Rayleigh rejection trade study - A Status Report

NGAO Team Meeting #5

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Presentation Outline

- Introduction - WBS dictionary definition
- Previously done work
- EC suggestions from after meeting #3.

- Single LGS model with secondary obscuration
- Yutaka's paper and looking through the Rayleigh scatter from another telescope
- Gemini MCAO fratricide issue
- Using model for Keck case
- Rayleigh rejection
  - Projector location
  - Background subtraction and sub-aperture de-weighting
  - Baffling, field stops.
- TS status.

WBS dictionary definition

- **3.1.2.2.5** : Evaluate the impact of unwanted Rayleigh backscatter to NGAO system performance. Consider the relative performance, cost, risk and schedule of various strategies for mitigation of LGS Rayleigh backscatter. Techniques include background subtraction, modulation and optimizing projection location. This issue is closely coupled to laser pulse format, with pulsed lasers generally providing more options for Rayleigh mitigation than CW lasers. Complete when NGAO baseline architecture selected.
- NGAO's baseline architecture requires multiple LGS's and to enable productive science it is important to reject the scatter from the lower atmosphere or subtract it effectively. This scattered light is unwanted in all parts of the AO system. In particular visible WFSs. This trade study looks at quantifying, mitigate and may be even eliminate the effect of this unwanted scatter.

Previously done work

- Simulated the effect of Rayleigh scatter from a single beacon (without any secondary obscuration) using Gardener's LIDAR model and geometric optics.

- Discussed laser types and pulse format options

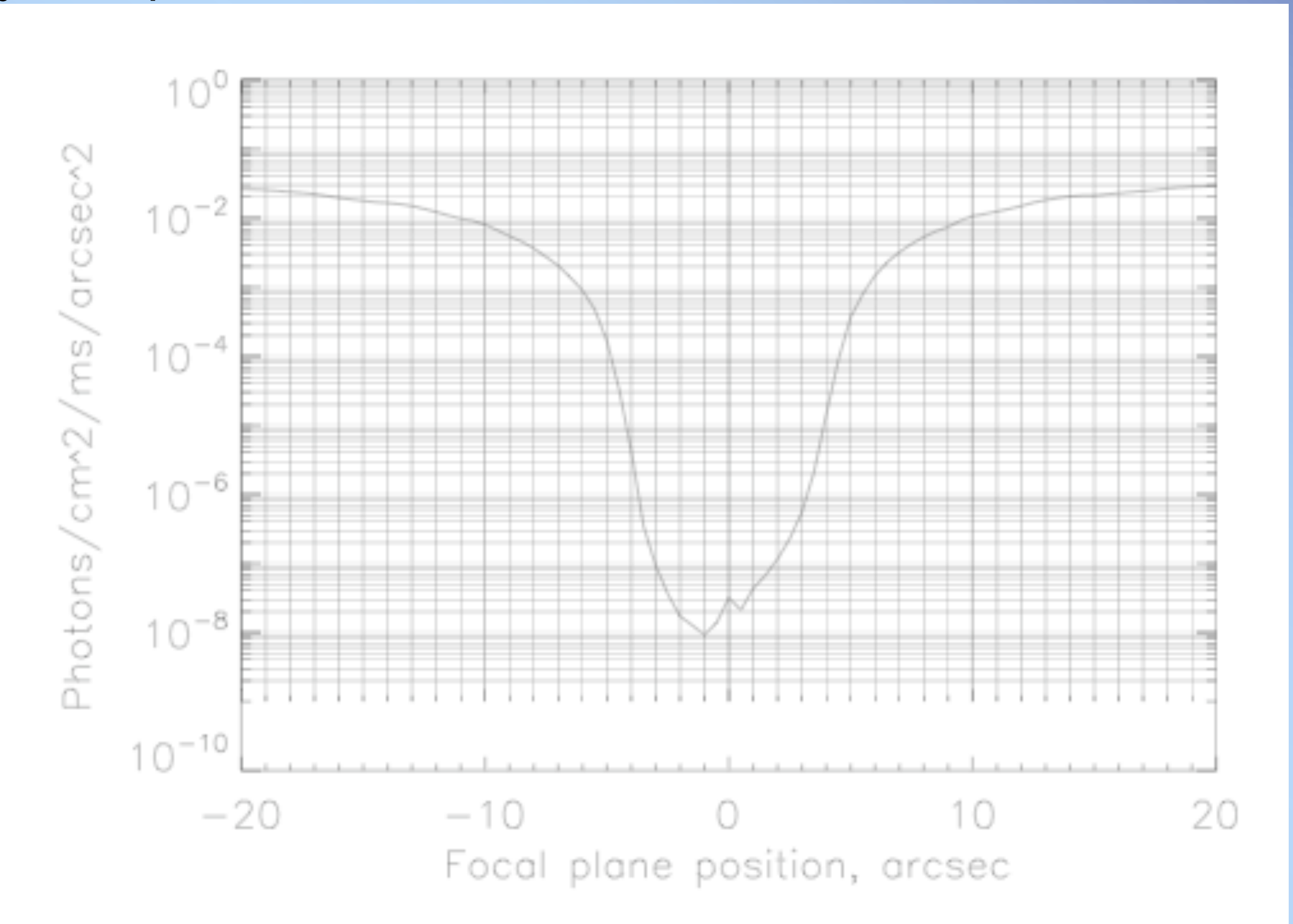
- Rayleigh rejection techniques

- Other concerns - atmospheric scatter fluctuations over short and long time scales, effect of sub-visual cirrus, and effect of volcanic eruptions

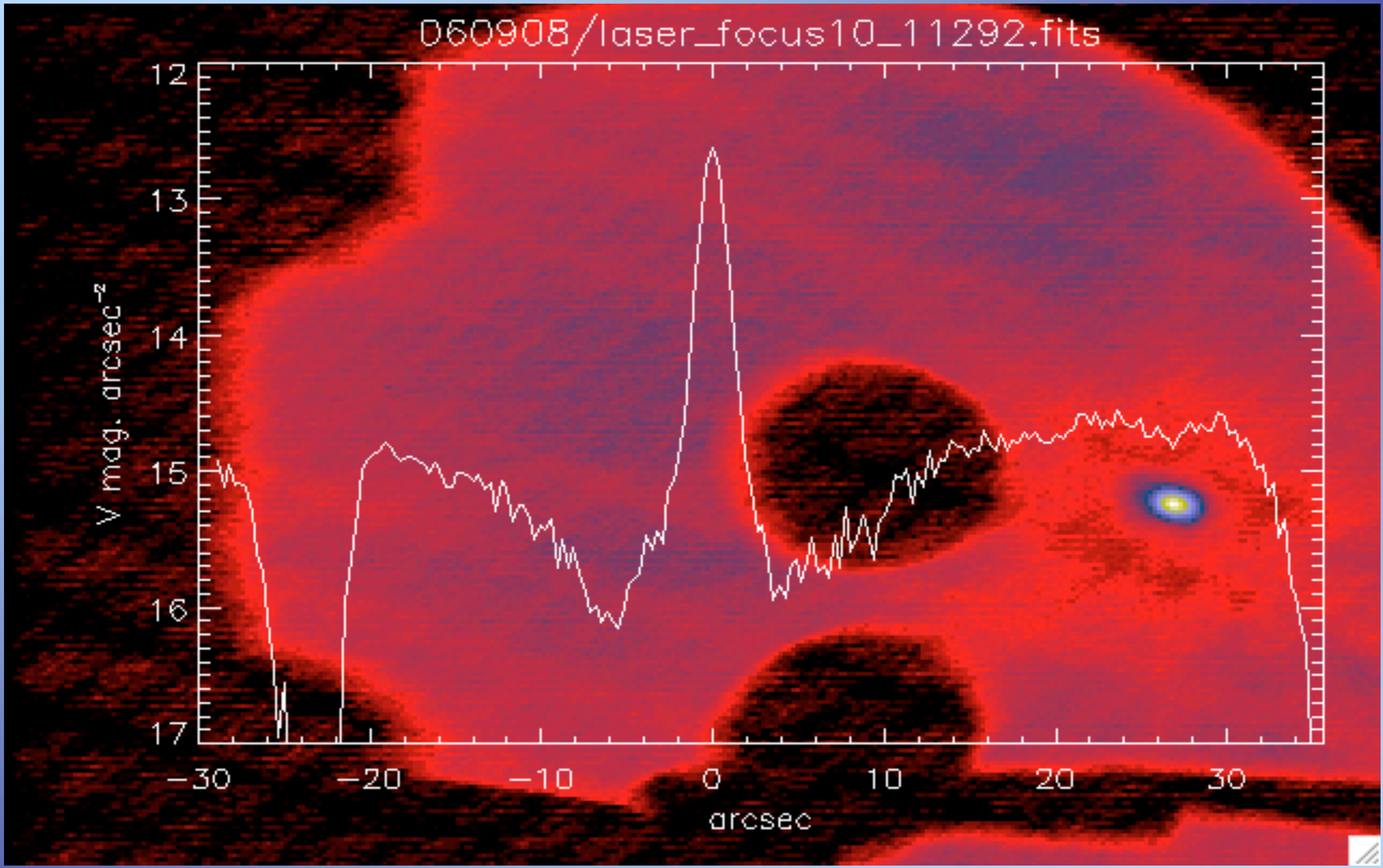
- Previous presentation: http://www.oir.caltech.edu/twiki_oir/pub/Keck/NGAO/061213_Remote_NGAO_Meeting_3/Rayleigh_rejection.ppt

Rayleigh return with obscuration

- Simulated the Keck system with a single beacon using Don's IDL code with a diffractive propagator.
- Was easy to implement.



Palomar return



Bouchez is to provide the same information with a detuned image and results will be anchored for a set up with the Palomar parameters.

Looking through Rayleigh from another telescope's laser

(Hayano et. al., PASP 115, 1419-1428, 2003 Dec.)

- If we are only concerned about the effect of Rayleigh scatter from a laser beam from another telescope on the (visible) WFSs; the pupil plane effect is important:
  - The flux is concentrated in a rectangle of size (d+Lθ)(f'/f)xD(f'/f)
  - The total flux is given by:

$$N_{ph}(\phi)\pi \; \frac{d^2}{2} \; \frac{D}{sin(\phi)} \; \frac{\pi(\theta/2)^2}{4\pi}$$

Where, d - distance to the laser beam from the receiving telescope

θ is the FoV of the WFS

Nph - number of scattered photons towards the receiver (using dipolar scattering model for Rayleigh and Mie scattering models).

Ø - angle between the optical axis of receiver and the laser beam.

D - diameter of the receiver

d - diameter of the laser

At the focal plane a ellipse of major and minor axes given by D/L and (D+d)/L [radians] is formed

Hayano's et. al's conclusion

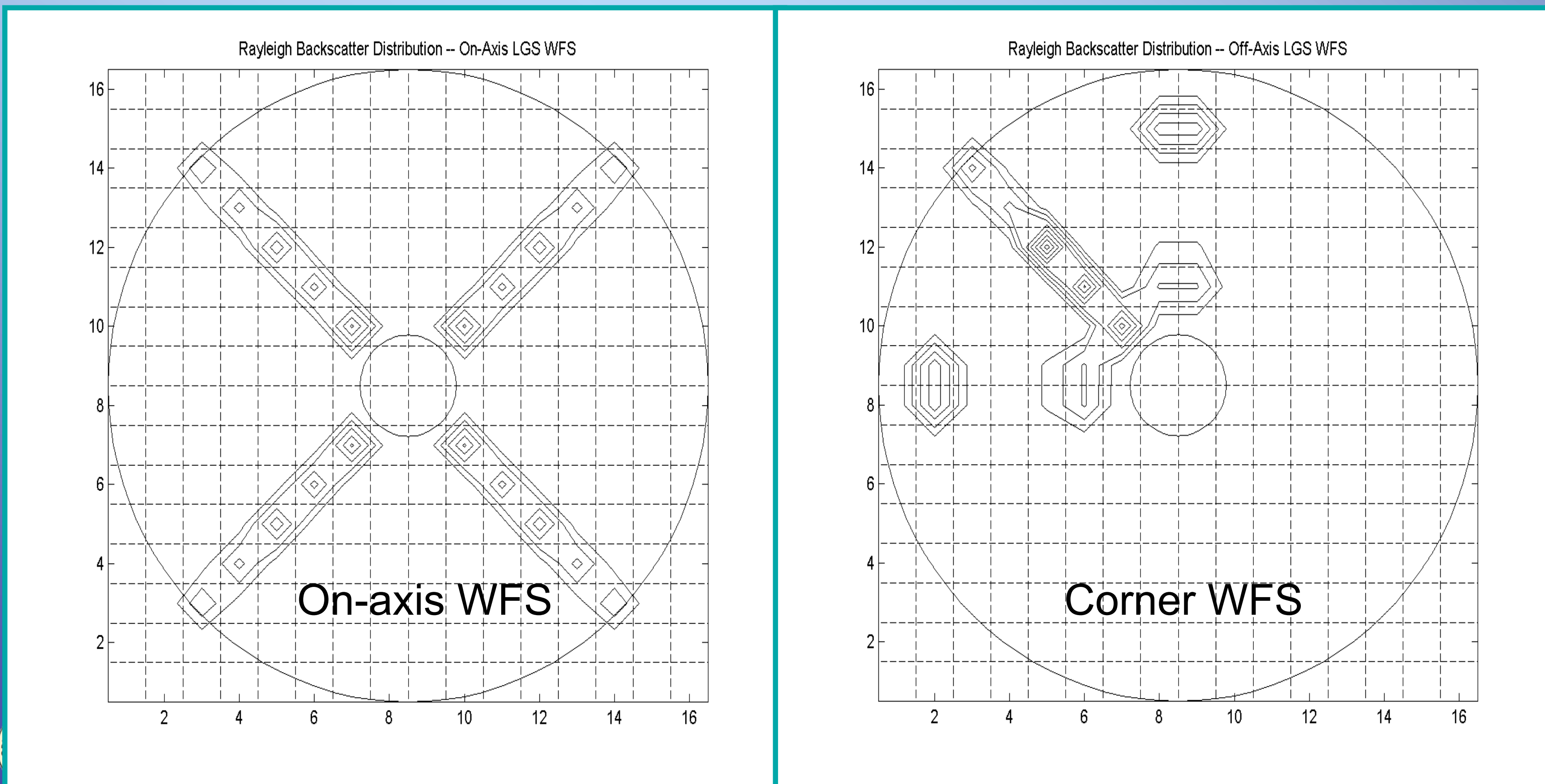
- Sky brightness is comparable to this effect and scales as the D^2 while this effect scales at D.
- The effect is of the order of 19.5 $m_v/(arcsec^2)$ (while sky background is about 20.4 $m_v/(arcsec^2)$.
- Not a concern for most observations.
- The contribution from Mie scatter is less than 1/10th of that from the Rayleigh scatter. This is probably due to low density of aerosols at the observatory location.

Multiple LGS beacons - the fratricide issues

- Results from Brent's and Don's previous simulations are reviewed
- NGAO baseline is a quincunx configuration. Gemini MCAO simulations use the same geometry.
- Gavel's code can show the effect of Rayleigh scatter at each sub-aperture.
- Simulation not yet scaled properly for Keck.
- Effective projection technique - it is better to align the 4 off-axis beacons to the telescope spiders.

Ellerbroek's results

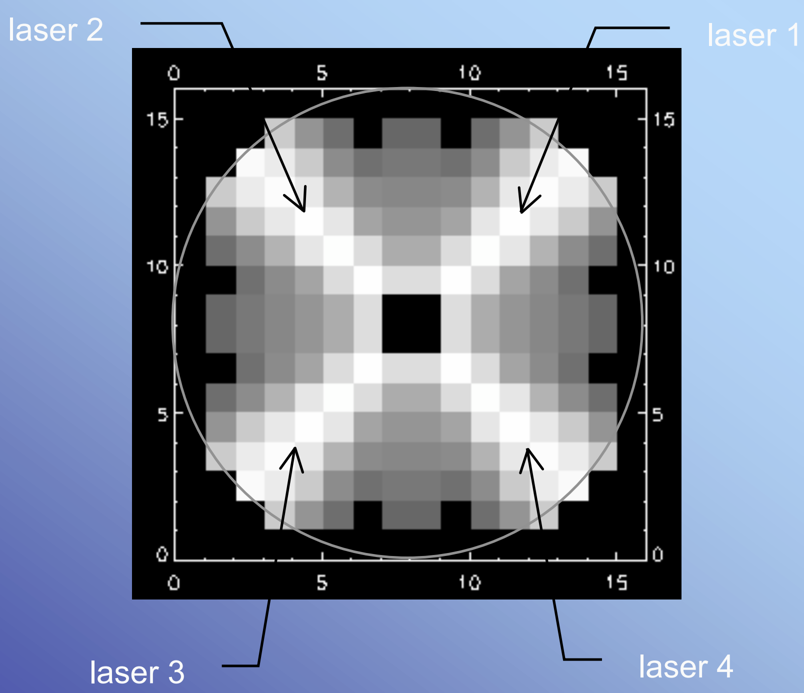
- Different set of sub-apertures are affected in different WFSs.
- There is an SNR reduction from 17 to 9 in the worst affected sub-apertures for the Gemini case.



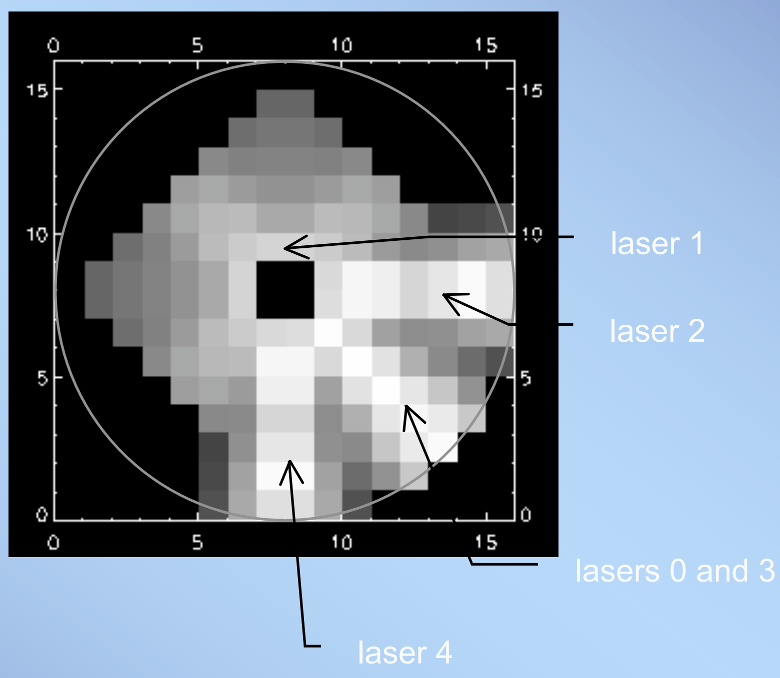
Gavel's simulations

- SNR goes down from 40 to 20 for the Gemini case.
- By visual observation:
  - ~75/180 sub-apertures are affected for the central WFS case.
  - ~75/180 sub-apertures are affected in case of corner WFS as well!

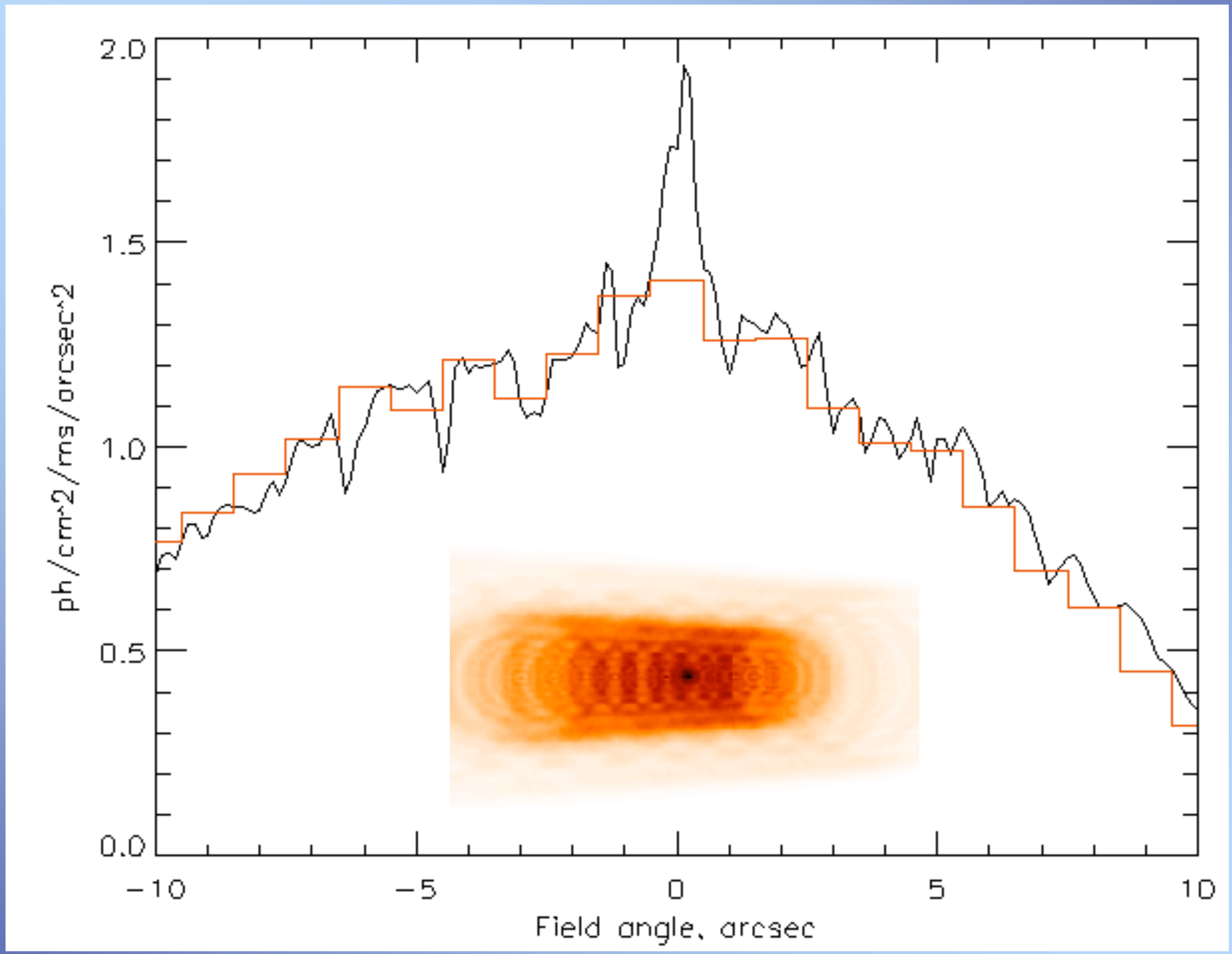
WFS 0 (center LGS)



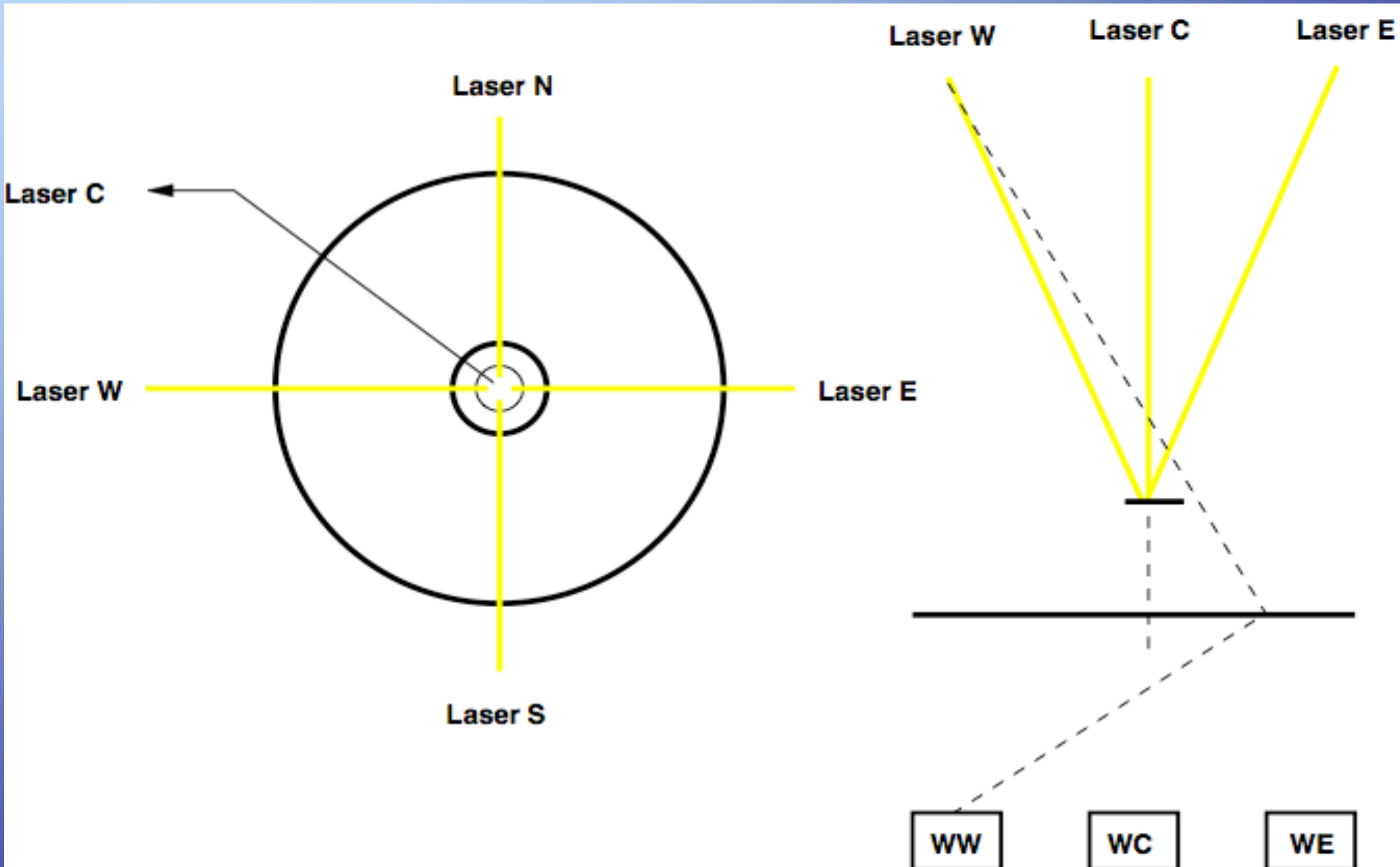
WFS 1 (corner LGS)



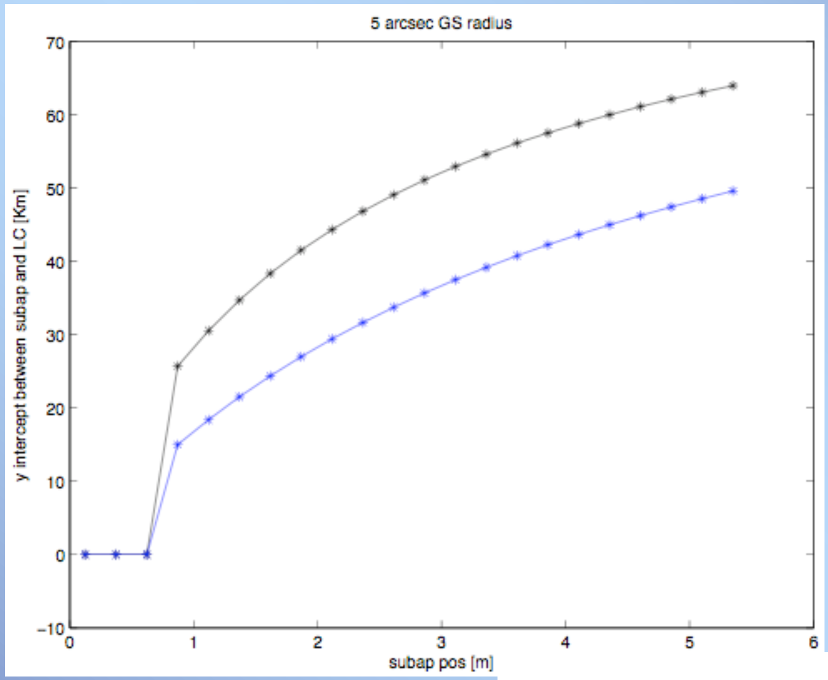
Worst affected sub-aperture (in case of center projection of 5 beacons)

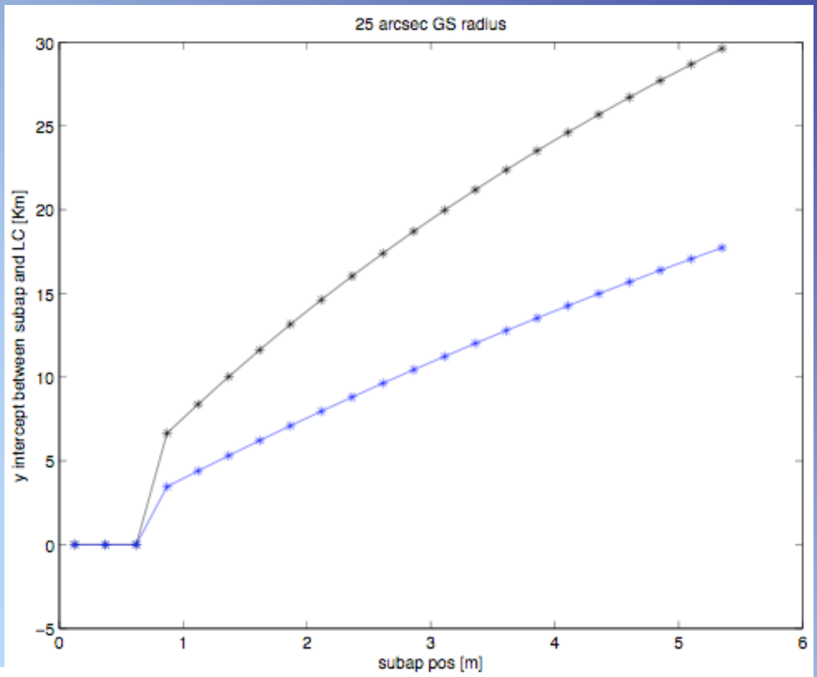


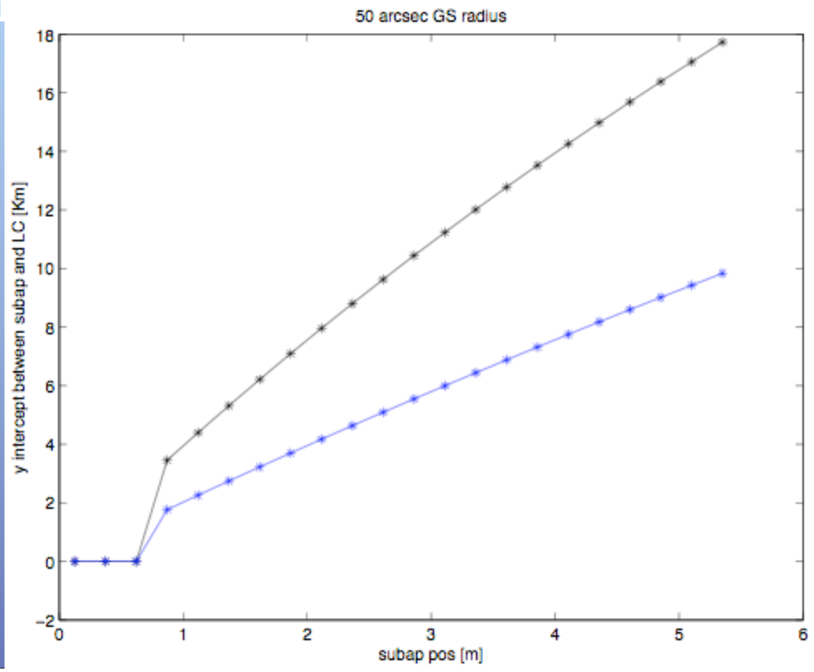
Keck geometry - as set up in simulation



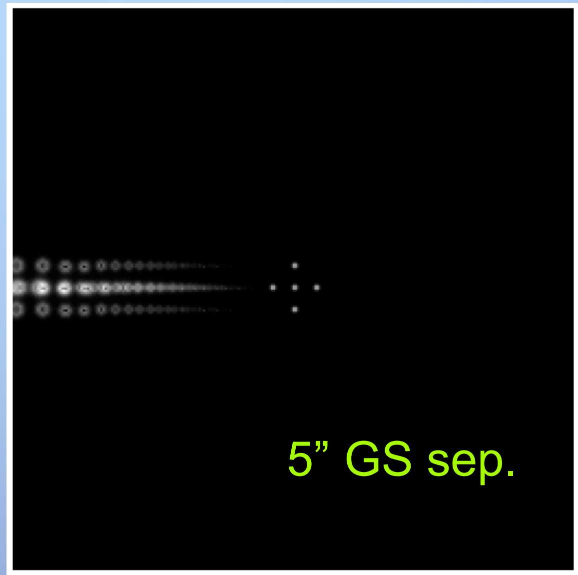
Y intercepts for LC and LE (44 subap case)

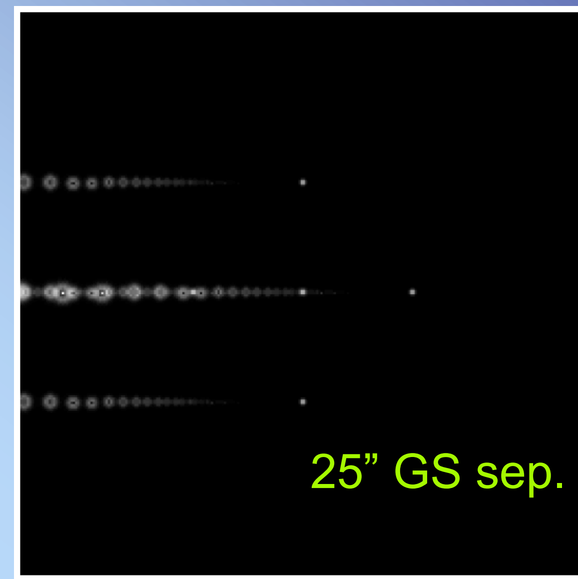


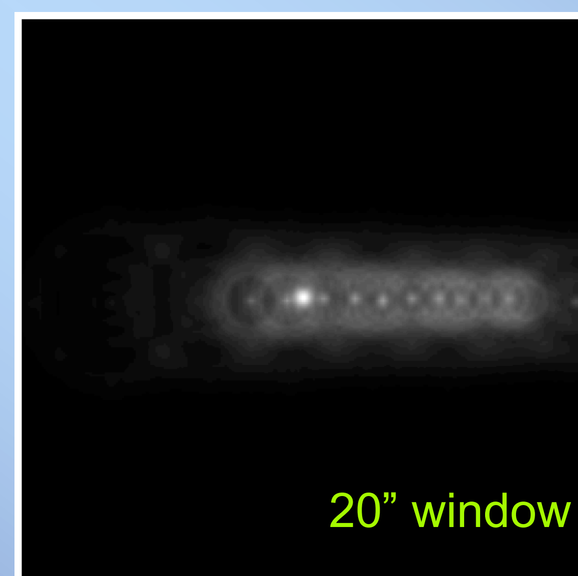




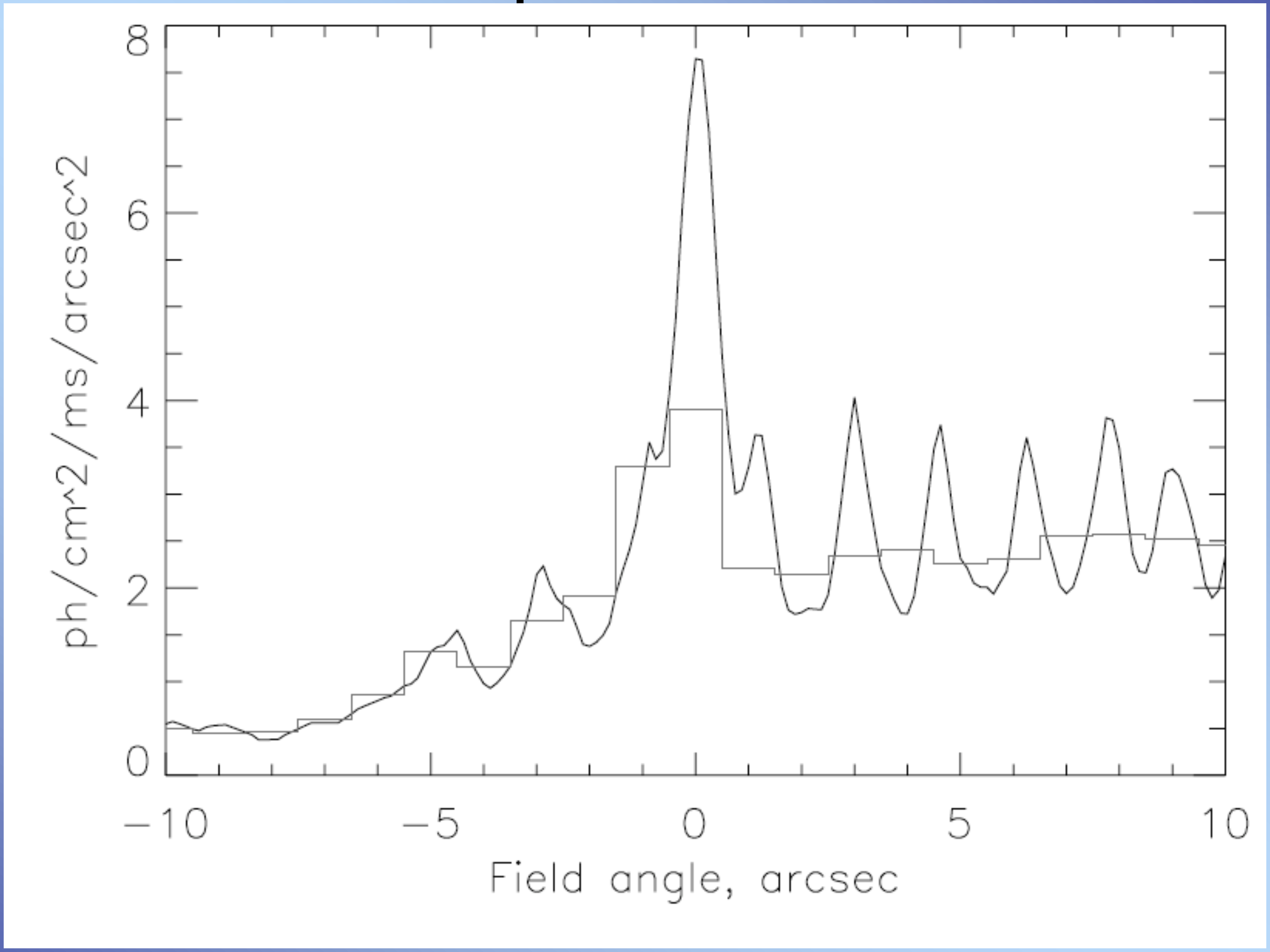
Keck case - preliminary results (probably has some scaling issue)







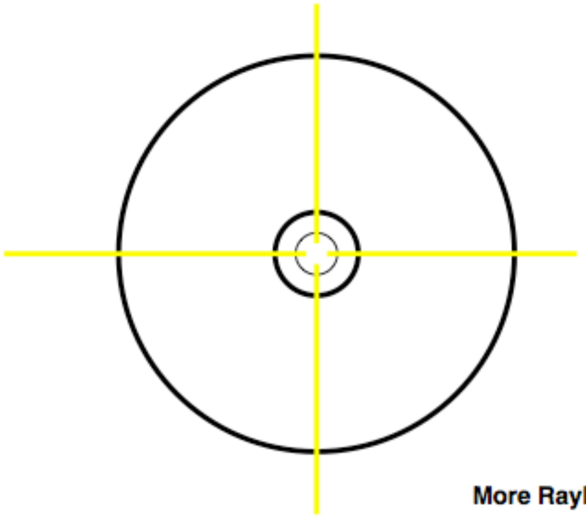
Sub-aperture flux



Rayleigh rejection techniques

- Optimizing projection configuration.
- Background subtraction - Noise model
- Baffles and stops

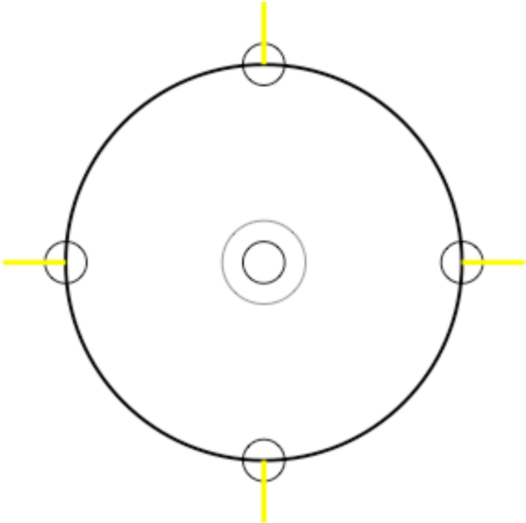
Projector location



More Rayleigh on affected sub–apertures

(2 RS for each corner WFS and 4 RS for central one!)

least spot elongation (CW lasers)



Expensive BTO, 4 LLTs

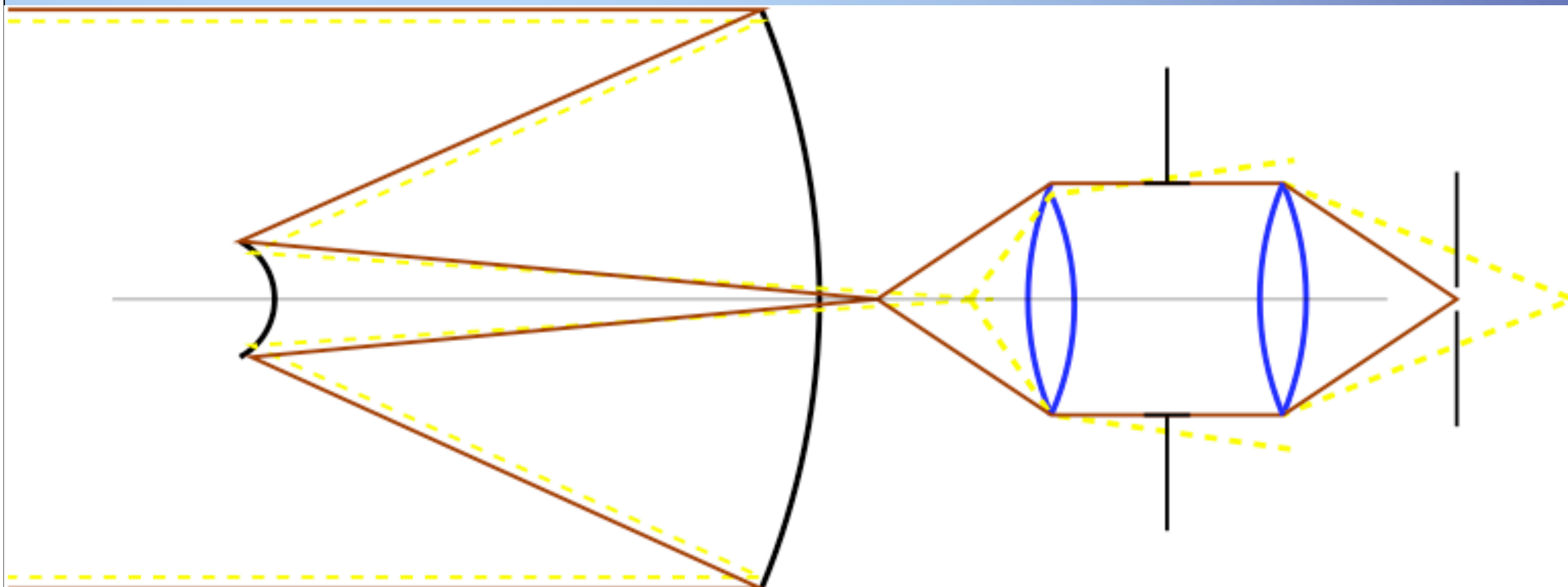
Spot elongation issue (not a problem for short–pulse laser)

Lesser Rayleigh scatter

Background subtraction

- An accurate model of the Rayleigh scatter will yield a SNR reduction due to Rayleigh scatter at each sub-aperture.
- All WFS are affected by all lasers but the distribution of Rayleigh scatter is different in different sub-apertures and the flux distribution is different in the central and the corner WFSs.
- We know from Hayano's measurements that 10% of the background comes from scatter due to aerosols. This has to be added as an allocation to the error budget to the Rayleigh scatter.
- Appropriate white noise component due to Rayleigh+ Mie scatter should also be added to the error budget. The % of affected sub-apertures is TBD after looking at simulation results, but is of the order of 40% in each WFS.
- A detailed simulation of the Rayleigh background will show the effect on various sub-apertures for each wavefront sensor. Based on this (and spider obscuration) a optimal reconstructor can be created.
- The worst case SNR loss is ~factor of 2 based on the Gemini MCAO work done by Gavel and Ellerbroek.

Baffling, field stops



Pupil stop and baffles around the optics of the AO system to prevent stray light problems

Adjustable field stop (to prevent Rayleigh, sky and cross–talk)

TS status

- Accurate model of a single beacon system has been established. But still have to anchor results to real #s (Bouchez's plot for a detuned image)
- The model for multiple beacons almost works, sans some scaling issues
- Detailed simulation will tell the effect on each sub-aperture for each WFS for each GS configuration. Model is set up to do this once the scaling effect is sorted out.
- Worked out a generic geometry of LGS beacons for Keck and how they intersect the chief ray from each LGS to sub-aperture.
- Have looked at work done by Gavel, Ellerbroek and Hayano and documented the results.
- Have looked at alternate projection location and baffling issue.