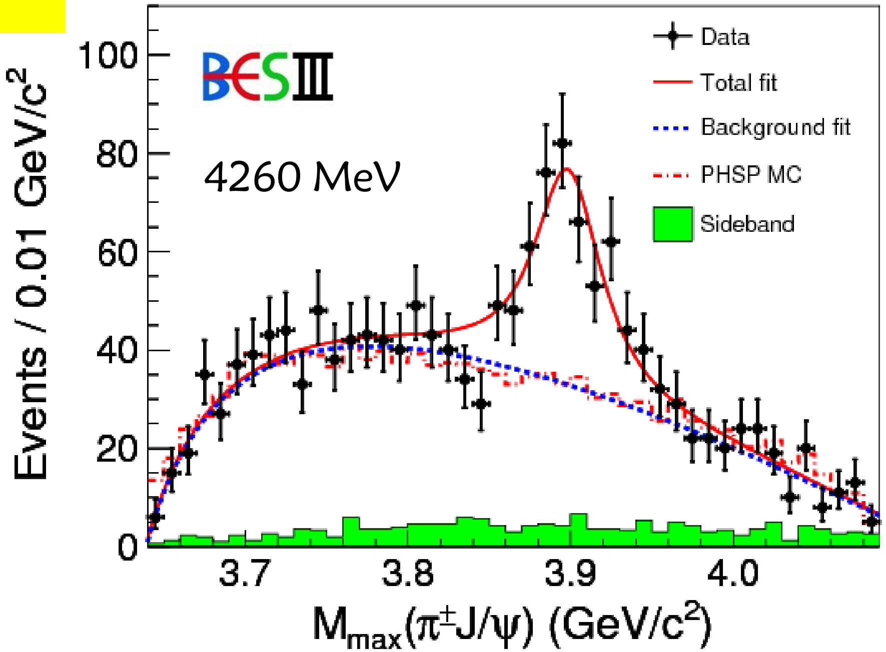
$Z_c(3900)^+$:

$$m = (3899.0 \pm 3.6 \pm 4.9)\ \mathrm{MeV}/c^2$$

$$\Gamma = (46 \pm 10 \pm 20)\ \mathrm{MeV}$$

Mass close to $D\bar{D}^*$ threshold

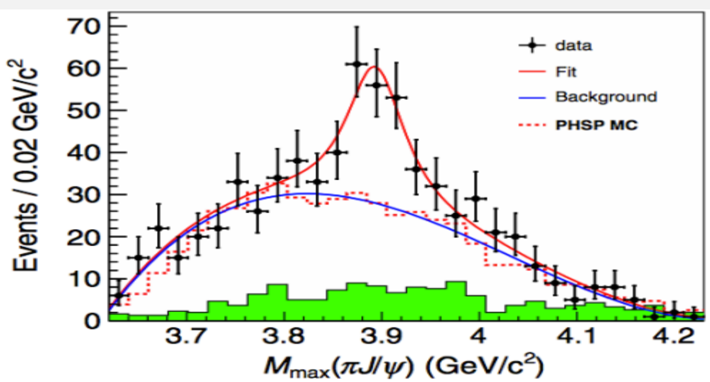
Decays to J/ψ → contains $c\bar{c}$
Electric charge → contains $u\bar{d}$



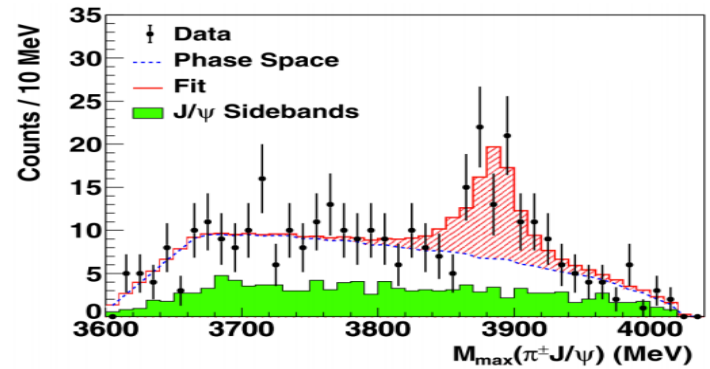
$$\sigma[e^+e^- \to \pi^+\pi^- J/\psi] = 62.9 \pm 1.9 \pm 3.7\ \mathrm{pb\ at\ 4.26\ GeV}$$

$$\frac{\sigma[e^+e^- \to \pi^{\pm} Z_c(3900)^{\mp} \to \pi^+\pi^- J/\psi]}{\sigma[e^+e^- \to \pi^+\pi^- J/\psi]} = (21.5 \pm 3.3 \pm 7.5)\%\ \mathrm{at\ 4.26\ GeV}$$

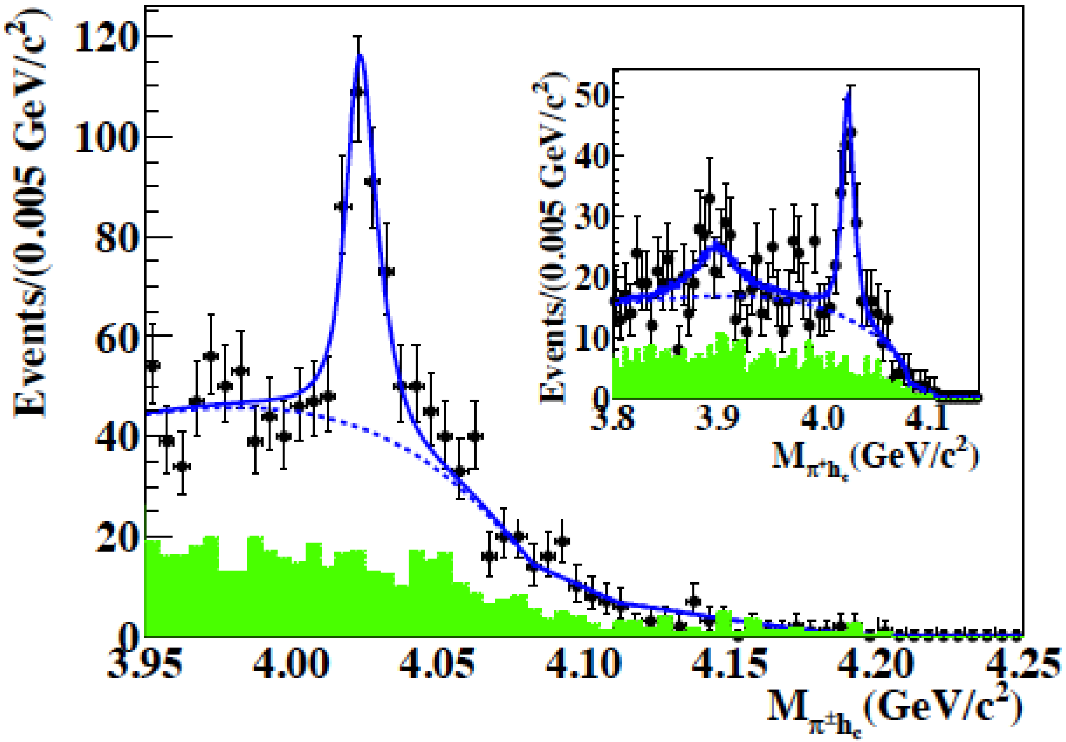
Belle with ISR data (PRL 110, 252002)



CLE0c data at 4.17 GeV (PLB 727, 366)



Observation of $Z_c(4020)^+$



BESIII: PRL111, 242001

Simultaneous fit to 4.23/4.26/4.36 GeV data, 16 η_c decay modes. 8.9σ

$M(Z_c(4020))$ = 4022.9±0.8±2.7 MeV;

$\Gamma(Z_c(4020))$ = 7.9±2.7±2.6 MeV

Close to $\bar{D}^*D^*$ threshold

$\sigma(e^+e^- \to \pi Z_c \to \pi^+\pi^- h_c)$:

8.7±1.9±2.8±1.4 pb @ 4.230 GeV

7.4±1.7±2.1±1.2 pb @ 4.260 GeV

10.3±2.3±3.1±1.6 pb @ 4.360 GeV

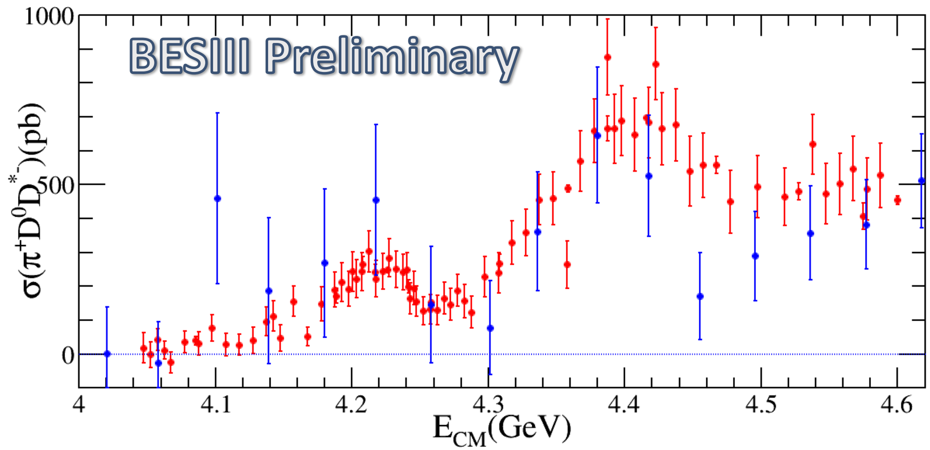
Significance: 8.9σ [$Z_c(4020)$]

No significant $Z_c(3900)$ (2.1σ)

Born Xsection of $e^+e^- \to \pi^+ D^0 D^{*-}$+c.c.

$$\sigma^B = \frac{N^{obs}}{\mathcal{L}(1+\delta^r)(1+\delta^V)B(D^0 \to K^-\pi^+)\varepsilon}$$

N^{obs}: signal yield;
$\mathcal{L}$: integrated luminosity;
$1+\delta^r$: radiative correction factor;
$1+\delta^V$: vacuum polarization correction factor;
ε: detection efficiency for signal process;
σ^B: The measured Born cross section.



The cross sections of $e^+e^- \to \pi^+ D^0 D^{*-}$+c.c. (red dots) are consistent with but more precise than those from Belle measurement (blue dots).

$\sqrt{s}$	$\mathcal{L}$ (pb^{-1})	N^{obs}	$1+\delta^r$	$1+\delta^v$	ϵ (%)	σ^B (pb)
4.0855	52.6	18.8±5.8	0.725	1.06	30.05	39.6±12.3±3.2
4.1886	43.1	95.5±11.8	0.749	1.07	41.05	172.1±21.3±13.8
4.2077	54.6	191.3±16.1	0.754	1.07	41.73	265.3±22.4±21.2
4.2171	54.1	176.2±15.6	0.765	1.07	41.86	242.5±21.4±19.4
4.2263	1091.7	3885.3±71.7	0.786	1.07	43.25	249.9±4.6±14.5
4.2417	55.6	157.5±15.3	0.858	1.06	39.65	199.1±19.3±15.9
4.2580	825.7	1816.7±56.1	0.903	1.06	38.40	152.3±4.7±8.8
4.3079	44.9	162.6±16.1	0.813	1.06	40.11	267.9±26.5±21.4
4.3583	539.8	3788.2±79.7	0.787	1.05	44.14	488.6±10.3±29.3
4.3874	55.2	509.1±27.7	0.798	1.05	42.01	665.3±36.2±53.2
4.4156	1073.6	10899.1±142.4	0.821	1.05	42.71	698.4±9.1±41.2
4.4671	109.9	868.9±39.9	0.887	1.06	38.34	557.4±25.6±44.6
4.5271	110.0	745.8±39.1	0.931	1.06	36.46	480.0±25.2±38.4
4.5745	47.7	271.4±25.2	0.925	1.06	36.37	406.9±37.8±32.6
4.5995	566.9	3605.2±100.9	0.916	1.06	36.67	454.5±12.7±27.7

The first statistical, and the second ones systematic uncertainty.

Systematic uncertainties in the Born cross section of $e^+e^- \to \pi^+ D^0 D^{*-}$+c.c.

CME (GeV)	4.2263	4.2580	4.3583	4.4156	4.5995	Other
Tracking	3.0	3.0	3.0	3.0	3.0	3.0
PID	3.0	3.0	3.0	3.0	3.0	3.0
Luminosity	1.0	1.0	1.0	1.0	1.0	1.0
$\mathcal{B}(D^0 \to K^-\pi^+)$	1.0	1.0	1.0	1.0	1.0	1.0
$(1+\delta^{\rm r})\epsilon$	3.0	3.0	3.0	3.0	3.0	3.0
Fit Range	0.1	0.2	0.1	0.1	0.1	0.2
Signal Shape	0.1	1.5	0.8	1.5	2.1	2.1
Background Shape	0.4	0.2	0.2	0.1	0.1	0.4
D^0 mass window	0.3	0.1	0.4	0.2	0.7	0.7
D^{*-} mass window	0.2	0.1	0.2	0.3	0.3	0.3
Intermediate states	1.7	0.9	2.2	1.3	1.2	5.3
Sum in quadrature	5.8	5.8	6.0	5.9	6.1	8.0

Considering the large statistical fluctuations at the energy points ("Other") with low luminosities, we conservatively take the largest systematic uncertainties from five energy points with large luminosities.

Systematic uncertainties on the resonant parameters in $e^+e^- \to \pi^+ D^0 D^{*-}$

Source	$Y(4220)$		$Y(4390)$	
	M (MeV/c^2)	Γ_{tot} (MeV)	M (MeV/c^2)	Γ_{tot} (MeV)
Beam Uncertainty	– (1.0)	–	– (1.0)	–
Beam Spread	4225.1 (1.2)	65.7 (0.6)	4400.5 (1.2)	177.6 (0.4)
Uncertainty on cross section[1]	4224.8 (0.1)	72.3 (0.1)	4400.1 (0.1)	181.7 (0.1)
Uncertainty on cross section[2]	4228.5 (3.7)	71.6 (0.7)	4401.4 (1.3)	179.1 (7.4)
Total	4.0	0.9	2.1	7.4

* The uncertainty from cross section measurement is composed of two parts: the common uncertainties (Uncertainty on cross section[1]) and other uncertainties related to the fitting methods used to extract the signal yields and determine the detection efficiency (Uncertainty on cross section[2]).

$M(Y(4220))$ = (4224.8±5.6±4.0) MeV/c^2, $\Gamma(Y(4220))$ = (72.3±9.1±0.9) MeV.

$M(Y(4390))$ = (4400.1±9.3±2.1) MeV/c^2, $\Gamma(Y(4220))$ = (181.7±16.9±7.4) MeV.

Fit to $e^+e^- \to \pi^+\pi^-\pi^0$ cross sections

BESIII Preliminary

Parameters	PDG	This result
χ^2/NDF	-	443/390
m_ω (MeV/c^2)	782.65 ± 0.12	$783.20 \pm 0.07 \pm 0.23$
m_ϕ (MeV/c^2)	1019.46 ± 0.02	$1020.00 \pm 0.06 \pm 0.30$
$m_{\omega'}$ (MeV/c^2)	$1400 \sim 1450$	$1388 \pm 39 \pm 52$
$m_{\omega''}$ (MeV/c^2)	1670 ± 30	$1699 \pm 9 \pm 6$
Γ_ω (MeV/c^2)	8.49 ± 0.08	PDG
Γ_ϕ (MeV)	4.26 ± 0.04	PDG
$\Gamma_{\omega'}$ (MeV)	$180 \sim 250$	$629 \pm 155 \pm 212$
$\Gamma_{\omega''}$ (MeV)	315 ± 35	$331 \pm 40 \pm 28$
$(\mathcal{B}_{\omega\to e^+e^-} \times \mathcal{B}_{\omega\to 3\pi})$ (10^{-5})	6.49 ± 0.11	$6.94 \pm 0.08 \pm 0.17$
$(\mathcal{B}_{\phi\to e^+e^-} \times \mathcal{B}_{\phi\to 3\pi})$ (10^{-5})	4.53 ± 0.10	$4.20 \pm 0.08 \pm 0.17$
$(\mathcal{B}_{\omega'\to e^+e^-} \times \mathcal{B}_{\omega'\to 3\pi})$ (10^{-6})	0.82 ± 0.08	$0.84 \pm 0.09 \pm 0.09$
$(\mathcal{B}_{\omega''\to e^+e^-} \times \mathcal{B}_{\omega''\to 3\pi})$ (10^{-6})	1.30 ± 0.20	$1.14 \pm 0.15 \pm 0.15$
$\mathcal{B}_{J/\psi\to 3\pi}(\%)$	2.11 ± 0.07	$2.18 \pm 0.03 \pm 0.06$

Born cross section of $e^+e^- \to \Lambda_c^+\Lambda_c^-$

The Born cross section of mode i:

$$\sigma_i = \frac{N_i}{L \cdot \varepsilon_i \cdot f_{VP} \cdot f_{ISR} \cdot BR_i} \quad (2)$$

The total Born cross section:

$$\sigma = \sum_i w_i \sigma_i, \; w_i = (1/\Delta\sigma_i^2) \Big/ \left(\sum_i 1/\Delta\sigma_i^2 \right) \quad (3)$$

and corresponding uncertainty takes the form

$$\Delta\sigma^2 = \sum_{i,j} w_i (\mathbf{M}_\sigma)_{ij} w_j \quad (4)$$

or approximately

$$\Delta\sigma^2_{stat.} = \sum_{i,j} w_i (\mathbf{M}_\sigma^{stat.})_{ij} w_j \quad \text{and} \quad \Delta\sigma^2_{syst.} = \sum_{i,j} w_i (\mathbf{M}_\sigma^{syst.})_{ij} w_j, \quad (5)$$

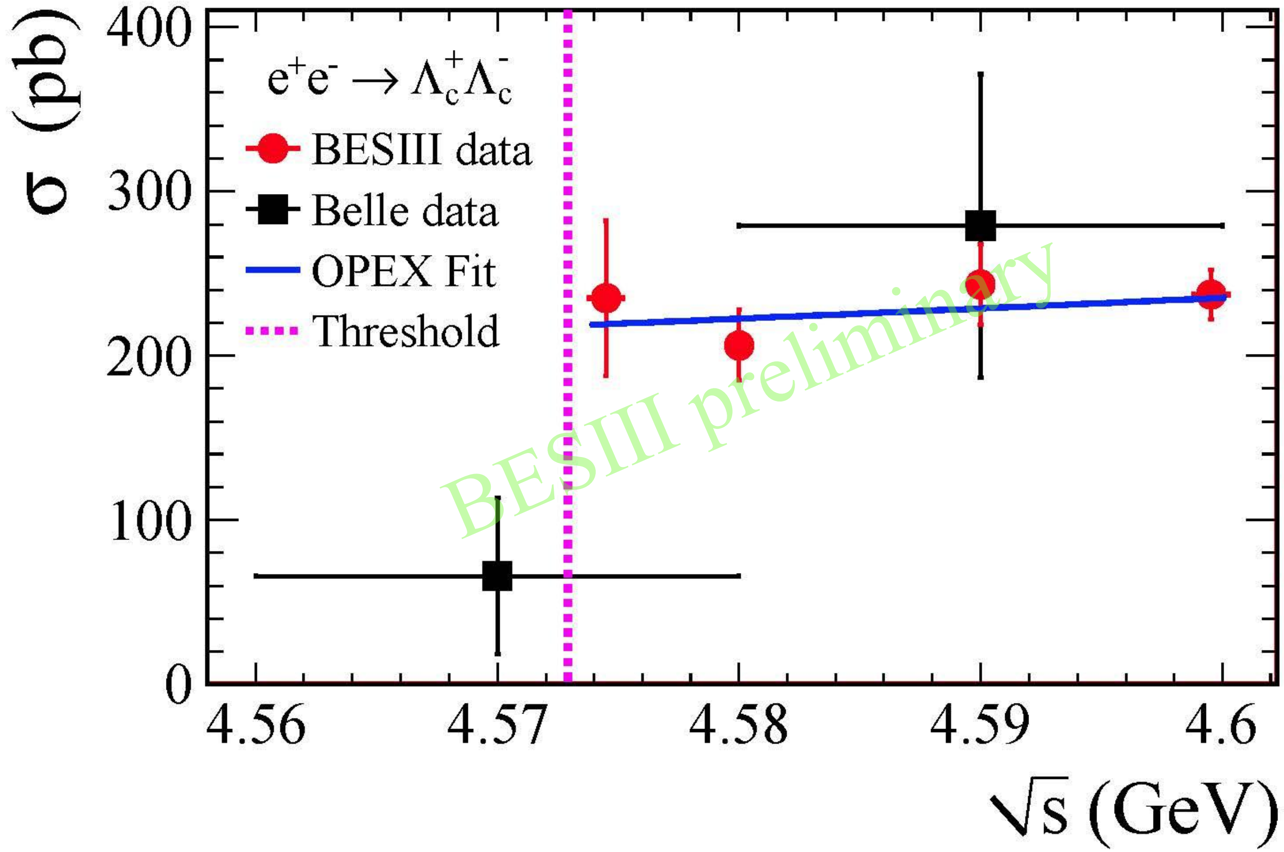
where the covariance matrix $\mathbf{M}_\sigma$ considered the correlation between all the individual measurements.

The calculated total Born cross sections:

$\sqrt{s}$ MeV	$L_{int.}$ (pb^{-1})	f_{ISR}	σ (pb)
4574.5	47.67	0.45	$235 \pm 11 \pm 46$
4580.0	8.545	0.66	$206 \pm 17 \pm 13$
4590.0	8.126	0.71	$243 \pm 19 \pm 15$
4599.5	566.9	0.74	$237 \pm 3 \pm 15$

Fit the cross section line-shape

The comparison and fit results of the line-shape:



- $|G_M|$ is supposed to be an unknown constant in this CMS energy region.
- The $|G_E/G_M|$ value of an arbitrary CMS energy is obtained from linear interpolation.
- $|G_M|$ is fitted to be 1.20 ± 0.03, the uncertainty includes statistical and systematic.

Cross Section for $e^+e^-\to DX$

Weimin Song
PhD thesis
IHEP, 2015

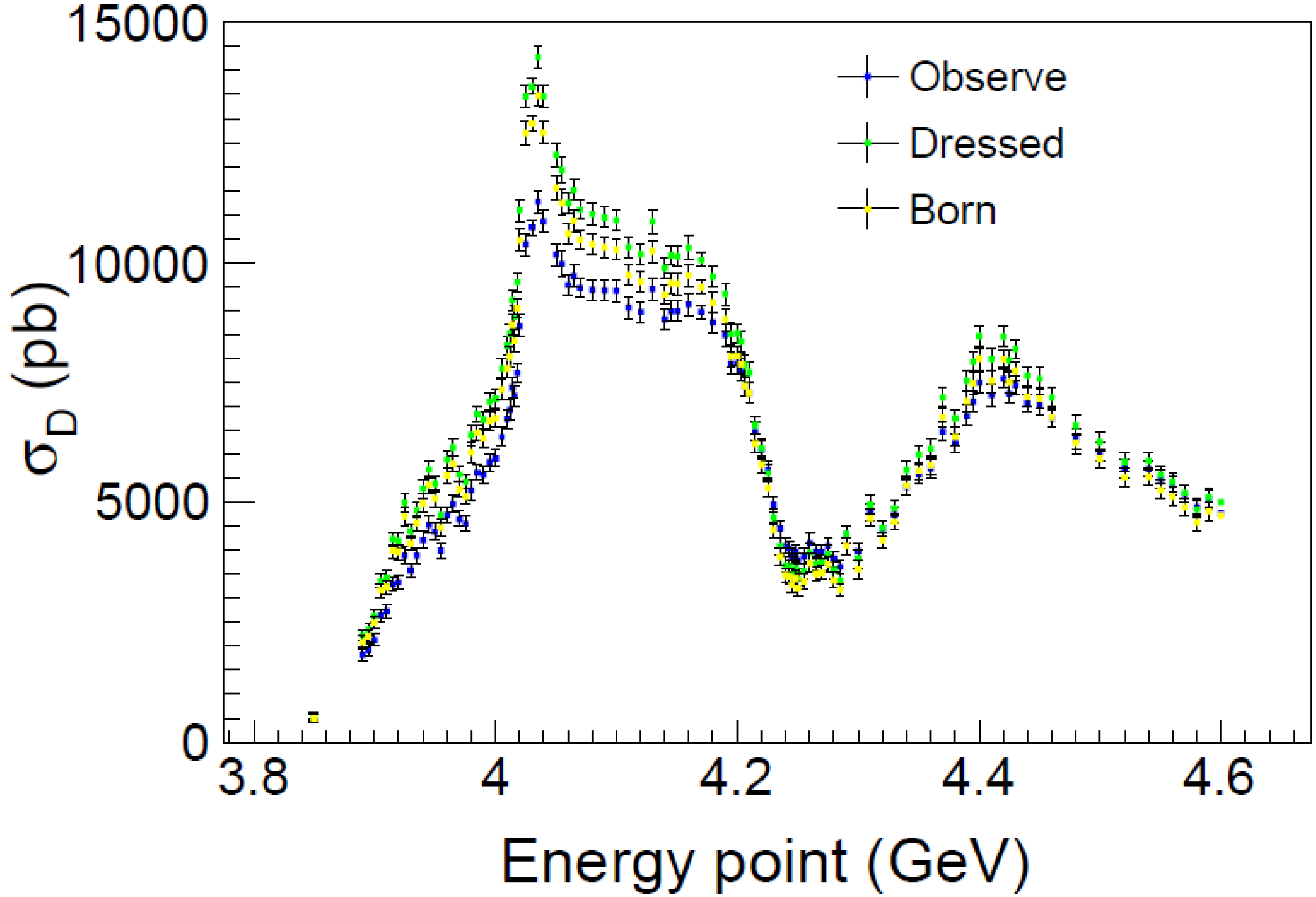


图 4.28: 含粲夸克末态的玻恩截面。

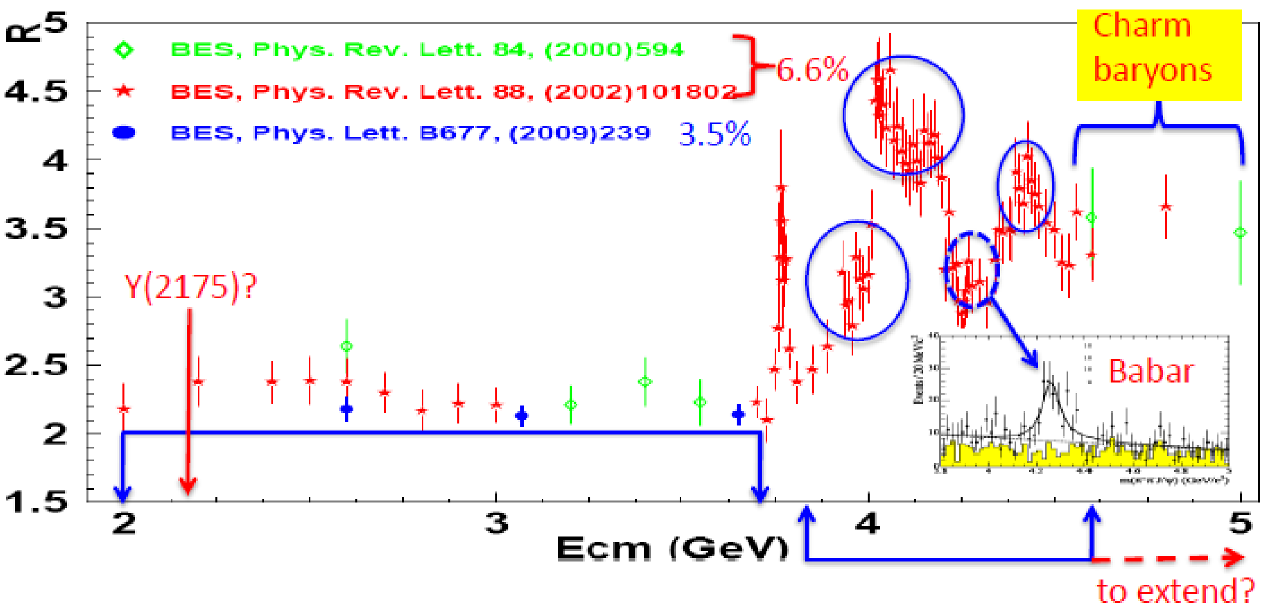
Status of R&QCD data taking

- Phase I: test run (2012)

  @ Ecm = 2.232, 2.400, 2.800, 3.400 GeV , 4 energy points, ~12/pb
- Phase II: fine scan for heavy charmonium line shape (2014)

  @ 3.800 – 4.590 GeV, 104 energy points, ~ 800/pb
- Phase III: R&QCD scan (2015)

  @ 2.000 – 3.080 GeV, 21 energy points, ~ 500/pb



R value line shape has scanned in whole BEPCII energies.

Present status of R value measurement

$$R = \frac{1}{\sigma_{\mu+\mu-}} \cdot \frac{N_{had} - N_{bg}}{L \cdot \varepsilon_{had} \cdot (1+\delta)}$$

N_{had} , N_{bg} $\rightarrow$ event selection:

below open charm finished, above open charm in progress.

L $\rightarrow$ integrated luminosity:

finished, error ~ 1%.

ε_{had} $\rightarrow$ hadronic generator, exclusive ⊕ LUARLW:

parameters are optimized, cross checks, largest error source?

$1+\delta$ $\rightarrow$ theoretical calculations:

finished, error ~1.5%, including the from $\Delta\sigma^0_{had}$

Error analysis:

$$\frac{\Delta R}{R} \cong \sqrt{(\frac{\Delta \tilde{N}_{had}}{\tilde{N}_{had}})^2 + (\frac{\Delta L}{L})^2 + (\frac{\Delta \epsilon_{trg}}{\epsilon_{trg}})^2 + (\frac{\Delta(1+\delta)}{(1+\delta)})^2}$$

- final goal $\Delta R/R$ ~2.5–3.0% [or better]

being reviewed with in BES Collaboration.