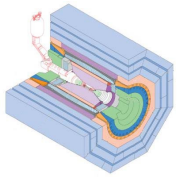
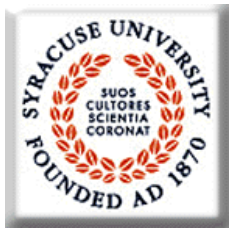


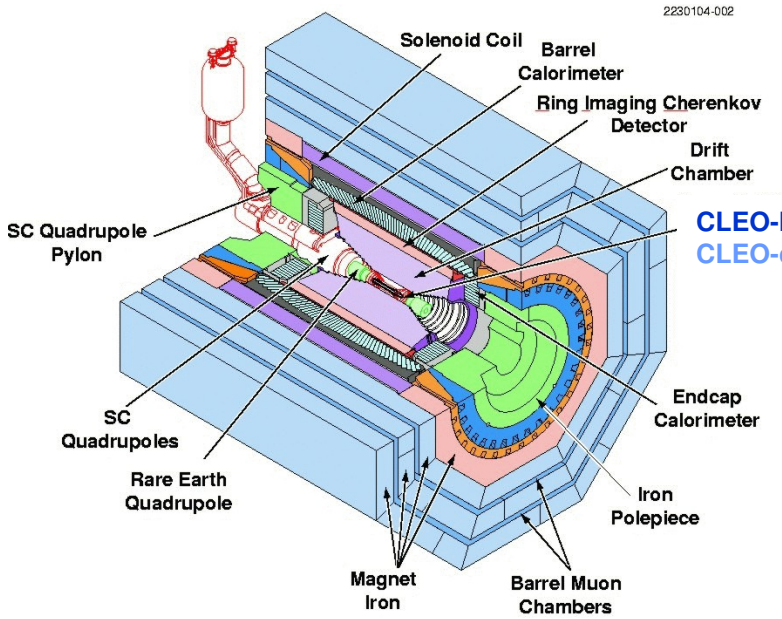
Measurement of R in various energy regions at CLEO

Tomasz Skwarnicki



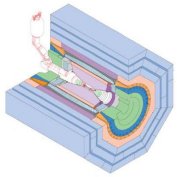
Two recent papers

- CLEO-III data ($s^{1/2}$ =6.96–10.54 GeV):
  - "Measurement of the Total Hadronic Cross Section in e^+e^- Annihilations Below 10.56 GeV", D. Besson et al., Phys. Rev. D76, 072008 (2007)
- CLEO-c data ($s^{1/2}$ =3.97-4.26 GeV) :
  - "Measurement of Charm Production Cross Sections in e^+e^- Annihilation at Energies between 3.97 and 4.26 GeV", submitted to Phys. Rev. D, arXiv:0801.3418 (2008)



CLEO-III: Silicon Vertex Detector; B=1.5T
CLEO-c: Inner Drift Chamber; B=1.0T

CESR-b (10.6 GeV): $L=1.2\ 10^{33}\ cm^{-2}s^{-1}$
CESR-c (4.0 GeV): $L=0.7\ 10^{32}\ cm^{-2}s^{-1}$



Motivation

$$R(s)=\frac{\sigma_o(e^+e^-\to hadrons)}{\sigma_o(e^+e^-\to\mu^+\mu^-)}$$

- R(s) in the continuum (the high-s data):
  - Test predictions of perturbative QCD for α_s dependence

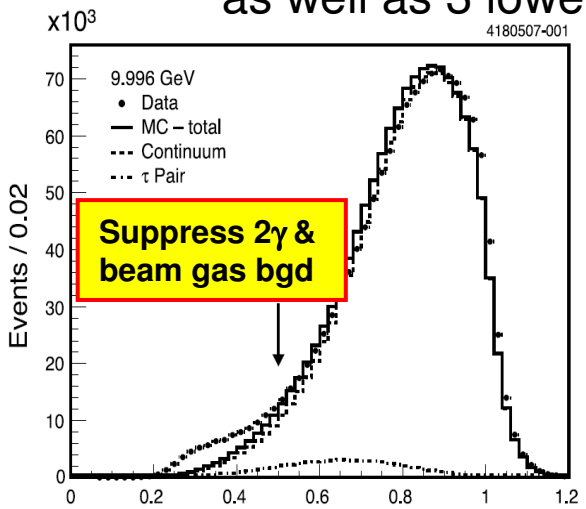
$$R(s)=R_0\left[1+C_1\frac{\alpha_s(s)}{\pi}+C_2\left(\frac{\alpha_s(s)}{\pi}\right)^2+C_3\left(\frac{\alpha_s(s)}{\pi}\right)^3+O\left(\alpha_s^4(s)\right)\right]$$

C_1=1, C_2=1.525 and C_3= −11.686

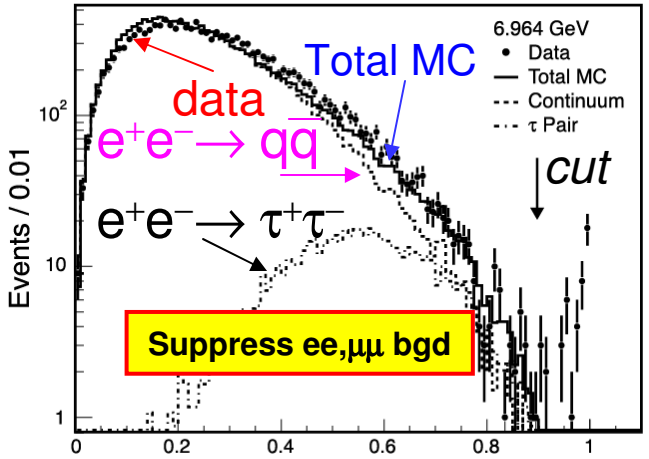
- R(s) in the resonance region (the low-s data):
  - needed for dispersion integrals of hadronic vacuum polarization (matters for g-2, $\alpha_{QED}(s)$ used in fits of the SM higgs mass to the precision EW data, precision QED MC generators for $e^+e^-\to l^+l^-$,…)
- Present also exclusive & inclusive open charm decomposition in the low-s data:
  - test phenomenological models, contribute to classification of resonances in this region

Selection of events (high-s data)

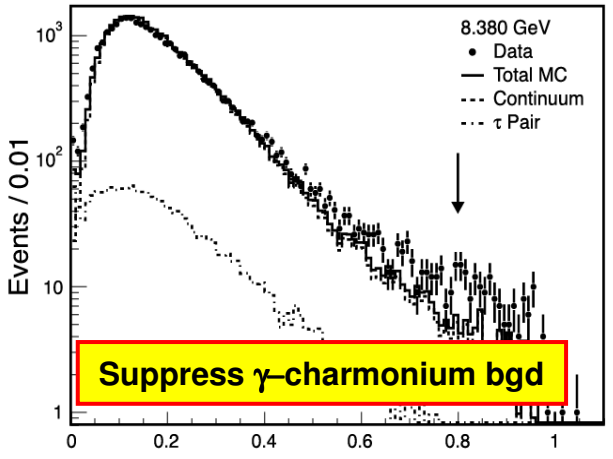
Use CLEO III "continuum" points just below $\Upsilon(4S)$, $\Upsilon(3S)$, $\Upsilon(2S)$, $\Upsilon(1S)$ as well as 3 lower energies



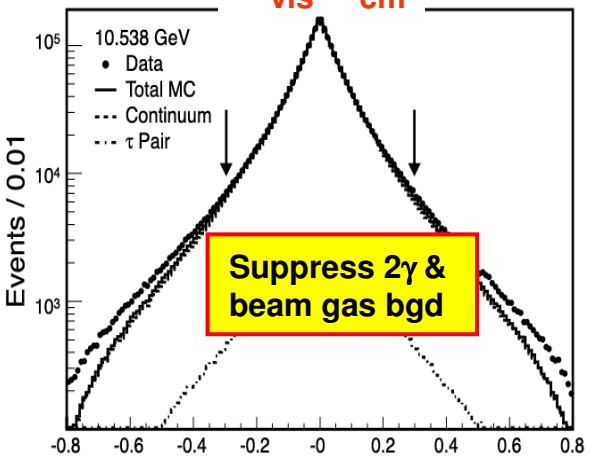
E_{vis}/E_{cm}



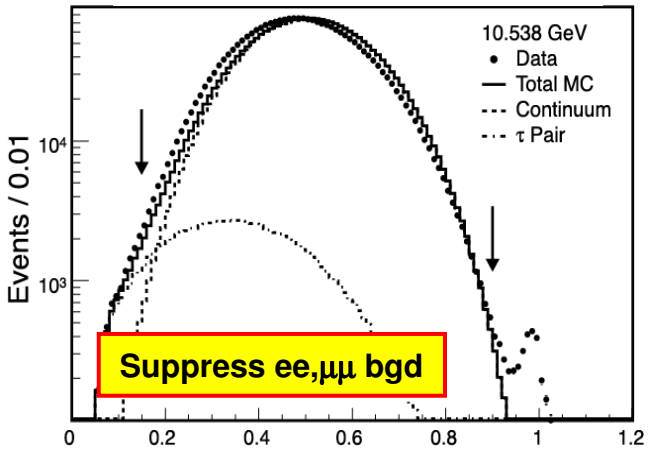
H_2/H_0 (Event Shape)



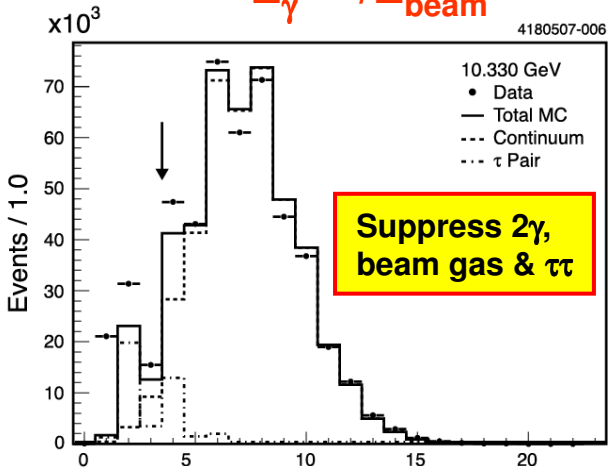
E_γ^{max}/E_{beam}



P_Z^{miss} / E_{vis}

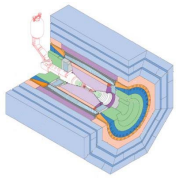


$E_{calorim}/E_{cm}$



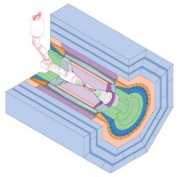
charged tracks

Suppress backgrounds by cutting loosely around the edges



Data Analysis

- Correct for the remaining $e^+e^- \to \tau^+\tau^-$ background
- Correct for tails of narrow lower mass resonances (0.03-2.1%)
- Correct for energy-dependent efficiency (82-88%)
- Make radiative corrections
- Measure luminosity for normalization (using $e^+e^- \to \gamma\gamma, e^+e^- \to \mu^+\mu^-, e^+e^- \to e^+e^-$)
- Evaluate systematic errors



Systematic Errors

Errors given in %

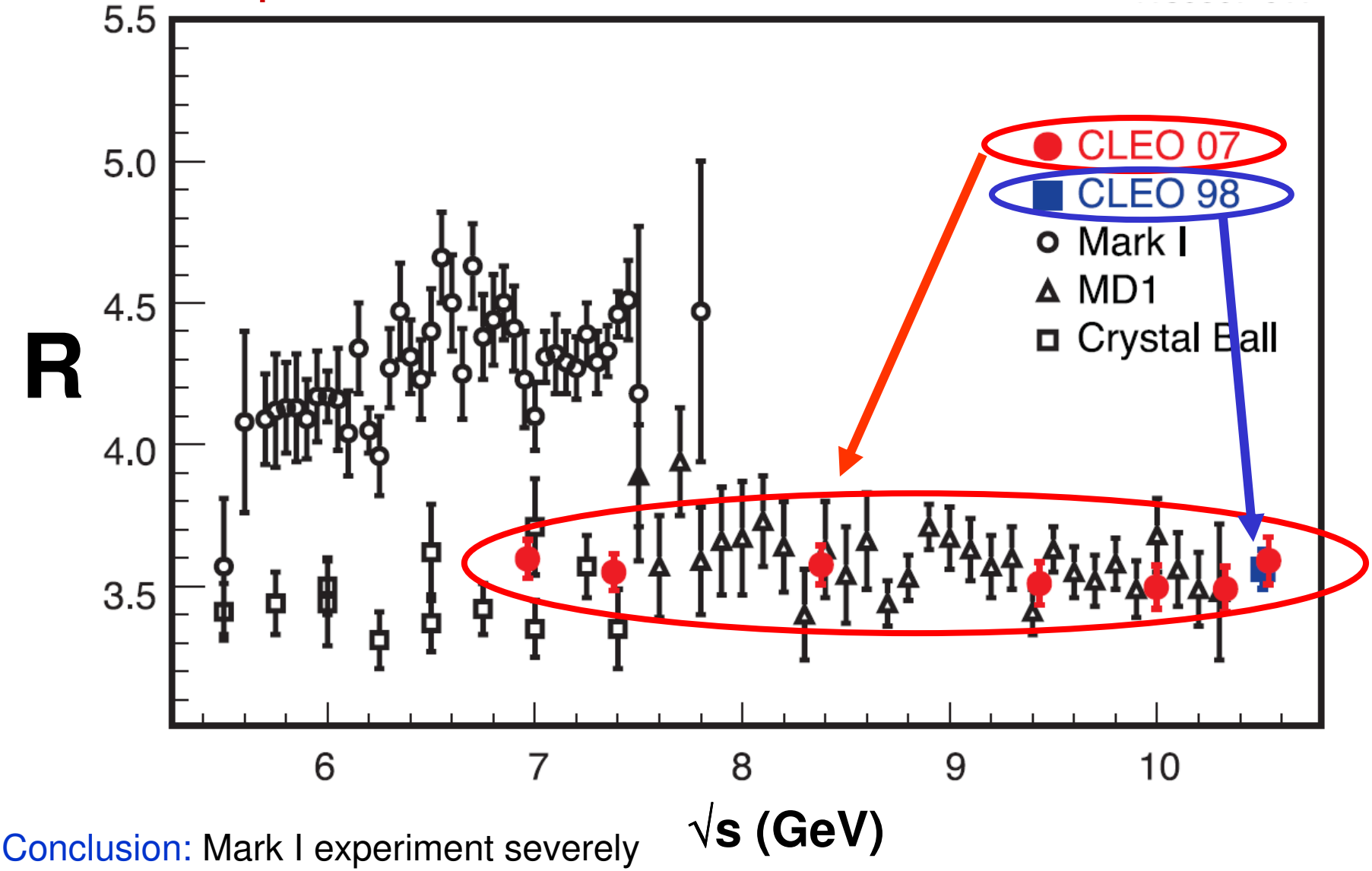
Energy (GeV)	10.538	10.330	9.996	9.432	8.380	7.380	6.964
Luminosity	1.00	1.10	1.10	1.10	0.90	0.90	1.00
Trigger	0.09	0.09	0.11	0.08	0.12	0.13	0.19
Radiative Correction	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Multiplicity Correction	1.06	1.38	0.99	0.84	0.43	0.38	0.38
Event selection (eff+bgd)	1.51	1.09	1.31	1.31	1.05	1.02	0.79
Total	2.32	2.30	2.21	2.15	1.76	1.74	1.68
Common	1.87	1.67	1.85	1.87	1.62	1.64	1.58
Uncorrelated	1.37	1.59	1.22	1.05	0.70	0.57	0.55

Sources of error spread around

~2%

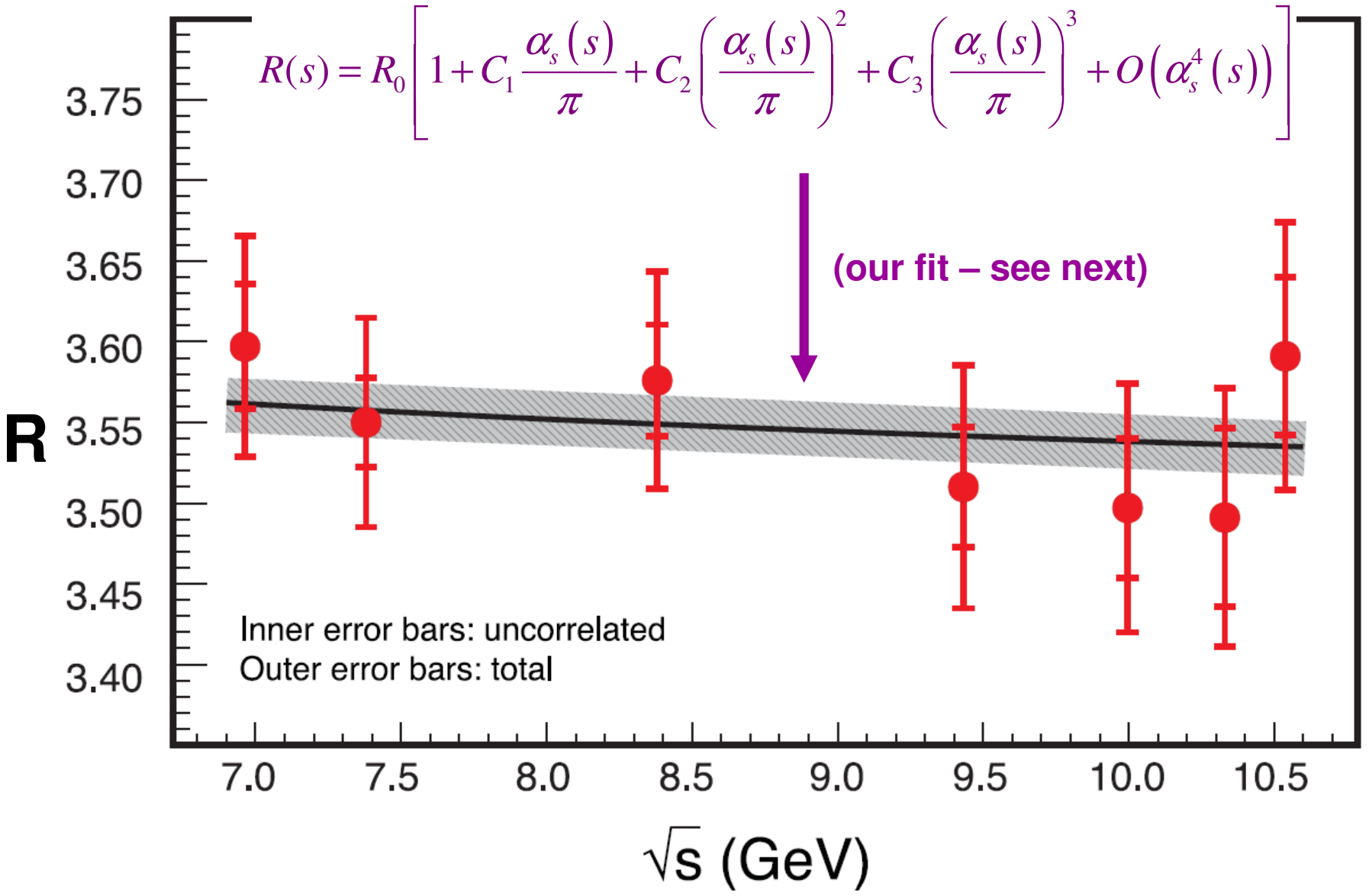
Mostly common

Comparison with other R Measurements



Conclusion: Mark I experiment severely underestimated its systematic errors

CLEO R Results



Test of QCD corrections

- Quantify the test with a α_s value
- Our determination, using massless quarks and 4-quark flavors: $\alpha_s\left(M_Z^2\right) = 0.126 \pm 0.005^{+0.015}_{-0.011}$

~14%

- Different theoretical approach, using quark mass effects & matching between 4 & 5 flavor effective theories

  J.H. Kuhn, M. Steinhauser and T. Teubner, Phys. Rev. D76, 074003 (2007)

$$\alpha_s\left(M_Z^2\right) = 0.110^{-0.010\,+0.010}_{-0.012\,-0.011}$$

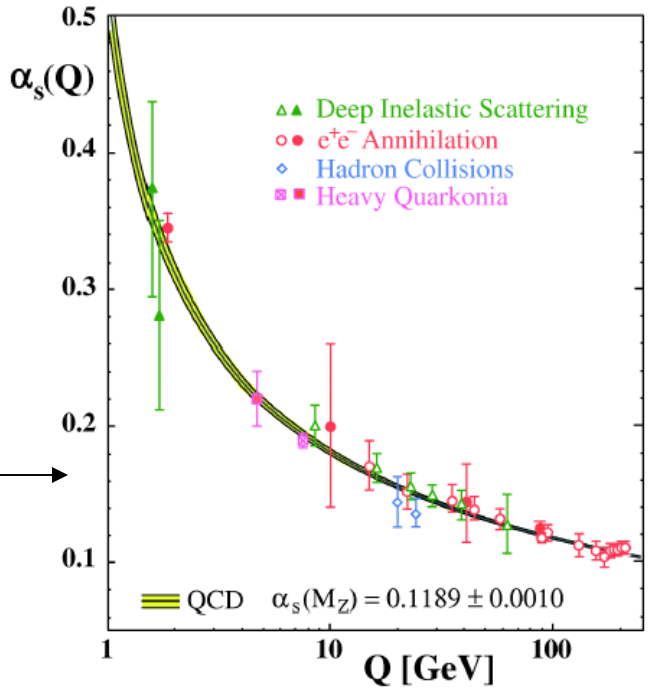
Different by ~13%

- Both consistent with the world average determination

  S. Bethke, Prog. Part. Nucl. Phys. 58, 351 (2007)

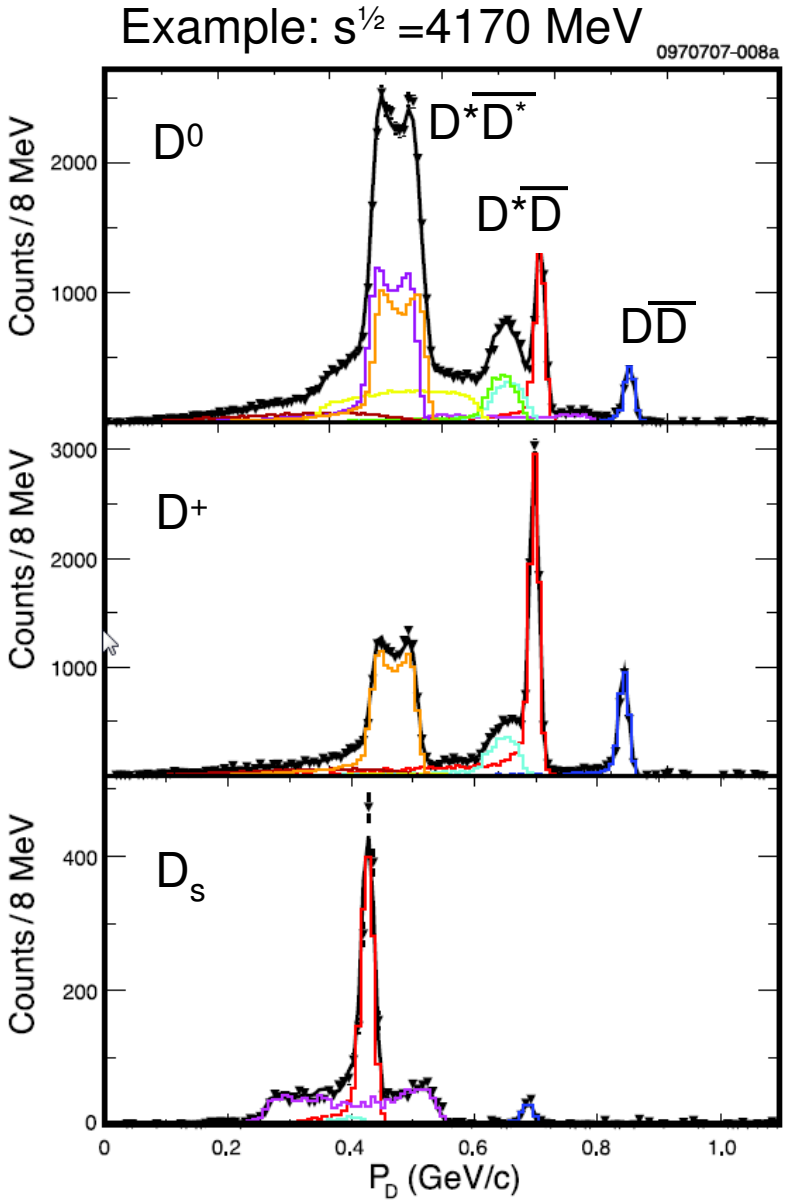
$$\alpha_s\left(M_Z^2\right) = 0.1189 \pm 0.0010$$

~1%



Low-s data: resonant region above ψ(3770)
Decomposition of charm cross-section

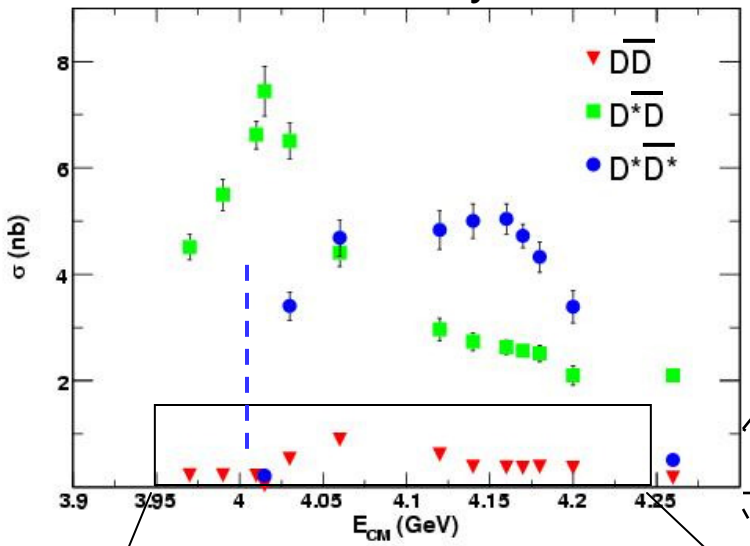
- Find candidate with ±15MeV of the nominal $D^{(0,+,}_{s)}$ mass among: $D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, $D_s \to \phi(K^-K^+)$ $(\pi^+$ or $\rho^+)$, $\eta(\gamma\gamma)$ $(\pi^+$ or $\rho^+)$, $K^{*0}(K^-\pi^+)\pi^+$, …(8 D_s modes)
- For each s-scan point, fit mass-sideband subtracted momentum spectrum of the $D^{(0,+,}_{s)}$ candidates to determine production channel



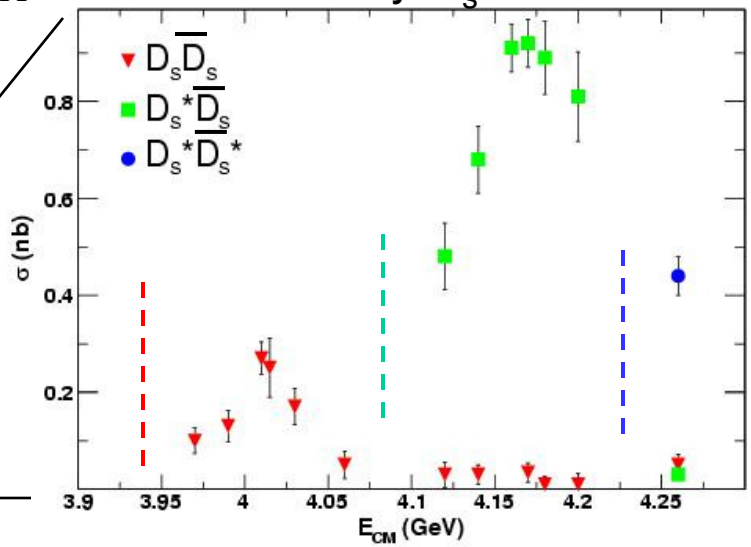
Exclusive Charm Cross Sections

Consistent with Belle's and BaBar's ISR-data arXiv:0801.3132, 0607083

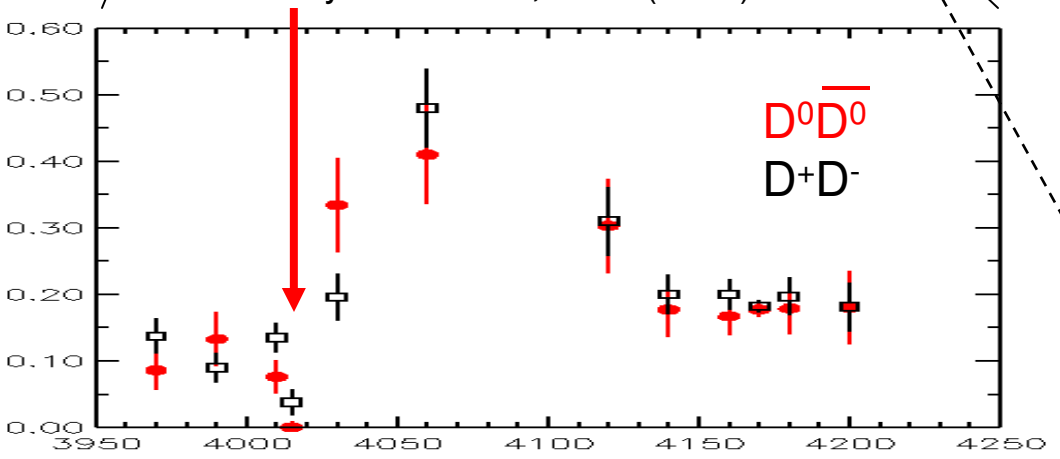
2-body



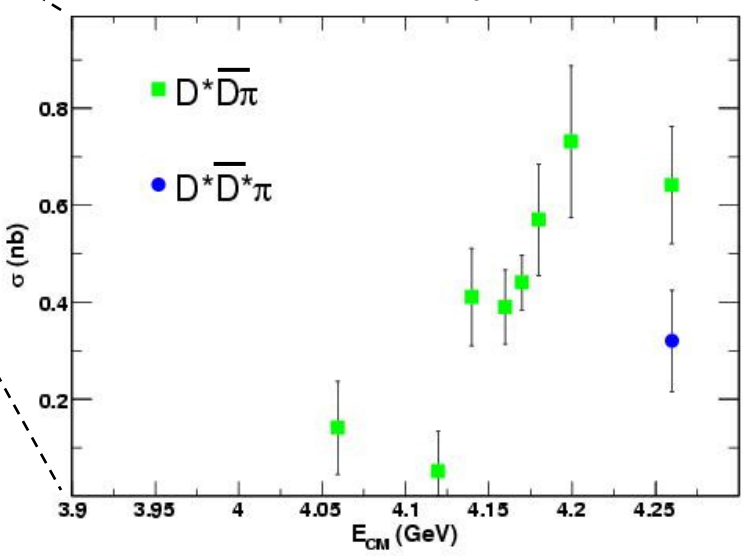
2-body D_s



Narrow resonance at 4015 MeV showing up as destructive interference? Dubynskiy & Voloshin Mod. Phys. Lett. A21, 2779 (2006)

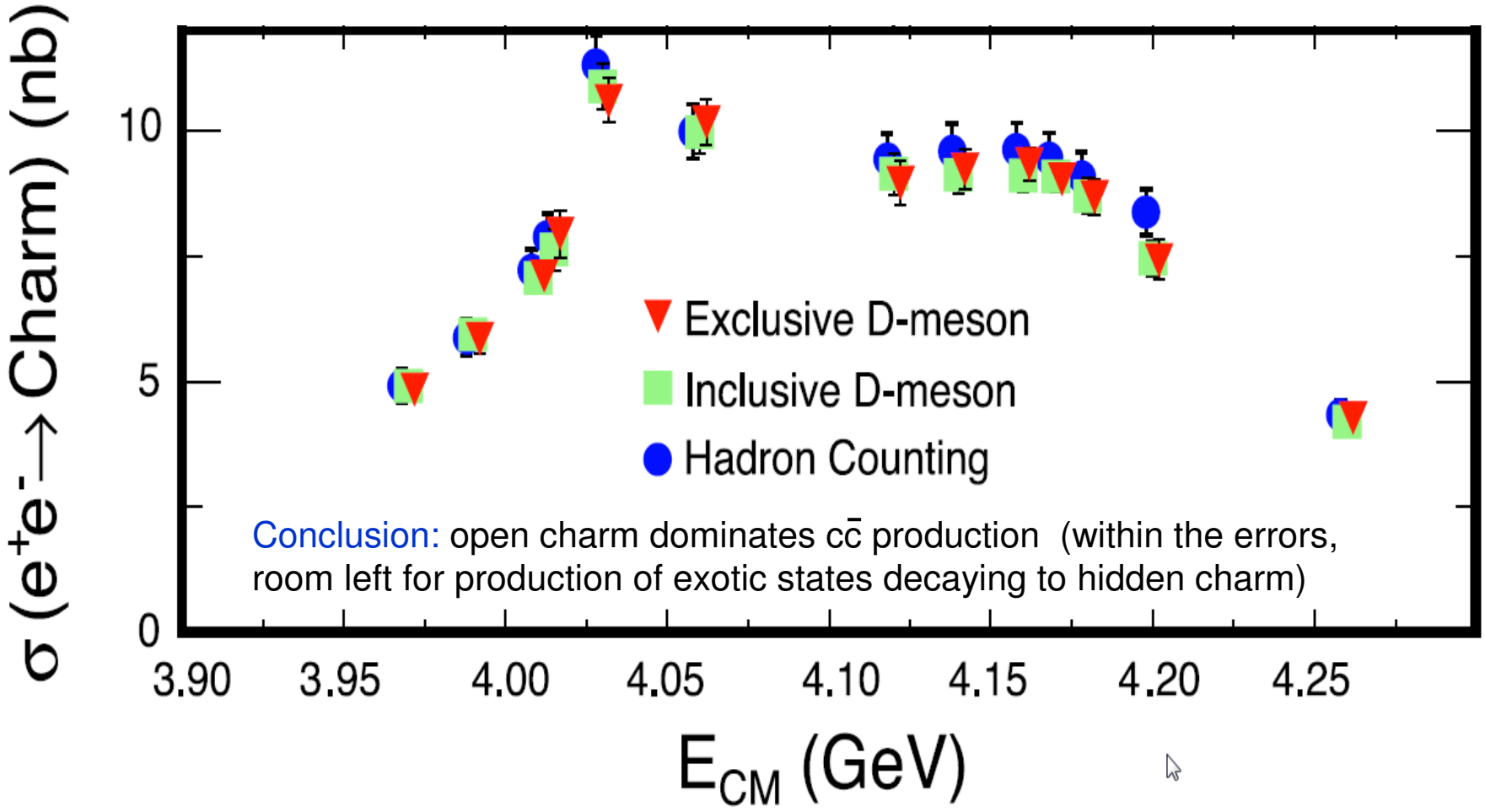


3-body



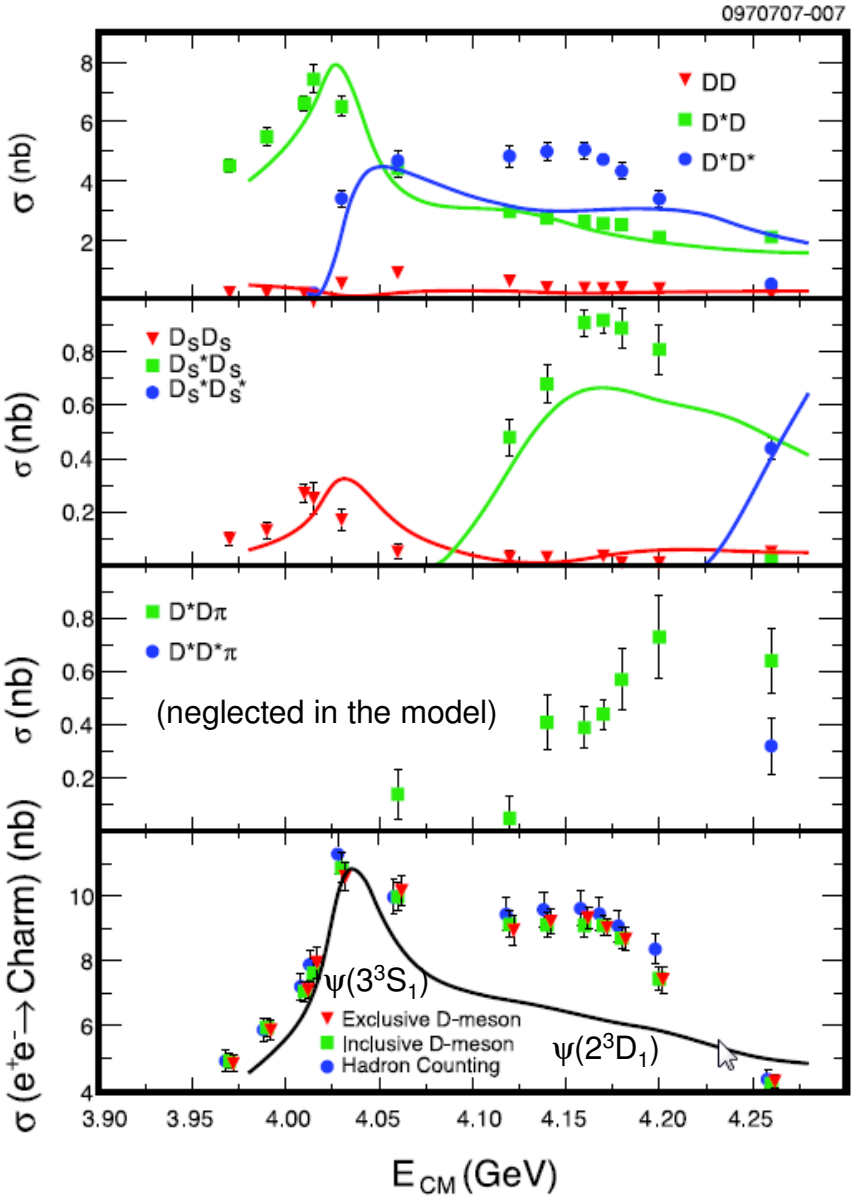
Inclusive Charm Cross Section

- Exclusive D-meson: sum of all determined exclusive cross-sections
- Inclusive D-meson: sum of inclusive D^0,D^+,D_s divided by 2
- Hadron Counting: like the analysis of the high-s data
  - Subtract uds contribution from the scaled continuum data taken below $\psi(2S)$
  - Subtract tails of the J/ψ,$\psi(2S)$,$\psi(3770)$ resonances



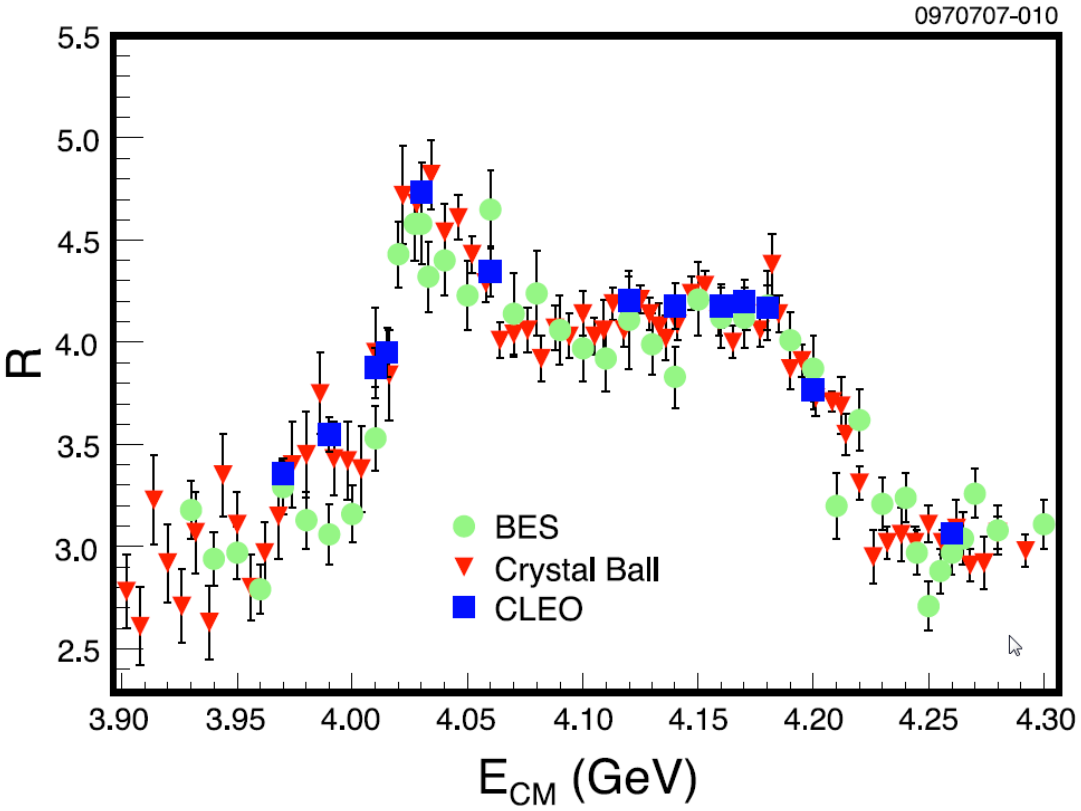
Comparison to coupled-channel potential model by Eichten et al

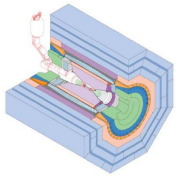
- Model (solid lines):
  - E. Eichten, K. Gottfried, T. Kinoshita, K.D. Lane, T.M. Yan, Phys. Rev. D21, 203 (1980)
  - Updated predictions presented at QWG workshop at BNL, June 2006
  - Different particle momenta in various decay channels probe different parts of the wave functions (nodes!) of 3S and 2D states, on top of opening $D(^*_s)D(^*_s)$ thresholds, spin counting factors and $(m_{u,d}/m_s)^4$ suppression of D_s production
- Reasonable qualitative agreement for most of the exclusive channels



R(s) in charm threshold region

- Use the inclusive charm cross-section determined via the hadron counting method
- Add back uds contribution from a 1/s fit to the world data on R(s) in 3.2-3.72 GeV range (2.285 ±0.03 nb)
- Apply radiative corrections





Summary

- Precise R measured for E_{cm}=6.96–10.54 GeV
  - Region of no structure as expected
    - Perturbative QCD corrections verified within the experimental and theoretical errors
  - Most precise; removes any doubts about old Mark I points
- Exclusive & inclusive charm for E_{CM}=3.97-4.26 GeV
  - Region of many thresholds & much structure
    - We have exclusively deconstructed its composition
    - Multi-body open charm measured for the first time
    - This deconstruction is useful input for model builders
      - Qualitative agreement with the coupled channel potential model predictions by Eichten et al.
  - Precision of R is improved at 13 points