The Status of R value Scan at BESIII

Liang Yan

(on behalf of BESIII)

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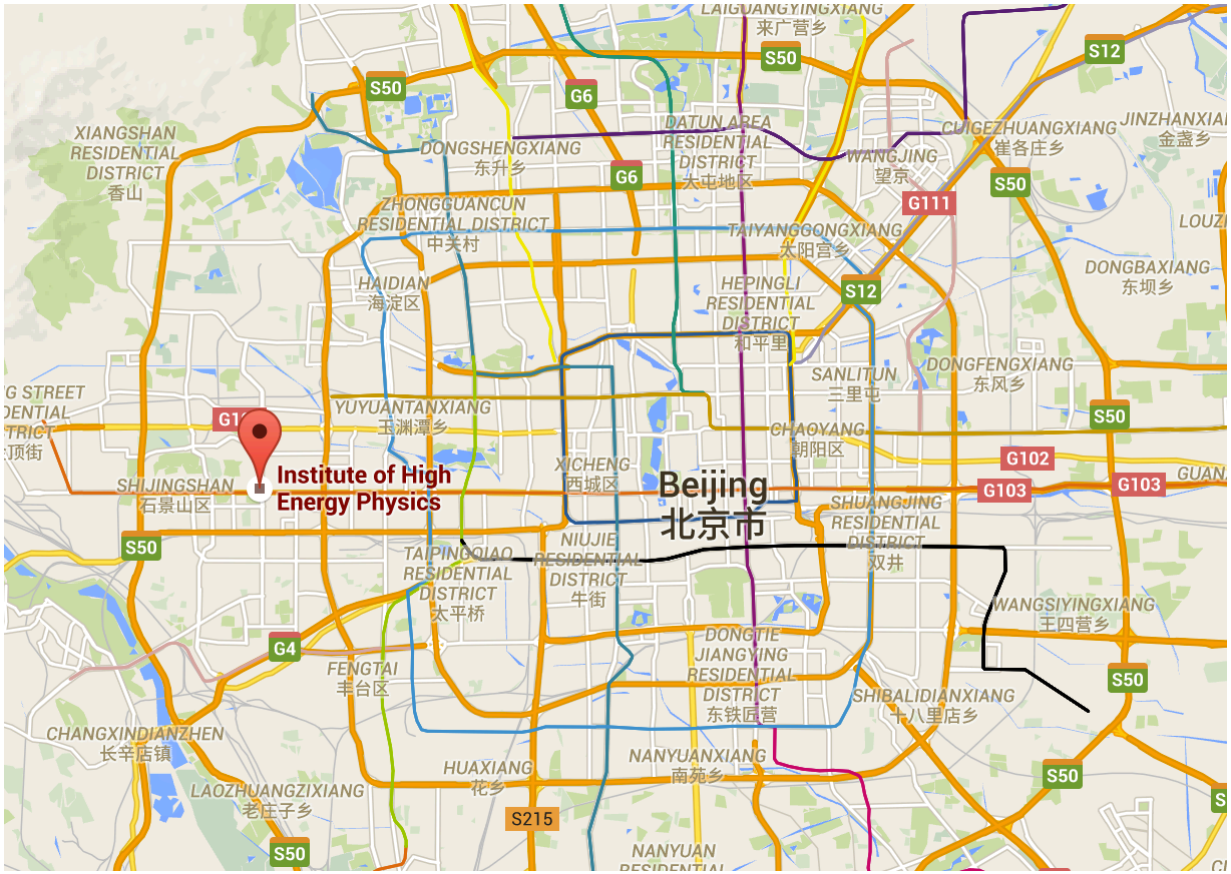
Istituto Nazionale di Fisica Nucleare

UNIVERSITÀ DEGLI STUDI DI TORINO

Outline

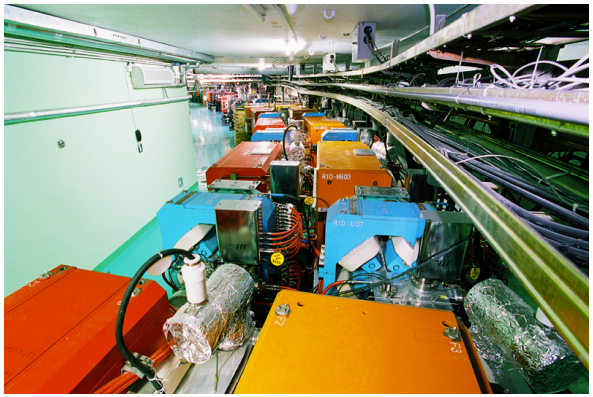
- Introduction of BEPC and BESIII
- Motivation
- Status of R measurement
- Summary

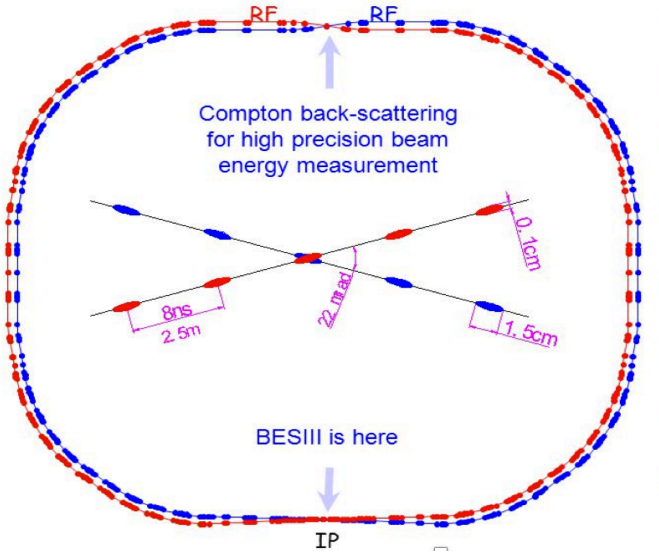
BEPC && BESIII

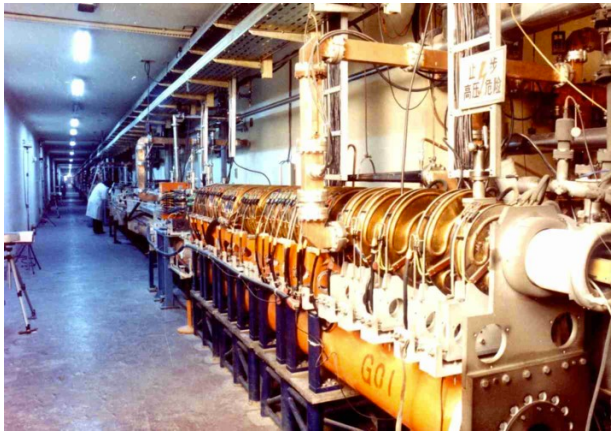


It will take less than 30 mins from the Forbidden City to IHEP by subway.

BECPCII storage rings: a τ-charm factory



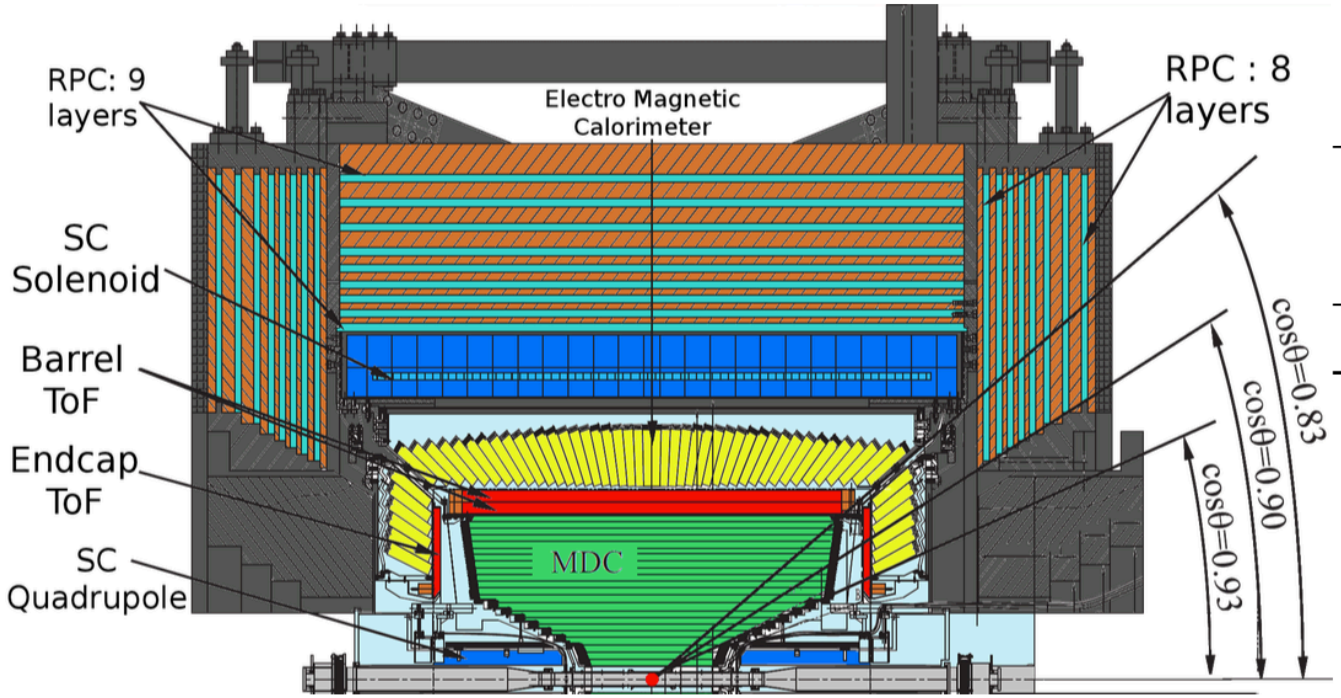




Update of BEPC (started 2004, first collisions July 2008)

Beam energy	1 - 2.3 GeV
Optimum energy	1.89 GeV
Single beam current	0.91 A
Crossing angle	11mrad
Design luminosity	1×10^{33} cm^{-2} s^{-1}
Achieved	0.998×10^{33} cm^{-2} s^{-1}

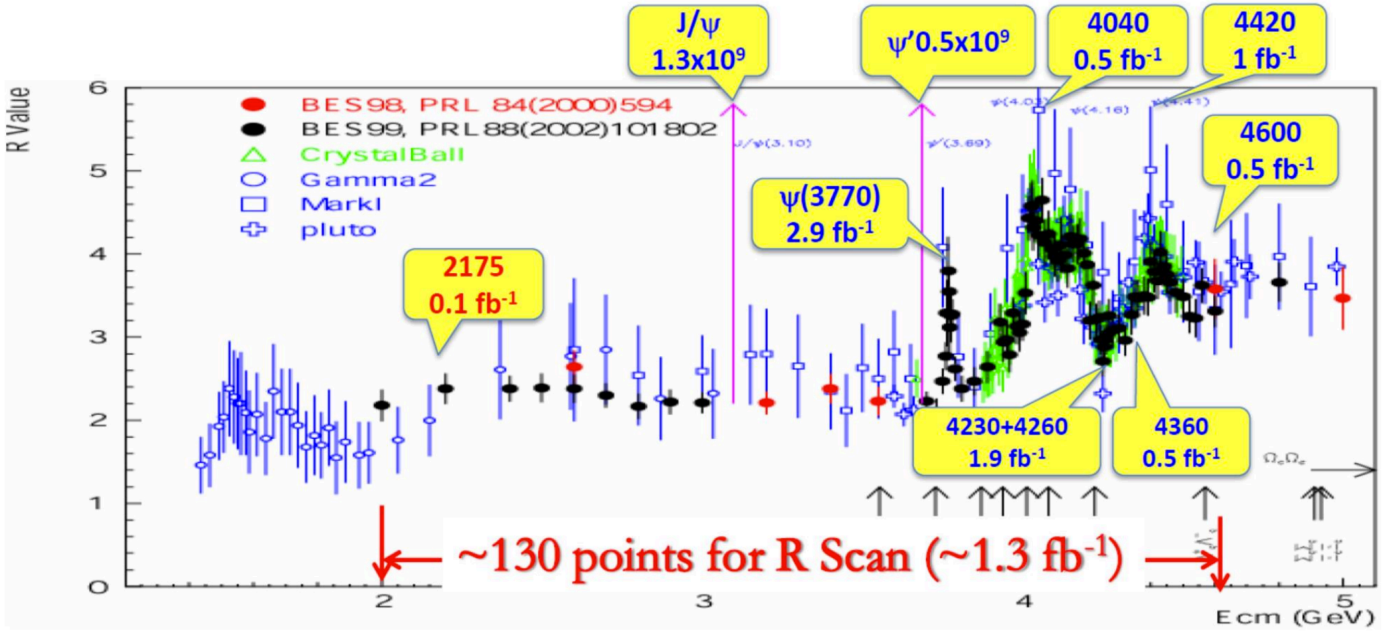
BESIII detectors

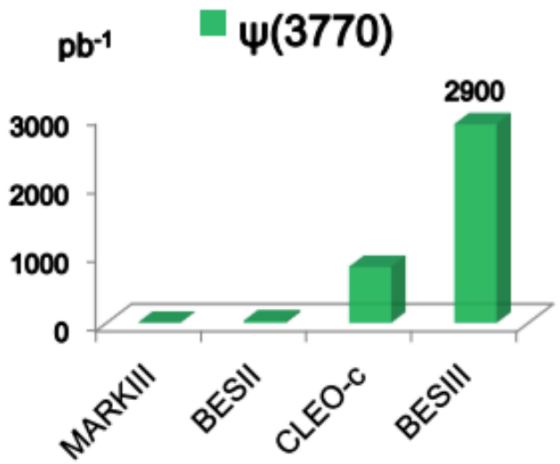


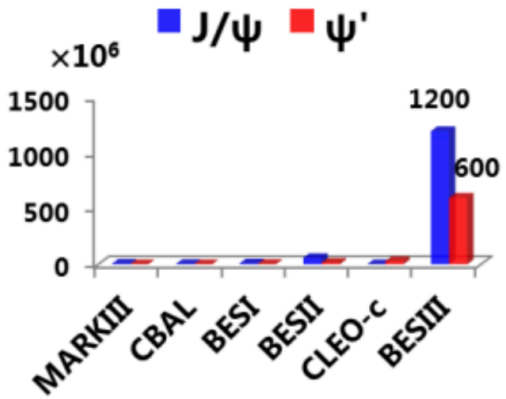
Expt.	MDC Wire resolution	MDC dE/dx resolution	EMC Energy resolution
CLEO	110 μm	5%	2.2 – 2.4%
BABAR	125 μm	7%	2.67%
Belle	130 μm	5.6%	2.2%
BESIII	115 μm	$<$ 5%	2.3%

Expt.	TOF time resolution
CDF	100 ps
Belle	90 ps
BESIII	68 ps (Barrel) 100 ps (ETOF)

BESIII data set

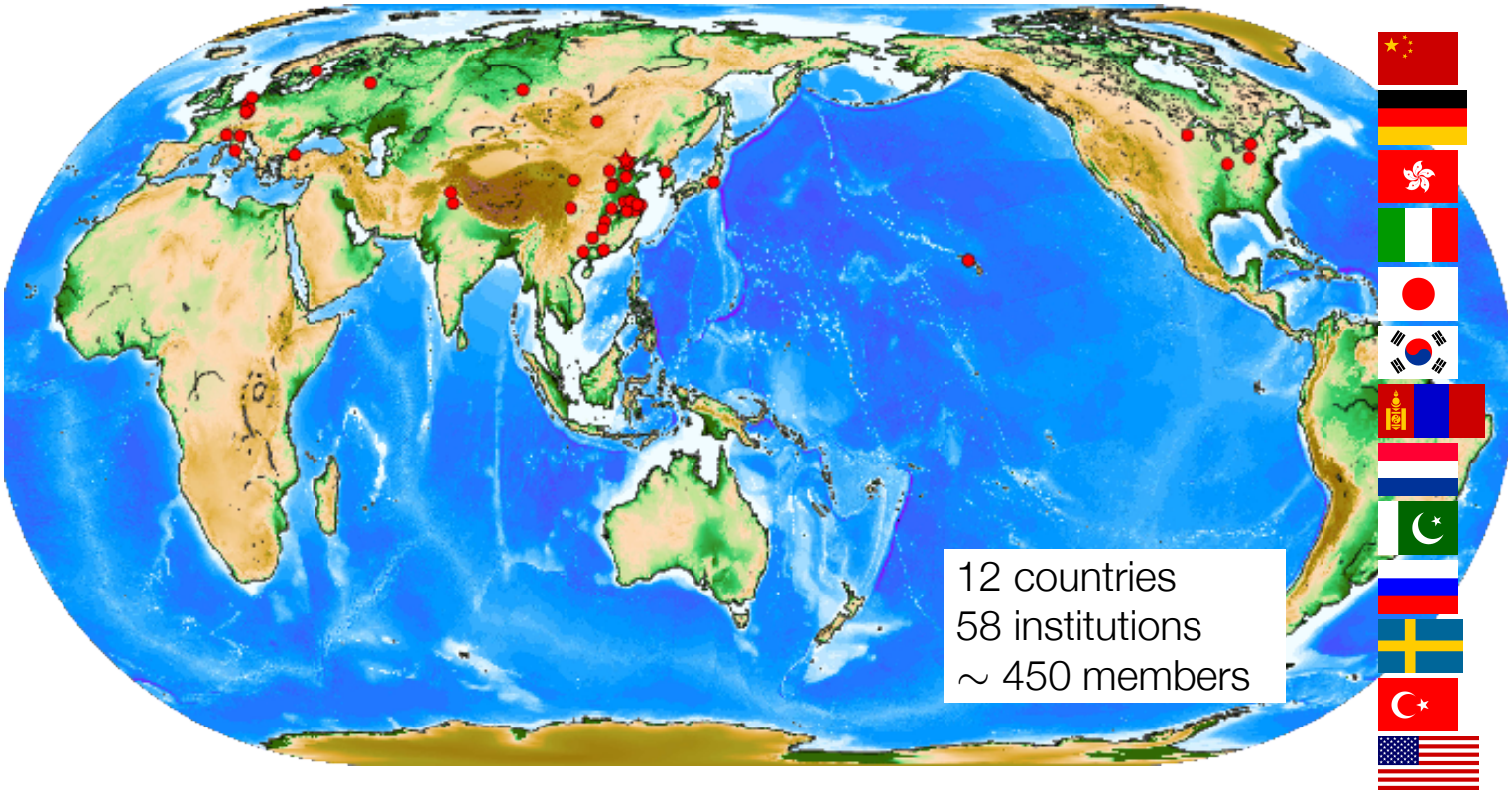






- ✓ World largest data sample on J/ψ, ψ' ψ(3770), Y(4260)... in e^+e^- collisions
- ✓ From light mesons spectroscopy to $\Lambda_c\Lambda_c$
- ✓ Also ISR, photon-photon physics, τ physics…

BESIII collaboration



What ?

The Born cross section of e^+e^- annihilation into hadrons normalized by theoretical $\mu^+\mu^-$ cross section.

$$R = \frac{\sigma^0_{had}(e^+e^- \to \gamma^* \to \text{hadrons})}{\sigma^0_{\mu\mu}(e^+e^- \to \gamma^* \to \mu^+\mu^-)}$$

Groups ever measured R value： BESII, VEPP, DAΦNE, DM2, DASP, PLUTO, Crystal-Ball, MARKI, MARKII, CLEO-c, AMY, JADE, TASSO, CUSB, MD-1, MARKJ, SLAC-LBL, MAC, γγ2……

Why?

- R value is the direct evidence of color number

$$R \equiv \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)} = 3\sum_f Q_f^2,$$

Where Q_f is the fractional charge of the quark, and the factor of 3 in front counts the three colors for each flavor

$$\begin{aligned} R &= 3[(2/3)^2 + (1/3)^2 + (2/3)^2] = 2 \ \text{ for } \ u, d, s \\ &= 2 + 3(2/3)^2 = 10/3 \ \text{ for } \ u, d, s, c, \\ &= 10/3 + 3(1/3)^2 = 11/3 \ \text{ for } \ u, d, s, c, b. \end{aligned}$$

The input parameter of α(s)

- The running of the electromagnetic fine structure constant is governed by the renormalized vacuum polarization function.

$$\alpha(s) = \frac{\alpha(0)}{1 - \Delta\alpha_{\text{lep}}(s) - \Delta\alpha_{\text{had}}(s)}$$

For the case of interest, s= M_z^2, the leptonic contribution at three-loop order has been calculated to be

$$\Delta\alpha_{\text{lep}}(M_Z^2) = 314.97686 \times 10^{-4}$$

Using analytic and unitarity, the dispersion integral for the contribution from the hadronic vacuum polarization

$$\Delta\alpha_{\text{had}}(M_Z^2) = -\frac{\alpha(0)\, M_Z^2}{3\pi} \operatorname{Re} \int_{4m_\pi^2}^{\infty} ds \, \frac{R(s)}{s(s - M_Z^2) - i\epsilon}$$

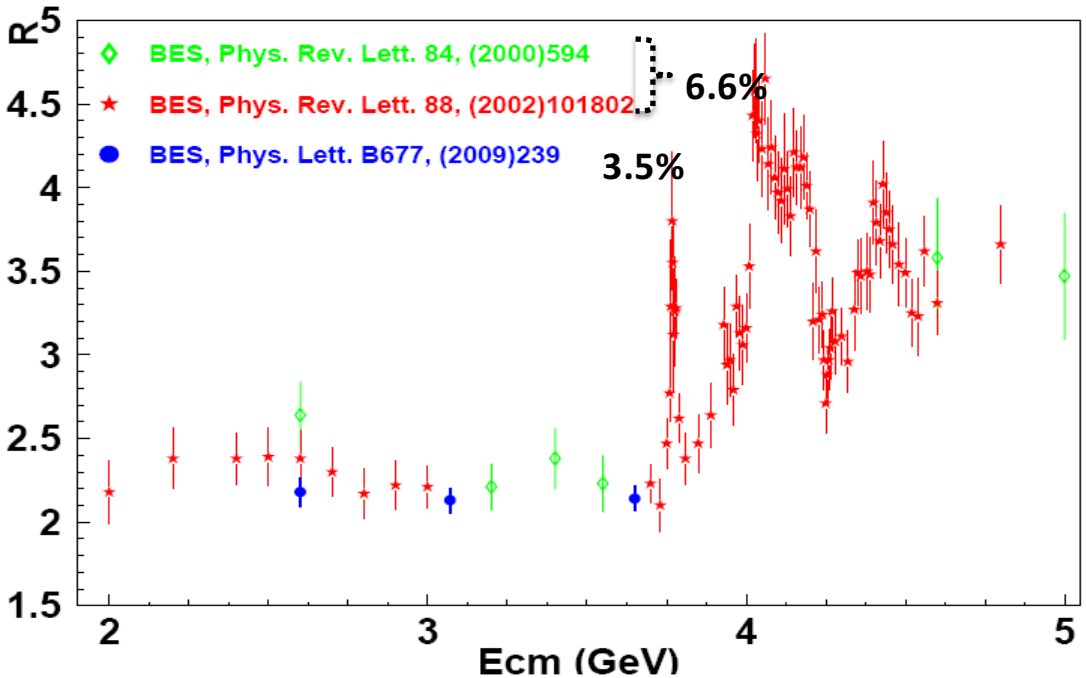
The input parameters of $(g\text{-}2)_\mu$

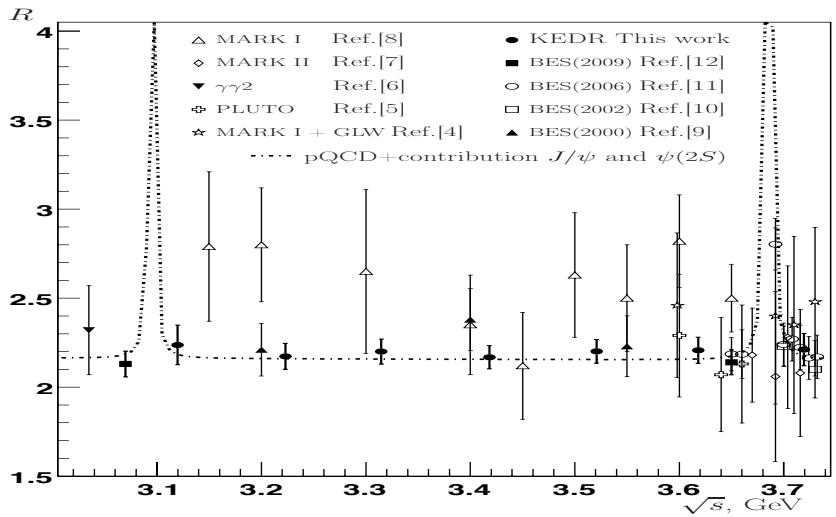
- Experimental: $a^{exp}_\mu = 1165\ 920\ 8.9\ (6.3) \times 10^{-10}$ (0.54 ppm) [BNL-E821: PRD 73 072003]
- Standard Model prediction: $a^{SM}_\mu = a^{QED}_\mu + a^{weak}_\mu + a^{had}_\mu$

Contribution	in units 10^{-10}	
QED(γ+lepton)	1165 847 1.8951± 0.0080	Kinoshita et.al. (2012)
EW	15.36 ± 0.10	Gnendiger, Stöckinger, Stöckinger-kim (2013)
HVP,LO	692.3 ± 4.2	Davier et. al. (2011)
HVP,NLO	-9.84 ± 0.07	Hagiwara et al. (2009)
HLbL	11.6 ± 4.0	Jegerlehner, Nyffler (2009)
Total	1165 918 1.3 ± 5.8	

$$a_\mu(\mathrm{had,LO}) = 4\alpha_0^2 \int_{m_\pi^2}^{\infty} \frac{ds}{s} K(s) \frac{1}{\pi} \mathrm{Im}\,\Pi^{\mathrm{had}}(s) = \frac{\alpha_0^2}{3\pi^2} \int_{m_\pi^2}^{\infty} \frac{ds}{s} K(s) R^{\mathrm{had}}(s)$$

R measurement: current status





R measurement in the energy interval 3.12-3.72 GeV from KEDR detector at the VEPP-4M. The total achieved accuracy is about or better than 3.3%.

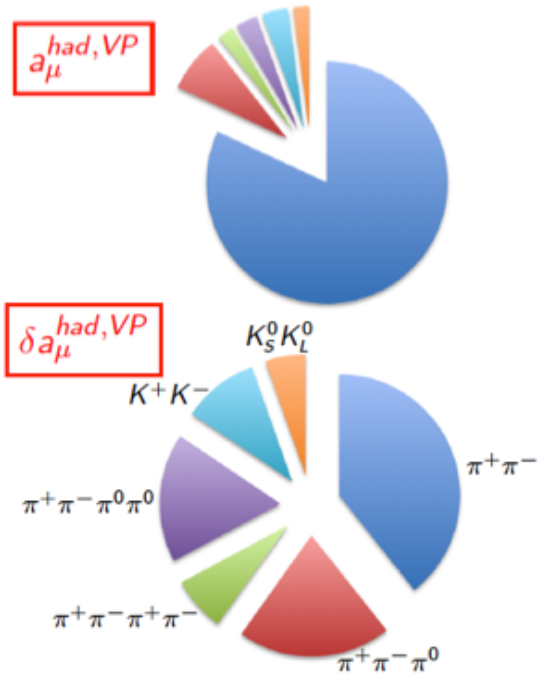
Phys. Lett. B 753 (2016) 533-541

$\Delta\alpha(M_z^2)$ and a_μ: current status

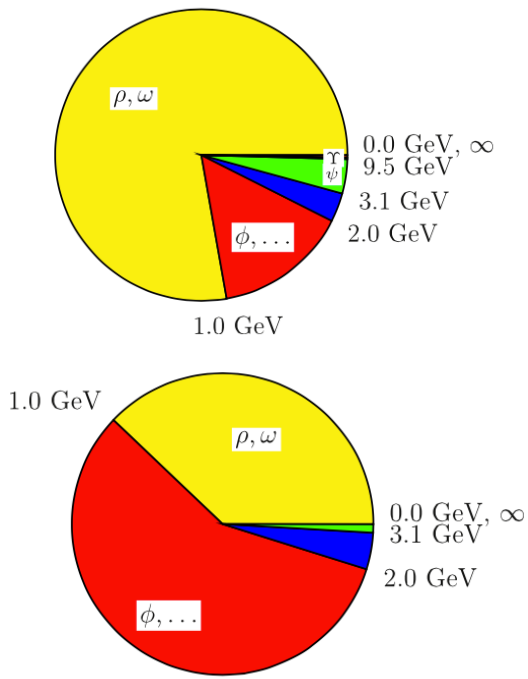
TABLE I: Contributions to $\Delta\alpha^{(5)}_{\rm had}(m_Z^2)$

Range $\sqrt{s}$, GeV	$\Delta\alpha$	Relative error
ρ	0.00349	0.5 %
Narrow resonances	0.00184	3.1 %
1.05 – 2.0	0.00156	15 %
2.0 – 5.0	0.00371	5.0 %
5 – 7	0.00183	6 %
7 – 12	0.00304	1.4 %
> 12	0.01203	0.2 %
	0.02750	1.2 %

Channel



Energy region



Less than 2.0GeV, exclusive cross sections are studied by ISR method($e^+e^- \rightarrow \gamma_{ISR}\pi^+\pi^-$)
[2.0 – 5.0] GeV, R value is measured with inclusive method.

How?

In experiment, R values are measured with

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

Tasks in experiment:

N_{had} observed hadronic events

N_{bg} background events

L integrated luminosity

ε_{had} detection efficiency for hadronic events

$1+\delta$ radiative correction factor

$\sigma_{\mu\mu}$ Born cross section of μ pair production in QED.

Data samples for R value

- Phase I: test run (2012)

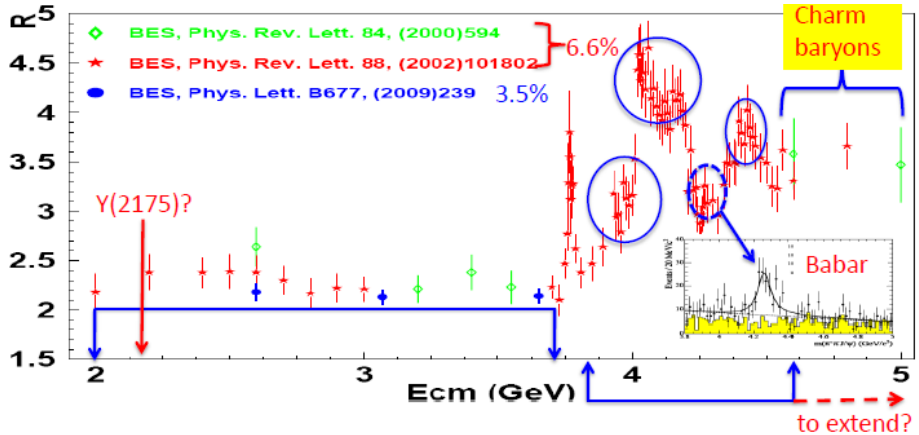
  @ Ecm = 2.232, 2.400, 2.800, 3.400 GeV , 4 energy points, ~12/pb

- Phase II: fine scan for heavy charm resonant line shape (2013–2014)

  @ 3.800 – 4.590 GeV, 104 energy points, ~ 800/pb

- Phase III: R&QCD scan (2015)

  @ 2.000 – 3.080 GeV, 19+2 energy points, ~ 500/pb



Present status of R value measurement

N_{had} , N_{bg} → event selection:

below open charm finished, above open charm in progress.

L → integrated luminosity:

finished, error ~ 1%.

ε_{had} → hadronic generator LUARLW tuning:

two schemes are doing, cross check, largest error source?

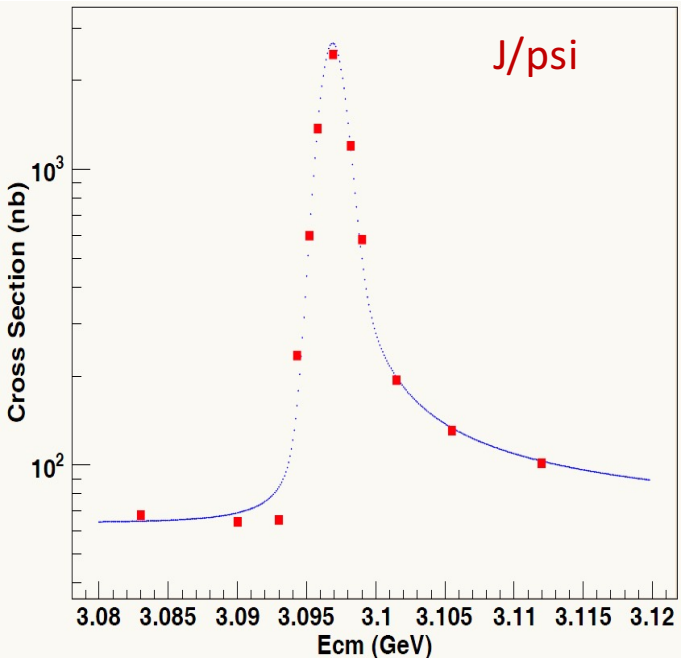
$1+\delta$ → theoretical calculations:

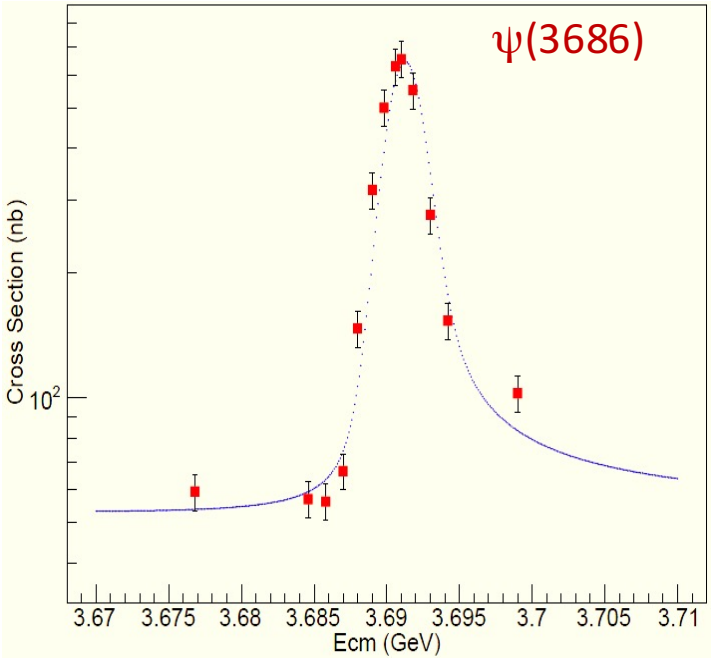
finished, error ~1.5%, including the contribution from $\Delta\sigma^0_{had}$

Error analysis:

on going, final goal $\Delta R/R$ ~ 3.0%

Energy calibration





During the data taking, several times J/psi and psi(3686) fast scan were done, and fit the online cross section to calibrate the beam energy.

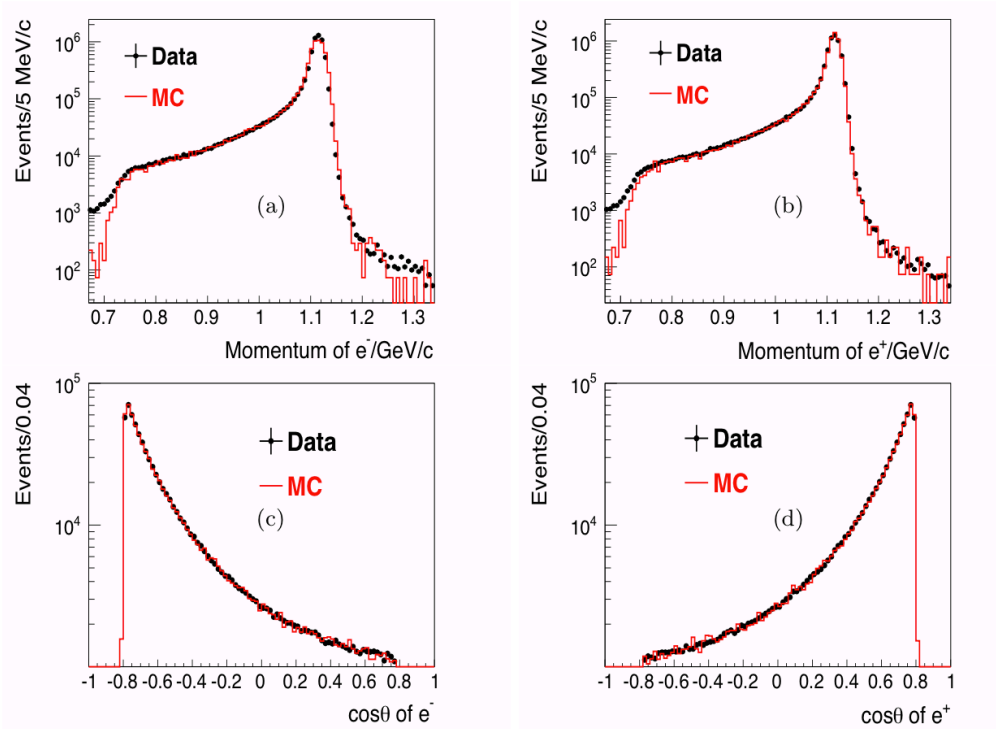
Luminosity measurement

- Quantum electrodynamics process of $e^+e^- \to e^+ e^-$ and $e^+ e^- \to \gamma\gamma$ are used to determine the integrated luminosity. The integrated luminosity is measured by:

$$\mathcal{L} = \frac{N_{obs}}{\sigma \cdot \varepsilon \cdot \varepsilon_{trig}}$$

The integrated luminosities of data taken from 2.2324 to 4.5900 GeV at BESIII are measured. For each energy point around J/ψ (from 3.0930 to 3.1200 GeV). Only the luminosity measured by e+ e- -> γ γ is obtained.

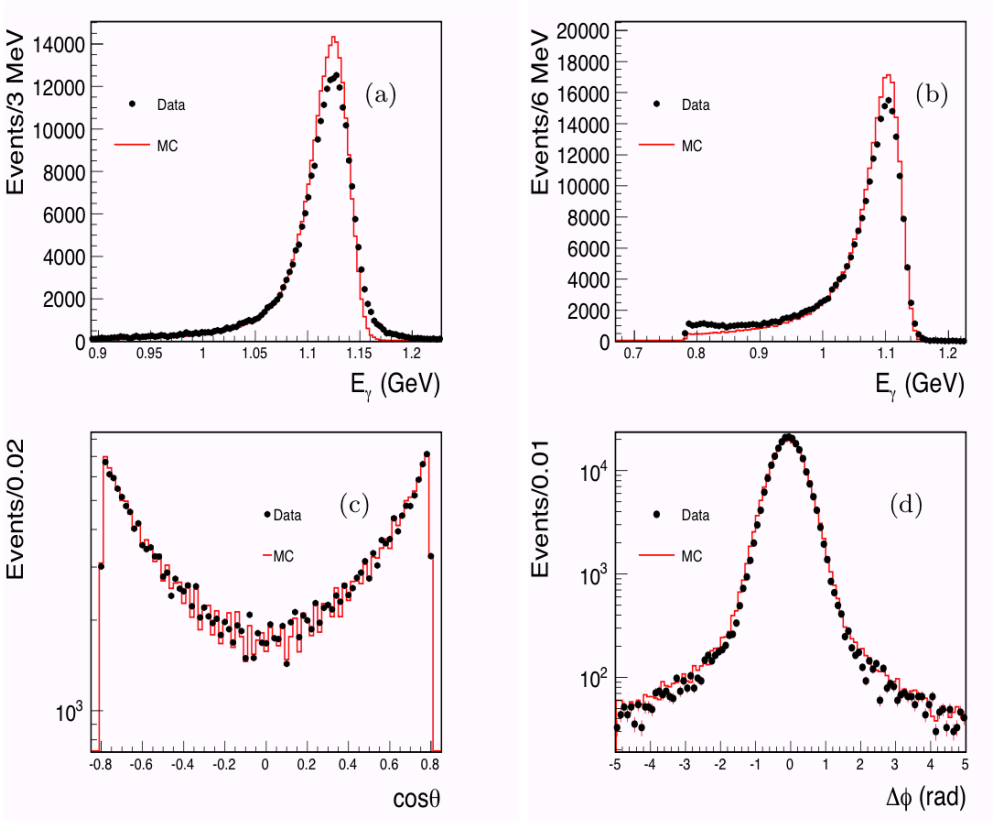
The $e^+ e^- \to e^+ e^-$ process



- Two good charged tracks
- $E > 0.65 \times E_{beam}$
- $|\delta\theta| < 10$ degree
- $|\delta\phi| < 5$ degree

Source	$\Delta^{sys}(\%)$
$\lvert cos\theta \rvert < 0.8$	0.12
$\lvert \Delta\theta \rvert < 10^\circ$	0.05
$\lvert \Delta\phi \rvert < 5^\circ$	0.01
Deposited energy of e^+	0.04
Deposited energy of e^-	0.05
Tracking efficiency	0.41
Beam energy	0.09
Cluster reconstruction	0.09
MC statistics	0.17
Background estimation	0.00
Trigger efficiency	0.10
Generator	0.50
Total	0.7

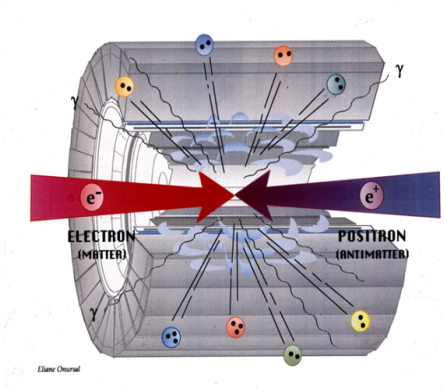
The $e^+ e^- \to \gamma\gamma$ process

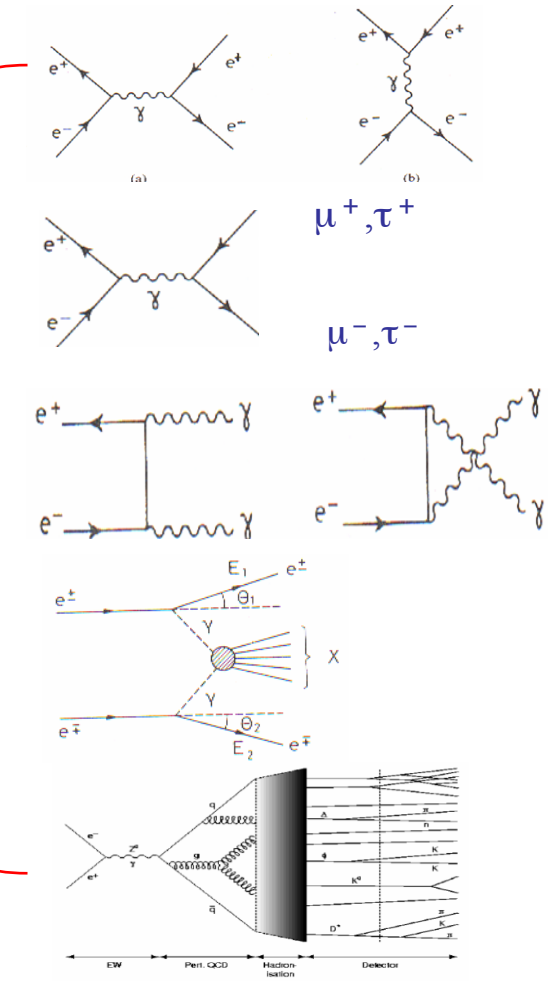


- No good charged tracks
- $E > 0.7\times E_{beam}$
- $E < 1.16\times E_{beam}$
- $|\delta\phi| < 2.5$ degree

Source	$\Delta^{sys}(\%)$
$\lvert cos\theta\rvert < 0.8$	0.18
$\lvert\Delta\phi\rvert < 2.5^\circ$	0.07
Deposited energy of γ	0.10
Cluster reconstruction	0.10
MC statistics	0.15
Background estimation	0.23
Trigger efficiency	0.10
Generator	1.00
Total	1.1

The generator used in R measurement





$e^+e^- \to e^+e^-$ BABAYAGA (OK)

$e^+e^- \to \mu^+\mu^-$ BABAYAGA (OK)
$e^+e^- \to \tau^+\tau^-$ KKMC (OK)

$e^+e^- \to \gamma\gamma$ BABAYAGA (OK)

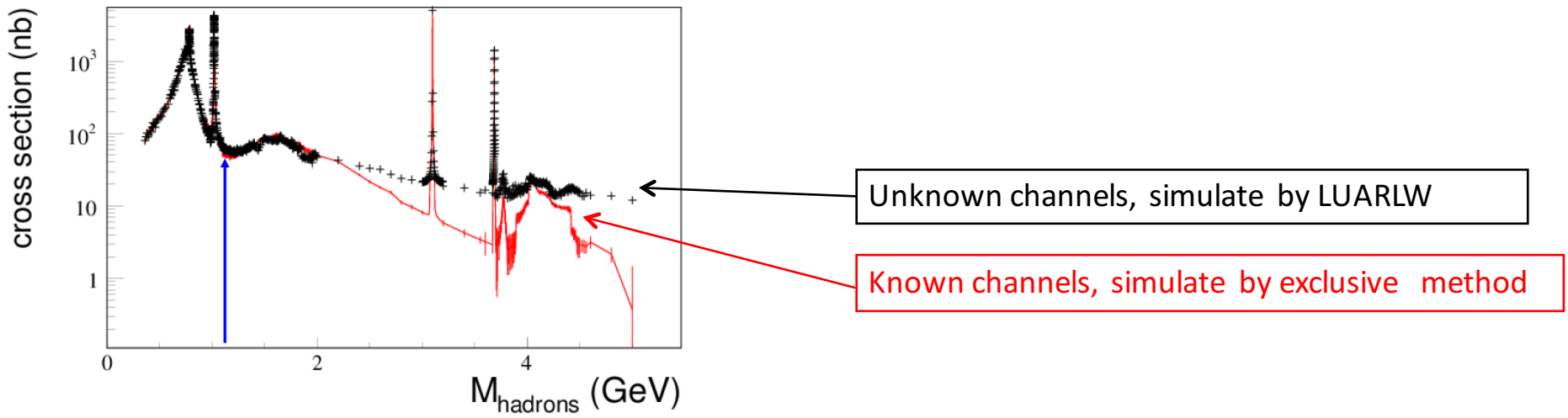
$e^+e^- \to e^+ e^- X$ TWOPHOTON

(need check)

$e^+e^- \to$ hadrons LUARLW

(need tuning)

Parameter tuning and optimization of LUARLW

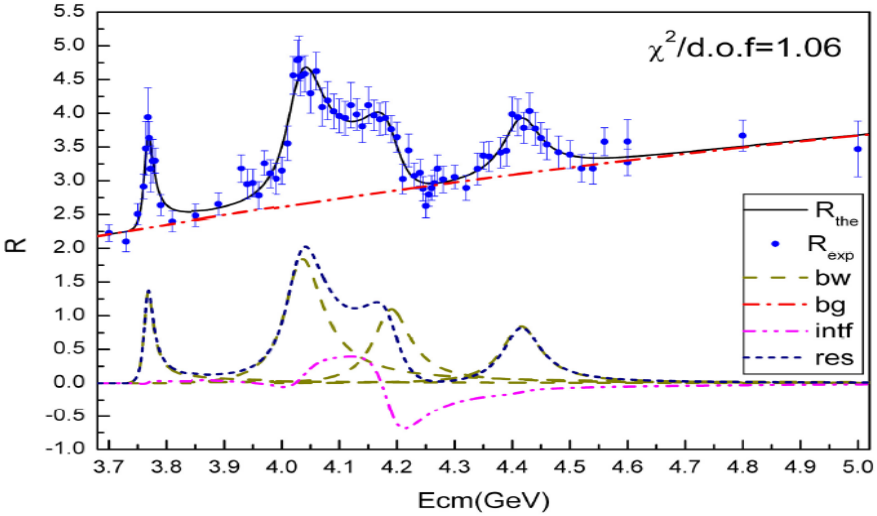


Assume LUARLW is approximately described by a parameterized response function. The phenomenological parameters in LUARLW are treated as free numbers in fit, the optimal values are obtained by simultaneously fit this function to the data.

Heavy vector charmonia line shape

Similar work like did at BESII, but improved measurement at BESIII

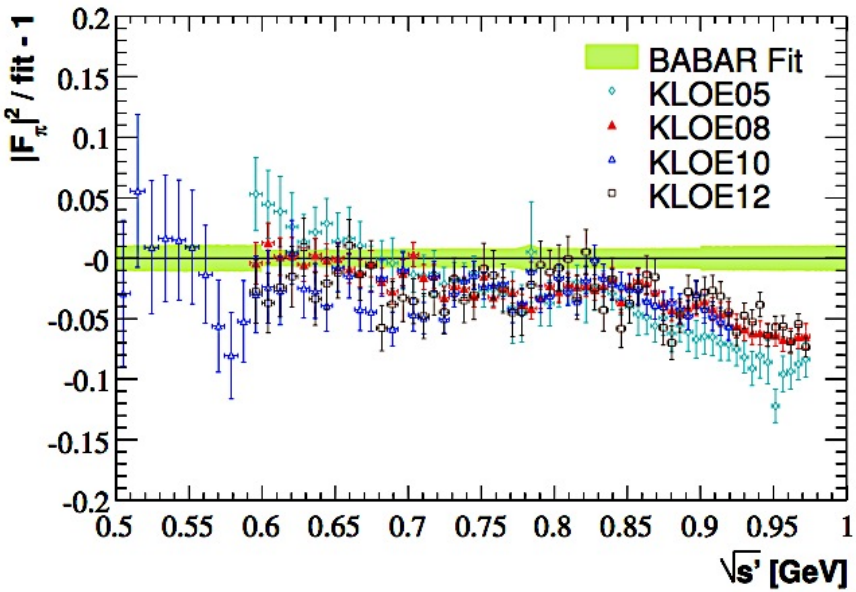
At BESII, parameters (M, Γ_{tot}, Γ_{ee}) of the $J^{PC} = 1^{--}$ conventional Charmonia $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, $\psi(4415)$ remain quite uncertain and model dependent:



Phys. Lett. B660 (2008)315

Most Relevant Channel: e+e- → $\pi^+\pi^-$

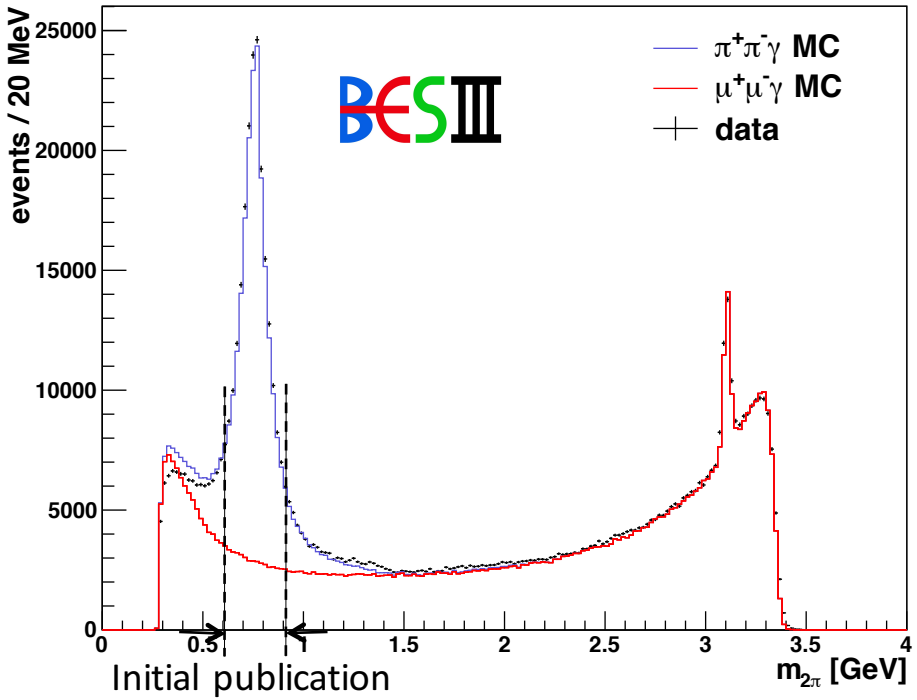
- KLOE and BABAR dominate the world average
- Both with uncertainties smaller than 1%
- Relatively large systematic differences, especially above ρ peak
- Knowledge of a_μ^{had} dramatically limited due to this difference



***Note**: KLOE05 superseded by KLOE08*

$e^+e^- \rightarrow \gamma_{ISR}\pi^+\pi^-$ at BESIII

Event yield after preliminary selection



Initial publication

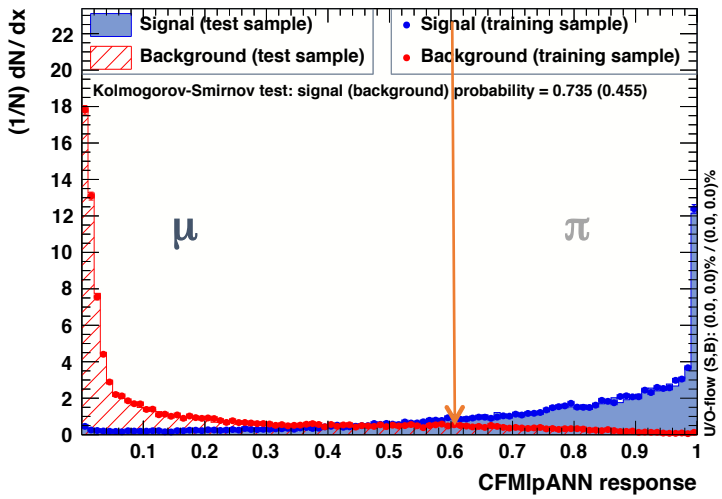
600 – 900 MeV

[Phys. Lett. B753 (2016) 629]

- $\psi(3770)$ data only (2.9 fb^{-1})
- Tag ISR photon
- No dedicated background subtraction

- $e^+e^- \rightarrow \gamma\pi^+\pi^-$: large statistics
- $e^+e^- \rightarrow \gamma\mu^+\mu^-$: dominate background
- Data - MC differences visible

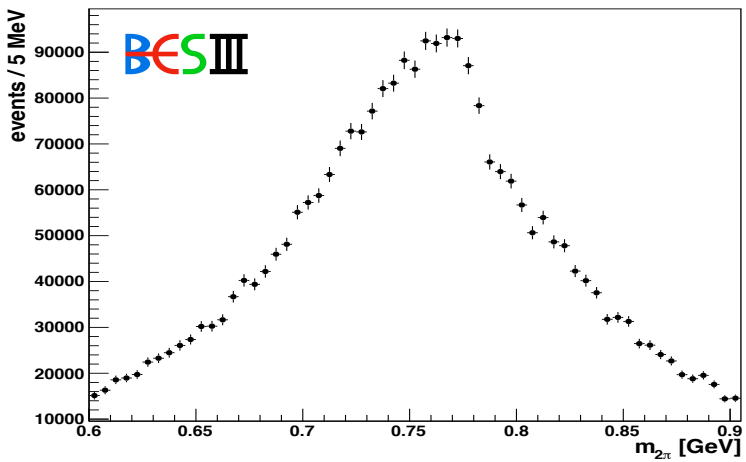
$e^+e^- \rightarrow \gamma_{ISR}\,\pi^+\pi^-$: π-μ separation



Event yield $\gamma\pi\pi$ after π-μ separation

TMVA method (Neural Network):

- Trained using $\gamma\mu\mu$ and $\gamma\pi\pi$ MC events
- Information based on track level
- Efficiency matrix (p,τ) for data, MC
- Correct for data - MC differences
- Cross checked for different TMVA



$e^+e^- \rightarrow \pi^+\pi^-$ Cross section

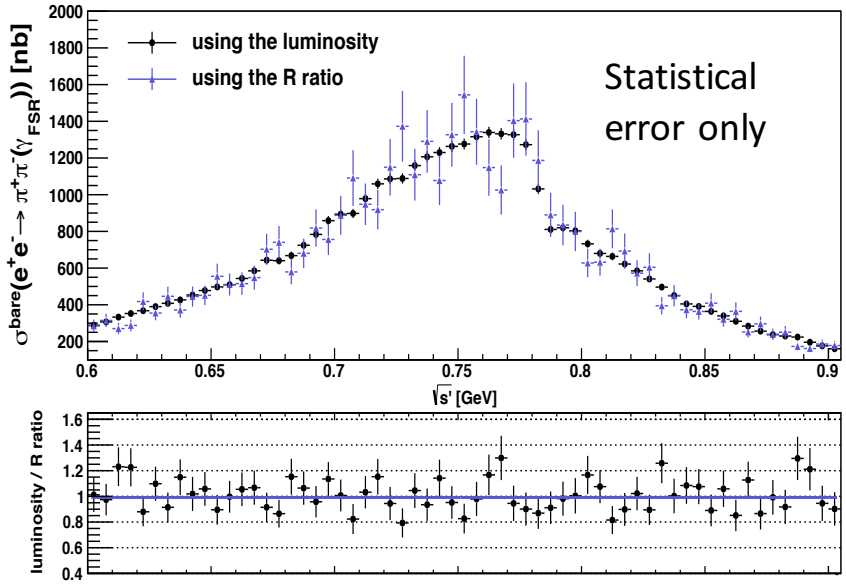
2 normalization methods:

- Normalization to L_{int} (obtained from Bhabha events)

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

- Normalization to $\gamma\mu\mu$ events, i.e. R ratio ($\gamma\pi\pi/\gamma\mu\mu$)

L_{int}, H_{rad}, δ_{vac} cancel in ratio



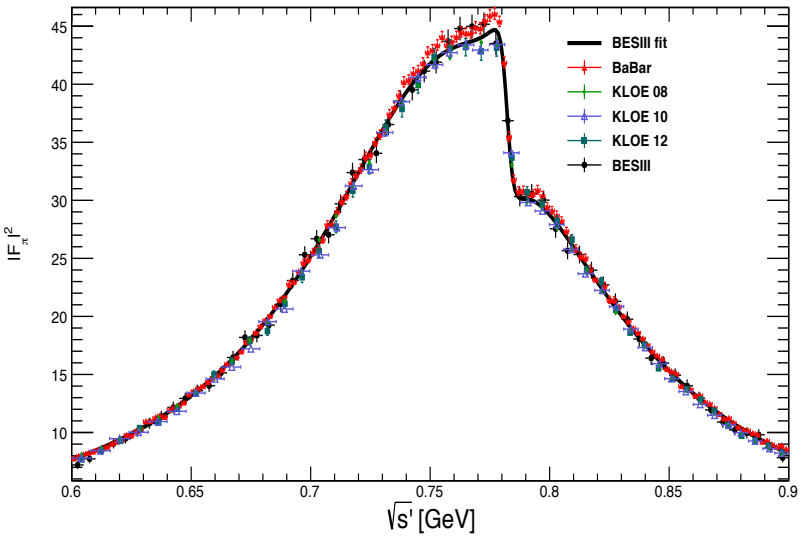
Good agreement between two methods

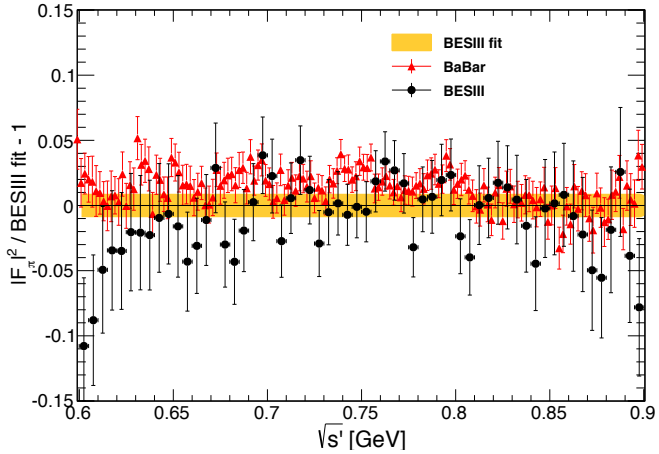
Luminosity / R ratio -1 = (0.85 ± 1.68) %

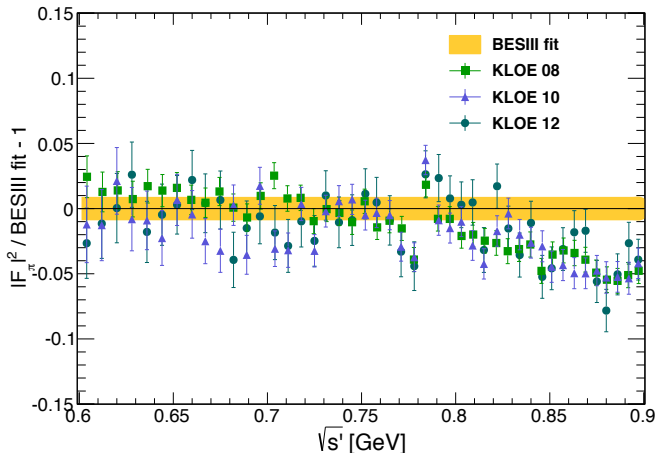
limited by low $\gamma\mu\mu$ statistics

Compare with Existing Data

Pion Form Factor F_π



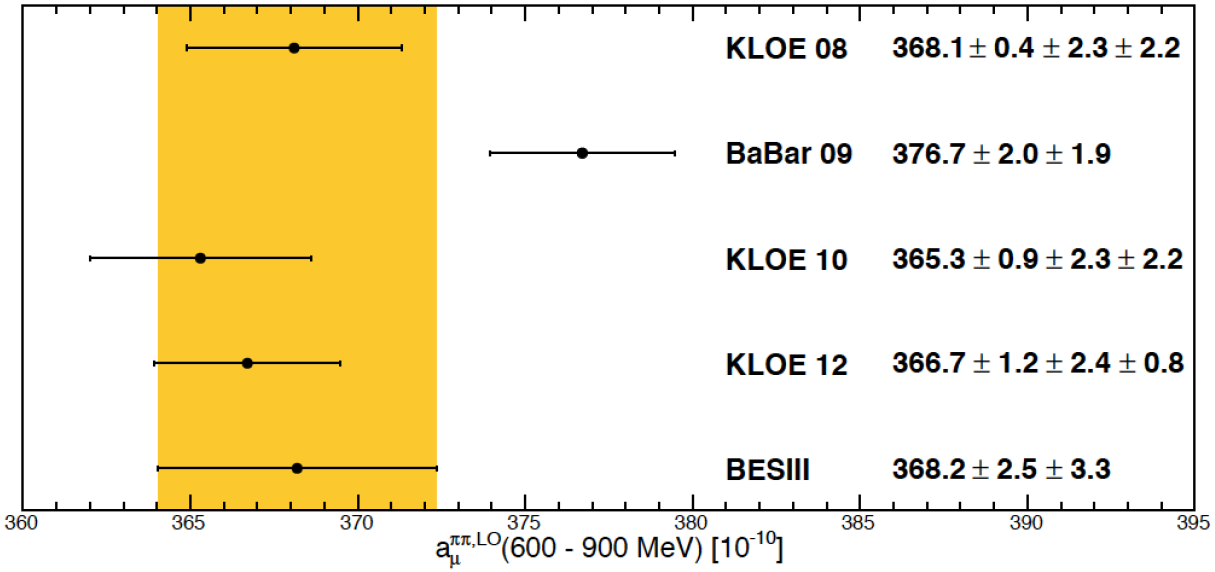




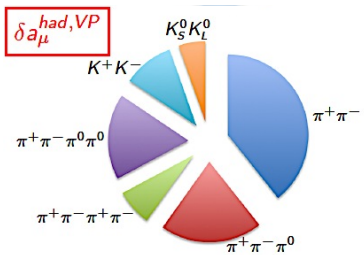
- 0.9 % accuracy (dominated by theory)
- Normalization to luminosity × radiator function
- Gounaris and Sakurai parameterization

G. J. Gounaris and J. J. Sakurai, Phys. Rev. Lett. **21**, 244

Impact on a_μ^{HVP}



Deviation on $(g-2)_\mu$ between experimental and SM has been confirmed



Study of $\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\pi^0\pi^0$ processes undergoing at BESIII

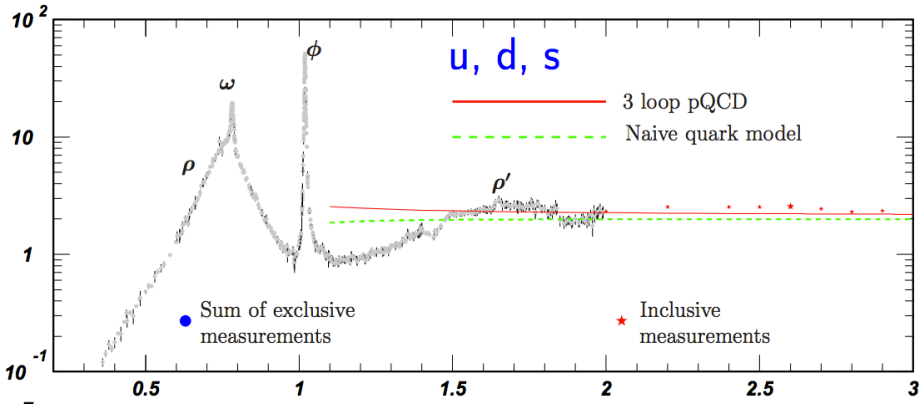
Summary

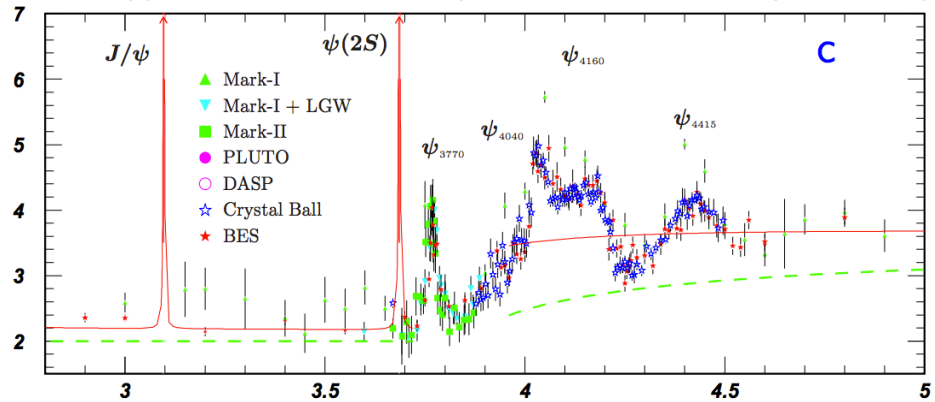
- Data taking plans of phaseI-III finished, data sets for R scan and QCD study between 2.0 – 4.6 GeV have been collected.
- The LUARLW parameter tuning are in progress, which is a tough and challenge work, and could be the largest error source (1.5-2.0%) for R value measurement.
- The related theoretical study about the heavy charmonia line shape fit are doing, which are crucial for obtaining reliable values.
- Preliminary results of R measurement between 2.2324-3.671 GeV have reported inside BES Collaboration, the analysis for other energy points are in going.
- $e^+ e^- \to \pi^+ \pi^-$ cross section is measured at BESIII with sys. below 1%. The deviation between experiment and theory is confirmed.

BACK UP

R in light flavor, charm regions

arXiv:hep-ph/0312114





The higher order QCD corrections to R have been calculated in complete third order perturbation theory.

$$R = 3\sum_f Q_f^2\left[1 + (\frac{\alpha_s(s)}{\pi}) + 1.411(\frac{\alpha_s(s)}{\pi})^2 - 12.8(\frac{\alpha_s(s)}{\pi})^3 + \ldots\right]$$

Results by fitting the R line shape in Higher region

	M, MeV	Γ_{tot} , MeV	Γ_{ee} , keV	δ, deg	
ψ(3770)	3772.92 ± 0.35	27.3 ± 1.0	0.265 ± 0.018		PDG09
	3772.0 ± 1.9	30.4 ± 8.5	0.22 ± 0.05	0	BES08
ψ(4040)	4039 ± 1	80 ± 10	0.86 ± 0.07		PDG09
	4039.6 ± 4.3	84.5 ± 12.3	0.83 ± 0.20	130 ± 46	BES08
ψ(4160)	4153 ± 3	103 ± 8	0.83 ± 0.07		PDG09
	4191.7 ± 6.5	71.8 ± 12.3	0.48 ± 0.22	293 ± 57	BES08
ψ(4415)	4421 ± 4	62 ± 20	0.58 ± 0.07		PDG09
	4415.1 ± 7.9	71.5 ± 19.0	0.35 ± 0.12	234 ± 88	BES08

PDG2014

$\psi(4160)$

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

$\psi(4160)$ MASS

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
4191 ± 5	**OUR AVERAGE**				
4191^{+9}_{-8}		AAIJ	13BC	LHCB	$B^+ \to K^+\mu^+\mu^-$
4191.7 ± 6.5		[1] ABLIKIM	08D	BES2	$e^+e^- \to$ hadrons

$\psi(4160)$ WIDTH

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
70 ±10	**OUR AVERAGE**				
65^{+22}_{-16}		AAIJ	13BC	LHCB	$B^+ \to K^+\mu^+\mu^-$
71.8 ± 12.3		[5] ABLIKIM	08D	BES2	$e^+e^- \to$ hadrons

$\psi(4160)$ PARTIAL WIDTHS

$\Gamma(e^+e^-)$ **Γ_1**

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
0.48 ± 0.22	[9] ABLIKIM	08D	BES2	$e^+e^- \to$ hadrons