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

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for the BESIII Collaboration

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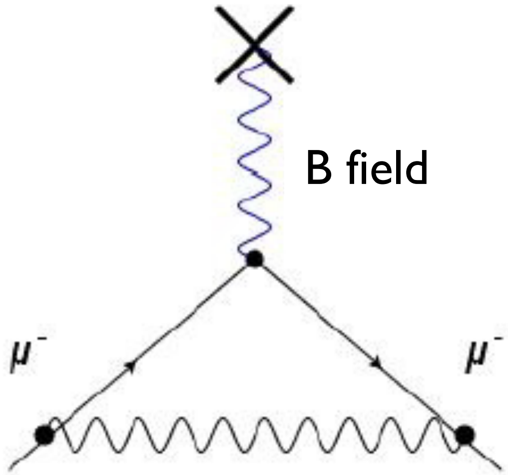
Very basic cross section and form factor!

Motivation:
The anomalous magnetic moment of the muon



The anomalous magnetic moment

Our goal: Measurement of hadronic cross section as input for

$$a_\mu = \frac{g_\mu - 2}{2}$$

experimental measurement: $a_\mu^{exp} = (11659208.9 \pm 6.3) \cdot 10^{-10}$

PRD 73, 072(2006)

theoretical prediction: $a_\mu^{SM} = (11659580.2 \pm 4.9) \cdot 10^{-10}$

Eur. Phys. J. C71, 1515(2011)

⇒ **discrepancy:** 3.6 standard deviations

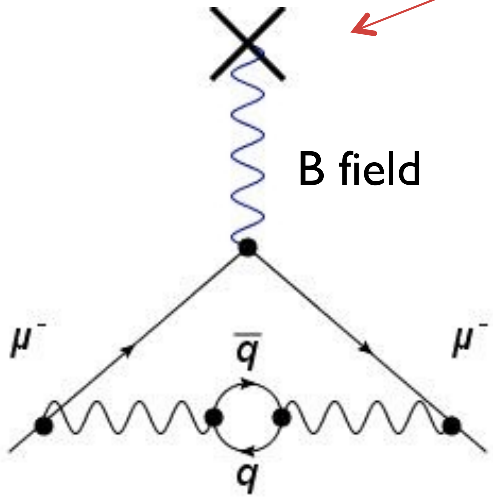
The anomalous magnetic moment

Theoretical prediction: $a_\mu^{SM} = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{hadr}$

↓ can not be calculated by means of perturbative calculations

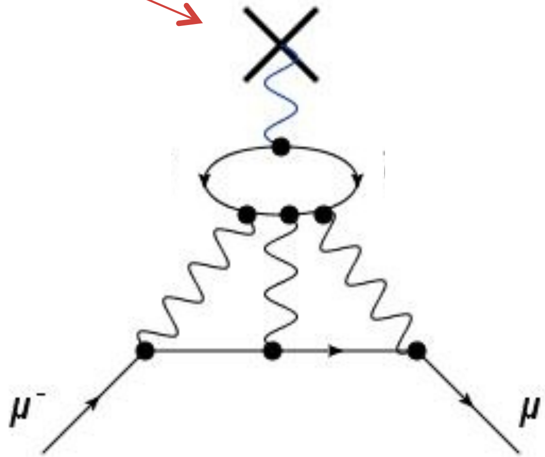
The anomalous magnetic moment

Theoretical prediction: $a_\mu^{SM} = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{hadr}$



hadronic vacuum polarization:

$a_\mu^{hadr,VP} = (692.2 \pm 4.2) \cdot 10^{-10}$ Davier et al.



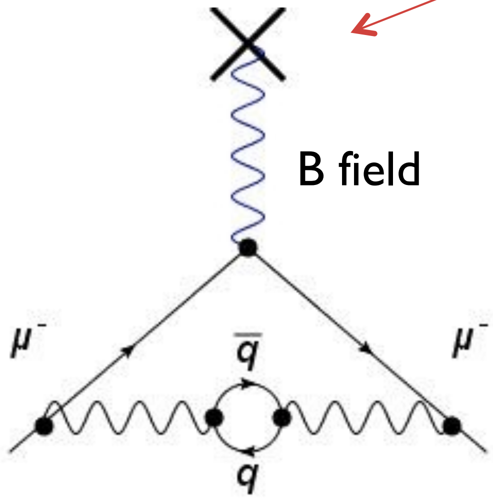
hadronic light-by-light scattering:

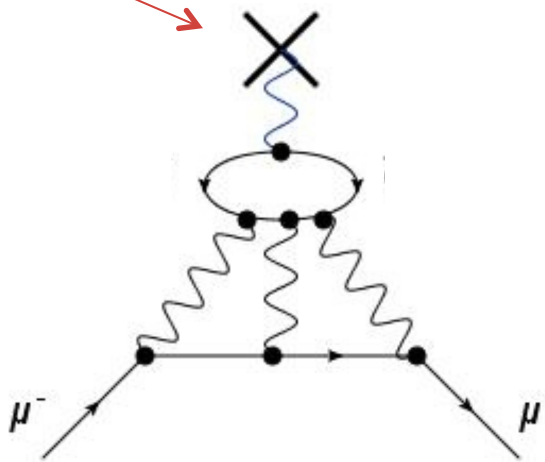
$a_\mu^{hadr,LBL} = (10.5 \pm 2.6) \cdot 10^{-10}$ Prades et al.

$(11.6 \pm 4.0) \cdot 10^{-10}$ Nyffeler

The anomalous magnetic moment

Theoretical prediction: $a_\mu^{SM} = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{hadr}$





hadronic vacuum polarization:

$a_\mu^{hadr,VP} = (692.2 \pm 4.2) \cdot 10^{-10}$ Davier et al.

Dispersion reslation

$$a_\mu^{hadr,VP} \cong \frac{1}{4\pi^3} \int_{4m_\pi^2}^{\infty} K(s)\sigma(e^+e^- \to hadr)ds$$

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

hadronic light-by-light scattering:

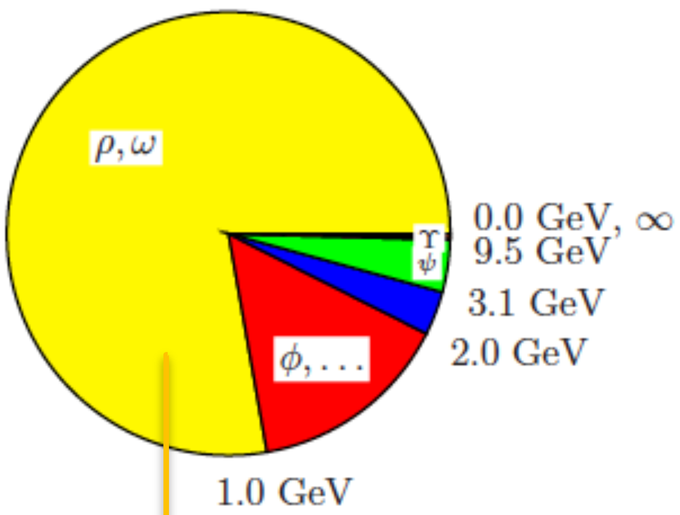
$a_\mu^{hadr,LBL} = (10.5 \pm 2.6) \cdot 10^{-10}$ Prades et al.

$(11.6 \pm 4.0) \cdot 10^{-10}$ Nyffeler

model dependent

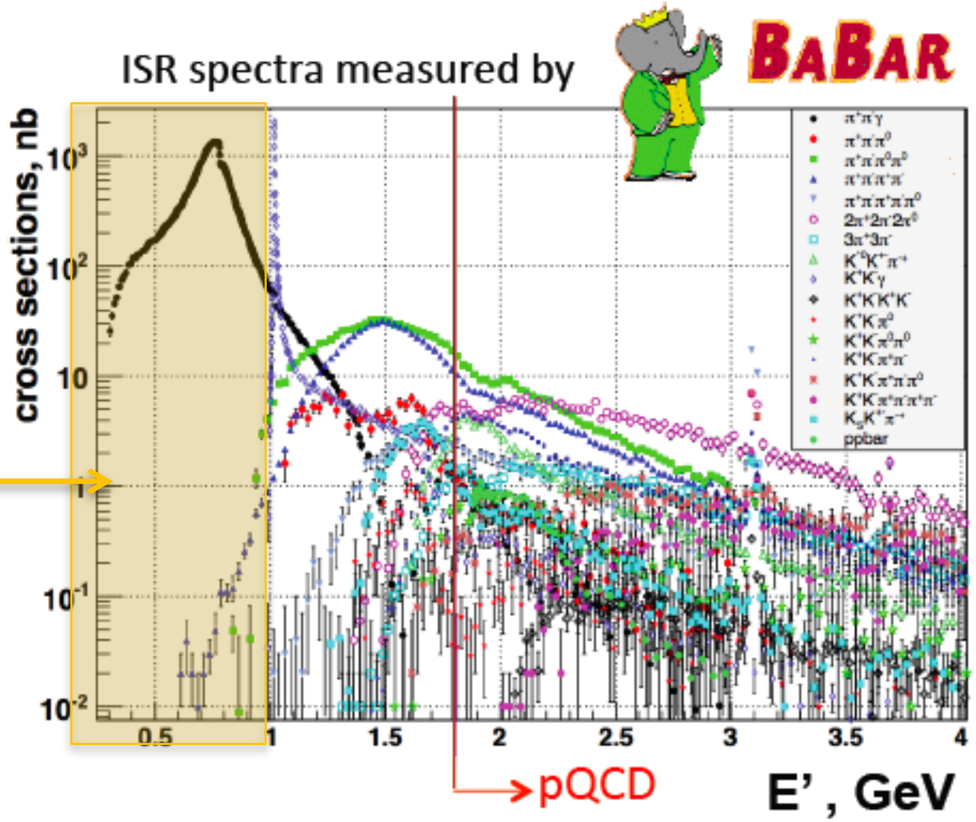
Hadronic Vacuum Polarization

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



The largest contribution is below 1 GeV.

Channel $e^+e^- \rightarrow \pi^+\pi^-$ is the most important one.

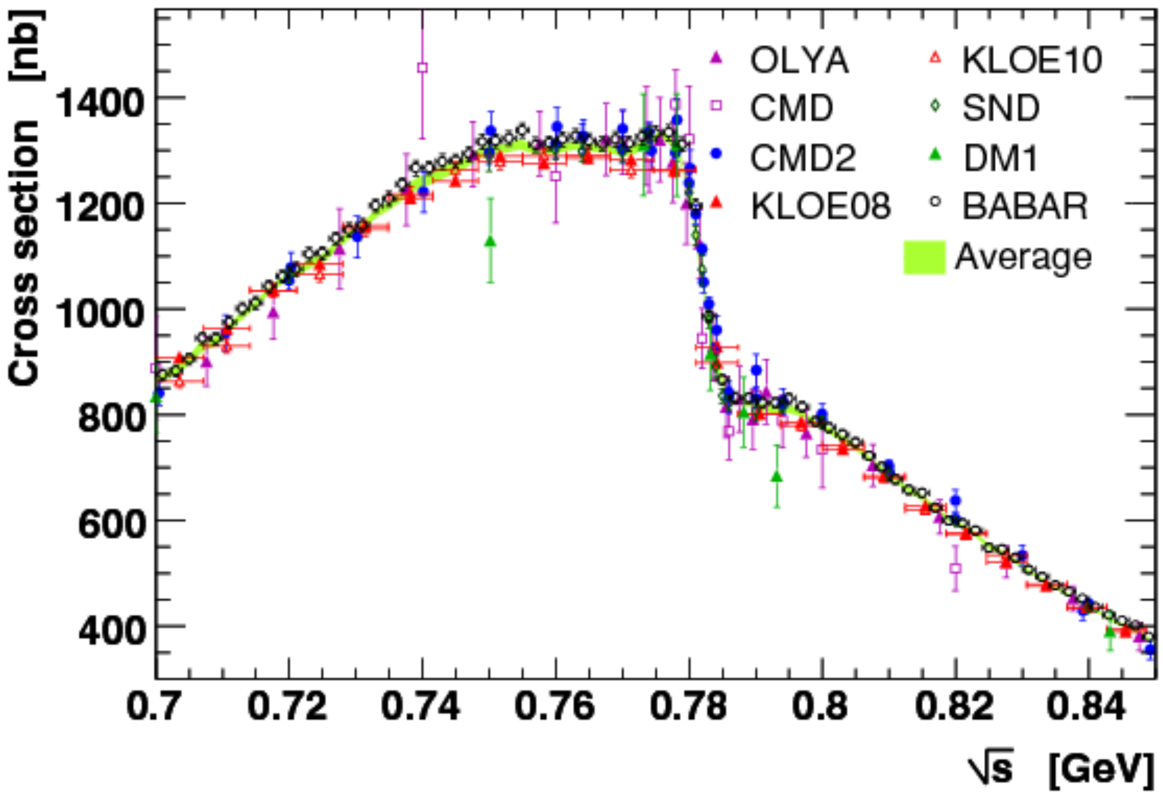


Kernel function $K(s) \propto \frac{1}{s}$

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

Hadronic Vacuum Polarization

This has already been measured with high precision among others at BaBar, KLOE, CMD2, and SND.



Systematic uncertainties:

BaBar:	0.5%
KLOE:	0.8%
CMD2:	0.8% (limited by statistics)
SND:	1.5% (limited by statistics)

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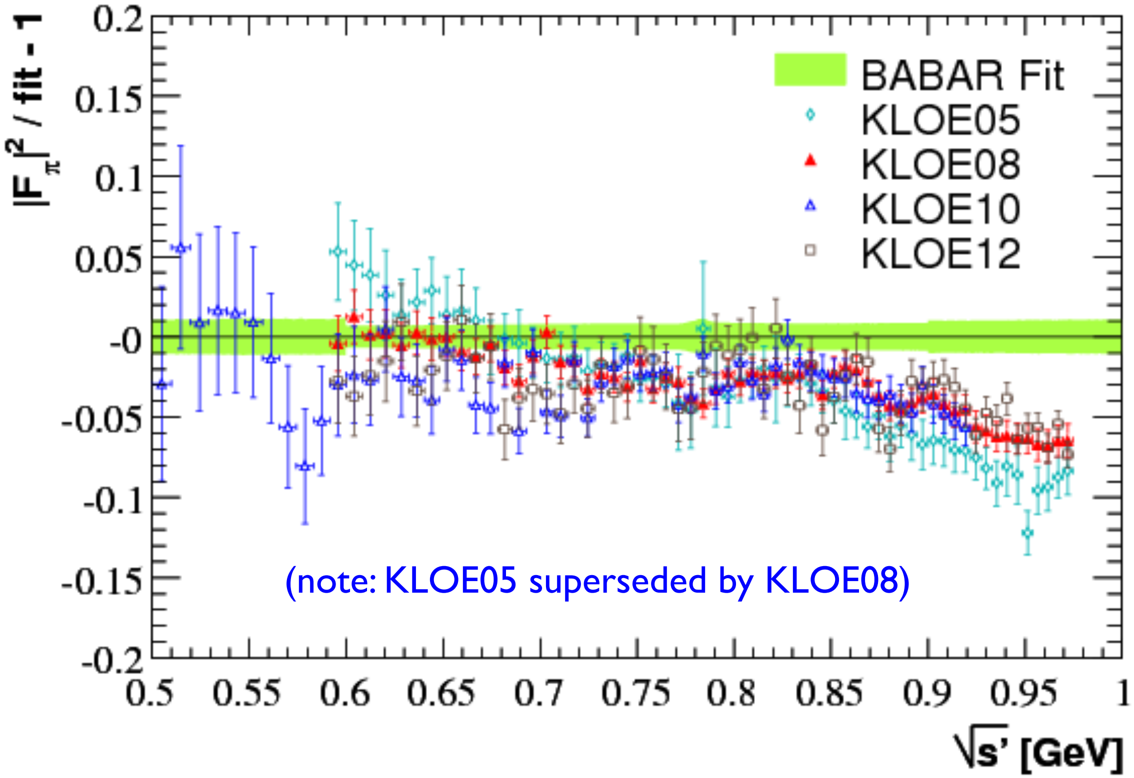
Hadronic Vacuum Polarization

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

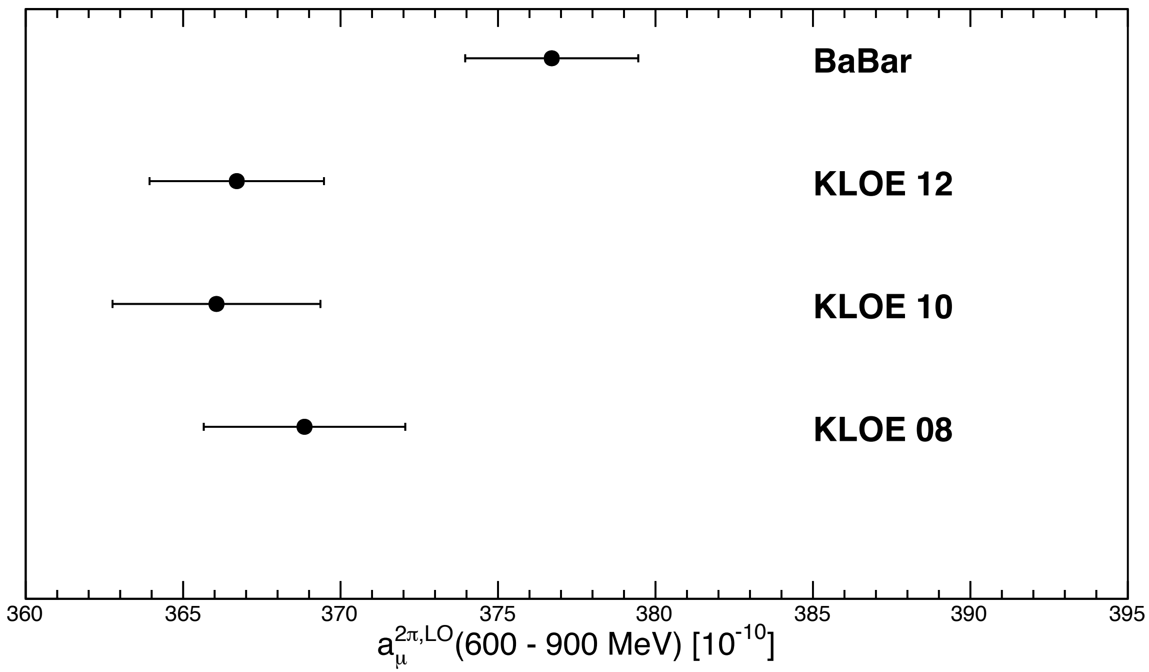


KLOE08: untagged ISR, normalization to radiator function
KLOE10: tagged ISR, normalization to radiator function
KLOE12: untagged ISR, normalization to $\mu^+\mu^-\gamma$ events (as BaBar)

Hadronic Vacuum Polarization

This leads to different values for $a_\mu^{hadr;VP} \cong \frac{1}{4\pi^3}\int_{4m_\pi^2}^{\infty} K(s)\sigma(e^+e^- \to hadr)ds$

Δa_μ reduces to 2.4σ, when using BaBar data only.



2π contribution

mass range we have studied at BESIII: 600 – 900 MeV

→ ~ 70% of 2π contribution

→ ~ 50% of $a_\mu^{hadr,VP}$

Hadronic Vacuum Polarization

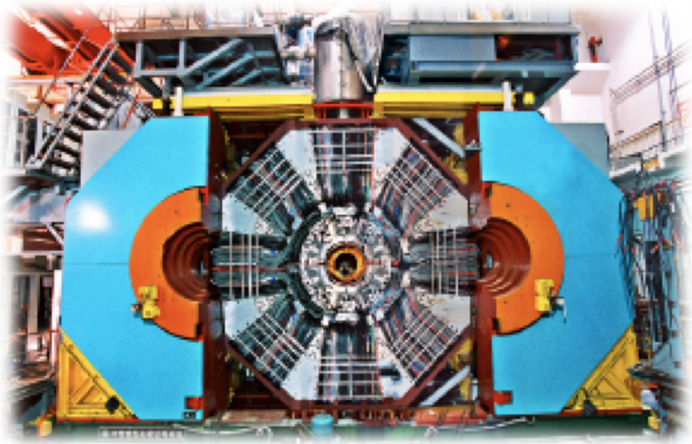
Our goal:

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



BESIII Collaboration

Political Map of the World, June 1999

Europe (13)

Germany: Univ. of Bochum, Univ. of Giessen, GSI, Univ. of Johannes Gutenberg, Helmholtz Ins. In Mainz

Russia: JINR Dubna; BINP Novosibirsk

Italy: Univ. of Torino, Univ. of Ferrara, Frascati Lab

Netherland : KVI/Univ. of Groningen

Sweden: Uppsala Univ.

Turkey: Turkey Accelerator Center

US (5)

Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

China(31)

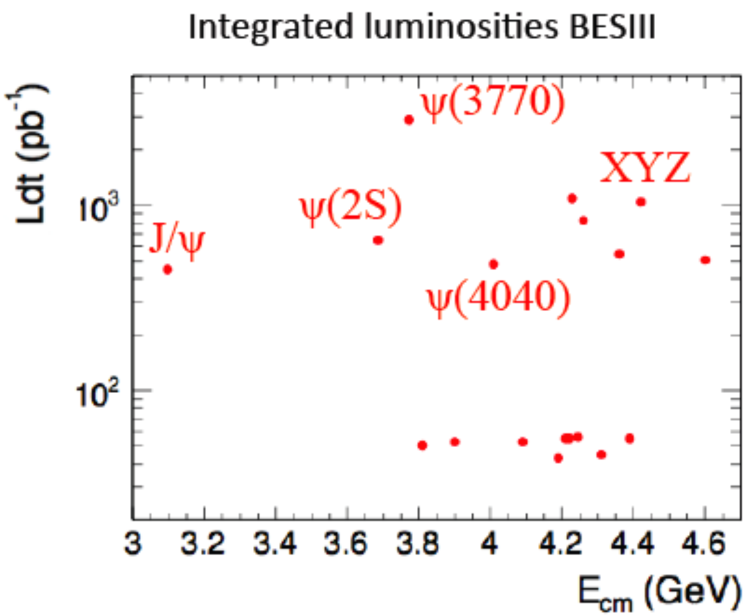
IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Beihang Univ., Beijing Petrol Chemical Univ.

BESIII

~400 members
53 institutions from 11 countries

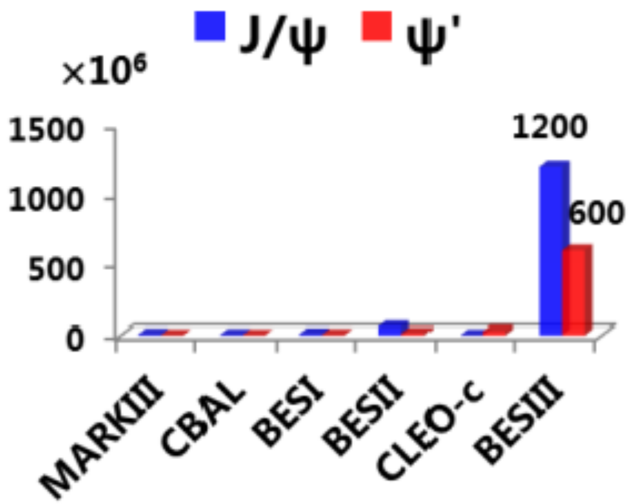
IHEP, Beijing

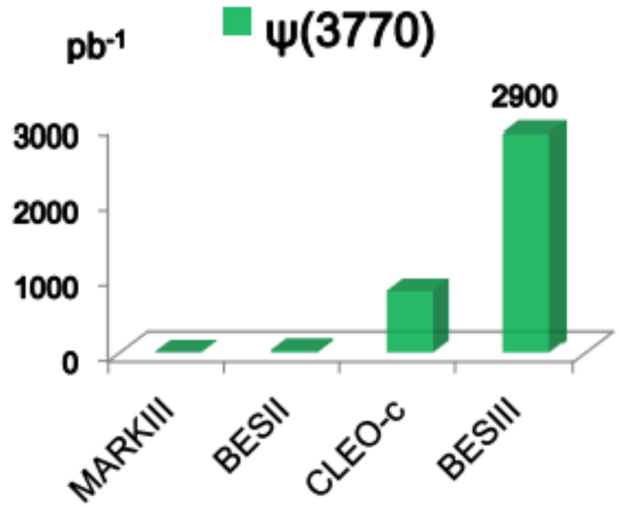
BEPCII



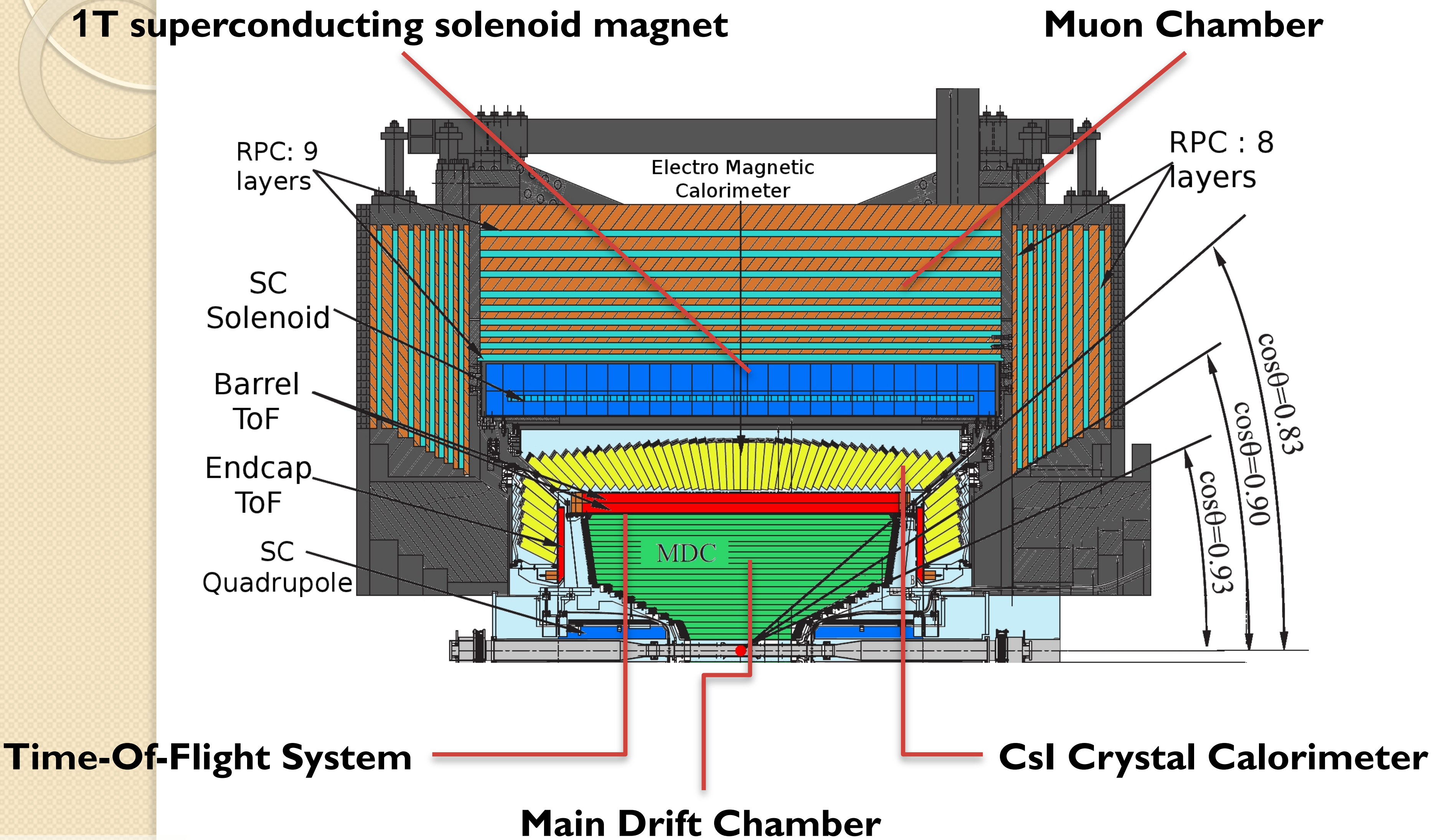
BEPCII Collider:

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



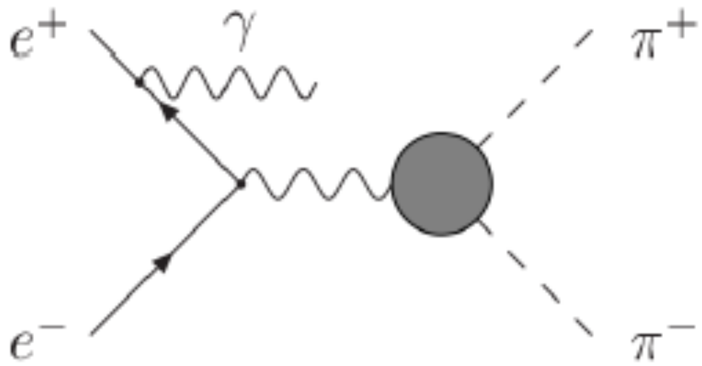


BESIII Detector



(Graphic produced by Matthias Ulrich, Gießen)

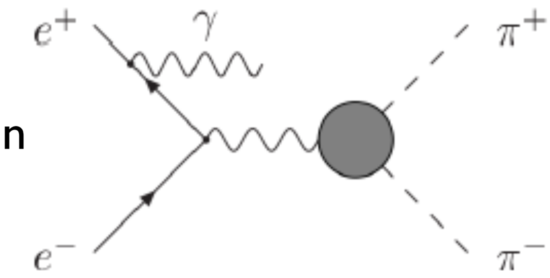
Initial State Radiation Analysis

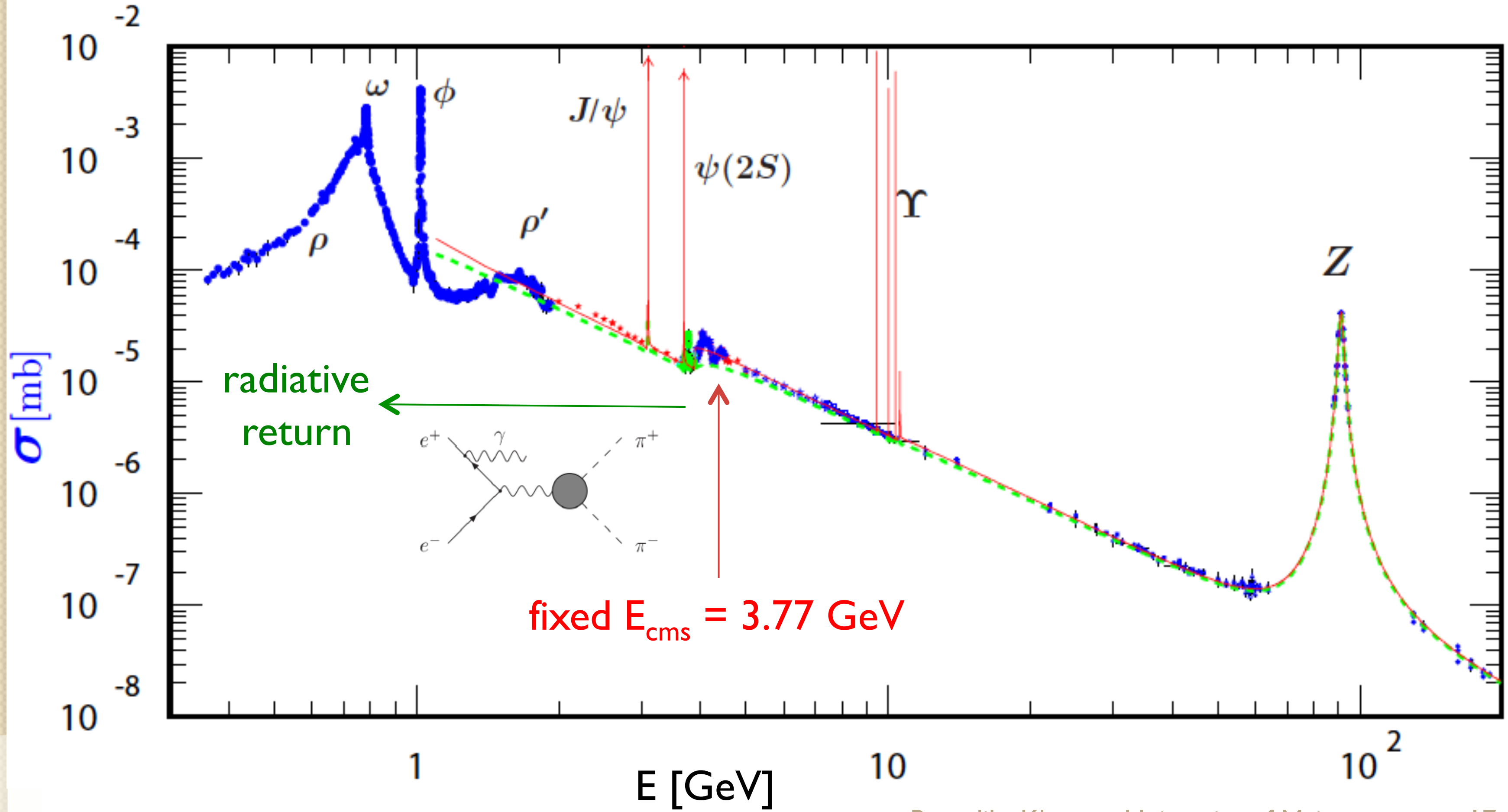


Initial State Radiation

- photon emitted in the initial state
- nominal energy lowered by the energy of the emitted photon

  ⇒ measurements at different energies possible

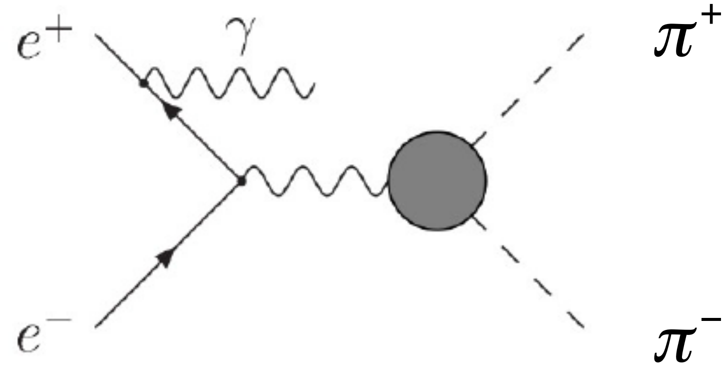




Initial State Radiation

Study the channel

$$e^+e^- \to \pi^+\pi^-\gamma_{ISR}$$



to measure the cross section of $e^+e^- \to \pi^+\pi^-$

via

$$\frac{d\sigma_{ISR}(M_{2\pi})}{dM_{2\pi}} = \frac{2M_{2\pi}}{s} W(s,x,\theta_\gamma)\cdot \sigma(M_{2\pi})$$

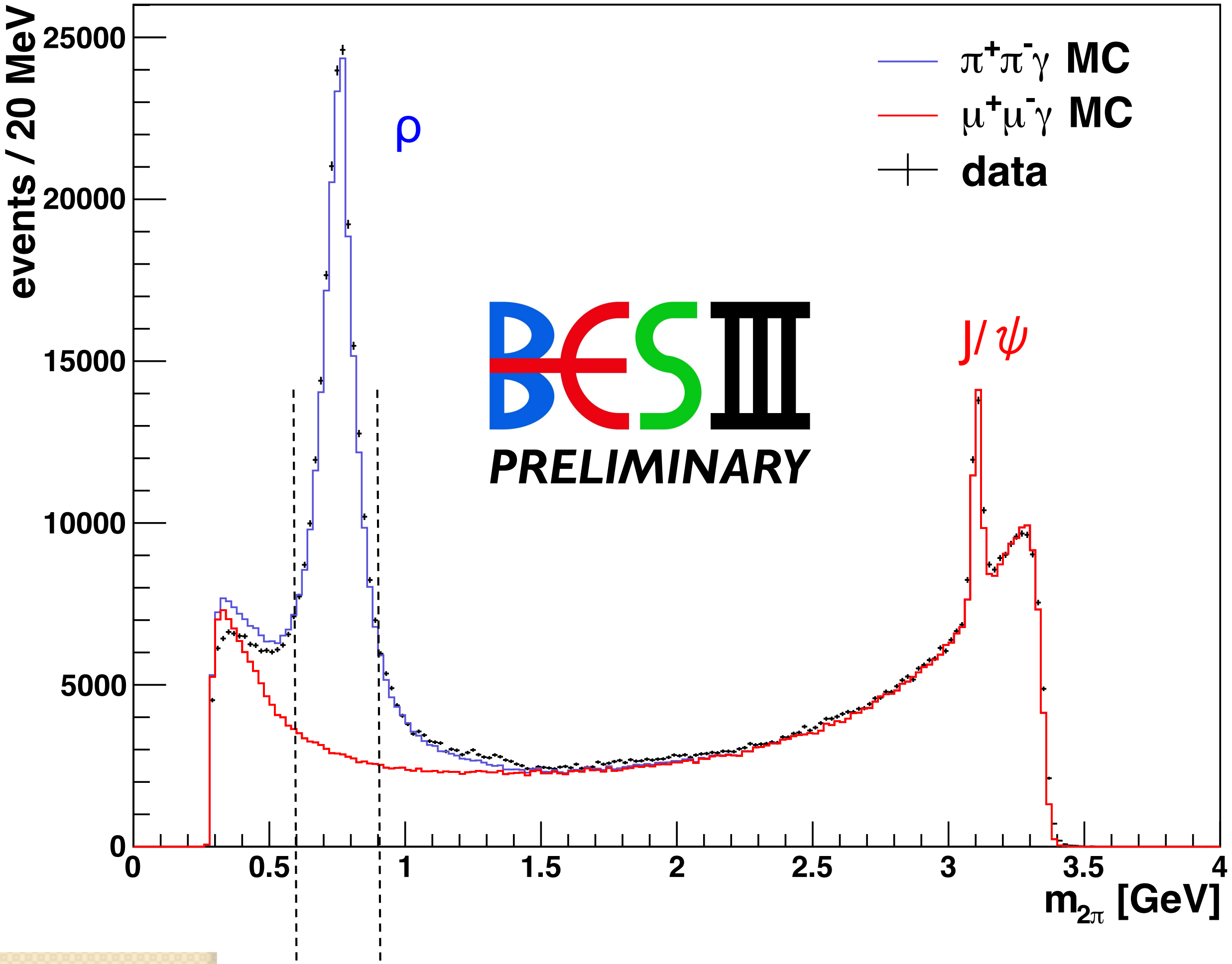
(neglecting FSR)

invariant mass of 2π

Radiator function

ISR analysis

acceptance requirements only



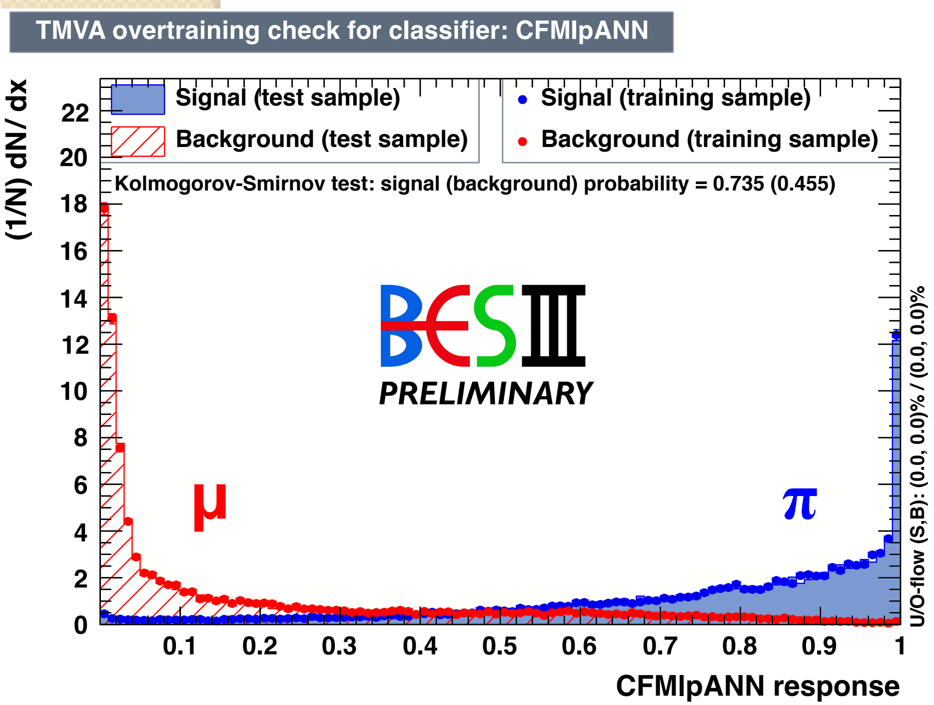
initial publication

- 2.9 fb^{-1}, taken at 3.77 GeV
- detected ISR photon
- MC produced with Phokhara
  Eur.Phys.J. C**24**:71-82 (2002)
- main background: $\mu^+\mu^-\gamma$
- data-MC differences visible
- initial publication: 600 – 900 MeV

ISR analysis

Muon suppression:

- TMVA method (Neural Network)
- trained with MC events
- efficiency matrix (p, Θ) for data-MC
- track-based data-MC corrections
- cross checked for different TMVA methods



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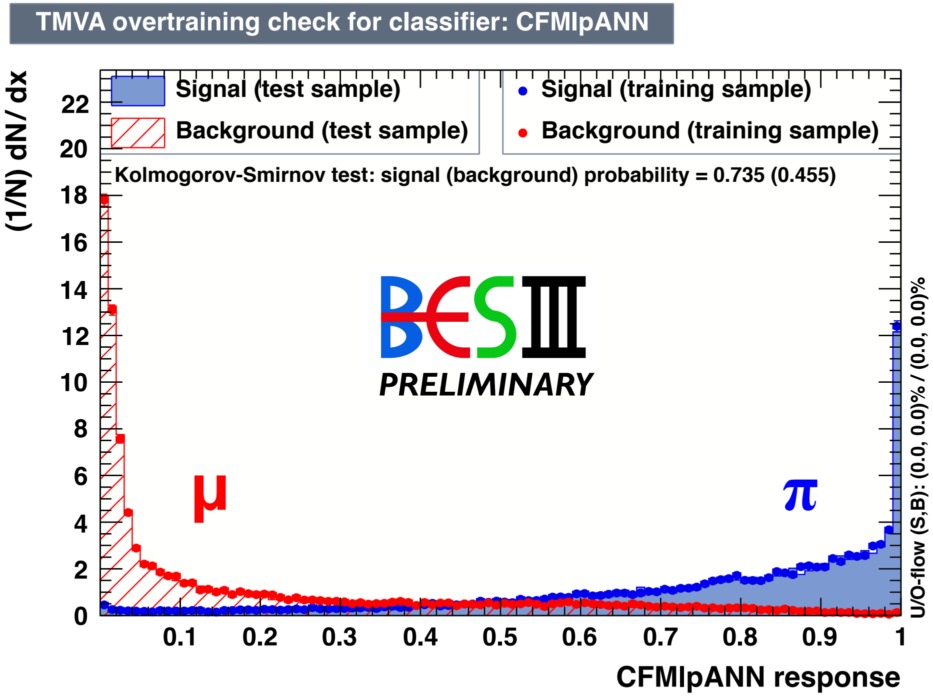
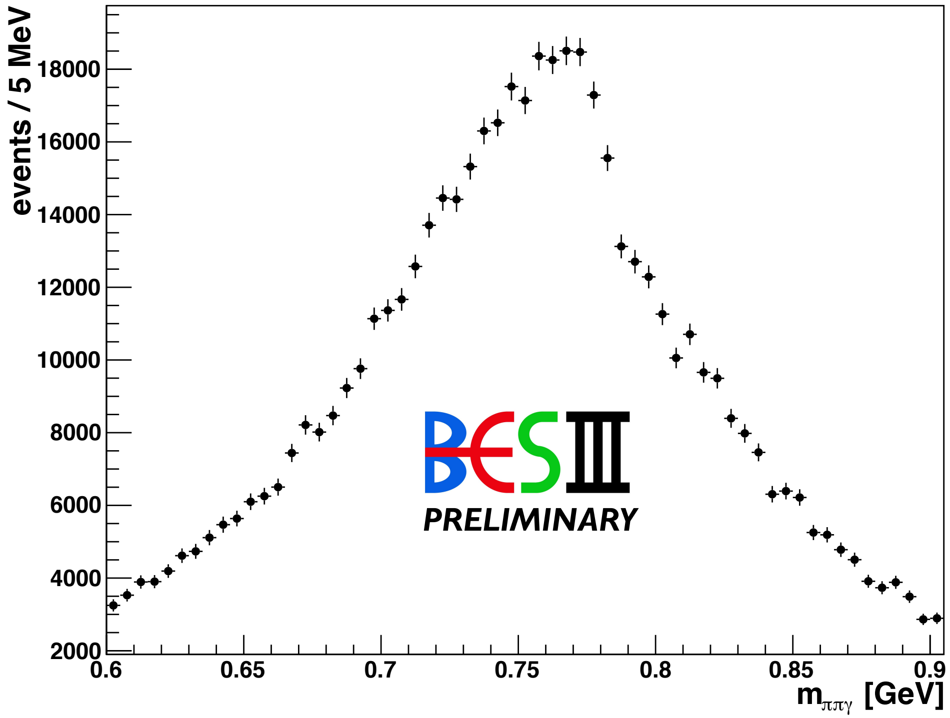


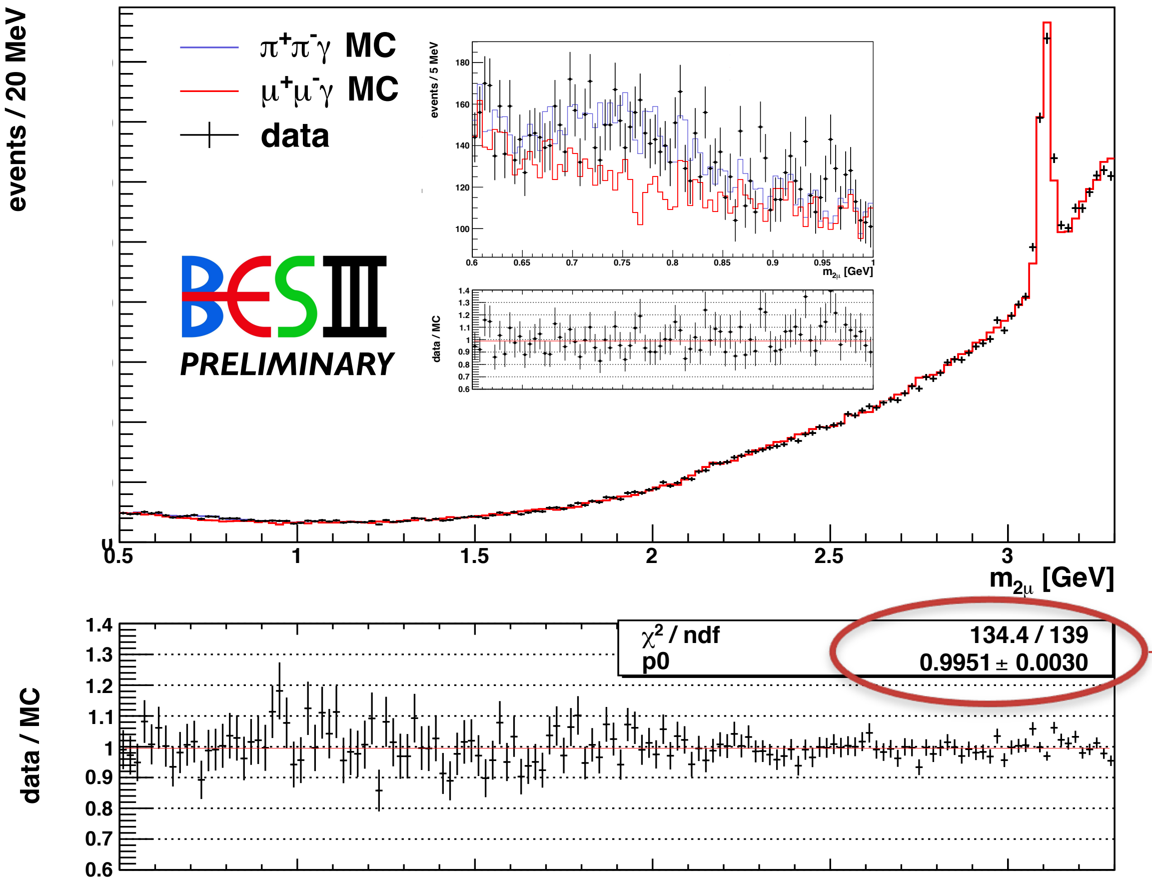
Event yield:

- selection requirements and ANN applied
- after background subtraction



Data vs. QED

reverse selection: $\mu^+\mu^-\gamma$



- $\pi^+\pi^-\gamma$ background very small
- PHOKHARA accuracy < 0.5%
- luminosity accuracy 1.0%
- after data-MC efficiency corrections

→ excellent agreement with QED

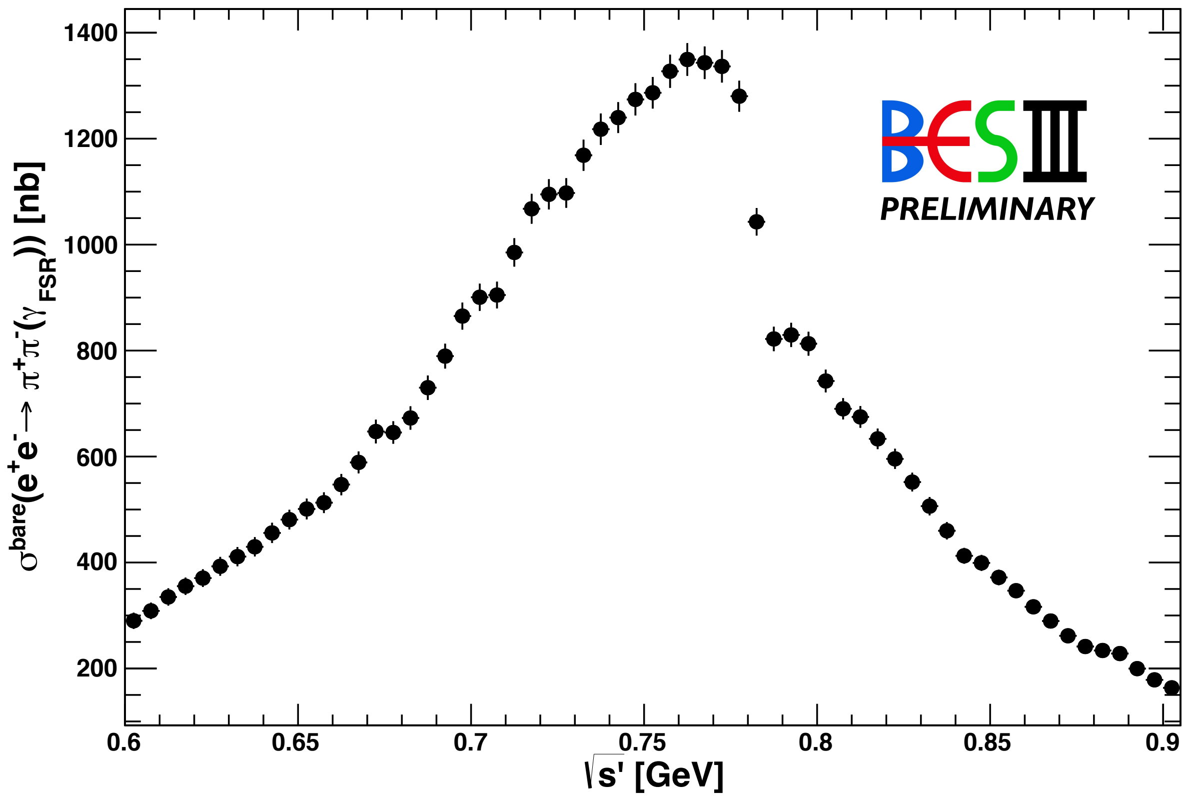
Δ(data/QED) = (0.49 ± 0.30) %

statistical error only

Normalization methods

1.) Normalization to integrated luminosity L_{int}

$$\sigma^{bare}(e^+e^- \rightarrow \pi^+\pi^-(\gamma_{FSR})) = \frac{N_{\pi\pi\gamma}/\varepsilon}{L_{\text{int}} \cdot H_{rad} \cdot \delta_{vac} \cdot (1+\delta_{FSR})}$$



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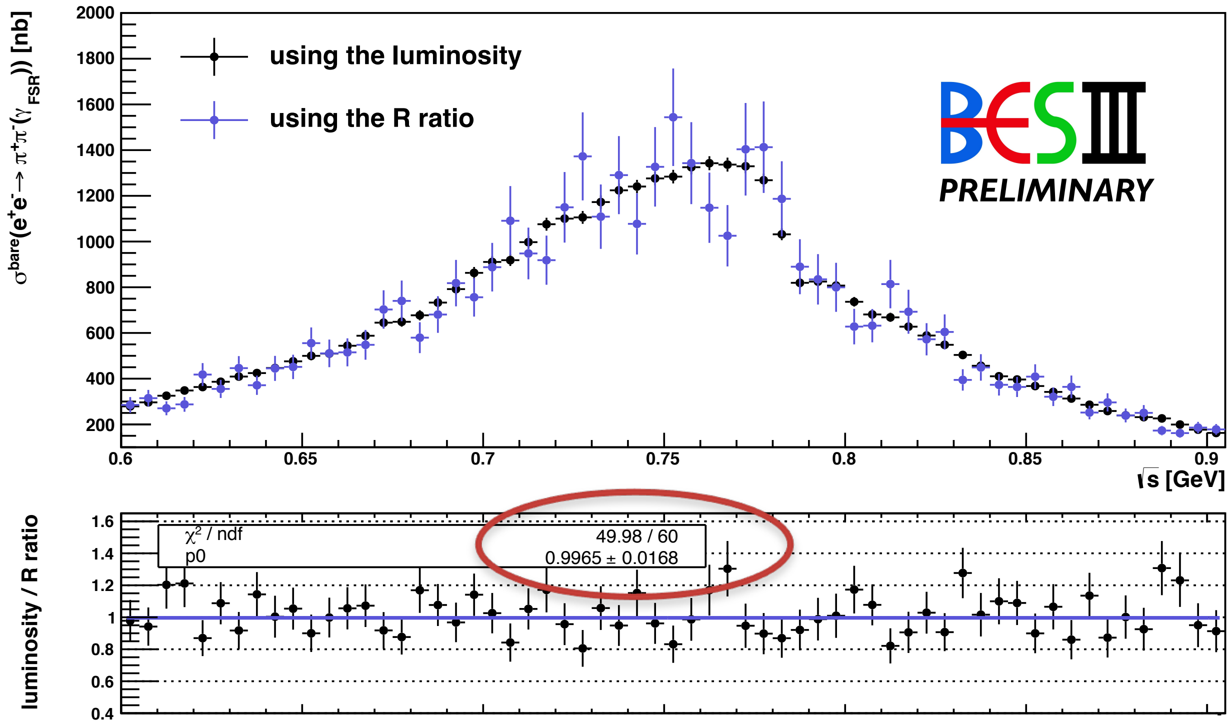
2.) Normalization to $\mu^+\mu^-\gamma$ events, i.e. R ratio $\pi^+\pi^-\gamma$ / $\mu^+\mu^-\gamma$

➔ L_{int}, H_{rad} and δ_{vac} cancel



Luminosity / R ratio – 1 = (0.35 ± 1.68) %

limited by $\mu^+\mu^-\gamma$ statistics

Summary of Systematic Uncertainties

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 δ_{FSR}	0.2
vacuum polarization correction δ_{vac}	0.2
radiator function	0.5
Luminosity $\mathcal{L}$	1.0
sum	**1.3**

BESIII PRELIMINARY

Luminosity is the limiting factor!

Our plan:
Redo the luminosity measurement and reduce its systematic uncertainty.

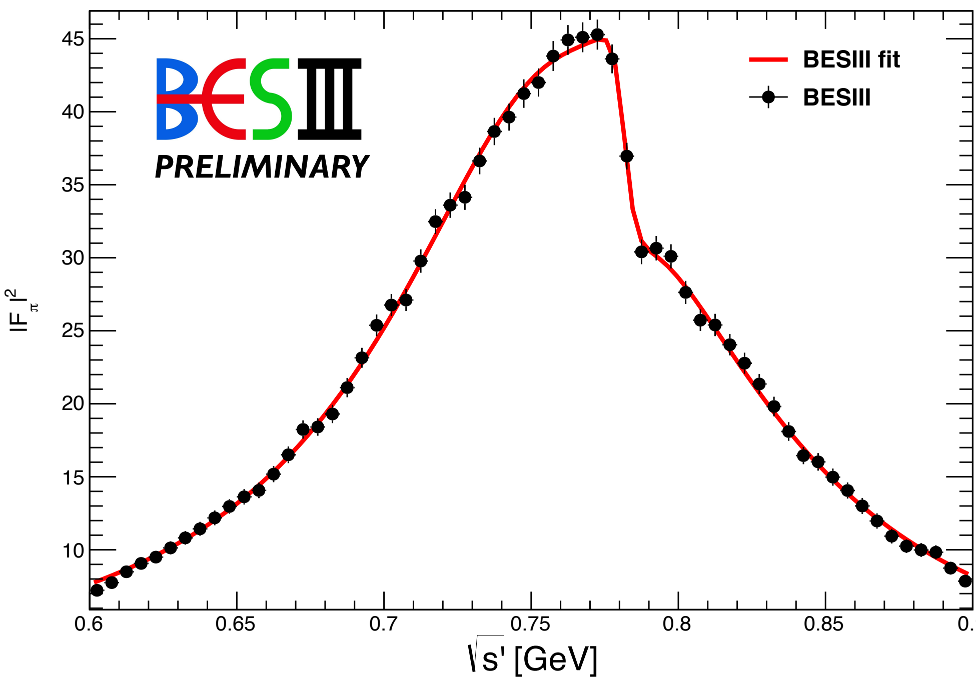
→ new tool: Babayaga@NLO
→ matter of weeks

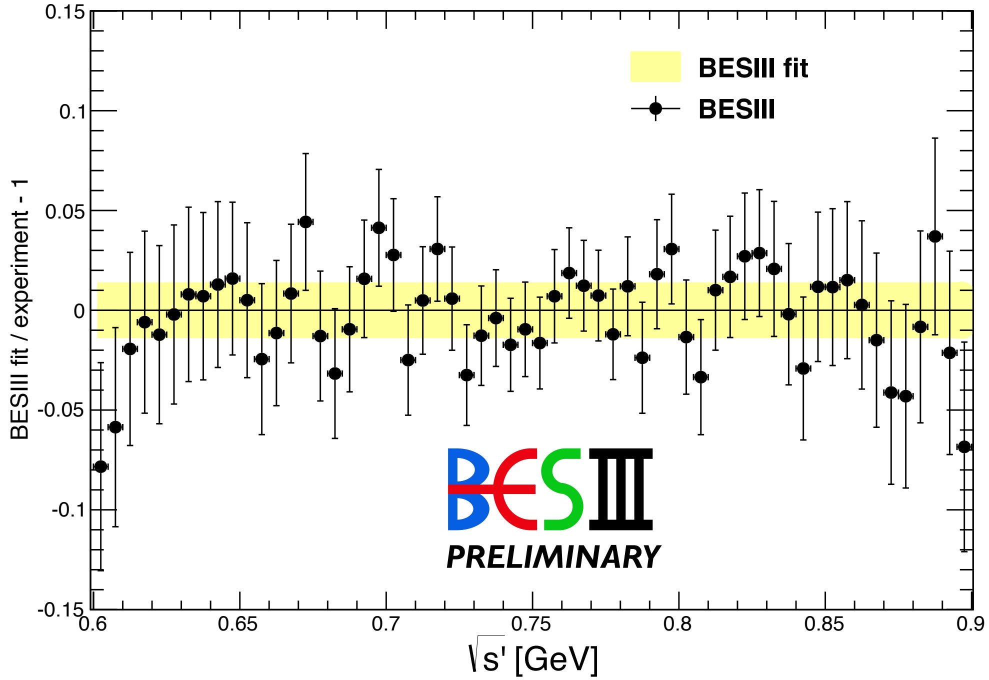
Results

BESIII

PRELIMINARY

Extracted Form Factor

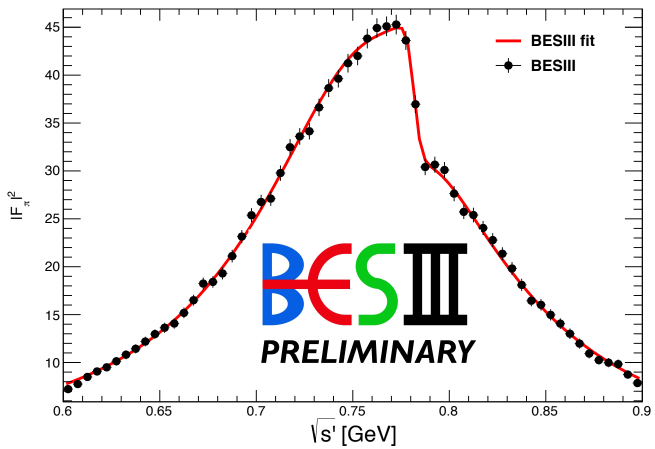




Fit function: Gounaris-Sakurai Parameterization

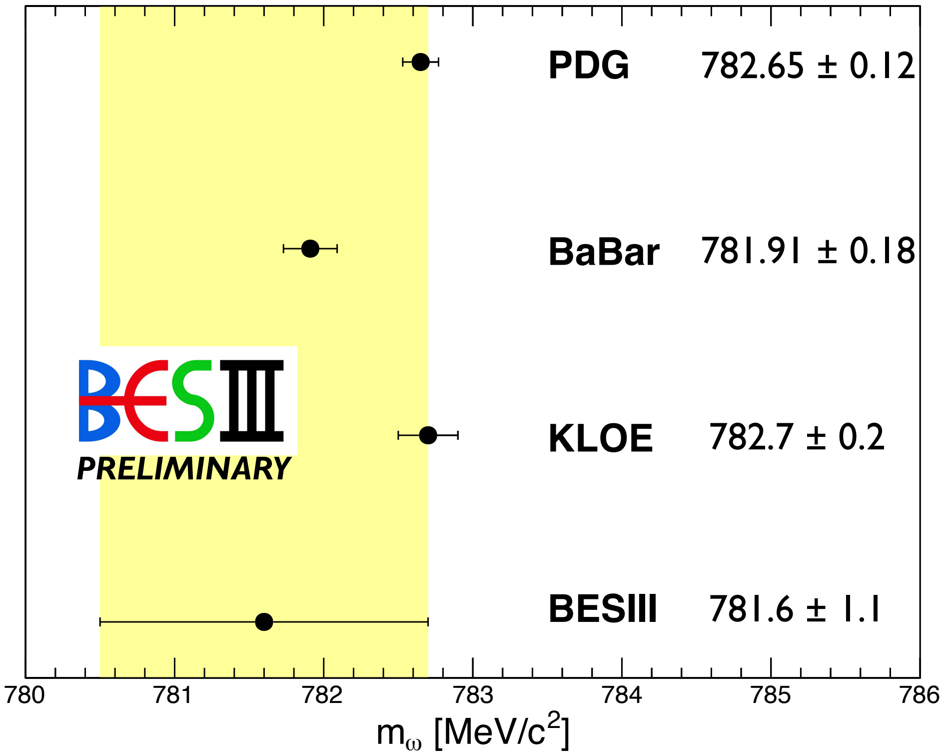
χ^2 / ndf = 33.2 / 51

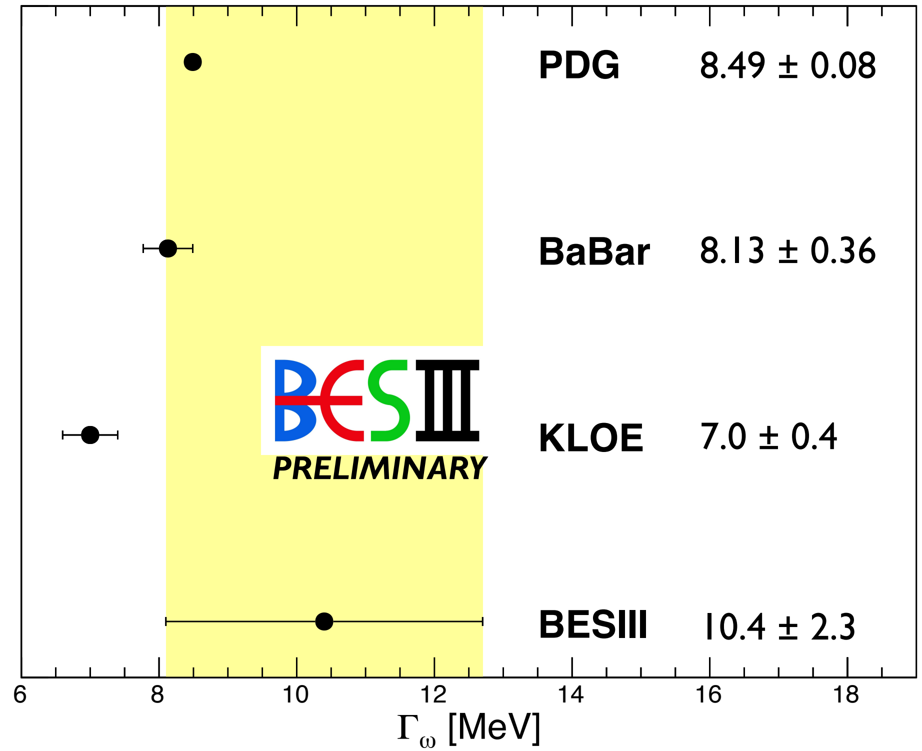
Fit parameters



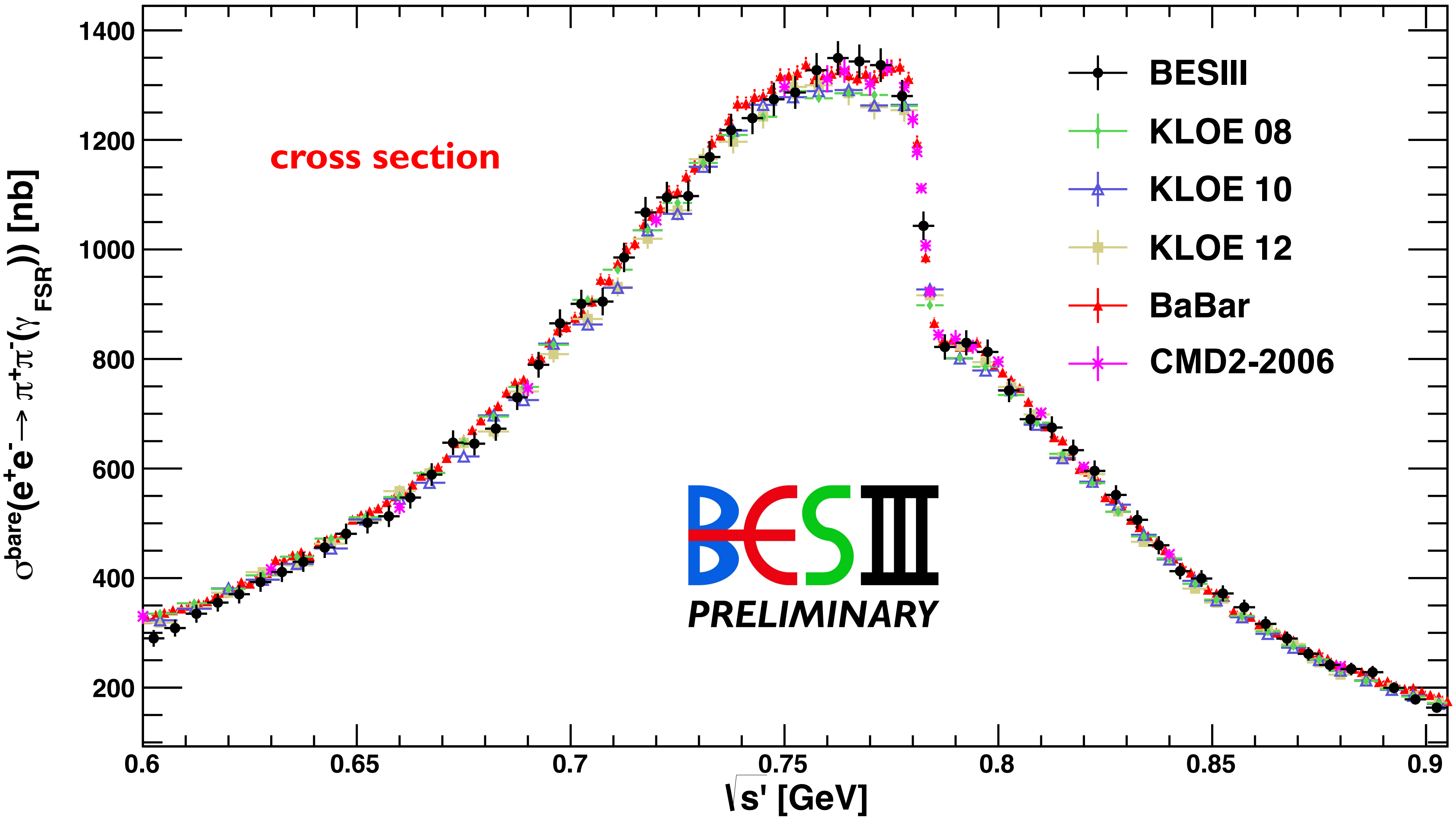
m_ω

Γ_ω

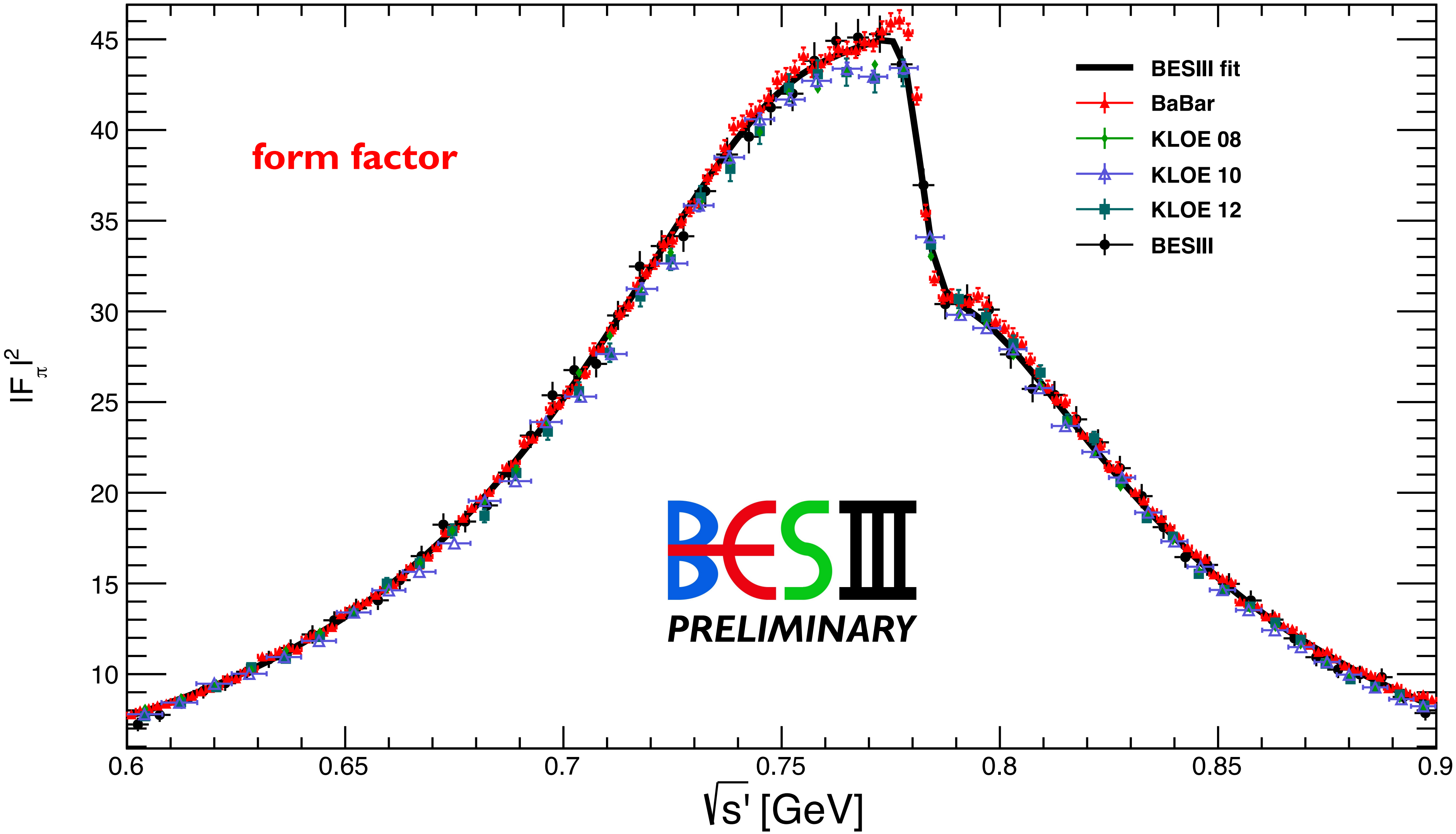




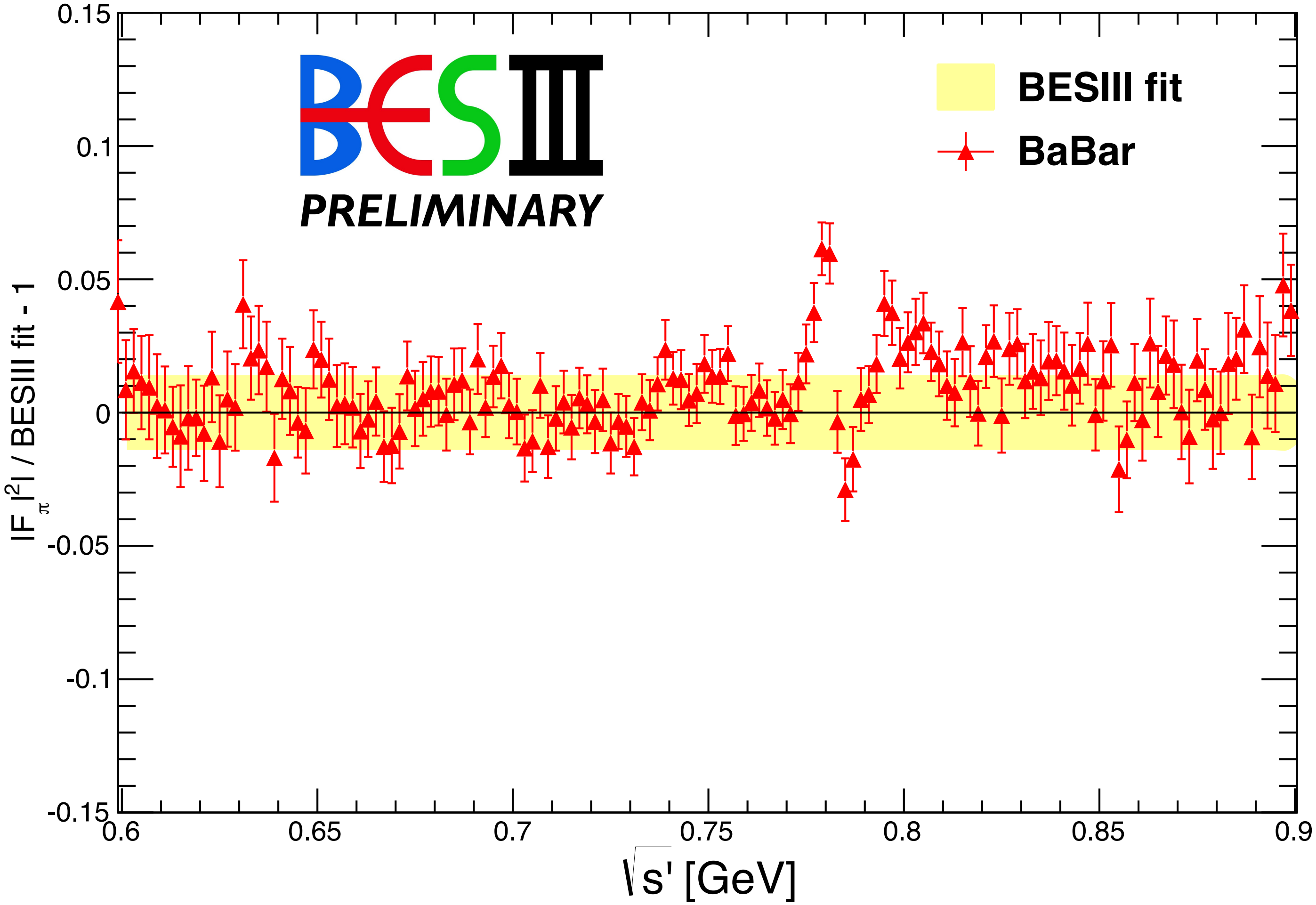
Comparison to other experiments



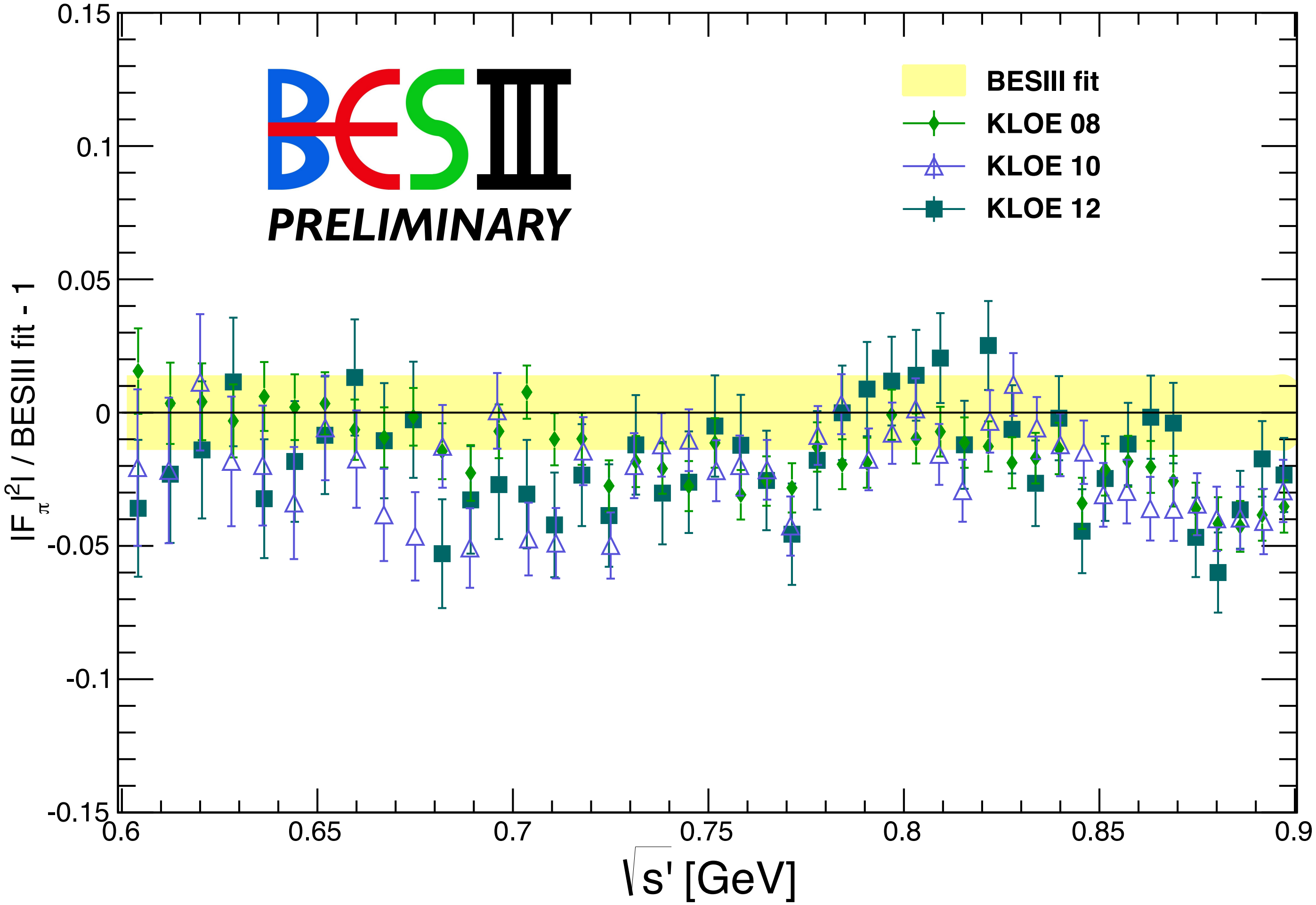
Comparison to other experiments



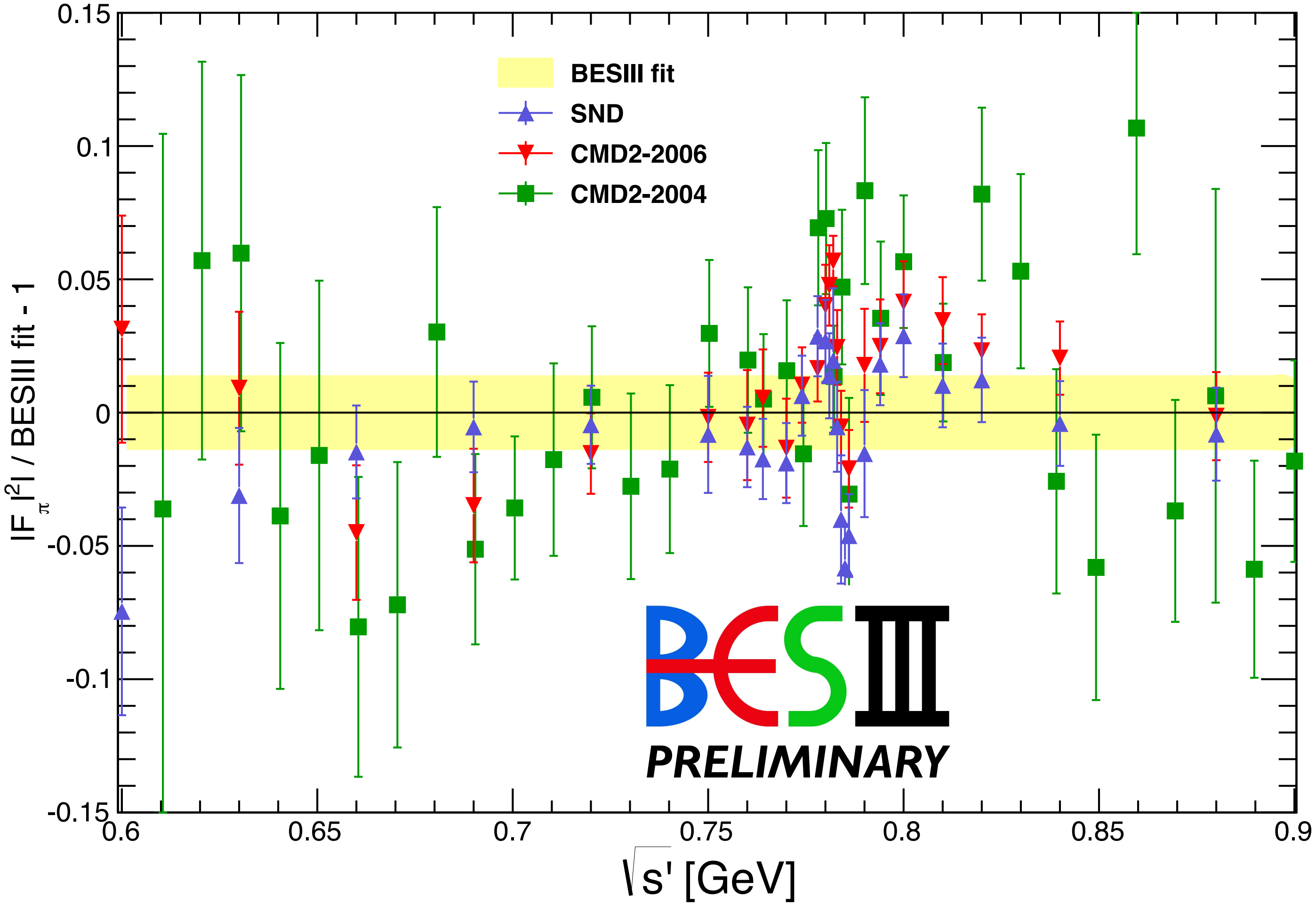
Comparison to BaBar



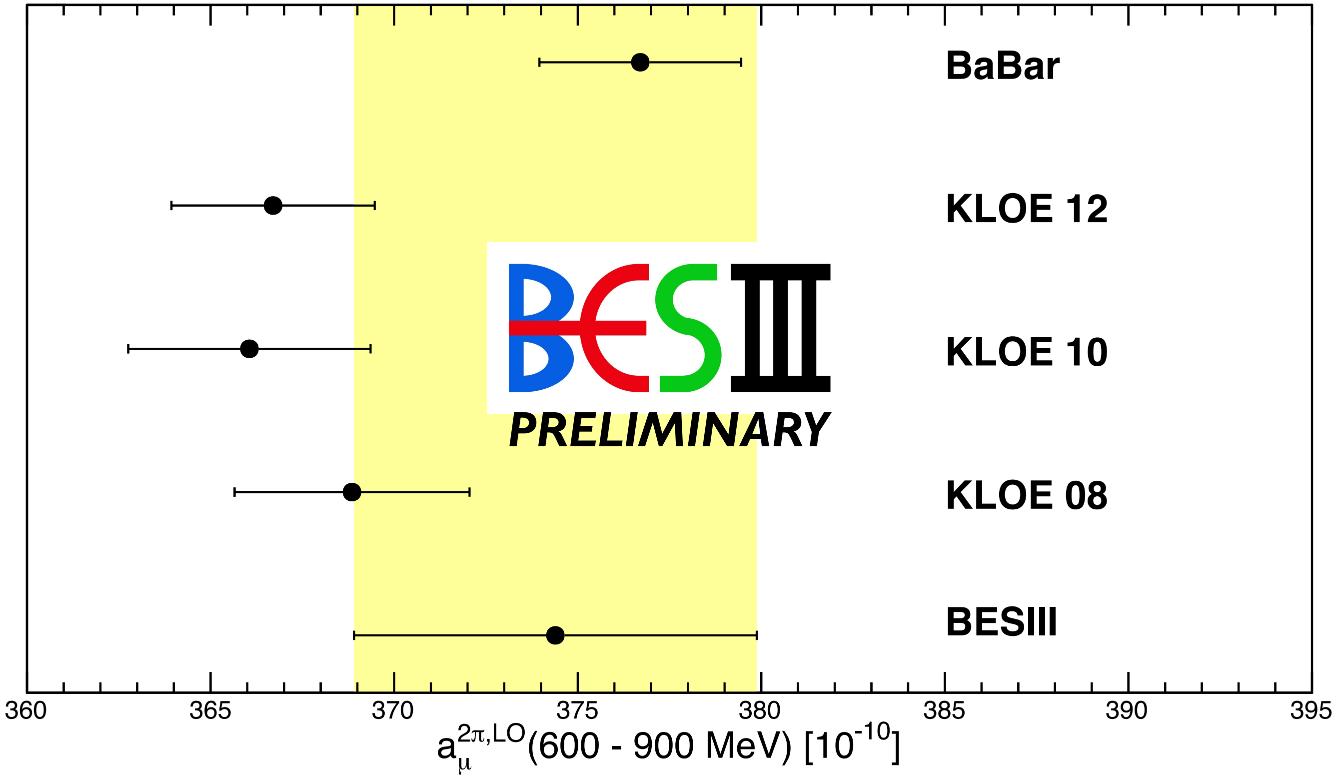
Comparison to KLOE



Comparison to CMD2 and SND



Result for (g-2)



Experiment	$a_\mu^{2\pi,LO}$ (600 – 900 MeV) [10^{-10}]
BaBar	$376.7 \pm 2.0_{stat} \pm 1.9_{sys}$
KLOE 08	$368.9 \pm 0.4_{stat} \pm 2.3_{sys,exp} \pm 2.2_{sys,theo}$
KLOE 10	$366.1 \pm 0.9_{stat} \pm 2.3_{sys,exp} \pm 2.2_{sys,theo}$
KLOE 12	$366.7 \pm 1.2_{stat} \pm 2.4_{sys,exp} \pm 0.8_{sys,theo}$
BESIII (preliminary)	$374.4 \pm 2.6_{stat} \pm 4.9_{sys}$

Summary

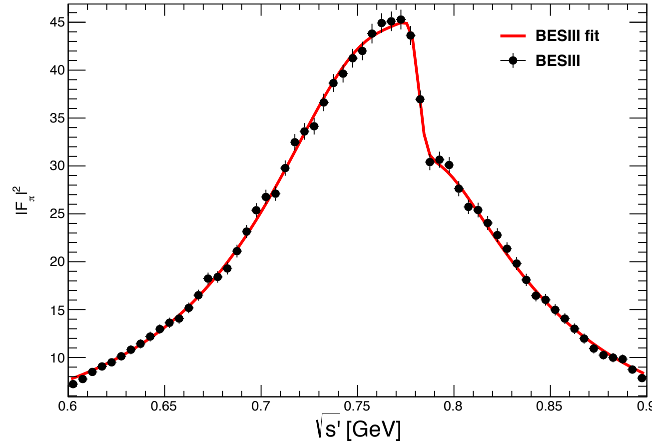
- Δa_μ is confirmed
- For the future: there is a factor 3 more data available at BESIII
- Systematic uncertainty still dominating
- Currently a systematic uncertainty of 1.3% is reached
- We want to redo the luminosity measurement to decrease this error
- Paper will be published as soon as possible

Thank you for your attention!

BESIII

Backup

Extracted Form Factor

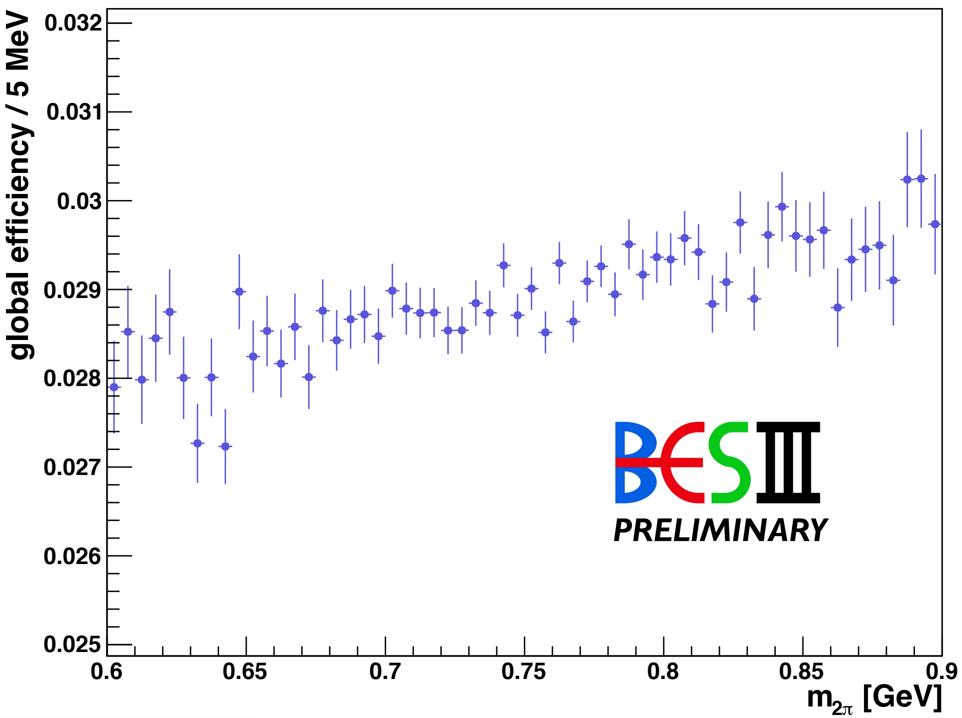


Parameter	PDG	BaBar	KLOE	BESIII
m_ρ (MeV)	775.49 ± 0.34	775.02 ± 0.31	774.3 ± 0.1	775.1 ± 0.5
Γ_ρ (MeV)	149.1 ± 0.8	149.59 ± 0.67	146.9 ± 0.2	150.6 ± 0.8
m_ω (MeV)	782.65 ± 0.12	781.91 ± 0.18	782.7 ± 0.2	781.6 ± 1.1
Γ_ω (MeV)	8.49 ± 0.08	8.13 ± 0.36	7.0 ± 0.4	10.4 ± 2.3
$\lvert c_\omega \rvert$ (10^{-3})		1.644 ± 0.061	1.45 ± 0.04	2.1 ± 0.3
ϕ_ω (rad)		-0.011 ± 0.037	0.18 ± 0.03	-0.02 ± 0.15

ISR analysis

Selection Efficiency:

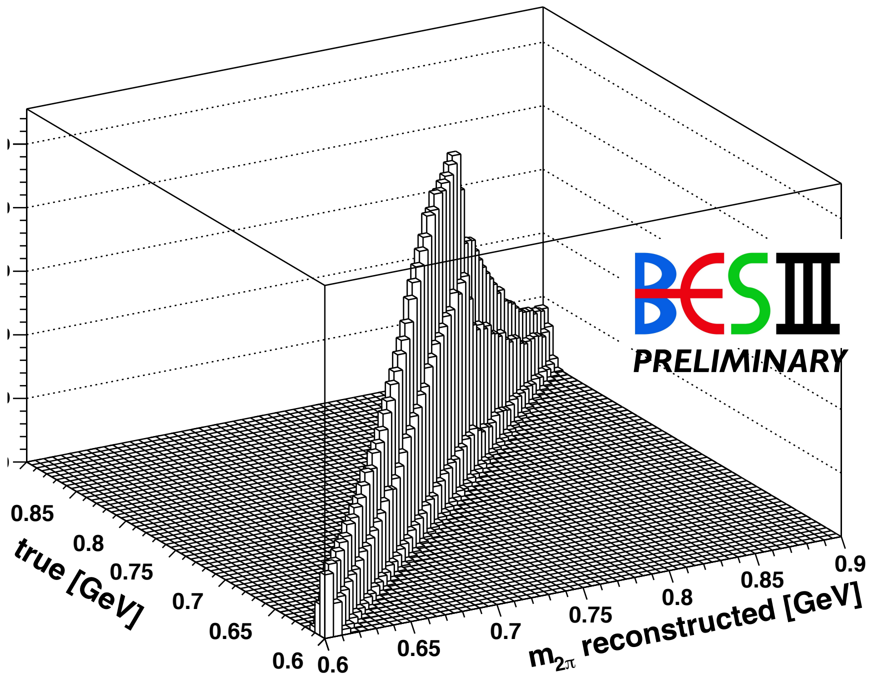
- determined with MC
- corrected for data-MC differences



Unfolding:

- using Singular Value Decomposition
  Nucl.Instrum.Meth. A**372**:469-481 (1996)

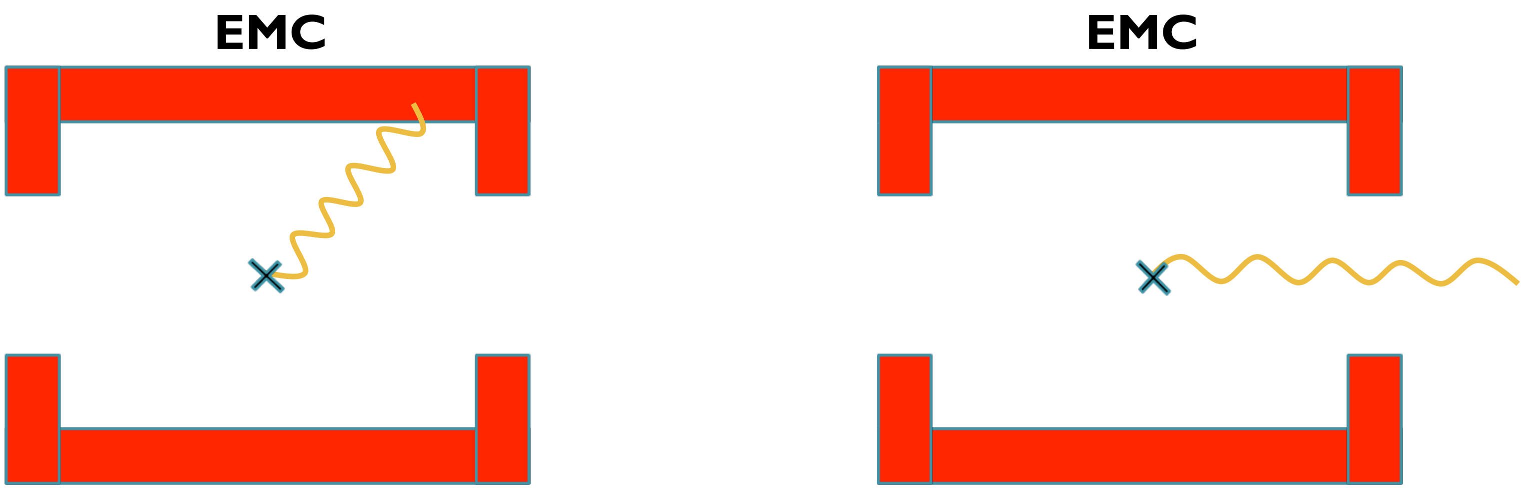
- response matrix determined with MC



Initial State Radiation

Two different analysis types:

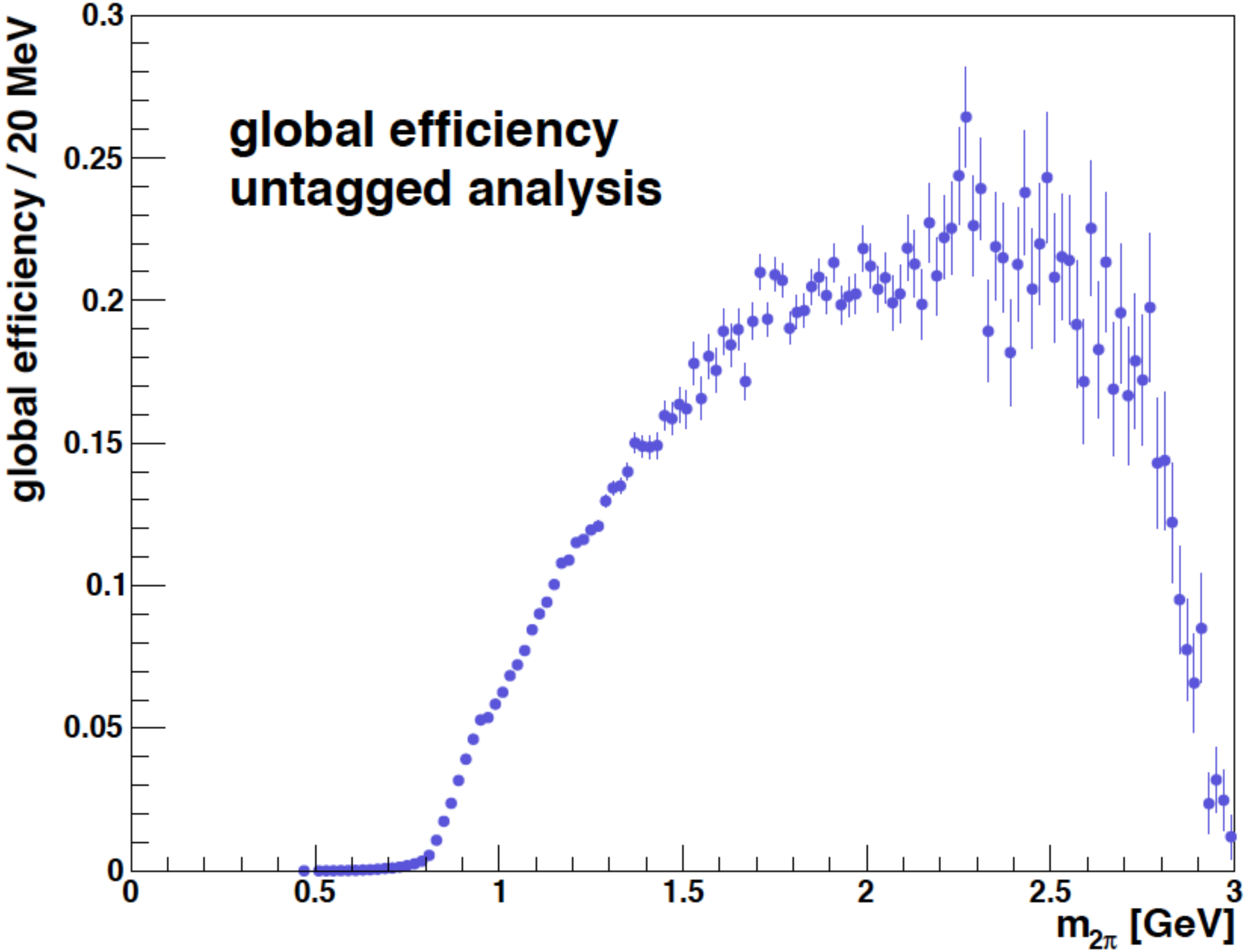
- tagged: photon is detected in the Electromagnetic Calorimeter
- untagged: photon leaves the detector (most probable case)



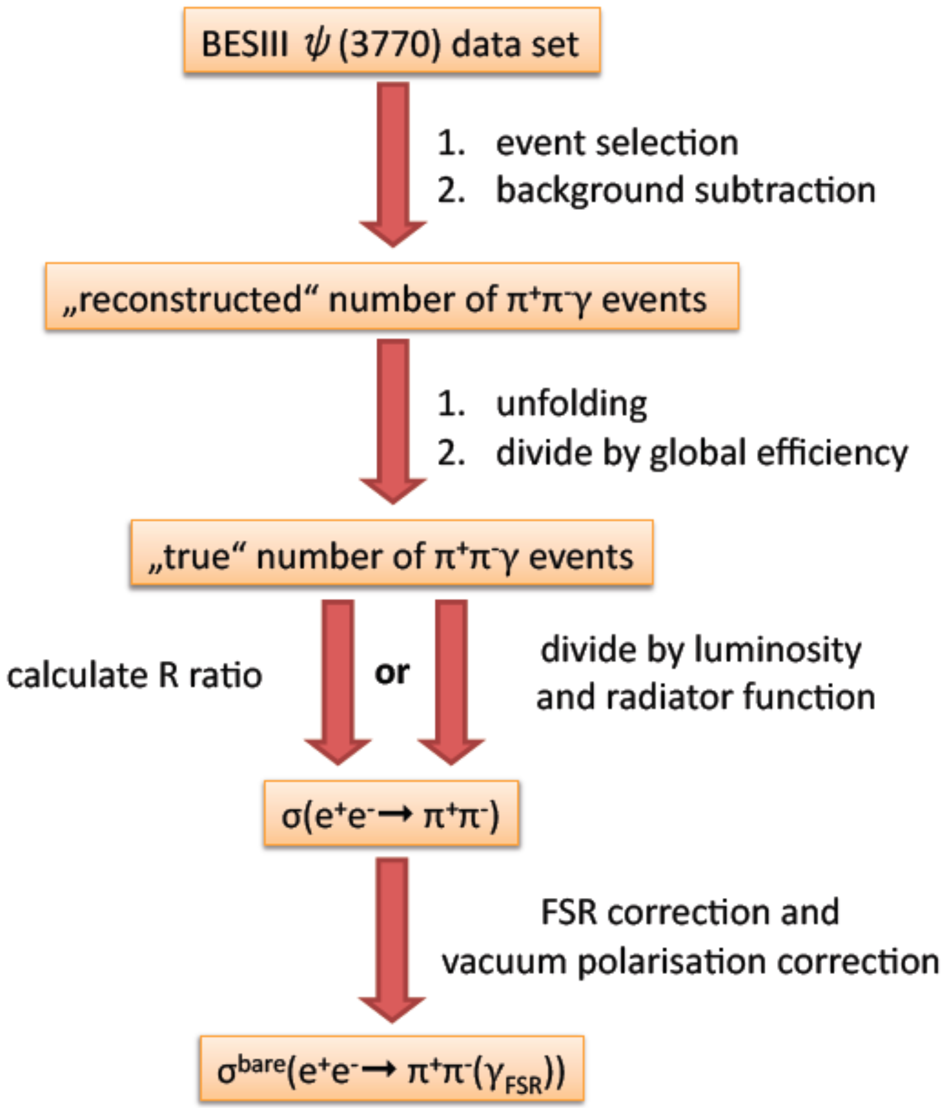
tagged:
photon hits EMC

untagged:
photon leaves the detector

Global efficiency



Structure of the analysis



Efficiency Corrections

Study	Status
pion tracking efficiency	✓
muon tracking efficiency	✓
photon efficiency	✓
pion PID efficiency (neural network)	✓
muon PID efficiency (neural network)	✓
electron PID efficiency	✓

Main part of the analysis.

Essential to reach high precision.