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FROM ELASTIC TRIGGERS TO LUMINOSITY

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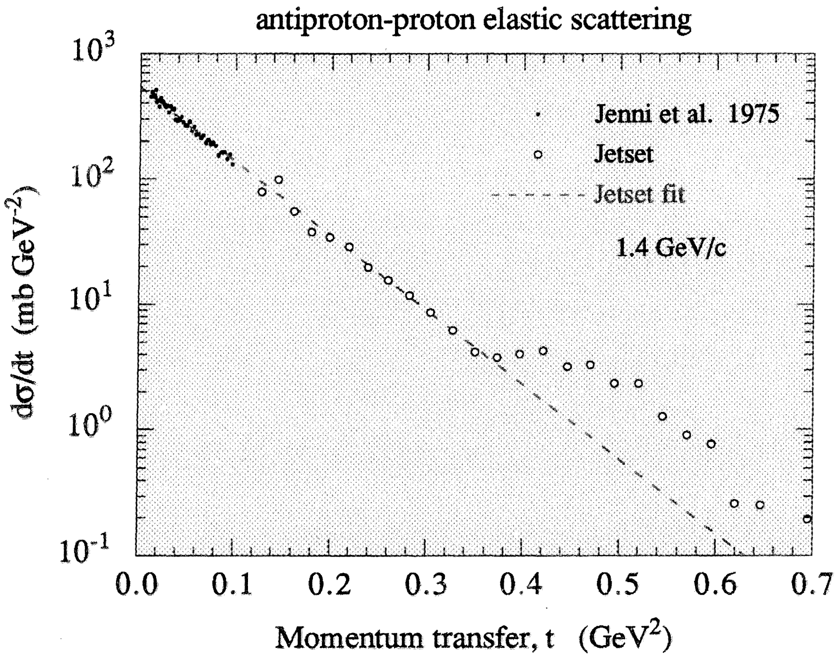

1. INTRODUCTION

By means of the same elastic events used for the study of the detector response [1] we have attempted a measurement of the luminosity accumulated during the April-July 1991 runs. The principle is that the elastic reactions are (a) easy to identify and (b) thoroughly studied by earlier *ad hoc* experiments. So one can use the existing cross section measurements [2] to derive from our data how much beam flux and target density had conspired to produce the observed elastic rates, in other words what was the luminosity of the run. Of course the separate components of the luminosity do not come out from this approach. This study is a complement of (and check upon) the study of luminosity based on the recorded flux and jet data initiated in Illinois [3].

We find that the values of the luminosity extracted from the elastic data are well below expectations, being even smaller than the disturbingly low values reported in the preliminary study of ref. [3]. Typically we seem to be dealing with luminosities of the order of a few 10^{28} cm^{-2} sec^{-1}. This is to be contrasted with the 10^{30} cm^{-2} sec^{-1} which appears in various — over-optimistic — *pre-experiment* broadcasts.

We could have withheld publication of this report while looking for more accurate and possibly larger results. On the other hand we felt it was probably better to stick to our usual heuristic approach and inform people of our results as they are at the moment. It is hoped that later refinements of the procedure outlined below will uncover possible causes of error (in either concept or execution) the accounting of which could bring forth values within the realm of the original wishes.

2. ELASTIC EVENTS

The selection criteria for filtering out the elastic events have been described in detail in our previous report [1]. Here we haven't done much more than converting the angular distributions from "numbers-per-unit-angle" into "numbers-per-unit -momentum-transfer" plus correcting for acceptance.

The important point to be kept in mind is that our "*elastic events*" are a **subsample** of those acquired during data-taking. The purpose of the study of ref. [1] was to investigate the performance of various detectors. For this, it was crucial to be dealing with events where no doubt subsisted on their identity. Thereby the need to apply stricter cuts than necessary and, for instance, to require the presence of *pixels* and *Silicon* hits along the tracks which are not necessarily present in all the elastic events. This is obviously a very important issue if we want to determine absolute cross sections or luminosities.

The acceptance correction took into account only the "trigger acceptance" and not the "reconstruction acceptance". In other words we have only calculated what portion of the differential cross section is accepted by the pipe-scintillators requirement for the elastic triggers. The latter was that there should be one (and only one) hit in the 15-45 pipe-sector and one (and only one) hit in the 45-65 pipe-sector. We have allowed the origin of the event to be spread out over a 3-dimensional Gaussian-shaped region around the detector center with an rms of 0.5 cm along each of the three directions. A listing of this simplified acceptance calculation appears in Appendix 1.

The acceptance curves at all momenta are shown in Fig. 1 as a function of the momentum transfer. We are fully aware that the acceptance of the detector is not quite the same as that of the trigger configuration, particularly when it comes to reconstructing tracks. It should be emphasised that we have made two bold assumptions, viz. (a) the reduction due to reconstruction is uniform and (b) the shape of the angular distributions doesn't suffer from the latter. If any one of these assumptions turns out to be wrong then the real luminosities are higher than those we find ....

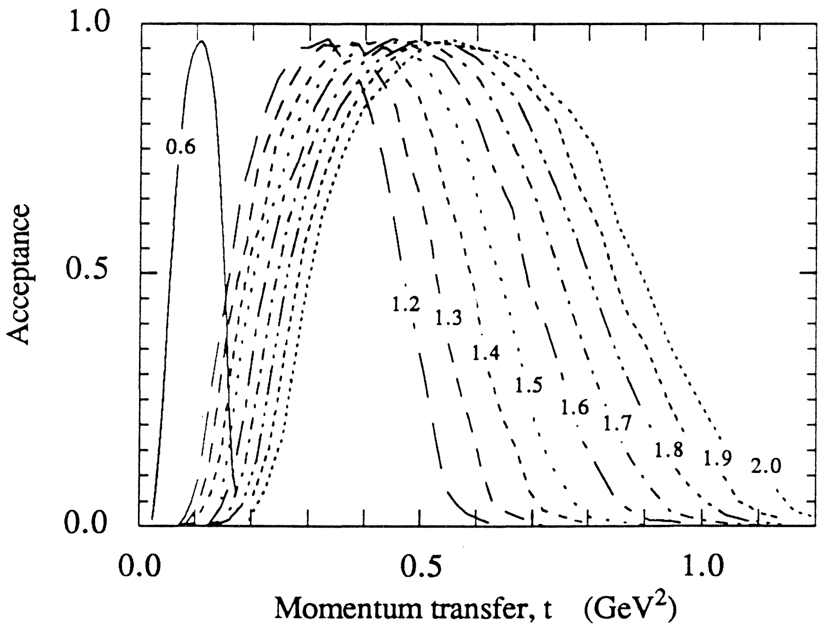

Fig. 1 Accceptance of the trigger. Values of the momenta in GeV/c appear on each curve.

After correcting the data for acceptance we have fitted them to an exponential form

$$\frac{dN}{dt} = A\,e^{-bt}$$

over the forward momentum-transfer (t) region most likely to have retained the original shape of what is usually referred to as the "diffraction slope" (b).

In the plots that follow (figs. 2 to 11) we have drawn the fitted (exponential) curve over a wider region than the one used for the fit. In this way we are able to show all the available data rather than only those used for the fit, so that everybody can judge by himself on the reasonability of the fit. On the same figures we have reproduced the acceptance curves used for the correction.

With the exception of the data in fig. 2 (for which see below) there is a well defined "forward region" in all plots where the agreement between exponential dependence and data is clearly visible. On each figure we have indicated the range of the t-region used for the fit.

The 0.6 GeV/c angular distribution (fig. 2) is a mixture of forward protons and antiprotons (which cannot be distinguished in our detector and do not create problems at higher energies because of the known negligible value of the backward cross section). For the moment we have not yet devised a method to make sense of these data, so we will ignore them.

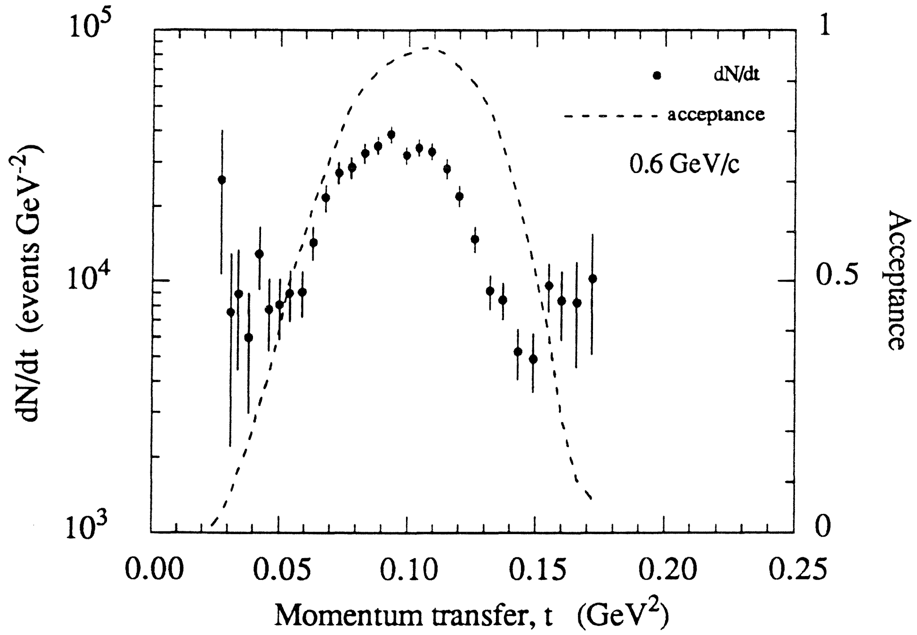

Fig. 2 Incident momentum 0.6 GeV/c

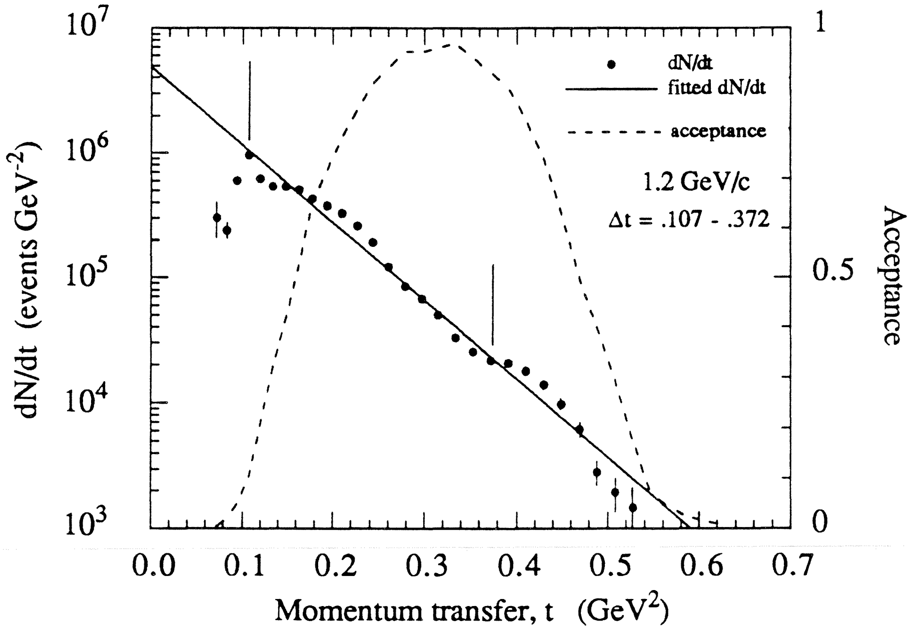

Fig. 3 Incident momentum 1.2 GeV/c

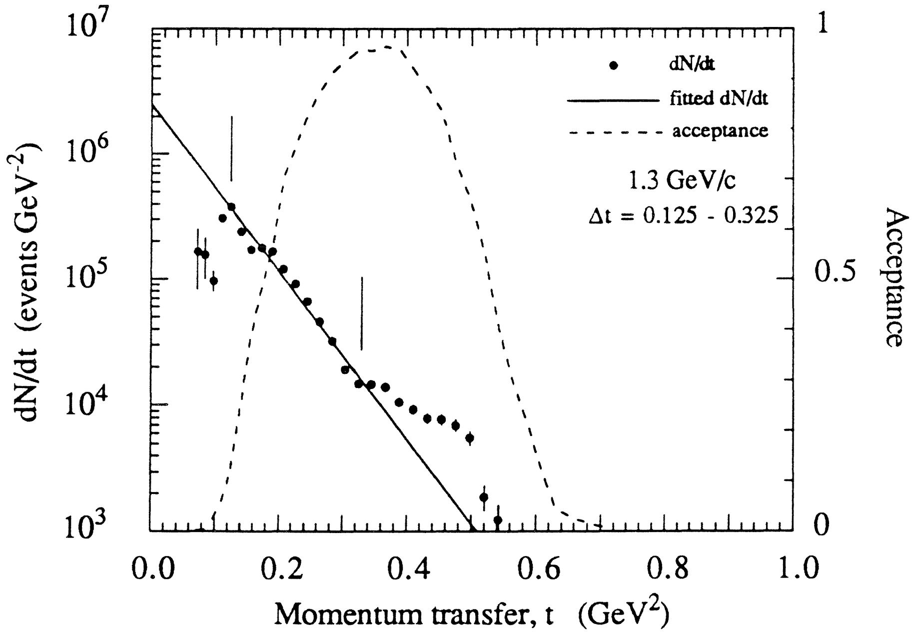

Fig. 4 Incident momentum 1.3 GeV/c

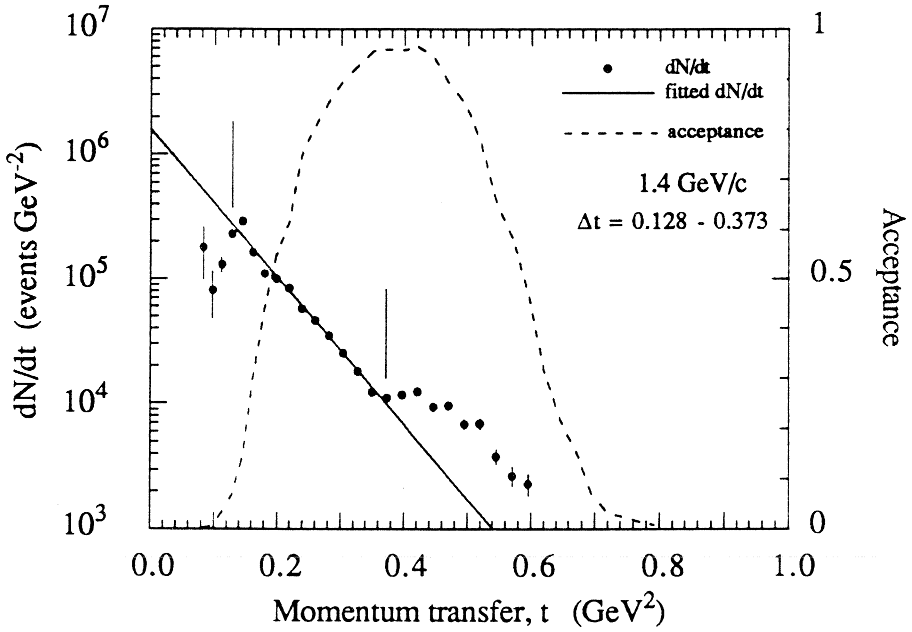

Fig. 5 Incident momentum 1.4 GeV/c

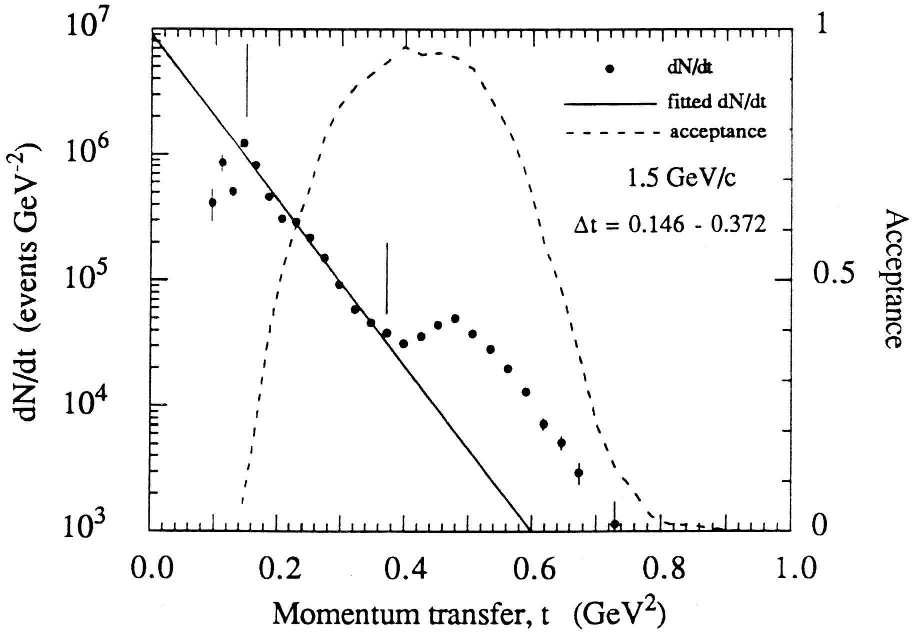

Fig. 6 Incident momentum 1.5 GeV/c

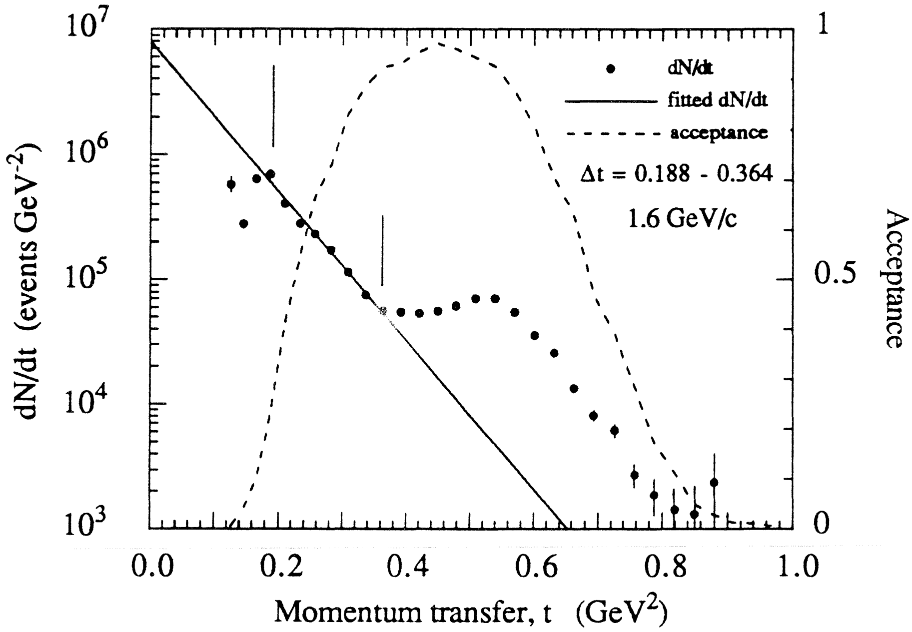

Fig. 7 Incident momentum 1.6 GeV/c

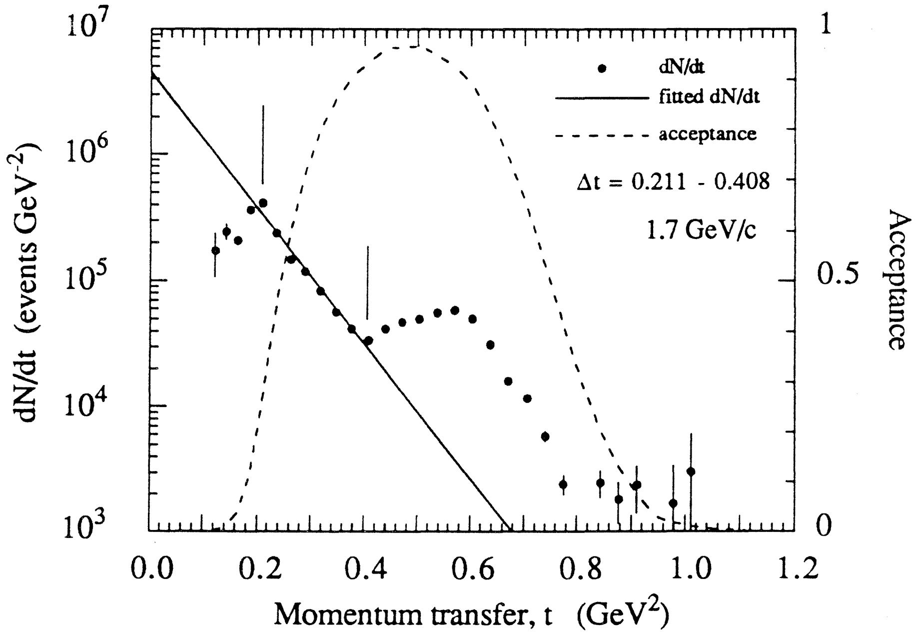

Fig. 8 Incident momentum 1.7 GeV/c

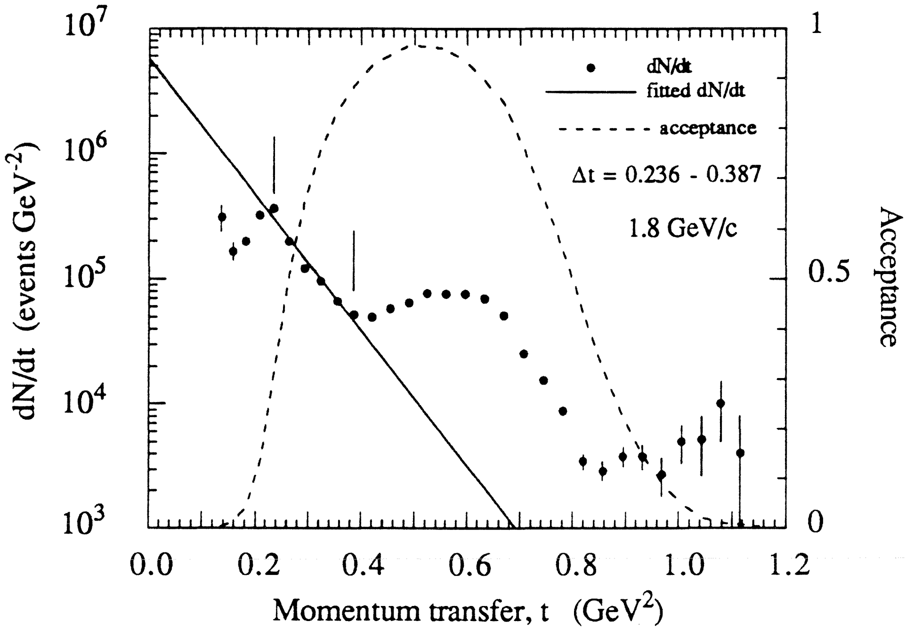

Fig. 9 Incident momentum 1.8 GeV/c

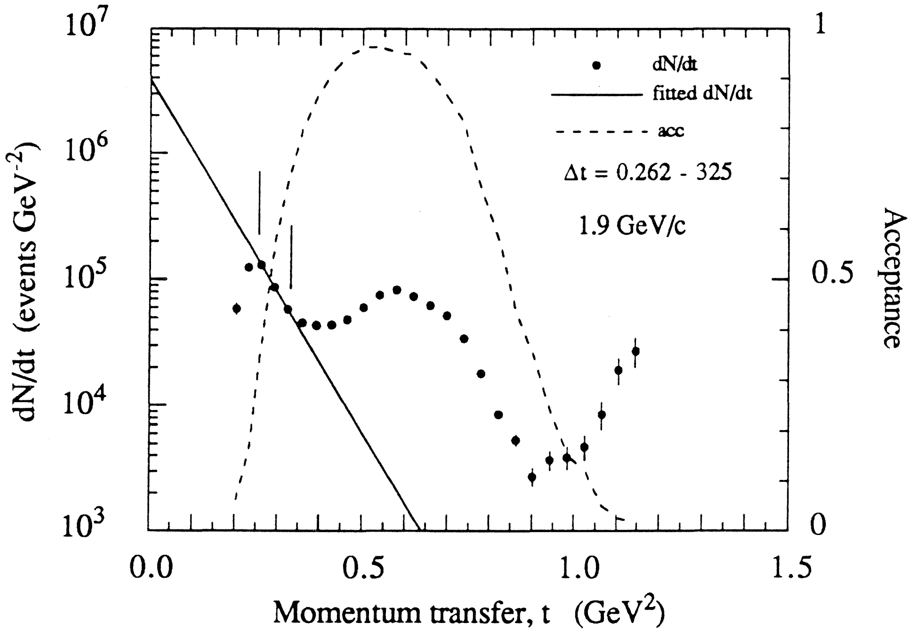

Fig. 10 Incident momentum 1.9 GeV/c

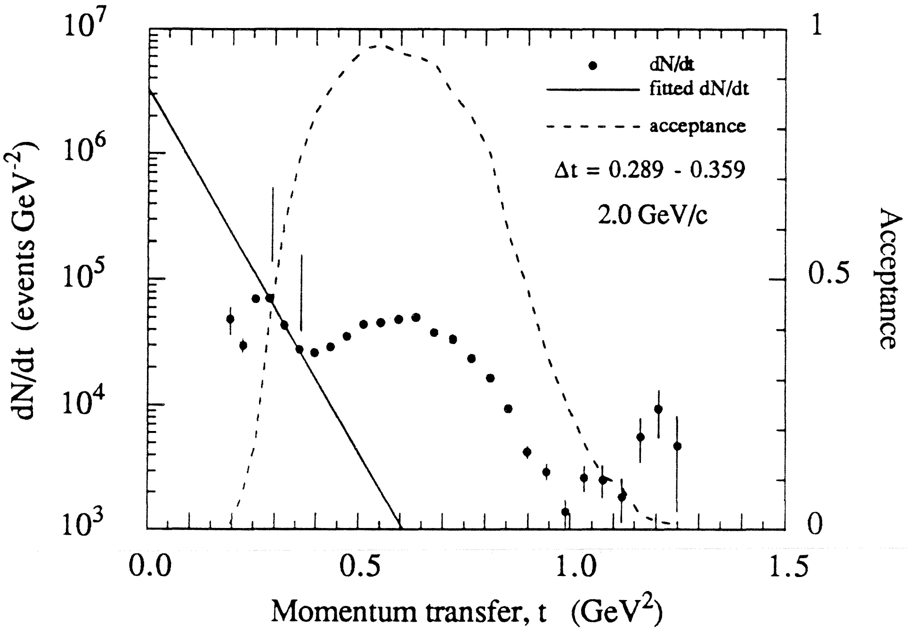

Fig. 11 Incident momentum 2.0 GeV/c

This being done, we have proceeded as follows. The differential cross sections can be expressed (in the very forward region of angles) as

$$\frac{d\sigma}{dt} = A\,e^{-bt}$$

where A is the forward value related to the total cross section σ_{tot} by the optical theorem[1]

$$A = \sigma_{tot}^2(1+\rho^2)$$

and b is the slope of the forward differential cross section and ρ is the ratio of the real to the imaginary part of the forward scattering amplitude.

The value of σ_{tot} used to calculate A has been taken from the measurements compiled in ref. [2] — essentially the Abrams et al. data which are by far the best available in the region. We have not bothered to compile the appropriate values of ρ (also available); notice that ρ is typically ≈ 0.25 in our region and its square has been neglected — a small effect in view of other more important uncertainties.

[1] Don't forget that the value of A from the above formula must be divided by $16\pi(hc/2\pi)^2 = 19.573$ if you use σ_{tot} in mb and if you want the result in mb × GeV^{-2}.

By dividing the value of A obtained from our fit by the value predicted via the optical theorem we have derived the normalisation factor needed to convert number of events into cross sections. Notice that the precise region of momentum transfers used for the fit is irrelevant as long as the slope obtained by our fit does not turn out to be very different from that of the measurements which have been used to determine A.

As an example of the reliability of this procedure we offer, on the front page and in brilliant colors, one of the many detailed comparisons that have been made between our data and those of an earlier experiment [4] in the very forward region ($t > -0.1$ GeV^2). For ease of inspection our data have been plotted in the normalised form described above. Notice that what counts is the slope comparison, not the absolute values of the cross sections. The two sets look extraordinarily consistent with each other.

Another check appears in Fig. 12 below, where we show our slopes compared to the best of the available data. The agreement again is very good.

A check on the validity of the general shape of our distributions at and beyond the forward region is provided by fig. 13 where we have plotted the position of the diffraction minima from our data as a function of the incident momentum and compare them with those found in earlier experiments [2]. The agreement can't be better.

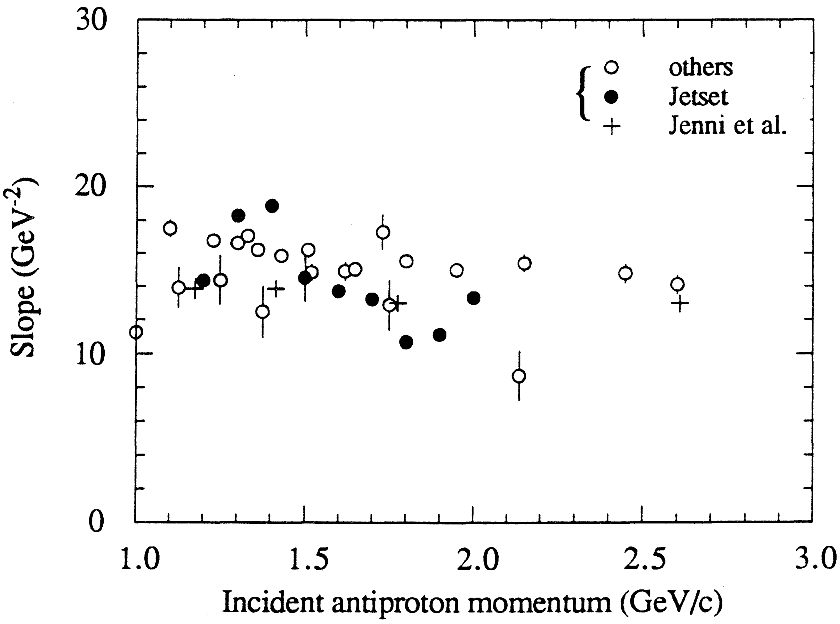

Fig. 12 Forward slopes summary.

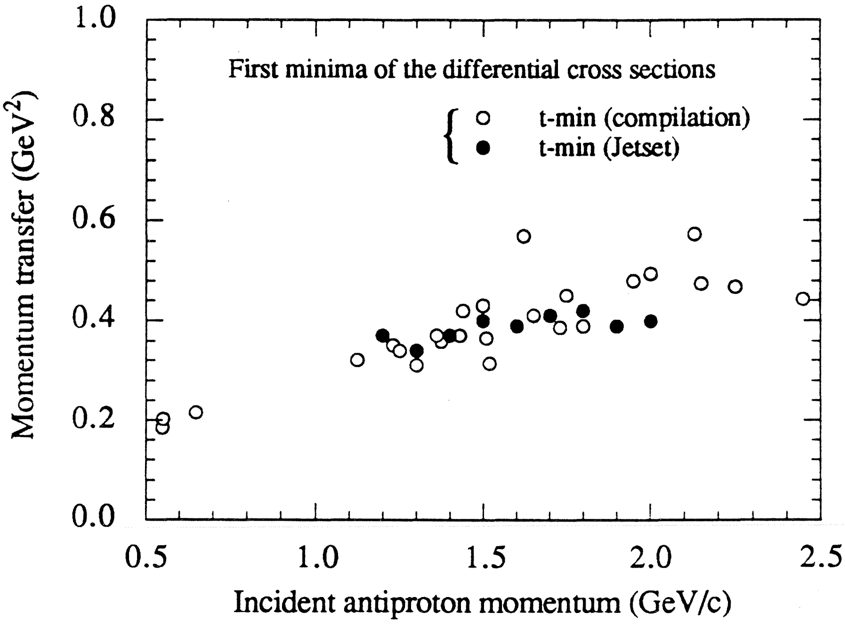

Fig. 13 Diffraction minima summary.

3. LUMINOSITY

In order to calculate the luminosity we need to take into account a number of correction factors. As we warned at the beginning of section 2 our elastic sample is a (small) subset of the total number recorded on tape. In order to account for this reduction we have applied the following simplified procedure.

On the basis of a cursory examination (to be improved and extended in the future) we boldly assumed that most if not all the events retained by the "first reduction" are in reality elastic events. There is probably a small loss at this stage but it is unlikely to be more than a few percent. Therefore we have introduced a factor (**f_1**) which brings us from the number of events certified in the second stage as "*elastic events*" to those emerging from the first stage of reduction. This factor has been calculated for each momentum setting on the basis of the N_2 and N_3 numbers listed in Table 1:

$$f_1 = \frac{N_2}{N_3}$$

The second factor (**f_2**) corrects for the "*elastic triggers*" which had been dropped at the acquisition stage because of the *prescaling* procedure. During the run we used an electronic scaling system where only one out of 2^n elastic triggers was recorded. Therefore the reduction from "*4K*" to "*elastic*" triggers was

$$f_2 = 2^n$$

The purpose of this exercise being a determination of the combined jet-plus-beam efficiency in generating 4K events, we must multiply the "*elastic*" luminosity by this factor $\mathbf{f_2}$. The exponent $\mathbf{n}$ in 2^n has been recorded for each run and is listed in Table 1. In principle this number should have been kept constant throughout a momentum setting; whenever this number was changed during the same setting we have resorted to the use of an "*average*" value of n.

The third factor ($\mathbf{f_3}$) accounts for the fraction of the time that the recording system was busy after each trigger thereby forbidding the acquisition of additional potential events. If τ is the fraction of available time over the total (the *live-time* fraction) then the correction factor is:

$$f_3 = \frac{1}{\tau}$$

Typically τ was 0.70 thus giving rise to a 1.43 correction.

Finally, we have divided the "*integrated luminosity*" thus calculated by the time during which the beam was operated ($\Delta\mathbf{t}$) to obtain the instantaneous luminosity.

All this is summarised by the following expression:

$$L_{4K} = 19.573 \, \frac{A \; f_1 \; f_2 \; f_3}{\sigma_{tot}^2 \; \Delta t}$$

where A is the fitted value of our angular distributions in events/GeV^2, σ_{tot} is the total cross section in mb and Δt is the duration of the data-acquisition run in seconds.

The results obtained are listed in Table 1 where the last two coulumn give the resulting luminosities in both the instantaneous ($\mathcal{L}$ in 10^{28}) and the integrated ($\int\mathcal{L}\,\mathbf{dt}$ in 10^{33}) form.

Table 1

Results of the fits and values of the luminosity[2]

P GeV/c	N_1 (triggers)	N_2 (1st red)	N_3 (2nd red)	A (10^6)	b (GeV^{-2})	σ_{tot} (mb)	Δt (sec)	n (in 2^n)	$\mathcal{L}$ (10^{28})	$\int\mathcal{L}\,dt$ (10^{33})
0.6	566588	42116	1981	-	-	154.3	10554	≈ 0	-	-
1.2	495268	164289	41129	4.91	14.38	109.0	59232	6	4.99	2.96
1.3	1330571	397499	13719	2.49	15.36	106.5	138818	6	8.28	11.49
1.4	1293821	364114	10223	1.59	13.64	102.8	150625	6	6.37	9.59
1.5	642100	158606	34107	9.10	15.21	100.0	62666	5	6.04	3.79
1.6	1406291	309329	39591	7.92	13.74	97.8	124497	5	4.65	5.79
1.7	799579	127819	28374	4.53	12.41	96.5	108984	6	3.60	3.92
1.8	1734032	283970	34488	5.72	12.49	94.5	217238	5	2.17	4.71
1.9	621943	71774	28028	3.86	12.93	92.5	90184	6	2.29	2.07
2.0	1181888	77773	18483	3.31	13.36	90.2	201600	8	6.07	12.25

Notice that the independent study of ref. [3] has suggested a value of 2.58 10^{29} (page 4 of the revised version). A further check comes from the total rates counted around the target region. Single rates of the pipe scintillators, with a 1.4 GeV/c beam of 1.88 10^{10} circulating antiprotons and the jet pressure at 12.5 bar, have been estimated to be in the region of 32 kHz (with an uncertainty of $\pm$ 4 kHz). With a 100 mb total cross section we expect this rate to arise from a luminosity

$$\mathcal{L} = (32 \pm 4) \times 10^3 / 100\ 10^{-27} = 3.20\ 10^{29}\ cm^{-2}\ sec^{-1}$$

(the real uncertainty here is not in the rates but in how many interactions escape through the beam pipe without being counted by the pipe-scintillators).

Both values are much larger than our results. From the original expectations — at 1.4 GeV/c for instance — based on nominal values for the jet surface-density (1.8 10^{13} g/cm^2 at

[2] col. 1 = incident momentum; col. 2 = number of elastic *triggers*; col. 3 = number of elastic *triggers* after 1st step of reduction; col. 4 = number of elastic events after 2nd step of reduction; col. 5 = forward cross section from the elastic events; col. 6 = slope of the forward elastic distribution; col. 7 = total cross section; col. 8 = duration of the run; col. 9 = average prescaling exponent n in $f_2 = 2^n$; col. 10 = instantaneous luminosity in $cm^{-2}\ sec^{-1}$; col. 11 = total luminosity in $cm^{-2}\ sec^{-1}$.

12.5 bar) and the antiprotons circulating in the machine at a frequency of 3.2 MHz (1.88 10^{10}) the luminosity should have been

$$\mathcal{L} = 1.8\ 10^{13} \times 1.88\ 10^{10} \times 3.2\ 10^{6} = 1.08\ 10^{30}\ \mathrm{cm^{-2}\ sec^{-1}}$$

We observe an apparent decrease over the above value of more than one order of magnitude. Whether this is due to a lack of beam or jet we cannot tell at the moment.

In the last figure (fig. 14) we have summarised the above considerations by showing the measured luminosities as a function of the momentum setting and the levels found via ref. [3] and the other arguments discussed earlier. In the present situation and lest people be tempted to retain an over-pessimistic view of our luminosity, we must stress that the **systematic** uncertainty on the points plotted in fig. 14 is quite large. The error bars in this plot show the maximum reacheable values of the measured luminosities if we assume that all the elastic triggers are elastic events (i.e. N_1 in Table 1). The reality is somewhere in between. On the other hand this plot seems to rule out values of the luminosity as large as those suggested by the nominal beam and jet densities.

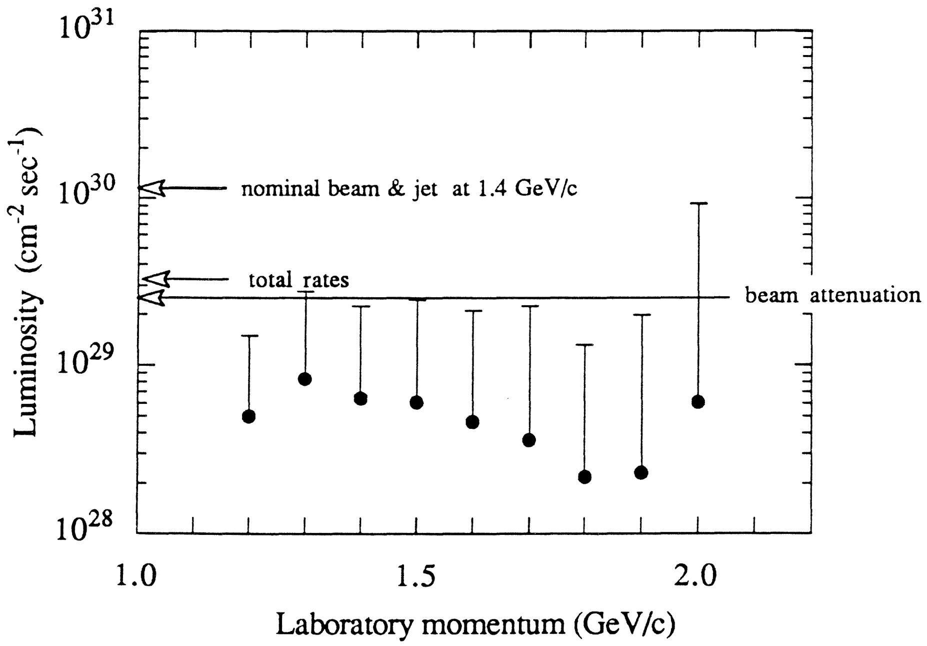

Fig. 14 Luminosity summary.

APPENDIX 1

Listing of the acceptance program used in this work.

```
Public pipeacc
COMMON/pipe/ae,be,bound15,bound45,dtheta,dphi,drho,theta0,const1,
1 rhomax,phimax,thetamax,x0,y0,z0,ddelta,nphistep
common / results/nphiacc(3),effphi(3)
COMMON/added/bound,bound1(2),bound2(2),promass,beta,gamma,pinc
common /geom/ aa,bb,cc,x0sae2,y0sbe2,x,y,z,v(3),delta,rhostep,rho,theta,phi
Common/Menus/NbMenus,MenuID(3),MenuHandle(3)
common /misc/vertex(3),sigvertex(3),jrnd(2)
Integer*2 MenuID
Integer*4 GetMenuBar
PARAMETER (pi=3.141592)
DATA ae/8./,be/4./,rhomax/100./,phimax/360./,thetamax/70./
DATA theta0/10./,dtheta/1./,drho/1./,ddelta/.01/,
1    nphistep/10007/
DATA promass/.93827231/
```

```
Program pipeacc
integer * 4 dt,tused
character *19 datime
  call mymenus
 jrnd(1)=45236 ; jrnd(2)=729304
  type *,' Give inc. mom. in GeV/c to use in kinematics  --> $'
  read *,Pinc
  type *,' Give min. and max. angle in degree  --> $'
  read *,theta0,thetamax
     call kinematics(pinc)
     print'(T10,' kinematics '/,T10,'incident momentum (GeV/c) = ',F10.4/,T10
*    ,'beta of the cm = ',T30,F10.4,T50,'Gamma of the cm = ',T70,F10.4)',pinc,beta,gamma
     print '(//,T10,'input parameters'/,T10,'a-ellipse = ',T30,F10.4,T50,'b-ellipse = ',
*     T70,F10.4/,T10,'rhomax = ',T30,F10.4,T50,'theta start = ',
*     T70,F10.4/,T10,'theta step = ',T30,F10.4,T50,
*     'no. of phi steps = ',T70,I10/,T10,'rho step = ',T30,F10.4,
*    /,T10,'delta limit = ',T30,F10.4//)',ae,be,rhomax,theta0,dtheta, nphistep,drho,ddelta

c       define vacuum pipe center
      call vzero(vertex,6)
      type *,'  x,y,z       of the vertex (cm) ?  $' ; read *,vertex
      type *,'  sigmas x,y,z of the vertex (cm) ?  $' ; read *,sigvertex
      type *,' give number of phi steps ( prime please like 101,503,1009,5003 or 10007...! $'
      read *,nphistep
      const1 = 1-(be/ae)**2 ; t1 = 15; t2 = 45 ; t3=65
     bound1(1)=1/(tan(t1*pi/180))**2 ; bound2(1)=1/(tan(t2*pi/180))**2
     bound1(2)=1/(tan(t2*pi/180))**2 ; bound2(2)=1/(tan(t3*pi/180))**2
      print '(1x,'origin shift: x,y,z = ',T20,3f10.4/,1x,'boundary at theta = ',T20,
*      f10.4,' is ',f10.4/,1x,'boundary at theta = ',T20,f10.4,' is ', f10.4,
*     /,1x,'boundary at theta = ',T20,f10.4,' is ', f10.4)',vertex,t1,bound1(1),t2
*     ,bound2(1),t3,bound2(2)
     theta=(theta0-dtheta)*pi/180. ; ngen=0; nacc=0; ntheta=0
      dphi=2.*pi/nphistep
     call time(datime) ; dt=tused() ; type *,'  ',datime
     dsigtot=0. ; dsigreal=0.
        amp=promass
       p1=pinc ; e1=sqrt(p1**2+amp**2)
        d=amp**2+e1*amp
     print '(1x,' theta   mom.tr.  delta-t  accept1  accept2   both   dt/dtheta')'
 1   theta=theta+dtheta*pi/180. ; thetadeg=theta*180./pi
       p2=2.*p1*cos(theta)*d/( (e1+amp)**2 - p1**2 * cos(theta)**2 )
```

```
      p3sin=p2*sin(theta) ; p2cos=p2*cos(theta)
      p3cos=pinc-p2cos ; thetarecoil=atan(p3sin/p3cos)
       tt1=theta*180./pi ; tt2=thetarecoil*180./pi
     call momtran(transf,dtdtheta)
     thetakeep=theta
     theta=theta-.5*dtheta*pi/180. ; call momtran(deltat1,dtdtheta)
     theta=theta+dtheta*pi/180. ; call momtran(deltat2,dtdtheta)
     deltat=deltat1-deltat2 ; theta=thetakeep
      if(thetadeg.gt.thetamax)then
     print '(T20,'theta maximum reached')' ; go to 100; endif
     ntheta=ntheta+1 ; nphi=0; nphiacc(1)=0 ; nphiacc(2)=0 ; nphiacc(3)=0
      phi=-dphi/2.; nout=0
2     phi=phi+dphi ; phideg=phi*180./pi
     call menuaction(mflag)
     if (mflag.eq.1) type '(' thetadeg',f8.2,' phideg =',f8.2,' nphi',i5)', thetadeg,phideg,nphi
      if (mflag.eq.2) goto 100
     call normal(jrnd,s1,s2) ; call normal(jrnd,s3)
     if (abs(s1).gt.3.) s1=3.*s1/abs(s1) ; x0=vertex(1)+sigvertex(1)*s1
     if (abs(s2).gt.3.) s2=3.*s2/abs(s2) ; y0=vertex(2)+sigvertex(2)*s2
     if (abs(s3).gt.3.) s3=3.*s3/abs(s3) ; z0=vertex(3)+sigvertex(3)*s3
     cc=(x0/ae)**2+(y0/be)**2-1 ; x0sae2=x0/ae**2 ; y0sbe2=y0/be**2
    if(phideg.gt.phimax-.1)then
      do i=1,3
     if(nphi.ne.0) effphi(i)=float(nphiacc(i))/float(nphi)
      enddo
     dsigdt=85.312*exp(3.6638*transf) ; dsig=dsigdt*deltat
     dsigtot=dsigtot+dsig ; dsigreal=dsigreal+dsig*effphi(3)
      print  '(1x,f6.2,5f10.3,e12.4)',thetadeg,transf,deltat,effphi,dtdtheta*(pi/180.)
       go to 1
    endif
      nphi=nphi+1; delta=0
       thetakeep=theta ;  phikeep=phi
3 Continue
    jacc1=0
    do itr=1,2
     if (itr.eq.2) then theta=thetarecoil ; phi=phi+pi
                  if (phi.gt.2.*pi) phi=phi-pi ; endif
     call check2
    if(bound.ge.bound2(itr).and.bound.le.bound1(itr)) then
          nphiacc(itr)=nphiacc(itr)+1
         if (jacc1.eq.1) nphiacc(3)=nphiacc(3)+1
          jacc1=1
     endif
    enddo
    theta=thetakeep; phi=phikeep
      goto 2

100  x=tused()/60. ; type *,' time used',x,'  seconds'
    stop
   end
```

```
   Subroutine check2
       v1=cos(phi)
       v2=sin(phi)
     aa=(v1/ae)**2 + (v2/be)**2
     bb= x0sae2*v1 +y0sbe2*v2
    dd=(bb**2-aa*cc)
    rho=( -bb +sqrt(dd))/aa
     x=rho*v1 ; y=rho*v2 ; z=rho/tan(theta)
     bound=(z+z0)**2/( (x+x0)**2 + (y+y0)**2 )
   return
   end
```

```
Subroutine kinematics(P)
gamma = 1.e12
E=sqrt(P**2+promass**2)
beta=P/(E+promass)
if((1-beta**2).ne.0) gamma=1/sqrt(1-beta**2)
return
end
```

```
Subroutine momtran(transf,dtdtheta)
elab = sqrt(pinc**2+promass**2)+promass
ecm = sqrt(2*promass**2+2*promass*sqrt(pinc**2+promass**2))
betacm = pinc/elab
st = sin(theta)
ct = cos(theta)
p3 = 2*promass*betacm*ct/(1-(betacm*ct)**2)
e1 = sqrt(pinc**2+promass**2)
e3 = sqrt(p3**2+promass**2)
transf = 2*(promass**2+pinc*p3*ct-e1*e3)
dtdtheta = -2*pinc*p3*st*(2-(e1/e3)*(p3/pinc)/ct*(1+(betacm*ct)**2))/(1-(betacm*ct)**2)
return
end
```

```
Subroutine MyMenus
integer*2 Id,Item
Id = 80   ! arbitrary
MenuID(1) = Id
Mh = NewMenu(MenuID(1),'Control')
MenuHandle(1) = Mh
call AppendMenu(Mh,'Status')
call AppendMenu(Mh,'Stop')
call InsertMenu(Mh,0)
call DrawMenuBar
Nbmenus=1
return
end
```

```
Subroutine MenuAction(Mflag)
Integer*2 Id,Item,Jtem
Mflag=0
call TestMenu(Id,Item)
call HiliteMenu(0)
if(Id.eq.0) return
call HiliteMenu(Id)
if (id.ne.80) return
Mflag=Item
return
end
```

REFERENCES

[1] Forward Cherenkov counters and silicon detector performance during the April-July 1991 runs.
CERN Jetset Group Note 91-21 (14 Nov. 1991)

[2] See for instance "NN and ND interactions"
Particle Data Group. (LBL-58) May 1972

[3] Estimating luminosity for Jetset.
D.W. Hertzog and M. Yairi. Jetset Note 91-6 (12 Sept. 1991)

[4] P. Jenni et al. (and guess who else ?), Nucl. Phys. B94 (1975) 1