GEM TN-92-193

PCHTHR - A Fast Simulation for Hadron Punchthrough

R. R. McNeil
Louisiana State University

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Abstract:

A GEANT simulation of single pions of various momenta from 5 to 800 GeV/c through iron absorber of thickness 6λ to 30λ is used to produce punchthrough shower profiles. These profiles are compiled in probability tables which are read by a program PCHTHR which produces fast punchthrough showers for use in muon triggering and pattern recognition studies. The following are transparencies of a talk given at the Rocky Mountain Consortium Workshop in Boulder, Colorado on July 21, 1992.

7/21/92
GEM Note 92-193

PCHTHR - A Fast Simulation for Hadron Punchthrough

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Outline

1. Introduction

2. Towards a Fast simulation of hadron punchthrough
   - GEANT simulation of single pions

3. The PCHTHR Code
   - Comparisons of PCHTHR and GEANT

4. Using PCHTHR
   - an example of its use (GEM Barrel "muon" rates)

5. Forthcoming Improvements - Plan for this workshop

Introduction

Hadron Punchthrough - Detectable particles exiting absorber initiated by hadrons entering calorimeter

For PCHTHR V2.3 or less = Charged Particles $KE_{OUT} > 1 MeV$

- GEANT has had some successful comparisons with Experimental data.

  More are needed - RD5 Experiment at CERN

but,

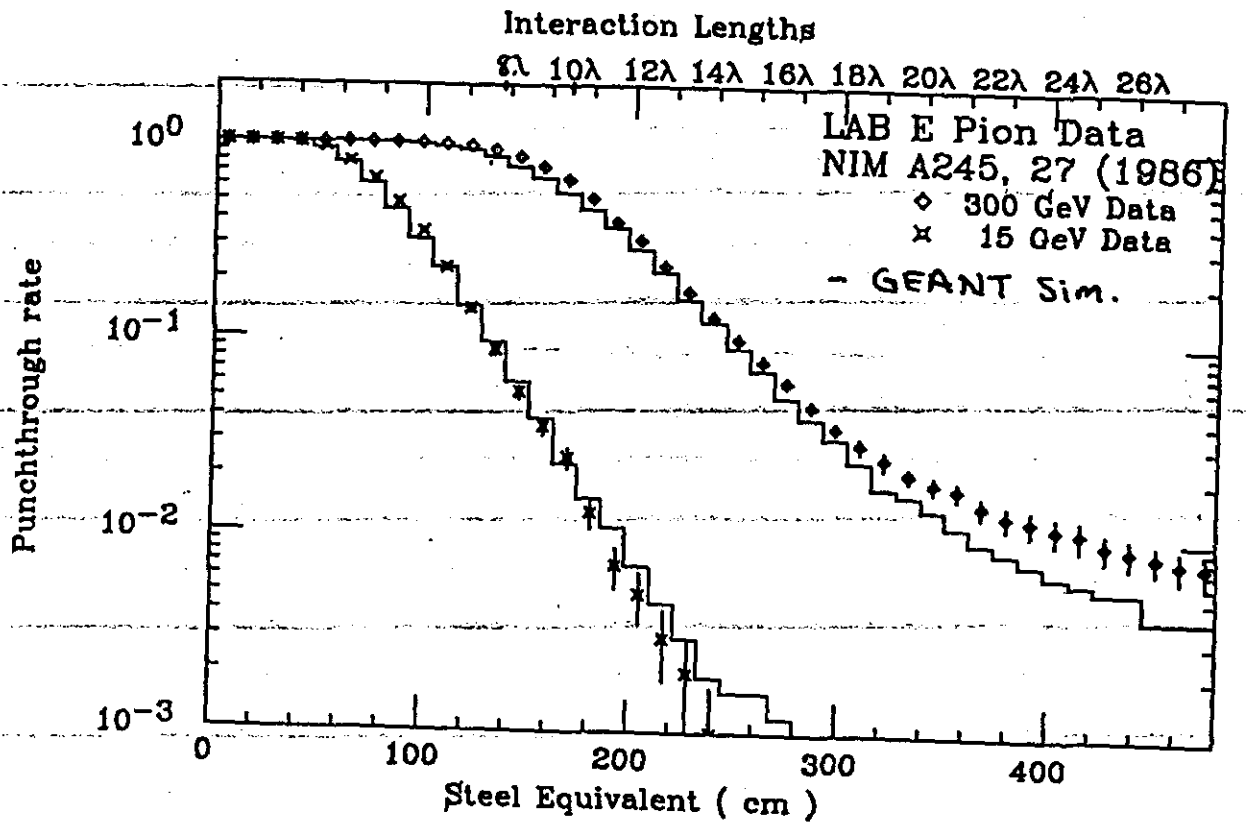
- A full-scale simulation of hadron showering for detector design optimization ala GEANT, CALOR, ... is impractical due to CPU time limits at the moment.

- Simple parameterization of the overall punchthrough is not sufficient to address detailed muon triggering, id, and pattern recognition issues.

We need a fast simulation which produces 4-vectors of the outgoing punchthrough particles down to minimum detection levels.

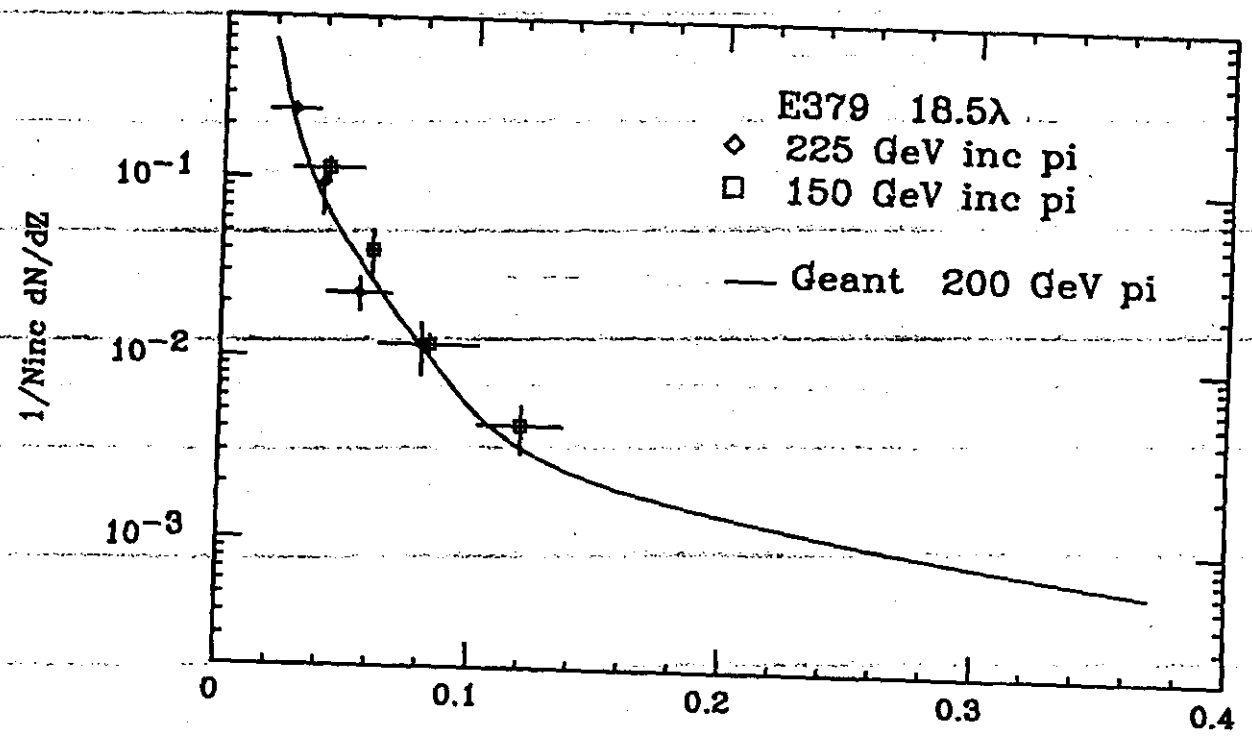
GEANT + GHEISHA Gives good agreement with CCFR data for π punchthrough 15-300GeV

Lab E detector - $\rho_{AVG} = 4.2\ gr/cm^3$



If you measure muons outside Calorimeter
Punchthru is at very low momentum

E379 Data — Karol Lang, Ph.D. Thesis U of Rochester UR908
& Dan Green & Dave Hedin FNAL - PUB - 90/18



GEANT Agrees Both Abs. Rate & Spectrum

$Z = P^*_{MU}/P_{IND}$ P_μ = Momentum Before Calorimeter

Can Easily reject Punchthru by Momentum Cut

Profile of a Hadron Punchthrough Shower

- Towards a Fast subroutine for Hadron Punchthrough

Punchthrough Shower Profile (depth in λ, Particle Type, P_{INC})

all
EANT
im

- Probability for ≥ 1 Punchthrough Particles
  - Prob. for "sail-through", Prob. of Primary decay of π/K in Cal.
- Multiplicity spectrum of Punchthrough particles
- Particle ID of punchthrough particles (depends on mult.)
- Momenta of punchthrough particles (depends on PID)
- Lateral Spread of punchthrough (w.r.t. parent track projection)
- Outgoing angle of particles (w.r.t. parent track direction)

Probability Tables

$\Downarrow$

Fast Subroutine (ID_{INC}, P_{INC}, Thickness)

$\Downarrow$

$\boxed{\text{4-vectors of outgoing particles}}$

Position and momentum information from PCHTHR allows for ν ID, Pattern recognition studies

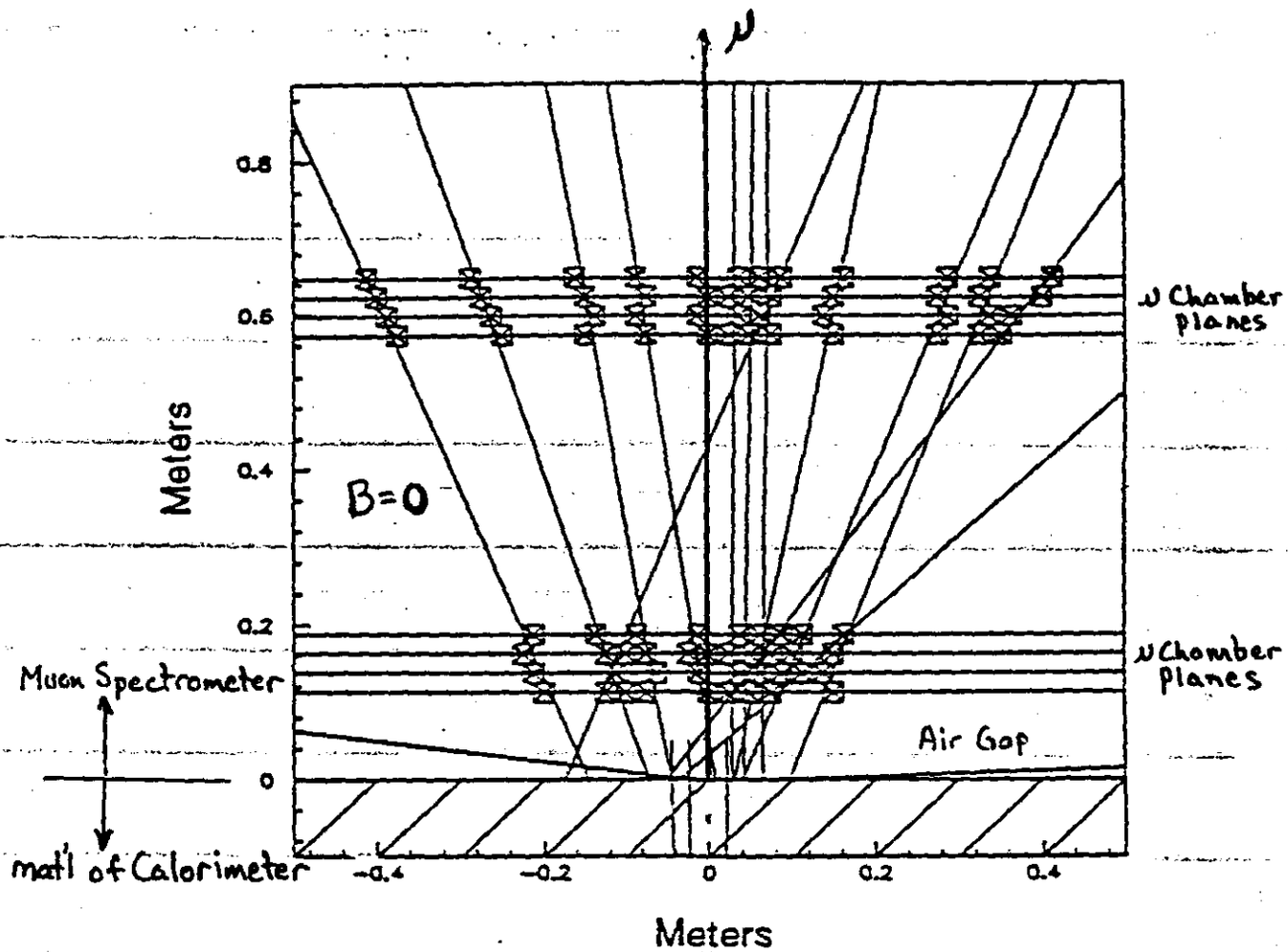


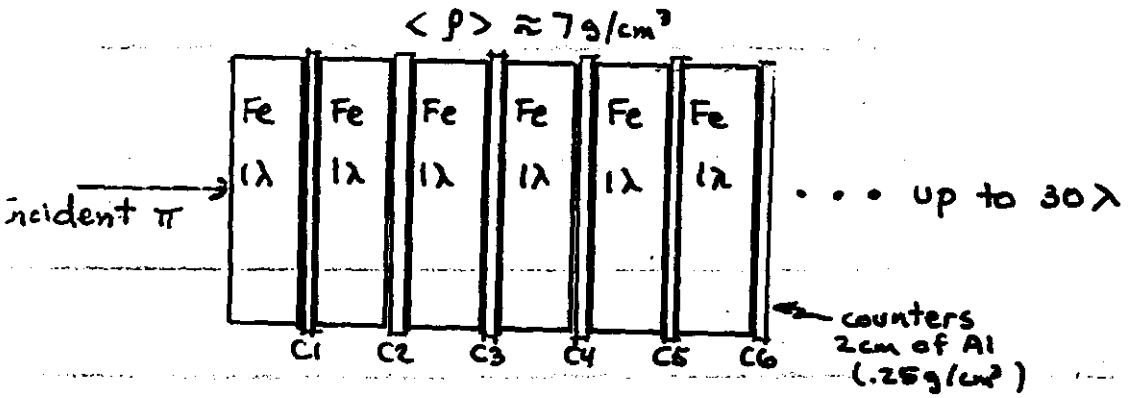
Figure 3-23 Muon track (vertical at 0) coming out of the calorimeter accompanied by the secondary particles resulting from hadronic punchthrough or muon radiation in a 250 $\frac{GeV}{c^2}$ high-p_T top event.

Simplified Detector Simulated by GEANT

V 3.13

All Process Flags = 1

Energy Cutoffs all 1 MeV



Record output charged particles in C_i

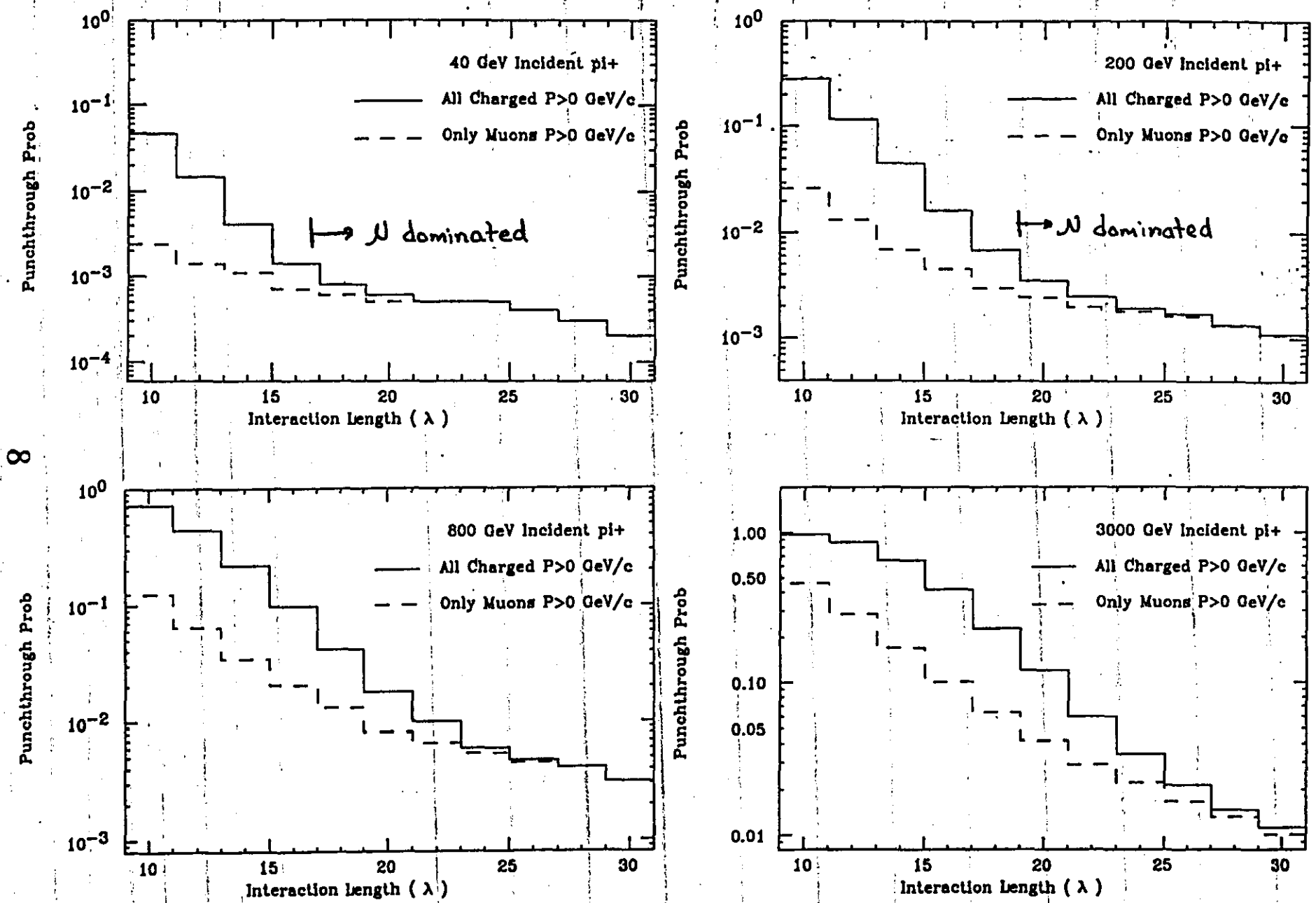
OUTPUT Record contains:

i, Particle type, charge, $x, y, z, P_x, P_y, P_z, P$

Simulated so far π^- with

Incident P	# Simulated
5 GeV/c	700k
10 GeV/c	400k
20 GeV/c	200k
40 GeV/c	200k
100 GeV/c	100k
200 GeV/c	100k
800 GeV/c	10k

GEANT MC

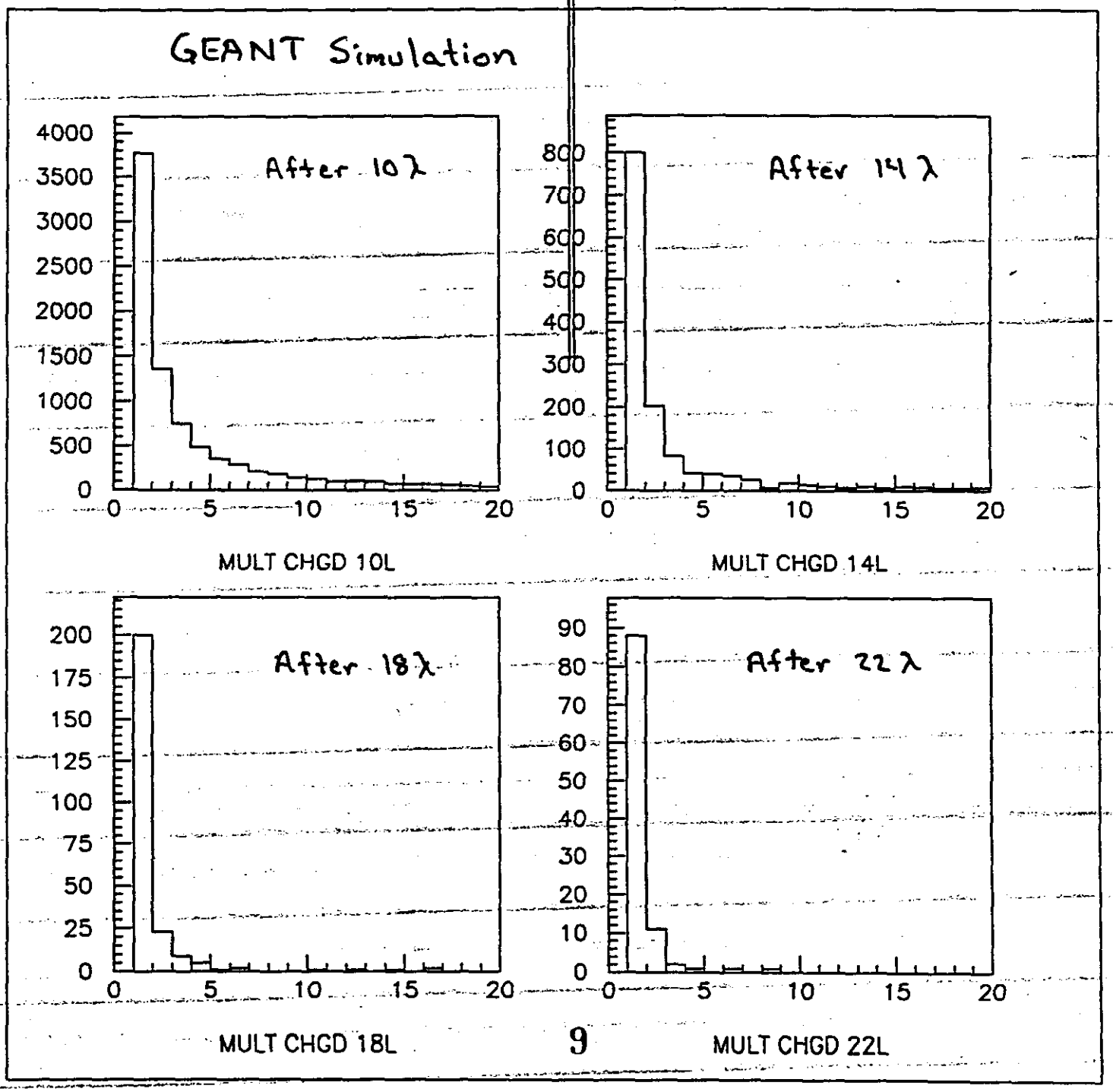


After Punchthru is MUON Dominated, adding Iron only Ranges out Muons

Charged Particle Multiplicity after Absorber

200 GeV/c Incident Pion

ZERO mult events not plotted

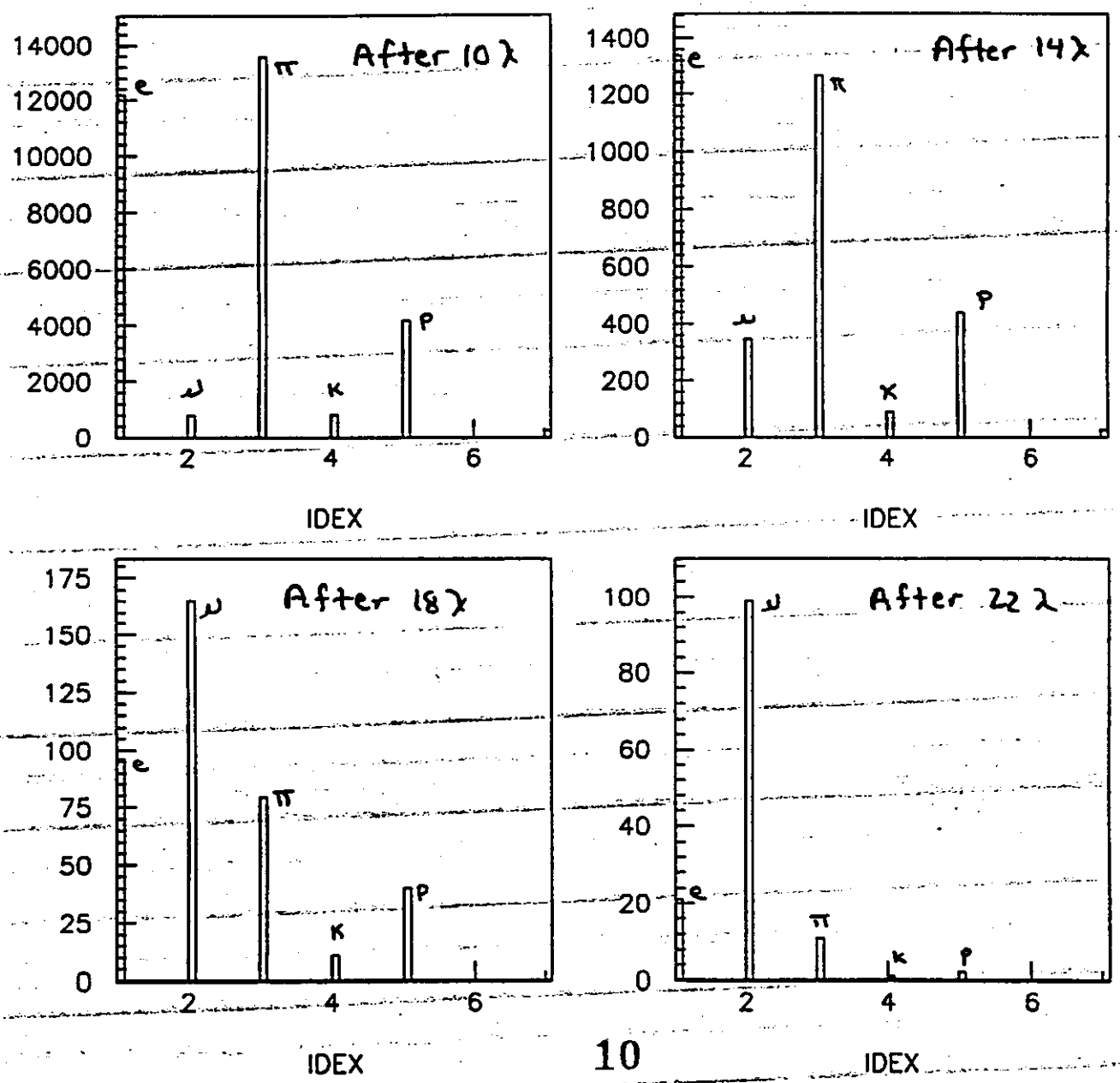


Exiting particle type after Absorber

200 GeV/c Incident pion

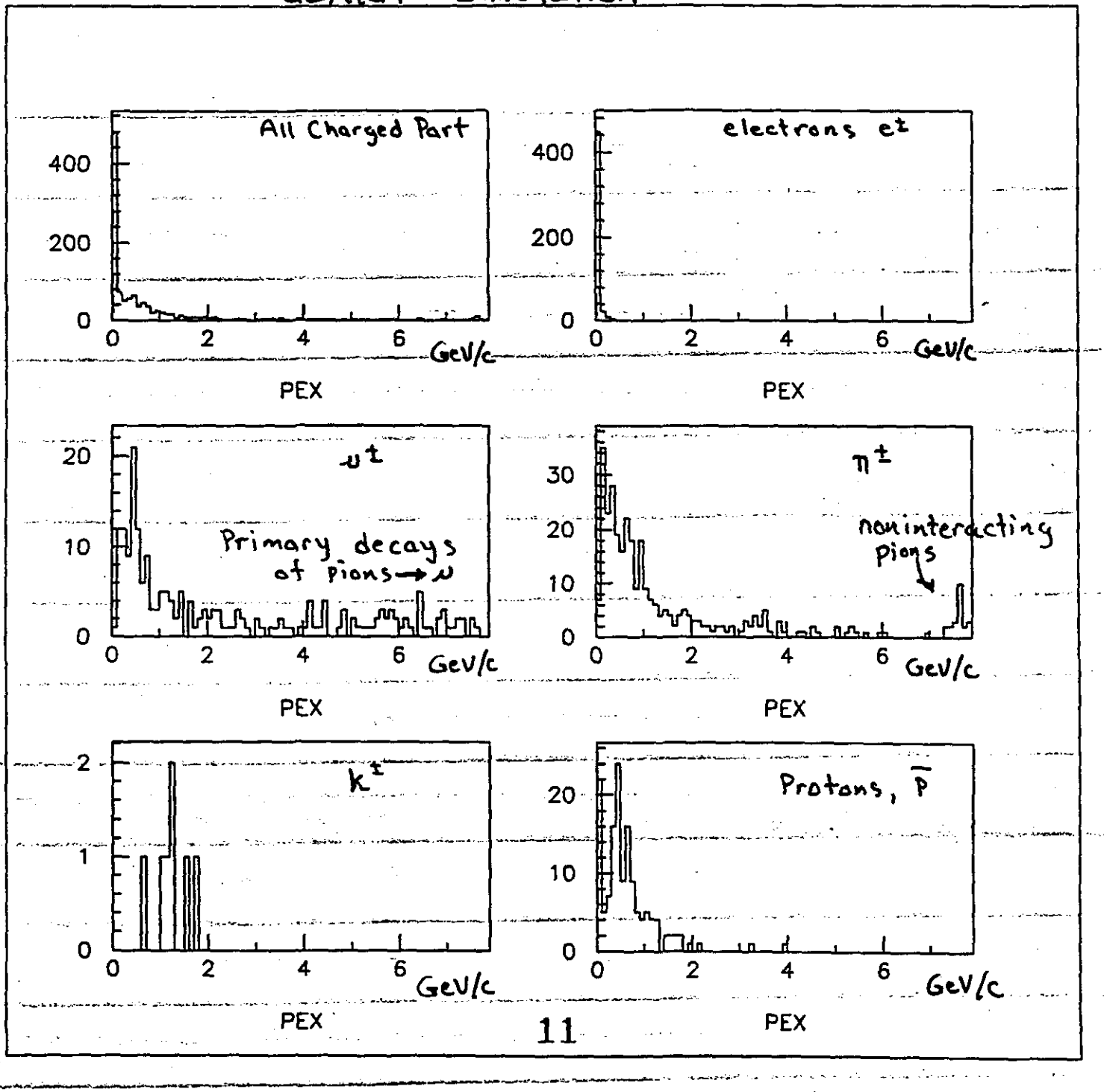
ID = 1 (electron), 2 (muon), 3 (Pion), 4 (Kaon), 5 (Proton)
only Charged particles (P_{OUT} > 1 MeV/c)

GEANT Simulation



- Momentum Distribution of exiting particles by type
- 10 GeV/c Incident Pions
- After 10λ

GEANT Simulation

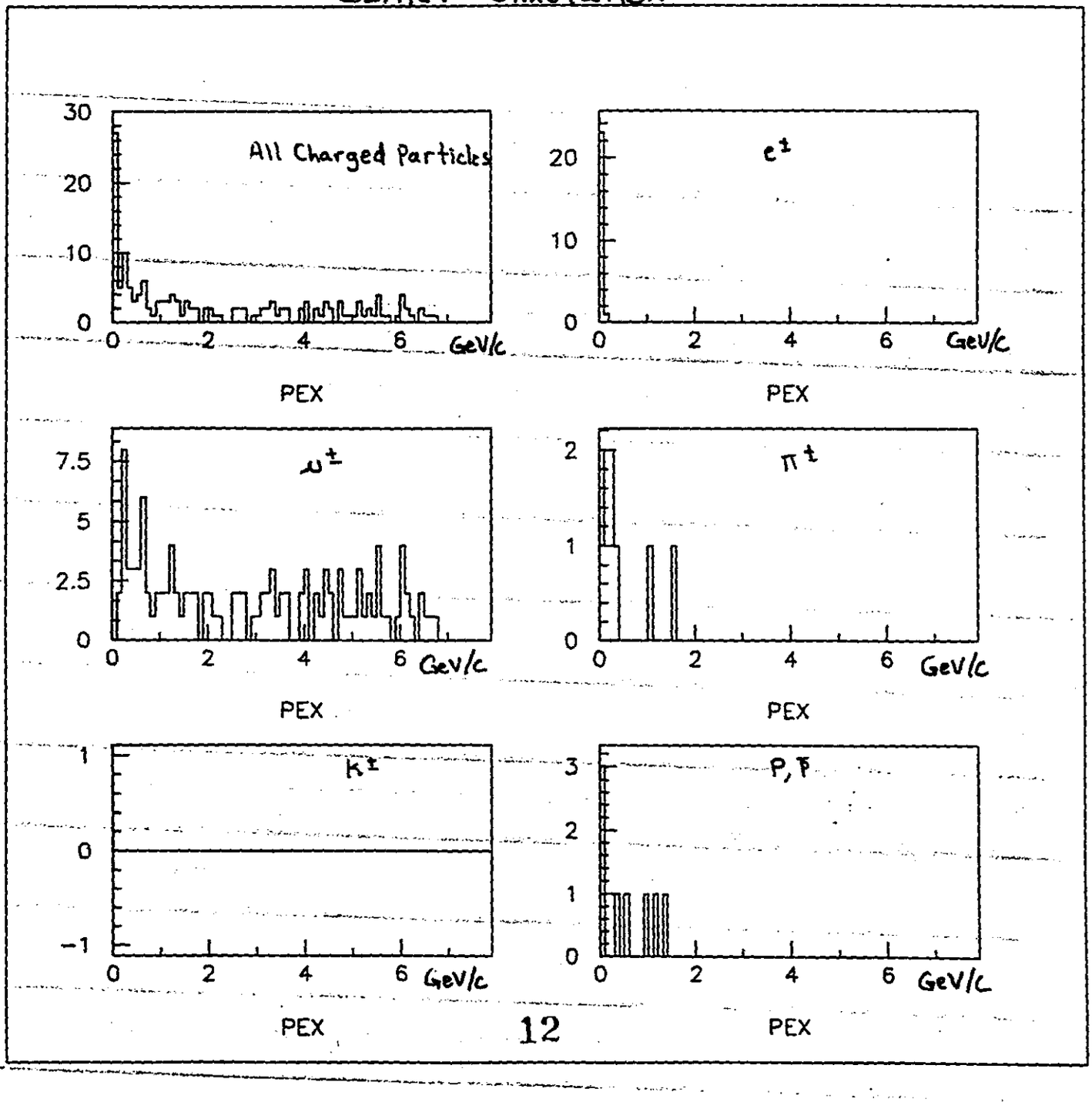


Momentum Distribution of exiting particles by type

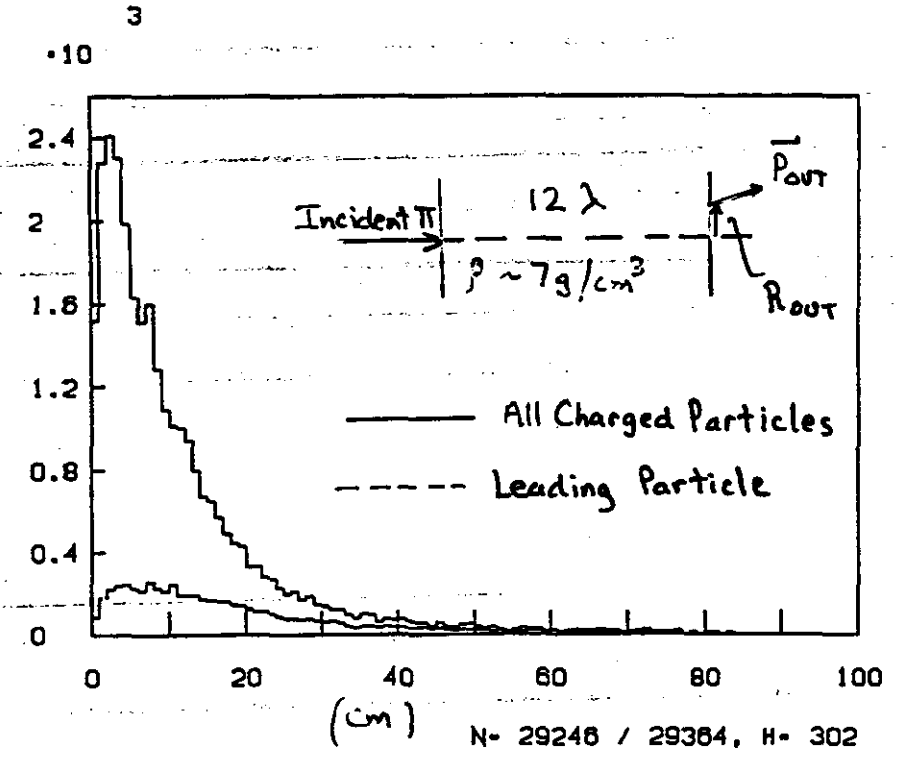
10 GeV/c Incident Pion

After 14 λ absorber

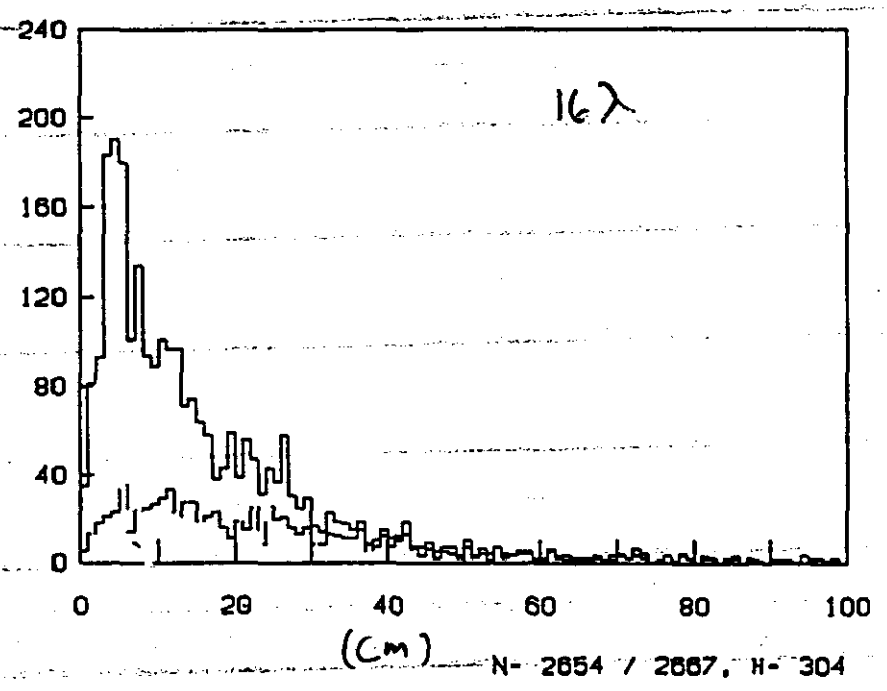
GEANT Simulation



Lateral Spread of Punchthrough Shower
200 GeV/c Incident pi- GEANT Simulation



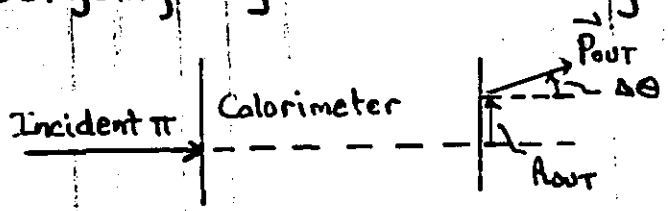
RØUT CHARGED 12L



RØUT CHARGED 16L

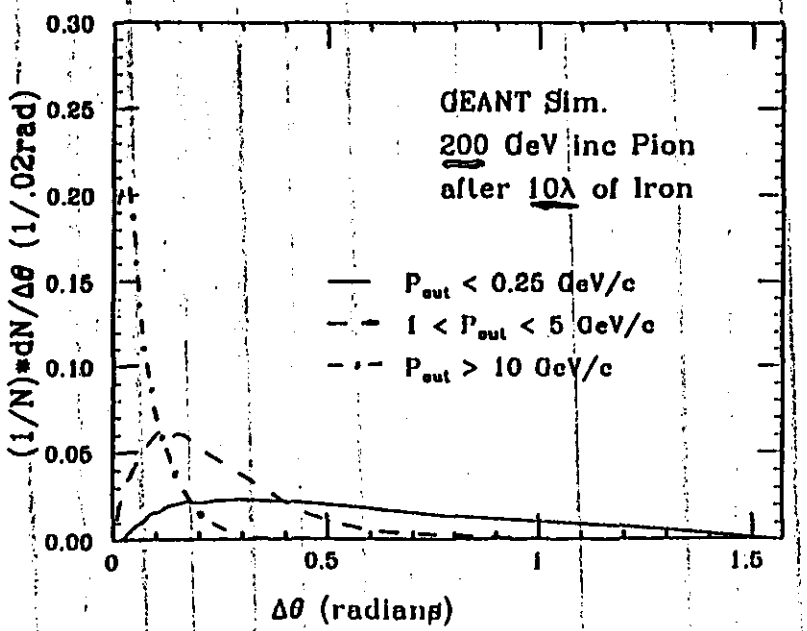
After Iron

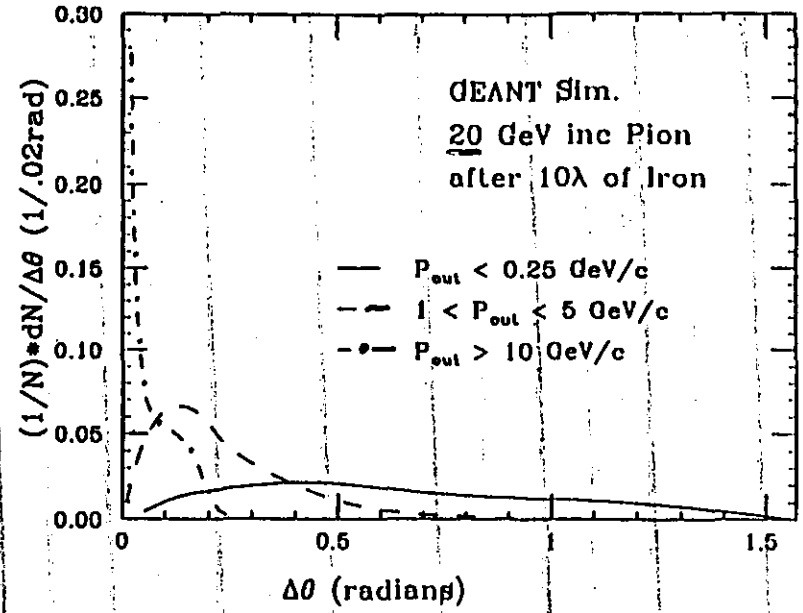
Outgoing angle of Punchthrough

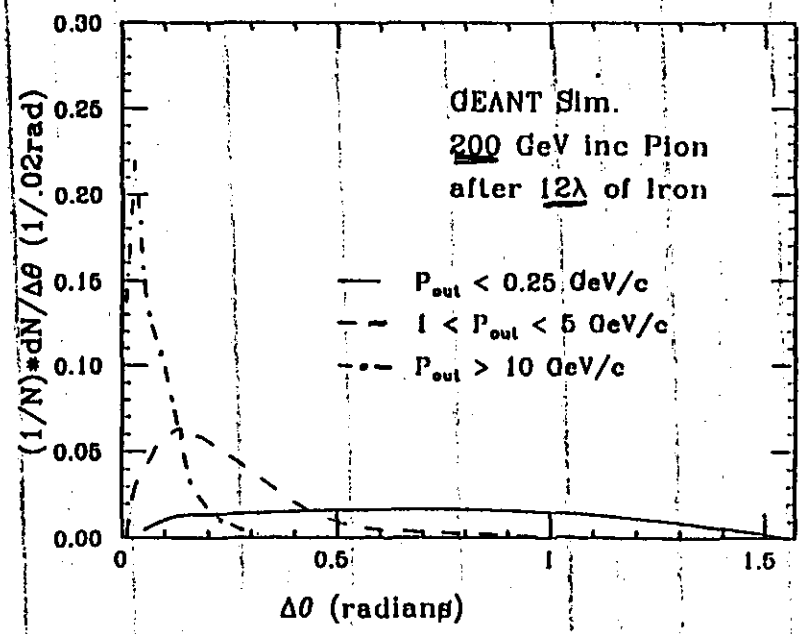


Δθ depends on $|\vec{P}_{OUT}|$

generally insensitive to P_{INC}, Thickness of mat'l







```
      SUBROUTINE PCHTHR(I1,ZCAL,IDIN,P,POUT,RO,IDOUT,NP,WT,NPOUT,IRET)
C-----------------------------------------------------------------------
C-                                                                     -
C-    Authors:    R. McNeil , W. Morse, and H. Ma                      -
C-    Date:       1-Nov-1990                                           -
C-    Revised and Maintained by R. McNeil and Chris Lyndon
C-
C-                                                                     -
C-    Revision:   V1.1 - 1-Aug-1991 Added new momentum table for <10GeV -
C-                V1.2 - 1-SEP-1991 Added non-interacting hadron       -
C-                V1.3 - 9-Oct-1991 Changed Prob tables reducing total -
C-                       number of bins and minimum thickness. Now all -
C-                       probabilities from GEANT simulation.          -
C-                V2.0 - 1-Nov-1991 Read in Punchthrough probability,  -
C-                       Multiplicity and momentum distributions once  -
C-                       per run in DATA block containing output       -
C-                       particle ID. Multiplicity range extended to   -
C-                       50 particles.   Also DATA block includes the  -
C-                       probability for non-interacting pion and      -
C-                       decay of primary pion to muon.                -
C-                V2.1 - 12-Dec-1991 Increase the punchthrough prob.   -
C-                       for K+ and K-. Input ID carries the sign of   -
C-                       charge of parent track. Output ID carries sign -
C-                       of charge punchthrough track.                 -
C-                V2.2 - 10-JAN-1992 Changed output ID code to be GEANT -
C-                       codes. Added return flag to indicate problem  -
C-                       with input variables out of range of the tables.-
C-                       Modified charge distribution to put in a      -
C-                       memory of the parent particle and asymmetry of -
C-                       electrons vs positrons and protons vs pbars.  -
C-                V2.3 - 21-JUN-1992 Put in some correlations between  -
C-                       particles type and multiplicity. Also smear   -
C-                       energy loss by muon traversing the calorimeter -
C-                       according to ELOS subroutine. See GEM Note    -
C-                       92-69. Apply Energy loss to determine         -
C-                       penetration probability and the output momentum -
C-                       of noninteracting charged hadrons and primary -
C-                       decays to muons.                              -
C-                                                                     -
C-      Send comments to Roger McNeil - Louisiana State University     -
C-                EMAIL:  LSUHEP::MCNEIL   or  PHMCNE@LSUVAX           -
C-                                                                     -
C-    Variables:                                                       -
C-      Input:                                                         -
C-                I1      -    Random Number Seed                      -
C-                ZCAL    -    The Thickness of Material in Lambda     -
C-                IDIN    -    Particle ID of the Parent Track         -
C-                P       -    Momemtum of the Parent Track (GeV/c)    -
C-                                                                     -
C-      Output:                                                        -
C-                POUT    -    Momentum of the Puncthrough Tracks (GeV/c) -
C-                RO      -    Radius of Punchthrough from the projected -
C-                             parent track in cm (at end of Mat'l)    -
C-                IDOUT   -    output ID of punchthrough.              -
C-                NP      -    Multiplicity of Punchthrough            -
C-                WT      -    Weight (probability for the punchthrough) -
C-                NPOUT   -    Multiplicity of Punchthrough to output  -
C-                IRET    -    Return flag (1=success, <0=failure)     -
C-----------------------------------------------------------------------
      IMPLICIT NONE

      INTEGER IDIN,IDABS,ICHARG,ICOUT,MUL,NP,NPOUT,NTRIES,IRET
      INTEGER I,IM,IP,IF,IL,IN,ID,J,K,ILAM,IDB(10),IDOUT(50)
      INTEGER IDO(48),IDC(48),IDOIN,IAOUT(50),ID1,ID2,MULEF
      SAVE IDB,IDC,IDO,IDOIN
      INTEGER IADD,MULE,IEVENT,MULE2
```

up to 50 punchthrough particles

```
      REAL POUT(50,4),RO(50),P(4),PUNCH,WT,ZCAL,PPU,TCAL,RR,PROB
      REAL THINC,PHINC,THOUTL,PHOUTL,PNI,RR2,PMOM,EPU,PTOT
      REAL PMAX,PMIN,PHIM,PLOM,RR3,RR4,RR5,PROB1,PROBML,PROB2
      REAL PDCLOM,PDCHIM,PDC,PNILOM,PNIHIM,ZINT1,ZINT2,PTINC
      REAL PMNID(5),ZPMNID

C       PUNCHTHROUGH shower profile from GEANT simulation.
      REAL ZLAM(17),ZP(8),ZPF(17),EPF(17),ZINTER
      SAVE ZLAM,    ZP,    ZPF,    EPF,    ZINTER
      REAL ZFRAC(7,6,17,5),PMULT(7,6,21,21,5),ZPUNCH(8,17,4)
      SAVE ZFRAC,          PMULT,            ZPUNCH
      REAL ZPJ(7,6,18,5)
      SAVE ZPJ
      REAL ZPM(7,6,18,5),XMUL(7,6,20),MULT(7,6,20)
      SAVE ZPM,          XMUL,        MULT
      DATA ZPF/  0.0001,0.0002,0.0005,0.001,0.002,0.005,
     &          0.010,0.020,0.05,0.100,0.15,0.200,0.300,0.400,0.500,
     &          0.600,0.750/
      DATA EPF/ 0.001,0.002,0.003,0.004,0.006,0.008,0.010,
     &          0.015,0.020,0.030,0.050,0.100,0.200,0.500,1.0,2.0,5.0/
      DATA ZLAM/6.,7.,8.,9.,10.,11.,12.,13.,
     &          14.,16.,18.,20.,22.0,24.0,26.0,28.0,30.0/
      DATA ZP/0.0,5.,10.,20.,40.,100.,200.,800./
      DATA IDB/2,3,5,6,8,9,11,12,14,15/
      DATA IDO/1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,
     &          21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,
     &          38,39,40,41,42,43,44,45,46,47,48/
C     DATA IDO/10,-12,12,11,-14,14,110,120,-120,-20,130,-130,1220,
C    &          1120,-1120,20,220,2130,1130,1230,2230,1330,2330,
C    &          3331,-1220,-2130,-1130,-1230,-2230,-1330,-2330,
C    &          -3331,-16,16,-240,240,-140,140,-340,340,2140,80,
C    &          -80,90,999,999,999,999/
      DATA IDC/0,1,-1,0,1,-1,0,1,-1,0,1,-1,0,1,-1,0,0,0,1,0,-1,0,-1,
     &         -1,0,0,-1,0,1,0,1,1,1,1,1,-1,0,0,1,-1,1,1,-1,0,1,
     &         -1,2,0/
C Minimum momentum for 1MeV Kinetic energy cutoff in GEANT.
      DATA PMNID/.0014,.0146,.0167,.0315,.0433/

C Dist of distance between parent and punchthrough after 14 lambda in 2cm
C bins. Taken from GEANT simulation for 200GeV pion.
C
      REAL      ROFRAC(25),ROUT,PHIOUT
      SAVE      ROFRAC
      DATA ROFRAC/.08,.20,.32,.43,.54,.62,.68,.74,.78,.82,.85,.87,
     1            .89,.91,.93,.94,.95,.960,.965,.970,.975,.980,.985,
     2            .99,1./
C
C Dist of angles between parent and punchthrough after 14lambda in radians
C bins. Taken from GEANT simulation for 200GeV pion.
C
      REAL THVAL(14),THFRAC(14,5),PVAL(5),THOUT,DPHI,DTHE
      SAVE THVAL,    THFRAC,      PVAL
      DATA THVAL/0.02,0.04,.06,.08,.10,.12,.14,.16,.18,.20,.30,
     1            .50,1.0,1.6/
      DATA THFRAC/0.0014,0.0051,.0100,.0152,.0234,.0342,.0469,.0594,
     1           .0728,.0865,.1653,.3401,.7438,1.0,
     2           0.0001,0.0005,.0092,.0242,.0385,.0575,.0798,
     3           .1069,.1352,.1661,.3131,.5890,.9205,1.0,
     4           0.0003,0.0296,.0691,.1191,.1723,.2329,.2979,
     5           .3593,.4246,.4821,.7115,.9200,.9967,1.0,
     6           0.0324,0.1365,.2486,.3836,.4878,.5927,.6882,
     7           .7451,.7995,.8414,.9526,.9968,.9992,1.0,
     8           0.1779,0.3881,.5483,.6747,.7504,.8221,.8623,
     9           .8913,.9171,.9436,.9839,.9928,.9984,1.0/
      DATA PVAL/0.,0.25,1.0,5.,10./
      INTEGER I1
```

Minimum 6λ

GEANT ID Codes

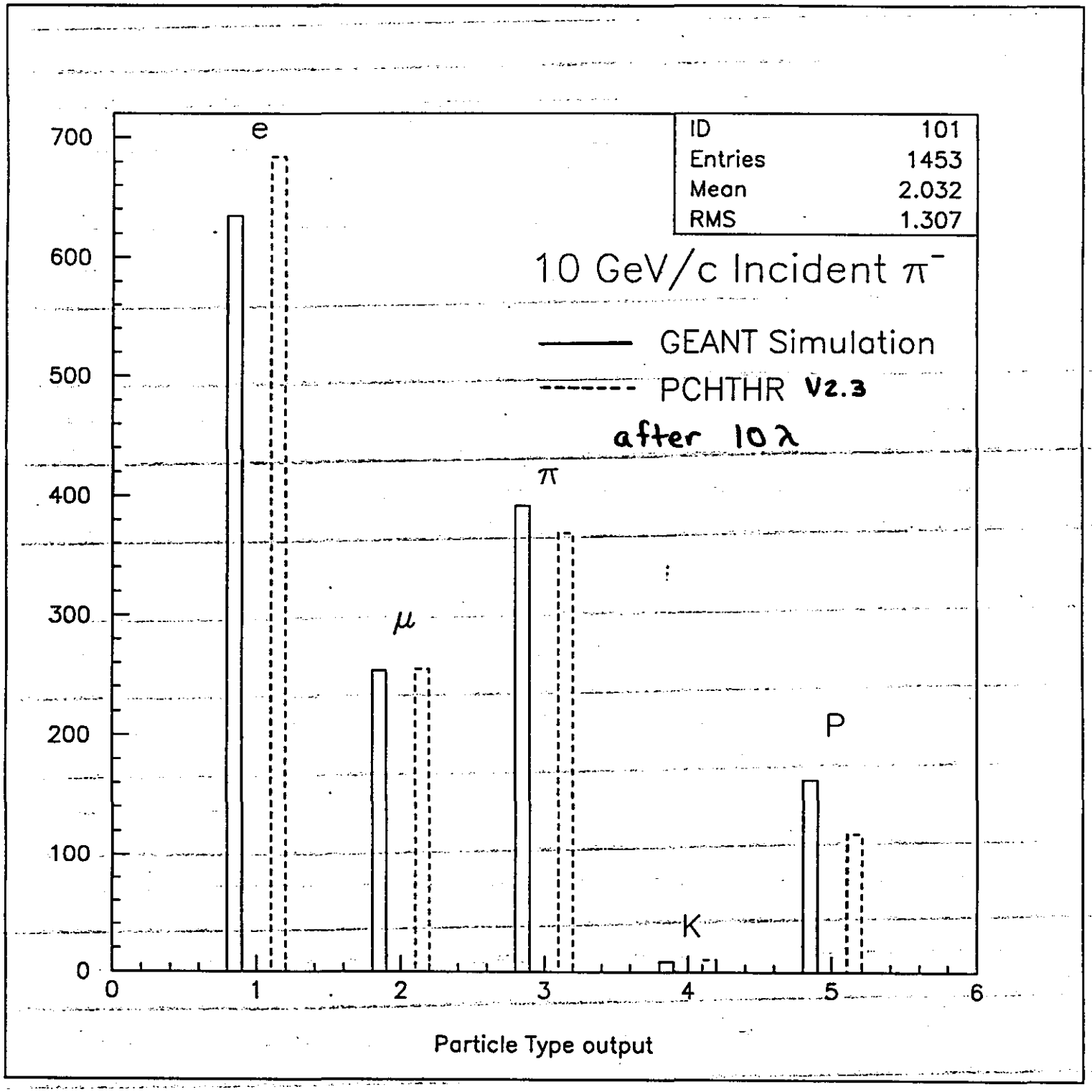
unchange from V1.0

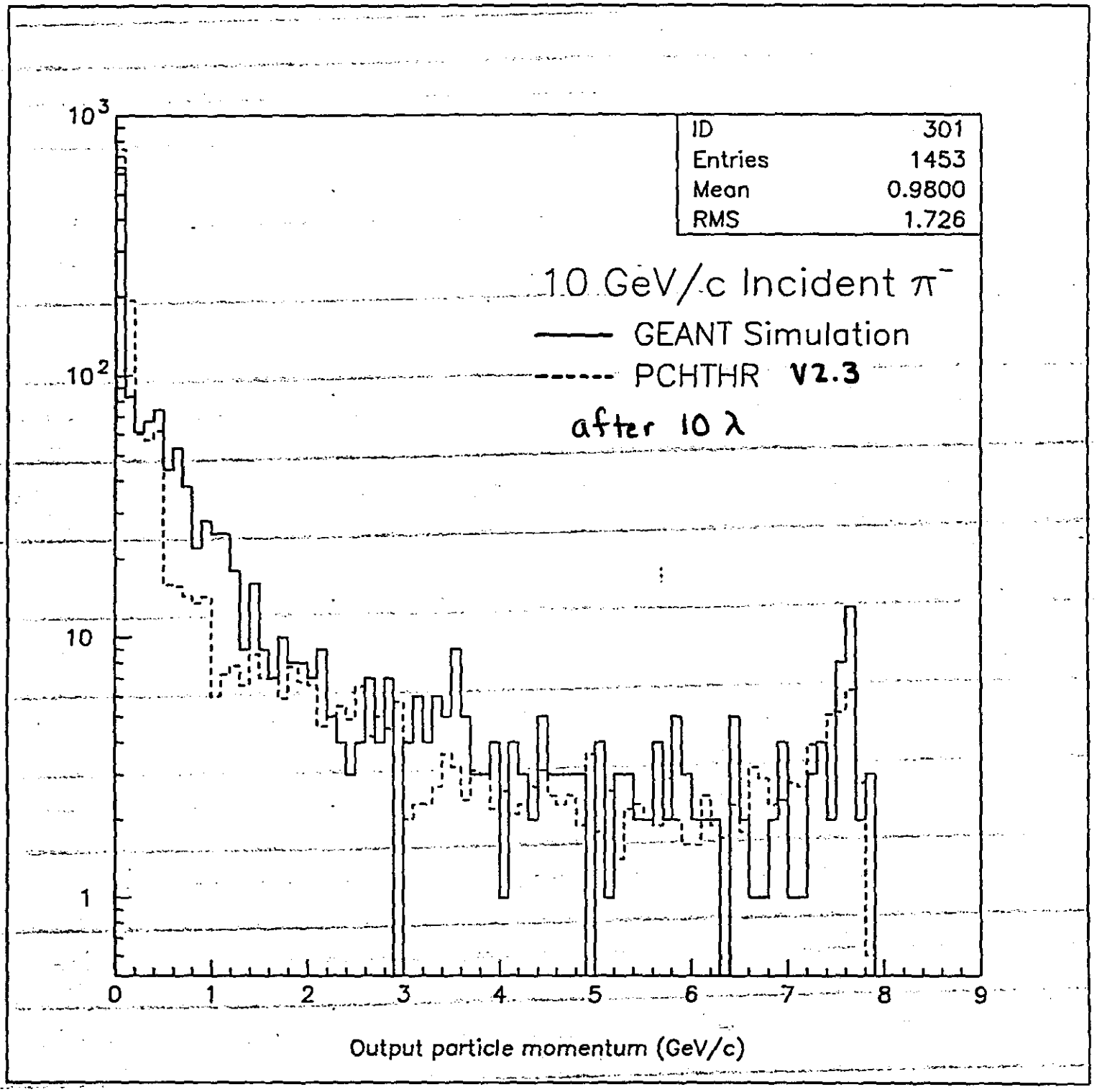
```
      REAL RAN
C     EXTERNAL RAN
C
      LOGICAL FIRST
      SAVE    FIRST
      DATA FIRST/.TRUE./

C
C          INITIALIZE
C
      IF(FIRST) THEN
        FIRST=.FALSE.
        DO 603 IM=1,8
          DO 602 IN=1,17
            DO 601 IP=1,4
              ZPUNCH(IM,IN,IP)=0.0
601         CONTINUE
602       CONTINUE
603     CONTINUE
        DO 610 IM=1,7
          DO 609 IL=1,6
            DO 605 IF=1,17
              DO 604 ID=1,5
                ZFRAC(IM,IL,IF,ID)=0.
604           CONTINUE
605         CONTINUE
            DO 608 IN=1,21
              IF(IN.NE.21)MULT(IM,IL,IN)=0.0
              DO 607 IP=1,21
                DO 606 ID=1,5
                  PMULT(IM,IL,IN,IP,ID)=0.0
606             CONTINUE
607           CONTINUE
608         CONTINUE
609       CONTINUE
610     CONTINUE
        FIRST=.FALSE.
        LUN=67
        OPEN (UNIT=LUN,FILE='WEEKU:PUNCH.TAB',STATUS='OLD',READONLY)
        DO 612 IM=1,7
          DO 611 IN=1,17
            READ(LUN,1001)(ZPUNCH(IM+1,IN,IP),IP=1,4)
611       CONTINUE
612     CONTINUE
        DO 617 IM=1,7
          DO 616 IL=1,6
            DO 615 IF=1,18
              READ(LUN,1002)(ZPJ(IM,IL,IF,ID),ID=1,5)
              IF(IF.GT.1)THEN
                DO 614 ID=1,5
                  DO 613 IP=1,IF
                    ZFRAC(IM,IL,IF-1,ID)=ZFRAC(IM,IL,IF-1,ID)
     &                  +ZPJ(IM,IL,IP,ID)
613               CONTINUE
614             CONTINUE
              ENDIF
615         CONTINUE
616       CONTINUE
617     CONTINUE
        DO 625 IM=1,7
          DO 624 IL=1,6
            DO 618 IN=1,20
              READ(LUN,1003)XMUL(IM,IL,IN)
618         CONTINUE
            DO 620 IN=1,20
              DO 619 IP=1,IN
```

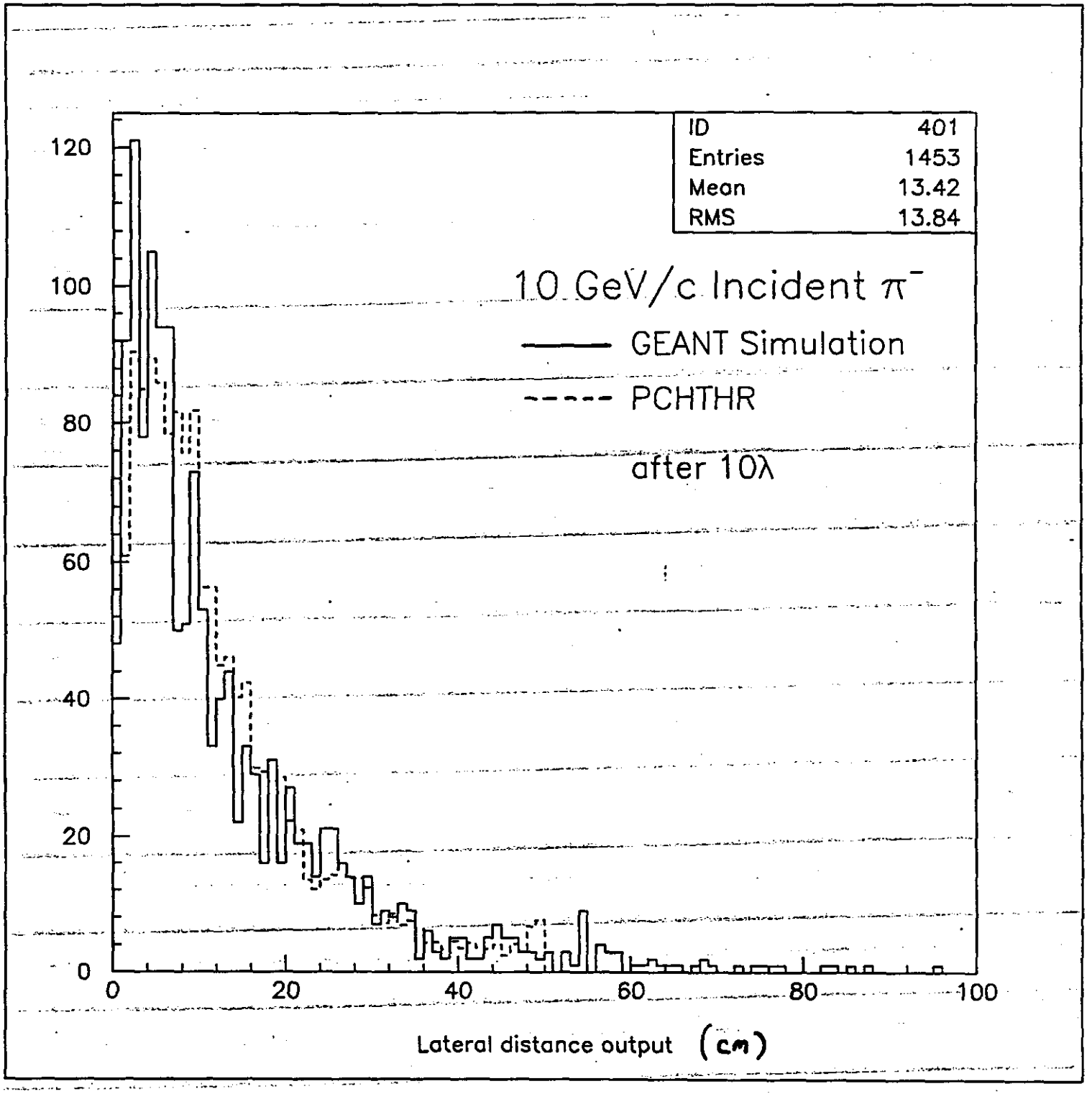
read in Punchthrough Probability Tables ~1MB disk file

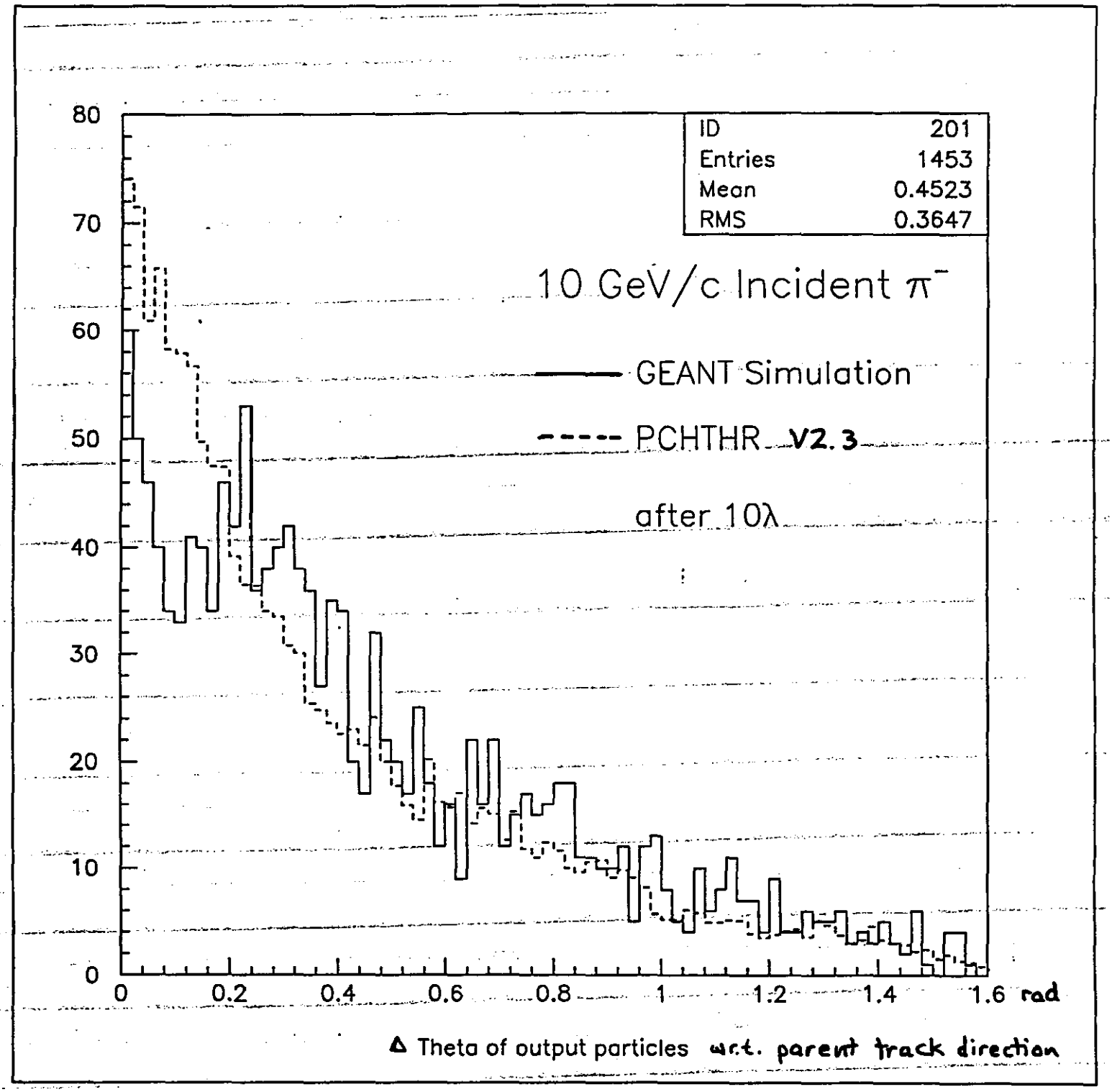
```
                MULT(IM,IL,IN)=MULT(IM,IL,IN)+XMUL(IM,IL,IP)
619           CONTINUE
620         CONTINUE
            DO 623 IN=2,21
              DO 621 IP=1,IN
               READ(LUN,1002)(PMULT(IM,IL,IN,IP,ID),ID=1,5)
621           CONTINUE
623         CONTINUE
325         CONTINUE
624       CONTINUE
625     CONTINUE
        CLOSE(UNIT=67)
C- End - First
        PRINT *, ' FINISHED READING PUNCHTHROUGH PROBABILITY TABLE'
      ENDIF
1001  FORMAT(4F)
1002  FORMAT(5F)
1003  FORMAT(F)
C
C  ZERO
        IEVENT=IEVENT+1
C       PRINT *,'EVENT NUMBER:  ',IEVENT
      IRET=0
      NP = 0
      NPOUT=0
      WT=0.
      DO 12 IM=1,50
        RO(IM)=0.
        IDOUT(IM)=0
        DO 11 IP=1,4
          POUT(IM,IP) = 0.
11      CONTINUE
12    CONTINUE
C  Check to see if hadron can possibly penetrate calorimeter.
C     TCAL=0.218*ZCAL    !MINIMUM DE/DX, AVERAGE OF PB AND U
c      TCAL=0.2*ZCAL      !minimum dE/dX for iron
      CALL ELOS(i1,ZCAL,p(4),TCAL)
      IF(P(4).LT.TCAL)THEN
C        WRITE(6,1007)P(4),ZCAL,TCAL
1007    FORMAT(' PCHTHR-ERROR: RANGES OUT',3F12.5)
        IRET=0
        RETURN
      ENDIF
      IDOIN=0
      DO I=1,48
        IF(IDIN.EQ.IDO(I))IDOIN=I
      ENDDO
      IF(IDOIN.EQ.0)THEN
        WRITE(6,3004)IDIN
3004    FORMAT(' PCHTHR-ERROR: CAN NOT HAVE IDIN PARTICLE TYPE = ',I8)
        IRET=-4
       RETURN
      ENDIF
      IF(IDOIN.LT.7.OR.IDOIN.EQ.17.OR.IDOIN.EQ.18.OR.IDOIN.EQ.22
     &  .OR.IDOIN.EQ.23.OR.IDOIN.EQ.24.OR.IDOIN.GT.29)THEN
        WRITE(6,3004)IDIN
        IRET=-5
        RETURN
      ENDIF
C Perform momentum and thickness interpolation.
      IF(ZCAL.LT.ZLAM(1))THEN
        WRITE(6,3001)ZCAL,ZLAM(1)
3001    FORMAT(' PCHTHR-ERROR: INPUT THICKNESS:',F8.2,
     &                    ' LESS THAN MINIMUM:',F8.2)
        IRET=-1
```

Energy loss Subroutine GEANT based.


ID 101
Entries 1453
Mean 2.032
RMS 1.307
10 GeV/c Incident π⁻
GEANT Simulation
PCHTHR V2.3
after 10λ
e
μ
π
K
P
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
Particle Type output


ID 301
Entries 1453
Mean 0.9800
RMS 1.726
10 GeV/c Incident π⁻
GEANT Simulation
PCHTHR V2.3
after 10 λ
10³
10²
10
1
0
1
2
3
4
5
6
7
8
9
Output particle momentum (GeV/c)


ID 401
Entries 1453
Mean 13.42
RMS 13.84
10 GeV/c Incident π⁻
GEANT Simulation
PCHTHR
after 10λ
120
100
80
60
40
20
0
0
20
40
60
80
100
Lateral distance output (cm)


ID 201
Entries 1453
Mean 0.4523
RMS 0.3647
10 GeV/c Incident π⁻
GEANT Simulation
PCHTHR V2.3
after 10λ
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6 rad
Δ Theta of output particles w.r.t. parent track direction

How To Use PCHTHR

Option 1 - Call it from ISAJET Analysis program

ISAJET Analysis Code

⋮

```
C       STABLE PARTICLES
            IF(IDABS.EQ.20.OR.IDABS.EQ.120
     1          .OR.IDABS.EQ.130.OR.IDABS.EQ.1120
     2          .OR.IDABS.EQ.1220.OR.IDABS.EQ.1130.OR.IDABS.EQ.1230
     3          .OR.IDABS.EQ.2130) THEN !STABLE PARTICLES
C  Store if momentum greater than TCAL
              WT=0.
              NP=0
              NPOUT=0
              IF(P(4).GT.TCAL)THEN
                NHAD = NHAD+1
                IF(NHAD.GT.1000)THEN
                  WRITE(1444)NHAD
1444              FORMAT(' NHAD MAX:',I8)
                ELSE
                PHAD(NHAD,1)=P(1)
                PHAD(NHAD,2)=P(2)
                PHAD(NHAD,3)=P(3)
                PHAD(NHAD,4)=P(4)
                ENDIF
                CALL PCHTHR(I1,ZCAL,ID,P,POUT,RO,IDOUT,NP,WT,NPOUT)
                IF(WT.EQ.0..OR.NP.EQ.0)
     &                WRITE(6,444)NPUN,ZCAL,IDABS,P,NP,WT,NPOUT
              ENDIF
444           FORMAT(I6,F7.1,I6,4F9.3,I5,F8.5,I5)
              WMD=WEIGHT*WT
              CALL HFILL(7,PT,0,WMD)
              CALL HFILL(107,PT,0,WMD)
              CALL HFILL(8,ETA,0,WMD)
              CALL HFILL(18,P(4),0,1.)
              IF(NPOUT.GT.0)CALL HFILL(19,P(4),0,1.)
              DO I=1,NP
                IF(POUT(I,4).EQ.0.)THEN
                  WRITE(6,445)I,(POUT(I,J),J=1,4)
                ENDIF
445             FORMAT(' IMUL,POUT:',I6,4F9.4)
                IF(NPOUT.GT.0)THEN
                  PPUN(NPUN+I,1)=POUT(I,1)
                  PPUN(NPUN+I,2)=POUT(I,2)
                  PPUN(NPUN+I,3)=POUT(I,3)
                  PPUN(NPUN+I,4)=POUT(I,4)
                  ROUT(NPUN+I)=RO(I)
```

"Stable" Particles $\pi^{\pm}, K^{\pm}, p, \bar{p}, n, \bar{n}$

$K_S, K_L, \Lambda, \Sigma^{\pm}, \Sigma^{0}$ — Assume Stable

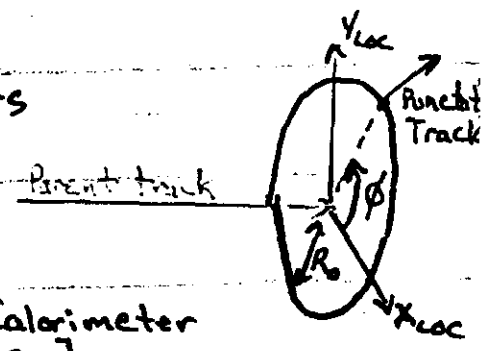
You supply — convert to GEANT ID code now.

Weight is weight of event (P_T)
WMD is punchthrough part. weight

OUTPUT 4-vectors

To Globally position punchthrough track:

1. Project Parent through Calorimeter
2. "Throw" ϕ uniform $[0, 2\pi]$
3. Use to locate Punchthrough track (R_0, ϕ)



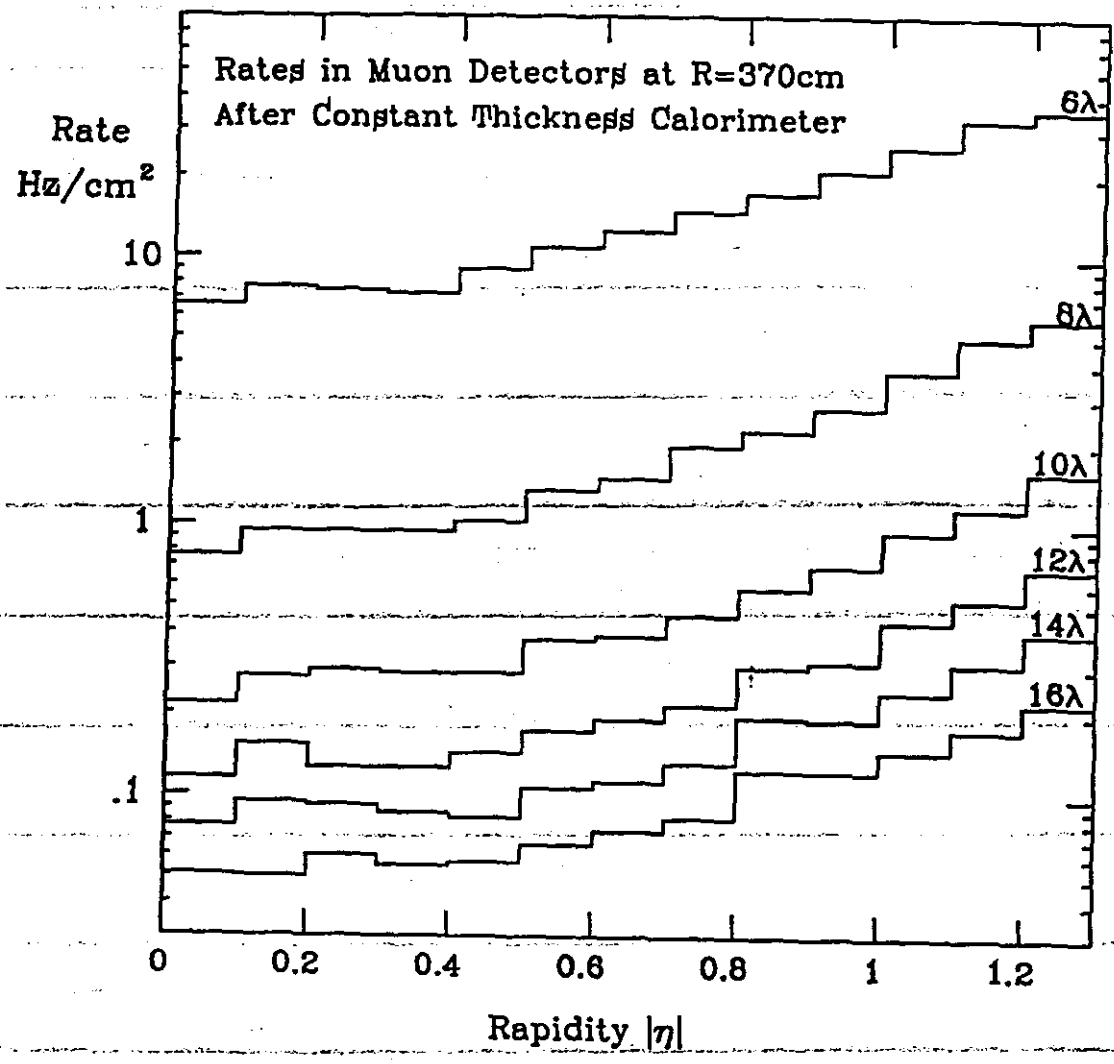
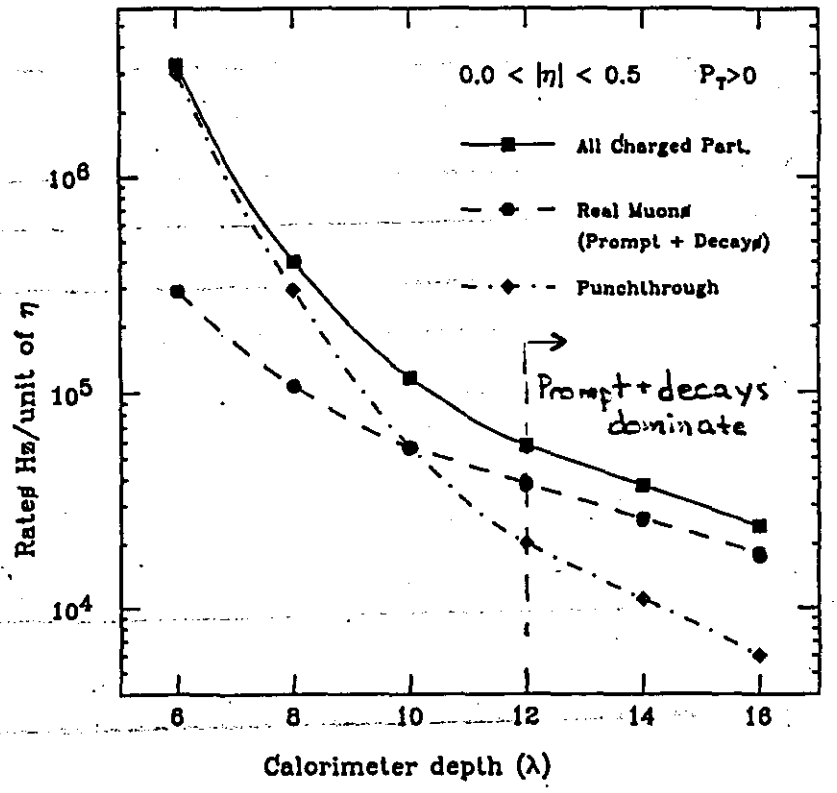


Figure 3. The hit occupancy in the first layer of the GEM barrel muon system at R=370cm at 10^33 cm^-2/s SSC luminosity as a function of rapidity for various constant calorimeter thicknesses.

Tracking volume for GEM : $R_{max} = 75cm$, $|Z_{max}| = 220cm$



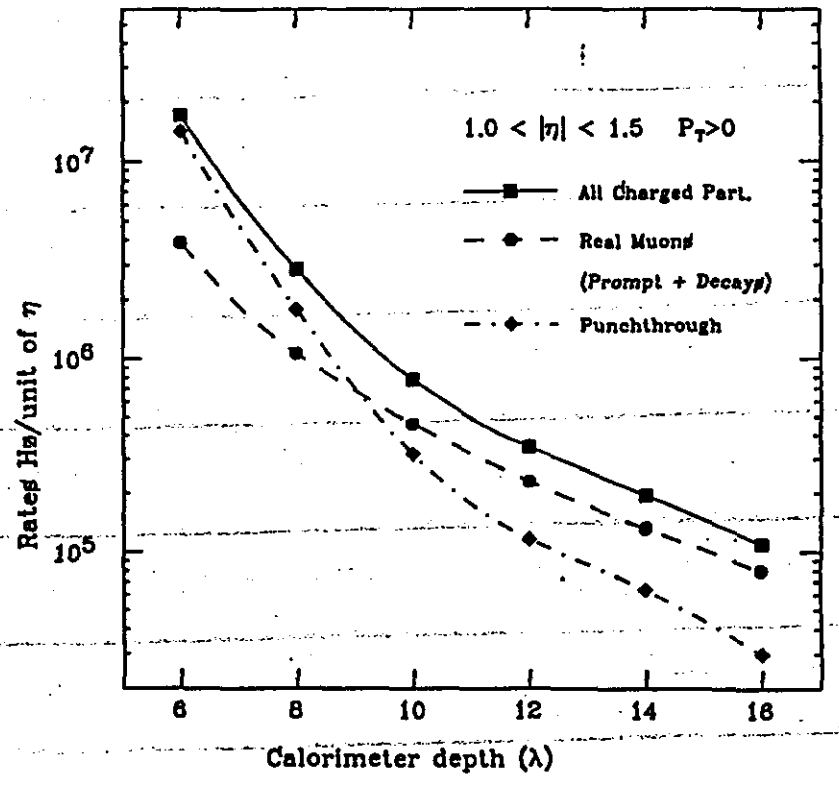
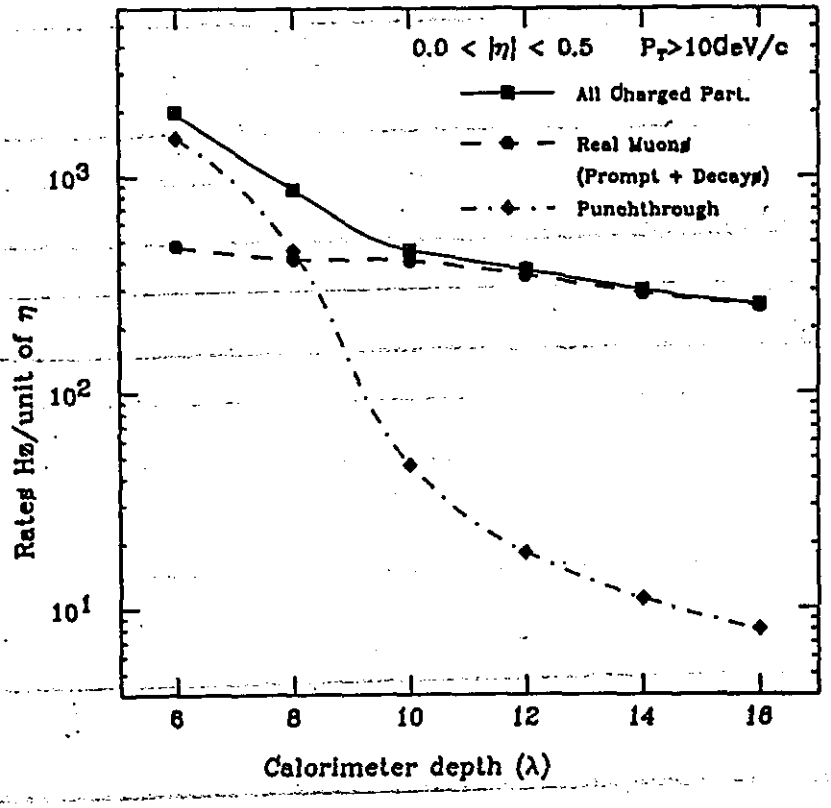


Figure 1. The rate of all charged particles rates at 10^33 cm^-2/s SSC luminosity exiting the barrel calorimeter for a) |eta|<0.5 and b) 1.0<|eta|<1.5 rapidity intervals. The solid curve is the total rate, the dashed curve is the rate from prompt muons and pi/K decays in the inner tracking region, and the dot-dashed curve is the rate from hadron punchthrough.



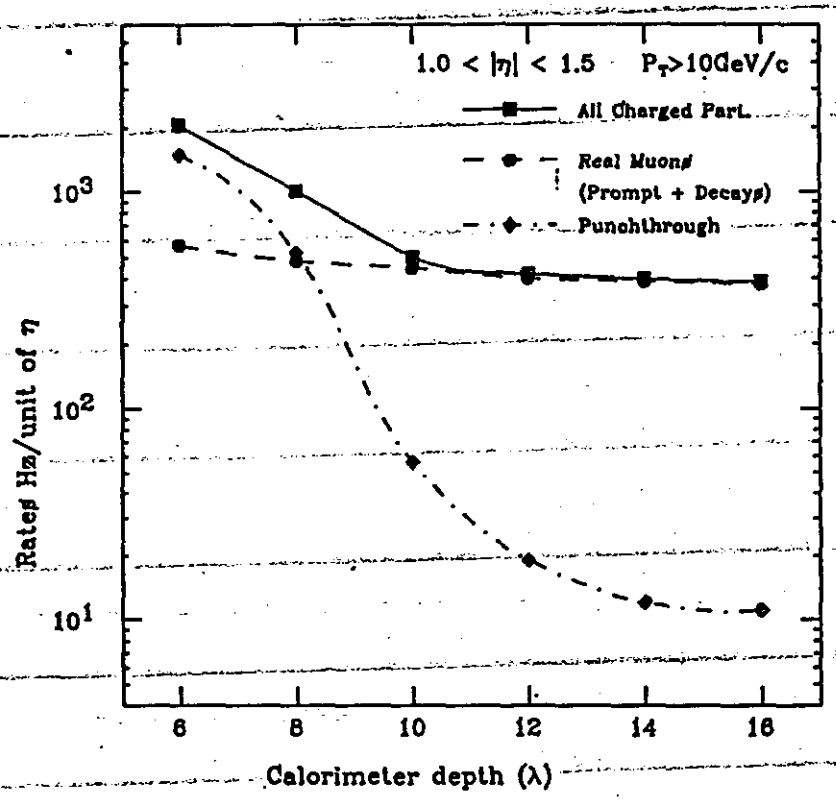
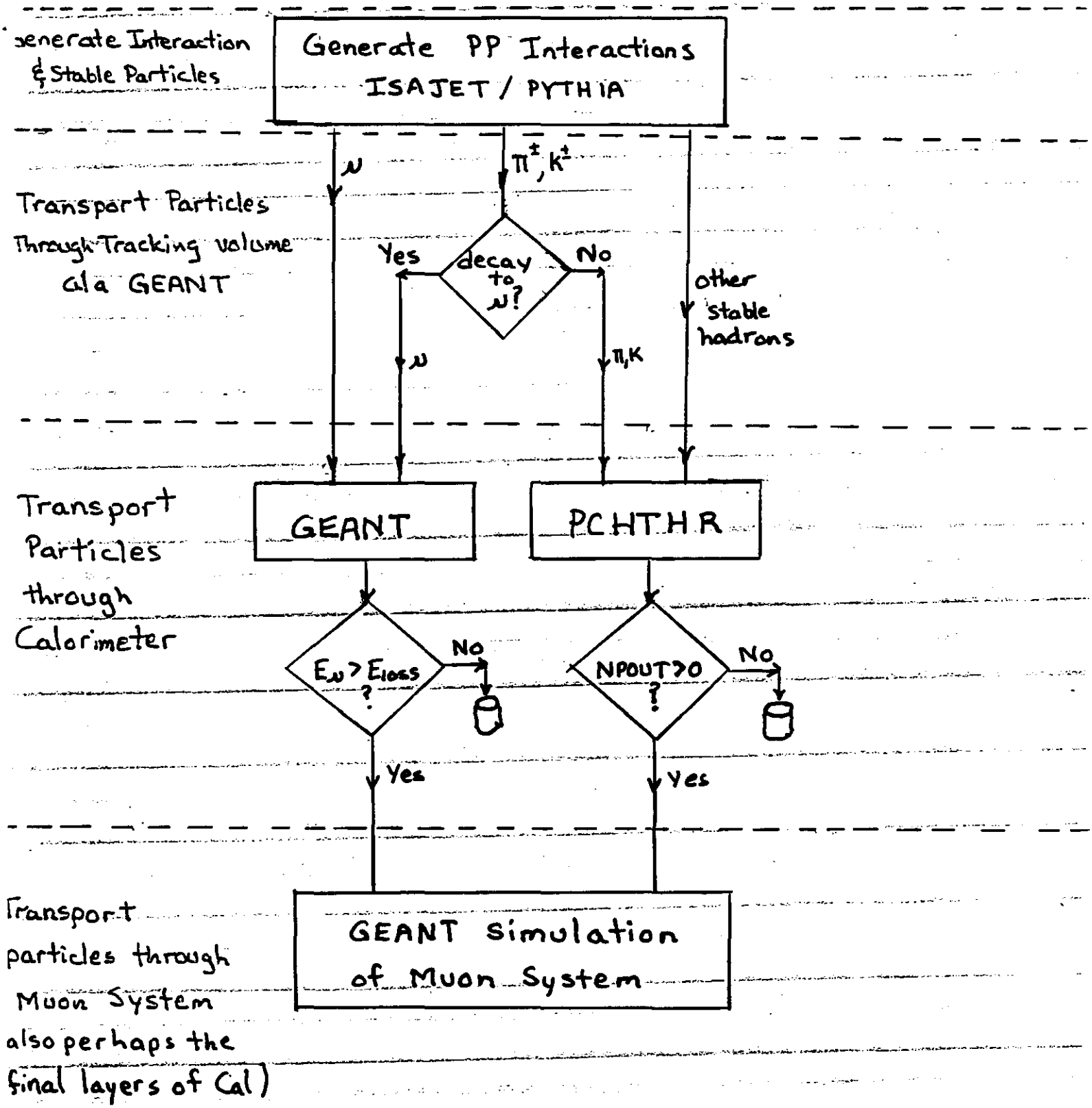


Figure 2. The rate of Charged particles with transverse momentum above 10GeV/c at 10^33 cm^-2/s SSC Luminosity exiting the barrel calorimeter for a) |eta|<0.5 and b) 1.0<|eta|<1.5 rapidity intervals. The solid curve is the total rate, the dashed curve is the rate from prompt muons and pi/K decays in the inner tracking region, and the dot-dashed curve is the rate from hadron punchthrough.

Option 2:


Generate Interaction & Stable Particles
Generate PP Interactions
ISAJET / PYTHIA
Transport Particles Through Tracking volume via GEANT
ν
π±, K±
Yes
decay to ν?
No
ν
π, K
other stable hadrons
Transport Particles through Calorimeter
GEANT
PCHTHR
Eν > Eloss ?
No
NPOUT > 0 ?
No
Yes
Yes
Transport particles through Muon System also perhaps the final layers of Cal)
GEANT Simulation of Muon System

Future Updates to PCHTHR

- Plans for this workshop

Version 3.0 of PCHTHR is ready for Pre-release

New features in V 3.0

- Neutrons and gammas in punchthrough shower KE > 1MeV only 5GeV, 10GeV, 20GeV, 40GeV, 100GeV probability tables now. Punchthrough table : 3.5MB of disk ⇒ memory

  DC neutron level must be done separately

- Correlations of $\Delta\Theta_{OUT}$ to ID - New code to determine ΔE

- Correlations of R_{OUT} to ID

Please Try it out !