# Beam steering and monitoring photon and electron beam energies with ion chamber array

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# Disclosure

**Receives research funding from Sun Nuclear Corporation.**

# Learning Objectives

1. To understand the use of Ion Chamber Array (ICA) to steer beams with the real-time feedback.
2. Monitoring of photon beam energy with ICA .
3. Using ICA combine with double wedge phantom measuring electron beam energy.

# Beam Steering using the IC PROFILER

## Device Setup:

100 cm source to the surface of device distance

### Photons:

Field: 30 x 30 $cm^2$ (maximum size on ICP)

Effective Depth: 2 cm solid water + 0.9 cm intrinsic (eliminates many of the contamination electrons)

### Electrons:

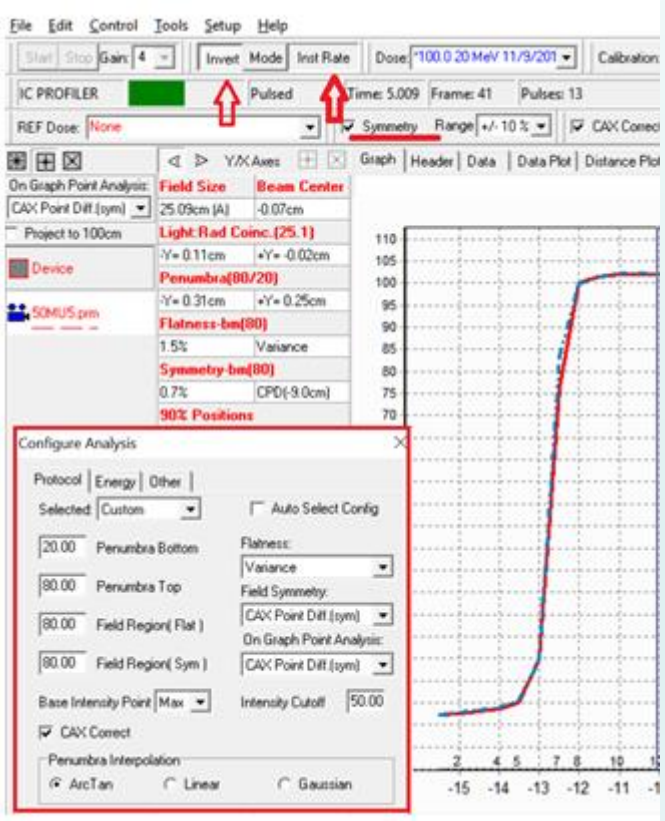
Cone: 25 x 25 $cm^2$

Effective Depth:  Energy dependent (1-3 cm)

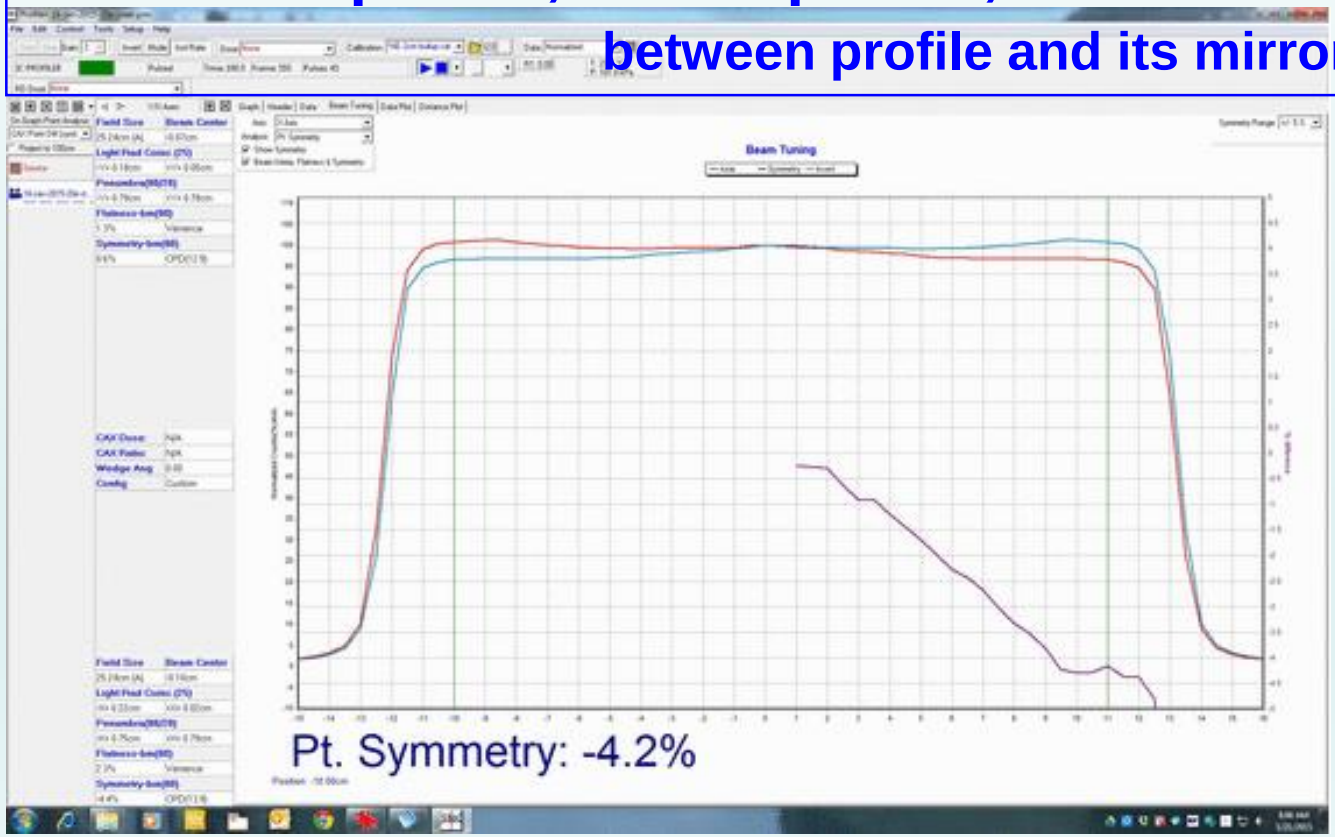
# Beam Steering using IC PROFILER

## Software Setup:

- CAX Point difference (CPD) Symmetry metric
- Instant Rate mode
- Invert: Real time




**Real time: profile, mirror profile, the deviation between profile and its mirror**

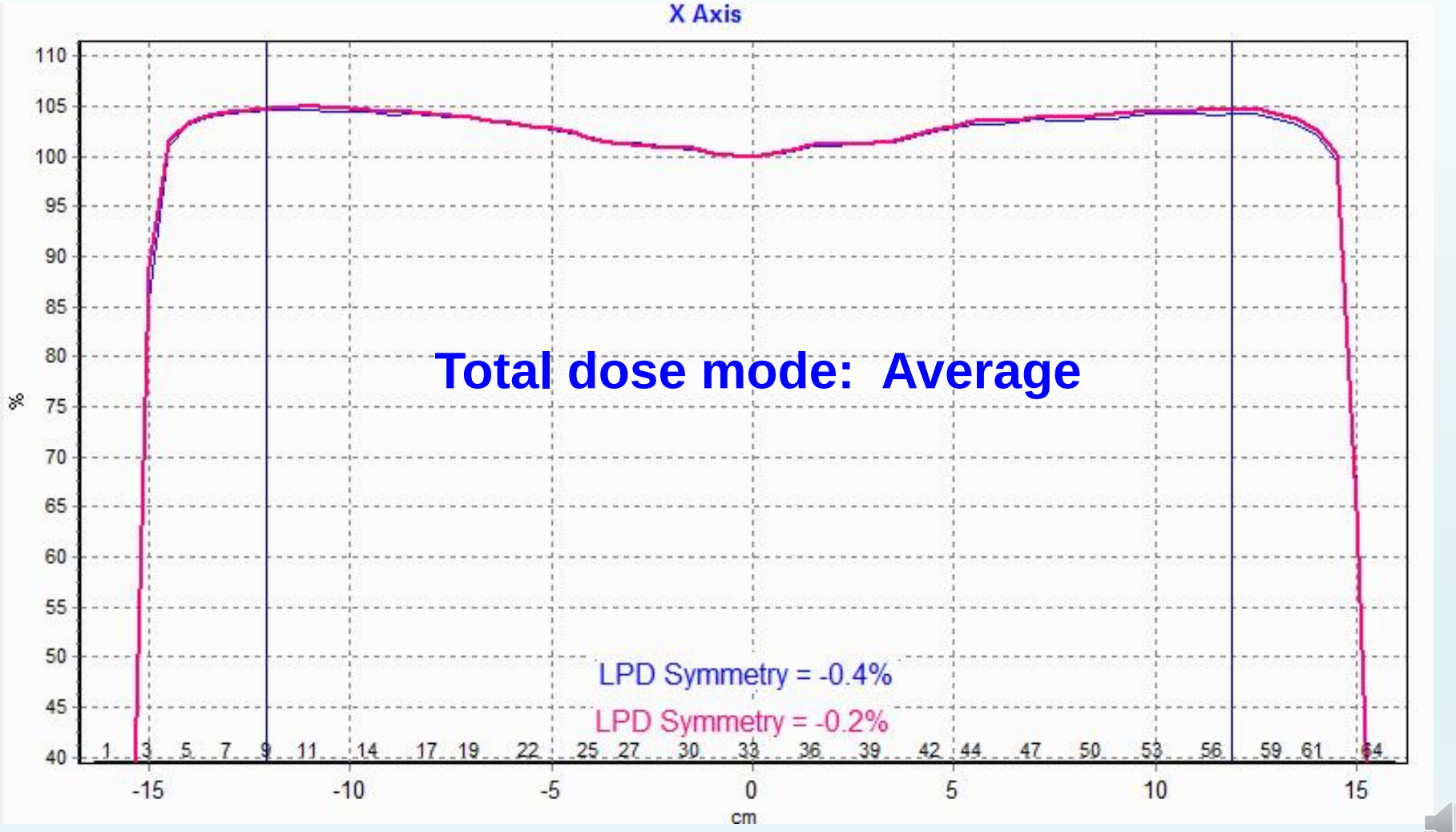


# Beam Steering using IC PROFILER

**Ensure machine was steered and working correctly.**

**Servos:**
**zeroed, enabled.**

**Symmetry:**
**≤ 0.5%**
**is achievable.**



# Evaluation of beam steering with ion chamber array

**After beams have been steered with ICA**

**Comparison of Profiles: ICA vs. 3D water scan:**

a) Compare the overlaid profile shapes

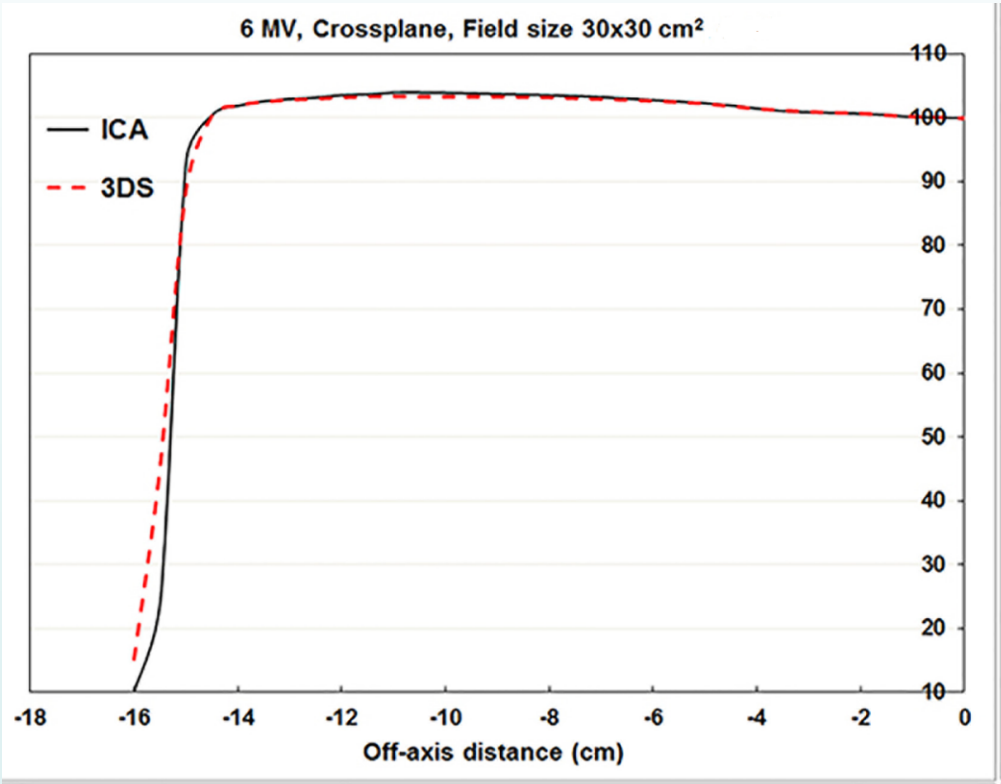
b) calculation of point-by-point differences.

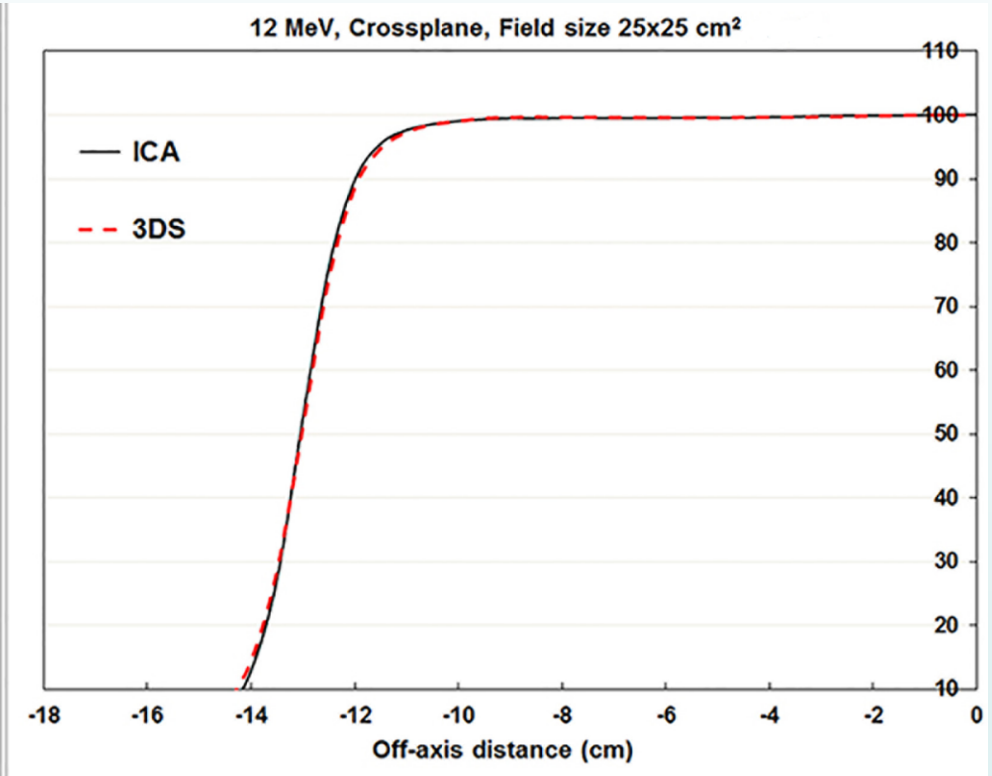
c) examining the symmetry differences in Varian's "Point Difference Symmetry" metric

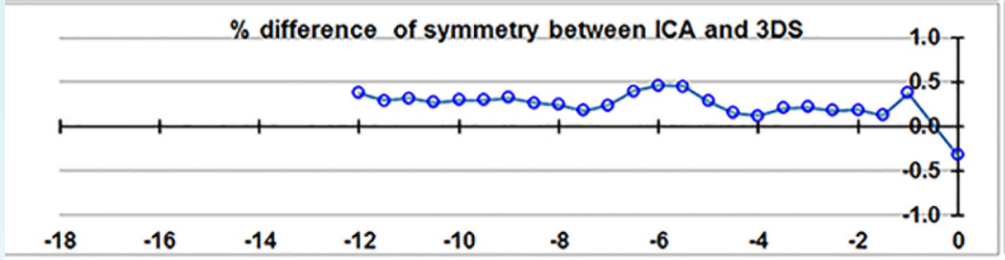
Gao, Balter, et al. Quantification of beam steering with an ionization chamber Array. JACMP, 19:168-176, 2018.

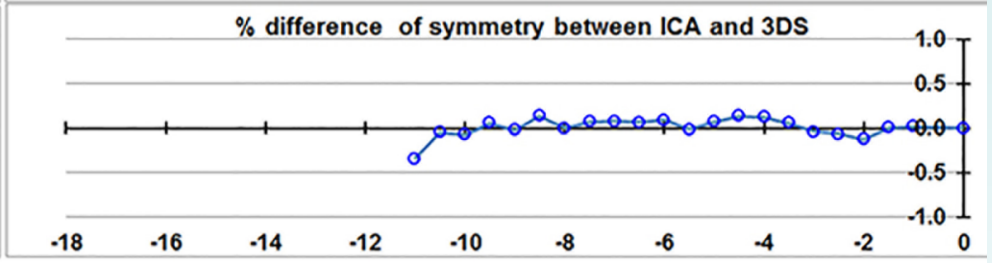
# Profiles: ICP vs. 3D SCANNER

a) Qualitative compare profiles: ICA vs 3DS
b) point-by-point symmetry differences: ICA vs. 3DS



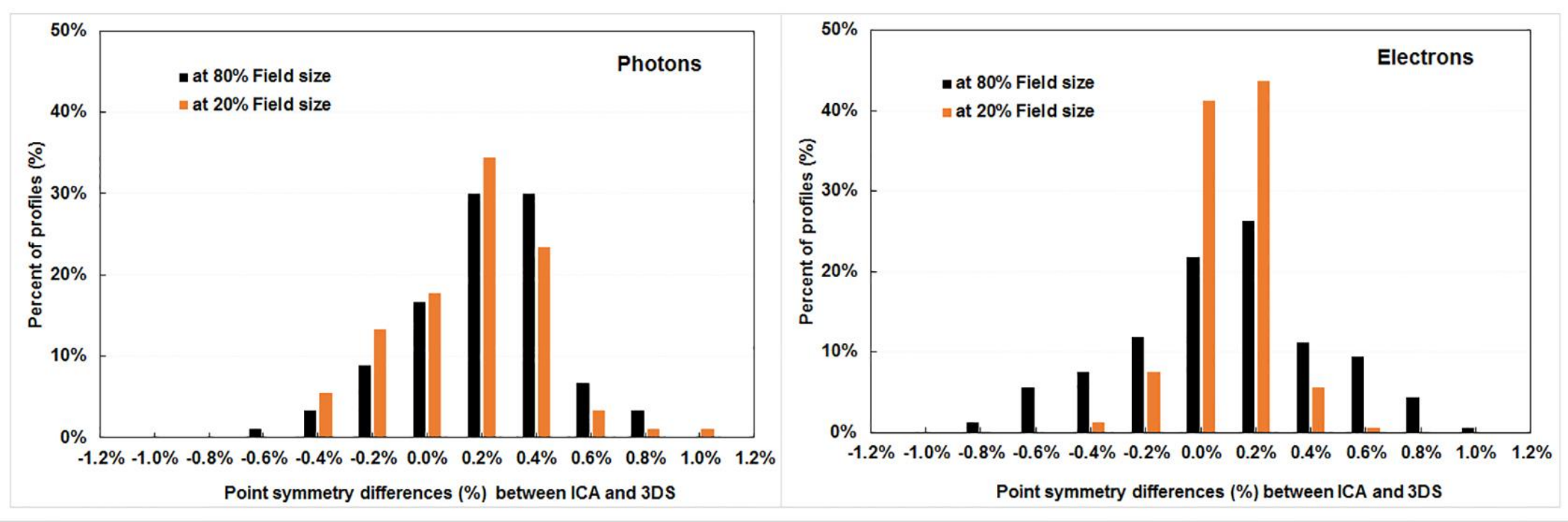



# Profile Comparison Results

## c) Difference of point symmetry between ICA and 3DS:

- 90 photon and 160 electron beams
- All beams were steered with the ICA.

**95% beam ≤ 0.7%;  100% beam ≤ 1.0%**



# Beam Steering using IC PROFILER

- Solid water was added during steering to ensure measurements were beyond the buildup region.
- Beam was steered in the radial and transverse directions with servos open.
- Make sure using “Instant Rate mode” and “CAX Point Difference Symmetry” metric.
- With steering complete, servos were zeroed and enabled. Symmetry ≤ 0.5% is achievable.

# Beam Steering using the IC PROFILER

- **2D Ion Chamber Array can be used to steer linear accelerator photon and electron beams**
- **IC Array is able to achieve beam symmetry matches that of 3D water scanning system.**

# Monitoring beam energy constancy with IC Array

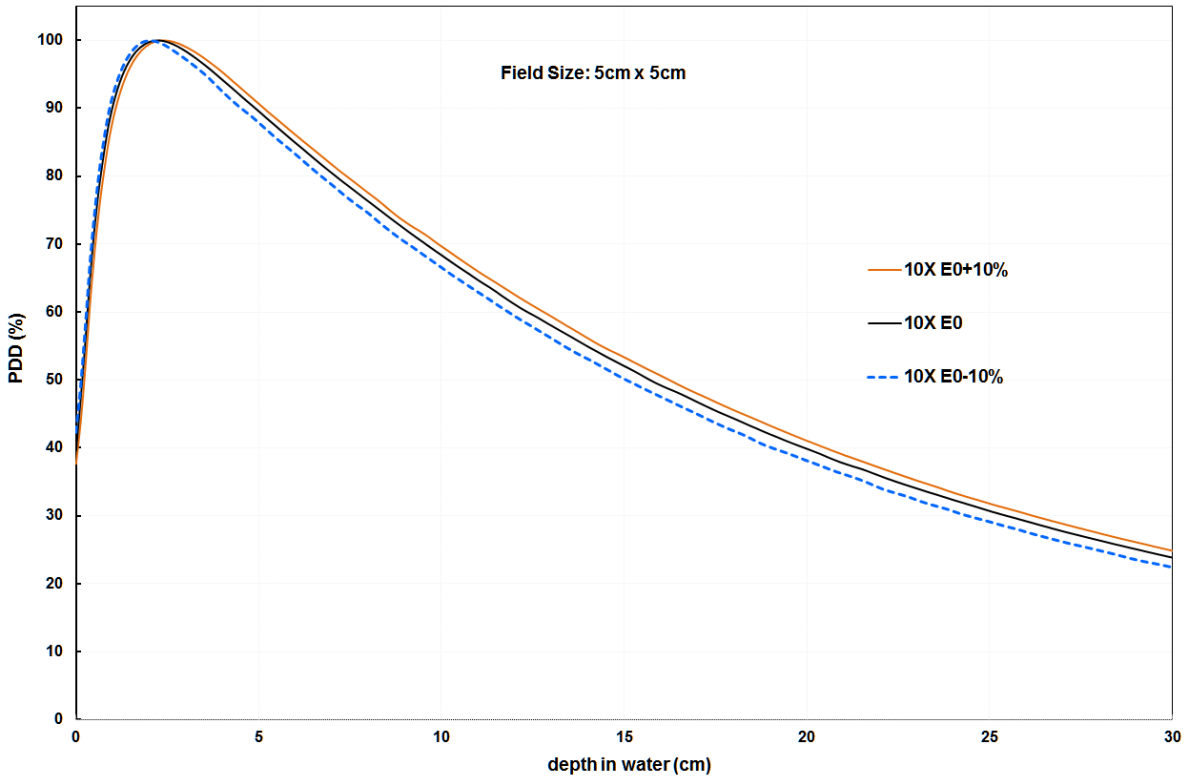
1. Monitoring changes in photon energy (off-axis ratio metric) with the ICA

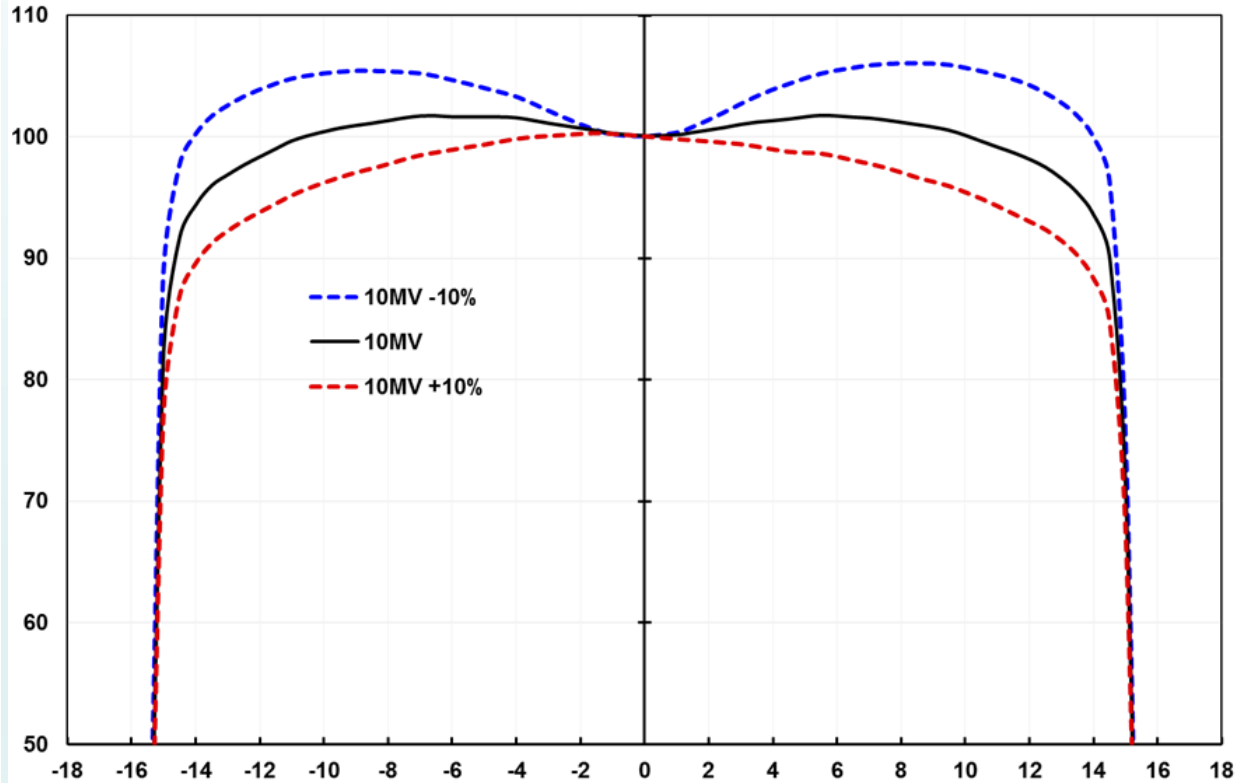
2. Monitoring changes in electron energy ($R_{50}$) with the combination of ICA and an aluminum double-wedge plate

# Monitoring photon beam energy with ICA

## Changes in photon energy (change bending magnet current)

- Percent depth dose (PDD)
- **Off-axis ratio (OAR) from beam profile**

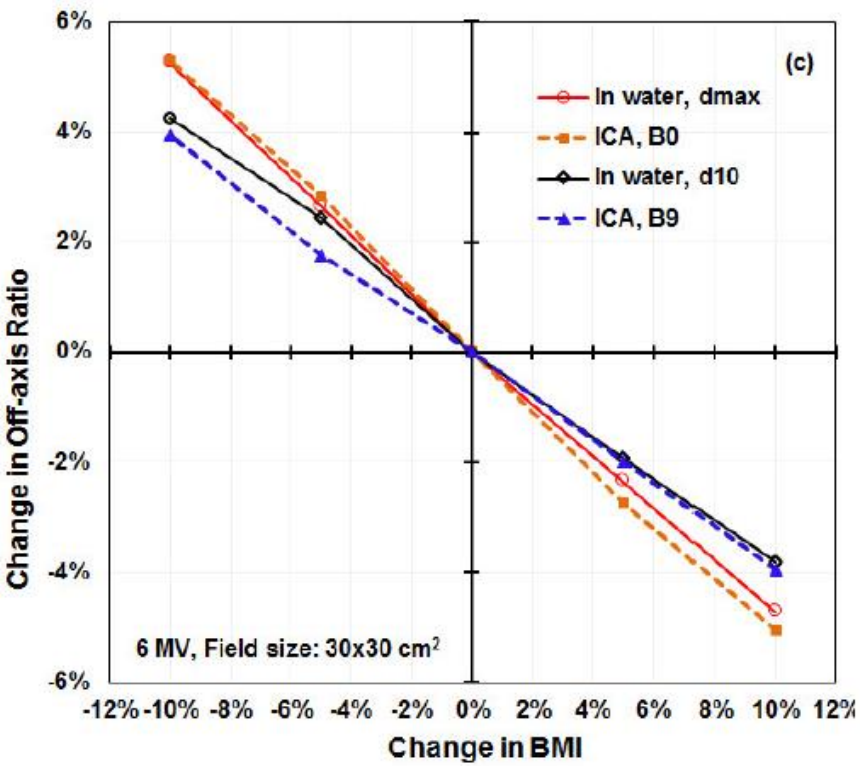


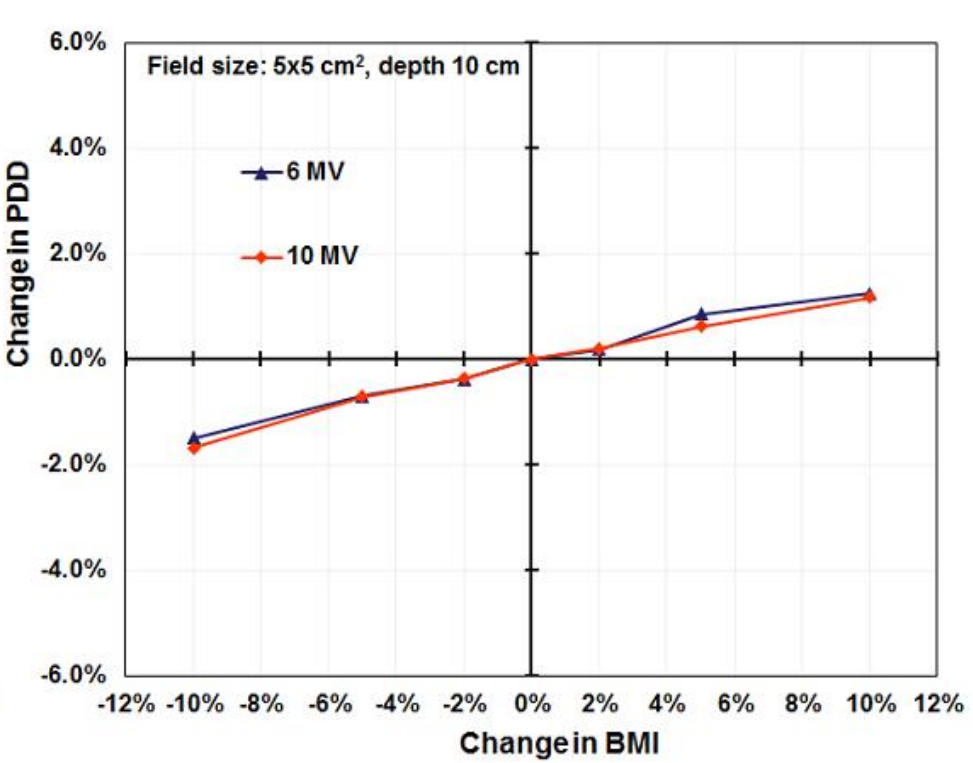




Gao, Balter et al., Monitoring photon beam energy constancy, JACMP (2016) 17(6) 242-253

# Off-axis ratio vs. PDD

## PDD vs. Off-axis ratio (OAR)




**Changes in OAR is ~ 3 times than changes in PDD**

Gao, Balter et al., Monitoring photon beam energy constancy, JACMP (2016) 17(6) 242-253

# Monitoring photon beam energy with ICA

## PDD vs. OAR

**Minimum detectable change in energy (%)**

- **PDD metric: ±2.5% changes in energy**
- **OAR metric: ±0.5% changes in energy**

**OAR-based metric is more sensitive to energy change than PDD metric**

Gao, Balter et al., Monitoring photon beam energy, JACMP (2016) 17(6) 242-253

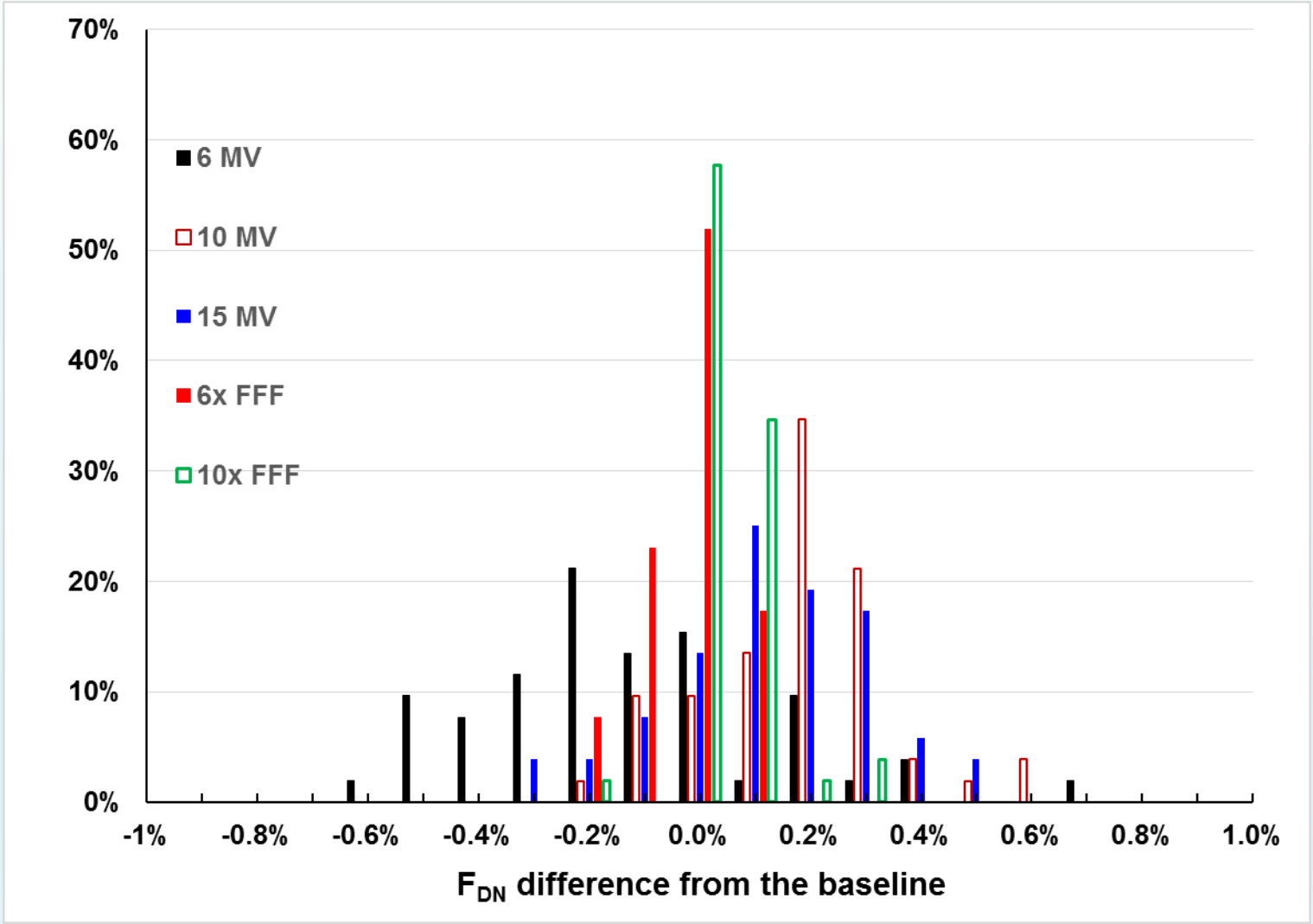
# Monitoring photon beam energy with ICA

## Long term Results:

- Monthly of 4 years
- 260 measurements
- Differences from the baseline:

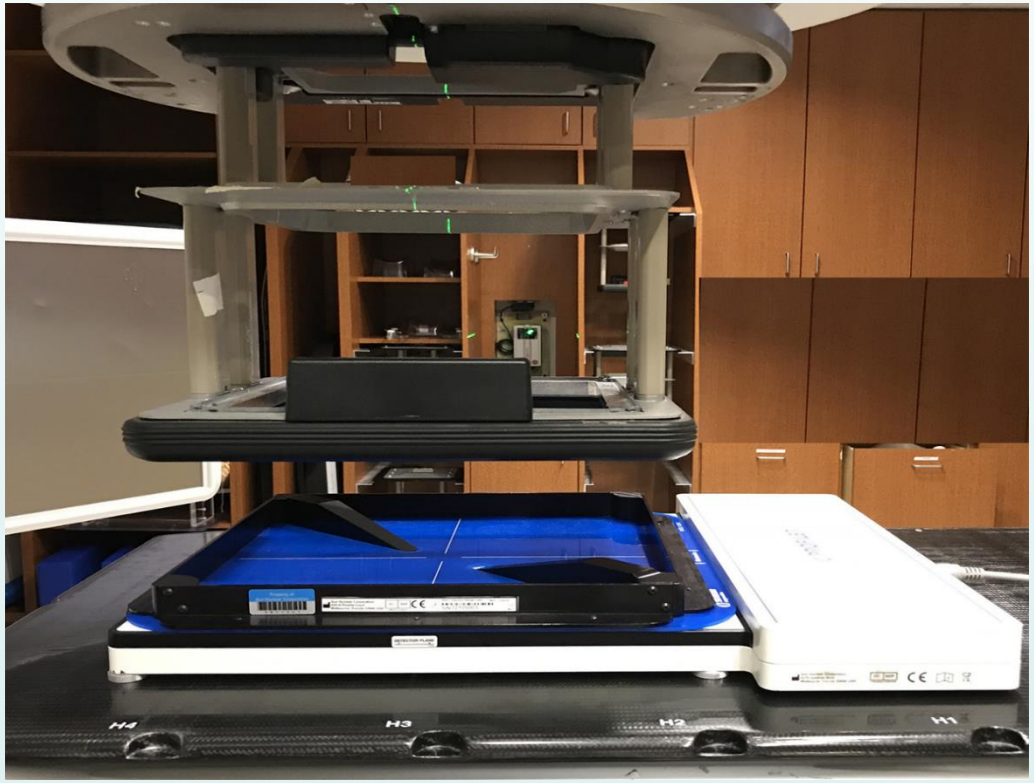
  98.4% ≤ ± 0.5%;

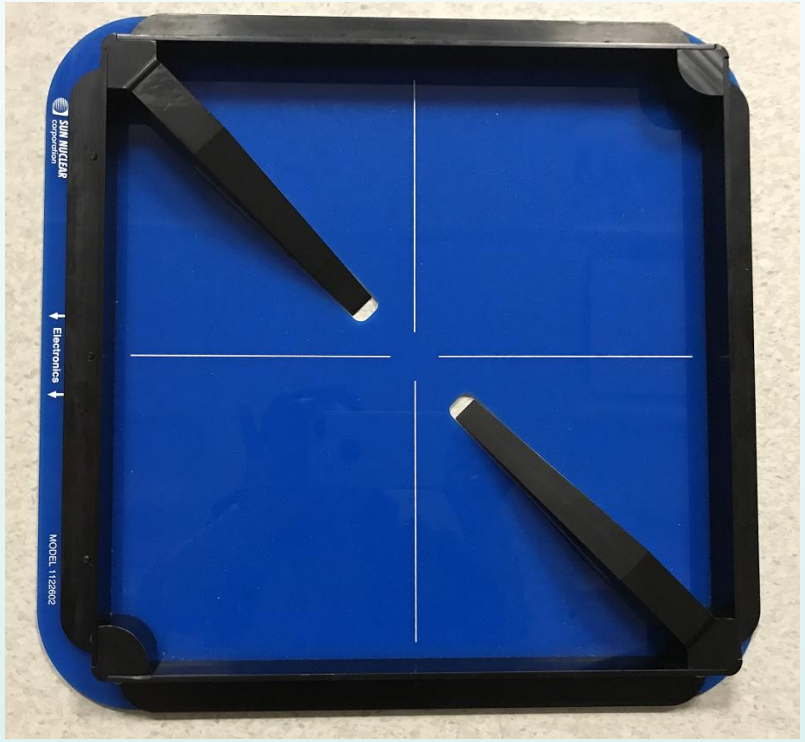
  100% ≤ ± 0.7%



# Electron beam energy constancy

## IC Profiler/double wedge plate combination

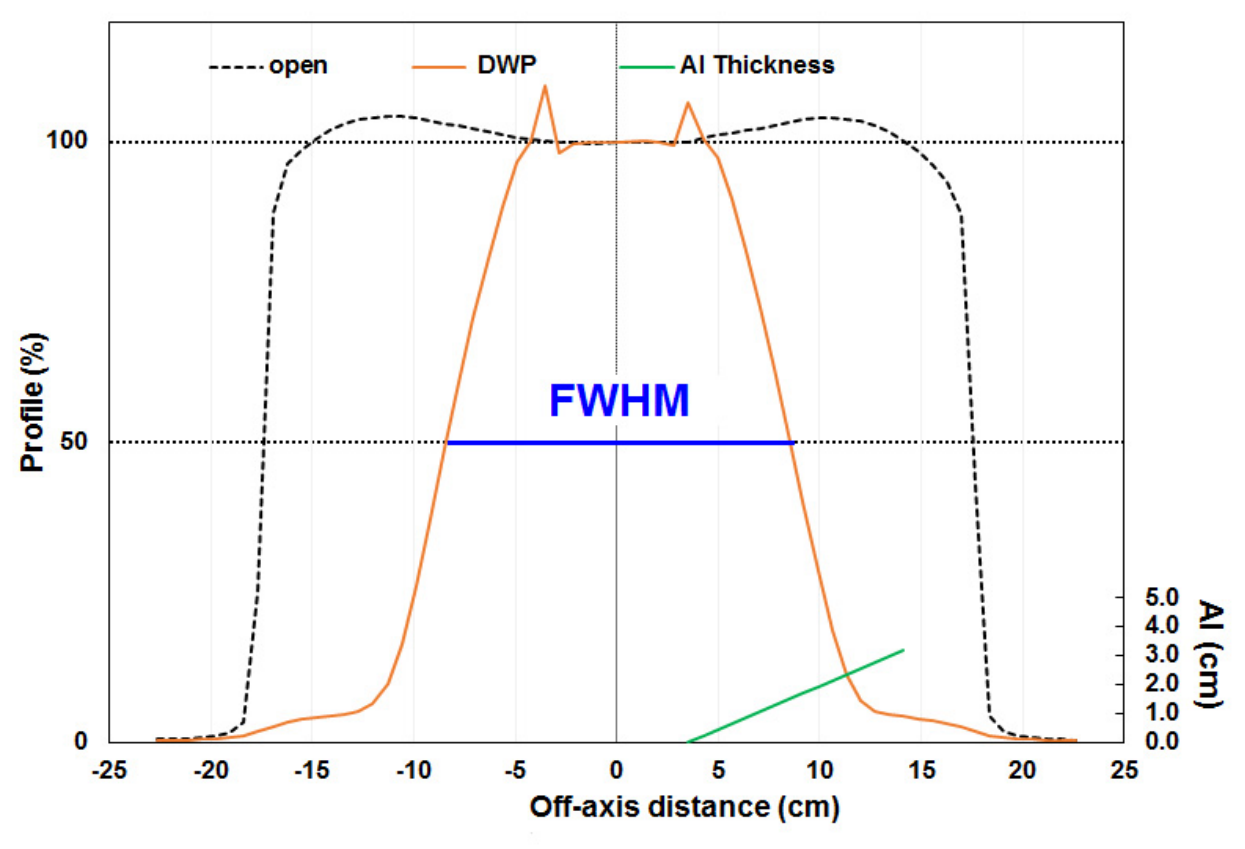


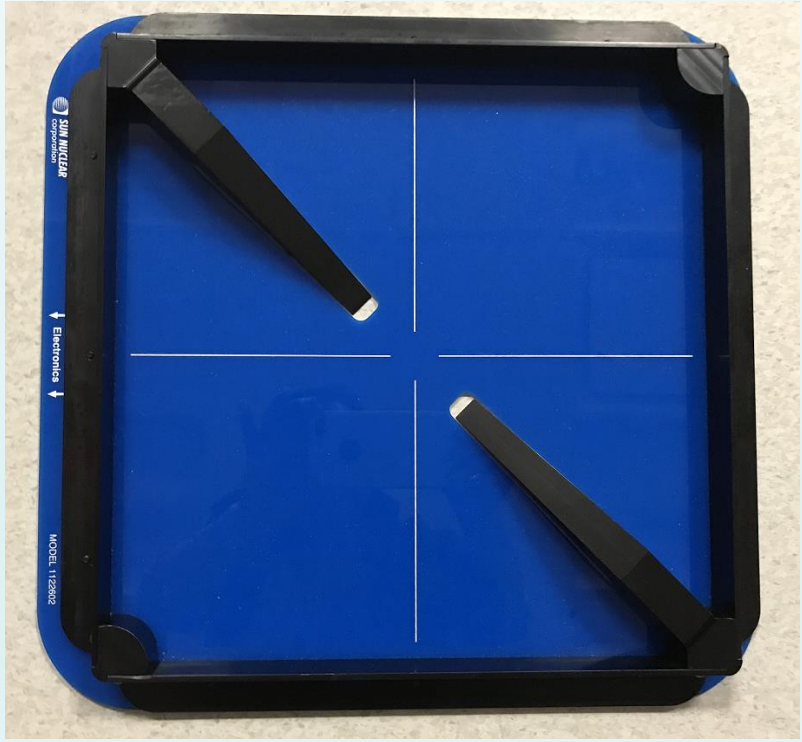




Gao, et al., Monitoring linear accelerators electron beam energy constancy with a 2D ionization chamber array and double-wedge phantom, JACMP (2020) 21(1): 18-25.

# Electron beam energy constancy

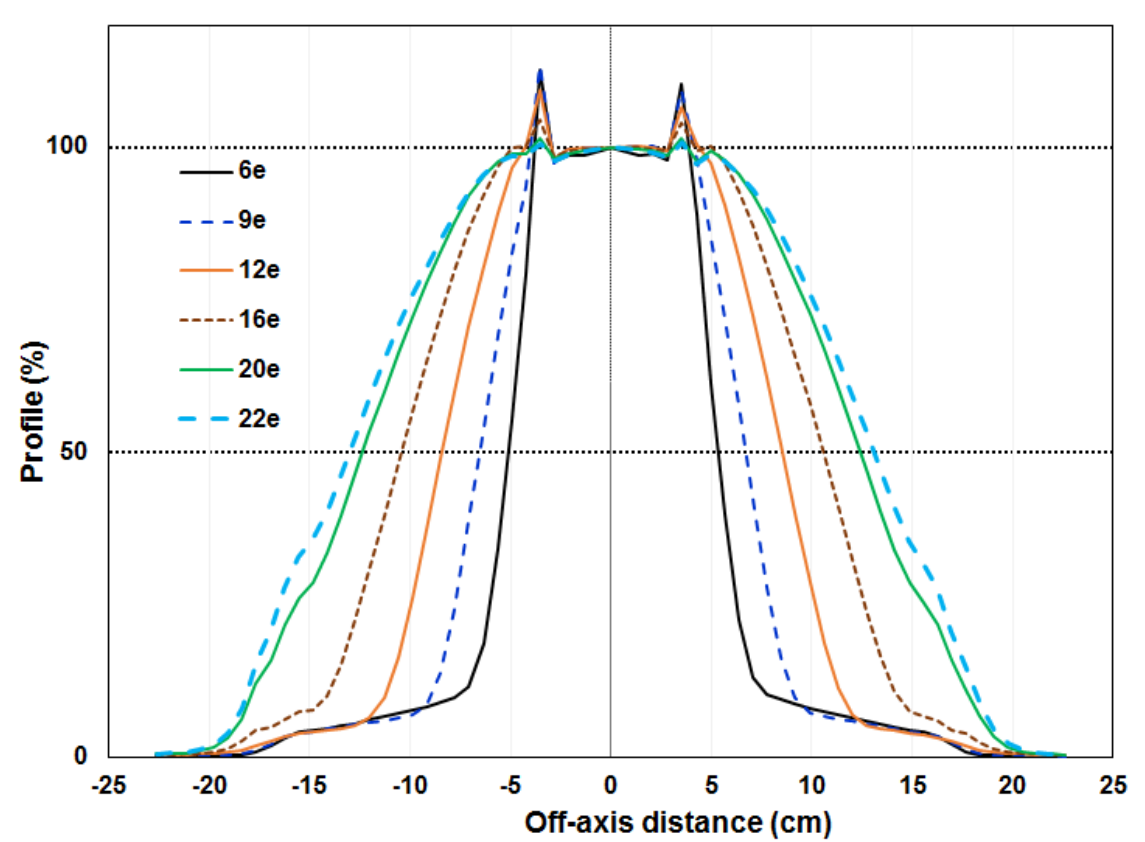
- In DW Profile: $D_{50}$ is directly related to the amount of Al in the beam, related to energy
- ($R_{50}$ FWHM) of the diagonal profile as its energy metric

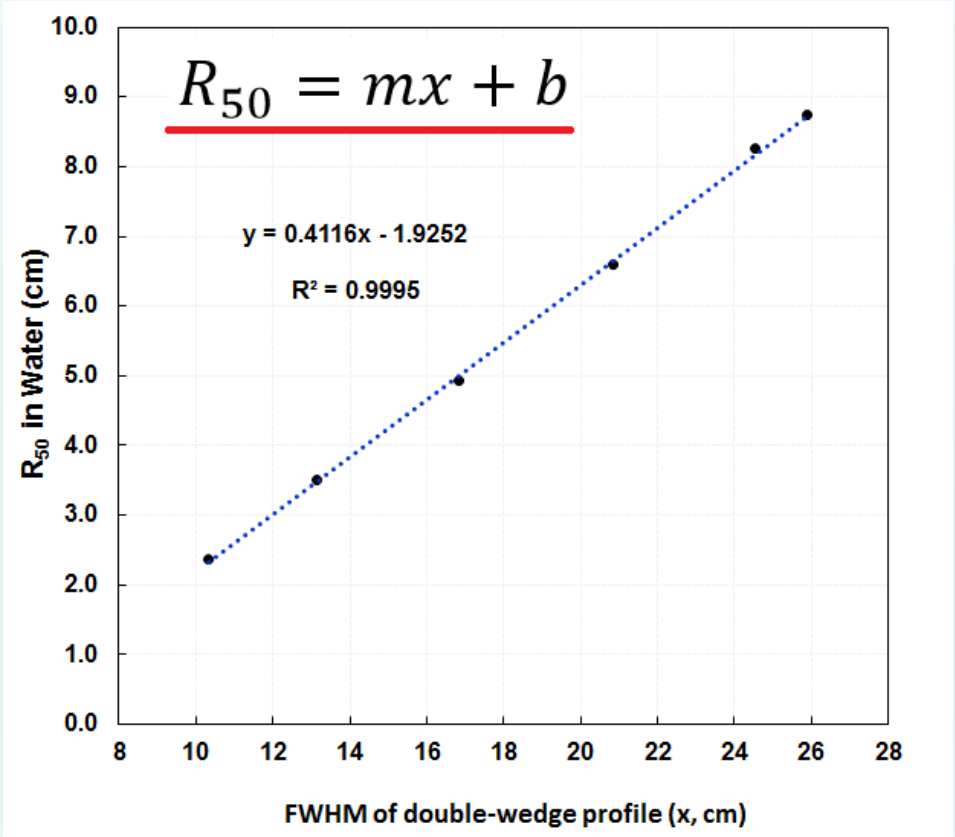


# Electron beam energy constancy

- **DW profiles:**
  **25x25 cm$^2$ cone at 100cm SSD with DW Plate**
- **$R_{50}$ values of known energy beams**



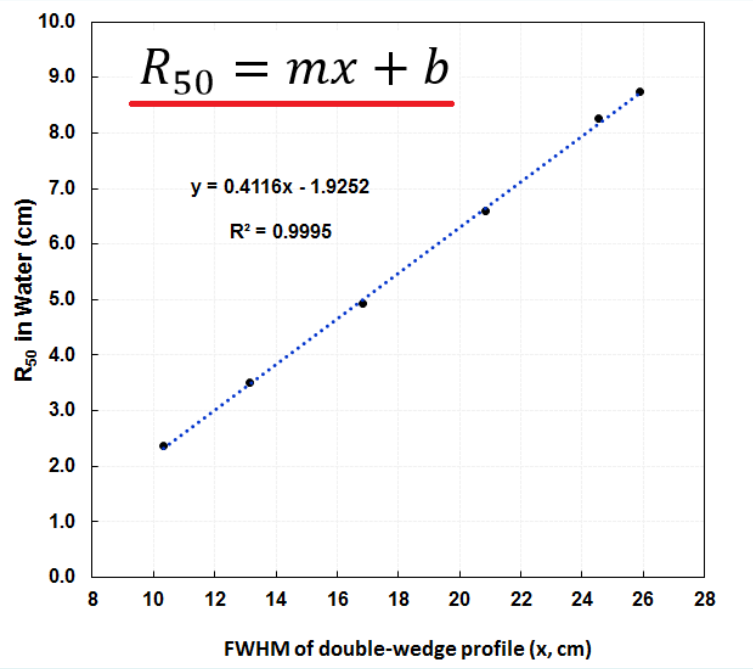



# Electron beam energy constancy

## Calibration:

Establish a linear relationship:

$R_{50}$ vs. FWHM ($x$)




## Measurement:

- $R_{50}$ can be determined from FWHM of the DW profile.
- IC Profiler software reports $R_{50}$.

# Evaluate $R_{50}$ measured with ICP/DWP

**$R_{50}$: ICP/DWP vs. in water scans**

**For 38 beams of known and unknown energies for the same Type of linac as the one for calibration.**

**$R_{50}$ measured with ICP/DWP agreed with $R_{50}$ in Water:**

- **mean ± σ: 0.1 ± 0.3 mm**
- **maximum discrepancy: 0.7 mm.**

**Gao, et al., Monitoring linear accelerators electron beam energy constancy with a 2D ionization chamber array and double-wedge phantom, JACMP (2020) 21(1): 18-25.**

# Electron beam energy constancy

## $R_{50}$: Long-term reproducibility with ICP/WD

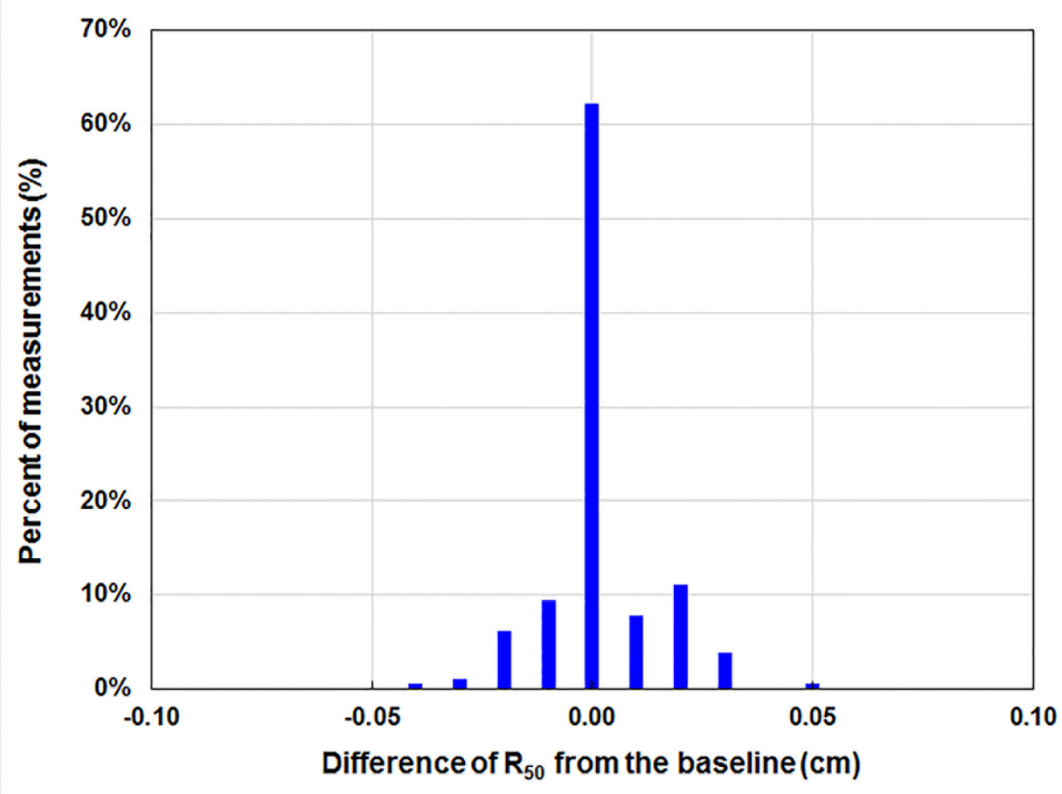
## 5 electron beams monthly over a 3 year

**$R_{50}$: Baseline vs. ICP/DW:**

**99.4% ≤ ± 0.5 mm**

**100% ≤ ± 1.0 mm**

**185 measurements**




| Energy | 6e | 9e | 12e | 16e | 20e |
|---|---|---|---|---|---|
| $\delta R_{50} \pm \sigma$ (cm) | 0.040±0.008 | 0.020±0.011 | 0.010±0.011 | 0.020±0.010 | 0.020±0.013 |

# Electron beam energy

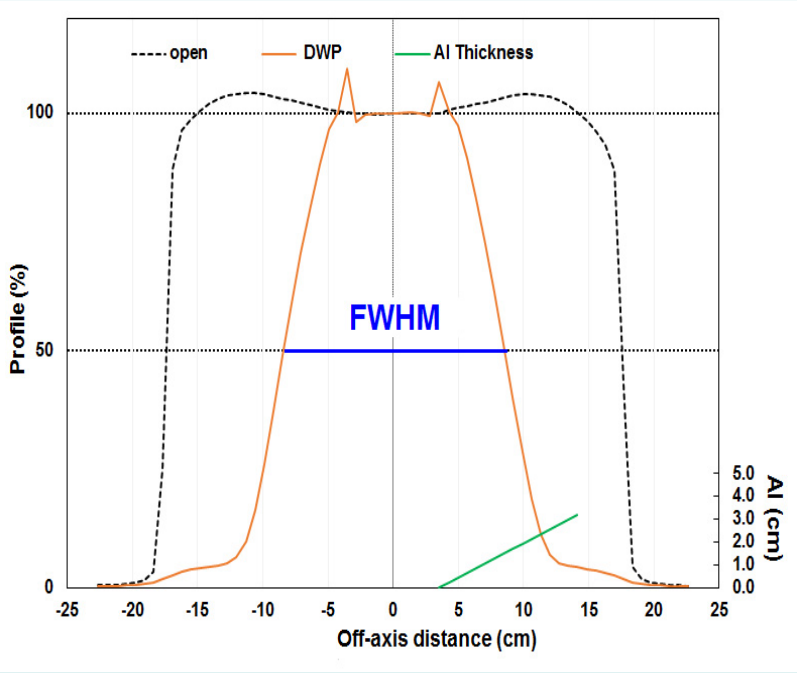
**For different Type of Linacs: Individual vs. universal calibration**

## Individual Calibration:

- **FWHM, DW profile normalized to CAX.**
- **Ignore off-axis effect**

## Universal Calibration:

- **FWHM, DW profile normalized to open field profile**
- **Taking into account off-axis corrections**

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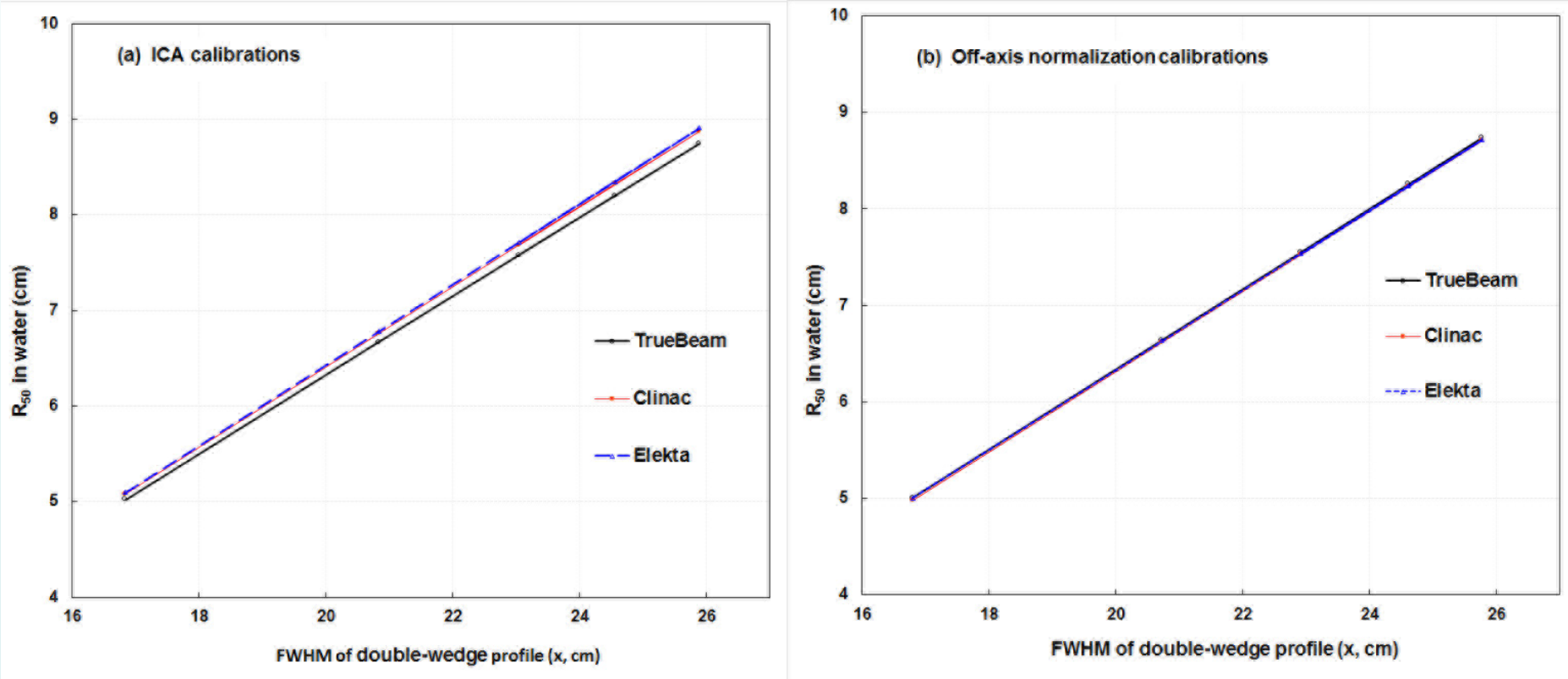
# Electron beam energy

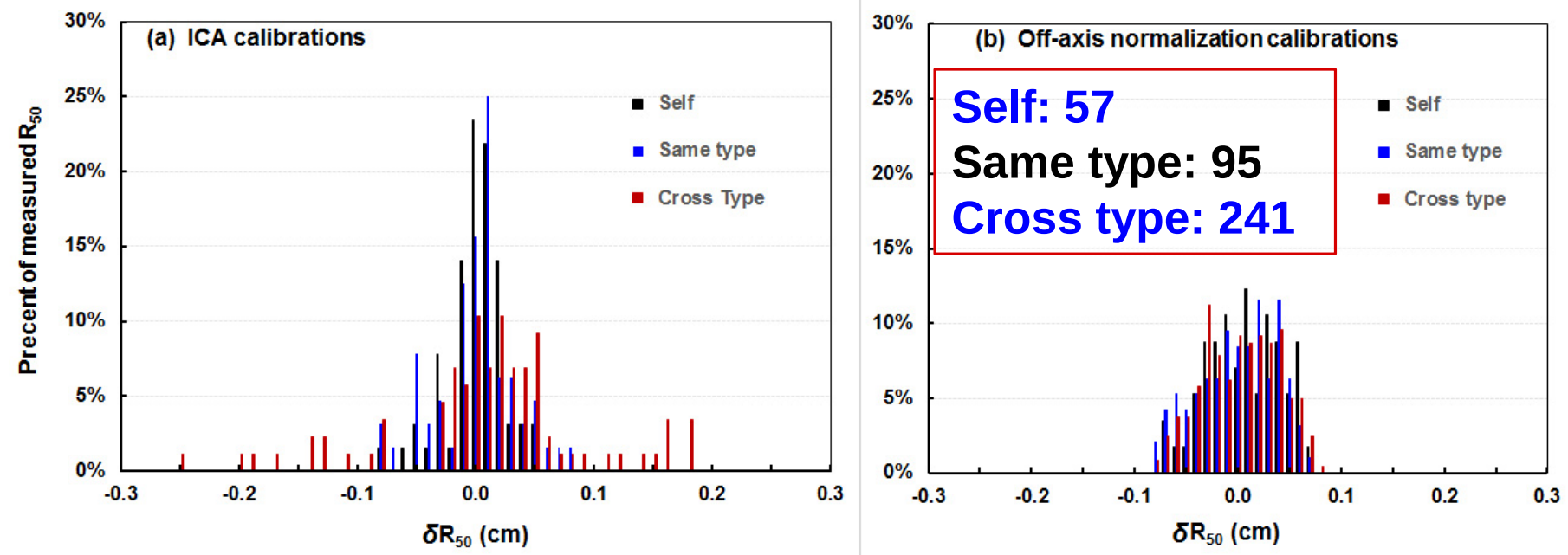
## Individual calibrations vs. Universal calibration



# Electron beam energy measurement

## $R_{50}$: Individual vs. universal calibration

**Total:**




**Maximum $\delta R_{50\_max}$ = $R_{50}$FWHM – $R_{50}$Water**

**2.5 mm vs. 0.6 mm**

# Conclusions

1. **Use of the ICA greatly speeds up the beam steering process because of its the real-time feedback and reduces effort by eliminating the need to setup a 3D water scanning tank.**

2. **Monitoring photon and electron beam energy with IC Profiler could be incorporated in routine QA procedures saving time while maintaining quality.**

# Acknowledgements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