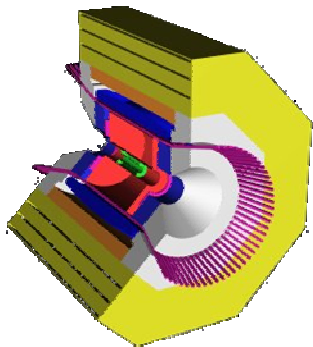

Charm – Production in e^+e^- Annihilation around 4 GeV

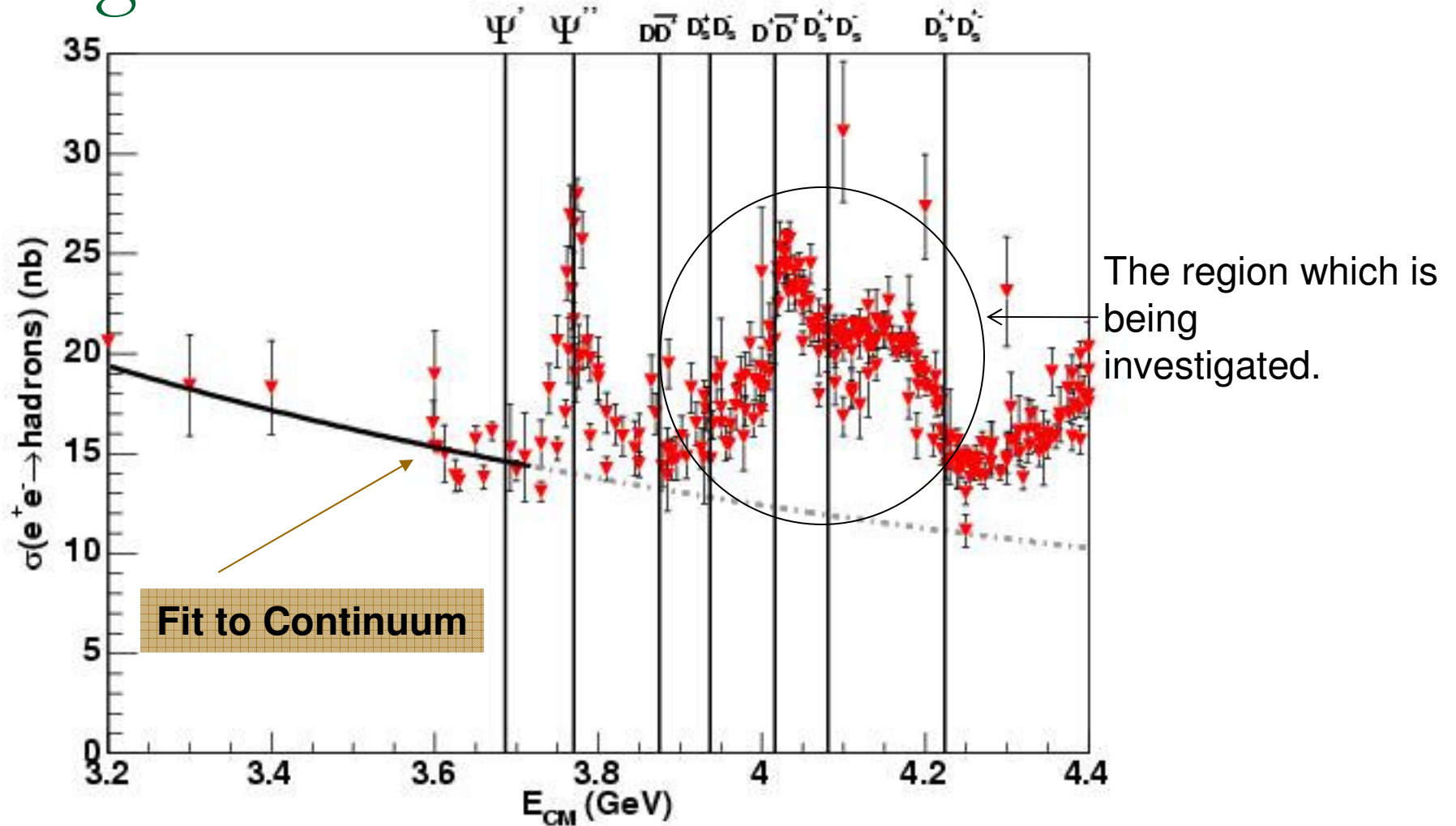


Brian Lang
University of Minnesota
on behalf of the CLEO Collaboration



Charm 2007
Cornell University, August 5th-8th 2007

Region of Interest



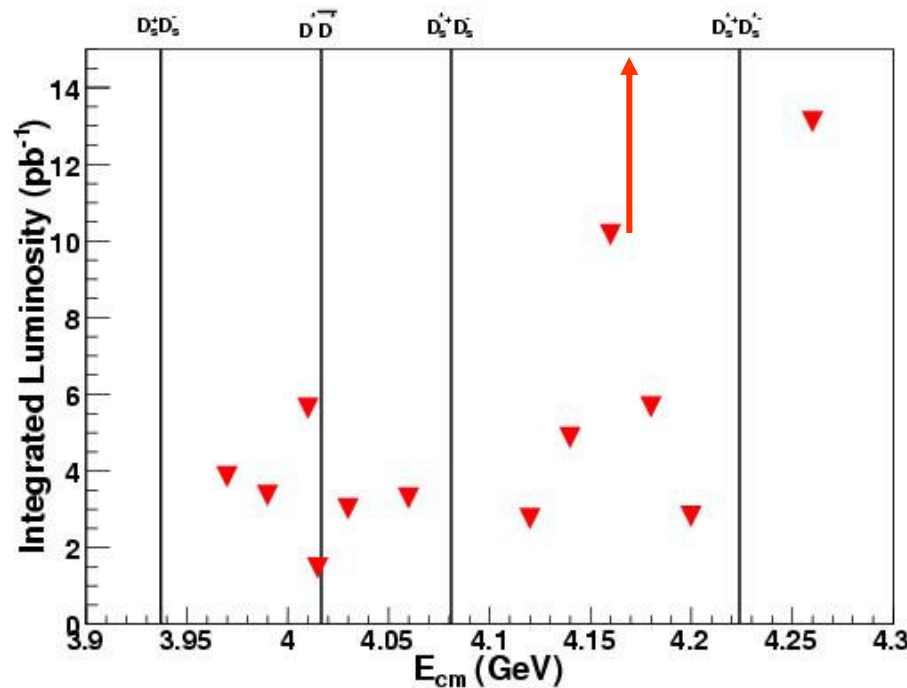
Cross section as a function of E_{cm} from the 2005 PDG

Why investigate this region:

- The cross sections to $D\bar{D}$, $D^*\bar{D}$, and $D^*\bar{D}^*$ 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 $D_s\bar{D}_s$.
 - Mark III measured the production cross section times branching ratio to $\phi\pi$ at 4140 MeV as 26 pb, production is largely $D_s\bar{D}_s^*$.
- **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) $\sim 60 \text{ pb}^{-1}$
- 4170 MeV $\sim 180 \text{ pb}^{-1}$

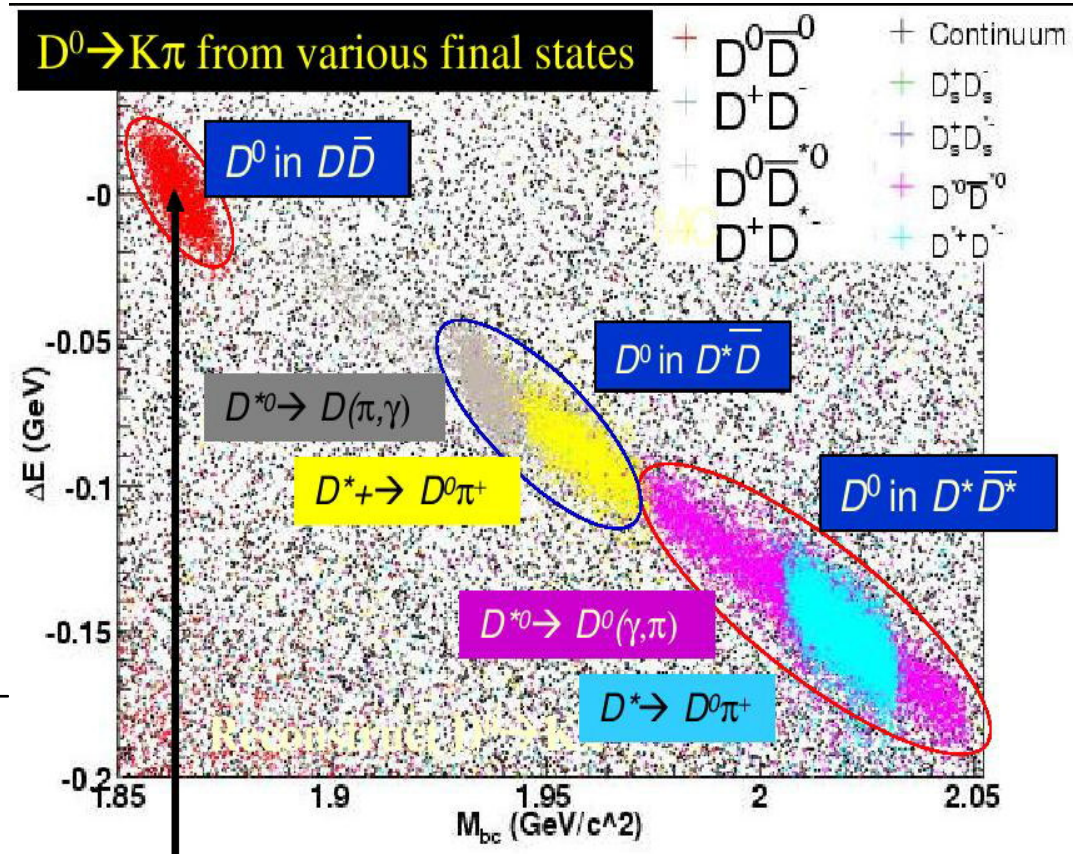
Cross Sections

MC Simulation $E_{CM}=4160$ MeV

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

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

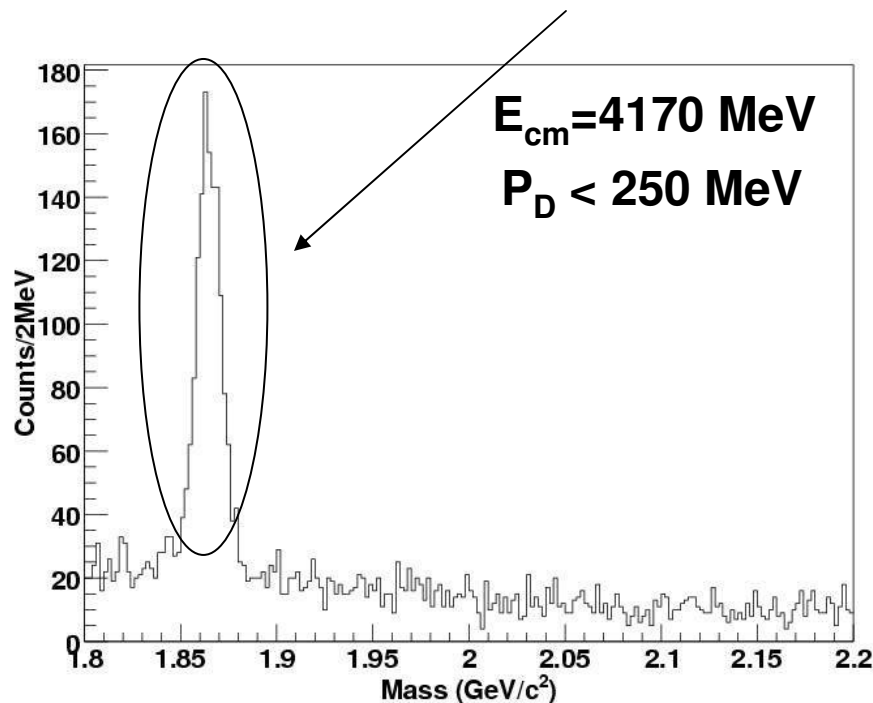
$$\Delta E = E_D - E_{beam}$$



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 $D_{(s)}^{(*)}\bar{D}_{(s)}^{(*)}$ exclusive event categories? Yes!



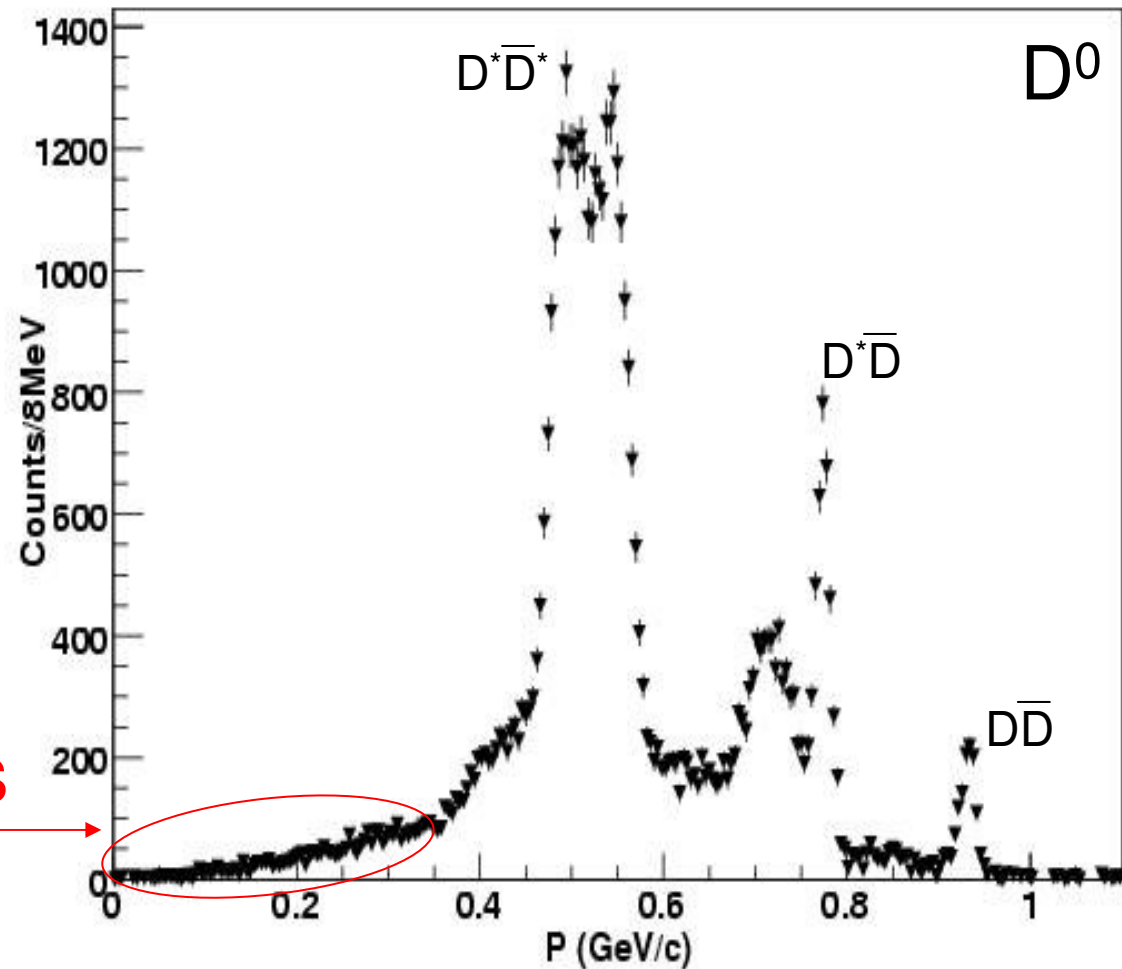
- Assuming only two body kinematics, NO D^0 mesons with a momenta below $\sim 350 \text{ MeV}$.
- Data shows a clear D^0 peak in the mass distribution for $K^-\pi^+$ candidates with momenta below 250 MeV .

Momentum Spectrum of D^0 at 4170 MeV

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

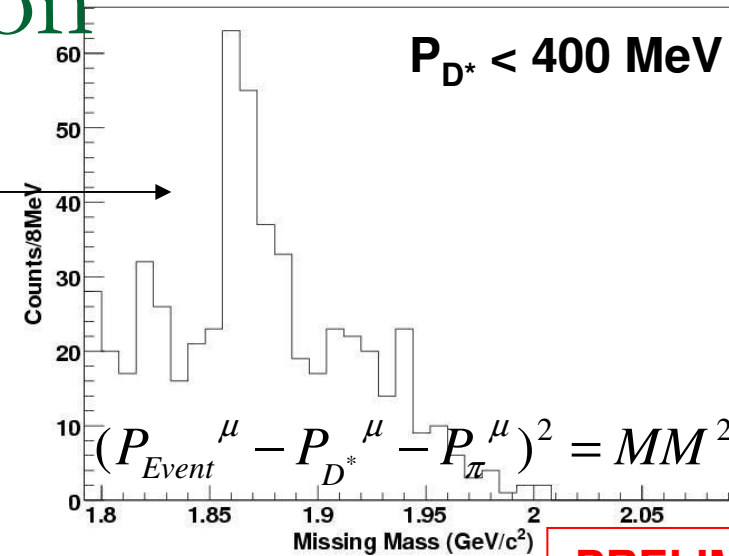
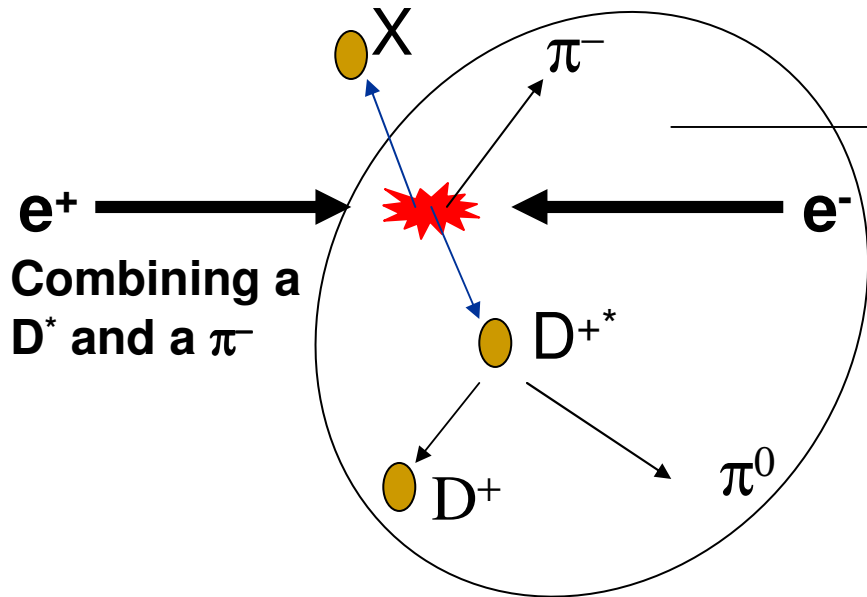
PRELIMINARY

What populates this region?

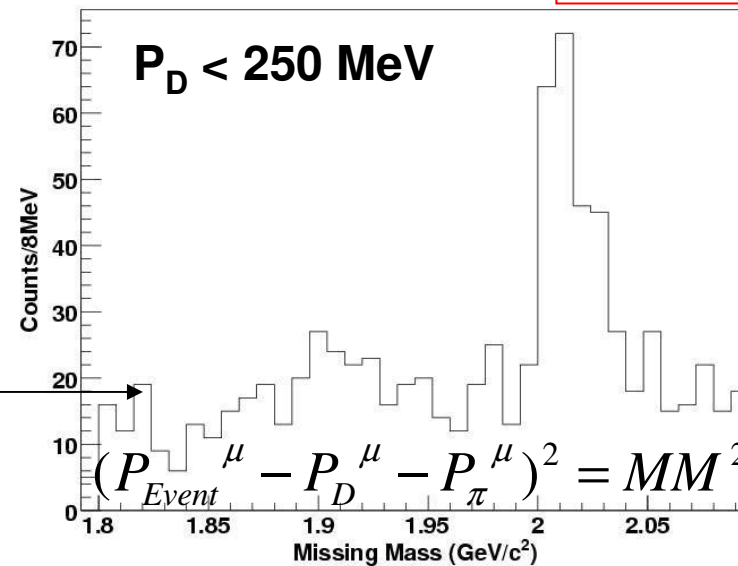
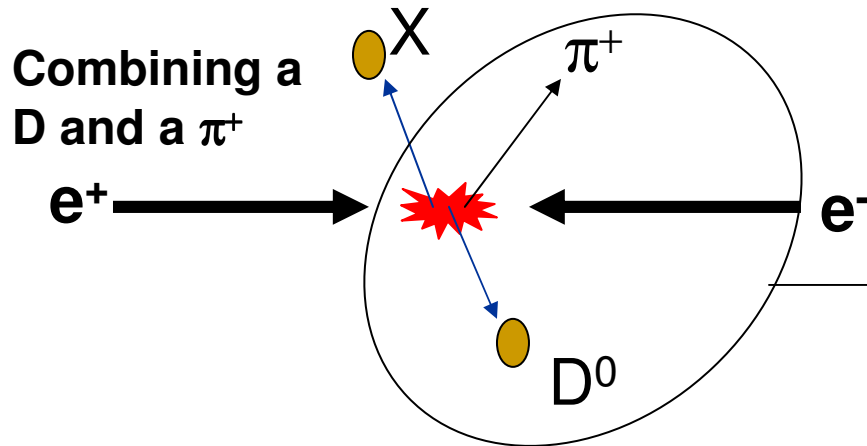


$E_{cm} = 4170 \text{ MeV}$

Multi-Body Production



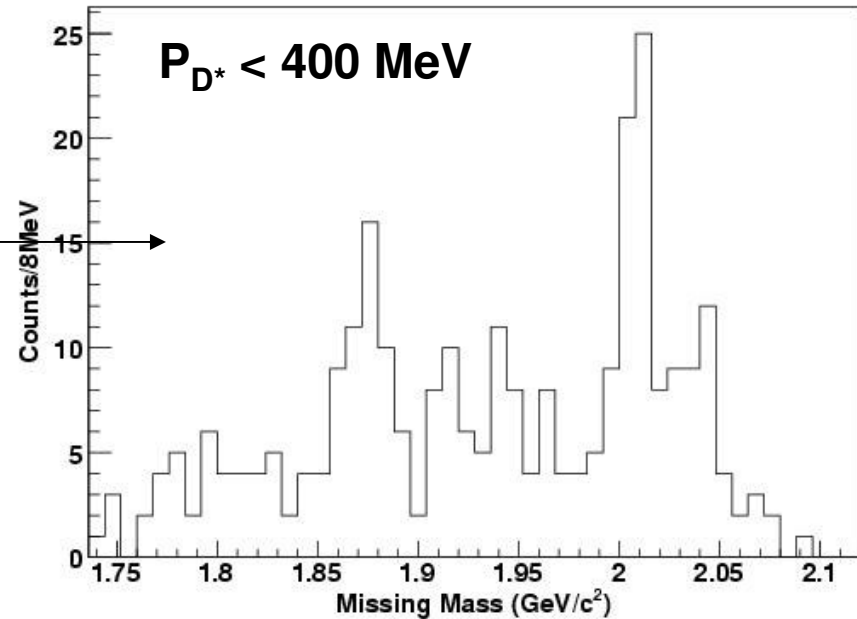
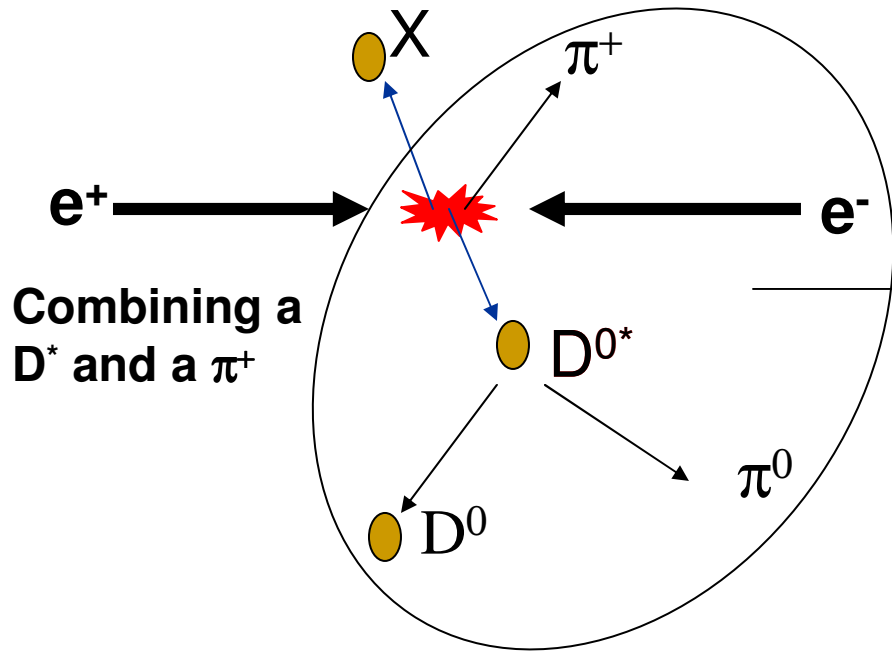
PRELIMINARY



Multi-Body Production

$E_{cm} = 4260 \text{ MeV}$

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.

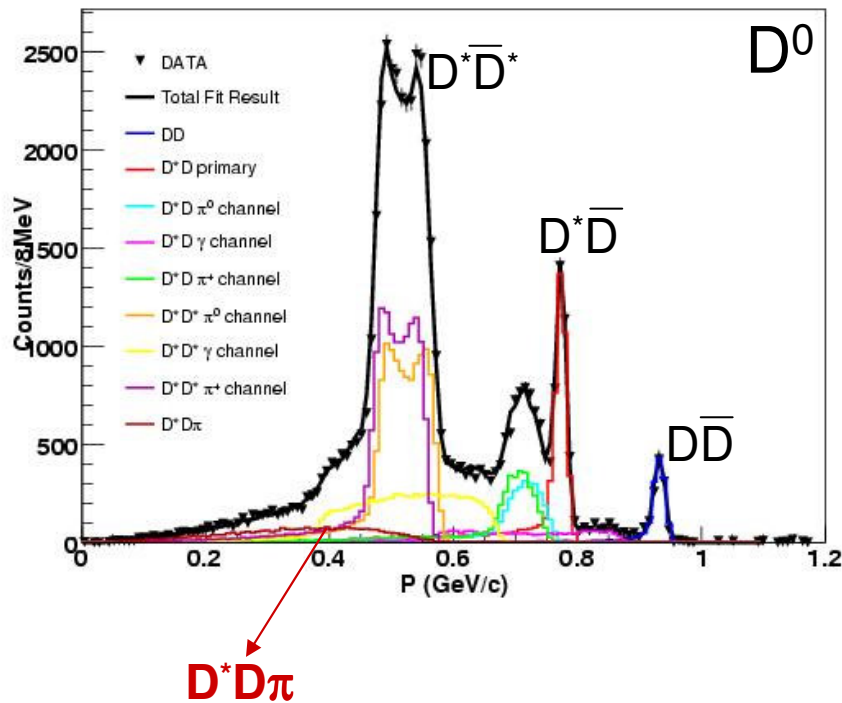
Momentum Fits using MC

$E_{cm} = 4170 \text{ MeV}$
 $\sim 180 \text{ pb}^{-1}$

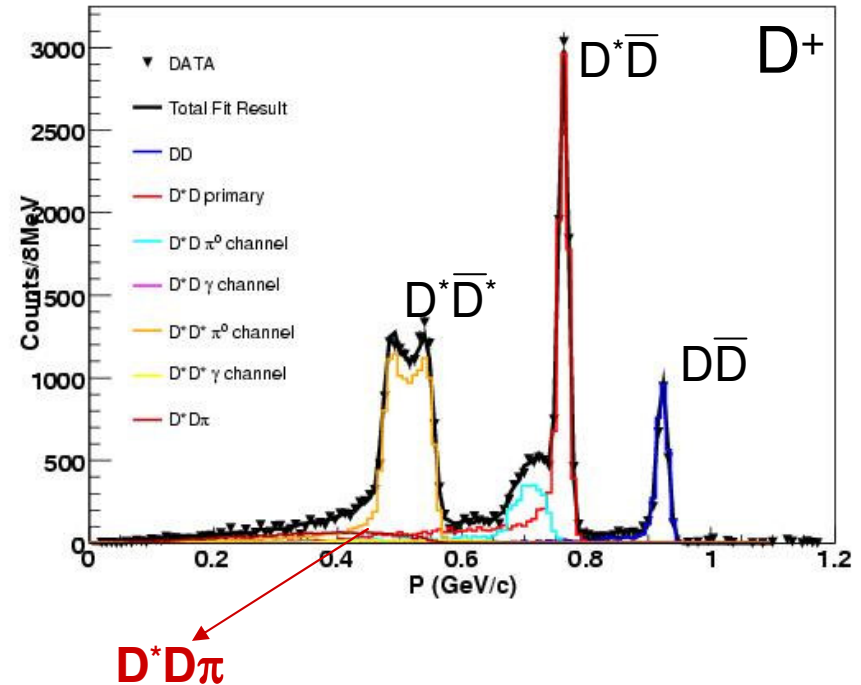
PRELIMINARY

Only assuming $D^*D\pi$ multi-body is present.

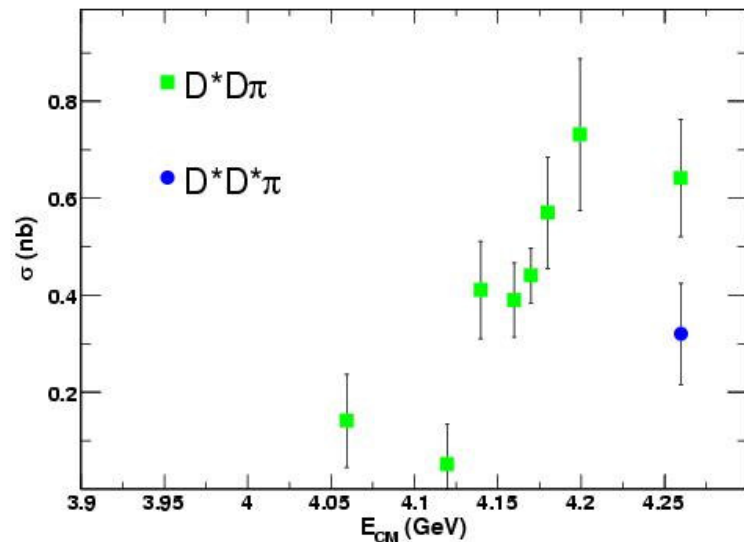
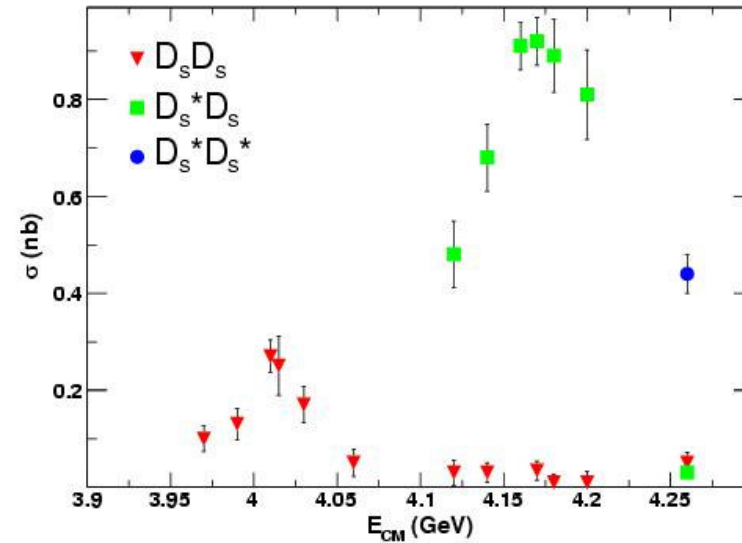
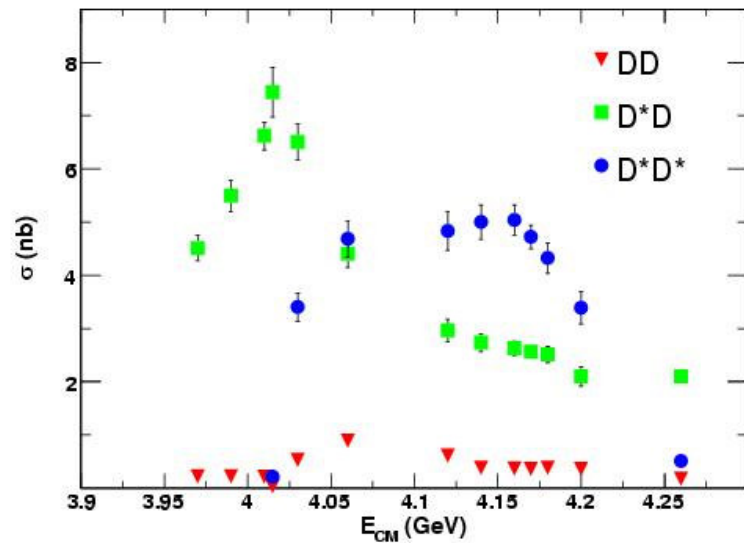
$D^0 \rightarrow K^- \pi^+$ Momentum Spectrum after sideband subtraction



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



Exclusive Cross Section Results



PRELIMINARY

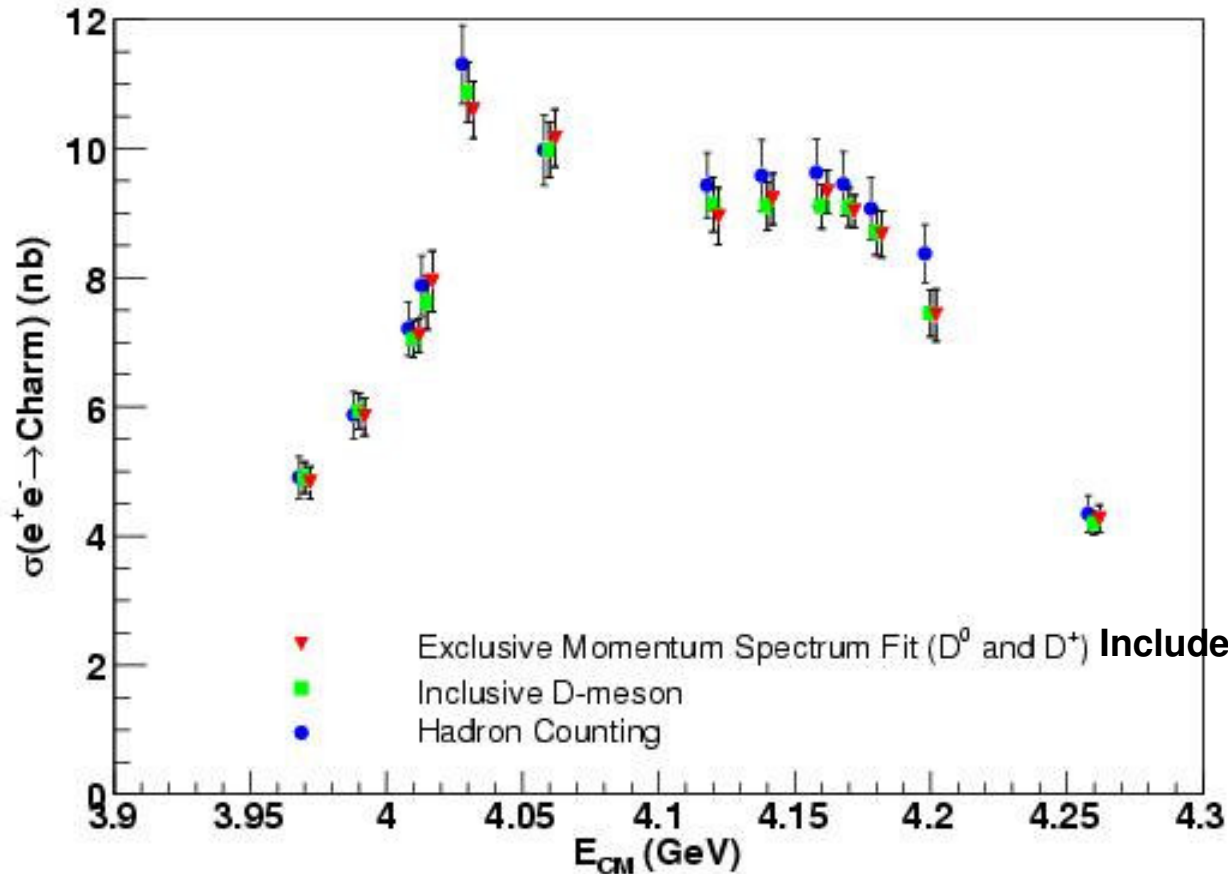
- No theoretical predictions for multi-body.
- No evidence of $D\bar{D}\pi$ in this region

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



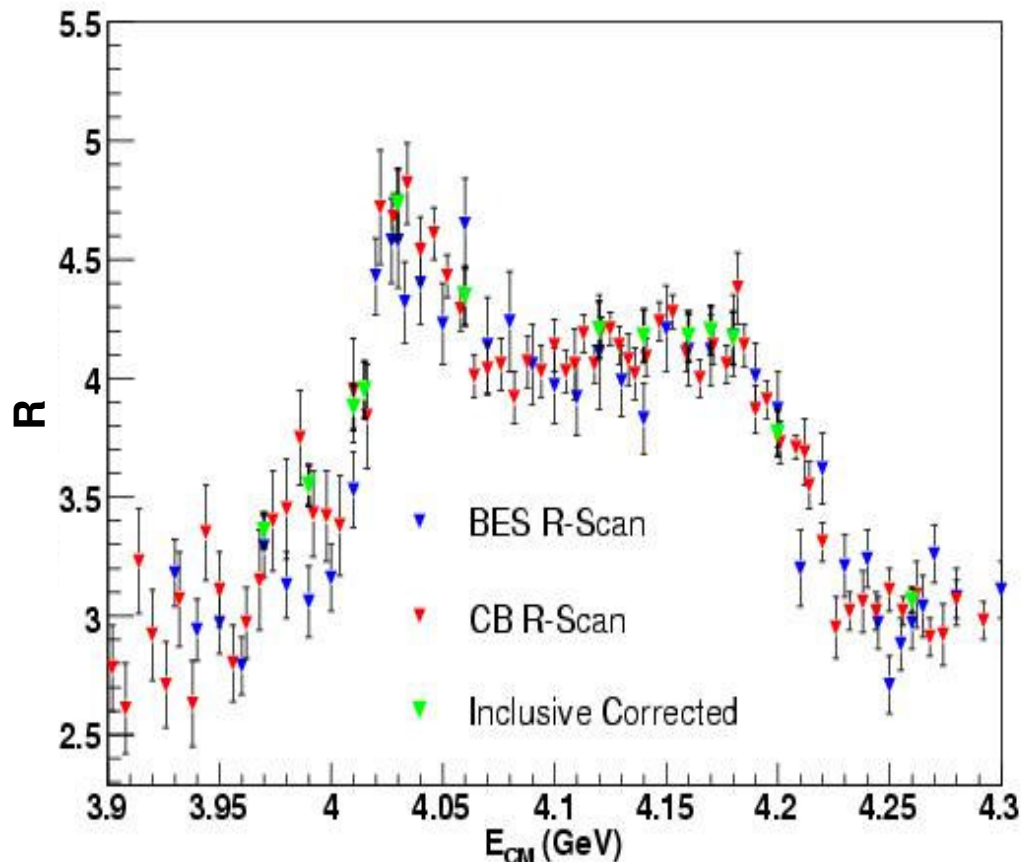
▼ Exclusive:
Sum of the two-body charmed mesons and multi-body

■ Inclusive charm:
 $D^0 + D^+ + D_s$

● Inclusive Hadrons:
Excess over uds

Radiative Corrections

PRELIMINARY



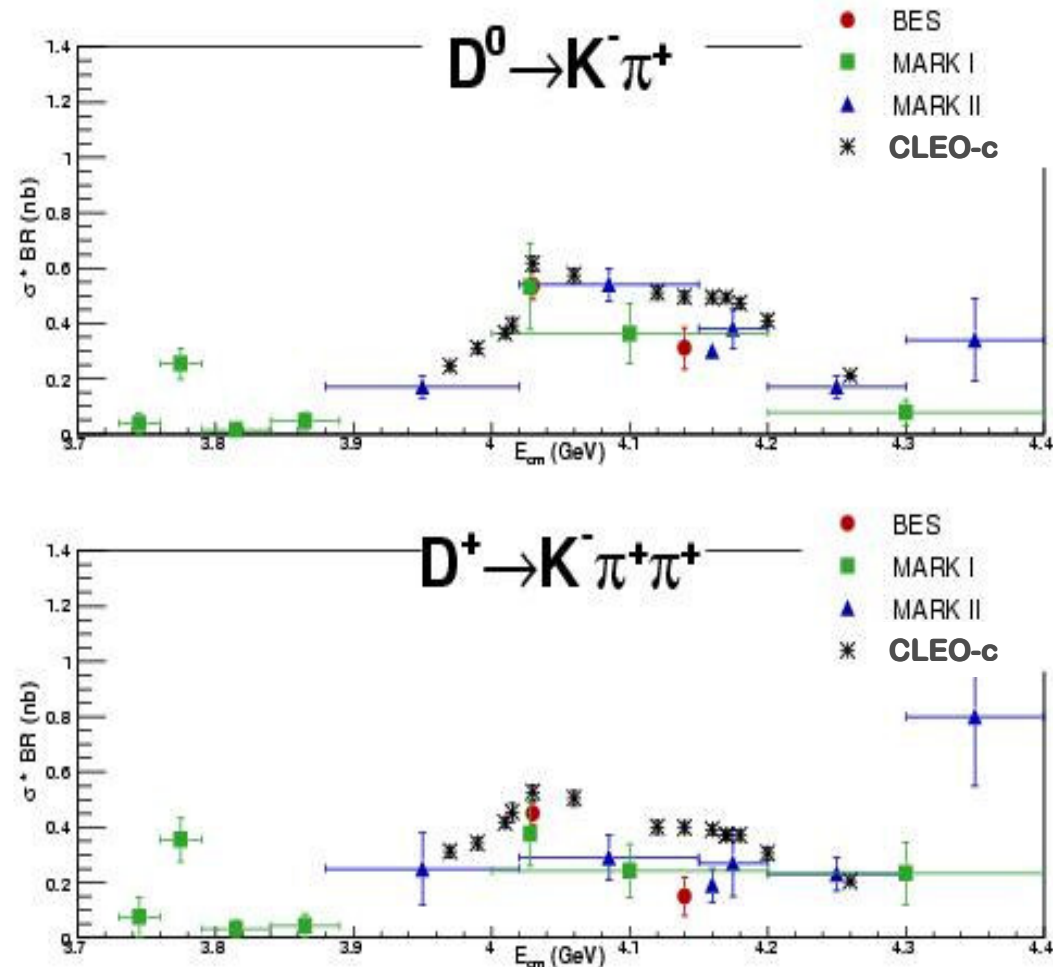
- In order to compare the observed cross sections to theory and previous experiments the cross sections need to be corrected for the effects of initial-state radiation.
- Using theoretical treatment of Kuraev and Fadin (Sov. J. Nucl. Phys. 41 466) and Crystal Ball R measurement

$$R = R_{uds} + R_{charm}$$
$$R_{uds} = 2.29 \pm 0.03$$

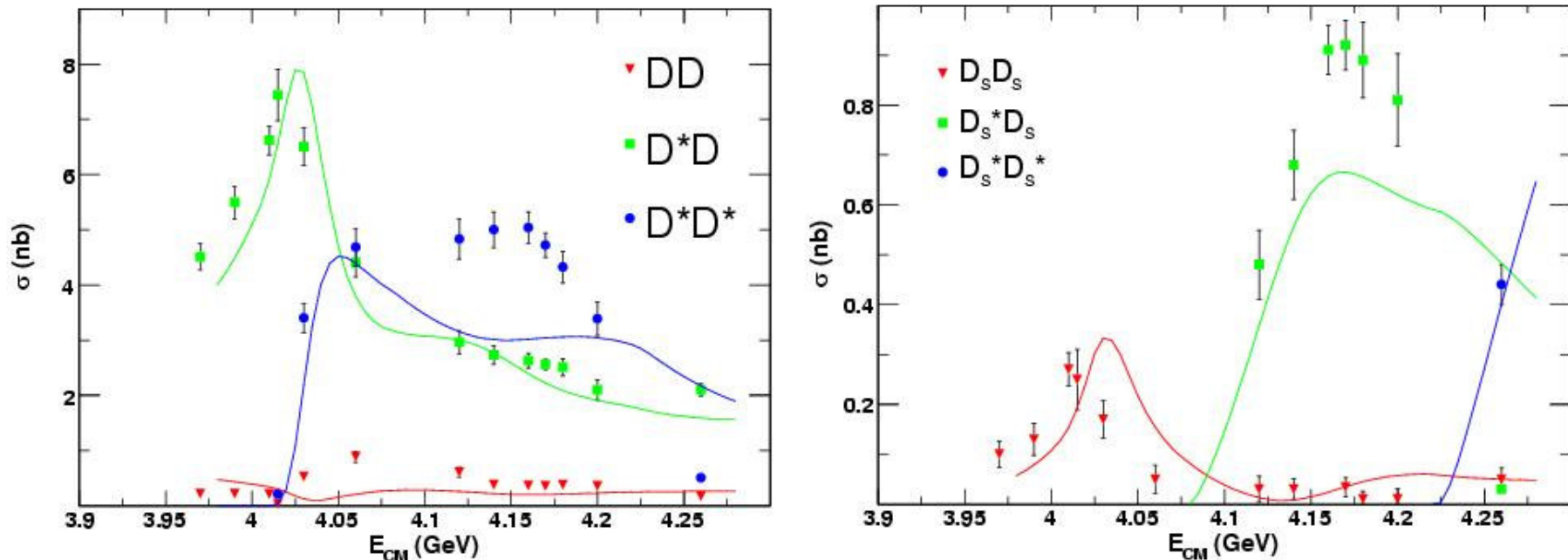
Inclusive Cross Section

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

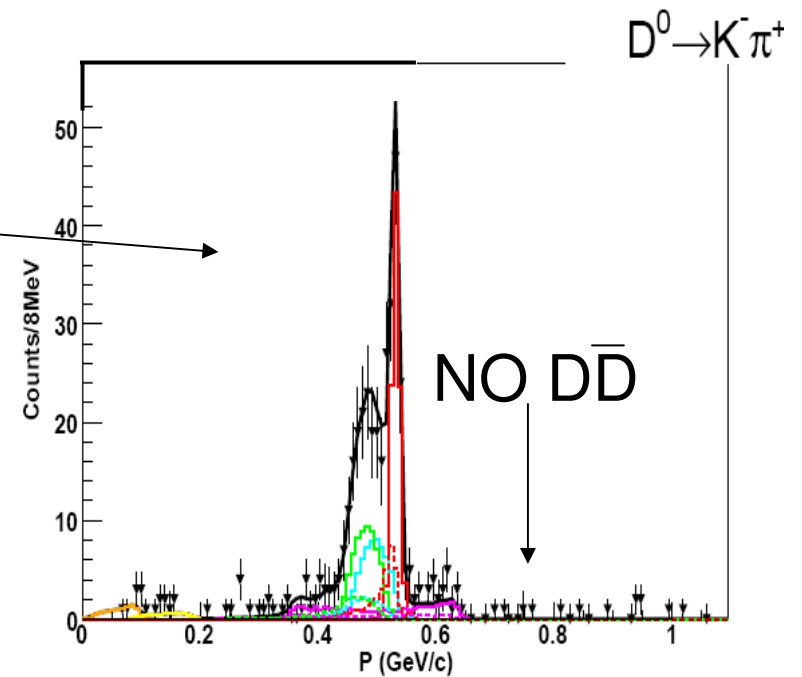
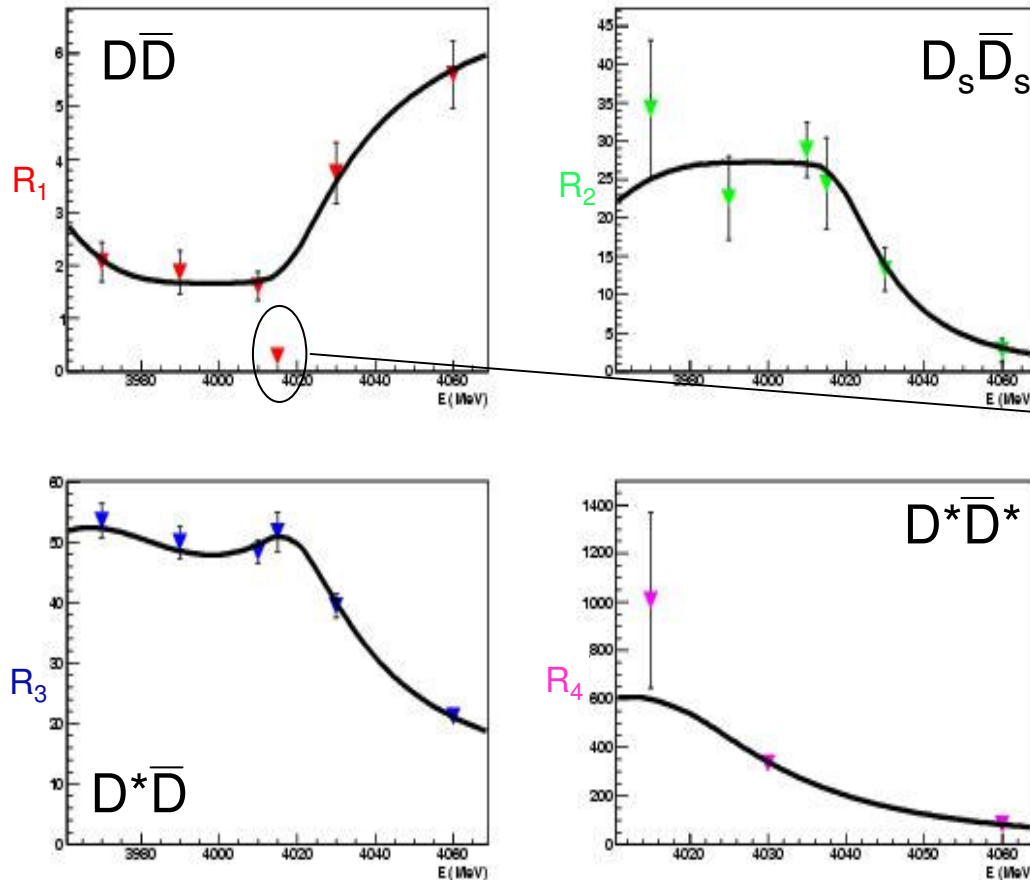
- Most noticeable difference in $D^*\bar{D}^*$ channel.
- Still reasonable qualitative agreement.

PRELIMINARY

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

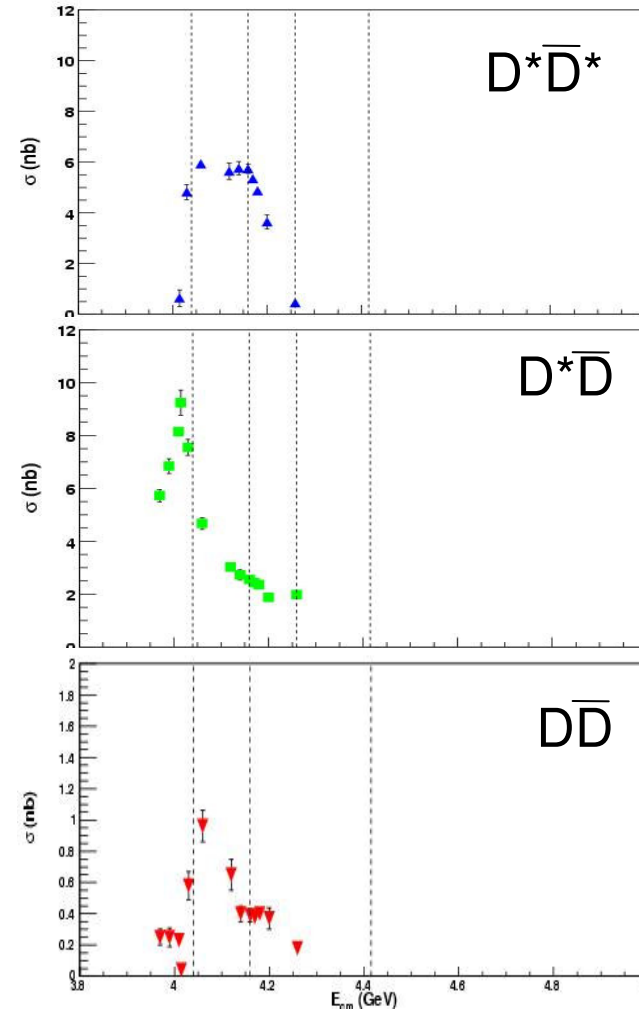
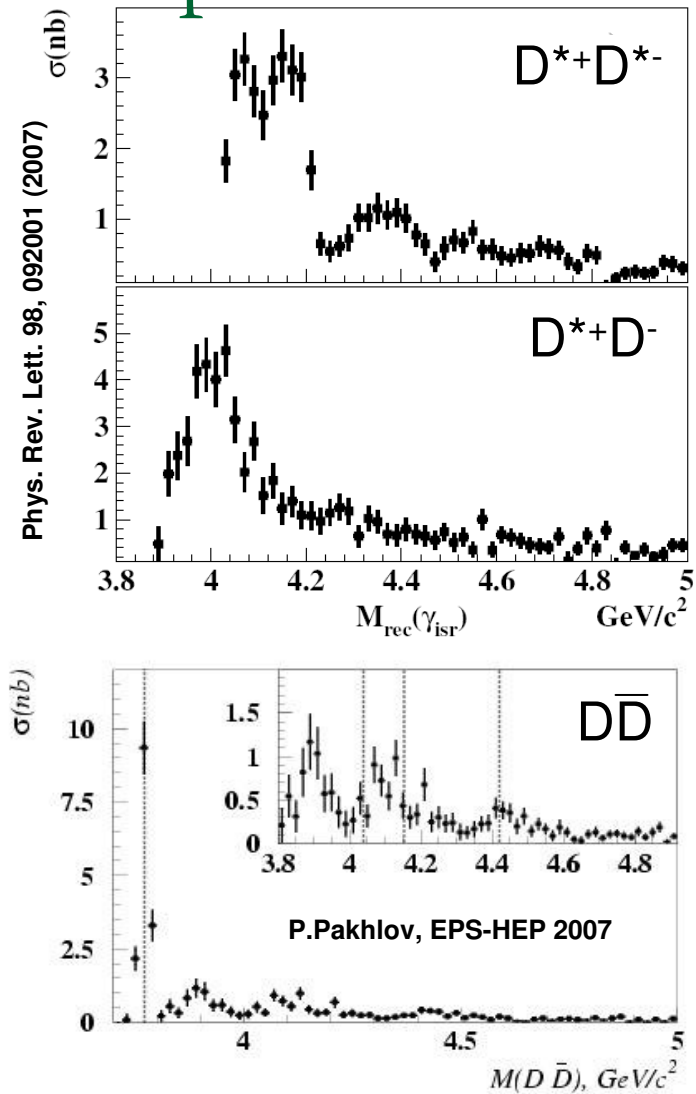
PRELIMINARY

- R is proportion to the cross section.
- Fit assumes only a single resonance.
- Introduction of another narrow resonance can explain the 'dip' in DD at 4015 MeV



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

Comparison with the Belle Collaboration



PRELIMINARY

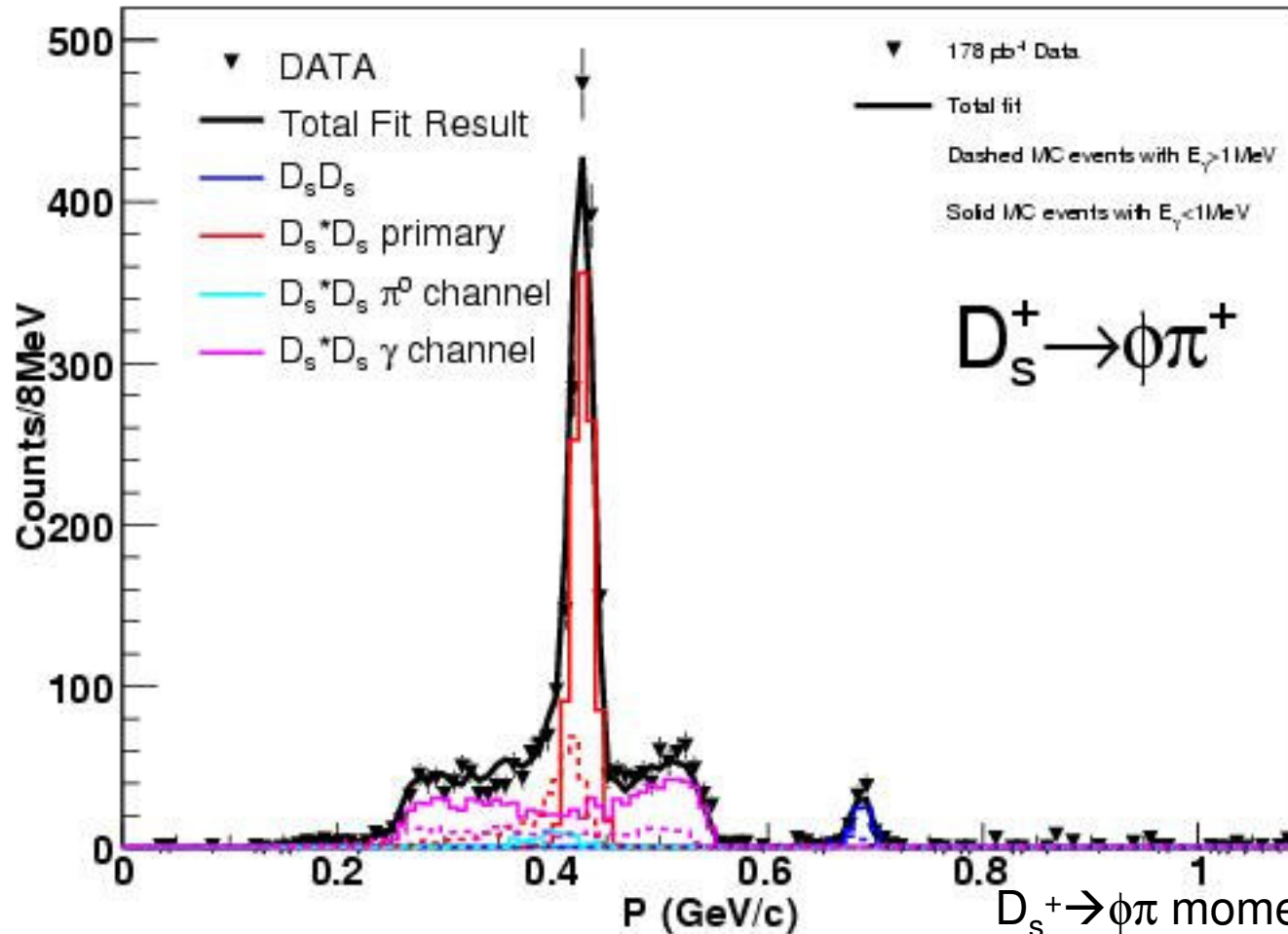
Conclusions

- 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

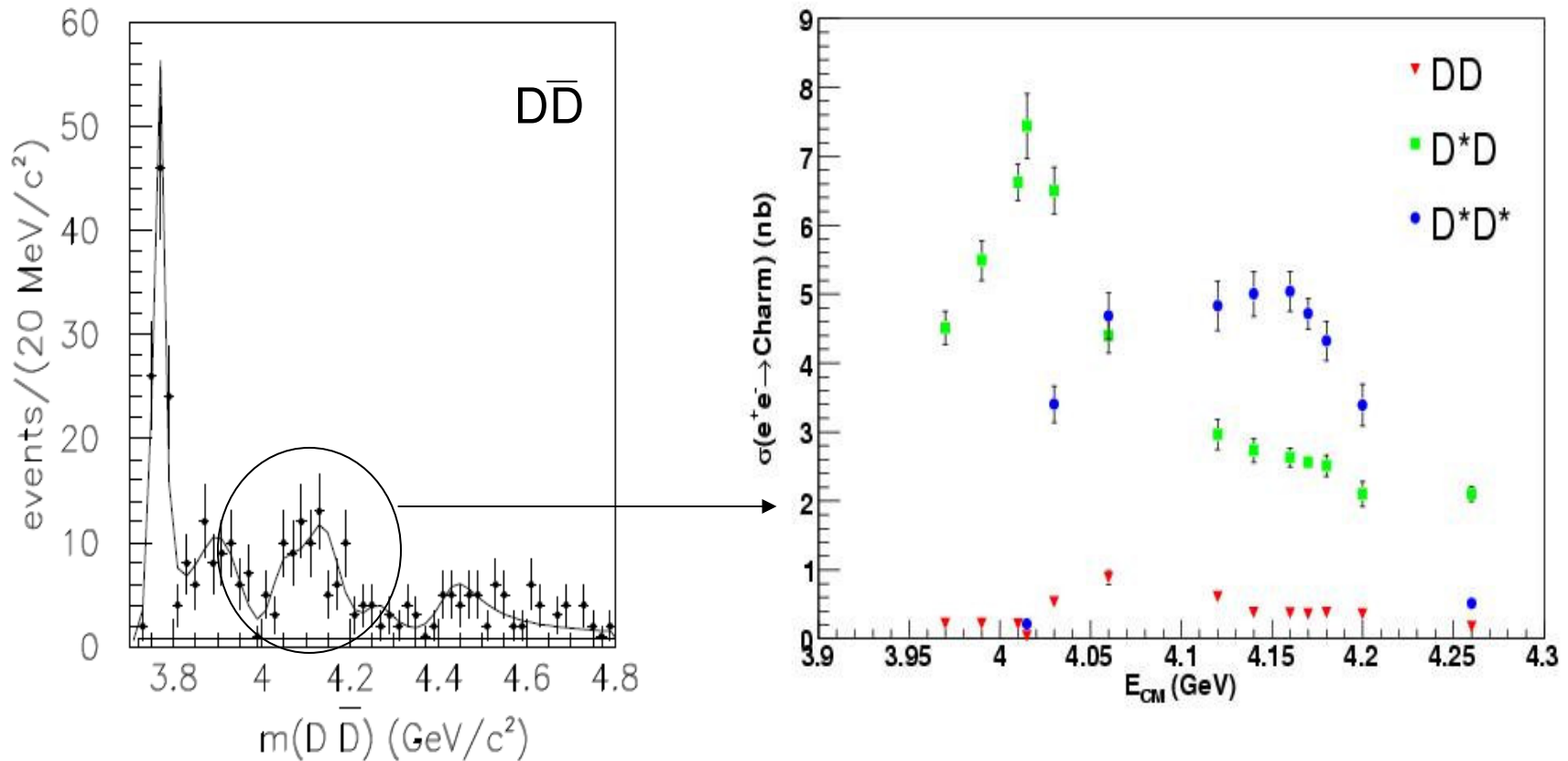
Momentum Fits to Data

$E_{cm} = 4170 \text{ MeV}$
 $\sim 180 \text{ pb}^{-1}$



$D_s^+ \rightarrow \phi \pi^+$ 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