Collimation of spot scanned proton therapy beams to sharpen the lateral edge of uniform dose volumes

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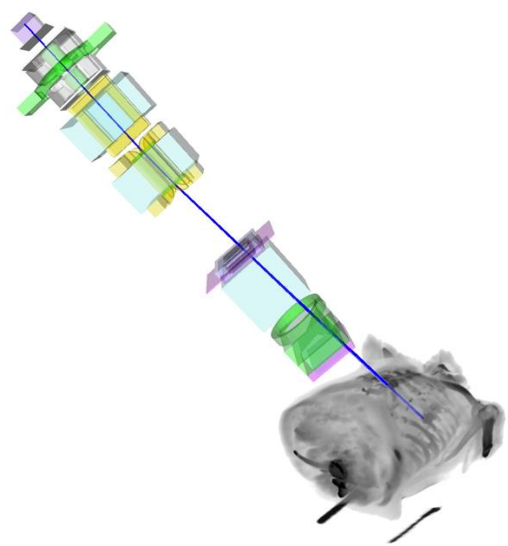
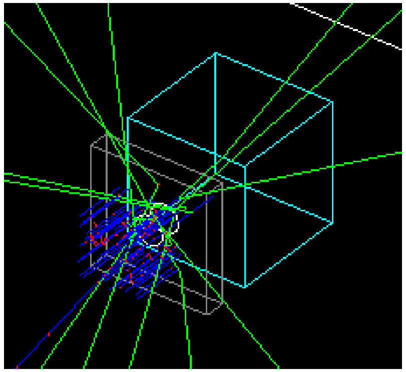


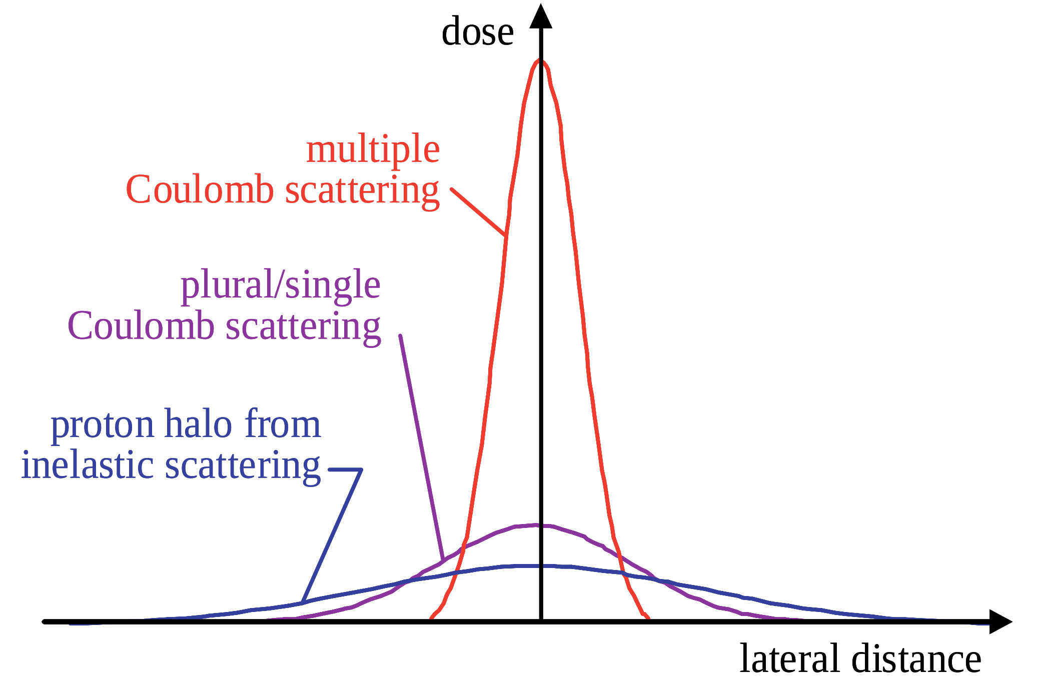
MSc project supervisors:
Adam Aitkenhead and Ranald Mackay, The Christie

Outline



- Aims of the project
- Origin of the lateral penumbra
- Validation of Monte Carlo results against analytical and experimental data
- Comparison of a broad beam and pencil beam lateral penumbra
- Effect of collimation, SSD and bolus on a monoenergetic pencil beam array
- Collimation of homogeneous spherical volumes
- Pinnacle^3 investigations into pencil beam collimation

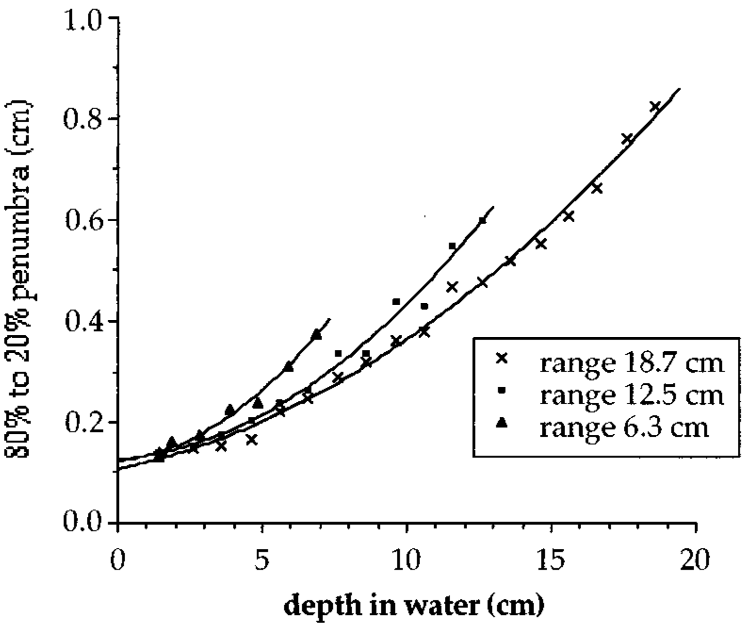
Lateral penumbra origin



Why is it important?

TPS uses the lateral penumbra to provide conformality as distal penumbra suffers range uncertainties

- Inelastic collisions – distal falloff of dose
- Multiple Coulomb elastic scattering dominates laterally – pencil beam has a Gaussian spread
- Large angle Coulomb scattering – broad tail
- Inelastic nuclear interactions attenuate the primary beam – proton halo is Gaussian, neutron halo escapes



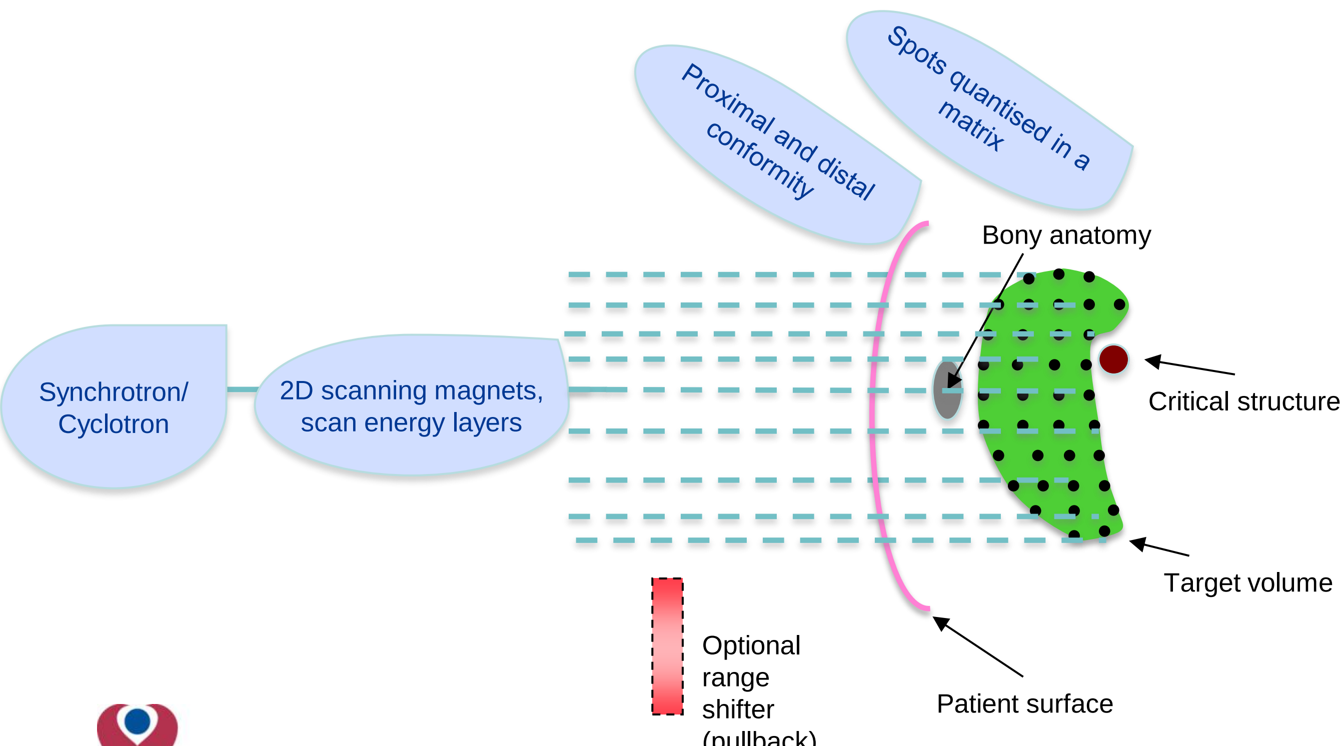
Spot scanning technique

To sharpen the lateral penumbra:

- Small spatial spot sigma
- Small energy sigma
- Optimisation of fluence pattern

Collimators and compensators:

- Short CSD but not too close!
- Minimum thickness of compensator
- Decrease gap between bolus and entrance to medium



GATE assumptions:

- Fixed σ at all energies
- No lateral rind around volumes
- Perfect Gaussian pencil beam
- No divergence

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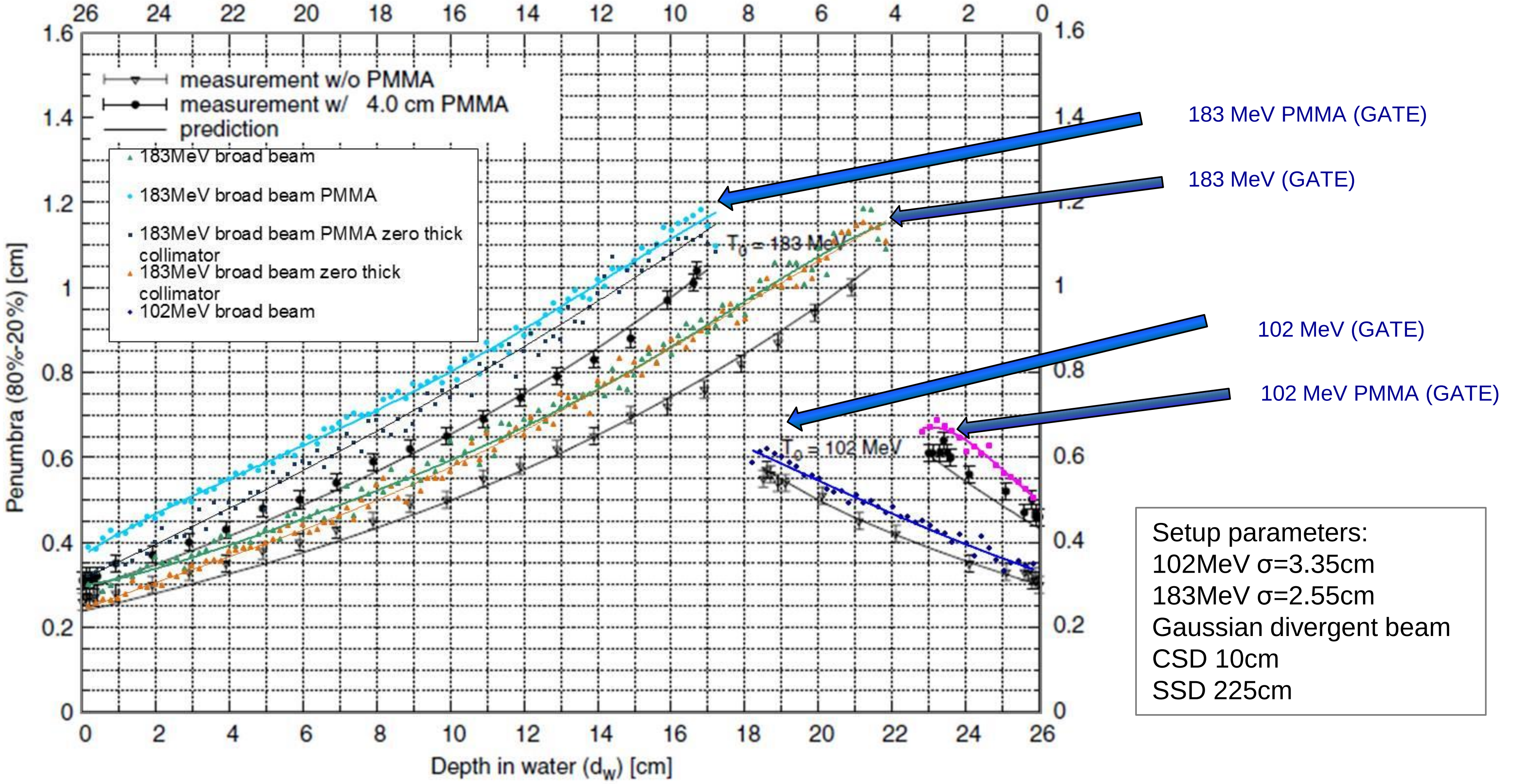
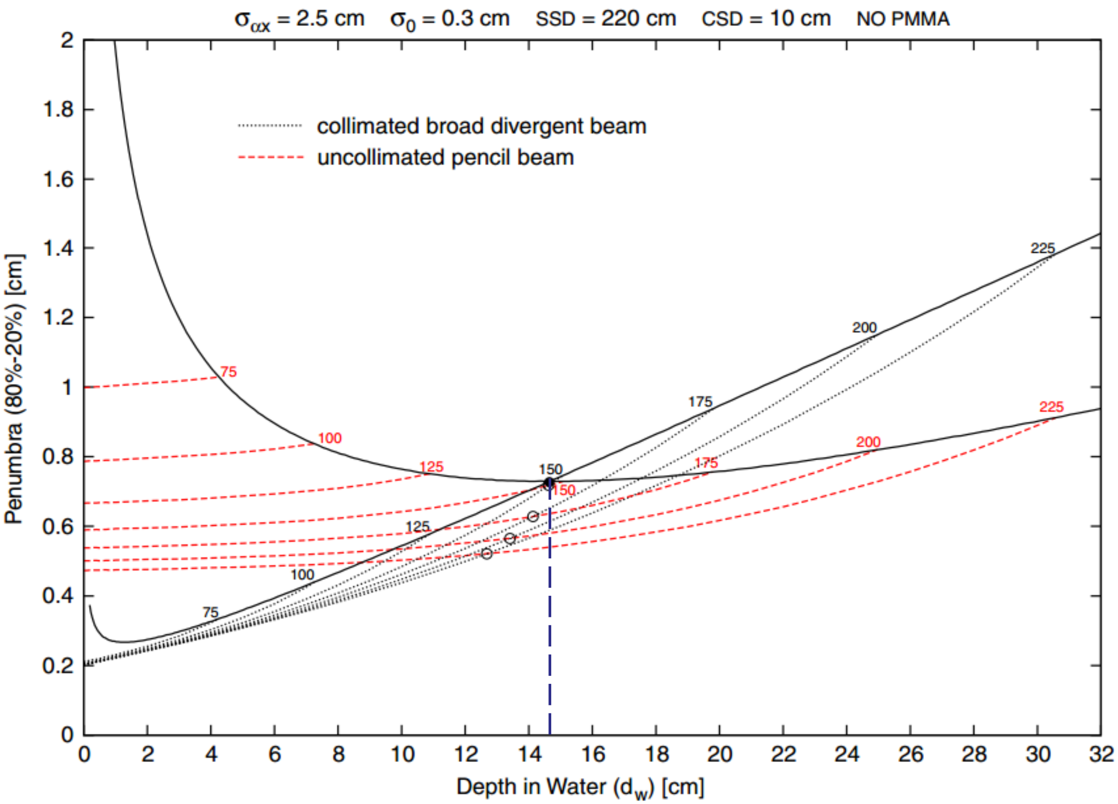
Lateral penumbra broad beam comparison



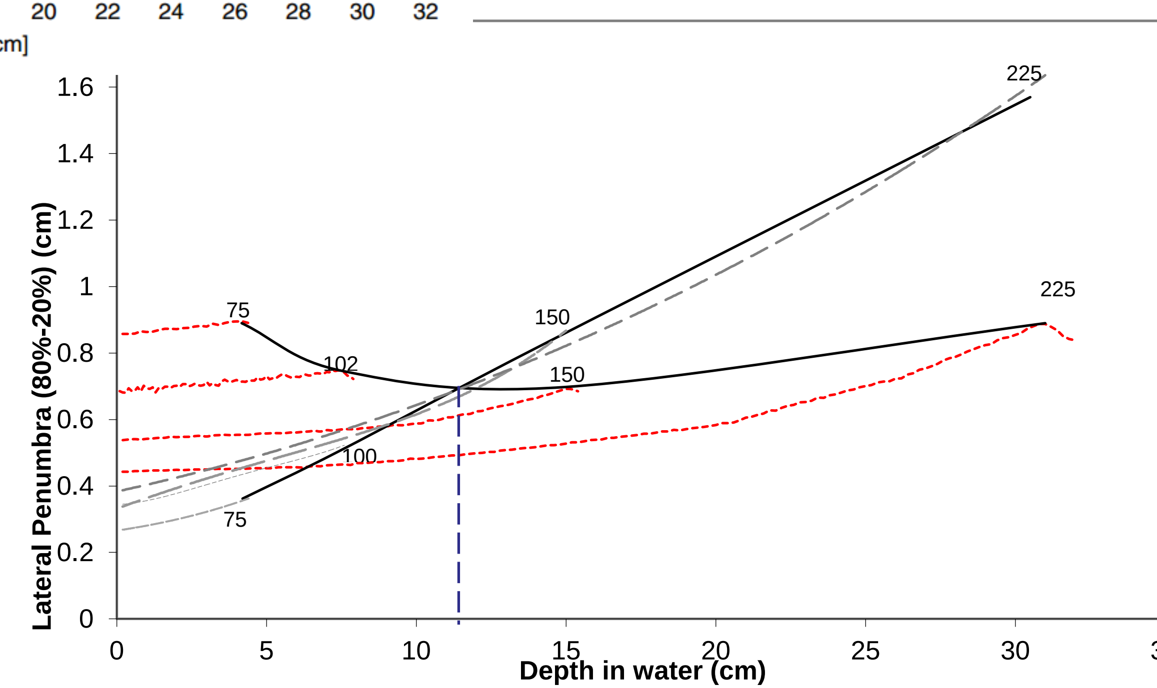
Setup parameters:
102MeV σ=3.35cm
183MeV σ=2.55cm
Gaussian divergent beam
CSD 10cm
SSD 225cm

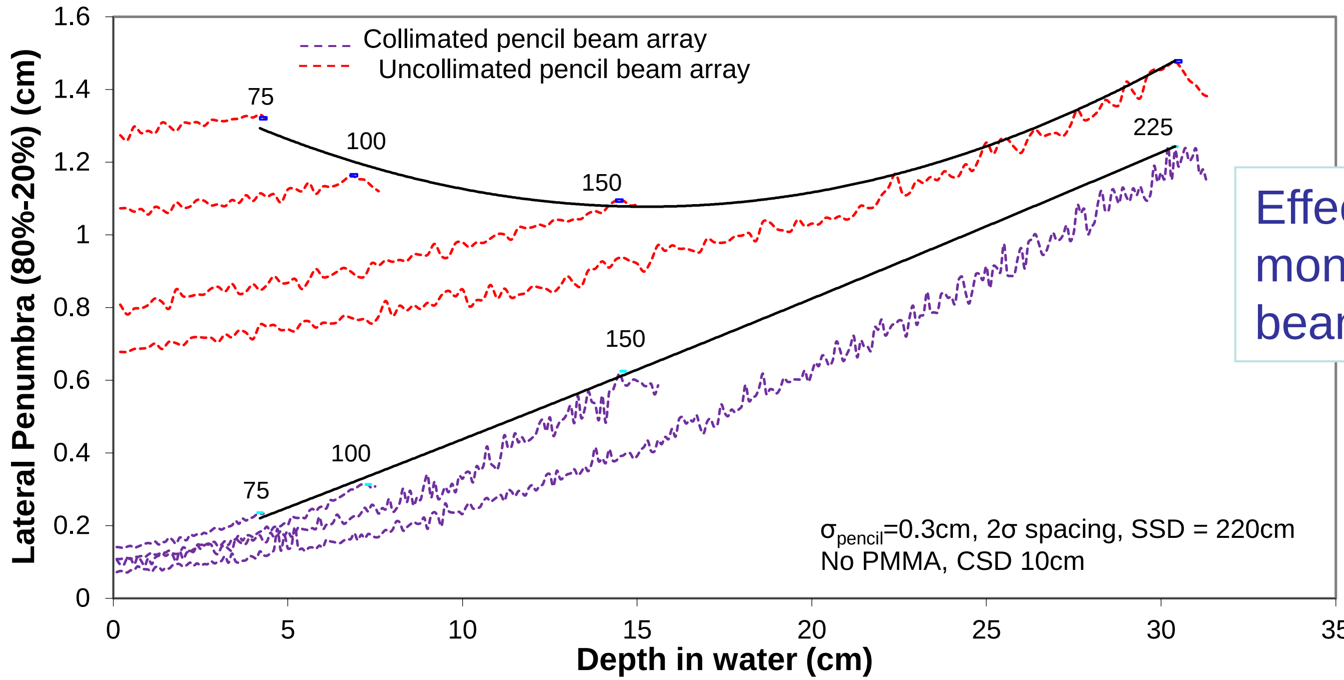
Validation of GATE results against Safai et al. (PMB 53(6) (2008) 1729) for a passively scattered broad beam



Safai et al. (2008) determined a crossover point below which the broad beam has a sharper lateral penumbra.

PBS/PSPT crossover point dependent on many parameters – SSD, CSD, use of bolus, spatial spot sigma, spot spacing, collimator properties…



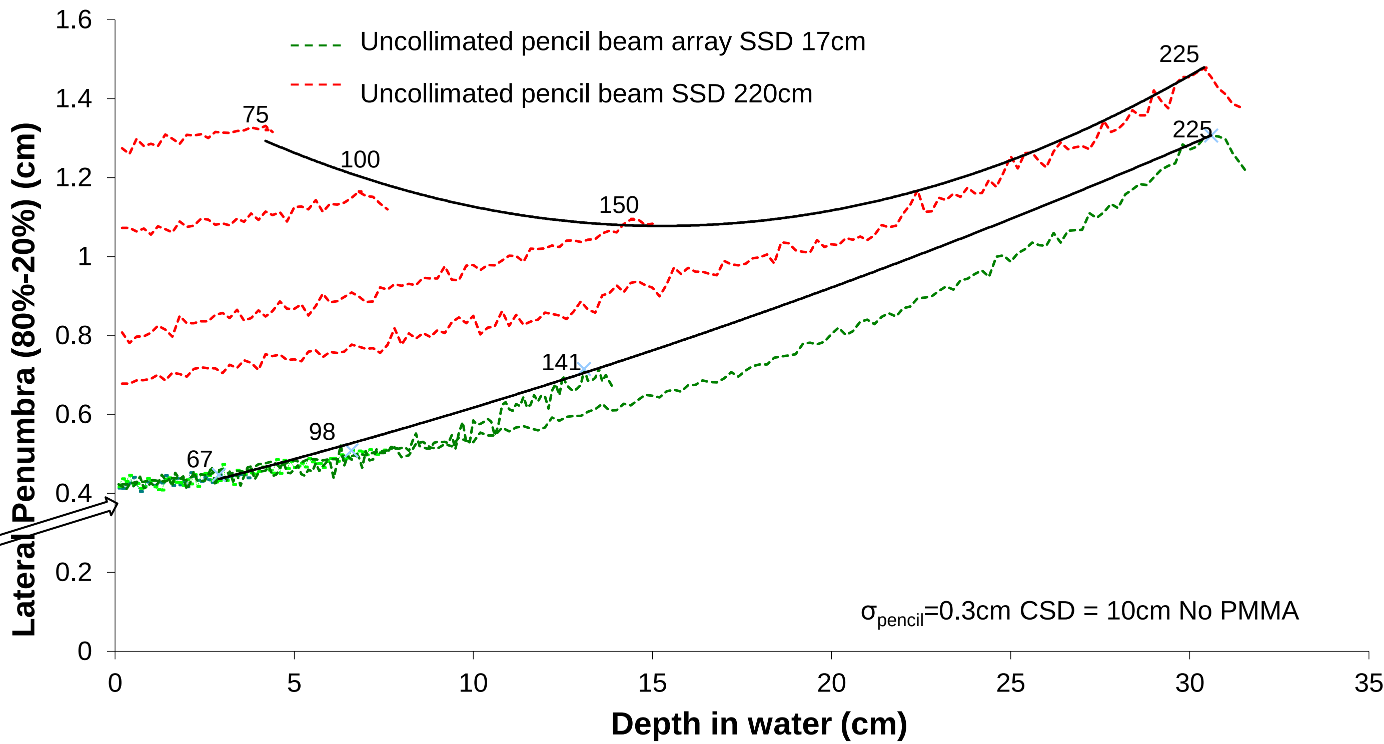


Effect of collimation on a monoenergetic pencil beam array

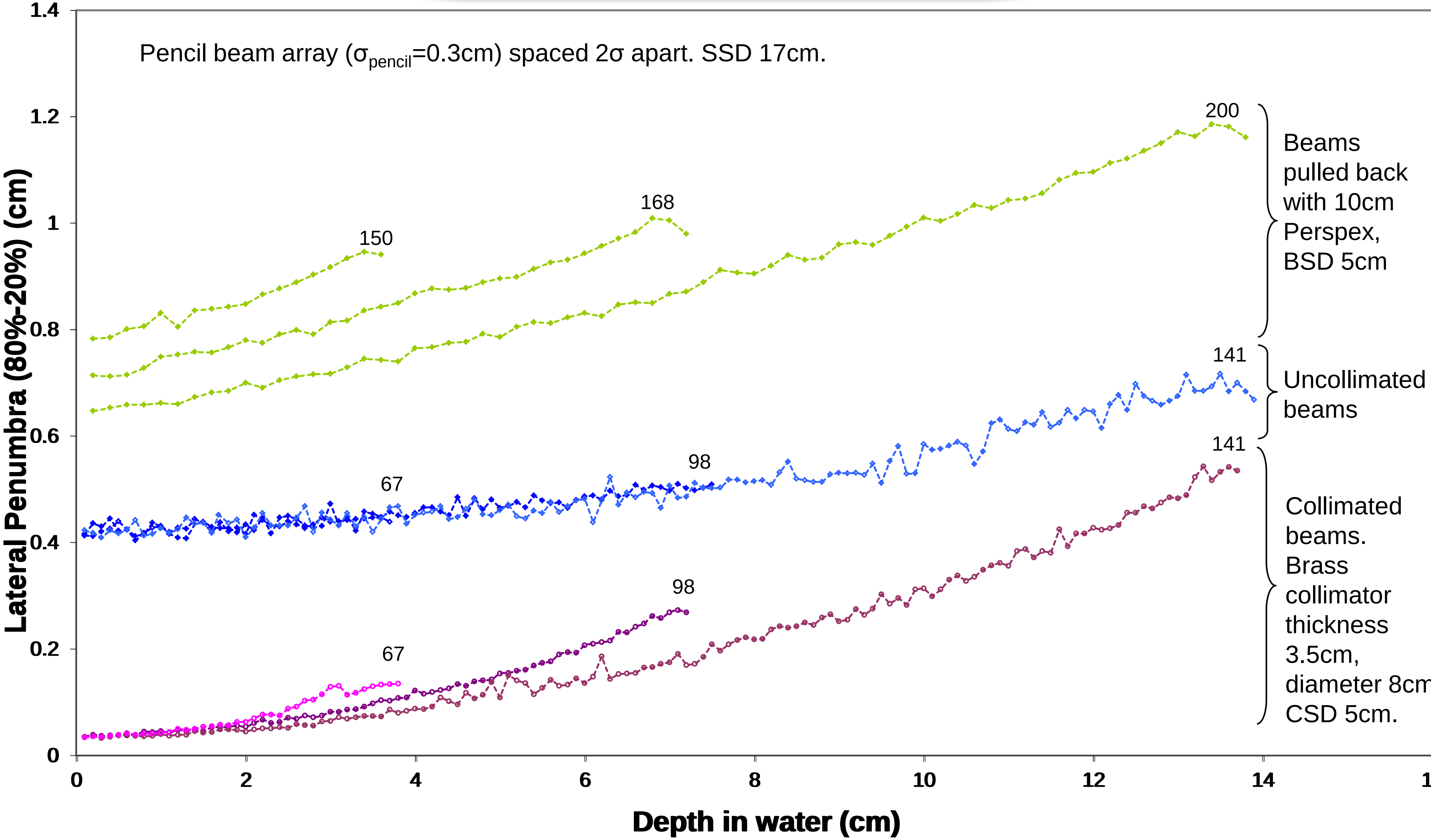
Reduction in penumbra from 0.6-1.2cm to 0.1-0.2cm.

Effect of 'virtual' SSD (air gap) on a monoenergetic pencil beam array

Shorter SSD may negate the need for a collimator



Effect of Perspex 'pullback' and higher beam energies

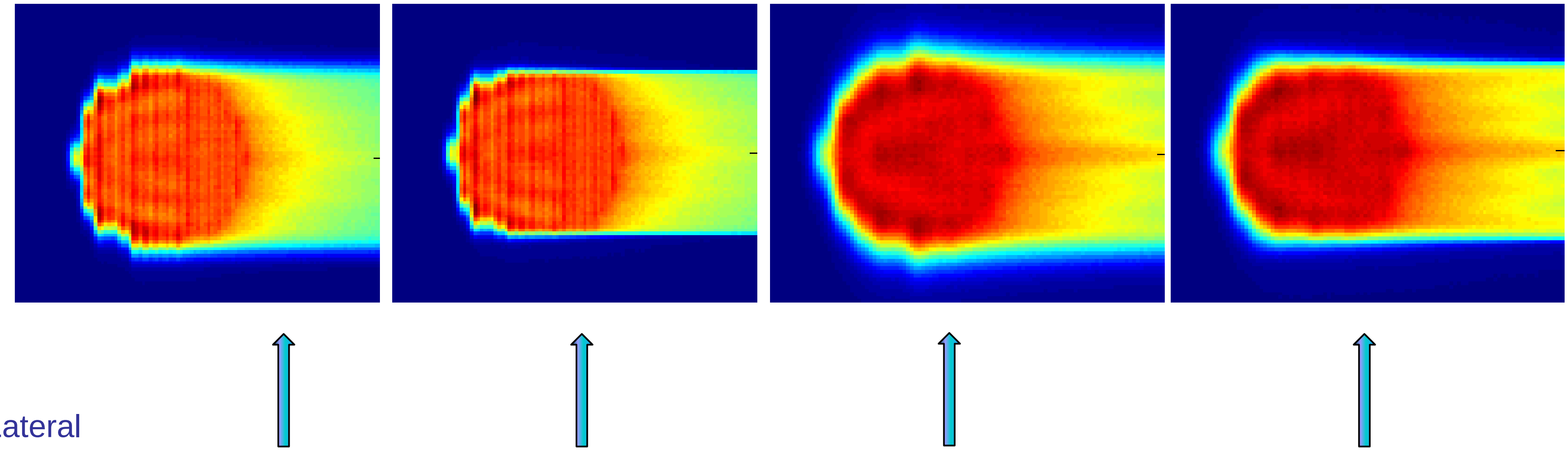


To achieve same range, higher energies pulled back through 10cm Perspex, broadening the penumbra.

Pullback necessary to achieve low energies <70-100MeV

Collimation of a homogeneous spherical volume

Uncollimated 70-110MeV beam	70-110MeV beam, single collimator at maximum sphere radius (2.38cm)	Uncollimated 152.5MeV-177.5MeV beam 10cm PMMA	Collimated 152.5MeV-177.5MeV beam 10cm PMMA



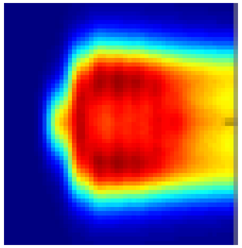
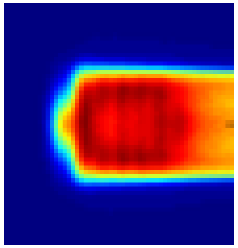
Lateral penumbra at max. radius (cm)	0.43	0.22	0.74	0.45

Collimation at maximum sphere radius improves lateral penumbra throughout volume, both for pullback and non-pullback beams

MLC effect collimation fails – need to include collimator in optimization

Results shown for:
SSD =17cm
σ=0.3cm
Lateral spacing = 0.3cm
BSD = 5cm
CSD = 1.5cm

Collimation of a homogeneous spherical volume at superficial depths

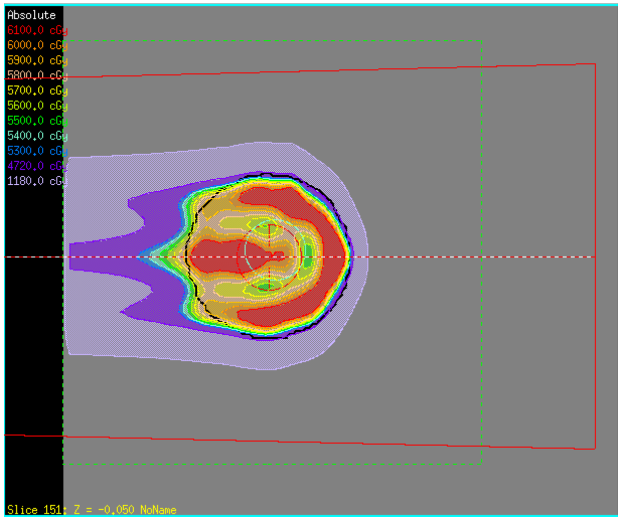
	Uncollimated	Single collimator at maximum sphere radius (1.2cm)
		
Lateral penumbra at max. radius (cm)	0.65cm	0.29cm

Collimation halves the lateral penumbra at superficial depths where range shifters are necessary

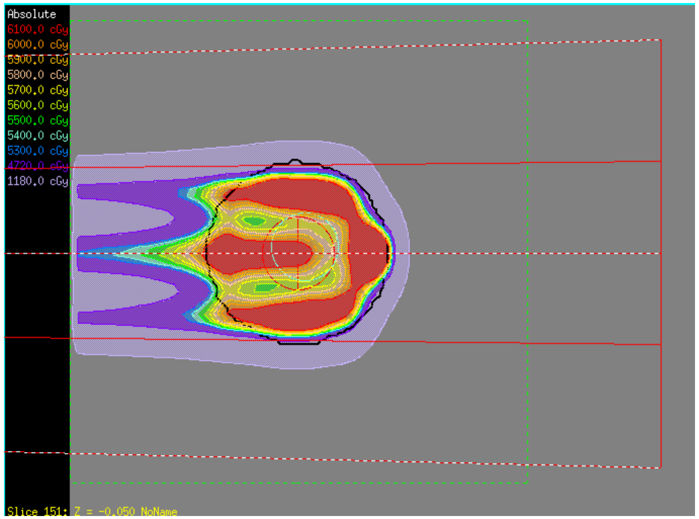
Setup parameters:
135-150MeV beam
σ=0.3cm
0.3cm spacing
10cm range shifter
BSD 10cm
CSD 1.5cm
SSD 17cm

Pinnacle^3 proton TPS comparisons

Uncollimated



Collimated



Homogeneous spherical volume

Setup parameters:
152.5-177.5MeV beam
σ~0.45cm
0.3cm spacing
10cm range shifter
SSD 224cm

Lateral penumbra at max. radius (cm)	0.94cm	0.80cm

No lateral margin applied – spots only inside sphere
Consequences of this lead to poor uniformity, which is a trade off against penumbra (Baumer et al. (2011))

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Summary

- GATE Monte Carlo broad beam and pencil beam simulations validated against Safai et al. (2008)

- At shallow depths, pencil beam comparable to broad beam penumbra for short SSDs or when collimated.

- If small spatial σ achievable at all energies, use of ‘pullback’ worsens penumbra.

- Collimating pencil beam at superficial depths improves penumbra significantly

- Collimation of homogeneous volumes also improves lateral penumbra throughout the volume

- Further work:
  - effects of beam divergence
  - use of lateral rinds to improve spot uniformity in Monte Carlo
  - comparison with TPS for same MC beam setup conditions
  - Use of MLC

Thanks for listening!

Any questions?