Measurement of charm production cross sections in e^+e^- annihilation at energies between 3.97 and 4.26 GeV

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Introduction

- Little intensive study about hadron production in electron-positron annihilations just above $c\bar{c}$ threshold.

- Any comprehensive program of precise charm-decay measurements demands a detailed understanding of charm production.

- There is a rich structure in this energy region, reflecting the production of $c\bar{c}$ resonances and the crossing of thresholds for specific charm-meson final states.

- Considerable theoretical interest and little experimental information .

Data sets and decay modes

TABLE I. Center-of-mass energies and integrated luminosity totals for all data samples used in this paper.

$E_{\text{c.m.}}$ (MeV)	$\int \mathcal{L}dt$ (pb^{-1})
3970	3.85
3990	3.36
4010	5.63
4015	1.47
4030	3.01
4060	3.29
4120	2.76
4140	4.87
4160	10.16
4170	178.89
4180	5.67
4200	2.81
4260	13.11

$$D^0 \to K^-\pi^+$$

$$D^+ \to K^-\pi^+\,\pi^+$$

$$D_s:$$

Modes	Reference	$\mathcal{B}$ (%)
$K^+K^-\pi^+, \lvert M_{KK} - M_\phi\rvert < (10\ \text{MeV}/c^2)$	[15]	1.99 ± 0.11
$\bar{K}^{*0}K^+, \bar{K}^{*0} \to K^-\pi^+$	[5]	2.2 ± 0.6
$\eta\pi^+, \eta \to \gamma\gamma$	[5,15]	0.62 ± 0.08
$\eta\rho^+, \eta \to \gamma\gamma, \rho^+ \to \pi^+\pi^0$	[5]	4.3 ± 1.2
$\eta'\pi^+, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma$	[5,15]	0.66 ± 0.07
$\eta'\rho^+, \eta' \to \pi^+\pi^-\eta, \eta \to \gamma\gamma, \rho^+ \to \pi^+\pi^0$	[5]	1.8 ± 0.5
$\phi\rho^+, \phi \to K^+K^-, \rho^+ \to \pi^+\pi^0$	[5]	3.4 ± 1.2
$K_SK^+, K_S \to \pi^+\pi^-$	[5,15]	1.03 ± 0.06

MC simulation

$$\Delta E \equiv E_{D_{(s)}} - E_{\text{beam}}$$

$$M_{\text{bc}} \equiv \sqrt{E_{\text{beam}}^2 - |\mathbf{P}_{D_{(s)}}|^2}$$

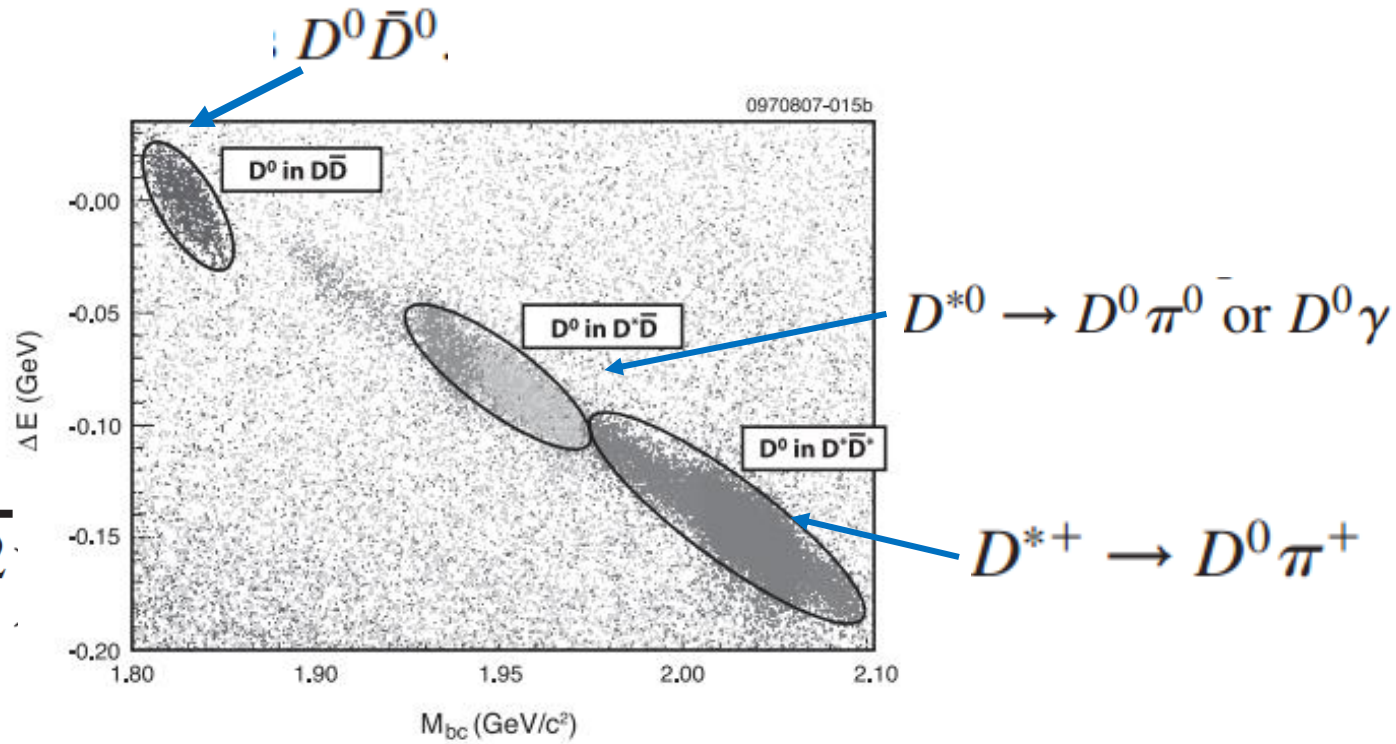


FIG. 1. ΔE vs M_{bc} for $D^0 \to K^-\pi^+$ candidates in a Monte Carlo simulation of CLEO-c data at a center-of-mass energy of 4160 MeV. Separation among the expected two-charm-meson final states is evident, as described in the text.

Momentum spectra

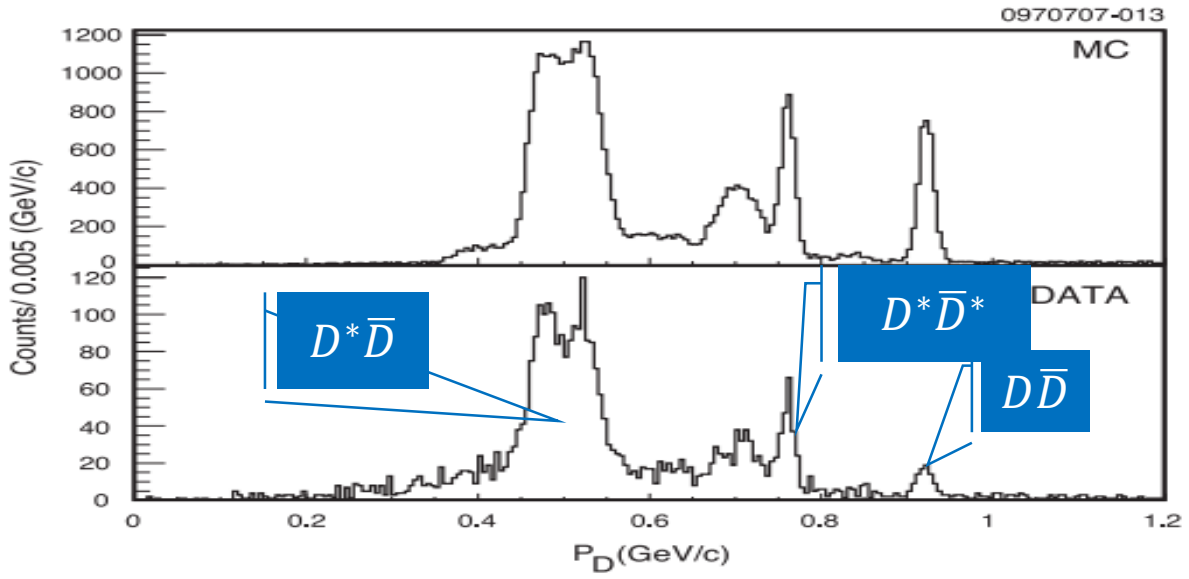


FIG. 2. Momentum spectra in Monte Carlo simulation (top) and data (bottom) at 4160 MeV for $D^0 \longrightarrow K^-\pi^+$ candidates with invariant masses within 15 MeV of the nominal value. There is reasonable agreement between the Monte Carlo simulation and data, with clear peaks corresponding to the expected final states with two charm mesons at this energy ($D\bar{D}$, $D^*\bar{D}$ and $D^*\bar{D}^*$). Quantitative interpretation of the momentum spectrum requires correction for non-charm-meson backgrounds, consideration of additional channels for charm-meson production, radiative effects, and other phenomena, as described in the text.

Fit

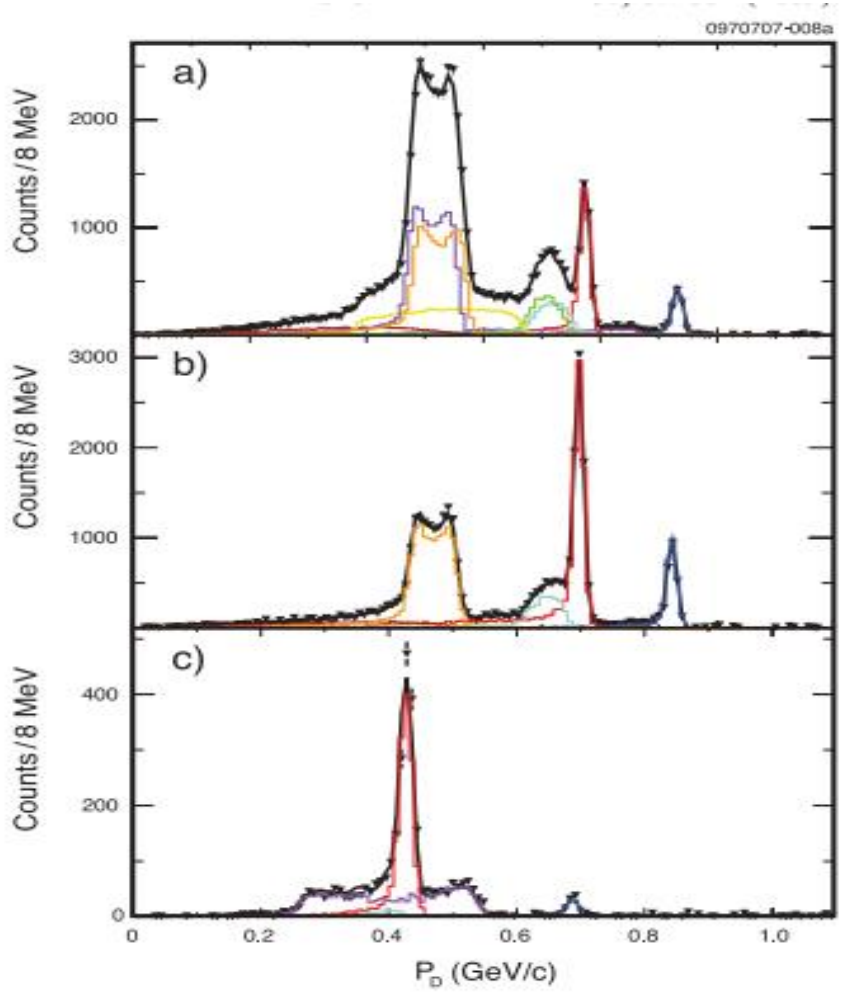
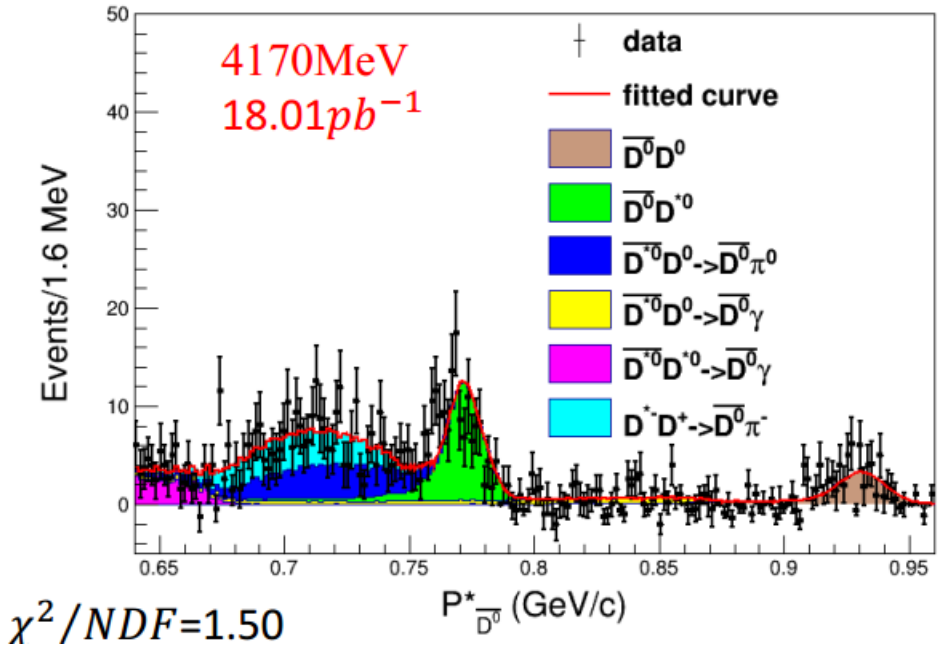


FIG. 4 (color). Sideband-subtracted momentum spectra for (a) $D^0 \to K^-\pi^+$, (b) $D^+ \to K^-\pi^+\pi^+$, and (c) $D_s^+ \to \phi\pi^+$ at 4170 MeV. Data are shown as points with errors and the total fit result is shown as the solid black line. The colored histograms represent specific $D_{(s)}$-production mechanisms, with shapes obtained from Monte Carlo simulations and normalizations determined by the fits. The color code for the components of the fits and the χ^2 values is given in the text.

4170 MeV

BES III



χ^2/NDF=1.50

Fit

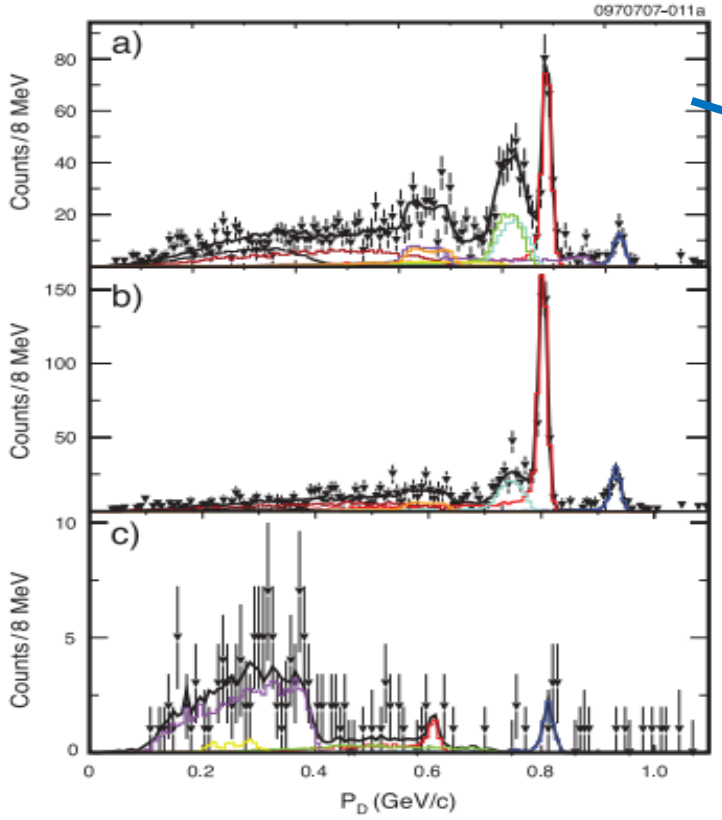
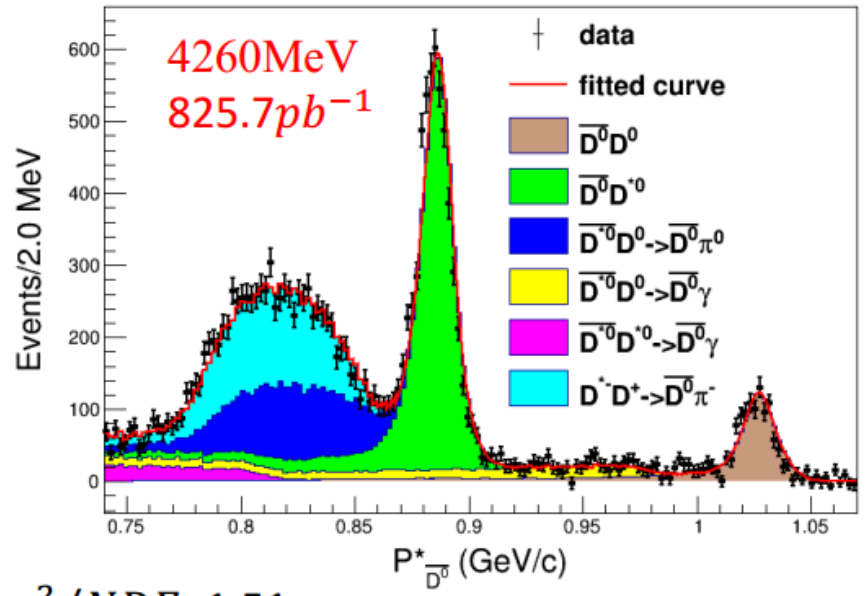


FIG. 5 (color). Sideband-subtracted momentum spectra for (a) $D^0 \to K^-\pi^+$, (b) $D^+ \to K^-\pi^+\pi^+$, and (c) $D_s^+ \to \phi\pi^+$ at 4260 MeV. Data are shown as points with errors and the total fit result is shown as the solid black line. The colored histograms represent specific $D_{(s)}$-production mechanisms, with shapes obtained from Monte Carlo simulations and normalizations determined by the fits. The color coding for the components matches that of Fig. 4, as described in the text. All peaks are shifted slightly higher in momentum, and the low-momentum region is populated by two multibody components: the $D^*\bar{D}\pi$ (dark red line) between 0 and 0.6 GeV/c, observed at 4170 MeV, and $D^*\bar{D}^*\pi$ (black line) between 0 and 0.4 GeV/c, which is not present at lower energy.

BES III



χ^2/NDF=1.51

Cross section

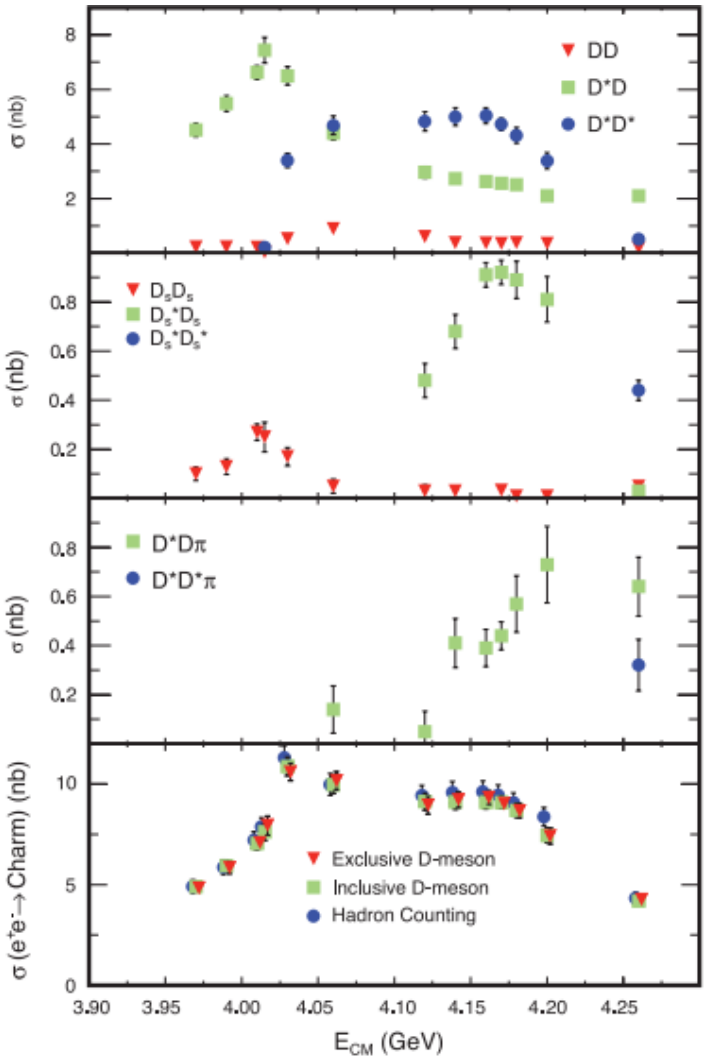


FIG. 6 (color). Exclusive cross sections for two-body and multibody charm-meson final states, and total observed charm cross section with combined statistical and systematic uncertainties.

None-ISR

TABLE IV. Measured cross sections for final states consisting of two neutral nonstrange charm mesons. The first error on each cross section is statistical and the second is systematic.

$E_{\text{c.m.}}$ (MeV)	$\sigma(D^0\bar{D}^0)$ (pb)	$\sigma(D^{*0}\bar{D}^0)$ (pb)	$\sigma(D^{*0}\bar{D}^{*0})$ (pb)
3970	$86 \pm 29 \pm 4$	$2280 \pm 134 \pm 78$	···
3990	$133 \pm 41 \pm 6$	$2740 \pm 157 \pm 93$	···
4010	$76 \pm 25 \pm 3$	$3320 \pm 13 \pm 113$	···
4015	<10 (90% C.L.)	$3840 \pm 283 \pm 131$	$213 \pm 76 \pm 9$
4030	$334 \pm 70 \pm 15$	$3200 \pm 183 \pm 109$	$2000 \pm 125 \pm 94$
4060	$410 \pm 72 \pm 18$	$2230 \pm 147 \pm 76$	$2290 \pm 132 \pm 108$
4120	$303 \pm 70 \pm 14$	$1400 \pm 135 \pm 48$	$2550 \pm 154 \pm 120$
4140	$177 \pm 40 \pm 8$	$1350 \pm 100 \pm 46$	$2443 \pm 116 \pm 115$
4160	$167 \pm 28 \pm 8$	$1252 \pm 69 \pm 43$	$2566 \pm 84 \pm 121$
4170	$177 \pm 7 \pm 8$	$1272 \pm 19 \pm 43$	$2363 \pm 19 \pm 111$
4180	$179 \pm 39 \pm 8$	$1211 \pm 92 \pm 41$	$2173 \pm 104 \pm 102$
4200	$180 \pm 55 \pm 8$	$1030 \pm 123 \pm 35$	$1830 \pm 139 \pm 86$
4260	$86 \pm 18 \pm 4$	$1080 \pm 59 \pm 37$	$269 \pm 42 \pm 13$

BES III will give the result of cross sections with the ISR at energies between 3.89 and 4.6 GeV .

Some problems at BES III

- 664P01:KKMC-00-00-44/src/bornv/RRes.F
- :703: KKMC/KKMC-00-00-57/src/bornv/RRes.F
- By Like:
- http://indico.ihep.ac.cn/event/4781/contribution/8/material/slides/0.pdf

ConExc

xs_user.txt

```
3.8900      293.004   0
3.8909      295.978   0
3.8918      299.475   0
3.8927      303.487   0
3.8936      308.004   0
3.8944      313.019   0
3.8953      318.522   0
3.8962      324.504   0
3.8971      330.958   0
3.8980      337.872   0
3.8989      345.235   0
3.8998      353.039   0
3.9007      361.271   0
3.9016      369.922   0
3.9024      378.981   0
3.9033      388.437   0
3.9042      398.281   0
3.9051      408.502   0
3.9060      419.089   0
3.9069      430.033   0
3.9078      441.321   0
```

```
void EvtXsection::ini_data_diy(){//user provide xs list
 xx.clear();yy.clear();er.clear();
 ifstream file("xs_user.txt");
 double xm,xs,xs_er;
 while(!file.eof()){
    file>>xm>>xs>>xs_er;
    //  std::cout<<"read XS: "<<xm<<" "<<xs<<" "<<xs_er<<std::endl;
    xx.push_back(xm);
    yy.push_back(xs);
    er.push_back(xs_er);
 }
 xx.pop_back();
 yy.pop_back();
 er.pop_back();
 nbins=yy.size();
 file.close();
  _unit="";
  msg="";
}
```

KMC

xs_user.dat

```
      IF(ICH.EQ.-2) THEN
         DO IJ=1,1000 !INITIALIZE ARRAY
            USER_XX(IJ)=0
            USER_YY(IJ)=0
         ENDDO
         NDIM = 0
         OPEN(unit=91, FILE='./xs_user.dat', STATUS='old')
         rewind 91
         DO IJ=1,1000
            NDIM = IJ
            READ(91,*,end=100) USER_XX(NDIM),USER_YY(NDIM)
c            print*, USER_XX(NDIM)-C50_XX(NDIM),USER_YY(NDIM)-C50_YY(IJ)
         ENDDO
 100     NDIM = NDIM-1
         IF(NDIM .EQ.1) THEN
            PRINT*, 'NO DATA ACCESIBLE IN THE FILE xs_user.dat'
            STOP
         ENDIF
         youxs= XLININT(USER_YY,USER_XX,SQRS,NDIM)
         XBORN= XLININT(USER_YY,USER_XX,CMS, NDIM)
      ELSEIF(ICH .GE.0) THEN
         youxs= XLININT(YY,XX,SQRS,N1)
         XBORN= XLININT(YY,XX,CMS, N1)
      ELSE
         PRINT*,'BAD MODE INDEX, I STOP'
         STOP
      ENDIF
```