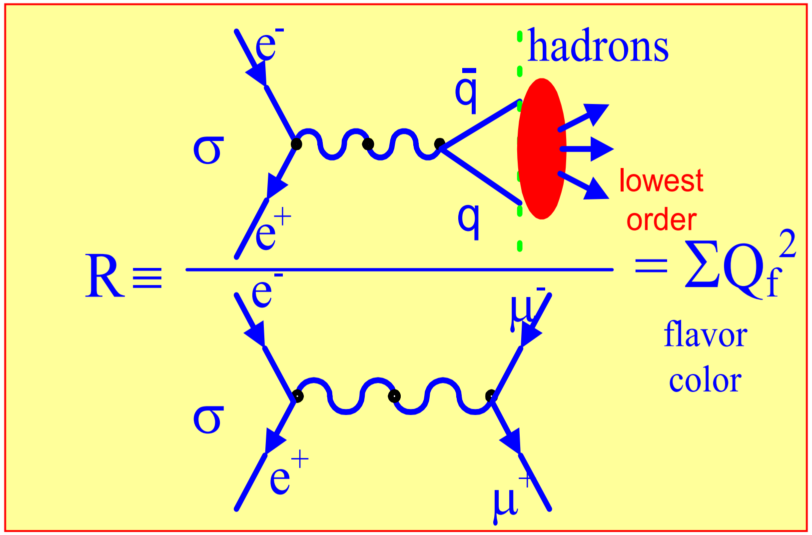
R in CLEO – past, present, future

S. Dytman
Univ. of Pittsburgh,
CLEO Collaboration

What is R?

$$R(s) = \frac{\sigma(e^+e^- \rightarrow hadrons)}{\sigma_0(e^+e^- \rightarrow \mu^+\mu^-)}$$



Linkage of R(s) to Fundamental Physics
Hadronic correction is largest theoretical uncertainty

$a_\mu=(g-2)_\mu$

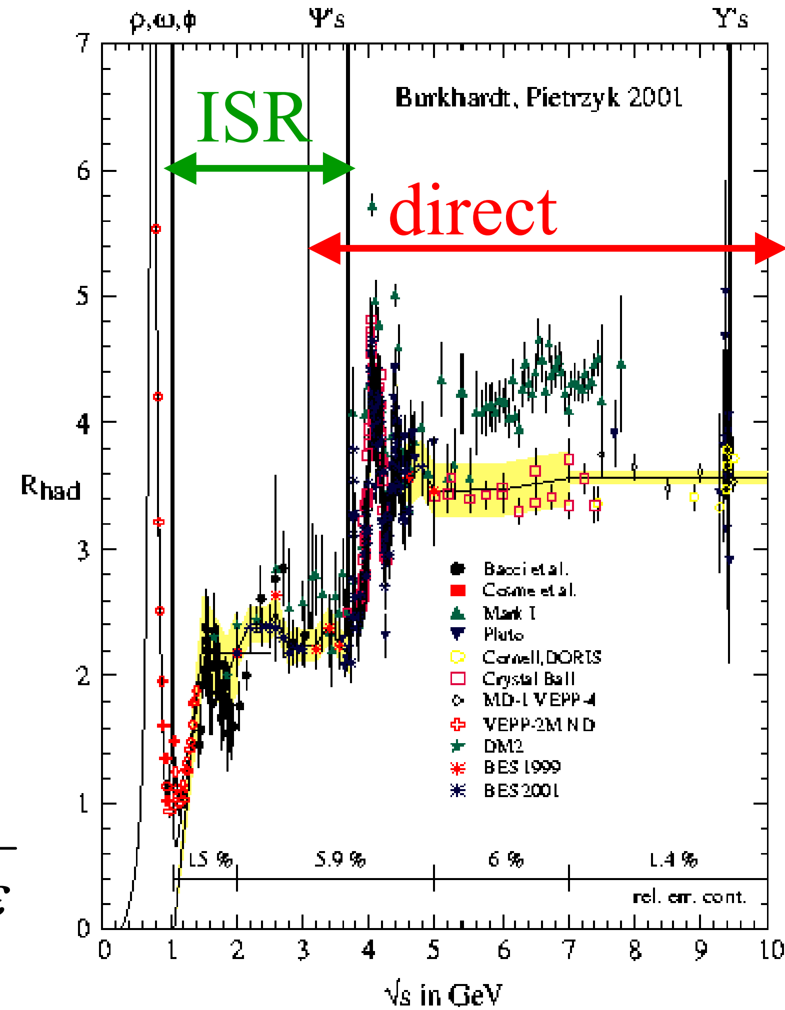
s^{-2} stresses low s

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

$\alpha_{QED}(M_Z^2)$

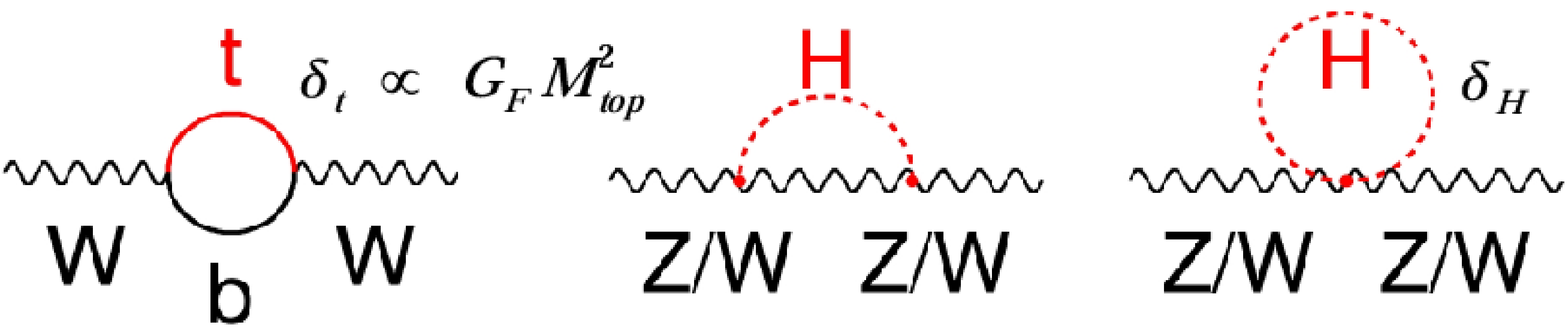
$$\Delta\alpha_{had}^{(5)}(M_Z^2) = -\frac{\alpha M_Z^2}{3\pi}\,\mathrm{Re}\int_{4m_\pi^2}^{\infty} \frac{R(s)}{s(s-M_Z^2)-i\varepsilon}$$

~s^{-1} puts emphasis on charm region

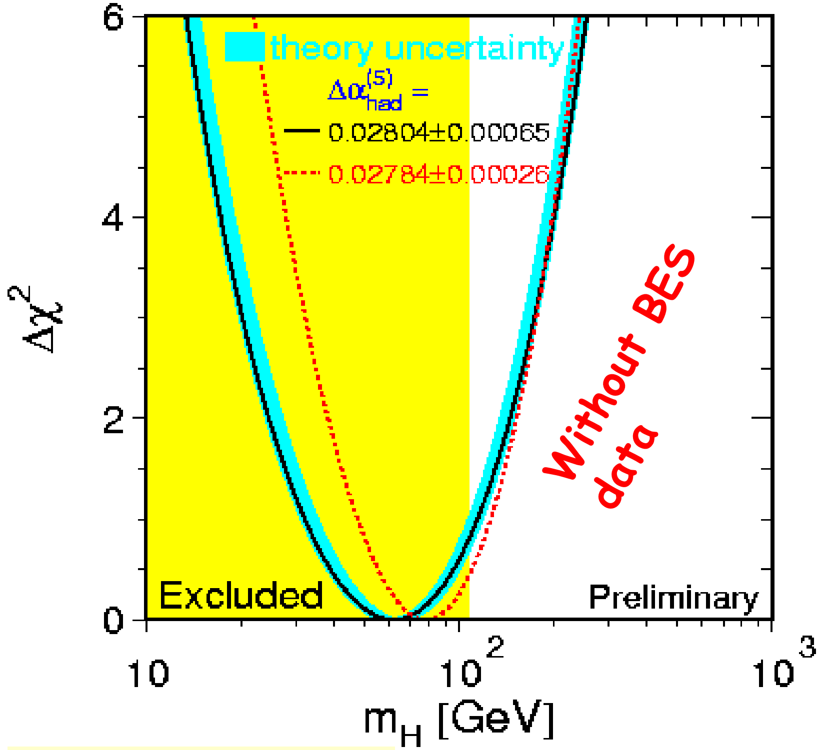


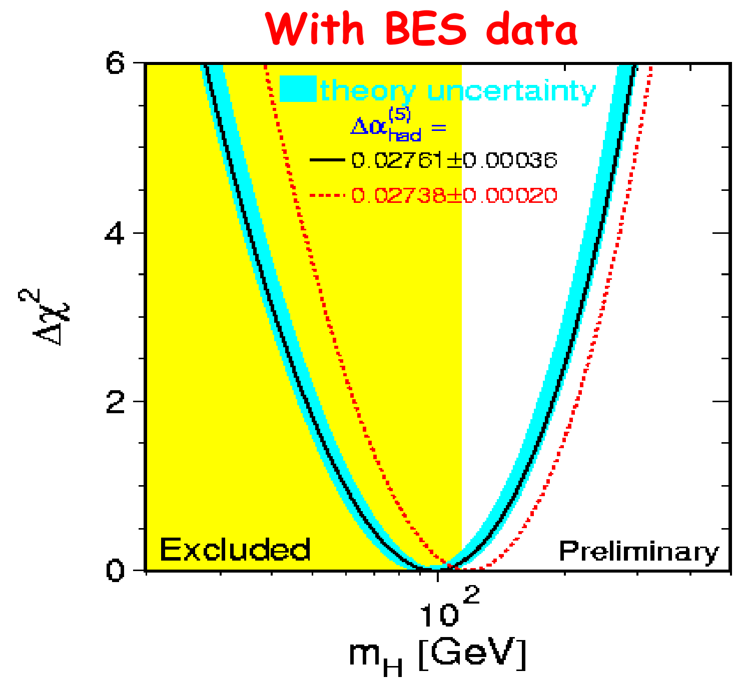
Global Standard Model Analysis LEP Electroweak Working Group

- Coordinated effort of theorists and experimenters!
- Fit to 20 observables from LEP and elsewhere
- Key input= $\Delta\alpha_{had}$, $\alpha_S(M_Z)$, M_Z, q masses, $\alpha(0)$, G_F
- Key output= M_H, M_{top} through loops
- F. Jegerlehner seeks 1% R meas. at low energy,
  will decrease error in $\Delta\alpha_{had}$ by factor of 7.



BES data had huge impact on Electroweak prediction of M_H





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

$m_H < 170\, GeV$ (95%

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

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

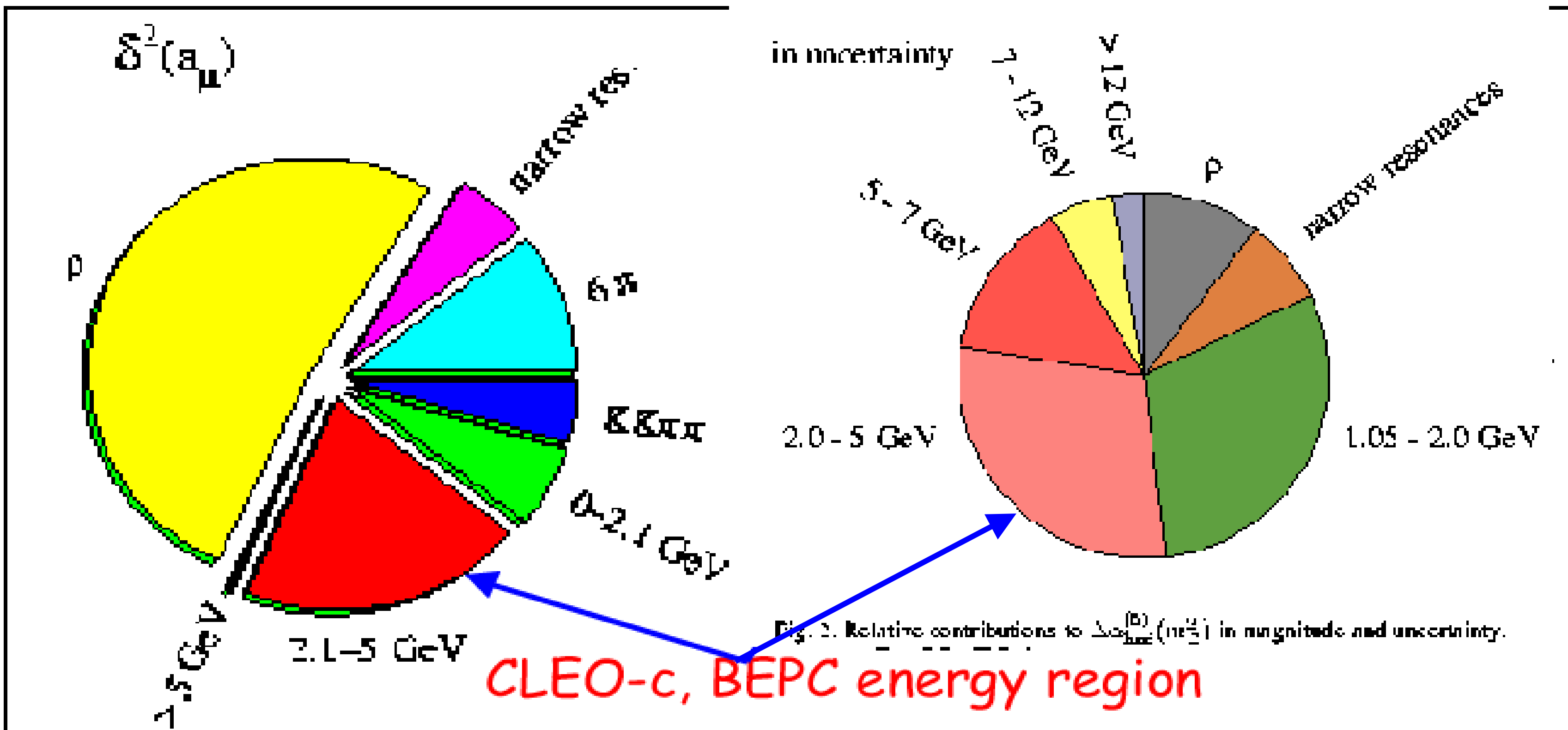
Best **value** will come from **data**, fantastic Confrontation with Standard Model!

Role of R(s) energy regions for Higgs' mass prediction (B. Pietrzyk)

	Data error	ΔM_H (GeV)	Dominant Expt.
ρ	2.3%	-4.9,5.0	CMD2
Narr.Res.	3.1%	-3.1,3.6	
1-2 GeV	15%	-13.6,15.2	
2-5 GeV	5.9%	-13.1,14.2	BES
5-7 GeV	6%	-6.7,7.3	Crystal Ball
7-12 GeV	1.4%	-2.5,2.7	
> 12 GeV	0.2%	-1.2,1.3	

Charm energy region is important!

Error in $(g\text{-}2)_\mu$ — Error in $\alpha_{QED}(M_Z)$



Error in both dominated by hadronic corr.

Burkhardt, Pietrzyk

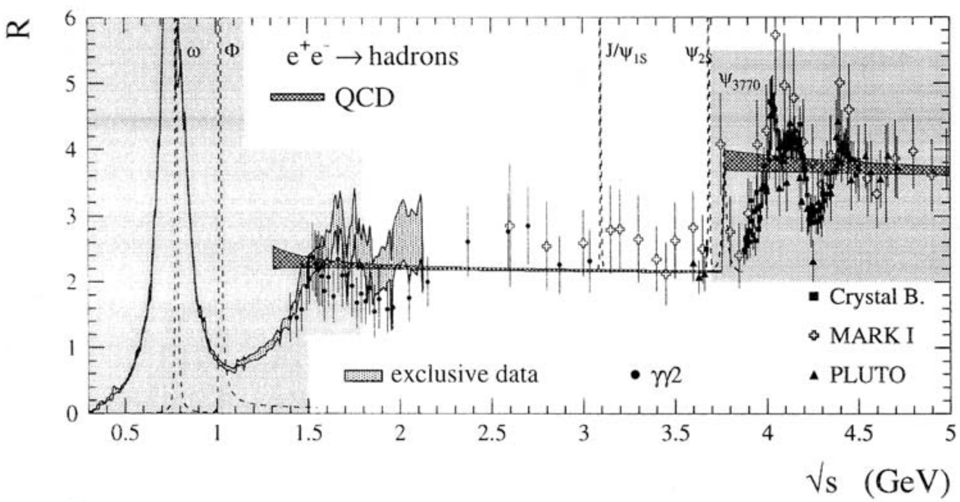
Est. Errors in Published Experiments

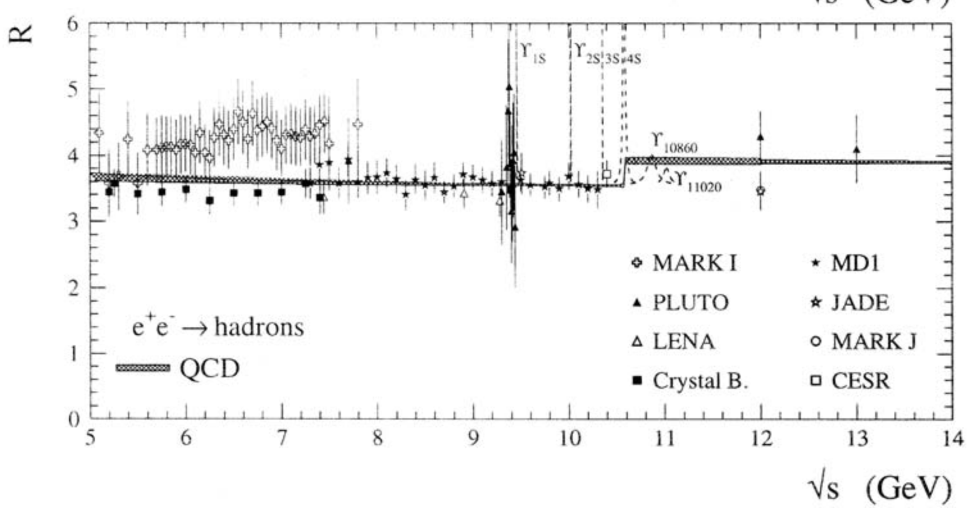
$$R(s) = \frac{N_{hadron}(1-c)}{\varepsilon_{had} * (1+\delta) * L * \sigma_{\mu\mu}}$$

	MarkI (1982)	CBall (1990)	MD-1 (1996)	CLEO (1997)	BES (2001)
$N_{had}(1\text{-}c)$	4.7%	3.4%	5-7%	0.4%	4.1%
L	6%	2.7%	1.9%	1.0%	2.3%
ε_{had}	8%	3.3%	1.8%	0.7%	3.0%
$1+\delta$		1.3%	1.0%	1.0%	1.3%
σ_{syst}	10.6%	4.0%	2.9%	1.8%	4.0%
σ_{stat}	3%	~2%	5-7%	0.3%	2.5%
$s^{1/2}$ (GeV)	4-7.5	4-7.5	7.3-10	10.52	2-5

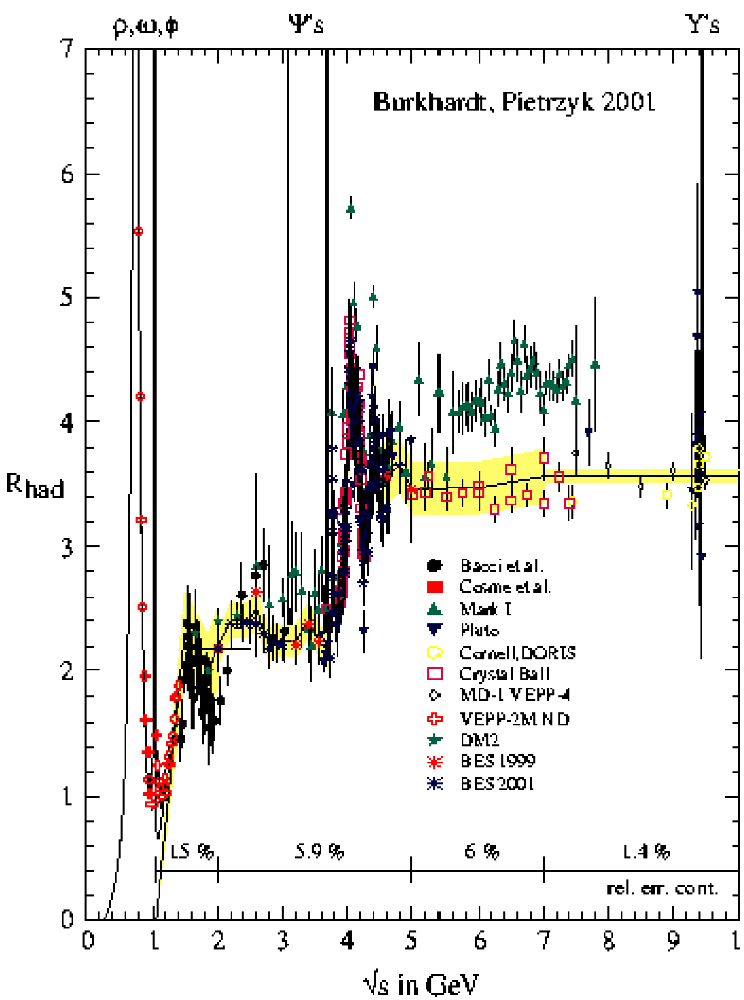
Previous data + input to fit

Davier, Hocker (more pert. QCD)





Burkhardt, Pietrzyk



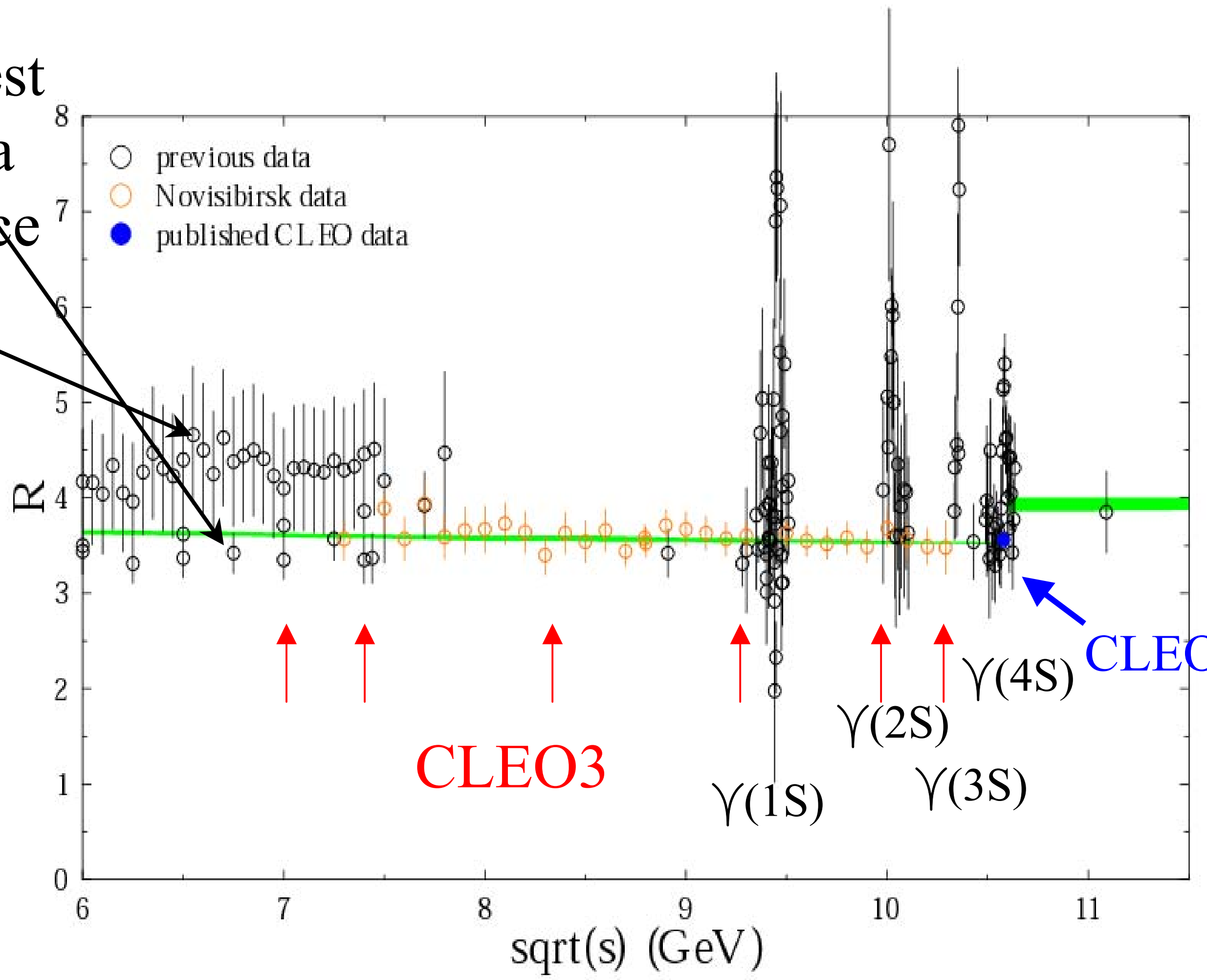
R measurements with CLEO

- Existing data (goal is $\sigma_{syst}<3\%$)
  - 7.0 GeV (2.8 pb^{-1})
  - 7.4 GeV (8.9 pb^{-1})
  - 8.4 GeV (4.6 pb^{-1})
  - 9.4 GeV (194 pb^{-1}) [1S continuum]
  - 10.0 GeV (150 pb^{-1}) [2S cont.]
  - 10.3 GeV (122 pb^{-1}) [3S cont.]
  - 11.2 GeV (721 pb^{-1}) [Λ_b thresh. scan]

- Data to come (?!)
  - Modern R measurement
    - 3.8-4.6 in 10 MeV steps, ~10,000 events per step
    - Measure R to $\lesssim$ 2% accuracy
    - Measure DD, D*D, D*D* content for cc resonant structure
  - Under active consideration for CLEOc!

Previous data + pQCD prediction

- CLEO2 (2%),
  Novosibirsk (5-7%) best
- MARK I vs. Cryst. Ball a long-standing annoyance
- How low in energy is pQCD valid?

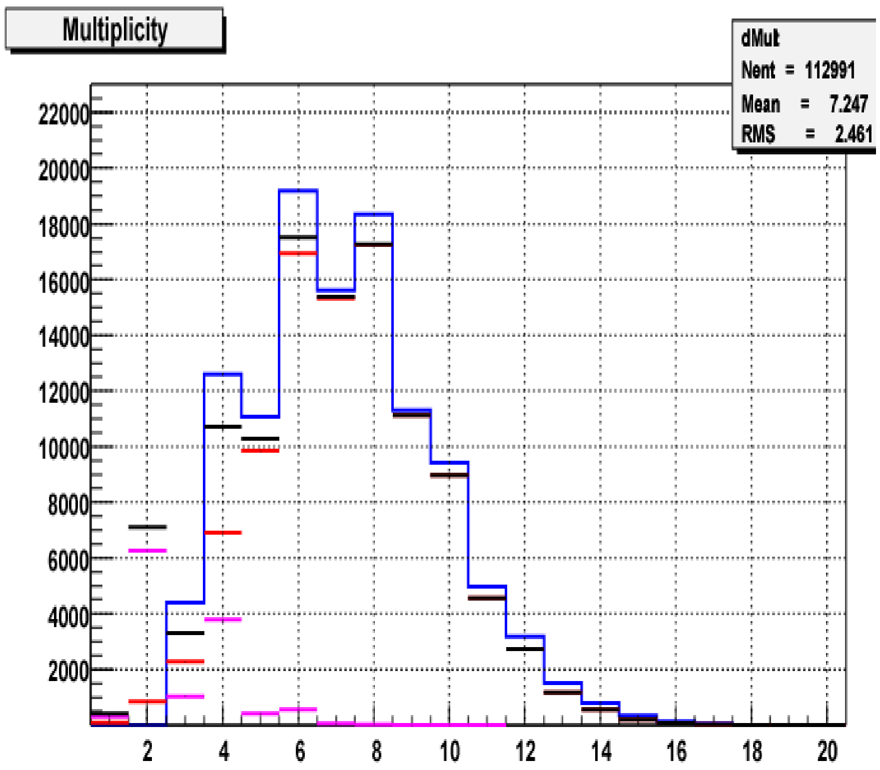


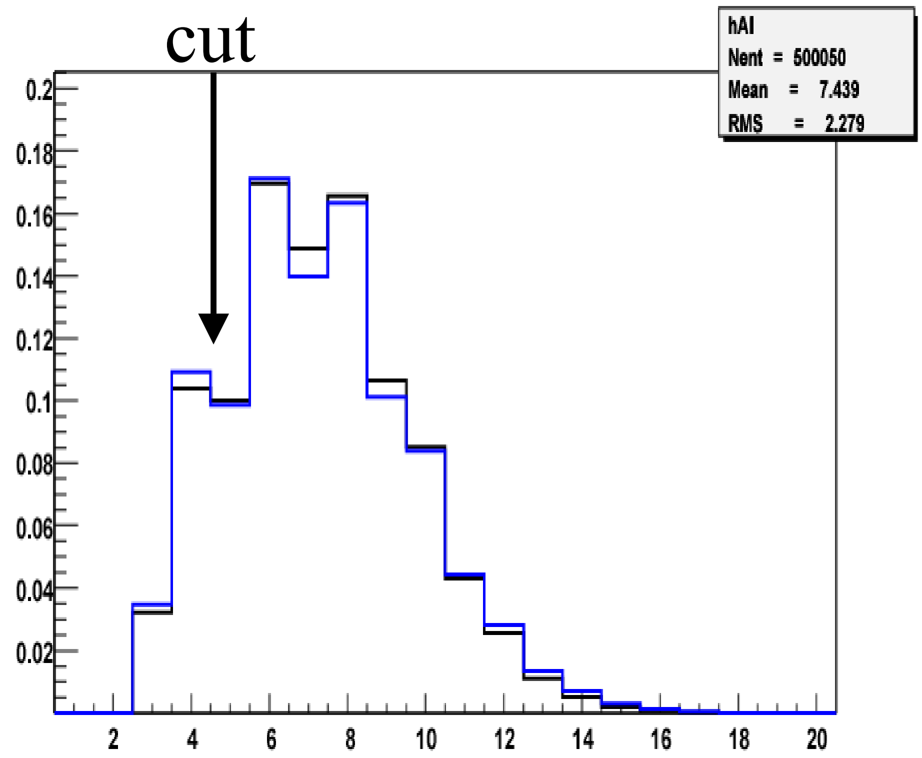
N.B. These are the values given by PDG, stat+syst errors. We really see the need for ϒ CLEO3 measurements!

Analysis

- Inclusive quantities only (e.g. multiplicity, P_z^{miss}, $E_{visible}$, Thrust….)
- Main Backgrounds expected
  - Beam gas/wall (cut)
  - $e^+e^- \rightarrow \tau^+ \tau^-$ (MC)
  - $e^+e^- \rightarrow e^+e^- \gamma\gamma \rightarrow e^+e^-$ hadrons (cut)
- Each cut implies correction, systematic error
- Other corrections=ISR, trigger
- Luminosity a major issue in quest for a small est. error
- Strategy similar to CLEO2 (1997) [σ_{syst}=1.8%]

Charged Particle Multiplicity (10.33 GeV)





BEFORE cuts

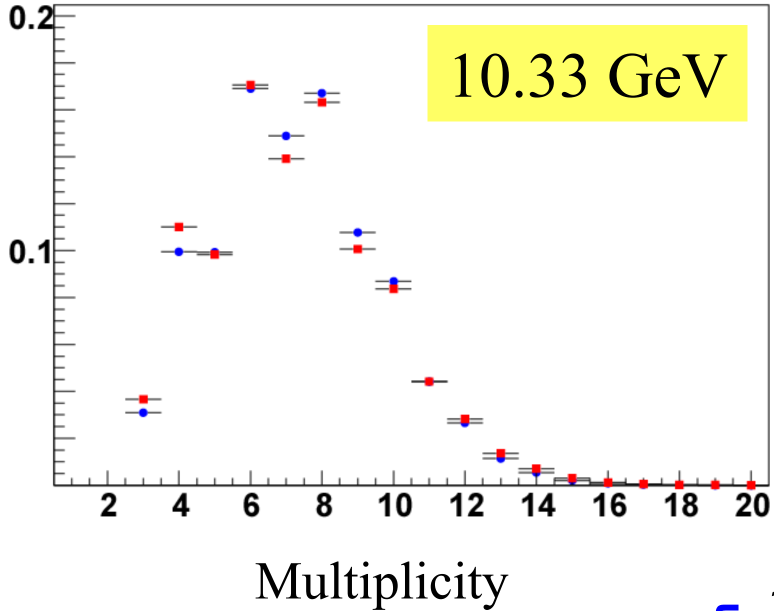
Purple=tau MC, red= cont. MC

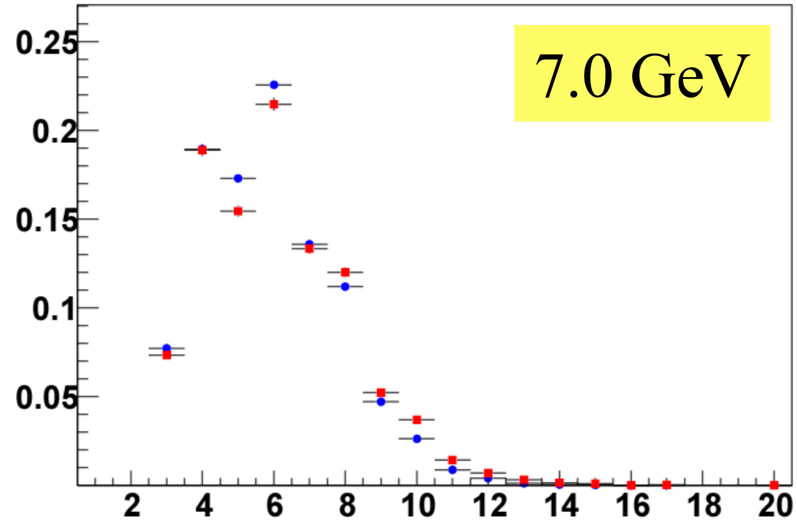
BLUE=data, BLACK=total MC

AFTER cuts

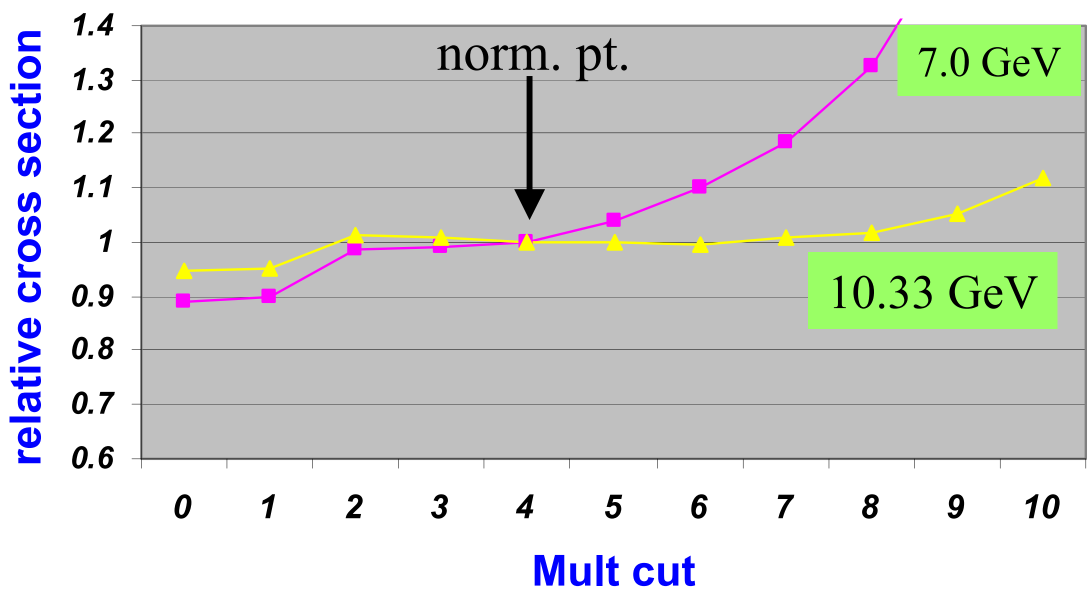
BLUE=data, BLACK=MC

Energy dependence of Multiplicity





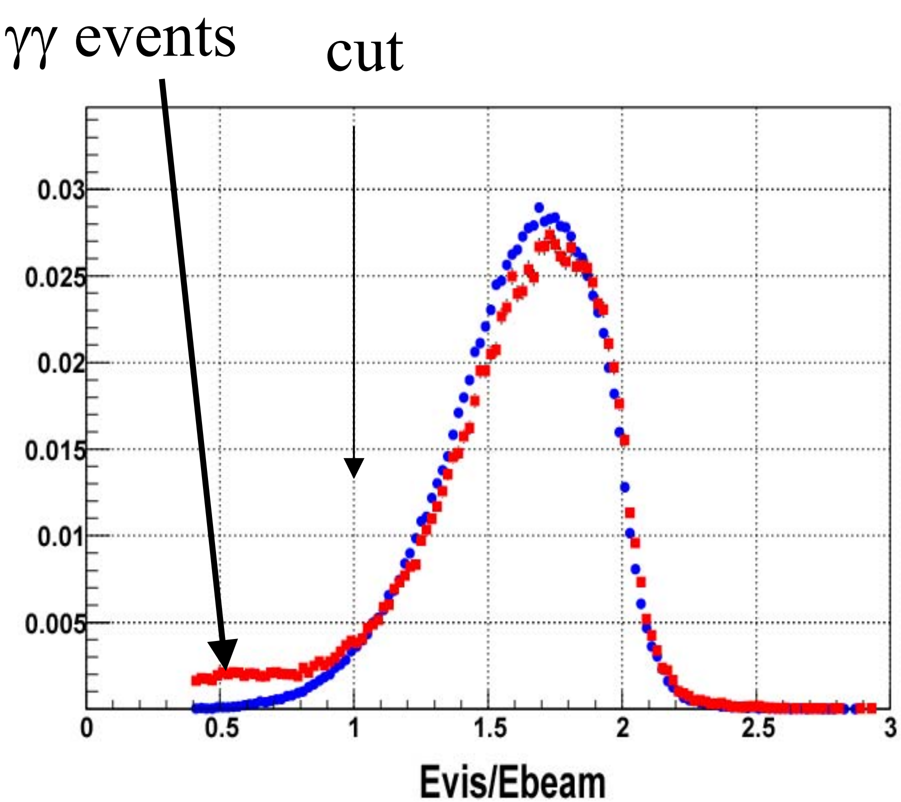
JETSET7.4 not reliable at lower energies, switching to LUARLW (H. Hu-BES).

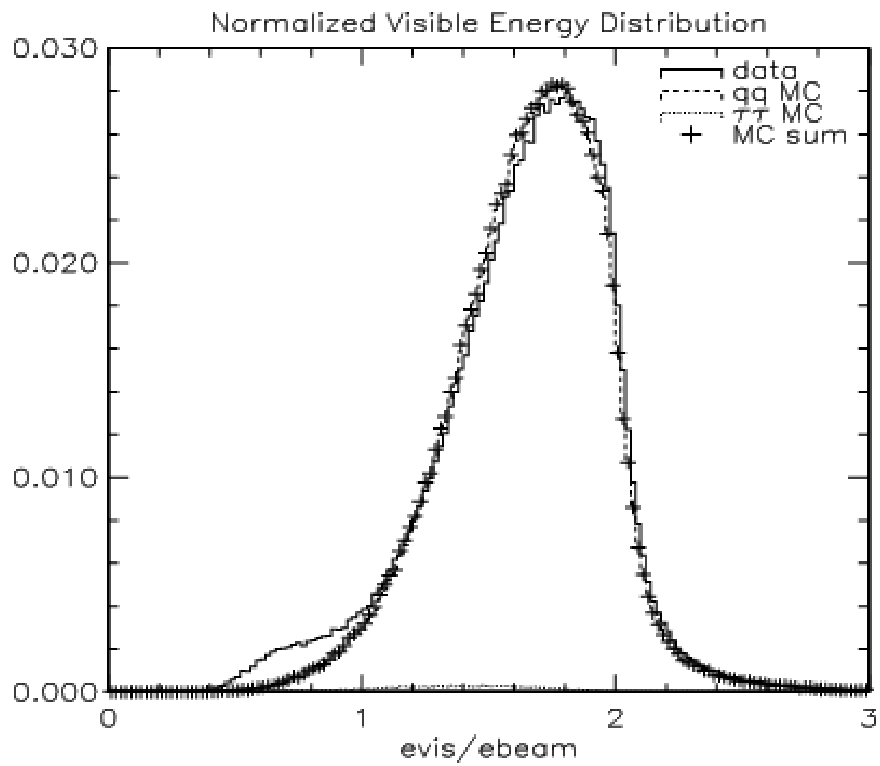


Normalized Total Visible Energy

New CLEO3 data at 10.33 GeV
Blue=MC (τ + cont.)

CLEO2 data at 10.52 GeV

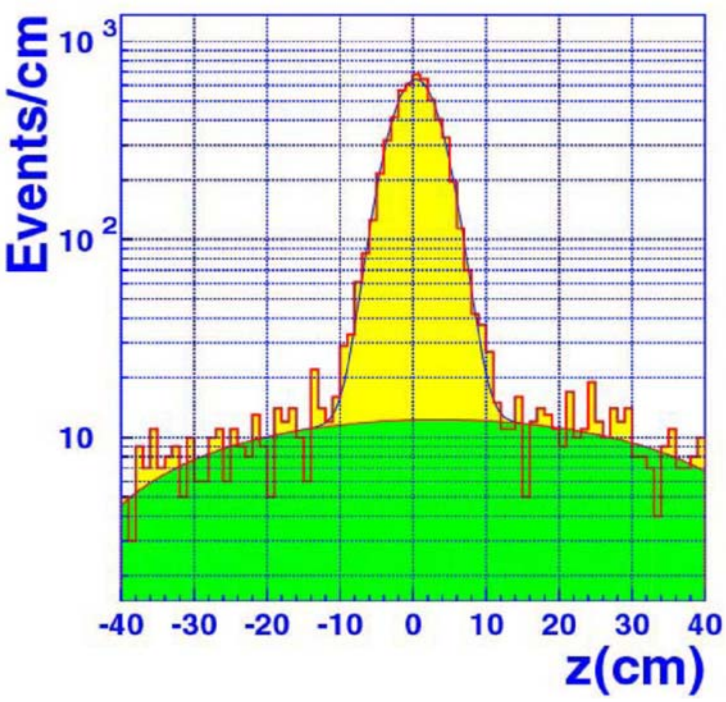




Zvertex (Beam Gas/Wall Background)

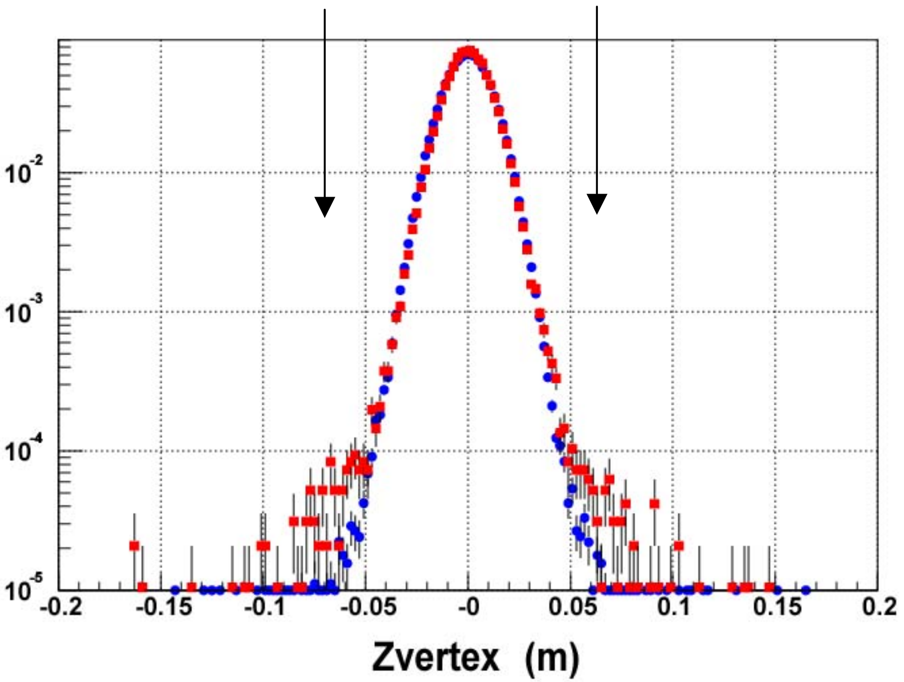
BESII(1999)

RED=data, LT BLUE=MC



CLEO3

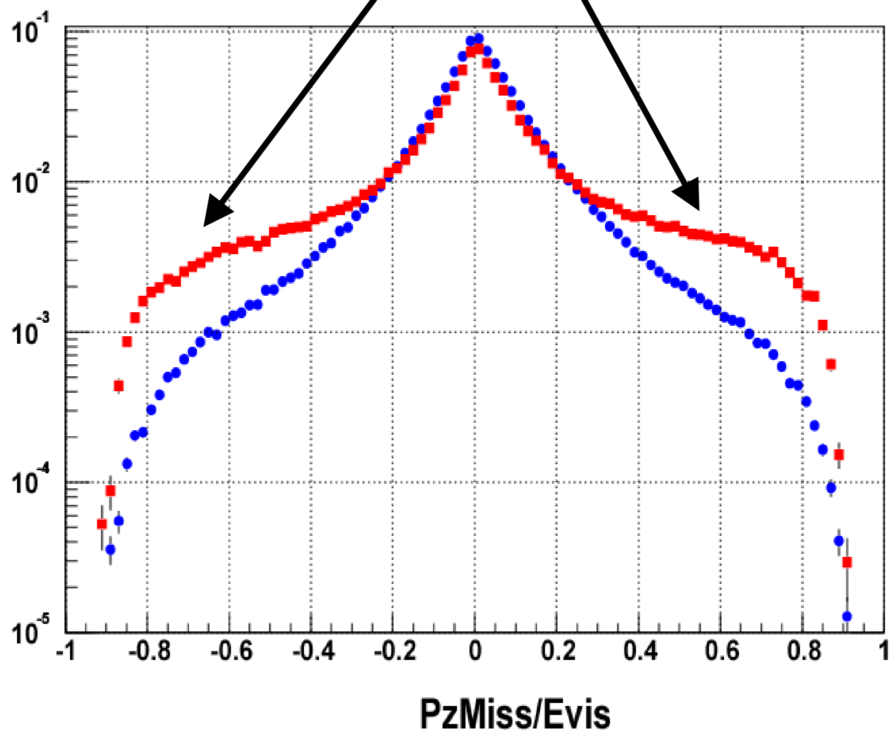
RED= data. BLUE = Monte Carlo



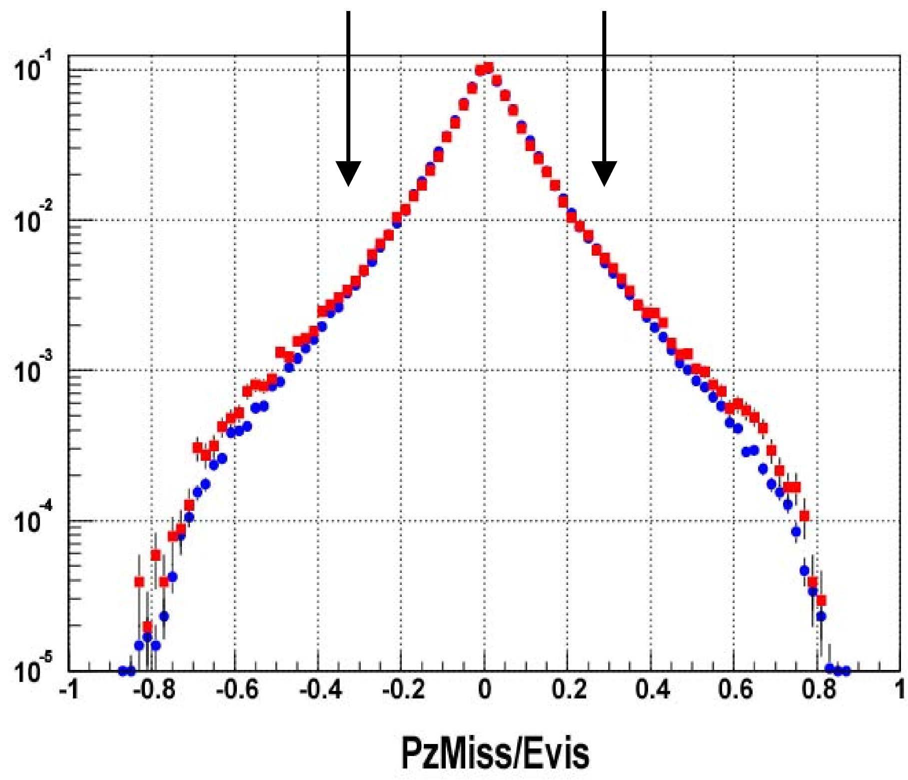
Normalized z-comp. of Missing Mom.

a good "signal" of background

(mostly γγ, some beam gas outside the cut)



BEFORE cuts



AFTER cuts (except Pzmiss)

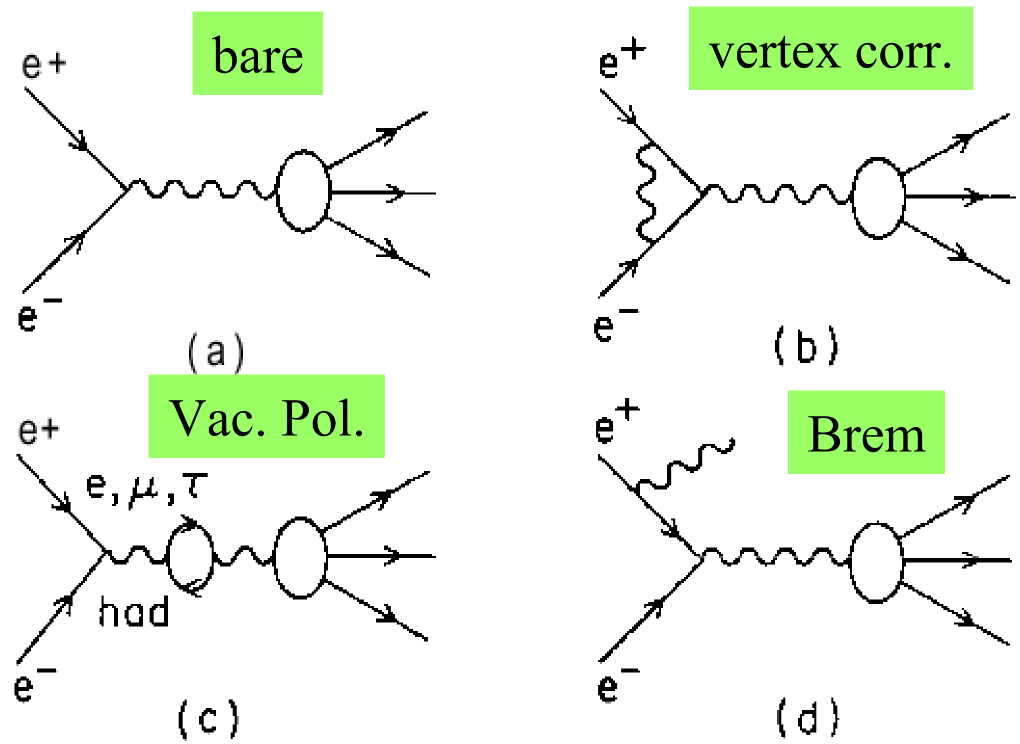
Study systematics of cuts at 10.33, 7.0 GeV

Bkgd	Cut	Good events	ΔR with ±20%	ΔR with ±20%
ττ,γγ,EM	Mult	>4	**0.2%**	**4.0%**
Beam gas	|zvertex|	<6cm	<0.1%	<0.1%
γγ	|Pzmiss|/Evis	<0.3	<0.1%	<0.1%
γγ	Evis/Ebeam	>1.0	**0.2%**	**0.3%**
EM	Charged part. Energy/Eb	<1.1	**0.2%**	**0.8%**
EM	MaxGam/Eb	<0.75	<0.1%	<0.1%
various	R2 (Fox-Wolfram)	<0.9	<0.1%	<0.1%

Initial state radiative correction

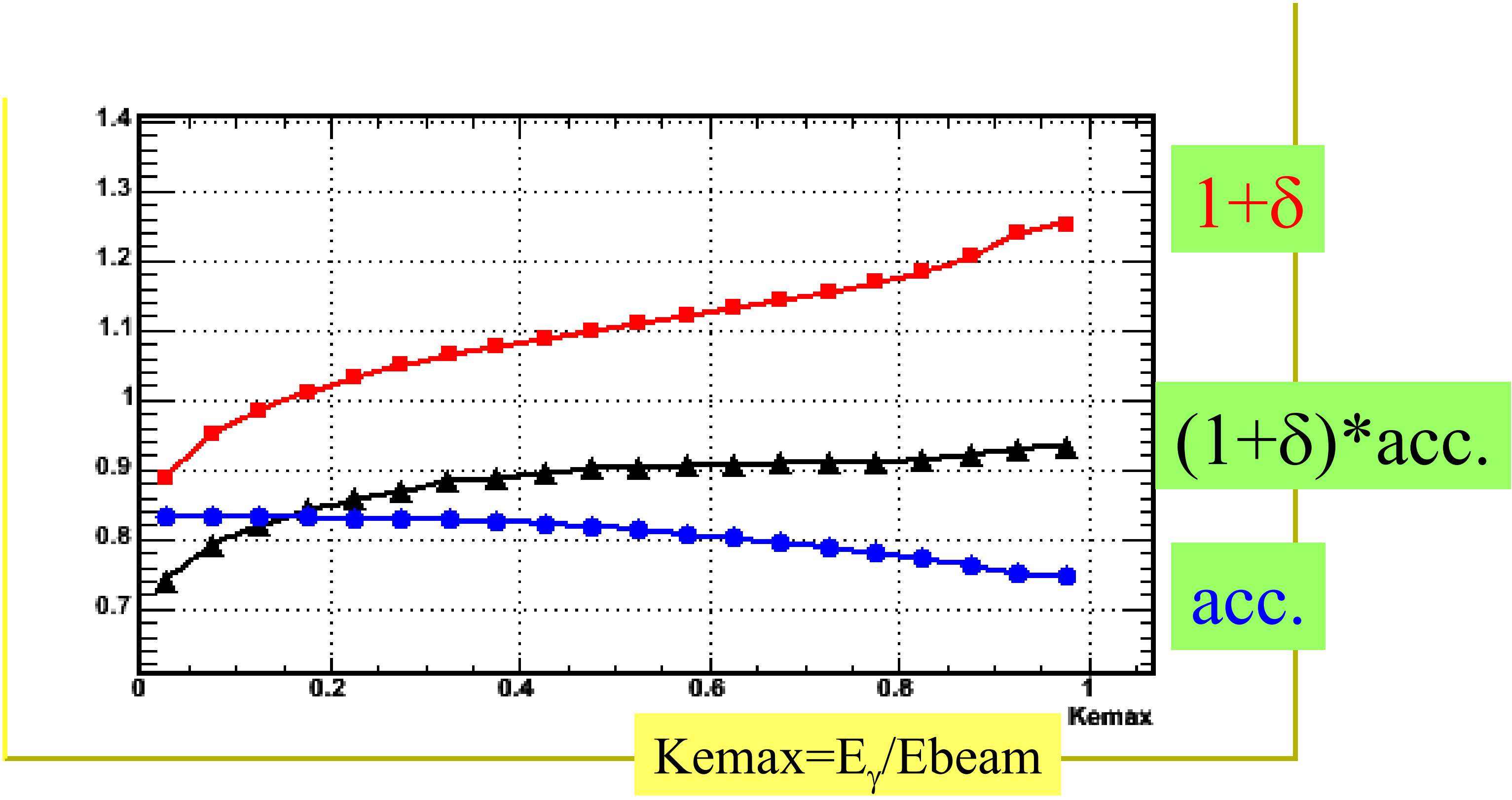
(Interesting- final state radiative corrections are much smaller via Lee-Nauenberg theorem.)

- Diagrams at order α shown here.
- At higher order, (b) and (d) merge.
- Had. vac. pol. and Brem depend on R(s') and detector.
- Calculations incomplete



*Radiative Corr.*Acceptance has a plateau*

Use Jetset7.4 at 10.33 GeV



Estimated Systematic Errors

$\sigma_{syst} \sim \text{sqrt}(\sigma_{\tau}{}^{2} + \sigma_{Pzmiss}{}^{2} + \sigma_{zvert}{}^{2} + \sigma_{acc}{}^{2} + \sigma_{Lumin}{}^{2} + \sigma_{\delta}{}^{2})$

$= \text{sqrt}(0.3\%^{2} + 0.4\%^{2} + 0.5\%^{2} + 3\%^{2} + 3\%^{2} + 2.5\%^{2})$

$= 5.0\%$

CLEO3 not as well understood as CLEO2 at this time,

particularly energy dependence of Monte Carlo!!

Studies of all 3 major components underway.

Preliminary (incomplete) values

$$R(s) = \frac{N_{hadron}(1 - c_{\tau} - c_{\gamma\gamma} - c_{beam-gas/wall})}{\varepsilon_{trigger} * A(1+\delta) * L * \sigma_{\mu\mu}}$$

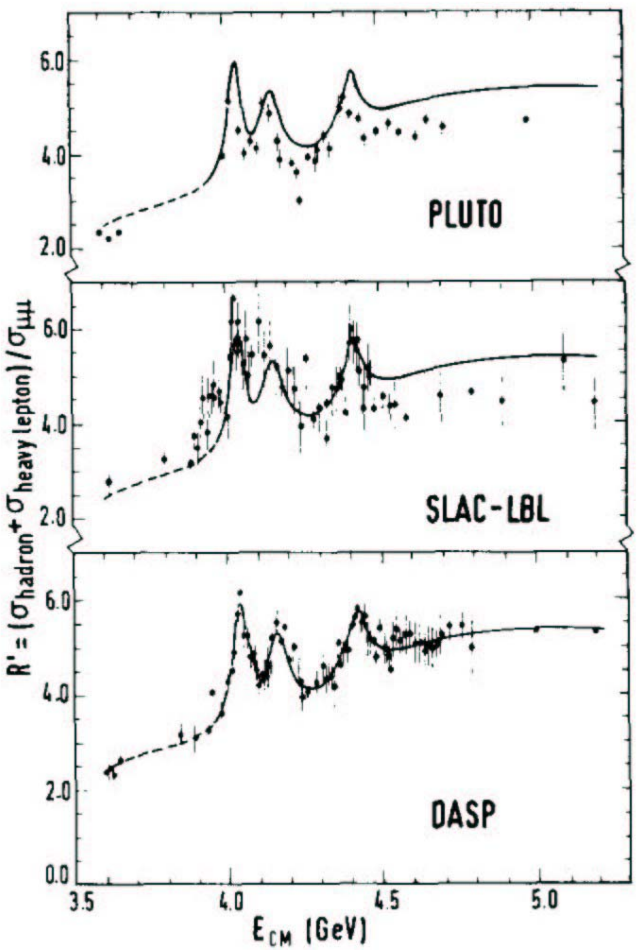
$s^{1/2}$	N_{had}	A	δ	$c_{\tau\tau}$	$c_{\gamma\gamma}$	c_{zv}	L (pb^{-1})	R
10.33	94305	0.77	?	.011	.007	.01	38.5	?
8.38	29812	0.75	?	.012	.005	.01	7.2	?
7.38	35945	0.66	?	.013	.008	.01	8.9	?
6.96	11726	0.63	?	.013	.006	.01	2.7	?

10.33 GeV has special correction for Υ(1S, 2S) ~ 1.7%

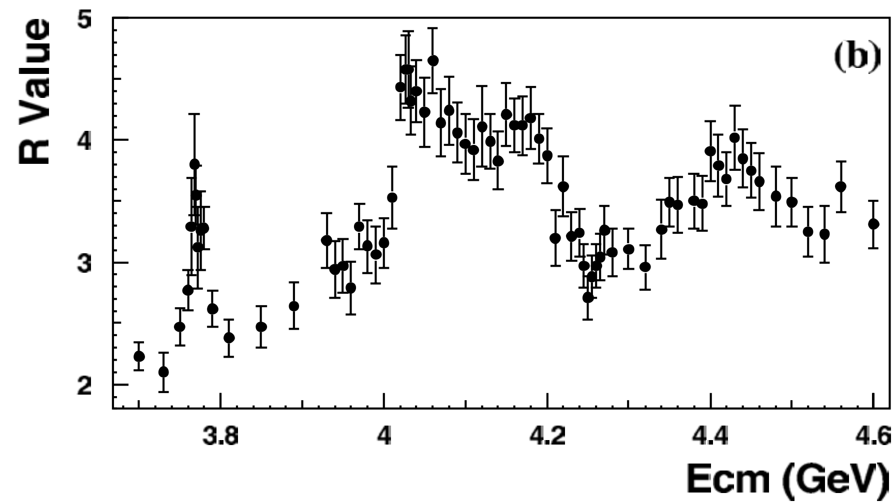
$\varepsilon_{trigger}$= 0.996 (measured at 10.33 GeV)

ψ Spectroscopy above $D\bar{D}$ threshold

Brandelink, et al. (1978)
PEAKS → ψ(4S), ψ(5S), ψ(6S)!!



BES (2001)
Peaks much less obvious



- BES did not measure decays → resonances
- MarkI (1970's) measured
  DD:D*D:**D*D*** =0.2:4:**128** at 4.028 GeV!!!
  (thresh for D*D* at 4.013 GeV)
- Theory (Close, Page) predicts D*D*:DD~1
- BES(1999) data consistent with MarkI
- Requires moderate statistics and good PID

BES & CLEO, past vs. projected

	CLEO2 (1997)	BESII (2001)	CLEO	BESIII
$N_{had}(1\text{-}c)$	0.3%	2-3%	1%	1%
L	1.0%	2-3%	1%	1%
ε_{had}	0.7%	3-4%	1%	1.5-2.5%
$1+\delta$	1.0%	1-2%	1%	1%
σ_{syst}	1.8%	4.0%	2%	2-3%
σ_{stat}	0.3%	2.5%	<1%	-
$s^{1/2}$ (GeV)	10.52	2-5	7-11, 3.7-4.6	3.7-4.1

Understanding error correlations is key!

Challenges for the Future

- Need for R data to settle fundamental physics issues is clear.
- Experimental needs are different than for D decays- no particle ID, emphasis on absolute xsec, need time for energy changes.
- New magnet with larger acceptance important for BES data of highest quality.
- If CLEO-c takes R data, BES can learn from our mistakes and improve error bars.
- If CLEO-c sticks with core program, BES will have this opportunity to itself.
- Getting help from phenomenologists to allow smaller errors in acceptance, radiative corr. important.