

# Babayaga at the BESIII experiment

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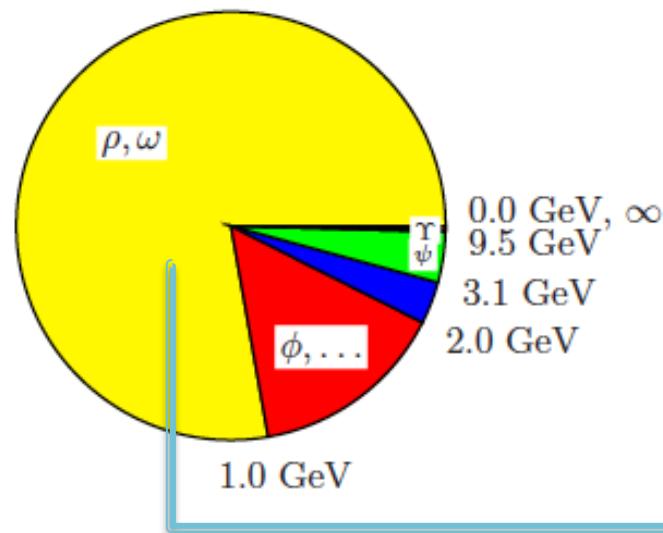
RadioMC Low in Frascati

April 20<sup>th</sup>, 2015



# Hadronic Vacuum Polarization

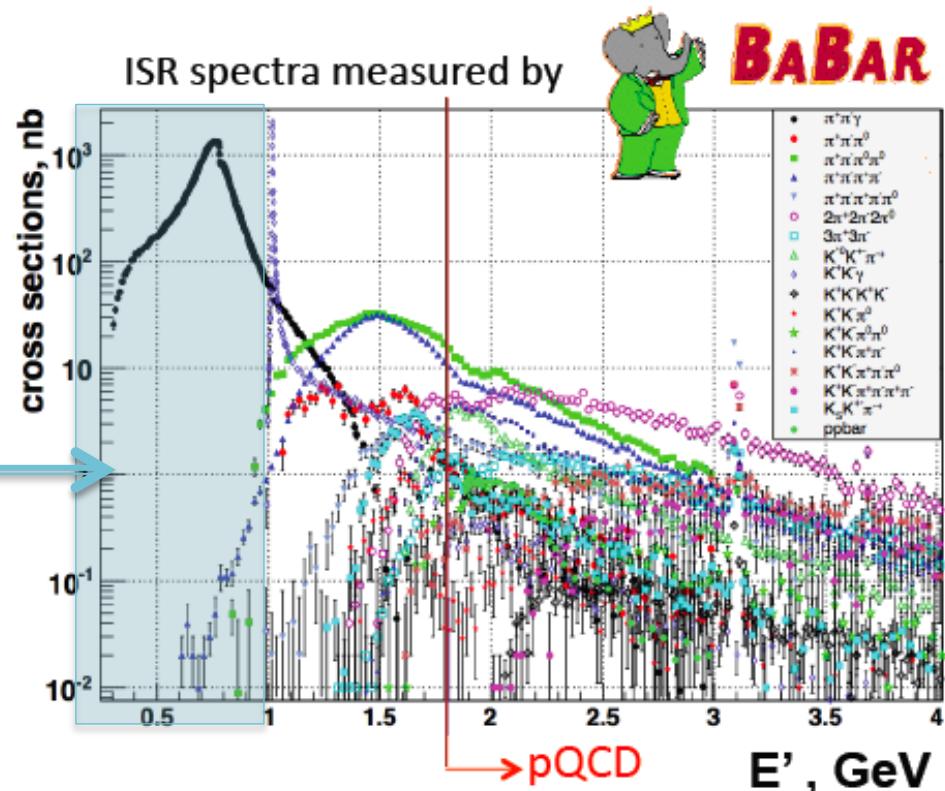
Contributions of hadronic cross sections  
to the hadronic content  $a_\mu^{\text{had}}$  of the  
(g-2) anomaly:



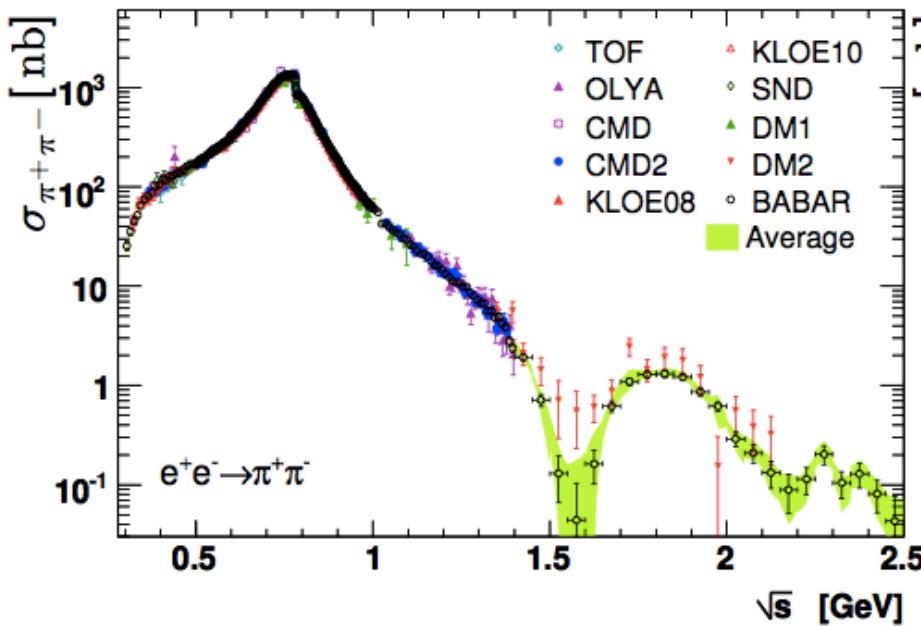
Kernel function  $K(s) \propto \frac{1}{s}$

and cross section  $\sigma(s) \propto \frac{1}{s}$

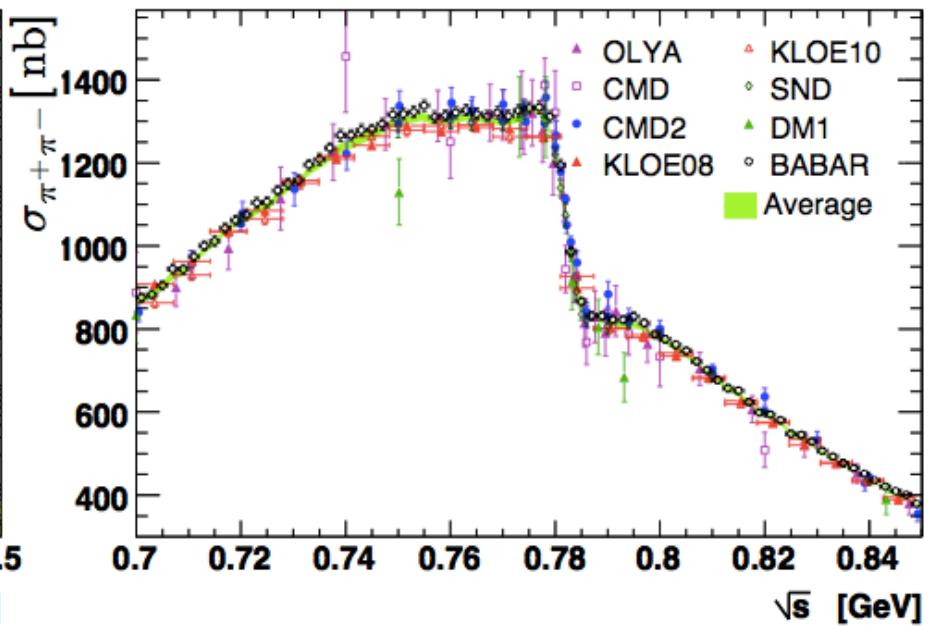
The largest contribution is below 1 GeV.  
Channel  $e^+e^- \rightarrow \pi^+\pi^-$  is the most important one.



# Motivation



- $\rho$  peak
- $\rho - \omega$  interference
- Dip at 1.6 GeV: excited  $\rho$  states
- Dip at 2.2 GeV
- Contribution to  $a_\mu^{\text{had}}$ : 75%!

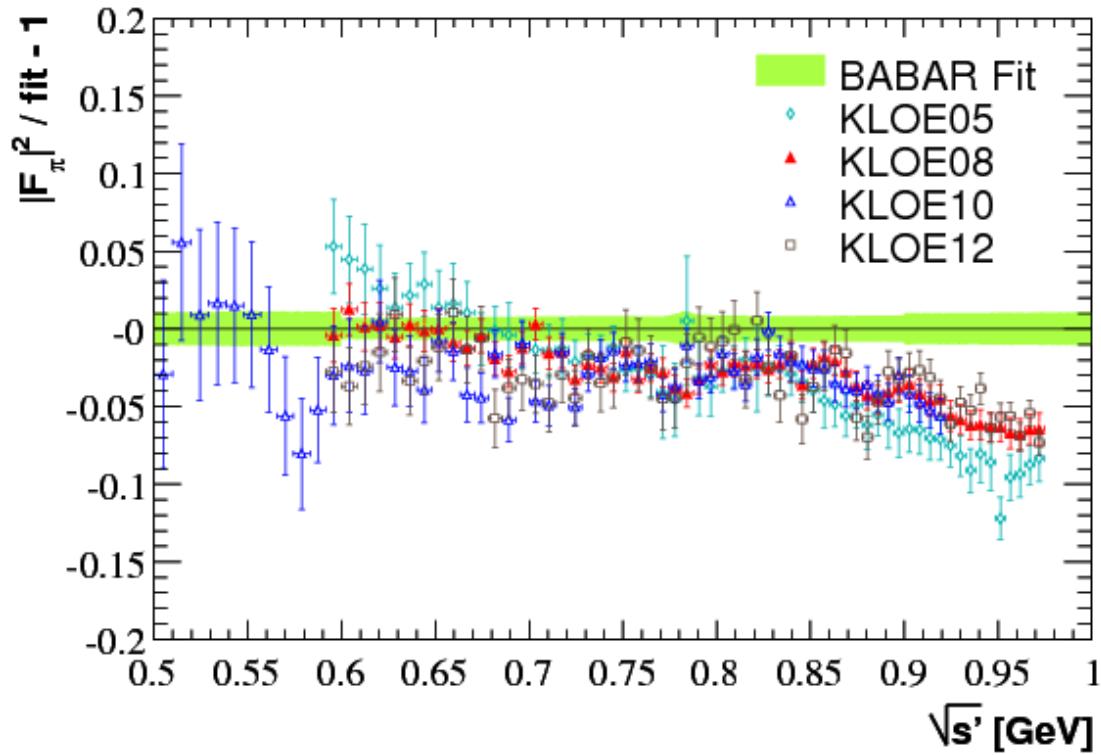


## Systematic Uncertainties ( $\rho$ -region)

$BaBar$ :	0.5%
CMD2:	0.8% (dom. by statistics)
SND:	1.5%
KLOE:	0.8%

# Motivation

Pion Form Factor:  $|F_\pi|^2(s') = \frac{3s'}{\pi\alpha\beta_\pi^3(s')} \sigma(e^+e^- \rightarrow \pi^+\pi^-)(s') , \quad \beta_\pi(s') = \sqrt{1 - \frac{4m_\pi^2}{s'}}$



(note: KLOE05 superseded by KLOE08)

# Motivation

Our goal:

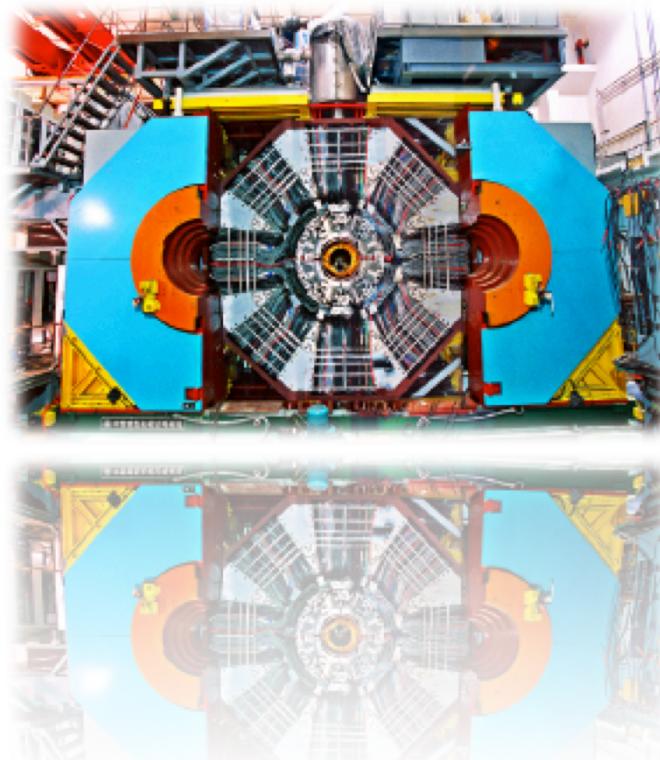
Measurement of the  $e^+e^- \rightarrow \pi^+\pi^-$  cross section  
at the BESIII experiment

with a precision

**in the order of 1%**



# The **BESIII** experiment



# BES III Collaboration

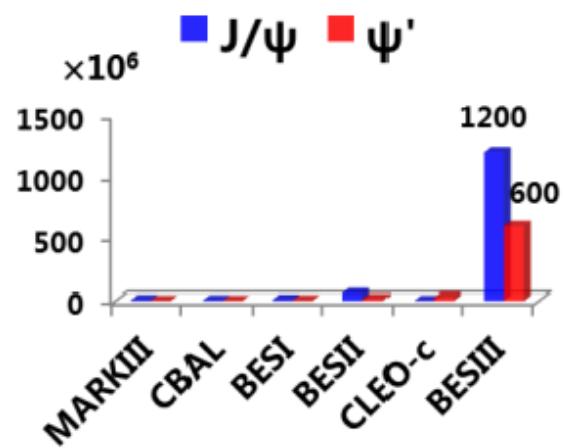
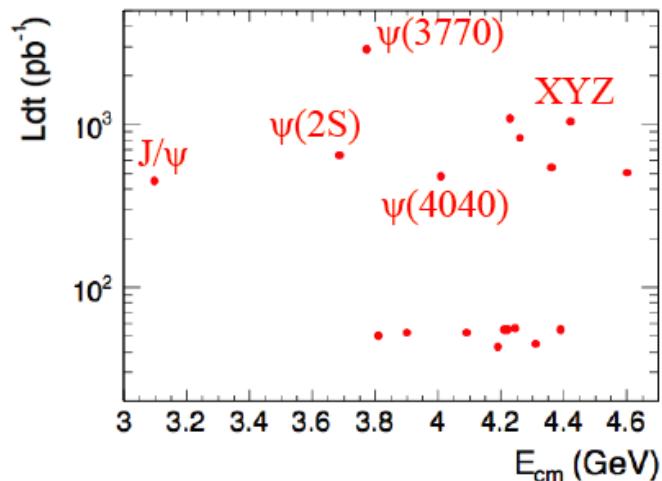
Political Map of the World, June 1999



# BEPC II

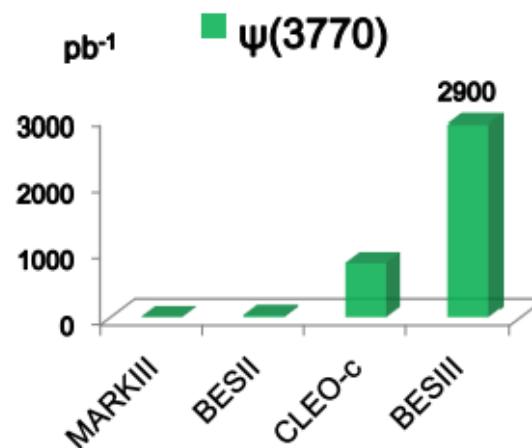


Integrated luminosities BESIII



## BEPCII Collider:

- located in Beijing, China
- symmetric  $e^+e^-$  collider
- $2 \text{ GeV} < E_{CMS} < 4.6 \text{ GeV}$
- data taken at  $\sqrt{s} = 3.77 \text{ GeV} : 2.9 \text{ fb}^{-1}$

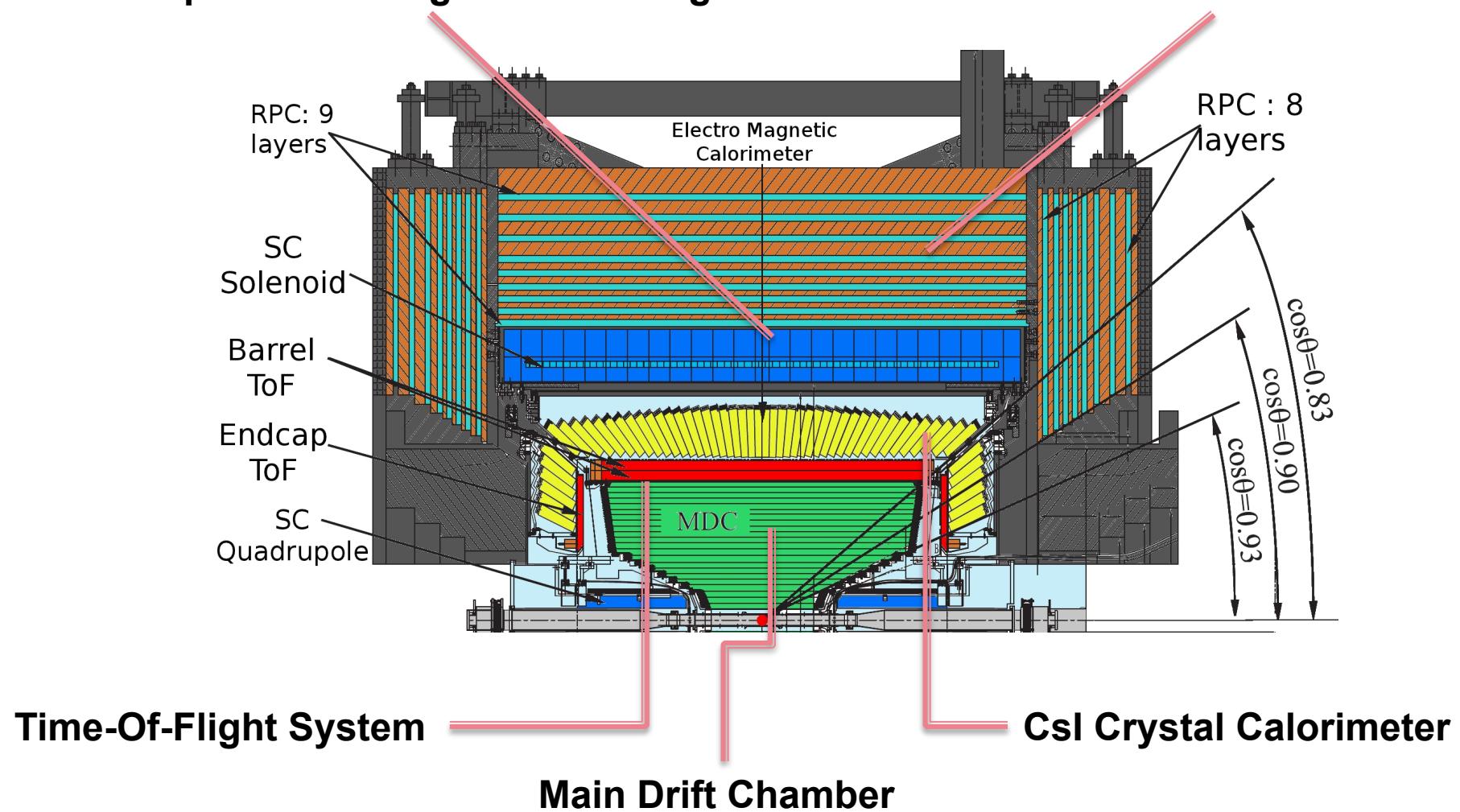


# BESIII detector



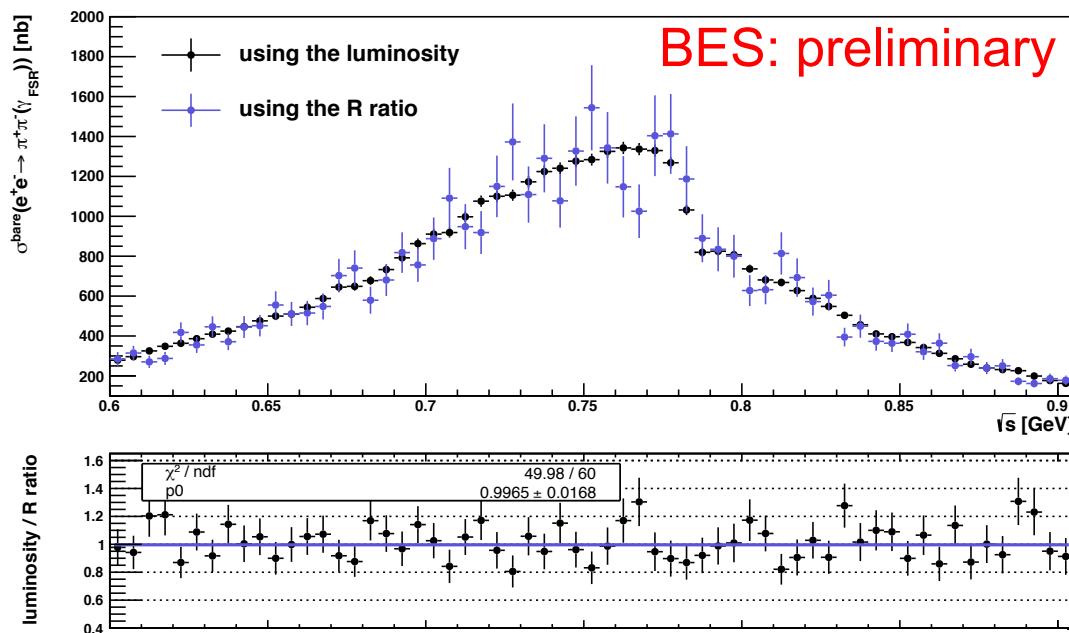
1T superconducting solenoid magnet

Muon Chamber



# Systematic Limitation

Need additional data for  $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$



source	uncertainty (%)
photon efficiency correction	0.2
pion tracking efficiency correction	0.3
pion ANN efficiency correction	0.2
pion e-PID efficiency correction	0.2
ANN	negl.
angular acceptance	0.1
muon background subtraction	0.06
non-muon background subtraction	0.03
unfolding	0.2
FSR correction $\delta_{\text{FSR}}$	0.2
vacuum polarization correction $\delta_{\text{vac}}$	0.2
radiator function	0.5
Luminosity $\mathcal{L}$	1.0
<b>sum</b>	<b>1.3</b>

Systematic uncertainty dominated by uncertainty of luminosity: 1.0%

→ Study the luminosity at  $\psi(3770)$  in detail!

# Luminosity at BESIII

Most precise method: Bhabha events:  $e^+e^- \rightarrow e^+e^-(\gamma)$

Status: Published @ $\psi(3770)$ : 1.0% uncertainty

Uncertainty dominated by:

- Polar angle cut: 0.75%
- Event Generator: 0.5%

Since then:

For XYZ-states: 0.97% uncertainty

Uncertainty dominated by:

- Event generator: 0.5%
- $E_{\text{CMS}}$  uncertainty: 0.42%
- Polar angle cut: 0.1-0.38%

BUT:

- Not Babayaga@NLO
- VERY conservative estimates:  
Largest deviation out of many samples

Sources	$\Delta^{\text{sys}} (\%)$
$ \cos\theta  < 0.80$	0.75
$E_{\text{EMC}}^{e^+} > 1 \text{ GeV}$	0.2
$E_{\text{EMC}}^{e^-} > 1 \text{ GeV}$	0.2
MDC information	0.3
EMC cluster reconstruction	0.03
Monte Carlo statistics	0.1
Background estimation	0.0
Signal region selection ( $\delta\phi$ )	0.01
Trigger efficiency [3]	0.1
Generator [4]	0.5
Total	1.0

Syst. uncertainties @ $\psi(3770)$

# Luminosity at BESIII

**Goal:** improve systematic uncertainty of the luminosity @ $\psi(3770)$

**Strategy:**

1<sup>st</sup> step: repeat  $\psi(3770)$  analysis with the same tools as the published analysis:

- Software framework: BOSS 6.6.2
- Event Generator: Babayaga.3.5
- Same event selection

2<sup>nd</sup> step: improve systematic uncertainties

- Event Generator
  - Different generator: Babayaga@NLO instead of Babayaga.3.5
  - $E_{\text{CMS}}$  smearing/ calibration study
  - Additional checks for Vacuum Polarization in Charmonium region
- Efficiency requirements of analysis selection

# Bhabha event generators

Generator	Theory	Accuracy at BESIII energy
Babayaga v3.5	Parton Shower	0.5%
Bhwid	$O(\alpha)$ + YFS	0.1%
Babayaga@NLO	$O(\alpha)PS$	0.1%

Let's use Babayaga@NLO instead of Babayaga.3.5.

Problem occurred with Babayaga@NLO:

- Numerical problems sampling the phase-space region close to Charmonium resonances
- Resulting problem: cross section uncertainty better than ~0.5% not feasible
- Babayaga authors wrote a special version
  - Numerical issue solved
  - Additional tool to test uncertainty due to VP

➤ Thanks to Carlo Carloni Calame, Guido Montagna, Oreste Nicrosini, Fulvio Piccinini

# Event Selection

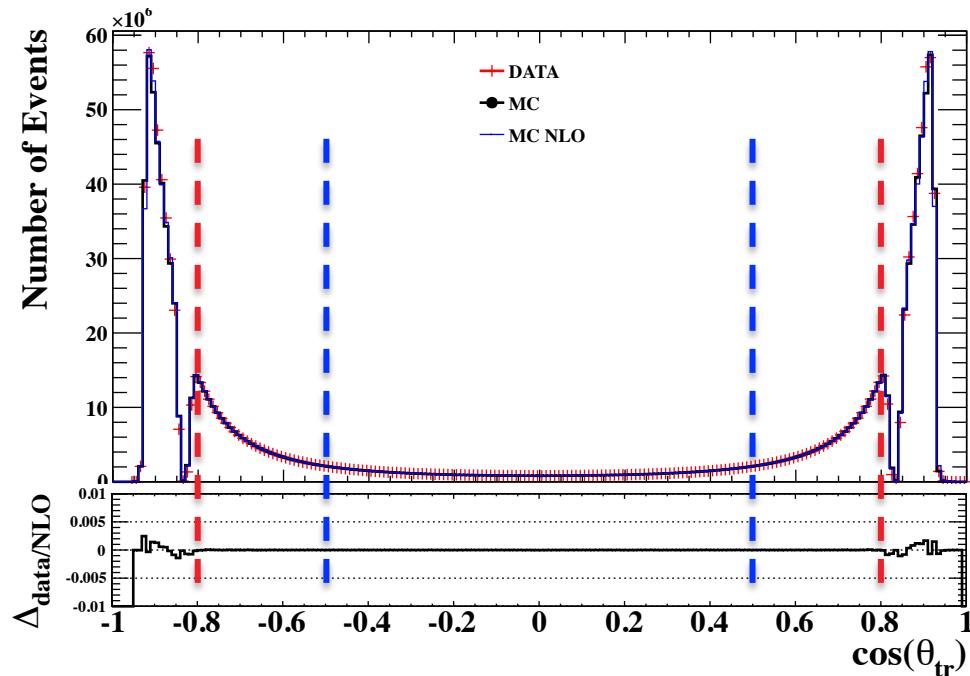
Selection of “clean”  $e^+e^- \rightarrow e^+e^-(\gamma)$  events:

- $V_{xy} < 1 \text{ cm}$
- $|V_z| < 10 \text{ cm}$
- $|\cos(\theta)| < 0.8$
- $E_{\text{EMC}} > 0.73 E_{\text{beam}} = 1.38 \text{ GeV}$
- $P > 0.94 E_{\text{beam}} = 1.77 \text{ GeV}$

➔ Well understood-region of the detector & no background

# Kinematic Distributions

Selection of “clean”  $e^+e^- \rightarrow e^+e^- (\gamma)$  events:  
Stay in **fiducial detection region**: barrel of EMC



standard selection:  $|\cos(\theta)| < 0.8$

$ \cos(\theta)  <$	$\Delta(\text{Data-MC})$
0.75	0.05%
0.7	0.08%
0.6	0.12%
0.5	0.16%

$N(|\cos(\theta)| < 0.8) = 3 * N(|\cos(\theta)| < 0.6)$  and data-MC difference is 0.12%!

# What do we measure?

Luminosity definition:

$$L = (N_{\text{data}} - N_{\text{bkg}}) / (\sigma_{\text{MC}} * \epsilon_{\text{MC}})$$

→ Need to test  $\epsilon_{\text{MC}}$  and  $\sigma_{\text{MC}}$

Babayaga	$\sigma_{\text{MC}}$	$\epsilon_{\text{MC}}$	Luminosity [pb-1]
3.5	$519.9 \pm 0.1_{\text{stat}}$	$(14.285 \pm 0.002) \%$	...
NLO	$511.4 \pm 0.2_{\text{stat}}$	$(14.478 \pm 0.007) \%$	...

- $\sigma_{\text{MC}}$  shows a difference of 1.6%!
- Relative  $\epsilon_{\text{MC}}$  difference cancels this effect to 0.2-0.3%
- Babayaga.3.5 produces additional inefficient MC events
- Highly energetic photons?

# Further systematic tests

Vacuum Polarization at the  $\psi''(3773)$  and  $J/\psi$

Parametrization depends on 3 parameters

Vary parameters within 1 s.d. of its uncertainties

$E_{CM}$ of $\psi(3773)$	$\sigma$ (nb)	$E_{CM}$ of $J/\psi$	$\sigma$ (nb)
standard	$511.34 \pm 0.7_{\text{stat}}$	standard	$2981 \pm 13_{\text{stat}}$
Upper deviation	$510.38 \pm 0.7_{\text{stat}}$	Upper deviation	$3022 \pm 13_{\text{stat}}$
Lower deviation	$511.31 \pm 0.7_{\text{stat}}$	Lower deviation	$2210 \pm 8_{\text{stat}}$

➔ < 0.01%

➔ up to 25%

VP uncertainty not important for  
the  $\psi''(3773)$ , but for the  $J/\psi$

# Further systematic tests

Center-of-Mass energy calibration:

Assume  $E_{CM} = (3773 \pm 2)$  MeV

$E_{CM}$ (MeV)	$\sigma$ (nb)	$\epsilon_{MC}$	Luminosity [pb-1]
3773	$511.3 \pm 0.7_{\text{stat}}$	$(14.478 \pm 0.007) \%$	...
3775	$510.8 \pm 0.7_{\text{stat}}$	$(14.528 \pm 0.011) \%$	...
3771	$511.8 \pm 0.7_{\text{stat}}$	$(14.472 \pm 0.011) \%$	...

→ < 0.2%

→ Propose systematic uncertainty of 0.2%

# Systematic Uncertainty

Sources	$\Delta^{\text{sys}} (\%)$
$ \cos\theta  < 0.80$	0.75
$E_{\text{EMC}}^e > 1 \text{ GeV}$	0.2
$E_{\text{EMC}}^e > 1 \text{ GeV}$	0.2
MDC information	0.3
EMC cluster reconstruction	0.03
Monte Carlo statistics	0.1
Background estimation	0.0
Signal region selection ( $\delta\phi$ )	0.01
Trigger efficiency [3]	0.1
Generator [4]	0.5
Total	1.0

sources	$\Delta^{\text{sys}} (\%)$
$ \cos\theta  < 0.8$	0.2
$E_{\text{EMC}} > 1.37 \text{ GeV}$	0.1
$P_{\text{tr}} > 1.4 \text{ GeV}$	0.2
$E_{\text{CMS}} \text{ calib.}$	0.2
Generator+VP	0.1
Rest: identical	0.3
Total	0.5-0.6

# Summary

- Luminosity with Babayaga@NLO @ $\psi(3770)$  measured
- Uncertainty due to VP negligible at the  $\psi(3770)$ , but not at J/ $\psi$
- Luminosity uncertainty of 0.5-0.6%
- Expected uncertainty for  $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ : 0.9-1.0%

# Back-Up

# Luminosity at BESIII

## Status:

Luminosity measurement for XYZ states:

16 scan points btw. 3.81- 4.42 GeV

Systematic uncertainty: 1%

Dominated by:

- 0.5% uncertainty due to Bhabha event generator: Babayaga.3.5
- 0.42% uncertainty due to energy calibration (VERY conservative!)

## Wanted:

Luminosity for  $\sigma(\pi^+\pi^-)$  ISR-measurement at  $\psi(2s)$  with systematic uncertainty <1%

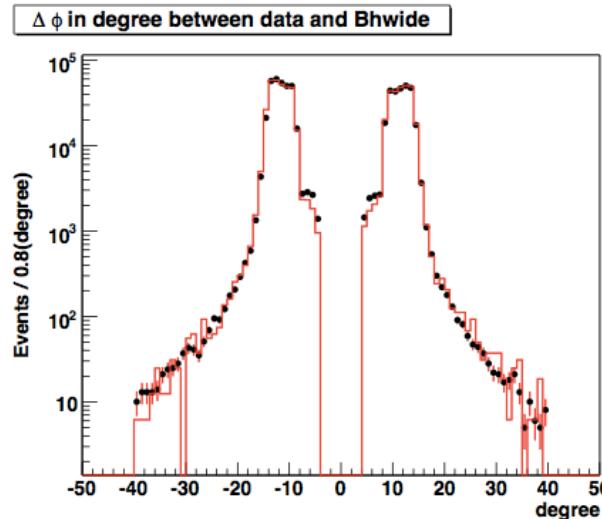
## Questions:

Why Babayaga.3.5 instead of Babayaga@NLO?

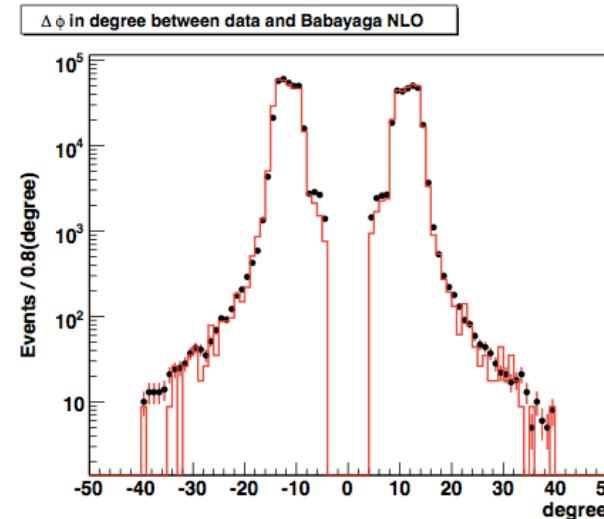
# Luminosity at BESIII

Why babayaga.3.5?

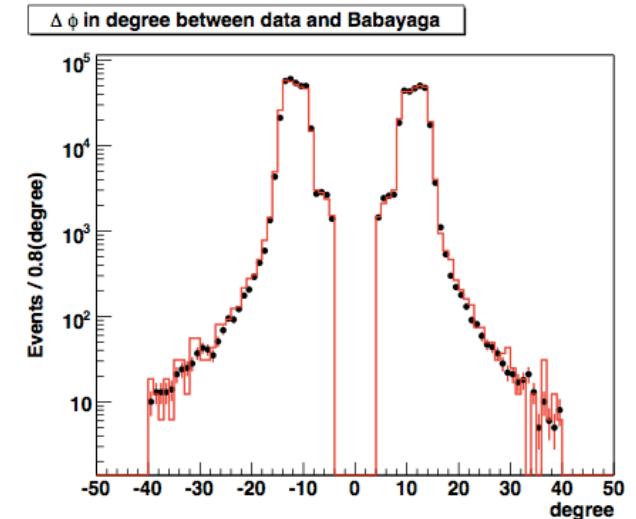
$$\Delta\phi = |\phi_{cluster1} - \phi_{cluster2}| - 180^\circ$$



(a) Bhwide

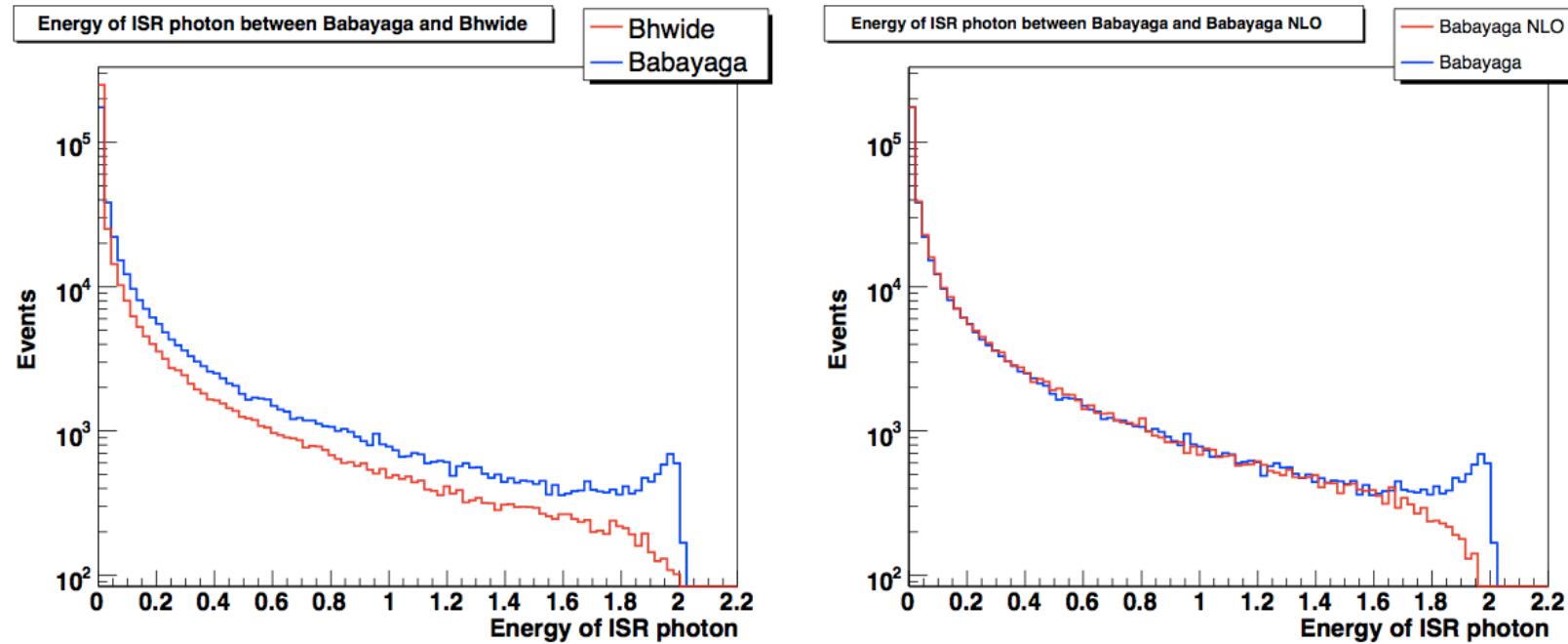


(b) Babayaga@NLO



(c) Babayaga v3.5

# Luminosity at BESIII



(a) Babayaga V3.5 V.S. Bhwide

(b) Babayaga V3.5 V.S.  
Babayaga@NLO

Do we understand difference btw. Babayaga.3.5 and Babayaga@NLO?  
Does it matter quantitatively?

# Summary

- understand 3.5 vs NLO difference quantitatively
- convince us to use babayaga@NLO
- reduce luminosity uncertainty on  $\psi(2s)$  to <1%

# $\pi^0$ -transition form factor

Do we understand difference btw. Babayaga.3.5 and Babayaga@NLO?  
Does it matter quantitatively?