Evaluation of an Electron Beam Energy Verification Method Using Statistical Process Control

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Conflicts of Interest

* I have no conflicts of interest to disclose

Outline

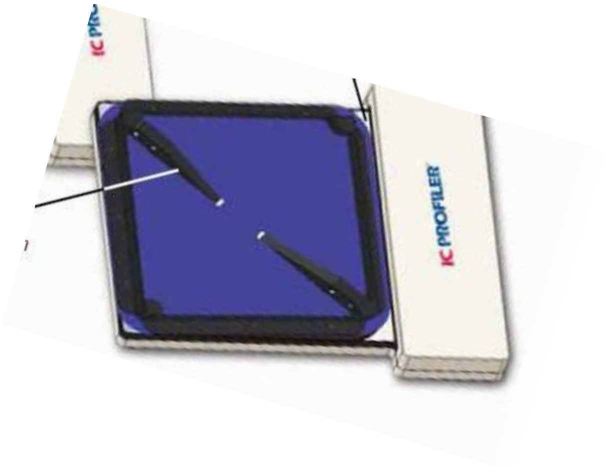
* Background
* Measurement Methods
* Specification Limits
* Statistical Process Control Techniques
  * Control Limits
  * Process Capability
  * Process Acceptability

Background

* Electron Energy Constancy
  * Important component of routine linac QA
  * TG142 – Monthly Check
  * Challenging Measurement
    * Rapid falloff of depth dose beyond D-Max
    * Multiple electron energies per machine

Background

* Electron Energy Constancy
  * Measurement method using detector array and wedge shaped filter
    * Described by several authors
      * 1991 - 2011
    * Automated feature of some array detectors



Background

* Electron Energy Constancy
  * Equipment may be limited at some facilities
    * Smaller Clinics
    * Satellite Facilities
    * Budget Constraints
  * Method described applicable to most array detectors

Outline

* Background
* Measurement Methods
* Specification Limits
* Statistical Process Control Techniques
  * Control Limits
  * Process Capability
  * Process Acceptability

Measurement Method

* Closely Followed Method Described by Watts in 1998

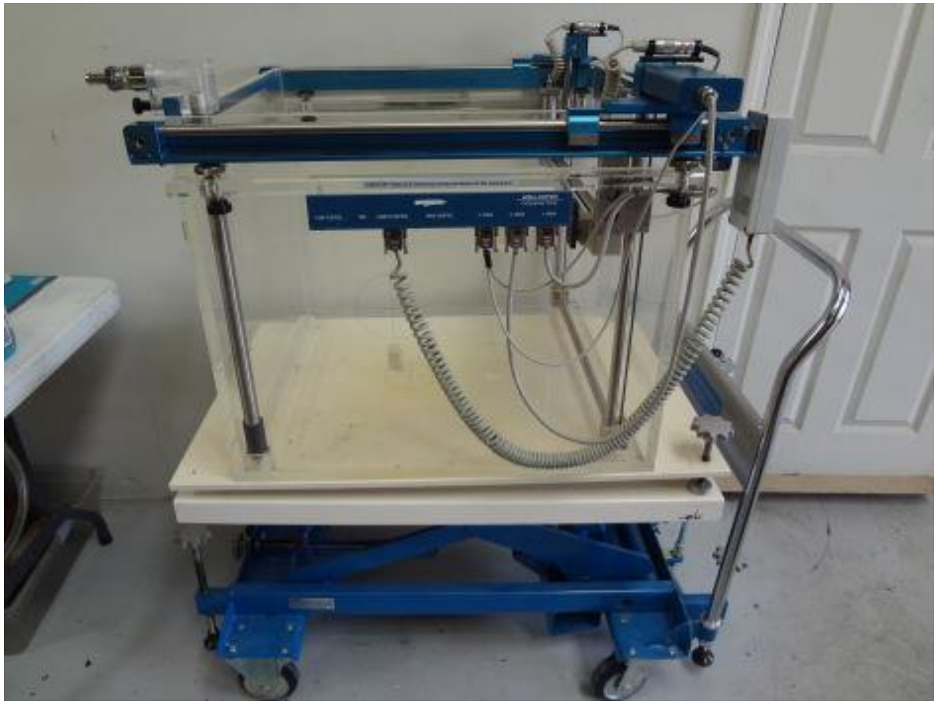
Evaluation of a diode detector array for use as a linear accelerator QC device

Ronald J. Watts[a)]
Live Oak Regional Cancer Center, San Antonio, Texas 78233

Med. Phys. 25 (2), February 1998

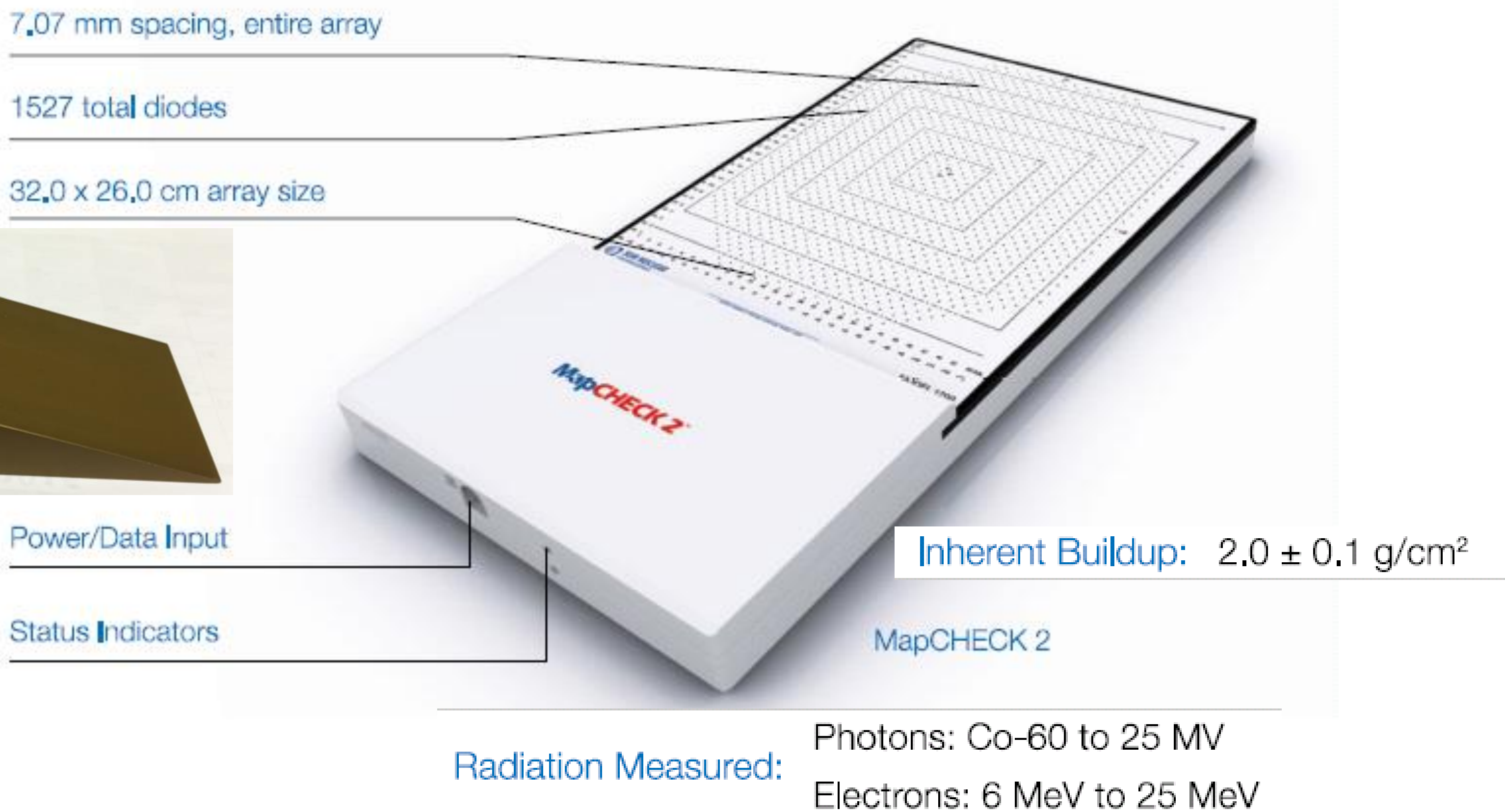
Measurement Method

- IBA Blue Phantom
  - Annual QA
  - $E_{p,0}$ Measured for Each Electron Beam



Measurement Method

- MapCheck2 Diode Array
- Aluminum Wedge

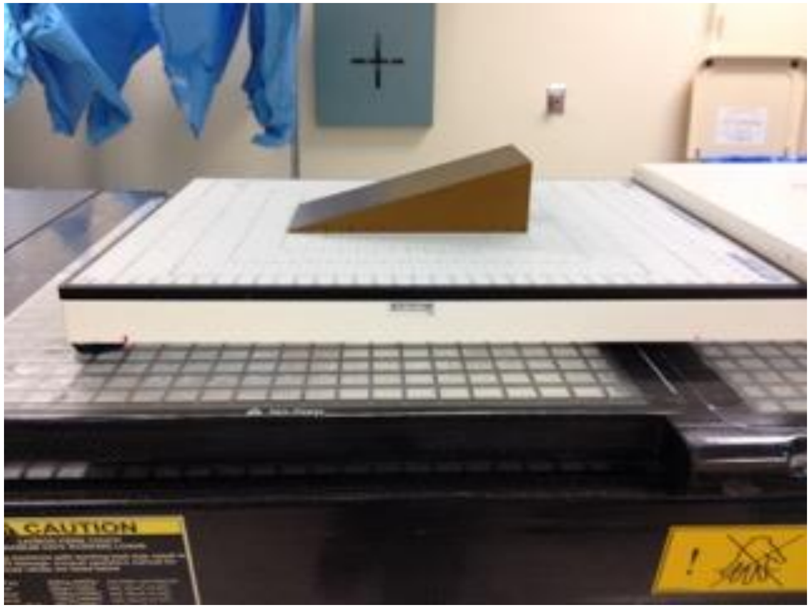


Measurement Method

- Equipment Setup
  - MapCheck2
    - Leveled
    - Centered with CAX
    - 100 cm SSD
  - 20 cm x 20 cm Electron Cone

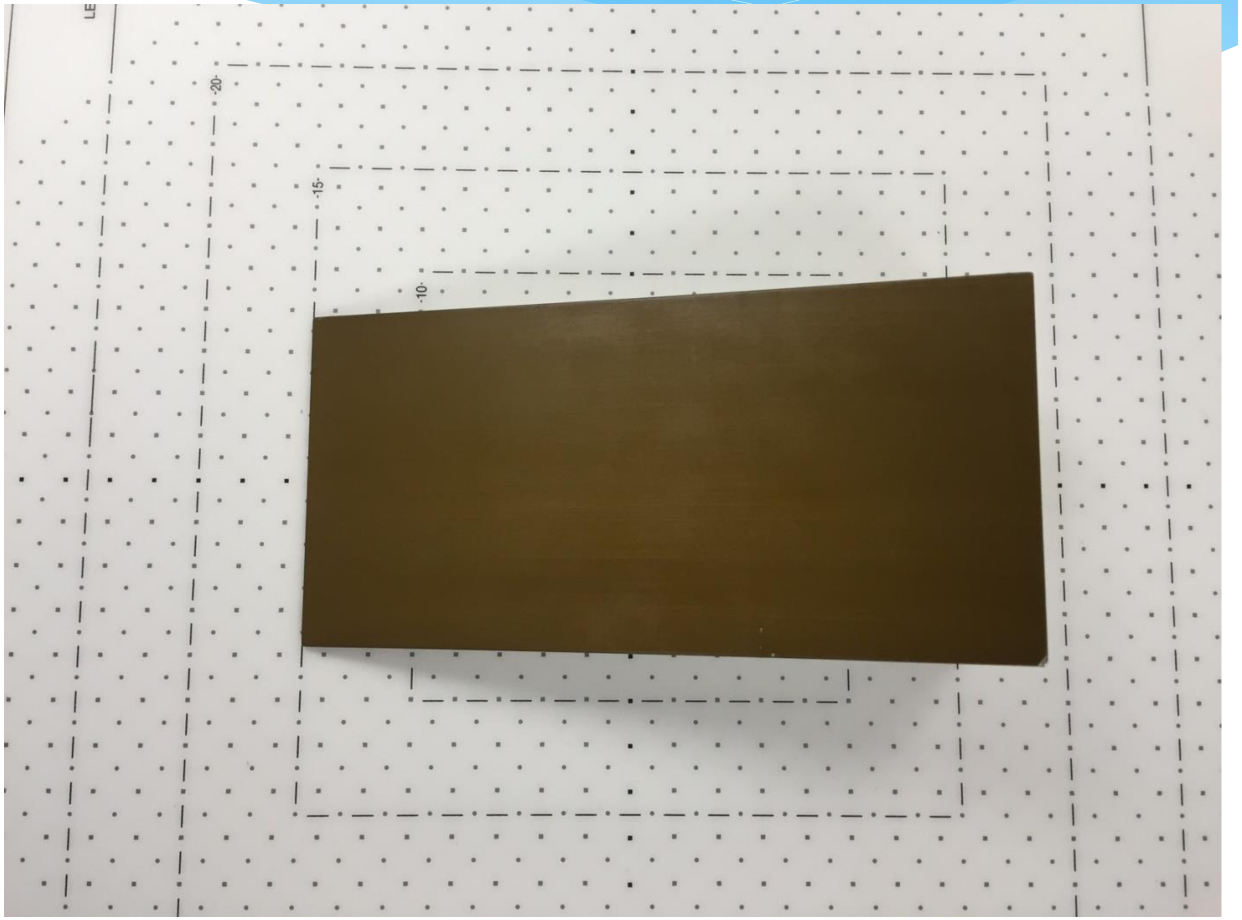
Measurement Method

* Equipment Setup
  * Aluminum Wedge
    * Wedge Direction Inplane
    * Toe Toward Gantry
    * Heel Right Angle on MapCheck2 Surface

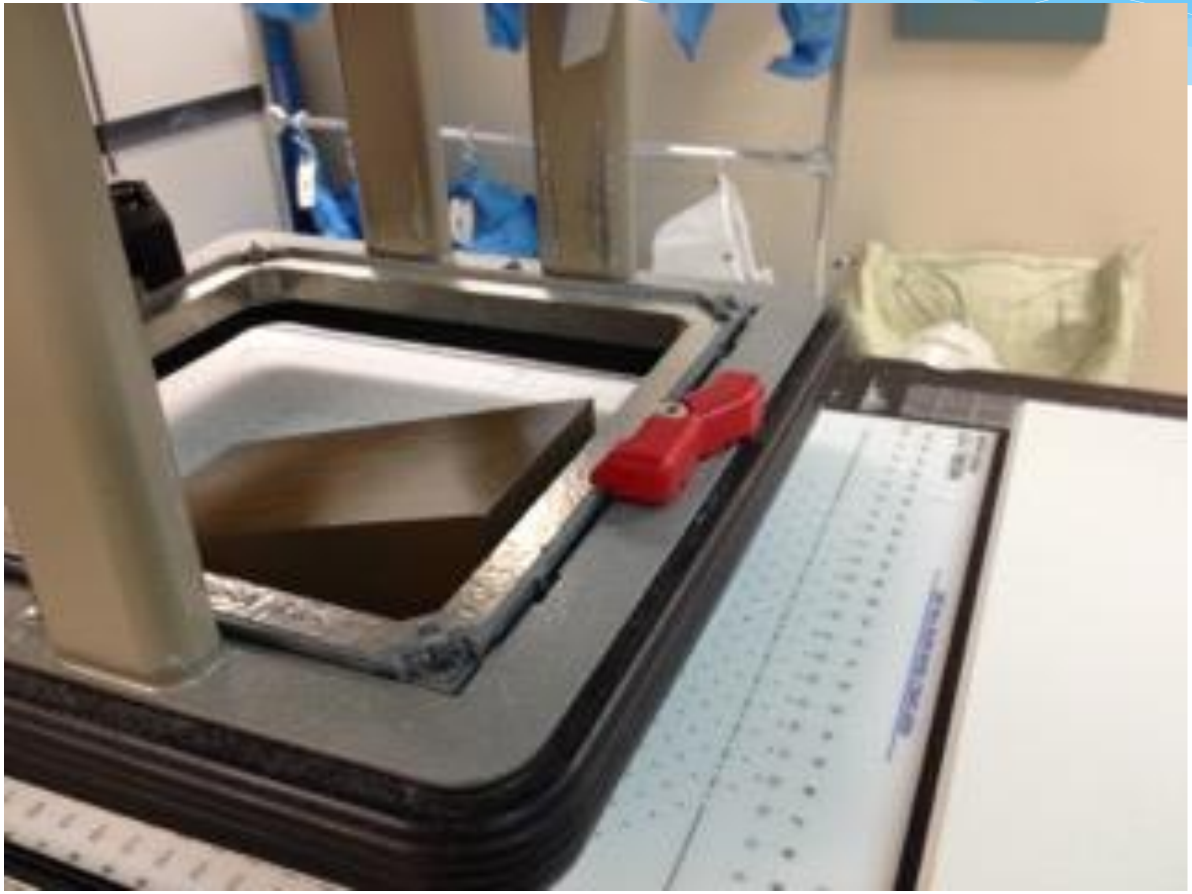


Measurement Method

- Equipment Setup
  - Aluminum Wedge
    - Toe Aligned with 15 cm Field Edge Demarcation

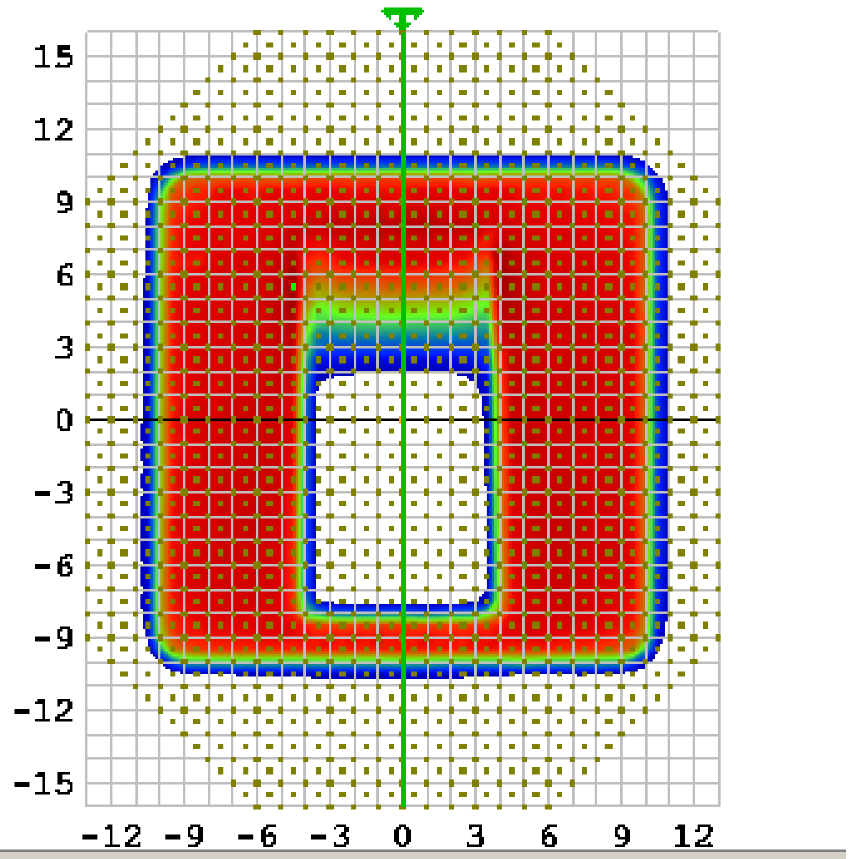


Measurement Method



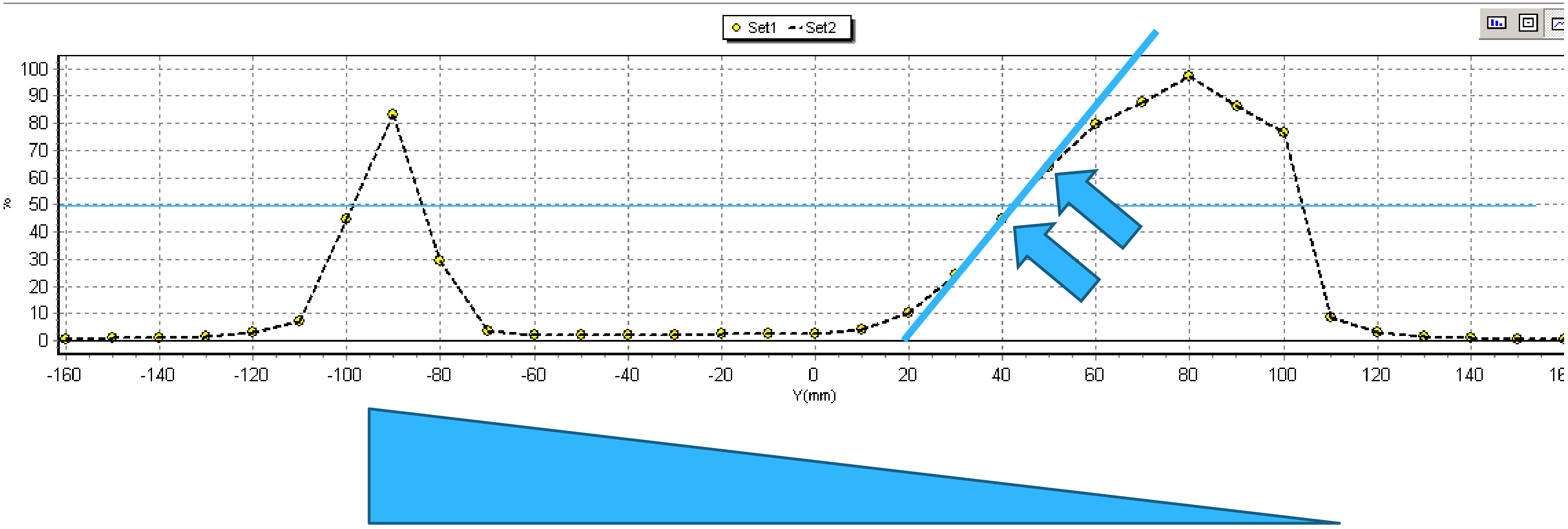
Measurement Method

- Planar Fluences were Measured for Each Electron Energy
- Only readings along center of detector in Y direction of interest



Measurement Method

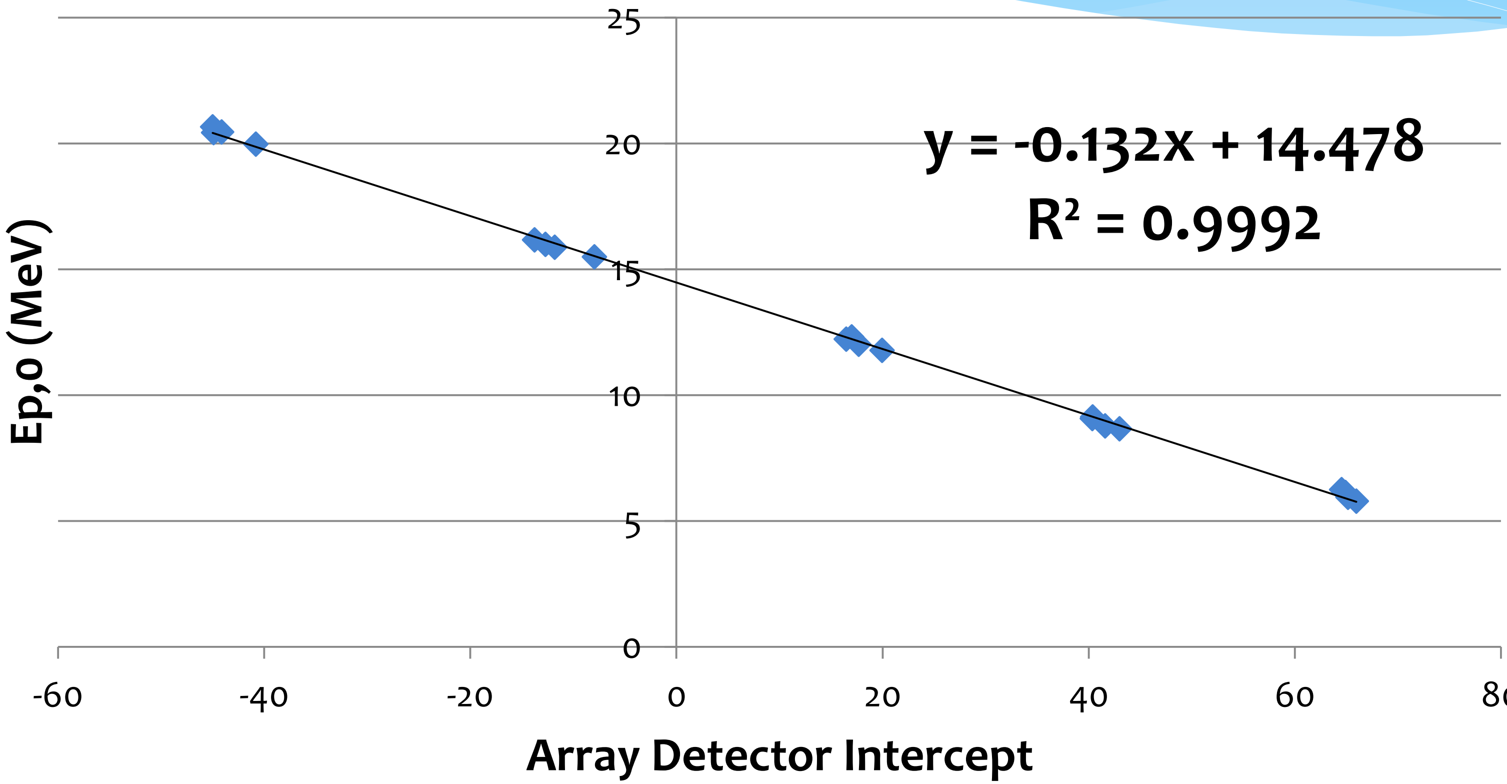
* Intercept of the tangent line to the 50% point on the "toe" end of profile calculated and recorded



Measurement Method

* 4 Linear Accelerators
  * 1 Varian 21iX
  * 2 Varian 21 EX
  * 1 Varian 21 EX-S
* 5 Electron Energies per Linac
  * 6, 9, 12, 16, 20 MeV
* Total of 20 Electron Beams

Measurement Method



Most Probably Electron Energy at Surface ($E_{p,o}$) vs. Array Detector Intercept

Measurement Method

* Efficiency
  * Same setup for each electron beam
  * Adds about 10 minutes to acquire fluences
  * Use same setup without wedge to measure profiles
    * Flatness/Symmetry

Outline

* Background
* Measurement Methods
* Specification Limits
* Statistical Process Control Techniques
  * Control Limits
  * Process Capability
  * Process Acceptability

Specification Limits

Task Group 142 report: Quality assurance of medical accelerators[a)]

TABLE II. Monthly.

Procedure	Machine-type tolerance	
	Non-IMRT	IMRT
Dosimetry		
X-ray output constancy		
Electron output constancy	2%	
Backup monitor chamber constancy		
Typical dose rate[a] output constancy	NA	2% (@ IMRT dose rate)
Photon beam profile constancy	1%	
Electron beam profile constancy	1%	
Electron beam energy constancy	2%/2 mm	

Specification Limits

* Need to correlate shift in PDD to change in $E_{p,0}$
* Referred to TG-70

Recommendations for clinical electron beam dosimetry: Supplement to the recommendations of Task Group 25

Gerbi *et al.*: TG70: Recommendations for clinical electron beam dosimetry

Med. Phys. 36 (7), July 2009

Specification Limits

$E_{p,0}$: Most probable energy (kinetic) of an electron beam at the surface of a water phantom for an electron beam. Unit: MeV.

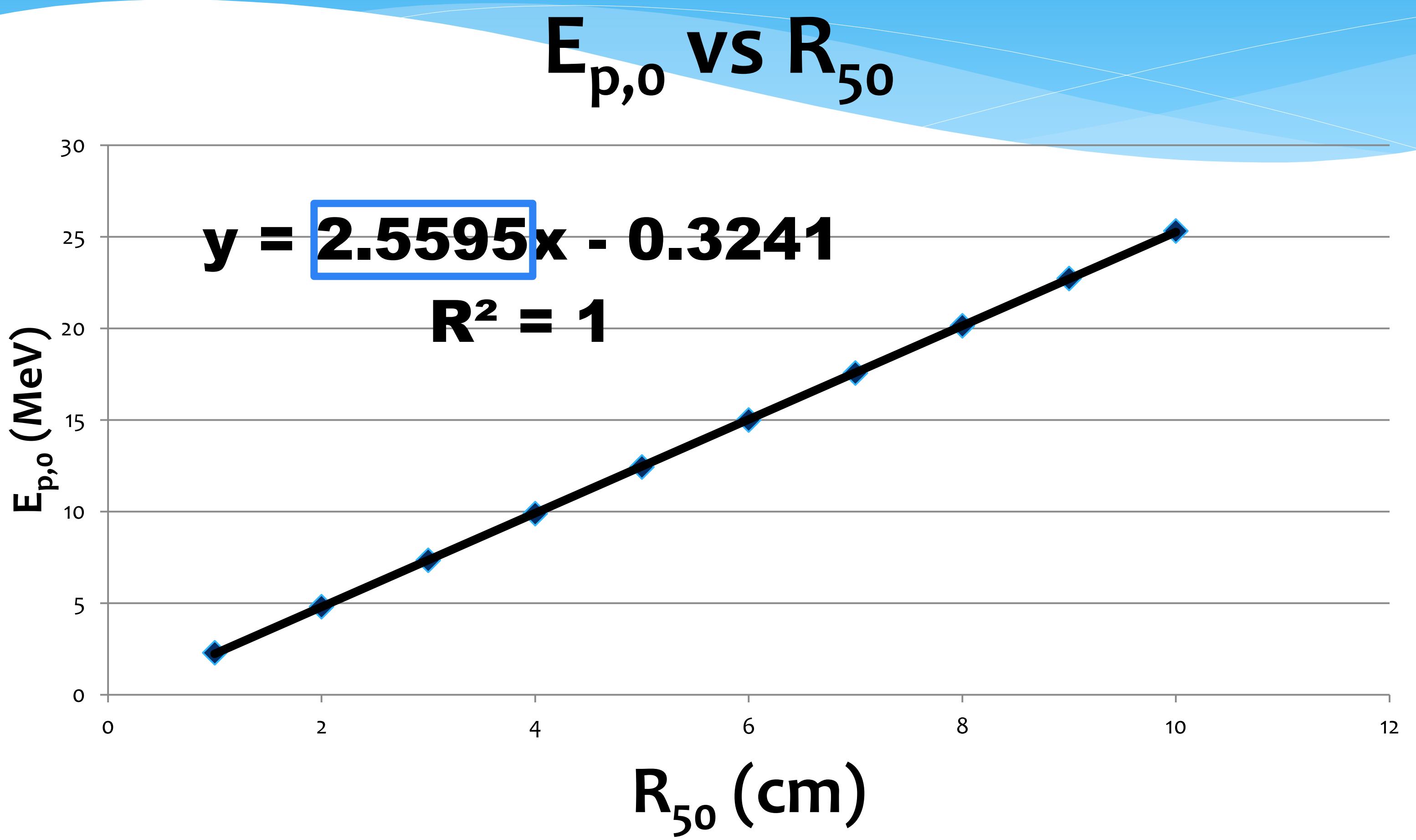
$$E_{p,0} = 0.22 + 1.98 R_p + 0.0025 R_p^2,$$

$$R_p = 1.271 R_{50} - 0.23 \quad (\mathrm{cm}).$$

Need to Know: Change in $E_{p,0}$ for a 2 mm change in R50

Gerbi *et al.*: TG70: Recommendations for clinical electron beam dosimetry

Specification Limits



Specification Limits

$$y = 2.5595x - 0.3241$$

- Slope = 2.56 MeV/cm
- Slope = 0.256 MeV/mm
- 2 mm Shift in R_{50} = 0.51 change in MeV
- Spec = +/- 0.5 MeV

Clinical Implementation

Electron Energy Checks

Setup: 100 cm SSD to Mapcheck Surface, No Buildup, Aluminum Wedge Placed on Mapcheck Surface with Toe toward gantry touching 15 cm line, Difference Between Baseline and Calculated Epo Should be ≤ 0.5 MeV

	6 MeV Electrons		9 MeV Electrons		12 MeV Electrons	
	A	B	A	B	A	B
Detector Location	70	80	60	70	40	50
Readings						
Calculated Intercept	#DIV/0!		#DIV/0!		#DIV/0!	
Calculated Epo	#DIV/0!		#DIV/0!		#DIV/0!	
Baseline	5.769		8.804		11.842	
Difference	#DIV/0!		#DIV/0!		#DIV/0!	

Statistical Process Control Techniques

- Remaining Questions
  - Stability of Method Over Time
  - Reproducibility of Setup
  - Inter-User Variability
- Turned to Statistical Process Control Techniques
  - A lot of options

Statistical Process Control Techniques

* Most Applicable
  * Control Limits & Control Charts
  * Process Capability
  * Process Acceptability

Control Charts

* Originated with Walter Shewhart
  * 1920's
  * Bell Laboratories
* Used to determine if Process:
  * Stable
  * Has Predictable Performance

Control Charts

* Shewhart Identified two sources of process variation
  * “Chance” Variation
    * Inherent in process
    * Stable over Time
  * “Assignable” Variation
    * Result of specific event outside system
    * Unstable over Time

Control Charts

* “Chance” Variation
  * Random Error
  * Common Cause
* “Assignable” Variation
  * Systematic Error
  * Special Cause

Control Charts Help Distinguish Between the Two Types of Error

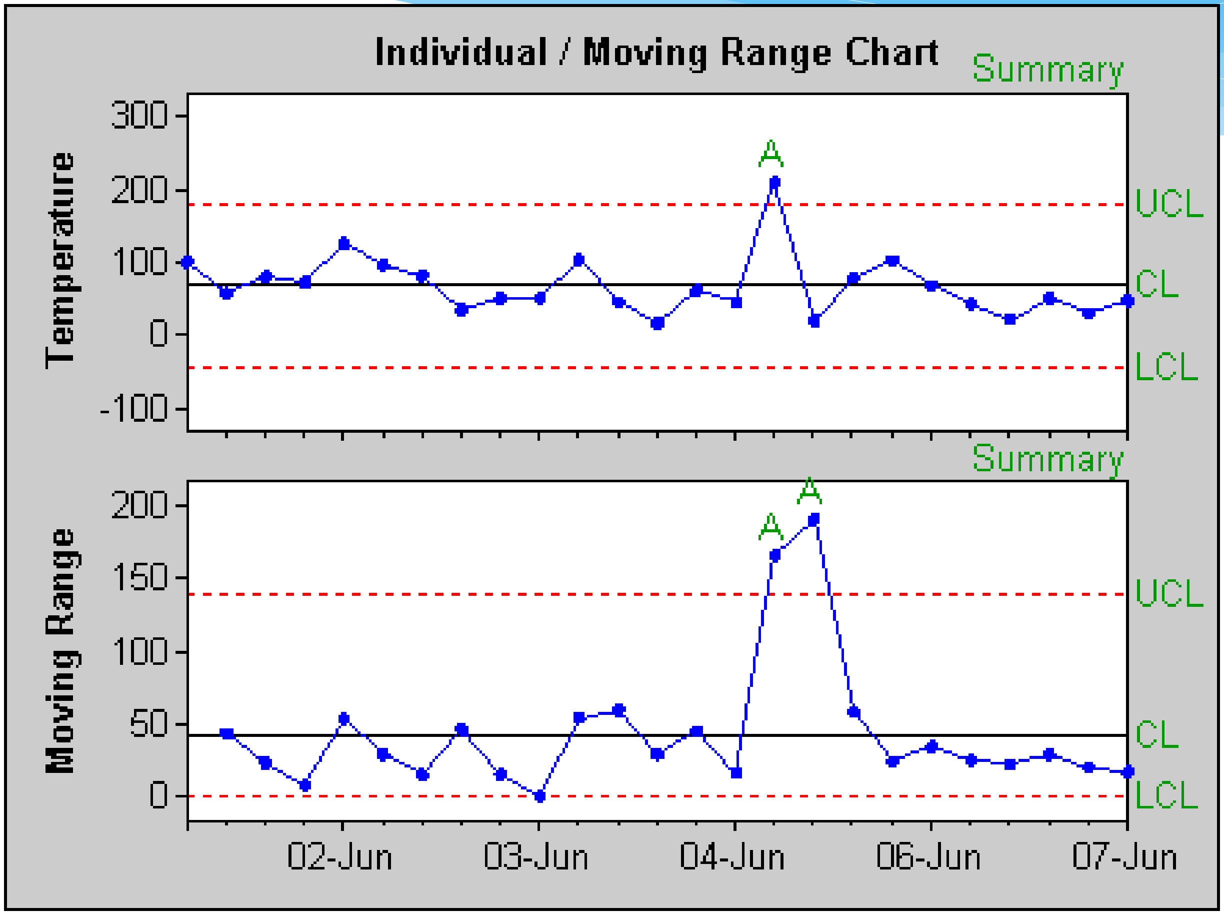
Control Charts

* Different Types of Control Charts
  * Attribute Data
    * Discrete
    * Y/N
    * Good/Bad
  * Variable Data
    * Continuous Scale

Control Charts

* Variable Data Charts (Actually Pairs of Charts)
  * X and Moving Range Chart
    * Sample Size (n) = 1
  * X-Bar and Range Chart
    * n = 2-9
  * X-Bar and S Chart
    * n > 10

Control Charts



Control Charts

* How do I apply control charts to $E_{p,o}$ measurements?

Statistical process control for radiotherapy quality assurance

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Arthur L. Boyer
Department of Radiation Oncology, Stanford University School of Medicine, Stanford, California 94305

Med. Phys. 32 (9), September 2005

Control Charts

- Steps
  - Collect Initial Data
    - Ensure meets specification
  - Establish Control Limits Using Collected Data
  - Create Charts
  - Record Data in Charts

Control Charts

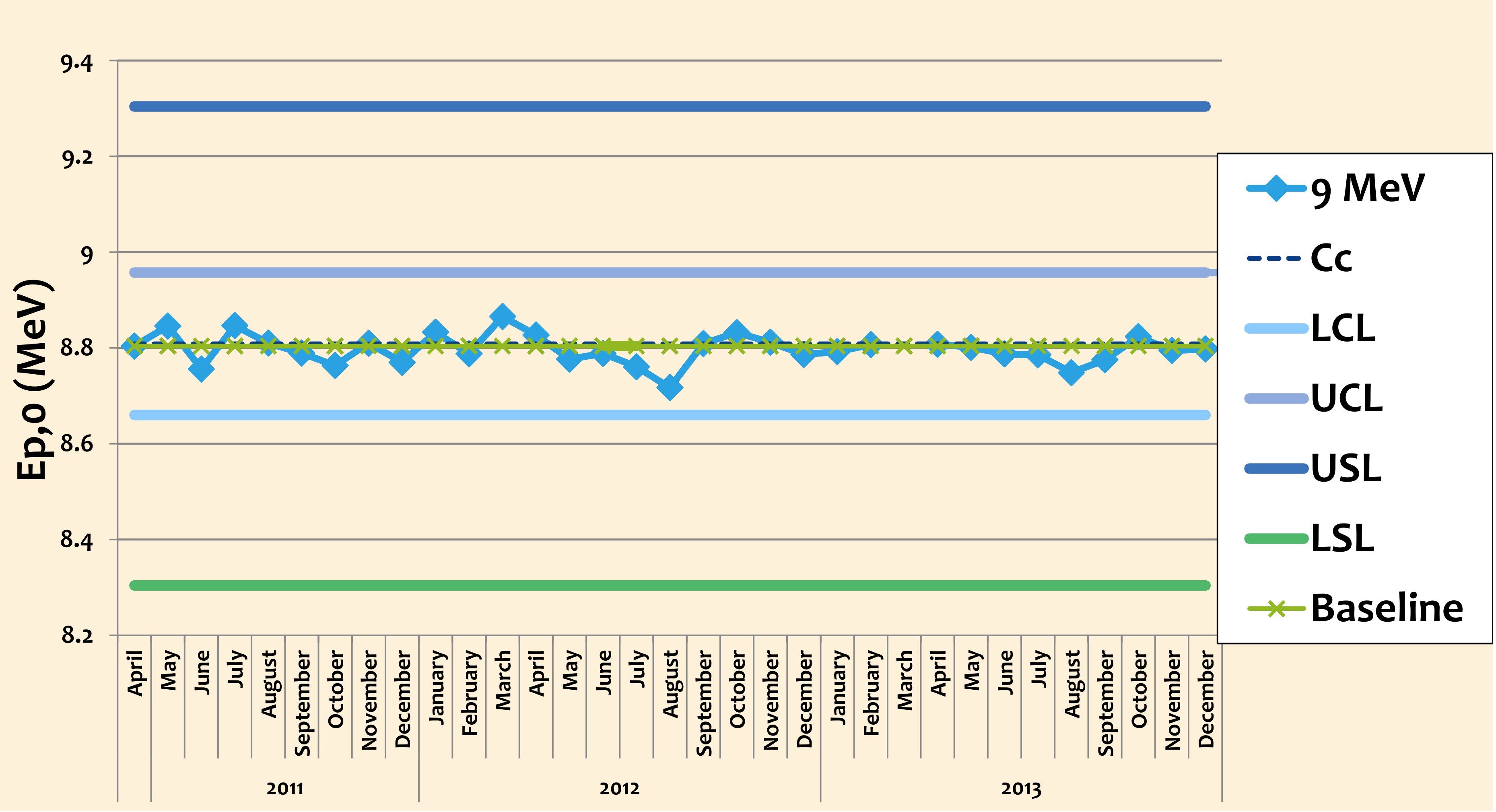
* 6 months of data collected for each electron beam
  * Calculated the Average ($\bar{x}$)
  * Calculated Range (R)
    * Absolute difference between two successive measurements
  * Calculated Average Range ($\bar{R}$)

Control Charts

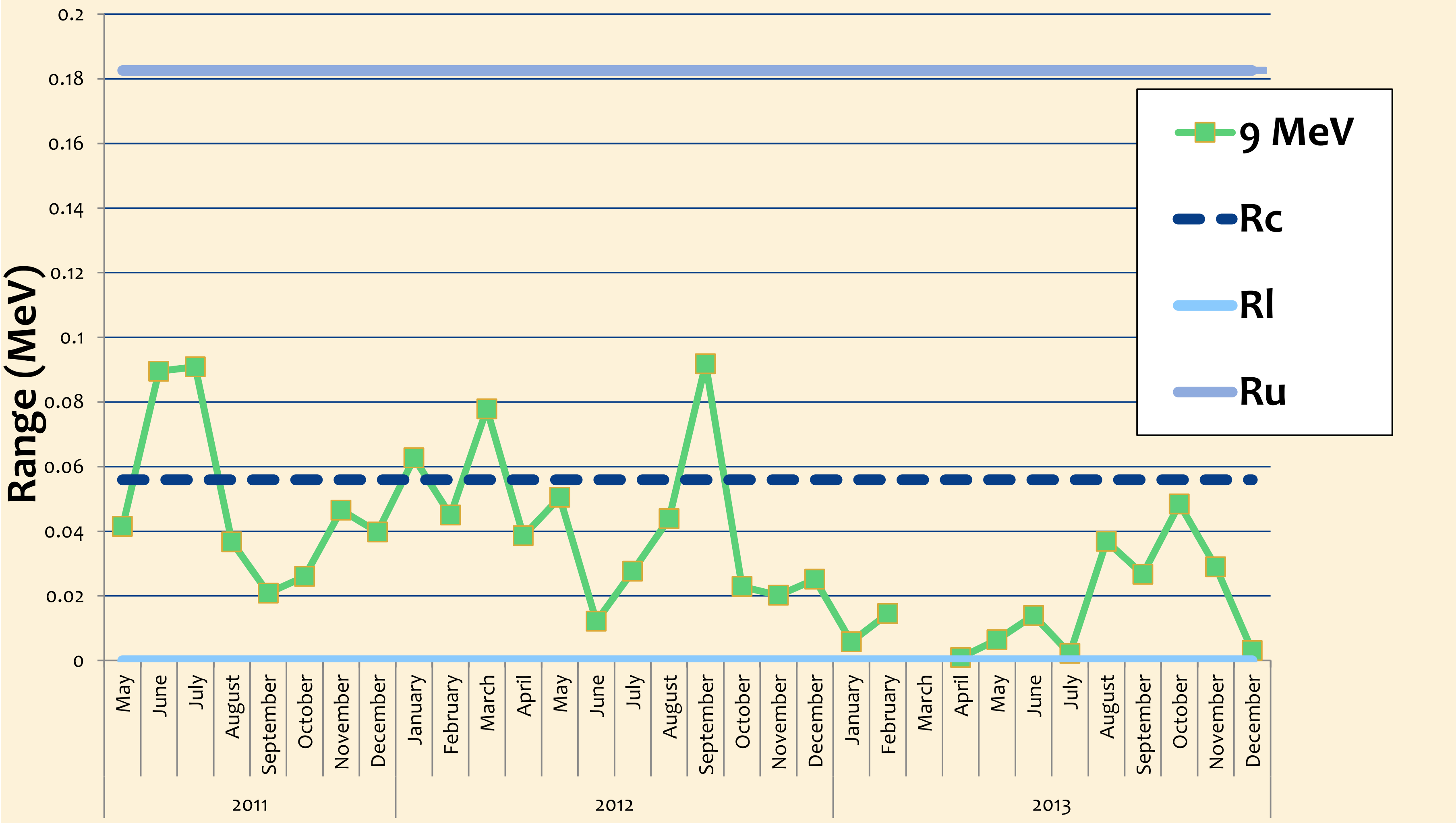
- Control Limits for Individual Control Chart
  - $Control\ Center(C_c) = \bar{x}$
  - $Upper\ Control\ Limit(UCL) = \bar{x} + 2.66\bar{R}$
  - $Lower\ Control\ Limit\ (\text{LCL}) = \bar{x} - 2.66\bar{R}$
- Control Limits for Moving Range Chart
  - $Range\ Center(R_c) = \bar{R}$
  - $Upper\ Range\ Limit(URL) = 3.27\bar{R}$
  - $Lower\ Range\ Limit(LRL) = 0$

Control Limits Represent 3 Standard Errors from the Mean

Individual Control Chart



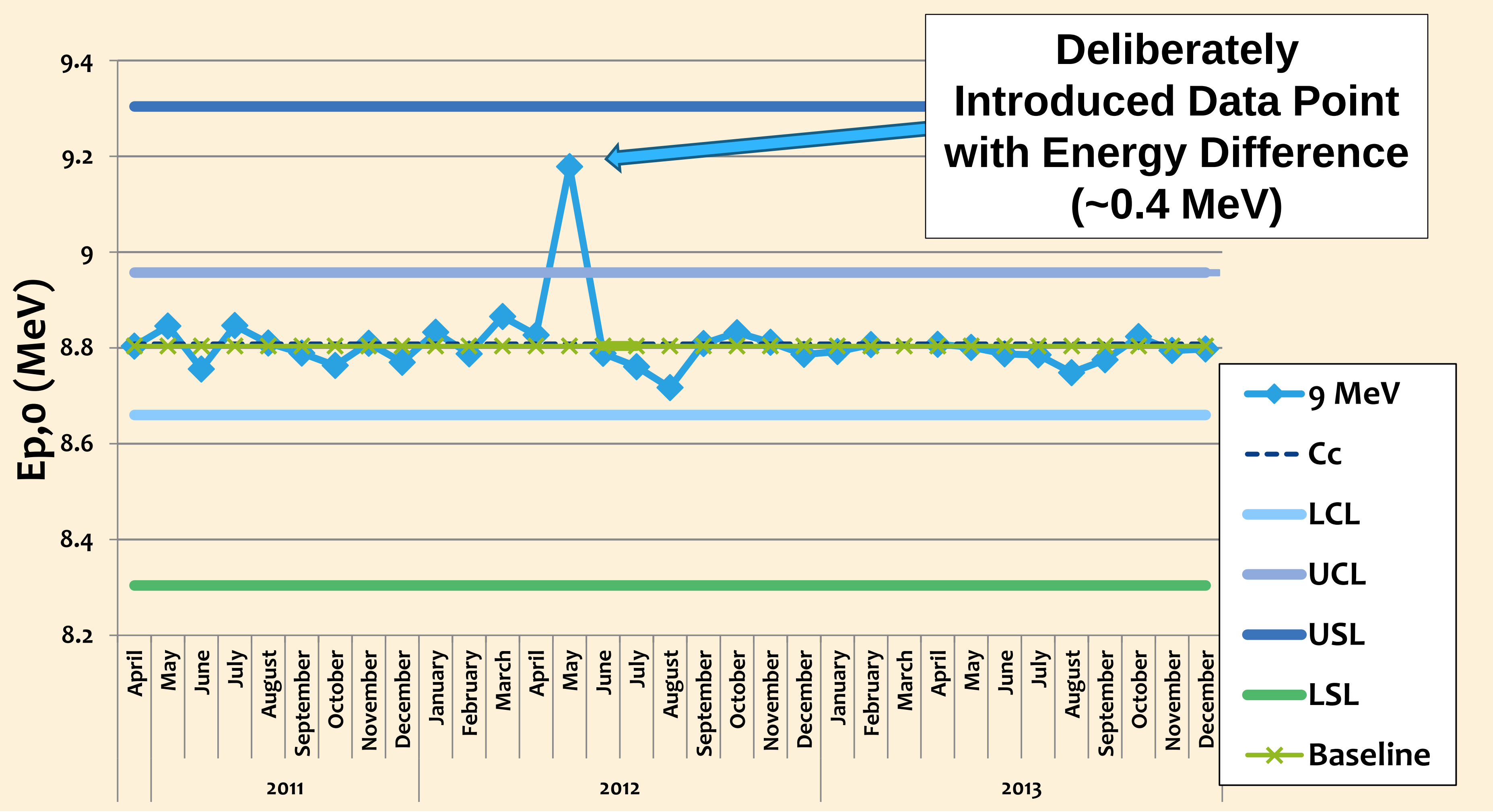
Moving Range Chart



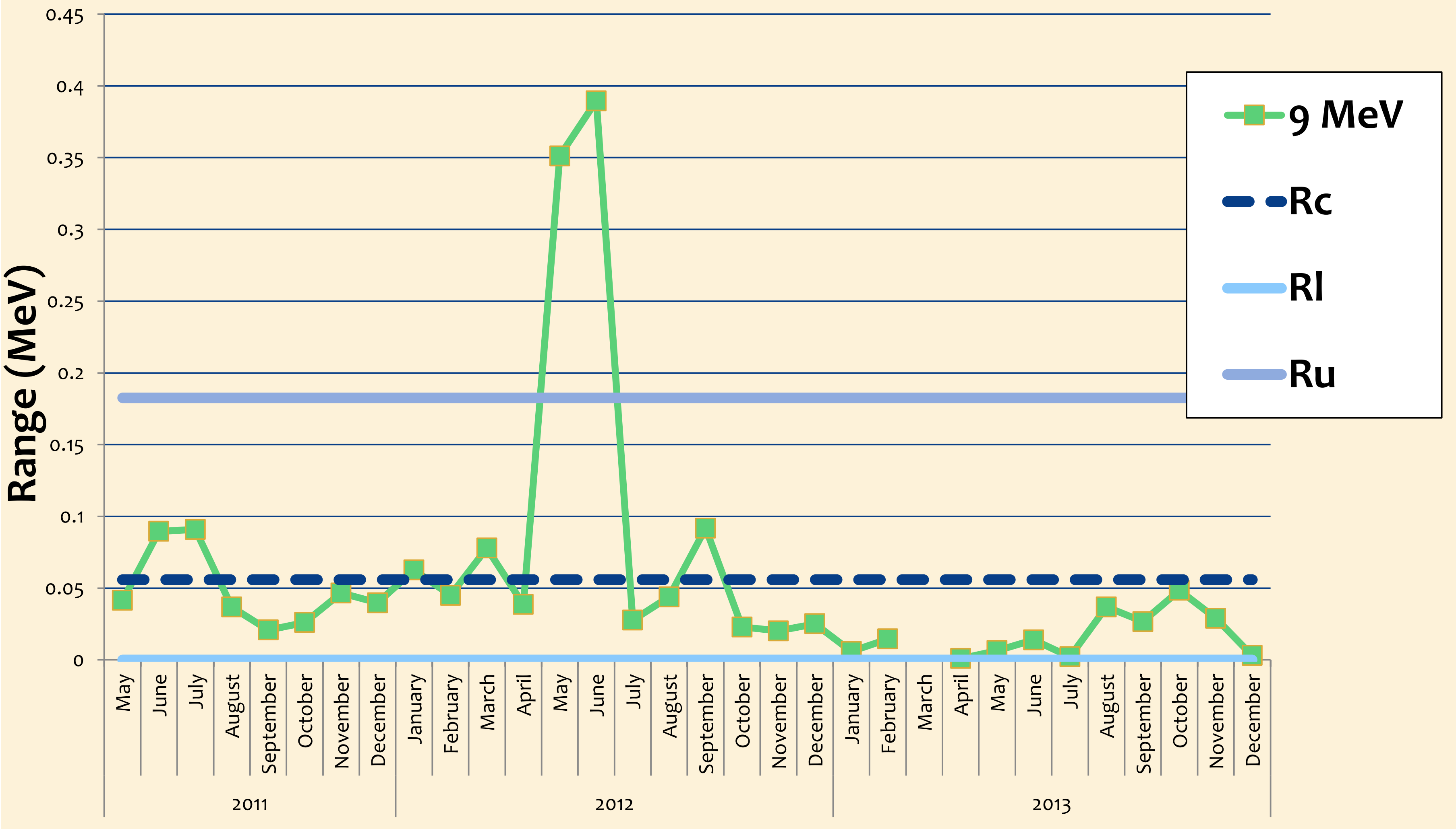
Control Charts

* All control limits well within specification limits
* Shows that the process is in control
  * All data points fall within control limits
  * Data follows a random pattern
* Process stability should allow for distinction between random and systematic errors
  * Noise small so signal should be able to be detected

Individual Control Chart



Moving Range Chart



Statistical Process Control Techniques

* Most Applicable
  * Control Limits & Control Charts
  * Process Capability
  * Process Acceptability

Process Capability and Acceptability

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 14, NUMBER 1, 2013

Retrospective analysis of linear accelerator output constancy checks using process control techniques

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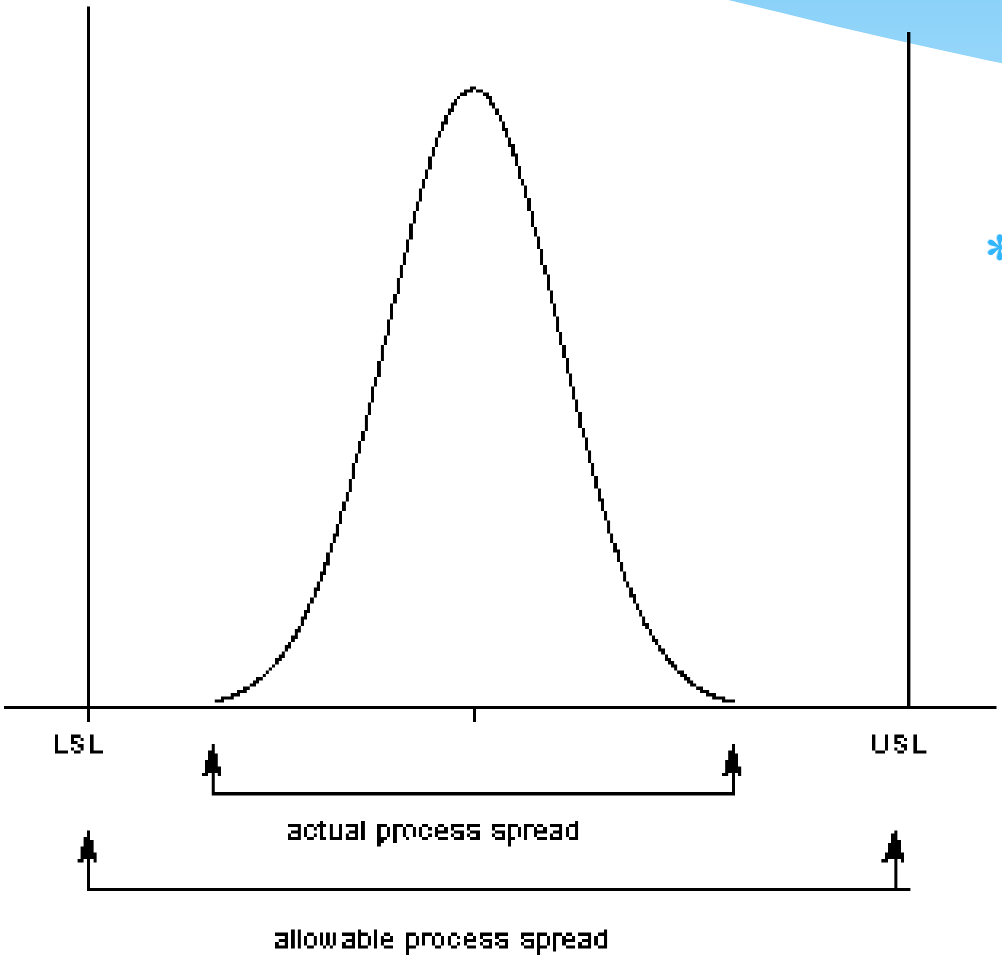
Process Capability and Acceptability

* Process Capability (C_p)
  * How well a process is capable of meeting specification
  * Comparison between:
    * Spread of data
    * Window size of specification limits
  * $C_p = \frac{USL - LSL}{6\sigma}$
  * σ = process standard deviation

Process Capability and Acceptability



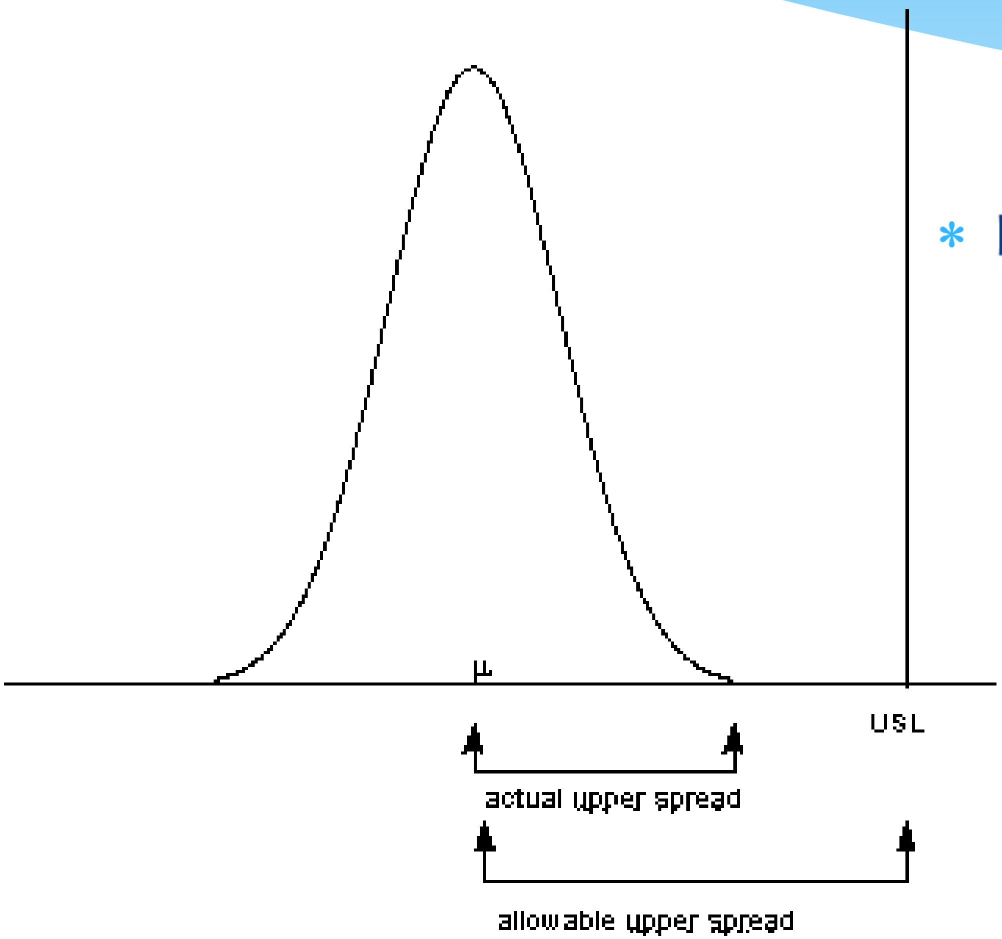
- Process Capability (C_p)
  - $C_p = \frac{USL - LSL}{6\sigma}$
  - If $C_p \geq 1$, process capable of meeting specs

NIST/SEMATECH e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook

Process Capability and Acceptability

* Process Acceptability (C_{pk})
  * How well a process is centered within the specification limits
  * $C_{pk} = \min\left(\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right)$
  * μ= process mean
  * σ = process standard deviation

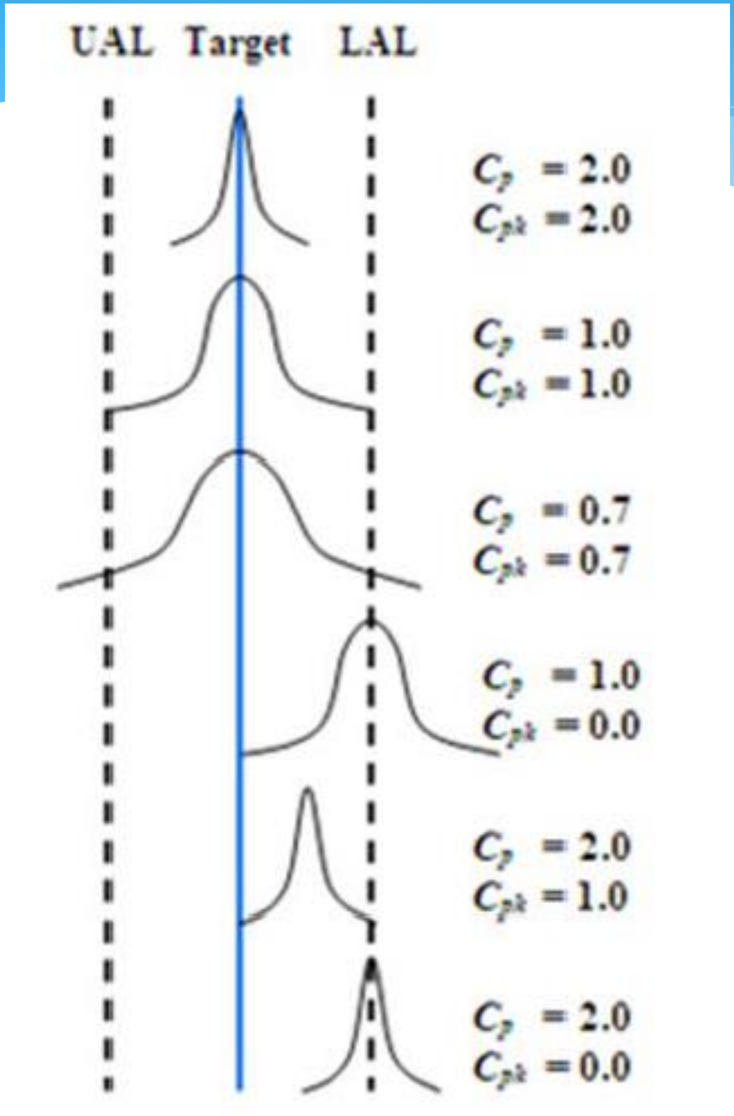
Process Capability and Acceptability



* Process Acceptability (C_{pk})
  * $C_{pk} = \min\left(\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right)$
  * If $C_{pk} \geq 1$, process centered within specs
  * If process perfectly centered, two solutions would be equal

NIST/SEMATECH e-Handbook of Statistical Methods, http://www.itl.nist.gov/div898/handbook/

Process Capability and Acceptability



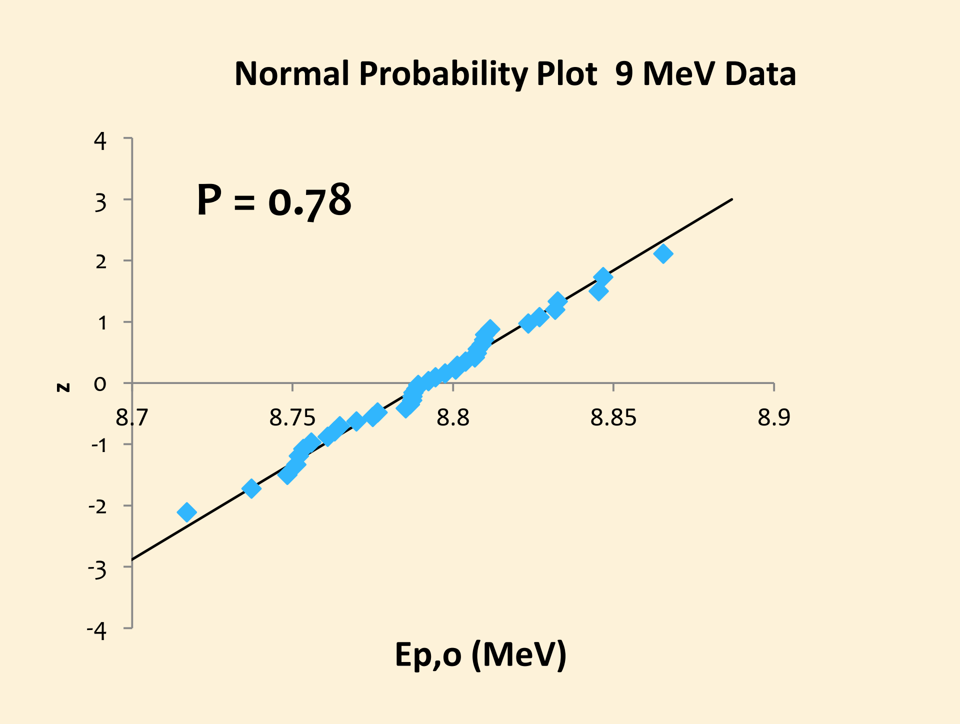
Sanghangthum et al, JACMP, Vol 14 (1), 2013, Pg 151, Used with Permission

Process Capability and Acceptability

- Data Requirements
  - Normal Distribution
  - “Large Enough” data sample
    - Typically $\geq$ 30 data points
  - Need to assess measured data to determine if requirements met

Process Capability and Acceptability

- Normal Distribution Assessment
  - Anderson-Darling Test
  - P ≥ 0.05, data considered normal
  - P values range 0.14 – 1.0
  - All data considered normally distributed
- Data Size ~ 40



Conclusion: Data Meets Requirements for Analysis Using C_p and C_{pk}

Process Capability and Acceptability

* C_p Results
  * All values > 1
  * 2.7 – 10
  * Process for all energies capable of meeting specifications

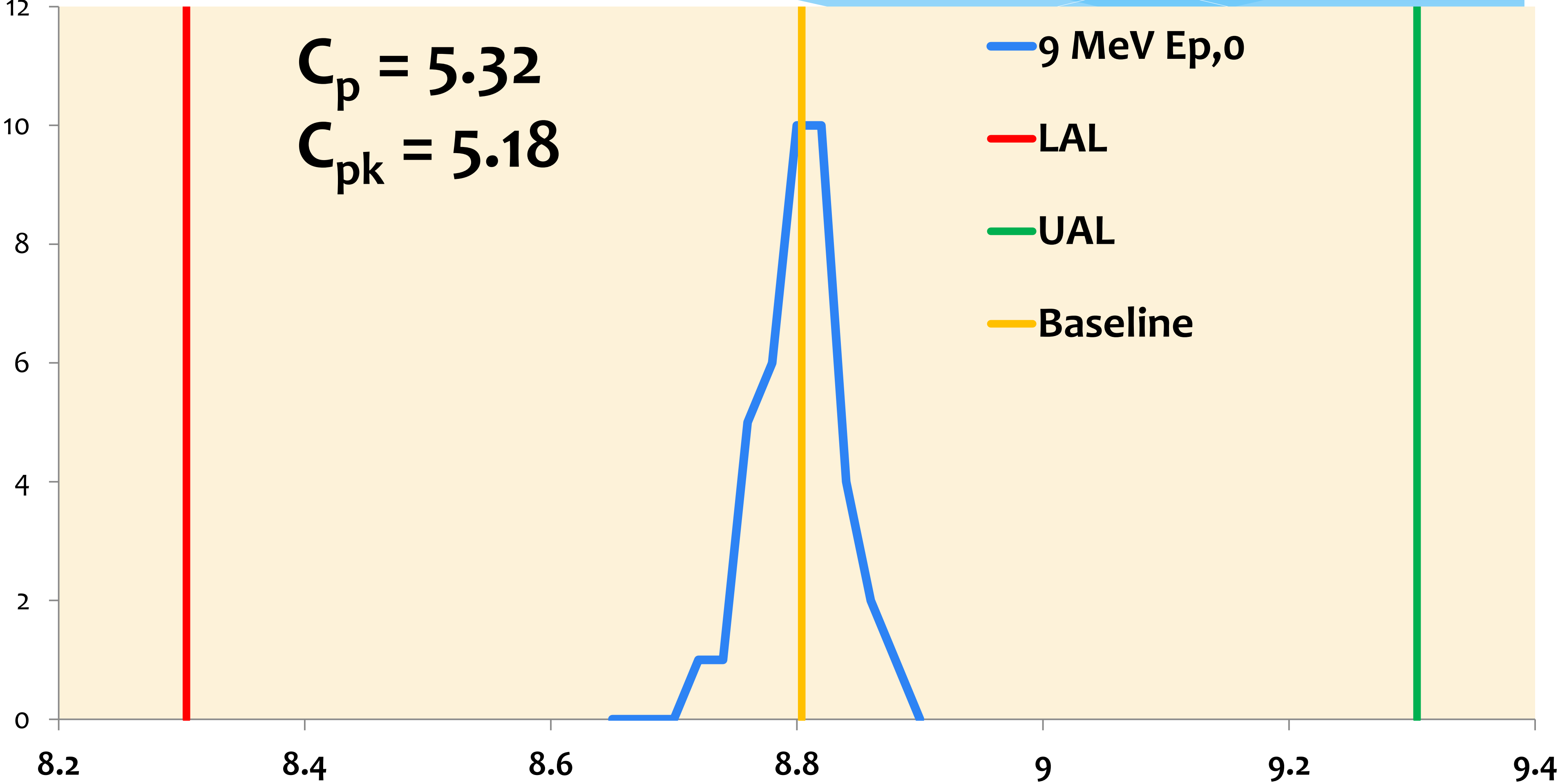
Process Capability and Acceptability

- C_{pk} Results
  - All values > 1
  - 1.8 – 9.6
  - Center of the process for all energies within specification limits

Process Capability and Acceptability

* Comparison of C_p and C_{pk}
  * $C_{pk} < C_p$ in all but 1 case
  * Indicated that process has some shift from baseline
  * Baseline value single measurement
  * Indicates that target value should be an average of in control values vs. single measurement

Process Capability and Acceptability



Summary

* Measurement Method Established to Measure $E_{p,0}$
  * MapCheck2 and Aluminum Wedge
* Specification Limits Established
  * 2 mm PDD shift = +/- 0.5 MeV
* Statistical Process Control Techniques
  * Control Limits
  * Process Capability
  * Process Acceptability

Summary

- Statistical Process Control Techniques Utilized
  - Control Limits
    - Process in Control
    - Control Limits well within Specification Limits
  - Process Capability
    - C_p >1 in all Cases
    - Process Capable of Meeting Specs
  - Process Acceptability
    - C_{pk} > 1 in all Cases
    - Process Centered within Specification Limits

Conclusion

* Electron energy verification method
  * Efficient
  * Effective
* Good option for centers with limited equipment
  * Small Centers
  * Satellite Centers
* Statistical Process Control
  * Tools useful for analyzing QA processes

La Fin

Merci

Me at the Marie Curie Museum in Paris

Questions?

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