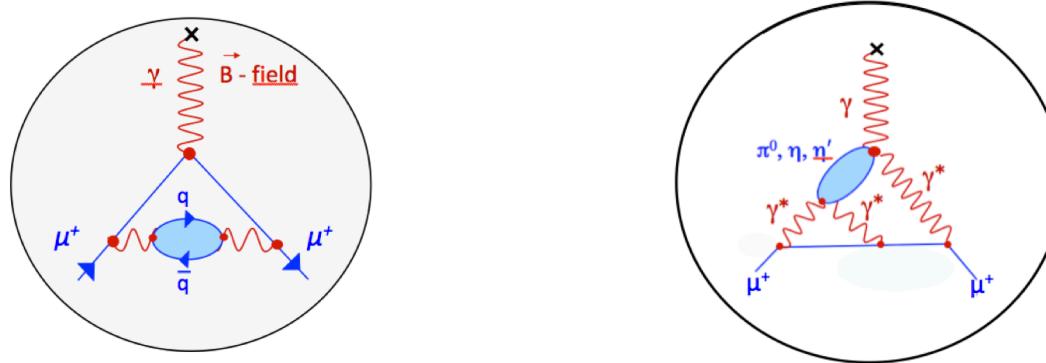


# ISR, R values and $\gamma\gamma$ measurements at BESIII



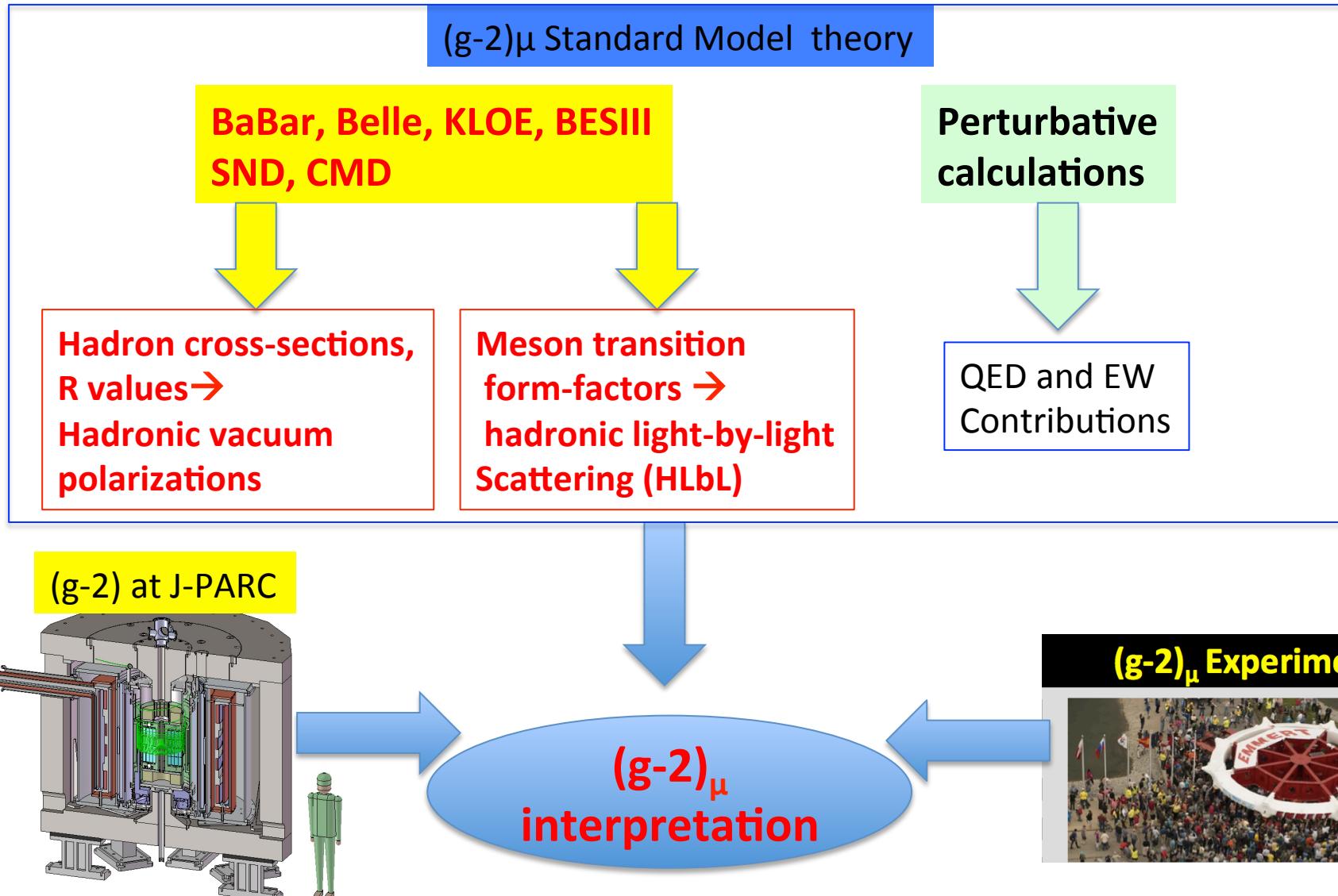
$$a_\ell = \frac{g_\ell - 2}{2} = \frac{\alpha}{2\pi} + \dots = 0.001161\dots$$

Hai-Bo Li

Institute of High Energy Physics, Beijing

3<sup>rd</sup> Workshop on Muon g-2, EDM and cLFV in the LHC Era,  
LPNHE, Paris, Dec. 9-12, 2014

# The hadronic contributions to $(g-2)_\mu$



# Comparison with experiments

D. Nomura (tau2012)

<b>QED contribution</b>	$11\ 658\ 471.808 (0.015) \times 10^{-10}$	Kinoshita & Nio, Aoyama et al
<b>EW contribution</b>	$15.4 (0.2) \times 10^{-10}$	Czarnecki et al
<b>Hadronic contribution</b>		
<b>LO hadronic</b>	$694.9 (4.3) \times 10^{-10}$	HLMNT11 in consistent with DHMZ10
<b>NLO hadronic</b>	$-9.8 (0.1) \times 10^{-10}$	HLMNT11
<b>light-by-light</b>	$10.5 (2.6) \times 10^{-10}$	Prades, de Rafael & Vainshtein
<b>Theory TOTAL</b>	$11\ 659\ 182.8 (4.9) \times 10^{-10}$	
<b>Experiment</b>	$11\ 659\ 208.9 (6.3) \times 10^{-10}$	world avg
<b>Exp – Theory</b>	$26.1 (8.0) \times 10^{-10}$	$3.3 \sigma$ discrepancy

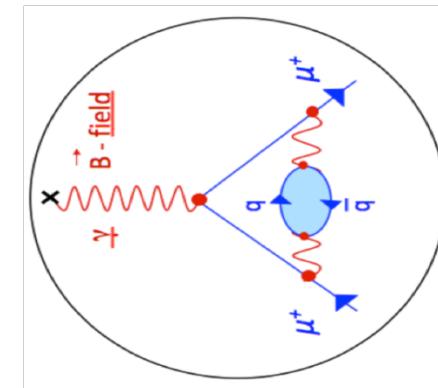
(Numbers taken from HLMNT11, arXiv:1105.3149)

Difference: experiment – SM

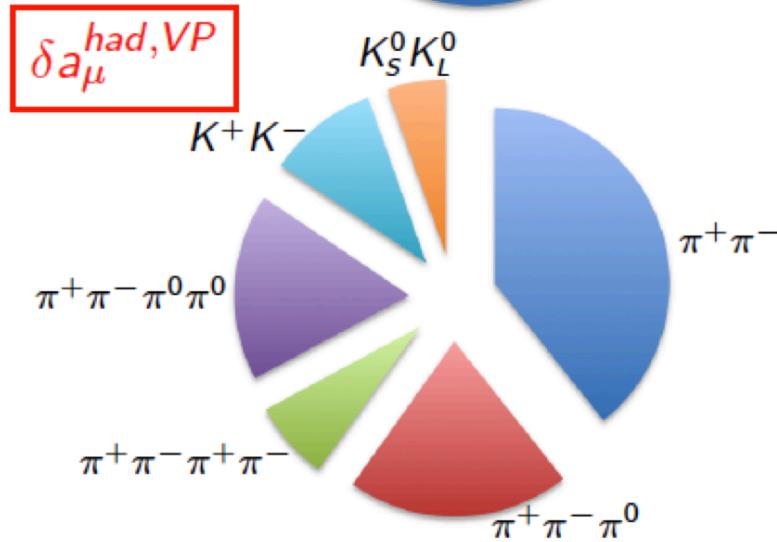
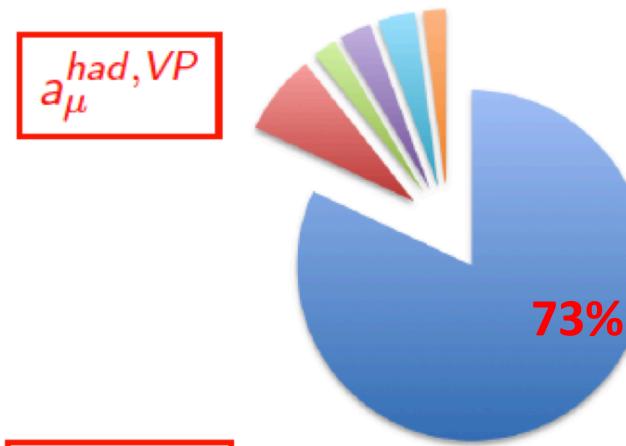
$$a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (26.1 \pm 8.0) \times 10^{-10}$$

⇒ 3.3 "standard deviations" ( $e^+e^-$ )

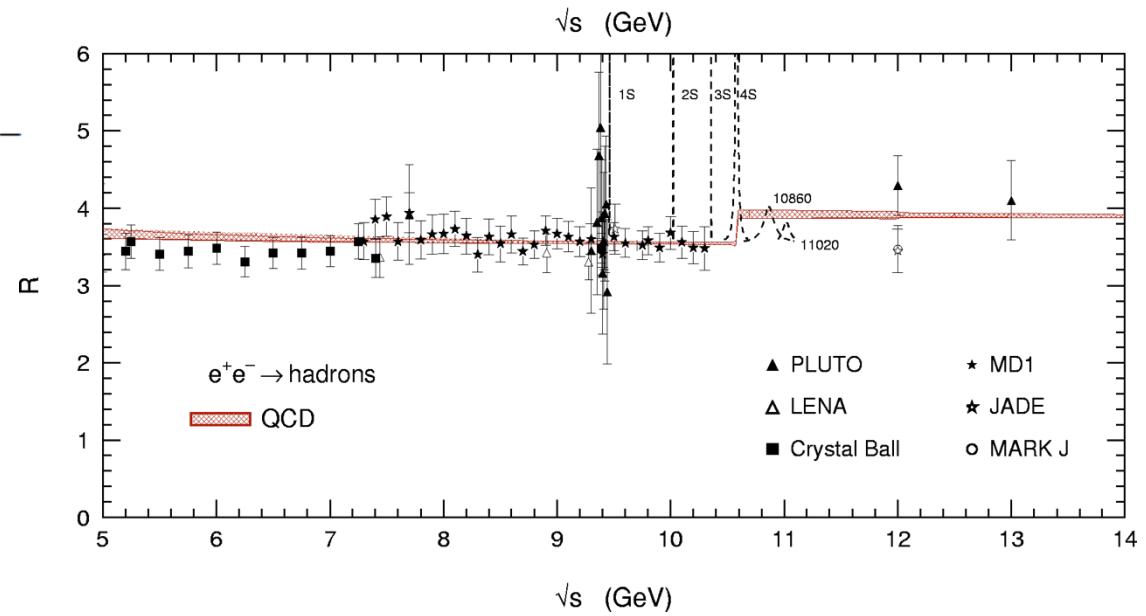
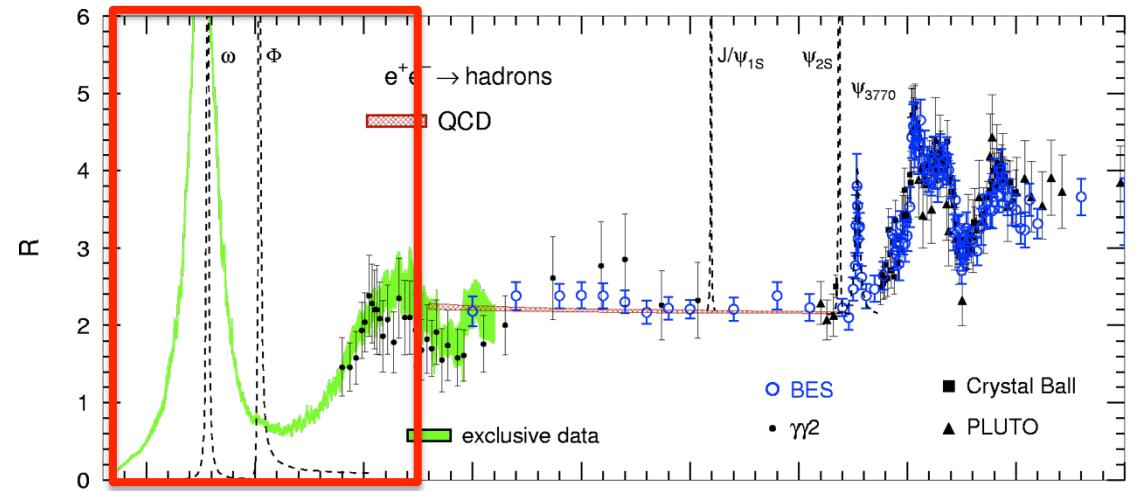
⇒ 2.4 "standard deviations" ( $\tau$ )



# Status of hadronic vacuum polarization

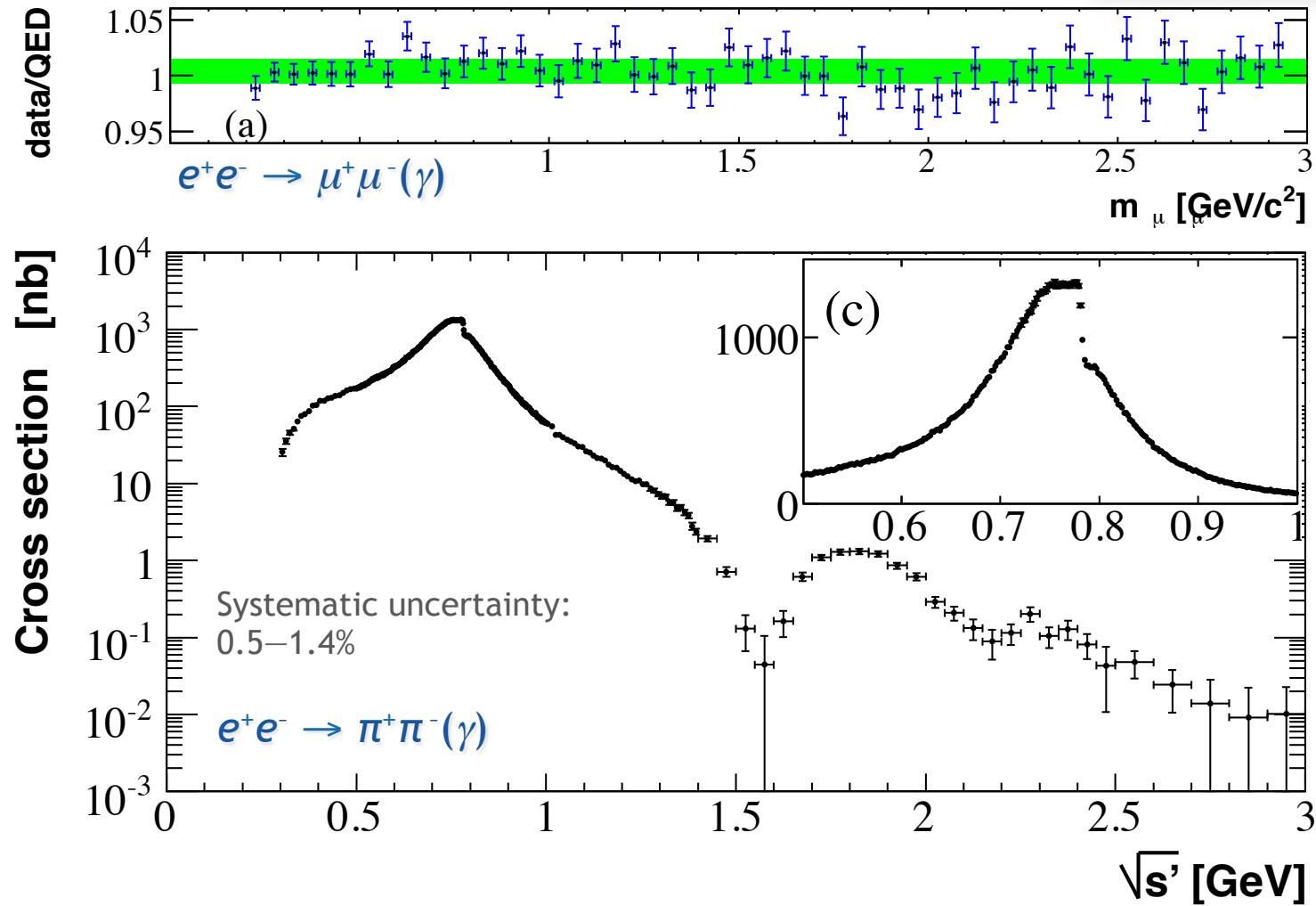


$$a_{\mu}^{\text{had, LO}} = \frac{\alpha^2}{3\pi^2} \int_{4m_{\pi}^2}^{\infty} ds \frac{K(s)}{s} R(s)$$

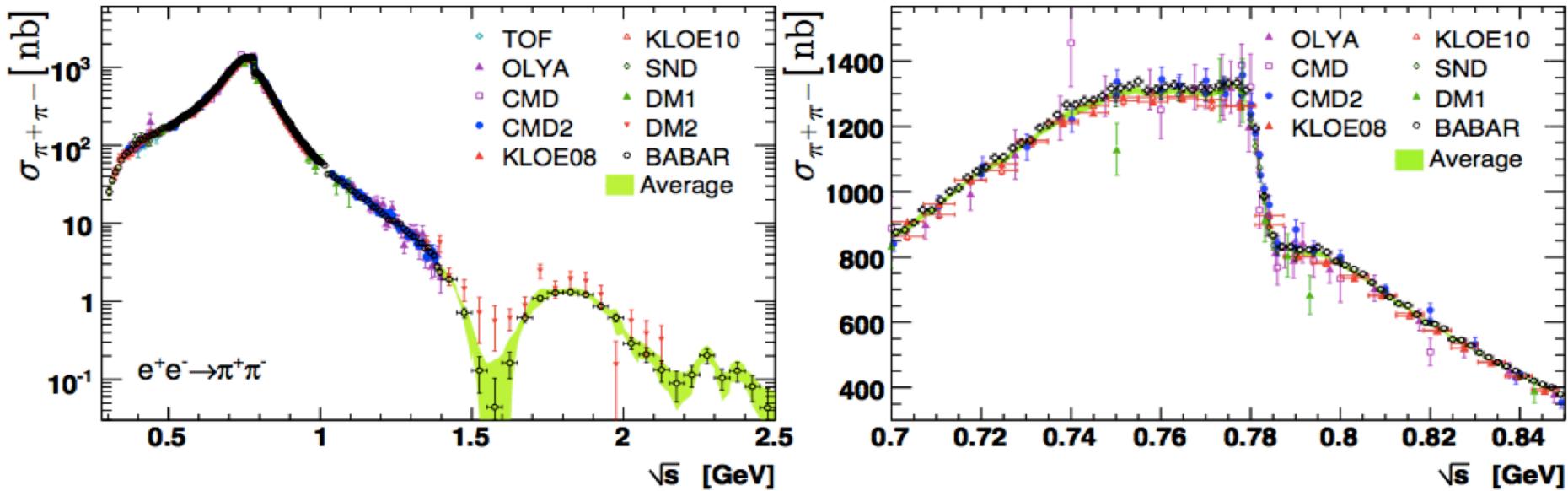


# $e^+e^- \rightarrow \pi\pi(\gamma)$ cross-sections from BaBar

BABAR, PRL 103, 231801 (2009)



# Comparisons of $e^+e^-$ data

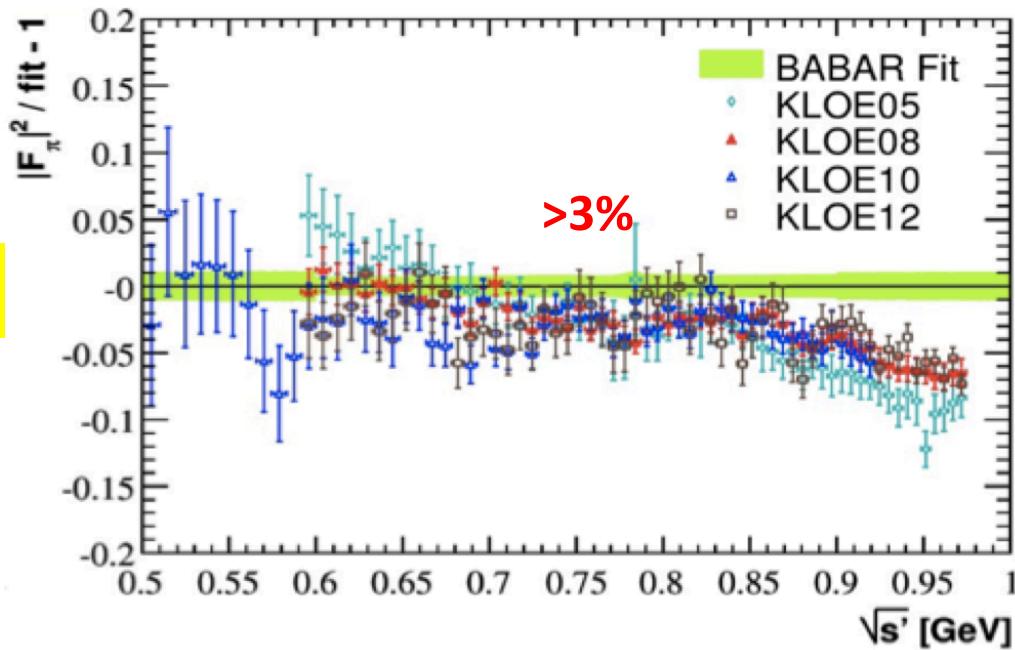


- $\rho$  peak
- $\rho - \omega$  interference
- Dip at 1.6 GeV: excited  $\rho$  states
- Dip at 2.2 GeV
- Contribution to  $a_\mu^{\text{had}}$ : 75%!

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

<i>BABAR:</i>	0.5%
CMD2:	0.8%
SND:	1.5%
KLOE:	0.8%

# Comparison of $e^+e^- \rightarrow \pi^+\pi^-$ in $\rho$ region

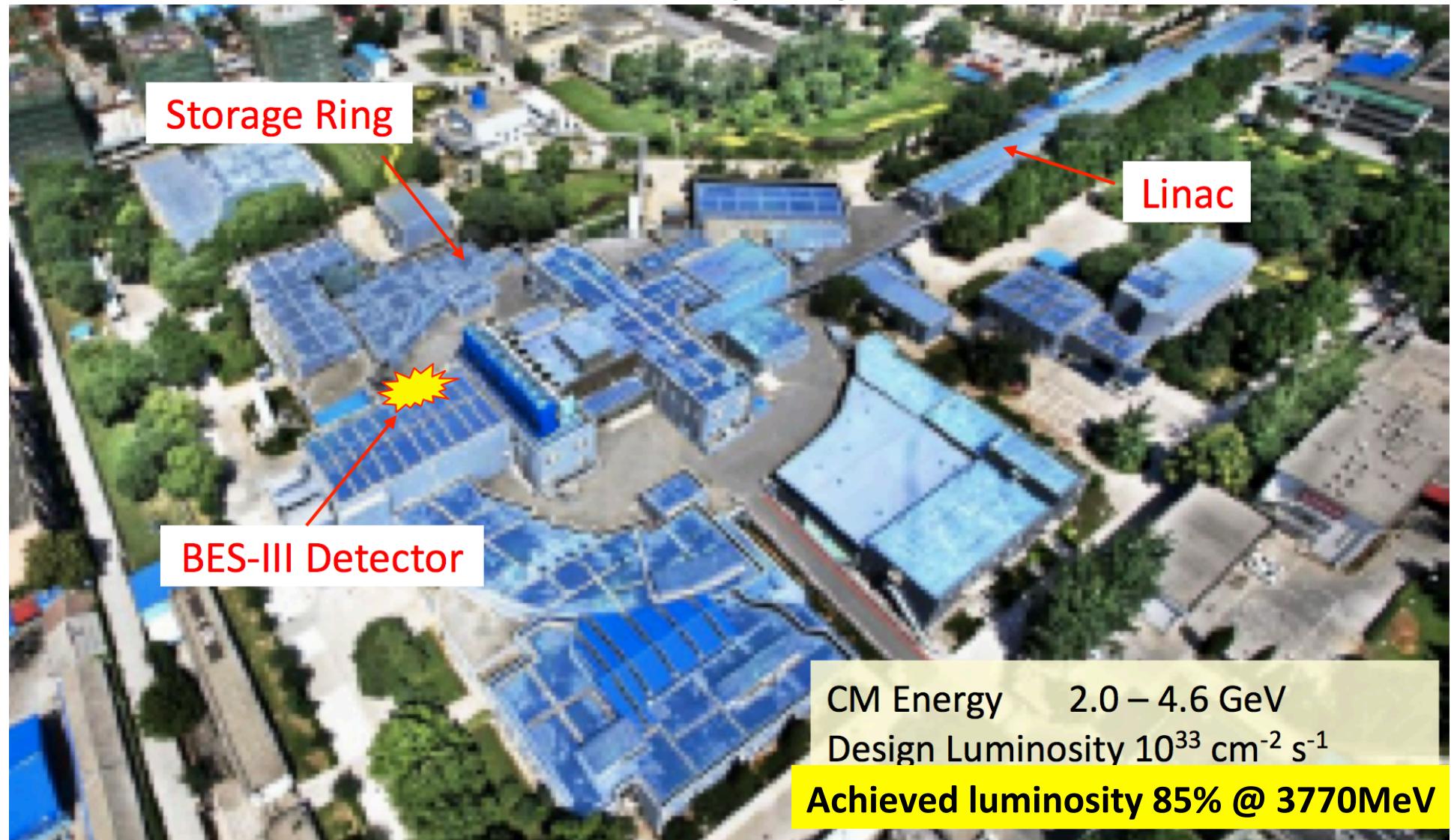


- KLOE and *BABAR* dominate the world average
- Uncertainty of both measurements smaller than 1%
- Systematic difference, especially above  $\rho$  peak
- Difference  $\rightarrow$  relatively large uncertainty for  $a_\mu^{\text{had}}$

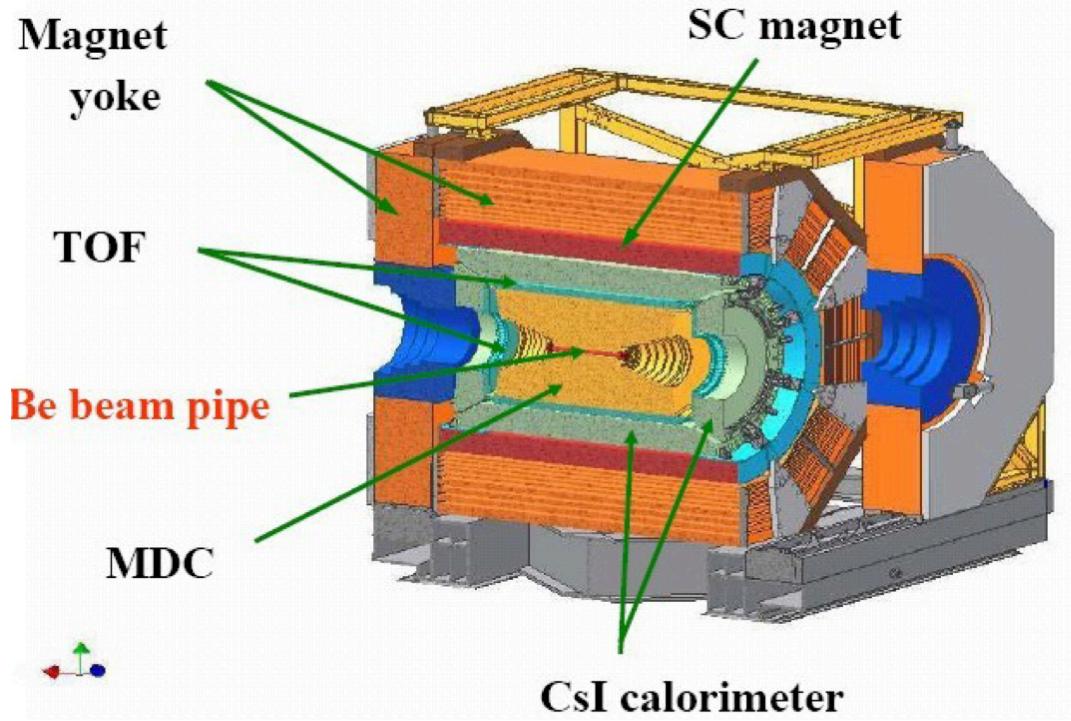
# Outline

- BESIII ISR program
- R scan for Ecm>2.0 GeV
- Overview on meson transition form-factors
- BESIII plan and prospects
- Conclusion and outlook

# BEPCII project



# BESIII detector



## Muon Chambers

- 8 – 9 layers of RPC
- $p > 400 \text{ MeV}/c$
- $\delta R\Phi = 1.4 \sim 1.7 \text{ cm}$

## Superconducting Magnet

- 1 T magnetic field

## Main Drift Chamber (MDC)

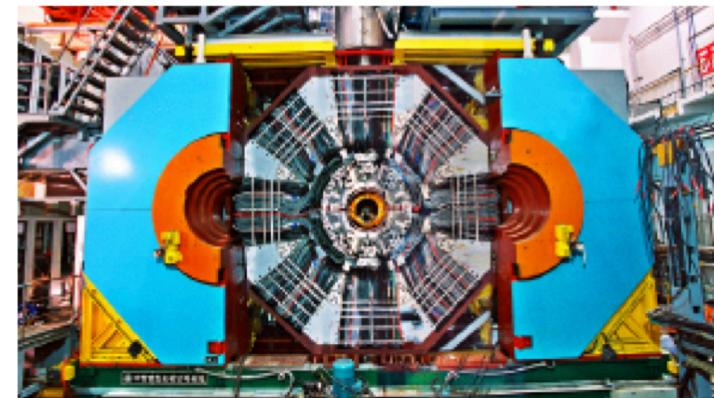
- $\sigma(p)/p = 0.5\% @ 1 \text{ GeV}$
- $\sigma_{dE/dx} = 6.0\%$

## Time-of-flight system (TOF)

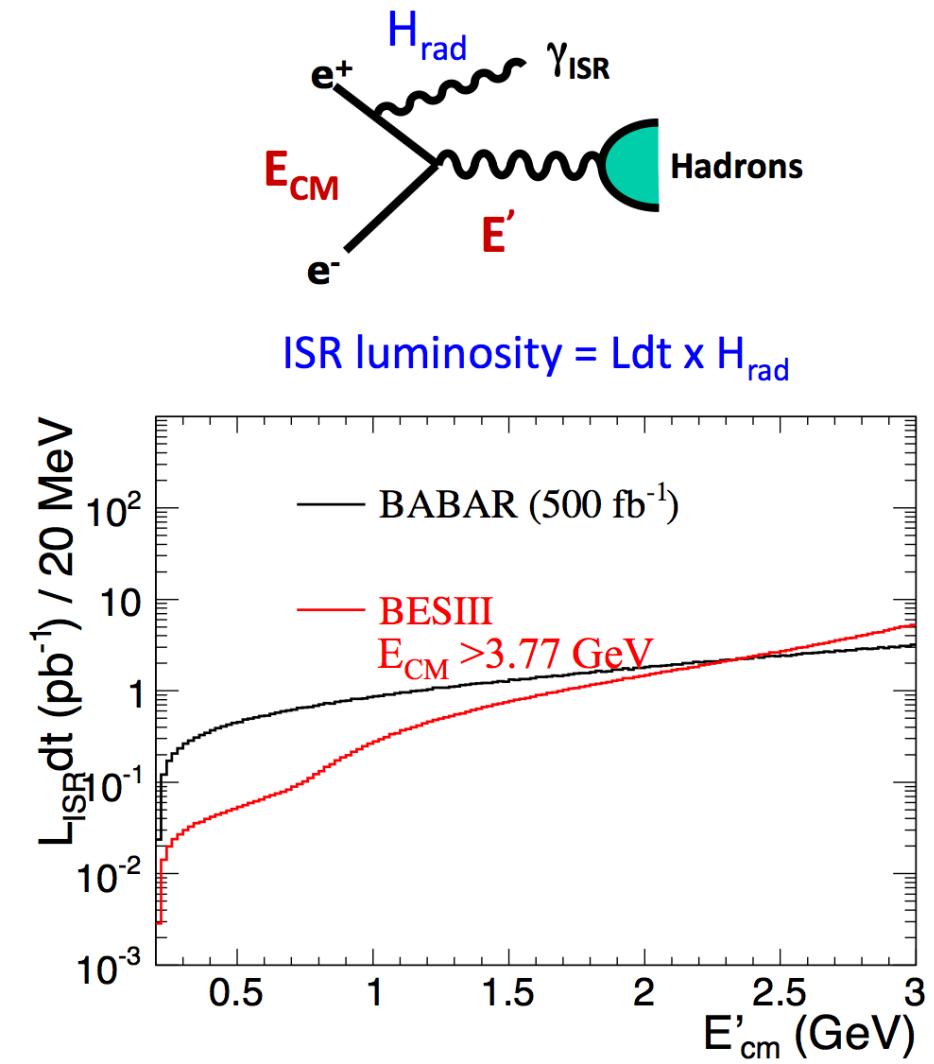
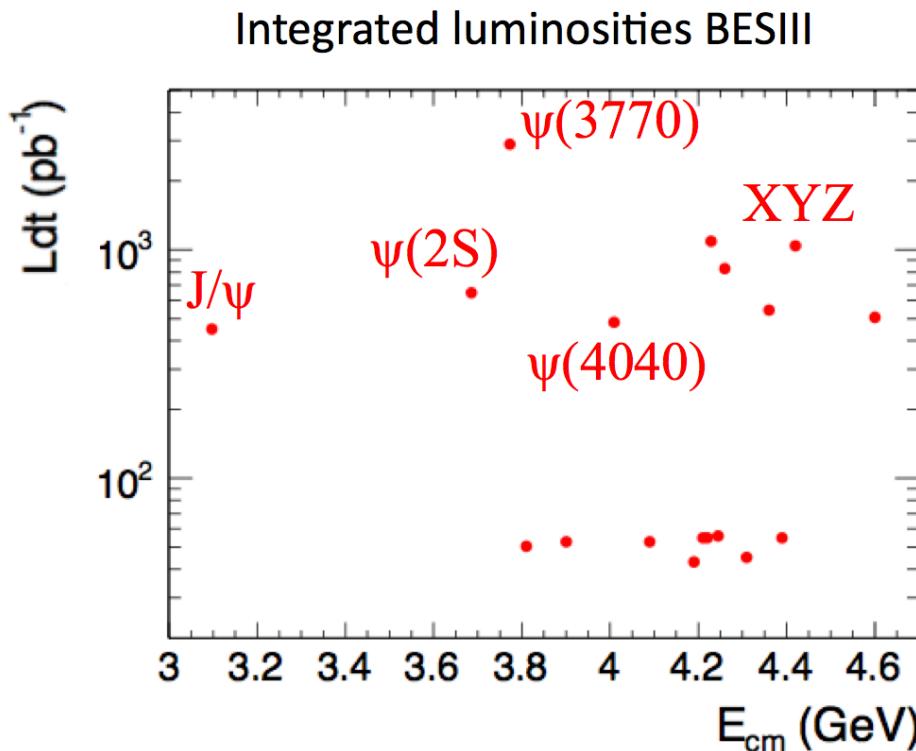
- $\sigma(t) = 80\text{ps}$  (barrel)
- $\sigma(t) = 120\text{ps}$  (endcap)

## EMC

- 6240 CsI(Tl) crystals
- $\sigma(E)/E = 2.5\%$
- $\sigma_{Z,\Phi}(E) = 0.5 - 0.7 \text{ cm}$

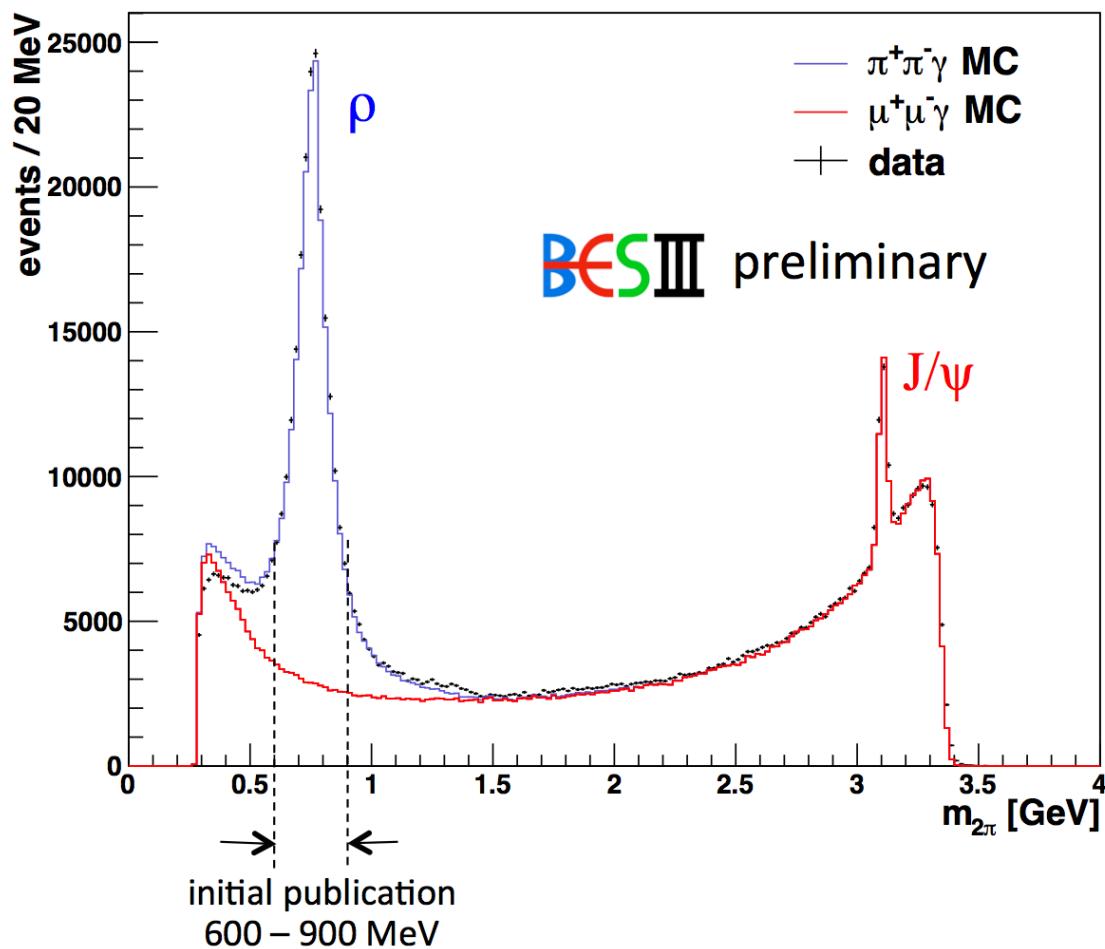


# Data samples for ISR physics



# ISR from BESIII at 3770 MeV?

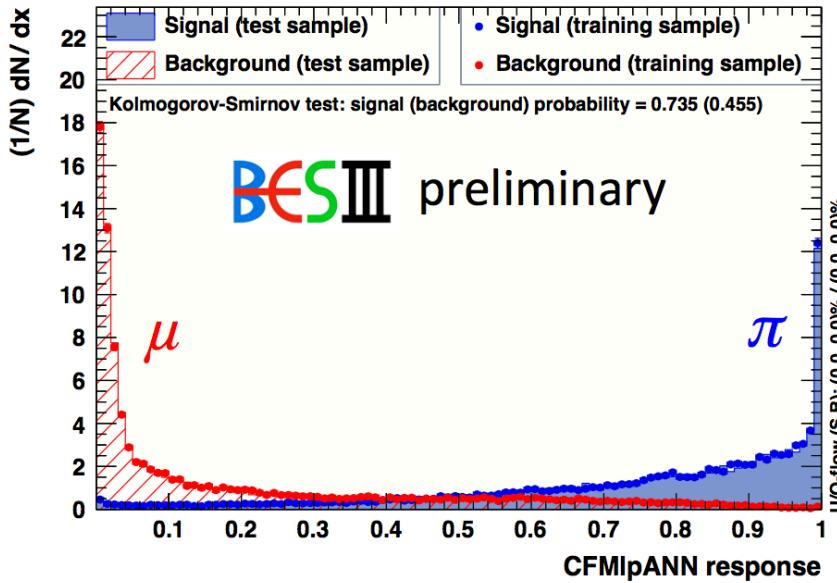
Event yield after acceptance cuts **only**



## Features:

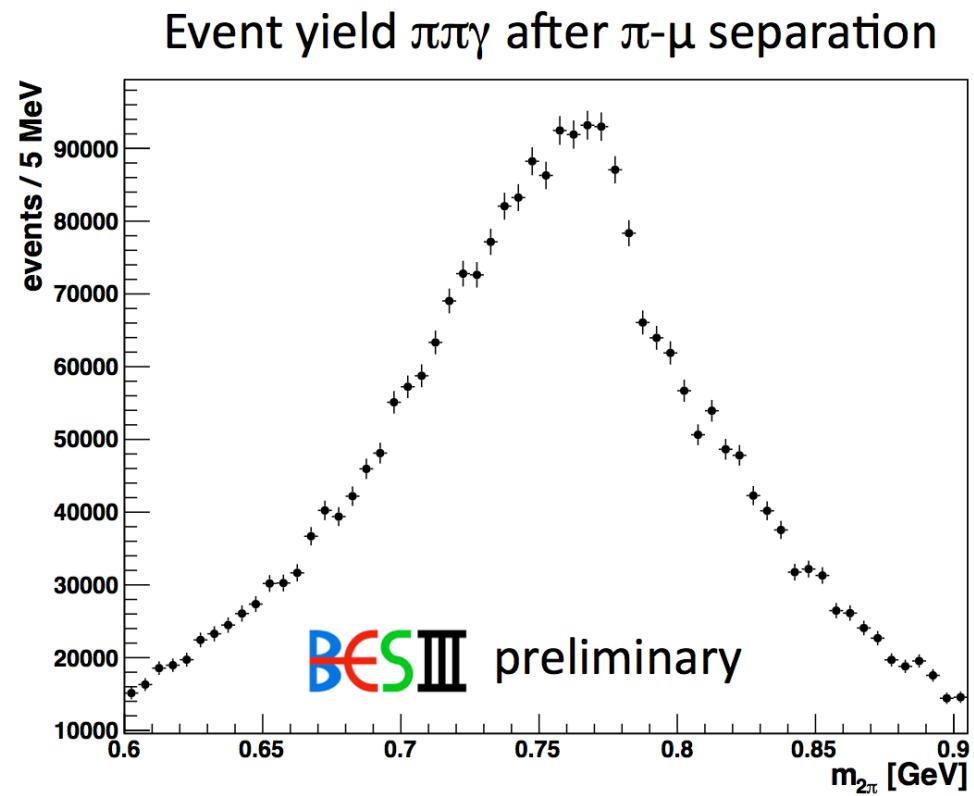
- $\psi(3770)$  data only ( $2.9 \text{ fb}^{-1}$ )
  - no dedicated background subtraction
  - tagged ISR photon
- large statistics of  $e^+e^- \rightarrow \pi\pi\gamma$  events  
→ background dominated by  $e^+e^- \rightarrow \mu\mu\gamma$   
→ data – MC differences visible

# $e^+e^- \rightarrow \pi^+\pi^- \gamma_{ISR}$ : after $\pi\text{-}\mu$ separation



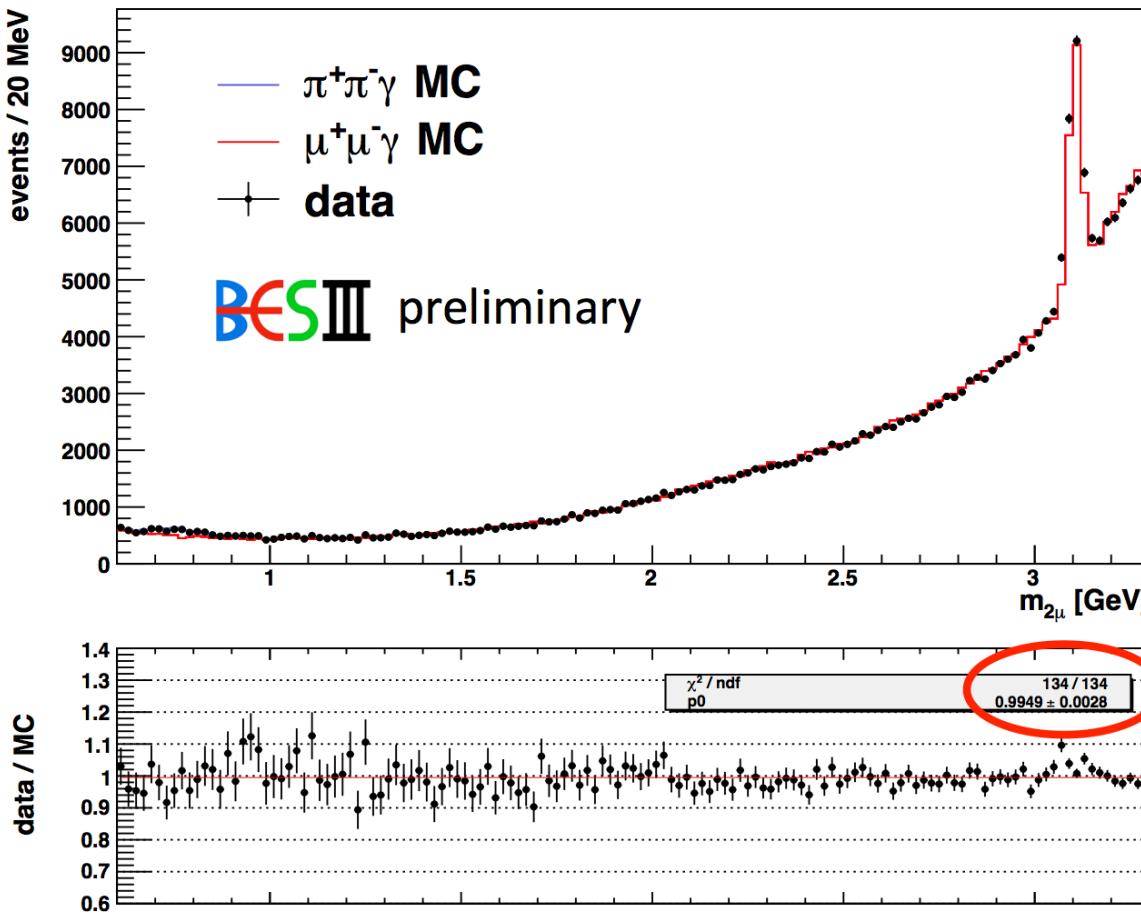
## TMVA method (Neural Network):

- trained using  $\mu\mu\gamma$  and  $\pi\pi\pi\gamma$  MC events
- information based on track level
- efficiency matrix ( $p, \Theta$ ) for data, MC
- correct for data - MC differences
- cross checked for different TMVA methods



# Measurements of $e^+e^- \rightarrow \mu\mu\gamma_{ISR}$ : data vs. MC

Event yield  $\mu\mu\gamma$  after  $\pi\text{-}\mu$  separation  
and all efficiency corrections



## Features:

- background from  $\pi\pi\gamma$  very small
- PHOKHARA accuracy <0.5%
- luminosity measurement based on Bhabha ev., 1.0% accuracy

→ excellent agreement with QED

$$\Delta(\text{MC/QED-data}) = (0.51 \pm 0.28) \%$$

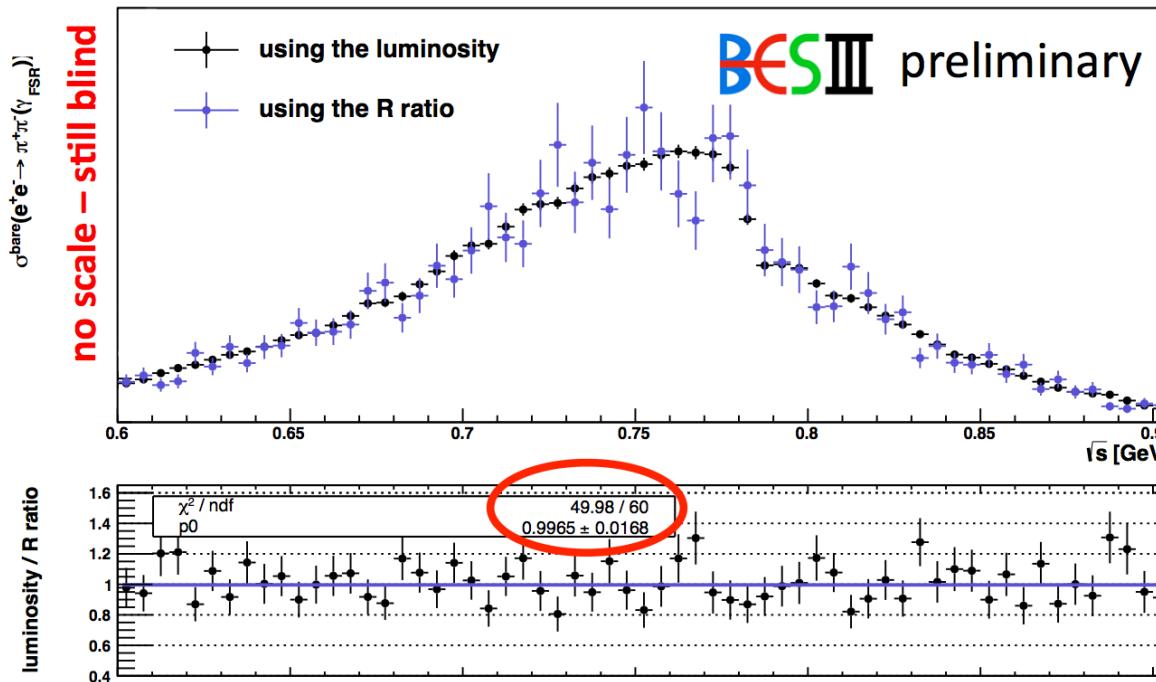
→ accuracy on 1% level as needed to be competitive !

# Results(still blinded): $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$

**2 normalization methods:** 1) normalization to  $L_{int}$  (obtained from Bhabha events)

$$\sigma_{bare}(e^+e^- \rightarrow \pi^+\pi^-) = \frac{N_{\pi\pi\gamma}/\epsilon_{exp}}{L_{int} \cdot H_{rad} \cdot \delta_{vac} \cdot (1 + \delta_{FSR})}$$

2) normalization to  $\mu\mu\gamma$  events, i.e. R ratio ( $\pi\pi\gamma/\mu\mu\gamma$ )  
 $\rightarrow L_{int}, H_{rad}, \delta_{vac}$  cancel in ratio!

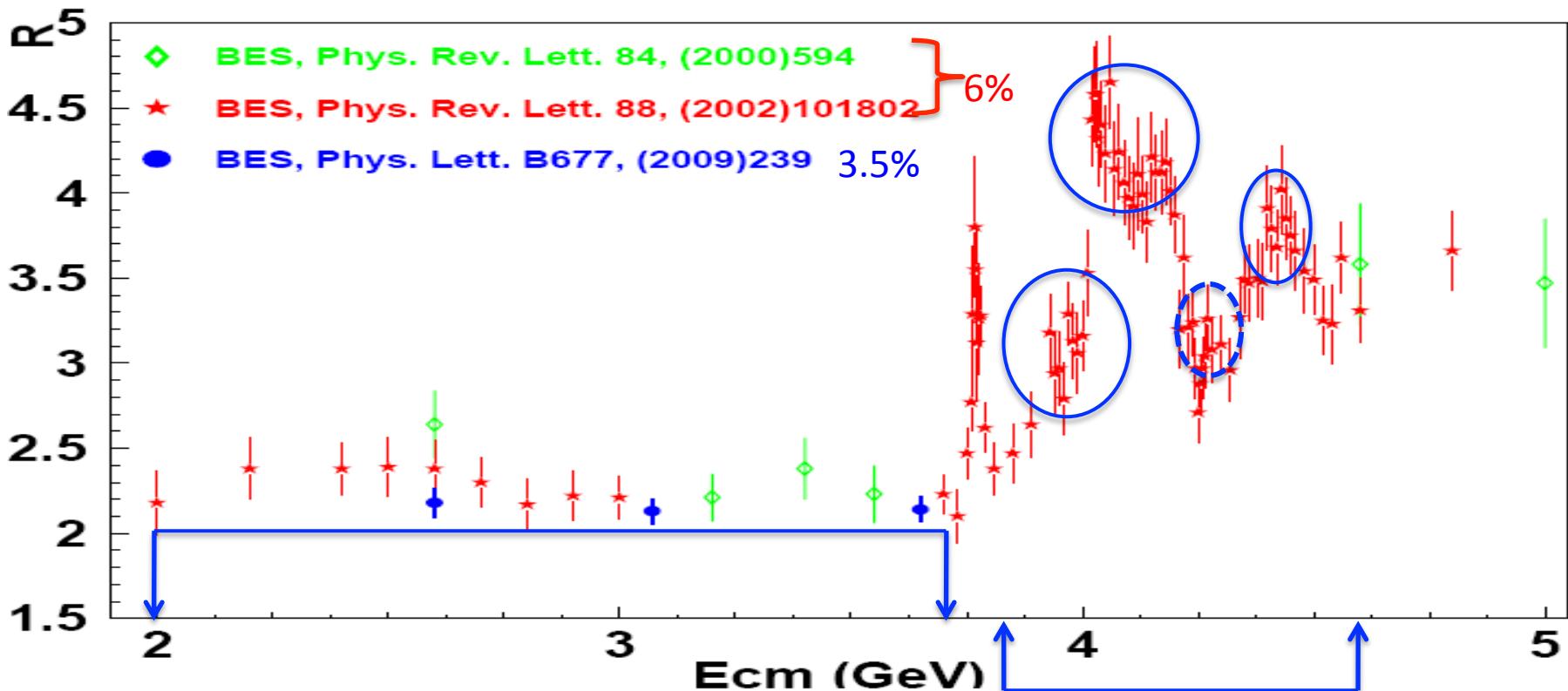


The uncertainty around the  $\rho$  peak is close to 1% for method 1.

**luminosity / R ratio -1  
 $= (0.35 \pm 1.68) \%$**

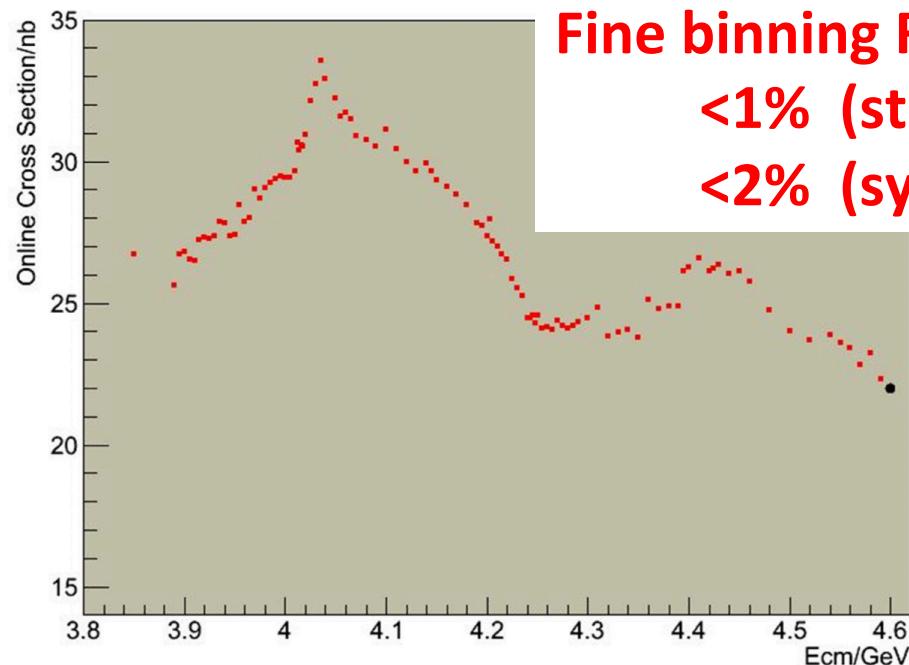
limited by low  $\mu\mu\gamma$  statistics

# R values scan in 3 Phases



- 😊 •Phase I: pre-study, ~7 days Done  
Machine study at 2.0, 2.5 and 4.2(4.6) GeV, MC tuning, ...
- 😊 •Phase II: scan resonance region, 2 months Done  
~104 points in 3.8-4.6 GeV, 100k events, step 2, 5,10, 20 MeV.  
Single/separated beam for beam associated background study.
- Phase III: scan continuum region, 6 months (2014-2015)  
15 points in 2.0-3.0 GeV, 10-20 pb-1 @ each point, step 100 MeV,

# R scan 2013-2014



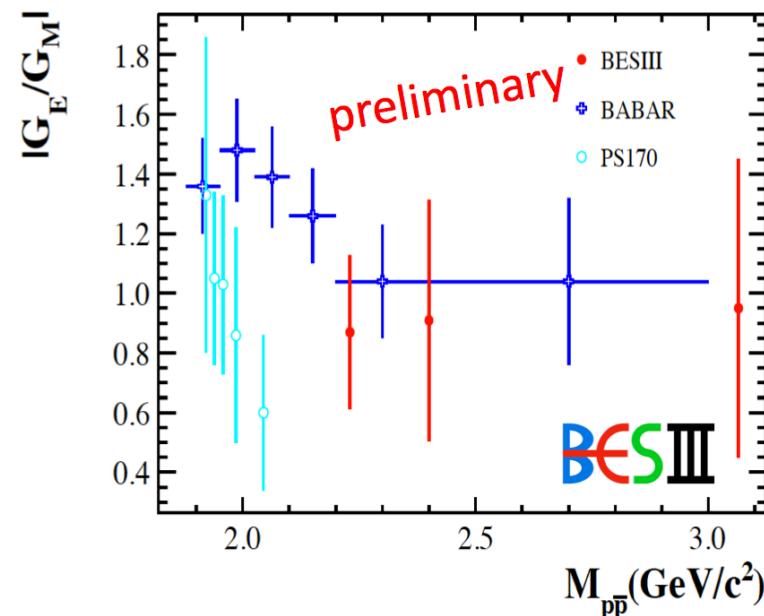
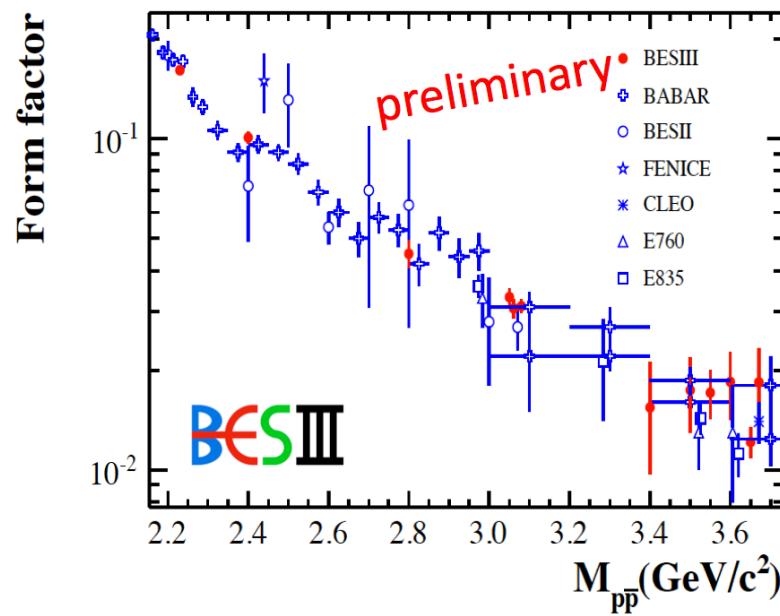
**Fine binning R ratio in Charmonium region:**  
**<1% (stat.)**  
**<2% (syst.)**

# Proton From factor: $e^+e^- \rightarrow p\bar{p}$

## Analysis Features:

- Radiative corrections from Phokara8.0 (scan)
- Normalization to  $e^+e^- \rightarrow e^+e^-$ ,  $e^+e^- \rightarrow \gamma\gamma$  (BABAYAGA 3.5)
- Efficiencies 60% (2.23 GeV) .... 3% ( $\sim 4$  GeV)
- $|G_E/G_M|$  ratio obtained for 3 cm energies

$E_{cm}/\text{GeV}$	$L_{int} / \text{pb}^{-1}$
2.23	2.6
2.40	3.4
2.80	3.8
3.05, 3.06, 3.08	60.7
3.40, 3.50, 3.54, 3.56	23.3
3.60, 3.65, 3.67	63.0

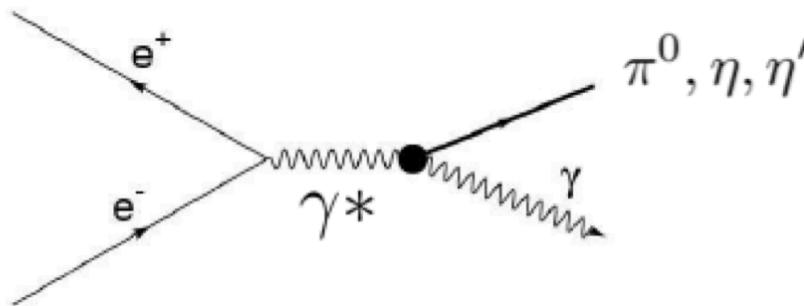
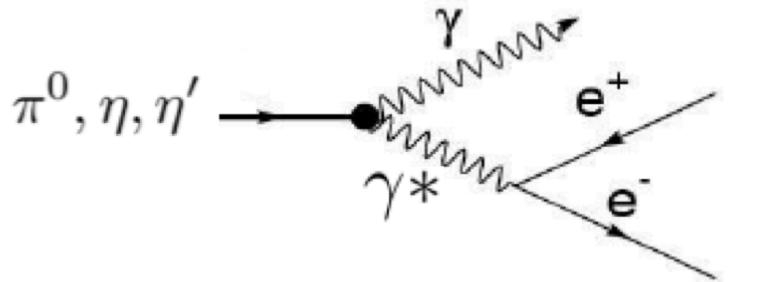


Our goal is to measure the ratio of form factors with 9% - 15% accuracy.

# Meson transition form-factors $P \rightarrow \gamma^* \gamma^*$

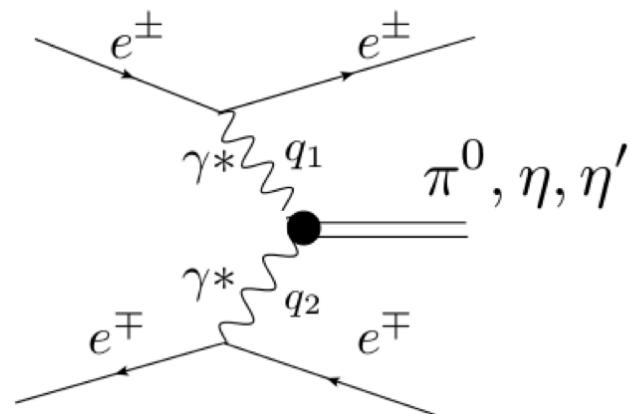
## Time-like transition form factors:

- Dalitz decays
  - $0 < q^2 < M_P^2$
- Annihilation process
  - $q^2 = s > M_P^2$



## Space-like transition form factors:

- Two-photon production of mesons in  $e^+e^-$



# Space like form-factor: single tag method

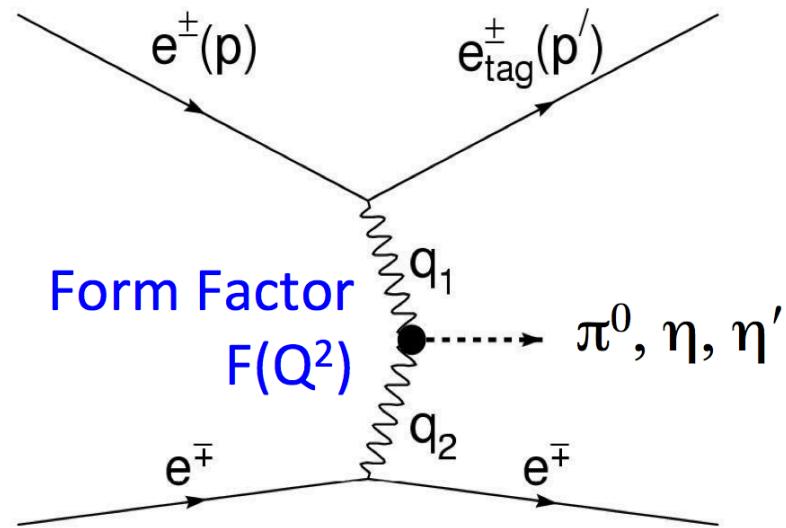
## Selection criteria

- 1 electron (positron) detected
- 1 positron (electron) along beam axis
- Meson fully reconstructed
- cut on angle of missing momentum

## Momentum transfer

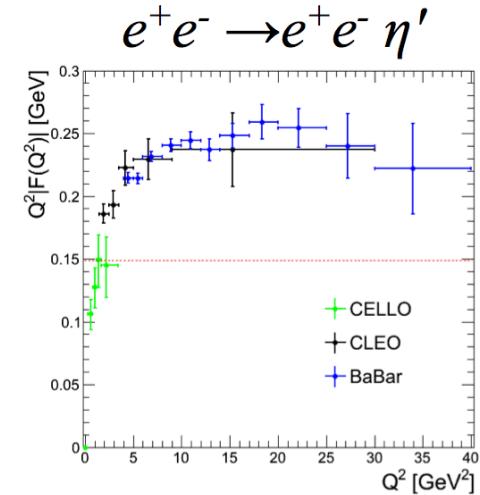
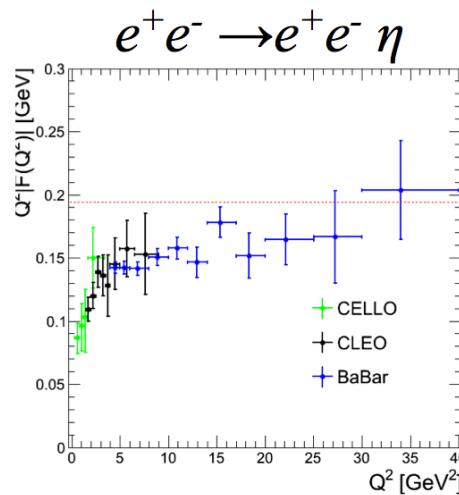
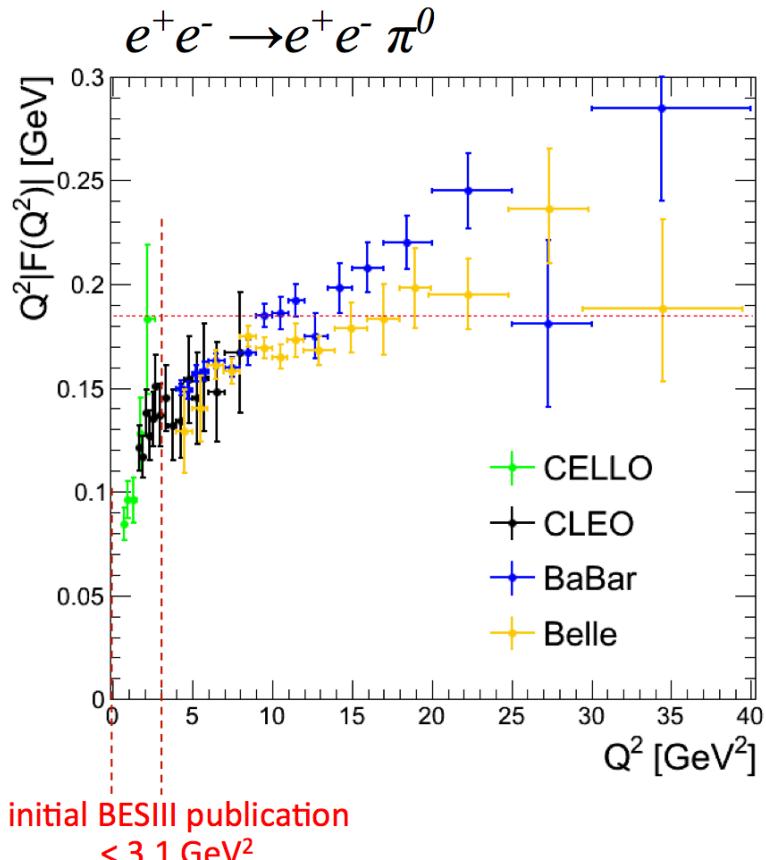
- tagged:  $Q^2 = -q_1^2 = -(p - p')^2$   
→ Highly virtual photon
- untagged:  $q^2 = -q_2^2 \sim 0 \text{ GeV}^2$   
→ Quasi-real photon

## Single Tag Method

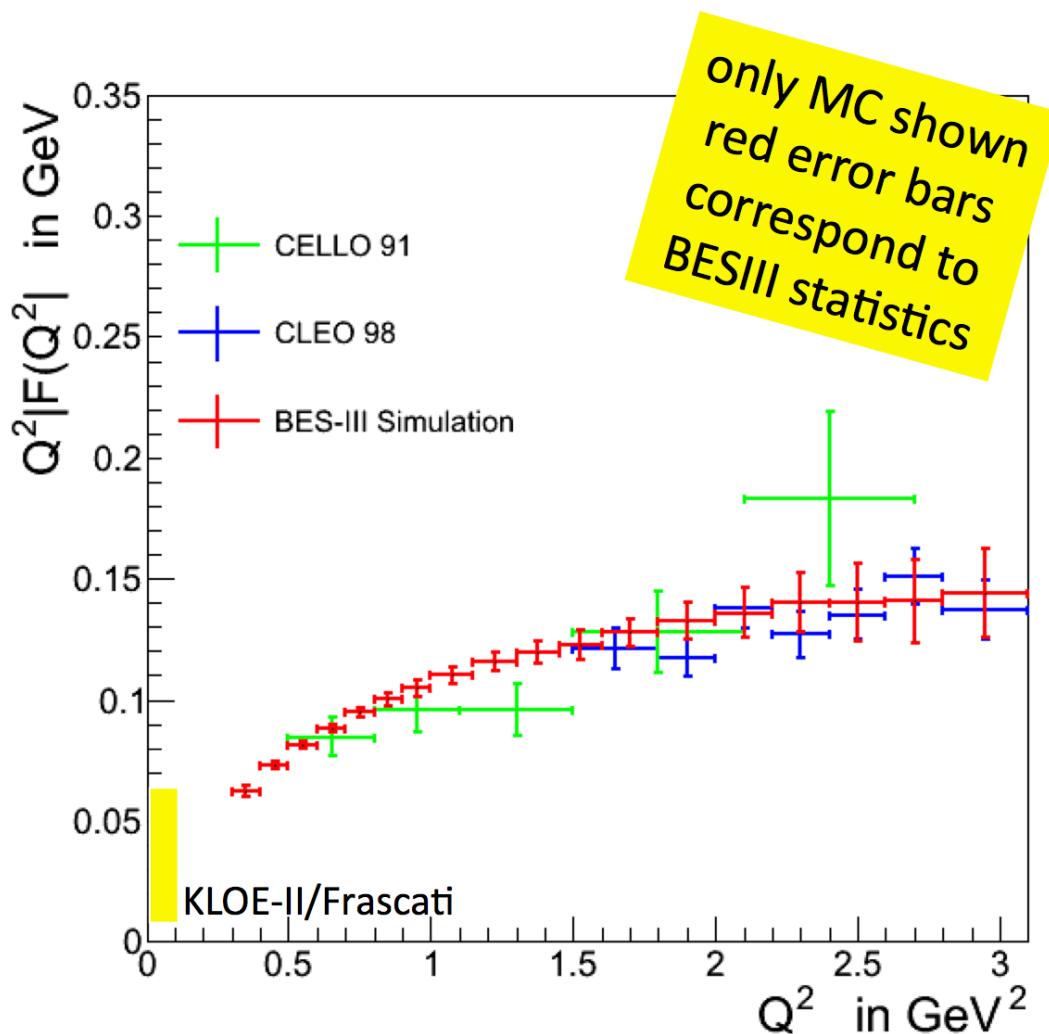


EKHARA event generator  
Czyż, Ivashyn

# Existing data on transition form-factors



# BESIII sensitivity for $e^+e^- \rightarrow e^+e^-\pi^0$

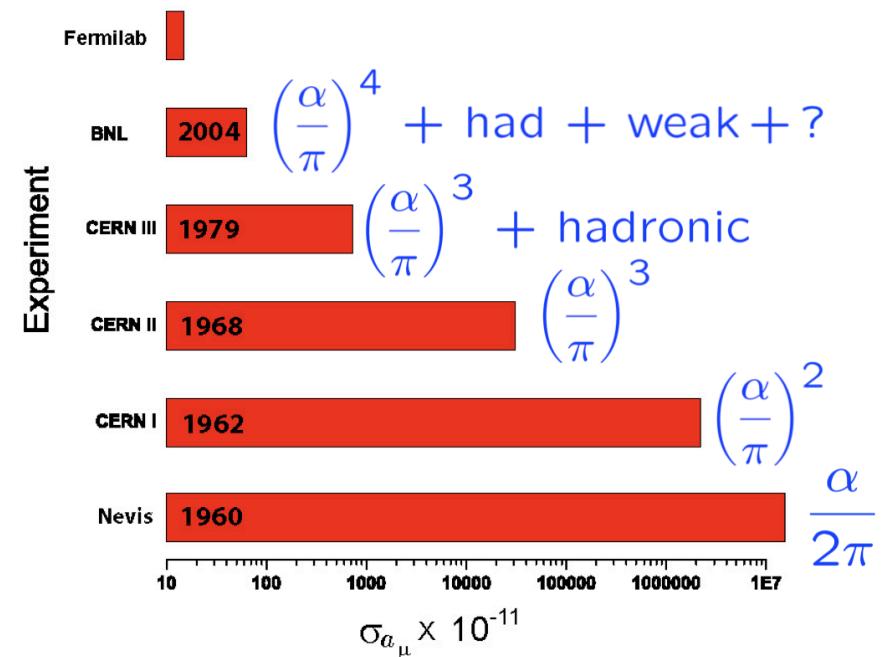
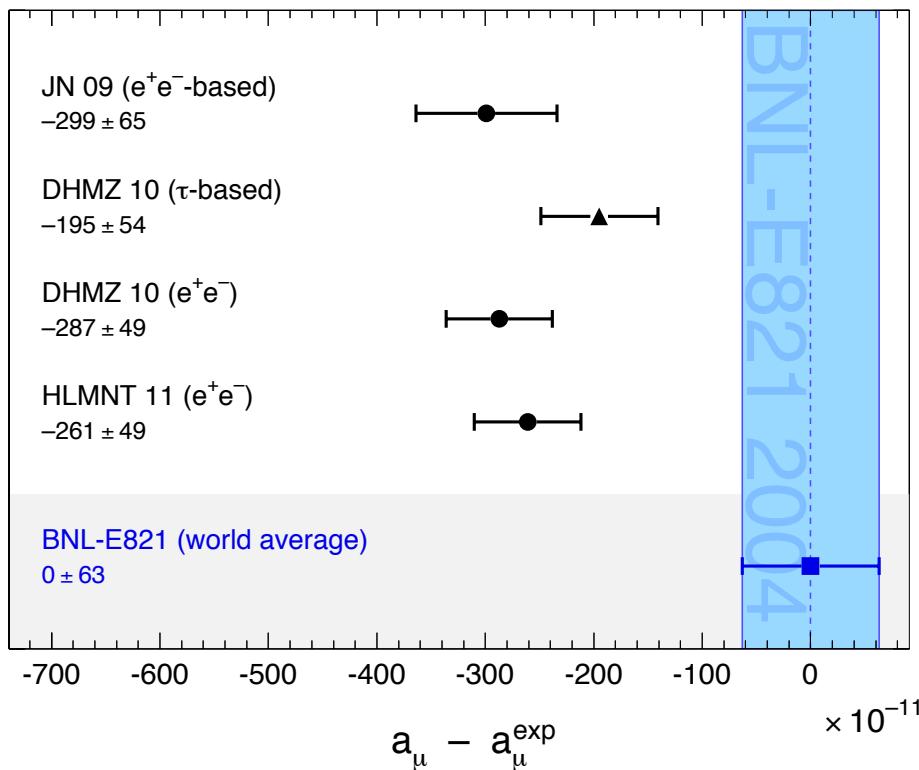


- Full Simulation
  - $L_{\text{int}}: 2.92 \text{ fb}^{-1}$
  - Single Tag with both,  $e^\pm$
- Extract TFF for  $0.3 \leq Q^2[\text{GeV}^2] \leq 3.1$

→ Unprecedented  
 $Q^2 < 1.5 \text{ GeV}^2$   
 Input for  $(g-2)_\mu$

# Outlook for $(g-2)_\mu$

New  $(g-2)_\mu$  experiments at H-Line/J-PARC and FNL will reach 0.1 ppm, almost 5 times better than that from BNL:



To improve the SM prediction, therefore, we need precision hadron cross-sections from  $e^+e^-$  machine, and better spectrum from tau decays.

# Conclusion

We expect results from BESIII soon

- Precision hadron cross-section measurements from BESIII → HVP →  $(g-2)_\mu$
- Space like time form factors → HLbL scattering

**With more measurements from CMD, SND, BESIII,  
The uncertainty on HVP can be reduced by a factor of 2?**

**Thanks!**

Special thanks to my BESIII colleague Achim Denig. I stolen many slides from Achim.