Standardization of the Beam Quality Metric

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Introduction

- This discussion concerns a beam quality metric for high-power lasers relevant to DoD Directed Energy Weapon applications
- DoD has multiple ongoing HEL development programs. To facilitate comparisons, Congress has requested that a standardized beam-quality metric be developed
- A suitable BQ definition for DoD HEL's can be different from those applicable to low-power lasers
  - e.g. DoD uses Power in Bucket (PIB) metric, others often use M^2
- One goal of the methodology presented here is for measurements that
  - Are "easily" performed
  - Can be reproduced by different teams with separate equipment

Outline

- The request from Congress
- Overview of the BQ standard
- Some details of interest
- Summary

2014 Budget - House Mark-Up

Standardization of directed energy weapon systems characterization

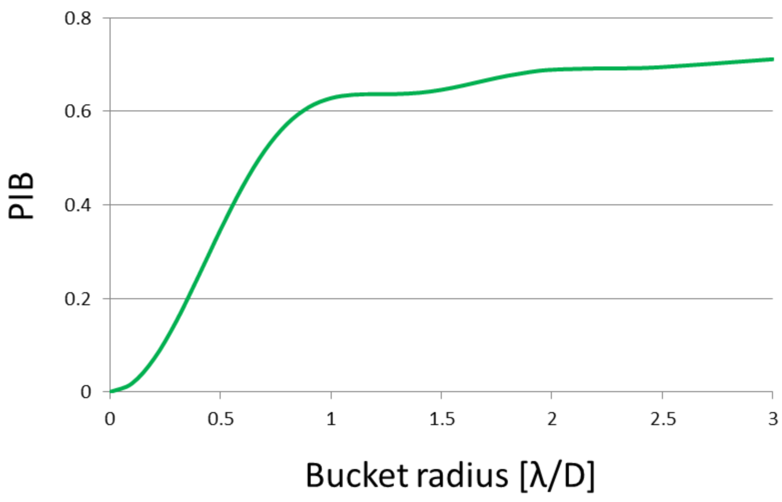
The committee is aware of several research, development, test, and evaluation (RDT&E) programs which pursue the development and eventual deployment of directed energy weapon systems. The committee understands the importance of the services and defense agencies' ability to leverage RDT&E investments whenever possible to maximize the mutual benefit of these investments. Therefore, the committee encourages the services and defense agencies to continue to work synergistically in the development of these systems whenever possible. However, the committee is concerned about the inconsistency of definition of system performance among the different programs which make comparison of technologies and identification of leveraging opportunities between programs difficult. System descriptors such as "beam quality" for laser systems have multiple definitions within the directed energy community at large, and are not directly comparable between different systems. Some descriptors may only be applicable to a limited subset of missions and therefore inhibit the extrapolation of system performance to other missions. The ability to perform such comparisons is vital in the assessment of the different laser technologies applicability for missions of national interest.

Therefore, the committee directs the Secretary of Defense to develop a common set of parameters to describe directed energy weapon system performance with standardized definitions to be employed on all Department of Defense directed energy programs.

Context and Scope of the Spec

- New "specification" is essentially a set of tightly-crafted guidelines for measuring a "standardized" PIB curve without ambiguity and with relatively simple hardware

- It puts slabs, fibers, DPAL, etc on equal footing
- It de-emphasizes use of reference beams
- It de-emphasizes use of single-parameter BQ values
- It is a tool for Program Managers



This Spec Has Little in Common with ISO-11140 (M-squared)

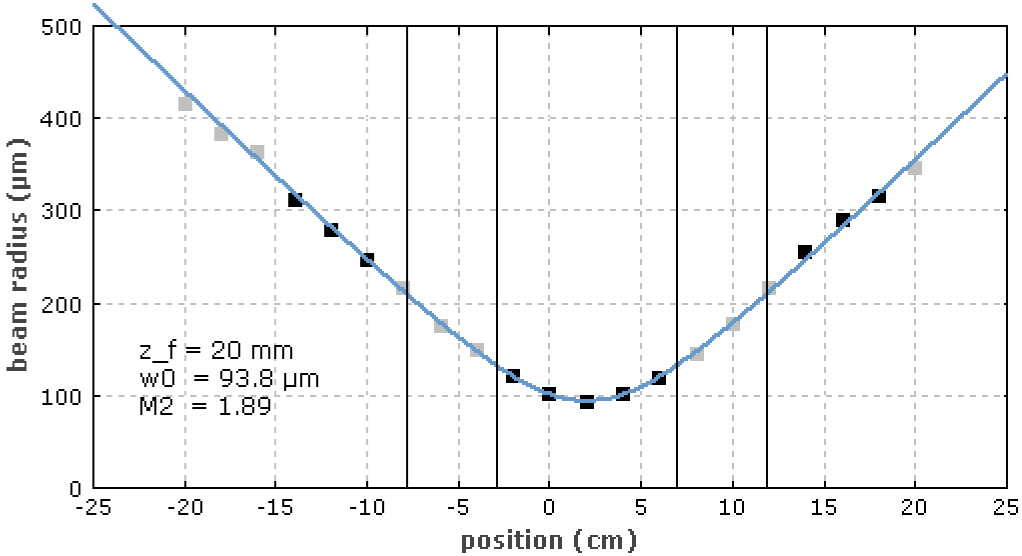
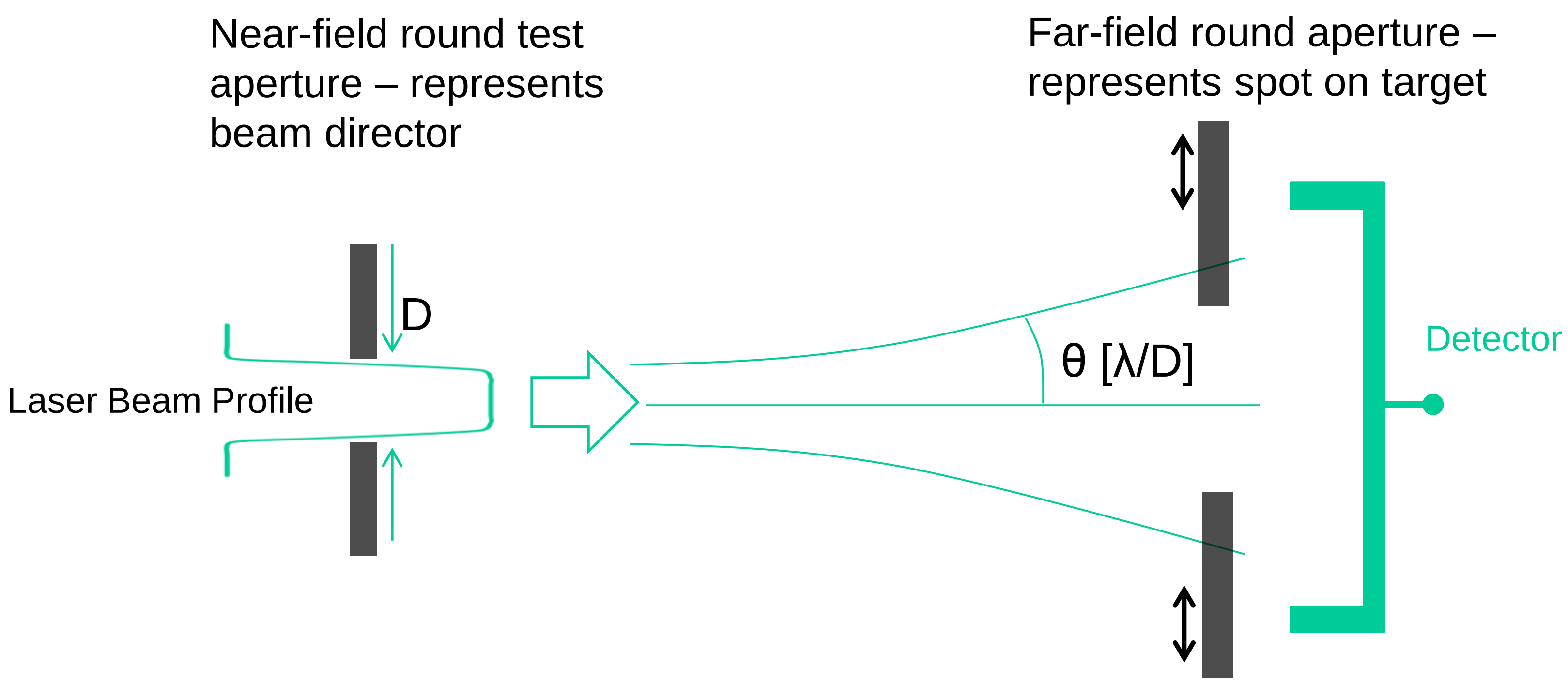


Figure from rp-photonics.com

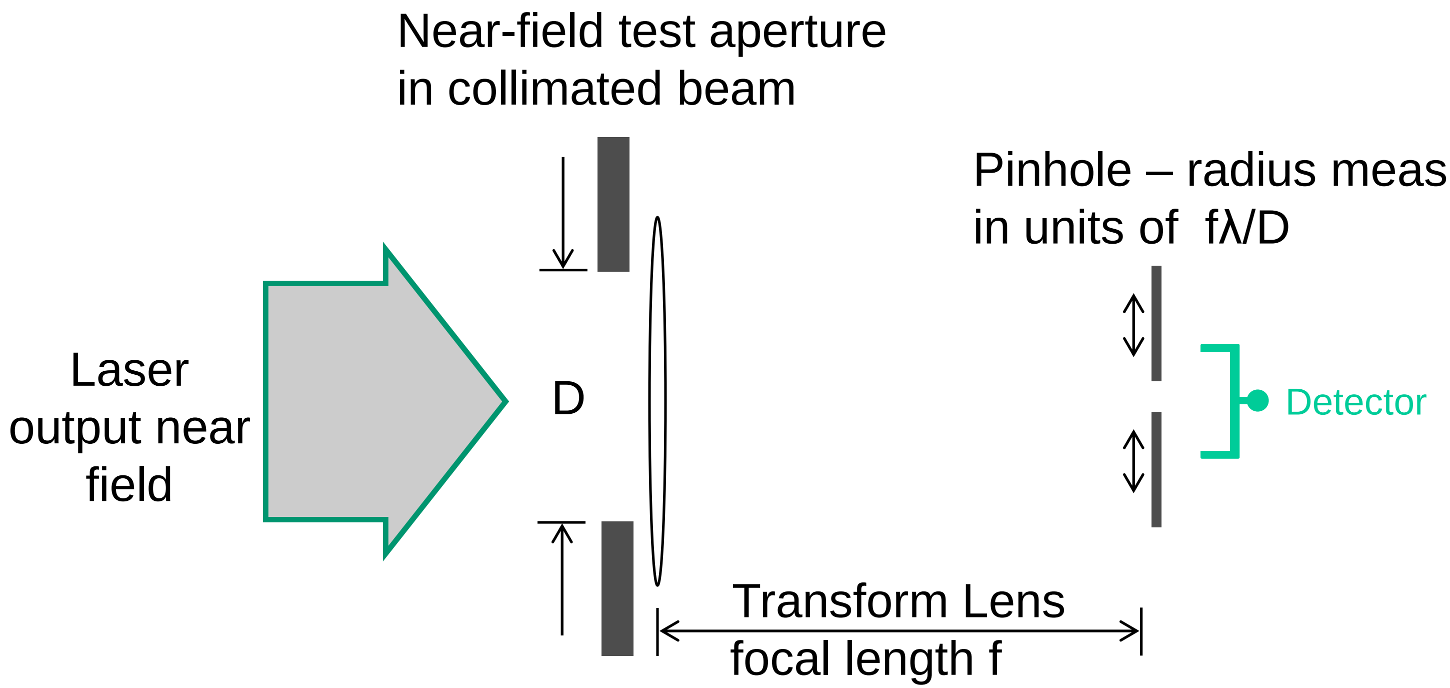
- The ISO-11140 method, often used with the “beam caustic”, is not well suited to DoD applications
- ISO-11140 is based on use of 2nd moment integrals to get the beam-waist size and divergence angle
  - Is a non-interceptive “whole beam” technique
- The DOD specification is Power in Bucket (PIB) based
  - Is interceptive – not a “whole beam” technique

Spec is Based on an Unambiguous PIB "Two Hard Aperture" Geometry



- Historically, PIB has been measured without a standard definition for scale size "D"
- New scheme connects "D" to the telescope

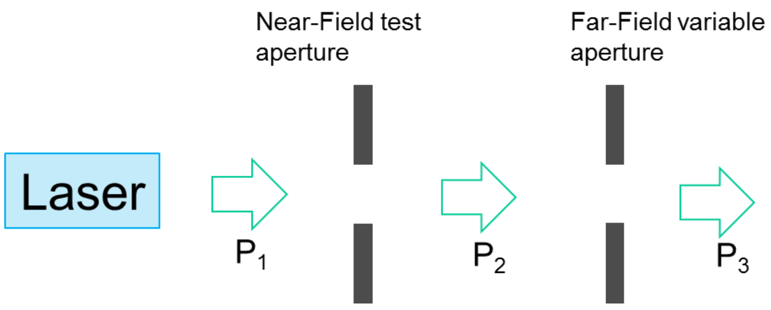
Laboratory Implementation

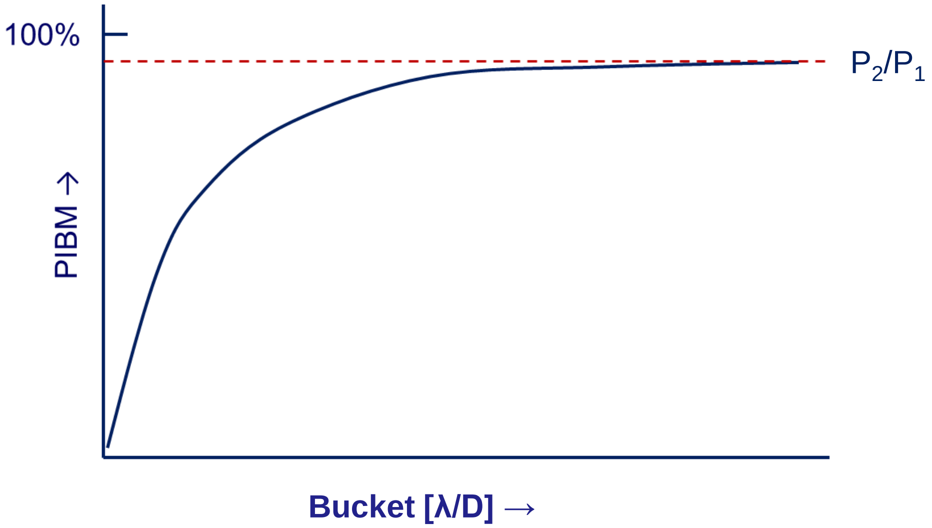


The Metric has Two "Reportables"

Reported data are:

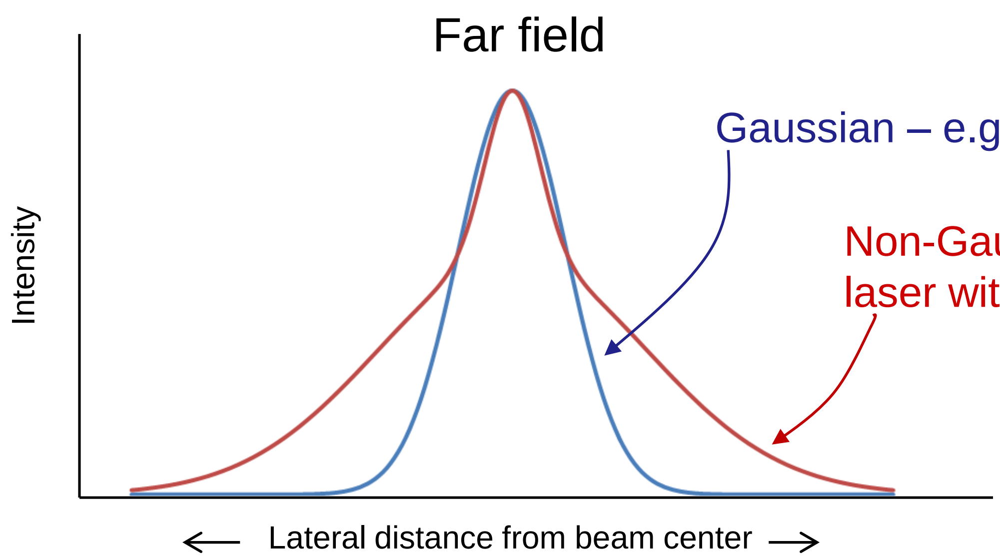
- Power P_1 (measured at the laser output)
- A "PIBM" curve (i.e. P_3/P_1)
  - "M" designates that this curve asymptotes to P_2/P_1





Systems Engineer decides how much power to cut in near-field

Why Emphasize The Whole PIBM Curve Instead of One Number?

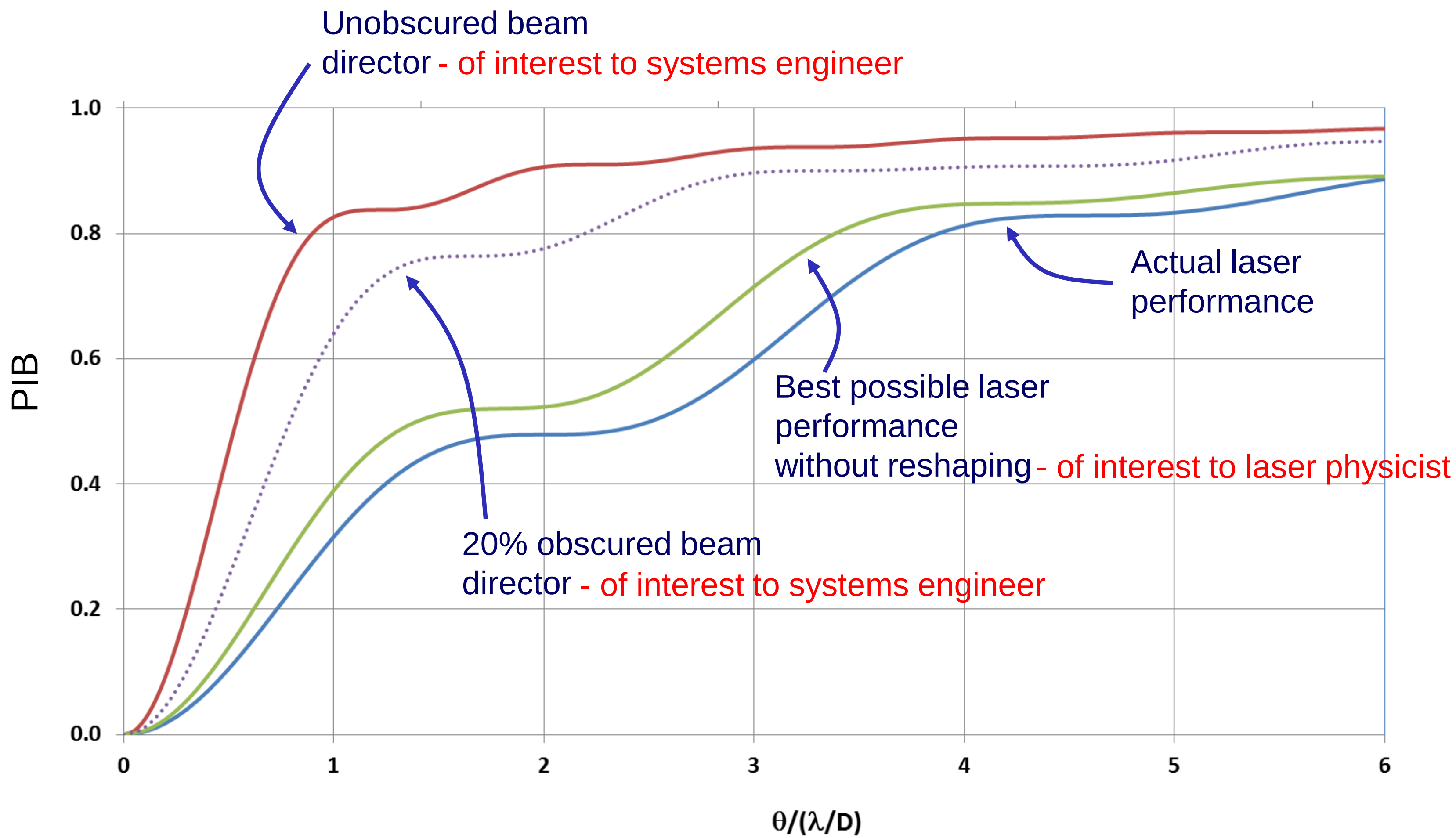


- HEL's have at least two distinctive far-field distribution functions
  - Gaussian – for fiber lasers
  - Hot-core on broad pedestal – for slab lasers with adaptive optics
- A single number (e.g. M^2 for width) cannot capture this distinction

Problems With Single-Value BQ’s

- Just a “beam width” (BQ-horizontal) is not enough: Has limited comparative value if laser intensity distribution is variable
- Just “central-core power” (BQ-vertical) is not enough: If BQ-v is low, this metric doesn’t show where the power is
- “Single-parameter” BQs rely on reference beams, which are their own source of confusion

Too Many Choices For A Reference Beam

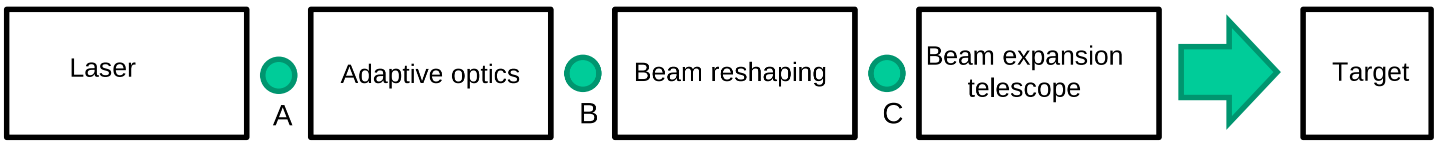


Mismatches of Lasers and Telescopes Are Compared “Apples to Apples”

- The BQ spec anticipates the situation of mismatches between the laser’s spatial format and the beam director’s format
  - e.g. unobscured beams driving Cassegrain telescopes
  - e.g. unstable resonators with magnification mismatch to the Cassegrain
  - e.g. unstable resonators driving unobscured beam directors
- Mismatches can be corrected by beam “re-shaping” downstream of the laser (e.g. AXICON)
- Issue is how to make meaningful comparisons in the presence of mismatches

Accounting for Beam Reshaping

- The approach to providing a proper comparison is that the correct BQ measurement is the one made when the beam is in its final format

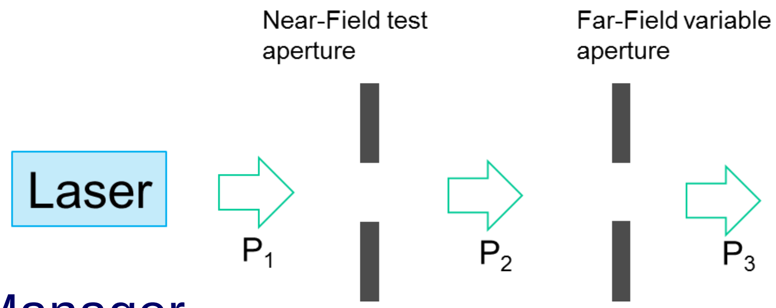


- If the beam will be reshaped, the correct BQ measurement is made at position C

- If PIBM is available at A or B but not C, numerical propagation to C is discouraged
  - The correct procedure is to measure at position C after reshaping optics are installed

Two More Details

- The BQ spec, i.e. P_3/P_1 , optimizes with near-field clipping for fiber lasers. The optimum clip for the metric may not be optimum for the laser weapon system. The Program Manager may direct that P_3/P_1 is reported under the condition of some maximum allowed clip (e.g. 0.5%)



- The spec provides for careful validation of camera PIB measurements with pinhole measurements. The pinhole is the gold standard; the camera is the laboratory workhorse
  - Without care, camera can produce improper PIB curve, especially if large FOV is needed to capture whole beam
  - After validation of camera to pinhole, the camera is used to freeze out jitter and provide PIB & PIBM curves

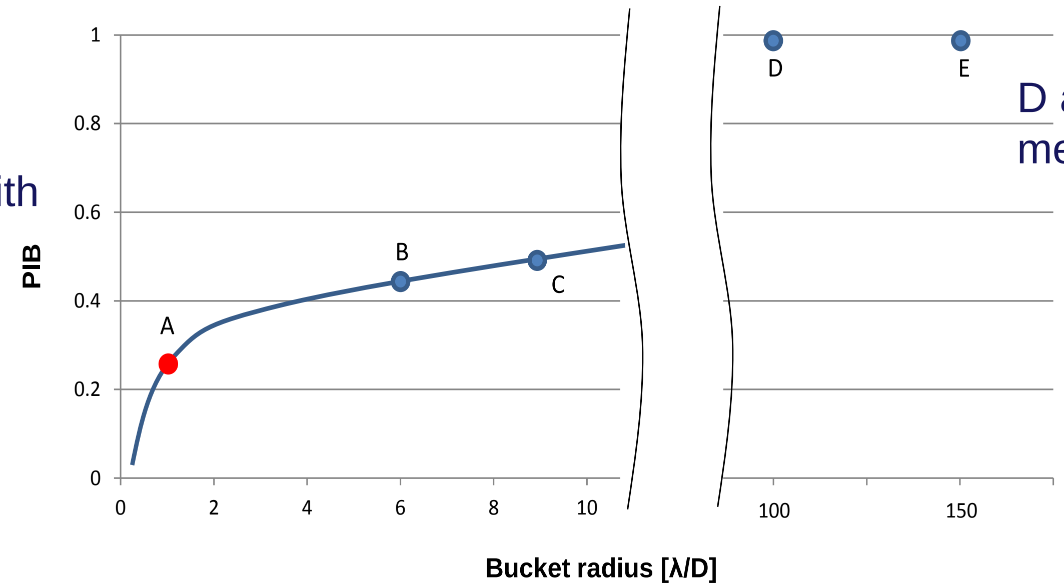
Validation of Camera With Pinholes

Basic idea is that pinhole data at B and D normalize the camera curve at 6 λ/D (as example). Point A is then read from the camera curve. Camera is used to solve alignment and jitter problems

Pinhole E shows that pinhole D did capture all the energy

Pinhole C provides an alternate calibration point for camera curve. If pinhole alignment is good, camera-derived value at Point A holds constant

Blue curve is from camera, initially with unknown normalization



D and E are pinhole measurements

Summary

- A BQ specification has been developed with community input at Congressional request
- Is tailored to DEW geometries through use of a near-field aperture as a stand-in for the beam director
- The “spec” is actually a series of guidelines for measuring PIB curves in a consistent manner
- The particular PIB normalization chosen is labeled as “PIBM”
- Consideration is given to combinations of obscured and unobscured beams, and Cassegrain and off-axis telescopes
- This is a tool for Program Managers