



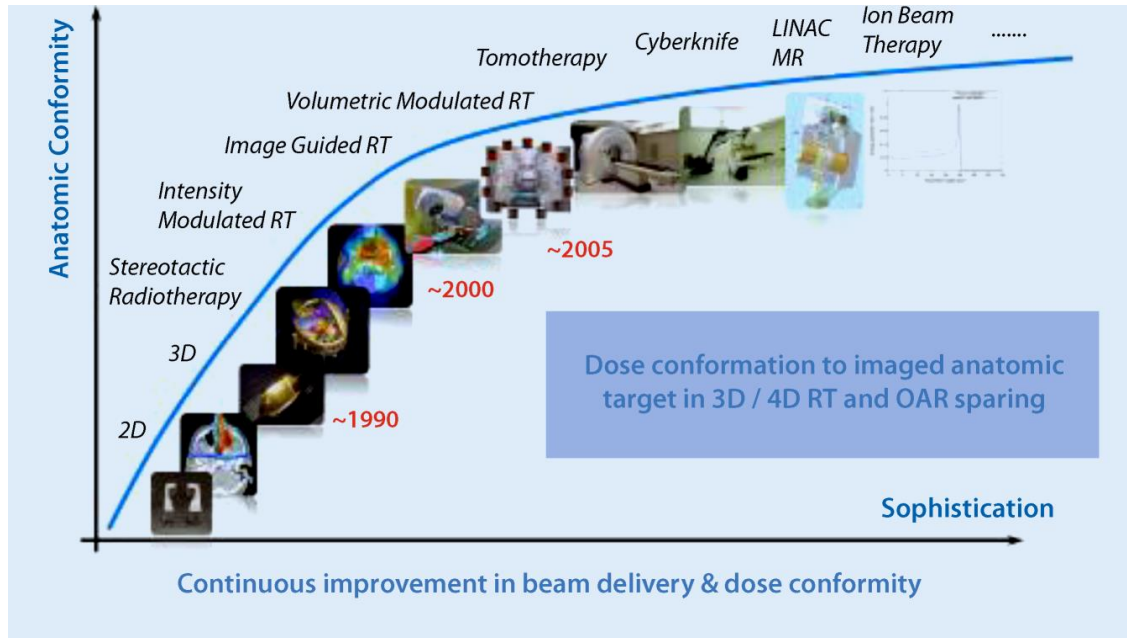
CONNECTING LIFE AND SCIENCE

# Practical Implementation of EPID-based QA for Linac

Baozhou Sun, Ph.D.



# Advancement in Radiation Therapy



- Treatment becomes more and more complex
- It will continue to evolve...  
for example: MR-guided radiotherapy  
Adaptive,  
flash therapy
- More procedures developed to treat patients  
  
More and more QA tests are added to ensure the safe delivery of radiation therapy

# QA Solutions for complex treatments

- **Improve QA efficiency without sacrificing effectiveness**

Need better/less tools;

Need more efficient analysis;

Increased automation;

Reduced human involvement.



## EPIDs as a dosimeter



### EPIDs are the obvious choice

- High resolution diode array
- Large array size
- All modern linacs have them (no third party detectors)
- Easy to standardize the QA process
- Easily deployable (change the detector position)
- Data (images) are readily analysable with digital format

# MPC is a great example

- An integrated QA tool using EPID check many aspects of linac performance
- Disclaimer from MPC document

\*MPC is an addition to the existing QA program of a hospital and must not replace any necessary QA checks.

- Not an independent tool
- Not available for all machines

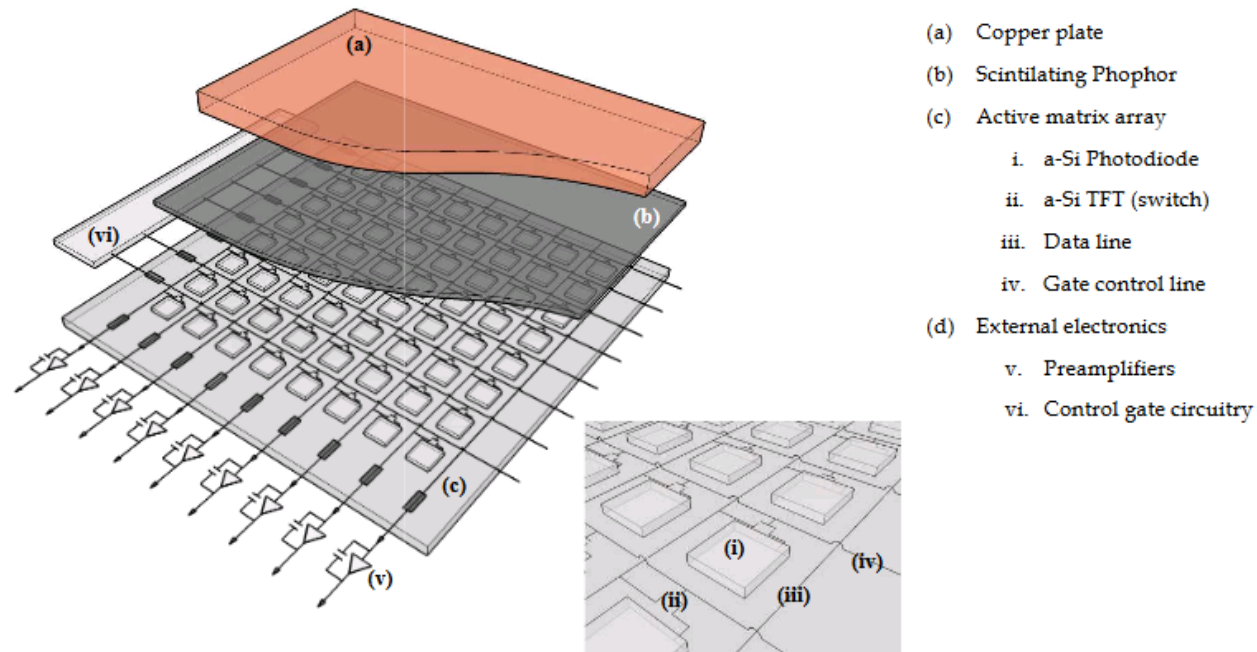


Figure 1: Isocal phantom with known geometry. Multiple MV and kV projections are acquired and automatically analyzed.

It is essential to understand physics, key operational characteristics, and limitations of aSi EPIDs before implementing them for machine QA

# Physics of EPID Technology

The modern EPID technology is based on aSi thin-film transistor semiconductor technology.



# EPID Characteristics

## 1. Resolution

EPID model	Active imaging area (cm <sup>2</sup> )	Pixels in imaging area	Pixel size (mm <sup>2</sup> )
Varian aS1200	43x43	1280x1280	0.34x0.34
Varian aS1000	40x30	1024x768	0.39x0.39
Varian aS500	40x30	512x384	0.78x0.78
Elekta iViewGT	41x41	1024x1024	0.40x0.40
Siemens Optivue 1000	41x41	1024x1024	0.40x0.40
Siemens Optivue 500	41x41	512x512	0.80x0.80

# EPID Characteristics

## 2. Acquisition modes

- Integrated (Dosimetry) mode:

Image frames are collected throughout the beam delivery, but only a single integrated (ie. summed) image is returned or reported at the end of the irradiation.

- Cine (Movie) mode:

Frames are collected throughout the beam delivery, but images are returned or reported at a frequency defined by the user.

# EPID Characteristics

## 3. Long Term Stability

aSi-based EPIDs show a large resistance to radiation damage

[Australas Phys Eng Sci Med](#). 2011 Dec;34(4):459-66. doi: 10.1007/s13246-011-0106-0. Epub 2011 Oct 27.

**Long-term two-dimensional pixel stability of EPIDs used for regular linear accelerator quality assurance.**

[King BW](#)<sup>1</sup>, [Clews L](#), [Greer PB](#).

⊕ **Author information**

### Abstract

The long-term stability of three clinical electronic portal imaging devices (EPIDs) was studied to determine if longer times between calibrations can be justified. This would make alternatives to flood-field calibration of EPIDs clinically feasible, allowing for more effective use of EPIDs for dosimetry. Images were acquired monthly for each EPID as part of regular clinical quality assurance over a time period of approximately 3 years. The images were analysed to determine (1) the long-term stability of the EPID positioning system, (2) the dose response of the central pixels and (3) the long term stability of each pixel in the imager. The position of the EPID was found to be very repeatable with variations less than 0.3 pixels (0.27 mm) for all imagers (1 standard deviation). [The central axis dose response was found to reliably track ion chamber measurements to better than 0.5%. The mean variation in pixel response \(1 standard deviation\), averaged over all pixels in the EPID, was found to be at most 0.6% for the three EPIDs studied over the entire period.](#) More than 99% of pixels in each EPID showed less than 1% variation. Since the EPID response was found to be very stable over long periods of time, an annual calibration should be sufficient in most cases. More complex dosimetric calibrations should be clinically feasible.

[Med Phys](#). 2004 Nov;31(11):2989-95.

**The long-term stability of amorphous silicon flat panel imaging devices for dosimetry purposes.**

[Louwe RJ](#)<sup>1</sup>, [McDermott LN](#), [Sonke JJ](#), [Tielenburg R](#), [Wendling M](#), [van Herk MB](#), [Mijnheer BJ](#).

⊕ **Author information**

### Abstract

This study was carried out to determine the stability of the response of amorphous silicon (a-Si)-flat panel imagers for dosimetry applications. Measurements of the imager's response under reference conditions were performed on a regular basis for four detectors of the same manufacturer. We found that the ambient temperature influenced the dark-field, while the gain of the imager signal was unaffected. Therefore, temperature fluctuations were corrected for by applying a "dynamic" darkfield correction. This correction method also removed the influence of a small, irreversible increase of the dark-field current, which was equal to 0.5% of the dynamic range of the imager per year and was probably caused by mild radiation damage to the a-Si array. [By applying a dynamic dark-field correction, excellent stability of the response over the entire panel of all imagers of 0.5% \(1 SD\) was obtained over an observation period up to 23 months.](#) However, two imagers had to be replaced after several months. For one imager, an image segment stopped functioning, while the image quality of the other imager degraded significantly. We conclude that the tested a-Si EPIDs have a very stable response and are therefore well suited for dosimetry. We recommend, however, applying quality assurance tests dedicated to both imaging and dosimetry.

# EPID Characteristics

## 4. Linearity with dose and dose rate

- aSi EPIDs display a mostly linear response
- There are small non-linearities at low doses due to image lag, ghosting, and frame drop.
- Very high dose rates (e.g. FFF beams) can saturate the panels.
- Newer panel (aSi 1200) panel works for a higher dose rate.

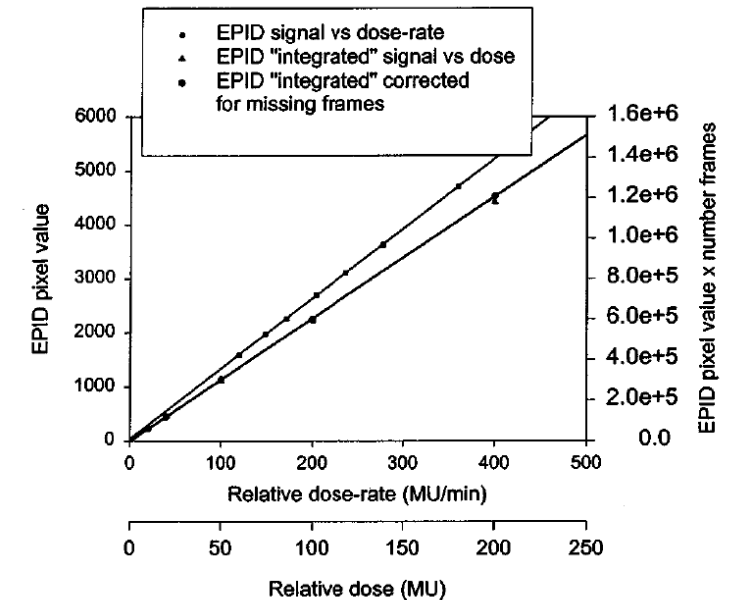
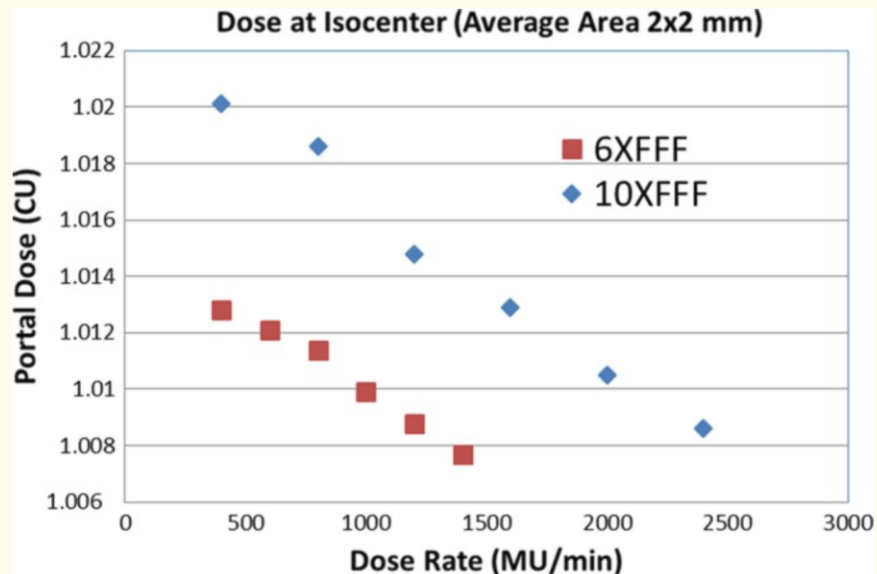


FIG. 2. Linearity of the EPID with dose rate and integrated dose. The dose rate to the EPID was varied by varying the source to detector distance. Ion-chamber readings were recorded at each EPID position in a mini-phantom to determine the relative dose rate. The relative dose rate is expressed in MU/min assuming a nominal output of 400 MU/min at 100 cm from the source. A measurement of integrated dose was obtained by multiplication of the image pixel values by the number of frames averaged, with and without correction for dead time in image acquisition. These were also compared to ion-chamber readings.

Ref. Greer and Popescu, 2003

# EPID Characteristics

Varian's DMI panel (aS1200) with faster read out electronics



[Figure 6](#)

Central portal doses as a function of dose rate for 100 MU and  $20 \times 20 \text{ cm}^2$  field size.

The linearity of the DMI detector response was better than 0.5% in the range of 20–500 MU for all energies. The residual image was extremely small and statistically undetectable.

Xu, 2018, JACMP

# EPID Characteristics

## 5. Energy dependence

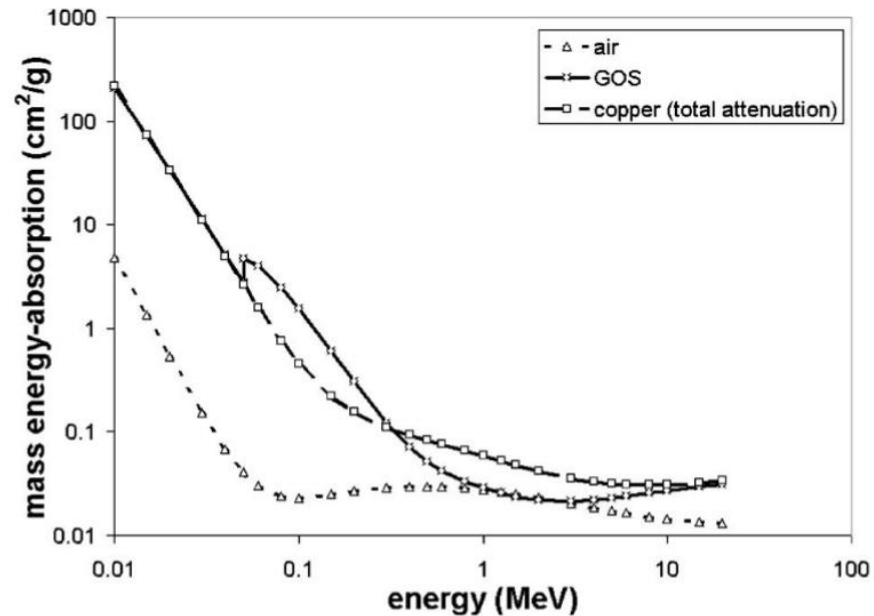


FIG. 3. Mass energy-absorption coefficients plotted as a function of photon energy for  $\text{Gd}_2\text{O}_2\text{S}$  (GOS) and air (Ref. 20). Air, the absorbing material of an ion chamber, has a reasonably uniform coefficient from 0.1 to 20 MeV. GOS, however, has a distinct rise below  $\sim 0.5$  MeV. The total attenuation coefficient for Cu has also been plotted to indicate the relative proportion of photons of a given energy that would interact in a Cu plate placed upstream from the phosphor.

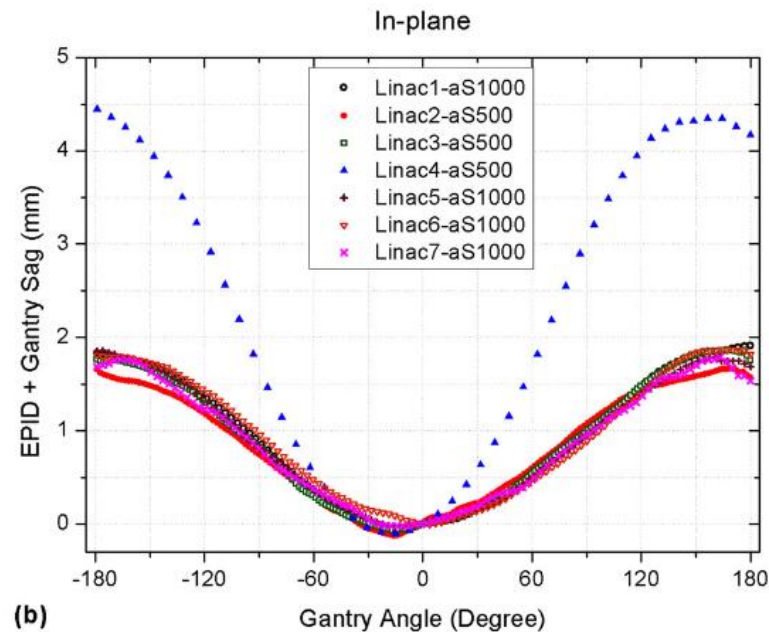
High atomic number ( $\text{Gd}_2\text{O}_2\text{S}$  and Cu) used in EPID over-response to low energy photos.

It is not a water-equivalent detector

Ref. Kirkby and Sloboda 2005

# EPID Characteristics

## 6. Mechanical Stability



- The EPID can sag can shift during gantry motion
- Gantry sag also comes into play
- New panel has much better accuracy

Ref. Rowshangarzar, et al, 2012

# EPID Characteristics: limitations

## Ghost effect and image lag

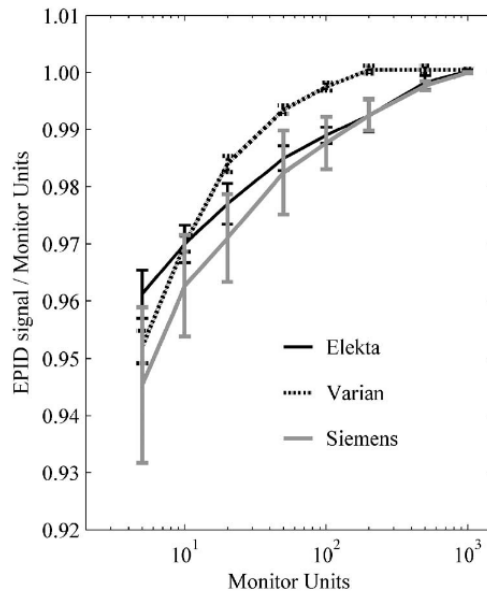


FIG. 1. Signal-to-MU ratios for Elekta, Varian, and Siemens *a*-Si EPIDs, averaged over two to three dose-rate settings for different energies, with one or two detectors for each brand. All points are normalized at 1000 MUs. One outlying series, Varian A, used a different acquisition mode and was therefore excluded for this figure. The standard deviations at each point were less than 1.4%, and are shown as error bars ( $\pm 1$  SD). Different scintillators employed by different brands will exhibit slight variation in ghosting effects, however there is a consistent under-response for fields of fewer MUs for all three brands.

Image lag is a residual signal present in image frames subsequent to the frame in which the residual signal was generated.

Ghosting refers to the change of detector pixel sensitivity (to X-rays) because of previous exposures of the detector.

Ref. McDermott, et al, 2006

# EPID Characteristics: limitations

## Backscatter from supporting arm

*Med Phys.* 2010 May;37(5):2269-78.

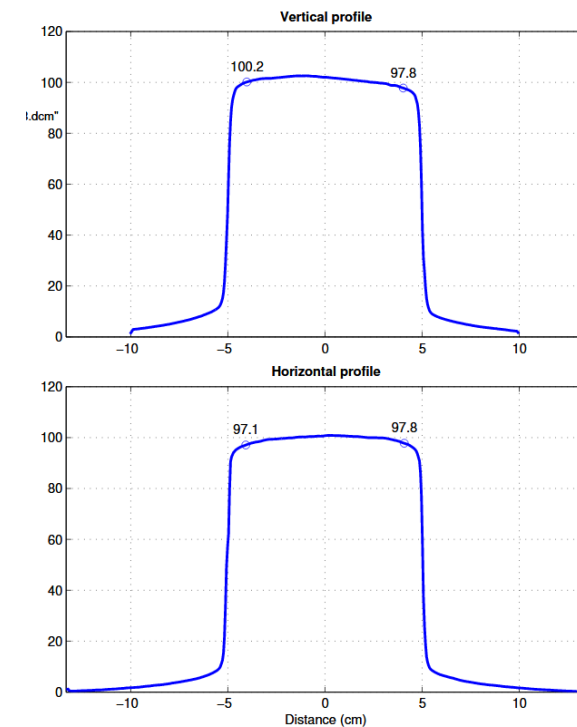
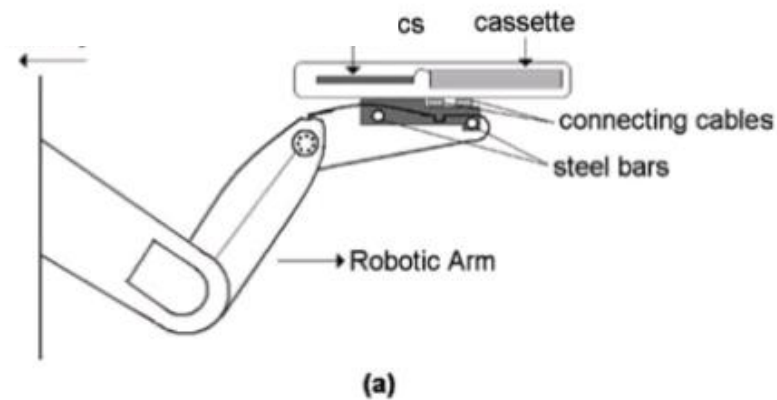
**Measurement and modeling of the effect of support arm backscatter on dosimetry with a varian EPID.**

Rowshanfarzad P<sup>1</sup>, McCurdy BM, Sabet M, Lee C, O'Connor DJ, Greer PB.

### Author information

### Abstract

**PURPOSE:** Amorphous silicon EPIDs have been used for planar dose verification in IMRT treatments for many years. The support arm used to attach some types of EPIDs to linear accelerators can introduce inaccuracies to dosimetry measurements due to the presence of metallic parts in their structures. **It is demonstrated that this uncertainty may be as large as approximately 6% of maximum image signal for large fields.** In this study, a method has been described to quantify, model and correct for the effect of backscattered radiation from the EPID support arm (E-Arm type, Varian Medical Systems).



# EPID Calibration

## 1. Conventional calibration

- “Dark field” calibration
- “Flood field” or gain calibration (assume uniform field)
- “Profile” correction
- “bad pixel corrections.

## 2. Pixel-sensitivity Map

- Calculate the relative gain correction for each pixel
- Independent of beam profile
- Changes in the beam profile of a treatment unit are visible on the acquired images.
- It is used often for beam energy check

# PSM Calibration

$$I(i,j) = F(i,j) \times G(i,j) \quad (1)$$

For the center image,

$$I_C(i,j) = F_C(i,j) \times G(i,j) \quad (2)$$

For the right image with a 10 pixel shift,

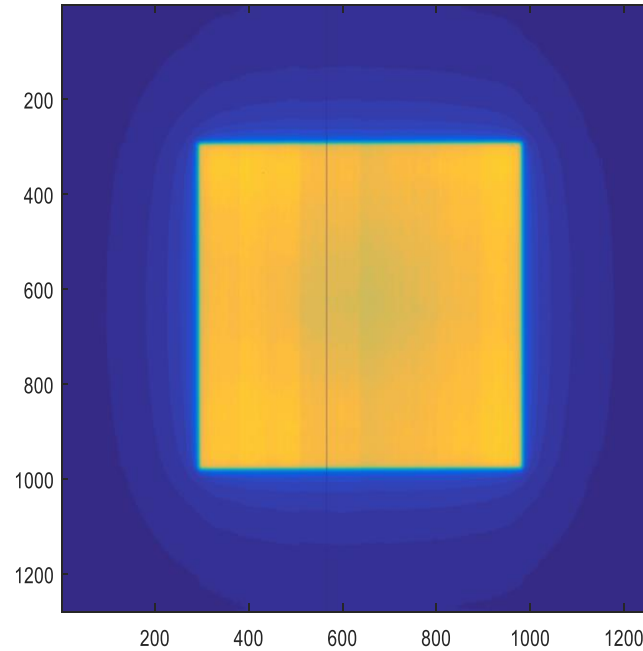
$$I_R(i+10,j) = F_R(i+10,j) \times G(i+10,j). \quad (3)$$

Assuming that the averaged fluence delivered from the machine does not change, then

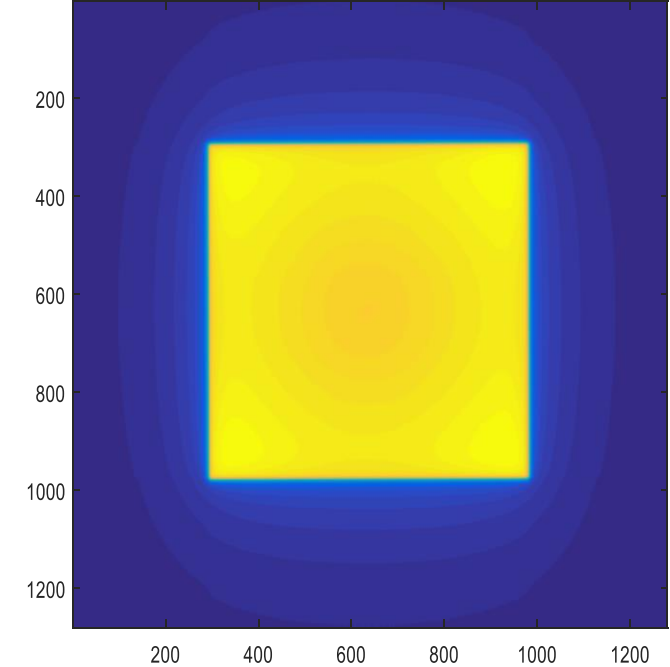
$$F_C(i,j) = F_R(i+10,j) \quad (4)$$

By applying eq. 4 to eqs. 2 and 3,

$$G(i+10,j) = \frac{I_R(i+10,j)}{I_C(i,j)} \times G(i,j) \quad (5)$$

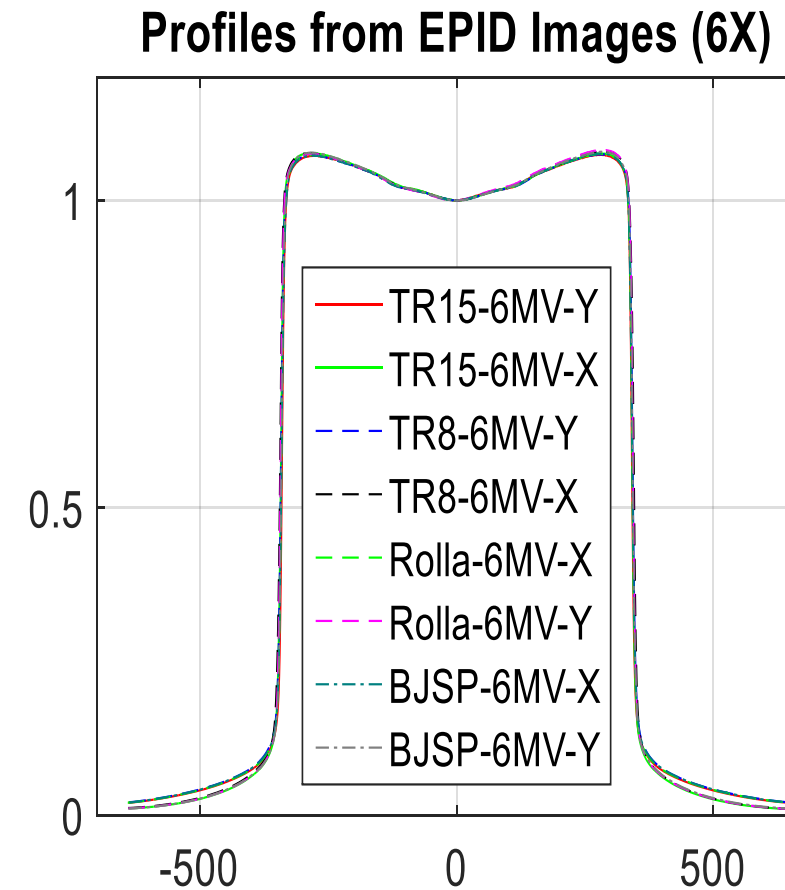
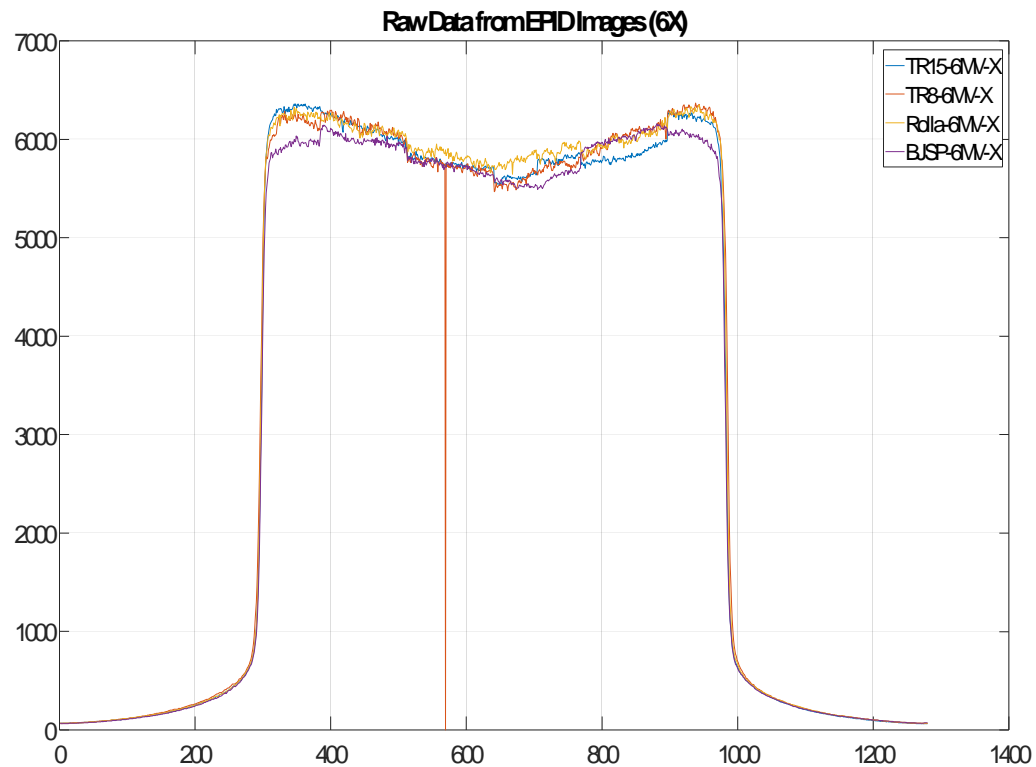


Uncorrected Image



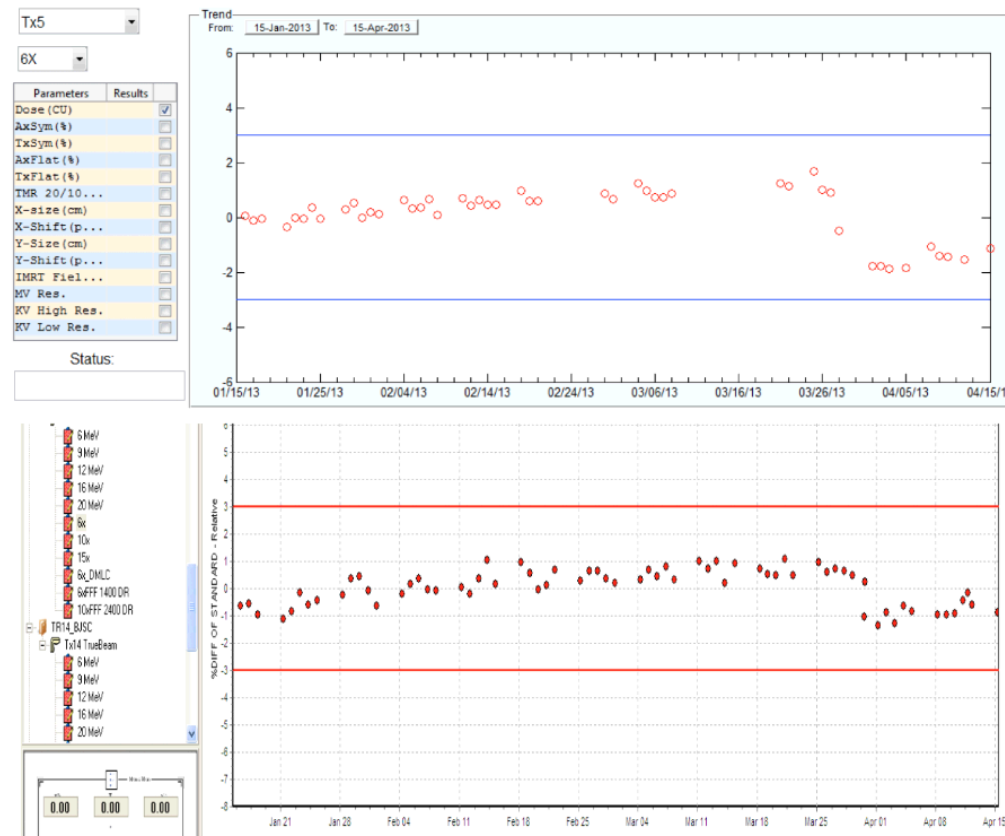
PSM Corrected Image

# PSM Calibration



# What EPID can do?

## 1. Output constancy check



Sun, et al, 2015

# What EPID can do?

## 2. Profile constancy

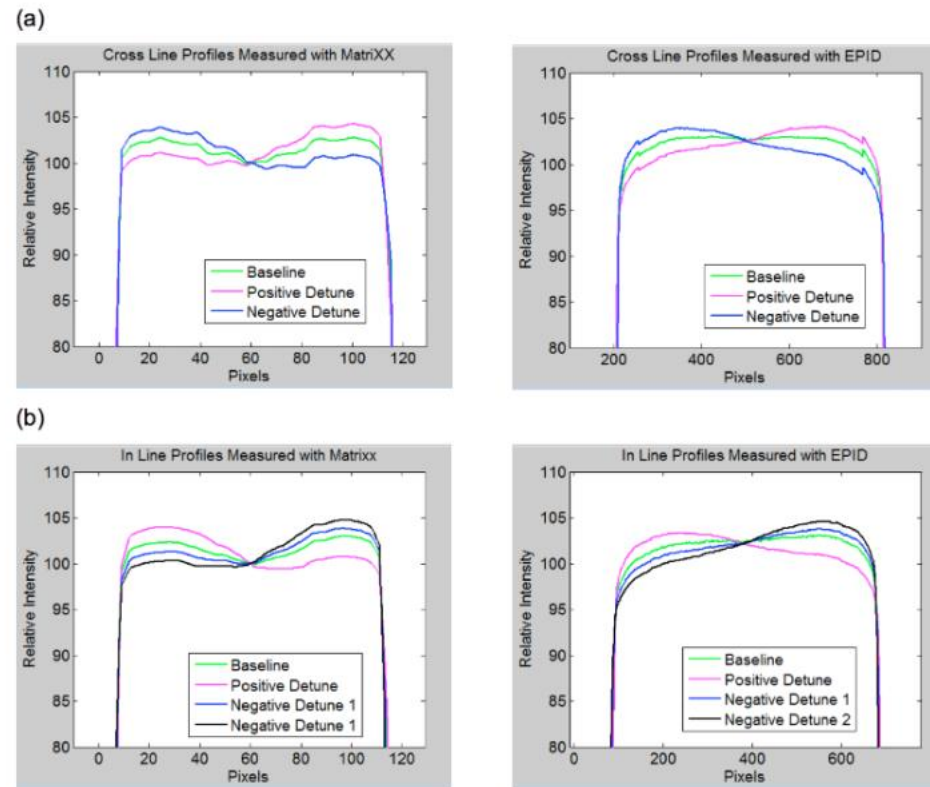


FIG. 4. Comparison of beam profile measurements with EPID and MatriXX. (a) shows the crossline profile comparison when the beam was detuned by  $\pm 3\%$ . (b) shows the inline profile comparison when the beam was detuned by  $+3\%$ ,  $-2\%$ , and  $4\%$ .

Sun, et al, 2015

# What EPID can do?

## 3. Jaw Position

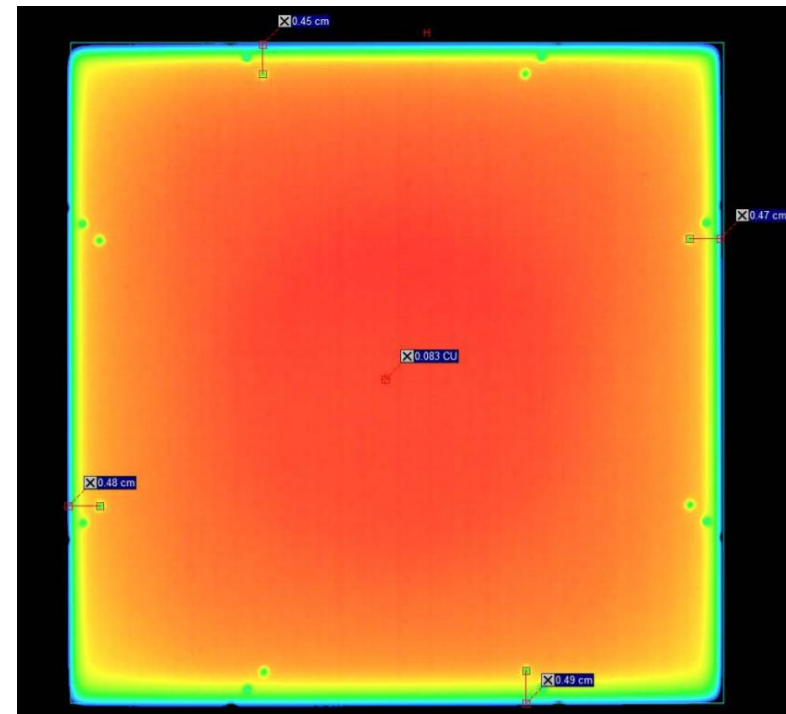
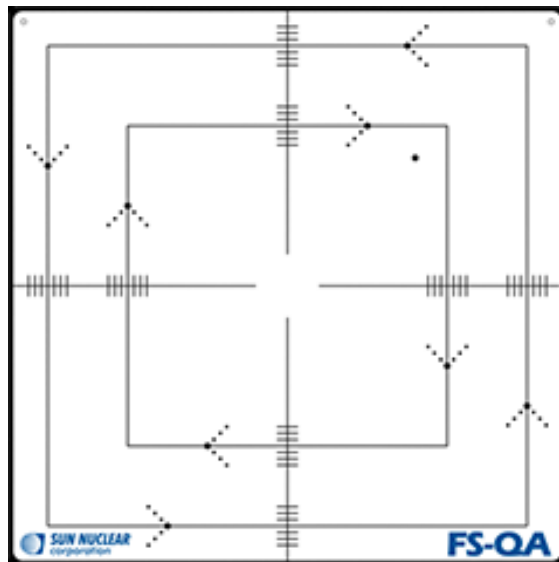
TABLE II. Field size tested with EPID and comparison with the jaw settings.

Field size setting (cm)		EPID (cm)	
X jaw	Deviation	X jaw	Deviation
22.0	—	22.10	—
22.1	0.10	22.18	0.08
21.9	-0.10	22.00	-0.10
Y jaw	Deviation	Y jaw	Deviation
22.0	—	22.05	—
22.2	0.20	22.25	0.20
21.8	-0.20	21.85	-0.20

Sun, et al, 2015

# What EPID can do?

## 4. Light/Radiation Coincidence



# What EPID can do?

## 5. MLC positioning and MLC speed

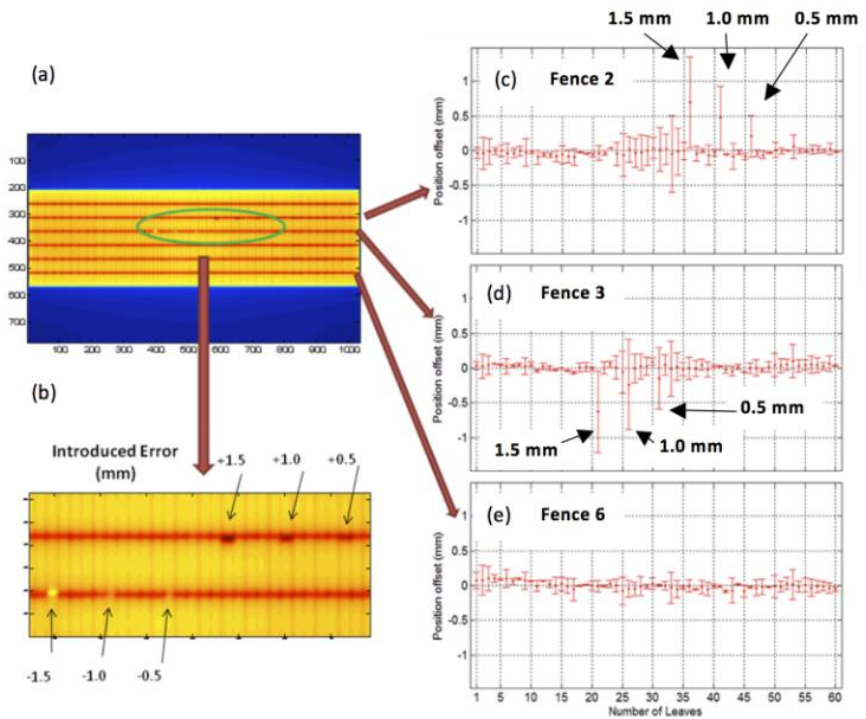


FIG. 5. The graphs automatically produced by the algorithm for the PF test analysis including  $\pm 1.5$ ,  $\pm 1.0$ , and  $\pm 0.5$  mm intentional errors. (a) EPID image (b) enlarged portion for visually view of intentional errors. (c)–(e) Peak positions of A bank and B bank leaf in fence 2, 3, and 6, respectively. Upper boundary corresponds to the A bank leaf position and lower boundary corresponds to the B bank leaf. The middle dot represents the central location of Gaussian fitting.

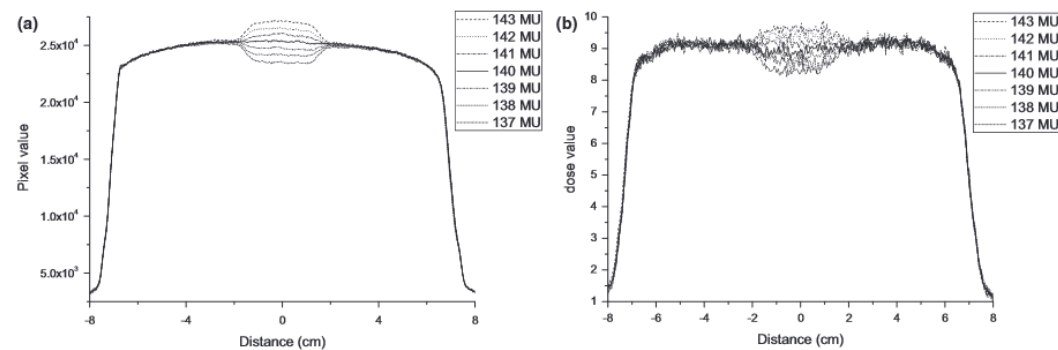
Sun, et al, 2015

# What EPID can do?

## 5. MLC Speed

**TABLE 7** The statistical results of leaf speed for the three MLC types measured by EPID and EBT3 film, using one leaf pair as an example. The averages of the speed profiles are presented with  $\pm 2$  SD.

	Millennium		MLCi		Agility	
	EPID	EBT3	EPID	EBT3	EPID	EBT3
$0.50 \text{ cm s}^{-1}$	$0.50 \pm 0.01$	$0.49 \pm 0.02$	$0.50 \pm 0.01$	$0.51 \pm 0.02$	$0.50 \pm 0.00$	$0.50 \pm 0.02$
$1.00 \text{ cm s}^{-1}$	$1.01 \pm 0.02$	$1.00 \pm 0.03$	$1.00 \pm 0.02$	$1.01 \pm 0.05$	$1.01 \pm 0.01$	$1.00 \pm 0.05$
$1.51 \text{ cm s}^{-1}$			$1.52 \pm 0.02$	$1.53 \pm 0.07$		
$1.91 \text{ cm s}^{-1}$			$1.93 \pm 0.04$	$1.93 \pm 0.11$		
$2.00 \text{ cm s}^{-1}$	$2.02 \pm 0.04$	$1.99 \pm 0.07$				
$2.50 \text{ cm s}^{-1}$					$2.52 \pm 0.05$	$2.53 \pm 0.14$
$2.98 \text{ cm s}^{-1}$	$2.97 \pm 0.05$	$2.94 \pm 0.12$				
$3.46 \text{ cm s}^{-1}$					$3.47 \pm 0.10$	$3.41 \pm 0.18$

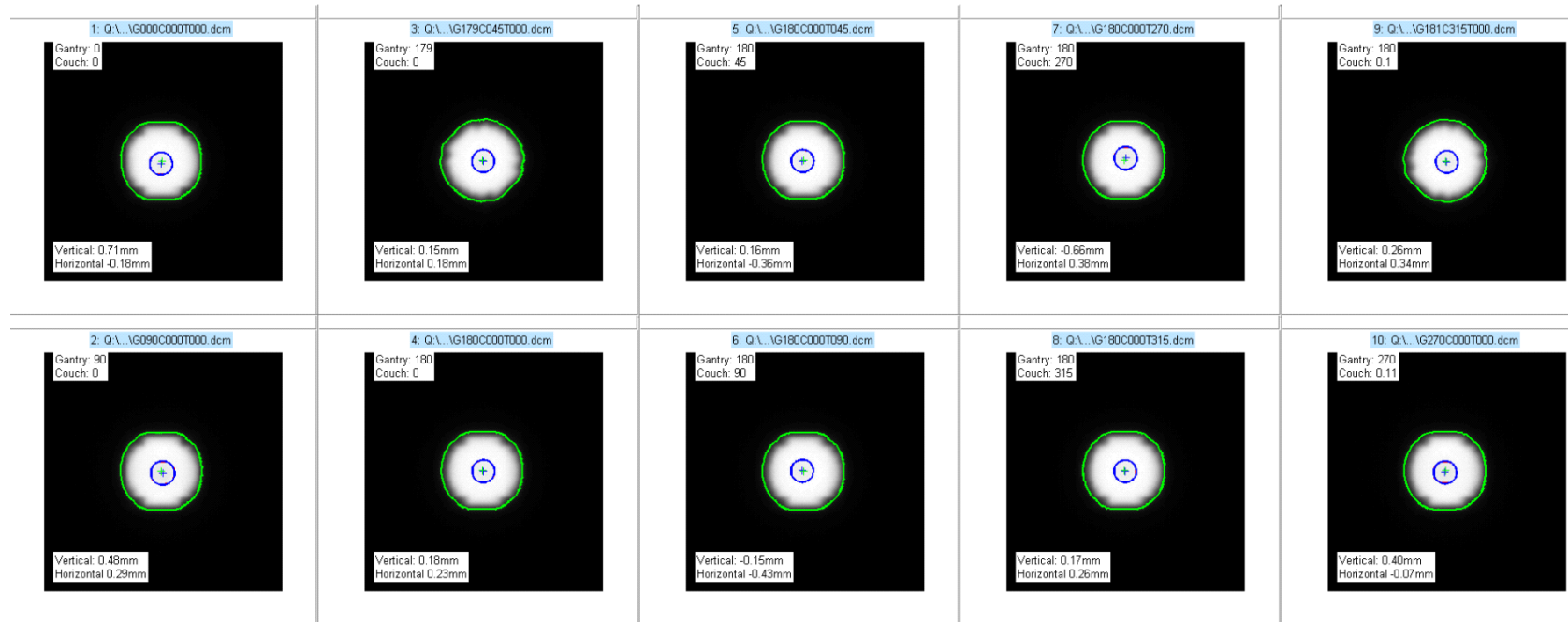
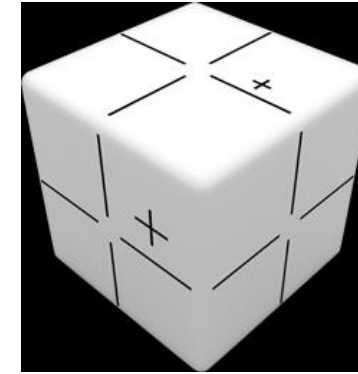


**FIG. 6.** The sliding profiles for Trilogy at the normal leaf speed and introduced leaf speed difference measured by EPID and EBT3 film. (a) EPID, (b) EBT3 film.

Yinghui Li, et al, 2017

# What EPID can do?

## 6. Isocentricity check



# What EPID can do?

## 7. Co-incident of kV and MV isocenter

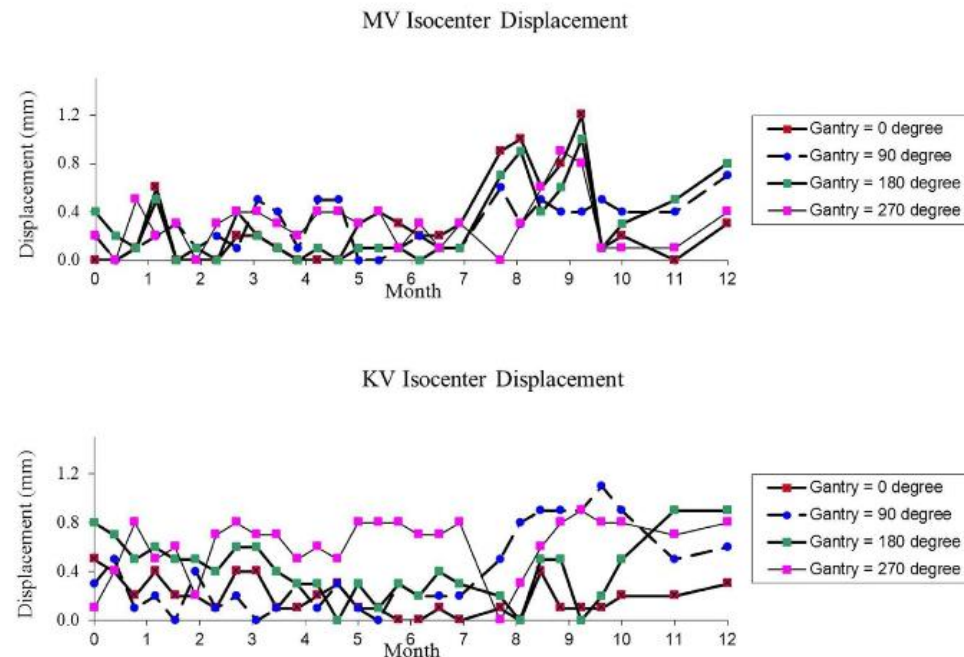
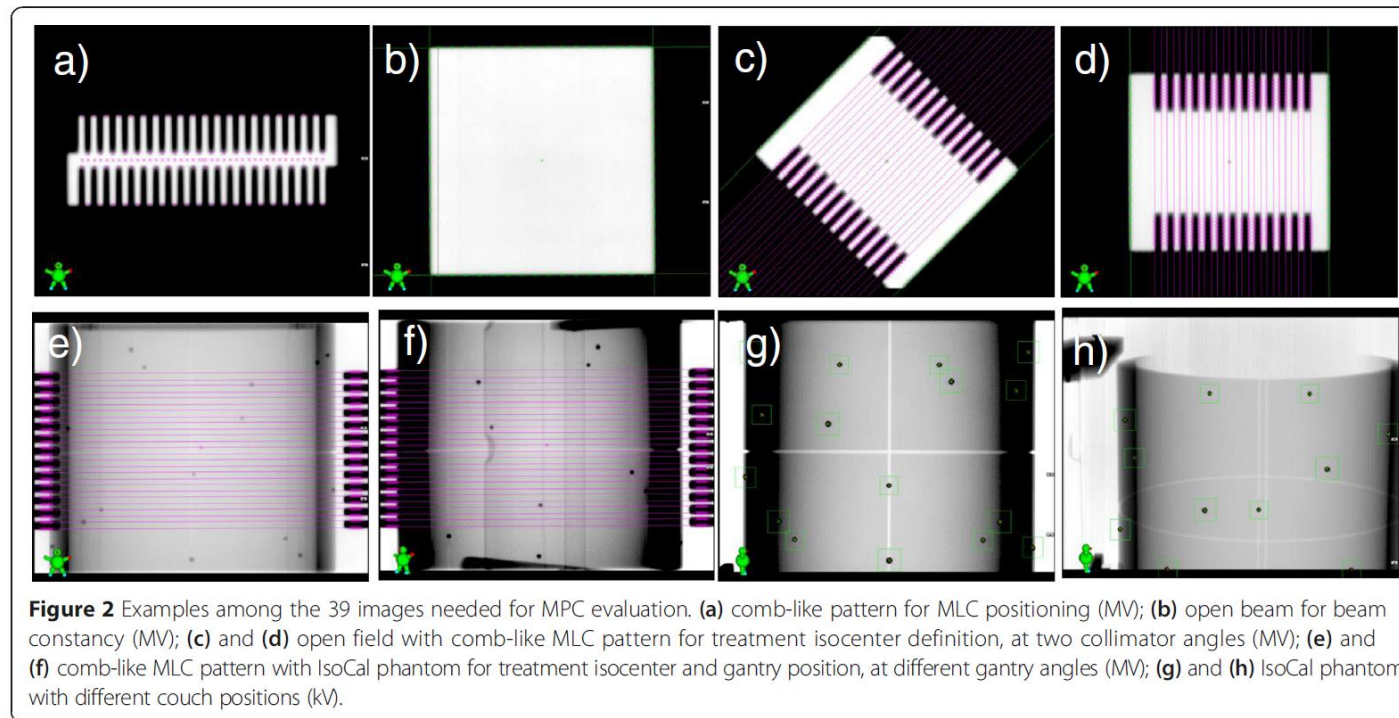


Fig. 9. Results of the 29 measurements of the QA of Imaging & Treatment Coordinate Coincidence over a period of 12 months: MV PV imaging isocenter accuracy (top) and KV OBI imaging isocenter accuracy (bottom). The vector displacement was measured between the center of the digital graticule and the center marker in the image.

Chang, et al, 2012

# What EPID can do?

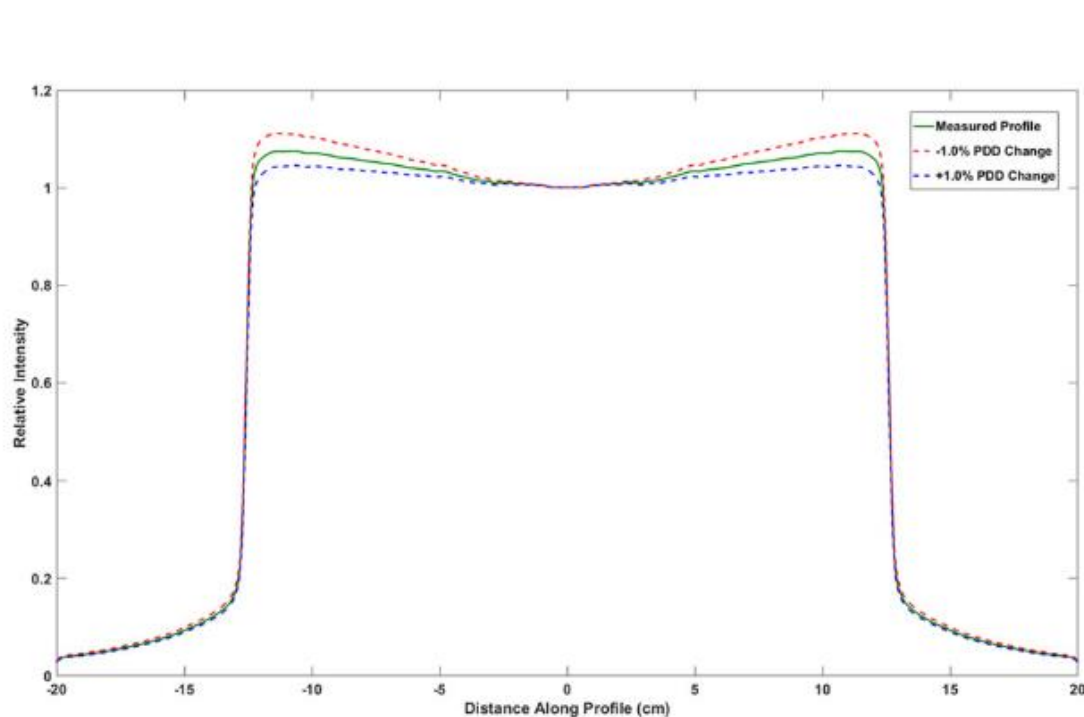
## 8. Mechanical tests on gantry, collimator and couch positioning and rotation accuracy



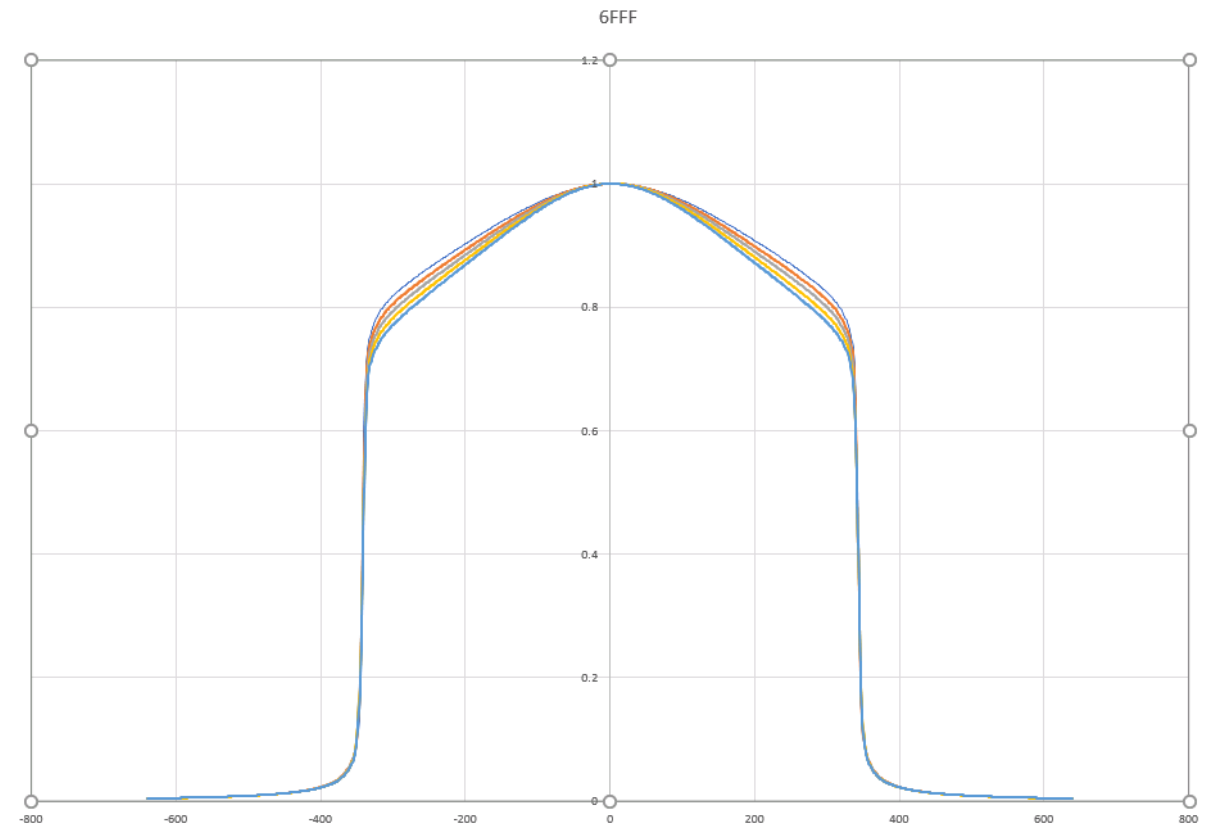
Clivio et al. Radiation Oncology (2015)

# What EPID can do?

## 9. Beam energy (photons) – PSM Calibration

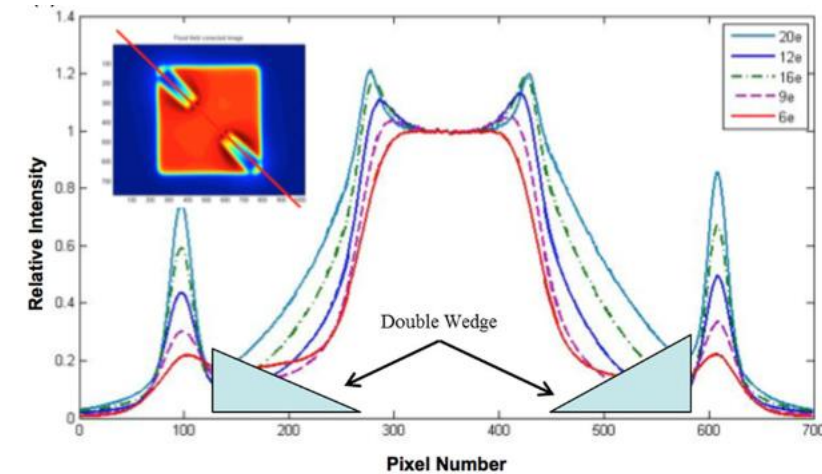
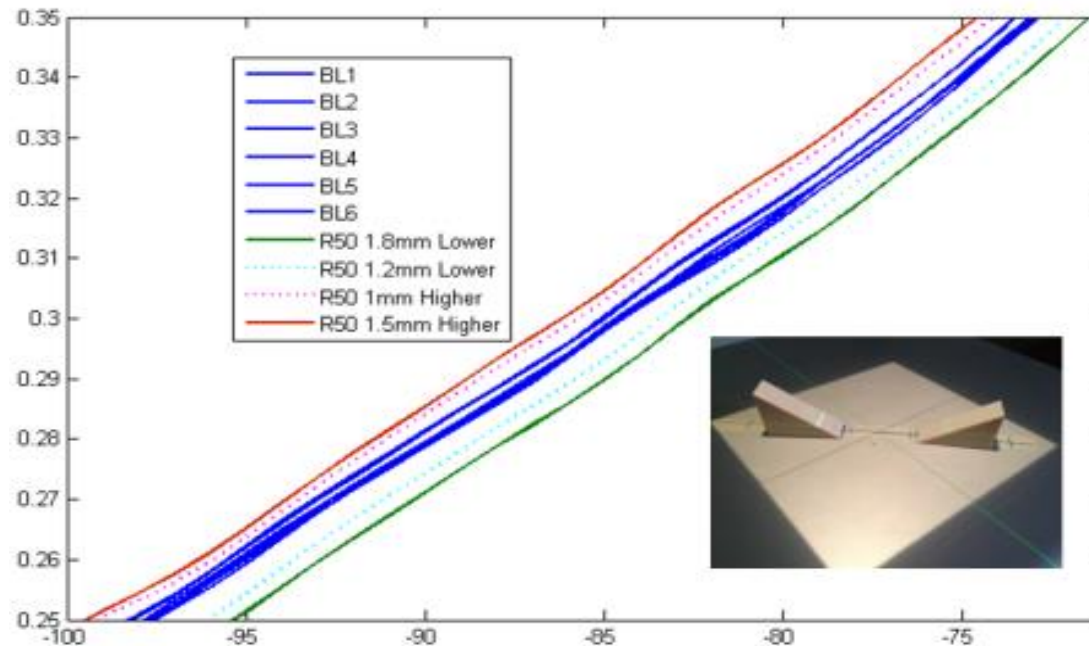


Yaddanapudi et al. 2017



# What EPID can do?

## 9. Beam energy (electrons)—PSM Calibration



Shift of PDI curve obtained from 20 MeV EPID images with electron beam energy changed.

B Cai, et al. 2017

# Example of EPID based QA tools

## Cloud-based linac daily QA tool using EPID

- Fully automated;
- Customizable to unique QA tests;
- No software to be installed;
- Highly efficient: daily QA can be performed ~10 minutes

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### Daily QA of linear accelerators using only EPID and OBI

Baozhou Sun, S. Murty Goddu, Sridhar Yaddanapudi, Camille Noel, Hua Li, Bin Cai, James Kavanaugh, Sasa Mutic

First published: 08 September 2015 | <https://doi.org/10.1118/1.4929550> | Cited by: 16

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 SECTIONS

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# Examples of EPID based QA tools

## Cloud-based linac daily QA tool using EPID

The screenshot displays the EpidQA.com web application. The header includes the site name and navigation links for Users, Facilities, Machines, Help, Hello Caleb!, and Log off. The main content area features a large image of a linear accelerator (linac) machine. To the left of the image, the text 'Epid QA' is displayed, followed by three blue links: 'Record Daily QA >>', 'View a Daily QA >>', and 'View Trend Chart >>'. Below the main content, there are four panels: 'What would you like to do?' with a list of actions like 'Create a new QA?', 'View a QA?', 'View trend chart?', 'Create/Edit a Machine', and 'Create/Edit a Facility'; 'Facilities' with a list including 'BJH', 'BJSC', and 'Coxhealth'; 'Beam Config' with sub-sections for 'BJH' (listing BJH\_TR5, BJH\_TR7, EdgeTR8) and 'BJSC' (listing BJH\_TR4); and 'Alerts' with a list of messages such as 'TrueBeam4\_1561 6x IMRT SW Needs configuration settings' and 'TrueBeam1\_2368 18x Open Needs a match file uploaded'. The footer contains the copyright notice '© 2019 Washington University School of Medicine' and a 'Screenpresso.com' watermark.

## EPID Daily QA

Date of QA: 2/21/2020  
 Approved By: Pryser, Eleanor  
 Approval Date: 2/21/2020

Institution: Washington University School of Medicine  
 Facility: BJH  
 Machine: BJH\_TR5  
 Created By: TR5, BJH

### Dosimetric and Geometric Test

Energy	Baseline output (cGy/MU)	MV Dose	Axial Flatness	Cross Flatness	Axial Symmetry	Cross Symmetry	Uniformity	X - Size	Y - Size
Tolerance		± 3 %	± 3 %	± 3 %	± 3 %	± 3 %	± 1.5 %	± 2 mm	± 2 mm
6x Open	1.00	-0.49	0.22	-0.11	0.35	-0.16	0.33	0.00	-0.36
6x FFF Open	1.00	-0.71	0.00	0.01	0.25	0.06	0.15	0.00	0.00
10x Open	1.00	-0.76	-0.01	0.01	0.07	0.07	0.17	0.00	0.00
10x FFF Open	1.00	-0.79	-0.10	0.00	-0.22	-0.15	0.15	0.00	0.00
15x Open	1.00	-0.75	0.07	0.00	0.02	0.02	0.07	0.00	0.00

[View Trend Chart](#)

### Gamma

	Tolerance Min %	Tolerance Warn %	Calculated
SW-IMRT % Passed	90	95	94.10
SS-IMRT % Passed	90	95	100.00

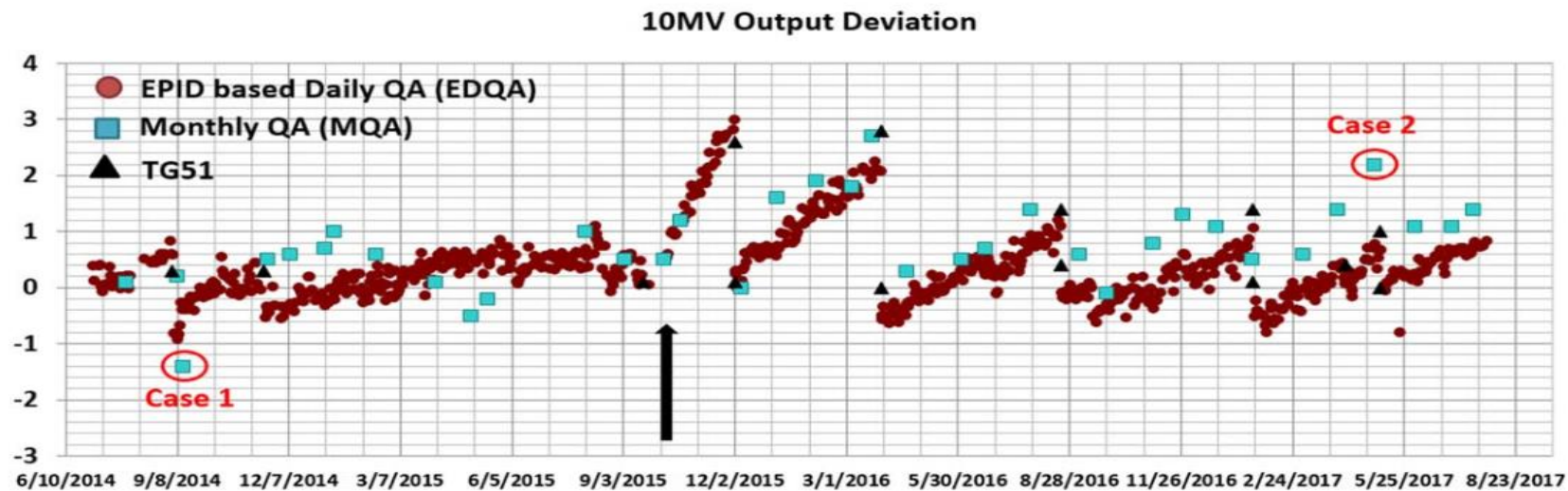
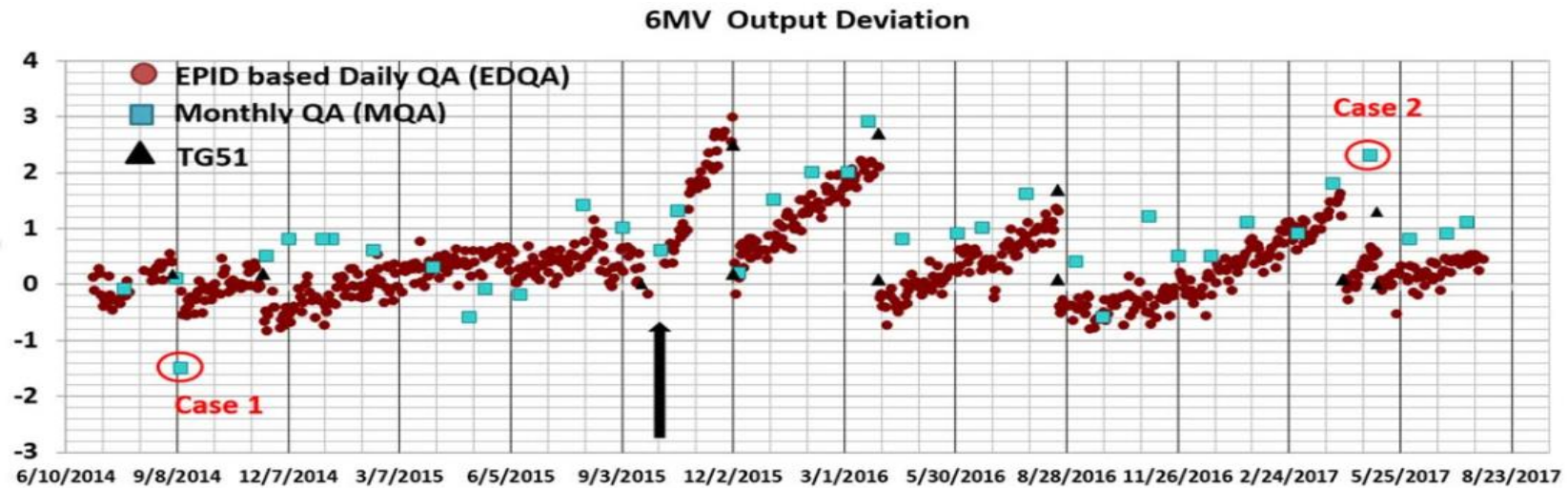
### Daily Constancy QA

Question	Answer
Water Level	<input checked="" type="radio"/> Normal <input type="radio"/> Low
Water Pressure	<input type="text" value="49"/>
Water Temperature	<input type="text" value="40"/>
Gas Pressure	<input type="text" value="30.8"/>
	Satisfactory?
Door Interlock	<input checked="" type="radio"/> Y <input type="radio"/> N <input type="radio"/> N/a
Video	<input checked="" type="radio"/> Y <input type="radio"/> N <input type="radio"/> N/a

### Daily OBI QA

	Expected	Observed	Difference	Tolerance	Satisfactory
Positional Verification: EPID at P5					
	<input type="text" value="-50"/>	<input type="text" value="-50"/>	<input type="text" value="0.00"/>	<input type="text" value="0.1"/>	
Pendant Readout	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0.00"/>	<input type="text" value="0.1"/>	<input checked="" type="radio"/> Y <input type="radio"/> N <input type="radio"/> N/a
	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0.00"/>	<input type="text" value="0.1"/>	
ODI on EPID	<input type="text" value="144"/>	<input type="text" value="144"/>	<input type="text" value="0.00"/>	<input type="text" value="0.5"/>	<input checked="" type="radio"/> Y <input type="radio"/> N <input type="radio"/> N/a
2D-2D Match Accuracy					

# Long-term Data of EPID-based Daily QA



# Validation of EPID-based QA tools

For commercial QA tools used for linac QA

1. Vendor should provide comprehensive documentation describing the system design algorithm, and theory of operation, and QA procedures.
2. The vendor should provide training for users. The training should include how to set appropriate action limits.

# Validation of EPID-based QA tools

## Physicist role:

1. Understand system design, theory of operation and calculation algorithm
2. Complete formal acceptance testing prior to use of an EPID QA system: end-to-end test.
3. Benchmark for new tools (including in-house tools), a second set of tools with a standard phantom system and software should be compared.
4. Sensitivity tests (by detuning beam parameters and make sure your QA tools can detect the deviations)

# Summary and Take-home messages

- EPID characteristics depend the EPID model; Understand the characteristics and limitations of your EPIDs
- EPIDs are be used for acceptance tests, on-going QA tests, etc
- Automation is the key to improve the efficiency
- Vendor provided QA tools should be validated before clinical use



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