Centro Tecnológico Avanzado de Energías Renovables
ANDALUCIA

Shadowing and blocking effect optimization for a variable geometry heliostat field

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Fernando Martínez, Jose Carballo

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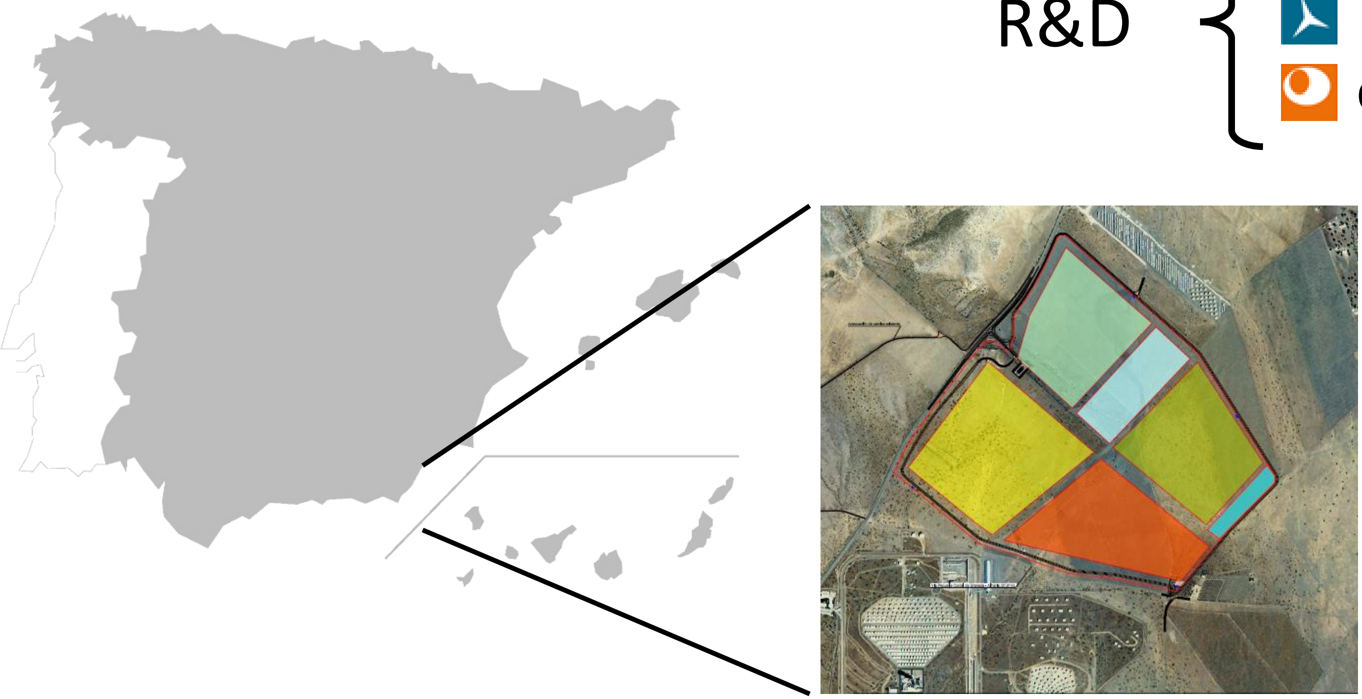
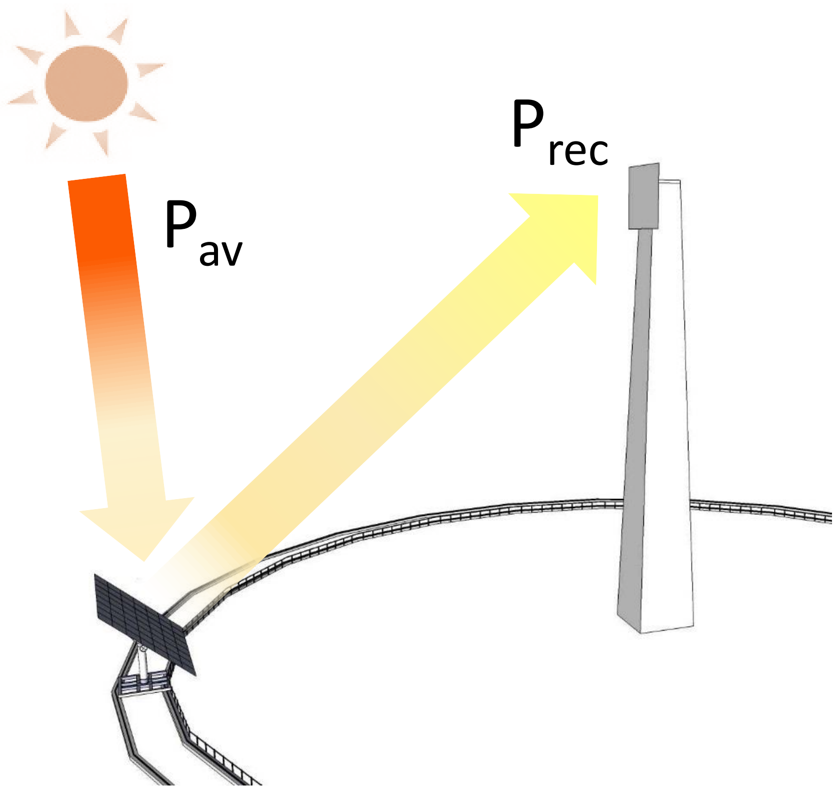
CTAER (**C**entro **T**ecnológico **A**vanzado de **E**nergías **R**enovables)

Advanced Technology Centre for Renewable Energies

R&D:
- Biomass *(Menjibar-Jaen)*
- Marine *(Tarifa-Cádiz)*
- CSP *(Tabernas-Almería)*



- Area: 91 ha
- Multidisciplinary:
  - PTC
  - CRS
  - H_2 & CPV
  - L/M Temp
  - Offices/Labs



Optical efficiency (η_{opt})

Available power

$$P_{av} = DNI \cdot A_{ap}$$

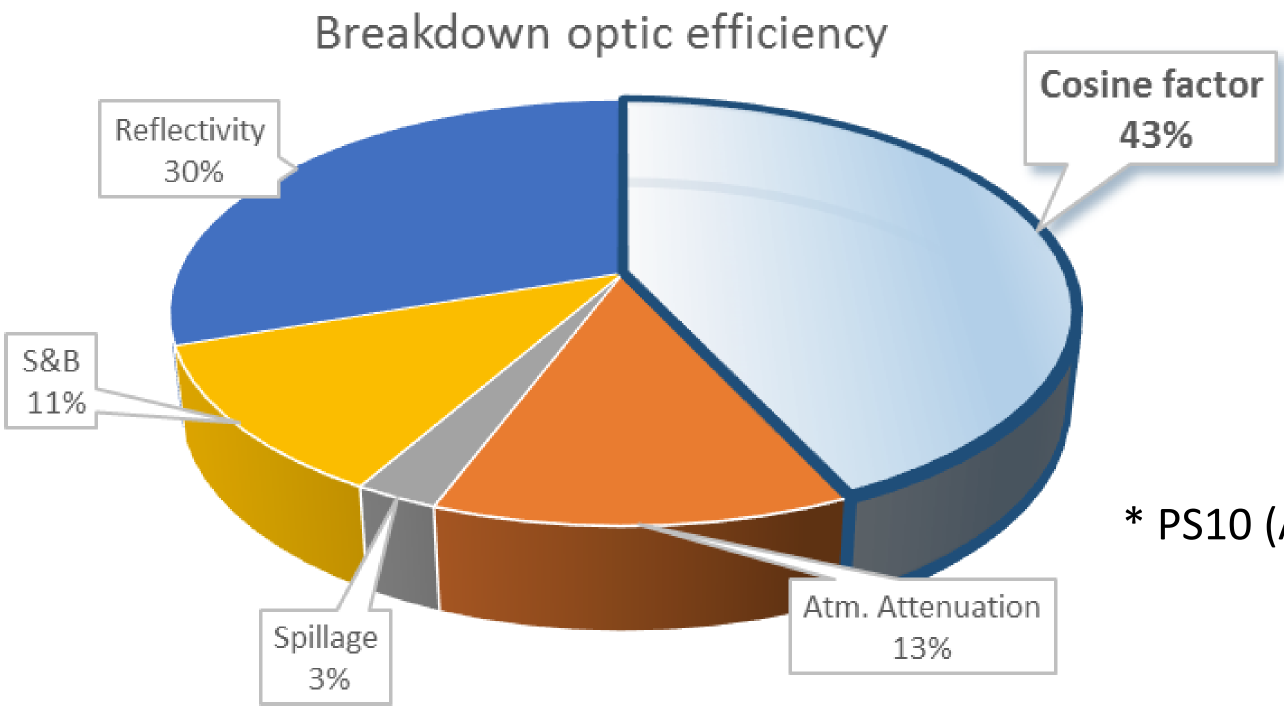
Power at the receiver

$$P_{rec}$$

$$\eta_{opt} = \frac{P_{REC}}{P_{av}}$$

$$\eta_{opt}(x,y,t) = \rho \cdot f_{\cos\theta}(x,y,t) \cdot f_{at}(x,y) \cdot f_{spill}(x,y,t) \cdot f_{sb}(x,y,t)$$

INTRODUCTION



* PS10 (Abengoa)

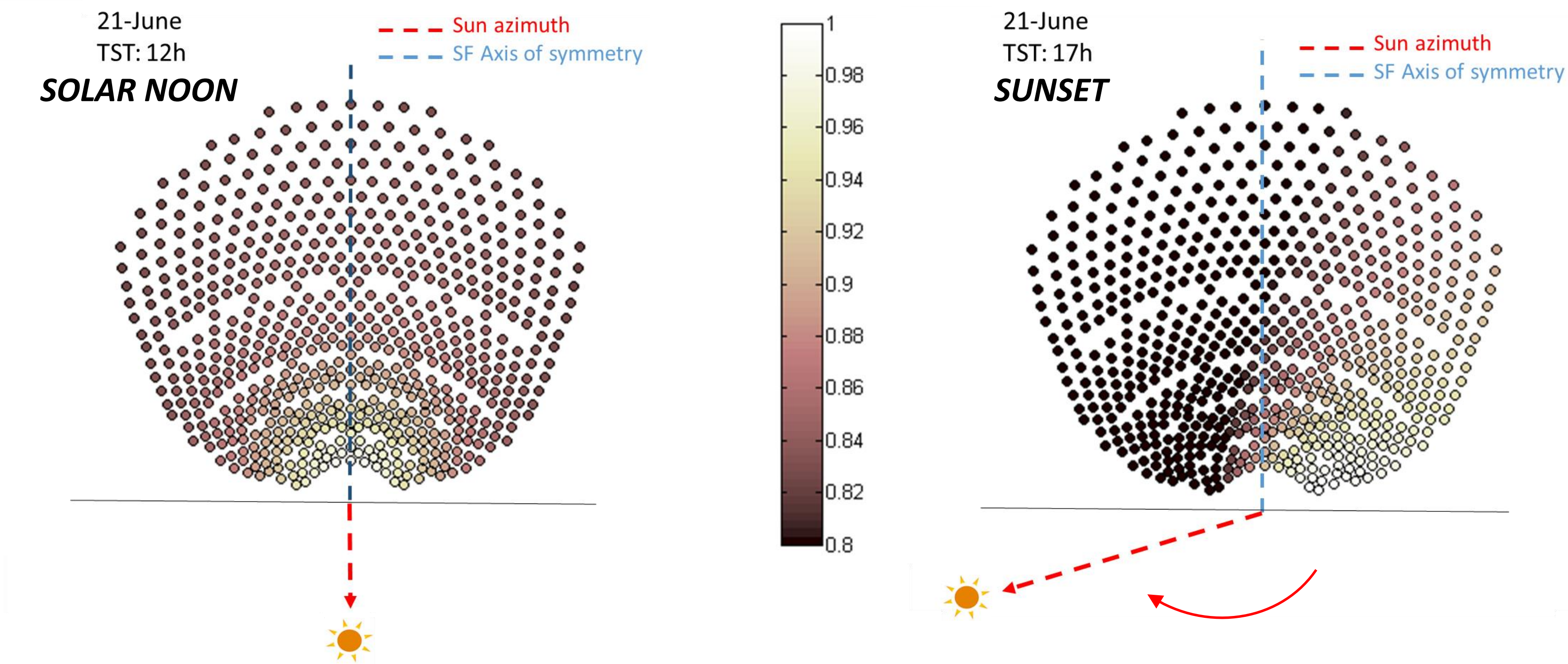
$$\eta_{opt}(x,y,t) = \rho \cdot f_{\cos\theta}(x,y,t) \cdot f_{at}(x,y) \cdot f_{spill}(x,y,t) \cdot f_{sb}(x,y,t)$$

ROTATING FIELD

IMPROVING THE COSINE FACTOR

CASE 1 --> f_{cos}=**0.87**

CASE 2 --> f_{cos}=**0.80**

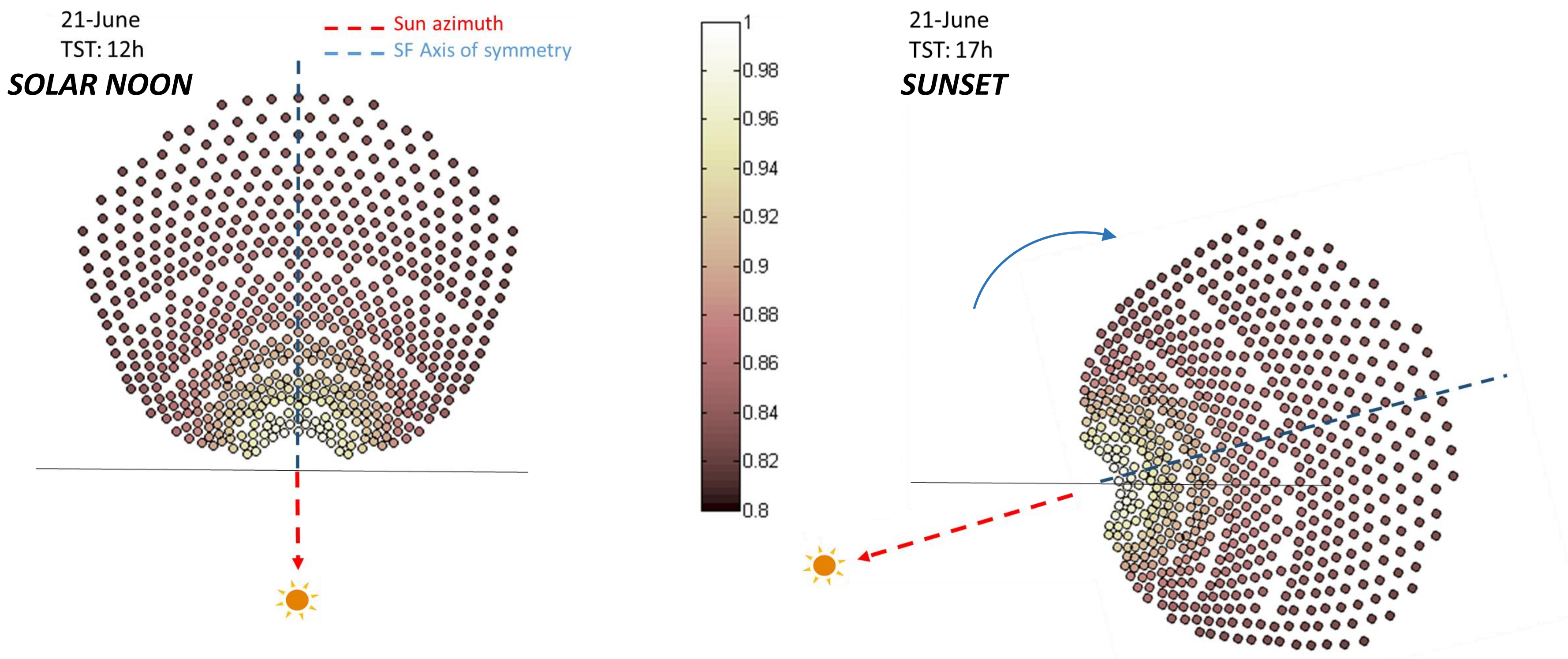


IMPROVING THE COSINE FACTOR

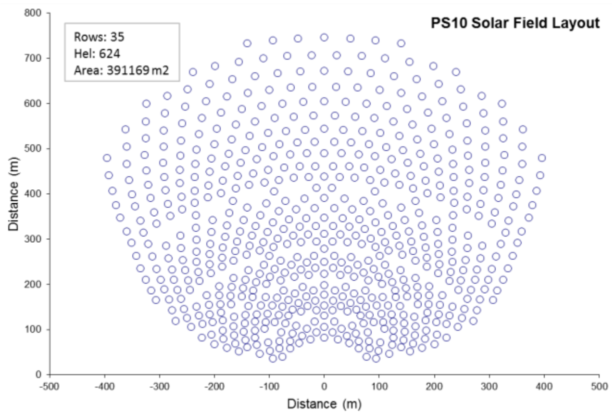
CASE 1 --> f_{cos}=**0.87**

CASE 2 --> f_{cos}=**0.80**

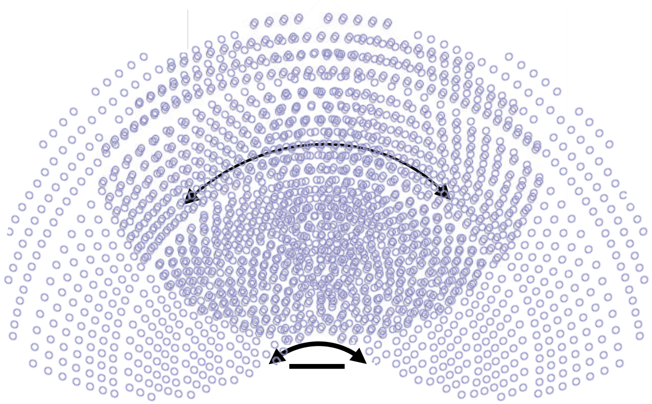
CASE 2a --> f_{cos}=**0.88**



ROTATING FIELD



CONVENTIONAL STAGGERED FIELD



VARIABLE GEOMETRY STAGGERED FIELD

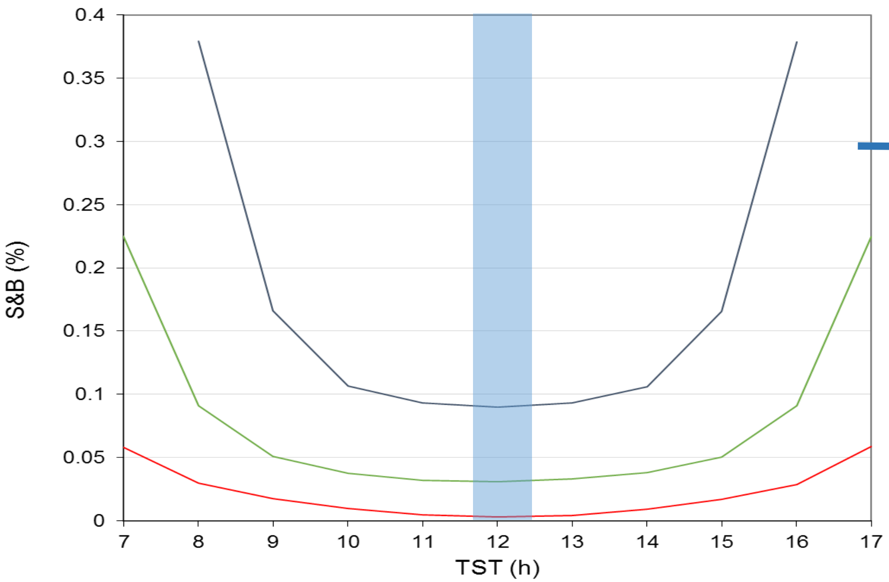
Mobile heliostats

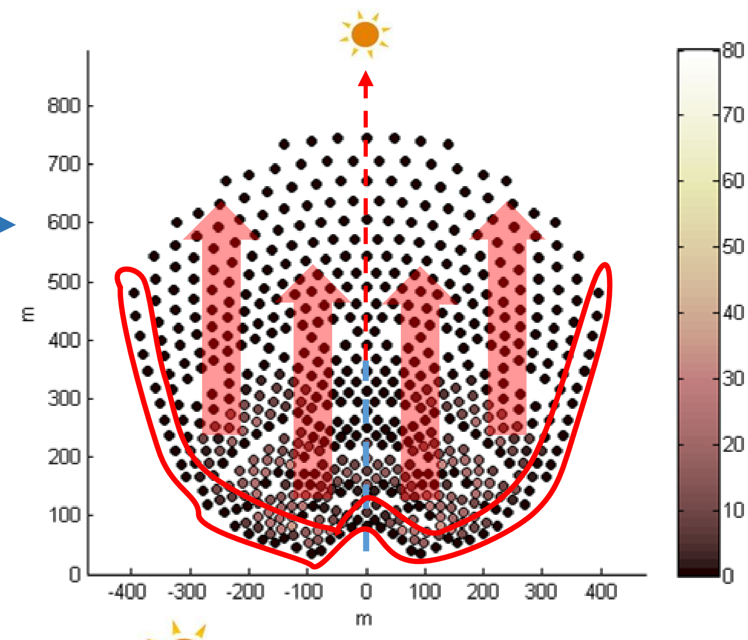
Concentric circular rails

ROTATING FIELD vs NORTH FIELD

$$\eta_{opt}(x,y,t) = \rho \cdot f_{\cos\theta}(x,y,t) \cdot f_{at}(x,y) \cdot f_{spill}(x,y,t) \cdot f_{sb}(x,y,t)$$

Shadowing & Blocking losses

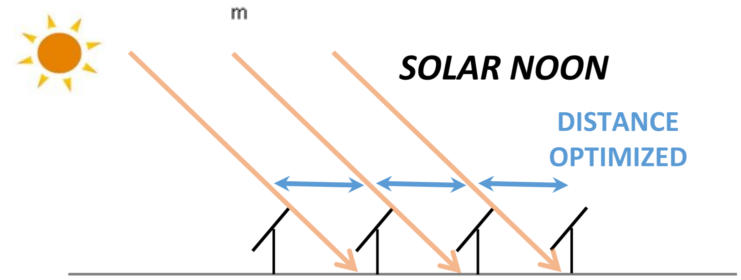




Winter solstice

Equinox

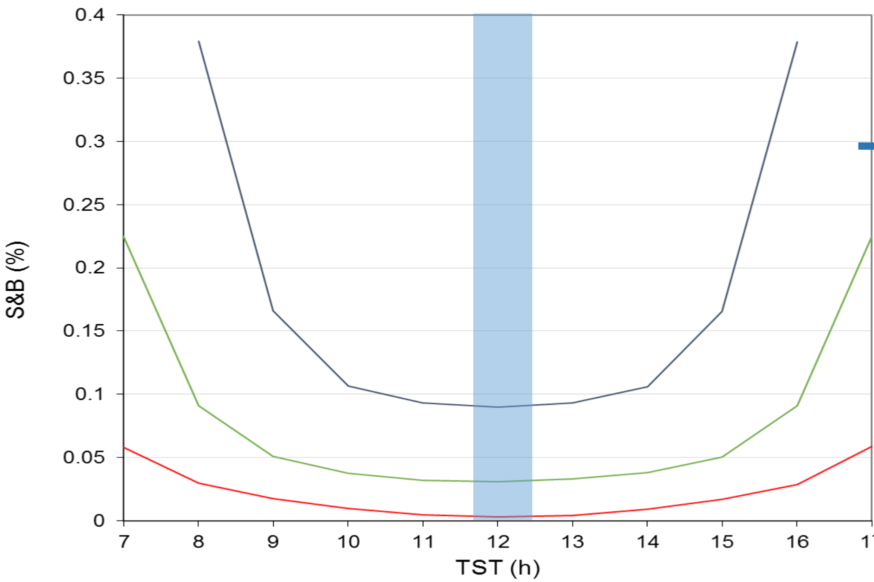
Summer solstice

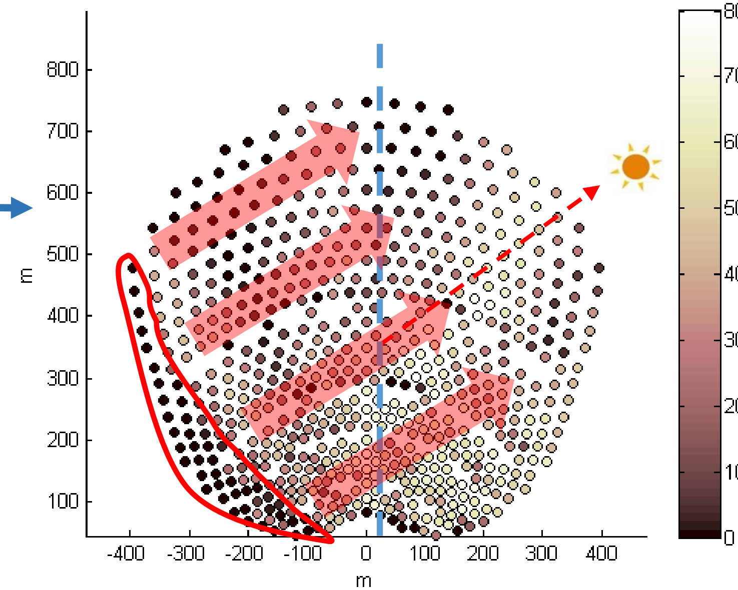


ROTATING FIELD vs NORTH FIELD

$$\eta_{opt}(x,y,t)=\rho\cdot f_{\cos\theta}(x,y,t)\cdot f_{at}(x,y)\cdot f_{spill}(x,y,t)\cdot f_{sb}(x,y,t)$$

Shadowing & Blocking losses

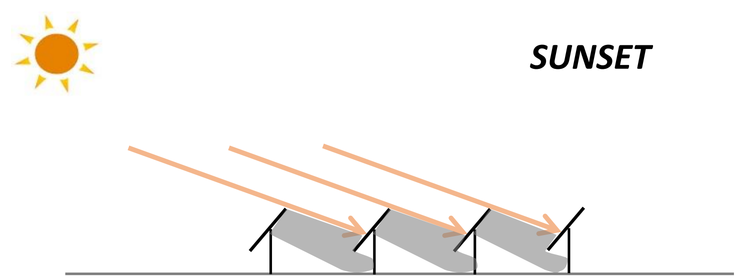




Winter solstice

Equinox

Summer solstice

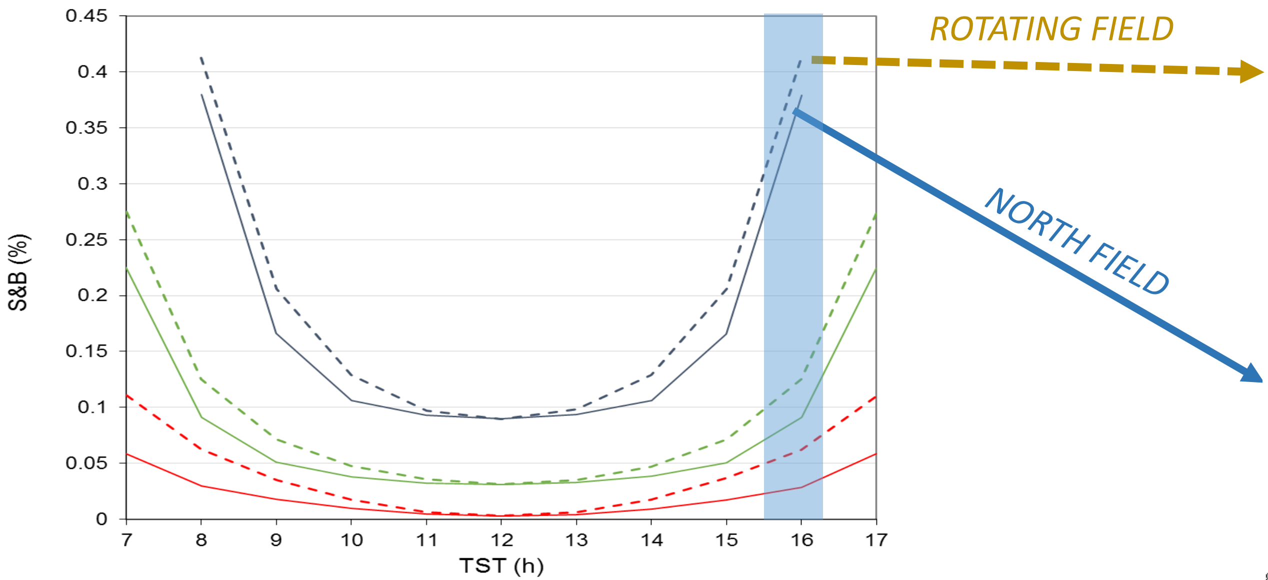


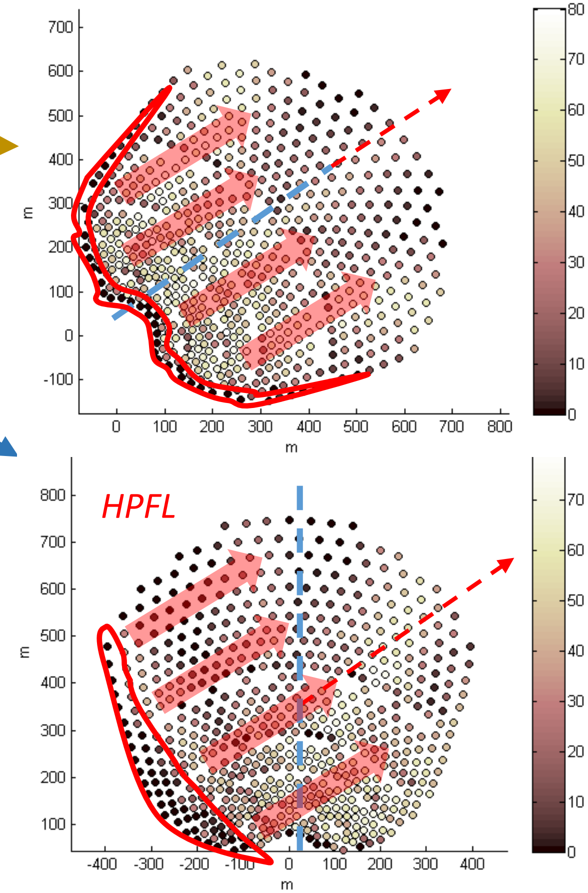
SUNSET

ROTATING FIELD vs NORTH FIELD

$$\eta_{opt}(x,y,t) = \rho \cdot f_{\cos\theta}(x,y,t) \cdot f_{at}(x,y) \cdot f_{spill}(x,y,t) \cdot f_{sb}(x,y,t)$$

Shadowing & Blocking losses





ANNUAL LOSSES (1 - f_{sb})	
NORTH FIELD	7%
ROTATING FIELD	8.7%

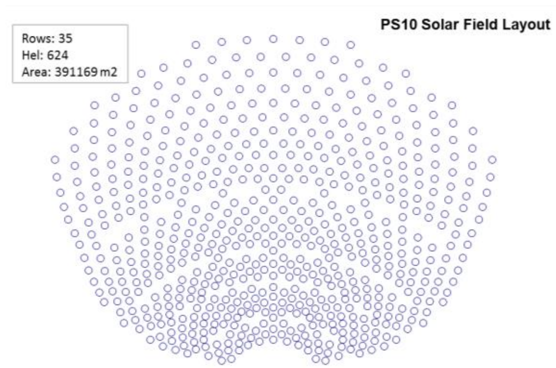
Winter solstice

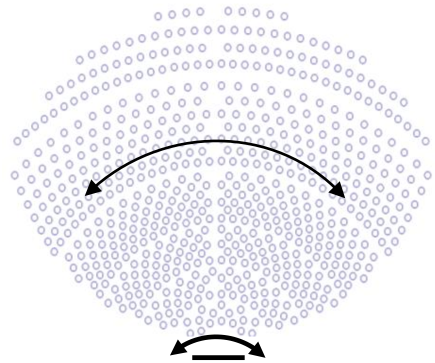
Equinox

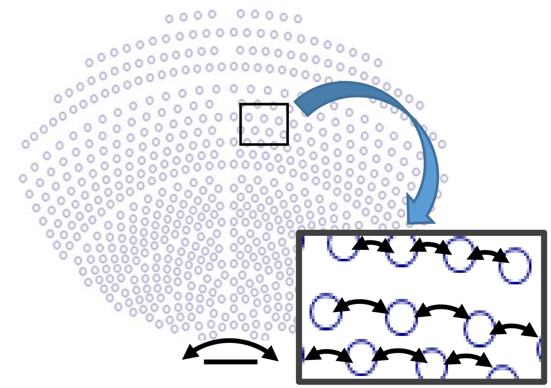
Summer solstice

ROTATING FIELD OPTIMIZATION CODE

Stationary Field	Variable Geometry Field Common Operation strategy	Variable Geometry Field Individual Operation strategy





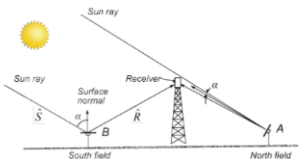


LAYOUT OPTIMIZATION	*LAYOUT OPTIMIZATION*	*LAYOUT OPTIMIZATION*
21 variables (radial distance, azimuthal distance, incremental spacing between rows…)	**18 variables** (radial distance, azimuthal distance, incremental spacing between rows…) + Field Velocity	**624 variables** (Heliostat position) + Field Velocity
Commercial codes	**Modification over existing codes**	**NEW CODE**

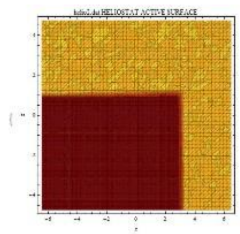
ROTATING FIELD OPTIMIZATION CODE

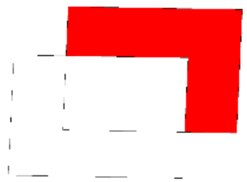
CODE STRUCTURE

New code developed in MatLab (Energy simulation)



Re-design Shadow & Blocking calculation engine





Validation

On field real validation

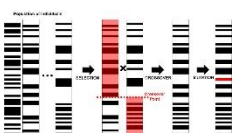
Ray-tracing

Commercial codes

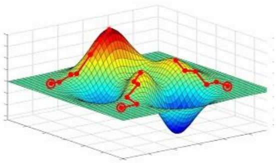
Optimization problem

Heliostat position with field simmetry
Int (n/2)
+
Field Velocity

Optimization algorithm



Genetic algorithm



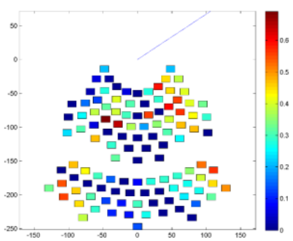
Modified deterministic hill-climbing

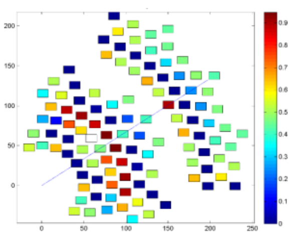
Validation

NSPOC

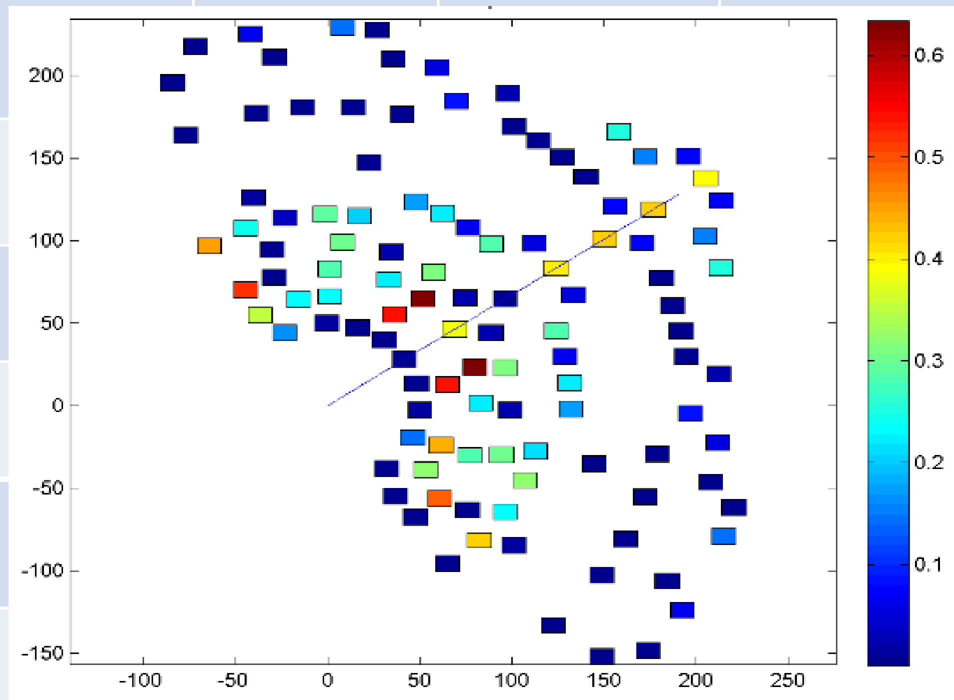
(Hourly Energy simulations)

RESULTS (4pm – 113hel)





FIELD	Cosine effect efficiency (CE)	Shadowing effect efficiency (SE)	Combined effect (CE*SE)
STATIONARY STAGGERED			
ROTATING STAGGERED COMMON OPERATION			
ROTATING INDIVIDUAL OPERATION			



SIMULATION TIME

8.3 min

2 weeks

CONCLUSIONS

- Although rotating fields show significant benefits in terms of optical efficiency, rotating the whole field keeping the staggered structure decreases the Shadowing & Blocking performance
- It is necessary to use an individual operation strategy instead of a common strategy
- To calculate the heliostat position in each moment is necessary to solve an optimization problem of a significant number of variables
- The code developed by CTAER reduces the time spent in S&B calculations and uses new optimization algorithms
- Using an individual control strategy the combined effect of the cosine factor and S&B can be improved more than 10% with respect to a north stationary field.

Thanks for your attention!

For further information please contact:

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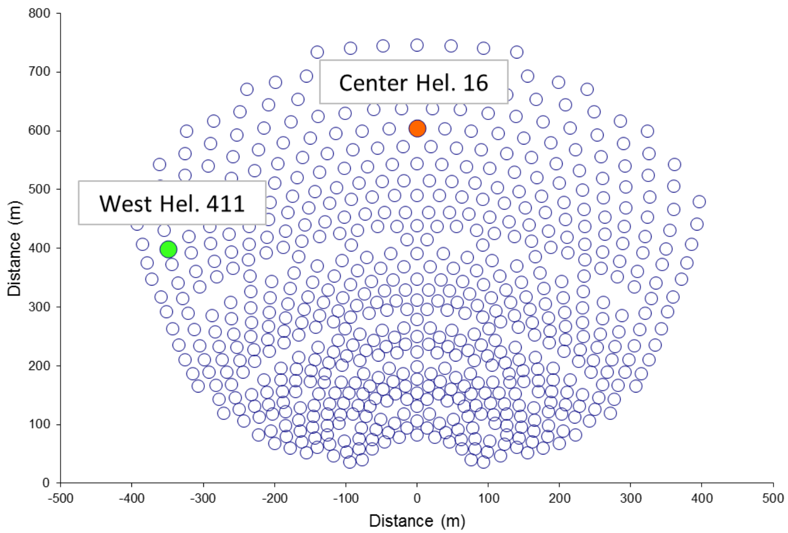
- Sol Luca de Tena sol.lucadetena@ctaer.com

APPENDIX

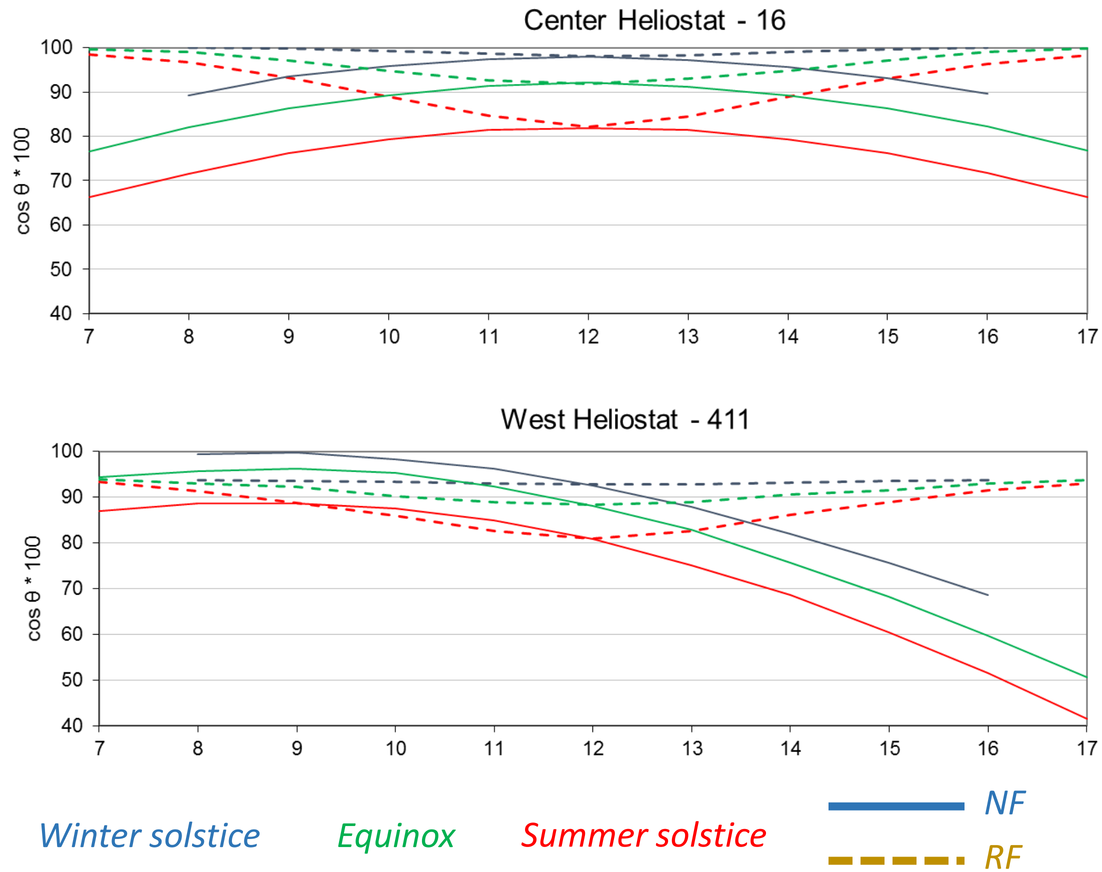
ROTATING FIELD vs NORTH FIELD

$$\eta_{opt}(x,y,t) = \rho \cdot \underline{f_{\cos\theta}(x,y,t)} \cdot f_{at}(x,y) \cdot f_{spill}(x,y,t) \cdot f_{sb}(x,y,t)$$

Cosine factor



ANNUAL LOSSES (1 - $f_{\cos\theta}$)	
NORTH FIELD	12.6%
ROTATING FIELD	6%



ROTATING FIELD vs NORTH FIELD

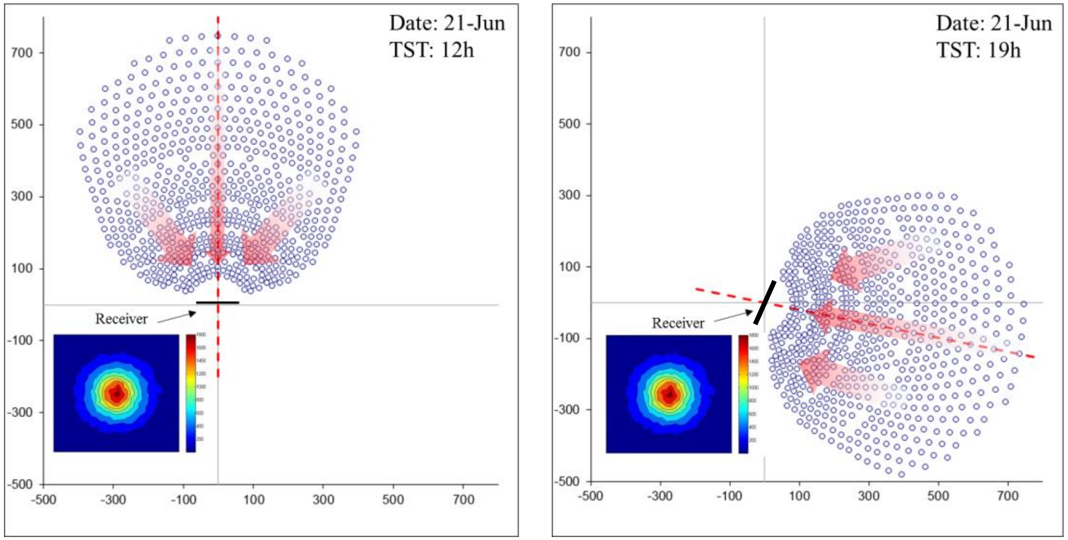
$$\eta_{opt}(x,y,t) = \rho \cdot f_{\cos\theta}(x,y,t) \cdot f_{at}(x,y) \cdot f_{spill}(x,y,t) \cdot f_{sb}(x,y,t)$$

Spillage

- ~~Size of the receiver~~
- ~~Slant range~~
- ~~Incidence angle on the receiver~~
- Optic aberration (Astigmatism)

CASE 1 = *CASE 2*

Same Incidence angle on the receiver in both cases



ROTATING FIELD vs NORTH FIELD

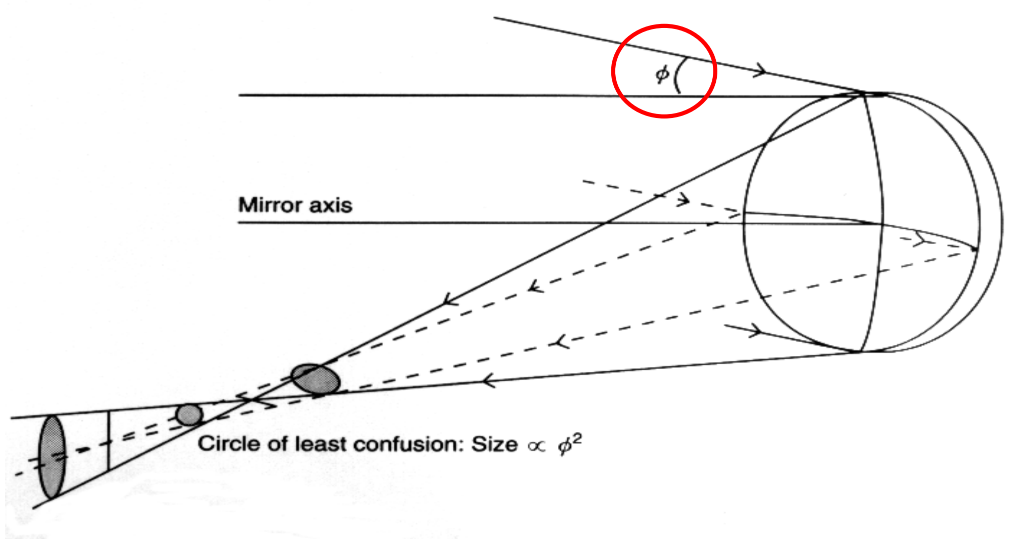
$$\eta_{opt}(x,y,t) = \rho \cdot f_{\cos\theta}(x,y,t) \cdot f_{at}(x,y) \cdot f_{spill}(x,y,t) \cdot f_{sb}(x,y,t)$$

Spillage

- ~~Size of the receiver~~
- ~~Slant range~~
- ~~Incidence angle on the receiver~~
- Optic aberration (Astigmatism)

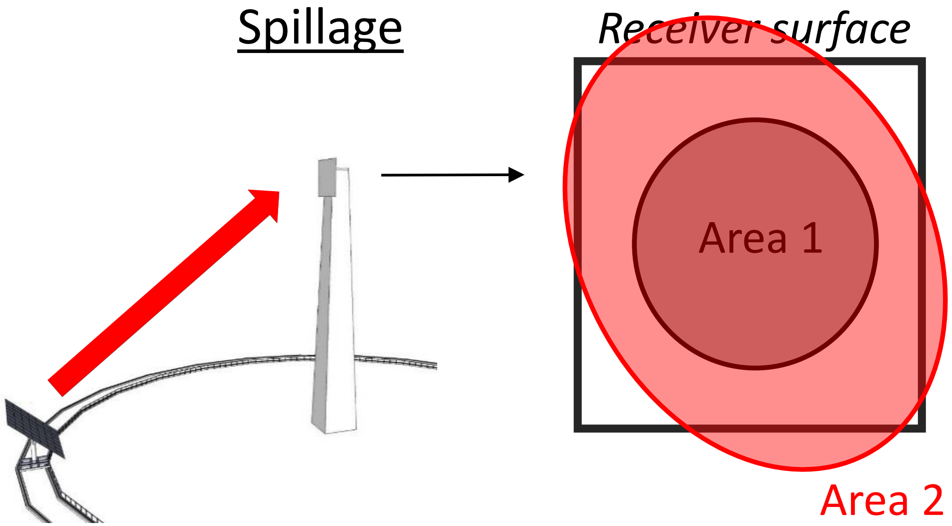
Depends on the incidence angle on the heliostat

CASE 1 ≠ CASE 2



$$\eta_{opt}(x,y,t) = \cancel{\rho} \cdot f_{\cos\theta}(x,y,t) \cdot f_{at}\cancel{(x,y)} \cdot \underline{f_{spill}(x,y,t)} \cdot f_{sb}(x,y,t)$$

Spillage



Reflected image	Incidence angle	Area
Ideal	*= 0*	**Area 1**

$$\left(\frac{h_s}{\beta_s \cdot d}\right) = \frac{Area\ 2}{Area\ 1}$$

Dimensionless size

Represents the increase of the reflected image with respect to the ideal one (incident angle equal to cero)