R value Measurement with BESII and BESIII

Haiming HU   Guangshun HUANG   Zhengguo ZHAO

R&QCD Working Group

BES Collaboration

Outline

- **Significance of R value**
- **R value measurement with BESII**
- **R value plan with BESIII**

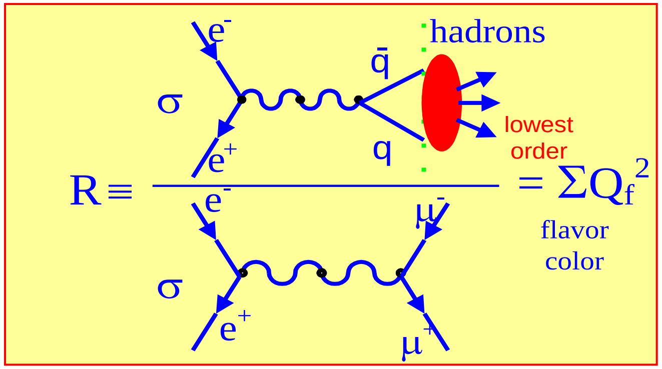
Part 1

Significance of R value

What is R value

Definition:

$$R = \frac{\sigma^0_{had}(e^+e^- \to \gamma^* \to \text{hadrons})}{\sigma^0_{\mu\mu}(e^+e^- \to \gamma^* \to \mu^+\mu^-)}$$



R value is the inclusive hadronic cross section in e^+e^- annihilation normalized by Born cross section of $\mu^+\mu^-$.

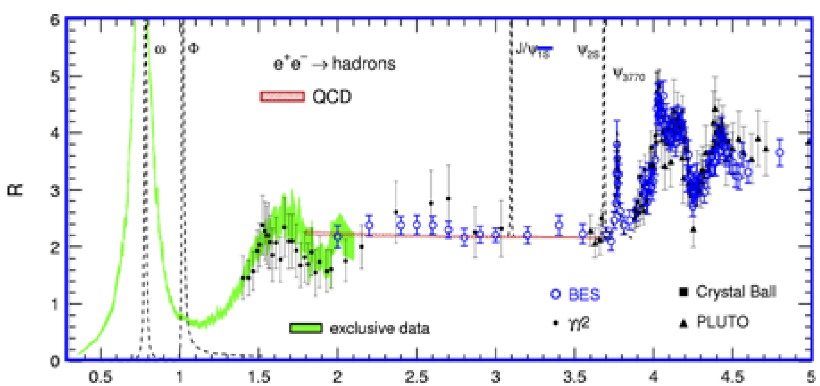
In quark model :

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

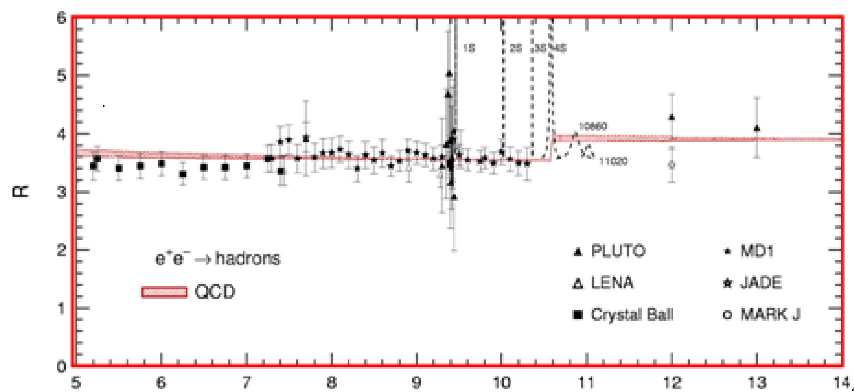
In pQCD :

$$R = 3\sum_f Q_f^2[1 + (\frac{\alpha_s(s)}{\pi}) + 1.411(\frac{\alpha_s(s)}{\pi})^2 - 12.8(\frac{\alpha_s(s)}{\pi})^3 + ...]$$

below 5 GeV



above 5 GeV



Why R value important

R – the important input parameter in SM
experimental error → uncertainty of SM calculation

below 5 GeV use measured value, above 5 GeV use pQCD prediction

- 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 magenetic moment of the muon $a_\mu = g_\mu - 2$

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

- Strong coupling constant α_s determination;
- Global fitting of most probable Higgs mass in SM
- Charm quark mass m_c determination;
- Resonance structure and components in open charm region
- X, Y, Z particles and other possible new resonances

Part 2

R value measurement with BESII

BES, Phys. Rev. Lett. 84, (2000)594

BES, Phys. Rev. Lett. 88, (2002)101802

BES, Phys. Lett. B677, (2009)239

Measurement of R Value with scan data

R value measured with

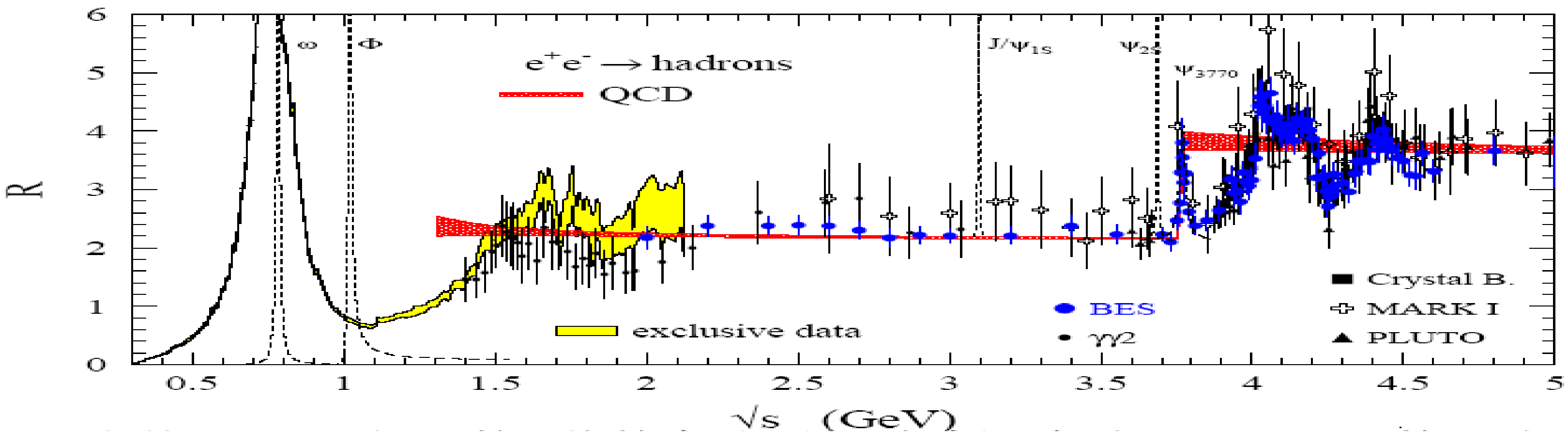
$$R = \frac{1}{\sigma_{\mu+\mu-}} \cdot \frac{N_{had} - N_{bg}}{L \cdot \varepsilon_{had} \cdot (1+\delta)}$$

Tasks in experiment:

- N_{had} observed hadronic events
- N_{bg} background events
- L integrated luminosity
- ε_{had} detection efficiency for N_{had}
- $1+\delta$ radiative correction factor
- $\sigma_{\mu\mu}$ Born cross section of μ pair production in QED.

R measurements with 1998 and 1999 data

- **R scan data were taken between** 2-5 GeV
- **Energy step:** in 3.7– 5.0 GeV are 10–20MeV, elsewhere is 100MeV
- **Generation simulation:** tuned LUARLW and JETSET
- **Detector simulation:** software based on EGS4
- **Event selection:** hadronic events with $N_{had} \geq$ 2-prong are selected
- **Statistic error:** about 2~3 %
- **Systematic error:** about 5~8 % (event selection and efficiency are dominant)
- **Results:** PRL 84 (2000) 594, PRL 88 (2002) 101802



R measurements with 2004 data

- **Data at** 2.60, 3.07 **and** 3.65 GeV **were taken**
- **Statistical error:** small, about 0.5%
- **Generation simulation:** LUARLW is retuned with improved way
- **Detector simulation:** is updated by GEANT3 based software
- **Event selection:** improved, $N_{had} \geq$ 1-prong events are selected
- **Systematical error:** about 3.5%

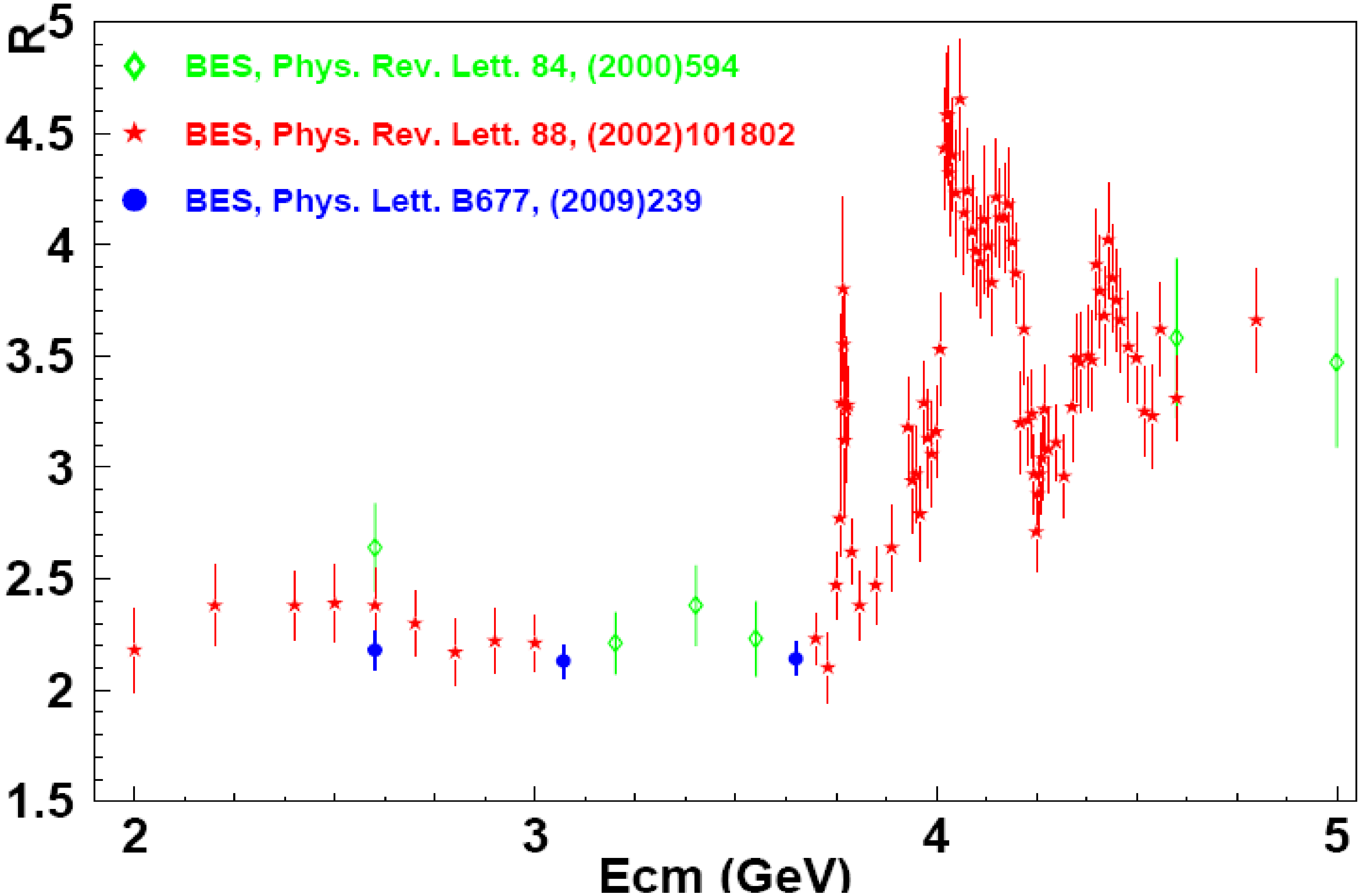
Measured values:

E_{cm} (GeV)	L (pb^{-1})	N_{had}^{obs}	N_{bg}	ϵ_{trg} (%)	ϵ_{had}^{0} (%)	$(1+\delta_{obs})$	R	σ_{sta}	σ_{sys}
2.60	1.222	24026	193	99.80	63.81	1.08	2.18	0.02	0.08
3.07	2.291	33933	208	99.80	67.63	1.11	2.13	0.02	0.07
3.65	6.485	83767	4937	99.80	71.83	1.21	2.14	0.01	0.07

Error terms (%):

E_{cm} (GeV)	L	N_{had}	N_{bg}	$\Delta\epsilon_{trk}$	ϵ_{trg}	$(1+\delta_{obs})$	Total
2.60	2.00	2.79	0.05	0.32	0.50	1.18	3.68
3.07	1.96	2.53	0.05	0.29	0.50	1.15	3.45
3.65	1.38	2.74	0.35	0.26	0.50	1.10	3.33

Overview of R value measured with BESII



Part 3

Determination of α_s with R

Phys. Lett.B677, 239(2009)

Determination of α_s with R value

E_{cm} (GeV)	R	$\alpha_s^{(3)}(s)$	$\alpha_s^{(4)}(25\ \mathrm{GeV}^2)$	$\alpha_s^{(5)}(M_Z^2)$
2.60	2.18	$0.266^{+0.030+0.125}_{-0.030-0.126}$		
3.07	2.13	$0.192^{+0.029+0.103}_{-0.029-0.101}$	$0.209^{+0.044}_{-0.050}$	$0.117^{+0.012}_{-0.017}$
3.65	2.14	$0.207^{+0.015+0.104}_{-0.015-0.104}$		

$\frac{\delta R}{R}$: sys $\sim 3.5\%$; stat $\sim 0.5 - 1\%$!

- perfect agreement with pQCD
- perfect agreement with
  - α_s from Z decay rate: $\alpha_s^{(5)}(M_Z^2) = 0.1185 \pm 0.0026$
  - τ-decays (Baikov, Chetyrkin, JK) $\alpha_s^{(3)}(m_\tau^2) = 0.332 \pm 0.005_{exp} \pm 0.015_{th} \Rightarrow \alpha_s^{(5)}(M_Z^2) = 0.120 \pm 0.019$
- relative importance of α_s^4-terms for BES e.g. at 2.606 GeV: $0.266 \pm 0.030 \pm 0.120 \quad \Rightarrow 0.286 \pm \ldots$

low energies (~ 2 GeV) of special interest

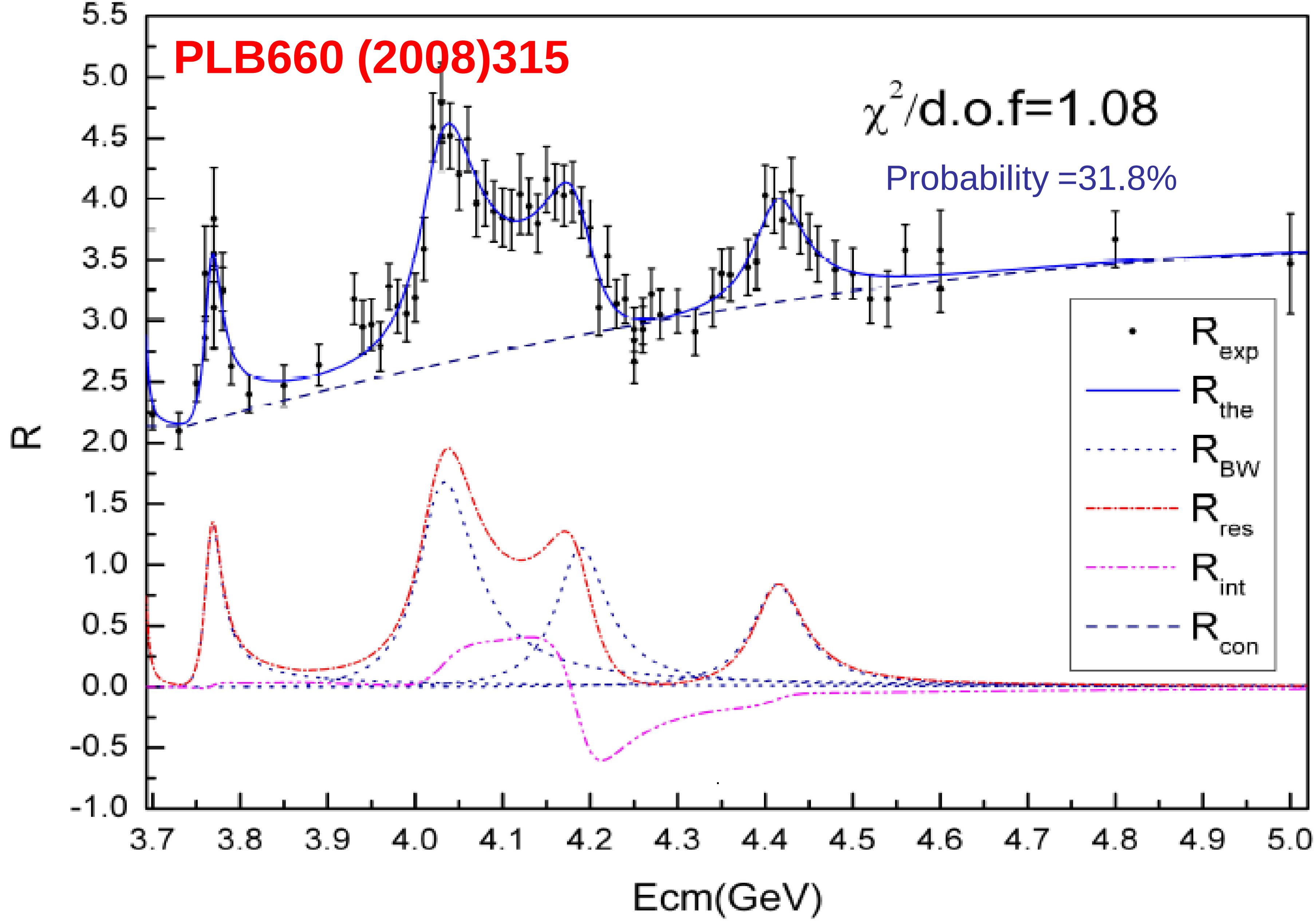
validity of pQCD? $\Rightarrow$ s-dependence!

Part 4

Parameters of heavy charmonium

Phys. Lett. B660, 315(2008)

Resonant structure



BESII results quoted by PDG

$\psi(3770)$ $I^G(J^{PC}) = 0^-(1^{--})$

$\psi(3770)$ MASS

OUR FIT includes measurements of $m_{\psi(2S)}$, $m_{\psi(3770)}$, and $m_{\psi(3770)} - m_{\psi(2S)}$.

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
3772.92±0.35 OUR FIT Error includes scale factor of 1.1.				
3775.2 ±1.7 OUR AVERAGE Error includes scale factor of 1.4. See the ideogram below.				
3772.0 ±1.9		[1] ABLIKIM 08D	BES2	$e^+e^- \to$ hadrons

$\psi(4040)$ $I^G(J^{PC}) = 0^-(1^{--})$

$\psi(4040)$ MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
4039 ± 1 OUR ESTIMATE			
4039.6± 4.3	[1] ABLIKIM 08D	BES2	$e^+e^- \to$ hadrons

$\psi(4415)$ $I^G(J^{PC}) = 0^-(1^{--})$

$\psi(4415)$ MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
4421 ± 4 OUR ESTIMATE			
4415.1± 7.9	[1] ABLIKIM 08D	BES2	$e^+e^- \to$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •			
4411 ± 7	[2] PAKHLOVA 08A	BELL	$10.6\ e^+e^- \to D^0 D^- \pi^+ \gamma$
4425 ± 6	[3] SETH 05A	RVUE	$e^+e^- \to$ hadrons
4429 ± 9	[4] SETH 05A	RVUE	$e^+e^- \to$ hadrons
4417 ±10	BRANDELIK 78C	DASP	e^+e^-
4414 ± 7	SIEGRIST 76	MRK1	e^+e^-

[1] Reanalysis of data presented in BAI 02C. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta = (234 \pm 88)^\circ$.

$\psi(4160)$ $I^G(J^{PC}) = 0^-(1^{--})$

$\psi(4160)$ MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
4153 ± 3 OUR ESTIMATE			
4191.7± 6.5	[1] ABLIKIM 08D	BES2	$e^+e^- \to$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •			
4151 ± 4	[2] SETH 05A	RVUE	$e^+e^- \to$ hadrons
4155 ± 5	[3] SETH 05A	RVUE	$e^+e^- \to$ hadrons
4159 ±20	BRANDELIK 78C	DASP	e^+e^-

[1] Reanalysis of data presented in BAI 02C. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta = (293 \pm 57)^\circ$.
[2] From a fit to Crystal Ball (OSTERHELD 86) data.
[3] From a fit to BES (BAI 02C) data.

$\psi(4160)$ WIDTH

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
103 ± 8 OUR ESTIMATE			
71.8±12.3	[4] ABLIKIM 08D	BES2	$e^+e^- \to$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •			
107 ±10	[5] SETH 05A	RVUE	$e^+e^- \to$ hadrons
107 ±16	[6] SETH 05A	RVUE	$e^+e^- \to$ hadrons
78 ±20	BRANDELIK 78C	DASP	e^+e^-

[4] Reanalysis of data presented in BAI 02C. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta = (293 \pm 57)^\circ$.
[5] From a fit to Crystal Ball (OSTERHELD 86) data.
[6] From a fit to BES (BAI 02C) data.

$\psi(4160)$ PARTIAL WIDTHS

$\Gamma(e^+e^-)$ Γ_1

VALUE (keV)	DOCUMENT ID	TECN	COMMENT
0.83±0.07 OUR ESTIMATE			
0.48±0.22	[7] ABLIKIM 08D	BES2	$e^+e^- \to$ hadrons

Part 5

Form factor of 4π

Chiral Dynamics 2006, World Scientific
Nucl. Phys. (Proc. Suppl.)B162, 5(2006)

Theoretical model

The most successful theory for $e^+e^-\to 2(\pi^+\pi^-)$ is the extend vector meson dominant model, which predicts :

N.N.Achasov and A.A.Kozhevnikov, Phys. Rev. D 55, 2663(1997)

Born cross section:

$$\sigma(e^+e^- \to 2\pi^+2\pi^-) = \frac{(4\pi\alpha)^2}{s^{3/2}} |F_{\rho^0\pi^+\pi^-}(s)|^2 W_{\pi^+\pi^-\pi^+\pi^-}(s)$$

Form factor:

$$F_{\rho^0\pi^+\pi^-}(s) = \left(\frac{m_\rho^2}{f_\rho}, \frac{m_{\rho_1'}^2}{f_{\rho_1'}}, \frac{m_{\rho_2'}^2}{f_{\rho_2'}}\right) G^{-1}(s) \begin{pmatrix} 2g_{\rho\pi\pi}^2 \\ g_{\rho_1'\rho^0\pi\pi} \\ g_{\rho_2'\rho^0\pi\pi} \end{pmatrix}$$

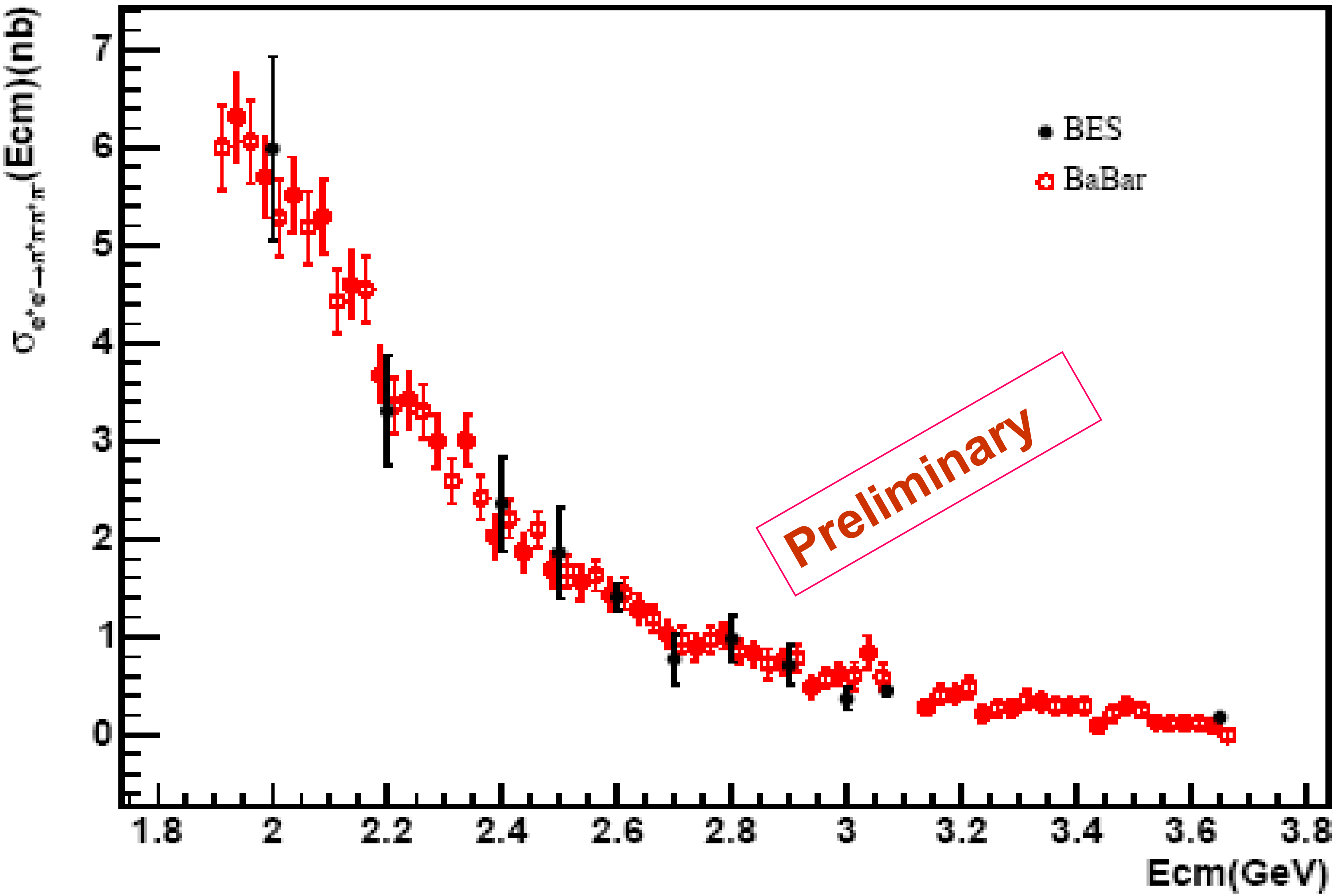
Final state factor :

$$W_{\pi^+\pi^-\pi^+\pi^-}(s) = \frac{1}{(2\pi)^3 4s} \int_{(2m_\pi)^2}^{(\sqrt{s}-2m_\pi)^2} dm_1^2 \rho_{\pi\pi}(m_1) \int_{(2m_\pi)^2}^{(\sqrt{s}-m_1)^2} \frac{dm_2^2}{2m_2} \times (1 + \frac{q^2(\sqrt{s}, m_1, m_2)}{3m_1^2}) q(\sqrt{s}, m_1, m_2) q(m_2, m_\pi, m_\pi)$$

$$G(s) = \begin{pmatrix} D_\rho & -\Pi_{\rho\rho_1'} & -\Pi_{\rho\rho_2'} \\ -\Pi_{\rho\rho_1'} & D_{\rho_1'} & -\Pi_{\rho_1'\rho_2'} \\ -\Pi_{\rho\rho_2'} & -\Pi_{\rho_1'\rho_2'} & D_{\rho_2'} \end{pmatrix}$$

$$\rho_{\pi\pi}(m) = \frac{\frac{1}{\pi} m \Gamma_\rho(m)}{(m^2 - m_\rho^2)^2 + [m\Gamma_\rho(m)]^2}$$

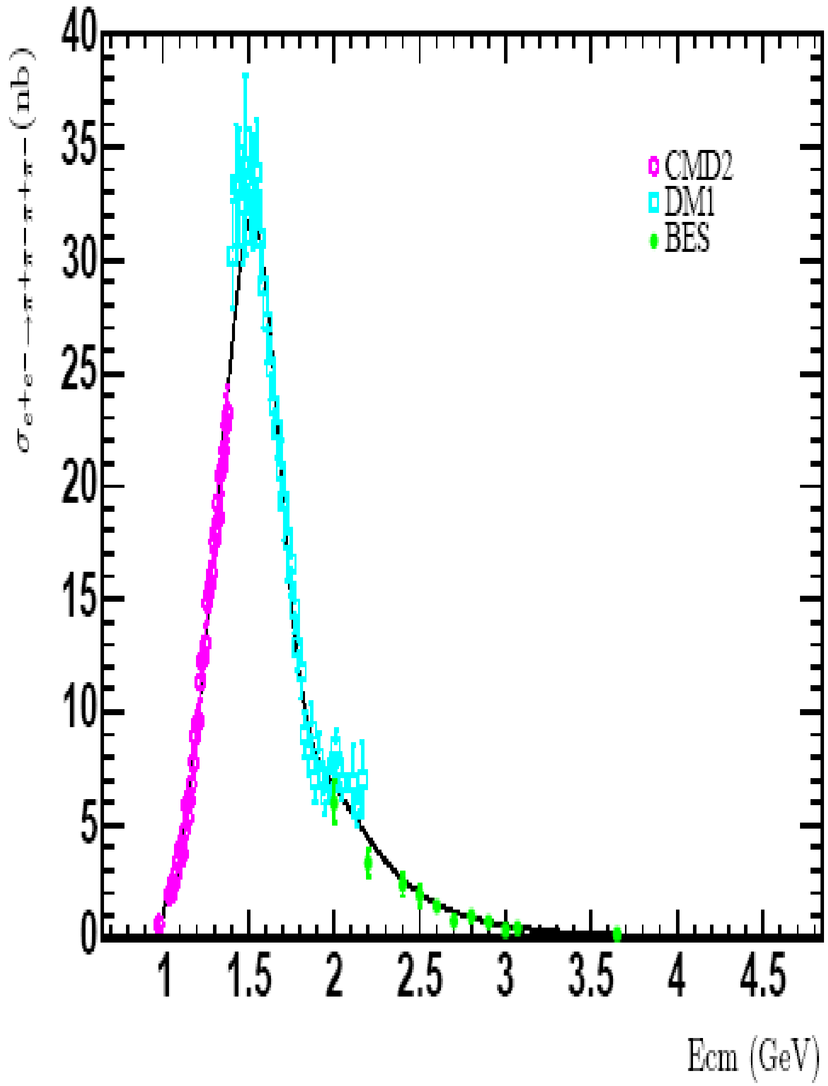
$2(\pi^+\pi^-)$ cross section

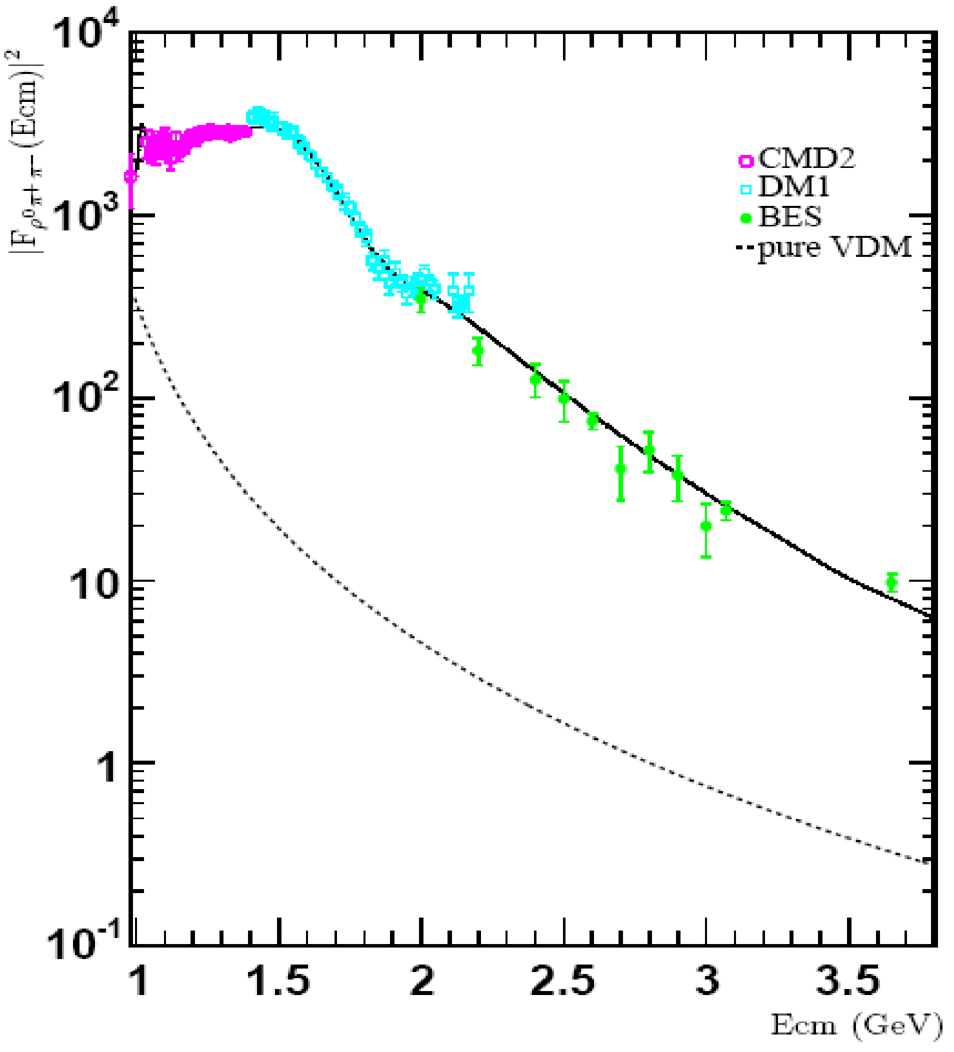


The measured cross sections by BaBar and BES agree well

Comparison between data and model

The measured cross sections and form factors by CMD2, DM1 and BES and the corresponding fitted curve with the VMD model





Part 6

$e^+ e^- \to p \bar{p}$

Phys. Lett. B630, 14 (2005)

Cross section

The total cross section of $e^+ e^- \to p\bar{p}$ is measured by

$$\sigma_T = \frac{N}{\mathcal{L} \cdot \varepsilon \cdot \varepsilon_{\text{trig}}}$$

Number of $p\bar{p}$

Luminosity

$p\bar{p}$ efficiency

Trigger efficiency

The interesting cross section in physics is the Born level, which may be obtained by performing the various corrections:

$$\sigma_0 = \frac{\sigma_T}{(1+\delta) \cdot F_c \cdot F_f}$$

Final state correction → J.Schwinger, Particle, Source and Field

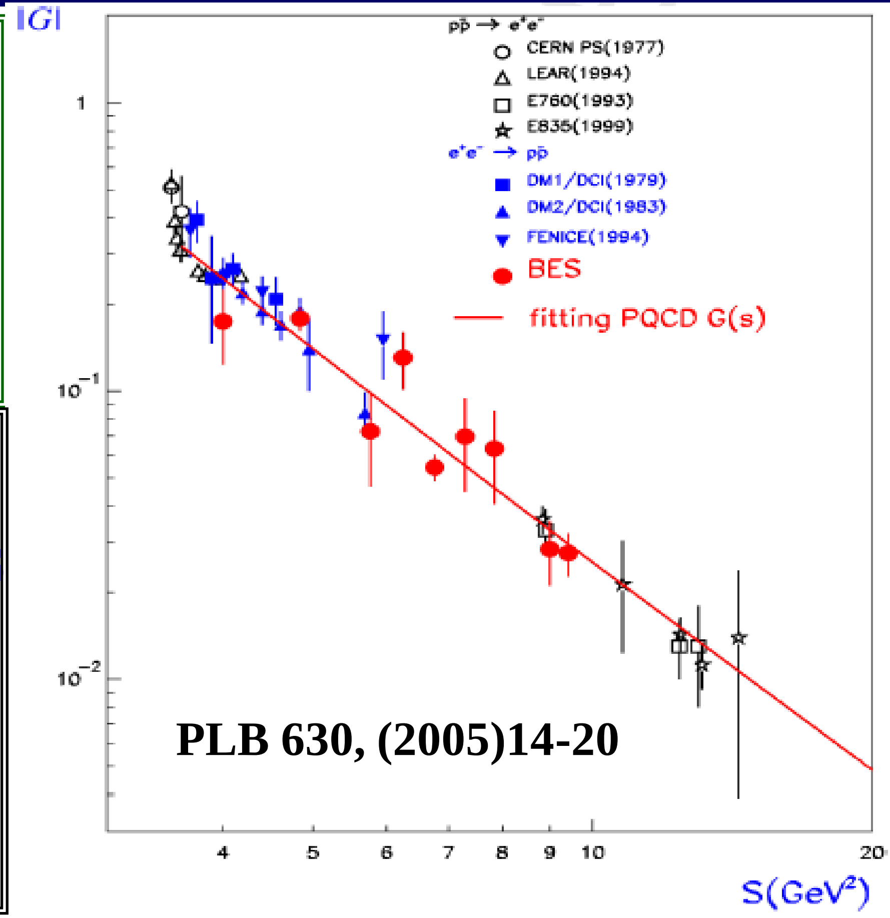
ISR correction → E.A.Kureav, V.S.Fadin, Sov. Nucl. Phys. 41, 1985, 466 - 472

Coulomb correction → Landau: $F_c = \frac{\pi\alpha / \beta}{1 - e^{-\pi\alpha / \beta}}$

$$\sigma^T(s) = \int_0^{x_{max}} dx \frac{\sigma^\circ(s')}{|1 - \hat{\Pi}_2(s')|^2} F(x,s) \quad 1 + \delta \equiv \sigma^T(s)/\sigma^\circ(s)$$

Form factor fitting

Due to the limited statistics, BESII data can not measure the electric G_E and magnetic G_M form factors separately.



Under the assumption of $|G_E| = |G_M| \equiv |G|$, cross section is simplified as:

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

pQCD predicts $p\bar{p}$ form factor $\sim[\alpha_s(s)]^2$, one often uses

$$|G| = \frac{C}{s^2 \ln^2(s/\Lambda^2)}$$

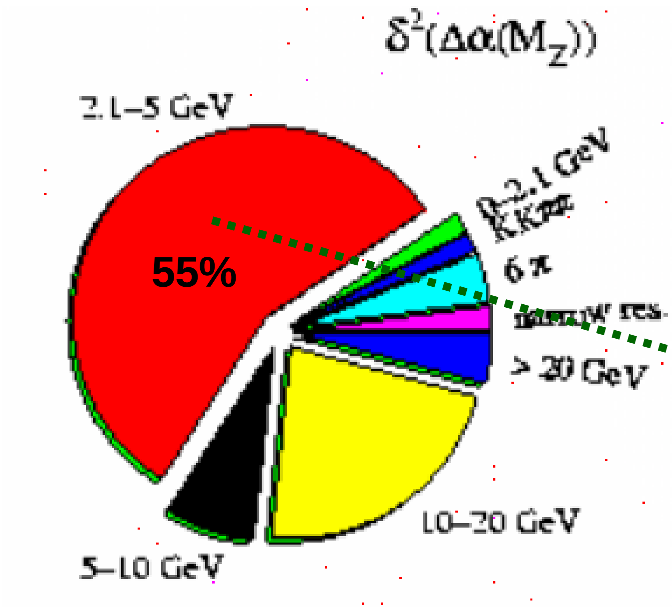
Λ= 0.3 GeV is the QCD scale parameter

C is the free parameter

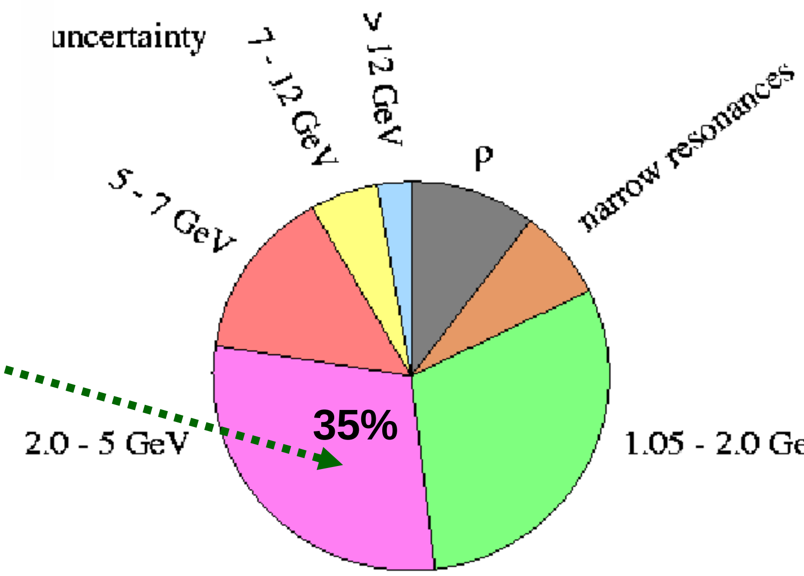
Part 7

BESII's results improved SM calculations

Contribution to $\Delta\alpha(M_Z)$



Before BESII measurement

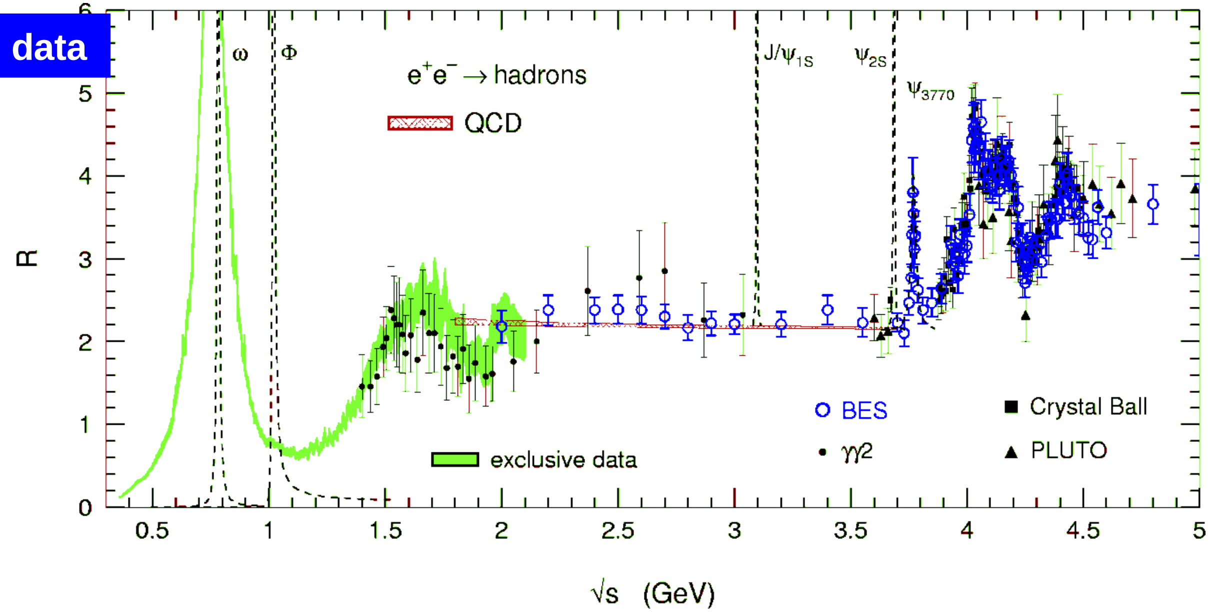


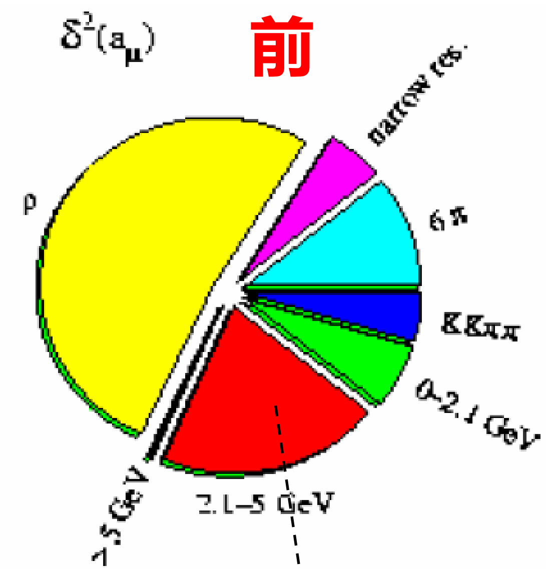
After BESII measurement

	S. Eidelman (1995)	H.Burkhardt & B.Pietrzyk (2001)
BES's R	no used	used
$\Delta\alpha^{(5)}_{had}(M_Z^2)$	0.0280 ± 0.0007	0.0276 ± 0.00036
$\alpha^{-1}(M_Z^2)$	128.90 ± 0.09	128.936 ± 0.0046

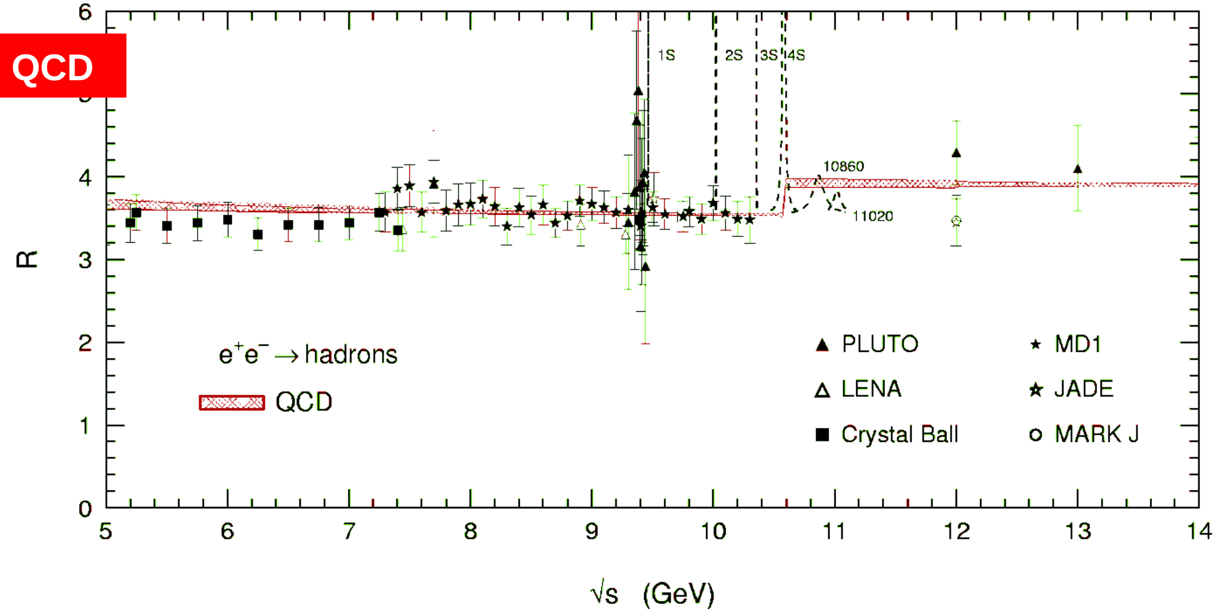
Contribution to (g-2) of μ

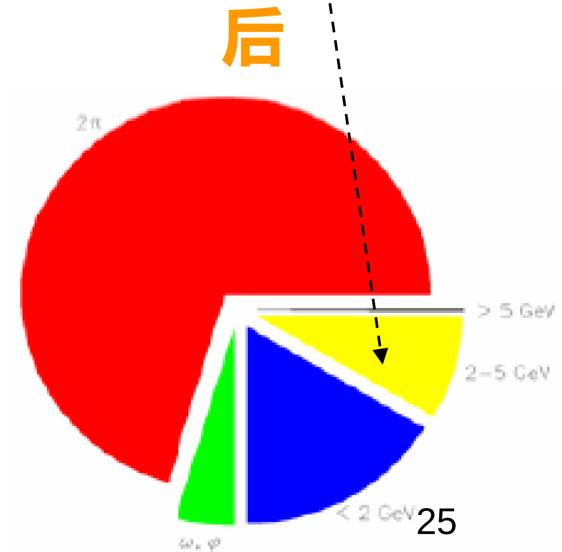
use data





use QCD





Progresses of g-2 measurement

实验时间	实验室	物理学家	粒子	实验结果	实验精度
1957	Nevis	L. Lederman 等	μ^+	0.00 ± 0.10	
1959	Nevis	L. Lederman 等	μ^+	0.00113(14)	12.4%
1961	CERN	G. Charpak 等	μ^+	0.001145(22)	1.9%
1962	CERN	G. Charpak 等	μ^+	0.001162(5)	0.43%
1968	CERN	J. Bailey 等	$\mu^\pm$	0.00116616(31)	265ppm
1975	CERN	J. Bailey 等	$\mu^\pm$	0.001165895(27)	23ppm
1979	CERN	J. Bailey 等	$\mu^\pm$	0.001165911(11)	7.3ppm
2000	Brookhaven	H. N. Brown 等	μ^+	0.0011659191(59)	5ppm
2001	Brookhaven	H. N. Brown 等	μ^+	0.0011659202(14)(6)	1.3ppm
2002	Brookhaven	G. W. Bennett 等	μ^+	0.0011659203(8)	0.7ppm
2004	Brookhaven	G. W. Bennett 等	μ^-	0.0011659214(8)(3)	0.7ppm
2004	Brookhaven	G. W. Bennett 等	$\mu^\pm$	0.00116592080(63)	0.54ppm

Comparison between experiments and SM

Summing all contribution terms in SM, one may see the difference between the prediction of SM and E821 experimentsE821：

$a_\mu^{EXP} = 116592089\ (63) \times 10^{-11}$

E821 – Final Report: PRD73 (2006) 072
with latest value of $\lambda=\mu_\mu/\mu_p$ (Codata '06)

$a_\mu^{SM} \times 10^{11}$	$(\Delta a_\mu = a_\mu^{EXP} - a_\mu^{SM}) \times 10^{11}$	σ
[1] 116 591 773 (53)	316 (82)	3.8
[2] 116 591 782 (59)	307 (86)	3.6
[3] 116 591 834 (49)	255 (80)	3.2
[4] 116 591 773 (48)	316 (79)	4.0
[5] 116 591 929 (52)	160 (82)	2.0

with $a_\mu^{HHO}(lbl) = 105\ (26) \times 10^{-11}$

[1] HMNT06, PLB649 (2007) 173.
[2] F. Jegerlehner and A. Nyffeler, arXiv:0902.3360.
[3] Davier et al, arXiv:0908.4300 August 2009 (includes BaBar)
[4] Hagiwara, Liao, Martin, Nomura, Teubner, Oct '09 (preliminary)
[5] Davier et al, arXiv:0906.5443v2 August 2009 (τ data).

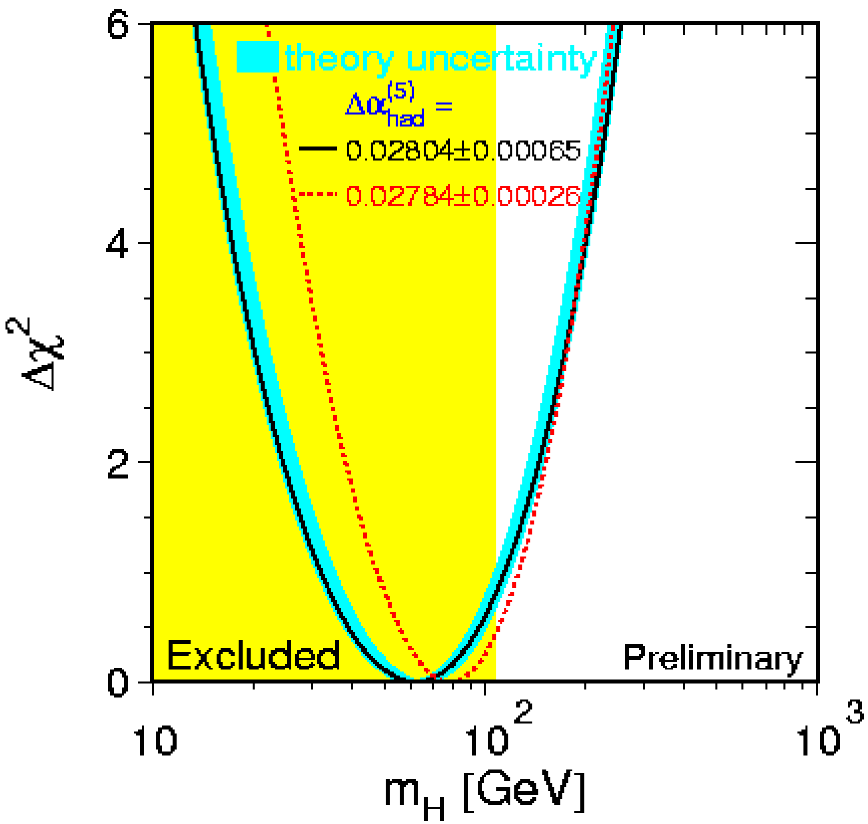
Status： considering error, experimental values and SM predictions are inconsistence significantly.

Reasons： whether calculations of QED, EW and QCD are correct? Or new physics? Or g-2 measurement error?

Solutions： before definite conclusion, need more precision measurements and theoretical calculations.

Contribution to global fit of Higgs mass

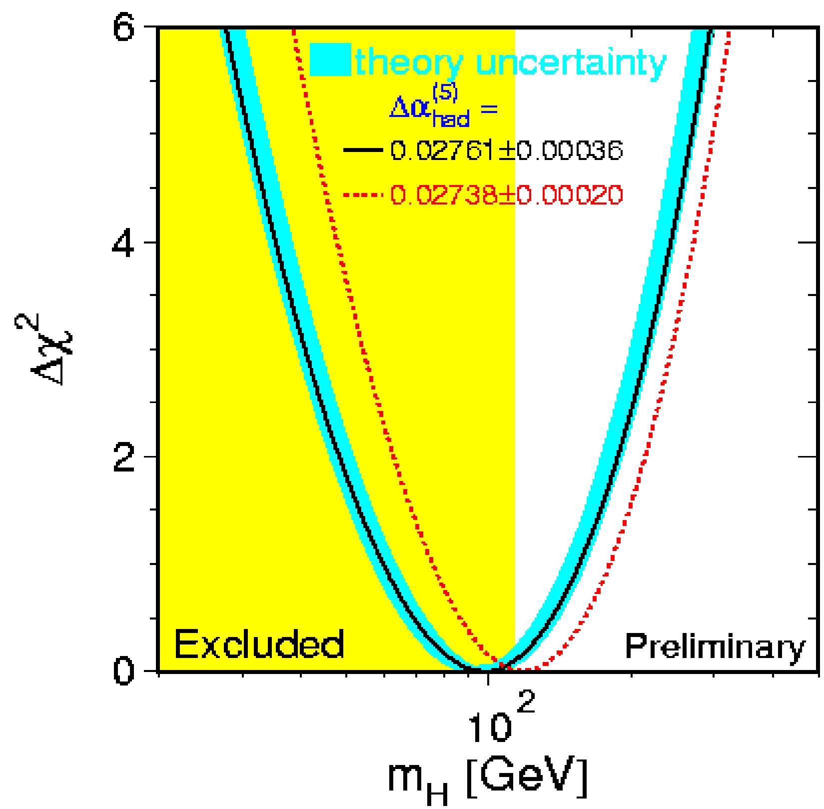
Without BESII data



$m_H = 62^{+53}_{-30}\,GeV$

$m_H < 170\,GeV$ (95% C.L.)

With BESII data



$m_H = 98^{+58}_{-38}\,GeV$

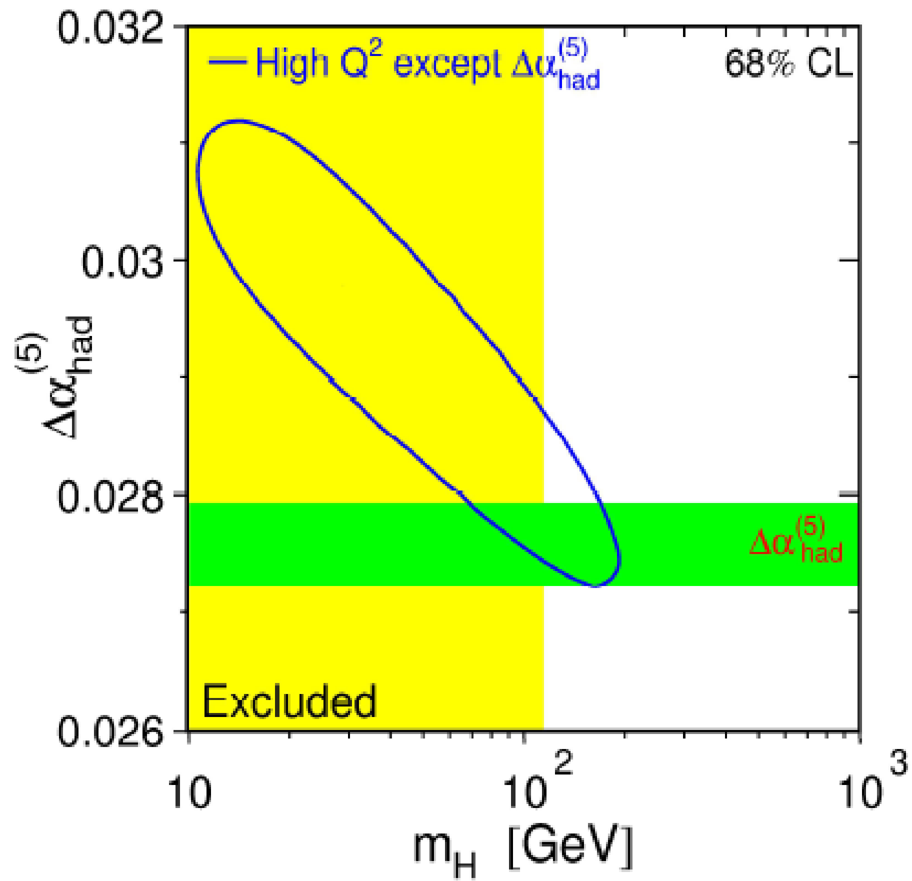
$m_H < 212\,GeV$ (95% C.L.)

The most probable fit of Higgs mass

SM predicts the global fitting in the two dimension

$$(\Delta\alpha^{(5)}_{had}(M_Z^2), M_H)$$

The update values of SM calculations and experiments search limit the possible Higgs mass into a very small region



Standard fitting with ZFITTER

Table 2. Fit to all data with ZFITTER

χ^2 / DoF (prob.)	$25.4/15$ (χ^2 prob. $= 4.5\,\%$)
m_Z [GeV]	91.1875 ± 0.0021
m_t [GeV]	174.3 ± 4.5
$\Delta\alpha^{(5)}_{\mathrm{had}}$	0.02767 ± 0.00035
α_s	$\mathbf{0.1186 \pm 0.0027}$
m_H [GeV]	$\mathbf{96^{+60}_{-38}}$
derived parameters	
$\sin^2\theta^{eff}_W$	0.23143 ± 0.00014
$\sin^2\theta_W$	0.22289 ± 0.00036
m_W	80.385 ± 0.019
largest correlations: $m_H - m_t$: 71 %	$m_H - \Delta\alpha^{(5)}_{\mathrm{had}}$: 48 %

When inspect the stability of the most probable Higgs mass in SM global fitting, when the error of $\Delta\alpha^{(5)}_{\mathrm{had}}$ change one standard error, the corresponding error of Higgs mass change 48%.

SM prediction for Higgs mass

- The dependence of SM predictions on the Higgs mass, via loops, provides a powerful tool to set bounds on its value.
- Comparing the theoretical predictions of M_W and $\sin^2\theta_{\rm eff}^{\rm lept}$

[convenient formulae in terms of M_H, M_{top}, $\Delta\alpha_{had}^{(5)}(M_Z)$ and $\alpha_s(M_Z)$ by Degrassi, Gambino, MP, Sirlin '98; Degrassi, Gambino '00; Ferroglia, Ossola, MP, Sirlin '02; Awramik, Czakon, Freitas, Weiglein '04 & '06]

with

M_W	= 80.399 (23) GeV	[LEP+Tevatron, Aug' 09]
$\sin^2\theta_{\rm eff}^{\rm lept}$	= 0.23153 (16)	[LEP+SLC]

and

$\Delta\alpha_{had}^{(5)}(M_Z)$	= 0.02760 (15)	[HLMNT Oct '09 Prelim]
M_{top}	= 173.1 (1.3) GeV	[CDF-D0, Mar '09]
$\alpha_s(M_Z)$	= 0.118 (2)	[PDG '08]

we get

$$M_H = 96^{+32}_{-25}\ \text{GeV} \quad \& \quad M_H < 153\ \text{GeV}\ \ 95\%\text{CL}$$

- The value of $\Delta\alpha_{had}^{(5)}(M_Z)$ is a key input of these EW fits...

Search for Higgs in experiments

The present conclusion：

If Higgs predicted by SM exists, its mass

$115.5\ GeV < M_H < 127\ GeV$ (at 95% CL)

CMS: $H \to ZZ \to llqq,\ llll,\ ll\nu\nu,\ ll\tau\tau,\ H \to WW,\ H \to \tau\tau,\ H \to bb,\ H \to \gamma\gamma$

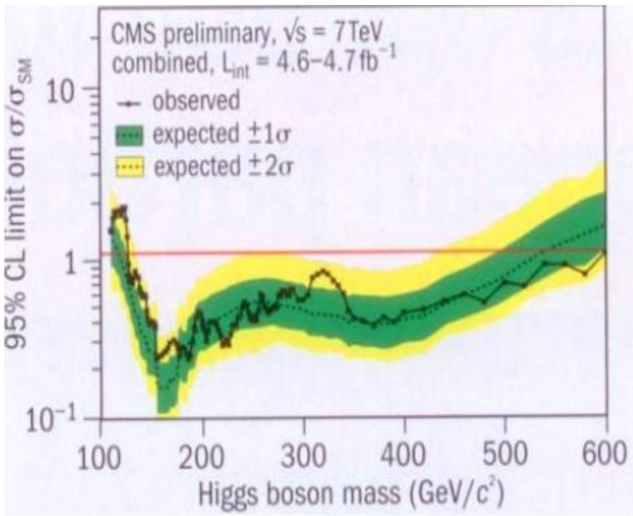
$M_H < 127\ GeV$

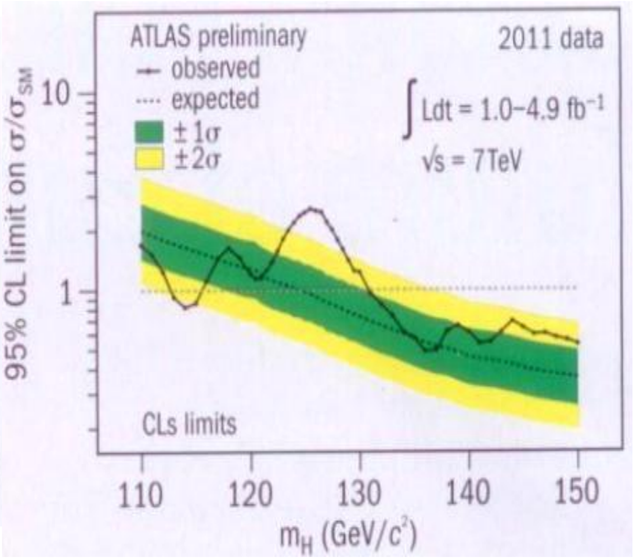
ATLAS: $H \to ZZ \to llll,\ H \to WW,\ H \to \gamma\gamma$

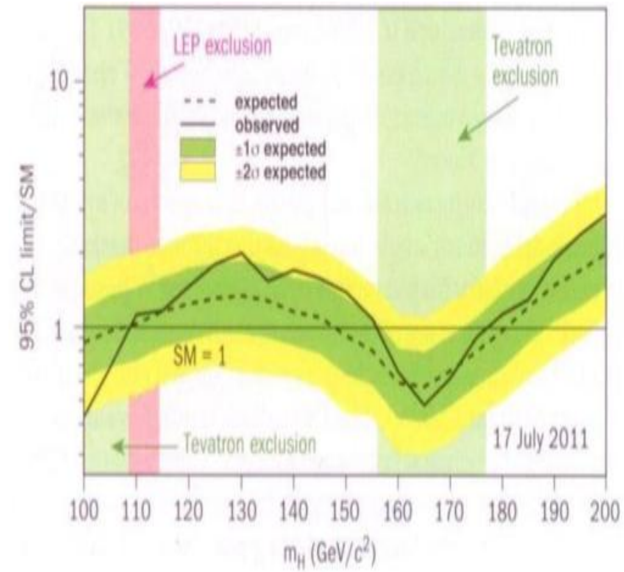
$M_H > 115.5\ GeV$ & $M_H < 131\ GeV$

Tevatron (CDF,D∅): $H \to ZZ, WW, \gamma\gamma, \tau\tau, bb$

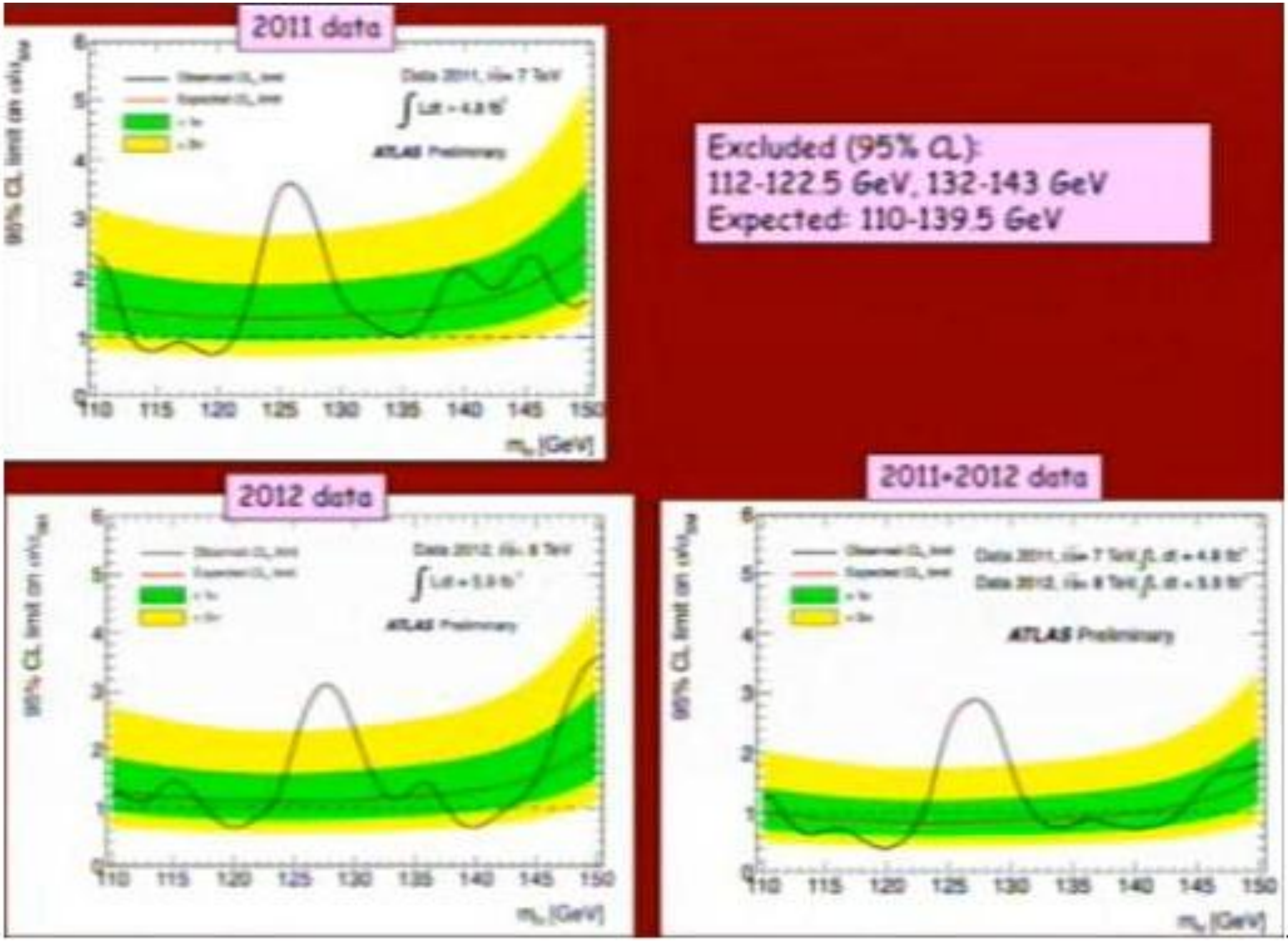
$M_H > 120\ GeV$, $M_H < 150\ GeV$, $M_H > 175\ GeV$



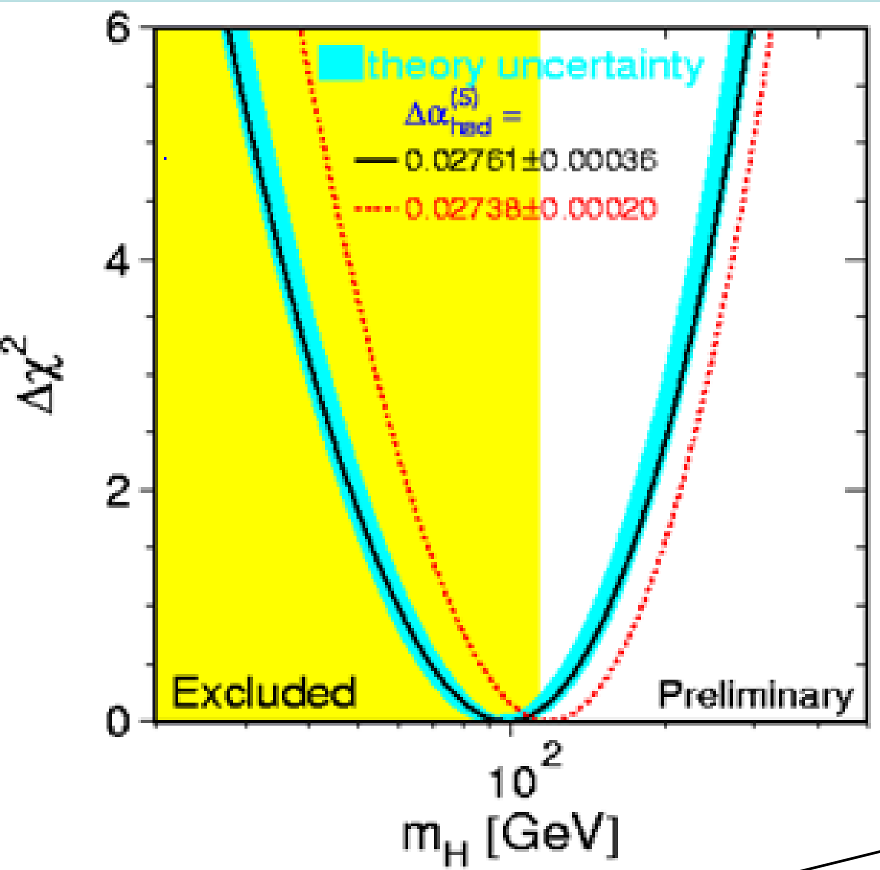




Search for Higgs in experiments



Higgs search vs MS global fitting

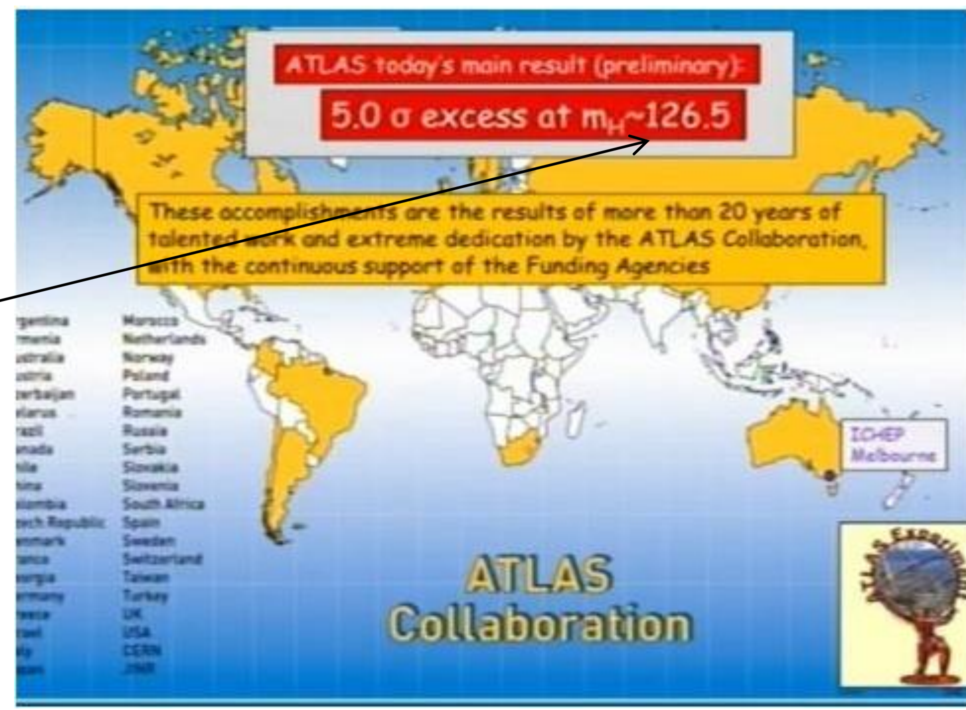


$$m_H = 98^{+58}_{-38} GeV$$

$$m_H < 212 GeV \quad (95\% \text{ C.L.})$$

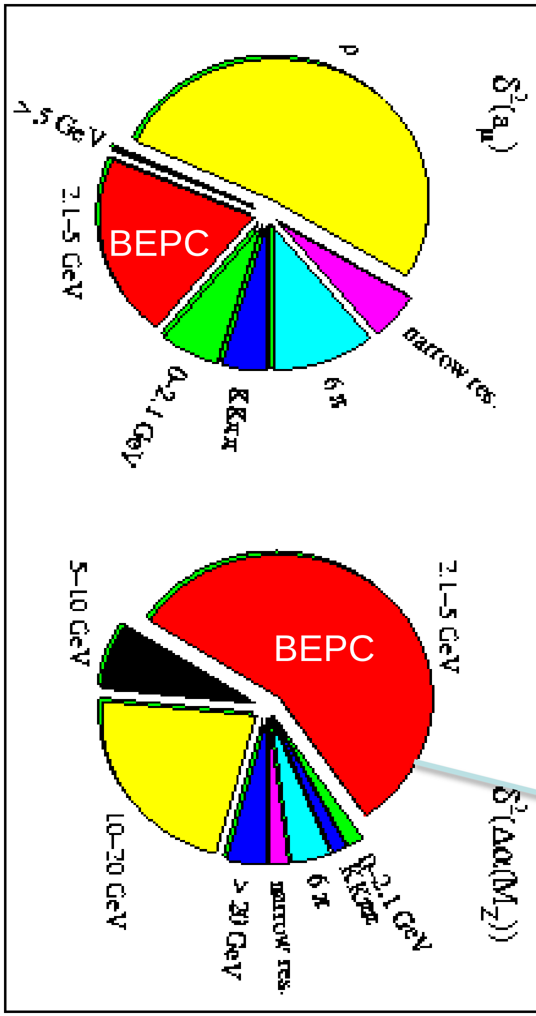
consistent
or
inconsistent

Need more precision SM parameters
…… R value ……

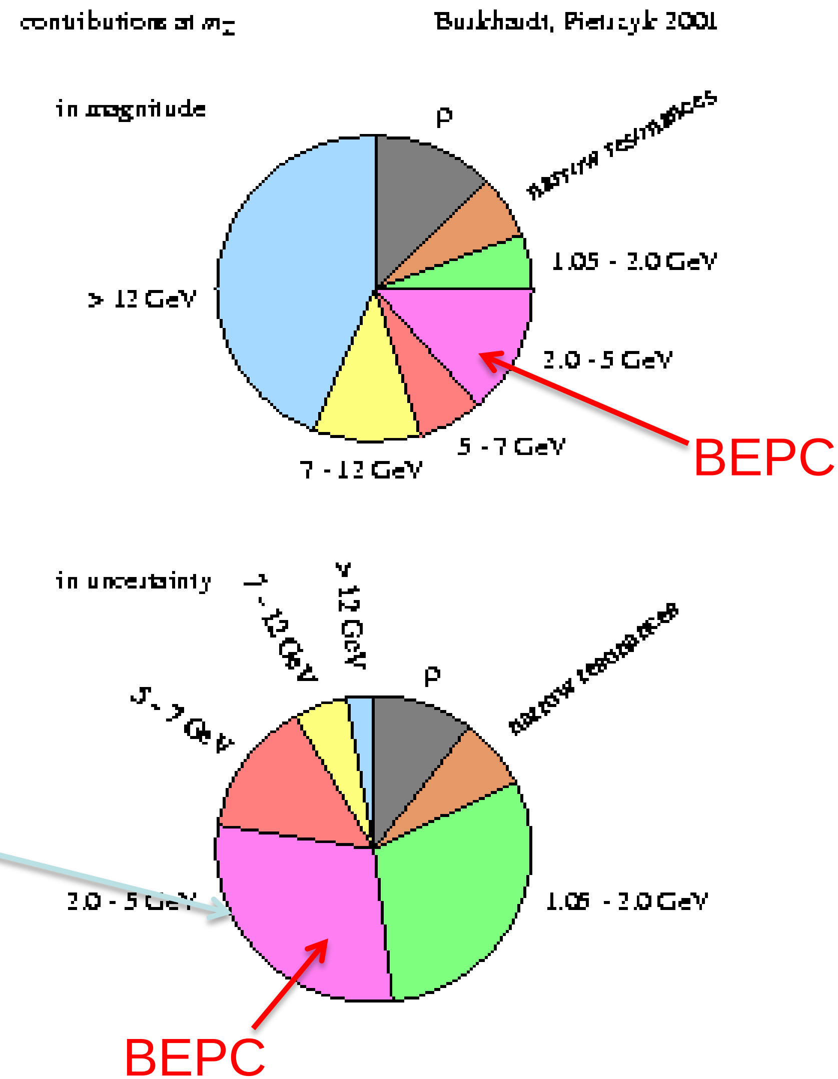


R value contribution to error of a_μ and $\Delta\alpha$

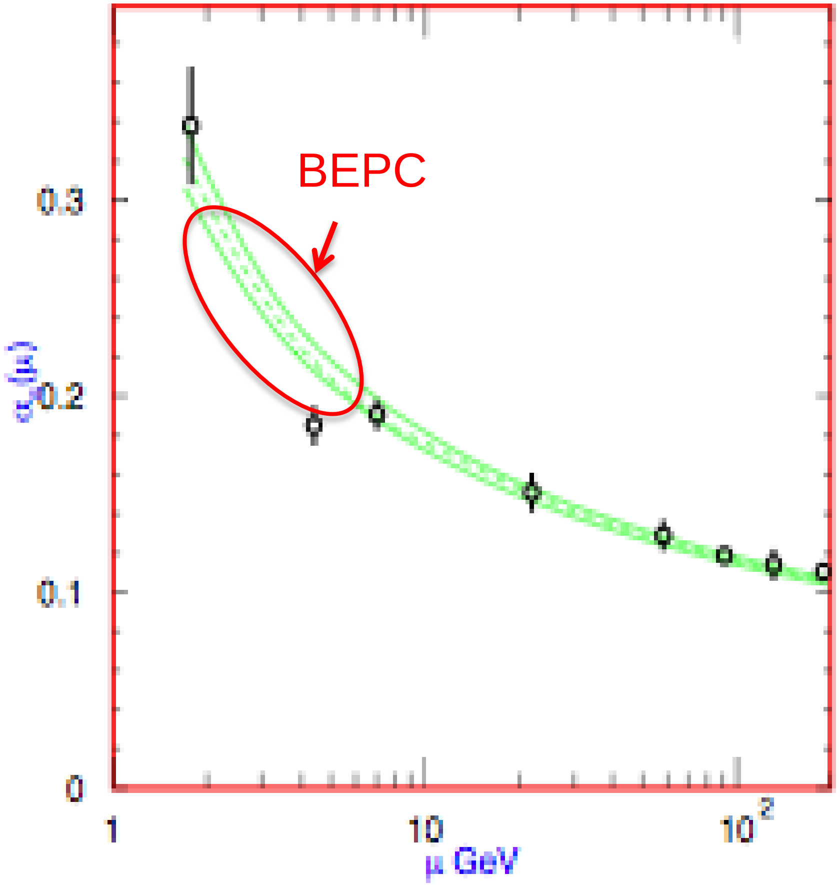
Before BESII R scan

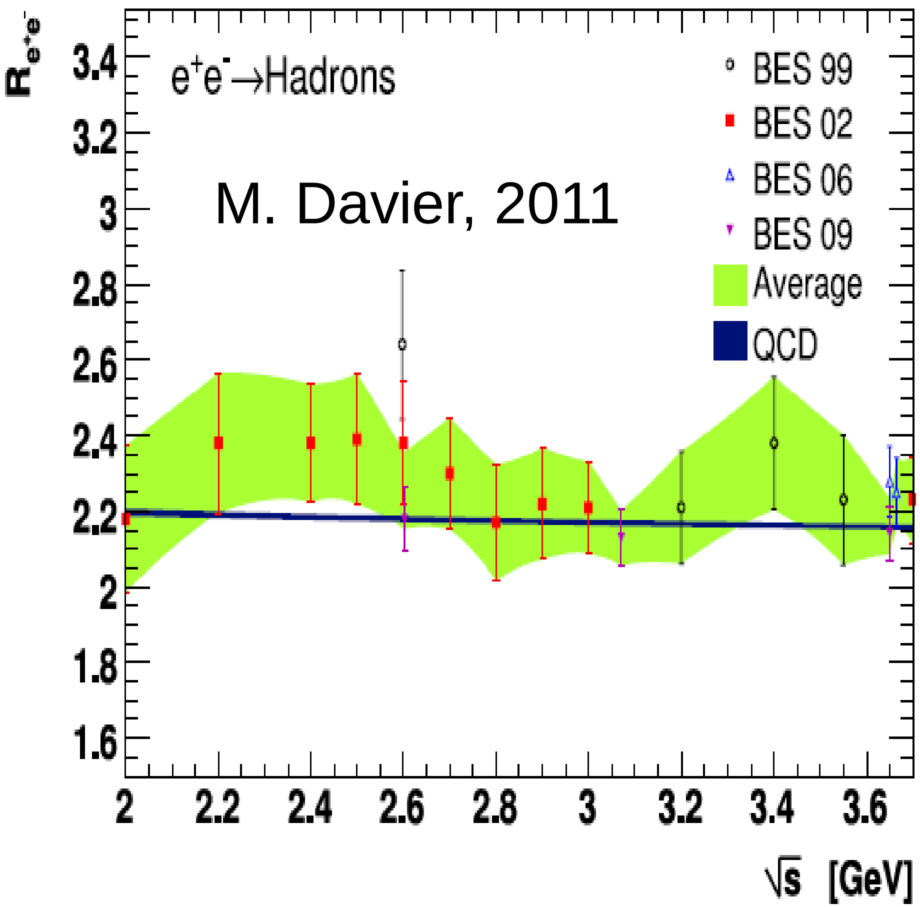


After BESII R scan



α_s measurement with R value





PDG10: $\alpha_s(M_Z)=0.1184 \pm 0.0007$

BESII: with $\sqrt{s}$=2.60, 3.07, 3.65GeV

$\alpha_s(M_Z)=0.117^{+0.012}_{-0017}$

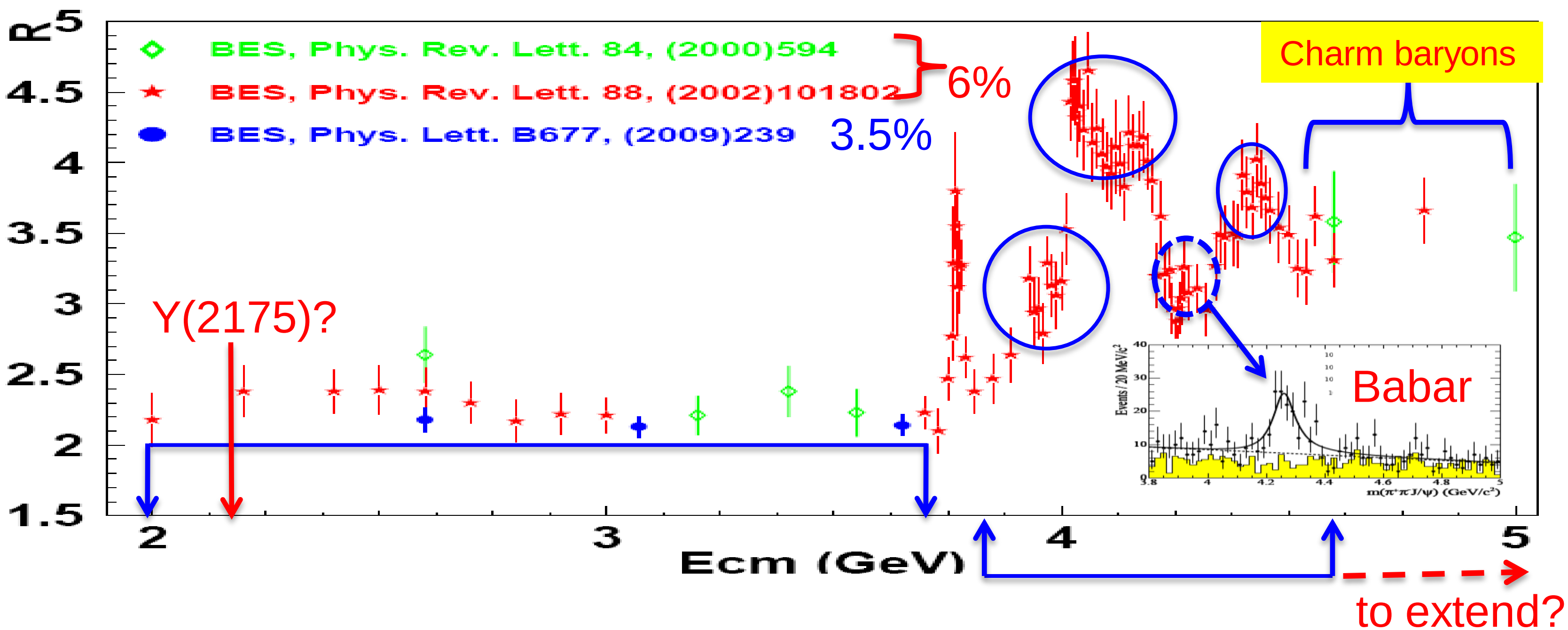
- pQCD calculation agrees well with BES data,
- with slight deviation in 2.2–2.5 GeV.

- R value measured with BESII improved some SM calculations
- But SM calculations are needed to further improved
- More accurate R value measurements are appealed
- What next to do?
- New plans are coming……

Part 8

Data taking (plan) with BESIII

R Scan Strategies with BESIII

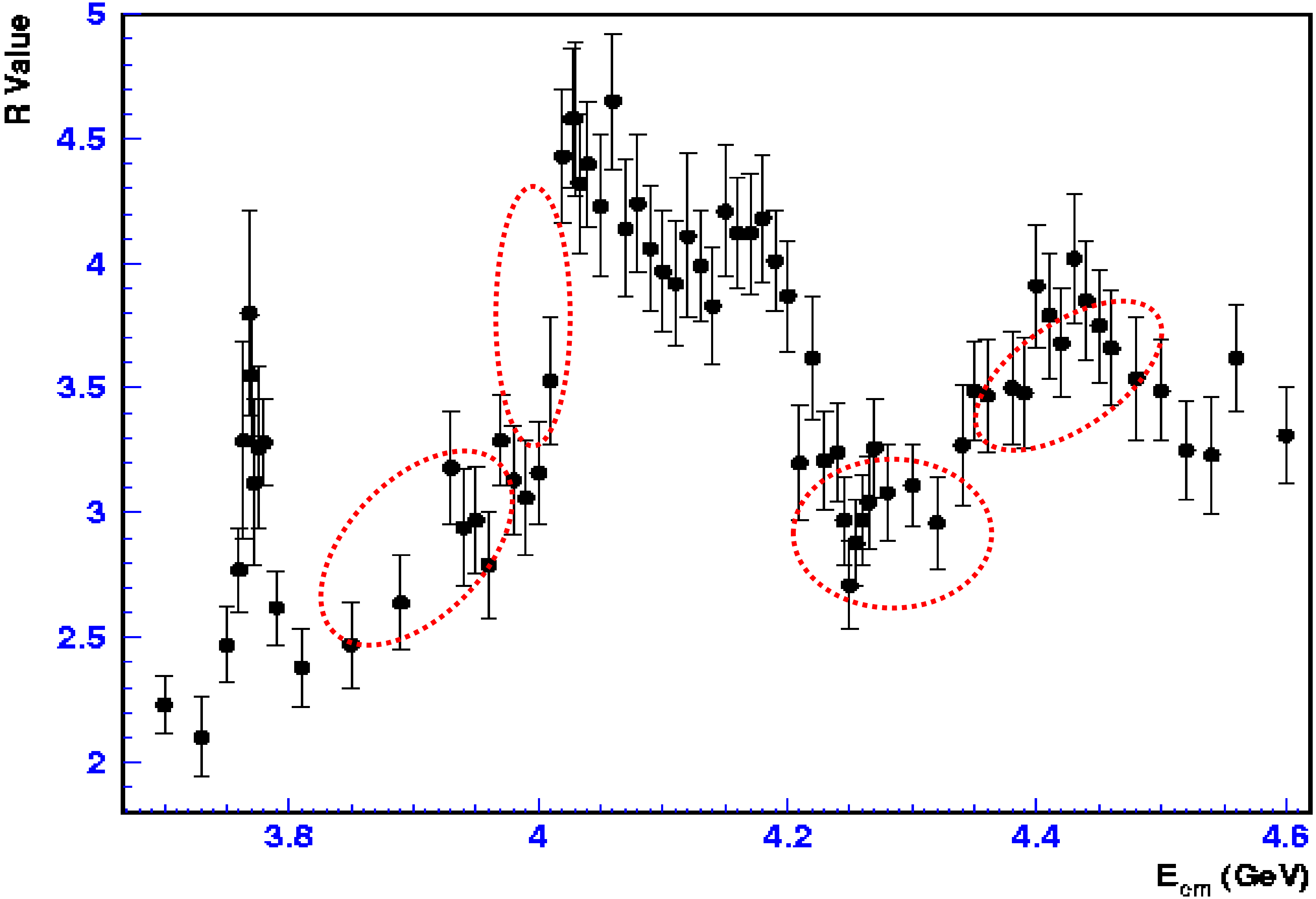


- **Phase I**: pre-study, ~7 days
  @ 2.2, 2.4, 2.8 and 3.4 GeV, MC tuning, …
- **Phase II**: scan continuum region, ~10 days for R, or ~100 day for FF
  @ 15 points in 2.0–3.6 GeV, step 100 MeV, 100k+ hadrons<3 GeV.
- **Phase III**: scan resonance region, ~10 days, or 2 months
  ~100 points in 3.8–4.6 GeV, 10k or 100k, step 1, 2 , 5, 10, 20 MeV.
  (10^8 hadrons at 4040, 4160, 4415 for radiative decay search?)

Full plan for R scan below charm

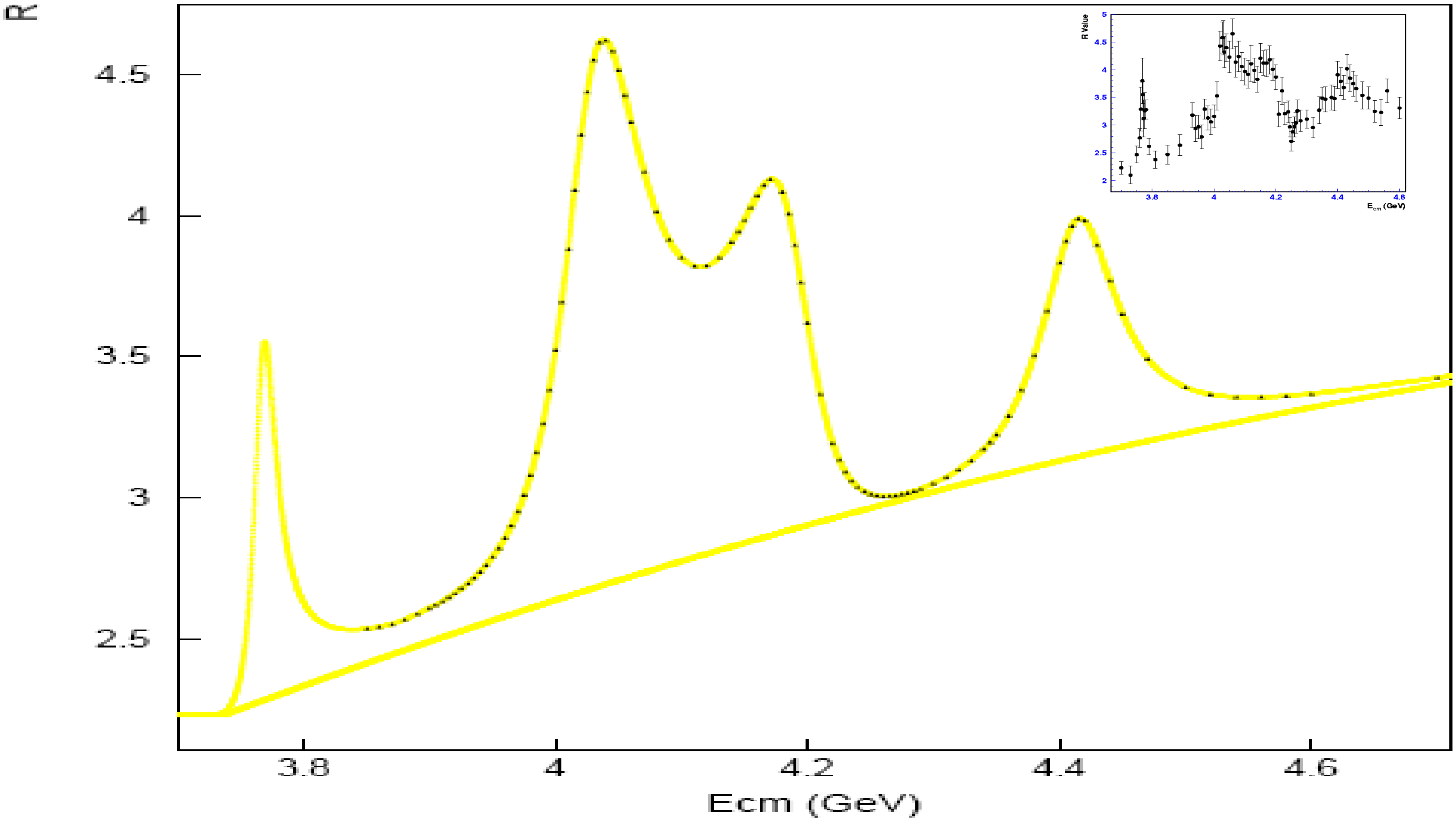
Ecm(GeV)	Nhad	Lum. (1/nb)	BESII rate(1/hr)	Time (hr)	Tuning (hr)
2.0	10000	417.0	8.66	23.1	12
2.1	10000	419.2	-	20.0	12
2.2	10000	420.8	16.7	12.0	12
2.3	10000	443.7	-	12.0	12
2.4	50000	2332.9	29.5	33.9	12
2.4	Separated beam			8.0	0
2.5	10000	489.5	18.9	10.6	12
2.6	10000	513.7	42.3	4.7	8
2.7	10000	554.2	33.9	5.9	8
2.8	50000	3068.0	35.8	27.9	8
2.9	10000	630.6	51.3	3.9	8
3.3	10000	717.7	-	4.2	4
3.4	20000	1493.5	47.7	8.4	4
3.4	Separeted beam			4.0	0
3.5	10000	775.9	-	4.2	4
Sum			12.5 days ←	182.8	+ 116

R scan with BESII in 1999



- Energy steps seem too large to figure out the fine charm resonant structures
- Error of R value are large for precision SM calculations

Coming R scan with BESIII



- Energy steps： 1~2MeV；
- Large enough samples for measuring R value and resonant parameters.

The taken data for R below charm

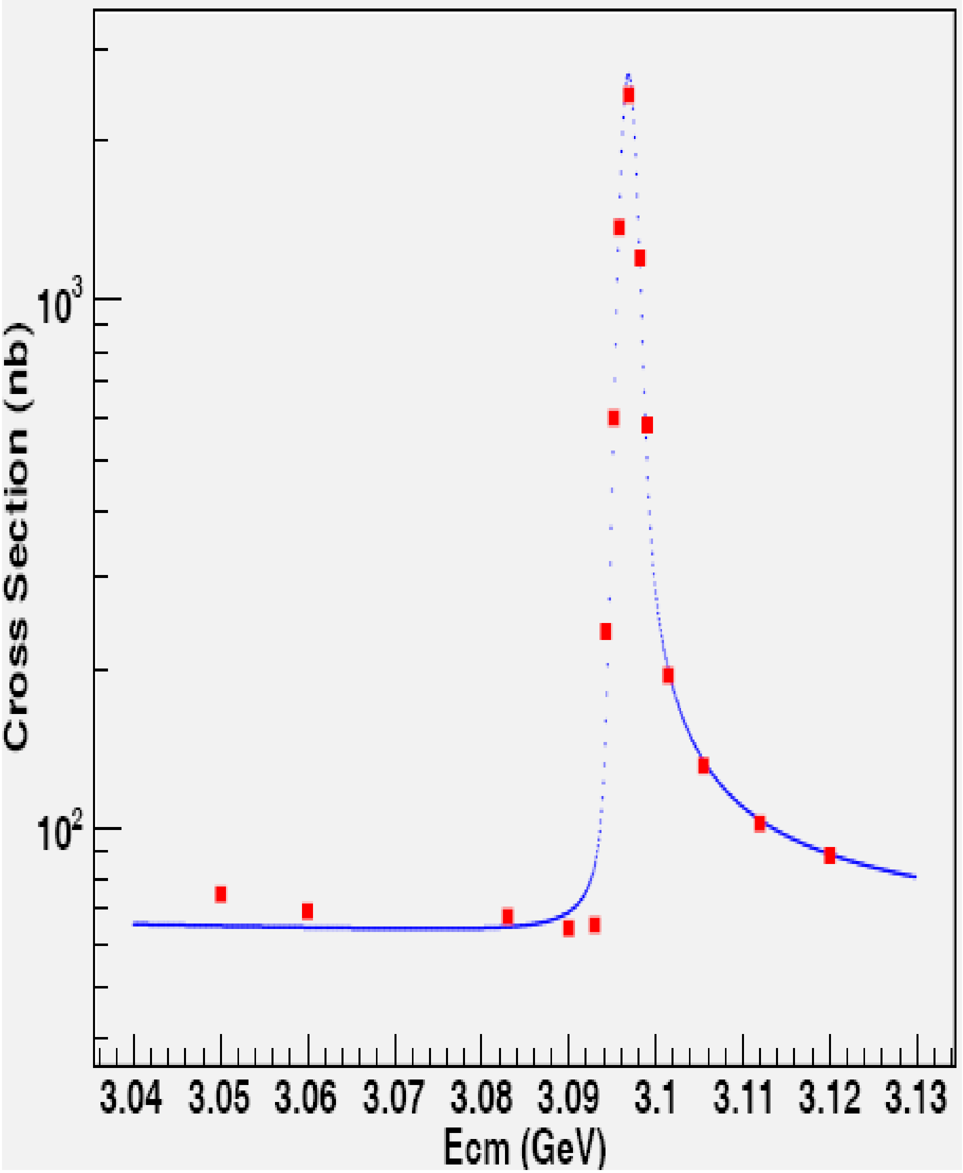
June 7-15, 2012

Ebeam (GeV)	Ecm (GeV)	Nhad (offline)	Lum. actual (plan) (1/pb)	$T_{estimated}$ (hour)	T_{actual}(T_{pure}) (hour)
1.7	3.4	20000	1.6583 (1.4935)	8.4+4	10 (4.8)
1.7	3.4	Separated beam		4	5.3 (4.0)
1.4	2.8	50000	3.0993 (3.0680)	28+8	37 (17.5)
1.2	2.4	50000	2.3409 (2.3329)	34+12	94 (35.4)
1.2	2.4	Separated beam		4	6.5 (4.1)
1.1162	2.2324	35000	1.4657 (1.5000)	42+12	45.6 (27.9)

- Data quality check and analysis • MC LUARLW tuning
- Statistic error < 1% • Systematic error ?

J/ψ scan (5.25–6.07)

No.	E_{beam} (MeV)	E_{cm} (MeV)	luminosity (pb^{-1})
1	1525.00	3050.0	14.0
2	1530.00	3060.0	14.0
3	1541.50	3083.0	2.50
4	1545.00	3090.0	14.0
5	1546.50	3093.0	14.0
Extra point	1546.90	3093.8	0.5
6	1547.25	3094.5	2.50
7	1547.60	3095.2	2.25
8	1547.90	3095.8	2.00
9	1548.45	3096.9	2.00
10	1549.10	3098.2	2.00
11	1549.50	3099.0	2.00
12	1550.75	3101.5	2.00
13	1552.75	3105.5	2.25
14	1556.00	3112.0	2.25
15	1560.00	3120.0	2.00



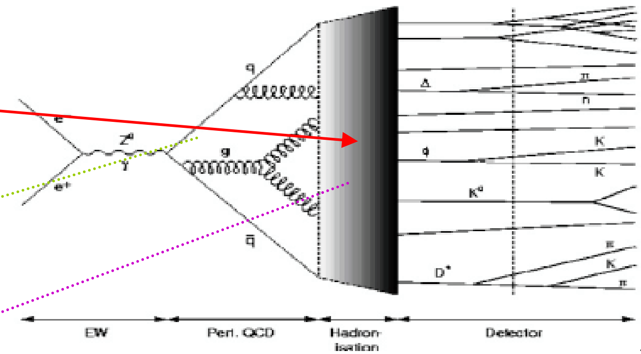
BEPCII Energy spread @J/Ψ : ~ 0.83MeV

Part 9

LUARLW tuning

Lund area law generator

Hadronization picture :



Hadron production via string fragmentation:

$$e^+e^- \Rightarrow q\bar{q} \Rightarrow \text{string} \Rightarrow m_1 + m_2 + \cdots + m_n$$

Effective matrix element (gluon emission is neglected)

$$\mathcal{M} \equiv \mathcal{M}_{\rm QED}(e^+e^- \to q\bar{q})\mathcal{M}_{\rm LUND}(q\bar{q} \to m_1, m_2, \cdots m_n)$$

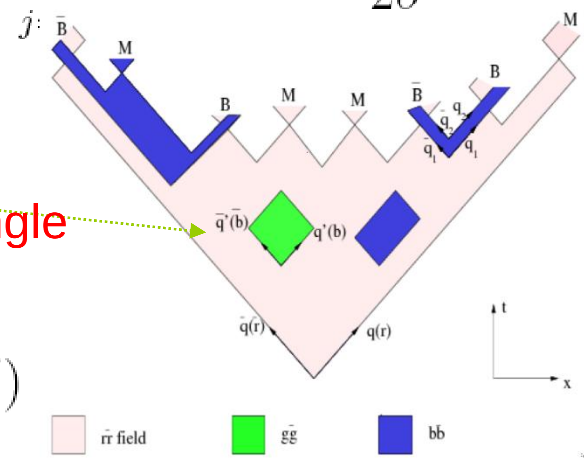
String fragmentation:

$$\mathcal{M}_{\rm LUND}(q\bar{q} \to m_1, m_2, \cdots m_n) = C_n \mathcal{M}_\perp \mathcal{M}_{//}$$

Transverse momentum (Gaussian) $\mathcal{M}_\perp = \exp(-\sum_{j=1}^{n} \vec{k}_j^{\,2})$ $\quad \vec{k}_j \equiv \dfrac{\vec{p}_{\perp j}}{2\sigma}$

Longitudinal momentum (Lund area law):

$$\mathcal{M}_{//} = \exp(i\xi\mathcal{A}_n) \qquad \xi = \frac{1}{2\kappa} + i\frac{b}{2}$$



Simulation of ISR has been built in LUARLW with the angle and momentum distributions

$$d\sigma^{HB}(s) = \frac{\alpha}{\pi^2}\frac{\sin^2\theta}{(1-a^2\cos^2\theta)}\frac{dk\,d\Omega_\gamma}{k}(1-k+\frac{k^2}{2})d\sigma^0(s')$$

Improvement of LUARLW

Up to now，LUARLU can simulate ISR inclusive continuous channels and $J^{PC} = 1^{--}$ resonances from hadronic threshold to 5 GeV. But parameters have been waiting for data to tune.

$$e^+e^- \Rightarrow \gamma^* \Rightarrow \begin{cases} V\ (\rho,\omega,\phi) \\ q\bar{q} \Rightarrow \text{string} \Rightarrow \text{hadrons} \\ gq\bar{q} \Rightarrow \text{string} + \text{string} \Rightarrow \text{hadrons} \end{cases}$$

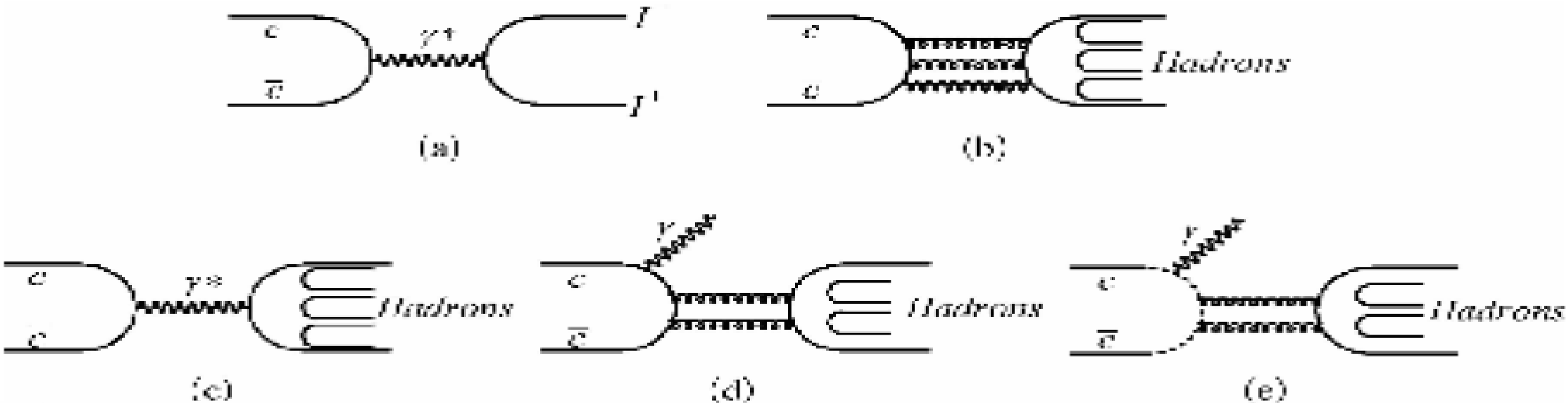
$$e^+e^- \Rightarrow \gamma^* \Rightarrow J/\psi \Rightarrow \begin{cases} \gamma^* \Rightarrow e^+e^-,\ \mu^+\mu^- \\ \gamma^* \Rightarrow \bar{q} \Rightarrow \text{string} \Rightarrow \text{hadrons} \\ ggg \Rightarrow \text{string} + \text{string} + \text{string} \Rightarrow \text{hadrons} \\ \gamma gg \Rightarrow \text{string} + \text{string} \Rightarrow \text{hadrons} \\ \gamma\eta_c \Rightarrow gg \Rightarrow \text{string} + \text{string} \Rightarrow \text{hadrons} \\ \gamma + \text{exclusive radiative decay channels} \end{cases}$$

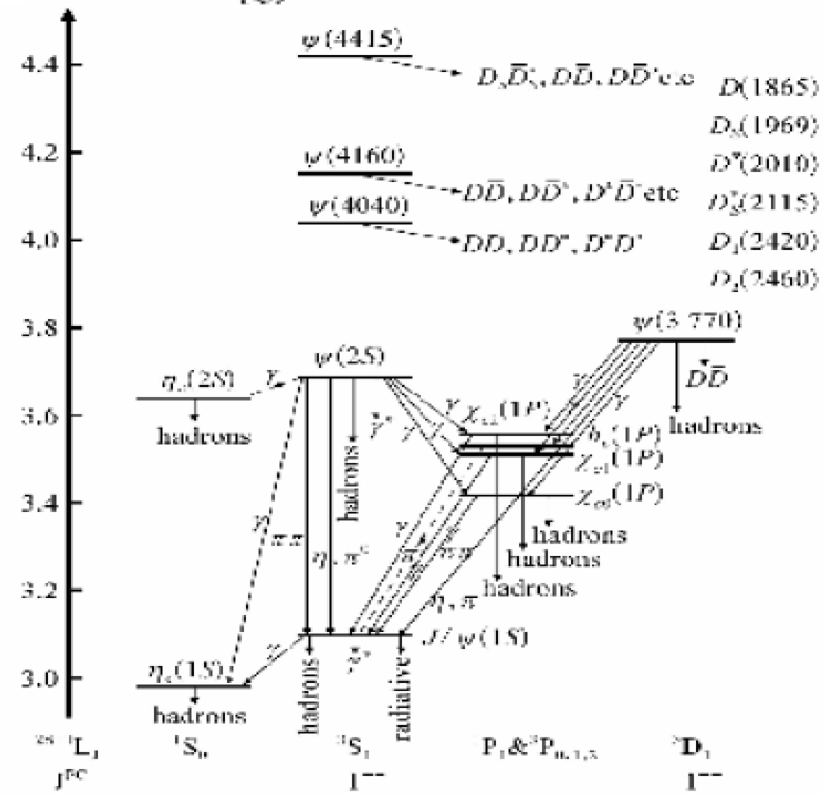
$$e^+e^- \Rightarrow \gamma^* \Rightarrow \psi(2S) \Rightarrow \begin{cases} \gamma^* \Rightarrow e^+e^-,\ \mu^+\mu^-,\ \tau^+\tau^- \\ \gamma^* \Rightarrow q\bar{q} \Rightarrow \text{string} \Rightarrow \text{hadrons} \\ ggg \Rightarrow \text{string} + \text{string} + \text{string} \Rightarrow \text{hadrons} \\ \gamma gg \Rightarrow \text{string} + \text{string} \Rightarrow \text{hadrons} \\ \gamma\eta_c \Rightarrow gg \Rightarrow \text{string} + \text{string} \Rightarrow \text{hadrons} \\ \pi\pi J/\psi,\ \eta J/\psi,\ \pi^0 J/\psi \\ \gamma + \text{exclusive radiative decay channels} \end{cases}$$

$$e^+e^- \Rightarrow \gamma^* \Rightarrow \psi(3770) \Rightarrow \begin{cases} \gamma^* \Rightarrow e^+e^-,\ \mu^+\mu^-,\ \tau^+\tau^- \\ D\bar{D} \\ \gamma^* \Rightarrow q\bar{q} \Rightarrow \text{string} \Rightarrow \text{hadrons} \\ ggg \Rightarrow \text{string} + \text{string} + \text{string} \Rightarrow \text{hadrons} \\ \gamma gg \Rightarrow \text{string} + \text{string} \Rightarrow \text{hadrons} \\ \pi\pi J/\psi,\ \eta J/\psi,\ \pi^0 J/\psi \\ \gamma + \text{exclusive radiative decay channels} \end{cases}$$

$$e^+e^- \Rightarrow \gamma^* \Rightarrow \begin{cases} \psi(4040) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, D^*\bar{D}, D_s\bar{D}_s, \text{other decay modes} \\ \psi(4160) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, D^*\bar{D}, D_s\bar{D}_s, D_s\bar{D}_s^*, \text{other decay modes} \\ \psi(4415) \Rightarrow D\bar{D}, D^*\bar{D}^*, D\bar{D}^*, D^*\bar{D}, D_s\bar{D}_s, D_s\bar{D}_s^*, D_s^*\bar{D}_s^*, \text{other decay modes} \\ X(4260) \Rightarrow \text{possible decay modes} \end{cases}$$

Charmonia decay modes



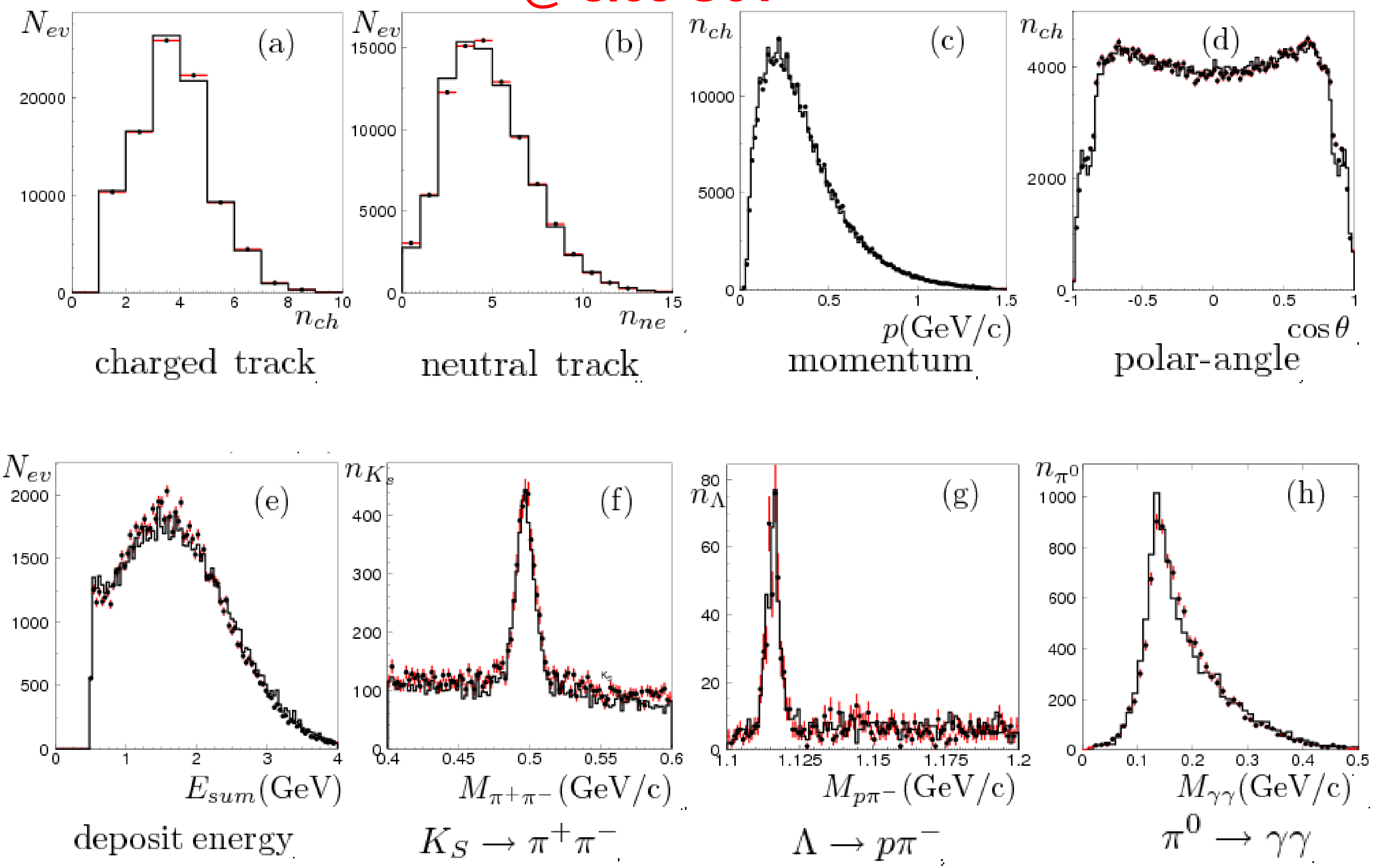


The productions and decays of the charmonia are simulated based on their Feynman figures, discovered or possible channels.

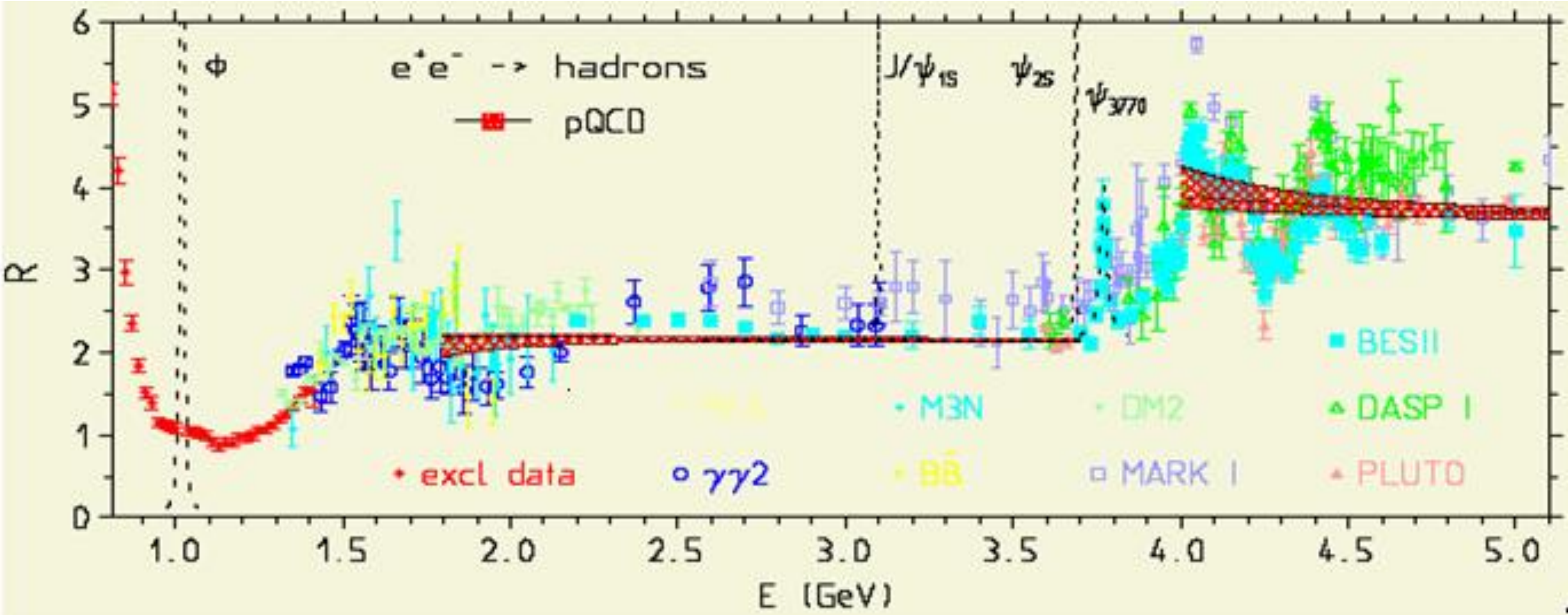
Branch ratio are phenomenological parameters and have to be set by data in MC tuning.

Comparisons between data and LUARLW

@ 3.65 GeV



LUARLW tuning with BESIII data



Non BEPC region

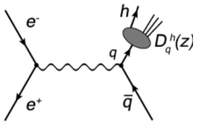
BEPC designed region

Hadronic state continuum | J/ψ | continuum | ψ(3686,3770,4040) | fine scan ψ(4150,4415)

Data sample status X √ X √ √ √ X X

Projects related to R scan data

- R value (scan and ISR return)： precision ～2.5%
- QCD running coupling constant $\alpha_s(s)$
- charm quark mass m_q ： precision ~30%
- charmonium parameters： fine scan, find new states
- form factors： proton $|G_M|$ and $|G_E|$， and other mesons and baryons FF
- multiplicity： $P_n(s)$, $<n>$, $R_2(s)$, F-B correlation $<n_f> = c_0 + c_1 <n_b>$
- fragmentation function： $D_q^h(z)$ $z = 2E_h/\sqrt{s}$



- inclusive distributions： x， y， η， ξ， p_t , $\cos\theta$, C_S , C_L
- topological properties ： sphericity S and thrust T
- Bose-Einstein correlation： $C_2(Q^2) \rightarrow$ hadronic space-time structure $f_c(x)$
- fractal properties of final state phase sace： $F^V(\delta y)$和 $F^H(\delta y) \rightarrow F_q \propto (Q^{-\phi})$