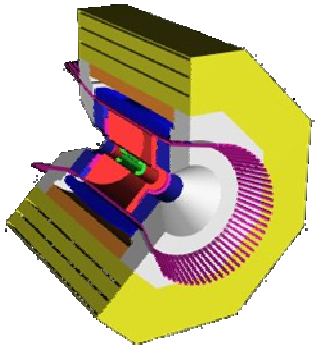
Charm – Production in e^+e^- Annihilation around 4 GeV

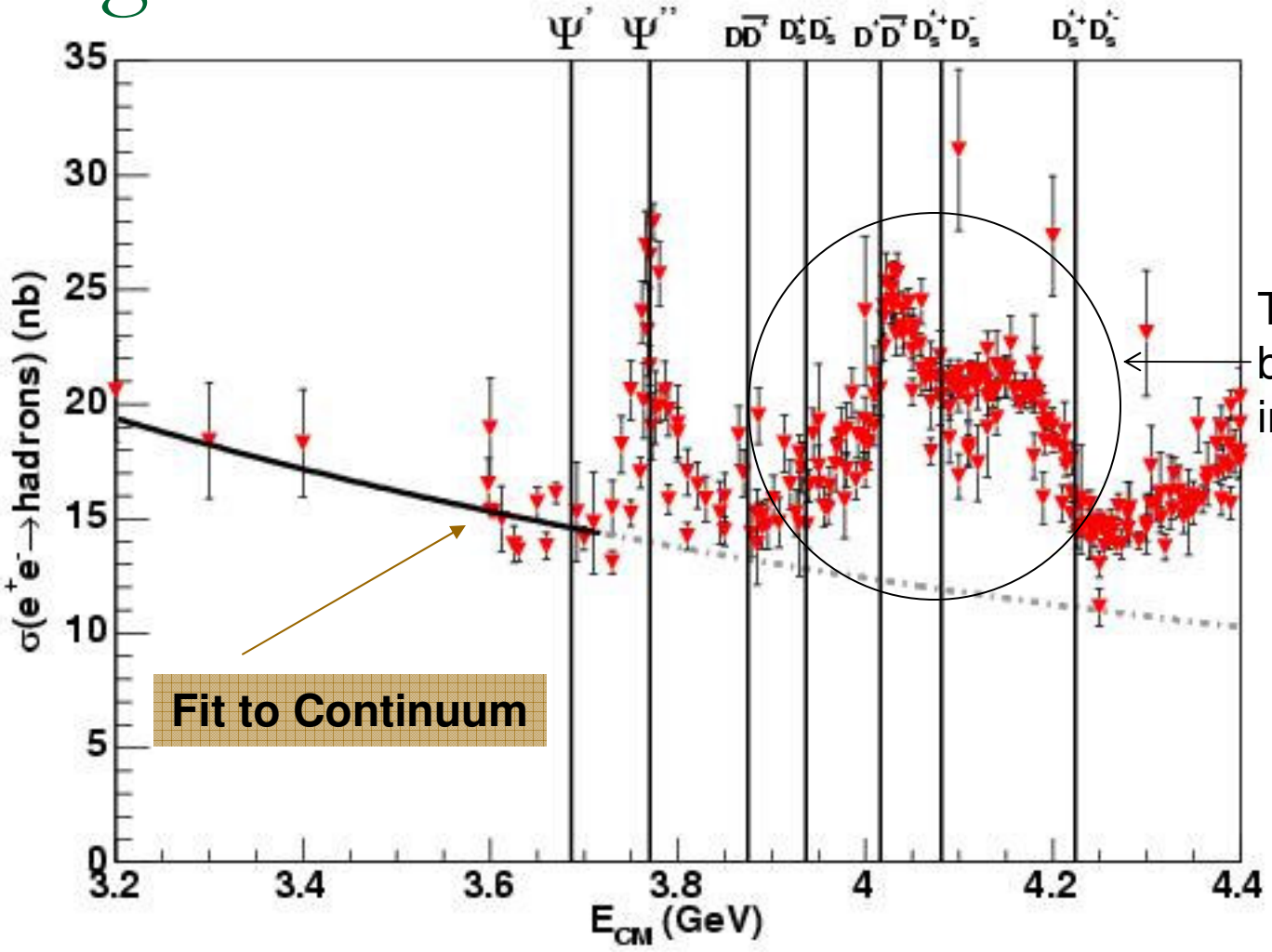


Brian Lang
University of Minnesota
on behalf of the CLEO Collaboration

Charm 2007

Cornell University, August 5th-8th 2007

Region of Interest



The region which is being investigated.

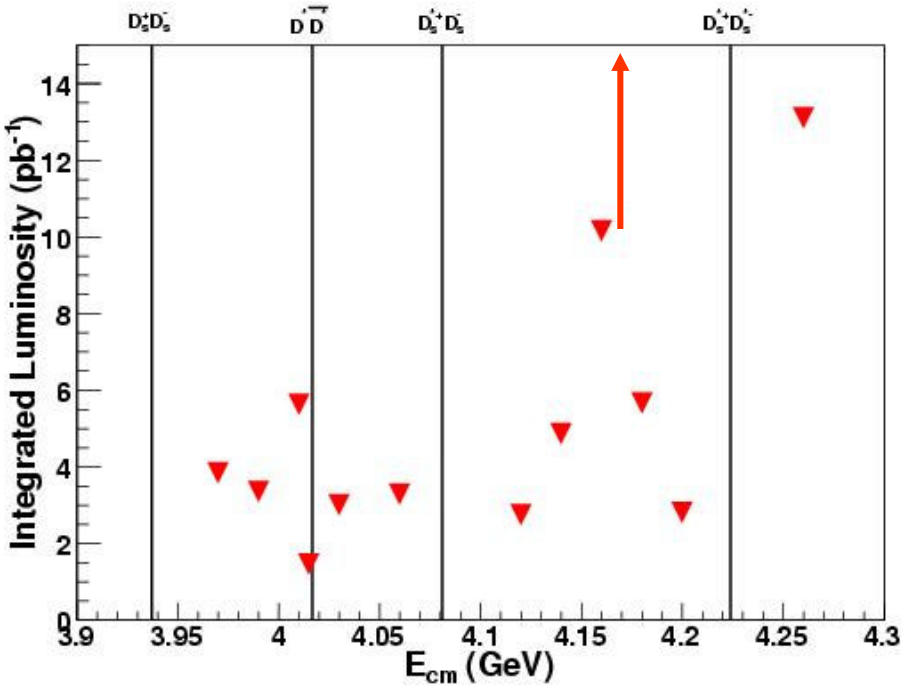
Cross section as a function of E_{cm} from the 2005 PDG

Why investigate this region:

- The cross sections to $D\overline{D}$, $D^*\overline{D}$, and $D^*\overline{D}^*$ are not well known at the energies of interest.
- The only previous measurements of D_s yields in this region:
  - BES measured the production cross section times branching ratio to $\phi\pi$ at 4030 MeV as 11.2 pb, due to $D_s\overline{D}_s$.
  - Mark III measured the production cross section times branching ratio to $\phi\pi$ at 4140 MeV as 26 pb, production is largely $D_s\overline{D}_s^*$.
- **Optimal** E_{cm} for D_s decay physics: balance of total production against event complexity.
- Test of theoretical predictions from Eichten et al in 1980 Phys. Rev. D21 203
  - Coupling of open charm channels to $c\bar{c}$ states

Data Sample from CLEO Scan

- Using the scan data which was collected between Aug. and Oct. of 2005.
- At each energy the data sample was sufficient to determine the cross sections for all expected charm states.

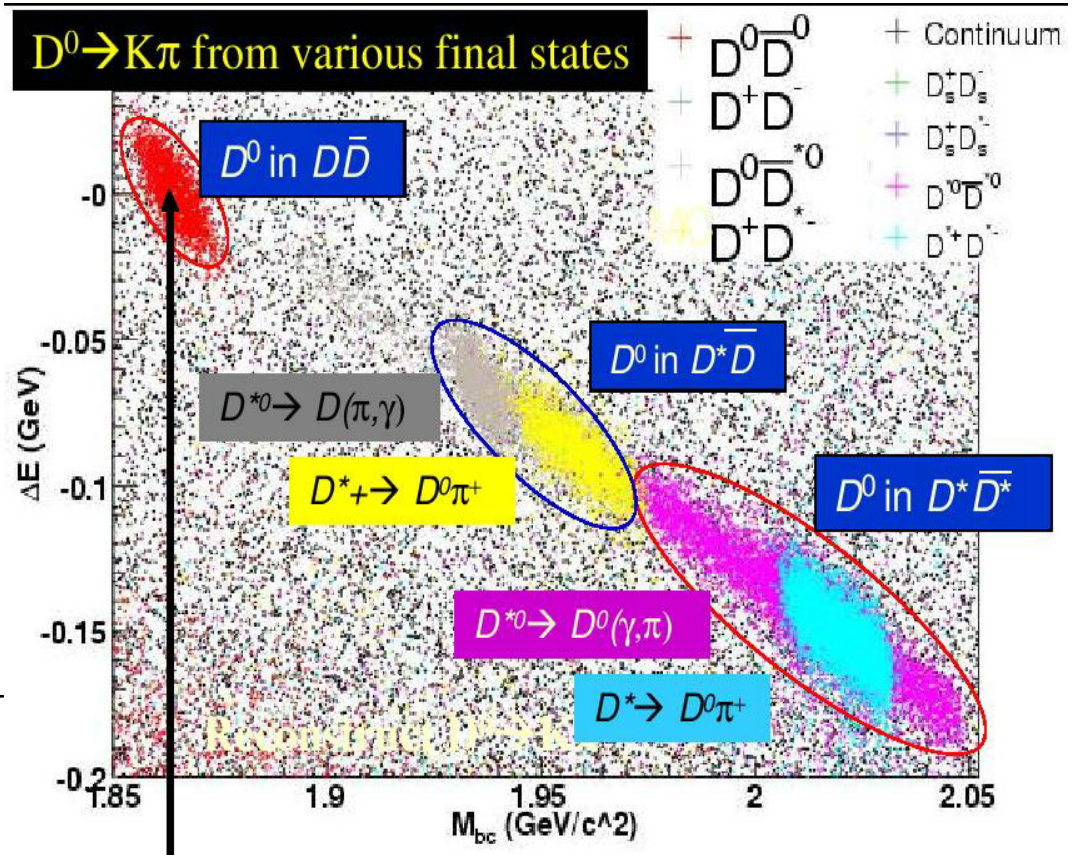


- **Total integrated Luminosity**
  - **Scan (12 energy points) ~ 60 pb^{-1}**
  - **4170 MeV ~ 180 pb^{-1}**

Cross Sections

MC Simulation E_{CM}=4160 MeV

- Do not reconstruct D^* since the momentum, in terms of M_{bc}, indicates event type



$$M_{bc} = \sqrt{E_{beam}^2 - |\, p_D \,|^2}$$

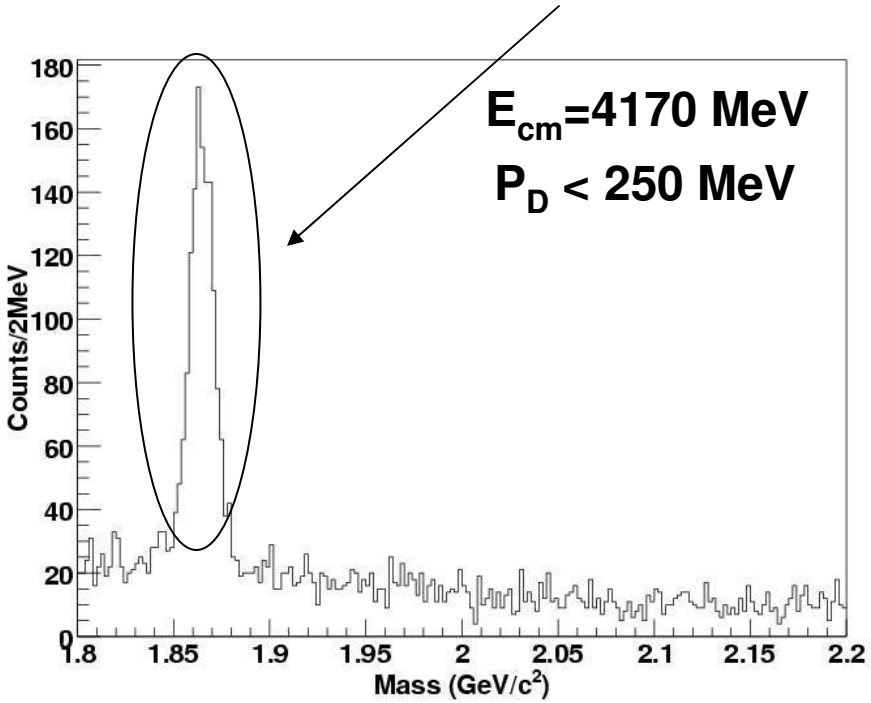
$$\Delta E = E_D - E_{beam}$$

$M_{bc} \approx M_D$ and $\Delta E \approx 0$ for $D\bar{D}$

Multi-Body Production

PRELIMINARY

- There is no reason why, for example, there can not exist multi-body events like $e^+e^- \rightarrow DD^*\pi$ or any other allowed combination of D-mesons and pions.
- First, are there events outside our two-body $D_{(s)}^{(*)}\overline{D}_{(s)}^{(*)}$ exclusive event categories? Yes!

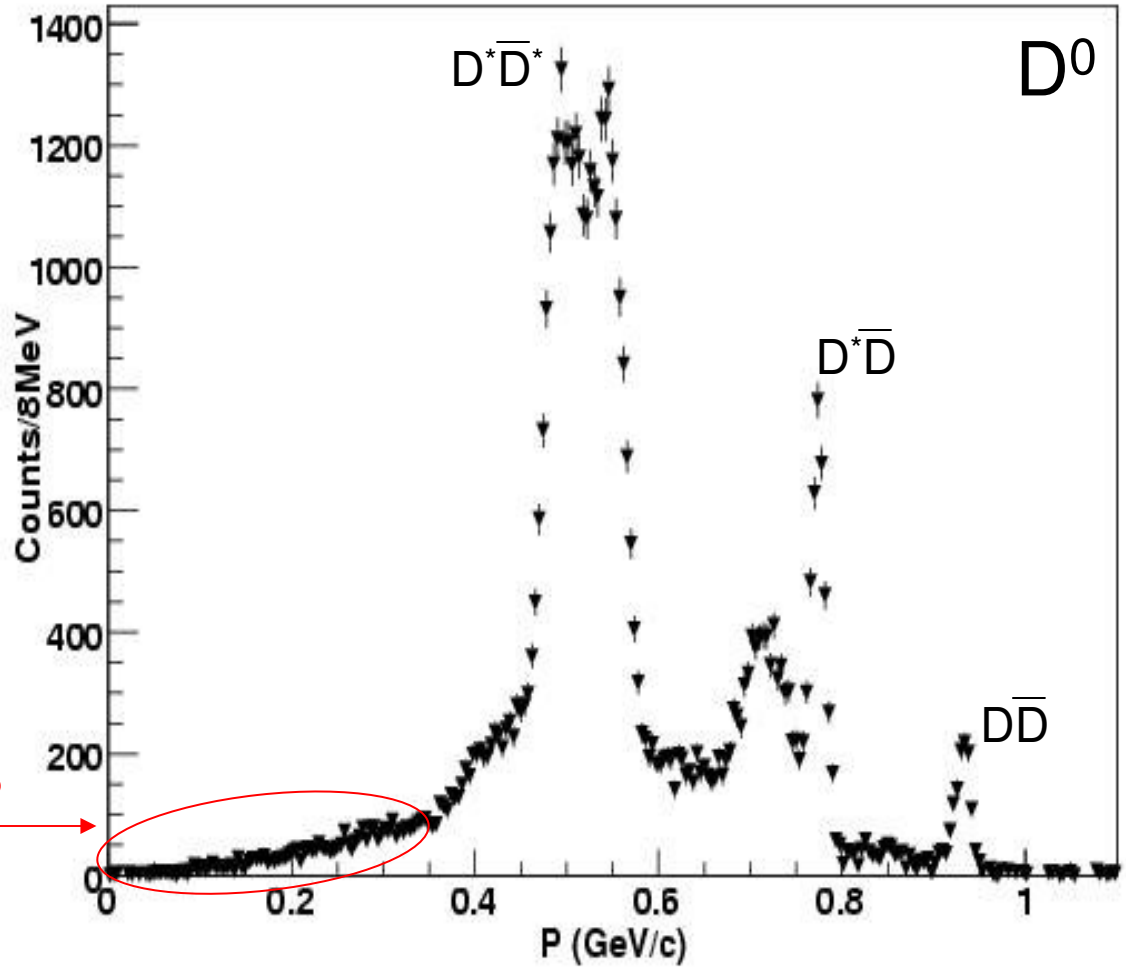


- Assuming only two body kinematics, NO D^0 mesons with a momenta below ~350 MeV.
- Data shows a clear D^0 peak in the mass distribution for $K^-\pi^+$ candidates with momenta below 250 MeV.

Momentum Spectrum of D^0 at 4170 MeV

- $D^0 \rightarrow K^-\pi^+$ momentum spectrum after sideband subtraction

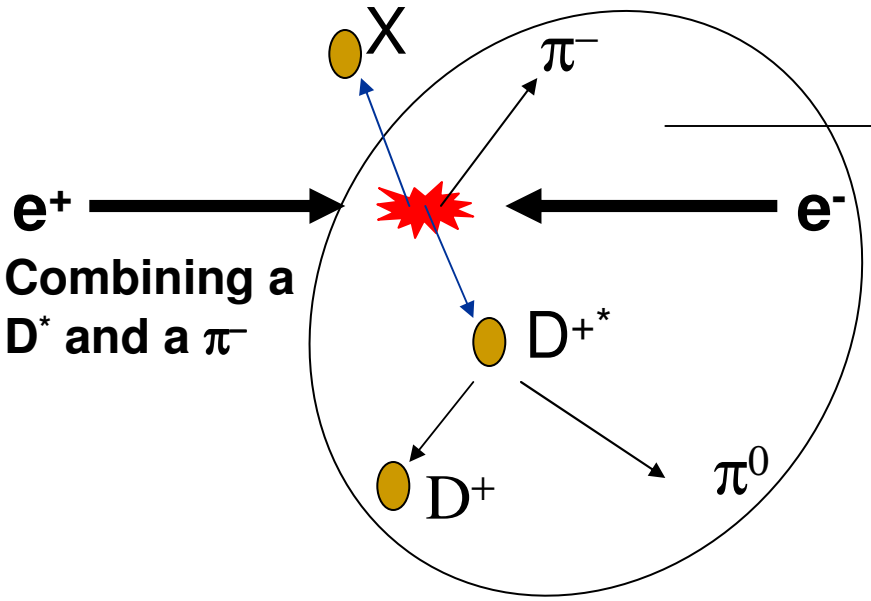
PRELIMINARY



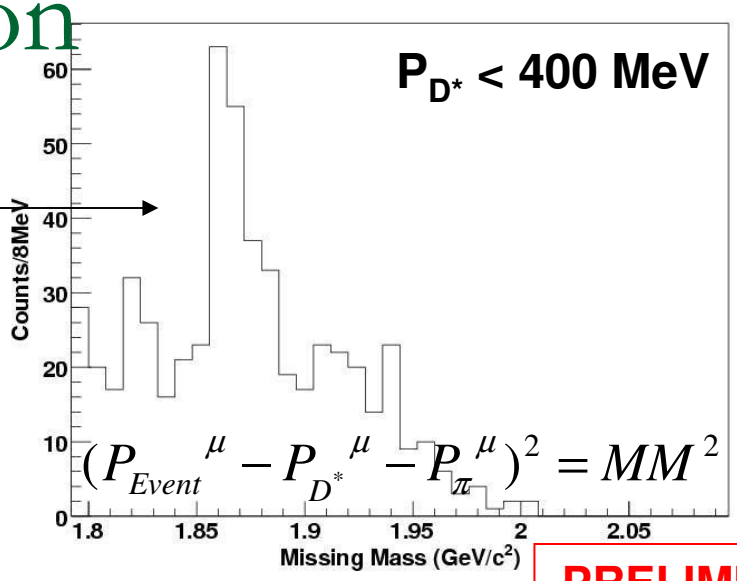
What populates this region?

Multi-Body Production

E_{cm} = 4170 MeV

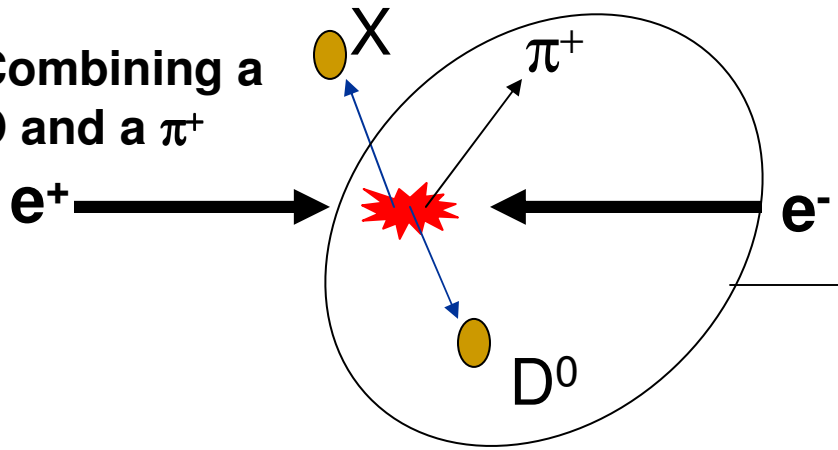


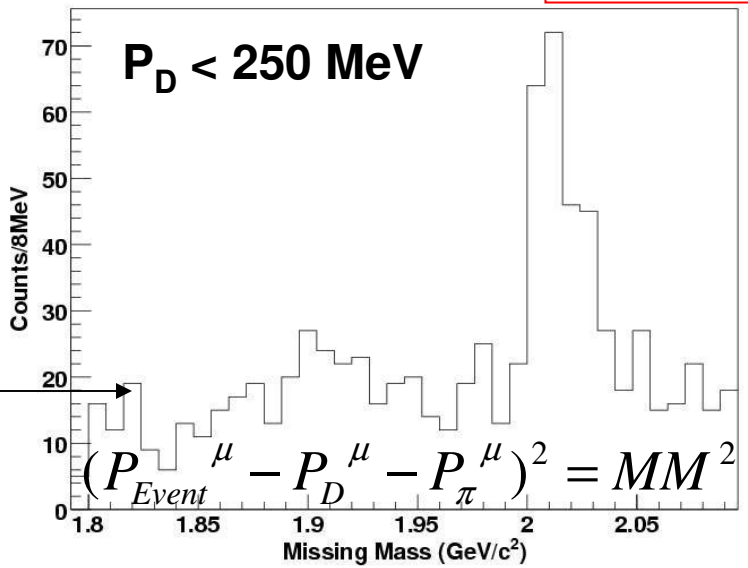
Combining a D^* and a π^-



PRELIMINARY

Combining a D and a π^+

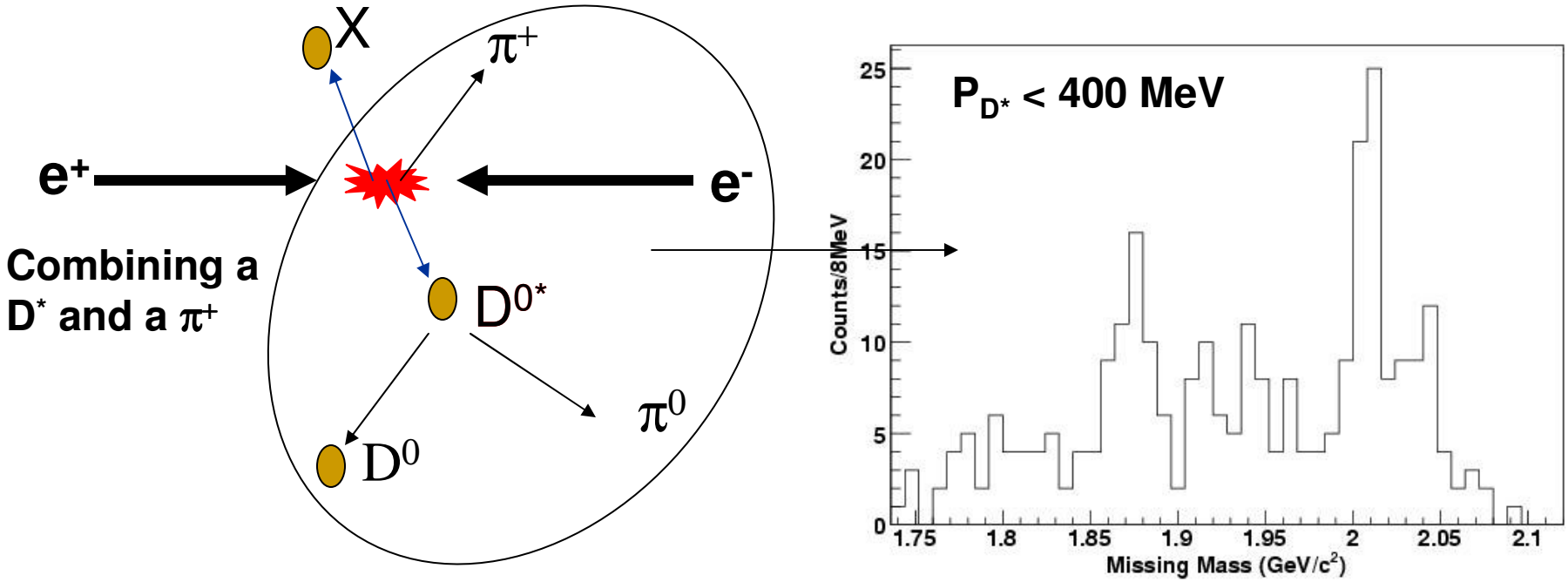




Multi-Body Production

E_{cm} = 4260 MeV

PRELIMINARY



$$(P_{Event}{}^{\mu} - P_{D^*}{}^{\mu} - P_{\pi}{}^{\mu})^2 = MM^2$$

Momentum Fits using MC

- How do we get a handle on the multi-body contribution?
- It is possible to estimate the contribution of multibody events by fitting the observed *D* momentum spectrum with MC predictions for the two-body processes and some representation of multi-body.

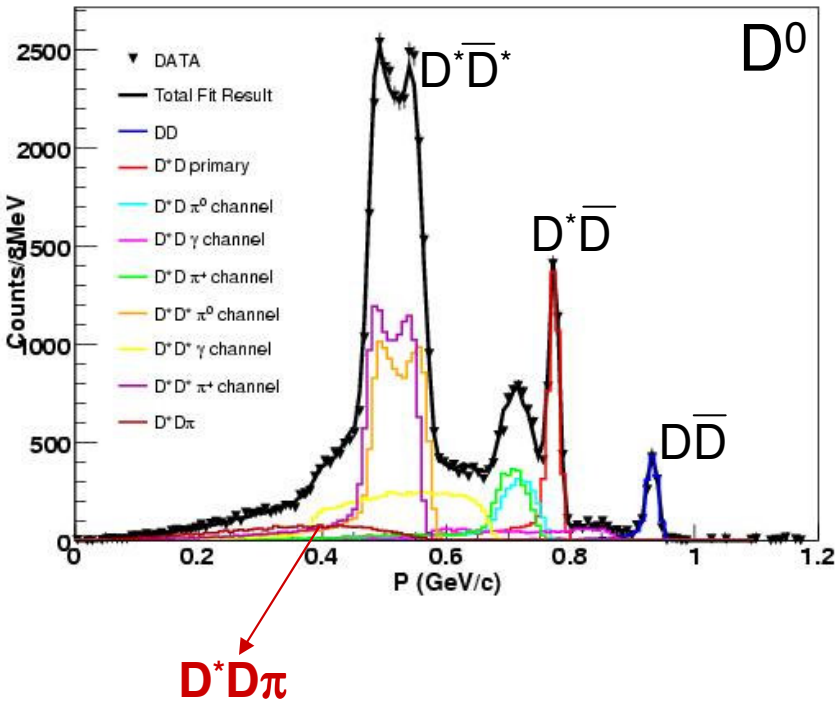
Momentum Fits using MC

E_{cm} = 4170 MeV
~ 180 pb^{-1}

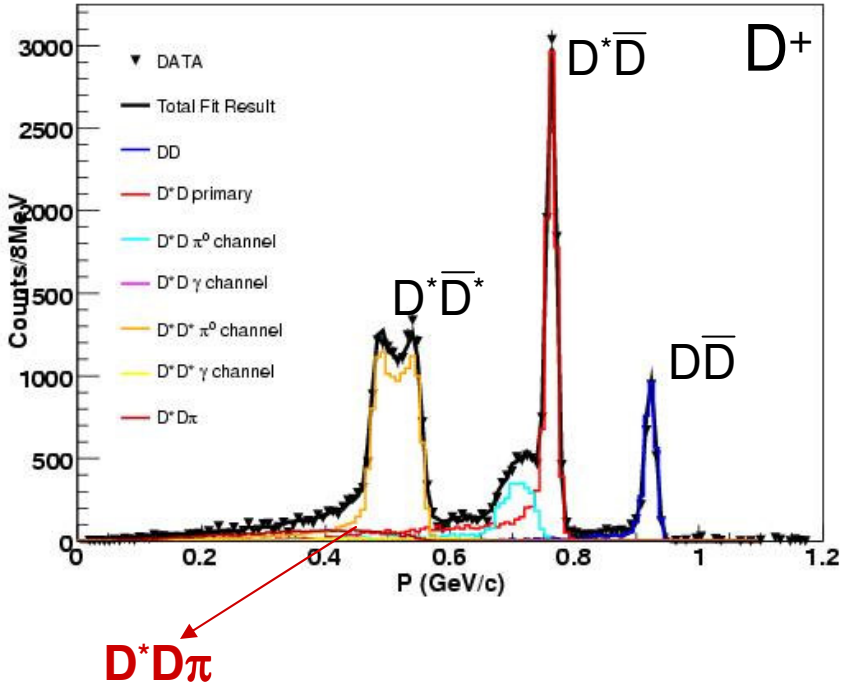
PRELIMINARY

Only assuming D*Dπ multi-body is present.

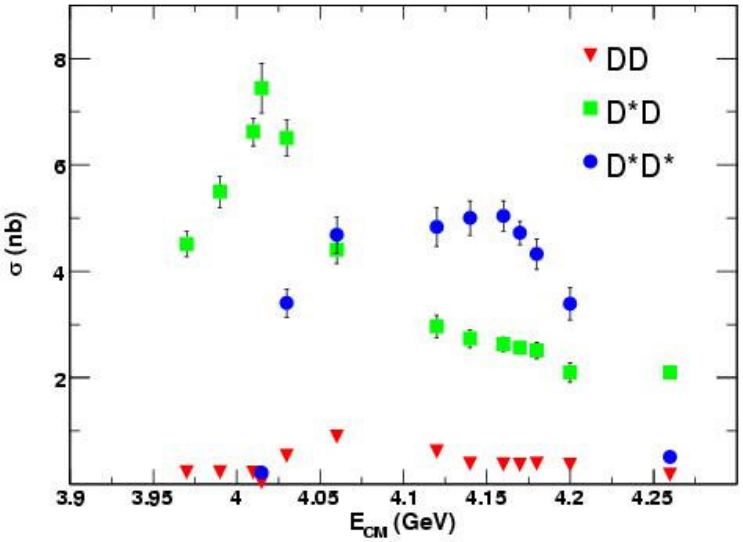
$D^0 \rightarrow K^-\pi^+$ Momentum Spectrum after sideband subtraction

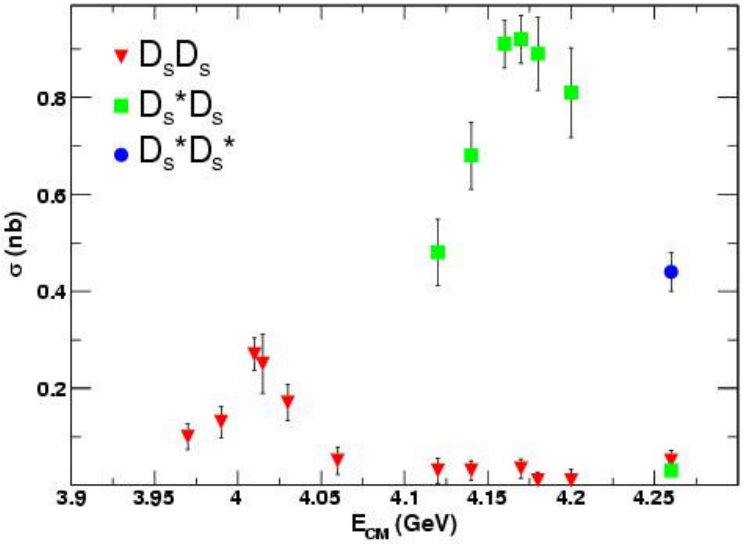


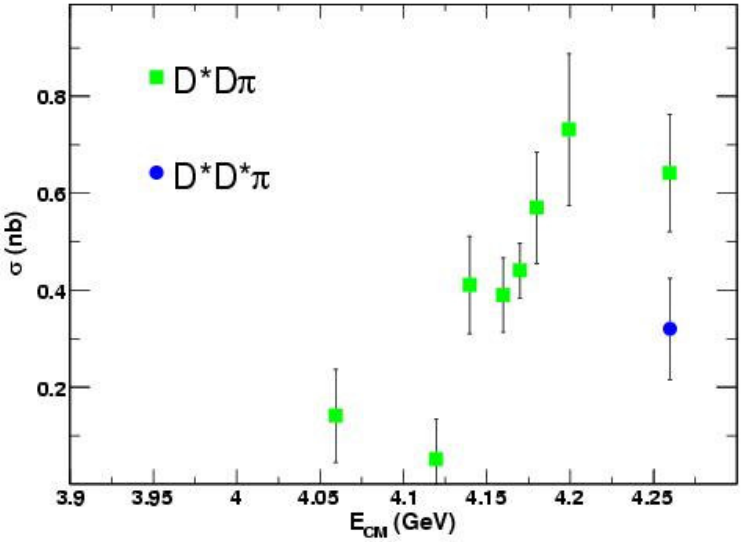
$D^+ \rightarrow K^-\pi^+\pi^+$ Momentum Spectrum after sideband subtraction



Exclusive Cross Section Results







PRELIMINARY

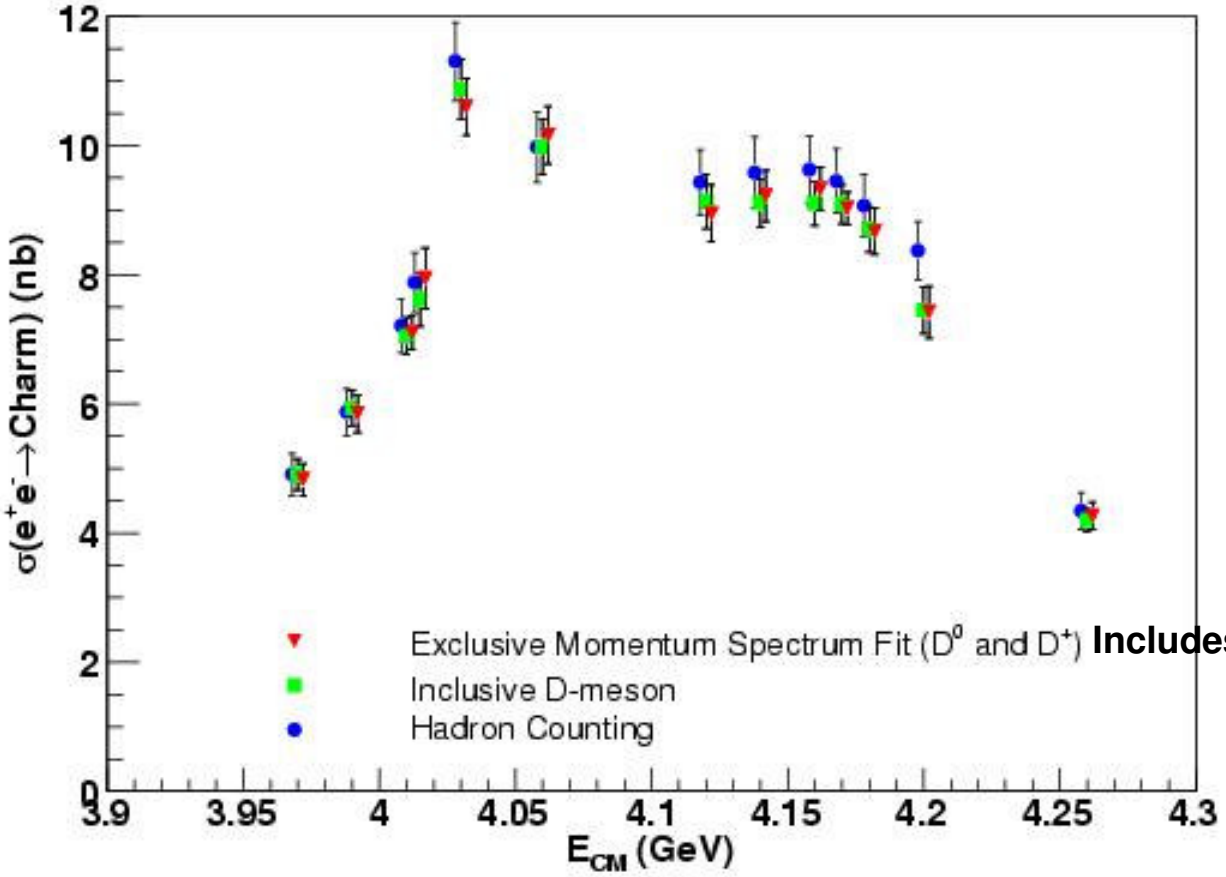
- No theoretical predictions for multi-body.
- No evidence of $D\bar{D}\pi$ in this region

Check of the Total Charm Cross Section

- One can perform an inclusive measurement as a cross check on the total charm cross section.
  - The invariant mass used to extract the yields.
  - Only using $D^0 \rightarrow K^-\pi^+$, $D^+ \rightarrow K^-\pi^+\pi^+$ and the high yield mode of $D_s^+ \rightarrow K^+K^-\pi^+$.
- Also, one can count the number of hadronic events above the *uds* continuum background as an additional check to the total charm cross section.

Comparison: Exclusive from Momentum Fits vs. Inclusive

PRELIMINARY



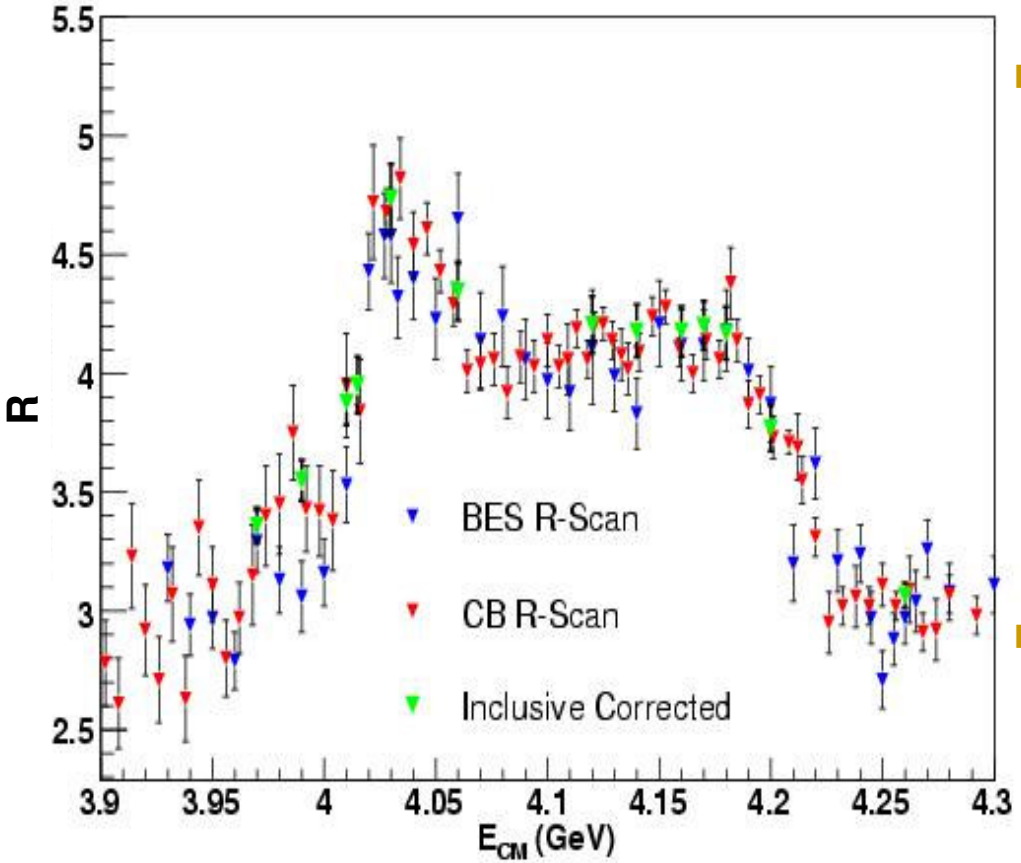
▼ Exclusive:
Sum of the two-body charmed mesons and multi-body

■ Inclusive charm:
$D^0 + D^+ + D_s$

● Inclusive Hadrons:
Excess over *uds*

Radiative Corrections

PRELIMINARY



- In order to compare the observed cross sections to theory and previous experiments the cross sections need to be corrected for the effects of initial-state radiation.
- Using theoretical treatment of Kuraev and Fadin (Sov. J. Nucl. Phys. 41 466) and Crystal Ball R measurement

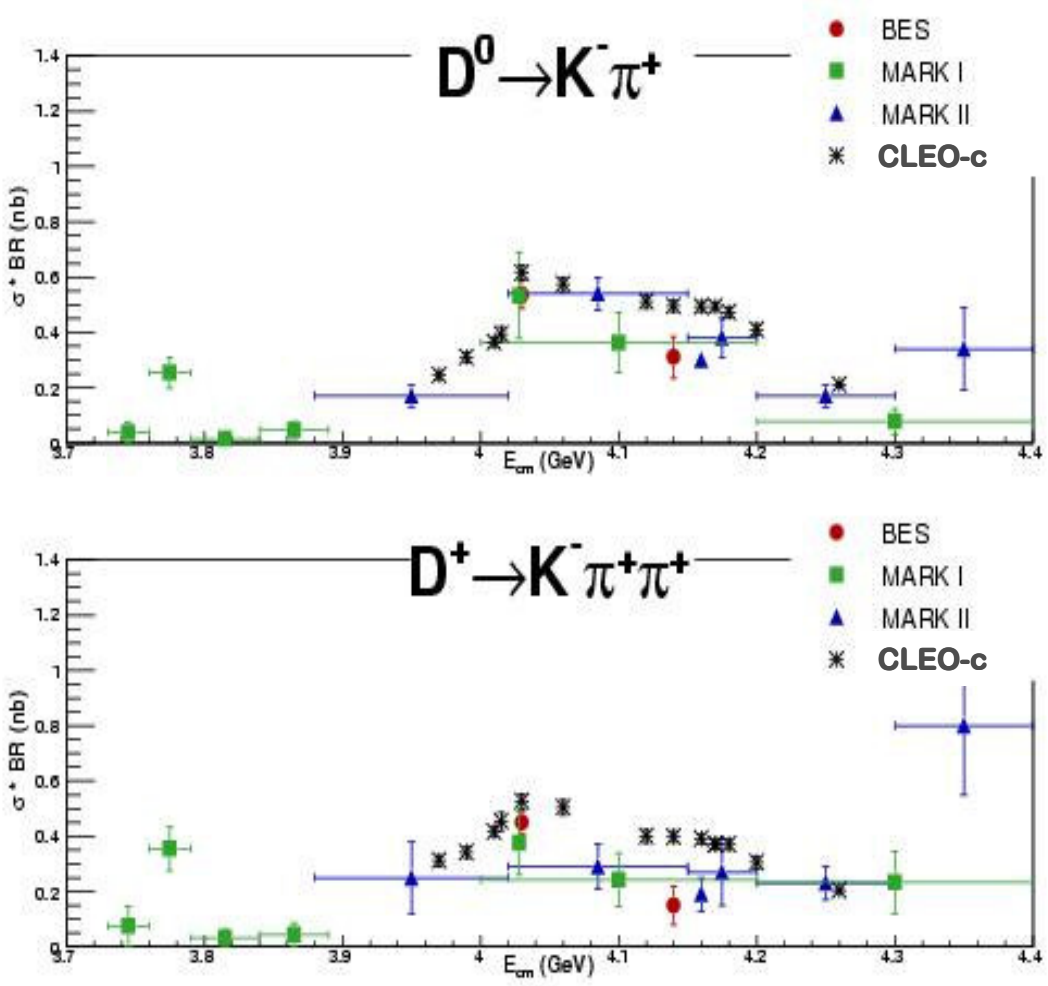
$$R = R_{uds} + R_{charm}$$

$$R_{uds} = 2.29 \pm 0.03$$

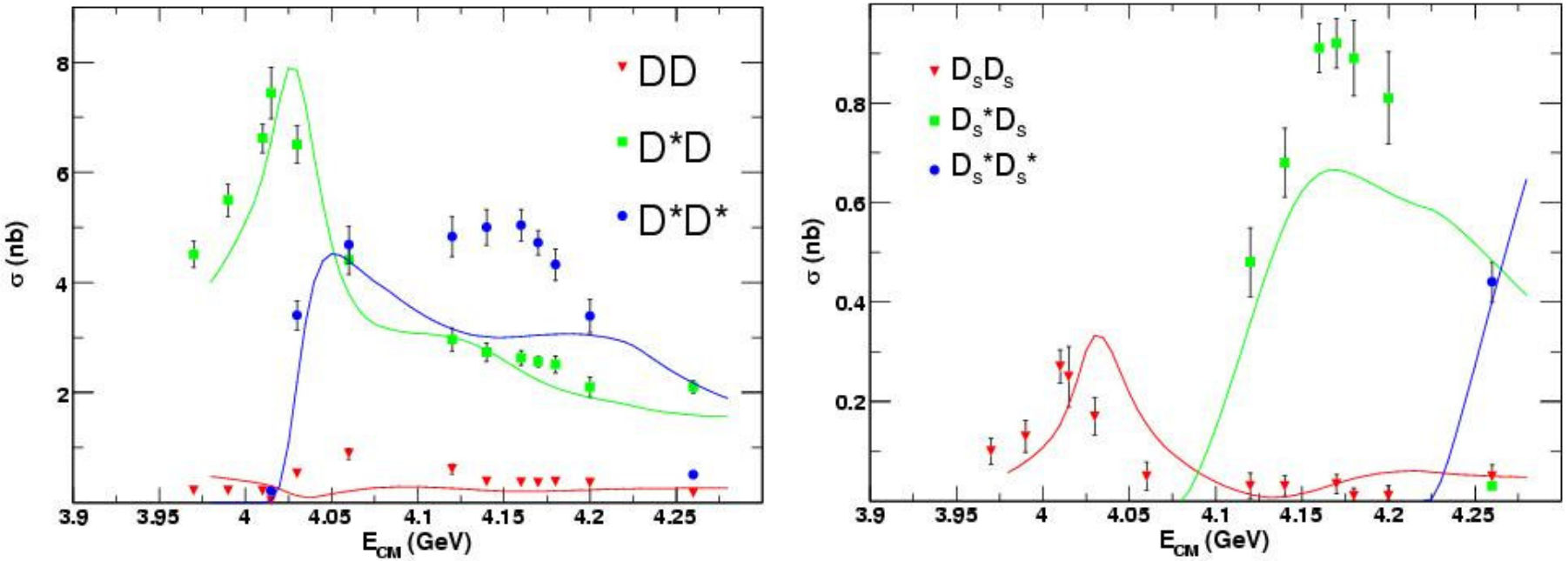
Inclusive Cross Section

PRELIMINARY

- These inclusive measurements can be compared to other experiments by the cross section times branching ratio for $D^0 \rightarrow K^-\pi^+$ and $D^+ \rightarrow K^-\pi^+\pi^+$.



Comparison with *Updated* Eichten et al.



E. Eichten, International Workshop on Heavy Quarkonium (BNL 2006) and personal communication

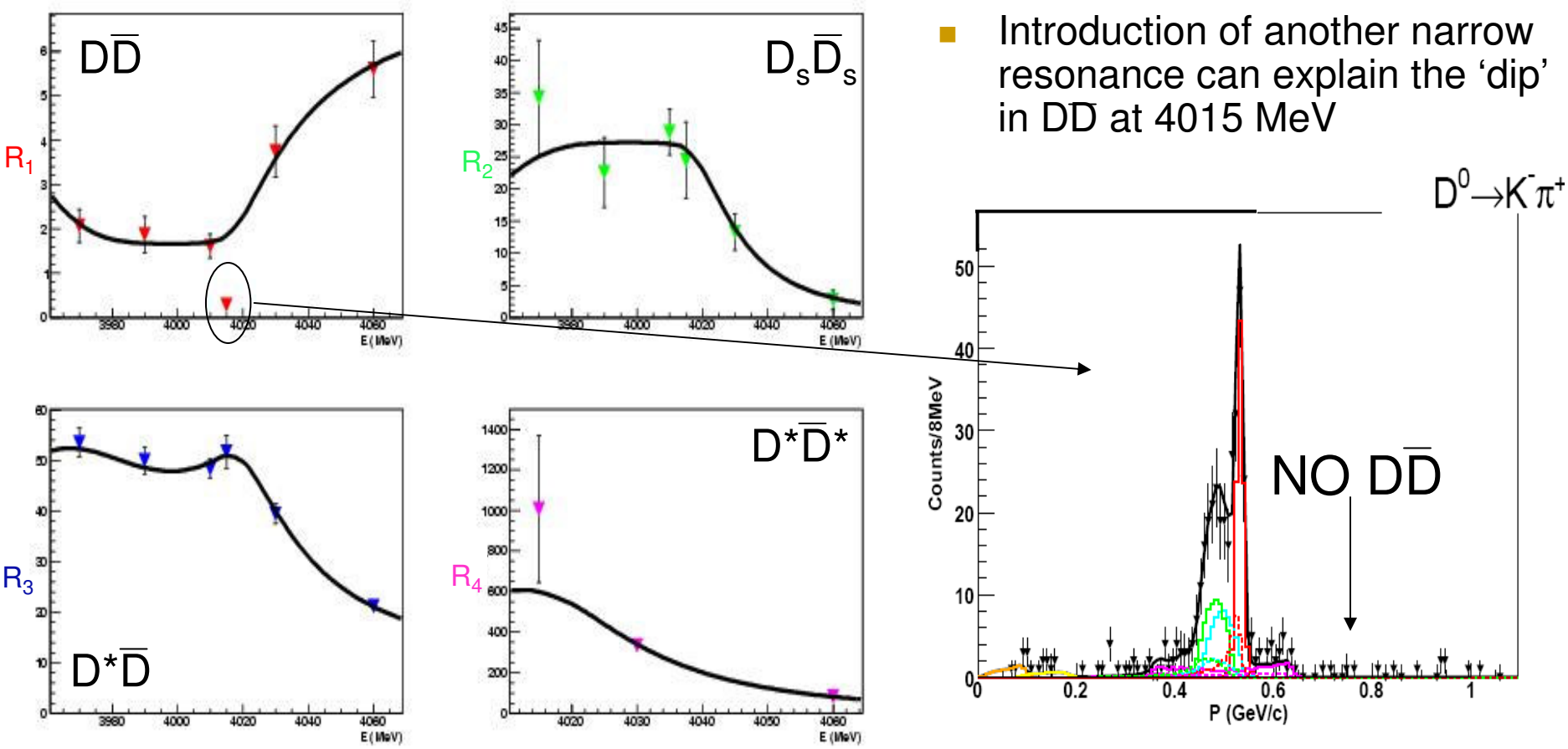
- Most noticeable difference in $D^*\overline{D}^*$ channel.
- Still reasonable qualitative agreement.

PRELIMINARY

Near D*$\bar{D}$* Threshold

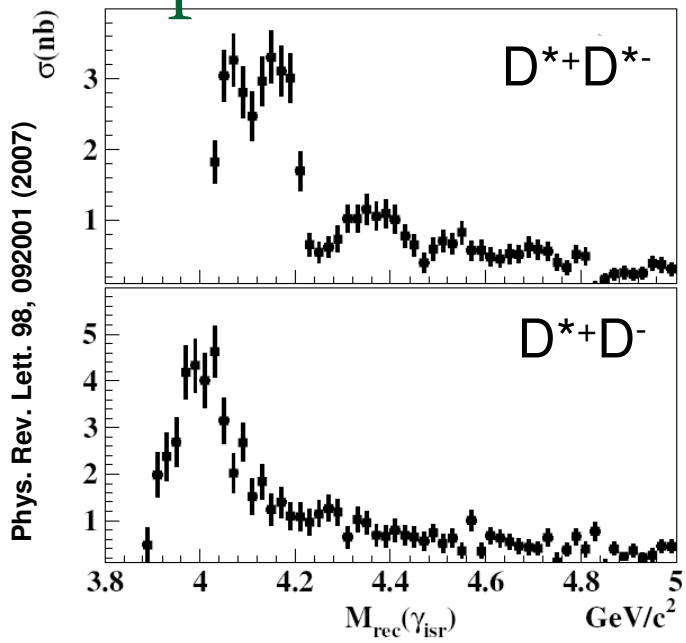
PRELIMINARY

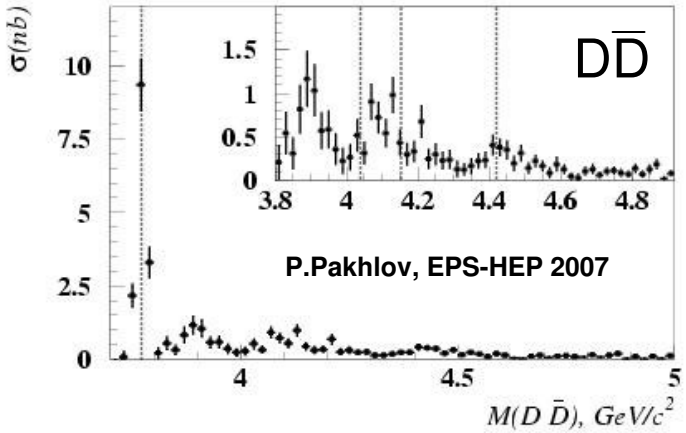
- R is proportion to the cross section.
- Fit assumes only a single resonance.
- Introduction of another narrow resonance can explain the 'dip' in D$\bar{D}$ at 4015 MeV

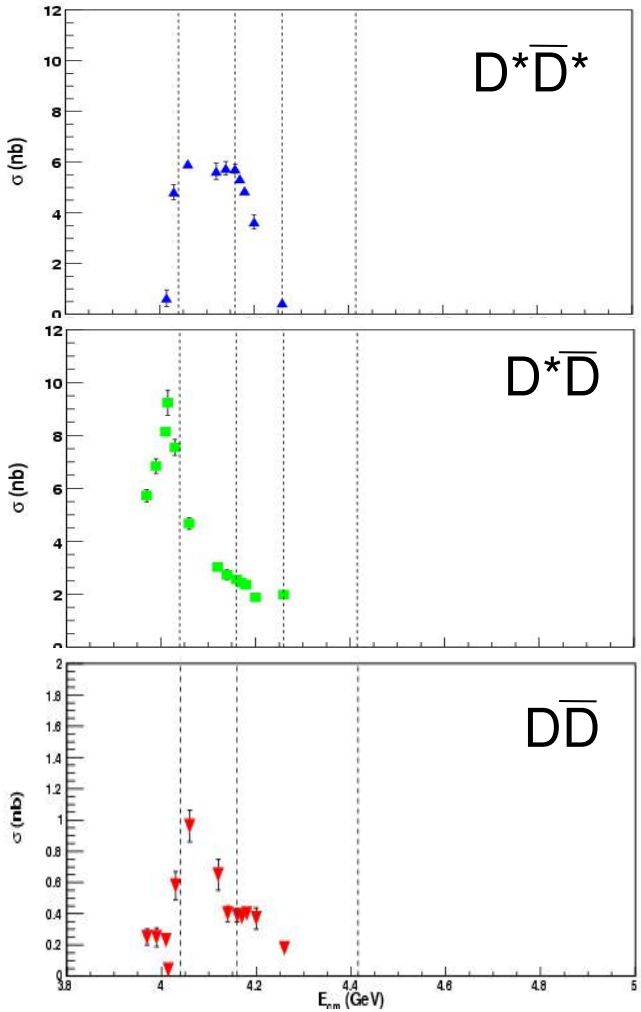


Updating S. Dubynskiy and M.B. Voloshin's results hep-ph/0608179

Comparison with the Belle Collaboration







PRELIMINARY

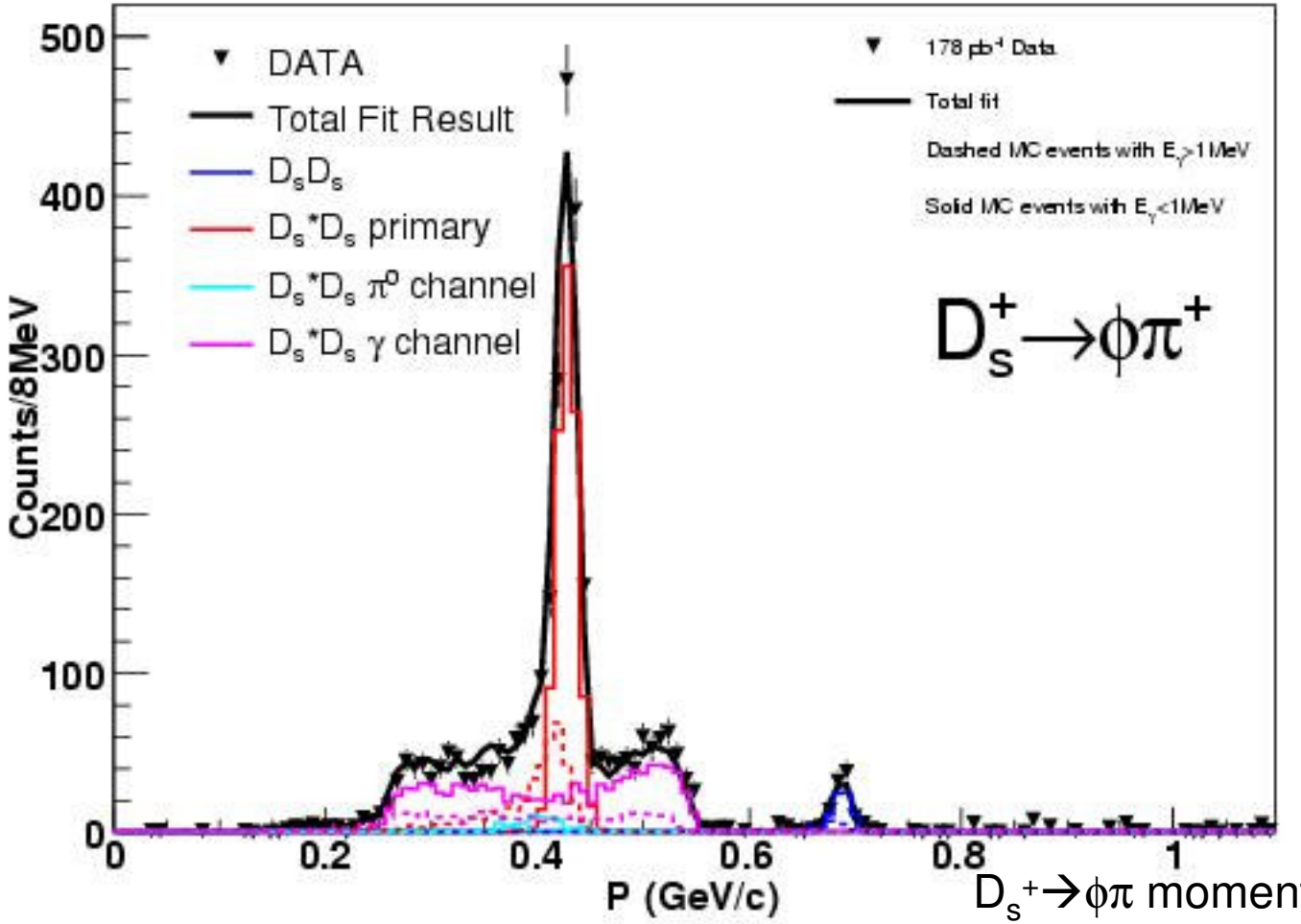
Conclusions

- Exclusive charm production above threshold have been measure.
  - $\sigma(D_s D_s)$ peaks at 4010 MeV
  - $\sigma(D_s^* D_s)$ peaks at 4170 MeV and is used by CLEO-c for D_s decay studies
- Interesting absence of $D\bar{D}$ at 4015 MeV (possibly a new resonance?)
- These studies will lead to a better understanding of QCD

Backup Slides

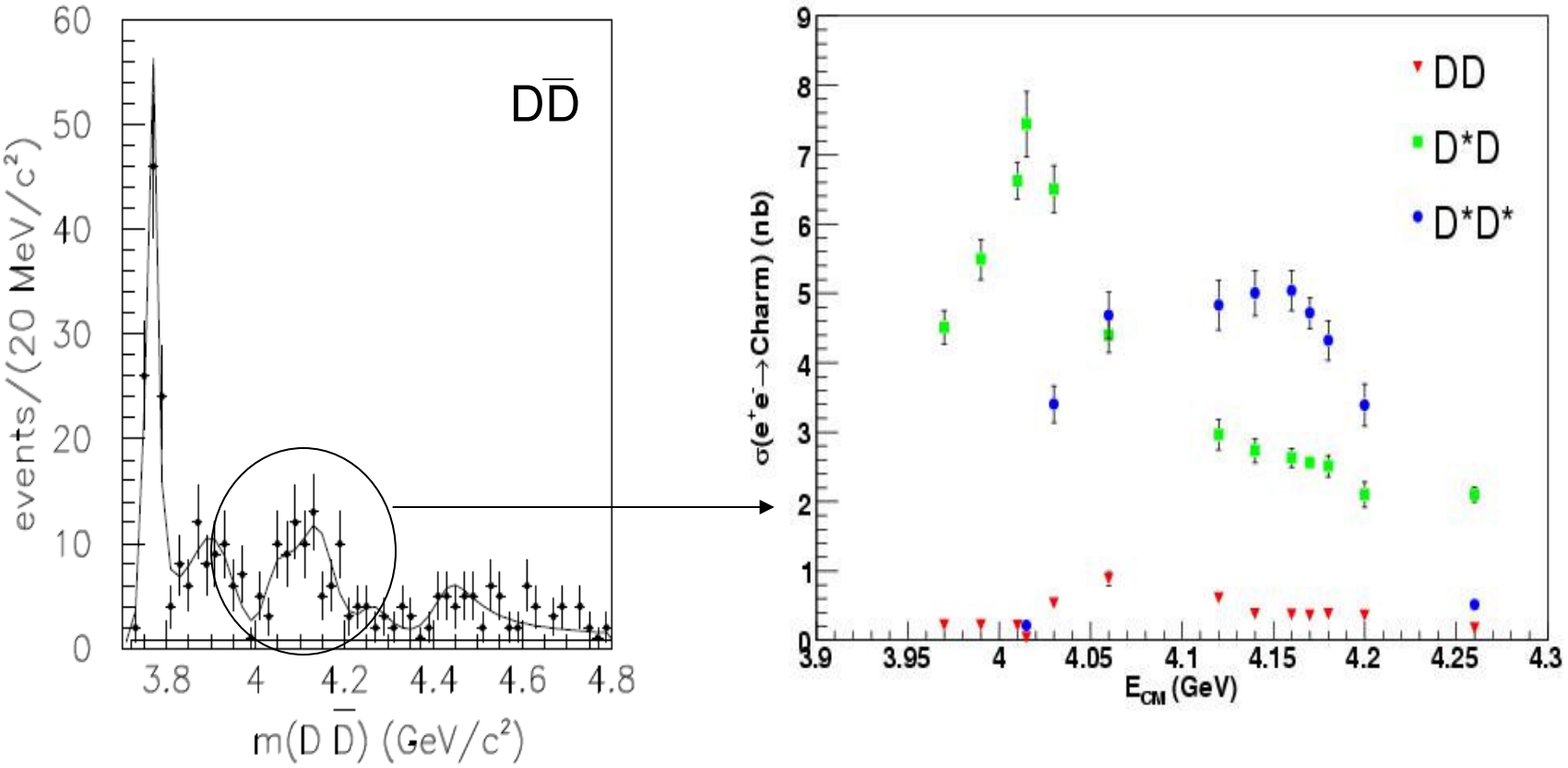
Momentum Fits to Data

E_{cm} = 4170 MeV
~ 180 pb^{-1}



$D_s^+ \to \phi\pi$ momentum spectrum after sideband subtraction

Comparison with the BaBar Collaboration



Theoretical Predictions

- Determined partial widths at two E_{CM} energies.

Partial widths in units of MeV

Center-of-Mass Energy	DD	D^*D	D^*D^*	$D_s^+D_s^-$	$D_s^{*+}D_s^-$	SUM	Exp.
4040 MeV	0.1	33	33	7.8	-	74	52±10
4159 MeV	16	0.4	35	8.0	14	74	78±20

hep-ph/0412057

Center-of-Mass Energy (MeV)	DD	D^*D	D^*D^*	$D_s^+D_s^-$	$D_s^{*+}D_s^-$
4160 (This Analysis)	3.9 ± 0.5	28.2 ± 1.8	54.1 ± 3.6	–	9.7 ± 0.6
4159 (Barnes)	21.6	0.5	47.3	10.8	18.9