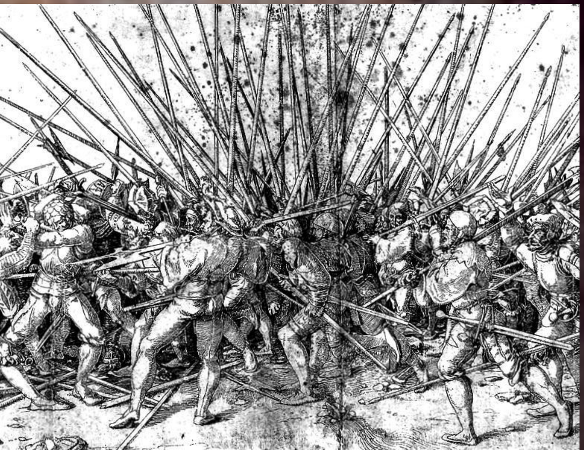
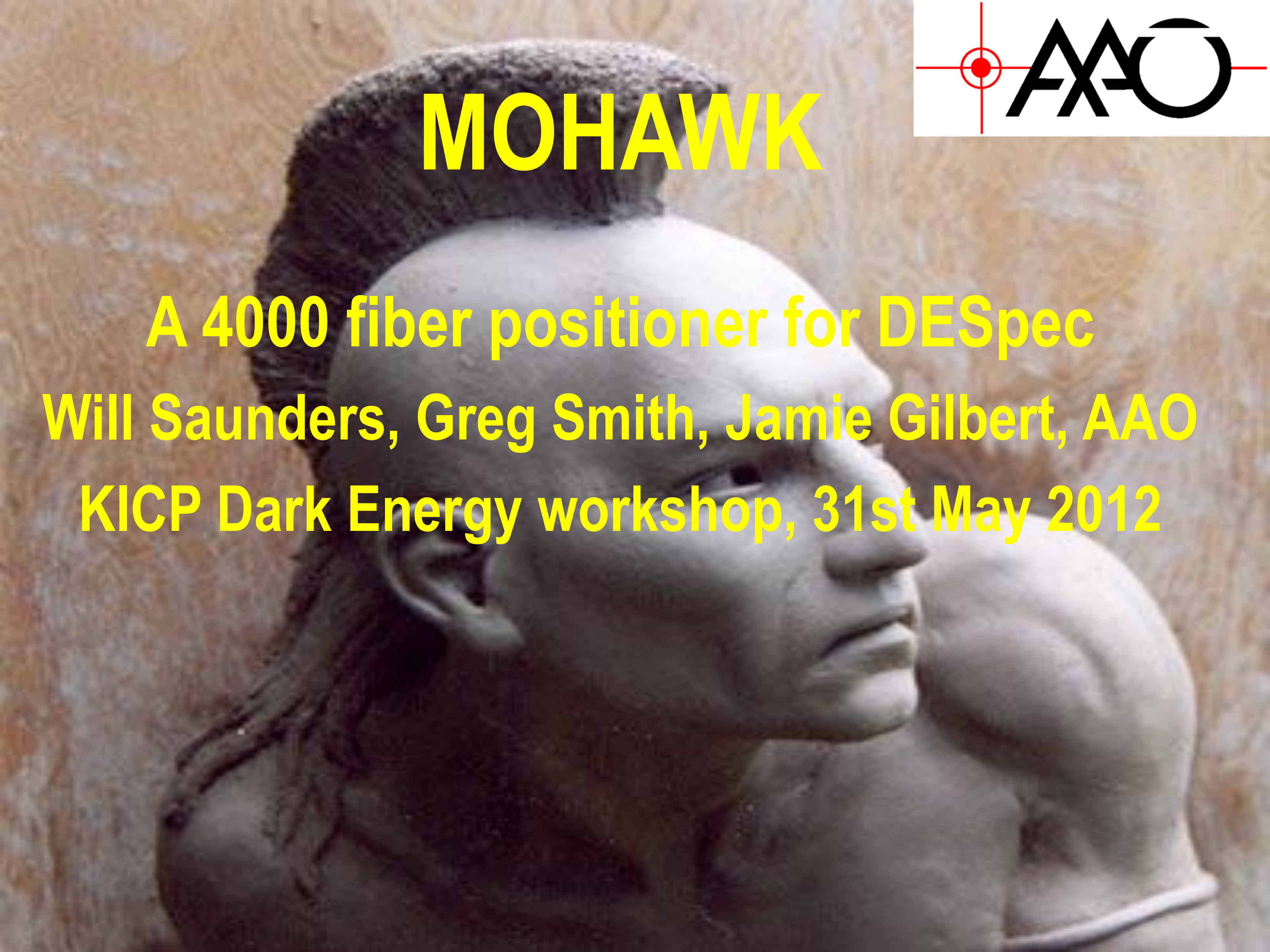
MOHAWK

A 4000 fiber positioner for DESpec

Will Saunders, Greg Smith, Jamie Gilbert, AAO

KICP Dark Energy workshop, 31st May 2012





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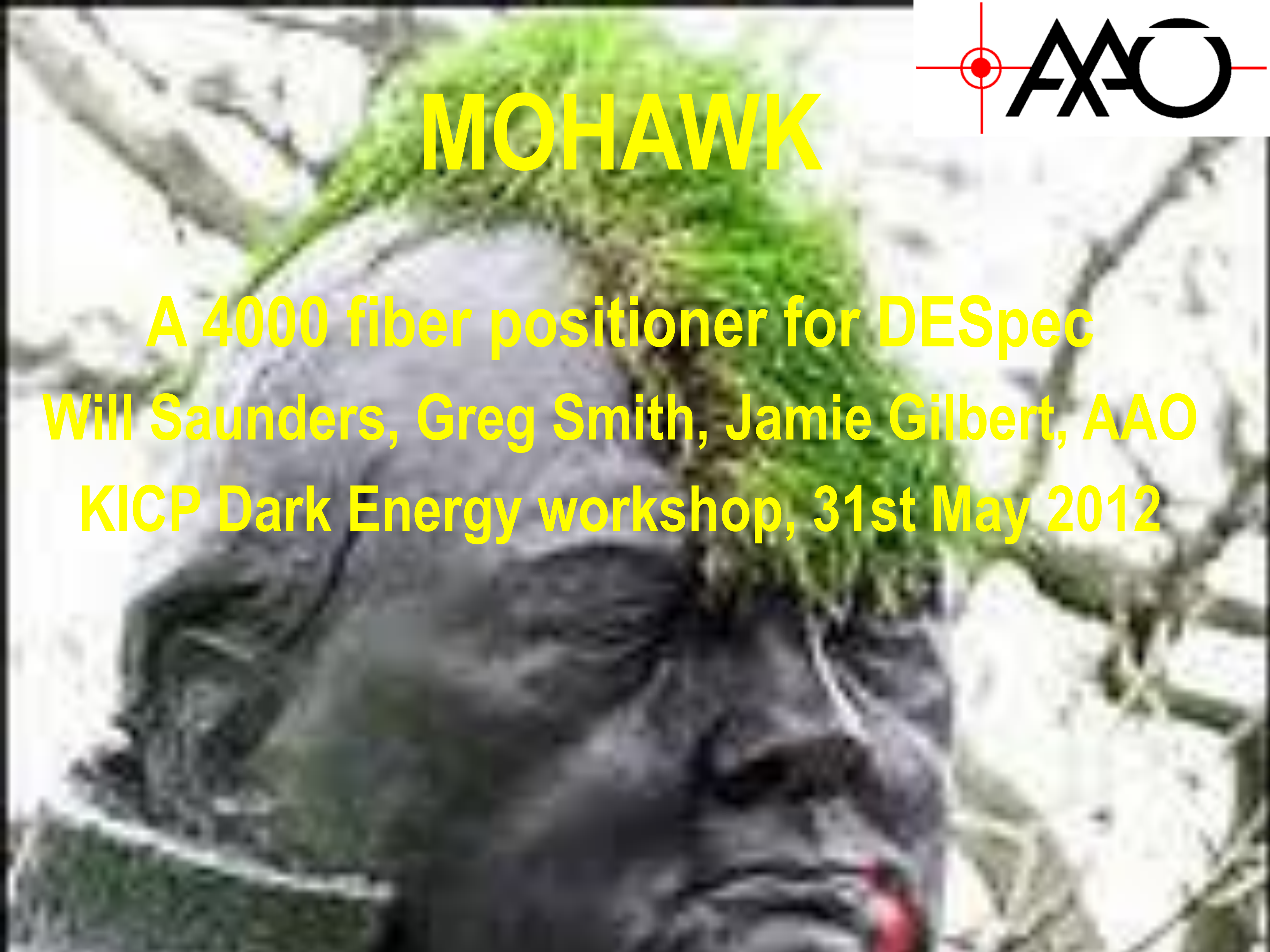

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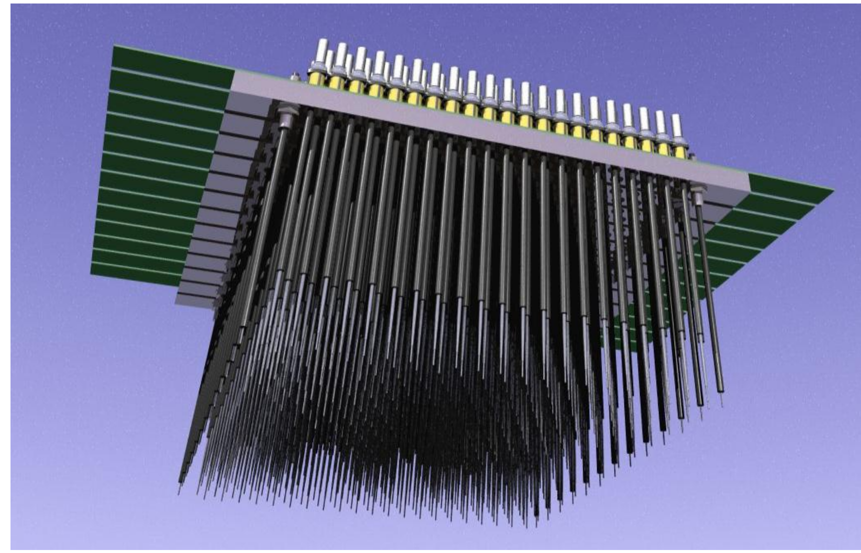
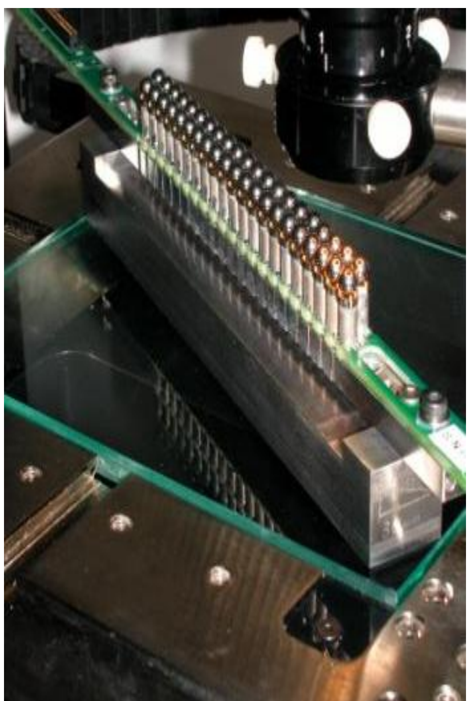
ECHIDNA

FMOS instrument for Subaru needed 400 fibres in 150mm diameter focal plane - so needed a completely new and very compact design.





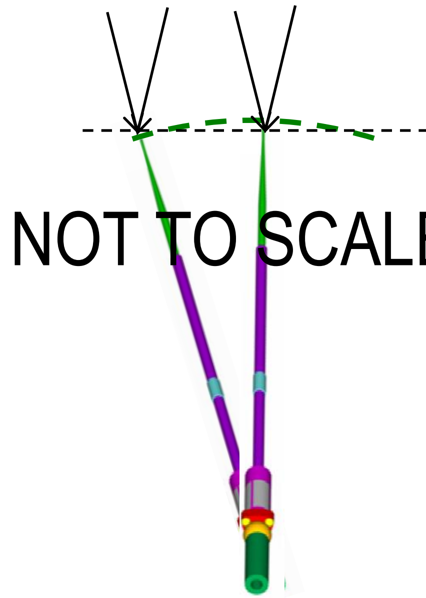
- Echidna uses 'spines' – carbon-fibre tubes, with a piezo-electric stick-slip actuator to position fibres.
- **7.2mm pitch** between fibres
- Short repositioning times*

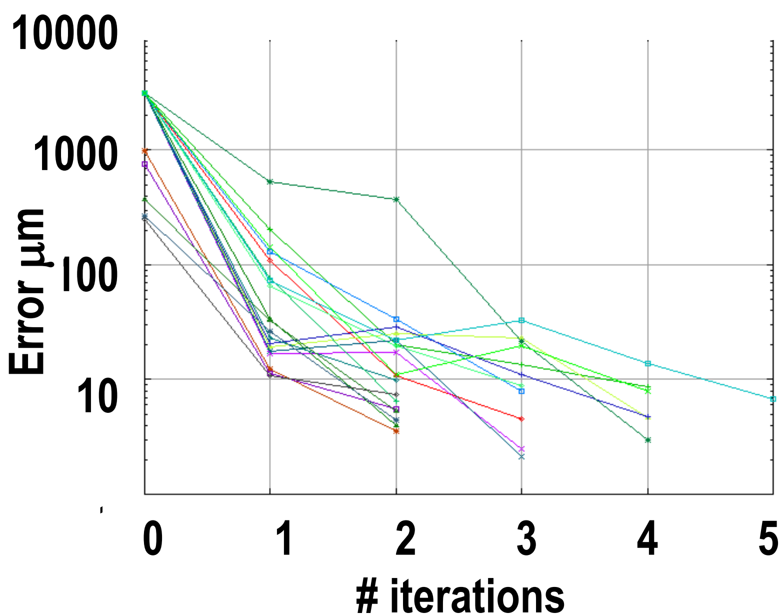
*** conditions apply**

ECHIDNA features

- Very close minimum target separation, < 1mm
- Patrol radius ~ pitch, so multiple coverage
- Spine tilt introduces focal errors (up to $\pm 86\ \mu$m), and telecentricity errors, (up to 2.75°)

  $\Rightarrow$ 5-10 % throughput and/or etendue loss



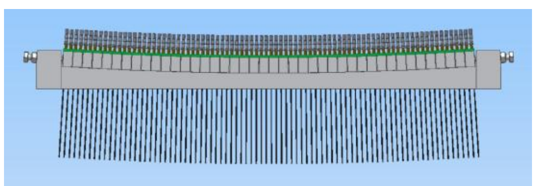


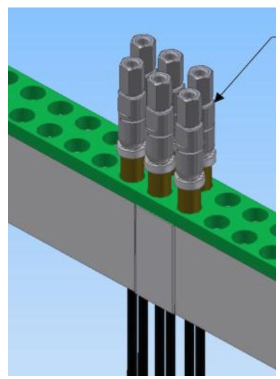
Spines reposition in parallel, several iterations per fibre, few seconds per iteration, <10 μm final positioning error.

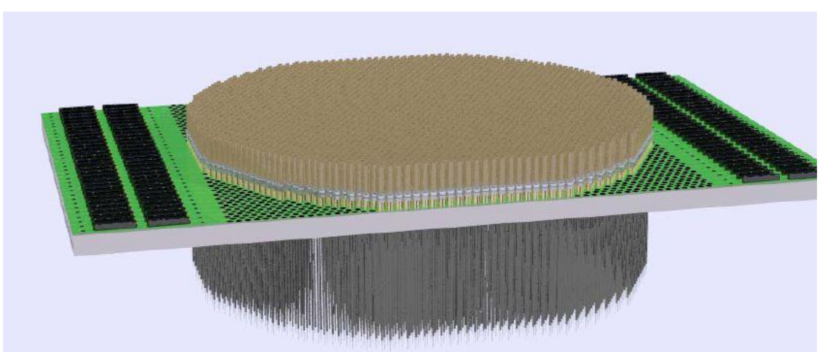
Echidna in operation

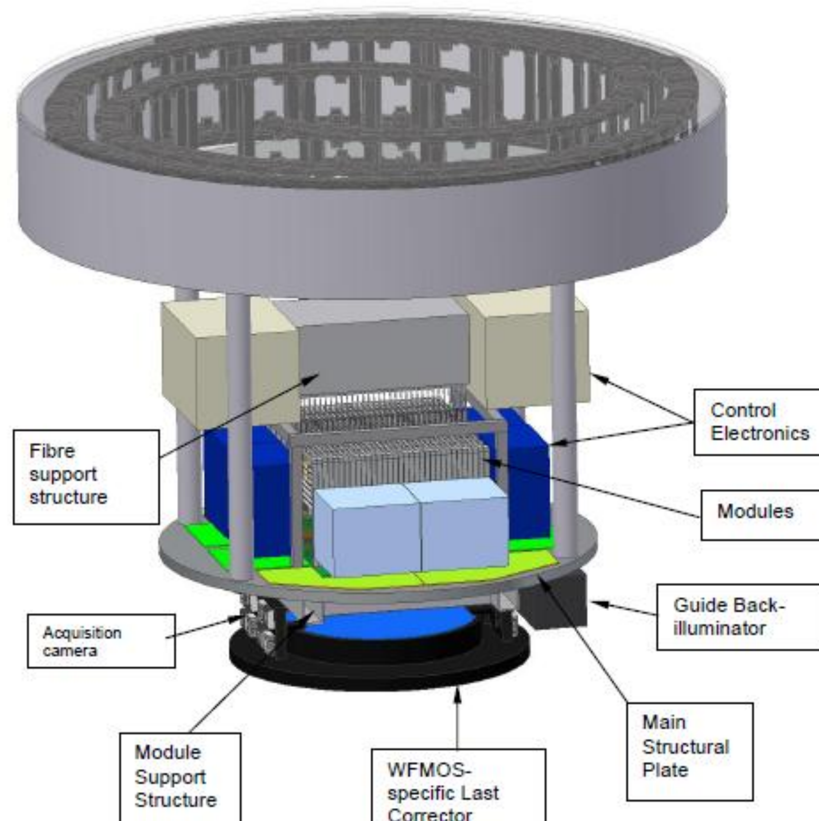
WFMOS concept design

- 2005 proposal for 4500 fibre positioner for Gemini or Subaru, primarily to study dark energy.
- Curved focal plane, 500mm diameter, 7-8mm pitch.
- Fully prototyped at AAO
- Lost out to COBRA!



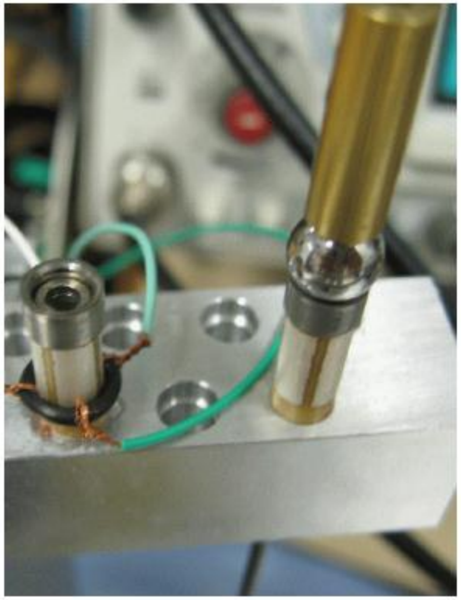




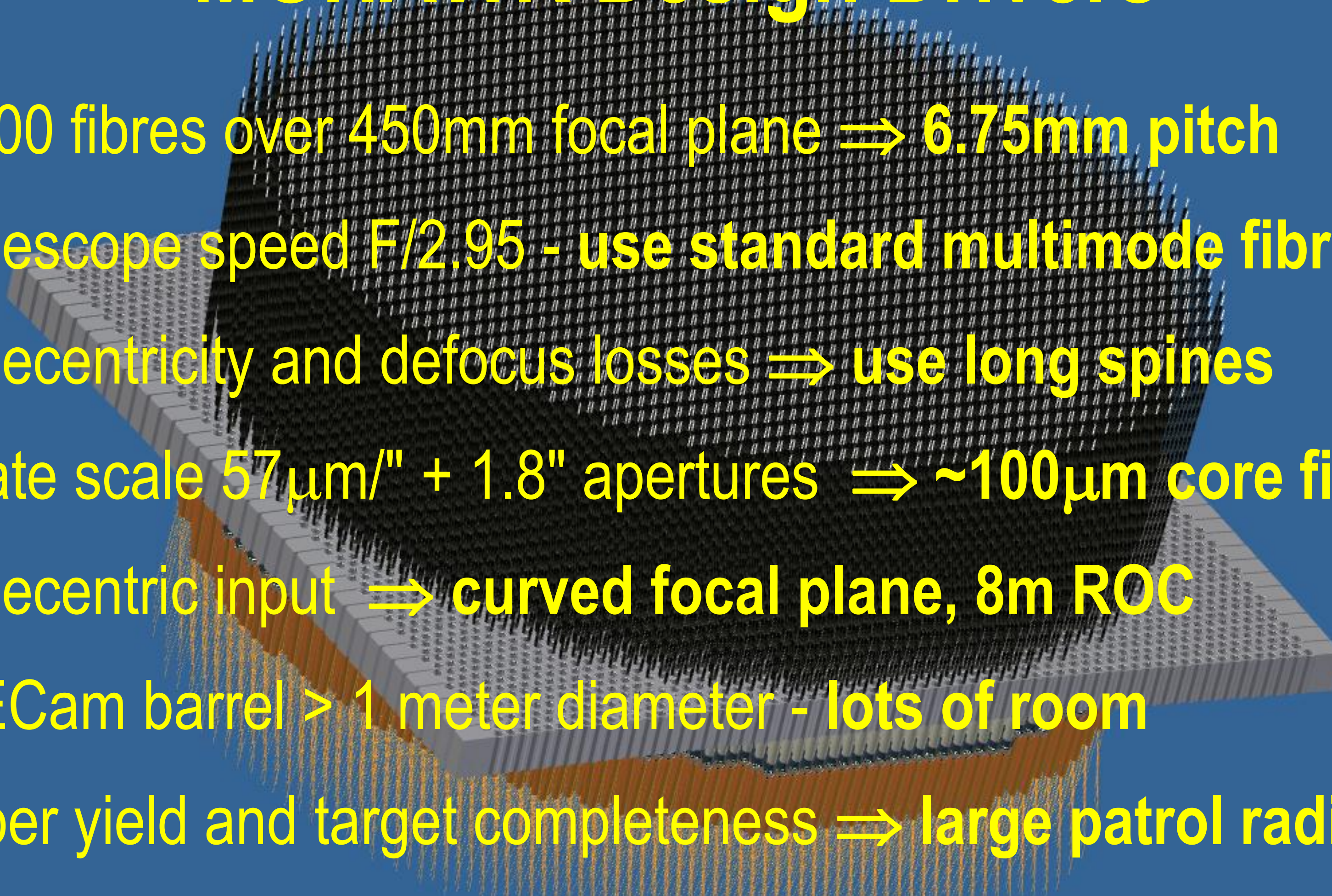


WFMOS-A concept design

- 2008 proposal to put cut-down WFMOS on AAT
- 1600 spines over 450mm FOV
- Simplified design – 7 parts per actuator, mostly off-the-shelf
- Prototype module built
- Costed at A$2.4M !

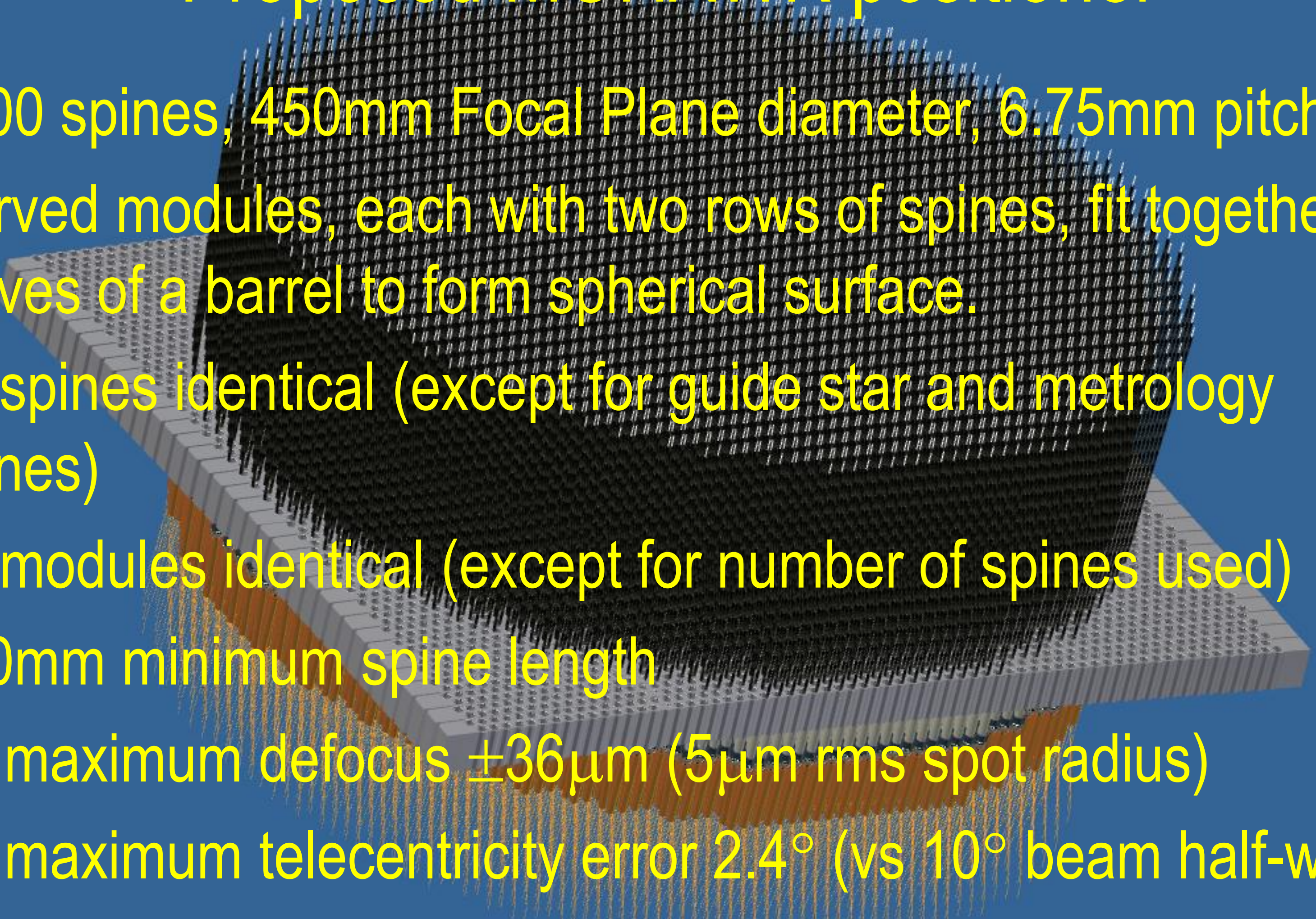


MOHAWK Design Drivers



- 4000 fibres over 450mm focal plane ⇒ **6.75mm pitch**
- Telescope speed F/2.95 **- use standard multimode fibres**
- Telecentricity and defocus losses ⇒ **use long spines**
- Plate scale 57μm/" + 1.8" apertures ⇒ **~100μm core fibers**
- Telecentric input ⇒ **curved focal plane, 8m ROC**
- DECam barrel > 1 meter diameter - **lots of room**
- Fiber yield and target completeness ⇒ **large patrol radius**
- Must be **low cost, low risk, simple, modular.**

Proposed MOHAWK positioner

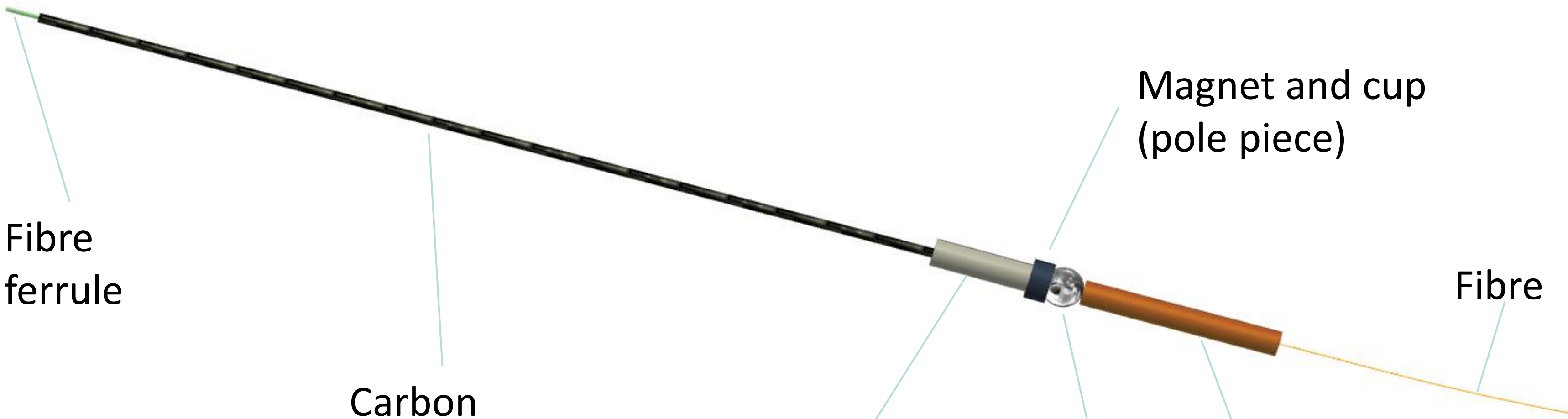


- 4000 spines, 450mm Focal Plane diameter, 6.75mm pitch.
- Curved modules, each with two rows of spines, fit together like staves of a barrel to form spherical surface.
- All spines identical (except for guide star and metrology spines)
- All modules identical (except for number of spines used)
- 160mm minimum spine length

  $\Rightarrow$ maximum defocus $\pm 36\mu$m (5μm rms spot radius)

  $\Rightarrow$ maximum telecentricity error $2.4°$ (vs $10°$ beam half-width)
- Now prototyping longer spines to further reduce these errors.

1 MOHAWK spine

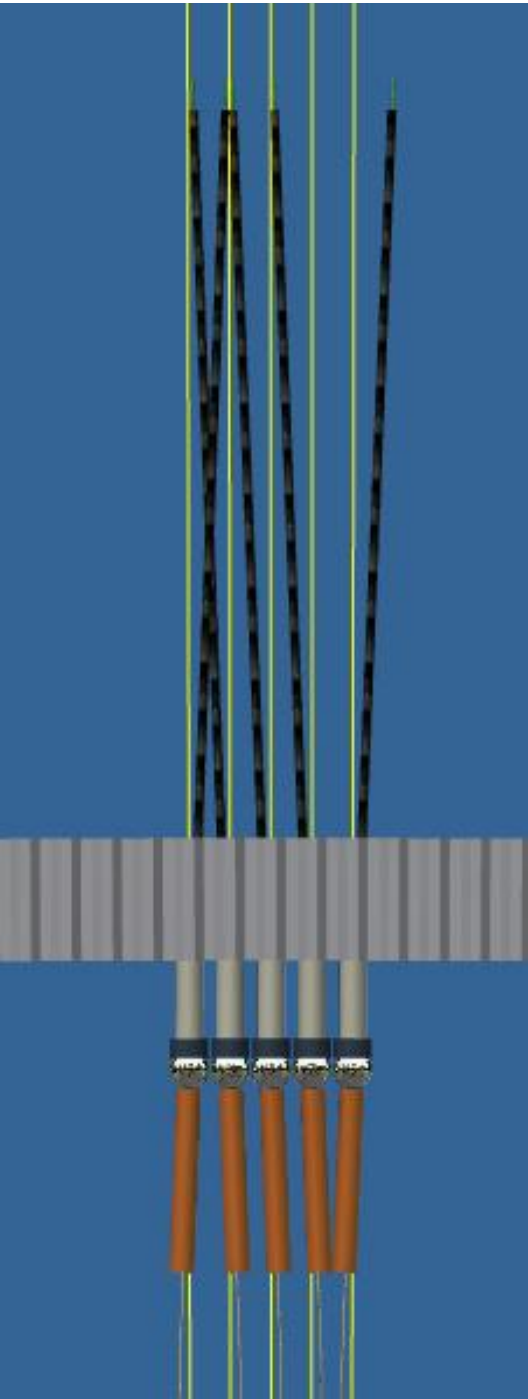


Spine length = 195mm

Ferrule protrudes 5mm past end of carbon fibre tube

Spine tip to ball distance = 162mm

Tungsten counterweight may be used if size becomes issue



5 MOHAWK spines

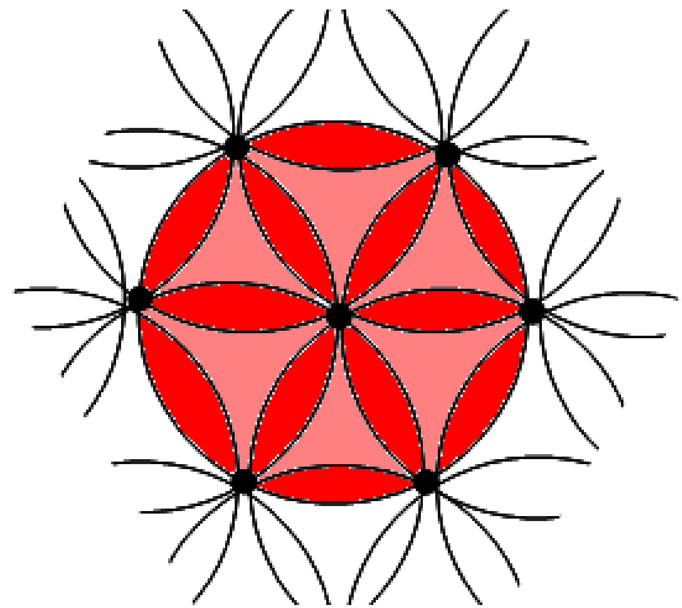
The yellow lines indicate home positions.

The first and last spines are pointing to the right as far as possible.

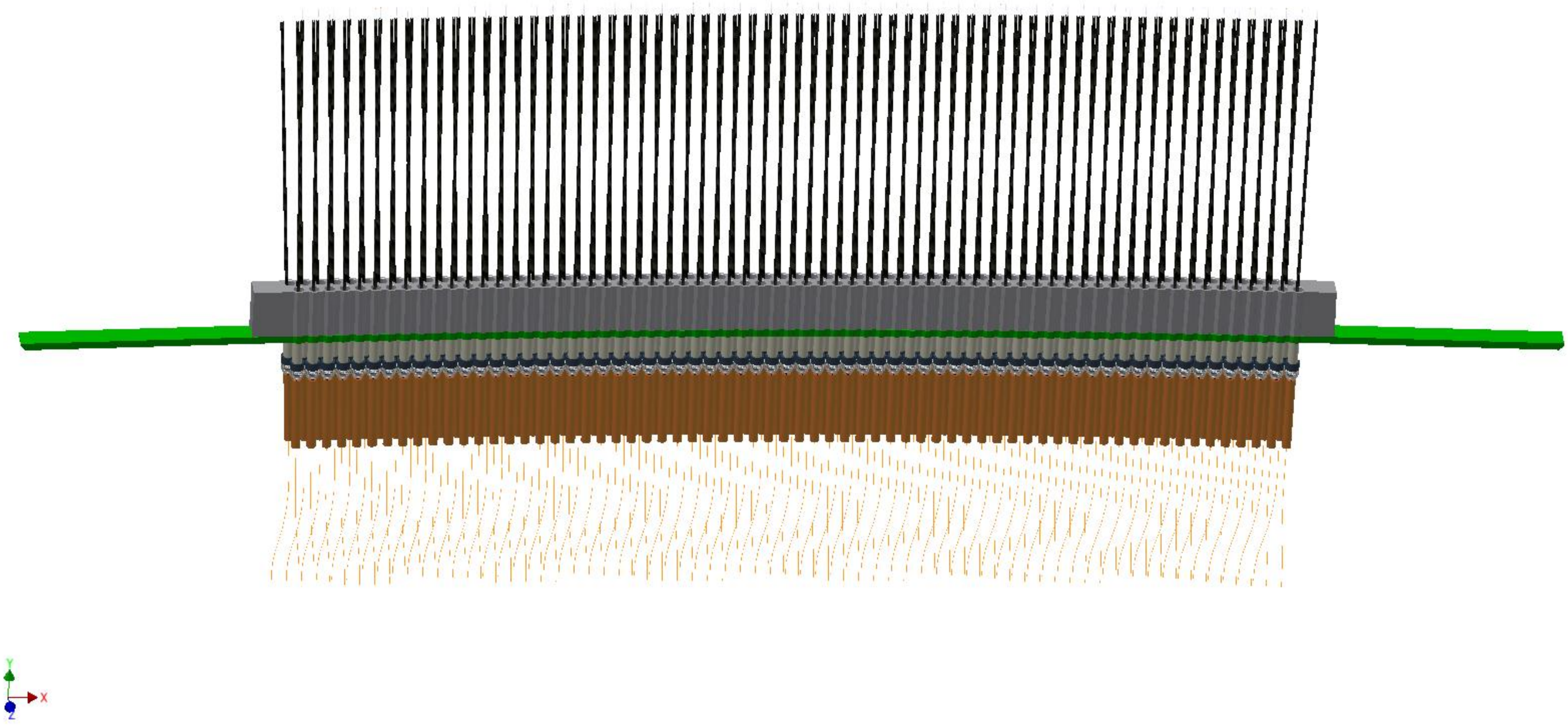
The central 3 spines are pointing as far left as possible.

The patrol radius is equal to the pitch

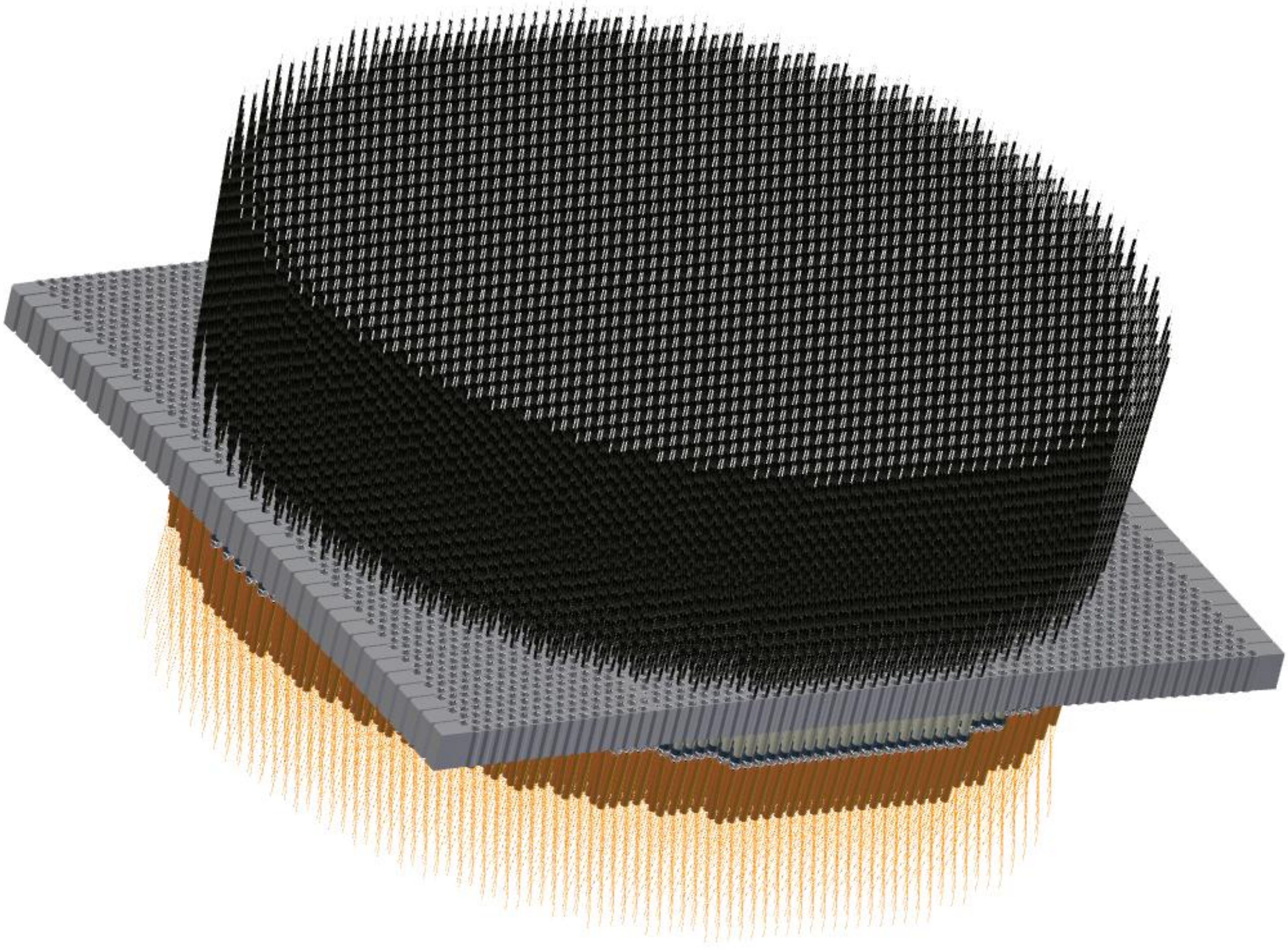
Each position on the Focal Plane is covered by at least 3 spines.

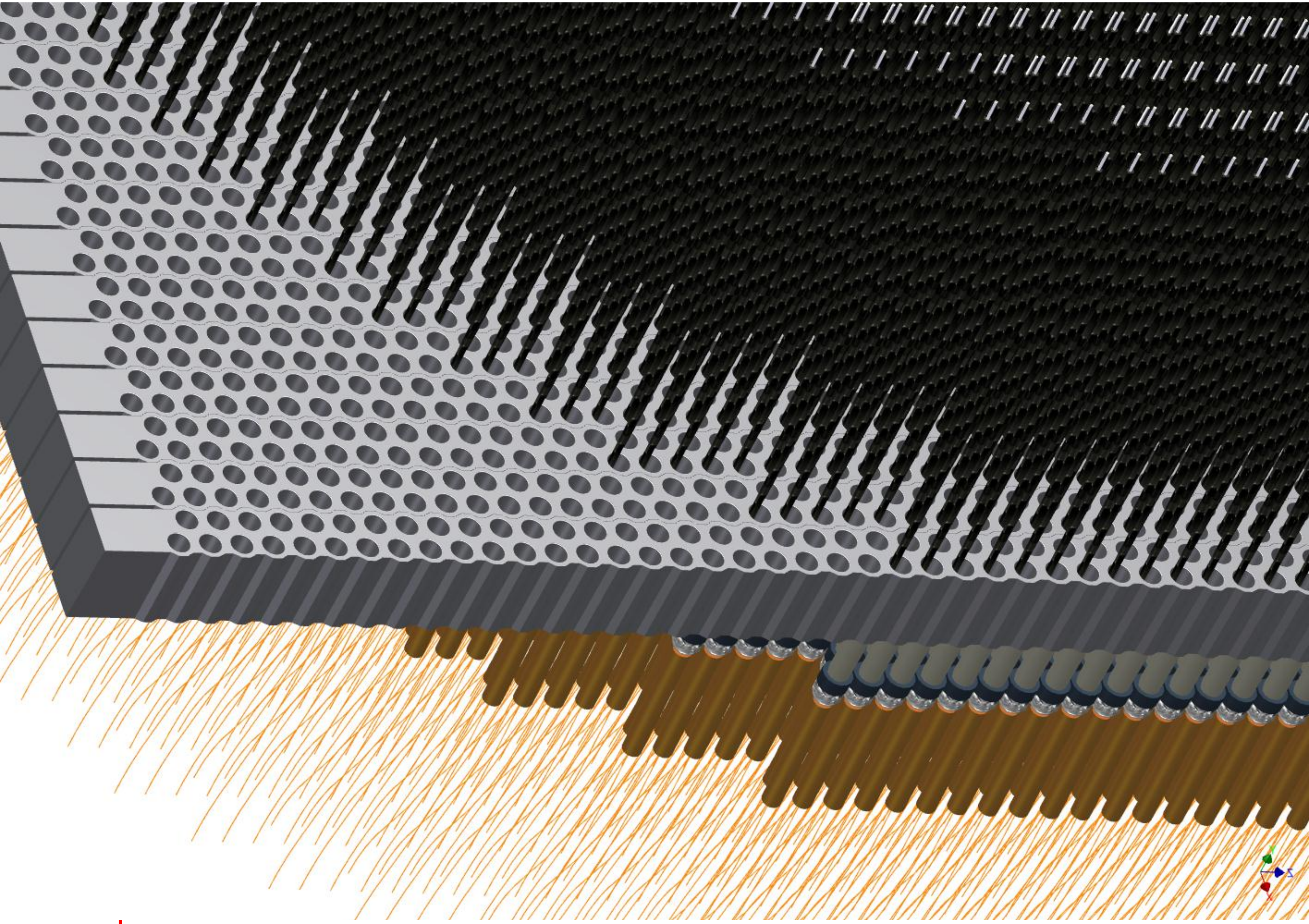


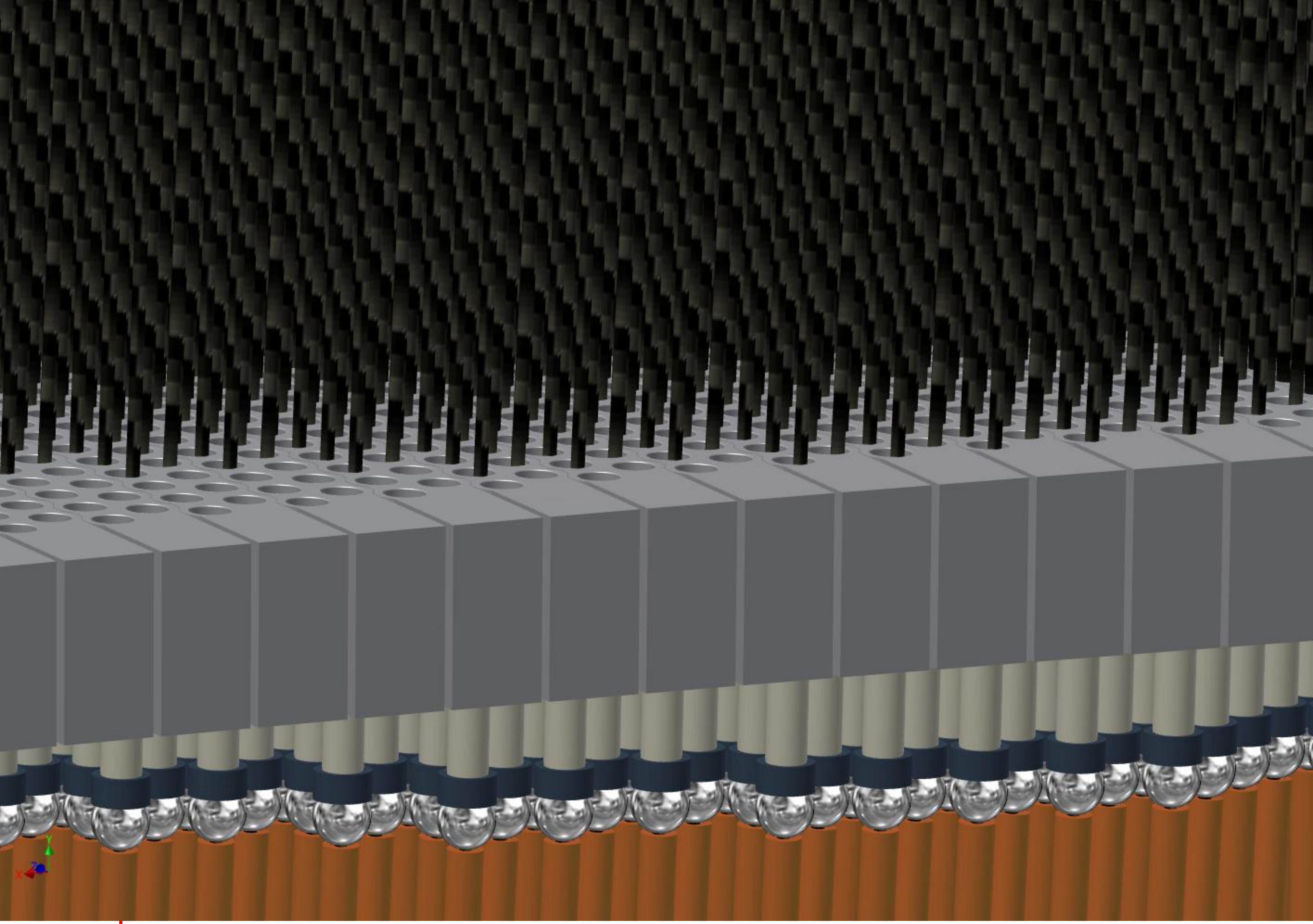
128 MOHAWK spines

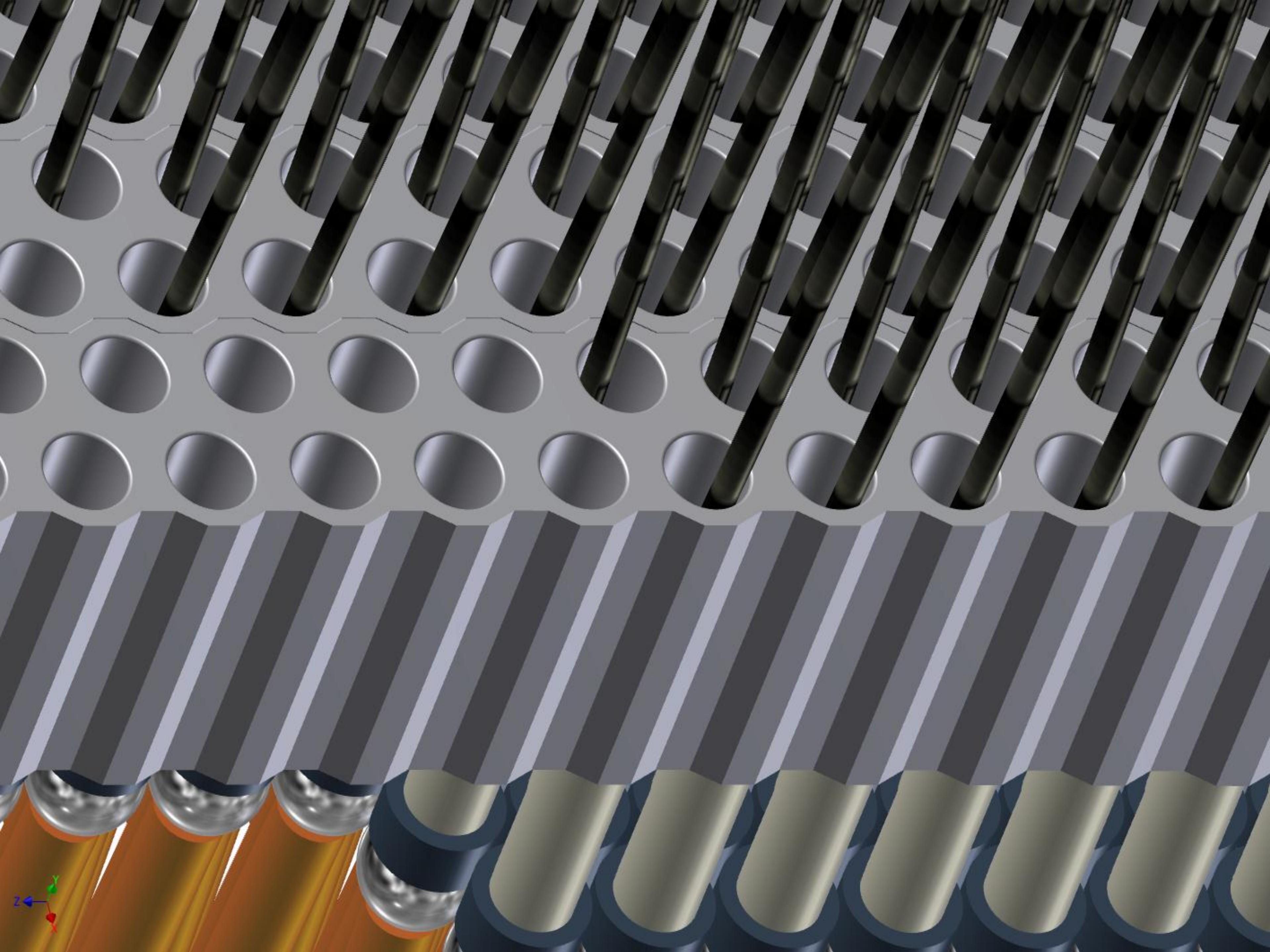


4000 MOHAWK spines

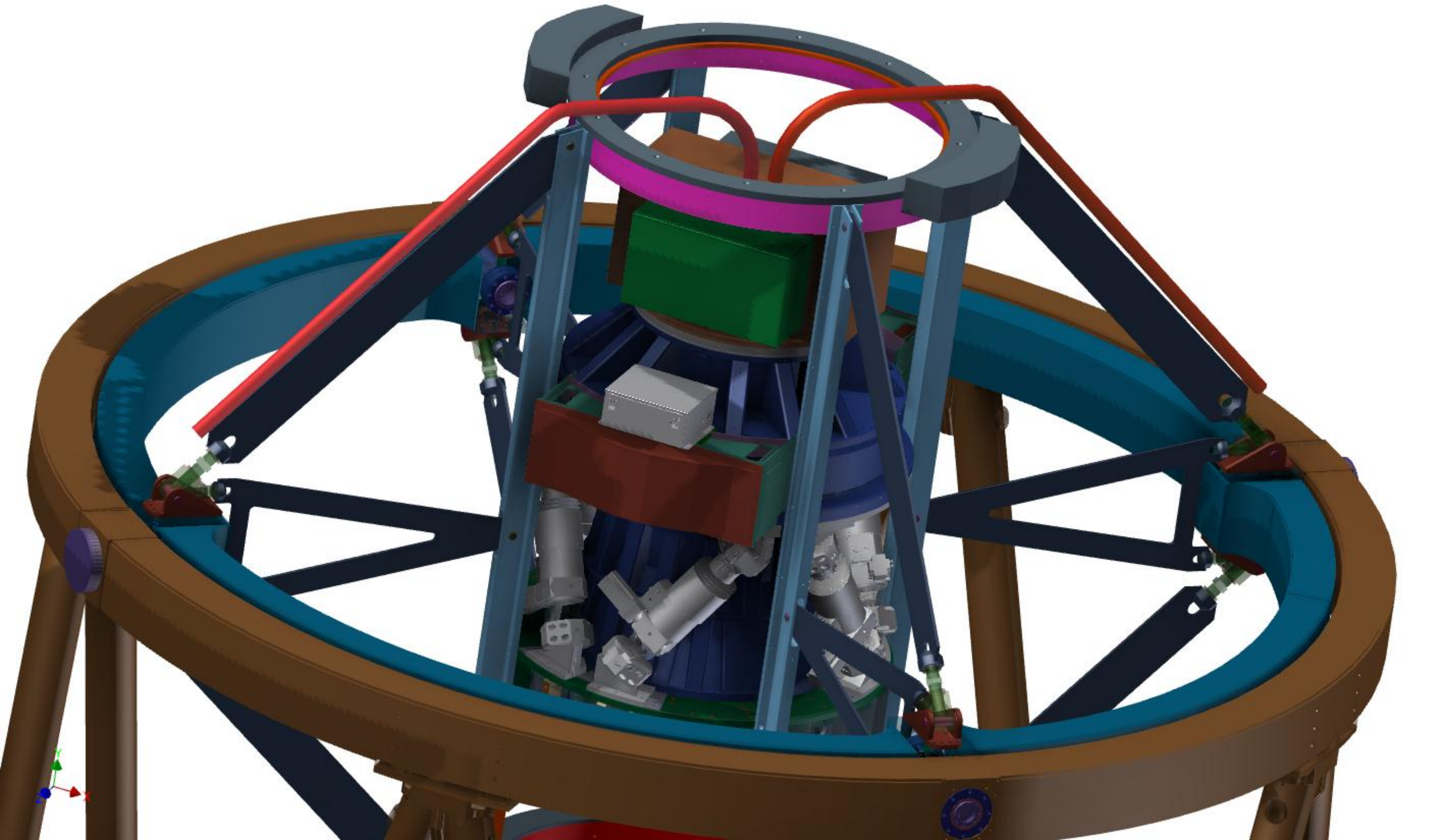




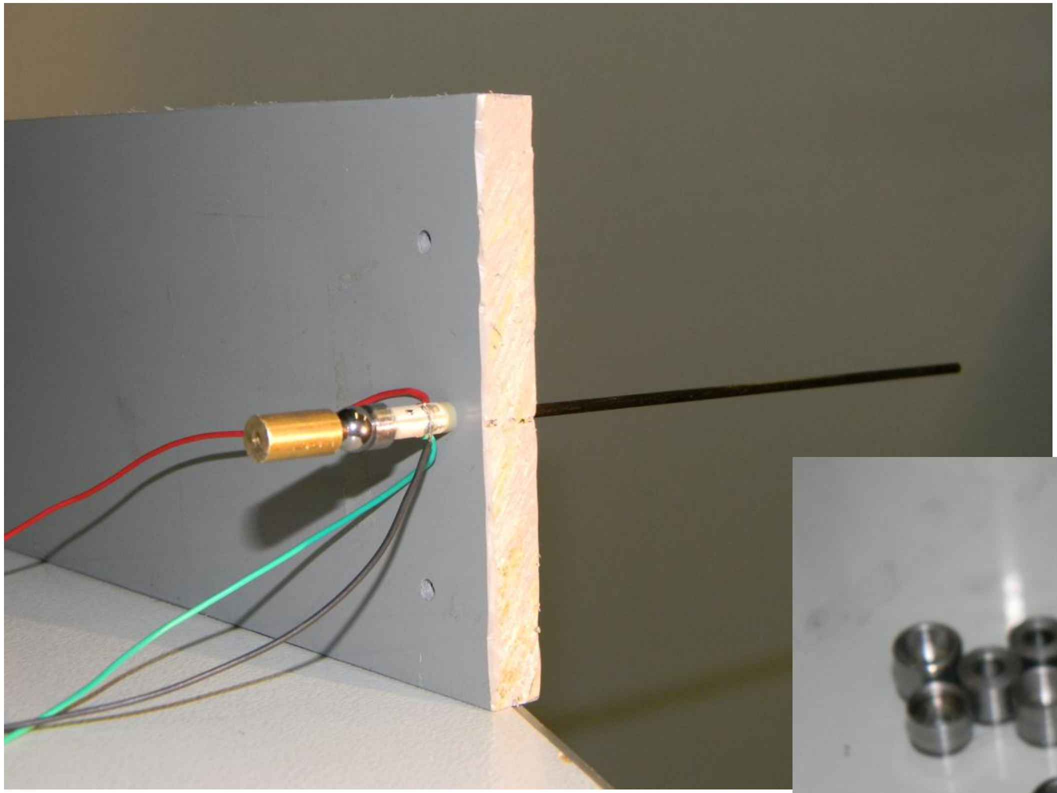


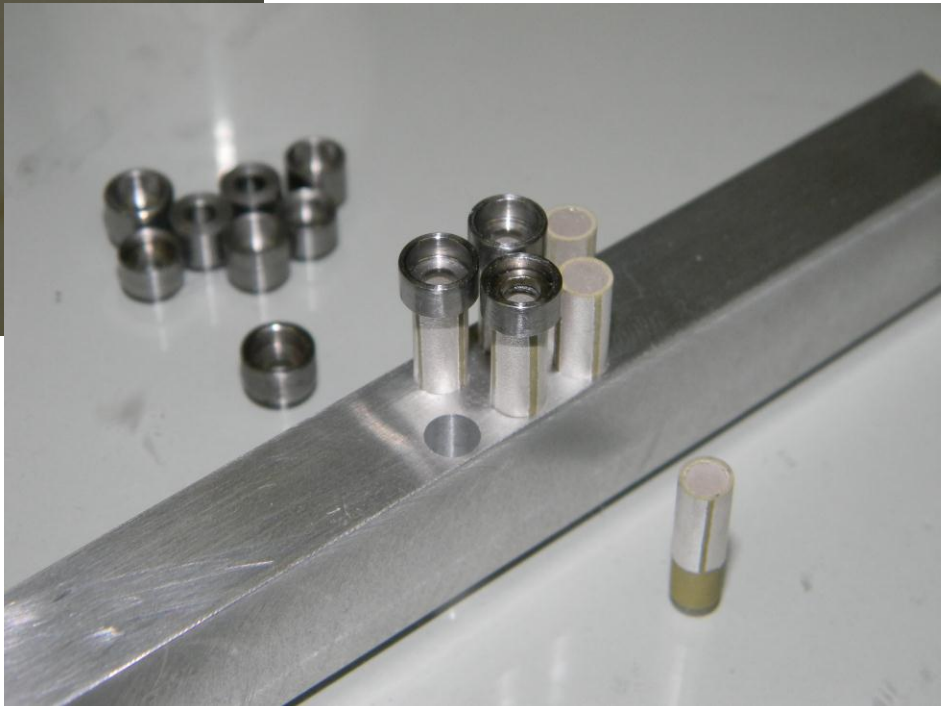


MOHAWK on the Blanco



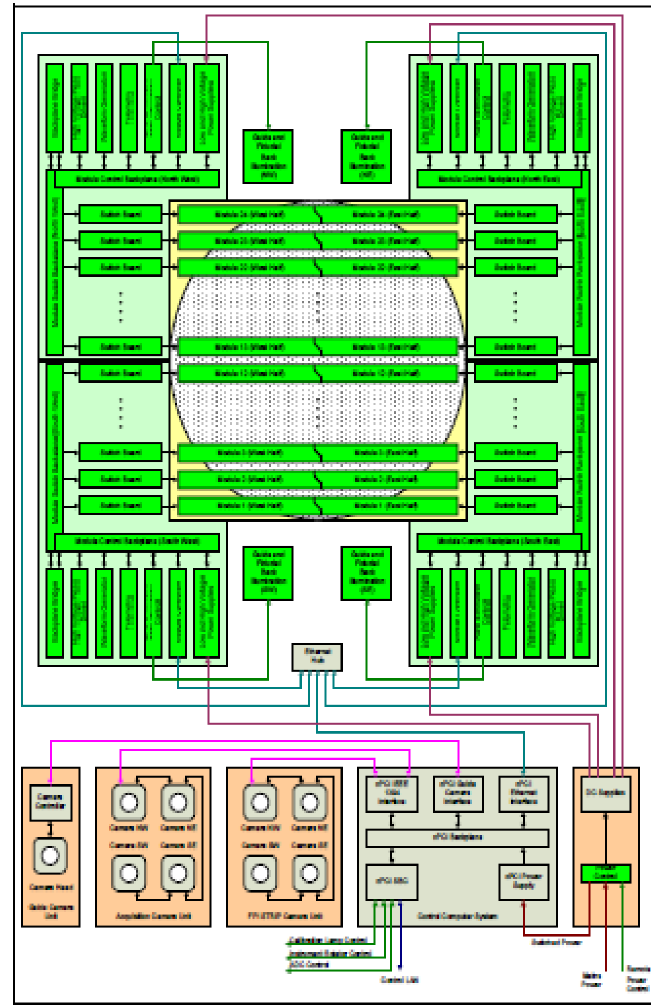
MOHAWK in reality





Proposed MOHAWK control

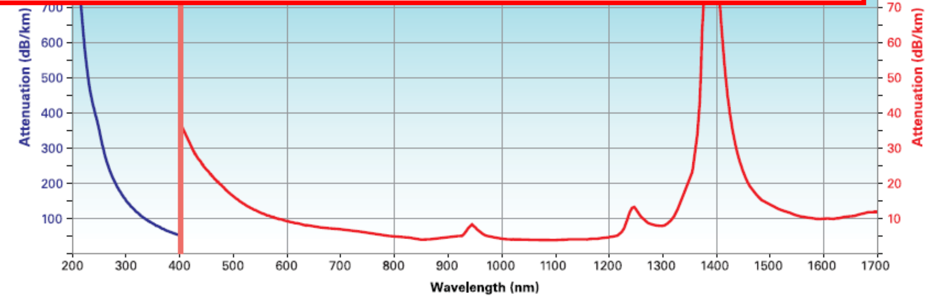
- 34-layer PCBs for each half-module
- Half-modules driven in quadrants.
- PCBs curved as needed (in one dimension) to take up relevant ROC,
- May drive first in X then Y, halves control electronics! But all spines driven simultaneously.
- Expect 5-6 iterations for repositioning, first iteration takes ~5s but others much faster. Should be easy to reposition during readout.



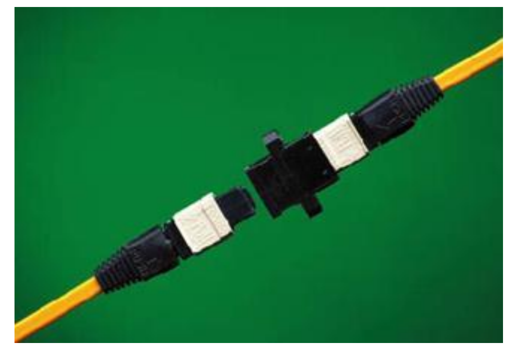
Proposed MOHAWK metrology

- Fibers must be back-illuminated, from within the spectrographs. Not easy to avoid light leakage to detector.
- Back-illumination can be 'flashed' to reduce CCD contamination during readout.
- Will image Focal Plane with an SBIG-type telescope and 4Kx4K+ camera, mounted in Cassegrain chimney.
- 1/20 pixel centroiding gives 6μm precision, good enough.
- Each module contains 'fiducial' spines, identical to others but fixed, to define positioner metrology.

Proposed MOHAWK design: Fibers



- Use Polymicro FBP fibre – cheap, available, excellent FRD and transparency (few % over 30m for 600-1000nm).



- Fiber cable must surely be connectorised (for instrument changes). Standard telco connectors are good (when gelled) $\Rightarrow$ need 125μm cladding.

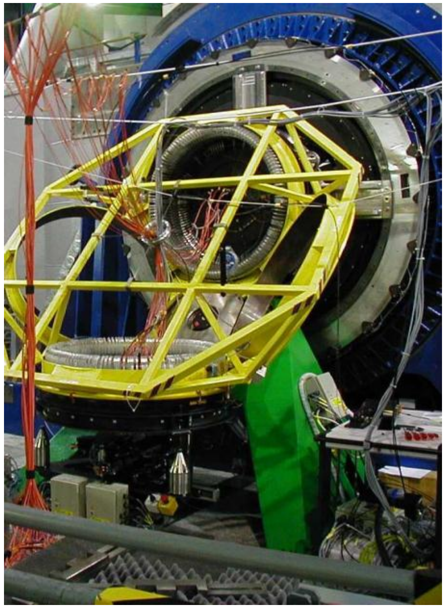
- Standard preforms are 1:1.2 or 1:1.4 core/cladding ratio. So want **89/125μm** or **104/125μm** core/cladding ratios.

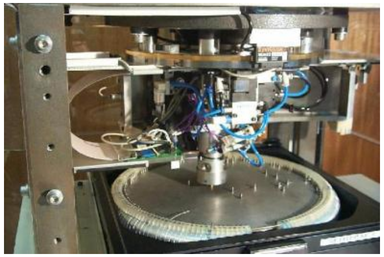
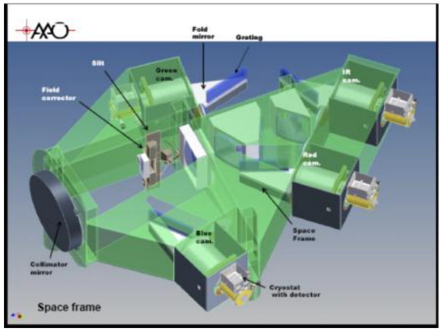
  $\Rightarrow$ **1.56"** or **1.83"** apertures on sky. Trade-off between light collection versus spectral resolution and spectrograph numbers.

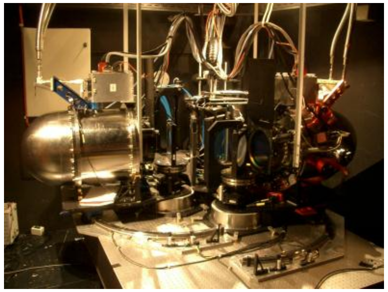
Rest of Package:

AAO provides whole data taking package, based on our 2dF, 6dF, AAOmega, Echidna, Ozpos, HERMES experience. Now routine to modify package for different instruments and telescopes. Package includes:

- Observing planning software
- Configuring software
- Interface between instrument and telescope (instrument usually drives telescope)
- Data reduction pipeline



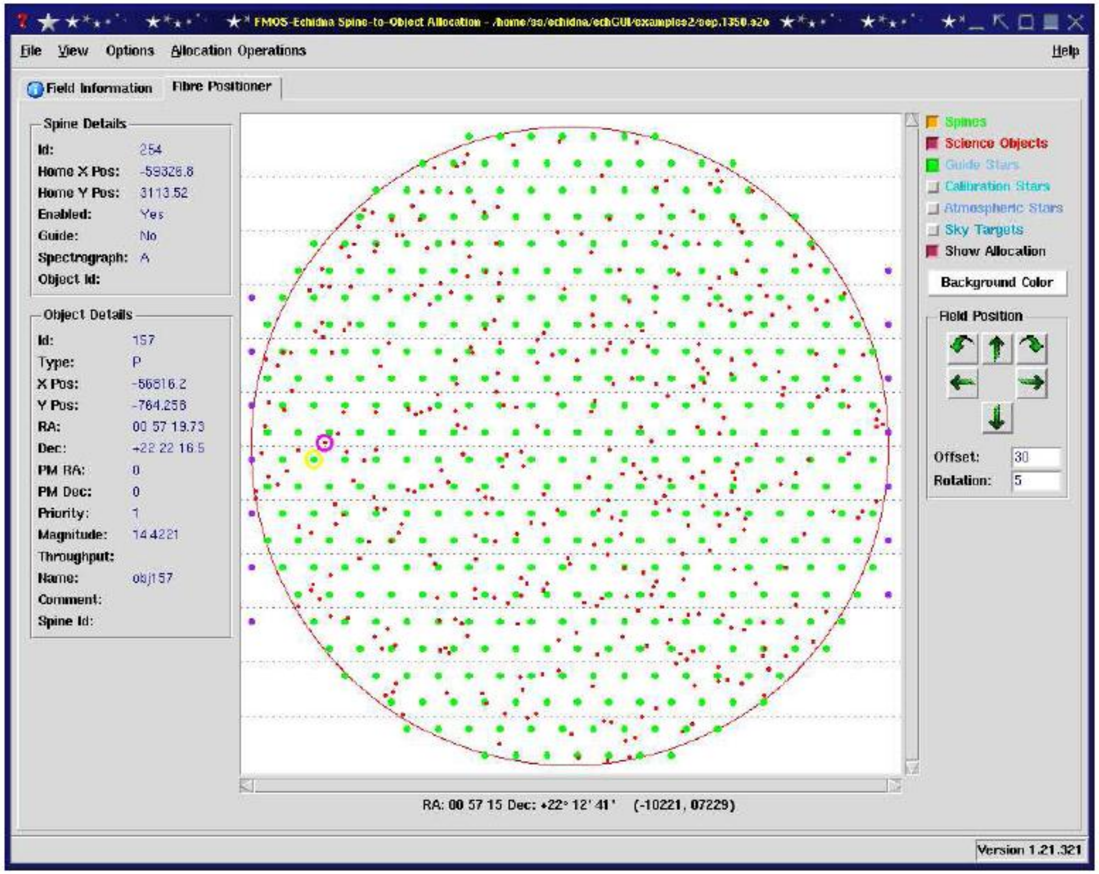






Configuring software

Configuring software includes guide stars, target priorities, checking for validity over range of Hour Angles, etc.

Now based on simulated annealing, can't do better!



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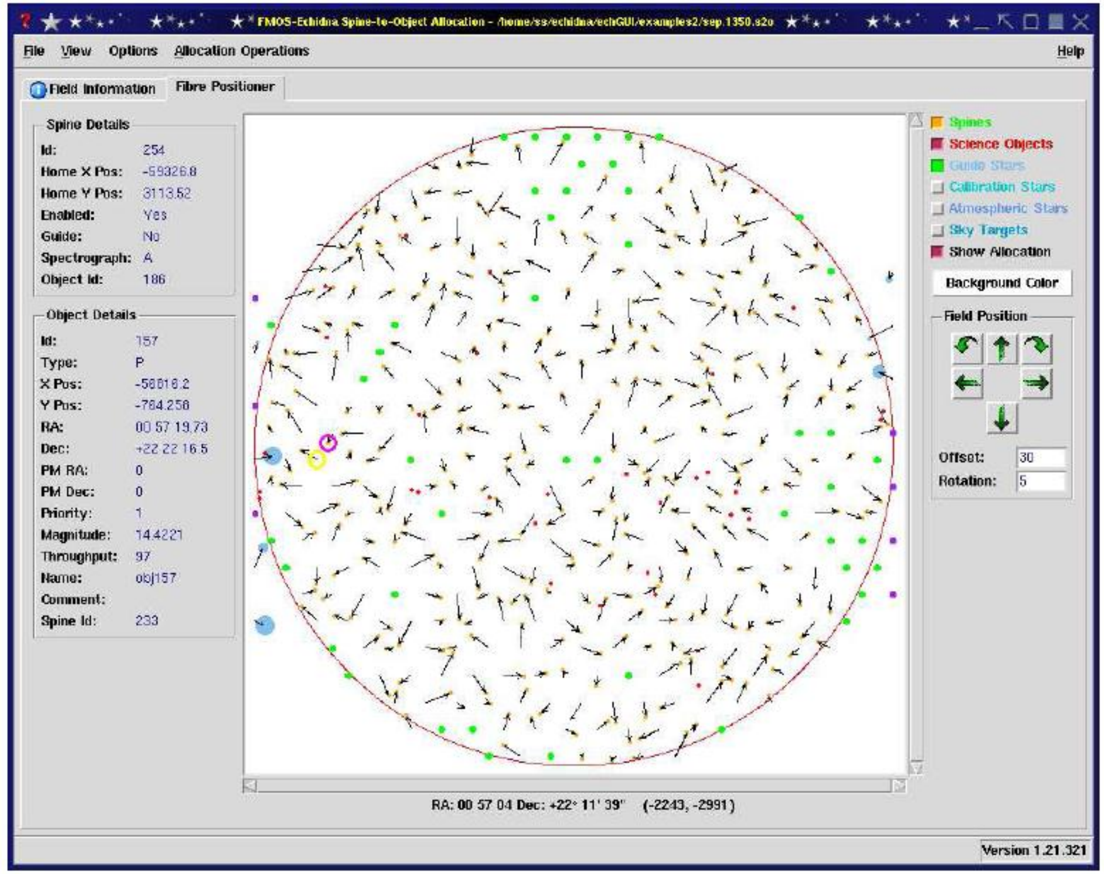
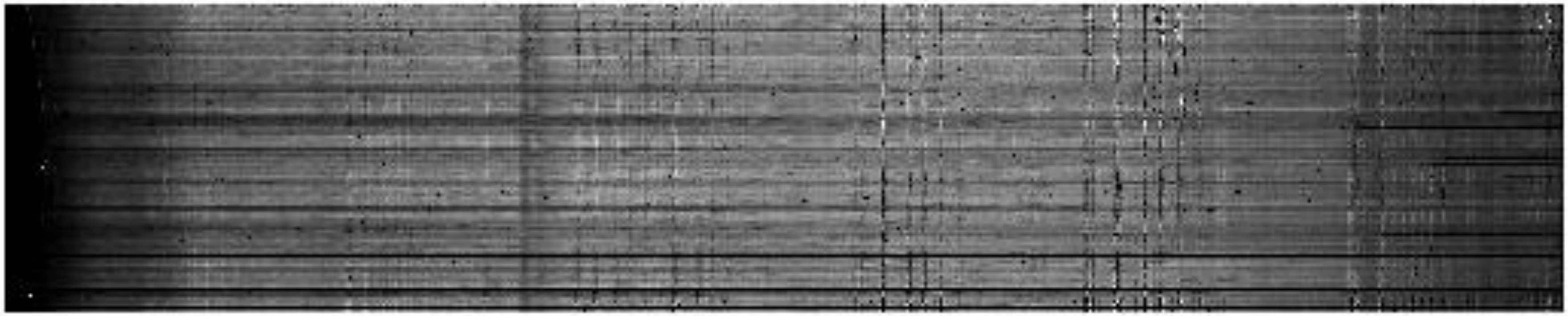


Data reduction

- AAO has state-of-the-art fibre spectroscopy data reduction pipeline. Very flexible and robust.

- PCA (Principal Component Analysis) sky subtraction now routine $\Rightarrow$ Poisson-limited sky subtraction with dedicated sky-fibres.



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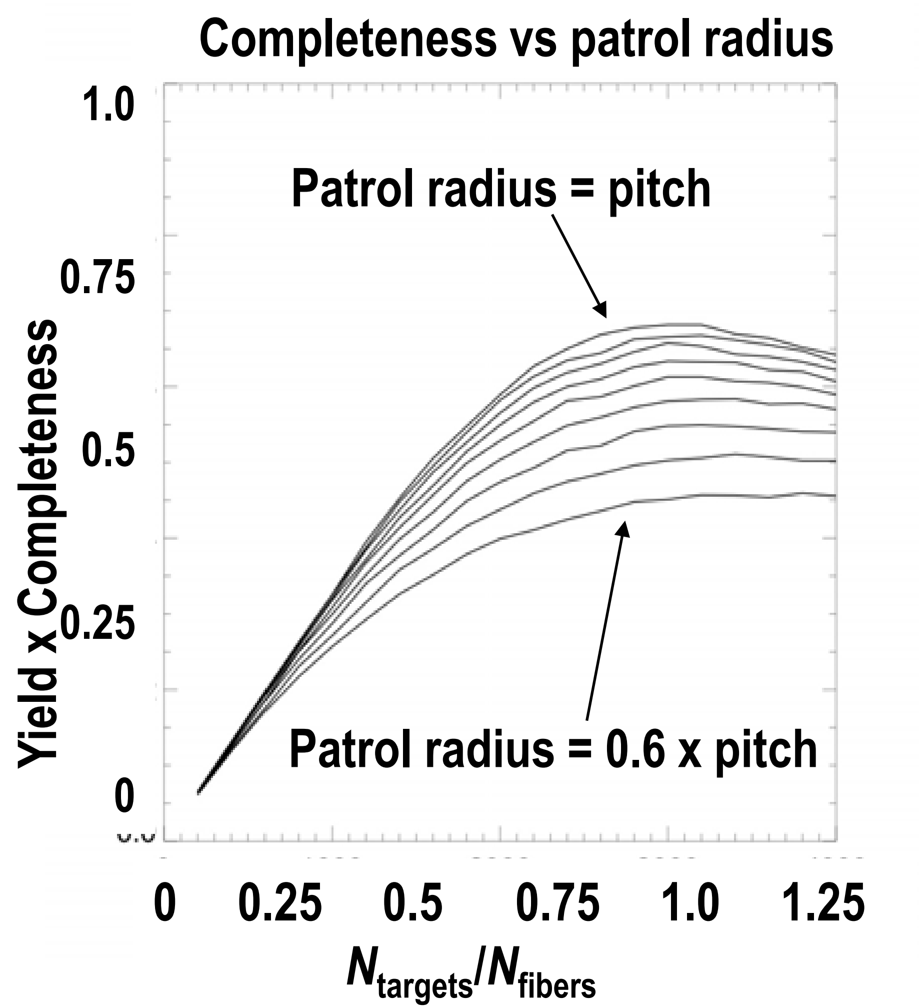
Patrol radius, yield, completeness

Yield (% fibers on targets) and **completeness** (% of targets observed) both increase with patrol radius.

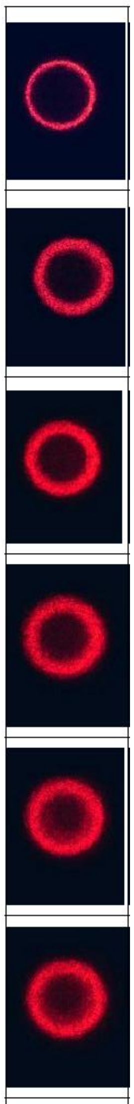
If patrol radius = 0.6 x pitch, yield x completeness ~ 0.45

If patrol radius = pitch, yield x completeness ~ 0.7, when $N_{\mathrm{targets}} \sim N_{\mathrm{fibres}}$

Gain diminishing for greater patrol radii



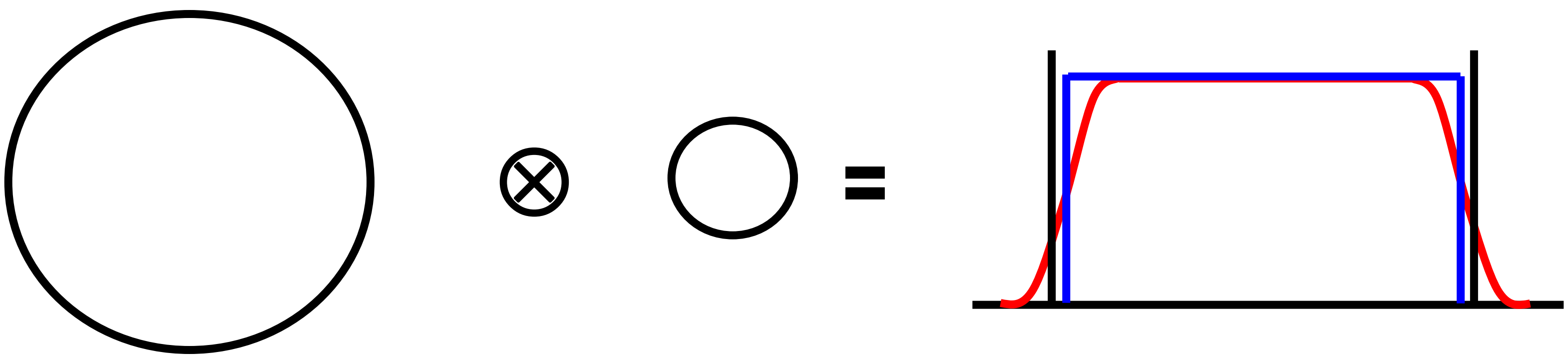
Focal Ratio Degradation



All fiber systems introduce FRD. FRD means accepting collimator losses, or increasing collimator speed ($\Rightarrow$ fewer spectral resolution elements, and fewer spectra per spectrograph).

FRD acts like a convolution of the input beam with an ~f/10-f/15 beam.

Spine tilt is just the same, like a convolution with beam of (up to) f/12.



Can estimate resulting collimator loss analytically. For f/2.9 telescope beam and f/2.75 collimator, get few % losses from each effect .

MOHAWK throughput losses

Principal throughput losses:

Additional aperture losses caused by spine defocus	0-2%
Fiber input faces not AR-coated	4%
Collimator losses as described in last slide	5%
Connectors	3%
Total losses	**12-14%**

MOHAWK positioner cost

- WFMOS positioner costed at A$8.5M for 4500 spines
- WFMOS-A design greatly simplified, positioner costed at A$2.4M in-house cost for 1600 spines
- MOHAWK will be cheaper than WFMOS, and cheaper per fiber than WFMOS-A. **Estimated cost A$7M**.
- **Includes positioning and data reduction software**