R-scan Programme at BESIII

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(For BESIII Collaboration)

Outline

- Status of BEPCII/BESIII
- R measurements at BES
  - A brief review for BESI/BESII
  - New efforts/prospects at BESIII
- Summary

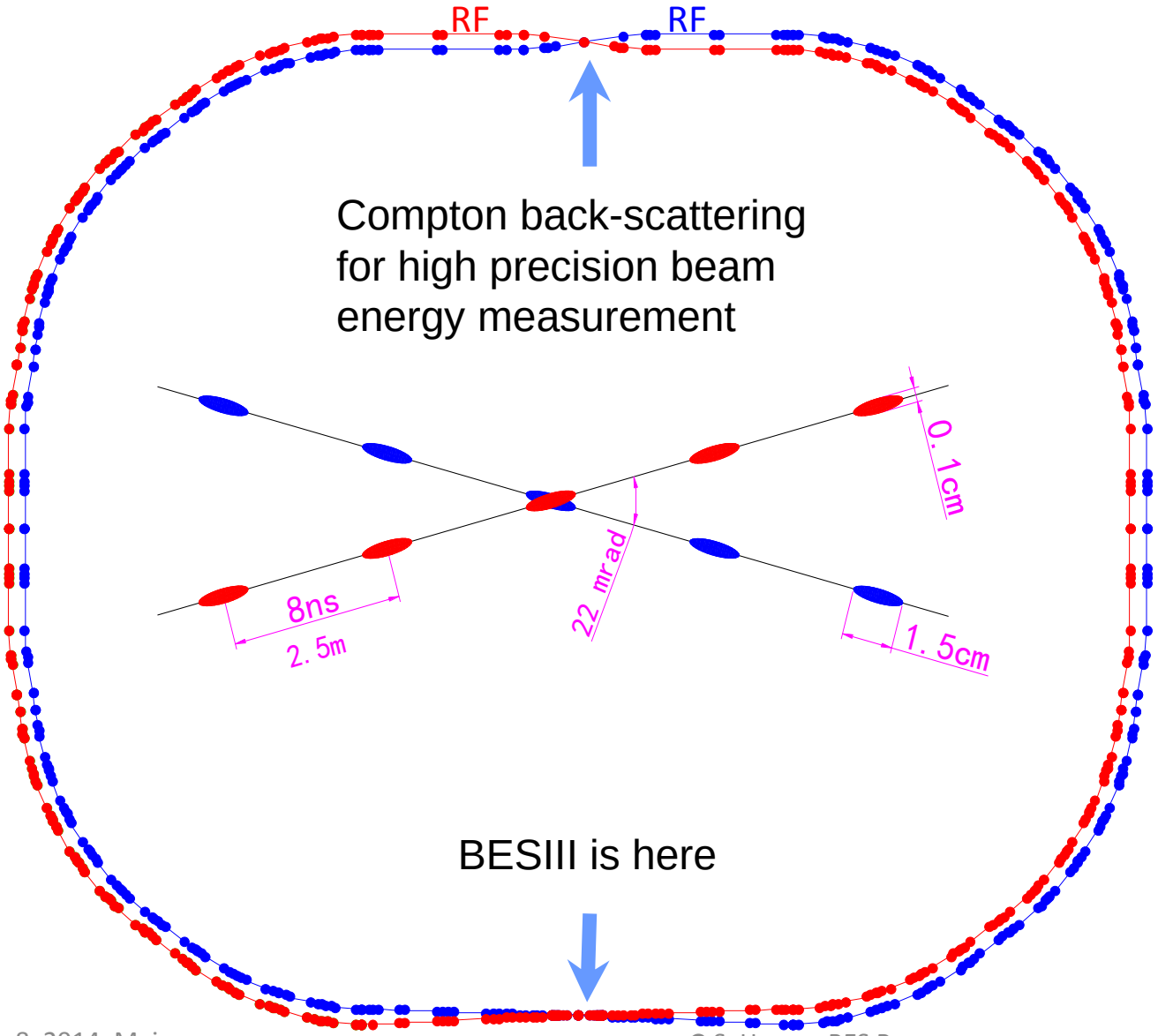
Bird View of BEPCII /BESIII

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

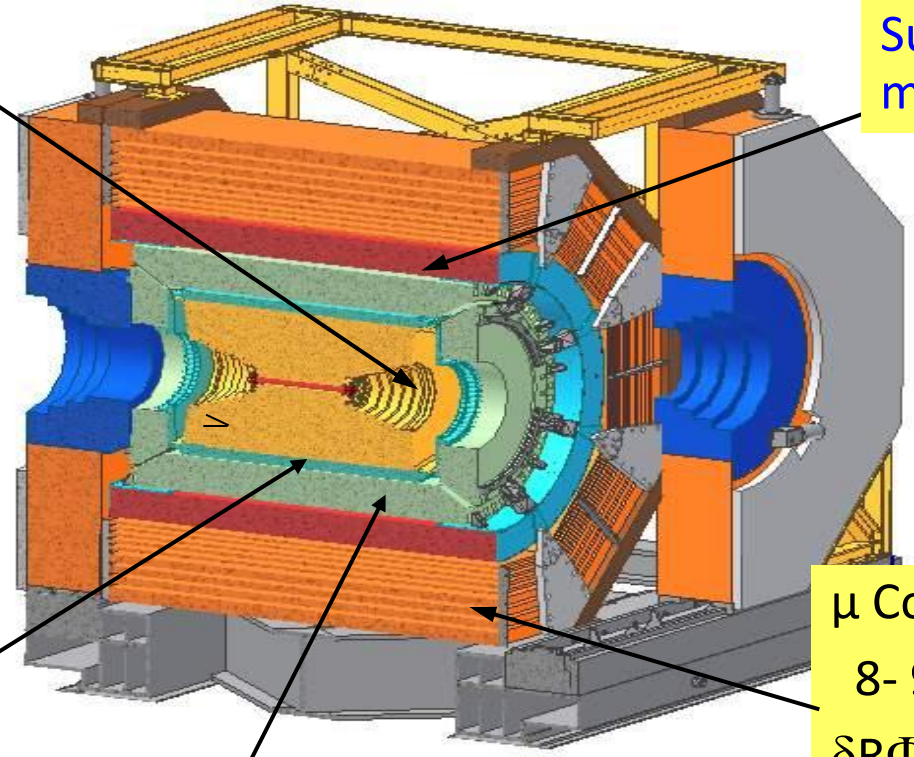
NIM A614, 345 (2010)

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.

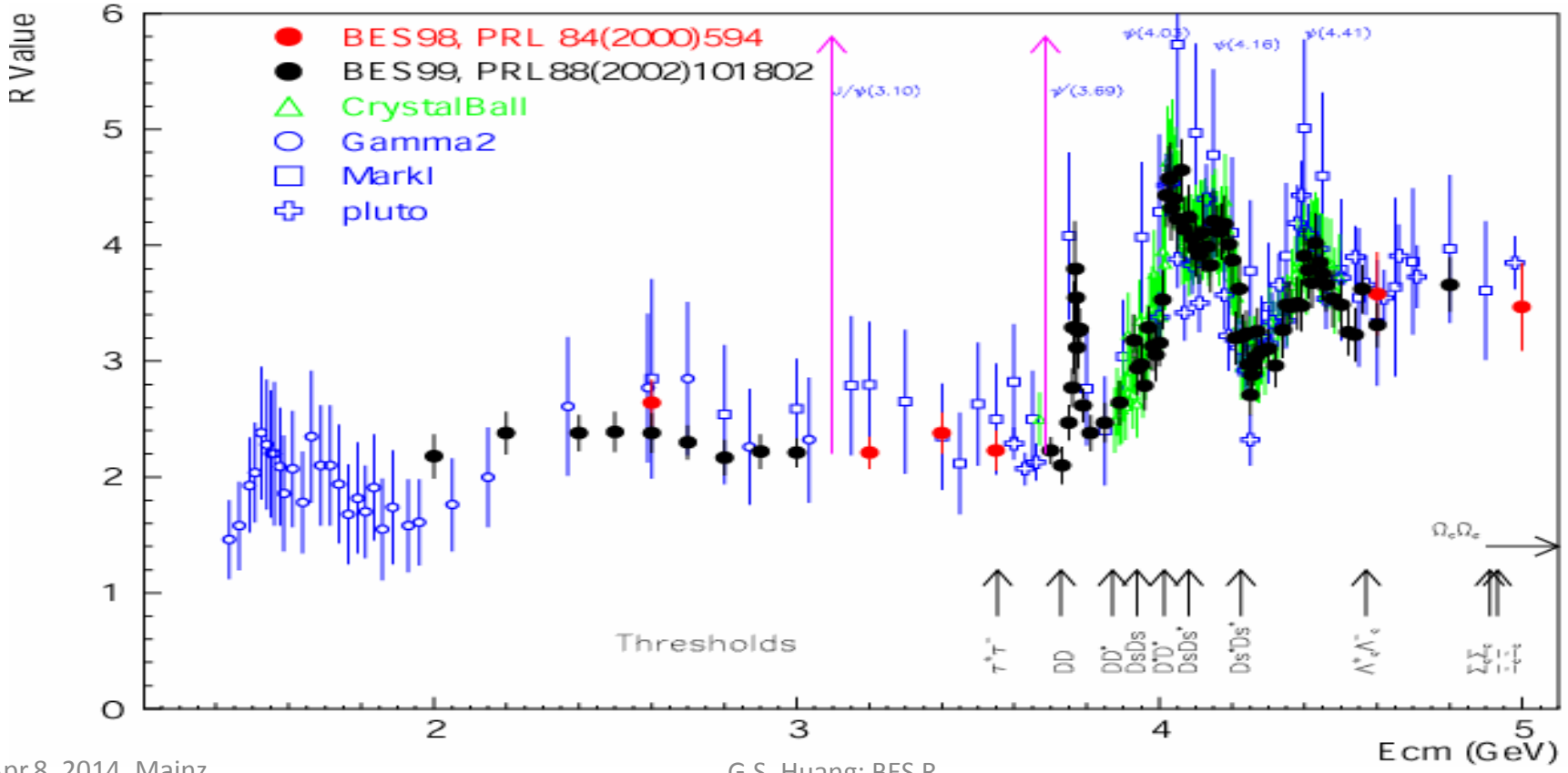
Pakistan (1)
Univ. of Punjab

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.

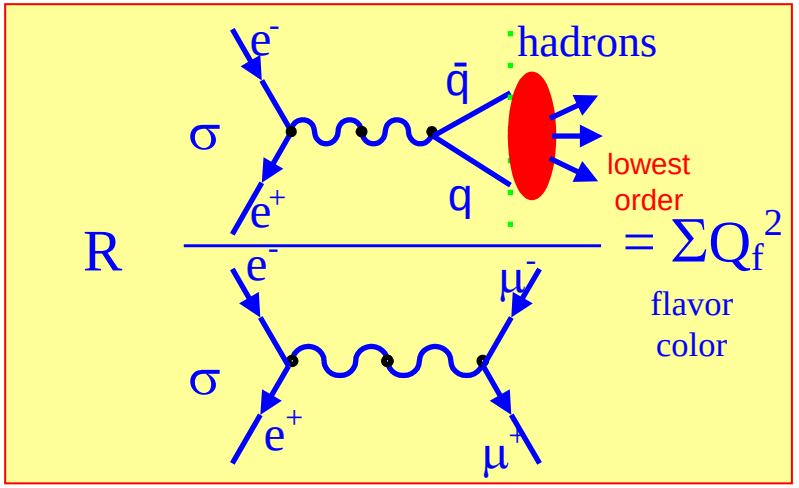
~350 physicists
50 institutions from 10 countries

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

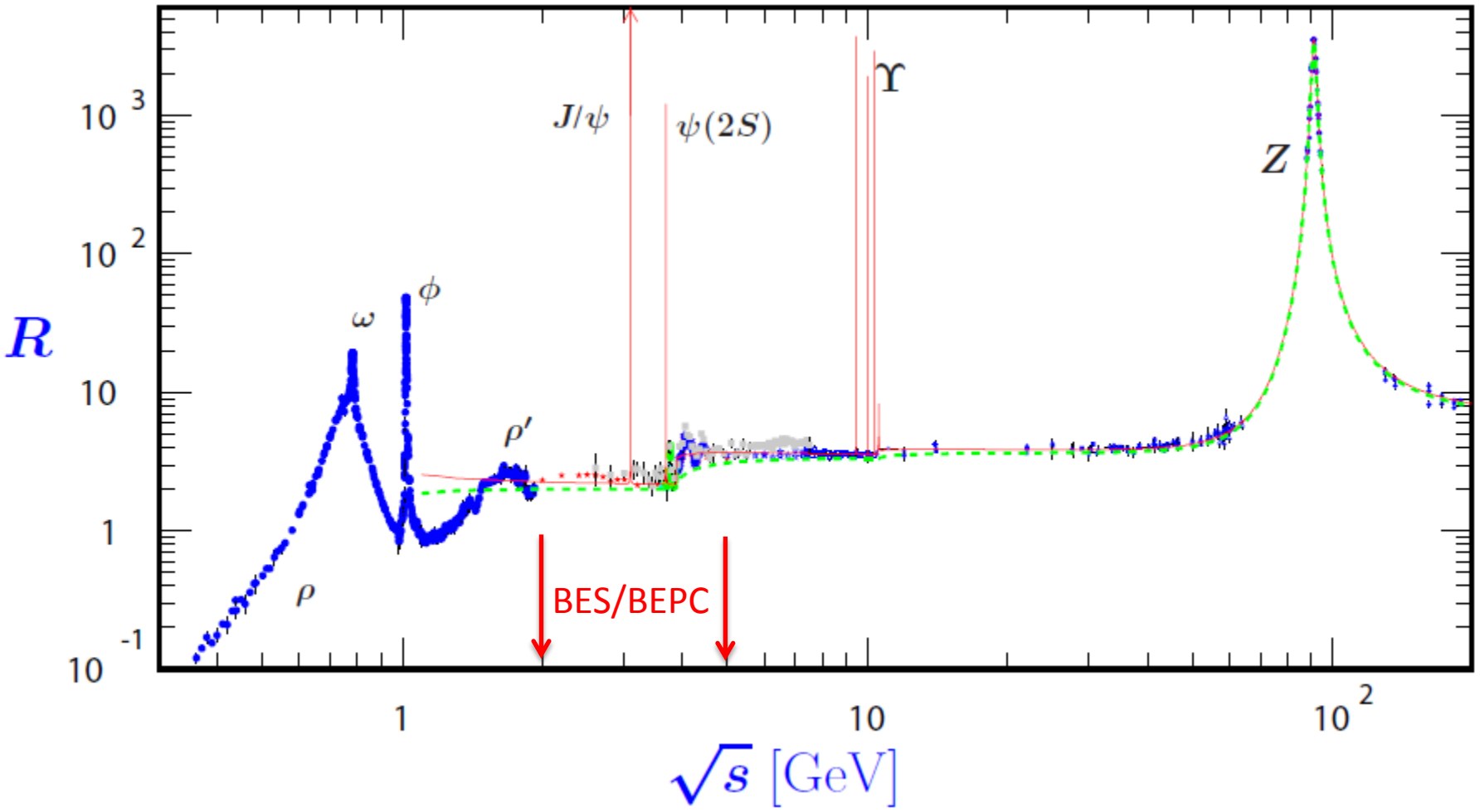
- At higher order

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

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

- 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 $\alpha_{QED}(M_Z)$

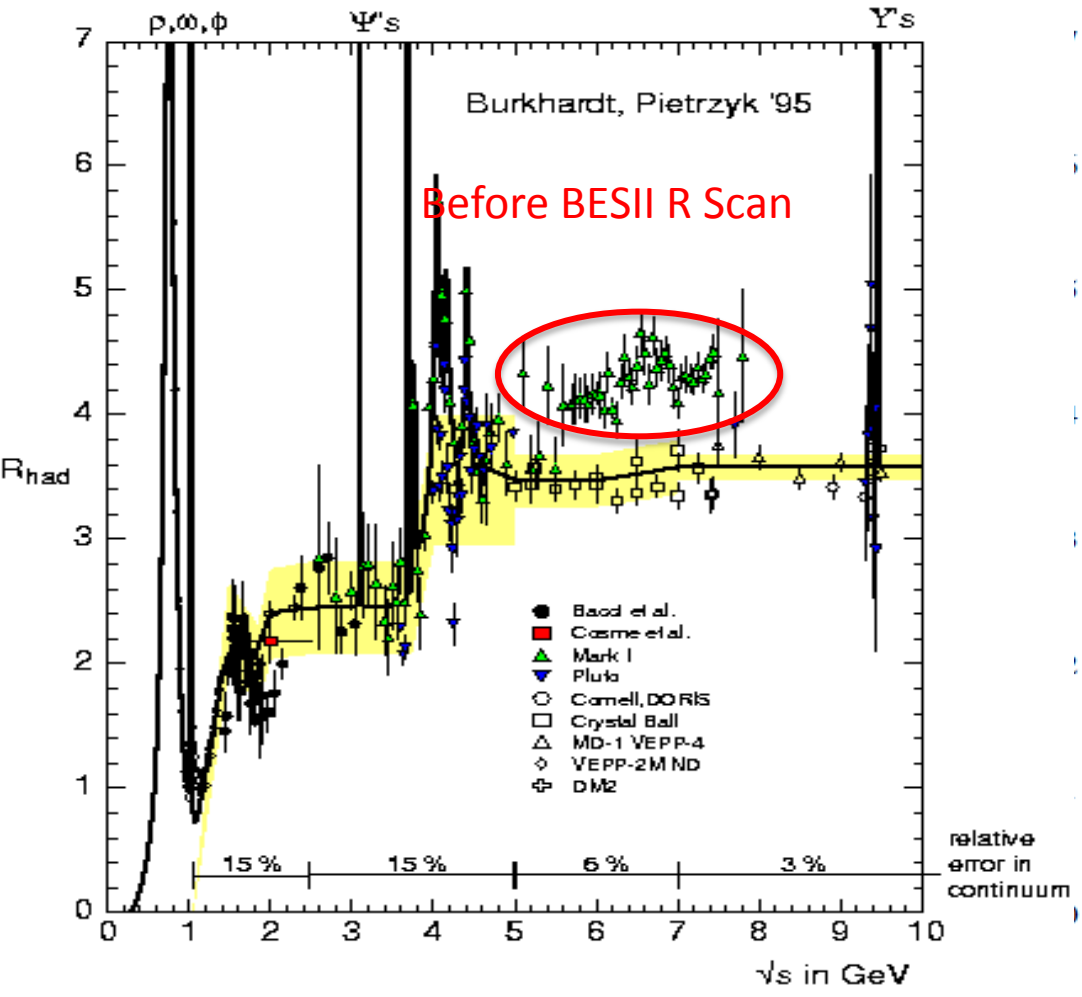
$$\Delta\alpha^{(5)}_{had}(s) = -\frac{\alpha s}{3\pi}\mathrm{Re}\int_{4m_\pi^2}^{\infty} ds' \frac{R(s')}{s'-s-i\varepsilon}$$

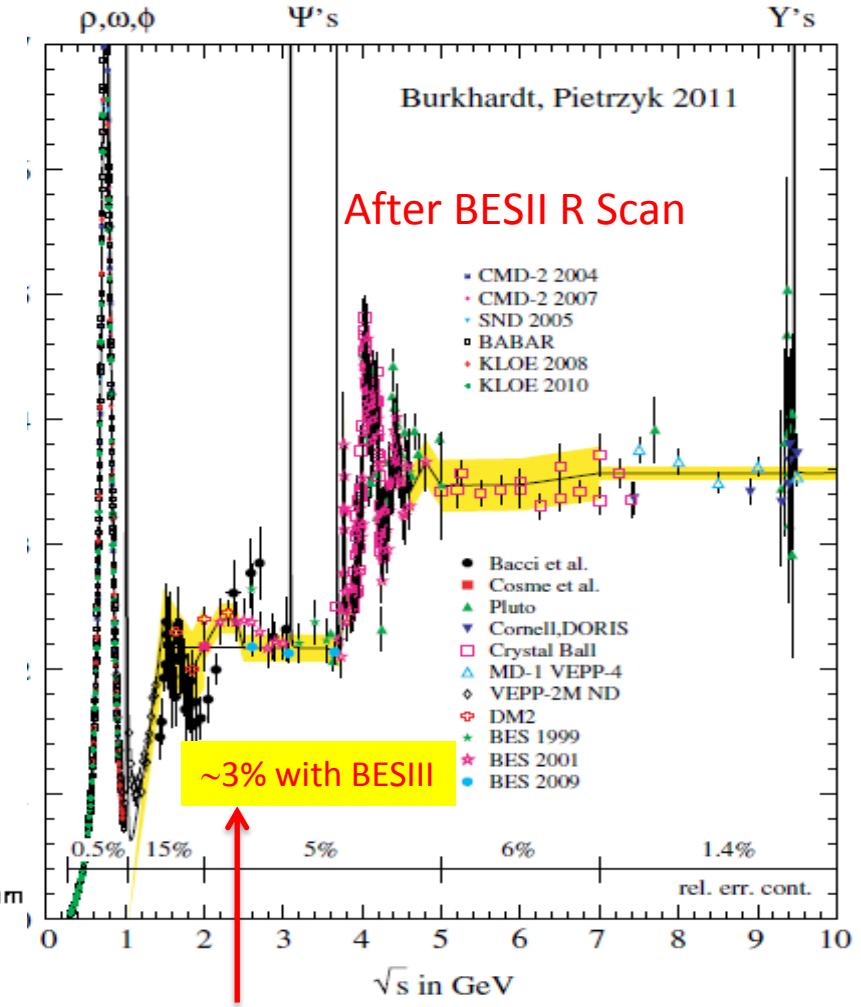
  - Anomalous magenet moment of the muon a_μ, or $(g_\mu - 2)$

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

- 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;
- ……

BESII R Measurement: A big Improvement



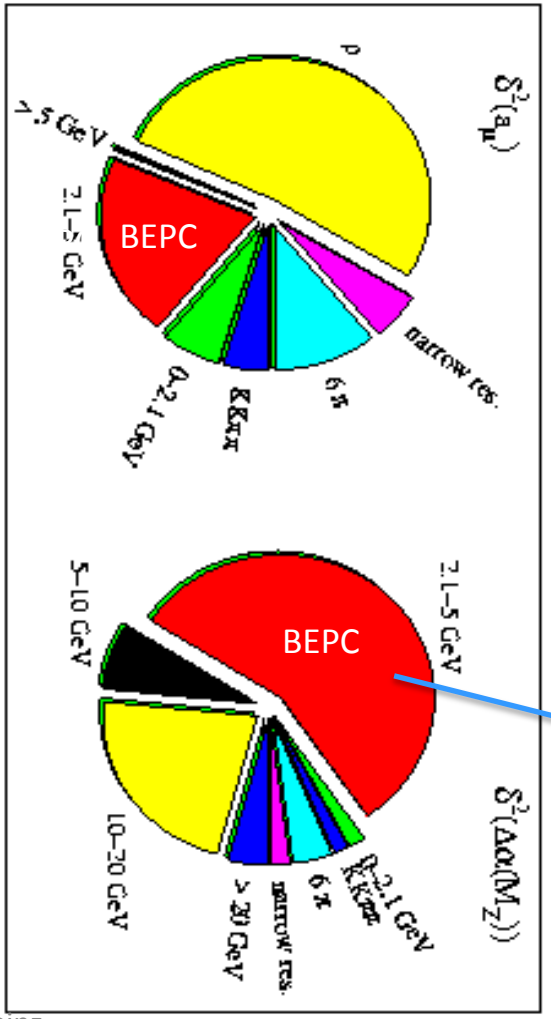


- ΔR/R~15-20% below 5 GeV
- Unclear & complex structure in 3.7-5GeV
- Values from Mark I much higher than others

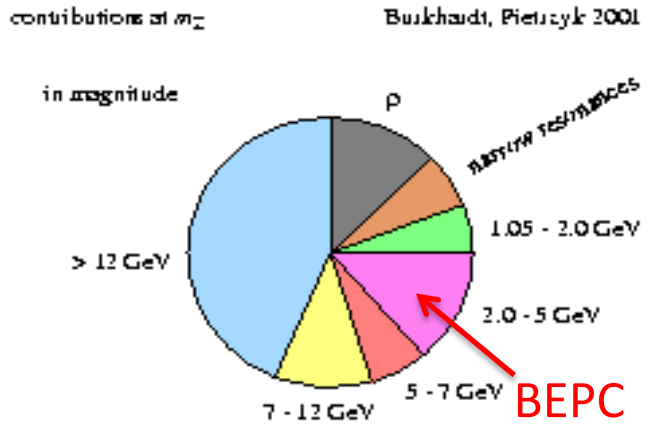
- ΔR/R~6% between 2 and 5 GeV
- Much clean structures in 3.7-5 GeV
- Mark I results is removed from PDG

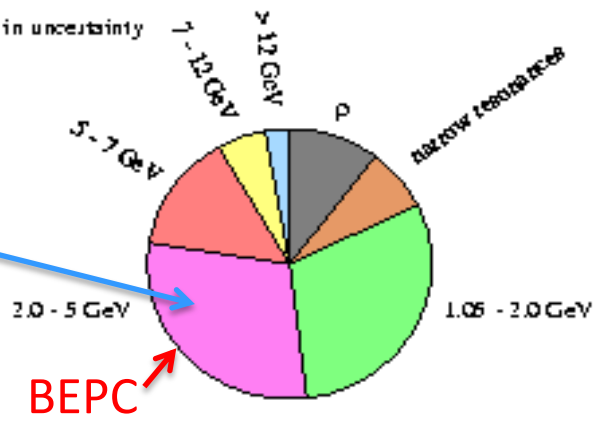
Relative Contributions to the Uncertainties of a_μ and $\Delta\alpha(M_Z^2)$

Before BESII R scan



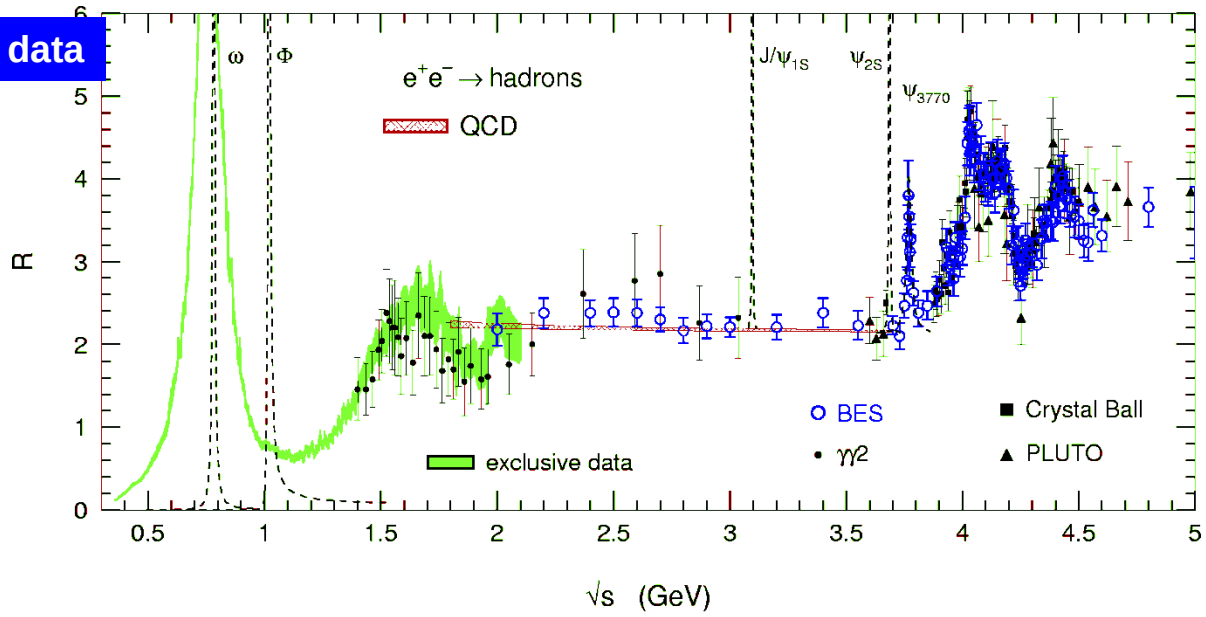
After BESII R scan



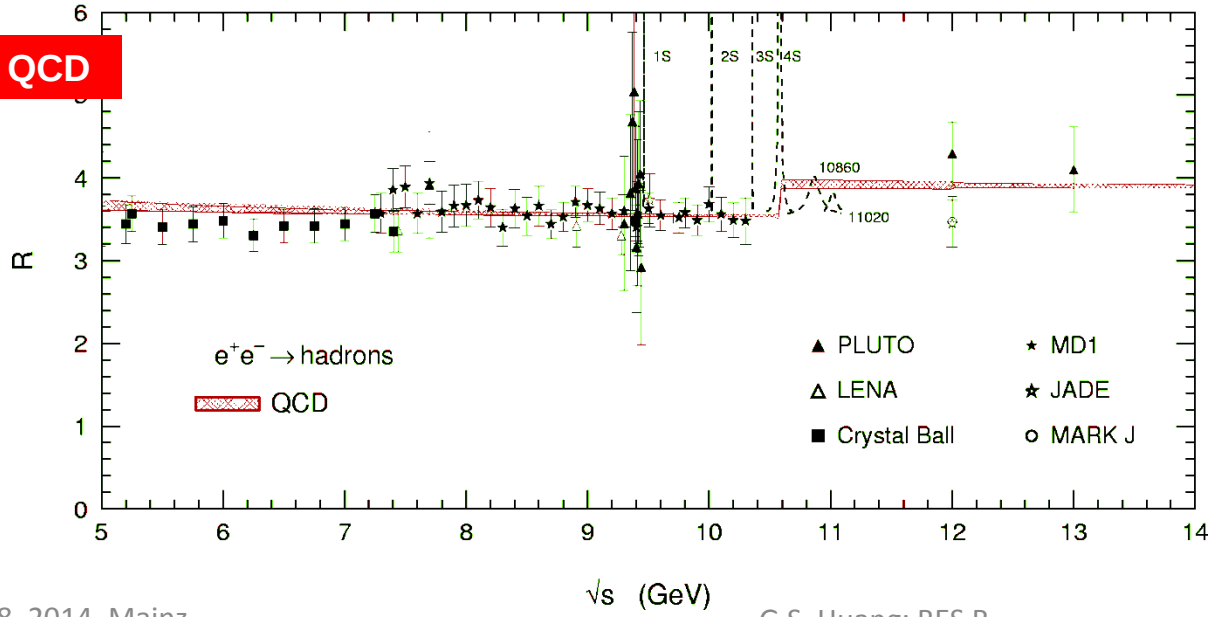


Impact of BESII R to muon (g_μ–2)

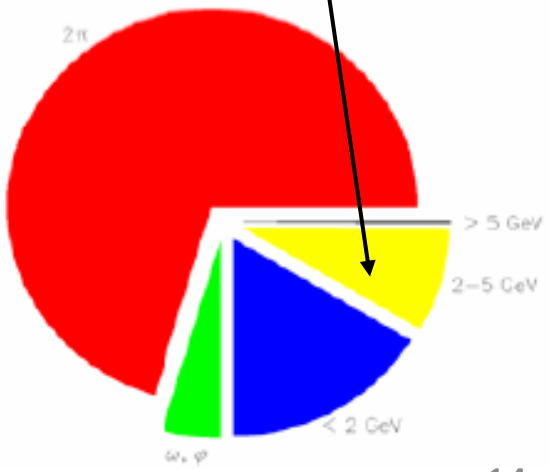
use data



use QCD



after



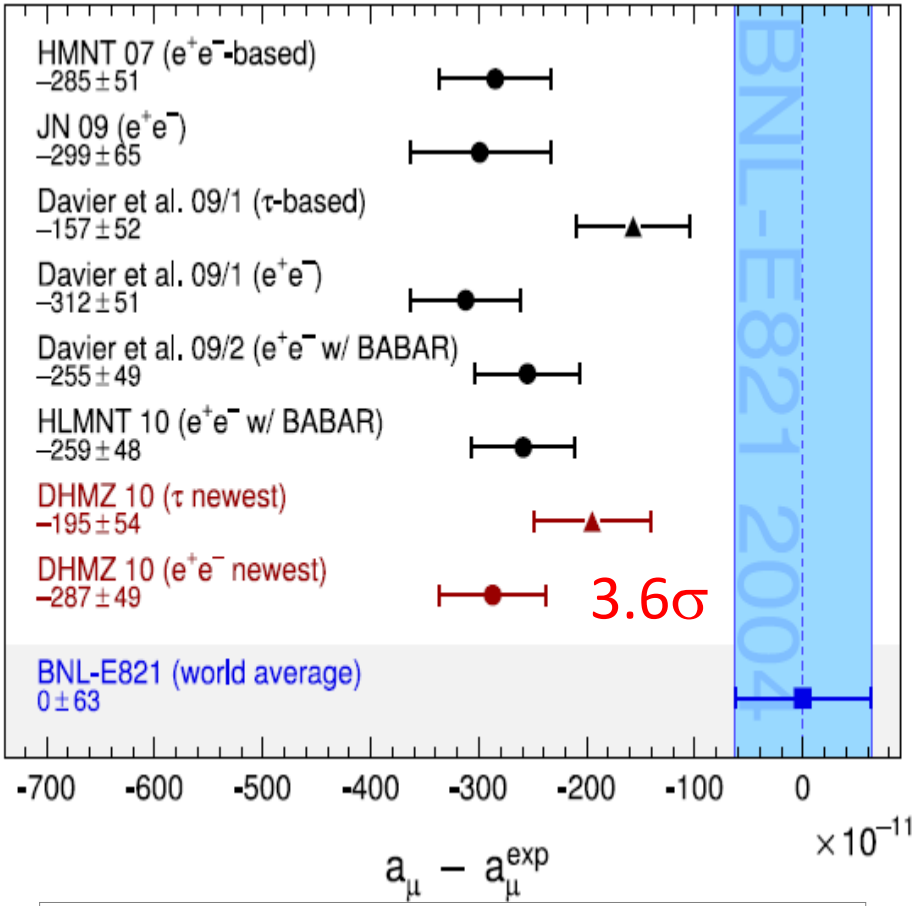
$\Delta\alpha(M_Z^2)$ and a_μ: Current Status

Burkhardt, Pietrzyk 2011

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

Range $\sqrt{s}$, GeV	$\Delta\alpha$	Relative error
$\rho\ (\pi^+\pi^-)$	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%

Still the 2nd largest one.



$a_\mu^{exp} = (11\,659\,208.9 \pm 6.3) \times 10^{-10}$ (E821)
$a_\mu^{SM} = (11\,659\,180.2 \pm 4.9) \times 10^{-10}$

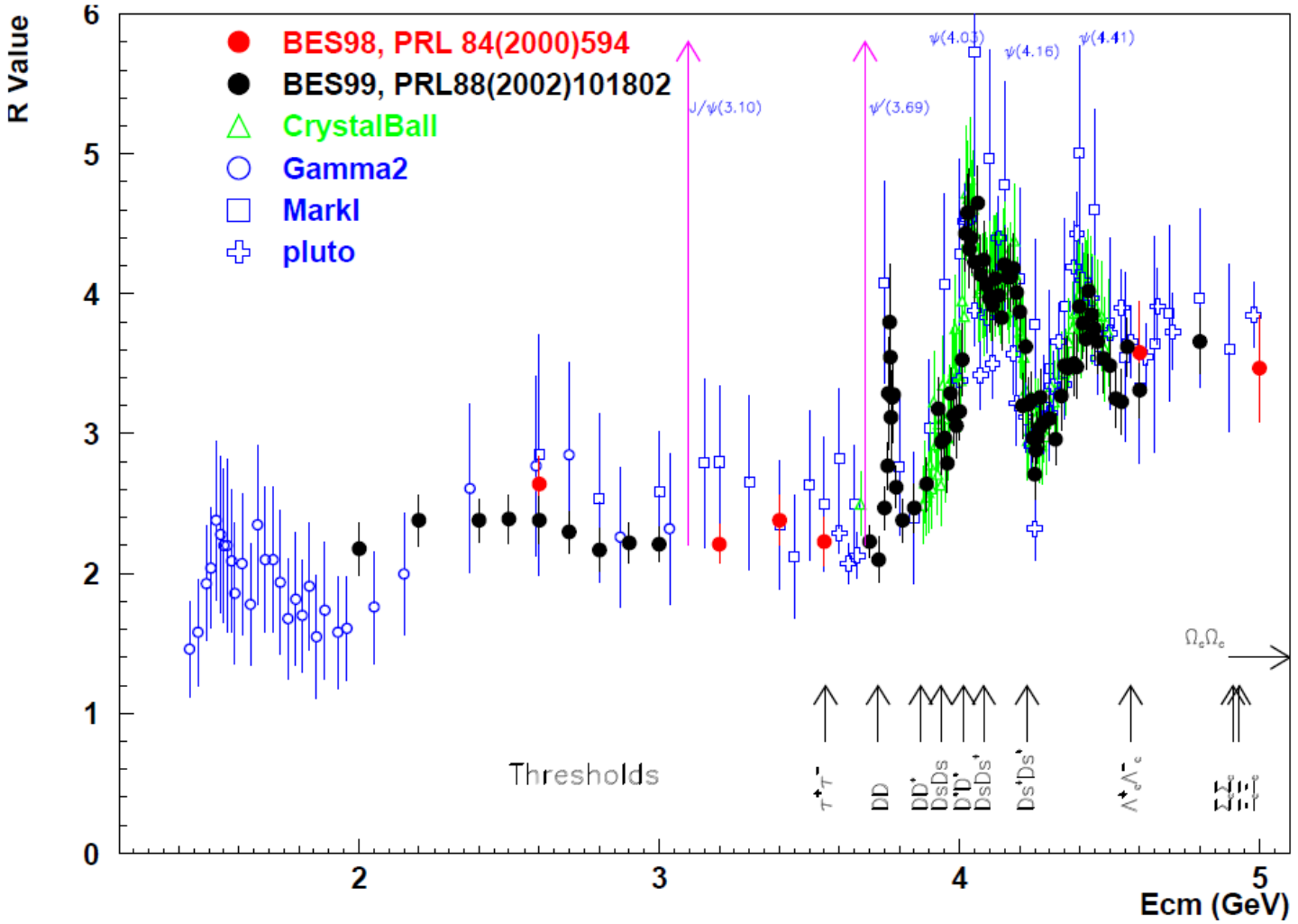
Davier 2010

Brief Review on BES R Measurements

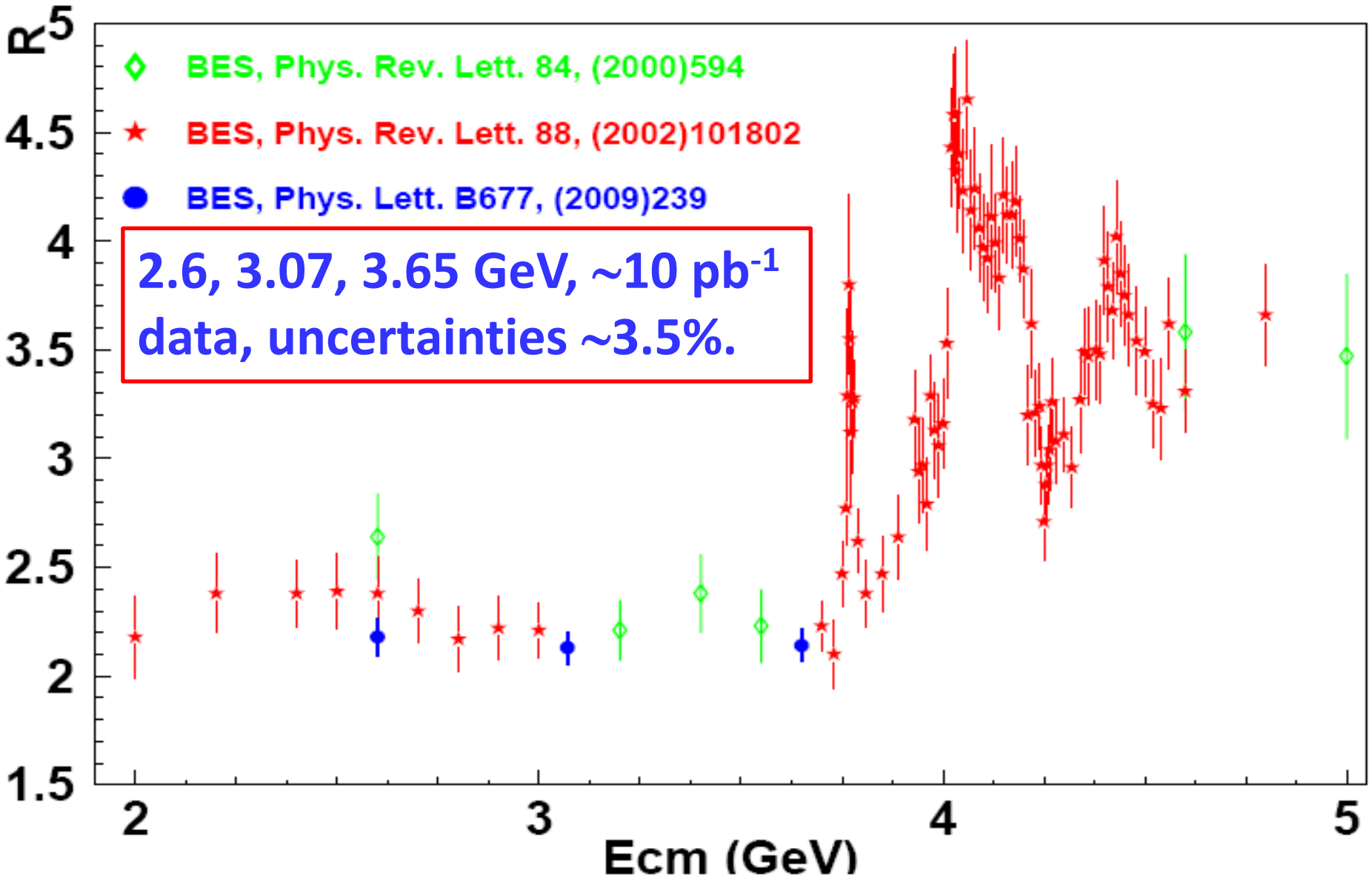
- Pre-study, using BESI tau mass data, 12 points around 3.55 GeV, ~8.5%, HEP&NP24, 609 (2000);
- Test run, 6 continuum points in 2.6 ~ 5.0 GeV, PRL84, 594 (2000);
- Full scan, 85 points in 2 ~ 4.8 GeV, PRL88, 101802 (2002);
- R around $\psi(3770)$, 2 points off-resonance, 1 on-resonance, PLB641, 145 (2006);
- Improvements at 3 continuum points, PLB677, 239 (2009).

R Scan at BESII

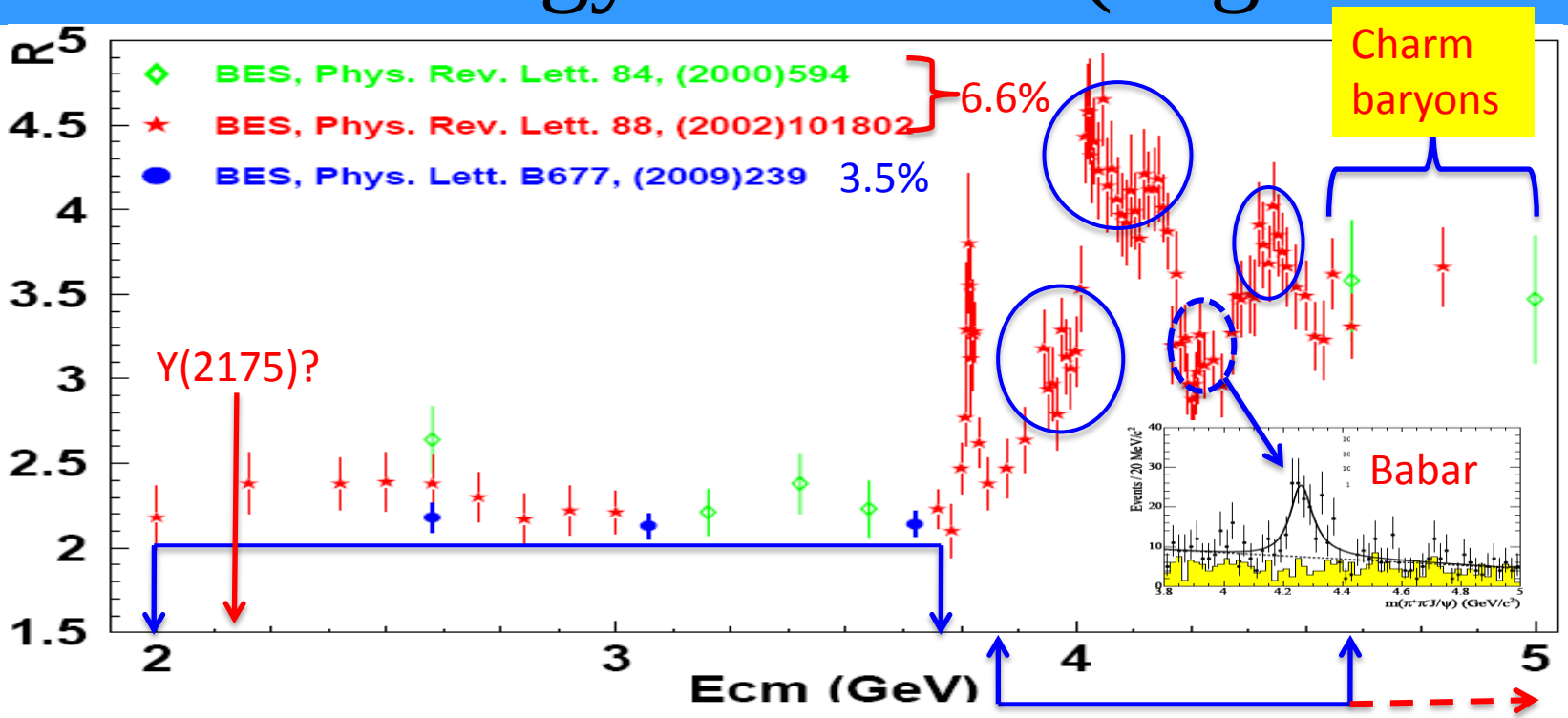
- 6 + 85 energy points, total ~5 pb^{-1} data, uncertainties 5~10% (average 6.6%).



Last Attempt at BESII



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

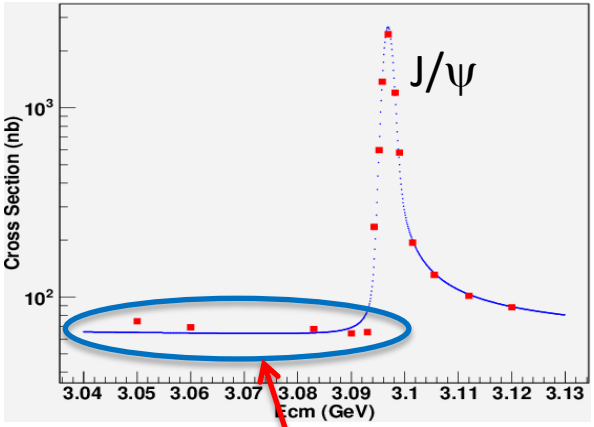
$\sigma_{\mu\mu}$: can be precisely calculated(QED). Measurement of R is to measure the total $\sigma(e^+e^- \rightarrow \text{hadrons})$

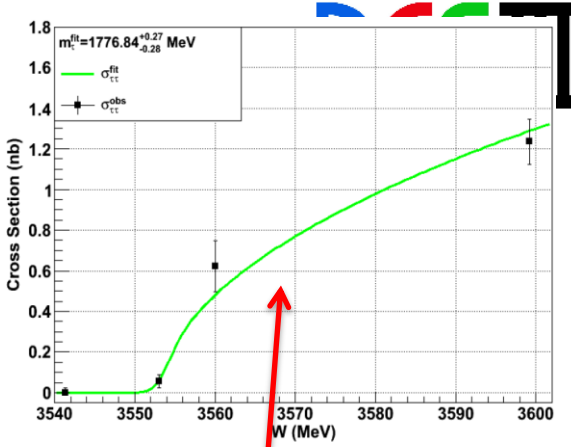
Except for controlling each item to the precision requested, stable long term machine and detector performance is crucial.

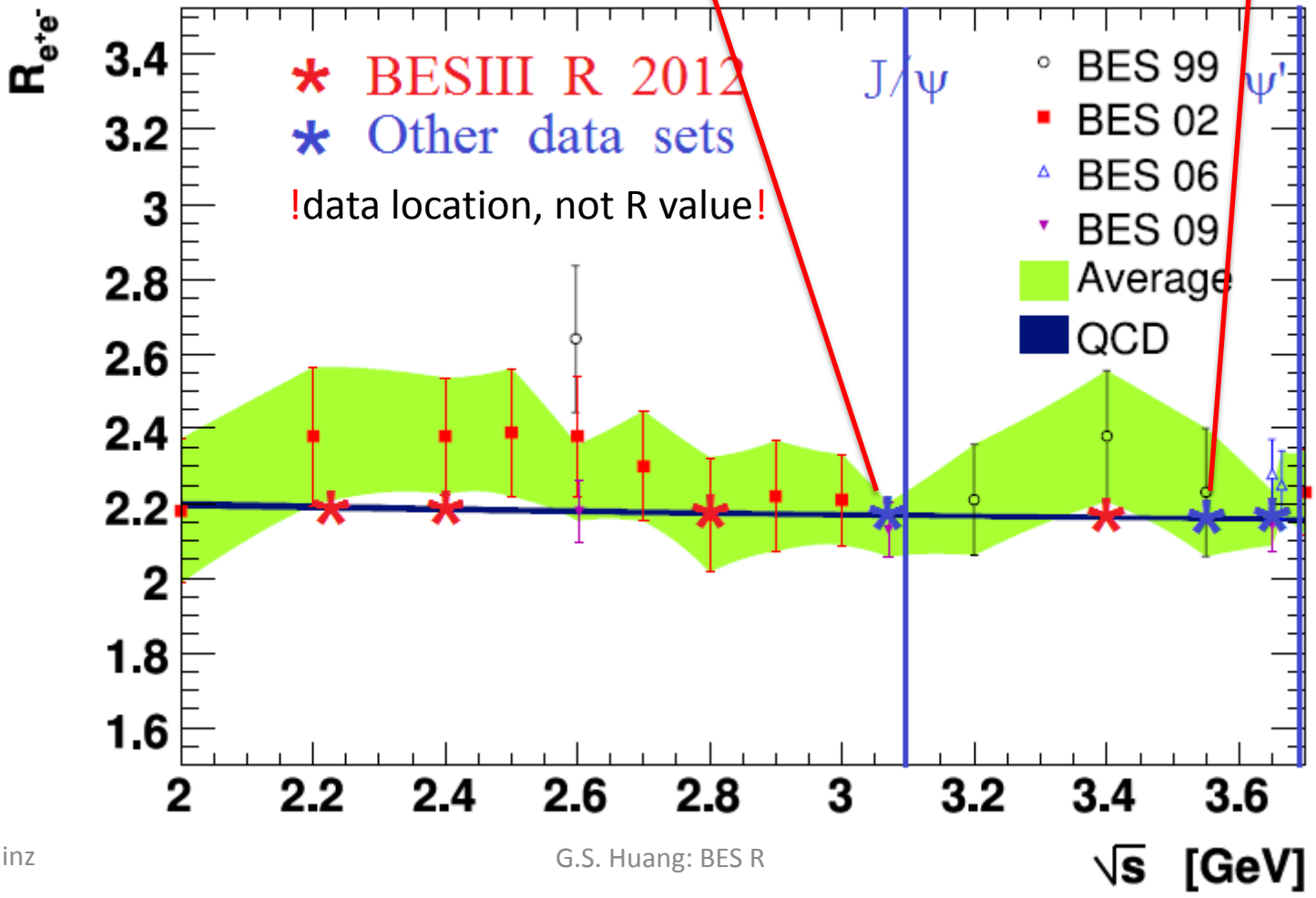
First R-QCD Run at BESIII

- 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.

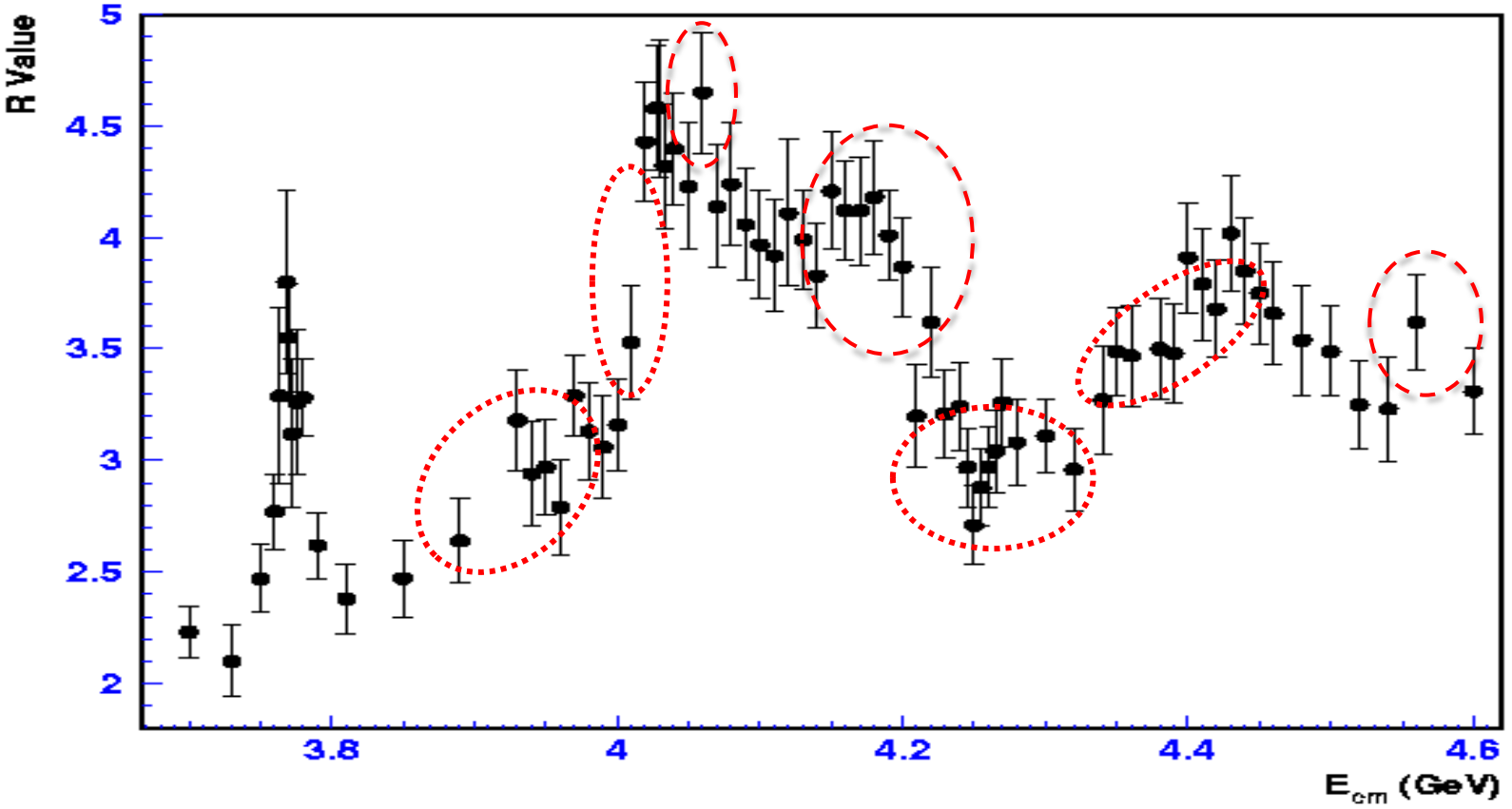
BESIII continuum data overview







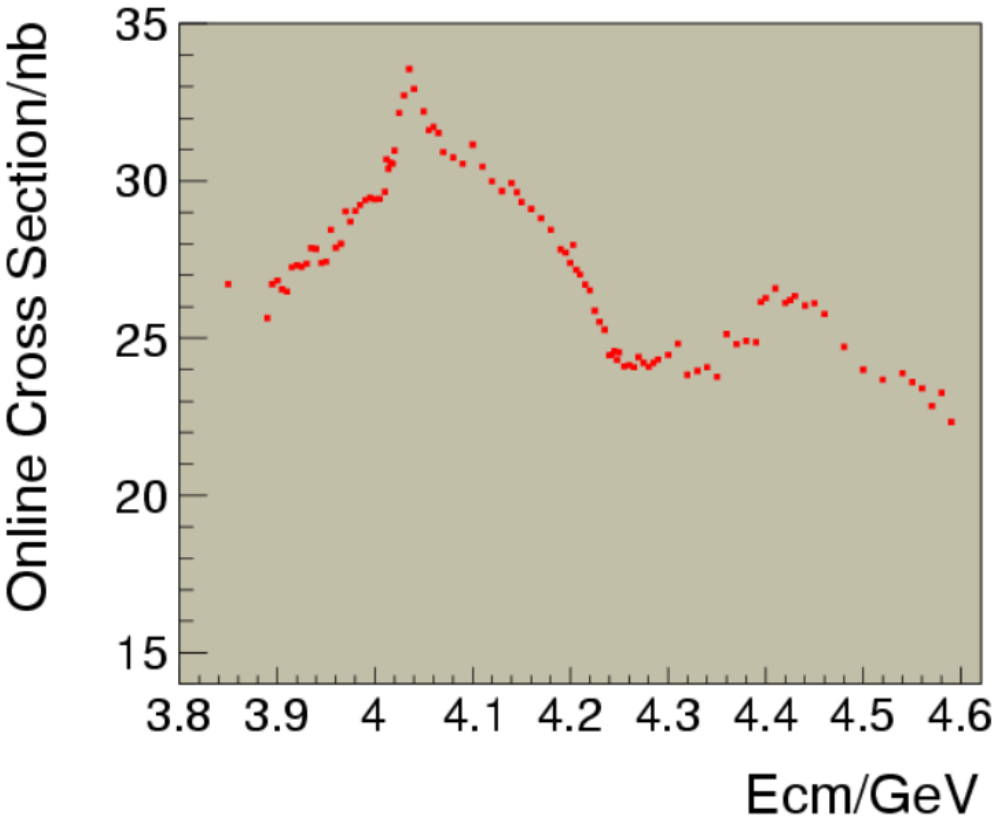
Resonance Structure in High Energy Region

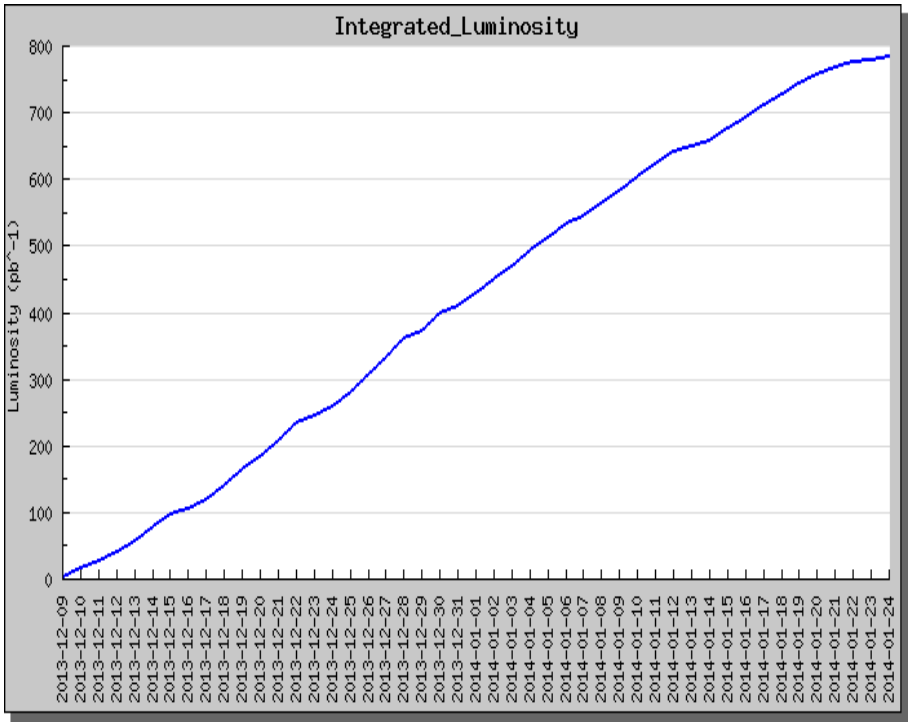


- What are these broad resonances?
- Mass resgion where some X, Y, Z particles are found.
- Possible new resonance that not yet discovered?

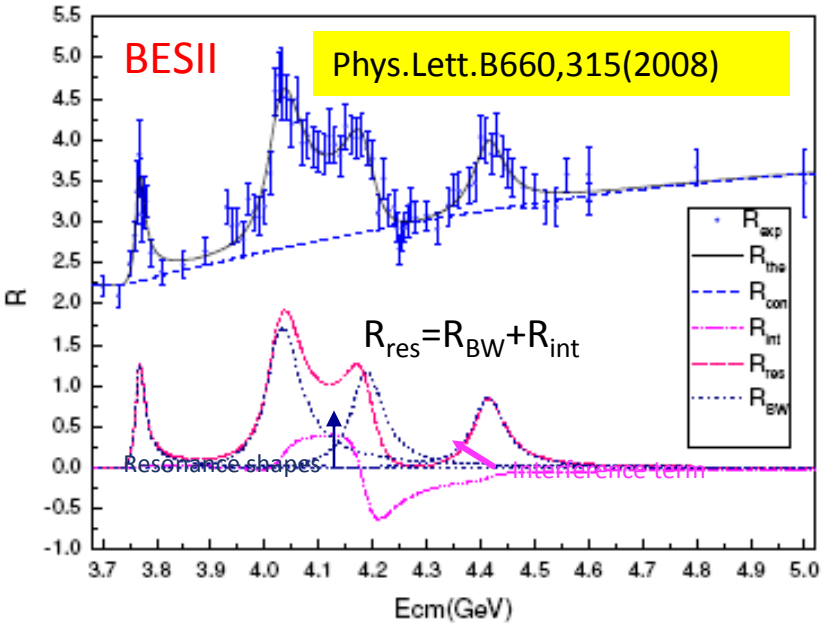
R Scan in 3.8 - 4.6 GeV

- Data taken 2013.12.9 - 2014.1.24;
- 104 energy points in total;
- >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	
$\psi(3770)$	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
$\psi(4040)$	4039 ±1	80 ±10	0.86 ±0.07		PDG09
	4039.6 ±4.3	84.5 ±12.3	0.83 ±0.20	130 ±46	BES08
$\psi(4160)$	4153 ±3	103 ±8	0.83 ±0.07		PDG09
	4191.7 ±6.5	71.8 ±12.3	0.48 ±0.22	293 ±57	BES08
$\psi(4415)$	4421 ±4	62 ±20	0.58 ±0.07		PDG09
	4415.1 ±7.9	71.5 ±19.0	0.35 ±0.12	234 ±88	BES08

2 - 3 GeV: R and Beyond

- Plan being discussed: ~15 points, 1 run-year;
- 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;
- ……

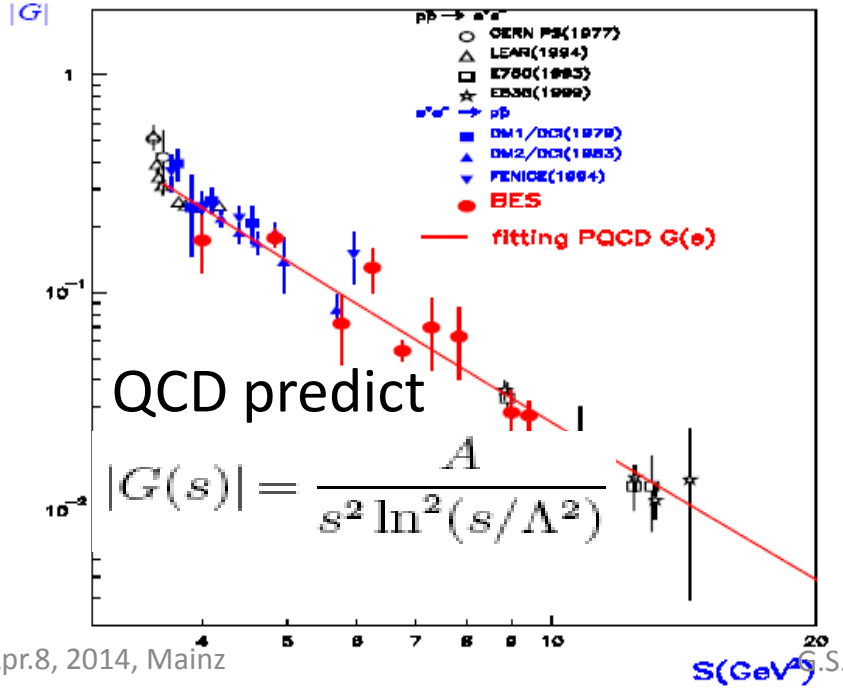
Form Factor: $p\bar{p}$

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2\beta}{4s} C\left[|G_M(s)|^2(1+\cos^2\theta) + \frac{1}{\tau}|G_E(s)|^2\sin^2\theta\right]$$

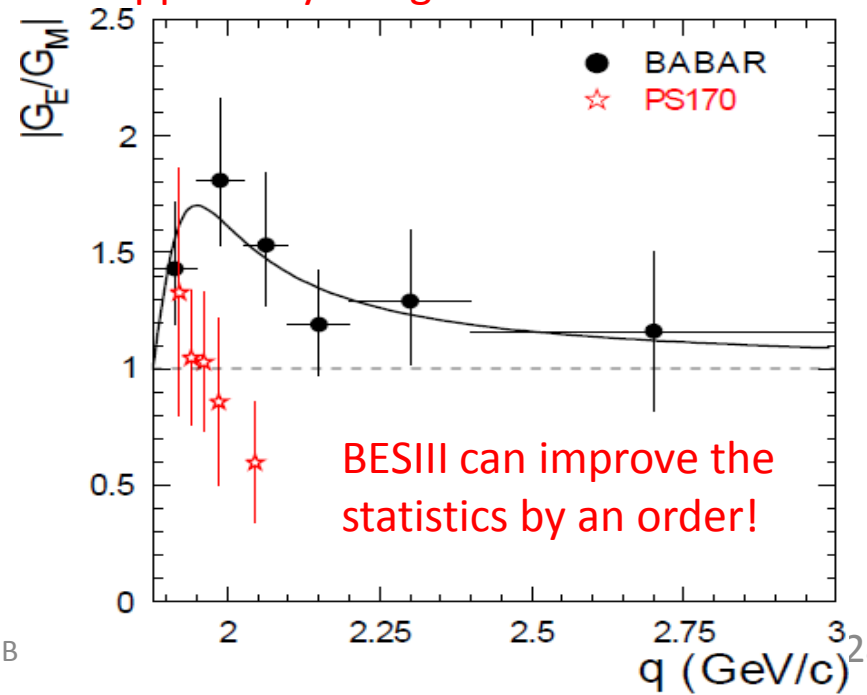
$$G_E = F_1 + \tau F_2 \qquad G_M = F_1 + F_2$$

$$\sigma_0 = \frac{4\pi\alpha^2\beta}{3s}\left(1+\frac{2M^2}{s}\right)|G(s)|^2$$

Most measurements assume $G_E=G_M$.

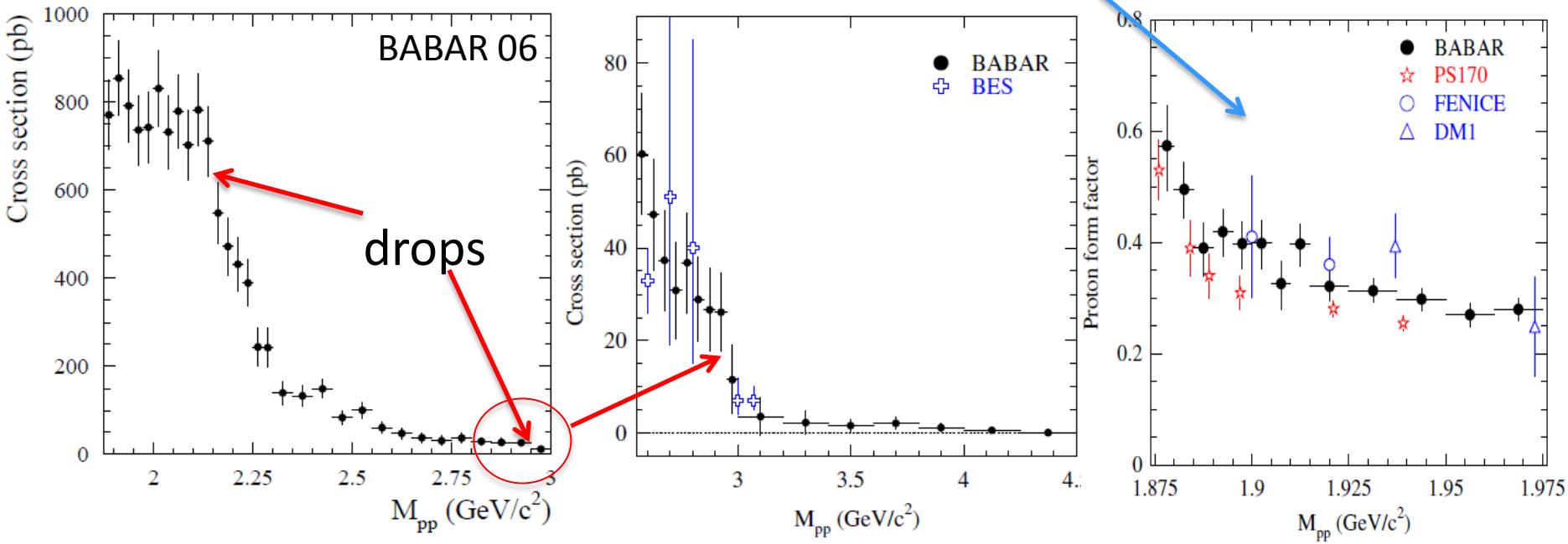


Only 2 experiments measured $|G_E/G_M|$, but apparently disagree with each other.



Structures in $p\bar{p}$

- Finer scan around 2.15 GeV: Y(2175)? Where there is also a drop in the $p\bar{p}$ invariant mass;
- And another drop at 2.9 GeV;
- To explore even lower energy 1.8–2 GeV.



Summary

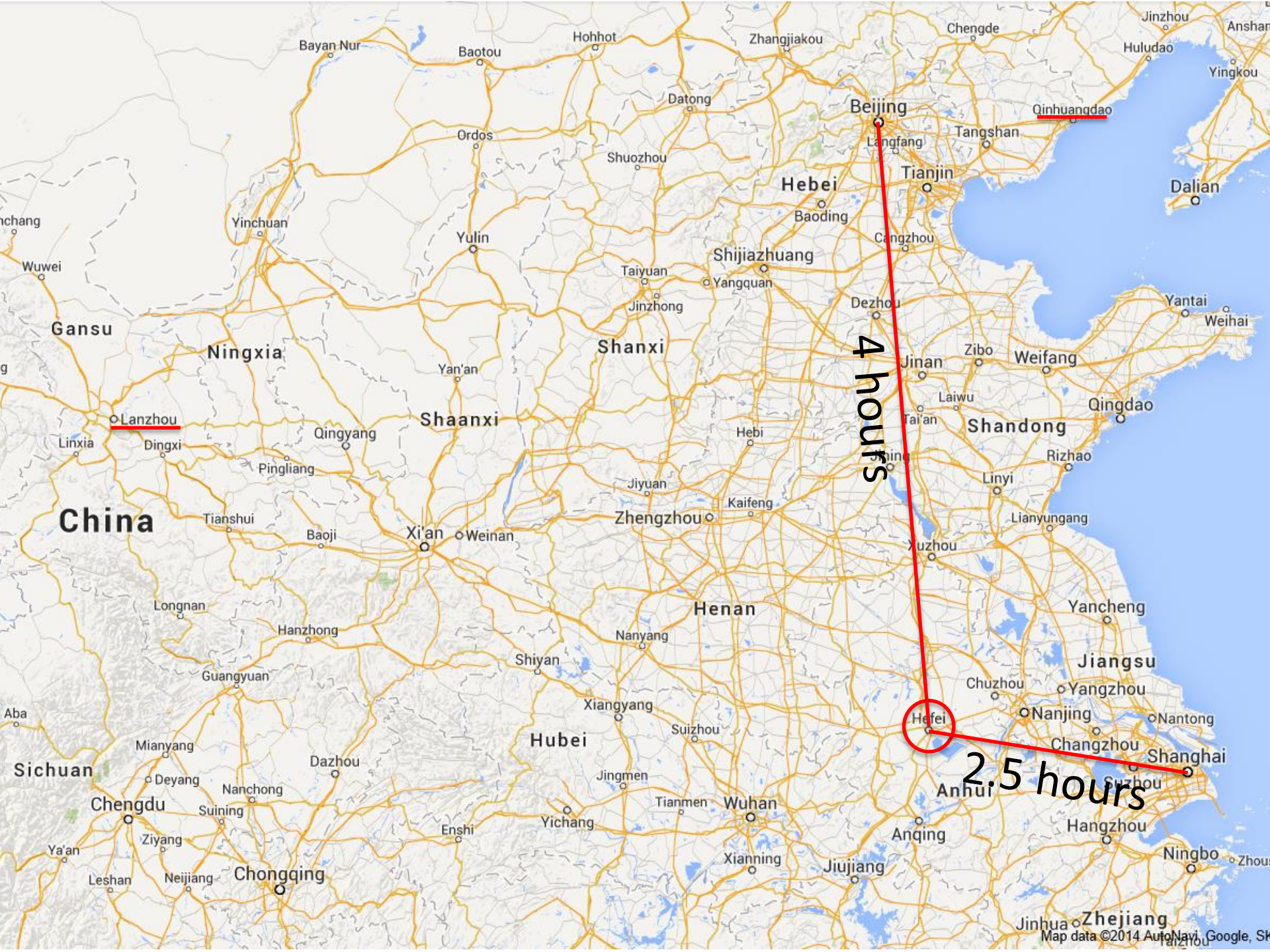
- BEPCII/BESIII has been in excellent status. Largest samples: 0.5B $\psi(2S)$, 1.2B J/ψ, 2.9 fb^{-1} $\psi(3770)$, 3.3 fb^{-1} for XYZ studies and more is taking;
- BESII reduced R uncertainties in 2–5 GeV to ~6% (improvement by a factor of 2~3);
- Precision R measurement still helps in $a_{QED}(M_Z)$ and a_μ evaluation, and a ~3% precision is expected at BESIII;
- BESIII collected data at 4 points in the low energy region;
- A 104-point scan between 3.8 GeV to 4.6 GeV just finished;
- High statistics data in 2 – 3 GeV will significantly improve measurements like proton form factor, event shapes, etc.

Invitation to Super τ-c Factory Workshop

- When: Jan.14-16, 2015
- Where: Hefei, China

- What we are proposing:
  - A STCF with 1x10^{35} $cm^{-2}s^{-1}$ at 4 GeV,
    - **E_{cm}= 2–7 GeV, polarized beam;**
  - Plus a synchrotron radiation facility;
  - Potential for free electron laser study.

- $\Rightarrow$ High Intensity Electron Positron Accelerator/Advanced Facility (HIEPAF).


4 hours
2.5 hours
Beijing
Qinhuangdao
Tangshan
Tianjin
Dalian
Hebei
Baoding
Cangzhou
Shijiazhuang
Yangquan
Taiyuan
Jinzhong
Dezhou
Yantai
Weihai
Zibo
Weifang
Jinan
Laiwu
Tai'an
Qingdao
Shandong
Rizhao
Linyi
Lianyungang
Xuzhou
Shanxi
Yan'an
Shaanxi
Ningxia
Gansu
Lanzhou
Linxia
Dingxi
Qingyang
Pingliang
Tianshui
Baoji
Xi'an
Weinan
China
Hebi
Jiyuan
Kaifeng
Zhengzhou
Henan
Nanyang
Shiyan
Xiangyang
Suizhou
Hubei
Wuhan
Tianmen
Yichang
Enshi
Jingmen
Dazhou
Nanchong
Suining
Guangyuan
Hanzhong
Longnan
Mianyang
Deyang
Chengdu
Ziyang
Ya'an
Leshan
Neijiang
Chongqing
Sichuan
Aba
Hefei
Anhui
Chuzhou
Yangzhou
Nanjing
Nantong
Changzhou
Shanghai
Suzhou
Anqing
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Invitation to PhiPsi2015 Workshop

- When: Sep.16-19 or 23-26, 2015? To be fixed.
- Where: Hefei, China

- 10^{th} in a series, to discuss physics at low energy e^+e^- colliders.
- Previous ones: Karlsruhe (1996), Novosibirsk (1999), SLAC (2001), Pisa (2003), Novosibirsk (2006), Frascati (2008), Beijing (2009), Novosibirsk (2011), Rome (2013).