EU SOLARIS

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CSP data-driven digital twin enhanced by real-time image obtention

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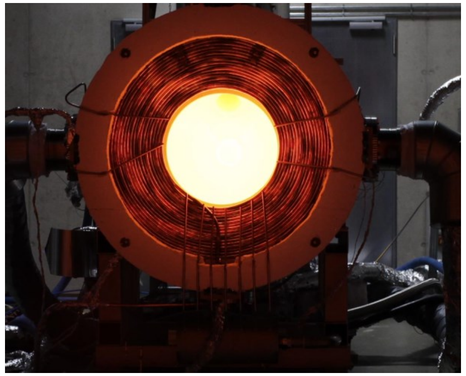
Contents

Contents

Introduction

Receivers

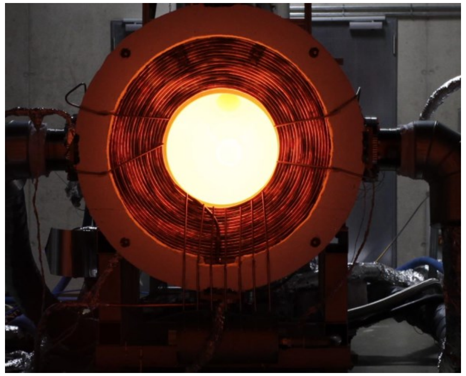
Cavity



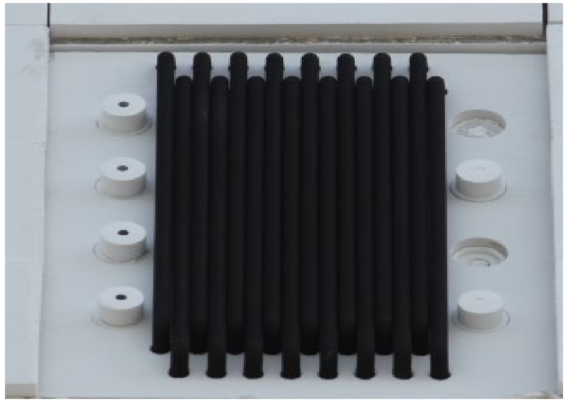
Introduction

Receivers

Cavity



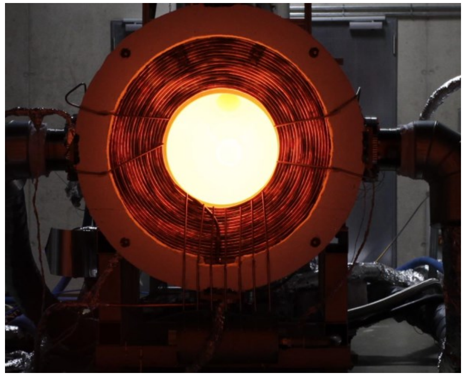
Tube



Introduction

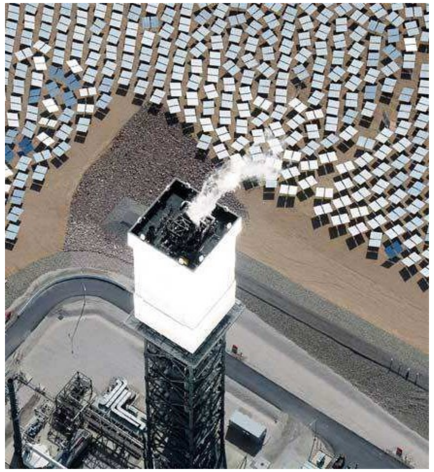
Receivers

Cavity



Open volumetric

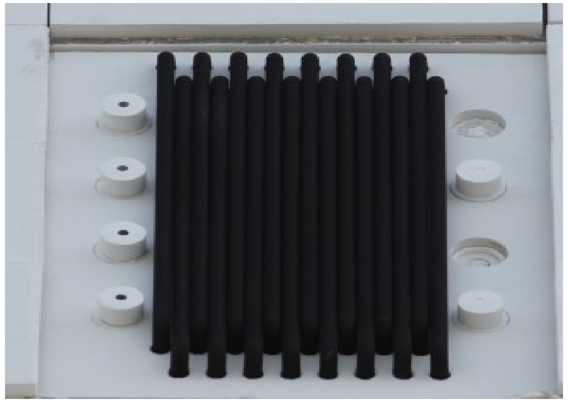
Flat



Curved

Cylindrical

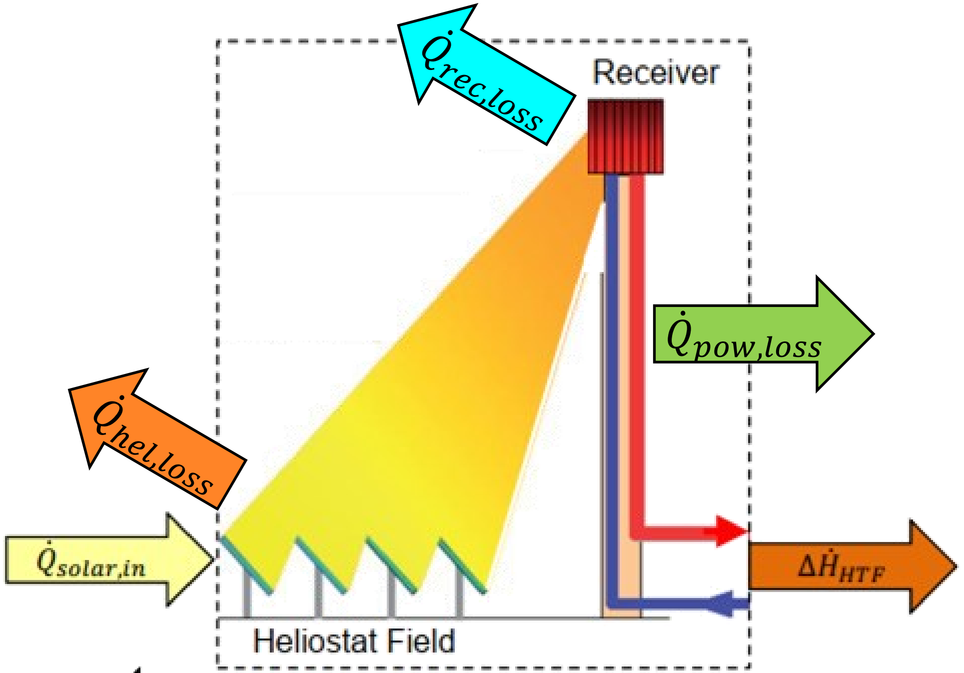
Tube



Synhelion → Industrial partner in CavMon

Introduction

- Flux Density Measurement (FDM) in the central receiver
  - Enhancement of average performance
  - Accurate tracking of heat losses → Possible decoupling between heliostat measurements and receiver measurements



Challenges:
- Universality
- Continuous and non-disruptive
- Harsh conditions
- Computing power
- Processing time

Contents

Aims

- (Near) real-time measurement
- Non-disruptive
- Easy user interface
- Connection between conventional measurements and possible future trends (data-driven models)
- Self-corrected with AI enhancement
- *"Towards Smart CSP"*

Contents

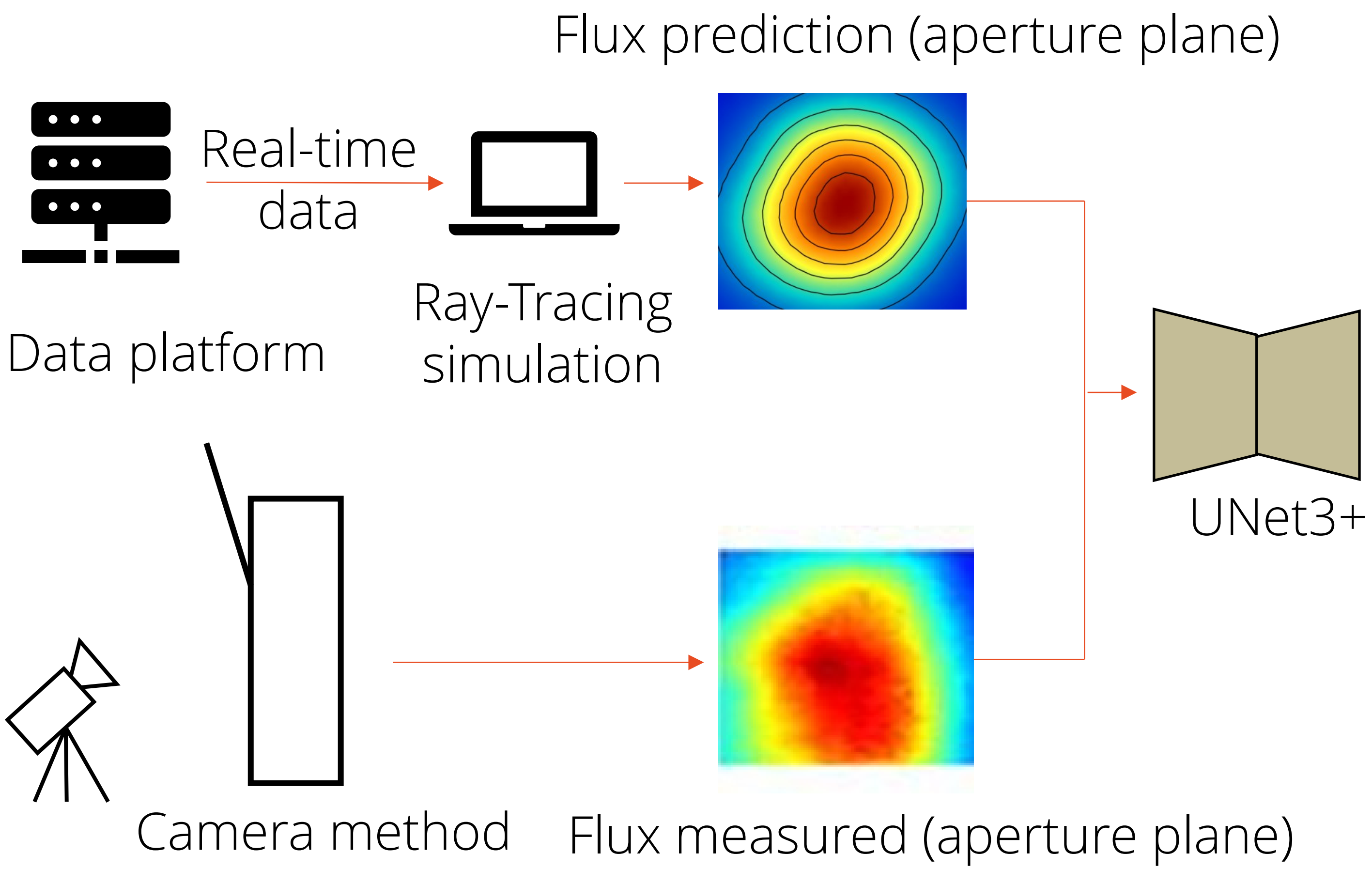
Current status

- Three sequentially coupled modules:
  - Real time digital twin
  - Deep learning correction
  - Ray projection inside cavities

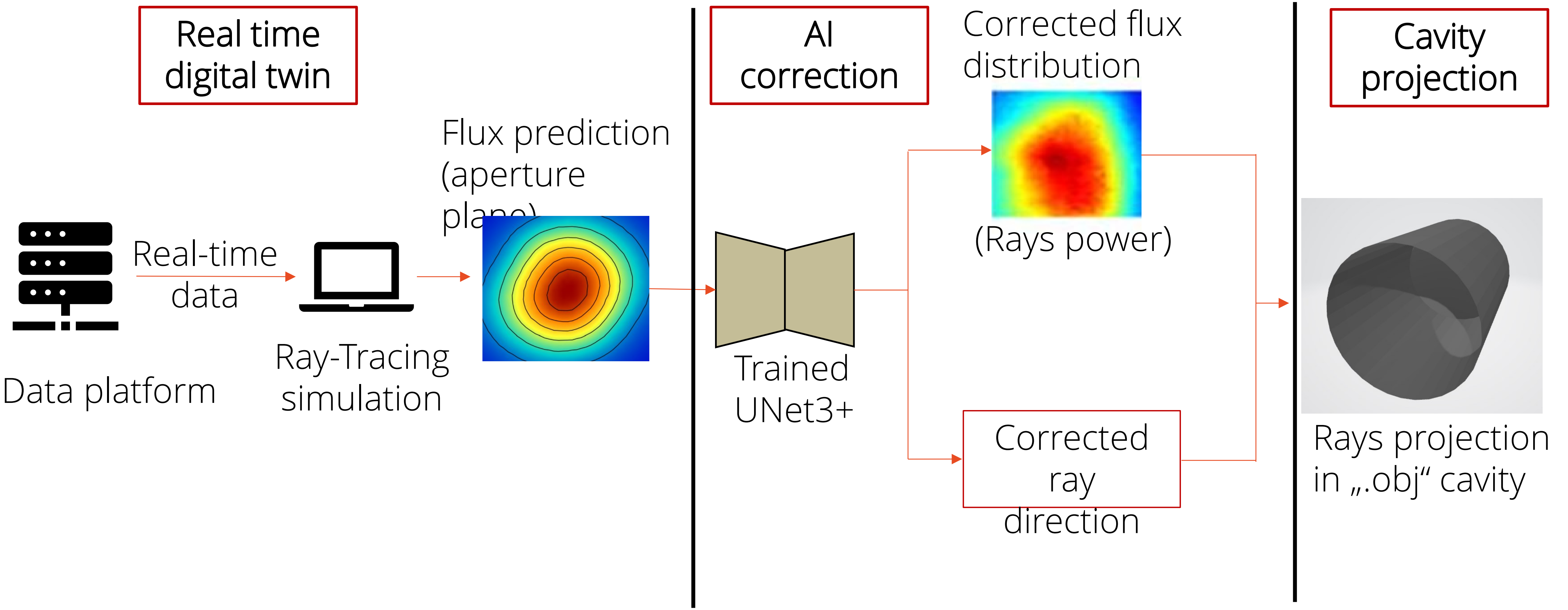
- For open receivers → Only two first modules are needed

Current status: training flow diagram

Possible training out of working hours



Current status: operation flow diagram



Contents

Real time digital twin

- Plant features: location, hel. Field
- Circumsolar ratio
- Receiver
- Atmospheric extinction

Static parameters

- Pyrheliometers
- Heliostat tracking (alignment and aimpoints)
- Ambient thermometer
- Time clock
- Sun tracking

Data platform: Dynamic parameters

Dynamic data packages

Auto setting

Data treatment

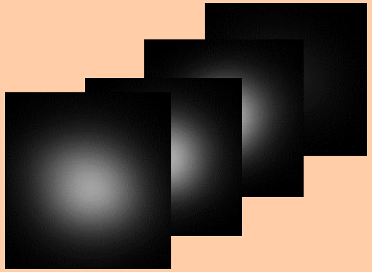
Iteration configuration and run

Automatic run and results processing

Python library

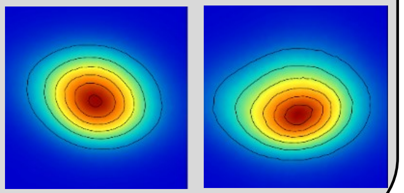
Periodic „get“ request

Grayscale results (ML)



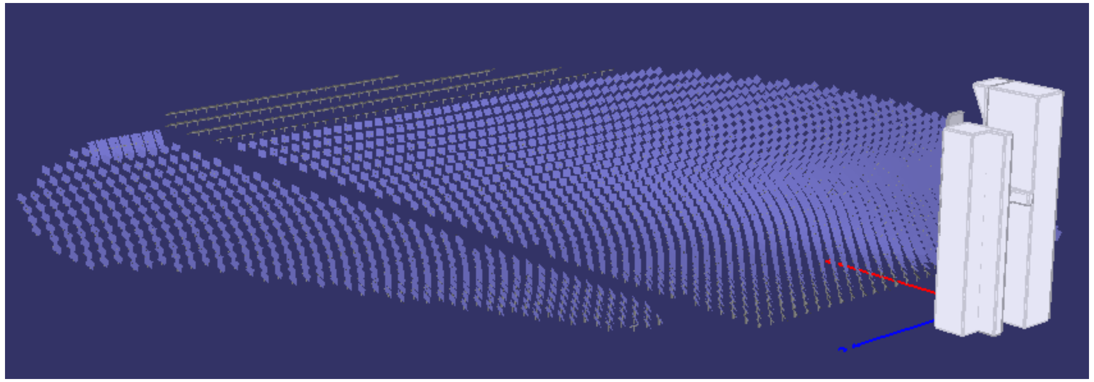
16x933

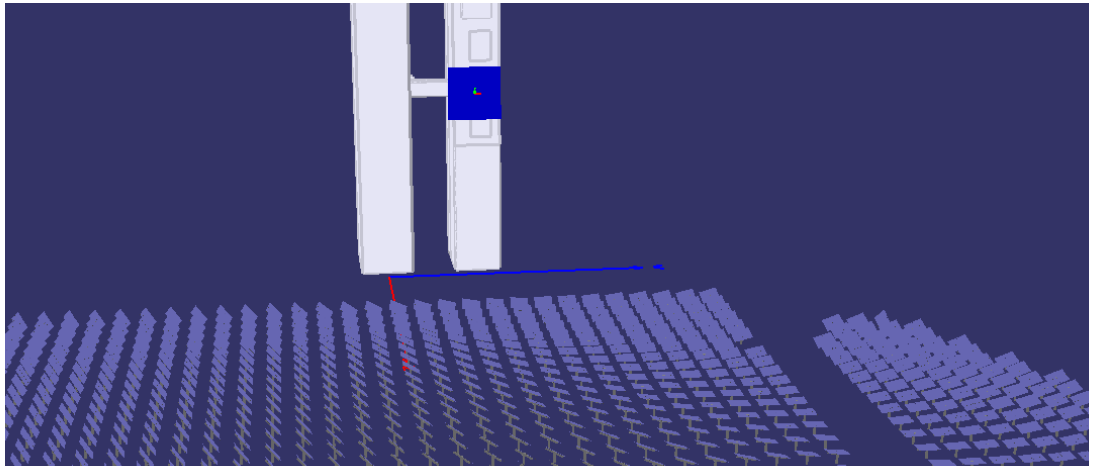
RGB high-resolution



Results: proof of concept

Asynchronous definition





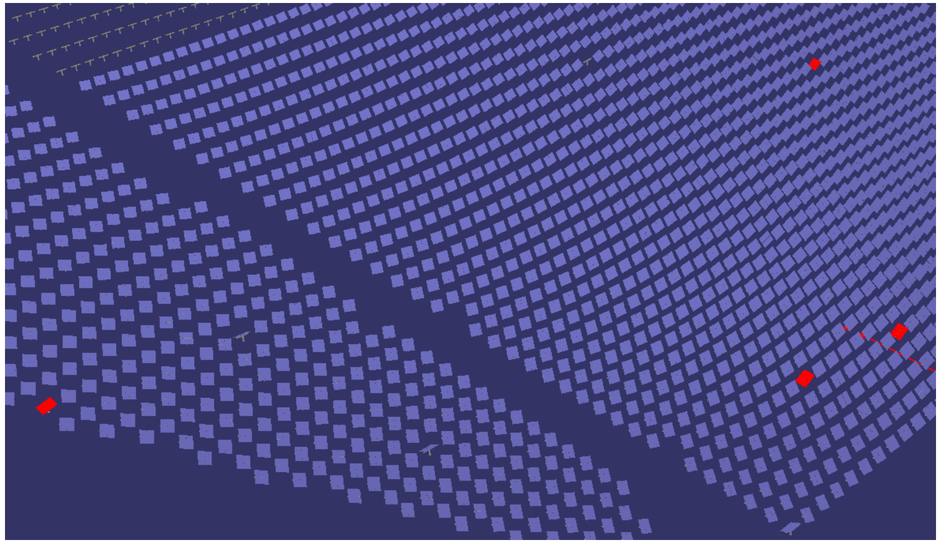
Static definition:
Accurate model of the Solar Tower Jülich defined automatically (less than one minute)

Results: proof of concept

Adjustment

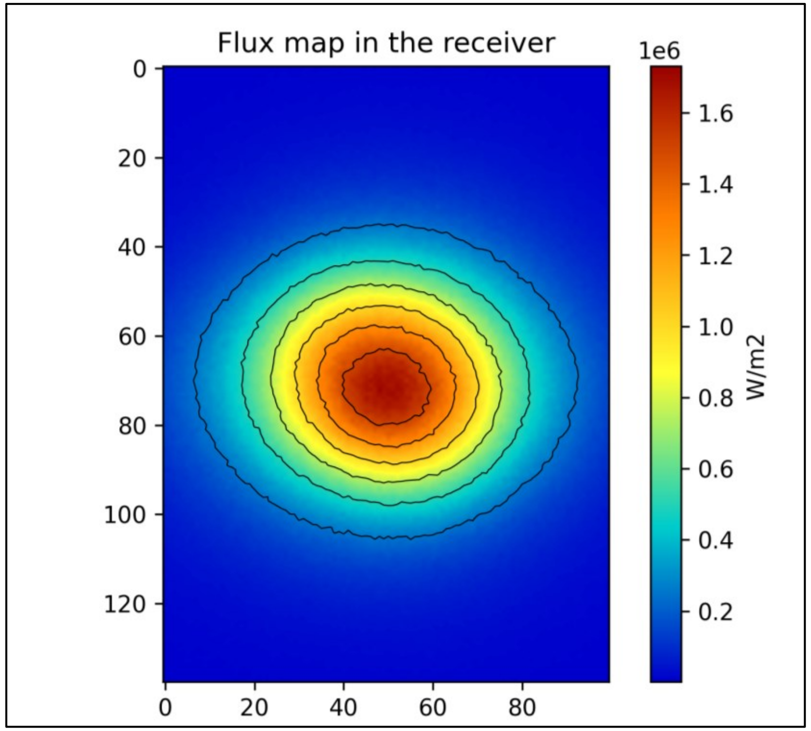
- List of heliostats to be modified
- Modification
  - Live defocus
  - Live change of tracking error
  - New aimpoint
- Time auto adjustment
  - DNI
  - Sun position change

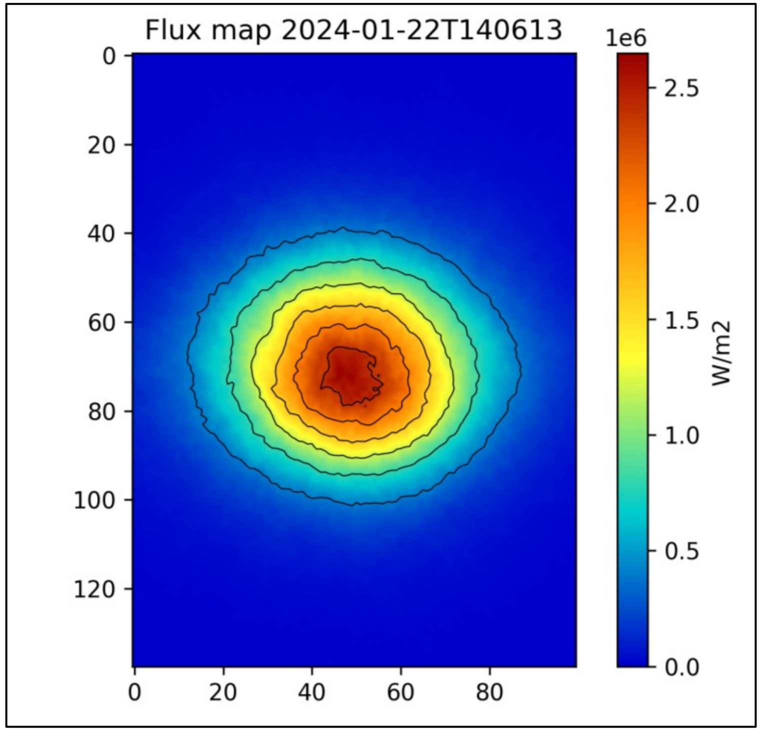
Real time influence



Results: proof of concept

Real time variation in the result

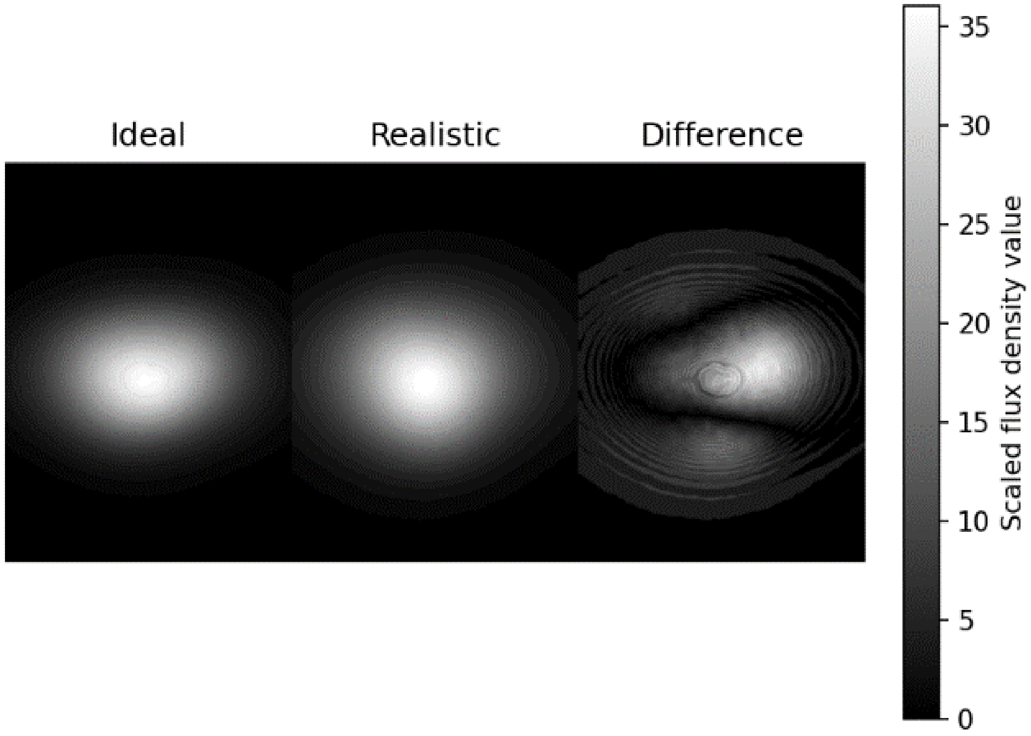




Latency < 10s

Results: tracking error models

2014-04-09T070000



Grayscale images → Normalized against the peak flux value in the data batch

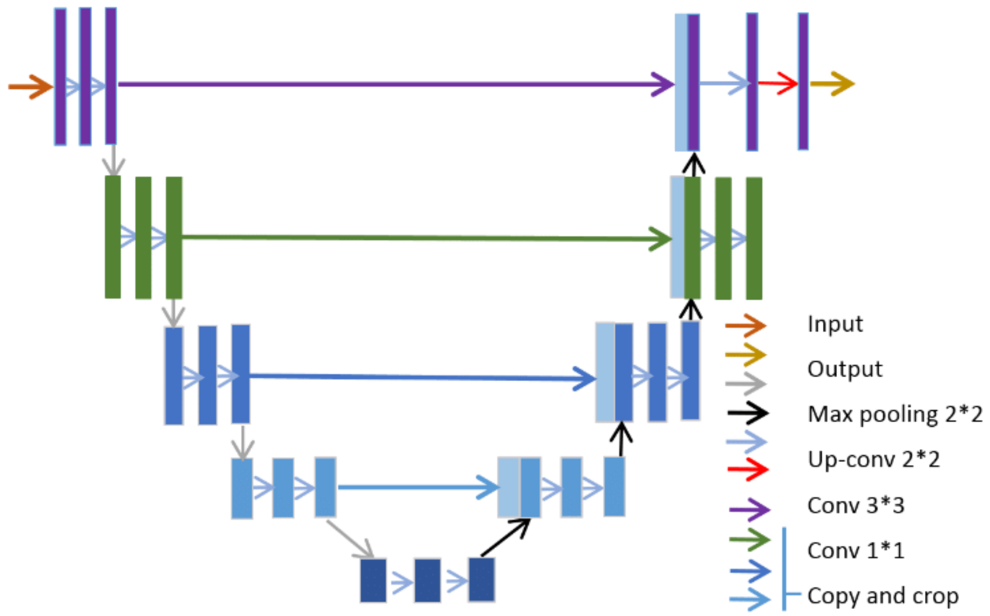
Max DNI		Conditions			
944.1		47.7	189.3	4/12/2016	2:00:00 PM

Influence of modelling tracking error → 6% of RMSE and peak value up to 78 kW/m^2

Contents

AI-correction

- Based on UNet3+ neural network



Schematic of UNet3+

- Neural net learning process: two phases
  - Pre-training
  - Training
- Input: simulated flux density
- Output: corrected flux density with accuracy close to camera methods

AI-correction: pre-training

- Synthetic (augmented) data batch → 14928 pairs of fluxmaps
- 933 real atmospheric conditions replicated
- **Aim** → Soften the learning process for flux and train ray direction

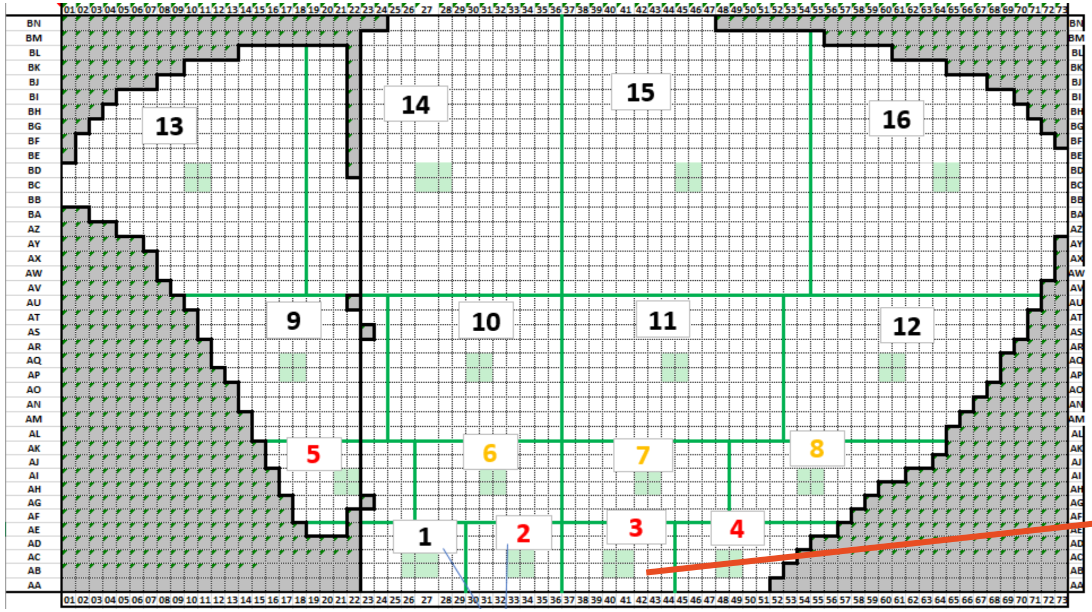
16-04-2014 @12:00:00

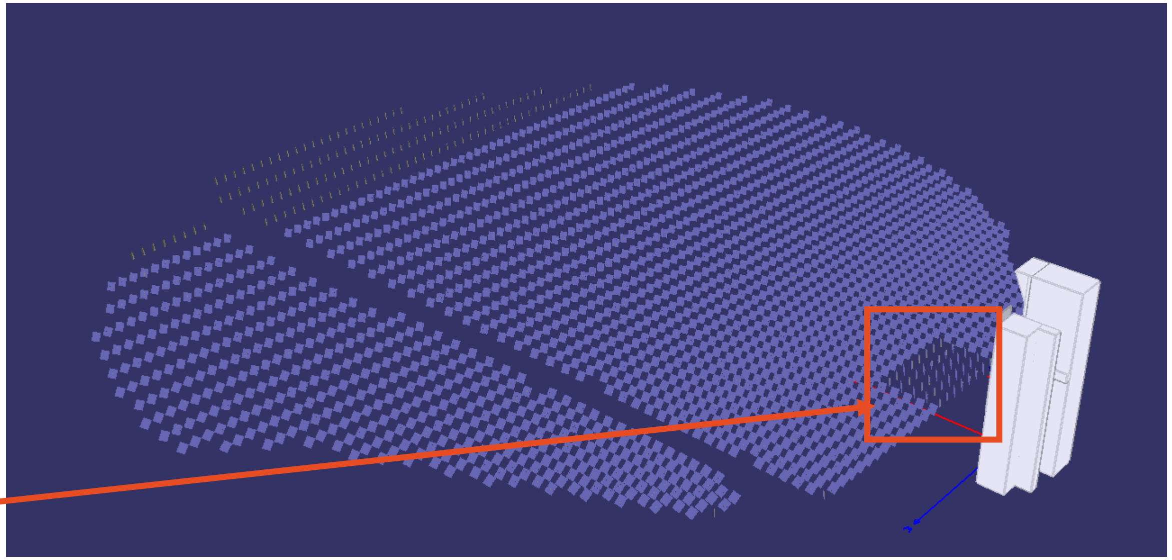
Input (simulation without tracking errors)

Input (simulation with tracking errors)

AI-correction: augmentation

- To increase from 933 simulations to 14928 → Heliostats disconnected area wise
- Bigger amount of cases considered in data batch

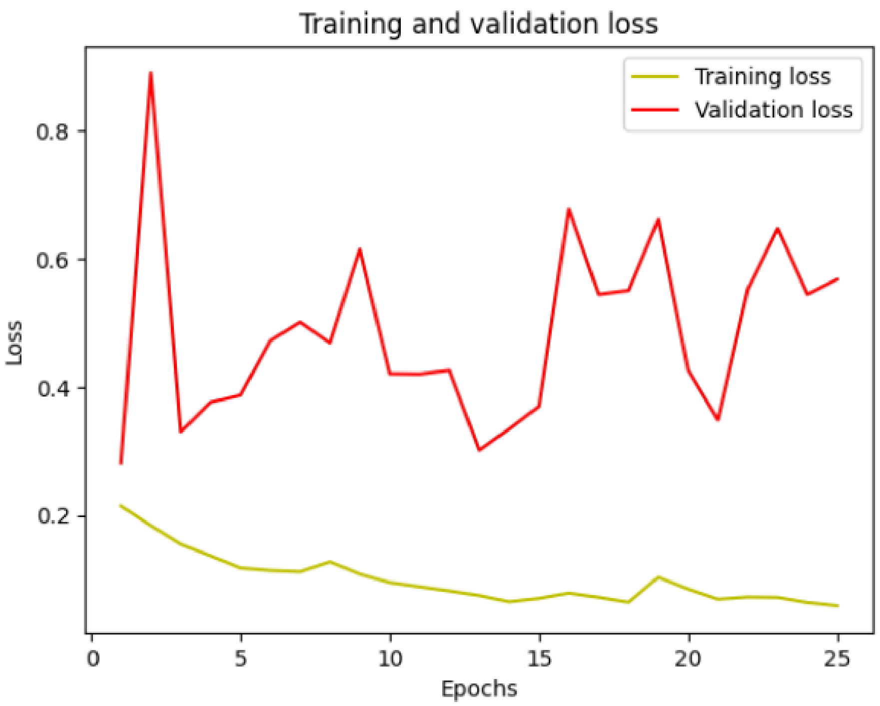


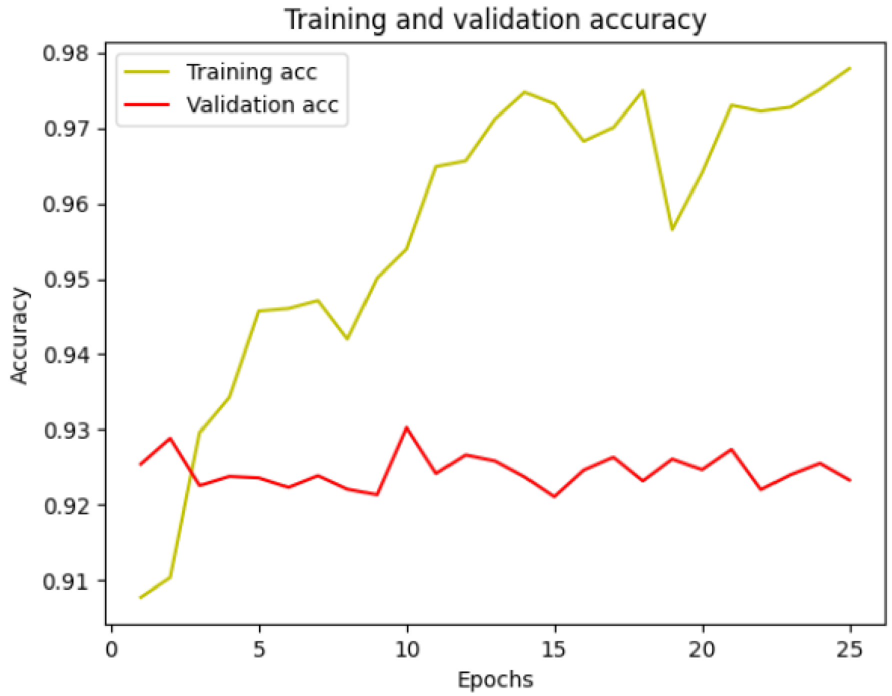


Pre-training results

- 220 pairs pre-analysis
  - Checking computing times
  - Usability of the method

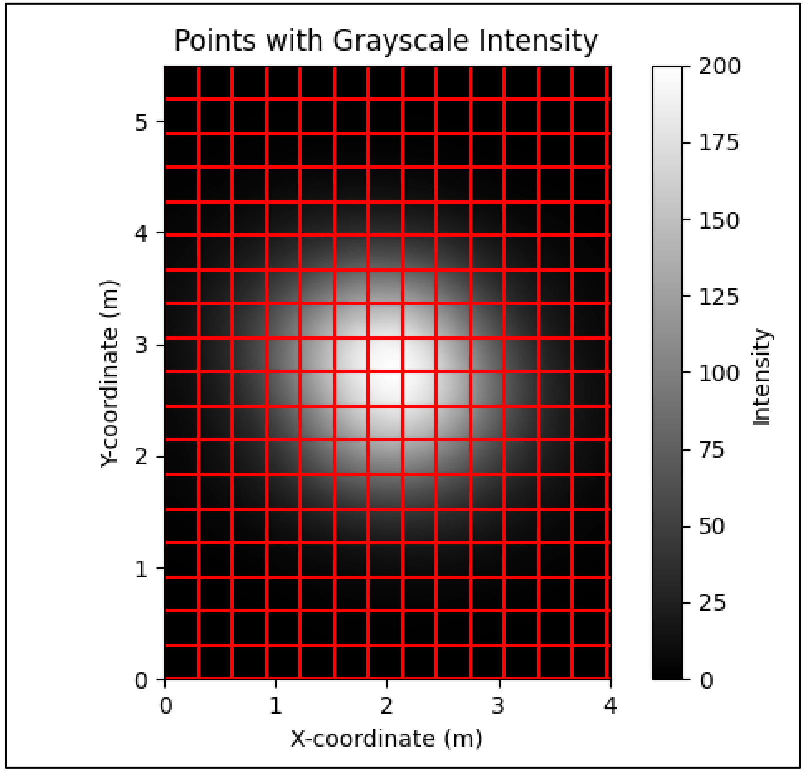
Not enough variability in the validation test set



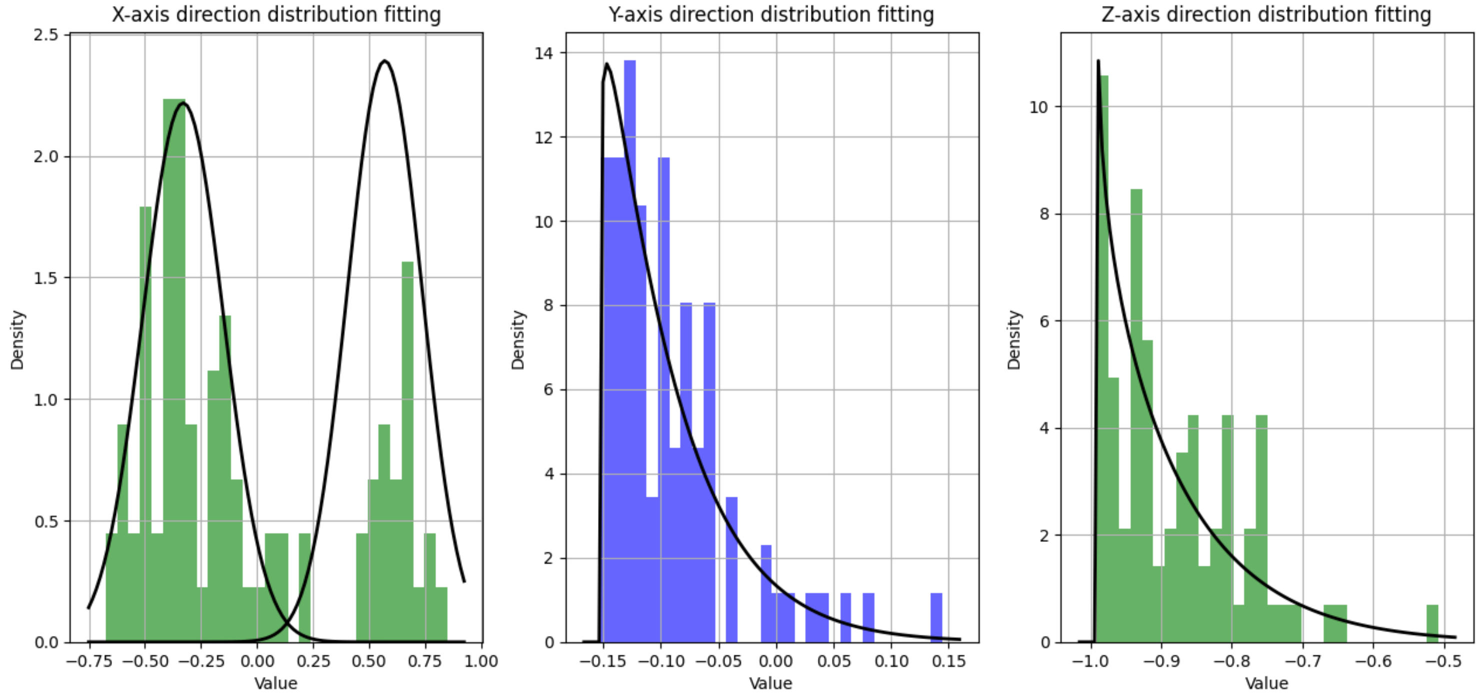


Pre-training results

- Correction factor for the power and distribution of directions of rays element-wise (252 elements mesh)

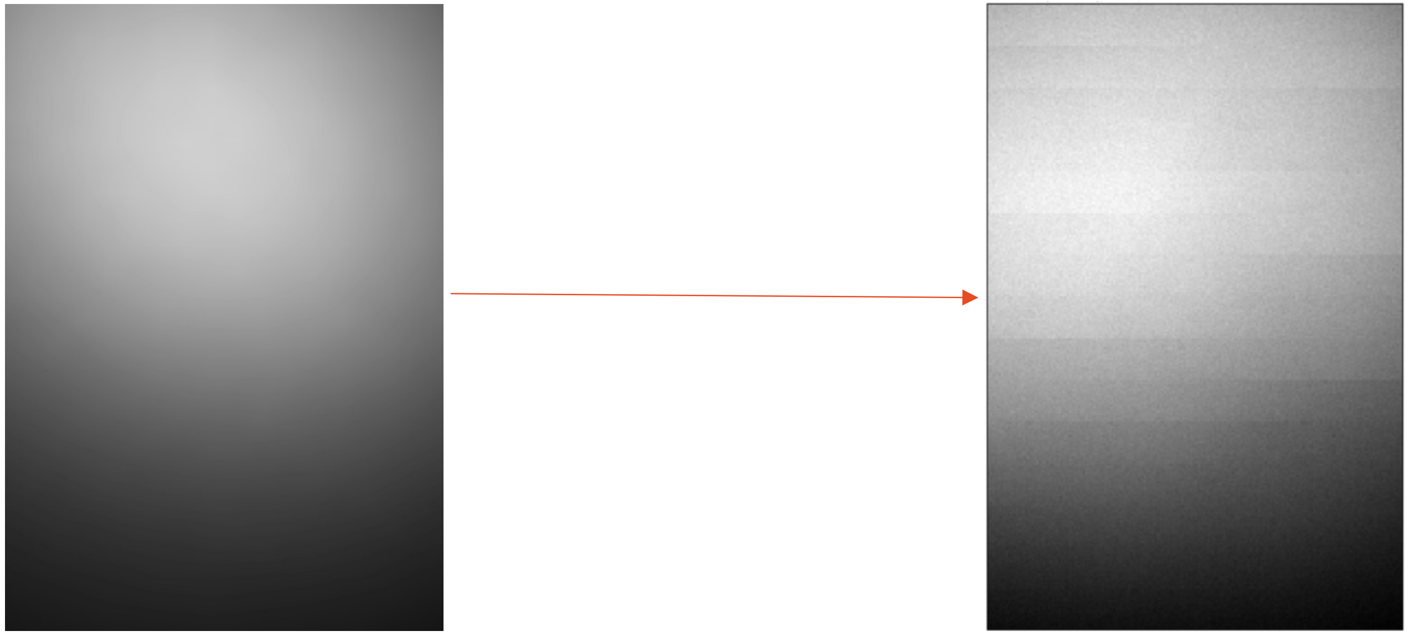


Element 73



Training

- Mapping from simulation with tracking errors to camera measurement



Prediction (simulation results)

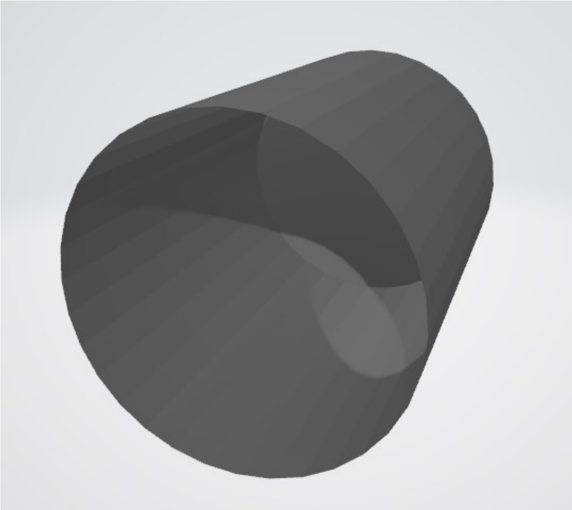
Measured fluxmap

Measurement campaign in process

Contents

Future steps

- Creation of a library of cavity receivers

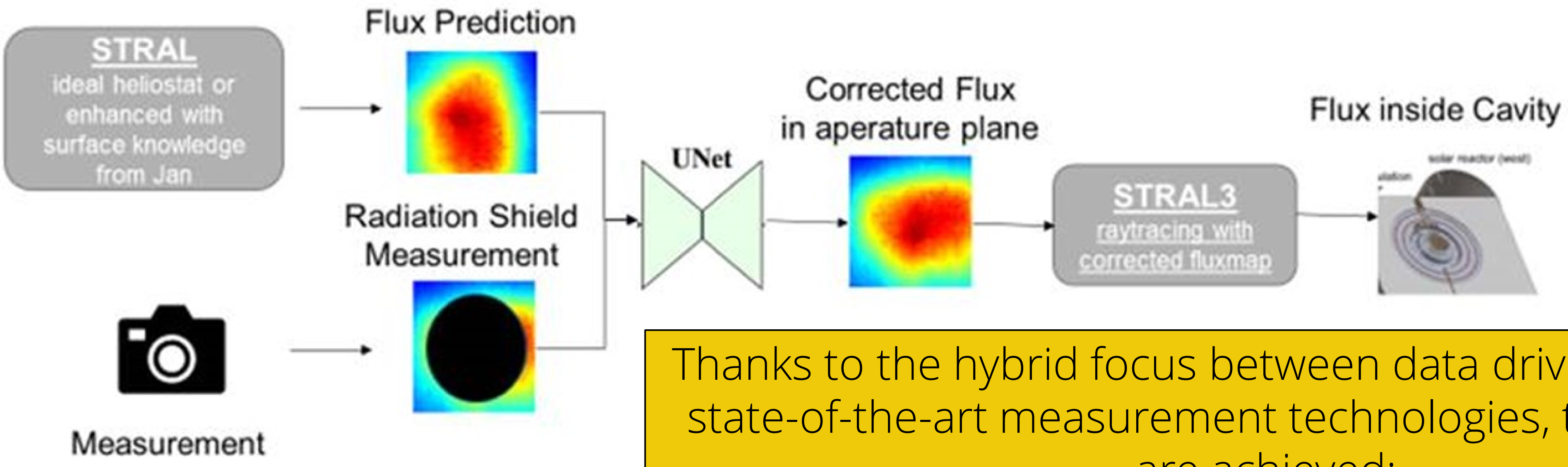


- Application of AI correction to rays direction and power in the aperture plane
- Projection of corrected rays inside of the cavity and result obtention

2 versions: cluster and commercial laptop

Future steps

- On duty control strategy for cavity receivers → There is not aperture target available to compare camera methods with simulation



Thanks to the hybrid focus between data driven models and state-of-the-art measurement technologies, two key points are achieved:

- FDM without operation disruption
- FDM inside of a cavity receiver

THE END

Thanks for listening!

Funded by the European Union (HORIZON MSCA Doctoral Network, Project number 101072537).

Marie Skłodowska--Curie Actions

TOP CSP

CORRECTION AND CAVITY INTEGRATION

- Projection of rays inside of the cavity → FDM and power obtained for differential elements of the cavity (cloud of points) → Possible representation in Paraview

```
x,y,z,flux,power,area
8.966667e-02,5.235473e-01,-1.917843e+00,0.000000e+00,0.000000e+00,1.920677e-03
8.566667e-02,5.412560e-01,-1.913100e+00,0.000000e+00,0.000000e+00,1.938521e-03
7.800000e-02,5.579987e-01,-1.908613e+00,0.000000e+00,0.000000e+00,1.952084e-03
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5.300000e-02,5.850450e-01,-1.901363e+00,0.000000e+00,0.000000e+00,1.952074e-03
3.666667e-02,5.940603e-01,-1.898950e+00,3.428814e+02,6.599731e-01,1.924785e-03
1.866667e-02,5.995337e-01,-1.897483e+00,1.673501e+02,3.261865e-01,1.949127e-03
0.000000e+00,6.014653e-01,-1.896963e+00,0.000000e+00,0.000000e+00,1.906737e-03
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-8.966667e-02,5.055167e-01,-1.922673e+00,3.477887e+02,6.680515e-01,1.920855e-03
```
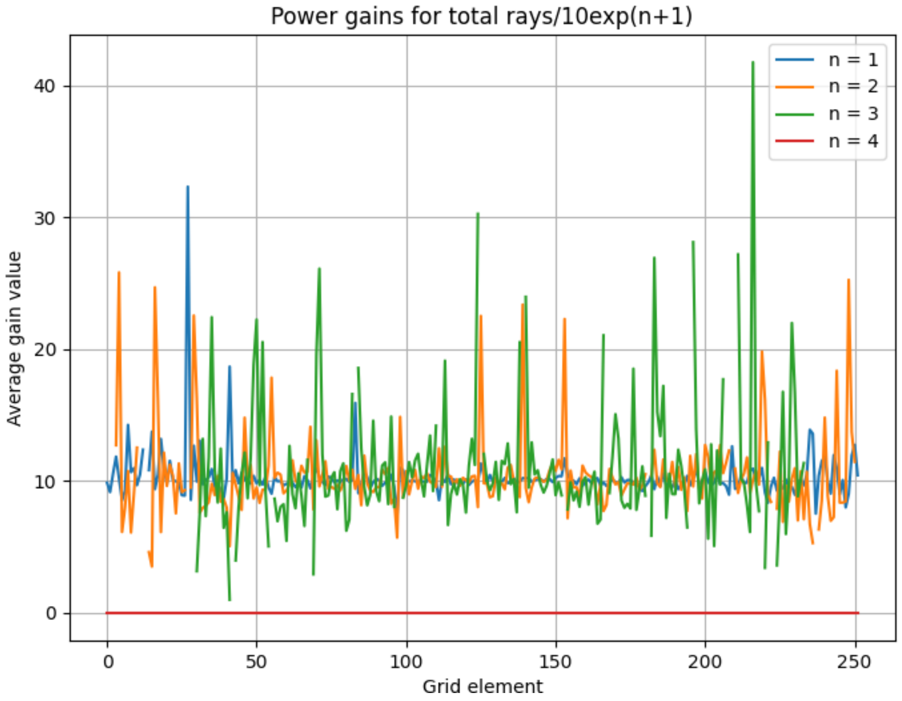

- Recommended comparison against radiometers/heat gauges inside of the cavity (consider how to do it to avoid excessive O&M due to high radiation and temperatures)

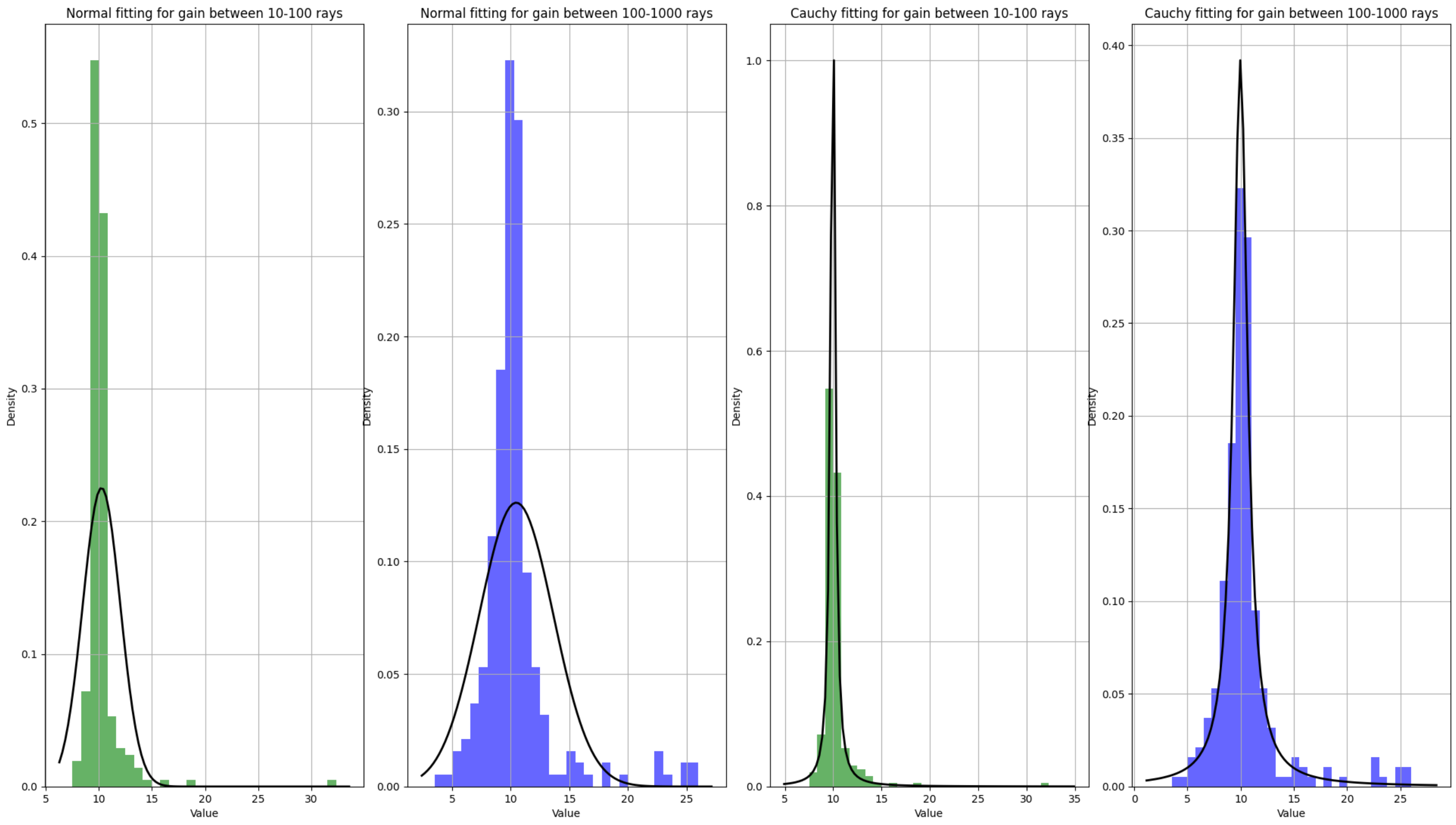
CORRECTION AND CAVITY INTEGRATION

- Drawbacks
  - >27M rays → Time consuming ray classification (few seconds in cluster but several hours in commercial computer)
  - Studying parallelization and ray number reduction



CORRECTION AND CAVITY INTEGRATION

- A trend is observed in the previous graph:



If 1 every 10 rays is projected, the power in each mesh element is approximately 1/10

Computing cost reduction technique: project 1 every 10 rays multiplying its power times 10

80% time reduction in commercial laptop. Original algorithm usable in cluster