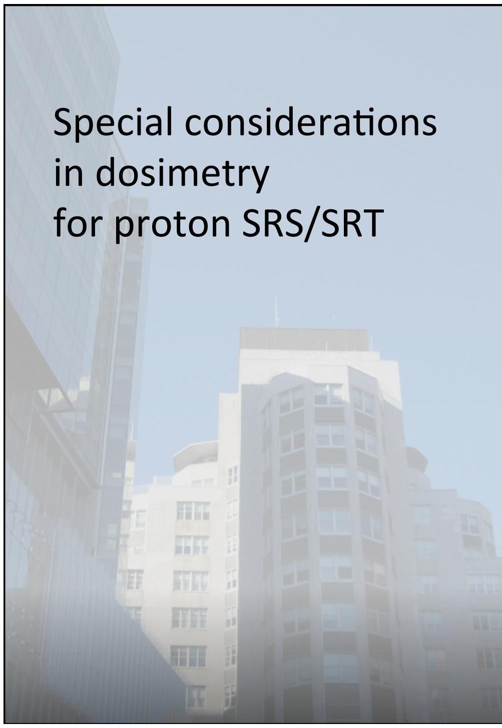


Special considerations in dosimetry for proton SRS/SRT

Juliane Daartz, PhD

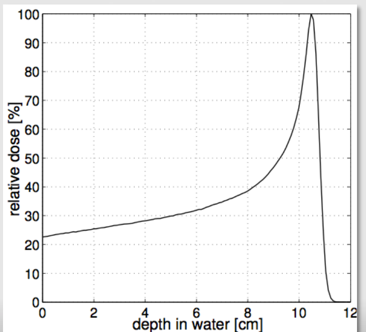
Special considerations for proton SRS/SRT

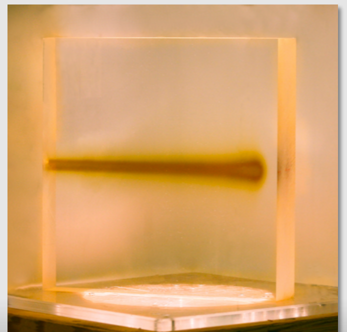
Learning objectives

- Proton dose distributions as a function of field size (important for all sites) – physics, modeling, measurement
- Problems with heterogeneities (specifically lung)

Basic physics

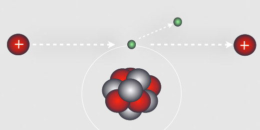
- Electromagnetic stopping -> depth dose
- Multiple Coulomb Scattering -> penumbra
- Nuclear interactions -> small built-up, large dose envelope





Basic physics

EM Stopping



- max E transferred from p+ to e-: 0.35MeV (160MeV p+)
- a negligible amount of stopping happens in em interactions with nuclei
- Bethe Bloch:

[see e.g. PDG 2010]

$$-\left\langle \frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right] [\cdot \rho]$$

densi

$K = 4\pi N_A r_e^2 m_e c^2 = 0.307$ MeV g^{-1} cm^2

$T_{max} = 2 m_e c^2 \beta^2 \gamma^2 / (1 + 2\gamma m_e/M + (m_e/M)^2)$ [Max. energy transfer in single collision]

$N_A = 6.022 \cdot 10^{23}$ [Avogardo's number]

$r_e = e^2/4\pi\varepsilon_0 m_e c^2 = 2.8$ fm [Classical electron radius]

$m_e = 511$ keV [Electron mass]

$\beta = v/c$ [Velocity]

$\gamma = (1-\beta^2)^{-2}$ [Lorentz factor]

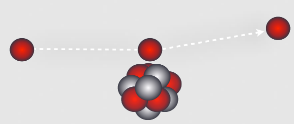
z : Charge of incident particle
M : Mass of incident particle
Z : Charge number of medium
A : Atomic mass of medium
I : Mean excitation energy of medium
δ : Density correction [transv. extension of electric field]

Validity: $.05 < \beta\gamma < 500$, $M > m_\mu$

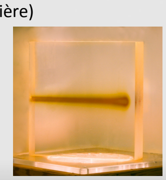
Source: KIP Heidelberg, Lecture Schulz-Coulon

S α $1/v^2$ -> the slower the p the more E is lost per length -> Bragg peak

Multiple Coulomb Scattering

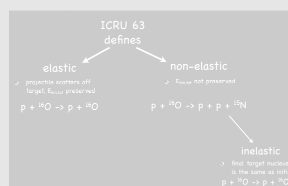


- proton undergoes electrostatic interaction with nuclei
- scattering angle per single interaction very small, multitude of interactions gives the effect (Molière)



mean scattering angle increases with decreasing particle energy
depends on material
higher Z: larger angle

Nuclear Interactions



- 20% of 200MeV protons undergo a non-em interaction with a nucleus on the way to full stop
- -> small nuclear built-up, large dose envelope (halo)

p	d	t	^{3}He	α	recoils	n
0.57	0.016	0.002	0.002	0.029	0.016	0.20

fraction of initial energy carried away, for nonelastic interactions of 150MeV p with ^{16}O (Seltzer et al)

Basic physics

- Ideal measurement & modeling conditions:
  - EM *&* nuclear equilibrium

Basic physics

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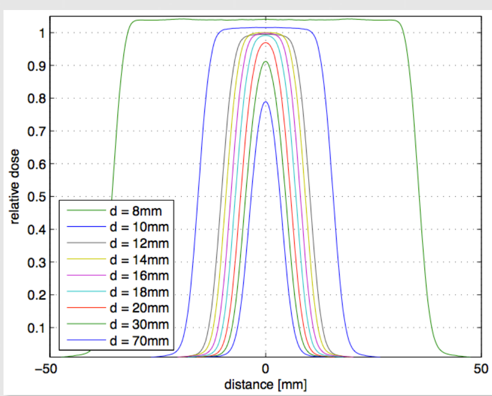
- EM equilibrium is lost for much smaller field sizes than nuclear equilibrium

Basic physics

- Ideal measurement & modeling conditions:
  - ➢ EM *&* nuclear equilibrium
- EM equilibrium is lost for much smaller field sizes than nuclear equilibrium
- proton dose distributions are field size dependent up to rather large diameters (~10cm)

Field size dependence

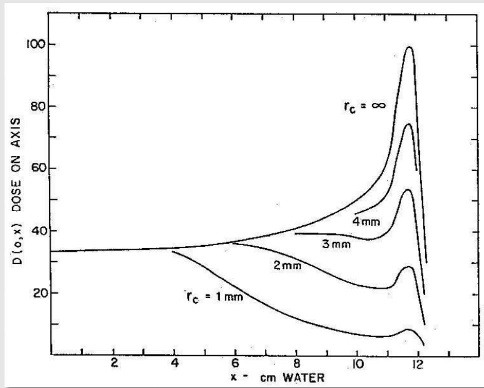
- Profiles vs field size



@ ~7cm depth, for R90 ~8.5cm M90 ~2.5cm

Field size dependence

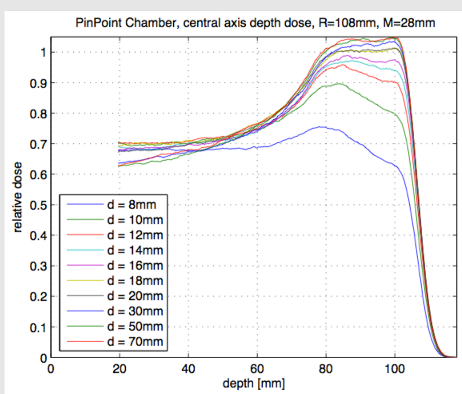
- Depth dose vs field size – loosing the Bragg Peak



Preston & Koehler 1968

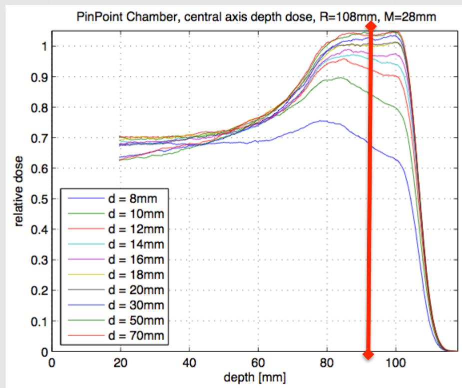
Field size dependence – passive scattering

- Depth dose vs field size – tilted SOBP



Field size dependence – passive scattering

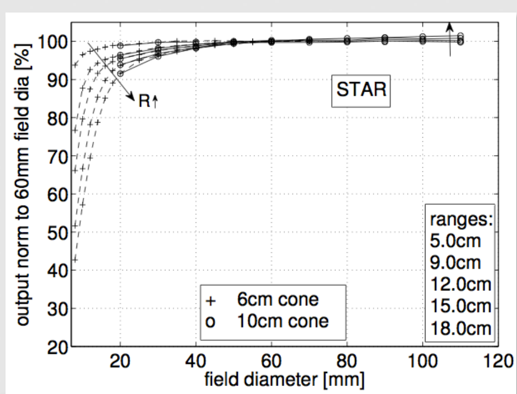
- dose @ reference point (SOBP center)



➢ range dependent

Field size dependence – passive scattering

- dose @ reference point (SOBP center)

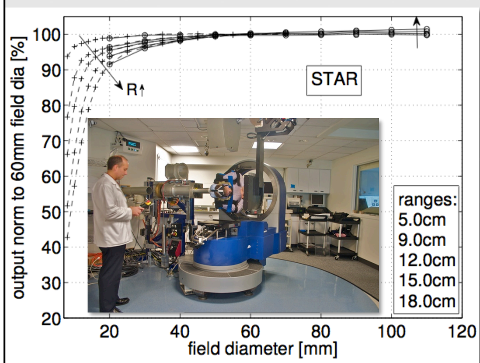


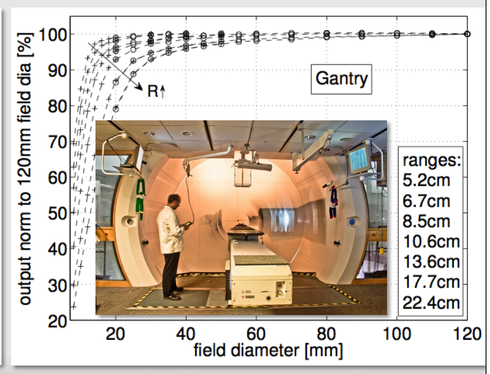
Measurement – PinPoint IC

Daartz et al, 2009

Field size dependence – passive scattering

- dose @ reference point (SOBP center)





Field size dependence – passive scattering

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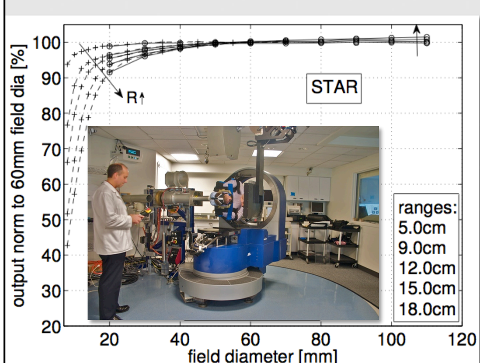
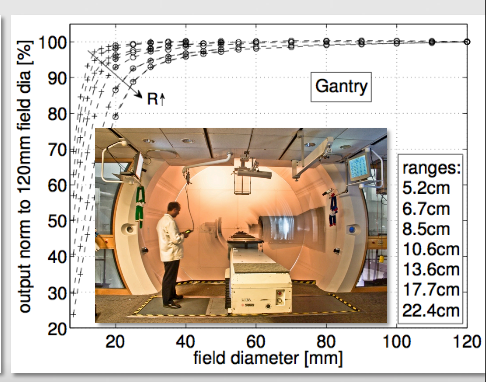




➢ beamline dependent

Which of the following have an impact on the function *F(x) = dose(field size)*

20%	1. Proton Energy, depth
20%	2. Beamline properties, T and P
20%	3. Beamline properties, depth
20%	4. Only energy
20%	5. Beamline properties, depth, energy

10

Which of the following have an impact on the function *F(x) = dose(field size)*

1. Proton Energy, depth
2. Beamline properties, T and P
3. Beamline properties, depth
4. Only energy
5. Beamline properties, depth, energy

10

Dose Calculation

- Pencil beam algorithms
  - ➢ limited accuracy, various versions

$$D(x,y,z)=\iint \psi_0(x',y')\frac{C(x',y',z)}{2\pi[\sigma_{tot}(x',y',z)]^2}\exp\left(-\frac{(x'-x)^2+(y-y')^2}{2[\sigma_{tot}(x',y',z)]^2}\right)dx'dy'$$

Hong et al, 1996

Dose Calculation

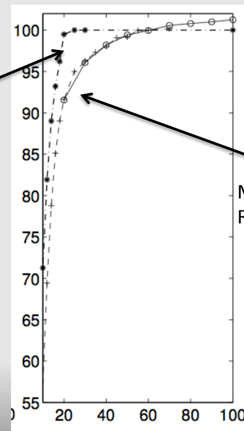
$$D(x,y,z)=\iint \psi_0(x',y')\frac{C(x',y',z)}{2\pi[\sigma_{tot}(x',y',z)]^2}\exp\left(-\frac{(x'-x)^2+(y-y')^2}{2[\sigma_{tot}(x',y',z)]^2}\right)dx'dy'$$

- common: input data for your reference field size only
- need to verify versus measurement:
  - ➢ relative decrease of dose with field size for clinically used range interval

Dose Calculation

$$D(x,y,z)=\iint \psi_0(x',y')\frac{C(x',y',z)}{2\pi[\sigma_{tot}(x',y',z)]^2}\exp\left(-\frac{(x'-x)^2+(y-y')^2}{2[\sigma_{tot}(x',y',z)]^2}\right)dx'dy'$$

- For instance: above formula yields:



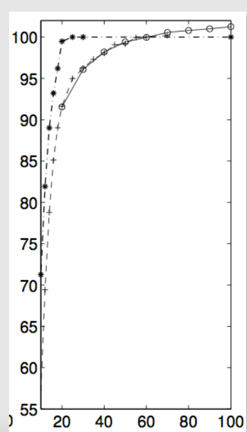
field diameter

Measurement
R90/M90 = 18/2cm

Dose Calculation

- How to deal with this?

➢ Ideally: improve dose calculation (e.g. add another, wider, Gaussian to deal better with halo)

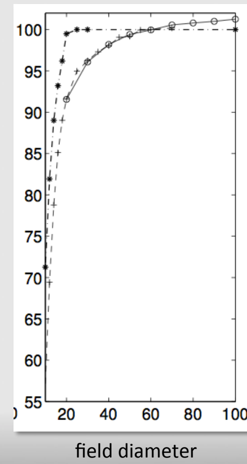


field diameter

Dose Calculation

- How to deal with this?

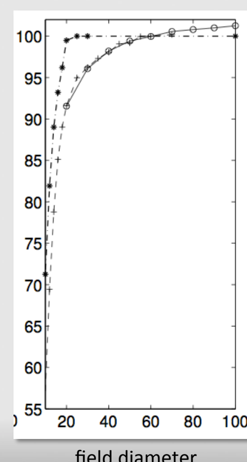
➢ Alternatively: determine reasonable minimum treatable field size, correct MU/field outside TPS with measured field size correction factor



Dose Calculation

- How to deal with this?

➢ Know your limits: consider referring too small, deep seated targets located in heterogeneous areas to photons



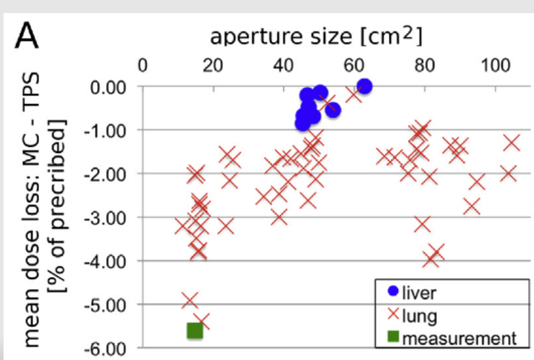
Measurements – Small fields

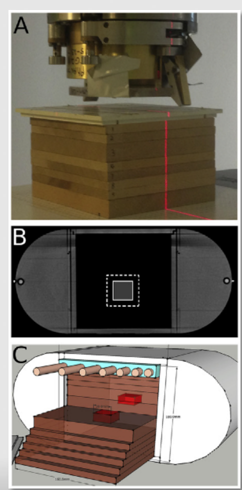
- Choice of detector
  - Small!
  - Watch out for: LET dependence, non-linearity with dose
  - Reliable but limited due to size: PinPoint IC

- Very careful setup necessary

Dose Calculation – heterogeneity & field size

- Most critical: lung





Grassberger et al, 2014

SRS with PBS

- define SRS: 1-2 fractions
- SRS with PBS: not currently done
- difficulty: robustness
- a note on conformality: likely for many cases apertures and perhaps range compensators will be beneficial, depending on spot size

When delivering proton SRS it is critical to be aware of uncertainties.

Rank according to level of increasing difficulty:

A - passive scattering intra cranial 4cm target
B - IMPT intra cranial 4 cm target
C - passive scattering lung 2cm target
D - IMPT lung 2cm target

20%	1. A – B – C - D
20%	2. C – D – B - A
20%	3. A – C – B - D
20%	4. C – A – B - D
20%	5. D – C – A - B

10

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1. A – B – C - D
2. C – D – B - A
3. A – C – B - D
4. C – A – B - D
5. D – C – A - B

Thank you!