Test of QCD in 2-5 GeV with BESII

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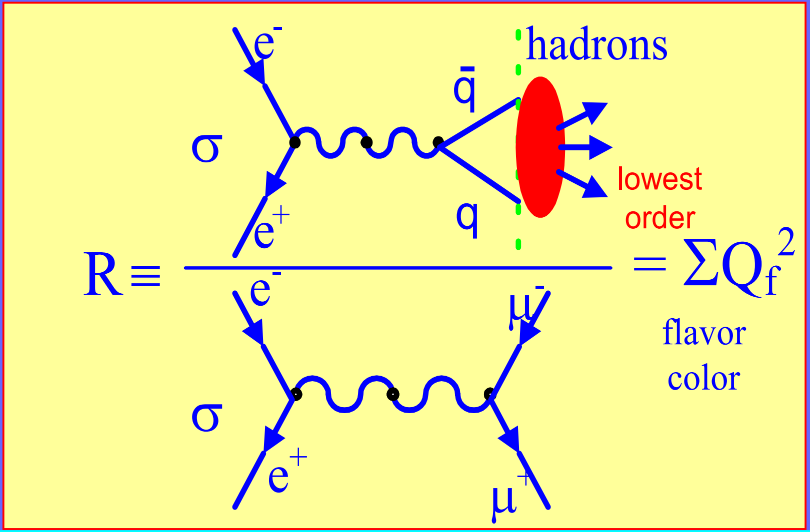
I. Final Results of R-values in 2-5 GeV
II. ξ distribution and 2nd binomial moment
III. Summary

Definition of R

R: one of the most fundamental quantities in particle physics, counts directly the number of quarks, their flavor and colors



Experimentally

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

N_{had}: observed hadronic events

N_{bg}: background events

L: integrated luminosity

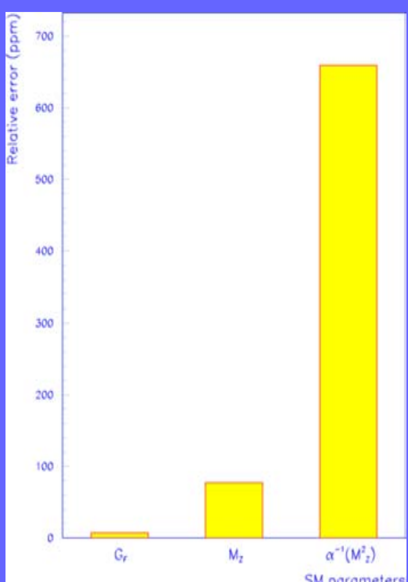
ε_{had}: detection efficiency for hadronic events

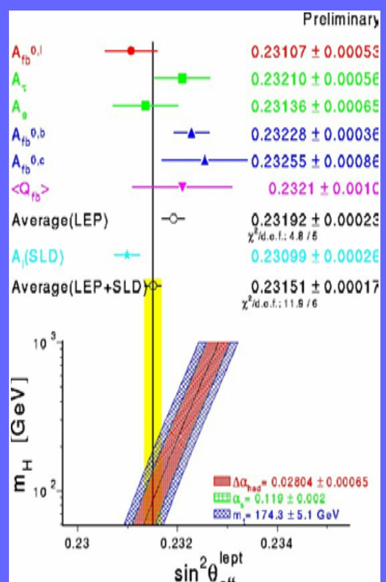
δ: radiative correction

Motivations of the R Scan

- Reducing the uncertainty of $\alpha(M_Z^2)$ → essential for precision tests of the SM

$$\Delta\alpha_{had}(M_Z^2) = -\frac{\alpha(0)M_Z^2}{3\pi}\,\mathrm{Re}\int_{4m_\pi^2}^{\infty} ds \frac{R(s)}{s(s-M_Z^2)-i\varepsilon}$$

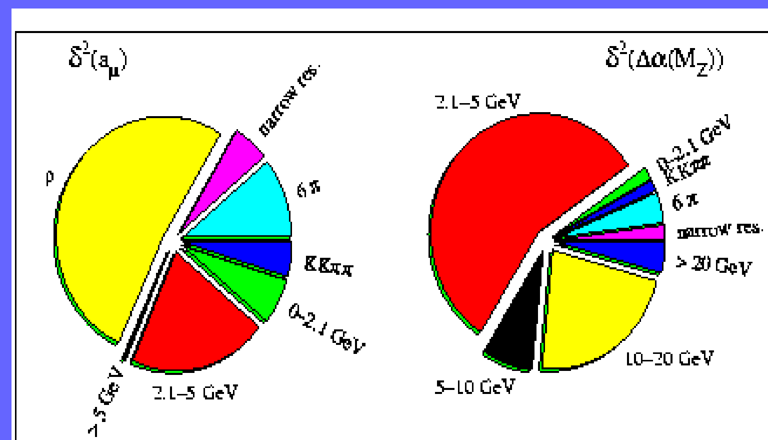




- Hunting for new physics from $a_\mu \equiv (g-2)/2$ → Interpretation of E821 at BNL

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

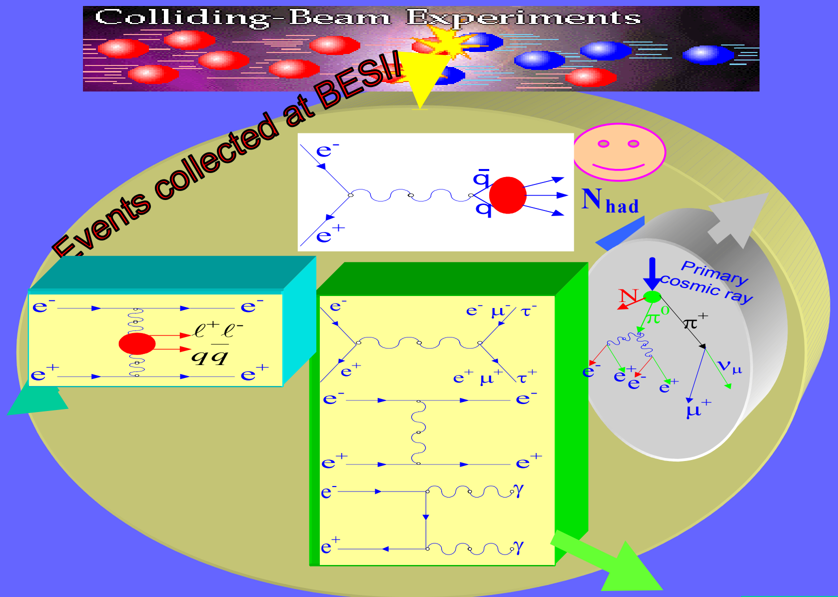
- Relative contributions to the uncertainties of a_μ and $\Delta\alpha(M_Z^2)$

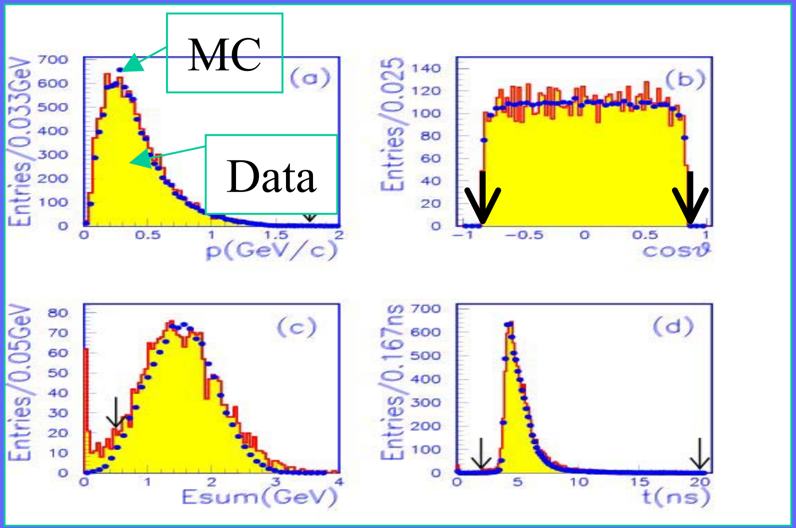


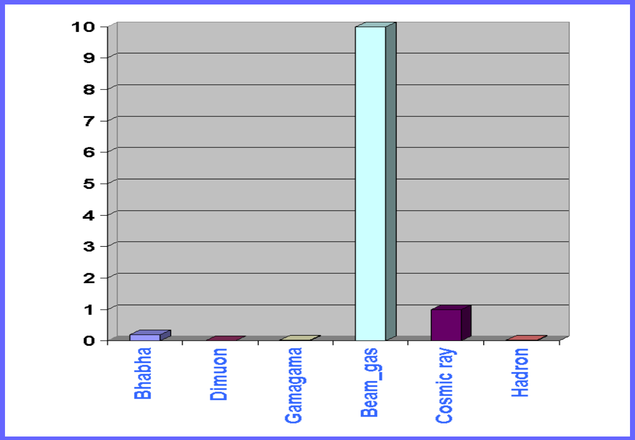
BES's R Scan

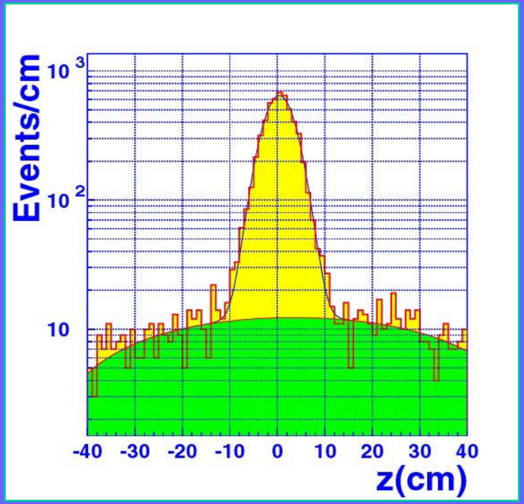
- Total 91 energy points in 2-5 GeV
- Single and separated beam
  collision to study beam associated background
- Special runs taken at J/ψ, 2.6, 3.0, 3.5 GeV with larger data sample to determine ε_{trg}
- L measured by large angle Bhabha
- LUARLW is developed to improve JETSET for ε_{had} low energy region, particularly for E_{cm}< 3 GeV
- D, D^*, D_s, D_s^* productions are simulated according to Eichiten Model
- A generator is built into LUARLW to handle decays of resonances in the radiative return processes $e^+e^- \rightarrow \gamma\ J/\psi$ or $\gamma\psi(2S)$

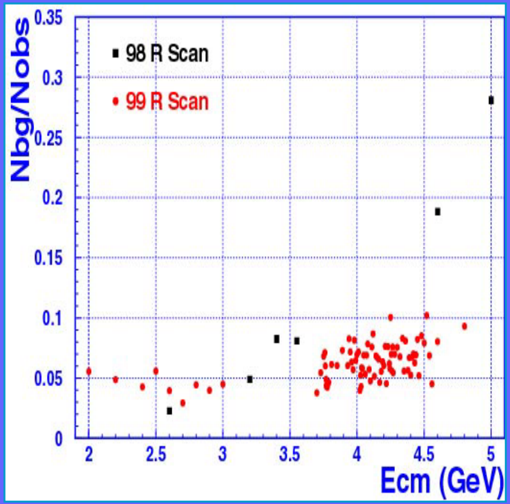
Events Recorded by BESII





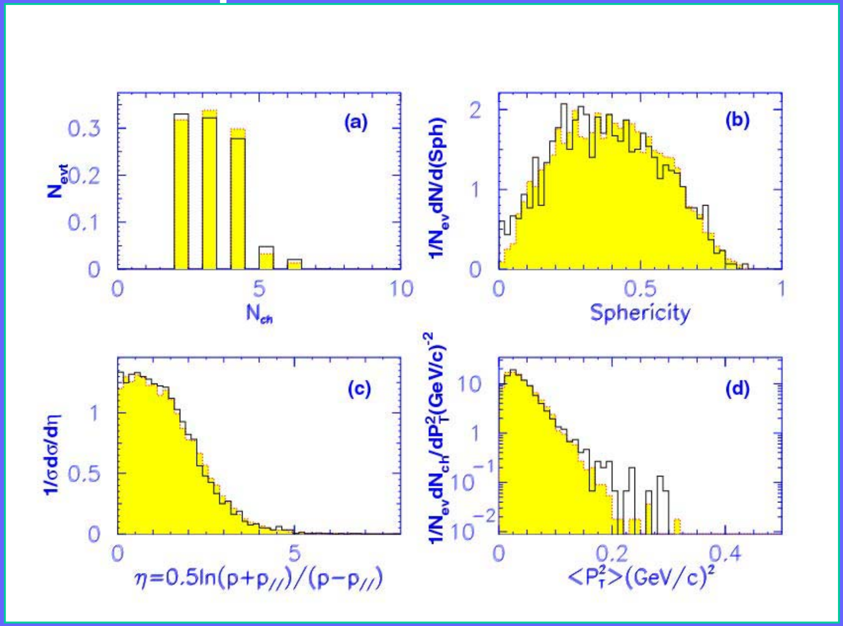






Some Hadronic Event Shapes at E_{cm}=2.2 GeV (LUARLW)

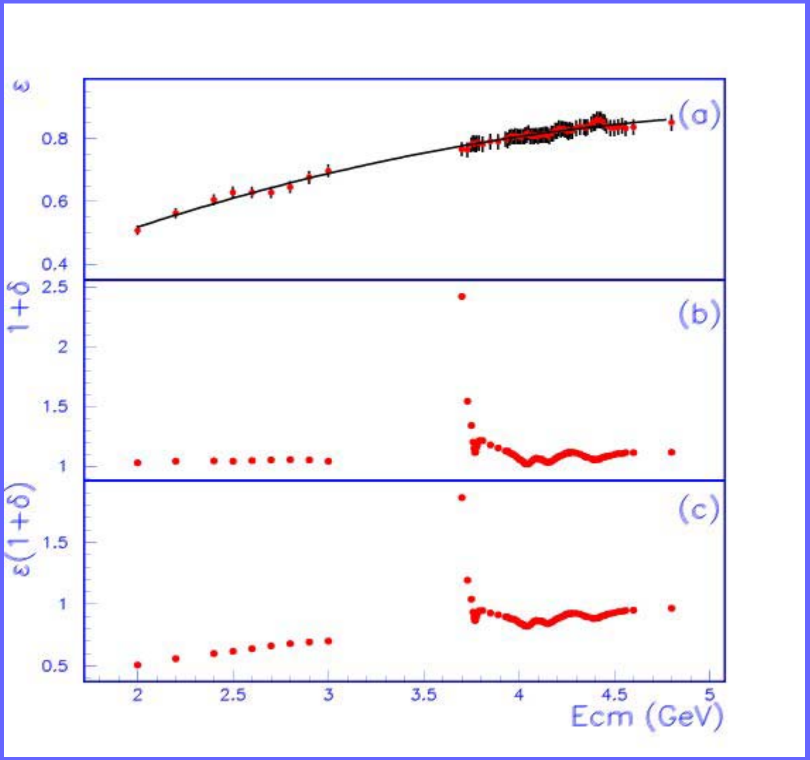
Tune the parameters to reproduce 14 distributions of the observed kinematic variables and hadronic event shape.



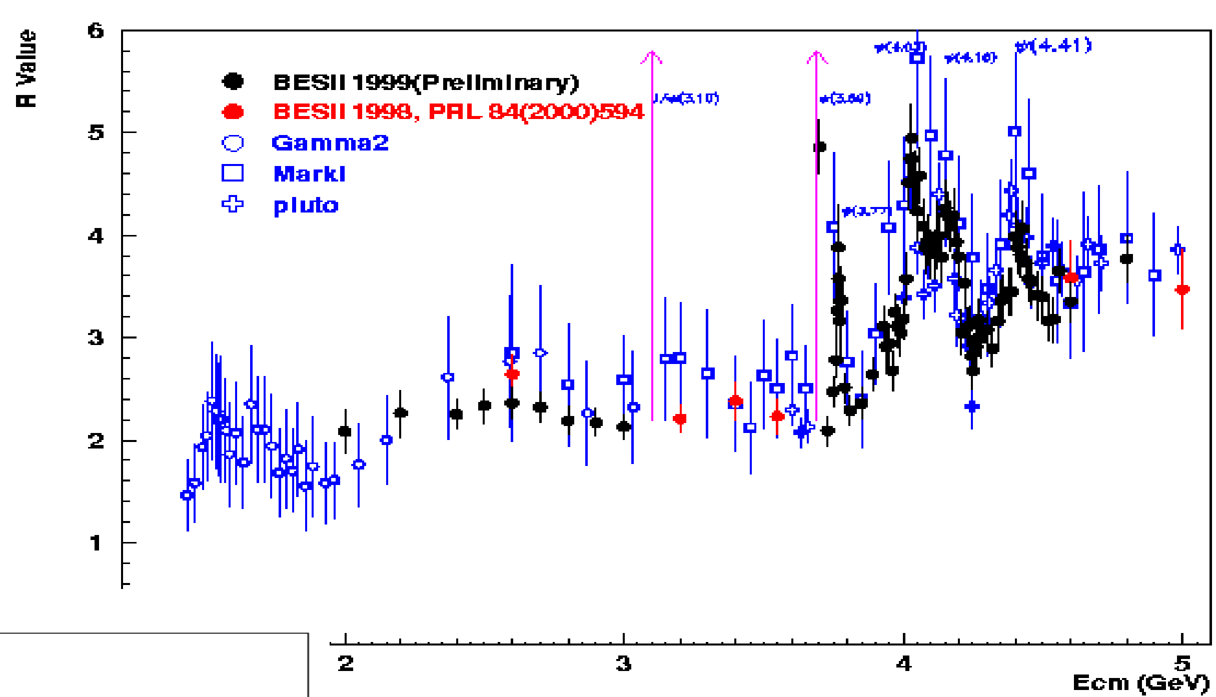
Hatched region: MC

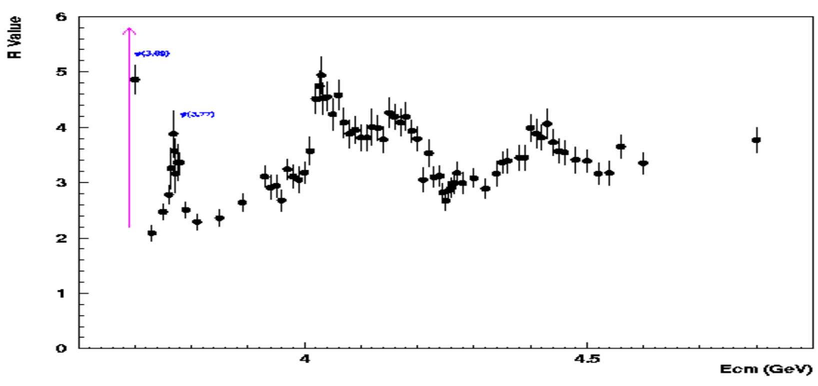
Histogram: Data

Variation of Detection Efficiency and ISR in 2-5 GeV

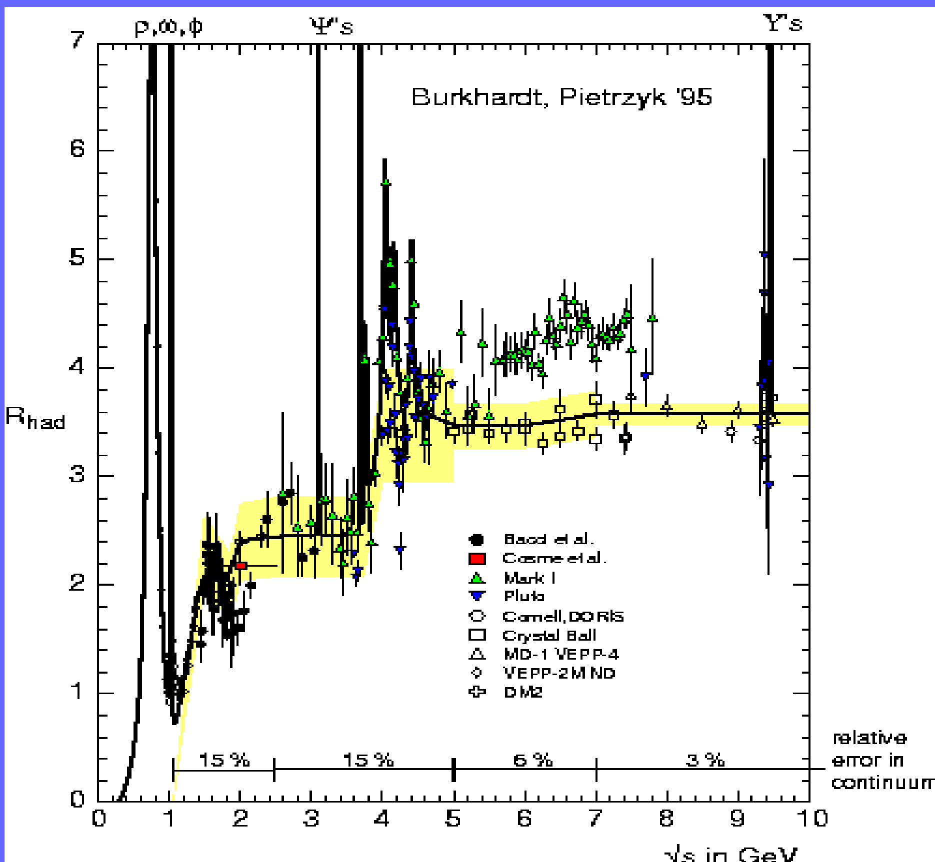


R Values in 2-5 GeV

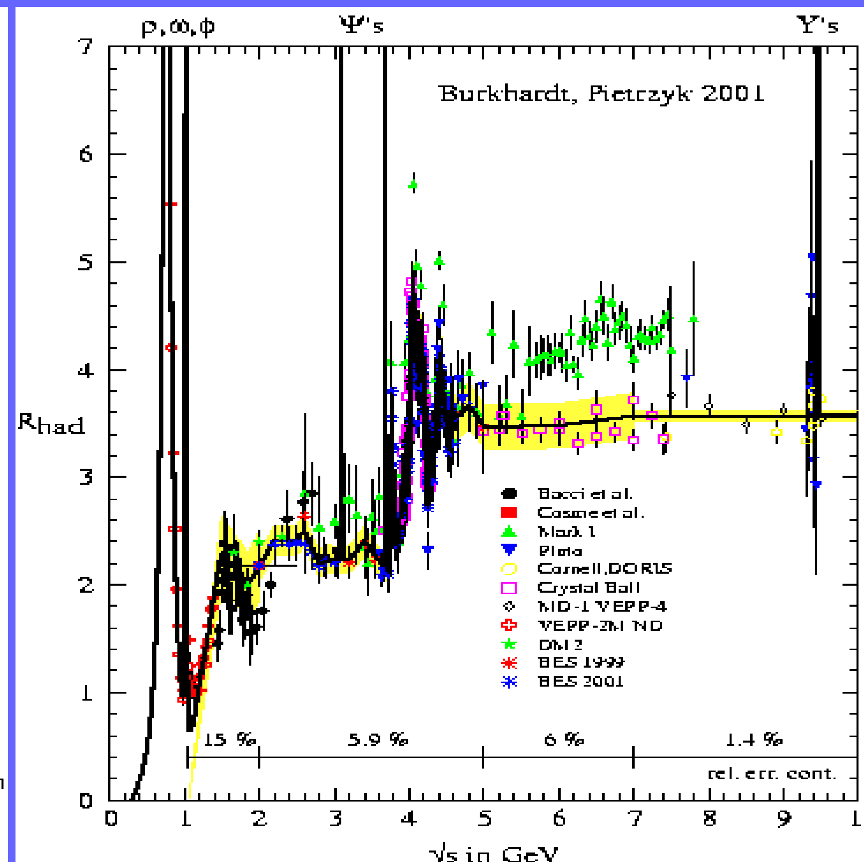




R Below 10 GeV

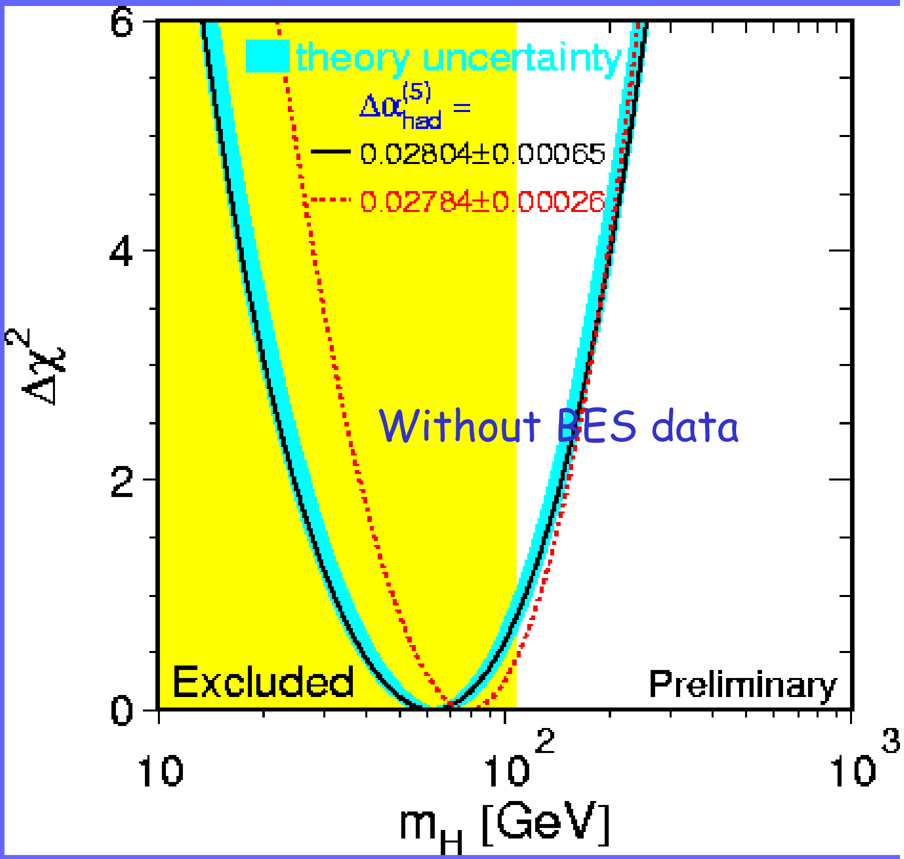


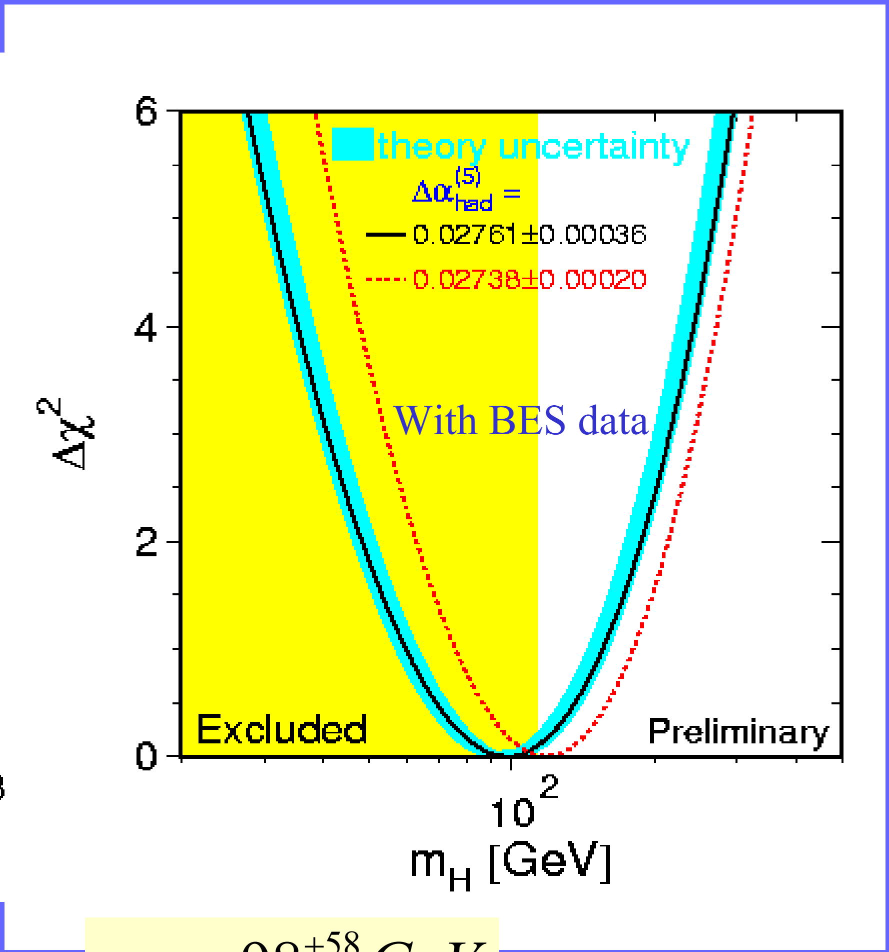
Before BES R Scan



After BES R Scan

The SM Fit to m_H





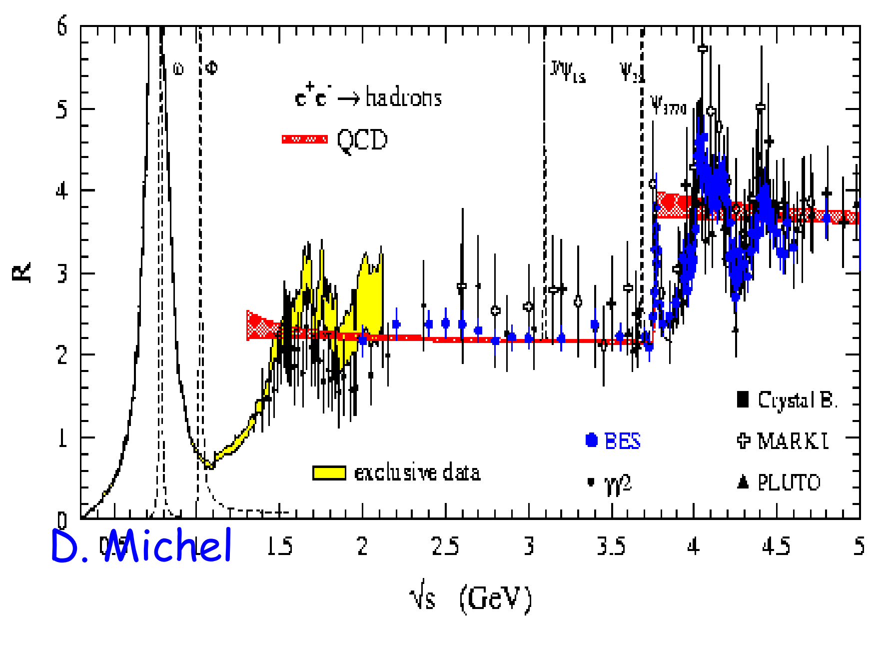
$$m_H = 62^{+53}_{-30}\,GeV$$
$$m_H < 170\,GeV$$

(95% C.L.)

$$m_H = 98^{+58}_{-38}\,GeV$$
$$m_H < 212\,GeV$$

(95% C.L.)

R(pQCD) and R(BES)



pQCD calculation agree amazingly well with BES data

Evaluation of α_s and $\alpha_s(M_Z)$ from R(BES)

$$R = 3\sum_q Q_q^2 \sum_{n=0} \left(\frac{\alpha_s}{\pi}\right)^n$$

Exhibits QCD correction known to $O(\alpha_s^3(s))$ so far. Precision meas. of R can determine α_s and thus evaluate $\alpha_s(M_Z)$.

Using R at 3.0 and 4.8 GeV, one has:

$$\alpha_s(3.0GeV) = 0.369^{+0.047+0.123}_{-0.046-0.130}$$

$$\alpha_s(4.8GeV) = 0.183^{+0.059+0.053}_{-0.064-0.057}$$

BES: $\alpha_s^{(5)}(M_Z) = 0.124^{+0.011}_{-0.014}$

PDG2000: $\alpha_s^{(5)}(M_Z) = 0.1181 \pm 0.002$

J.H. Kuhn, M.Rreinhauser Nucl. Phys. B619(2001)588

ξ Distribution: ξ=-ln(2p/√s)

MLLA/LPHD calculations

$$\frac{1}{\sigma^h}\frac{\sigma^h}{\xi} = 2K_{LPHD} \times f(\xi, Q_0, \Lambda_{eff})$$

$$0 \le \xi \le \ln(0.5 \times \sqrt{s} / \Lambda_{eff})$$

Limiting spectrum when $Q_0=\Lambda_{eff}$

$$f_{MLLA}(\xi, \tau = \sqrt{s}/\Lambda_{eff}) =$$

$$\frac{4C_F}{b}\Gamma(B)\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}}\frac{dx}{\pi}e^{-B\alpha}\left[\frac{\cosh\alpha + (1-2\zeta)\sinh\alpha}{\tau\frac{4N_c}{b}\frac{\alpha}{\sinh\alpha}}\right]^{\frac{B}{2}}$$

$$I_B\{\frac{16N_c}{b}\tau\frac{\alpha}{\sinh\alpha}[\cosh\alpha + (1-2\zeta)\sinh\alpha]\}$$

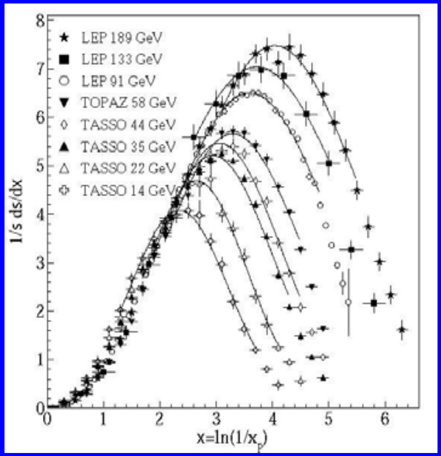
$B=a/b$, $a=11N_c/3+2n_f/3N_c^2$, $b=(11N_c-2n_f)/3$

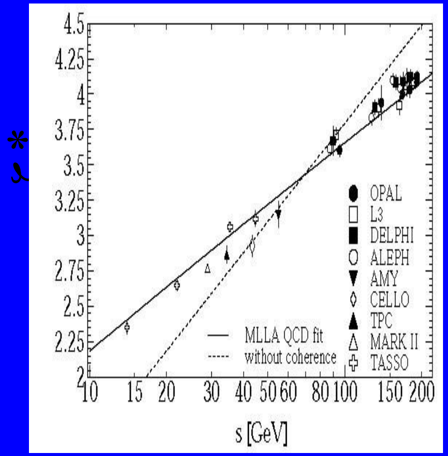
$C_F=(N_c^2-1)/2N_c=4/3$, N_c: quark flavor = 3

n_f: # qark flavor produced

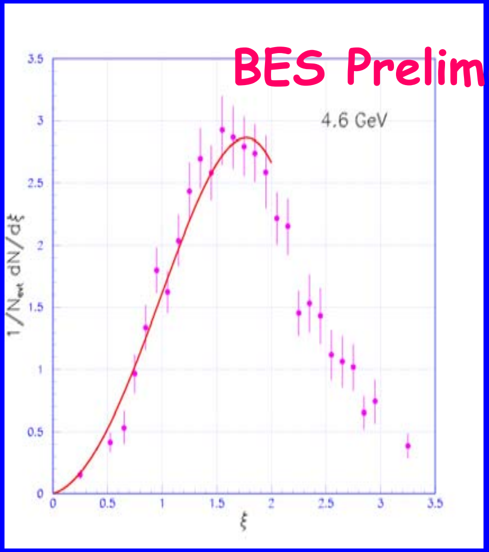
I_B: modified Bessel Function.

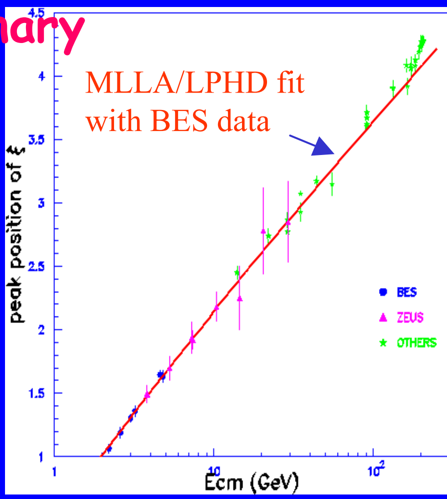
$\alpha= \alpha_0+ix$, where $\tanh \alpha_0 =2\zeta -1$, $\zeta=1-\xi/\tau$





BES Preliminary





Multiplicity and Second Binomial Moment

Average multiplicity:

$$\langle n_{ch} \rangle \equiv \sum_{n=0}^{\infty} n_{ch} P(n_{ch})$$

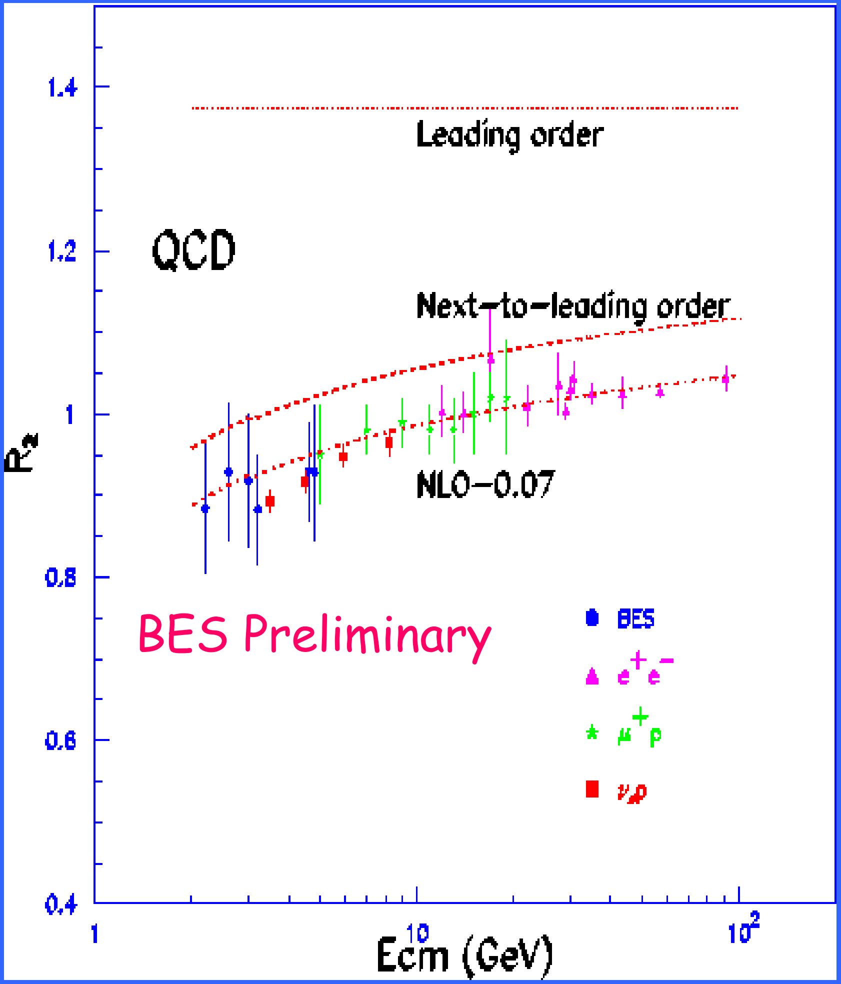
NLO:

$$\langle n_{ch} \rangle = a \cdot [\alpha_s(s)]^b \cdot e^{c/\sqrt{\alpha_s(s)}} \cdot [1 + d\sqrt{\alpha_s(s)}]$$

$$b = \frac{1}{4} + \frac{10 n_f}{27(11 - 2n_f/3)}, c = \frac{\sqrt{96\pi}}{11 - 2n_f/3}$$

$$R_2 \equiv \frac{\langle n_{ch}(n_{ch}-1) \rangle}{\langle n_{ch} \rangle^2} = \frac{11}{8}(1 - c\sqrt{\alpha_s(s)})$$

$$c = (4455 - 40 n_f)/1728\sqrt{6\pi}$$



Summary

- BES measured R in 2-5 GeV with average uncertainties of 6.6% (a factor of 2-3 improvement)

  → **significant impact on the SM fit: m_{Higgs} moves up from 61 GeV to 90 GeV, up limit from 170 GeV to 210 GeV**

- R scan data at continuum can be used to test QCD
  - Preliminary results of ξ and R_2 are consistent with e^+e^-, ep and νN data at high energy.
  - ξ consistent with MLLA/LPHD predictions, R_2 consistent with NLO – 0.07.

- CLEOC and BESIII can provide more accurate data at continuum to test QCD at a few percent level.

Error of R Measurement at BESII

Source	BESII (%)	BESIII Goal(%)
Luminosity	2 – 3	1
Detection effi.	3 – 4	1 - 2
Trigger effi.	0.5	0.5
Radiation corr,	1 - 2	1
Hadron decay model	2 - 3	1 – 2
Statistical	2.5	--
Total	6 – 7	2 - 3

Thrust and Mean Thrust

Thrust: $T \equiv \max \frac{\sum_i |\vec{p}_i \cdot \vec{n}_T|}{\sum_i |\vec{p}_i|}$

Mean thrust: $\tau \equiv 1-T$

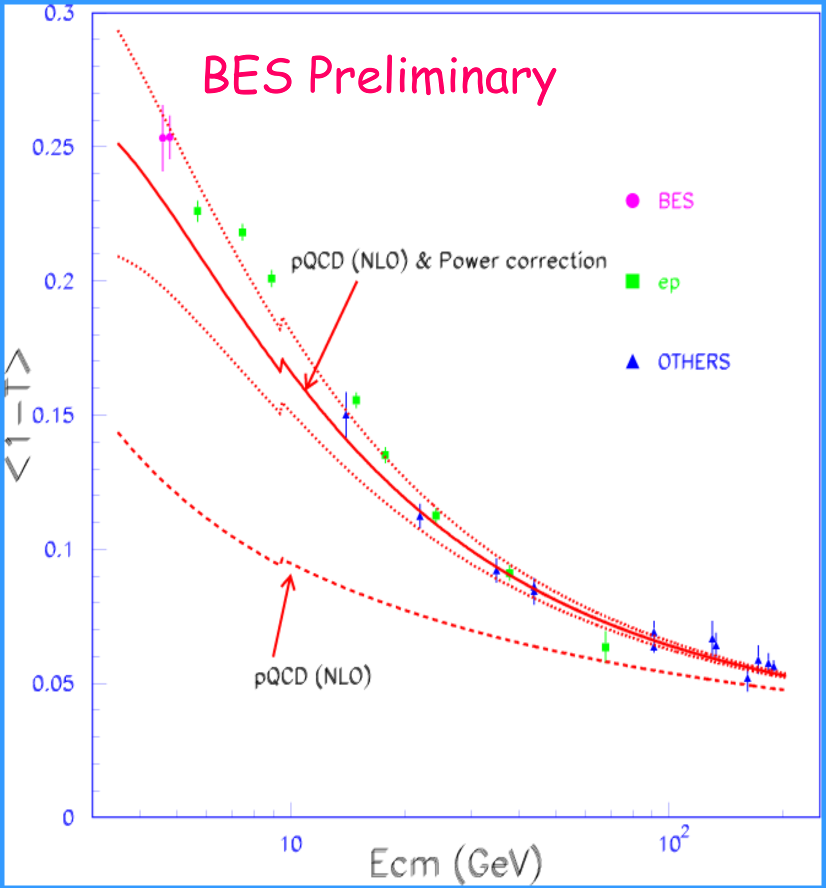
$$\langle \tau \rangle = \langle \tau^{pert} \rangle + \langle \tau^{power} \rangle;$$

$$\langle \tau^{pert} \rangle = A \cdot \tilde{\alpha}_s + (B - 2A)\tilde{\alpha}_s^2;$$

$\tilde{\alpha}_s = \alpha_s(\sqrt{s})/2\pi$; A, B constant

$$\langle \tau^{power} \rangle = \frac{4C_F}{\pi}\frac{2M}{\pi}\left(\frac{\mu_I}{\sqrt{s}}\right)\cdot[\tilde{\alpha}_0(\mu_I) - \alpha_s(\sqrt{s}) - \frac{\beta_0}{2\pi}\left(\ln\frac{\sqrt{s}}{\mu_I} + \frac{K}{\beta_0} + 1\right)\alpha_s^2(\sqrt{s})]$$

$$\tilde{\alpha}_0(\mu_I) \equiv \frac{p}{\mu_I}\int_0^{\mu_I}\frac{d\mu}{\mu}\alpha_s(\mu)$$



Free para. $\alpha_s(M_Z), \tilde{\alpha}_0(2GeV)$

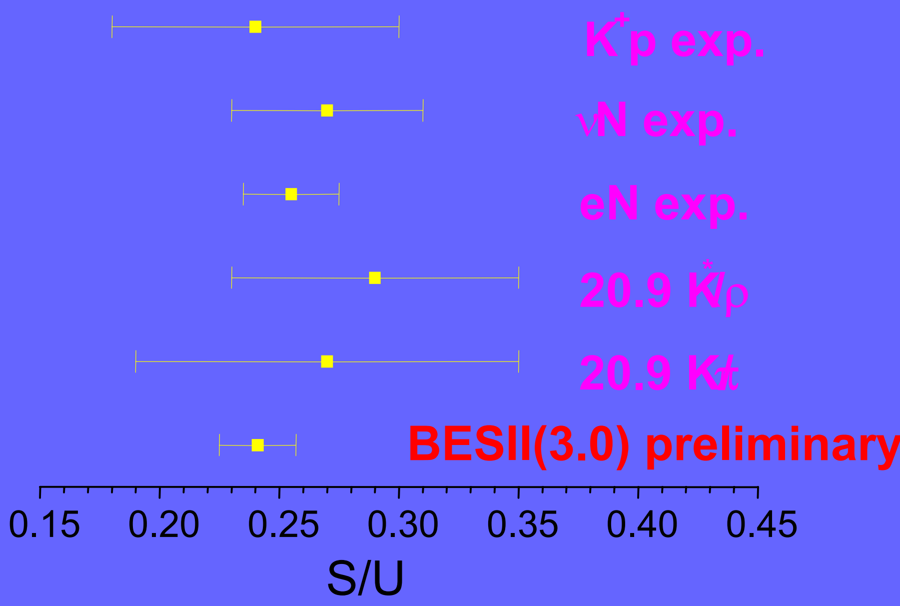
$\sigma[e^+e^- \to \pi^\pm(K^\pm) + X]$ and Fragmentation Function, S/U Ratio

Fragmentation function

$D_q^h(x,\sqrt{s})$

$$\frac{1}{\sigma_{tot}}\frac{d\sigma(e^+e^- \to h+X)}{dx} = \sum_q \int_z^1 \frac{dz}{z} D_q^h(x,\sqrt{s}) \frac{d\sigma_q}{dx}(x/z,\sqrt{s})$$

$\sigma[e^+e^- \to \pi^\pm(K^\pm) + X]$ are also needed to help determine polarized parton density



S/U: input parameters in hadron production generator →needed for determining ε_h