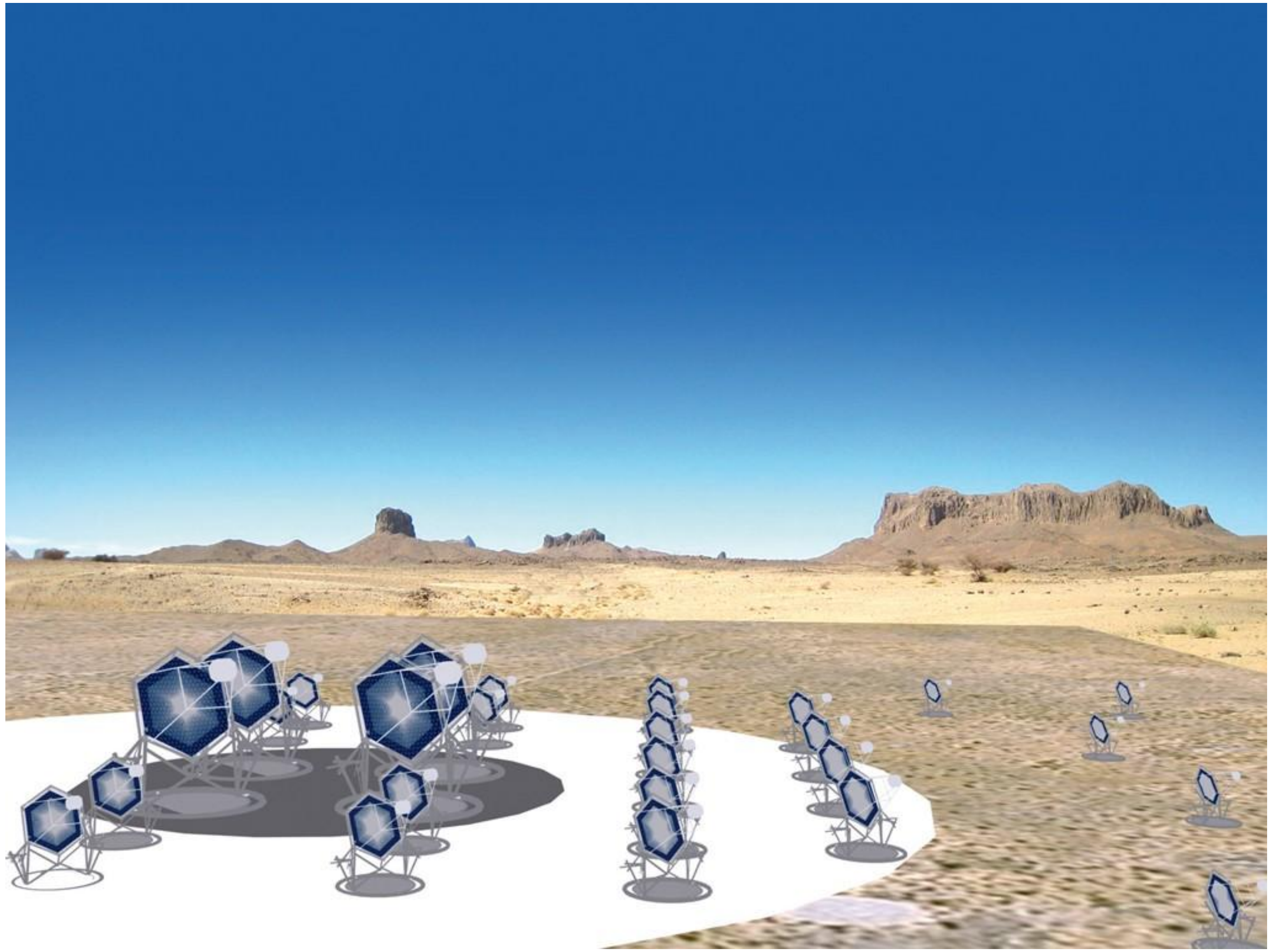
A two-mirror design for the high energy section of the Cherenkov Telescope Array

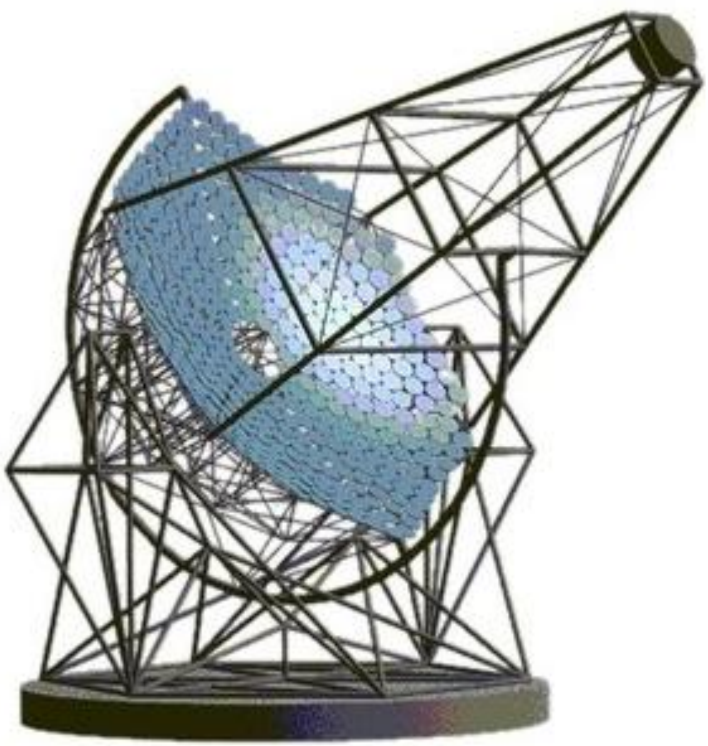
- Introduction.
- Optical design studies:
  - "Exact Optics".
  - ZEMAX.
- Mechanical design.
- Summary.



- Tim Greenshaw,
  for Durham, Leeds,
  Leicester and Liverpool
  CTA groups.

Introduction

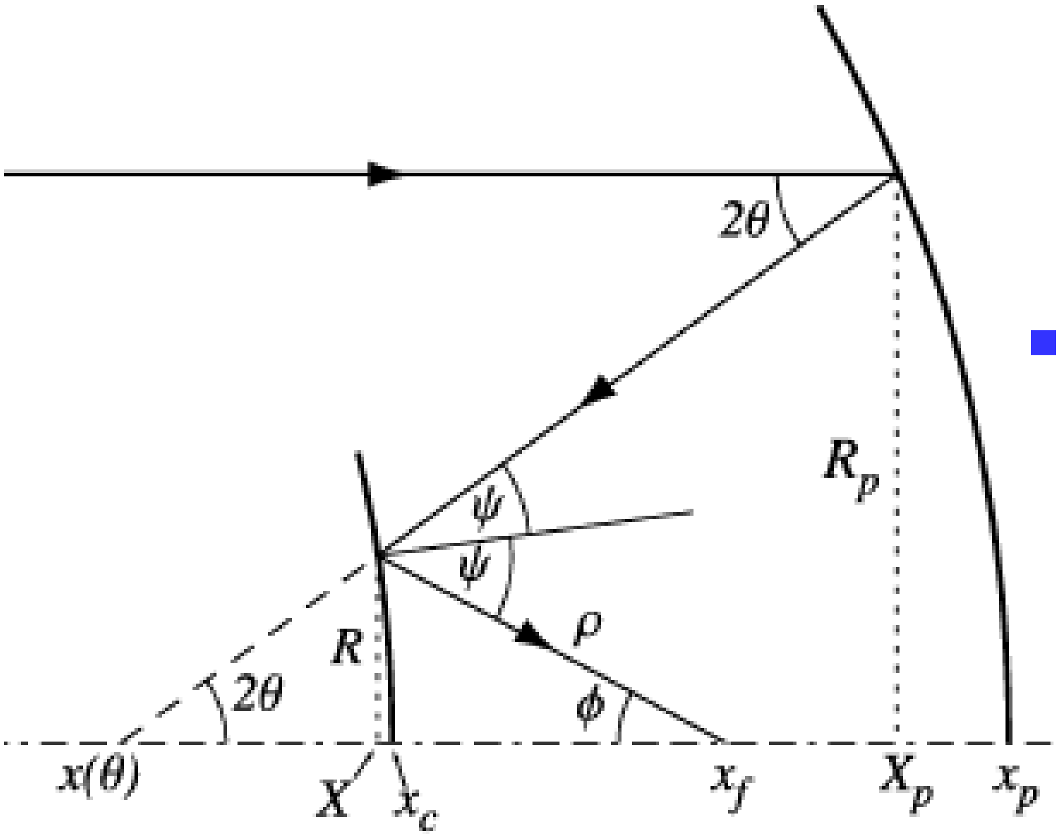
- Cost of camera ("conventional" photomultiplier tubes etc.) about six times that of telescope for Davies-Cotton design of size required for high energy section of CTA.



- Can significantly reduce camera cost if use multi-anode PMs, silicon PMs, micro-channel plates...
- ...but smaller pixel sizes require two-mirror optics; telescope becomes more expensive.
- Investigate whether smaller camera and two-mirror optics allows higher resolution/increased sensitivity for a given cost.
- Look first at optical design of two-mirror telescope.
- C.f. "Exact Optics" and "ZEMAX" approaches to optimisation.

Exact Optics

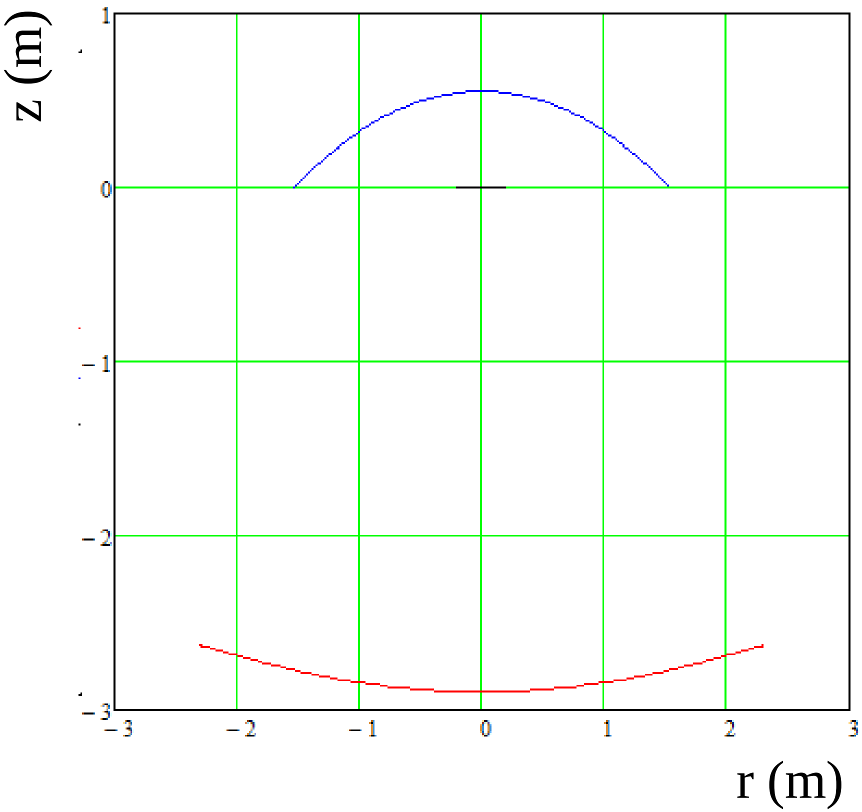
- "Exact Optics" introduced by Lynden-Bell, Mon. Not. R. Astron. Soc. **334**, 787-796 (2002).



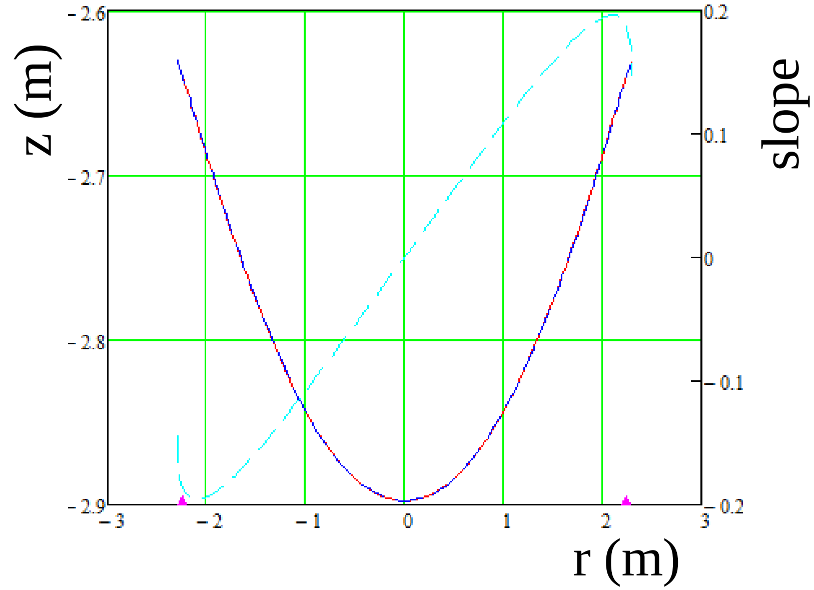
- Specifies all two-mirror telescopes which are free of coma and spherical aberration in terms of:
  - F – effective focal length.
  - s × F – mirror separation.
  - K × F – distance from secondary to focus.
- Mirror shapes described in terms of parameter T = tan φ/2 but…
  - Cannot use parameterised form for ray tracing.
  - Mirror radii not specified.
  - Position (for focus ≠ ∞) and shape of focal surface not known.

Exact Optics

- Exact Optics mirrors for telescope with F = 2.3 m, s = 1.5 and K = 0.24 (similar to Schwarzschild-Couder).



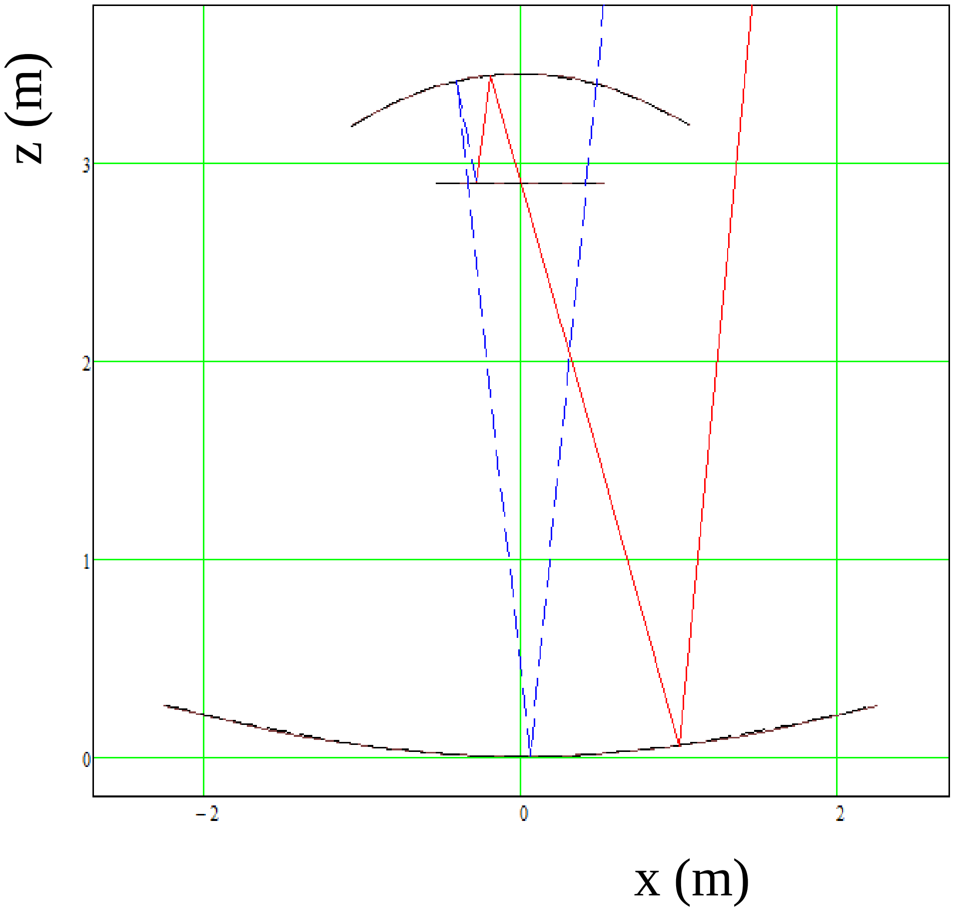
- Fit parametric shapes with cubic splines.
- E.g. primary, using 337 knots.



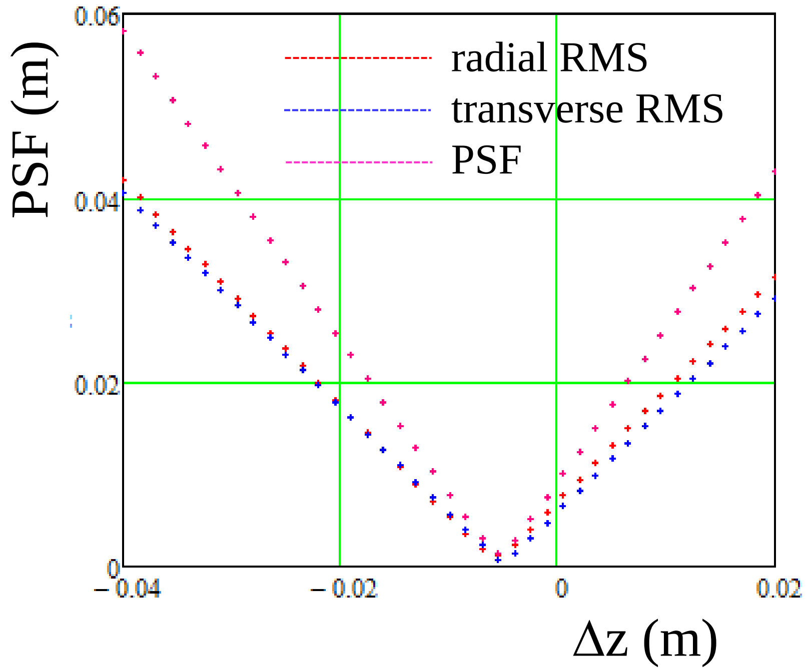
- Max. deviation ~ 1×10^{-9} m.
- Choose R_p = 2.25 m (F/D = 0.513), R_s = 1.07 m.

Ray tracing

- Trace rays from source at height of z_c = 10 km, field angles δ of up to 5°.

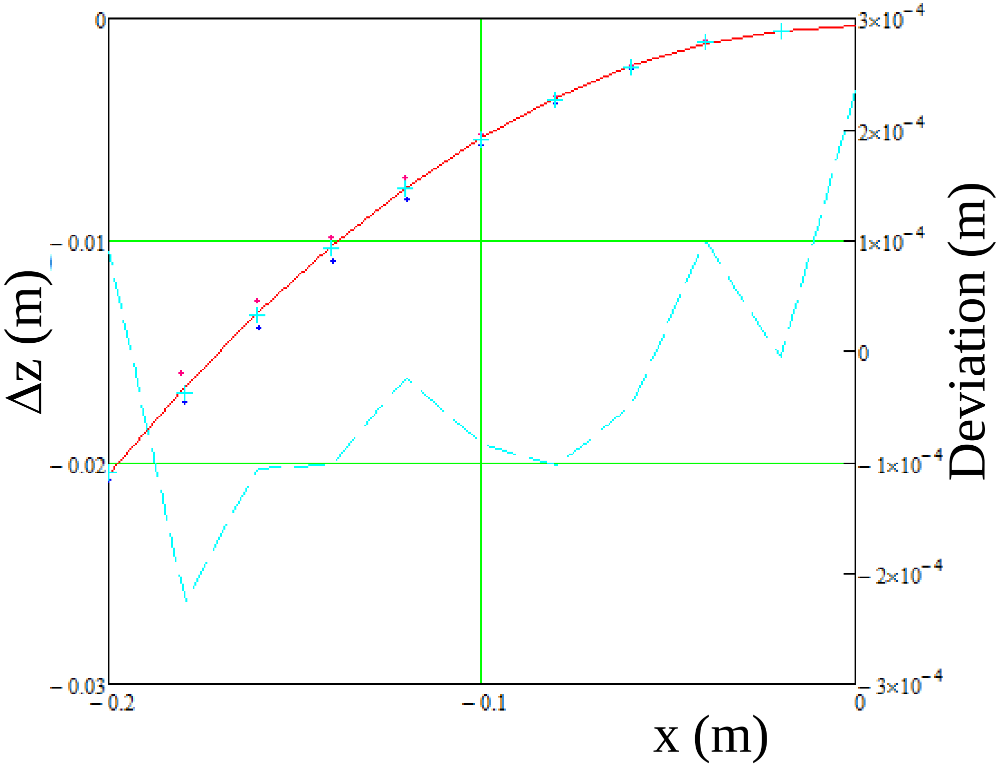


- Look at Point Spread Function, root of sum of squared radial and transverse RMS spot sizes.
- Vary Δz, height of focal plane w.r.t. nominal position; result for δ = 2.5°:



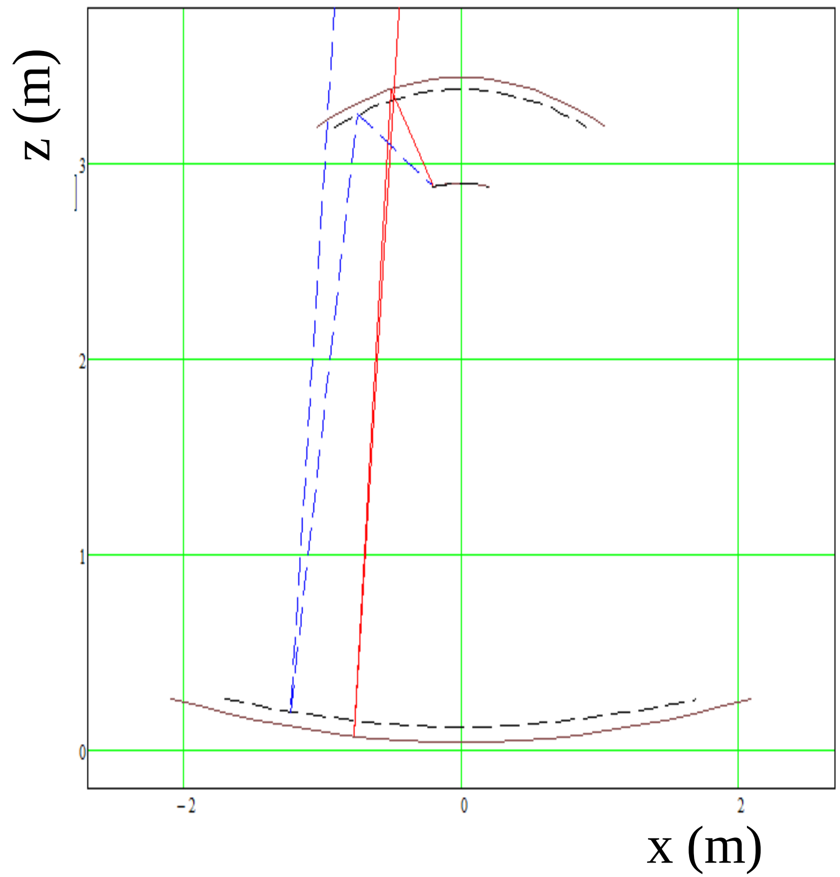
Ray tracing and optimisation of focal surface

- Fit spherical surface to height/ transverse position curve of min PSF:



- Rad. of curv. of camera ρ_c = 1.01 m.

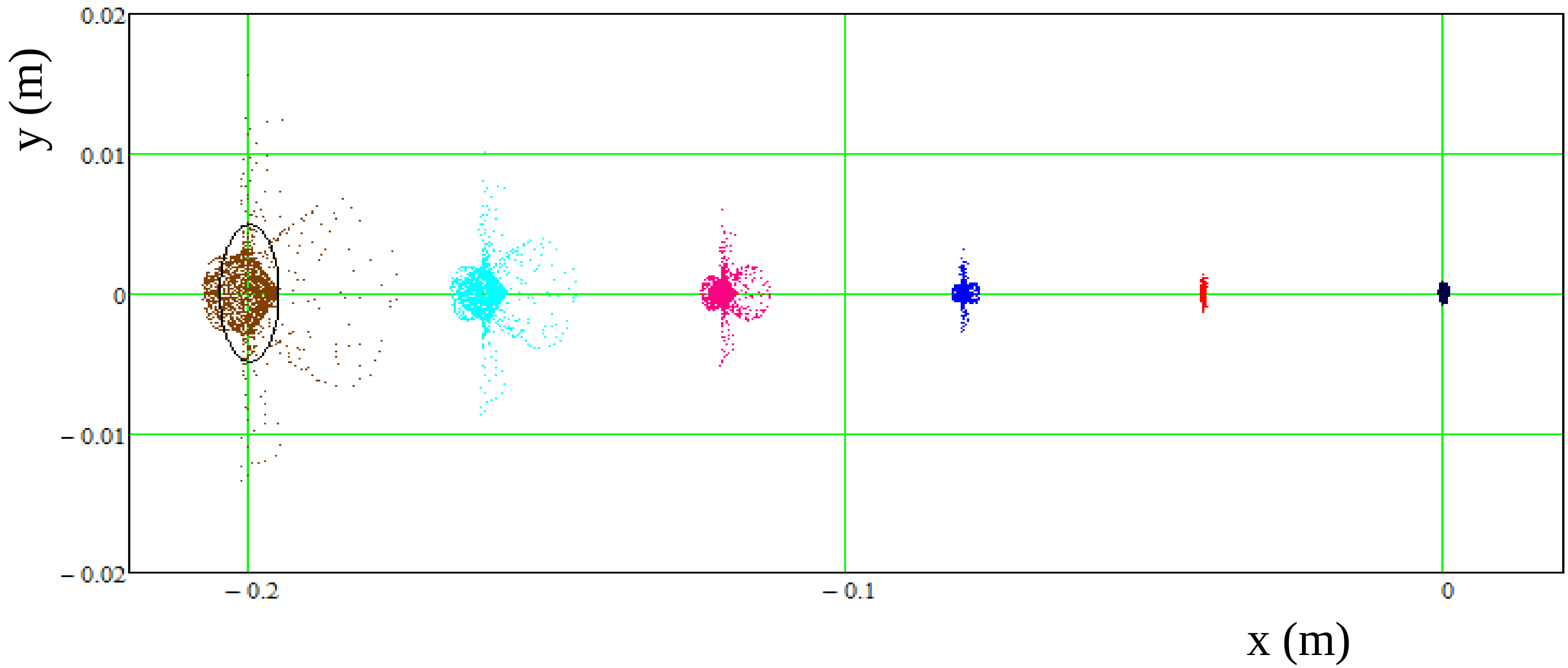
- Ray trace with spherical focal surface.



- Radius of camera R_c = 21 cm.

Images of points at height of 10km

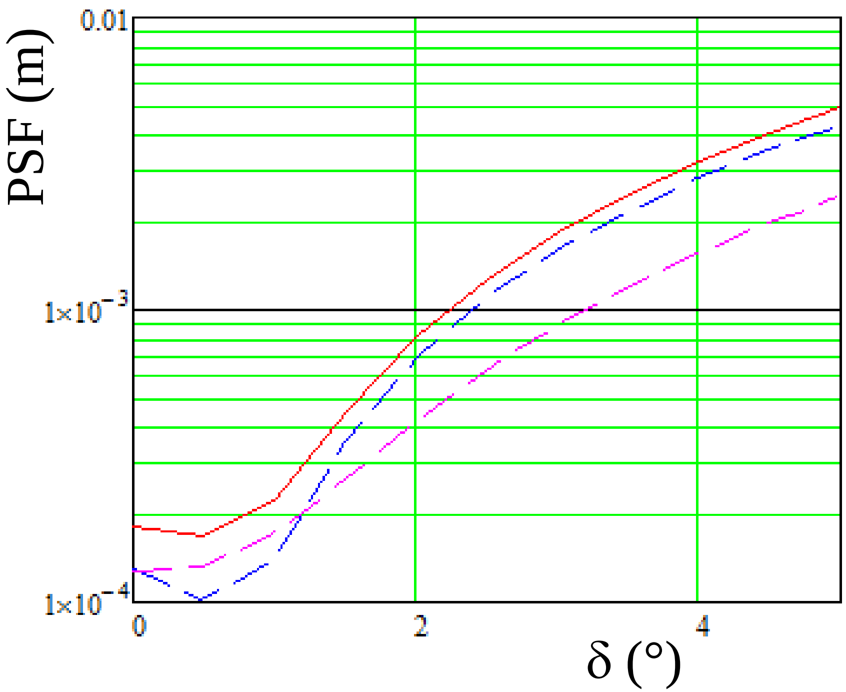
- Images on curved focal surface, δ = 0...5°.



- Analysing these images, circle with radius of PSF contains > 75% of photons.

PSFs

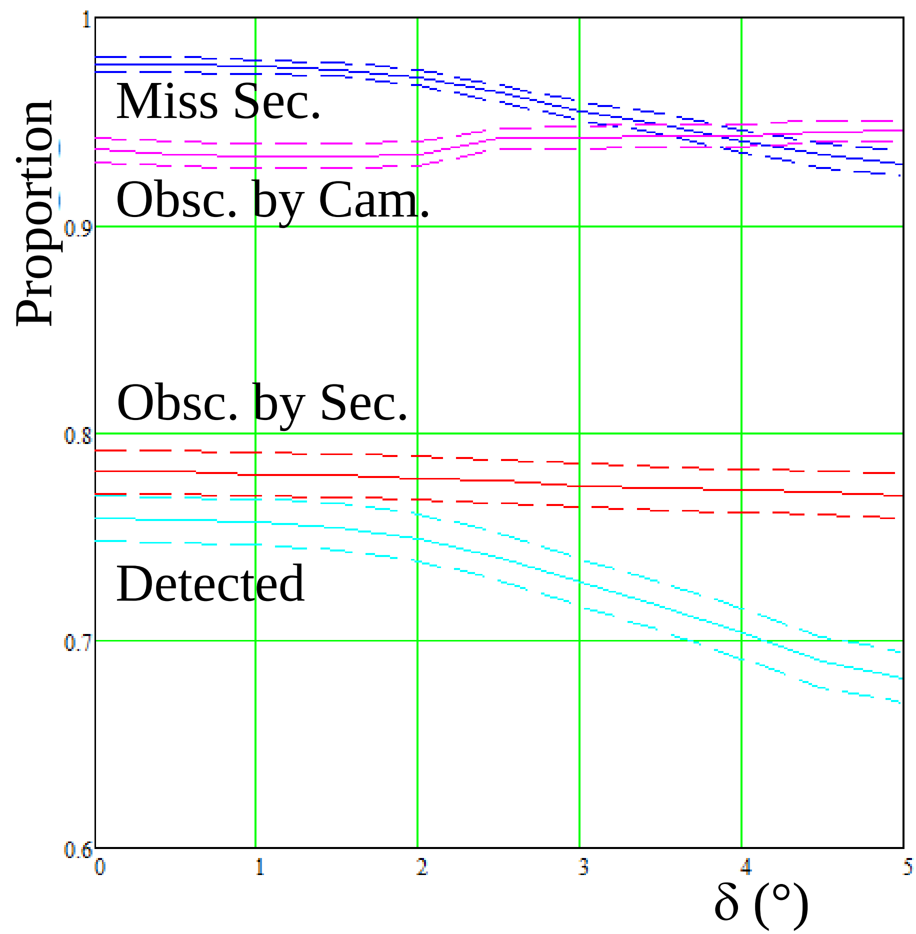
- Resulting PSFs:



- Pixel sizes of few millimetres squared achievable.
- Rays hit camera surface at up to 76°.

Light throughput

- Proportion of photons detected as function of field angle:



ZEMAX studies

- ZEMAX is commercial software for optical system design.
- Used here to study two-mirror telescope of Schwarzschild-Couder type:
  - $F = 2.0$ m.
  - $R_p = 2$ m ($F/D = 0.50$).
  - $R_s = 1$ m.
  - Mirror separation 3 m ($s = 1.50$).
  - Separation of secondary and camera 0.4 m ($K = 0.20$).
  - Camera rad. of curv. $\rho_c = 1.5$ m
  - Camera radius $R_c = 28$ cm.

- Ray tracing for $\delta = 0°$, 2.5° and 5°:

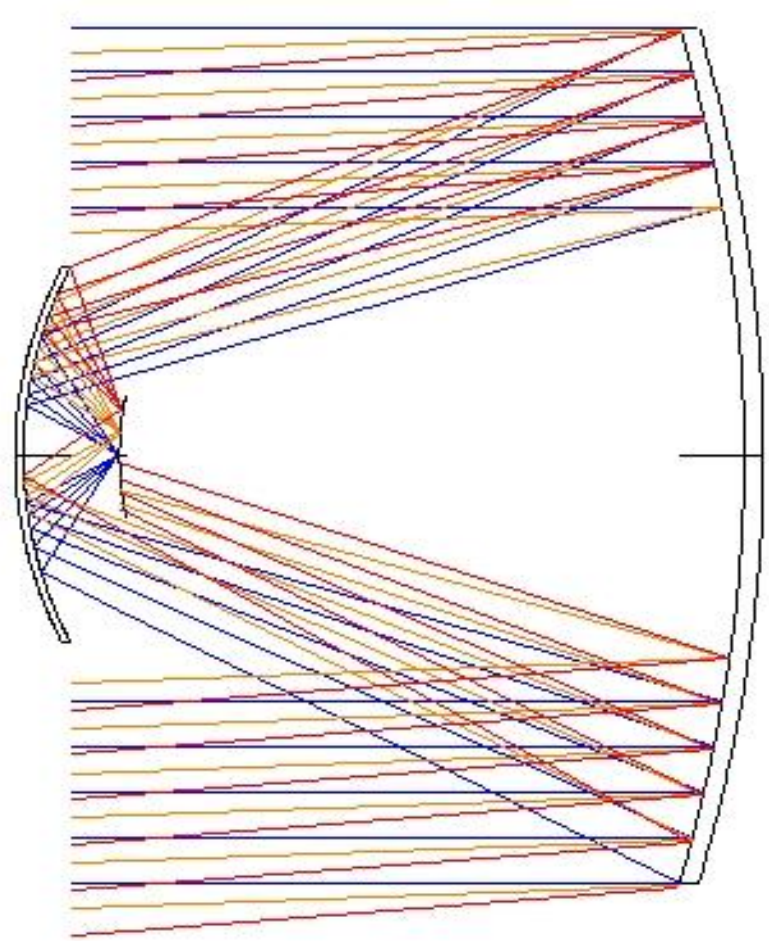
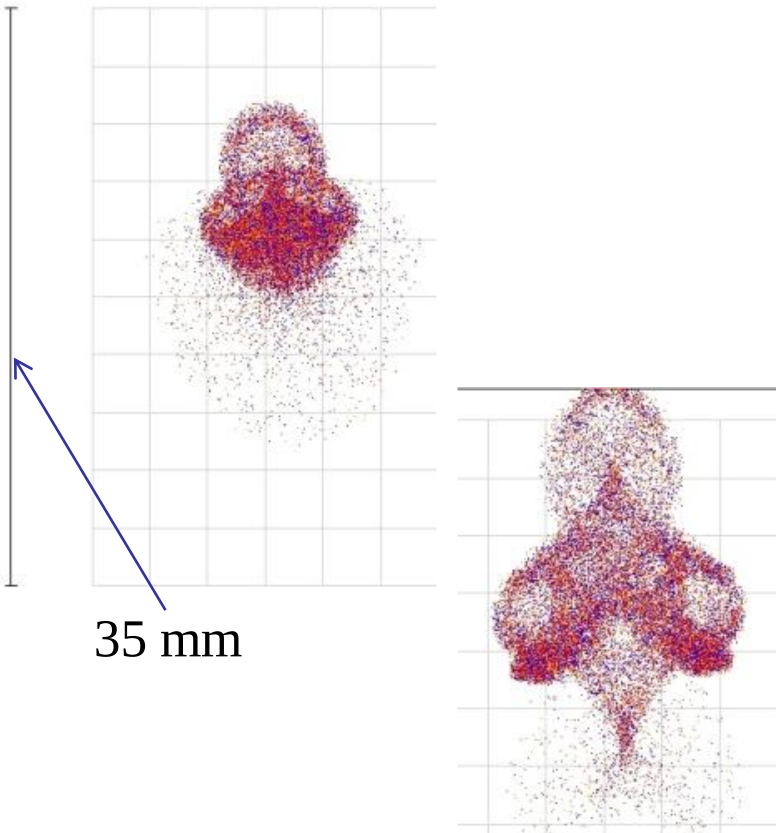


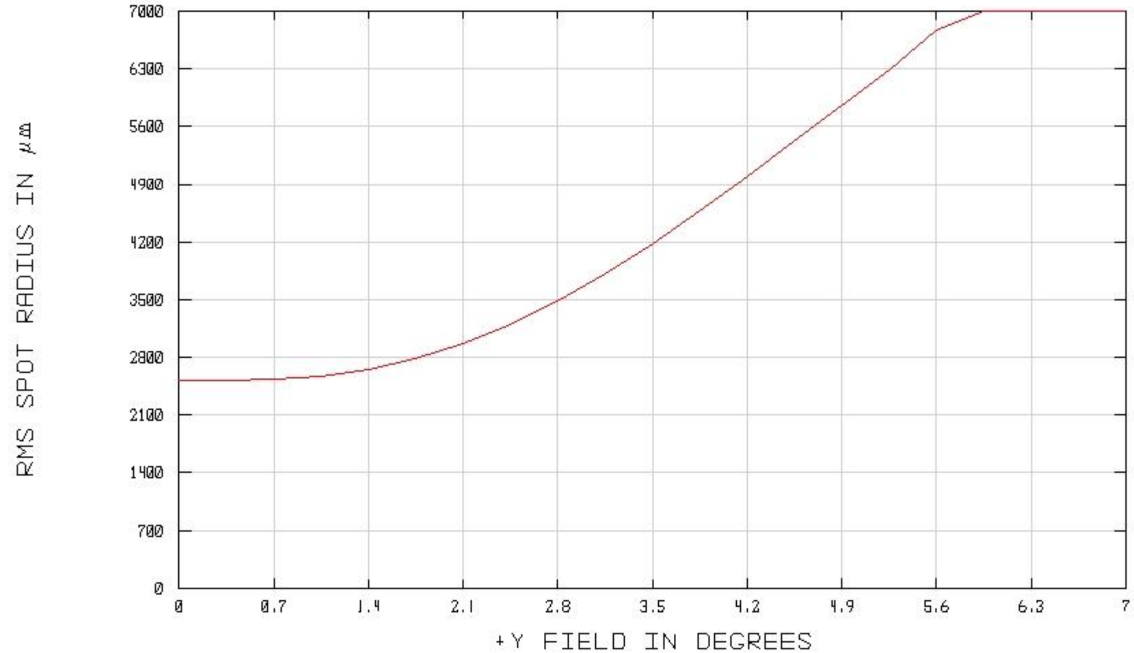
Image quality

- Spot diagrams for δ = 2.5° and 5°:



- Angle of rays on camera surface up to 63°.

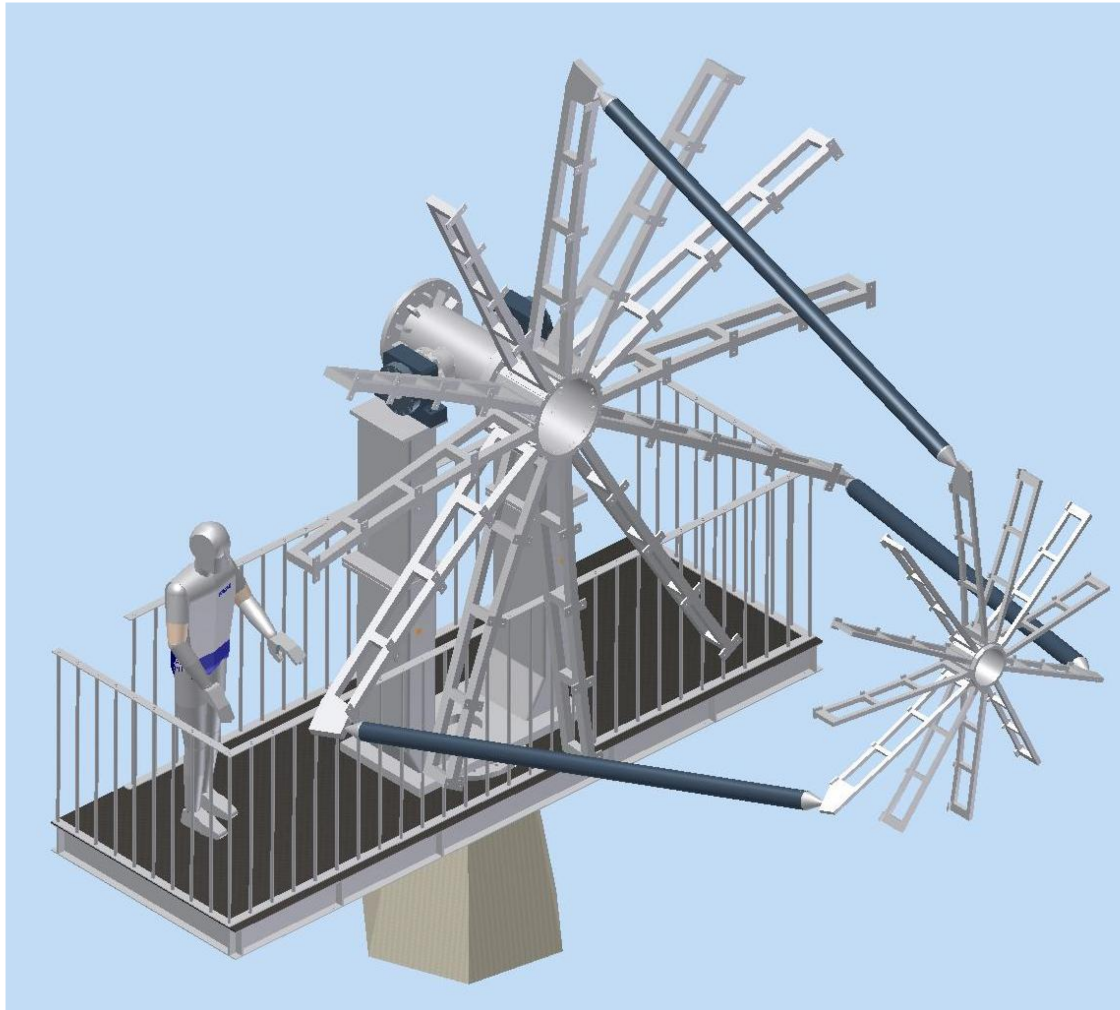
- RMS spot size:



- E.g. 6.4 mm radius circle encloses 70% of photons at 5°.
- ZEMAX optimisation gives telescope similar to Exact Optics design.

Mechanical design

- Start mechanical design and costing for two mirror telescope.
- Support structure pre-fabricated from TIG welded aluminium ribs, e.g. 50 × 50 mm^2 box section for primary.
- Mount is fork design, welded from 400 × 200 mm^2 rectangular Al sections (12 mm thickness).
- Drives worm gear or friction roller.
- Hexagonal 2 m high concrete pedestal.
- All painted red!



Summary

- Results of independent approaches to study of performance of two-mirror telescopes are in good agreement.
- Optical performance compatible with pixel sizes of a few × a few mm^2 are achievable for 10° field of view.
- Not shown here, but tolerances required are acceptable.
- Perhaps the most challenging aspect of the optical design is the angle with which the rays impinge on the camera.
- Much optimisation can still be done, but sensible to start initial mechanical design and costing now.
- Start Monte Carlo simulations of two-mirror option: these are now being prepared.
- Studies of possible sensors initiated:
  - Multi-anode photomultipliers.
  - Micro-channel plates.
  - Silicon photomultipliers.
  - ...
- Look also at Davies-Cotton design to allow reliable cost-benefit analysis of two- and one-mirror solutions for HE section of CTA.