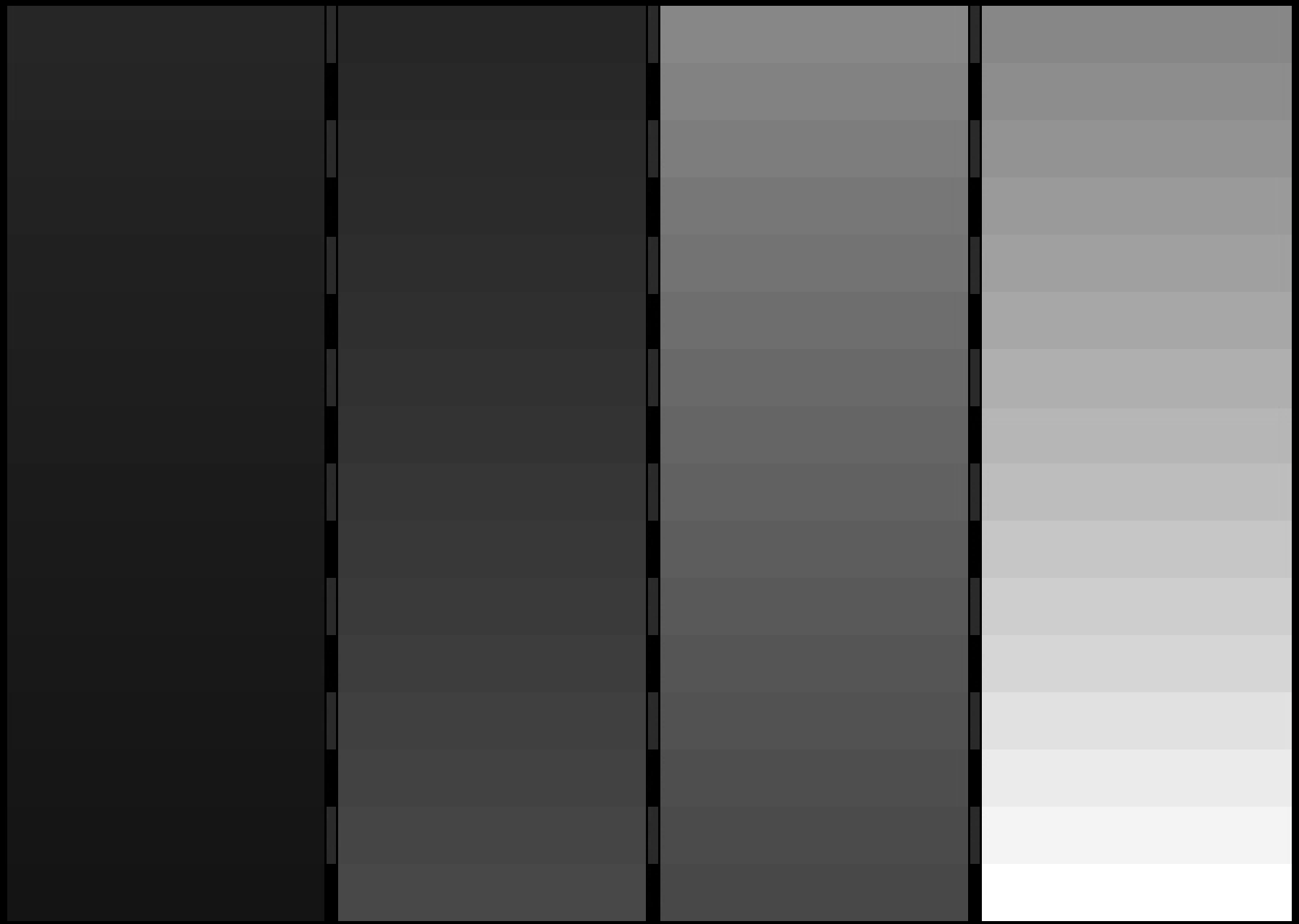
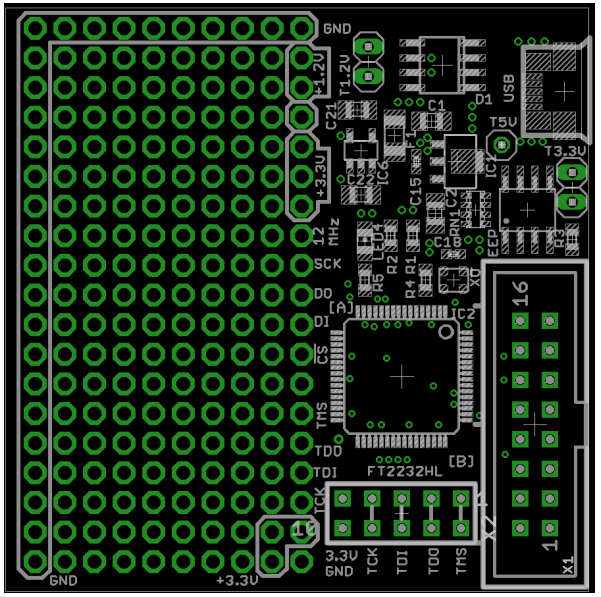
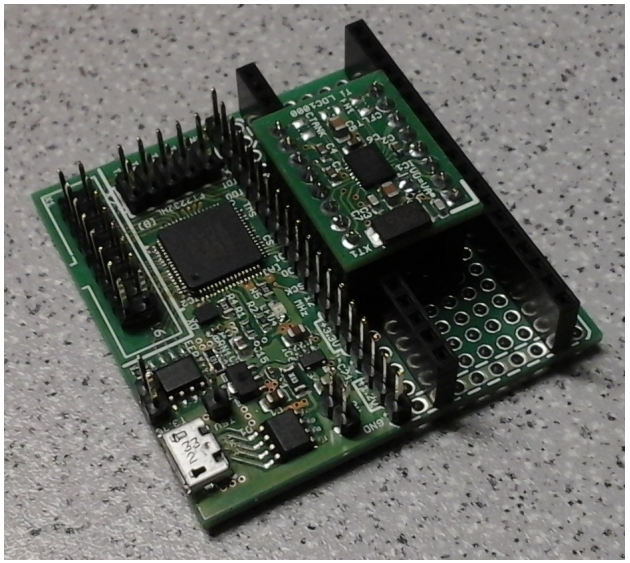
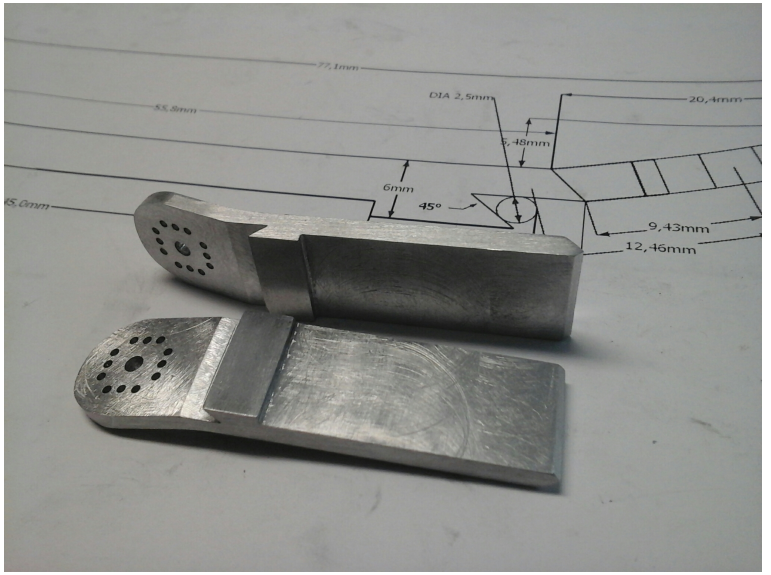


# Background - hardware development

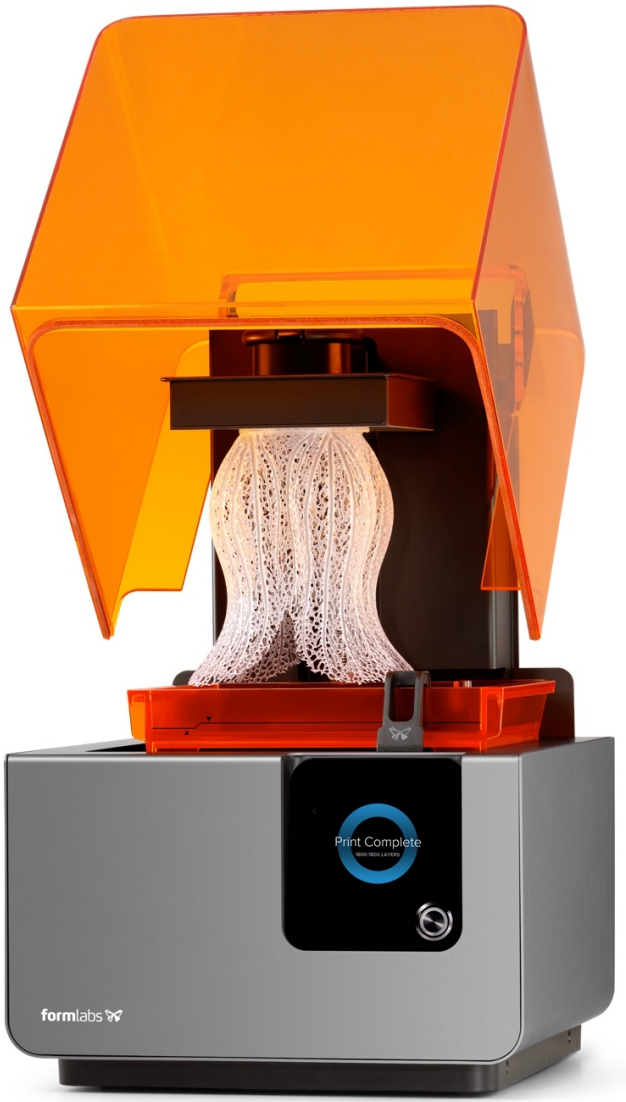




# Introduction - 3D printers

stereo lithography printers (SLA) - FDM printer style? Price point?



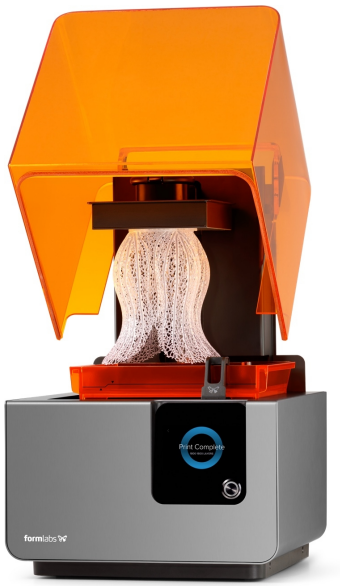

[1] http://shop.prusa3d.com/en/3d-printers/59-original-prusa-i3-mk2-kit.html
[2] https://formlabs.com/de/3d-printers/form-2/

# Introduction - 3D printers

fused deposition modeling

- around 1k€
- reasonably mature
- parts and filament : many suppliers
- sensors, auto bed leveling
- easy entry, community

stereo lithography apparatus



- starts at 4k€
- reasonably mature
- pricey resin, 3rd party support
- z increment "peel off" motion
- non-stepped DLP alternatives low-res

# Introduction - 3D printers

Can we do better?

# Introduction - 3D printers

Can we do better?

## Stratasys Objet30 Pro

Description: One of 10 PolyJet printers in the Design Series.

Feature highlight: Sub $50k price tag.

Without that? → Price: $43,000

Material: 5 Vero resin materials, 2 advanced fuction materials + support material

Build capacity: 11.57 x 7.55 x 5.85 in / 294 x 192 x 148.6 mm

Build rate: n/a

but have that → Resolution/Layer thickness: 0.0011 inches / 28µm (microns)

Machine dimensions: 32.28 × 24.4 × 23.22 in / 82.5 × 62 × 59 cm

# Outline

**Concept**
avoid fancy components
profit from economies of scale
design for manufacture

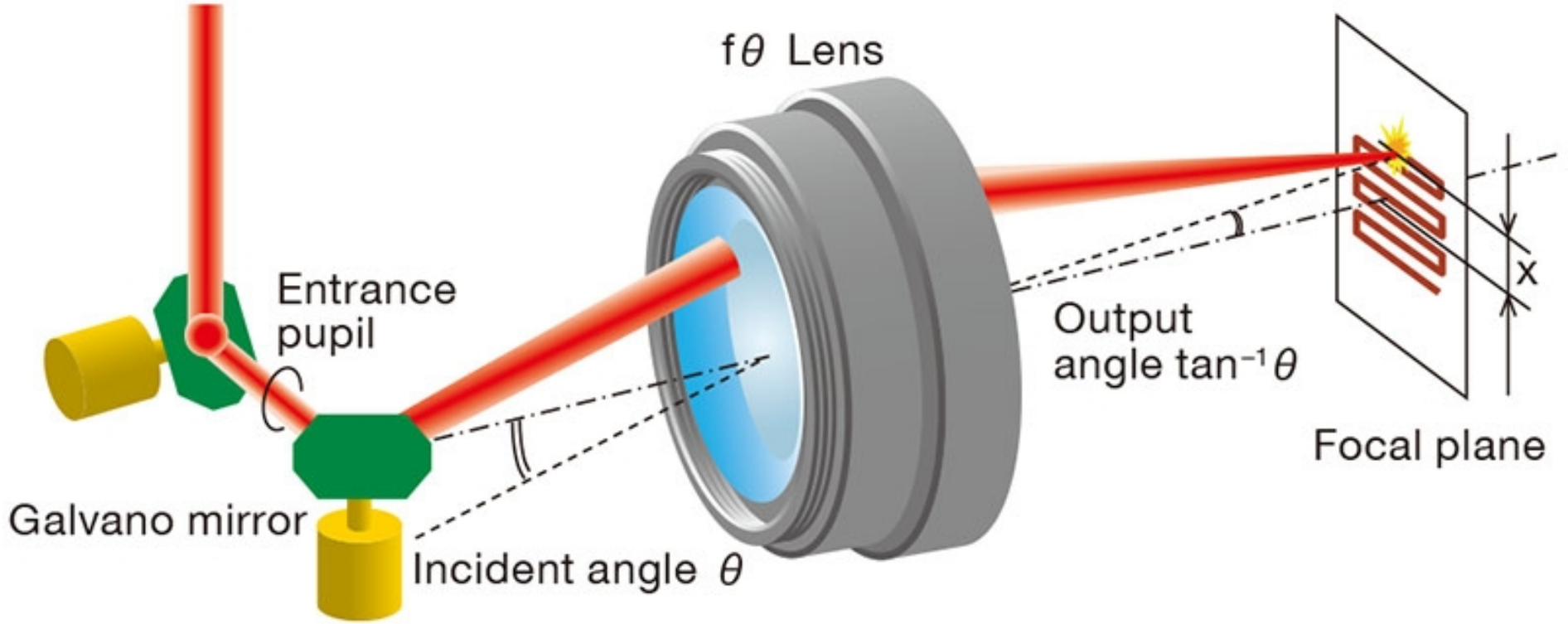
**Feasibility**
demonstrate working principle
answer hard questions

**Design**
prototype concept with minimum number of detours

**Outlook / Evaluation**

# Concept

F-Theta fisheye lenses: commonplace for laser scanning applications




[3]http://www.f-theta.com/technology/7-f-theta-lenses-for-co2-laser.html

# Concept

## F-Theta lens

+ off-the-shelf
+ AR coated for UV
+ high quality
+ known properties
+ proven geometry
+ low field curvature
+ acceptable distortion

- price: 0.5-1.5k€
- multiple elements
- also need galvo scanners
- galvo closed loop controller calibration
- single, pricey emitter


*helgewurst@web.de*

# Concept

Alternatives:

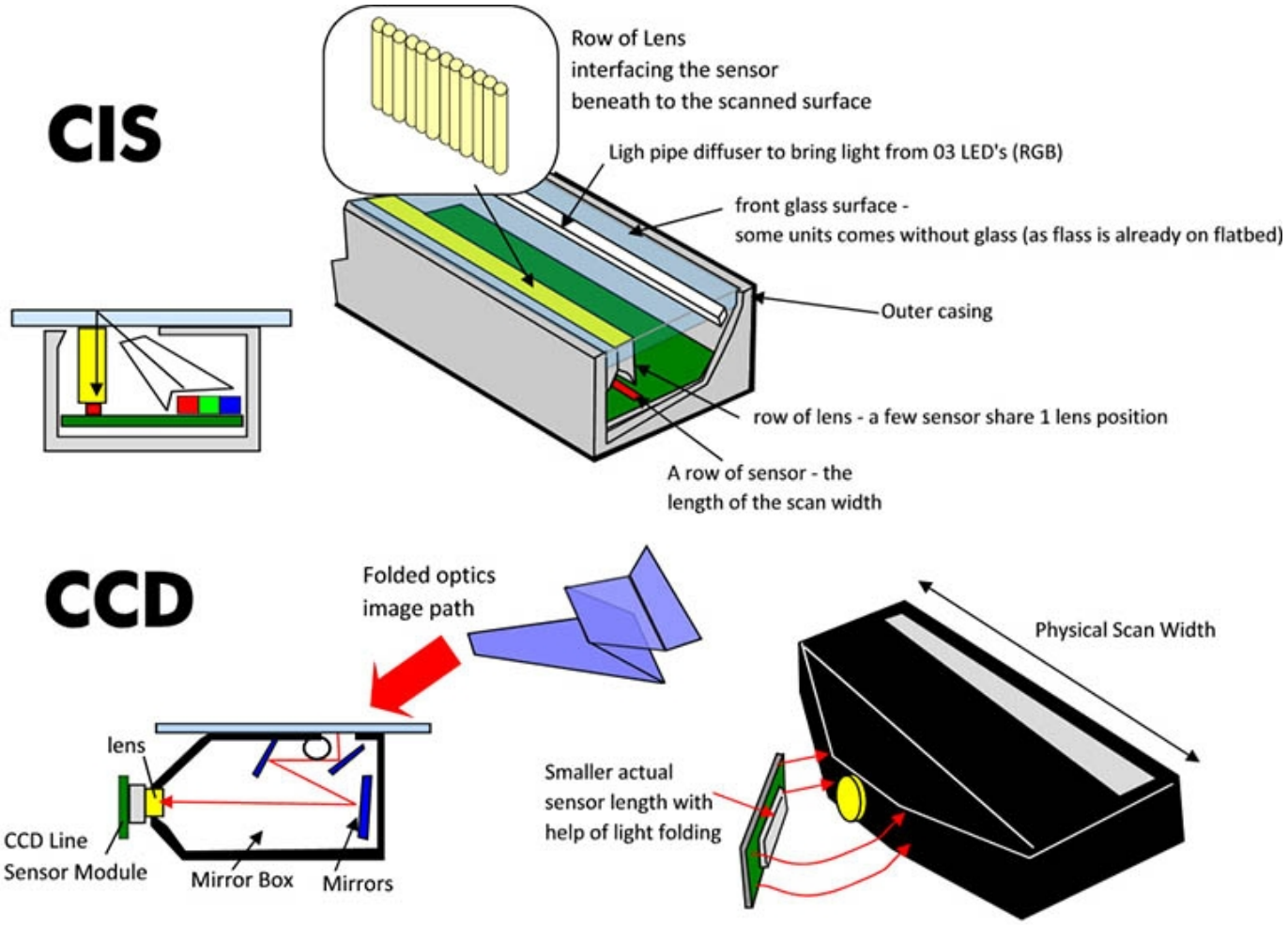
use direct laser beam:
field curvature: poor focus and/or servo optics
still have galvo scanners, large beam angles

use DLP projector:
expensive imaging lens w/ many elements
or poor light yield, resolution

come up with something different?

# Concept

Something along the lines of flatbed scanners?




[4]https://chriseatsacrisp.wordpress.com/2011/10/

# Concept

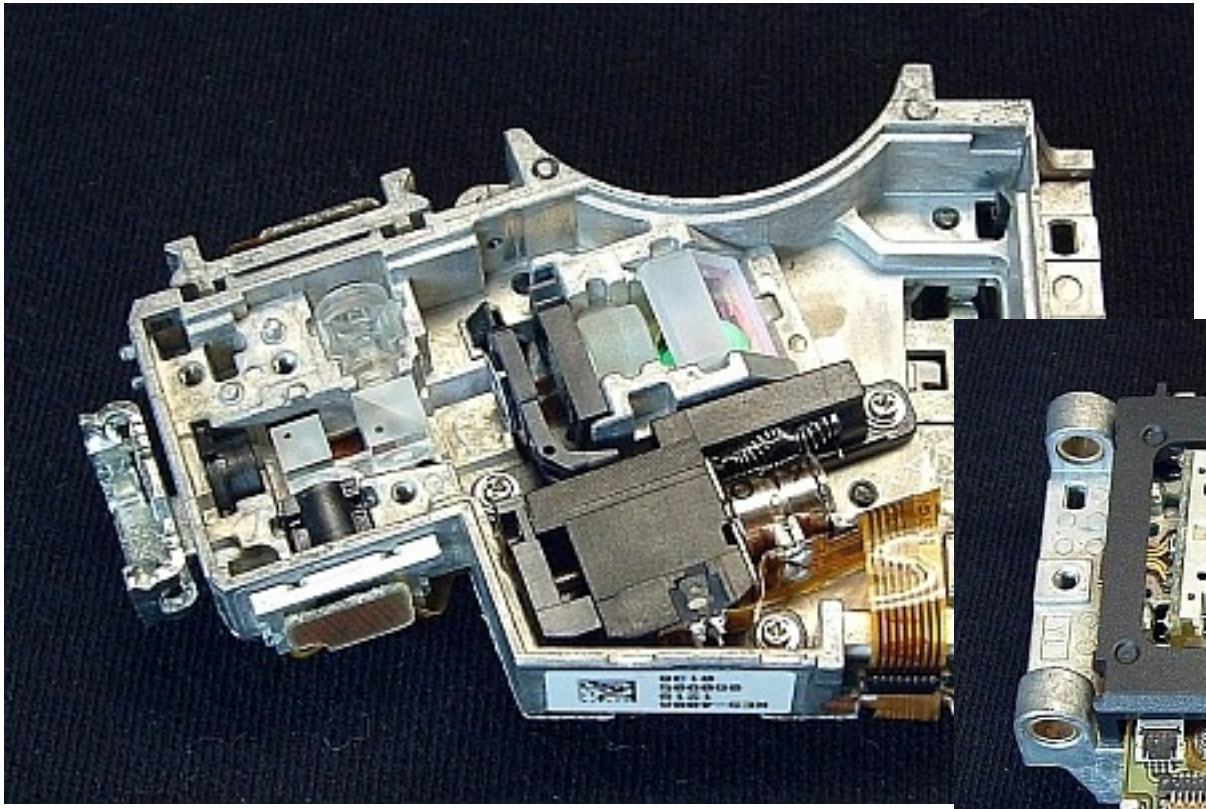
Do:

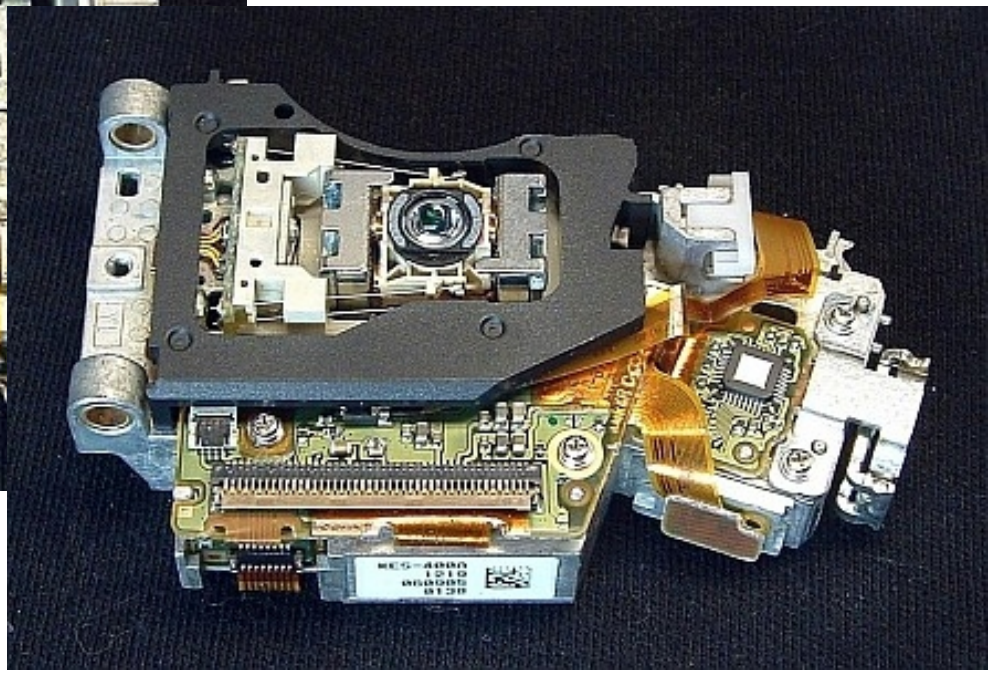
- small scan angle
- low number of surfaces and elements
- cheap light source
- redundancy
- modular
- compact, low profile geometry
- avoid folding / mirrors
- closed loop actuators, direct feedback
- try auto calibration


*helgewurst@web.de*

# Concept

commercial "look and feel", design elegance





[5]http://www.repairfaq.org/sam/Blu-ray/site1/optics.html

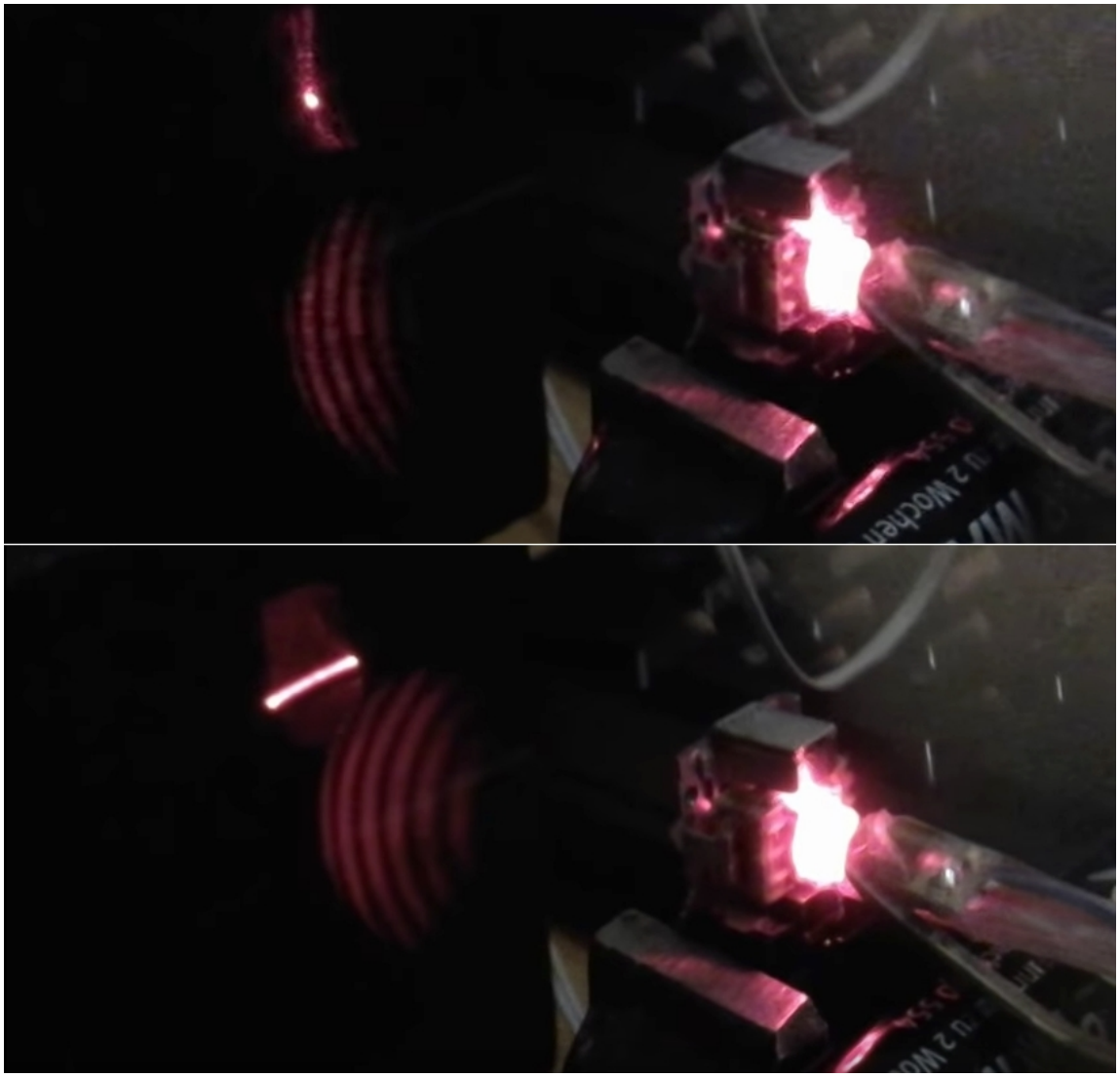
# Concept

combine flatbed and pickup head properties

- use short focal length, good magnification
- small lateral displacement
- single bi-aspherical molded PMMA lenses
- single wavelength, no CA issues
- use OTS where possible
- single set of actuators
- design light engine first,
  ...but have plans for device

# Concept

## Getting a feel for it



DVD pickup
modified servo
with asp lens, 50 Hz

# Feasibility

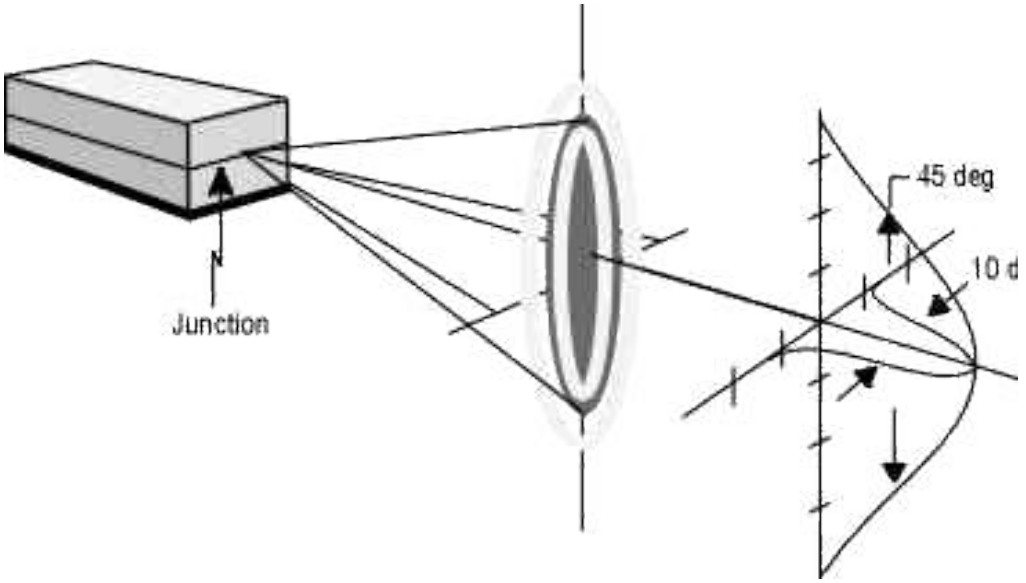
Lens?
Laser diode?
How bad is it actually?

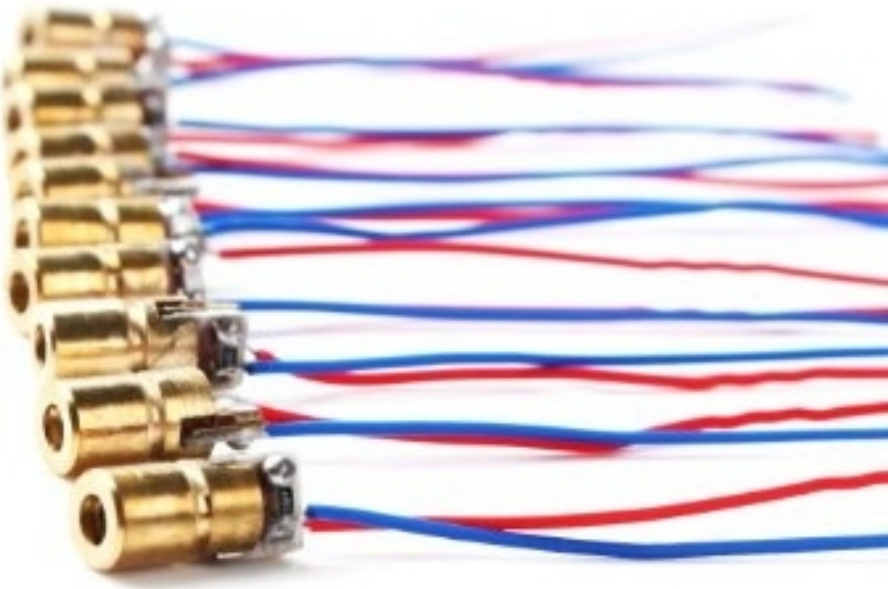

*helgewurst@web.de*

# Feasibility

## Lens

uncoated PMMA collimating lenses
for next to nothing
beam truncation inevitable

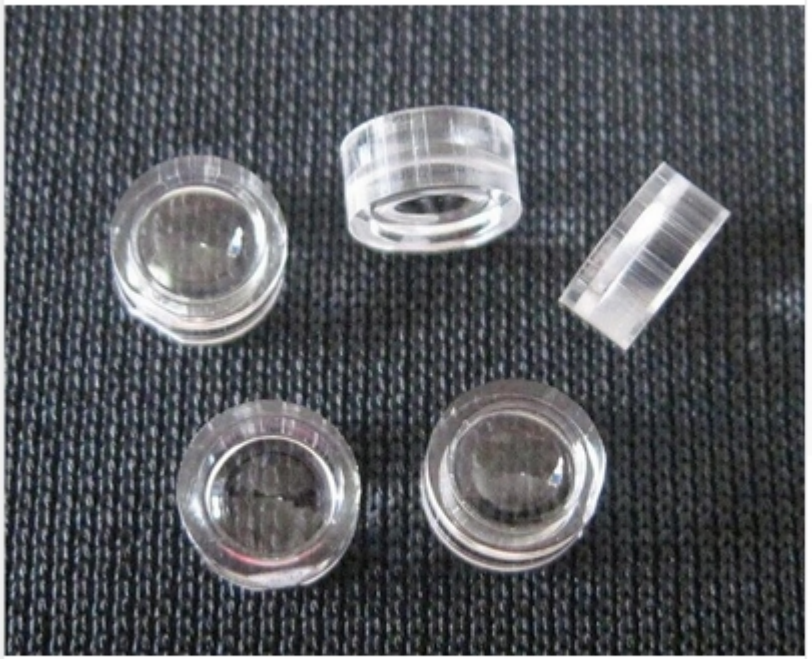


[6] https://forum.formlabs.com/t/a-response-to-sam-jacoby/3398/84

# Feasibility

## Lens - unknown shape



Zum Hereinzoomen mit der Maus über das Bild fahren

# ORG-5 Hohe qualität Laserlinse, Laser Pointer objektiv, größe: 5X2,3mm, brennweite: 4,8mm, PMMA materialien, farbe: Transparent

Originaltitel in englischer Sprache

4.8 (39 Stimmen) | 54 Bestellungen

Preis: **US $6.00** / Los 20 stücke / Los , US $0.30 / stück

Versand: **Kostenloser Versand an Germany per China Post Registered Air Mail**

Lieferung: 26-49 Tage

Menge: – 1 + Los (871 Lose available)

Gesamtpreis: **US $6.00**

Jetzt kaufen | In den Einkaufswagen

Zur Wunschliste hinzufügen (54 Zusätzlich)

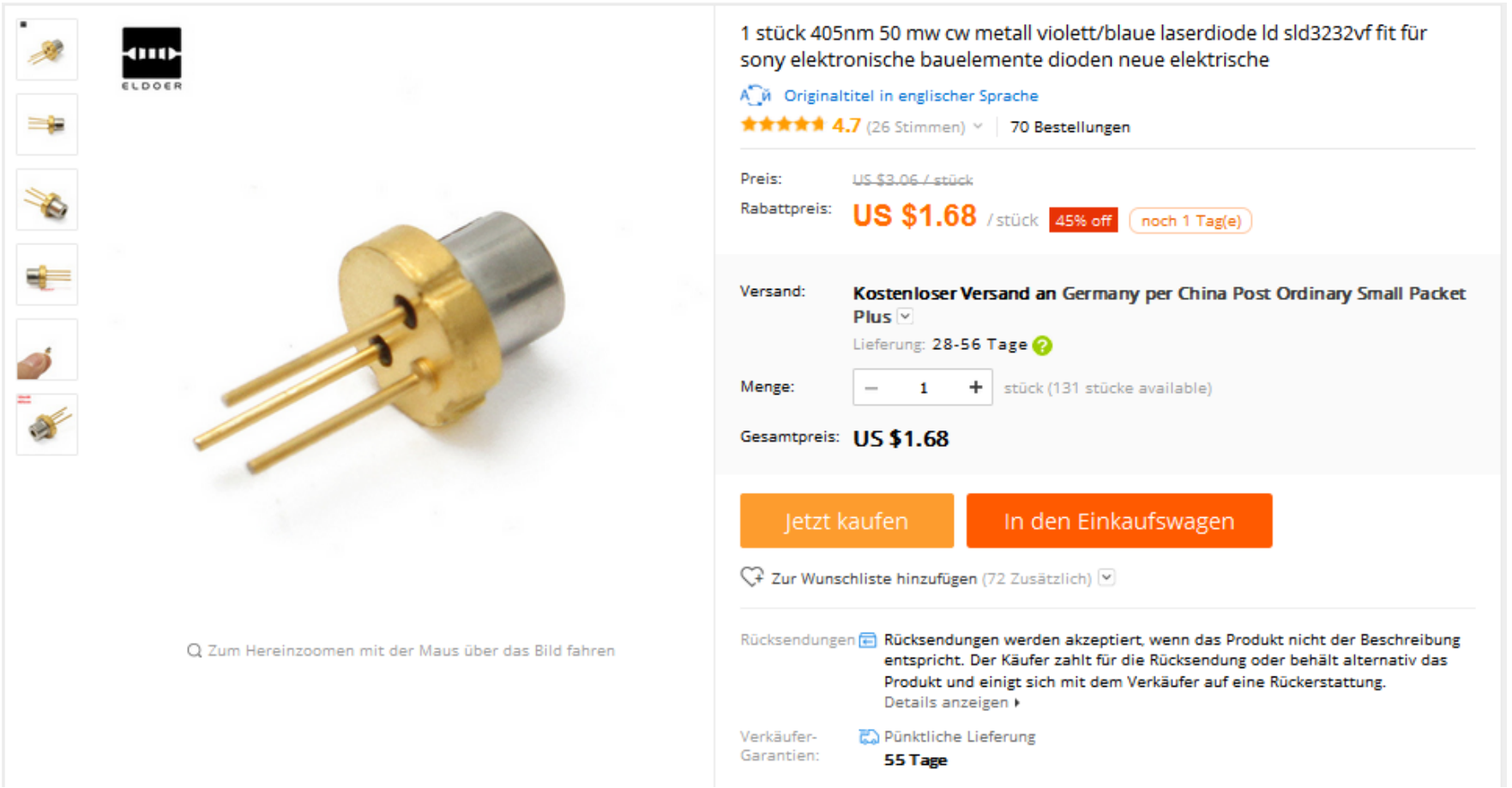
Rücksendungen: Rücksendungen werden akzeptiert, wenn das Produkt nicht der Beschreibung entspricht. Der Käufer zahlt für die Rücksendung oder behält alternativ das Produkt und einigt sich mit dem Verkäufer auf eine Rückerstattung. Details anzeigen

Verkäufer-Garantien: Pünktliche Lieferung **60 Tage**

[7] https://de.aliexpress.com/item/ORG-5-High-quality-Laser-Lens-Laser-Pointer-lens-Size-5X2-3mm-Focal-length-4/32649747812.html

# Feasibility

## Laser diodes?




[8] https://de.aliexpress.com - multiple suppliers

# Feasibility

## How bad is it actually?

finite image distance:
- collimating lens deviates from best form

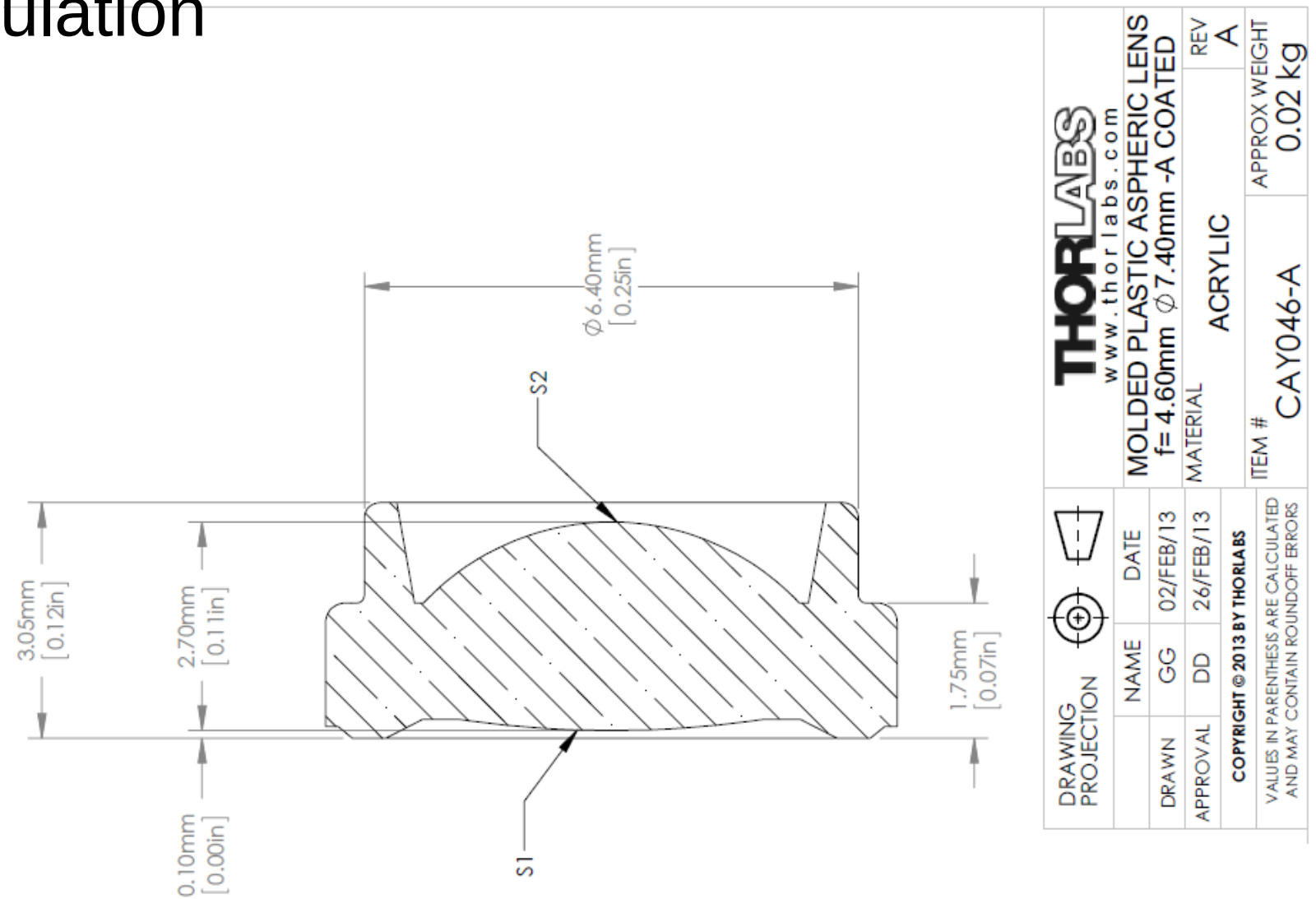
off-axis ray perfomance?
- expect lower order aberrations
- introduce vignetting

field curvature and control
- can we get away with it?
- trade in mechanical degrees of freedom for optical simplicity

tolerances

# Feasibility

## Simulation



# Feasibility

## Simulation

Von Helge Wurst

Betreff **CAY046-A model (for OSLO)**

An Europe@thorlabs.com

Dear Ladies and Gentlemen,

we were delighted to see that a selection of Thorlabs lenses is already part of the OSLO simulation tool.

But as Murphy would have it, the one we chose is apparently not part of that selection and the datasheet does not go into details.

Could you provide surface profile formulae for both sides or an OSLO compatible library file?

Looking forward to your reply.

Best Regards,

Helge B. Wurst

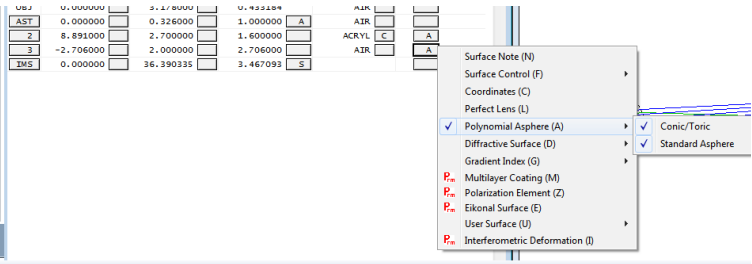
# Feasibility

## Simulation: Zemax vs. OSLO

Lens Data

Surface 3 Properties — Configuration 1/1

| | Surf:Type | Comment | Radius | Thickness | Glass | Coating | Semi-Diam | Conic | TCE x 1E-6 | 2nd Order | 4th Order | 6th Order | 8th Order | 10th Order | 12th Order | 14th Order | 16th Order |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | OBJECT Standard | | Infinity | Infinity | | | 0.000 | 0.000 | 0.000 | | | | | | | | |
| 1 | STOP Standard | | Infinity | 5.000 | | | 5.000 | 0.000 | 0.000 | | | | | | | | |
| 2 | Standard | | 22.965 V | 5.000 | N-BK7 | | 6.000 | 0.000 | - | | | | | | | | |
| 3 | Even Asphere | | 186.114 F | 46.283 V | | | 5.658 | 0.000 | 0.000 | 0.000 | 6.796E-0( V | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 4 | IMAGE Standard | | Infinity | - | | | 4.917E-0( | 0.000 | 0.000 | | | | | | | | |



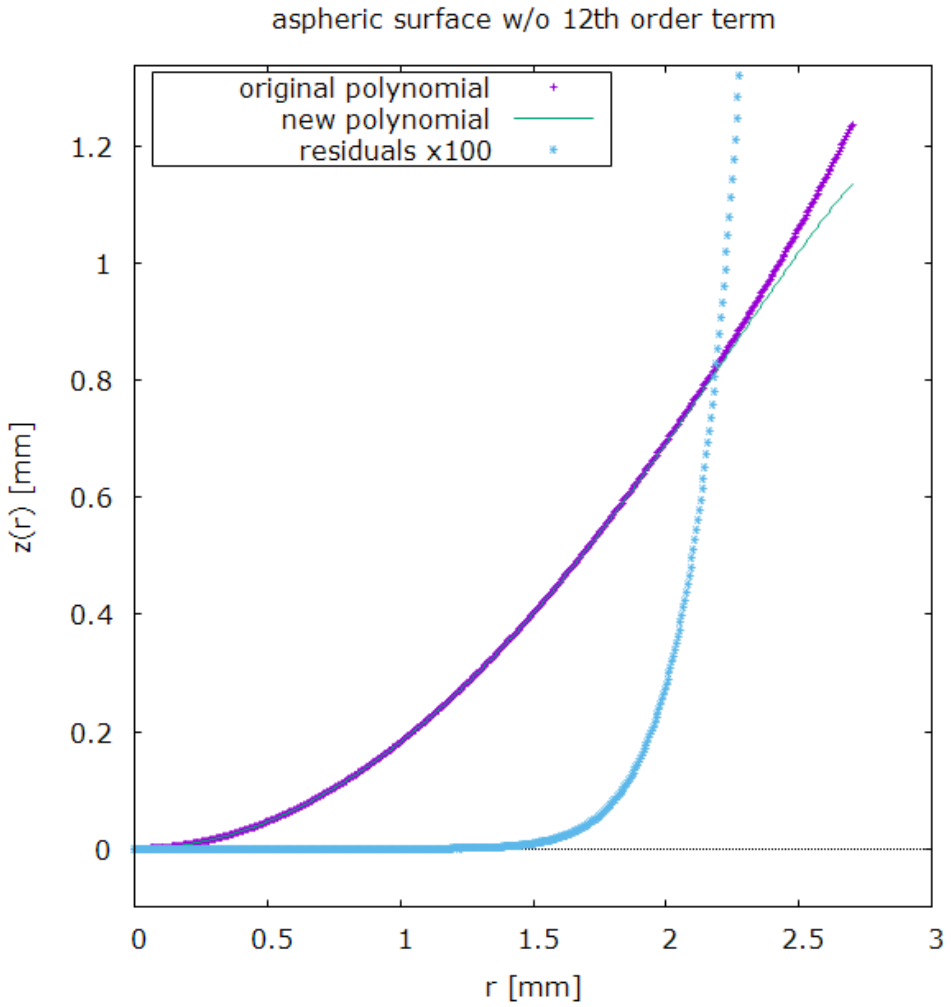

Lens Data Editor

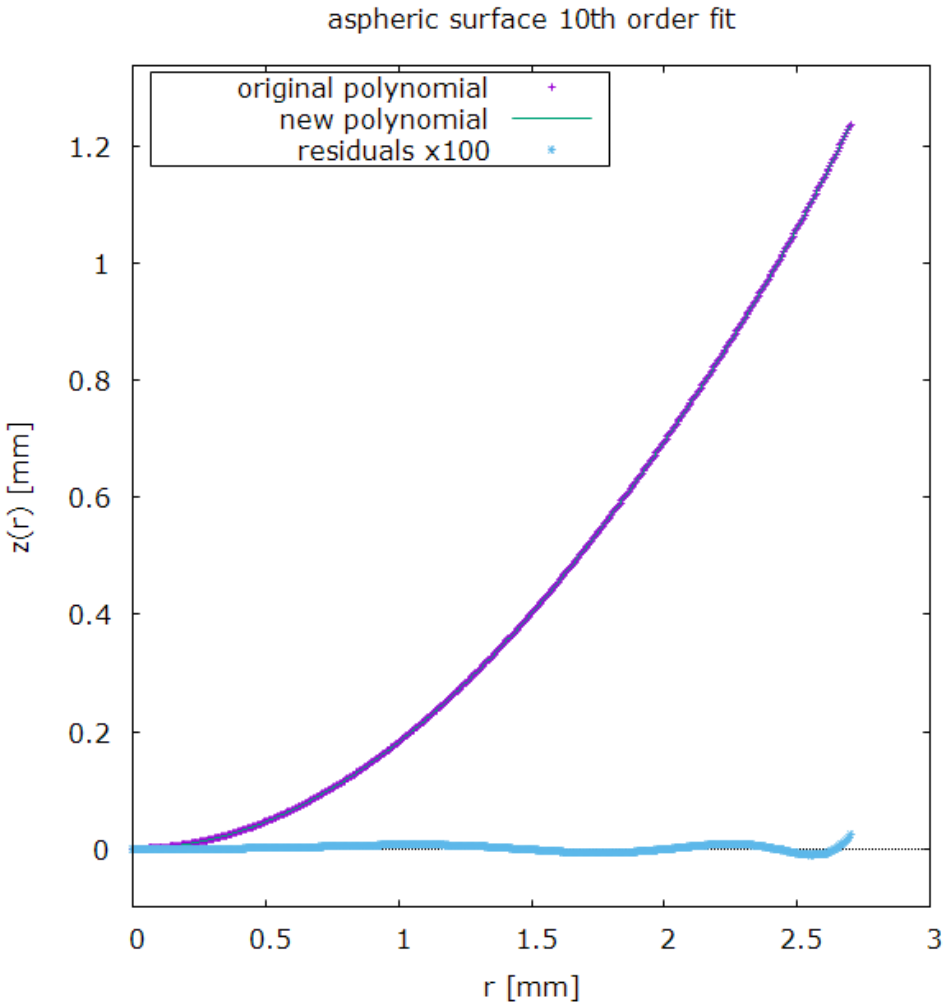
Edit Solves View Help

| | Surf:Type | Comment | Radius | Thickness | Glass | | Semi-Diameter | | Conic | Par 0 (unused) | Par 1 (unused) | Par 2 (unused) | Par 3 (unused) | Par 4 (unused) | Par 5 (unused) | Par 6 (unused |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OBJ | Standard | | Infinity | 0.550 | | | 0.000 | | 0.000 | TCE x 1E-6 | 2nd Order | 4th Order | 6th Order | 8th Order | 10th Order | 12th Order |
| 1* | Standard | | Infinity | 0.250 | BK7 | | 1.000 | U | 0.000 | | | | | | | |
| 2* | Standard | | Infinity | 2.378 | | | 1.000 | U | 0.000 | | | | | | | |
| 3* | Even Asph.. | | 8.891 | 2.700 | ACRYLIC | | 1.600 | U | -1.000 | | 0.000 | -5.510E-003 | 8.759E-004 | -8.708E-005 | 8.529E-006 | 0.000 |
| * | Even Asph.. | | -2.706 | 2.000 | | | 1.850 | U | -1.000 | | 0.000 | -2.629E-003 | -8.719E-005 | 2.572E-005 | -5.360E-006 | 6.763E-007 |
| IMA | Standard | | Infinity | - | | | 1.717 | | 0.000 | | | | | | | |

# Feasibility

## Simulation: Oslo, no 12th order coefficient?





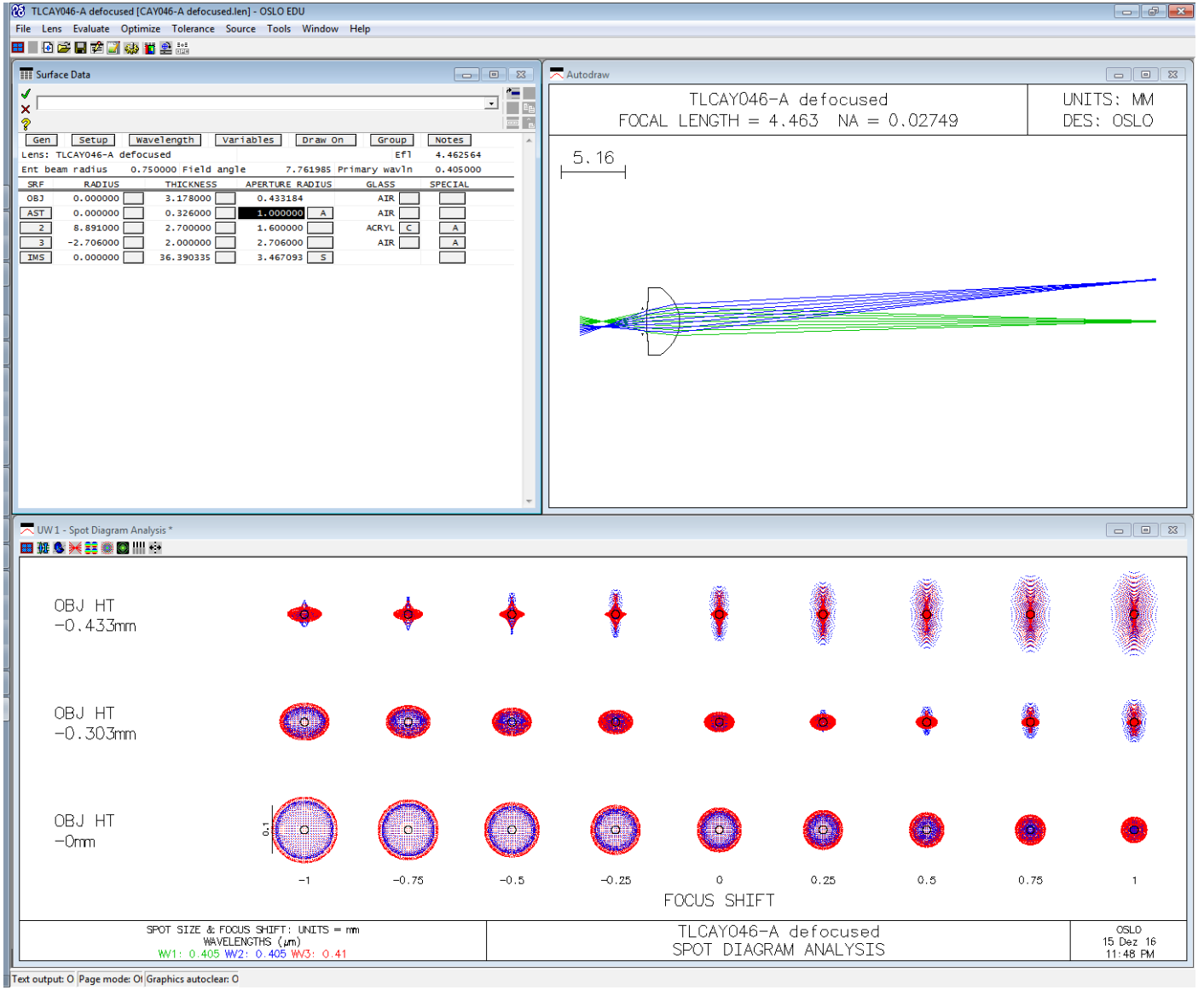
*helgewurst@web.de*

# Feasibility

ad hoc

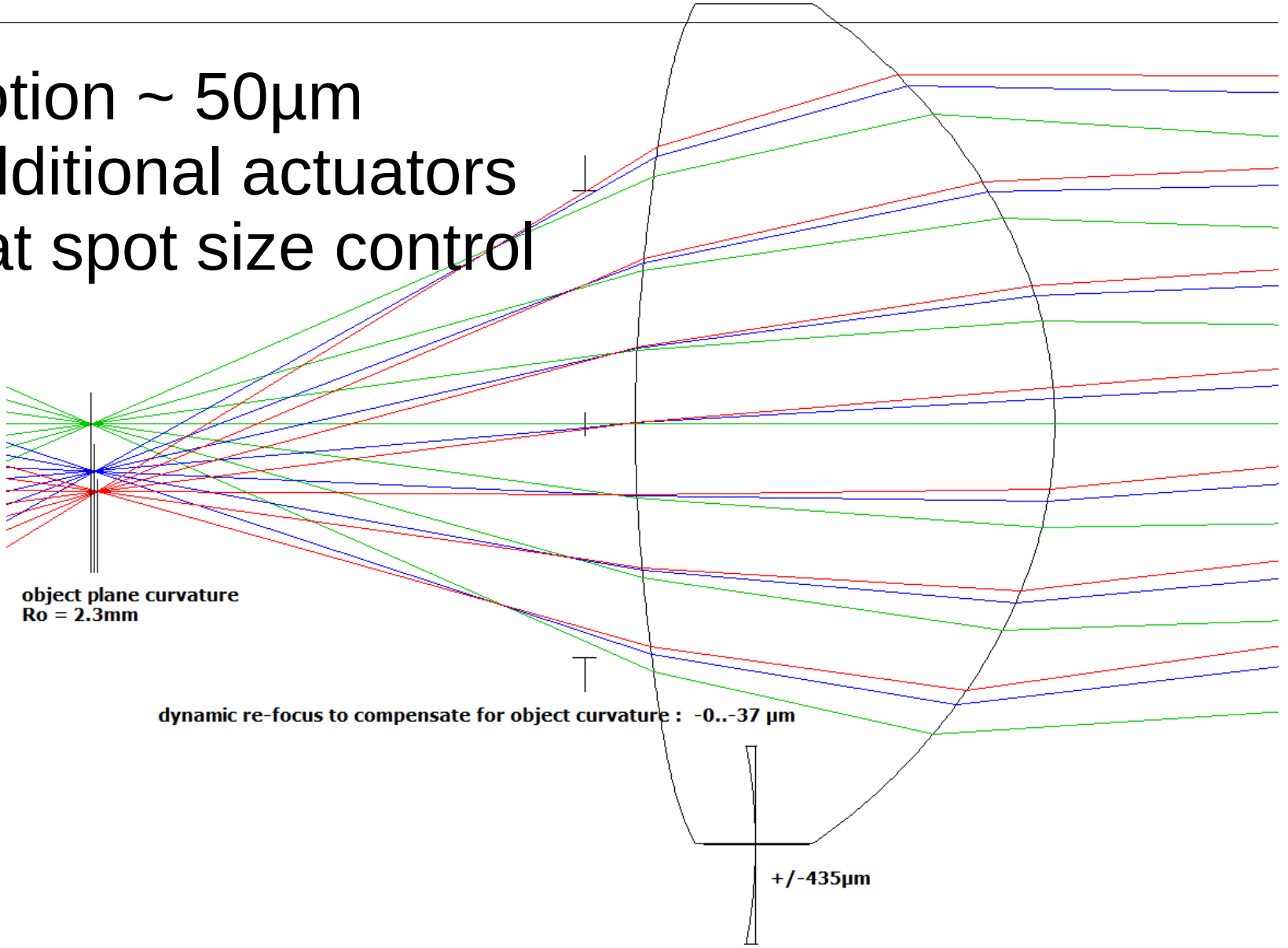
spot size
<0.15mm

astigmatism
field curvature!



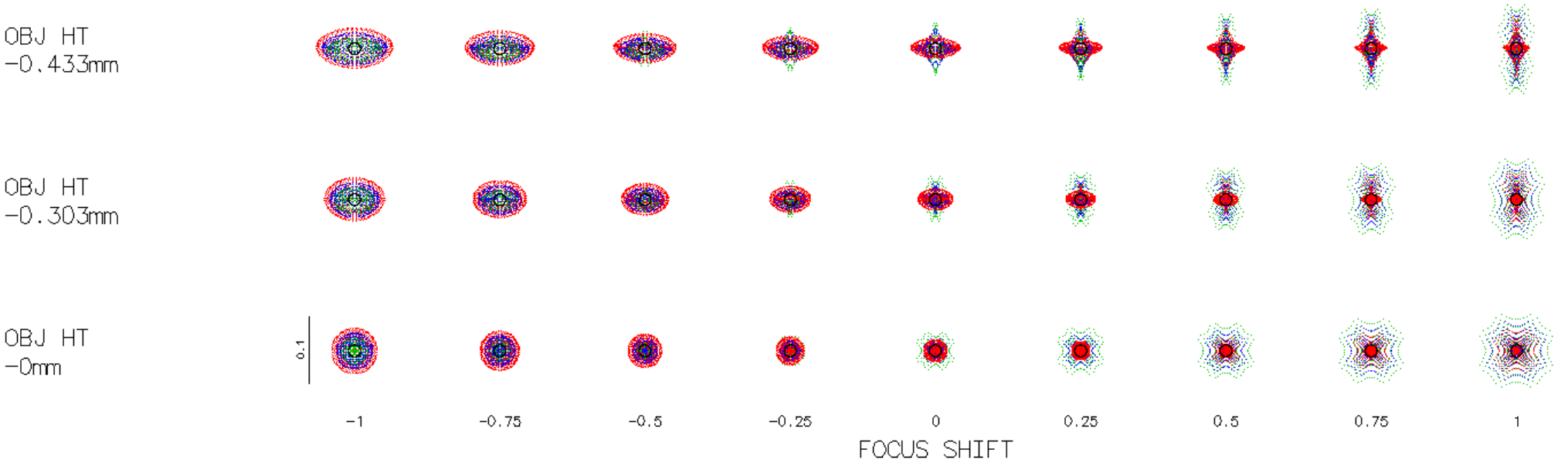
# Feasibility

add z motion ~ 50µm
needs additional actuators
gain great spot size control



# Feasibility

## ok better

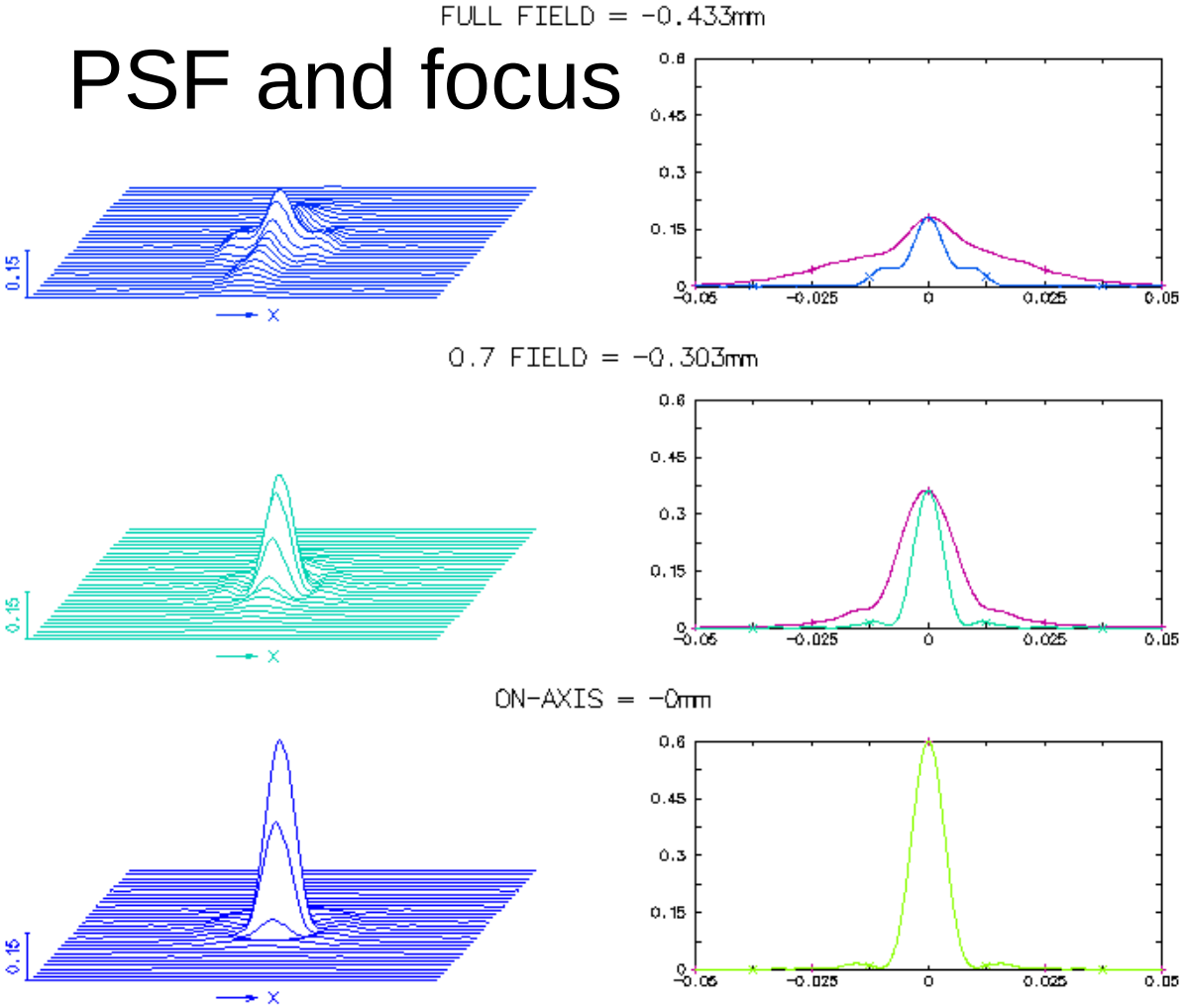


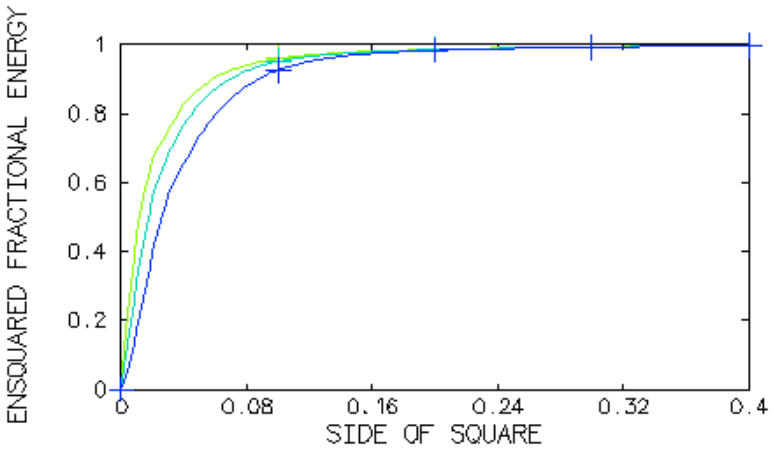


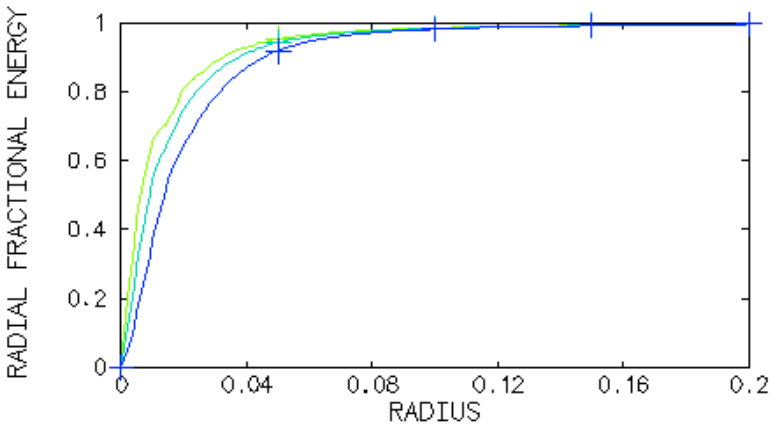
*helgewurst@web.de*

# Feasibility

## PSF and focus




| | | |
|---|---|---|
| IMAGE PATCH SIZE: 0.1 mm<br>Wavelength 1 = 0.400000 µm | TLCAY046-A defocused<br>POINT SPREAD FUNCTIONS | OSLO<br>18 Dez 16<br>01:07 AM |

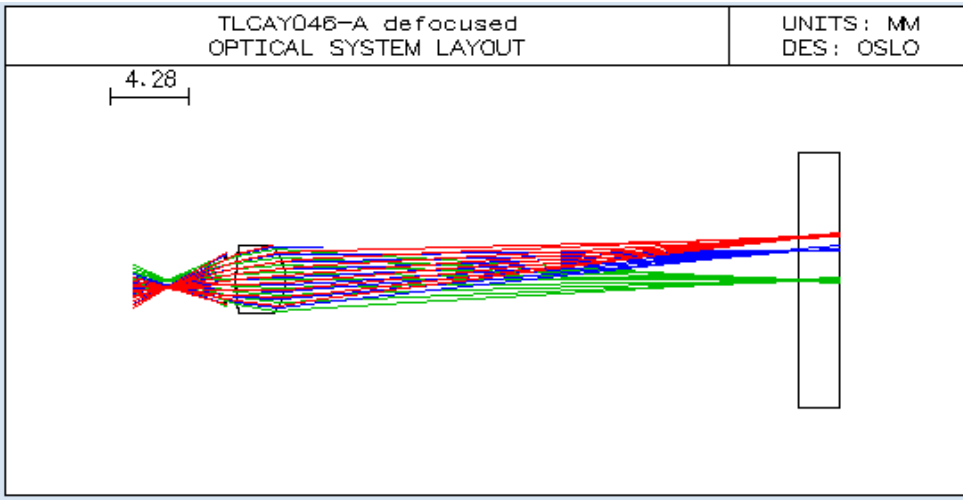
# Feasibility - lens behavior

Gen | Setup | Wavelength | Variables | Draw On | Group | Notes

Lens: TLCAY046-A defocused  EFL 4.442167

Ent beam radius 0.750000  Field angle 7.500000  Primary wavln 0.400000

| SRF | RADIUS | | THICKNESS | | APERTURE RADIUS | | GLASS | | SPECIAL |
|---|---|---|---|---|---|---|---|---|---|
| OBJ | 4.000000 | | 3.178000 | | 0.418392 | | AIR | | |
| AST | 0.000000 | | 0.540000 | | 1.250000 | AK | AIR | | NF |
| 2 | 8.891000 | | 2.700000 | | 1.600000 | K | ACRYL | C | NA |
| 3 | -2.706000 | | 2.000000 | | 1.850000 | K | AIR | | NA |
| 4 | 0.000000 | | 26.000000 | | 1.650000 | K | AIR | | N |
| 5 | -21.700000 | | 2.300000 | | 7.000000 | | H-K9L | C | NCA |
| 6 | -24.000000 | | 0.000000 | | 7.000000 | | AIR | | NA |
| IMS | 0.000000 | | 0.000000 | | 2.538283 | S | | | |



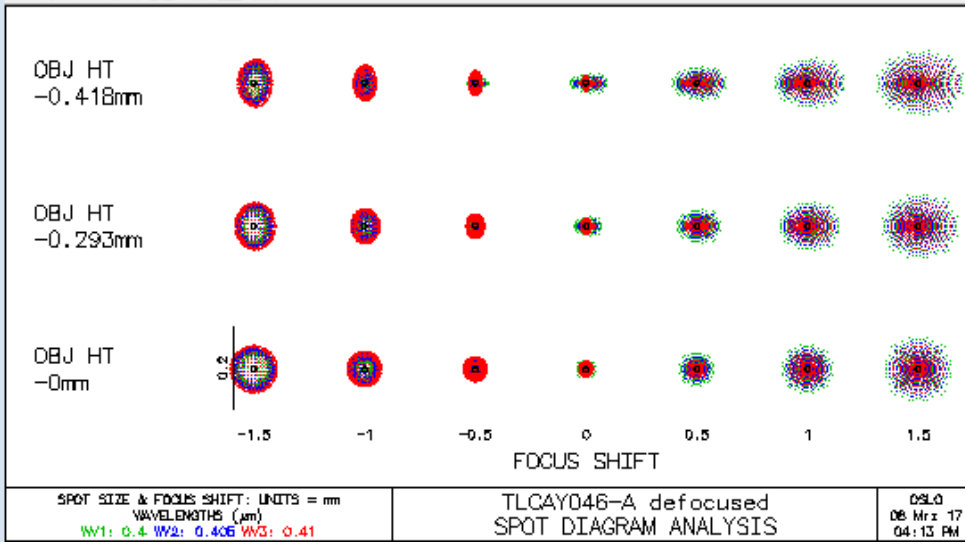

TW 1 *

Len Spe Rin Ape Wav Pxc Abr Mrg Chf Tra Sop Ref Fan Spd Auf Var One Ite

*LENS DATA
TLCAY046-A defocused

| SRF | RADIUS | THICKNESS | APERTURE RADIUS | GLASS | SPE | NOTE |
|---|---|---|---|---|---|---|
| OBJ | 4.000000 | 3.178000 | 0.418392 | AIR | | |
| AST | -- | 0.540000 | 1.250000 AK | AIR | | * |
| intentional de-focus, creates finite image distance. Additional front aperture. | | | | | | |
| 2 | 8.891000 | 2.700000 | 1.600000 K | ACRYL | C | * |
| CAY046-A first aspheric surface (towards LD) | | | | | | |
| 3 | -2.706000 | 2.000000 | 1.850000 K | AIR | | * |
| CAY046-A second surface (towards infinity/image) | | | | | | |
| 4 | -- | 26.000000 | 1.650000 K | AIR | | |
| main part of the image distance, adds lens exit stop | | | | | | |
| 5 | -21.700000 | 2.300000 | 7.000000 | H-K9L | C | * |
| glass tube inner wall (N-BK7) | | | | | | |
| 6 | -24.000000 | -- | 7.000000 | AIR | | * |
| glass tube outer surface | | | | | | |
| IMS | -- | -- | 2.538283 S | | | |

UW 1 - Spot Diagram Analysis *



# Feasibility

Summary:

- <1mm displacement for full scan width (6mm image)
- option to increase to <2mm to overlap faulty emitters
- spot size < 50 µm achievable
- no working area scaling issues, just extend in x
- adding z motion fixes curvature, provisions for spot size control
- cheap 50mW LD, total Power 1-2W
- cheap optics, custom optimized shape later on
- calibration and dynamic control done in SW

# Design

typical embodiments

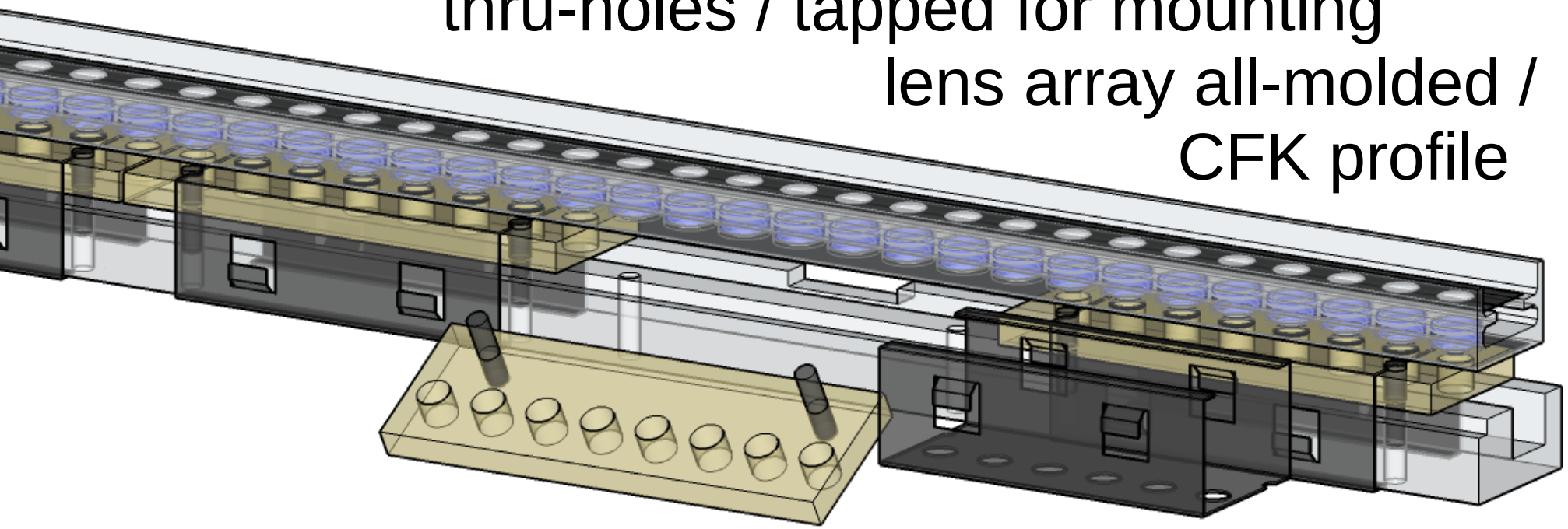
flatbed scanner geometry
- drop-in replacement for working printer geometry
- maskless photoresist exposer (stencils, PCBs)
- cyanotypes for art and photography

photoplotter geometry
- inverted arrangement without glass surface

scrolling cylinder geometry
- continuous peel, intrinsic resin transport

# Design

General idea:
LDs grouped on tiles, factory calibrated
all precision machining: 3-axis CNC, single setup
thru-holes / tapped for mounting
lens array all-molded /
CFK profile



# Design

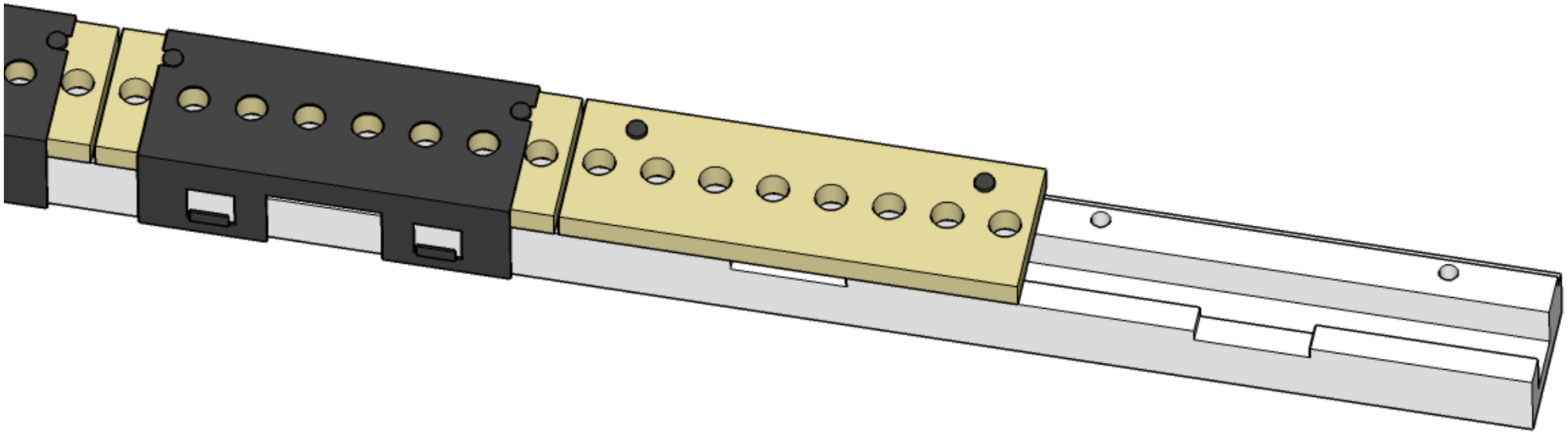
LD tiles:

surface milled on bottom (flat w/ or w/o surf finish)
only critical after LD assembly
LD z calib needed anyway (50-70µm die pos tol)
holes all in-line
lateral position error calibrated and absorbed in rasterizer
flex PCB w/ temp sensor, NVM for calibration info (power, temp coeff, position), PD+ADC monitoring
economical replacement

# Design

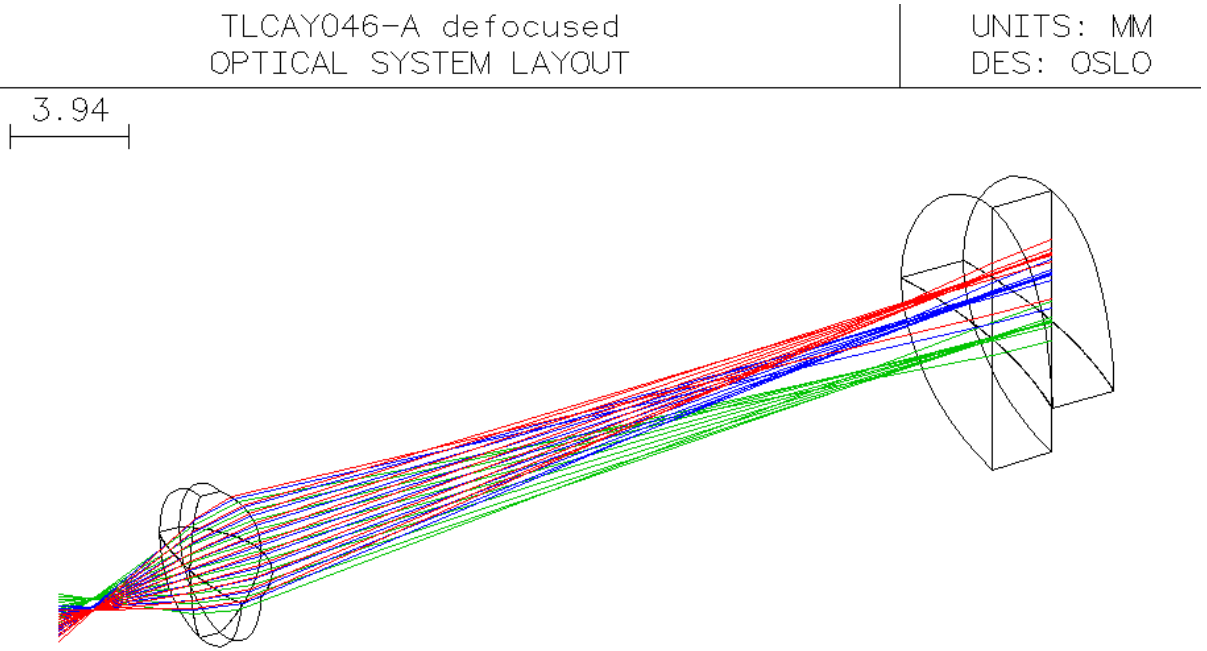
main bar:

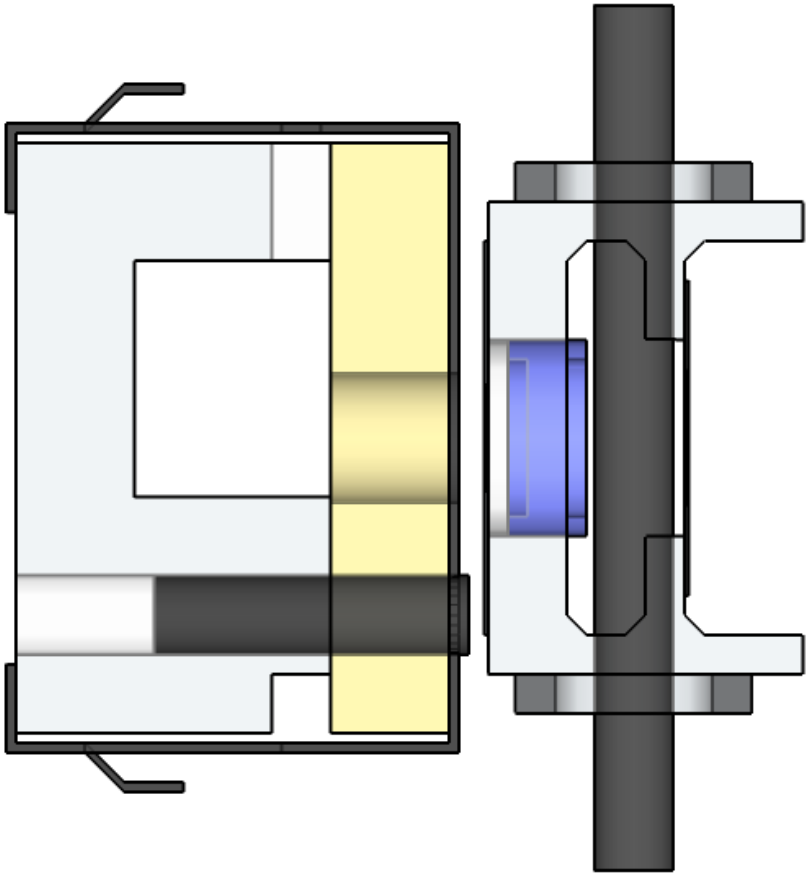
provides rigidity, alignment,
sheet metal clip hold down, contact cooling option



# Design

## relation to previous simulation



# Design

actuators

- piezo bimorph / trimorph  ($10-15/pc)
- mounted underneath the main profile
- mixed coordinates
- tilting triangle mount (small metal parts: shapeways)
- integrated HV driver (Texas instruments)

# Design - Summary

Most critical: initial precision achievable

achieve base flatness and positional accuracy by harnessing the power of
production grade 3-axis CNC milling (not fancy)

LD press fit assembly = in-line optical calibration, can be automated, can be done manually - turning a micrometer and observing the far field spot of active LD, same goes for lens array

# Design - Summary

lightweight lens array has potential for injection molding

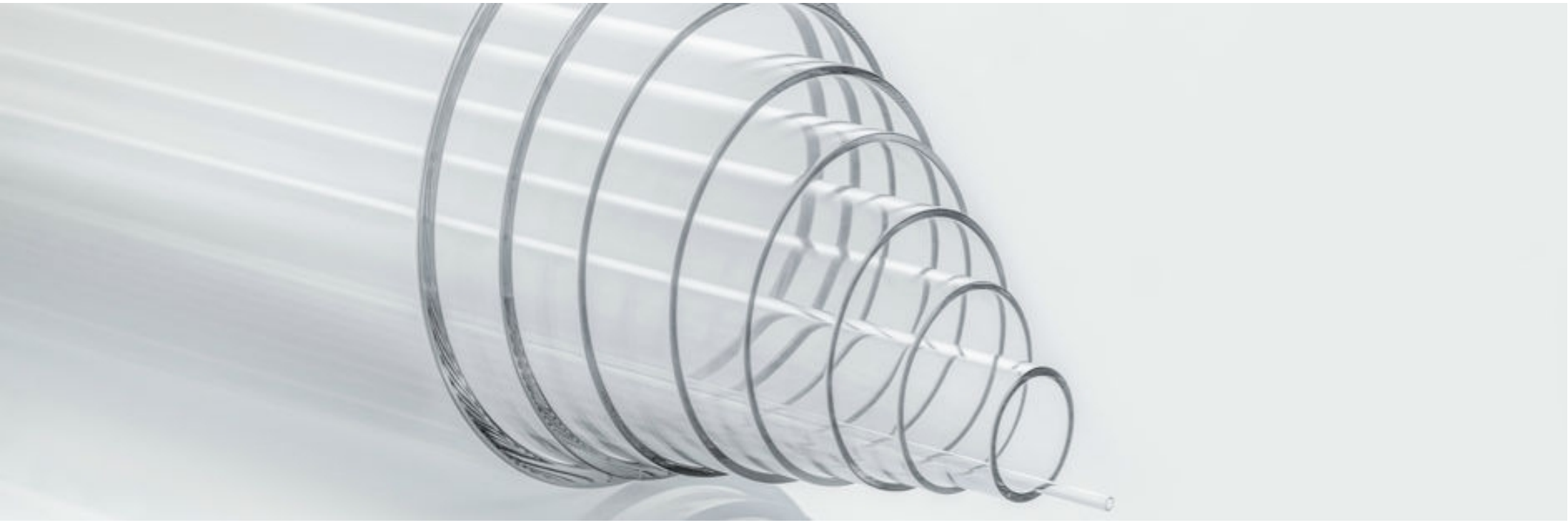
closed loop motion control using piezo actuators and capacitive distance sensing

direct optical feedback possible (reflection) onto cheap camera modules

spot size, scan range per emitter, thermal dissiplation benign

# Outlook

regular glass tubes might be "good enough"
otherwise: Schott KPG (precision glass tubes with ID calibrated on a stainless steel mandrel)
operation possible within CoC tolerance



# Outlook

calibration

- via reflected light from cover glass or glass tube with cheap smartphone camera modules w/o lens
- global calibration by viewing through the build plate during the first layers (filter out laser spectrum, transmit only fluorescence light (green-ish) - best results
- PD monitoring factory calibrated: track LD power

# Outlook

Thank you for your attention!


*helgewurst@web.de*