Clinical and operational aspects of beam delivery. From Double Scattering to Pencil Beam Scanning,

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>95% of new particle treatment rooms under construction and planning are proton PBS.

PBS is replacing DS as the dominant proton delivery modality. Can it replace photon as the main radiotherapy modality?

Clinical applications. Cost. Operation

Requirements for Ideal Proton Delivery Modality

- Clinical:
- Good conformality for complex shaped targets
- Large fields
- Low dose to normal tissue proximal to the tumor
- IMPT
- Can be used for static and moving targets
- Small penumbra
- Low secondary neutrons

Requirements for Ideal Proton Delivery Modality

- Cost:
- Initial purchase
- Operation (manpower)
- Maintenance

- Operation:
- Ease of planning, QA, delivery
- Efficiency

Clinical limitations of DS/US versus PBS Conformality

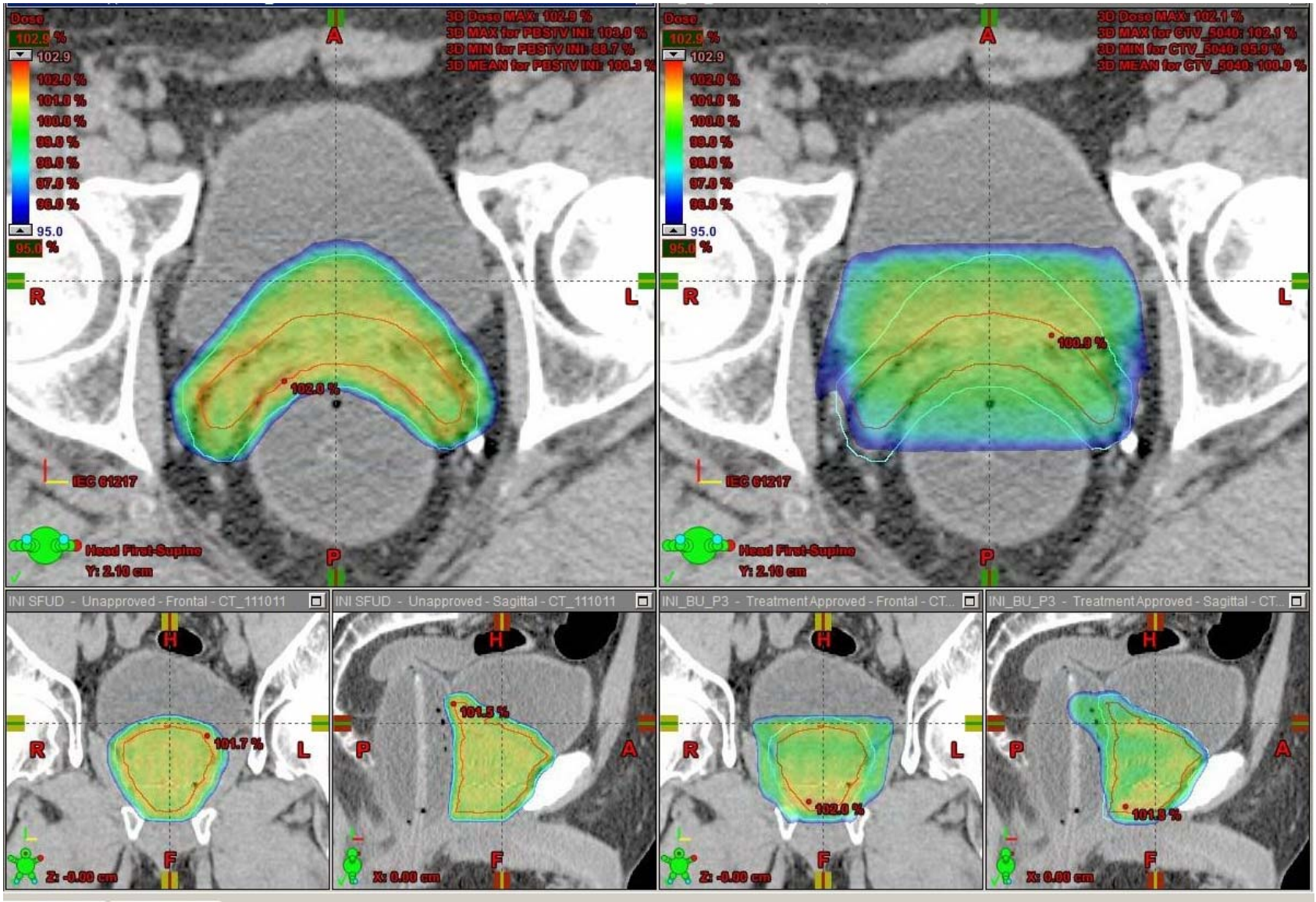
DS/ US

- Limited conformality- base of skull, spinal cord-need patching.
- Patching is problematic.

PBS

- Very good conformality
- No need for patching

PBS DS


Dose
102.9 %
102.9
102.0 %
101.0 %
100.0 %
99.0 %
98.0 %
97.0 %
96.0 %
95.0
95.0 %
A
R
L
P
102.0 %
IEC 61217
Head First-Supine
Y: 2.10 cm
3D Dose MAX: 102.9 %
3D MAX for PBSTV INI: 103.0 %
3D MIN for PBSTV INI: 88.7 %
3D MEAN for PBSTV INI: 100.3 %
3D Dose MAX: 102.1 %
3D MAX for CTV_5040: 102.1 %
3D MIN for CTV_5040: 95.9 %
3D MEAN for CTV_5040: 100.0 %
100.0 %
INI SFUD - Unapproved - Frontal - CT_111011
INI SFUD - Unapproved - Sagittal - CT_111011
INI_BU_P3 - Treatment Approved - Frontal - CT...
INI_BU_P3 - Treatment Approved - Sagittal - CT...
H
F
101.7 %
101.5 %
102.0 %
101.8 %
Z: -9.00 cm
X: 0.00 cm

Clinical comparison of DS/US versus PBS Field size

DS/ US

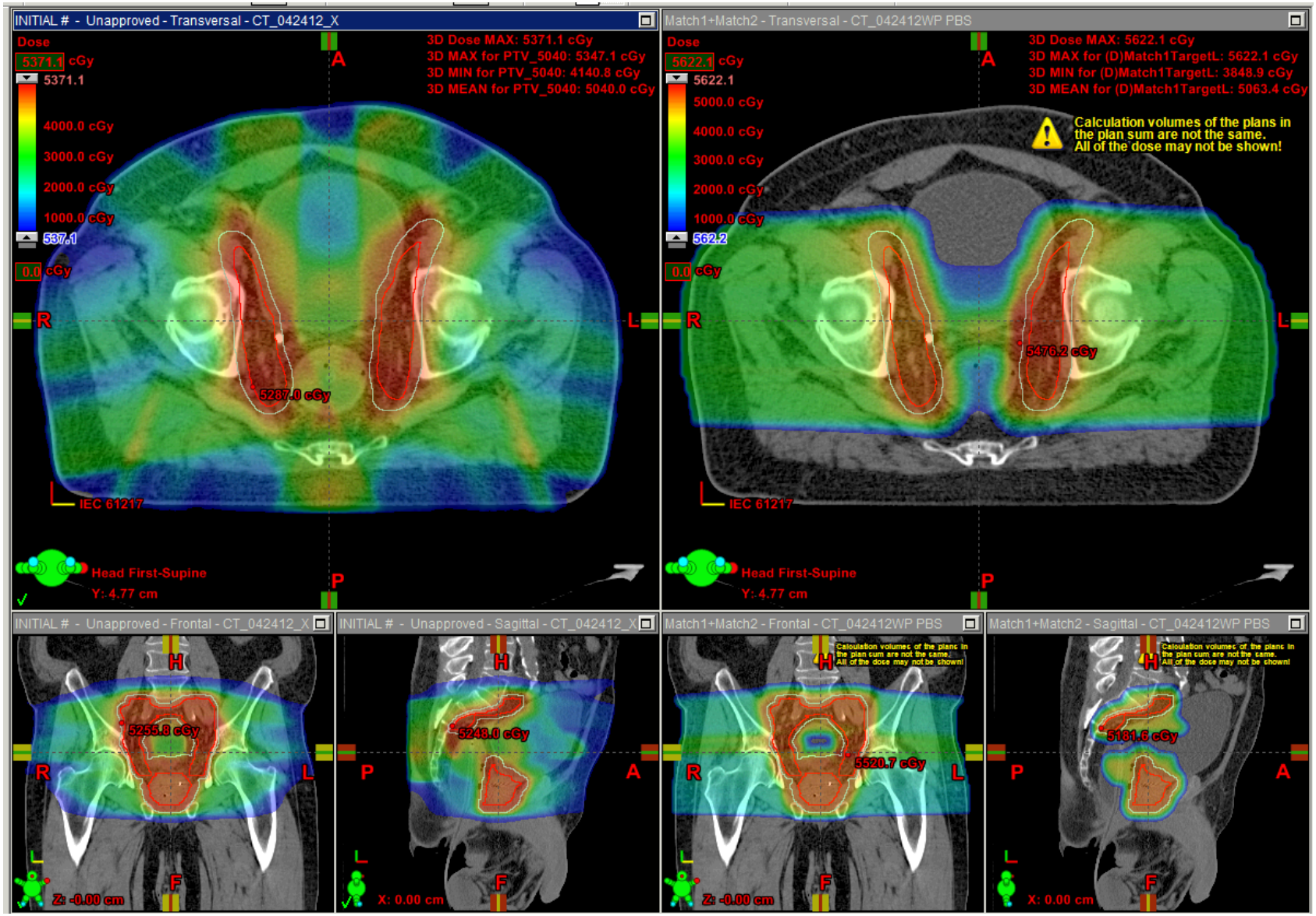
- Limited field size- Maximum of 25cm- can not treat large fields- Whole pelvis, chest wall and LN, lymphoma- mediastinum and neck, head and neck.

PBS

- Large field size~ 35cm (vendor dependent)- can treat all body sites.

IMRT

PBS

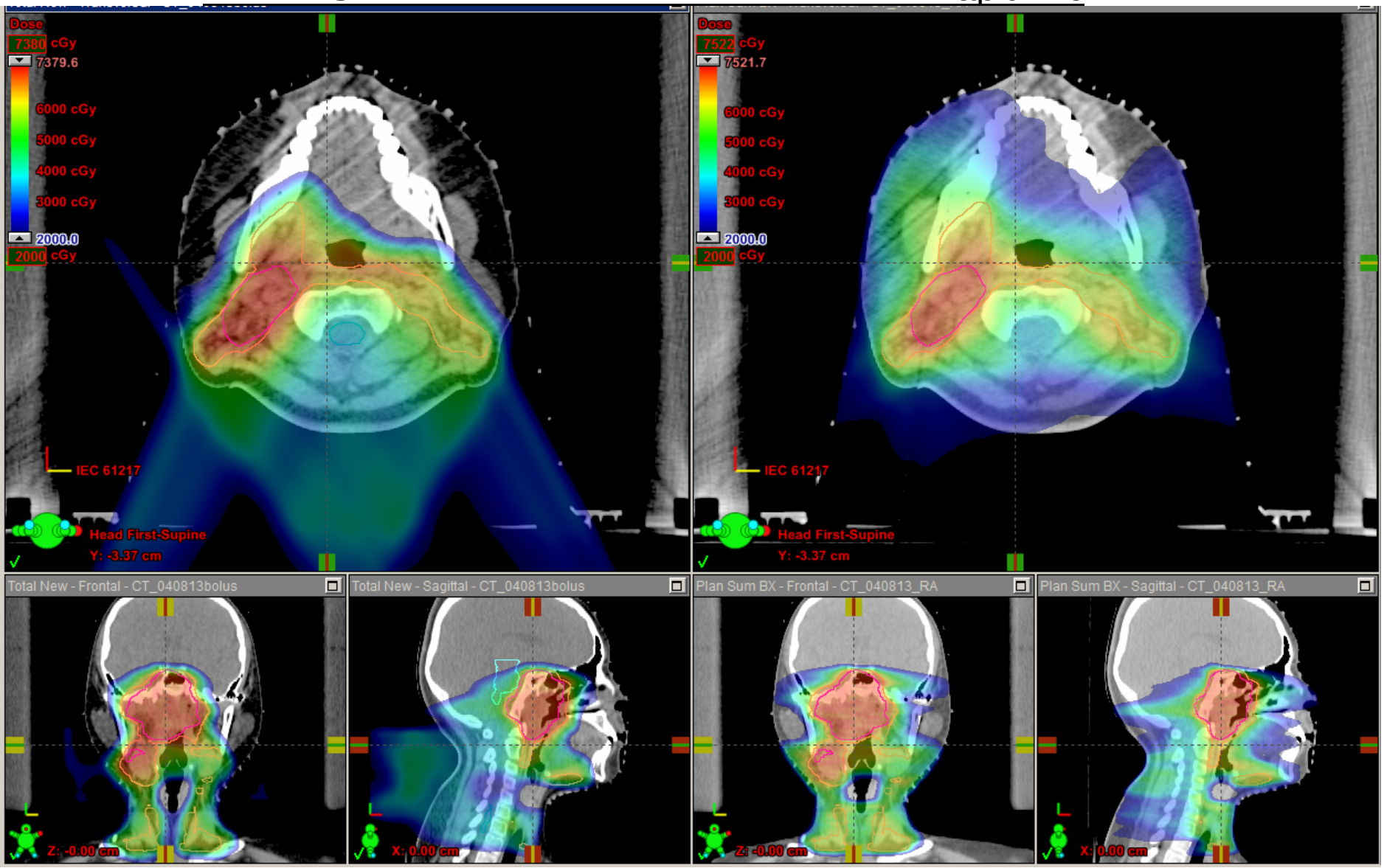

INITIAL # - Unapproved - Transversal - CT_042412_X
Dose
5371.1 cGy
5371.1
4000.0 cGy
3000.0 cGy
2000.0 cGy
1000.0 cGy
537.1
0.0 cGy
3D Dose MAX: 5371.1 cGy
3D MAX for PTV_5040: 5347.1 cGy
3D MIN for PTV_5040: 4140.8 cGy
3D MEAN for PTV_5040: 5040.0 cGy
5287.0 cGy
IEC 61217
Head First-Supine
Y: 4.77 cm
Match1+Match2 - Transversal - CT_042412WP PBS
Dose
5622.1 cGy
5622.1
5000.0 cGy
4000.0 cGy
3000.0 cGy
2000.0 cGy
1000.0 cGy
562.2
0.0 cGy
3D Dose MAX: 5622.1 cGy
3D MAX for (D)Match1TargetL: 5622.1 cGy
3D MIN for (D)Match1TargetL: 3848.9 cGy
3D MEAN for (D)Match1TargetL: 5063.4 cGy
Calculation volumes of the plans in the plan sum are not the same. All of the dose may not be shown!
5476.2 cGy
IEC 61217
Head First-Supine
Y: 4.77 cm
INITIAL # - Unapproved - Frontal - CT_042412_X
5255.8 cGy
Z: -0.00 cm
INITIAL # - Unapproved - Sagittal - CT_042412_X
5248.0 cGy
X: 0.00 cm
Match1+Match2 - Frontal - CT_042412WP PBS
5520.7 cGy
Z: -0.00 cm
Match1+Match2 - Sagittal - CT_042412WP PBS
5181.6 cGy
X: 0.00 cm

Clinical limitations of DS/US versus PBS

DS/ US	PBS
No IMPT option	IMPT enabled

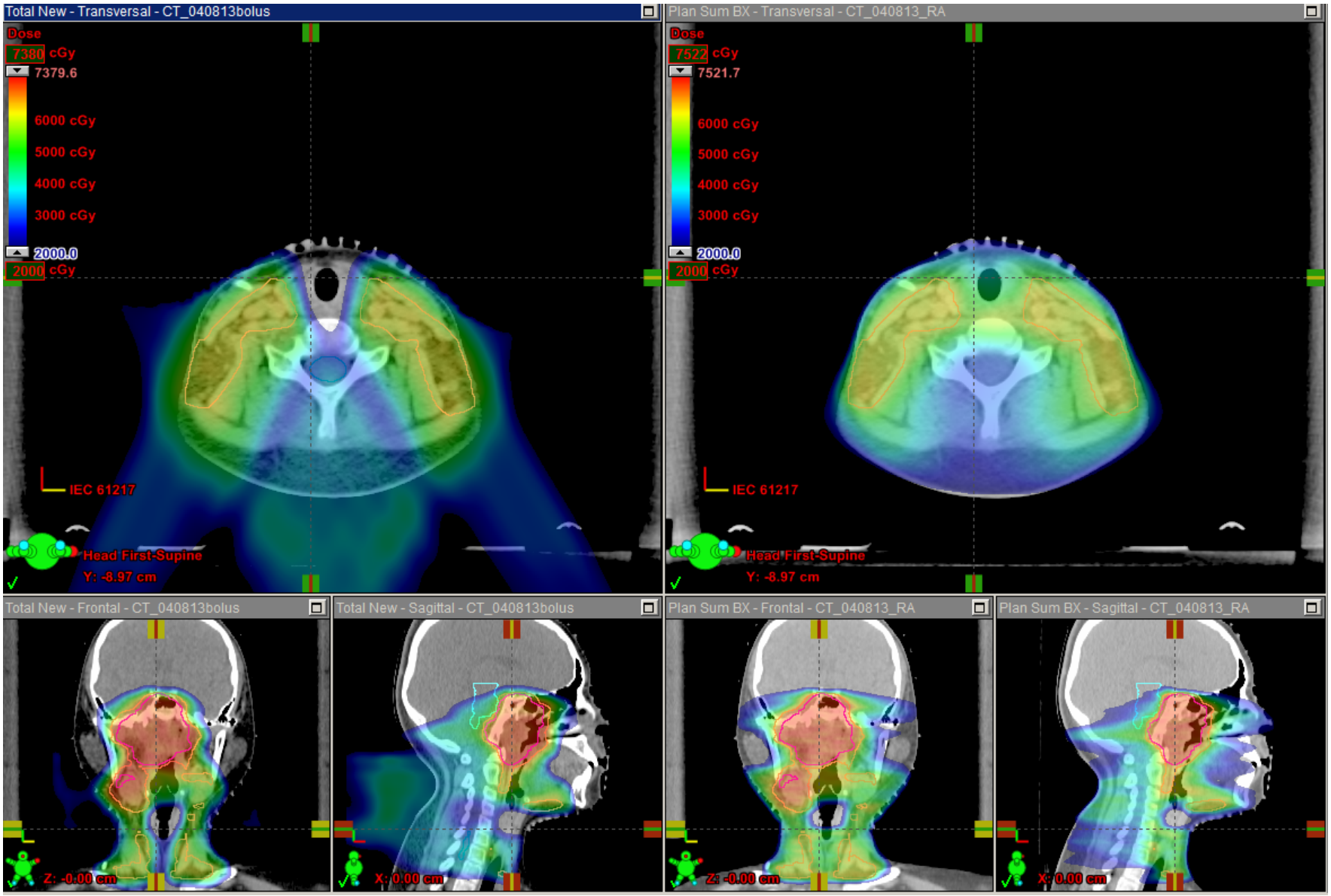
PBS

Rapid Arc



PBS

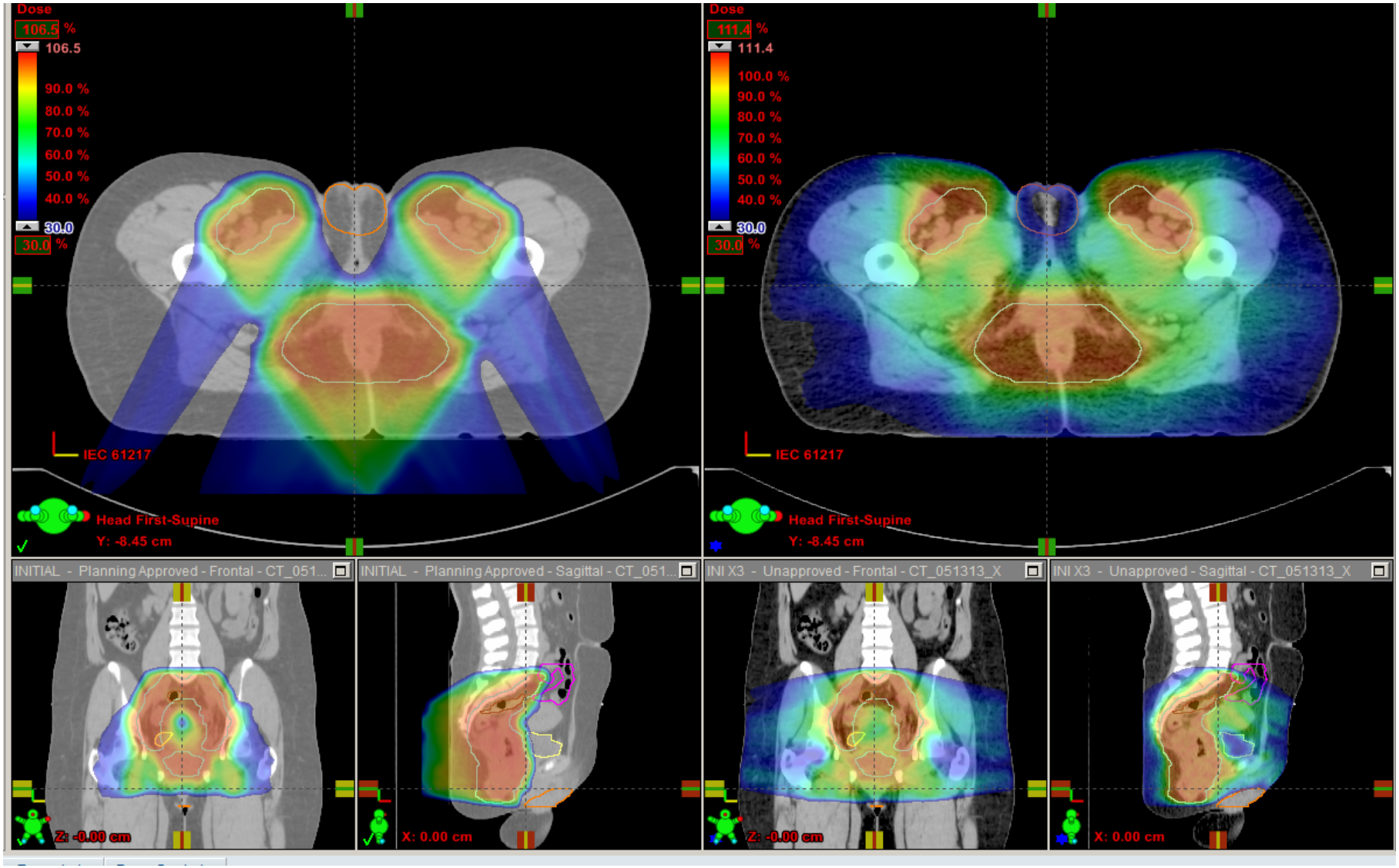
Rapid Arc



Anal Cancer

PBS

Rapid Arc



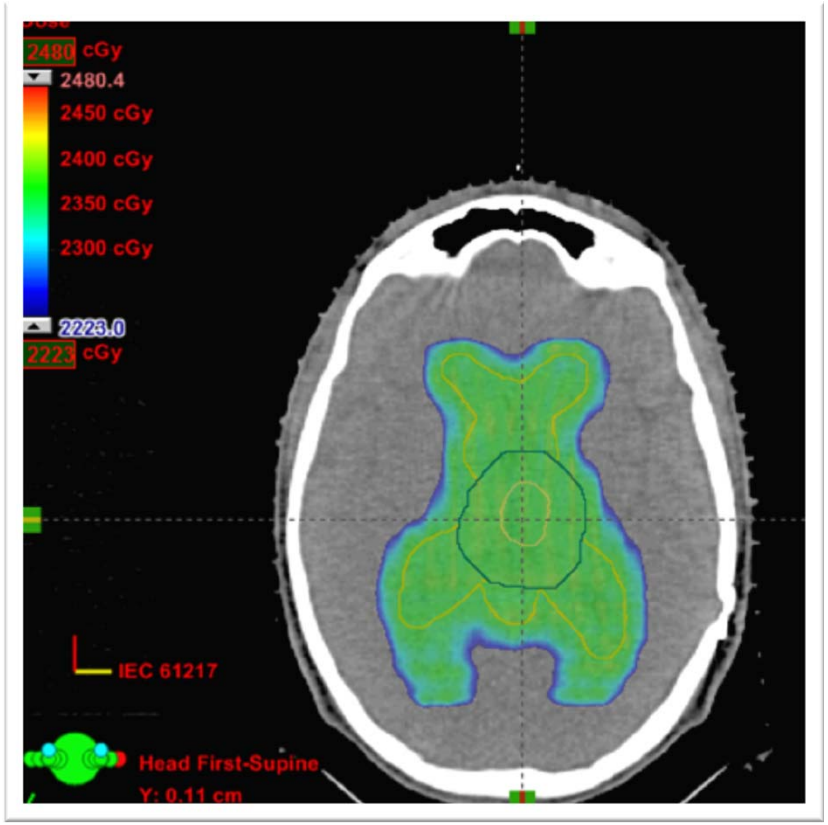
Clinical limitations of DS/US versus PBS

DS/ US	**PBS**
High dose to normal tissue in proximal beam	Lower dose to normal tissue in proximal beam

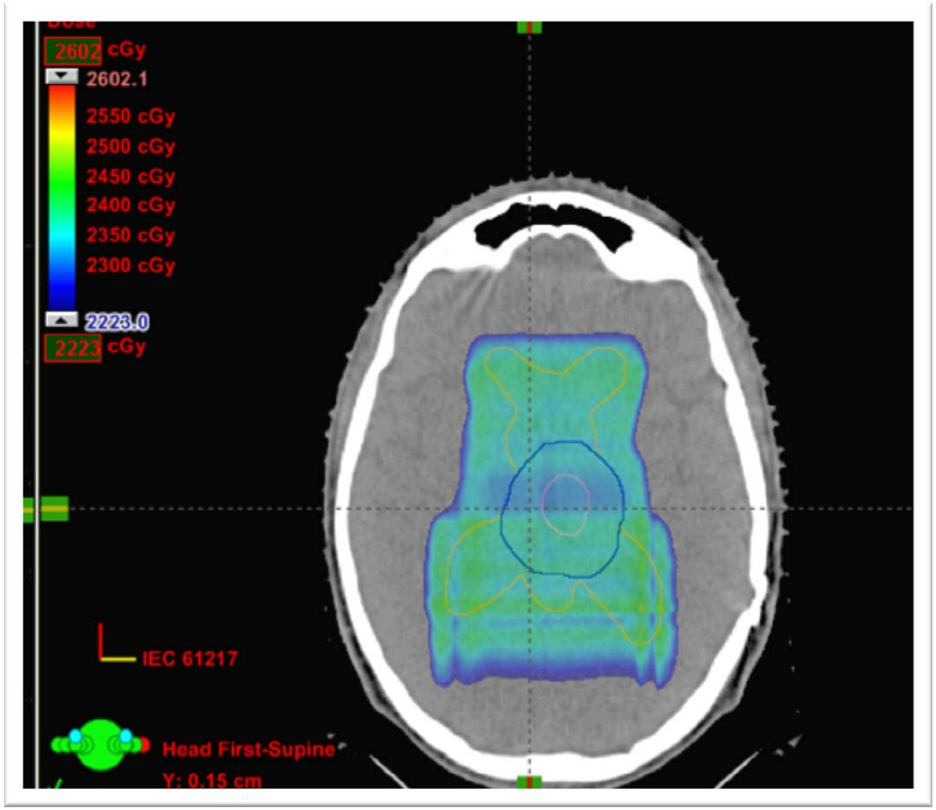
Brain tumors- PBS vs. DS/US

Major improvement for deep targets

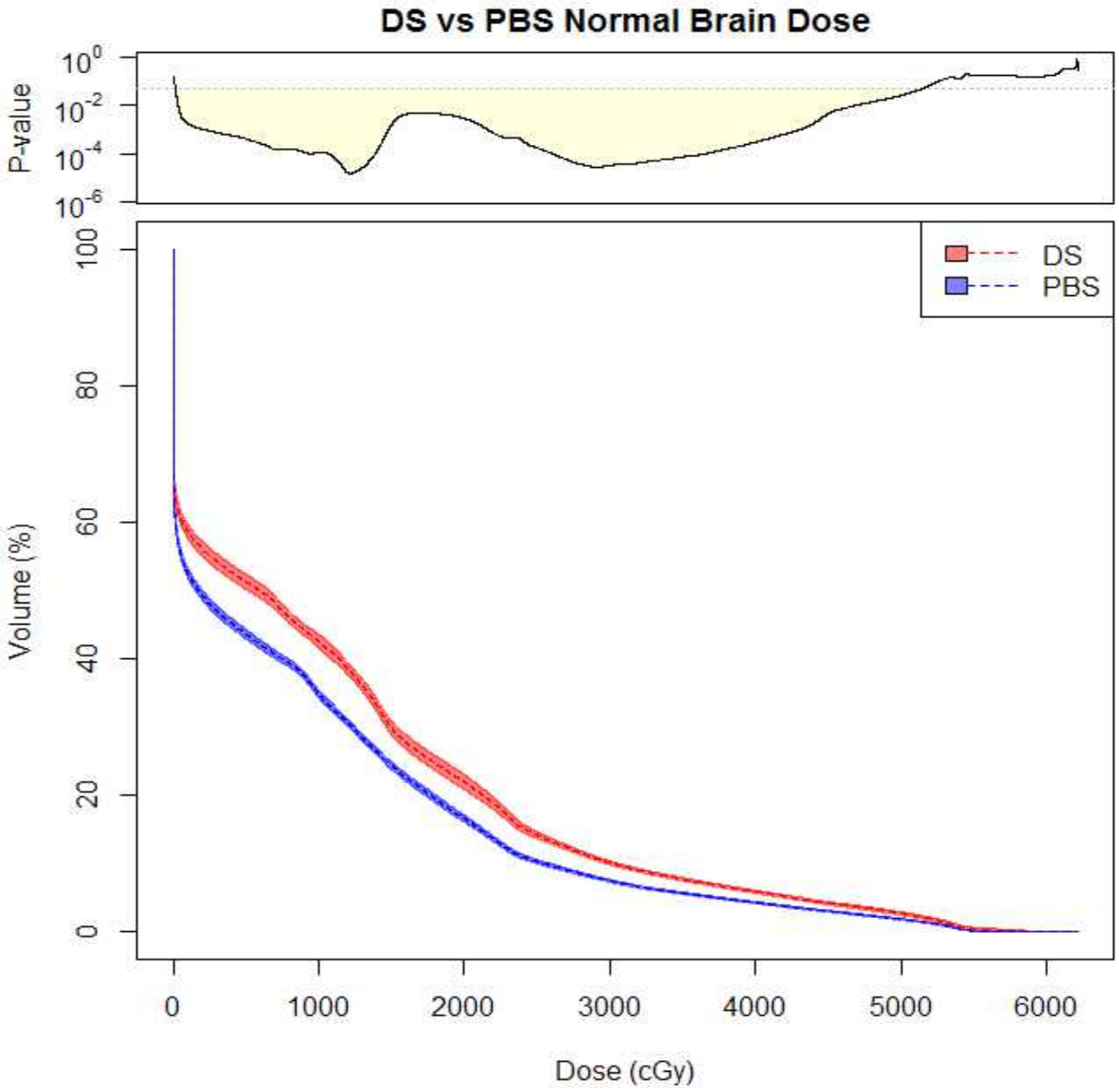
D95%, better conformality with PBS. Coverage more homogeneous

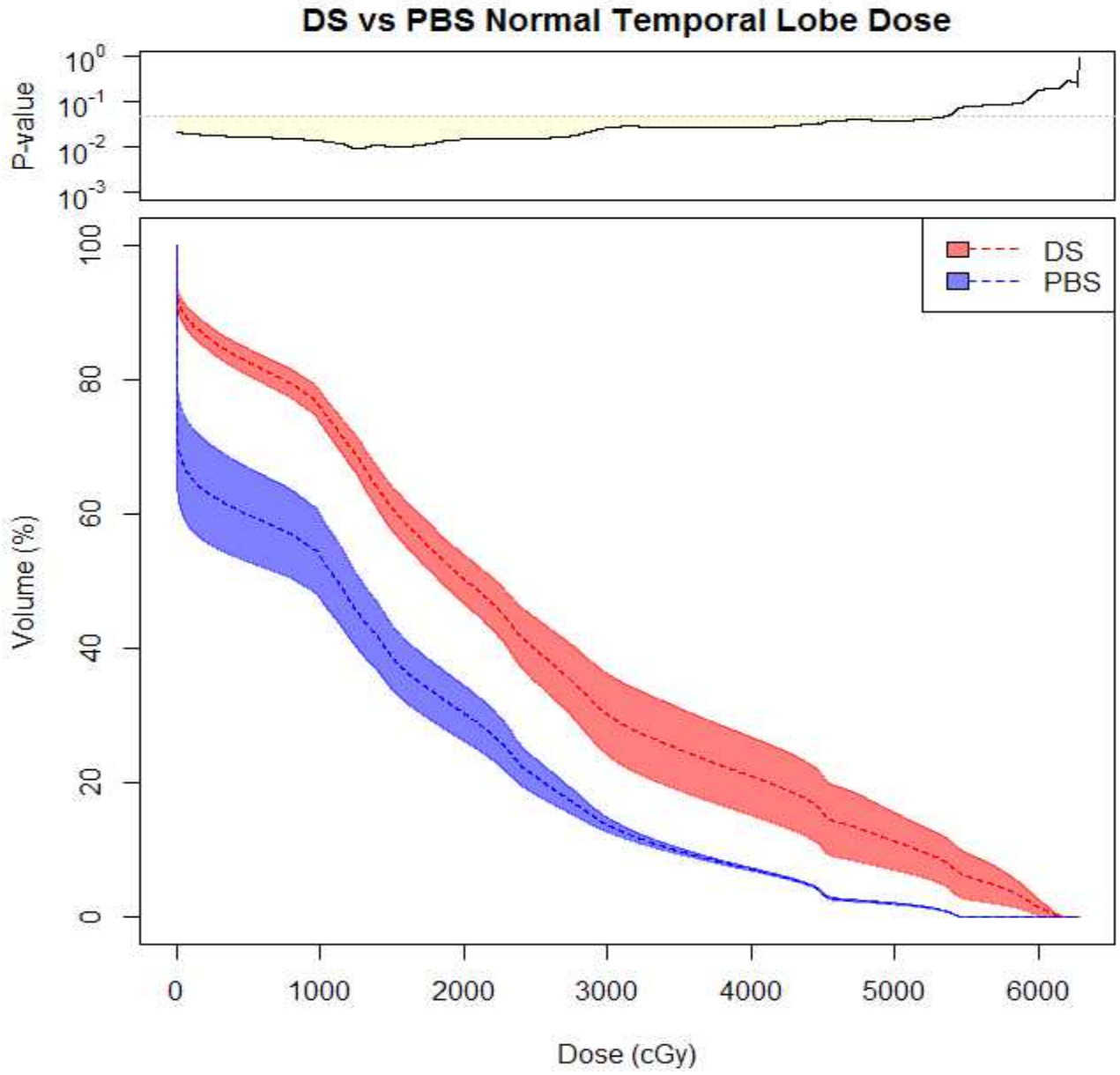


PBS



DS


DS vs PBS Normal Brain Dose
P-value
10^{0}
10^{-2}
10^{-4}
10^{-6}
DS
PBS
Volume (%)
0
20
40
60
80
100
0
1000
2000
3000
4000
5000
6000
Dose (cGy)


DS vs PBS Normal Temporal Lobe Dose
P-value
10^{0}
10^{-1}
10^{-2}
10^{-3}
Volume (%)
0
20
40
60
80
100
DS
PBS
0
1000
2000
3000
4000
5000
6000
Dose (cGy)

Craniospinal irradiation- one of the most challenging treatments in radiotherapy

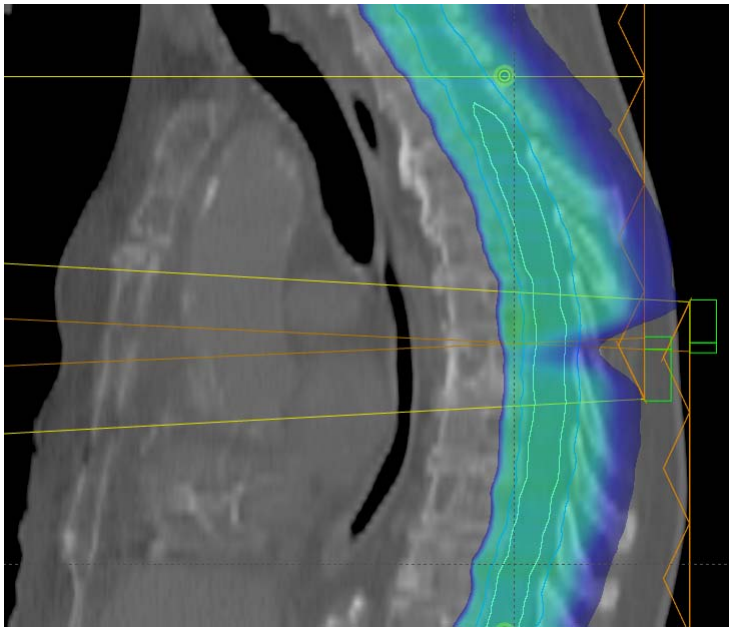
DS- Patient prone , difficult and long planning and QA, difficult set us, long daily delivery time.

PBS- Can treat supine, fast planning, easier set up , shorter delivery time

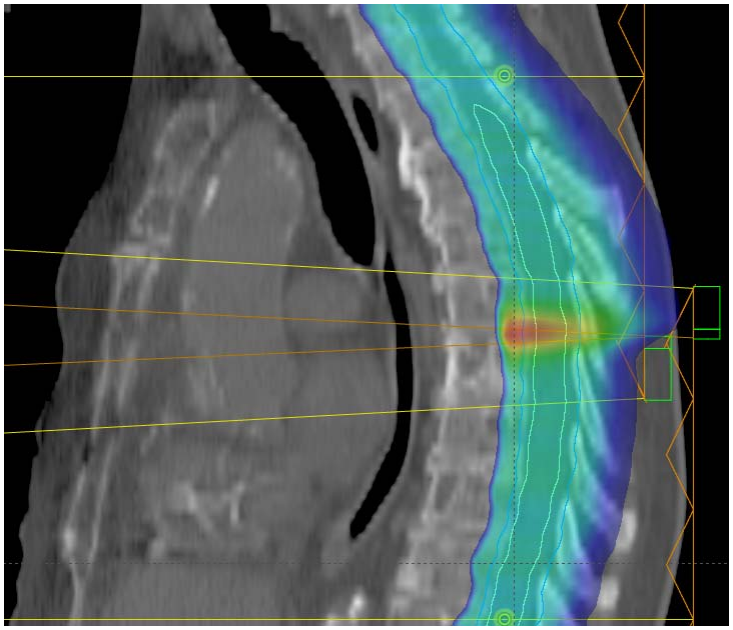
Planning Craniospinal Pre-PBS

- **Match is subject to large uncertainties based on setup**

Nominal Plan



5mm Overlap



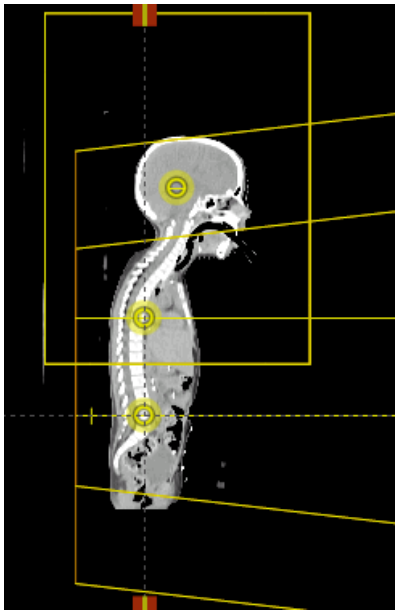
- **A 5mm shift results in ~30% increase in hotspot**

- **This is why we have to feather the match!**

Planning with PBS- UPENN technique

Field Setup

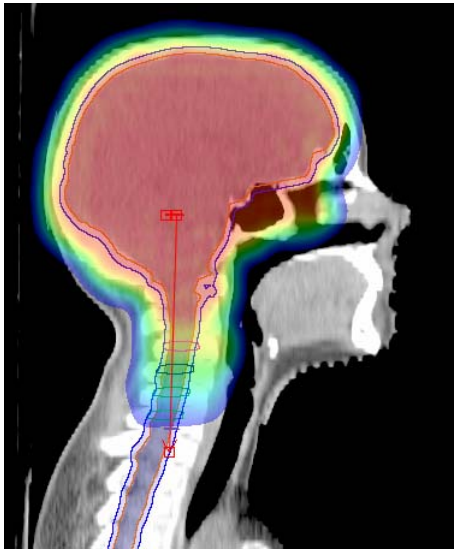
- **Two lateral PBS fields are used to treat the brain**
- **One or more posterior fields are used to treat the spine**
- **Fields overlap for 5-7cm**
- **A shallow gradient is created between the fields in order to create a safe, smeared match**

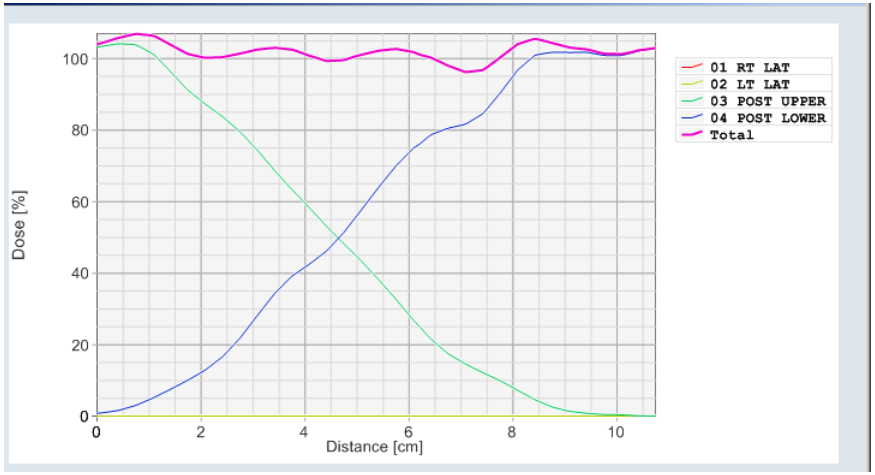


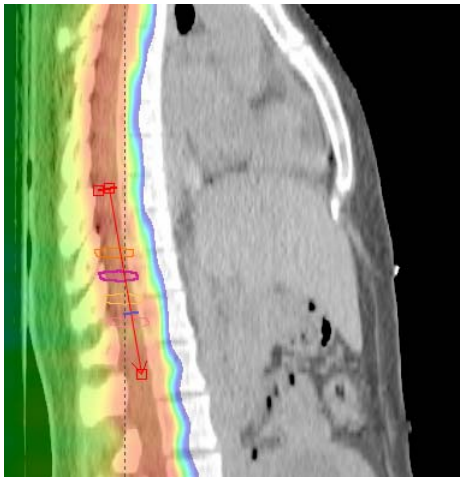
Planning with PBS-UPENN technique

Dose Gradient at the Match

Dose profile through the spine match





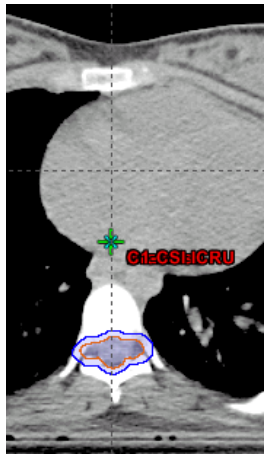


Planning with PBS-UPENN technique

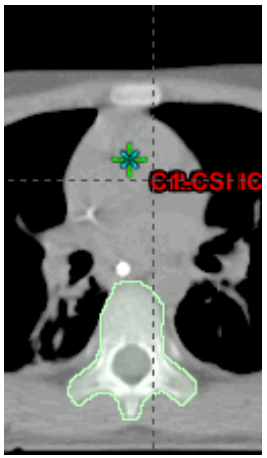
Volumes

- **Inverse planning with PBS requires careful contouring of the target volumes**

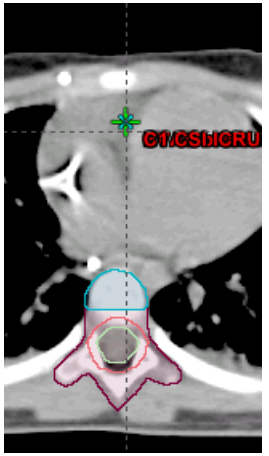
Thecal Sac (Adults)



Vertebral Body (Children)

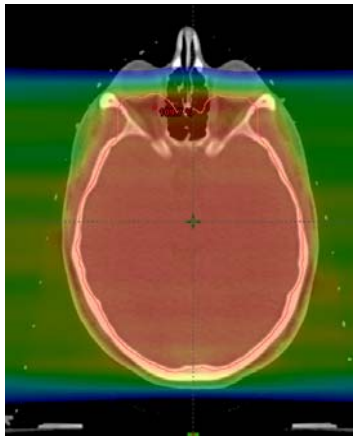


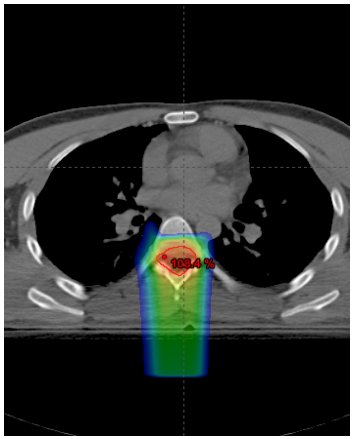
Differential Vertebral Body (children)

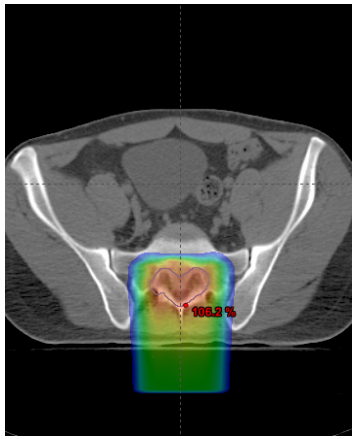


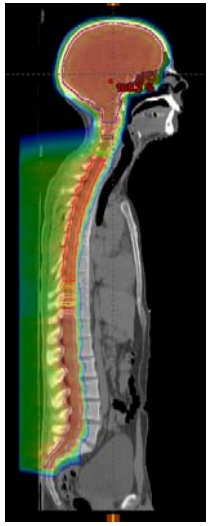
Planning with PBS- UPENN technique

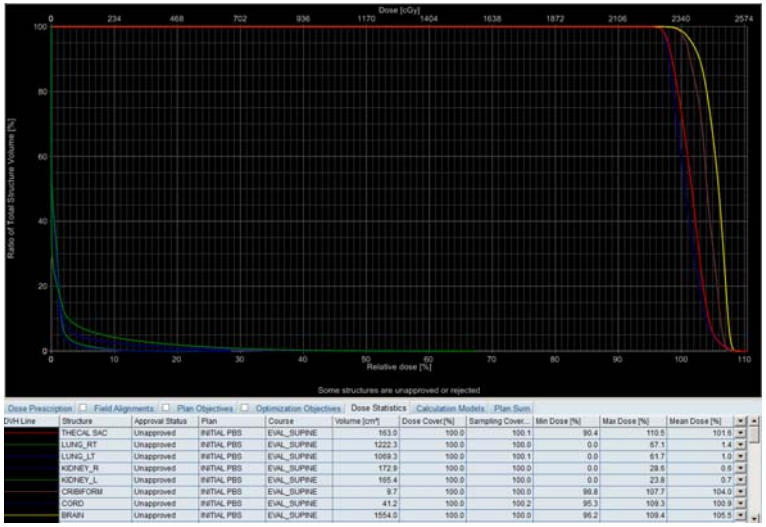
Example Dose Distribution:





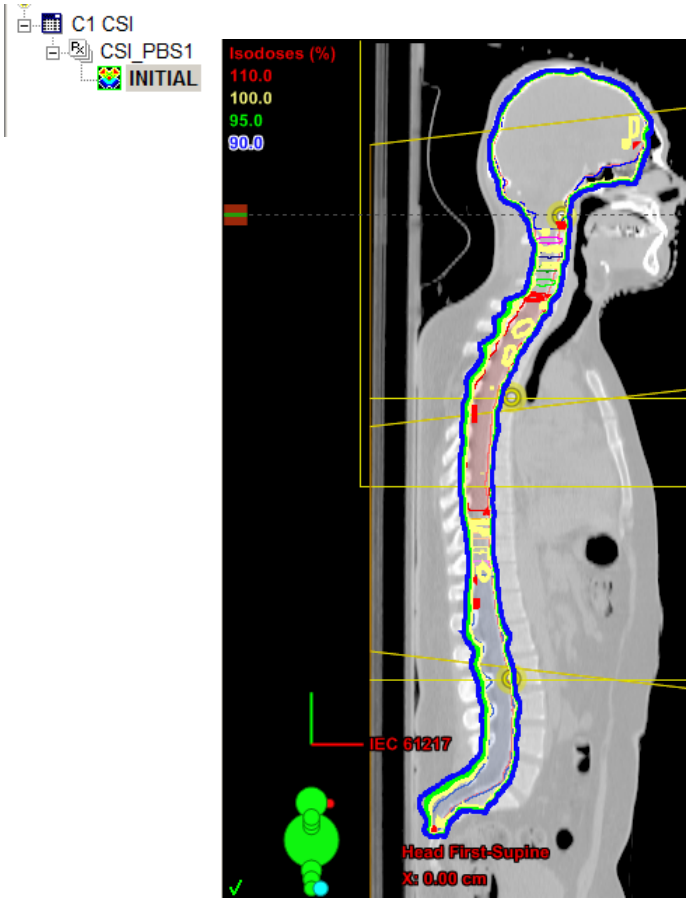




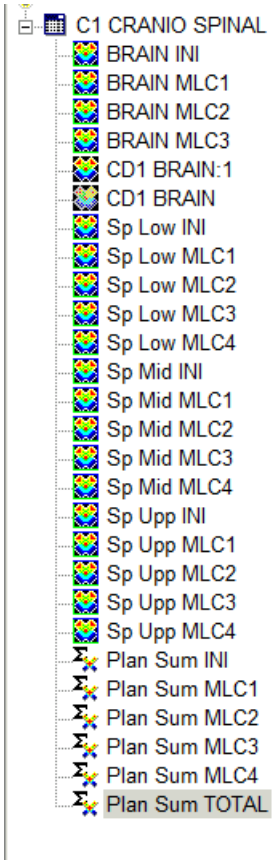


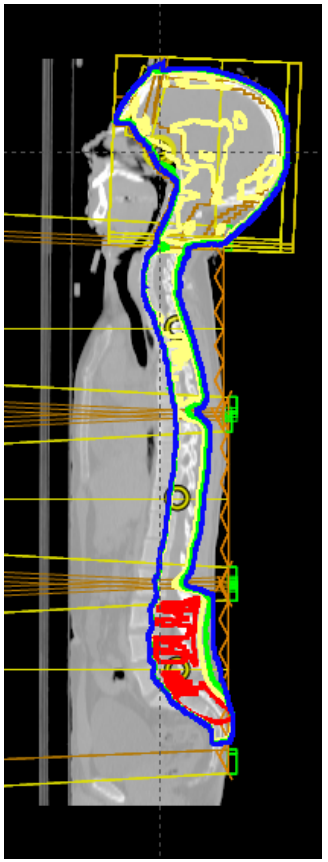
Result of PBS Plan-UPENN technique

PBS



DS





TREATMENT OF MOVING TARGETS- DS

- With DS routine treatments of mediastinum, lungs, hepatobiliary and upper abdomen.

- Can treat up to 1cm motion
- 4DCT simulation
- Gating/ Deep Inspiration Breath Hold- in some institutions

TREATMENT OF MOVING TARGETS- PBS

Currently only targets with no or limited motion- up to 5-10mm can be treated.

Need fast PBS- rescanning

Gating/ Deep Inspiration Breath Hold

Cone Beam CT

Solution to treat moving targets expected in 2-3 years

For Proton to replace x-rays as the main radiotherapy modality

Every site of the body need be treated efficiently with proton

We are already treating with PBS, every site of the body except motion over 5-10mm(peripheral lungs, liver). Next generation of PBS- faster scanning with better motion control and imaging (CBCT) will allow treatment of all sites.

For Proton to replace x-rays as the main radiotherapy modality

Every site of the body should be treated efficiently with proton (average of 19 minutes in room)

For Proton to replace x-rays as the main radiotherapy modality

The cost of purchasing proton system and operation should be reduced significantly

PBS-no need for compensator and aperture-saving of manpower and time for planning and treatment. Fewer beams per plan-higher thru put. Similar personnel to run a proton PBS room to Linac.

Proton will replace x-rays as the main radiotherapy modality

1. Every site of the body will be treated efficiently with proton (almost there!)

2. The cost of purchasing proton system and operating it will be reduced significantly (10-15 years?)

PBS will allow to achieve the two objectives