# A comparison of TRIM 2008, MCNPX 2.4 and 2.5 with measurements in a non-modulated 29 MeV proton beam

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## Coming up...

- Motivation for comparison of 29 MeV protons
- Experimental and simulation setup
- TRIM and MCNPX: features and limitations
- Comparison of depth dose curves with exp't
- Discussion of differences



## Motivation (1)

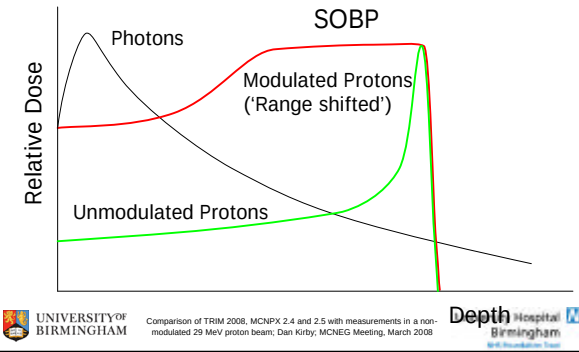
- Proton therapy:
  - Approaching 30 centres worldwide
  - Energies required ~250 MeV (~30cm range)
  - Only UK centre at Clatterbridge (62 MeV ~3cm)
- → LIBRA project (Laser Induced Beams of Radiation)
- Pulsed laser accelerated proton beam
- Birmingham to attempt dosimetry on laser proton beam (with input from NPL)

## Motivation (2)

- Preliminary dosimetry performed on the Birmingham Cyclotron at 29 MeV
- Crucial meausurement for radiotherapy is the percentage depth dose (PDD) curve for the radiation field in phantom (water or equivalent)
- Range of 29 MeV protons in water = 8mm
  - So thin sheets of perspex used as phantom
  - Ratio of stopping powers can convert to effective depth in water

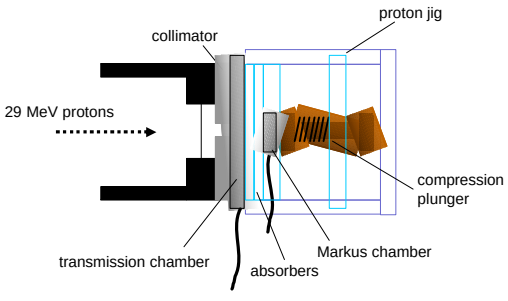


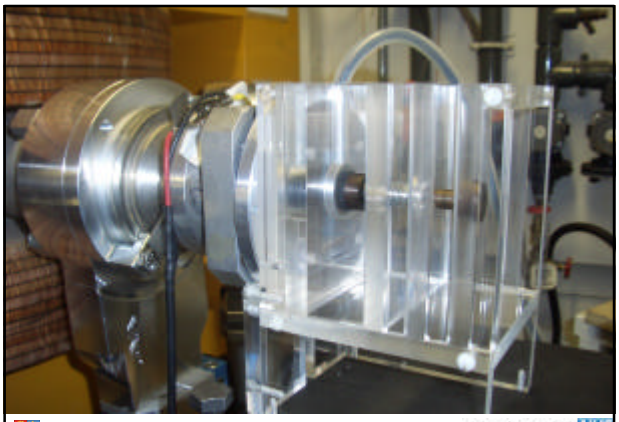
## Comparison of depth doses






## Experimental setup







## Features of TRIM

- **TR**ansport of **I**ons in **M**atter
- Simulates pencil beam of ions into a multi-layered target of different materials.
- Examples of outputs:
  - energy lost to ionization with depth in target
  - nuclear collision history for each ion
- Can infer depth dose from proton energy loss between collisions at known depths



## Limitations of TRIM

- Limited physics
  - No nuclear (inelastic) reactions
  - Hence no reduction in fluence with depth
- Simple geometry of laterally infinite layers
  - Hence central axis depth ionisation not produced, only average ionisation in ev/Å across entire infinite “slab”
  - Only pencil source intrinsically available

(Beam generator available from supporting software by Pavlovic and Strašík, at www.nuc.elf.stuba.sk/srim )

## Features of MCNPX

- Mesh tallies useful for binning energy deposition in 3D elemental volumes
  - (only 1D mesh required for depth dose)
- Much more complex geometry possible than with TRIM
- Can simulate detector response more accurately by simulating a real beam and tallying over equivalent active area of ion chamber



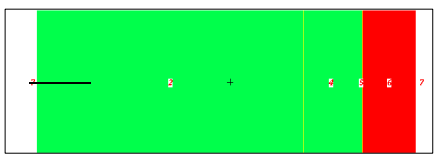
## Limitations of MCNPX

- Only protons above 1 MeV are tracked
  - (1 MeV p → 20 µm in perspex)
- Only tallies energy lost by protons –
  - No secondary electrons
  - Can be equated to dose if range of secondary electrons is small enough – typically < 50 µm for 29 MeV protons (much less at Bragg peak!)

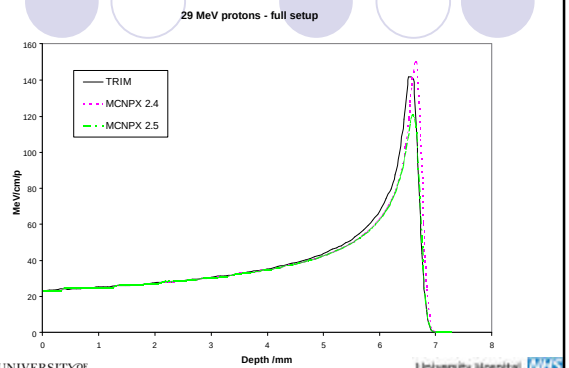


## Simulation setup

- All layers and materials defined with ICRU compositions
- Point-source of 29 MeV protons perpendicular to layers



## Depth dose curves (2)

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Comparison of TRIM 2008, MCNPX 2.4 and 2.5 with measurements in a non-modulated 29 MeV proton beam; Dan Kirby; MCNEG Meeting, March 2008

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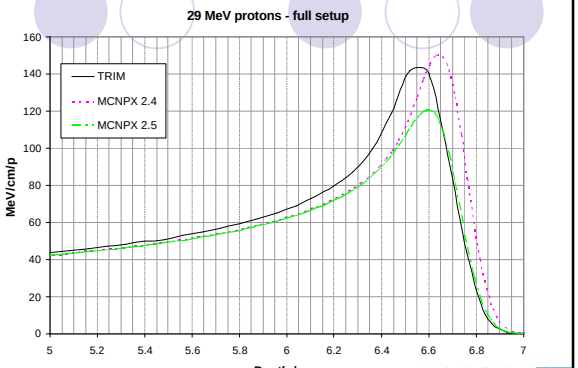
## Depth dose curves (2)

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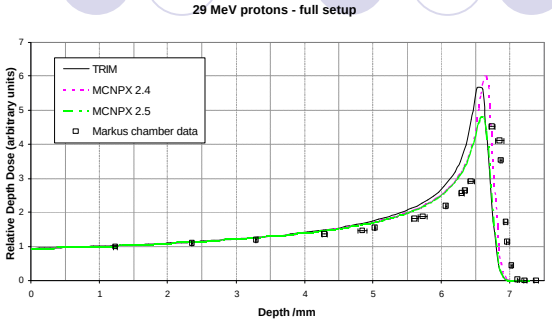
## Depth dose curves (3)

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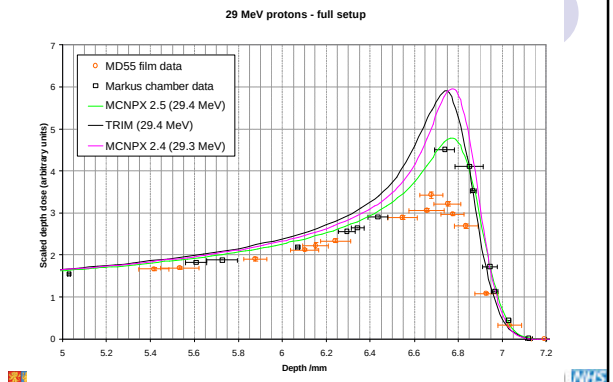
## Increased energies to fit measurements



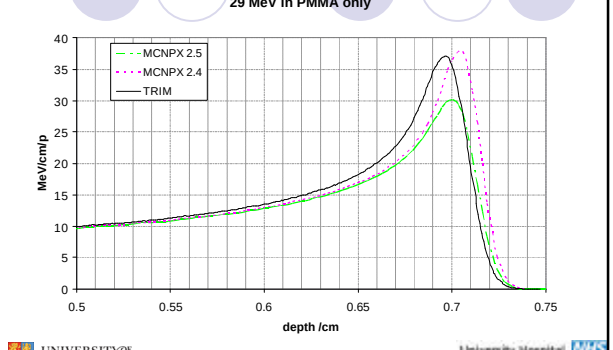



## Initial conclusions

- Peak height of MCNPX 2.5 agrees best with measurements
- TRIM and MCNPX 2.4 overestimate peak by ~20-25%
- Cyclotron energy unknown so cannot conclude which simulates range the best
- Beam appears to have little if any energy spread



## Investigate by simplifying problem

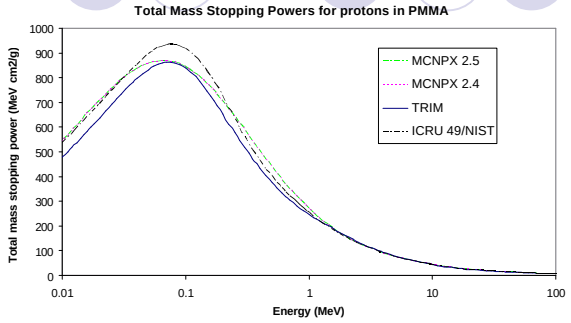


## Possible reasons for differences

- Are stopping powers different?



## Stopping power comparison



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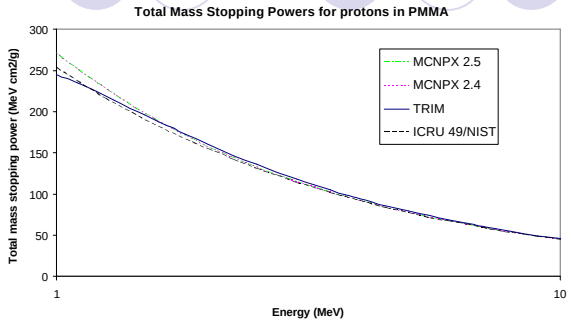

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- Are stopping powers different?
  - → YES: TRIM > MCNPX for $E_p$ ~ 2-10 MeV
  - → NO: MCNPX 2.4 = MCNPX 2.5



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  - → YES: TRIM > MCNPX for $E_p$ ~ 2-10 MeV
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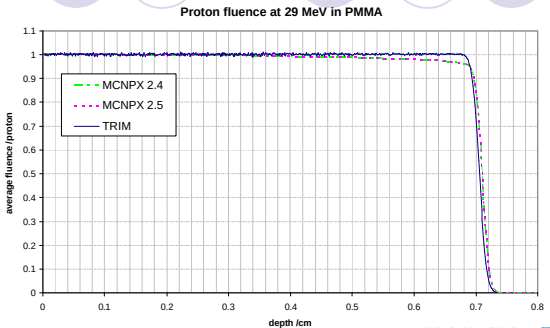
- Is the relative fluence with depth different?



## Fluence comparison



## Possible reasons for differences (1)

- Are stopping powers different?
  - → YES: TRIM > MCNPX for $E_p$ ~ 2-10 MeV
  - → NO: MCNPX 2.4 = MCNPX 2.5
- Is the relative fluence with depth different?
  - → YES: TRIM fluence stays constant
  - → NO: MCNPX 2.4 = MCNPX 2.5 (again)



## Possible reasons for differences (2)

- Range difference of ~ 0.05 mm from 50% entrance fluence depth...
  - = difference between bragg peak depths of TRIM and MCNPX 2.5
- But why is 2.4 showing a longer range and taller Bragg peak when stopping powers and fluence are identical to 2.5?



## Possible reasons for differences (2)

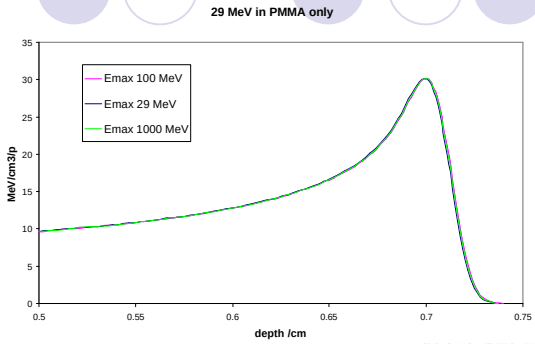
- Range difference of ~ 0.05 mm found from 50% entrance fluence depth...
  - = difference between Bragg peak depths of TRIM and MCNPX 2.5
- But why is 2.4 showing a longer range and taller Bragg peak when stopping powers and fluence are identical to 2.5?
  - → Investigate PHYS:H options for 2.5

## PHYS:H options

- Main options:
  - (1) Max energy cut-off (default 100 MeV)
  - (2) Straggling: Vavilov, CSDA, old Vavilov (2.2.4)
  - (3) Use data tables (avail. <150 MeV) or models

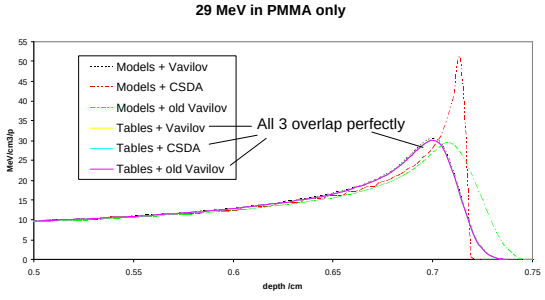


## (1) Max energy cut-offs






## (2) Straggling & (3) Tables/Models

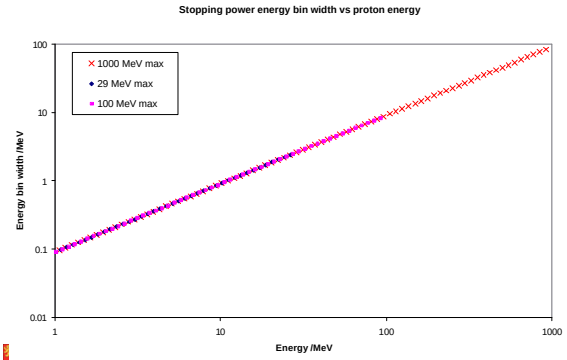


## A note on MCNPX stopping powers

- MCNPX manual states to avoid using a max proton energy cut-off that is significantly higher than energies in problem (default = 100 MeV)
  - Reason: will lead to coarser binning of stopping powers



## Stopping power binning

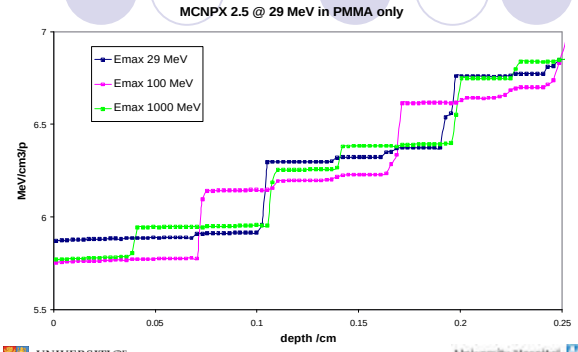





## A note on MCNPX stopping powers

- MCNPX manual states to avoid using a max proton energy cut-off that is significantly higher than energies in problem (default = 100 MeV)
  - Reason: will lead to coarser binning of stopping powers
- DOESN'T HAPPEN < 1 GeV

## Closer look at MCNPX depth dose



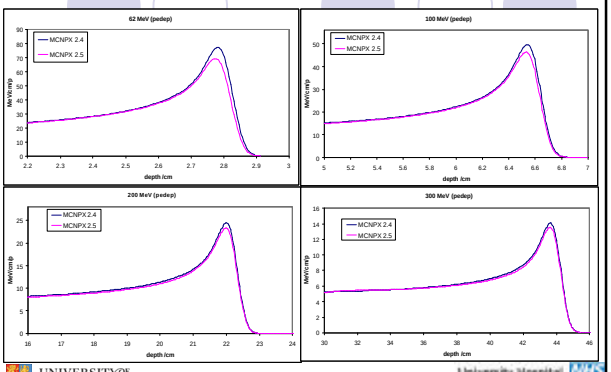



## Interpolation problem?

- Distance between main steps consistent with range difference between the energies at which S values tabulated
- Number of sub-steps is set to 3 as default
- Option to increase this will exist in 2.6.x
- Is it a problem?
  - May not be the best approximation
  - Only apparent when energy spectrum is narrow

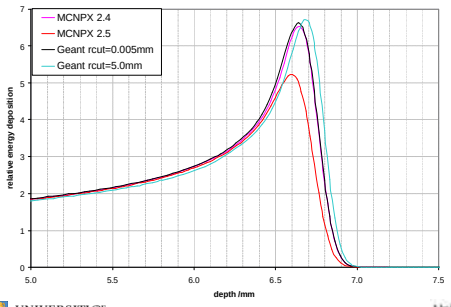


## A look at higher energies (EM scatter only)



## Quick comparison with Geant4...

**Scaled depth energy deposition curves for MCNPX 2.4, 2.5, and Geant with rcut = 0.005mm and 5.0mm - FULL EXP. SETUP**




Geant simulations kindly provided by David Shipley, NPL



## Further investigation

- What will MCNPX 2.6.x beta version show?
- Ask Los Alamos about the difference?
  - To summarise the main question:
    - What difference between 2.4 and 2.5 causes difference in Bragg peak height and depth?



## Further investigation

- What will MCNPX 2.6.x beta version show?
- Ask Los Alamos about the difference?
  - To summarise the main question:
    - What difference between 2.4 and 2.5 causes difference in Bragg peak height and depth?
- Alternatively...
  - Answers on a postcard please!

Dear Dan,

I think the difference between MCNPX versions 2.4 and 2.5 that causes different Bragg peaks is.....

MCNPX Difference Challenge
c/o Medical Physics
University of Birmingham
Edgbaston
Birmingham
B15 2TT

(Or email me at djk191@bham.ac.uk)