Experimental Validation of Plasma Tomography Algorithms at ISTTOK

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Introduction

- **Plasma tomography** is an optical diagnostic used to reconstruct the **emissivity profile** of the plasma cross-section.
- Reconstructions are performed by sampling the plasma through **lines of sight** with **pinhole cameras** and linear arrays of optical sensors.
- Due to the **scarcity** of the **lines of sight**, **regularizations** are often used to impose a **smooth solution**.
- Given a set of measurements $\mathbf{f}$ and a geometry matrix $\mathbf{T}$, the tomography problem consists of finding the emissivity $\mathbf{g}$ that best satisfies

$$\mathbf{f} = \mathbf{T} \cdot \mathbf{g}$$

while also complying with the regularization conditions.

- The solution is found by minimizing [1]

$$\varphi = \|\mathbf{T} \cdot \mathbf{g} - \mathbf{f}\|^2 + \lambda \left(\mathbf{g}^{\mathbf{T}} \cdot \mathbf{H} \cdot \mathbf{g}\right),$$

where $\mathbf{H}$ is the regularization matrix and λ is the regularization constant.

Objectives

- The geometry matrix $\mathbf{T}$ is a key element of the reconstruction algorithm.
- The simplest approximation is to assume that each sensor samples a straight line, **line of sight**.
- A more complete description takes into account the finite dimensions of both pinhole and sensor yielding a **cone of sight**.
- Our goal is to **experimentally compare both methods** (**figure 1**).

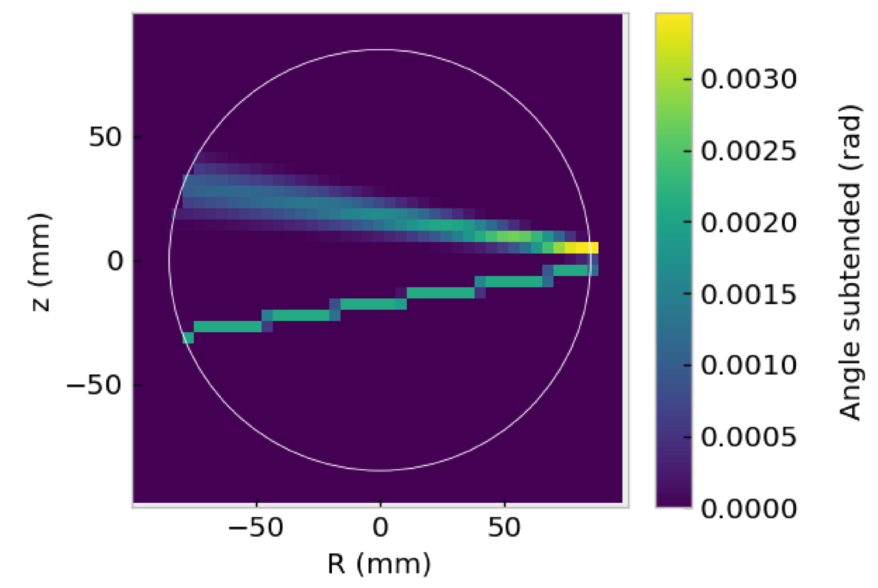

***Figure 1**: Line of sight versus cone of sight. The value in each pixel is: **line of sight** – length of the cord contained by the pixel; **cone of sight** – angle subtended by the detector visible from the center of the pixel.*

Methods

- Use a cylindrical **cold cathode lamp** as a **light source** (50 x 4 mm).
- The lamp can be **moved** to **different** radial and angular **positions**.
- Acquire camera signals from various positions with the set-up of **figure 2**.
- The **signals** are fed into a **minimum Fisher algorithm** [1] and the **reconstructed image** is compared to the **expected image**.

***Figure 2**: Experimental apparatus used for the absolute test of reconstruction algorithms, allowing exact calibration of sampled volumes.*

Results & Discussion

From the experimental results, we found that the description of **the cone of sight:**

- **Reproduced better** the **camera signals** obtained **from experiment** (**figure 3**).
- Provided **reconstructions** that were **more accurate** and contained **less artifacts** (**figure 4**).
- Provided **smoother** reconstructions **without** the need to use **strong regularization** (**figure 5**).

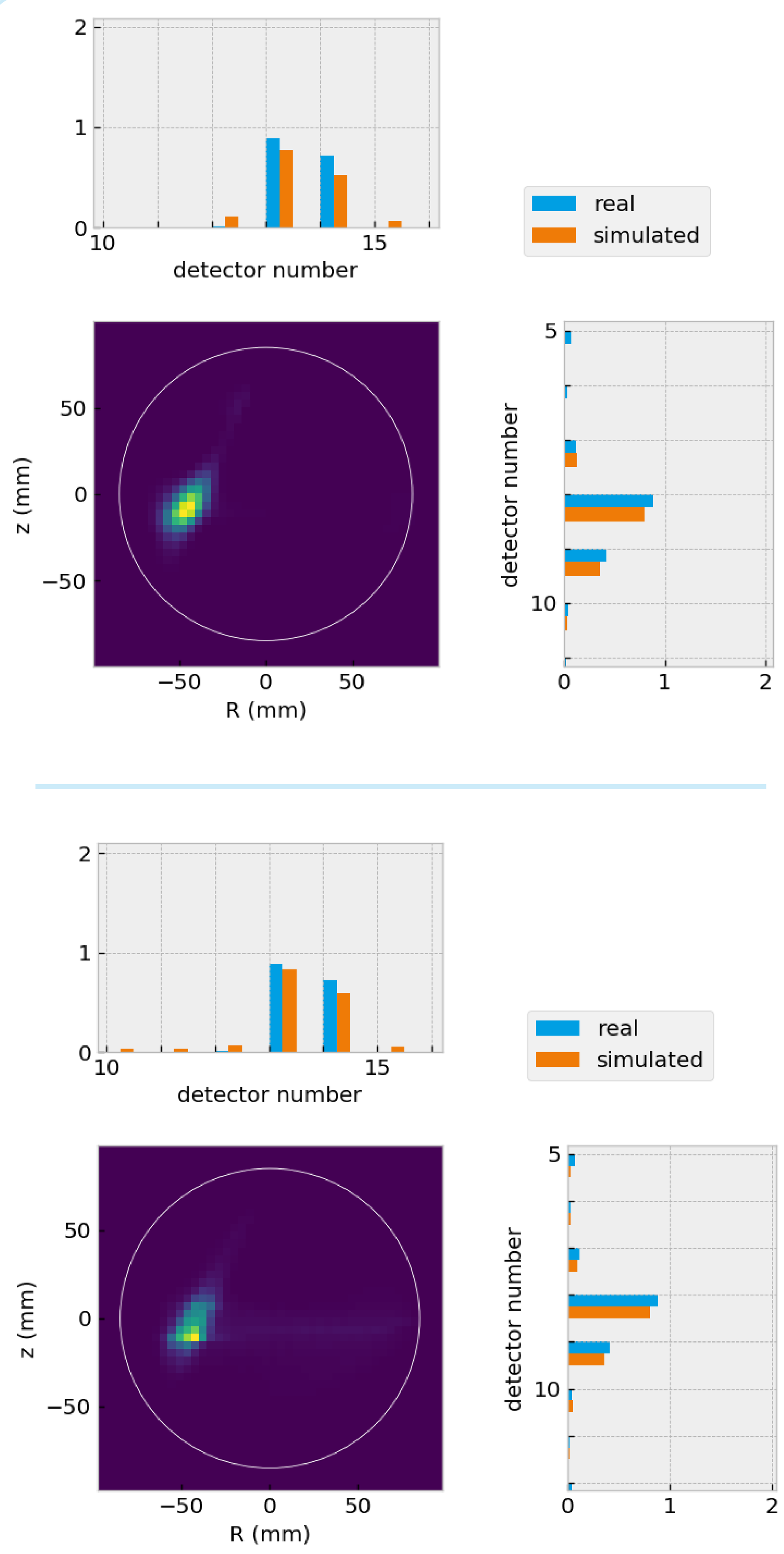

***Figure 4**: Reconstruction of one experiment. **Top**: **cone of sight** approximation; **bottom**: **line of sight** approximation. Both reconstructions were performed with the same regularization constant. Line artifacts are visible in the bottom image reconstructed by the line of sight approximation.*

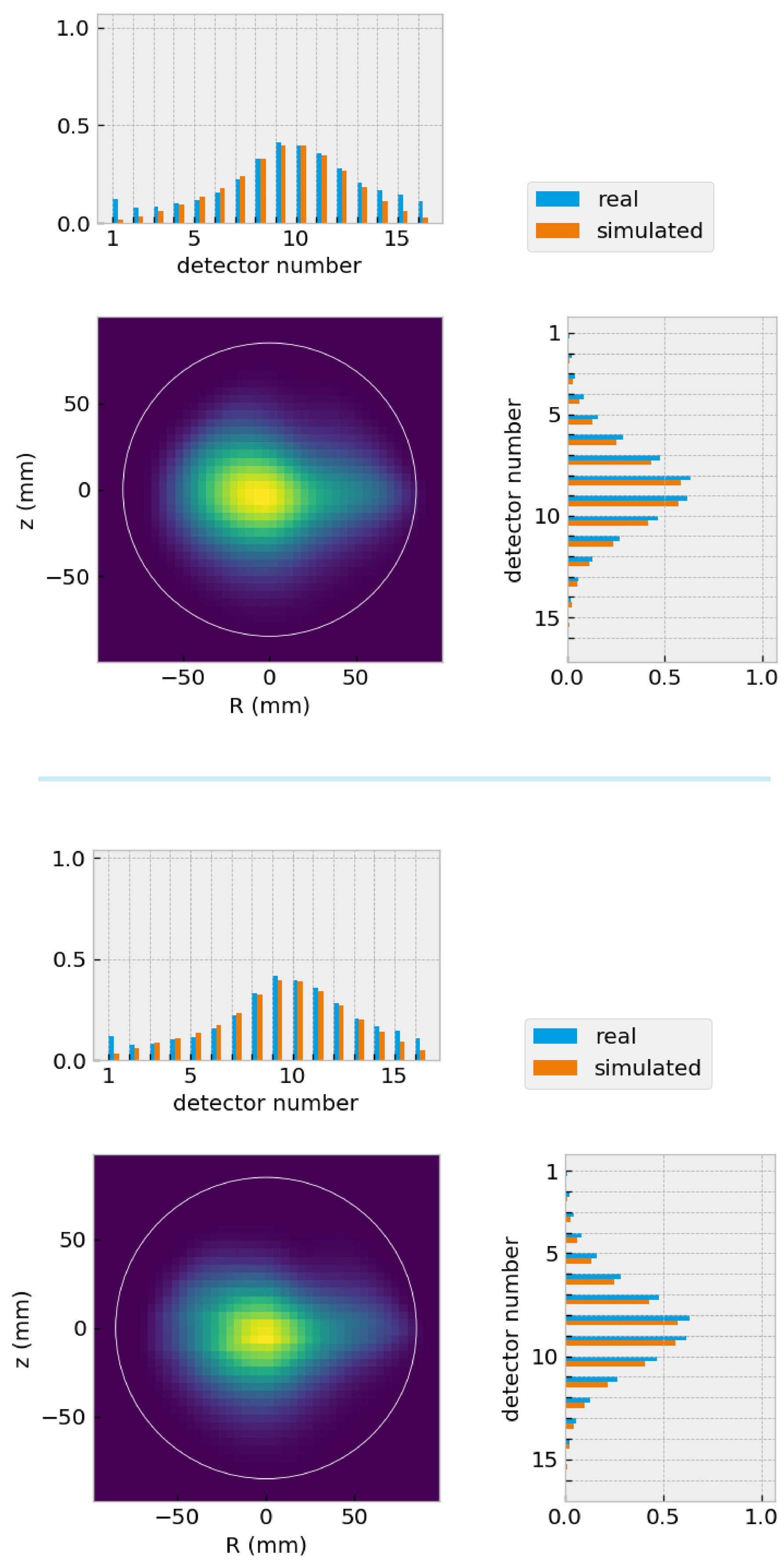

***Figure 5**: Reconstruction of a real plasma from ISTTOK shot #45988 with the two competing methods. **Top**: **cone of sight** approximation; **bottom**: **line of sight** approximation. For the same value of the regularization constant the top image shows a smoother profile, and with less artifacts.*

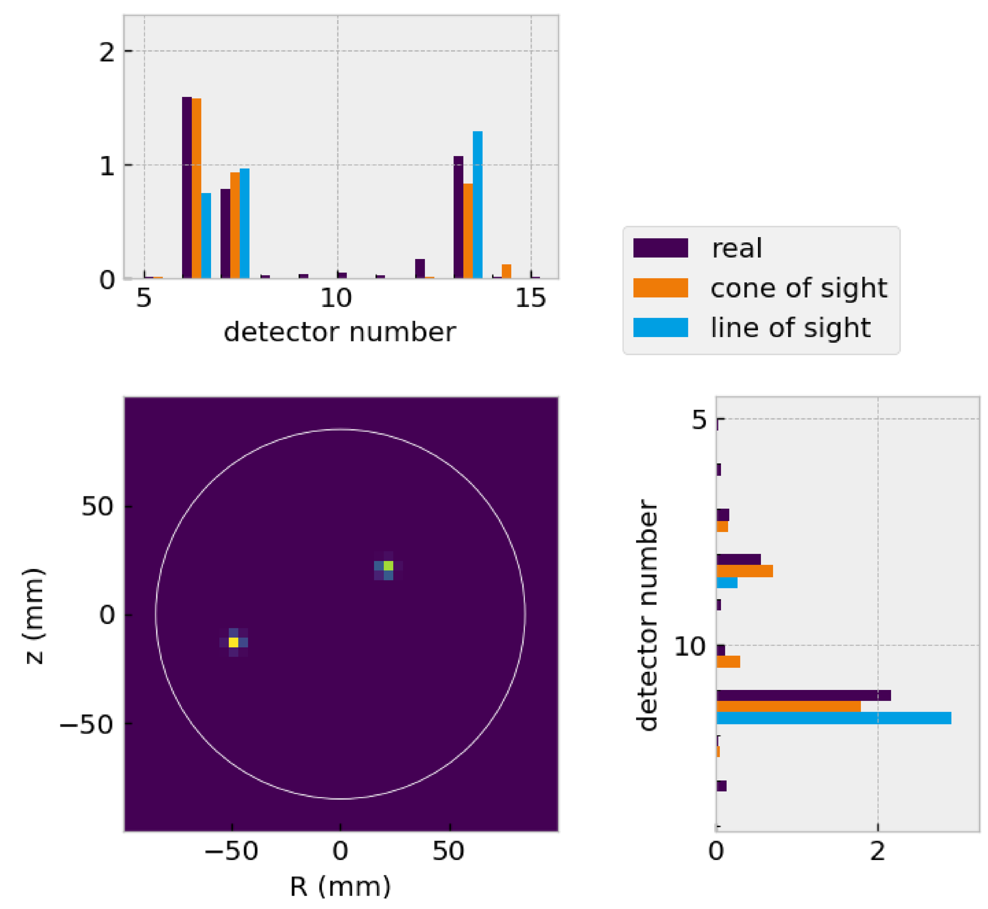

***Figure 3**: Comparison of the real signals obtained experimentally with the expected signals from a point-like source using the line of sight and the cone of sight approximation. It is visible that the orange bars (cone of sight) are more similar to the dark bars (measured signals).*

Although the **point-like emissivity** profile does not resemble a typical plasma, it is an important tool to **validate experimentally** the accuracy of the geometry matrix. Previous studies have relied on **digital phantoms** and **simulated signals** to determine the impact of different geometry matrices [2].

Conclusions

- The **cone of sight** approximation **improved** the **quality** of the reconstructions.
- It is **recommended**, especially because it **does not increase** the **computation time**.
- This experimental procedure can be used to **calibrate** other **tomography algorithms** and objectively compare them.

[1] J. Mlynar et al., ***Current Research into Applications of Tomography for Fusion Diagnostics***, Journal of Fusion Energy(2018)

[2] M. Carr et al., ***Description of complex viewing geometries of fusion tomography diagnostics by ray-tracing***, Review of Scientific Instruments 89 (8, 2018) 083506.

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