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MCNPX Photo-pion Production from Graphite

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

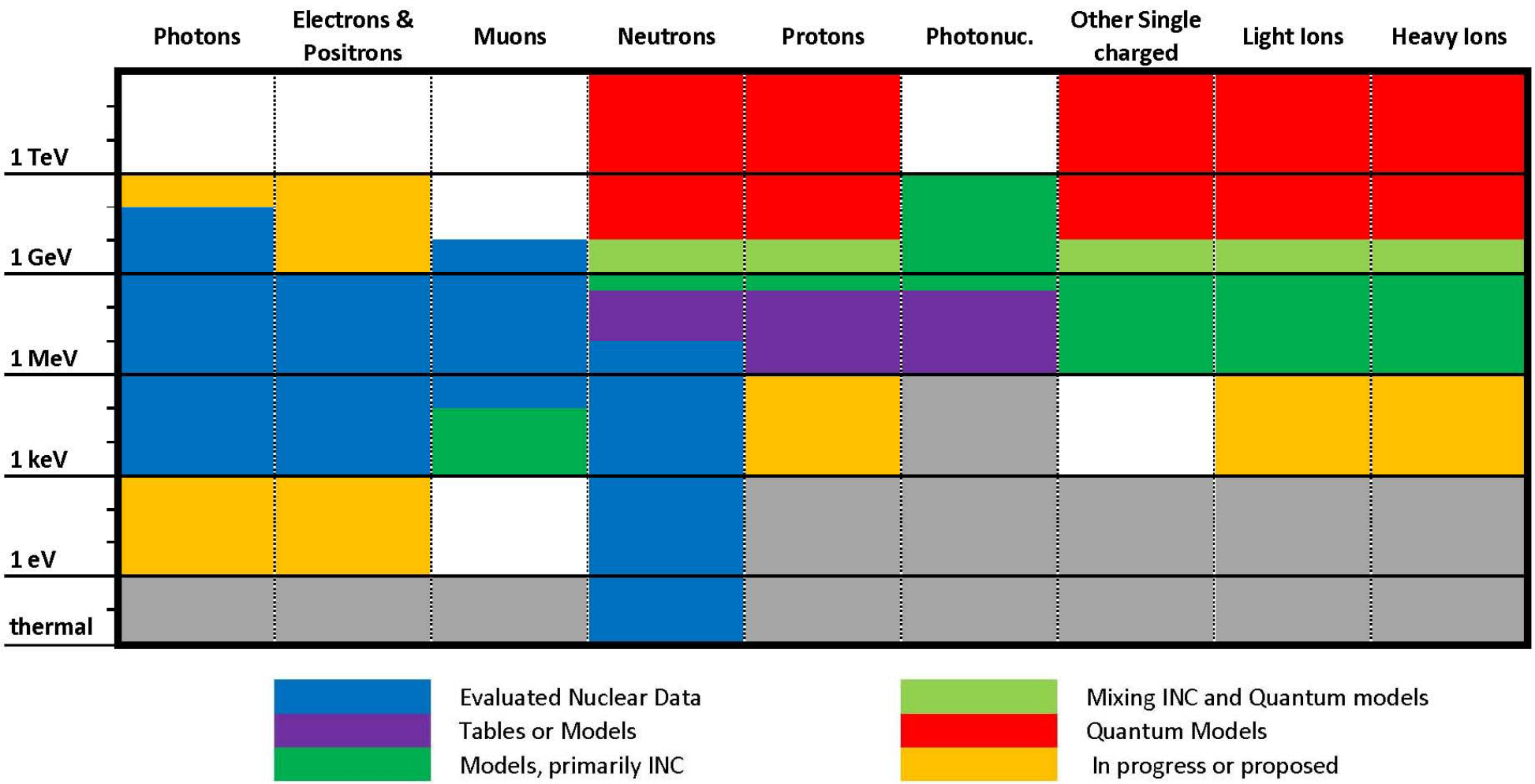
Outline

- What is MCNPX?
- Motivation
- Photo-pion production
- Pion decay & muon production
- Muonic x-rays
- Conclusions

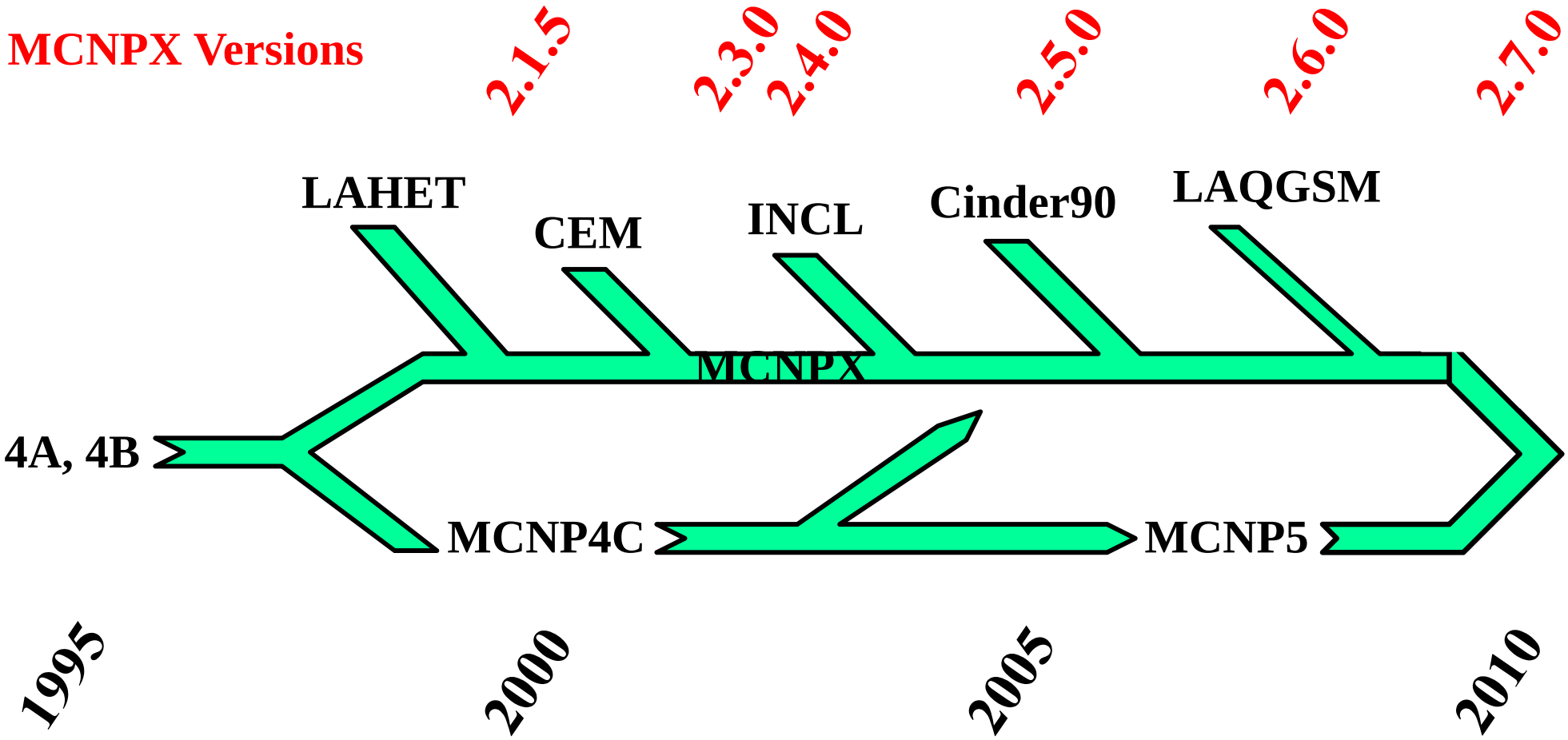
What is MCNPX?

- 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



Recent history of MCNPX



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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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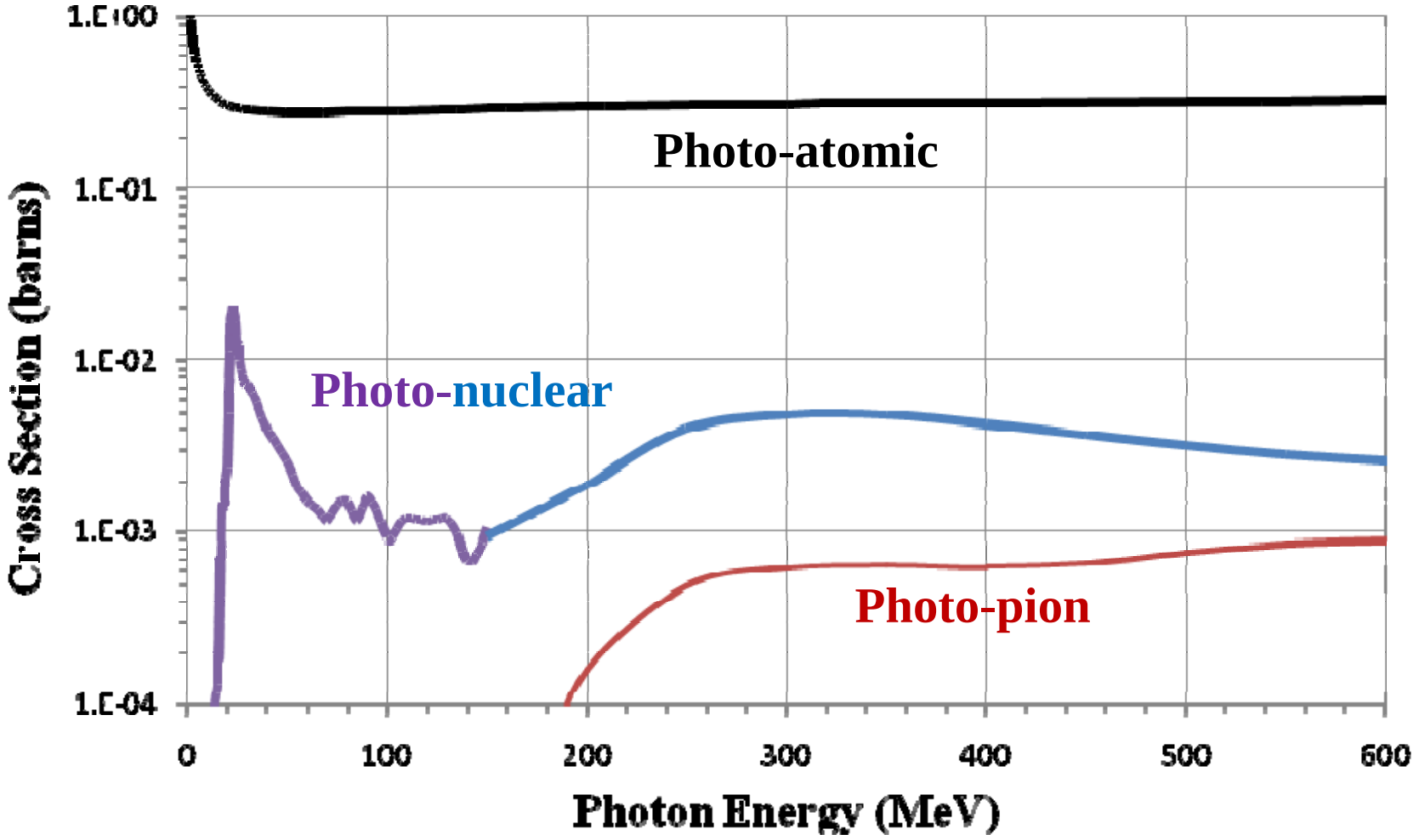
Photo-pion production

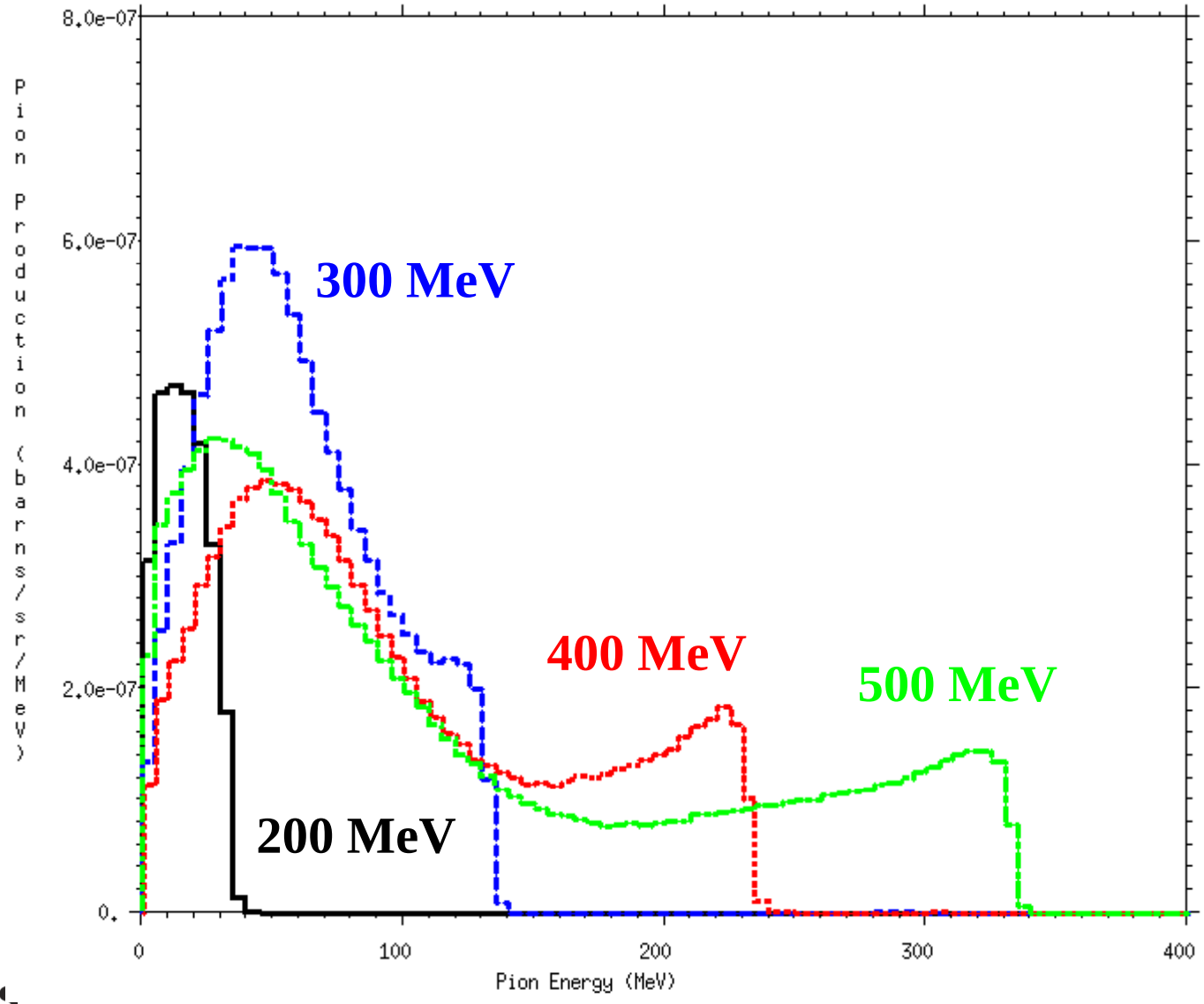
```
C-12 photo-pion production with x-s tallies
c  cell cards
1  1 -2.1   -1    imp:p=1
2  0         1    imp:p=0

c  surface cards
1  so 20

c  physics cards
m1     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
si1   L 180 200 250 300 350 400 450 500 550 600
sp1       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

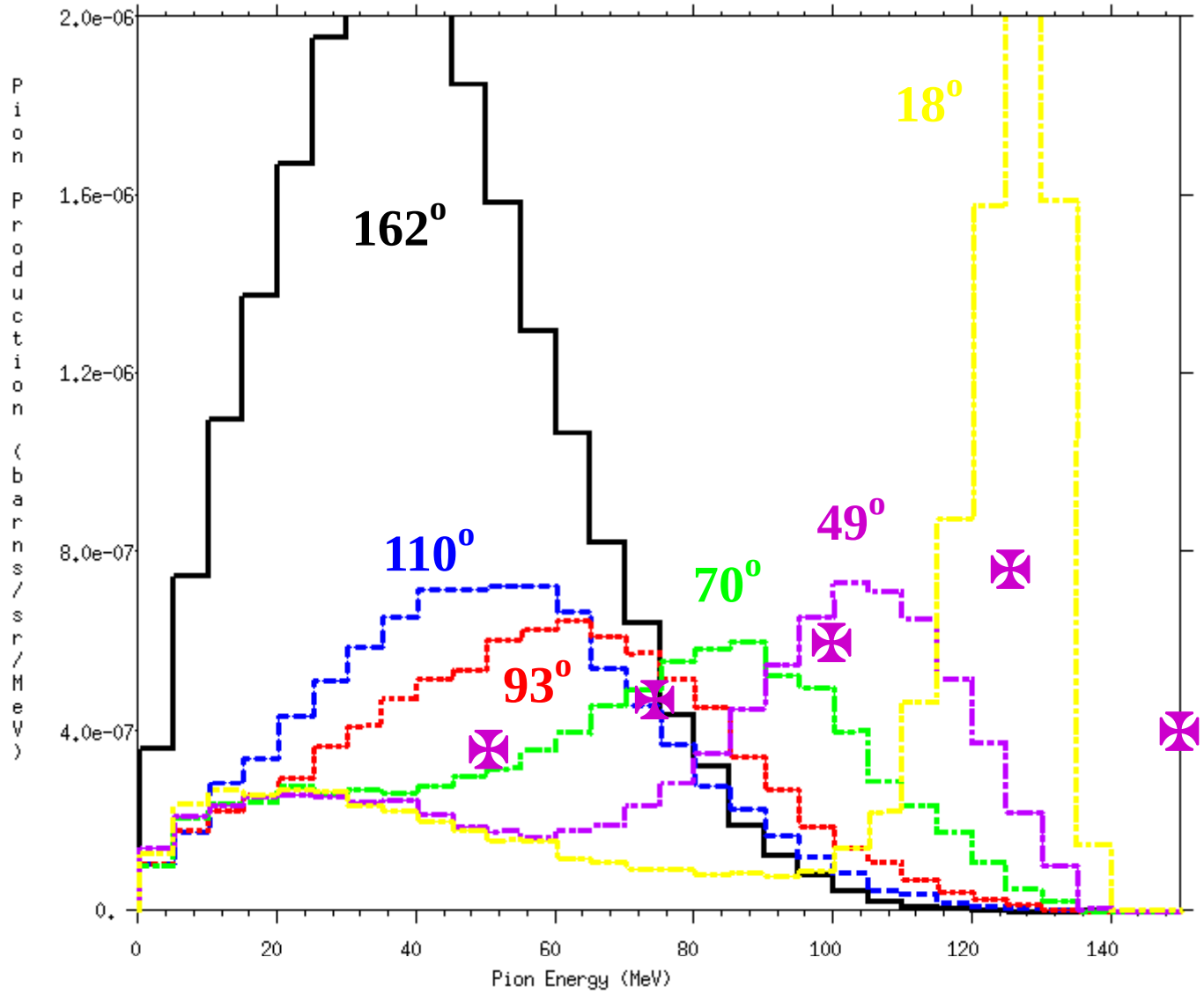


Angle-averaged double-differential cross sections



Double-differential cross sections, E=300 MeV

✠ Arends et al. for 305 MeV incident photons and a 48° detection angle.



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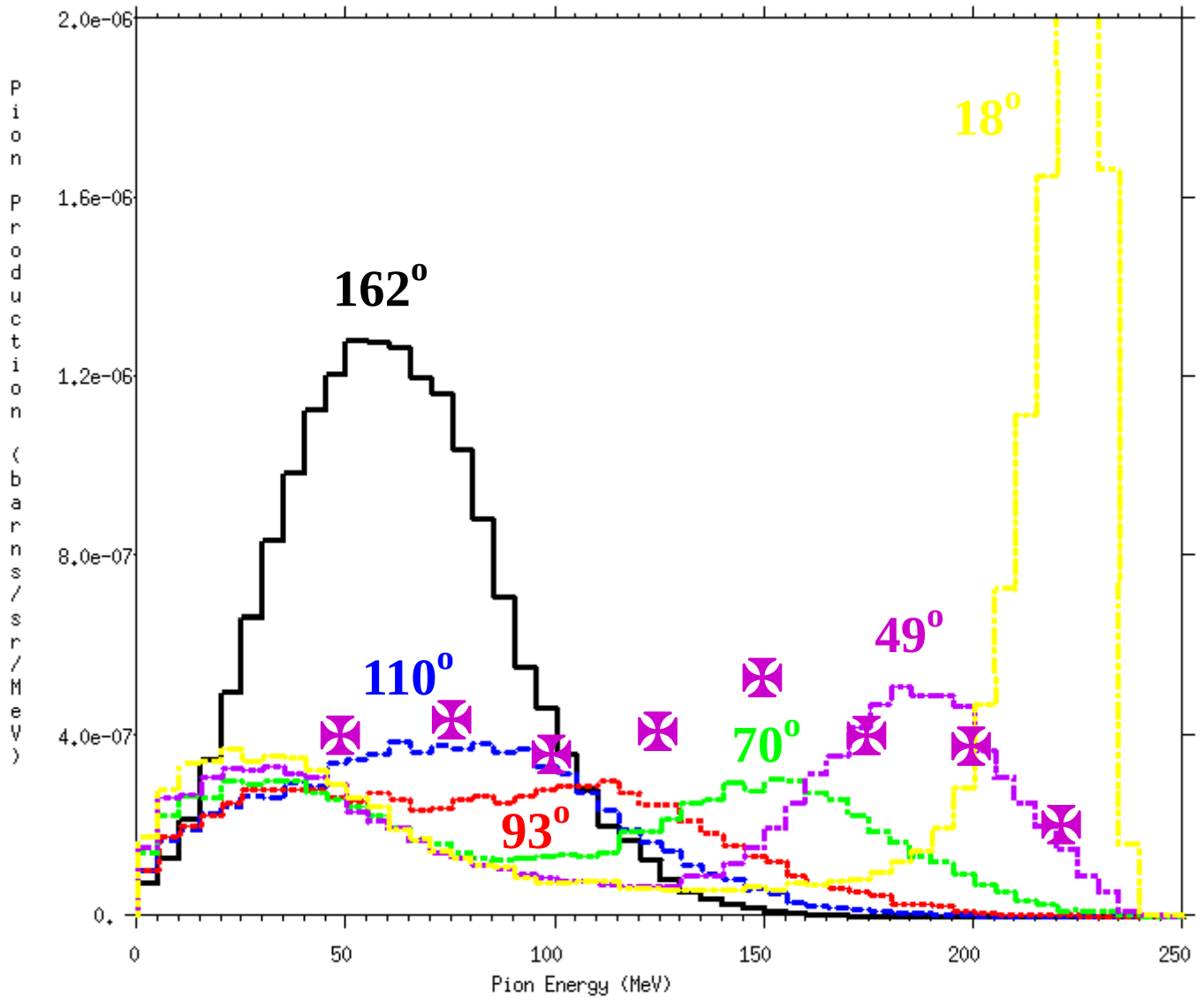
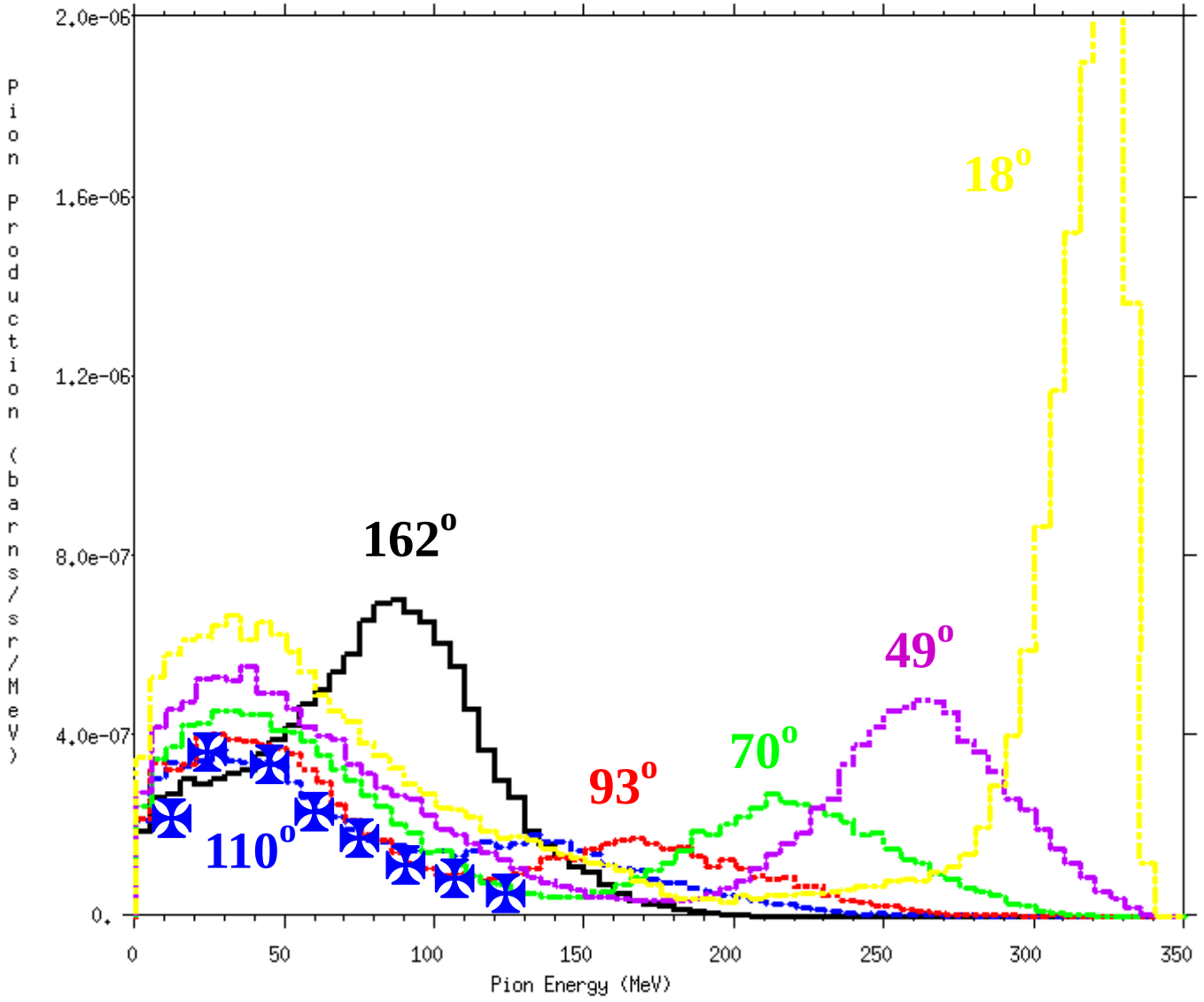
Double-differential cross sections, E=400 MeV

✠ Arends et al. for 381 MeV incident photons and a 48^{o} detection angle.



Double-differential cross sections, E=500 MeV

✠ Boyd et al. for 500 MeV incident Brems. Photons and a 110^{o} detection angle.



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Pion decay & muon production

```
C-12 photo-pion production with decay
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
m1     6012 1
mode   p h n / z |
phys:p 3j 1 $ Turn on photonuclear
phys:n 610
lca    7j j 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
si1   L 180 200 250 300 350 400 450 500 550 600
sp1       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)
rmesh1:/   flux
cora1   -5e4   299i 5e4
corb1   -5e4        5e4
corc1   -5e4   299i 5e4
c  muon flux tally (#/cm2/sp)
rmesh11:|  flux
cora11  -1.1e6 299i 1.1e6
corb11  -1.1e6      1.1e6
corc11  -1.1e6 299i 1.1e6
ENDMD
```

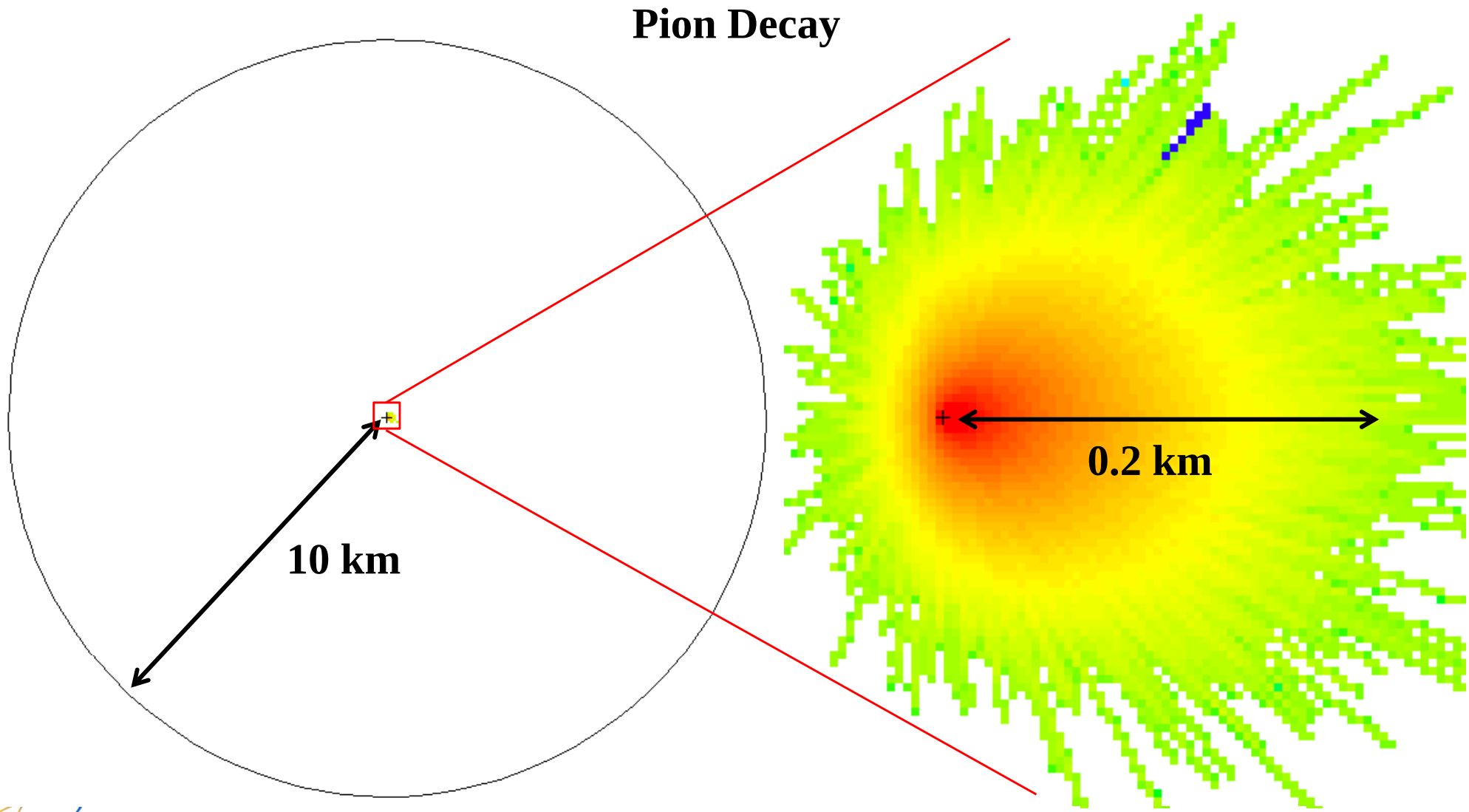
$\pi^- \text{--> } \mu^- + \nu_\mu$

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

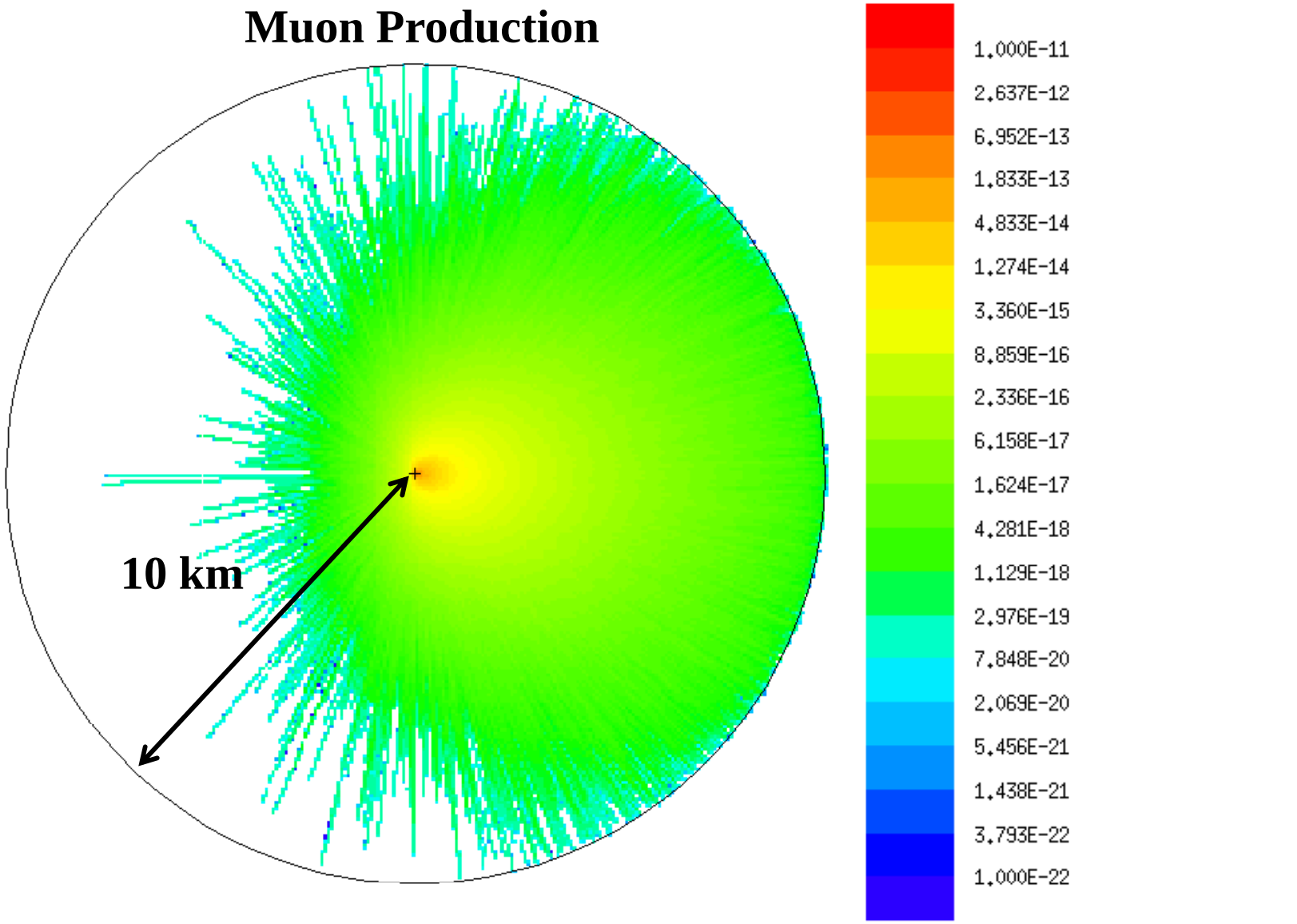
$\mu^- \text{--> } e^- + \nu_\varepsilon + \nu_\mu$

$(\tau = 2.2\text{e-}6 \text{ s})$

Pion decay & muon production



Pion decay & muon production



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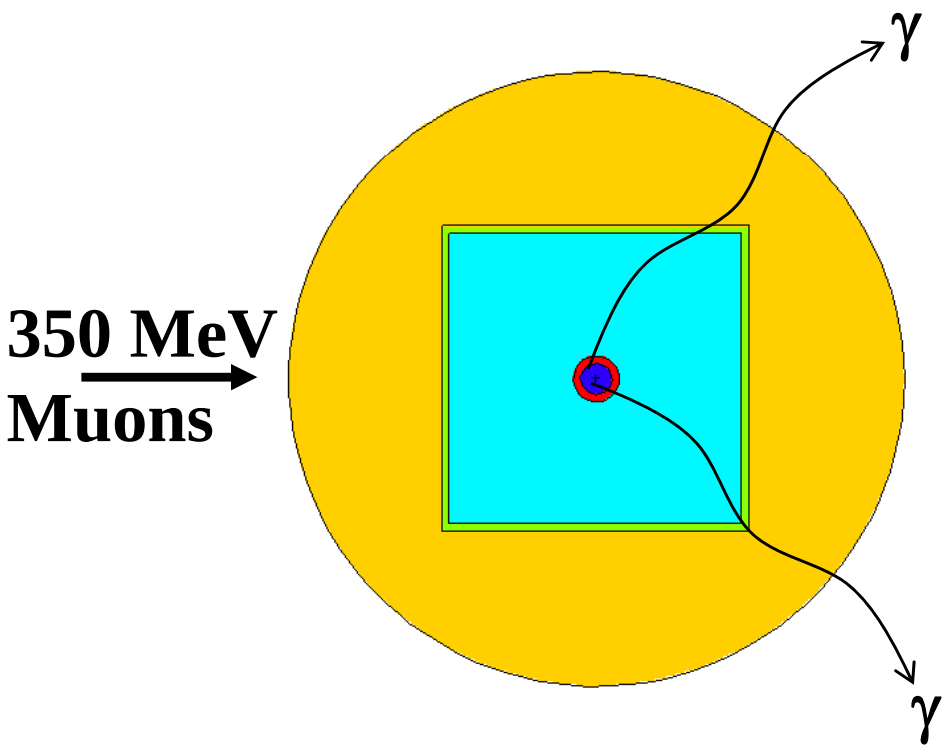
Muonic x-ray production

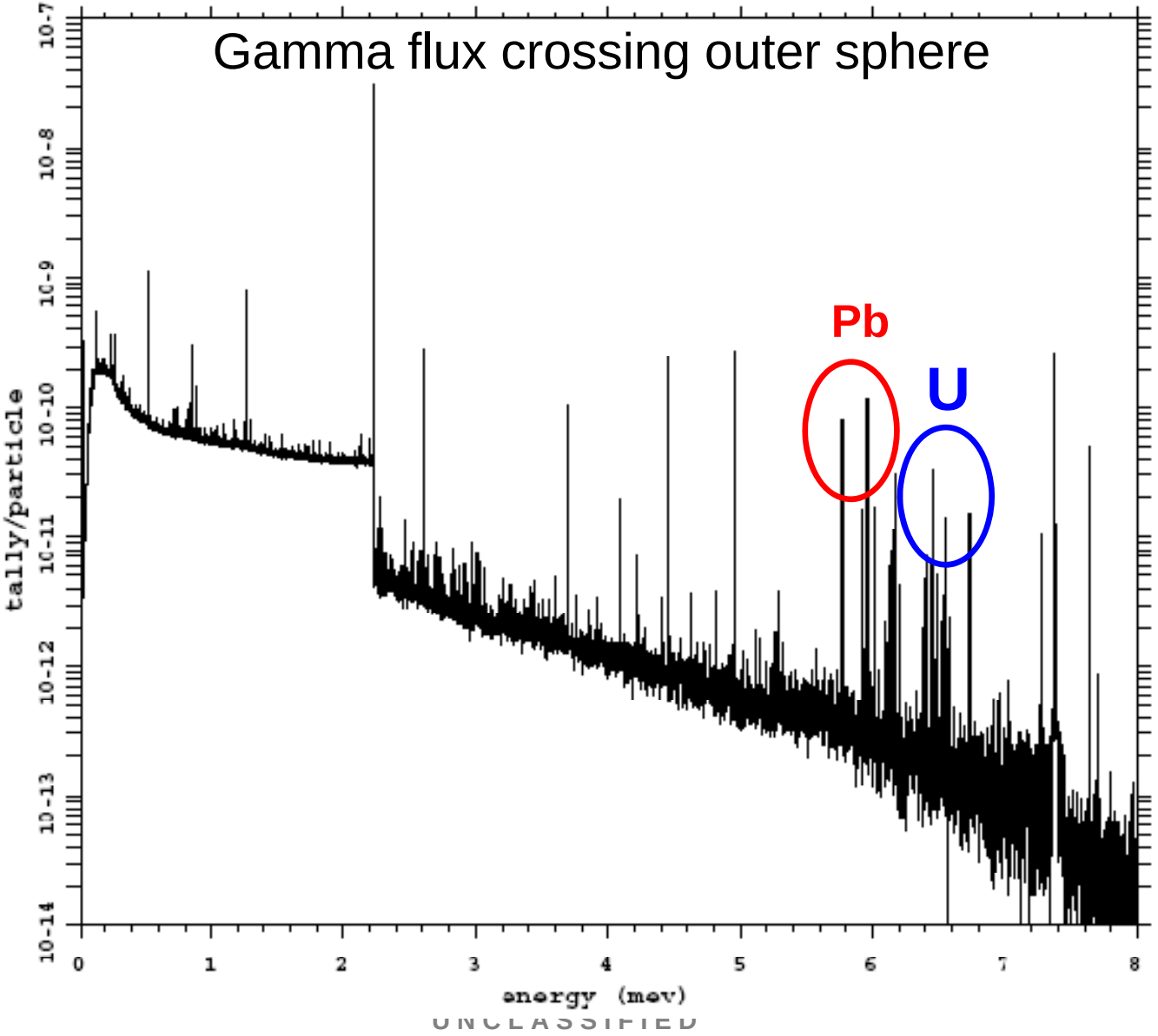
```
350 MeV muons into Pb surrounding HEU
1 1 -18.95  -1          imp:|,p=1
2 8 -11.35  1 -2        imp:|,p=1
3 3 -1.0  2 -3          imp:|,p=1
4 4 -7.8 3 -4           imp:|,p=1
5 5 -1.205e-3  4 -100   imp:|,p=1
100 0  100              imp:|,p=0

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 y=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
m5   1000 -6e-4 8000 -0.2353 7000 -0.7513
     18000 -0.0128
m8   82204 1.4   82206 24.1    82207 22.1
     82208 52.4
e2 0.0 9999i 10.0
f2:p 100
```



Muonic x-ray production



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Conclusions

- 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)