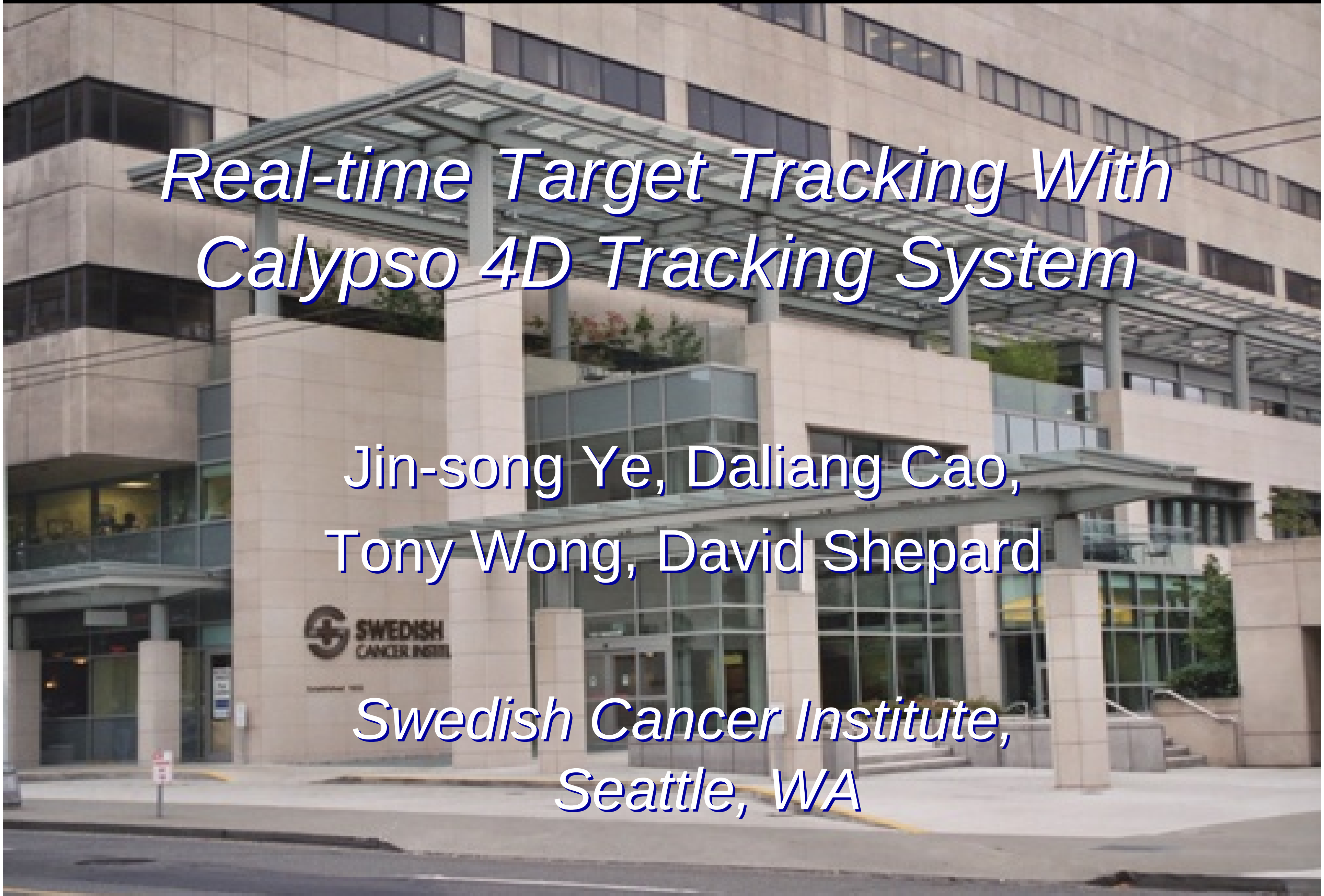


Real-time Target Tracking With Calypso 4D Tracking System

Jin-song Ye, Daliang Cao,

Tony Wong, David Shepard

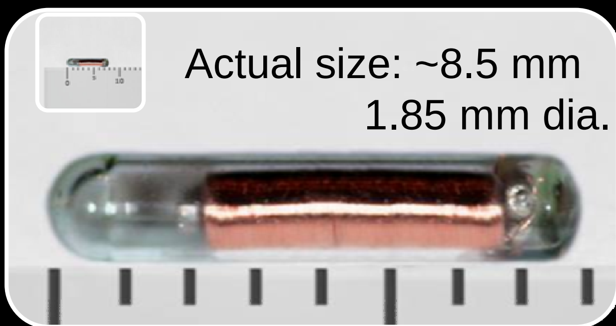
Swedish Cancer Institute,

Seattle, WA

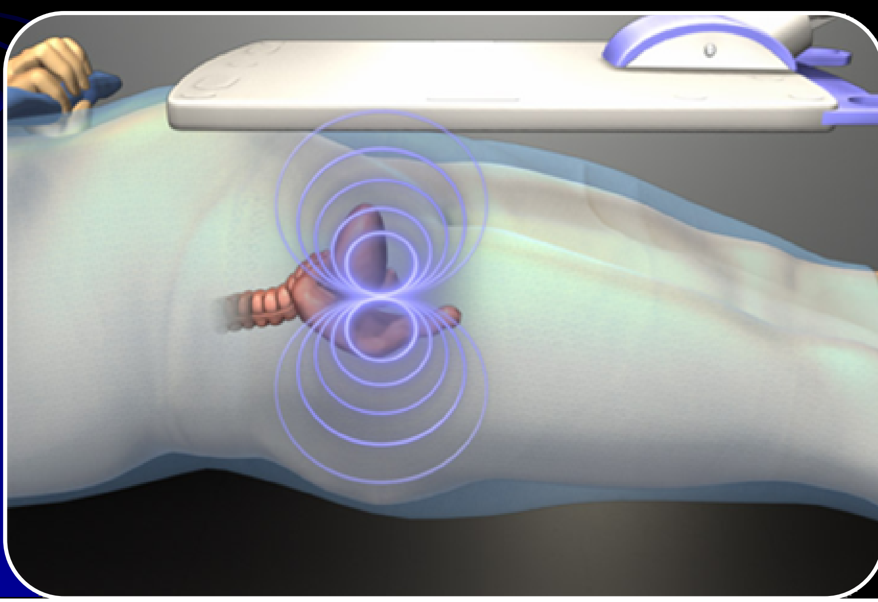
Image Based Target Localization

- MV/KV 2-D imaging:
  film, EPID
  imaging at two angles
- MV/KV 3-D volumetric imaging:
  CBCT, Tomo, CT-on-rails
- Fluoroscopy: 2-D, continuous
- Ultrasound: subjective to interpret

Radio frequency (RF) signals



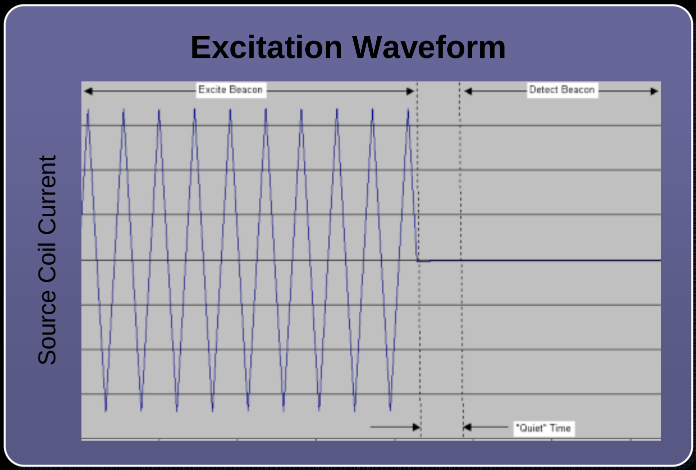
Beacon® Electromagnetic Transponder

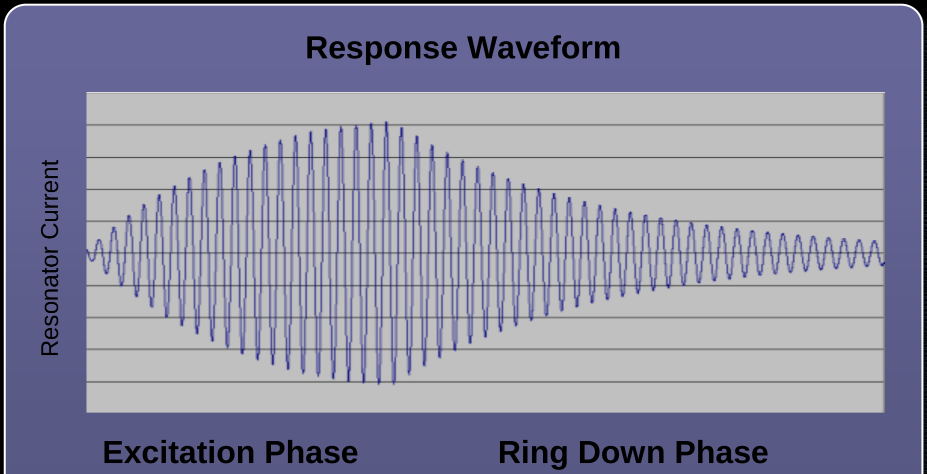


Electromagnetic Signals:
Locate and Track Continuously

Transponder Signals

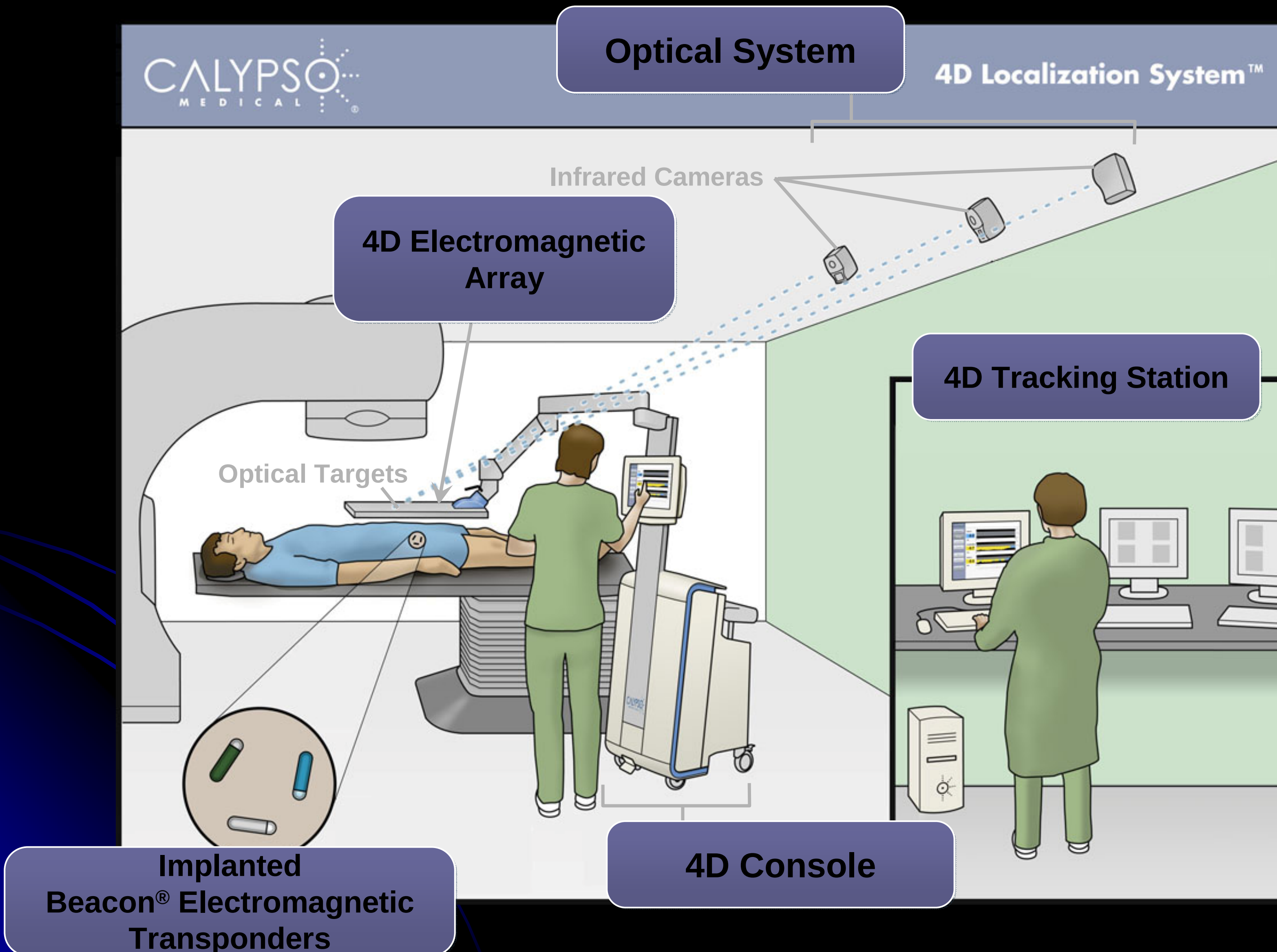
- Transponders are excited sequentially at each of three unique resonant frequencies
- Each transponder subsequently responds with a decaying magnetic field
- Process of excitation and sensing is repeated several hundred times to improve signal/noise for each transponder localization





Curtsey of Calypso

Platform Overview

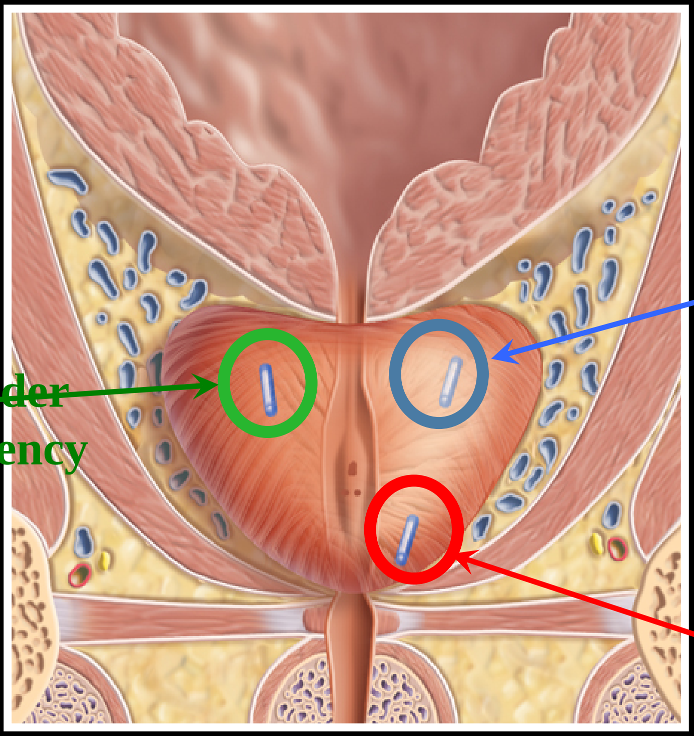


Clinical procedure (prostate localization and tracking)

1. Three transponders each with different frequency were implanted inside the prostate of the patient

2. Planning CT was taken and the three transponders were identified in the treatment planning system (TPS)

3. The coordinates of the three transponders as well as the treatment iso-center were then recorded and input into the Calypso 4D tracking station along with the patient demographic information



Input Calypso data into the system

CALYPSO MEDICAL

Localization Plan

Patient: Test, Case
Patient ID:Test12345678
Modified: Oct 25, 2007 10:08 AM
Reported: Oct 25, 2007 10:08 AM

Patient Information

Patient:	Test, Case
Patient ID:	Test12345678
Patient or Plan Last Modified:	Oct 25, 2007 10:08:30 AM

Localization Plan

Implantation Date:	Oct 25, 2007
Patient Orientation:	Supine
Usage Mode:	Localize and Track
Physician:	
Dosimetrist:	
Medical Physicist:	
Geometric Residual Limit (cm):	0.20
Rotational Alignment Limit (deg):	10.00

Localization limits

Transponders

Transponders	X	Y	Z	Frequency
Apex Location (cm):	-0.53	-0.74	-0.42	Low
Left Base Location (cm):	0.35	0.58	0.60	Med
Right Base Location (cm):	-1.60	0.45	0.79	High
Treatment Isocenter (cm):	-0.64	-0.06	0.19	
Coordinate Reference Frame:	CMS XiO			

Transponders and Iso-center coordinates

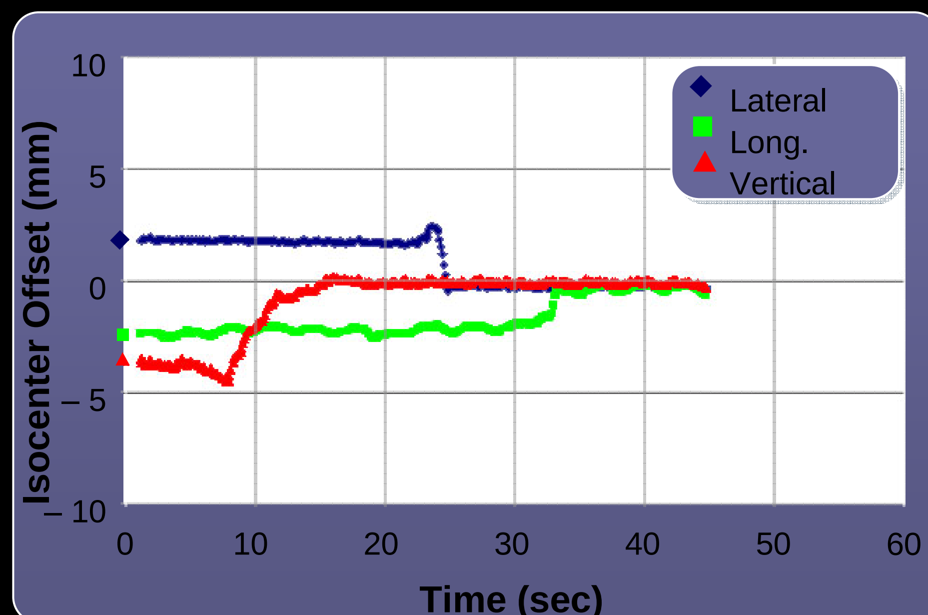
Tracking

Tracking	Lat(Left+)	Long(Sup+)	Vert(Ant+)
Upper Tracking Limits (cm):	0.40	0.40	0.40
Lower Tracking Limits (cm):	-0.40	-0.40	-0.40

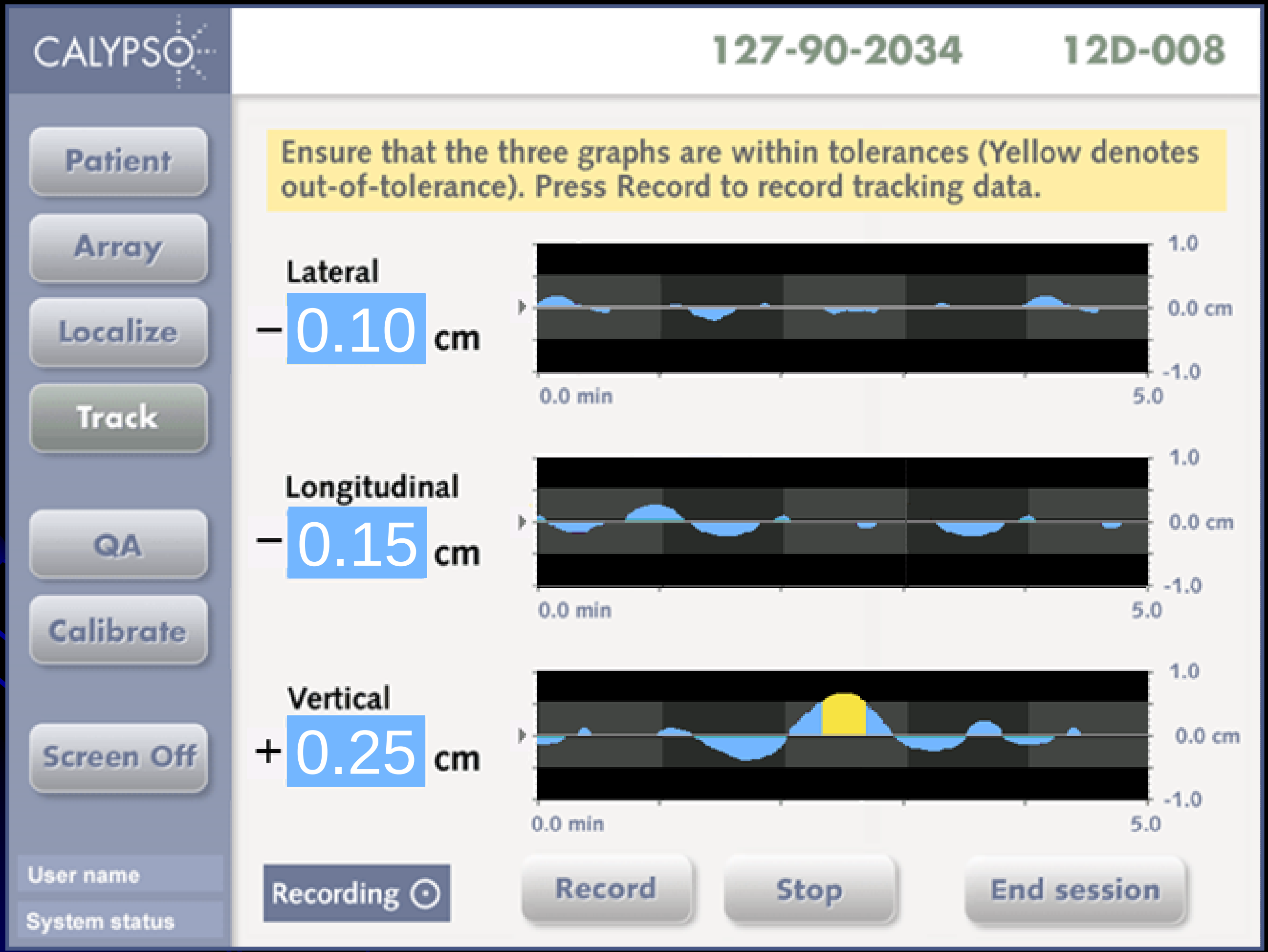
Tracking limits

Localization and tracking using Calypso system

1. Patient was first aligned to the external marks with in-room lasers.
2. Continue the set up using Calypso system under localization mode. Couch shift along the lateral, longitudinal, and vertical axes is determined in Calypso system by comparing the planned and measured coordinates of the three transponders.
3. Calypso switches to tracking mode to monitor the real-time target motion.



Real-time tracking of target motion



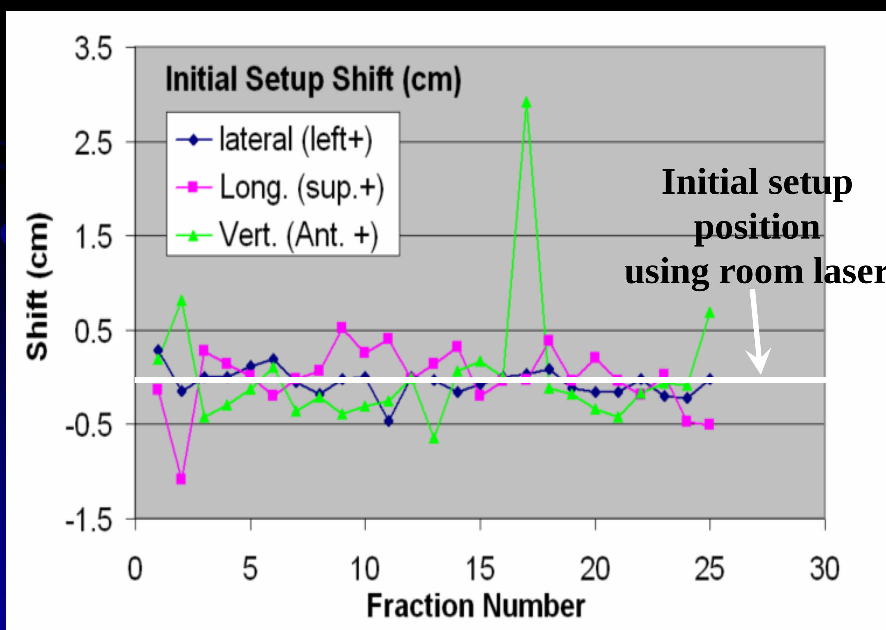
Calypso System: advantages and disadvantages

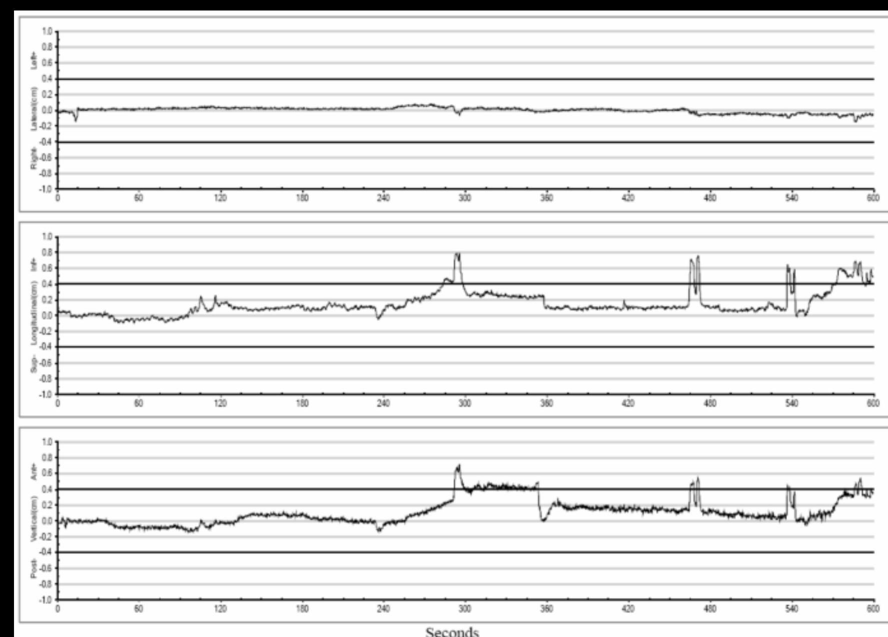
- Direct target tracking
- 4D and real-time
- Localization: objective
- Fast feed back
- No imaging dose
- Efficient workflow
- Signal can be used for gating

- Need Beacon® implantation
- Lack of anatomy images
- Interference:
  - conductive material
  - metal
  - prosthesis
  - carbon-fiber couch top
- MRI artifacts
- Limited tracking region:
  - tracking depth 16 cm
  - localization depth 20 cm

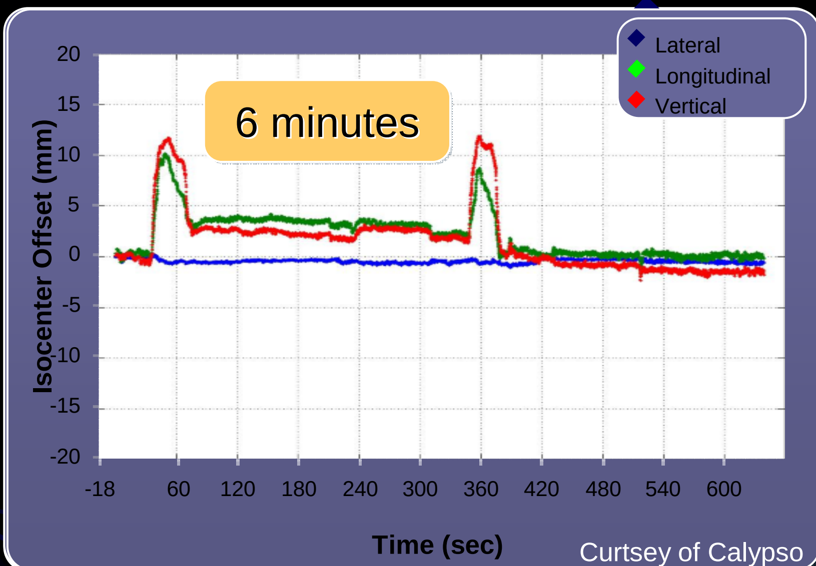
- The first FDA approved Calypso system was installed and commissioned at Swedish Cancer Institute in January 2007
- About 100 patients with prostate cancer have been treated or currently under treatment using Calypso system
- Over 2500 patient localization and tracking sessions were performed and recorded
- Average set up and prostate localization time for each patient is less than 2 minutes

- Localization Mode:
  - The average daily initial setup shifts for all patients are 1.1, 2.2 and 4.0 mm along lateral, longitudinal and vertical direction.
- Tracking Mode:
  - Real-time iso-center motion is recorded at a freq of 10 Hz.
  - The prostate intra-fraction motion can be significant. The max ranges of motion in this treatment session were 2.9, 8.9, and 8.5 mm along lateral, longitudinal, and vertical direction, respectively.





Variable motion for individual patients



Drifting Excursion

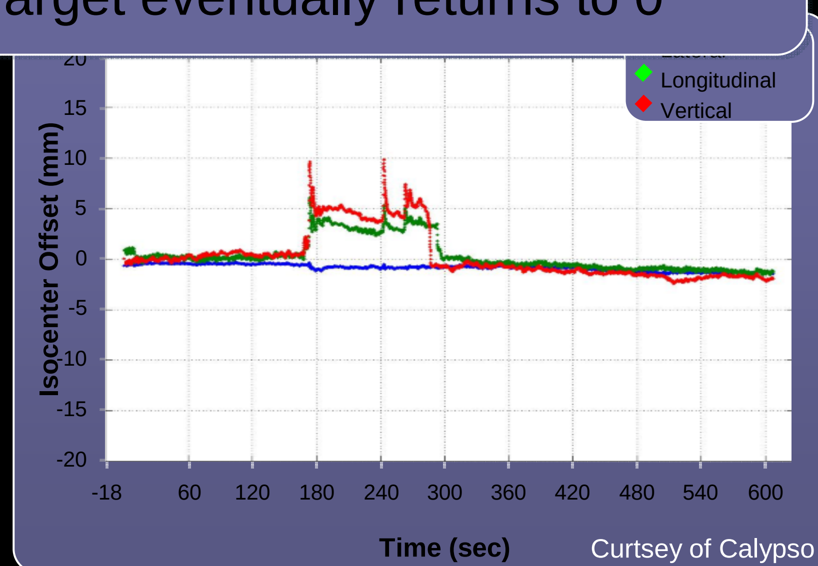
← Sustained and Transient Excursions

6 of 10 minutes target misaligned

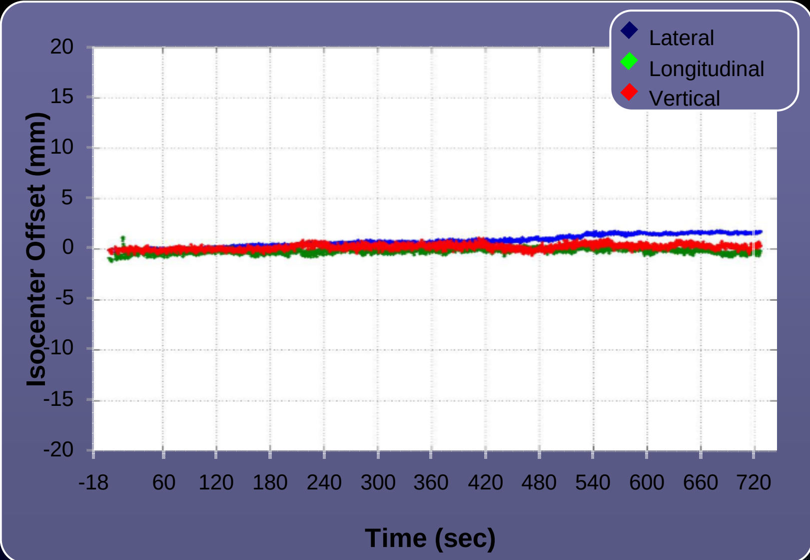
Target eventually returns to 0

Transient Excursion

Prostate excursion ~ 2 minutes realignment without intervention



Variable motion for same patient on different day

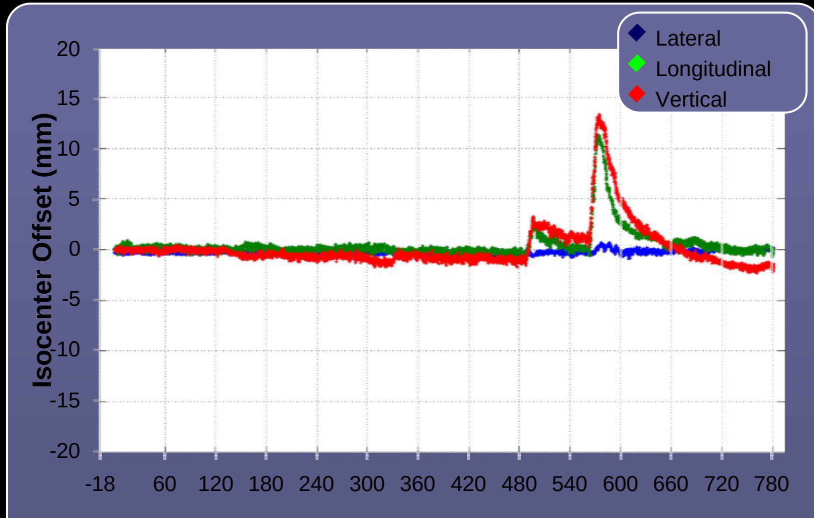


←Stable

Prostate is stable throughout fraction

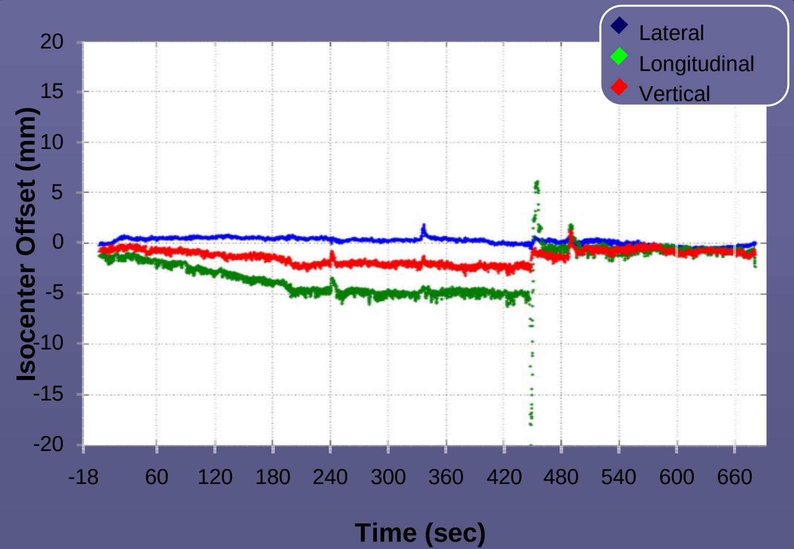
Transient Excursion →

Same patient, later in the week prostate shifts at end of fraction



Curtsey of Calypso

Intervention by therapists



←Sustained Excursion

Prostate drifts from isocenter

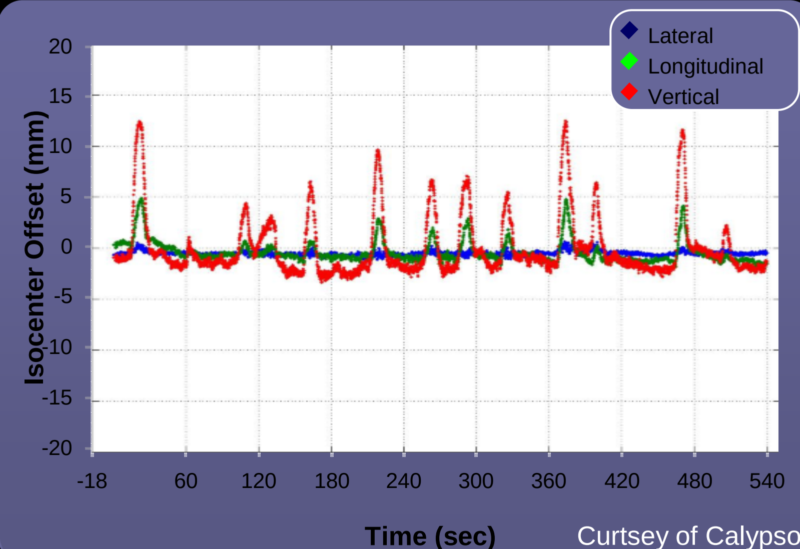
Longitudinal and posterior motion

Stop beam and shift table during treatment

High Frequency, Transient Excursion

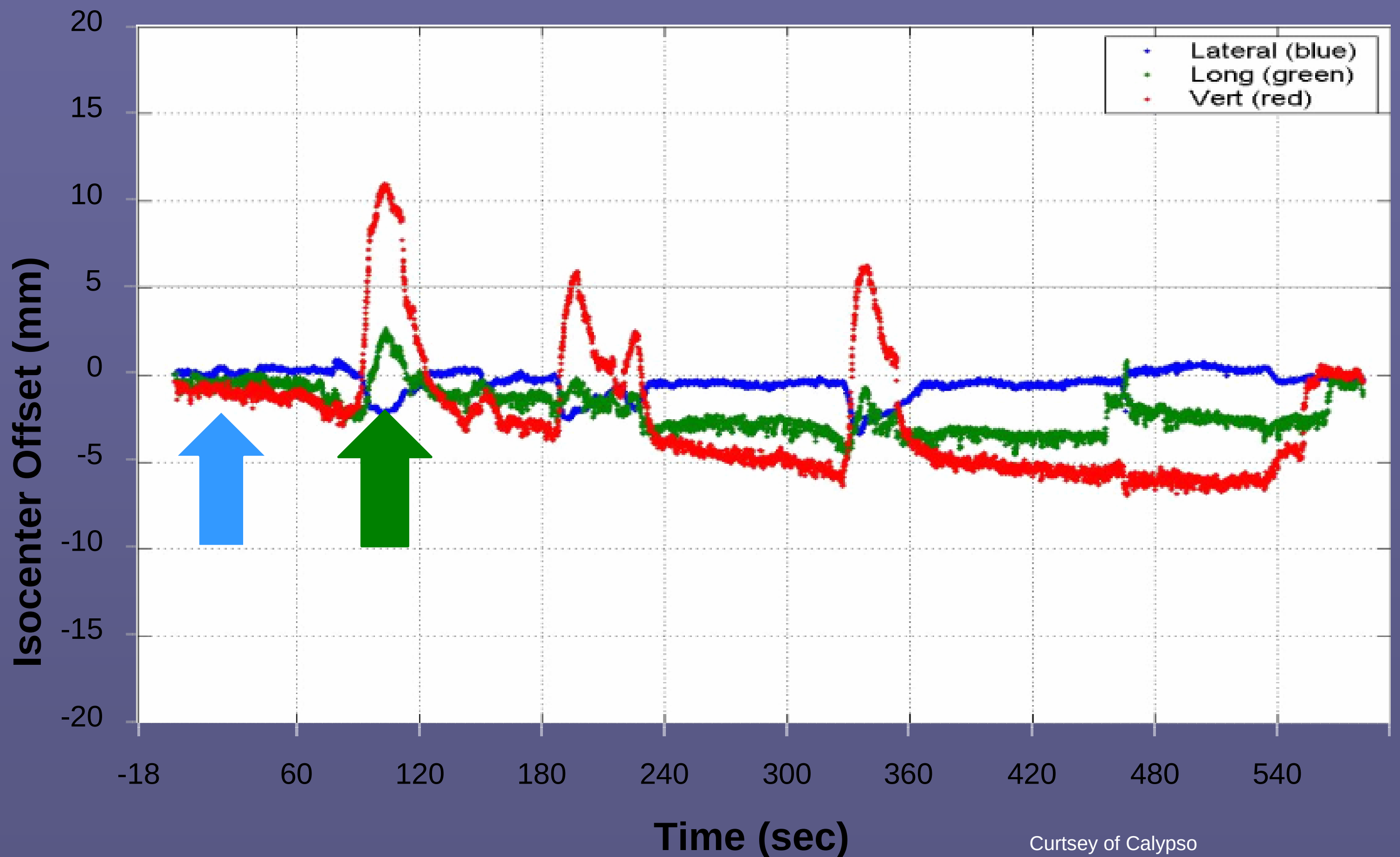
Prostate shifts erratically - 9 min

Manually gate the beam during treatment



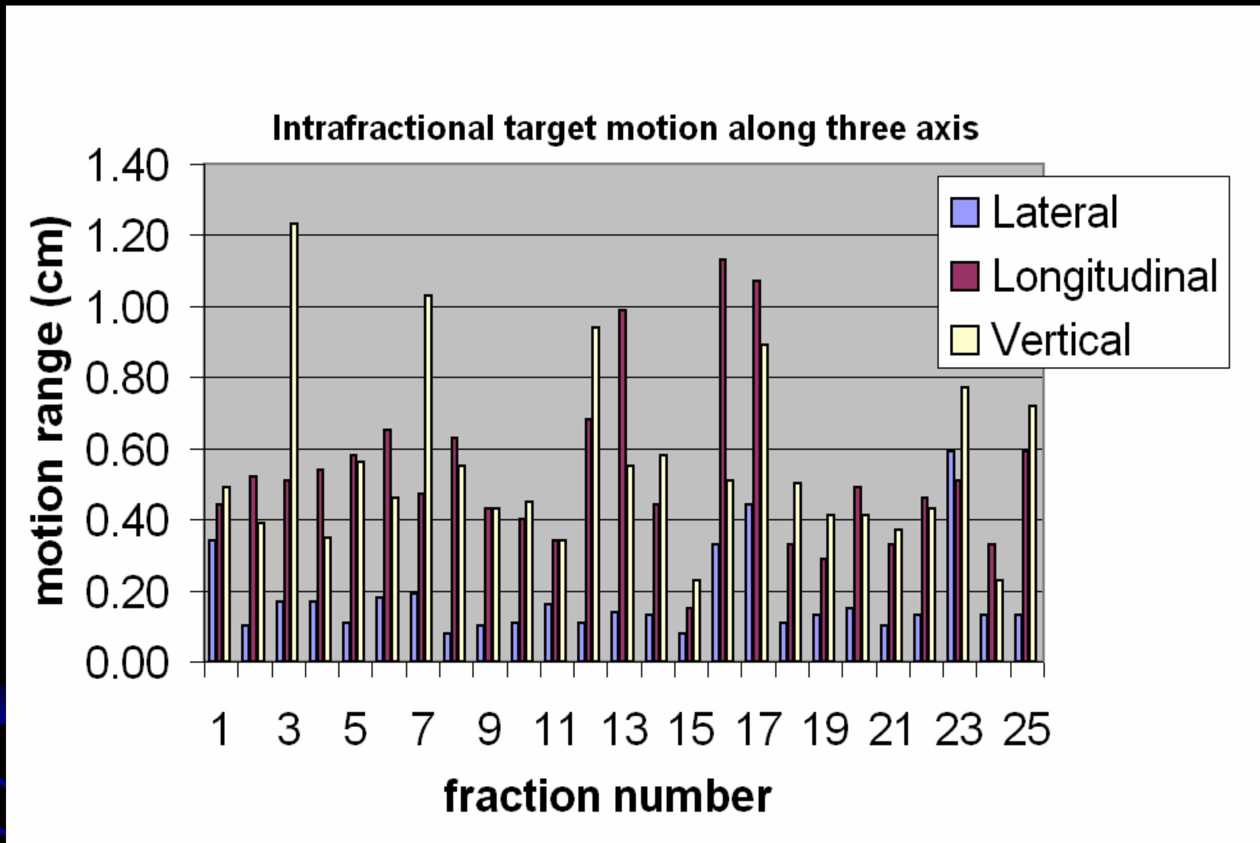
Curtsey of Calypso

Prostate localization with gold markers: Pit falls



Curtsey of Calypso

Intra-fractional target motion: Is daily CBCT sufficient?

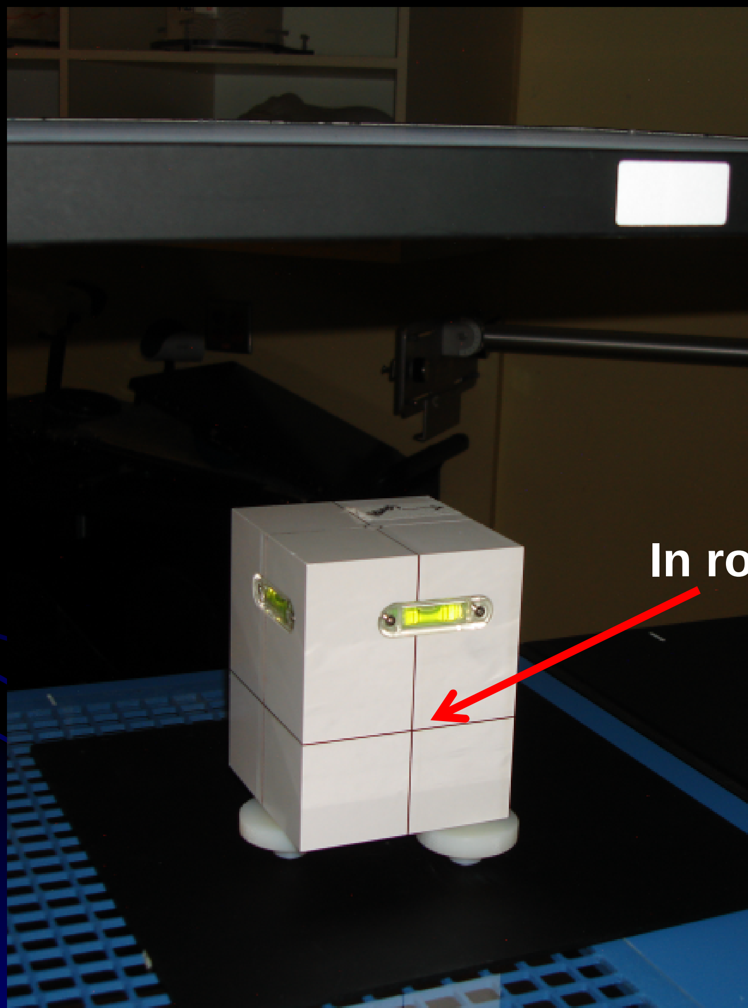


The maximum range of the prostate intra-fractional motion were 5.9 mm (lateral), 11.3 mm (longitudinal) and 12.3 mm (vertical) mm over 25 fractions for this patient.

Calypso Quality Assurance (QA)

- Daily QA: Performed using daily QA phantom before the first Calypso patient of the day. QA normally takes less than 5 minutes.
- Monthly QA (system calibration): Performed using monthly QA phantom to check the system accuracy. It normally takes about 20~30 minutes.
- Annual QA (camera calibration & system calibration): Full calibration for the infra-red camera and system accuracy. This takes about 1 hour.

Daily and Monthly QA setups

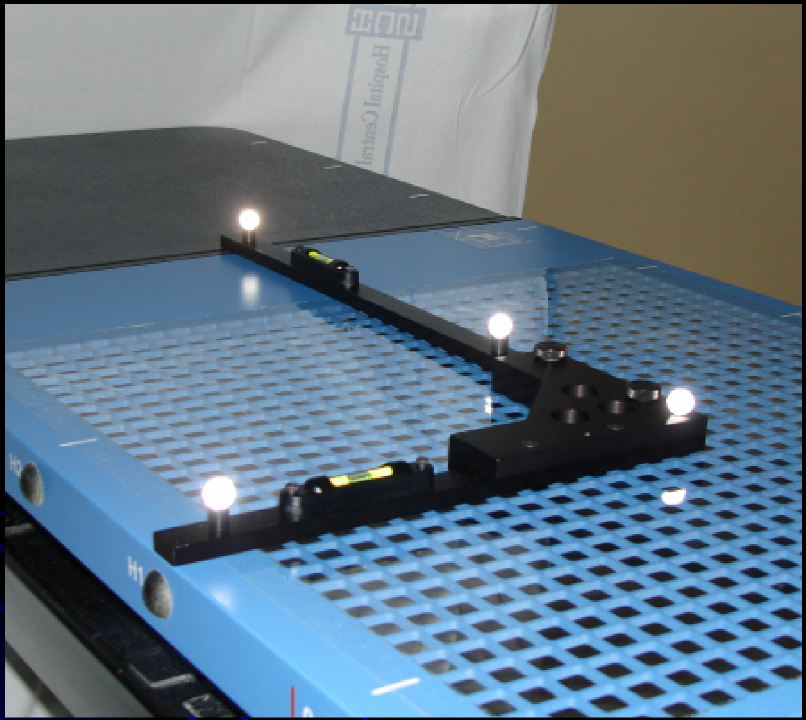


In room lasers

Daily QA

Monthly QA

Camera calibration



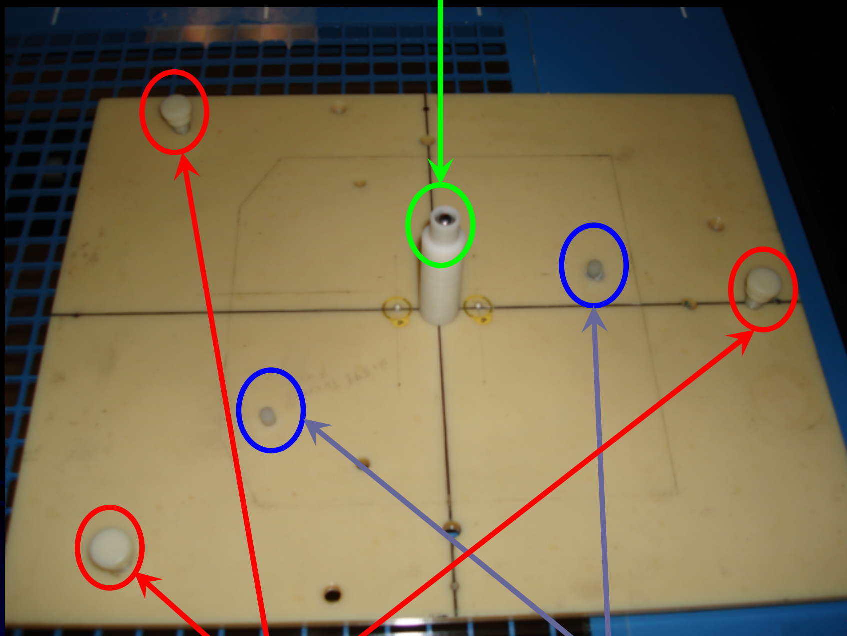
L-shape

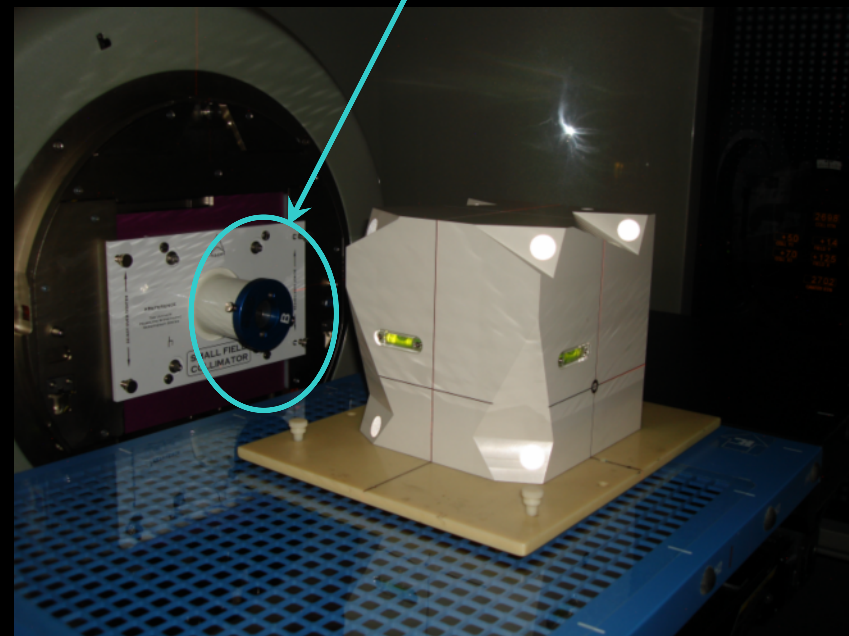
Infra-red wand

System calibration accuracy

- The Calypso system is calibrated off in-room lasers which may have up to 2 mm error from machine radiation isocenter
- A stereotactic radiosurgery (SRS) cone based method was developed in house to improve the Calypso system calibration accuracy
- Comparison was made between the two calibration methods

SRS based calibration platform

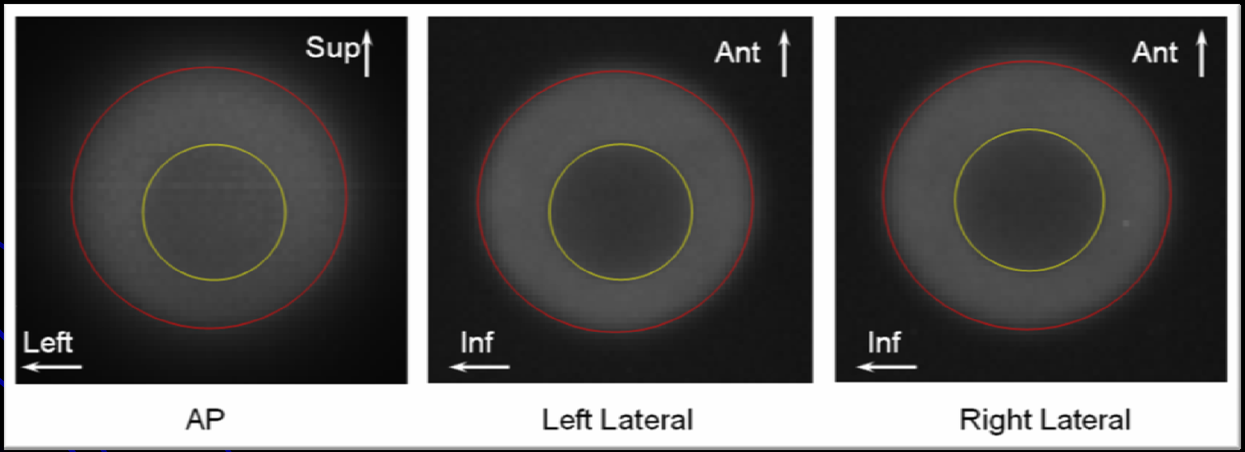




The discrepancy between the center of the tungsten ball and the Calypso phantom isocenter is ~0.1 mm

Calibration comparison procedures

- The Calypso system calibration was first performed by aligning the monthly phantom using room lasers
- The Calypso phantom was then replaced by the tungsten ball and three films (Anterior, Left lat and Right lat) were taken with the SRS cone
- The radiation isocenter was determined based on the film results, which has an overall accuracy of better than 1.0 mm



- The above film results showed that the Calypso suggested isocenter is about 0.6mm away from radiation isocenter (0.3mm lateral, 0.2mm longitudinal and 0.5mm vertical)

Calypso system long-term stability

	lateral shift (cm)	longitudinal shift (cm)	vertical shift (cm)	isocenter shift (cm)
Week 1	-0.02	-0.02	0.04	0.05
Week 2	-0.01	-0.02	0.02	0.03
Week 3	-0.02	-0.01	0.04	0.04
Week 4	-0.03	-0.01	0.03	0.03
Mean	-0.02	-0.02	0.03	0.04
Standard Deviation	0.01	0.01	0.01	0.01

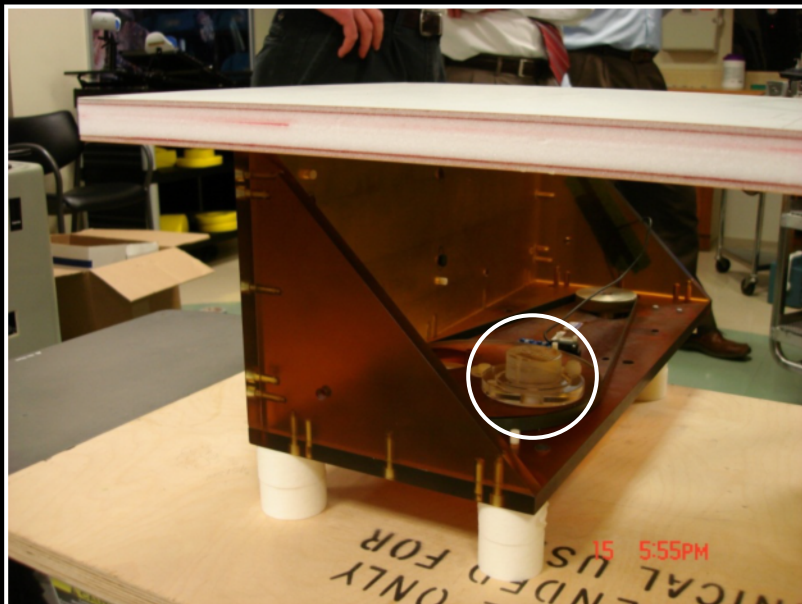
The system stability (defined by 2σ) is 0.2 mm

Beam gating with Calypso

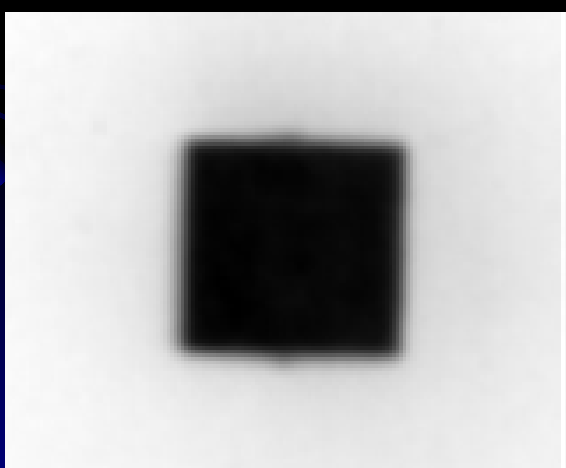
- Calypso signals can be used for beam gating when intra-fractional motion is significant, such as respiratory motion for lung cancer
- Comparing to other gating techniques, Calypso gating is more accurate as it is based on the position of transponders implanted inside or near the target

Gating phantom experiment at SCI: Open Field

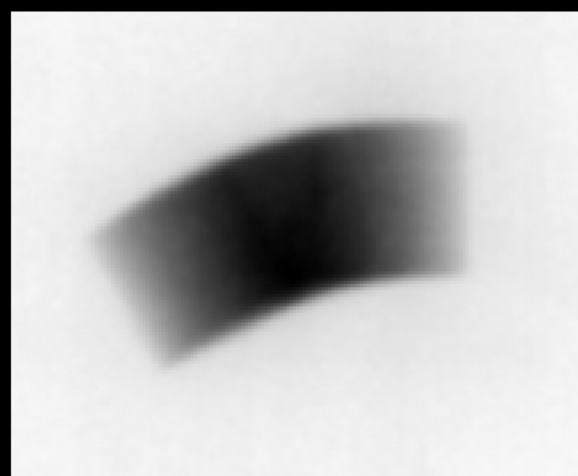
- Varian 23EX
- Field size: 2 cm by 2 cm
- A disc with 3 embedded transponders was place on a moving platform to simulate target motion and to generate the signal using Calypso to gate the linac
- 3 Film measurements were performed
  - Static beam delivery
  - Non-gated delivery with motion
  - A gated delivery using Calypso system with 2mm gating window



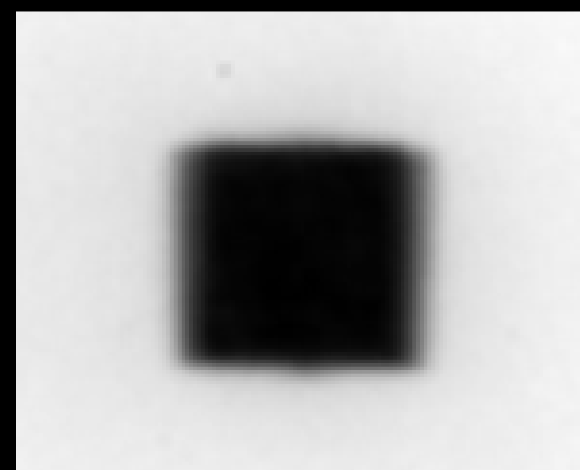
The disc was place on an arc motion platform: 2.8 cm arc span with a speed of 1.2 cm/sec



Static

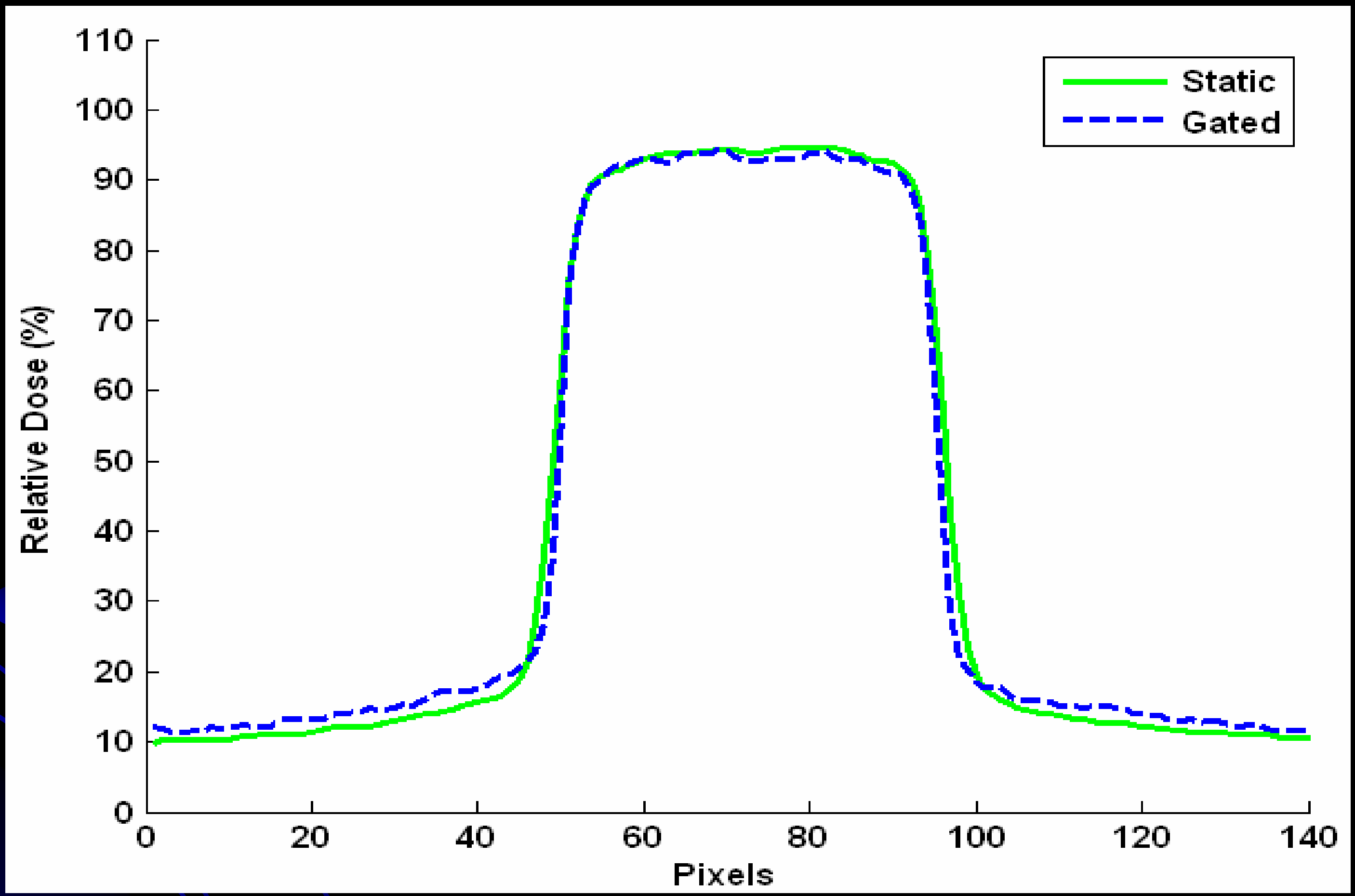


Non-gated



Gated

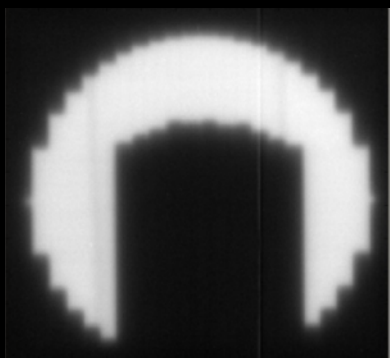
Cross plane profiles

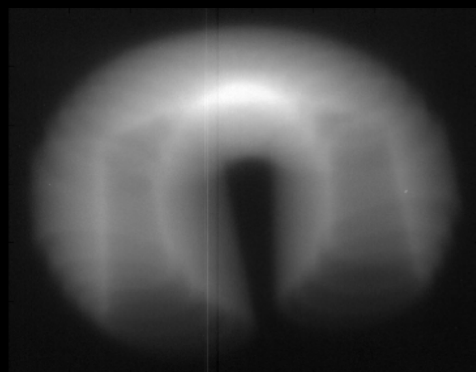


Gating experiment at SCI: C-shaped Field & EDW

- Phantom designed to move in an elliptical pattern that mimics respiratory motion in lung treatment
- Static, non-gated-with-motion, and gated-with-motion film measurements were performed
  - for a C-shaped field formed by MLC
  - for a 10cm x 10cm field with 30 degree EDW

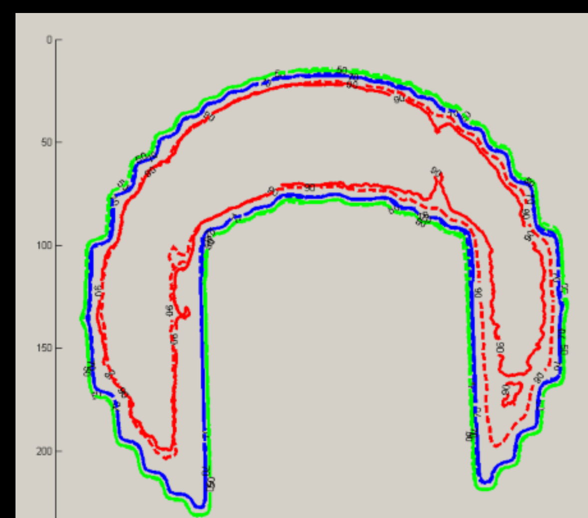
C-shaped MLC field



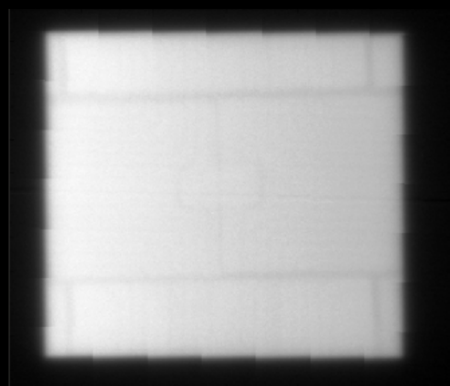


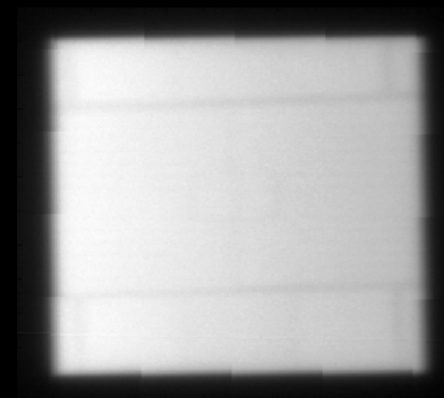
Static **Non-gated** **Gated**

Isodose Overlay

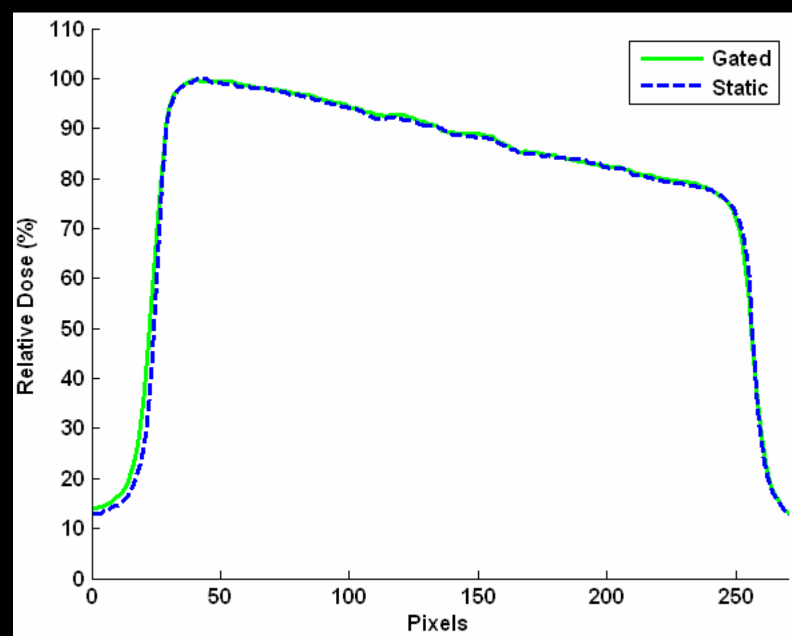


Film measurement: 30 degree EDW delivery





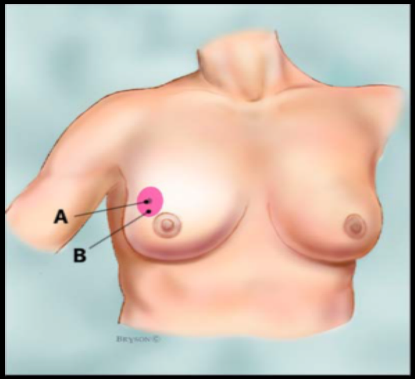
Static **Non-gated** **Gated**



Other potential applications of Calypso

- With transponders embedded in a bite-block, Calypso can be used for head-&-neck cancer treatment
- Studies are also carried out at Swedish on the application of Calypso for Partial Breast Irradiation (PBI)

Other potential applications of Calypso

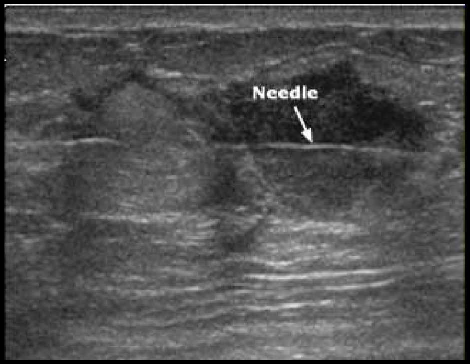


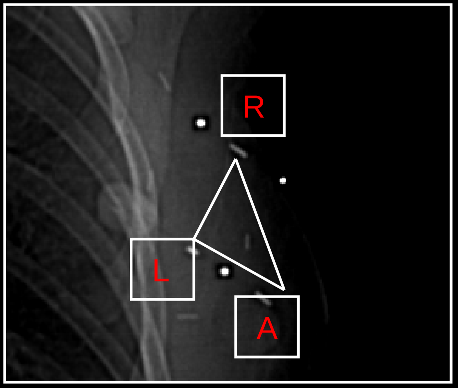
For study subjects who will require MRI follow-up:

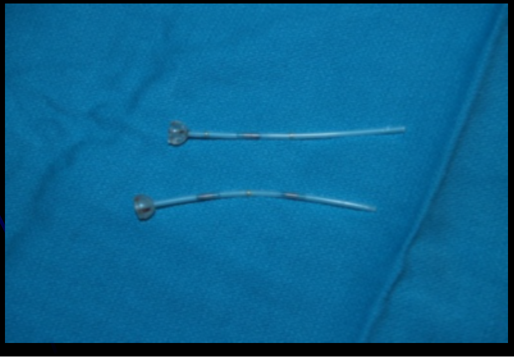
•Two 13G brachytherapy catheters inserted under US guidance using local anesthetic.

•Gold markers and Beacon transponders used for localization and continuous tracking respectively.

•Catheters removed after final APBI treatment







Summary

- Using Calypso system in beam gating can provide accurate dose delivery when intra-fraction motion exists.
- Calypso system also has potential applications in other treatment sites, such as head-&-neck and breast.