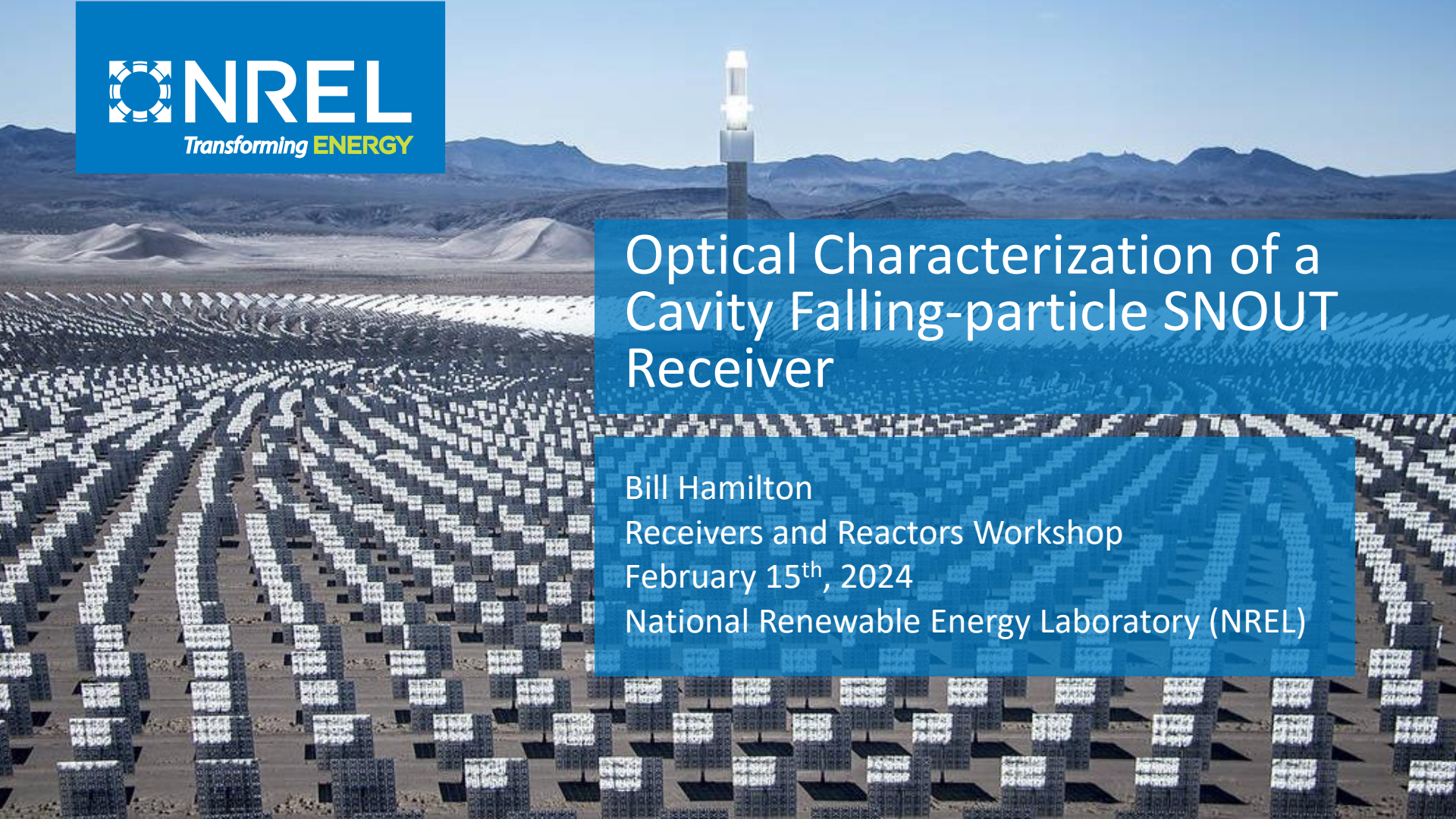

Optical Characterization of a Cavity Falling-particle SNOUT Receiver

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Receivers and Reactors Workshop

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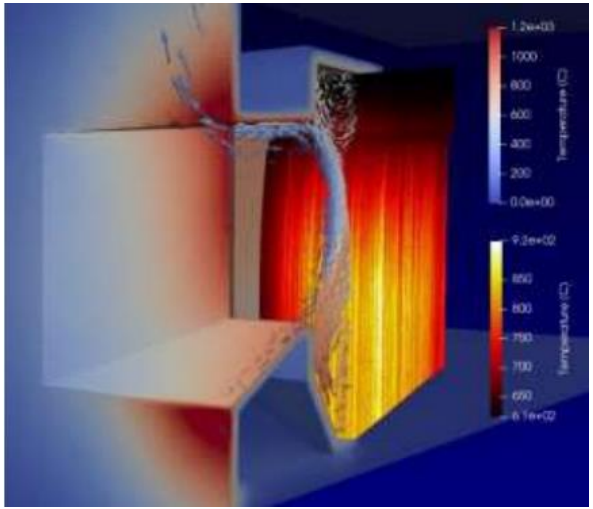
National Renewable Energy Laboratory (NREL)

Free-falling Particle Receiver

- Waterfall “catch-and-release” particle curtain within a cavity
- Curtain is exposed to ambient conditions which can result in particle loss
- A SNOUT is a passive approach to reduce the receiver’s sensitivity to wind conditions
- The SNOUT can negatively affect the heliostat field view of receiver
- The optical impact on layout and aimpoint strategy has not been fully investigated.
- To address this, we implemented a general free-falling particle receiver geometry into SolarPILOT



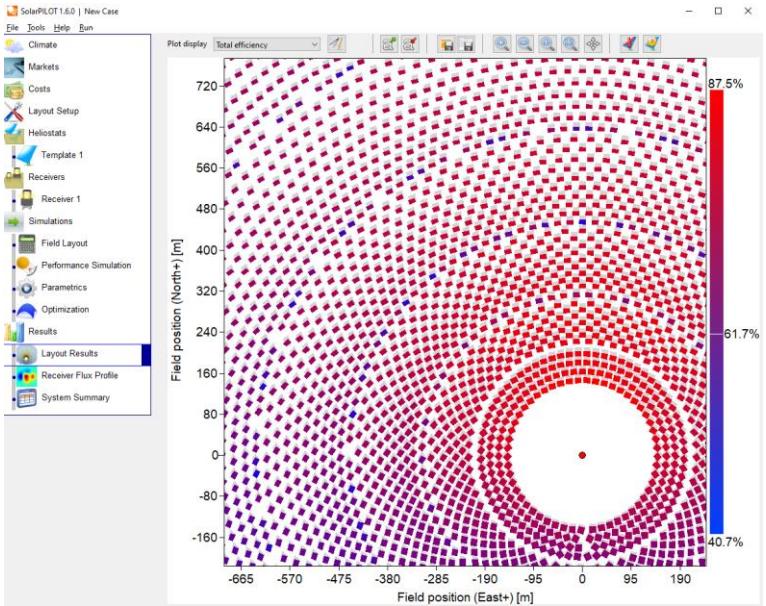
Ho et.al. Gen 3 Particle Pilot Plant (G3P3) -- High-Temperature Particle System for Concentrating Solar Power (Phases 1 and 2). United States: N. p., 2021. Web. doi:10.2172/1832285.

SolarPILOT Background

Solar Power Tower Integrated Layout and Optimization Tool (SolarPILOT)

- Generates and characterizes power tower heliostat fields
- Access to two flux characterization engines:
  - (analytical) Hermite series expansion[1]
  - (numerical) SolTrace ray tracing engine
- Open-source project with a publicly available executable
- Python API available

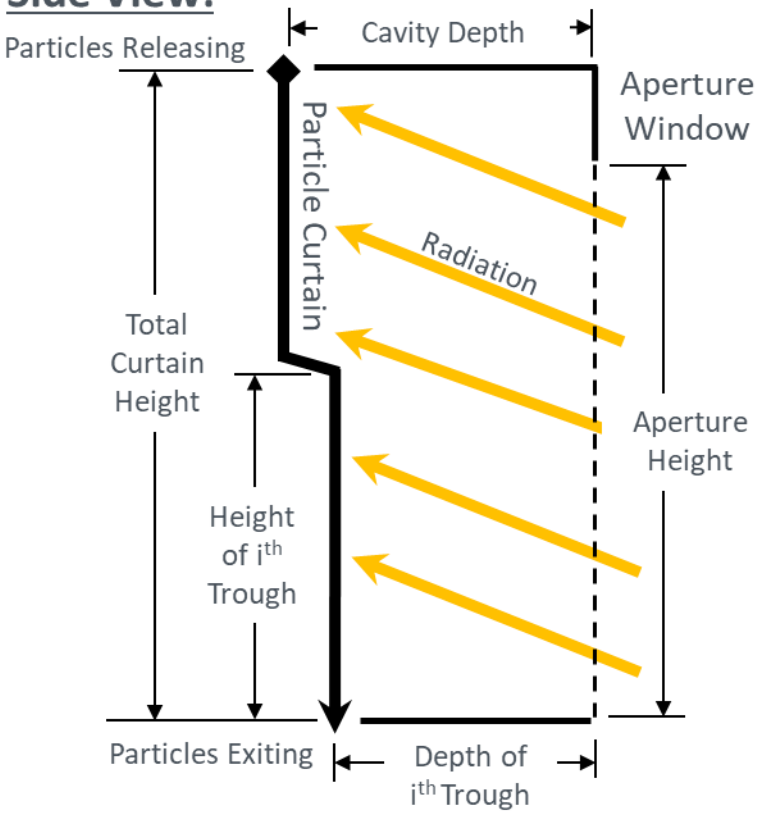
https://www.nrel.gov/csp/solarpilot-download.html



[1]Kistler, "A User's Manual for DELSOL3."

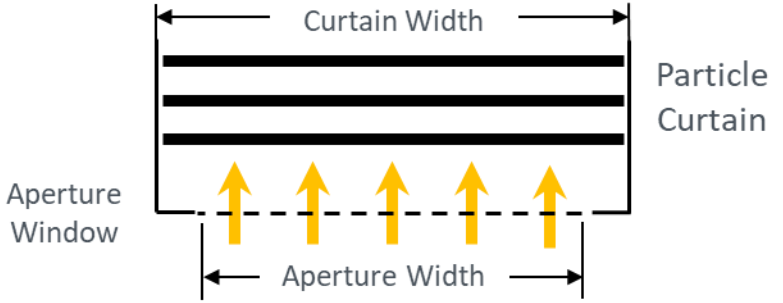
General Free-falling Particle Receiver Geometry

Side View:

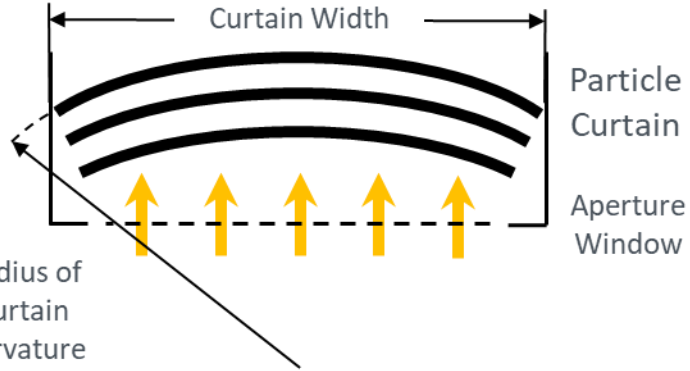


Top View:

1. Flat Curtain



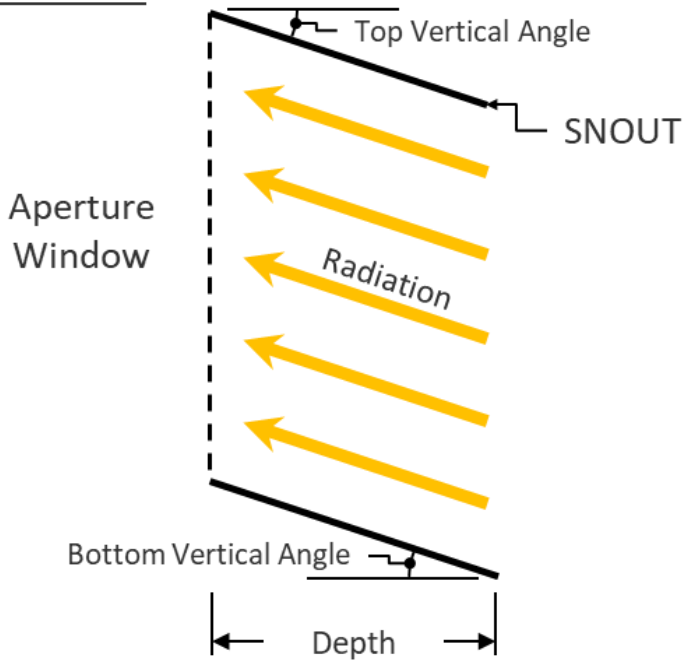
2. Curved Curtain



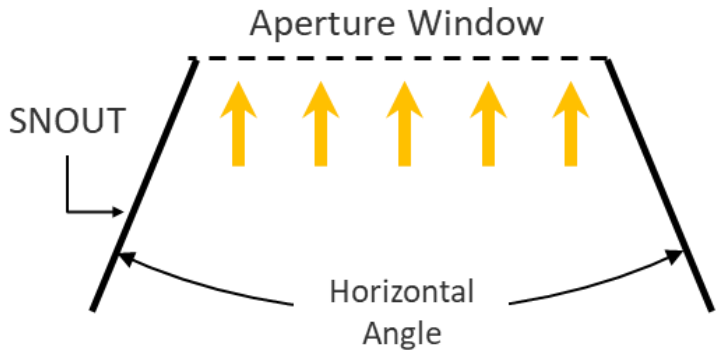
General Free-falling Particle Receiver

SolarPILOT's users can toggle the SNOUT on and off

Side View:



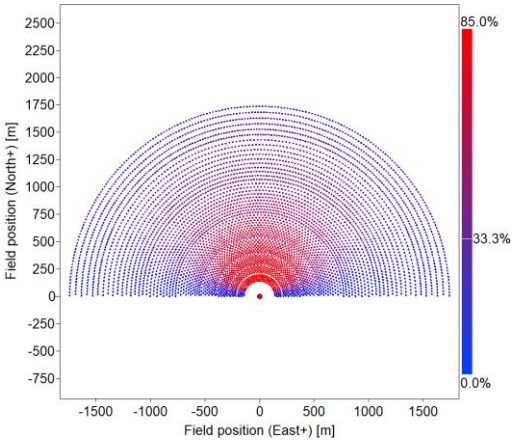
Top View:

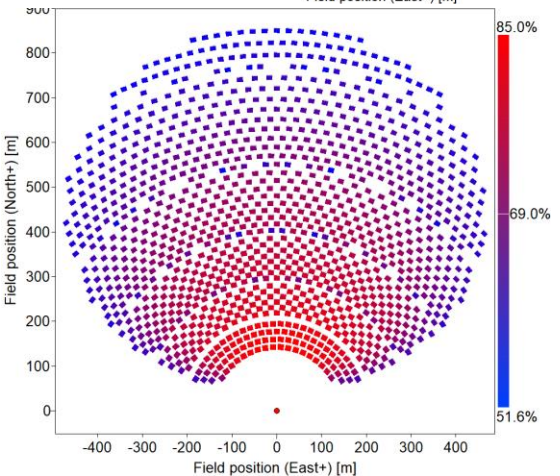


Zero horizontal angle will result in parallel SNOUT sides

SolarPILOT's Layout Algorithm

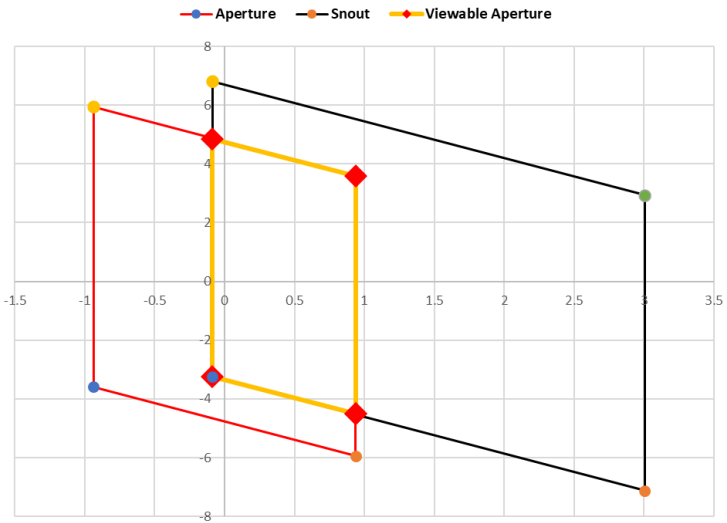
1. Generate all possible heliostat locations based on layout method
2. Evaluate heliostat efficiencies using the **Hermite polynomial expansion**
3. Order heliostats based on the heliostat selection criteria
4. Eliminate the worst performing heliostats until the **target power** is achieved at design conditions





Updates to the Hermite Series Integral

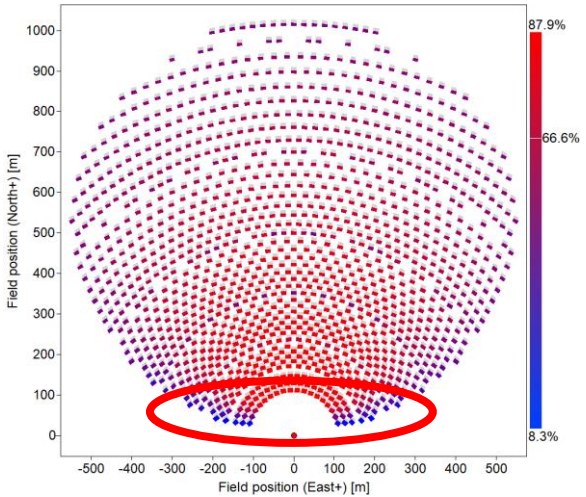
- Our approach is to modify the size of the “receiver” for each heliostat depending on its specific view of the receiver’s aperture.
- We calculate the “viewable” receiver aperture size by projecting the aperture and SNOUT window boundaries onto the heliostat image plane.
- The aperture projection can be (relative to the SNOUT):
  1) Completely within -> SNOUT does not block
  2) Completely outside -> SNOUT completely blocks
  3) Overlaps the SNOUT window -> SNOUT partially blocks
     - Sutherland-Hodgeman polygon clipping algorithm is used to determine overlap area bounding points
     - Project bounding points back onto the receiver plane to get the “viewable” receiver aperture height and width



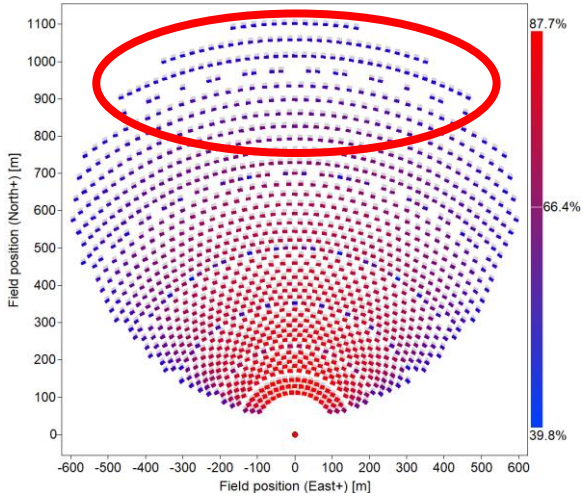
Partially overlapping projections onto the heliostat image plane.

Layout Accounting for SNOUT

SNOUT depth	1	[m]
Vertical SNOUT angle	20	[deg]
Horizontal SNOUT angle	120	[deg]



Field layout without accounting for SNOUT

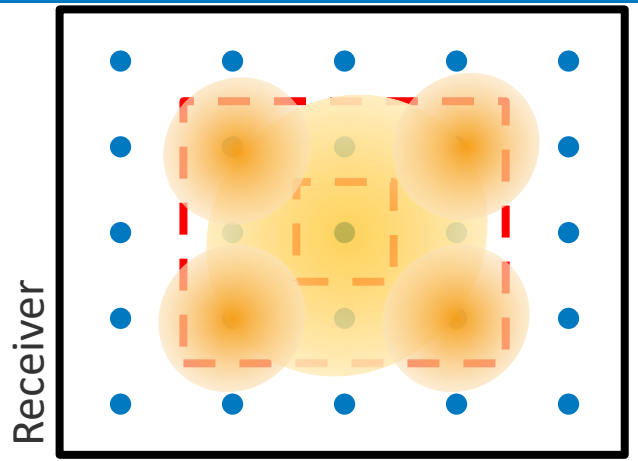


Field layout with accounting for SNOUT

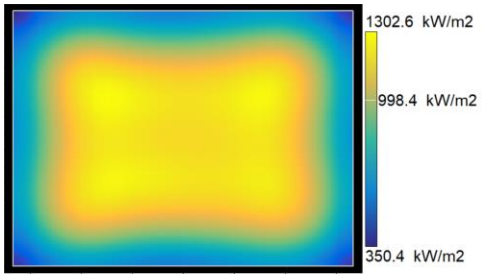
- Without accounting for the SNOUT results in low efficiency (i.e., 8.3%) heliostats near receiver.
- Layout not accounting for the SNOUT results in a 4% shortage in receiver power at design.
- New layout removes low efficiency heliostats near the receiver and adds heliostats to the back of the field to achieve the desired receiver power.
- In this case, the SNOUT layout does have a slightly lower solar field efficiency because the SNOUT limits field view and requires heliostats to be located further from the receiver

Image Size Priority Aim Heuristic

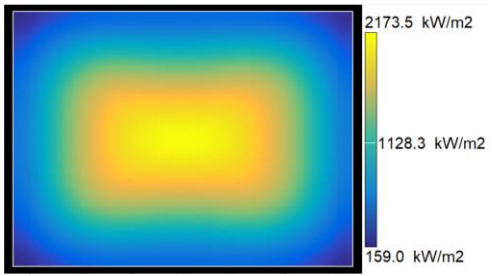
1. Sort heliostats based on image size in descending order.
2. Place each heliostat image in the lowest flux position on the receiver subject to a user-defined standard deviation cutoff



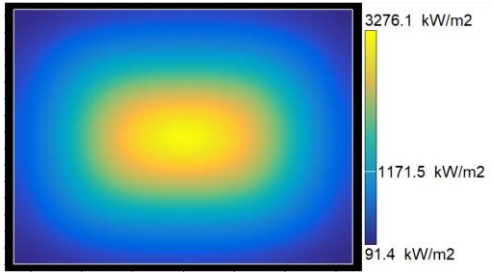
Offset Sigma = 2



Offset Sigma = 3

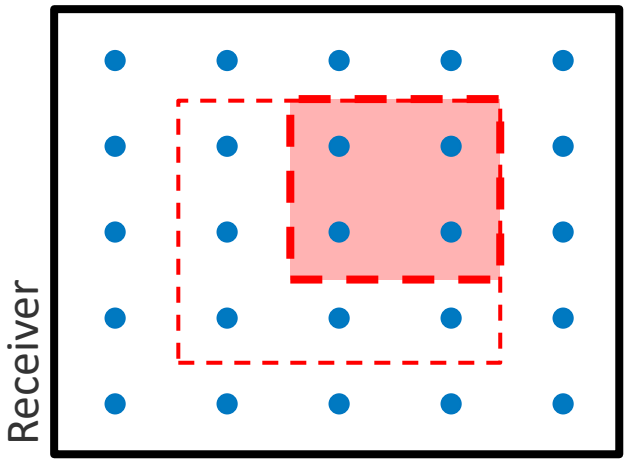


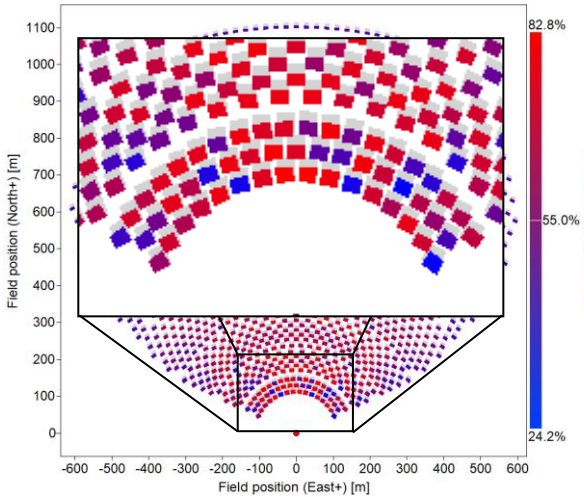
Offset Sigma = 4



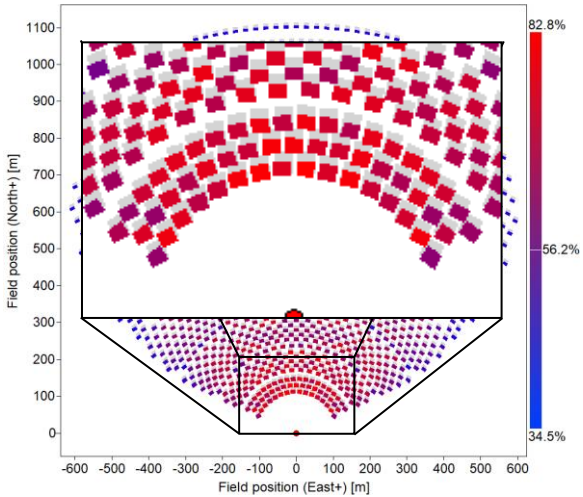
Update to Image Size Priority Aim Heuristic

- Algorithm was updated to limit heliostat aimpoints within the heliostat's viewable receiver area
- If the heliostat image is bigger than the receiver viewable area, the image is placed in the center of the viewable area, thereby minimizing spillage
- We observed approximately a 2% increase in receiver power after this update; however, this impact is sensitive to the SNOUT design parameters





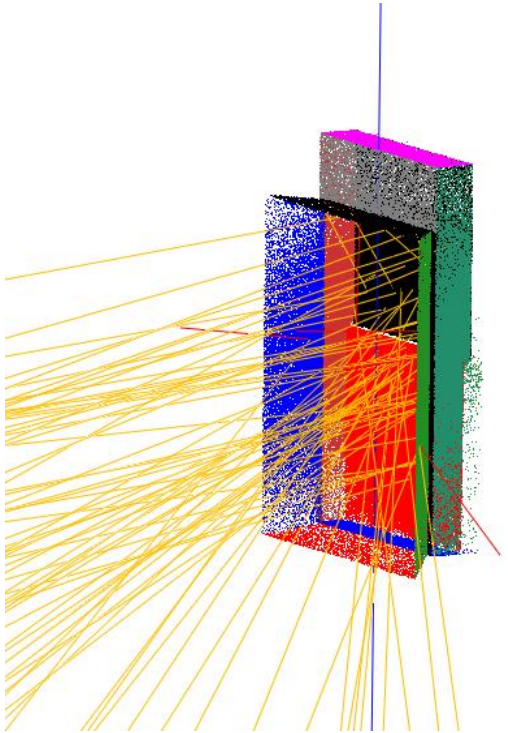
Previous image size priority method



Updated image size priority method

Generate SolTrace Objects from SolarPILOT

- Falling particle receiver geometry can be automatically generated for SolTrace
- Required a “virtual” stage to be added at the receiver aperture
- Virtual stage allows for the counting of incoming rays to estimate the field intercept efficiency
- SolTrace result processing was updated for new receiver geometry
- SolTrace (i.e., ray tracing) enables more detailed optical properties for SNOUT, cavity, and curtain surfaces; however, this is not currently available through SolarPILOT user interface

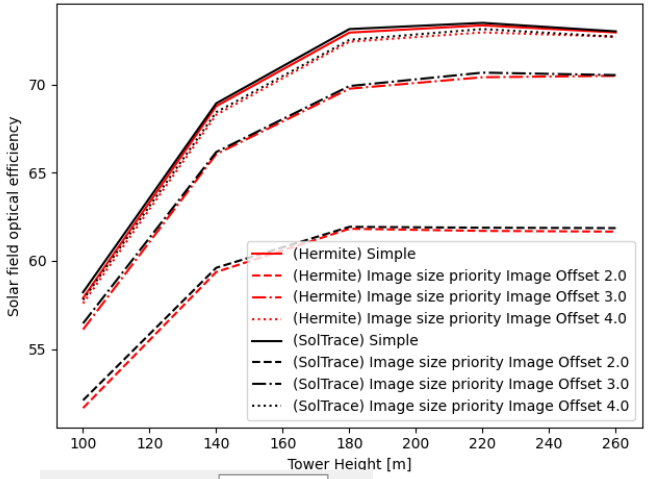


Validation Hermite Method Against SolTrace

- The Hermite method cannot account **secondary reflections**!
- To validate our Hermite integral approach, we have adjusted SolTrace's assumed optical properties to make surfaces consistent with how Hermite handles them.
  1. SNOUT reflectivity set to 0 **(i.e., no secondary reflections into the cavity)**
  2. Particle curtain reflectivity set to 1 – assumed absorptivity **(i.e., opaque particle curtain)**
  3. Cavity reflectivity set to 1 **(i.e., Hermite assumes all flux that enters aperture hits the particle curtain)**

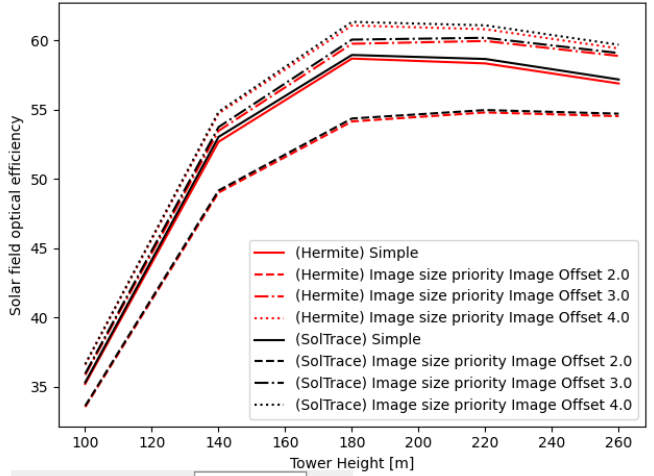
Receiver power: 100 MWt
Aperture width: 10 m
Aperture height: 10 m

Curtain depth: 1.5 m
Curtain width: 11 m
Curtain height: 11 m
Curtain type: flat



SNOUT depth	1	[m]
Vertical SNOUT top angle	10	[deg]
Vertical SNOUT bottom angle	45	[deg]
Horizontal SNOUT angle	90	[deg]

Nominal SNOUT Design



SNOUT depth	3.0	[m]
Vertical SNOUT top angle	0	[deg]
Vertical SNOUT bottom angle	0	[deg]
Horizontal SNOUT angle	0	[deg]

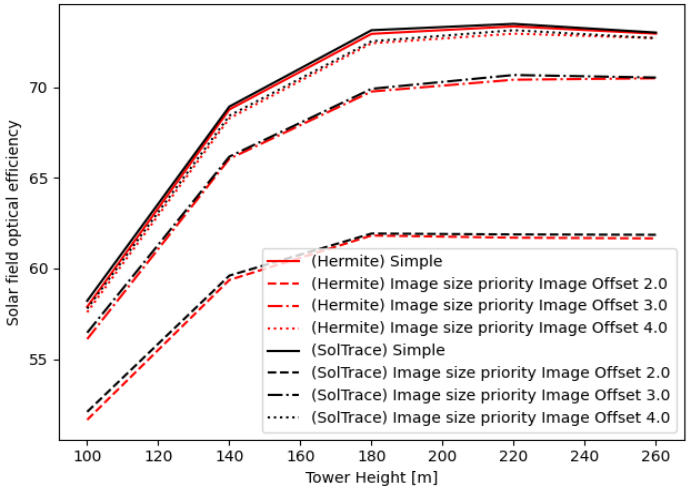
Tight SNOUT Design

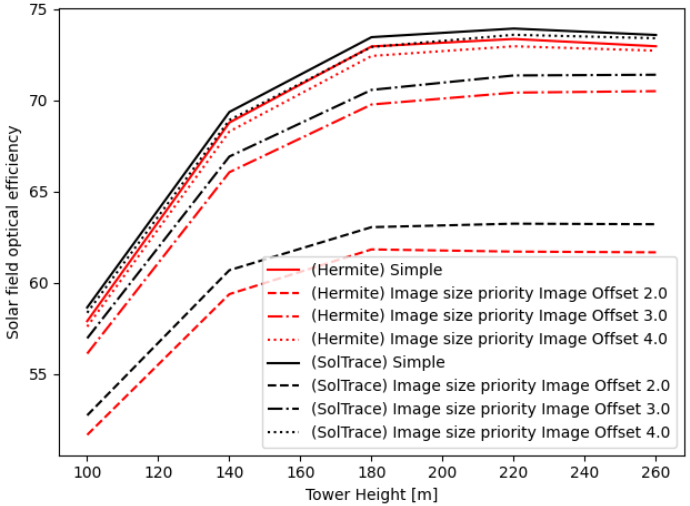
SNOUT Reflections Can Improve Efficiency

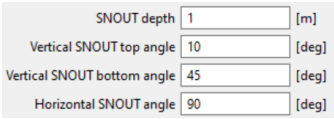
- Modeling the SNOUT and cavity as a diffuse surface with a reflectivity of 80% does improve field optical efficiency
- This improvement is due to an increase in field image intercept efficiency
- The improvement will be sensitive to the SNOUT specific geometry and aiming method

Receiver power: 100 MWt
Aperture width: 10 m
Aperture height: 10 m

Curtain depth: 1.5 m
Curtain width: 11 m
Curtain height: 11 m
Curtain type: flat







Nominal SNOUT Design

Summary of Work

- Incorporate the free-falling particle receiver geometry into SolarPILOT
- Update the heliostat layout and image size priority aimpoint methods to handle this new receiver geometry
- Generate SolTrace geometry of free-falling particle receiver via SolarPILOT for comparison
- Validate Hermite method using SolTrace (ray tracing) as comparison
- Development of a thermal receiver model for system analysis within SAM (not presented here)

Q&A

www.nrel.gov

Email: William.Hamilton@nrel.gov

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