MASSACHUSETTS GENERAL HOSPITAL
CANCER CENTER℠

Treatment Planning for Proton Radiotherapy

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Judy Adams
Hanne Kooy
Department of Radiation Oncology

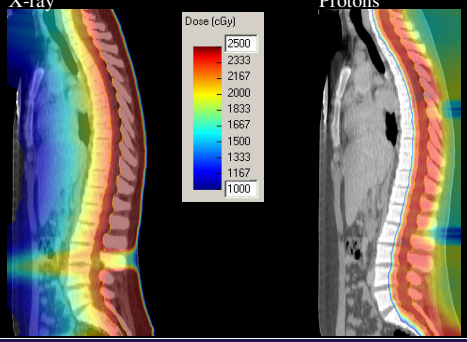
DANA-FARBER/PARTNERS CANCERCARE

Outline

- Treatment Planning Considerations
- SOBP Fields (Scattered or Uniform Scanning)
  - Beam properties
  - Treatment devices
  - Accounting for uncertainties
  - Techniques
- Pencil Beam Scanning

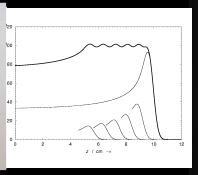
The Proton Advantage – no exit dose

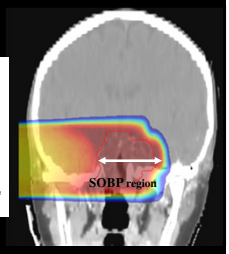
X-ray



Protons

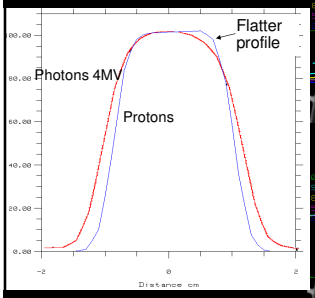
Modulation
Homogeneous Dose



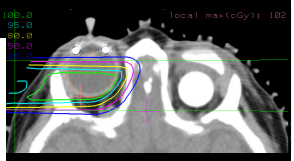


Modulator Wheel or
Uniform Scanning

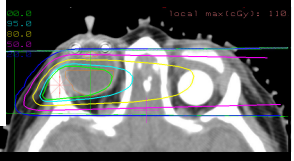
Penumbra/Beam Profile
Block edge



Protons



4MV Photons

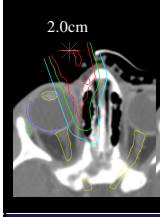


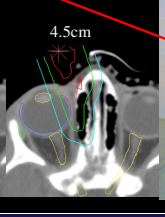
Penumbra and Airgap

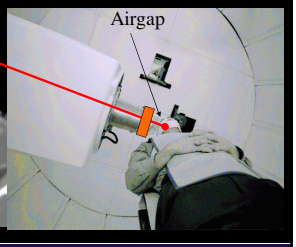
Source Size ~ 5 cm

DS: Produces large virtual source size
US: ~0.5-1.5 cm

Patient source size ~ Air Gap / (SAD – Air Gap)







Treatment Devices

– Apertures
  - Penumbra and 2D Shaping

– Range compensator
  - Depth – the 3d dimension unique to protons

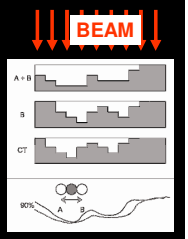
R and M Uncertainty

- Calculations require patient-specific stopping power in lieu of electron density available from patient CT
- We only have a universal conversion curve for HU's to S (rel water)
- We use sampling of HU to "calibrate" curve to the patient
- Considerable (~+/-3.5%) uncertainty
- Account for by increasing range by 3.5% + 1 mm
- Similar increase required for modulation

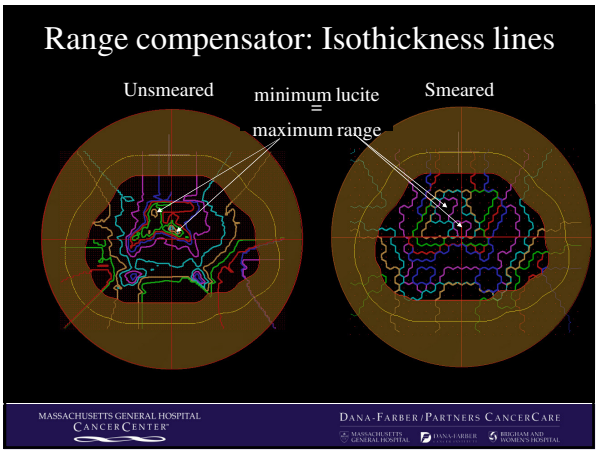
Setup Error

Compensator smearing

- Smearing considers the effect of non-systematic uncertainties and effectively creates the "worst" case range-compensator to ensure that the target is always covered.
- Smearing results in more dose beyond the distal edge.
- Very effective and necessary methodology



Range compensator: Isothickness lines



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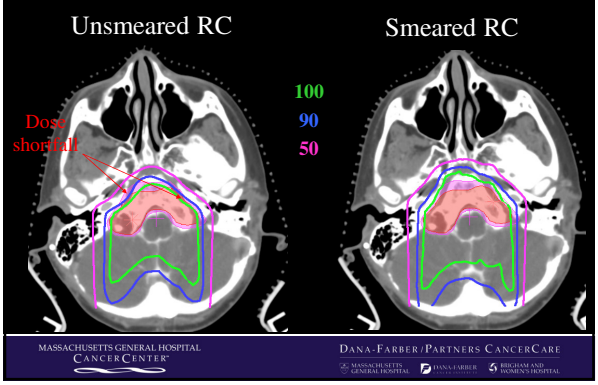
Range compensator and Dose



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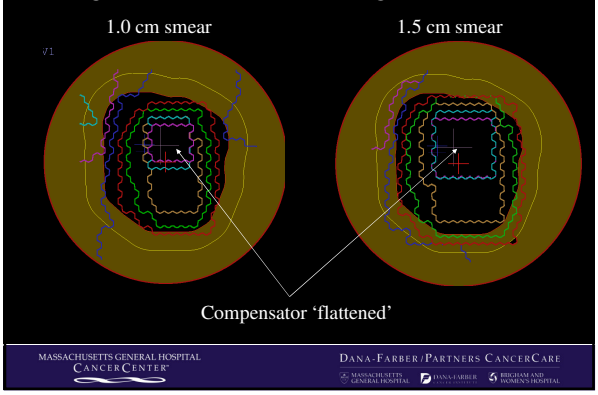
Organ motion and smearing



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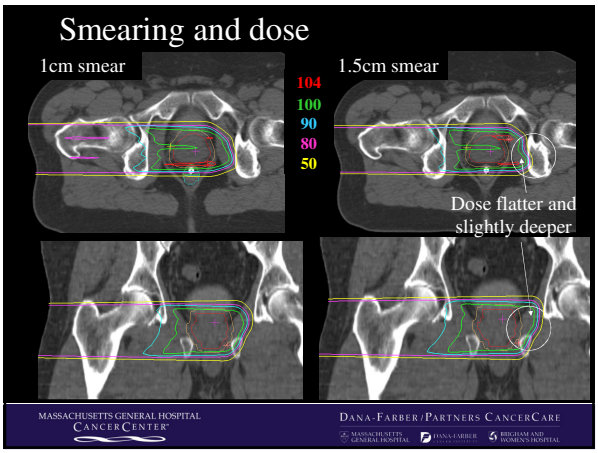
Smearing and dose
1cm smear
1.5cm smear
104
100
90
80
50
Dose flatter and slightly deeper
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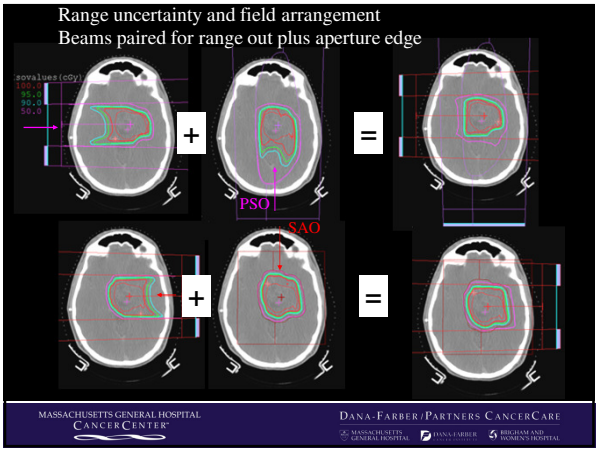
Range uncertainty and field arrangement
Beams paired for range out plus aperture edge
PSO
SAO
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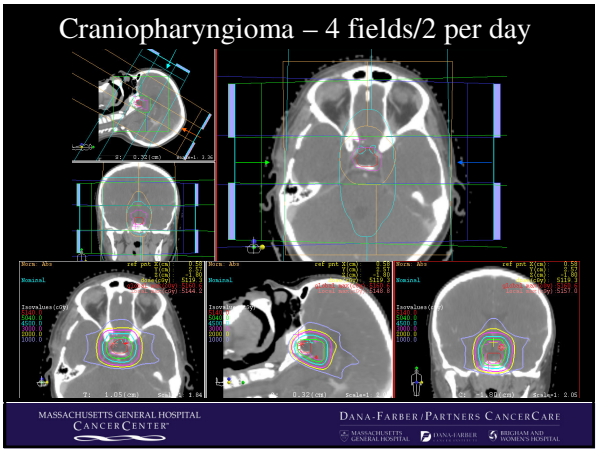
Craniopharyngioma – 4 fields/2 per day
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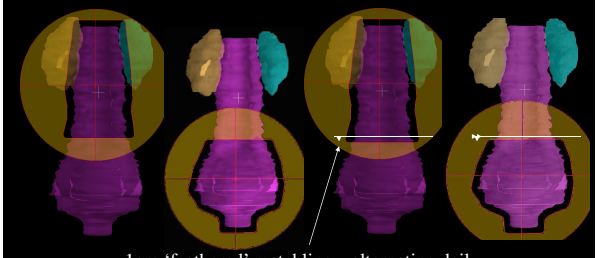
Matching Techniques

- Large tumors
- CSI
- Head and Neck
- Changing target geometries
- Feathering matchlines minimizes dose uncertainties at matchlines

Field Matching
Para Aortic Lymph Nodes

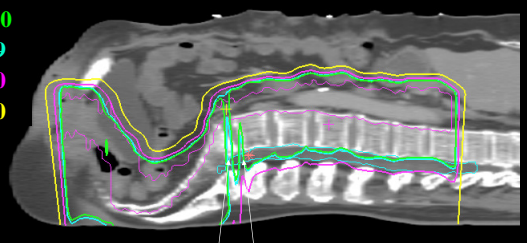
Level 1 Level 2



1cm 'feathered' matchline – alternating daily

Field Matching
Para Aortic Lymph Nodes

100
99
90
50



Matchlines

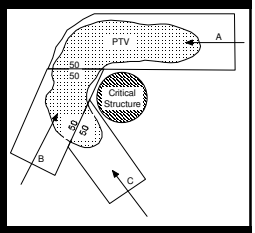
Patching Technique

- Unique to proton therapy
- Target volume(s) segmented
- Automated ‘patch volume’ generated
- Manual or automated range compensator design

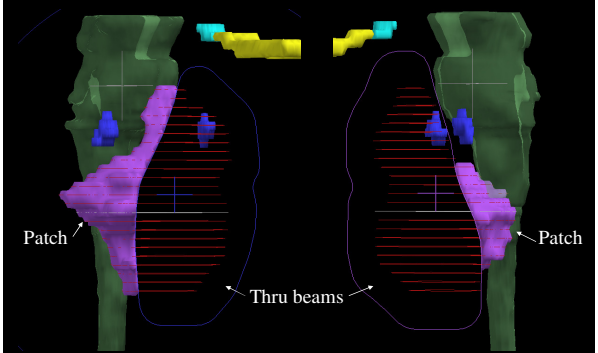
Field Patching

•Patching is a hierarchical sequence of proton fields.

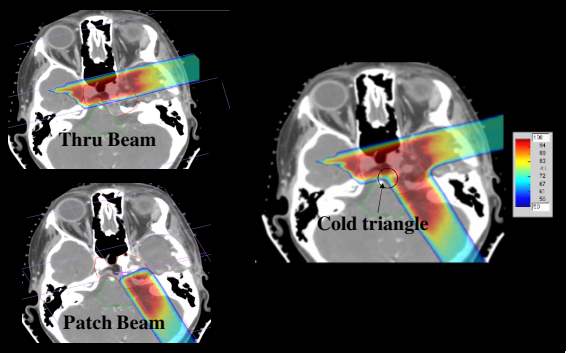
- “THROUGH” Field A: Achieved distal conformation to TV with the Range Compensator.
- PATCH Field B: Achieve matching of distal edge of B with the Range Compensator at the lateral (50%) field edge of A
- Match at 50% isodose, lateral + distal, levels



Automatically generated patch volumes



Patch Technique



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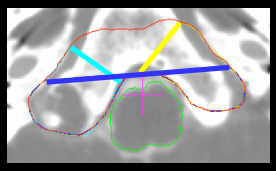
Accounting for uncertainty

- Multiple (2 or 3) patch combinations usually required
  - move around hot and cold regions
  (hot at patchline, but cold triangle at aperture intersections)



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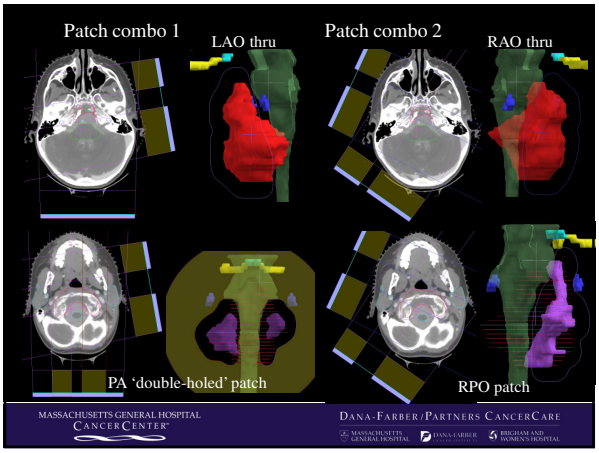

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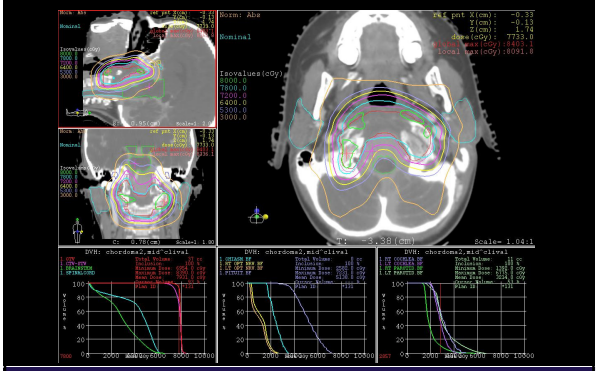
Composite to 78Gy(RBE)



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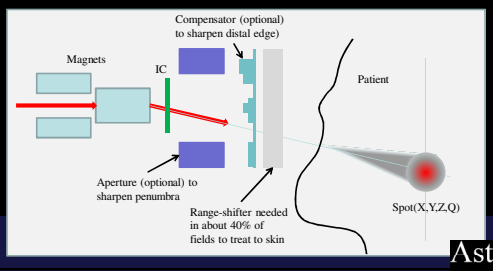
Pencil-Beam Scanning

- Control all parameters of narrow proton "pencil" beams
  - Position [X,Y] with magnets, depth [Z] with beam energy E
  - Dose in patient with total charge [Q] in the pencil-beam
  - Dose resolution proportional to pencil-beam width σ (3 - 12 mm)
- Allows local dose modulation not possible in DS fields



Astroid

Pencil-Beam Scanning: Robustness

Mitigate the greater sensitivity to uncertainties

- Geometric:
  - "Appropriate" expansion of TV's (Lomax: STV)
- Optimization:
  - variable lateral and distal margins and SFUD non-uniformity index

layer spacing:	1 distal W80
spot spacing:	1 sigma
lateral margin:	15 mm
distal margin:	10 mm
max SFUD non-uniformity:	10 %

  - Robustness: Incorporate uncertainties directly into the Astroid MCO optimizer to yield plans that are invariant, as quantified by constraints, to stated uncertainties

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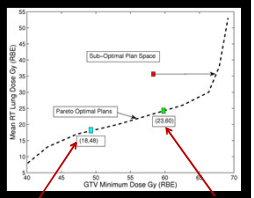
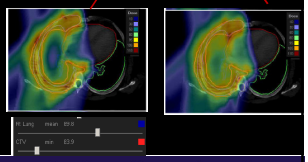
Multi-Criteria Optimization

- Large # of spots means
  - Constraint-based optimization *only* will not yield clinically "best" plan
  - Opportunity for healthy tissue dose trade-off analysis greater compared to IMRT
- MCO
  - Minimal set of absolute constraints –
    - D(GTV) > 50 Gy(RBE)
  - Specify competing objectives –
    - Trade-off Lung v GTV dose
- Implementation
  - ~30 sec / objective / CPU thread
    - 2 GHz





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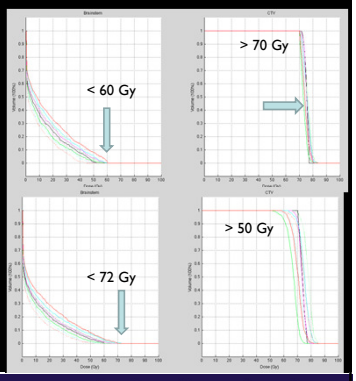
Robust MCO

•PBS requires explicit consideration of uncertainties in the optimization.
•Ensures that every plan meets the constraints

Robust

•Optimization of the nominal plan only and analysis of errors on that plan demonstrates violation of constraints.

Non-robust



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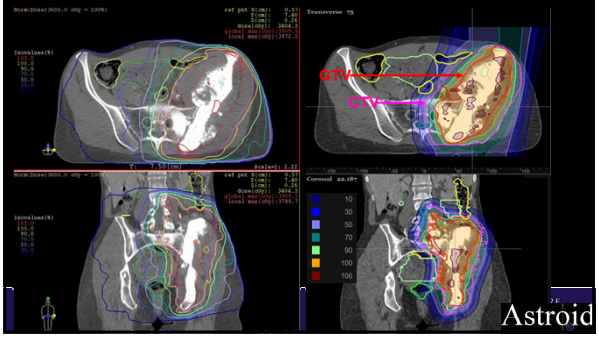
Osteosarcoma – 2 treatment fields (LA + PA)

Prescription:
- IMRT 36 Gy to CTV / 10 fractions
- p PBS 36 Gy(RBE) to GTV and 14.4Gy(RBE) to CTV / 20 fractions

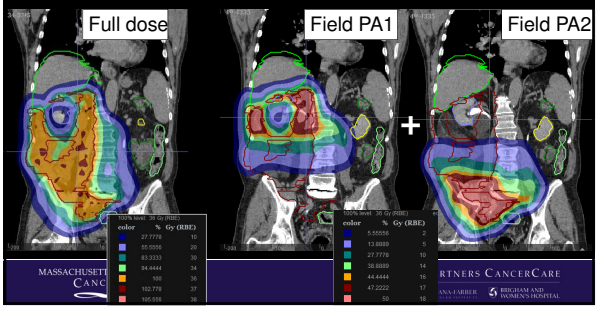


Retroperitoneal Sarcoma with Overlapping Fields

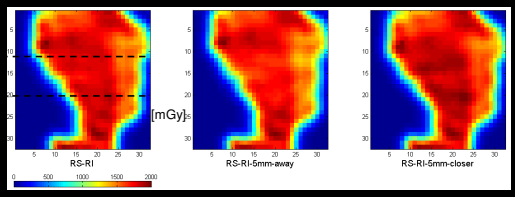
Prescription:

- IMRT 20 Gy to CTV /16 fractions
- p PBS 36 Gy(RBE) to retroperitoneal margin /18 fractions

PBS plan with tapered dose distribution at matchline (N. Depauw)



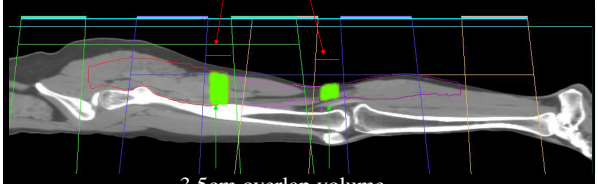
Retroperitoneal Sarcoma with Overlapping fields



- Change in dose within overlap region for ±5 mm relative shift between fields is < 0.2 Gy

PBS fields – no apertures or range compensators

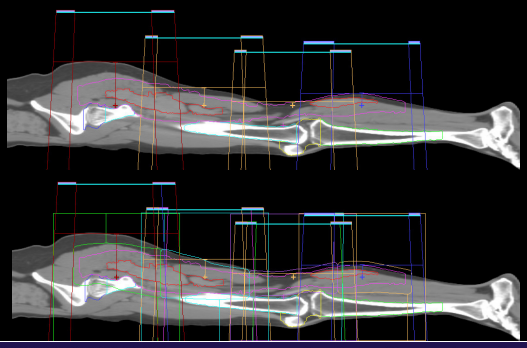
3 flds overlapping by 5.5cm



3.5cm overlap volume

Optimizer controls dose in overlap region

SOBP protons:
3 level moving matchline technique



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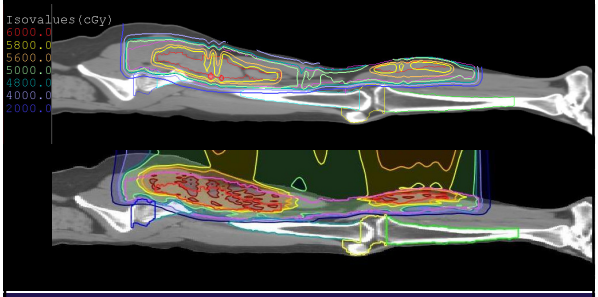
Comparison: DS and PBS protons



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Thank you

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