Measurement Perturbations and their Effects on Array Calibrations

Thomas Simon
Sun Nuclear Corporation
October 18, 2010

The author is employed by Sun Nuclear Corporation

Outline

- Medical physics errors in the news
- Detector arrays
  - Common applications
  - Array calibration methods
  - IC PROFILER
- Wide field array calibration dependencies
- Array calibrations and ADCLs

MEDICAL PHYSICS ERRORS IN THE NEWS

THE RADIATION BOOM

Radiation Offers New Cures, and Ways to Do Harm

By WALT BOGDANICH
Published: January 23, 2010

As Scott Jerome-Parks lay dying, he clung to this wish: that his fatal radiation overdose — which left him deaf, struggling to see, unable to swallow, burned, with his teeth falling out, with ulcers in his mouth and throat, nauseated, in severe pain and finally unable to breathe — be studied and talked about publicly so that others might not have to live his nightmare.

Enlarge This Image

For his last Christmas, Scott Jerome-Parks rested his feet in buckets of sand his friends had sent from a childhood beach. More Photos »

The Radiation Boom

When Treatment Goes Awry

This is the first in a series of articles that will examine issues arising from the increasing use of medical radiation and the new technologies that deliver it.

Multimedia

Sensing death was near, Mr. Jerome-Parks summoned his family for a final Christmas. His friends sent two buckets of sand from the beach where they had played as children so he could touch it, feel it and remember better days.

Mr. Jerome-Parks died several weeks later in 2007. He was 43.

A New York City hospital treating him for tongue cancer had failed to detect a computer error that directed a linear accelerator to blast his brain stem and neck with errant beams of radiation. Not once, but on three consecutive days.

Soon after the accident, at St. Vincent's Hospital in Manhattan, state health officials cautioned hospitals to be extra careful with linear accelerators, machines that generate beams of high-energy radiation.

But on the day of the warning, at the State University of New York Downstate Medical Center in Brooklyn, a 32-year-old breast cancer patient named Alexandra Jn-Charles absorbed the first of 27 days of radiation overdoses, each three times the prescribed amount. A linear accelerator with a missing filter would burn a hole in her

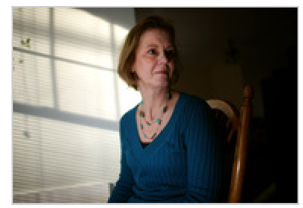
THE RADIATION BOOM

As Technology Surges, Radiation Safeguards Lag

By WALT BOGDANICH
Published: January 26, 2010

In New Jersey, 36 cancer patients at a veterans hospital in East Orange were overradiated — and 20 more received substandard treatment — by a medical team that lacked experience in using a machine that generated high-powered beams of radiation. The mistakes, which have not been publicly reported, continued for months because the hospital had no system in place to catch the errors.

Enlarge This Image



Chang W. Lee/The New York Times

Lorraine Raymond, a radiation therapist, raised concerns about overradiation in the treatment of Frederick Stein at a Veterans Affairs hospital in New Jersey in 2006. More Photos »

The Radiation Boom

Protecting Patients

Articles in this series examine issues arising from the increasing use of medical radiation and the new technologies that deliver it.

Previous Article in the Series »

Multimedia

In Louisiana, Landreaux A. Donaldson received 38 straight overdoses of radiation, each nearly twice the prescribed amount, while undergoing treatment for prostate cancer. He was treated with a machine so new that the hospital made a miscalculation even with training instructors still on site.

In Texas, George Garst now wears two external bags — one for urine and one for fecal matter — because of severe radiation injuries he suffered after a medical physicist who said he was overworked failed to detect a mistake. The overdose was never reported to the authorities because rules did not require it.

These mistakes and the failure of hospitals to quickly identify them offer a rare look into the vulnerability of patient safeguards at a time when increasingly complex, computer-controlled devices are fundamentally changing medical radiation, delivering higher doses in less time with greater precision than ever before.

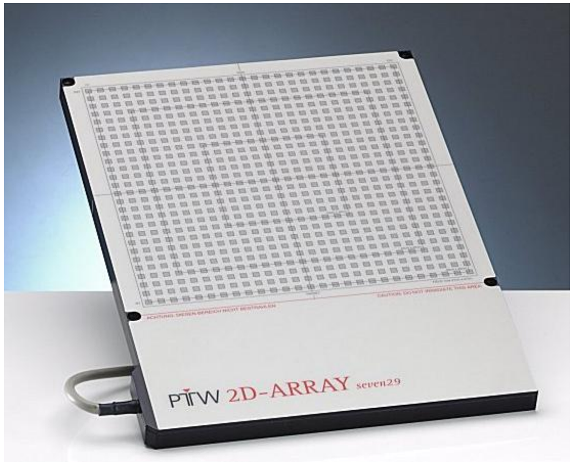
Serious radiation injuries are still infrequent, and the new equipment is undeniably successful in diagnosing and fighting disease. But the technology introduces its own risks: it has created new avenues for error in software and

DETECTOR ARRAYS

Common Applications

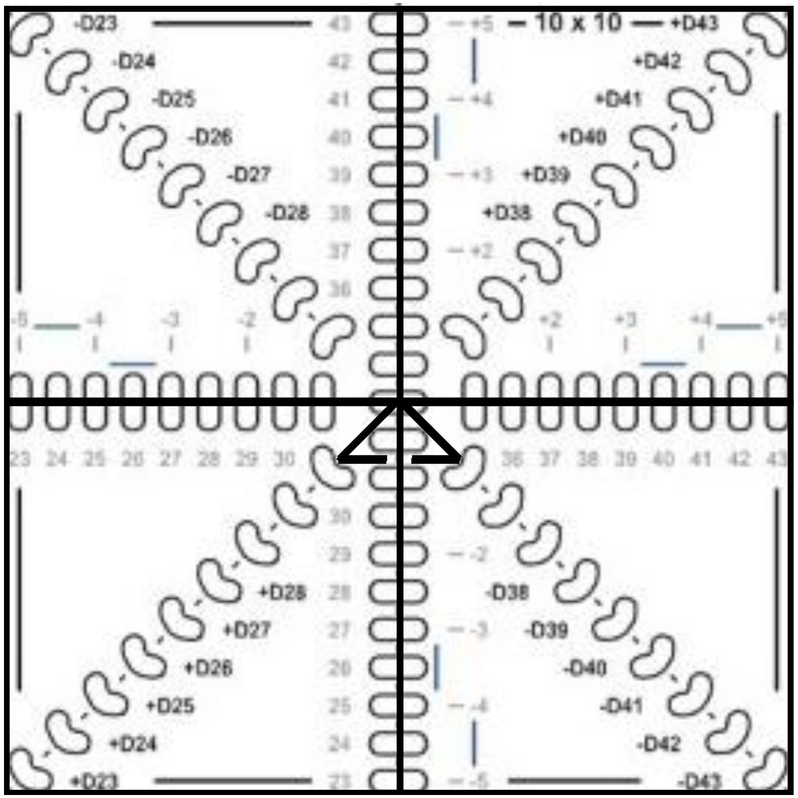
- Beam profile measurements
- Patient specific quality assurance (QA)

- Arrays offer
  - Increased measurement efficiency
  - Requirement for minimal measurement skills



Array

- Small field
- Wide field



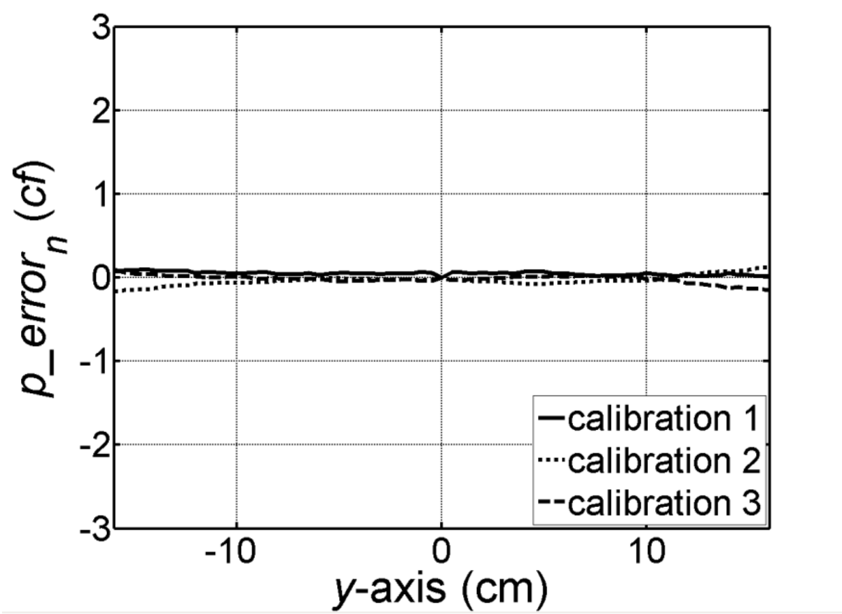
IC PROFILER

- Ionization chambers
  - 0.05 cm^3
- 32 x 32 cm^2 active area
- Multi-axis
  - *x*-axis
  - *y*-axis
  - *pd*-axis
  - *nd*-axis

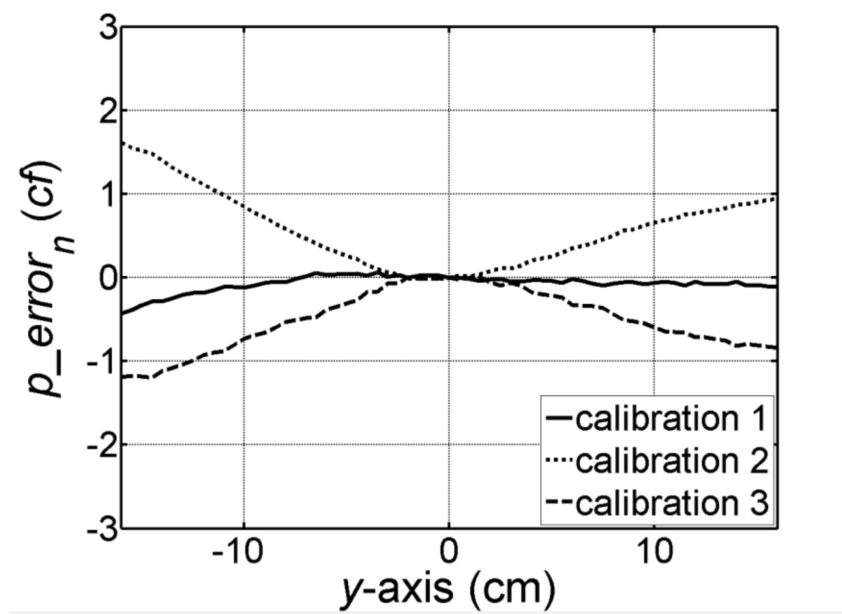
WIDE FIELD ARRAY CALIBRATION DEPENDENCIES

Wide Field Calibration Reproducibility

Varian

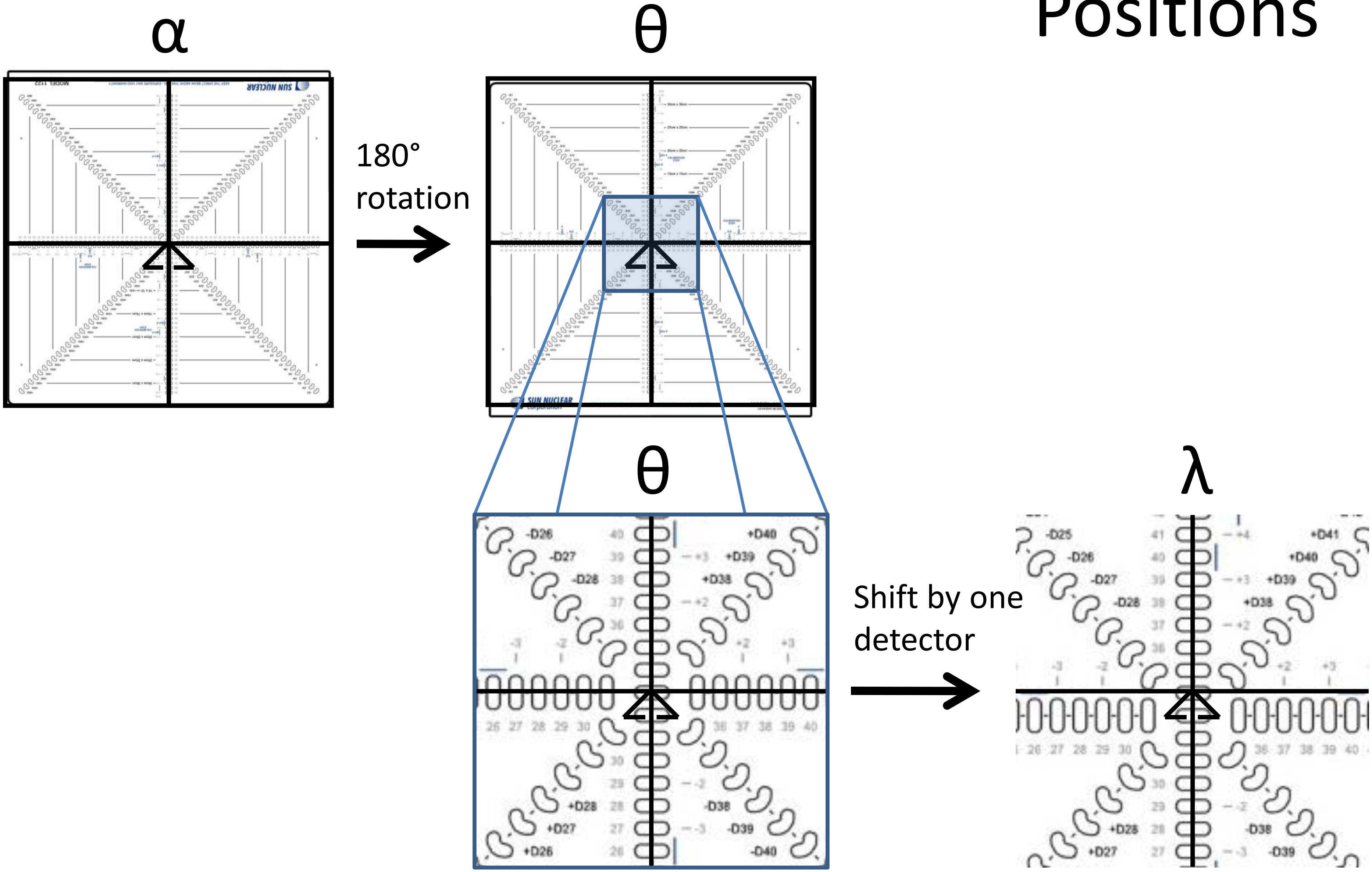


Elekta



$$\mathrm{p\_error}_n(\mathrm{cf}) = \left[\left(\frac{\mathrm{cf}}{\overline{\overline{\mathrm{cf}}}} \right)_n - 1 \right] \cdot 100$$

Calibration Measurement Positions

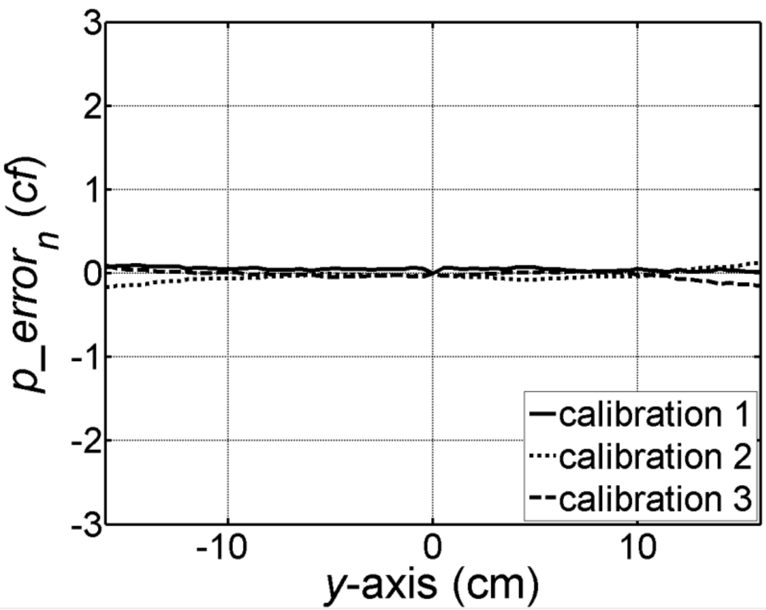


Wide Field Array Calibration

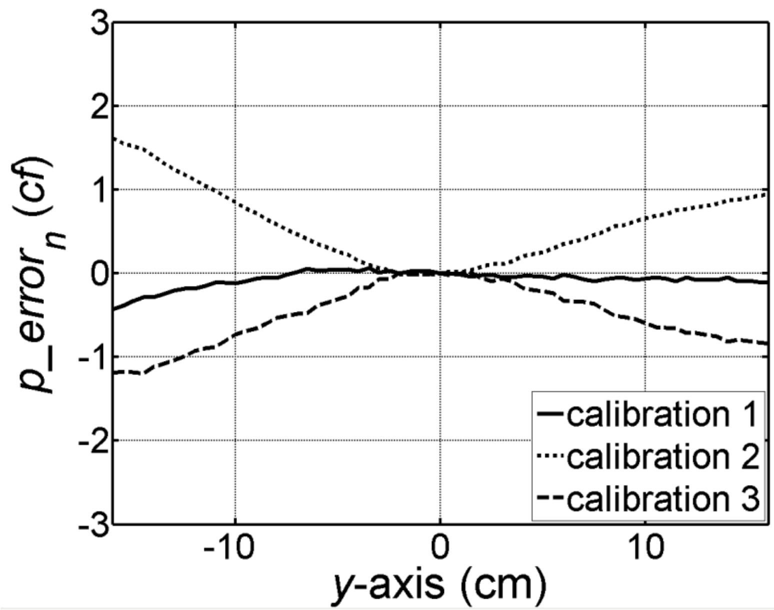
- $$cf_n = \left[\prod_{i=1}^{n-1} \frac{\theta_i}{\lambda_{i+1}} \right] \cdot \left(\sqrt{\alpha_{\lambda\theta} \cdot S_{\lambda\theta}} \right)^{n-1}$$
- Three measurements required:
  - α (array rotated by 180 from θ position)
  - θ (array aligned to radiation beam crosshairs)
  - λ (array shifted by one detector from θ position)
- Three calibration postulates:
  - Scatter to array does not change
  - Dose distribution does not change
  - All detectors change sensitivity as a group

Wide Field Calibration Reproducibility

Varian



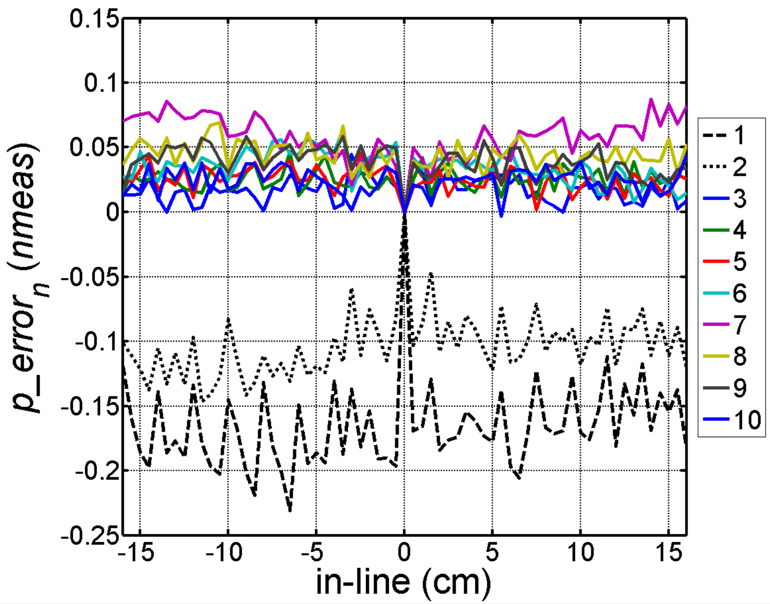
Elekta



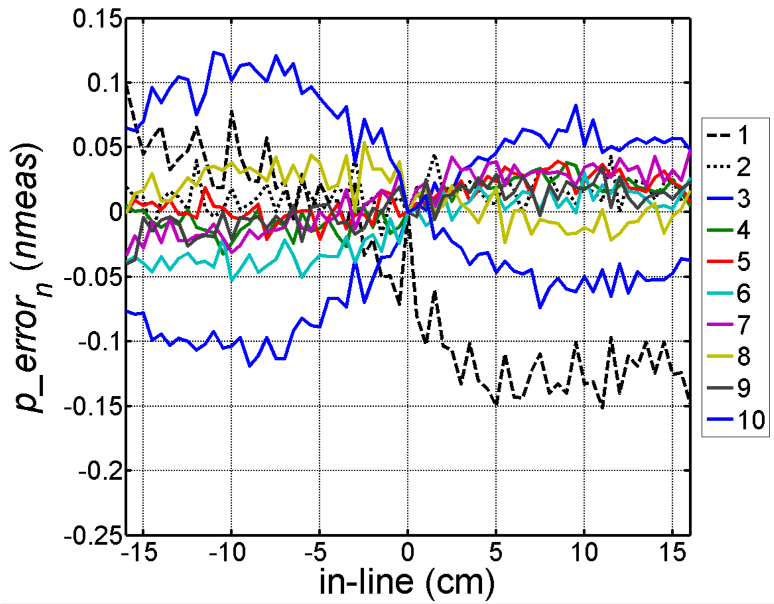
$$\mathrm{p\_error}_n(\mathrm{cf}) = \left[\left(\frac{\mathrm{cf}}{\overline{\overline{\mathrm{cf}}}} \right)_n - 1 \right] \cdot 100$$

Beam Micro-Variations

Varian



Elekta



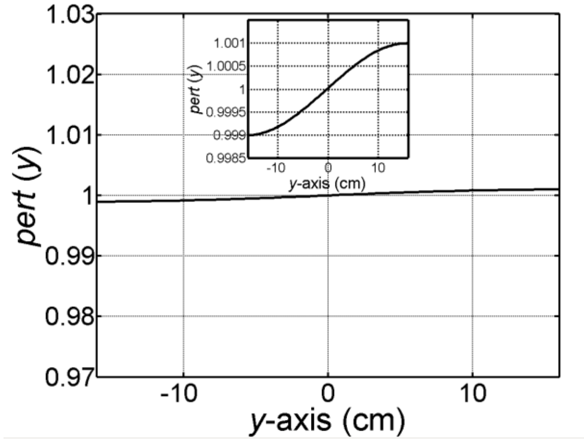
$$\mathrm{p\_error}_n(n\mathrm{meas}) = \left[\left(\frac{n\mathrm{meas}}{\overline{n\mathrm{meas}}} \right)_n - 1 \right] \cdot 100$$

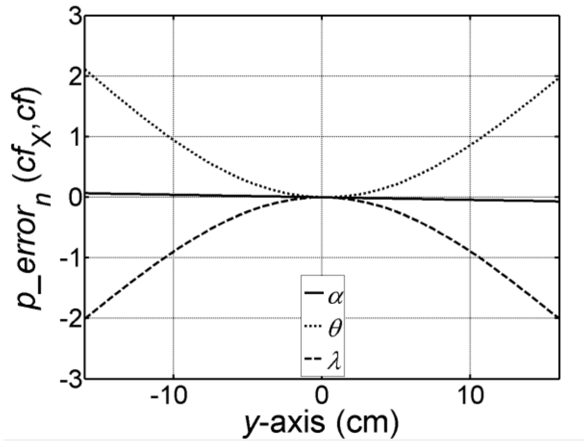
Effects of Micro-Perturbations in the Calibration Beam

- Perturbation
  - Sine shaped
  - 0.1% at edges
  - Applied to α, θ, or λ
- θ and λ are susceptible:

  (±) 2% error
- α is not susceptible:

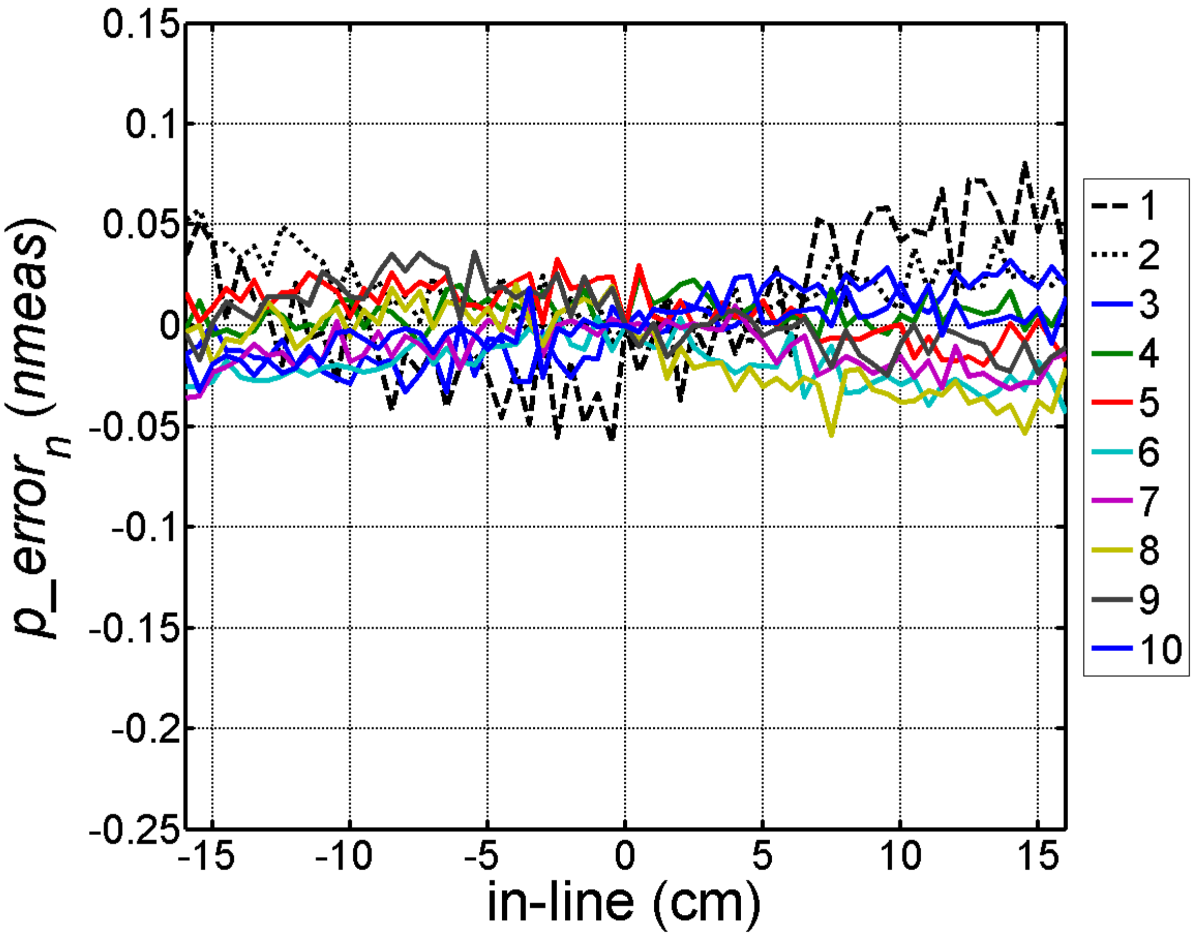
  (±) 0.07% error





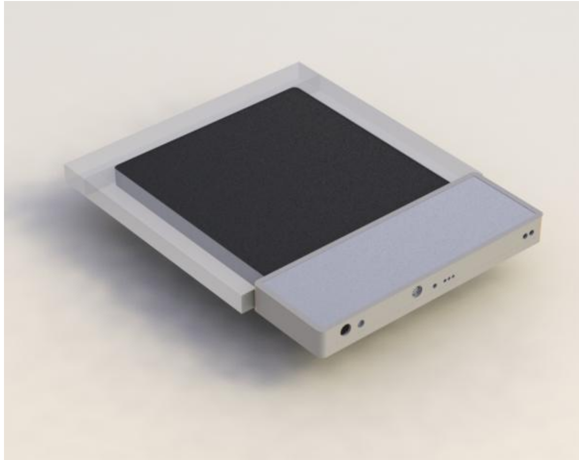
Improving the Reproducibility of Calibrations with an Unstable Beam

- Clini
  - N
    su
  - P
    ca
    b
- Solu
  - E
  - C
    d



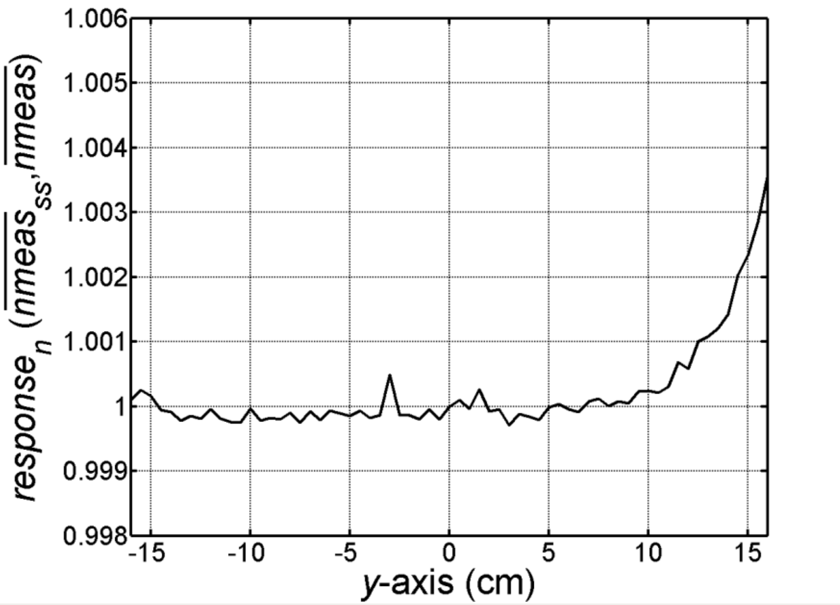
Effect of Side Scatter on Wide Field Array Calibration

- *ss* = side-scatter
- Acrylic strip
  - 4 cm width
  - 4.2 cm height
  - Device perimeter



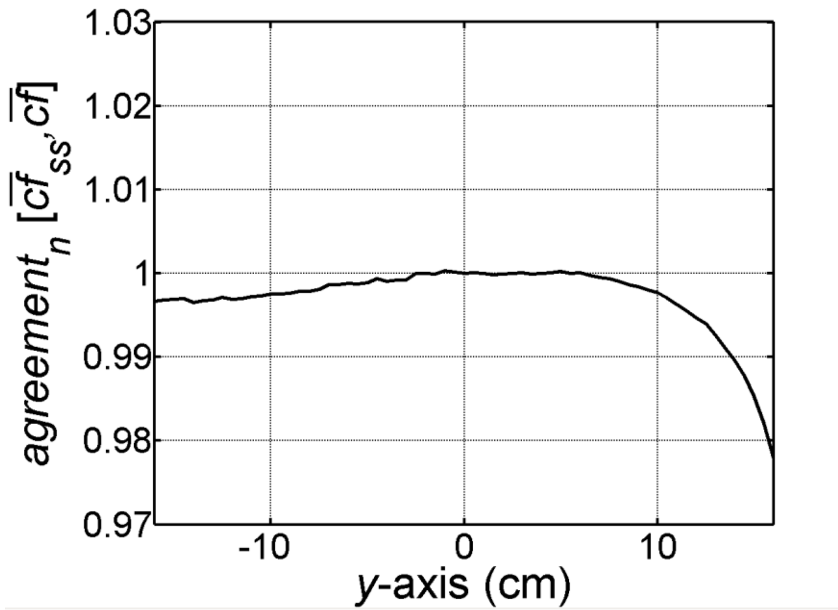
Effect of Side Scatter on …

Measurements



$$response_n \;\; \overline{nmeas}_{ss}, \overline{nmeas} \;\; = \left(\frac{\overline{nmeas}_{ss}}{\overline{nmeas}} \right)_n$$

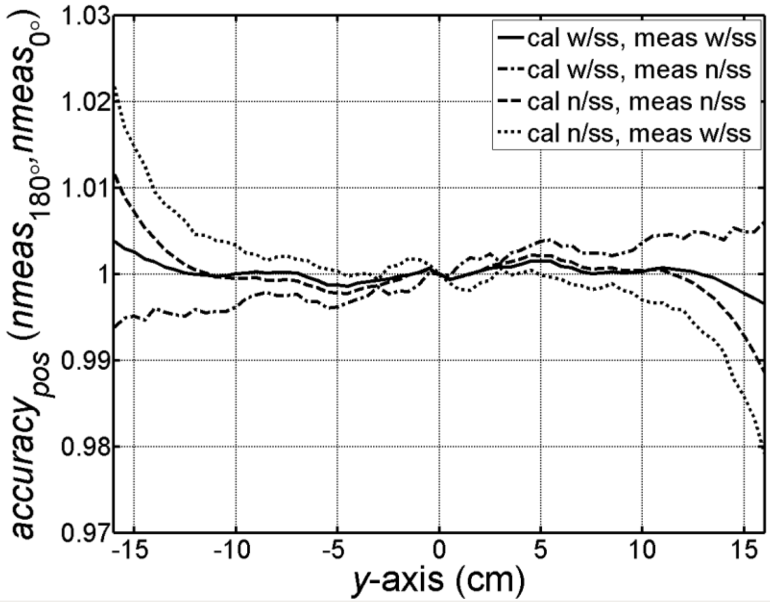
Calibration



$$agreement_n \;\; \overline{cf}_{ss}, \overline{cf} \;\; = \left(\frac{\overline{cf}_{ss}}{\overline{cf}} \right)_n$$

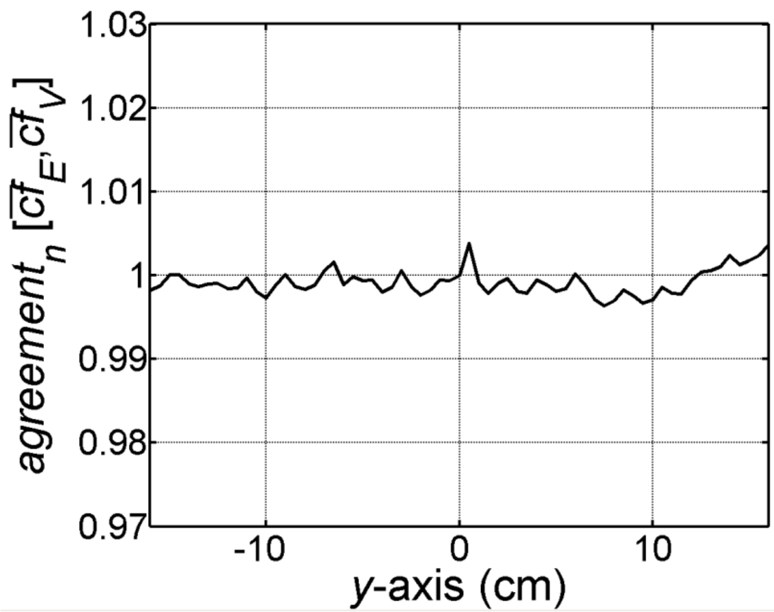
Evaluating the Solution

Test of ss



$$accuracy_{pos} \quad nmeas_{180^\circ}, nmeas_{0^\circ} \quad = \left(\frac{nmeas_{180^\circ}}{nmeas_{0^\circ}}\right)_{pos}$$

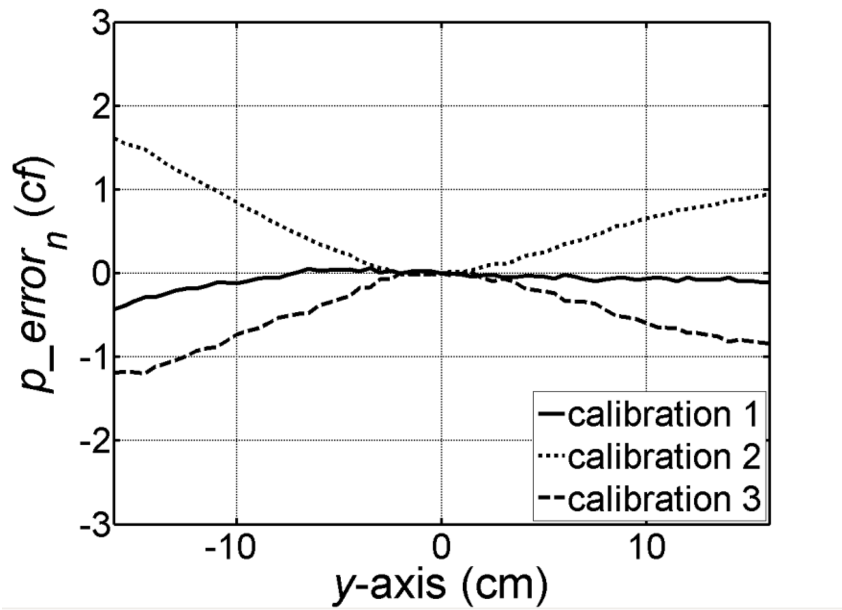
Standard vs continuous with ss



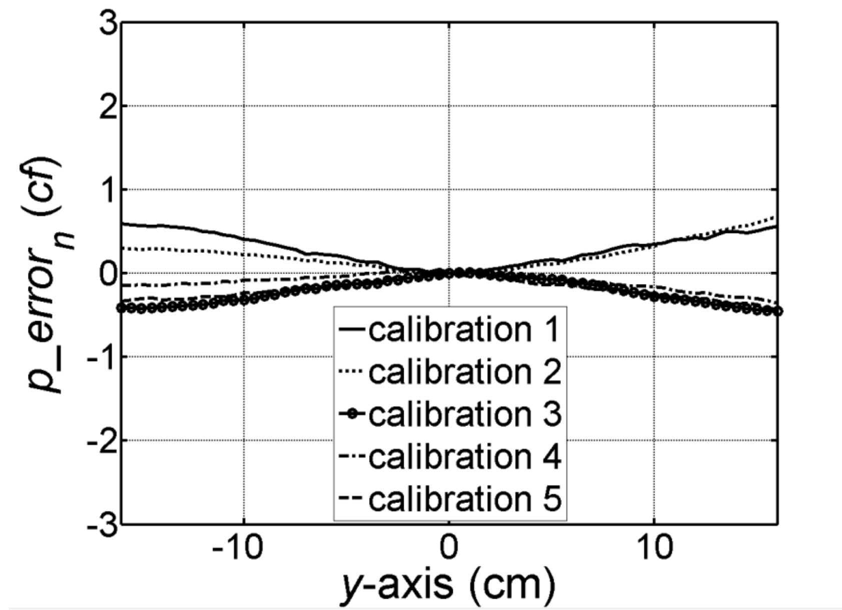
$$agreement_n \quad \overline{cf}_E, \overline{cf}_V \quad = \left(\frac{\overline{cf}_E}{\overline{cf}_V}\right)_n$$

Evaluating the Solution

Elekta standard calibration



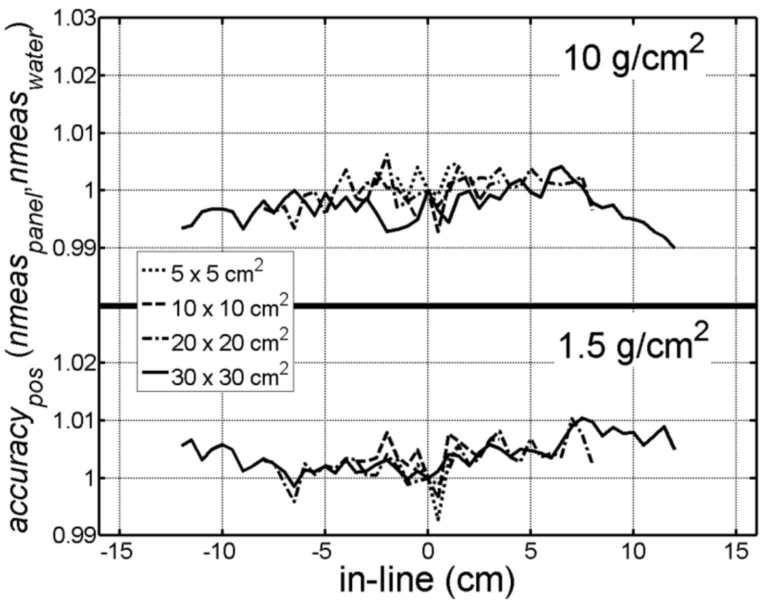
Elekta using a continuous beam with side scatter

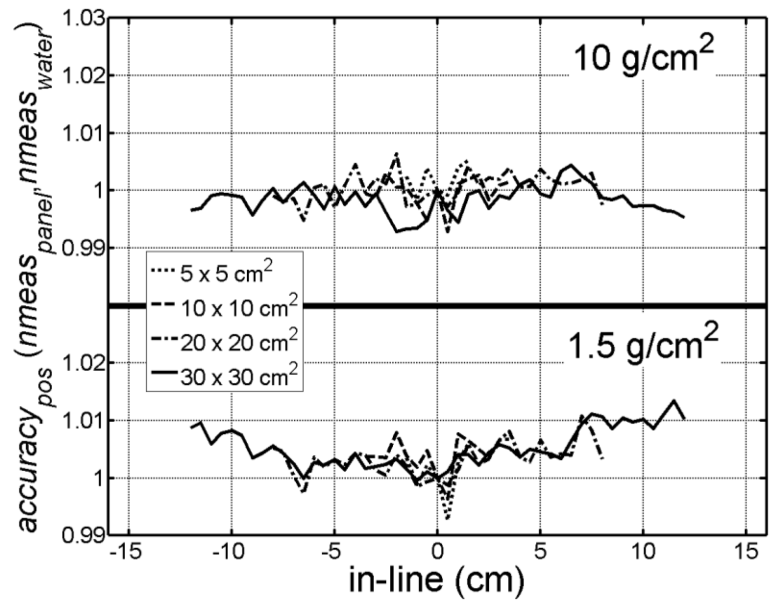


Water Tank Agreement

With ss

Without ss





$$\text{accuracy}_{\text{pos}}(n\text{meas}_{\text{panel}}, n\text{meas}_{\text{water}}) = \left(\frac{n\text{meas}_{\text{panel}}}{n\text{meas}_{\text{water}}}\right)_{\text{pos}}$$

ARRAY CALIBRATIONS AND ADCL’S

Clinical Implications

- Calibration reproducibility dependent on:
  - Beam stability
  - Array size
- Beam Steering
  - Symmetry is important
  - Unlikely to impact
- Patient specific QA
  - Unlikely to impact with loose QA tolerances
  - Potential to impact as beam modeling improves

Array Calibrations and Standards

- An argument can be made that array calibrations are becoming just as important as $N_{D,w}^{60\text{Co}}$ and P_{elec} values
  - Arrays are simple and easy to use
  - Arrays are used to diagnose and aid in beam problem resolution
  - Arrays are used to verify treatment planning systems
- There may be a need/market/argument for an ADCL provided array calibration (for special circumstances)

Thank you for your attention

Questions?

Simon *et al.*, Med. Phys. **37** (7) pp. 3501-3509
"Array calibration dependence on dose distribution stability"