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In-focus performance from intra-focal measurements for large X-ray mirrors

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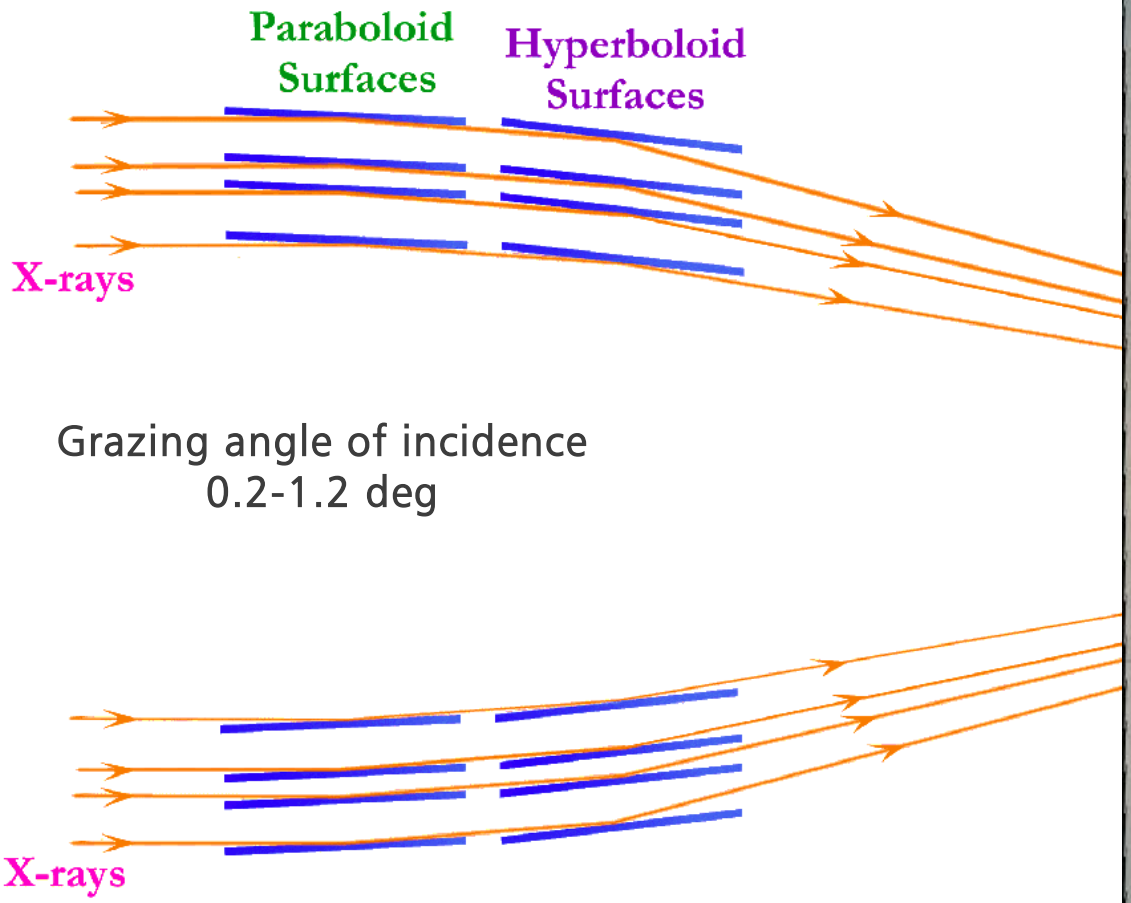
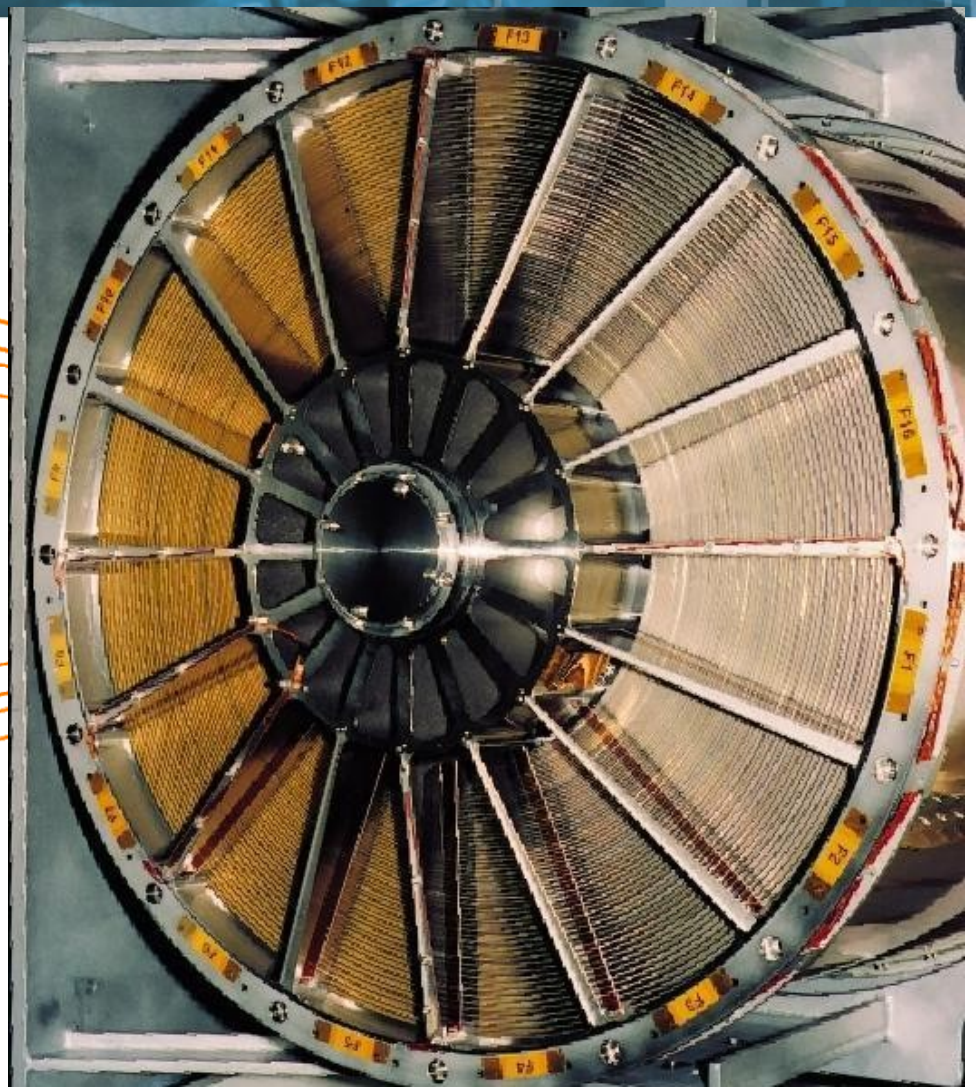
MEADOW 2013, Trieste, 28-30 October, 2013

Wolter I optics

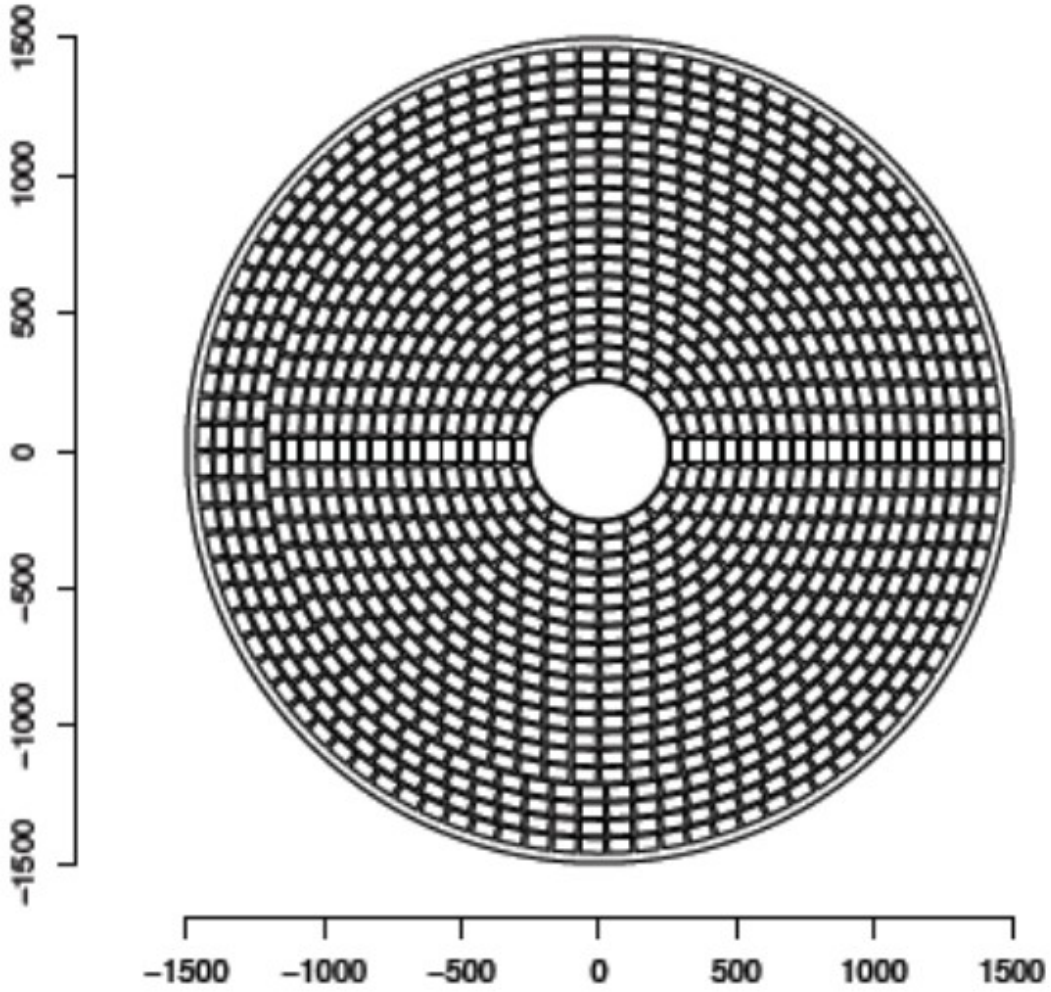


Grazing angle of incidence
0.2-1.2 deg



- Typical X-ray astronomy optics
  - Often approximated by two conical frustra
  - Full shells

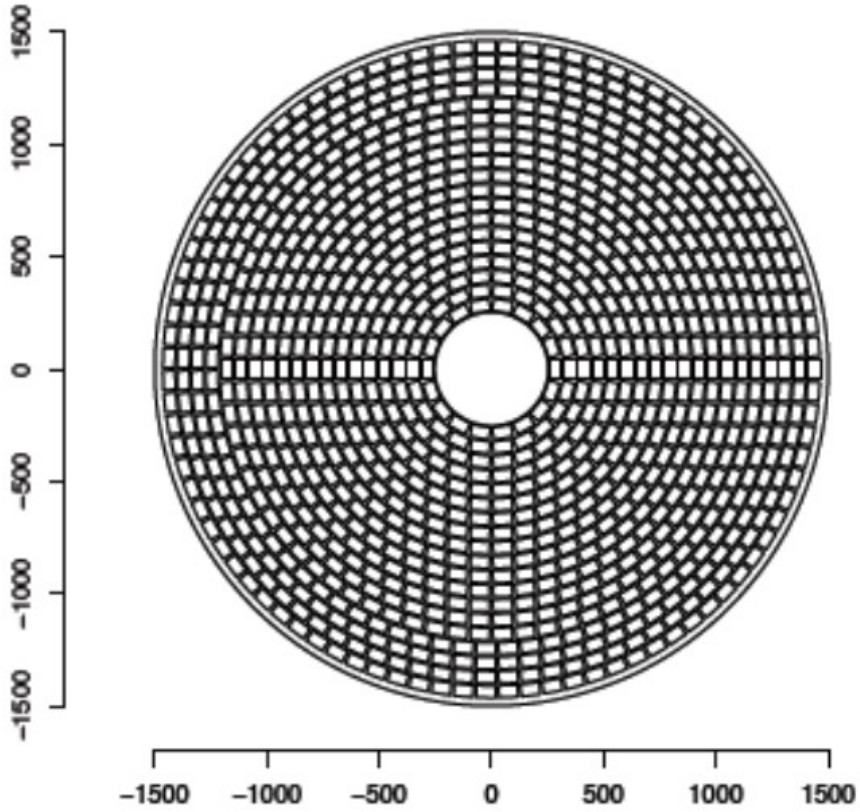
Possible next large mission



- More than 2m diameter
- More than 10m focal length
  - Need to keep incidence angles small
- Segmented
  - Because single shell approach does not scale

What do we want to do?

- Characterize large aperture (>2m) long focal length (>10m) X-ray mirrors
  - Before they are finished
    - Modular construction: feedback data into on-going production
  - In spite of their size
    - Facilities cannot accommodate them when finished



What are the problems?

Why F=20m? Focal length of ATHENA proposal to the European Space Agency

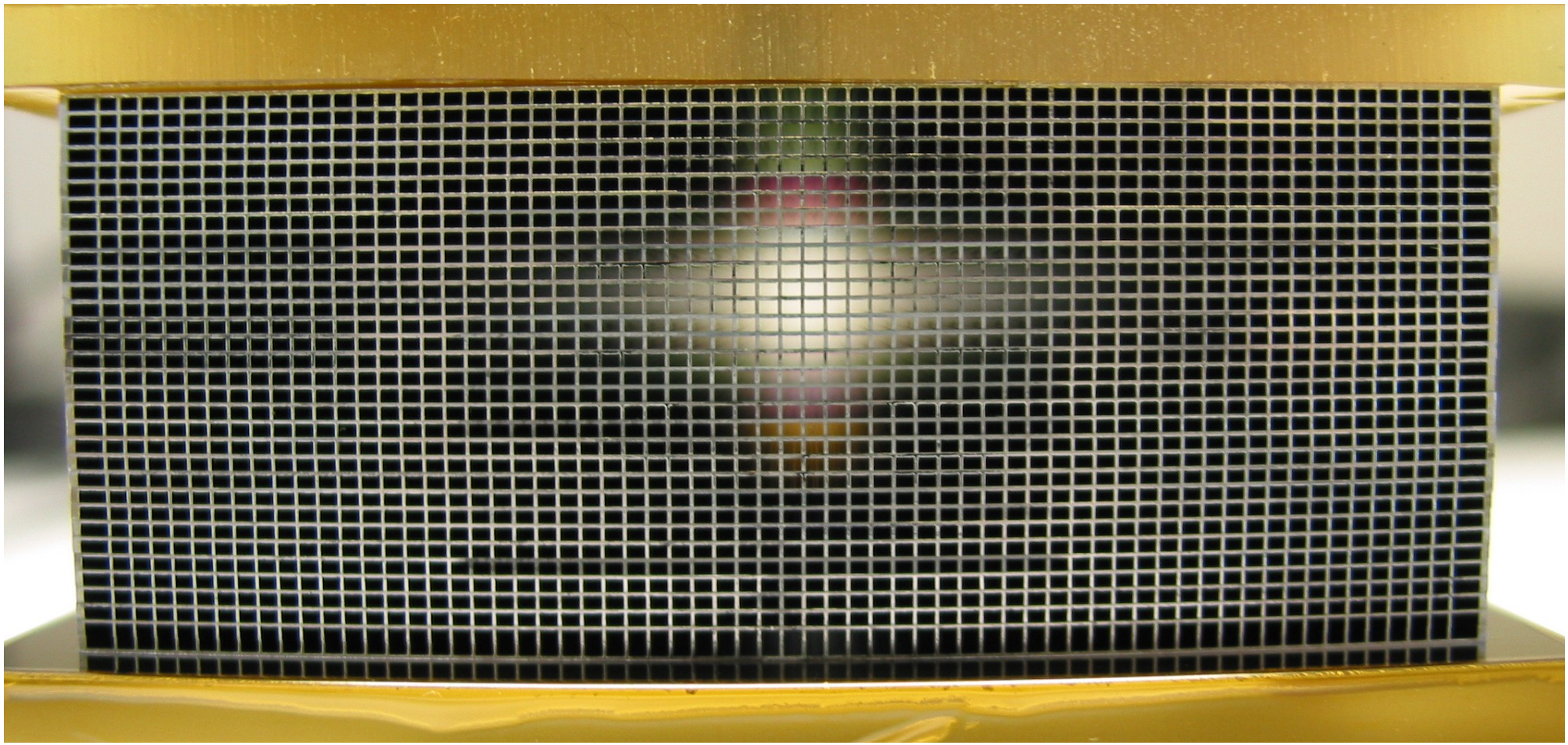
- X-ray facilities are too small
  - Might accommodate F=20m (PANTER and BESSY II can)
  - Cannot accommodate complete aperture
- Full-aperture illumination not possible
  - Beam would have significant divergence
- Need early feedback on mirror production
  - Cannot wait the 1-2 years required to complete the mirror
  - Want to be able to screen/select modules during production
- Would like to garner information to feed a model of the optics
  - Develop numerical model of the performance of the mirror
  - Use lab metrology to predict performance without complete X-ray characterization

What can one hope to have?

- Full illumination of sub-modules
  - @ PANTER (see presentations by Vadim Burwitz and Benedikt Menz)
- Intra-focal pencil beam measurements
  - @ BESSY II XPBF, detector @ 5m
- For F=20m, in focus pencil beam measurements
  - @ BESSY II X-ray Pencil Beam Facility
  - Only 3-4 weeks/year
- We routinely use the BESSY II XPBF facility

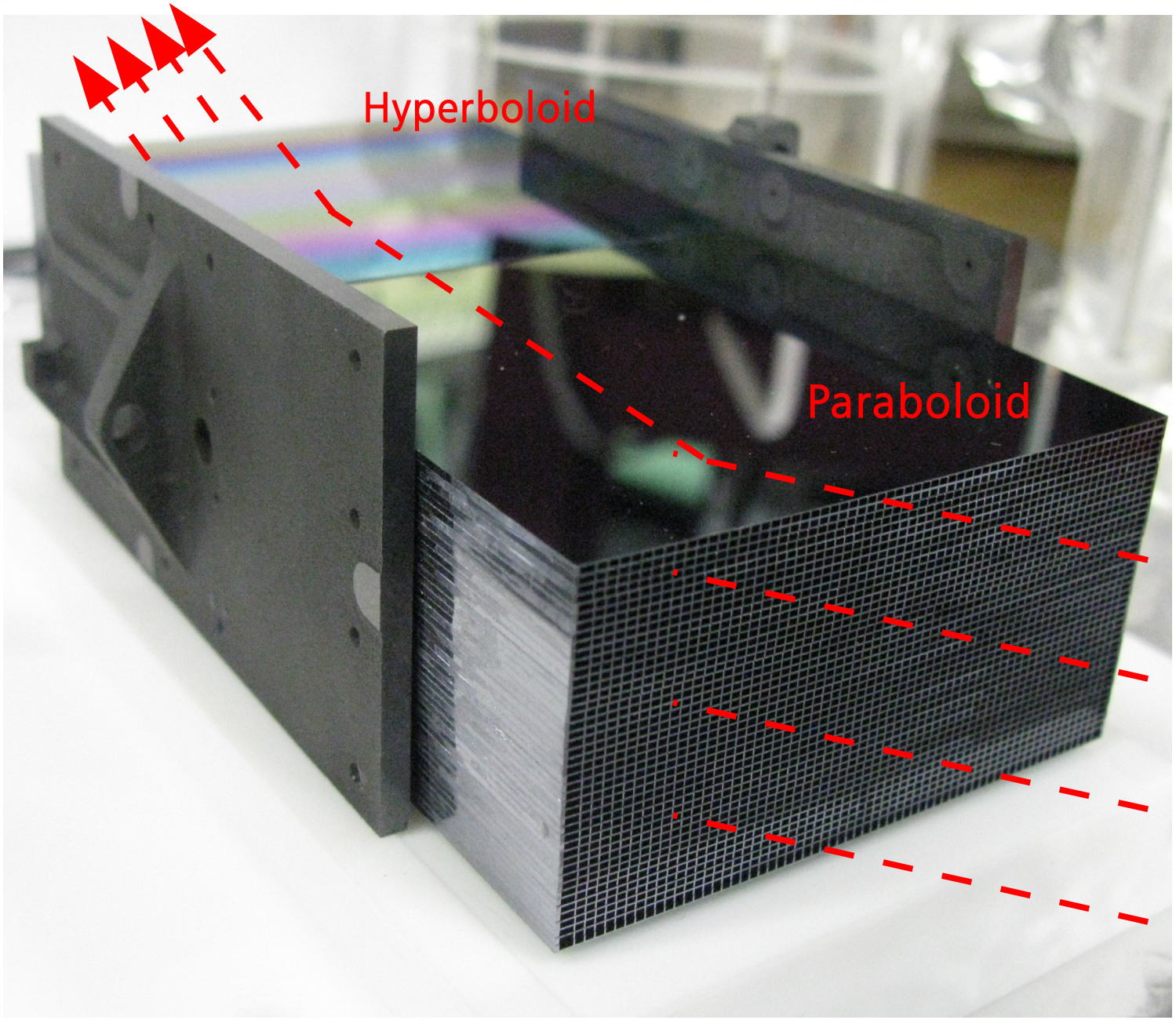
Silicon pore optics: reminder of what they look like

66mm

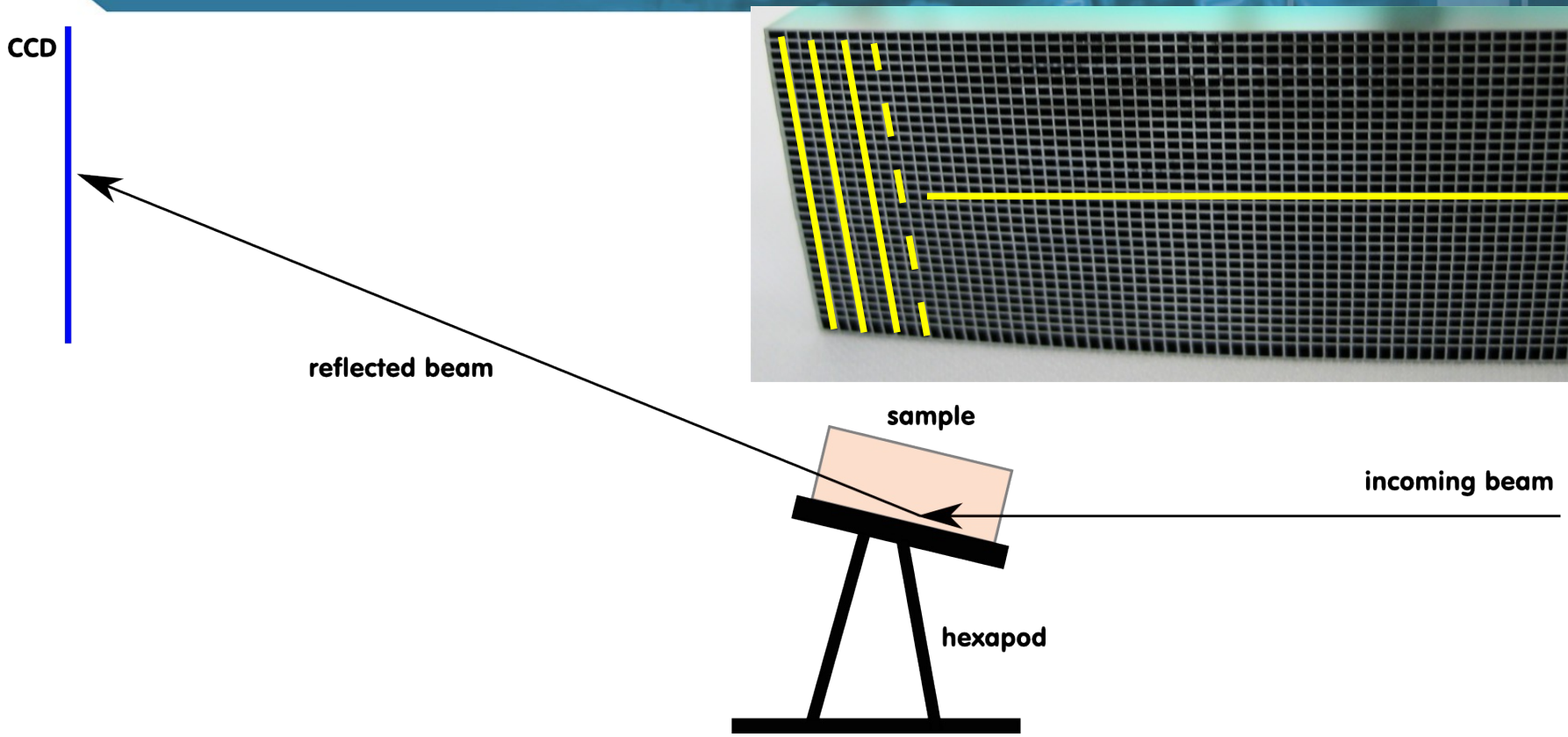


Silicon Pore Optics fabrication was explained yesterday by Marcelo Ackermann

Two SPO modules in a Wolter I configuration

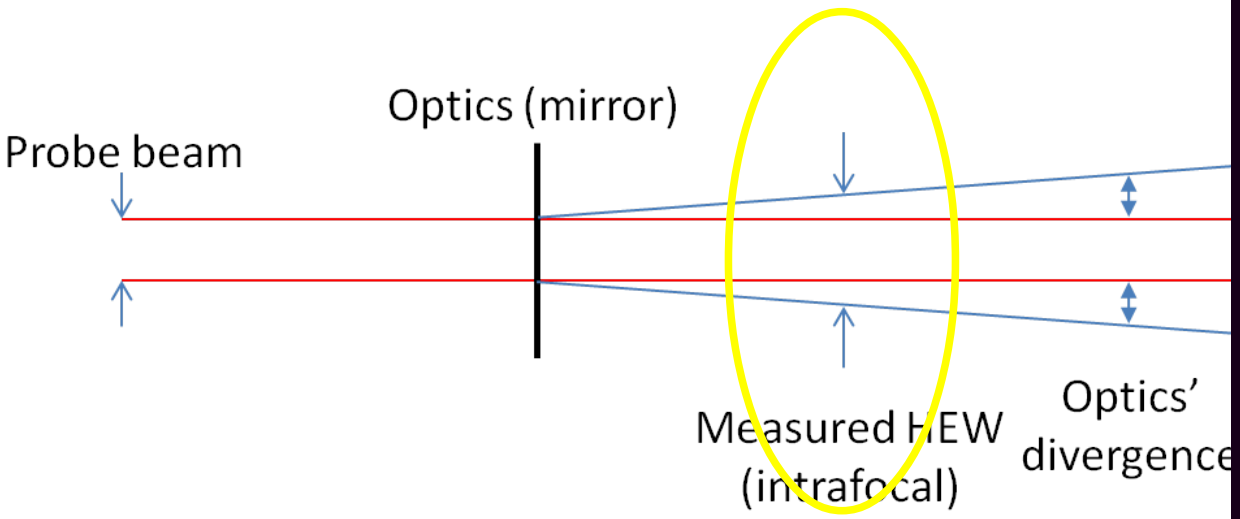


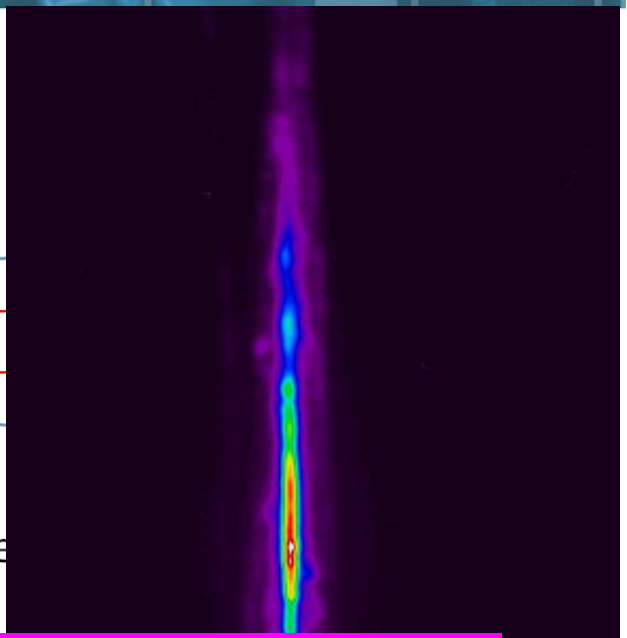
Pencil beam measurements

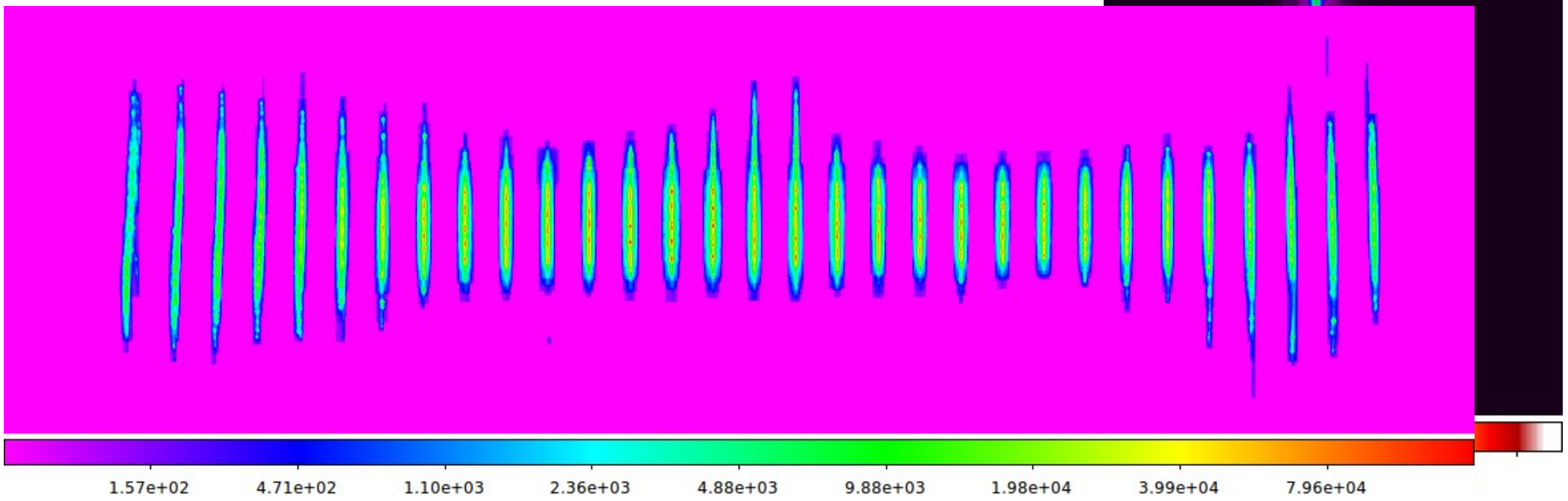


- Sample moved across the beam
  - Top hat, 100 μm squared, divergence somewhat less than 1"
- CCD moved to intercept the beam
- Software re-assembles picture as if the beam had moved across the sample

Pencil beam measurements







Extract information from measurements

- Use the shape of the reflected beam to derive statistical information on the surface properties (see poster by Mark Vervest)
- Predicted vs measured position of the reflected spot to measure the large scale deformations
- Feed into numerical model of the optics to predict performance
- Predict 20m (in-focus) performance from 5m (intra-focal) data

Pencil beam measurements and predictions so far

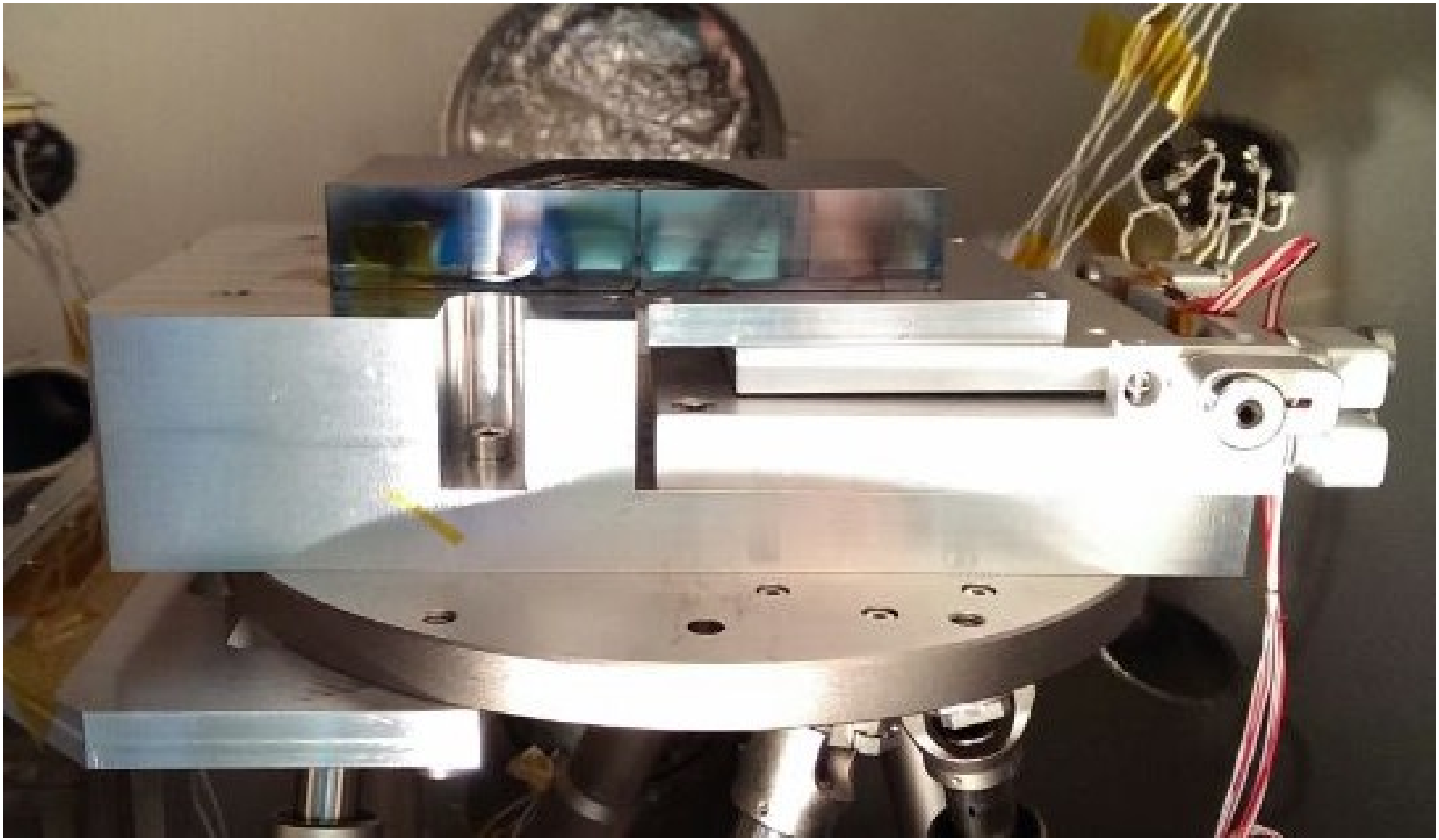
- Samples measured at 5m or 20m in various stages of production
- Forward tracing method used extensively
- One SPO mirror module measured at BESSY II (5m, 20m) and PANTER (in focus)
  - HEW results are in agreement within a few seconds of arc
  - Forward tracing from intra-focal measurements seems to work.
- Validating the method and validating the algorithm at the same time
  - Less than ideal
  - Wish to validate the algorithm with reference optics that have extensive metrology

Concerted validation effort with reference optics

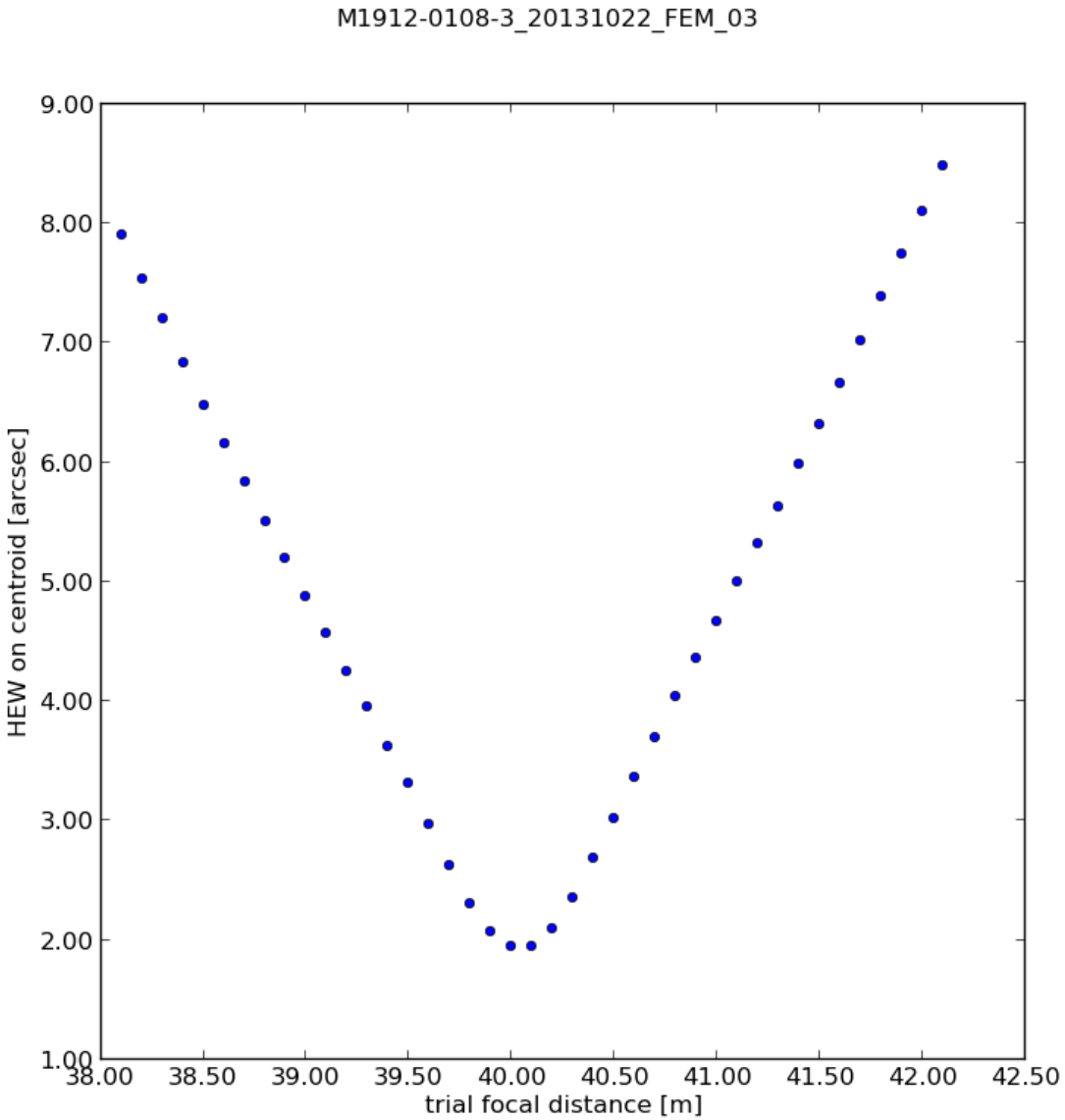
- Two mandrels that will eventually be used for SPO production
  - Conical: approximate paraboloid/hyperboloid
  - Surface better than 1" rms (Zeiss)
  - Measured also at NOM
  - Will be measured with our own metrology set up (fringe reflection technique)
- X-ray measurements at BESSY II (5m configuration, done)
  - Individually and as a Wolter I system
  - Does the method work on reference optics?
  - Predict in-focus performance of Wolter I system for later verification
- Same measurements at BESSY II in 20m configuration (to be done, week 47)
  - Do 5m predictions match in-focus measurements?

Reference optics: two mandrels

Radius of curvature 737mm
Dimensions 65x65 mm^2

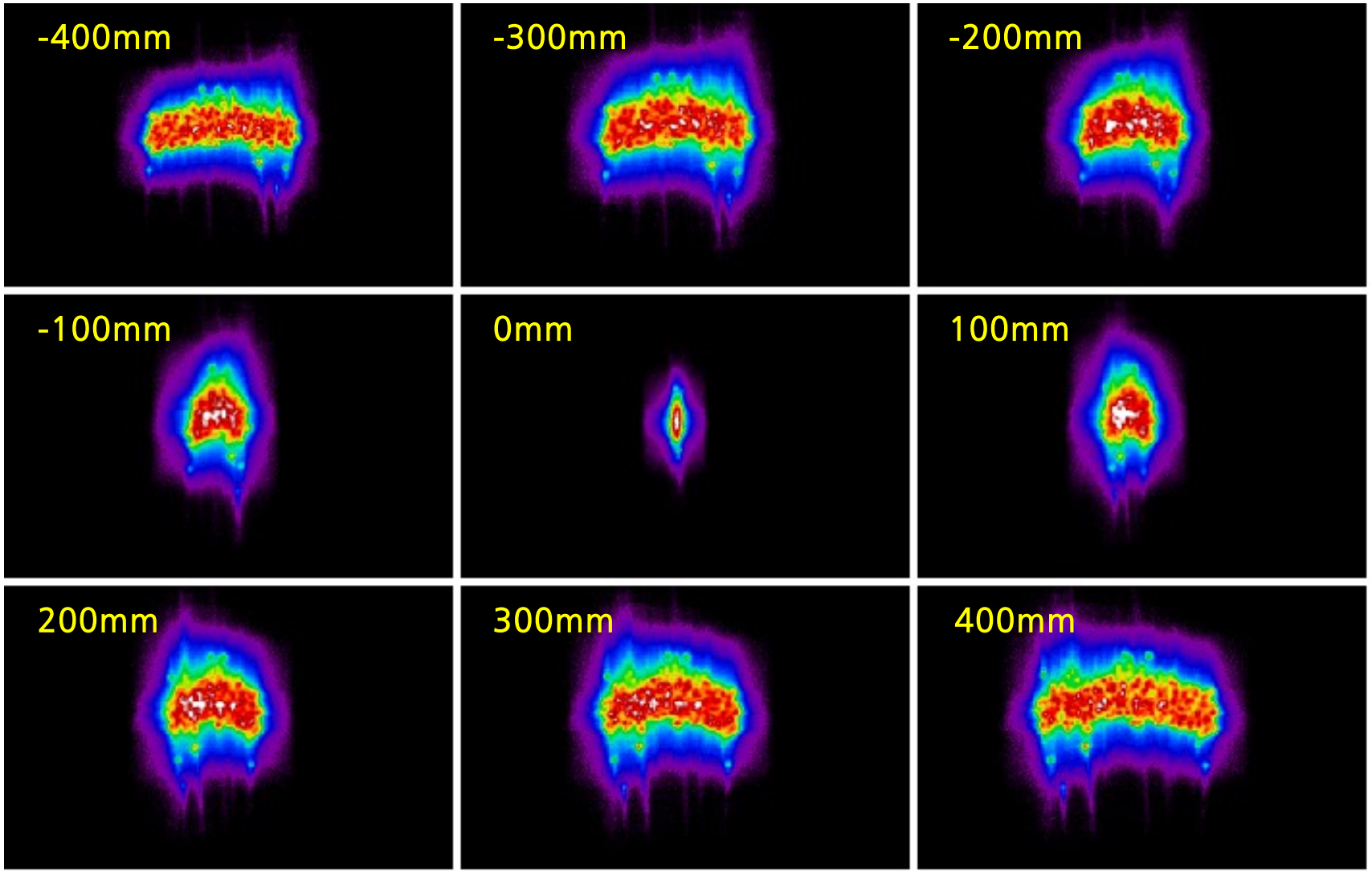


Parabolic mandrel focuses at 2xF=40m (preliminary result)



- 5m data used to calculate where the optics focus
- Use Half Energy Width to determine the best focus
  - HEW = Half Power Diameter
- Exact focus expected at 40013mm
- The optics have a depth of focus of a few mm

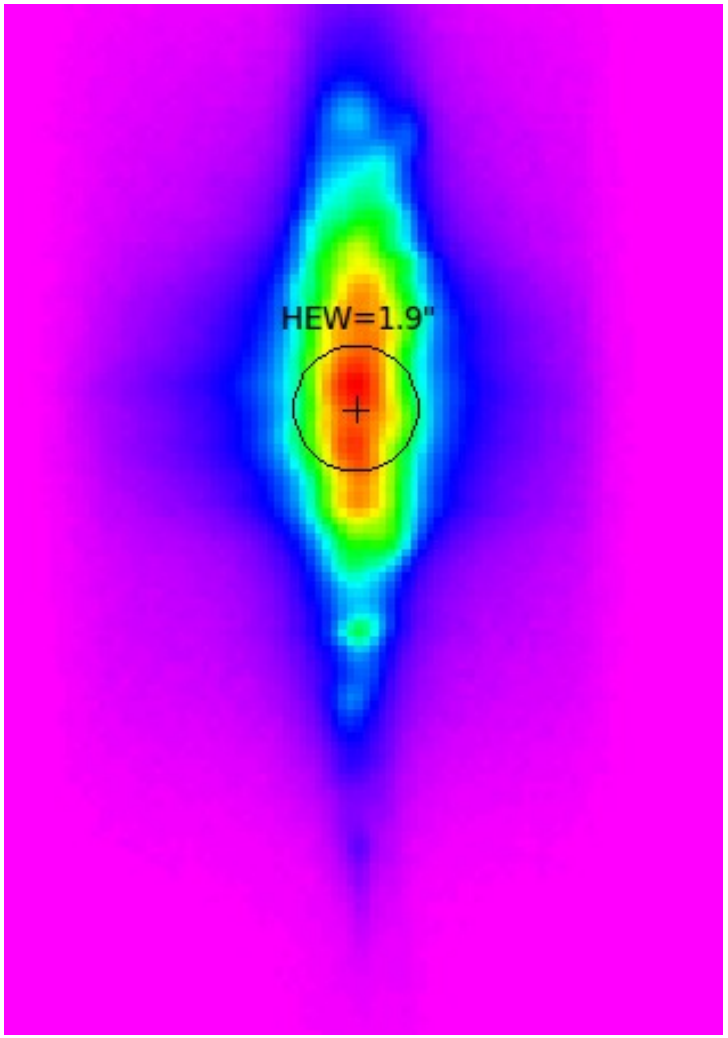
Conical mandrel: tracing around the expected focus



Based on 5m/intra-focal data

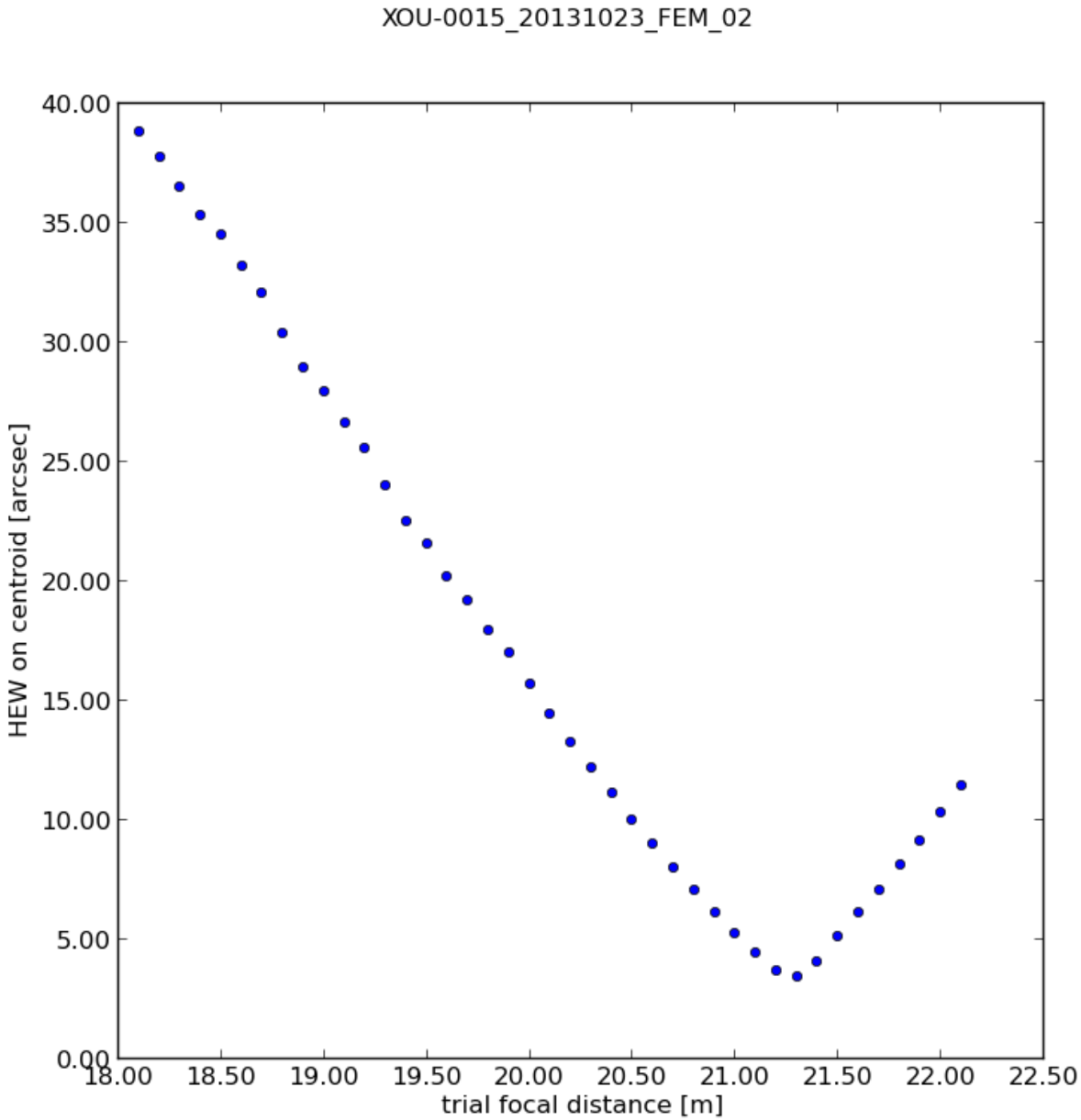
Predicted in-focus performance

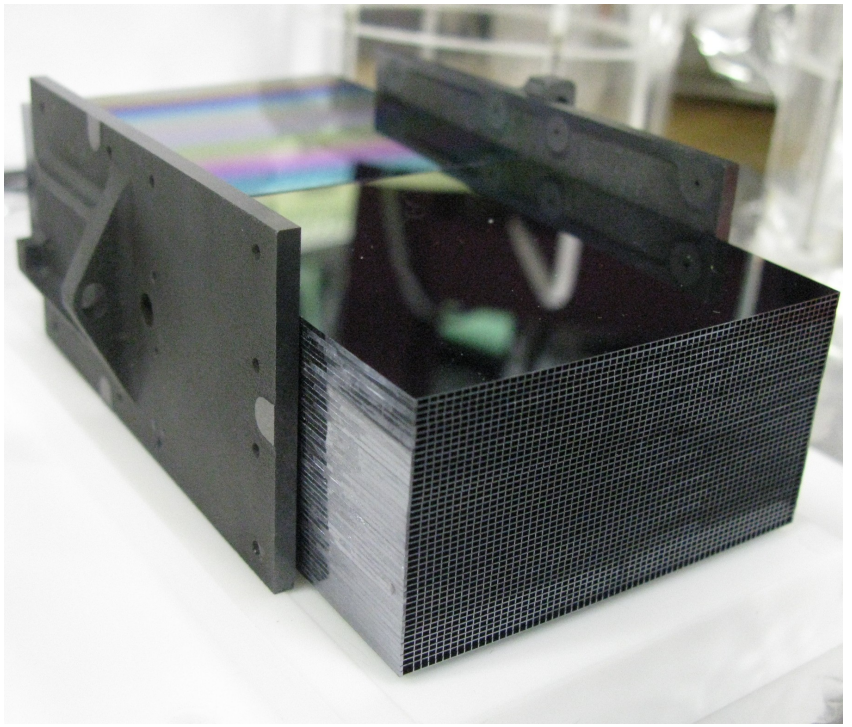
Parabolic mandrel: based on geometry and metrology expect HEW about 2”



- Forward tracing algorithm puts the focus at the expected distance and with the expected optical performance

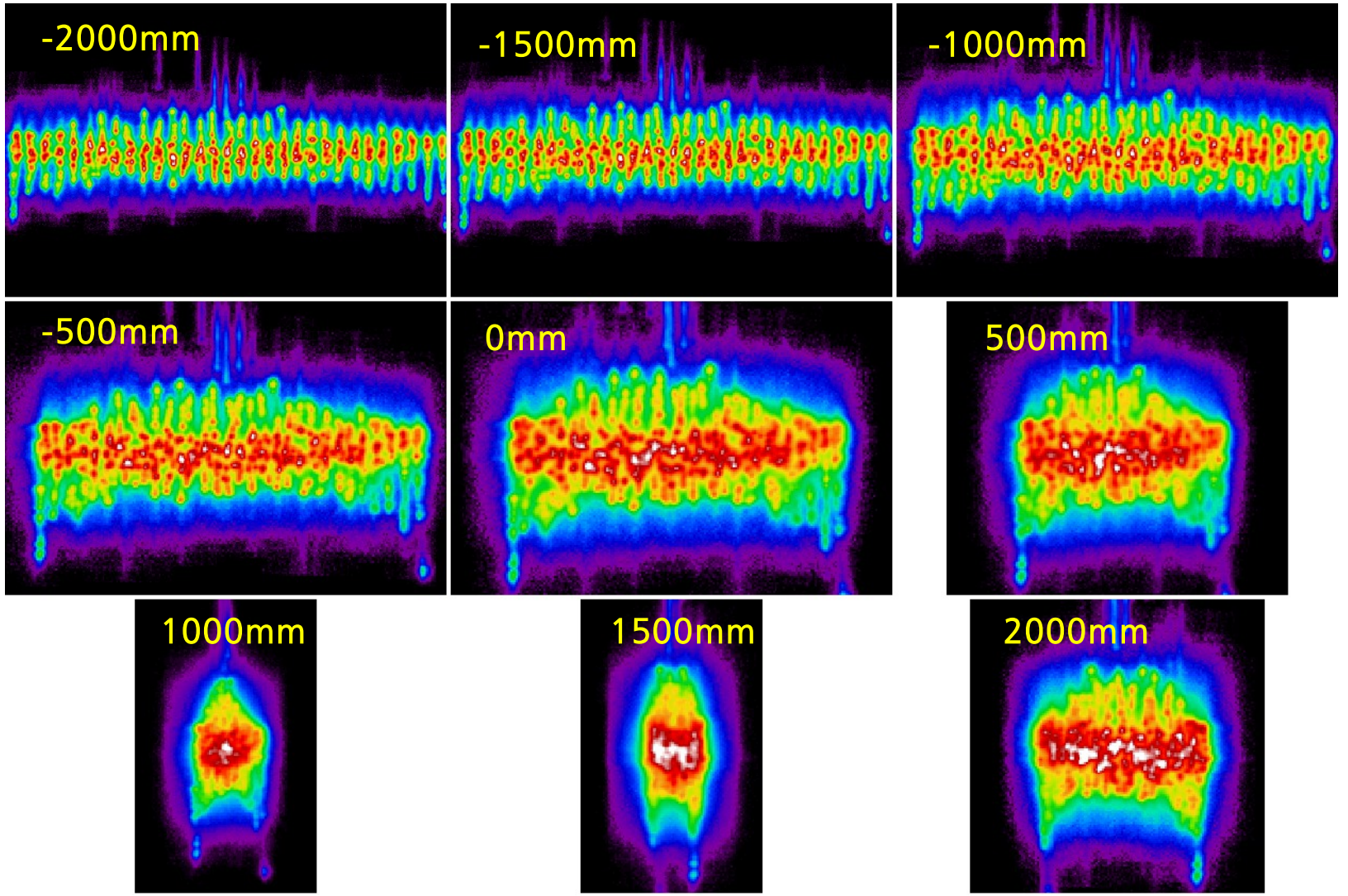
Wolter I combination (F=20m)





Shallower kink angle puts focus at somewhere beyond 21m

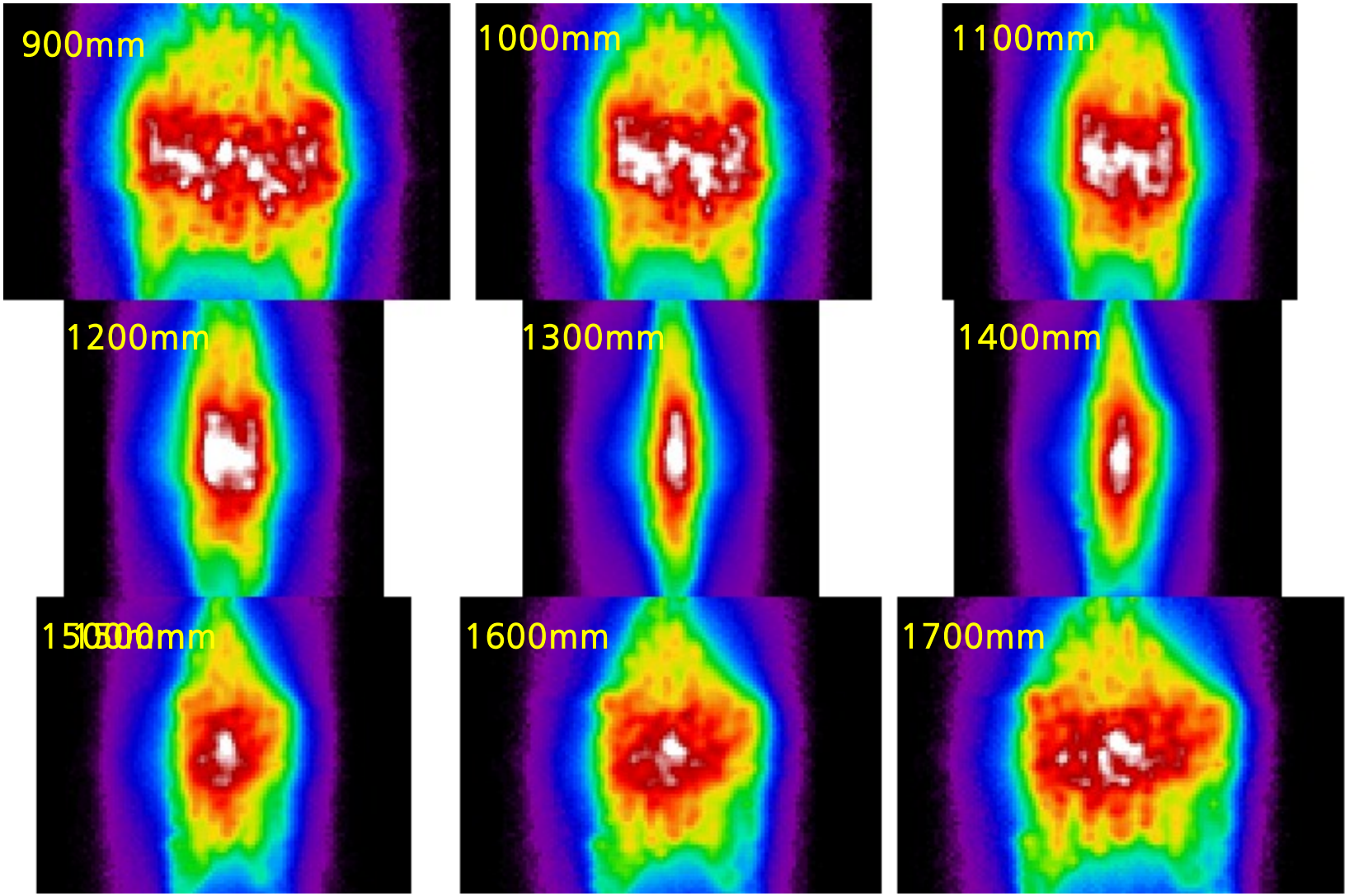
Wolter I combination: forward tracing



Based on 5m/intra-focal data

Wolter I combination: forward tracing

Best focus HEW around 4”



Based on 5m/intra-focal data

Final remarks

- Characterization of large X-ray optics with pencil beam a necessity
- Working on theoretical understanding of BESSY II pencil beam data
  - But method of wider applicability
- Tracing of 5m data to 20m and comparison with in-focus measurements in agreement on one SPO mirror module
  - But it was not a reference optics
- Tracing 5m/20m on reference optics
  - Mandrels + Wolter I combination @ 5m
  - Mandrels + Wolter I @ 20m (week 47 @ BESSY II)
- Aim to fully validate the method and the software in order to speed up the characterization of mirror modules without the need for in-focus measurements
- Aim to couple measurements to metrology and simulations to select/evaluate optics to limit the need for X-ray measurements

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