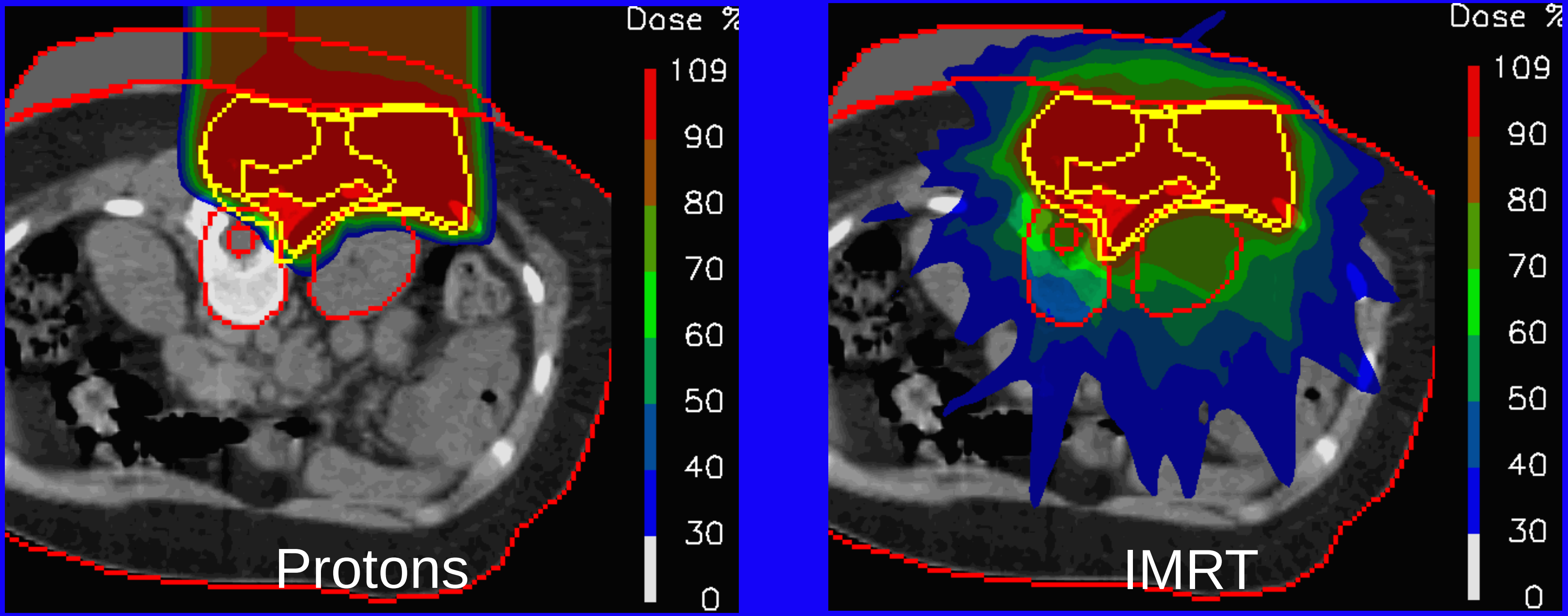
Radiation protection issues in proton therapy

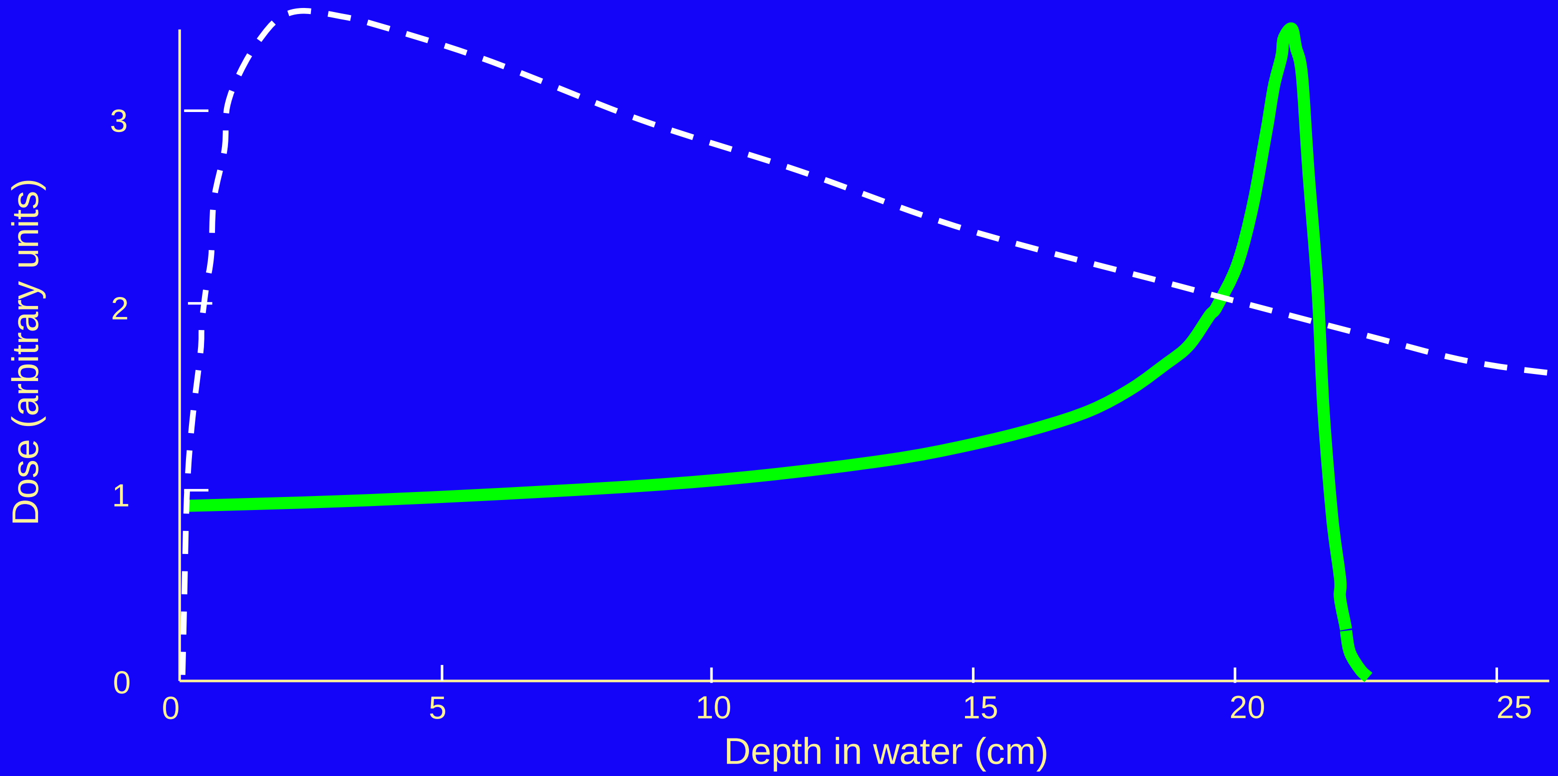


Tony Lomax, Centre for Proton Radiotherapy,
Paul Scherrer Institute, Switzerland

Overview of presentation

1. Proton therapy: An overview
2. Radiation protection issues: Staff
3. Radiation protection issues: The patient
4. Summary

Depth dose curves for photons (15MV) and protons (177MeV)



Dose concentrated in small volume in Bragg peak.

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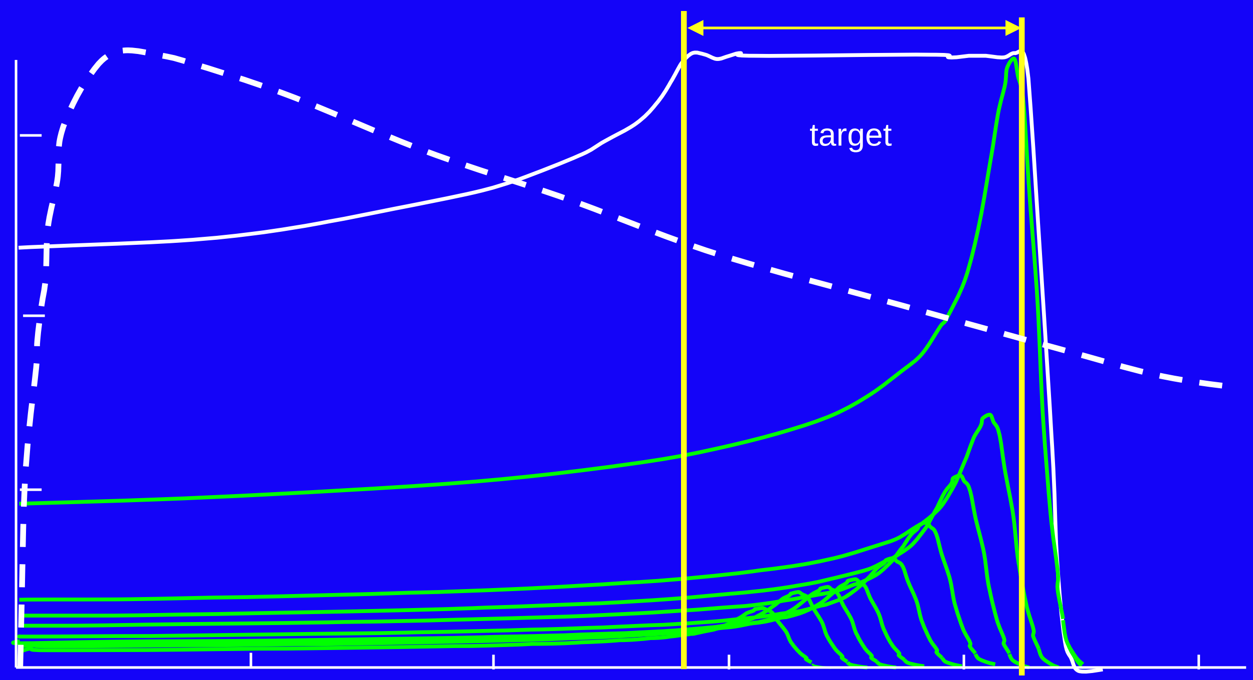
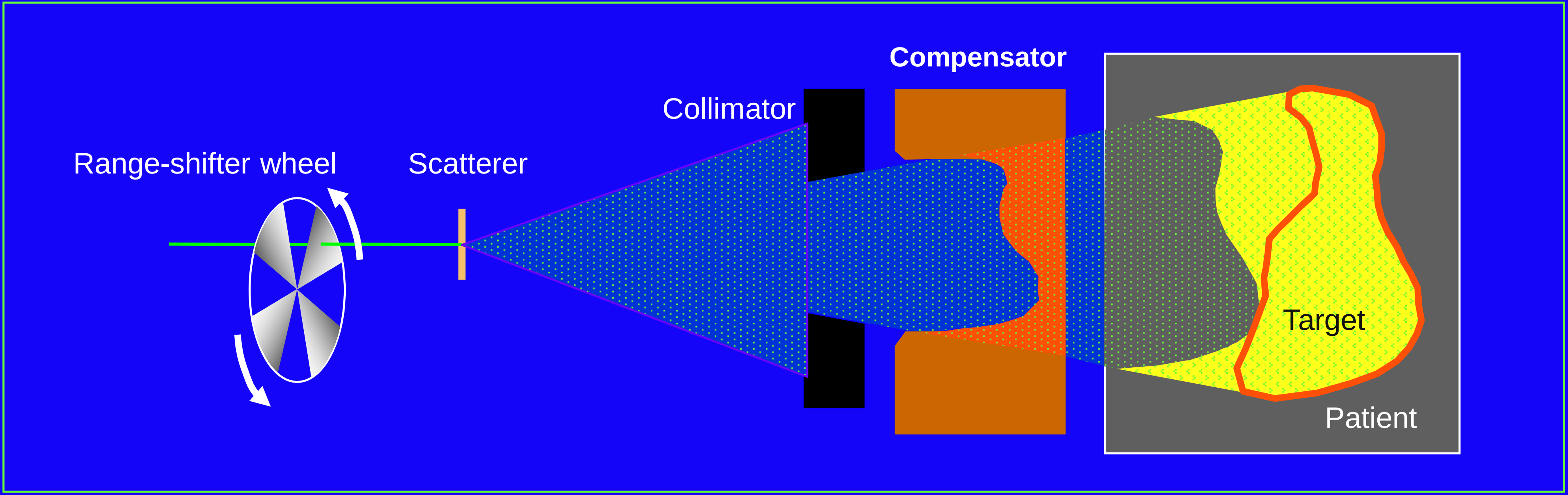
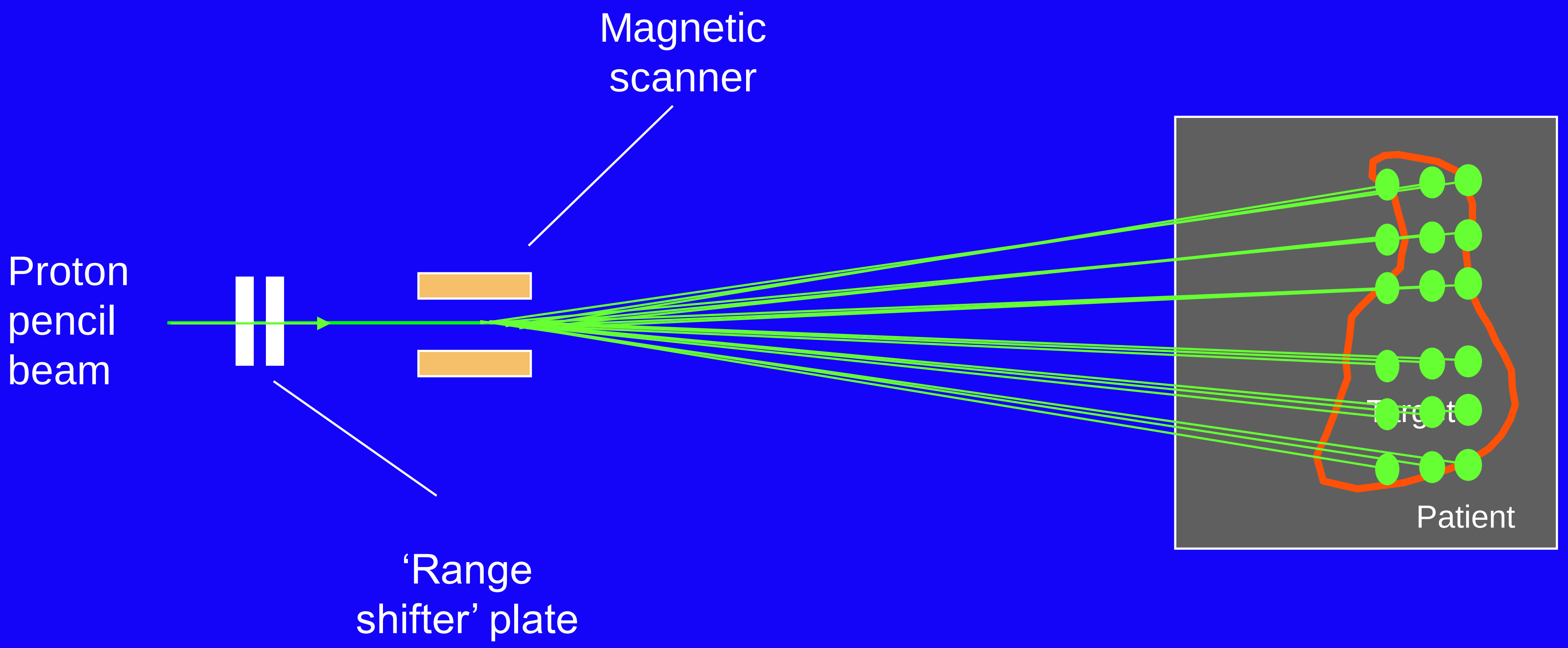
The 'Spread-Out-Bragg-Peak'



Passive scattering in practice



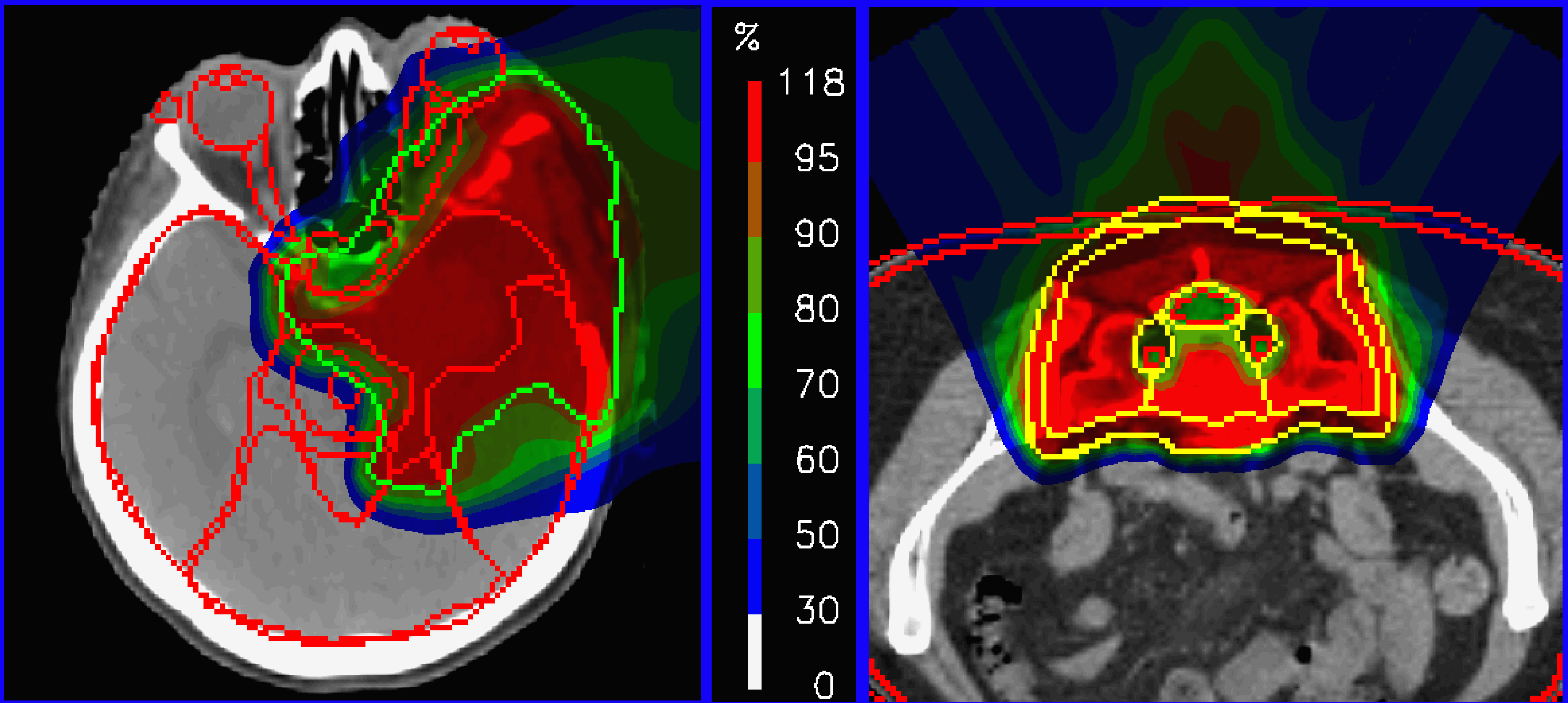
Active scanning



Example actively scanned proton treatments

Meningioma (3 fields)

Sacral chordoma (2 fields)



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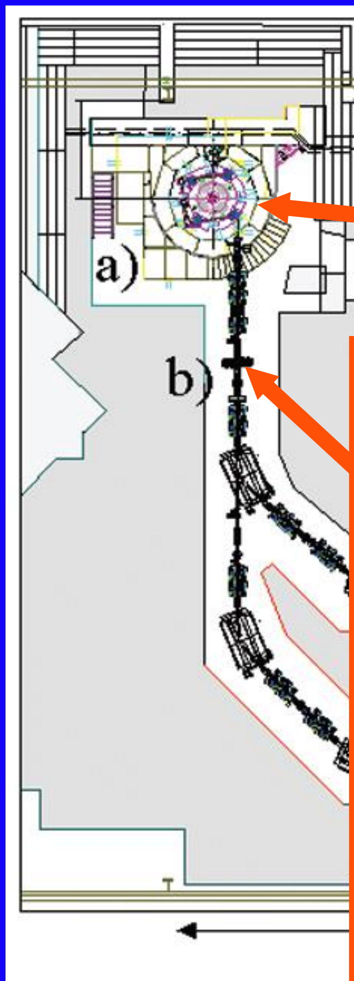
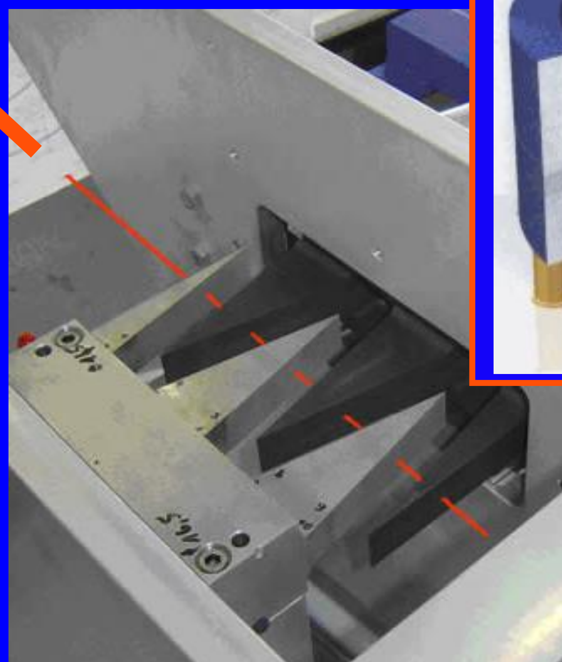
A ‘typical’ proton therapy facility (e.g. PSI)





• Scatters beam, which must be then sharpened by collimators and slits

• Inefficient and ‘lossy’, but fast.

250 MeV proton Cyclotron

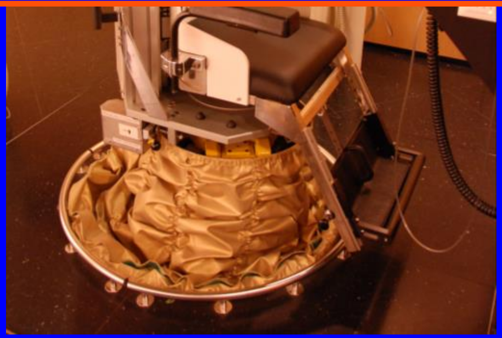
• A fixed energy accelerator

• To vary energy, the extracted beam must be degraded after extraction (Energy Selection System)

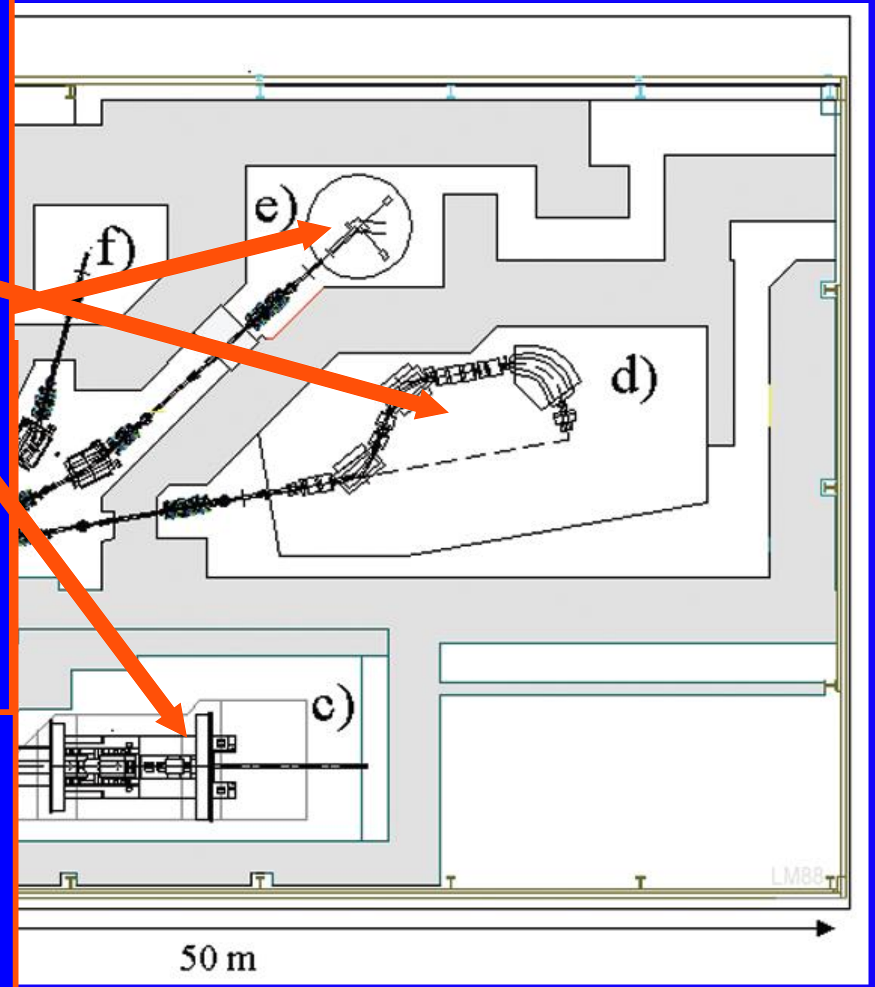
A ‘typical’ proton therapy facility (e.g. PSI)

Gantries (G1/G2)

- Rotating beam lines
- 70-250 MeV beam
- Max range ~32 cm
- Active scanning
- G1 - 15-20 patients a day
- G2 in service from end 2012



- Maximum range 3.5cm
- Passive scattering delivery
- 4-8 patients a day



Radiation protection issues for proton therapy

- Even the highest energy protons (250MeV) stop in a few centimeters of concrete
- So the main concern from the radiation protection point of view are not protons but secondary particles, in particular neutrons.

Radiation protection issues: Staff

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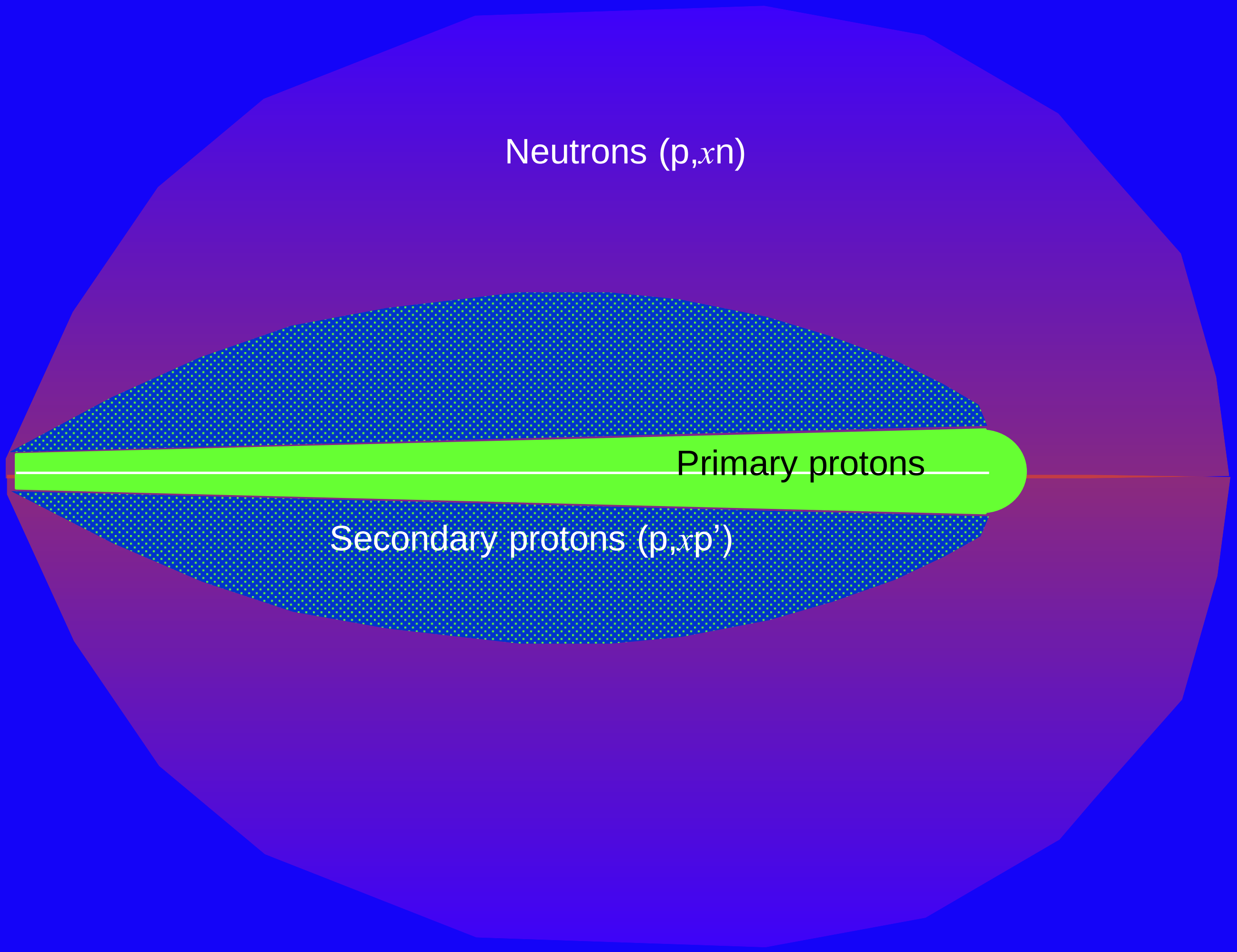
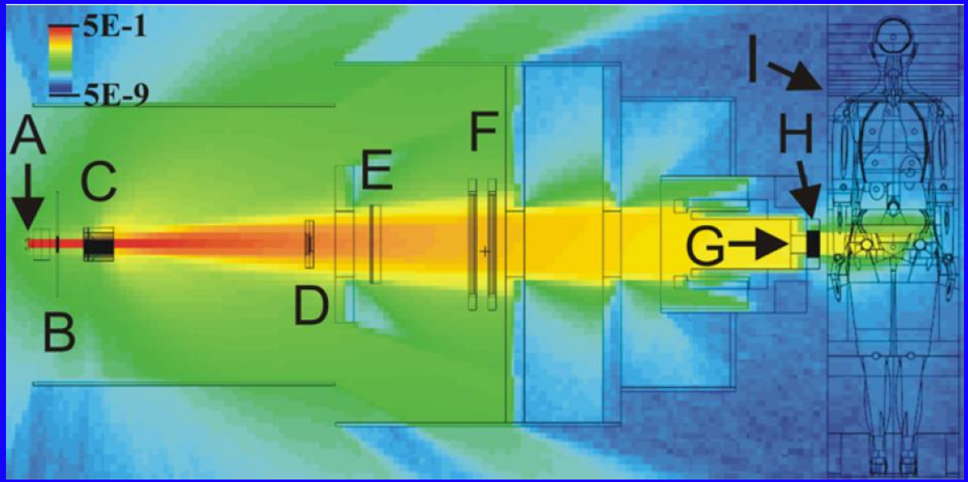
~1%/cm of primary protons are lost due to interactions with atomic nuclei, which then produce secondary particles. E.g.

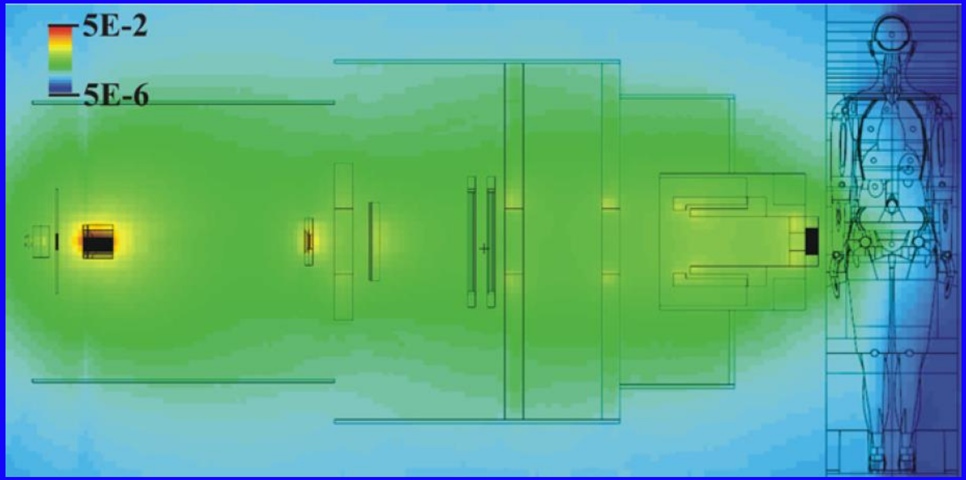


Secondary particle production by protons

E.g. MCNPX Monte Carlo calculations for a passive scattering nozzle (Hitachi, Houston)



p and p' flux



n flux

Fontenot et al, Phys. Med. Biol. **53** (2008) 1677–1688

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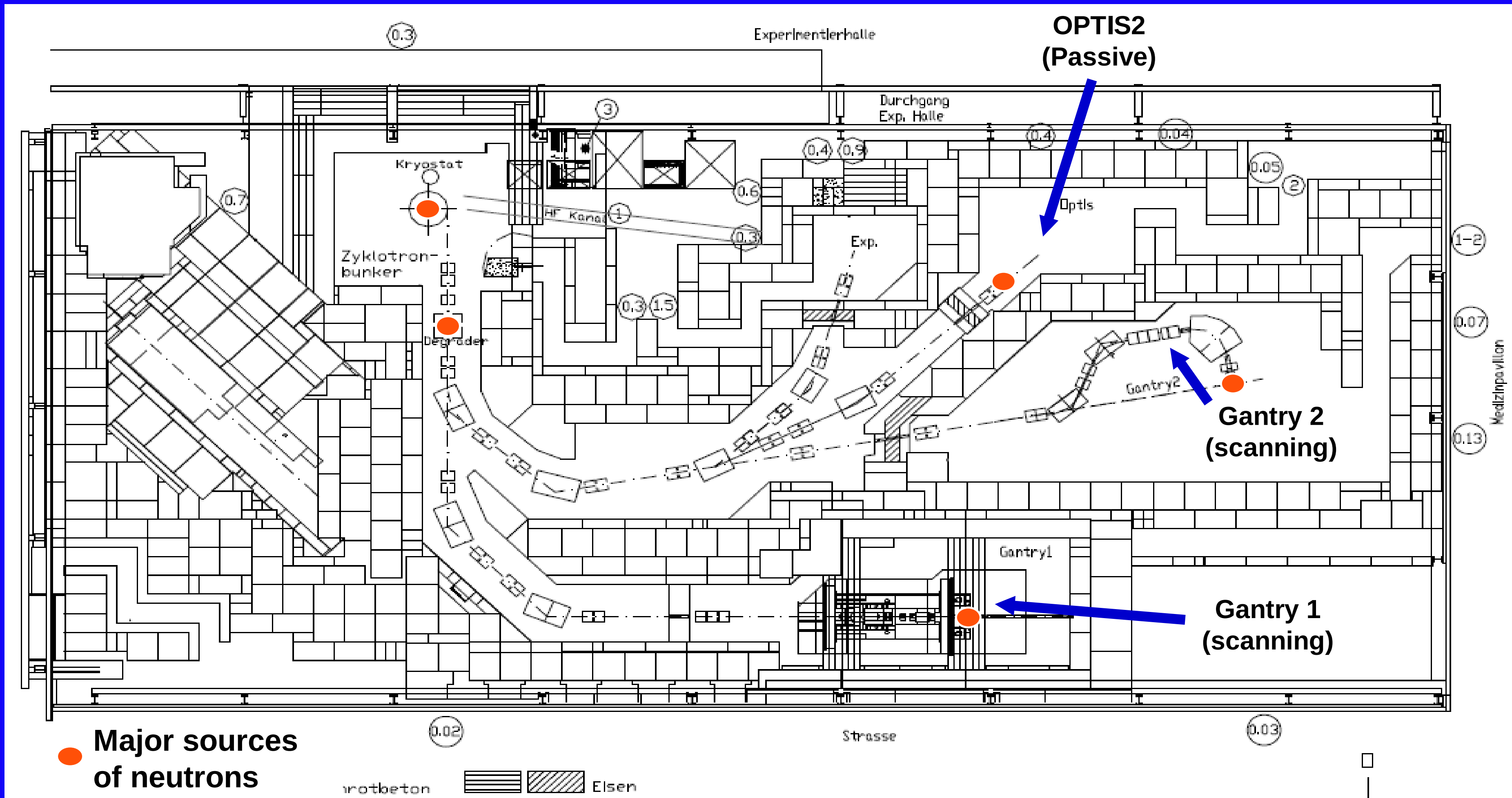
The PSI proton therapy facility and it's major neutron sources



Radiation protection issues: Staff

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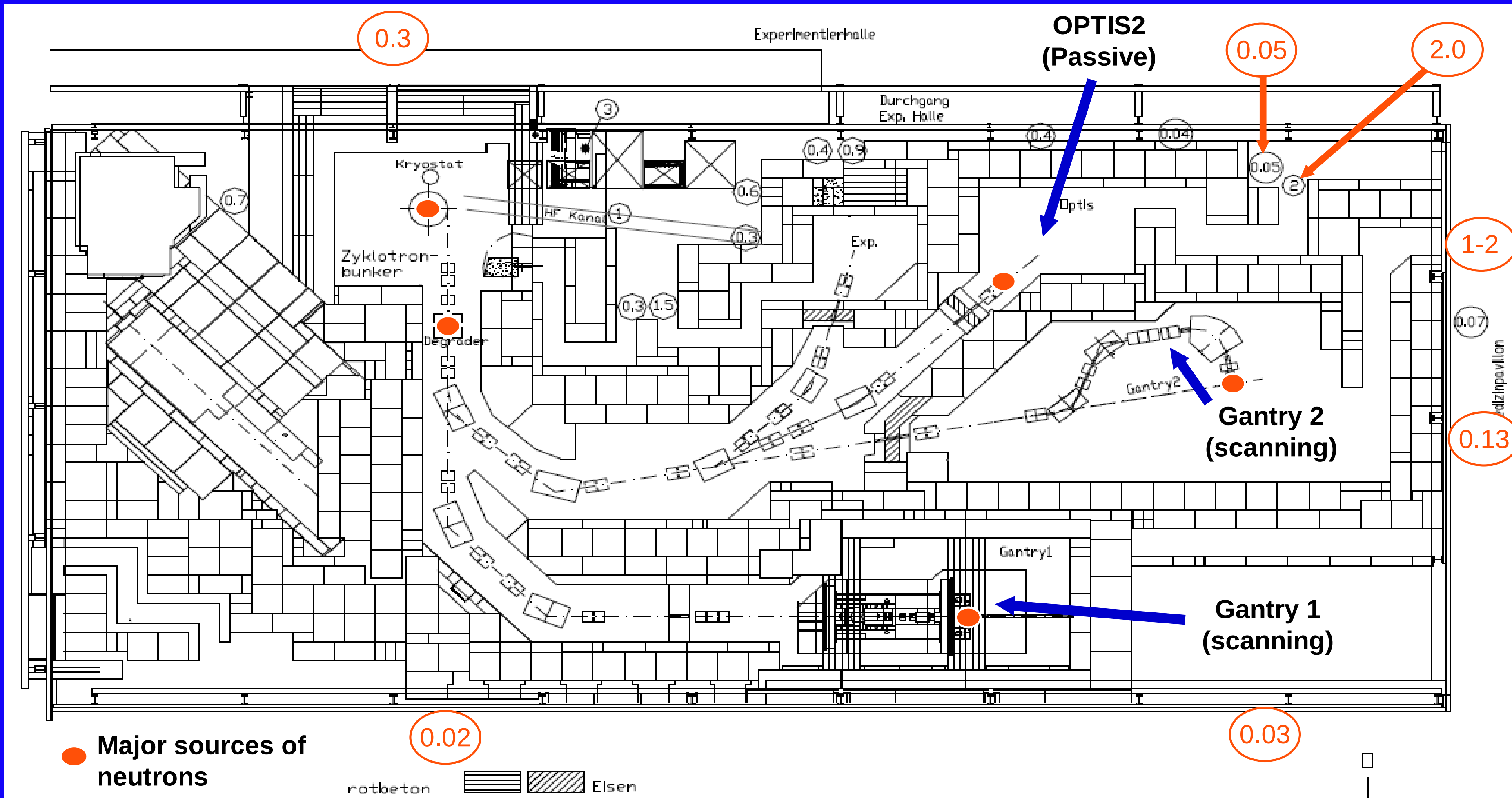
Analytically calculated equivalent dose rates (μSv/h)



Teichmann 2004, Internal PSI report

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Shielding for proton therapy facilities

- Based on analytical calculations (confirmed by measurements) dose rates in entrances, control rooms and public areas can be reduced below legal limits
- For the PSI facility, to reduce extraneous neutron dose minimum of 2-4 meters of concrete is required
- For a single treatment room, concrete costs alone can be of the order of 500000 pounds or more…

How accurate are analytical calculations?

Position	*Hm*	*Analytical*		*Monte Carlo (MCPNX)*	
		Hc	*Hc/Hm*	*Hc*	*Hc/Hm*
A	7.0×10^{-10}	1.1×10^{-8}	**15**	2.8×10^{-10}	**0.4**
B	2.6×10^{-8}	1.0×10^{-7}	**4**	3.0×10^{-8}	**1.2**
C	4.1×10^{-10}	2.6×10^{-8}	**63**	1.0×10^{-9}	**2.4**

Analytical calculations can be up to two orders of magnitude too conservative. MC calculations seem to be more accurate (within a factor 2) but more difficult. Consequences for shielding costs?

Newhauser et al 2002, Nucl. Inst. Meth. Phys. Res. 476, 80-84

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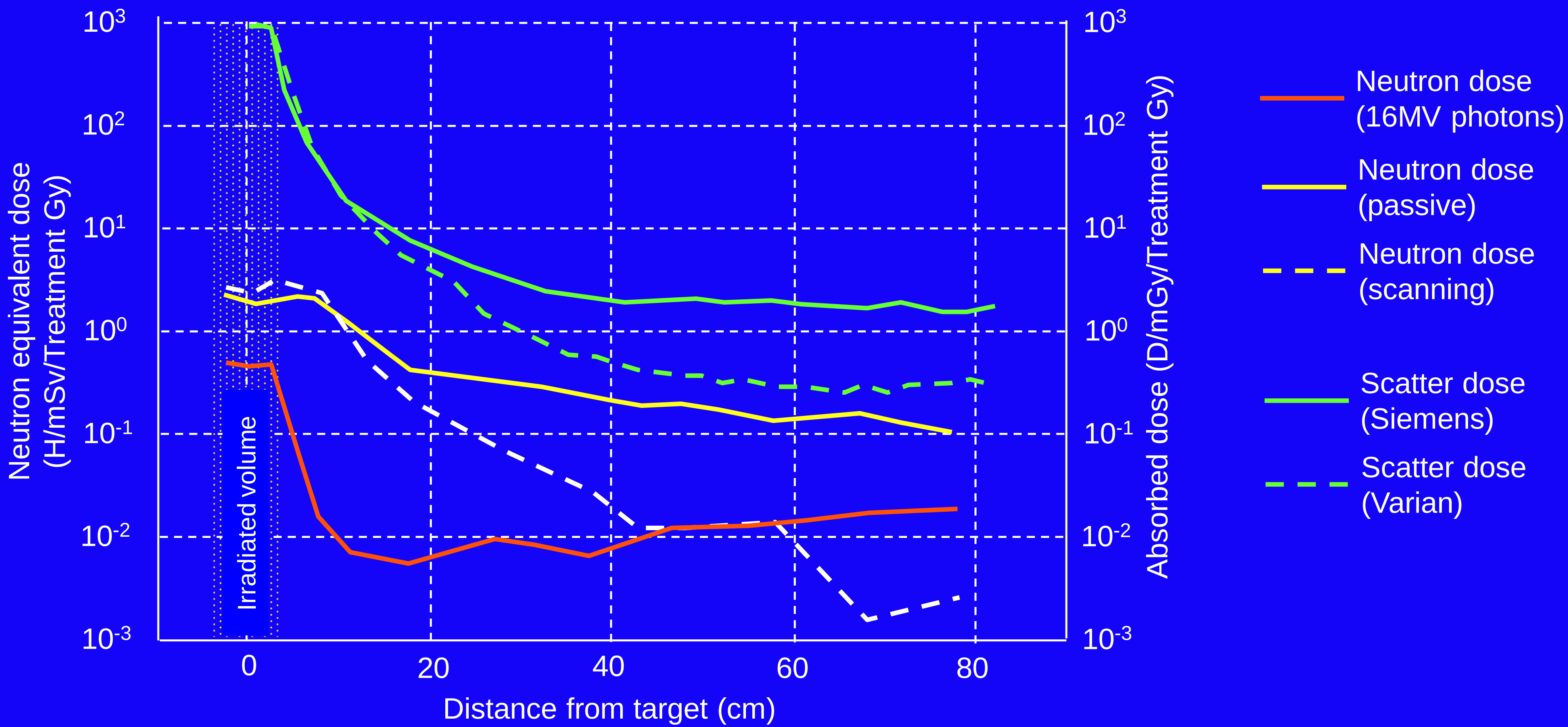
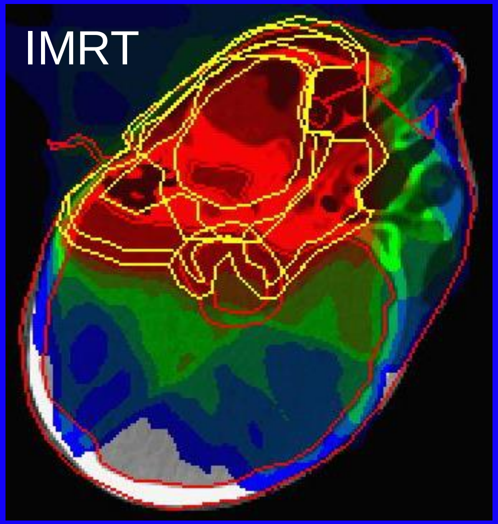
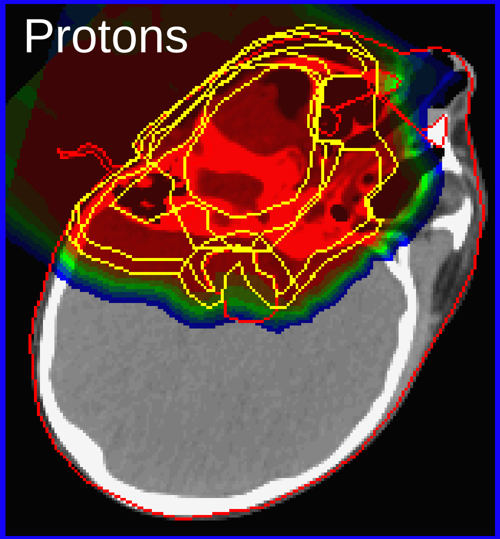
Neutron and photon scatter doses for protons and photons



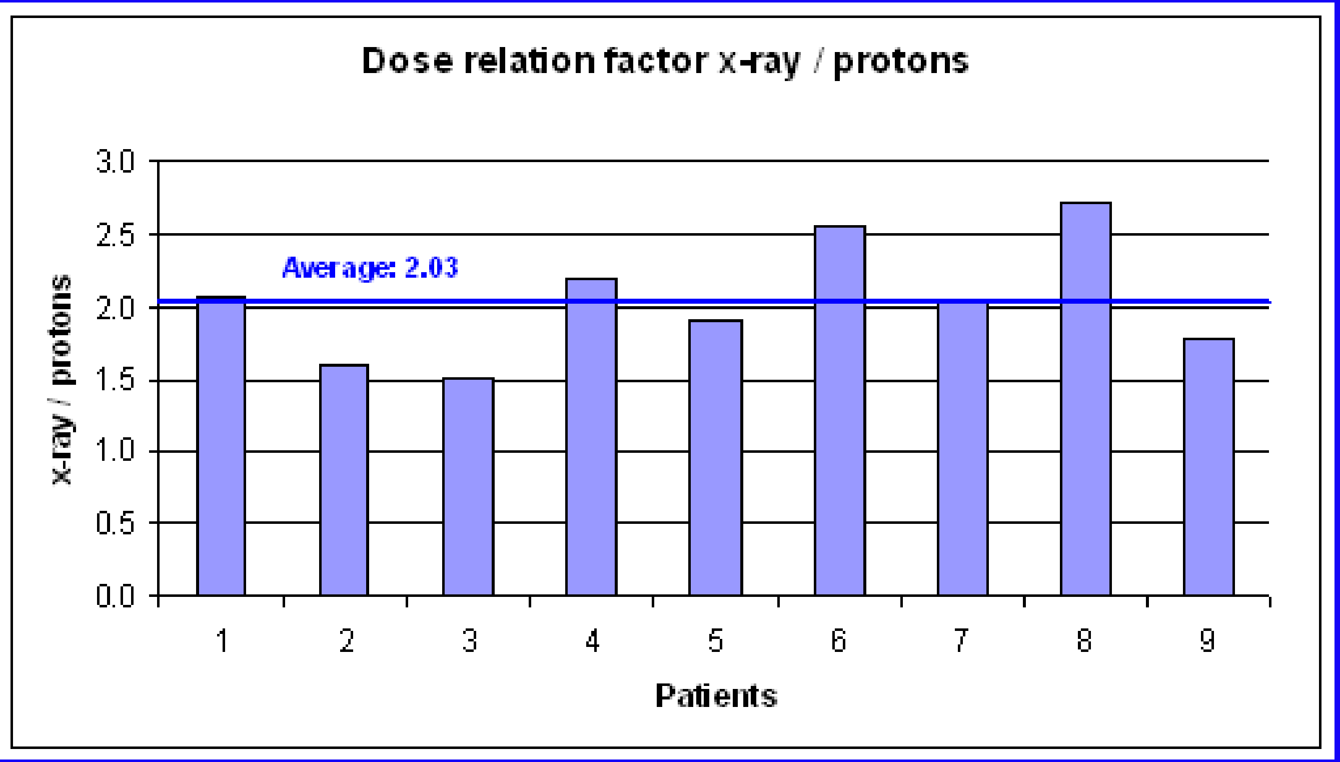
Adapted from Haelg et al 2012, Submitted to Medical Physics

… but don't forget the primary dose





A comparison of non-target integral doses for IMRT and scanned protons for nine pediatric cases



On average, protons reduced integral dose by a factor 2

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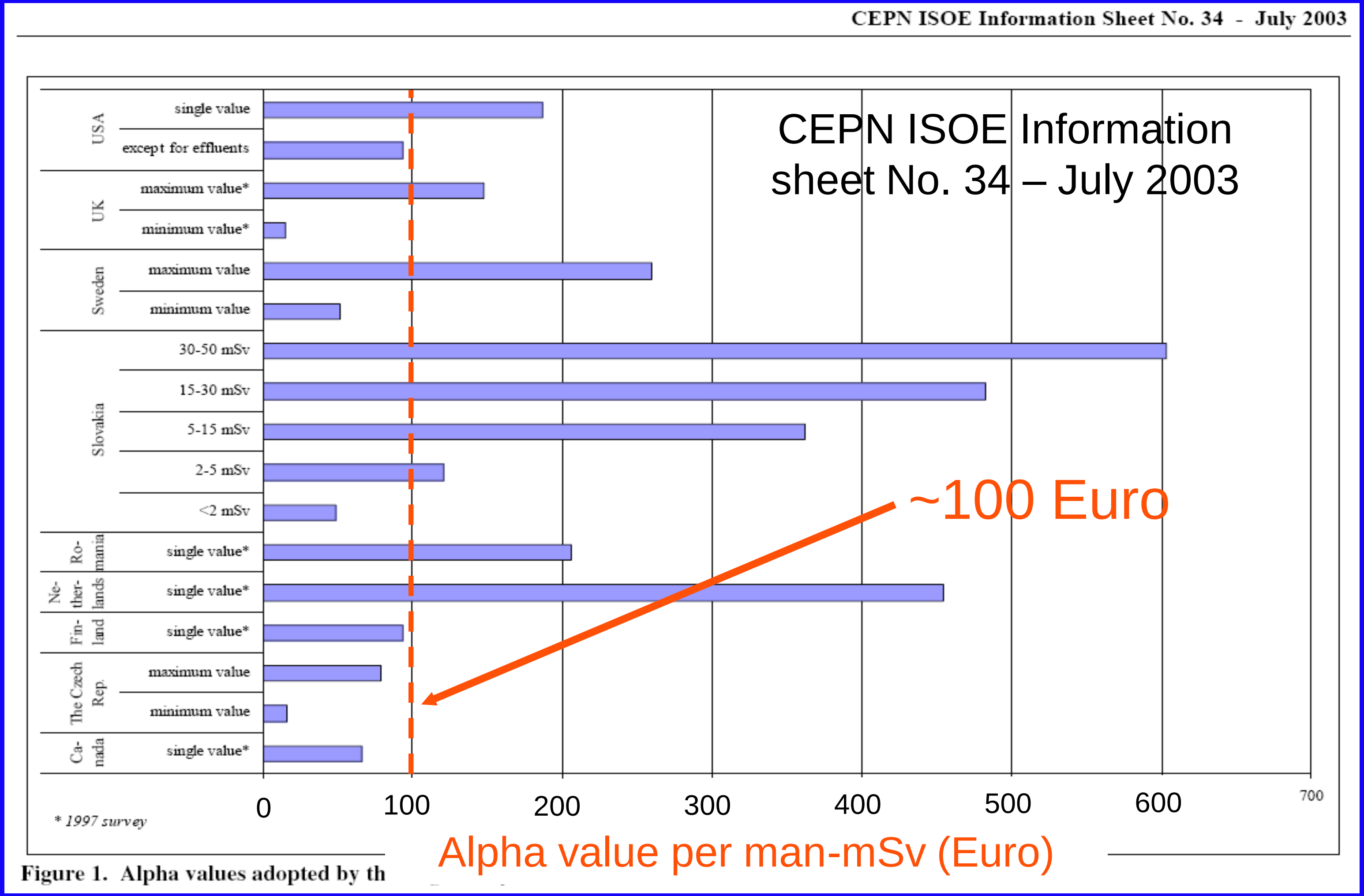
Are there potential cost consequences from reducing integral dose?*



* With thanks to Hakan Nystrom, Skandion Clinic, Sweden

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Are there potential cost consequences from reducing integral dose?*

TABLE VII. Organ equivalent doses (shaded in light grey) in units of Sv per unit photon Gy delivered to isocenter were calculated by summing the neutron and x-ray components of equivalent dose for each organ. The effective doses (shaded in dark grey) were calculated, for each beam energy, by summing the product of equivalent dose and the appropriate tissue weighting factor for all organs.

		Organ equivalent dose (Sv per unit photon Gy delivered to isocenter)					
		6 MV		15 MV		18 MV	
Organ	W_T	Conv	IMRT	Conv	IMRT	Conv	IMRT
Effective dose		7.78E−02	5.43E−02	7.81E−02	5.51E−02	7.54E−02	5.54E−02

Medical Physics, Vol. 33, No. 2, February 2006

For 74Gy treatment:

Effective dose (IMRT) = 54mSv x 74Gy ≈ 4000mSv

Effective dose (protons) = 4000mSv / 2 ≈ 2000mSv

Alpha value saving = 2000mSv x 100€ = 200000€ per patient!

* With thanks to Hakan Nystrom, Skandion clinic, Sweden

Summary

- Due to the Bragg peak characteristics of the depth dose curve, proton therapy can deliver highly conformal treatments with significantly reduced integral dose to the patient.
- Due to the limited range of therapeutic protons (<=32 cm in water), challenges for radiation protection and shielding are mainly to do with secondary neutron production
- Analytical shielding calculations are relatively straightforward but tend to overestimate transmitted dose rates. MC calculations are more accurate . Consequences for shielding costs?
- The significantly reduced integral dose of protons may have important radiation protection (and cost?) consequences for the patient, particularly pediatrics.

Thank you!