Measurement of R at CLEO

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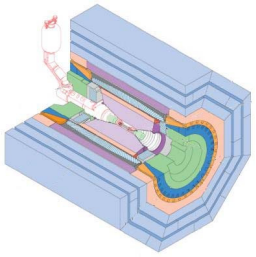
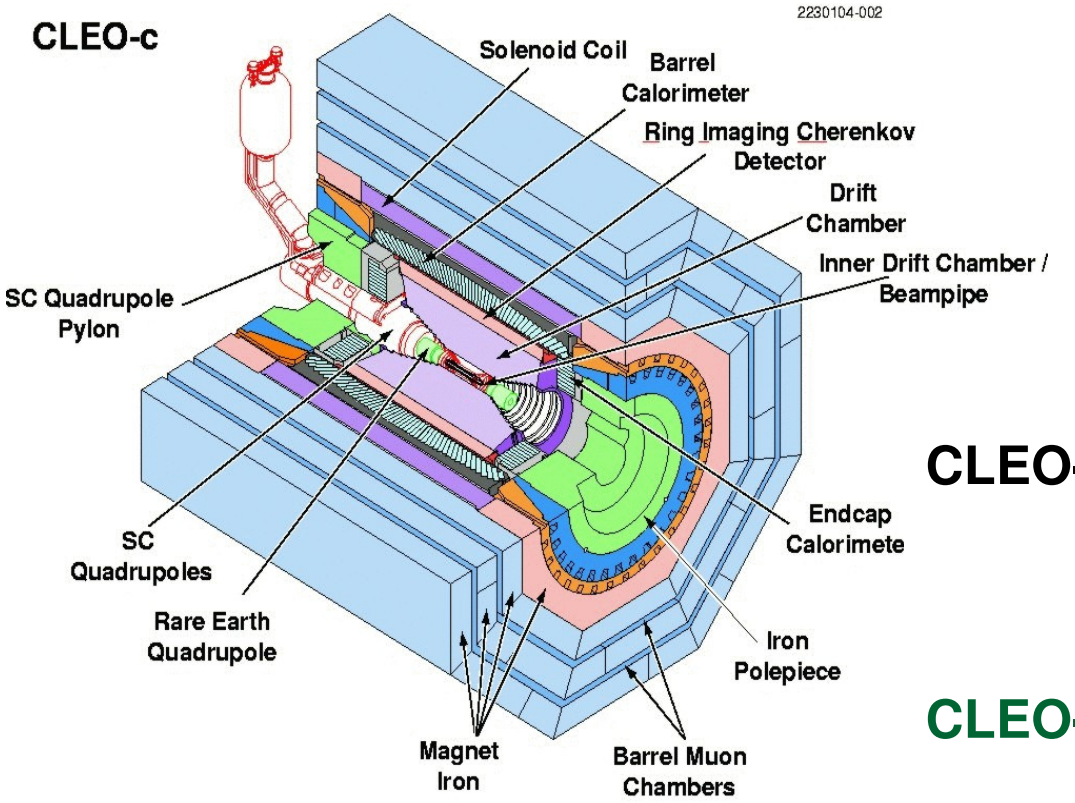


Outline

- CLEO-III and CLEO-c
- Motivation
- Two recent results
  - 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)
- Conclusion

CLEO-III(c) and CESR-b(c)

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



CLEO-III: Silicon Vertex Detector; B=1.5T

Improve low-p tracking

CLEO-c: Inner Drift Chamber; B=1.0T

Motivation

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

- R(s) in the continuum ($s^{1/2}$ = 6.96-10.54 GeV): **CLEO-III**
  - determine α_s

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

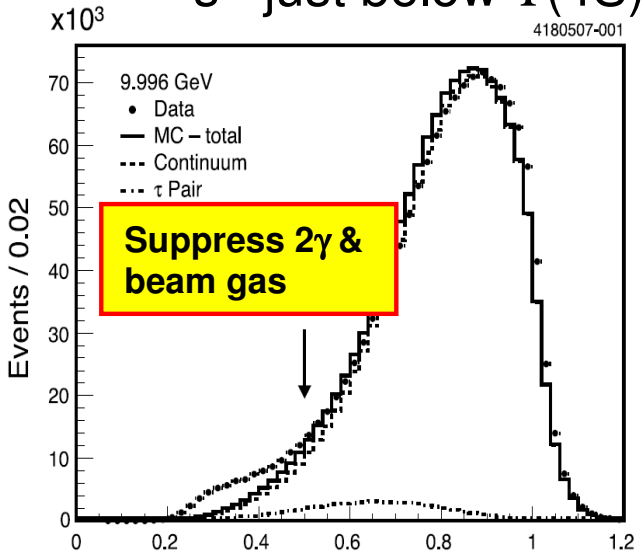
C_1=1, C_2=1.525 and C_3= −11.686

- R(s) in the resonance region ($s^{1/2}$ = 3.95-4.25 GeV):
  - needed for dispersion integrals of hadronic vacuum polarization
    - g-2,
    - $\alpha_{QED}(s)$ used in fits to SM Higgs and **CLEO-c**
    - precision QED MC generators for $e^+e^- \to l^+l^-$
- In addition, exclusive & inclusive open charm final state decomposition

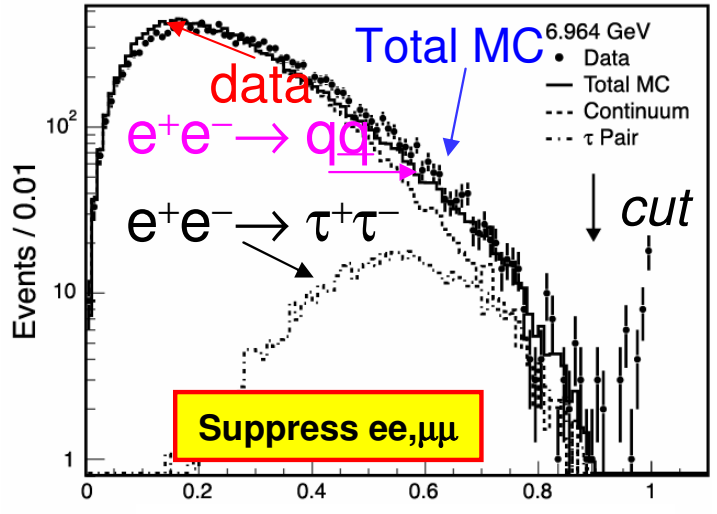
CLEO-III - $s^{1/2}$ =6.96–10.54 GeV

Event selection

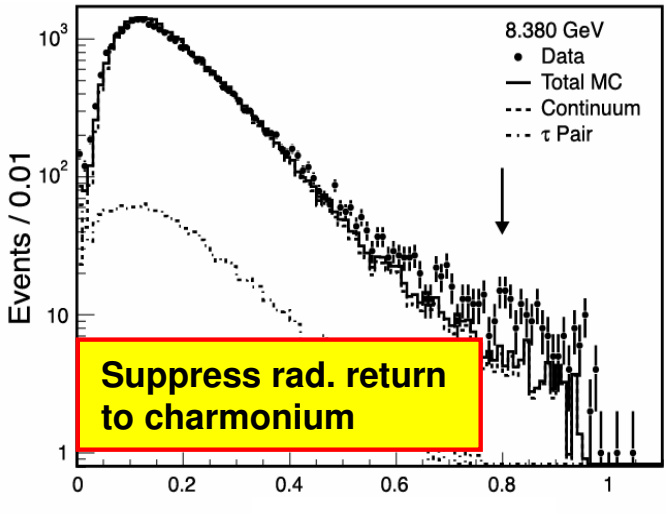
$s^{1/2}$ just below $\Upsilon(4S)$, $\Upsilon(3S)$, $\Upsilon(2S)$, $\Upsilon(1S)$ + 3 lower energies



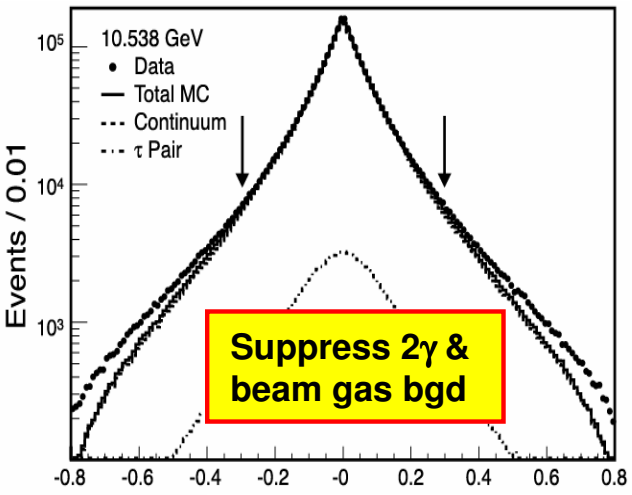
E_{vis}/E_{cm}



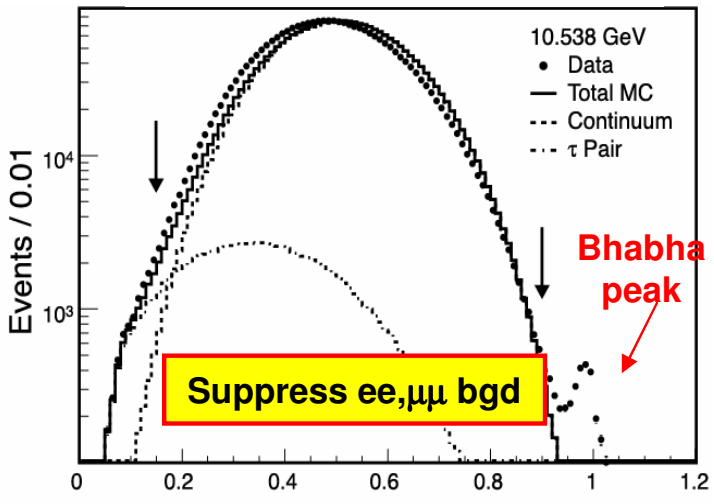
H_2/H_0 (Event Shape)



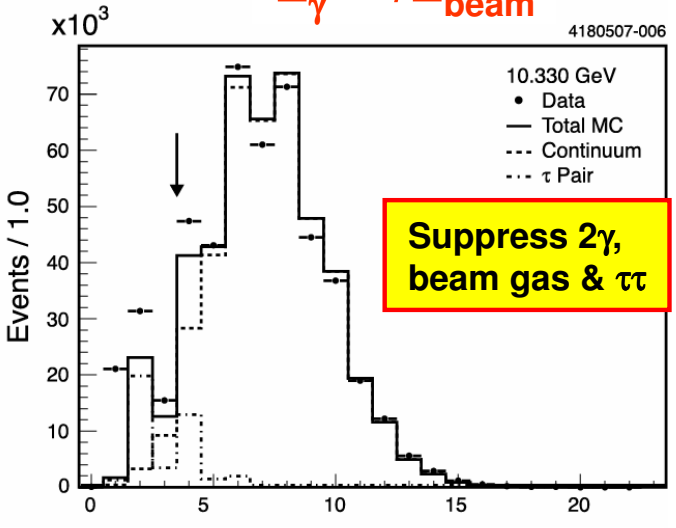
E_γ^{max}/E_{beam}



P_Z^{miss} / E_{vis}



$E_{calorim}/E_{cm}$



No. of charged tracks

Data Analysis

- Corrections:
  - for the remaining $e^+e^- \to \tau^+\tau^-$ etc. background
  - energy-dependant efficiency
    - Variation 82.1-87.4%
  - radiative corrections:
    - soft photon and vacuum polarisation
    - hard photon emission: low mass resonances and continuum
  - interference with Υ resonances
- Measure luminosity for normalization
  - 3 processes: $e^+e^- \to \gamma\gamma$, $e^+e^- \to \mu^+\mu^-$, $e^+e^- \to e^+e^-$
- Evaluate systematic errors

Systematic uncertainties

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	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

Dominated by hadronic vacuum polarisation

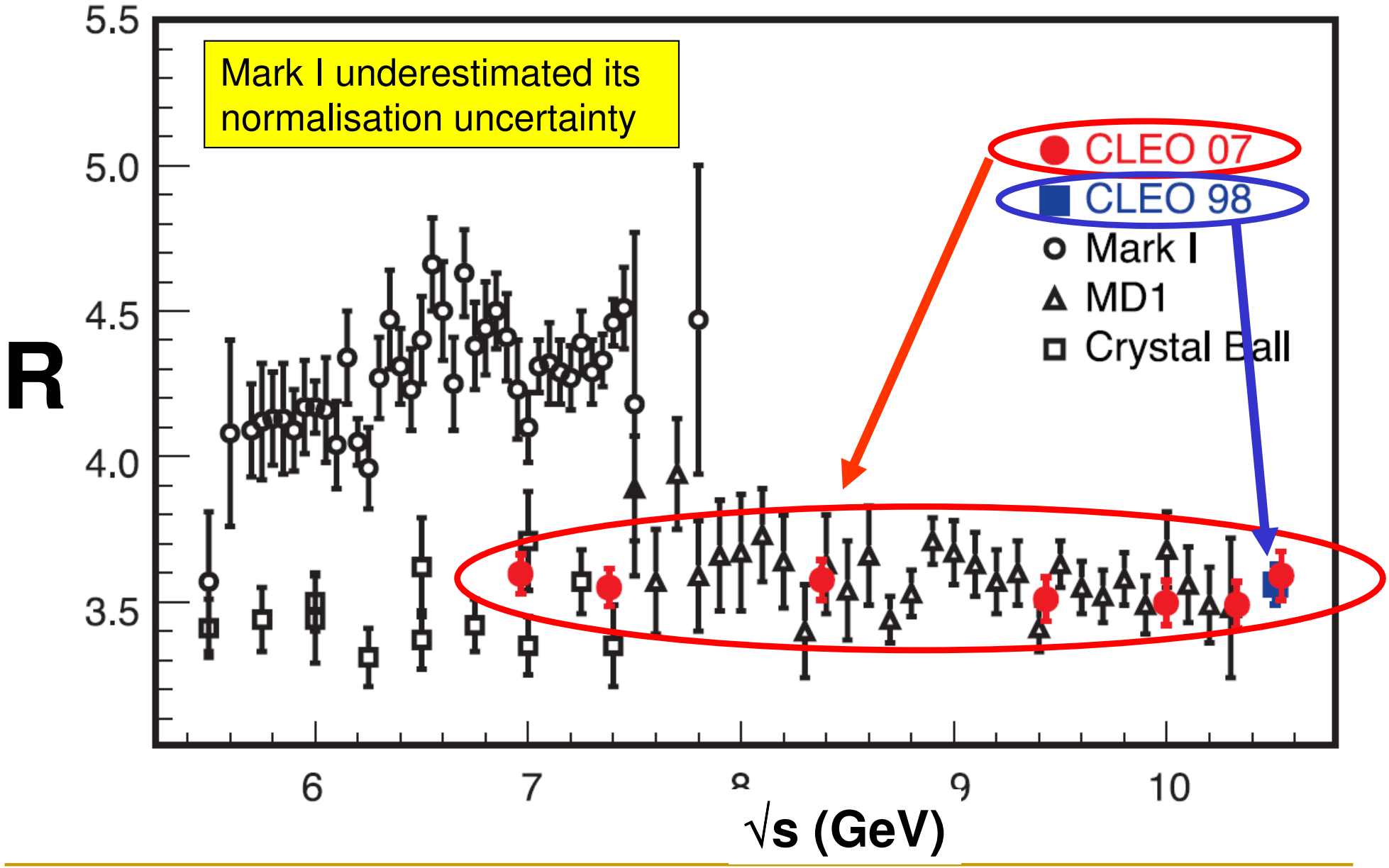
MC/data efficiency reweighting

Efficiency and background subtraction

~2%

Correlated uncertainties dominate

Comparison with previous measurements



Determination of α_s

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

- Determination, using massless quarks and 4-quark flavours

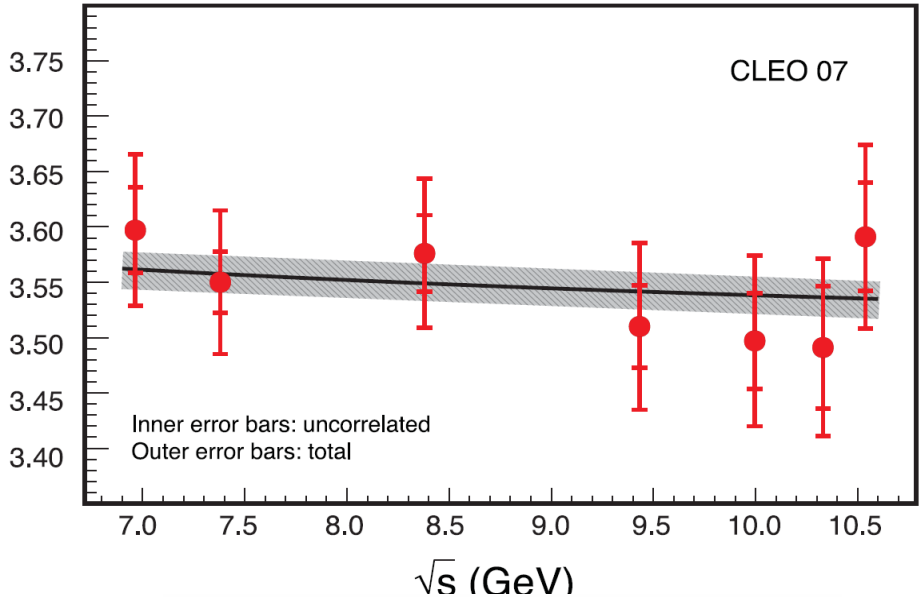
$$\alpha_s\left(M_Z^2\right) = 0.110^{-0.010\,+0.010}_{-0.012\,-0.011}$$

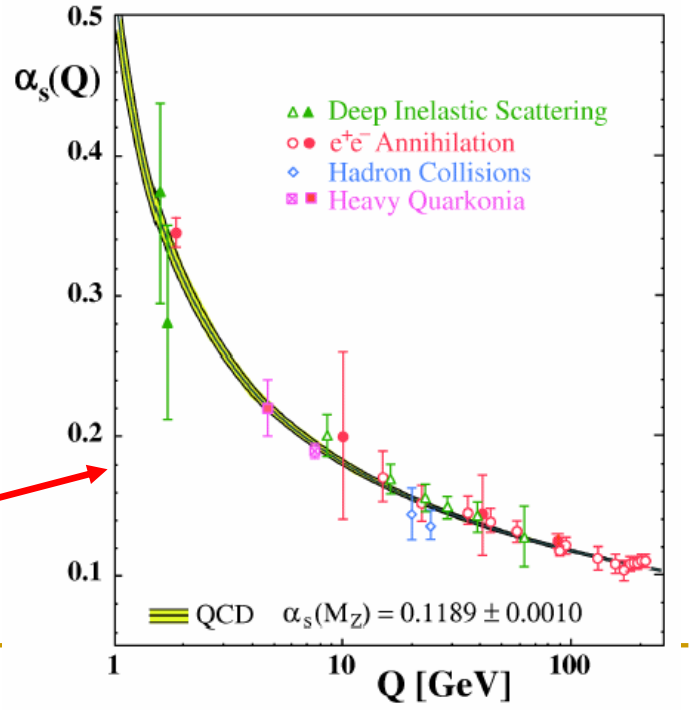
- Alternate determination using
  - quark mass effects and
  - matching between 4 and 5 flavour effective theories
  - J.H. Kuhn, M. Steinhauser and T. Teubner, Phys. Rev. D76, 074003 (2007)

$$\alpha_s\left(M_Z^2\right) = 0.126 \pm 0.005^{+0.015}_{-0.011}$$

- The world average determination
  - S. Bethke, Prog. Part. Nucl. Phys. 58, 351 (2007)

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

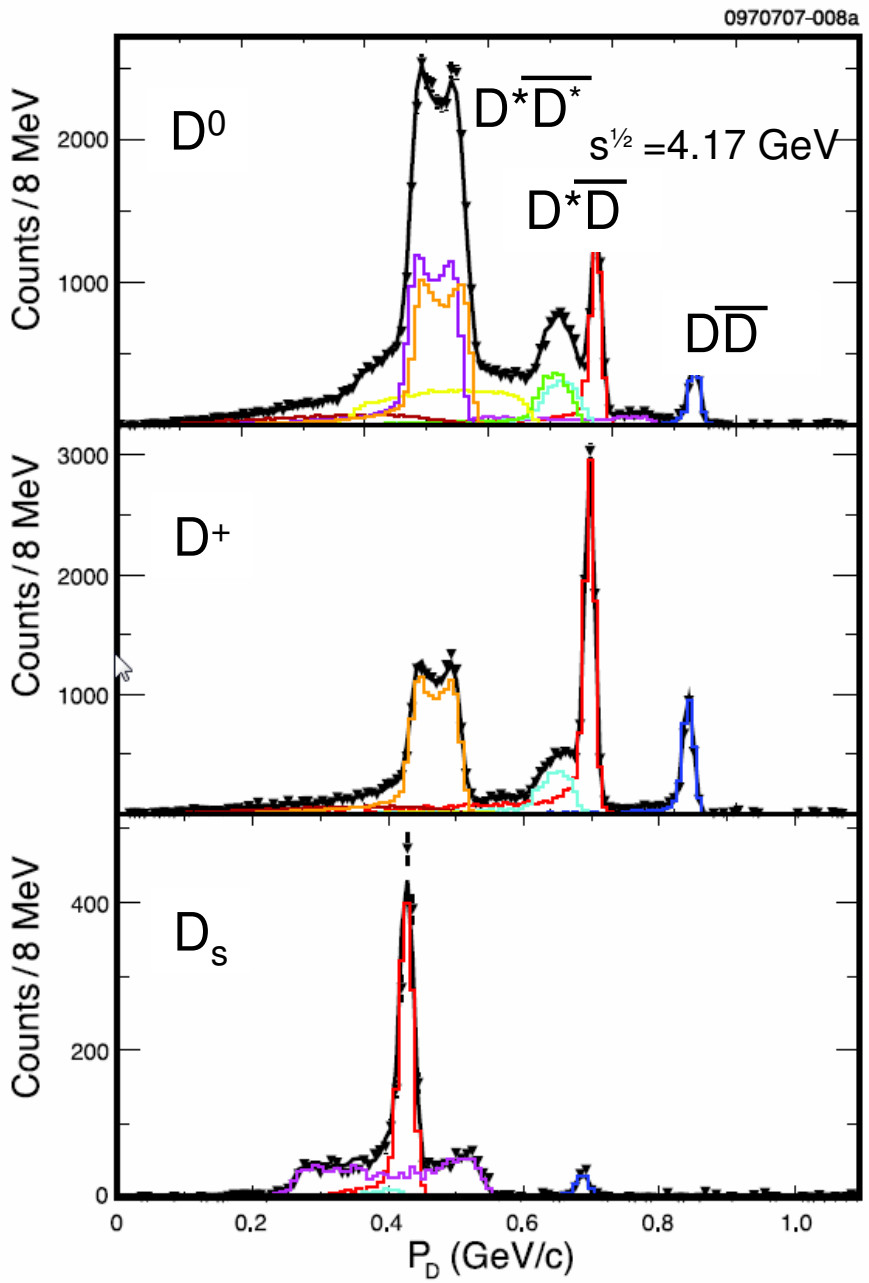




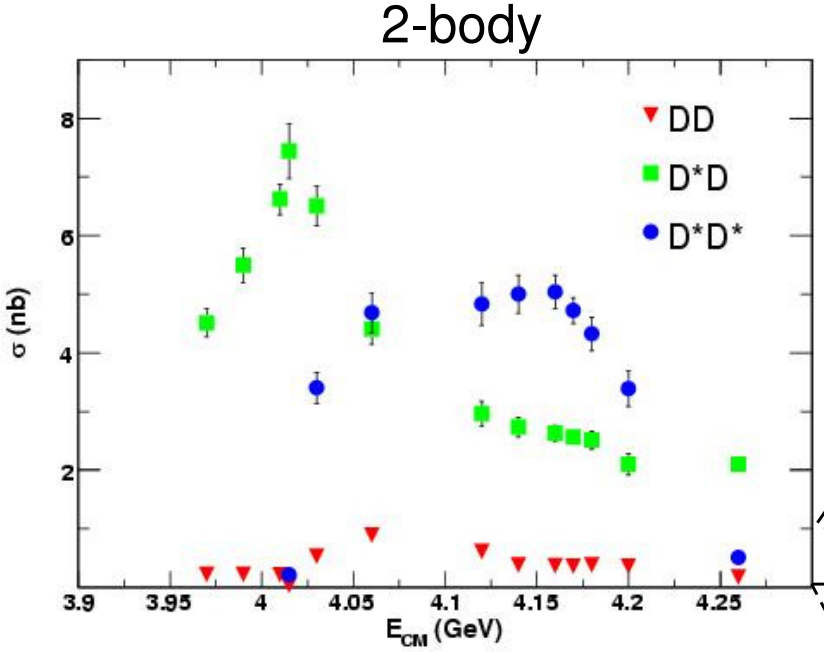
CLEO-c - $s^{1/2} = 3.97\text{-}4.26$ GeV

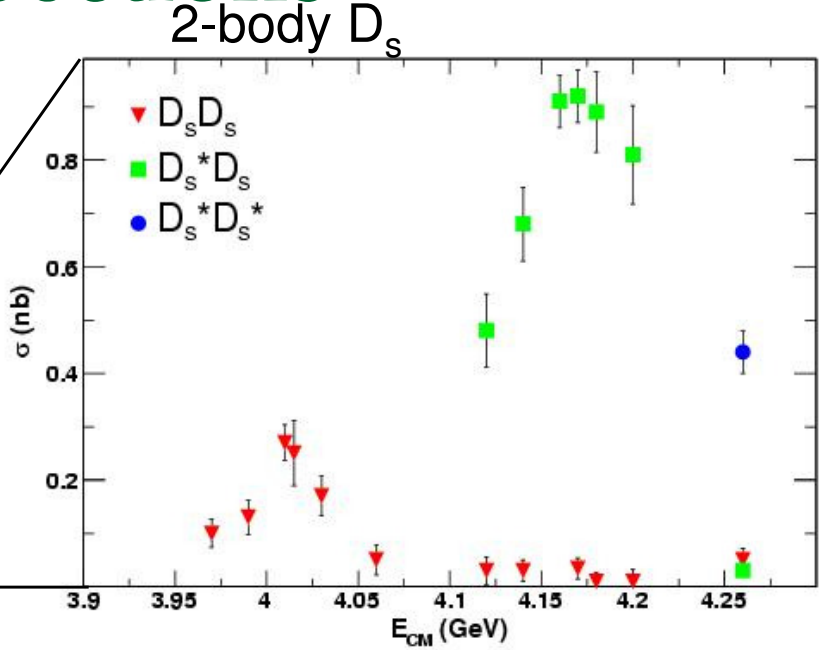
Decomposition of charm cross section

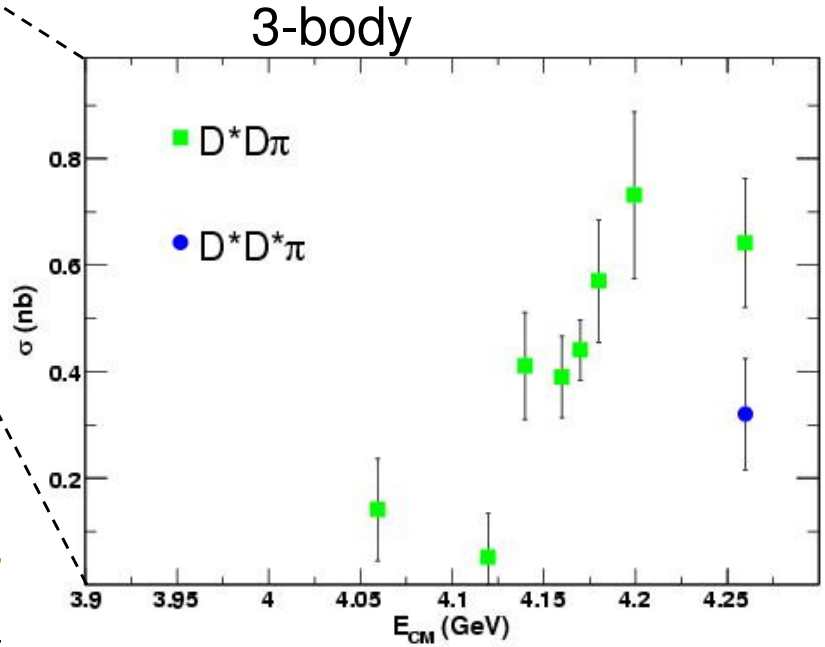
- Resonant region above $\psi(3770)$
  - 12 scan points between 3.97-4.26 GeV
  - Integrated luminosity normally between 1.5 and 13.1 pb^{-1}
  - Exception: 179 pb^{-1} at 4.17 GeV
- Find candidate with ±15MeV of the nominal D^0, D^+ or D_s mass:
  - $D^0 \rightarrow K^-\pi^+$
  - $D^+ \rightarrow K^-\pi^+\pi^+$
  - $D_s \rightarrow \phi[K^-K^+]\pi^+ (\rho^+)$, $D_s \rightarrow \eta[\gamma\gamma]\ \pi^+(\rho^+)$, $D_s \rightarrow K^{*0}[K^-\pi^+]\pi^+$, $D_s \rightarrow \eta'[\eta\pi^+\pi^-]\pi^+(\rho^+)$ and $D_s \rightarrow K^0_S K^+$ (16% of total BF)
- For each scan point, fit mass-sideband subtracted momentum spectrum of the D^0, D^+ or D_s candidates to determine production channel



Exclusive Charm Cross Sections







Consistent with BELLE determination with ISR

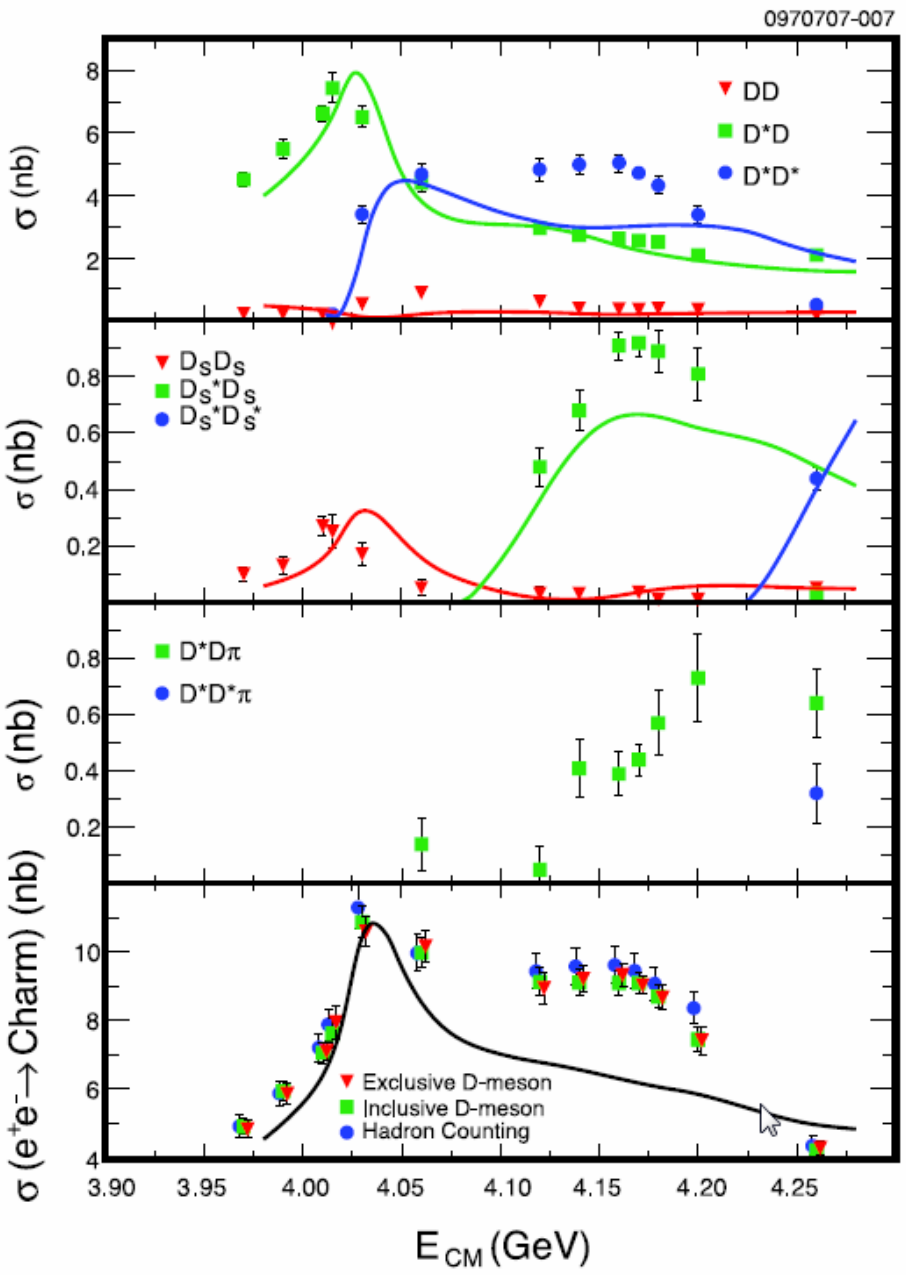
- Phys. Rev. Lett. 100, 062001 (2008)

No evidence for $D\bar{D}\pi$

No theoretical prediction for multi-body

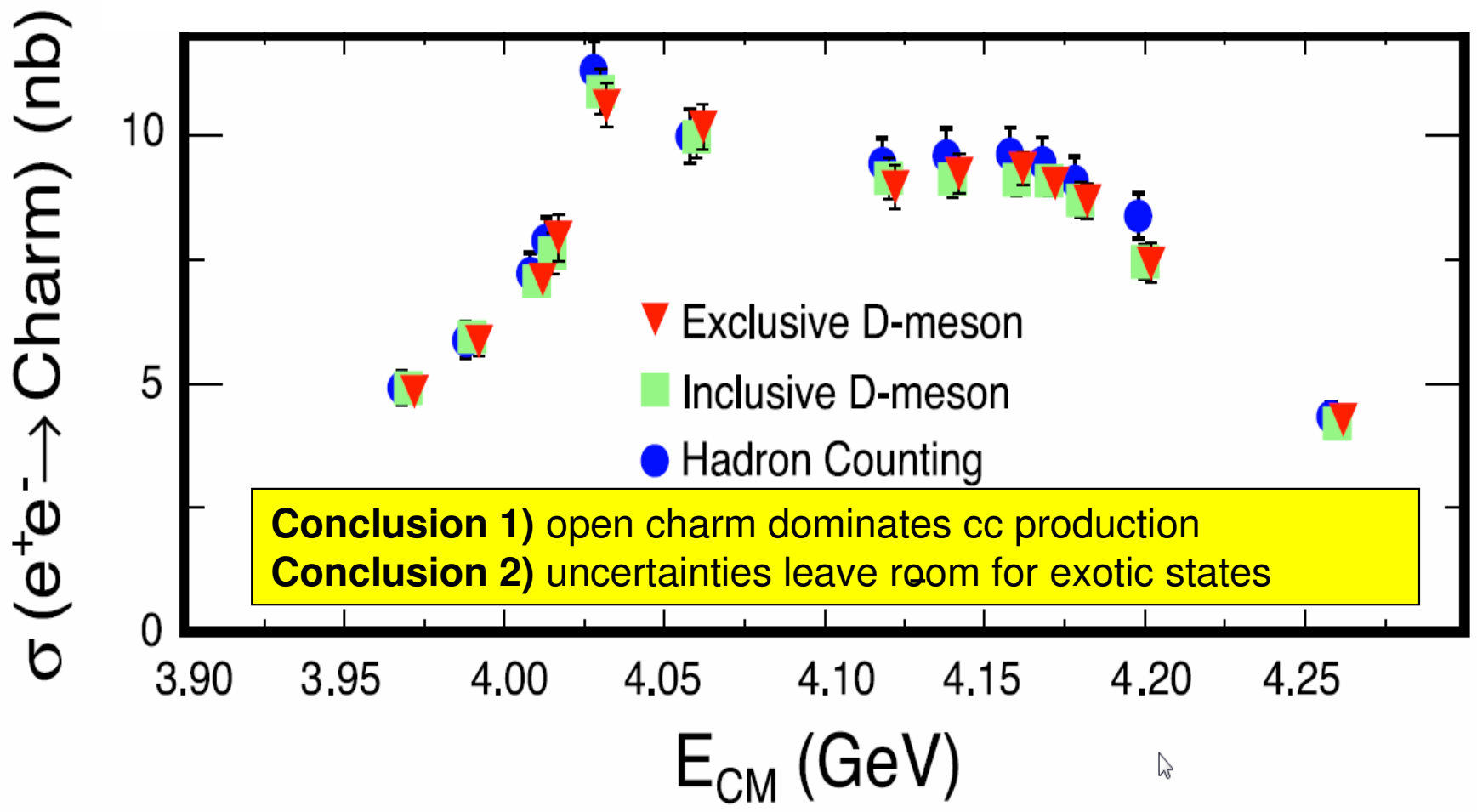
Comparison to coupled-channel model

- 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
- Reasonable qualitative agreement for most of the exclusive channels
  - Worst in D*D*



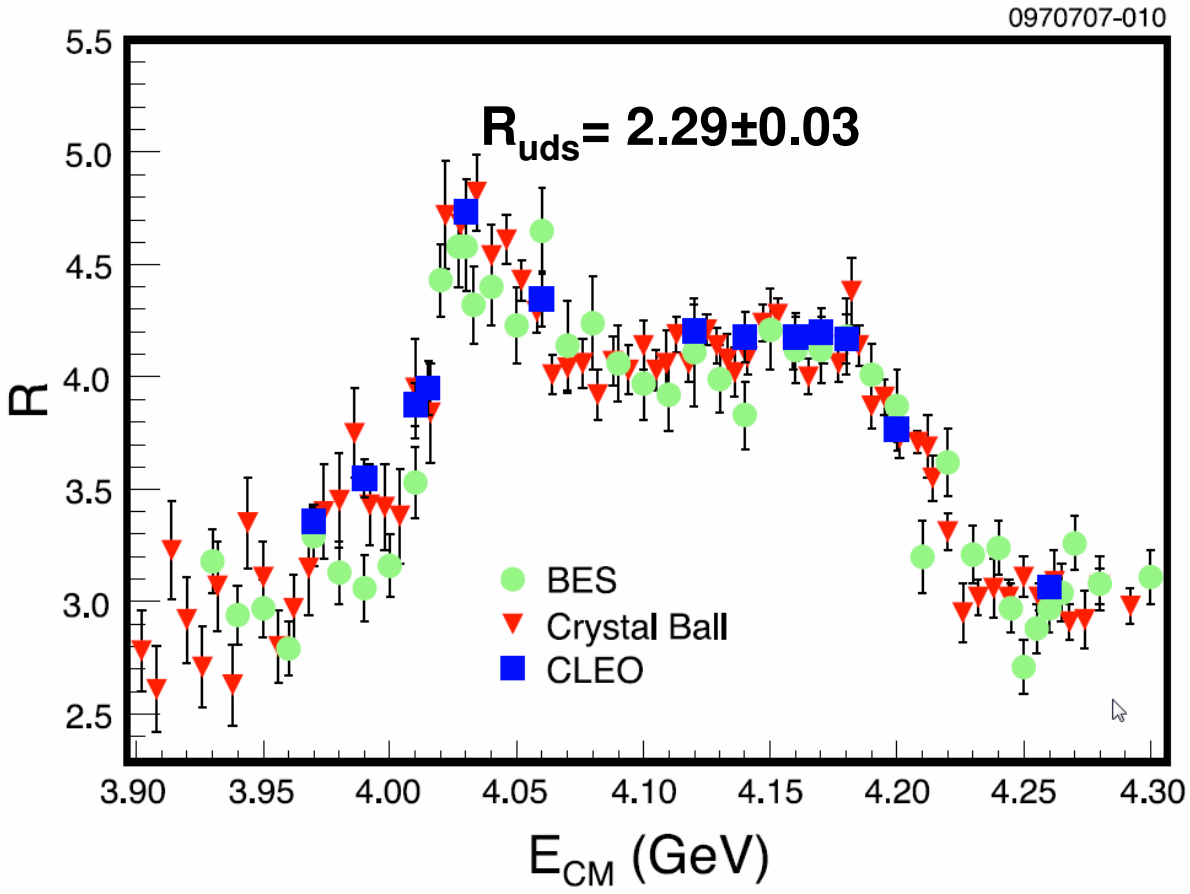
Inclusive Charm Cross Section

- 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: similar to the analysis of the $s^{1/2}$ =6.96–10.54 GeV data
  - Subtract uds contribution from the scaled continuum data taken below ψ(2S)
  - Subtract tails of the J/ψ,ψ(2S),ψ(3770) resonances



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



Most accurate determinations in this region

Conclusion

- R measured for $s^{1/2}$ =6.96–10.54 GeV
  - **Most precise**
  - Determines $\alpha_S(M_Z^2)$ with ~10% uncertainty
    - Consistent with world average from alternate techniques
- Exclusive & inclusive charm for E_{CM}=3.97-4.26 GeV
  - Region of many thresholds & much structure
    - Exclusively deconstructed its composition
    - **Multi-body open charm measured for the first time**
    - This deconstruction is useful input for model builders
      - Qualitative agreement with coupled channel predictions
  - **Precision of R is improved at 13 points**