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Title: Variance Reduction with Pulse-Height Tallies in MCNP

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Variance Reduction with Pulse-Height Tallies in MCNP

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Abstract

The forthcoming release of MCNP5 (version 1.50) will include an advanced implementation of T. E. Booth's method for estimation of pulse-height tallies in the presence of variance reduction techniques, including DXTRAN. This presentation will provide a brief, heuristic introduction to the method and illustrate the technique with a calculational example.

Developers

- Tom Booth
  - Original theory and prototype implementation.
    - *Monte Carlo Variance Reduction Approaches for Non-Boltzmann Tallies* LA–12433 (1992).
    - *Pulse Height Tally Variance Reduction in MCNP* LA–13955 (2004).
- John Hendricks and Gregg McKinney
  - First released implementation into MCNPX.
- Avneet Sood
  - General transport issues and implementation into MCNP5.
  - Analytic benchmarking.
- Jeff Bull
  - Further development, testing, and implementation for threading.
  - Implementation for MCNP5 and 6.

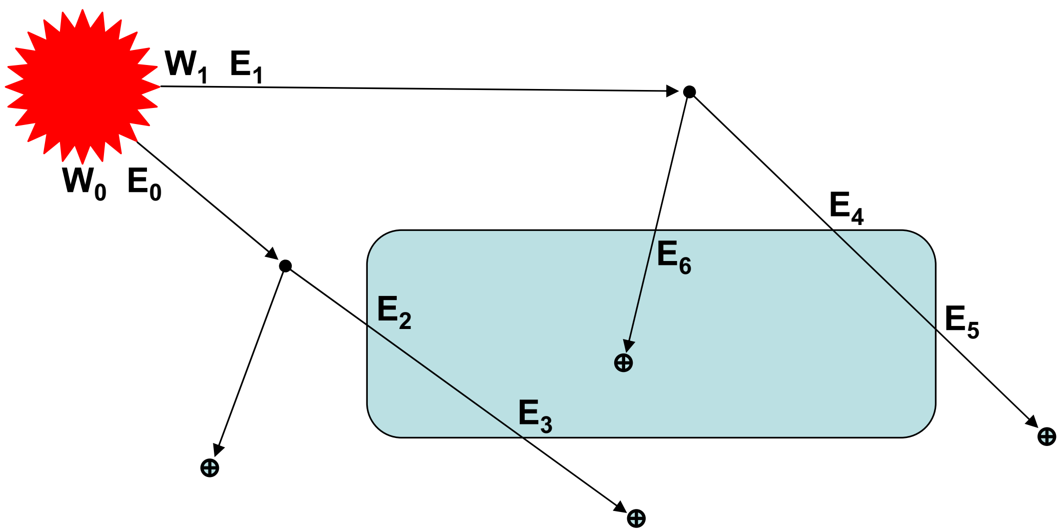
Variance Reduction Methods Supported

- Source biasing (was always allowed)
- Implicit capture and weight cutoff (CUT)
- Cell splitting/roulette (IMP)
- Cell-based weight windows (WWN, etc.)
- Weight window mesh (MESH)
- Forced collisions (FCL)
- Exponential transform (EXT)
- Energy splitting (ESPLT)
- Time splitting (TSPLT)
- DXTRAN (DXT, DD, DXC)

Algorithm before PHTVR

- During each history accumulate energy deposition by cell.
  - Add source weight*energy
  - Add entering weight*energy
  - Subtract exiting weight*energy
  - (Positrons: include 2×rest mass energy)
- After each history divide accumulation by source weight.
  - The resulting energy determines the pulse-height tally bin.
  - The source weight is the contribution to that bin.
- After transport divide tally by total source weight.
- Result is “fraction of source weight resulting in various amounts of energy deposition” *i.e.* “counts.”
- This algorithm works correctly only for analog problems.
  - (Except that source biasing is allowed.)

What does a pulse-height tally measure?



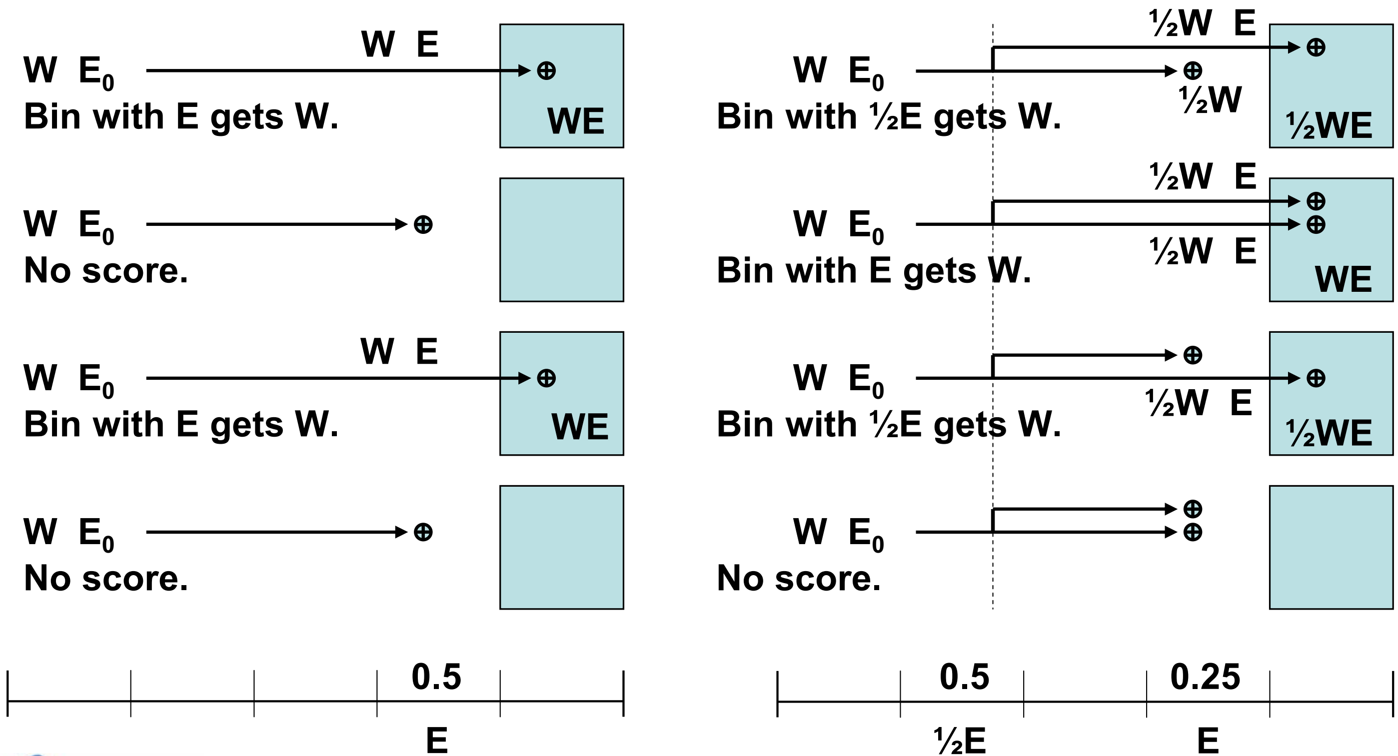
Contributions: W_0 in energy bin containing $E_2 - E_3$

W_1 in energy bin containing $E_4 - E_5 + E_6$

Why Ordinary Variance Reduction Fails

Analog

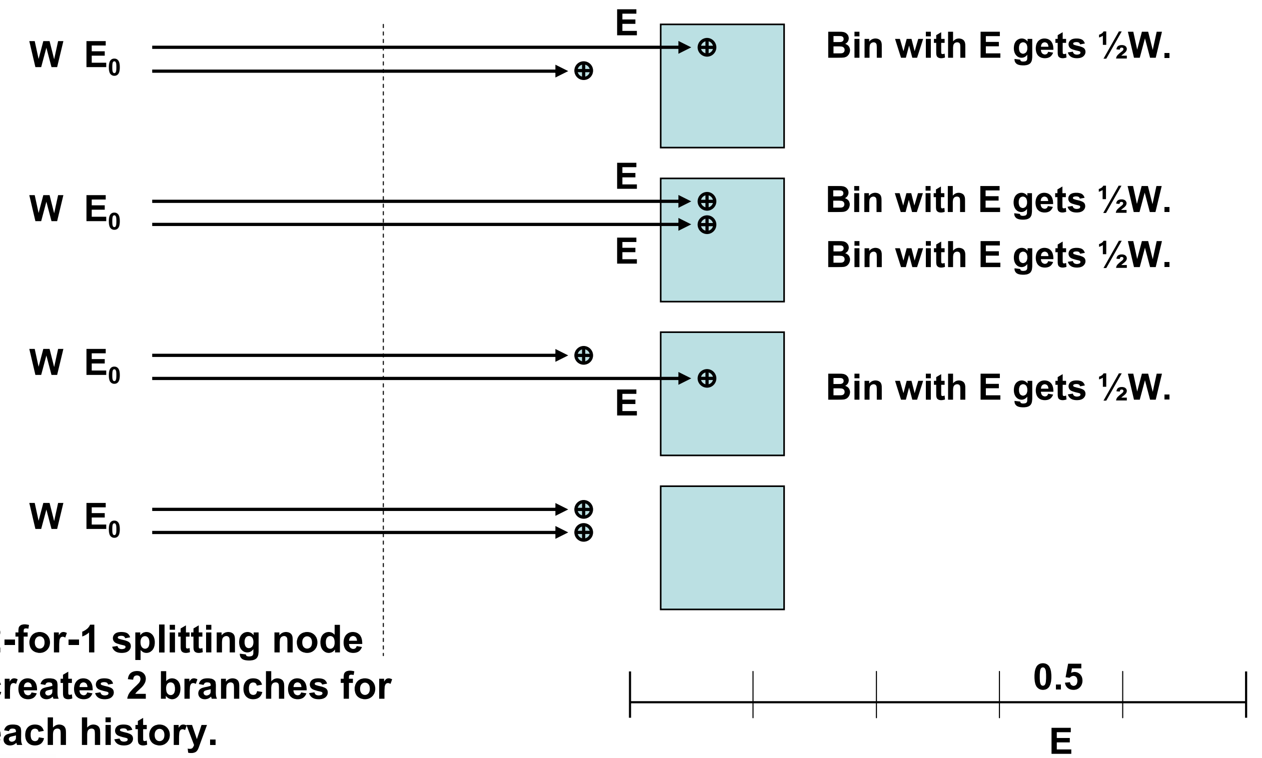
Cell Importance



Branches = Physically Realizable Tracks

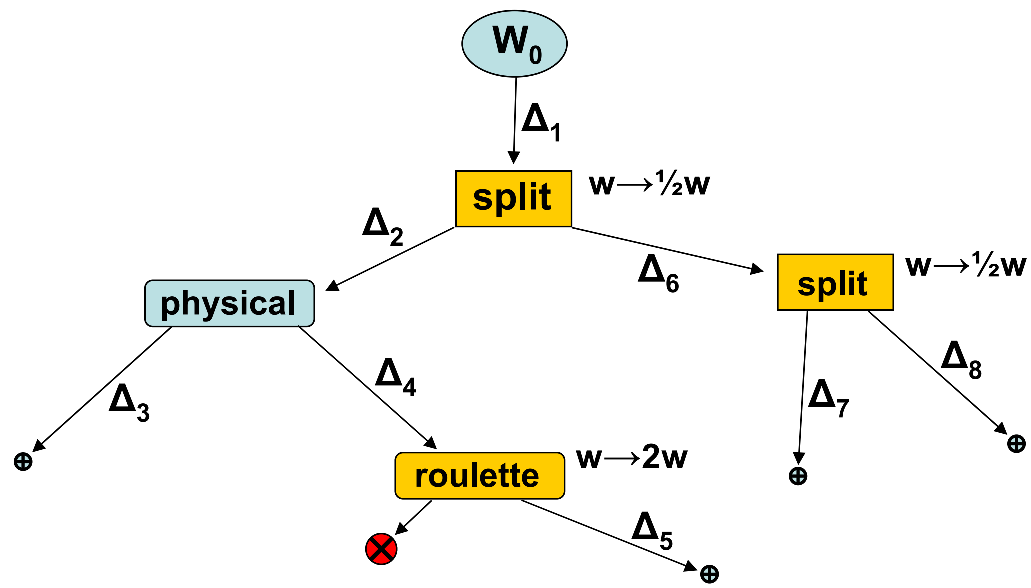
Euratom VI Framework Programme

Each branch weight = ½



2-for-1 splitting node creates 2 branches for each history.

View a history as a tree



Energy bin containing $\Delta_1 + \Delta_6 + \Delta_7$ gets $\frac{1}{4}W_0$
Energy bin containing $\Delta_1 + \Delta_6 + \Delta_8$ gets $\frac{1}{4}W_0$
Energy bin containing $\Delta_1 + \Delta_2 + \Delta_3 + \Delta_4$ gets 0
Energy bin containing $\Delta_1 + \Delta_2 + \Delta_3 + \Delta_4 + \Delta_5$ gets W_0

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New Approach to History Tracking

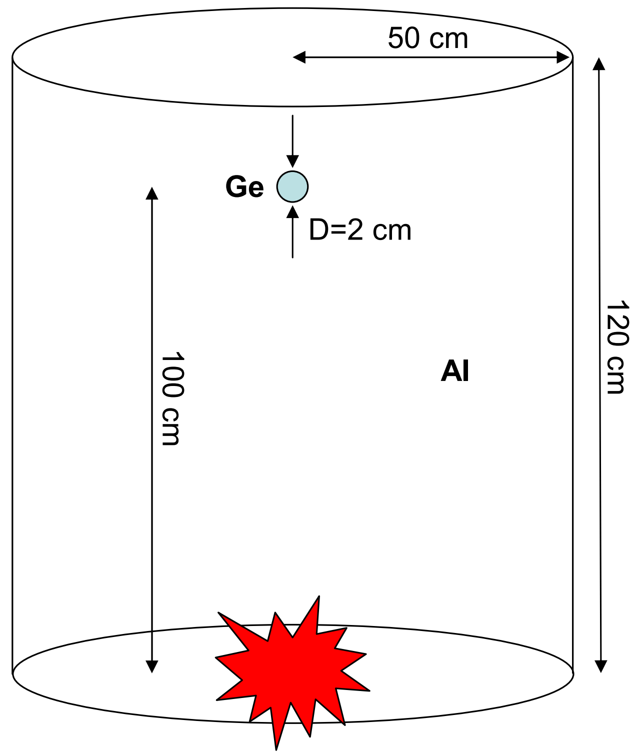
Euratom VI Framework Programme

- Selected pieces of entire history must be kept in memory.
- With PHTVR a single history becomes a collection of separate physically-realizable branches.
- Physical nodes are distinguished from variance-reduction nodes.
- Roulette introduces some potential complexity.
- DXTRAN (which includes roulette) introduces much greater complexity.
- PHTVR is a natural application of tree structures.

An Example with Variance Reduction

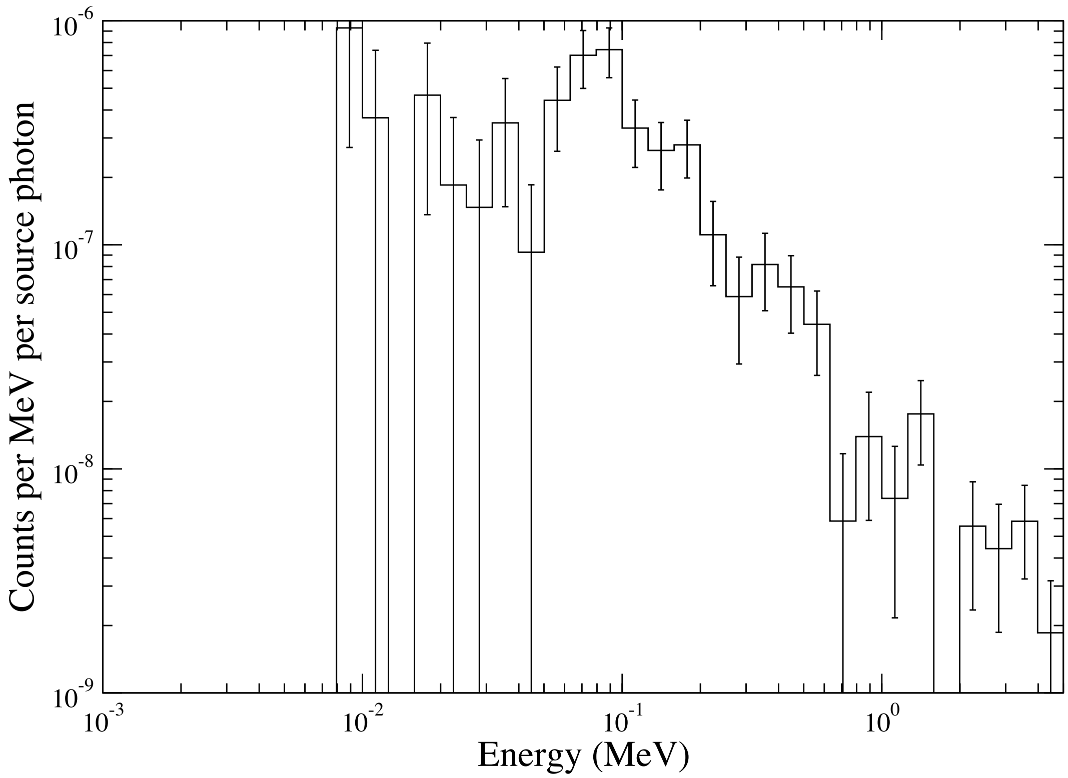
Euratom VI Framework Programme

```
PHT with weight windows.
1  21 -2.7   -11 12  imp:p = 1
2  22 -10.0  -12     imp:p = 1
3   0          11    imp:p = 0

11 RCC  0   0  0   0  120  0   50
12 SPH  0 100  0   1

wwp:p  j j j j -1
mode p
mesh geom=rzt ref 0 .1 0 axs 0 1 0
origin -.1 -.1 -.1 imesh 50.2 iints 5
jmesh 120.2 jints 12 kmesh 1
m21    13000 1     $ aluminum
m22    32000 1     $ germanium
sdef  erg 5 pos 0 .01 0
f8:p 2
e8   0  1.0e-06  .001  39ilog  10.
```



Point isotropic source
5-MeV photons

Results of an Analog Calculation



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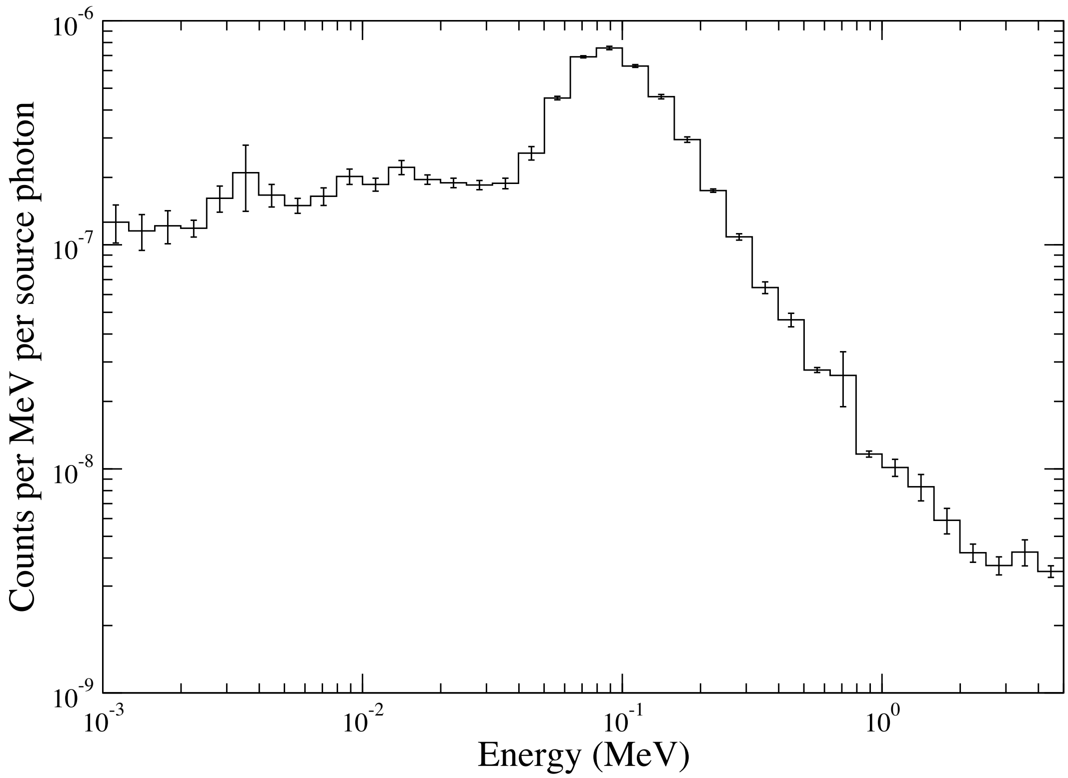
Results with Weight Windows



Testing

- Regression test set with 215 problems
  - Compare with analog results
  - Compare with MCNPX where applicable
  - Compare different VR techniques
- Internal structure tests
  - Valid tree structure
  - Array bounds checking
- Analytical test problems
  - Report by Avneet Sood forthcoming

Restrictions and/or Future Work

- No PHYS:E card variance reduction techniques
  - B_{NUM}, X_{NUM}, R_{NOK}, and E_{NUM}
    - Changed to unity unless set to zero by user
  - No NUM_B biasing
- Only one DXTRAN sphere
- Non-analog physics still not addressed (e.g. neutrons)