The Physics Behind the IQM Signal

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Presentation Goals:

- Describe the calculation model for IQM in terms of the physical characteristics and behavior of linear accelerators
  - Outline the basis of the calculation
  - Review the approximations in the model
  - Present data on the level of agreement

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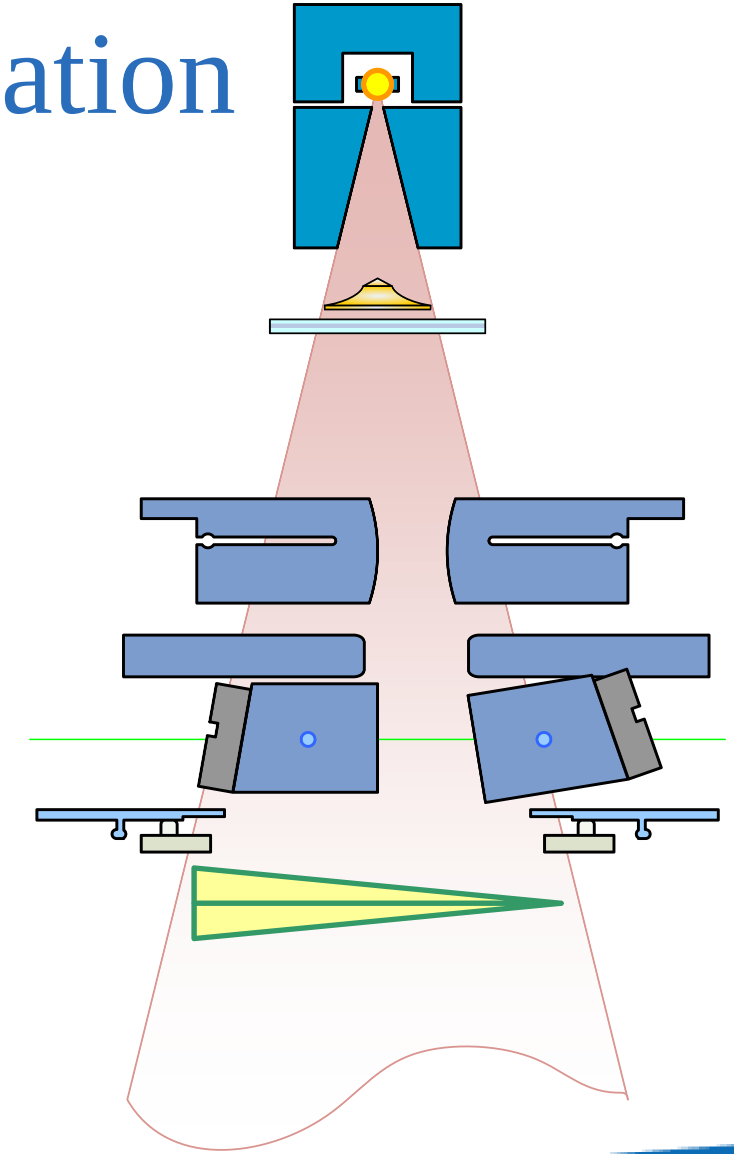
What inputs are expected?

- Predict the signal from IQM chamber based on:
  – Chamber characterization
  – Treatment unit (Linac) characterization
    - Collimation attenuation
    - Fluence profiles
  – Patient treatment description
    - Both static field-in-field and dynamic delivery modes
- Prediction accuracy = error detection
  – Target 2% accuracy throughout…

Linac Properties & IQM Calculation



- Scope of calculation
  - Chamber description and response
  - Linac Models
    - Source description assumptions
    - Geometry approximations
- Source Parameterization
  - Propagation of fluence to IQM signal generation

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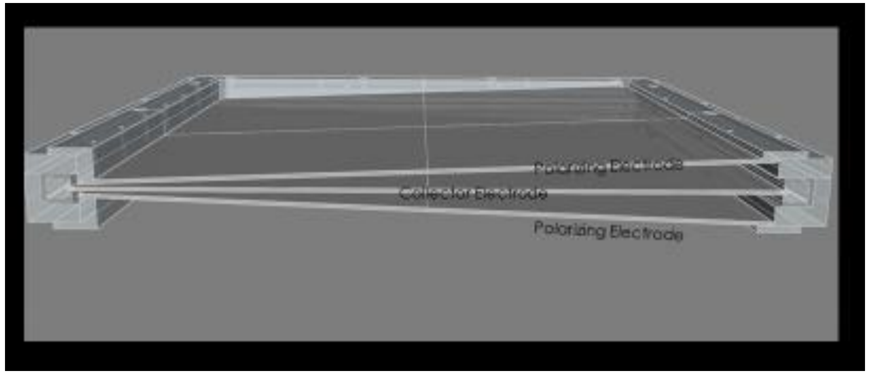
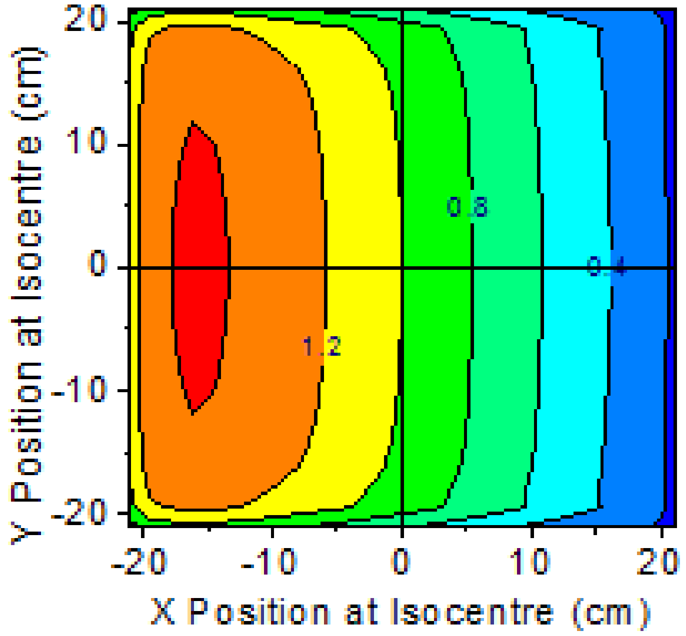
IQM Chamber Properties

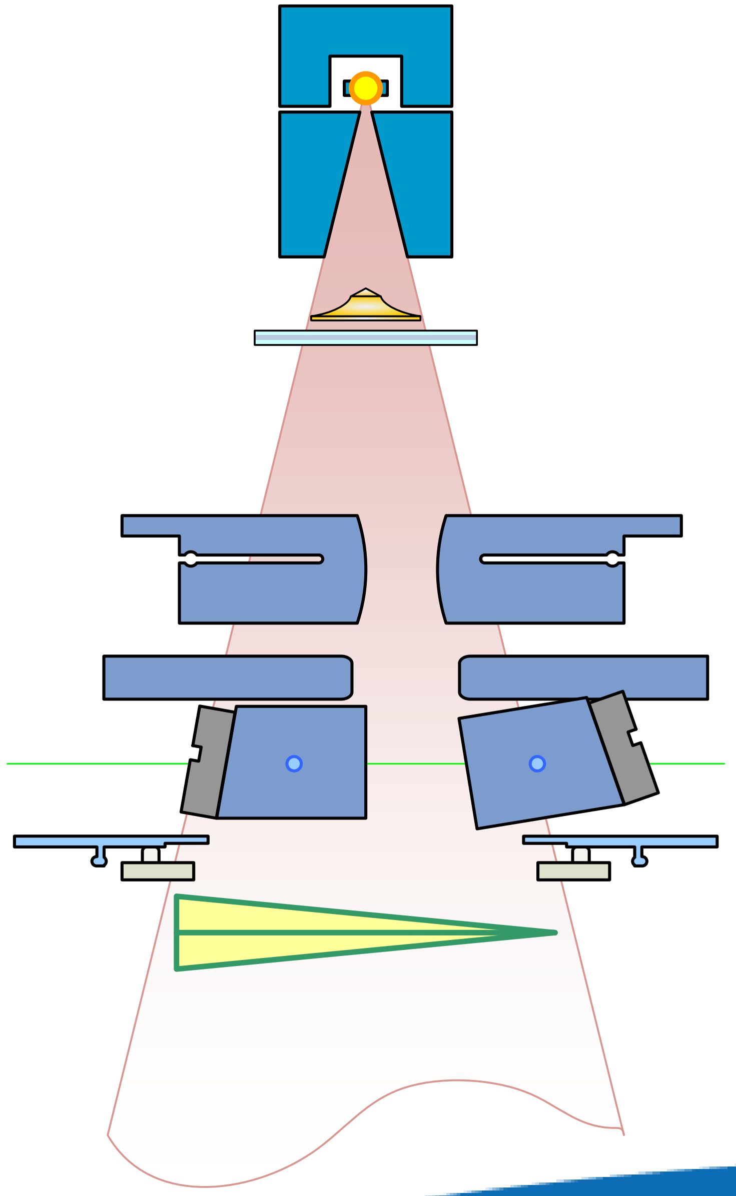
- Sloped electrode chamber
  - Spatial gradient = delivery position encoding
- Characterized by
  - Reference field normalization
  - Gradient (sensitivity) map
  - CSM, (S_{IQM})





Linac Characterization

- Behaviour to capture:
  - Output change with field size
  - Radial Profile
  - Transmission through collimating elements
- Source Assumption
  - Primary point source
  - Extended secondary source



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Fundamentals of Signal Calculation

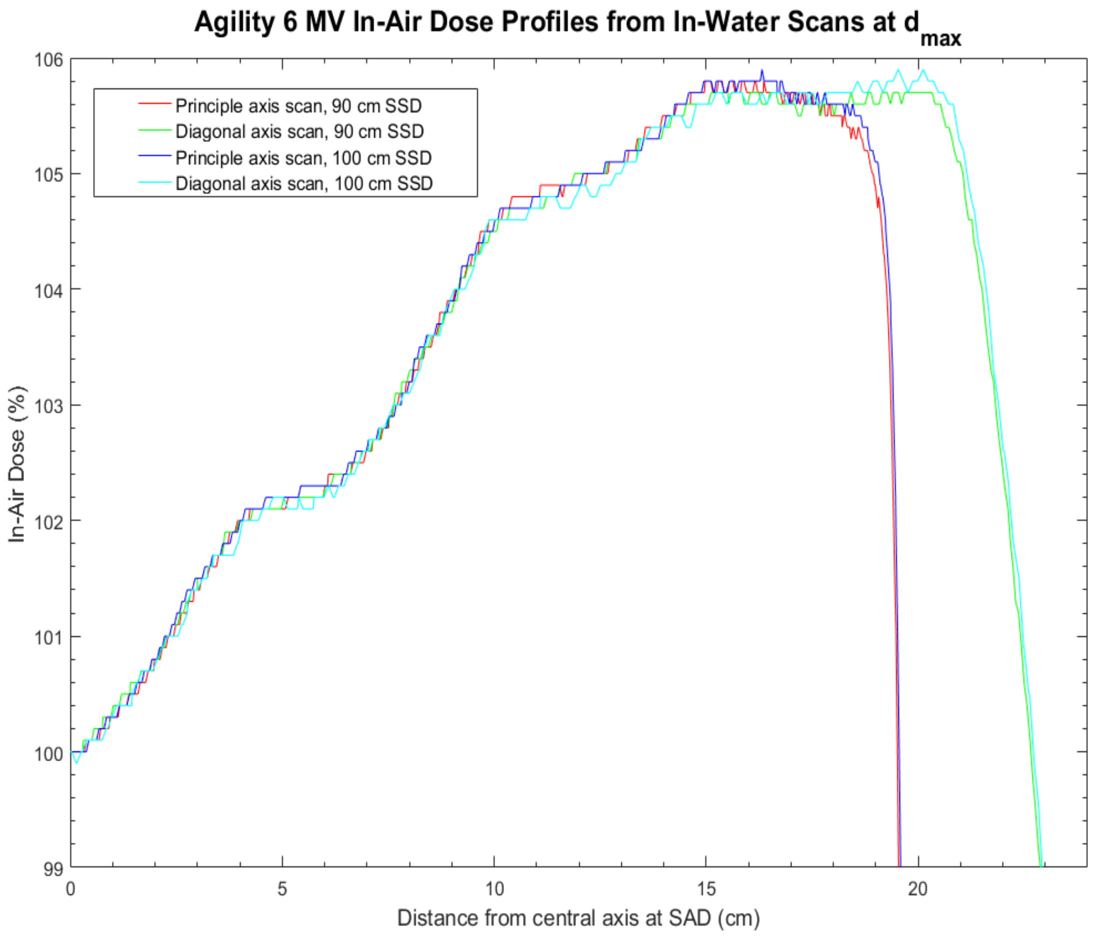
- IQM Signal for a Segment:

$$C_{IQM} = U \cdot AOF(x,y) \cdot \frac{N_{IQM}}{n \times m} \cdot \sum_{i,j}^{n,m} S_{IQM}(i,j) \cdot \left((1 - f_S)I_P + f_S I_S\right)$$

  - U = MU setting for segment
  - AOF = output change with field size (residual…)
  - $\frac{N_{IQM}}{n \times m}$ = normalization (electrometer reading)
  - I_P, I_S = primary and secondary source intensity matrix
  - f_S = fractional contribution from secondary source
  - S_{IQM} = chamber positional sensitivity matrix

Primary Source Intensity I_P

- Starts with open source profile
  - Assume radially symmetric intensity profile
  - Apply effect of collimation attenuation
  - Works on an area weighted average rather than an intensity to a point



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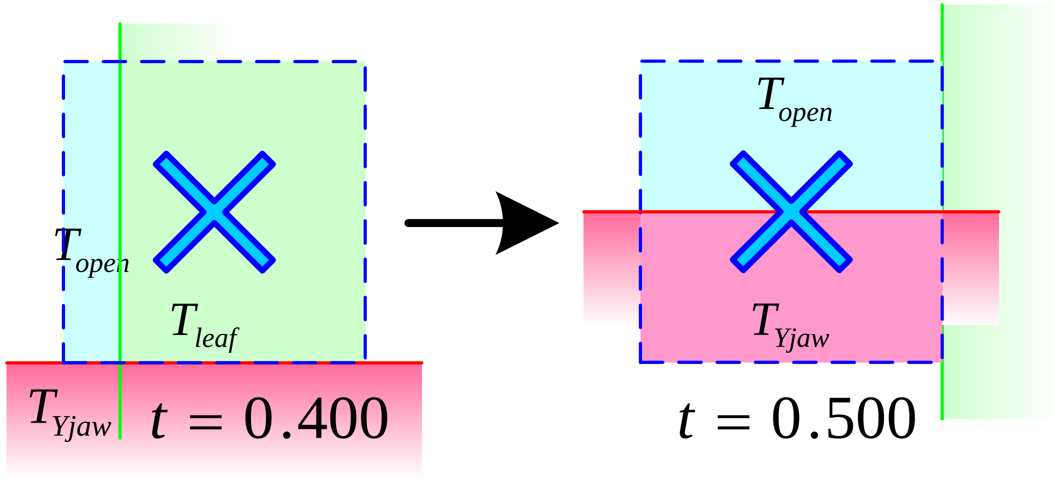
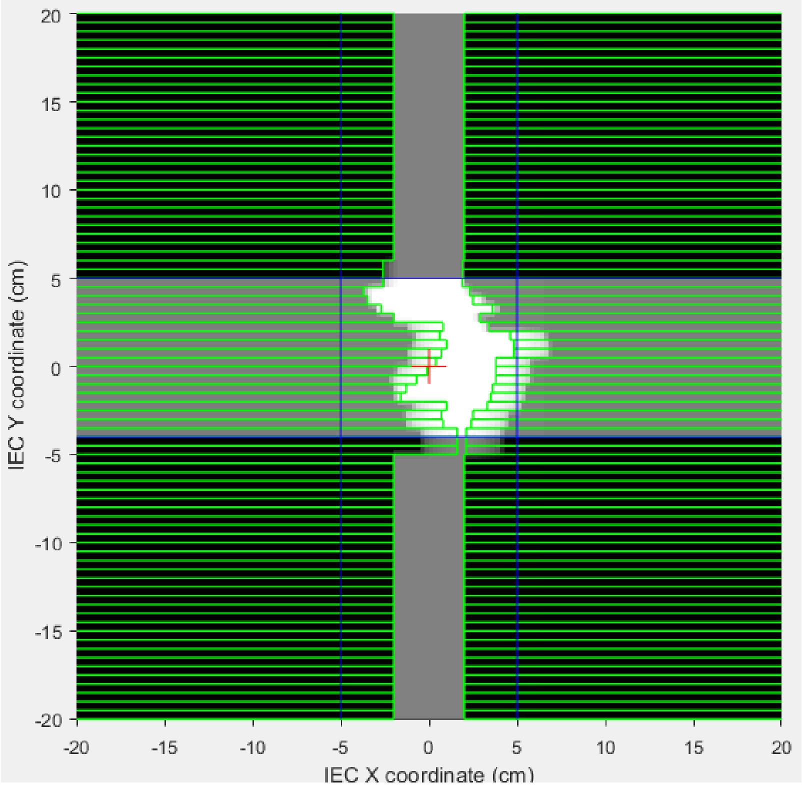
Primary Source Modulation

- Area-Weighted Transmission through collimating elements subdivided in regions of transmission and time for each pixel:

$$\bar{T} = \sum_{l} \sum_{m=1}^{n} T_m \cdot \int_{t_{l-1}}^{t_l} A_m(t)dt$$

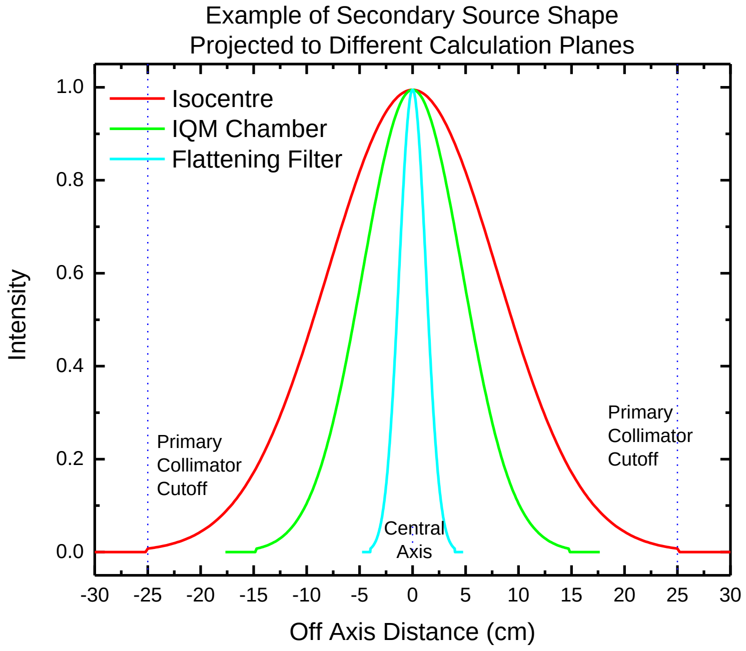
$$\int_{t_{l-1}}^{t_l} A_m(t)dt = \left[\frac{1}{3}\Delta v_x \Delta v_x t^3 + \frac{1}{2}\left(\Delta v_x \Delta s_y + \Delta v_x \Delta s_y\right)t^2 + \Delta s_x \Delta s_y t\right]_0^{t_l - t_{l-1}}$$

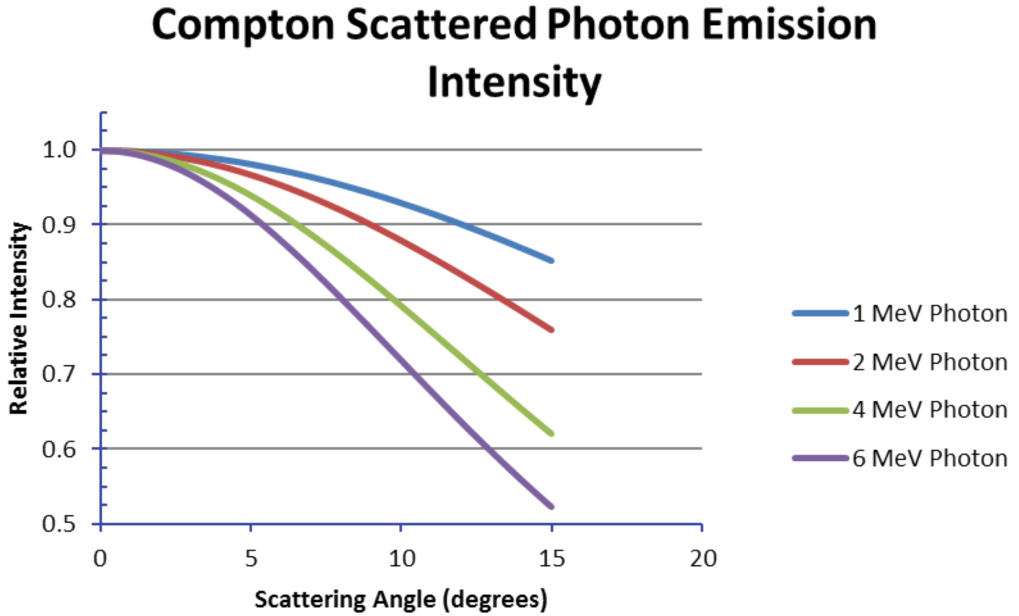


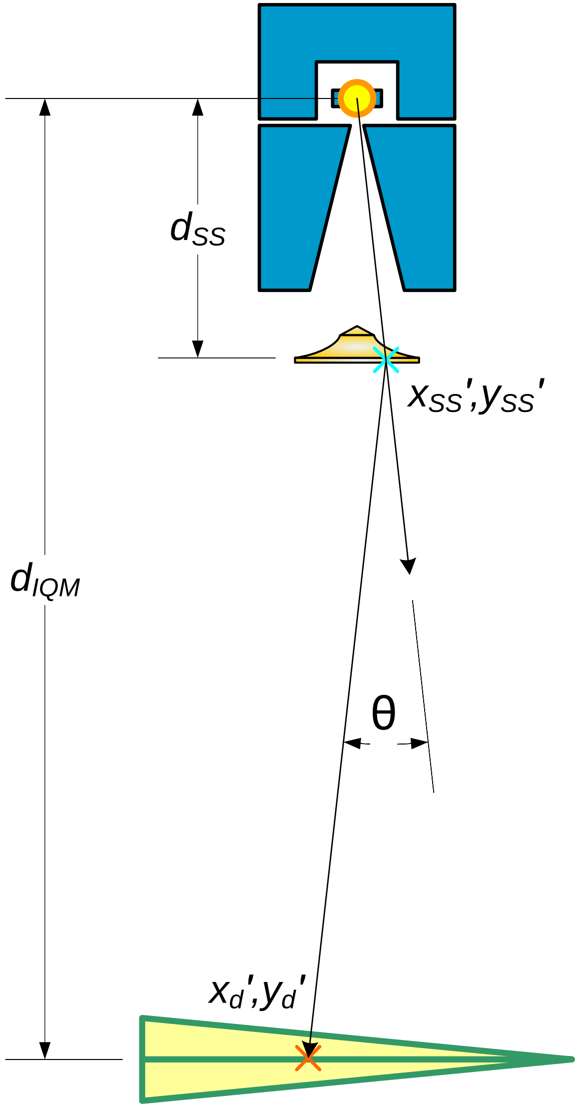


Secondary Source

- Extended source geometry
  - Positioned at bottom of flattening filter

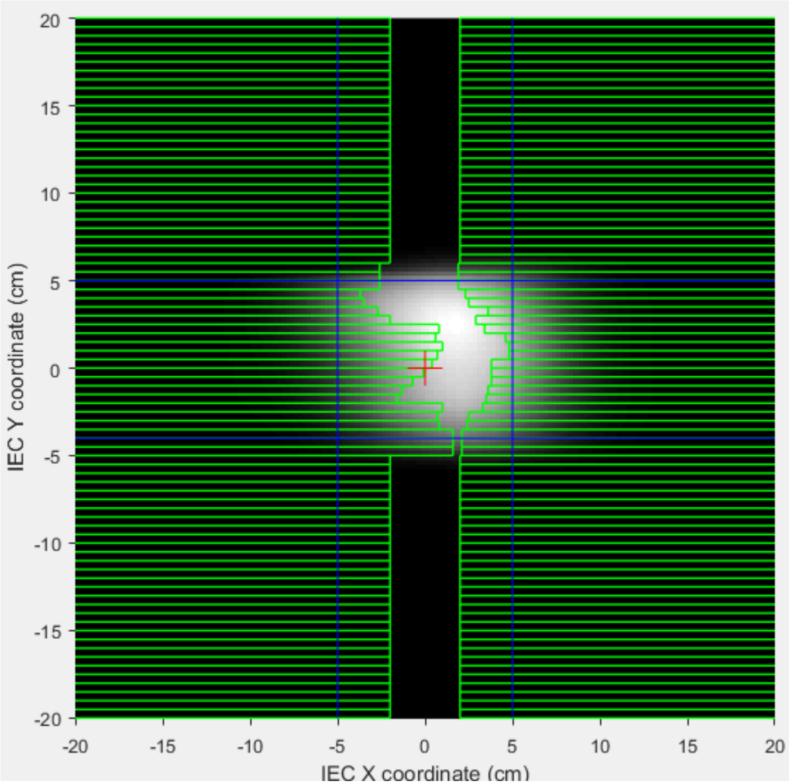


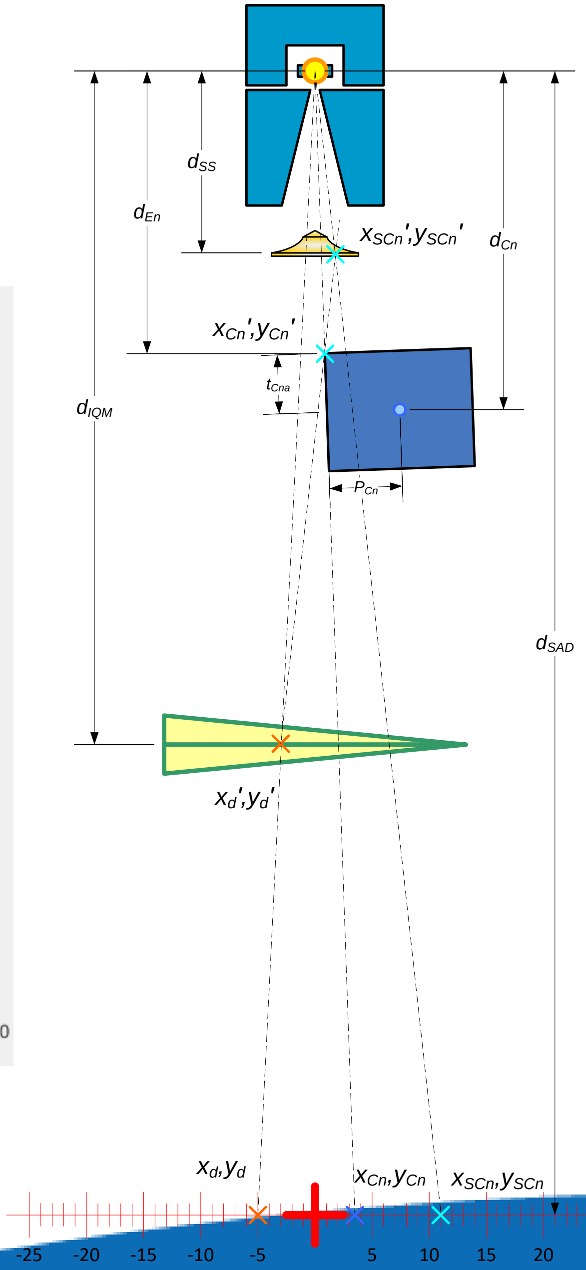




Secondary Source Modulation

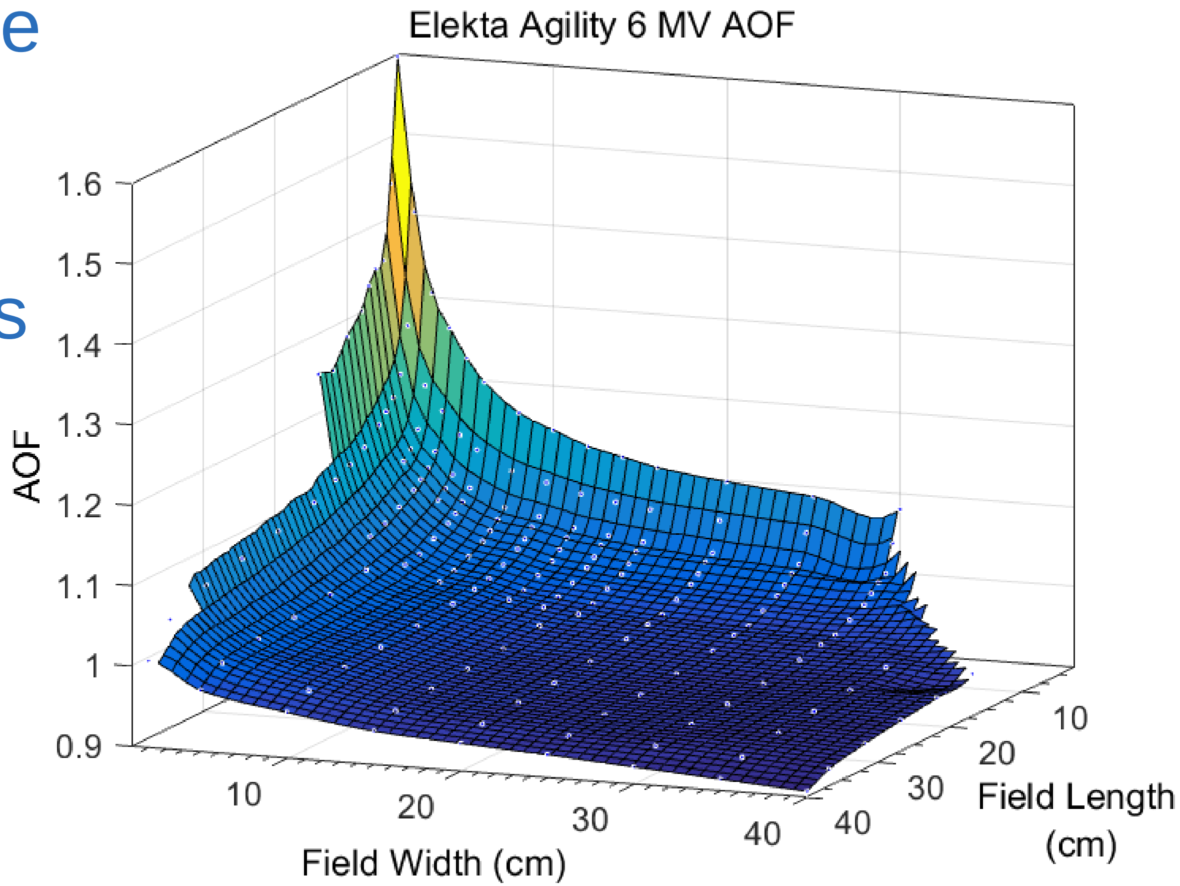
- More complex geometry:
  - Non-divergence matched
  - Multiple off-axis sources
  - Complex element shape shading
- Simplify calculation
  - Static “snapshot” calculation
  - Sampling point geometry
  - Layered collimating element





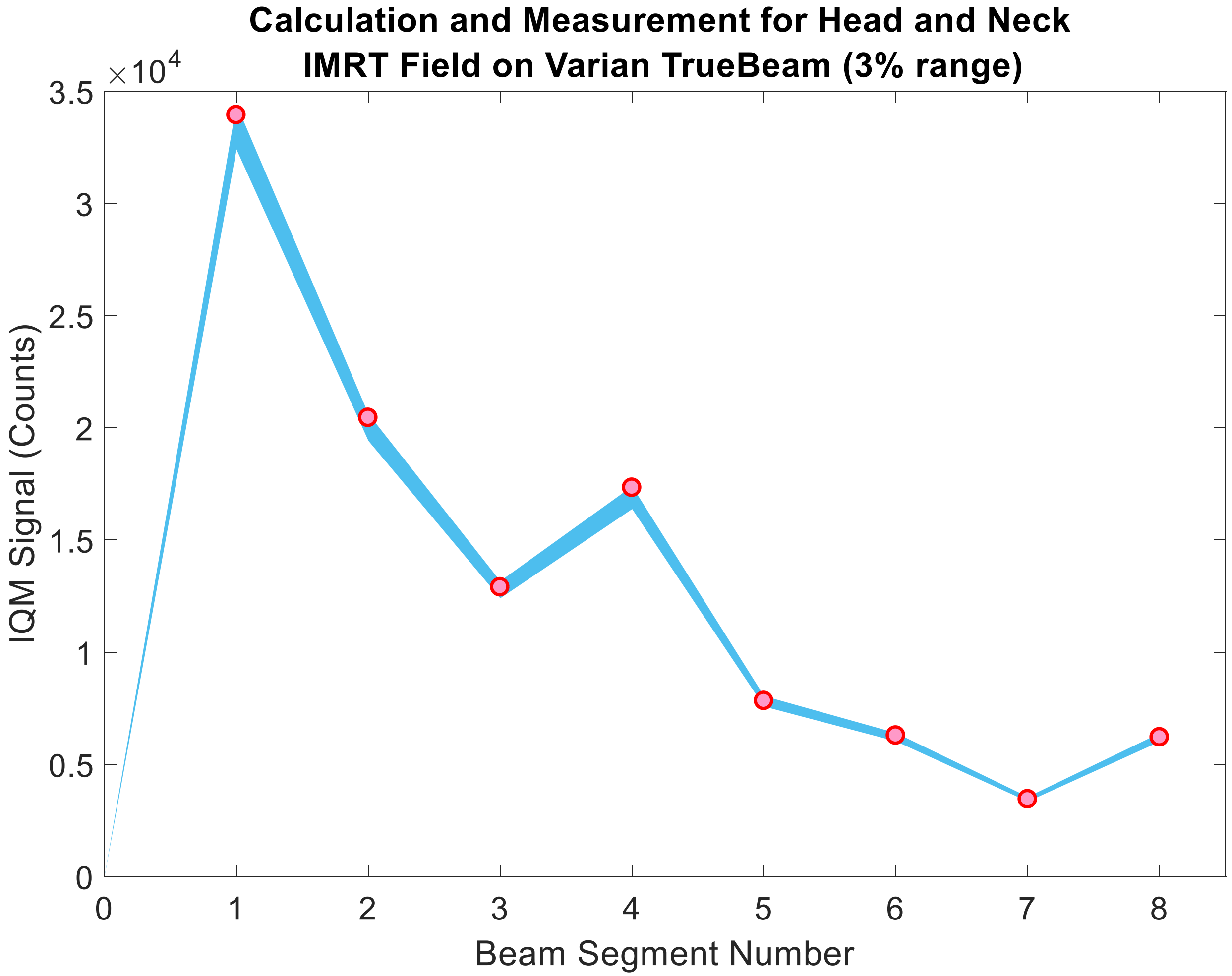
AOF Characterization

- Captures changes in output due to field size effects
- Derived from a series of rectangular field measurements
- Behaves as a “residual”
  - Some effects accounted for by extended source
  - Rederived for tweaks in source description & transmission
- Look-up according to average field width, length



Example of an IMRT Field Measurement

- Example of clinical IMRT field on a TrueBeam accelerator
  - Measurement corrected for daily output
  - Calculation shown for ±3% range
  - All segments < ±5% for 9 IMRT fields



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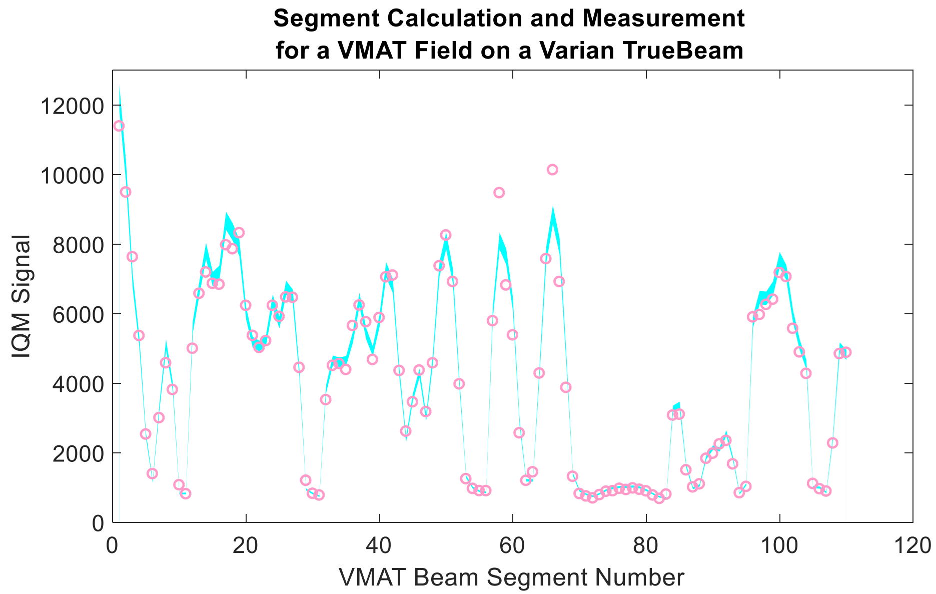
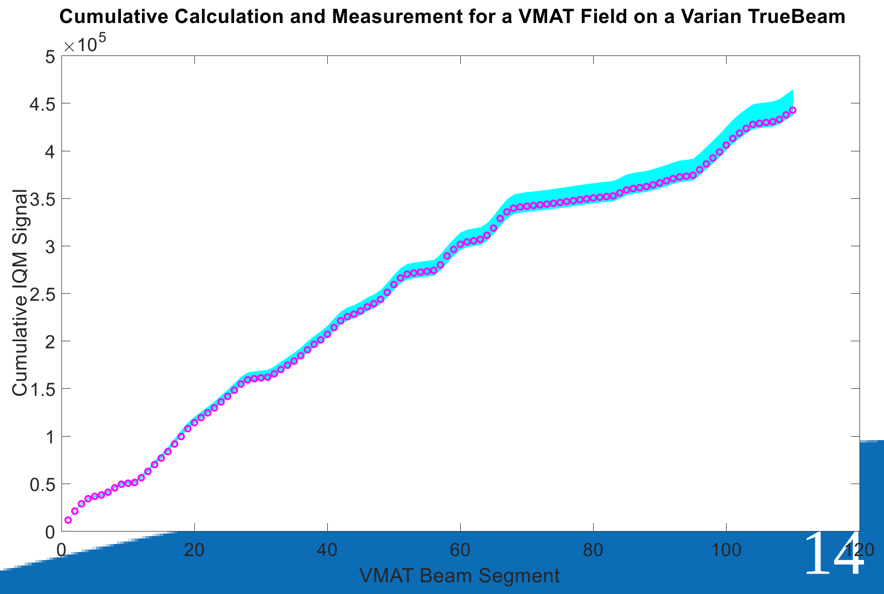
Example of a VMAT Field Measurement

- Head and neck VMAT field on Varian TrueBeam
- Calculation shown with±3% range
- Large deviations shown on a segment by segment basis
- Good agreement on cumulative basis





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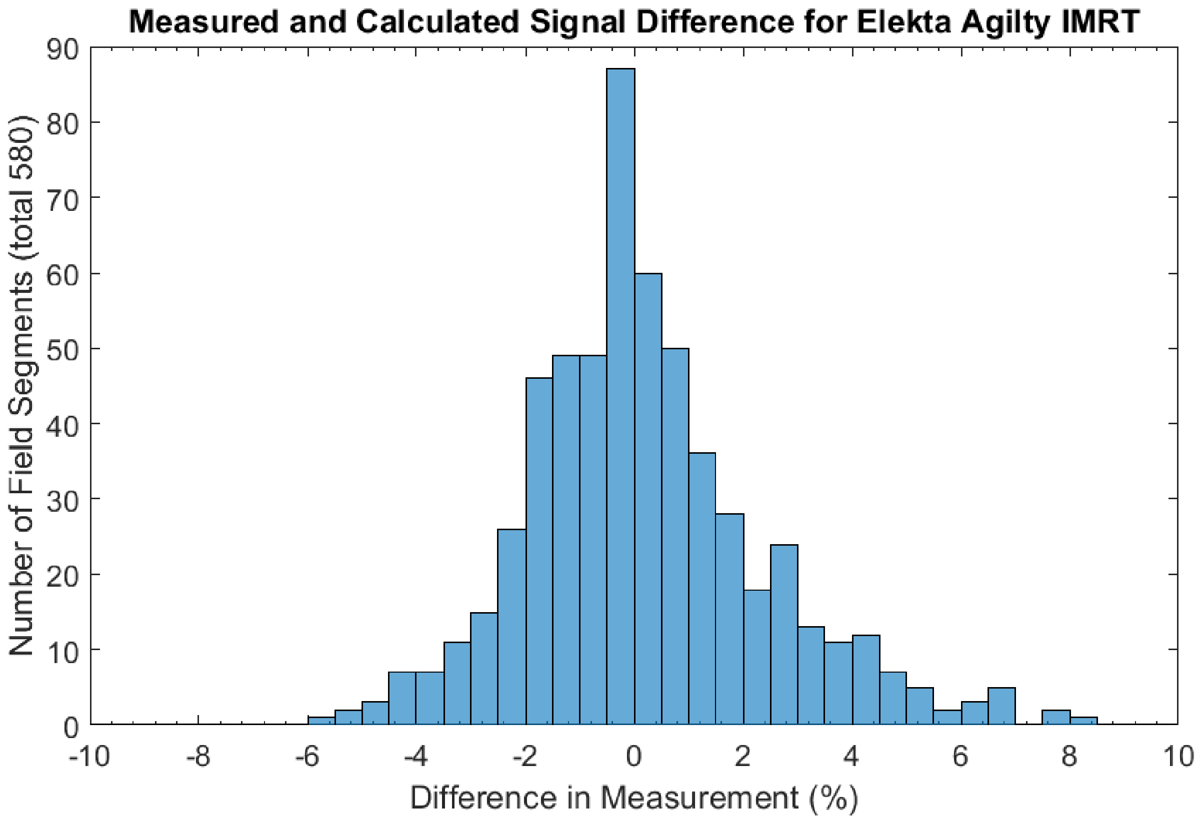
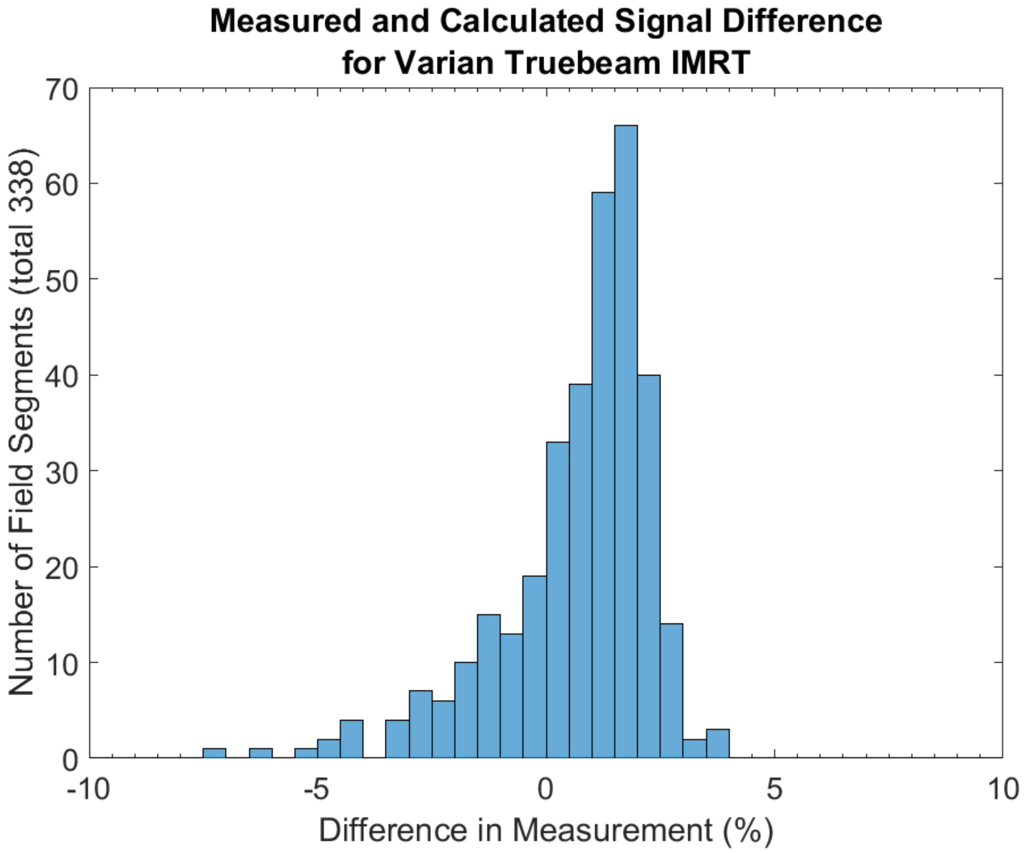
Algorithm Performance for IMRT Delivery

580 apertures on Elekta Agility



338 apertures on Varian Truebeam



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Summary

- IQM Calculation has been presented
  - Includes characterization:
    - Primary point source (dynamic motion, divergence matched collimation)
    - Extended secondary source (Compton based, oblique transmission)
  - Measurements show good agreement with calculations
- Continuing work:
  - Refinement of AOF parameterization
  - Speed increases in calculation

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