Magnetron Diagnostics with a Novel Optical Fibre-Cherenkov Detector

A. Jones[1,2], J. Wolfenden[1,2], L. Eley[1,2], C. P. Welsch[1,2], H. Zhang[1,2]
1: Cockcroft Institute; 2: Physics Dept., University of Liverpool
sgajon11@liverpool.ac.uk

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Detector operation

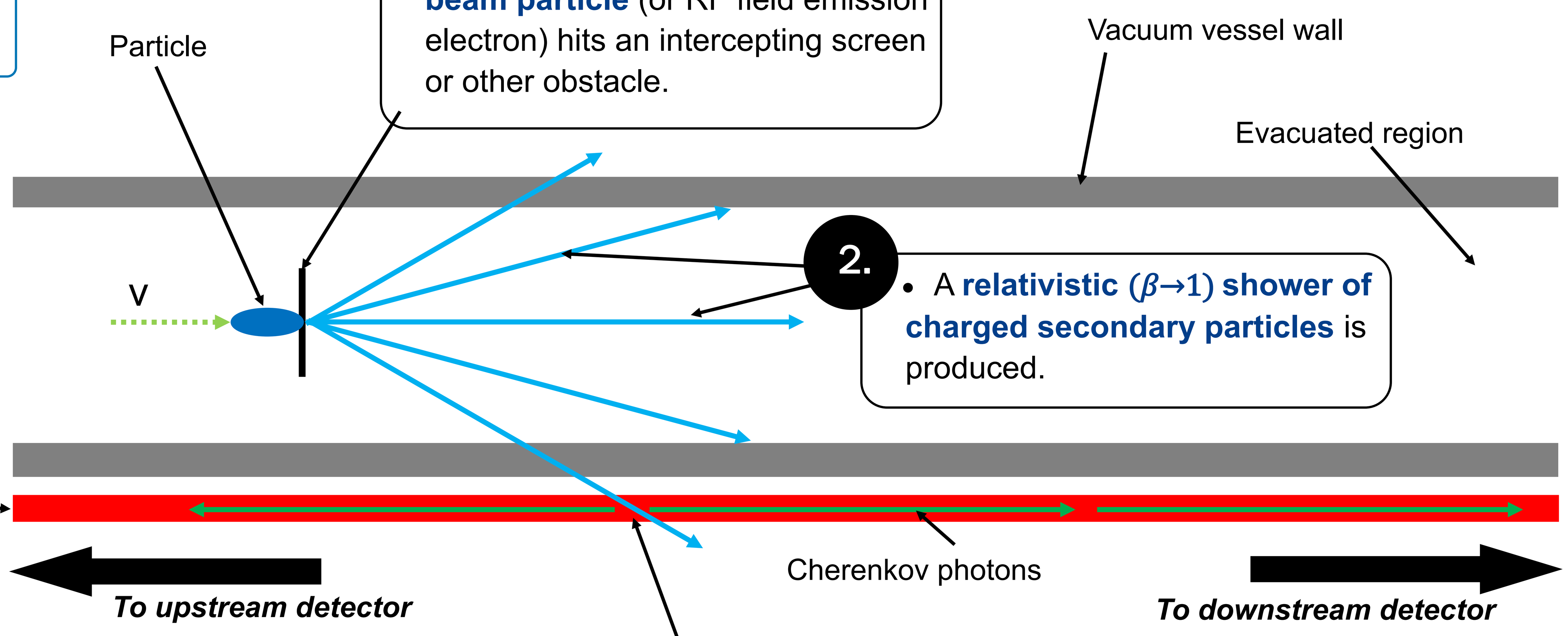
Benefits of optical fibre detectors

- **High sensitivity** to low-level beam losses, down to ~ 10 pC. **[1, 2]**
- Distributed monitors provide **continuous coverage** - no unmonitored "dark spots".
- Fully **non-invasive.**
- **Immunity to magnetic fields** allows for monitoring inside magnetic structures like undulators.
- Spatial accuracy < 0.5 m; smaller than most accelerator components.

Optical fibre detectors & RF systems

- Beam losses and RF breakdowns can both be monitored **with the same system.**
- However, in previous studies a high minimum RF input power (~10 MW) was required to detect breakdowns. New, higher -sensitivity photodetectors were added, aiming to reduce this power requirement.

Fig. 1 (right) [1]
Beam loss detection mechanism.

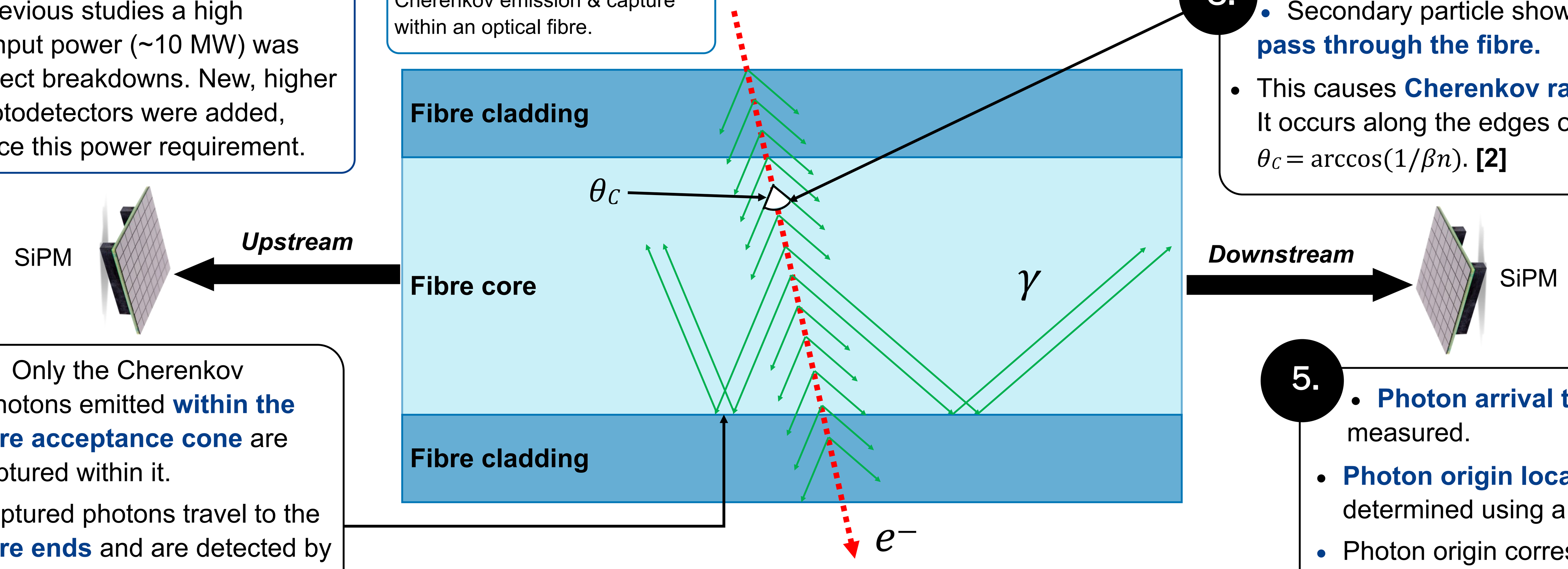


1. A **high-energy accelerator beam particle** (or RF field emission electron) hits an intercepting screen or other obstacle.

2. A **relativistic ($\beta \to 1$) shower of charged secondary particles** is produced.

3.
- Secondary particle showers can **propagate to and pass through the fibre.**
- This causes **Cherenkov radiation emission** in the fibre. It occurs along the edges of a cone with opening angle $\theta_C = \arccos(1/\beta n)$. **[2]**

Fig. 2 (below) [1]
Cherenkov emission & capture within an optical fibre.



4.
- Only the Cherenkov photons emitted **within the fibre acceptance cone** are captured within it.
- Captured photons travel to the **fibre ends** and are detected by **Si photomultipliers (SiPMs).**

5.
- **Photon arrival time** at the SiPMs is measured.
- **Photon origin location** in the fibre is determined using a **time-of-flight calculation.**
- Photon origin corresponds to **beam loss location. [3]**

Proof-of-Concept Testing at Teledyne e2v, Chelmsford

Magnetrons & Testing

- Magnetrons are a type of RF power source.
- A rotating cloud of electrons in the central cavity, fed by an electron emission current from the cathode, excites standing RF waves in the resonant tanks **[4]**.
- RF breakdowns (electrical arcing) in the magnetron can damage the cathode emission surface, reducing the emission current and degrading magnetron performance.
- Proof of concept measurements were undertaken at Teledyne e2v, Chelmsford, to determine if RF breakdowns in the magnetron produced visible signals in the optical fibre detector system.

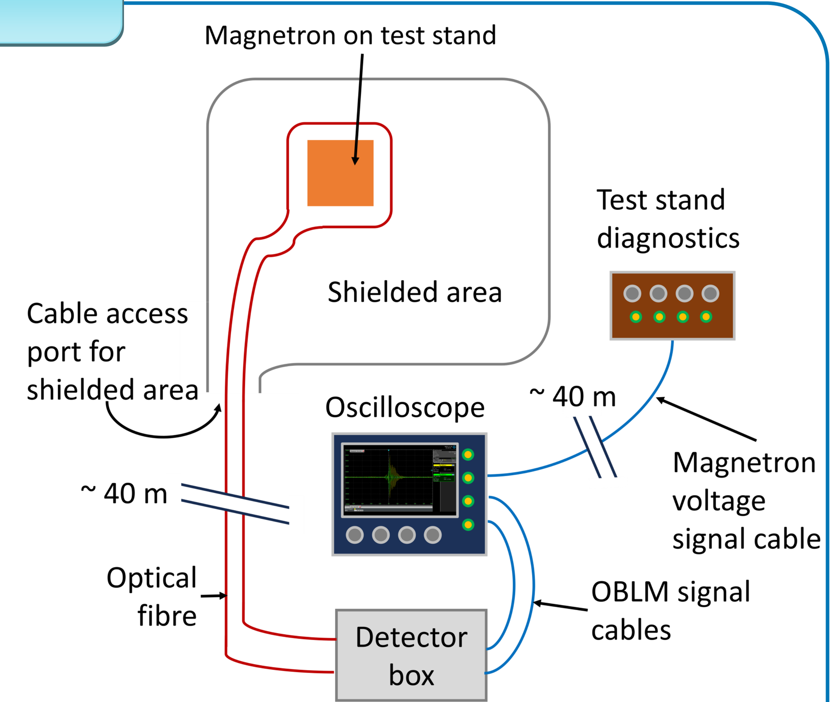
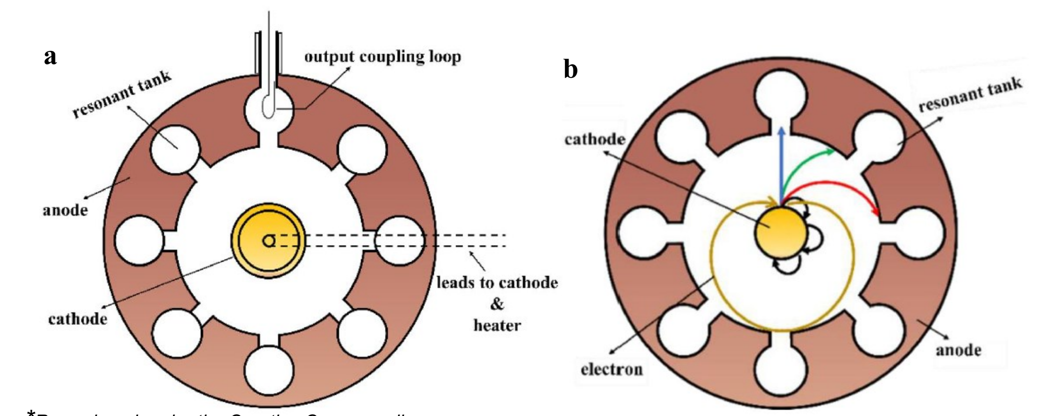


Figure 4: A diagram of the experimental set-up of the optical fibre detector system at e2v. The detector box housed the SiPMs, and fed their outputs to the oscilloscope.

Figure 3: Cutaway view of a magnetron (a) and example electron paths within an operating magnetron (b) **[5]***.



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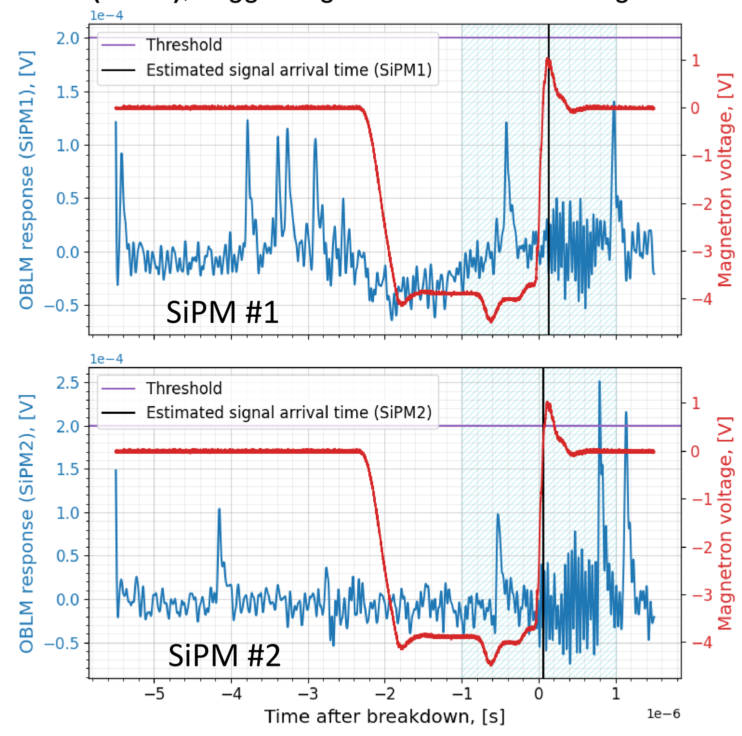
Measurements at e2v

- Detector system response was measured in comparison to signatures of RF breakdown.
- The main signature was the sharp rise in the (inverted) magnetron voltage that occurs at the onset of breakdown.

Results and Analysis

- Cherenkov radiation is expected to be visible in both detectors.
- Assuming uniform emission of electrons around the breakdown, the delay times between the arrival of the breakdown signature and the Cherenkov radiation signals were estimated (to 1s.f.) based on signal time-of-flight: ~ 130 ns for SiPM #1, ~ 60 ns for SiPM #2 (SiPM #1 monitored a longer arm of fibre.)
- Signals appearing in coincidence with these arrival times and above the background rejection threshold (**purple** line in **Fig. 5**) were searched for.
- 22 data sets (from 462 total) crossed the background rejection threshold in the (wide) initial region of interest [–1 μs, 1 μs]
- None of these data sets contained events matching the expected signal arrival times.

Figure 5: An example RF breakdown event. Breakdown signature **(red)** is estimated to occur at time t=0. Signal peaks **(blue)** are visible in both detectors on the right-hand edge of the wider region of interest **(hatched blue region)**. They are far from the estimated signal arrival times **(black)**, suggesting these arise from background.



Conclusions

- The results suggest that RF breakdowns either do not produce signals visible in the optical fibre detector, or that their signals are not as uniform as expected.
- Peak RF input power was high (> 6 MW), but discussion with the e2v team suggested the magnetron voltage (and corresponding electric field) was likely too low to produce electrons of the required energy to generate Cherenkov radiation. (Magnetron voltage was < 49 kV, required electron energy is ≥ 186 keV **[1]**).
- Some further analysis is required — to investigate the coincidence of signals that appear in both detectors within the region of interest, or following features in the magnetron voltage prior to breakdown.

References

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