CARBON STORIES IN CALCIUM

mary.chin@cern.ch

1st FLUKA Advanced Course & Workshop
Ericeira 4-8 Oct 2010
ICODE 102 (PARTICLE DECAY)
PARENT: 13 (π⁺) 0.139569953 GeV decays at rest
DAUGHTERS: EACH 0.00411977619 GeV
$^3\text{He}$
Fluka incident beam properties:
Beam particle: HEAVYION Id: -2 (Fluka) 9999 (PDG) Charge: 6 Baryon n.: 12
Mass: 11.17 (GeV/c^2) Mean life: 1.0000E+18 (s) Weight: 1.000
Average beam momentum : 11.415723 (GeV/c)
Average beam kinetic energy: 4.800000 (GeV)
Momentum deviation at FWHM (rectangular): 0.0000000 (GeV/c)
Beam hit position : 0.00000000 0.00000000 0.00000000 cm
Beam direction cosines: 0.00000000 0.00000000 1.00000000
Beam spot FWHM X-width (Rectangular ): 0.0000 cm
Beam spot FWHM Y-width (Rectangular ): 0.0000 cm
Beam FWHM angular divergence (Isotropic ): ********* (mrad)
(Spatial distribution, polarization, and angular direction and distribution
are given in the beam frame of reference)
Beam reference frame (world coordinates):
Beam X axis: 1.00000000 0.00000000 0.00000000
Beam Y axis: 0.00000000 1.00000000 0.00000000
Beam Z axis: 0.00000000 0.00000000 1.00000000
The nominal beam position belongs to region: 3(RSEA ), lattice cell: 00

Heavy ion beam requested, properties:
Mass number of the projectile: 12
Charge number of the projectile: 6
Isomer number of the projectile: 0
Laboratory momentum of the projectile : 0.9513 (GeV/c/amu)
Laboratory kin. energy of the projectile: 0.4000 (GeV/amu)
Laboratory tot. energy of the projectile: 1.331 (GeV/amu)

**COLLISION TAPE**
Source particle(s), n. of: 1
Part.id.: -30 Tot.en.: 15.9748669 Weight: 1.
Position : 0. 0. 0.

400 MeV/A
\(^{12}\text{C}\) source
starts here
SO MANY NEUTRONS
where do they come from?

<table>
<thead>
<tr>
<th>count</th>
<th>icode</th>
<th>parent</th>
<th>siblings</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>101</td>
<td>$^{12}\text{C} + ^{40}\text{Ca}$</td>
<td>$^{24}\text{Mg} + ^{4}\text{He} + ^{2}\text{H} + ^{9}\text{p} + ^{13}\text{n} + 2\pi^+ + 2\gamma$</td>
</tr>
<tr>
<td>5</td>
<td>101</td>
<td>p</td>
<td>n+p</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>n+3p+3\gamma</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>n+3p</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2n+2p+\gamma</td>
</tr>
<tr>
<td>3</td>
<td>101</td>
<td>\pi^-</td>
<td>p+3n+4\gamma</td>
</tr>
<tr>
<td>103</td>
<td>101</td>
<td>n</td>
<td>2 to 12 siblings</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>many $x_1n+x_2p+x_3\gamma$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2p+4n+2\gamma+^2\text{H}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3n+3p+2\gamma+\pi+^2\text{H}+^3\text{He}+2\alpha</td>
</tr>
<tr>
<td>3998</td>
<td>100, 101 or 300</td>
<td>n</td>
<td>solo</td>
</tr>
</tbody>
</table>
instead of the usual $N_p, K_{part}, T_{ki}$

IF (ICODE.EQ.101 .AND. JTRACK.EQ.-2 .AND. npheav.GT.0) THEN
  DO I=1,npheav
    WRITE(IODRAW) NCASE,SNGL(ETRACK),SNGL(PTRACK), npheav, kheavy(I), ibheav(kheavy(I)), icheav(kheavy(I)), SNGL(tkheav(I)), SNGL(pheavy(I))
  END DO
END IF

<table>
<thead>
<tr>
<th>count</th>
<th>icode</th>
<th>parent</th>
<th>siblings</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>101</td>
<td>$^{12}\text{C} + ^{40}\text{Ca}$</td>
<td>$^{24}\text{Mg} + ^{4}\text{He} + ^{2}\text{H} + ^{9}\text{p} + 13n + 2\pi^+ + 2\gamma$</td>
</tr>
<tr>
<td>5</td>
<td>101</td>
<td>$p$</td>
<td>n+p&lt;n+3p+3\gamma &lt;n+3p &lt;2n+2p+\gamma</td>
</tr>
<tr>
<td>3</td>
<td>101</td>
<td>$\pi^-$</td>
<td>p+3n+4\gamma</td>
</tr>
<tr>
<td>103</td>
<td>101</td>
<td>$n$</td>
<td>2 to 9 siblings&lt;br&gt;many $x_1n + x_2p + x_3\gamma$&lt;br&gt;2p+4n+2\gamma+^{2}\text{H} &lt;br&gt;3n+3p+2\gamma+\pi^-+^{2}\text{H}$</td>
</tr>
<tr>
<td>3998</td>
<td>100, 101 or 300</td>
<td>$n$</td>
<td>solo</td>
</tr>
</tbody>
</table>
8 steps in 1.9292605e-10 s

Inelastic interaction

\[ {}^{12}_{6}C + {}^{40}_{20}Ca \rightarrow {}^{24}_{12}Mg + {}^{4}_{2}He + {}^{2}_{1}H + 9^{1}_{1}p + 13^{1}_{0}n + 2\pi^{+} + 2\gamma \]
\(^{12}_6\text{C} + ^{40}_2\text{Ca} \rightarrow ^{24}_{12}\text{Mg} + ^4_2\text{He} + ^2_1\text{H} + ^9_{1p} + 13_0^1n + 2\pi^+ + 2\gamma\)
PROTONS

<table>
<thead>
<tr>
<th>Tk ,(\text{GeV})</th>
<th>\text{next step}</th>
<th>\text{icode}</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.85969377e-01</td>
<td>( (p,2n+2p+\gamma) )</td>
<td>101</td>
</tr>
<tr>
<td>7.94009790e-02</td>
<td>( (p,n+3p) )</td>
<td>101</td>
</tr>
<tr>
<td>6.70373663e-02</td>
<td>10 steps to cutoff</td>
<td></td>
</tr>
<tr>
<td>3.00997659e-03</td>
<td>1 step to cutoff</td>
<td></td>
</tr>
<tr>
<td>2.87470937e-01</td>
<td>( (p,n+3p+3\gamma) )</td>
<td>101</td>
</tr>
<tr>
<td>1.83140948e-01</td>
<td>( (p,np) )</td>
<td>101</td>
</tr>
<tr>
<td>9.14871842e-02</td>
<td>11 steps to cutoff</td>
<td></td>
</tr>
<tr>
<td>1.23939060e-01</td>
<td>13 steps to cutoff</td>
<td></td>
</tr>
<tr>
<td>5.24589885e-03</td>
<td>1 step to cutoff</td>
<td></td>
</tr>
</tbody>
</table>

**CUTOFF (GeV)**

1.000000000e-02

\[ ^{12}_{6}C + ^{40}_{20}Ca \rightarrow ^{24}_{12}Mg + ^{4}_{2}He + ^{2}_{1}H + ^{9}_{1}p + 13^{1}_{0}n + 2\pi^{+} + 2\gamma \]
### 2nd generation of protons

<table>
<thead>
<tr>
<th>Tk$i$ (GeV)</th>
<th>fate</th>
<th>icode</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.85969377e-01</td>
<td>1 step to cutoff</td>
<td>101</td>
</tr>
<tr>
<td>7.94009790e-02</td>
<td>1 step to cutoff</td>
<td>101</td>
</tr>
<tr>
<td>6.70373663e-02</td>
<td>10 steps to cutoff</td>
<td></td>
</tr>
<tr>
<td>3.00997659e-03</td>
<td>1 step to cutoff</td>
<td></td>
</tr>
<tr>
<td>2.87470937e-01</td>
<td>(p,n+3p)</td>
<td>101</td>
</tr>
<tr>
<td>1.83140948e-01</td>
<td>(p,2n-2p+\gamma)</td>
<td>101</td>
</tr>
<tr>
<td>9.14888886e-01</td>
<td>6 steps to cutoff</td>
<td></td>
</tr>
<tr>
<td>3.61582404e-03</td>
<td>1 step to cutoff</td>
<td></td>
</tr>
<tr>
<td>1.02260048e-02</td>
<td>2 steps to cutoff</td>
<td></td>
</tr>
</tbody>
</table>

### CUTOFF (GeV)

1.00000000e-02
4.0526269e-03 GeV γ travels 2.3 cm

4.9829512e-4 γ travels 14 cm

pair production

positron annihilation at rest

Compton

END PRODUCTS

<table>
<thead>
<tr>
<th>END PRODUCTS</th>
<th>Tki (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHOTON</td>
<td>ELECTRON</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.64209894e-04</td>
</tr>
<tr>
<td>2.9550173e-04</td>
<td>2.15497887e-04</td>
</tr>
<tr>
<td>2.53742037e-04</td>
<td>2.57257023e-04</td>
</tr>
<tr>
<td>1.93167754e-04</td>
<td>3.05127382e-04</td>
</tr>
</tbody>
</table>

CUTOFFs

<table>
<thead>
<tr>
<th>CUTOFFs</th>
<th>Tki (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.33333333e-04</td>
</tr>
</tbody>
</table>

\[
\frac{^{12}_6\text{C} + ^{40}_{20}\text{Ca}} \rightarrow ^{24}_{12}\text{Mg} + ^{4}_2\text{He} + ^{2}_1\text{H} + ^{9}_1\text{p} + ^{13}_0\text{n} + 2\pi^+ + 2\gamma
\]
11 steps to ICODE 102
[particle decay]
Etrack=1.39569953e-01 GeV
decay at rest: ETRACK=m₀
age =6.70014799e-08 s
π⁺
4.62922305e-02 GeV

μ⁺ 4.11977619e-03 GeV
ν_μ 2.97917854e-02 GeV

12\,^6\,C + 40\,Ca \rightarrow 24\,^{24}_{12}\,Mg + 4\,^{4}_{2}\,He + ^2\,H + 9\,^1_{1}\,p + 13\,^1_{0}\,n + 2\pi^+ + 2\gamma
\[ \pi^+ \]

\[ 4.62922305 \times 10^{-2} \text{ GeV} \]

Number of decay products produced per beam particle:

Prompt radiation  |  Radioactive decays
--- | ---
1.2000E+01 (100.%)  |  0.0000E+00 (100.%)  
2.0000E+00 (16.7%)  |  0.0000E+00 ( 0.0%)  POSITRON
2.0000E+00 (16.7%)  |  0.0000E+00 ( 0.0%)  NEUTRIE
2.0000E+00 (16.7%)  |  0.0000E+00 ( 0.0%)  PHOTON
2.0000E+00 (16.7%)  |  0.0000E+00 ( 0.0%)  MUON+
2.0000E+00 (16.7%)  |  0.0000E+00 ( 0.0%)  NEUTRIM
2.0000E+00 (16.7%)  |  0.0000E+00 ( 0.0%)  ANEUTRIM
\[ \pi^+ \]

4.62922305e-02 GeV

Number of particles decayed per beam particle:

<table>
<thead>
<tr>
<th>Prompt radiation</th>
<th>Radioactive decays</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0000E+00 (100.%)</td>
<td>0.0000E+00 (100.%)</td>
</tr>
<tr>
<td>2.0000E+00 (40.0%)</td>
<td>0.0000E+00 (0.0%)</td>
</tr>
<tr>
<td>2.0000E+00 (40.0%)</td>
<td>0.0000E+00 (0.0%)</td>
</tr>
<tr>
<td>1.0000E+00 (20.0%)</td>
<td>0.0000E+00 (0.0%)</td>
</tr>
</tbody>
</table>

\( \gamma \rightarrow 2p + 2\pi^+ + 2\gamma \)
11 steps to icode 102
[particle decay]
ETRACK=1.39569953e-01 GeV
age =4.77300999e-9 s

π + 7.92727247e-02 GeV

positron bremsstrahlung followed by pair production

νμ 2.97917854e-02 GeV
μ + 4.11977619e-03 GeV

EM shower

12/6 C + 40 Ca → 24 Mg + 4/2 He + 2 H + 9 1 p + 13 0 n + 2π^+ + 2γ
11 steps to icode 102
[particle decay]
ETRACK=1.39569953e-01 GeV
age =4.77300999e-9 s

EXACTLY IDENTICAL TO THE OTHER $\pi^+$ because this is a decay at-rest
ETRACK=m_o
recoil, elastic | recoil, inelastic | local energy deposition | below threshold | target recoil

heavyIon, p, n, π- | e-, e+, γ

Counts:
- recoil, elastic: 41
- recoil, inelastic: 37
- local energy deposition: 2
- below threshold: 603
- target recoil: 4052

Counts for particles:
- heavyIon: 1
- p: 4
- n: 31
- π-: 1
- e-: 427
- e+: 13
- γ: 163
Dear Contributor,

we are happy to announce you that on the basis of the abstract you submitted we allocated a 30min slot for your presentation (including 8min of discussion) in the program of the workshop taking place along with the 1st FLUKA advanced course.

We would like to point out that special emphasis should be given to:
- the technical implementation of the simulation carried out;
- the evaluation of main sources of uncertainties;
- comparison with experimental outcome when available;
- possible open points for further discussion;

The presentation should be intended in a didactive style more than as a conference talk.

Looking forward seeing you in Portugal

The FLUKA course team
THIS HISTORY
(in no way representative)
IN THE CONTEXT OF
THE OTHER HISTORIES
the history in here

$^{12}\text{C}$ steps before absorption / collision