

Krzysztof Genser/Fermilab

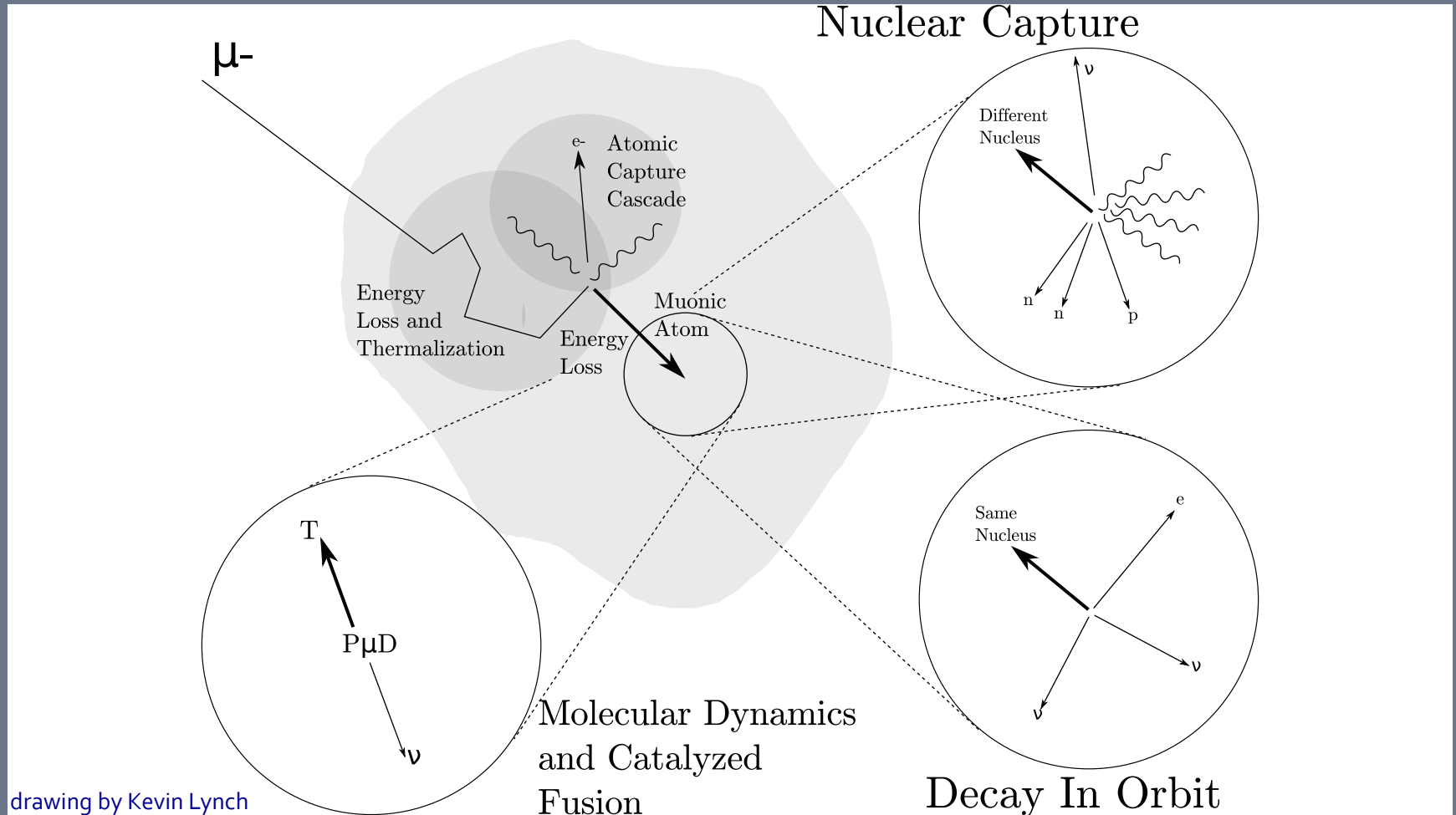
18th Geant4 Collaboration Meeting
Seville, September, 2013

Muon Stopping Progress Report

Outline

- Recent History/Changes
- Validation Results
- Plans

Muon Capture Physics



drawing by Kevin Lynch

Changes in muon capture since 9.5.p02

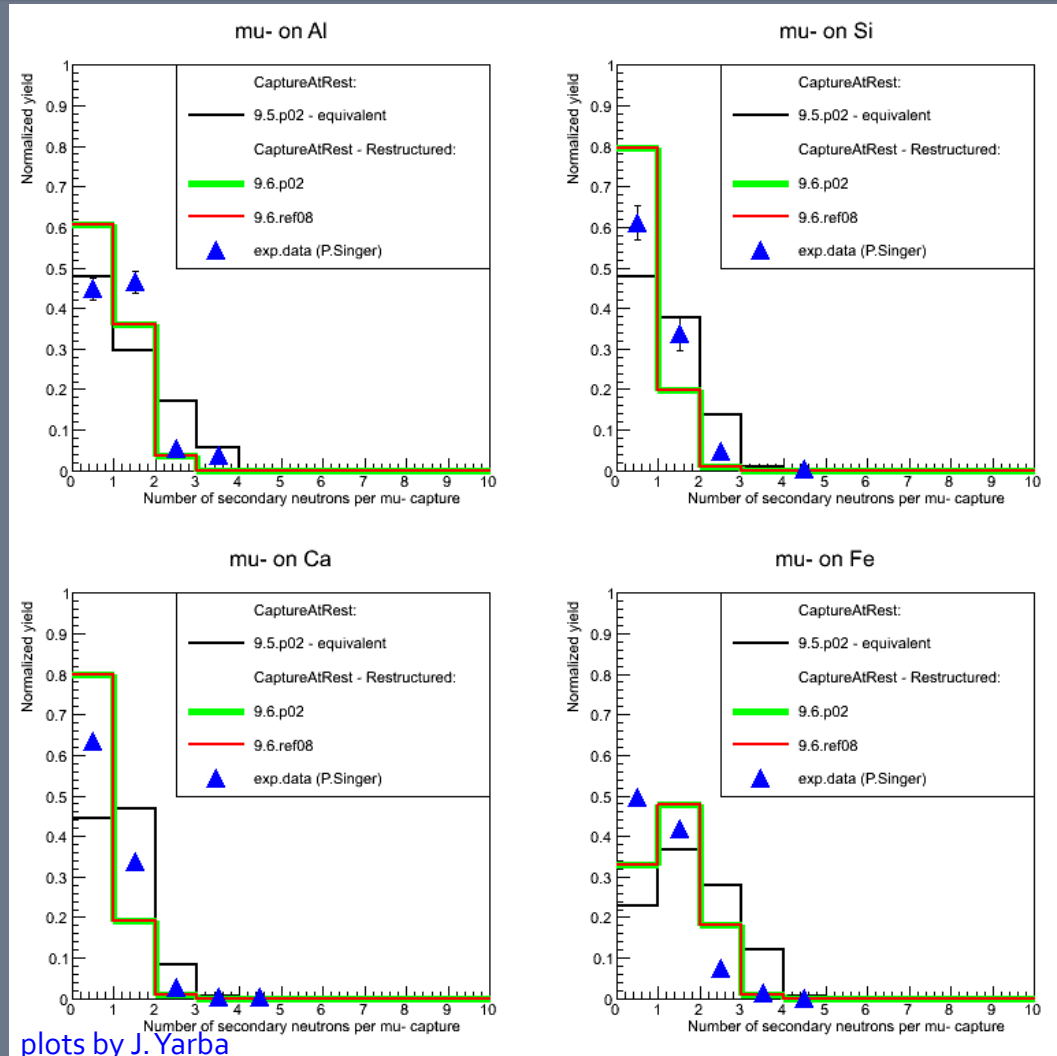
- V. Ivanchenko responding to K. Lynch's proposal had restructured/rewrote the Muon Stopping code to make it more modular
 - the code was subsequently slightly modified and extended along the lines described at the last collaboration meeting (see my talk "Muon Stopping Discussion" there) to allow for user extensions to the code and an input of experimental data
 - validation was performed and it (**G4MuonMinusCapture**) became part of the 9.6 release and "production" physics lists

Changes in muon capture since 9.5.p02 – cont'd

- Since the AlCap experiment was delayed (where the input data about secondaries released after muon capture is to come from) the urgency of further code modifications decreased
- Instead, responding to user reports, Bound Muon Capture and Decay Rate Functions were corrected and improved

Muon Stopping Validation

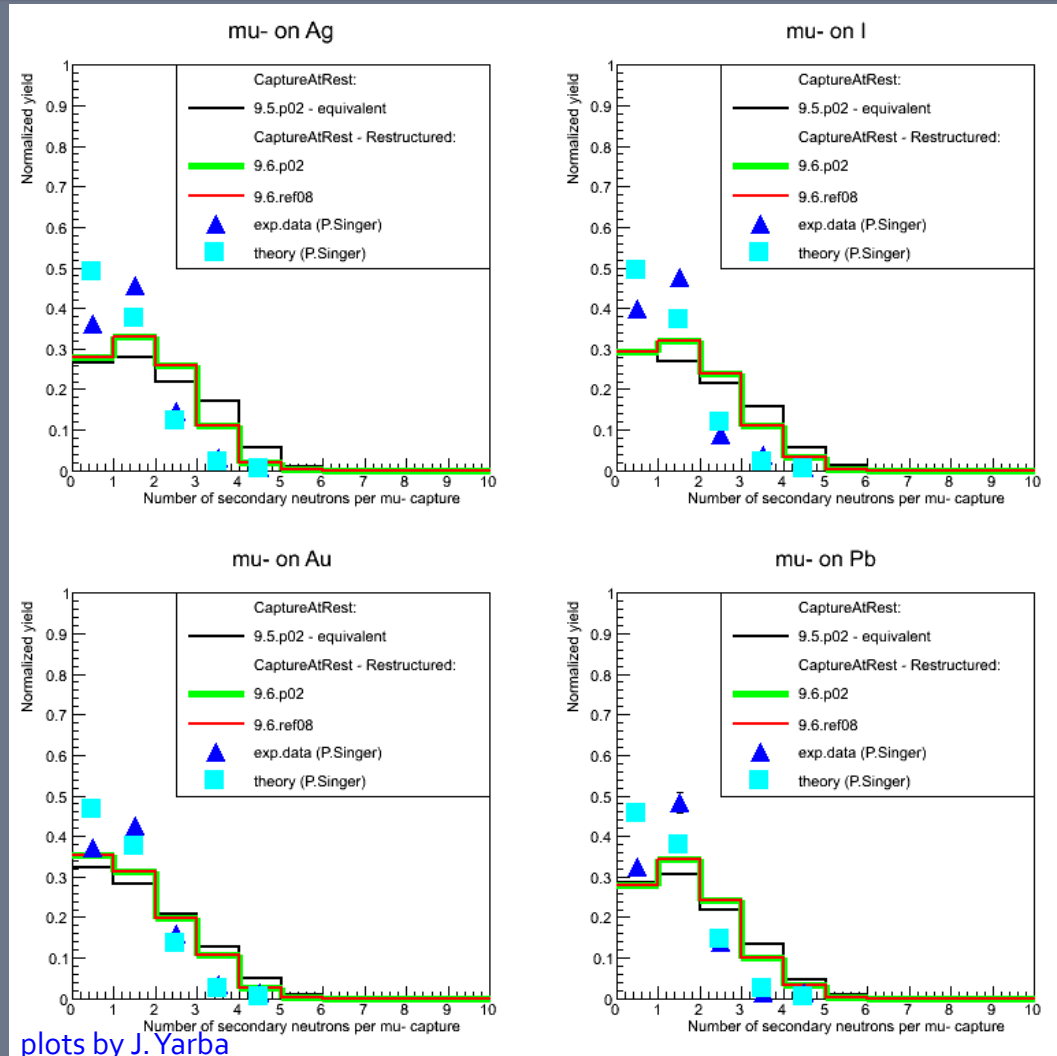
- Number of secondary neutrons per muon capture data/theory points from P. Singer, Springer Tracts in Modern Physics, 71, 39 (1974)



plots by J. Yarba

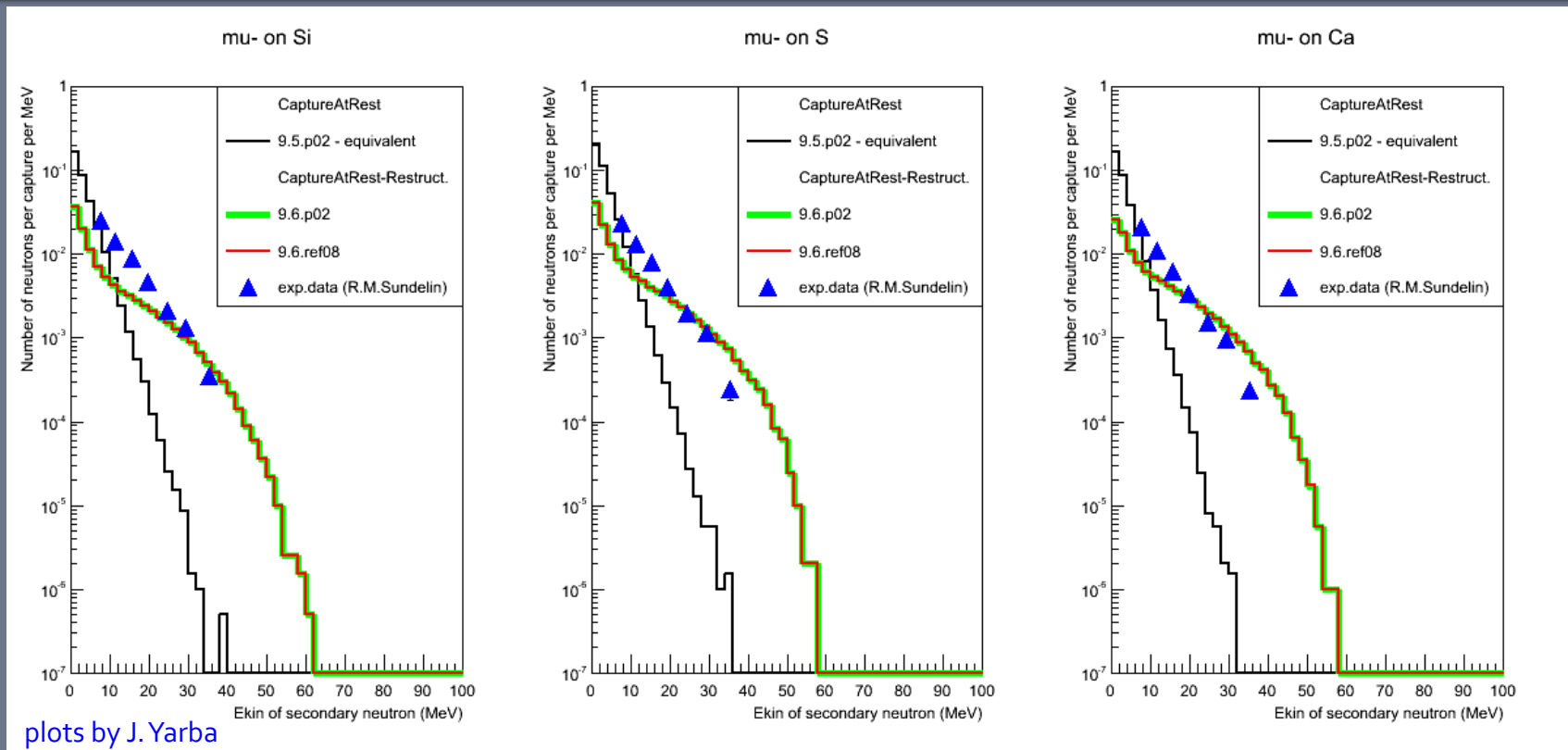
Muon Stopping Validation – cont'd

- Number of secondary neutrons per muon capture data/theory points from P. Singer, Springer Tracts in Modern Physics, 71, 39 (1974)



plots by J. Yarba

Muon Stopping Validation – cont'd



kinetic energy of secondary neutrons

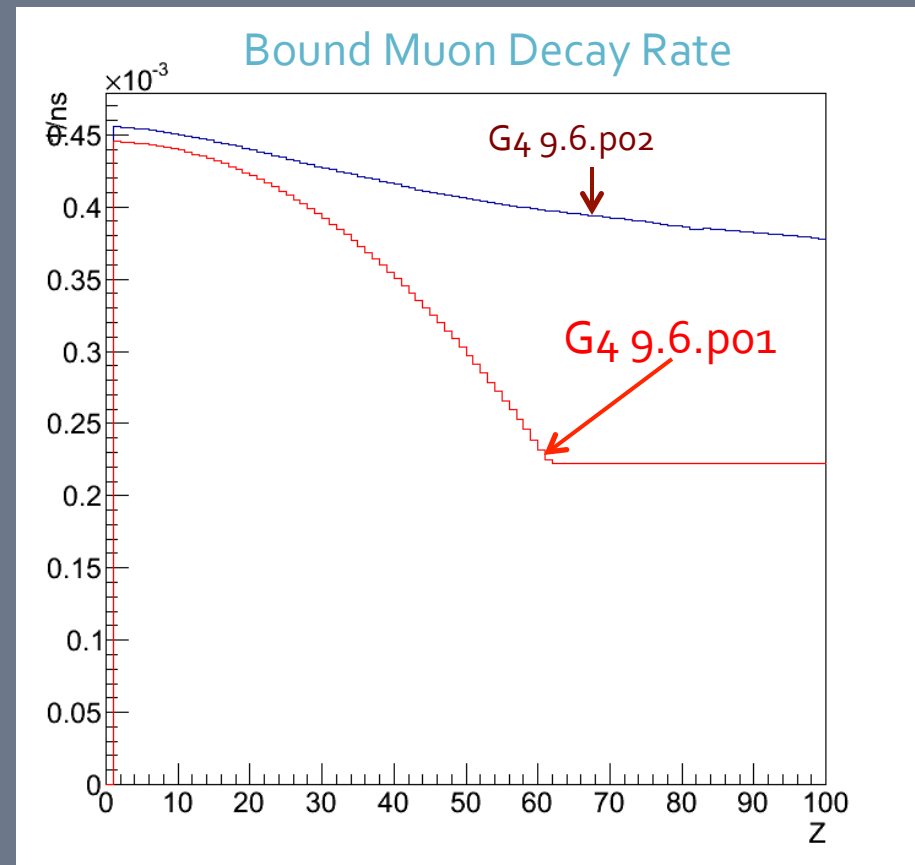
data from R.M.Sundelin et. Al., Phys.Rev.Lett., Vol.20, Number 21, 11

Changes to Bound Muon Capture and Decay Rate Functions

- There were some problems with bound muon capture and decay rate functions
 - The formula used to calculate the capture rate was returning values which were significantly too low; Indices used to lookup the Capture Rate were shifted by 1 for $Z < 79$ in the newer `G4MuonsBoundDecay`; in the old `G4StopElementSelector` the lookup was shifted by 1 for $Z \geq 79$
 - The bound muon decay rate was quite low especially for nuclides with higher atomic number Z
 - the capture rate dominates decay rate at higher Z , so the total effect was not that significant

Changes to Bound Muon Capture and Decay Rate Functions – cont'd

- The decay rate formula was corrected assuming the Z was the so called effective Z (Z_{eff}) as “seen” by the muon; (current PDG2012 muon lifetime was used)
 - the updated formula when normalized to the free muon decay rate is within $\sim 4\%$ of the Huff factor for a given Z

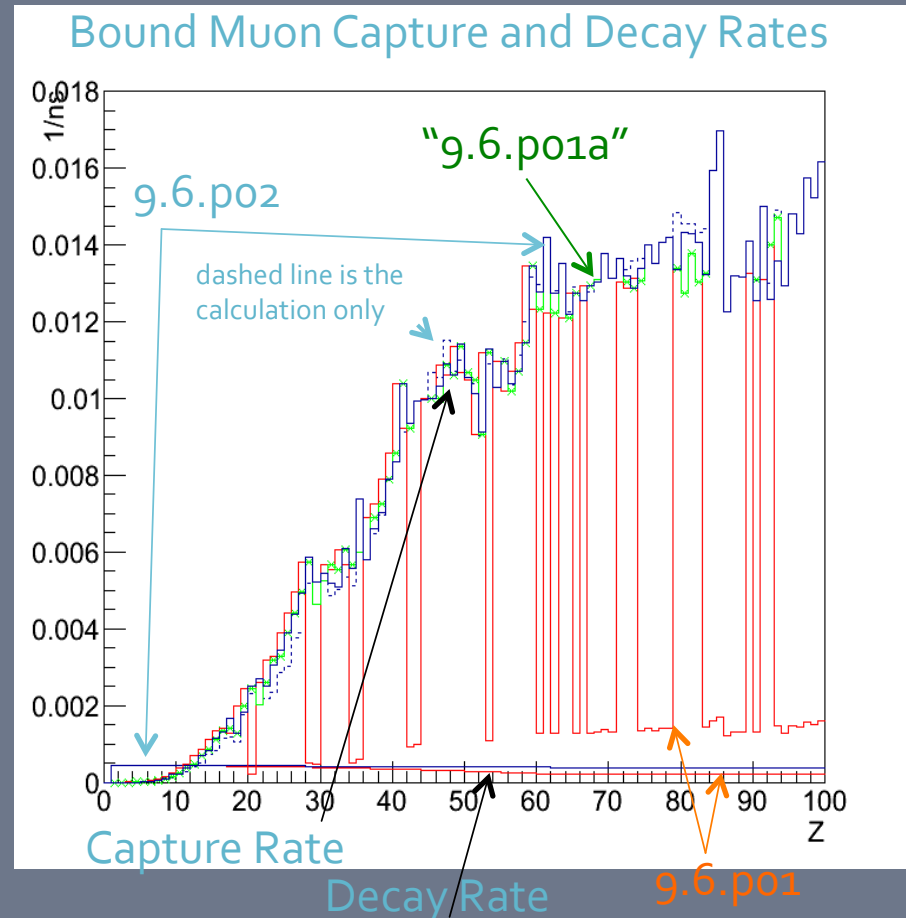


Changes to Bound Muon Capture and Decay Rate Functions – cont'd

- The capture rate data arrays used for lookup were replaced with a different data structure taking both Z and A into account (the rate does depend strongly on A for a given Z)
 - the new data structure (an array of structs) should be easier to maintain
- the data was updated based on review paper:
 - T. Suzuki, D. F. Measday, J.P. Roalsvig Phys.Rev.C35:2212,1987 (existing H and He data were kept as they were newer)
 - the capture rate used is a weighted average of the two most accurate measurements
 - although not used, the measurement uncertainty is included in the new data structure for completeness and for potential future use

Changes to Bound Muon Capture and Decay Rate Functions – cont'd

- The capture rate formula was corrected as suggested by J.Miller, Y.Oksuzian/Muze (multiplied by factor of 10)
 - lookup was corrected for for all nuclides including those with $Z \Rightarrow 79$
- the old class `G4StopElementSelector` was modified to call the new functions from `G4MuonsBoundDecay`
 - the rate and Z_{eff} functions were declared public



(capture rate is a weighted average over the mass number A)

Plans

- Short term:
 - Be ready for the data from the AlCap experiment (summer?)
 - study of muon capture for muon to electron conversion experiments, at PSI
 - initially charged particle (p , d , α) emission after muon capture on Al, Ti, Si)
- Longer term:
 - Follow ideas from Kevin's original proposal, to be able to simulate muon capture on lighter targets
 - Introduce "transportable" light muonic atoms and molecules
 - H, D, T, He₃, and He₄, P-mu-P, ...
 - include proper spin treatment

Summary

- The rewritten by Vladimir last year **G4MuonMinusCapture** code was slightly modified and extended to allow for user extensions and an input of experimental data
 - validation was performed and it became part of the 9.6 release and “production” physics lists
 - more work to be done to incorporate expected AlCap data
- Bound muon capture and decay rate functions were corrected and extended
 - the capture and decay rate formulas were corrected
 - data from a newer review paper was used
 - the new capture rate lookup tables take both Z and A into account (the rate is a strong function of A for a given Z)