(A) Few things that I know about Monte Carlo

- o Introduction
- o Event Generator
- o Detector Simulation
- o A Few Final Words

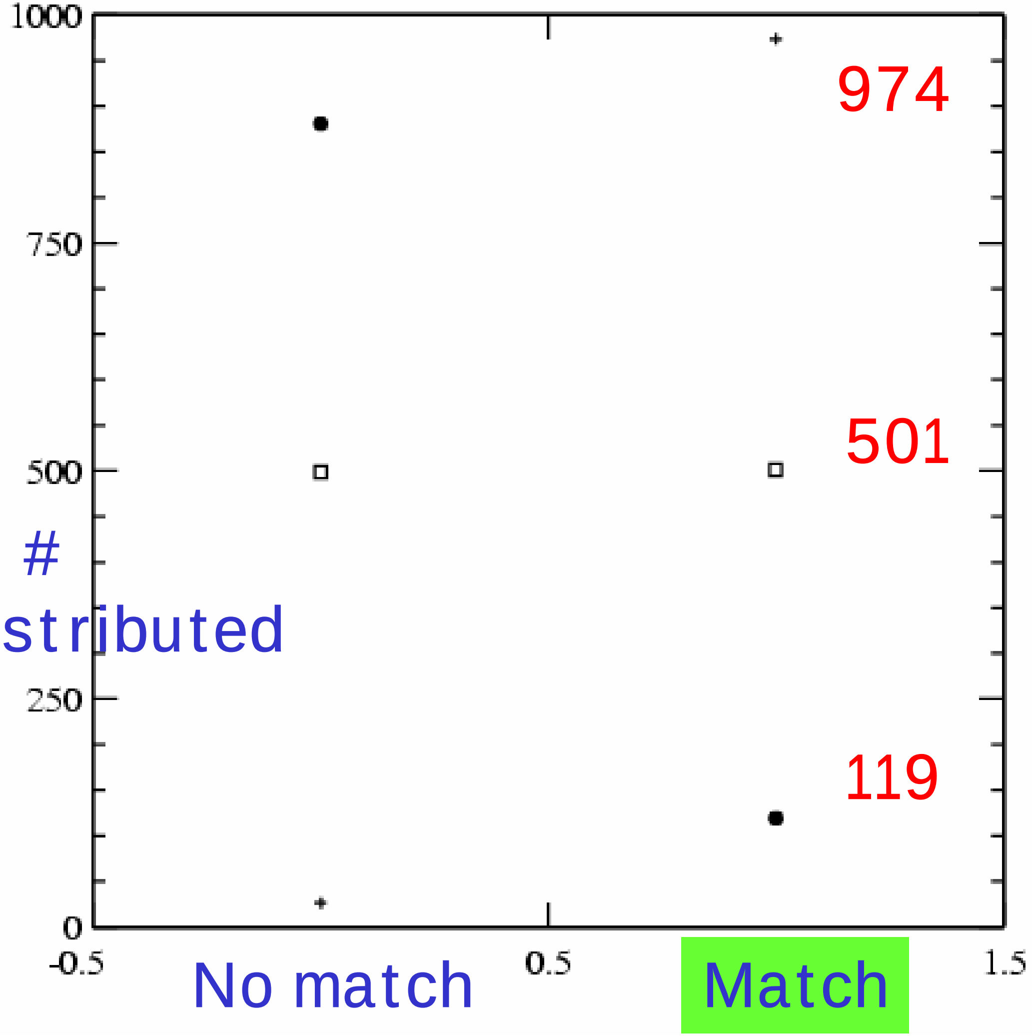
Probability for the Same Birthday

Suppose that in a room of N persons each of the 365 days of the year is equally likely to be someone's birth day. The probability that at least 2 out of N people will have the same birthday is

$$1 - 365!/N!/(365)^N$$

Simulation for the Same Birthday

	N
●	5
□	23
+	50



No match

Match

Use random # uniformly distributed

1000 trials
For each N

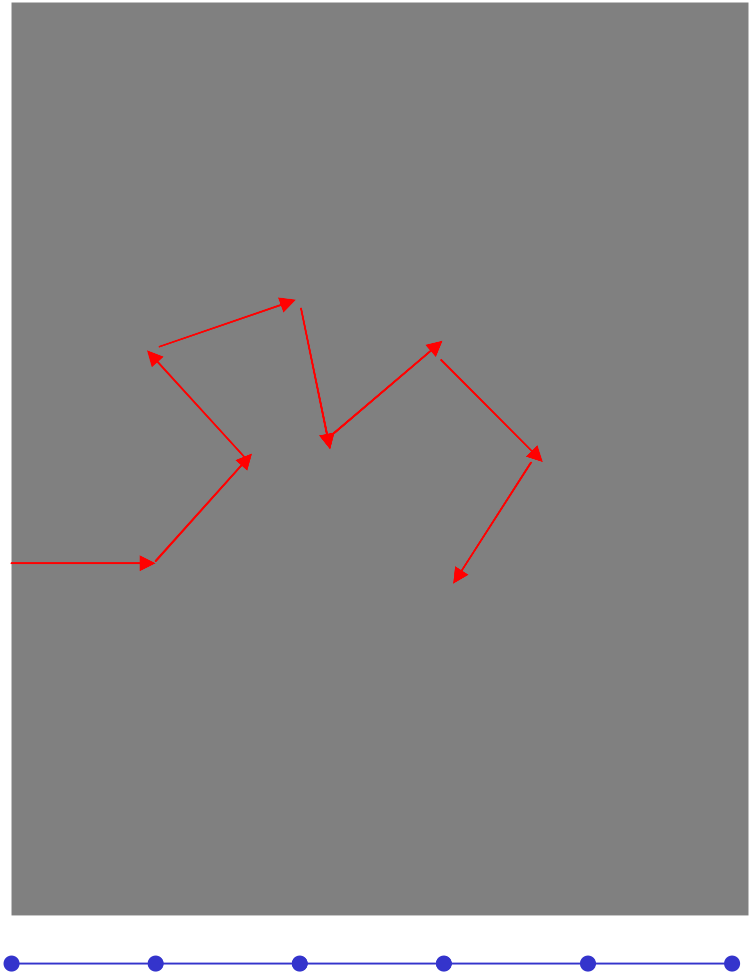
Probability for the Same Birthday

N	Prob. Calculation
5	0.027
10	0.117
15	0.253
20	0.411
23	0.507
25	0.569
30	0.706
35	0.814
40	0.891
45	0.941
50	0.970
55	0.986

Probability for the Same Birthday

N	Prob. Calculation	Prob. Simulation
5	0.027	
10	0.117	0.119
15	0.253	
20	0.411	
23	0.507	0.501
25	0.569	
30	0.706	
35	0.814	
40	0.891	
45	0.941	
50	0.970	0.974
55	0.986	

An (overly simple) Neutron Shielding



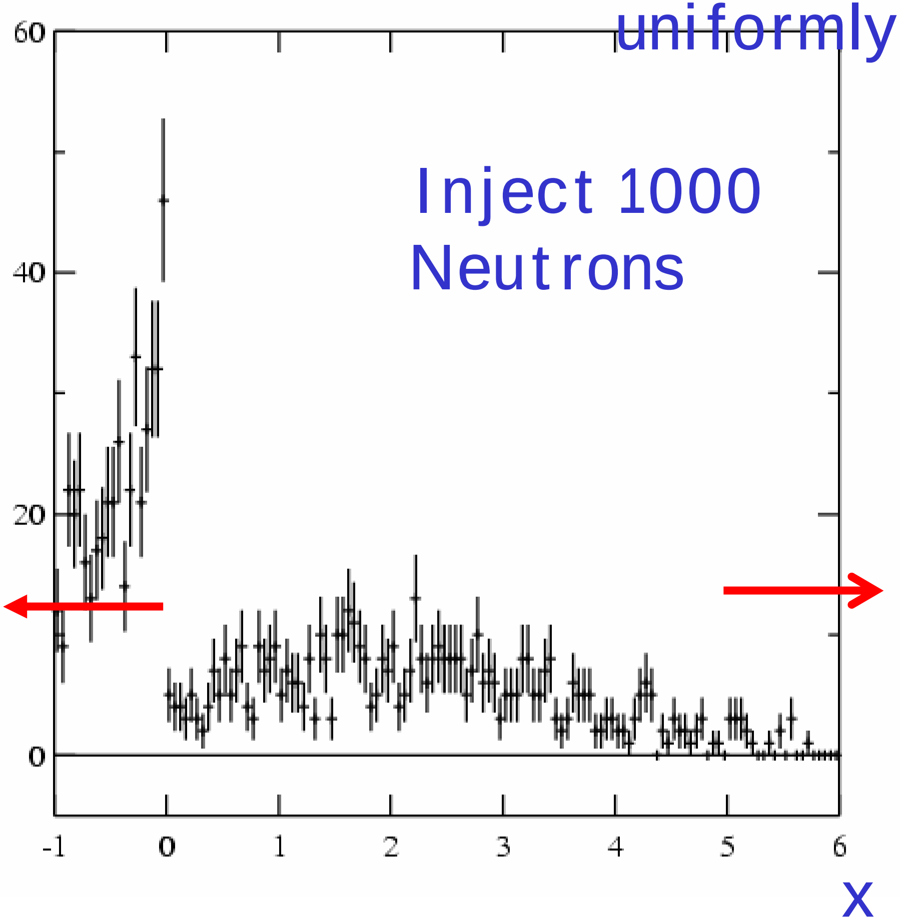
5 units of lead along x
Infinite units of lead along y

Initially neutrons move in along x. Neutrons free-fly over one unit of lead, then scatter uniformly in x-y plane. Again free-fly over One unit, then scatter uniformly. But they loose all energy after flying over 8 units of lead.

Prob. for a neutron coming out of the shielding ?

Let’s Simulate !

Use random # uniformly distributed



Inject 1000 Neutrons

Backward
(x < 0)
444/1000
=44.4%

Forward
(x > 5)
19/1000
=1.9%

Very Bad Shielding

OK Shielding

What is Monte Carlo Simulation ?

What do we mean by "simulation?"
S***imulations*** are analytical/computational methods to imitate real systems,
which are mathematically complex or too difficult to reproduce
many many times.

One type of simulation is **Monte Carlo simulation**,
which randomly generates values for the quantities that
we are interested in with real systems.

What does "Monte Carlo" have to do with Simulation ?

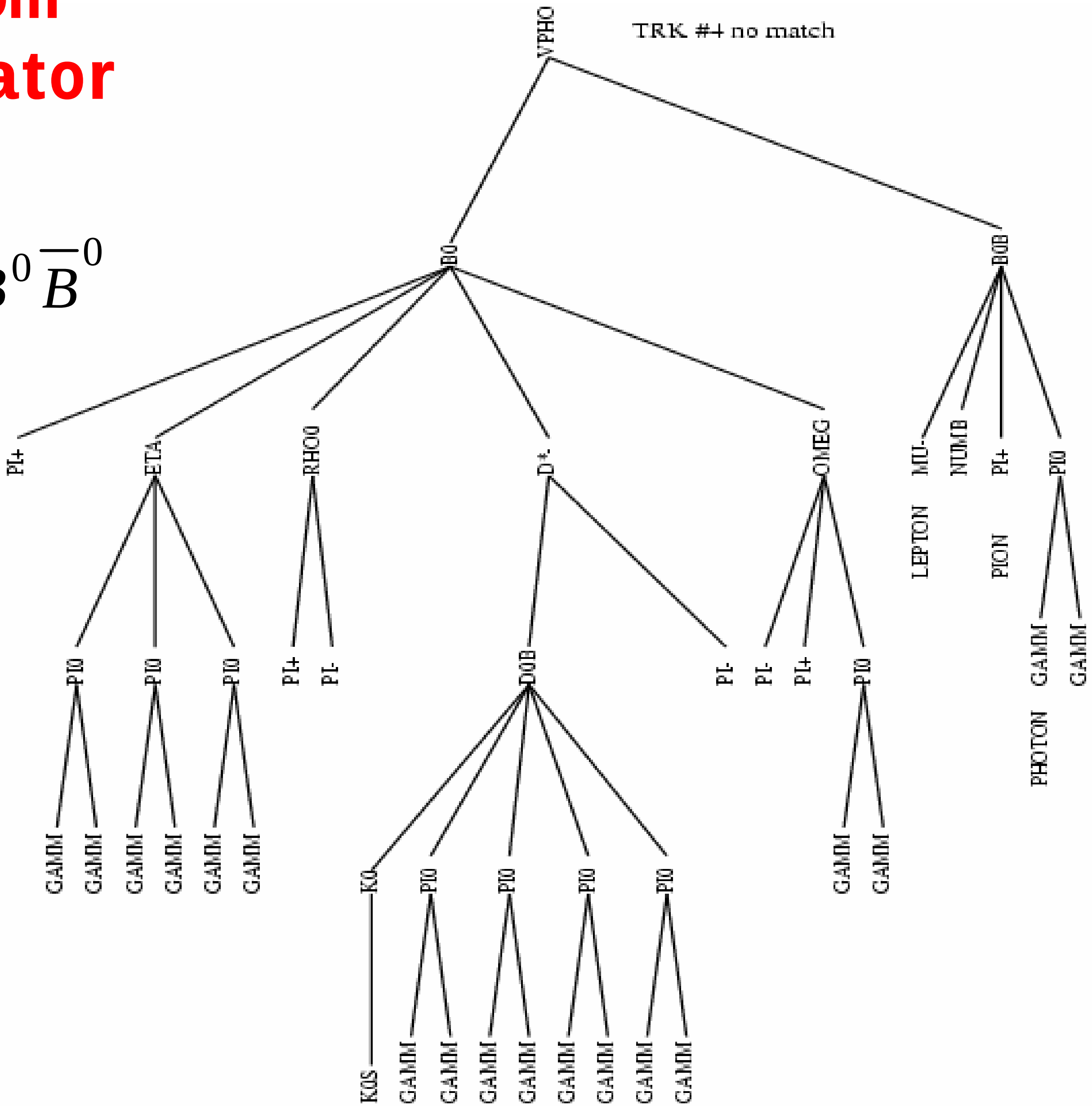
Monte Carlo Simulation was named after
Monte Carlo, Monaco!

Casinos -> Games of Chances -> Randomness

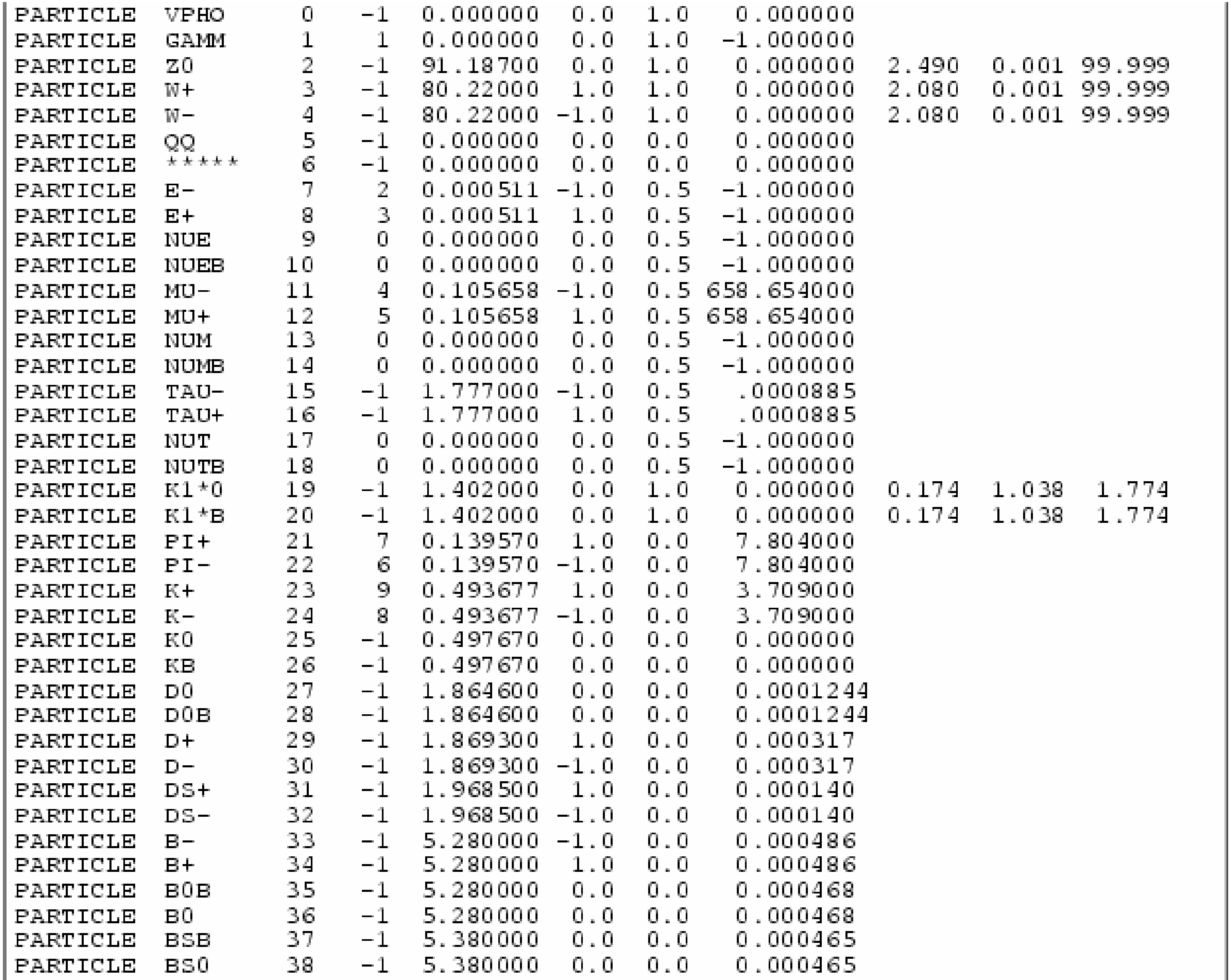
Just a Question :
All-In works in this business of chances ???

An Event from Event Generator

$$e^+e^- \to \gamma^* \to B^0\overline{B}^0$$

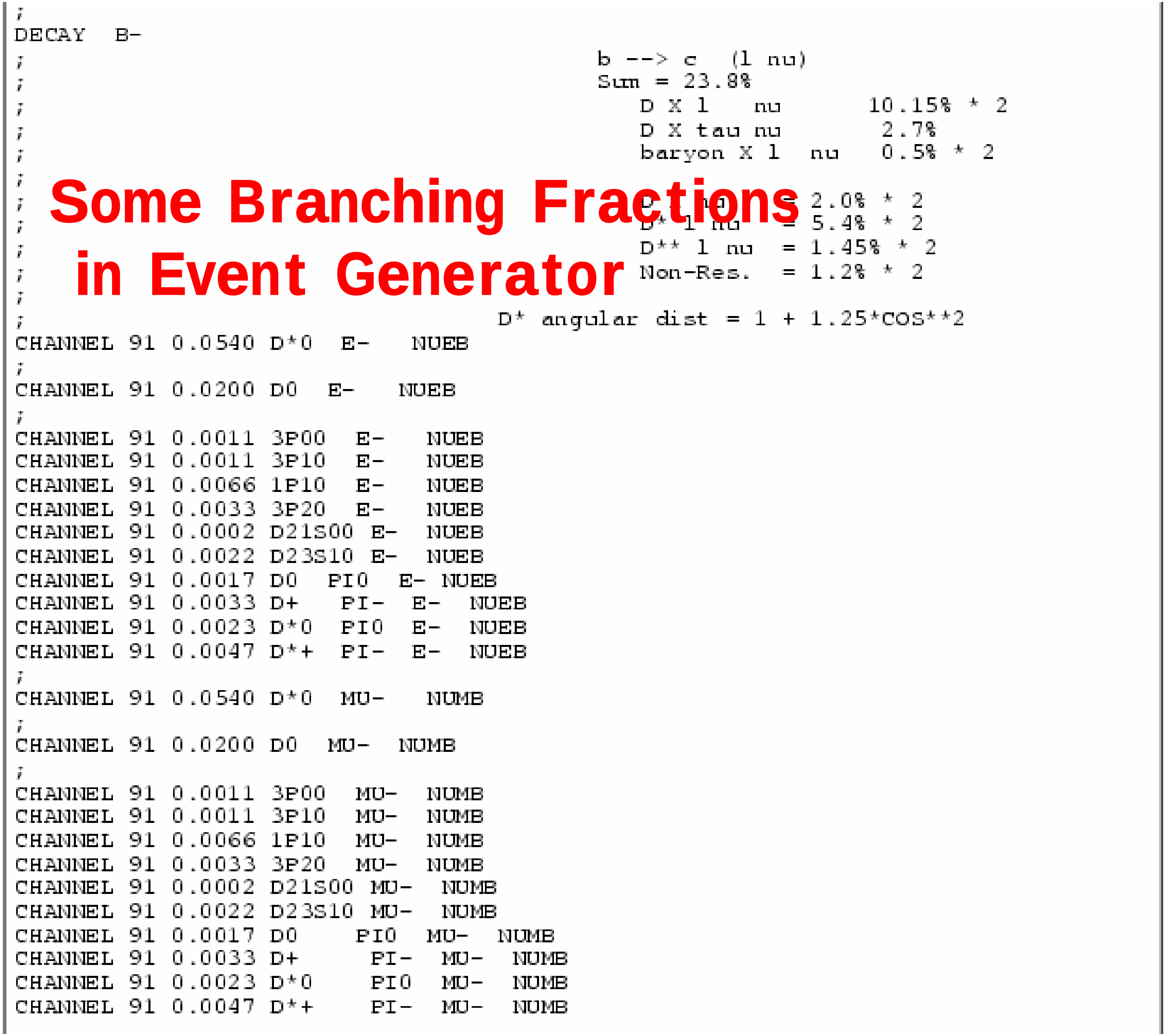


Particle Properties in Event Generator



```
PARTICLE  VPHO     0   -1  0.000000  0.0  1.0   0.000000
PARTICLE  GAMM     1    1  0.000000  0.0  1.0  -1.000000
PARTICLE  Z0       2   -1  91.18700  0.0  1.0   0.000000  2.490  0.001 99.999
PARTICLE  W+       3   -1  80.22000  1.0  1.0   0.000000  2.080  0.001 99.999
PARTICLE  W-       4   -1  80.22000 -1.0  1.0   0.000000  2.080  0.001 99.999
PARTICLE  QQ       5   -1  0.000000  0.0  0.0   0.000000
PARTICLE  *****    6   -1  0.000000  0.0  0.0   0.000000
PARTICLE  E-       7    2  0.000511 -1.0  0.5  -1.000000
PARTICLE  E+       8    3  0.000511  1.0  0.5  -1.000000
PARTICLE  NUE      9    0  0.000000  0.0  0.5  -1.000000
PARTICLE  NUEB    10    0  0.000000  0.0  0.5  -1.000000
PARTICLE  MU-     11    4  0.105658 -1.0  0.5 658.654000
PARTICLE  MU+     12    5  0.105658  1.0  0.5 658.654000
PARTICLE  NUM     13    0  0.000000  0.0  0.5  -1.000000
PARTICLE  NUMB    14    0  0.000000  0.0  0.5  -1.000000
PARTICLE  TAU-    15   -1  1.777000 -1.0  0.5   .0000885
PARTICLE  TAU+    16   -1  1.777000  1.0  0.5   .0000885
PARTICLE  NUT     17    0  0.000000  0.0  0.5  -1.000000
PARTICLE  NUTB    18    0  0.000000  0.0  0.5  -1.000000
PARTICLE  K1*0    19   -1  1.402000  0.0  1.0   0.000000  0.174  1.038  1.774
PARTICLE  K1*B    20   -1  1.402000  0.0  1.0   0.000000  0.174  1.038  1.774
PARTICLE  PI+     21    7  0.139570  1.0  0.0   7.804000
PARTICLE  PI-     22    6  0.139570 -1.0  0.0   7.804000
PARTICLE  K+      23    9  0.493677  1.0  0.0   3.709000
PARTICLE  K-      24    8  0.493677 -1.0  0.0   3.709000
PARTICLE  K0      25   -1  0.497670  0.0  0.0   0.000000
PARTICLE  KB      26   -1  0.497670  0.0  0.0   0.000000
PARTICLE  D0      27   -1  1.864600  0.0  0.0   0.0001244
PARTICLE  D0B     28   -1  1.864600  0.0  0.0   0.0001244
PARTICLE  D+      29   -1  1.869300  1.0  0.0   0.000317
PARTICLE  D-      30   -1  1.869300 -1.0  0.0   0.000317
PARTICLE  DS+     31   -1  1.968500  1.0  0.0   0.000140
PARTICLE  DS-     32   -1  1.968500 -1.0  0.0   0.000140
PARTICLE  B-      33   -1  5.280000 -1.0  0.0   0.000486
PARTICLE  B+      34   -1  5.280000  1.0  0.0   0.000486
PARTICLE  B0B     35   -1  5.280000  0.0  0.0   0.000468
PARTICLE  B0      36   -1  5.280000  0.0  0.0   0.000468
PARTICLE  BSB     37   -1  5.380000  0.0  0.0   0.000465
PARTICLE  BS0     38   -1  5.380000  0.0  0.0   0.000465
```

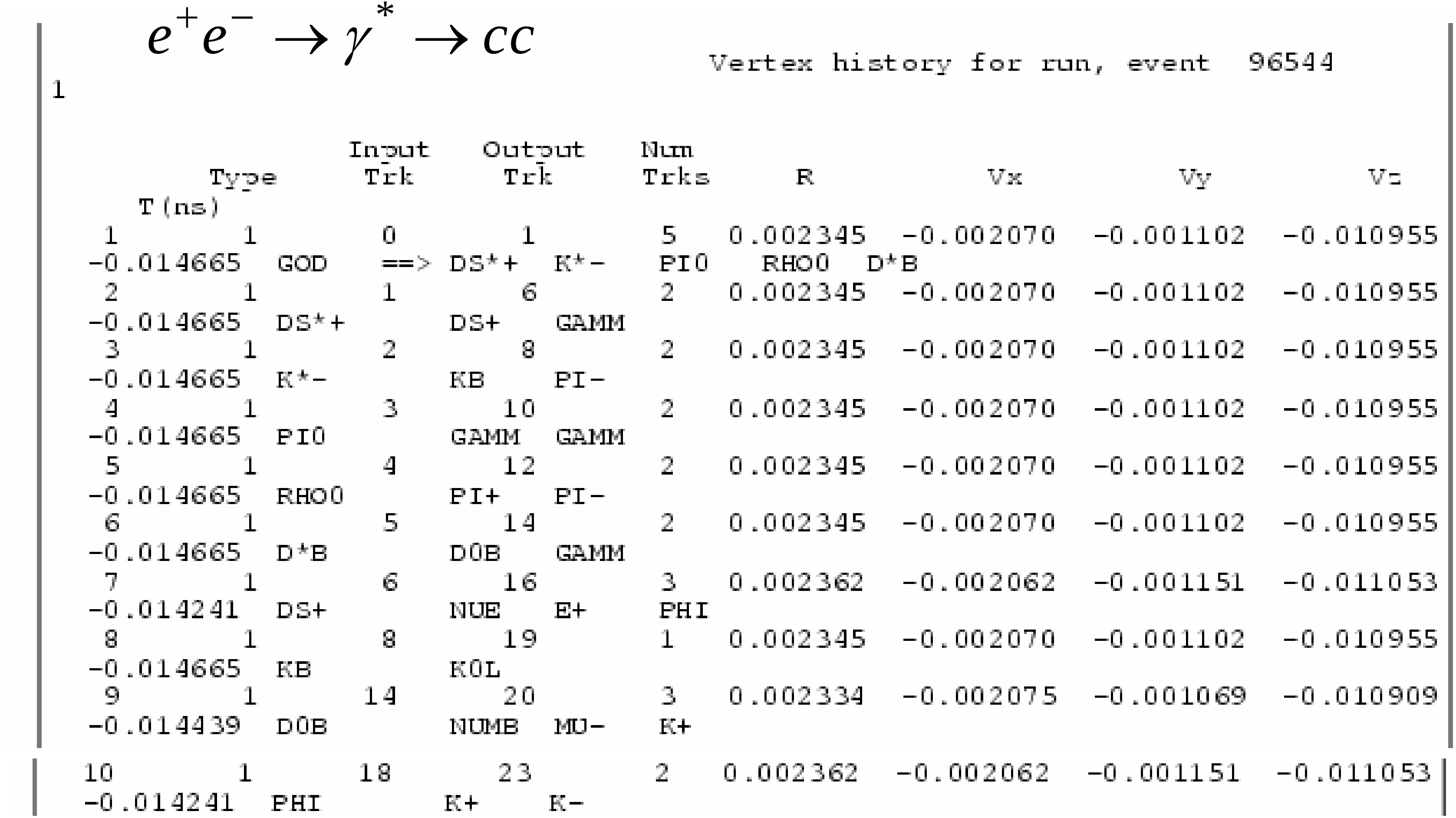
Some Branching Fractions in Event Generator



```
;
DECAY   B-
;                                          b --> c  (1 nu)
;                                          Sum = 23.8%
;                                             D X l    nu      10.15% * 2
;                                             D X tau nu        2.7%
;                                             baryon X l  nu    0.5% * 2
;
;                                             D l nu     = 2.0% * 2
;                                             D* l nu    = 5.4% * 2
;                                             D** l nu   = 1.45% * 2
;                                             Non-Res.   = 1.2% * 2
;
;                                    D* angular dist = 1 + 1.25*COS**2
CHANNEL 91 0.0540 D*0  E-   NUEB
;
CHANNEL 91 0.0200 D0  E-   NUEB
;
CHANNEL 91 0.0011 3P00  E-   NUEB
CHANNEL 91 0.0011 3P10  E-   NUEB
CHANNEL 91 0.0066 1P10  E-   NUEB
CHANNEL 91 0.0033 3P20  E-   NUEB
CHANNEL 91 0.0002 D21S00 E-  NUEB
CHANNEL 91 0.0022 D23S10 E-  NUEB
CHANNEL 91 0.0017 D0  PI0  E- NUEB
CHANNEL 91 0.0033 D+   PI-  E-  NUEB
CHANNEL 91 0.0023 D*0  PI0  E-  NUEB
CHANNEL 91 0.0047 D*+  PI-  E-  NUEB
;
CHANNEL 91 0.0540 D*0  MU-   NUMB
;
CHANNEL 91 0.0200 D0  MU-  NUMB
;
CHANNEL 91 0.0011 3P00  MU-  NUMB
CHANNEL 91 0.0011 3P10  MU-  NUMB
CHANNEL 91 0.0066 1P10  MU-  NUMB
CHANNEL 91 0.0033 3P20  MU-  NUMB
CHANNEL 91 0.0002 D21S00 MU-  NUMB
CHANNEL 91 0.0022 D23S10 MU-  NUMB
CHANNEL 91 0.0017 D0    PI0  MU-  NUMB
CHANNEL 91 0.0033 D+     PI-  MU-  NUMB
CHANNEL 91 0.0023 D*0    PI0  MU-  NUMB
CHANNEL 91 0.0047 D*+    PI-  MU-  NUMB
```

Another event from Event Generator

$$e^+e^- \rightarrow \gamma^* \rightarrow c\bar{c}$$

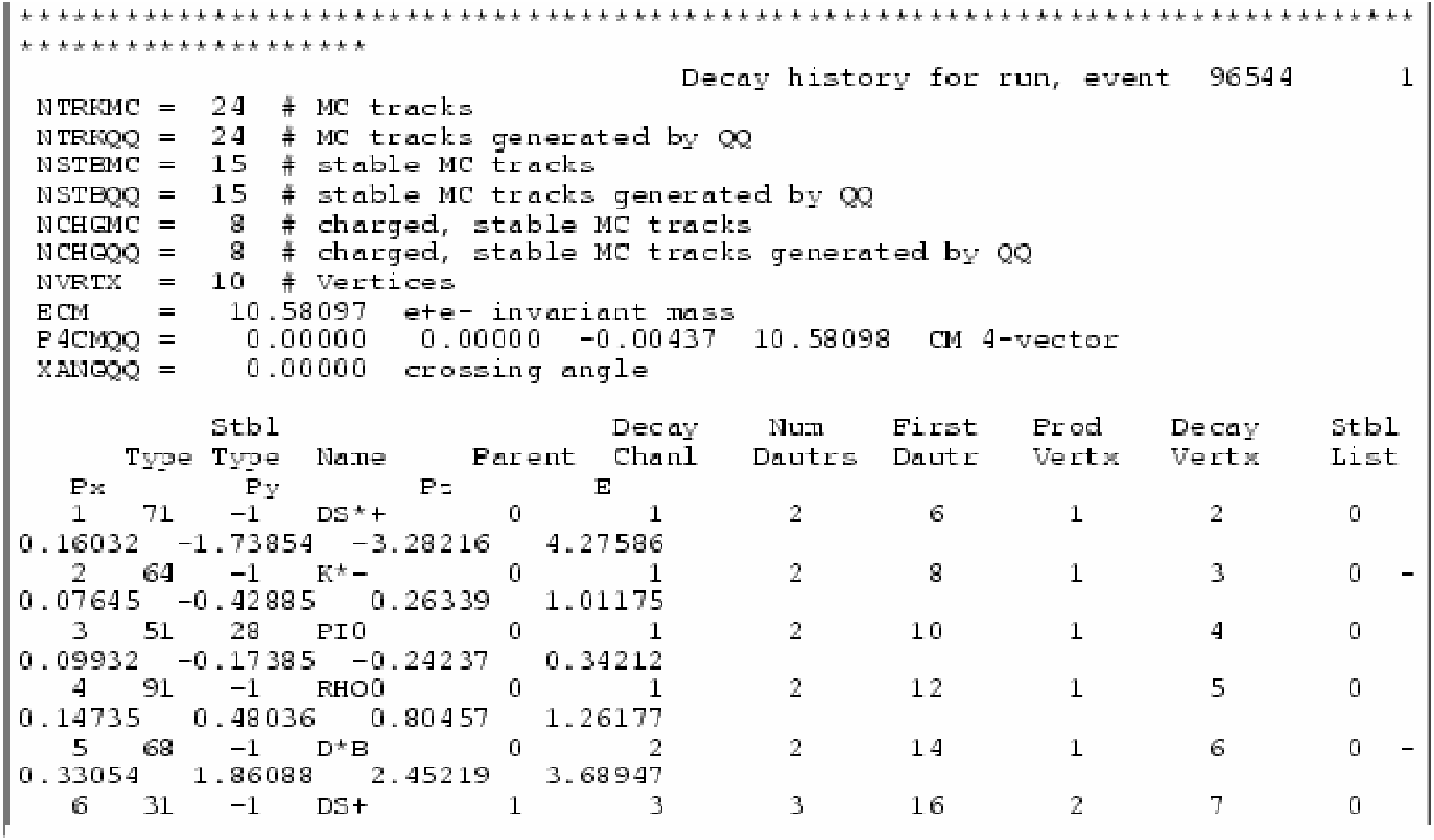


```
                                    Vertex history for run, event   96544
1

             Type         Input    Output    Num
                           Trk      Trk      Trks      R            Vx            Vy            Vz
    T(ns)
  1          1          0        1        5    0.002345   -0.002070   -0.001102   -0.010955
 -0.014665   GOD        ==> DS*+    K*-      PI0    RHO0    D*B
  2          1          1        6        2    0.002345   -0.002070   -0.001102   -0.010955
 -0.014665   DS*+           DS+     GAMM
  3          1          2        8        2    0.002345   -0.002070   -0.001102   -0.010955
 -0.014665   K*-            KB      PI-
  4          1          3       10        2    0.002345   -0.002070   -0.001102   -0.010955
 -0.014665   PI0            GAMM    GAMM
  5          1          4       12        2    0.002345   -0.002070   -0.001102   -0.010955
 -0.014665   RHO0           PI+     PI-
  6          1          5       14        2    0.002345   -0.002070   -0.001102   -0.010955
 -0.014665   D*B            D0B     GAMM
  7          1          6       16        3    0.002362   -0.002062   -0.001151   -0.011053
 -0.014241   DS+            NUE     E+       PHI
  8          1          8       19        1    0.002345   -0.002070   -0.001102   -0.010955
 -0.014665   KB             K0L
  9          1         14       20        3    0.002334   -0.002075   -0.001069   -0.010909
 -0.014439   D0B            NUMB    MU-      K+

 10          1         18       23        2    0.002362   -0.002062   -0.001151   -0.011053
 -0.014241   PHI            K+      K-
```

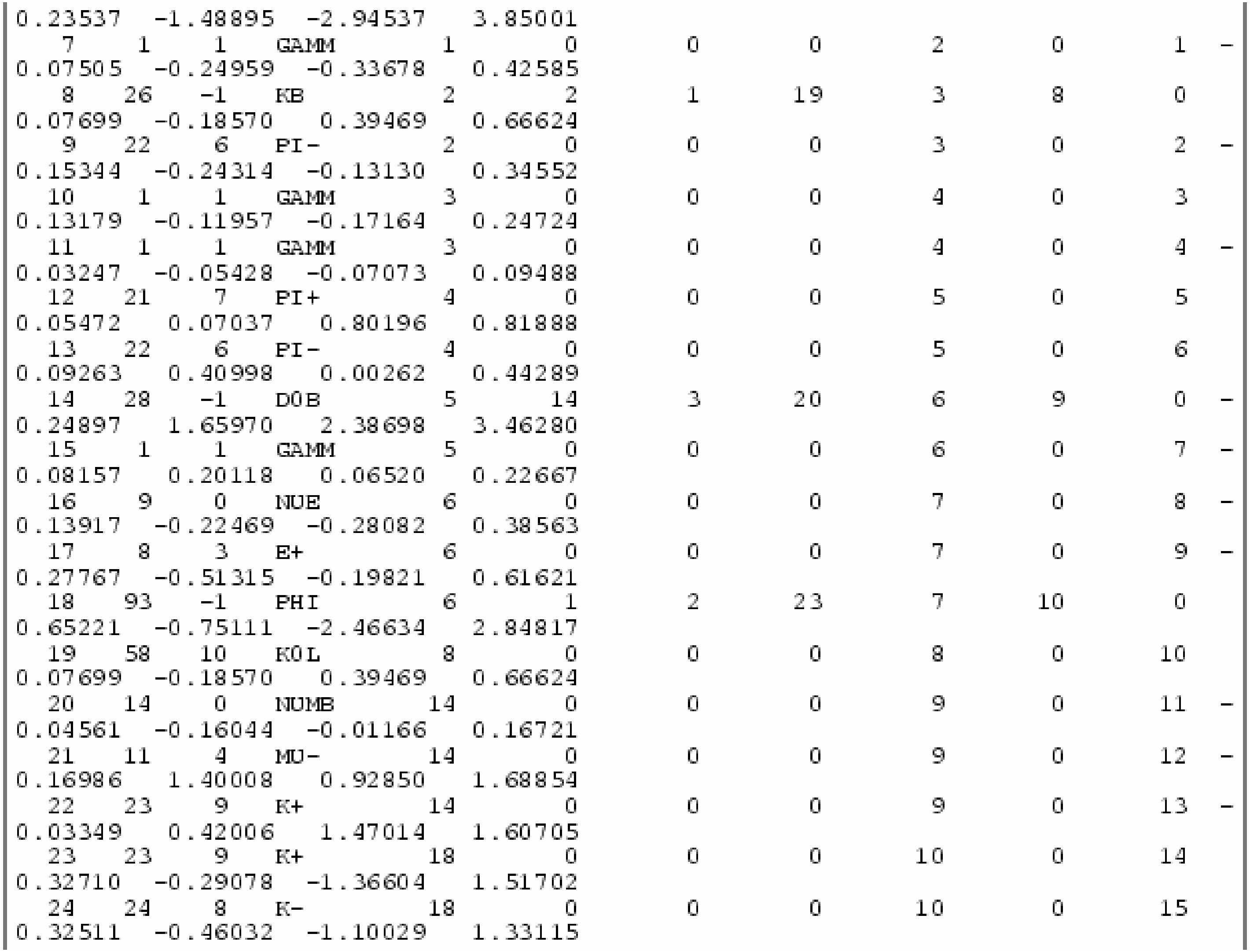
Another event from Event Generator cont’ed



```
****************************************************************************
*******************
                                    Decay history for run, event  96544      1
 NTRKMC =  24  # MC tracks
 NTRKQQ =  24  # MC tracks generated by QQ
 NSTBMC =  15  # stable MC tracks
 NSTBQQ =  15  # stable MC tracks generated by QQ
 NCHGMC =   8  # charged, stable MC tracks
 NCHGQQ =   8  # charged, stable MC tracks generated by QQ
 NVRTX  =  10  # Vertices
 ECM    =   10.58097  e+e- invariant mass
 P4CMQQ =    0.00000    0.00000   -0.00437   10.58098   CM 4-vector
 XANGQQ =    0.00000  crossing angle

          Stbl                  Decay    Num    First   Prod    Decay    Stbl
     Type Type  Name     Parent Chanl   Dautrs  Dautr   Vertx   Vertx    List
   Px         Py         Pz         E
   1   71   -1   DS*+        0       1       2       6      1       2       0
0.16032  -1.73854  -3.28216   4.27586
   2   64   -1   K*-         0       1       2       8      1       3       0  -
0.07645  -0.42885   0.26339   1.01175
   3   51   28   PI0         0       1       2      10      1       4       0
0.09932  -0.17385  -0.24237   0.34212
   4   91   -1   RHO0        0       1       2      12      1       5       0
0.14735   0.48036   0.80457   1.26177
   5   68   -1   D*B         0       2       2      14      1       6       0  -
0.33054   1.86088   2.45219   3.68947
   6   31   -1   DS+         1       3       3      16      2       7       0
```

Another event from Event Generator cont'd



```
0.23537  -1.48895  -2.94537   3.85001
   7      1     1     GAMM         1        0        0        0        2        0        1   -
0.07505  -0.24959  -0.33678   0.42585
   8     26    -1     KB           2        2        1       19        3        8        0
0.07699  -0.18570   0.39469   0.66624
   9     22     6     PI-          2        0        0        0        3        0        2   -
0.15344  -0.24314  -0.13130   0.34552
  10      1     1     GAMM         3        0        0        0        4        0        3
0.13179  -0.11957  -0.17164   0.24724
  11      1     1     GAMM         3        0        0        0        4        0        4   -
0.03247  -0.05428  -0.07073   0.09488
  12     21     7     PI+          4        0        0        0        5        0        5
0.05472   0.07037   0.80196   0.81888
  13     22     6     PI-          4        0        0        0        5        0        6
0.09263   0.40998   0.00262   0.44289
  14     28    -1     D0B          5       14        3       20        6        9        0   -
0.24897   1.65970   2.38698   3.46280
  15      1     1     GAMM         5        0        0        0        6        0        7   -
0.08157   0.20118   0.06520   0.22667
  16      9     0     NUE          6        0        0        0        7        0        8   -
0.13917  -0.22469  -0.28082   0.38563
  17      8     3     E+           6        0        0        0        7        0        9   -
0.27767  -0.51315  -0.19821   0.61621
  18     93    -1     PHI          6        1        2       23        7       10        0
0.65221  -0.75111  -2.46634   2.84817
  19     58    10     K0L          8        0        0        0        8        0       10
0.07699  -0.18570   0.39469   0.66624
  20     14     0     NUMB        14        0        0        0        9        0       11   -
0.04561  -0.16044  -0.01166   0.16721
  21     11     4     MU-         14        0        0        0        9        0       12   -
0.16986   1.40008   0.92850   1.68854
  22     23     9     K+          14        0        0        0        9        0       13   -
0.03349   0.42006   1.47014   1.60705
  23     23     9     K+          18        0        0        0       10        0       14
0.32710  -0.29078  -1.36604   1.51702
  24     24     8     K-          18        0        0        0       10        0       15
0.32511  -0.46032  -1.10029   1.33115
```

What is an Event Generator?

Event Generator generates events according to input distributions (BF, Kinematics, spin, theoretical prediction, etc.)

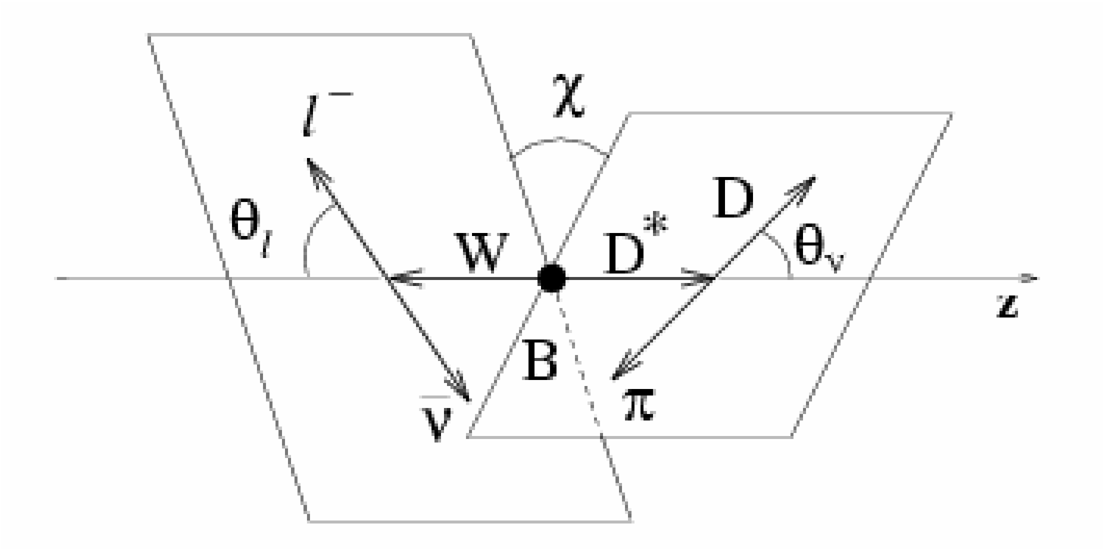
-> Distributions involved
-> Monte Carlo

What kind of distributions?

Differential Decay Rate of B -> D* l v

B : Pseudoscalar (spin 0) initial state Meson

D* : Vector (spin 1) final state Meson



Differential Decay Rate of B -> D* l v

$$\frac{d\Gamma(P\to V\ell\nu,\ V\to P_1P_2)}{dq^2\,d\cos\theta_V\,d\cos\theta_\ell\,d\chi}=\frac{3}{8(4\pi)^4}G_F^2|V_{q'Q}|^2\frac{p_V q^2}{M^2}\mathcal{B}(V\to P_1P_2)$$
$$\times\{(1-\eta\cos\theta_\ell)^2\sin^2\theta_V|H_+(q^2)|^2$$
$$+(1+\eta\cos\theta_\ell)^2\sin^2\theta_V|H_-(q^2)|^2$$
$$+4\sin^2\theta_\ell\cos^2\theta_V|H_0(q^2)|^2$$
$$-4\eta\sin\theta_\ell(1-\eta\cos\theta_\ell)\sin\theta_V\cos\theta_V\cos\chi\,H_+(q^2)H_0(q^2)$$
$$+4\eta\sin\theta_\ell(1+\eta\cos\theta_\ell)\sin\theta_V\cos\theta_V\cos\chi\,H_-(q^2)H_0(q^2)$$
$$-2\sin^2\theta_\ell\sin^2\theta_V\cos2\chi\,H_+(q^2)H_-(q^2)\}.$$

$\eta = +1$

Theoretical inputs

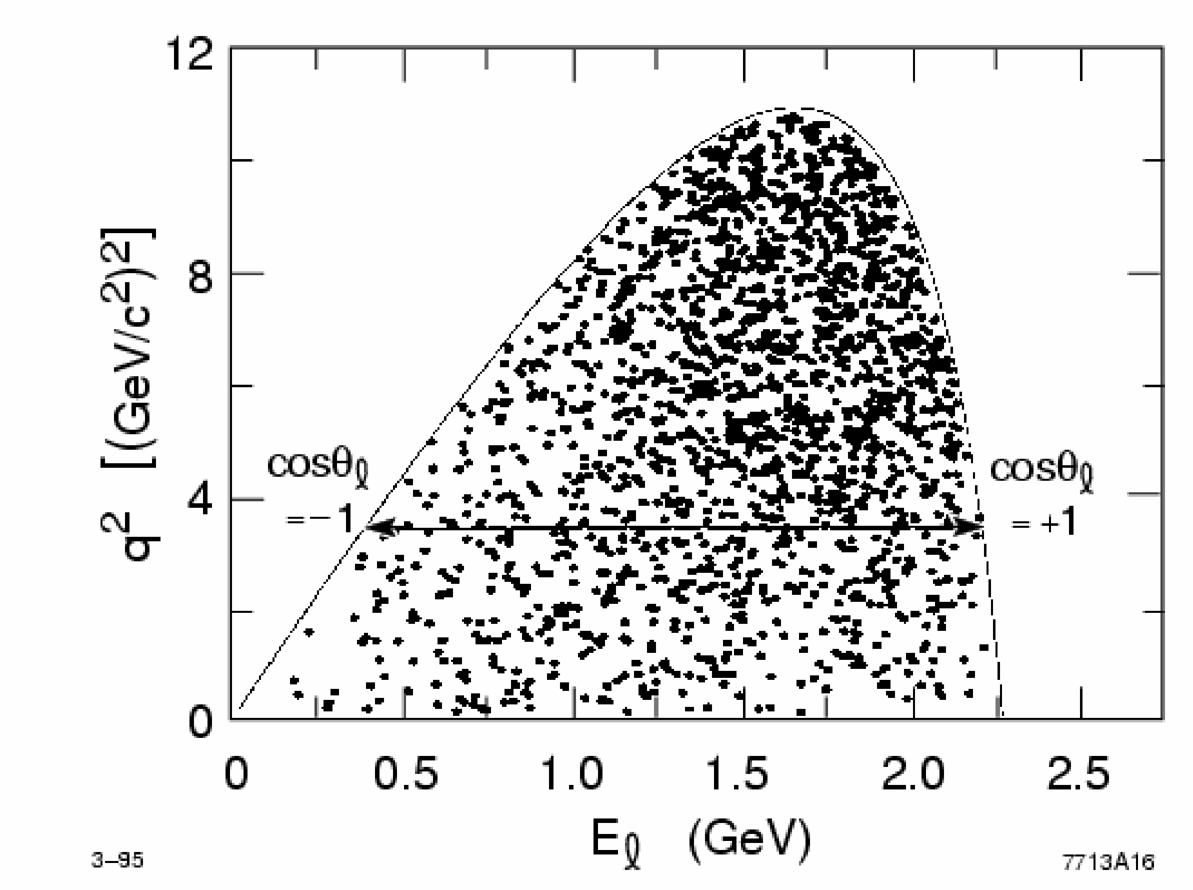
H+(q2) , H-(q2) , H0(q2)

: Form Factors in helicity basis

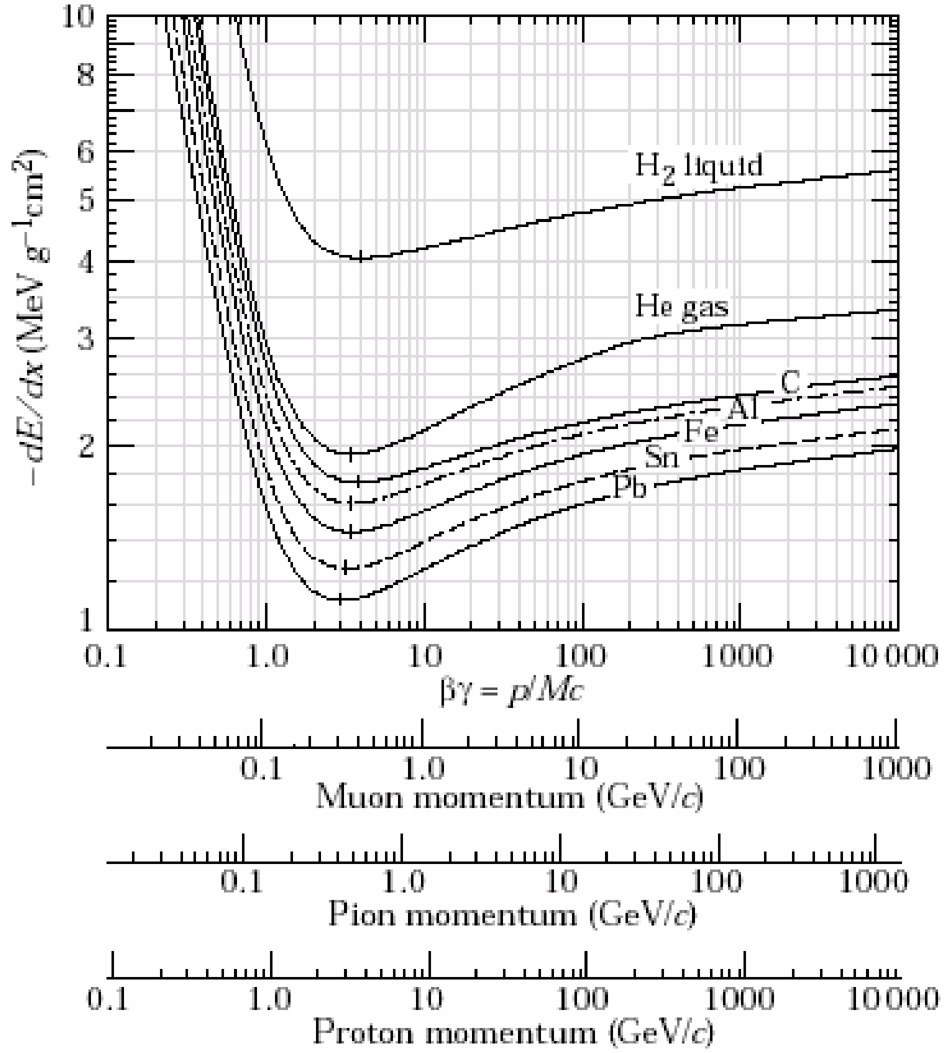
Dalitz Plot for B -> D* l v

$\bar{B} \to D^* \ell^- \bar{\nu}$

MC

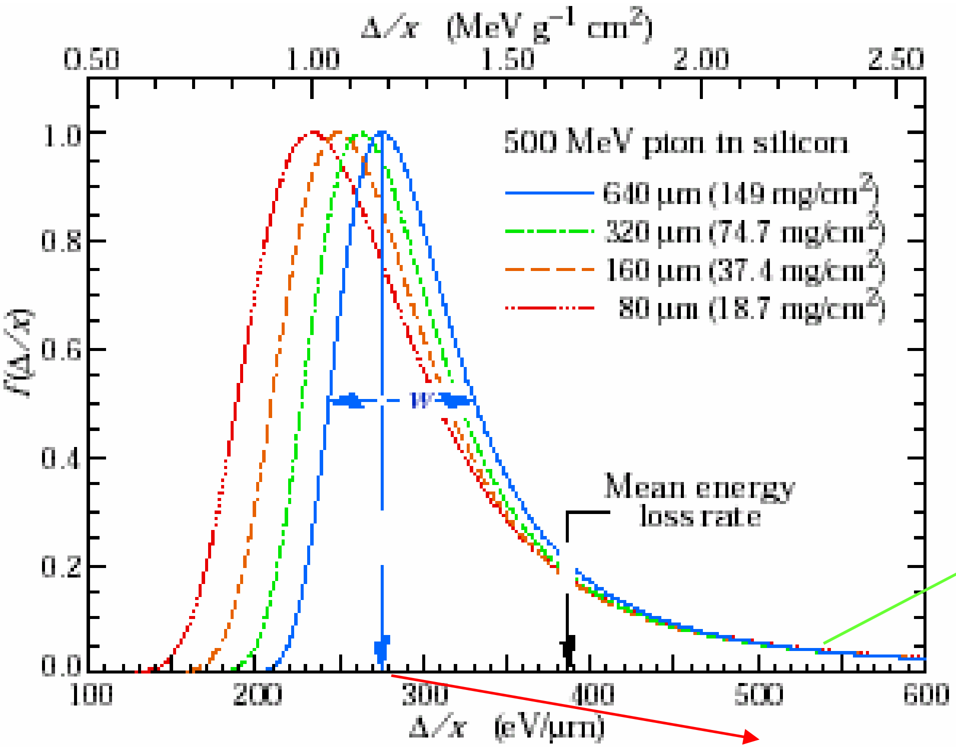


dE/dx of μ,π,proton in several materials



dE/dx is of random nature

Probability density Function ~ Landau Function plus some broadening



Due to δ rays: Knock-on electron

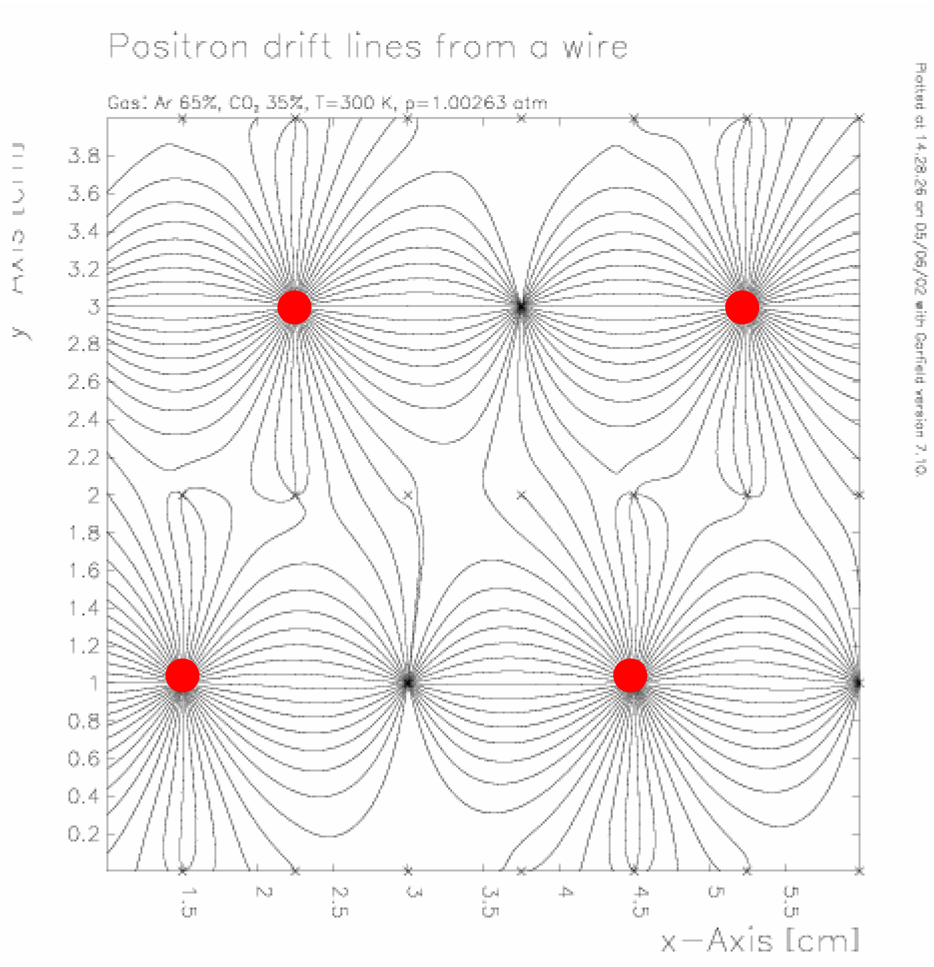
Most probable dE/dx

Landau function

$$f_L(\lambda) = 1/\pi \int_0^\infty du \quad \exp[-u(\ln u + \lambda)] \sin \pi u$$

Drift Chamber Simulation

MC

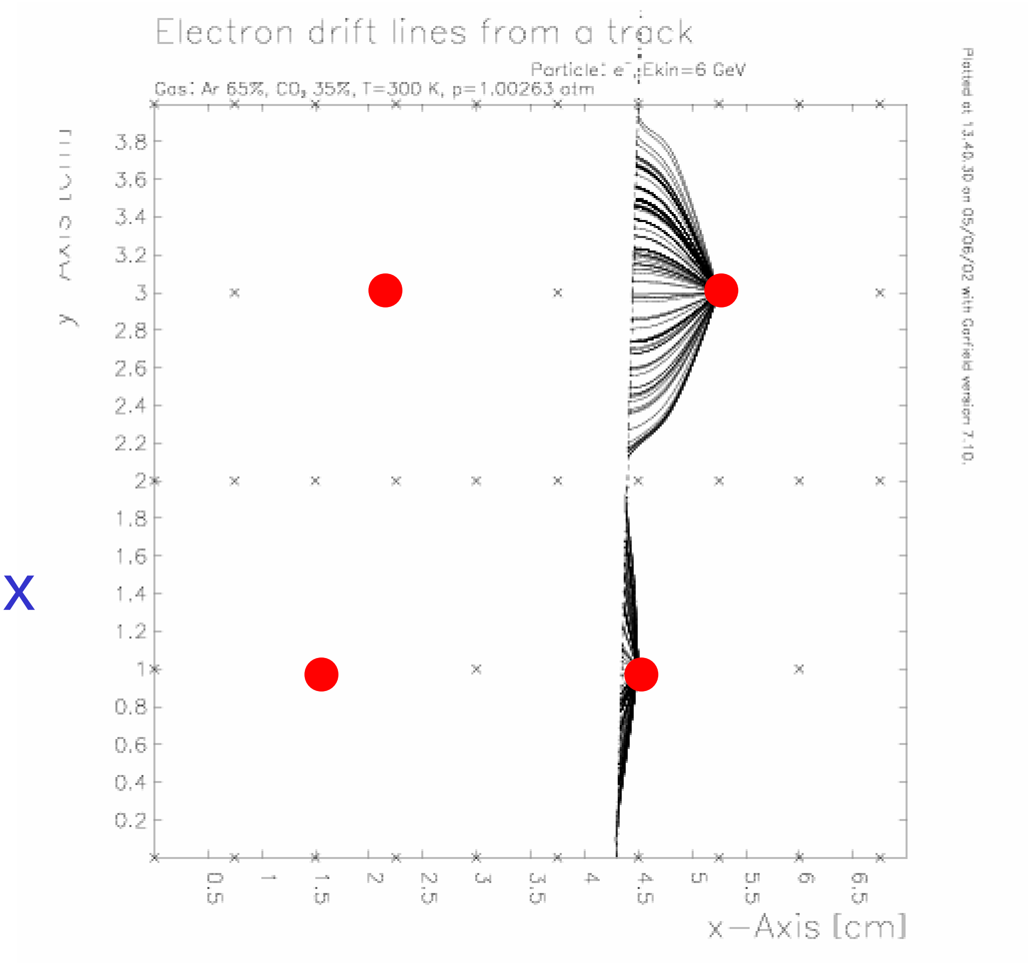


GARFIELD
Software

● Sense Wires
At + High Voltage

Drift Chamber Simulation

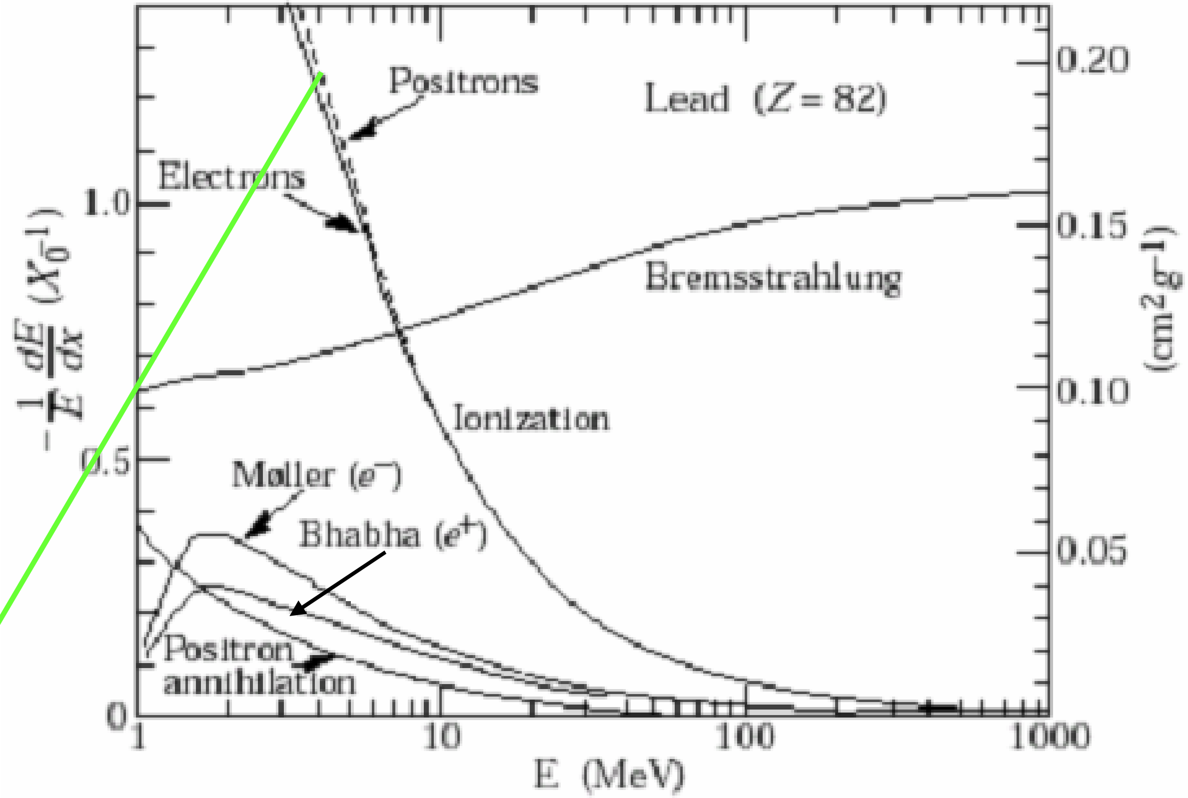
MC



Collect charges
on sense wires
-> Measure dE/dx

Energy loss by electrons (and positrons)

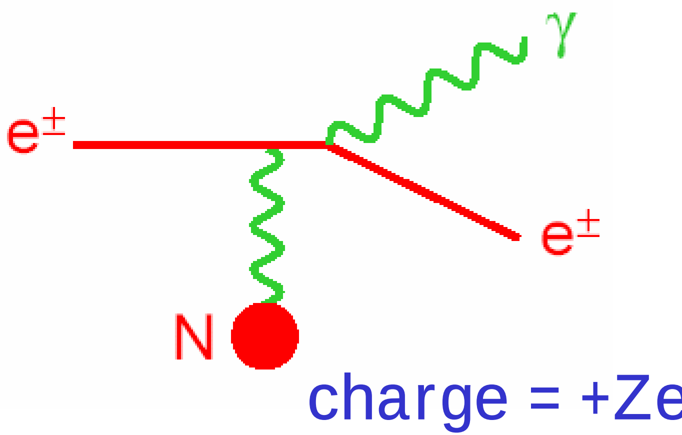
Fractional energy loss per radiation length



onization energy loss summed for distant + close collisions : n close collisions, electrons in the target are free. Shown re the contribution from close collisions (Moller for e-, habha for e+).

Energy loss by electrons (and positrons)

Energy loss by Bremsstrahlung (radiation due to Coulomb interaction with nuclei)



$$dE/E = -dx/X_0$$

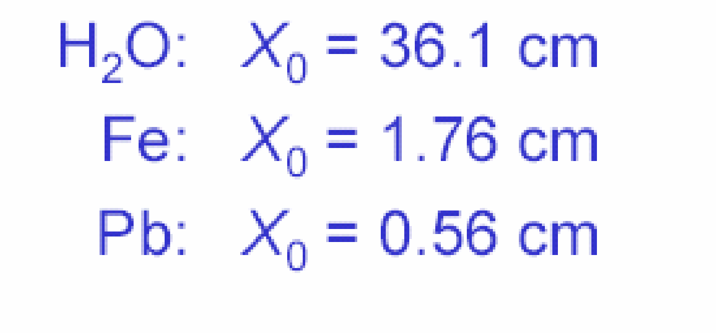
$$<E> \;=\; E_0 \exp(-X/X_0)$$

X0 : Radiation Length

The thickness of target matter traveled by an electron that reduces the electron average energy by the factor of e.

Energy loss by electrons (and positrons)

Some values of radiation length :



H_2O: $X_0 = 36.1$ cm

Fe: $X_0 = 1.76$ cm

Pb: $X_0 = 0.56$ cm

Energy loss by electrons (and positrons)

$$R = (dE/dx)_{Brem} / (dE/dx)_{ion} \sim ZE/580MeV$$

Critical Energy at R=1

Two examples of Ec approximations :
Ec ~ 580MeV/Z (=580/82=7.1MeV for lead)
~ 800MeV/(Z+1.2)

For E > Ec, electrons lose energy mainly by bremsstrahlung.

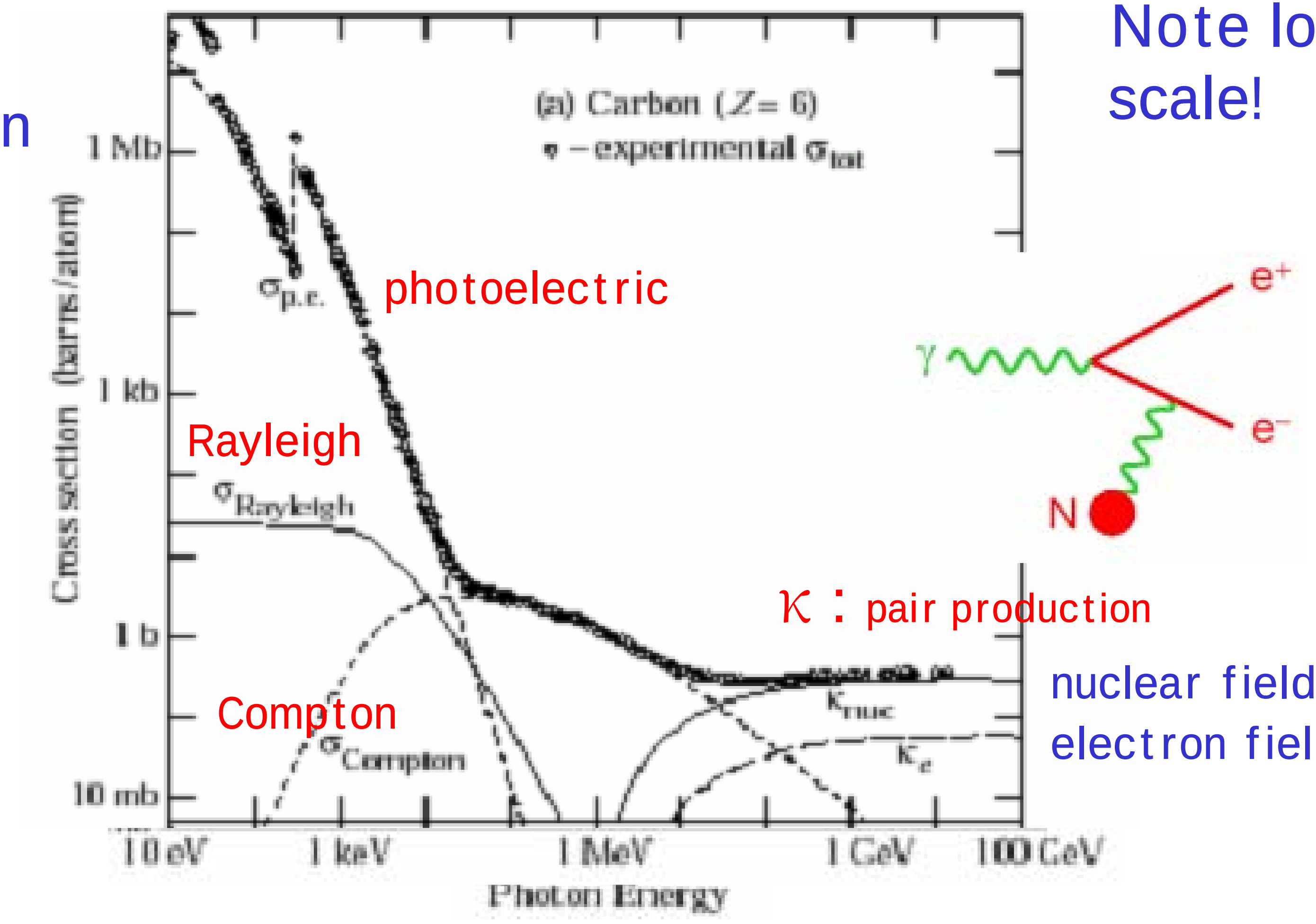
For heavier charge particles of mass M, this bremsstrahlung loss is suppressed by $(m_e/M)^2$

Energy loss by photons

Photon cross section

Carbon
(Z=6)

Note log-log
scale!



photoelectric

Rayleigh

Compton

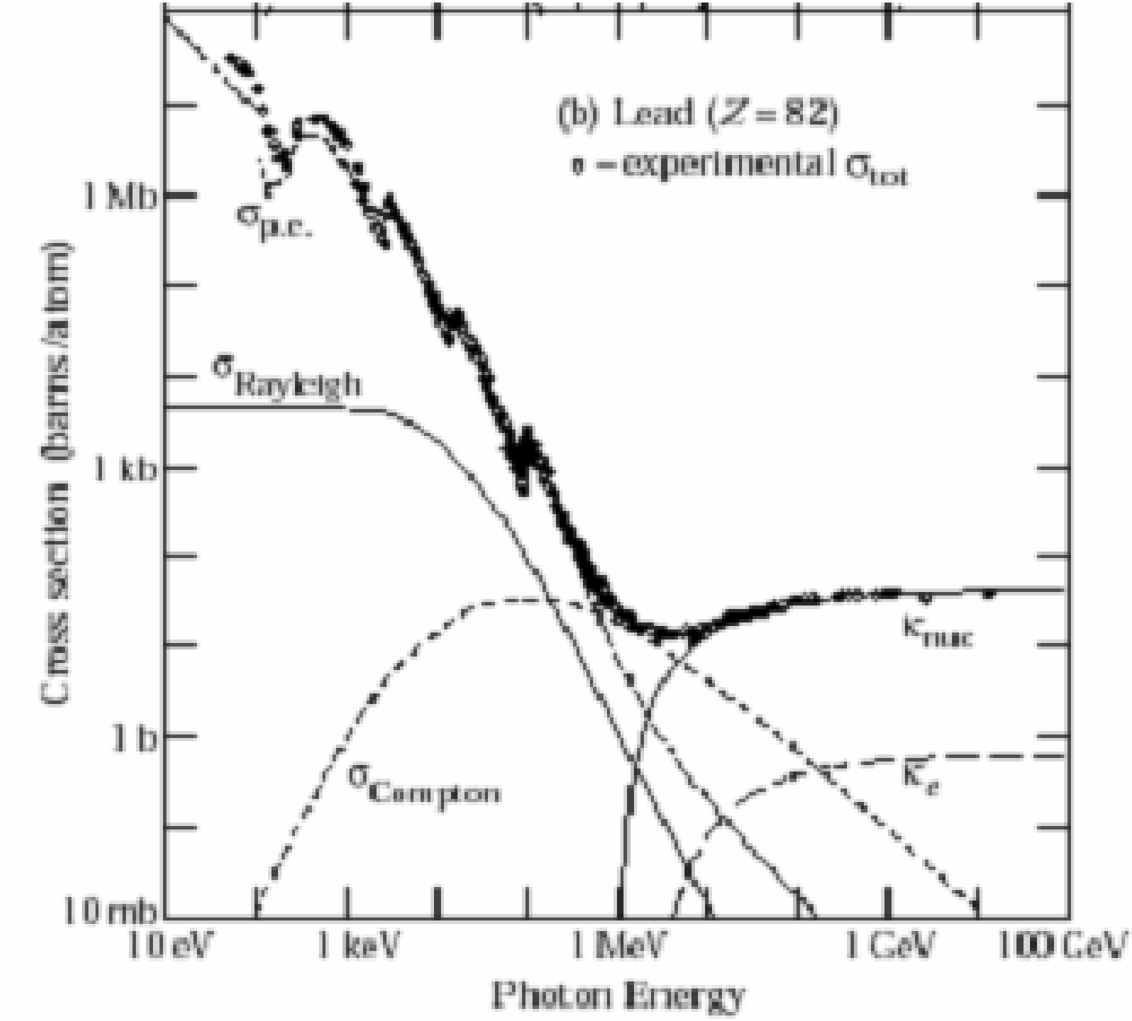
κ : pair production

nuclear field

electron field

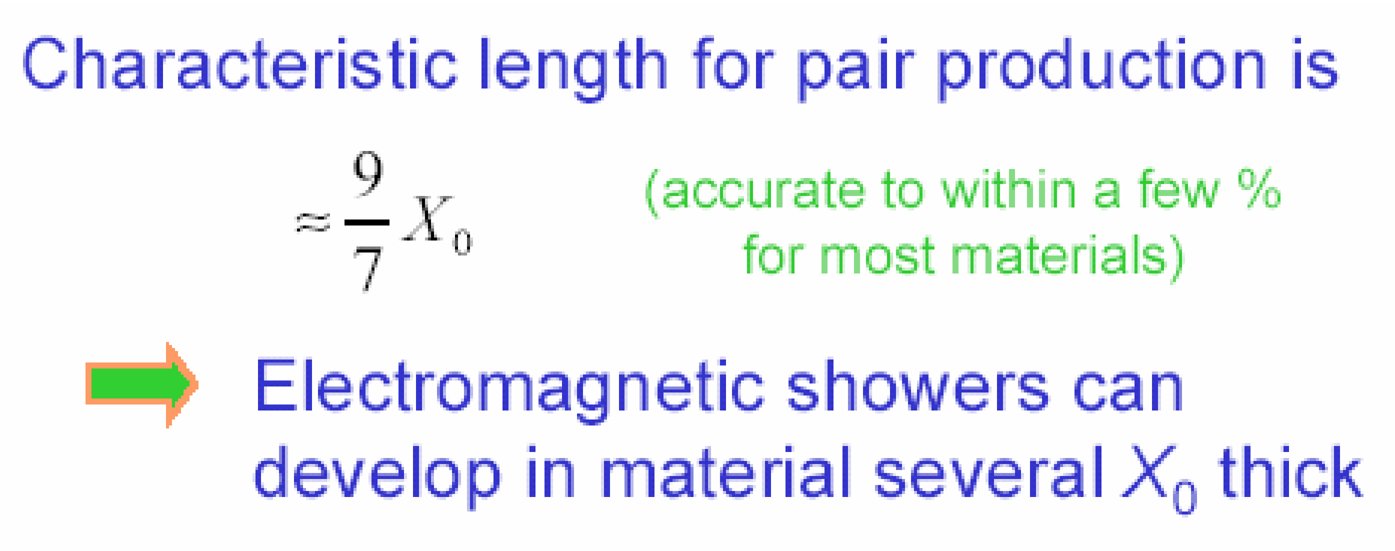
Energy loss by photons

Lead (Z=82)



Note log-lo
scale!

Energy loss by photons



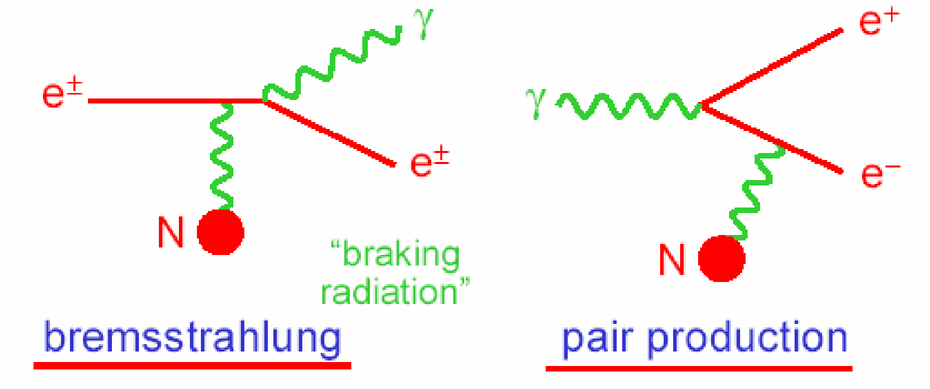
Characteristic length for pair production is

$$\approx \frac{9}{7} X_0$$

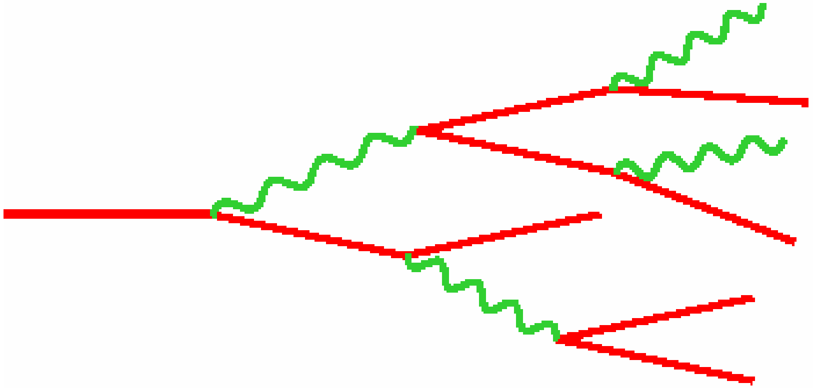
(accurate to within a few % for most materials)

⇒ Electromagnetic showers can develop in material several X_0 thick

Electromagnetic Showers



A combination of these two processes builds up an electromagnetic shower:

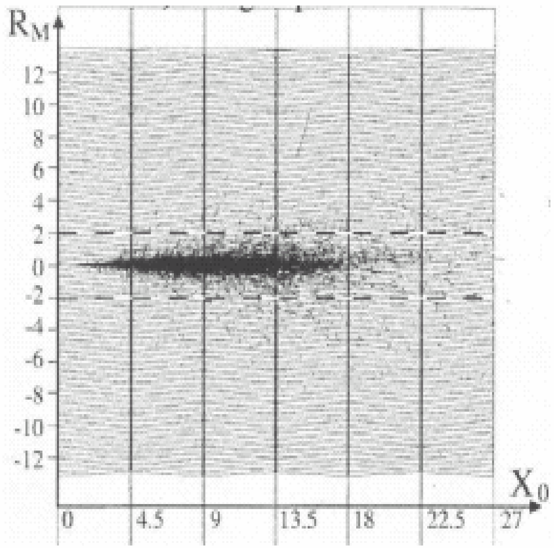


mixture of e^{+}, e^{-}, γ

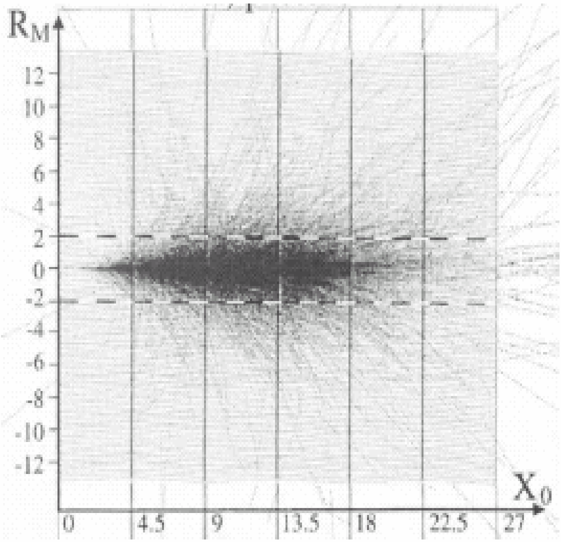
Electromagnetic Showers

MC

charged particle ($e^{\pm}$) component of shower :



neutral particle (γ) component of shower :



Simulation of a 100 GeV e^- incident on a liquid krypton EM calorimeter :

Electromagnetic Showers

MC

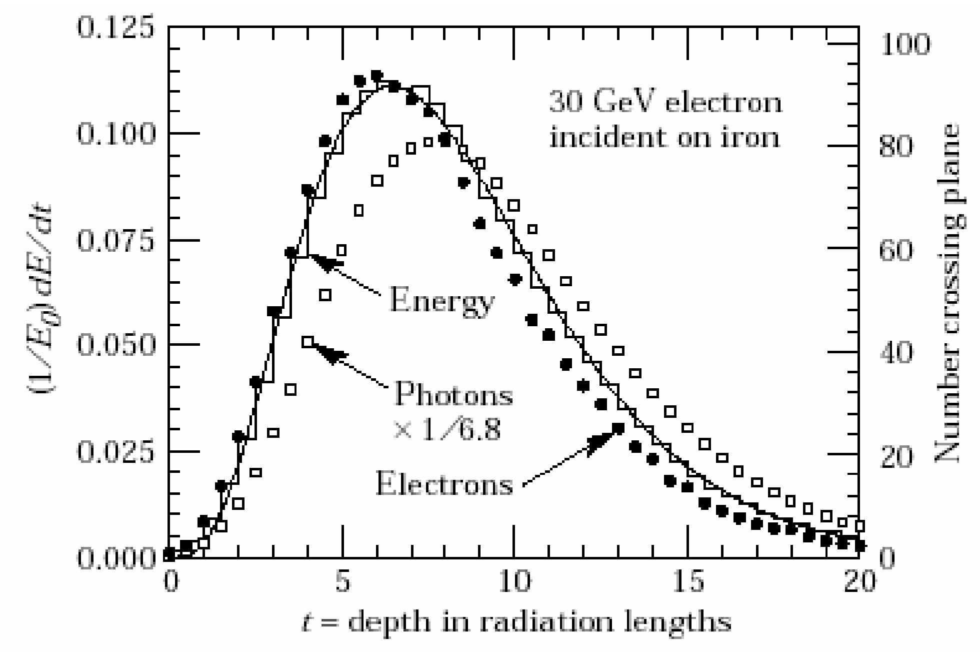
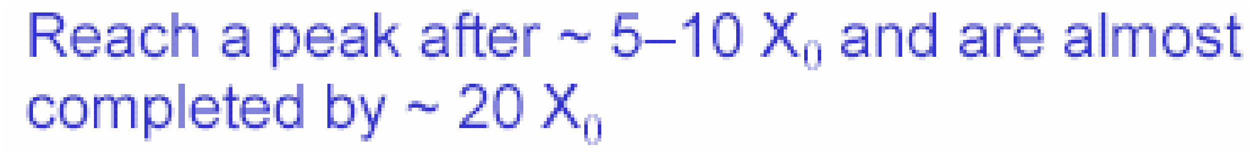


Figure 26.17: An EGS4 simulation of a 30 GeV electron-induced cascade in iron. The histogram shows fractional energy deposition per radiation length, and the curve is a gamma-function fit to the distribution. Circles indicate the number of electrons with total energy greater than 1.5 MeV crossing planes at $X_0/2$ intervals (scale on right) and the squares the number of photons with $E \geq 1.5$ MeV crossing the planes (scaled down to have same area as the electron distribution).

MC simulation of Electromagnetic Showers Says


Reach a peak after ~ 5–10 X_0 and are almost completed by ~ 20 X_0

$$X_0^{\max} = 3.9 + \ln E_0 \qquad (E_0 \; in \, GeV)$$

~3.9+3.4=7.3 X0 for E0 = 30GeV


Transverse size of shower (RM : Moliere radius)

$$R_M \sim X_0 E_s / E_c$$
$$(E_s \sim 21 MeV)$$

Electromagnetic Showers

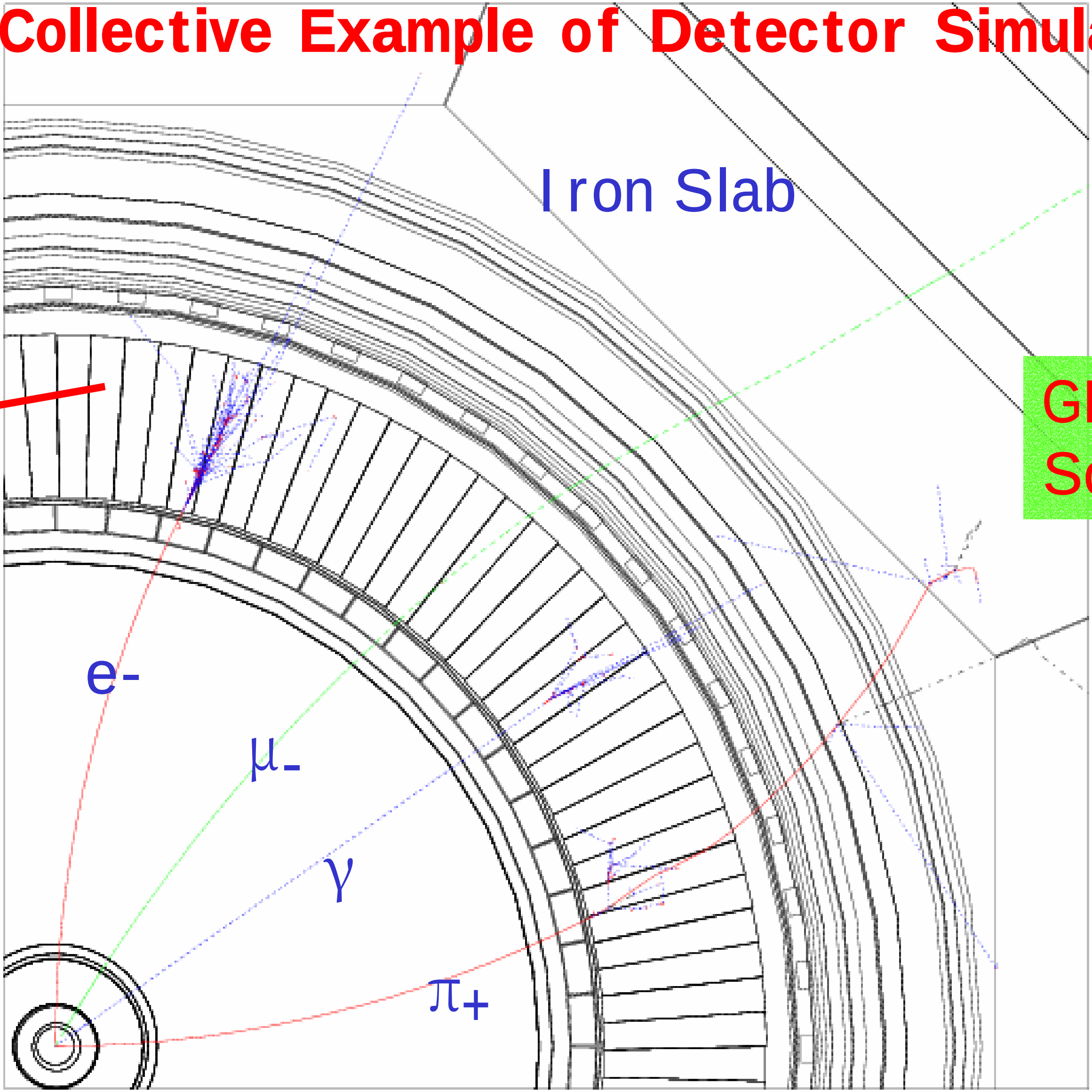
Towards end of shower

Once e+- in shower drop below critical energy Ec, ionization takes over and e+- stop rapidly.

For photons, Compton scattering and then photoelectric absorption take over.

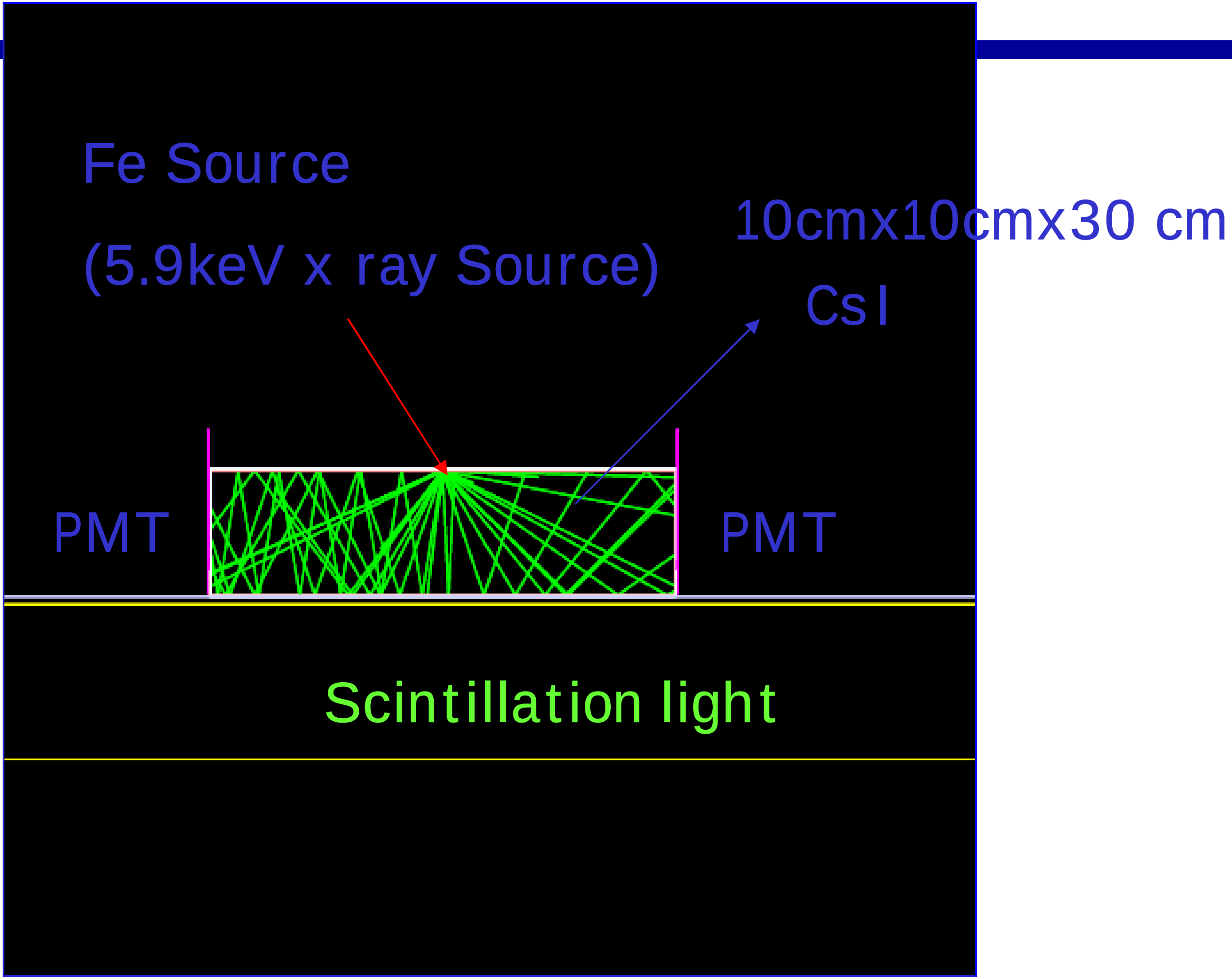
Energy of original incident particle is ultimately deposited mainly as ionization energy loss.

A Collective Example of Detector Simulation



sI crystal
alorimeter

GEANT
Software



Fe Source

(5.9keV x ray Source)

10cmx10cmx30 cm

CsI

PMT

PMT

Scintillation light

A Few Final Words (my presonal view on MC)

Never ever trust any MC simulations 100%.

For your data analysis, keep use of any MC as small as possible.

Please pay attention to the next talk.

All-In never worked for me.