Validation of proton range in Water

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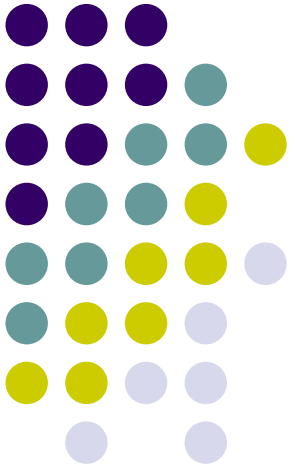
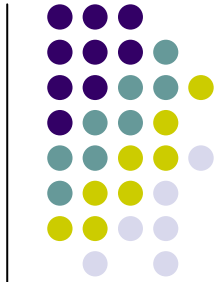
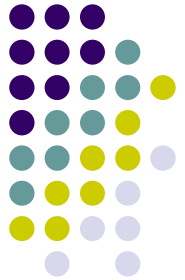
JST CREST



History



- One of important physics value in hadron therapy is “Range”, because it is directly relevant to patient treatment
  - Simulated Bragg peak should agree with the measurement
    - Bragg peak = dE/dX(Range) + MSC + Fragmentation + Nozzle materials + ….
    - e.g < 1 mm discrepancy
  - “Range” of simulation should agree with ICRU/NIST prediction based on a calculation of integrating stopping power function
    - Basically, simulation uses these stopping power function for dE/dX calculation
    - Must agree with each other in high precision (e.g. < 0.5 mm discrepancy)
- We found strange behaviors about proton range.
  - Connectivity of stopping power functions at transition energy.
  - Energy fluctuation calculation

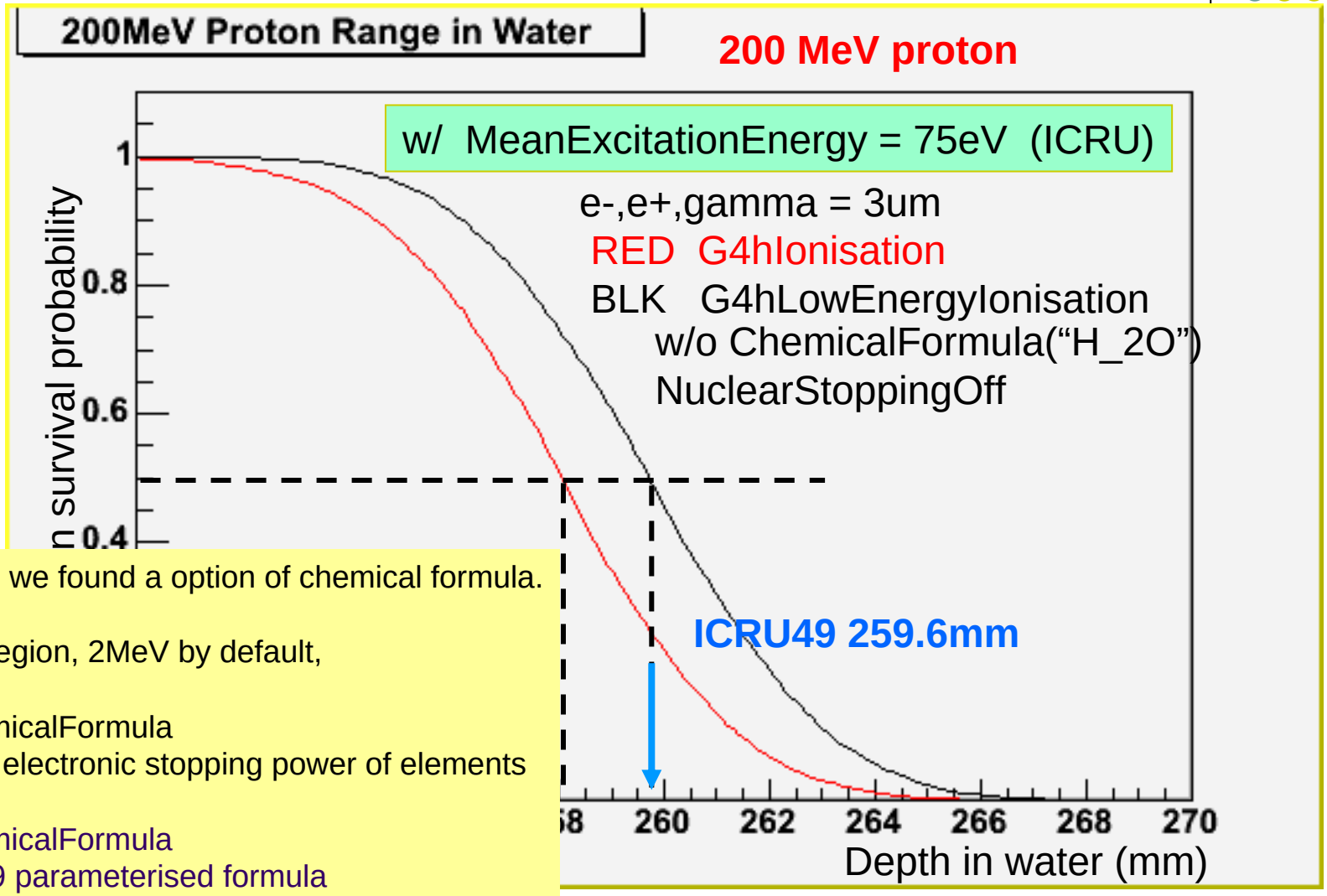


Stopping power function connectivity

Proton Range in Water

Ionisation process only

G4v7



However, we found a option of chemical formula.

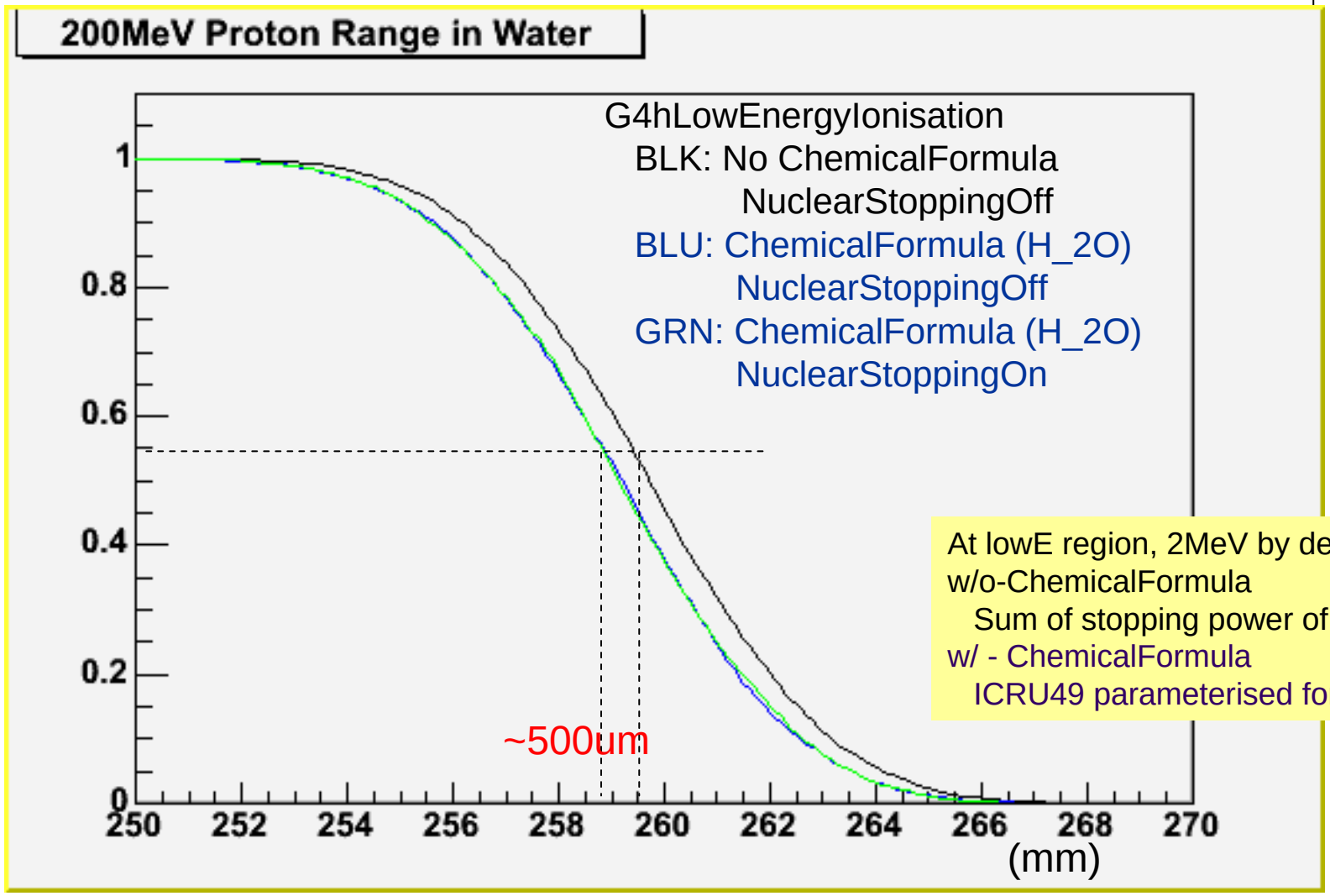
At lowE region, 2MeV by default,

w/o-ChemicalFormula
Sum of electronic stopping power of elements

w/ - ChemicalFormula
ICRU49 parameterised formula

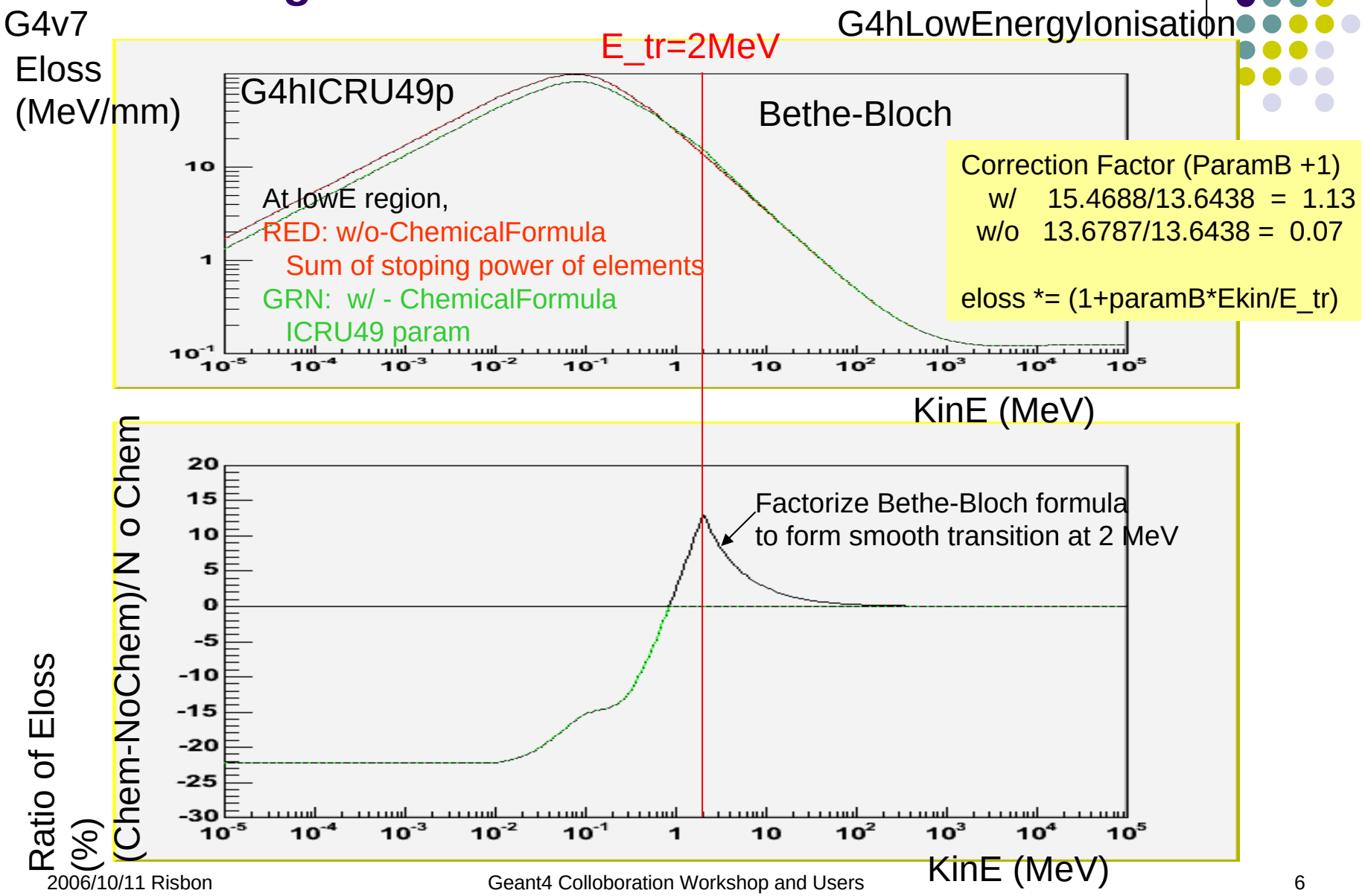
Proton Range in water - ChemicalFormula -

G4v7



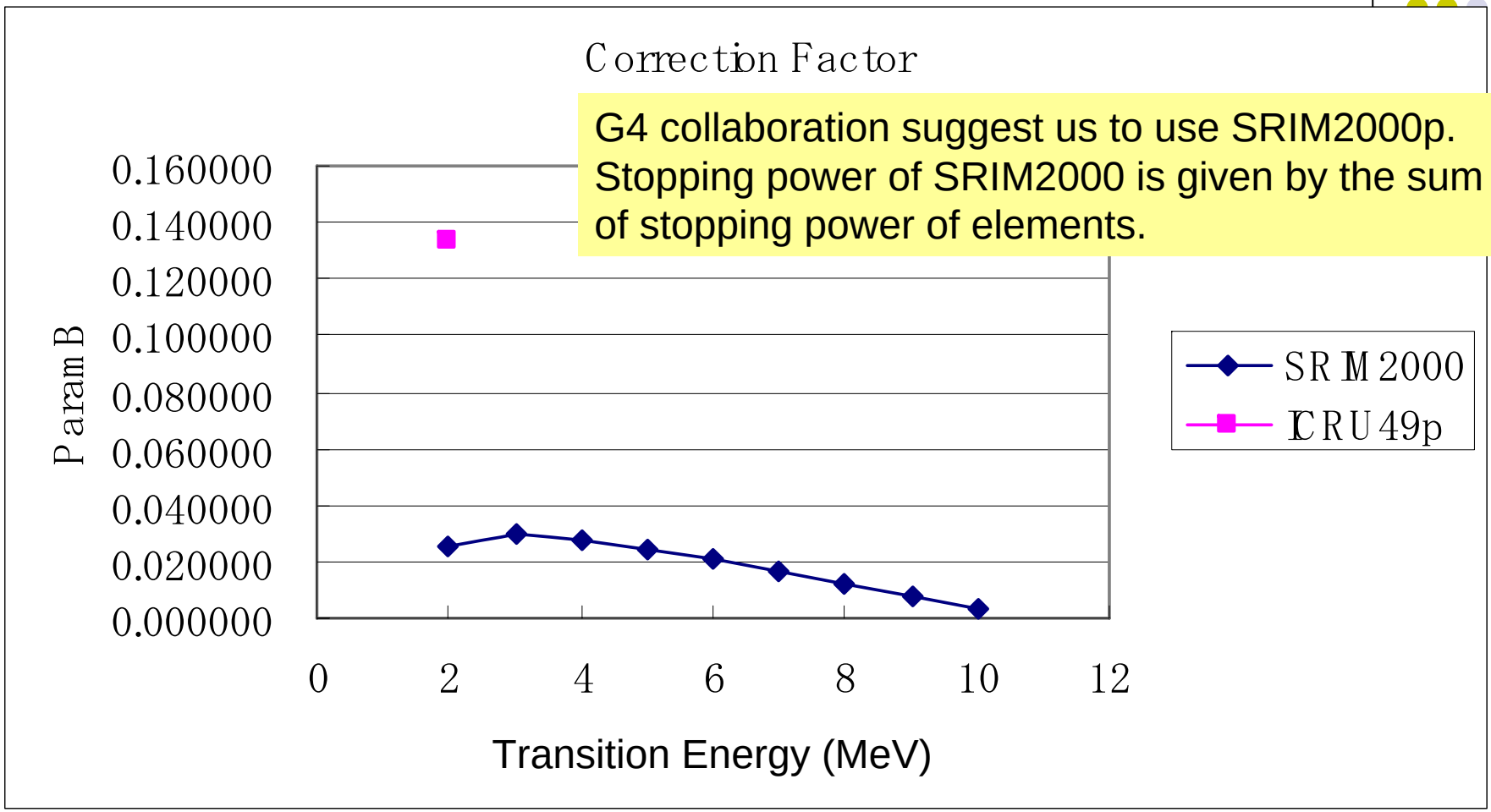
At lowE region, 2MeV by defult,
w/o-ChemicalFormula
Sum of stopping power of elements
w/ - ChemicalFormula
ICRU49 parameterised formula

Proton Range in water - Ionization Loss Table -



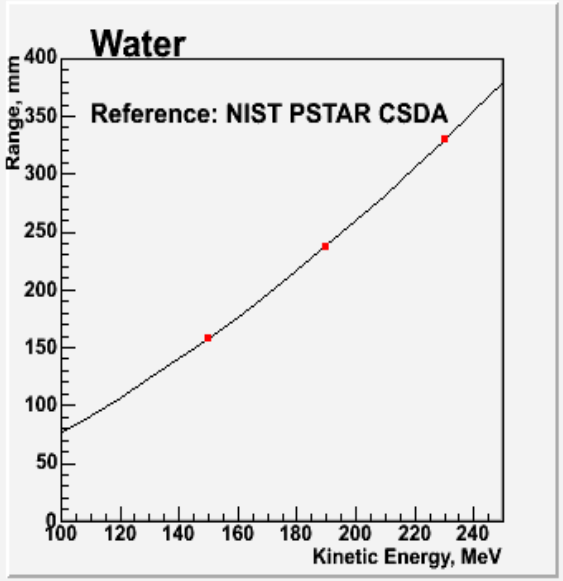
Correction Factor: ParamB

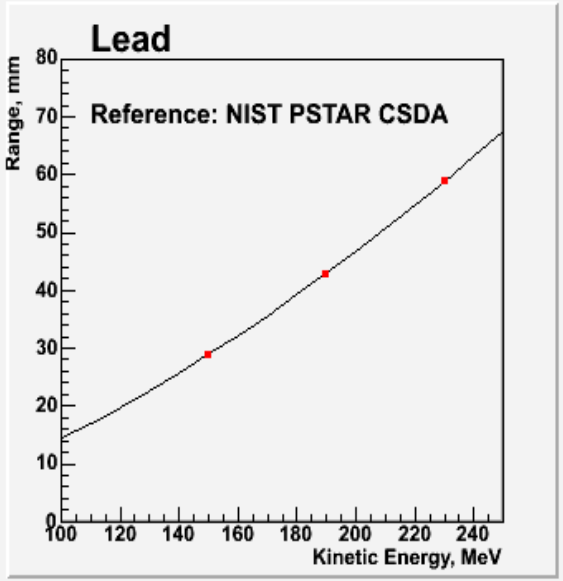
G4v7

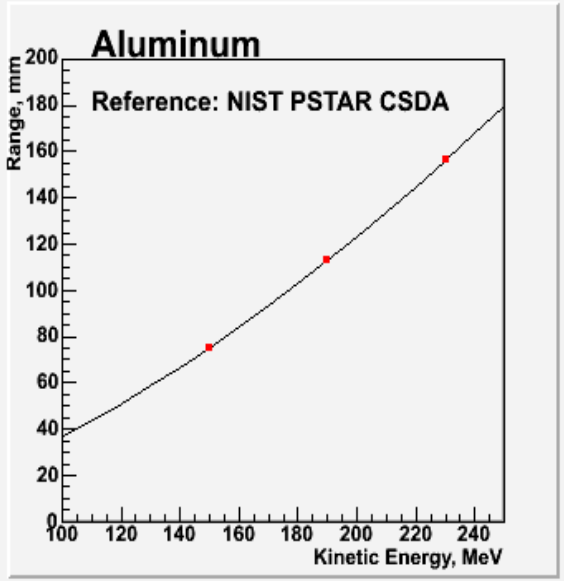


Material Validation: Range of protons

G4v7





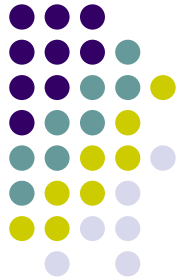


Ranges of proton are obtained in the simulation by switching off all processes except for ionization process.

As a reference, the PSTAR program (National Institute of Standards and Technology, NIST) was used for comparison.

The ranges obtained from Geant4 simulation are good agreement with reference values.
The agreement is better than 0.1%, 0.3%, and 0.2% for water, lead, and aluminum, respectively.

Lines : PSTAR NIST
Red symbols: Simulation

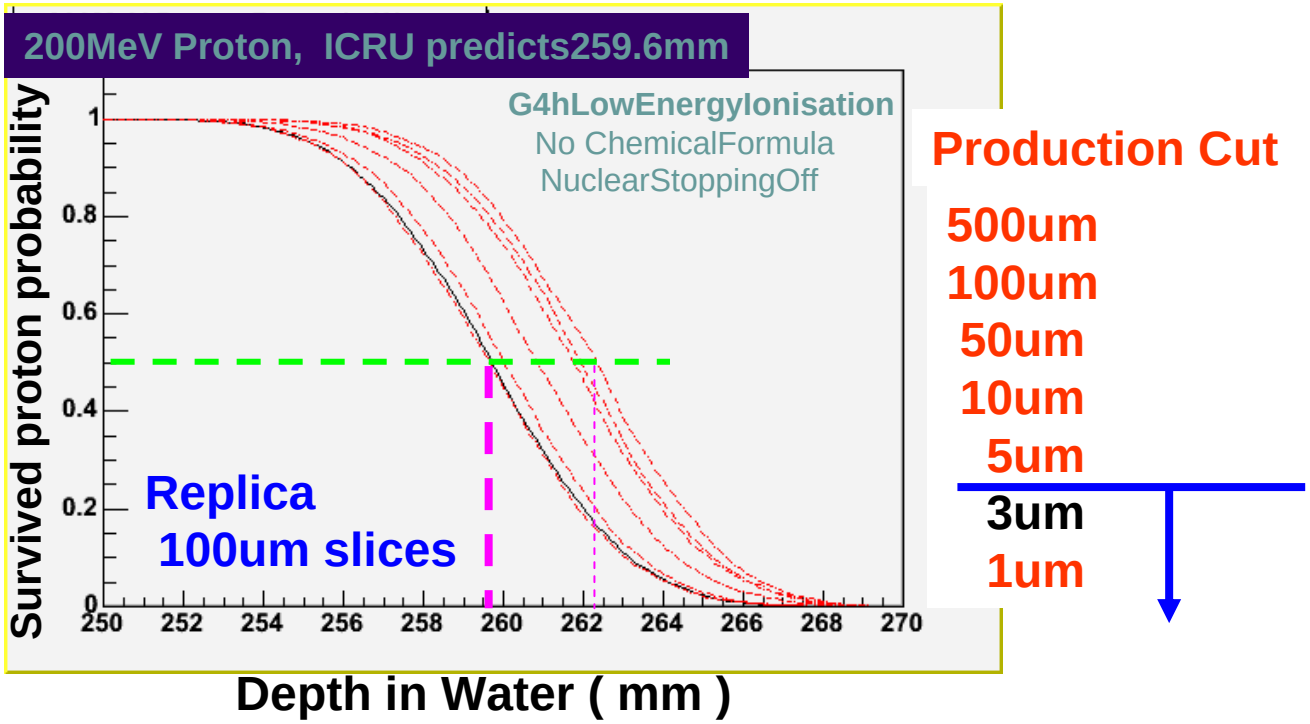


Range cut / step limit

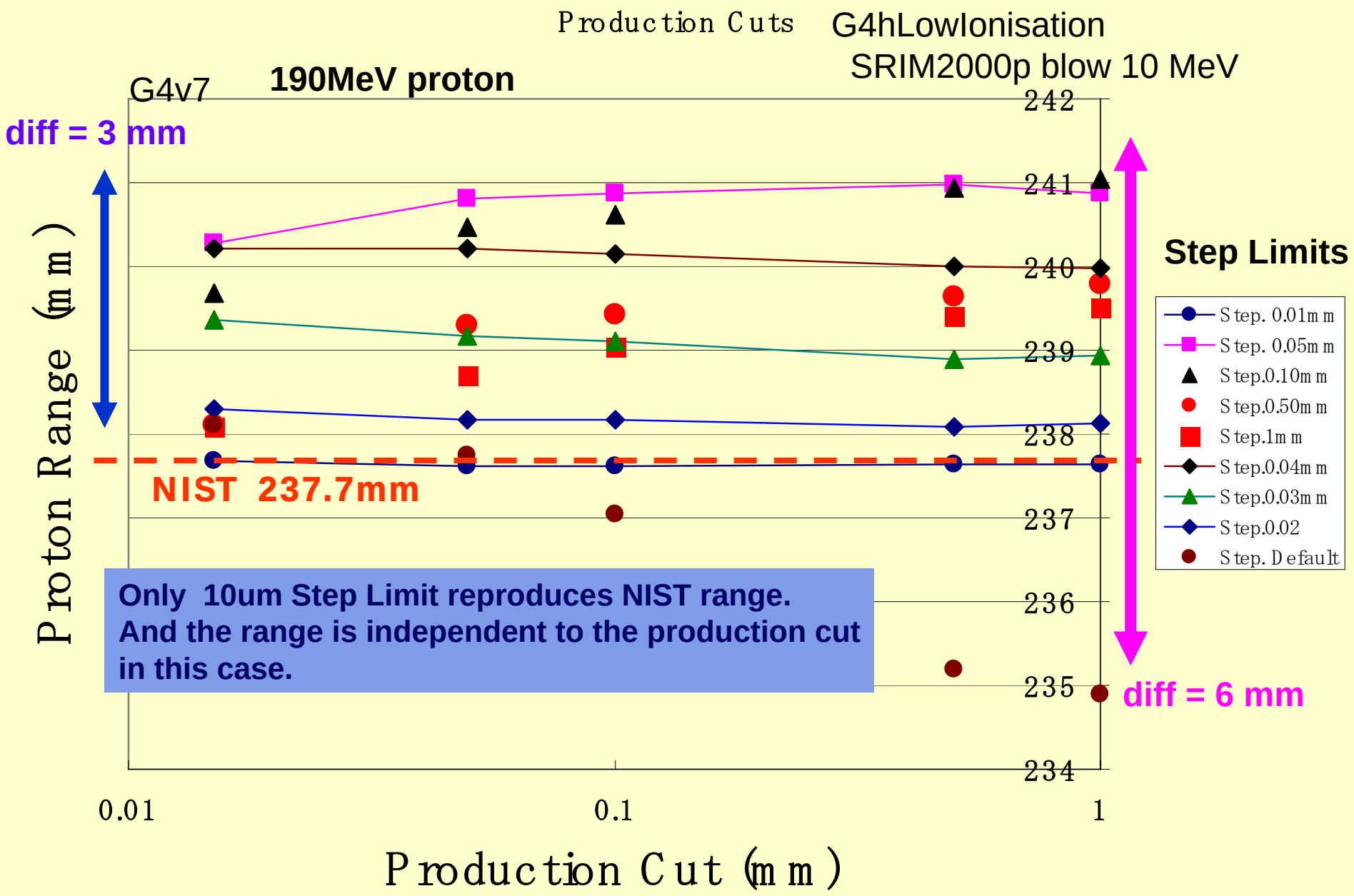
Objective

- Hadron therapy using protons for cancer treatment requests better than 1% agreement with measurements and ICRU/NIST protocol data.
- We had reported a proton range shift problem in water about 3 year before. e.g. the range of **200 MeV** proton become longer about 3 mm than NIST prediction by applying a long production cut.

G4v7

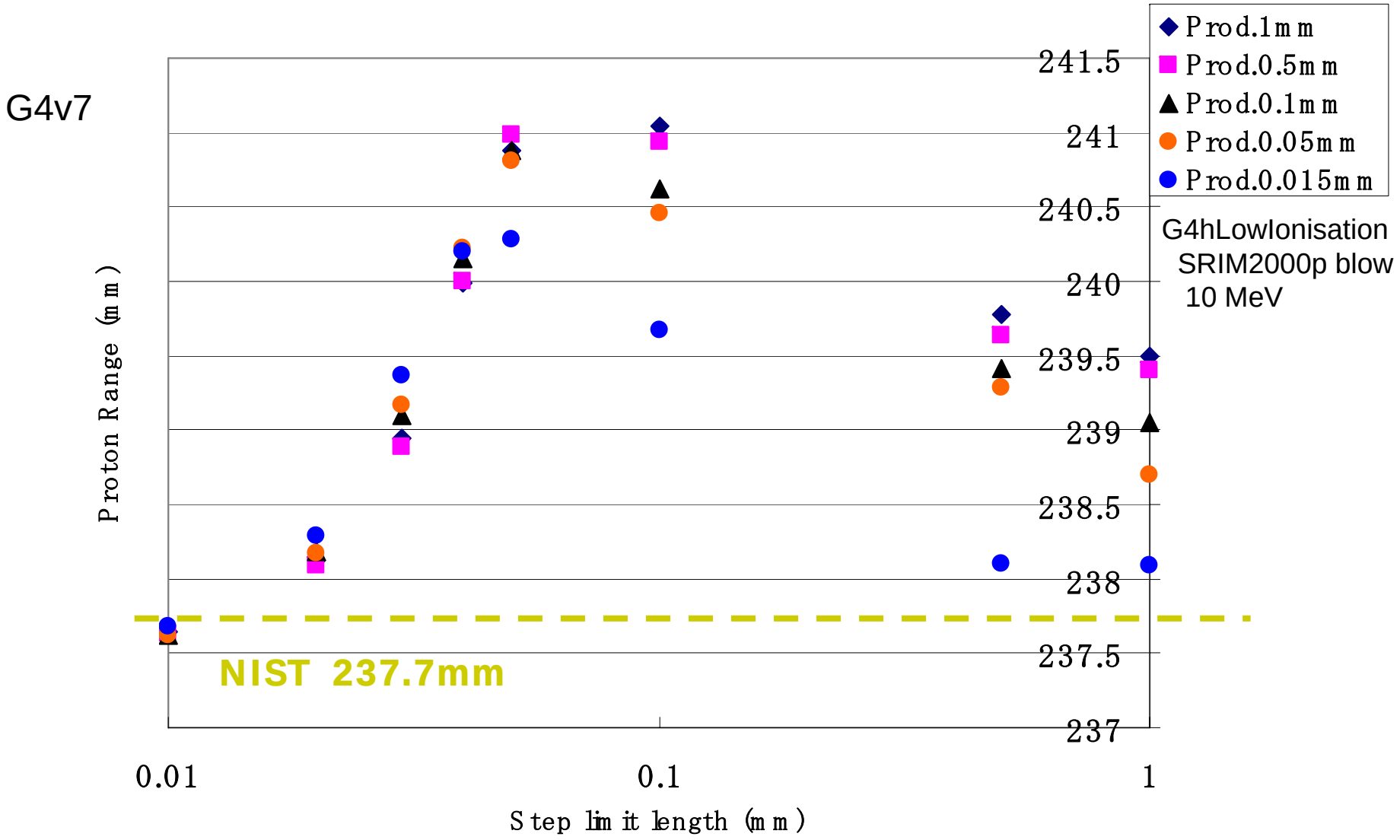


Proton Range in bulk water



Proton Range in bulk water

Simulated Range changes with the step limit size.
Range becomes longest when step limit was set around 100um.



Ranges in various settings

G4v8.p01

- 225 MeV protons
- 500um thick sliced water phantom
- NIST prediction = 317.4 mm

Production Cut	Step Limits	Rang
10 mm	Default(500um)	320.6
1mm	Default(500um)	320.689mm
1mm	10 um	317.716mm
1mm	100 um	322.465mm
10mm	100 um	322.475mm

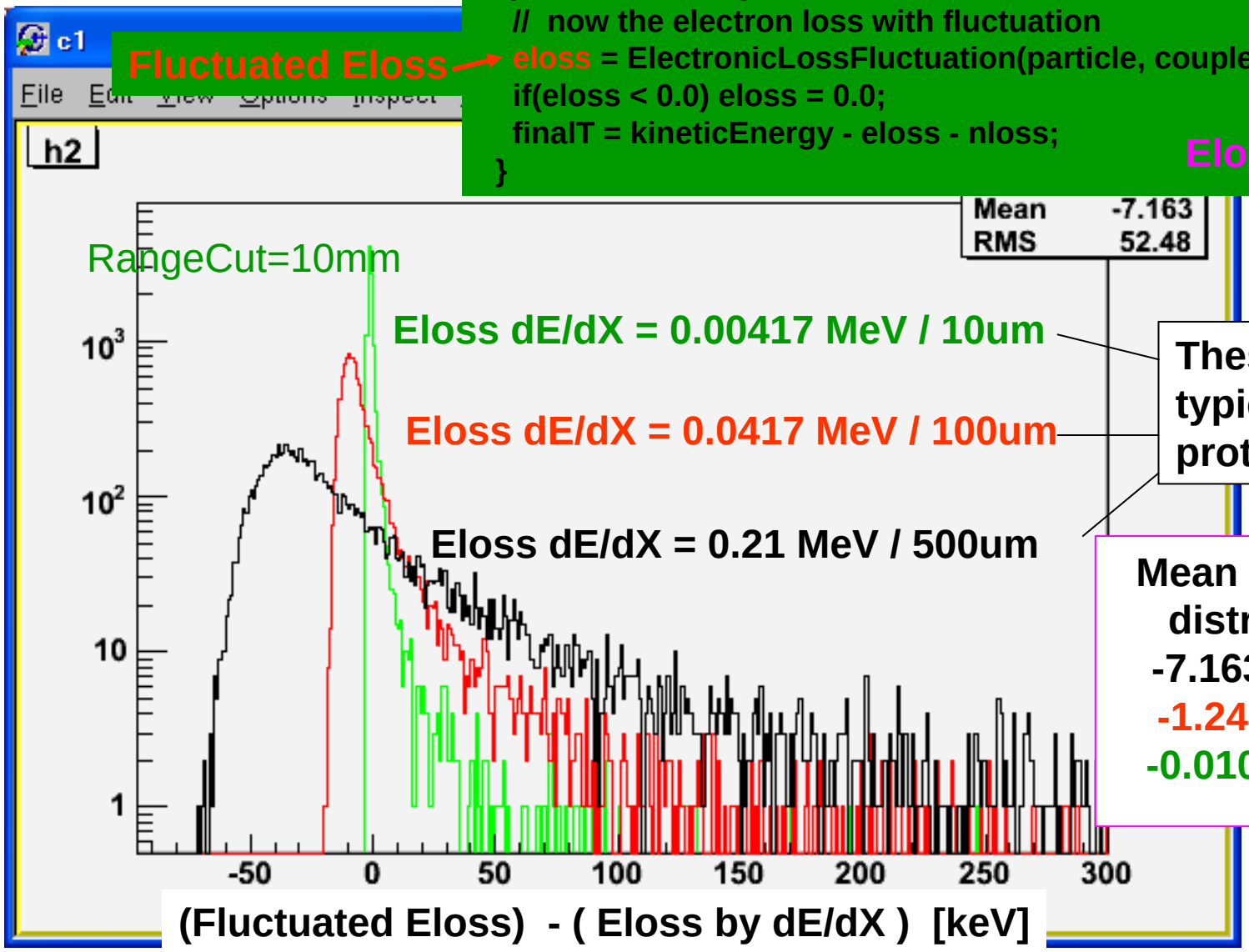
ElectronicLossFluctuation calculates less energy loss than the mean energy loss calculated by dE/dX table!!

ElectronicLossFluctuation

```
if( EnlossFlucFlag && 0.0 < eloss && finalT > MinKineticEnergy) {
  //  now the electron loss with fluctuation
  eloss = ElectronicLossFluctuation(particle, couple, eloss, step) ;
  if(eloss < 0.0) eloss = 0.0;
  finalT = kineticEnergy - eloss - nloss;
 }
```

Fluctuated Eloss

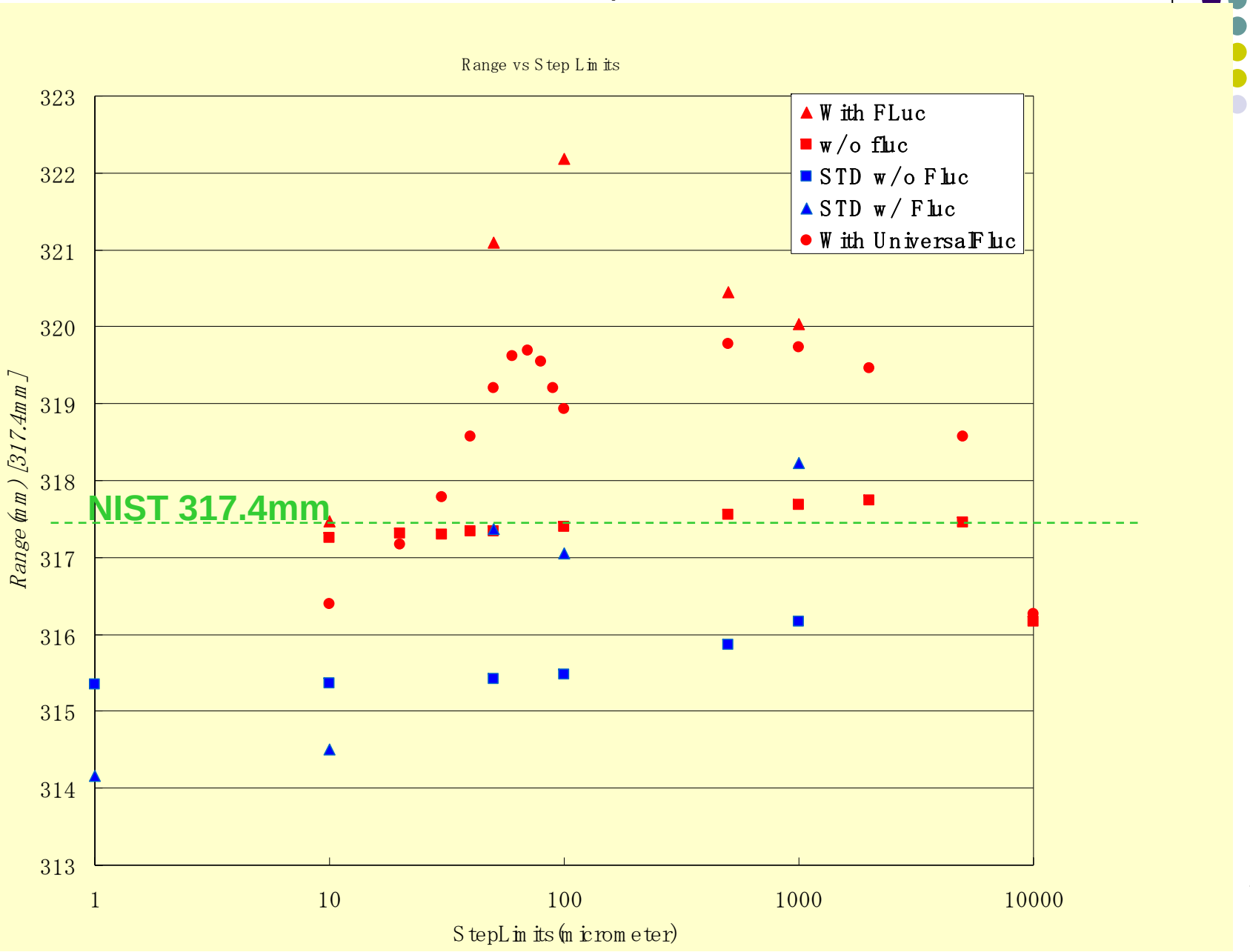
Eloss by dE/dX Table



These values are typical for 225MeV proton

Mean value of these distributions are:
-7.163 (keV)/500um
-1.244(keV)/100um
-0.01013(keV)/10um

Range (2) 225 MeV proton in Water



Summary/Discussion

- Import stopping power function
  - Low EM has many options of parameterization at low energy region and has capability to change the transition energy between Bethe-Bloch and parameterization.
  - Std EM: There is no option to replace parameterization, and there is no way to change transition energy.
    - Since v.8, G4_WATER uses PSTAR stopping power. But it is applied only at the energy region below 2 MeV.
      - Is the PSTAR stopping power available only for G4_WATER?
    - Can we import stopping power function of PSTAR in whole range?

- Choice of Energy fluctuation model
  - Low Energy EM : ElectronicFluctuationModel() method
  - Std EM: G4UniversalFluctuation class
    - Can we use more general fluctuation model such as a model based on landau distribution?
    - It will be convenient for users to give a chance to switch the model.