# ORIGIN

# Optical fibre sensors for *in vivo* dosimetry

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The ORIGIN project is an initiative of the Photonics Public Private Partnership (www.photonics21.org), and has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement n° 871324

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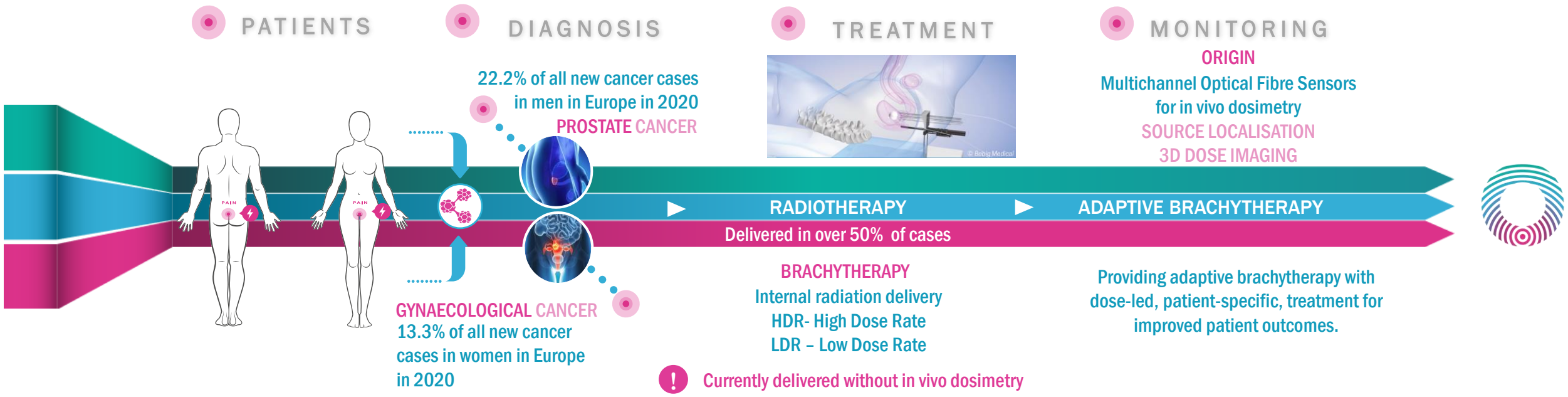


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optical fibre dose imaging for adaptive brachytherapy

H2020-ICT-05-2019: APPLICATION DRIVEN PHOTONIC COMPONENTS RIA (II): *PHOTONICS SYSTEMS FOR ADVANCED IMAGING TO SUPPORT DIAGNOSTICS DRIVEN THERAPY*

FUNDED: €4.82M - 48 MONTHS

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optical fibre dose imaging for adaptive brachytherapy

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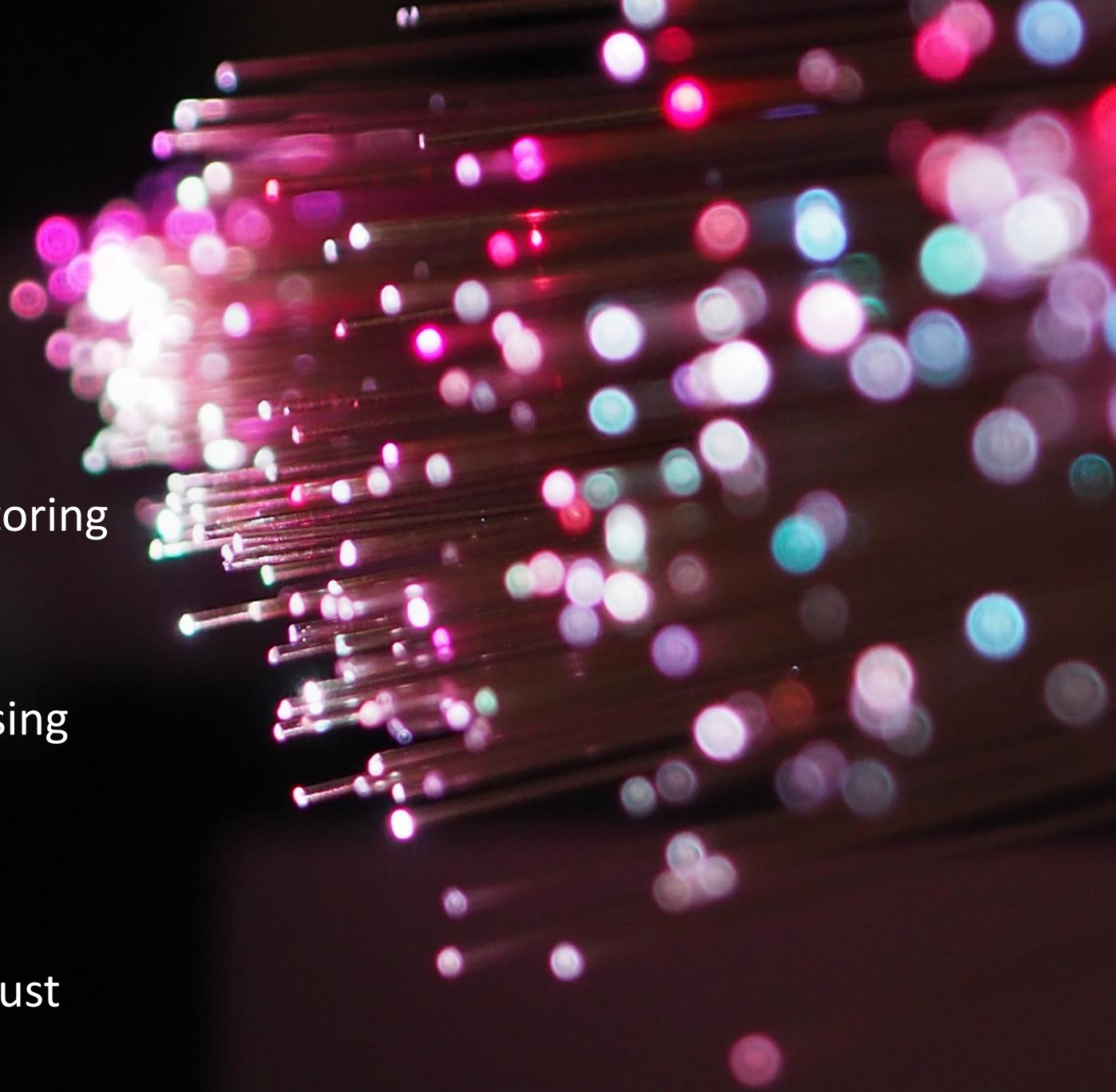
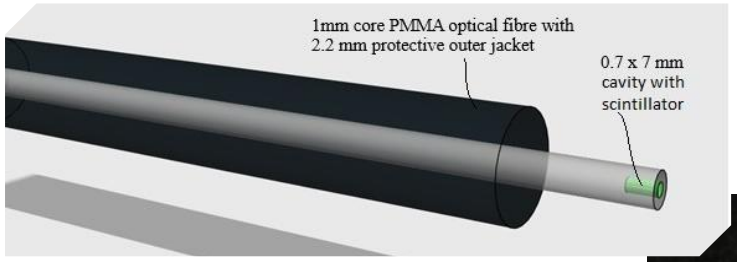
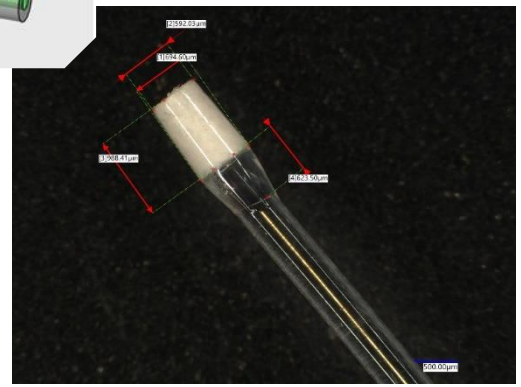
# Advantages of Optical Fibre Sensors

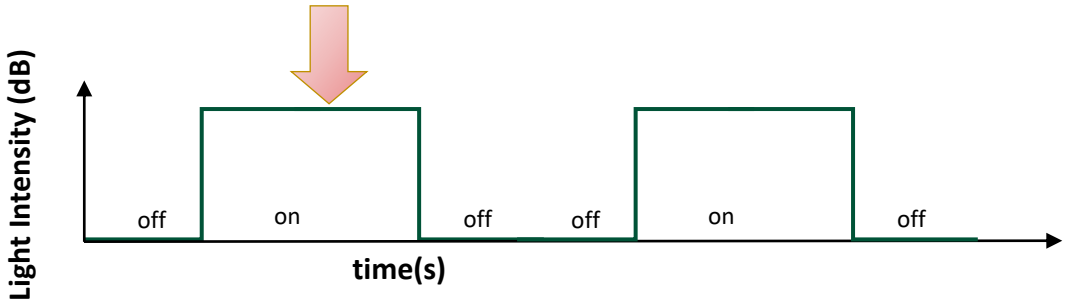


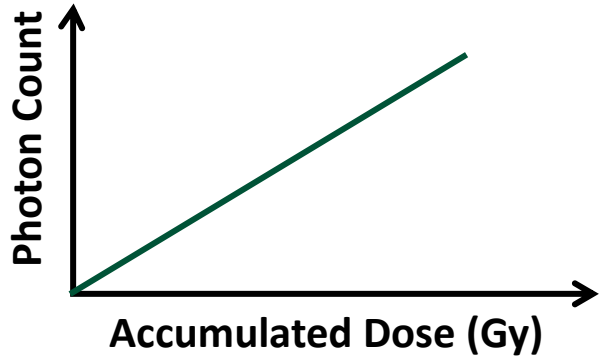
- Small size, lightweight & flexible
    - minimally invasive in vivo monitoring
- Provide remote real-time monitoring
- Easy to handle
- Can be multiplexed for multi-point sensing
- Electrically passive
- Waterproof
- Unperturbed by magnetic fields (MRI)
- PMMA – near tissue equivalence & robust

# Optical Fibre Dosimeter

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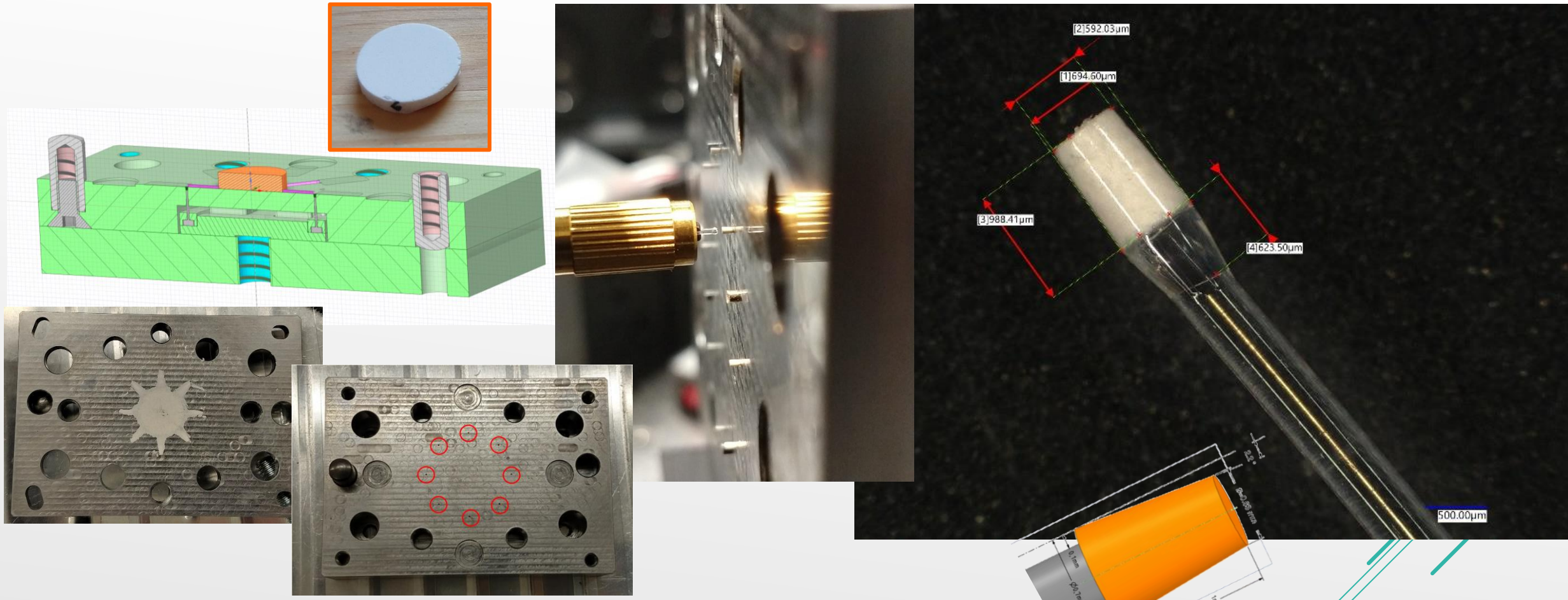
# OPTICAL FIBRE SENSORS FOR MASS MANUFACTURABILITY




- HDR: Europium doped Yttrium Orthovanate ($4YVO_4:Eu+1Y_2O_3:Eu$)
- LDR: Terbium doped Gadolinium Oxysulphide ($Gd_2O_2S:Tb$)

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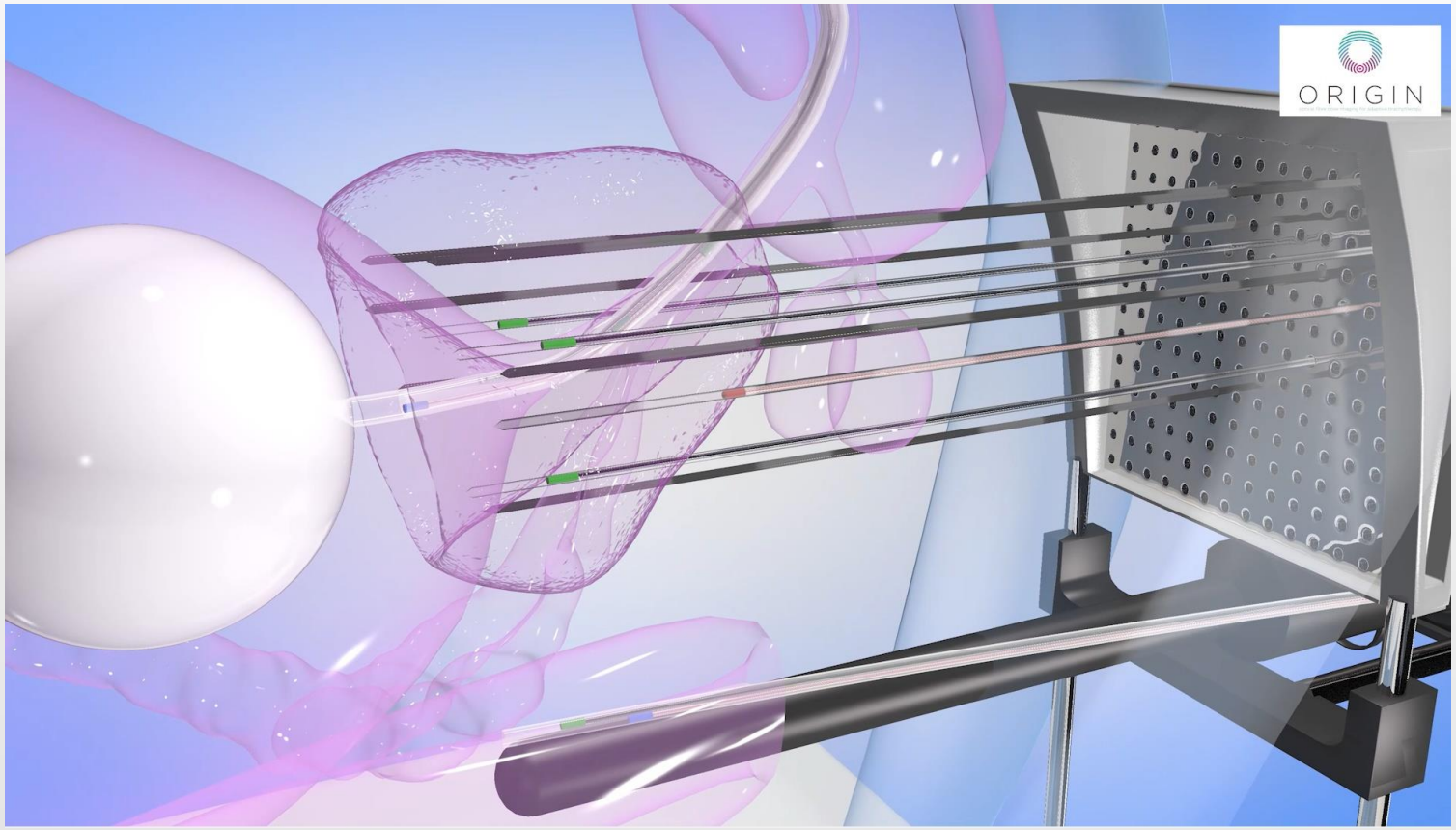
# CLINICAL CONSTRAINTS

- Target area: Brachytherapy needles/catheters – 18 Gauge (1mm inner diameter)
- Urethra/Bladder: Foley catheter – 14 French (2mm inner diameter)
- Rectum: Sheath surrounding trans-rectal ultrasound probe




- Optical fibre sensor
  - 500um Ø fibre
  - 1mm Ø with jacket

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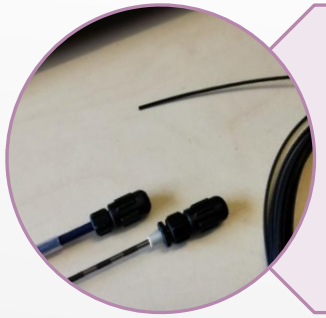
# PRACTICALITIES OF PLACEMENT

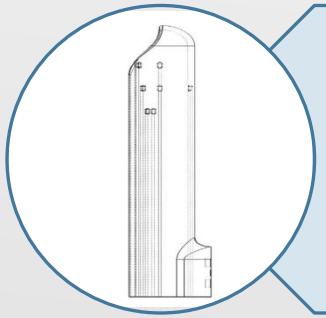


## Prostate

- Within brachytherapy needles/catheters
- 1 – 3 depending on prostate volume
- Sensor stability during treatment crucial to ensure accurate source localisation.

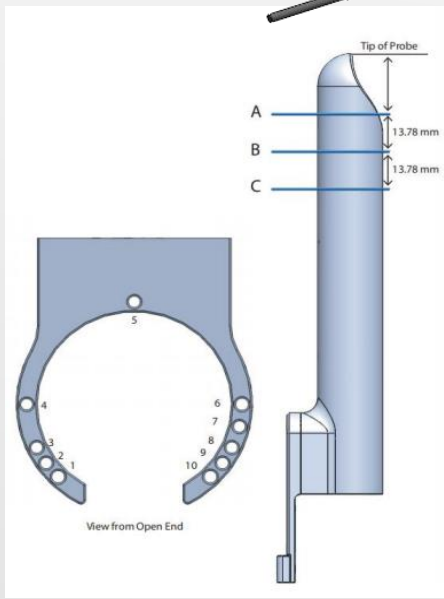
## Urethra

- 3 fibre sensors and 2 EMT sensors are fixed in pre-prepared bundles.
- Placed within a sterile universal brachytherapy catheter before inserting it in Foley catheter.



## Rectum

- A sleeve containing up to 9 optical fibres and an electromagnetic tracking sensor will be placed over the rectal US for insertion into the rectum to the superior border of the prostate.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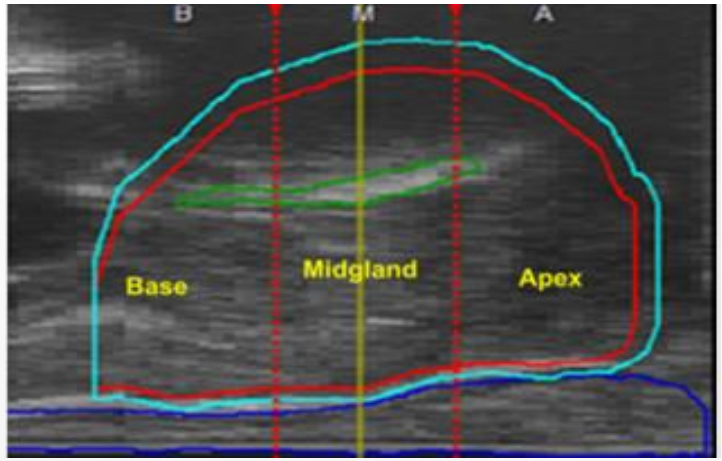
# SENSOR POSITIONING



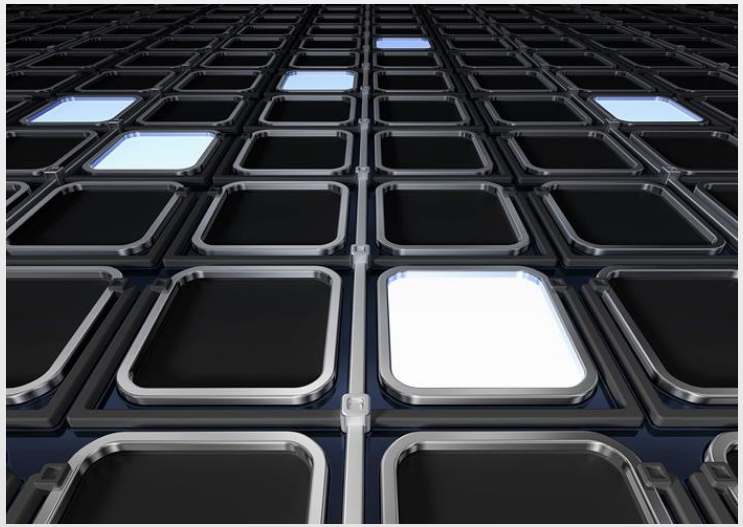

- Given the variability in dose demonstrated throughout prostate sectors, fibres will be placed at the midpoint of the base, midgland & apex.
- 30 patients, 2-step LDR brachytherapy, NICC.
- Positions within urethra:
  - Coordinates of dosimeter locations converted to length along the catheter by calculating arc length distance between the bladder neck and each dosimeter location (to compensate for non-straight path of the urethra within the prostate).
  - Median distance from bladder neck to midpoint of urethra within base, midgland & apex of prostate:
    - 0.6 cm (base); 1.8 cm (midgland); 3.2 cm (apex).
- Positions within rectum:
  - Median distance from superior prostate to midpoint of rectum within base, midgland & apex of prostate:
    - 0.7 cm (base); 2.1 cm (midgland); 3.5 cm (apex).

# PHOTON DETECTION SYSTEM

- **The choice of detector, front-end electronics, & digitization depends on the source activity and scintillation characteristics, notably the LIGHT YIELD and DECAY TIME.**
  - When the decay time is long (500 μs for the ORIGIN material), scintillating light is "diluted" in time, so every interaction results in a trail of single photons

**+ Pro: "multiplication factor": 1 gamma ray → N photons out**

**- con: you need a single photon sensitive detector**



The baseline sensors for ORIGIN are Silicon-Photomultipliers - single photon sensitivity

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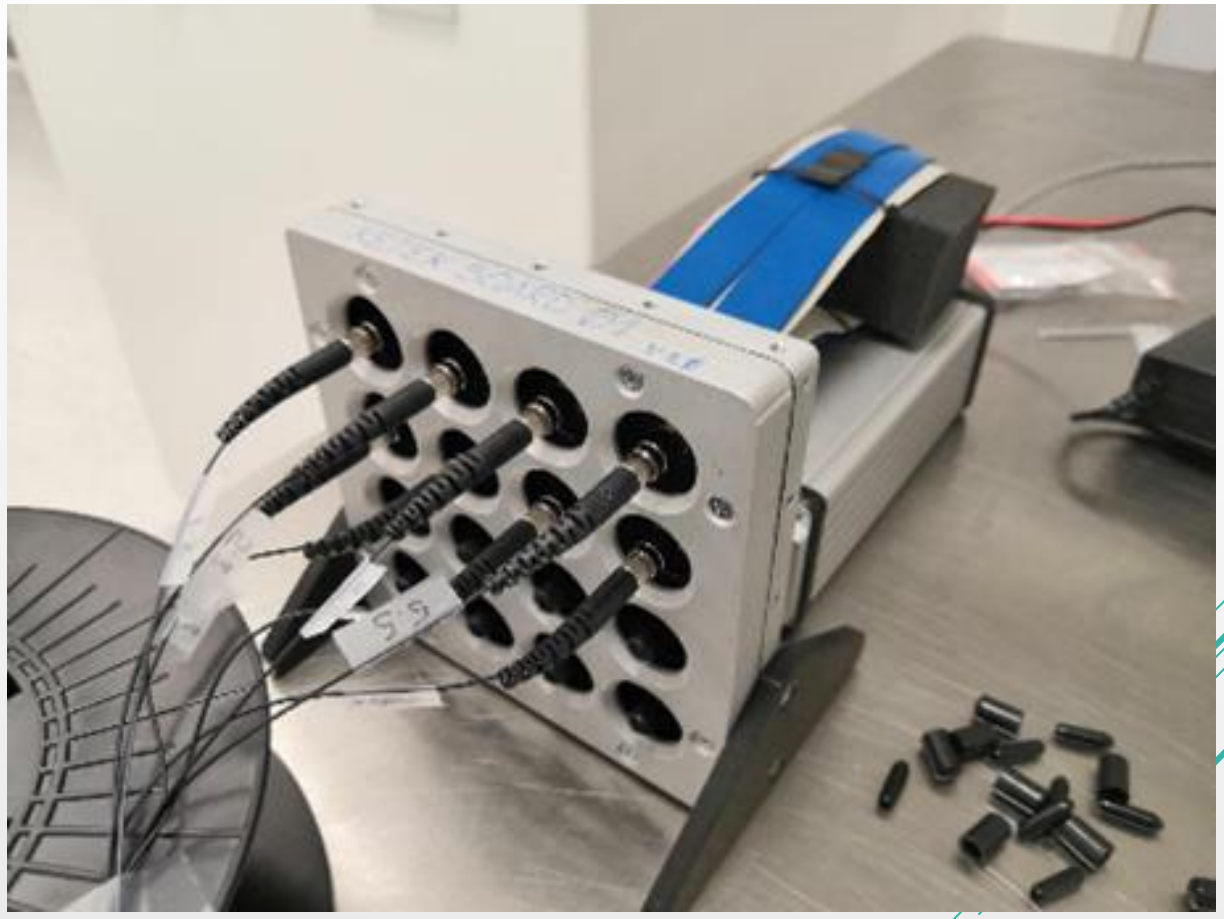
# MULTI-CHANNEL SYSTEM

- SiPMs
  - HDR: KETEK non-cooled SiPMs
  - LDR: Hamamatsu TE-cooled SiPMs for improved sensitivity
- CAEN A5202 FERS
  - Front-end board
  - Embedding 2 Citiroc1A (64 channels)



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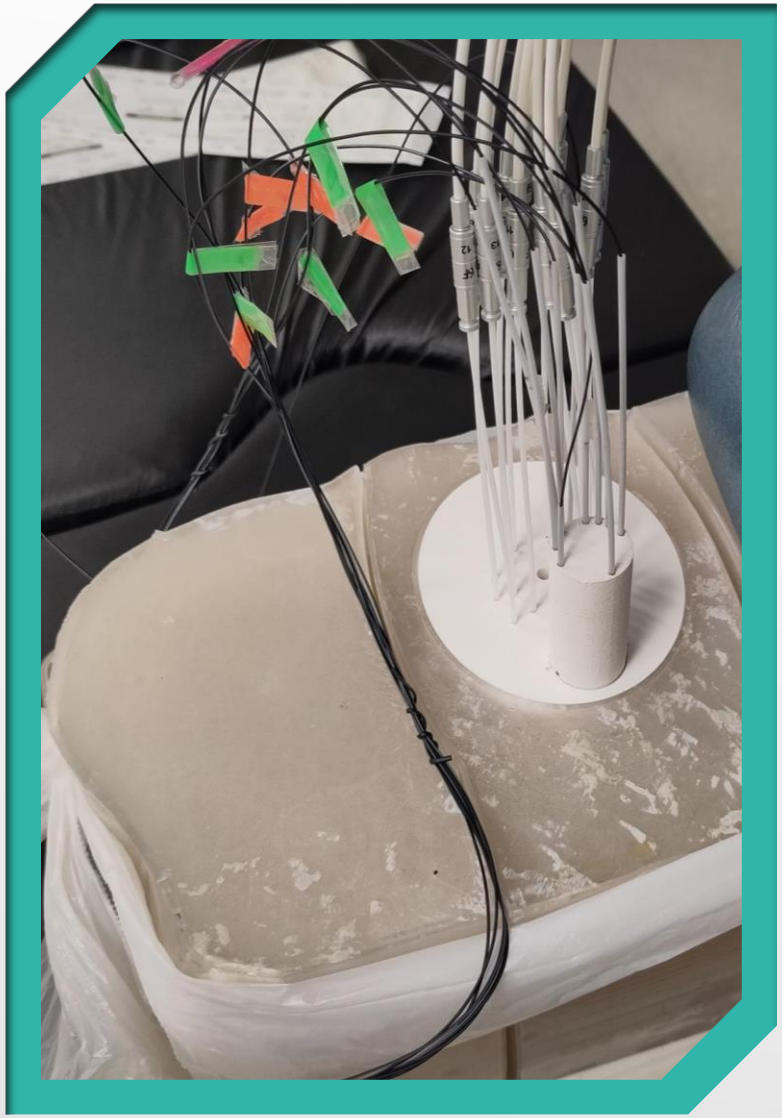
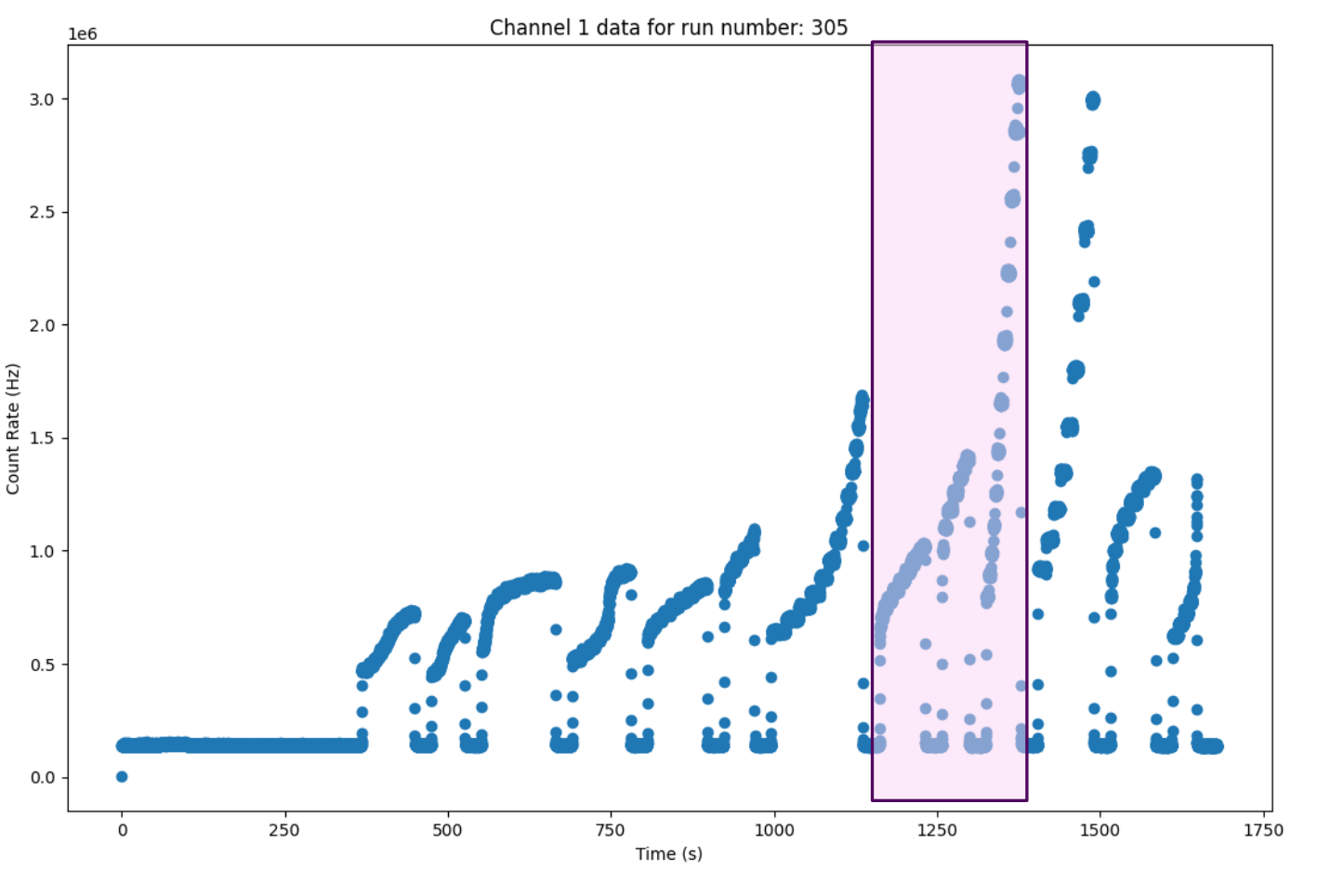
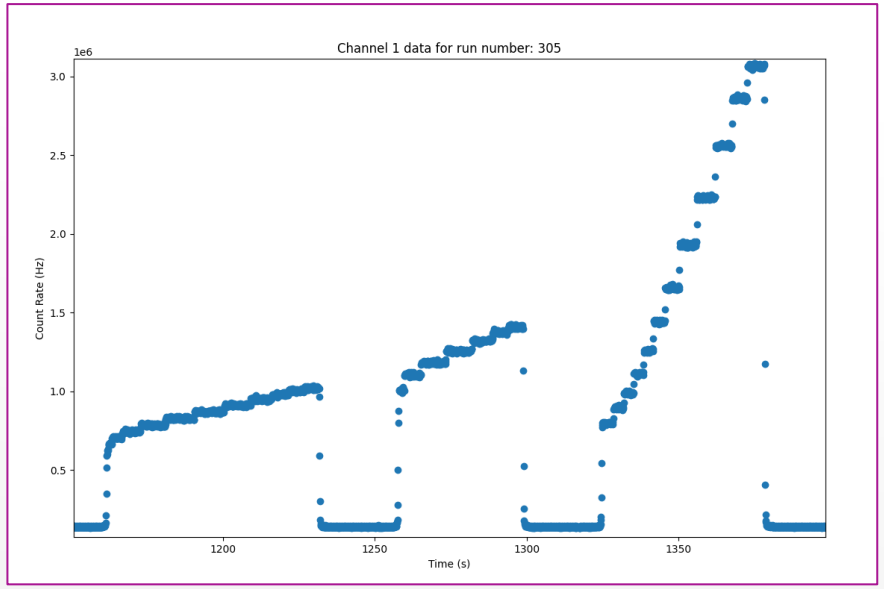


# HDR PROSTATE TREATMENT

- Prostate phantom printed
  - 15 channels for needles/ fibres
  - Rectal cavity insert mimicking a probe
  - Urethral cavity to hold a 12 gauge catheter
- CT imaging
  - Organs contoured
- Needle positions verified using EM tracking

# HDR MEASUREMENTS

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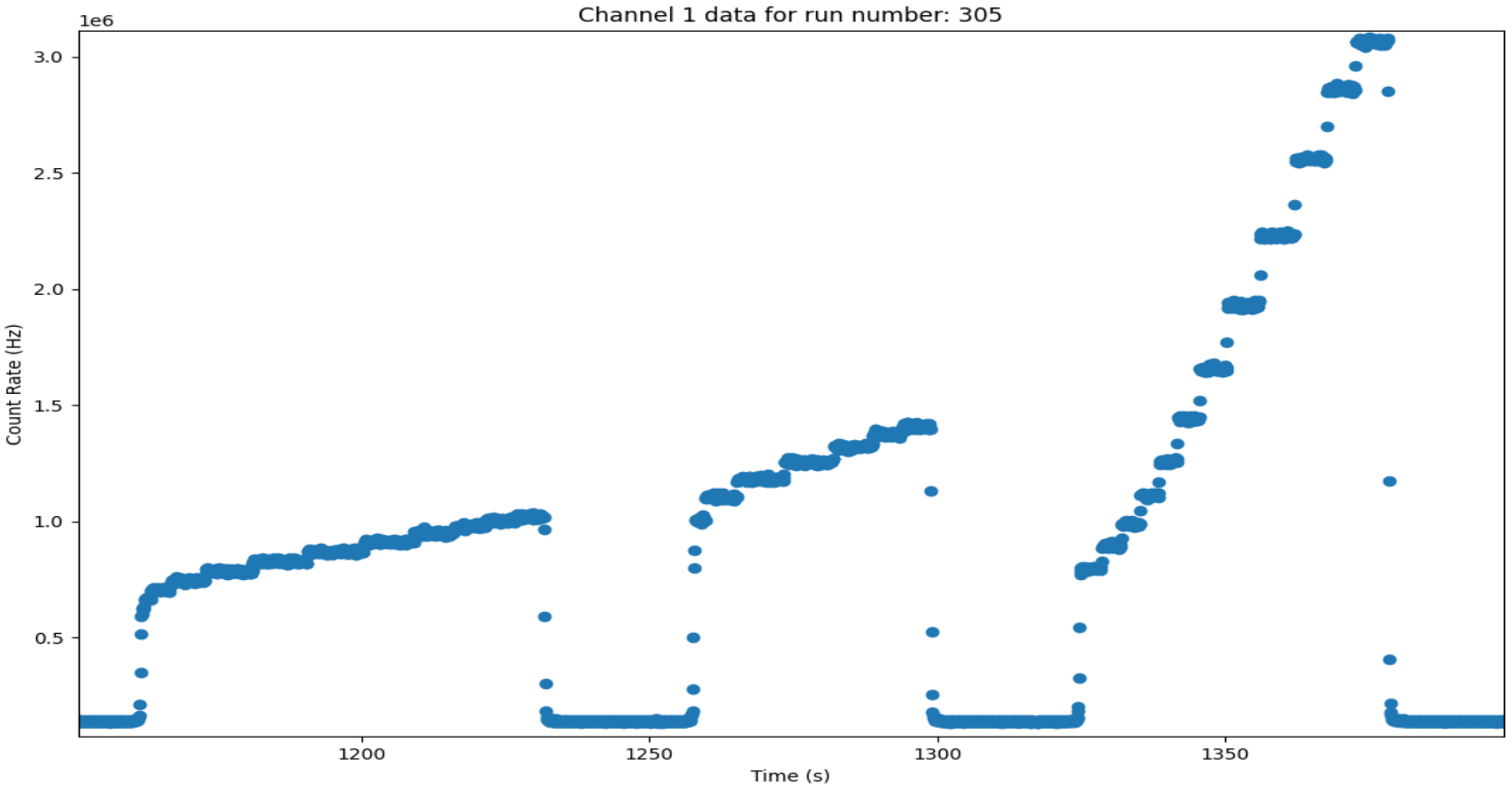
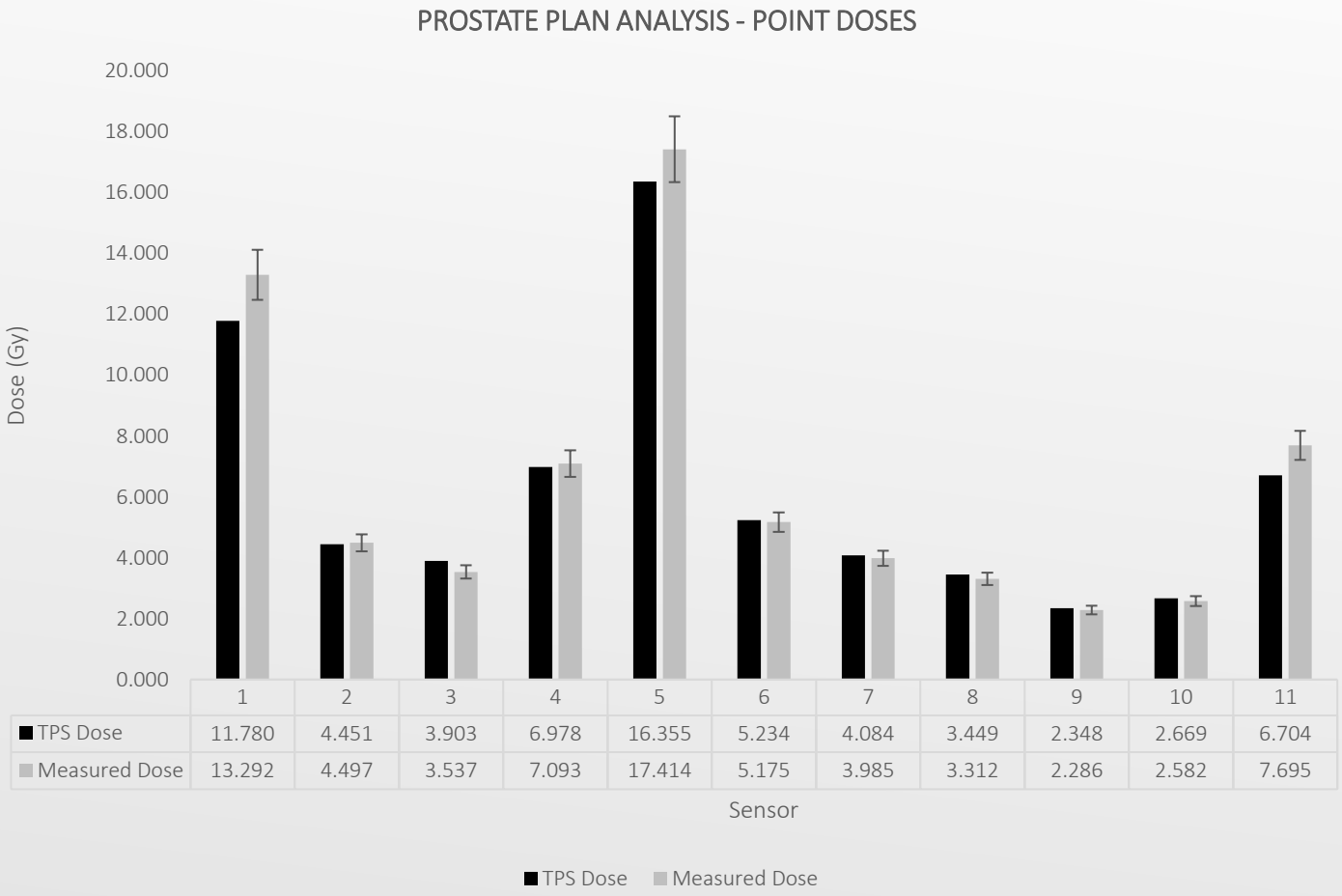
# HDR MEASUREMENTS



# CUMULATIVE DOSE – RESULTS




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| TPS Dose | 11.780 | 4.451 | 3.903 | 6.978 | 16.355 | 5.234 | 4.084 | 3.449 | 2.348 | 2.669 | 6.704 |
| Measured Dose | 13.292 | 4.497 | 3.537 | 7.093 | 17.414 | 5.175 | 3.985 | 3.312 | 2.286 | 2.582 | 7.695 |

- Measured dose summed across all dwell positions
- Point doses compared to dose points added in TPS
- Composite uncertainty of 6.2% used

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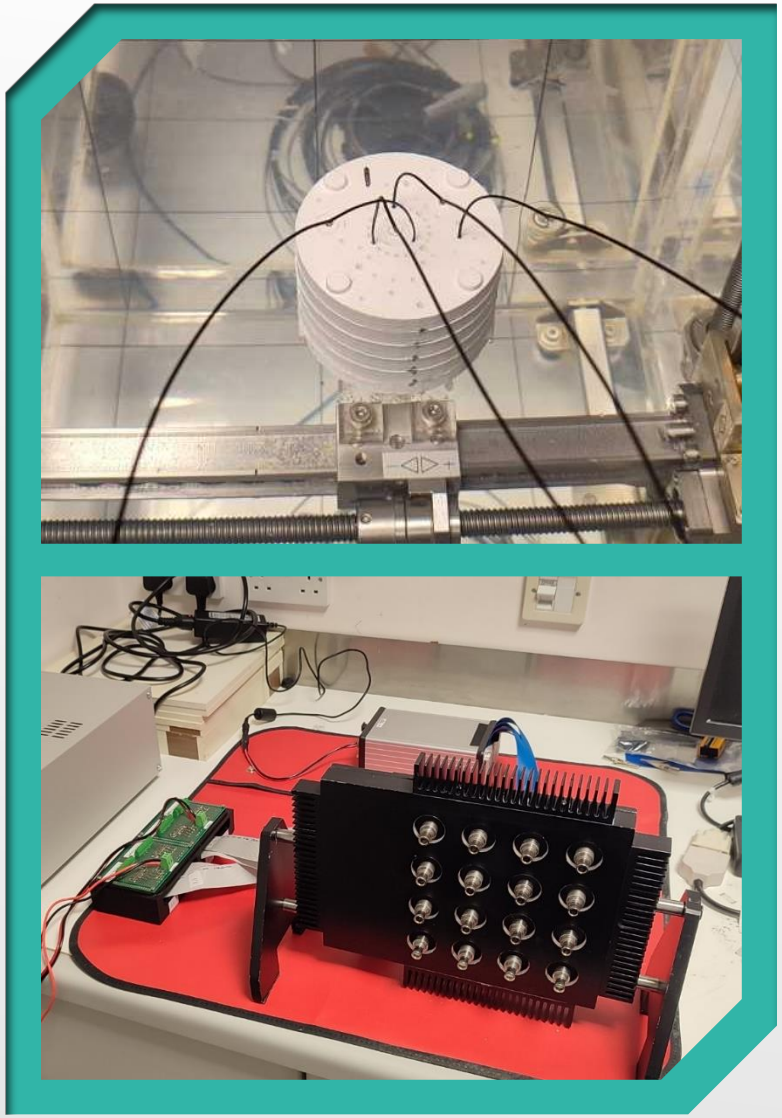
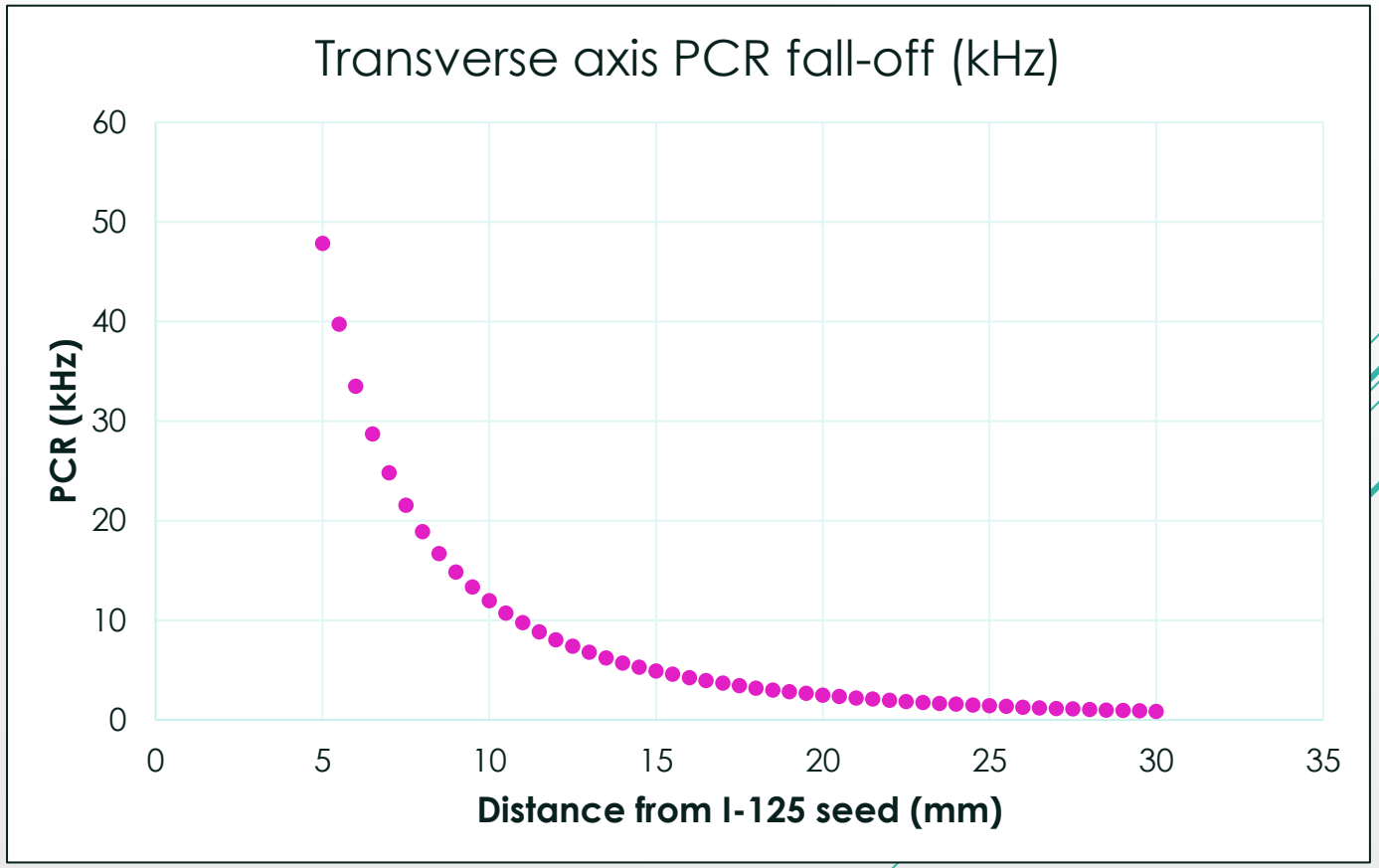


# LDR PROSTATE TREATMENTS

- **TE-cooled SiPM system**
  - Designed to **reduce dark count rate** (DCR) through thermoelectric cooling of SiPMs
  - **Improved sensitivity** through cooling was required for application in Low Dose Rate Brachytherapy (dose rate < 2 $Gy.h^{-1}$)
  - Allows measurement up to 3 cm from I-125 seed, meeting specifications of ORIGIN system for LDR-BT

# LDR RESULTS

- Photon Count Rate
  - Measured PCR @ 1 cm: 7.63 kHz
  - Seed activity at time of measurement: 0.26 mCi
  - Seed activity at BT implantation: 0.41 mCi (monotherapy)
  - Thus, PCR @ 1cm during implantation: 11.97 kHz
  - Using characterised fall-off behavior, **PCR @ 3 cm: 0.87 kHz**

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# SOURCE LOCALISATION

### Step 1:

- Given sensor readings, calculate most likely distance to source using a Bayesian approach

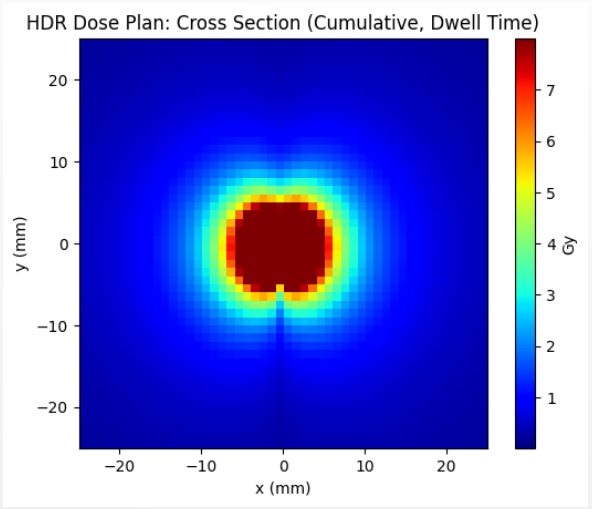
### Step 2:

- Given most likely distances and EMT location of sensors, use tri-lateration to locate most likely position of the source

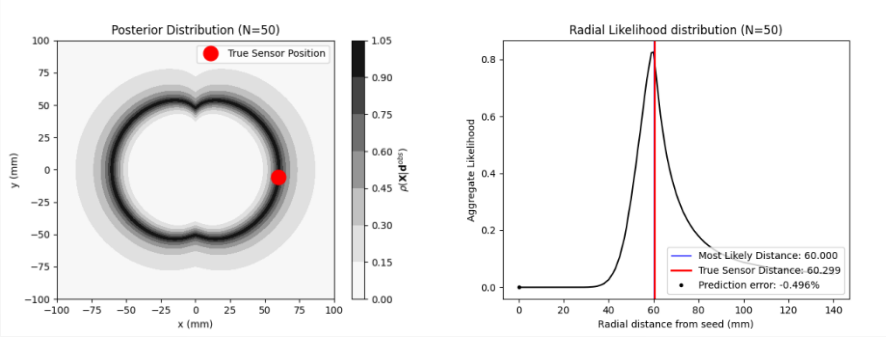
### Step 3:

- With most likely position of source, map dosage onto ultrasound images

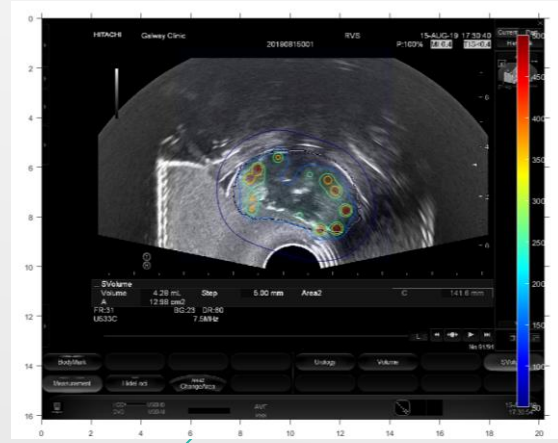
## Dose distribution

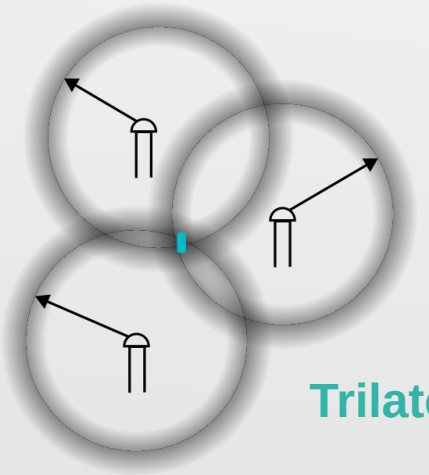



## Single sensor algorithm




## Dose Mapping





## Trilateration

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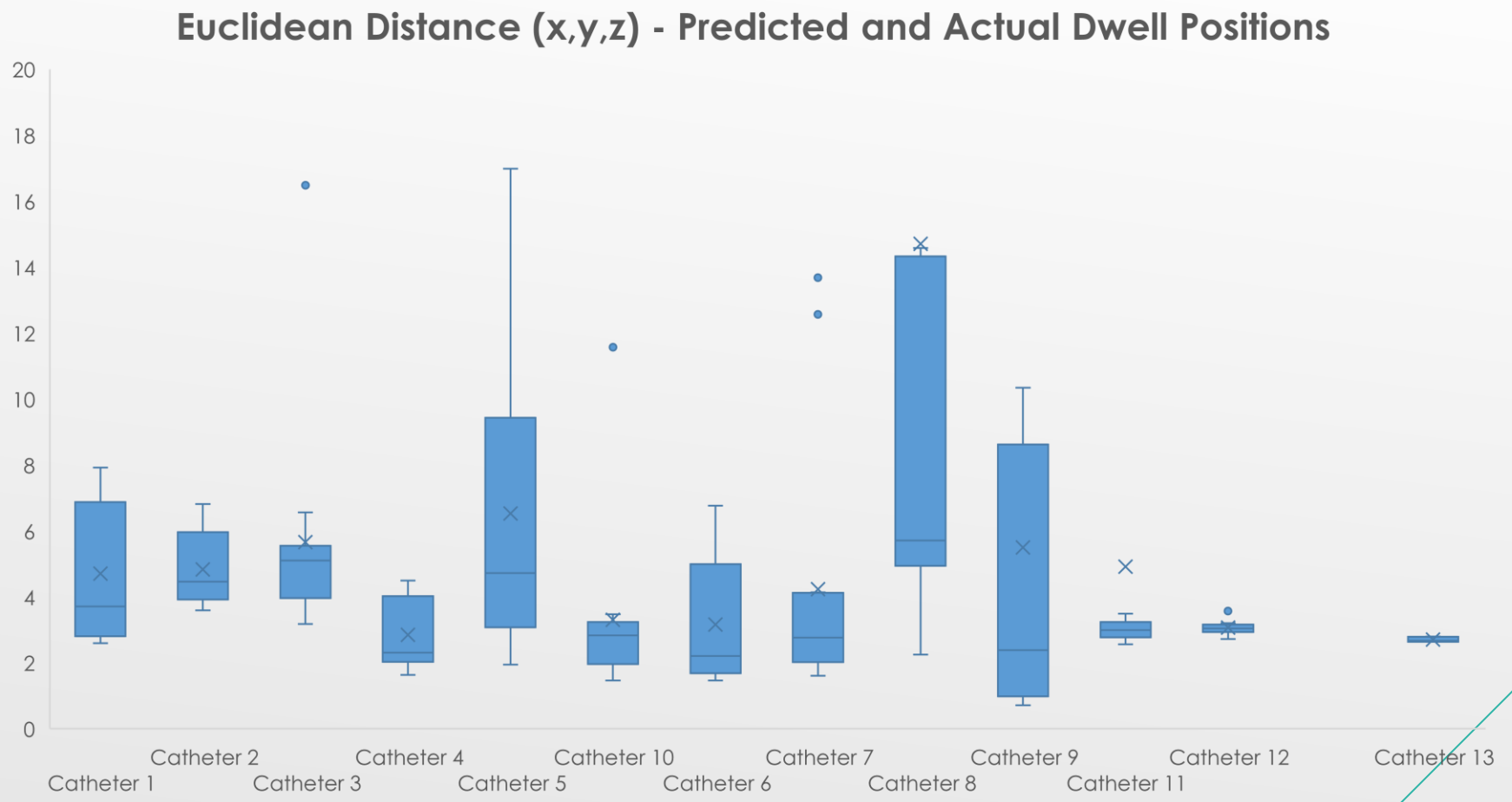
# SOURCE-LOCALISATION – HDR RESULTS

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# ENGINEERING SPECIFICATIONS

| | Prototype | |
|---|---|---|
| | LDR | HDR |
| No of fibre sensors | 16 | 16 |
| Sensitivity | 107 counts/mGy | 30000 counts/mGy |
| Sensitivity (clinically relevant) | 1 kHz @ 3cm | 27±3 kHz @ 10cm |
| Dose/dose rate measurement resolution (statistical precision) | 5% (lab)<br>15% (clinically) in 0.5s @ 1 cm | 2.95±0.08% in 0.1s @ 10cm |
| Linearity & dynamic range vs dose/dose rate | 1 mGy to 10 Gy | 1 mGy to 10 Gy |
| Repeatability | Not exceeding 1% | Not exceeding 1% |
| Energy Response | 125I | 192Ir/60Co |
| Spatial Resolution (point dose) | 6mm (clinical)<br>1.8mm (lab) @ 1cm | 0.4±0.03 mm @ 5mm |
| Spatial Resolution (source localisation) | ? | 3mm |
| Time Resolution | 0.5s | 0.1s |
| Temperature Range | 0.1%/°C | 0.1%/°C |

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# SUMMARY

- Optical fibre sensors are uniquely positioned to provide *in vivo* brachytherapy dosimetry
- EC Funded ORIGIN system provides multipoint sensing for source localisation and dose mapping for HDR and LDR Brachytherapy.
- Demonstrated required sensitivity at clinically relevant distances for both HDR and LDR, with good precision and spatial resolution.
- Machine learning methods improve the accuracy of our source localisation algorithms for more precise monitoring

# ACKNOWLEDGEMENTS



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# FOR MORE INFORMATION:


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thank you


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