OUTLINE

- **What's next after IMRT and VMAT ?**
  - Digital LINAC
  - Beam level imaging & imaging of RT beams
  - Station parameter optimized radiation therapy (SPORT)
  - New QA tools for emerging RT technologies

ACKNOWLEDGEMENT

National Cancer Institute &
Varian Medical Systems

Ruijiang Li, Karl Bush, Benjamin Fahimian, Dimitre Hristov, Victor Yu, Bin Han, Gary Luxton

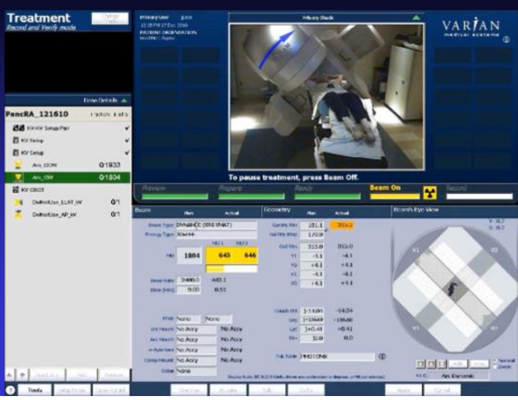
New Generation of Digital LINACs

Versa - Elekta

TrueBeam™ STx at Stanford

One of the first three TrueBeam LINACs - installed in 2009, Commissioning & acceptance test: July 2010, First SBRT patient: Sept. 2010

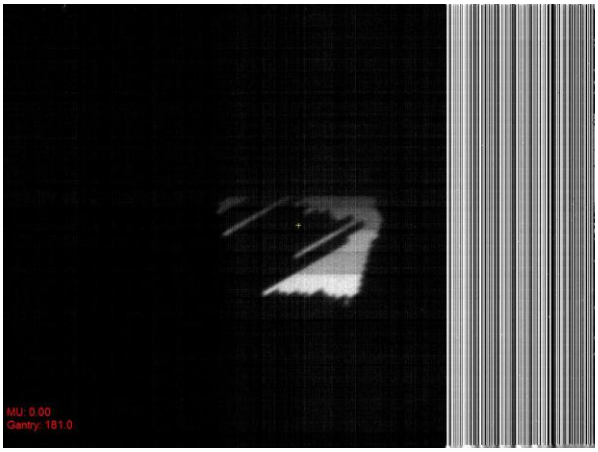
Gated RapidArc Treatment Delivery



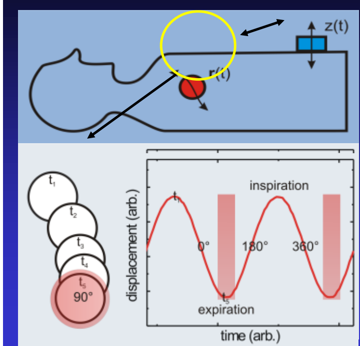
Beam-Level Imaging: Verification of Geometric Accuracy

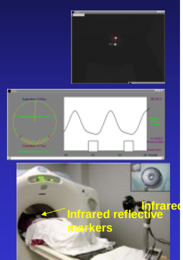
- During treatment, acquire kV images at the beginning of beam on for every breathing cycle.
- For each image,
  - Detect fiducials
  - Estimate 3D positions
  - Compare fiducials with software "markers"

Ruijiang Li et al, Stanford



Real-time Image Guidance for Gated RT





TrueBeam STx & SBRT at Stanford

- High geometric accuracy (~1 mm)
- HDMLC –for small lesions
- Fast delivery – 1400/2400 MU/Min for 6/10 MV FFF photons
- Motion management – onboard kV imaging during dose delivery

Programmable station-by-station (node-by-node) delivery

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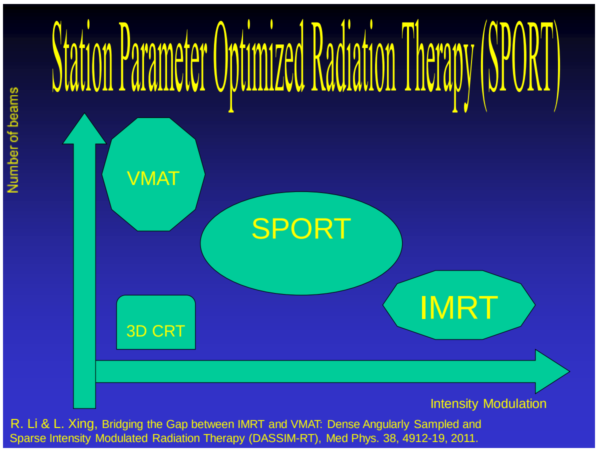
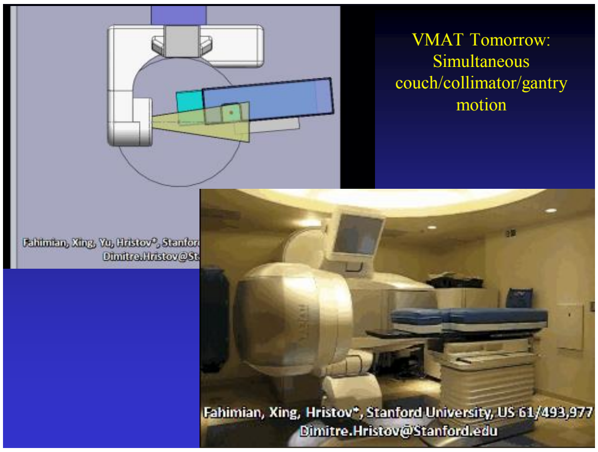




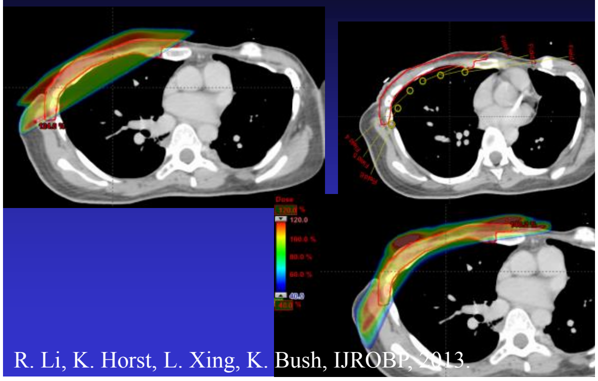
Station Parameter Optimized Radiation Therapy (SPORT)

- RT will be delivered station by station, instead of field by field.

  -An intensity modulated field consists of a number of stations at the same gantry angle (i.e., segments).

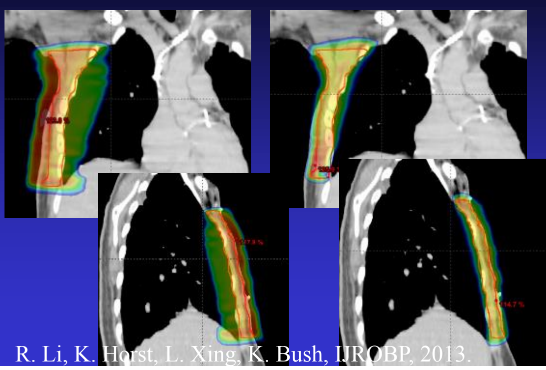
  -An arc consists of a large number of stations at different gantry angle.
- SPORT planning –depending on the specific delivery scheme!

SPORT: Non-isocentric Treatment



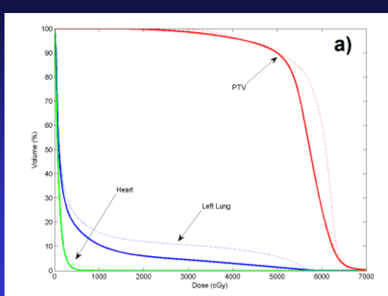
R. Li, K. Horst, L. Xing, K. Bush, IJROBP, 2013.

SPORT: Non-isocentric Treatment



R. Li, K. Horst, L. Xing, K. Bush, IJROBP, 2013.

SPORT: Non-isocentric Treatment

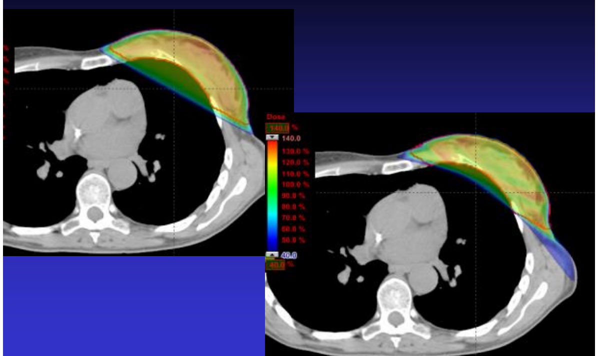


R. Li, K. Horst, L. Xing, K. Bush, IJROBP, 2013.

SPORT: Non-isocentric Treatment

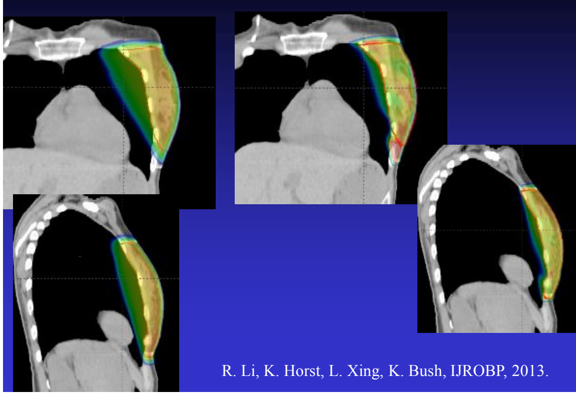
R. Li, K. Horst, L. Xing, K. Bush, IJROBP, 2013.

Non-isocentric Tx Bush and Li



R. Li, K. Horst, L. Xing, K. Bush, IJROBP, 2013.

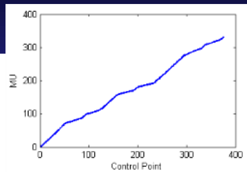
Non-isocentric Trteatment



R. Li, K. Horst, L. Xing, K. Bush, IJROBP, 2013.

TrueBeam developer mode

- Custom beam data in xml

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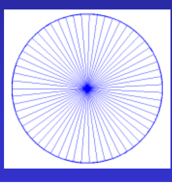
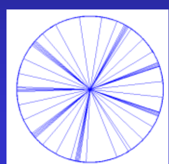
SPORT implementations for replacing RapidArc:

Method I: Segmentally boosted VMAT – adding a few segments in certain directions and optimize the RapidArc plan together with the added segments.

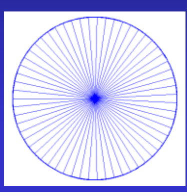
Improved dose distribution with a single arc.

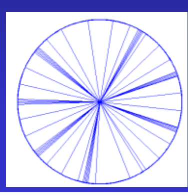




SPORT implementations for replacing RapidArc :

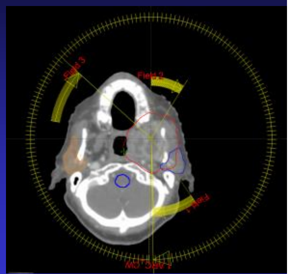
Method II: Differentially boosted VMAT – adding a few apertures to certain angular regions and optimize the system. An adaptive optimization algorithm has been developed for this purpose.



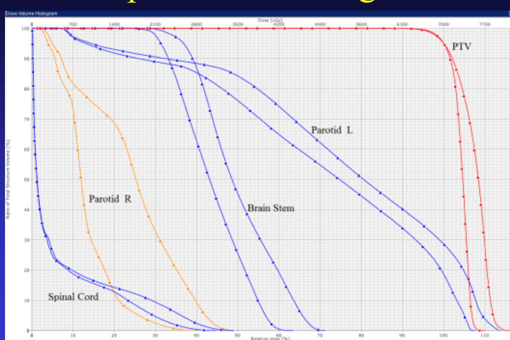


Field Setup

- Single full arc VMAT
- Boosted partial arcs
  - 3 arcs in this HN case
  - each ~30 deg
- Treatment planning
  - VMAT optimization

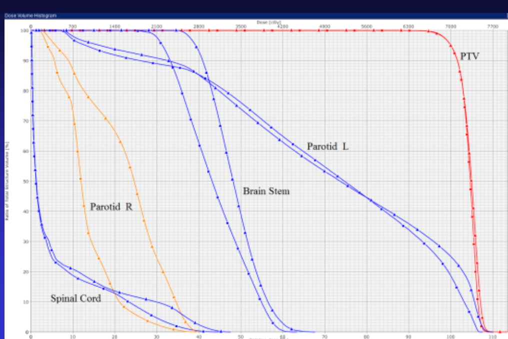


Comparison with single-arc



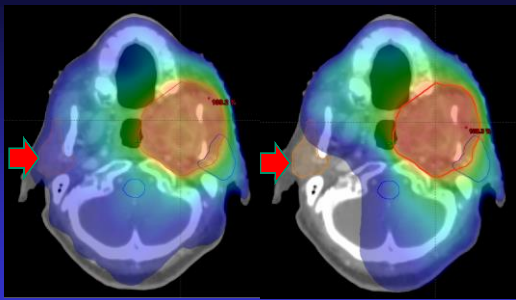
Triangle: 1-arc VMAT
Square: Segmented boost

Comparison with double-arc VMAT



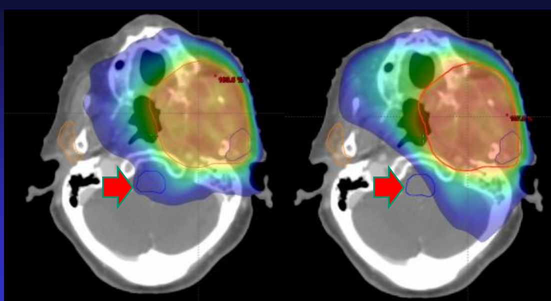
Triangle: 2-arc VMAT
Square: Segmented boost

Iso-dose distributions (20% and above)



2-arc VMAT   Segmented boost

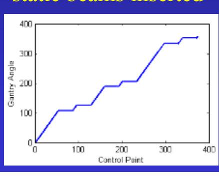
Iso-dose distributions (45% and above)

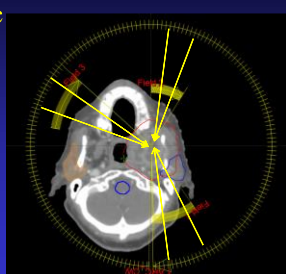


2-arc VMAT   Segmented boost

Treatment delivery

- Delivered in a single-arc
  - Each of the 3 partial arcs is converted into 2 static sub-fields.
  - 1 continuous arc with 6 static beams inserted

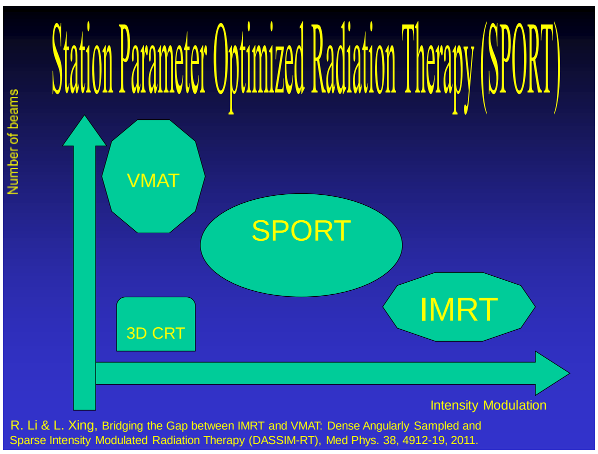


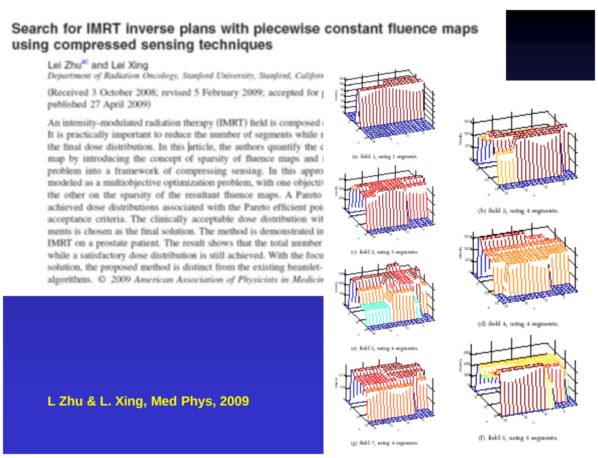


Delivery summary

- Rx: 200 cGy times 35 fractions

	MU	Control Points	Gantry span (deg)	Delivery time
1-ARC VMAT	276	178	360	1 min
2-ARC VMAT	520	376	720	2 min
Segmented boost	331	376	450	1 min 55 sec





Search for IMRT inverse plans with piecewise constant fluence maps using compressed sensing techniques

Lei Zhu[a)] and Lei Xing
Department of Radiation Oncology, Stanford University, Stanford, Califor

(Received 3 October 2008; revised 5 February 2009; accepted for
published 27 April 2009)

An intensity-modulated radiation therapy (IMRT) field is composed
It is practically important to reduce the number of segments while
the final dose distribution. In this article, the authors quantify the
map by introducing the concept of sparsity of fluence maps and
problem into a framework of compressing sensing. In this appro
modeled as a multiobjective optimization problem, with one objecti
the other on the sparsity of the resultant fluence maps. A Pareto
achieved dose distributions associated with the Pareto efficient poi
acceptance criteria. The clinically acceptable dose distribution wit
ments is chosen as the final solution. The method is demonstrated in
IMRT on a prostate patient. The result shows that the total number
while a satisfactory dose distribution is still achieved. With the focu
solution, the proposed method is distinct from the existing beamlet-
algorithms. © *2009 American Association of Physicists in Medicin*

L Zhu & L. Xing, Med Phys, 2009

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Compressed Sensing-Based Inverse Planning Framework

minimize

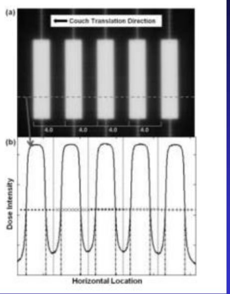
$$\begin{cases} \phi_1(x) = \sum_i \lambda_i (A_i x - d_i)^T (A_i x - d_i), \\ \phi_2(x) = \sum_{f=1}^{N_f} \sum_{u=2}^{N_u} \sum_{v=2}^{N_v} |\nabla_{u,v} x(u,v,f)| \end{cases}$$

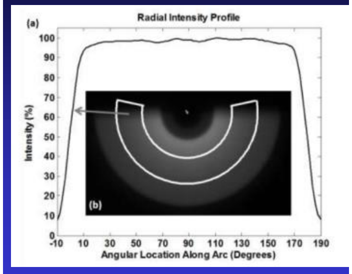
subject to

$$x \succeq 0.$$

$$\nabla_{u,v} x(u,v) = |x_{u,v} - x_{u-1,v}| + |x_{u,v} - x_{u,v-1}|,$$

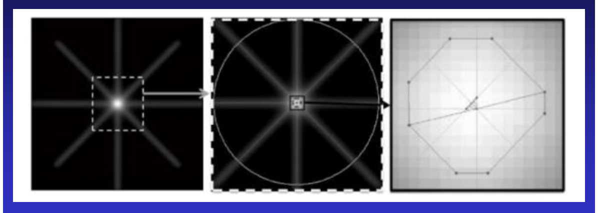
Quality Assurance of SPORT





V. Yu, B. Fahimian, L. Xing & D. Hristov, Med Phys, in press, 2014

Quality Assurance of SPORT



V. Yu, B. Fahimian, L. Xing & D. Hristov, Med Phys, in press, 2014

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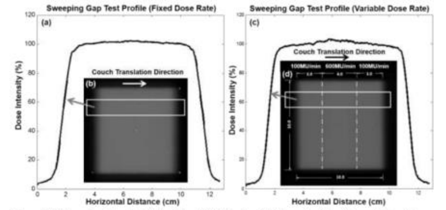
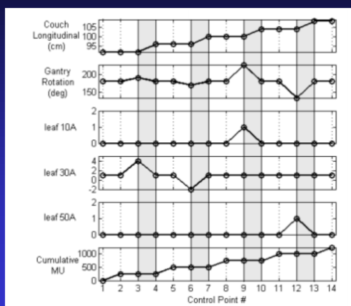


Figure 6. (a) Sweeping Gap Test (Fixed Dose Rate). Profile of relative dose intensity vs. horizontal location (cm). (b) Resultant film image with the indication of the location of the profile shown in (a). (c) Sweeping Gap Test (Variable Dose Rate). Profile of relative dose intensity vs. horizontal location (cm). (d) Resultant film image with the indication of the location of the profile shown in (c). To test dose rate variation, the test was delivered in three segments with maximum dose rates of 100, 600, and 100 MU/min, separations shown by the vertical dashed lines.

V. Yu, B. Fahimian, L. Xing & D. Hristov, Med Phys, in press, 2014

Quality Assurance of SPORT



V. Yu, B. Fahimian, L. Xing & D. Hristov, Med Phys, in press, 2014

Quality Assurance of SPORT

Table 2. "Tracking Test" Results

	Left to fiducial[a]		Right to fiducial[b]		End to end[c]	
Couch Direction	mean	std	mean	std	mean	std
Lateral	1.950	0.020	2.047	0.015	3.997	0.006
Longitudinal	1.970	0.010	2.033	0.006	4.003	0.006

[a] Left to fiducial: distance from left beam edge to fiducial in cm.
[b] Right to fiducial: distance from right beam edge to fiducial in cm.
[c] End to end: size of beam along the translational axis in cm.

Table 1. "Sweeping Gap Test" Results.
Deviations relative to mean in (%) for the case of fixed and variable dose rate during the delivery of the sweeping gap.

Deviation relative to the mean (Fixed Dose Rate) (%)		
Couch movement direction	standard deviation	maximum deviation
Lateral	0.37	1.04
Longitudinal	0.52	1.10
Deviation relative to the mean (Variable Dose Rate) (%)		
Lateral	0.95	1.98
Longitudinal	1.12	2.42

V. Yu, B. Fahimian, L. Xing & D. Hristov, Med Phys, in press, 2014

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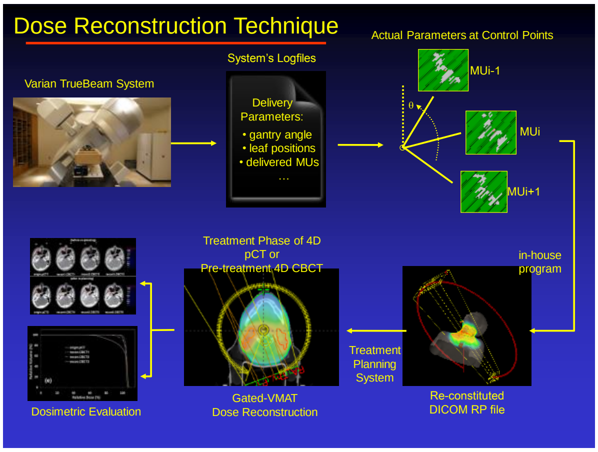

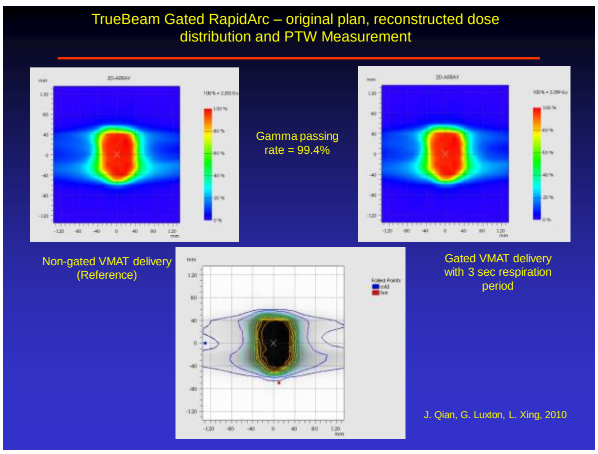

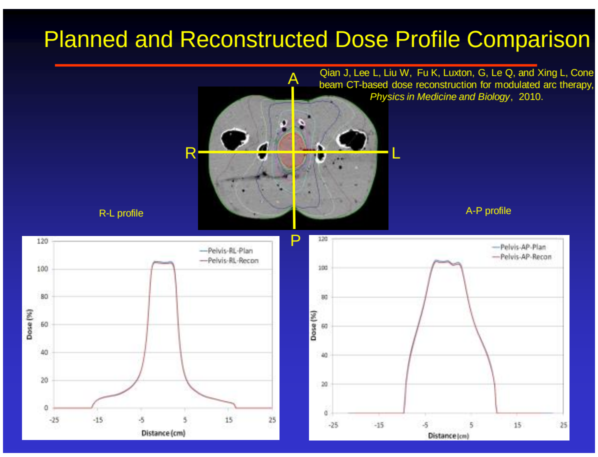

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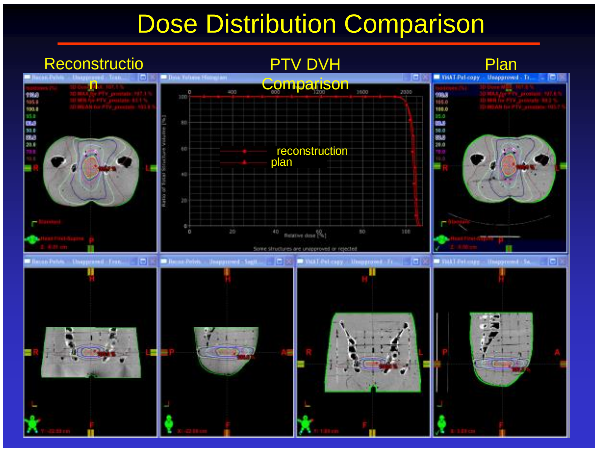
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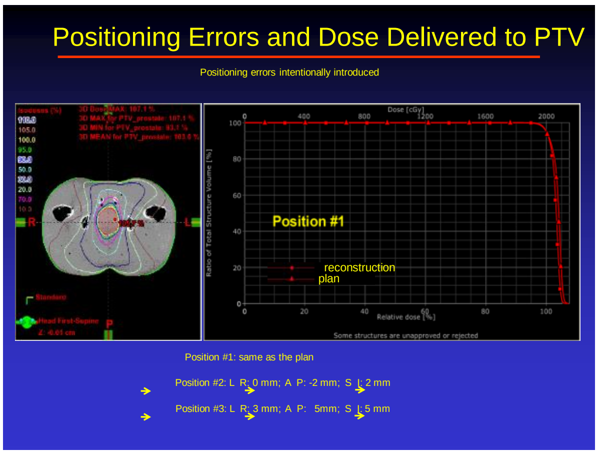
Reconstruction
PTV DVH Comparison
Plan
reconstruction
plan
Relative dose [%]
Some structures are unapproved or rejected


Positioning Errors and Dose Delivered to PTV
Positioning errors intentionally introduced
Position #1
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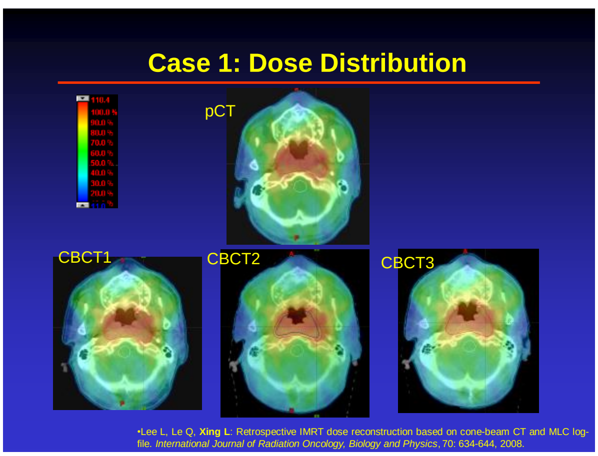
plan
Relative dose [%]
Some structures are unapproved or rejected
Position #1: same as the plan
Position #2: L R: 0 mm; A P: -2 mm; S I: 2 mm
Position #3: L R: 3 mm; A P: 5mm; S I: 5 mm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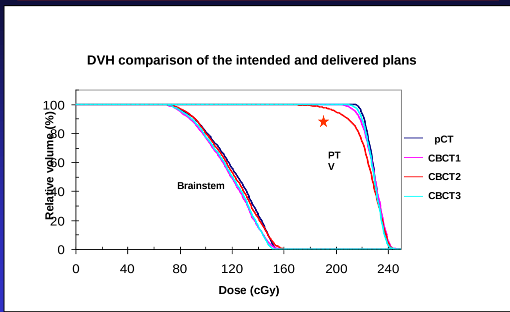
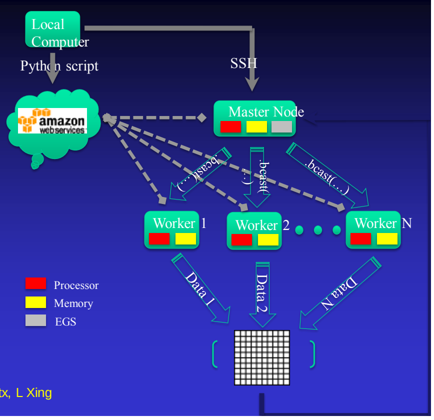
CBCT1
CBCT2
CBCT3
•Lee L, Le Q, Xing L: Retrospective IMRT dose reconstruction based on cone-beam CT and MLC log-file. International Journal of Radiation Oncology, Biology and Physics, 70: 634-644, 2008.

Case 1: DVHs

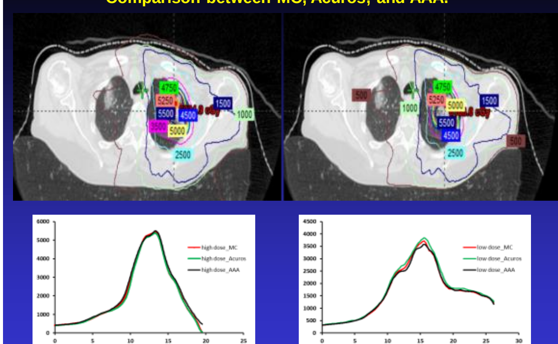


Cloud-Computing based Monte Carlo infrastructure



K. Bush, H. Wang, G. Pratx, L Xing

Comparison between MC, Acuros, and AAA.



X Chen, K Bush, A Zhang & L Xing, Med Phys Lett, submitted , 2014

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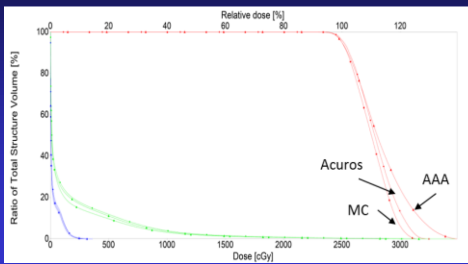
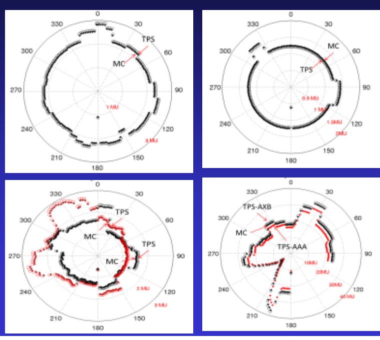
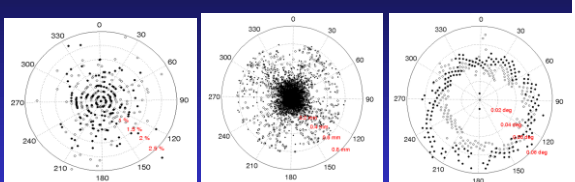
MU verification for VMAT



MU verification for VMAT



MU verification for VMAT



EPID-based absolute dosimetry for digital linac

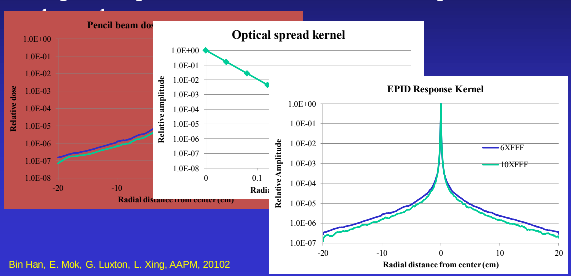
- unflattened beam
- high dose rate
- small sized fields in (SBRT)

Routine SBRT QA
- High efficiency
- High dose resolution
- Ease of use

Bin Han, E. Mok, G. Luxton, L. Xing, ASTRO, 2013

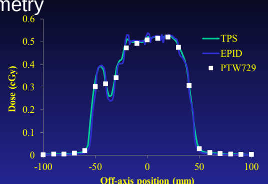
EPID Response Core

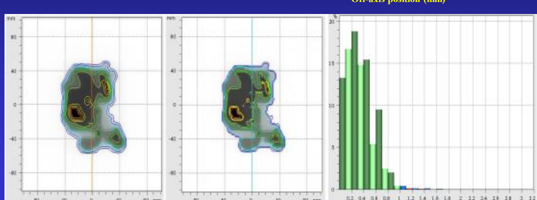
- Monte Carlo dose distribution kernel, Optical spread kernel, Total EPID response



Bin Han, E. Mok, G. Luxton, L. Xing, AAPM, 20102

EPID-based absolute dosimetry





Bin Han, E. Mok, G. Luxton, L. Xing, 20102

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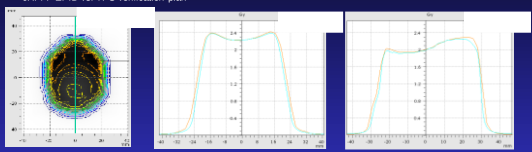
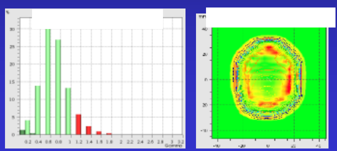
Result: EPID dosimetry for SBRT pt QA

6XFFF EPID vs. TPS verification plan





- Gamma results:
  3mm/3%: 99.9%
  2mm/3%: 98.5%
  2mm/2%: 92.8%
  1mm/3%: 63.0%

SUMMARY

- Features available in new generation of LINACs facilitate RT workflow and improve the efficiency & accuracy.
- Mechanical accuracy & imaging.
- SPORT.
- New QA tools are urgently needed.