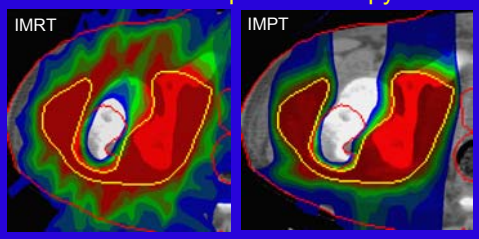
An overview of compensated and intensity modulated proton therapy



Tony Lomax, Department of Radiation Medicine,
The Paul Scherrer Institute, Switzerland

A disclaimer.....

Learn something you can use?

England has great beer…….

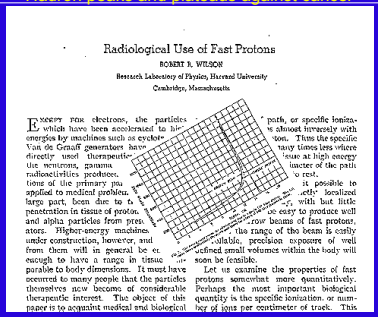
Switzerland has great skiing…….

Don't play 'ultimate frisby' after a 12 hour transatlantic flight

Overview of presentation

1. Proton interactions with matter
2. Treatment delivery
3. Clinical experience and applications
4. The future of proton therapy

Hadron peaks and plateaus against cancer



Radiological Use of Fast Protons

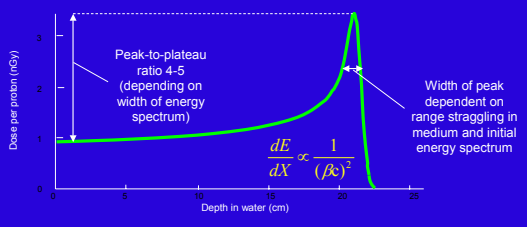
ROBERT R. WILSON
Research Laboratory of Physics, Harvard University
Cambridge, Massachusetts

R.R. Wilson, Radiology 47(1946), 487-491

Proton interactions with matter.

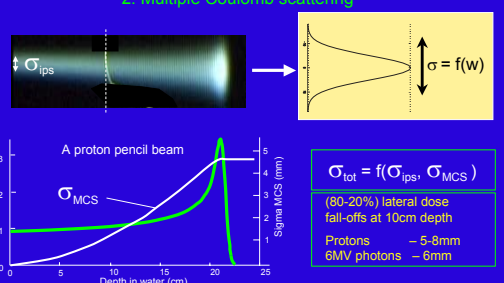
1. Energy loss

E.g. Depth-dose curve for 177 MeV protons



Proton interactions with matter

2. Multiple Coulomb scattering

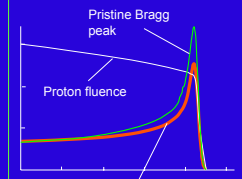


Proton interactions with matter

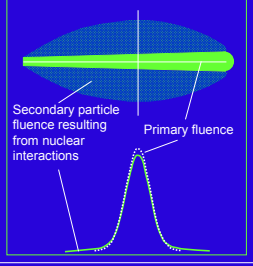
3. Nuclear interactions

About 20% of primary protons lost to interactions with atomic nuclei

Effect on the depth dose curve

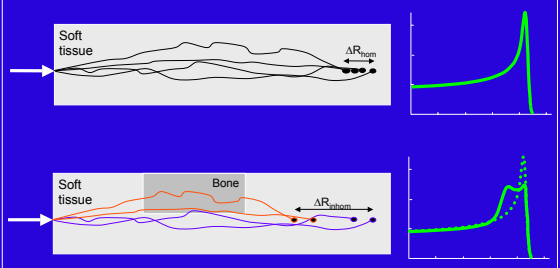


Effect on the lateral dose distribution



Proton interactions with matter

4. Density heterogeneity effects – effect on Bragg peak shape



Overview of presentation

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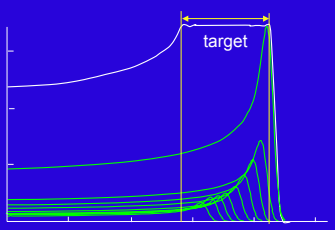
Treatment delivery

Making protons useful 1. Passive scattering

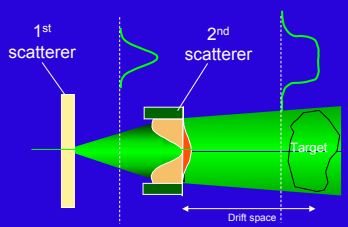
Extending the dose in depth – the 'Spread-out-Bragg-peak'



Treatment delivery

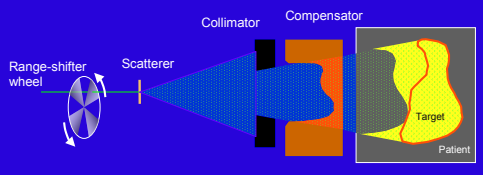
Making protons useful 1. Passive scattering

Extending the dose laterally – single and double scattering



Treatment delivery

Making protons useful 1. Passive scattering in practice

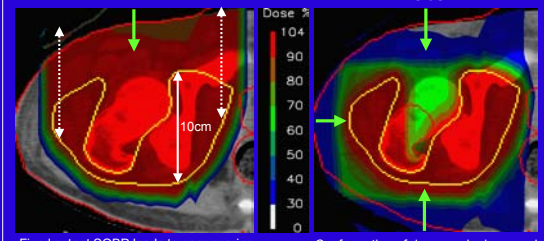


Treatment delivery

Making protons useful 1. Passive scattering in practice

Single passively scattered field

Three passively scattered fields

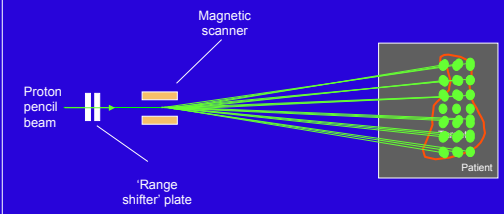


Fixed extent SOBP leads to poor sparing of normal tissue proximal to target

Conformation of dose can be improved through the use of multiple fields

Treatment delivery

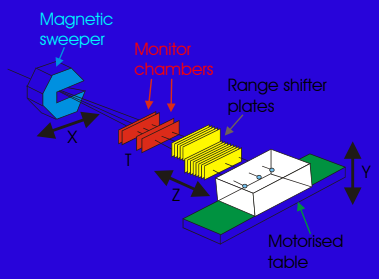
Making protons useful 2. Active scattering



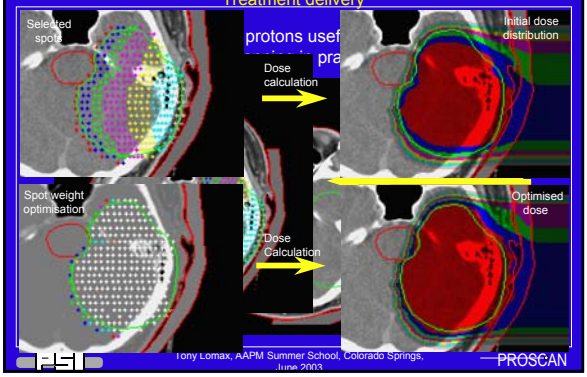
Treatment delivery

Making proton useful 2. Active scanning

The 'four' dimensional, pencil beam scanning system at PSI.



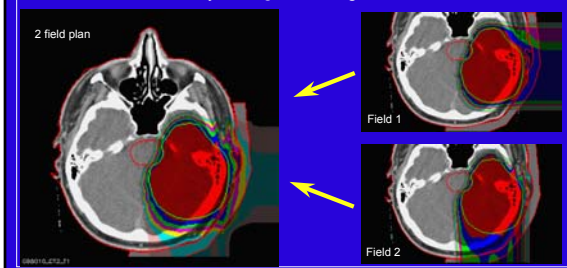
Treatment delivery



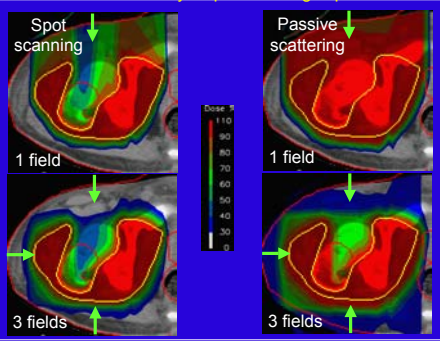
Treatment delivery

Making protons useful 2. Spot scanning in practice

A final plan is then the linear combination of multiple, individually *homogenous* single field doses



Treatment delivery – spot scanning in practice

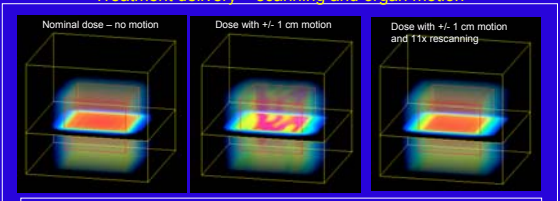


Treatment delivery

Passive and scanning delivery – a comparison.

Passive		Scanning	
Mature technology	+	New technology	-
Insensitive to organ motions	+	Very sensitive to organ motions	-
Lateral fall-off	+	Lateral fall-off	- (?)
Inflexible	-	Very flexible	+
Field specific hardware required	-	No field specific hardware required	+
Large gantries required	-	Smaller gantries can be used	+

Treatment delivery – scanning and organ motion



Using a double scanning system (currently under development at PSI) 11 times rescanning could be implemented in similar time to current delivery times (~ 2-3 minutes for 1 litre volume per field)

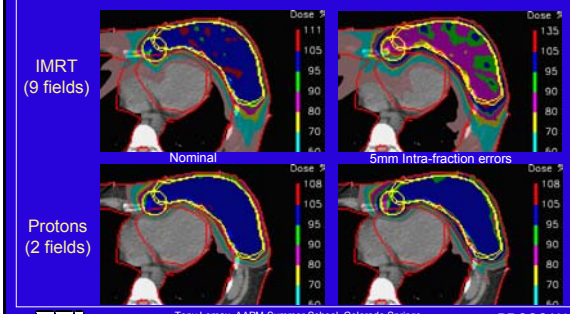
(Thanks to Christian Hilbes)

Treatment delivery – scanning and lateral fall-off

Lateral fall-offs (80-20%) at 12 cm depth	IPS(σ)=3mm	=	5mm
	6MV photons	=	~ 6mm
	PSI, 1cm air gap	=	6.5mm
	PSI, 17cm air gap	=	8mm
Lateral fall-offs (80-20%) at 20 cm depth	IPS(σ)=3mm	=	10mm
	15MV photons	=	~8mm

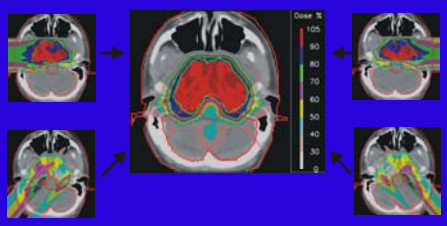
Protons vs. Photons. Non-IM protons against IMRT

Breast and regional node irradiation



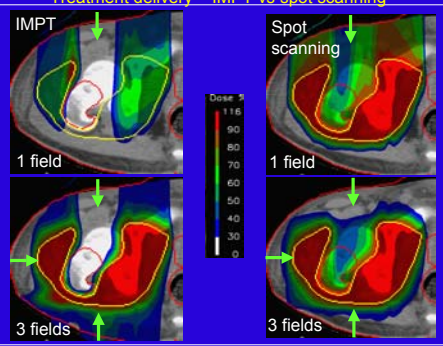
Treatment delivery

Making protons useful 3. Intensity Modulated Proton Therapy (IMPT)



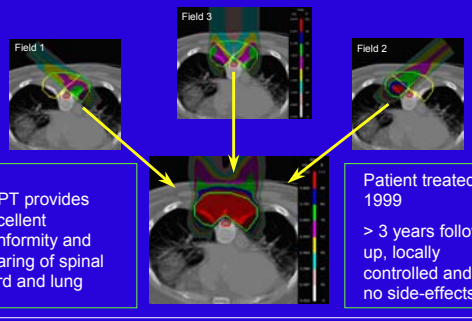
The application of many optimised, individually *inhomogenous* proton fields which together provide a homogenous coverage of the target volume

Treatment delivery – IMPT vs spot scanning



Treatment delivery

Making protons useful 3. IMPT – a clinical example.



IMPT provides excellent conformity and sparing of spinal cord and lung

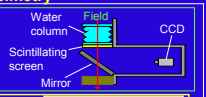
Patient treated in 1999

> 3 years follow-up, locally controlled and no side-effects

IMPT in practice – CCD dosimetry

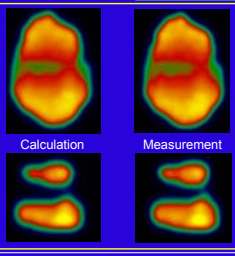
2D CCD dosimetry of posterior field

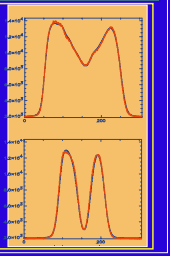
The CCD dosimetry system



D(w) = 4.3cm

D(w) = 7.8cm

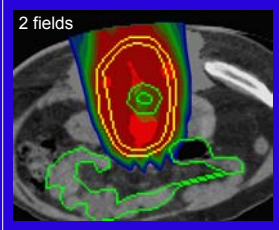


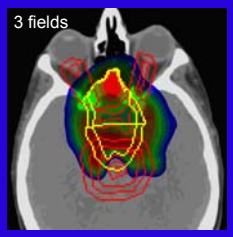


Treatment delivery – clinical experience with IMPT

4 cases treated. First in 1999, 3 more in 2002.

Two examples





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Clinical experience and applications.

Example results for deep seated tumours (passive scattering)

Prostate cancer (Loma Linda, >300 Patients)
- Stage T1-T2b
- 5 year disease free survival – 97 and 88% respectively

Skull base sarcomas (Harvard, 622 Patients)
- Chondrosarcomas: 98% tumour free after 5 years.
  95% tumour free after 10 years.
- Chordomas: 65% tumour free after 10 years (m)
  42% tumour free after 10 years (f)

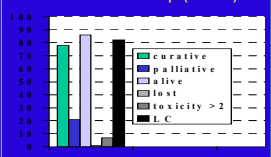
Hepatocellular carcinomas (Tsukuba, >120 Patients)
- Local Control Rate > 90%

Clinical experience and applications.

Initial clinical experience with spot scanning at PSI

99 patients treated by end 2001 (129 by end 2002)

Initial clinical follow-up (-2001)



99 Patients treated

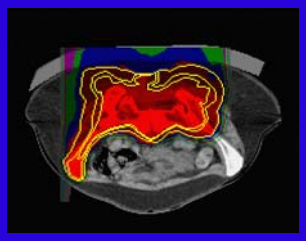
Curative 78, Palliative 21,

82 Local control,

86 surviving after 8 – 69 months.

Clinical experience and applications.

An example case - Sacral chordoma



4.5Y. after therapy (72 CGE) LC, no toxicity, back at work

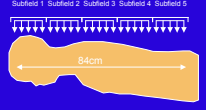
Clinical experience and applications.

Cranio-spinal irradiations (In collaboration with Beate Timmerman).

The plan

(Calculated for and delivered to an Alderson phantom)

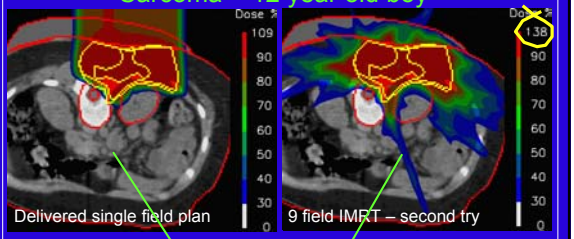
The irradiation



Volume ~ 2400ml
Length – 84cm
Fields – 1
Patches – 'automatic' patching of 5, parallel sub-fields
Spots > 30000
Time ~ 10-15 Mins

Clinical applications – IMRT vs IMPT

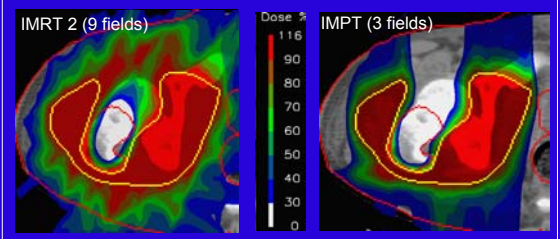
Sarcoma – 12 year old boy



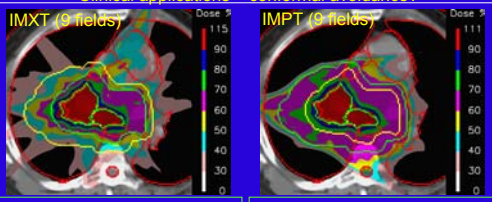
Factor 6 lower integral dose for protons

Clinical applications – IMRT vs IMPT

Ewings Sarcoma



Clinical applications – conformal avoidance?



Mean doses (Gy/CGE)

	Left lung	Right lung	Heart
IMXT	14.6	23.4	18.2
IMPT	15.3	20.9	19.1
IMPT-IMXT	0.7	-2.5	0.9

Total dose to additional CTV region (CTV2-CTV1) increased by factor 1.4

CTV volume increased1.8 times

When may protons be useful?.

A brief (and probably incomplete) history of radiotherapy

Ortho-voltage | Co^{60} | LINACS | 3d-planning | IMRT | P+/IMPT | ?

Improved dose distributions

Protons can simply be considered to be the next logical step in the advancement of radiotherapy

However, Protons are NOT necessarily competitive to conventional radiotherapy –

They could simply provide an additional treatment modality for those cases that can't be satisfactorily treated using other techniques.

When may protons be useful?.

- Factor 2 or more reduction of integral dose to normal tissues
- 3D modulation of Bragg peaks provides great flexibility in conforming dose, even in very challenging situations.
- Protons have the ability to reduce doses to critical structures in comparison to IMXT, whilst preserving target homogeneity.
- Possible applications:
  - Pediatric patients
  - Large treatment volumes (conformal avoidance?)
  - Patients with concomitant treatments
  - Pre-irradiated patients
  - Patients with co-morbidity

Proton therapy in the future.

The PSI gantry – diameter 4 meters

Current estimates against IMRT

Protons 2.4 times more expensive

1.7 times with likely improvements in efficiency and production facilities

(C.f. Chemotherapy)

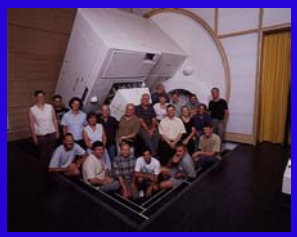
(Estimates courtesy of Mike Goitein and Martin Jermann)

Proton therapy in the future.

Firms currently supplying or developing proton therapy equipment.	Hospital based facilities as of end 2002.	Probable new hospital facilities in the near future.
Optivus (USA)	Loma Linda (California)	M.D. Anderson (Houston)
IBA (Belgium)	MGH (Boston)	U Florida (Jacksonville)
Hitachi (Japan)	Plus 4 in Japan.	U Penn (Philadelphia)
Accel/(Siemens?) (Germany)	>25 facilities world wide, mostly in research institutes.	RPTC (Bavaria)
		+ China and Taiwan

Why protons in Switzerland?

The PSI proton therapy team.



Gudrun Goitein, Eros Pedroni, Ralph Bearpark, Terence Boehringer, Dolf Coray, Emmanuel Egger, Frank Emert, Pavel Fuksa, Martin Grossman, Christian Hilbes, Daniel Lempen, Lydia Lederer, Shixiong Lin, Tony Lomax, Anita Obrist, Frieda Obrist, Benno Rohrer, Hanspeter Rutz, Sairos Safai, Otto Stadelmann, Beate Schulz, Hansueli Staueble, Beate Timmerman, Alexander Tourovsky, Jorn Verwey, Damien Weber.