



# Measurement of $J/\psi$ parameters at BESIII

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# Outline

👉 **Motivation**

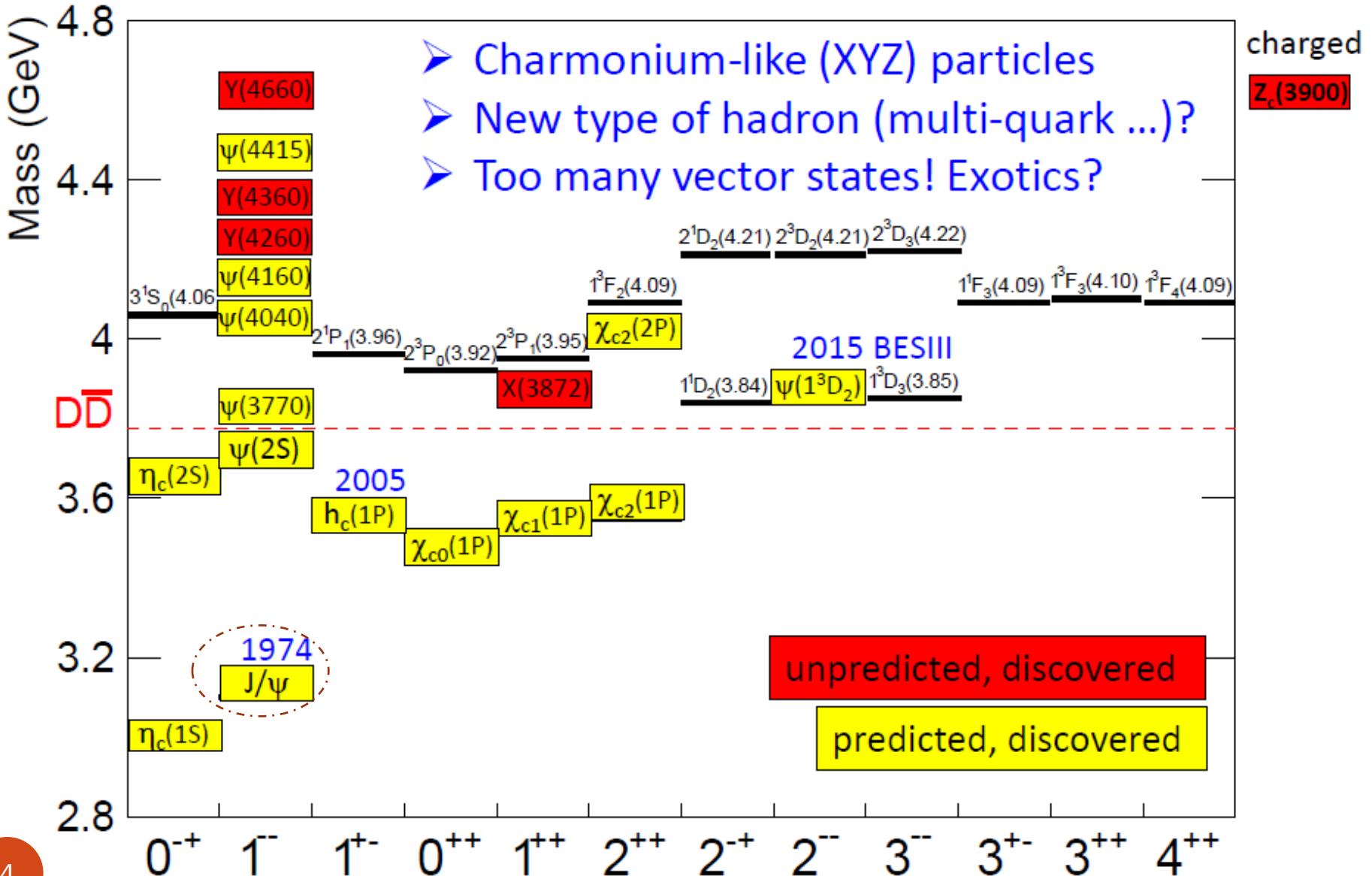
👉 **Experiment analysis**

👉 **Results**

👉 **Summary**

# Motivation

# Charmonium family



# Discovery of J/ $\psi$

“November Revolution of Particle Physics” in 1974.

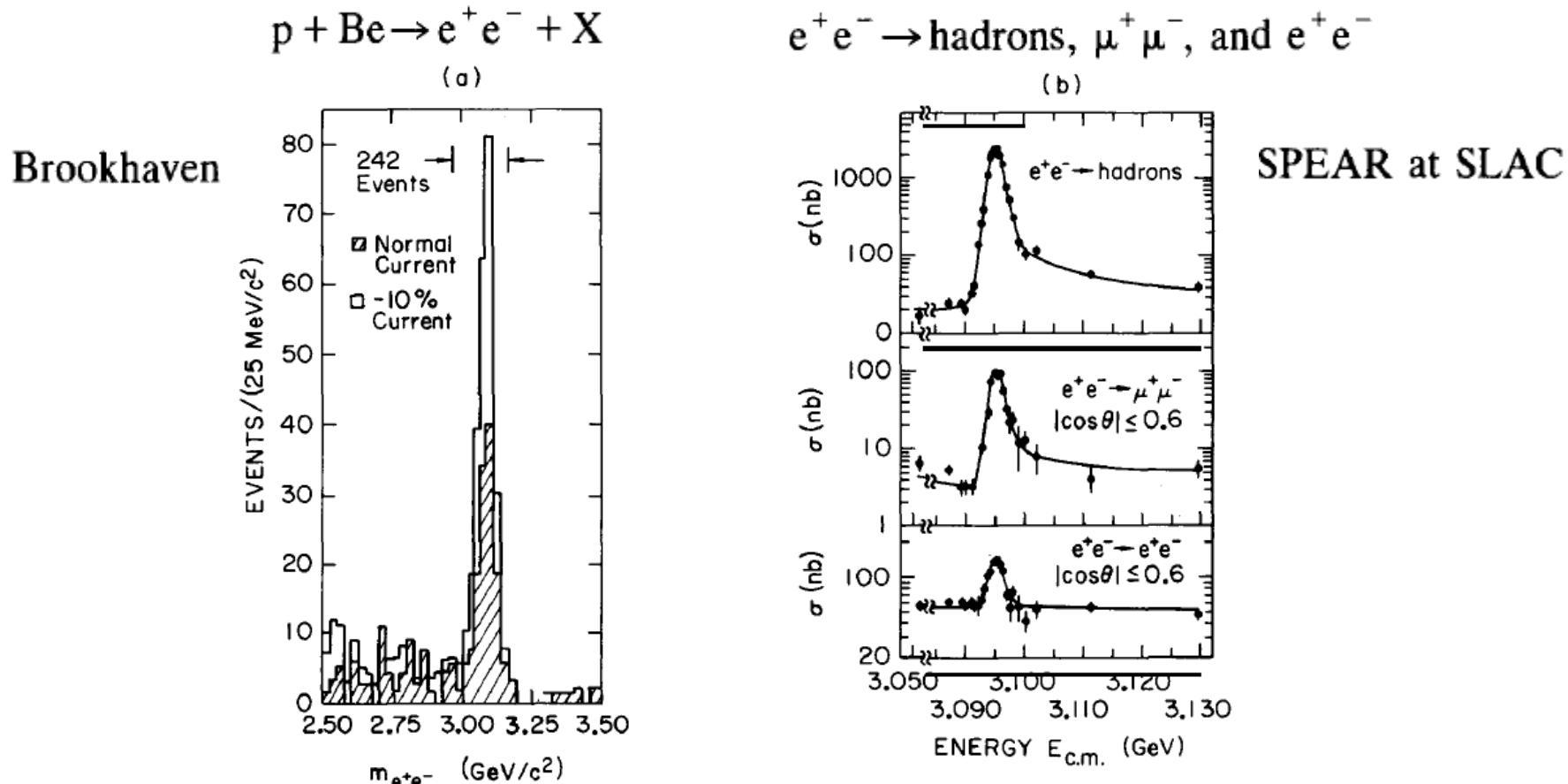


Fig. 1. Discovery of the J/ $\psi$  particle at BNL and at SLAC. (a) J discovery at BNL, showing the  $e^+ e^-$  invariant mass distribution of the reaction  $p + Be \rightarrow e^+ e^- + X$ . The unshaded area is the result after a deliberate 10% shift in the spectrometer momentum [6]. (b)  $\psi$  discovery at SLAC. A very strong rise of the cross sections for hadron,  $\mu\mu$ , and  $e^+ e^-$  final states is observed [7].

# Breit-Weigner form

- In quantum mechanics, unstable particle wave function

$$\psi(t) = \theta(t)\psi(0) \cdot e^{i\omega t} \cdot e^{-t/2\tau} = \theta(t)|\psi(0)|e^{i\delta} \cdot e^{-it(M-i\Gamma/2)}$$

- Transfer amplitude about time to function of energy (Fourier)

$$\mathcal{T}(W) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \psi(t) e^{iWt} dt = \frac{1}{\sqrt{2\pi}} \frac{i|\psi(0)|e^{i\delta}}{(W-M)+i\Gamma/2} \quad \int_0^{\infty} e^{-pt} dt = \frac{1}{p}, \quad (\text{Re } p > 0)$$

time-zero wave function  $|\Psi(0)|$  is determined by normalization condition

$$\mathcal{T} = \frac{1}{\sqrt{2\pi}} \frac{i\Gamma e^{i\delta}}{(W-M)+i\Gamma/2} = \frac{1}{\sqrt{2\pi}} \frac{i\sqrt{\Gamma \cdot \Gamma}}{(W-M)+i\Gamma/2} e^{i\delta}$$

- Consider initial state be  $e^+e^-$ , final state be  $f$  channel

$$\mathcal{T}^f = \frac{1}{\sqrt{2\pi}} \frac{i\sqrt{B_r^e \Gamma \cdot B_r^f \Gamma}}{(W-M)+i\Gamma/2} e^{i\delta} = \frac{1}{\sqrt{2\pi}} \frac{i\sqrt{\Gamma^e \Gamma^f}}{(W-M)+i\Gamma/2} e^{i\delta}$$

- In relativity, negative energy state should be included

$$\begin{aligned} \mathcal{T}^f &= \frac{1}{\sqrt{2\pi}} \left[ \frac{i\sqrt{\Gamma^e \cdot \Gamma^f}}{W-M+i\Gamma/2} + \frac{i\sqrt{\Gamma^e \cdot \Gamma^f}}{-W-M+i\Gamma/2} \right] e^{i\delta} \\ &= \frac{1}{\sqrt{2\pi}} \frac{i2M\sqrt{\Gamma^e \Gamma^f}}{W^2 - M^2 + i\Gamma M} e^{i\delta} \end{aligned}$$

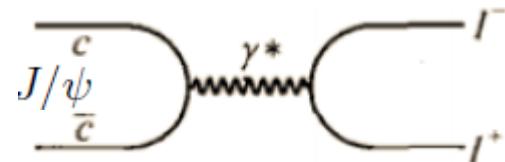
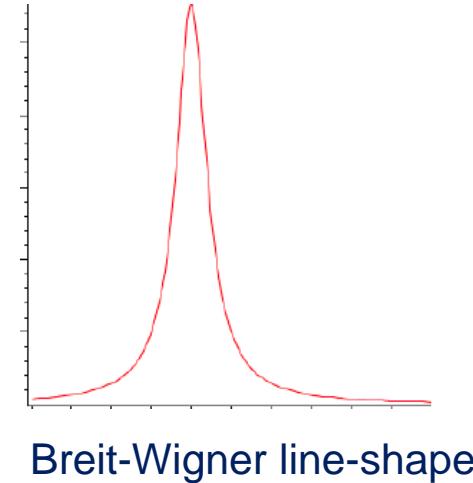
# Three basic parameters

- J/ $\psi$  production and decay cross section

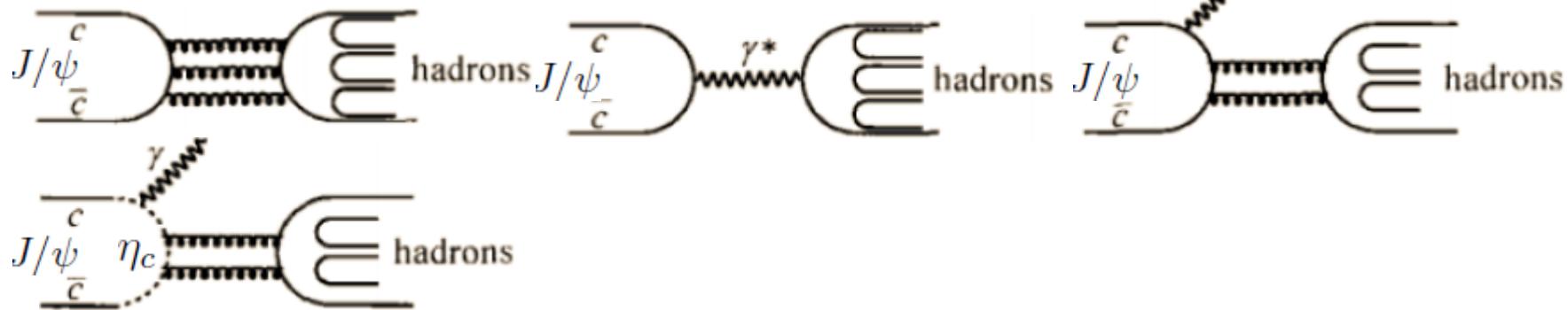
$$e^+ e^- \rightarrow J/\psi \rightarrow X$$

$$\sigma_B^X(s) = \frac{12\pi\Gamma_{ee}\Gamma_X}{(s - M^2)^2 + M^2\Gamma_{tot}^2}$$

- J/ $\psi$  decay modes



X: leptons, hadrons, (photon)



- Breit-Wigner parameters

# Theory predictions of the parameters

## ➤ Mass

Non-relativistic Schrodinger equation + potential model

$$[-\frac{\hbar^2}{2\mu} \frac{d^2}{dr^2} + \frac{l(l+1)\hbar^2}{2\mu r^2} + V(r)]u_{n,l}(r) = E(n, l)u_{n,l}(r)$$

$$V(r) = -\frac{\kappa}{r} + \frac{r}{a^2}$$

Cornell potential

PHYSICAL REVIEW D VOLUME 21, NUMBER 1 1 JANUARY 1980

State	Mass (GeV)	$\Gamma_{ee}$ (keV) <sup>b</sup>	$\left\langle \frac{v^2}{c^2} \right\rangle$	$\langle r^2 \rangle^{1/2}$ (fm)	Candidate	
1S	3.095 <sup>a</sup>	4.8	0.20	0.47	$\psi(3095)$	$m_c = 1.84 \text{ GeV},$
1P	3.522 <sup>a</sup>		0.20	0.74	$\chi_{0,1,2}(3522 \pm 5)$	$a = 2.34 \text{ GeV}^{-1},$
2S	3.684 <sup>a</sup>	2.1	0.24	0.96	$\psi'(3684)$	
1D	3.81		0.23	1.0	$\psi'(3772)^c$	$\kappa = 0.52,$
3S	4.11	1.5	0.30	1.3	$\psi(4028)$	
2D	4.19		0.29	1.35	$\psi(4160)^d$	
4S	4.46	1.1	0.35	1.7	$\psi(4414)$	
5S	4.79	0.8	0.40	2.0		$\lambda = \kappa(m_c a)^{2/3} = 1.37$

### states

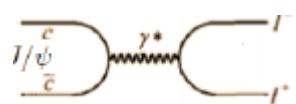
	Cornell	Experiment
1 s	3.068	3.067 5
2 s	3.697	3.663
3 s	4.144	4.159 <sup>*</sup>
4 s		
1 p	3.526	
2 p	3.993	
3 p	4.383	
1 d	3.829	
2 d	4.234	

# Theory predictions of basic parameters

## ► Widths

- perturbative QCD using lowest-order expressions
- first-order QCD corrections

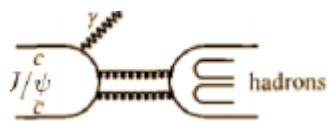
PHYSICS REPORTS (Review Section of Physics Letters) 174  
Nos. 2 & 3 (1989) 67–227. North-Holland, Amsterdam



$$\Gamma(J/\psi \rightarrow \ell^+ \ell^-) = \frac{16}{3} \pi \alpha^2 e_c^2 N_c \frac{|\Psi(0)|^2}{M_\psi^2} (1 - \frac{16}{3} \alpha_s / \pi)$$



$$\begin{aligned}\Gamma(J/\psi \rightarrow ggg) &= \frac{40}{81} (\pi^2 - 9) \alpha_s^3 \frac{|\Psi(0)|^2}{m_c^2} (1 + 4.9 \alpha_s / \pi) \\ &= \frac{5}{18\pi} (\pi^2 - 9) \frac{\alpha_s^3}{\alpha^2} \Gamma(J/\psi \rightarrow \ell^+ \ell^-) (1 + 10.3 \alpha_s / \pi) \approx 5 \text{ keV}\end{aligned}$$



$$\Gamma(J/\psi \rightarrow \gamma gg) = \frac{32}{9} (\pi^2 - 9) \alpha_s^2 \alpha e_c^2 \frac{|\Psi(0)|^2}{m_c^2} (1 - 0.9 \alpha_s / \pi)$$



$$\Gamma(J/\psi \rightarrow \gamma \eta_c) = (940 \pm 285) \text{ eV}$$



$$\Gamma_{\text{elm}}(J/\psi \rightarrow q\bar{q}) = 3 \sum e_q^2 \cdot \Gamma(J/\psi \rightarrow \ell^+ \ell^-) = (10.2 \pm 0.6) \text{ keV}$$

$$\frac{\Gamma(J/\psi \rightarrow \gamma gg)}{\Gamma(J/\psi \rightarrow ggg)} = \frac{16}{5} (\alpha / \alpha_s) (1 - 5.8 \alpha_s / \pi) \approx 10.3\%$$

$$\Gamma_{\text{elm}}(J/\psi \rightarrow \text{hadrons}) = R(\text{off-resonance}) \Gamma(J/\psi \rightarrow e^+ e^-) = (13.2 \pm 1.1) \text{ keV}$$

# Measurement values of basic parameters

(PDG2016)

$J/\psi(1S)$

$I^G(J^{PC}) = 0^-(1^- -)$

## $J/\psi(1S)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
<b>3096.900 ± 0.006 OUR AVERAGE</b>				
3096.66 ± 0.19 ± 0.02	6.1k	<sup>1</sup> AAIJ	15BI	LHCb $p p \rightarrow J/\psi X$
3096.900 ± 0.002 ± 0.006		<sup>2</sup> ANASHIN	15	KEDR $e^+ e^- \rightarrow$ hadrons
3096.89 ± 0.09	502	<sup>3</sup> ARTAMONOV	00	OLYA $e^+ e^- \rightarrow$ hadrons
3096.91 ± 0.03 ± 0.01		<sup>4</sup> ARMSTRONG	93B	E760 $\bar{p}p \rightarrow e^+ e^-$
3096.95 ± 0.1 ± 0.3	193	BAGLIN	87	SPEC $\bar{p}p \rightarrow e^+ e^- X$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
3096.917 ± 0.010 ± 0.007		AULCHENKO	03	KEDR $e^+ e^- \rightarrow$ hadrons
3097.5 ± 0.3		GRIBUSHIN	96	FMPS 515 $\pi^- Be \rightarrow 2\mu X$
3098.4 ± 2.0	38k	LEMOIGNE	82	GOLI 185 $\pi^- Be \rightarrow \gamma\mu^+\mu^- A$
3096.93 ± 0.09	502	<sup>5</sup> ZHOLENTZ	80	REDE $e^+ e^-$
3097.0 ± 1		<sup>6</sup> BRANDELIK	79c	DASP $e^+ e^-$

## $J/\psi(1S)$ WIDTH

VALUE (keV)	EVTS	DOCUMENT ID	TECN	COMMENT
<b>92.9 ± 2.8 OUR AVERAGE</b> Error includes scale factor of 1.1.				
96.1 ± 3.2	13k	<sup>1</sup> ADAMS	06A	CLEO $e^+ e^- \rightarrow \mu^+ \mu^- \gamma$
84.4 ± 8.9		BAI	95B	BES $e^+ e^-$
91 ± 11 ± 6		<sup>2</sup> ARMSTRONG	93B	E760 $\bar{p}p \rightarrow e^+ e^-$
85.5 ± 6.1 5.8		<sup>3</sup> HSUEH	92	RVUE See $\gamma$ mini-review
• • • We do not use the following data for averages, fits, limits, etc. • • •				
94.1 ± 2.7		<sup>4</sup> ANASHIN	10	KEDR $3.097 e^+ e^- \rightarrow e^+ e^-, \mu^+ \mu^-$
93.7 ± 3.5	7.8k	<sup>1</sup> AUBERT	04	BABR $e^+ e^- \rightarrow \mu^+ \mu^- \gamma$

# Measurement values of basic parameters

## $J/\psi(1S)$ PARTIAL WIDTHS

(PDG2016)

### $\Gamma(\text{hadrons})$

VALUE (keV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
74.1 $\pm$ 8.1	BAI	95B	BES $e^+e^-$
59 $\pm$ 24	BALDINI...	75	FRAG $e^+e^-$
59 $\pm$ 14	BOYARSKI	75	MRK1 $e^+e^-$
50 $\pm$ 25	ESPOSITO	75B	FRAM $e^+e^-$

### $\Gamma(e^+e^-)$

VALUE (keV)	EVTS	DOCUMENT ID	TECN	COMMENT
<b>5.55 <math>\pm</math> 0.14 <math>\pm</math> 0.02 OUR EVALUATION</b>				
• • • We do not use the following data for averages, fits, limits, etc. • • •				
5.71 $\pm$ 0.16	13k	1 ADAMS	06A	CLEO $e^+e^- \rightarrow \mu^+\mu^-\gamma$
5.57 $\pm$ 0.19	7.8k	1 AUBERT	04	BABR $e^+e^- \rightarrow \mu^+\mu^-\gamma$
5.14 $\pm$ 0.39		BAI	95B	BES $e^+e^-$
5.36 $^{+0.29}_{-0.28}$		2 HSUEH	92	RVUE See $\tau$ mini-review
4.72 $\pm$ 0.35		ALEXANDER	89	RVUE See $\tau$ mini-review
4.4 $\pm$ 0.6		2 BRANDELIK	79c	DASP $e^+e^-$
4.6 $\pm$ 0.8		3 BALDINI...	75	FRAG $e^+e^-$
4.8 $\pm$ 0.6		BOYARSKI	75	MRK1 $e^+e^-$
4.6 $\pm$ 1.0		ESPOSITO	75B	FRAM $e^+e^-$

### $\Gamma(\mu^+\mu^-)$

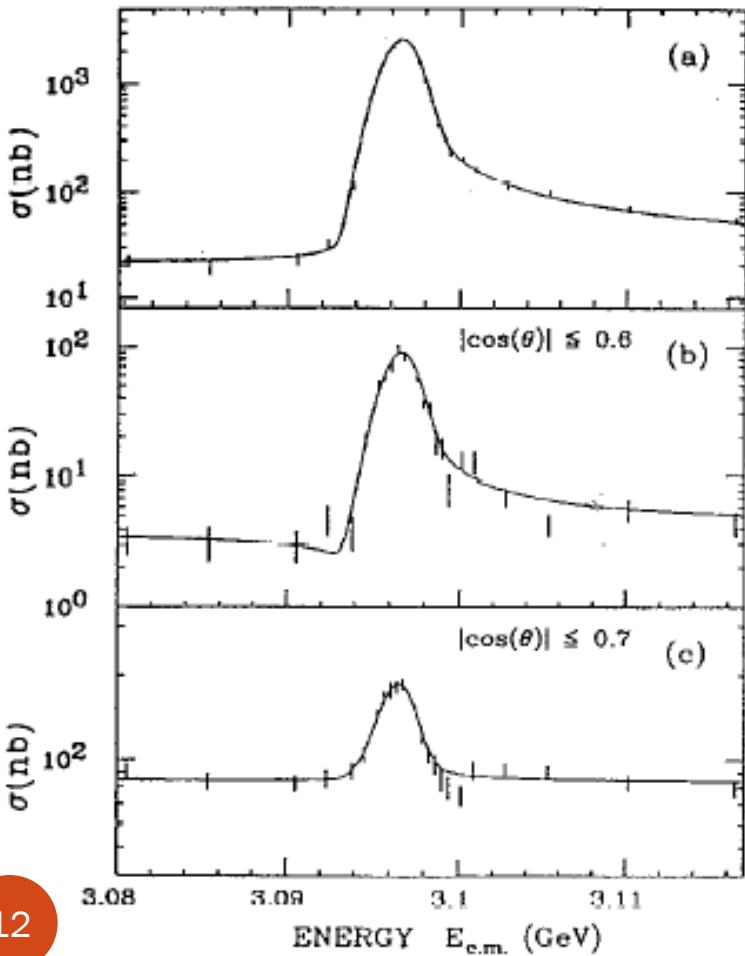
VALUE (keV)	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •			
5.13 $\pm$ 0.52	BAI	95B	BES $e^+e^-$
4.8 $\pm$ 0.6	BOYARSKI	75	MRK1 $e^+e^-$
5 $\pm$ 1	ESPOSITO	75B	FRAM $e^+e^-$

# J/ $\psi$ parameters measurement at BESII

Phys. Lett. B355 (1995)

Energy points: 23

Total luminosity: 82.28/nb



Channels analyzed:

- $e^+ e^- \rightarrow \text{hadrons}$
- $e^+ e^- \rightarrow J/\psi \rightarrow \text{hadrons}$
- $e^+ e^- \rightarrow e^+ e^-$
- $e^+ e^- \rightarrow J/\psi \rightarrow e^+ e^-$
- $e^+ e^- \rightarrow \mu^+ \mu^-$
- $e^+ e^- \rightarrow J/\psi \rightarrow \mu^+ \mu^-$

Results:

$\Gamma$	$84.4$	$\pm 8.9$	keV
$\Gamma_h$	$74.1$	$\pm 8.1$	keV
$\Gamma_e$	$5.14$	$\pm 0.39$	keV
$\Gamma_\mu$	$5.13$	$\pm 0.52$	keV
$\Gamma_h/\Gamma$	$0.878$	$\pm 0.005$	
$\Gamma_e/\Gamma$	$0.0609$	$\pm 0.0033$	
$\Gamma_\mu/\Gamma$	$0.0608$	$\pm 0.0033$	
$\Gamma_e/\Gamma_\mu$	$1.00$	$\pm 0.07$	

Maximum error : 11%

# J/ $\psi$ parameters measurement at KEDR

arXiv:0912.1082v2 [hep-ex] 25 Jan 2010

Measurement of  $\Gamma_{ee}(J/\psi) \cdot \mathcal{B}(J/\psi \rightarrow e^+e^-)$  and  $\Gamma_{ee}(J/\psi) \cdot \mathcal{B}(J/\psi \rightarrow \mu^+\mu^-)$

$$\Gamma_{ee} \times \Gamma_{ee} / \Gamma = 0.3323 \pm 0.0064 \text{ (stat.)} \pm 0.0048 \text{ (syst.) keV,}$$

$$\Gamma_{ee} \times \Gamma_{\mu\mu} / \Gamma = 0.3318 \pm 0.0052 \text{ (stat.)} \pm 0.0063 \text{ (syst.) keV.}$$

$$\Gamma_{ee} \times (\Gamma_{ee} + \Gamma_{\mu\mu}) / \Gamma = 0.6641 \pm 0.0082 \text{ (stat.)} \pm 0.0100 \text{ (syst.) keV,}$$

$$\Gamma_{ee} / \Gamma_{\mu\mu} = 1.002 \pm 0.021 \text{ (stat.)} \pm 0.013 \text{ (syst.)}$$

$$\Gamma_{\ell\ell} = 5.59 \pm 0.12 \text{ keV}$$

$$\Gamma = 94.1 \pm 2.7 \text{ keV}$$

$\sigma_{\text{obs}}$ , nb

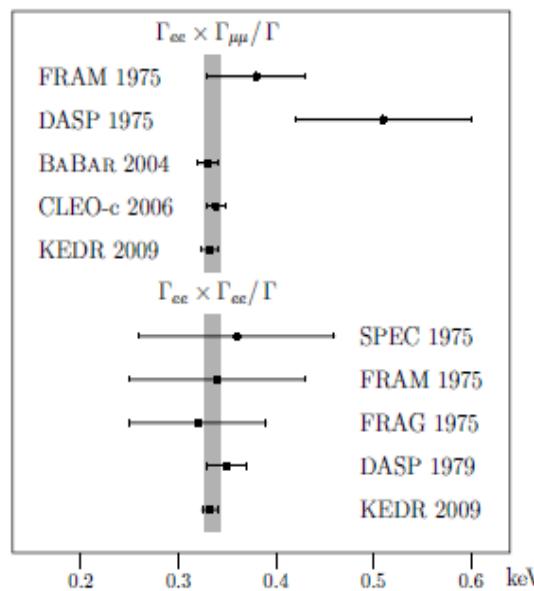
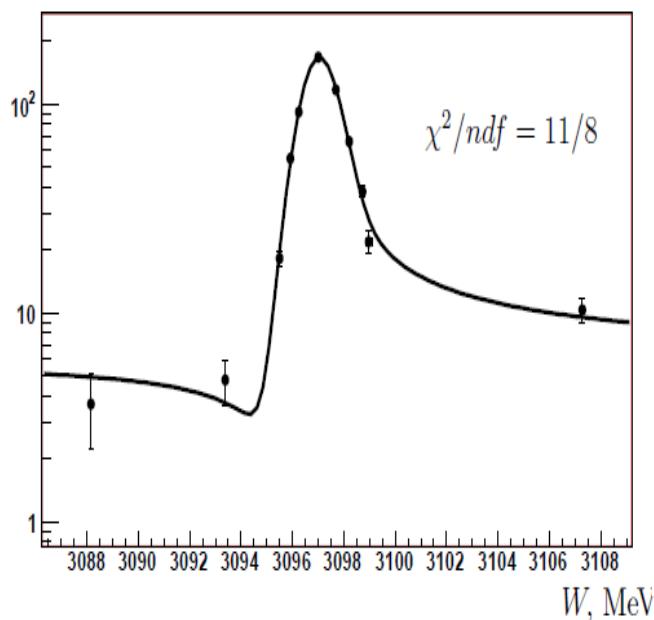


Table 1: Systematic uncertainties in  $\Gamma_{ee} \times \Gamma_{ee} / \Gamma$ .

Systematic uncertainty source	Error, %
Luminosity monitor instability	0.8
Offline event selection	0.7
Trigger efficiency	0.5
Energy spread accuracy	0.2
Beam energy measurement (10–30 keV)	0.3
Fiducial volume cut	0.2
Calculation of radiative corrections	0.2
Cross section for Bhabha (MC generators)	0.4
Final state radiation (PHOTOS)	0.4
Background from $J/\psi$ decays	0.2
Fitting procedure	0.2
<b>Total</b>	<b>1.4</b>

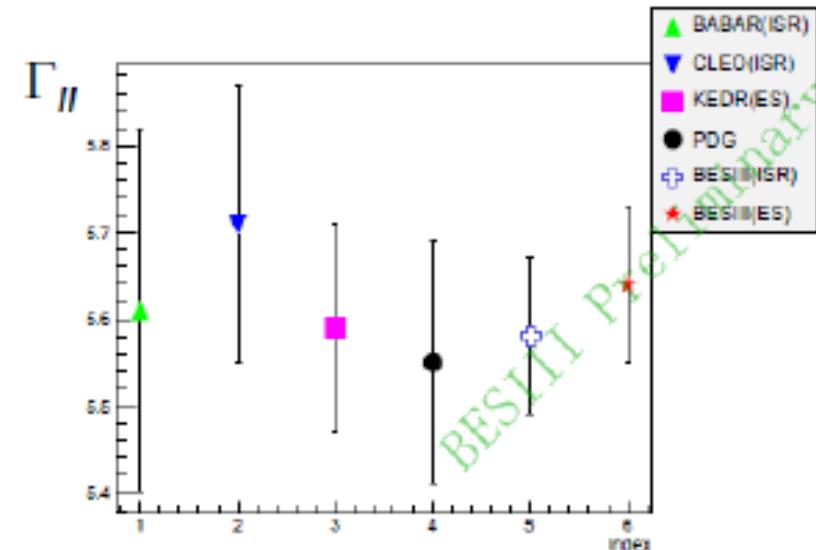
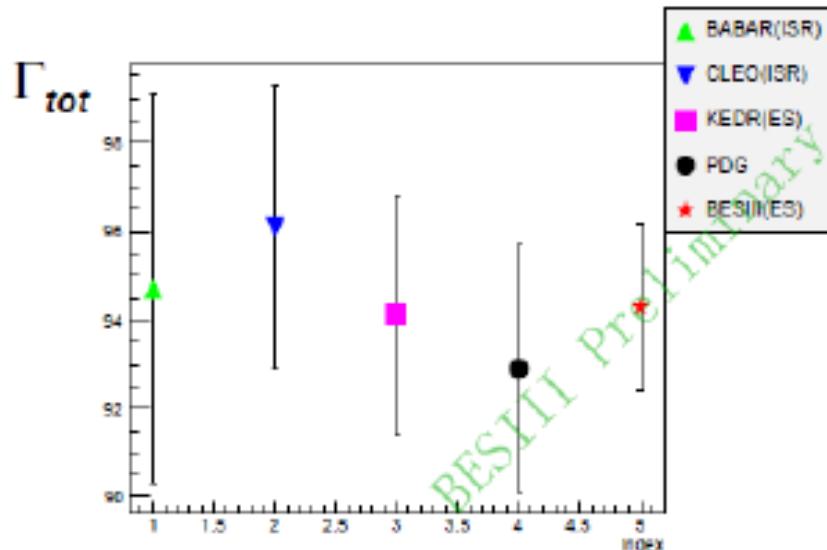
Table 2: Systematic uncertainties in  $\Gamma_{ee} \times \Gamma_{\mu\mu} / \Gamma$ .

Systematic uncertainty source	Error, %
Luminosity monitor instability	0.8
Absolute luminosity calibration by $e^+e^-$ data	1.2
Trigger efficiency	0.5
Energy spread accuracy	0.4
Beam energy measurement (10–30 keV)	0.5
Fiducial volume cut	0.2
Calculation of radiative corrections	0.2
Final state radiation (PHOTOS)	0.5
Nonresonant background	0.1
Background from $J/\psi$ decays	0.6
<b>Total</b>	<b>1.9</b>

# The published results

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

This talk



# Experiment analysis

# Energy calibration of J/ $\psi$ scan

## ► Fast scan and fit

Results ① — using BEPC energy values:

FCN= 54.10758 FROM MIGRAD STATUS=CONVERGED 63 CALLS 1098 TOTAL  
EDM= 0.11E-05 STRATEGY=1 ERROR MATRIX UNCERTAINTY= 0.1%

EXT PARAMETER STEP FIRST

NO. NAME VALUE ERROR SIZE DERIVATIVE

1 MASS 3.0965 0.42408E-06 0.26873E-06 0.0

2 WDEE 0.55500E-05 constant

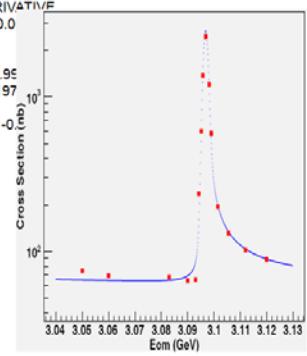
3 WDTE 0.92900E-04 constant

4 CO 10.225 0.21869 0.32998E-04 0.95

5 C1 -1.00000 1.9982 -0.11375E-01 -0.197

6 C2 0.0000 constant

7 ESPD 0.84166E-03 0.22302E-04 0.15006E-03 -0.0



$$M_{J/\psi} = 3096.5 \text{ MeV}$$

$$\sigma_{Ecm} = 0.8417 \pm 0.0223 \text{ MeV}$$

$$\Delta M = M_{J/\psi} - M_{PDG} = -0.4 \text{ MeV}$$

$$\Delta E_{cm} = M_{\psi}^{FIT} - M_{\psi}^{PDG}$$

$$E_{cm}^{reset} = E_{cm}^{preset} + \Delta E_{cm}$$

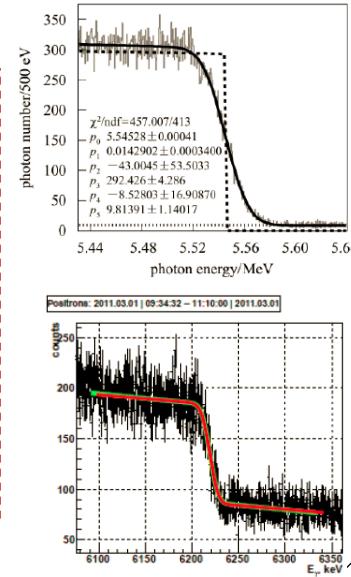
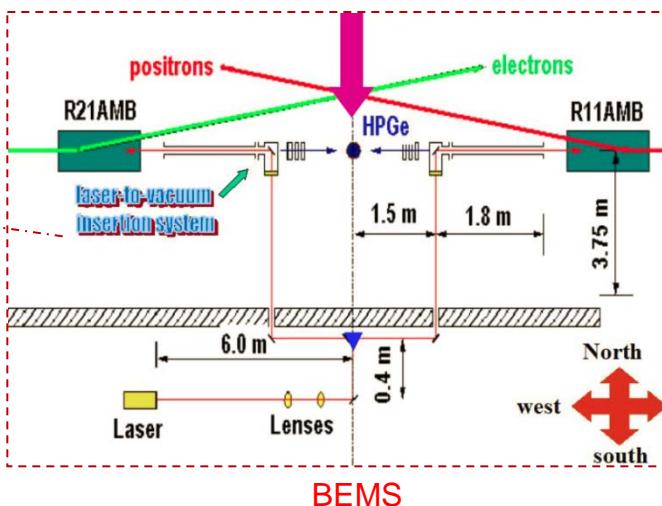
$$\Delta E_{beam} = \Delta E_{cm}/2$$

$$E_{beam}^{reset} = E_{beam}^{preset} + \Delta E_{beam}$$

15 energy points and luminosities

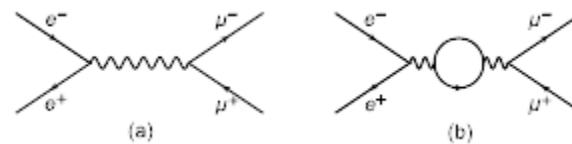
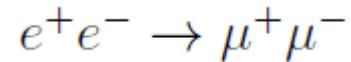
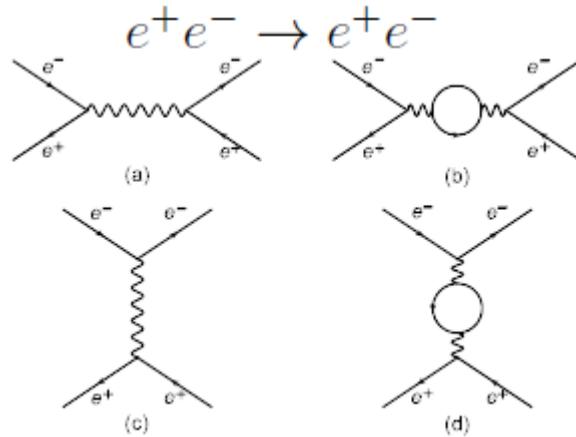
Prop. $\sqrt{s}$ (GeV)	BEMS $\sqrt{s}$ (GeV)	Int. $L$ ( $\text{pb}^{-1}$ )
3.0500	$3.050206 \pm 0.000026$	$14.919 \pm 0.161$
3.0600	$3.059257 \pm 0.000028$	$15.060 \pm 0.161$
3.0830	$3.083060 \pm 0.000023$	$4.769 \pm 0.055$
3.0900	$3.089418 \pm 0.000022$	$15.558 \pm 0.165$
3.0930	$3.092324 \pm 0.000025$	$14.910 \pm 0.160$
3.0943	$3.095261 \pm 0.000084$	$2.143 \pm 0.025$
3.0952	$3.095994 \pm 0.000081$	$1.816 \pm 0.021$
3.0958	$3.096390 \pm 0.000075$	$2.135 \pm 0.025$
3.0969	$3.097777 \pm 0.000076$	$2.069 \pm 0.026$
3.0982	$3.098904 \pm 0.000075$	$2.203 \pm 0.025$
3.0990	$3.099606 \pm 0.000093$	$0.756 \pm 0.011$
3.1015	$3.101923 \pm 0.000106$	$1.612 \pm 0.021$
3.1055	$3.106144 \pm 0.000090$	$2.106 \pm 0.025$
3.1120	$3.112615 \pm 0.000093$	$1.720 \pm 0.021$
3.1200	$3.120442 \pm 0.000115$	$1.264 \pm 0.016$

## ► BEMS calibration



# Event selection

## ► Signal events



## ► Signal events selections

- |  |  |  |  |
|--|--|--|--|
| <p>event level</p> <ul style="list-style-type: none"><li>• <math>N_{\text{chrgds}} = 2</math></li><li>• <math>\sum_{i=1}^2 Chrg_i = 0</math></li></ul> | <p>event level</p> <ul style="list-style-type: none"><li>• <math>N_{\text{chrgds}} = 2</math></li><li>• <math>\sum_{i=1}^2 Chrg_i = 0</math></li><li>• <math>N_{\text{ntrs}} = 0</math></li><li>• <math> Tof_1 - Tof_2  &lt; 1.5 \text{ ns}</math></li></ul> | <p>tracking level</p> <ul style="list-style-type: none"><li>• <math> V_r  &lt; 1 \text{ cm},  V_z  &lt; 10 \text{ cm}</math></li><li>• <math> \cos \theta  &lt; 0.8</math></li><li>• <math>P &gt; 0.7 E_{\text{beam}}</math></li><li>• <math>E/P &gt; 0.6</math></li></ul> | <p>tracking level</p> <ul style="list-style-type: none"><li>• <math> V_r  &lt; 1 \text{ cm},  V_z  &lt; 10 \text{ cm}</math></li><li>• <math> \cos \theta  &lt; 0.8</math></li><li>• <math>P &gt; 0.8 E_{\text{beam}}</math></li><li>• <math>0 &lt; E/P &lt; 0.25</math></li><li>• <math>Tof &gt; 0</math></li></ul> |
|--|--|--|--|

# Monte Carlo event generators

## ► Functions of MC generators

- optimize event selection criteria
- determine detection efficiencies
- correct detector simulation bias

## ► MC generators

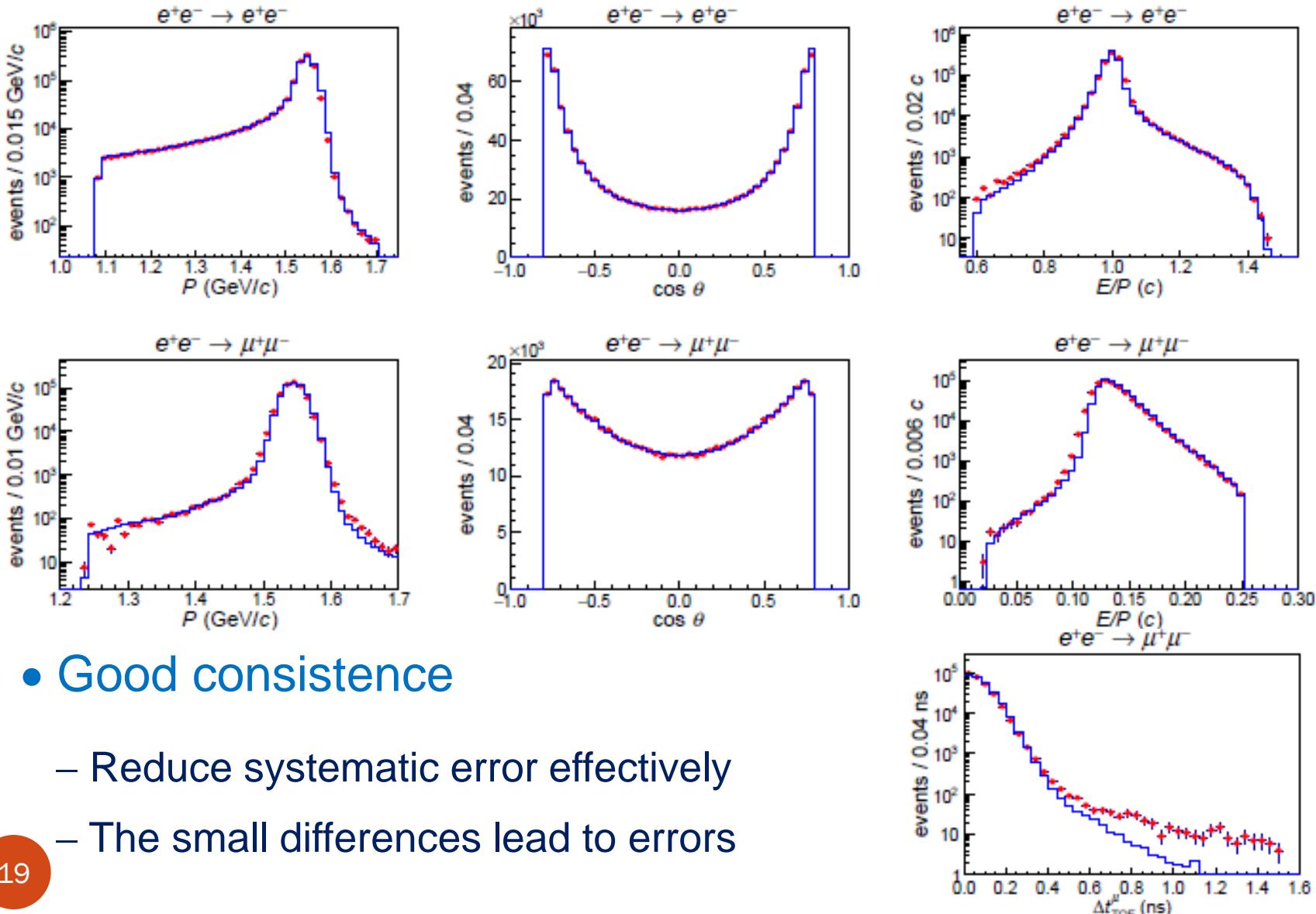
	processes	MC generators	N <sub>event</sub>	θ ranges (°)
Signals	$e^+ e^- \rightarrow e^+ e^-$	Babayaga-3.5	5000000	34-146
	$e^+ e^- \rightarrow \mu^+ \mu^-$	Babayaga-3.5	5000000	34-146
BGs	$e^+ e^- \rightarrow \text{hadrons}$	ConExc	500000	0-180
	$e^+ e^- \rightarrow \gamma\gamma$	Babayaga-3.5	500000	20-160
	$e^+ e^- \rightarrow e^+ e^- \gamma^* \gamma^*$	BesTwogam	500000	0-180

### Model precisions

- Babayaga ~ 0.5%
- BES Twogam ~ 1%
- ConExc ~ 3%

# Comparisons between Monte Carlo

- The distributions related to event selections



- Good consistence

- Reduce systematic error effectively
- The small differences lead to errors

# Cross sections measured with data

- Original experiment formula

$$\sigma = \frac{N_{\text{sig}} - N_{\text{bkgs}}}{L \cdot \epsilon_{\text{trg}} \cdot \epsilon_{\text{recsel}}}$$

- Correction to the imperfection of detector simulations

$$\sigma = \frac{N_{\text{sig}} - N_{\text{bkgs}}}{L \cdot \epsilon_{\text{trg}} \cdot \epsilon_{\text{recsel}}} \cdot f \quad \leftarrow \text{correction factor}$$

- Cause tracking and event reconstruction efficiency bias for data and MC
- Bias can be corrected bin-to-bin for MDC and EMC by

$$f = \frac{N_{\text{obs}}^{\text{MC}}}{\sum_m \sum_n N_{\text{obs}}^{\text{MC}}(m, n) \cdot \frac{\epsilon_{\text{trk}}^{\text{data}}(m)}{\epsilon_{\text{trk}}^{\text{MC}}(m)} \cdot \frac{\epsilon_{\text{trk}}^{\text{data}}(n)}{\epsilon_{\text{trk}}^{\text{MC}}(n)} \cdot \frac{\epsilon_{\text{clst}}^{\text{data}}(m)}{\epsilon_{\text{clst}}^{\text{MC}}(m)} \cdot \frac{\epsilon_{\text{clst}}^{\text{data}}(n)}{\epsilon_{\text{clst}}^{\text{MC}}(n)}}$$

\* Meanings of the symbols explained in the BES memo/draft

# Cross sections calculated by theory

- Structure function scheme

- Vacuum polarization
- Initial state radiation (ISR)
- Final state radiation (FSR)
- Interferences

$$\sigma(s) = \int_0^X \frac{d\bar{\sigma}}{d\Omega}(s(1-x), \cos\theta) F(s, x) dx d\Omega$$

- Beam energy spread considered

$$\sigma(W) = \int \sigma_0(W_0) \left( \frac{1}{\sqrt{2\pi}\sigma_W} e^{-\frac{(W_0-W)^2}{2\sigma_W^2}} \right) dW_0$$

- Five parameters to be determined

$$M, \quad \Gamma_{tot}, \quad \Gamma_{ee}, \quad \Gamma_{\mu\mu}, \quad \sigma_W$$

- Instead 5 free values in fit
- But 4 combinations

$$M \quad \Gamma_{ee}\Gamma_{ee}/\Gamma_{tot} \quad \Gamma_{ee}\Gamma_{\mu\mu}/\Gamma_{tot} \quad \sigma_W$$

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Analytic forms for cross sections of di-lepton production from  $e^+e^-$  collisions around the  $J/\psi$  resonance \*

Xing-Yu Zhou(周兴玉)<sup>1;1)</sup> Ya-Di Wang(王雅迪)<sup>2,3;2)</sup> Li-Gang Xia(夏力钢)<sup>4;3)</sup>

# Extraction of parameters

- Method – fit by least square method with MIMUIT
- Objective function – global  $\chi^2$

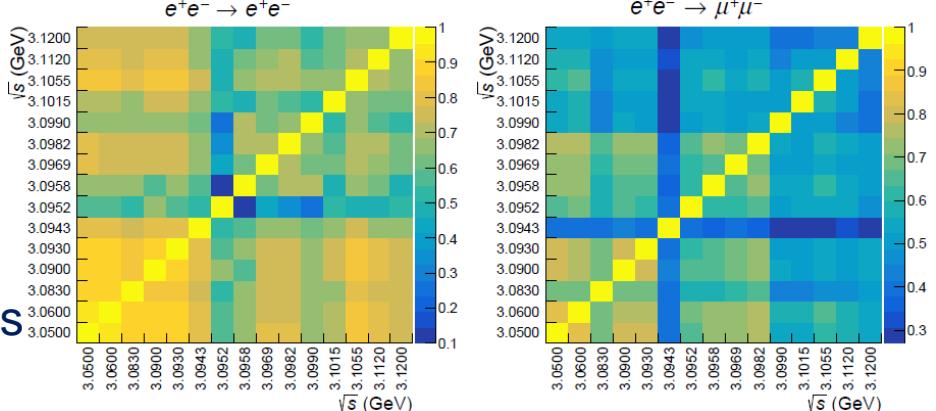
$$\chi^2 = \Delta\sigma^T \cdot V^{-1} \cdot \Delta\sigma$$

$$\Delta\sigma(i) = \begin{cases} \sigma_{ee}^{\text{exper}}(i) - \sigma_{ee}^{\text{theor}}(i) & i = 1, 2 \dots 14, 15 \\ \sigma_{\mu\mu}^{\text{exper}}(i-15) - \sigma_{\mu\mu}^{\text{theor}}(i-15) & i = 16, 17 \dots 29, 30 \end{cases}$$

$$V(i, j) = \begin{cases} V_{ee}(i, j) + \delta(i, j) \left( \frac{\partial \sigma_{ee}^{\text{theor}}}{\partial W}(i) \Delta W(i) \right)^2 \\ \frac{\sigma_{ee}^{\text{exper}}(i) \sigma_{\mu\mu}^{\text{exper}}(j-15)}{L(i) L(j-15)} V_L(i, j-15) + \delta(i, j-15) \frac{\partial \sigma_{ee}^{\text{theor}}}{\partial W}(i) \frac{\partial \sigma_{\mu\mu}^{\text{theor}}}{\partial W}(i) (\Delta W(i))^2 \\ \frac{\sigma_{ee}^{\text{exper}}(j) \sigma_{\mu\mu}^{\text{exper}}(i-15)}{L(i-15) L(j)} V_L(i-15, j) + \delta(i-15, j) \frac{\partial \sigma_{ee}^{\text{theor}}}{\partial W}(j) \frac{\partial \sigma_{\mu\mu}^{\text{theor}}}{\partial W}(j) (\Delta W(j))^2 \\ V_{\mu\mu}(i-15, j-15) + \delta(i-15, j-15) \left( \frac{\partial \sigma_{\mu\mu}^{\text{theor}}}{\partial W}(i-15) \Delta W(i-15) \right)^2 \end{cases}$$

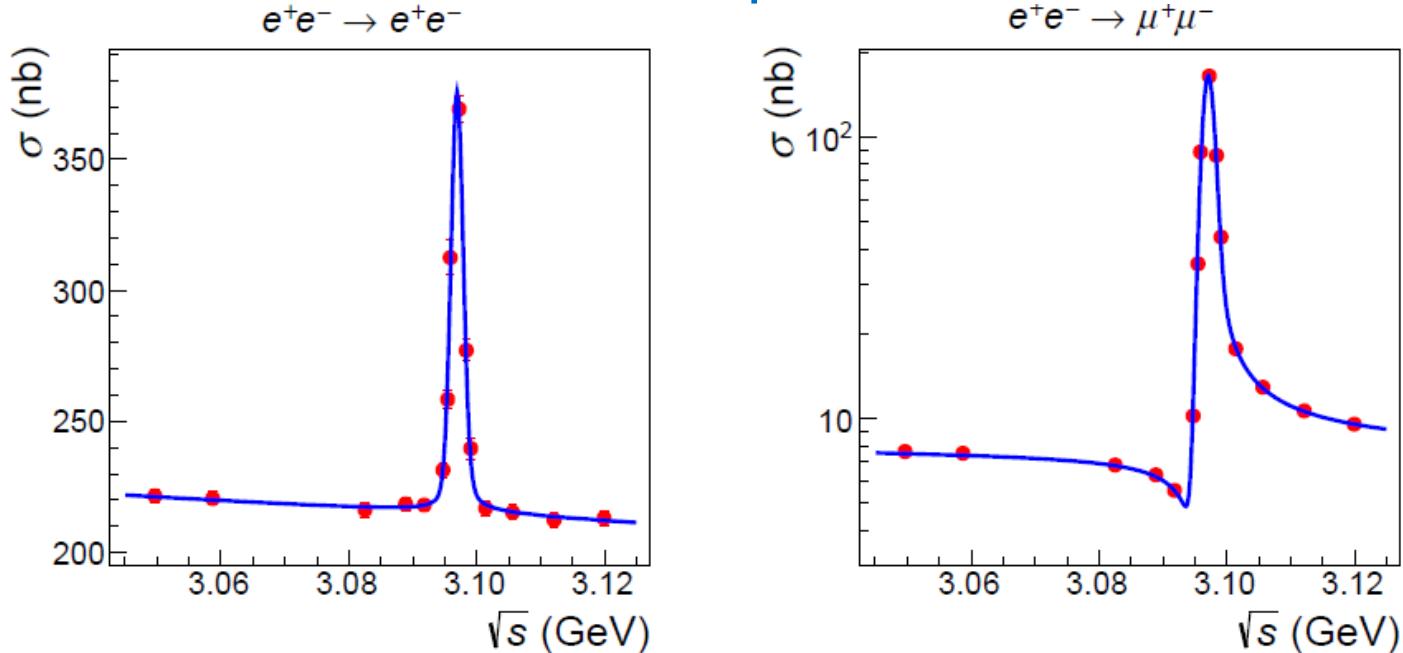
## Covariance matrix V

- Same channel at different energies
- Different channels at same energy
- Different channels at different energies



# Fit results

- Cross sections and fit line-shapes



- Parameters values

$$\Gamma_{ee}\Gamma_{ee}/\Gamma_{\text{tot}} = (0.348 \pm 0.009) \text{ keV},$$

$$\Gamma_{ee}\Gamma_{\mu\mu}/\Gamma_{\text{tot}} = (0.339 \pm 0.006) \text{ keV},$$

$$\Gamma_{ll}\Gamma_{ll}/\Gamma_{\text{tot}} = (0.337 \pm 0.006) \text{ keV},$$

$$\Gamma_{ee}/\Gamma_{\mu\mu} = 1.025 \pm 0.014,$$

$$\Gamma_{\text{tot}} = (94.3 \pm 2.1) \text{ keV},$$

$$\Gamma_{ll} = (5.64 \pm 0.11) \text{ keV}.$$

$$\chi^2/ndf \approx 37.1/26 \approx 1.4$$

# Summary

Collab.	Method	Year	$\Gamma_{\text{tot}}$ (keV)	$\Gamma_{ll}$ (keV)	Ref.
BaBar	ISR	2004	$94.7 \pm 4.4$	$5.61 \pm 0.21$	[14]
CLEO	ISR	2006	$96.1 \pm 3.2$	$5.71 \pm 0.16$	[15]
KEDR	ES	2010	$94.1 \pm 2.7$	$5.59 \pm 0.12$	[16]
PDG	—	2016	$92.9 \pm 2.8$	$5.55 \pm 0.14$	[3]
BESIII	ISR	2016	—	$5.58 \pm 0.09$	[19]
This work	ES	2017	$94.3 \pm 2.1$	$5.64 \pm 0.11$	Preliminary



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