MCNPX Photo-pion Production from Graphite

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http://mcnpx.lanl.gov/documents.html
Outline

• What is MCNPX?

• Motivation

• Photo-pion production

• Pion decay & muon production

• Muonic x-rays

• Conclusions
What is MCNPX?

• Monte Carlo all-particle transport code
  – 34 different particle types + 2205 heavy ions
    • Neutrons, photons, electrons, protons, pions, muons, light-ions, etc.
  – Continuous energy (~0 -1 TeV/n)
  – Data libraries below ~150 MeV (n, p, e, h) & models otherwise

• General 3-D geometry
  – 1st & 2nd degree surfaces, tori, 10 macrobodies, lattices

• General sources and tallies
  – Interdependent source variables, 7 tally types, many modifiers

• Supported on virtually all computer platforms
  – Unix, Linux, Windows, OS X (parallel with MPI)
### MCNPX physics treatments

<table>
<thead>
<tr>
<th>Photons</th>
<th>Electrons &amp; Positrons</th>
<th>Muons</th>
<th>Neutrons</th>
<th>Protons</th>
<th>Photonuc.</th>
<th>Other Single charged</th>
<th>Light Ions</th>
<th>Heavy Ions</th>
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</table>

- **Evaluated Nuclear Data Tables or Models**
- **Models, primarily INC**
- **Mixing INC and Quantum models**
- **Quantum Models**
- **In progress or proposed**
Recent history of MCNPX

MCNPX Versions

- LAHET
- CEM
- INCL
- Cinder90
- LAQGSM

- 4A, 4B
- MCNP4C
- MCNP5

- 1995
- 2000
- 2005
- 2010
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Motivation

- Muon production & transport of interest to DHS
  - Passive interrogation for land-based systems
  - Active interrogation for other systems

- Muon production via two mechanisms
  - Pion decay
  - Pair production

- Questions of MCNPX’s photo-pion capabilities
  - Pion production (integral & differential)
  - Pion decay
  - Muon capture physics
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C-12 photo-pion production with x-s tallies

c cell cards
1 1 -2.1 -1 imp:p=1
2 0  1 imp:p=0

c surface cards
1 so 20

c physics cards
ml  6012 1
mode p h n / z
phys:p 3j 1 $ Turn on photonuclear
phys:n 610
lca 7j -2 1 $ First interaction only

c source cards
c wgt=10 to account for 10 source energies
sdef erg=d1 par=p vec=1 0 0 dir=1 wgt=10
sil L 180 200 250 300 350 400 450 500 550 600
spl 1 1 1 1 1 1 1 1 1 1

c control cards
print
nps 10e6
prdmp j 1e6

c tally cards
fc1 pion- prod. x-s (barns)
f1:/ 1
ft1 SCX 1
fm1 .1600 $ 0.32 barns/2 (pion- ~1/2)
c
fc11 pion- prod. angle ave. (barns/sr/MeV)
f11:/ 1
e11 0 99i 500
ft11 SCX 1
fm11 .0127 $ 0.32 barns/4pi/2

c
fc21 pion- prod. dbl-diff. (barns/sr/MeV)
f21:/ 1
e21 0 99i 500
c21 -0.9 8i 0.0 9i 1.0 $ 20 cosine bins
ft21 SCX 1 FRV 1 0 0
fm21 .2540 $ 0.32 barns*20/4pi/2
Integral cross sections

Photo-atomic

Photo-nuclear

Photo-pion
Angle-averaged double-differential cross sections

![Graph showing pion production cross sections at 200 MeV, 300 MeV, 400 MeV, and 500 MeV.](image)

Operated by the Los Alamos National Security, LLC for the DOE/NNSA
Double-differential cross sections, E=300 MeV

Arends et al. for 305 MeV incident photons and a 48° detection angle.
Double-differential cross sections, $E=400$ MeV

Arends et al. for 381 MeV incident photons and a 48° detection angle.
Double-differential cross sections, $E=500$ MeV

Boyd et al. for 500 MeV incident Brems. Photons and a $110^\circ$ detection angle.
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**Pion decay & muon production**

**C-12 photo-pion production with decay**

```plaintext
c cell cards
1 1 -2.1 -1 imp:p=1
2 0 1 -2 imp:p=1
3 0 2 imp:p=0

c surface cards
1 so 20.0
2 so 1e6

c physics cards
ml 6012 1
mode p h n / z |
phys:p 3j 1 $ Turn on photonuclear
phys:n 610
lca 7j 1 $ Full transport

c source cards
c wgt=10 to account for 10 source energies
sdef erg=d1 par=p vec=1 0 0 dir=1 wgt=10
sil L 180 200 250 300 350 400 450 500 550 600
spl 1 1 1 1 1 1 1 1 1 1

c control cards
print
nps 10e6
```

**c tally cards**

TMESH

**c pion flux tally (#/cm2/sp)**

```plaintext
rmesh1:/ flux
coral1 -5e4 299i 5e4
corb1 -5e4 5e4
corcl -5e4 299i 5e4
c muon flux tally (#/cm2/sp)
rmesh11:| flux
corall -1.1e6 299i 1.1e6
corbll -1.1e6 1.1e6
corcll -1.1e6 299i 1.1e6
ENDMD
```

**\( \pi^- \rightarrow \mu^- + \nu_\mu \)**

\( (\tau = 2.6e^{-8} \text{ s}) \)

**\( \mu^- \rightarrow e^- + \nu_e + \nu_\mu \)**

\( (\tau = 2.2e^{-6} \text{ s}) \)
Pion decay & muon production

10 km

0.2 km

Pion Decay
Pion decay & muon production

Muon Production

10 km
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Muonic x-ray production

350 MeV muons into Pb surrounding HEU

1 1 -18.95 -1
2 3 -11.35 1 -2
3 3 -1.0 2 -3
4 4 -7.8 3 -4
5 5 -1.205e-3 4 -100
100 0 100

1 rcc -10.0 0.0 0.0 20.0 0.0 0.0 5.0
2 rcc -12.5 0.0 0.0 25.0 0.0 0.0 7.5
3 rpp -47.5 47.5 -47.5 47.5 -47.5 47.5
4 rpp -50.0 50.0 -50.0 50.0 -50.0 50.0
100 so 100.0

mode | p
phys: | p 350.0
sdef par=| erg=350.0 x=d1 y2=d2 z=-60.0
        vec=0 0 1 dir=1
si1 -12.5 12.5
sp1 0 1
si2 -7.5 7.5
sp2 0 1
m1 92238 -.20 92235 -.80
m3 1001 2 6012 1
m4 26054 5.9 26056 91.72 26057 2.1 26058 .28
Muonic x-ray production

Gamma flux crossing outer sphere
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• MCNPX provides accurate photon physics packages
  – Photo-atomic libraries from 1 keV to 100 GeV
  – Photo-nuclear libraries (E<150 MeV) and/or models (CEM)
    • Improved GEM2 photofission and PN secondary distributions
    • New coalescence model and improved Fermi Breakup

• MCNPX is capable of photo-pion production
  – Integral cross sections agree with published values
  – Double-differential spectra also show reasonable agreement

• MCNPX treats decay & muonic capture
  – Includes free (π,μ) and bound (μ) lifetimes
  – Includes muonic x-ray production with possible absorption
  – Accounts for annihilation & spallation with fission (Z>90)