R Scan Between 2-5 GeV with BESII at BEPC

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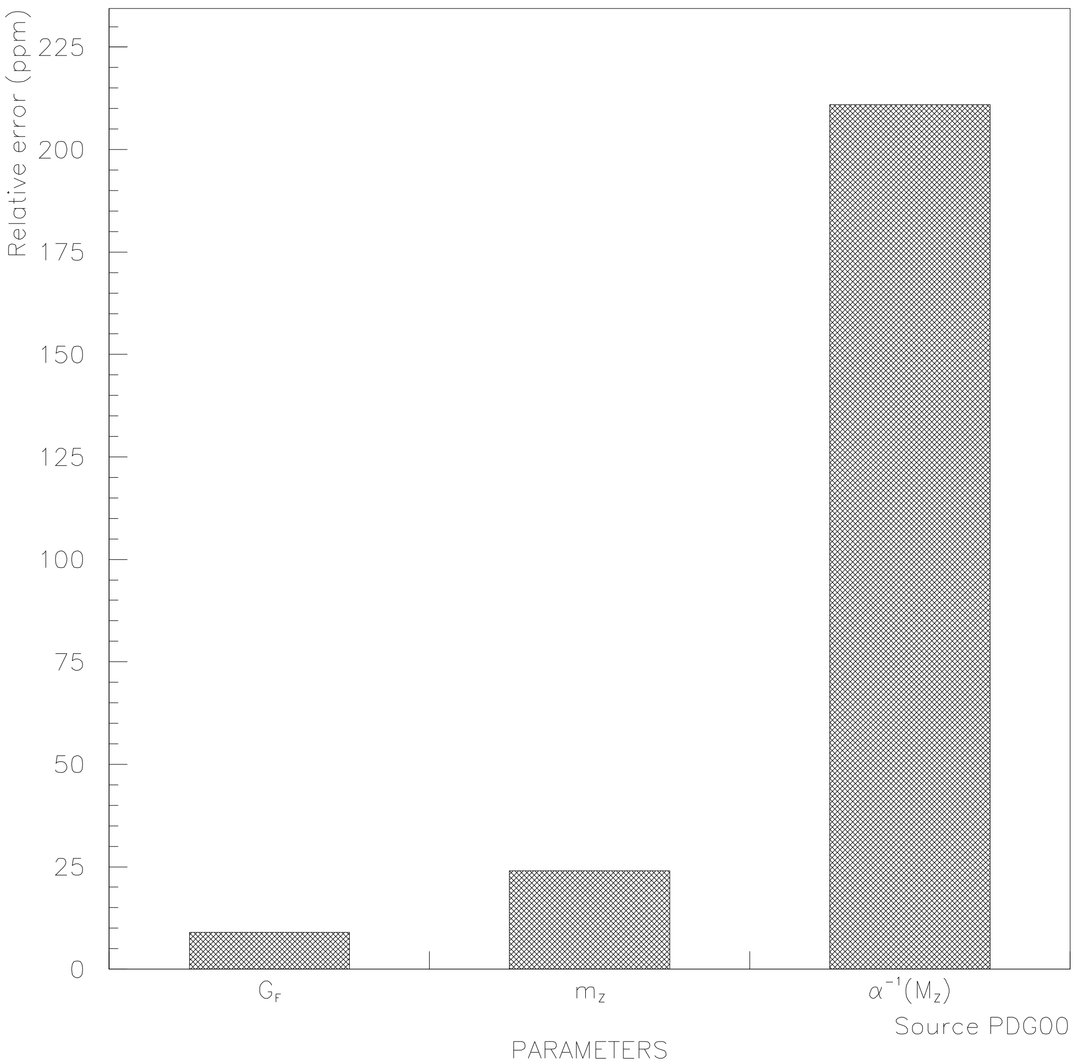
Introduction

"The uncertainty [in $\alpha(M_Z)^{-1}$], due to the low energy hadronic contribution to vacuum polarization, is the dominant theoretical uncertainty in the interpretation of precision data. . . . Further improvement will require better measurements of the cross section for $e^+e^- \to$ hadrons at low energy" — PDG98, page 90.

Motivation

$\alpha^{-1}(M_Z^2)$, along with G_F and M_Z can be used as one of three input parameters to the standard model. However, when comparing uncertainties of the three, the error in $\alpha^{-1}(M_Z^2)$ stands out. Reducing this error is critical for precision tests of the SM.



$\alpha^{-1}(M_Z^2)$ is needed for evaluation of m_{Higgs}:

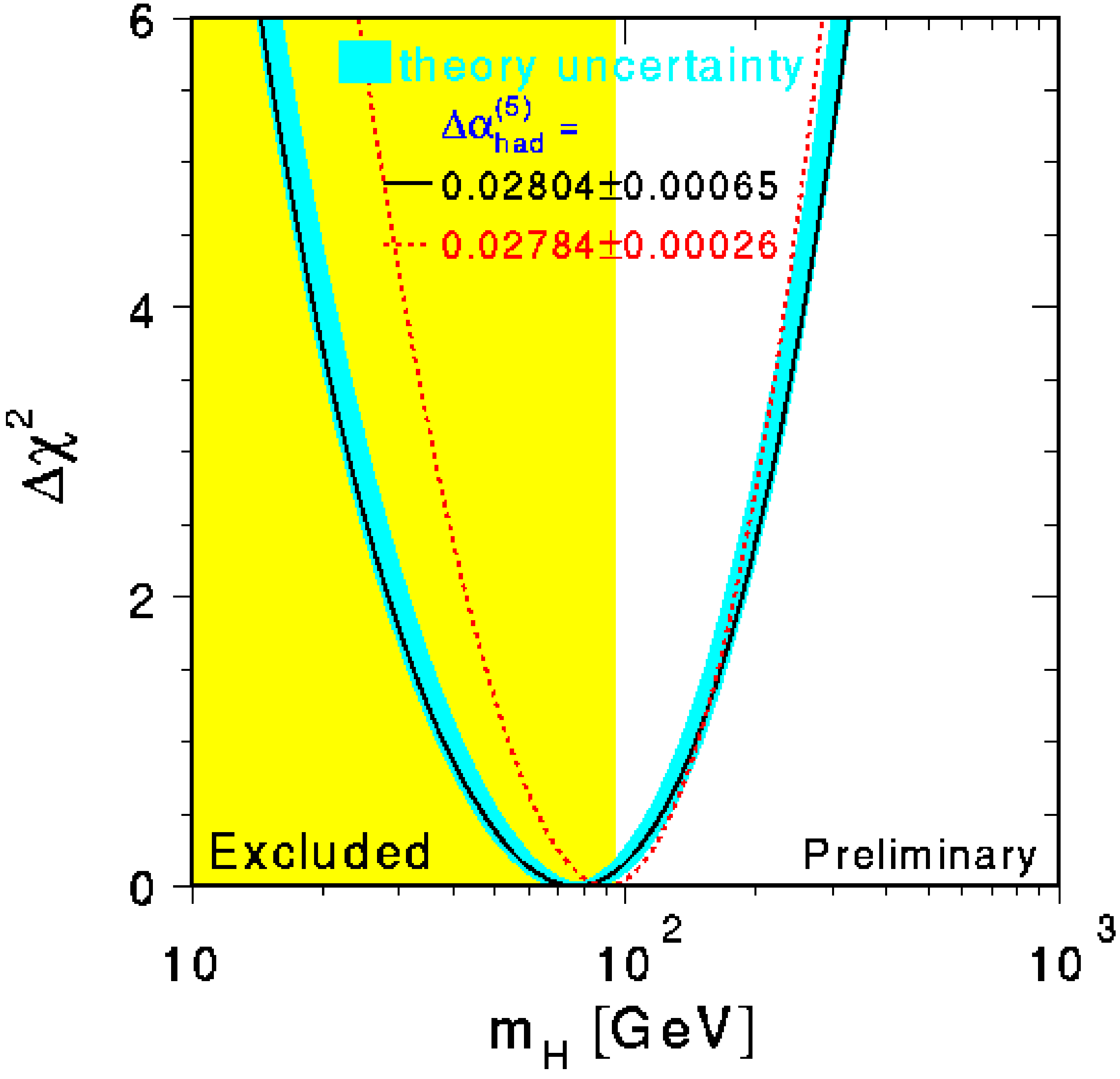


Figure from B. Pietryzk.

Theory of α_{QED}

α runs as a function of $\sqrt{s}$, and is given by

$$\alpha(s) = \frac{\alpha(0)}{1 + \Pi_{\gamma\gamma}(s)} \quad (1)$$

$$\Delta\alpha(s) = -\Pi_{\gamma\gamma}(s) \quad (2)$$

We can then distinguish the contributions to $\Delta\alpha$ in three parts: leptonic, the 5 light quarks (hadronic), and the top quark:

$$\Delta\alpha = \Delta\alpha_l + \Delta\alpha_{had} + \Delta\alpha_{top} \quad (3)$$

The leptonic contribution to the above correction is well understood and calculated and the top quark must be treated separately. However, the light quark contribution, $(\Delta\alpha_{had}^{(5)}(s))$, cannot be reliably calculated using perturbative QCD; we require data on R:

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

Anomalous Magnetic Moment of Muon

$a_\mu \equiv \frac{(g-2)}{2}$ is potential key to discovering new physics.

$$a_\mu = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{had} \tag{5}$$

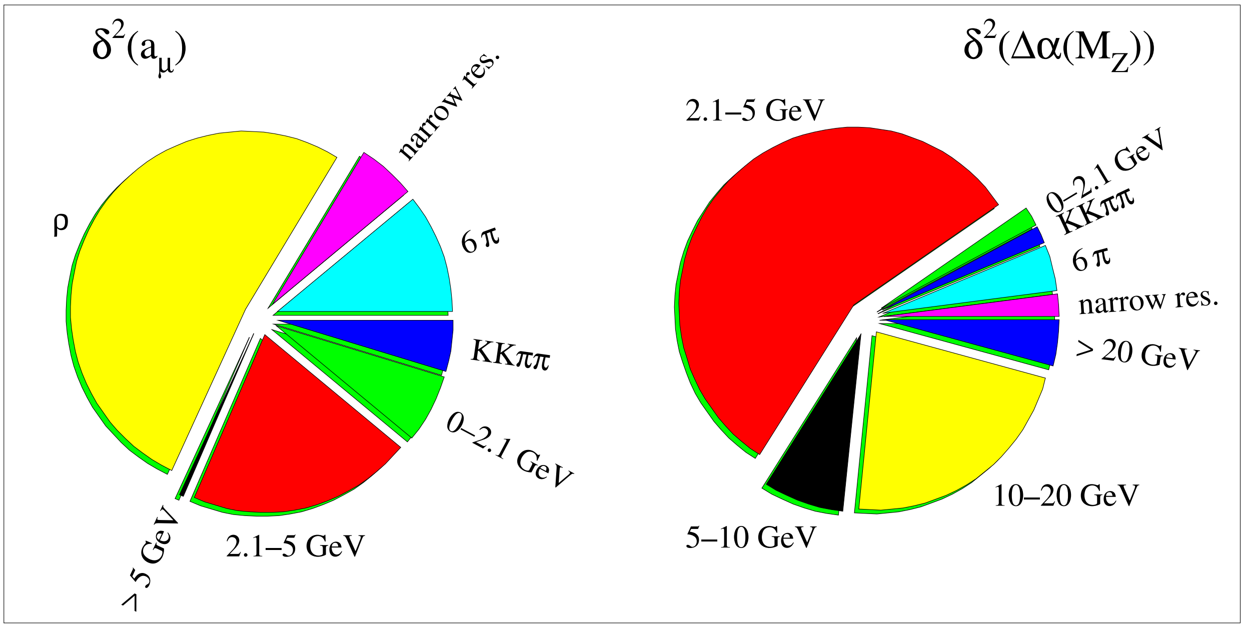
Dominant source of error from a_μ^{had}. Similar dependence on dispersion integral of R:

$$a_\mu^{had} = \left(\frac{m_\mu \alpha}{3\pi}\right)^2 \int_{4m_\pi^2}^{\infty} ds \frac{R(s)K_2(s)}{s^2} \tag{6}$$

a_μ^{had} more dependent on lower energy data than $\alpha^{-1}(M_Z^2)$.

BES Contributions to $\delta^2(a_\mu)$ and $\delta^2(\alpha^{-1}(M_Z^2))$

BES has data in energy range from $E_{cm} = 2.0$ to 5.0 GeV (entire operating range).

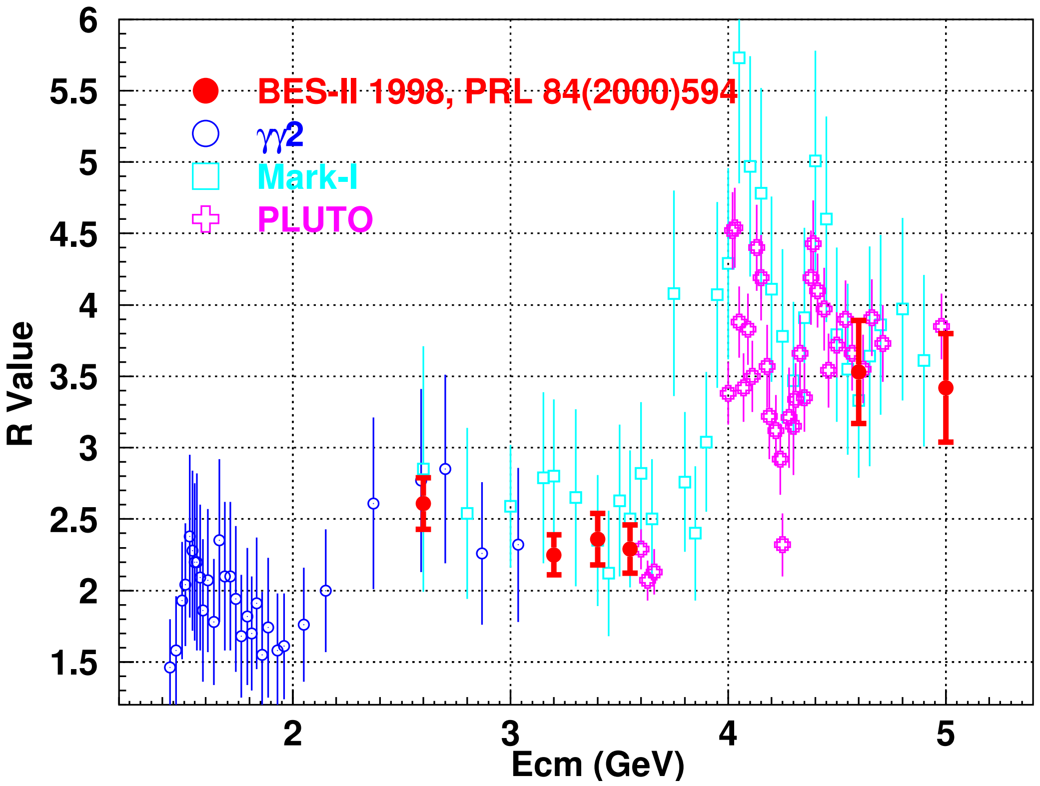


Spring 98 Results

R-scan data taken at 6 energy points: 2.6, 3.2, 3.4, 3.55, 4.6, 5.0 GeV. >1000 hadronic events collected at most energy points (3% statistical error).

Verified MC (JETSET/LUND) tuning parameters, data quality, run stability.

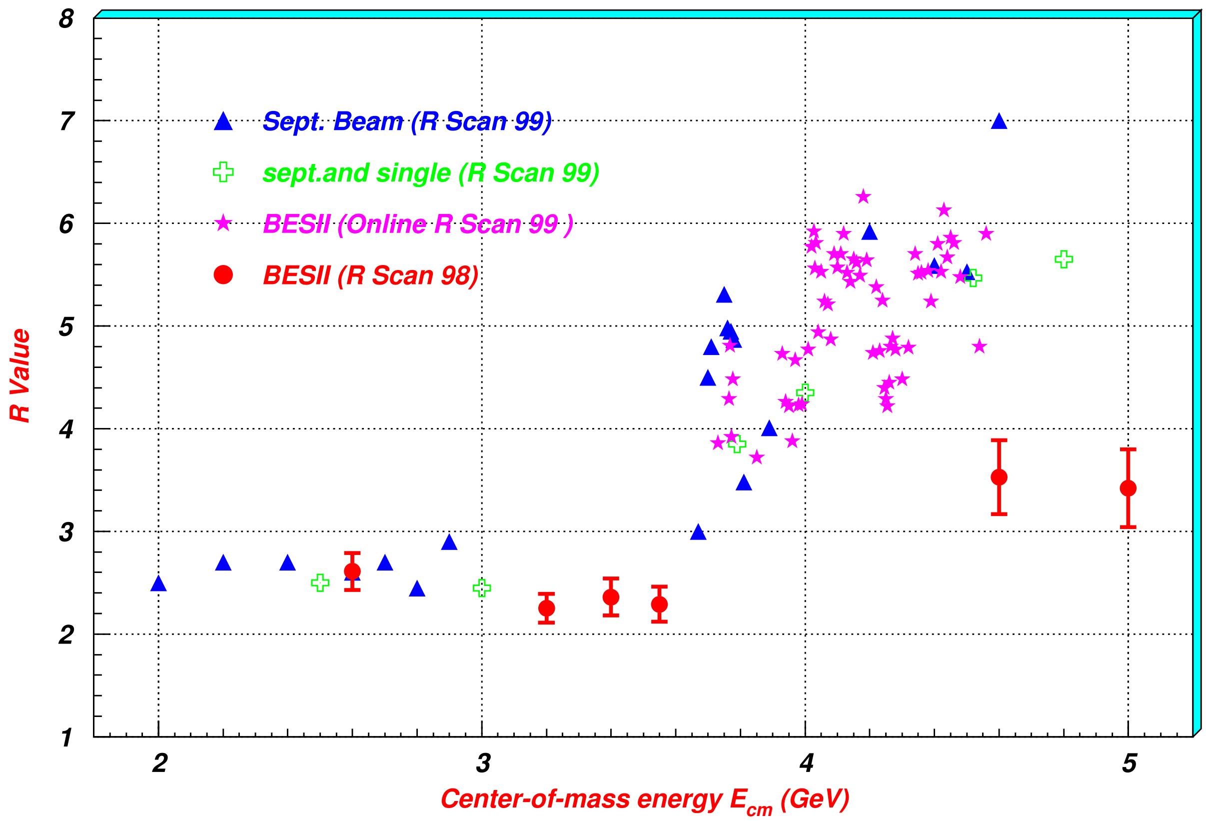
Results published in PRL 84 (2000) 594-597.



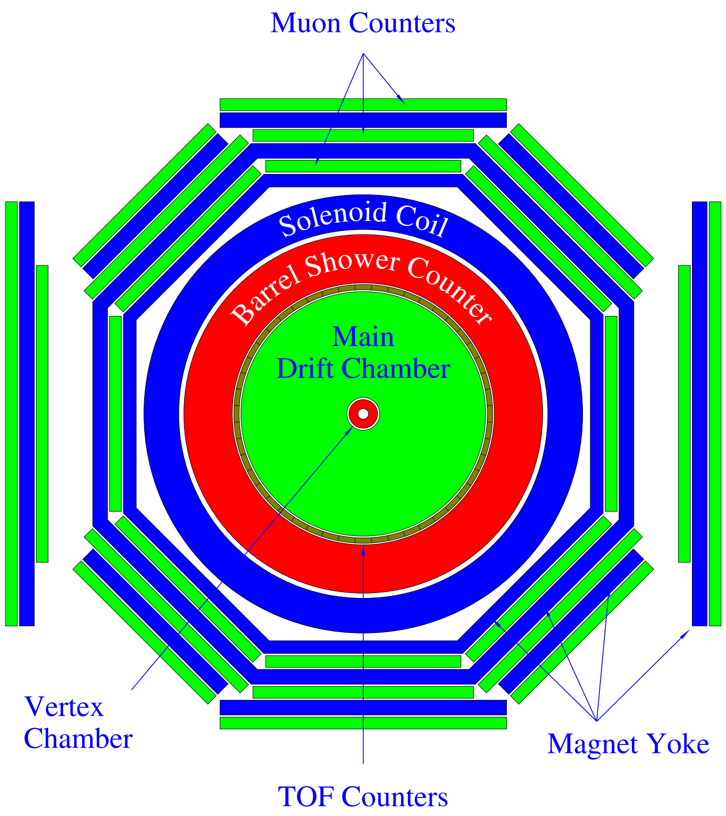
1999 R-scan

Data taken at 85 energy points from 2.0 to 4.8 GeV.

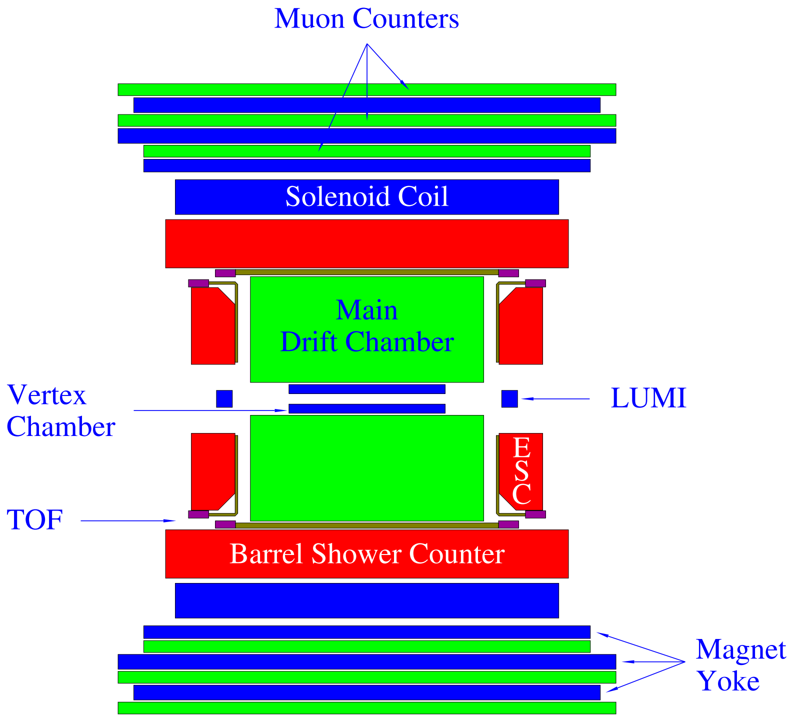
Separated(single) beam data also collected at 24(7) points.



BES Detector



End view of the BES detector



Side view of the BES detector

Experimental Determination of R

$$R \equiv \frac{\sigma^0_{had}}{\sigma^0_{\mu^+\mu^-}} = \frac{N^{obs}_{had} - N^{tot}_{bg}}{\sigma^0_{\mu^+\mu^-} \cdot \epsilon_{had} \cdot \epsilon_{trig} \cdot (1+\delta) \cdot \mathcal{L}} \tag{7}$$

N^{obs}_{had} : number of observed hadronic events

N^{tot}_{bg} : total number of background events

$\sigma^0_{\mu^+\mu^-}$: tree level $e^+e^- \to \mu^+\mu^-$ cross-section

ϵ_{had} : hadronic detection efficiency

ϵ_{trig} : trigger efficiency

$(1+\delta)$: radiative correction

$\mathcal{L}$: integrated luminosity

Hadronic Event Selection

Basic scheme is to identify and remove clear Bhabha/ dimuon/cosmic events, then examine the events to pick out true hadronic events.

General cuts:

- Fiducial and vertex cuts for tracks
- Track fit quality cut
- Maximum and minimum energy deposition
- TOF and momentum cuts

Special attention is paid to 2 prong events; additional cuts insure that they are not cosmics, Bhabhas, etc.

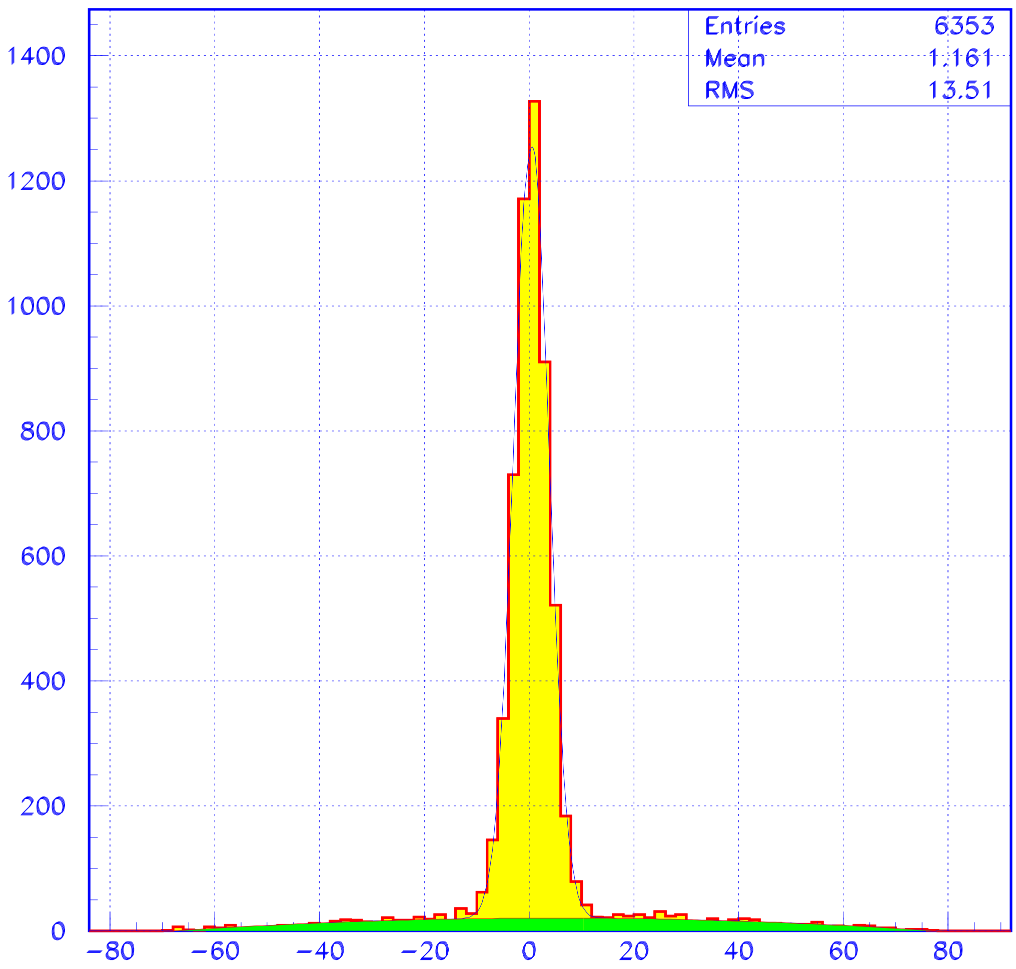
Background Subtraction

Four sources of background considered:

- Cosmic rays. Removed via TOF, vertex cut, muon ID.
- Residual lepton pairs. Back-to-back cut and rejection of radiative events to remove. Subtraction based on MC simulation.
- Two-photon events. Subtraction based on 2γ MC generator.
- Beam-associated background. Measured from z-vertex distribution of events. Separated beam data provides a cross-check.

Beam-Associated background

Method A: Fit z-component of event vertex



This is our most signifigant source of background.

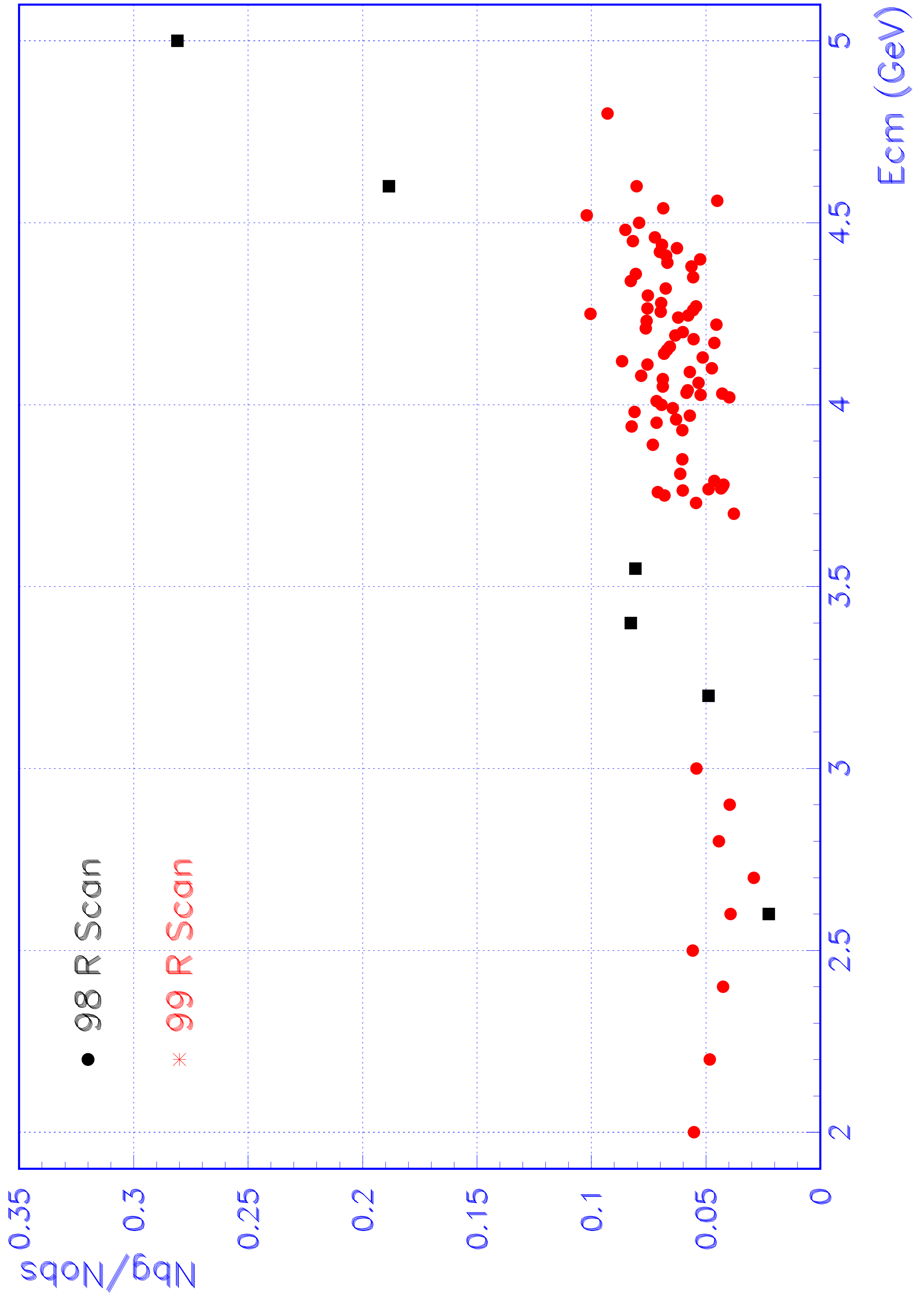
Method B: Scale separated beam data

N_{sep} = events in separated beam data passing hadronic selection.

$$\begin{aligned} N_{beamgas} &= f \times N_{sep} && (8) \\ f &= \frac{\int_{run} P_{run} \cdot I_{run}\ dt}{\int_{sep} P_{sep} \cdot I_{sep}\ dt} && (9) \end{aligned}$$

Cross-check via single-beam data.

Methods A and B produce consistent results!



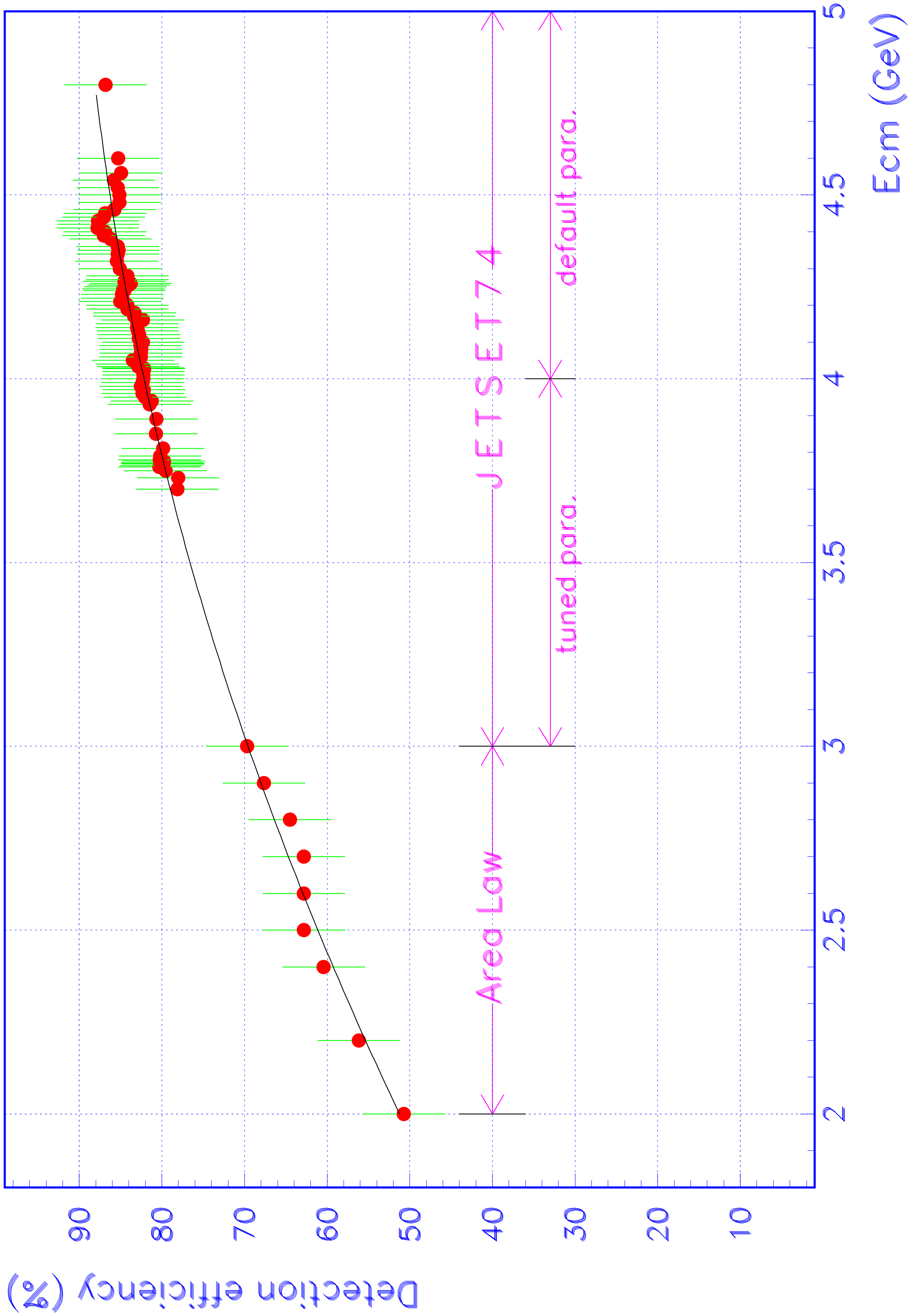
98 R Scan
99 R Scan
Nbg/Nobs
Ecm (GeV)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
2
2.5
3
3.5
4
4.5
5

Hadronic Detection Efficiency

Two MC generators used: JETSET74 (Lund model) and LUARLW (Area law model).

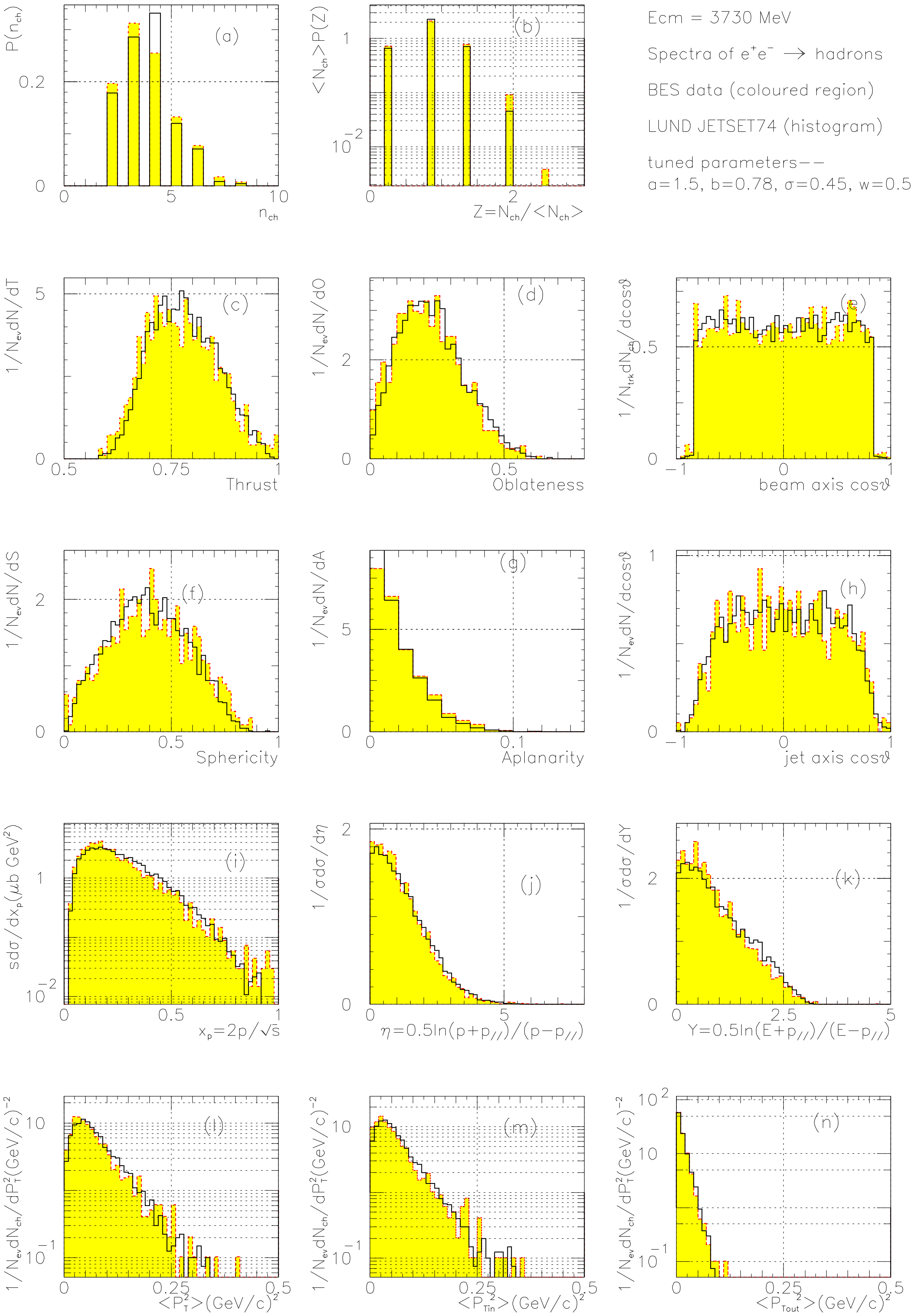
JETSET parameters tuned for 3-4 GeV energy region (with help from T. Sjostrand and B. Andersson). Default parameters used for 4-5 GeV.

Area Law (B. Andersson and H. Hu) used for 2-3 GeV range. Removes high-energy assumption and left-right symmetry assumption in string fragmentation for more accurate low energy results.



Detection efficiency (%)
Ecm (GeV)
Area Law
J E T S E T 7 4
tuned para.
default para.
10
20
30
40
50
60
70
80
90
2
2.5
3
3.5
4
4.5
5

Parameter Fitting



ISR calculations

Initial state radiation calculations performed by H.M. Hu at IHEP.

Four different schemes examined:

- Berends and Kleiss (1981)
- Bonneau and Martin (1971)
- Edwards, et al (Crystal Ball) (1990)
- Kureav and Fadin (1985)/Alexander (1989)

The radiative correction $(1 + \delta)$ calculated by these methods are all consistent to within 1% in the continuum.

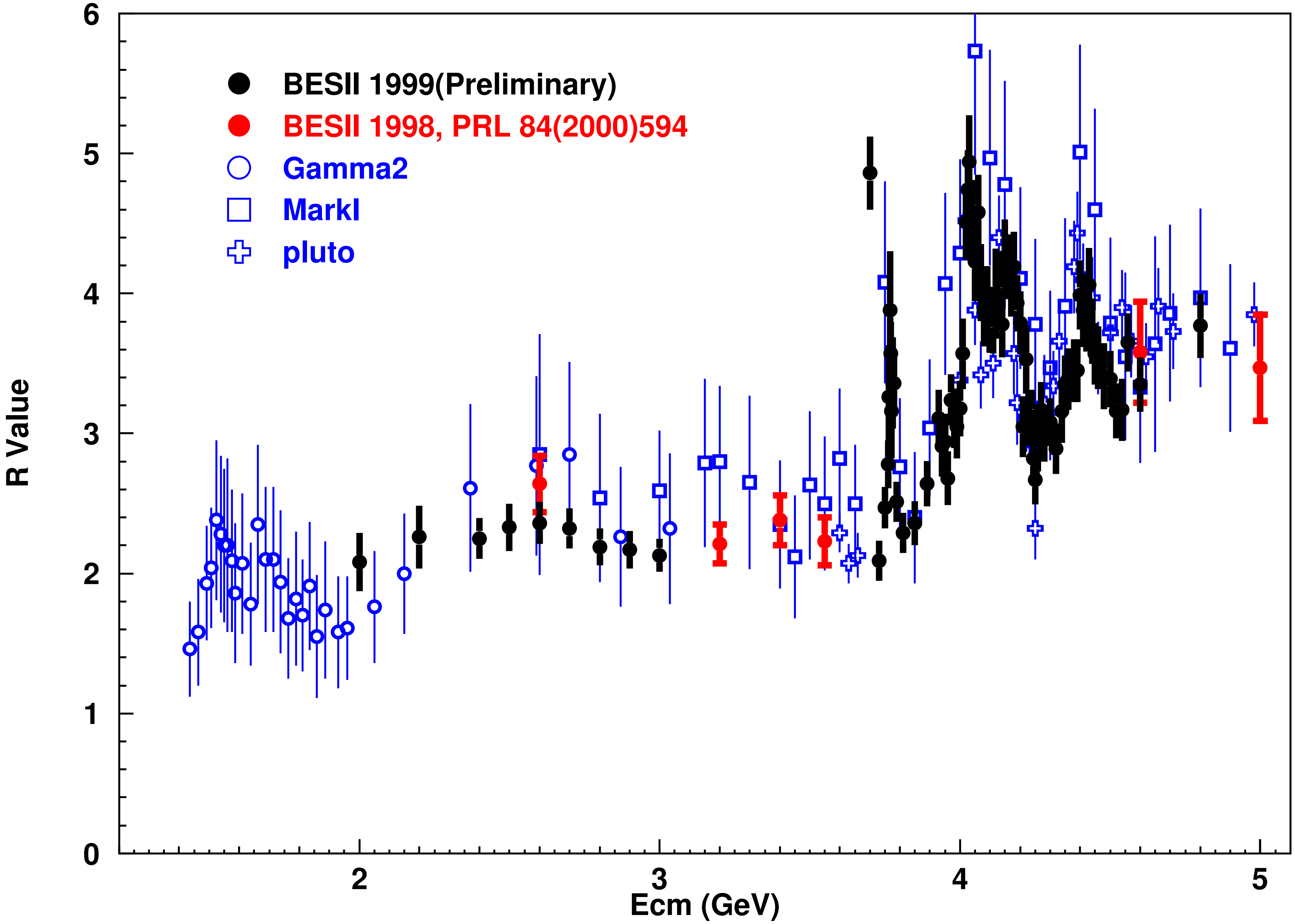
Bonneau and Martin scheme selected.

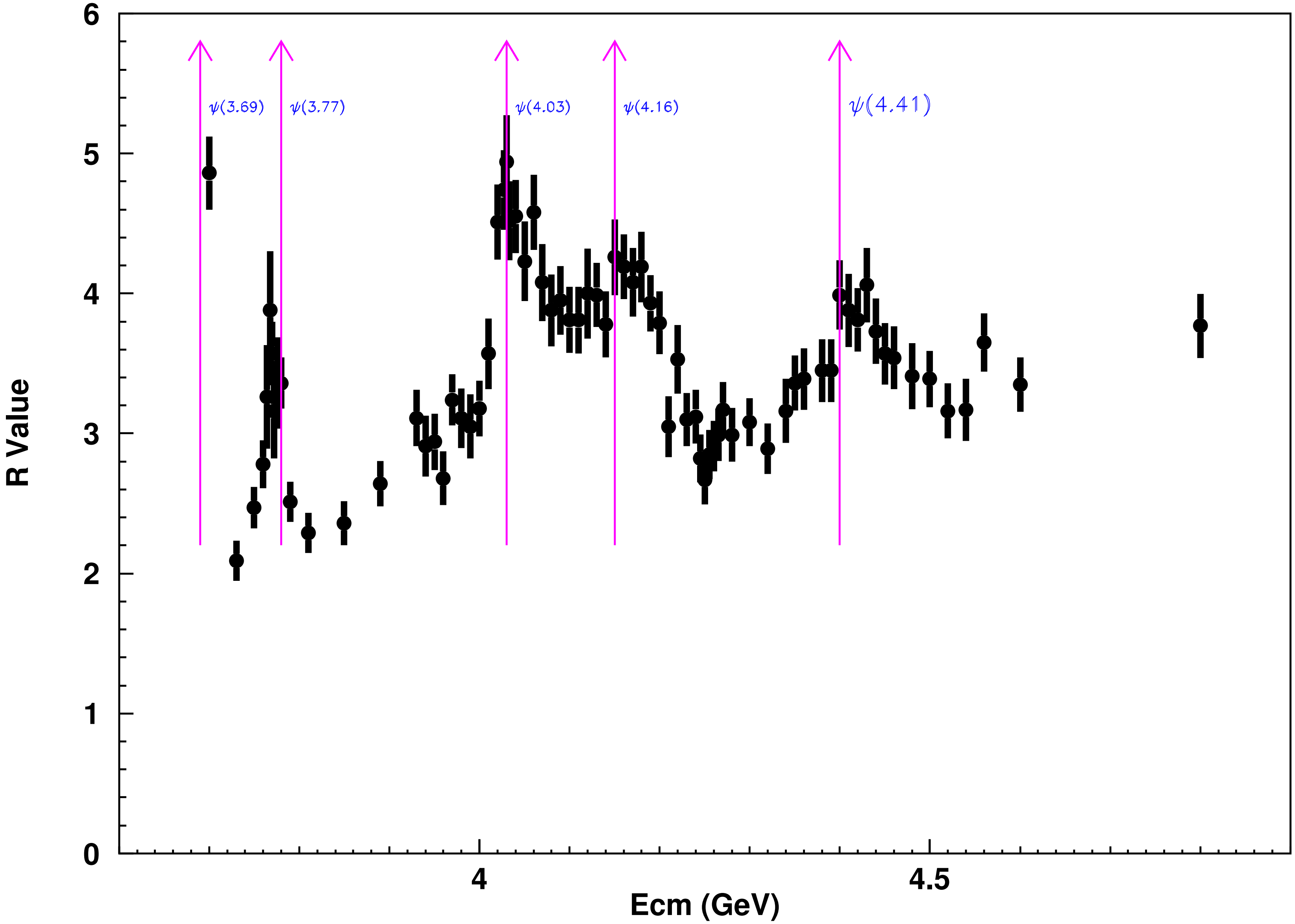
Results of R-scan

These are **preliminary** numbers.

Total errors are $\approx 7\%$.

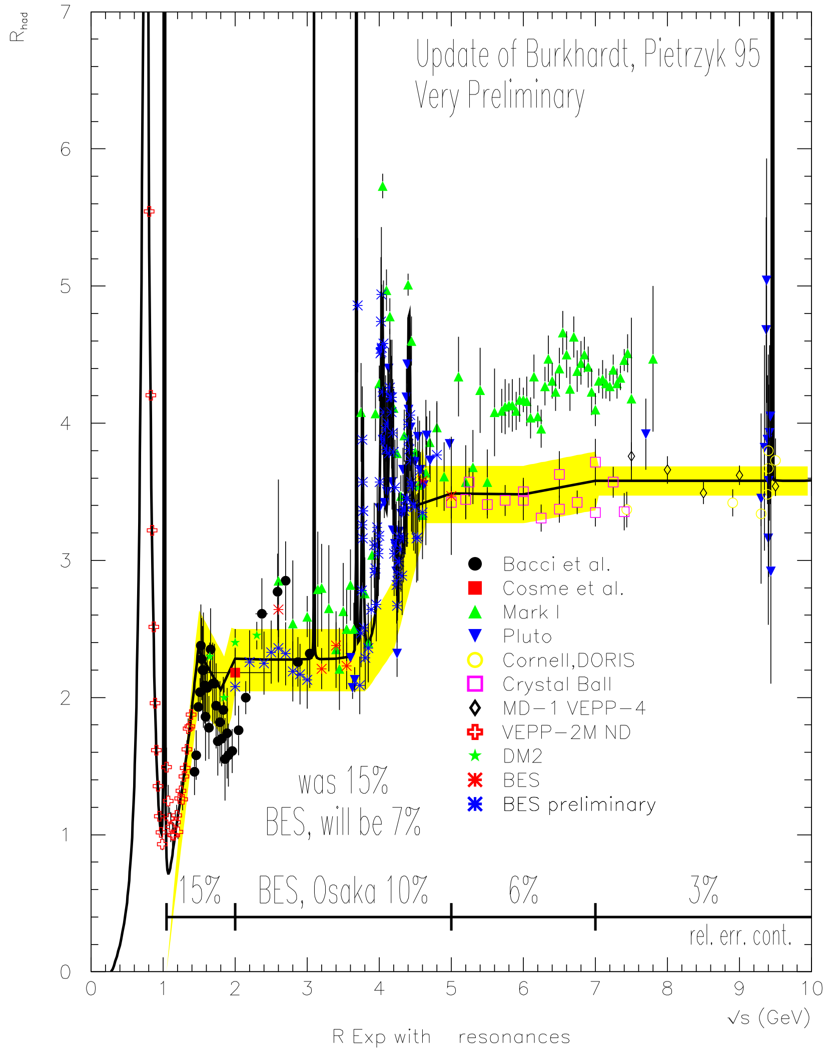
Error Sources (3.0 GeV)	
Source	Error contribution (%)
N_{had}	3.3
$\mathcal{L}$	2.3
$1+\delta$	1.3
ϵ_{had}	3.0
Systematic	5.2
Statistical	2.5
Total	5.8


BESII 1999(Preliminary)
BESII 1998, PRL 84(2000)594
Gamma2
MarkI
pluto
R Value
Ecm (GeV)
0
1
2
3
4
5
6
2
3
4
5



R Value
Ecm (GeV)
0
1
2
3
4
5
6
4
4.5
ψ(3.69)
ψ(3.77)
ψ(4.03)
ψ(4.16)
ψ(4.41)

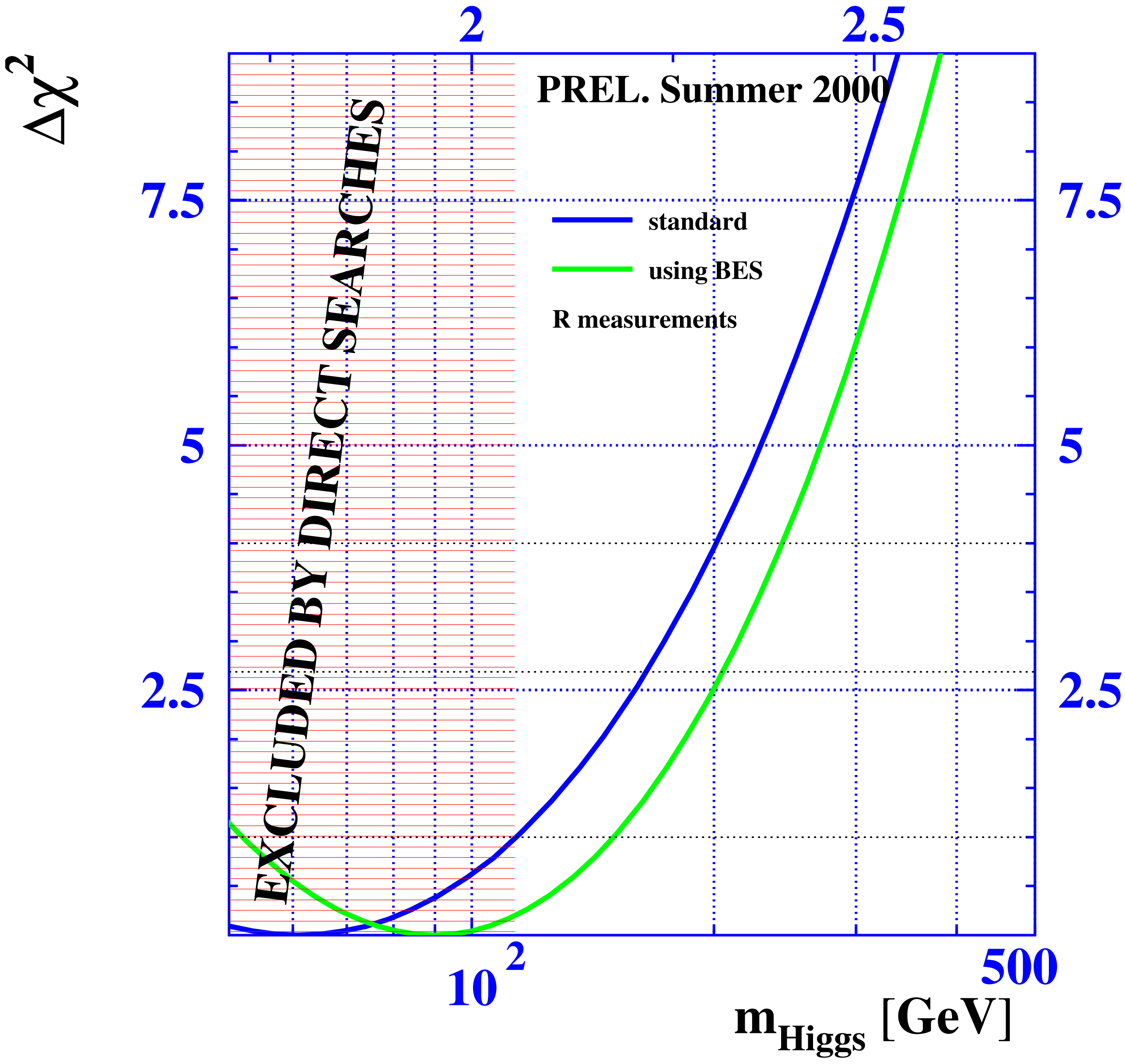
Effects on $\alpha^{-1}(M_Z^2), m_{Higgs}$



VERY PRELIMINARY results from B. Pietrzyk (from ICHEP2000):

$$\begin{aligned} \text{Old } \Delta\alpha^{(5)}_{had}(s) &= 0.0280 \pm 0.0007 \\ \text{New } \Delta\alpha^{(5)}_{had}(s) &= 0.02755 \pm 0.00046 \\ \alpha^{-1}(M_Z^2) &= 128.945 \pm 0.060 \end{aligned}$$

Note: 10% errors used in preliminary study.



Minimum moves from 60 to 90 GeV, upper limit moves to 210 GeV. Plot from B. Pietryzk.

Additional Work With R data

Other analysis topics using R-scan data:

- Pion form factor
- $e^+e^- \to p\bar{p}$
- ψ'' resonance parameters

All such analyses are in preliminary stages.

Summary

- R values have been obtained at 85 points from 2.0 to 4.8 GeV.
- Typical uncertainties are $\approx 7\%$; factor of 2-3 improvement over previous data.
- Largest sources of error are N_{had} and ϵ_{had}.
- **Preliminary** results give:

$$\boxed{\begin{array}{rcl} da^{(5)}_{had}(s) & = & 0.02755 \pm 0.00046. \\ \alpha^{-1}(M_Z^2) & = & 128.945 \pm 0.060. \end{array}}$$

- Error in $\alpha^{-1}(M_Z^2)$ reduced signifigantly; m_{Higgs} fit shifted upwards by 30 GeV.
- Possible contribution to reduction in error of a_μ^{had}.