Optical design of Dark Matter Telescope: improving manufacturability of telescope

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The attached slides contain some talking point that could be useful during discussions on manufacturability.

Design specifications for Dark Matter Telescope

- Diameter: 8.4 m
- Length: ~9.0 m
- Focal length: 10.5 m
- Focal ratio: f/1.25
- Field of view: +/- 1.5 degrees
- Back focal distance: 300 mm (Xenon fill)
- Energy collection >80% within 0.33 arcsec
- Obscuration: ~25% on axis
  ~40% full field
- Spectral band 500nm - 800 nm

- Baffled to prevent light from outside field of view reaching the detector
- Focal plane may be weakly curved, even aspheric
- Design type: Paul 3-mirror telescope
  - Primary focal ratio f/1
  - Window: 1 cm thick to contain Xenon gas at ambient pressure
  - Additional corrector lenses near detector as required

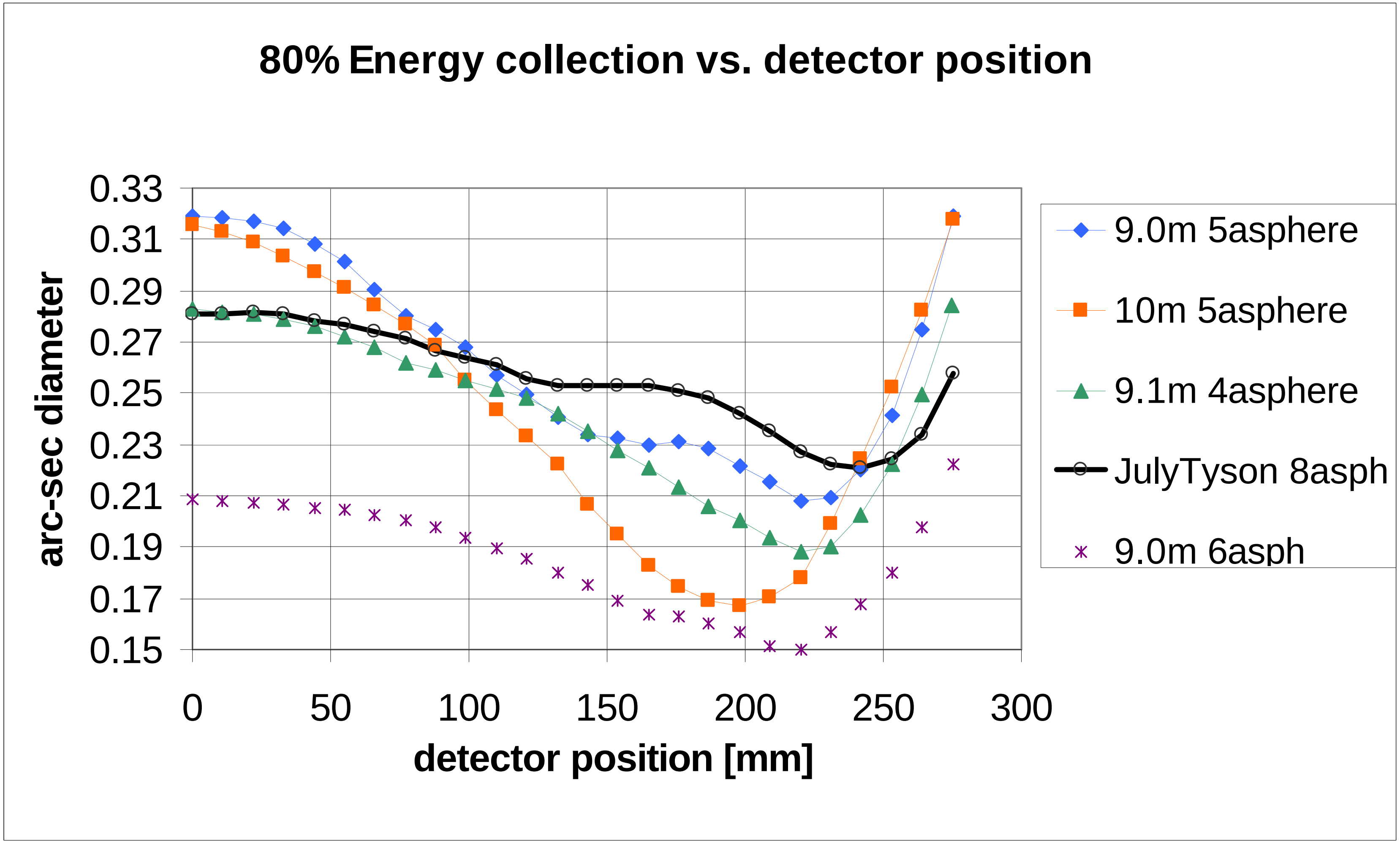
Additional design requirements have been considered to improve manufacturability

- Fabrication/testing of large (~3.5 m) convex secondary is technically challenging:
  - Aspheric departures on the secondary should be as small as possible
- Minimum number of aspheres to reduce fabrication difficulty
  - Minimize aspheric departures if possible
  - Keep the added aspheric terms to lowest possible power series [< 8^{th} order]
- Minimum numbers of components to reduce scattering and ghost focus problems
  - Two corrector elements are required to contain xenon gas and provide 300 nm bandpass correction
  - Additional plane substrate is included for possible bandpass filter
- Reasonable refractive element thicknesses
  - Plane window: 1 cm thick
  - Corrector elements: edge or center thickness at least 3.5 cm

Status of current design study

- We have started to examine other system design parameters such as:
  - System length
  - Obscuration on-axis
  - Focal ratio leaving secondary
  - Distribution, number of aspherics and magnitude of aspheric departures
- For each design, we compare:
  - System performance in terms of angular sub tense of 80% energy collection
  - Vignetting losses
  - Component diameters
  - Aspheric departures of each component
  - Sag of detector at edge
- A summary of four designs is presented and compared to a July 2001 Tyson design
- Telescopes with 4 and 5 aspheres with reduced asphericities are attractive
- Designs are broadly achromatic over > 300 nm bandwidth
- Future work: comparisons should include sensitivities to element fabrication and telescope assembly/alignment/dynamic errors

Energy collection for 4 LLNL designs and July 2001 Tyson design



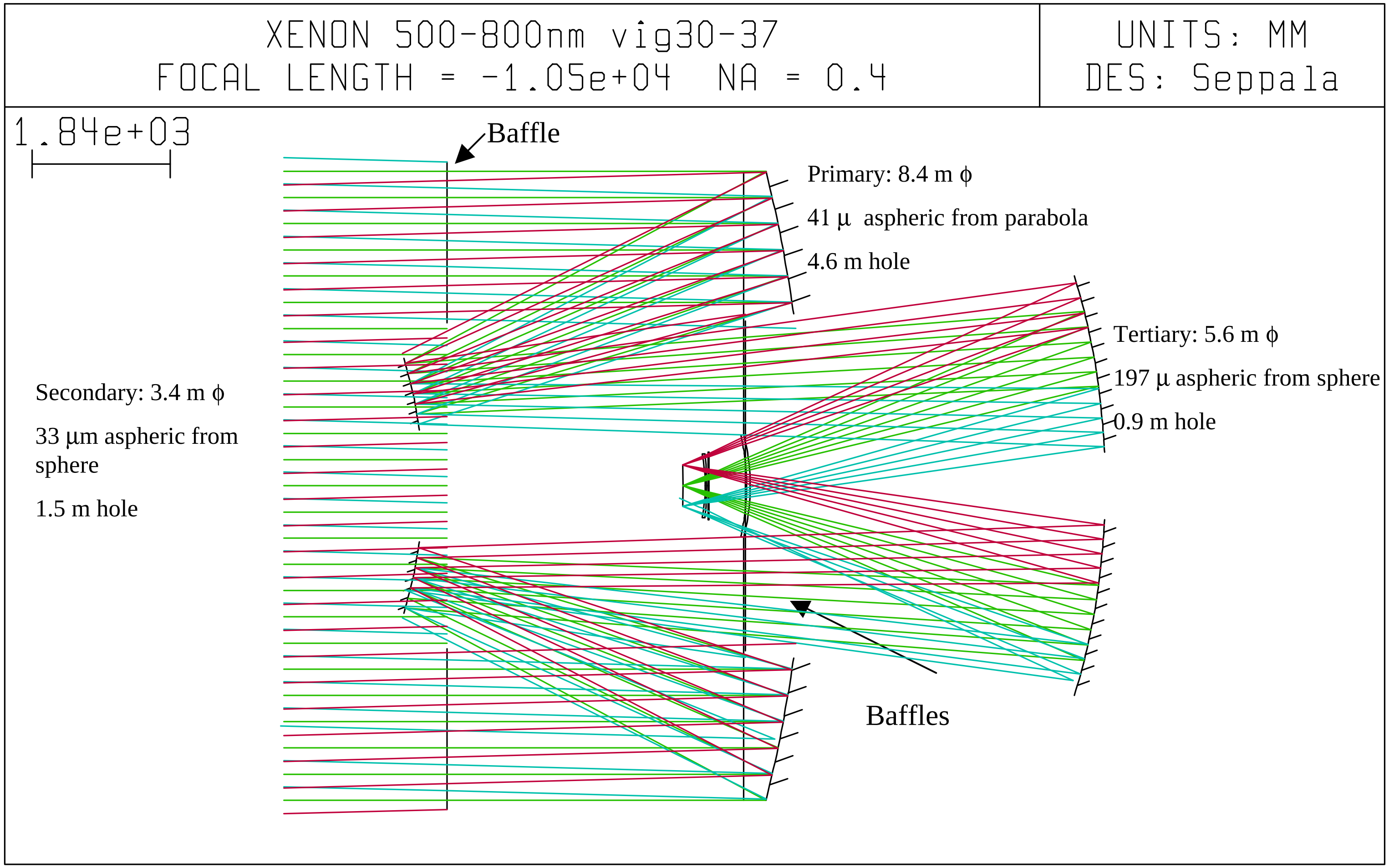
Design summary for 5 designs including July 2001Tyson design:

xxx : more desirable

xxx: less desirable

300 nm bandwidth designs	LLNL-6 asphere 3 corr elements	LLNL -5 asphere	LLNL -5 asphere	LLNL -4 asphere	July Tyson- 8 asphere
System length (m)	***9***	***9***	***10***	***9.1***	***9***
8.4 m Primary	**-**	**-**	**-**	**-**	**-**
aspheric departure(parabola)(mm)	0.155	0.054	0.081	0.041	0.002
Secondary diameter(m)	***3.4***	***3.3***	***3.3***	***3.4***	***3.56***
aspheric departure(mm)	0.552	0.031	0.028	0.033	0.483
Tertiary diameter(m)	***4.6***	***5.2***	***5.2***	***5.6***	***4.92***
aspheric departure(mm)	0.108	0.137	0.047	0.198	0.163
Window diameter(m)	***1.28***	***1.27***	***1.3***	***1.33***	***1.39***
S1: aspheric departure(mm)	0	0	0	0	2.434
S2: aspheric departure(mm)	0.011	0.194	0.036	0.092	1.873
Corrector diameter(m)	***0.85***	***0.85***	***0.85***	***0.85***	***0.867***
S1: aspheric departure(mm)	0	0	0	0	0.258
S2: aspheric departure(mm)	0.398	0	0.007	0	0.328
0.55 m Detector	**-**	**-**	**-**	**-**	**-**
detector sag at edge(mm)	2.56	1.43	1.55	1.02	3.46
aspheric departure(mm)	0.039	0.006	0.011	0	0.020
80% energy collection diameter	***0.22 arc-sec***	***0.33 arc-sec***	***0.31 arc-sec***	***0.28 arc-sec***	***0.28 arc-sec***
Obstruction %:on axis/full field	25-38	25-42	25-42	30-37	26-37
Focal ratio:after 2ndary	f/31	f/9.1	f/9.6	f/7.6	collimated

LLNL 4 asphere design: 500 nm- 800 nm
Telescope: 9.1 m length

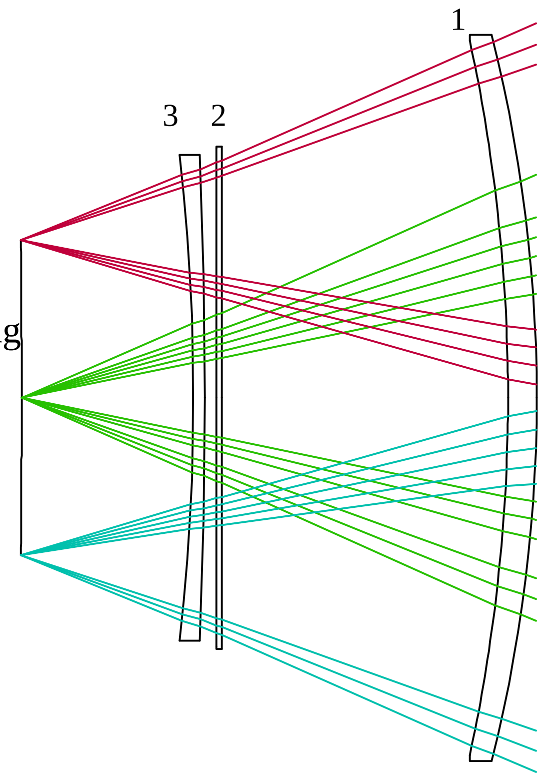


LLNL 4 asphere design: 500 nm- 800 nm
Telescope: 9.1 m length

XENON FOCAL LENGTH = -1.05e+04 NA = 0.4	UNITS: MM DES: Seppala

55 cm diameter detector:

- 1.02 mm convex sag
- Spherical surface



1 Aspherical corrector lens:

- 5 cm thick, 1.25 m ϕ
- Aspheric on concave surface; 92 microns departure

2 Window/ spectral filter: 1.0 cm thick

3 Spherical corrector lens:

- 3.5 cm edge thickness,85 cm ϕ

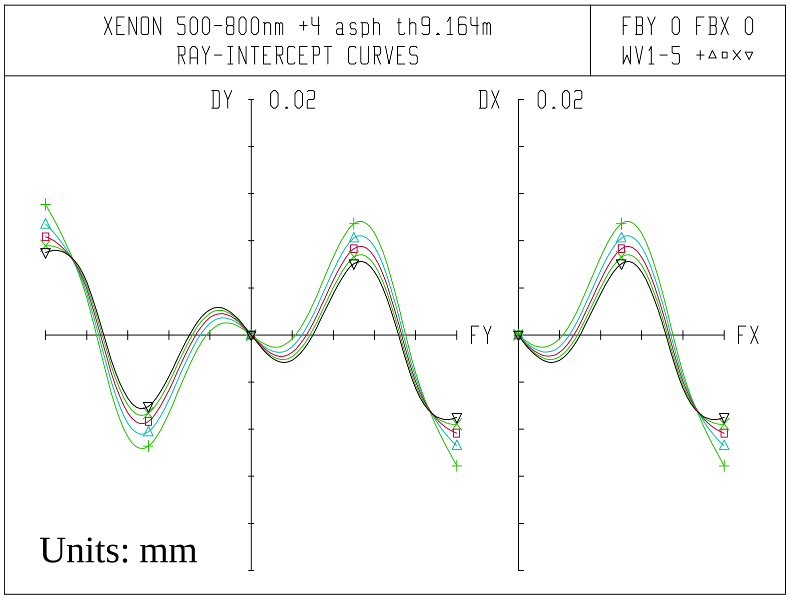
Additional comments for 4 asphere design

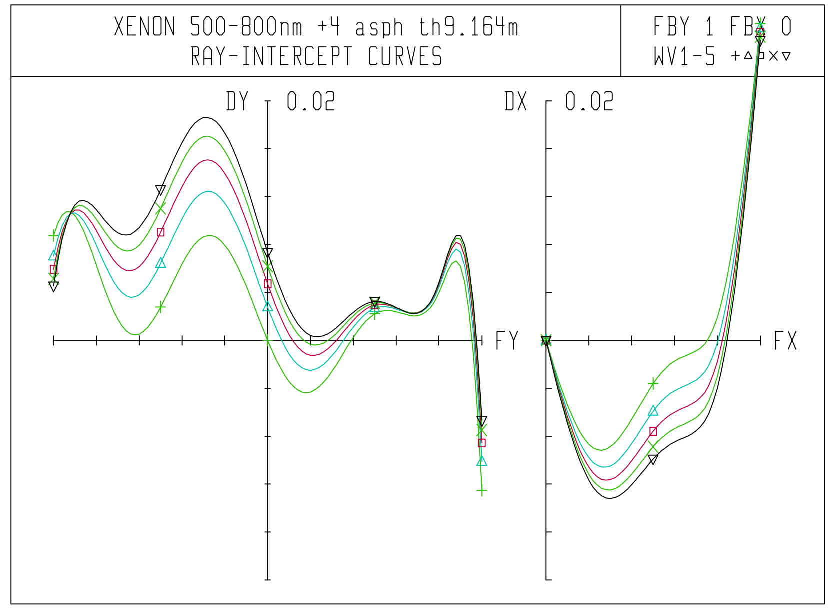
- Light from secondary is diverging at f/7.6
- Aspheric departures on the 4 aspheric surfaces
  - Primary mirror
    - 41 μm aspheric departure from best fit parabola
    - Conic + 6th order aspheric
  - Secondary mirror
    - 33 μm aspheric departure from best fit sphere
    - Conic + 6th , 8th order aspheric
  - Tertiary mirror
    - 197 μm aspheric departure from best fit sphere
    - Conic + 6th order aspheric
  - Refractive corrector
    - 92 μm aspheric departure from best fit sphere
    - 4th , 6th , 8th order aspheric
- Spherical detector, 1.02 mm sag at edge
- Focal shifts of the detector and corrector lenses will accommodate a different bandwidth with minor loss of resolution
- Inner hole on secondary is larger than detector/dewar: support detector from secondary

Four-asphere design with two corrector elements: design performs well over a broad spectral range

Ray intercept curves with no obstruction, 500-800 nm : on-axis and full detector diameter

- Performance is dominated by monochromatic aberrations



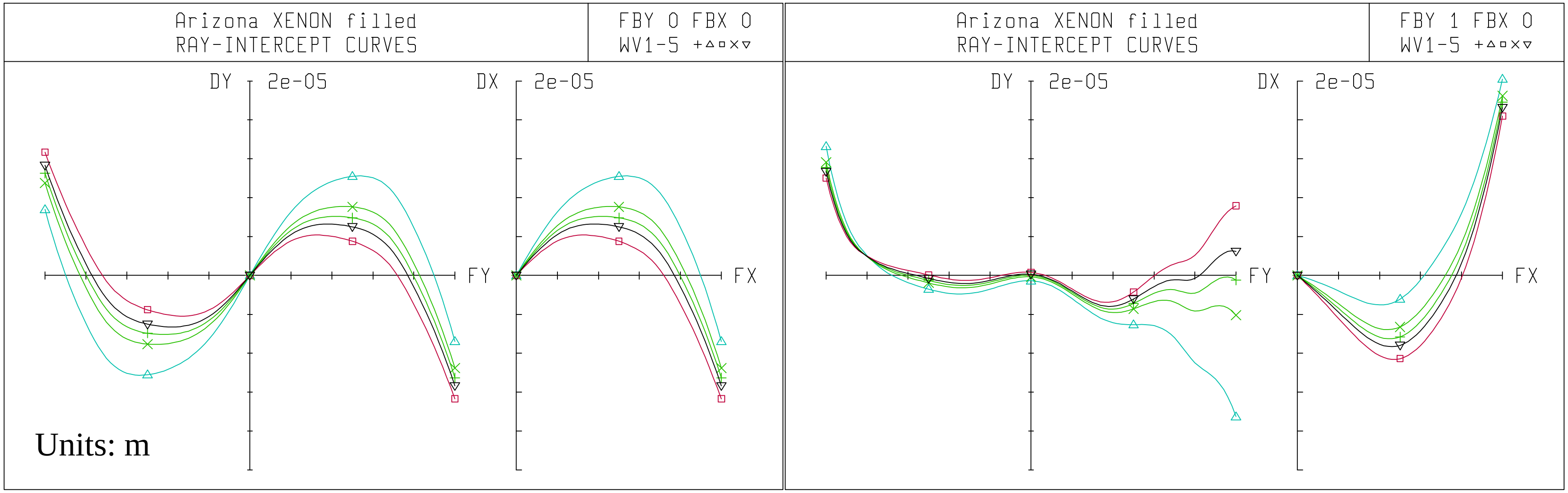


- One can increase the spectral range to 600 nm [0.4 µm – 1.0 µm]:
- 80% energy collection: <0.33 arc-sec over a detector diameter of 53 cm [96%]

July 2001 Tyson design

Ray intercept curves with no obstruction, 500-800 nm : on-axis and full detector diameter

- Performance is dominated by monochromatic aberrations



July Tyson xenon-filled design

July Tyson XENON filled
FOCAL LENGTH = -10.5   NA = 0.4

UNITS: M
DES: OSLO