Low f/# optics for laser-wire

- Requirements
- Constraints
- Methodology
- Designs
    - f#/2 design (532 nm)
    - First lessons from the f#/2 lens
    - f#/1 design (532 nm)
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Requirements for a micrometre resolution laser-wire

- To create a ~1 micrometre spot size with 532nm light, one need to focus the focus the light with low f# optics near the limit set by diffraction (f#=focal length/aperture)
- Very few commercial lens available with f#/1 or f#/2, none suits our needs
- Diffraction limited systems are challenging
- An aspheric element is likely to be needed
- The spot size must remain constant over a "scanning" range.

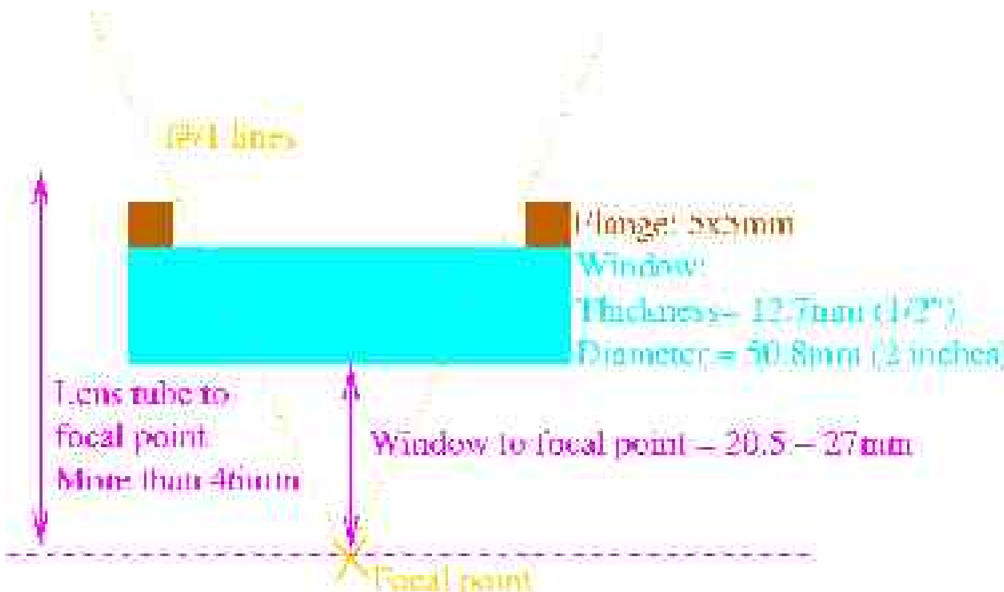
Constraints on the optics design (1/3)

- Constraints from the laser
  - High power: 1J/200ps = 1 GW@532nm
    Ghost focus formed by single or double bounces of the light on the surfaces of the lens may be an issue.
  - Limited choice of glass: must not absorb too much power, only glasses compatible with high power lasers (Fused silica, BK7,...) are acceptable.
  - Must be coated to limit internal reflections
  - Bandwidth: Nd:YAG laser
    => bandwidth required <1nm

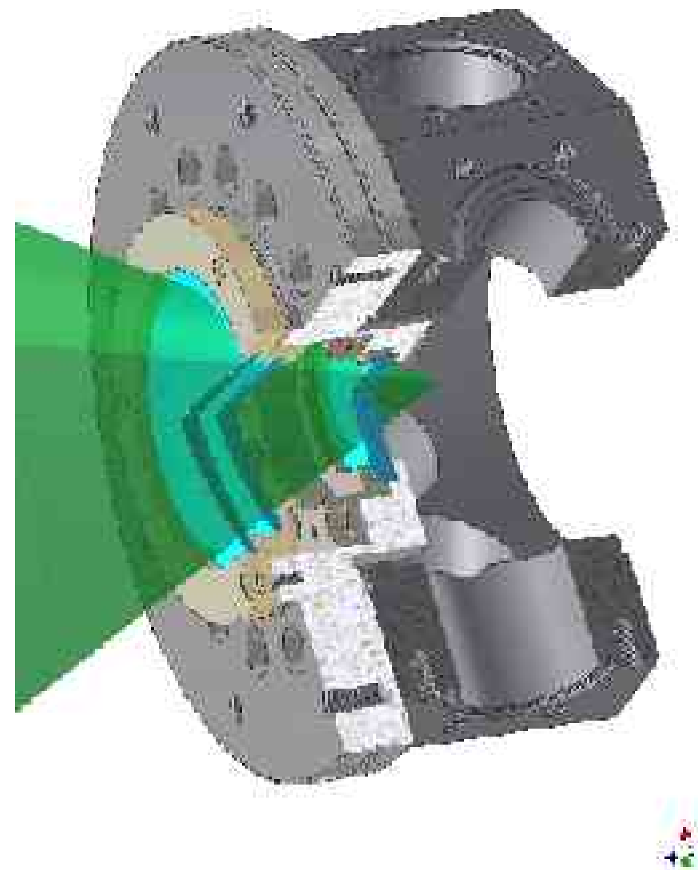
Constraints on the optics design (2/3)

- Constraints from the accelerator:
  - Clearance: Must leave enough clearance for the beam during tuning
    => Back focal length>15mm (20mm in fact)
  - Radiations: Glass must be resistant to the radiation level experienced near the accelerator
    At the ATF, a BK7 lens has survived this year's run without damage.
  - Vacuum: Need a window to allow the transition from air to vacuum; deformations of the window may be an issue at high power
    => fused silica window, 12.7mm thick, Indium seal.
- Constraints from the scanning: Must be able to move the spot's vertical position over ~1-2 mm to search and "scan" the e- beam.

Constraints on the optics design (3/3)



Mechanical constraints on the lens



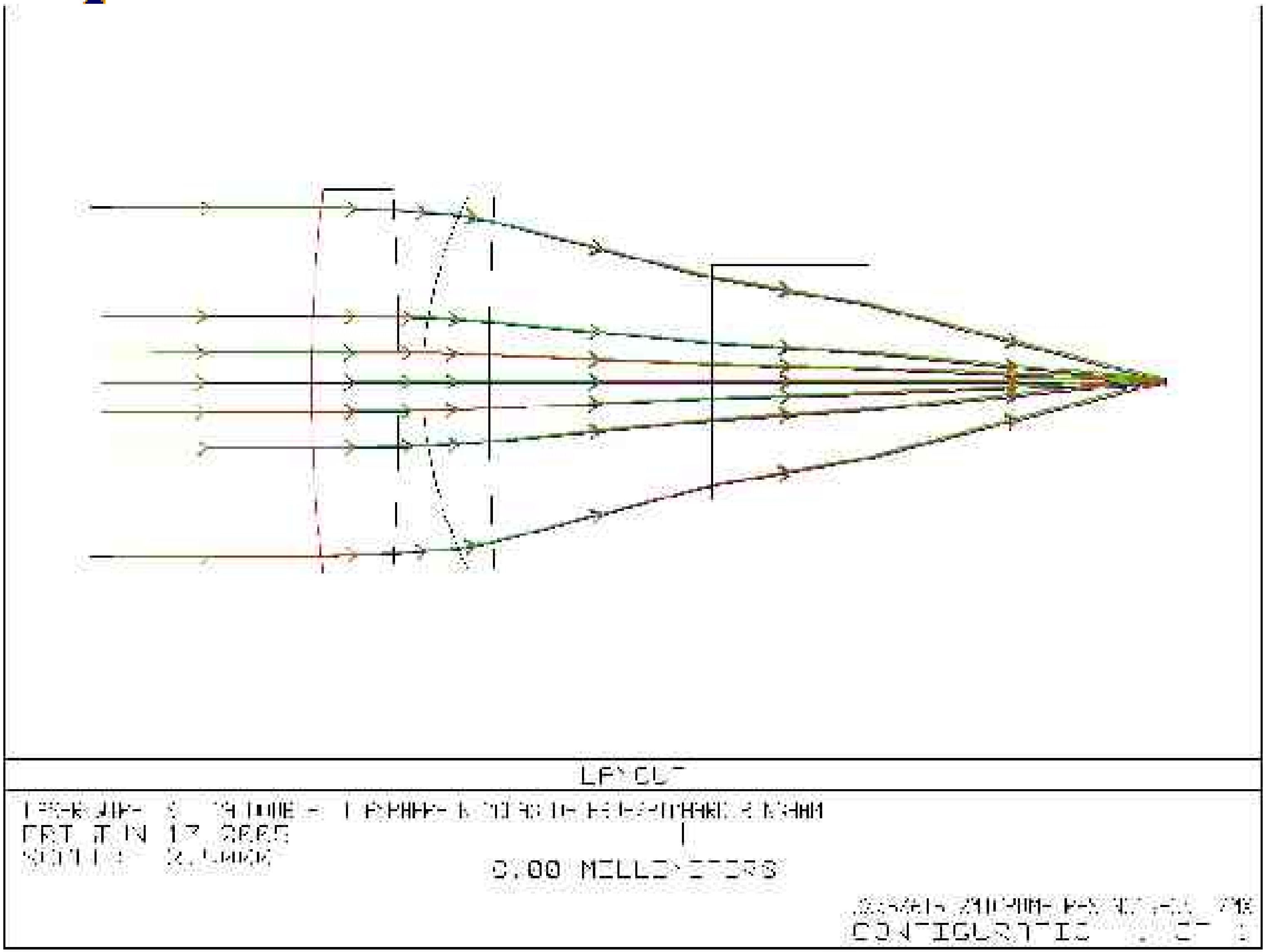
Methodology for the lens design (1/2)

- Design done with a dedicated software (Zemax)
- Design start with basic layout and constraints: 3 elements (aspheric, spheric and window)
- A "merit function" is defined to define how to evaluate a given design:
  - What is the spot size variation acceptable over the scanning range?
  - Is a smaller spot size better than a smaller f#/?

Methodology for the lens design (2/2)

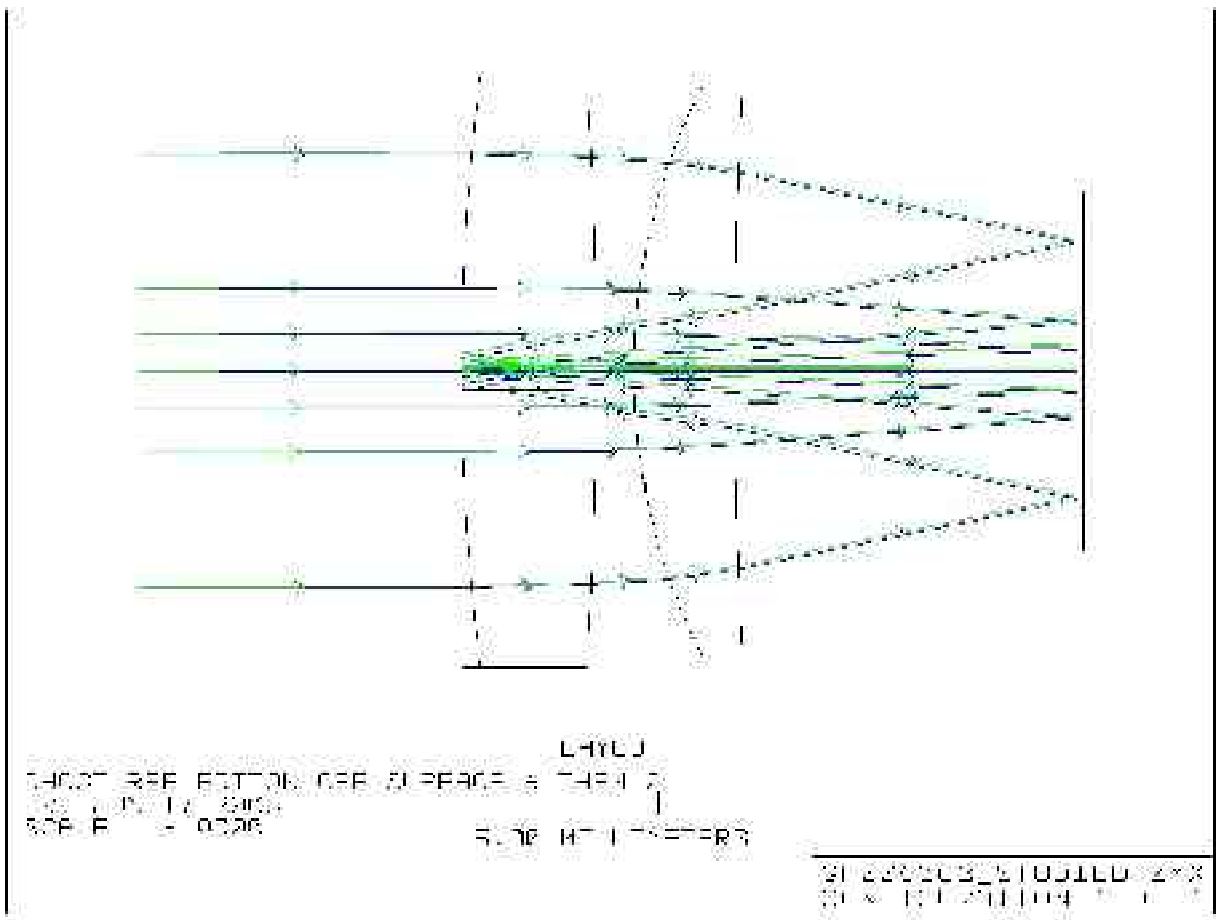
- An initial optimization is done with a “genetic” algorithm and a basic merit function.
- Once a correct design is found, it is optimized with a more advanced merit function (but much slower to calculate).
- A Damped Least Square (DLS) algorithm is used to do the final optimization of the lens design with a final merit function.

f#/2 lens design@532nm



- Design started by R. Bingham
- Focal length: 56mm
- Back focal length: 24mm
- Aperture f#/2
- All elements in fused silica
- No primary ghosts, one secondary ghost
- Expected sigma ~2 micrometres

f#/2 lens design: Ghost issues



- This design has a second order ghost
- Ghost is weakly focused
- Assuming less than 0.5% reflection on each surface, risks of damages are limited (calculations indicate that it should not be a problem at our operating power)

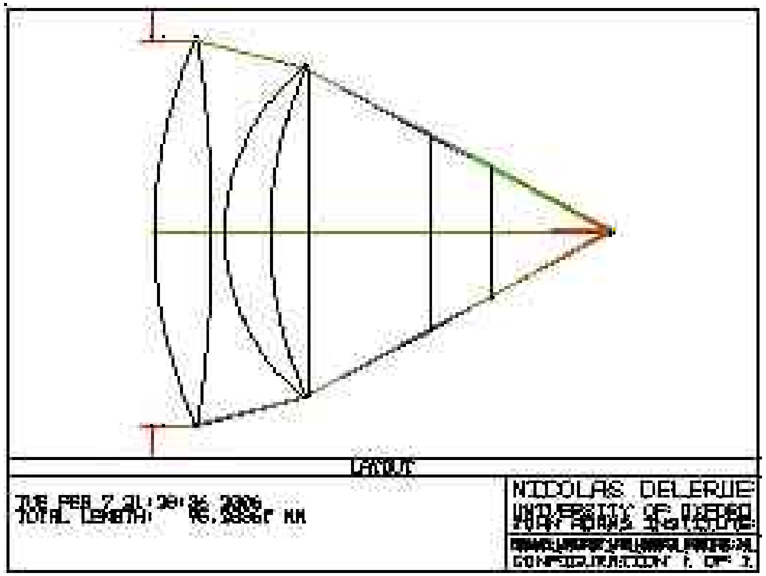
f#/2 lens design@532nm: Tuning and spot adjustment

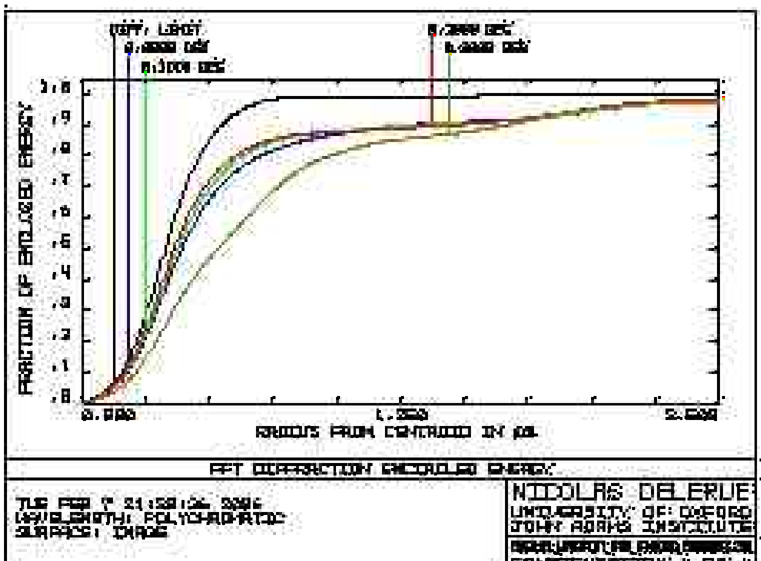
- The spot size can be adjusted from 30 um to 2um by varying the laser beam aperture & divergence
  => important for tuning
- The spot can be translated along the laser axis by varying the gap between the window and the 2 other elements.
- The spot can be moved in a plane parallel to the window by translating the 2 other elements in that plane.

f#/2 lens design@532nm: First lessons

- Lens has been manufactured and is ready for testing.
- Testing will be done this summer.
- Due to budget constraints we did split the construction of different elements with different supplier. This has resulted in significant delays later.
- Over-specification of the mount also caused significant delays (and loss of a supplier).

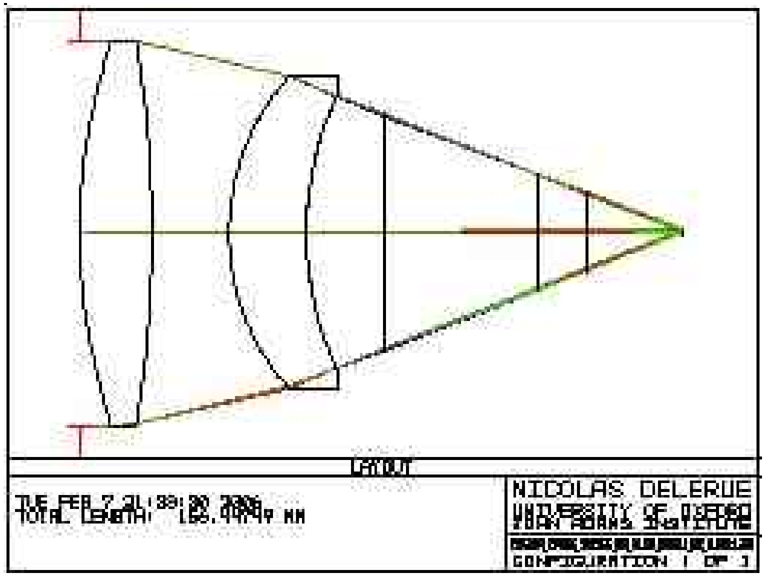
F/#1 lens @532nm (1/3): Candidate design 1

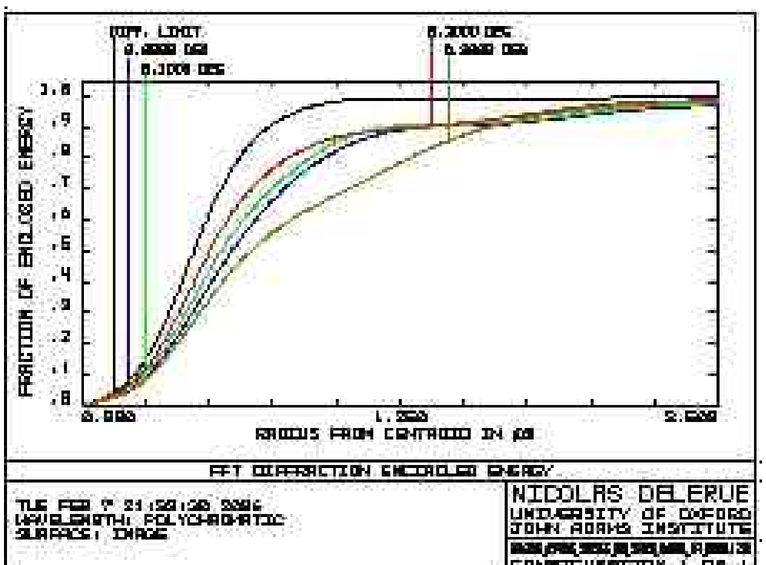




- Aspheric doublet
- Wavefront optimized
- F/# 1.05
- Ray at 0.3 degree produce a bigger spot!
- Performance estimator: 0.09

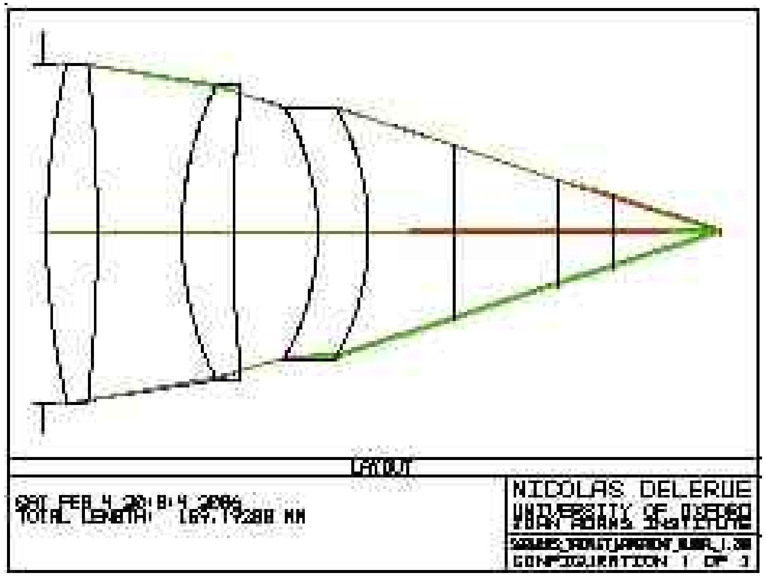
F/#1 lens (2/3): Candidate design 2

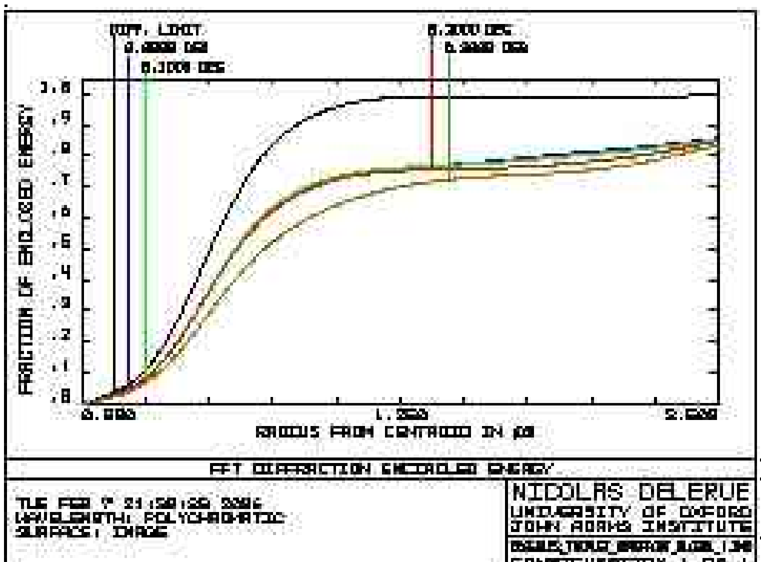




- Aspheric doublet
- Spot size optimized
- F/# 1.37
- The size of the spot size varies less with the angle
- Perf. estimator: 0.07
- Worse F/# but better estimator due to the large angle rays

F/#1 lens (3/3): Candidate design 3





- Spheric triplet
- Wavefront optimised
- F/# 1.62
- Very good homogeneity (<10%)
- Probably cheaper than an asphere
- Estimator: 1.44

f#/1 lens design@266nm

- In the U.V., the design is much more difficult.
- Work is still very preliminary
- Some candidate designs found so far with spot below 1 micrometre but none is satisfactory (inconsistent scanning).
- Zemax seems to be less adapted to work in the UV
- More designs under study...

Outlook

- The design of low f# optics for laser-wire applications is challenging.
- A f#/2 lens has been produced and will be tested this summer.
- Several f#/1 designs @532nm have been studied, optimisation still to be done.
- First f#/1 designs @266nm under study: difficult but some solutions seem to exist.