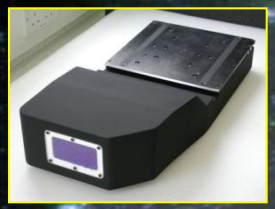
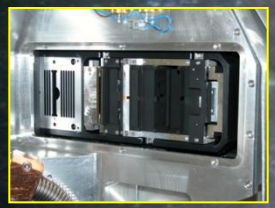
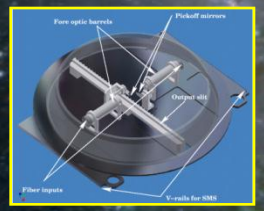
Fibre systems for cosmology







Jeremy Allington-Smith and Graham Murray

Centre for Advanced Instrumentation

University of Durham

Content

- Some critical issues for DESpec
- Some technology examples
- A radical approach to make DESpec unique

Note: due to MOA with BigBOSS I can't give details of specific technologies developed with LNBL

Durham University

CfAI

Centre for Advanced Instrumentation


Rochester Building

Astronomy spectroscopy and Adaptive Optics,
Nuclear fusion, Biophysics, Earth observation
Latest spectroscopy news:
Instruments: KMOS, SALT-HRS, JWST-NIRSpec IFU
R&D: Diverse Field Spectroscopy, Astrophotonics,
3D-Heliospectropolarimetry


NetPark Research Institute

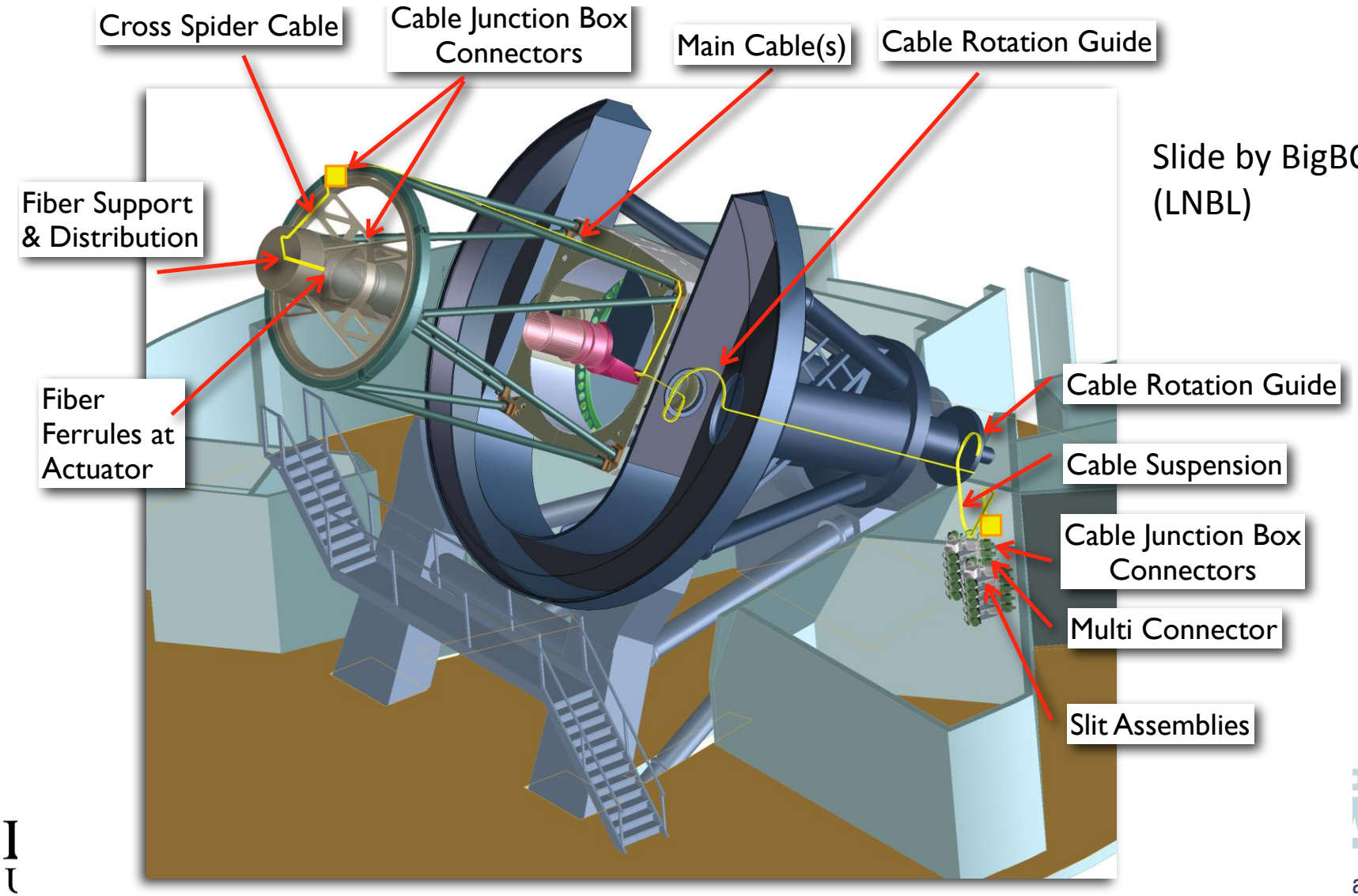
BigBOSS and DESpec

	BigBOSS	DESpec	
FOV (linear)	3.0	2.2	deg
N Targets	5000	4000	
Subfield	180	110	arcmin
Pitch	12	6.8	mm
Fibre input focal ratio	F/4.5	F/3	
Wavelength range	340-1060	600-1000	nm
Resolving power	3000-4800	1900-3300	

Durham University

CfAI Centre for Advanced Instrumentation

BigBOSS fibre system



Slide by BigBOSS (LNBL)

The BigBOSS philosophy

- Scrupulous attention to all sources of uncertaintiy
  - Throughput
    - “Soup to nuts” models
  - Variation of throughput
    - fibre-to-fibre
    - Position-to-position
    - Time-to-time
- Dynamic error budgets (systems engineering)
    - Top-down reallocation of error sources
    - Top-down must match Bottom-up
- Minimise cost/fibre

Some generic issues for fibre system

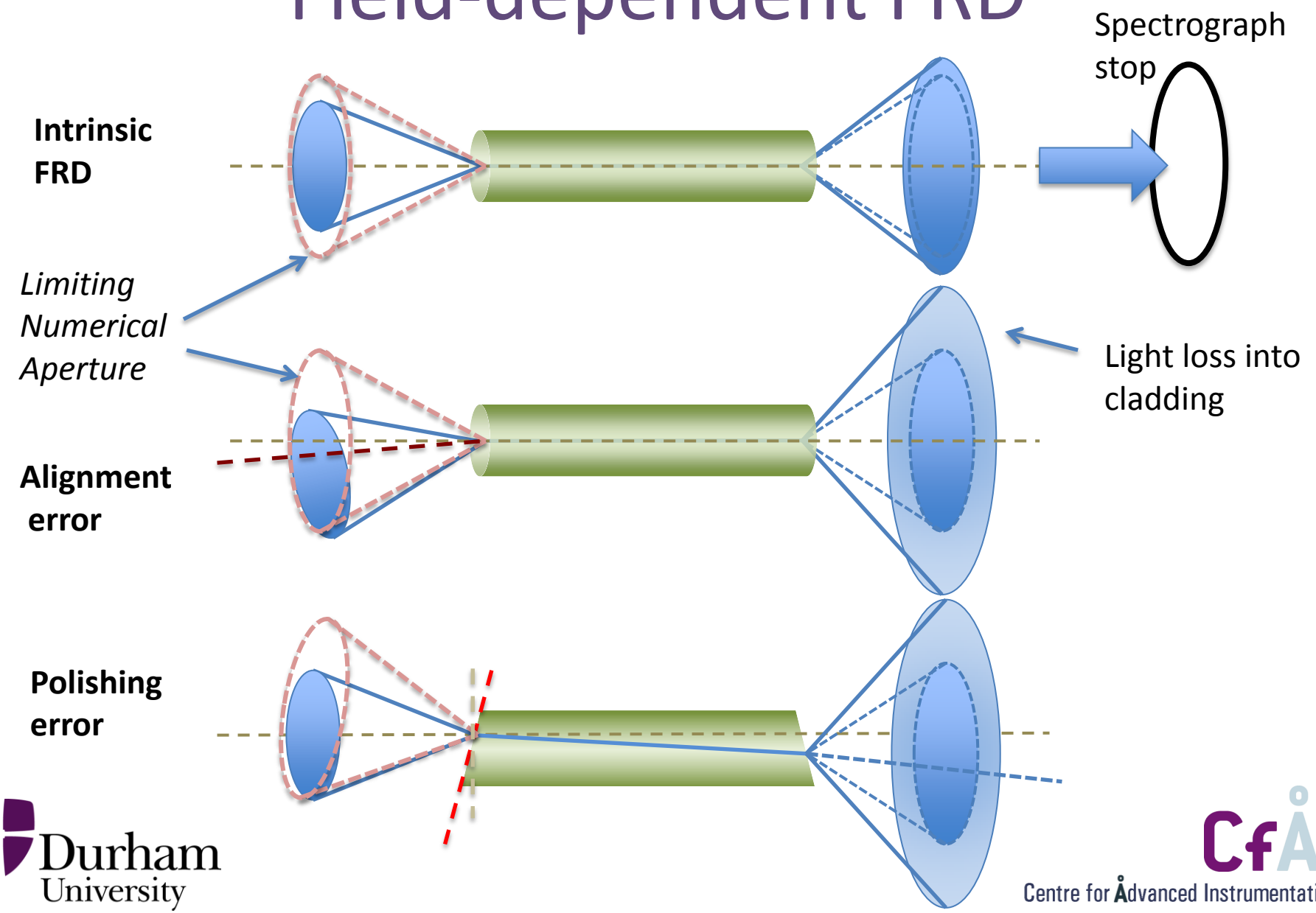
Number of actuators	> speed of survey
Pitch & filling factor	> speed of survey/clustering
Fibre throughput & AR coatings	> speed of survey, λ λ, cable length
Positional accuracy/repeatability	> throughput & survey strategy
Alignment to telescope exit pupil	> FRD & Numerical Aperture
Alignment to spectrograph pupil	> slit design, Lenslets?
Repeated fibre flexure, torsion	> breakage, wind-up, light loss
Environmental changes	> modal noise -> SNR limit
Mechanical flexure of focal plane	> holey structure, weak?
Fibre replacement strategy	> how and when?
Connector strategy	> how many, where?

Etendue violation

Non-conserve of Etendue: ***Focal Ratio Degradation***

- **Intrinsic effect** due to modal diffusion from defects
  - Caused by manufacture and stress during operation
  - Critically dependent on fibre termination
  - Macrobending (if ROC < 1000 x fibre radius)
- **Extrinisic effects** due to misalignment with fibre axis
  - Intentional (tilting spines)
  - Unintentional (errors in construction)
- **Extrinsic effect** due to scattered light (e.g. D. Haynes et al)
  - Requires good polishing and/or index-matched immersion to smooth optic

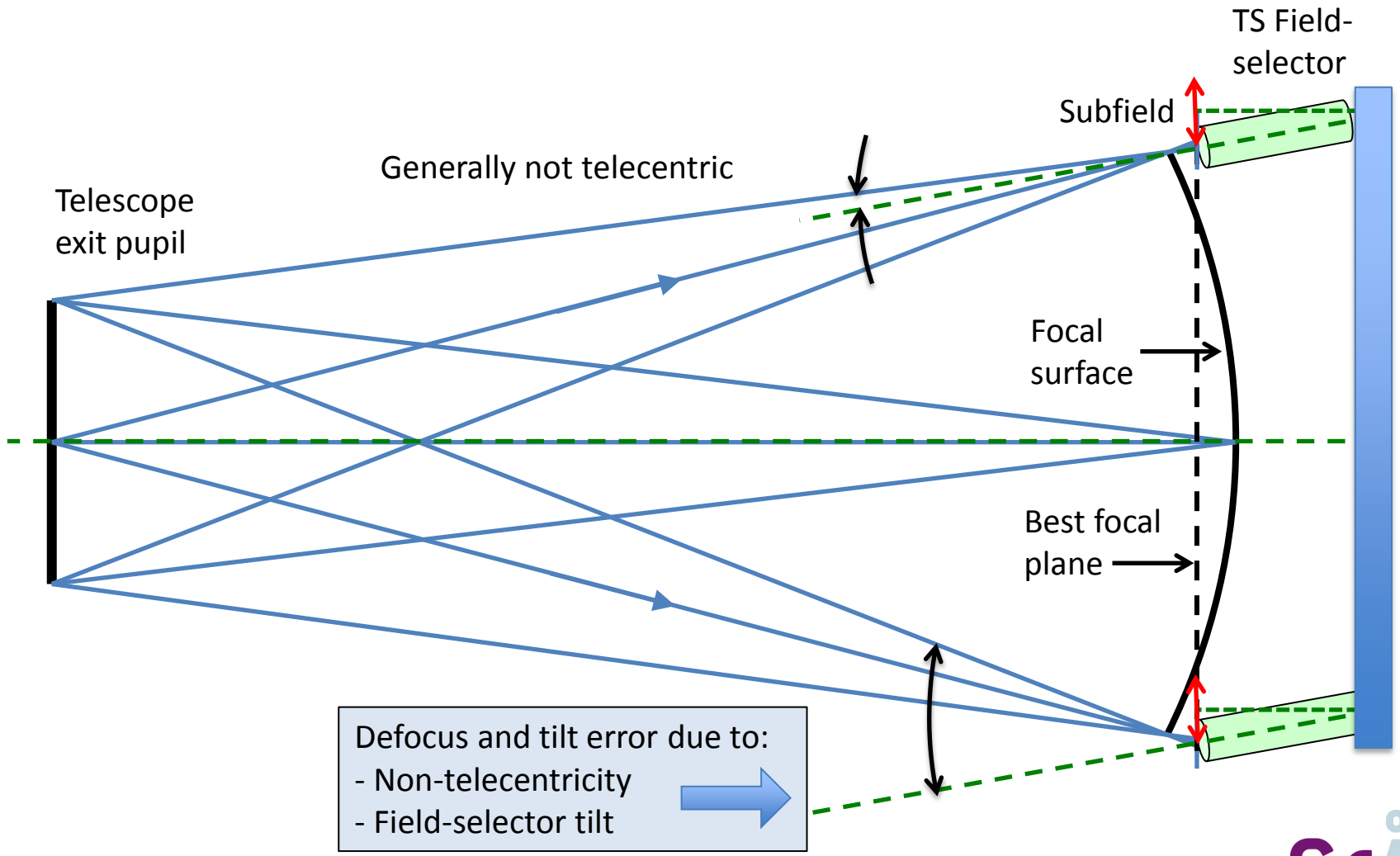
Field-dependent FRD



Durham University

CfAI Centre for Advanced Instrumentation

Telescope exit pupil match

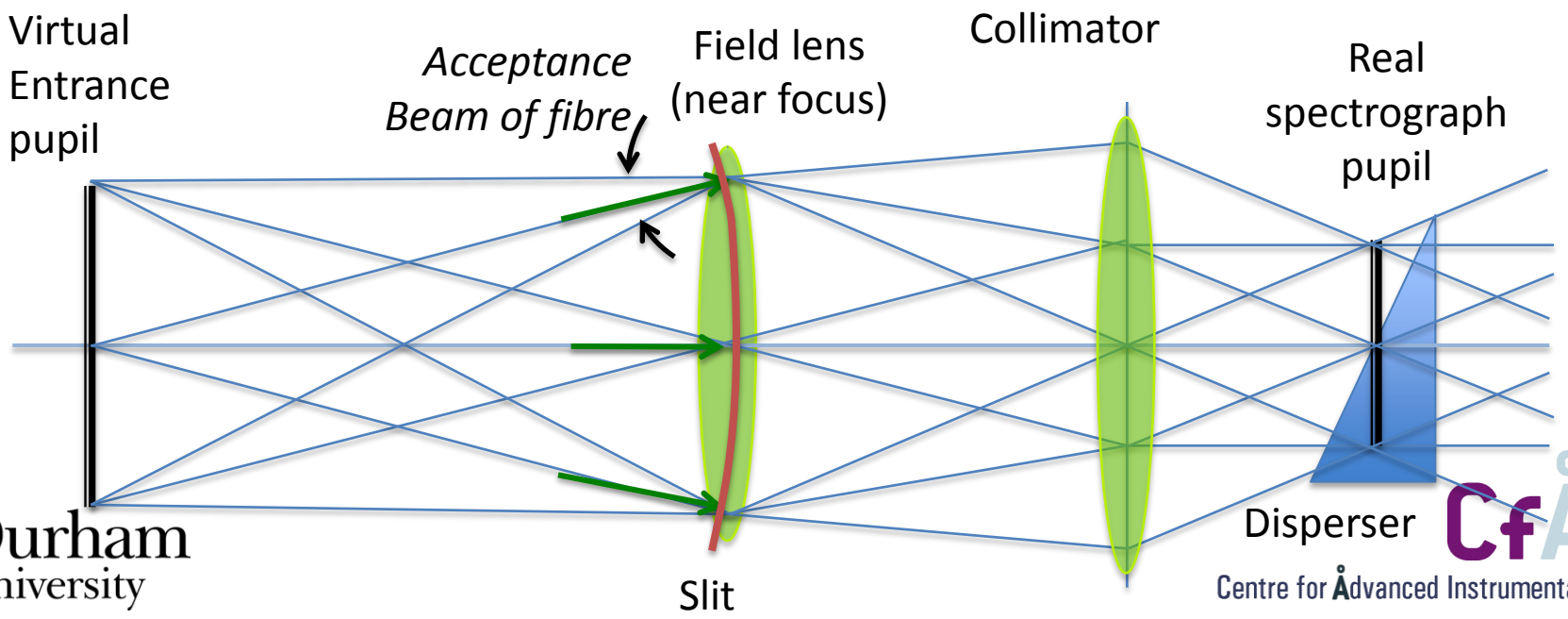


Pupil configuration at slit

`To place pupil on spectrograph disperser requires a field lens close to the input spectrograph focal plane.

This creates a virtual input pupil to which fibres must be aligned.

(For a beam-fed spectrograph, the virtual spectrograph pupil would be coincident with the telescope exit pupil.)



Durham University

CfAI Centre for Advanced Instrumentation

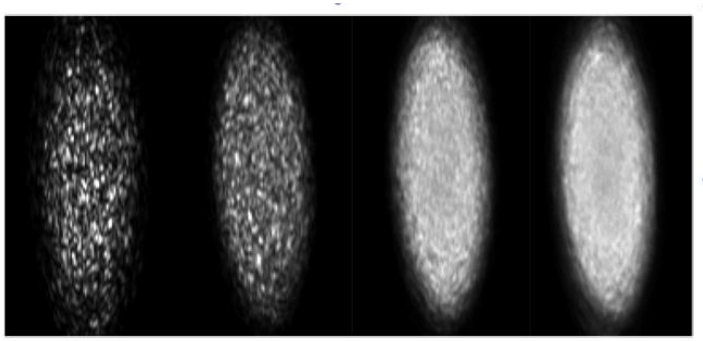
Modal noise

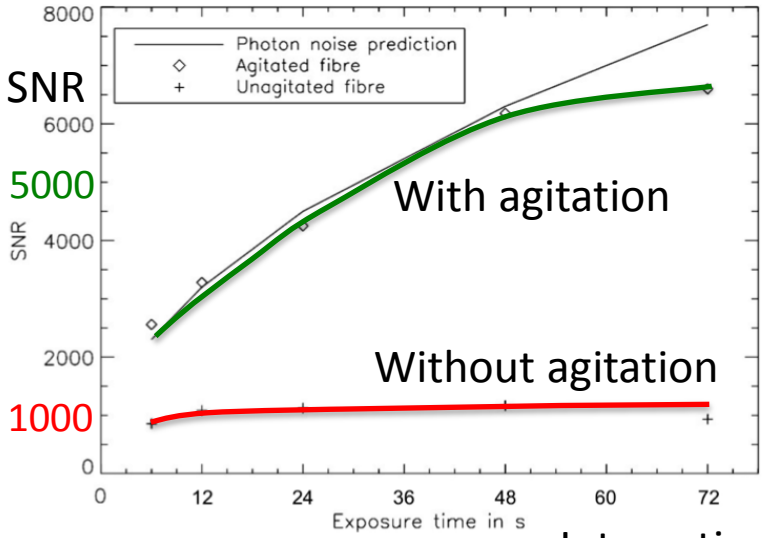
Limit to fibre spectroscopy SNR

- interference between partly-coherent waveguide modes
- Speckle statistics altered by limiting apertures (e.g. spectrograph stop)
- may affect line position and shape
- Affects higher spectral resolution?

Traditional solutions: *agitation*

- Feasibility for a multi-fibre system?





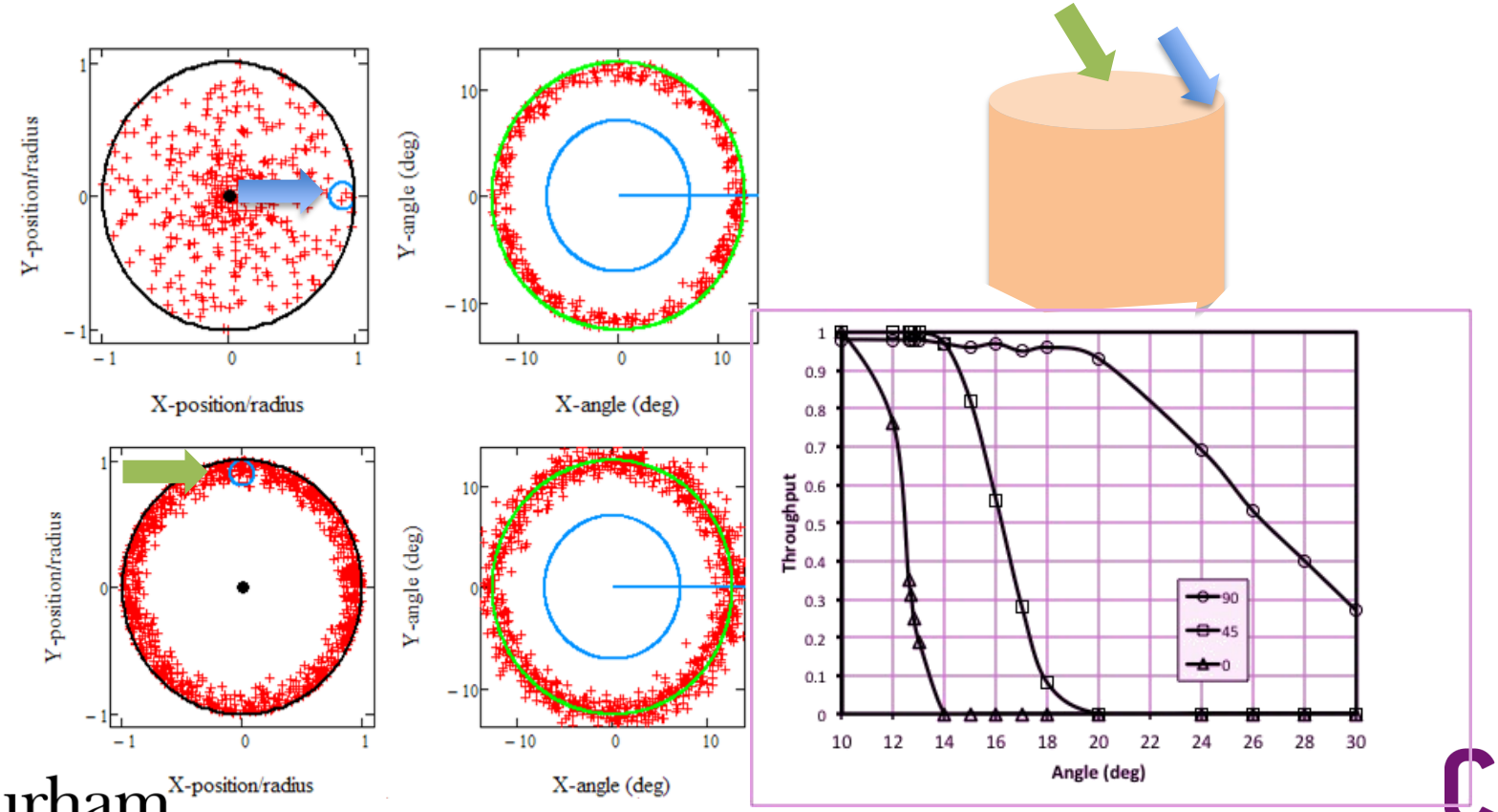
Integration time

Modal noise prediction in fibre-spectroscopy I: Visibility and the coherent model, U. Lemke, J. Corbett, J. Allington-Smith, G. Murray. MNRAS 404, 1349.

Limiting Numerical Aperture

Caution near LNA: Need special fibre to avoid light loss

Near LNA, sensitive to misalignments and FRD (softened cutoff)



Allington-Smith et al. SPIE 2012

Connectors?

Pro

- Easier to integrate fibre system with telescope
- Routing thousands of fibres from pickoff to slit may be otherwise impossible
- Easier/possible to replace damaged fibres
- Easier to share work between fabricators/collaborators

Con

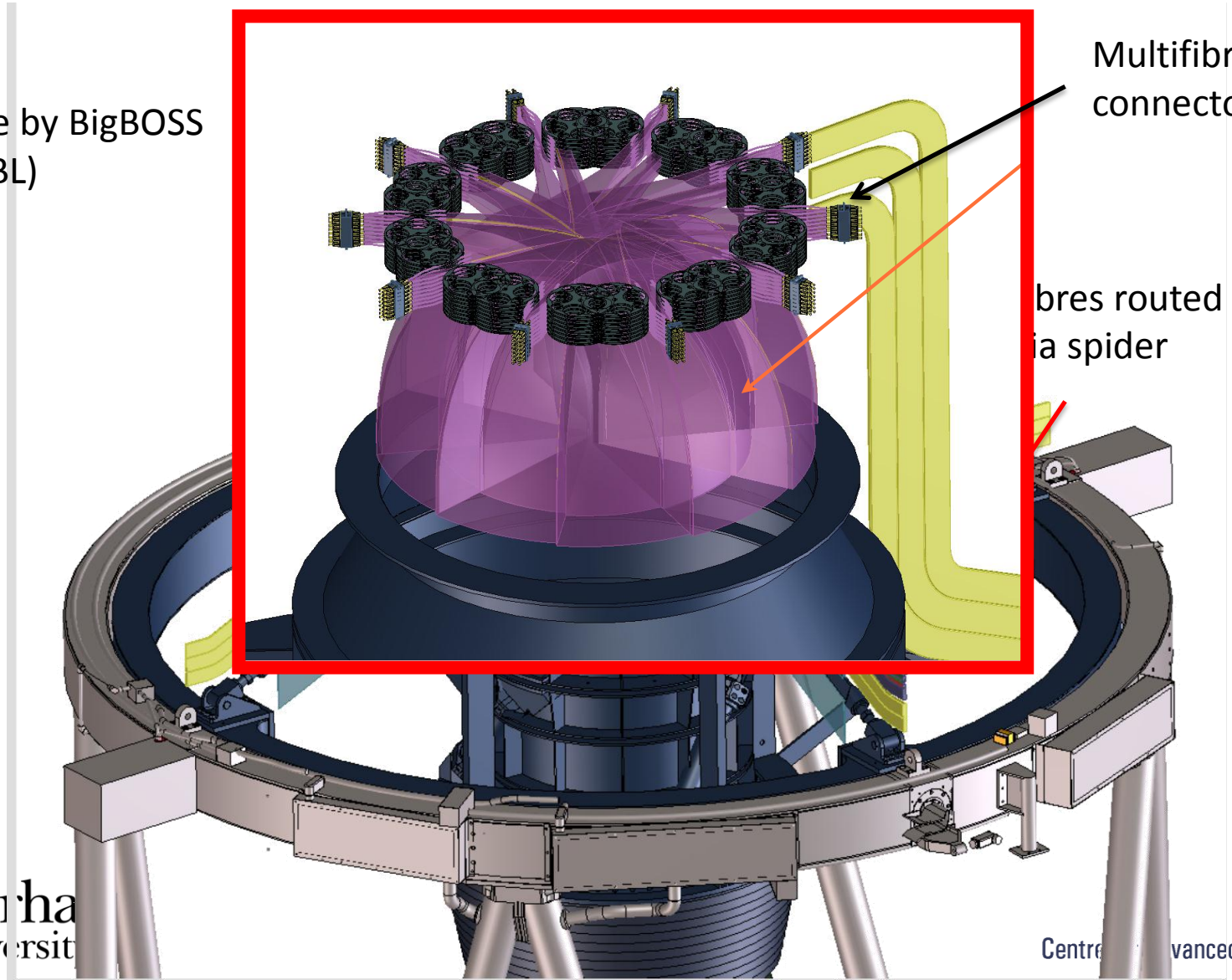
- Throughput loss
- Variable insertion loss

Note

- *Throughput for FMOS fibre system alone >80% (Kimura et al. 2010)*
- Make/break connectors once-only (or once/year)?
- *New technology using GRIN lenses has been prototyped*
- *Commercial options under investigation*

Nida de Ratos

Slide by BigBOSS (LNBL)



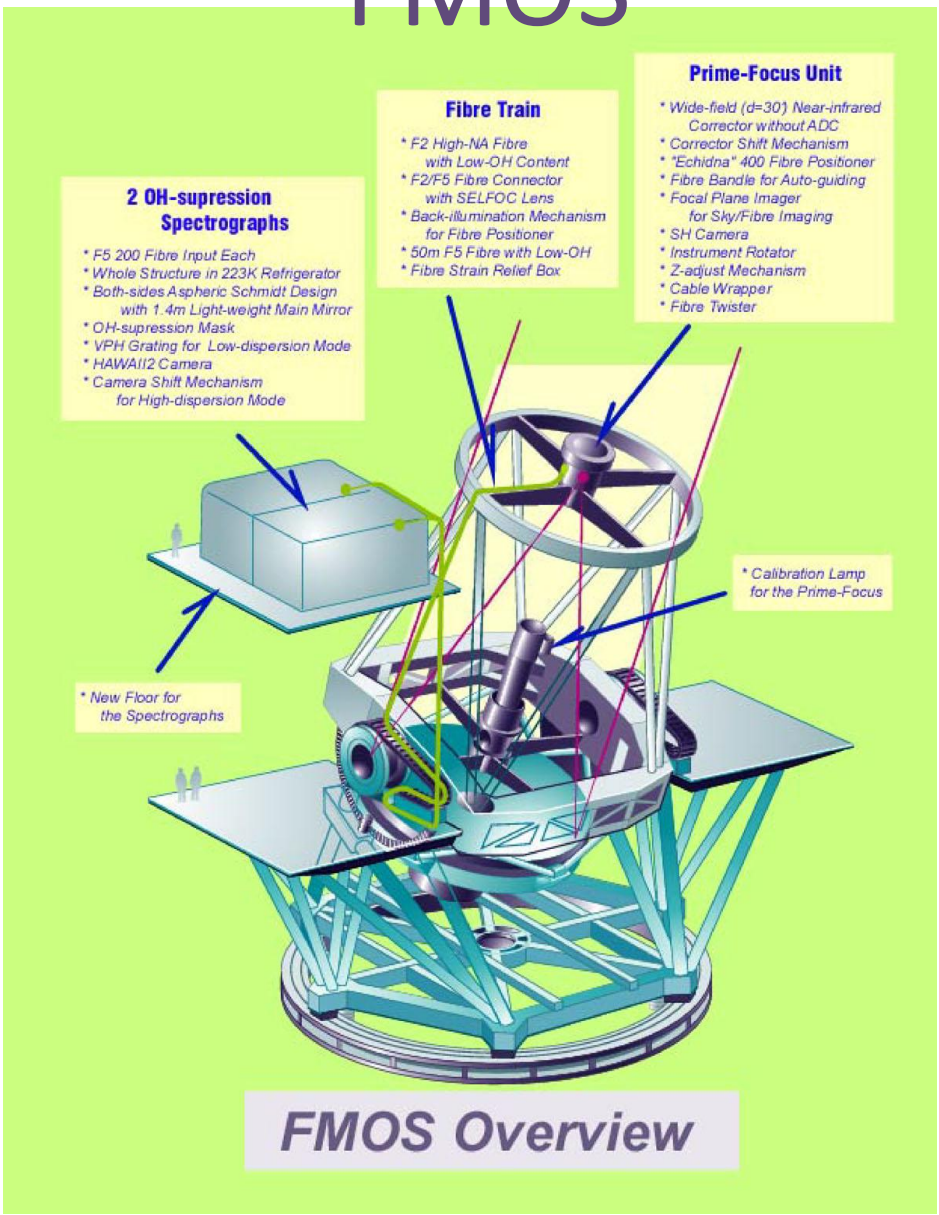
Durham University

CfAI Centre for Advanced Instrumentation

Technology adapted from FMOS

- CfAI developed the fibre system:
  (Cable, connectors, strain relief, slit units)
- Fibres terminated at connector or focal surface
- Routed to through telescope structure
- Protected from stress by sophisticated yet robust cable and strain relief units
- Measured on-telescope throughput of the fibre system >80% (Kimura et al. 2010)

FMOS

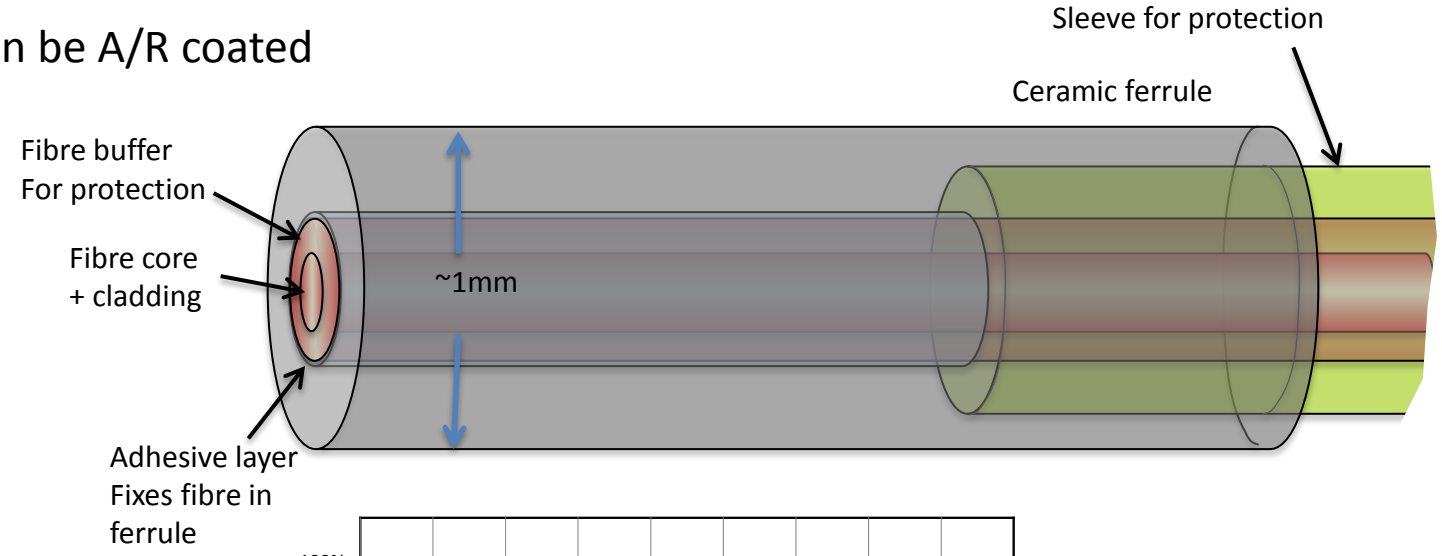


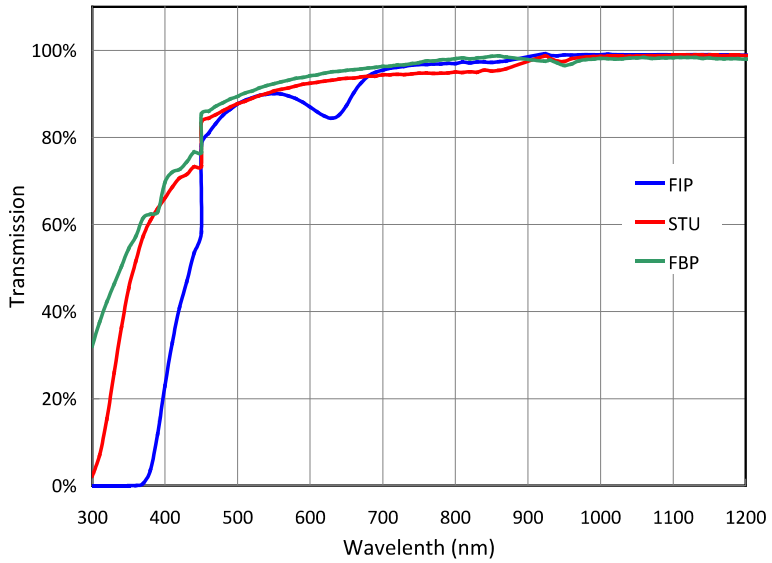
Durham University

CfAI
Centre for Advanced Instrumentation

Fibres

Fibres can be A/R coated

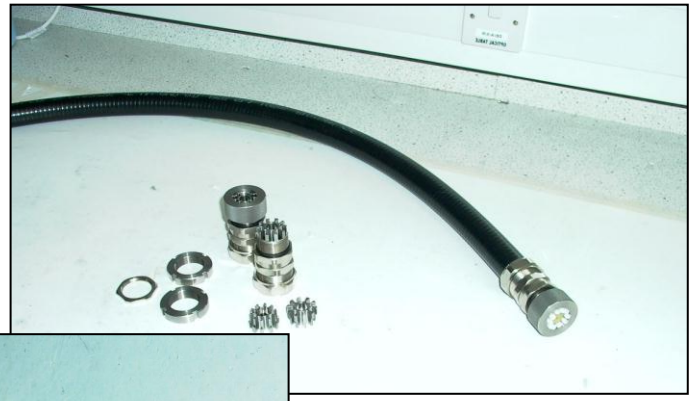


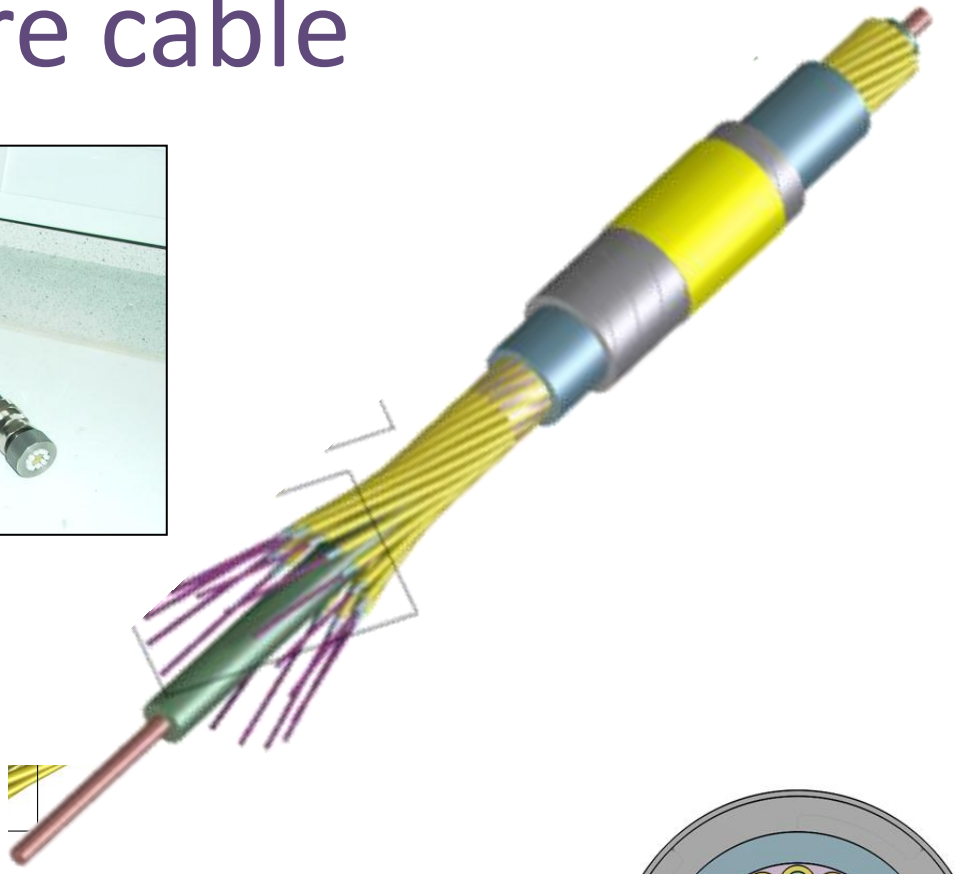


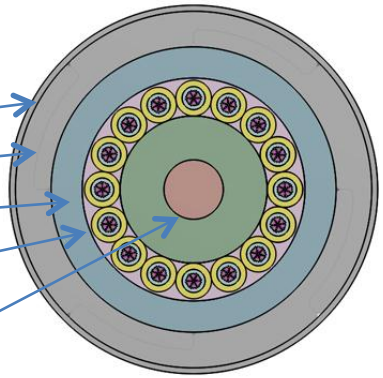
Durham University

CfAI
Centre for Advanced Instrumentation

Fibre cable







PVC waterproof coating, ~30 mm dia.

Steel spiral-wrapped conduit

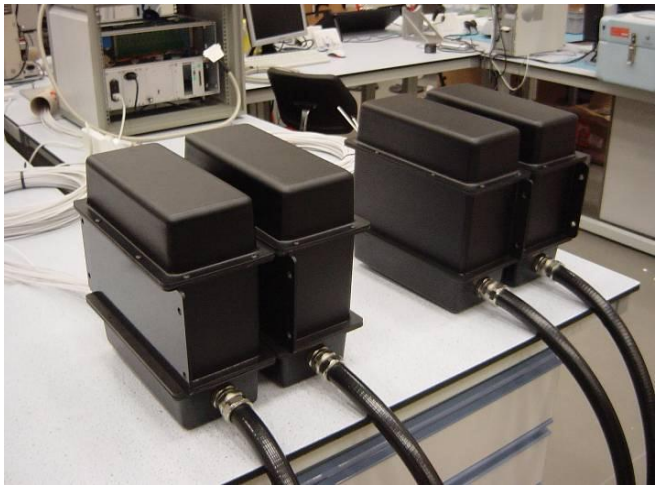
'gel tape' winding

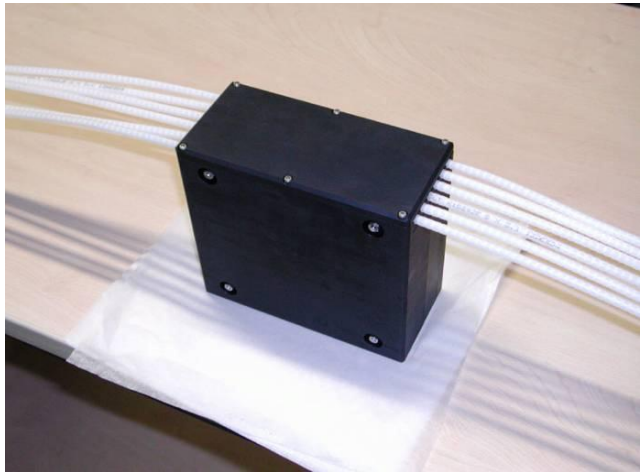
16 x 3 mm Furcation tubes

Aramid fiber tensile element

Polymer Core 12.3 mm dia.

Strain relief





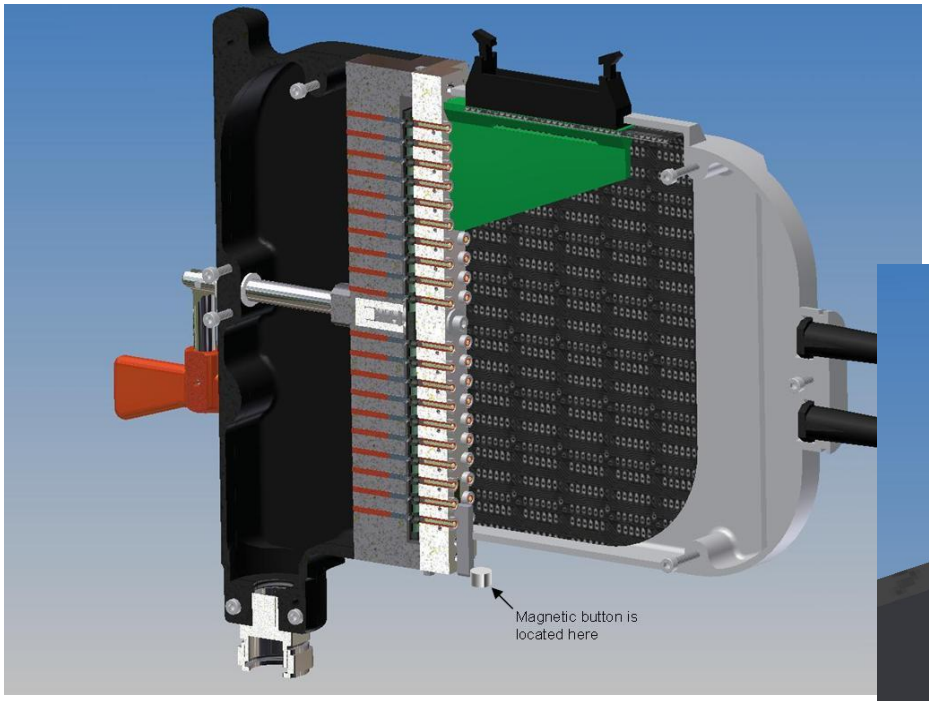
Durham University

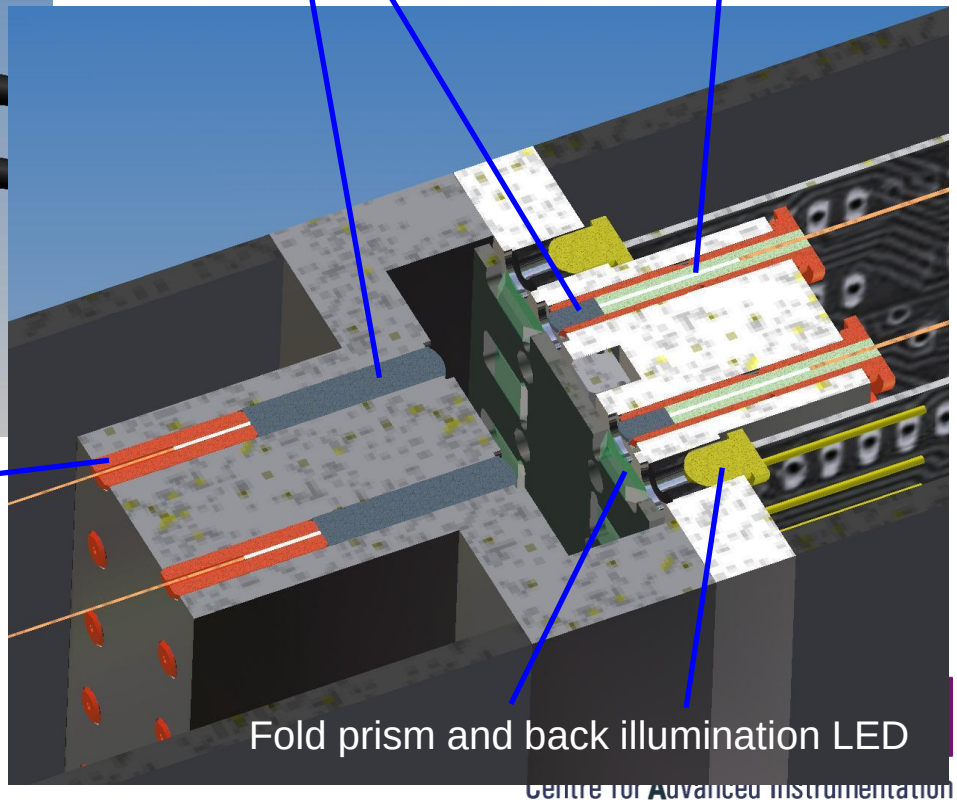
CfAI Centre for Advanced Instrumentation

Slit units

Fibres immersed to glass meniscus with A/R coating

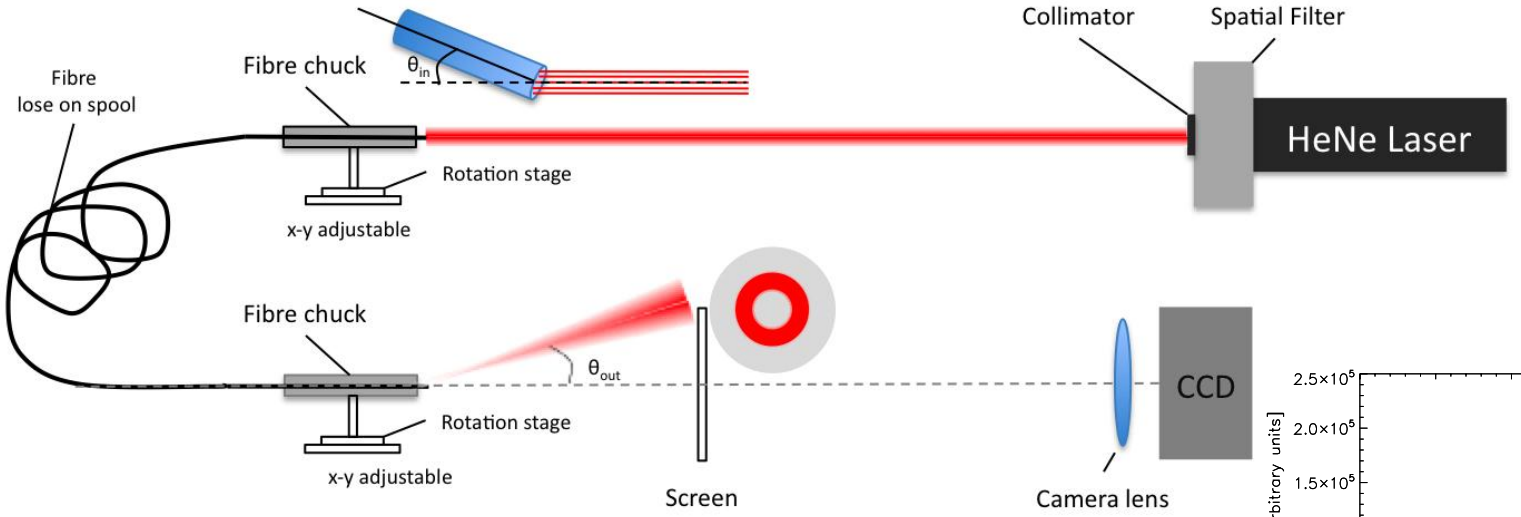
Fibre connectors

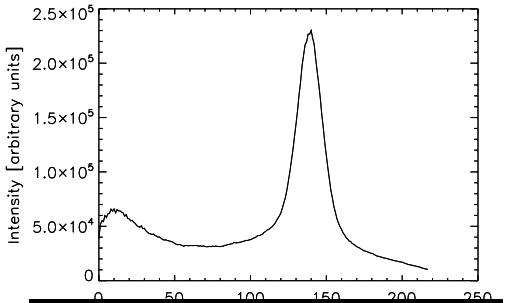


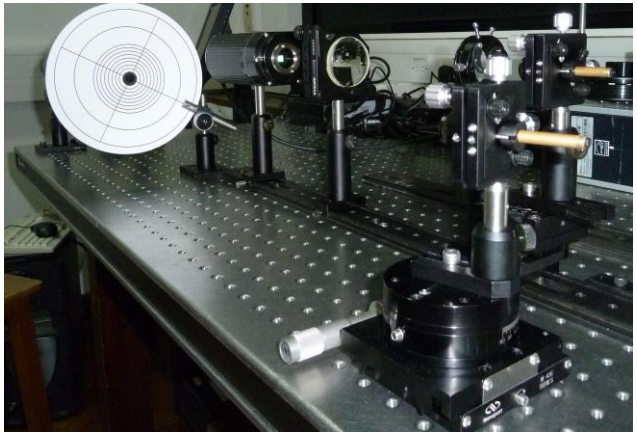


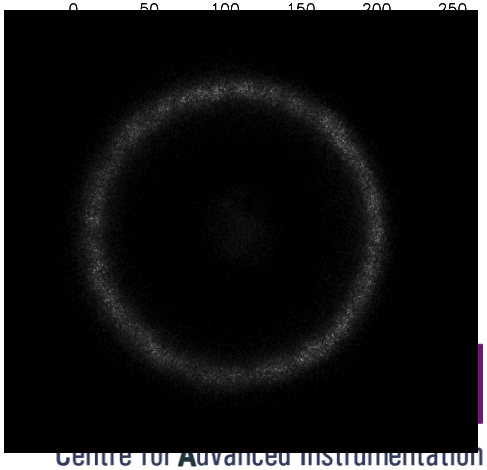
Built-in back-illumination
Upgradable to multiband

Vigorous underpinning R&D









Fibres are not the only fruit

DEXMOS: Higher SNR with 10,000 slits

Better background-subtraction and calibration, spatial information

-> BAO: [OII[-emitters 4000 targets/deg^2 for z < 1.5 => 20million redshifts in 200 nights*

-> Galaxy evolution: kpc-Mpc scale dynamical information for galaxies and groups

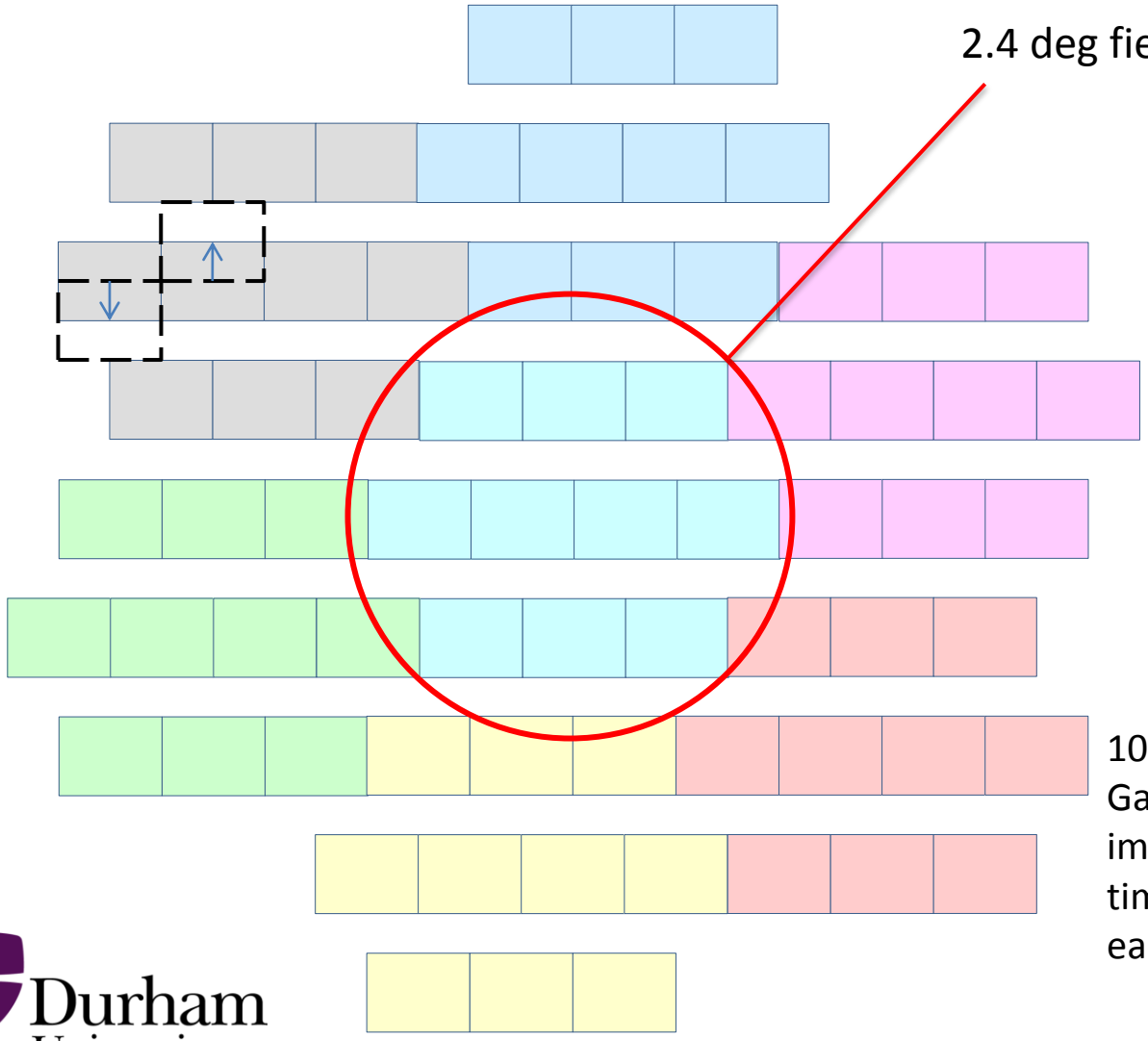
- **10 modular spectrographs** (120 x 120 x 720mm^3)
  - Instantaneous field: 2.5 sq.deq with 1 slit mask
  - Full corrector field in 1 passband in 2 visits
  - Mix and match bandpass and field coverage
- **3 bands via** exchange of VPH-grism & adjacent optics
  - 560-750nm R=1500
  - 750-900nm R=3000
  - 840-870nm R=5000
- **Hardware costs $4M**

* Tom Shanks

Durham University

CfAI Centre for Advanced Instrumentation

Tiling the sky



2.4 deg field (50% vignetting)

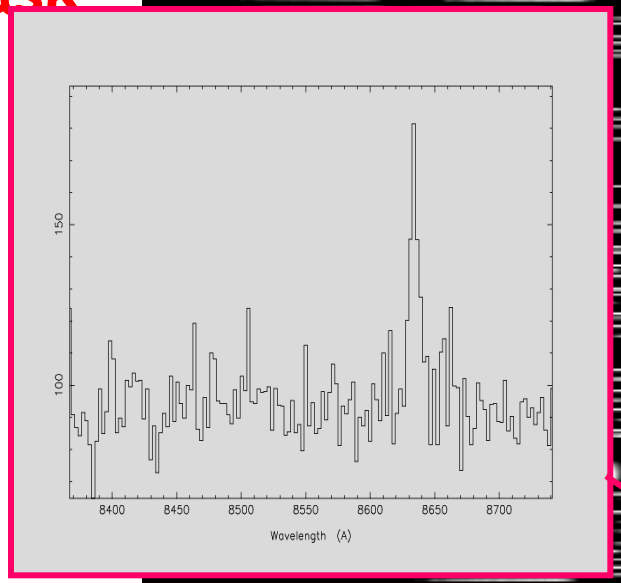
50% of field in one passband simultaneously

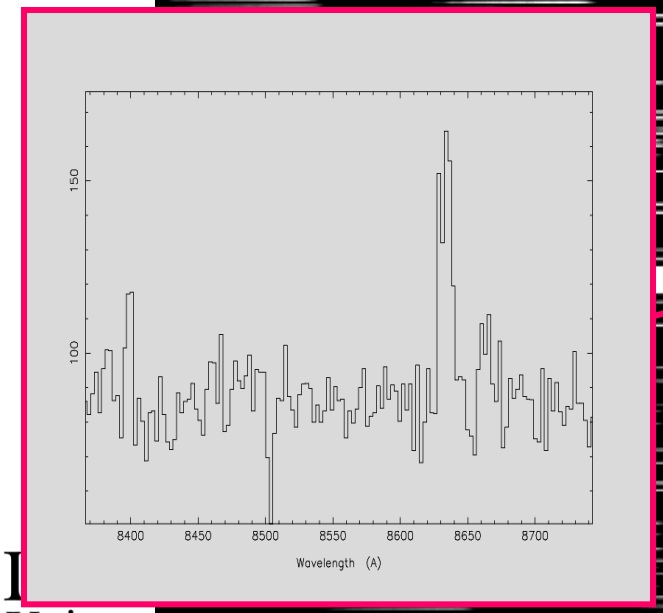
10 spectrographs 34’ x 26’ -> 2.5 deg^2. Gap size = half of field width so 3 images (moving by gaps size each time) give uniform transmission with each source observed twice.

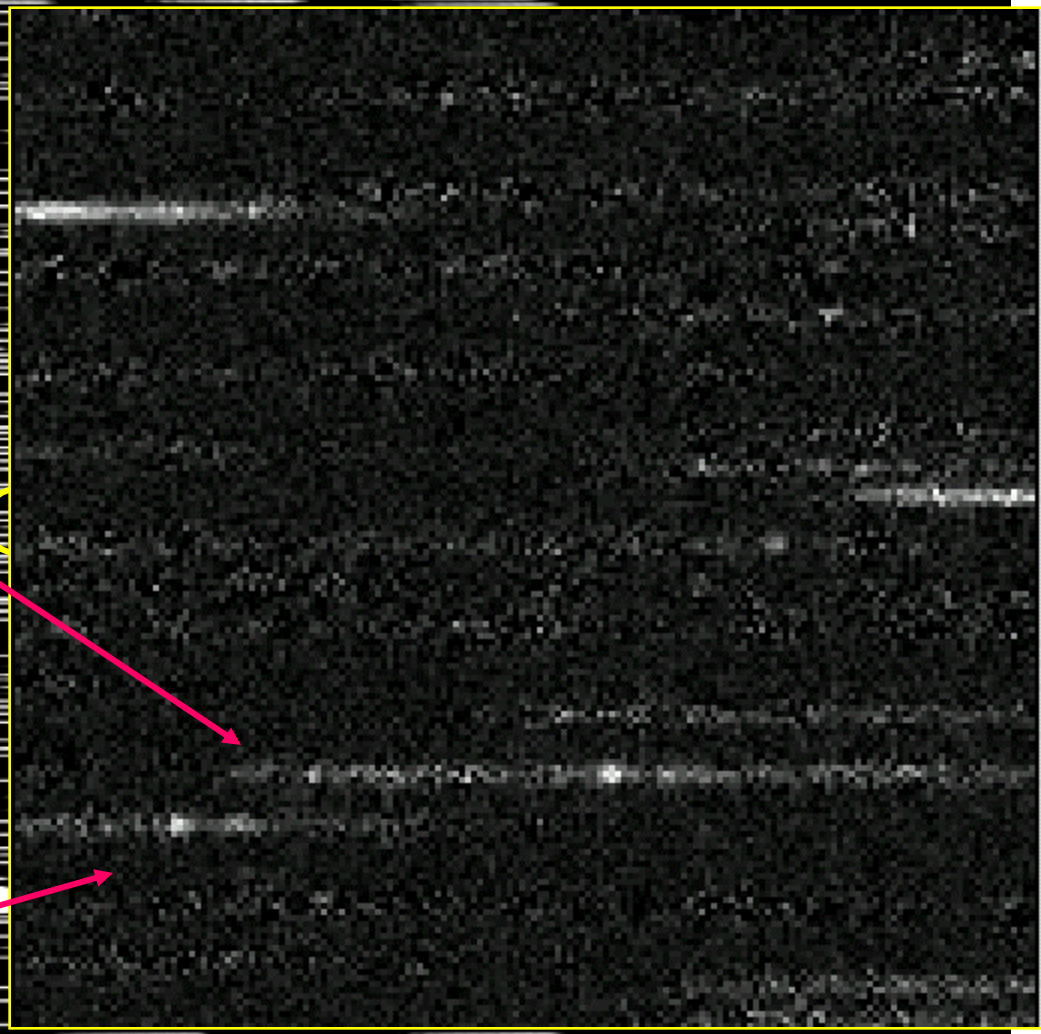
Durham University

CfAI Centre for Advanced Instrumentation

AC114 Mask

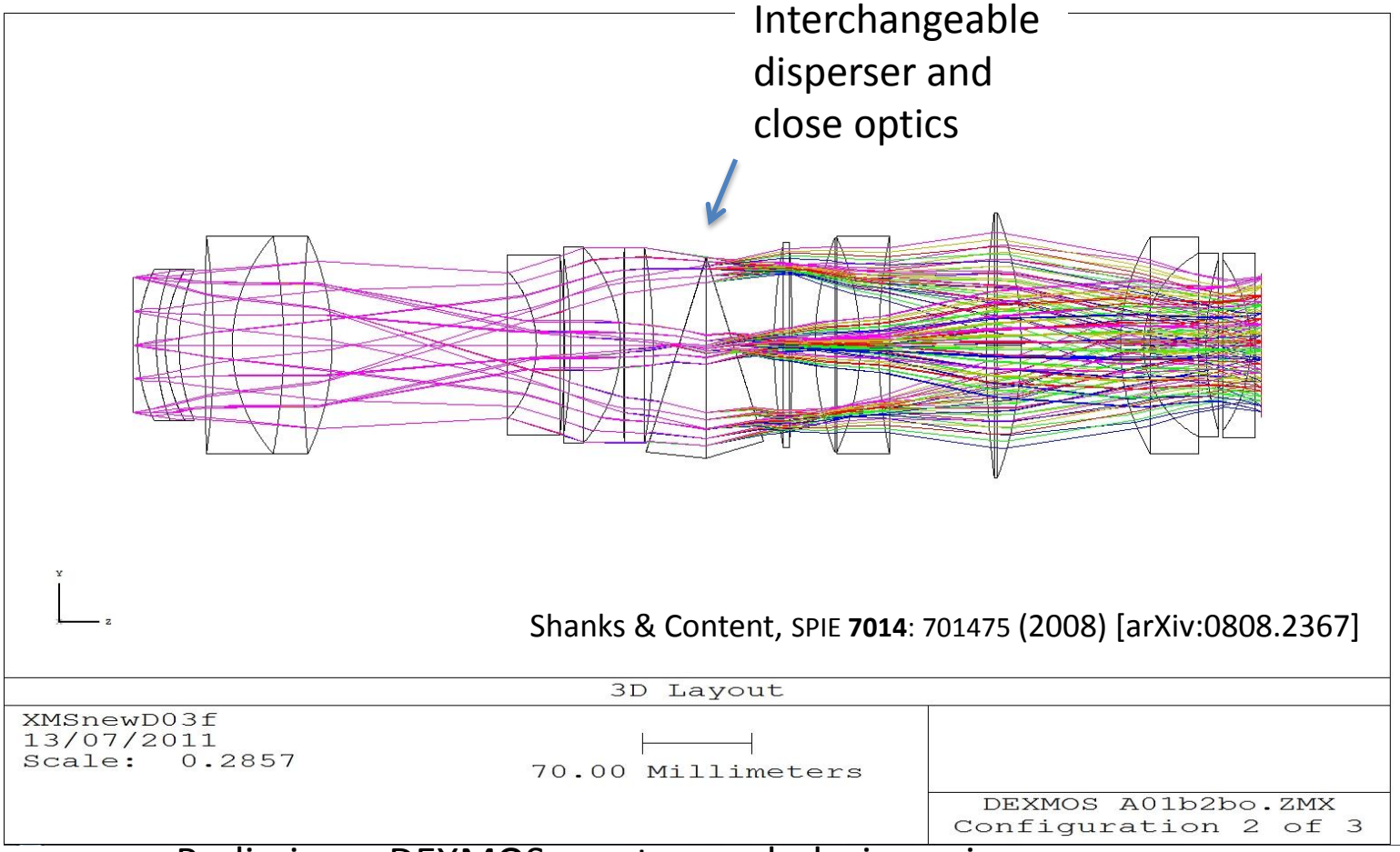






Univers

Cheap unit spectrographs



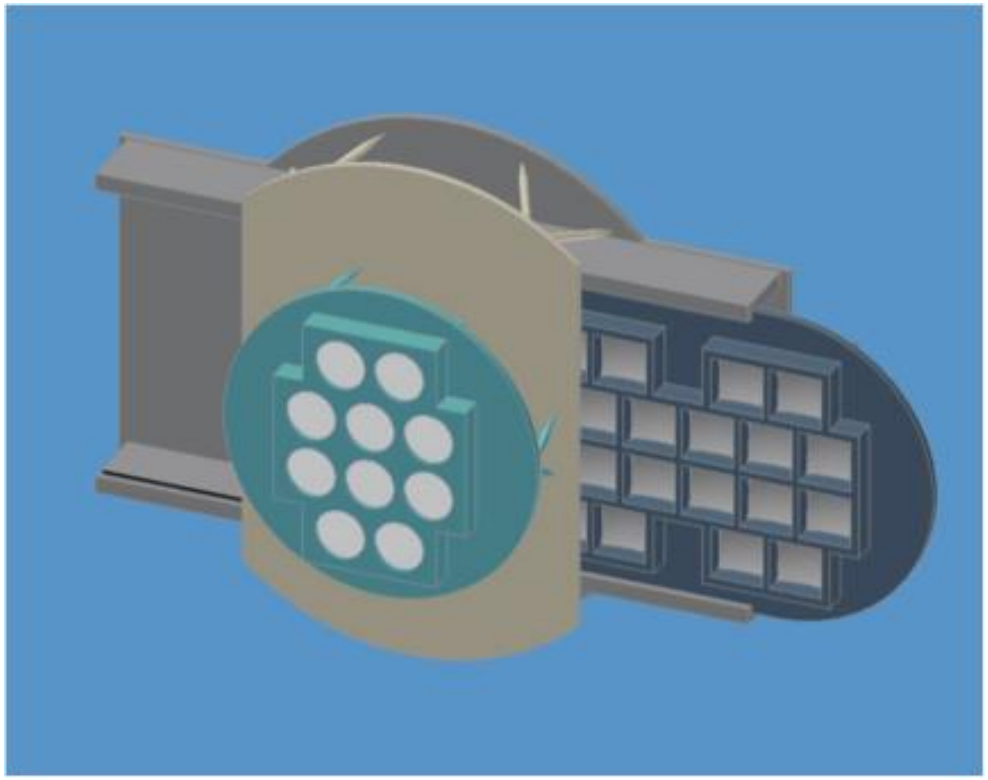
Preliminary DEXMOS spectrograph design using field scale and F-ratio of corrector and 720 mm between focal planes. Image quality (50%EED) already better than slit width on average.

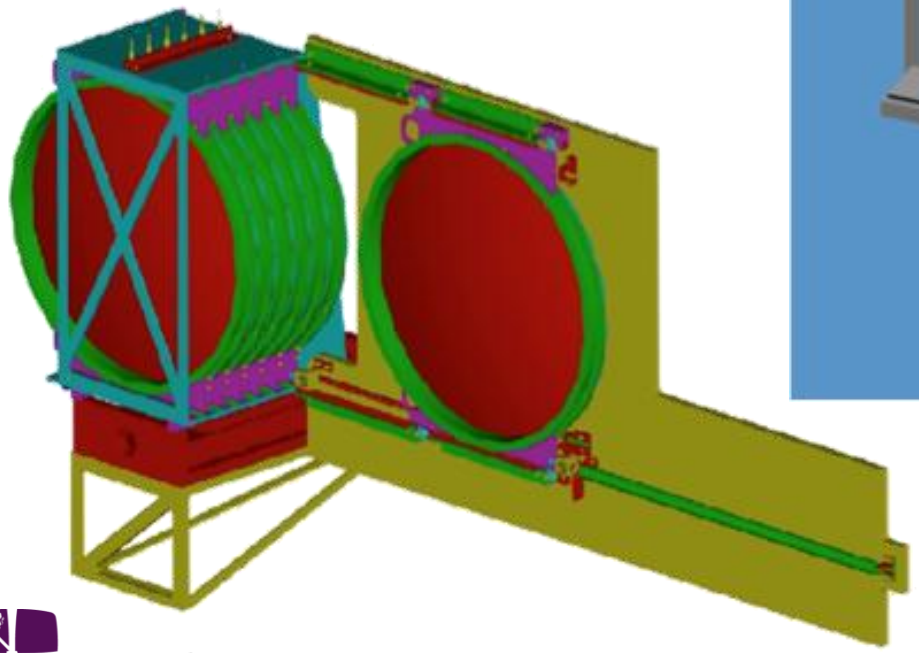
Durham University

CfAI Centre for Advanced Instrumentation

Mask & disperser exchangers

One mask/field
Set of 10 dispersers/field





Designs for VISTA implentation

Durham University

CfAI Centre for Advanced Instrumentation

Concluding remarks

- Do BigBOSS and DESpec need to compete on hardware?
  - Can you (time-)share in knowledge and/or hardware?

- Otherwise can DESpec do something unique and/or complementary?
  - E.g. DEXMOS

Fin