Spectrograph design for POLLUX: preliminary estimations

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Problem statement

- POLLUX is a high-resolution UV spectropolarimeter for the future LUVOIR large space telescope with the following target parameters

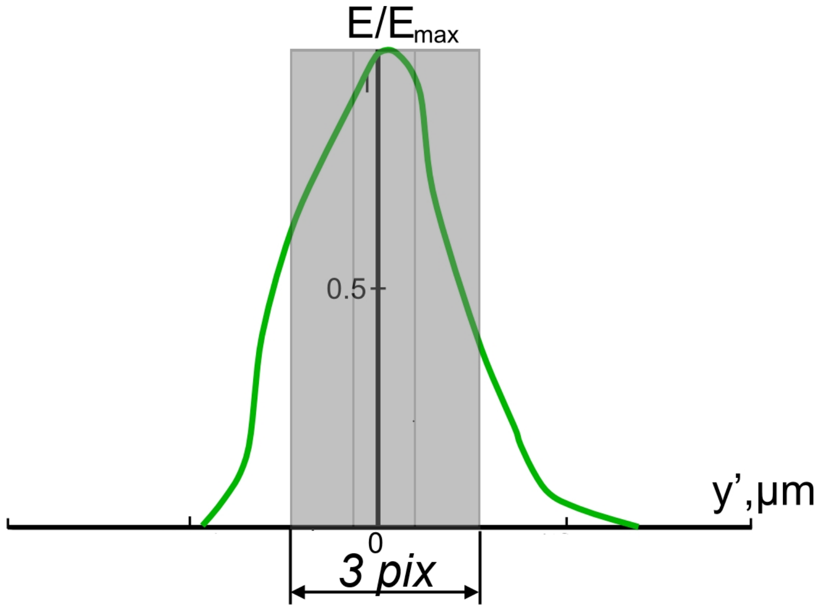
Parameter	Target value	Top goal	Comment
Shortest wavelength	98 nm	90 nm	
Longest wavelength	390 nm	visible	
Spectral resolution	120000	200000	
Aperture size	0.03”	0.01”	y_{slit}=45 um
Telescope F/#	20	-	NA=0.025
Entrance pupil diameter	15 m	-	
Sampling	2.5-3 pix per resolution element	-	β=0.413 y_{slit}’=18 um
Spectral length in the shortest image line	6 nm	-	

Conceptual/principal assumptions (I)

- On the current stage the spectrograph is considered separately from the polarimeter
- It's supposed to be a multi-channel echelle spectrograph with following parameters of the channels (*see presentation by Sebastien Vives, @ this workshop*)
  - 1st (FUV) channel - 90-120nm,
  - 2nd (MUV) channel - 120-220nm,
  - 3rd (NUV) channel - 220-400nm.
- The channels uses similar optical designs with minor changes. All the design concepts and estimations are demonstrated <u>on the example of the 2nd channel</u>
- The design uses the minimum possible number of optical surfaces in order to increase the throughput:
  - OAP mirror as the collimator,
  - Echelle grating,
  - Single reflective grating as the cross-disperser.

Conceptual/principal assumptions (II)

- The previous assumptions implies that the optical system is limited by aberrations (at least for a part of the working range).
  - So the spectral resolution value used for analytical computation should be higher than the target value, i.e. the collimated beam diameter and/or echelle AOI is intendenly increased.
  - Possible alternative is a higher energy concentration in the spot due to use of additional surfaces



Typical instrument function of the spectrograph

Technological assumptions

- The detectors have the following parameters (or higher)
  - 90-120nm and 120-220nm is registered with MCPs of about 100x100mm. Pixel size is 6 um.
  - 220-400nm is registered with CCD of about 4kx4k (13 um pixel).
  - Mosaic designs are possible
  - Increase of one dimension or curving is possible for the MCP detector

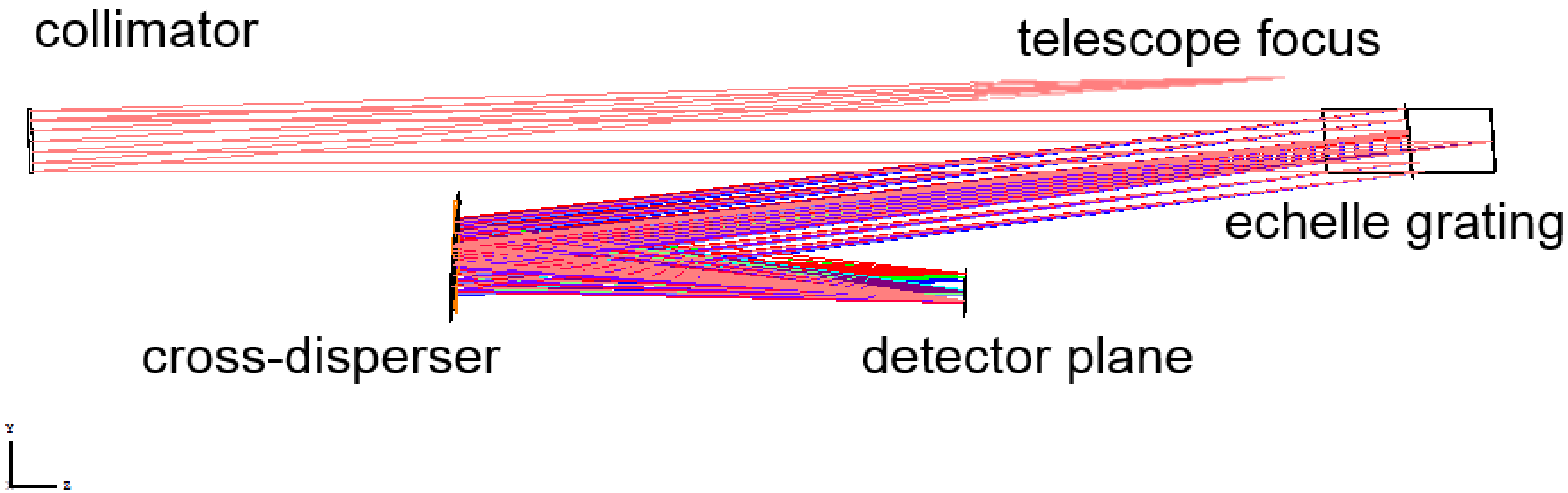
- "Technologically safe" parameters for the echelle are
  - Grooves frequency <100 gr/mm
  - AOI <80°.

- Camera mirror and the cross-disperser represents a single element, which has the following features
  - Can have any shape, including aspherics and Zernike-based freeforms.
  - Can have a complex grooves pattern.

Current baseline design concept

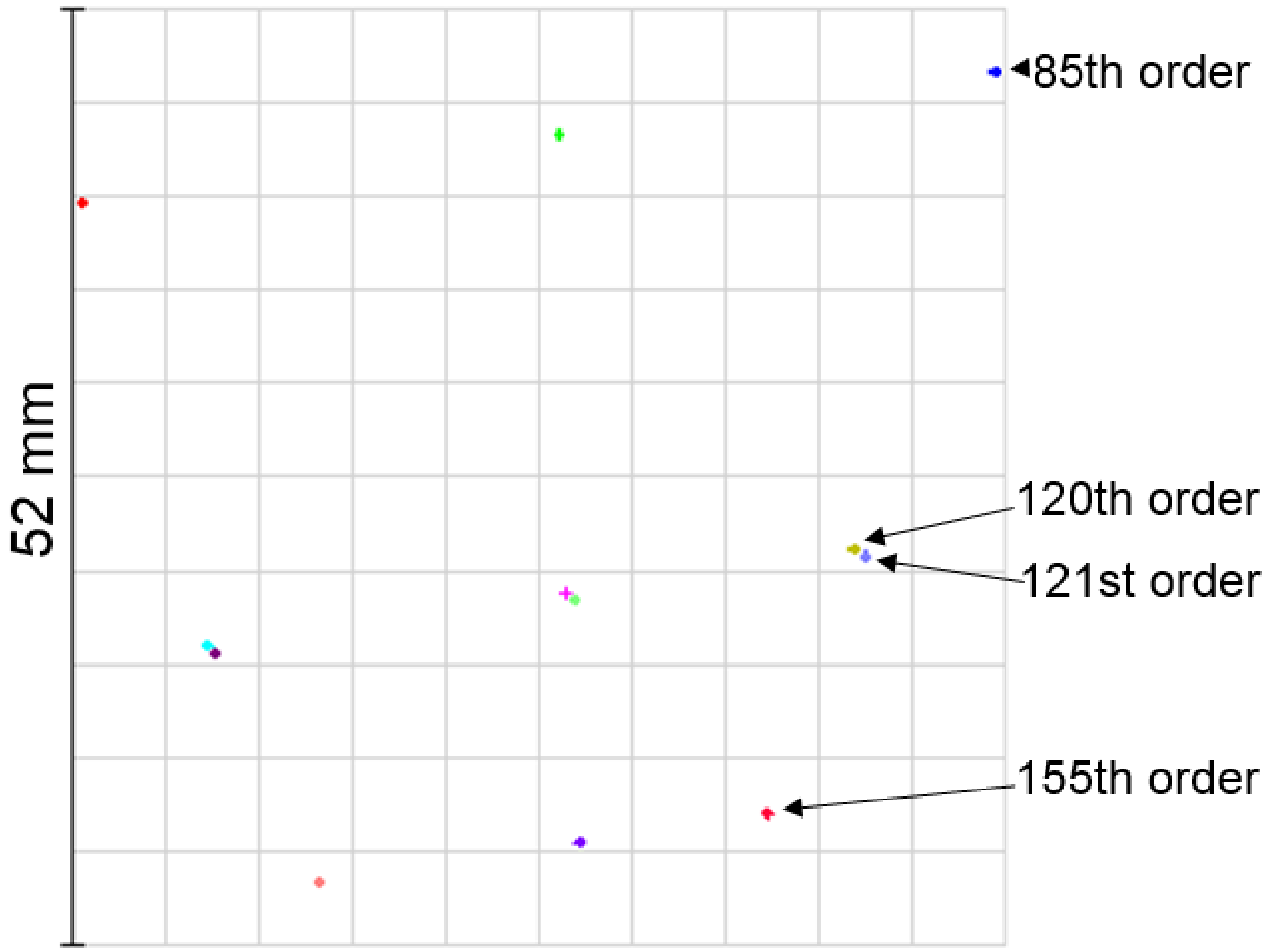
Parameters	Value	Comments
Collimator focal length	1939.5 mm	= Largest dimension of the instrument
Echelle grooves frequency	101 gr/mm	In the safe zone
Echelle AOI	69.436 °	In the safe zone
Orders	85-155	Feasible high-order mode
Detector format	50.8x45.1 mm	Can be single square detector
Cross-disperser grooves frequency	500 gr/mm	Manufacturable
Cross-disperser focal length	800 mm	Manufacturable
Length of the image lines		
1st	50.84 mm	
Last	24.97 nm	
Spectral length of the orders		
1st	**2.6 nm**	**Factor of 2 difference**
Last	**0.7 nm**	**Order of magnitude difference**

Optical scheme

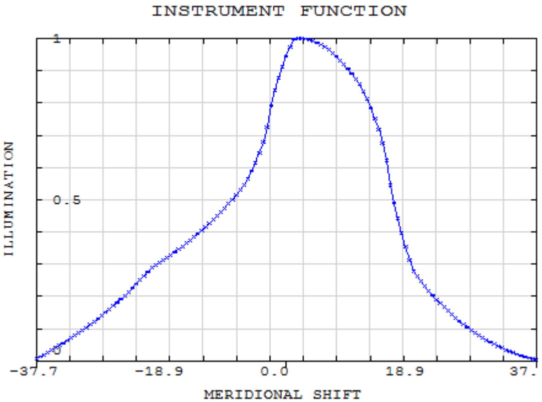


The optical scheme represents almost classical echelle spectrograph
In a quasi-Littrow mounting with a single cross-disperser

Spectrum format



Optical quality and resolution (I)



WIDTH

ENTRANCE SLIT WIDTH, MICRONS 18.0000
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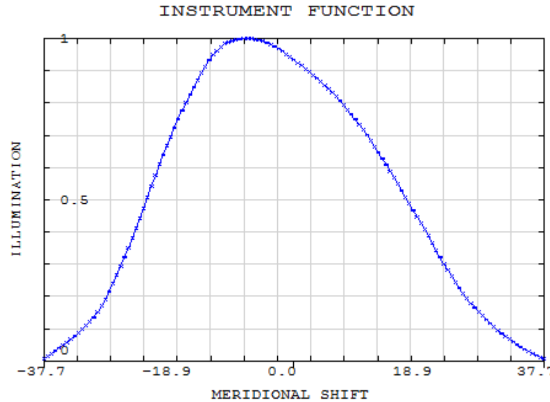
WIDTH ON LEVEL 0.1, MICRONS 57.6000



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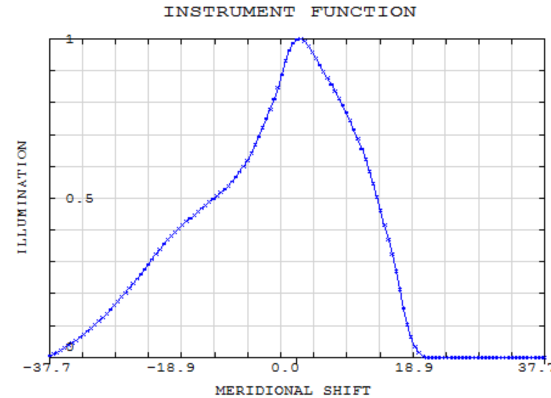

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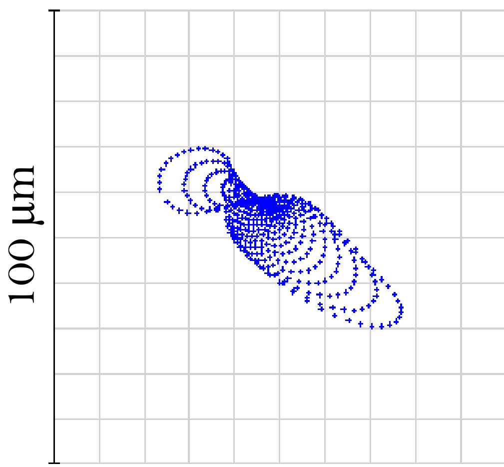
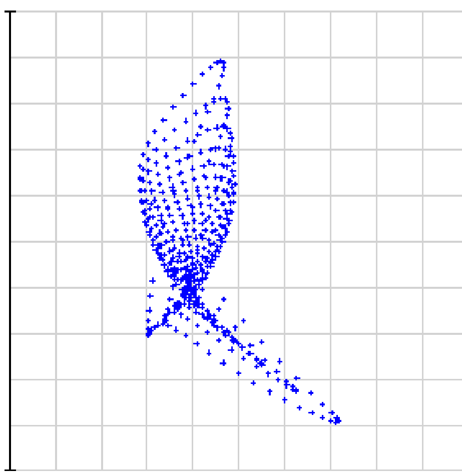
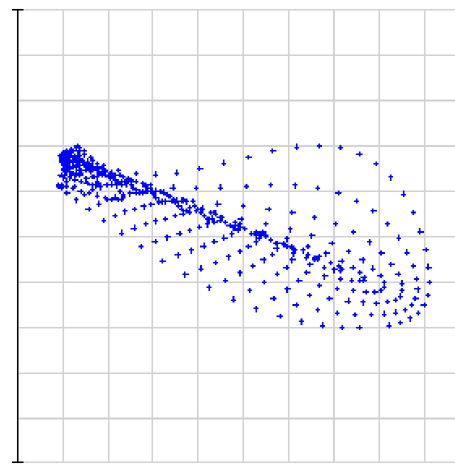


217.4 nm
IF FWHM = 24.2 µm
Spot RMS = 27.2 µm

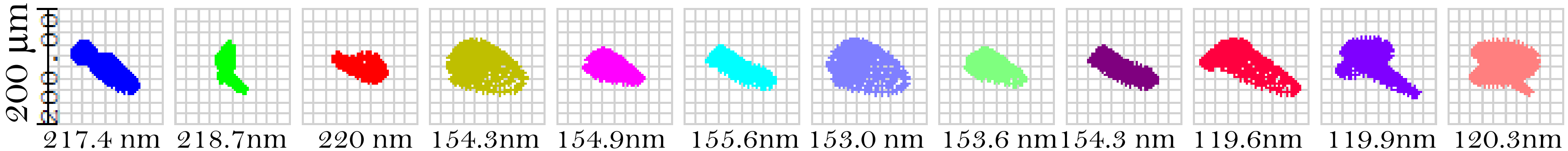


218.7 nm
IF FWHM = 39.2 µm
Spot RMS = 20.1 µm

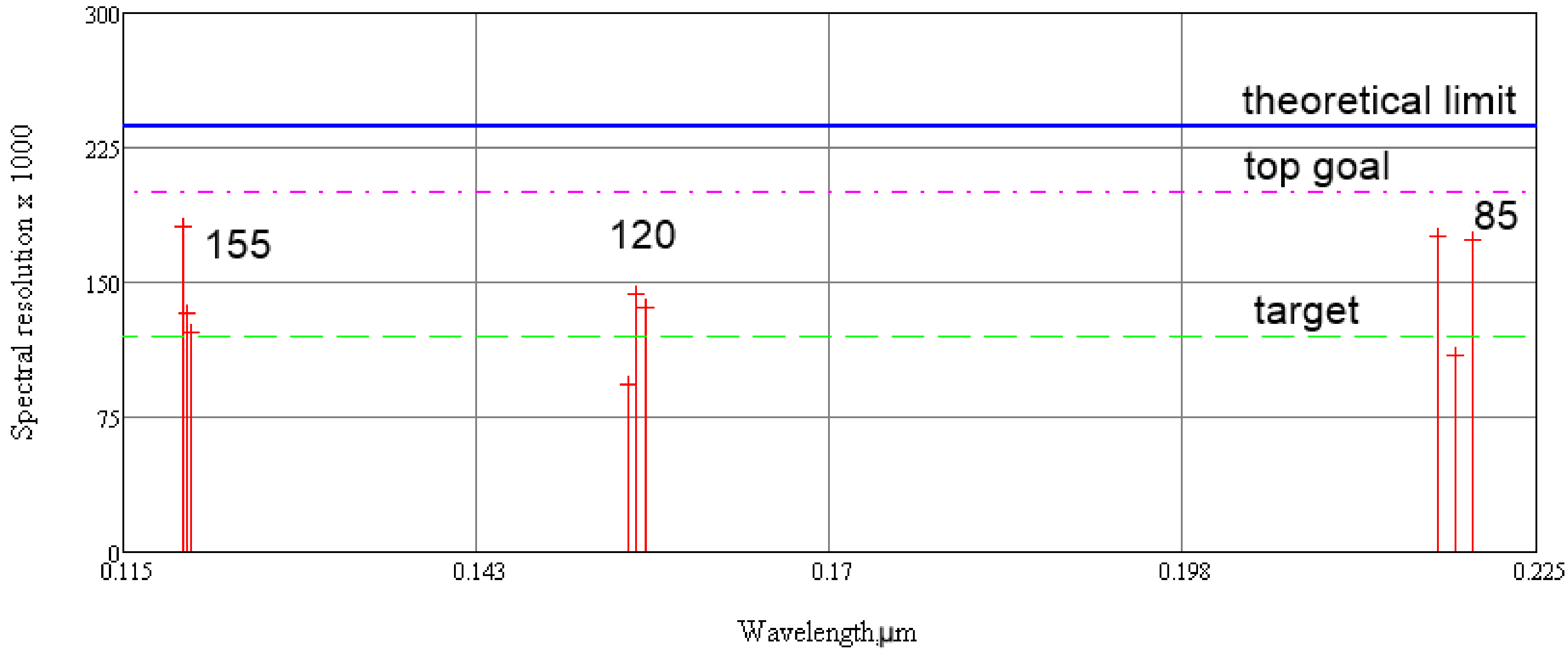


220.0 nm
IF FWHM = 24.8 µm
Spot RMS = 30.2 µm

Optical quality and resolution (II)

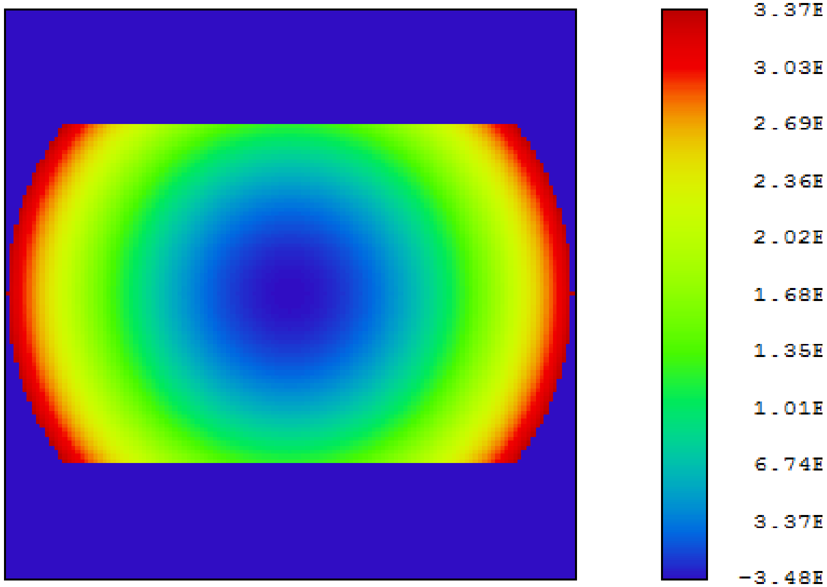


Spot diagrams for all the control wavelengths

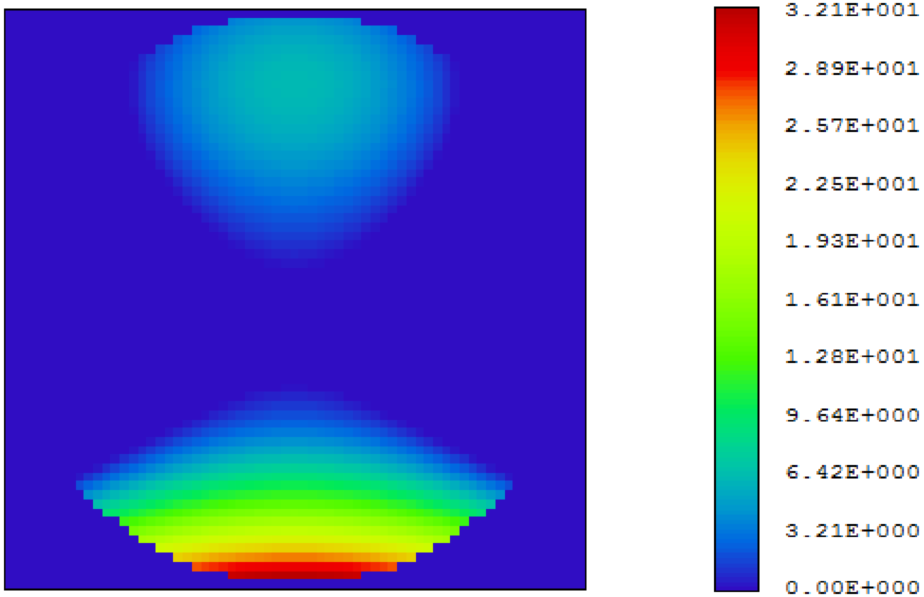


Spectral resolution in the 85th, 120th and 155th orders vs the target values

Notes on the cross-disperser (I)



Cross-disperser grating sag:
Sphere R=1601.05 mm
+Zernike modes:
V. ast 1 and 2, V. coma 1, V. tref, V. quadrof., Prim sph.

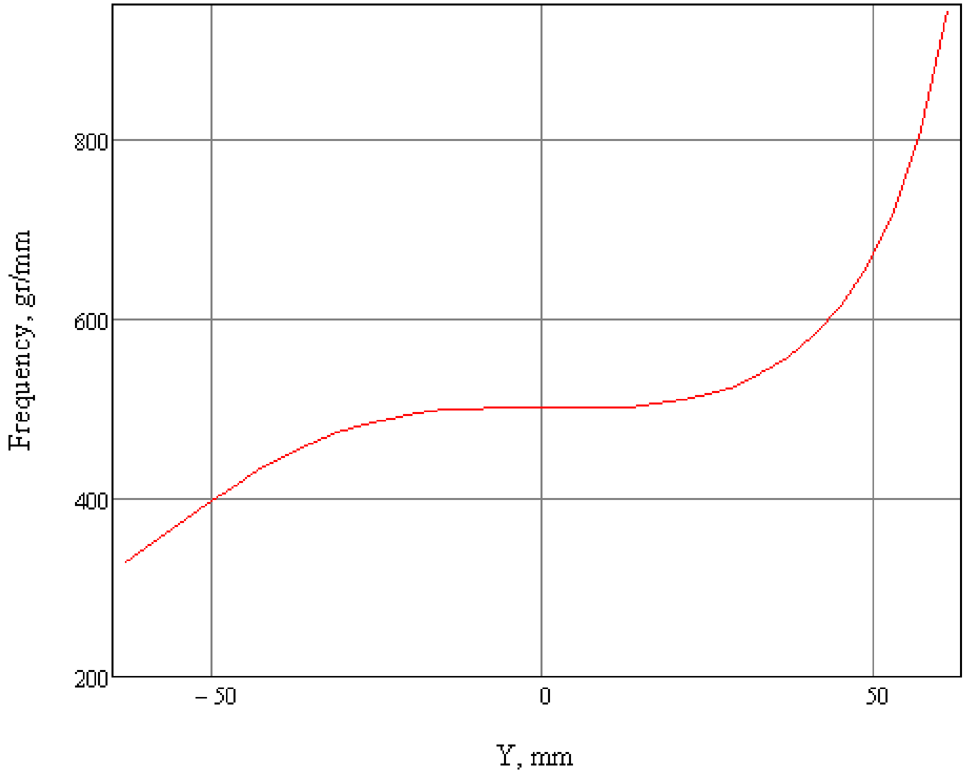


Residual after the BFS subtraction
RMS error = 6.65 µm
Max error = 32.12 µm

Notes on the cross-disperser (II)

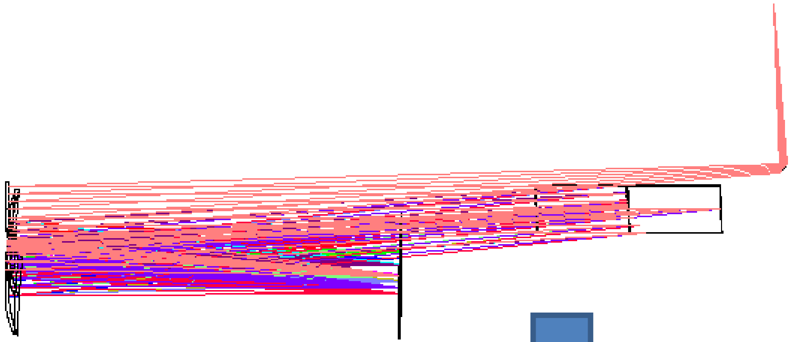
The grating has variable line spacing defined by the equation:

$$d_{eff} = \frac{1}{T} + \alpha \cdot y \quad + \beta \cdot y^2 + \gamma \cdot y^3 + \delta \cdot y^4 + \varepsilon \cdot y^5$$



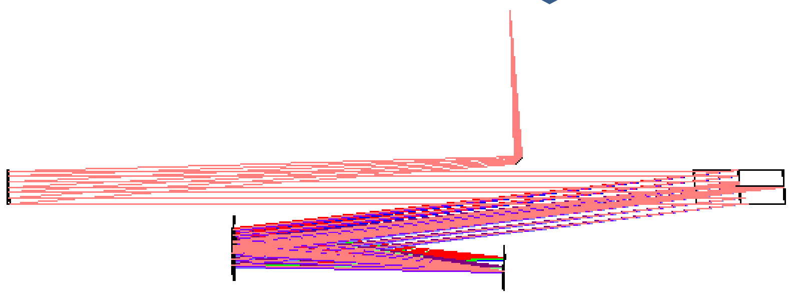
Grooves frequency vs. the Y coordinate on the cross-disperser surface

Other configurations considered



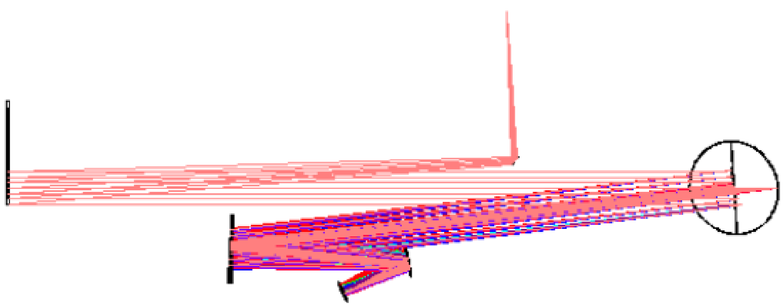
Scheme 0

F_{col}=1212mm
F_{cam}=500 mm
$N_{echelle}$=229gr/mm
Orders=39-71
dλ=3.1nm
Det.W x H
=117x65 mm
FWHM~31.7um

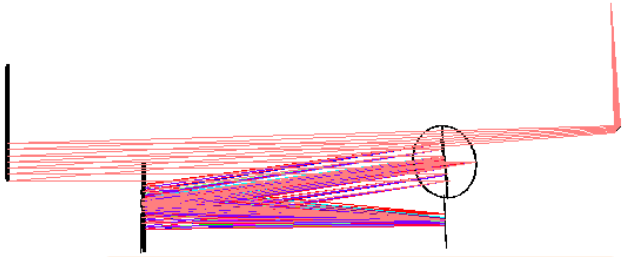


Scheme 1

F_{col}=1939.5mm
F_{cam}=800 mm
$N_{echelle}$=101gr/mm
Orders=85-155
dλ=0.7nm
Det.W x H =
51x45 mm
FWHM~39.2um

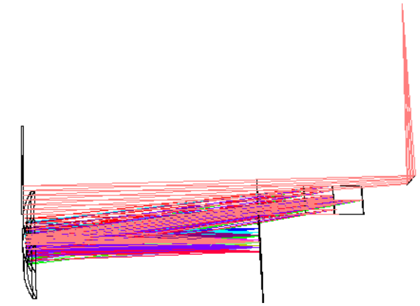


Scheme 1m
=
Scheme 1+
Additional
mirror
FWHM~19 um



Scheme 2e

F_{col}=3124 mm, F_{cam}=1490 mm
$N_{echelle}$=350gr/mm,Orders=21-27
Range = 179-240 nm,dλ=6nm
Det.W x H = 243x53 mm
FWHM~32.8um

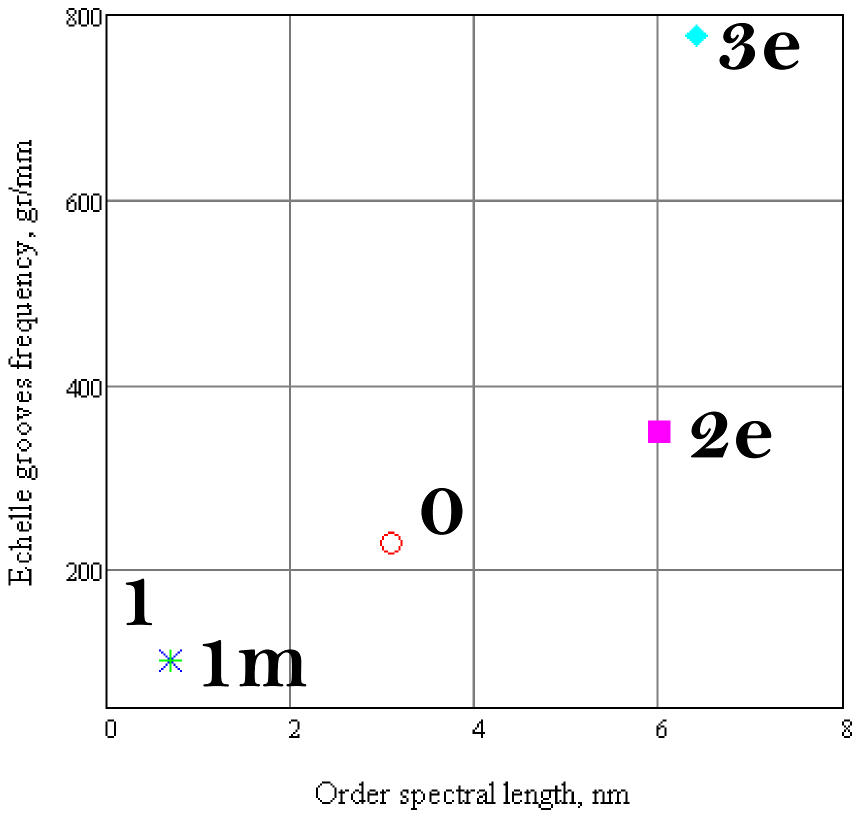


Scheme 3e

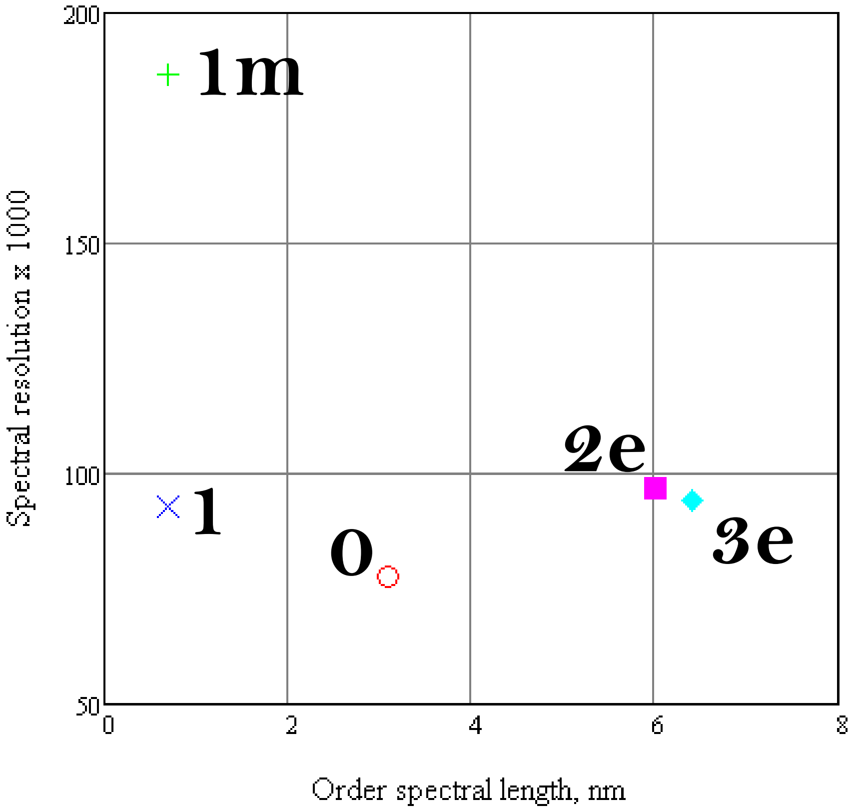
F_{col}=1504 mm, F_{cam}=600 mm
$N_{echelle}$=778gr/mm, Orders=11-19
dλ=6.4 nm
Det.W x H = 259x72 mm
FWHM~36.3um

Bykov+ Appl. Spectrosc. 67, 873-883 (2013)

Comparison of the trial designs

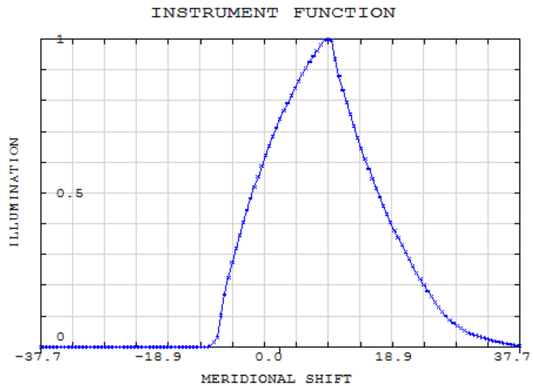


Echelle grooves frequency
VS
Spectral length of the shortest line
in the spectrogram



Spectral resolution for the worst point
VS
Spectral length of the shortest line
in the spectrogram

Optical quality and resolution with additional mirror

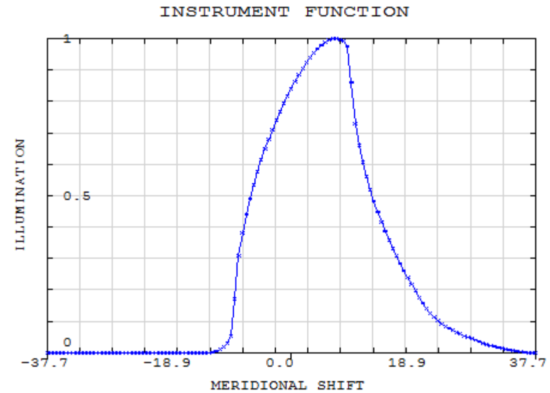


WIDTH

ENTRANCE SLIT WIDTH, MICRONS 18.0000
FULL WIDTH ON A HALF OF THE MAX, MICRONS 19.5840
WIDTH ON LEVEL 0.1, MICRONS 35.1360

217.4 nm

IF FWHM = 19.6 µm

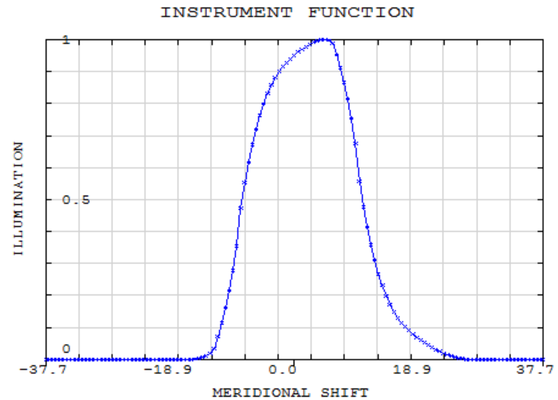


WIDTH

ENTRANCE SLIT WIDTH, MICRONS 18.0000
FULL WIDTH ON A HALF OF THE MAX, MICRONS 18.4320
WIDTH ON LEVEL 0.1, MICRONS 31.6800

218.7 nm

IF FWHM = 18.4 µm

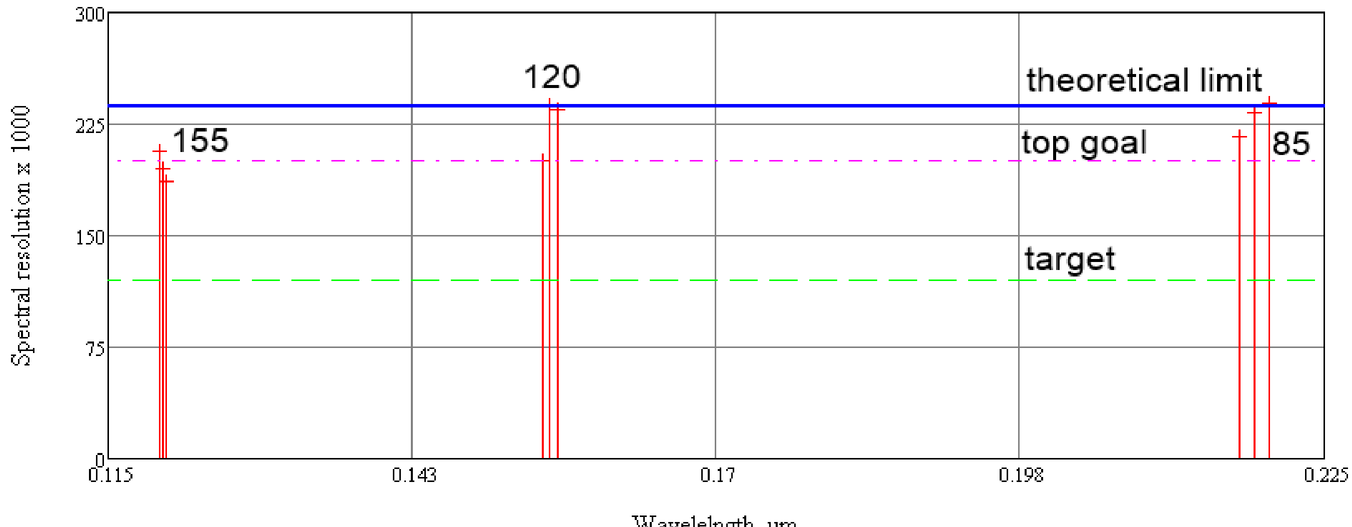


WIDTH

ENTRANCE SLIT WIDTH, MICRONS 18.0000
FULL WIDTH ON A HALF OF THE MAX, MICRONS 17.8560
WIDTH ON LEVEL 0.1, MICRONS 28.2240

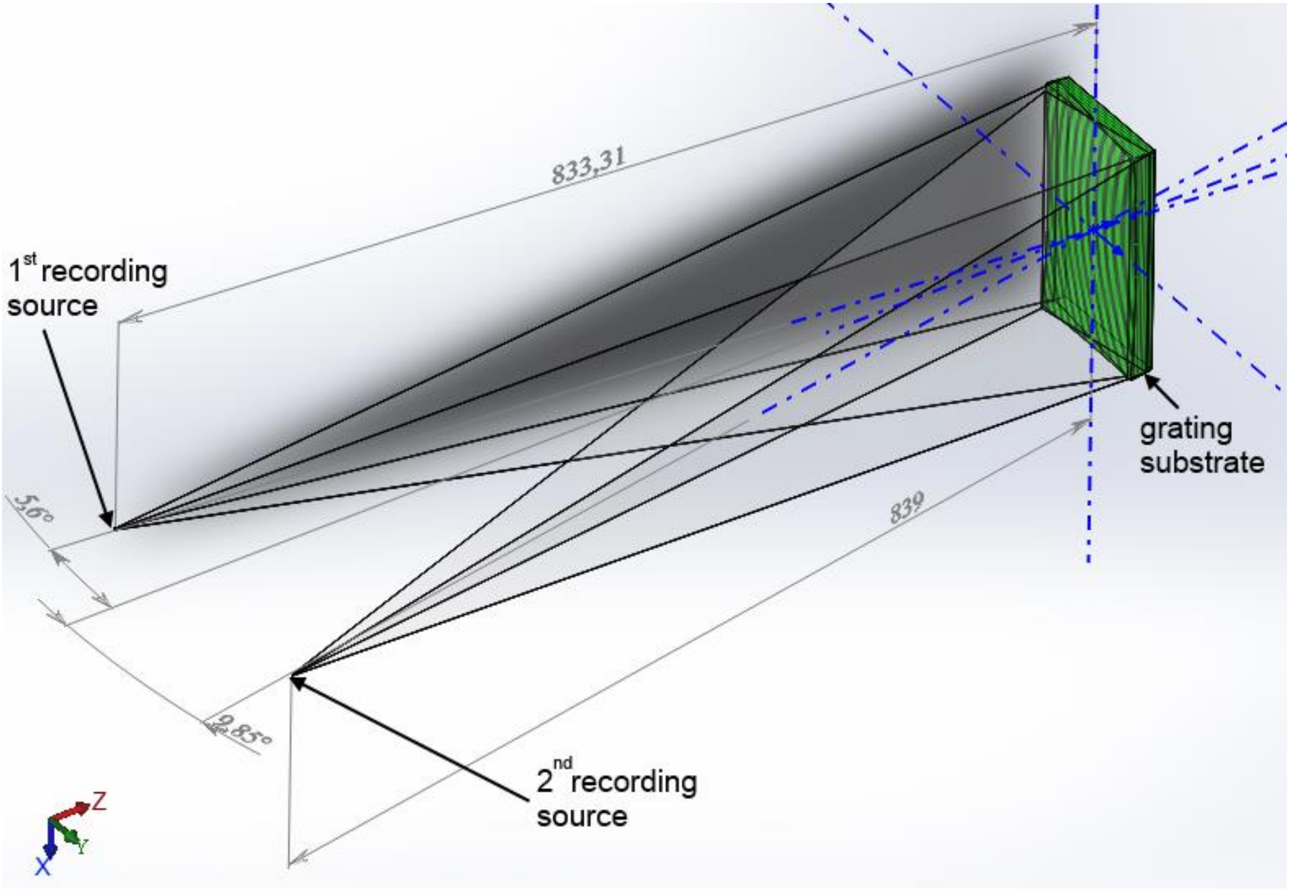
220.0 nm

IF FWHM = 18 µm

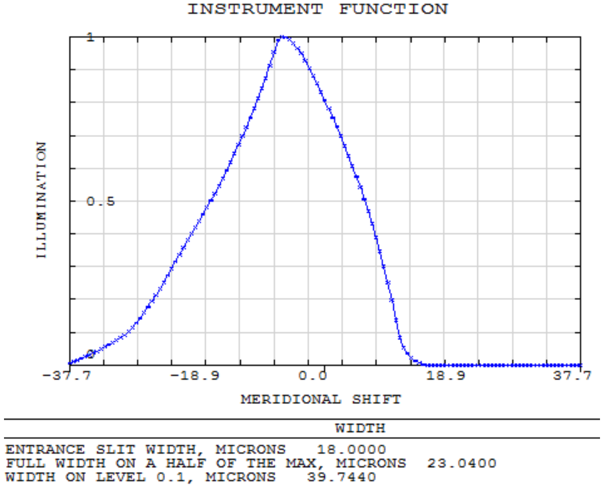


Spectral resolution in the 85th, 120th and 155th orders vs the target values

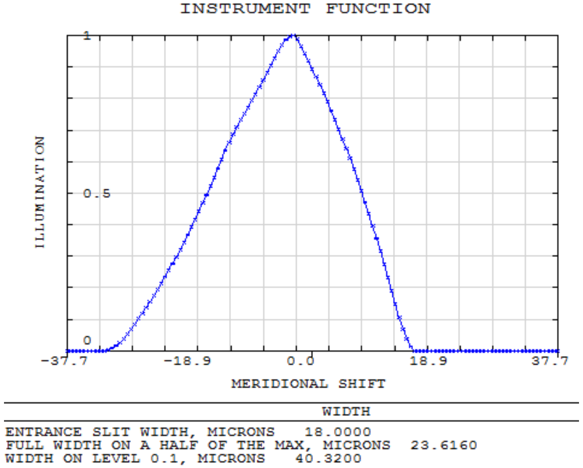
Possible implementation of the cross-disperser grating



The holographic grating recording scheme:
The two sources are points emitting @ 532 nm.



IF @ 120.3 nm with VLS grating
IF FWHM = 23 µm



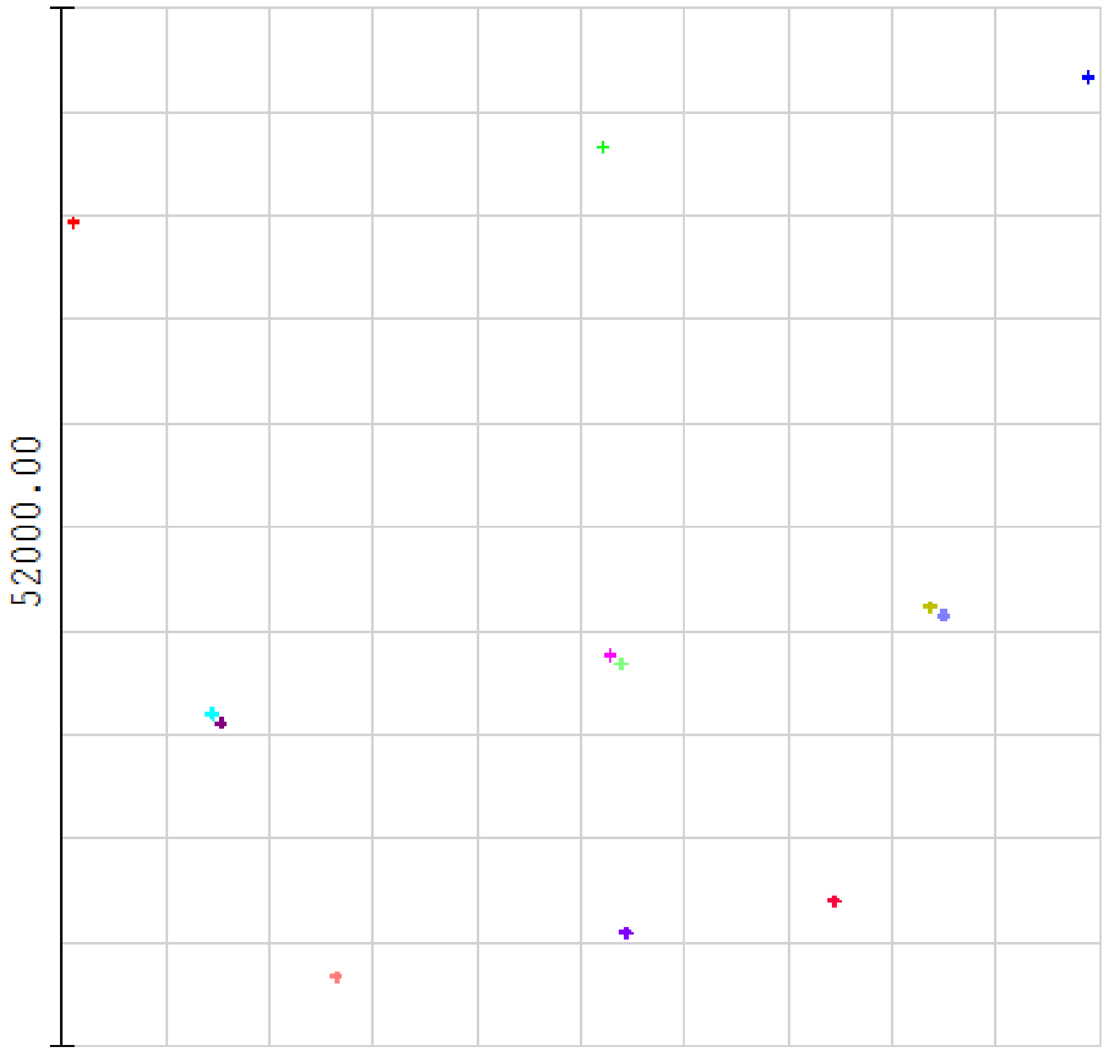
IF @ 120.3 nm with hologr. grating
IF FWHM = 23.6 µm

Conclusions and open questions

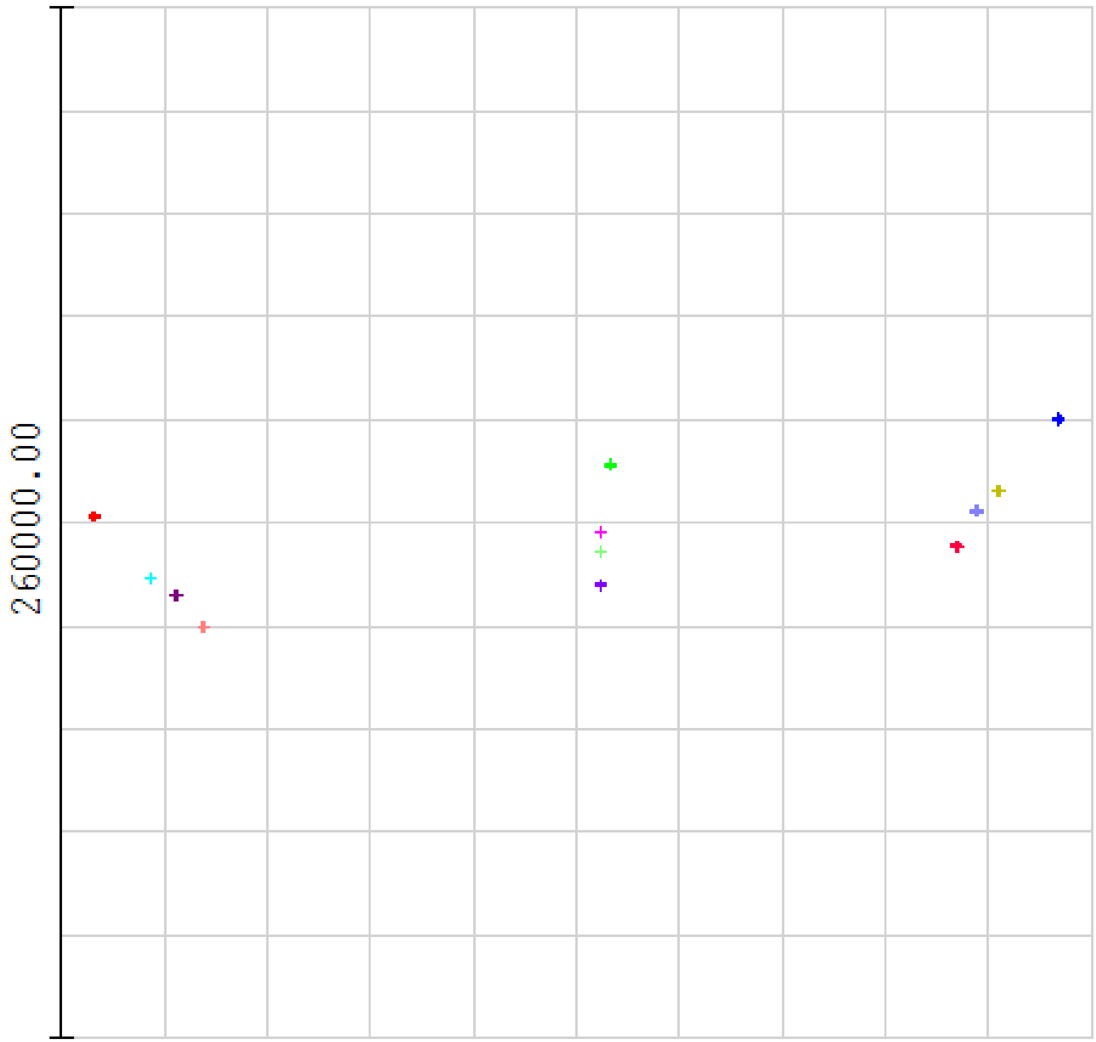
- **Conclusions on the optical design**
  - The most of the requirements can be met with the current baseline design concept
  - The critical requirement is the spectral length of the shortest order
  - All the design parameters can be within the current or expected technological limits

THANK YOU FOR YOUR ATTENTION!

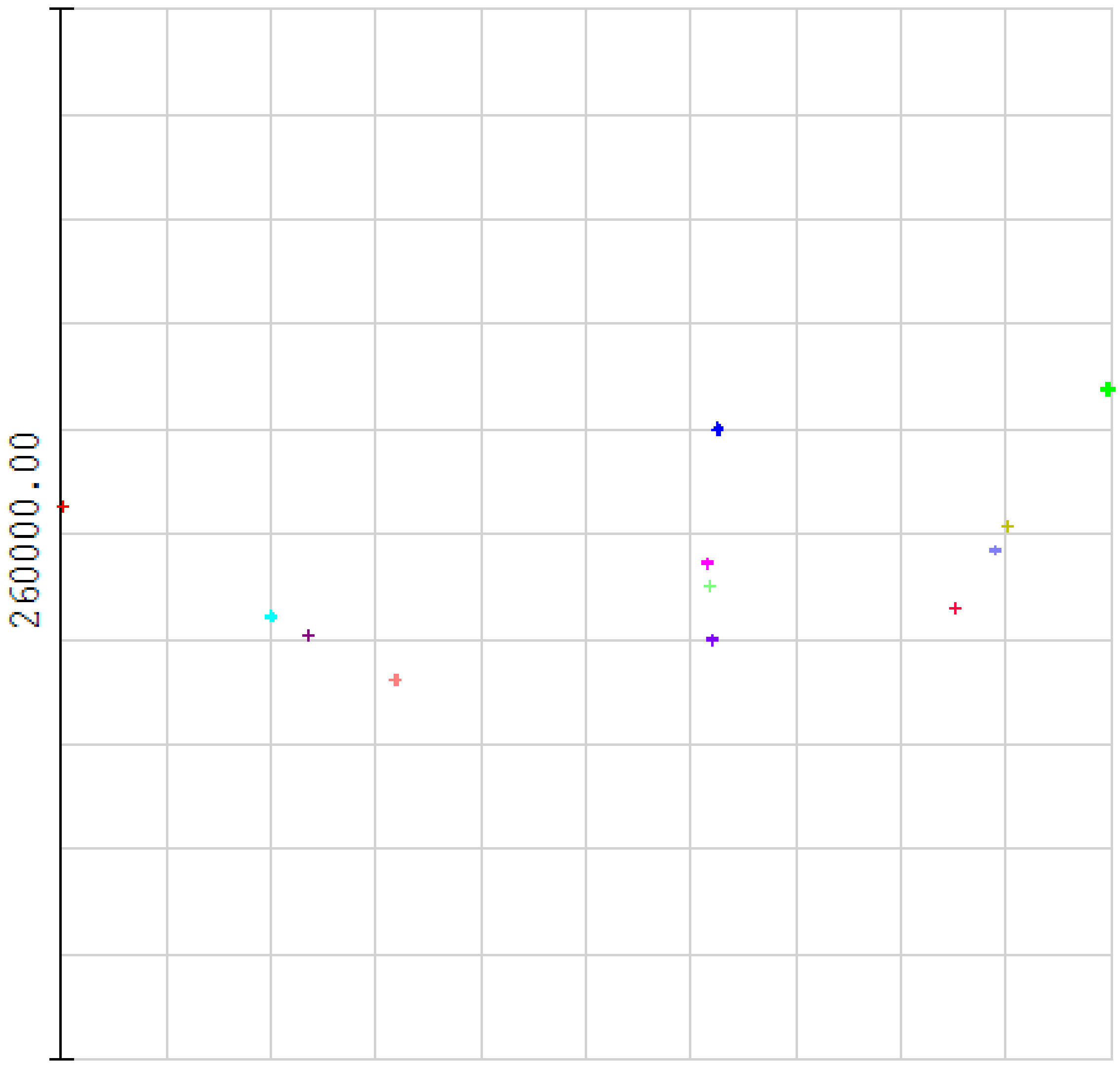
Design 1 and 1e – detector format



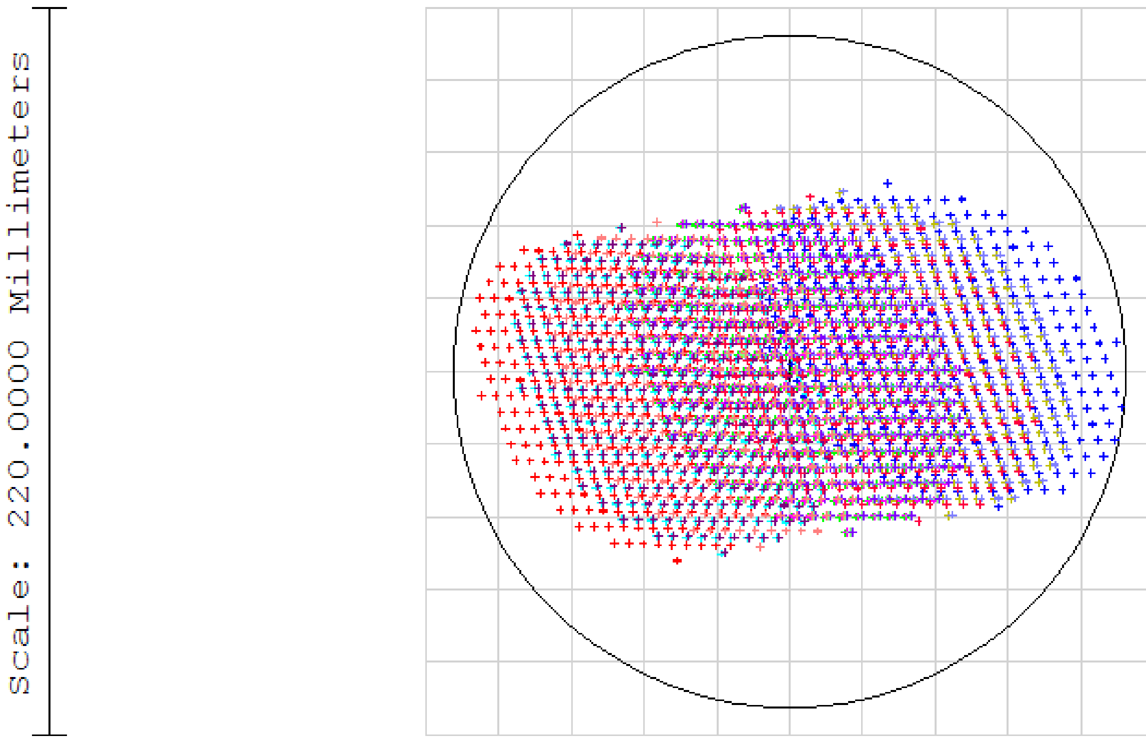
Design 2e – detector format



Design 3e – detector format



Design 1 and 1m – footprint on the cross-disperser



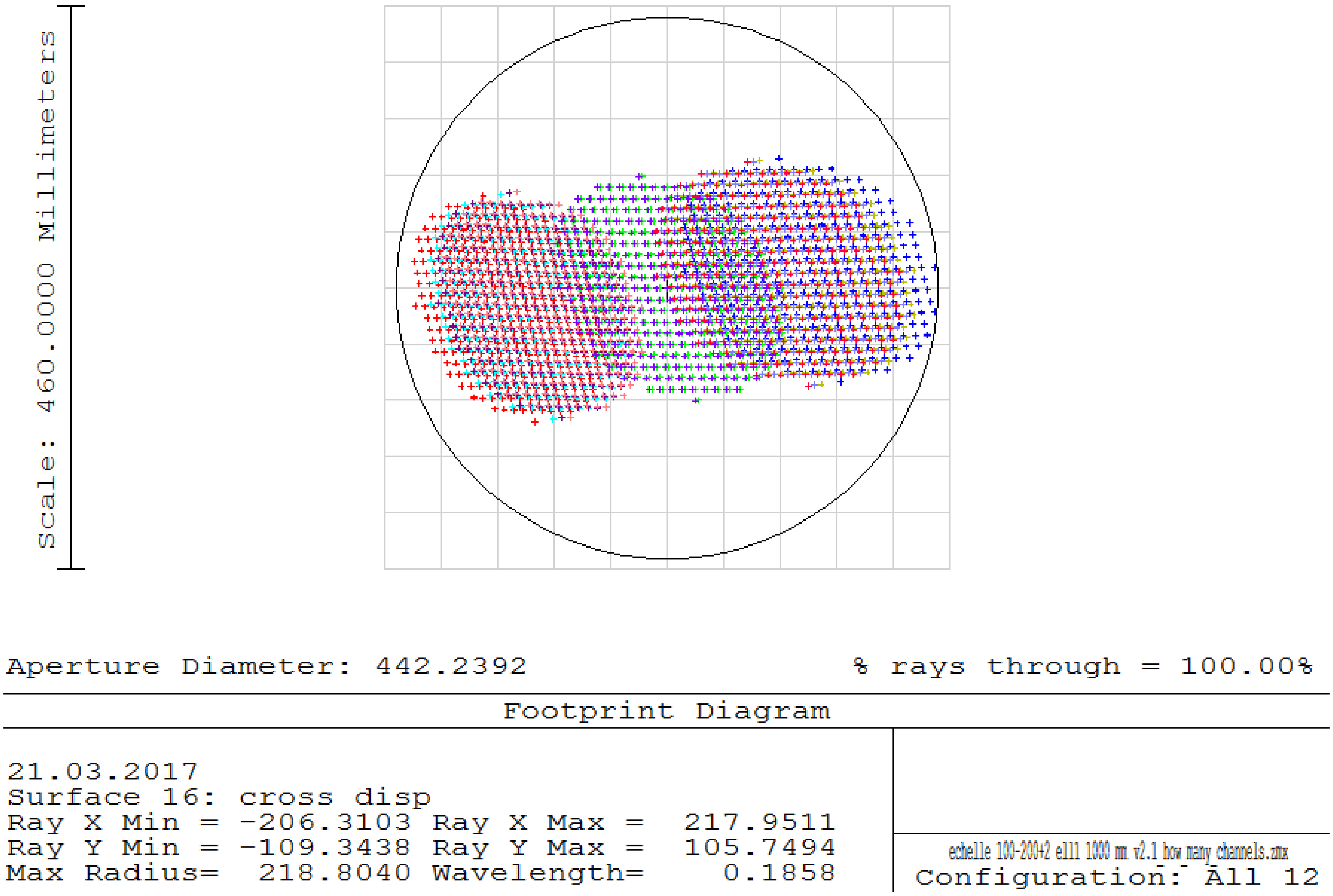
Aperture Diameter: 203.2593 % rays through = 100.00%

Footprint Diagram

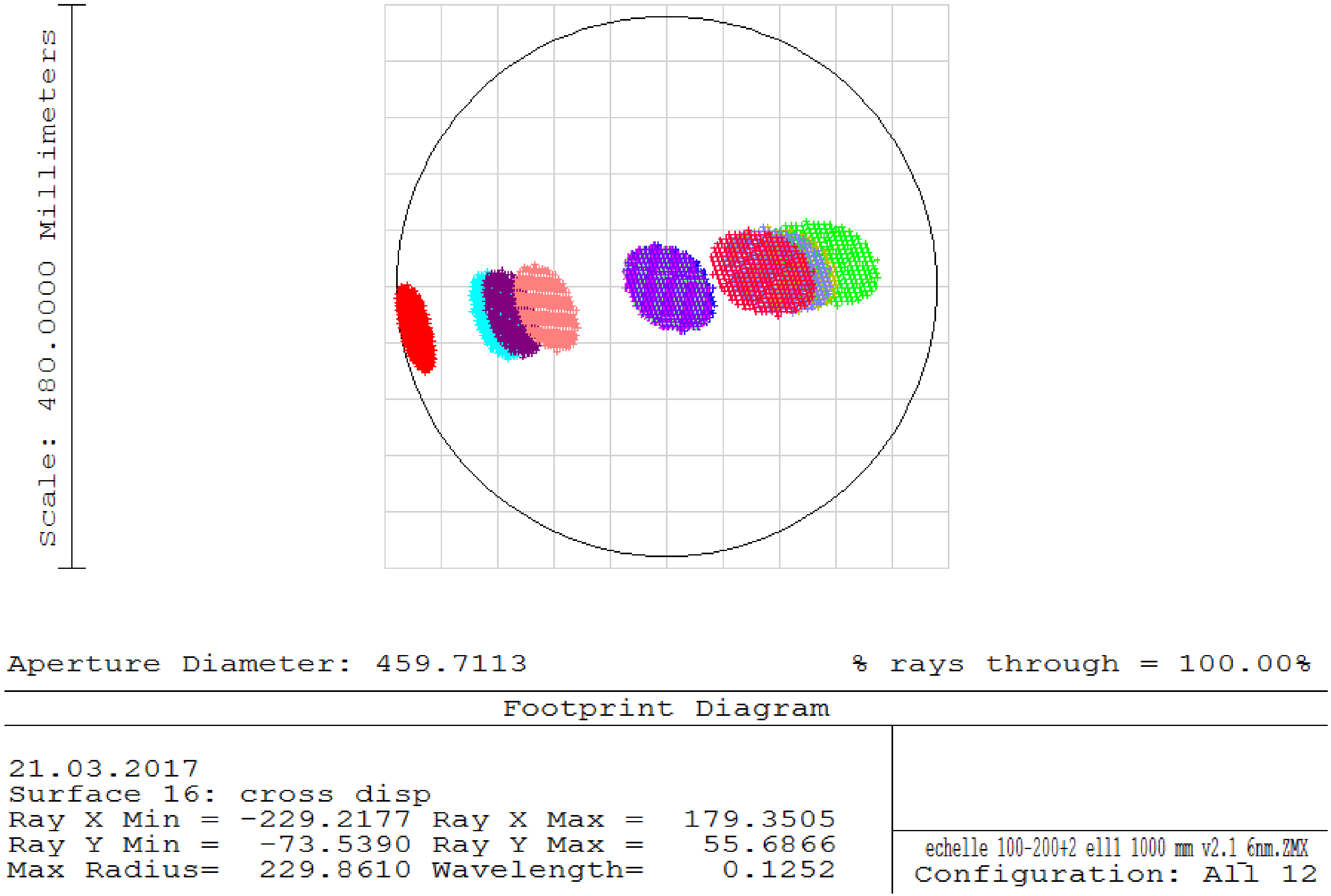
21.03.2017
Surface 16: cross disp
Ray X Min = -94.9471 Ray X Max = 100.1646
Ray Y Min = -57.3711 Ray Y Max = 56.5782
Max Radius= 100.7688 Wavelength= 0.1203

echelle 100-200+2 ell1 1000 mm v2.1 100 gr mm.ZMX
Configuration: All 12

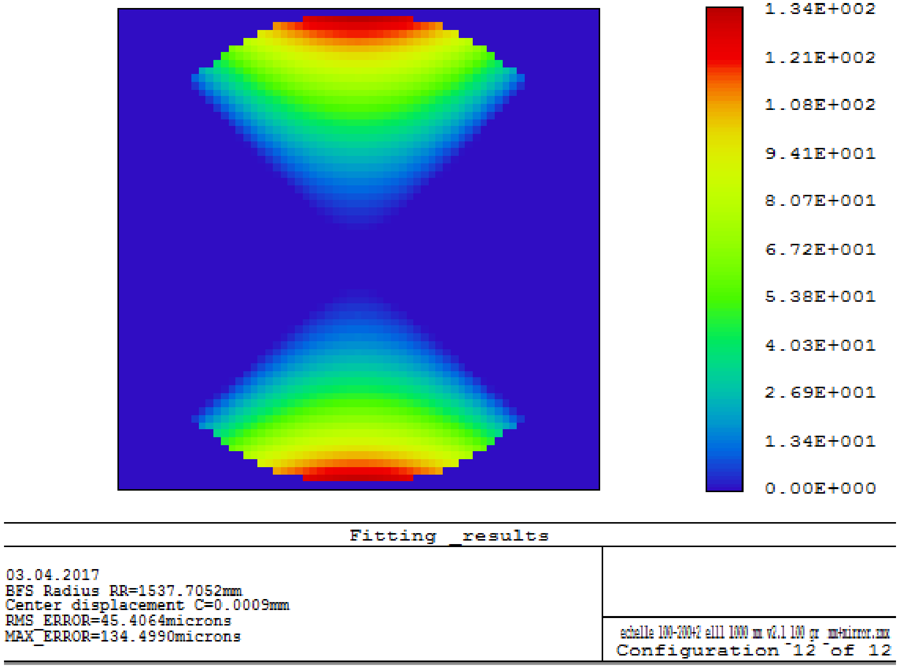
Design 2e – footprint on the cross-disperser



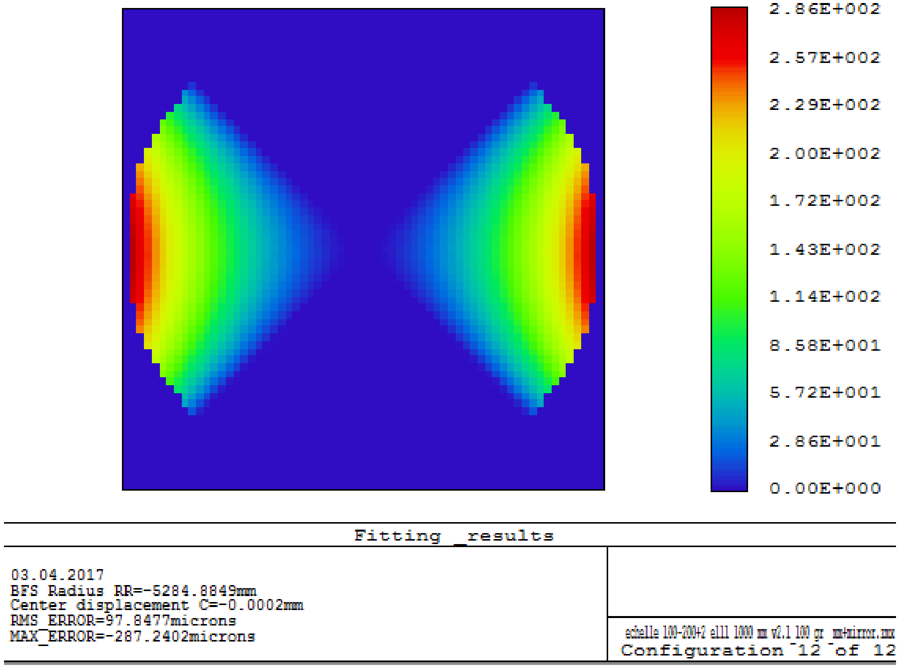
Design 3e – footprint on the cross-disperser



Design 1m – freeforms shapes

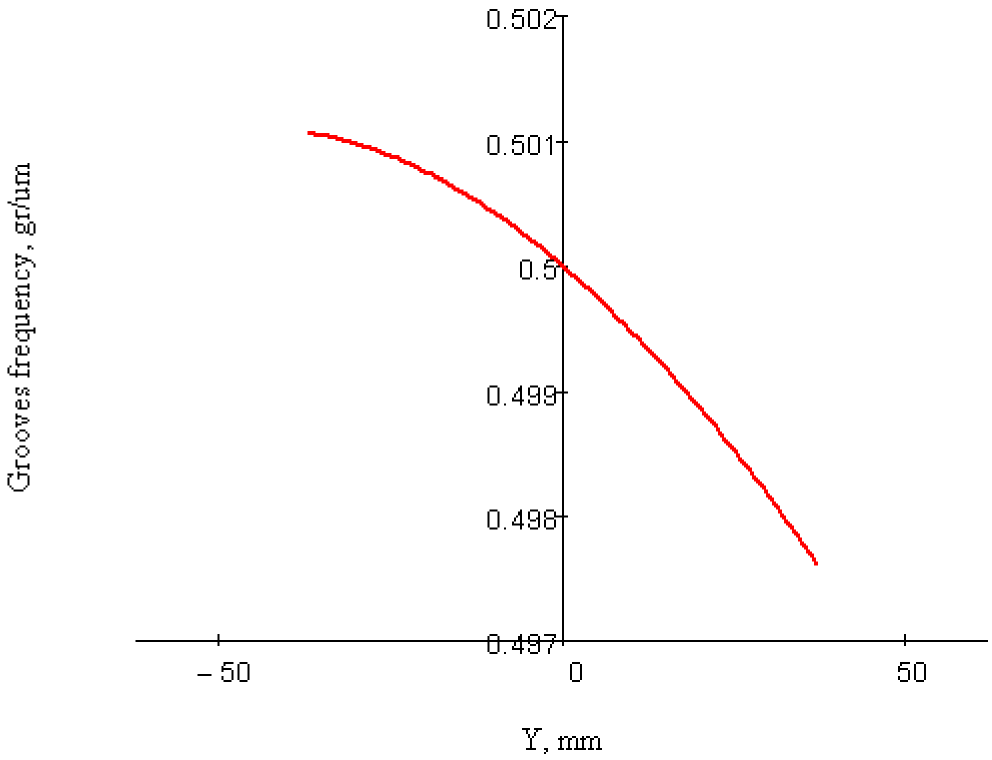


Grating



Mirror

Design 1m – VLS grating



Cross-disperser grating frequency law