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Calibration of dosimeters for small mega voltage photon fields at ARPANSA

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Collaborators

RMIT UNIVERSITY

Australian Government
Australian Radiation Protection and Nuclear Safety Agency

Austin Health

Outline:

- Targets for the small field dosimetry at ARPANSA
- Dosimetric challenges in small field measurements
- Establishment of dose area product in small field measurements
- Graphite calorimetry measurements in small fields
- Profile and output factor measurements with various detectors
- Further work to be done
- Conclusions

What is small field?

- 4 x 4 cm^2 to 40 x 40 cm^2 fields are used in conventional radiotherapy.
- Narrow or sub-cm fields are used in advanced treatment modalities such as Intensity modulated radiotherapy (IMRT) or Streotactic radiosurgey (SRS).
- A small photon field is defined as one having dimensions smaller than the lateral range of the charged particles released by the photons that contribute to the dose.

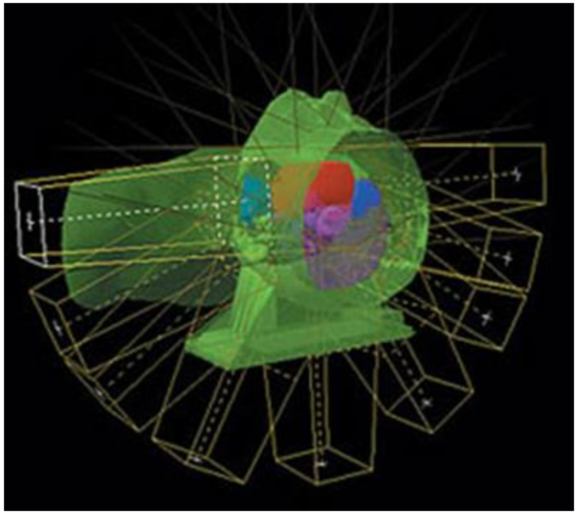
"If the output factor changes by ± 1.0 %, given a change in either field size or detector position of up to ± 1 mm, then the field should be considered very small"
– Paul Charles et al. Medical Physics, 41 041707 (2014)

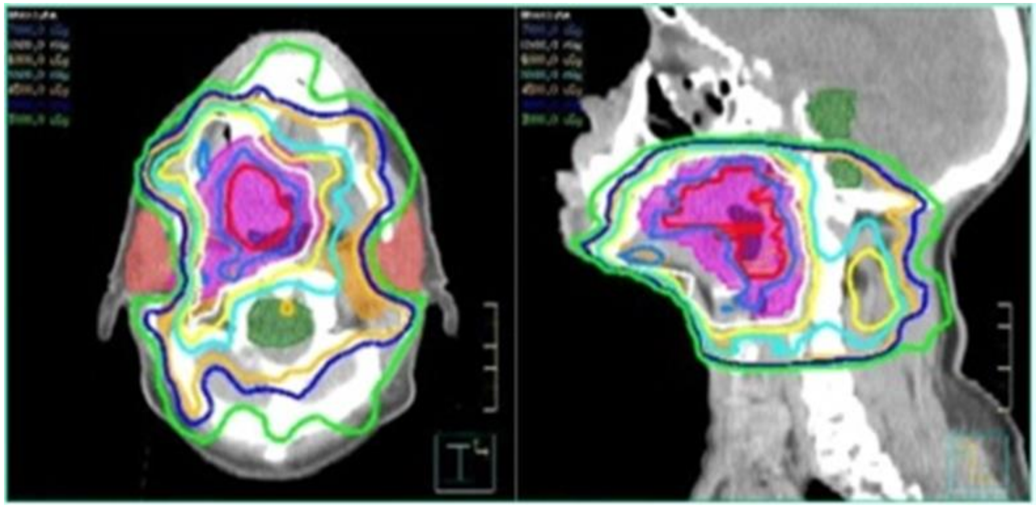
Clinical situations where small fields are used

Intensity Modulated Radiation Therapy (IMRT)

Brain Tumors

Head and Neck Cancer



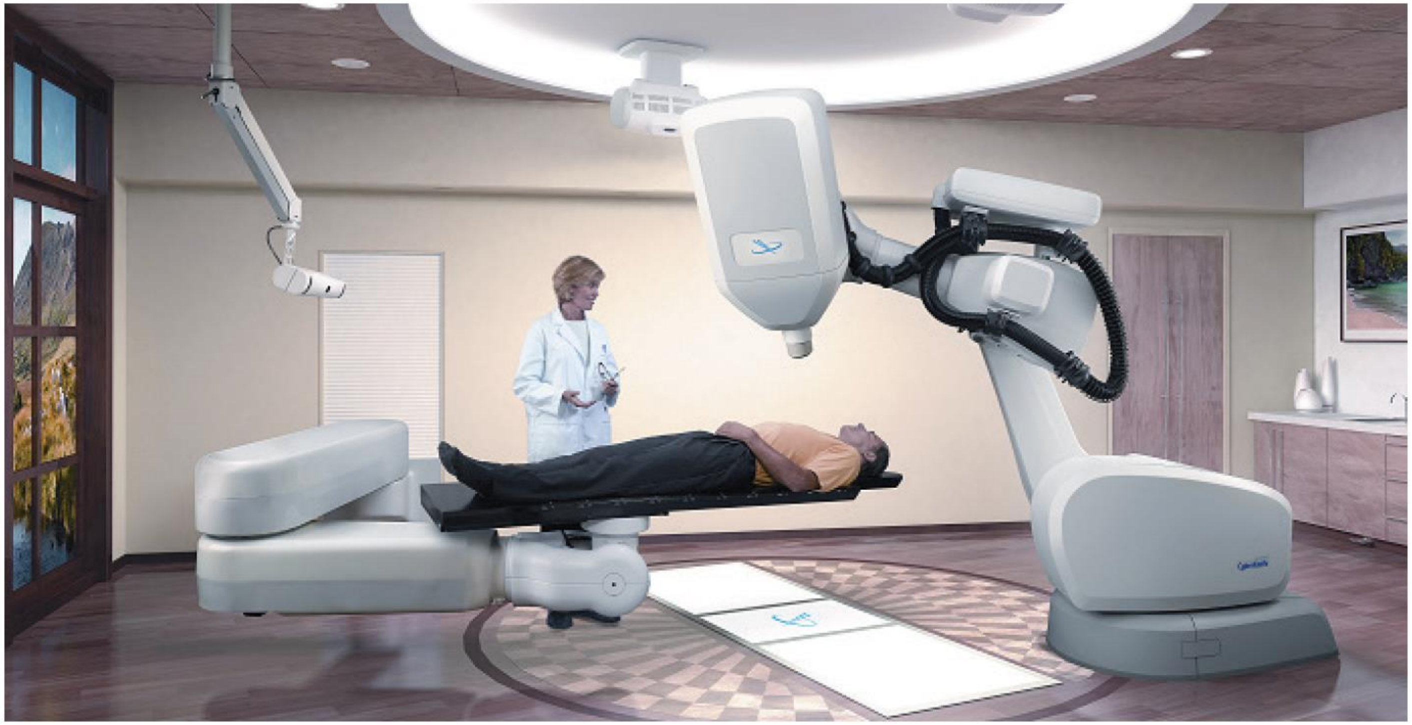


Typical beamlet sizes used in IMRT are: square fields of 0.5×0.5 cm², and 1.0×1.0 cm², to 6.0×6.0 cm²

Clinical situations where small fields are used

Stereotactic Radiosurgery (SRS)

Brain Tumors

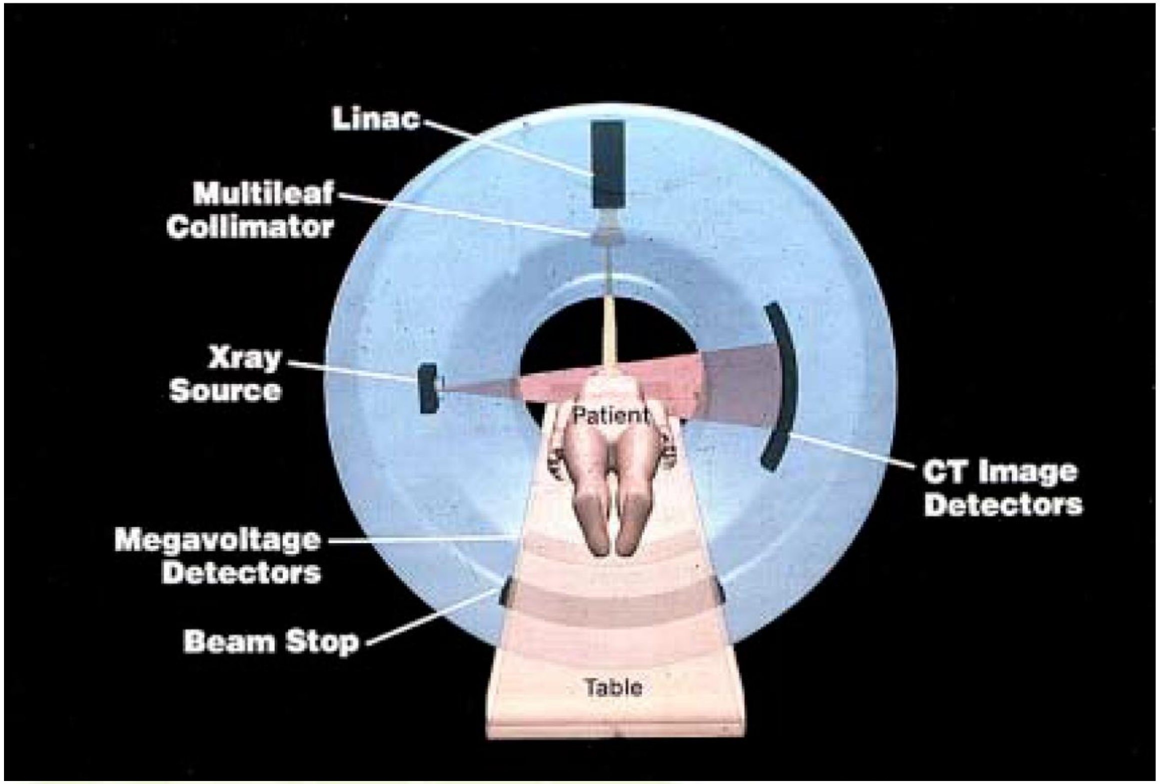


small fields of 6–30 mm in diameter are used

Clinical situations where small fields are used

Helical Tomotherapy

Prostate Tumour



1 cm to 5 cm wide helical fan beams are used

Small Field Dosimetry at ARPANSA

Project Plan

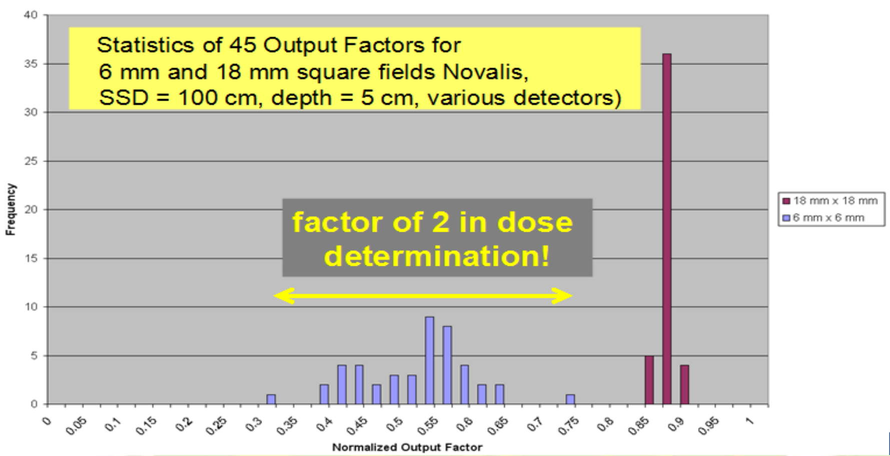
Target outcomes:

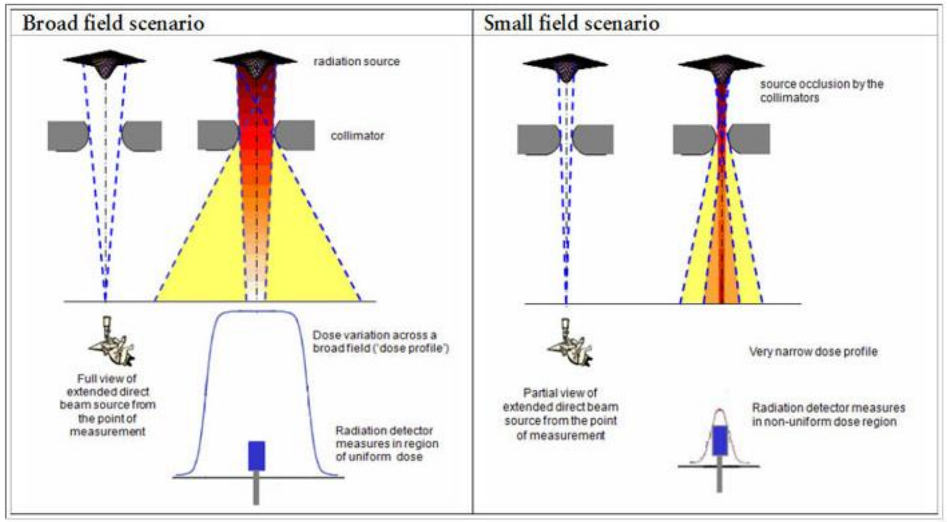
1. Ability to characterise detectors (e.g. OSLD, diode or pinpoint chamber) for field size down to 5 mm
2. Calibration service for DAP chambers in water
3. Publish field-size correction factors for detector types
4. Issue advice on appropriateness of certain detectors for small field measurements and any other issues of small field measurements

Dosimetric challenges

- There is no primary standard available for absolute dosimetry
- Output factors derived from reference dosimetry based on IAEA TRS-398/AAPM TG-51 have wide variations with smaller field sizes
- Availability of small detectors for sizes comparable to field dimensions

Example: Large differences in Output Factors among users/machines

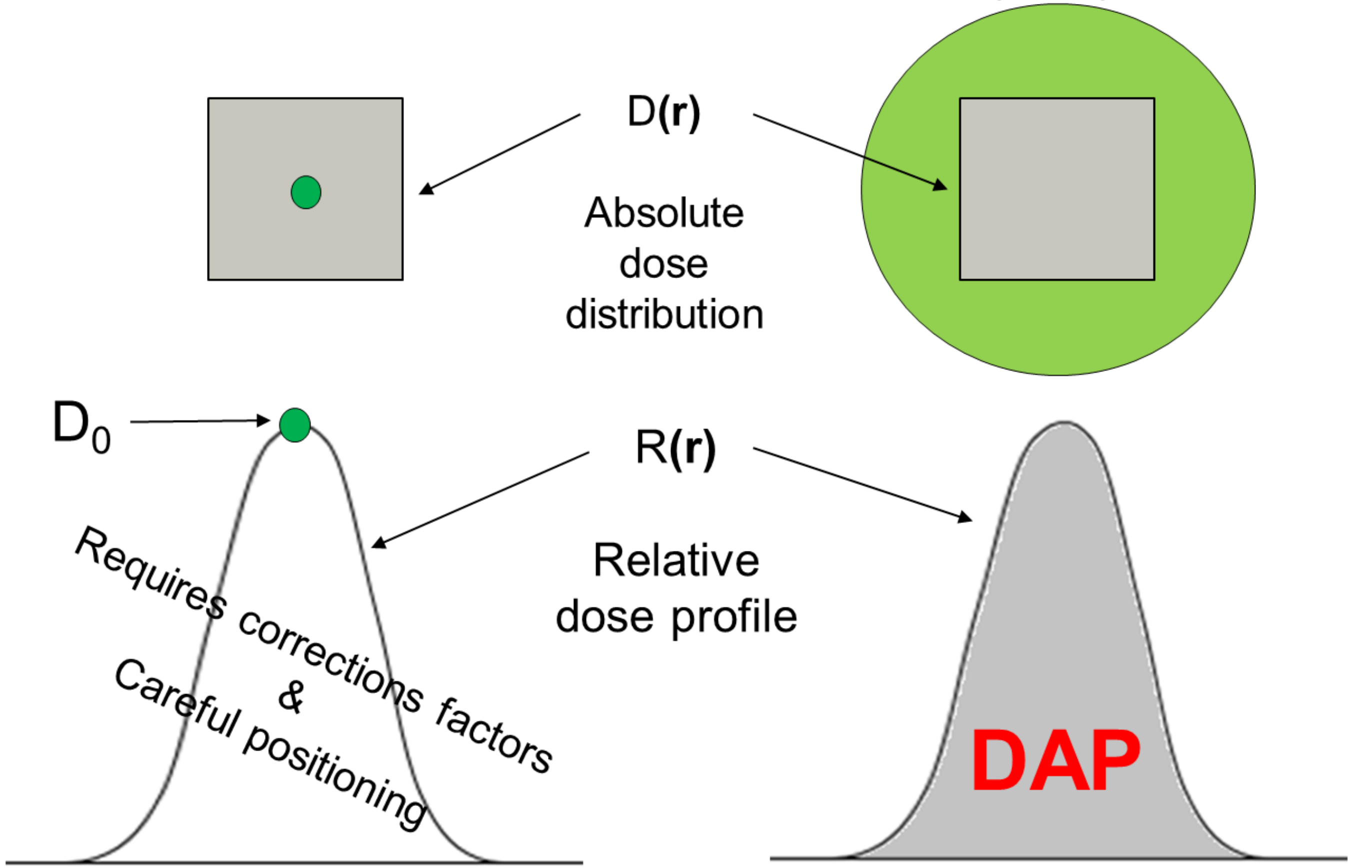




Courtesy: Brainlab

Dosimetric challenges

Current method using point dose | Method using dose-area product (DAP)

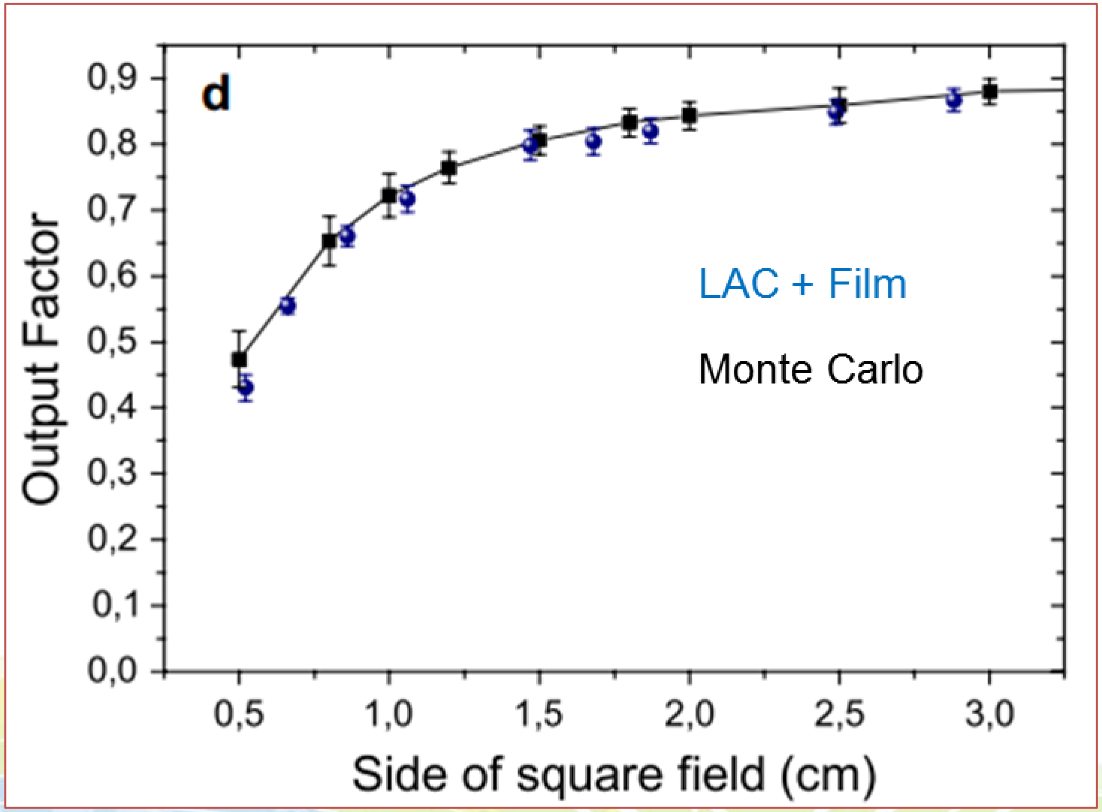


Dose Area Product Measurements

ORIGINAL PAPER

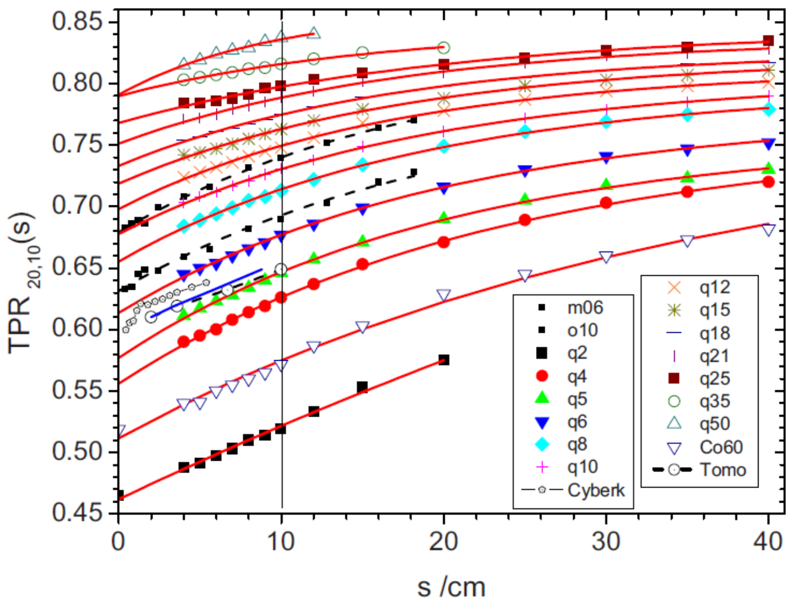
A new method for output factor determination in MLC shaped narrow beams

F. Sánchez-Doblado [a,b,*], G.H. Hartmann [c], J. Pena [d], J.V. Roselló [e], G. Russiello [c], D.M. Gonzalez-Castaño [d]



Beam quality index Q

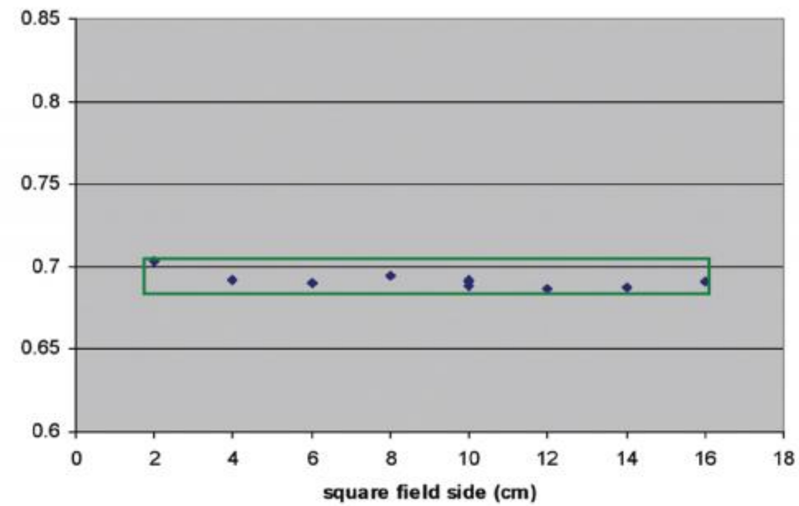
$TPR_{20,10}$



O. Sauer,Med Phys. 2009 Sep;36(9):4168-72.

- Beam quality index Q is field size dependent
- Problem if reference field size is not available

Dose-area product ratio



(S. Duane, NPL, UK 2010)

- Q independent of field size?

Research aims for DAP measurements

- Investigate the suitability of a large-area ionization chamber (LAC) for measurements of dose-area products (DAP)
- Experimentally investigate the field size dependence of the beam quality index Q with the LAC chamber.
- Find other useful applications of the LAC chamber

- PTW 34070 Bragg Peak chamber has been used for the studies

Linacs used

ARPANSA

Elekta Synergy

6,10,18 MV with flattening filter

1 cm wide MLC

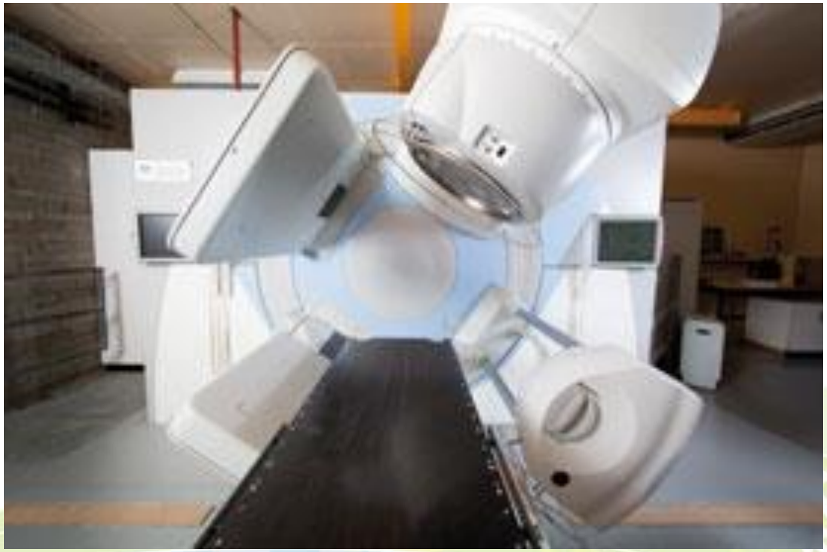
Stereotactic cones

Austin Health

Elekta Agility

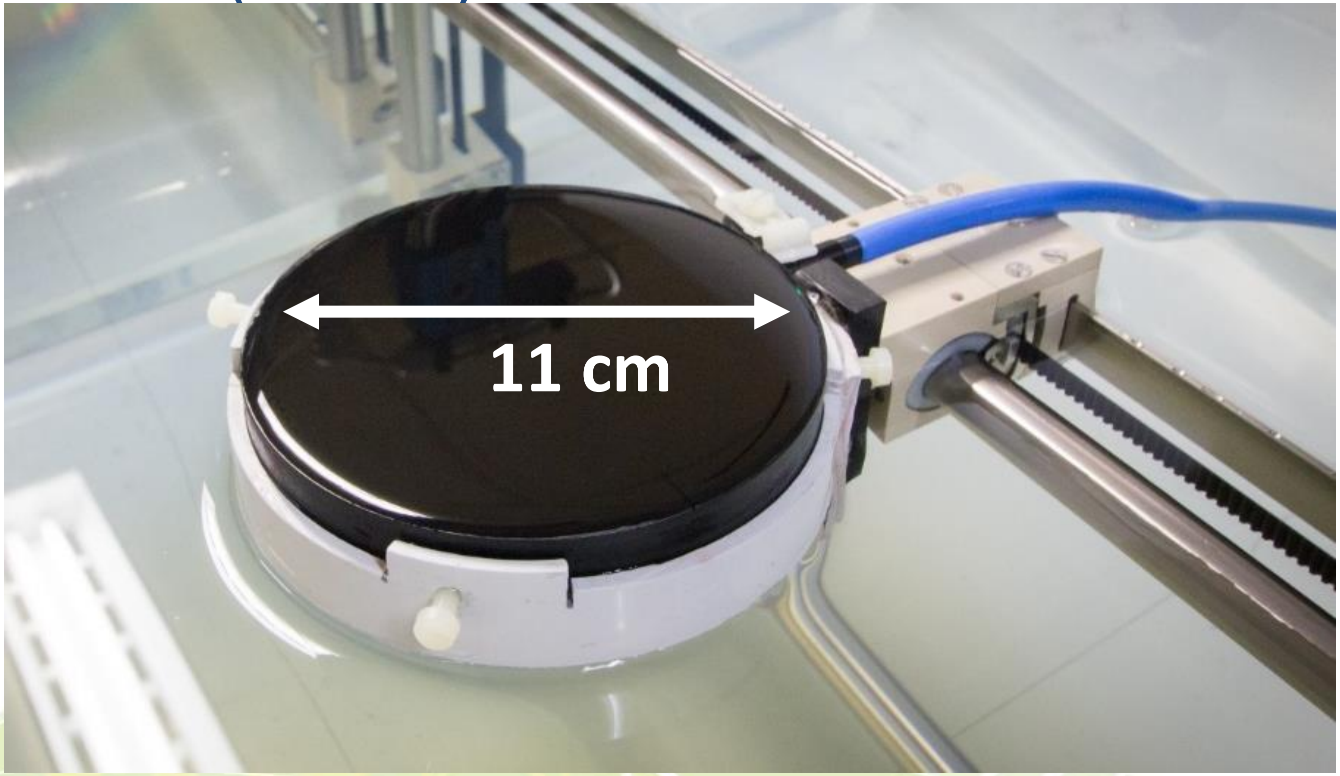
6,10 MV with and without flattening filter

0.5 cm wide MLC



PTW 34070 Bragg Peak chamber (mounted in water tank)

Waterproof, vented chamber body, nearly water equivalent (PMMA)

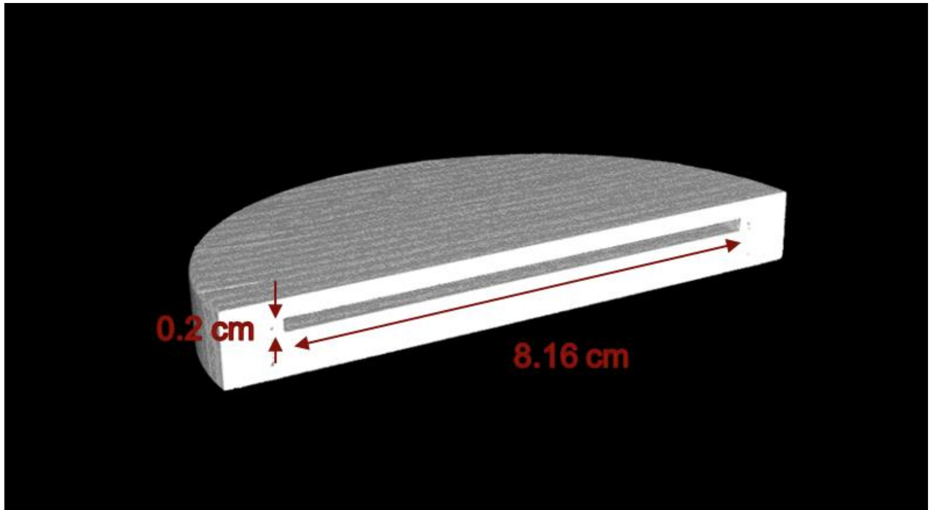


Sensitive volume:

8.16 cm diameter &

0.2 cm height

Operating bias +400 V



microCT render, T. Kupfer

Commissioning tests:

- Uniform plate separation (determined with microCT),
- Ion collection efficiency,
- polarity effect,
- Response anisotropy,
- Response long term stability.

Results – LAC commissioning test 1/6

- Electrode separation sampled across volume and found to be uniform: 2.01 +/-0.03 mm (1SD) & no discernable or systematic pattern

- Ion collection efficiency corrections: < 0.3%

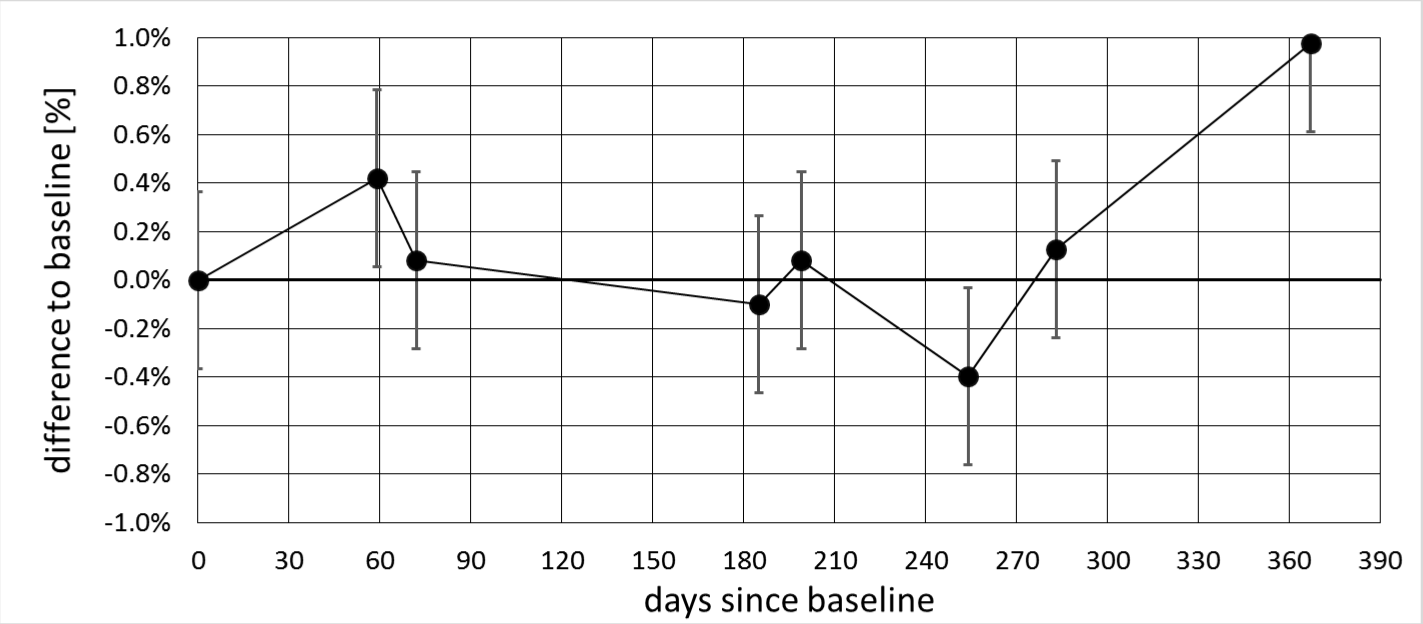
- Polarity effect: very small <0.2%

Results – LAC commissioning tests 3/6

- Sr-90 check source (20 MBq)
- Stable over long term with

1 SD = 0.4%.

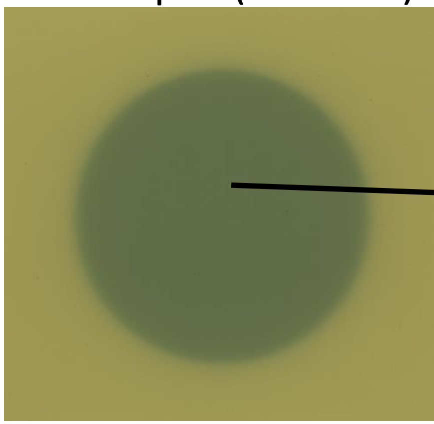
.



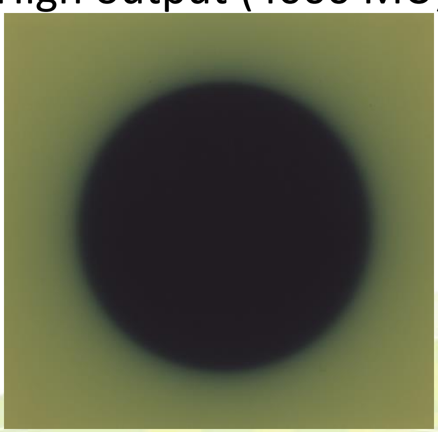
Results – LAC commissioning test 4/6

Relative dose distribution measurement with EBT3 film

Low output (400 MU)

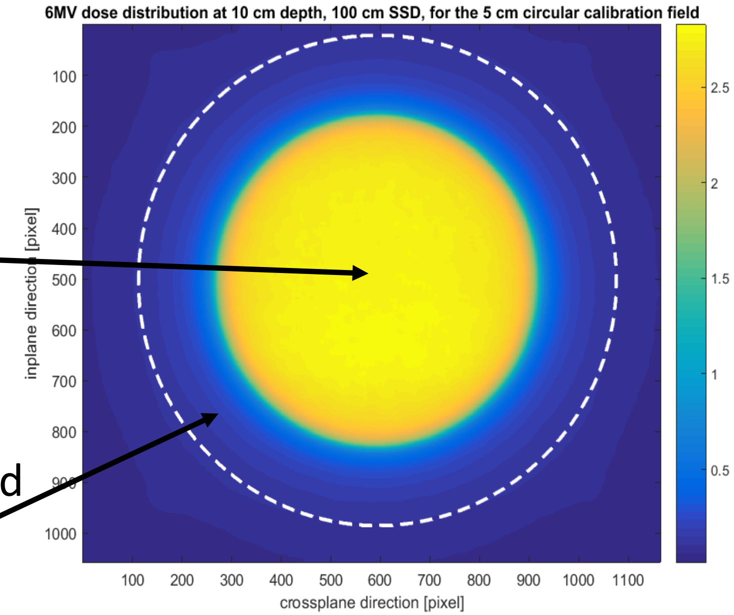


High output (4000 MU)



Low MU in-field dose

High MU out-of-field dose scaled by 1/10

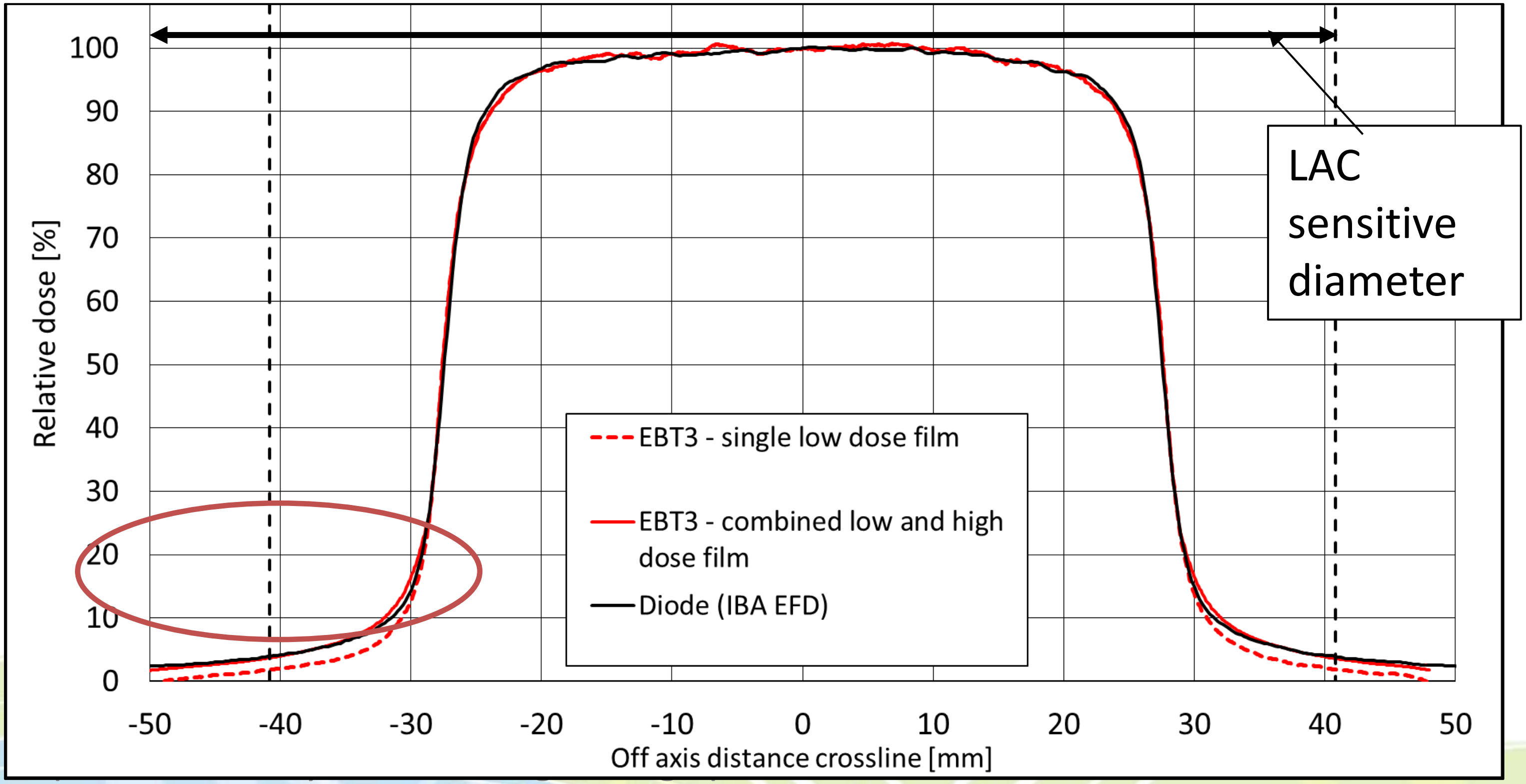


Final 2D relative dose distribution more accurate in low dose region

Results – LAC commissioning tests 5/6

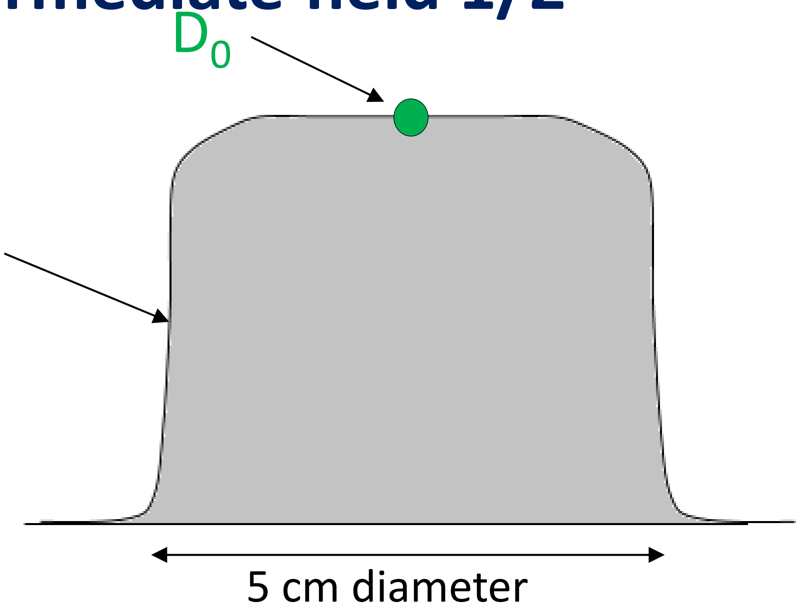
EBT3 relative dose distribution compared to other dosimeters

Improved agreement in low dose region with 2-film method



Calibration of LAC in intermediate field 1/2

$$DAP = \int D(\boldsymbol{r})d\boldsymbol{r} = M_{LAC} \cdot N_{LAC} \cdot k_i$$



DAP can be separated into an absolute and a relative component

$$\int D(\boldsymbol{r})d\boldsymbol{r} = D_0 \cdot \int R(\boldsymbol{r})d\boldsymbol{r}$$

D_0 determined with reference detector $D_0 = M_{ref} \cdot N_{Ref} \cdot k_{i,Ref} \cdot$

R(**r**) determined with film

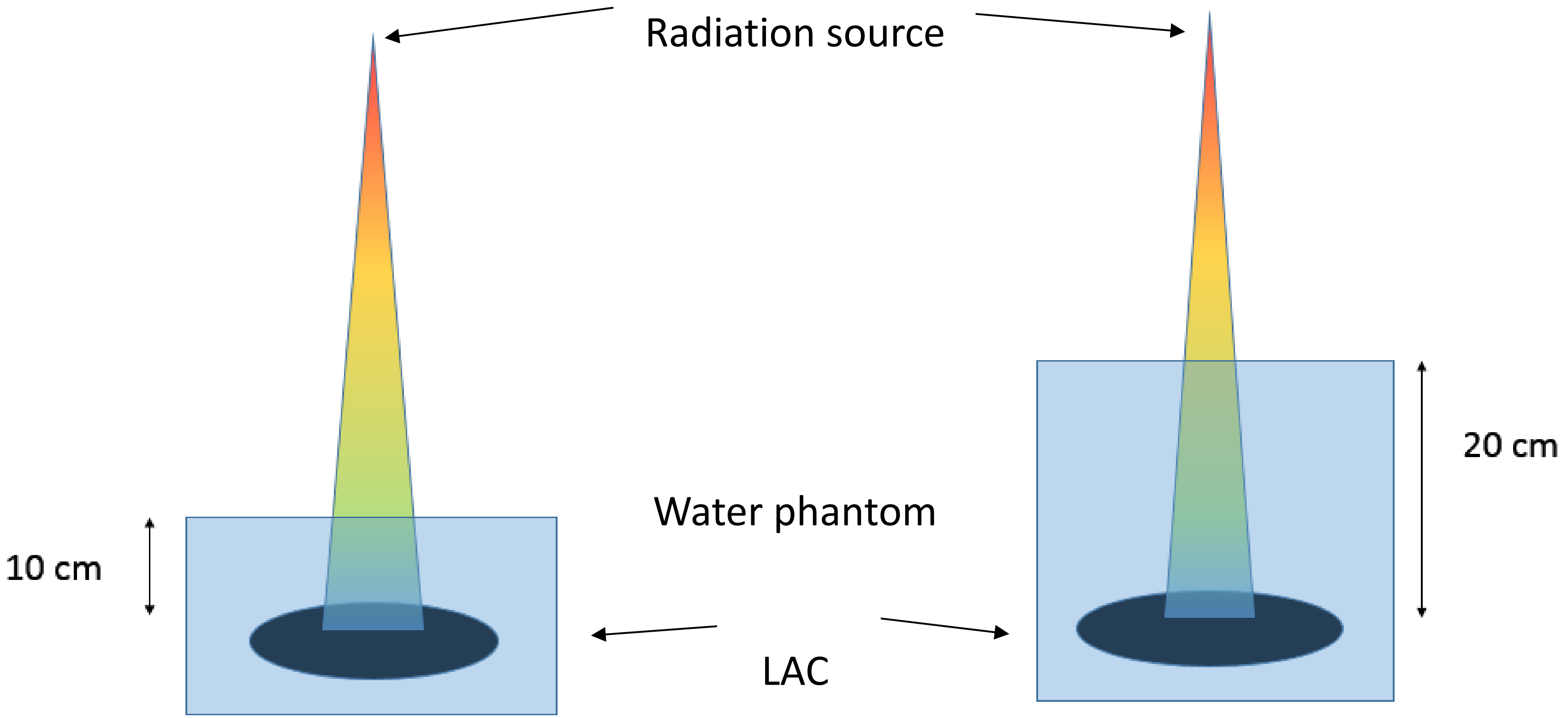
$$N_{LAC} = \frac{M_{ref} \cdot N_{Ref} \cdot k_{i,Ref} \cdot \int R(\boldsymbol{r})d\boldsymbol{r}}{M_{LAC} \cdot k_{i,LAC}}$$

Calibration of LAC in intermediate field 2/2

- 5 cm diameter cone
- Farmer reference chamber (ARPANSA standard)

- Relative dose distribution was measured with radiochromic film

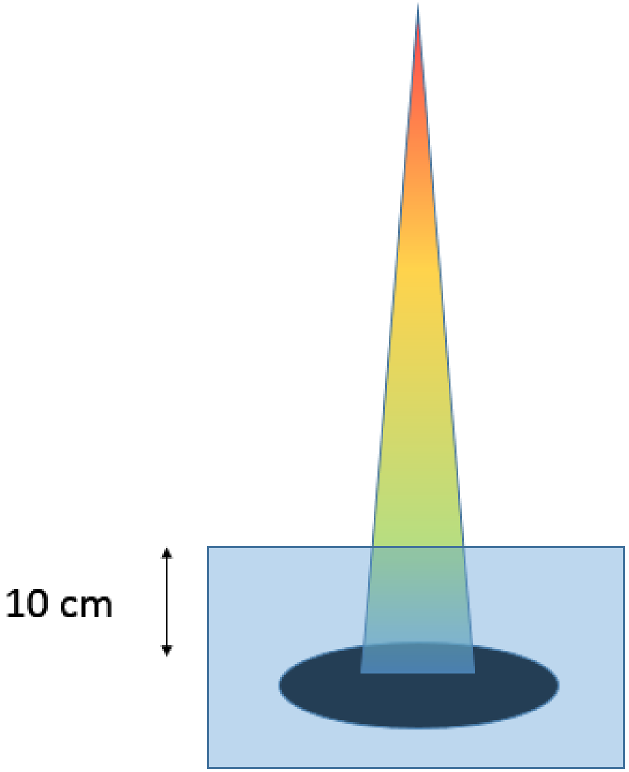
beam quality index Q



$Q = DAP_{20cm} / DAP_{10cm}$ = $\mathbf{DAPR_{20,10}}$ "dose-area product ratio 20 to 10"

Q measured at ARPANSA and Austin Health

Investigate LAC vs TPS



Measure DAP with LAC in water

Calculate DAP in clinical treatment planning system (Austin)

Field size side length:

1x1 to 5x5 cm

Normalized result to the 5x5 cm field and compare

Calibration of DAP chamber

1) Scale central axis to 1.0

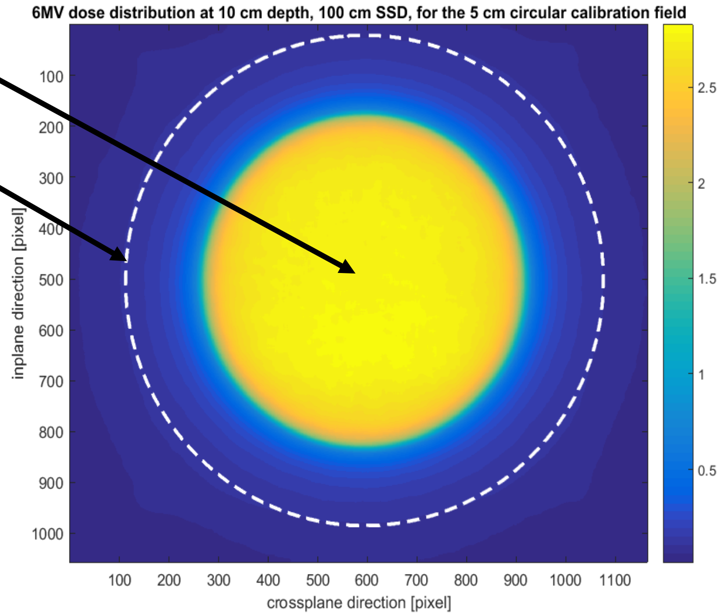
2) Numerical integration over LAC's diameter

3) Multiply by CAX dose (measured with reference detector)

$$DAP = D_0 \cdot \int R(\boldsymbol{r})d\boldsymbol{r}$$

$$N_{LAC} = \quad DAP/(M_{LAC} \cdot k_i)$$

= 16.3 cGy cm^2 nC^{-1} (1 SD = 1.4%)

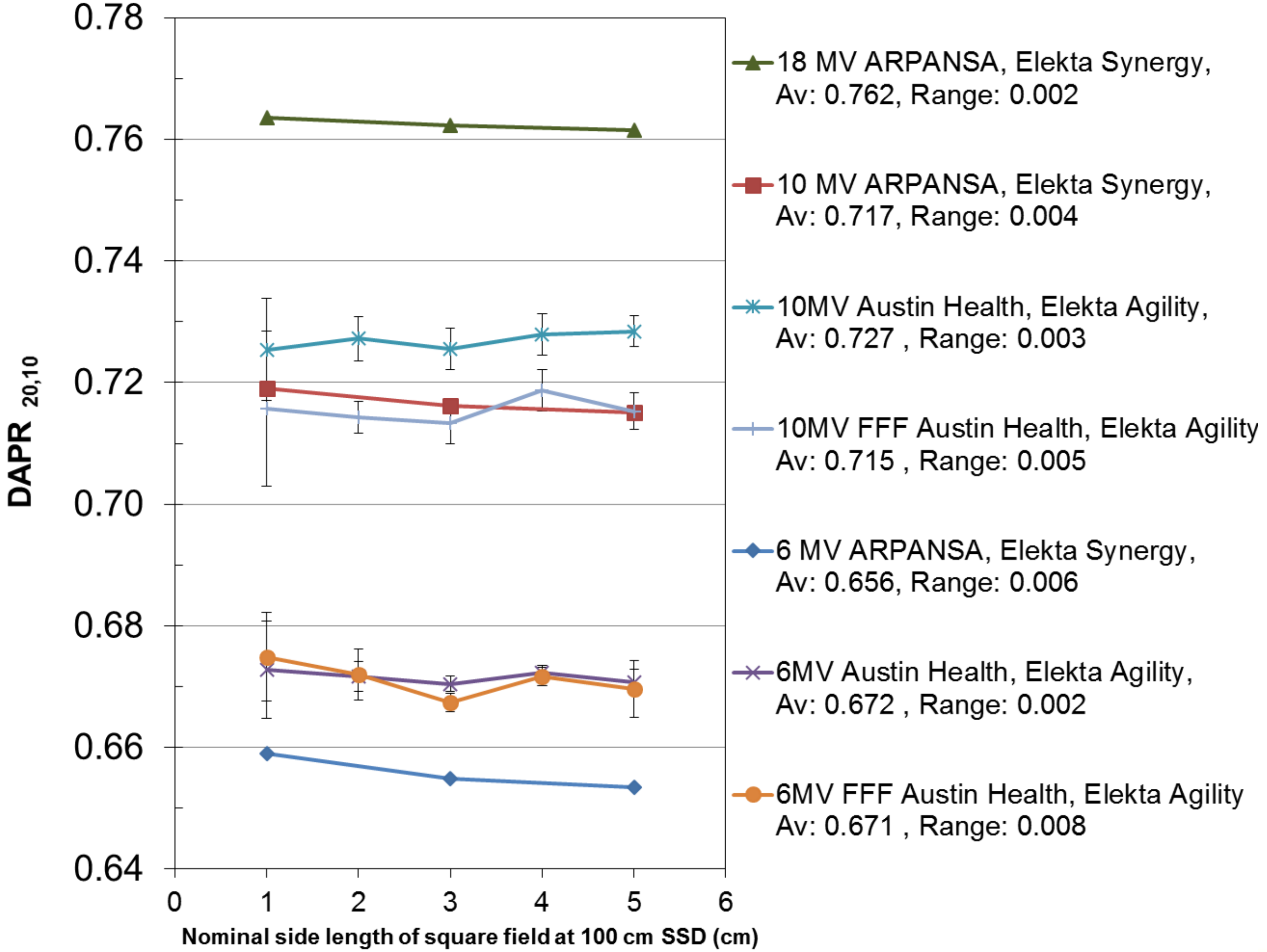


- Other authors: 16.8 cGy cm^2 nC^{-1} Diff: 3.2% (Djougouela et al. 2006)
- ARPANSA 10x10 cm field: 15.88 cGy cm^2 nC^{-1} Diff: 2.6%

Possible reasons: edge effects? Uninsulated collecting wire??

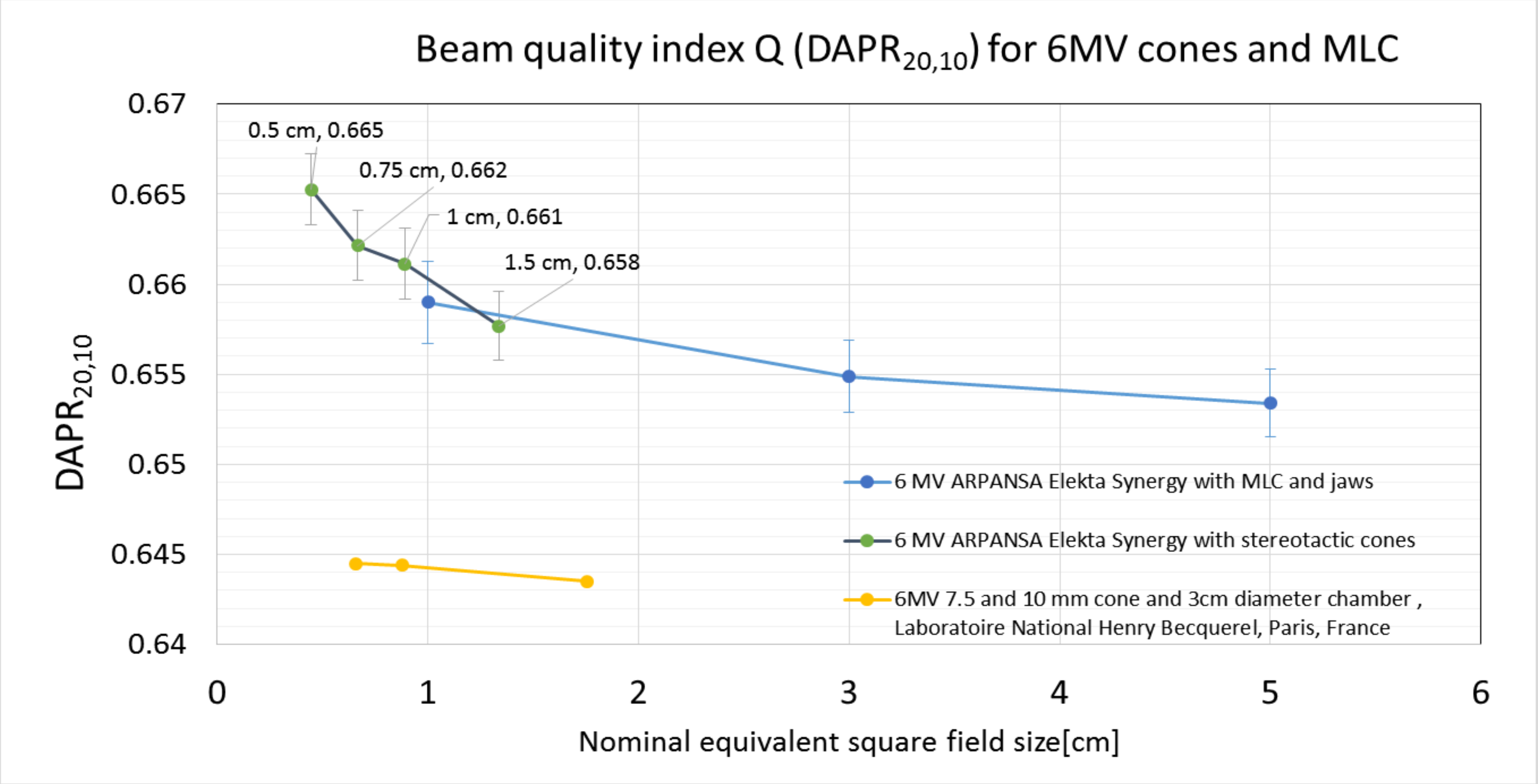
Results – beam quality index

- Q does not appear to depend on field size for MLC 1x1 – 5x5 cm

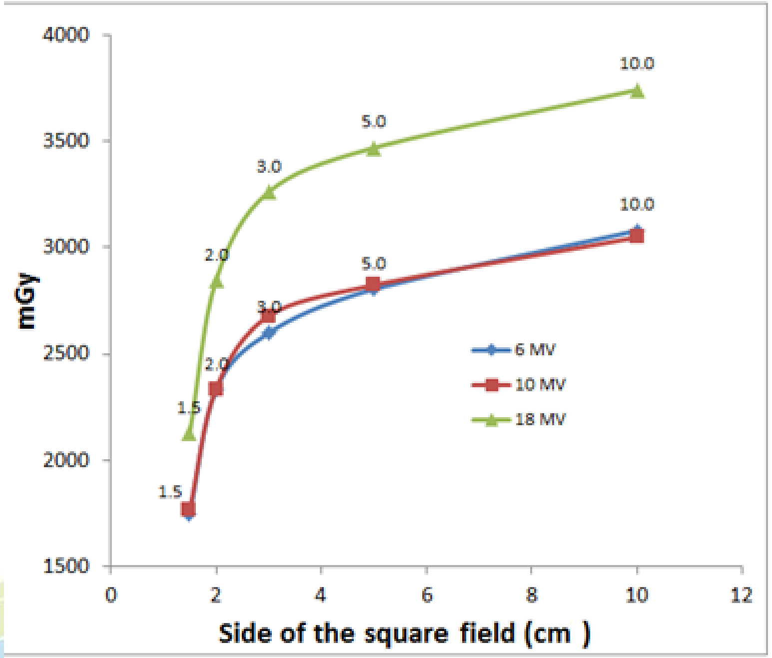


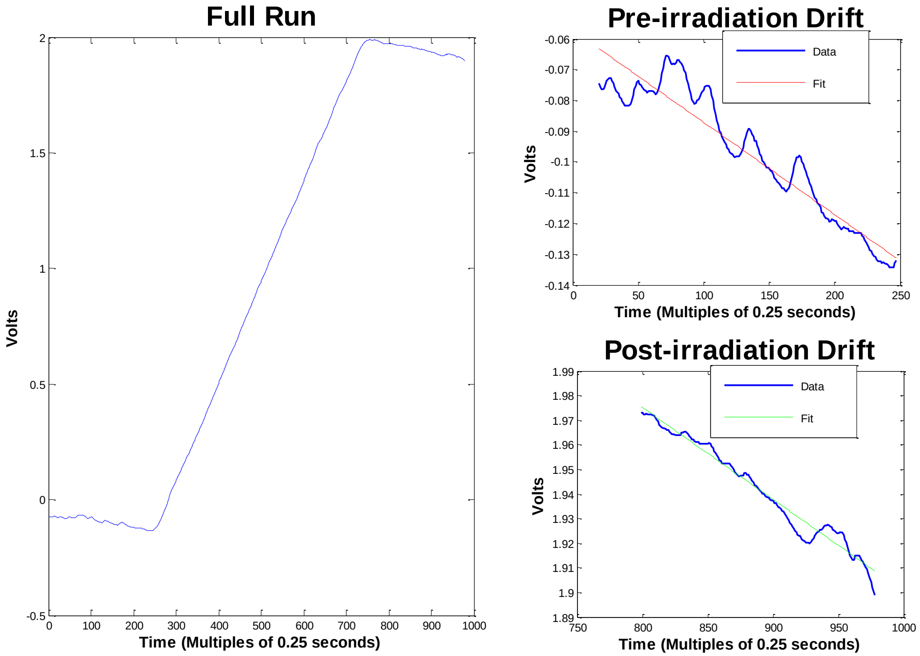
Results – beam quality index

- Slight increase with reduced field size below 1x1cm
- Other authors use 3 cm diameter and get flatter curve
- Dependent on field size, detector radius or both?

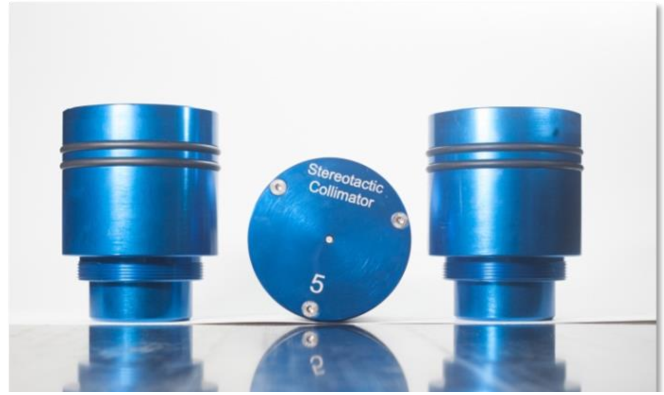


Calorimetry with MLC fields

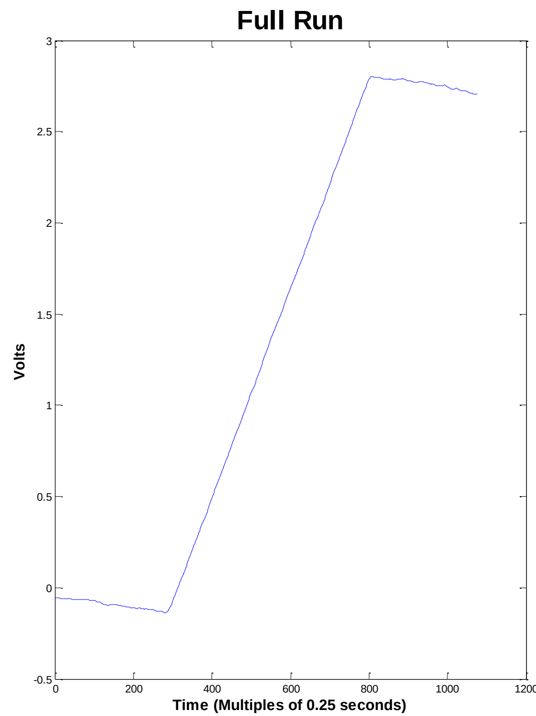


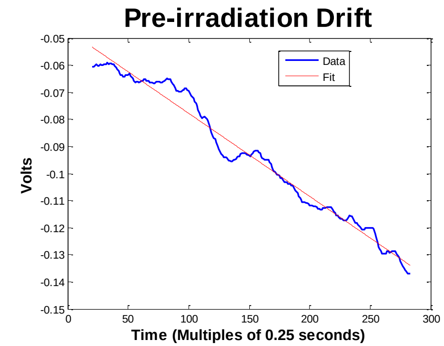


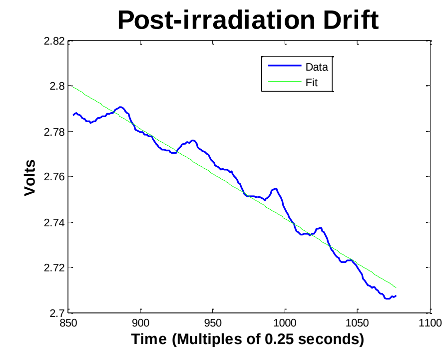
Calorimetry with SRS cones



Cone size mm	Dose/MU mGy	ESDM %
50	7.31	0.40
15	4.26	0.91
10	2.02	1.04
5	0.72	0.81



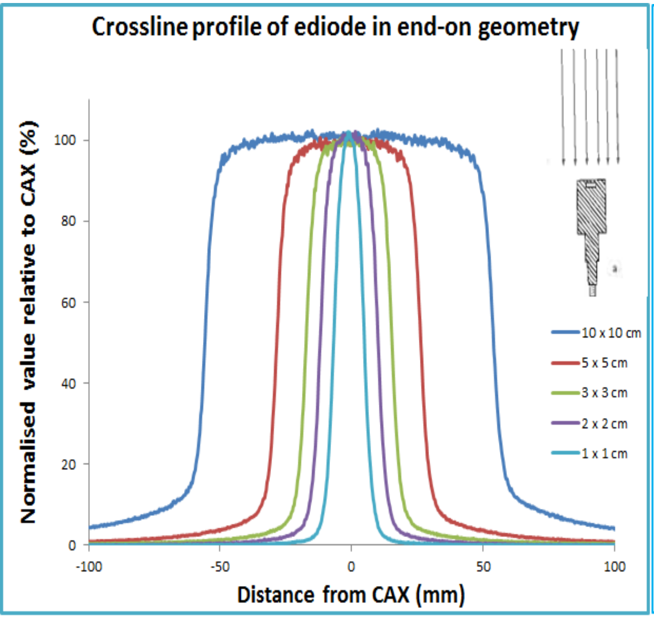


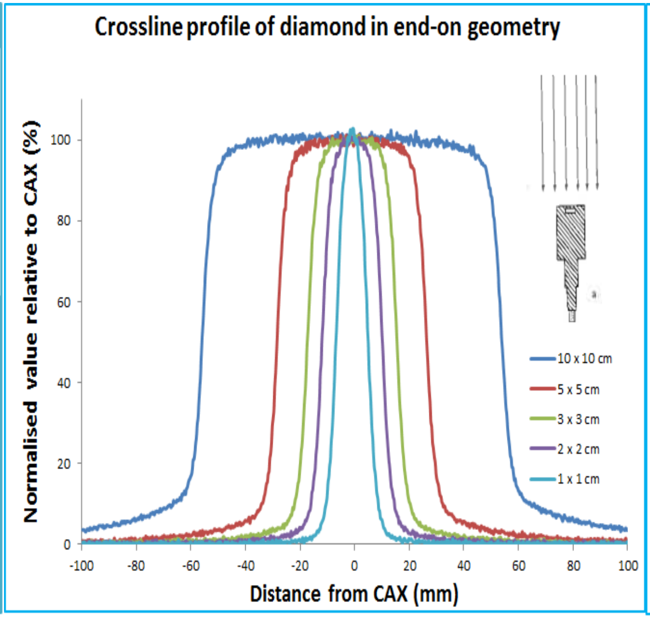


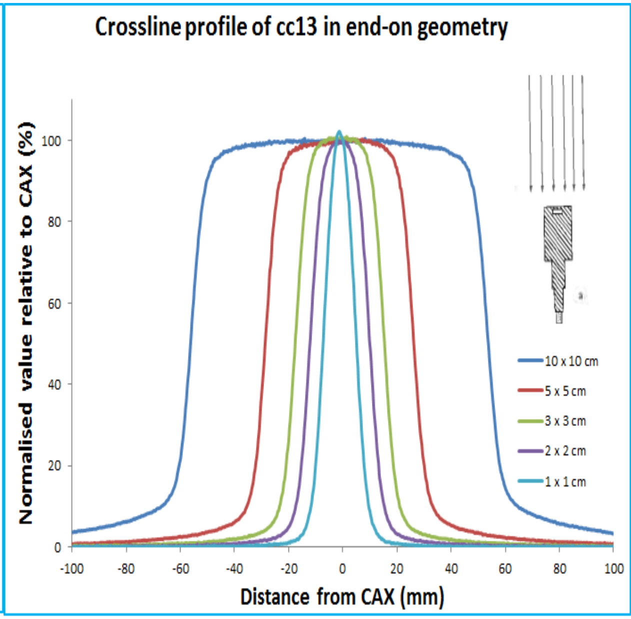
Dose values are average for 10 runs

6 MV photon beam profile measurements with MLC fields

Detectors used: PTW 60017 electron diode, PTW 60019 microdiamond and cc13 ionisation chamber

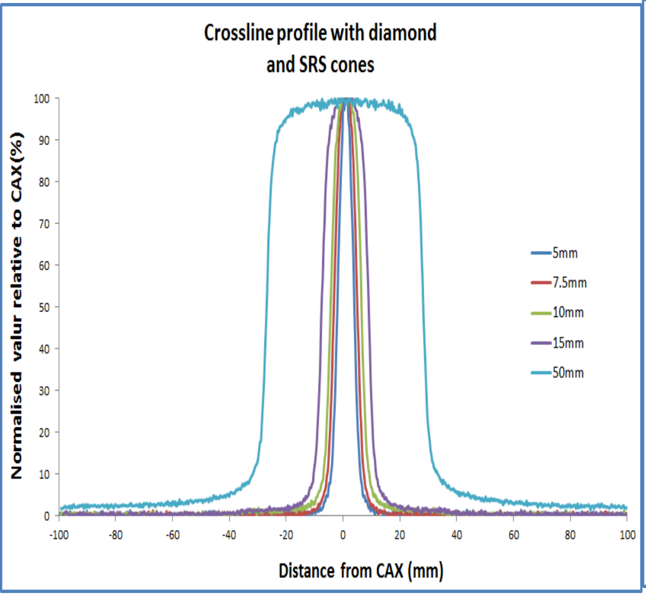


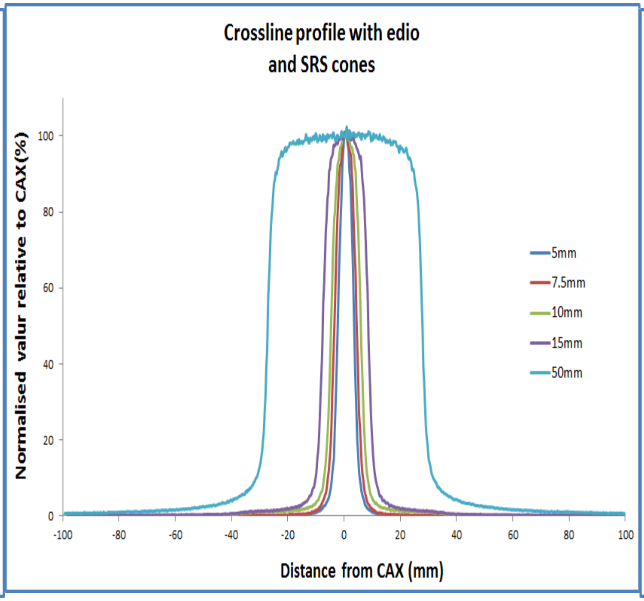


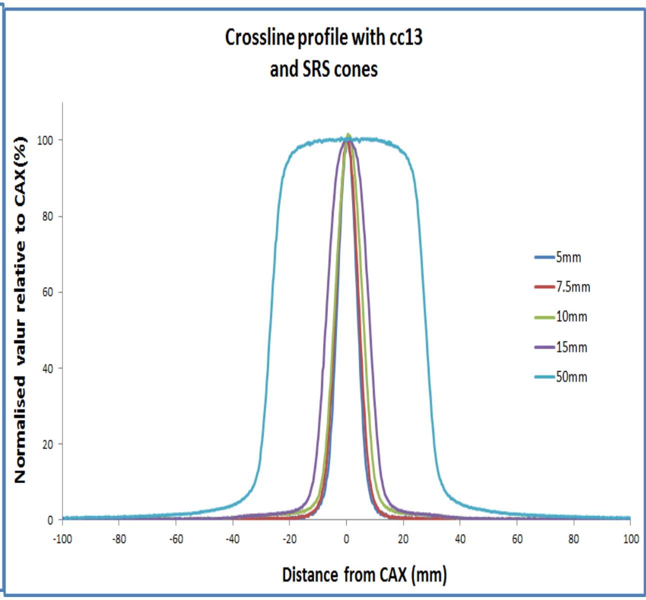


6 MV photon beam profile measurements with SRS cones

Detectors used: PTW 60017 electron diode, PTW 60019 microdiamond and cc13 ionisation chamber







Comparison of penumbra widths of profiles with SRS cones

Penumbra width (mm) (80% - 20%)			
Cone size (mm)	Ediode PTW60017	Microdiamond PTW 60019	IBA cc13 chamber
5	1.47	1.72	3.03
7.5	1.69	1.99	3.54
10	1.91	2.39	4.18
15	2.01	2.38	4.74
50	2.67	3.09	5.49
Radius of the detector	0.6	1.1	3.0

Effective field size for SRS cones with detectors

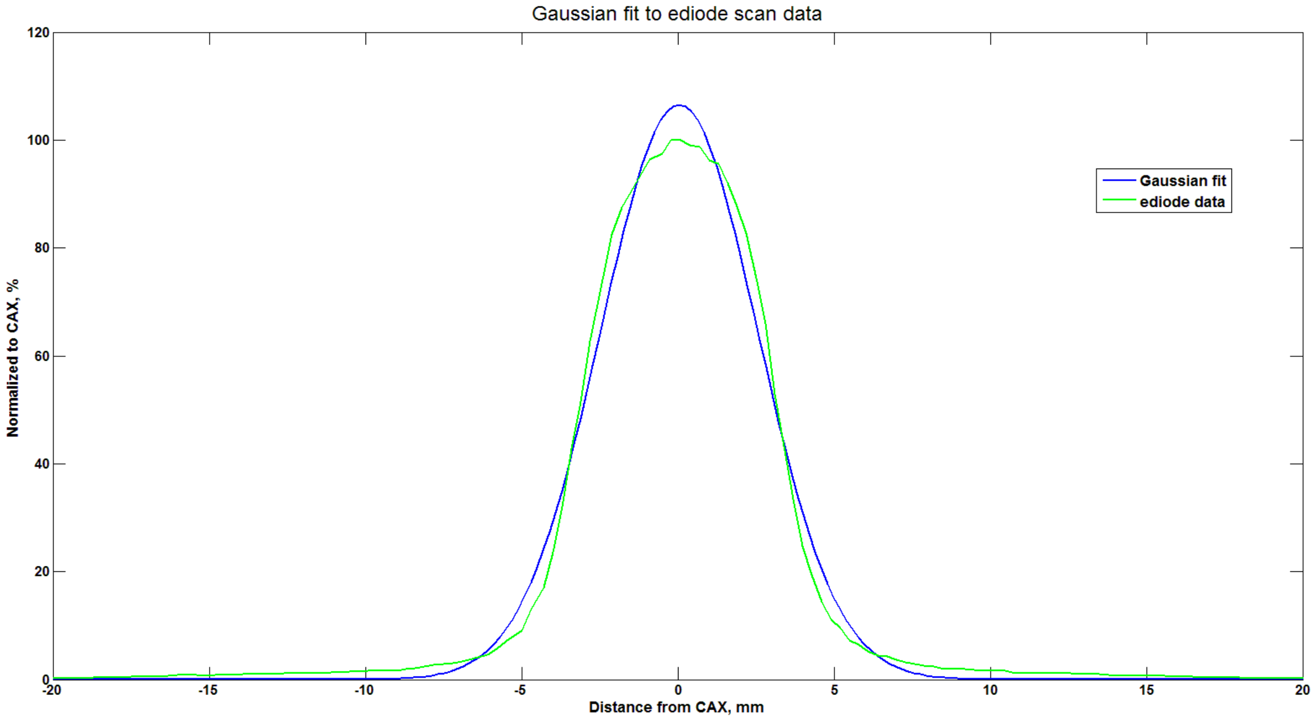
Detector	5 mm	7.5 mm	10 mm	15 mm	50 mm
Ediode PTW60017	6.28	8.41	10.92	16.29	52.76
Microdiamond PTW 60019	6.46	8.51	11.18	16.66	54.15
Pinpoint Chamber PTW 31014	6.74	8.58	11.13	16.68	53.92

Note:

1. Effective field size (mm) = $\sqrt{(FWHM_{crossline} * FWHM_{inline})}$
2. FWHM was evaluated using Matlab function (script shown in the next slide)
3. The cone diameters are quoted for iso-centre which is 100 cm but the measurements have been made in water phantom with 100 cm SSD and 10 cm depth.

```
function[Fullw]=fwhm(data)
% This function determines  full width at half
% maximum of a peak if the input data  has two columns:
% Column 1 = x
% Column 2 = y
%Coded by Ebo Ewusi-Annan
%University of Florida
%August 2012
x = data(:,1);
y= data(:,2);
maxy = max(y);
f = find(y==maxy);
cp = x(f);% ignore Matlabs suggestion to fix!!!
y1= y./maxy;
ydatawr(:,1) = y1;
ydatawr(:,2) = x;
newFit1=find(x>= cp);
newFit2=find(x < cp);
ydatawr2 = ydatawr(min(newFit1):max(newFit1),:);
ydatawr3 = ydatawr(min(newFit2):max(newFit2),:);
sp1 = spline(ydatawr2(:,1),ydatawr2(:,2),0.5);
sp2 = spline(ydatawr3(:,1),ydatawr3(:,2),0.5);
Fullw = sp1-sp2;
 end
```

Volume averaging in 5mm SRS cone fields



FWHM (ediodedata)	6.3373	General model Gauss1:
		fit1(x) = a1*exp(-((x-b1)/c1)^2)
FWHM(Gaussian fit)	5.9206	Coefficients (with 95% confidence bounds):
		a1 = 106.6 (105.7, 07.4)
		b1 = 0.04406 (0.02096, 0.06715)
		c1 = 3.553 (3.521, 586)

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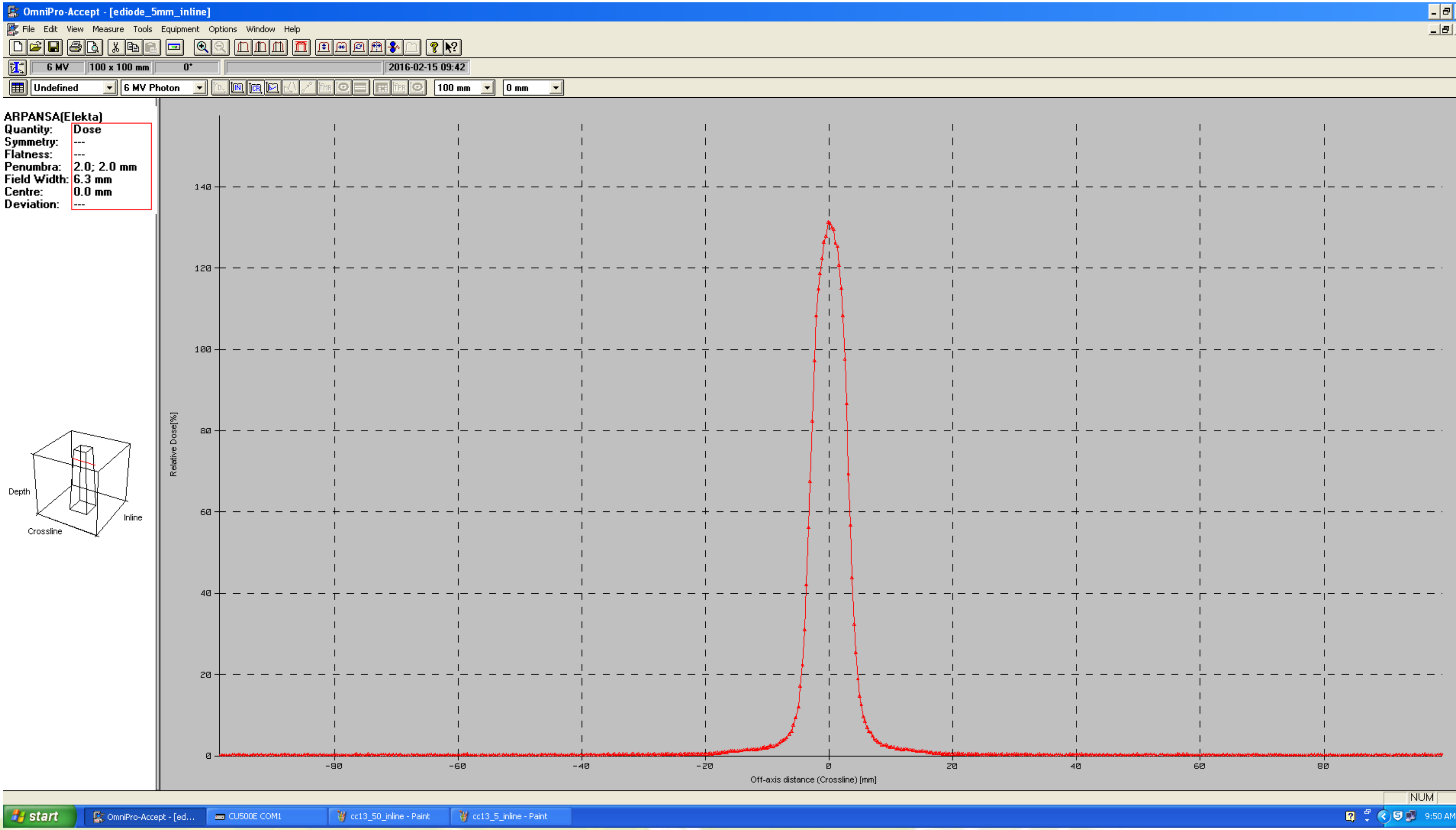
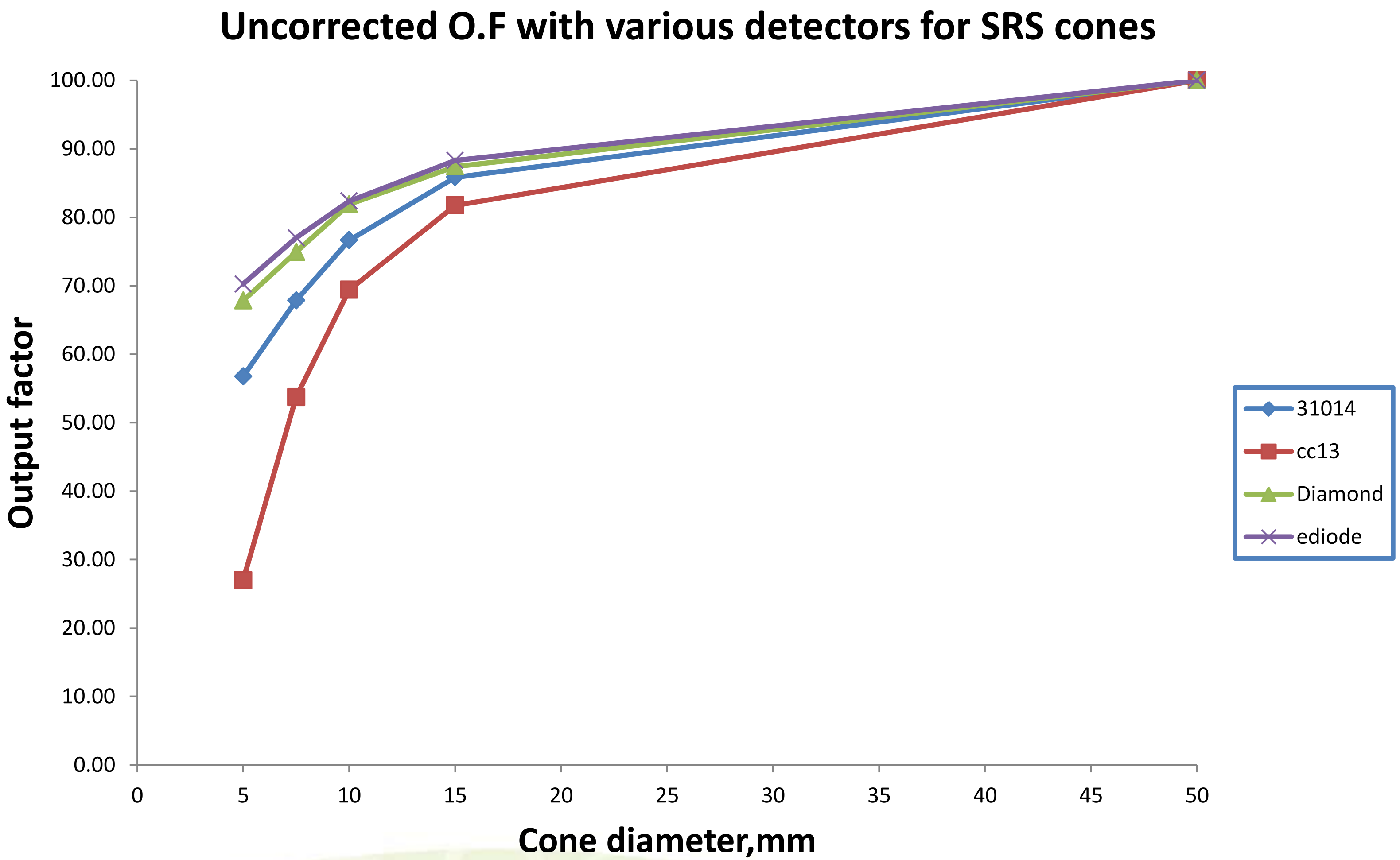
Centred profile taken before O.F. measurements for 5mm SRS cone




Uncorrected O.F with various detectors for SRS cones
Output factor
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
5
10
15
20
25
30
35
40
45
50
Cone diameter,mm
31014
cc13
Diamond
ediode

Output factor measurements with 5mm SRS cone

Detector	Charge Measured (nC) A	C.F	Corrected Charge (nC) B	10 x 10 Measured Charge (nC) C	O.F Uncorrected A/C	O.F Corrected B/C
Ediode PTW 60017	-23.03	0.96	-22.13	-36.64	0.63	0.60
Microdiamond PTW 60019	1.94	1.03	1.99	3.27	0.59	0.61
Pinpoint Chamber PTW 31014	0.70	1.13	0.79	1.39	0.50	0.57

Note:

1. Charges have been measured for 400 MU at 400 MU/min
2. Correction factors for 5mm cone CyberKnife fields for PTW 60017 and PTW 31014 have been taken from Medical Physics 40, 071725 (2013) and for PTW 60019 from Phys. Med. Biol. 60 (2015) 905–924
3. All measured charges have been corrected for polarity and recombination

Summary

- **Small Field Dosimetry is important with advanced modalities of radiotherapy using smaller field sizes for which calibration techniques are under development**
- **Education and understanding of the physicists is important as can be seen from the reports of over exposure incidents**
- **IAEA-AAPM report TG-155 is expected to provide guidelines and recommendations for accurate determination of dosimetric data for small fields**
- **DAP measurements are promising because they avoid positioning errors and variation of beam quality index with field size**
- **Monte Carlo calculations of the correction factors for small fields are in progress.**