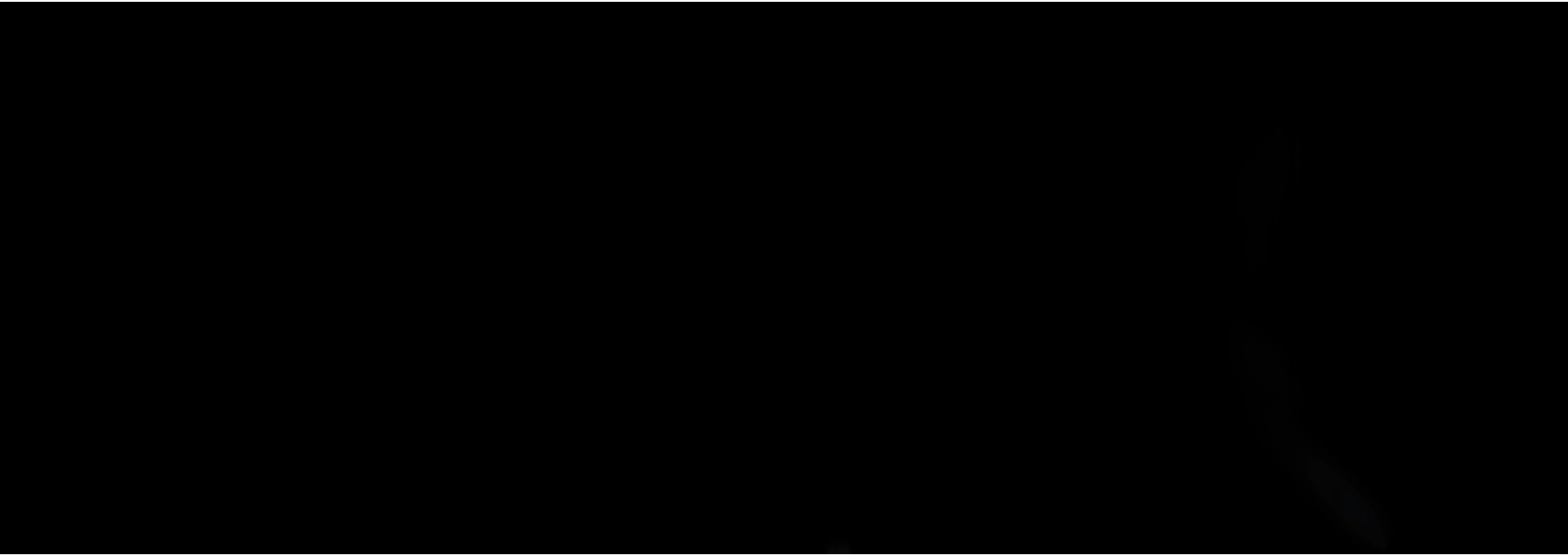
Fast Optimization of Multi-Element Optic, Electro-Optic and Photonic Assemblies in Manufacturing



The Emergence of Intelligent Positioning in High-Throughput Photonics Manufacturing

About PI

PI Karlsruhe

PI Ceramic

PI Auburn, MA

PI Shanghai

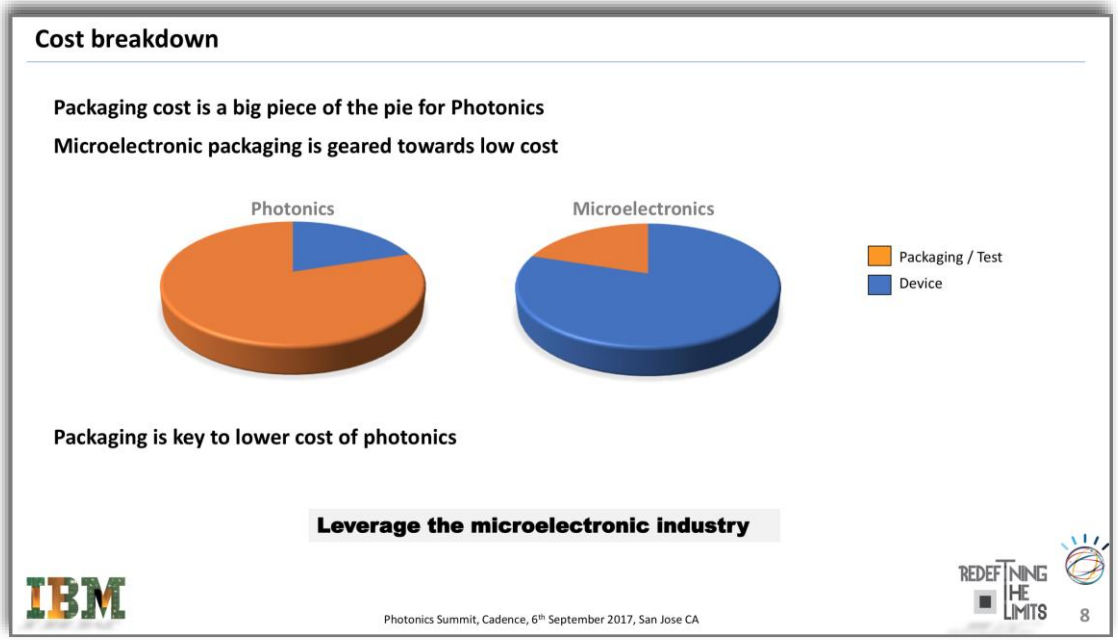
- **Specialized in Nano & Micro-Positioning**
- Karlsruhe, Germany HQ
- ~1500 Employees, ~€200M Global Sales
- Founded 1970
- **>100 man years of alignment expertise**
  - Global Photonics team
  - German precision
- **Whole Range of Control Electronics**
  - Digital, Analog, High Altitude, …
- **Global Manufacturing & Design Capability**
  - R&D/Production & Metrology Labs on 3 Continents
- **Privately Owned – Not Driven by Quarterly Results**
  - Key Decision Makers are Scientists & Engineers
  - Seek Long Term Relationships with Customers and Suppliers

PI's spectrum spans the world of ultra-precision

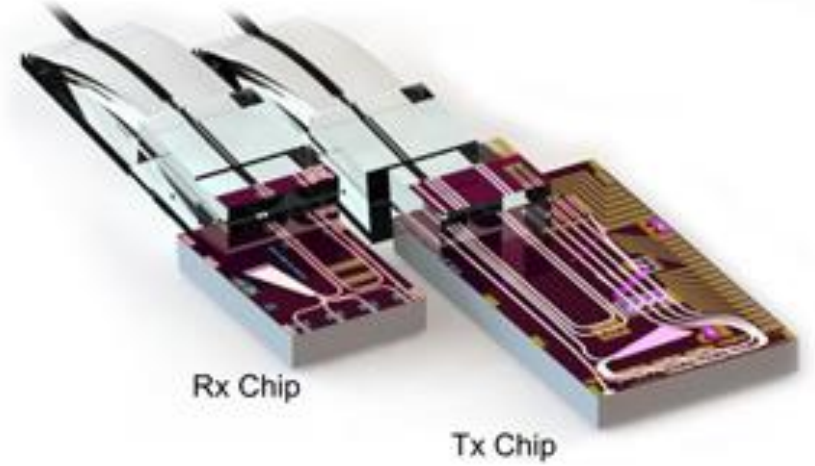
ACS MOTION CONTROL

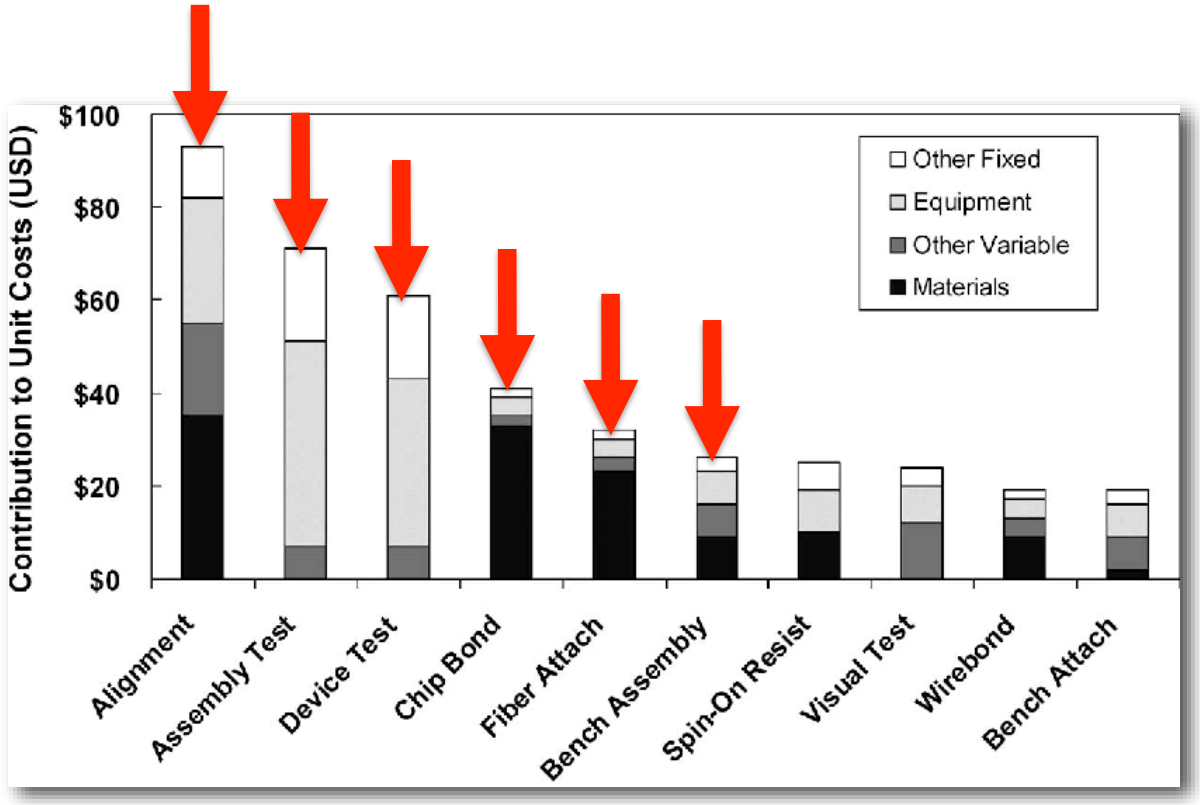
PI's Engineered Systems Group Builds World-Class Automation Platforms

Alignment: The Repetitive Cost



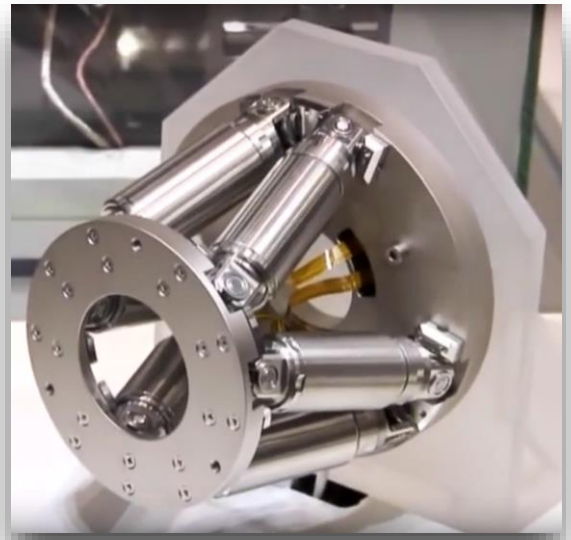
"Automated High-Throughput Assembly for Photonic Packaging", Barwicz et al, *Photonics Summit*, Cadence, 2017, https://www.cadence.com/content/dam/cadence-www/global/en_US/documents/company/Events/summits/photonics/fortier-2017.pdf



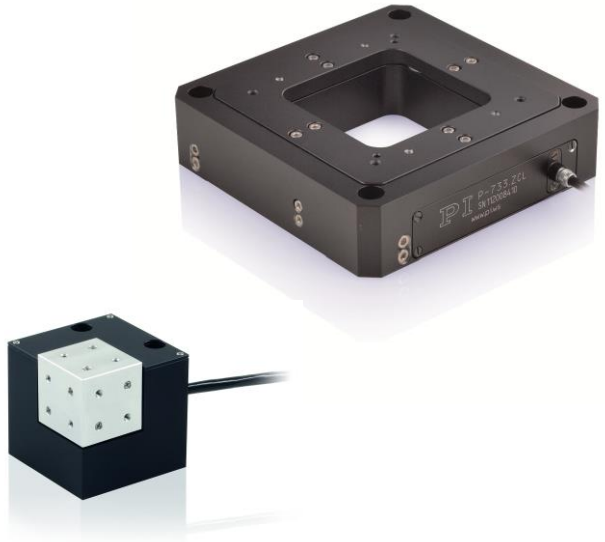


"Process-based cost modeling of photonics manufacture…", E. Fuchs et al, J. Lightwave Tech., 2006, https://www.semanticscholar.org/paper/Process-based-cost-modeling-of-photonics-the-cost-a-Fuchs-Bruce/125e24b2e2e71860f088526441ee5ce16e6ce42c

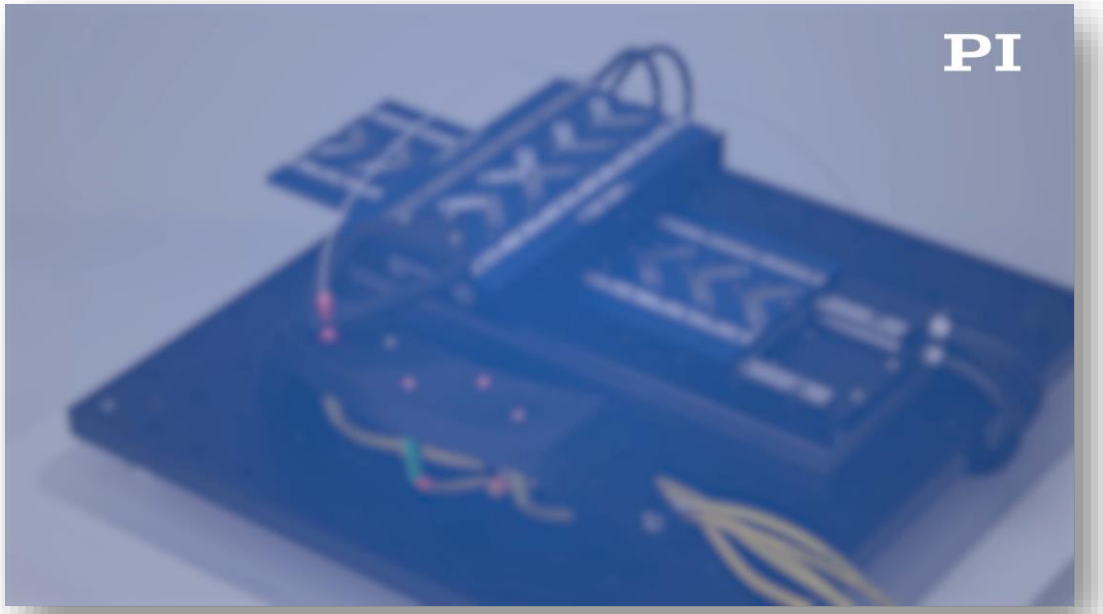
A modular approach to meet all needs



Hexapods

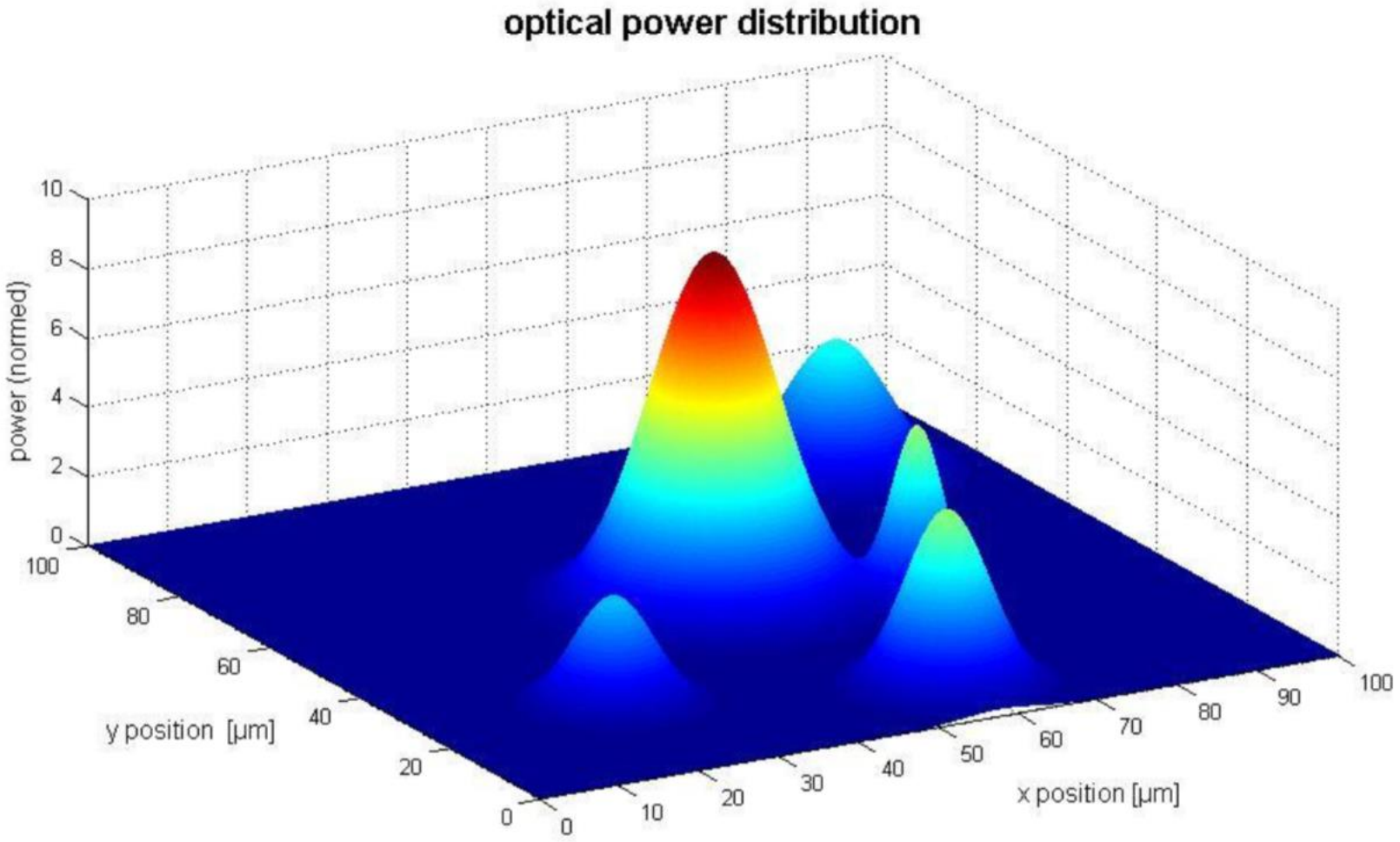


Nanopositioners



Stage stacks:

- Motor-driven
- Linear motor
- Voice coil…

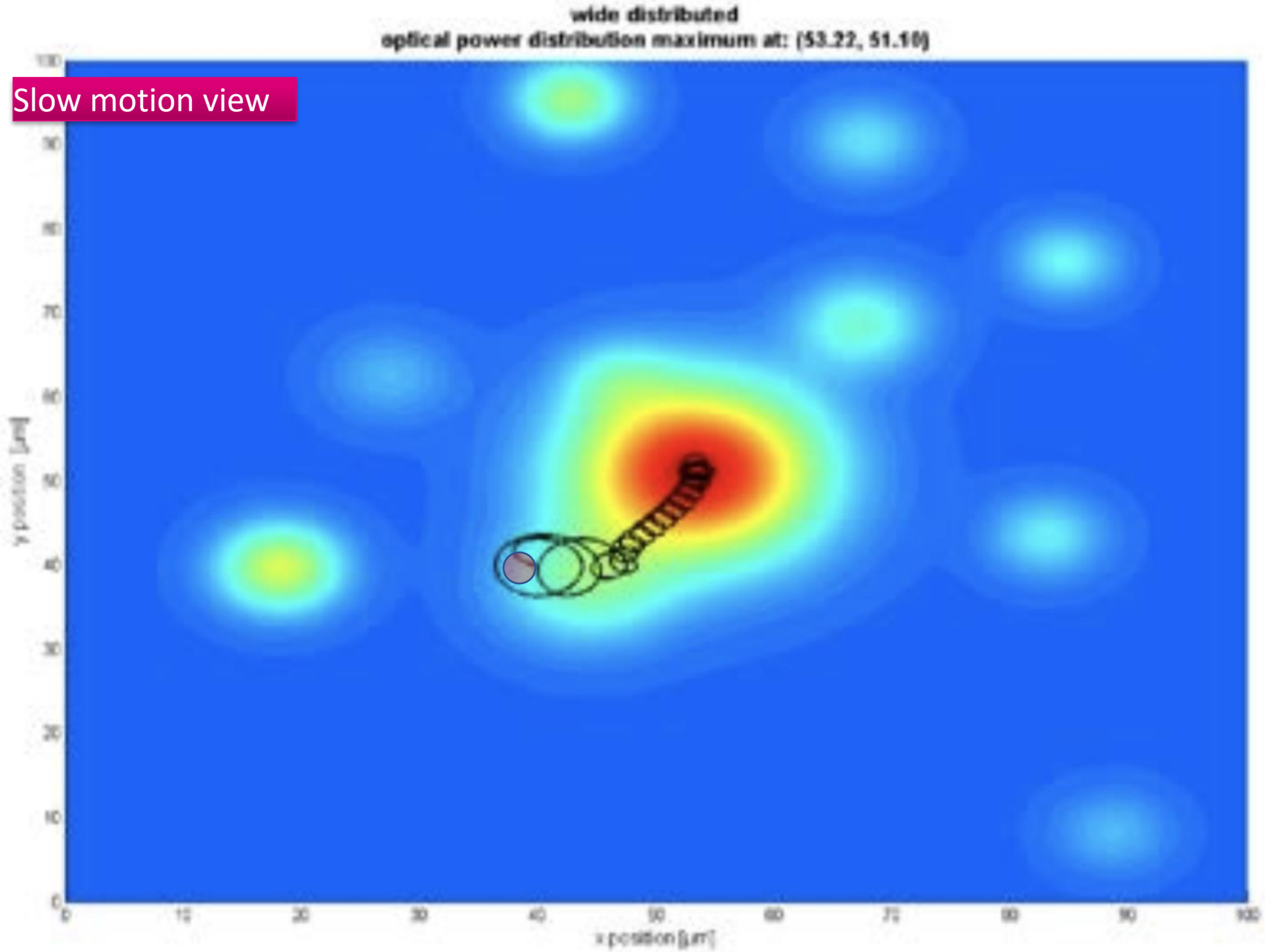


PI's Optimization Technology

Challenges we addressed:

- Select global optimum
- Tracking
- Multiple channels, elements, DOFs which interact
- Many possible figures of merit
- Avoid implicit assumptions
  - Symmetry
  - Circularity
  - "Gaussian-ness"
  - …

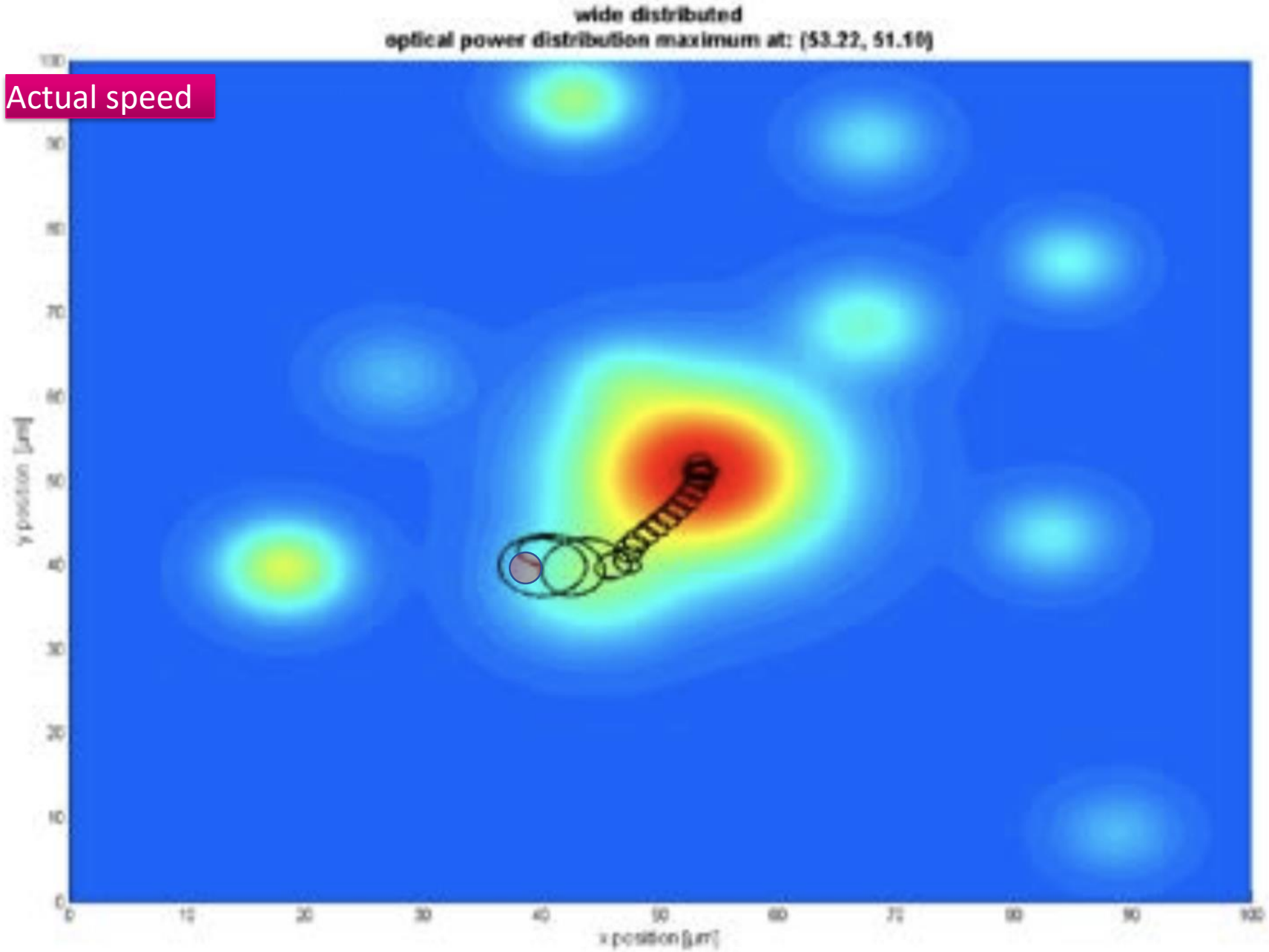
Suitable for Edge-coupling or diffractive-couplers



PI's Novel Parallel Gradient Search

- Super fast optimization
- Tracking
- Compensation of drift
- Parallel implementations for multi-I/O, multi-element, multi-DOF single-step alignments

EXAMPLE:
Fast, efficient
fine optimization
…with tracking if desired



PI's Novel Parallel Gradient Search

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EXAMPLE:
Fast, efficient
fine optimization
…with tracking if desired

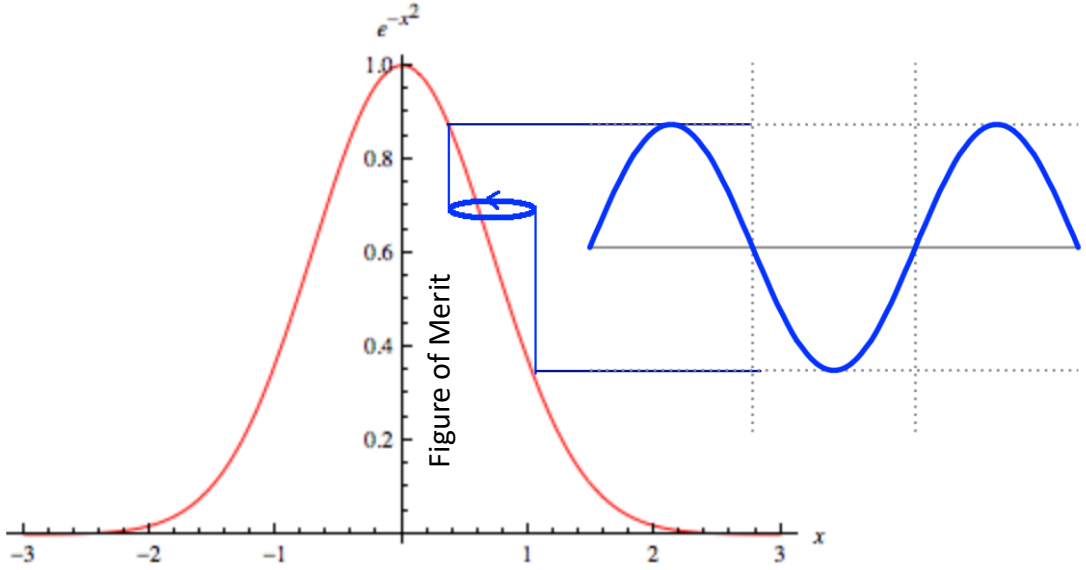
How it works

- θ_{dither} is the instantaneous phase of the physical dither
- $\theta_{dither}(t) = F_{dither} \cdot t$
- Error signal $\varepsilon(\theta)$ is ~sinusoidal
- Input and output alignment dithers are additive at the power meter, as are channel combinations
  - We cracked the math for separating these, enabling parallel, multichannel alignments

PI's groundbreaking FMPA algorithm allows simultaneous alignment of all inputs and outputs and all DOFs.

This is something new.

And essential.



$\varepsilon(\theta)$

An *Aha!*

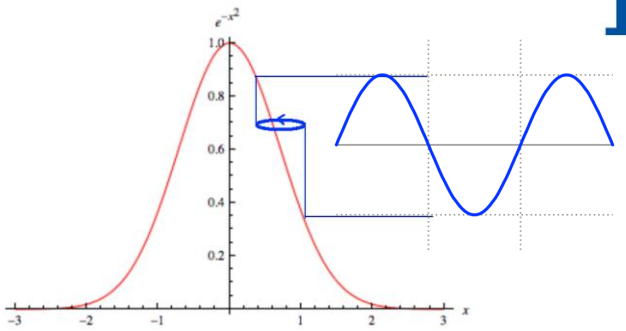
…About that metrology…

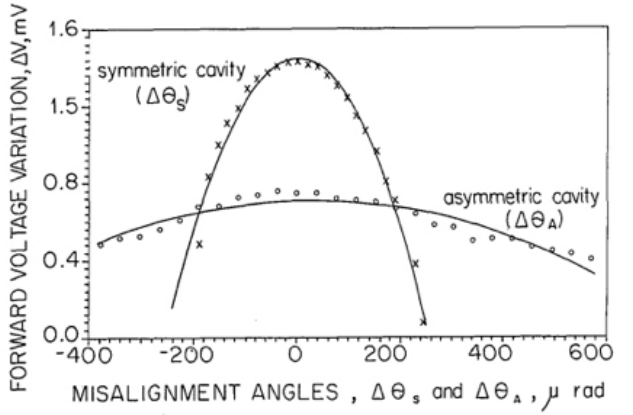
- Most photonic applications want to optimize optical throughput
  - There are exceptions

- More broadly, many positioning applications involve hill-shaped *figures of merit* or *quality criteria* as functions of position!
  - Manufacturing a laser
    - *Power, modal purity, linewidth*, etc.
  - Building a camera
    - "Image quality" …*MTF, 2DFFT*, etc.

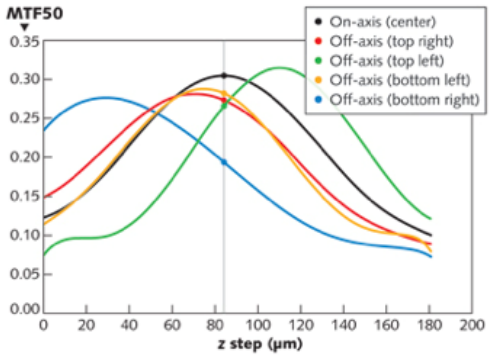
This technology is metrology-agnostic.

This technology maps to broad manufacturing challenges!





"Asymmetric alignment-stabilized external-cavity semiconductor laser", L.Codá, J. von der Weid, E. Conforti, Optics Letters Vol. 17, Issue 23, pp. 1682-1684 (1992), https://doi.org/10.1364/OL.17.001682



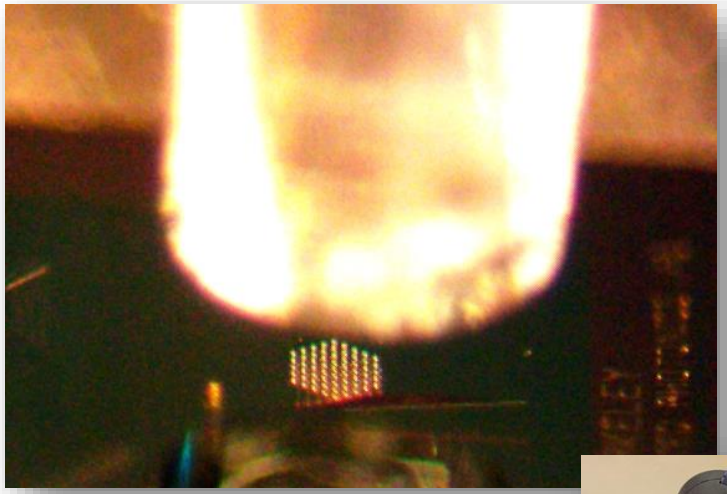
"Adaptive software eases camera lens-to-sensor alignment", J. Roe, A Israelski, Laser focus World, 3/2013

Parallelism: Key to Process Economics

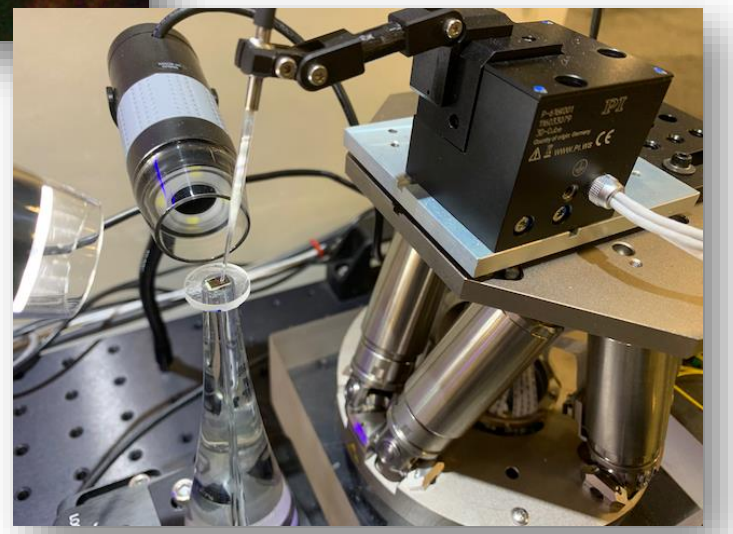
Parallelism is the enemy of time-consuming loops

Loops formerly required because Optimization 1 would mess up Optimization 2, and so on

- **Array devices dominate PICs**
- Multiple input/outputs… lots of them
- Bleeding-edge example: Chiral Photonics PROFA
  - To >90 channels, to 10 micron pitch



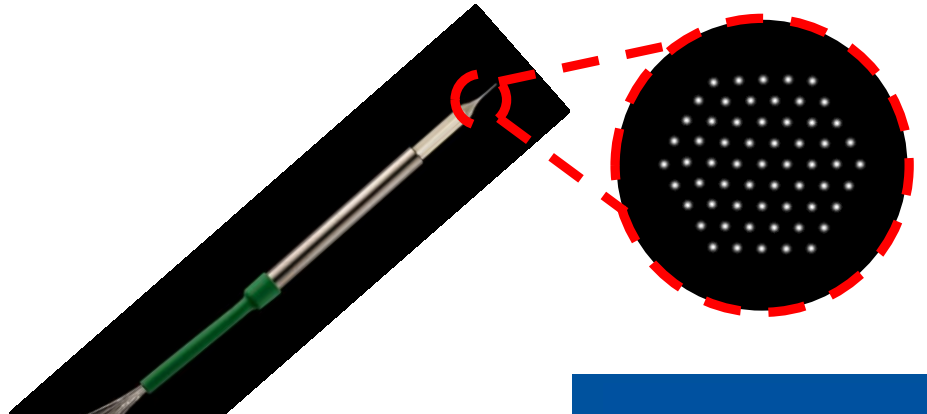
Chiral Photonics



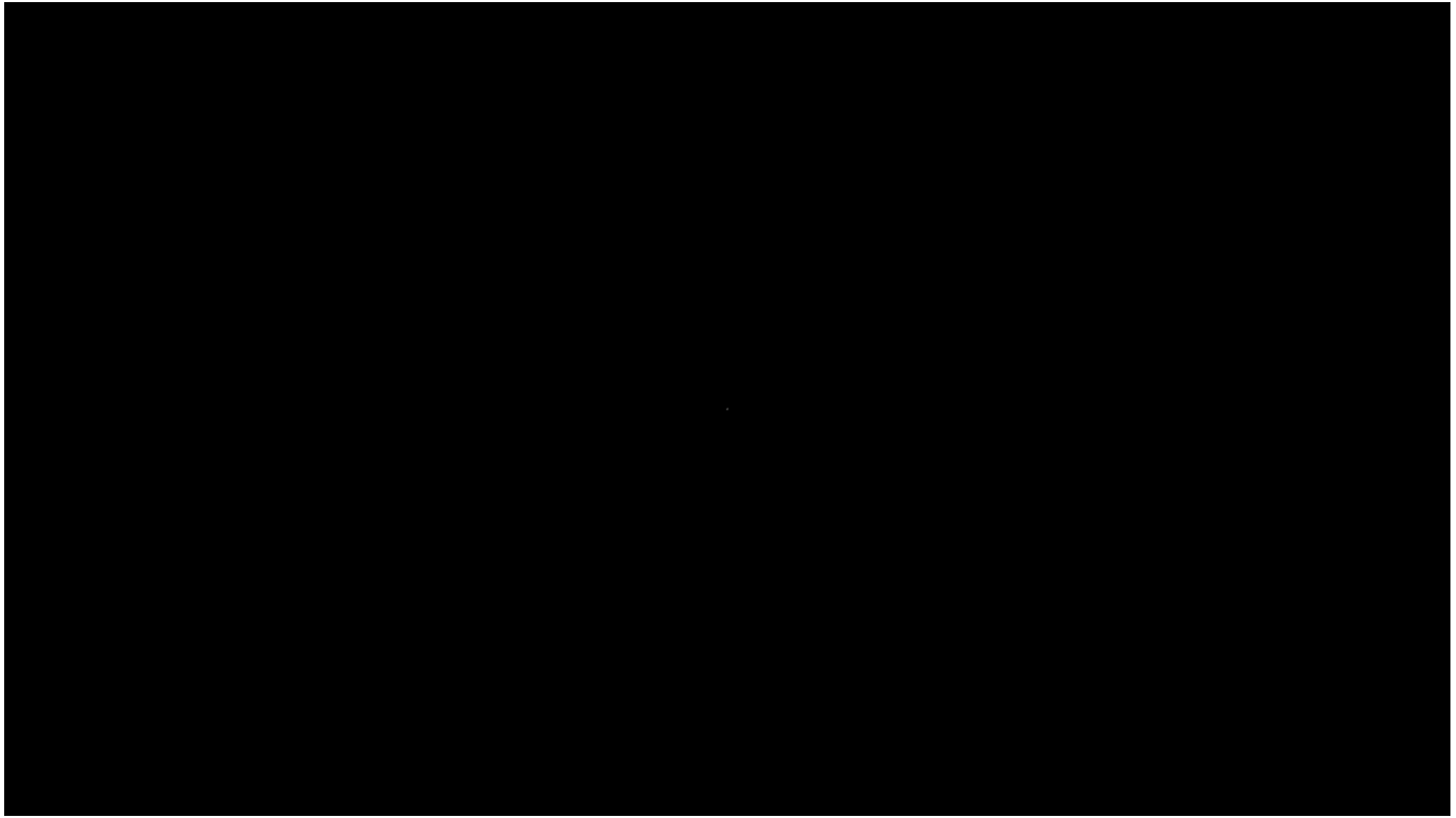
- Traditional alignment loop:
  1. Align XY
  2. Make small theta-Z adjustment
  3. Go to 1

  …Several minutes to complete

- *Or:*
  Parallelism to optimize
  XY & theta-Z *in one step*



Parallelism in Action

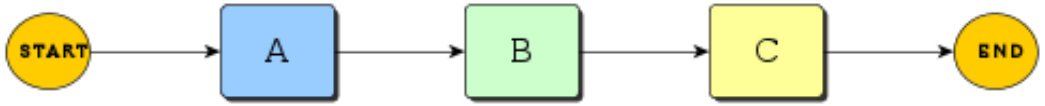


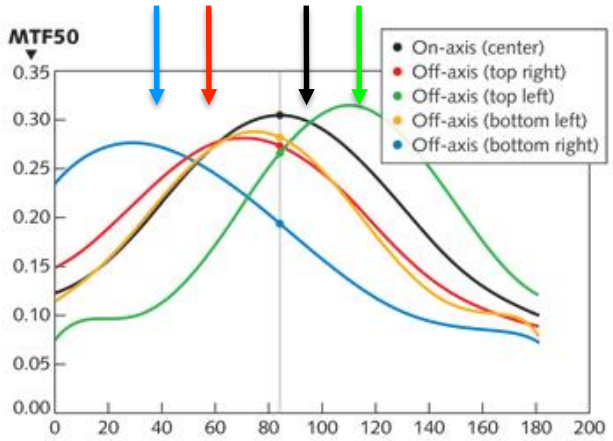
Probing examples

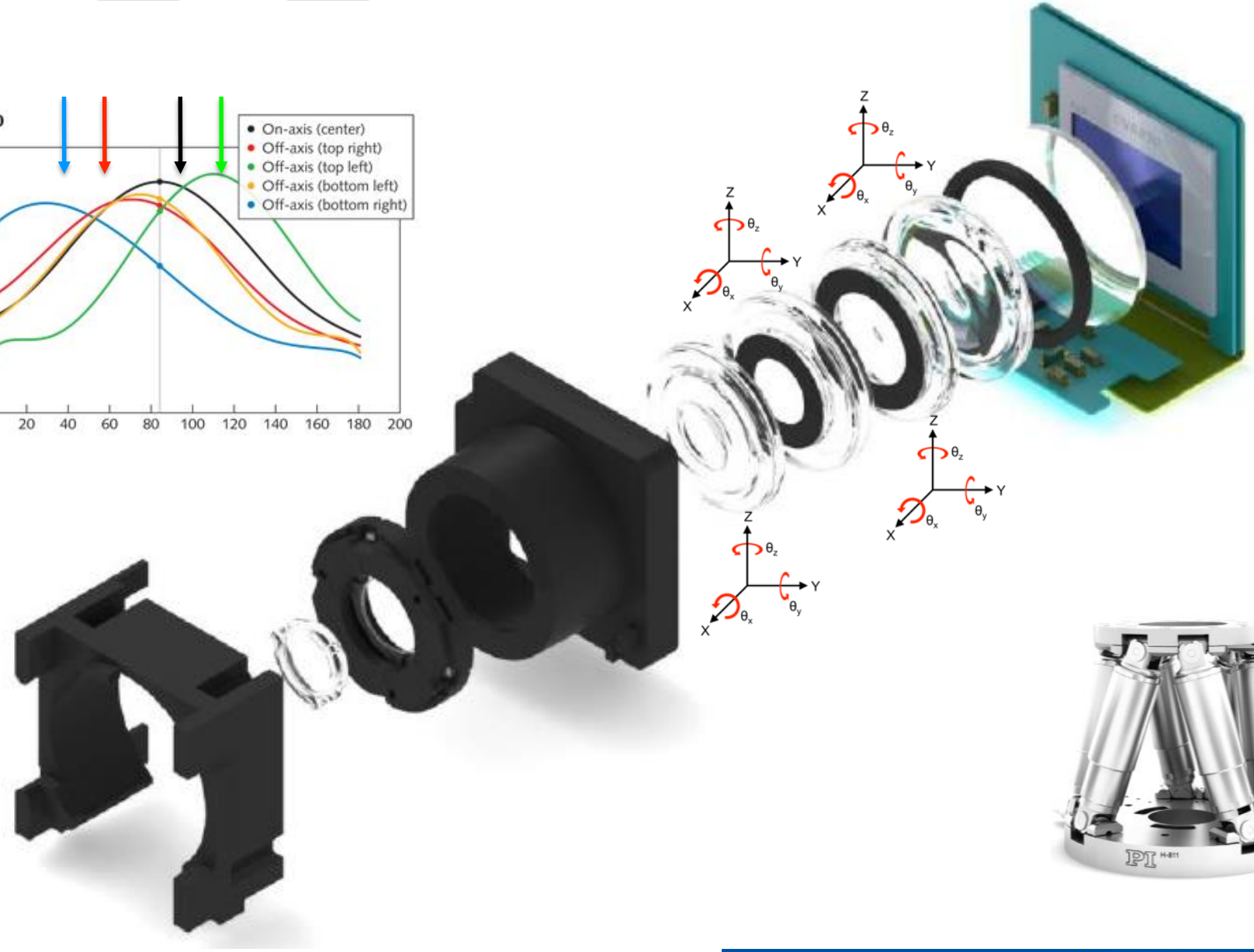
Excerpted from https://www.TinyURL.com/new-FF-video

FormFactor™

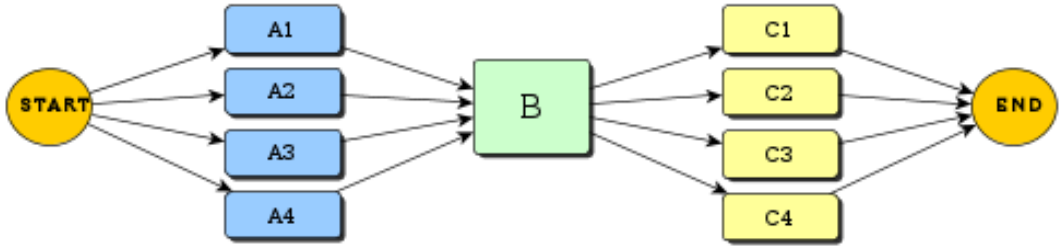
FORTUNE 100 FASTEST GROWING COMPANIES

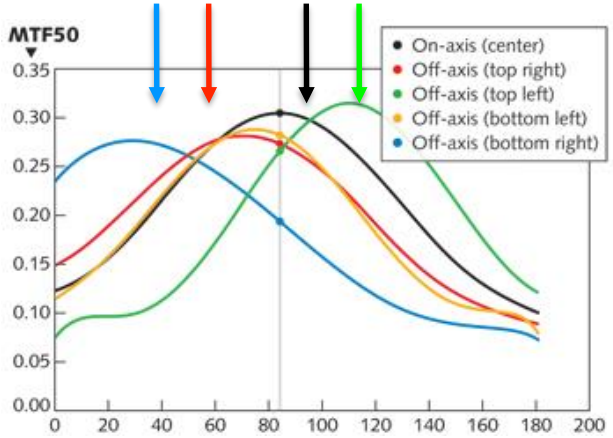

START
A
B
C
END


MTF50
On-axis (center)
Off-axis (top right)
Off-axis (top left)
Off-axis (bottom left)
Off-axis (bottom right)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
20
40
60
80
100
120
140
160
180
200


Z
θz
Y
θy
X
θx

PI


START
A1
A2
A3
A4
B
C1
C2
C3
C4
END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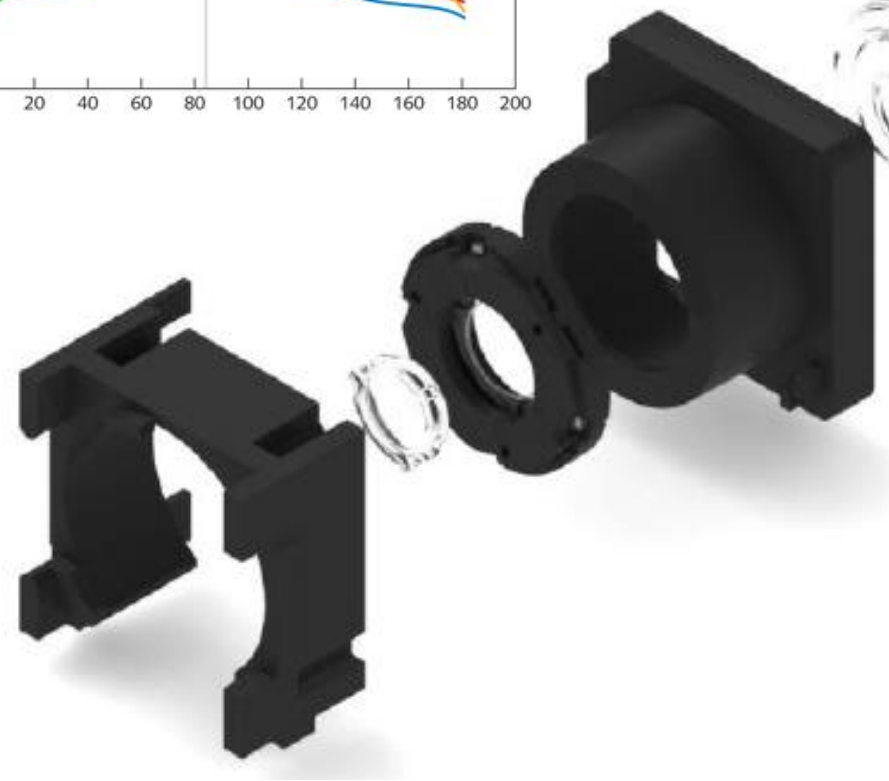

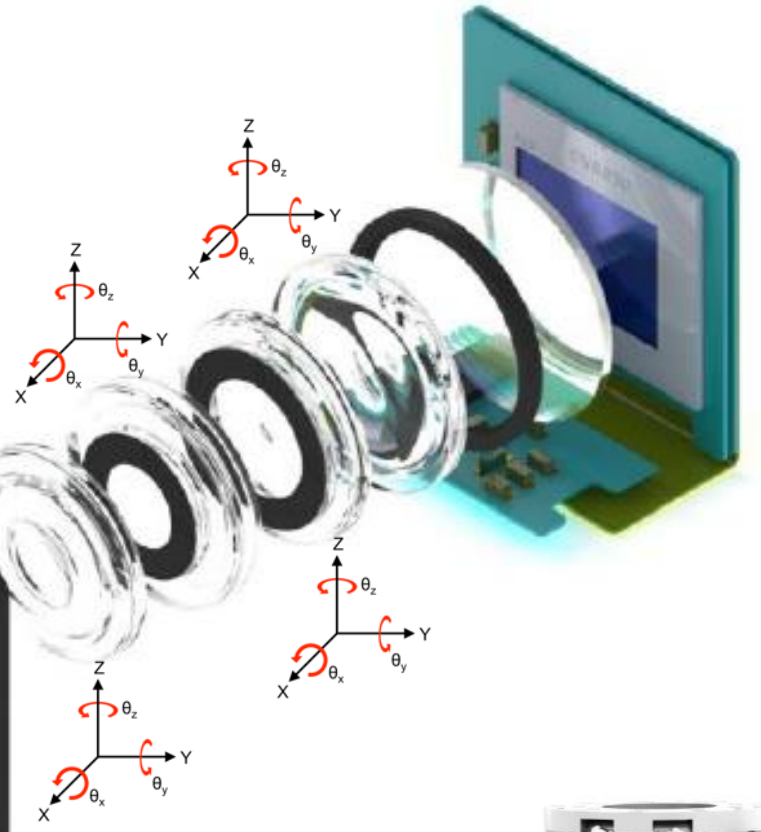
Z
θz
Y
θy
X
θx

PI

The Dawn of Intelligent Optimization

A manufacturing revolution, and not just for Photonics

Save the date!

29-30 October 2020

EPIC event at PI Karlsruhe

Working title:

"Technologies for Efficient Photonic & Optical Assembly and Test"

Physik Instrumente

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Ask for a free Tech Note on Parallelism in Optimization

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