Patient Dose Verification for IMRT/VMAT Treatments

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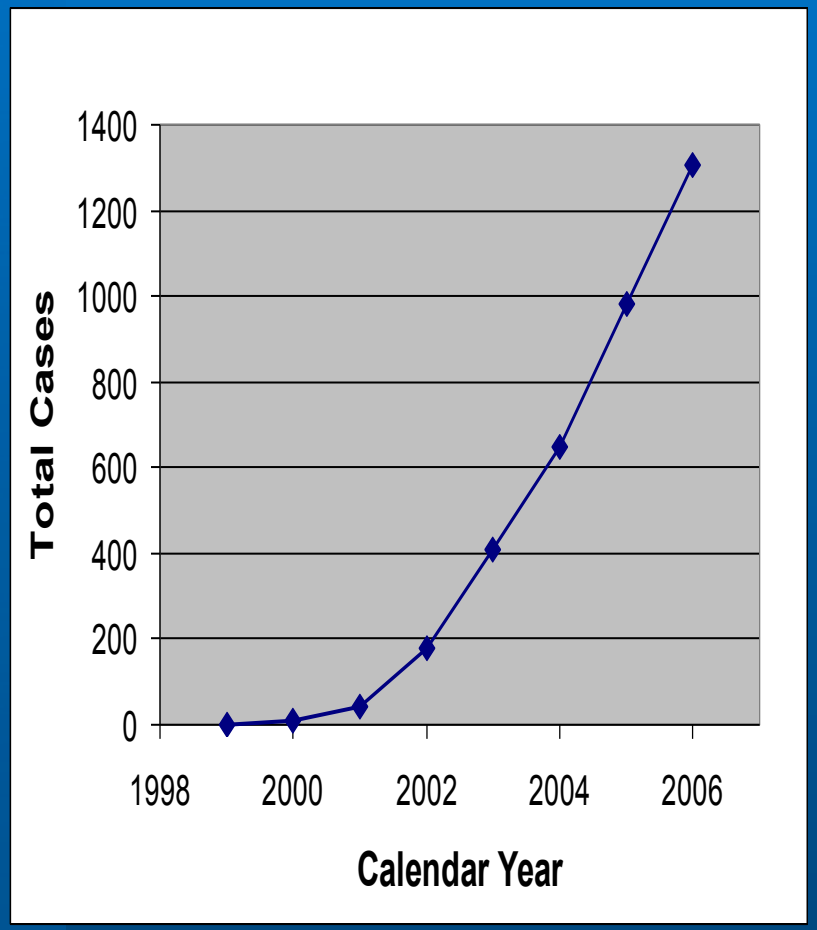
MD Anderson Cancer Center
Making Cancer History®

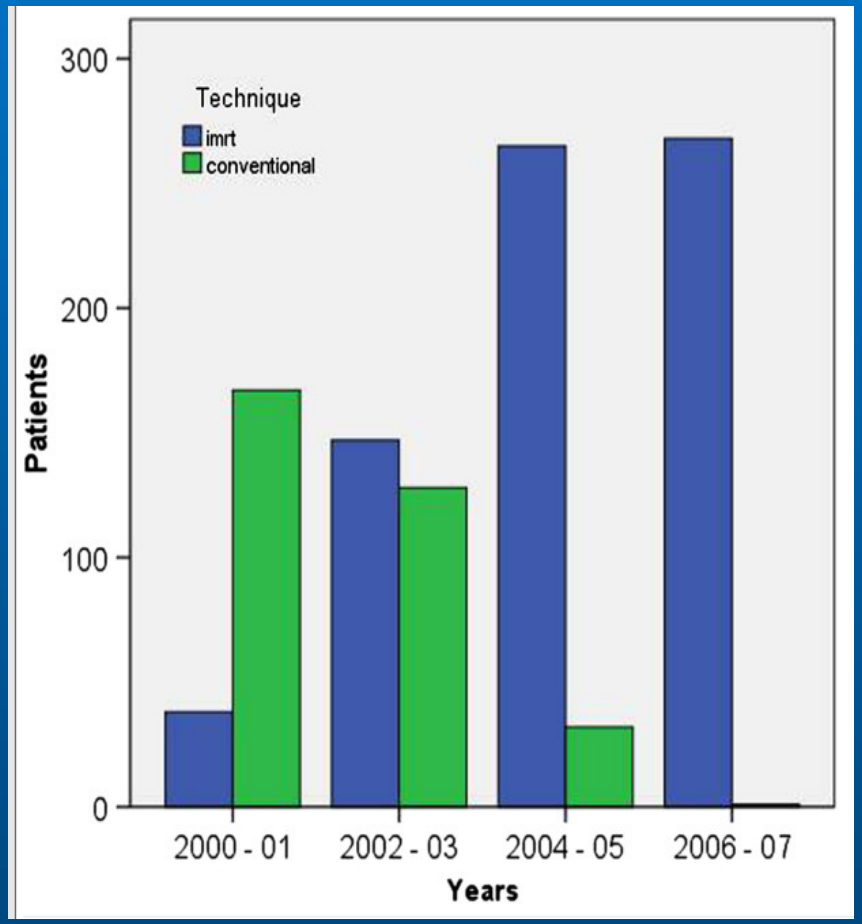
Milestones for H&N IMRT

Case Number	As of Date
1	12/28/1998
20	9/1/2000
100	7/1/2001
1000	1/24/2005

Trend of H&N IMRT Treatments



All HN IMRT cases



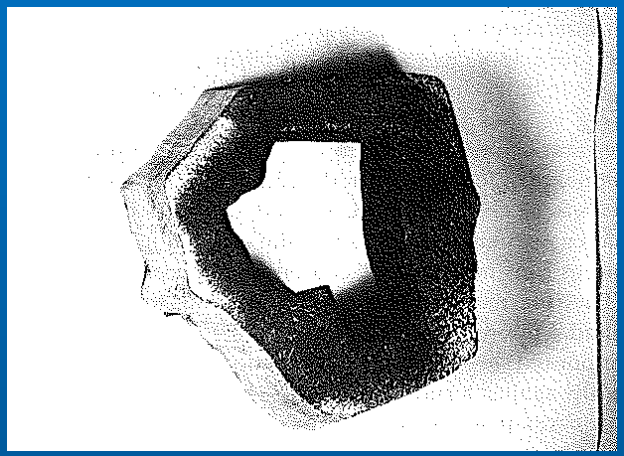
Advanced OPX cases

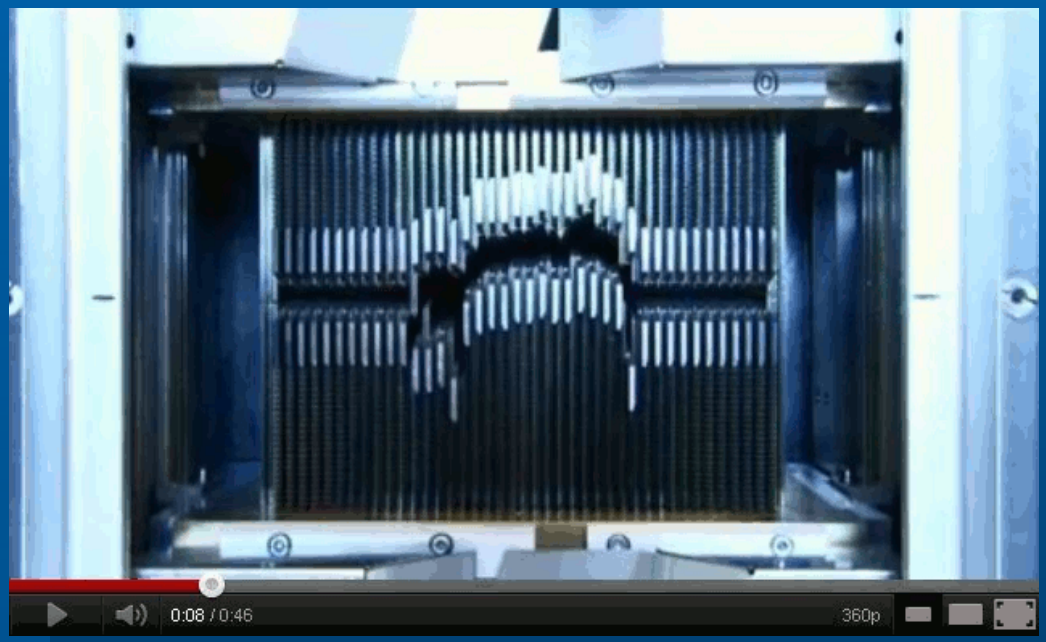
Milestones for H&N IMRT

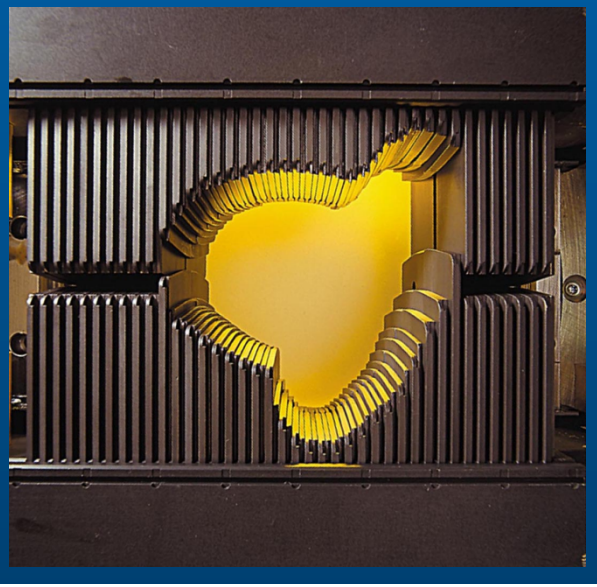
Case Number	As of Date
1000	1/24/2005
2000	7/6/2007
3000	6/24/2009
~600 per year	Currently

Multi Leaf Collimators (MLC)

- **3D-CRT→ From cerrobend blocks to multiple leaves**
- **Dynamic MLC → Intensity Modulation**







Software Systems for IMRT Planning

- **The NOMOS CORVUS V3 was used to treat the first H&N case on 12/28/98.**
- **It was soon upgraded to V4.**
- **On December 2003, the system was about to upgrade to V5.**
- **However, we decided to switch to Philips Pinnalce^3 V6 TPS instead.**

Software Systems for IMRT Planning

- On December 2003, Philips Pinnalce^3 V6 was used to optimize fluence maps and for step-and-shoot IMRT
- Since April 2005, started Pinnalce^3 V7 with DMPO technique
- Wide-Field Technique V8
- Currently, Pinnalce^3 V9.8 SmartArc used for VMAT planning

Why QA DMLC procedures?

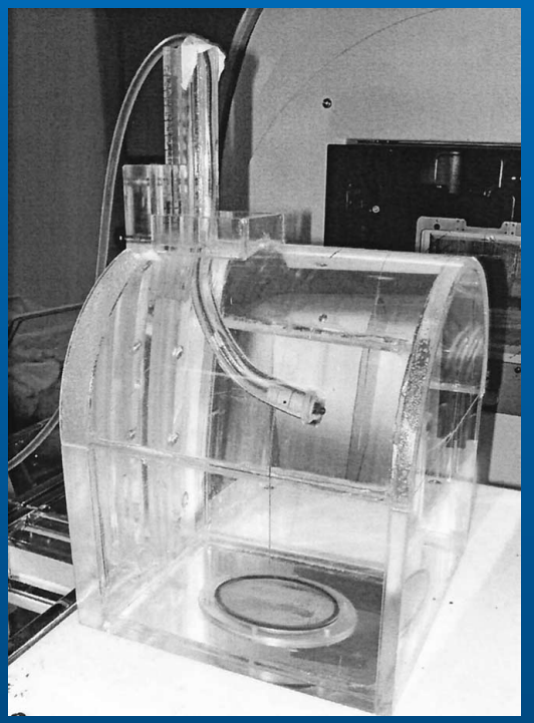
- **Complex dose distributions**
- **Steep dose gradients**
  - **Moving MLCs**
  - **Precision of MLC motion**
- **Dose calculations are less intuitive – Inverse planning**
- **MLC modeling → From TPS to the LINAC**
  - **Leaf leakage, position, transmission, synchronization, speed**
- **VMAT → Gantry and MLC moving at the same time**

IMRT/VMAT Plan QA Protocol

- **Purpose:**
  - Verify each patient plan
  - Deliver on phantom of known reproducible geometry
  - Compare measurements to approved plan

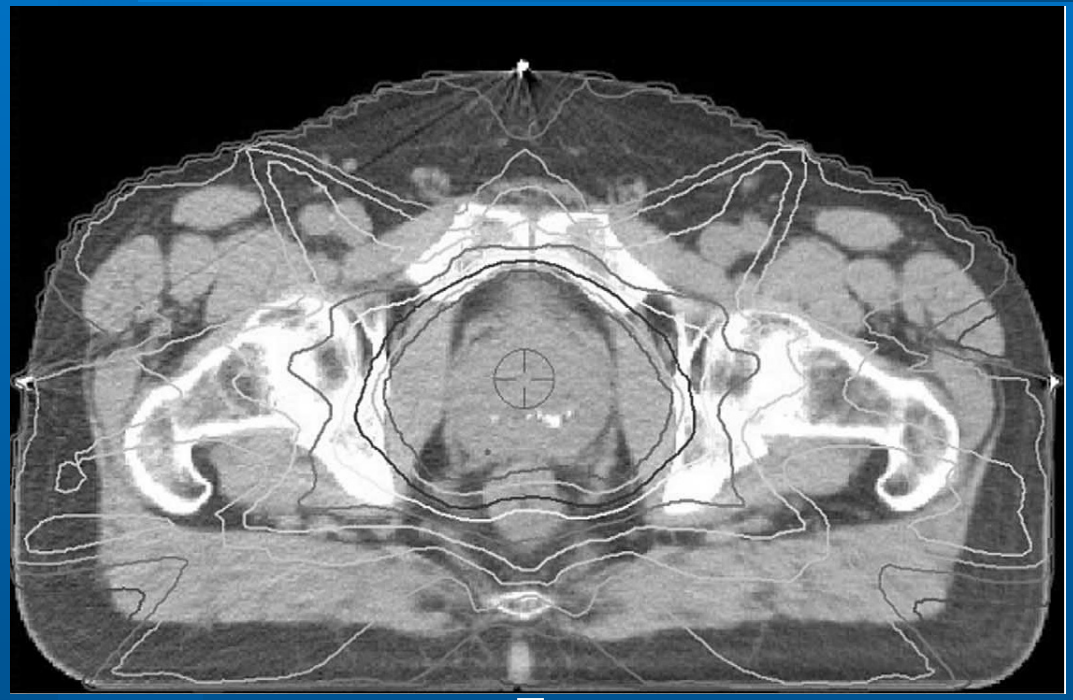
Traditional IMRT/VMAT QA protocol

- MDACC Arc Phantom
- Absolute dose measurements
  - Water prove ion chamber
  - Dose differences verified at several points
  - Need use solid water phantom to do film measurements



Arc Phantom

Traditional IMRT/VMAT QA protocol



Hybrid Plan in Arc Phantom

MU/Dose Delivered Analysis

	6MV				18MV			
Readings @ 90:	1.268	1.268	1.269	nC	----------	----------	----------	nC
Readings @ 270:	1.277	1.278	1.277	nC	----------	----------	----------	nC
Average Reading:	1.273			nC (R_{avg})	----------			nC (R_{avg})

Dose Factor = $\frac{113.2\ \text{cGy}}{R_{avg}} = 88.94\ \text{cGy/nC}$

Dose Transfer Factor

Measurements In the following tables, Dose is the product of the reading and the above dose factor.

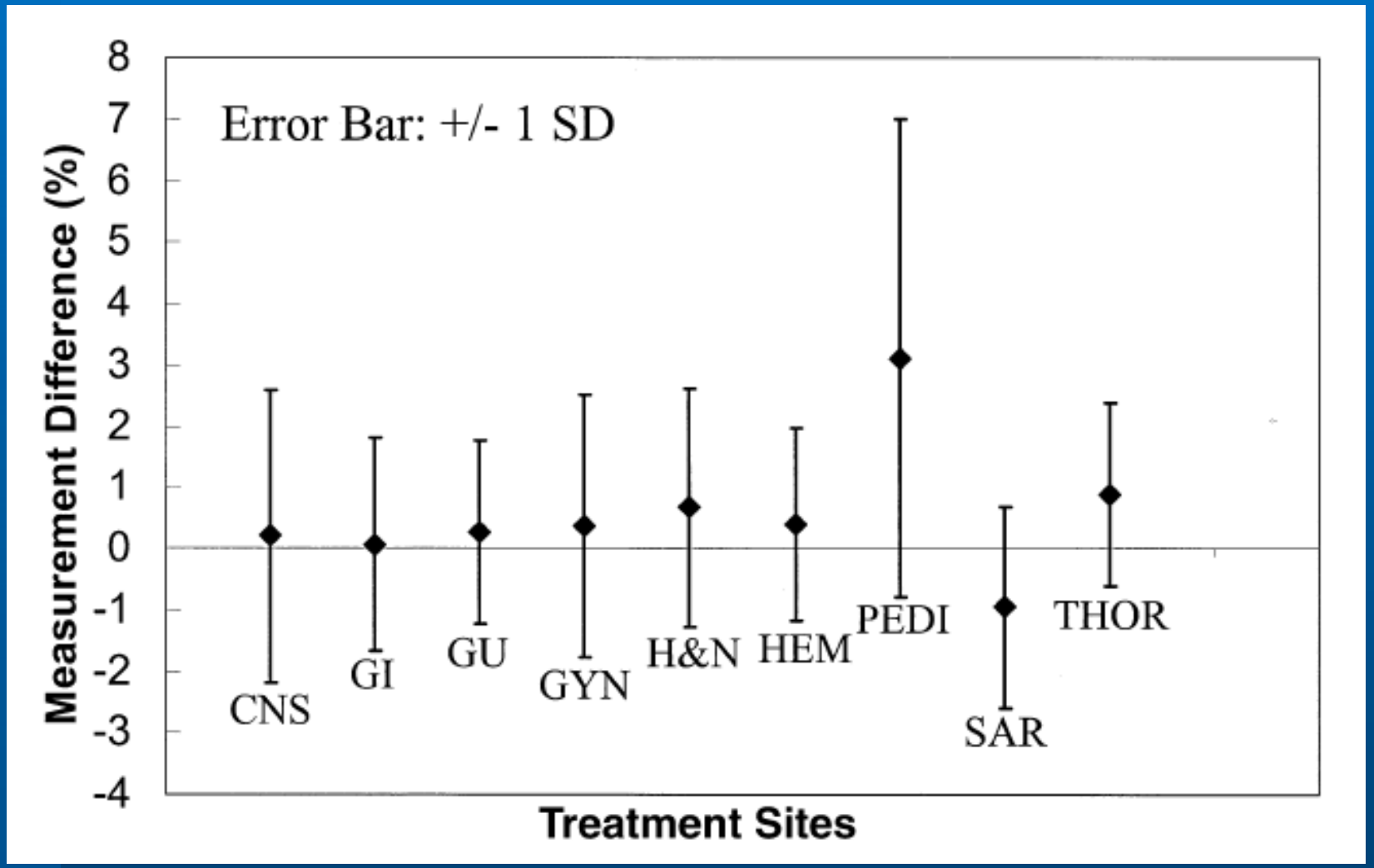
Field	Energy (MV)	Couch	Coll	Gantry	MU	Ion Chamber Readings (nC)	Ion Chamber Dose (cGy)
A	6	0	0	225	109	0.292	26.0
B	6	0	0	280	75	0.285	25.3
C	6	0	0	330	63	0.352	31.3
D	6	0	0	30	100	0.397	35.3
E	6	0	0	60	106	0.237	21.1
F	6	0	0	90	71	0.222	19.7

Total Measured	158.7
Calculated Dose	155.4
% diff*	2.2%

Absolute Point Dose

Difference < 3.5 % ?

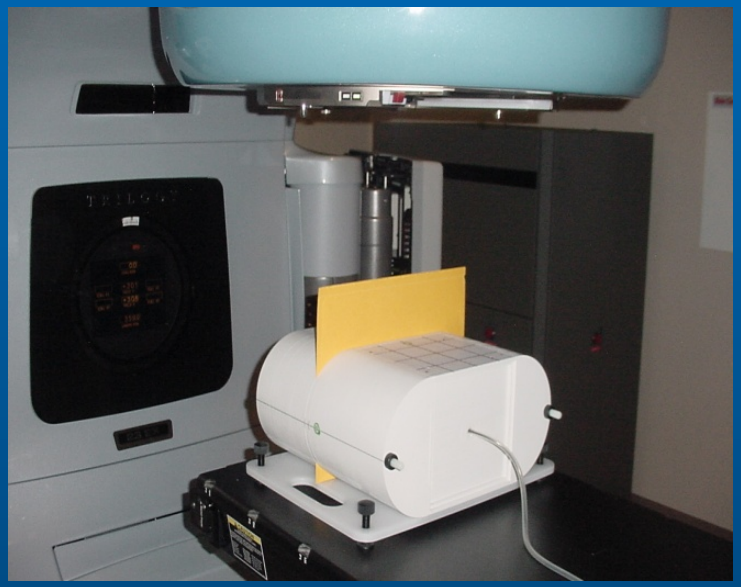
Traditional IMRT/VMAT QA protocol



Traditional IMRT/VMAT QA protocol

- IBA I'mRT Phantom

- **Ion Chamber:**
  - Absolute dose measurements
  - Dose difference of a single point
- **Film:**
  - Relative dose measurements
  - Dose distribution in a coronal plane through the phantom
  - Gamma analysis



IBA I'mRT Phantom

Traditional QA Analysis

	6MV				18MV			
Readings @ 90:	1.268	1.268	1.269	nC	----------	----------	----------	nC
Readings @ 270:	1.277	1.278	1.277	nC	----------	----------	----------	nC
Average Reading:	1.273			nC (R_{avg})	----------			nC (R_{avg})

Dose Factor = $\frac{113.2\ \text{cGy}}{R_{avg}} = 88.94\ \text{cGy/nC}$

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F	6	0	0	90	71	0.222	19.7
						Total Measured	158.7
						Calculated Dose	155.4
						% diff*	2.2%

< 3% or 5% ?

Absolute Point Dose

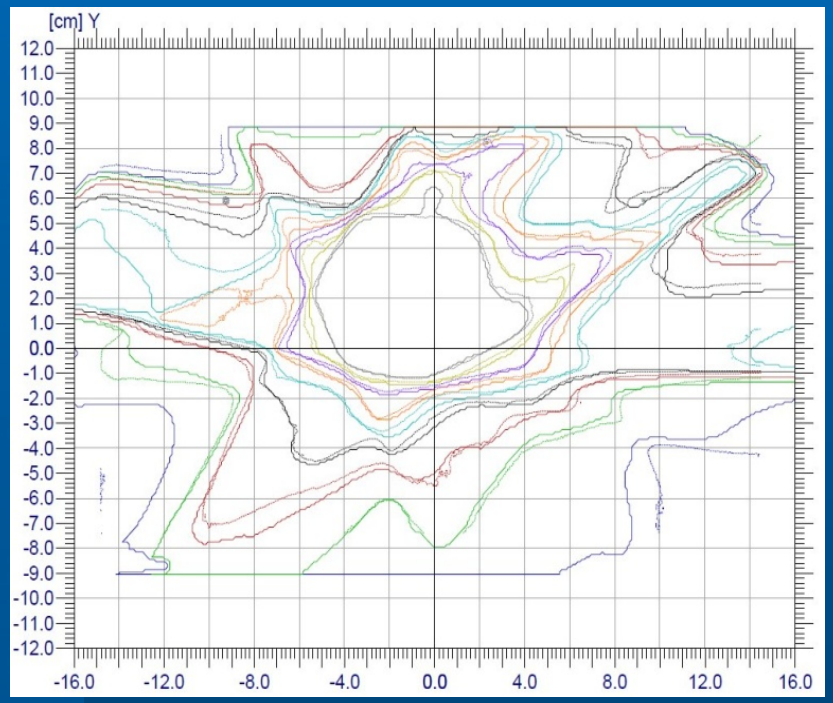
Traditional QA Analysis

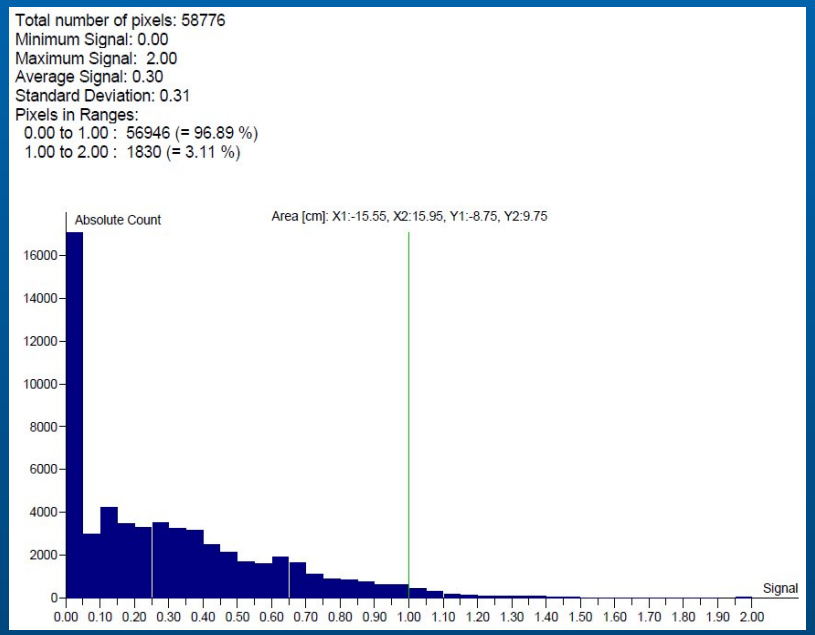
Relative Dose

$$\Gamma(\vec{r}_e,\vec{r}_r)=\sqrt{\frac{r^2(\vec{r}_e,\vec{r}_r)}{\Delta d^2}+\frac{\delta^2(\vec{r}_e,\vec{r}_r)}{\Delta D^2}}$$

>90%

3mm **5%**

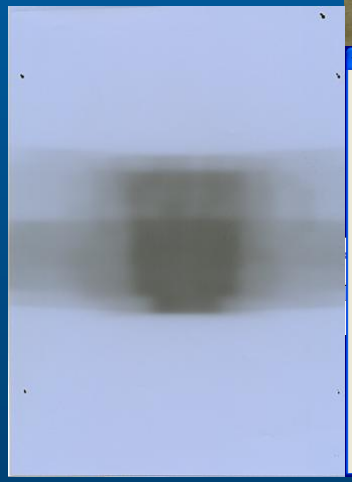


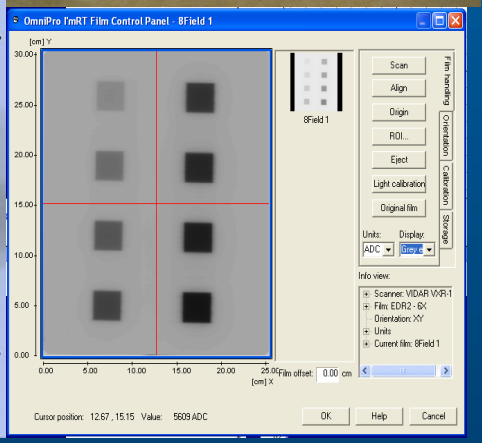


Why change QA procedure?

1. Issues with Relative Dose

- **Depend on film processor**
  - **Not reproducible**
  - **Time delay between exposure and processing**
- Film : Spatial and Energy dependence
  - Needs calibration curve
  - Relative measurements

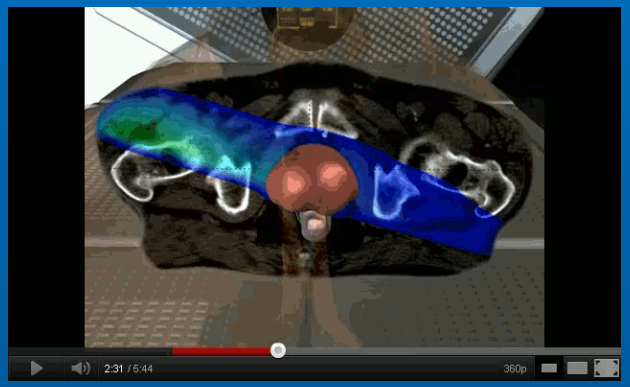


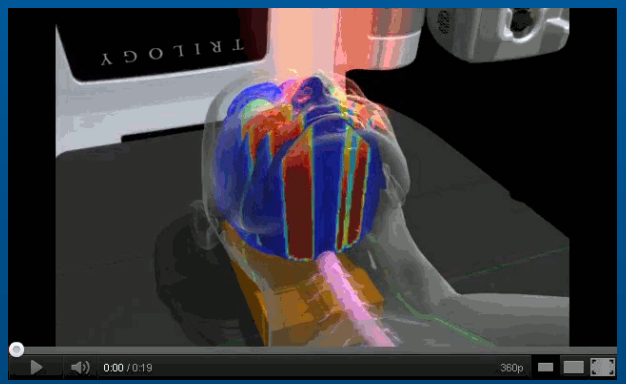


Why change QA procedure?

2. Increased treatment complexity

- **IMRT – Gantry moves to specified angle → Beam delivered → MLCs move**
- **VMAT – Gantry Angle, Dose Rate, and MLCs move at the same time**



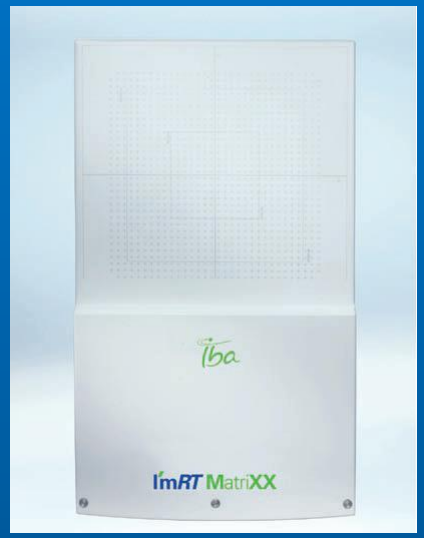


Additional variables

- Cumulative dose measurement
- Greater measurement area

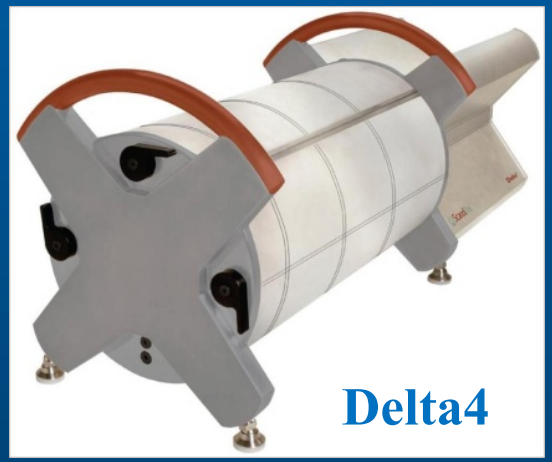
Detector Array Devices

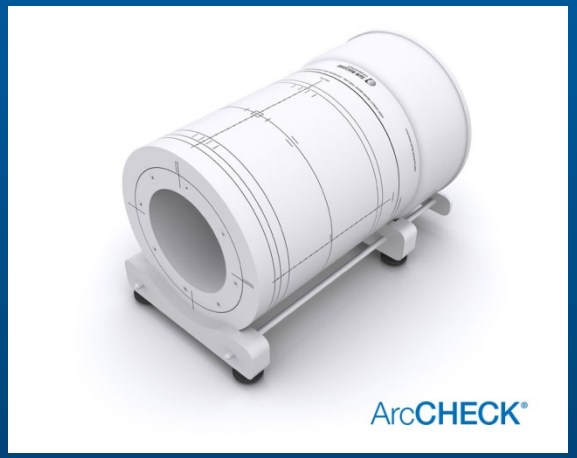
- **2D Dosimetry Systems**
  - **IBA MatriXX**
  - **Map Check**
  - **EPID**



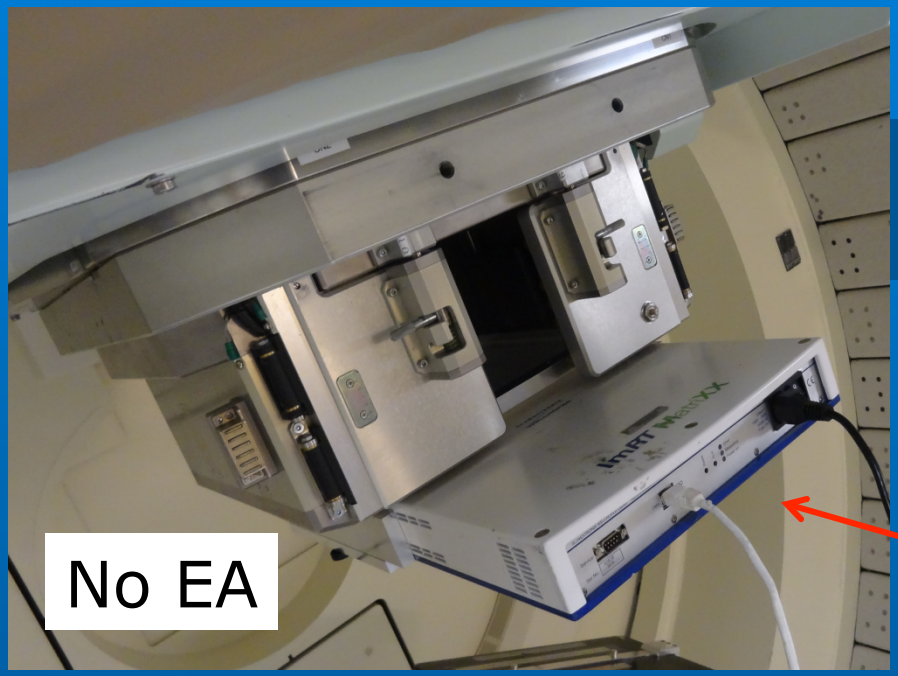
Detector Array Devices

- **3D Dosimetry Systems**
  - **Scandidos Delta4**
  - **ArcCheck**
  - **Gel**

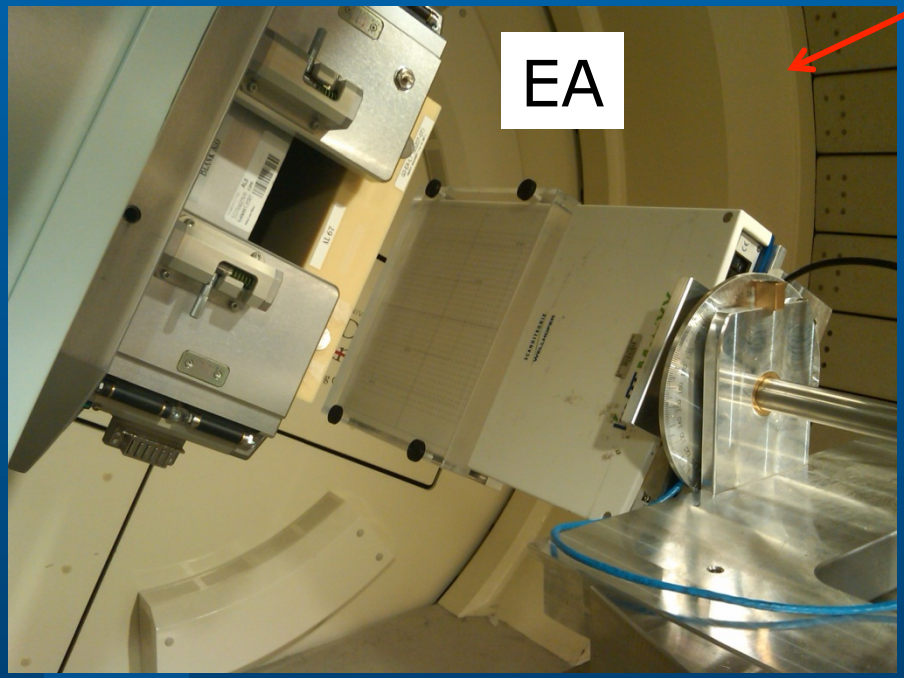




Proton Patient QA



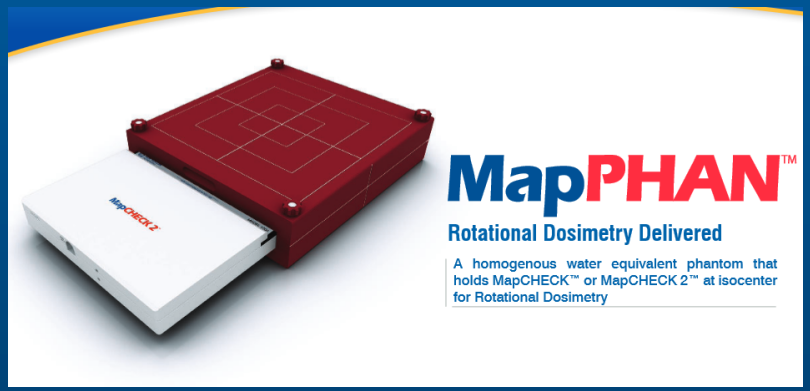
ACS: Tx mode



Patient Specific QA for Proton Tx

- Exclusively using 2D ionization chamber MatriXX (IBA dosimetry):
  - 2D dose measurements at treatment gantry angles through EMR (QA-mode) and ACS (Treatment-mode)
  - 2D dose measurements at gantry 270° or 90° in the physics model of ACS at multiple depths:
    - Simple target volumes – 3 depths
    - Complex target volumes – 5 to 7 depths

MapCheck With MapPhan for QA



EPIDs For IMRT QA

Advantages

- Many centers have installed EPIDs and being primarily used for patient-specific pretreatment field verification and MLC QA
  - Logical extension to investigate dosimetric applications
- Mounted to linear accelerator – known geometry with respect to the beam
  - Detector sag must be accounted for at different gantry angles
  - Positioning reproducibility important
- Real time digital evaluation
  - No processor, data acquisition takes less time

EPIDs For IMRT QA

Challenges

- EPIDs were primarily designed for patient localization
  - High resolution, good contrast images
  - Additional dose to the patient should be minimized
- The conversion of imager response to dose is complex
  - Imaging system dependent
- Other problems
  - Ghosting
  - Lag

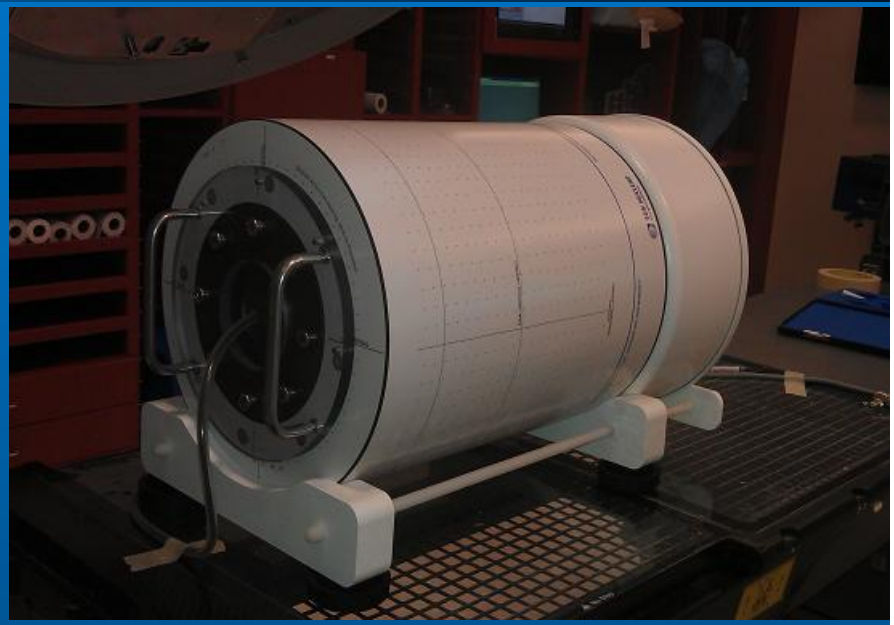
EPIDs For IMRT QA

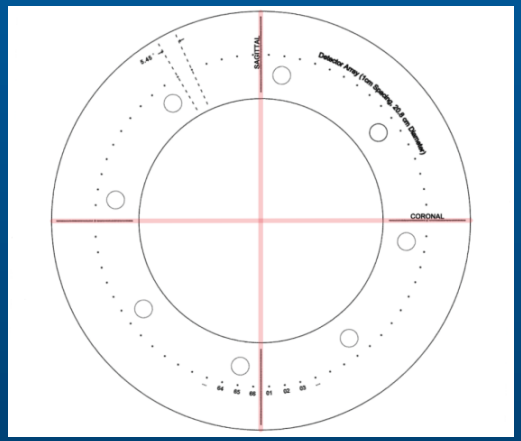
Factors for EPID Response

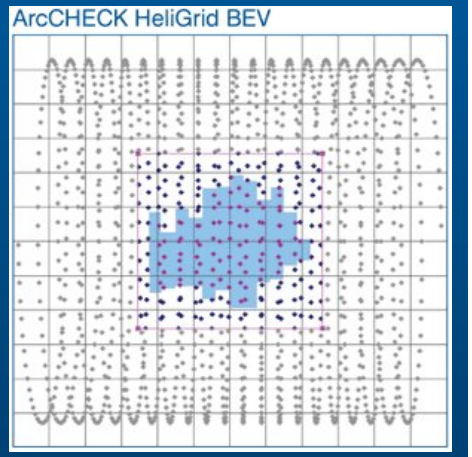
- Water-equivalent depth of the detector
- Field size dependence and scatter properties within the imager
- Short- and long-term reproducibility
- Dose rate
- Energy dependence
- Spatial integrity

ArcCheck For Rotational Beams

- Water equivalent material
- Weighs 16 Kg
- 1386 (0.8x0.8 mm^2) diode detectors
- Detector spacing: 10 mm
- Helical grid
- Measure entrance and exit doses

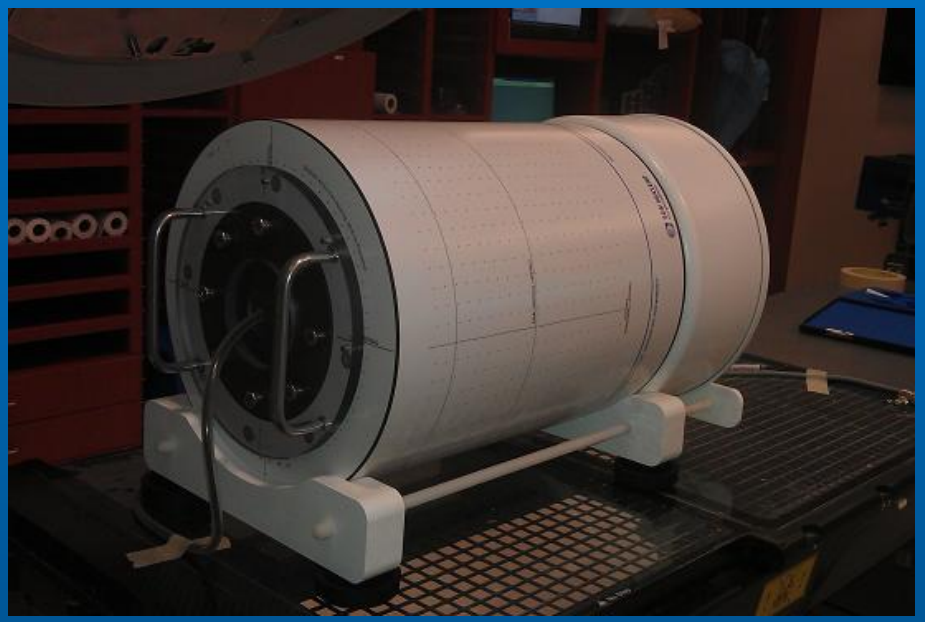


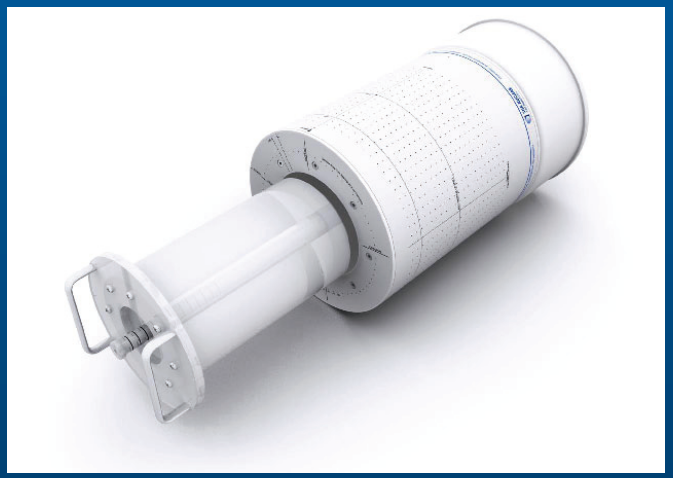




ArcCheck Physical Dimensions

- Build up: 2.85 cm
- Detector array length: 21 cm
- Plug diameter: 15 cm
- Array diameter: 21 cm

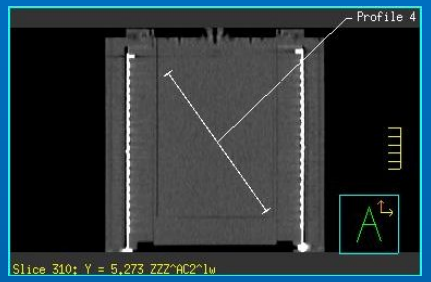




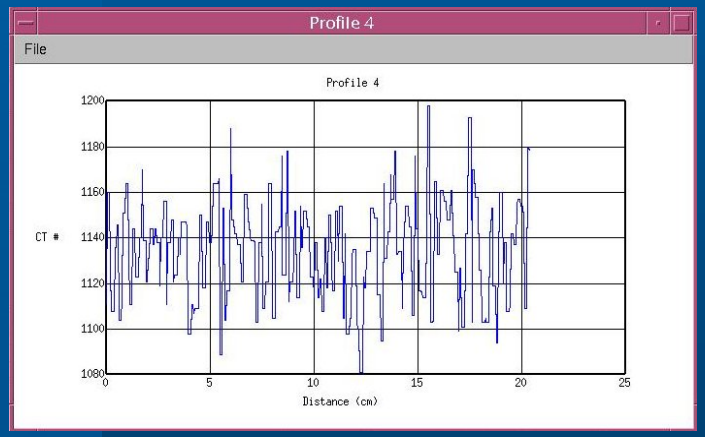
ArcCheck Advantages

- 3D dose distribution
- Beam is always normal to the detector surface
- Allows for Ion Chamber measurement
- Real-time measurements (50ms frame rate)
- Easy set up with virtual inclinometer
- Composite and per control point analysis

Spatial Integrity and Uniformity

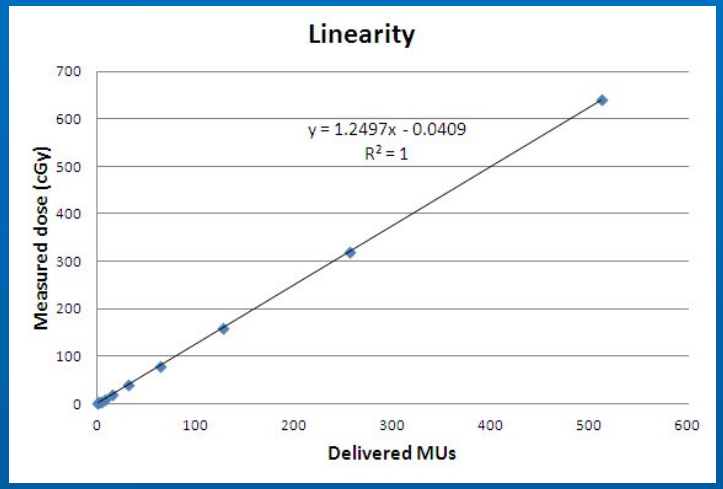


Test	Measurement (cm)	Specifications (cm)
AC diameter	26.56	26.59
Detector array diameter	20.79	20.8
Detector array length	20.91	21
Detector depth	2.89	2.85

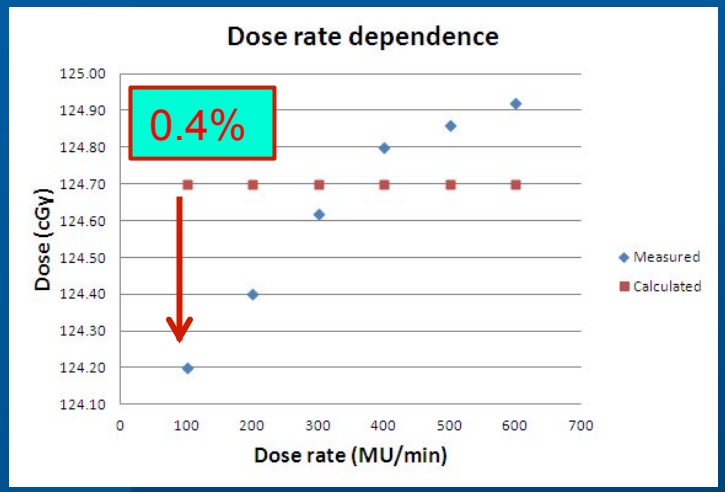


- CT scan full phantom
- Verify physical integrity
- Spatial measurements compared with specs
- HU uniformity (compare between devices)

ArcCheck Response Characteristics



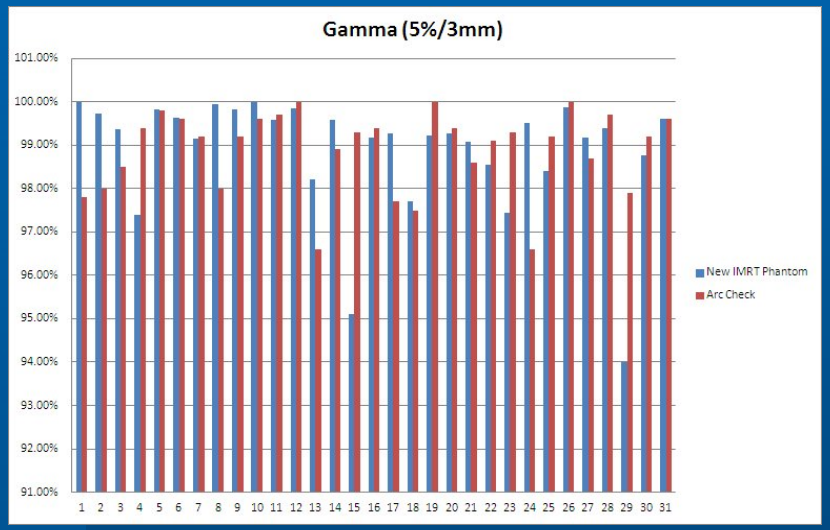
- **Linearity**
  - Dose response over a range of delivered MUs



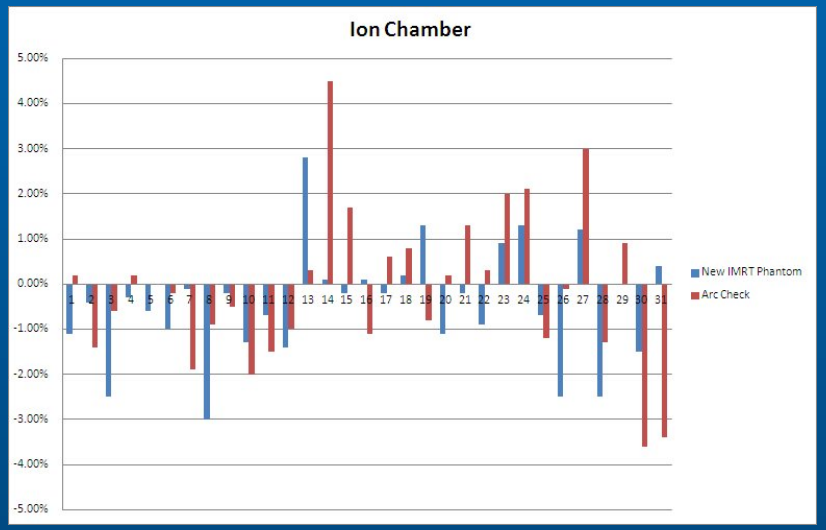
- **Dose rate dependence**
  - Dose response for different dose rates

Patient QA Comparison

- **Old and new system delivery for 31 patients**
- **26 IMRT and 5 VMAT cases**
- **No statistically significant difference**



Arc Check = 99.0 ± 1.1 %
IMRT Phantom = 98.9 ± 1.4 %



Arc Check = - 0.10 ± 1.7 %
IMRT Phantom = - 0.45 ± 1.3 %

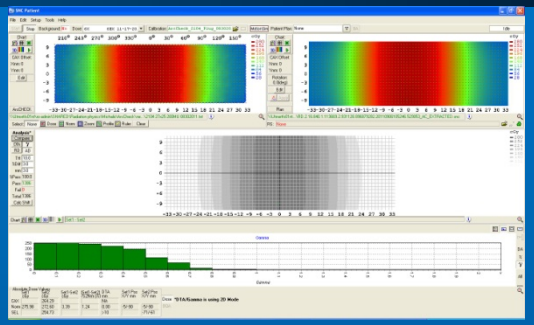
Error Test Analysis

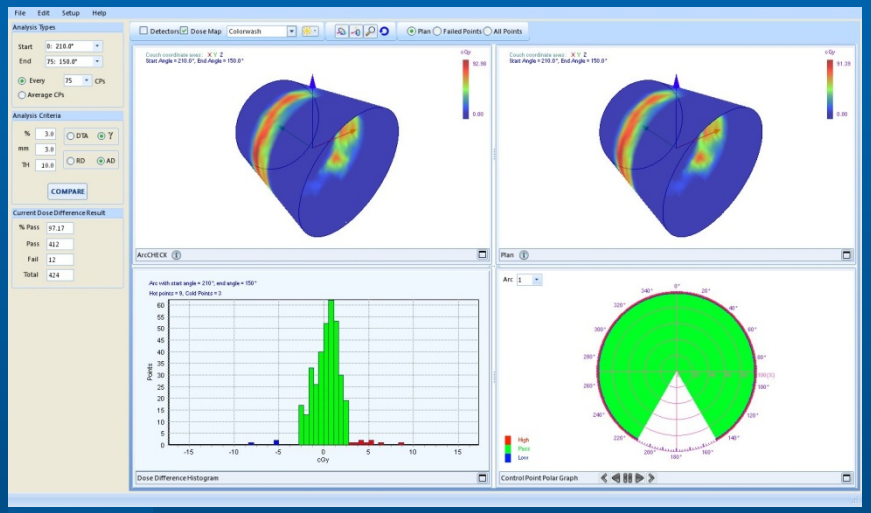
- **Simple field deliveries with various induced errors**
  - 5 -10% difference in MUs
  - 5 -10mm shifts in all directions
  - Jaw closed (2.5 -5mm) on each side
  - Evaluated at 3%/ 3mm

MU	Shift	Rotation	Jaws	Γ(3%/3mm)
200	0	0	10x10	100.0
190	0	0	10x10	100.0
210	0	0	10x10	72.5
180	0	0	10x10	77.0
220	0	0	10x10	63.9
200	5mmLeft	0	10x10	88.5
200	5mmOut	0	10x10	84.8
200	5mmUp	0	10x10	99.6
200	10mmDown	0	10x10	99.6
200	10mmLeft	0	10x10	85.2
200	10mmOut	0	10x10	77.9
200	0	5	10x10	95.1
200	0	10	10x10	88.9
200	0	0	9x10	84.4
200	0	0	10x9	90.6
200	0	0	10x9.5	98.0

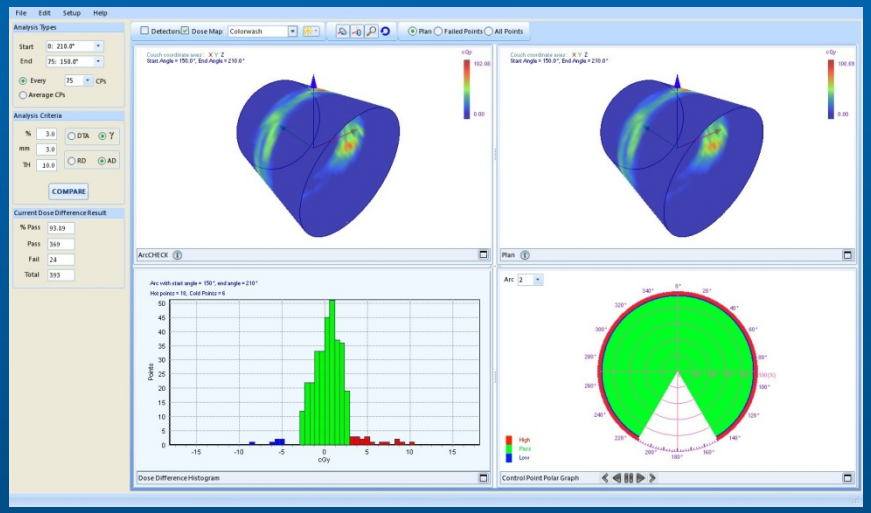
Result Analysis

- **Control Point (CP) real-time analysis**



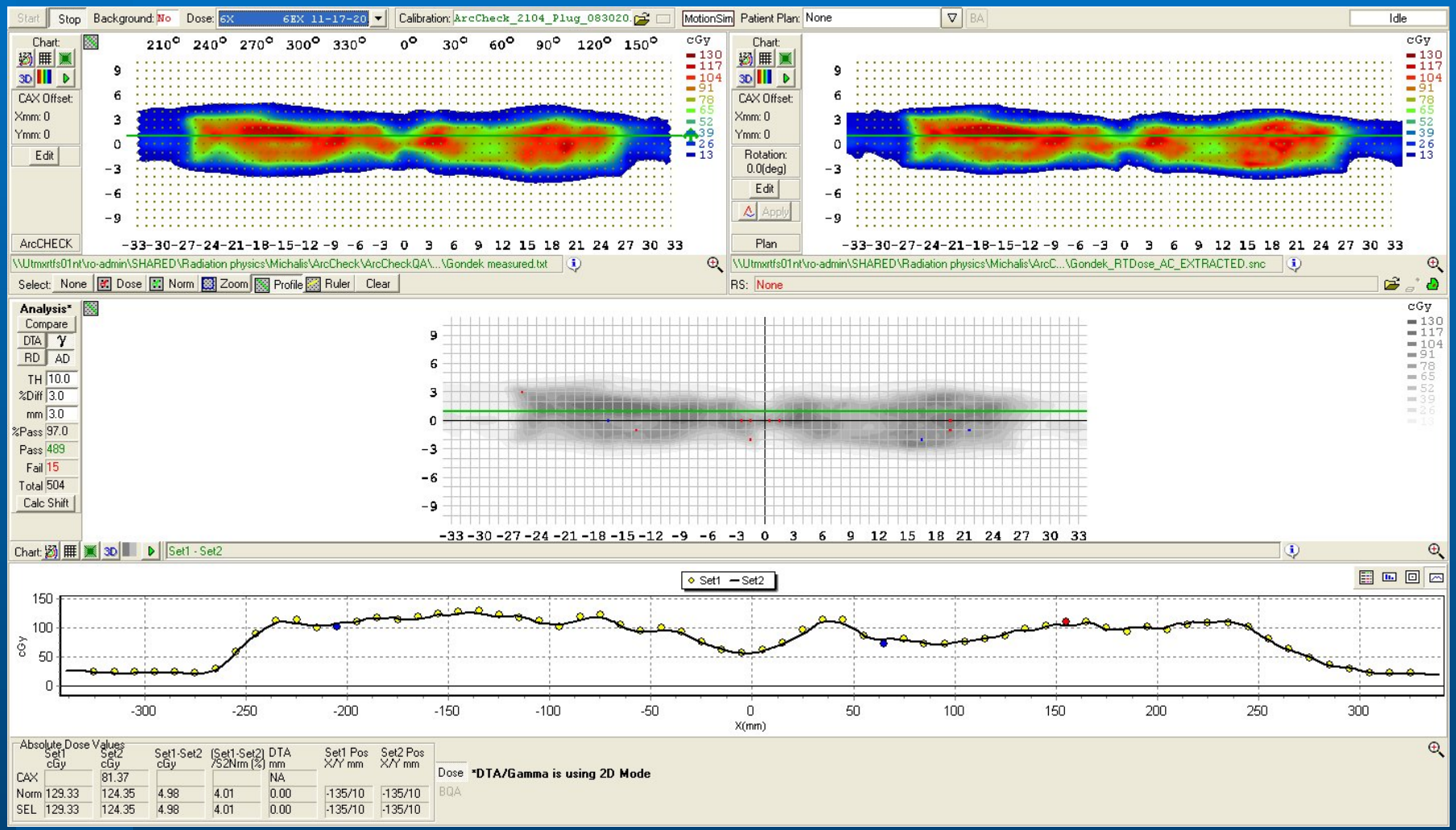


Arc 1 CW



Arc 2 CCW

Composite Distribution Analysis



Result summary – HN IMRT

Date: 10/2/2013 ArcCHECK QA of Dose Distribution Hospital Name: M.D. Anderson Cancer Center

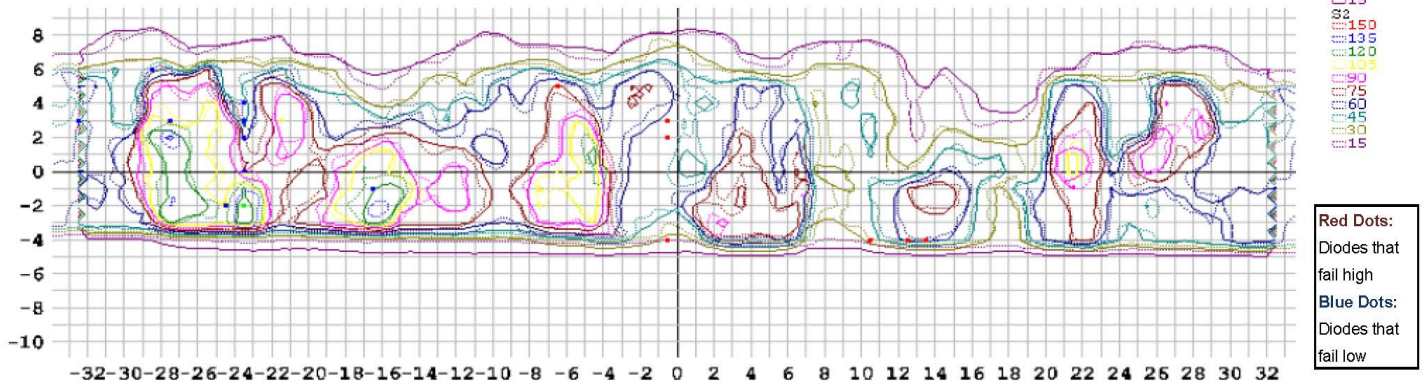
Gamma Overlay Map

Patient Name		QAD	RH	Pinnacle	v9.4
MRN		Linac	ACB3	Energy	6X
Physician	Phan	Service	HN	Date	10/2/2013

Dose Normalization
The ArcCheck is setup isocentrically and aligned to the markers at SSD = 86.7cm.
200 Mus are delivered with a 10 x 10 cm field size
Transfer Factors: 6 MV = 246.7 cGy, 15 MV = 263.9 cGy, 18 MV = 265.1 cGy

Calibration Information
Cal File: RH_ACB3_10-02-2013_86177018.cal
Dose Info: 6X RH_ACB3_10-02-2013

QA Notes
Only doses greater than 10% of the maximum dose included in the analysis



Red Dots: Diodes that fail high
Blue Dots: Diodes that fail low

Cumulative Statistics
Absolute Dose Comparison (Gamma) *using 3D Mode

% Diff	: 3.0
Distance (mm)	: 3.0
Threshold	: 10.0
Meas Uncertainty	: Yes
Dose Diff Thresh	: 0.0
Use VanDyk	: Yes
Total Points	: 766
Passed	: 750
Failed	: 16
% Passed	: 97.9

3% & 3mm Gamma

> 90% Passed?

Set1 File: S:\SHARED\Radiation physics\IMRT\ArcCheck_IMRTQA\10-02-2013\ 9-0_meas.txt
Set2 File: S:\SHARED\Radiation physics\IMRT\ArcCheck_IMRTQA\10-02-2013\Angelen934529-0_DOSE_AC_EXTRACTED.snc

Result summary – GYN IMRT

Date: 10/3/2013 ArcCHECK QA of Dose Distribution Hospital Name: M.D. Anderson Cancer Center

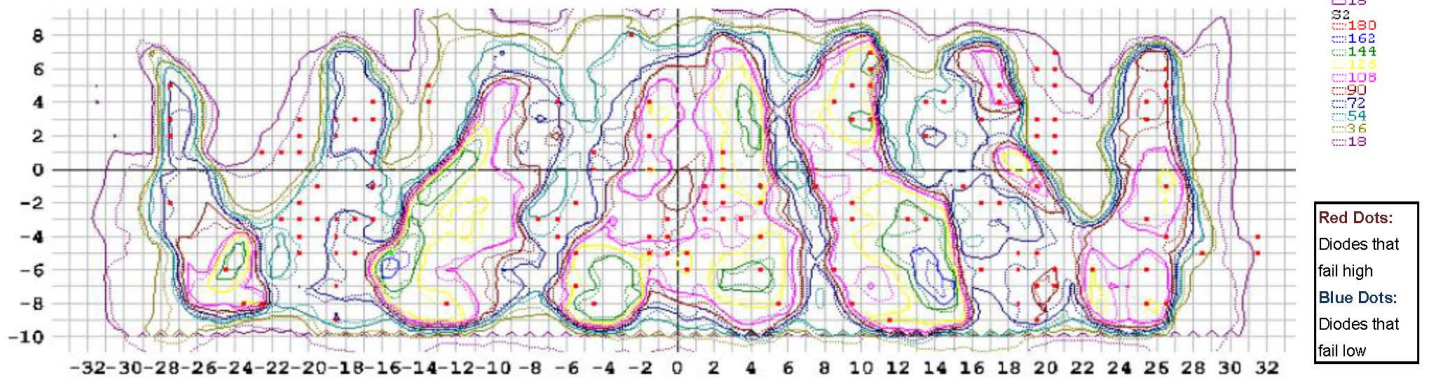
Gamma Overlay Map

Patient Name		**QAD**	RH	**Pinnacle**	v9.4
MRN	1020308	**Linac**	ACB3	**Energy**	6x
Physician	Jhingran	**Service**	GYN	**Date**	10/3/2013

Dose Normalization
The ArcCheck is setup isocentrically and aligned to the markers at SSD = 86.7cm.
200 Mus are delivered with a 10 x 10 cm field size
Transfer Factors: 6 MV = 246.7 cGy, 15 MV = 263.9 cGy, 18 MV = 265.1 cGy

Calibration Information
Cal File: RH_ACB3_10-02-2013_86177018.cal
Dose Info: 6x RH_ACB3_10-03-2013

QA Notes
Only doses greater than 10% of the maximum dose included in the analysis



Red Dots: Diodes that fail high
Blue Dots: Diodes that fail low

Cumulative Statistics

Absolute Dose Comparison (Gamma) *using 3D Mode

% Diff	: 3.0
Distance (mm)	: 3.0
Threshold	: 10.0
Meas Uncertainty	: Yes
Dose Diff Thresh	: 0.0
Use VanDyk	: Yes
Total Points	: 1133
Passed	: 997
Failed	: 136
% Passed	: 88.0

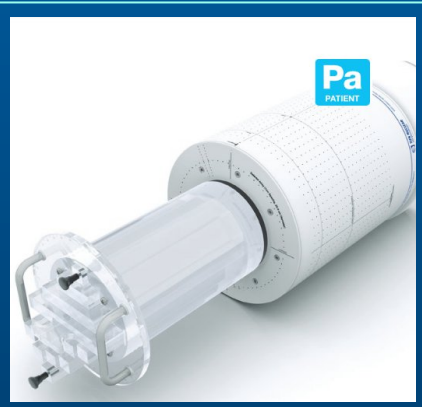
Set1 File: S:\SHARED\Radiation physics\IMRT\ArcCheck_IMRTQA\10-03-2013\ 1020308-1_meas.txt
Set2 File: S:\SHARED\Radiation physics\IMRT\ArcCheck_IMRTQA\10-03-2013\ 1020308-1_DOSE_AC_EXTRACTED.snc

Failed due to very large field sizes?

ArcCheck For IMRT/VMAT QA

- Currently 2 ArcChecks commissioned
- Required comprehensive analysis of reproducibility and sensitivity
- Developed a device QA program to monitor its performance
- Issues
  - Diode Drifting
  - Measurement of peripheral dose
  - Small/Large Fields

Multiplug Insert



Patient Dose Verification for IMRT/VMAT Treatments

- QA tools for patient “pre-treatment” plan check discussed
- In “homogeneous” phantom
- Goal is for “safe” treatment delivery
- TLD in vivo dosimetry per physician request only

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