American Association of Physicists in Medicine (AAPM) Task Group on Monte Carlo Validation Sets: Geant4 Related Findings

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What is an AAPM TG?

- American Association of Physicists in Medicine (AAPM):
  - Scientific, educational and professional association of medical physicists
  - 7,946 members
  - Publisher of *Medical Physics* journal, leading scientific journal on medical physics
  - Annual meeting is largest medical physics meeting

What is an AAPM TG?

- AAPM Task Groups are committees formed for a specific task
  - Final TG report has to be approved by TG and all parent committees (normally 2-3)
  - Report is published on AAPM website and summarized version in *Medical Physics* (after peer-review)
  - TG reports become “unofficial” standards in the medical physics community

Task Group Members

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} Geant4

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Andreu Badal, FDA
Aldo Badano, FDA
Iacovos Kyprianou, FDA
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} Penelope

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} EGSnrc

Michael McNitt-Gray, UCLA
Adam Turner, University of Arizona
} MCNP

John Boone, UC Davis
} Sierra

Task Group Charge

- Define a set of Monte Carlo simulations relevant to diagnostic radiology
- Provide all needed information
  - Geometry
  - Source
  - Material composition
  - Energy spectra
  - Scoring
  - etc
- Provide results from a group of MC codes
  - Geant4, EGSnrc, MCNP, Penelope
- Investigators can use these “standardized” simulations as validation of their code

Simulations Developed

- Currently diagnostic x-ray imaging
- If successful, envision follow-up reports:
  - Nuclear medicine
  - Radiotherapy?

Simulations Developed

- Production of x-rays
- Half-value layers
- Radiography (including tomosynthesis):
  - Dose
  - X-ray scatter
- Mammography (including tomosynthesis):
  - Dose
  - X-ray scatter
- CT:
  - Dose in simple solids
  - Dose in voxelized phantom

Geant4 Simulations

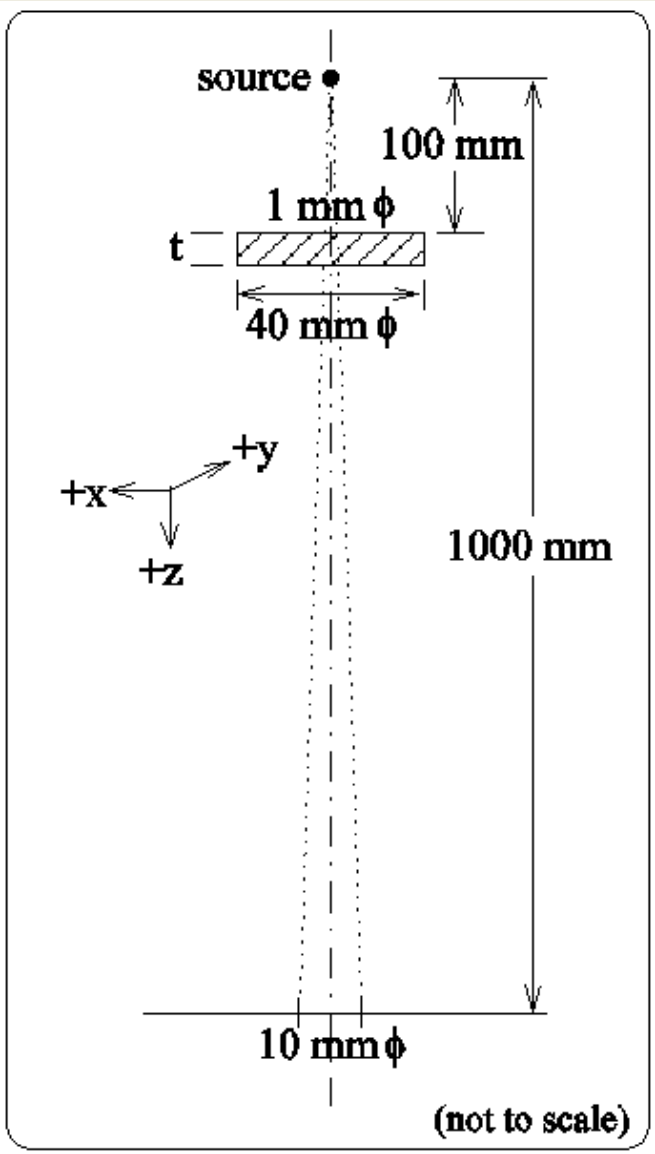
- v9.5 patch 1
- Except where noted:
  - G4EmLivermorePhysics
  - Cuts: 1.0 mm
- All elements are from NISTmanager

Good Results

- Good matches in results have been found in:
  - Half value layer
  - Radiography (dose and scatter)
  - Mammography (dose and scatter)

- For example…

Half-Value Layers
(X-ray absorption in simple geometries)



- Mono-energetic and poly-energetic source of photons
- Aluminum absorber
  - Thickness set to achieve HVL and QVL
- Ideal, energy discriminating photon counter detector

Results Comparison

Geant4

Summary:	Primary Only	Total
30 keV		
HVL:	0.500	0.500
QVL:	0.250	0.250
100 keV		
HVL:	0.499	0.499
QVL:	0.249	0.249
30 kVp		
HVL:	0.525	0.525
QVL:	0.269	0.269
100 kVp		
HVL:	0.504	0.504
QVL:	0.253	0.253

Penelope

Summary:	Primary Only	Total
30 keV		
HVL:	0.500	0.500
QVL:	0.254	0.254
100 keV		
HVL:	0.498	0.498
QVL:	0.247	0.247
30 kVp		
HVL:	0.539	0.539
QVL:	0.282	0.282
100 kVp		
HVL:	0.509	0.509
QVL:	0.256	0.256

Geant4 / Penelope

Summary:	Primary Only	Total
30 keV		
HVL:	1.00	1.00
QVL:	1.02	1.02
100 keV		
HVL:	1.00	1.00
QVL:	0.99	0.99
30 kVp		
HVL:	1.03	1.03
QVL:	1.05	1.05
100 kVp		
HVL:	1.01	1.01
QVL:	1.01	1.01

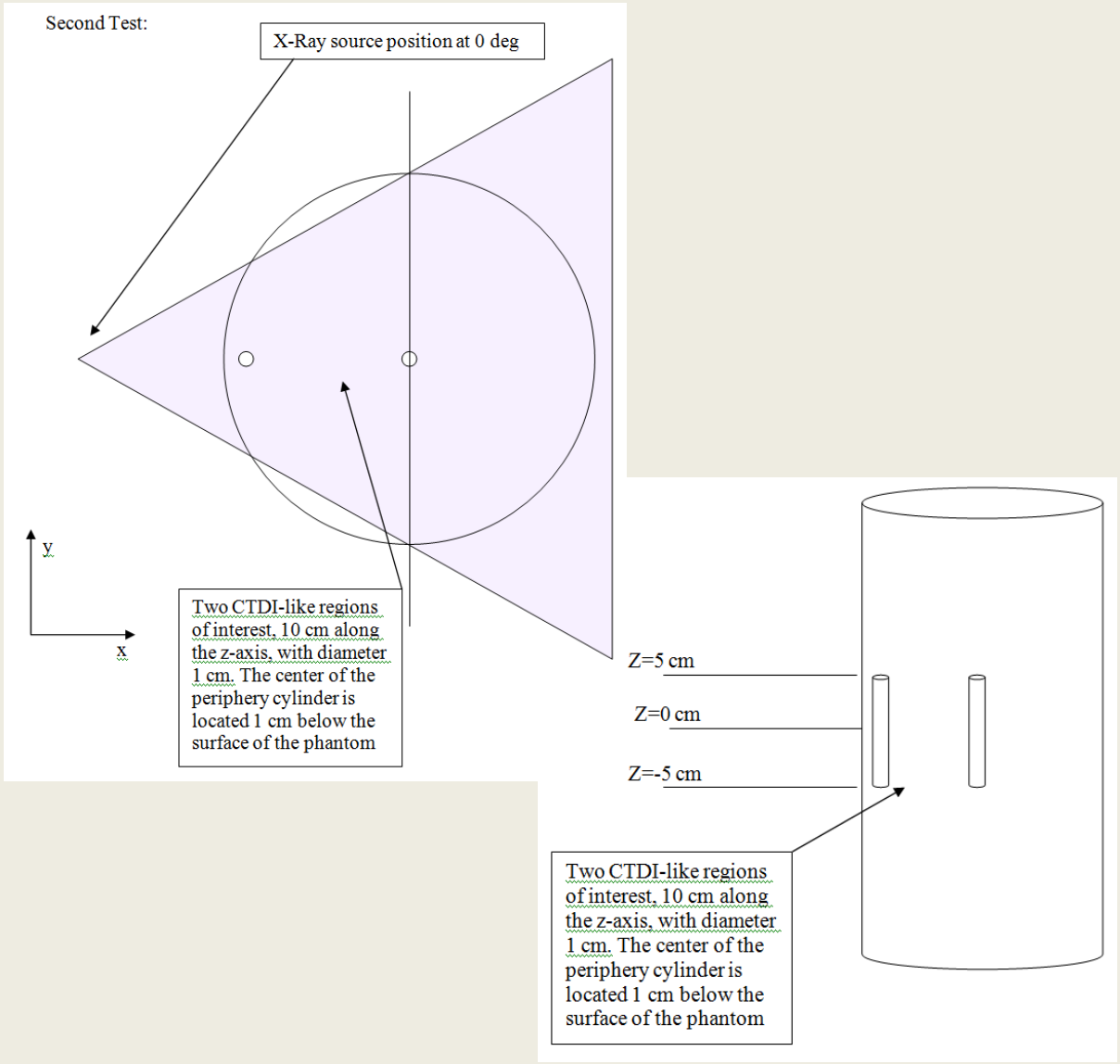
Geant4 and Penelope match well in simple simulations of photon absorption with simple geometries

Results from other MC codes are coming.

Problems encountered in other simulations

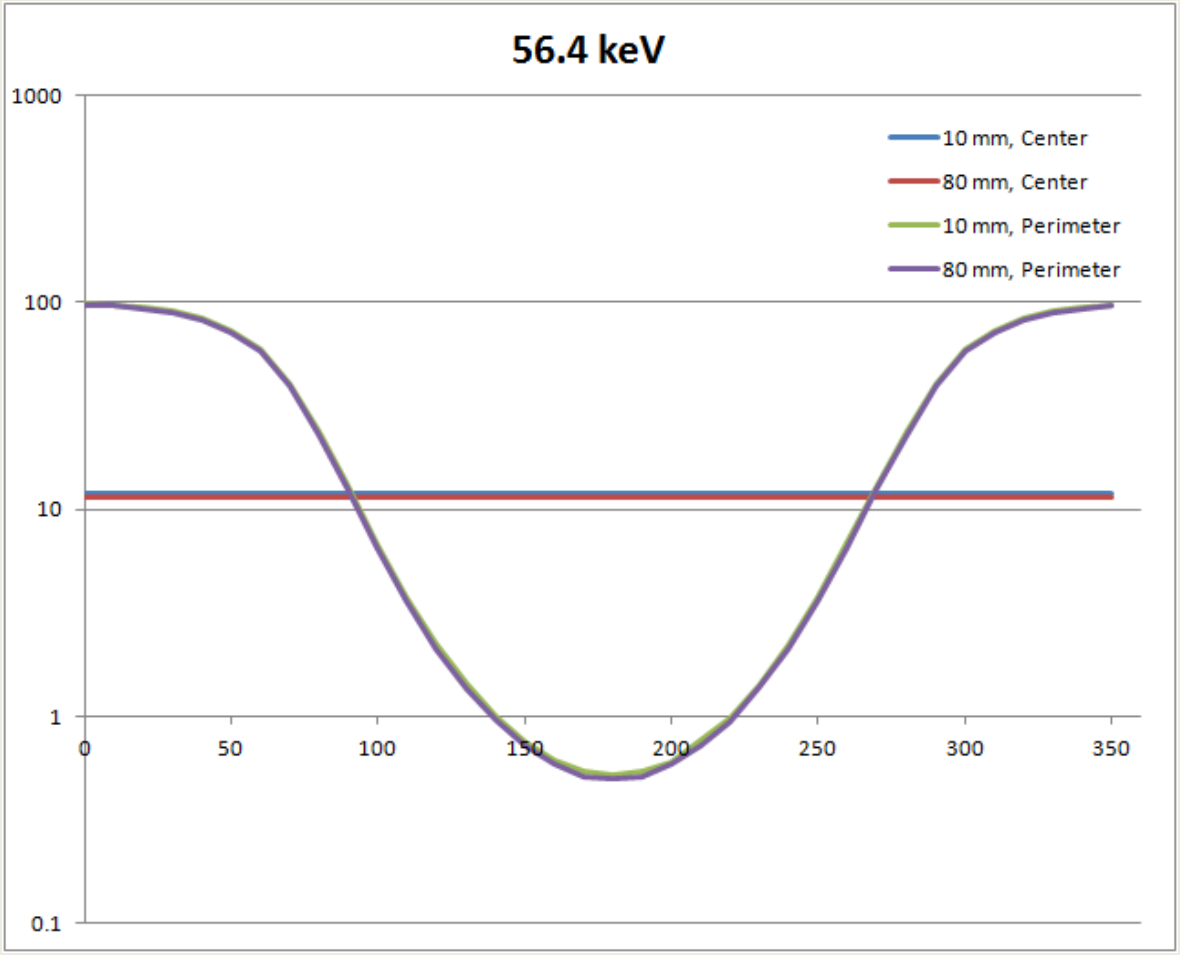
- Simple and voxelized CT
  - Still investigating
- X-ray generation
  - Problems with:
    - G4EmLivermorePhysics
    - Splitting

Example of Mismatch Still Under Investigation: CT with Simple Volumes

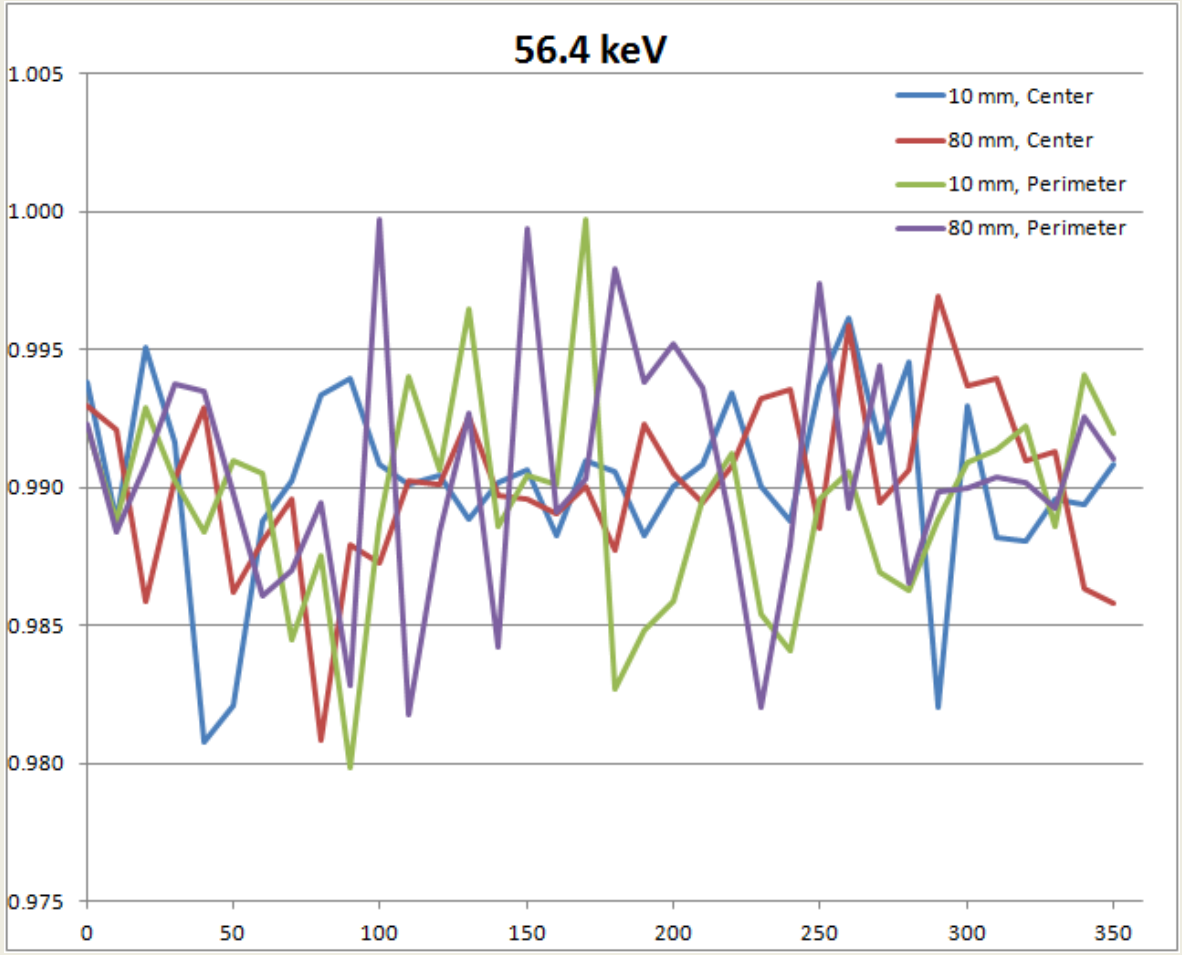


- Simulation of CT with simple CT phantom solid
- Dose at two small cylinders from rotating photon source
- Mono-energetic and poly-energetic photon source

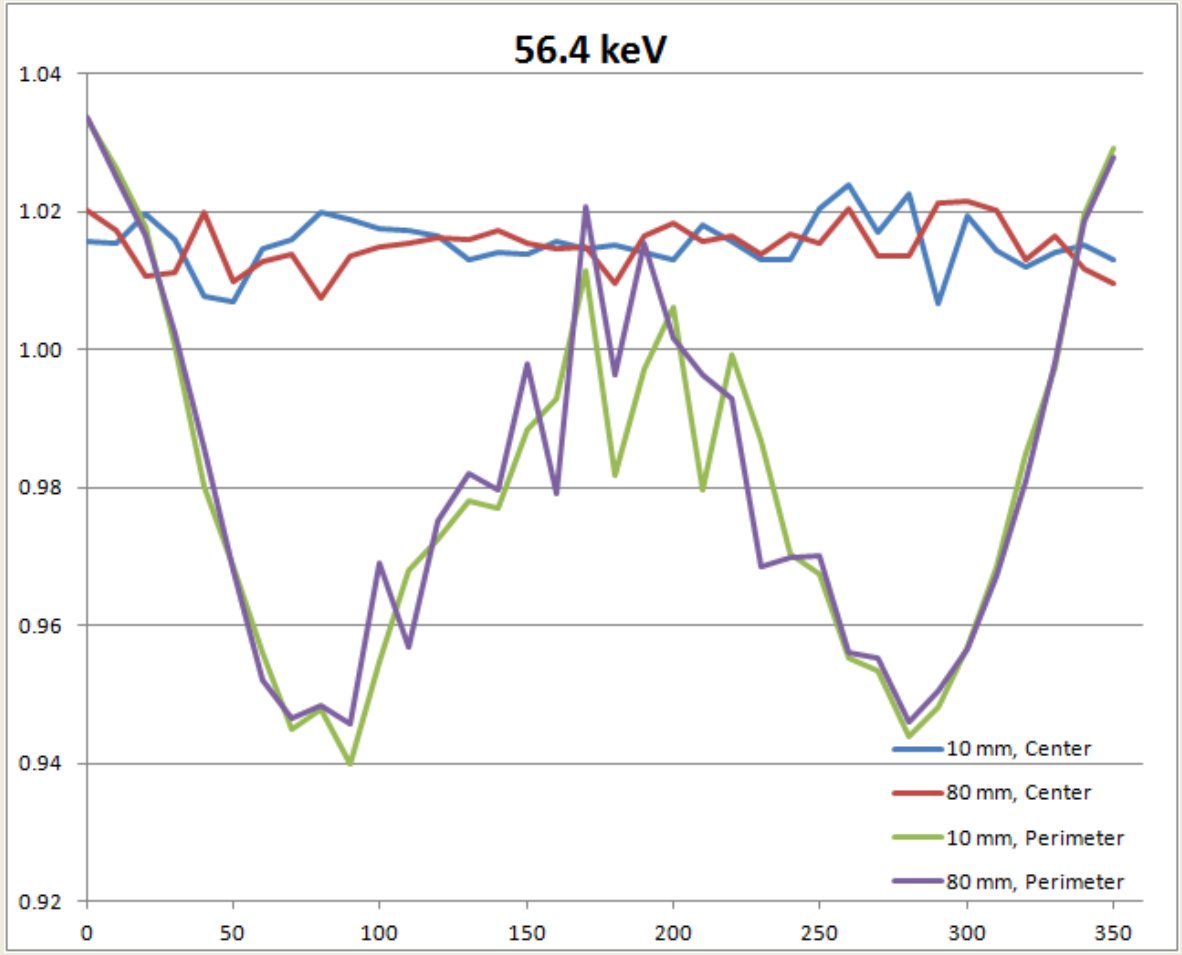
Geant4 Results



Penelope / EGSnrc



Penelope / Geant4
(similar to EGSnrc / Geant4)



So there is some error there, but still not sure where. Under investigation.

Problems with G4: Production of X-rays

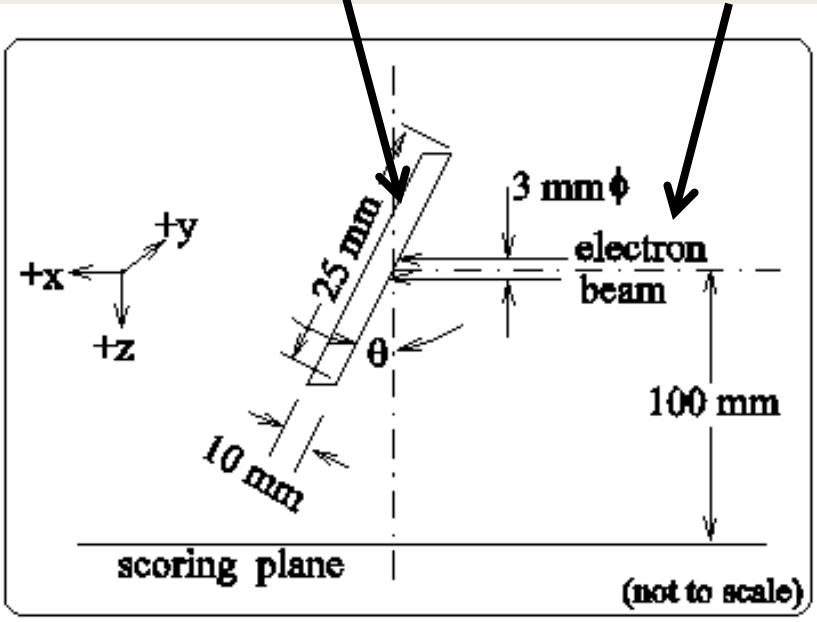


Figure 1: Geometry for x-ray production measurements.

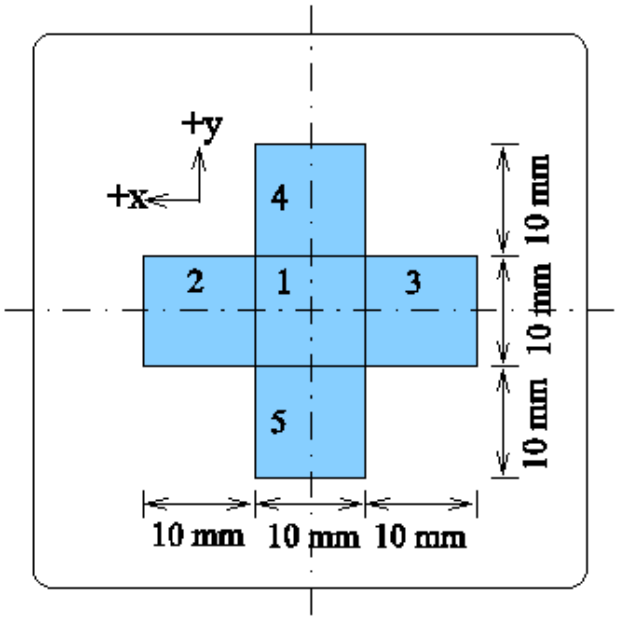
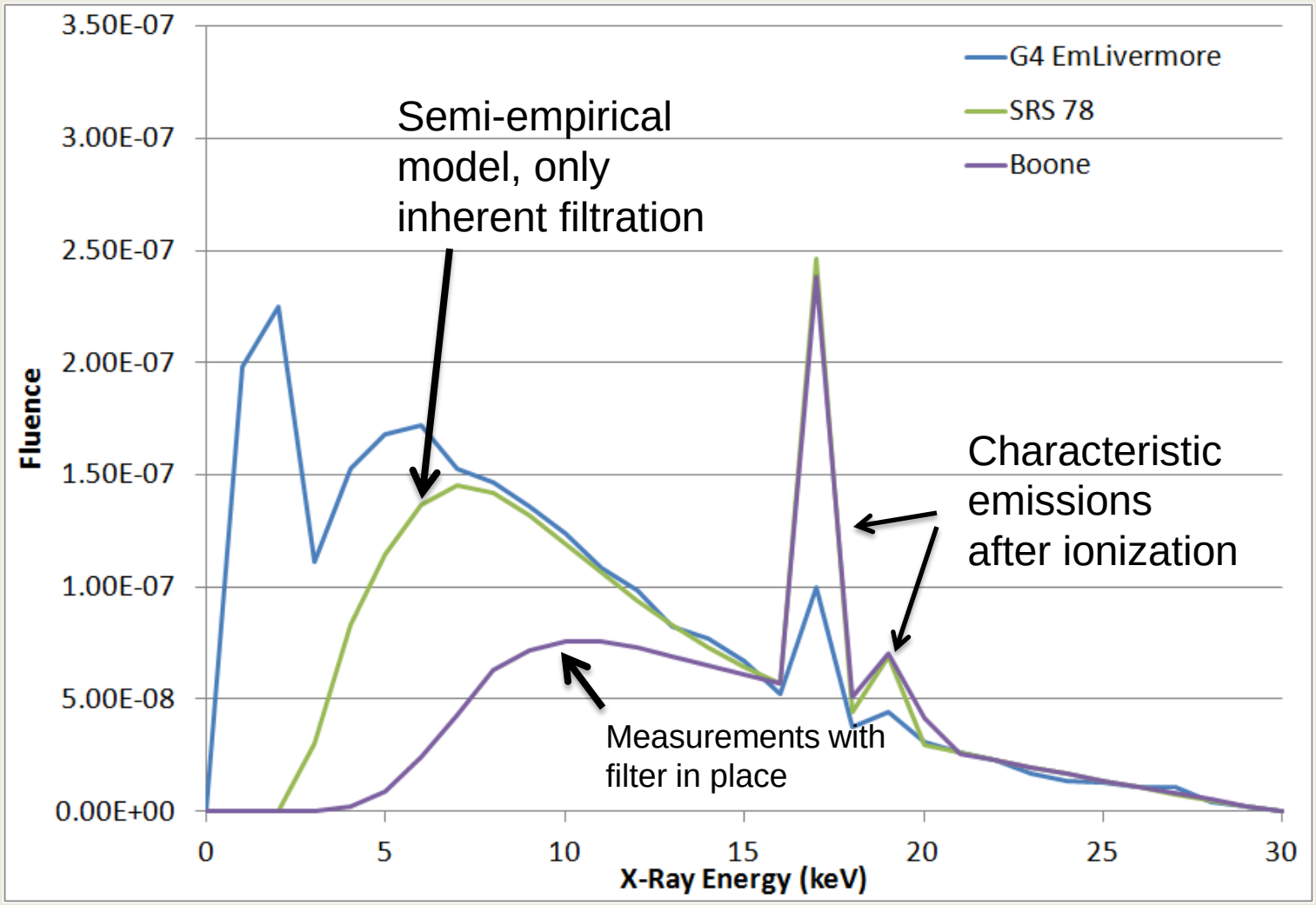
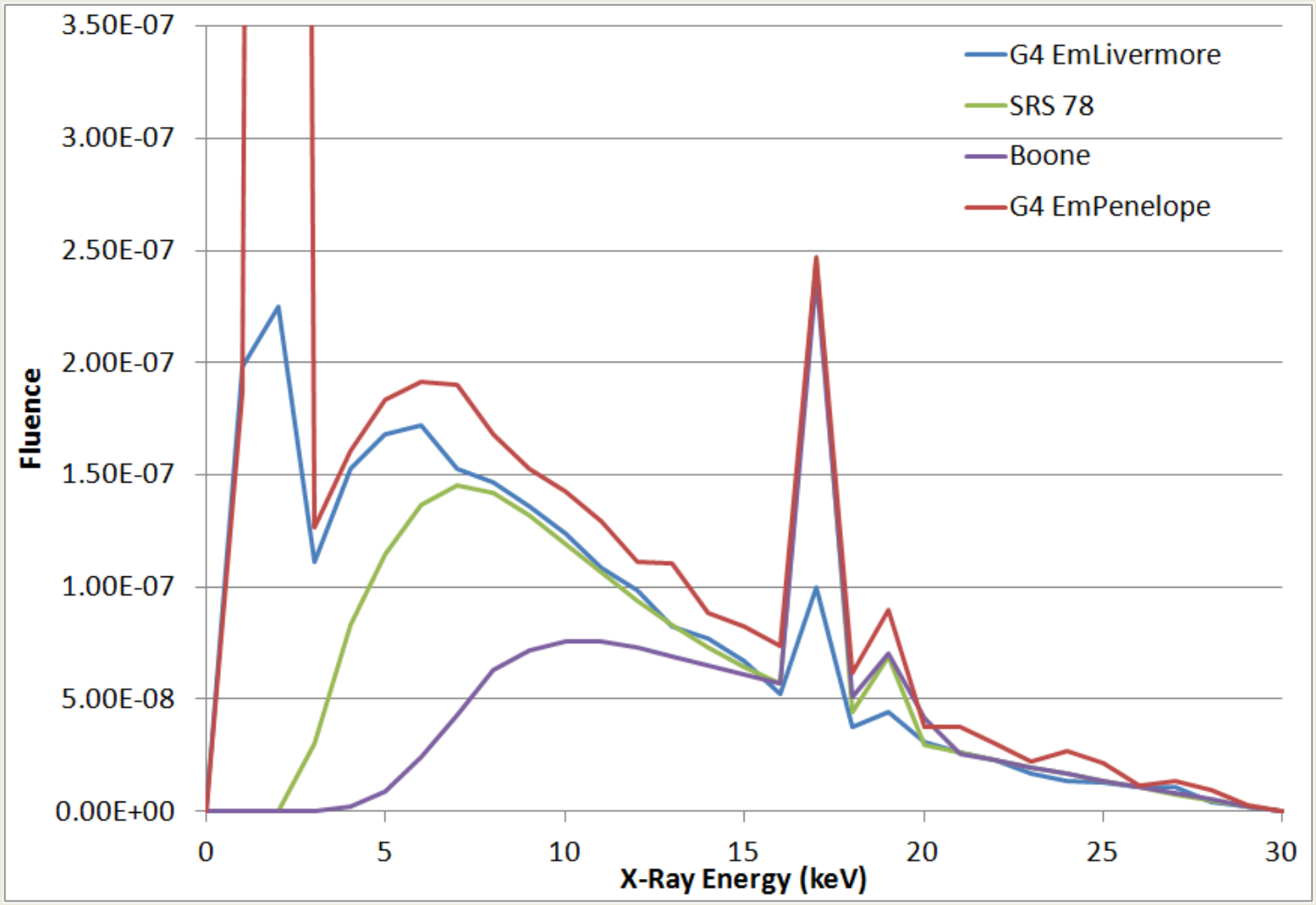


Figure 2: Five square areas of measurement (dark) at the scoring plane.

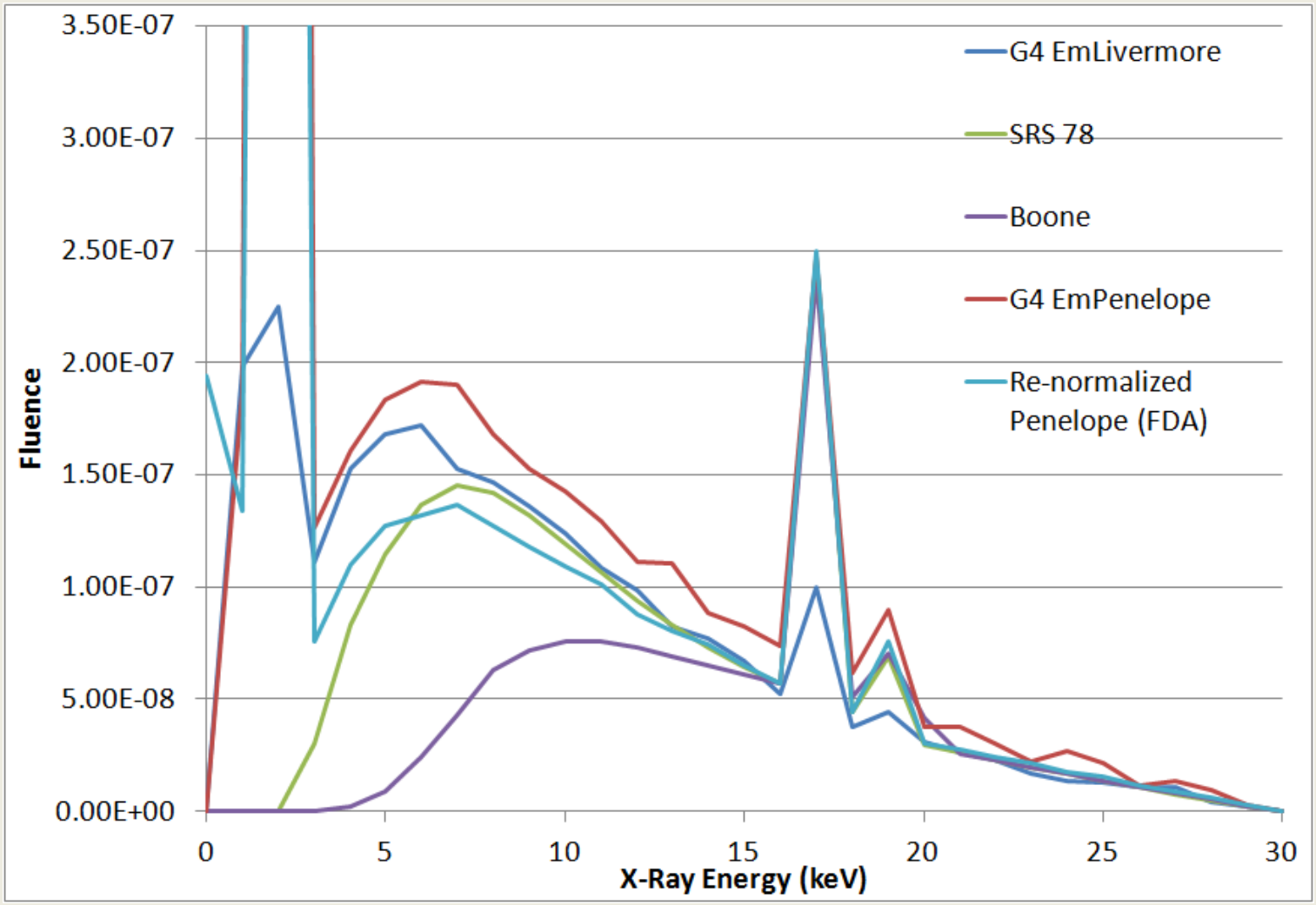
Production of X-Rays
Mo Target, 30 keV electrons



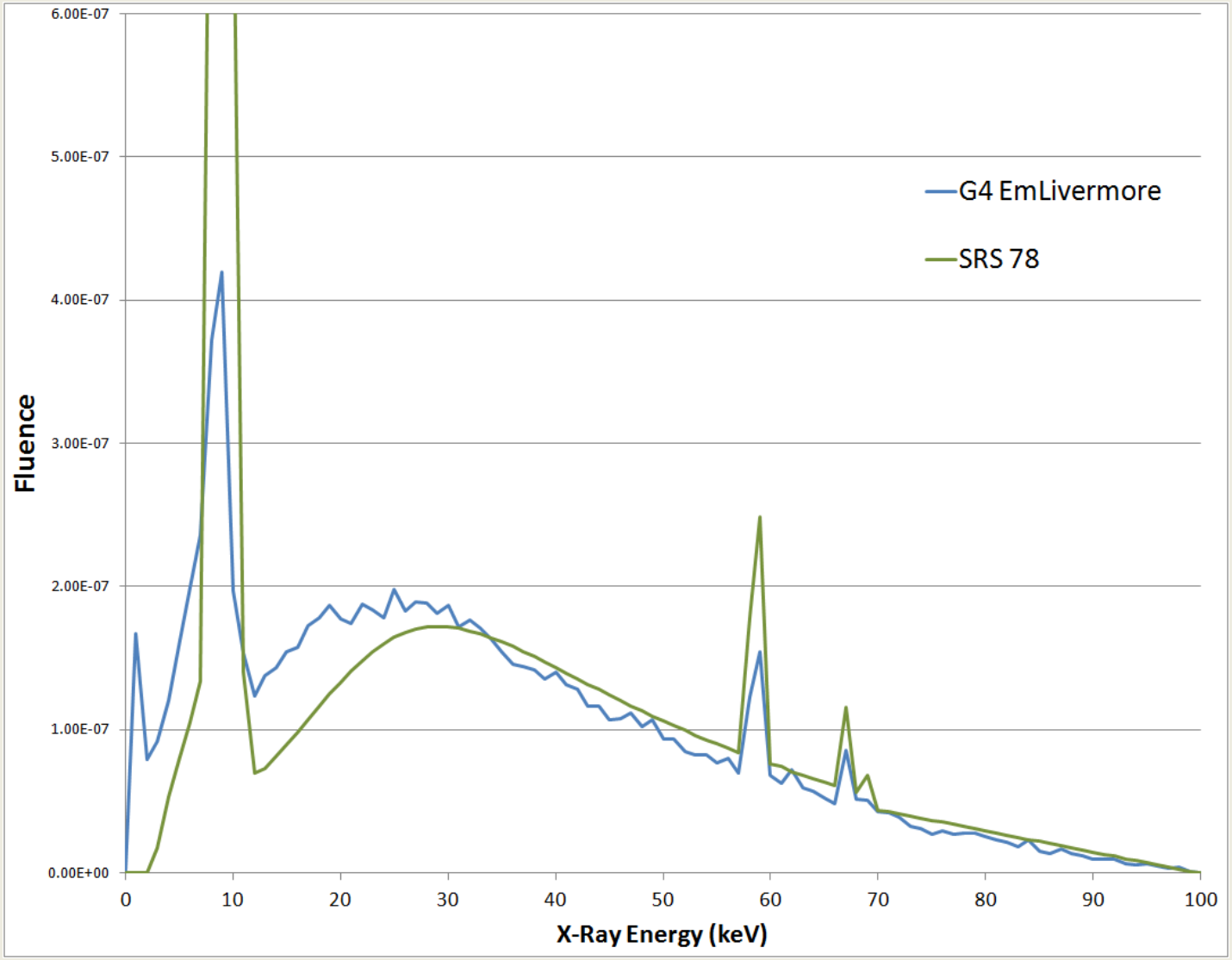
Production of X-Rays
Mo Target, 30 keV electrons



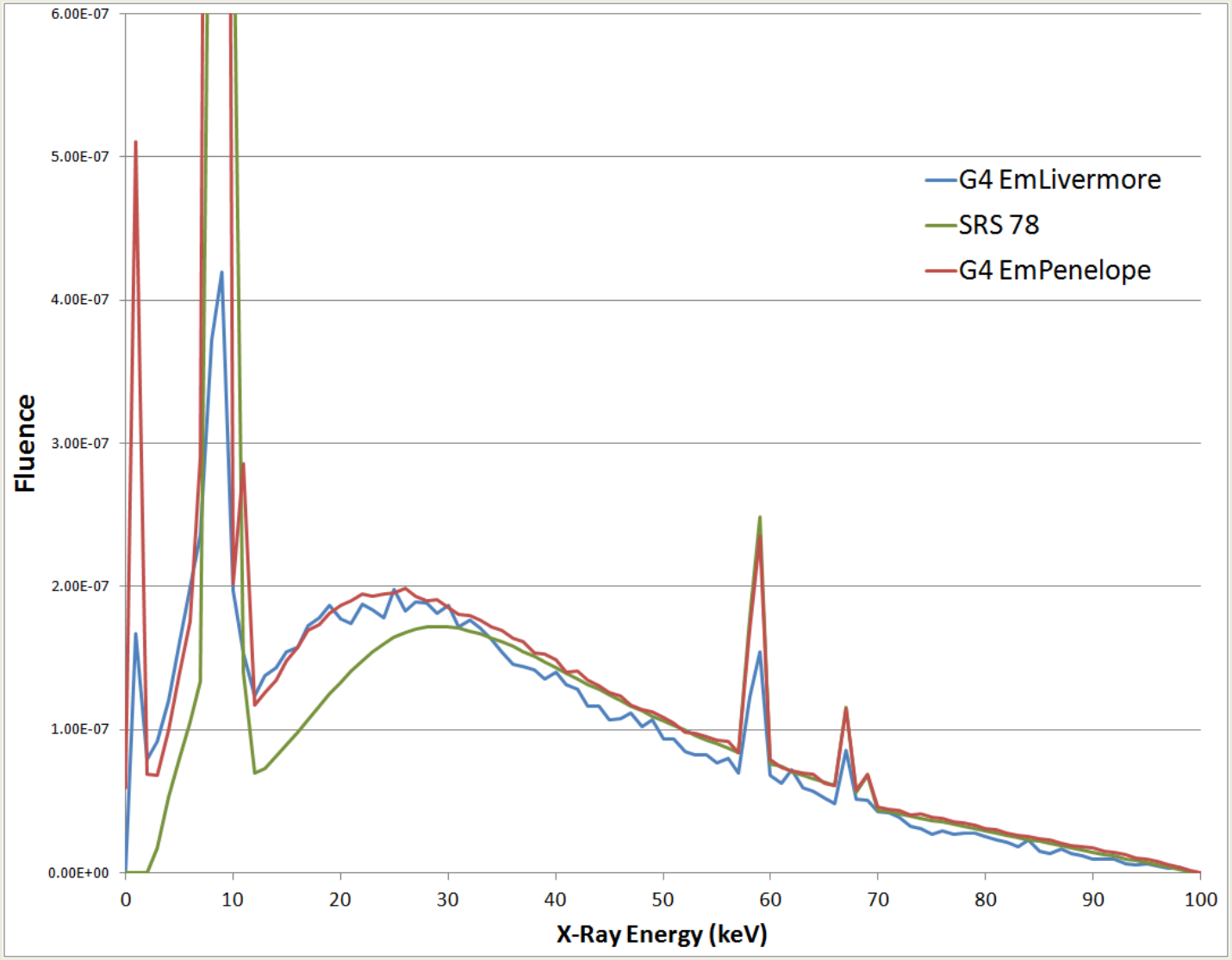
Production of X-Rays
Mo Target, 30 keV electrons



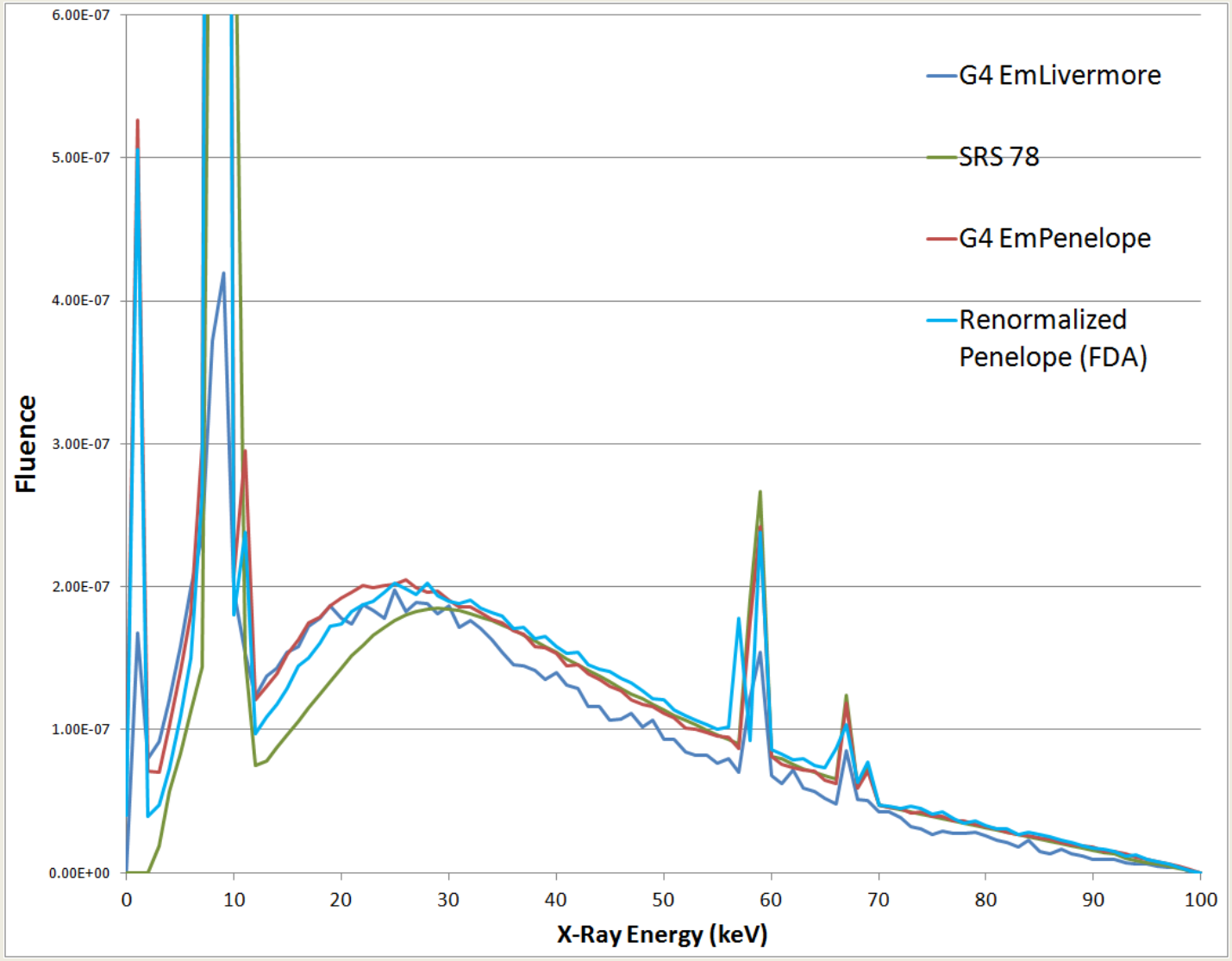
Production of X-Rays
W Target, 100 keV electrons



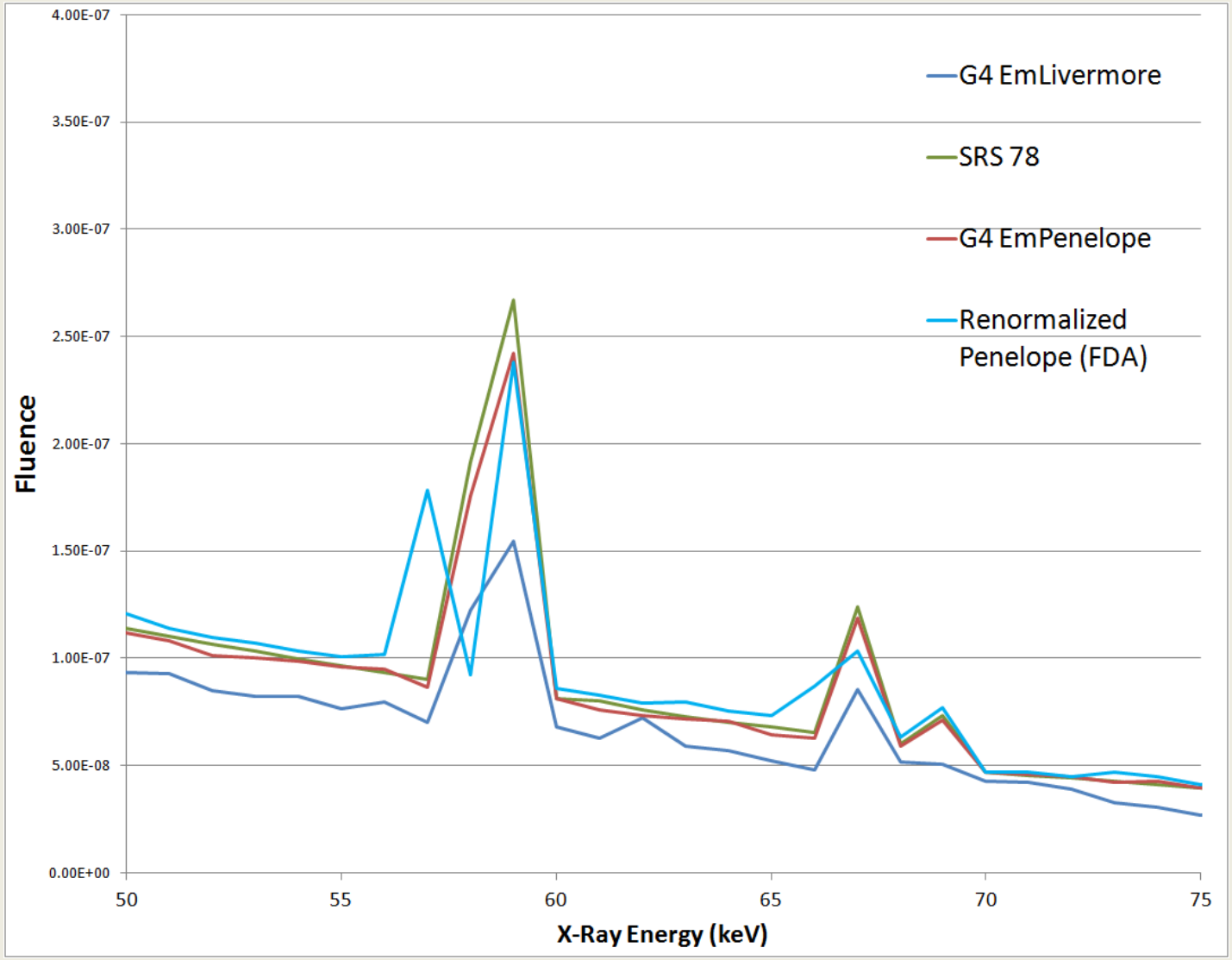
Production of X-Rays
W Target, 100 keV electrons



Production of X-Rays
W Target, 100 keV electrons



Production of X-Rays
W Target, 100 keV electrons



Production of X-Rays

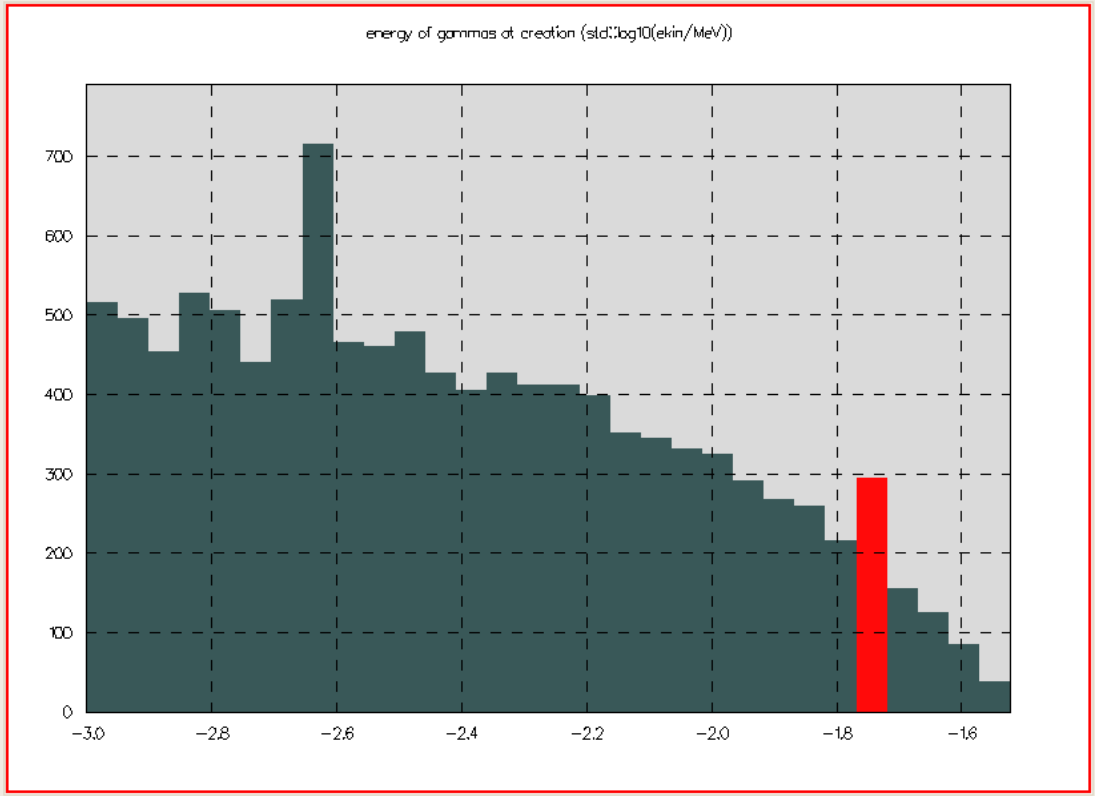
- So characteristic emission from electron interaction with materials seems too low.
- Tracking output showed that:
  - NO characteristic emission after ionization was taking place
  - The low peak is from characteristic emission after photoelectric effect from bremsstrahlung x-rays

Similar test with TestEm5 emLivermore

Tree options | Append off

/home/ioannis/Desktop/g4/moly.root
- 3;1 class=TH1D title="energy of gammas at creation (std::log10(ekin/MeV)
- 20;1 class=TH1D title="(transmit, neutral) : kinetic energy at exit (keV)"
- 40;1 class=TH1D title="(reflect , neutral) : kinetic energy at exit (keV)"

/home/ioannis/Desktop/g4/moly_penelope.root
- 3;1 class=TH1D title="energy of gammas at creation (std::log10(ekin/MeV)
- 20;1 class=TH1D title="(transmit, neutral) : kinetic energy at exit (keV)"
- 40;1 class=TH1D title="(reflect , neutral) : kinetic energy at exit (keV)"




```
* MIN = 38          * MAX = 717
* ANNOTATIONS :
*  Title = energy of gammas at creation (std::log10(ekin/MeV))
Lib::DumpAction::execute : SbBin1D informations (1 objects) :
   index      height       error  entries   lowerEdge   upperEdge       name
      25         295     17.1756      183    -1.76907    -1.71983        3;1
```

Similar test with TestEm5 emPenelope

Tree options | Append off

/home/ioannis/Desktop/g4/moly.root
- 3;1 class=TH1D title="energy of gammas at creation (std::log10(ekin/MeV)"
- 20;1 class=TH1D title="(transmit, neutral) : kinetic energy at exit (keV)"
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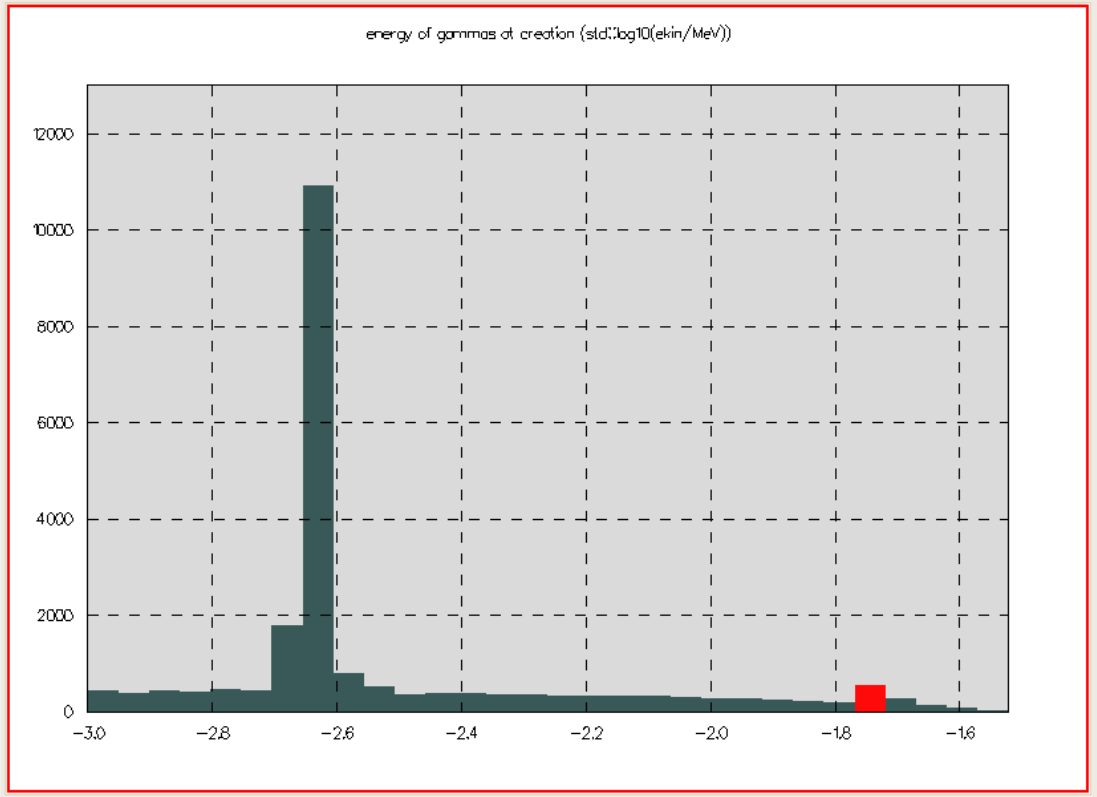
/home/ioannis/Desktop/g4/moly_penelope.root
- 3;1 class=TH1D title="energy of gammas at creation (std::log10(ekin/MeV)"
- 20;1 class=TH1D title="(transmit, neutral) : kinetic energy at exit (keV)"
- 40;1 class=TH1D title="(reflect , neutral) : kinetic energy at exit (keV)"




```
* MIN = 32            * MAX = 10920
* ANNOTATIONS :
*  Title = energy of gammas at creation (std::log10(ekin/MeV))
Lib::DumpAction::execute : SbBin1D informations (1 objects) :
   index      height       error  entries   lowerEdge   upperEdge       name
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```
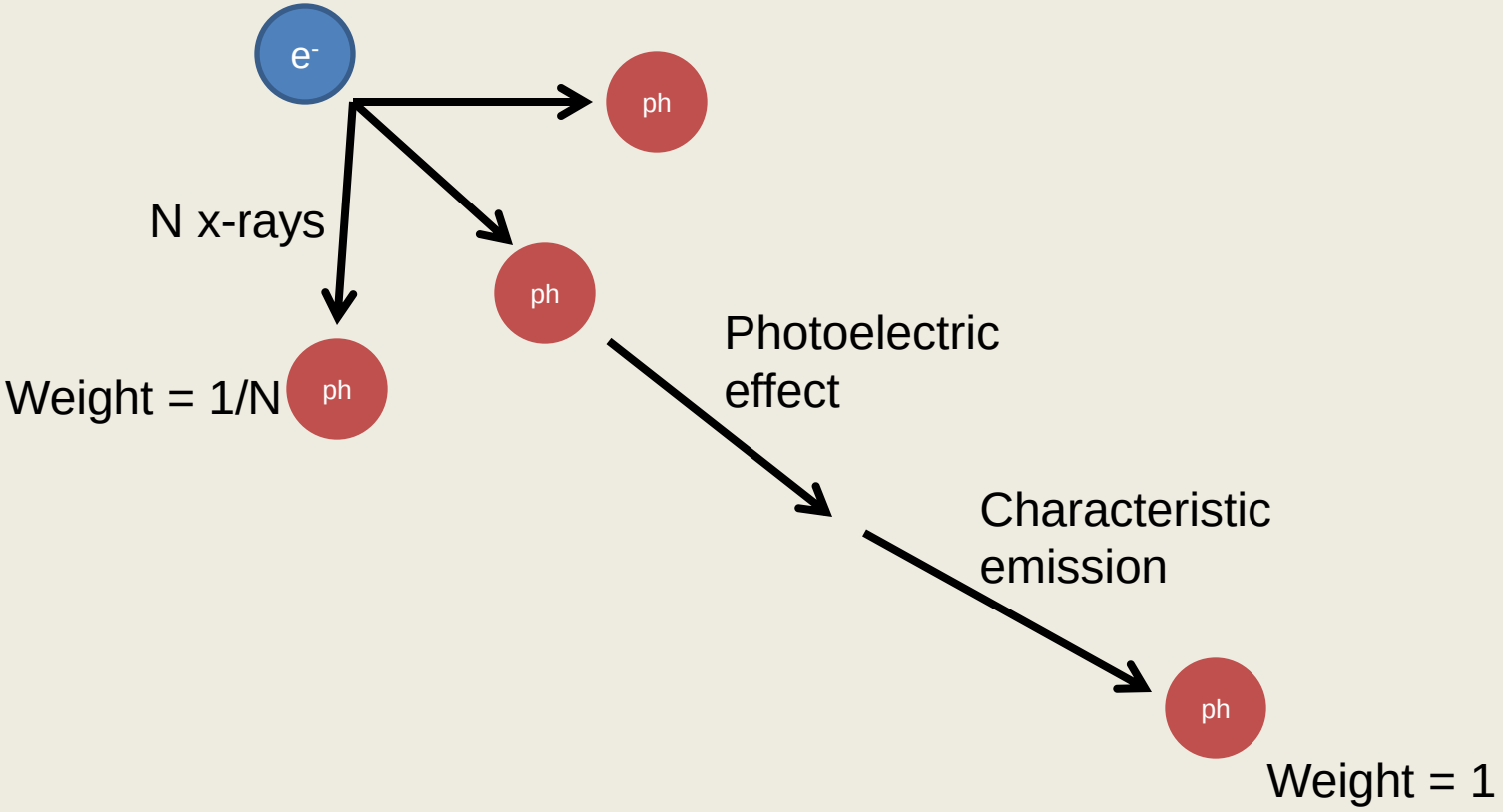

Biased Bremsstrahlung with /process/em/setSecBiasing



Biased Bremsstrahlung with /process/em/setSecBiasing

- Vladimir Ivantchenko provided a patch for this problem (April 2012).
- Patch works if applied to v9.5p1, but does not fix the issue if applied to v9.5.
  - This was also seen by another investigator.

Summary

- The task group is still working on obtaining all MC results and comparing them.
  - Hopefully I can present final results next year!
- ~Half of result comparisons up to now have shown good match
- 2 different cases need further investigation
- In 1 case (x-ray production) problems were identified with emLivermore
  - Daughter generation after atomic de-excitation is too low/non-existent
  - Splitting weights was inconsistent (patch fix ready for v9.5p1)
  - emPenelope gives correct results

Thank You

Questions?