Upstream MLC Leaf Position Detection in Complex Radiotherapy Fields

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Radiotherapy

- Radiotherapy uses MeV photons to target cancerous tissues within a patient
- Aim is to kill cancerous tissues and spare healthy tissue being irradiated

Radiotherapy treatment suite

MLC & IMRT

- MLC consists of two banks of tungsten ‘leaves’ which move independently of each other
- Delivers IMRT treatments which are static or dynamic
- LINAC gantry rotates 360^{o} around patient
- Treatment beam is delivered from multiple angles
- Beam is collimated so it conforms to cancerous tissue volume & shields healthy tissue from being irradiated
- Treatment precision is dependent on MLC precision

MLC with single leaf extended into field

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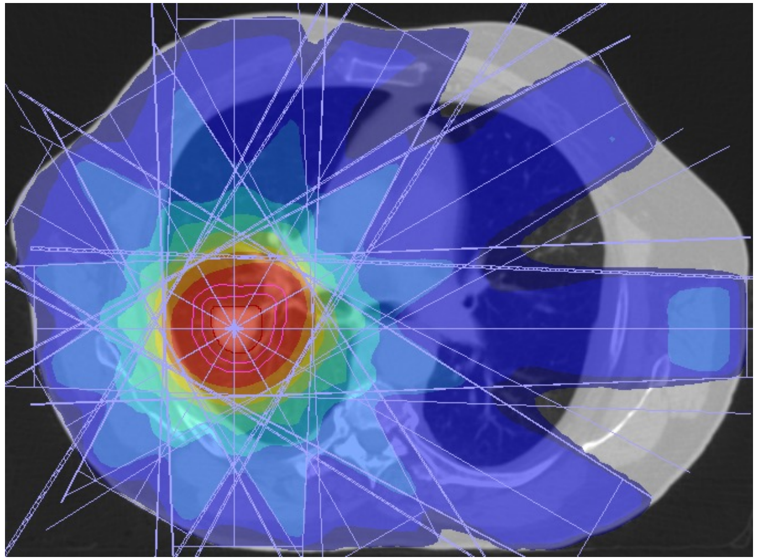


IMRT treatment plan

Treatment Verification & QA

- Standard MLC position calibration uses radiographic film or EPID
- Best resolution of radiographic film and EPID is ~ 500 μm
- Calibration standard set as ± 1 mm for MLC edges (TG-142)
- Treatment verification is performed pre/post treatment
- Normally, manual calibration of MLC leaf position occurs monthly

MLC tungsten leaves

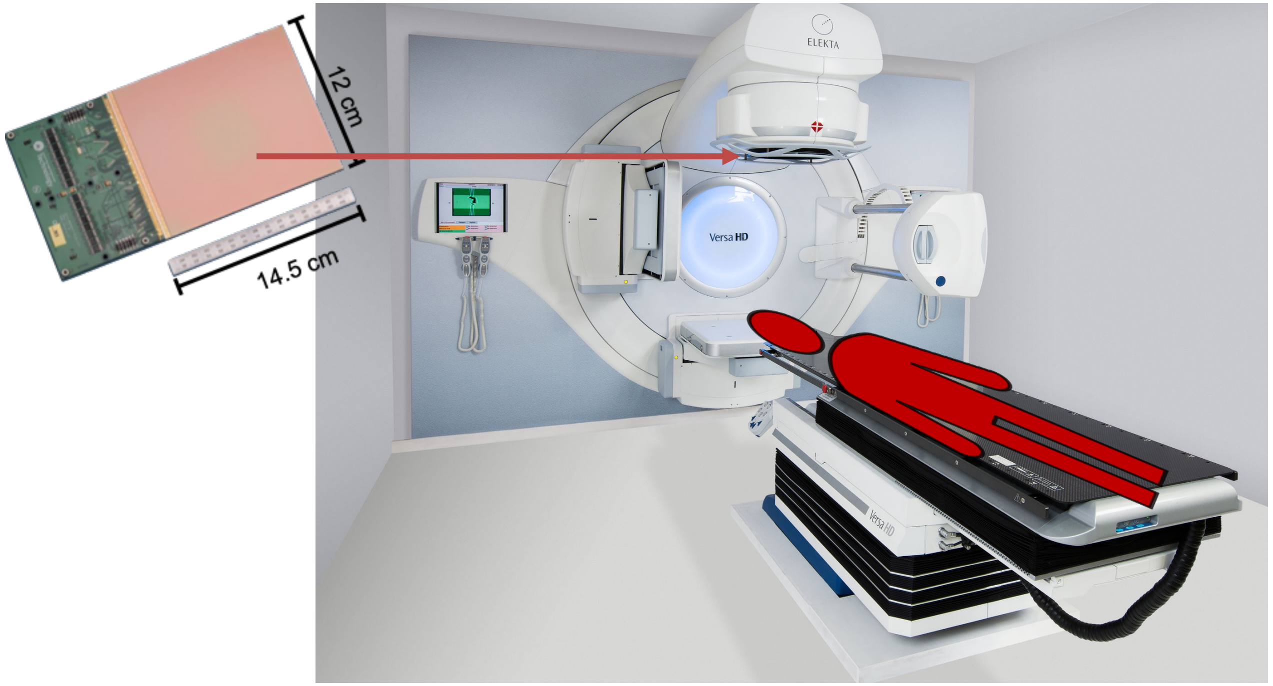
Consequences of Uncertainty

- Advanced therapies such as IMRT use small, complex treatment fields
- Systematic MLC offsets of ± 1 mm can alter total prescribed dose by 2 – 4% for such treatments
- MLC position uncertainty can create localised over/under exposures of radiation in the patient
- MLC positions should be calibrated to ± 300 μm to keep dose error below 2% for complex treatments

MLC tungsten leaves

MAPS

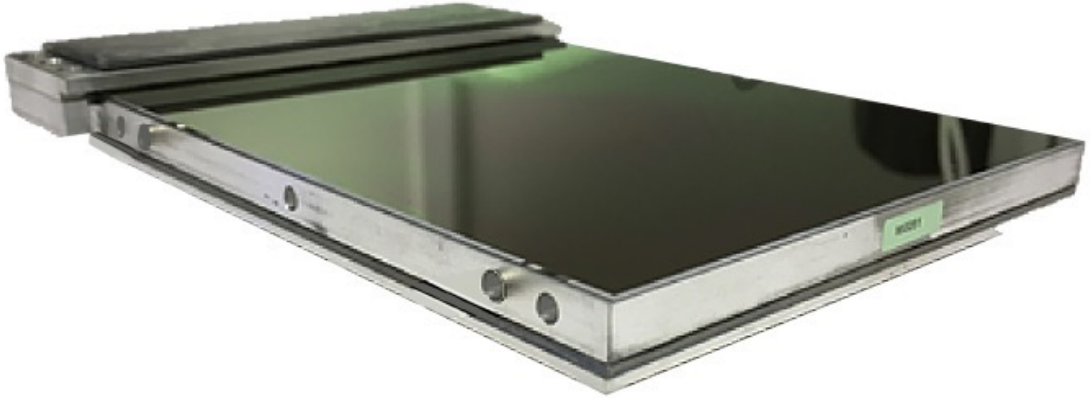
- Place a 2x2 array of Lassena Monolithic Active Pixel Sensor (MAPS) upstream of patient in LINAC head
- MAPS are imaging sensors used in smart phones
- Can be made very thin O(100 μm)
  - Beam attenuation therefore < 1%
  - Minimise scatter



Lassena MAPS placed upstream

Lassena

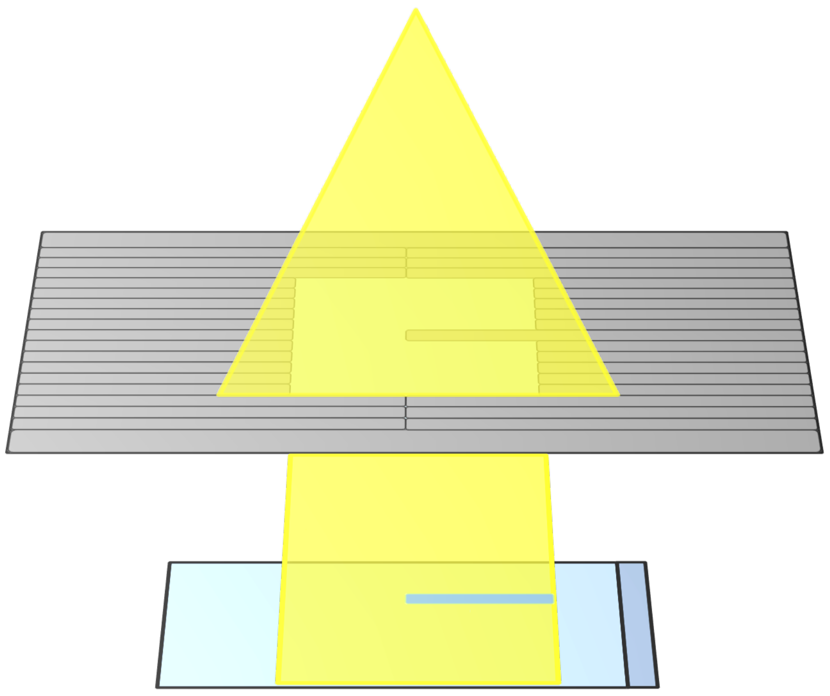
- Lassena is a CMOS with 3T pixel architecture
- 50 µm pixel pitch
- Lassena is 12 x 14.5 cm^2
- Wire bonds on 1 side only
- 2x2 configuration covers full treatment field
- Readout rate of 34 frames per second (fps)



Lassena MAPS situated on metal support frame. Note: support frame not used in practice.

Edge Detection

- Treatment beam is collimated by MLC leaves
- Open field produces high signal
- Shielded regions of field produces low signal
- Cross section of treatment field can be observed



Schematic of experimental setup

Single Leaf Edge Detection

- Previously published results for a single central MLC leaf extended into a square treatment field using Lassena as a proof of principle
- Resolution values range from 60.6 ± 8 to 109 ± 12 μm using 0.3 s of treatment data

392 IEEE TRANSACTIONS ON RADIATION AND PLASMA MEDICAL SCIENCES, VOL. 5, NO. 3, MAY 2021

High-Resolution MLC Leaf Position Measurements With a Large Area MAPS

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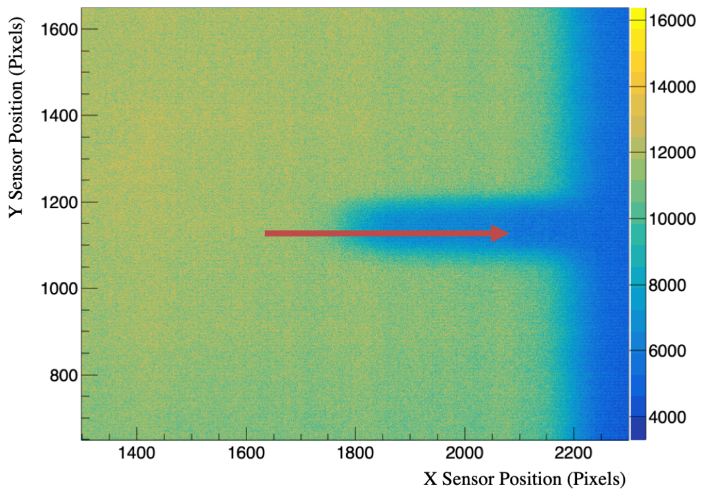
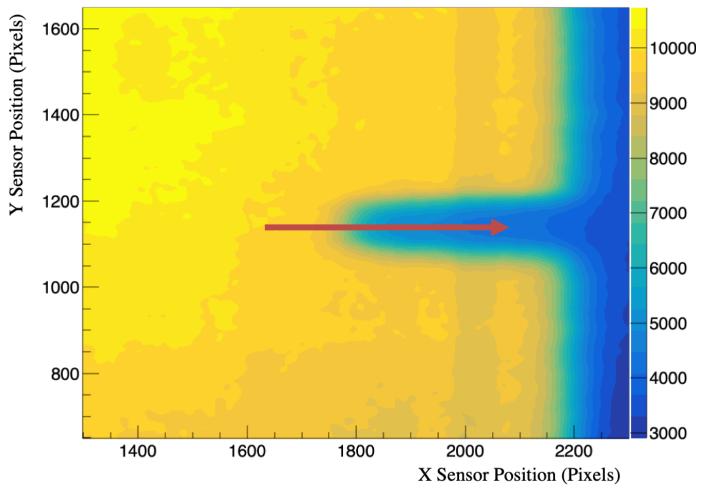
Setup & Raw Data Processing

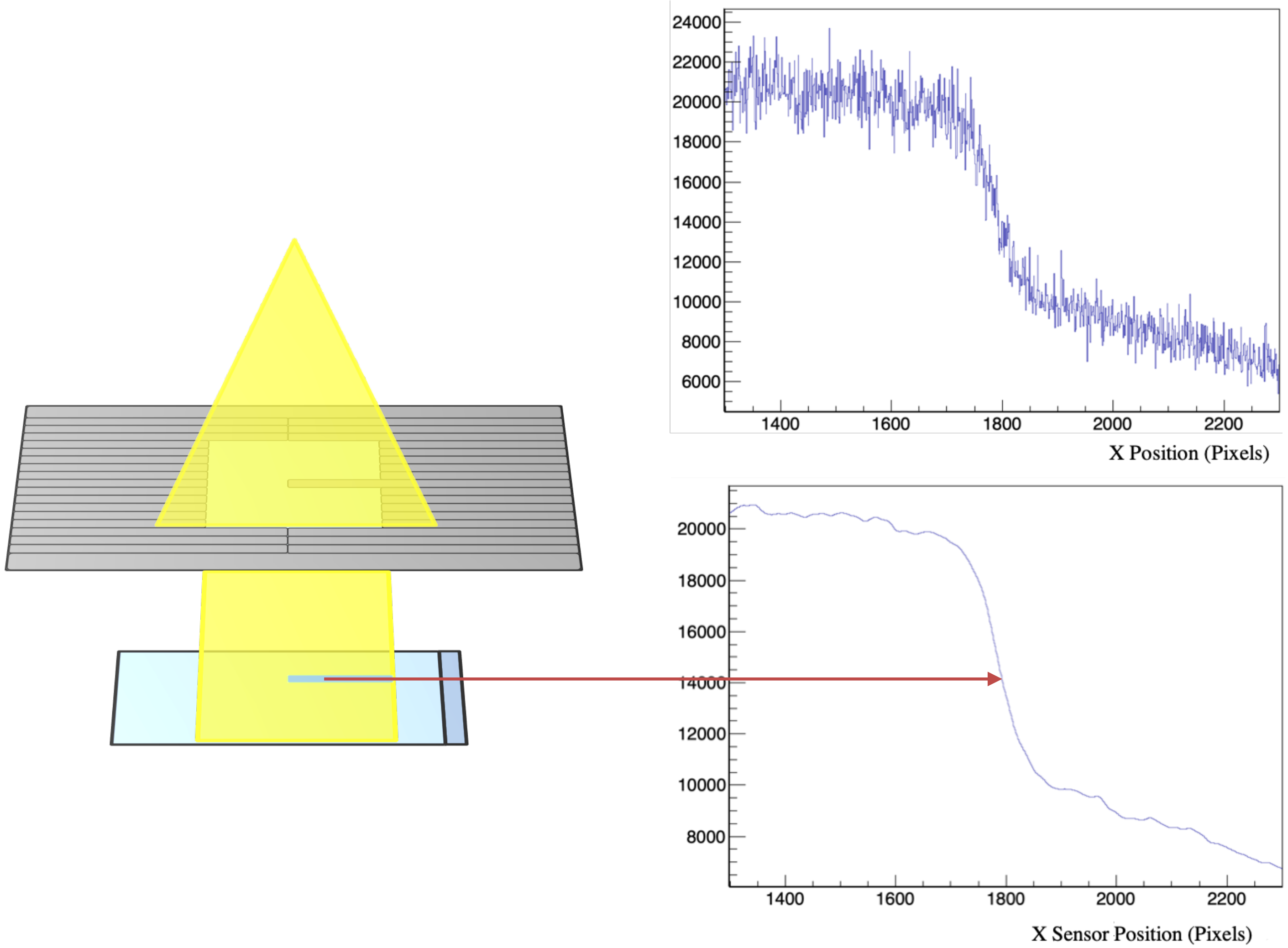
- Lassena placed on LINAC couch
- 6 MeV square treatment field selected
- MLC leaves extended into treatment field
- Apply pedestal correction
- Bad pixel mask applied to correct bad pixels
- Gaussian smoothing applied to reduce pixel-to-pixel variation





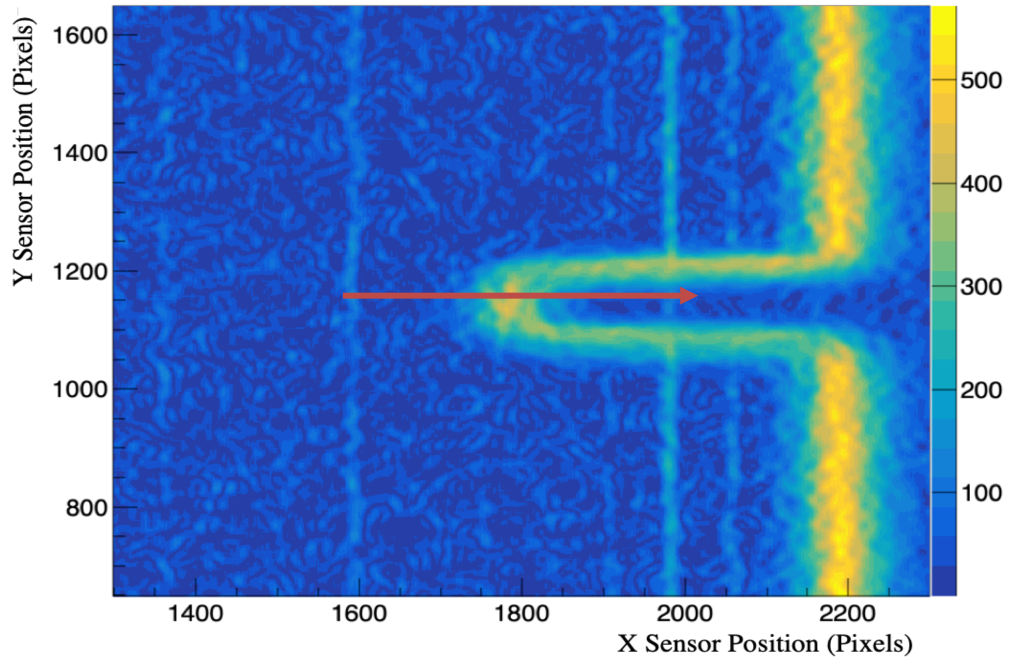
Data Smoothing

- Gaussian smoothing reduces high frequency pixel-to-pixel variation
- Need to find leaf edge, defined as the point of maximum gradient



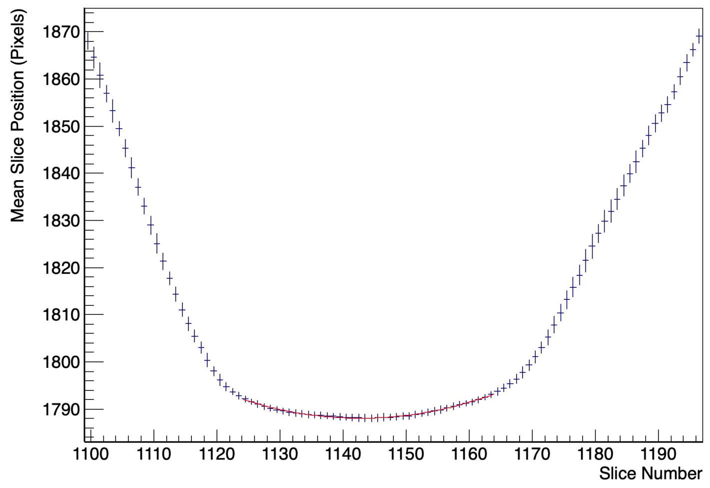
Edge Detection

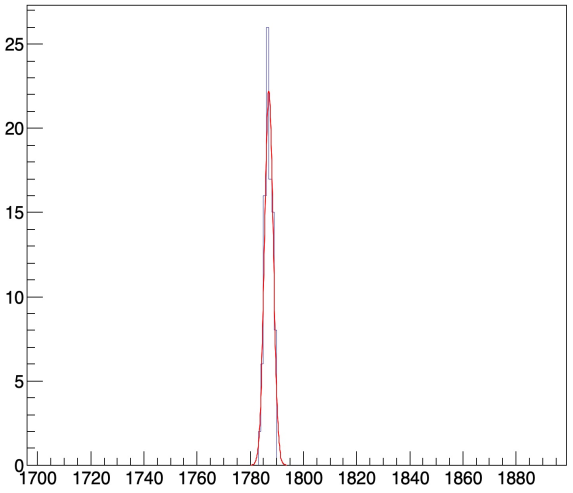
- Sobel operators are standard image processing filters
- These act as differential operators to identify image gradients
- Leaf edge is therefore identified by gradient
- Project along pixel row → Apply Gaussian fit → Extract fit mean → Repeat for each pixel row that intersects leaf edge



Leaf Edge Reconstruction & Results

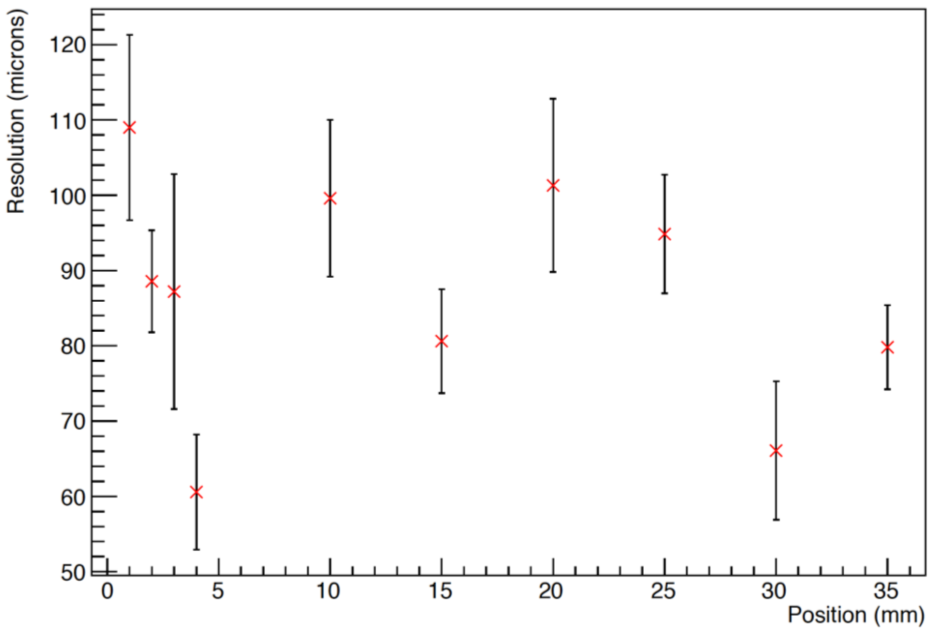
- Plot Gaussian means as a function of pixel row number to reconstruct leaf edge
- Make 2nd order polynomial fit and extract turning point as leaf edge position
- Resolution is defined as the Standard Deviation of the Gaussian Fit

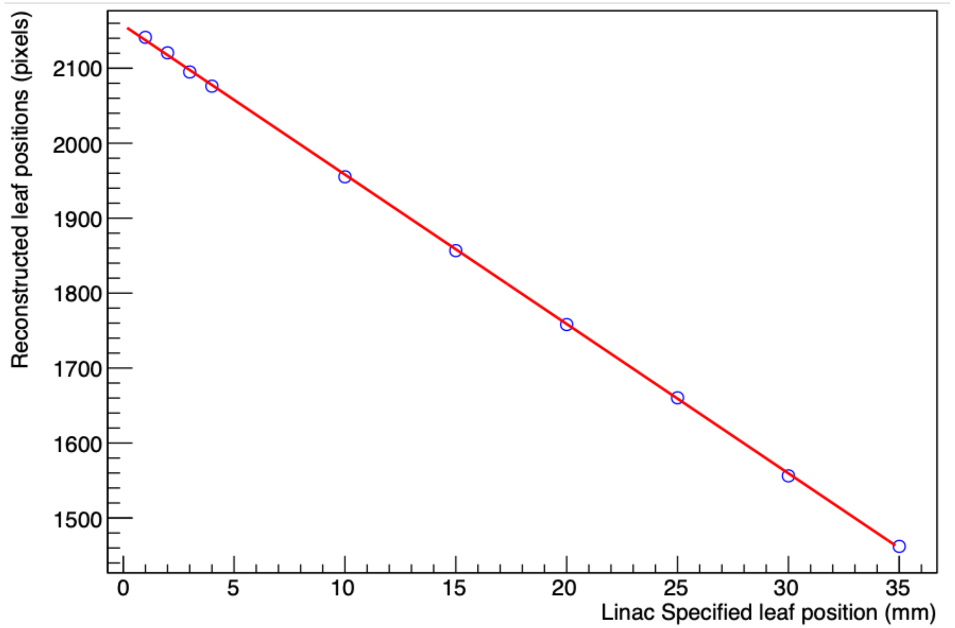




Leaf Position (Pixels)

Resolution and Accuracy

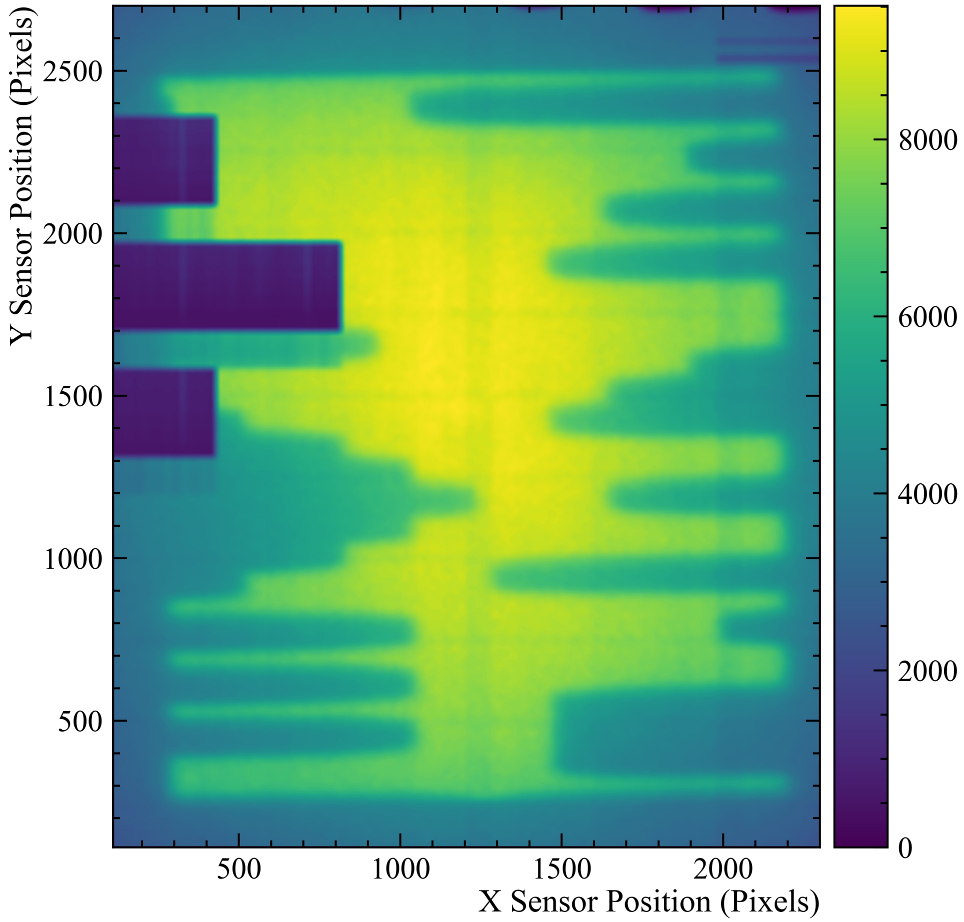




- Resolution values range from 60.6 ± 8 to 109 ± 12 µm using 0.3 s of treatment data
- Correspondence is excellent and positions can be accurately predicted
- Much better than the 300 µm requirement

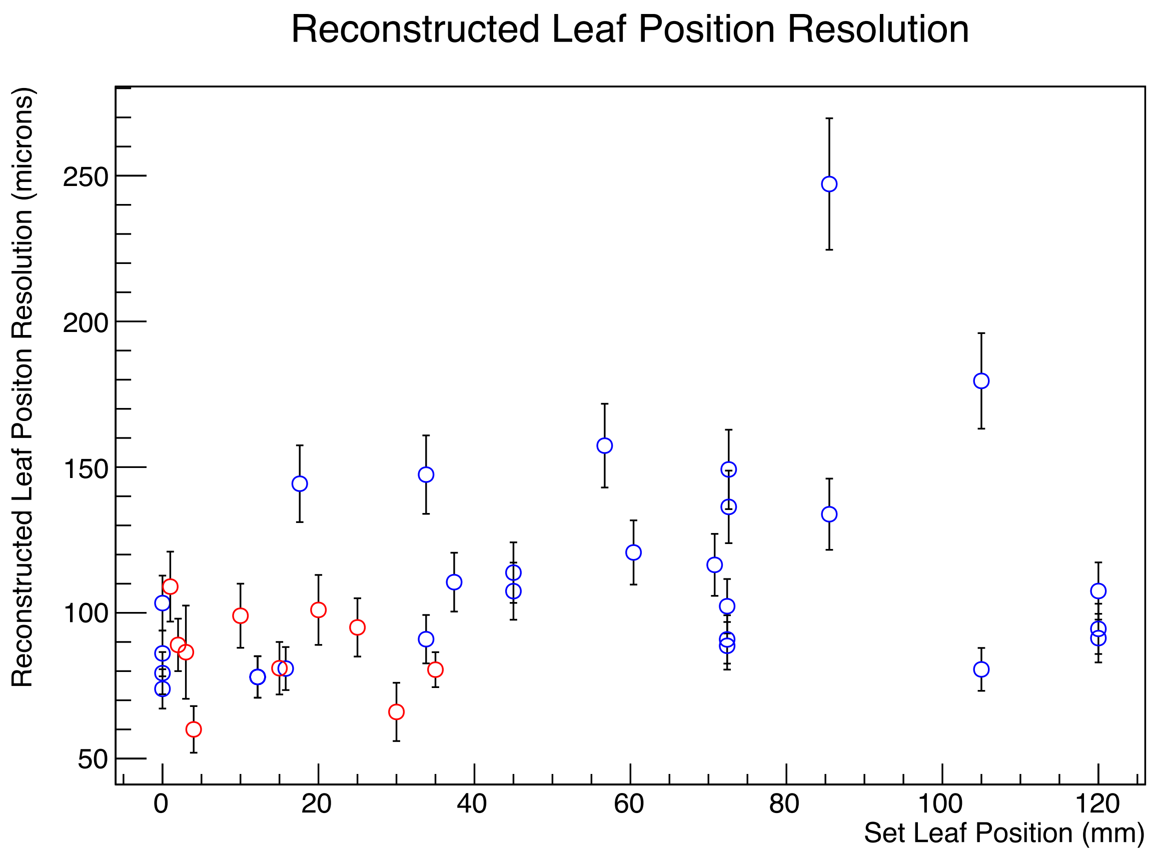
Complex MLC Positions

- Works well for single leaves, but need to investigate more complex MLC leaf positions as in clinical use
- Leaves positioned: close to MLC bank, extended, retracted, off-centre, adjacent and opposing
- Different scattering of electrons and photons incident on Lassena, potentially changing position and resolution measurements
- Place Lassena on LINAC couch, 6 MeV, 12x14 cm field, extend MLC leaves into field, record data frames at 34 fps



Resolution Results

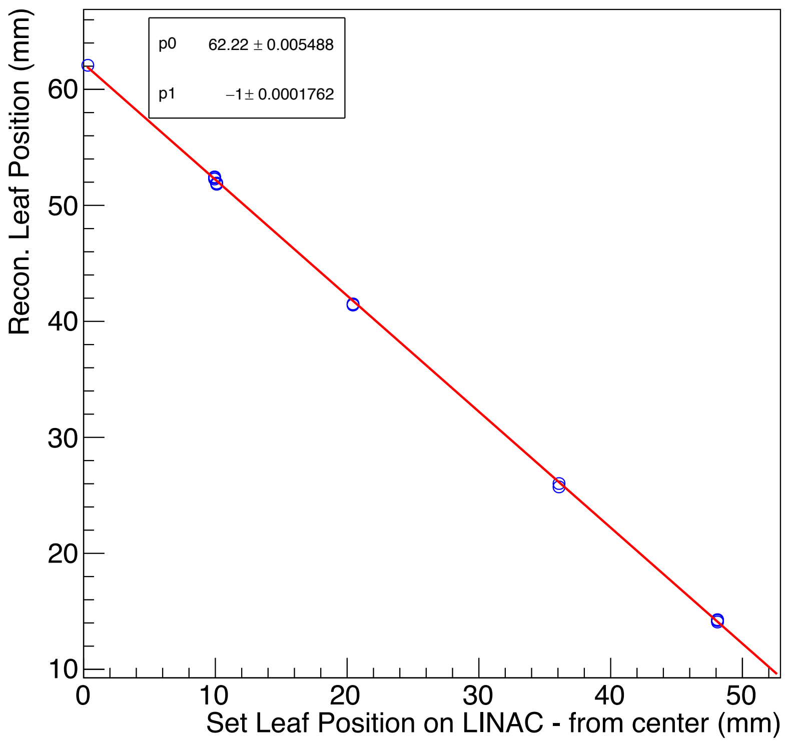
- Resolution values range from 78 ± 7 to 149 ± 14 μm (When excluding outlier)
- Again, much better than the 300 μm requirement
- Only uses 0.15 s of treatment data which is half that used for single leaf data



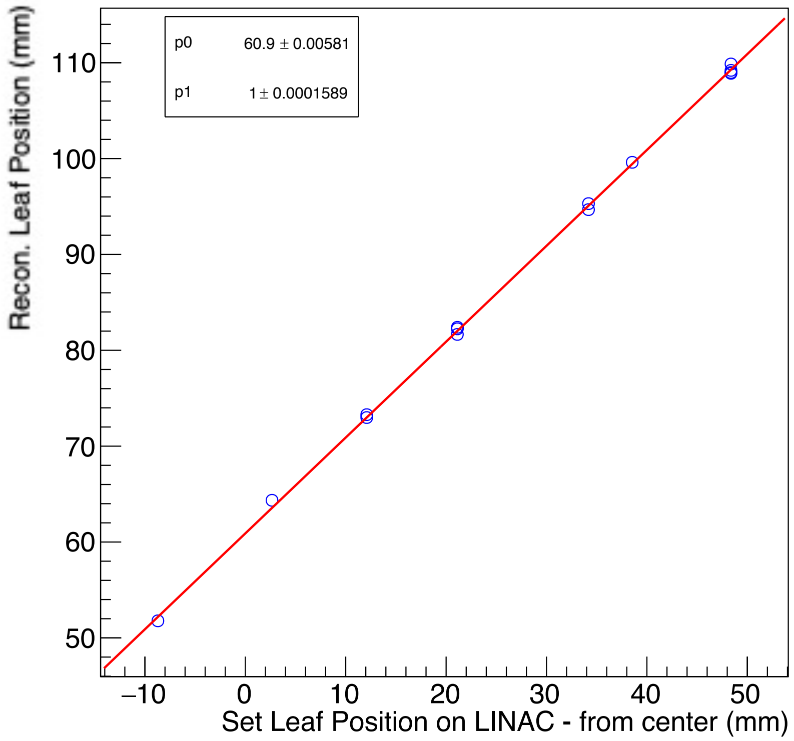
Accuracy Results

- Results are sufficiently accurate for current current clinical use
- Maximum deviations from predicted fit are ~ 500 μm
- However, our target is < 300 μm

Left leaf bank

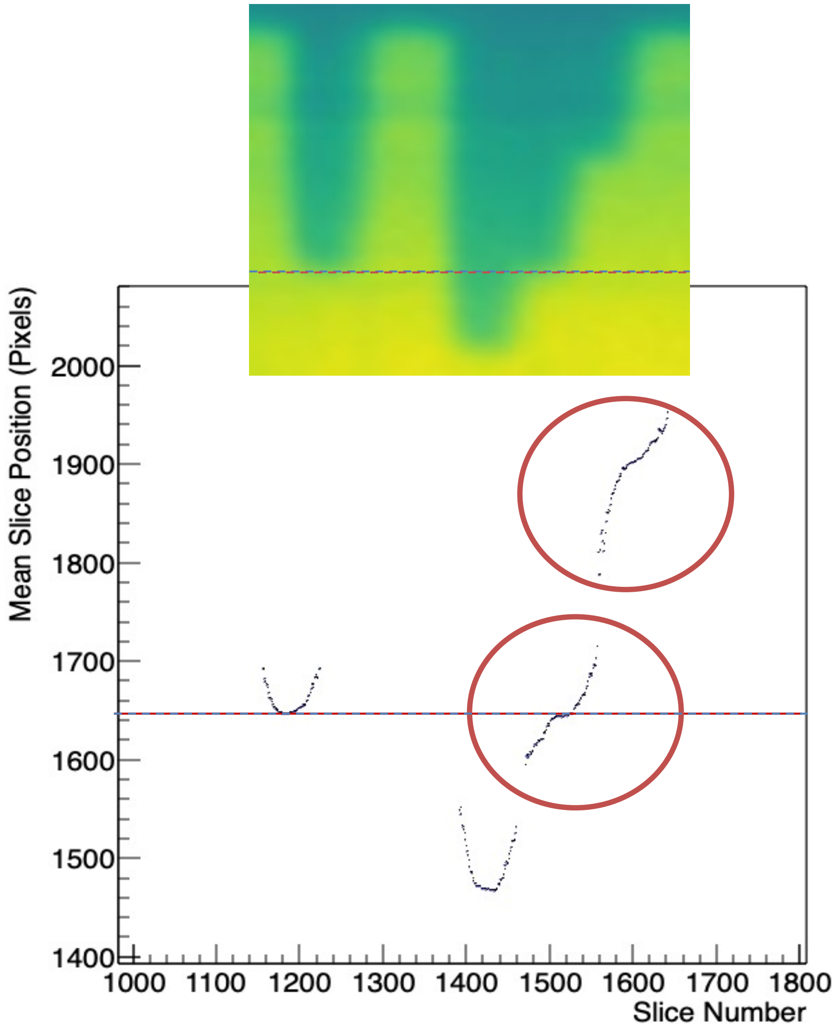


Right leaf bank



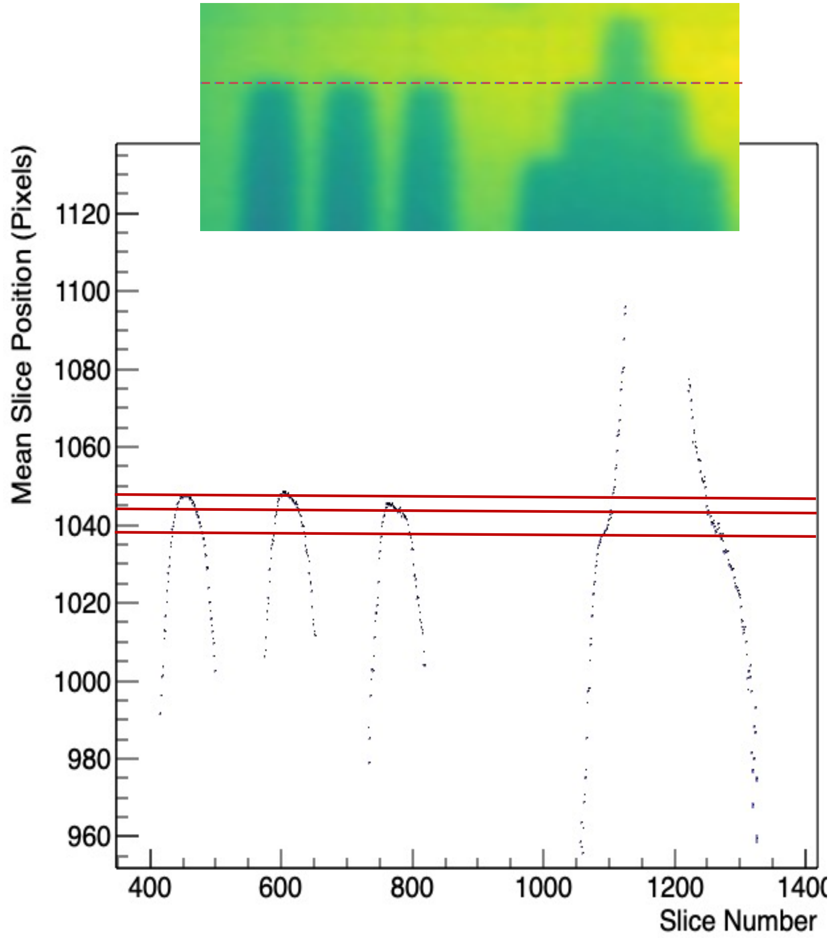
Scattering Effects

- Reconstructing single and adjacent leaves requires a different fitting routine to get position due to leaf scatter
- The correct positions are reconstructed for single and adjacent leaves, however an offset is observed for adjacent leaves
- This effect has been observed prior to image processing and reported in the literature



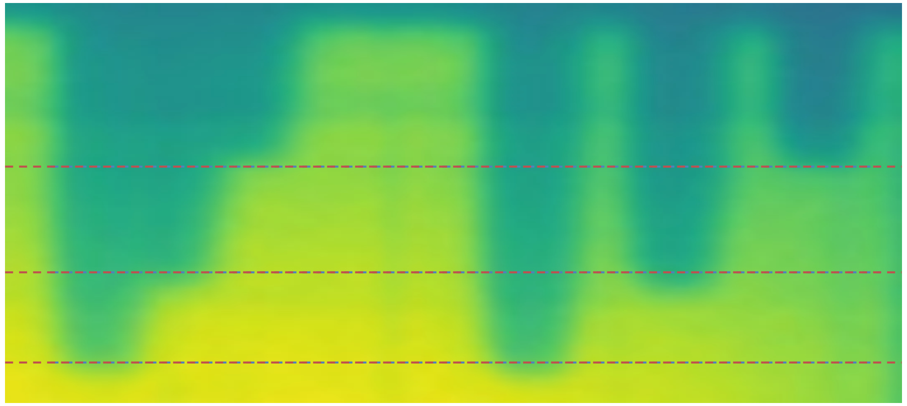
Scattering Effects

- Comparing single and adjacent leaf extensions allows us to see this effect
- Three single leaves at same extension give the same reconstructed position within error
- Adjacent leaves at same extension should also give the same reconstructed position
  - Single leaves = 42.2 ± 0.129 mm
  - Adjacent leaves = 41.8 ± 0.160 mm
- Offset ~ 400 μm



Scattering Effects

- Again, deviation between single an adjacent leaves is observed
- Repeating for multiple data sets again shows an offset for single and adjacent leaves
- Single & Adjacent leaf offsets:
  - 503 ± 16.9 μm
  - 469 ± 17.7 μm
- Single leaf pair offset:
  - 241 μm ± 16.0 μm
- This effect is understood and can be corrected for



Conclusion

- We are developing an upstream live treatment monitoring device
- Lassena MAPS covers full treatment field, has low attenuation (< 1%), readout of 34 fps & is radiation hard
- Resolution values of MLC edge detection ranges from 78 ± 7 to 149 ± 14 μm for complex fields
- Systematic offset has been observed for adjacent leaves. This is understood and can be corrected for, this will achieve the < 300 μm target
- This can be done in real time as it only require 0.15 s of treatment data and can be implemented in a Field-Programmable Gate Array (FPGA), hence real time treatment verification can be achieved
- This is a working solution which can be used in clinical practice and we are close to a commercial prototype

Thank you