R measurement at BESIII

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(For the BESIII Collaboration)

Outline

- BEPCII/BESIII
- R measurements at BESIII
  - Energy scan in 2 – 4.6 GeV
  - Initial State Radiation (ISR) for <2GeV
- Summary

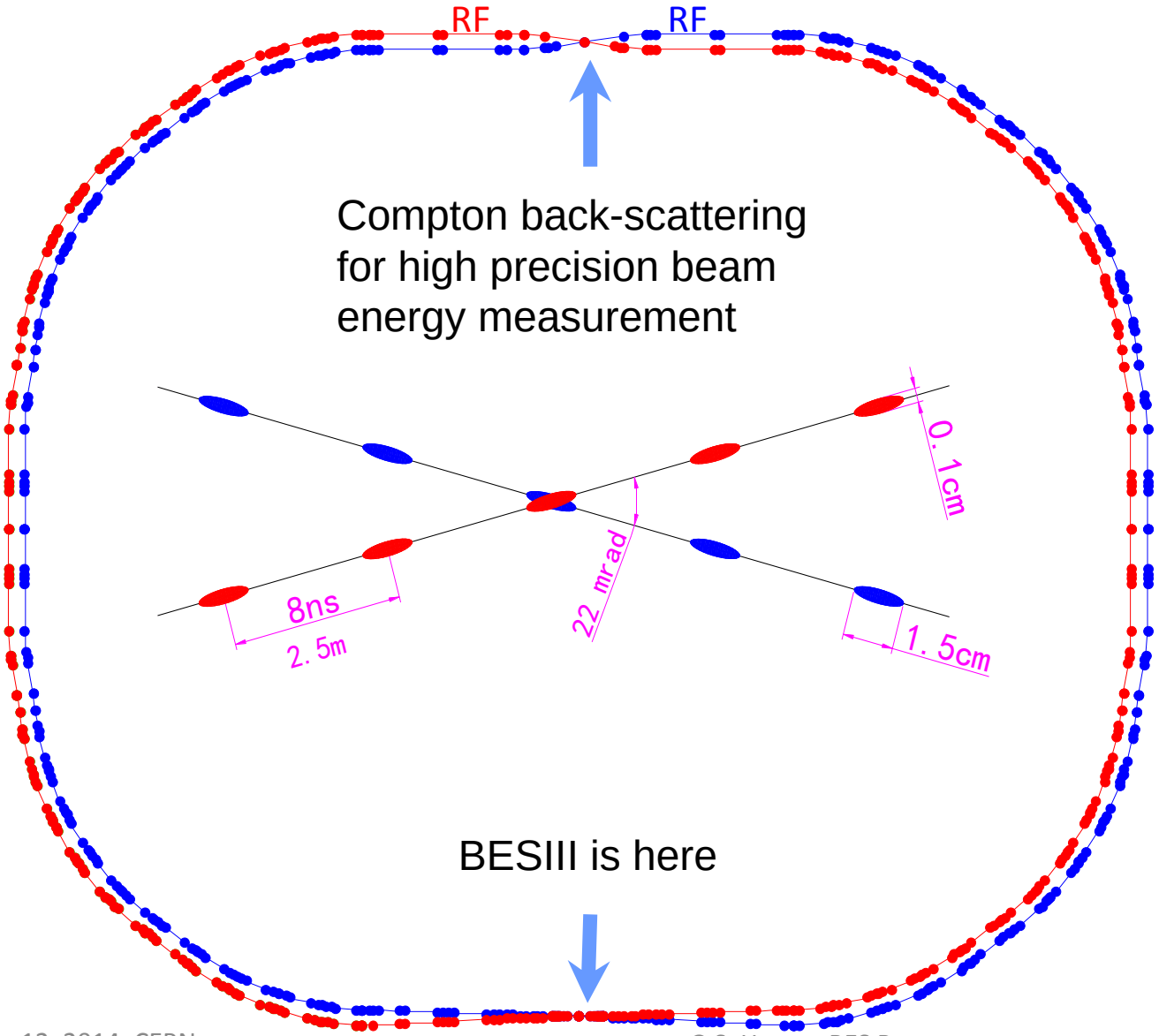
Bird View of BEPCII /BESIII

Beam energy 1.0-2.3 GeV
Energy spread: 5.16×10^{-4}

Design luminosity
$1 \times 10^{33}/cm^2/s$ @ $\psi(3770)$
Achieved luminosity
$\sim 0.7 \times 10^{33}/cm^2/s$

2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking

BEPC II: Large Crossing Angle, Double-ring



Beam energy:
1-2.3 GeV
Luminosity:
1×10^{33} $cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A
SR mode:
0.25A@2.5GeV

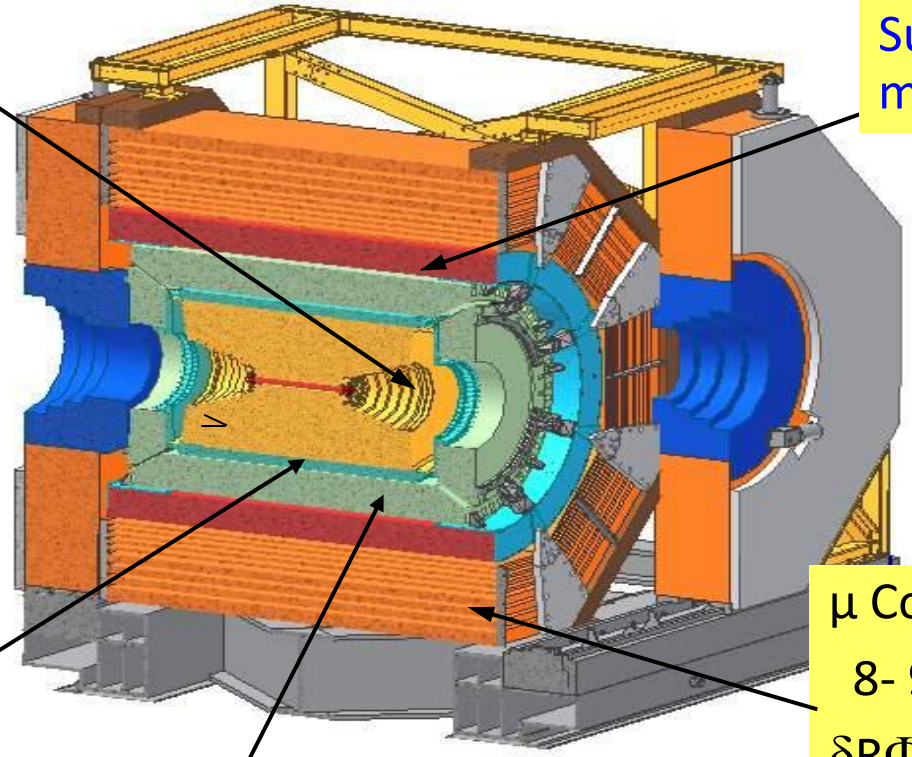
NIM A614, 345 (2010)

The BESIII Detector

Drift Chamber (MDC)

$\sigma p/p\ (^0/_0) = 0.5\%(1GeV)$

$\sigma_{dE/dx}\ (^0/_0) = 6\%$



Super-conducting magnet (1.0 Tesla)

Time Of Flight (TOF)

σ_T : 90 ps Barrel

110 ps endcap

μ Counter

8- 9 layers RPC

$\delta R\Phi$=1.4 cm~1.7 cm

EMC: $\sigma E/\sqrt{E}(^0/_0) = 2.5\ \%\ (1\ GeV)$

(CsI) $\sigma_{z,\phi}(cm) = 0.5 - 0.7\ cm/\sqrt{E}$

BESIII Data Sets

- July 19, 2008: first e^+e^- collision event in BESIII
- Nov. 2008: ~14M $\psi(2S)$ events for detector calibration
- 2009: 106M $\psi(2S)$ 4×CLEO-c
  225M J/ψ 4×BESII
- 2010: ~0.9 fb^{-1} $\psi(3770)$
- 2011: ~2.0 fb^{-1} $\psi(3770)$
  ~0.5 fb^{-1} @ 4.01 GeV

  } 3.5×CLEO-c

World's largest sample of J/ψ,$\psi(2S)$ and $\psi(3770)$

- 2012: tau mass scan: ~5.0 pb^{-1} ; $\psi(2S)$: 0.4B; J/ψ: 1B;
  J/ψ lineshape, R scan (2.23, 2.4, 2.8, 3.4 GeV)
- 2013: ~3.3 fb^{-1} @ 4.26, 4.36 GeV, …, for XYZ studies;
- 2014: ~0.8 fb^{-1} R scan 3.8-4.6 GeV, more for XYZ.

Future plans: R scan & QCD study in 2-3 GeV, D_s physics (E_{cm} = 4170 MeV), τ scan, 10 fb^{-1} or more ψ (3770) for DD physics, ……

The BESIII Collaboration

http://bes3.ihep.ac.cn

US (6)
Univ. of Hawaii
Univ. of Washington
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Europe (11)
Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. ofJohannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino， Frascati Lab
Netherland: KVI/Univ. of Groningen
Turkey: Turkey Accelerator Center

Korea (1)
Seoul Nat. Univ.

Japan (1)
Tokyo Univ.

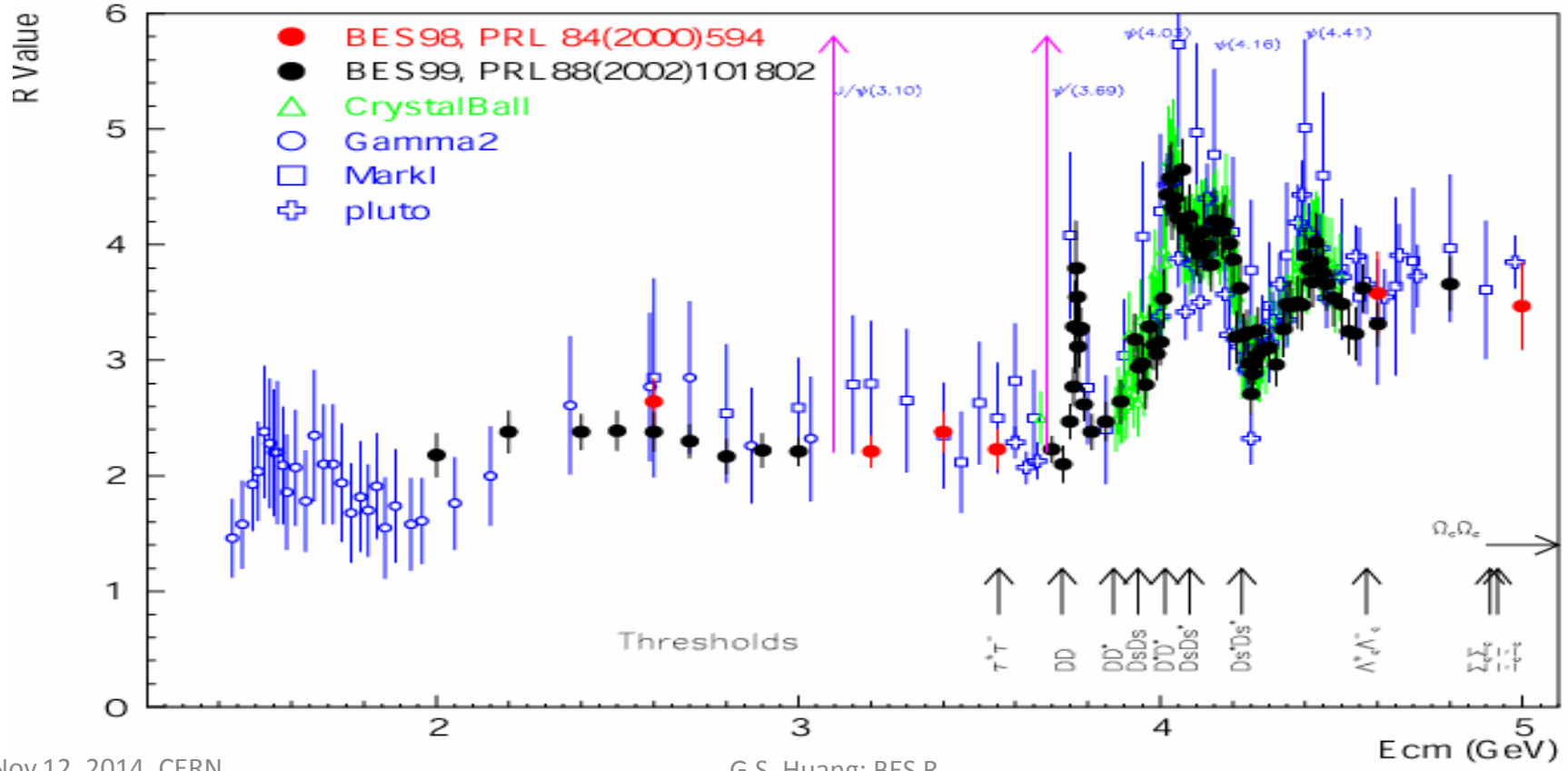
Pakistan (1)
Univ. of Punjab

China(30)
IHEP, CCAST, 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
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.
Hong Kong Univ., Hong Kong Chinese Univ.
Univ. of South China, UCAS.

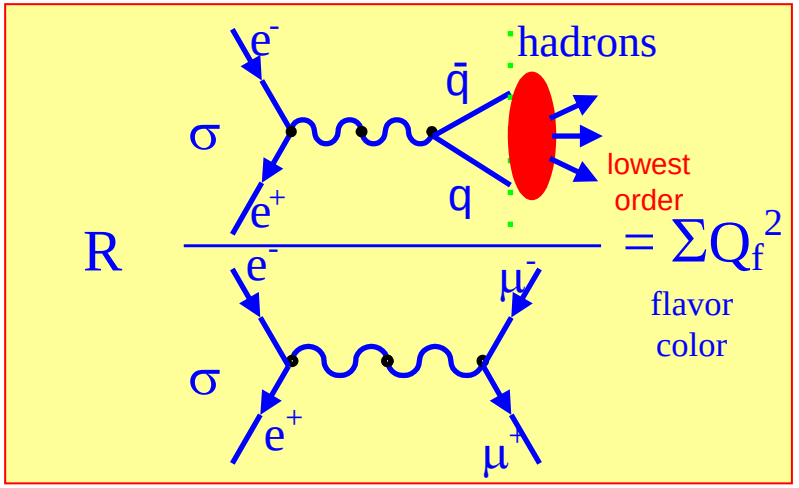
~350 physicists
50 institutions from 10 countries

Features of the BEPC Energy Region

- Rich of resonances, charmonium and charmed mesons
- Threshold characteristics (pairs of τ, D, D_s, charmed baryons…)
- Transition between smooth and resonances, perturbative and non-perturbative QCD
- Energy location of the gluonic matter and glueball, exotic states and hybrid



Definition of R:



- At lowest order

$$R \equiv \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)} = \frac{\sum_q \sigma(e^+e^- \to q\bar{q})}{\sigma(e^+e^- \to \mu^+\mu^-)} = 3\sum_q Q_q^2$$

Number of quark colors

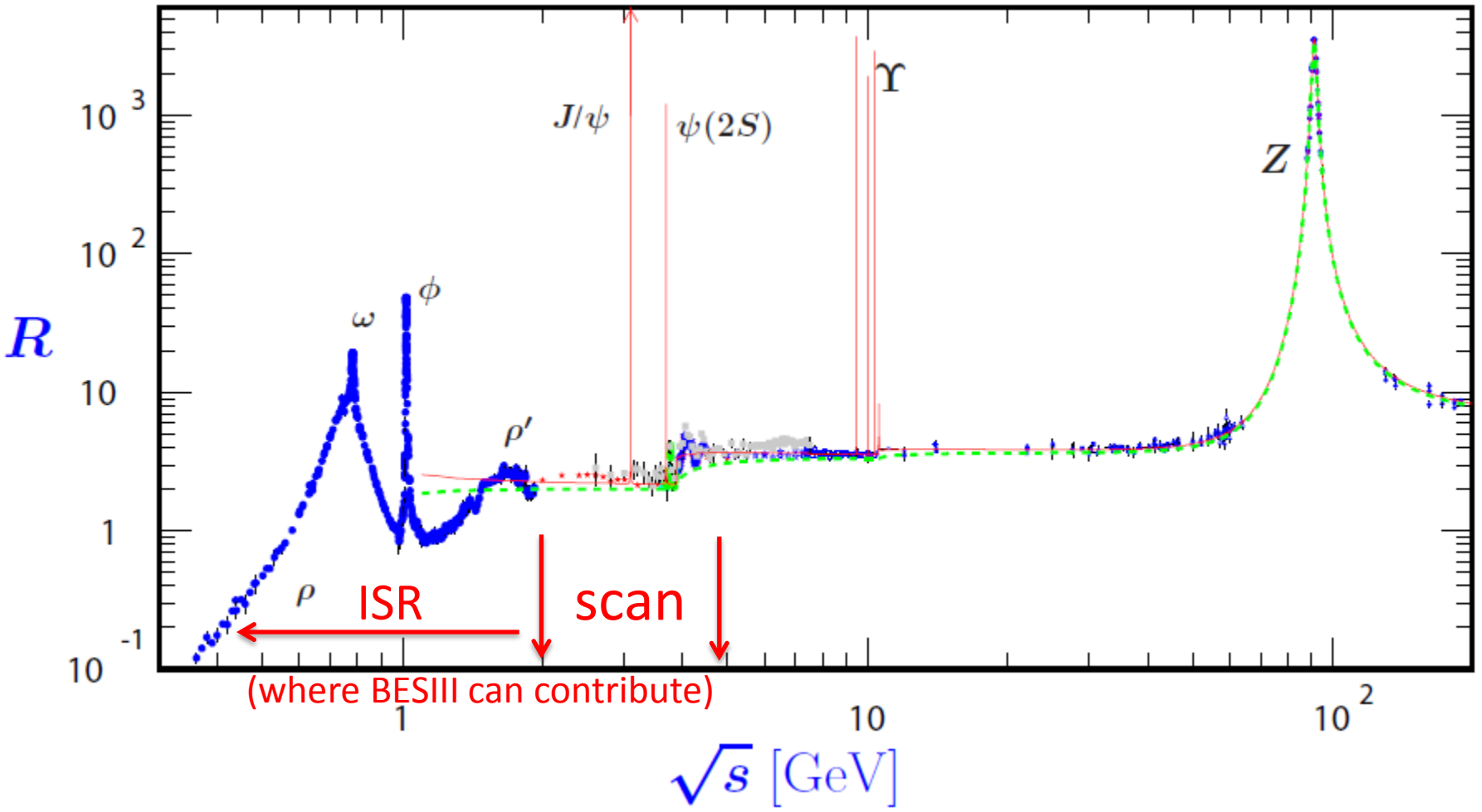
- At higher order

$$R = 3\, K_{QCD} \sum_q Q_q^2 ,$$

$$K_{QCD} = 1 + \frac{\alpha_S(\mu^2)}{\pi} + \sum_{n\geq 2} C_n \left(\frac{s}{\mu^2}\right) \left(\frac{\alpha_S(\mu^2)}{\pi}\right)^n$$

- R is one of the most fundamental quantities in particle physics that directly reflect the flavor and color of quarks.
- Directly test quark model & QCD, and discover new particles.

R: from threshold to Z



Motivations

- Hadronic contribution to
  - QED running coupling constant $\alpha_{QED}(M_Z)$

$$\Delta\alpha^{(5)}_{had}(s) = -\frac{\alpha s}{3\pi}\mathrm{Re}\int_{4m_\pi^2}^{\infty} ds' \frac{R(s')}{s' - s - i\varepsilon}$$

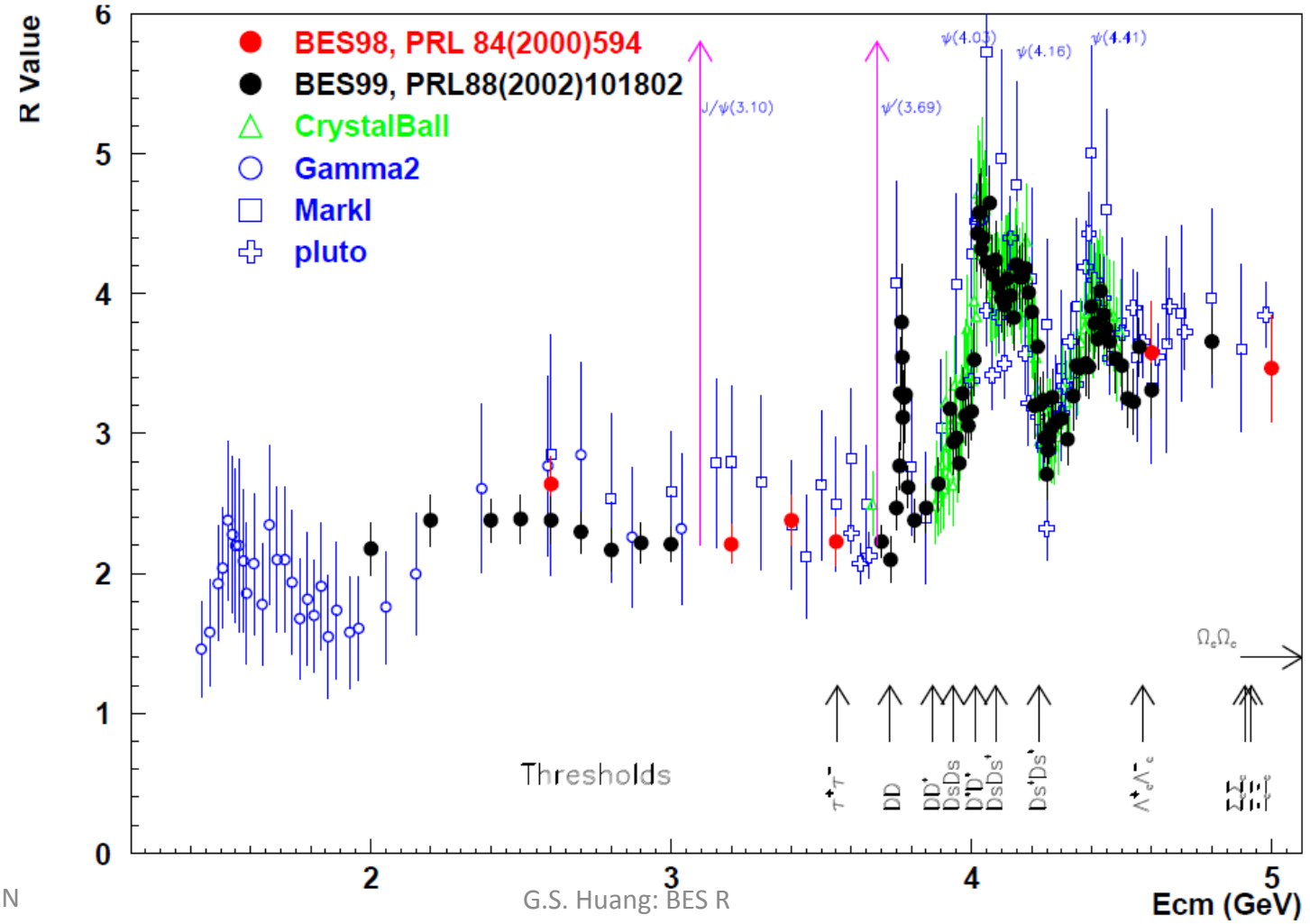
  - Anomalous magenet moment of the muon a_μ, or $(g_\mu - 2)$

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

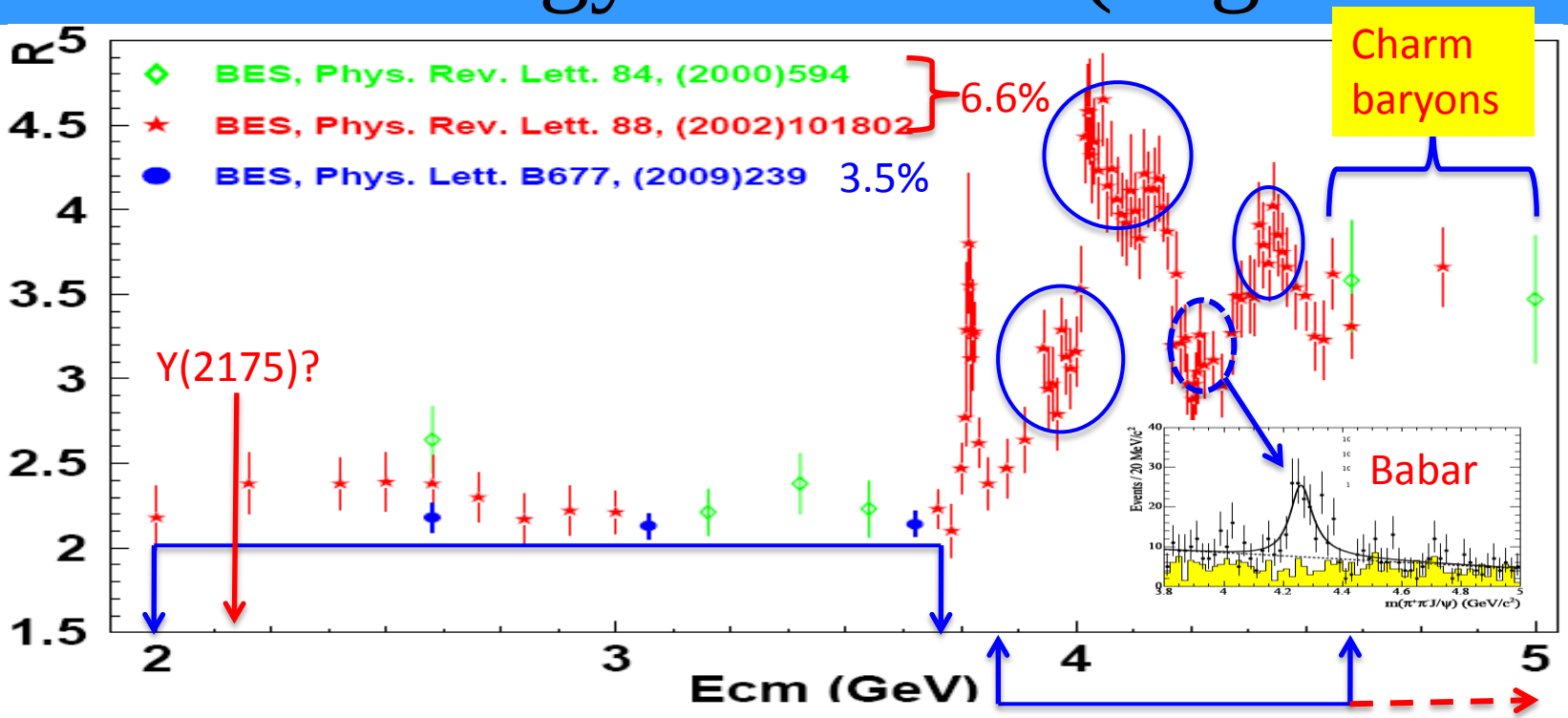
- Resonance structure and component in open charm region;
- Strong coupling constant α_s determination;
- Baryon form factors;
- Charm quark mass m_c determination;
- X, Y, Z particles and other possible new resonances;
- ……

R Scan at BESII

- 6 + 85 energy points, total ~5 pb^{-1} data, uncertainties 5~10% (average 6.6%).



R Scan Strategy at BESIII (Big Picture)



- Phase I: pre-study,
  Machine study at 2.0, 2.5 and 4.2(4.6) GeV, MC tuning, …
- Phase II: scan continuum region,
  15 points in 2.0–3.6 GeV, step 100 MeV, 100k+ hadrons<3 GeV.
- Phase III: scan resonance region,
  ~100 points in 3.8–4.6 GeV, 100k events, step 2, 5,10, 20 MeV.
  (10^8 hadrons at 4040, 4160, 4415 for radiative decay search?)

Measurement of R Values

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

Our goal:
3% precision

N_{had}: observed hadronic events

N_{bg}: background events

L: integrated luminosity

ε_{had}: detection efficiency for N_{had}

δ: radiative correction factor

$\sigma_{\mu\mu}$: can be precisely calculated(QED). Measurement of R is to measure the total $\sigma(e^+e^- \rightarrow \text{hadrons})$

Except for controlling each item to the precision requested, stable long term machine and detector performance is crucial.

First R-QCD Run at BESIII

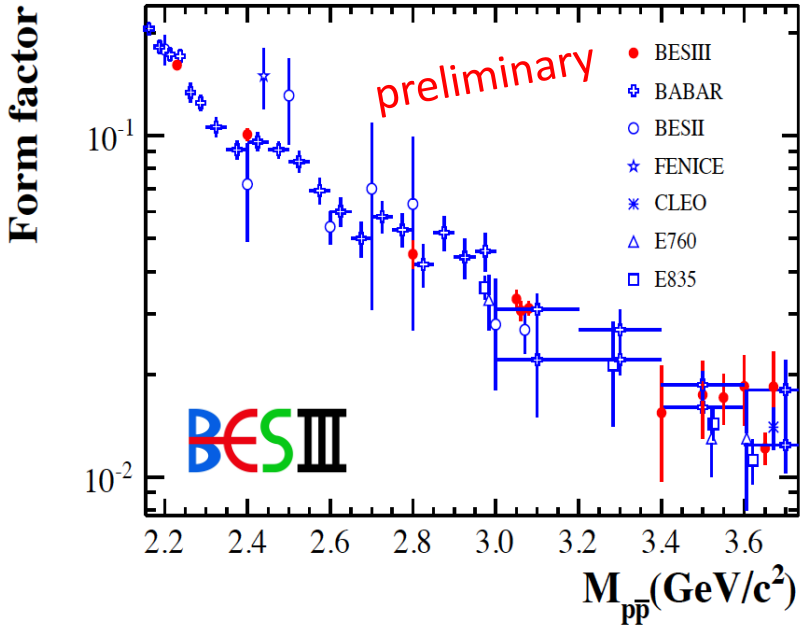
- BESIII collected data at 2.23, 2.4, 2.8 and 3.4 GeV during June 8–16, 2012;
- Total integrated luminosity ~12 pb^{-1};
- Useful information for machine at low energy;
- The data being used for MC generator tuning;
- Necessary to establish analysis chain;
- Baryon form factors, fragmentation function study underway.

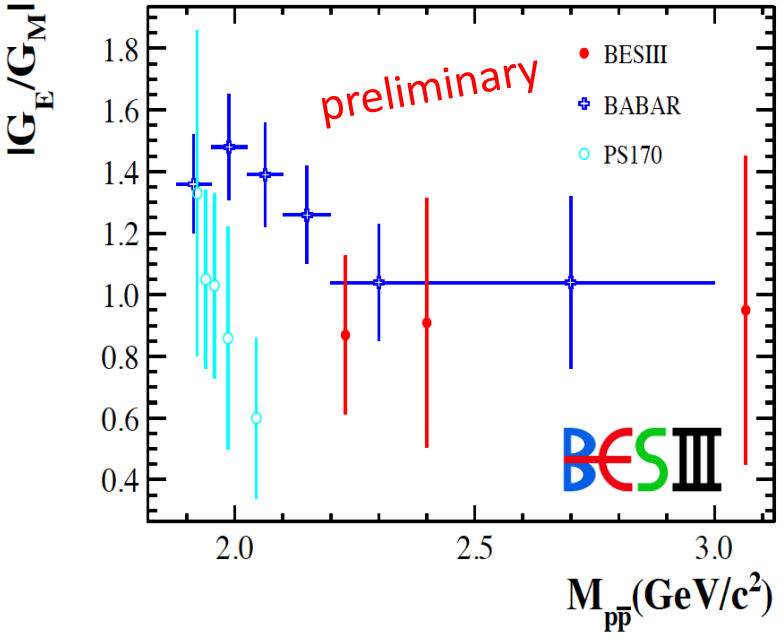
Proton Form Factors from test run

Analysis Features:

- Radiative corrections from Phokhara8.0 (scan)
- Normalization to $e^+e^- \rightarrow e^+e^-$, $e^+e^- \rightarrow \gamma\gamma$ (BABAYAGA 3.5)
- Efficiencies 60% (2.23 GeV) .... 3% (~4 GeV)
- $|G_E/G_M|$ ratio obtained for 3 c.m. energies

E_{cm}/GeV	L_{int} / 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

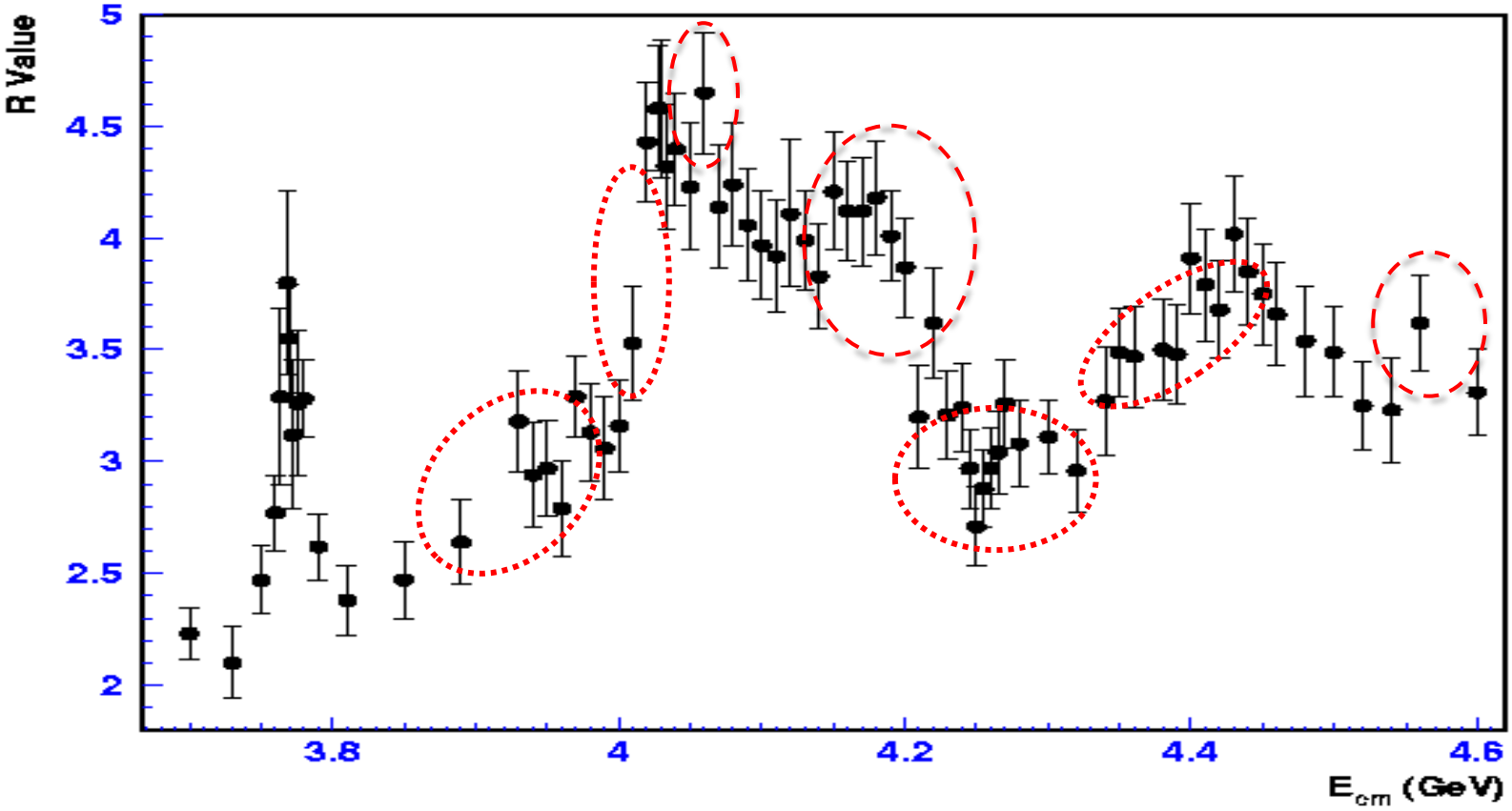




2 - 3 GeV scan: R and Beyond

- To take data soon: 19 points, ~500 pb^{-1};
- Precision of R measurement expected: ~3%;
- Nucleon form factors: 9-15% accuracy. For proton $|G_E/G_M|$, top BaBar results;
- Suspicious structures in the $p\bar{p}$ invariant mass;
- Hyperon form factor studies;
- Studies of threshold effects (Λ, Σ, Ξ);
- Determination of α_s and charm quark mass;
- Quark fragmentation functions;
- ……

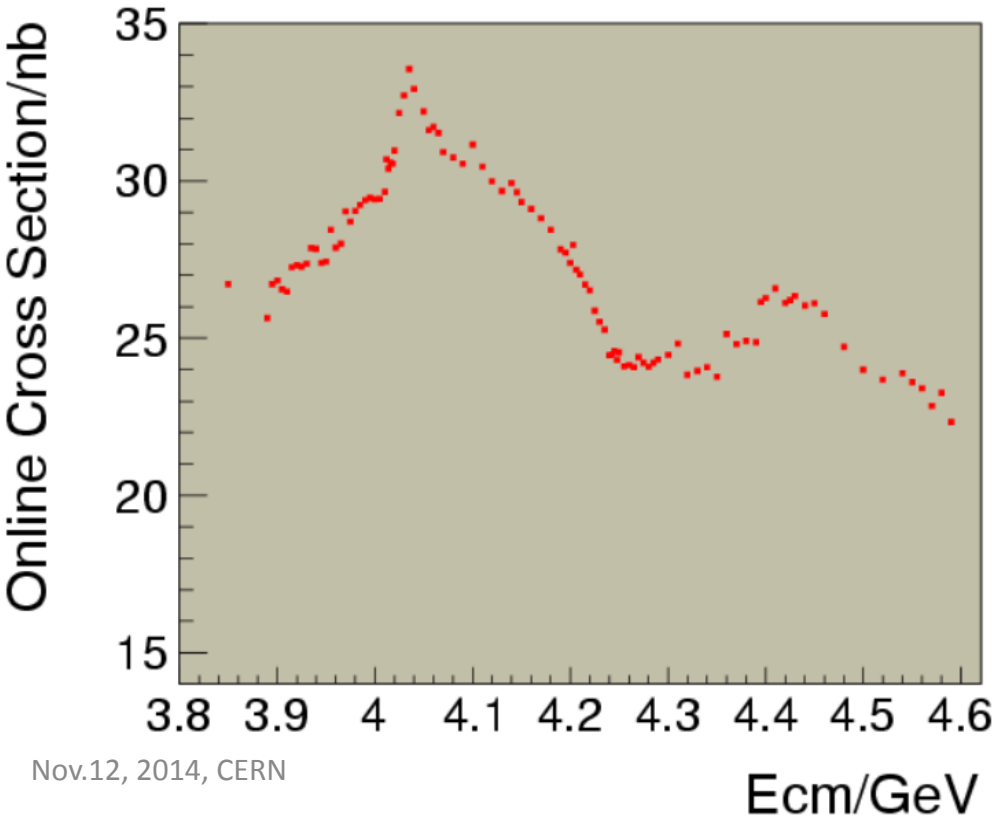
Resonance Structure in High Energy Region

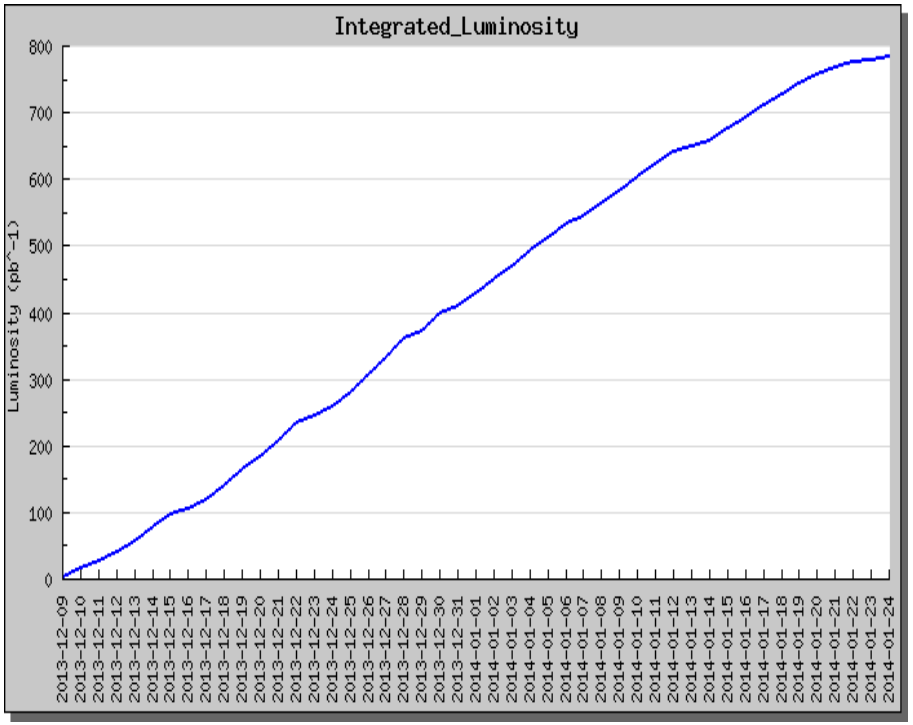


- What are these broad resonances?
- Mass region where some X, Y, Z particles are found.
- Possible new resonance that not yet discovered?

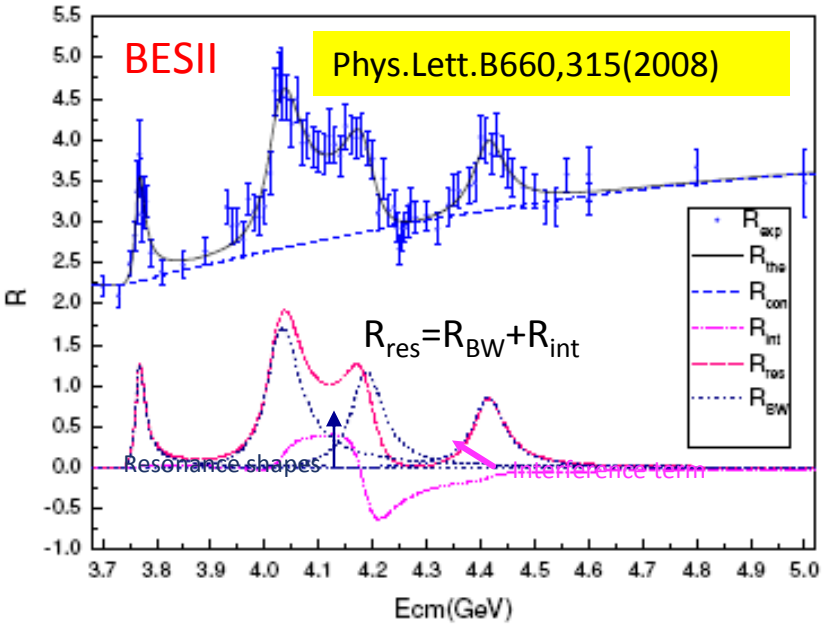
R Scan in 3.8 - 4.6 GeV

- Data taken 2013.12.9 - 2014.1.24;
- 104 energy points in total, ~800 pb^{-1};
- >100k hadronic events each points.





Aim to Understand Resonance Structures



- All possible two-body decays of ψ(3770), ψ(4040), ψ(4160), ψ(4415) are included in the fit.
- Interference, phase and energy-dependent width must be taken into account in the fit.

$$
\begin{aligned}
\psi(3770) &\Rightarrow D\bar{D};\\
\psi(4040) &\Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s;\\
\psi(4160) &\Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s, D_s\bar{D}_s^*;\\
\psi(4415) &\Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, \bar{D}D^*, D_s\bar{D}_s, D_s\bar{D}_s^*, D_s^*\bar{D}_s^*.
\end{aligned}
$$

We need high statistic data taken at each peak position to measure the resonance parameters by knowing the cross section of their exclusive decay channels.

- Non-resonant contribution
- Open charm threshold

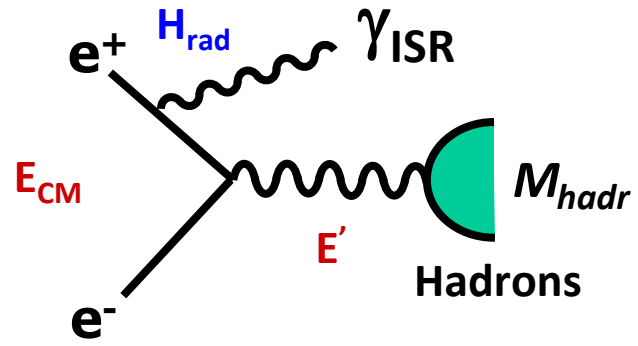
Parameters of the Broad Resonances

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:

	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

Initial State Radiation (ISR)

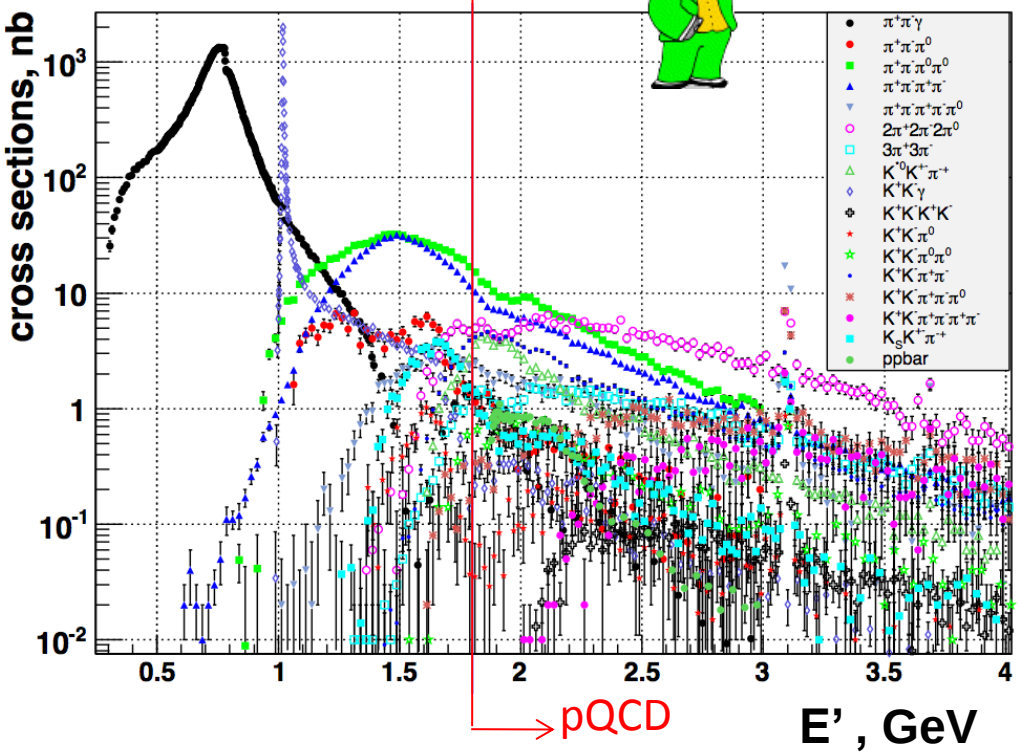
Rev. Mod. Phys. 83, 1545–1588 (2011)



- Needs **no** systematic variation of beam energy
- High statistics thanks to high integrated luminosities
- Precise knowledge of radiative corrections mandatory (H_{rad})

PHOKHARA event generator Czyż, Kühn, et al.

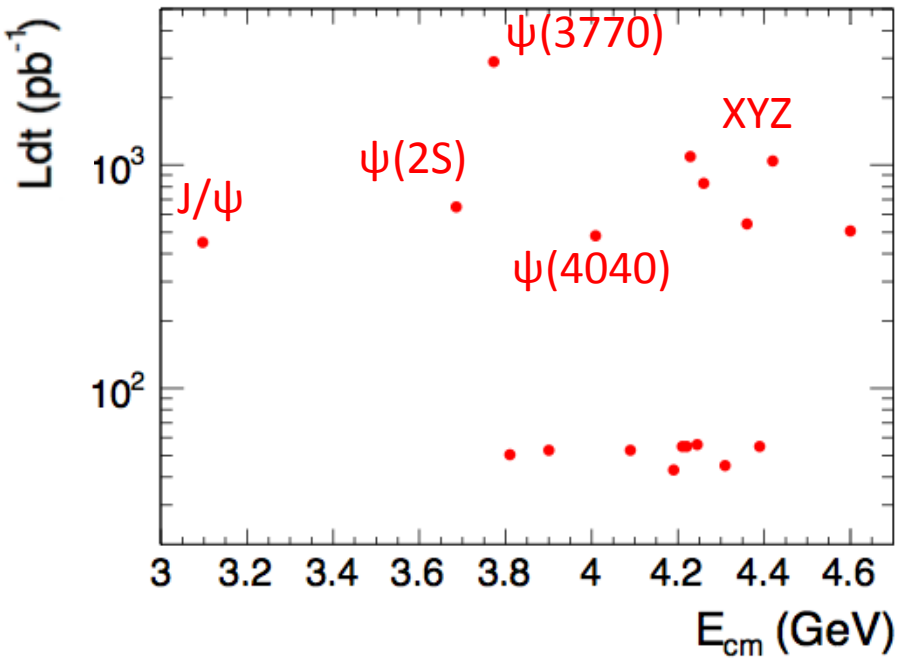
ISR spectra measured by BABAR

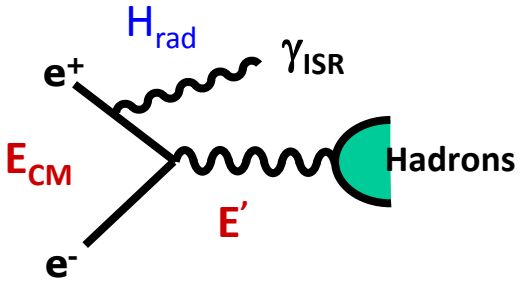


→ **Entire E range <E_{CM} accessible**

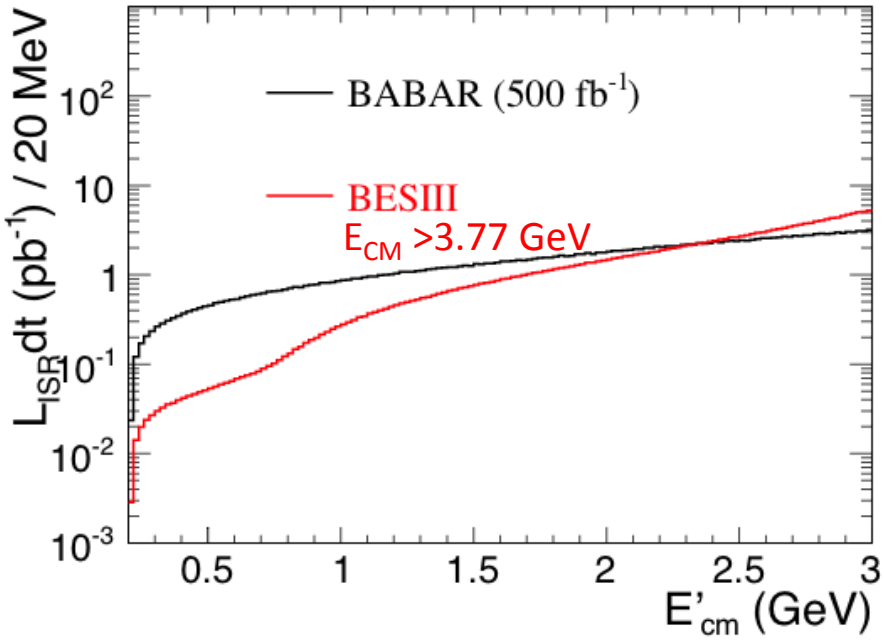
Data Samples for ISR Physics

Integrated luminosities BESIII





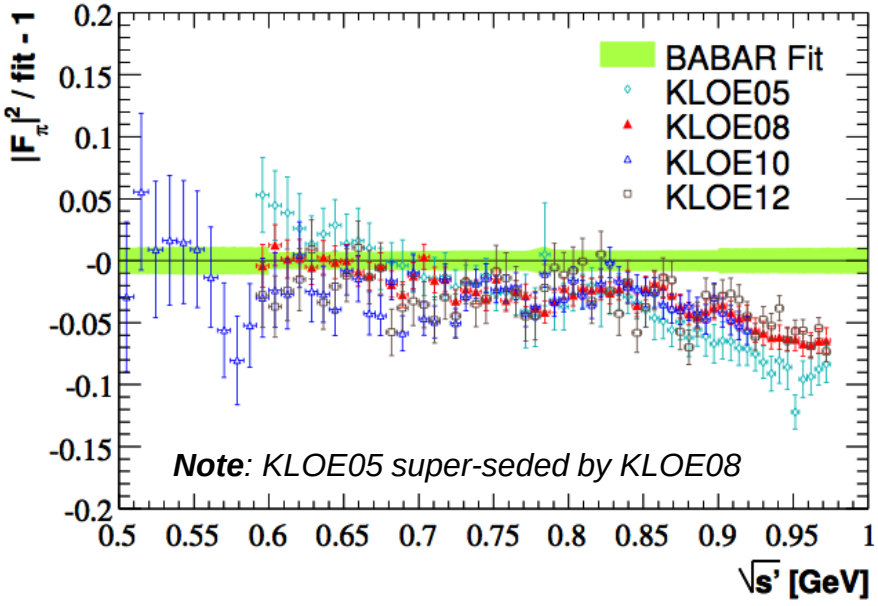
ISR luminosity = Ldt x H_{rad}



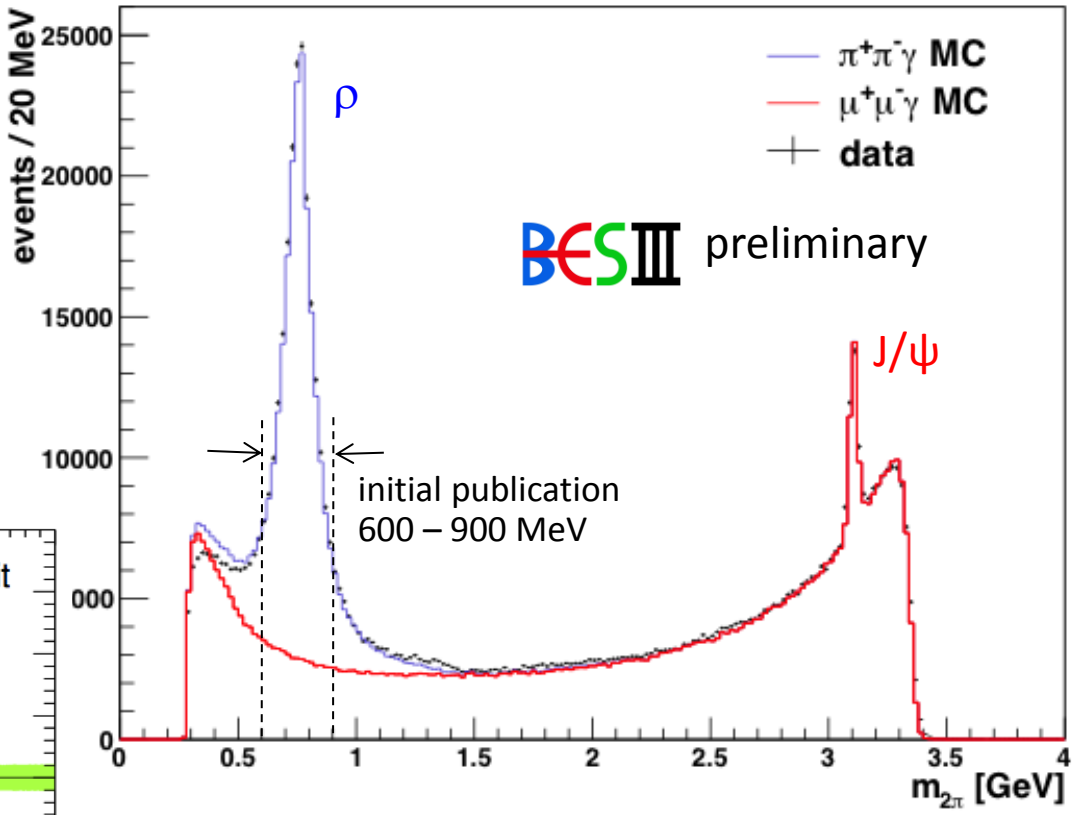
Flagship ISR Analysis: $e^+e^- \to \pi^+\pi^-\gamma_{ISR}$

The most relevant Channel

- KLOE and BABAR dominate the world average
- Relatively large systematic differences, esp. above ρ peak
- Knowledge of a_μ^{had} dramatically limited due to this difference



Event yield after acceptance cuts **only**



Features:

- ψ(3770) data only (2.9 fb^{-1})
- no dedicated background subtraction
- tagged ISR photon

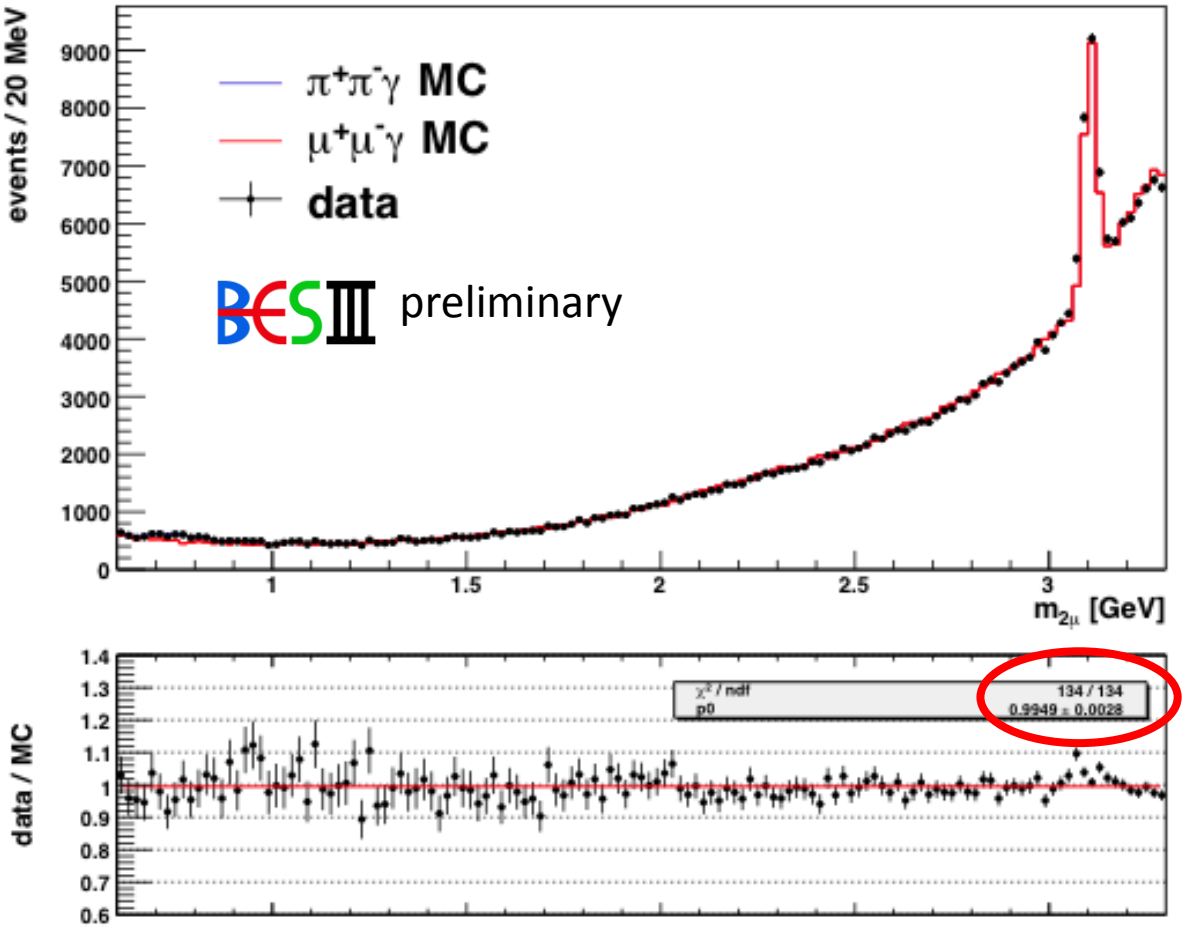
→ large statistics of $e^+e^- \to \pi\pi\gamma$ events

→ background dominated by $e^+e^- \to \mu\mu\gamma$

→ data – MC differences visible

Measurement of $\mu^+\mu^-\gamma$: Data vs. QED

Event yield $\mu\mu\gamma$ after π-μ separation and all efficiency corrections



Features:

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

→ excellent agreement with QED

Δ(MC/QED-data) = (0.51 ± 0.28) %

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

$\sigma(e^+e^- \to \pi^+\pi^-)$ - still blind

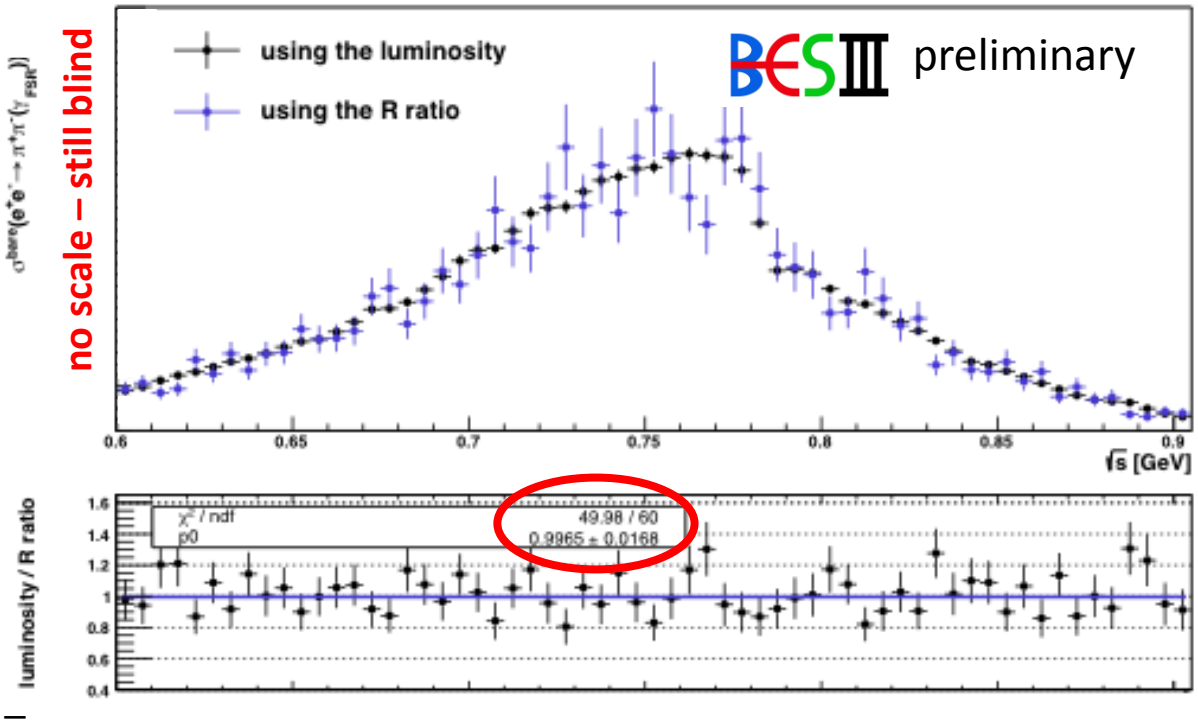
2 normalization methods:

1) normalization to L_{int} (obtained from Bhabha events)

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

2) normalization to μμγ events, i.e. R ratio (ππγ/μμγ)

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

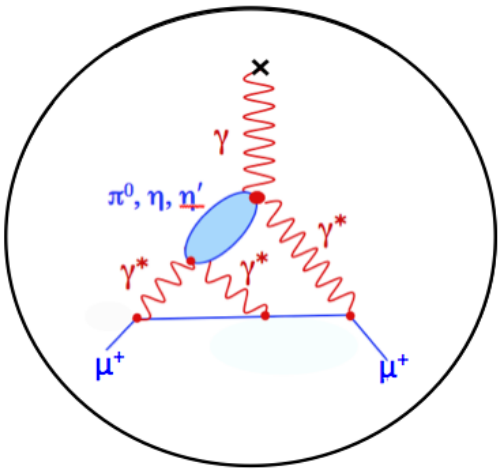


luminosity / R ratio -1
= (0.35 ± 1.68) %

limited by low μμγ statistics

Meson Transition Form Factors

$F(Q_1^2, Q_2^2)$



Important to $(g-2)_\mu$ HLbL.

Extract Space-Like FFs using $\gamma\gamma^* \to P$

Selection criteria

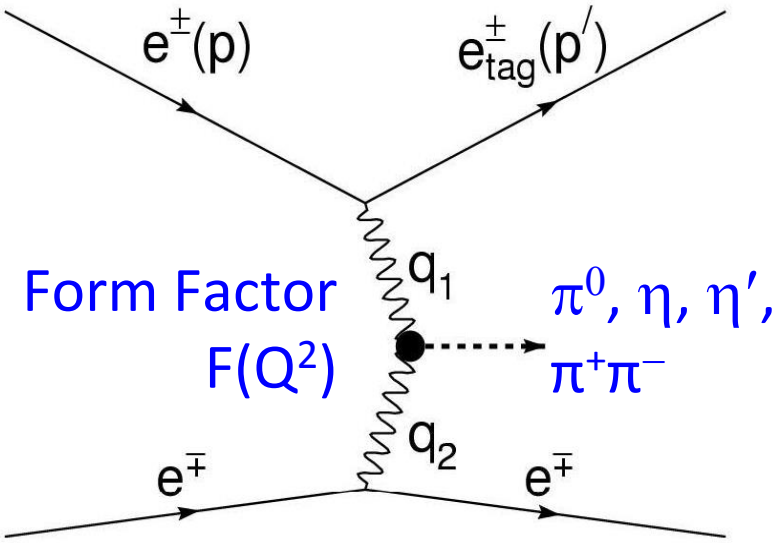
- 1 electron (positron) detected
- 1 positron (electron) along beam axis
- Meson fully reconstructed

→ cut on angle of missing momentum

Momentum transfer

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

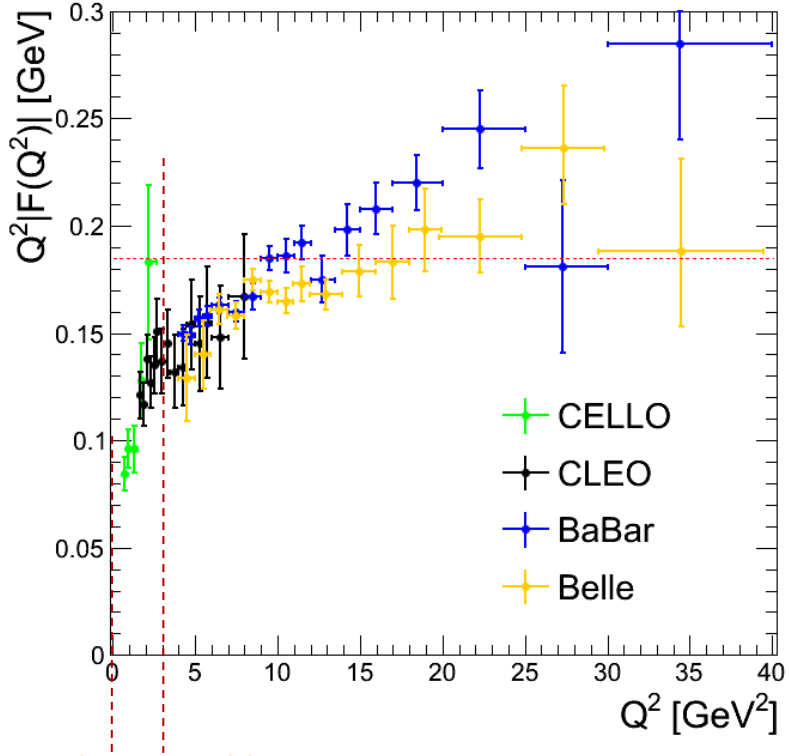
Single Tag Method



EKHARA event generator
Czyż, Ivashyn

Existing Data on SL Transition FFs

$e^+e^- \to e^+e^- \pi^0$



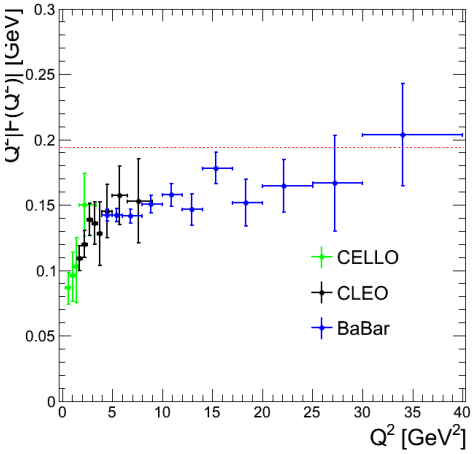
initial BESIII publication
< 3.1 GeV^2

Features:

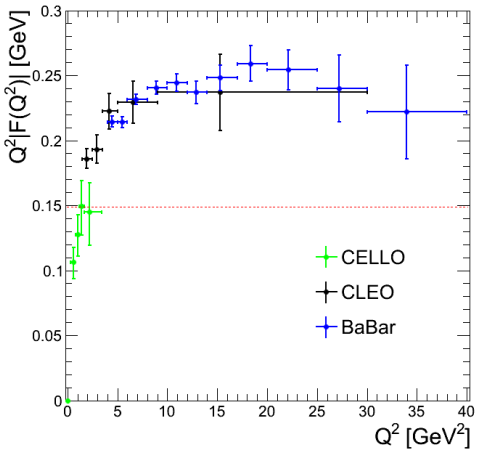
- recent high-Q^2 data from BABAR and BELLE $Q^2 > 4$ GeV^2
- above 1.5 GeV^2 data from CLEO
- below 1.5 GeV^2 data from CELLO, very poor accuracy

→ low Q^2 range not covered
most relevant for HLbL contribution to $(g-2)_\mu$
→ most relevant channels: π^0, η, η', $\pi\pi$

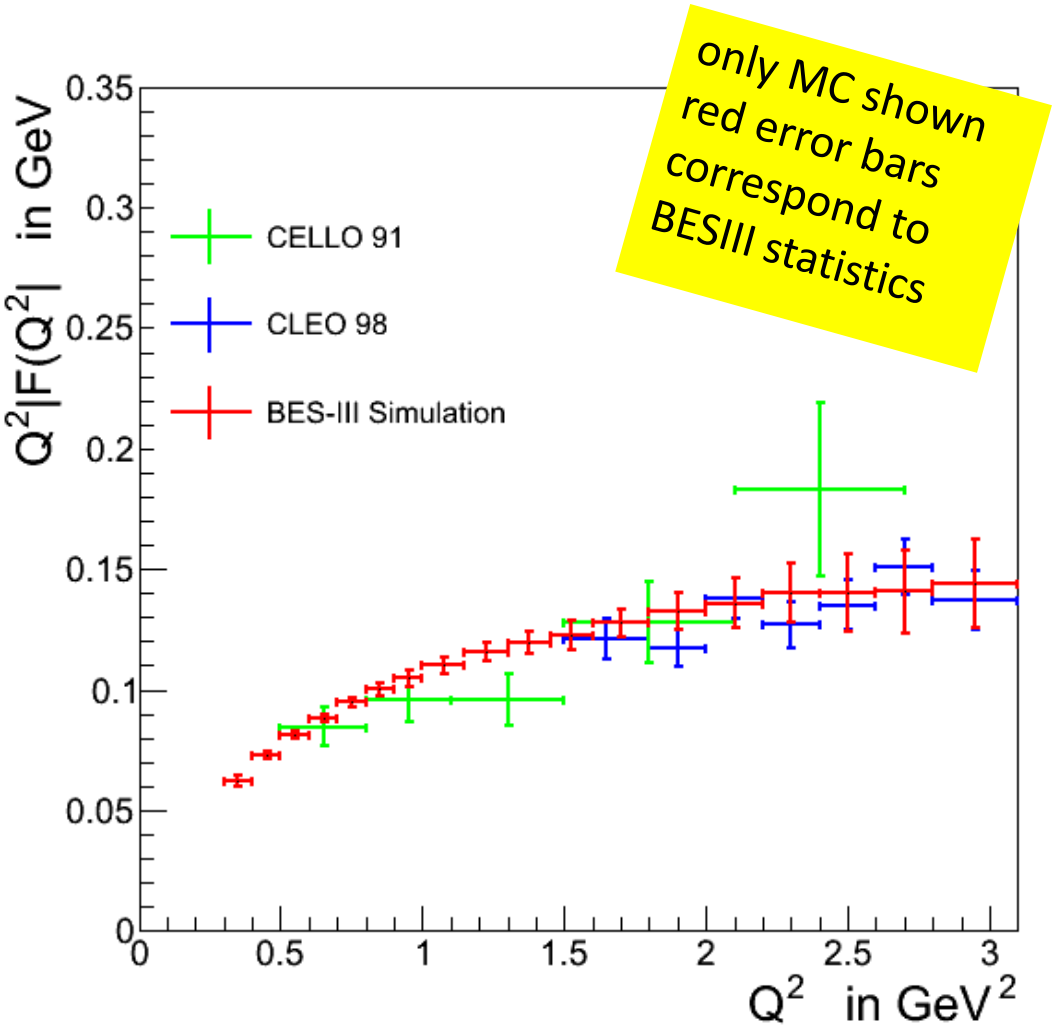
$e^+e^- \to e^+e^- \eta$



$e^+e^- \to e^+e^- \eta'$



BES III Analysis: $e^+e^- \to e^+e^- \pi^0$



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

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

Summary

- BEPCII/BESIII has been in excellent status. Largest samples: 0.5B $\psi(2S)$, 1.2B J/ψ, 2.9 fb^{-1} $\psi(3770)$, 5 fb^{-1} for XYZ studies, and more is taking;
- Precision R measurement helps in $\alpha_{QED}(M_Z)$ and a_μ evaluation, and a ~3% precision is expected at BESIII;
- A 104-point scan between 3.8 GeV to 4.6 GeV has been finished, ~800 pb^{-1};
- High statistics data in 2 – 3 GeV will significantly improve measurements like proton form factor, event shapes, etc;
- ISR technique allows access to energy below 2 GeV: exciting results to be expected!