More BES Results

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Hadron Spectroscopy, Chiral Symmetry and Relativistic Description of Bound Systems
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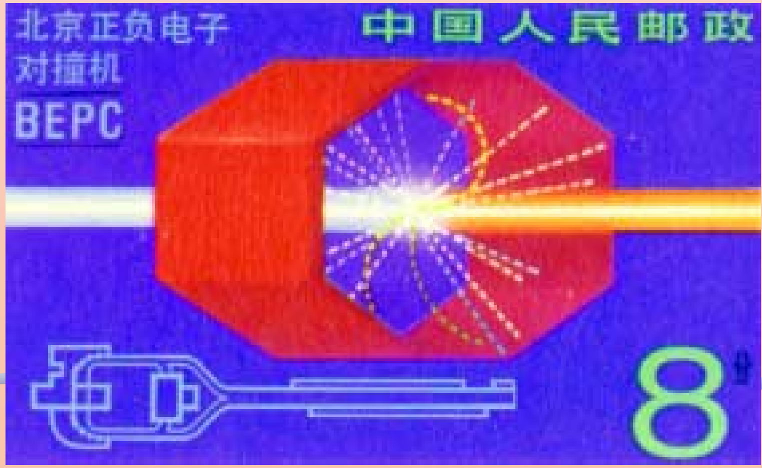


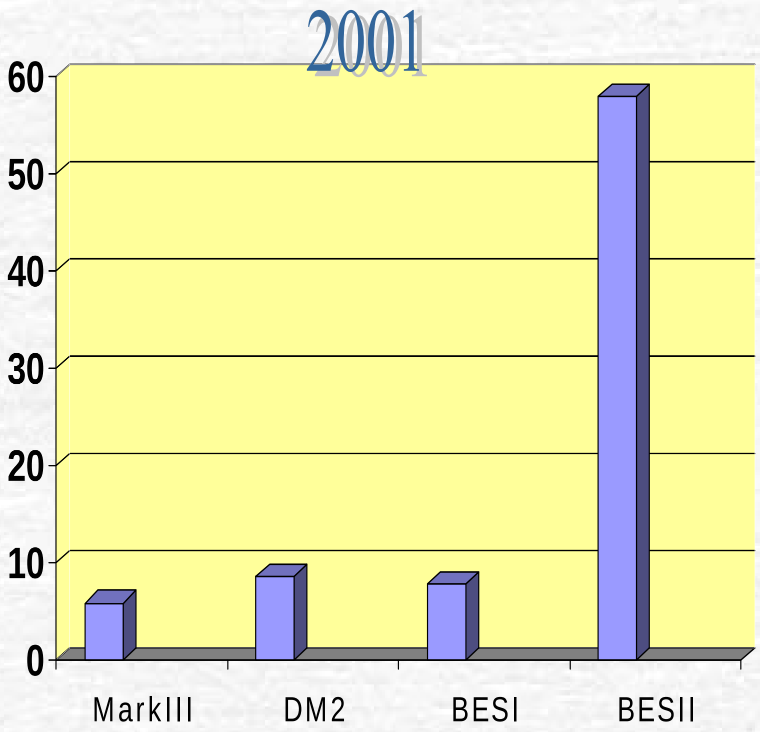
OUTLINE

- Introduction
- Search for $J/\psi \to e\ \mu$
- R Measurement
- QCD tests
- Observation of $\psi'' \to \pi^+\pi^- J/\psi$
- Summary

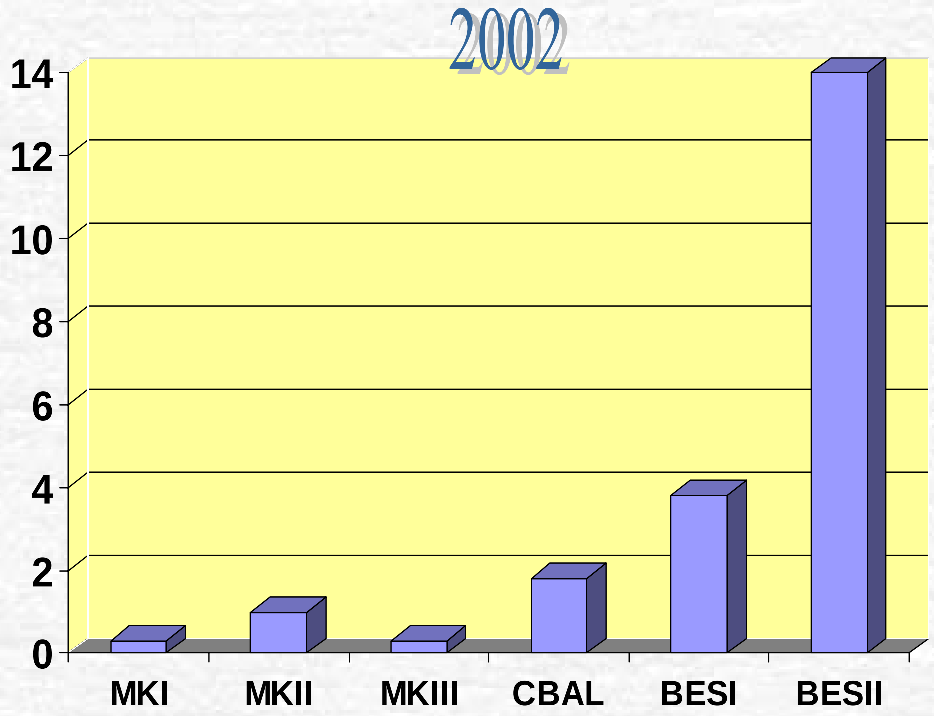
World J/ψ and ψ(2S) Samples (10^6)

Largest from BES

J/ψ



ψ(2S)



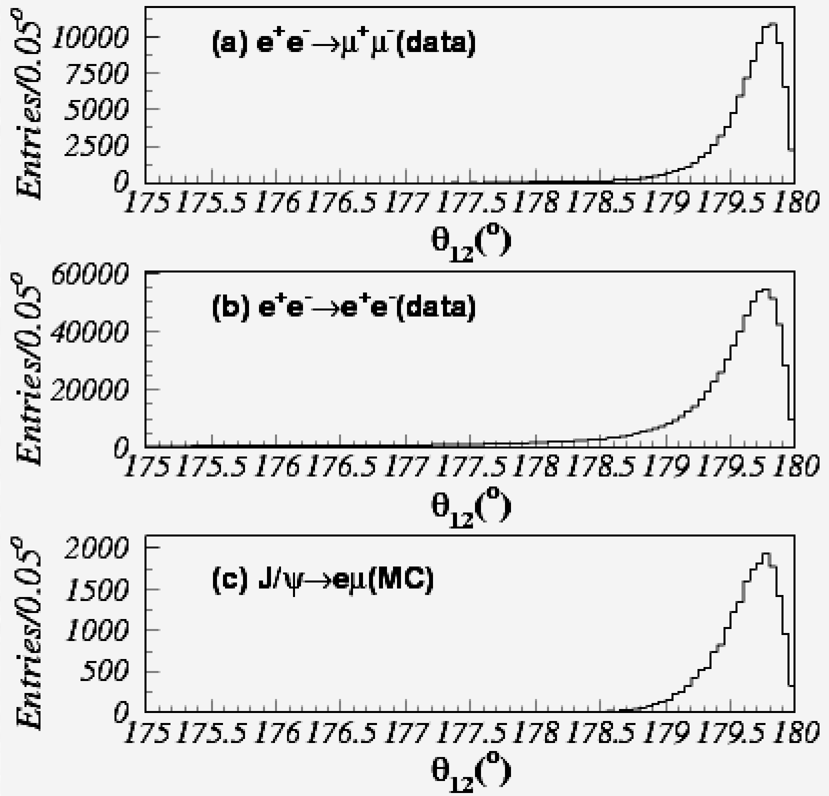
Search for $J/\psi \rightarrow e\ \mu$

- Lepton number conserved in minimal SM.
- Neutrino oscillations imply mixing and lepton flavor violation. (Super Kamiokande, SNO, KamLAND)
- Lepton number conservation may be broken in grand unified, SUSY, and left-right symmetric models.
- Important to test.
- Use BES 58 M J/ψ events to search for lepton flavor violation in $J/\psi \rightarrow e\ \mu$.

Search for J/$\psi \to e\ \mu$

Initial selection:

- 2 charged tracks with opposite charge
- No isolated photons
- Good vertex
- $1.45 < P < 1.65$ GeV/c
- $\Theta_{12} > 178.5^o$
- $2.95 < M_{e\ \mu} < 3.25$ GeV/c^2



Search for J/ψ → e μ

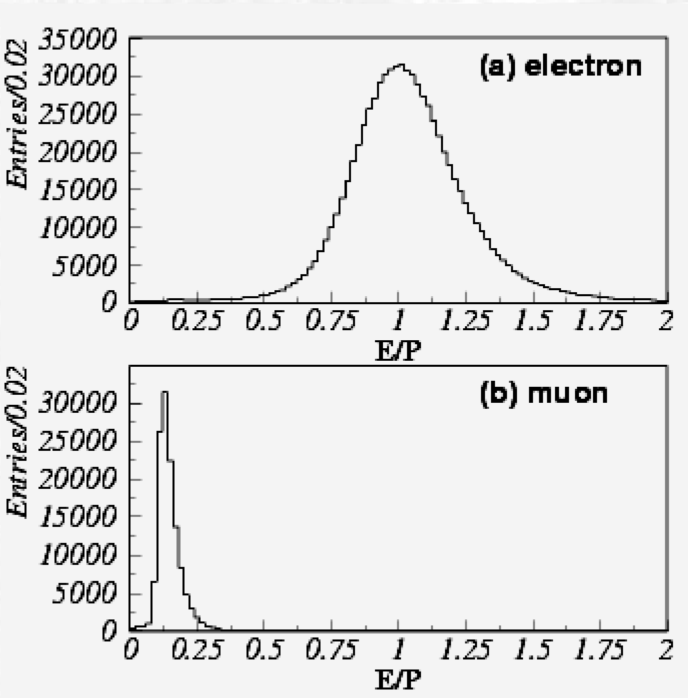
Lepton selection: Use BSC and μ system.

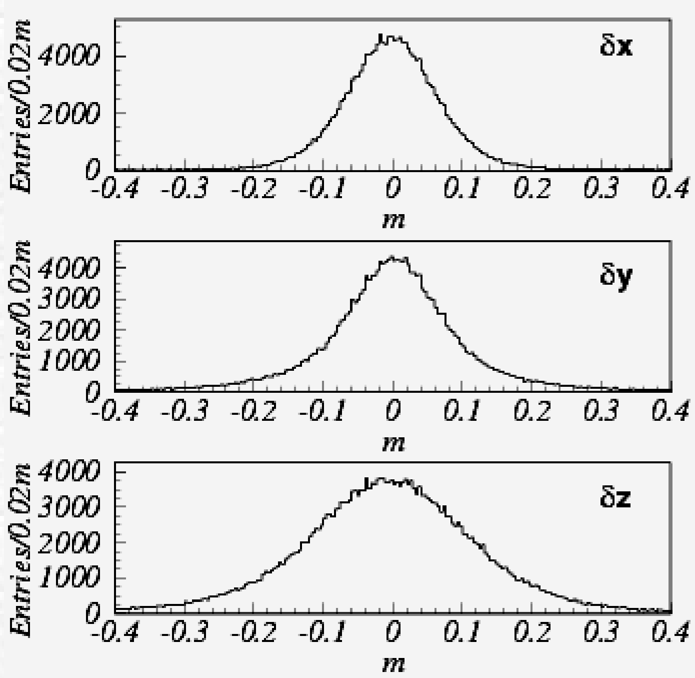
e's

- No μ hits
- E/p > 0.7

μ's

- E/p < 0.3
- Good μ hits (< 1 σ)





Layer 3

Search for J/ψ → e μ

Four candidates found:

RUN No.	14676		16419		18940		19149	
REC No.	16877		26352		27010		9196	
$M_{e\mu}$ (GeV)	3.113		3.117		3.201		3.143	
θ_{12}	179.5		179.8		179.6		179.5	
track	e	μ	e	μ	e	μ	e	μ
P (GeV/c)	1.591	1.522	1.570	1.543	1.587	1.611	1.605	1.535
E/P	0.7188	0.1758	0.8577	0.1778	0.8835	0.1415	0.7155	0.1035
μ_{hit}^{good}	0	3	0	3	0	3	0	3

Use Monte Carlo to determine geometric efficiencies.

geometric efficiencies.

channel		MC Efficiency
$J/\psi \to ee$	ϵ_{ee-MC}	(61.47±0.02)%
$J/\psi \to \mu\mu$	$\epsilon_{\mu\mu-MC}$	(58.32±0.02)%
$J/\psi \to \pi\pi$	$\epsilon_{\pi\pi-MC}$	(52.74±0.29)%
$J/\psi \to KK$	ϵ_{KK-MC}	(24.38±0.24)%
$e^+e^- \to e^+e^-(\gamma)$	$\epsilon_{ee(\gamma)-MC}$	(32.51±0.03)%
$e^+e^- \to \mu^+\mu^-(\gamma)$	$\epsilon_{\mu\mu(\gamma)-MC}$	(42.96±0.29)%

Search for $J/\psi \rightarrow e\ \mu$

Use ee and $\mu\ \mu$ events to measure PID efficiency.

Use $J/\psi \rightarrow \rho\ \pi$ and K* K events to measure PID misidentification efficiencies.

Table 3
The particle identification/misidentification efficiencies.

	regarded as e	regarded as μ
e sample	95.3%(1±0.02%)	—
μ sample	—	19.0%(1±0.6%)
π	3.6%(1±2.1%)	0.46%(1±5.98%)
K	3.11%(1±5.79%)	0.38%(1±16.8%)

Table 4
The misidentification rates and backgrounds from hadronic channels.

decays	misidentification rate	number of background
$J/\psi \rightarrow \pi\pi$	1.74×10^{-4}	1.49
$J/\psi \rightarrow KK$	5.77×10^{-5}	0.79
total		2.3

Search for $J/\psi \to e\ \mu$

- Can not use data for $e\ \mu$ misidentification
- Monte Carlo estimates 7 $e\ \mu$ background events.
- Conservatively use only hadronic background.
- Obtain upper limit based on 4 events with 2.3 background.

$B(J/\psi \to e\ \mu) < 1.1 \times 10^{-6}$ (90% CL)

Preliminary

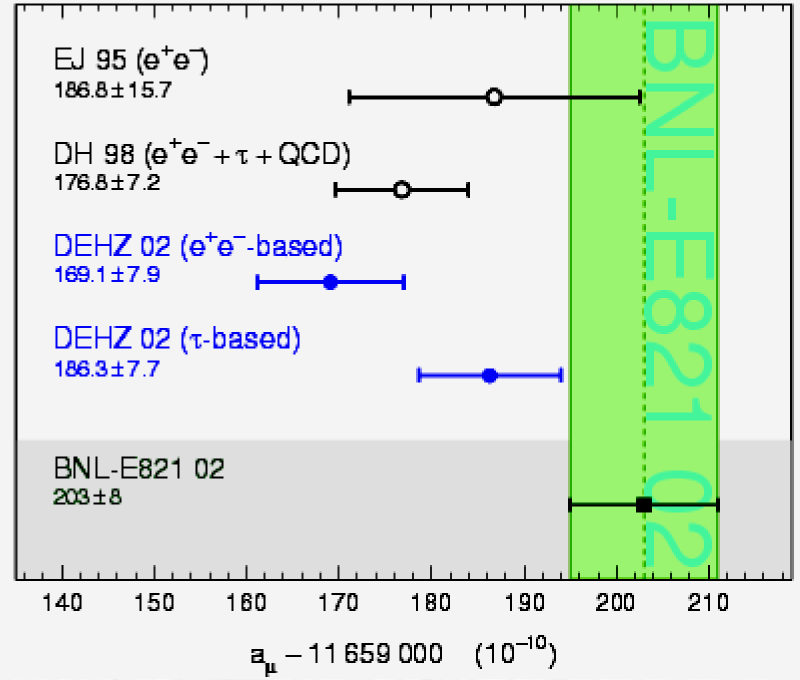
R Measurement

$$R(s) = \frac{\sigma_{tot}(e^+e^- \rightarrow hadrons)}{\sigma_{tot}(e^+e^- \rightarrow \mu^+\mu^-)}$$

Improved R values are very important:

- Needed for interpretation of $a_\mu = (g-2)/2$.

Much of the theoretical uncertainty from R - but mostly from $E_{CM} < 2$ GeV region.



M. Davier et al., hep-ph/0208177.

R measurement

- Needed to improve precision of $\alpha(M^2_Z)$:
  - Uncertainties in α introduced when it is extrapolated to the Z-pole:

$$\alpha(q^2) = \frac{\alpha_0}{1 - \Delta\alpha(q^2)}$$

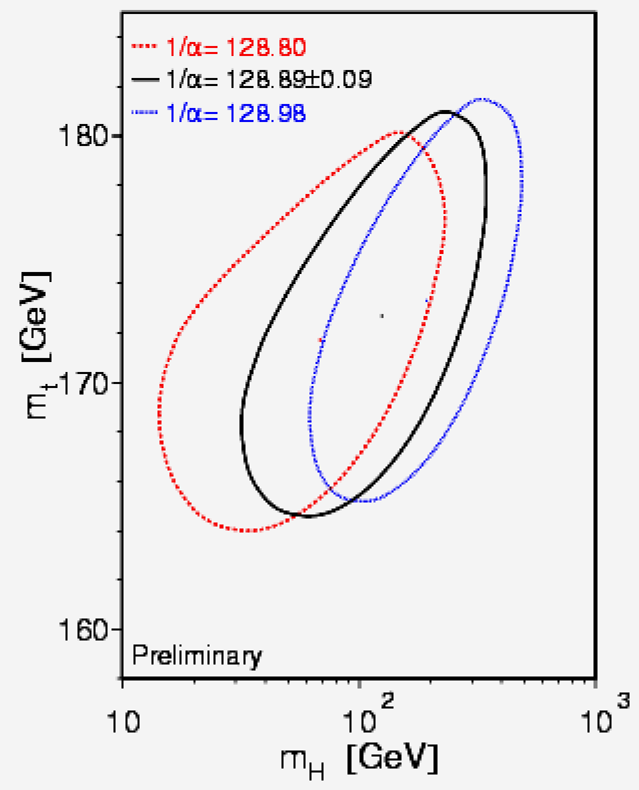
$$\Delta\alpha(q^2) = \Delta\alpha_l(q^2) + \Delta^{(5)}_{\text{had}}\alpha(q^2) + \Delta_{\text{top}}\alpha(q^2)$$

  - Dominant uncertainty due to effects of vacuum polarization.
  - Experimentally determined R values are used with dispersion relations to determine this.

R measurement

- The Higgs mass determined from radiative corrections in the SM is very sensitive to the uncertainty in $\alpha(M^2_Z)$.

B. Pietrzyk and H. Burkhardt (1997).



BES R Measurement

Determination of R:

$$R = \frac{\sigma^0_{had}}{\sigma^0_{\mu\mu}} = \frac{N_{obs} - N_{bg}}{\sigma^0_{\mu\mu} \cdot \epsilon_{had} \cdot \epsilon_{trig} \cdot (1+\delta) \cdot L}$$

$$N_{bg} = N_{cr} + N_{bm} + N_{ll} + N_{\gamma\gamma}$$

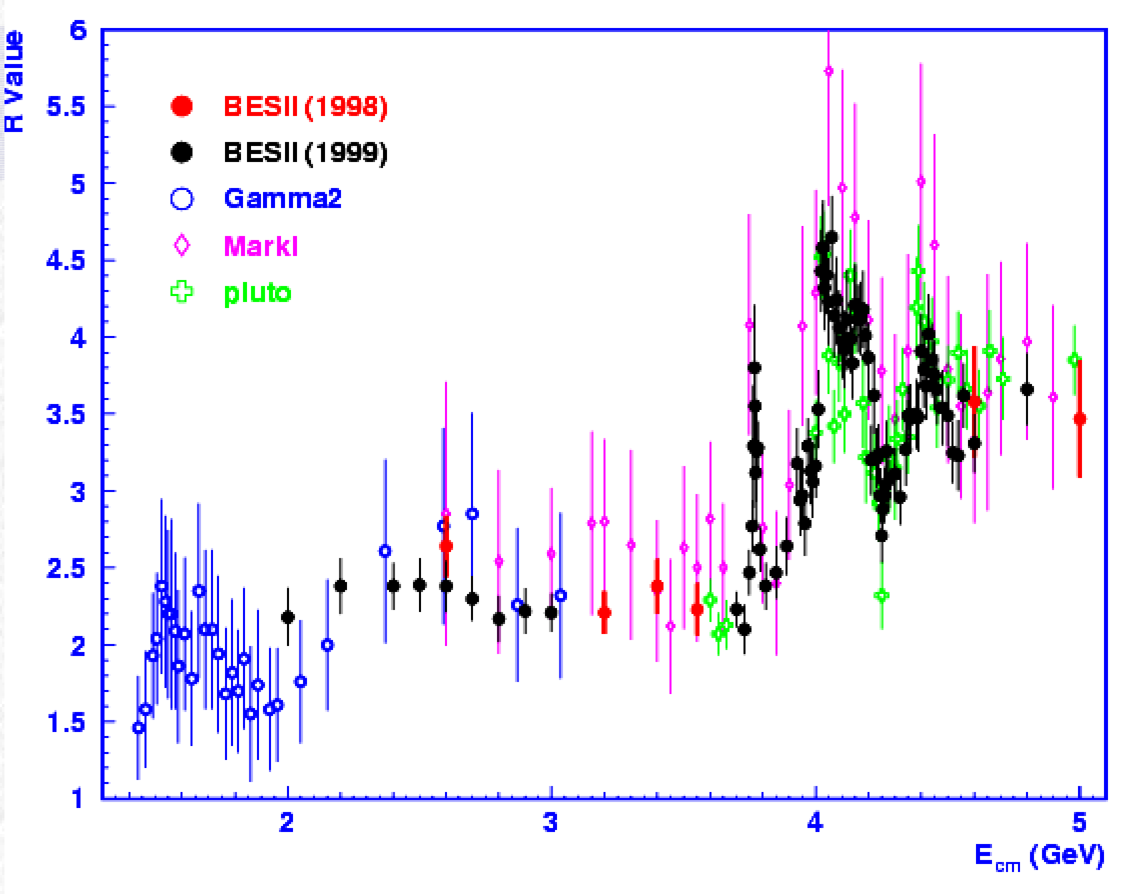
$$\sigma^0_{\mu\mu}(s) = 4\pi\alpha^2/3s$$

Runs

Year	E (GeV)	Pts	Single Beam Pts	Separated Beam Pts	Time Spent (days)
1998	2.6 - 5.0	6	1	6	40
1999	2.0 - 4.8	85	7	24	105

~1000 events per energy point

BES R-scan

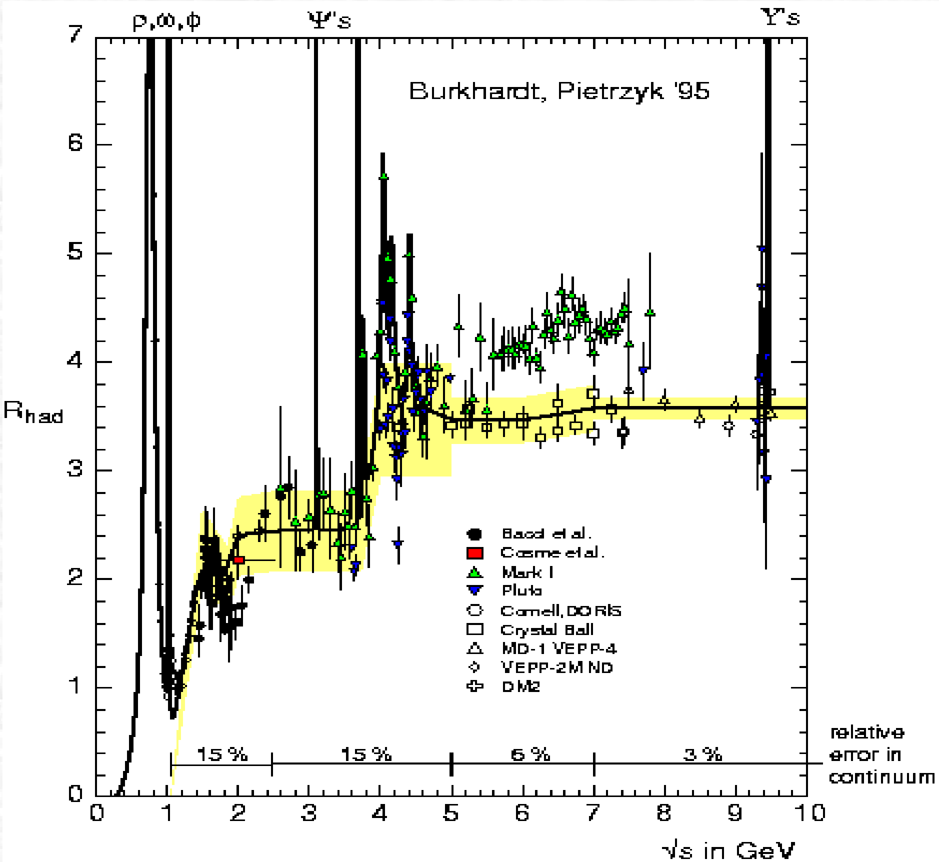


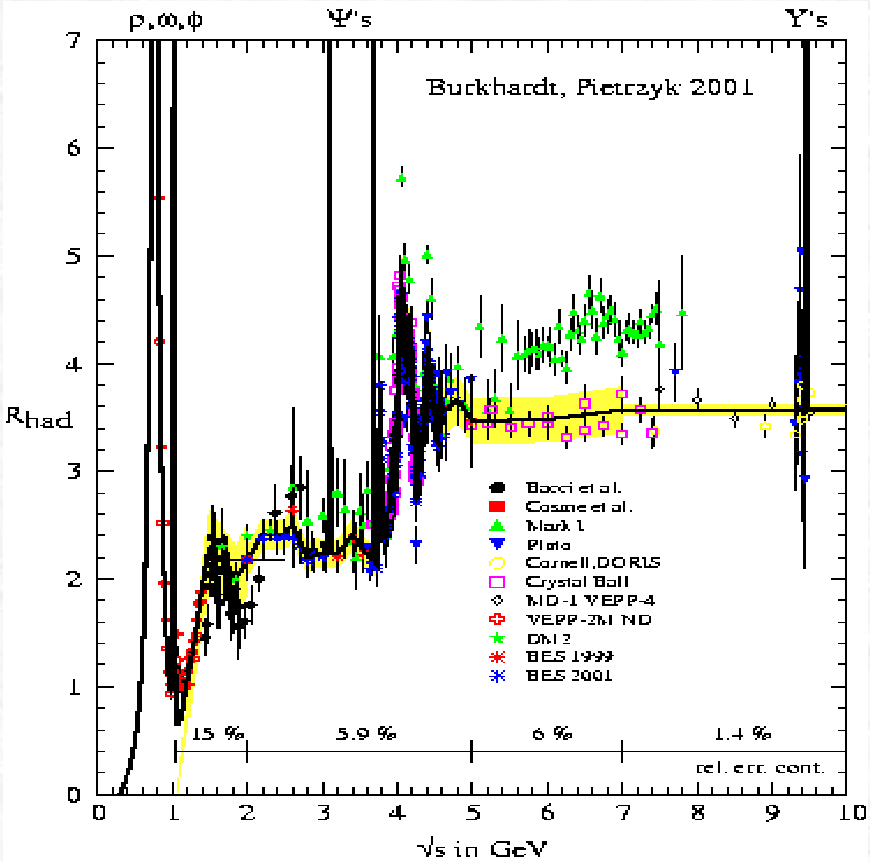
Results published: J.Z. Bai et.al., Phys. Rev. Lett. **88**, 101802 (2002).

69 citations so far; tau mass paper - 93

R Below 10 GeV

BES reduces R errors from 15 – 20 % to an average of 6% in the 2 – 5 GeV region.





Before BES R Scan **After BES R Scan**

Current Status

Burkhardt and Pietryzk have updated analysis [Phys. Lett. **B513**, 46 (2001).]

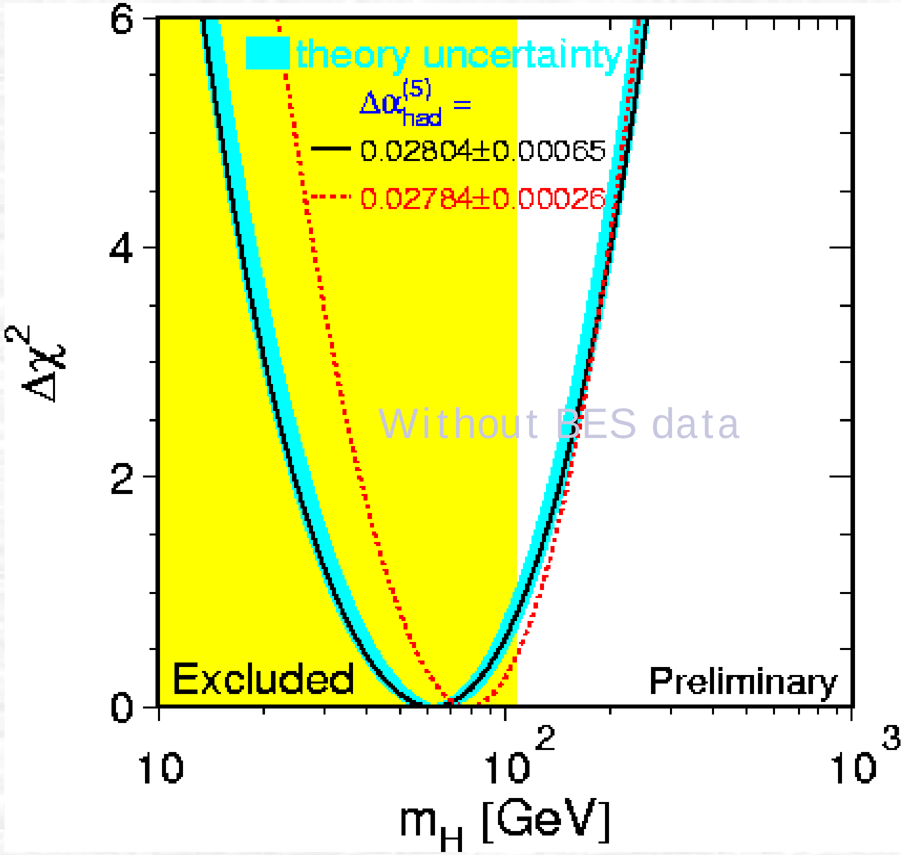
$$\alpha^{-1}(M_Z^2) = 128.936 \pm 0.046$$
$$\Delta\alpha^{(5)}_{\rm had} = 0.02761 \pm 0.00036$$

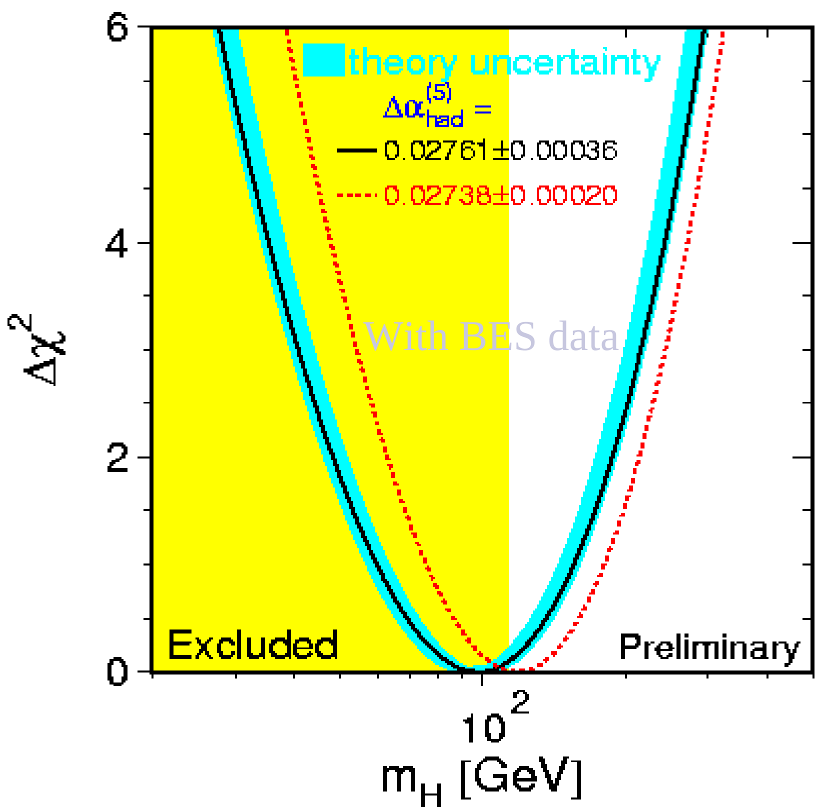
Previously:

$$\alpha^{-1}(M_Z^2) = 127.90 \pm 0.07 \ (\mathrm{PDG1998})$$

Shifts Standard Model Higgs mass upward.

The SM Fit to m_H





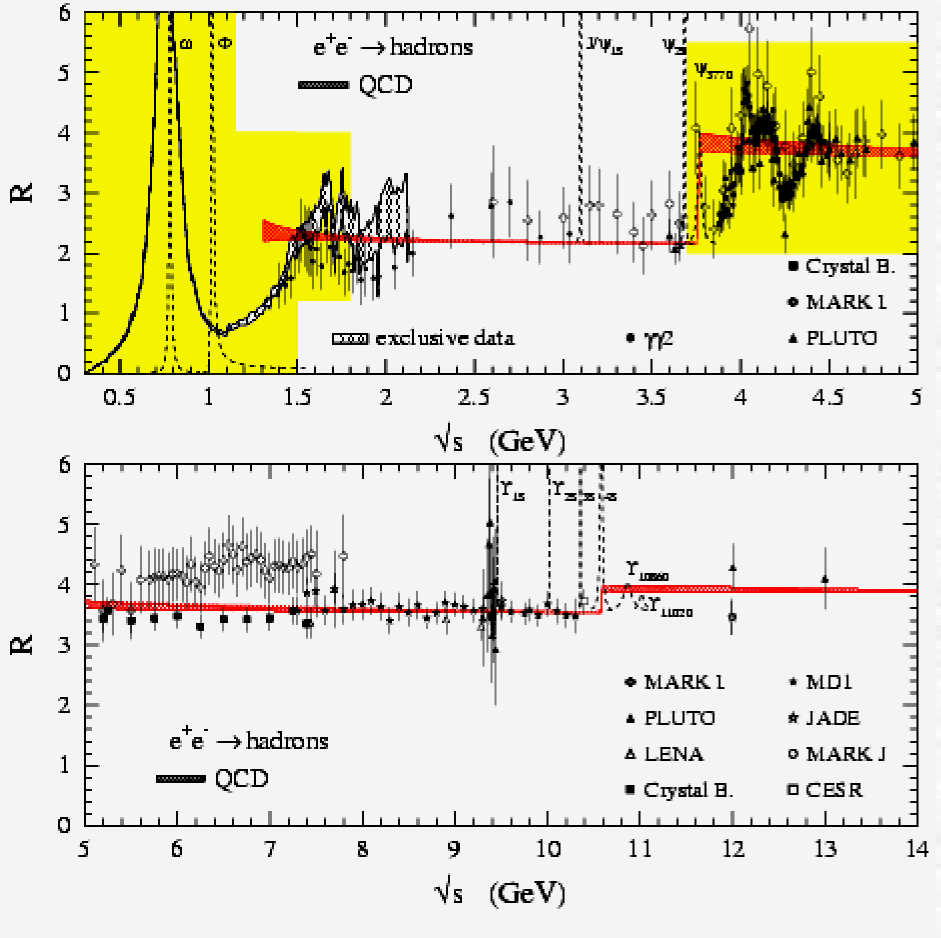
$$m_H = 62^{+53}_{-30} GeV$$
$$m_H < 170 GeV$$
(95% C.L.)

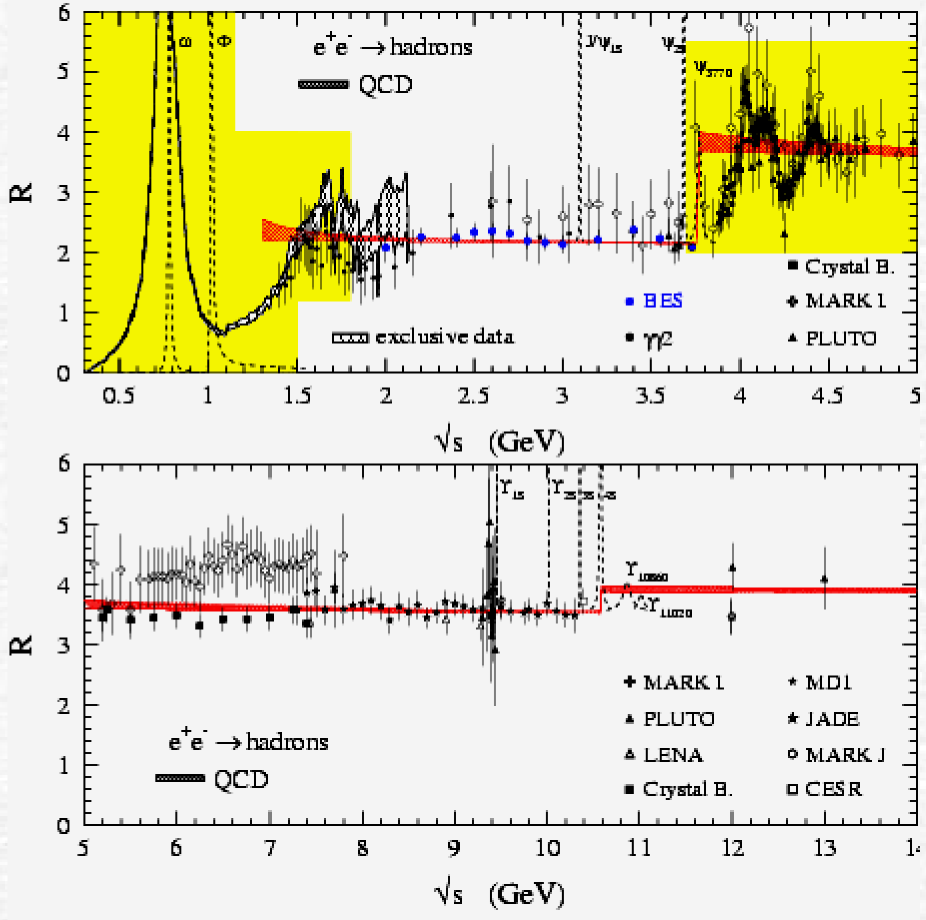
$$m_H = 98^{+58}_{-38} GeV$$
$$m_H < 212 GeV$$
(95% C.L.)

Current Status

Experimental R-values below 5 GeV confirm QCD calculations

(M. Davier and A. Höcker, Phys. Lett. **B419**, (1998).





Current status

- Low energy R values (< 10 GeV) including BES R data and pQCD used to determine $\alpha_s(M_Z)$:

(J. H. Kühn and M. Steinhauser, Nucl. Phys. B619, 588, 2001).

$$\alpha_s(5\text{ GeV}) = 0.235\,^{+0.047}_{-0.047}$$
$$\alpha_s(M_Z) = 0.124\,^{+0.011}_{-0.014}$$

agrees with other determinations, but errors larger.

- Precise BES data from the charm threshold region

Allows the determination of the $\overline{\text{MS}}$ quark mass:

$$M_c = 1.304(27)\text{ GeV}$$

more accurate than other recent determinations.

Kühn wants 1% R measurements. BESIII?

Inclusive Momentum Spectra and Charged Particle Multiplicities at $\sqrt{s} \sim 2$ to 5 GeV

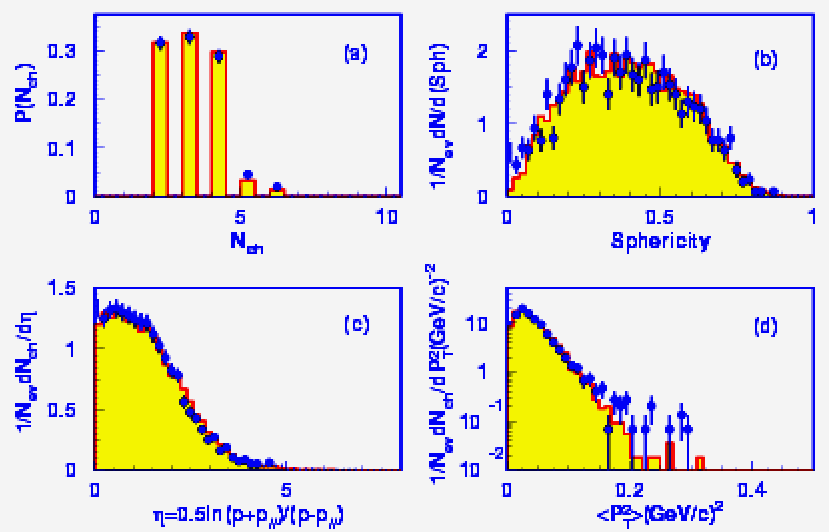
- Inclusive hadron production from $e^+ e^-$ annihilations important to test QCD.
- pQCD using the Modified Leading Logarithmic Approximation (MLLA) gives quantitative preditions.
- Many experimental results at high energy; few at low energy.
- Important to test pQCD at low energy.
- Use R-scan data at E_{CM} = 2.2, 2.6, 3.0, 3.2, 4.6 and 4.8 GeV to study:
  - Inclusive momentum spectrum, ξ
  - Multiplicity distribution
  - Second binomial moment, R_2

Inclusive Momentum Spectra and Charged Particle Multiplicities at $\sqrt{s}$ ~ 2 to 5 GeV

- Use same hadron selection as in R-scan measurement.
- Monte Carlo:
  - Specially developed LUARLW at 3 GeV and below.
  - JETSET with tuned parameters from 3 to 4 GeV.
  - JETSET with default parameters above 4 GeV.

Table 1
Background contribution to the hadron sample.

E_{cm} (GeV)	N_{had}	Beam-assoc. (%)	e^+e^- (%)	τ pair (%)
2.2	1410	3.82	0.61	—
2.6	4968	3.72	0.48	—
3.0	2030	3.01	0.56	—
3.2	1828	4.53	0.35	—
4.6	1315	6.86	0.18	6.98
4.8	1282	8.72	0.14	6.34



2.2 GeV

Inclusive momentum spectrum

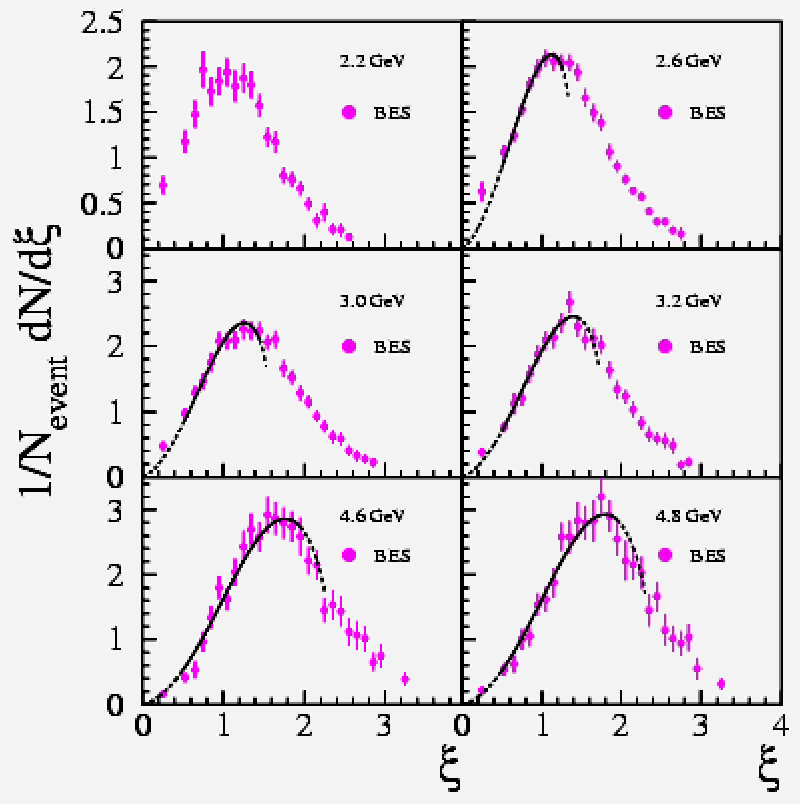
- $\xi = -\ln(2p/\sqrt{s})$
- QCD using MLLA:

$$\frac{1}{\sigma_{had}}\frac{d\sigma}{d\xi} = K_{LPHD} \times f_{MLLA}(\xi, \Lambda_{eff}, N_c, n_f)$$

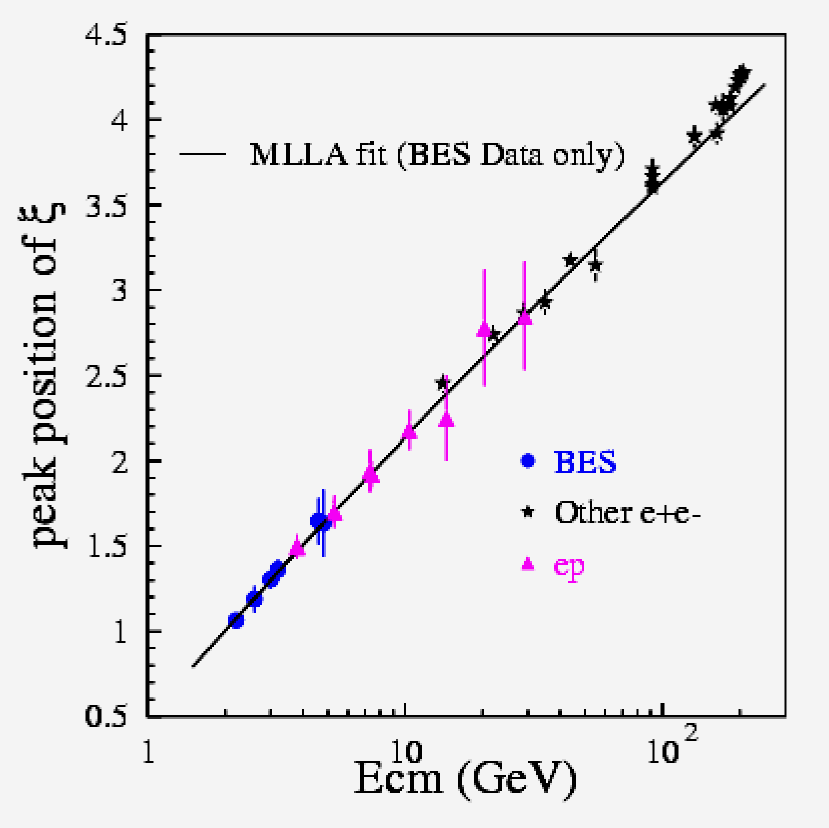
K_{LPHD} is overall normalization factor
f_{MLLA} is a complex function of ξ
N_C is a color factor
N_f is the number of active quarks

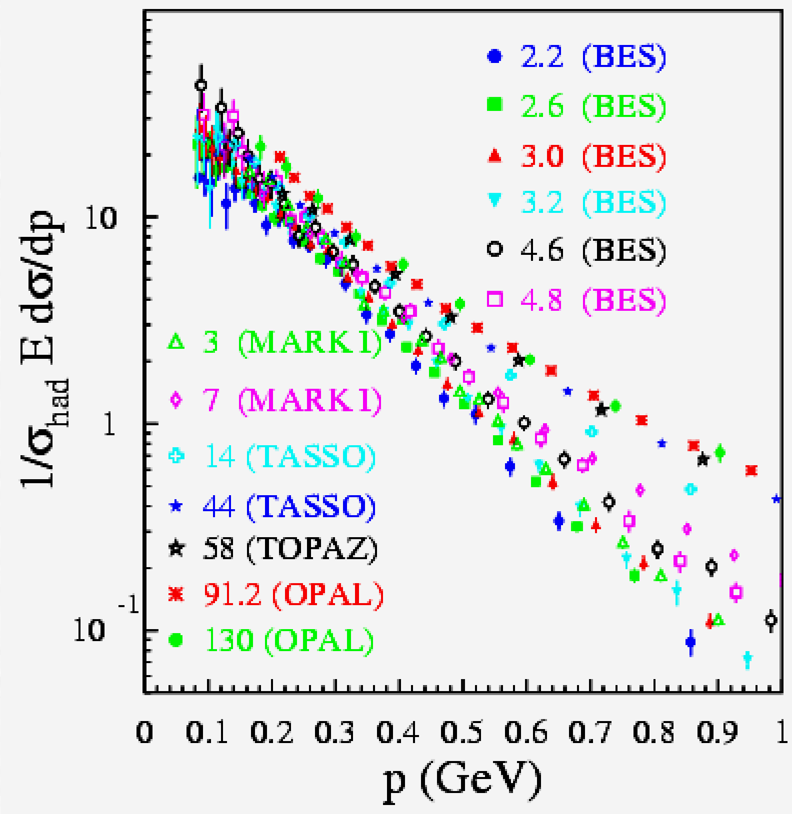
Only valid: $0 \leqslant \xi \leqslant \ln(0.5\sqrt{s}/\Lambda_{eff})$

Ecm	Λ_{eff} (MeV)	K_{LPHD}
2.6	$342 \pm 7 \pm 23$	$1.523 \pm 0.018 \pm 0.023$
3.0	$325 \pm 9 \pm 25$	$1.573 \pm 0.027 \pm 0.026$
3.2	$286 \pm 17 \pm 37$	$1.532 \pm 0.028 \pm 0.052$
4.6	$239 \pm 14 \pm 32$	$1.472 \pm 0.029 \pm 0.039$
4.8	$238 \pm 15 \pm 32$	$1.482 \pm 0.029 \pm 0.038$



Inclusive momentum spectrum



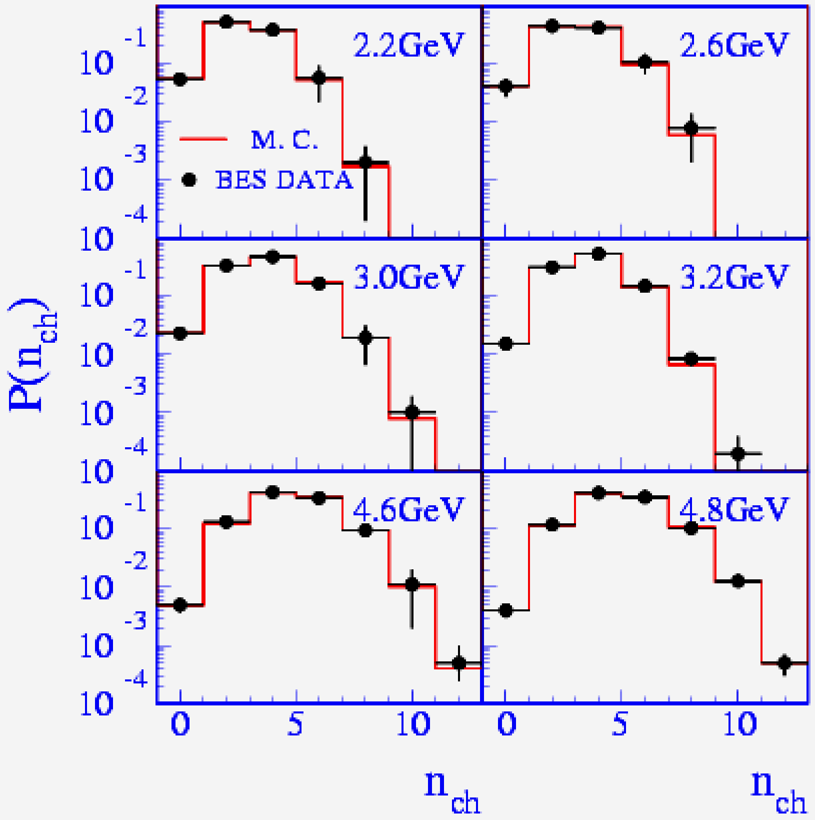


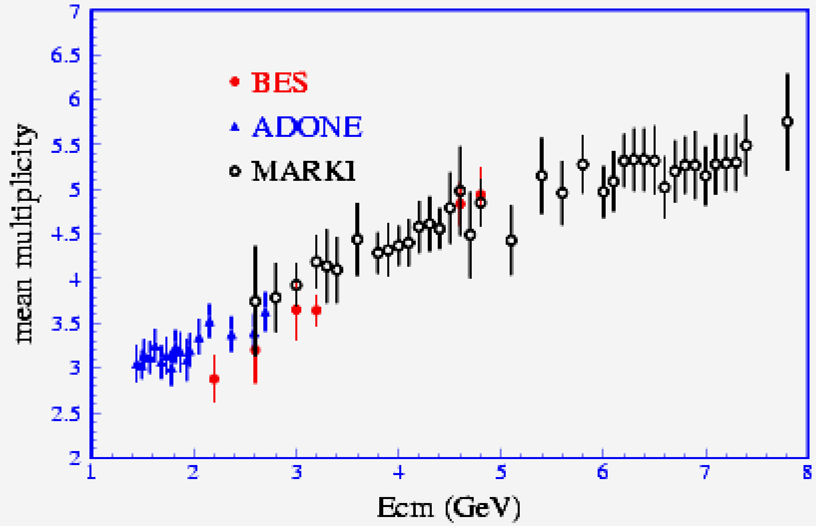
*Peak position, ξ *, versus* E_{CM}

$E^2 = P^2 + Q^2_o$

$Q^2_o = 0.27\ GeV$

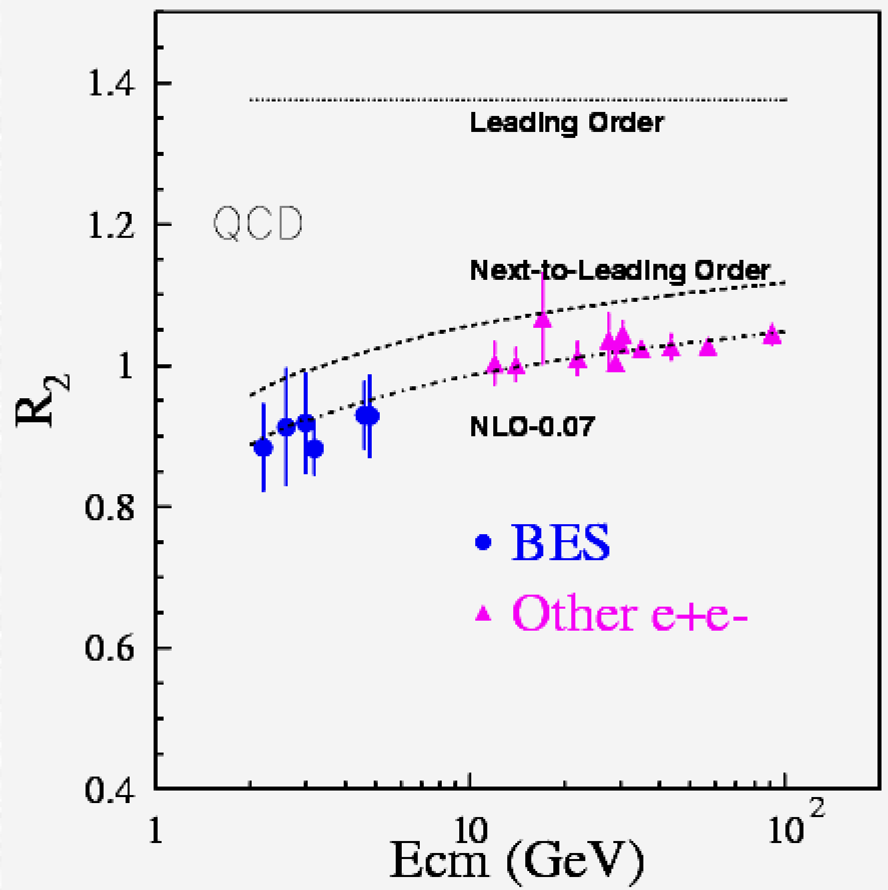
Multiplicity





Second binomial moment, R_2

- $R_2 = \langle n_{ch} (n_{ch} - 1)\rangle / \langle n_{ch} \rangle^2$
- Measure of hadron-hadron correlations.
- Long standing discrepency with NLO predictions.



$\psi'' \rightarrow \pi^+\pi^-$ J/ψ

- ψ'' thought to decay entirely to D D-bar. (PDG)
- Lipkin: non D D-bar could be large.

  H. J. Lipkin, Phys. Lett. B179 (1986) 278.
- ψ'' could decay to $\pi^+\pi^-$ J/ψ.
- Kuang using Chen-Kuang potential model:

  Γ ($\psi'' \rightarrow \pi^+\pi^-$ J/ψ) = 25 to 113 keV

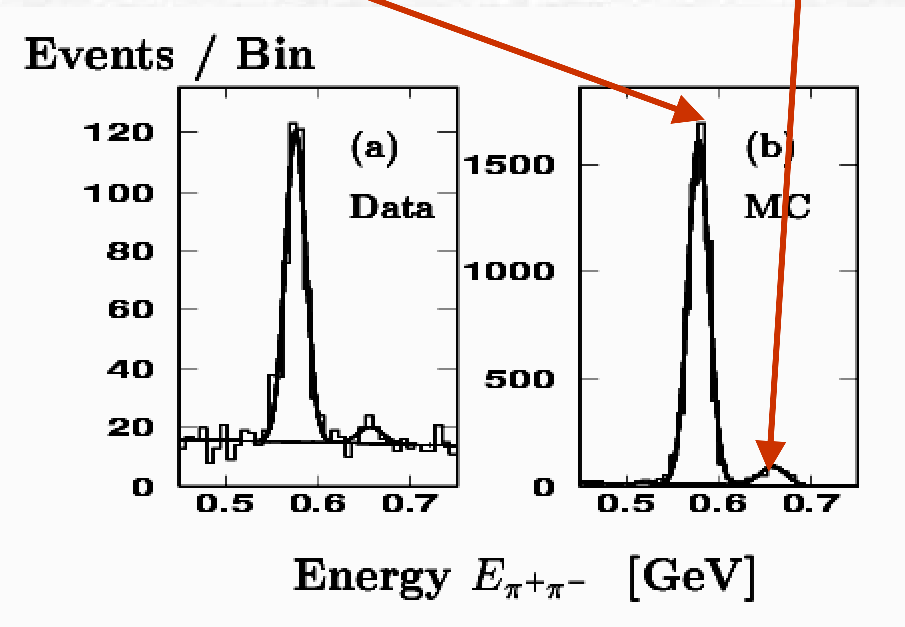
  Y. P. Kuang, Phys. Rev. D65, 09024 (2002).

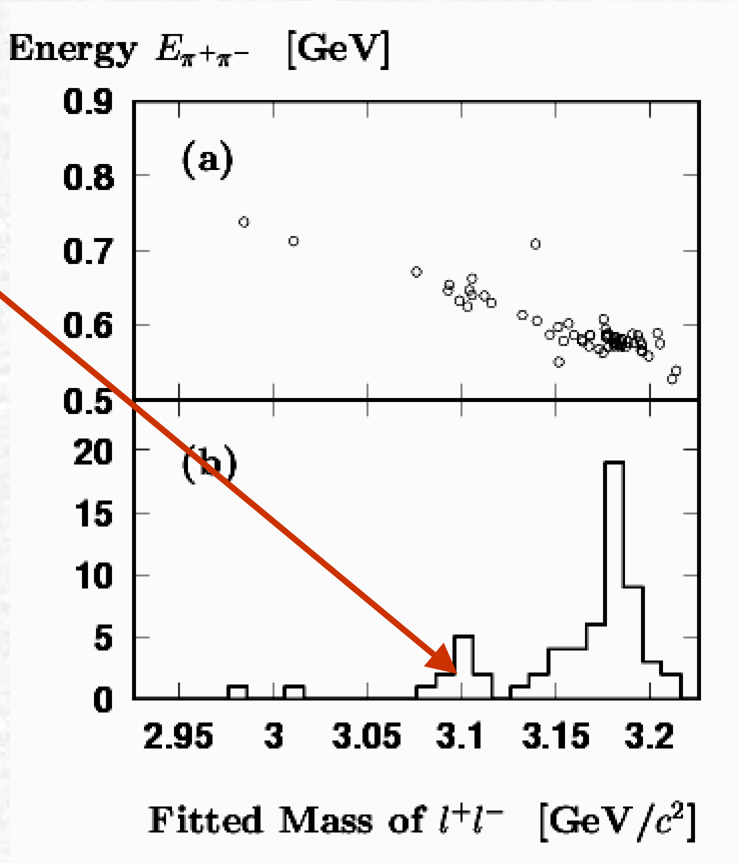
- Look for $\psi'' \rightarrow \pi^+\pi^-$ J/ψ, J/$\psi \rightarrow l^+ l^-$ using BES 7.3 pb^{-1} at 3.773 GeV.

$\psi'' \to \pi^+\pi^- J/\psi$

$\psi'' \to \pi^+ \pi^- J/\psi$

$e^+ e^- \to \gamma \psi'$, $\psi' \to \pi^+ \pi^- J/\psi$





$\psi'' \rightarrow \pi^+\pi^-$ J/ψ

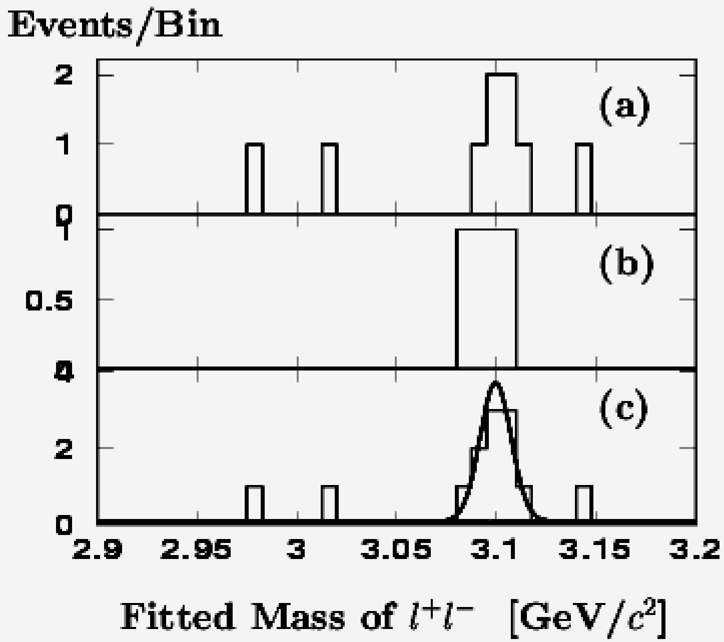


FIG. 3: Fitted mass of Di-lepton. (a) the mass of e^+e^-, (b) the mass of $\mu^+\mu^-$, (c) combined the mass plots of e^+e^- and $\mu^+\mu^-$ together.

Branching ratio soon.

Very preliminary

Summary

- Searched for $J/\psi \to e\ \mu$:

  $B(J/\psi \to e\ \mu) < 1.1 \times 10^{-6}$

  (90% CL)

- *BES has improved the precision of R measurements in the 2 – 5 GeV CM region: shifts SM prediction of Higgs mass up by 50%.*
- *R scan data also useful for testing QCD at low energy.*
- *Observe non D D-bar process* $\psi'' \to \pi^+\pi^- J/\psi$.